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## III. CORONATION ISLAND

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## ABSTRACT

CORONATION ISLAND, the largest of the South Orkney Islands, is composed predominantly of regionally metamorphosed rocks which include quartzo-feldspathic schists, less abundant mica-schists, hornblende-schists, garnetiferous and sillimanite-bearing rocks, and rare marbles. At its eastern end, these are overlain by the unmetamorphosed Mesozoic Spence Harbour Conglomerate, and at several localities the schists are intruded by late Cretaceous or early Tertiary dolerite dykes and sills. The schists have a polymetamorphic history which can be related to three phases of folding. The initial folding caused an albite-epidote-amphibolite- to amphibolite-facies metamorphism, $F_2$ was followed by a cataclastic to greenschist-facies metamorphism, and $F_3$ was possibly related to a weak prehnite-pumpellyite-facies metamorphism. The Coronation Island schists are thought to represent a metamorphosed sandstone–shale sequence in which there were interbedded tuffs and basic lavas and/or basic minor intrusions. The age of these rocks is not known but they are generally referred to the Precambrian or Lower Palaeozoic. The age of $F_1$ is also unknown, whereas $F_2$ is probably related to the Upper Triassic–Lower Jurassic dates obtained from the schists, and $F_3$ could be a reflection of either the Andean orogeny or the formation of the Scotia Sea.

The gently folded Spence Harbour Conglomerate was deposited subaqueously on low land adjacent to an ancient metamorphic landmass. Dark basal breccias, formed against an existing scarp, pass upwards into buff or light grey conglomerates with thin sandstone intercalations. At one locality the conglomerate is separated from the underlying metamorphic complex by a thin bed of marine shale (Gibbon Bay Shale) containing (?) Cretaceous invertebrate fossils.

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# I. INTRODUCTION

CORONATION ISLAND (lat. 60°38′S., long. 45°35′W.) is the largest island of the South Orkney Islands (Fig. 1), a group of islands trending west–east and situated on the southern limb of the Scotia Ridge. Coronation Island itself lies to the north of the smaller but generally better known Signy Island (Matthews and Maling, 1967; Thomson, 1968), on which the British Antarctic Survey maintains a permanent biological station and from which geological surveys have been carried out.

Although the Falkland Islands Dependencies Survey did not begin geological observations on Coronation Island until 1947 (Adie, 1958), rock specimens were collected on the island as early as 1902–04 by the Scottish National Antarctic Expedition (Pirie, 1905, unpublished) and again in 1933 and 1937 by Discovery Investigations (Tilley, 1935). The present report is based on the 1933 and 1937 data and on rock collections made by Falkland Islands Dependencies Survey and British Antarctic Survey personnel since 1947 (Table I). It represents a continuation of a laboratory study of the South Orkney Islands (Thomson, 1968, 1971, 1973) and is based largely on the field work of D. H. Matthews. He made an extensive survey of Coronation Island but was unable to gain much information from the central snow-covered peaks and the inhospitable northern and north-western coasts, where rock exposure is poor. However, he made a considerable collection of rock specimens from the eastern and north-eastern part of the island and he collected additional data for the south coast, where previous geological work had been done, because of the easily accessible and relatively large area of exposed rock there. Fig. 2 shows the positions of the geological stations on Coronation Island and it indicates the greater concentration of work along the south coast.

TABLE I
ROCK COLLECTIONS MADE ON CORONATION ISLAND SINCE 1947

| *Date* | *Collector* | *Station numbers* | *Remarks* |
|---|---|---|---|
| 1947 | R. J. Adie | S.F.1–5 | West Coronation Island |
| 1948–49 | D. H. Maling | H.182–202<br>H.215–217<br>H.231–260 | Coronation Island and Robertson Islands |
| 1953 | A. G. Tritton | H.546–571 | Coronation Island |
| 1956–57 | D. H. Matthews | H.1101–1121<br>H.1143–1332<br>H.1337, 1339, 1340, 1342<br>H.1347–1349 | Coronation Island |
| 1964–65 | D. W. Matthews | H.2201–2215 | Coronation and Matthews Islands |

*Physiography and glaciation*

Coronation Island is elongated parallel to the overall trend of the South Orkney Islands and it extends in an approximately west-north-west to east-south-east direction for a length of 48 km. The coastline is indented and generally precipitous, with sharp rocky ridges forming bold headlands between ice cliffs (Plate Ia and b), but along the south coast there are a few small bays and coves where boat landings are possible. The interior of the island is mountainous and rugged. The highest mountain is Mount Nivea (1,266 m.) and several nearby peaks reach a height of approximately 1,000 m. These include Brisbane Heights, Rime Crests and isolated peaks farther east, e.g. Mount Sladen, Mount Noble and Pulpit Mountain. The much lower group of sharp-crested peaks north of Cape Vik (Cragsman Peaks; 290–485 m.) has an alpine aspect and is probably the result of mature cirque sculpture (Linton, 1964, fig. 5). That part of the island west of Brisbane Heights is much lower and less rugged, being formed by the

300–400 m. high Pomona Plateau and the slightly higher Sandefjord Peaks (550–600 m.). A group of low-lying islands, the Robertson Islands, is separated from the south-eastern tip of Coronation Island by a narrow gap known as The Divide (cf. Thomson, 1971, fig. 2).

The greater part of Coronation Island is covered by permanent ice. Ice-free areas are confined to the coastal areas or to inland nunataks. The extent of ice-free rock during the 1956–57 season can be seen in the sketch map of the island (Fig. 1). Ice-free patches are scarce on the northern and western coasts where there is maximum precipitation from the prevailing westerly and north-westerly winds. Rocky areas and promontories are more common on the relatively sheltered southern and south-eastern coasts (Plate Ic), bordering Orwell Bight and Lewthwaite Strait.

The glacierization of Coronation Island is of a typically highland character (Marr, 1935). The maximum development of highland ice is in the north and towards the west, where the high central ridge of Brisbane Heights falls away rapidly and all the land is covered by the practically continuous ice cap of Pomona Plateau. Coronation Island is narrowest (approximately 4·5 km.) near Deacon Hill; the land here is completely glacierized and forms a long stretch of unbroken ice cliffs around Norway Bight (Marr, 1935, pl. XVII, fig. 1). At the island's steep west coast the ice cap spills over in a series of hanging glaciers and heavily crevassed ice falls. The eastern half of Coronation Island is topographically higher and highland ice has merely developed in patches. In the extreme east the highland ice passes directly into the fringing piedmont glaciers of Lewthwaite Strait but on the precipitous southern slopes of the island's central ridge it descends as large ice falls or hanging glaciers.

On Coronation Island there are many short glaciers which produce low ice cliffs of considerable width at the coast (Plate Ia); Marr (1935) regarded these as piedmont glaciers similar to those known in northern Graham Land. The largest and best-known glaciers on Coronation Island are Laws and Sunshine Glaciers flowing south, and Roald Glacier flowing east. However, according to John (1934), even the biggest glaciers are too heavily crevassed to withstand the strain of being pushed out to sea and therefore none of their snouts are floating. Apart from piedmont glaciers, on the southern and eastern coasts there are several small cliff glaciers, some of which reach the sea whilst others hang precariously on the rock face. Although Marr (1935, p. 362) regarded the northernmost of the glaciers flowing into Petter Bay as the only true valley glacier of the South Orkney Islands, Pirie (1913, p. 862) observed a small valley glacier west of Cape Bennett.

# II. GENERAL GEOLOGY OF CORONATION ISLAND

## A. Stratigraphy

The relatively simple stratigraphy of Coronation Island (Table II) is similar to the successions given previously for the South Orkney Islands (Matthews, 1959; Adie, 1964*a*; Matthews and Maling, 1967) but it differs from them by the exclusion of the Derived Series and the post-Spence Harbour Conglomerate age assigned to the doleritic intrusions (cf. p. 31). No new information concerning the probable age of the metamorphic complex is available. Although it has been pointed out that both the schists of the metamorphic complex and slightly metamorphosed sediments of the Greywacke–Shale Formation crop out in the same cliff face on nearby Powell Island (Thomson, 1973), the true relationship between the two rock sequences is unknown and, as yet, there is no evidence to support Trendall's (1953, p. 24) suggestion that the schists and "greywackes" form part of a single metamorphic series.

Table II
THE STRATIGRAPHY OF CORONATION ISLAND

| | |
|---|---|
| **(?) Upper Cretaceous or Tertiary** | Dolerite dykes and sills |
| **(?) Cretaceous** | { Spence Harbour Conglomerate<br>{ Gibbon Bay Shale |
| | ~~~~~~~~ (unconformity) |
| **Precambrian or younger** | Metamorphic complex |

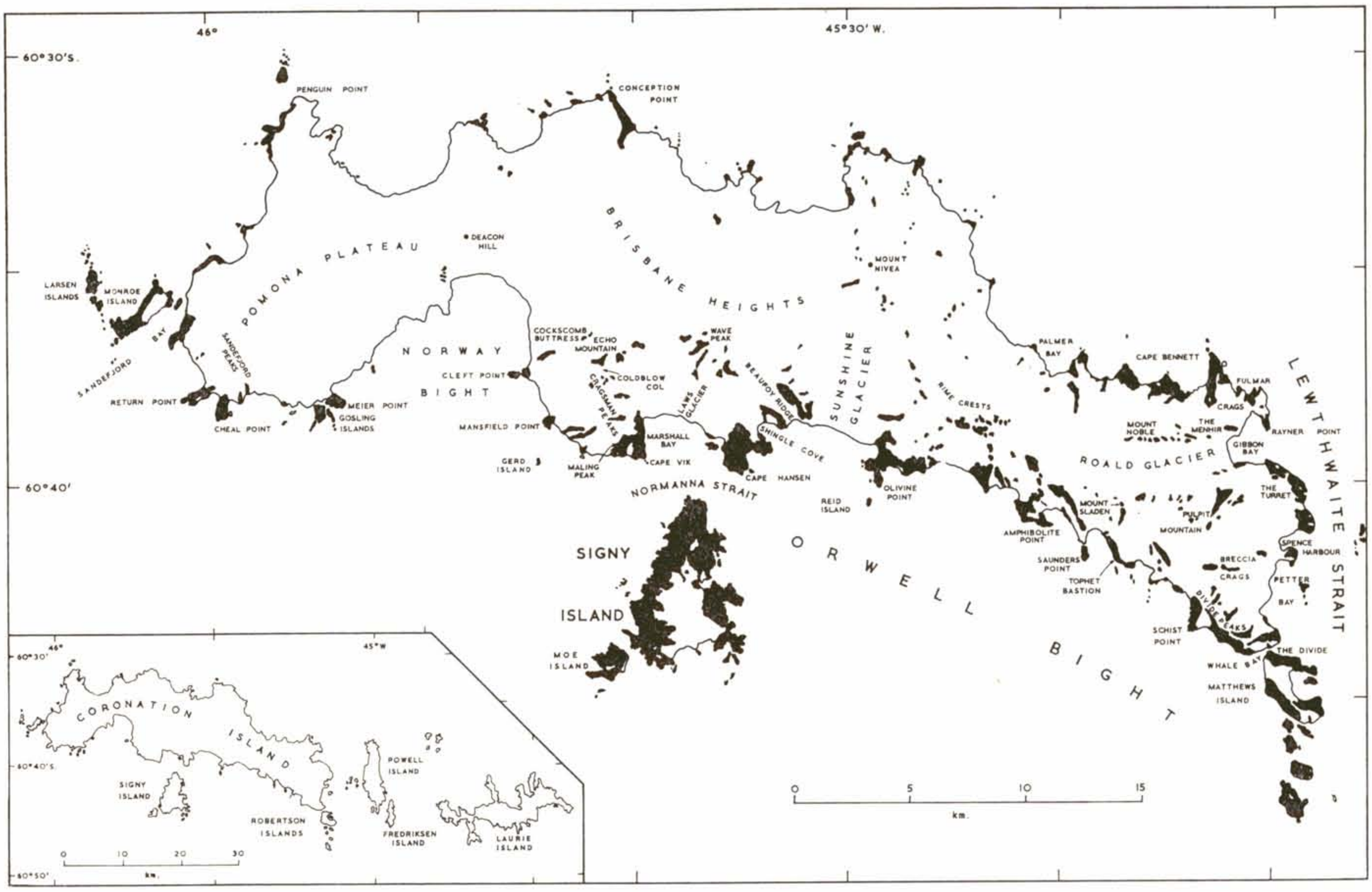


FIGURE 1

Sketch map of Coronation Island showing the place-names mentioned in the text and the extent of ice-free rock during the 1956–57 season. The inset shows the position of the island within the South Orkney Islands group.

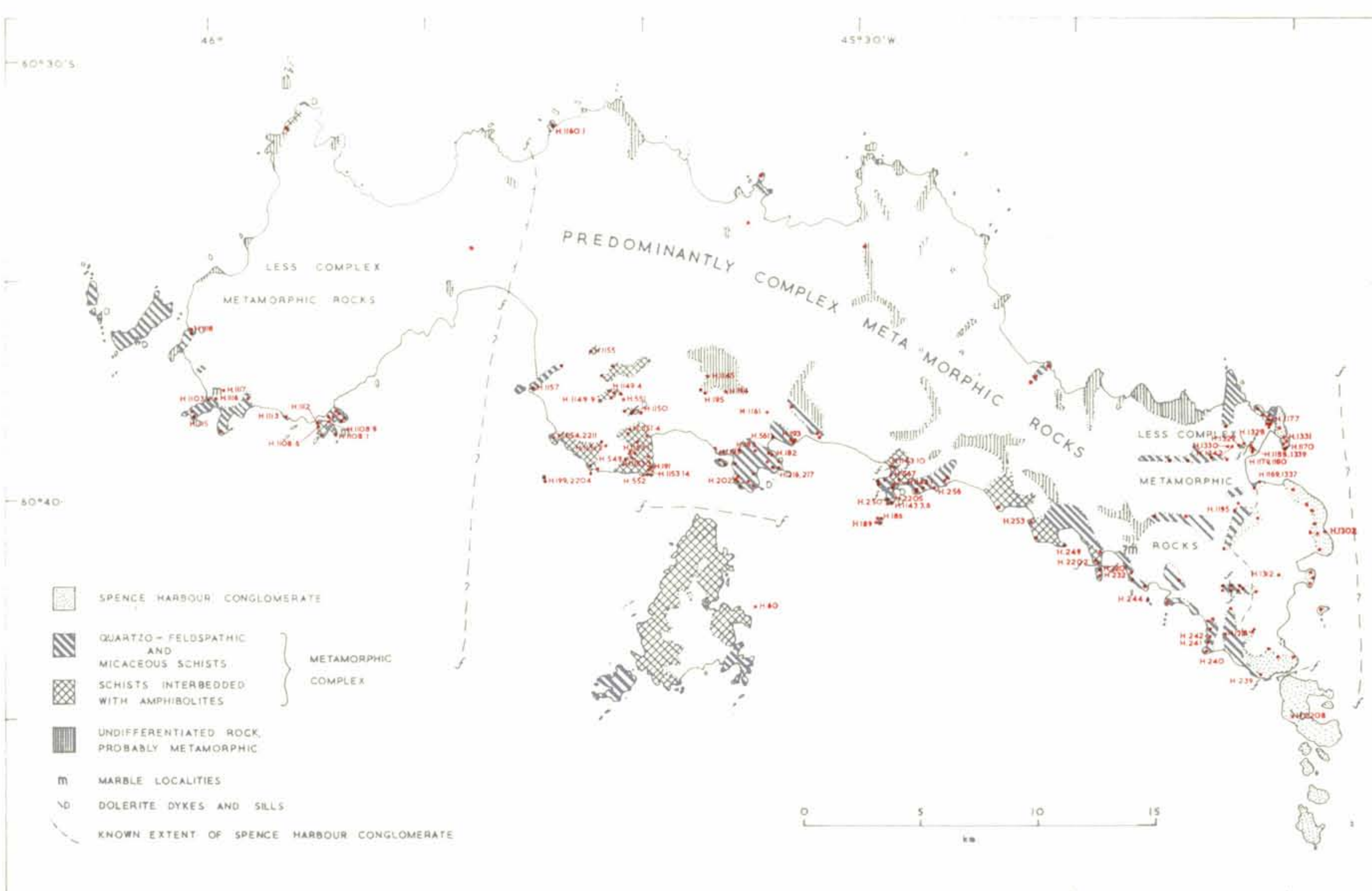


FIGURE 2

Geological sketch map of Coronation Island; the extent of exposed rock shown is schematic. The approximate positions of the geological stations are shown in red on the map but only those stations mentioned in the text are numbered.

[*face page 4*

At the eastern end of Coronation Island the metamorphic rocks are unconformably overlain by a sequence of conglomerates and sandstones, referred to as the Spence Harbour Conglomerate. However, at several localities, dark brecciated schists overlain by dark basal breccias are interposed between the normal light-coloured conglomerates and the metamorphic rocks. The conglomerates consist almost entirely of metamorphic debris derived from the underlying metamorphic complex but fossiliferous calcareous sandstone boulders have been collected from Rayner Point (Plate IIa), and at the south-west corner of Gibbon Bay (Plate IIb) the base of the conglomerate appears to rest conformably on a 1·8 m. thick black shale bed containing a fauna of brachiopods, bivalves and gastropods. The poor preservation of the fauna from the shale bed precludes any positive identification of the fossils but they are thought to be Mesozoic, possibly Cretaceous, in age (cf. p. 29). Fragmentary fossils in moraine specimens of the conglomerate on Matthews Island suggest that the conglomerate there is possibly Cretaceous in age (Thomson, 1971, p. 56).

The altered doleritic intrusions are the only igneous rocks recorded on Coronation Island and until recently it was thought that they intruded the metamorphic rocks but not the overlying conglomerates. It is now known that a comparable dolerite dyke cuts the (?) Cretaceous Spence Harbour Conglomerate on Matthews Island (Thomson, 1971) and thus the minor intrusions are believed to be possibly Upper Cretaceous or even Tertiary in age.

## B. Structure

The South Orkney Islands extend in a west–east direction parallel to the sweep of the Scotia arc in this area. Coronation Island, being the longest and largest island of the group, emphasizes this overall trend. However, headlands which project from both the north and south coasts, in a direction slightly west of north or due north, indicate that there are underlying structures controlling the more detailed topographical features of the island. A similar approximately north–south trend can be seen in the elongation of Signy, Powell and Fredriksen Islands, and also in the trend of several peninsulas on Laurie Island.

The overall structure of Coronation Island is difficult to ascertain because of the scattered distribution and often small size of the rock outcrops. Numerous local variations in the dip and strike of the foliation have been noted for the metamorphic rocks but, from field observations, D. H. Matthews was able to delineate four structurally similar areas:

i. An area of south-westerly dipping foliation at the western end of the island (from Return Point to Meier Point).
ii. One of major north–south trending folds in Cragsman Peaks.
iii. An area of low dips in the central part of the island (between Marshall Bay and Olivine Point).
iv. An area of easterly dips in eastern Coronation Island.

The north coast is not sufficiently well known to fit clearly into any of these four structural areas.

### 1. *Folding*

Major north–south trending folds are present in Cragsman Peaks (unpublished report of D. H. Matthews) and they are presumably comparable to those observed on Signy Island by Matthews and Maling (1967). Recent work by Dalziel (1971) has suggested that these large-scale folds on Signy Island are secondary structures which re-fold earlier isoclinal folds, and there is also evidence from Coronation Island that early isoclines have undergone subsequent re-folding. Small-scale isoclinal folds are common in the schists at, and to the east of, Cape Hansen (unpublished report of D. W. Matthews) but traces of the earliest isoclines have only been detected in a few of the specimens studied in the laboratory: isoclines with extremely attenuated limbs and small, disconnected isoclinal fold hinges are present in pink quartz-garnet segregations at Cragsman Peaks, Amphibolite Point and Saunders Point. In a specimen from Mansfield Point (Fig. 3) it is apparent that the early isoclinal folds have been recumbently re-folded along axes which are essentially similar to the initial north–south trending fold axes.

Petrographic investigations indicate that at least three tectonic episodes have affected the Coronation Island metamorphic rocks but in most schists the dominant structures are the result of the second phase of folding. Irrespective of the phase of folding, the style of micro-folding differs with the lithology of the original rocks. For example, at Meier Point, where micaceous quartzites are interbedded with quartz-mica-schists, the quartzites have developed open micro-folds and boudinage structures whereas the quartz-mica-schists exhibit recumbent micro-folds. Disharmonic relations exist between the quartzo-feldspathic and

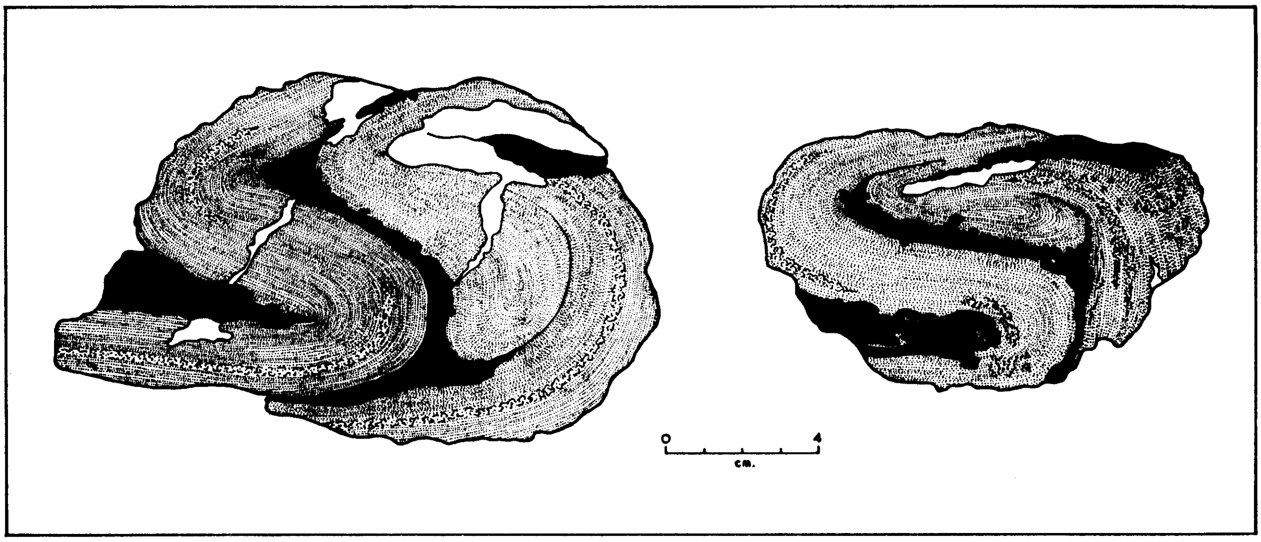


FIGURE 3

A recumbently re-folded $F_1$ isocline preserved in laminated quartz-garnet segregations (lines of stipple) in a Mansfield Point schist. Graphitic micaceous laminae (black), clots of hornblende (patterned) and pure quartz segregations (white) are also shown. The two cross-sections illustrated are 13 cm. apart in the hand specimen; Mansfield Point (H.2211.15).

micaceous laminae of many quartz-mica-schists (Plate IIIa), such that smooth rounded folds developed in the quartzo-feldspathic laminae and more numerous, irregular and angular folds in the micaceous folia. The majority of these folds are asymmetrical and have amplitudes which vary between 0·25 and 6 cm.; the limbs of many of them are lensed and discontinuous, and most are thickened in the hinge area. Many of the folds change in style along their axial plane. Chevron folds are particularly well developed in the greenschists, a few hornblende-schists and in some of the porphyroblastic albite-schists.

