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THE GEOLOGY OF SOUTH GEORGIA—II

By

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Falkland Islands Dependencies Scientific Bureau

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(Manuscript received December 1954)

ABSTRACT

THIS report augments the observations recorded in an earlier publication (*Falkland Islands Dependencies Survey Scientific Reports*, No. 7) on the sedimentary succession of South Georgia, and also includes the results of field and laboratory work on the igneous complex in the south-eastern part of the island.

The application of recently published work on the origin of greywacke facies deposits to the sedimentary rocks of South Georgia has led to the conclusion that the Mesozoic *Cumberland Bay type greywackes*, which are composed mainly of volcanic material and form the greater part of the island, were laid down by a succession of northward-flowing turbidity currents on a gentle submarine slope on the north side of a volcanic archipelago. Although additional information is given on the *Sandebugten type greywackes*, which are not of volcanic origin, their precise relationship to the younger Cumberland Bay type rocks is still uncertain. Pillow and massive lavas, including basalts and spilites, are interbedded with part of the Cumberland Bay type rocks.

The intrusive igneous complex at the south-eastern end of South Georgia is composed of granite, granite-gneiss, migmatite and quartz-diorite as well as large gabbro bodies, which are sometimes layered. The emplacement of the acid intrusive rocks was probably contemporaneous with orogenic movements, which resulted in the folding and local metamorphism of the sedimentary rocks, while the basic rocks were probably intruded at a later date. Two intersecting sets of dykes cut both the igneous complex and the local sediments and lavas.

A synthesis of the structural evolution of South Georgia in its regional setting is also presented.

CONTENTS

I. INTRODUCTION

A. SCOPE OF THIS REPORT

THIS report embodies the results of geological field work carried out by the second South Georgia Expedition (October 1953 to April 1954) under the leadership of Duncan Carse, and subsequent laboratory work at the University of Liverpool. It augments and amends the previous report (Trendall, 1953), which was based on field and laboratory work carried out in 1951 and 1952. Although new evidence has modified earlier opinions, the first report contains much factual information not included here.

The routes followed in South Georgia during 1951 and 1953–4 are shown in figure 1.

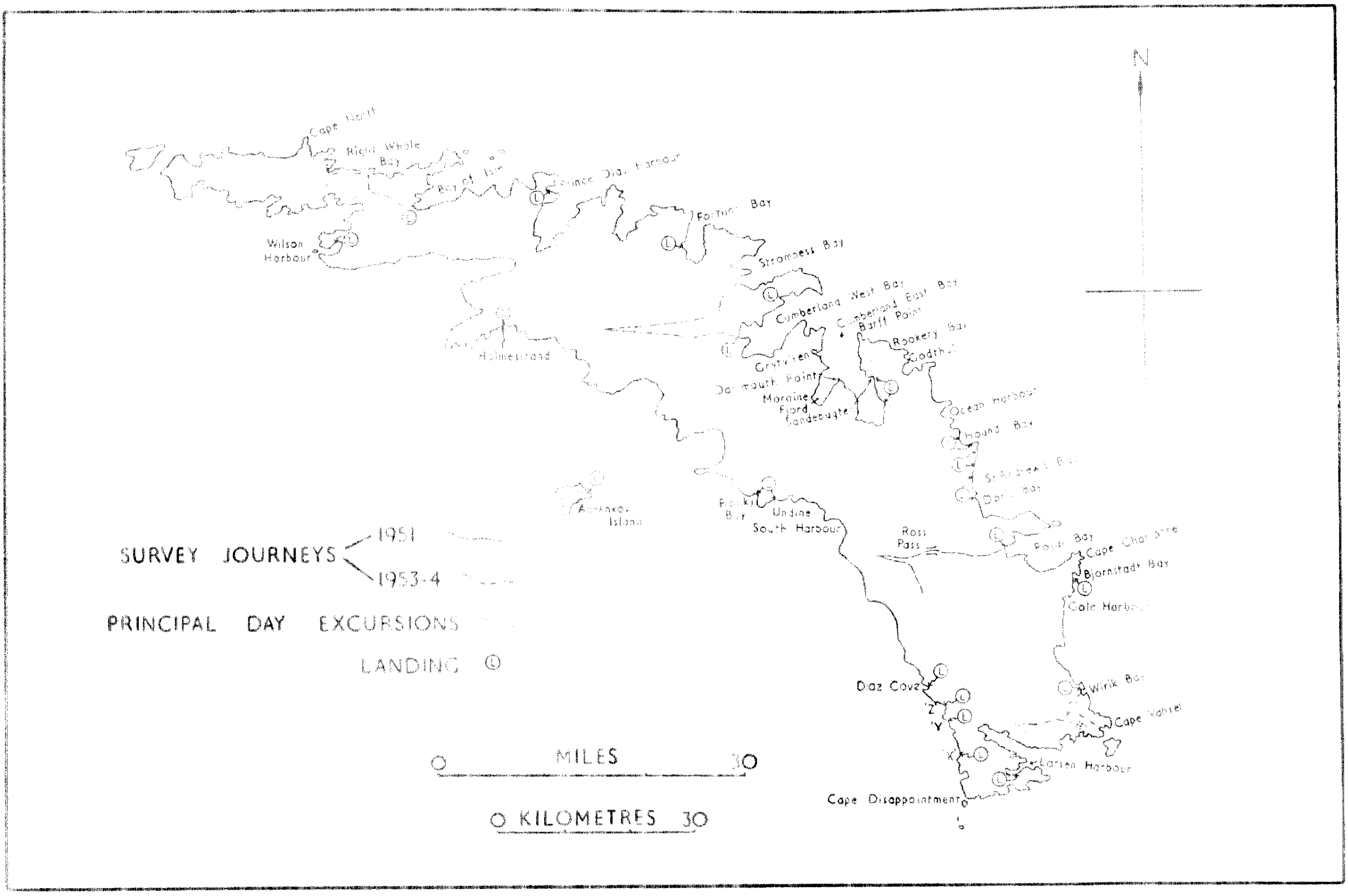

FIGURE 1

Map showing the writer's routes in South Georgia during 1951 and 1953–4.

The petrographic descriptions in this report are based on the examination of thin sections cut from:

(i) 35 specimens collected in 1951.

(ii) 192 specimens collected in 1953–4.

(iii) 109 specimens collected by G. V. Douglas, geologist to Shackleton's *Quest* Expedition of 1921. These slides are now in the collection of the British Museum (Natural History).

(iv) 79 specimens collected by D. Ferguson in 1915. These slides are now in the Hunterian Collection of the University of Glasgow.

A review of geological work carried out in South Georgia between 1884 and 1929, and a map showing the position of the island in the Scotia Arc has already been published (Trendall, 1953).

B. OUTLINE OF THE GEOLOGY OF THE ISLAND

The chief features of the geology of South Georgia are shown on the folding map at the end of this report. The island is composed principally of slightly metamorphosed sedimentary rocks. Between Cumberland Bay and Cape Charlotte there are grey quartzose greywackes while the remainder of the sedimentary rocks consist of greywackes probably formed entirely of volcanic debris. The upper part of the sedimentary succession contains intercalated lavas, and fossils of Upper Aptian age have been found on Annenkov Island (Wilckens, 1947). At the south-eastern end of the island there are both acid and basic intrusive igneous rocks, the injection of which is probably essentially contemporaneous with the earth movements responsible for the folding and metamorphism of the sediments. Although the acid intrusive rocks locally form migmatites, the precise mode of origin of which is uncertain, there is no widespread development of high grade regional metamorphism. The rocks immediately adjacent to the edge of the acid intrusion are chlorite/amphibole phyllites which pass quickly into sedimentary rocks with clearly recognisable clastic grains.

In this report the sedimentary rocks are described in Section II and the igneous rocks in Sections III, IV and V. The later sections are concerned with a factual and theoretical synthesis of the geology of the island.

C. ACKNOWLEDGMENTS

The writer wishes to thank his fellow-members of the South Georgia Survey, 1953–4, for the many ways in which they helped; the map outlines used in this report have been drawn and supplied by G. Smillie. Thanks are also due to the three whaling companies of the island, Compañia Argentina de Pesca S.A., Chr. Salvesen and Co., and Tønsbergs Hvalfangeri, without whose assistance nothing could have been accomplished, and to members of the administrative community at King Edward Point, Grytviken.

Thin sections have been lent by Professor T. Neville George from the Hunterian Collection of the University of Glasgow and by the British Museum (Natural History). The laboratory work was carried out in the Jane Herdman Laboratories of Geology, University of Liverpool, with the permission of Professor R. M. Shackleton, who has been most hospitable. Dr. J. C. Harper, also of the University of Liverpool, and Dr. L. F. Spath, of the British Museum (Natural History), kindly examined various fossils. There are many others, too numerous to thank individually, who have patiently discussed parts of this report. Finally, the author wishes to thank Ph. H. Kuenen, whose researches on turbidity currents and sedimentation have inspired much of the palaeogeographical interpretation given on pp. 9–10.

II. THE SEDIMENTARY ROCKS

A. INTRODUCTION

THE sedimentary rocks of South Georgia are of two types: quartzose greywackes (Sandebugten Series of Trendall, 1953) and tuffaceous greywackes (Cumberland Bay Series of Trendall, 1953). It is uncertain whether these two types represent two distinct series or form parts of a single sedimentary series of varying lithology. The evidence for and against these two views, set out by the writer in 1953, is supplemented by additional evidence in this paper, but it is still inconclusive. However, it has been decided to include the entire sedimentary succession in the Cumberland Bay Series, and to refer to the tuffaceous greywackes as "Cumberland Bay type" and to the quartzose greywackes as "Sandebugten type". The following account is concerned with new evidence and with the re-interpretation of previous evidence. Greater familiarity with the literature on turbidity current deposits has particularly affected the section dealing with "facies".

B. FACIES

1. *General Description*

a. The Typical Graded Bed

Kuenen (1953, figure 1A and p. 1050) refers to an "ideal type" of graded bed. Such a bed is not simply a "highest common factor" of the graded beds of any one locality; it is probably also the result of a cycle of events taking place in the simplest possible way. It is such a bed which is referred to here and its essential features are tabulated below. Typical graded beds are shown in plate Ib.

(i) Each bed is between 6 in. and 6 ft. thick, and the top and bottom are sharply defined, the top by the overlying coarse base of the bed above, and the bottom by the underlying fine top of the bed below. The mean thickness of measured beds is close to 2 ft.