The first two phases of folding were about axes trending approximately north–south or north-north-west–south-south-east but D. H. Matthews recorded cross folds with west–east axes at several localities at the eastern end of Coronation Island (Plate IIIb), and Matthews and Maling (1967, p. 26) and Dalziel (1971) reported local warping of the secondary north–south folds on Signy Island. Such folds occur in the schists at Flag Hill, Cape Bennett and Pulpit Mountain, and they are probably contemporaneous with the gentle folding, about west–east axes, of the Spence Harbour Conglomerate.

The absolute age of the various phases of folding has not yet been ascertained. Quartz-mica-schists from both Signy and Coronation Islands have been dated by the K-Ar method and have yielded average ages of 176–199$\pm$5 m. yr. (Miller, 1960), 177$\pm$7 m. yr. (Rex, 1967) and 205–235 m. yr.* (Grikurov and others, 1967). According to Kulp's (1961) geological time-scale, this reflects an Upper Triassic–Lower Jurassic tectonic event. It is possible that the secondary folding about north–south axes can be correlated with this event. The west–east folds are locally significant and they represent a late post-conglomerate event which occurred possibly at the end of the Cretaceous or during Tertiary time.

## 2. *Faults*

Two sets of faults, trending approximately north–south and west-east, cut the metamorphic complex and the Spence Harbour Conglomerate on Coronation Island. The major faults shown in Fig. 2 have been inferred from either marine geophysical data or topographical features on land, whereas the small faults are known from field observations. Marine seismic investigations carried out over the South Orkney Islands shelf suggest that west–east faults displace the inferred major north–south ones (Harrington, 1968, p. 39) but it is, nevertheless, probable that most of the faults developed contemporaneously during Tertiary times, perhaps coincident with the formation of the Scotia Sea (Barker, 1971).

* When recalculated with constants used by western geologists, these become 195–224 m. yr. (Halpern, 1971).

The most important of the faults shown in Fig. 2 are:

i. A north–south trending fault, downthrown to the east, along Lewthwaite Strait; its presence is suggested by marine geophysical data (Harrington, 1968, p. 8).

ii. An inferred fault, downthrown to the west, which probably extends from the bay east of Tickell Head to Norway Bight. It is indicated by the marked change in relief between Brisbane Heights (1,000 m.) and Pomona Plateau (300–400 m.), the extensive coastal erosion in Norway Bight and more especially by the differing geology west of Deacon Hill (the schists and marbles exposed at Return Point and Meier Point, particularly the graphitic schists, are unique to this area). This fault could be a northerly extension of the geophysically detected submarine Signy Island trough, one arm of which lies to the west of Signy Island and extends in a southerly direction for more than 100 km. (Harrington, 1968, p. 38–39).

iii. A west–east tear fault along Normanna Strait (Adie, 1964*a*, p. 128) which has a supposed lateral displacement of approximately 10 km. (Harrington, 1968, p. 8).

iv. A fault at The Divide, downthrown to the south, indicated by a prominent fault scarp in the sea cliffs of Coronation Island (cf. Thomson, 1971, fig. 2).

Small west–east trending faults, often with associated fault breccias, have been recorded at several localities near the eastern coast of the island (e.g. at Fulmar Crags, The Menhir, Breccia Crags) and also at Saunders Point and Olivine Point. A north-west–south-east trending fault or thrust affects the rocks at Beaufoy Ridge (unpublished field notes of D. H. Maling) and other small faults, of unspecified trend, are present at Cape Vik, south of Echo Mountain and at Return Point.

## III. THE METAMORPHIC COMPLEX

METAMORPHIC rocks are exposed over the greater part of Coronation Island and they belong to the same metamorphic complex as the schists on Signy Island (Matthews and Maling, 1967; Thomson, 1968), the Larsen and Inaccessible Islands (West, 1968) and those exposed in parts of northern and eastern Powell Island (Dalziel, 1971; Thomson, 1973). The largest area of metamorphic rocks occurs on Coronation Island, where the lithologies, although not evenly distributed over the island, are similar to those found on the smaller islands. For example, on Signy Island greenschists, hornblende-schists and marbles are almost as common as the quartzo-feldspathic and micaceous schists, with which they are often interbedded on a small scale, but on Coronation Island their distribution is less widespread. Quartzo-feldspathic and micaceous schists are by far the predominant types (they have been recorded at nearly every locality visited on the island), whereas greenschists and hornblende-schists are apparently confined to the southern coast and marbles have been observed *in situ* only at Return Point and in the Gosling Islands.

### A. LITHOLOGY AND PETROGRAPHY

Each of the main schist types from Coronation Island has been subdivided into several lithological varieties, based on the macroscopic appearance of the specimens in the laboratory. It has not been possible to attach any stratigraphical significance to these lithologies but it seems that the schists from the central part of the island are texturally more complex than those at either its eastern or western ends. The modal analyses of a few representative schists are given in Table III.

#### 1. *Quartzites and quartzo-feldspathic schists*

Rare quartzites, forming lenticular beds within graphitic schists, are known only at Cheal Point and Meier Point (Plate IIIc), south-western Coronation Island. Field descriptions indicate that the quartzites are usually iron-stained (derived from small amounts of iron pyrites) but the specimens studied in the laboratory are white or light grey in colour. All of them contain thin and discontinuous dark grey laminae of mineral impurities such as small flakes of muscovite and chlorite, streaks of graphite and occasionally clusters or laminae of small polygonal garnet crystals; thin sections of the quartzites show that quartz has a semi-flasered structure.

The quartzo-feldspathic schists are divisible into three main sub-types, each sub-type being generally confined to a particular geographical area (Fig. 4).

TABLE III

MODAL ANALYSES OF REPRESENTATIVE SCHISTS FROM CORONATION ISLAND

| | H.199.1 | H.189.1 | H.242.1 | H.1113.1 | H.1155.3 | H.1108.1 | H.551.1 | H.2211.3 | H.2211.4 |
|---|---|---|---|---|---|---|---|---|---|
| Quartz | 36 | 36 | 44 | 22 | 33 | 3 | 7 | 7 | 7 |
| Plagioclase | 26 | 37 | 27 | 27 | 11 | 19 | 25 | 2 | 21 |
| Hornblende | — | — | — | — | — | — | 43 | — | — |
| Muscovite | 8 | 4 | 3 | 26 | 38 | — | — | 13 | 21 |
| Biotite | 25 | 19 | 12 | 8 | 4 | — | 5 | 10 | 8 |
| Chlorite | * | * | 4 | 12 | 5 | 17 | * | 5 | 18 |
| Sillimanite | — | — | — | — | — | — | — | — | 13 |
| Epidote | 2 | 4 | 9 | 1 | * | 60 | 17 | 24† | 4 |
| Garnet | 1 | * | * | — | 8 | — | * | 33 | * |
| Other accessory minerals | 2 | * | 1 | 4 | 1 | 1 | 3 | 6 | 8 |
| *Plagioclase composition* | $An_6$ | $An_4$ | $An_7$ | $An_6$ | ? | $An_8$ | $An_6$; $An_{40}$ | ? | ?;$An_{44}$ |

* Less than 1 per cent present.
† Mostly clinozoisite.

H.199.1 Thinly laminated quartz-albite-biotite-muscovite-schist, Gerd Island.
H.189.1 Porphyroblastic albite-quartz-biotite-schist, Reid Island.
H.242.1 Flaggy quartz-albite-biotite-muscovite-chlorite-schist, north of Schist Point.
H.1113.1 Graphitic albite-muscovite-quartz-schist, mainland coast north-west of the Gosling Islands.
H.1155.3 Graphitic muscovite-quartz-albite-schist, Cockscomb Buttress.
H.1108.1 Epidote-albite-chlorite-schist, Gosling Islands.
H.551.1 Hornblende-albite-epidote-schist, south of Coldblow Col.
H.2211.3 and 4 Mansfield Point schists, Mansfield Point.

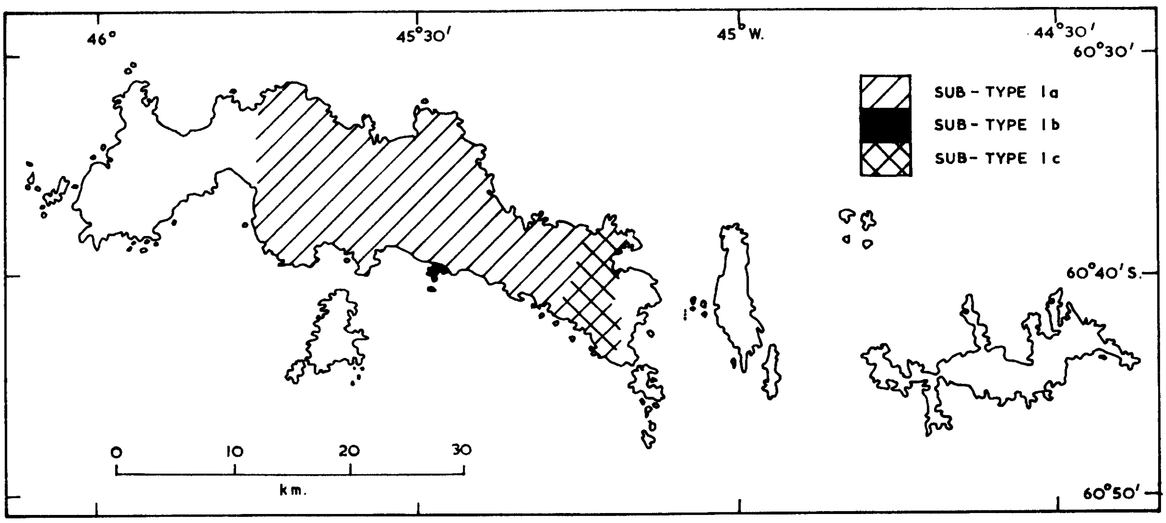


FIGURE 4

Sketch map of Coronation Island showing the geographical distribution of the three major sub-types of quartzo-feldspathic schists.

a. *Thinly laminated quartz-albite-biotite-muscovite-schists* are the dominant type in all exposures between Saunders Point and Deacon Hill; numerous specimens have been collected from the Cape Hansen area especially, and Cragsman Peaks. They are typically well-foliated, fissile rocks with 0·5–1·0 mm. laminations of white quartzo-feldspathic material alternating with grey or brown laminae of predominantly micaceous minerals; the overall colour of the schists is light grey or buff and there is an obvious bronze or silver sheen on the schistosity planes. These schists are invariably fine-grained and usually uncontorted (H.182.2) but several of the hand specimens exhibit open-style micro-folds and a few show small isoclines and chevron folds. Garnet porphyroblasts are small and rarely visible macroscopically but thin quartz veins cross-cutting the foliation are common. Lenses and segregations of yellowish quartz lying sub-parallel to, and folded with, the schistosity are present in a small number of specimens (H.199.1).

The grain-size is generally 0·1–0·2 mm. with some mica flakes up to 0·5 mm. in length but some of the micro-folded schists tend to be slightly coarser-grained (0·5–1·0 mm.). The quartzo-feldspathic laminae are composed of strained polygonal quartz crystals, small irregular plagioclase porphyroblasts, scattered flakes of biotite and tiny rare crystals of epidote and sphene. The plagioclase is typically "vermicular", containing minute bleb-like and vermicular quartz inclusions (Plate Va), and the porphyroblasts are usually crudely zoned and partially sericitized. Extinction angles measured on cleavage flakes parallel to (010) are indicative of albite ($An_4$). Not all the albite porphyroblasts are "vermicular". In the biotite-rich laminae some have replaced biotite, interdigitating with the mica at their margins and also enclosing slivers of biotite and epidote. These porphyroblasts are generally less sericitized and show a marked elongation parallel to the schistosity; polysynthetic glide twins are rare and they occur only in this type. In several of the schist specimens the albite porphyroblasts are most heavily sericitized adjacent to quartz segregations and these are the ones which contain the highest quantity of quartz inclusions.

Biotite is the predominant mica and it is usually a strongly pleochroic brown variety ($\alpha$ = straw, $\beta = \gamma$ = deep orange-brown) but greenish brown biotite has been observed in a schist adjacent to a dolerite dyke at station H.217. When present, muscovite interdigitates with biotite and both micas have crystallized mimetically around the crests of micro-folds; bundles of small prehnite lenses (0·05–0·1 mm. in length) push aside the cleavage in a number of partially chloritized biotite flakes. Accessory minerals are: epidote (pistacite and strongly pleochroic green or orange-yellow allanite), sphene, (?) topaz, semi-translucent haematite and rare graphite. Garnet is present in only a limited number of specimens, the larger porphyroblasts (1·5 mm. in diameter) containing helicitic inclusions of epidote, sphene and a little quartz. A few garnet porphyroblasts are pseudomorphed by a scaly mass of biotite or an aggregate of biotite, muscovite and feldspar.

b. *Porphyroblastic albite-quartz-biotite-schists.* These are common at Olivine Point and on Reid Island but they are rare elsewhere on Coronation Island. Similar rocks crop out on Outer Island (H.60), off the east coast of Signy Island, and it is interesting that they also occur on the far more distant Elephant Island in the South Shetland Islands (Dalziel, 1972). The schists (H.186.1) are darkish grey, fine- to medium-grained rocks with a "saccharoidal" texture formed by tiny closely packed albite porphyroblasts (1–2 mm. in diameter). A slight flattening of the porphyroblasts parallel to the plane of the schistosity gives a vague lamination to an otherwise massive rock and this has been accentuated by the development of thickish concordant quartz segregations. Garnet crystals are not visible in the hand specimen.

In thin section, they are characterized by large and complex albite porphyroblasts packed closely together in a pseudo-augen structure. The porphyroblasts are irregularly zoned with an albite core grading into a usually narrow rim of a different (?) albitic composition, and they are riddled with both large and small inclusions of quartz, clinozoisite and sphene (Plate Vb). Some of the inclusions have a relict parallel elongation and, although they are all generally smooth, several of the larger quartz inclusions have dentate sutured grain boundaries against plagioclase; vermicular quartz has developed along the margins of partially sericitized porphyroblasts. Small flakes of biotite (sometimes with minute lenses of prehnite along the cleavage), muscovite and secondary chlorite surround the albite porphyroblasts in anastomosing layers and in places they interdigitate with the feldspar. However, mica is rarely included in albite. The accessory minerals include clinozoisite, sphene, garnet, (?) topaz, graphite, allanite and tourmaline, with calcite as a rare secondary mineral. Garnet forms smallish semi-idioblastic porphyroblasts which are crowded with inclusions of sphene and epidote.

c. *Flaggy quartz-albite-biotite-muscovite-chlorite-schists* are the typical rocks at all exposures to the east of a line between Mount Noble and Tophet Bastion. They are fine- to medium-grained, grey or dark greenish grey, non-fissile schists (H.241.1) with thick concordant quartz segregations enhancing their flaggy appearance. No garnets are visible macroscopically.

In thin section, they are characterized by flattened granoblastic aggregates of quartz and zoned plagioclase crystals (0·2–0·5 mm. in diameter) interleaved with poorly defined and discontinuous laminae of muscovite and chlorite, and medium-grained segregations of quartz (Plate Vc). The plagioclase is water-clear, usually untwinned and sometimes zoned gradationally from an albite core ($An_8$) to a narrow rim of a different (?) albitic composition; specks of black opaque dust are crowded at the core of many crystals. Muscovite and chlorite interdigitate with each other and with relatively uncommon small slivers of brown biotite, and they are associated with abundant accessory minerals: epidote, sphene (occasionally having a dark brown core of rutile), allanite, tourmaline, graphite and garnet. Several specimens show signs of crushing, such as incipient mylonitization and the formation of a vague augen structure around the larger garnet porphyroblasts. Garnet crystals in the crush zones have undergone marginal diaphthoresis to chlorite and biotite.

In addition to these three lithological sub-types, several other minor varieties were noted in the laboratory. Although macroscopically distinct, they differ little in thin section from those already described. The ones related to sub-type 1a are:

i. Greenish grey laminated schists with a complex set of sheared isoclines (H.193.1); these crop out around Shingle Cove and near Cape Hansen. Similar, slightly graphitic schists with thick quartz segregations (H.195.1) are exposed near Wave Peak and Cockscomb Buttress.
ii. Well-foliated schists with dark grey, buff and white laminae, and a highly graphitic mica content (H.561.1). A set of disrupted, slightly recumbent micro-folds are a distinctive feature. Specimens of these were collected from the Shingle Cove area, Beaufoy Ridge and also in Cragsman Peaks.
iii. Highly quartzo-feldspathic non-fissile schists, from Cape Vik (H.1153.14), which have uncontorted thin grey and white laminae. Irregular margins to the white laminae are caused by abundant tiny white feldspar porphyroblasts.

Specimen H.232.1, from Saunders Point, is a thinly laminated schist similar to sub-type 1a but it also resembles sub-type 1b in having a slight "saccharoidal" texture, due to the development of minute albite porphyroblasts; in thin section it is more like sub-type 1c. At Meier Point and at one locality in the Gosling Islands there are thickly, but unevenly, laminated and uncontorted quartzo-feldspathic schists in which small red garnet crystals are visible macroscopically (H.1107.3); in thin section these are also similar to sub-type 1c.

2. *Semi-micaceous schists*

The semi-micaceous schists have features characteristic of both the quartzo-feldspathic schists and the micaceous ones. They are not common in the rock collection from Coronation Island but there are at least three notable sub-types.

a. *Quartz-muscovite-chlorite-albite-garnet-schists*. This type of schist is not widespread on Coronation Island and specimens have been collected only from the Amphibolite Point area and at Saunders Point. In the hand specimen, the schists (H.249.2) are poorly fissile, light greenish grey rocks studded with large dark red garnet porphyroblasts (2–5 mm. in diameter). Laminations are obvious in thin section and these are enhanced by thick quartz segregations. Large and simply zoned, untwinned albite porphyroblasts (1·0–1·5 mm. in length), elongated parallel to the schistosity, are present in the thin and discontinuous micaceous laminae and they interdigitate with flakes of muscovite, chlorite and biotite. They also include lineated slivers of mica and elongate blebs of quartz, some of which have dentate sutured crystal boundaries. Muscovite and chlorite are much more abundant in these schists than biotite and they are associated with coarse-grained accessory minerals such as lozenge-shaped sphene crystals, tourmaline, (?) topaz, epidote and graphite. Garnet is present both as small, inclusion-free idioblastic crystals and as large porphyroblasts containing trails of included graphite. Some of the garnet porphyroblasts appear to have crystallized syntectonically but there is also clear evidence of a post-tectonic crystallization phase (Fig. 5); a few of the larger porphyroblasts are marginally altered to chlorite.