(ii) Each bed is divisible into two parts separated by a sharp break; the lower part is coarse and graded whereas the upper part is finer and not graded. Although their relative thickness varies widely, the upper part is usually less than half the thickness of the lower part.

(iii) The lower part consists of coarse greywacke at the base grading into fine, dark tuff or siltstone at the top; the thicker the lower part of the bed the coarser the greywacke at the base. The coarsest greywacke seen in South Georgia had abundant grains 6 mm. in diameter (Cumberland Bay type; Ross Pass area). Most of the larger grains are sub-rounded to sub-angular, but in the Cumberland Bay type there are abundant angular crystals of plagioclase. At any level in the bed the sorting is poor, the interstices between the recognisable grains being filled by clay material in the original sediment.

(iv) The upper part may be formed entirely of fine dark tuff or siltstone, though bands of coarser material may be present. In part, at least, it is finely laminated with as many as twenty darker- and lighter-coloured bands within an inch, and the individual laminae may be well graded.

b. Variations from Type

In both the Cumberland Bay and Sandebugten types, variations from this ideal graded bed are the rule rather than the exception. Although the variations may be so great as to make interpretation on the model described above difficult, two forms may be recognised:

(i) Omissions, and (ii) Variations in the nature of the grading.

(i) It is common for the fine-grained top of the lower part to be omitted, the upper part resting directly on medium-grained greywacke. It is also common for the whole of the upper part to be missing, the base of the next complete bed resting directly on the fine top of the lower part.

(ii) The lower part may consist of a series of grades, each slightly finer than the one below (*intra-grades*; see Trendall, 1953, p. 7 and 16). The lower part is either not graded at all or is so uneven that the grading is difficult to see.

c. Other Features of the Graded Beds

With the exception of those noted in Section VI, the depositional structures described below, while not essential to the typical graded bed described above, occur more or less commonly.

(i) Slumping on a large scale is rare in both the Sandebugten and Cumberland Bay types. Minor distortions of the bedding are common, and in small-scale structures it is difficult to distinguish between slumping and convolute bedding. This has been pointed out by Kuenen (1953, p. 1054), who sees a sharp difference between the origins of the two structures. Typical examples of these structures are shown in figures 2 and 3. It is common for beds with slumping or convolute bedding to show even margins (figures 2D and 3E) and it is possible that the frequency of occurrence of these structures has been underestimated, since they are only visible on clean surfaces. Slumping and convolute bedding may occur in either the upper or lower parts of a graded bed.

(ii) *Load casts* (Kuenen, 1953, p. 1058) or *flow casts* (Schrock, 1948, pp. 156–60) are also common throughout the Cumberland Bay Series (figure 3B). The structures already described by Trendall (1953, pp. 7–8) as "antidune ripple-mark" (Schrock, 1948, p. 161) are undoubtedly load casts. They are present at the base of the graded beds and may pass into minor slumps. Similar structures may be produced tectonically (figure 2E).

(iii) Fragments of fine-grained dark tuff or siltstone are commonly included in the graded greywacke of the lower parts of the beds. These may be angular and elongate, suggesting considerable compaction of the upper part of a graded bed before erosion by a subsequent turbidity current. Alternatively, they may be rounded and equidimensional. Apart from the type of structure shown in figures 2B and C no evidence

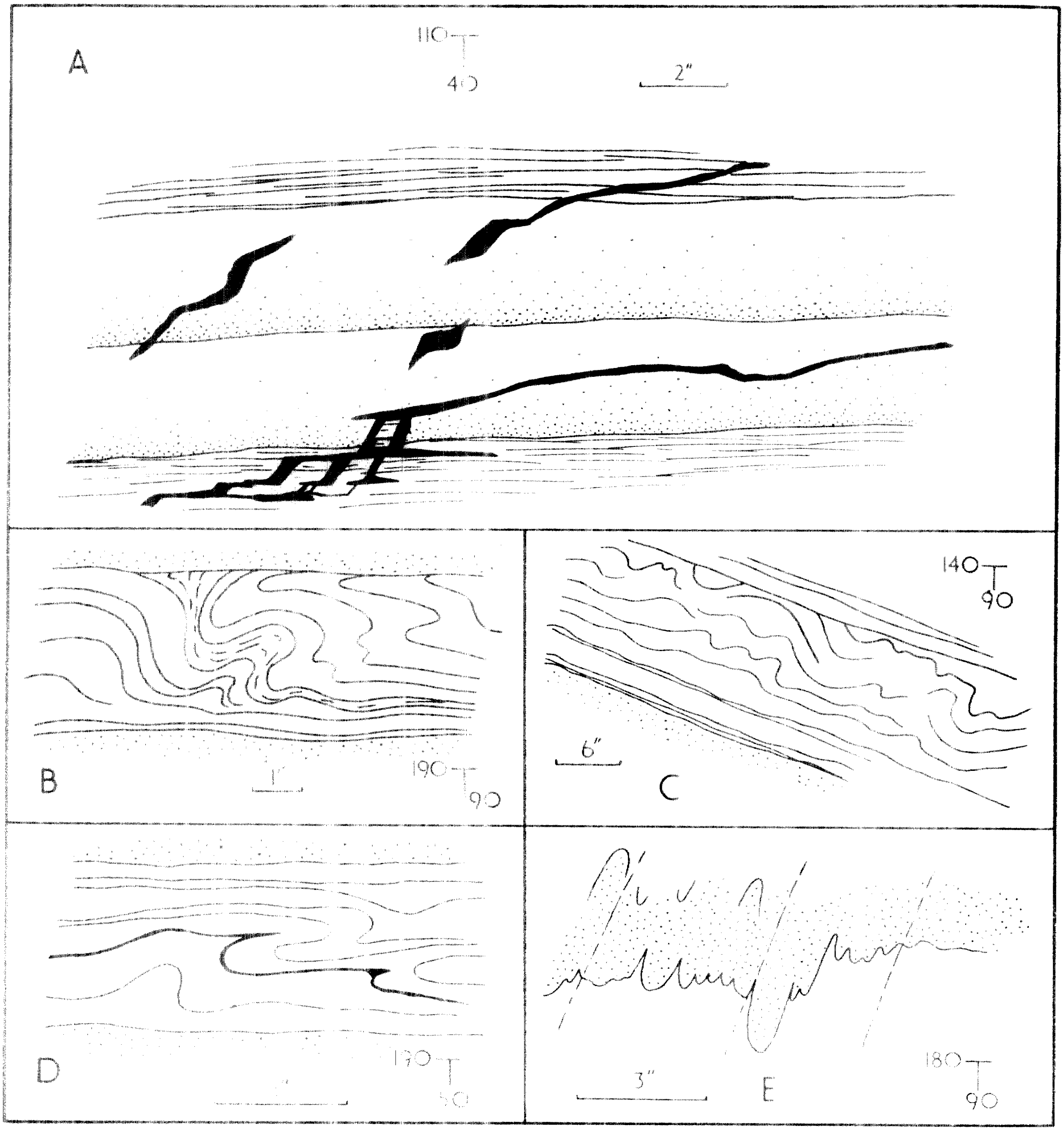

FIGURE 2

Structural features of the Cumberland Bay type:

A. Irregular cracks filled by fine tuff. The thin successive graded beds are not a common feature. Traced from a photograph taken approximately three miles due south of the northern tip of Dartmouth Point.

B. Slumping in green tuffaceous siltstone at Holmestrand. Part of the siltstone appears to have been eroded before deposition of the overlying tuff.

C. Convolute bedding with slight erosion. The folds are slightly asymmetrical and suggest that the original bottom slope was from left to right. Traced from a photograph taken in Right Whale Bay.

D. Convolute bedding with no erosion before deposition of the overlying tuff. The original bottom slope was from left to right. Right Whale Bay.

E. Serrated bedding plane probably of tectonic origin. The grains in the coarse (stippled) tuff above are elongated parallel to the cleavage in the underlying fine dark tuff, in the direction indicated by the pecked lines. Traced from a photograph taken in Right Whale Bay.