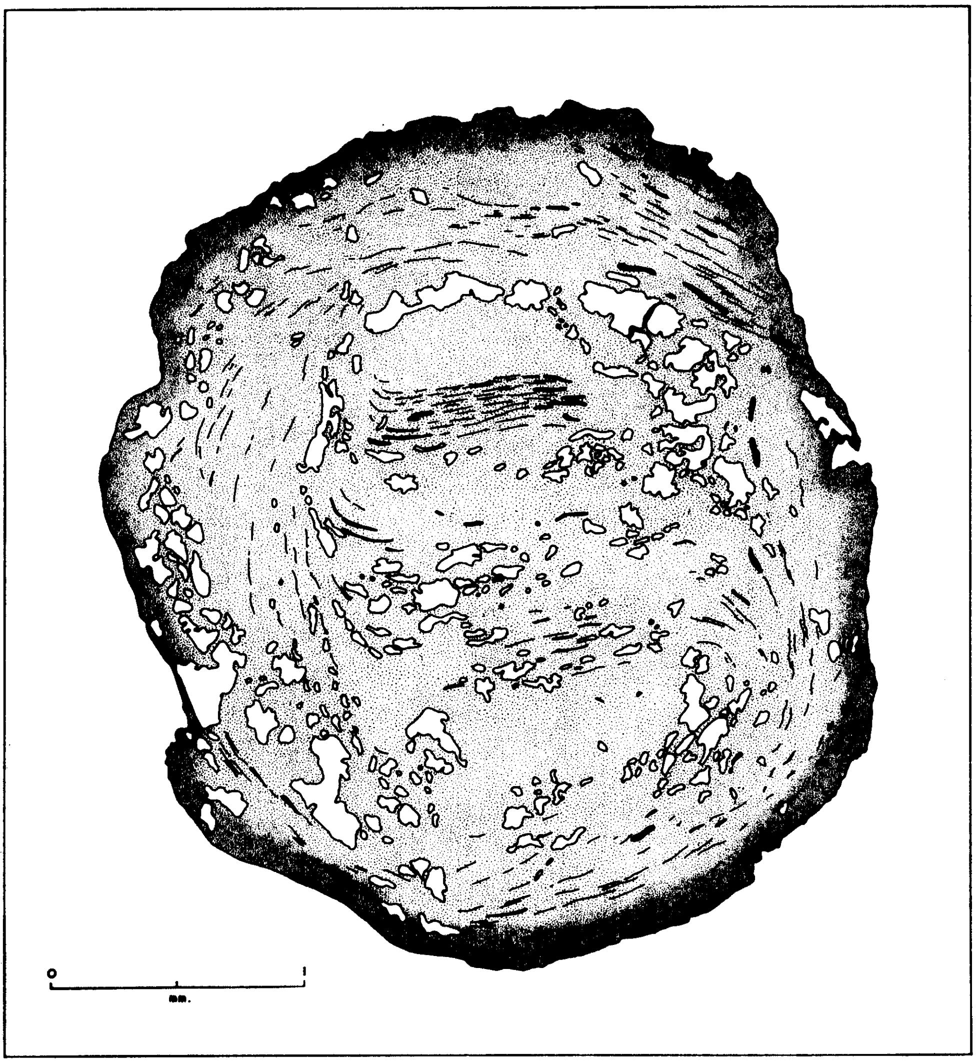


FIGURE 5

A garnet porphyroblast showing two phases of crystallization. The core represents syntectonic crystallization during $F_1$ and the essentially spherical pattern of inclusions in the outer zone indicates a post-tectonic crystallization phase (cf. Harvey and Ferguson, 1973); semi-micaceous schist; Amphibolite Point (H.253.2).

b. *Graphitic quartz-biotite-muscovite-albite-schists* (H.552.1) have been collected from a limited number of exposures at Cape Vik, and near Shingle Cove and Olivine Point. They are thinly laminated, dark grey rocks similar to the quartzo-feldspathic schists of sub-type 1a but in the hand specimen they are characterized by abundant glistening black plates of graphitic mica; a few specimens are slightly porphyroblastic (H.256.1).

In thin section these schists are essentially similar to sub-type 2a. However, in specimen H.552.1 the zoned feldspar porphyroblasts are rather complex, with fresh albite ($An_2$) replacing and enclosing heavily sericitized, sometimes "vermicular" plagioclase and biotite; elongate and irregular serrated quartz grains and wisps of graphite are also present as inclusions in these porphyroblasts. In specimen H.256.1 some albite porphyroblasts contain trails of graphite which lie at an angle to the present schistosity, as shown by coarse flakes of muscovite, and there are occasional aggregates of fibrous prehnite associated with secondary chlorite. The garnet porphyroblasts are large and sieve-like, and in places they are heavily chloritized.

c. *Graphitic albite-muscovite-quartz-schists* (H.1103.1) are fine-grained but coarsely foliated lustrous black schists with thick irregular sub-concordant segregations of white quartz. They are the typical schists at

Return Point, Cheal Point and in the Sandefjord Peaks. Tight micro-folds are visible in thin section, particularly in the thick micaceous laminae where the micas have crystallized mimetically around the crests of the folds. Small irregular albite porphyroblasts ($An_6$; 0·2–0·8 mm. in length) are associated with the muscovite, biotite and chlorite in these laminae and minute crystals of sphene and epidote, and specks of graphite are common. Thick quartz segregations, and aggregates of granoblastic quartz and untwinned albite crystals (about 0·5 mm. in diameter), form bands between the micaceous laminae and they show a more open style of folding.

Other semi-micaceous schists are the quartz-muscovite-albite-chlorite-schists (H.240.1), observed at a few localities between Saunders Point and Schist Point, and the quartz-biotite-muscovite-albite-schists (H.198.1) which crop out near Marshall Bay. Both types are well-foliated rocks, the ones near Marshall Bay being typical quartz-mica-schists. They are similar in appearance to the quartzo-feldspathic schists (sub-type 1a) but they are slightly more micaceous.

3. *Mica-schists*

Mica-schists are relatively rare on Coronation Island compared with the quartzo-feldspathic schists but they are nevertheless lithologically varied and have been divided into the following sub-types:

a. *Graphitic muscovite-biotite-quartz-albite-schists* (H.183.2) crop out at several localities in central southern Coronation Island, between Cleft Point and Olivine Point, and also at station H.1195, near Pulpit Mountain. Similar schists are interbedded with quartz-rich and garnetiferous quartz-mica-schists at a locality on the north coast, near Conception Point. These are the commonest of the mica-schists and in the hand specimen they are the micaceous equivalent of the thinly laminated quartzo-feldspathic schists, comprising paper-thin dark grey micaceous laminae and white layers of quartzo-feldspathic material. A leaden grey sheen on the schistosity planes is a typical feature and sporadic garnet porphyroblasts (2–4 mm. in diameter) are present in one highly graphitic specimen (H.2211.7).

b. *Graphitic muscovite-chlorite-albite-quartz-schists* (H.1157.1) are exposed at Cleft Point, Mansfield Point, in Cragsman Peaks and at Olivine Point. They are highly fissile, buff and greenish grey rocks mottled by dark concentrations of graphite; red garnet porphyroblasts (1–2 mm. in diameter) are present in a few specimens. In thin section, they are similar to many of the rocks already described in detail, having both large and small albite porphyroblasts (0·5–3·0 mm. in length), and large irregular garnet porphyroblasts which contain helicitic trails of graphite. However, in specimen H.1157.1 the porphyroblastic albite is more complex than usual and the crystals are riddled with wisps and patches of sericite and schistose material. The sericitic patches contain numerous small blebs of quartz and larger, elongate quartz inclusions with dentate margins; well-defined fans of myrmekite are present only in those albite porphyroblasts near areas of sericitization. The larger porphyroblasts are clearly zoned, often with polysynthetic glide twins in the outer zone, and one or two display Carlsbad twins. Biotite (sometimes with small lenses of either epidote or prehnite along the cleavage), muscovite and garnet are all partially chloritized and the accessory minerals in these schists include rutile, zoned crystals of green tourmaline, (?) topaz and a little iron ore.

c. *Graphitic muscovite-quartz-albite-schists* are the commonest type of mica-schist in the Cragsman Peaks area and they also crop out at Cockscomb Buttress, Echo Mountain, Mansfield Point, near Olivine Point and in Palmer Bay. They are well-foliated and thickly laminated, almost black schists with frequent glistening black graphitic mica flakes and sporadic dark red garnet porphyroblasts (H.1153.1); the quartzo-feldspathic laminae are discontinuous and grey or greenish in colour. In thin section, these schists are similar to sub-type 3b but they contain a much greater quantity of graphite, most of which is included as contorted helicitic trails in albite porphyroblasts and in the coarse muscovite flakes. A few of the simply zoned albite porphyroblasts have a discontinuous film of graphite separating the inner zone from the outer one, and thin graphite zones are also present in a few garnet porphyroblasts.

d. *Muscovite-chlorite-quartz-albite-garnet-schists* (H.244.1). These are thinly laminated and fine- to medium-grained silvery grey-green rocks with scattered large dark red garnet porphyroblasts (3–5 mm. in diameter). They are not common rocks but specimens have been collected near Olivine Point, Saunders Point and Tophet Bastion. In thin section, these schists have few distinctive features.

4. *Phyllites and phyllonites*

Only six specimens belonging to this category have been collected on Coronation Island. The most typical phyllite (H.1161.1) is a dark grey graphitic rock with paper-thin laminae of both micaceous and quartzo-feldspathic material. Although similar to the mica-schists (sub-type 3a), it is much finer-grained and slightly more siliceous. Other extremely fine-grained quartzo-feldspathic rocks have been collected from Marshall Bay and Sandefjord Bay. Two specimens from a locality in the Divide Peaks are black fine-grained but non-schistose rocks with a characteristic lenticular lamination. These were collected from a fault zone and are probably phyllonites (H.1318.2 and 3).

5. *Greenschists*

Greenschists are uncommon on Coronation Island and only 17 specimens are present in the entire rock collection. Of these, more than half were collected from the south-western end of the island and in particular from the Gosling Islands. Macroscopically, they are characterized by a light green, yellow-green or silvery green colour and lithologically they can be subdivided into soft flaky schists, hard and generally more massive ones and epidotic schists. The following varieties have been recognized in the laboratory:

a. *Talc-actinolite-sphene-schist.* This crops out on the largest of the Gosling Islands as a 6 m. thick bed lying between quartz-mica-schists. It has sharp contacts with the quartz-mica-schists but its foliation is not exactly concordant with the contact of the two rock types (unpublished field notes of D. H. Matthews). No other talc-schists have been recorded on Coronation Island but there are talc-schists interbedded with impure quartzites on the Larsen Islands (West, 1968, p. 54). In the hand specimen, the talc-schist (H.1108.6) is a soft fine-grained and thinly laminated, light silvery green rock with darker green lenses of (?) actinolite. Long decussate blades of actinolite are also present on the schistosity planes and the rock is cut by thin concordant veins and small segregations of calcite. In thin section, flattened sharp-angled micro-folds are visible in the talc ($\alpha : c = 3°$) laminae and superimposed upon these are a felted mass of needles and blades of post-tectonic actinolite (pleochroic from colourless to a pale green; $\gamma : c = 18°$). Minute grains of sphene are abundant in the talc laminae but crystals of (?) topaz and small feldspar porphyroblasts are rare.

b. *Actinolite-epidote-sphene-albite-schists.* These are less friable but equally fine-grained, light green schists with paper-thin actinolitic laminae (H.1118.3).

c. The *actinolite-albite-epidote-schists* are medium-grained light grey-green schists with a slightly "saccharoidal" texture. The thin laminations present are not immediately obvious in the hand specimen (H.549.1) but the axes of the sharp-angled micro-folds are well defined; these micro-folds are not as flattened as those in the soft flaky schists. Small blades of actinolite ($\gamma : c = 12°$; 0·1–0·5 mm. in length) have crystallized mimetically around the crests of the micro-folds and they are far more abundant than small crystals of epidote, (?) topaz and sphene and smallish porphyroblasts of albite (containing inclusions of epidote and acicular actinolite). This type of schist has been collected at Mansfield Point and near Maling Peak but it has not been recorded elsewhere.

d. *Albite-actinolite-epidote-schists* are exposed at Olivine Point and near Wave Peak. They are similar to sub-type 5c but have a much more pronounced "saccharoidal" texture. Some specimens are poorer in actinolite and muscovite than others (H.1143.1 and 1145.1). The "saccharoidal" texture is due to the abundance of elongate albite porphyroblasts (0·3 mm. in length) which have grown within the mass of actinolite parallel to the well-defined schistosity. Actinolite and epidote inclusions are always present in the albite crystals and a few of the porphyroblasts are simply zoned. In addition to epidote crystals (some of which have simple zoning) there are small crystals of sphene and (?) topaz and rare flakes of pale brown biotite and muscovite.

e. *Actinolite-biotite-albite-schists* crop out in Cragsman Peaks. They have paper-thin grey-green actinolitic laminae alternating with those of biotite and quartzo-feldspathic material and a "saccharoidal" texture is faintly visible in the hand specimen (H.1151.4).

f. *Epidote-albite-chlorite-schists* are rare and are known only in the Gosling Islands, off the south-western coast of Coronation Island. They are light yellow-green, fine- to medium-grained crystalline rocks with a massive appearance although the epidote occurs as irregular, finely laminated segregations (H.1108.1). In thin section, the epidote is pleochroic from colourless to a pale lemon colour and it forms a closely packed aggregate interlaminated with thin segregations of quartz. Large flakes of chlorite and thick laminae of granoblastic albite crystals are also present and there are scattered concentrations of granular sphene; (?) topaz is a rare accessory mineral.

A gradation between the quartz-mica-schists and greenschists is exemplified by specimens H.1112.2 and 3 which are fine-grained hard grey-green rocks containing abundant muscovite, biotite and quartz and some garnet (0·3–0·5 mm. in diameter), in addition to actinolite, chlorite, albite and epidote.

6. *Hornblende-schists*

Hornblende-schists crop out at various localities along the southern coast of Coronation Island (particularly at Mansfield Point, Olivine Point, Amphibolite Point and Saunders Point) and also in Cragsman Peaks, where they are locally abundant; more than 60 m. of amphibolitic rocks lie beneath the quartz-mica-schists at Cape Vik, situated at the southern end of Cragsman Peaks. Individual beds of hornblende-schist are rarely thicker than 2–3 m. and their contacts are usually sharp and concordant with the schistosity of the adjacent rocks. However, at Mansfield Point and Saunders Point, the margins of hornblende-schists interbedded with quartz-mica-schists are often bounded by pink garnetiferous laminae which then grade into a poorly defined sequence of bands composed of schists in which garnet is conspicuous (unpublished report of D. W. Matthews). Most of the hornblende-schists are fine- to medium-grained, non-fissile dark green rocks but several textural and mineralogical variations have been noted in the laboratory.

a. *Hornblende-albite-epidote-schists* (H.191.2) are massive rocks with a well-defined mineral lineation and a slightly "saccharoidal" texture. Discontinuous streaks of epidote and quartzo-feldspathic material are the only laminar feature visible in the hand specimen. In thin section, acicular and prismatic hornblende crystals, elongated parallel to each other ($\gamma : c = 22°$; $\alpha$ = colourless, $\beta$ = green, $\gamma$ = blue-green), are associated with abundant epidote crystals and occasional flakes of an olive-green biotite. These lepidoblastic laminae are interrupted by "eyes" of large water-clear albite porphyroblasts ($\simeq$1 mm. in length; $An_7$) which contain numerous inclusions of quartz (sometimes dentate), epidote, hornblende and sphene (Plate Vd). Many of the albite crystals are simply zoned and several are twinned, either simply or polysynthetically according to the albite law; glide twins are the commonest. In a few of the schists (H.551.2, 1149.9, 1151.2 and 1155.1) the albite porphyroblasts are accompanied by both myrmekite and sericite, and one or two relict andesine crystals ($An_{40}$) are present. In these particular specimens, epidote ($\alpha : c = 28°$) is abundant, usually occurring as large zoned crystals (0·3–0·7 mm. in length) which consist of a pleochroic yellow core riddled with dusty inclusions, surrounded by a colourless and inclusion-free rim (Plate Ve); coarse-grained segregations or lenses of granular epidote are rare. Accessory minerals in the hornblende-schists include sphene (occasionally with a yellow-brown rutile core), (?) topaz, skeletal blades of ilmenite (infrequent and sometimes rimmed by leucoxene) and garnet porphyroblasts (0·5 mm. in diameter) containing inclusions of epidote and specks of (?) graphite. Alteration of the hornblende-schists to an aggregate of chlorite, sphene, iron ore, quartz, feldspar and calcite occurs only in shear zones.

b. *Porphyroblastic albite-hornblende-epidote-schists* are faintly laminated rocks with a pronounced "saccharoidal" texture (H.1149.4). Small white albite porphyroblasts are abundant and concordant quartzo-feldspathic segregations and veins enhance the poorly defined foliation. In thin section, these schists are similar to sub-type 6a but they contain considerably more porphyroblastic albite and relatively less hornblende.

c. *Hornblende-albite-biotite-epidote-schists.* Although only a few specimens of this type are present in the rock collections, these schists have been observed *in situ* at Saunders Point, Olivine Point and in Cragsman Peaks. They are similar to the other hornblende-schists but can be distinguished from them by the presence of thin yellow-green epidotic laminae glistening with bronze-coloured biotite flakes (H.1153.3).

d. *Garnet-bearing hornblende-schists* are uncommon on Coronation Island but amongst the most impressive of them macroscopically are the *hornblendegarbenschiefer* collected from Penguin Point, at the north-western tip of Coronation Island. Although these particular specimens have only been seen in thin section (Discovery Investigations station 1964, slide Nos. 38820 and 38821), they are apparently similar to the *hornblendegarbenschiefer* of Signy Island (Thomson, 1968, pl. Vc). The garnetiferous hornblende-schists usually have only a few, sporadic small garnet porphyroblasts but those at Mansfield Point are riddled with large brick-red garnets ($\simeq$2–4 mm. in diameter) which have disrupted the quartzo-feldspathic laminae in the schists and give the rock an augen-like texture (H.2211.13). Apart from the presence of garnet, the microscopic features of these schists are essentially similar to those of sub-types 6a and b.

7. *Mansfield Point schists*

An unusual set of rocks, macroscopically unlike any other recorded schists on either Signy or Coronation Islands, has been collected from Mansfield Point (H.1154 and 2211) and at isolated localities in Cragsman Peaks (H.551, 1149 and 1151). They are interbedded with normal quartz-mica-schists and hornblende-schists (with which they are concordant) but differ from them in being less homogeneous and generally coarser-grained. Their main characteristics are the abundance and variability in crystal size of garnet and the presence of thick but irregular rusty yellow quartzo-feldspathic segregations interleaved with silvery green fibrous laminae; the segregations contain relicts of mafic material and sillimanite (Plate Vf) included in a coarse-grained saussuritized and myrmekitic quartz-feldspar assemblage. The abundance of myrmekite (Plate VIa) accompanying late albite porphyroblasts in both the quartzo-feldspathic and hornblende-rich types suggests that these rocks originally contained some potash feldspar or basic plagioclase, although these are now rarely apparent.

All the garnet crystals in these schists are dark red or brick red in colour but they show a considerable variation in grain-size, even within a single specimen. For example, some parts of the quartzo-feldspathic schists are peppered with tiny garnet crystals (0·5 mm. in diameter) whilst adjacent layers contain much larger garnet porphyroblasts ranging in size from 2 to 10 mm. (H.2211.3 and 5); in a few hand specimens the garnets form prominent "eyes" 2 cm. or more in diameter. The minute garnet crystals are usually associated with lenses of quartz and feldspar, whereas the larger porphyroblasts are present in the micaceous laminae of the quartz-mica-schists. None of the large porphyroblasts is inclusion-free and many of them are darkened by a high content of graphite inclusions. In the hornblende-schists from these localities, garnet occurs either as discrete large porphyroblasts scattered throughout the rock or as largish crystal aggregates in quartzo-feldspathic segregations. These two forms never occur in the same hornblende-schist.

Thinly laminated pink bands of microcrystalline garnet and quartz are a conspicuous feature of some specimens (H.2211.14 and 15), the bands varying in thickness from 0·6 to 3·5 cm. Similar garnetiferous bands occur in hornblende-schists at Gerd Island (H.2204.1) and Saunders Point (H.2202.4) but in these rocks the microcrystalline garnet is brick red in colour and it is accompanied by large irregular iron-ore porphyroblasts. These bands are the equivalent of the "pink veins" on Signy Island (Matthews and Maling, 1967, p. 12). Specimen H.2201.4, also from Saunders Point, is a particularly gneissose rock with disrupted blebs, lenses and micro-folded laminae of pink microcrystalline garnet and quartz in a greenish quartz-mica-schist. At first glance, these garnetiferous blebs resemble irregular weathered porphyroblasts of an acid feldspar.

Coarse flakes of orange-brown biotite are an important mineral constituent in a few of the Mansfield Point schists (H.2211.3 and 4) and large blades of black iron ore (lozenge-shaped and skeletal when seen in thin section and commonly altered to leucoxene or associated with sphene and yellow-brown rutile) are present in several specimens. Clinozoisite and chlorite are common minerals in most of the quartzo-feldspathic schists, where they form pale silvery green layers in the hand specimens; (?) topaz and tourmaline are less widespread. Minute lenses of fibrous prehnite replacing mica are generally uncommon but particularly large lenses have developed in biotite and chlorite associated with acicular actinolite in specimen H.1151.2 (Plate VIb).

8. *Marbles*

Marbles are extremely rare on Coronation Island. They are represented in this collection by five specimens from Return Point (stations H.1103, 1116 and 1117) and two from islands in the Gosling Islands group (station H.1108). Other marble localities on the island are not proven, although D. H. Matthews recorded inaccessible (?) marble bands in the cliffs along the west coast of Coronation Island, both at Sandefjord Bay and to the north of it, and there are possibly marbles near the outcrops of *hornblende-garbenschiefer* at Penguin Point. D. W. Matthews also observed some thin white bands high up on the south face of Mount Sladen near Tophet Bastion, and the presence of small boulders of white marble in a nearby moraine at Saunders Point suggests that these Mount Sladen bands are marble horizons.

The marbles at Return Point are lithologically varied. Those at station H.1103 are thin fine-grained, buff or light grey rocks (7·5 cm. in thickness) interbedded with lustrous black semi-micaceous schists. Although thin, the marbles are impure since they contain irregular and discontinuous dark grey laminae of quartz, albite, muscovite, graphite and chlorite (H.1103.4). Farther inland from Return Point, at stations H.1116 and 1117 there is a thicker marble band (3–10 m.) and two thinner ones. The thick one is complexly infolded with the adjacent semi-micaceous schists and it changes in colour from black at the base of the bed to a light grey rock at the top; its contact with the schists is disrupted by shears. The *black marble* (H.1116.1a–c) is a fine- to medium-grained crystalline rock with thin ($\simeq$1 mm.) graphite-rich black laminae and light grey ones of pure calcite; blades and sheaves of (?) tremolite are present on the surface of one hand specimen. In thin section, the graphite occurs as finely disseminated black specks whilst the calcite forms an interlocking mosaic of twinned crystals, some of which are very irregular and enclose apophyses and apparently discrete blebs of adjacent calcite crystals (similar microscopic features to those of the calcite have been observed by Rigsby (1968, figs. 7–15) in ice crystals). The upper part of the bed is composed of a coarse-grained massive *light grey marble* (H.1116.2) which is buff-coloured adjacent to its contact with the quartz-mica-schist. In places this type of marble becomes rather flaggy. Mortar structure is well defined in the marble and the larger calcite crystals (1·0 mm. in length) tend to be flattened in one direction. Deformation twinning in calcite is common and the twin lamellae are often gently curved or kinked. Isolated quartz crystals and muscovite flakes are present in the marble near its contact with the schist and these become more abundant as the contact is approached. However, in the schist the calcite is present only in strained and granulated quartz-calcite segregations which have partially replaced the micaceous laminae.

Pure *white marble* crops out only in the Gosling Islands. There are apparently several thin bands on the two larger islands of the group and a light greenish cream marble, interbedded with micaceous schists, crops out on an islet between Meier Point and the Gosling Islands (H.1108.9); this specimen is spangled with tiny flakes of muscovite and chlorite.

## B. Mineralogy

Because the detailed mineralogy of the Coronation Island schists is similar to that of the Signy Island schists (Thomson, 1968, p. 14–21), only those minerals from Coronation Island which are of special interest will be discussed here.

### 1. *Feldspar*

The quartzo-feldspathic schists have been subdivided lithologically according to the crystal texture of the feldspars they contain. These feldspars form three well-defined textural types, mostly of an albitic composition ($An_{5\text{-}10}$) but oligoclase-andesine ($An_{28\text{-}36}$) is present in some of the schists from Mansfield Point and Cragsman Peaks; potash feldspar is usually absent.

a. "*Vermicular*" *plagioclase and myrmekitic feldspar*. "Vermicular" plagioclase is the typical feldspar in the fine-grained quartzo-feldspathic schists (sub-type 1a). In these it occurs as small irregular crystals (0·2–0·4 mm. in length) containing minute blebs and vermicular inclusions of quartz (Plate Va); the plagioclase is crudely zoned and partially sericitized with the most heavily sericitized crystals containing the greatest number of quartz inclusions. Poorly defined polysynthetic glide twins have been observed in some crystals and patchy extinction is usual. Similar but much larger feldspars are present in the coarser-grained schists from Mansfield Point, where they are recognizable as albite porphyroblasts projected into by well-defined myrmekite fans (Plate VIa).

Myrmekitic intergrowths are generally believed to be a product of the replacement of potash feldspar by acid plagioclase (Becke, 1908; Deer and others, 1963, p. 76) and the "vermicular" plagioclases so common in the quartzo-feldspathic schists of Coronation Island could be explained by albite replacing earlier potash feldspar during a subsequent phase of albite porphyroblastesis. Staining techniques (Rosenblum, 1956) have failed to reveal any relict grains of potash feldspar in these schists but their lithology and metamorphic grade suggest that either orthoclase or microcline were probably once present.

Numerous other theories have been put forward to explain the formation of myrmekite. These include the belief that myrmekite was the result of a special kind of albitization (Tronquoy, 1912) and the suggestion that in certain cases myrmekite was probably formed, at a late stage of crystallization, by quartz replacing plagioclase and microcline (Sugi, 1930, p. 67). In the Coronation Island schists, vermicular quartz is most abundant in those albite crystals adjacent to thick quartz veins or heavily sericitized areas and this could either corroborate Sugi's hypothesis or indicate a causal relationship between the sericitization of plagioclase and the formation of myrmekite (Barker, 1970). The myrmekite/sericitization relationship has yet to be proved (Phillips, 1972) but other theories concerning myrmekite imply that its formation is connected with deformation of the host rock. For example, Shelley (1970) believed that myrmekitic plagioclase was formed by the porphyroblastic growth of plagioclase around a recrystallizing groundmass of strained quartz, and Phillips and others (1972) have suggested that myrmekite and muscovite could develop at the expense of potash feldspar under retrograde metamorphic conditions. Since the Coronation Island schists have been subjected to retrograde metamorphism, it is possible that this latter mechanism has played some part in the formation of the myrmekitic and "vermicular" plagioclases under discussion. However, the replacement of an original potash-feldspar component by albite was probably the most important factor in their development.

b. *Porphyroblastic plagioclase* forms irregularly shaped, elongate crystals interdigitating with mica (cf. Thomson, 1968, fig. 5) in the micaceous laminae of the thinly laminated schists (sub-type 1a) or closely packed rounded or lensoid porphyroblasts (0·5–1·0 mm. in diameter) in the "saccharoidal" schists (sub-type 1b); porphyroblasts up to 2·0 mm. in diameter are present only in the highly micaceous schists. Inclusions are invariably present and they range from rounded or elongate grains of quartz, epidote, sphene and hornblende to slivers of mica and black specks and trails of graphite. The quartz inclusions often have dentate sutured margins (Plate VIc) which sometimes grade into graphic or vermicular quartz/feldspar intergrowths (possibly an effect of recrystallization during retrograde metamorphism) and all elongate inclusions are orientated with their length parallel to the schistosity of the rock. Helicitic swirls and trails of included mica and graphite occur particularly in those albites present in the micaceous and graphitic schists and indicate their post-kinematic crystallization but there is some evidence for rotation of the porphyroblasts during subsequent ($F_2$) movements. The porphyroblasts commonly have a crude compositional zoning with an irregular narrow rim of a slightly different albitic plagioclase surrounding a core of albite; a film of graphite occasionally separates these two zones. Twinning is rare and nearly always simple rather than polysynthetic, but polysynthetic glide twinning is sometimes present in the outer zone of the plagioclase porphyroblasts. The patchy appearance of some plagioclase porphyroblasts may have resulted from albite replacing earlier crystals of microcline (Starkey, 1959) but it could also be due to reaction between the growing porphyroblast and its inclusions.

The growth of albite porphyroblasts in the Coronation Island schists is unrelated to any surface evidence of igneous activity and it is therefore believed to be the result of metamorphic differentiation (Turner and Verhoogen, 1960, p. 583), the necessary excess soda being derived from authigenic albite present in the original sediments from which these schists were formed. Partial absorption of white mica by the growing albite (Jones, 1961, p. 54) could also have assisted in the development of the porphyroblasts and, since the highly micaceous schists contain the largest albite porphyroblasts, there seems to be a marked relationship between these two minerals. This suggests that the white mica is probably a sodic one, perhaps a mixture of muscovite and paragonite (Thomson, 1968, p. 15); paragonite is only stable in very sodium-rich, low temperature–pressure environments (Iiyama, 1964) and it is known that albite generally replaces it in higher-grade assemblages or low-grade ones which are poor in alumina (Thompson, 1957).

c. *Granoblastic plagioclase.* Metamorphic differentiation has also caused the formation of lenses or thickish laminae of granoblastic plagioclase, associated with microcrystalline or granoblastic quartz, in the flaggy quartzo-feldspathic schists (sub-type 1c). This type forms fine- to medium-grained aggregates of polygonal water-clear crystals (0·2–0·4 mm. in diameter) in which inclusions are rare, although minute black specks of graphite are occasionally present. Twinning and crude compositional zoning of the crystals are uncommon but the cleavage is generally well defined.

### 2. *Garnet*

Garnetiferous rocks are less common on Coronation Island than on Signy Island but they have nevertheless been collected from widely scattered localities over the whole island; additional field information has shown that their distribution is less restricted than was previously thought (Thomson, 1968, p. 23). Garnet porphyroblasts are particularly abundant in, and occur as large dark red crystals protruding from the weathered surfaces of, the Mansfield Point schists and some hornblende- and mica-schists. They are less obvious in the semi-micaceous schists and generally not visible macroscopically in the quartzo-feldspathic schists, but minute crystals of pale pink garnet are present in the quartz-garnet veins and in the rare specimens of quartzite. In thin section the garnets are colourless or pale pink and they are all completely isotropic. Their physical properties ($n = 1{\cdot}79$–$1{\cdot}80$; $a = 11{\cdot}63$Å; $D = 4{\cdot}0$) are more typical of spessartine than almandine (Deer and others, 1962, p. 77, tables 14 and 18) but chemical analyses (Table IV) indicate an average molecular composition of $Alm_{62}Gross_{24}Sp_7Pyr_5And_2$.

Small polygonal and dodecahedral garnet crystals (0·1–0·2 mm. in diameter) or granular aggregates of garnet are present in the quartz-garnet veins and quartzites, whereas crystals developed in the micaceous laminae of the schists are larger (0·3–1·0 mm. in diameter) and form rounded xenoblasts, usually riddled with inclusions; some of these larger xenoblasts become skeletal or web-like towards quartz at their margins. Large porphyroblastic garnets (2+ mm. in diameter) containing helicitic trails of mineral inclusions (quartz, graphite, epidote, sphene and some iron ore) are present in a few of the mica-schists and in the Mansfield Point schists. Simple zoning, in which a rounded and imperfectly shaped core (often riddled with dusty inclusions) is surrounded by an idioblastic and inclusion-free rim, is apparent in the small garnet crystals of the quartz-garnet veins but most large crystals are unzoned. However, one large garnet crystal in a mica-schist shows well-defined repetitive hexagonal zones enhanced by planes of included (?) graphite dust (H.1153.1).

One or two of the larger garnet porphyroblasts have a small core which apparently underwent slight rotation during crystallization (Fig. 5) but most of the porphyroblasts crystallized post-tectonically to $F_1$ (Fig. 6a). A subsequent phase of deformation ($F_2$) produced a second foliation, which wraps around the garnet crystals, and caused slight rotation of a few of them such that *Si* is no longer concordant with *Se* (Fig. 6b and c). Rare fragmentation of the garnet crystals, the growth of quartz and chlorite in the pressure shadows of the porphyroblasts and marginal alteration to orange-brown biotite or to chlorite are associated with this second phase of movements. Complete pseudomorphs of garnet are rare and they are represented either by a scaly mass of biotite and chlorite, with a continuous narrow rim of iron ore, or by a mass of biotite and indeterminate felsic material. Some of the pseudomorphs contain relict inclusion trails (H.2211.9).

### 3. *Epidote*

Small prismatic grains and closely packed granular aggregates of *pistacite* ($\alpha$ = pale yellow or colourless, $\beta$ = greenish yellow, $\gamma$ = yellowish green) are common in the micaceous laminae of the quartz-mica-schists and abundant in many of the hornblende-schists but large zoned epidote crystals (0·5 mm. in length) are present only in a few hornblende-schists (Plate Ve). These zoned crystals have a slightly pleochroic lemon-yellow core, riddled with numerous small specks of dust, and an outer colourless inclusion-free zone which is separated from the core by a plane of black opaque dust; some of the crystals have a semi-idioblastic outer zone and a few have simple post-zoning twins. *Clinozoisite* is present particularly in the Mansfield Point schists where it forms bladed crystals and granular aggregates associated with sericite, muscovite, chlorite, quartz and garnet; the mineral displays anomalous "Prussian blue" interference colours. Scattered grains of *allanite* are uncommon in the Coronation Island schists but they are nevertheless more widespread than in the Signy Island rocks. The crystals are usually strongly pleochroic in shades of yellow, greenish brown or deep reddish brown and they occasionally have an outer narrow irregular zone of colourless pistacite.

TABLE IV

CHEMICAL ANALYSES AND MOLECULAR COMPOSITIONS OF GARNETS FROM CORONATION ISLAND

| | | H.2201.4 | H.2202.3 | H.2211.2 | H.2211.3 |
|---|---|---|---|---|---|
| $SiO_2$* | | 32·9 | 47·1 | 36·7 | 35·4 |
| $TiO_2$ | | 1·9 | 0·1 | 0·1 | 1·8 |
| $Al_2O_3$ | | 23·1 | 16·9 | 22·3 | 21·8 |
| $Fe_2O_3$ | | 0·7 | 0·4 | 1·0 | 8·0 |
| $Cr_2O_3$ | | <0·1 | <0·1 | <0·1 | <0·1 |
| FeO | | 27·3 | 22·2 | 28·7 | 20·0 |
| CaO | | 9·7 | 6·3 | 8·9 | 9·5 |
| MgO | | 1·6 | 1·0 | 1·2 | 1·5 |
| MnO | | 2·3 | 5·9 | 1·1 | 1·5 |
| $Na_2O$ | | 0·3 | <0·1 | <0·1 | 0·3 |
| $K_2O$ | | 0·2 | <0·1 | <0·1 | 0·2 |
| | | NUMBER OF IONS ON THE BASIS OF 24 OXYGENS | | | |
| Si | | 5·32 | 6·01† | 5·86 | 5·61 |
| $Ti^{+4}$ | | 0·23 | — | 0·01 | 0·21 |
| $Al^{+4}$ | | 0·45 | — | 0·13 | 0·18 |
| Ti | $R^{+3}$ | — | 0·01 | — | — |
| $Al^{+3}$ | $R^{+3}$ | 3·95 | 3·87 | 4·06 | 3·89 |
| $Fe^{+3}$ | $R^{+3}$ | 0·05 | 0·06 | — | 0·11 |
| $Fe^{+3}$ | $R^{+2}$ | 0·04 | — | 0·12 | 0·84 |
| $Fe^{+2}$ | $R^{+2}$ | 3·78 | 3·61 | 3·83 | 2·65 |
| Ca | $R^{+2}$ | 1·68 | 1·31 | 1·52 | 1·61 |
| Mg | $R^{+2}$ | 0·39 | 0·17 | 0·29 | 0·35 |
| Mn | $R^{+2}$ | 0·31 | 0·97 | 0·15 | 0·20 |
| Almandine | | 62 | 59 | 67 | 62 |
| Grossular | | 26 | 20 | 26 | 26 |
| Spessartine | | 5 | 16 | 2 | 3 |
| Pyrope | | 6 | 3 | 5 | 6 |
| Andradite | | 1 | 2 | — | 3 |

* $SiO_2$ value checked colorimetrically on 1 mg. portion.
† Quartz confirmed by X-ray powder pattern; 16 per cent by weight deducted before calculation of formulae.

H.2201.4 Pink quartz-garnet segregation; north-eastern cliffs of island at Saunders Point.
H.2202.3 Pink quartz-garnet segregation; mainland north of Saunders Point.
H.2211.2 and 3 Garnet porphyroblasts in Mansfield Point schists; Mansfield Point.

(All analyses by A. J. Easton.)

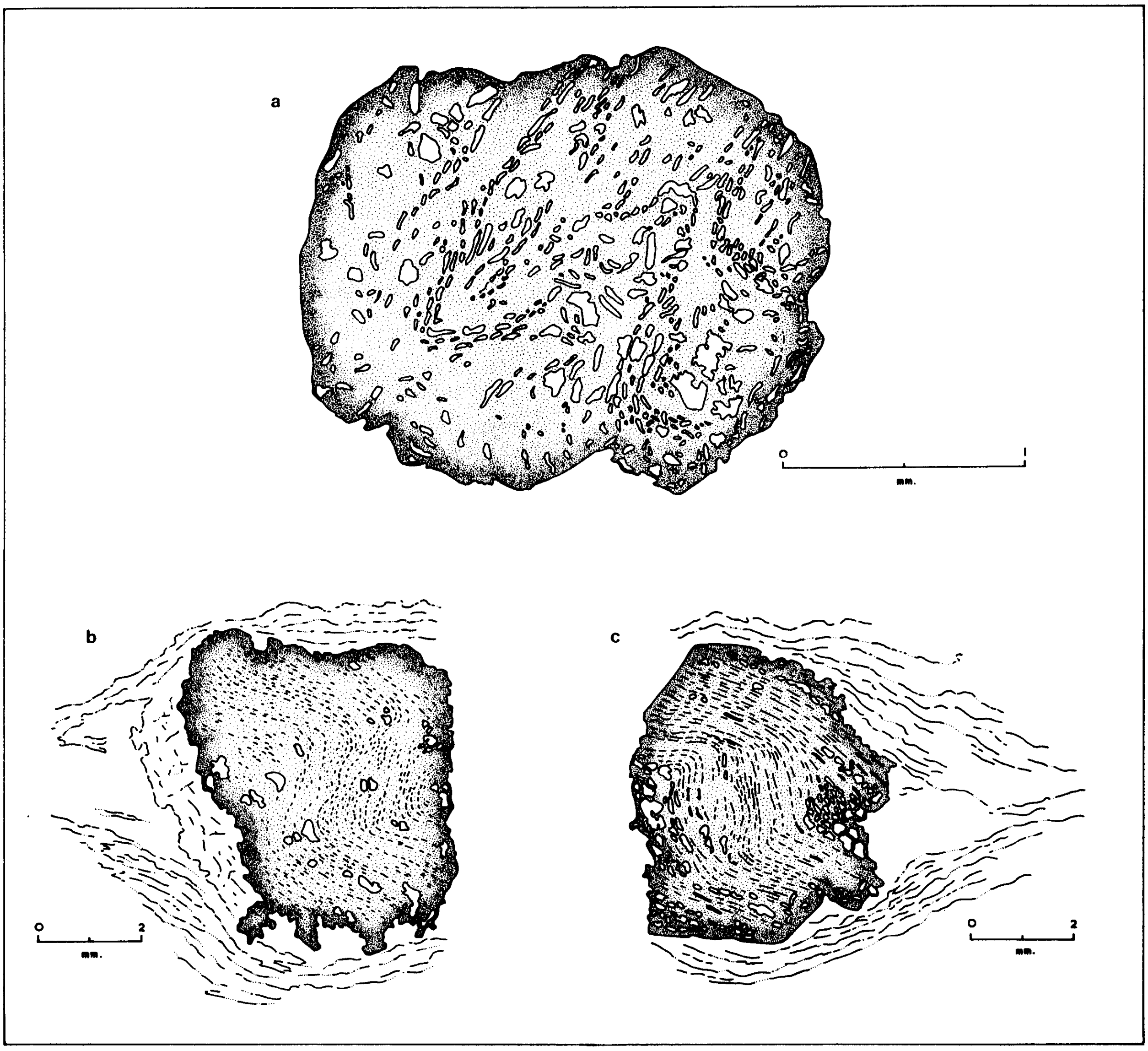


FIGURE 6

a. Helicitic structure in a post-$F_1$ garnet porphyroblast; the contorted trails of inclusions are mostly of epidote crystals but there is some quartz and sphene present; quartzo-feldspathic schist; near Olivine Point (H.2205.2).
b. A post-$F_1$ garnet porphyroblast which has been rotated during $F_2$; the new foliation ($s_2$) is at an angle to the trails of graphite specks included in the porphyroblast. Small kinks in the inclusion trails and their sharp angles suggest that these structures are helicitic rather than rotational; biotite-rich Mansfield Point schist; Mansfield Point (H.2211.8a).
c. As Fig. 6b; semi-micaceous schist; Amphibolite Point (H.249.2).

### 4. *Other accessory minerals*

*Sphene* is the most abundant of the accessory minerals, occurring as pinkish grey lozenges and xenoblasts in most specimens of all the metamorphic rocks. It is particularly associated with mica and amphibole, and some crystals contain relict cores of iron ore (ilmenite) or they are riddled with (?) iron-ore dust; others have a core of dark yellowish brown rutile. Interstitial masses of slightly pleochroic reddish brown rutile are present in only a small number of schists, where they usually accompany biotite and/or garnet. *Iron ore*, although uncommon in the quartz-mica-schists, is abundant in a few of the hornblende-schists (H.551.1–3) where it occurs as triangular, tabular or skeletal black crystals of ilmeno-magnetite, some of which contain inclusions of epidote and cut across large crystals of chloritized hornblende. Similar large skeletal crystals of ilmeno-magnetite are present in one of the quartz-garnet segregations (H.2204.1). Small xenoblasts of (?) topaz occur in most rock types whereas *graphite*, which is more abundant on Coronation Island than in the Signy Island rocks, is only widespread in the mica-schists.

Minute prisms of olive-green *tourmaline* (schorlite; $\omega$ = olive-green, $\epsilon$ = colourless) are scattered throughout the micaceous laminae of all the quartz-mica-schists but they are particularly abundant in the Mansfield Point schists. Many of the small crystals are full of black specks of (?) carbonaceous dust but only a few crystals (H.567.1) are large and poikiloblastic towards quartz, sphene and iron ore. The tourmaline in the normal quartz-mica-schists probably originated from boron trapped in the original sediments from which these schists were derived (Reed, 1958) but the abundant tourmaline in the sericite-clinozoisite-chlorite-quartz laminae of the schists from Mansfield Point is perhaps more typical of that produced by boron metasomatism.

### C. Mineral Veins

Mineral veins or segregations and patches of mineralization are present in approximately 50 per cent of the metamorphic rocks collected from Coronation Island. Quartz is the commonest vein mineral in all the rock types (Table V) and it is often accompanied by other low-temperature minerals such as albite, calcite,

TABLE V

DISTRIBUTION OF MINERAL VEINS IN THE METAMORPHIC ROCKS OF CORONATION ISLAND

| | Q | Q–Ab | Ab | Ab–Chl | Q–Chl | Chl | Q–Pr | Pr | Ca | Q–G | Ep | Others |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quartzo-feldspathic schists | 64 | 4 | 2 | 3 | 3 | 5 | 2 | 1 | 14 | 2 | 1 | 3 |
| Semi-micaceous schists | 14 | — | — | — | — | — | — | — | 1 | 3 | — | 1 |
| Mica-schists | 10 | — | — | — | — | 1 | — | — | 1 | — | — | — |
| Greenschists | 5 | 1 | — | — | — | 1 | — | — | 4 | — | — | — |
| Hornblende-schists | 13 | — | 1 | — | — | 1 | — | — | 6 | 3 | 11 | 2 |

Q quartz, Ab albite, Chl chlorite, Pr prehnite, Ca calcite, G garnet, Ep epidote.

vermicular chlorite (Plate VId) and prehnite. Extensive sericitization is a common feature in many of the rocks immediately adjacent to these veins. The vein albite ($An_{3-8}$) displays well-defined polysynthetic twinning in the wider veins (2–4 cm. in width) but in the narrow veinlets (0·1–0·35 cm. in width) it is represented by cloudy crystals, with characteristic patchy extinction, of the variety pericline (MacKenzie, 1957, p. 512). Laminated pink quartz-garnet veins and segregations are similar to, but apparently less common than, the ones described from Signy Island (Matthews and Maling, 1967, p. 12; Thomson, 1968, p. 22) and they have developed particularly within, or at the contact of, semi-micaceous schists and hornblende-schists; a considerable amount of ilmeno-magnetite is also present in one of these quartz-garnet segregations (H.2204.1). It is interesting to note that quartz-garnet rocks are exposed along part of the south-western coast of Elephant Island, South Shetland Islands (Dalziel, 1972) and these could be comparable to the quartz-garnet segregations described above. In addition to the veining on Coronation Island, sulphide mineralization has been reported in the schists at Saunders Point (unpublished field notes of D. W. Matthews) and in the chilled margin of a dolerite dyke at Olivine Point.