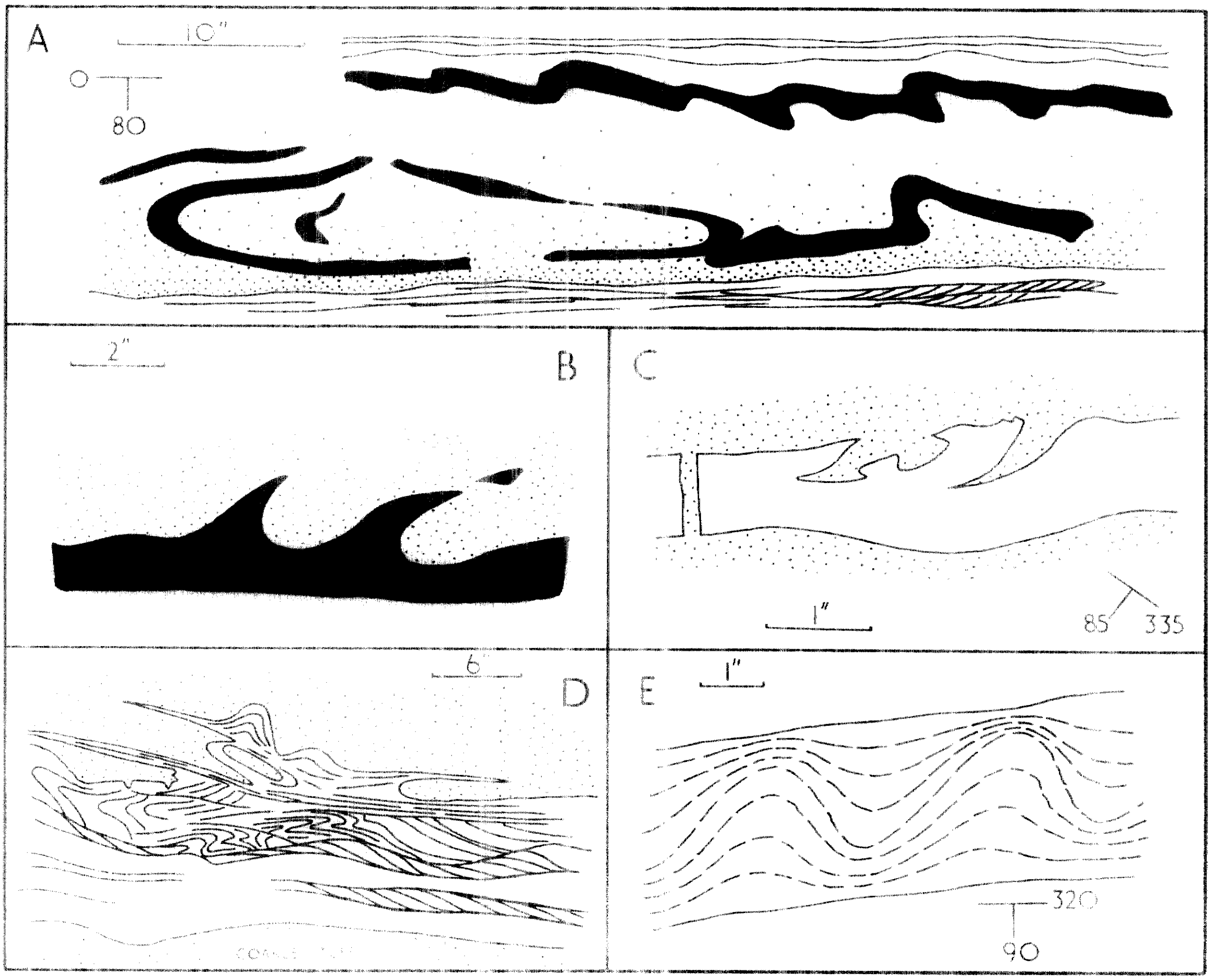

FIGURE 3

Depositional structures in the Cumberland Bay type.

A. Long fragments of fine black tuff within a graded bed. West coast of Moraine Fjord.

B. Load casts at the base of a graded bed near the Ross Pass. The structure indicates a bottom slope from left to right.

C. A "pull-apart" and irregular breaking of the upper surface of a thin bed of fine green tuff between two beds of coarse tuff. Right Whale Bay.

D. Cross-bedding and contortion in the upper part of a graded bed, which has an irregular junction with the base of the graded bed above. Part of a large beach boulder at Grytviken.

E. Exceptionally regular convolute bedding in fine tuff at Right Whale Bay. The slight asymmetry of the folds suggests a bottom slope from left to right.

has been found of the erosion of the upper part of graded beds, although this was specifically searched for in the tops of beds immediately below those with abundant fragments. The angular, elongate (generally about 6:1) fragments rarely exceed 6 in. in length but the rounded lumps are usually larger. One rounded, fine-grained, dark block in the Cumberland Bay type at Holmestrand was ovoid, 1 ft. long and 6 in. thick, and centrally placed in the lower part of a graded bed 1 ft. thick. This is not unusual. Another common feature is the occurrence of a string of small fragments at a single level in the lower part of a graded bed. Figure 3A shows strips of dark rock which have withstood disintegration. It is possible that the occasional appearance of *in situ* brecciation is due to the final breaking up of large blocks which have been carried safely for long distances.

(iv) Cross-bedding commonly occurs in the upper parts of graded beds of both the Cumberland Bay and Sandebugten types. The cross-bedded units are usually thin, being seldom greater than two inches and usually between a half and one inch thick. They are of even thickness and several are often found in succession. The upper part of the foreset beds may be truncated but the cross-bedding is often complete.

(v) Pull-aparts (figure 3C) have been seen rarely in the upper parts of graded beds but small cracks and veinlets filled with later tuff are fairly common throughout the Cumberland Bay Series (figure 2A). Also, two larger sedimentary dykes (strike 140° true), filled with coarse tuff, were noted in Right Whale Bay.

(vi) Kuenen and Carozzi (1953, p. 365) have pointed out that "each ancient basin" (in which graded beds have been studied) "appears to be entirely or partly characterised by emphasis on some features, while other properties may be scarce or poorly developed." Thus, the sediments of South Georgia do not exhibit all the features which commonly occur in rocks of similar facies elsewhere. No *flow marks*, *flow grooves*, or *flow rolls* of the type most fully described by Rich (1950) were observed. Although their absence may be due partly to tectonic obliteration, these structures are also absent in the least distorted parts of the Cumberland Bay type, at Annenkov Island and along the south-west coast. Neither *current ripple-marks* nor *slide conglomerates* have been found.

2. *Lateral Variation*

a. Small Scale

Both the Cumberland Bay type and Sandebugten type greywackes are remarkably uniform within the boundaries of a single exposure. Nowhere was a recognisable graded bed seen to die out or to change significantly in thickness laterally. At Grytviken, the only locality where there was time for detailed measurements, the total thickness of a sequence of four graded beds varied from 15 ft. 10 in. to 15 ft. 6 in. in 100 ft. Within this measured sequence the lower part of a single graded bed varied from 15 in. to 18 in. while the upper part of the same bed varied from 5 in. to 4 in. Also, in the same bed individual stripes less than half an inch thick in the upper part were seen to persist throughout the 100 ft. between the two measured sections.

Apart from the consistency in thickness, the structural features of each graded bed are constant throughout each exposure. For example, a bed having convolute bedding, which is absent in the adjacent beds, is likely to show convolute bedding throughout the exposure, whereas the adjacent beds are unlikely to develop this structure. Kuenen and Carozzi (1953, p. 364) have noted this fact in beds of similar facies.

b. Large Scale

On the island of South Georgia there is very little lateral variation in the facies of the sedimentary rocks. In all the localities visited between Cape Charlotte and Foul Bay the rocks conform to the description above. However, on Annenkov Island, and to a lesser extent in the exposures south of Cape Charlotte, there is a difference in facies.

The sediments of Annenkov Island differ from the typical Cumberland Bay type in the following ways:

(i) They consist mainly of thin (between 3 in. and 1 ft.) alternating beds of fine-grained, dark striped tuff and coarser (up to 4 mm. grain diameter) tuffs. Considerable thicknesses of fine, dark tuff occur alone, and the coarser grades are confined to thin beds.

(ii) Grading is inconspicuous though sometimes present in the coarser tuffs.

(iii) Cross-bedding, load casts, slumping or convolute bedding, dark fragments in the coarse tuffs, flow marks and ripple-marks were not seen. On the contrary, the evenness and regularity of the bedding is striking (plate Ia).

South of Cape Charlotte (Wirik Bay and Cooper Bay area) the Cumberland Bay type, while essentially similar to the exposures further to the north-west, appears to have some characters in common with the Annenkov Island rocks. Although typical graded beds are clearly recognisable, there are great thicknesses of fine, dark tuff and the coarse graded greywackes are often thin. Cross-bedding was not found, even in an excellent clean exposure in the centre of the glacier snout at Wirik Bay. In most exposures the deformation is too severe to expect the preservation of depositional structures.

C. CONDITIONS OF DEPOSITION

1. *Cumberland Bay Type*

a. Current Direction

Wherever possible, the current direction, indicated by cross-bedding in the upper parts of graded beds, was estimated. The consistency of direction at each locality examined made this estimation straightforward. The directions are shown in figure 4.

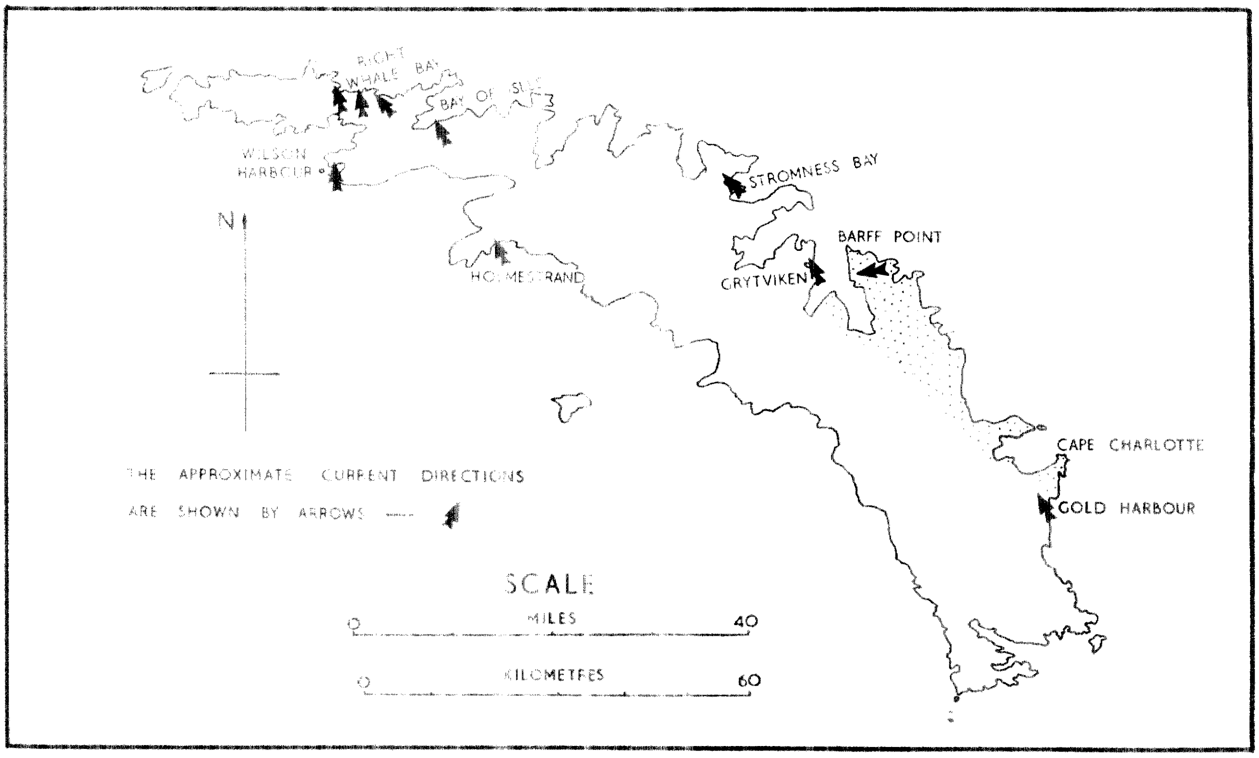

FIGURE 4
Map showing current directions indicated by cross-bedding.

b. Bottom Slope

The bottom slope may be assumed to be parallel to the current direction. This was in fact confirmed by observations on convolute bedding and minor slumping (figure 2), and of load or flow casts. Only load casts of the type shown in figure 3B can be used to determine the direction of the bottom slope. Kuenen is of the opinion that convolute bedding is formed during, rather than immediately after, deposition. Most of the convolute bedding in the Cumberland Bay type is transitional to slumping and, because of the common association of convolute bedding and elongate load casts, it is considered to have been formed by post-depositional flow.

Kuenen (1953, p. 1060) has set out criteria for the recognition of graded deposits formed on gentle slopes or on level basin floors. These are listed below with comments (in italics) only when the description is *not* appropriate to the Cumberland Bay type:

(i) Extreme regularity of bedding.

(ii) Absence of true slump structures, *which are present in South Georgia but there is no large-scale slumping.*

(iii) Pelagic deep-water beds between the graded beds.

(iv) Upward grading in each bed to very fine sediment. *The grading in the Cumberland Bay type is often only to a fine grey tuff with clastic grains visible in the hand specimen.*

(v) Thin graded beds of fine grain. *These are present in the Cumberland Bay type but are not common (figure 2A).*

(vi) Absence of current ripple-marks.

(vii) Supply from varying directions. *The current direction in the Cumberland Bay type is very consistent.*

The precise slope of the bottom is difficult to estimate from evidence available in the literature. However, it is clear that coarse sands may be carried for long distances in turbidity currents over slopes of 1 or 2° (Shepard, 1951; with further references). It also seems possible that a slope of this order would be sufficient to produce slumping, since Kuenen (1953, p. 1053) has noted the presence of a coarse slide conglomerate on a slope of less than 5°.

c. Depth of Water

If the sea-floor, on which the Cumberland Bay type sediments accumulated, is assumed to have sloped evenly in the direction shown in figure 4 for a distance of 100 km. with an inclination of 2° there would be a drop of 3500 m. from south to north. This disregards any contraction of the distance by folding. The small lateral variation in this distance suggests that the entire succession is of deep water origin.

2. *Sandebugten Type*

Too few observations of cross-bedding in the Sandebugten type sediments have been made to be certain of the dominant current direction. A succession of six cross-bedded units near Sandebugten indicates that the source of the sediment was to the east-north-east. Scattered observations between Cumberland Bay and Royal Bay, however, reveal no consistent orientation. It is therefore clear that the depositional environment of the Sandebugten type was different from that of the Cumberland Bay type with its consistent cross-bedding direction.

D. PETROGRAPHY

Four petrographic topics, about which information was lacking in 1953 or which have since been studied in greater detail are discussed in this section:

(i) the presence of almost undeformed grains (notably of sandstone) preserved within a calcareous concretion in the Sandebugten type,

(ii) a review of the petrographic variation within the Cumberland Bay type,

(iii) the composition of clastic felspar grains, and

(iv) the mode of occurrence of prehnite.

1. *Sandebugten Type*

A thin section from a large calcareous concretion in coarse greywacke, approximately one mile south-south-west of Rookery Bay, reveals that the interstitial calcite has protected the grains from serious distortion. A "cleavage" direction runs through the concretion parallel to that in the surrounding greywacke. In thin section it is defined by a preferred orientation of the long axes of the grains and by thin, dark indeterminate lines, which are sub-parallel and irregularly undulating. Part of the thin section is shown in plate IVc. Owing to the absence of distortion the grains are clearly recognisable and 86 rock fragments larger than 0.5 mm. diameter in the section were identified as:

	No. of grains		No. of grains
Quartz	24	Single felspars	5
Sandstone	24	Quartzite	5
Lava	9	Indeterminate	12
"Slate" (contemporaneous?)	7		

Of these grains, which are rounded to sub-angular, sandstone has not previously been seen in Sandebugten type rocks, and quartz is normally distorted to some extent. The quartz is quite clear and shows no sign of strain extinction. Two grains are strikingly embayed but this may be due to replacement by the surrounding calcite.

The variation among the 24 angular to sub-angular sandstone grains is slight and is mainly in grain-size, the largest being 0.3 mm. in diameter. They are composed essentially of quartz which almost invariably shows strain extinction. A few grains of sericitised felspar, of similar size and shape, are also present. The sorting is poor and the interstices between the grains are filled with material which is indeterminate under the microscope but which probably consists of sericite and cryptocrystalline silica. In some of the finer sandstones there is a long axis orientation of the grains, possibly representing the bedding of the original sediment, but this is absent in the coarser grades. A typical sandstone grain is illustrated in plate IVc.

2. *Cumberland Bay Type*

Since 1953 it has been possible to examine thin sections of Cumberland Bay type rocks from many localities along the north coast between Elsehul and Prince Olav Harbour, from Cape Paryadin, Holmestrand, Rocky Bay and Undine South Harbour on the south coast, and from Annenkov Island and the Cape Charlotte–Cooper Bay area. The following brief summary is intended to augment the petrographic description in *The Geology of South Georgia—I* (pp. 19–20), which was based on a less representative collection of slides.

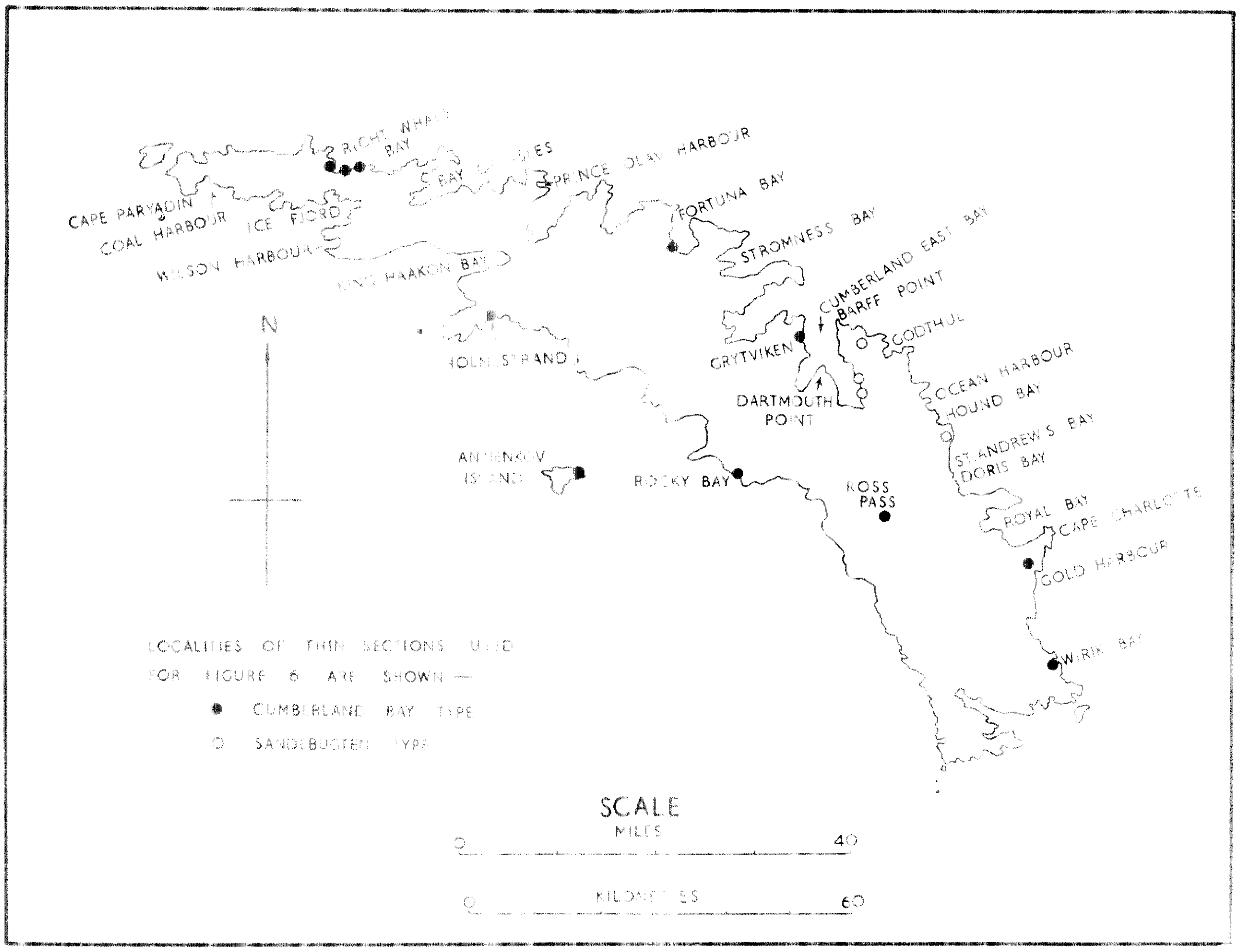

FIGURE 5

Map showing the localities from which thin sections of Cumberland Bay type rocks have been available for examination, and the localities used for the determination of the composition of plagioclase fragments in both Sandebugten and Cumberland Bay types shown in figure 6.

There is strikingly little petrographic variation in the Cumberland Bay type between the Ross Pass area and the north-western tip of South Georgia. In thin section the coarser grades are composed of rounded to sub-angular grains of lava, together with more angular grains of felspar (single crystals) and subsidiary amounts of quartz, detrital amphibole and pyroxene. The appearance in thin section varies widely with the local variation in distortion of the rock, described below, but the character of the sediment before distortion is still discernible. The secondary minerals such as calcite, clinozoisite, chlorite, biotite and muscovite only begin to mask the original nature of the rock in the Wirik Bay–Cooper Bay area. These thoroughly metamorphosed rocks are described later (p. 18).

On Annenkov Island the coarse tuff is similar in thin section to that of the main island, but the following slight differences were noted:

(i) The large grains are more angular.

(ii) Although the sorting is poor there is less pelitic material. The larger grains are closely packed and the interstices are filled by secondary calcite.

3. *Felspar Composition*

The compositions of 89 clastic felspars from nineteen thin sections were determined.* Seventy-nine of these were from fifteen thin sections of Cumberland Bay type tuff and 10 from four thin sections of Sandebugten type rocks, the localities of which are shown in figure 5. All the grains proved to be plagioclase and the distribution of compositions is shown by a histogram in figure 6. Of the albites, 20 from the Cumberland Bay type were confirmed to be the low temperature form by measurement of the 2V. The 10 albites from the Sandebugten type were all low temperature forms.