The distribution and general character of the mineral veins suggest that they are metamorphic differentiates (Eskola, 1932) derived locally from the rocks in which they occur. The isoclinally folded quartz-garnet and concordant quartz-feldspar segregations represent segregation banding developed during the initial amphibolite to albite-epidote-amphibolite facies regional metamorphism, whereas the narrow discordant quartz and/or chlorite, albite, prehnite and calcite veins, some of which also cut the dolerite dykes, were emplaced during a much later phase of mineralization. The network of (?) datolite veins (Plate VIe) impregnating a fault breccia (H.1143.10) near Olivine Point is probably associated with this later set of veins.

## D. Metamorphism and Metamorphic History

The Coronation Island metamorphic rocks are predominantly quartzo-feldspathic schists with less abundant mica-schists, relatively uncommon hornblende-schists and rare marbles. In general, they are lithologically similar to the Moe Island Series of Signy Island (Matthews and Maling, 1967, p. 9) and, like the other metamorphic rocks of the South Orkney Islands, they are believed to represent a regionally metamorphosed sedimentary sequence (Tilley, 1935; Matthews and Maling, 1967). Possibly they are the metamorphic derivatives of a sandstone-shale sequence similar to that forming the Greywacke–Shale Formation of Powell, Fredriksen and Laurie Islands (Thomson, 1973) but the graphitic schists, quartzites and thin beds of marble exposed between Return and Meier Points could be the metamorphic equivalents of a black shale-chert-limestone sequence of the type deposited in a restricted depositional environment. The hornblende-schists on Coronation Island differ from those of Signy Island because they are not interbedded with nor do they crop out near any marbles. Therefore, they probably represent either metamorphosed basic lavas and tuffs interbedded with the original sandstone-shale sequence or a pre-$F_1$ set of basic minor intrusions. Pink quartz-garnet laminae and highly garnetiferous schists bordering the hornblende-schists at Mansfield Point and a few other localities possibly represent the interaction of the hornblende-bearing assemblage with adjacent semi-micaceous schists during the initial higher-grade metamorphism. Some of the greenschists exposed in the Gosling Islands crop out near bands of marble and they may represent metamorphosed calcareous shales; others on Coronation Island possibly represent post-$F_1$ basic minor intrusions.

The present fabric of the Coronation Island schists results from a complex interplay of at least three phases of regional dynamo-thermal metamorphism (Table VI). Nevertheless, thin-section investigations

TABLE VI

COMPOSITE STRUCTURAL AND METAMORPHIC HISTORY OF THE CORONATION ISLAND METAMORPHIC COMPLEX

| *Phase* | *Structural event* | *Metamorphic event* |
|---|---|---|
| $F_1$ | Formation of large north–south trending recumbent folds and isoclinal microfolds; development of $s_1$ | Metamorphism of sandstone-shale sequence containing a small number of interbedded lavas or basic igneous sheets. Metamorphic grade varied from albite-epidote-amphibolite to amphibolite facies. Pre-, syn- and post-tectonic crystallization of minerals, especially garnet. Development of pink quartz-garnet segregations and thick quartz veins |
| $F_2$ | Renewed isoclinal folding about north–south axes and formation of large S-shaped folds; development of axial planar foliation ($s_2$) in some rocks and brecciation of others | Retrogressive metamorphism (greenschist facies) of schists in central part of Coronation Island. Some greenschists metamorphosed for first time. Incipient mylonitization but generally no recrystallization of schists at western and eastern ends of island |
| $F_3$ | Formation of open cross folds and gentle warping about west–east axes; noted only at east end of island. Local faulting | No major recrystallization of schists apparent. Weak prehnite-pumpellyite facies metamorphism possibly occurred at this time or later; associated emplacement of thin quartz, calcite, chlorite, albite and prehnite veins in all rock types |

indicate that not all the rocks have a similar metamorphic history, the ones at the western and eastern ends of Coronation Island being mineralogically and texturally less complex than those forming the central part of the island. Such differences can be interpreted in two ways:

i. The central part of the island is older than the western and eastern ends, and it has been subjected to more phases of metamorphism, the earliest metamorphic event being of higher grade than the later ones.

ii. All the rocks are of the same age but they have been affected by differing grades of metamorphism. During successive metamorphic events the distribution of isograds showed similar variations over the island, with the rocks in the centre always being metamorphosed at higher grades than those at either end of the island.

Because the schists throughout Coronation Island seem to have had a similar structural history, the second interpretation is considered to be more probable. It is thought that the highest grade of metamorphism was reached after the primary folding and that, during both the first and second metamorphic events, the locus of metamorphism was in the Cragsman Peaks–Mansfield Point area.

The first metamorphic event on Coronation Island was probably induced by isoclinal and possibly recumbent folding of an original sedimentary sequence. Traces of the folding have been detected in a limited number of specimens, particularly those collected from Mansfield Point, Cragsman Peaks and Saunders Point, but from the mineralogy of the rocks, it is believed that this metamorphic event affected most of the schists exposed on Coronation Island. Although during this episode most rocks reached only the albite-epidote-amphibolite facies (Fyfe and Turner, 1966) of regional metamorphism, the presence of sillimanite (fibrolite) and oligoclase-andesine in a few schists at Mansfield Point indicates that at least some of the rocks were subjected to an amphibolite-facies grade of metamorphism, perhaps the sillimanite-almandine-muscovite sub-facies of Turner and Verhoogen (1960, p. 548). The sillimanite here has a similar mineral association (quartz-muscovite-tourmaline-epidote-garnet) to sillimanite formed by late metasomatic processes in other parts of the world (Williams, 1934; Watson, 1948; Huang, 1957) but as yet, there is no evidence of large-scale igneous intrusion on Coronation Island to support such a derivation.

Later metamorphic events have partially or completely obliterated the crystallization history of the rocks during the first metamorphism but the inclusion trails contained in garnet and albite porphyroblasts indicate that, while some crystallization was pre- and syn-tectonic, most of it was post-tectonic; helicitic inclusion trails in the larger porphyroblasts sometimes represent tight isoclines or show the Z-shaped style of micro-folding initiated during $F_1$. Several of the small garnet crystals in the pink quartz-garnet segregations have simple zoning and a few of the large garnet porphyroblasts are also zoned, indicating that there was more than one phase of garnet crystallization.

Subsequent folding about near-horizontal, north–south-trending axes ($F_2$) produced many of the structures now visible in the Coronation Island schists and it was accompanied by a lower grade of metamorphism in parts of the island. This varied from the chlorite zone of the greenschist facies at Amphibolite Point to the biotite zone in Cragsman Peaks. The schists exposed at the western and eastern ends of Coronation Island are mineralogically and texturally less complex than those cropping out between Norway Bight and Tophet Bastion, and it seems that they were only affected cataclastically by this later metamorphic event. The new foliation ($s_2$) produced during the second period of folding wraps around the post-$F_1$ garnet and albite porphyroblasts, and it is axial planar to the early folds; where these were isoclines, it is indistinguishable from $s_1$ unless there are porphyroblasts present containing relict $s_1$ inclusion trails. In some rock specimens from the central part of the island, only one foliation is apparent and it is assumed that in these $s_2$ has completely destroyed all traces of $s_1$. Widespread mineral growth followed $F_2$ and caused such retrogressive effects as the chloritization of biotite and garnet, the sericitization of plagioclase and sillimanite, the renewed growth of albite as rims around earlier albite porphyroblasts and, in association with the latter, the development of "vermicular" and myrmekitic plagioclases where there was once (?) potash feldspar or oligoclase-andesine present. In all examples of new mineral growth (chlorite, muscovite, some biotite, actinolite, tourmaline, epidote and albite) crystallization was apparently post-tectonic. A few of the hornblende-schists partially retrogressed to actinolite-chlorite-schists but a number of the actinolite-schists probably crystallized for the first time during this event; these may represent the post-$F_1$ emplacement of basic minor intrusions. The schists exposed around Meier and Return Points and those which crop out at the eastern end of Coronation Island were mineralogically unaffected by the second metamorphism and they are distinguished in thin section by an incipient mylonitic or brecciated texture. Mechanically deformed crystals (e.g. kinked or bent mica flakes, strained quartz and albite crystals) are relatively common in these schists.

The complex history of the Coronation Island metamorphic rocks has tended to mask the earlier events and the age of the first folds and metamorphism is not known. However, the second major movement phase ($F_2$) is believed to be contemporaneous with the folding and incipient metamorphism of the

Greywacke–Shale Formation in the eastern South Orkney Islands and both it and the ensuing metamorphism are probably related to the Upper Triassic–Lower Jurassic dates obtained from the South Orkney Islands schists (Miller, 1960; Rex, 1967; Grikurov and others, 1967).

A third phase of less intense deformation ($F_3$) formed the open cross folds in the schists at Cape Bennett, Flag Hill and Pulpit Mountain, and probably also caused the gentle warping about west–east axes of the unmetamorphosed Spence Harbour Conglomerate. Minute lens-shaped aggregates of prehnite, similar to those described by Hjelmqvist (1937), Wrucke (1965), Field and Rodwell (1968) and Zeck (1971), are present in biotite and chlorite flakes both in the schists and in the younger, post-conglomerate dolerite dykes, and, in addition, there are traces of pumpellyite in a few of the dolerites. It would therefore seem that, at a late stage in the geological history of Coronation Island, a weak prehnite-pumpellyite facies metamorphism (Coombs, 1960, p. 342; *see also* Coombs and others, 1970) affected all of the rocks. However, it is not certain whether this metamorphism was related to $F_3$ or was caused by a later event, such as the mid-Tertiary opening of the Scotia Sea.

## IV. SPENCE HARBOUR CONGLOMERATE

THE Spence Harbour Conglomerate, named after the locality from which Pirie (1905) collected the first specimens, crops out at a limited number of localities at the eastern end of Coronation Island (Fig. 7)

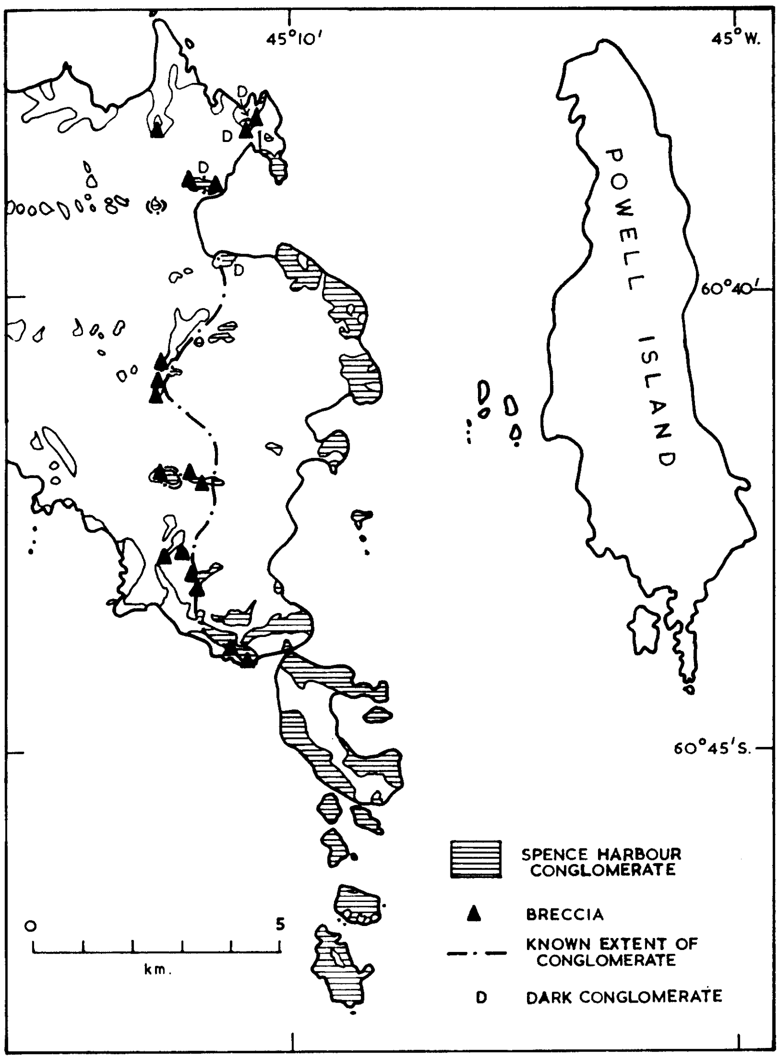


FIGURE 7

Sketch map of the eastern end of Coronation Island showing the known extent of the Spence Harbour Conglomerate and the localities at which breccias and dark conglomerates are present.

and on the Robertson Islands. Although it rests in obvious unconformity on the metamorphic complex of Coronation Island, the exact nature of the contact between the two rock successions is problematical, in part due to the lack of good exposures. Postulated contact surfaces appear to dip more steeply than the bedding in the conglomerate and it is possible that the basal unconformity represents a buried landscape (unpublished report of D. H. Matthews); bedding in the conglomerate generally dips at 20–30° eastward. The conglomerate attains its present maximum thickness of approximately 518 m. at The Turret, the highest point on the east coast of the island.

## A. Base of the Conglomerate

The south-west corner of Gibbon Bay (Plate IIb) is the only locality where the base of the conglomerate has been observed in any detail. Elsewhere the actual contact between schist and conglomerate is obscured by either ice or scree and in some cases by faulting or possibly thrusting.

### 1. *Gibbon Bay*

At Gibbon Bay, the Spence Harbour Conglomerate is separated from the underlying highly sheared schists of the metamorphic complex by a thin bed of slightly sheared black shale, approximately 2 m. in thickness (Fig. 8; Plate IVa). This shale, known as the Gibbon Bay Shale, contains rounded pebbles of

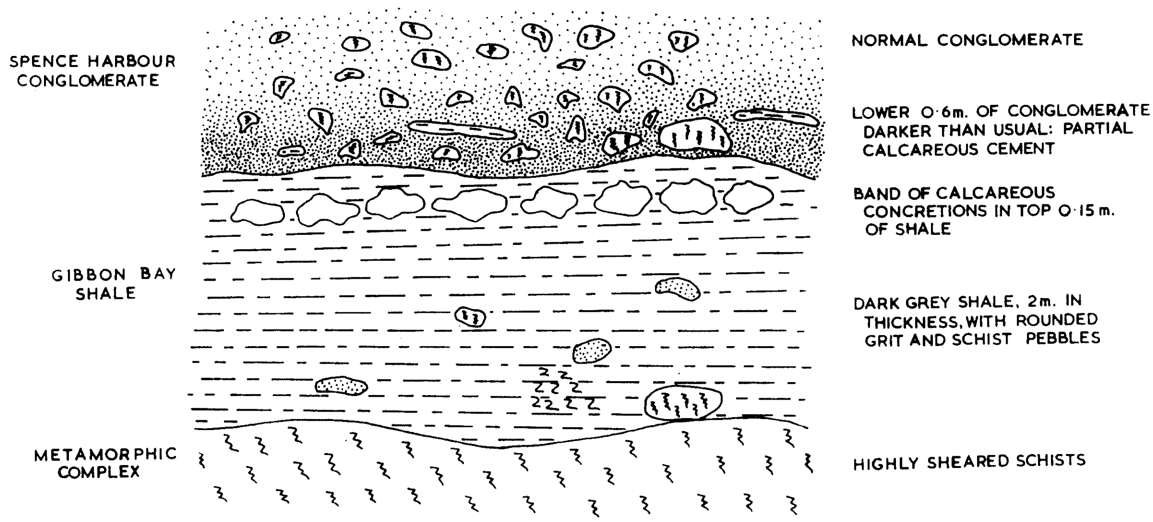


FIGURE 8

Schematic drawing showing the relationship between the metamorphic complex, Gibbon Bay Shale and Spence Harbour Conglomerate at the south-west corner of Gibbon Bay (H.1169 and 1337). The shale close to its basal contact with the schists is sheared into small north–south crumples. (From a field sketch by D. H. Matthews.)

schist, siliceous grit and calcareous grit, a poorly preserved fauna of probable Cretaceous age (Matthews, 1959, p. 435), and towards the top of the bed a band of slightly sheared calcareous concretions; the base and the top of the shale are locally irregular. The lower 0·6 m. of the overlying conglomerate is darker than usual and, although metamorphic debris is predominant, slivers of shale (up to 0·3 m. in length) are also present. This dark conglomerate rapidly passes upwards into the normal light grey or buff-coloured conglomerate.

### 2. *Fulmar Crags, The Menhir and Breccia Crags*

At outcrops along the western limit of the Spence Harbour Conglomerate, the typical light grey conglomerate is associated with a dark grey conglomerate and both black and grey brecciated schists of the underlying metamorphic complex. Brecciation of the schists at Fulmar Crags and Breccia Crags resulted from pre-conglomerate folding (Plate IIId) about north–south axes (the overlying conglomerates contain rounded fragments of brecciated schists identical to the folded and brecciated schists seen *in situ* at these localities) but some breccias were caused by faulting of an age, relative to the conglomerate, which is not always apparent. From laboratory investigations, the relationship between the brecciated schists and the dark conglomerate, with its sometimes chaotic arrangement of angular fragments, appears to be a gradational one and there is an apparently similar gradation from the dark conglomerate upwards into the normal light grey, water-borne rock which forms the bulk of the Spence Harbour Conglomerate.

The contact relations of the schists and conglomerates at both Fulmar Crags and Breccia Crags are obscure but at The Menhir (Plate IIc) the position of the plane of unconformity between the two can be inferred (Fig. 9). On the eastern side of The Menhir, the plane of contact appears to be sub-horizontal whereas that on the western side dips more steeply (unpublished field notes of D. H. Matthews), although it is not clear whether this steep dip is an original pre-conglomerate feature or a subsequent fault surface.

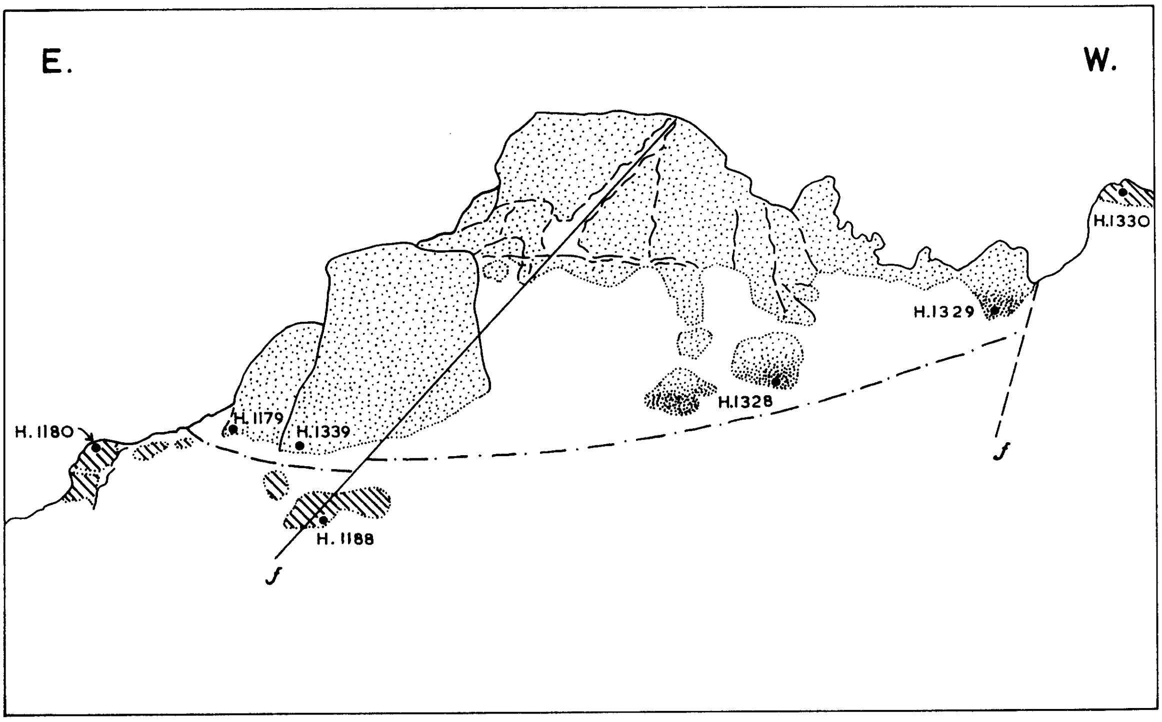


FIGURE 9

Sketch showing the inferred position of the contact between the metamorphic complex (shaded), normal Spence Harbour Conglomerate (stipple) and dark conglomerate (fine stipple) at The Menhir. The Menhir is 397 m. in height and station H.1180 is at an altitude of 145 m. (From a field sketch by D. H. Matthews.)

3. *The Divide*

An easterly dip of the schist–conglomerate contact can be clearly seen in the cliffs on the north side of Whale Bay, from The Divide westward along Divide Peaks. Near The Divide the contact occurs at 24 m. a.s.l. but at station H.239 it is at 37 m. a.s.l. and farther west it reaches 90–120 m. a.s.l. (unpublished field notes of D. H. Maling). Although the dip of the contact has not been recorded, the conglomerate itself near The Divide has an easterly dip of approximately 8°. Dark green brecciated schists, which occur beneath the conglomerate at station H.239, are similar to the brecciated rocks present on the north-western Robertson Islands (H.236 and 237; cf. Thomson, 1971).