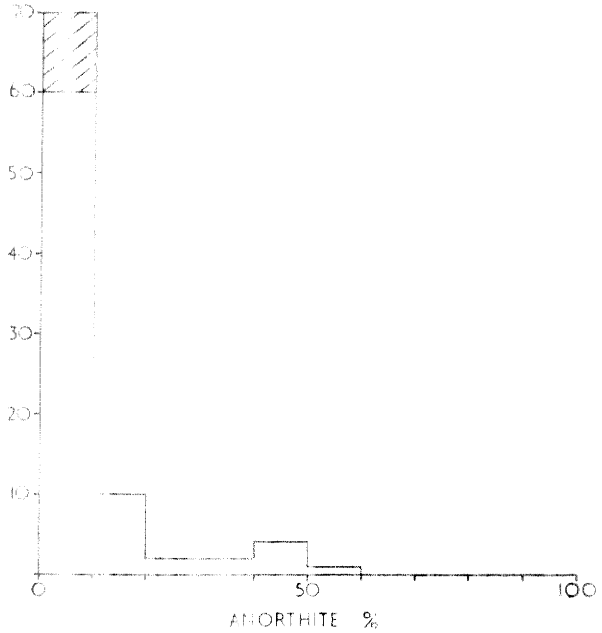

FIGURE 6

Histogram showing the compositions of 79 plagioclase fragments from Cumberland Bay type tuffs, and of 10 plagioclase fragments from Sandebugten type greywackes (diagonal ruling) from the localities shown in figure 5.

4. *Prehnite*

Prehnite occurs as a secondary mineral in all the Cumberland Bay type exposures at and north-west of the Ross Pass area. It has not been seen either in the undeformed rocks of Annenkov Island (where secondary calcite is abundant) or in the highly metamorphosed rocks of the south-east. Within its area of

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*The method of plagioclase determination is described in Appendix I.

occurrence it appears to be more abundant in the north-west but this may be due to the fact that it is more conspicuous in the field in that direction. In the field, four types of occurrence are recognisable:

(i) Small, irregularly-shaped, pale conspicuous clots scattered indiscriminately through either fine black or coarse grey tuff (figure 7A).

(ii) Similar, but exceptionally abundant clots in bleached aureoles (p. 17).

(iii) Small (about 2 mm.), closely-packed symmetrical spheroids slightly lighter in colour than the enclosing rock, thus giving a vaguely speckled appearance to the tuff. Such clots very rarely attain a diameter of 10 mm.

(iv) Sharply defined, thin white bands intercalated with the black laminated tuffs of the upper parts of graded beds.

Prehnite clots of the first type may be easily confused in the hand specimen with clastic felspars.

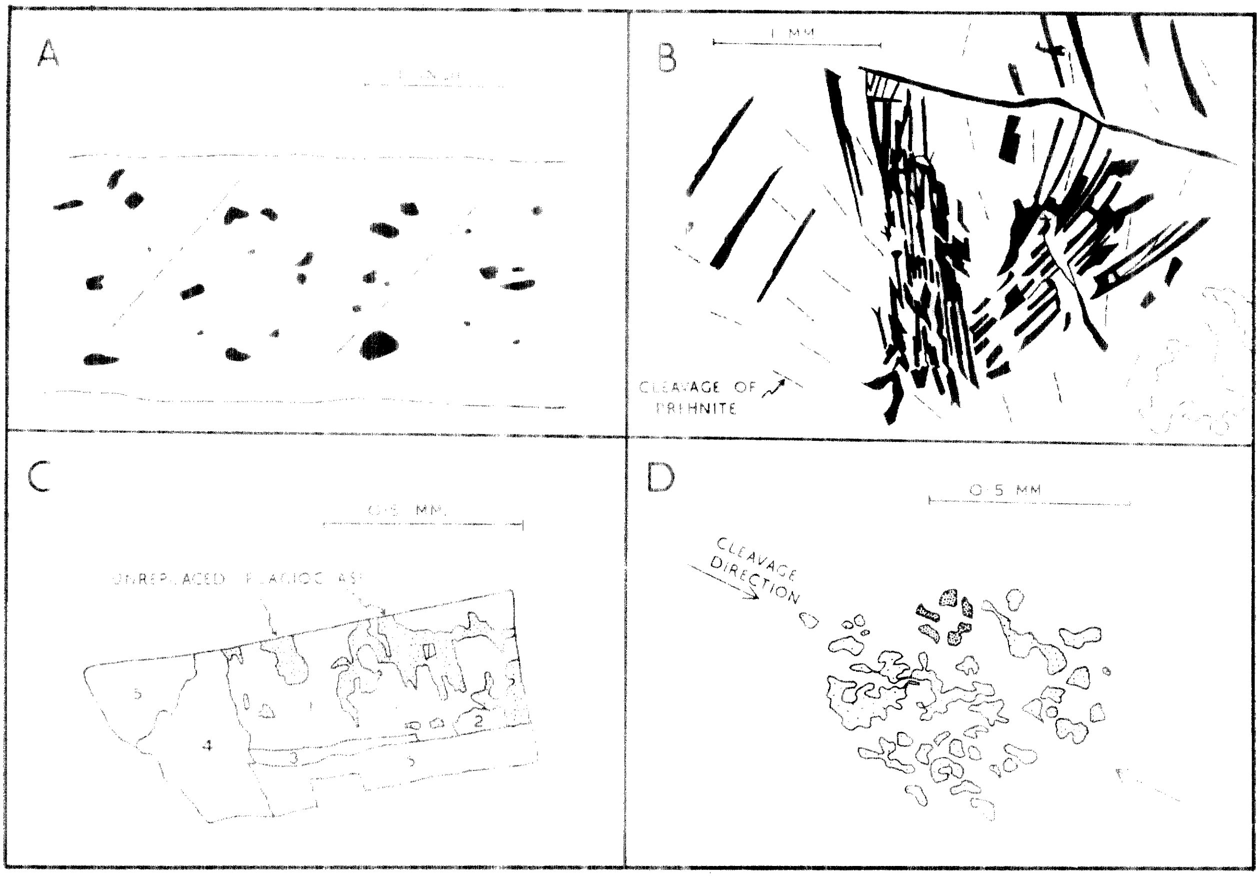

FIGURE 7

The occurrence of prehnite.

A. Prehnite clots (black) in the fine dark tuffs of Right Whale Bay. The clots are irregular in both shape and orientation.

B. Part of a thin section of a clot similar to those shown in "A". Calcite (black) fills sub-parallel groups of cracks in "fans" of prehnite. There are also small irregular areas (stippled) filled by an aggregate of quartz and sericite.

C. A single plagioclase fragment almost entirely replaced by six (numbered) optically distinct areas of prehnite. Ross Pass Area.

D. A rounded skeletal aggregate made up of three sets of optically continuous blebs, shown by different densities of stippling. Wilson Harbour.

A thin section of a large (15 × 6 mm.) clot in black tuff from Right Whale Bay reveals that it is composed of fan-like aggregates of prehnite with the cracks filled by calcite (figure 7B). Prehnite was first described as such from the sedimentary rocks of South Georgia by Tyrrell (1930, p. 39), whose identification was confirmed by Campbell Smith. To confirm that the mineral of the clots is that described previously, a thin section was examined on a universal stage and the positive 2V was found to be 70°, with γ perpendicular to the prominent cleavage and radial to the fans. The high refractive indices and birefringence also confirm the identification.

In thin section the boundaries of the clots in the fine tuffs are sharply defined. However, in the coarser tuffs the prehnite commonly replaces a single felspar (?) in an aggregate of irregular areas, each optically continuous (figure 7C). Prehnite aggregates may also cut across the grain boundaries and replace both grain and matrix. In the "speckled" type of occurrence (iii, above) the ellipsoidal bodies are made up of irregular skeletal aggregates in vague optically continuous areas (figure 7D).

E. FEATURES OF DIAGENESIS

Two demonstrably pre-tectonic and post-depositional features of the sedimentary rocks are described in this section. Both of these were mentioned briefly in the *Geology of South Georgia—I*. They are:

(i) Ellipsoidal calcareous concretions from the Sandebugten type (Trendall, 1953, p. 8), which are now believed to be the same as the "limestone nodules" of the Cumberland Bay type (Trendall, 1953, p. 16).

Such concretions appear to be a common feature of a wide variety of sedimentary rocks, but there is little published information concerning them. Weeks (1953) has recently described similar concretions from Cretaceous shales of Colombia. Since they occur in rocks of approximately the same age and of the same geosynclinal belt, the concretions of South Georgia are described in some detail below.

(ii) Bleached aureoles around dark tuffs or mudstones, either *in situ* or as fragments in coarser rocks (Trendall, 1953, p. 8, 16).

1. *Calcareous Concretions*

a. Occurrence, Size and Undeformed Shape

Calcareous concretions are abundant throughout both the Sandebugten and Cumberland Bay types. They range in size from less than 1 in. to a maximum observed length of 15 ft. On Annenkov Island, where the Cumberland Bay type is virtually undeformed by folding, they are oblate spheroids with the short axis perpendicular to the bedding. The small concretions (2 in. or less in diameter) show an elongation along the bedding of about 3:2 or 2:1, but the larger ones are generally elongated by 5 or 6:1. Their shape after deformation is described below.

The concretions have a tendency to be confined within individual beds, either a complete graded bed or the upper or lower part of one. This seems to be due to their inability to grow across a sharply defined bedding plane and thus gives rise to such curious shapes as that in figure 8A. This property may cause them to resemble bedded limestones, for which some were originally mistaken (figure 8B). Sometimes, however, clear bedding planes may be crossed and one example of a concretion, 6 ft. in thickness and including parts of three complete graded beds, has been observed.

The concretion size bears some relationship to the grain size of the enclosing rock. At any one locality the coarser greywackes contain large scattered concretions whereas the finer rocks have smaller, more abundant concretions. In the cliffs of Right Whale Bay, where the concretions in the Cumberland Bay type were carefully studied, there appears to be a predisposition of certain beds to grow concretions. These beds do not appear to differ in any other respect from those possessing fewer concretions (figure 8C).

b. Petrography

In thin section the material of the concretions is similar to the greywacke immediately outside the boundary except that it is replaced by calcite to a variable degree. Normally only the matrix and the small grains are replaced, leaving the larger grains of lava, felspar or quartz unchanged. Exceptionally, the entire rock may be replaced (figure 8D). Under the microscope the finer tuffs show very finely crystalline calcite, dark with carbonaceous and other matter, and without chemical analysis it is impossible to assess the amount of replacement.