## B. Lithology and Petrology

The Spence Harbour Conglomerate is essentially a sequence of conglomerates interbedded with thin, impersistent sandy partings (Plate IVb) and occasional lenses of siltstone and shale. The conglomerates are mostly pebble grade but boulders of variable size up to 2·5 m. in length have been recorded at Rayner Point (Plate IVc), The Menhir, Petter Bay and in the northern cliffs of Divide Peaks. Towards the south-east, the proportion of sandy matrix in the conglomerates increases markedly relative to the amount of coarse debris and the sandstone partings themselves become thicker and more abundant. For example, sandstone partings in the sandy conglomerates near The Turret and in the easternmost exposures on the south side of Petter Bay are 1–3 m. in thickness, whereas those in the normal pebble conglomerates at Rayner Point are as little as 0·6 cm. in thickness (unpublished report of D. H. Matthews).

Bedding in the conglomerate is poorly developed (Plate IId) as it is defined merely by differences in the relative proportions of phenoclasts to matrix and by variations in the size of the phenoclasts. Sandstone and siltstone partings provide some additional indication of the bedding but they thin out within a few metres; the contact between the sandstone partings and the overlying coarser grits or conglomerates is often sharp but this is not invariable. Beds of coarser debris extend over greater distances (up to 50 m.), whereas pockets of the coarsest debris containing blocks more than 1 m. in length are very restricted. Although the distribution of lithological types is lenticular, the bedding is essentially flat. There are neither current bedding nor wash-out structures in the sediments and there is rarely any disturbance of the bedding around large boulders in the sandstone beds. Ripple marks have only been observed in blocks of sandstone which have fallen into Petter Bay from the cliffs of Divide Peaks.

1. *Conglomerates*

The typical Spence Harbour Conglomerate (H.1312.1) is a well-indurated light grey or buff-coloured rock composed of closely packed, pebble-size lithic fragments (1·0–2·5 cm. in length) embedded in a matrix of grit or coarse sand. On weathered surfaces the conglomerate has a bleached appearance and at some localities the clasts are coated with a thin film of limonite. The matrix is a fine- to medium-grained aggregate of angular crystal and lithic fragments (0·5–1·0 mm. in grain-size), petrographically identical to the sandstones which form partings within the conglomerate sequence.

The lithic debris in these rocks is derived predominantly from a metamorphic source (approximately 90–95 per cent), although white pebbles of vein quartz are widespread and form the second most important constituent of the conglomerates (approximately 5–7 per cent). The metamorphic debris comprises quartzo-feldspathic schists (particularly the thinly laminated and non-fissile types), graphitic schists and less commonly garnetiferous quartz-mica-schists, quartzites, garnet-quartz veins and fragments of brecciated schist. Clasts of greenschist and hornblende-schist are rare and as yet no pebbles of marble have been observed. The remaining 0–3 per cent of the lithic debris are represented by clasts of calcareous grit, rare volcanic pebbles and slivers of (?) penecontemporaneous black shale and siltstone. The calcareous grit boulders present in the conglomerate at Rayner Point were originally referred to the "Derived Series" (Matthews, 1959, p. 434) but they are somewhat similar petrographically to the sandstones from partings within the conglomerate and they *could* represent fragments of penecontemporaneous deposits.

The schist fragments are platy and generally more angular than the well-rounded pebbles of vein quartz but, according to a field survey of approximately 280 phenoclasts from or near station H.1331 at Rayner Point (unpublished field notes of D. H. Matthews), the degree of roundness varies considerably: 20 per cent of the clasts are angular, 31 per cent sub-angular, 28 per cent sub-rounded and 21 per cent rounded. Marked angularity of the lithic debris has been observed only in the dark conglomerates. Pebble orientation is barely apparent in the conglomerate specimens studied in the laboratory, although D. H. Matthews (unpublished report) noted that tabular schist fragments usually lie with their flat surfaces parallel to the bedding plane of the rock.

The *dark conglomerates* (H.1177.1) are poorly sorted sediments, of limited distribution, which contain angular schist fragments and tabular quartz clasts embedded in a dark grey, almost black micaceous matrix. The polycrystalline quartz clasts display flaser structures and they were probably derived from the sub-concordant quartz lenses so widespread in the schists of Coronation Island; the lithic fragments are commonly of brecciated schists. The poorly sorted character and marked angularity of the clasts in these dark conglomerates suggests that they are more or less *in situ* and probably represent fossil talus deposits formed against an ancient metamorphic landmass. Although difficult to distinguish from the breccia,

D. H. Matthews (unpublished report) noted two field criteria used in identifying the dark conglomerates:

i. They have bands of coarse debris and occasional rounded vein-quartz pebbles (not verifiable in the laboratory).
ii. They never show the rude foliation which is sometimes present in the brecciated schists.

2. *Sandstones*

The sandstones which form thin partings within the Spence Harbour Conglomerate are highly micaceous, light brownish grey rocks (H.1302.1) composed of fresh-looking angular to sub-rounded crystal fragments of quartz and plagioclase (0·1–0·3 mm.), together with abundant flakes of muscovite, biotite and chlorite and variable amounts of heavy minerals including garnet, sphene, epidote, apatite, tourmaline, allanite and iron ore. Lithic detritus is uncommon in the few specimens available for laboratory study but occasional fragments of polycrystalline quartz and graphitic quartz-mica-schists (1–3 mm. in length) have been observed.

Although a small number of poorly preserved fossil invertebrates have been found in micaceous sandstone blocks on Matthews Island (Thomson, 1971), no similar fossils have been recorded in the Coronation Island sandstone partings. However, faint black streaks in sandstones from Divide Peaks are possibly (?) plant remains (unpublished report of D. H. Matthews). Shell debris is absent from the few sandstone specimens studied in thin section.

3. *Shales*

The Gibbon Bay Shale, which lies beneath the Spence Harbour Conglomerate at the south-western corner of Gibbon Bay, is a dark brown or black gritty shale containing well-rounded pebbles of schist and both calcareous and grey siliceous grits. The calcareous grits are lithologically and petrographically similar to those included in the conglomerate at Rayner Point, whilst the siliceous grits are similar to but much fresher in appearance than the sandstones of the Greywacke–Shale Formation on Laurie and Powell Islands. The shale itself is slightly sheared and it contains occasional thin laminae of sand-sized quartz, plagioclase and epidote grains (0·2 mm.). Flakes of biotite and muscovite are also abundant in these laminae and throughout the shales. Slivers of black shale included in the dark basal part of the conglomerate at this locality indicate that the shale was reasonably solid when the conglomerate was deposited but it is nevertheless believed to form part of the Spence Harbour Conglomerate sequence. Small poorly preserved fossil invertebrates have been collected from the shale here and trace fossils are also present, although they are visible only in thin section. Towards the top of the Gibbon Bay Shale there is a well-defined horizon of calcareous concretions, the largest of which measures 20 cm. by 15 cm. by 8 cm. The concretions are dark pinkish grey, gritty calcite-mudstones in which there are no obvious fossils. Shearing has produced glossy surfaces on several of the concretions, and also tension gashes, which have been infilled by calcite.

There is only one other known shale locality on Coronation Island, at Fulmar Crags, but unfortunately it is not clear from the field data whether the few specimens available for study were collected from a shale parting or a pebble of shale included in the conglomerate. The shale is dark brown in colour and, besides having a higher proportion of silty material, it also contains more clearly defined trace fossils than those in the Gibbon Bay Shale.

## C. Palaeontology

The small fossil collections recovered from the Gibbon Bay Shale and from calcareous grit boulders in the Spence Harbour Conglomerate at Rayner Point have been studied by G. M. Bennison of the Department of Geology, University of Birmingham. The grit boulders have yielded a fragmental molluscan fauna of Bivalvia and Belemnoidea, together with some fragments of fossil wood and one or two echinoid spines. Shell debris is abundant in the grits and a few of the fragments examined microscopically have a lamellar shell structure similar to that of *Ostrea*. Adie (1964*a*, p. 126) implied that several fossils had been recovered from the conglomerate matrix between the calcareous grit boulders but only one fossiliferous specimen (H.1170.1), containing one fragment of a belemnite, can be identified with any certainty as part of the normal conglomerate matrix. A few other fossiliferous specimens, although conglomeratic in appearance, are highly calcareous and generally unlike the usual conglomerate.

The Gibbon Bay Shale has yielded an abundant but poorly preserved small fauna of Bivalvia, occasional brachiopods and gastropods, and a small amount of plant debris. The Bivalvia are rarely larger than 2·5 mm. in diameter and the one more or less complete gastropod in the collection is approximately 1 mm. across. Trace fossils, in the form of vermicular structures, are present in the shales from Gibbon Bay (H.1169.60) and those from Fulmar Crags (H.1177.4). They are visible only in thin section, being about 0·2 mm. in width and between 0·5 and 1·0 mm. in length, and in general they are similar to the vermicular structures present in the Aptian sediments of Alexander Island (Taylor, 1967) and those described by Thomson (1967) from the (?) Cretaceous sediments of Crabeater Point, Bowman Coast. The Gibbon Bay Shale has been examined for plant spores but without any success (unpublished report of D. H. Matthews).

Owing to the poor preservation of the fossils, even generic identifications are generally impossible, and no positive age has been assigned to the fauna. However, G. M. Bennison was of the opinion that the whole fauna is indicative possibly of a Cretaceous age, and L. E. Willey, who has examined the belemnite fragments, considered that the belemnites have either Upper Jurassic or possibly lowest Cretaceous affinities.

## D. Provenance and Depositional Environment

The conglomerate specimens studied in the laboratory show local variations in the degree of roundness and sorting of the clasts. For example, the conglomerates collected from sites close to the schist–conglomerate contact have angular clasts, which have obviously not been transported far, whereas those from outcrops around Spence Harbour and The Turret contain a large proportion of rounded pebbles and relatively few angular clasts. Sorting into bands of coarse and fine debris is also more pronounced in the eastern part of the conglomerate, i.e. at The Turret and the easternmost exposures on the south side of Petter Bay.

The clasts in the conglomerate studied at Rayner Point (unpublished report of D. H. Matthews) suggest that the probable source area of the Spence Harbour Conglomerate was composed predominantly of *para*metamorphic rocks with some vein quartz and minor amounts of grit, shale and volcanic debris. The metamorphic rocks can be identified with those now forming the metamorphic complex of Coronation Island, both on lithology and in the relative abundance of the various rock types; the quartzo-feldspathic schist clasts are generally comparable to the schists from the eastern part of the exposed metamorphic complex, whilst the lack of hornblende-schist and marble fragments in the conglomerate also reflects the paucity of these two rock types in eastern Coronation Island. Although the origin of the vein-quartz pebbles is uncertain, they could have been derived from the numerous quartz veins cutting the local metamorphic rocks; nevertheless some of the larger quartz pebbles are wider than the width of the quartz veins so far recorded on Coronation Island.

The calcareous grit boulders collected from the Gibbon Bay Shale and the conglomerate at Rayner Point are similar in detrital content to the grit partings within the conglomerate sequence. Unfortunately, none of the fossiliferous grits has been observed *in situ* in the South Orkney Islands and, because of this lack of field evidence, it seems unwise either to suggest that they belong to the Spence Harbour Conglomerate or to refer them to the so-called "Derived Series" (Matthews, 1959, p. 434). Volcanic debris (also referred by Matthews (1959) to the "Derived Series") and clasts of siliceous grit resemble the grit and volcanic pebbles which are present in greater abundance in the Powell Island Conglomerate. It appears therefore that, while most of the detritus in the Spence Harbour Conglomerate was derived locally from the west (off the metamorphic complex of Coronation Island), a little debris was introduced from the east or the south-east.

The dark conglomerates were formed perhaps by subaerial mass-wasting of the brecciated metamorphic complex of eastern Coronation Island, whereas the typical light grey Spence Harbour Conglomerate is the result of subaqueous, probably fluviatile, deposition on the lowland beneath a scarp of the ancient metamorphic landmass; large angular blocks of metamorphic rock incorporated in the conglomerate could represent blocks fallen from a scarp face of this old landmass. The Gibbon Bay Shale, which probably accumulated in a shallow pool situated on the old metamorphic lowland, was formed prior to the deposition of the Spence Harbour Conglomerate at this locality. The fossils included in the shale are very poorly preserved but the presence of a few fragments of inflated and strongly ribbed shells, which may be rhynchonellid brachiopods, suggest that the pool was marine rather than fresh-water (personal communication from M. R. A. Thomson); occasional fragments of fossil wood in the shale indicate a proximity to land. Widespread bioturbation of the shales by burrowing organisms is shown by the presence of vermicular structures.

### E. Comparison of the Spence Harbour Conglomerate with Other Late Mesozoic Conglomerates in the Scotia Arc and Adjoining Areas

Although the Spence Harbour Conglomerate and the Powell Island Conglomerate are lithologically similar, there is at present no palaeontological basis for correlating the two. Faunal remains in the Gibbon Bay Shale suggest a (?) Cretaceous age for the overlying Spence Harbour Conglomerate, whereas the palaeobotanical evidence obtained from the Powell Island Conglomerate indicates that the latter is (?) Lower Jurassic in age (personal communication from H. A. Orlando). A detailed comparison of the two conglomerates has already been made (Thomson, 1973) but the relative age of the two formations cannot be understood until further fossils are collected from both of the conglomerates.

A similarly unfossiliferous cobble conglomerate occurs at the base of the Cretaceous sequence on James Ross Island, situated to the south-east of Trinity Peninsula. The conglomerates and finer-grained sediments higher in the sequence are more fossiliferous, containing a well-preserved ammonite fauna which has enabled them to be dated as Campanian (Bibby, 1966). However, the lowest ammonite remains found in this succession are fragments of an indeterminate puzosiinid (Bibby, 1966, p. 19) and they provide an interesting comparison with the few indeterminate ammonite fragments, one a (?) puzosiinid (personal communication from M. R. A. Thomson), which have been collected from sandstone blocks on Matthews Island, South Orkney Islands (Thomson, 1971). The James Ross Island sequence has also yielded a small number of derived fossils: one a (?) Lower Cretaceous bivalve included in a sandstone pebble (Bibby, 1966, p. 20) and another an Upper Jurassic ammonite form.

On the mainland of Graham Land, massive conglomerates and finer-grained sediments have been recorded at Sobral Peninsula and Pedersen Nunatak (Elliot, 1966, p. 14–18). The dominantly conglomeratic sequence at Sobral Peninsula is similar to the Powell Island Conglomerate in having plant-bearing shale beds whose flora could be compared with the Middle Jurassic plant-bearing beds at Hope Bay (Elliot, 1966, p. 18). Nevertheless, the sandstones interbedded with the plant-bearing shales contain a considerable amount of volcanic detritus which was probably derived from the Upper Jurassic Volcanic Group and, because sedimentation in nearby north-western James Ross Island began with coarse conglomerates of Upper Cretaceous age, Elliot (1966) has tentatively assigned the Graham Land conglomerates to the Cretaceous. Similar conglomerates to those on Sobral Peninsula are present on Joinville Island (lying off the north-eastern tip of Trinity Peninsula) but they contain no volcanic debris and a Lower to Middle Jurassic age is more likely for them (Elliot, 1967*b*, p. 31). Fossiliferous sediments of Upper Cretaceous age have also been recorded due south of Sobral Peninsula, at Robertson Island, Seal Nunataks (Cordini, 1959, p. 145; Fleet, 1966); they are represented by approximately 152 m. of thinly bedded siltstones which have yielded fossil serpulids and a few lamellibranchs (Fleet, 1966).

Cretaceous sediments in the South Shetland Islands are represented by ammonite and plant-bearing tuffs on Livingston Island (González-Ferrán and others, 1970) and Upper Cretaceous plant-bearing sediments interbedded with the volcanic rocks on King George Island (Barton, 1965) but there are apparently no thick conglomeratic deposits comparable to those of the South Orkney Islands. However, in the Patagonian Andes of South America, there are considerable thicknesses of locally lenticular conglomeratic beds (the Lago Sofía conglomerates) within the Upper Cretaceous Cerro Toro Formation (Katz, 1963; Scott, 1966). These conglomerates differ from the Spence Harbour Conglomerate in having abundant sole structures, such as load and flute casts and scour channels, and a generally higher proportion of fine-grained intercalated sediments, including widespread pebbly mudstones. In southern Chile there are local occurrences of a (?) Lower Cretaceous sedimentary breccia (Halpern, 1970), which contains clasts of basement schists, and similar sedimentary breccias directly overlying basement schists are also present between Ushuaia and Lapataia in southern Argentina (Palmer and Dalziel, 1973); these possibly are similar to the dark conglomerates of the Spence Harbour Conglomerate on Coronation Island.

## V. MINOR INTRUSIONS

Basic minor intrusions have been observed mostly in the western part of the South Orkney Islands, in particular on Matthews Island and at several localities along the southern coast of Coronation Island (cf. Fig. 2). Nevertheless, Stewart (1937) noted that an altered (?) diabase specimen was collected from Jessie Bay, Laurie Island, by the Scottish National Antarctic Expedition, 1902–04, and there is also a sheet or sill of extremely altered greenstone within the Greywacke–Shale Formation at Fredriksen Island (Thomson, 1973). Stewart did not state whether the Jessie Bay specimen was collected *in situ* or from a boulder but it could have been derived from one of the green chloritic segregations Pirie (1913) observed in the "greywackes" at this locality.

On Coronation Island, vertical or steeply dipping dolerite dykes intrude the metamorphic rocks at Olivine Point, Cape Hansen and near Shingle Cove, and sheet-like intrusions, dipping at 45°, are present at Cragsman Peaks and Return Point. Two dolerite dykes have been observed on one of the Larsen Islands (West, 1968), situated off the west coast of Coronation Island, and two (?) sills, consisting of microdiorite overlying andesite (Kempe, 1973, p. 359), occur at Discovery Investigations station 1963 (south-western Monroe Island); a number of sills have also been seen at a locality half-way along the south-east coast of Monroe Island (personal communication from J. M. Hudson). Another small sill of dolerite intrudes the schists at the base of the cliff at Penguin Point, on the northern coast of Coronation Island (Discovery Investigations station 1964). The dykes have a general trend of approximately west-north-west to east-south-east, although one of those at Olivine Point is almost west–east and the Return Point intrusion trends approximately north–south. The dykes vary in width from 0·3 to 9·0 m., the widest one forming a prominent ridge across Cape Hansen and appearing also as stacks on either side of the headland. No major faults displace any of the intrusions.

As a result of the earlier geological surveys of these islands, it was thought that the dykes and sheets cut the metamorphic rocks but did not intrude the younger conglomerates. Therefore, they were assumed to be pre-conglomerate in age, possibly Cretaceous (Matthews, 1959, table 1) or (?) Upper Jurassic (Adie, 1964*a*, p. 127). However, subsequent observations have revealed a similarly altered dolerite dyke cutting the Spence Harbour Conglomerate on Matthews Island (Thomson, 1971) and the minor intrusions are now believed to be post-conglomerate, possibly Upper Cretaceous or even Tertiary, in age. Unfortunately, the dolerites are altered and, from the samples available, it has not yet been possible to confirm their age by radiometric methods.

The source of the basic dykes may lie in the southern part of the South Orkney Islands shelf, where submarine geophysical investigations have revealed a large and complex magnetic anomaly which possibly represents a granite–gabbro intrusive complex (Harrington and others, 1971). This complex could be similar to the post-Aptian igneous complex of South Georgia and the Andean Intrusive Suite of the Antarctic Peninsula, both of which are associated with younger basic minor intrusions. Shallow-origin magnetic anomalies detected in an area to the south-east of Laurie Island and in the north-west of the group, around the Inaccessible Islands, could also be interpreted as concentrations of basic dykes (Barker and Griffiths, 1972, p. 161).

## A. Petrography

The Coronation Island dolerites (Table VII) are petrographically similar to those described from Matthews Island (Thomson, 1971) and the Larsen Islands (West, 1968). They are generally dark green, medium-grained rocks (0·3–0·5 mm. in grain-size) with an ophitic or sub-ophitic texture, the larger dykes having an aphanitic, sometimes porphyritic, chilled margin. All of the dolerites are altered; the *plagioclase* laths ($An_{50-56}$) and phenocrysts (1–3 mm. in length) are completely saussuritized, although relict polysynthetic albite twinning is still discernible in the laths, and the buff to pale green *augite* ($\gamma : c = 44°$) crystals (some of which are possibly pigeonitic) are partially altered to a greenish brown *hornblende* ($\gamma : c = 18°$). Many of the larger augite crystals are also marginally uralitized and the smaller crystals in the groundmass are altered to either diffuse brown biotite or pale blue-green chlorite. Well-cleaved flakes or mesh-like fibrous aggregates of strongly pleochroic yellow-green *chlorite* and serpentine commonly pseudomorph (?) original olivine or orthopyroxene and they also occur as slivers along the cleavage traces of clinopyroxene crystals. Tilley (1935) referred to the large ones as bastite pseudomorphs after hypersthene but no hypersthene has since been identified in thin section. Rare crystals of *olivine* are present in only one of the dolerites from Olivine Point.

Large skeletal crystals of *ilmeno-magnetite* are marginally altered to sphene/leucoxene, whereas the smaller ones are often completely leucoxenized. *Iron pyrites* is rare in these dolerites but it is exceptionally abundant in a light-coloured specimen (H.1143.6c) collected from the chilled margin of a dyke at Olivine Point. Well-defined plumose aggregates of *quartzo-feldspathic* material and micrographic quartz-feldspar

TABLE VII

MODAL ANALYSES OF DOLERITES FROM CORONATION AND MATTHEWS ISLANDS

| | H.202.3 | H.216.1 | H.250.1 | H.1115.3 | H.1150.6 | H.2208.2 |
|---|---|---|---|---|---|---|
| Plagioclase (altered) | 43 | 47 | 47 | 49 | 38 | 40 |
| Olivine | — | — | * | — | — | — |
| Augite | 25 | 30 | 20 | 5 | 24 | 22 |
| Hornblende | 3 | * | 3 | — | 2 | 2 |
| Biotite | 6 | 1 | 1 | — | 5 | 2 |
| Chlorite/serpentine | 8 | 14 | 19 | 13 | 9 | 17 |
| Iron ore† | 5 | 7 | 7 | 6 | 5 | 7 |
| Epidote | * | — | — | 9 | — | — |
| Prehnite | * | * | * | 6 | * | 1 |
| Pumpellyite | — | * | — | — | * | ? |
| Quartzo-feldspathic mesostasis | 10 | 1 | 3 | 12 | 17 | 9 |
| *Plagioclase composition* | $An_{51}$ | ? | ? | $An_{44}$ | $An_{56}$ | $An_{50}$ |

* Less than 1 per cent present.
† Includes alteration products.

H.202.3 Coarse-grained dolerite from centre of 9 m. wide dyke, west side of Cape Hansen, Coronation Island.
H.216.1 Medium-grained dolerite from 2·5 m. wide dyke at Shingle Cove, Coronation Island.
H.250.1 Coarse-grained dolerite from 6 m. wide dyke on west side of Olivine Point, Coronation Island.
H.1115.3 Medium-grained (?) dolerite from 2·5 m. wide sheet, Return Point, Coronation Island.
H.1150.6 Coarse-grained dolerite from dyke $\simeq$3 m. in width, south-east of Coldblow Col, Coronation Island.
H.2208.2 Coarse-grained dolerite from centre of 9 m. wide dyke cutting the Spence Harbour Conglomerate on Matthews Island.

intergrowths (Plate VIf) fill the interstices of the coarser-grained dolerites but in the finer-grained specimens these appear as fibrous structures and small interstitial quartz crystals. Concentrically zoned radial clusters of (?) *thomsonite* have been observed in a few of the dolerite specimens.

Although several of the dykes on Coronation Island are veined by *prehnite* and/or *calcite*, only one specimen, from a boulder in Shingle Cove (Discovery Investigations station 1093, slide No. 36053), is cut by a narrow prehnite vein which has a discontinuous selvage of granular, bright blue-green *pumpellyite* and strongly pleochroic yellow-green epidote. Sporadic granules of (?) pumpellyite also occur in other prehnite veins cutting the dykes at Cape Hansen and near Shingle Cove, and minute lenses (0·05 mm.) of prehnite, pale green (?) pumpellyite and yellowish green epidote have developed in several of the biotite/chlorite flakes present in the groundmass of the dolerites. Bundles of minute prehnite crystals also occur within the biotite laminae of a quartz-mica-schist collected from the schist–dolerite contact at Cape Hansen; the bundles appear in the hand specimen as numerous small white spots 0·05–1·0 mm. in diameter. Interstitial, semi-fibrous sheaves or rosettes of acicular yellow-green *epidote*, sometimes surrounded by patchy prehnite, are widespread in the (?) dolerite specimens collected from Return Point, the scree in Sandefjord Bay and from Discovery Investigations station 1963 (Monroe Island).

The petrography of the South Orkney Islands dolerites is apparently consistent with the petrographic criteria of tholeiites put forward by Yoder and Tilley (1962, p. 353) and subsequently enlarged upon by Wilkinson (1967, p. 182–84). Nevertheless, there are few positive microscopic criteria for distinguishing between tholeiites and alkali-basalts; in the absence of chemical analyses, these dolerites are only tentatively referred to the tholeiitic series.

## B. DISCUSSION

Several Mesozoic tholeiitic volcanic and hypabyssal episodes have been recognized in the southern continents, the principal ones being represented by the late Triassic to mid-Jurassic* Karroo dolerites of South Africa (McDougall, 1963), the Middle Jurassic dolerites of Tasmania and east Antarctica (McDougall, 1961, 1963; Gunn, 1962) and the Lower Cretaceous Serra Geral Formation of South America (Creer and others, 1965; Amaral and others, 1966; McDougall and Rüegg, 1966). The many dolerite dykes present in the Falkland Islands were originally believed to be late Triassic to Jurassic in age (Baker, [1924]) but it has since been suggested that they may be contemporaneous with the Serra Geral Formation, and therefore of Lower Cretaceous age (Greenway, 1972); one of the Falkland Islands dolerites has been described petrographically as a tholeiite (Brown, 1967).

Younger (Tertiary–Recent) basic dykes and lavas are widespread in the Antarctic Peninsula, the Scotia arc and Patagonia, but only a few of them have tholeiitic affinities. Tertiary or (?) Tertiary doleritic and basaltic dykes have been described from a number of localities both in the Antarctic Peninsula and on several of the offshore islands (e.g. Nichols, 1955; Goldring, 1962; Elliot, 1965, 1966; Fraser, 1965; Hooper, 1966; Fleet, 1968; Dewar, 1970), and to these can probably be added the basic dykes, of unspecified age, described by Gourdon (1914), Tyrrell (1921), Stewart (1937) and Barth and Holmsen (1939). The age of these dykes has been inferred from their association with the Tertiary James Ross Island Volcanic Group (Nelson, 1966) and the fact that at a few localities (Scott, 1965; Fleet, 1968) they intrude plutonic rocks of the late Cretaceous to early Tertiary Andean Intrusive Suite (Adie, 1955); the youngest radiometric ages yielded by the plutonic rocks of this suite are 60–45 m. yr. (Rex, 1971).

Basic dykes which post-date the plutonic rocks are also present in the South Shetland Islands; those on King George Island are apparently associated with Tertiary and Quaternary volcanic centres (Hawkes, 1961*a*; Barton, 1965) and on Robert Island a basalt dyke cuts volcanic conglomerates of a mid-Tertiary age (Caballero and Fourcade, 1959). On South Georgia numerous dolerite dykes are associated with the post-Aptian intrusive complex (Adie, 1964*b*, p. 308) which is exposed in the south-eastern part of the island. No basic dykes have been discovered so far in the sedimentary rocks to the north-east of the intrusive complex nor have they been recorded elsewhere on South Georgia (Trendall, 1959) but highly sheared and altered dolerites, possibly pre-tectonic sills, have been described from several localities along the northern coast of the island (Tyrrell, 1930; Barth and Holmsen, 1939). The altered dolerite sills which intrude the Yahgan Formation of Isla Navarino, southern Chile (Katz and Watters, 1966), are probably of a similar age to the pre-tectonic sills of South Georgia, whereas the many dolerite sheets cutting the Upper Cretaceous Cerro Toro Formation in southern Patagonia (Fujiwara and others, 1968) are probably contemporaneous with the basaltic volcanism which was widespread in Patagonia during late Tertiary (Pliocene) and Quaternary times (Mercer, 1969; Zambrano and Urien, 1970, p. 1394).

Relatively few of the minor intrusions described from the Antarctic Peninsula have tholeiitic affinities, the few exceptions being some of the dykes from the Nordenskjöld Coast and one from Mount Jacquinot, north-western Trinity Peninsula (Elliot, 1967*a*, p. 93). Nevertheless, there is evidence of tholeiitic magmatic activity during Tertiary and Quaternary times in both the South Shetland Islands and the South Sandwich Islands. Hawkes (1961*a*, p. 27) believed that the earliest of the Tertiary lavas on King George Island and the Recent volcanic sequence of Deception Island (Hawkes, 1961*b*, p. 39) were possibly derived from a parental tholeiitic magma, and, in the South Sandwich Islands, tholeiitic lavas were extruded during the late Tertiary (Baker, 1971).

Although the absolute age of the South Orkney Islands dolerites is not known, their altered appearance in thin section indicates that they may belong to an early Tertiary, rather than a late Tertiary–Recent episode of magmatic activity. It is thought they could be of a similar age to the dykes associated with the igneous complex on South Georgia.

* According to the geological time-scale of Kulp (1961).

# VI. DISCUSSION

TABLE VIII indicates that the metamorphic rocks of Coronation Island were affected by at least three phases of folding and, to a certain extent, it is possible to relate these to movements on a regional scale within the Scotia arc. It has long been held that the Scotia arc was produced by the disruption and fragmentation of a once continuous Andean–Antarctandean cordillera (Barth and Holmsen, 1939; Matthews, 1959; Hawkes, 1962; Dalziel and Elliot, 1971) and most reconstructions generally suggest that this continental belt was originally rectilinear in shape, although Barker and Griffiths (1972) assumed that "the cuspate shape of the junction between South America and the Antarctic Peninsula existed before the breakup of Gondwanaland". As yet there is no certainty about when the actual disruption occurred but many authors favour a post-Cretaceous, Middle to late Tertiary age (Dalziel and Elliot, 1971; Barker and Griffiths, 1972; Dott, 1972) and this is consistent with the post-Middle Tertiary age suggested for most of the Scotia Sea (Barker, 1971).

TABLE VIII
COMPOSITE GEOLOGICAL HISTORY OF CORONATION ISLAND, SOUTH ORKNEY ISLANDS

| *Age* | *Structural event* | *Metamorphic grade* | *Other events* |
|---|---|---|---|
| (?) Middle Tertiary | [Formation of Scotia Sea] | (?) Prehnite-pumpellyite facies* | |
| (?) Late Cretaceous–early Tertiary | $F_3$ folding about west–east axes<br>Local faulting | | Intrusion of dolerite dykes and sills |
| (?) Early Cretaceous | | | Deposition of Gibbon Bay Shale and Spence Harbour Conglomerate on lowland beneath scarp of ancient metamorphic landmass |
| (?) Late Triassic–early Jurassic | $F_2$ folding about north–south axes | Cataclastic to greenschist facies | Possible intrusion of small basic sheets |
| Age unknown | $F_1$ folding about north–south axes | Albite-epidote-amphibolite to amphibolite facies | |

* Age of prehnite-pumpellyite facies metamorphism depends on age of dolerite intrusions (see text).

According to recent reconstructions of the Scotia arc, the South Orkney Islands formed part of the main Andean–Antarctandean cordillera. On the basis of marine geophysical data, it has been suggested that they were originally situated close to Elephant and Clarence Islands, in the South Shetland Islands, and not far from the north-eastern tip of the Antarctic Peninsula (Dalziel and Elliot, 1971, fig. 3). The metamorphic rocks of Elephant and Clarence Islands (Tilley, 1930; Tyrrell, 1945) are lithologically similar to those of the South Orkney Islands and they also have a similar polyphase structural history (Dalziel and others, 1970). (?) Late Precambrian micro-fossils (Acritarcha) have been described from the phyllites of Clarence Island (Iltchenko, 1971) and, although no comparable fossils have been discovered in the South Orkney Islands schists, they are generally referred to as (?) Precambrian or early Palaeozoic in age (Adie, 1964*a*). The schists from Signy Island have recently yielded a Rb-Sr whole-rock age of 300±50 m. yr. (Rex and Baker, 1973, p. 57) but the K-Ar age determinations made on the metamorphic rocks from the two groups of islands have yielded dates which differ considerably. The ones obtained from the South Orkney Islands schists range from Upper Triassic to Lower Jurassic and may represent the effects of the early Mesozoic Gondwanian orogeny (they are possibly related to the second phase of folding on Coronation Island), whereas those obtained from the Elephant Island rocks (78–88 m. yr. (Dalziel, 1972); 100 m. yr. (Rex and Baker, 1973)), and from two low-grade schists on Clarence Island (30 and 55 m. yr. (Grikurov and others, 1970)) to some extent reflect the late Mesozoic–early Tertiary Andean orogeny. Although it is clear that a third phase of deformation (involving gentle tilting and brittle fracture of the rocks) affected the unmetamorphosed (?) Cretaceous Spence Harbour Conglomerate on Coronation Island, the South

Orkney Islands schists have not yielded any "Andean" dates. This is possibly because the deformation was too weak to produce any apparent change in the internal fabric of the schists or cause the release of radiogenic argon. The discrepancy in the dates suggests that either these two groups of islands were not contiguous during late Mesozoic–early Tertiary times or that the dates obtained from the South Shetland Islands rocks have been re-set by subsequent plutonism.

In Graham Land, the Jurassic and younger rocks are essentially undeformed and it seems that here, as in the South Orkney Islands, the folding associated with the Andean orogeny was also weak (Adie, 1964*a*). However, in Tierra del Fuego the deformation was apparently much more intense since it caused the regional metamorphism of some of the Jurassic and Cretaceous sediments and volcanic rocks (Kranck, 1932, p. 81; Katz, 1964). These differences in the intensity of deformation associated with the Andean movements led to the suggestion that the initial break between South America and Antarctica had occurred by the end of the Jurassic to the beginning of the Cretaceous (Dalziel and Cortés, 1972), the two parts of the cordillera then evolving separately. Nevertheless, it appears that in southern South America, throughout the Scotia arc and in the Antarctic Peninsula, there was a late, very low-grade (prehnite-pumpellyite facies) regional metamorphism. The effects of this metamorphism are particularly noticeable in the Mesozoic volcaniclastic rocks of the Yahgan Formation, Tierra del Fuego (Watters, 1965), the Cumberland Bay Series of South Georgia (Trendall, 1959; Skidmore, 1972), the Mesozoic volcanic and volcaniclastic rocks of part of the Antarctic Peninsula (Fraser and Grimley, 1972) and the Lower Cretaceous sediments of south-eastern Alexander Island (Horne, 1968). Although it is rare because of inappropriate host-rock composition, prehnite is also present in the South Orkney Islands schists and dolerites, and it has been reported in a few metamorphic and igneous rocks of Graham Land (e.g. Hoskins, 1963; Fraser, 1965). The age of this metamorphism is not certain but, depending on the age of the slightly prehnitized dolerite dykes of the South Orkney Islands, it could be related to either the Andean orogeny or the further disruption and dispersal of the north and south Scotia Ridges during the mid- to late-Tertiary opening of the Scotia Sea.

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# PLATES

PLATE I

a. Looking north across Borge Bay (foreground) and Normanna Strait to Cape Hansen (right of centre), one of several prominent headlands situated along the southern coast of Coronation Island; the low ice cliffs of Laws Glacier are visible to the west of Cape Hansen. (Photograph by D. H. Matthews.)

b. A view towards the west of the indented southern coast of Coronation Island from the north-western end of Divide Peaks. Cape Hansen is the most distant headland visible. (Photograph by D. H. Matthews.)

c. Large patches of exposed rock in the north-facing cliffs of Divide Peaks; the low ice cliffs in the foreground are in Petter Bay. (Photograph by D. H. Matthews.)

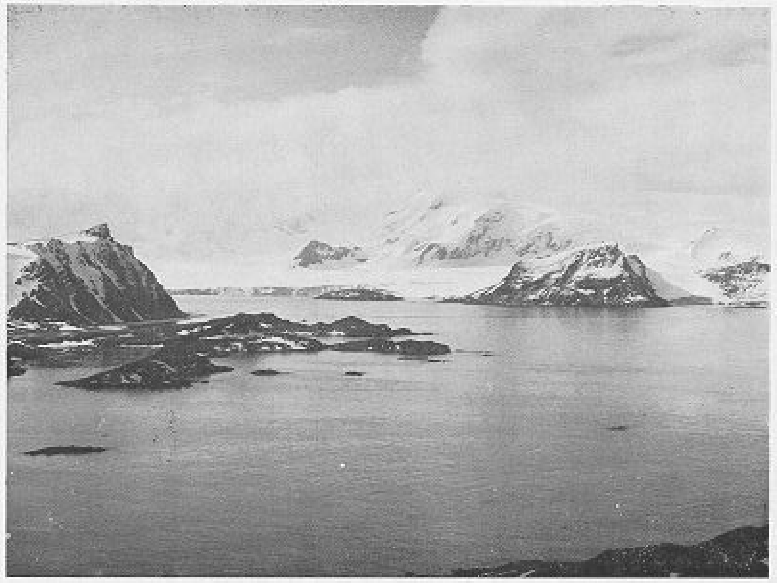

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PLATE I

## PLATE II

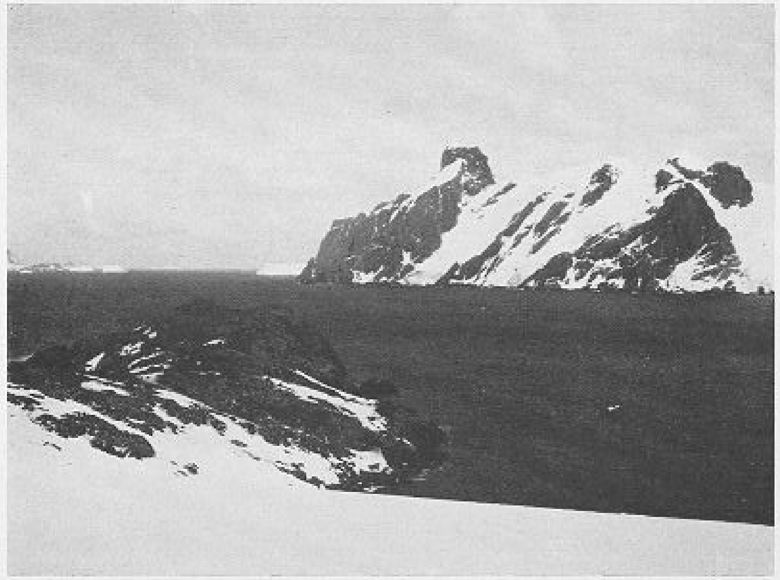
a. Looking south across Gibbon Bay to the massive conglomerate cliffs of The Turret. The low promontory in the foreground is Rayner Point. (Photograph by D. H. Matthews.)

b. The locality at the south-west corner of Gibbon Bay (×) where the Spence Harbour Conglomerate–Gibbon Bay Shale–schist contacts are exposed. Plate IVa shows a close-up of the conglomerate–shale contact. (Photograph by D. H. Matthews.)

c. A view of The Menhir showing its massive blocky summit, composed of conglomerate; the lowest outcrops, near the edge of the ice cliff, are of schist (cf. Fig. 9). This photograph depicts the area a short distance to the right of that shown in Plate IIb. (Photograph by D. H. Matthews.)

d. Looking up at the massive cliffs of conglomerate in the north face of the peak due south of The Turret. (Photograph by D. H. Matthews.)

PLATE II



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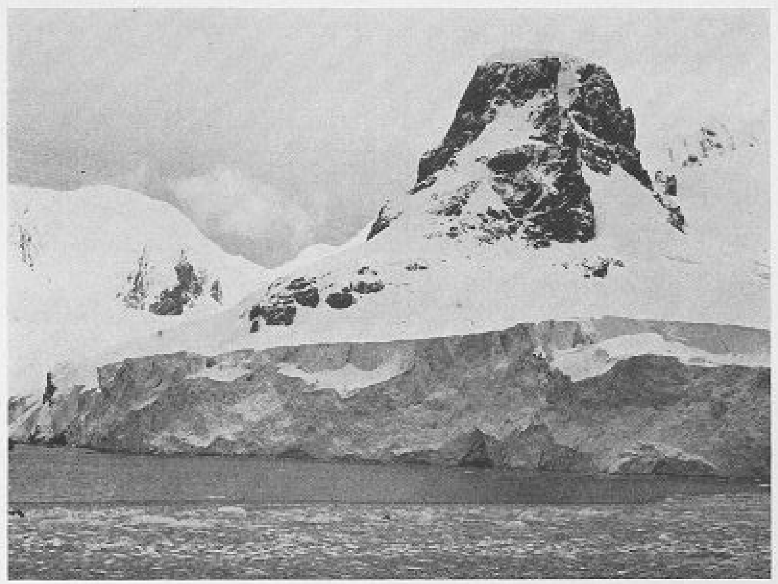

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PLATE III

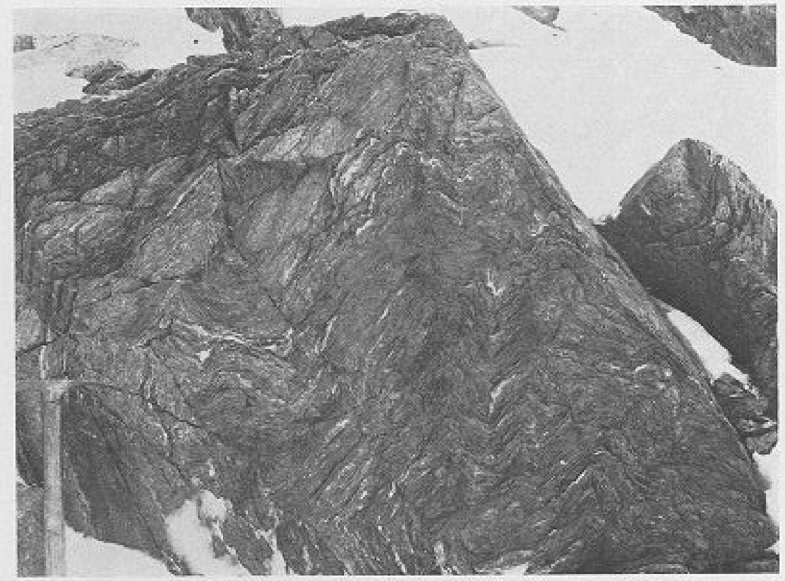
a. Typical recumbent and asymmetric micro-folds, with disharmonic features, in a thinly laminated quartz-albite-biotite-muscovite-schist from the central part of Coronation Island (H.194.2; ×2).

b. Angular cross folds in an outcrop of flaggy quartzo-feldspathic schists at station H.1342. (Photograph by D. H. Matthews.)

c. The eastern sea cliffs at Meier Point showing quartzites interbedded with black graphitic quartz-mica-schists. (Photograph by D. H. Matthews.)

d. The core of a small brecciated $F_2$ fold exposed in flaggy quartzo-feldspathic schists on the south-east face of Fulmar Crags; clasts of such brecciated schists are included in the overlying Spence Harbour Conglomerate. The hammer shaft is about 30 cm. in length. (Photograph by D. H. Matthews.)