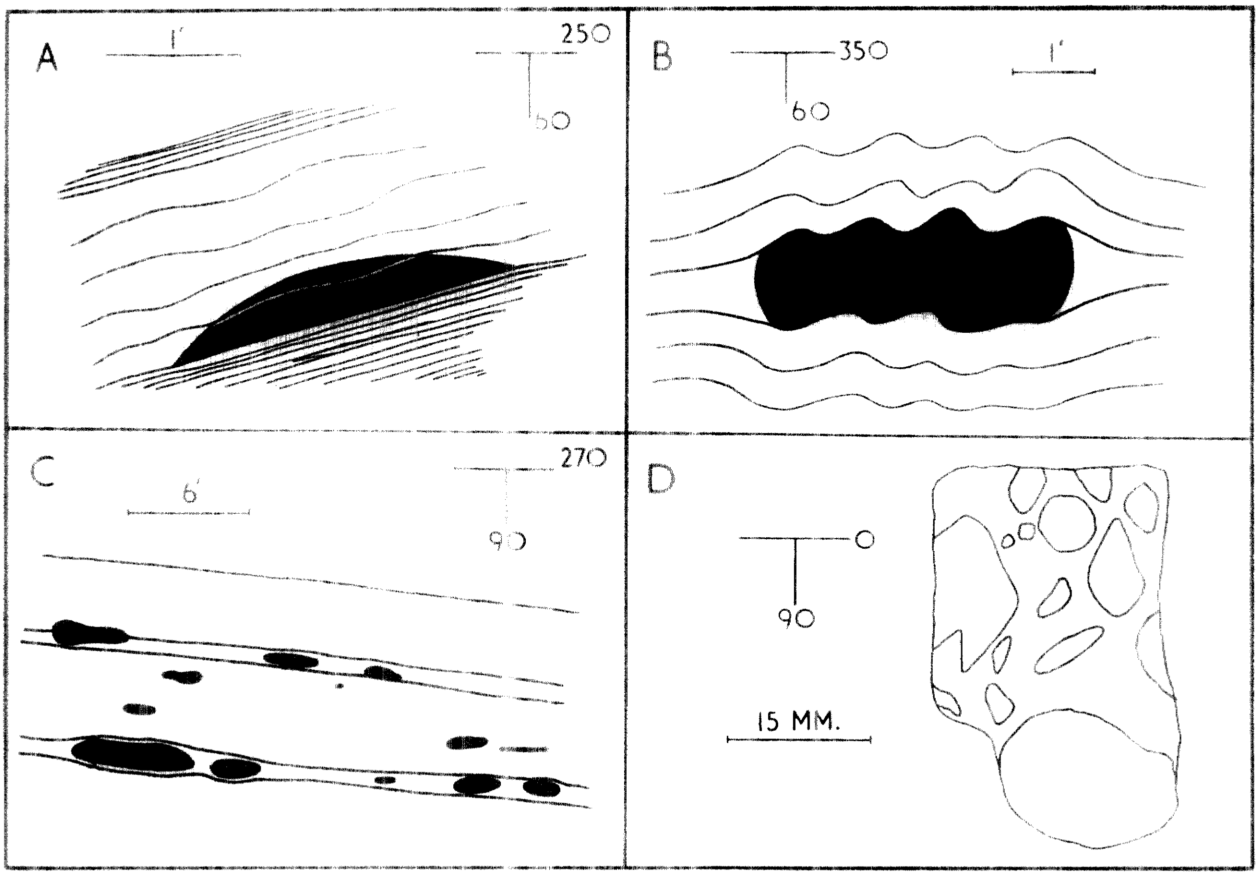

FIGURE 8

Calcareous concretions from Right Whale Bay.

A. Concretion (black) with the shape controlled by a well-defined bedding plane.

B. Concretion with upper and lower surfaces controlled by bedding planes.

C. Cliff showing: (i) greater abundance of concretions in some beds, (ii) concretions sometimes controlled by and sometimes cutting across bedding planes, (iii) "flowing" of bedding around concretions, (iv) thin calcareous band resembling bedded limestone, and (v) average elongation of about 5:1.

D. Thin section from concretion in coarse tuff. The "grains" are clear but the rock consists entirely of calcite of varying grain-size.

c. Evidence for Time of Origin

(i) The concretions are, as described below, deformed by the folding and their calcite shows clear evidence of distortion. In the Sandebugten type they contain grains of unstrained quartz, which does not appear outside the boundary of the concretion. They are therefore of pre-tectonic origin.

(ii) One of the two sedimentary dykes found in Right Whale Bay (see p. 8) cuts through a calcareous concretion (figure 9A). It seems unlikely that such a concretion would be formed in two separate parts without affecting the tuff of the dyke.

(iii) Bedding planes can be traced through concretions and are also slightly curved around them (figures 8A; 9B). This was first noted in Right Whale Bay, where the concretions are deformed, but it was later observed on Annenkov Island. The concretions must therefore have been formed before complete compaction.

(iv) The continuation of cross-bedding through the concretions (figure 9F) indicates that the calcite is of a replacement origin and was not formed during deposition.

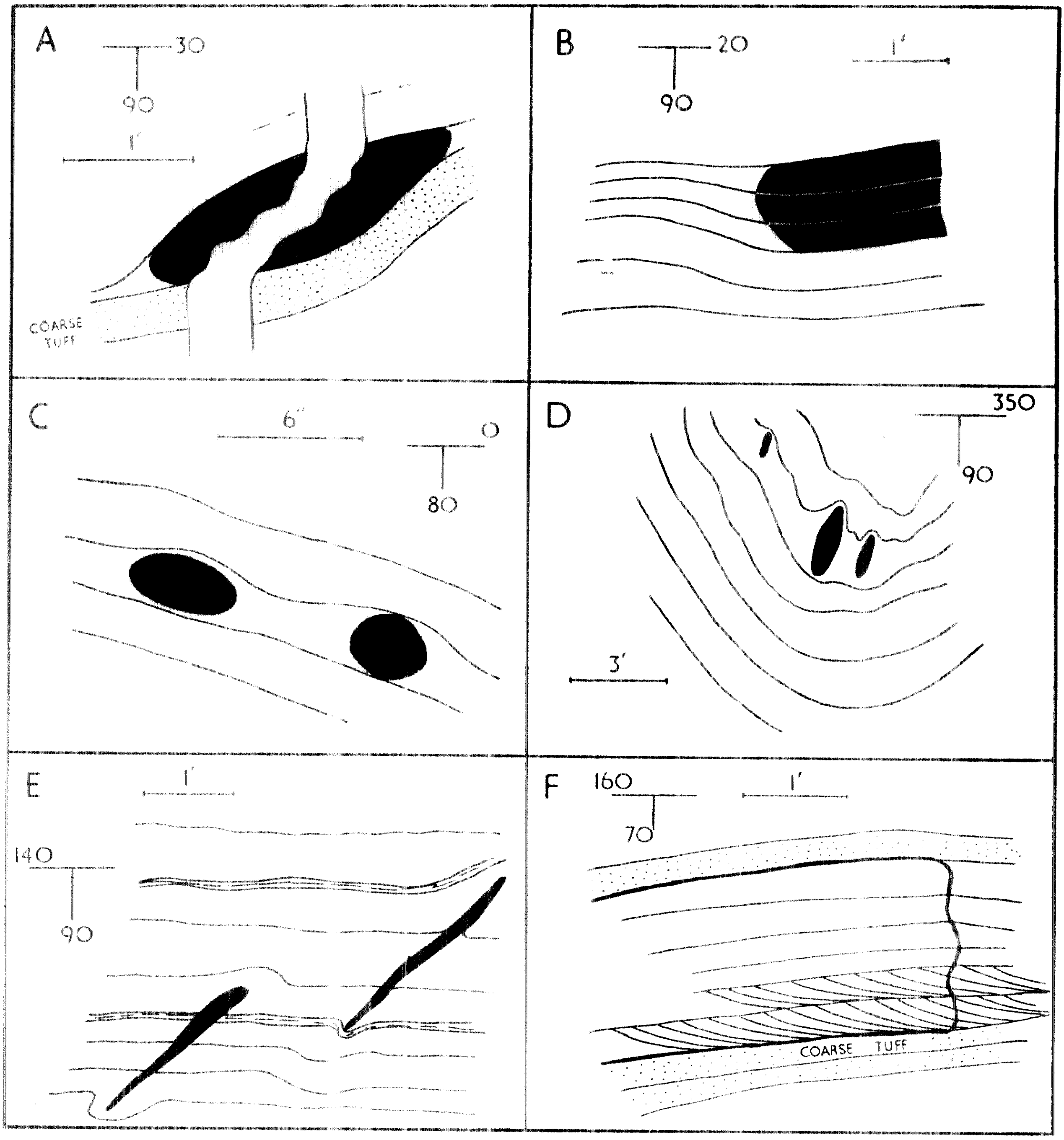

FIGURE 9

Features of calcareous concretions.

A. Sedimentary dyke cutting through a concretion in Right Whale Bay. Traced from a photograph.

B. Concretion showing: (i) "flowing" of bedding planes and (ii) continuation of bedding planes through the concretion. Right Whale Bay.

C. *ac* section of concretions in Right Whale Bay with the beds not folded.

D. *ac* section of concretions in Right Whale Bay in the axial plane region of a small local fold

E. *ac* section of concretions on the west coast of Moraine Fjord.

F. Cross-bedding continuing through a large concretion (thick lines) in Right Whale Bay.

d. Deformation

From the evidence of the concretions on Annenkov Island it is assumed that if a concretion is sufficiently small not to be controlled by bedding planes then it was originally an oblate spheroid with the shortest axis perpendicular to the bedding. The direction *b* is defined here as the direction of the fold axes, the direction *c* as the direction in the axial plane (cleavage, foliation) which is perpendicular to *b*, and the direction *a* as the direction perpendicular to both *c* and *b* (i.e. perpendicular to the axial plane).

Both in the Sandebugten type and Cumberland Bay type the concretions are flattened in the cleavage (axial plane of the folds). The elongation in *c* relative to *a* is proportional to the intensity of the immediately local folding. In the Right Whale Bay area, where the cleavage strikes east-west and dips steeply southwards, much of the bedding has a southerly dip less than 30°. In such beds the concretions are apparently un-

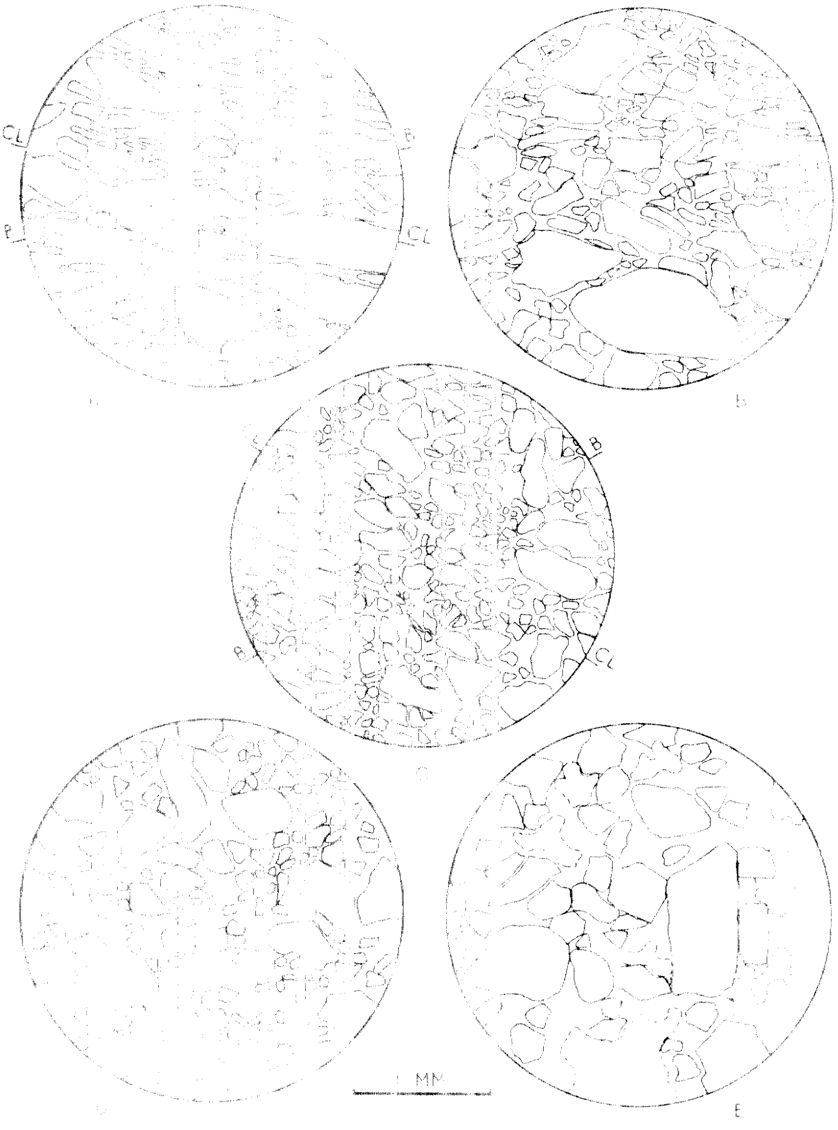

FIGURE 10

Outlines of the grains in five thin sections of coarse tuff from the Cumberland Bay type of A, Grytviken; B, Prince Olav Harbour; C, Right Whale Bay; D, Cape Paryadin; and E, Annenkov Island. The lines B–B and CL–CL show the direction of bedding and cleavage respectively. In "A" the grains are deformed. In "C", although there is a long axis orientation of the grains which cannot be a depositional feature, it is possible that the grains have been rotated rather than deformed. In "D" and "E" there is apparently neither deformation nor rotation.

distorted but in the axial regions of local folds there is considerable distortion (figures 9C, D). Around Grytviken, where the cleavage is much stronger, the $a:c$ distortion may be as much as 1:20 (figure 9E).

The relative elongation in b is much more difficult to estimate. In Right Whale Bay a cliff with a cb (cleavage) surface showed an average elongation of the concretions in b of 5:1 (figure 8C). An ac (joint) face at the end of the same cliff showed that the concretions were elongated 2:1 in c. These two proportions could not have been achieved from nodules originally circular in plan and without elongation in b. Along the east coast of Cumberland East Bay ab sections of Sandebugten type greywackes commonly show concretions with an elongation of 10:1 in b. Exposures where all three dimensions of single concretions can be measured are difficult to find. From observations of average elongations on separate faces it can be concluded that:

(i) As a result of folding the nodules are flattened in the axial planes of the folds, i.e., there is elongation in both b and c relative to a.

(ii) The relative elongation in c is dependent on the local intensity of folding.

(iii) The elongation in b relative to c is not known.

2. *Bleached Aureoles*

Concerning these structures, which are demonstrably pre-tectonic, it was previously stated (Trendall, 1953, p. 16) that "it is not clear whether they are of depositional origin or formed by later leaching". At that time it was clear that some of the bleaching was not of depositional origin, since it was known to occur adjacent to bedded tuffs and to cut across bedding planes (Trendall, 1953, figure 15A, p. 17). It was, however, thought possible that the aureoles around angular black fragments, which occurred singly or in clusters, might represent mud accumulated by the fragments rolling down submarine slopes. This interpretation is now thought to be incorrect, because in a beach boulder at Grytviken it was noted that bedding planes in the aureole of bleached laminated siltstone surrounding a fragment continued unbroken into the similar, but unbleached, siltstone outside the aureole. Since the tuff within the aureoles is frequently more abundantly prehnitised than that outside, it often appears to be devoid of structure.

F. METAMORPHISM

1. *Development of Secondary Minerals*

A number of secondary minerals, principally prehnite, are widely distributed through the sedimentary rocks. The occurrence and nature of these have already been described in Section D above and in *The Geology of South Georgia—I* (Trendall, 1953, p. 15, 20). The present description of metamorphism is only concerned with the various rocks containing few or no remaining clastic constituents. These have been examined near the north-east boundary of the south-eastern igneous complex in the Wirik Bay–Cooper Bay area (figures 19, 20).

2. *The Wirik Bay–Cooper Bay Area*

Bedding planes were seldom seen in the rocks examined on the ridge north of Glacier "C" (figure 19) and in the immediate vicinity of Cooper Bay. Evidence of way-up was never found. The only clear structural feature of the sediments in these areas is a strong planar structure (which is locally either a cleavage, fracture cleavage or foliation), the strike of which is sub-parallel to the margin of the nearby igneous complex and which usually has a steep north-easterly dip. These rocks range from grey-green, fine-grained phyllites to dark "cherty" sediments, showing vague residual banding which is often intensely folded.

In thin section the green phyllites consist of amphibole and chlorite with varying amounts of plagioclase, quartz and epidote. A typical example is shown in plate IVd. In this section the small chlorite flakes (0.01 to 0.002 mm. in length) are sometimes slightly bent around the puckers and sometimes arranged undeformed tangentially to the puckering, each flake being at a very slight angle to the last. Amphibole, in crystals up to 0.5 mm. in diameter, is the dominant mineral in a section from Cooper Bay. Streaks of finely crystalline chlorite and sericite "flow" around the amphiboles and smaller crystals of oligoclase, and bands of granular clinozoisite are also present. In a thin section from the ridge north of Glacier "C", thin streaks of finely sheared mosaic quartz alternate with bands of small epidote granules. This rock is similar in all respects to that composing some of the "rafts" of sedimentary origin within the igneous complex described on pp. 34–35.

G. STRUCTURE

1. *The Wirik Bay-Cooper Bay Area*

Planar structures in the intensely metamorphosed rocks along the north-east boundary of the igneous complex have been noted but there is insufficient information to enable a correlation of these steep planar structures to be made with either the axial plane deformation of the tuffs on the coast of Wirik Bay or with the fracture cleavage in the same sediments and in the rocks farther to the north-east. The rocks forming the exposures in the immediate vicinity of Wirik Bay are less metamorphosed and possess recognisable bedding planes and clastic grains. The bedding planes usually dip steeply with a general strike of about 150° true. The axial plane cleavage, which is marked by an intense flattening of the grains in the coarser tuffs and by slaty cleavage in the finer-grained rocks, is usually at a low angle (less than 30°) to the bedding planes. In two places on the north-west coast of Wirik Bay and at many points on the north face of the hill approximately one mile south of the island in the bay, graded bedding proved that the beds in the tight folds were not inverted. This is shown in the cross-section of figure 22.

A local fracture cleavage, observed in the cliffs forming the north-west coast of the bay, dips gently to the north-east with a strike parallel to that of the cleavage associated with the grain deformation. When it is present the fracture cleavage is axial to small folds and puckers but there is no appreciable plastic deformation in these folds.

2. *The Remaining Sedimentary Rocks*

a. Axial Plane Deformation in the Cumberland Bay Type

The axial plane cleavage in the Cumberland Bay type was described in *The Geology of South Georgia—I* (Trendall, 1953, pp. 18–19). Where it is most intense (for example, at Grytviken) it is defined, in the coarse tuffs, by a distinct flattening of the individual lava grains. The crystals of felspar are either arranged with their long axes parallel to this direction or are shattered with the individual fragments pulled out along it. As the cleavage is traced north-westwards from Cumberland East Bay its intensity gradually diminishes, the inclination steepens and the strike (corrected for plunge) swings anticlockwise. Thus at Right Whale Bay the cleavage strikes east–west and has an average dip of 80° to the south which is little affected by the westerly plunge of less than 10°.

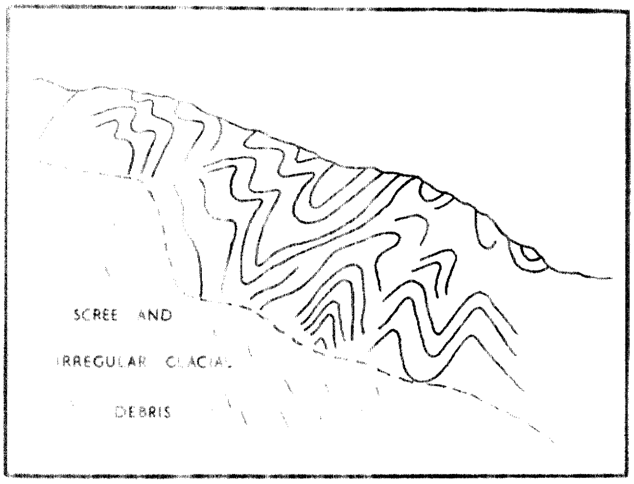

FIGURE 11

Large-scale folding of Sandebugten type greywackes in a cliff near Sandebugten, looking due east.