a



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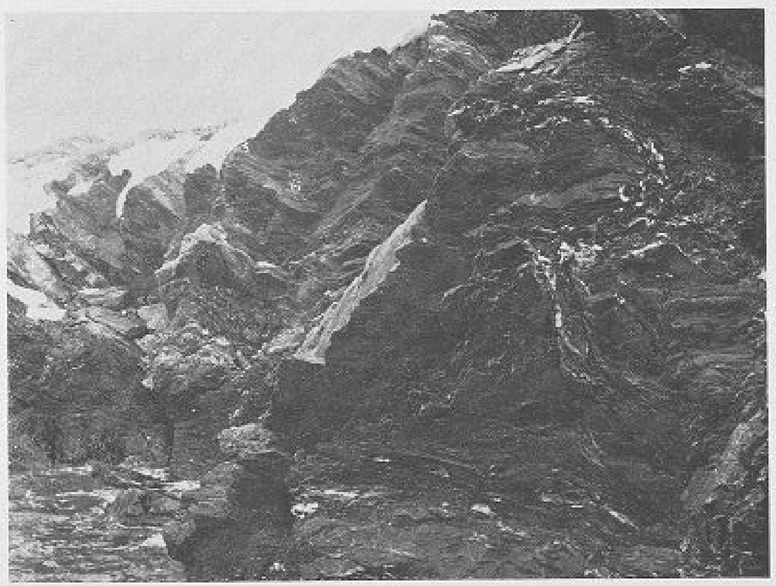

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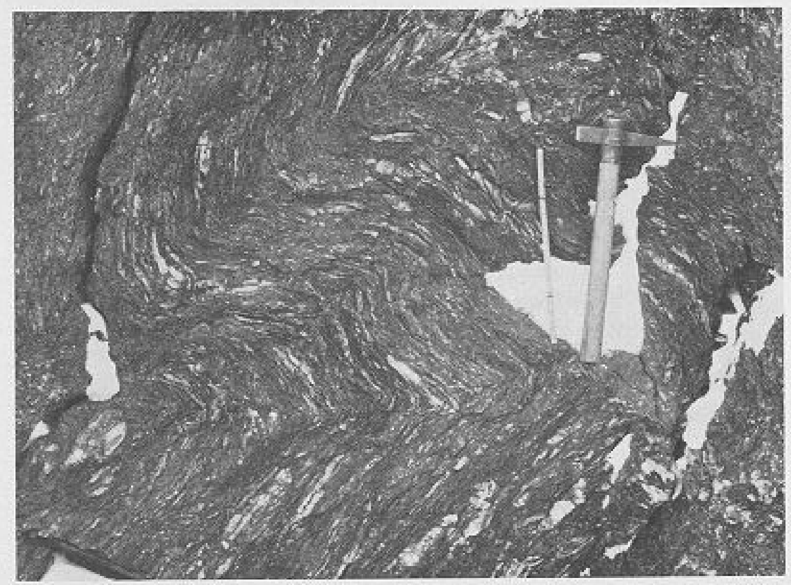

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PLATE III

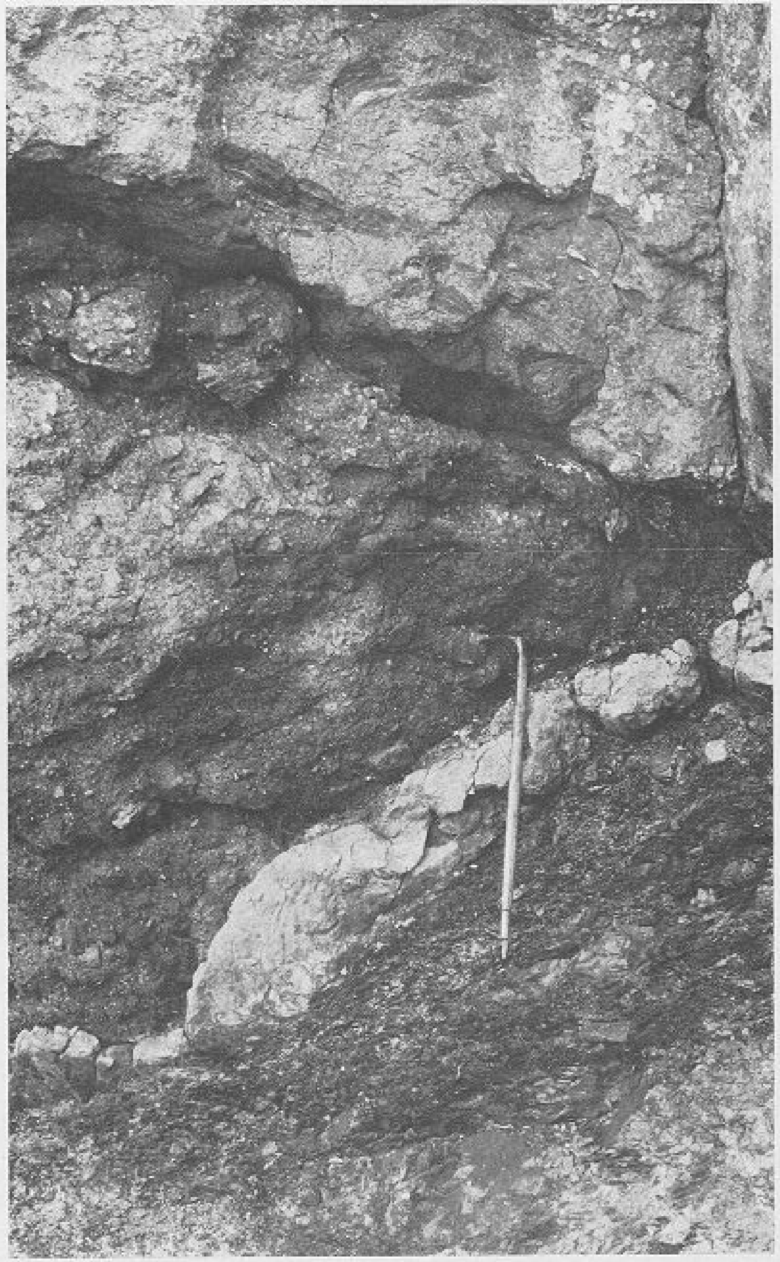
## PLATE IV

a. Spence Harbour Conglomerate overlying Gibbon Bay Shale at the south-west corner of Gibbon Bay (see Plate IIb). The shale contains scattered pebbles and boulders, and lies below the horizon of light-coloured calcareous concretions; the head of the ice-axe is about 30 cm. in length. (Photograph by D. H. Matthews.)

b. Pebble conglomerate exposed in the sea cliff at Rayner Point. Coarser debris is present higher up the cliff and the hammer head rests on an impersistent sandy parting; the hammer head is 15 cm. in length. (Photograph by D. H. Matthews.)

c. Boulders of varying size in a coarse conglomerate horizon exposed on the east side of Rayner Point; the penguin is about 50 cm. in height. (Photograph by D. H. Matthews.)

PLATE IV



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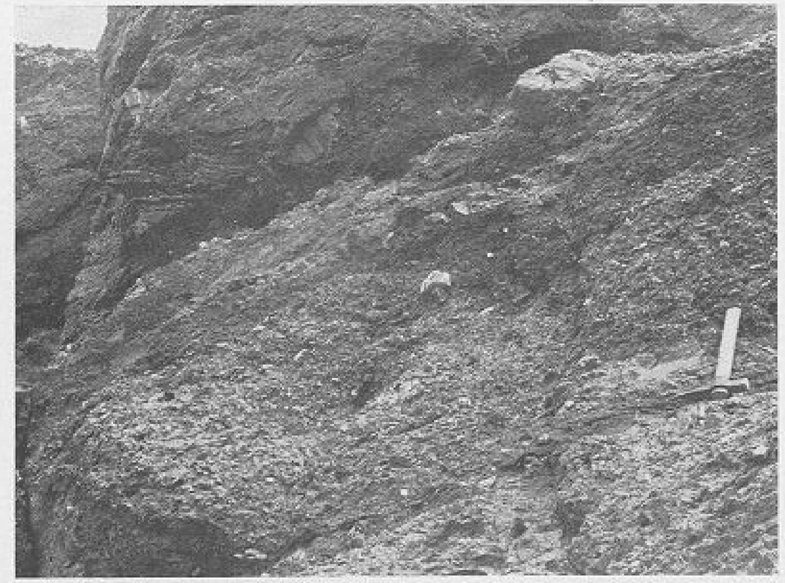

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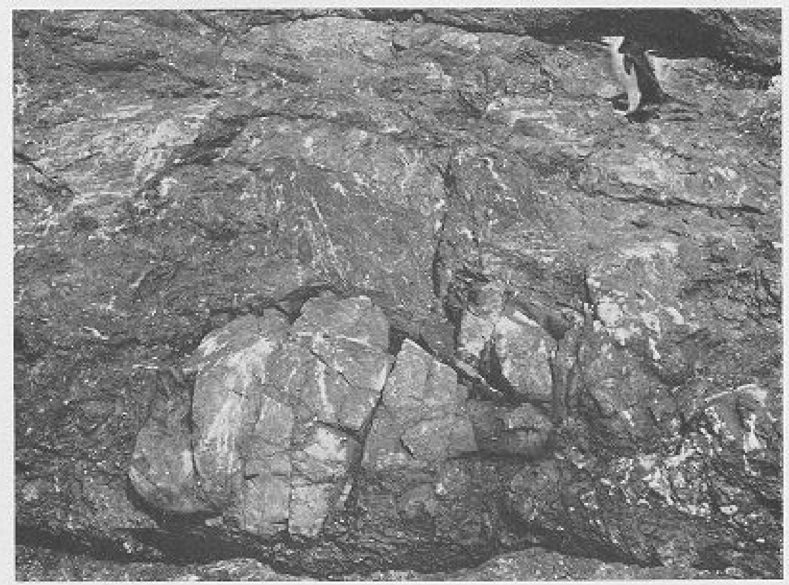

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## PLATE V

a. Small blebs and vermicules of quartz enclosed by albite crystals in a thinly laminated quartz-albite-biotite-muscovite-schist (H.199.1; X-nicols; ×160).

b. An albite porphyroblast riddled with inclusions of quartz, epidote and sphene; porphyroblastic albite-quartz-biotite-schist (H.189.1; X-nicols; ×155).

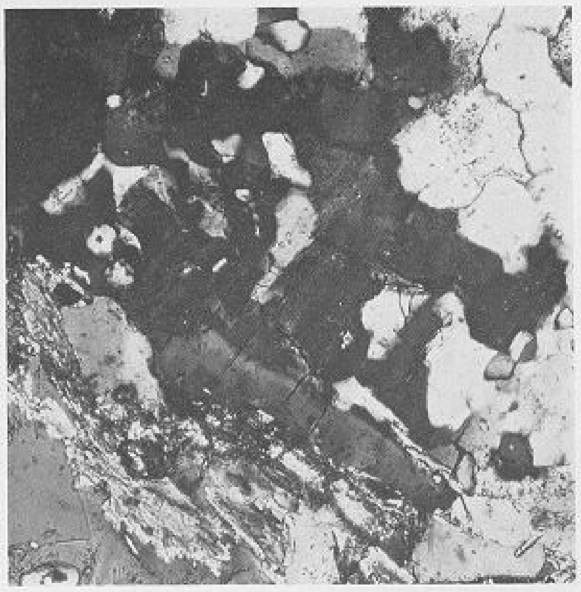
c. Flattened aggregates of granoblastic albite in a flaggy quartz-albite-biotite-muscovite-chlorite-schist (H.242.1; X-nicols; ×165).

d. "Eyed" texture in a hornblende-albite-epidote-schist; the water-clear albite porphyroblasts contain inclusions of hornblende and epidote (H.1149.9; ordinary light; ×40).

e. A zoned epidote crystal in a hornblende-albite-epidote-schist; the inner zone is strongly pleochroic and full of inclusions (H.551.2; X-nicols; ×200).

f. Sillimanite (fibrolite) altering to muscovite in a Mansfield Point schist (H.2211.4; X-nicols; ×180).

PLATE V



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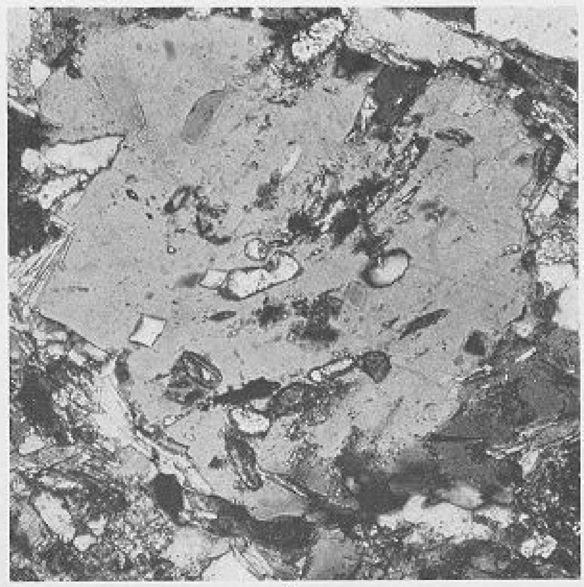

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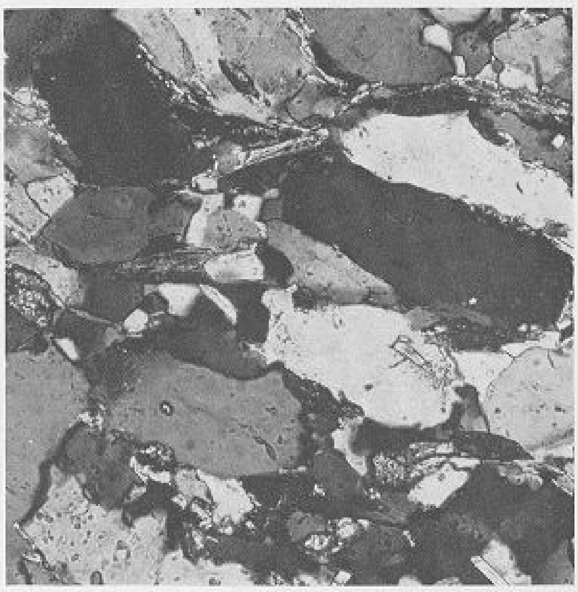

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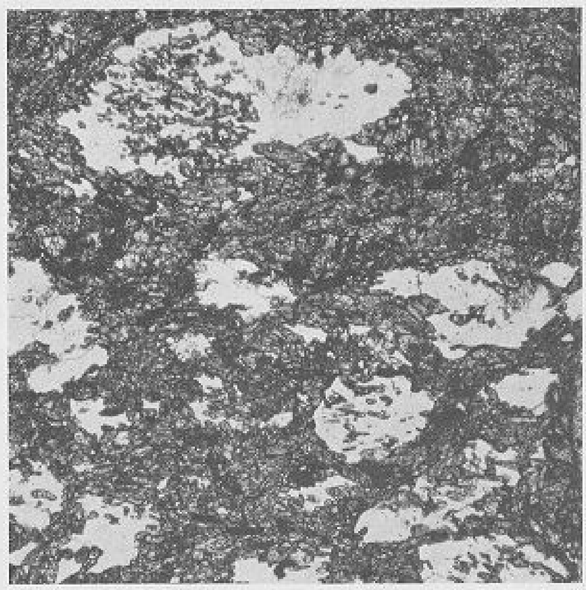

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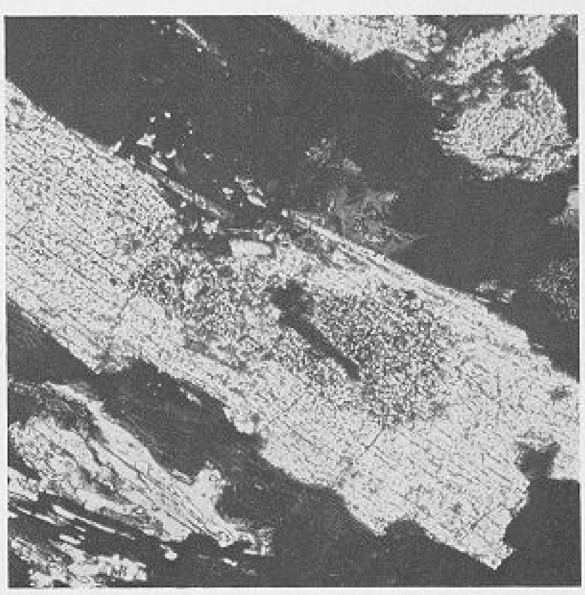

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## PLATE VI

a. Myrmekite developed near late albite porphyroblasts in a biotite-rich Mansfield Point schist (H.2211.1a; X-nicols; ×200).

b. Minute lenses of prehnite pushing aside the cleavage of biotite and chlorite flakes; a little acicular actinolite is also present; hornblende-rich Mansfield Point schist (H.1151.2; X-nicols; ×200).

c. Dentate quartz inclusions in a large albite porphyroblast; trails of graphite specks and small crystals of garnet are also included in the porphyroblast; graphitic muscovite-quartz-albite-schist (H.1155.3; X-nicols; ×165).

d. A vein of pericline and vermicular chlorite cutting a thinly laminated quartzo-feldspathic schist (H.1160.1; X-nicols; ×200).

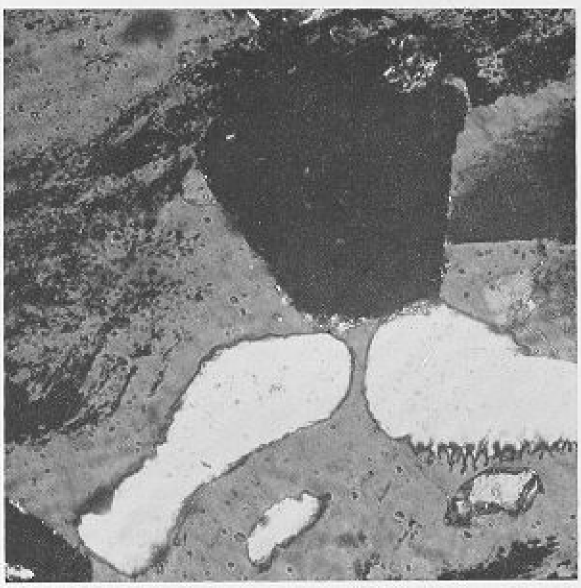
e. Crystals of (?) datolite from a network of veins impregnating a fault breccia (H.1143.3; X-nicols; ×200).

f. Micrographic quartz-feldspar intergrowth in one of the coarser-grained dolerite dykes (H.1150.6; X-nicols; ×200).

PLATE VI

a

b



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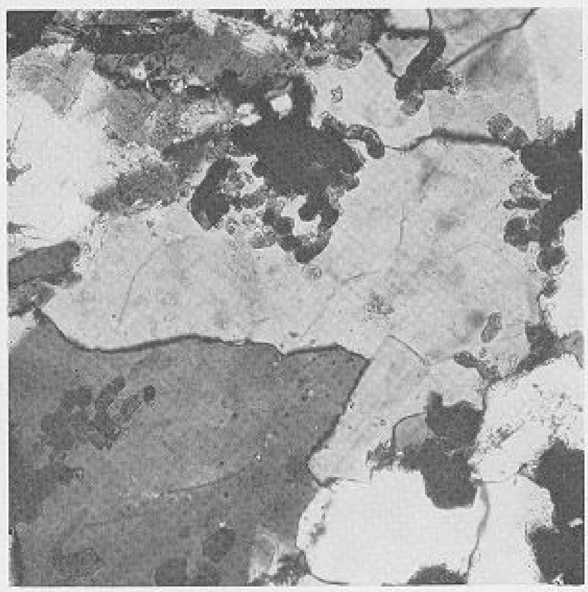

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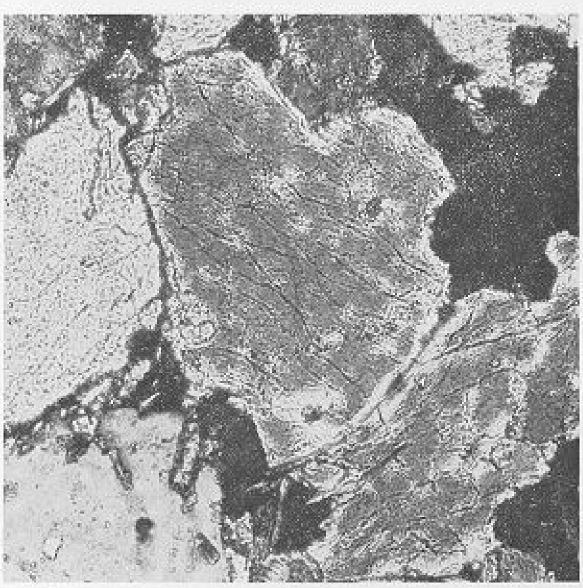

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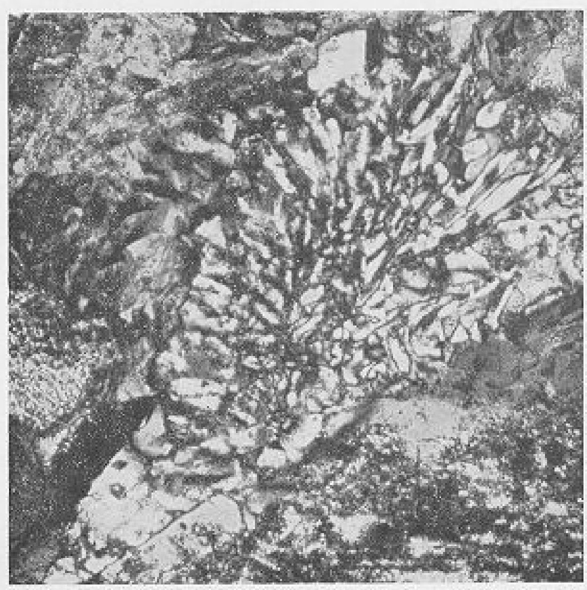

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