As in the calcareous concretions (figure 9), the intensity of the cleavage throughout the tuffs is directly related to the intensity of the local folding. A practical difficulty of estimating the cleavage intensity in a single exposure is that this relationship also applies on a small scale. The estimated average cleavage intensity is shown on the end folding map and figure 10 illustrates the approximate range of intensity.

b. Axial Plane Deformation in the Sandebugten Type

An axial plane cleavage similar to that in the Cumberland Bay type is also present in the Sandebugten type. It is clearly defined by a flattening of the more plastic grains in the coarser greywackes and by a slaty cleavage in the mudstones. The cleavage intensity throughout the Sandebugten type is comparable to that in the Cumberland Bay type at Grytviken (figure 10 and plate IVa). The cleavage dips to the north-east in most of the country between Hound Bay and Cumberland East Bay (Trendall, 1953, pp. 8–14). On the east side of the valley leading northward from the bay north of Sandebugten, the nature of the folding is easily seen and is sketched in figure 11.

c. Structural Relationship between the Cumberland Bay and Sandebugten Types

It was stated (Trendall, 1953, p. 21) that the greywackes and the tuffaceous greywackes each possess a characteristic tectonic orientation and that the junction between them was likely to be found on Dartmouth Point. During 1953 and 1954 ten days were spent on Dartmouth Point peninsula but it was not possible to determine the structural relationship between these two groups of rocks. However, it is certain that:

(i) Sandebugten type greywackes of similar orientation to those on the east coast of Cumberland East Bay are present at the extreme northern end of the Dartmouth Point peninsula.

(ii) As these rocks are followed southward the axial planes dip less steeply until they become almost horizontal, the tightly folded beds becoming progressively younger towards the south-west.

(iii) Typical Cumberland Bay type rocks at the south end of Moraine Fjord have an orientation similar to those at Grytviken with an axial plane cleavage dipping at about 30° to the south-west.

(iv) As these tuffaceous rocks are traced north-eastwards the cleavage dips less steeply until it becomes almost horizontal, when the tightly folded beds face north-east.

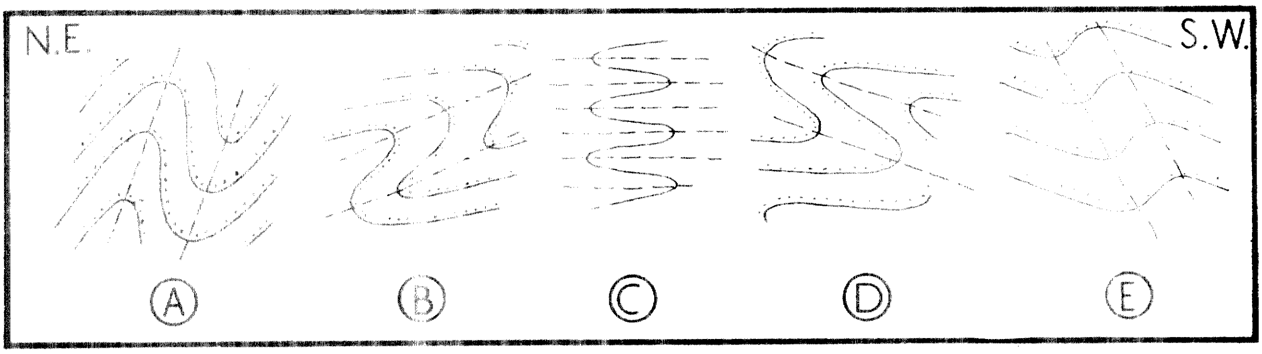

FIGURE 12

Diagrammatic representation of five successive and gradational areas of a cross-section from north-east to south-west through the Dartmouth Point peninsula. The dotting is a conventional representation of graded bedding and indicates the way-up in each area.

A. East side of Cumberland East Bay: Sandebugten type greywackes with axial plane cleavage dipping steeply to the north-north-east (see figure 10).

B. North end of Dartmouth Point peninsula: Sandebugten type greywackes with cleavage dipping gently to the north-north-east.

C. Central part of Dartmouth Point peninsula: cleavage flat or nearly so; beds intensely folded and bedding vertical; no graded bedding.

D. South end of Dartmouth Point peninsula: Cumberland Bay type greywackes with cleavage dipping gently south-south-west; strongly deformed.

E. Central south-west part of the island: occasional folds with axial planes dipping steeply south-west.

(v) Recognisable members of both groups are absent from a broad central zone of the peninsula. In this zone there is an intense undulating cleavage which is seldom steeply inclined (always less than 30°) and never laterally consistent in orientation.

These points are illustrated by the diagrammatic cross-section in figure 12. Whatever the structural significance of these observations (possible interpretations are discussed later) it is difficult to discriminate between two axial plane structures which cannot be distinguished on the ground.

d. Fracture Cleavage

As the Sandebugten type greywackes are followed south-eastwards from St. Andrews Bay, the axial plane or slaty cleavage becomes subordinate to a later fracture (Trendall, 1953, p. 10, 11). At first the original cleavage is easily followed by an elongation of the grains at an angle to both bedding and fracture cleavage (figure 13). In Royal Bay it is difficult to detect any structures other than bedding and fracture cleavage, but it is not clear whether the first cleavage has been obliterated or whether it was never present.

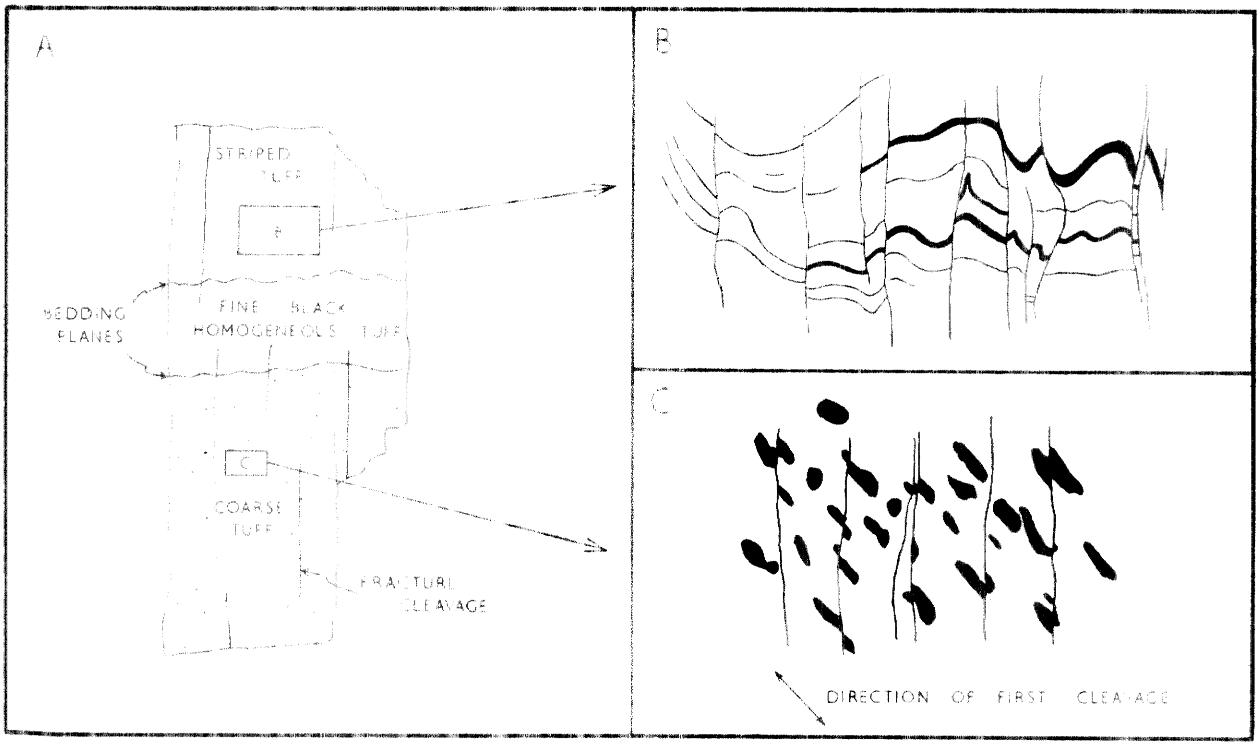

FIGURE 13

Cut surface of greywacke from Doris Bay showing the fracture cleavage. When this is more strongly developed other structures are indiscernible. The specimen is eight inches high.

In the northern part of the Cape Charlotte peninsula the fracture cleavage is present, but it varies locally in intensity and dips gently (at never more than 45°) to the south or south-west. Towards the southern part of the peninsula the fracture cleavage becomes steadily less conspicuous until it gives way to Cumberland Bay type tuffs with a typical cleavage marked by grain flattening. The fracture cleavage affects a part of the Cumberland Bay type, which at the southern end of the peninsula has a slightly steeper cleavage and dips at 30° to the west-south-west.

3. *Deformation of Grains*

In *The Geology of South Georgia—I* a grain elongation in *c* was described in both the Cumberland Bay and Sandebugten types. Further careful examination of the grain shape has shown that:

(i) In the Sandebugten type there is a consistent elongation in *c* (defined on p. 17).

(ii) In the Cumberland Bay type the elongation may be in either *c* or *b*.

(iii) Throughout the sedimentary rocks which have an axial plane cleavage the most striking feature of the deformation is an axial plane *flattening* of the grains. This may be regarded as a simultaneous elongation in both *c* and *b*. The local conditions of stress causing one or other of these to be greater have not yet been determined. This problem is referred to again on p. 47.

H. TRACE-FOSSILS

With the exception of the bodies described below, fossils are rare in the Cumberland Bay type and their occurrence has already been described (Trendall, 1953, pp. 2–4). However, a common feature of the upper parts of graded beds is the presence of "trace-fossils", "fucoid markings" or "lebenspuren" (Wilckens, 1947). These marks, which are illustrated in figure 14, are simply defined either by pale colouring on the dark bedding surface or by a shallow groove corresponding to a ridge on the base of the overlying bed. Occasionally these marks are tubular or flattened in the bedding plane, and are composed of sediment paler than that either above or below. They often have a characteristic manner of branching (figure 14B). Although the usual size of these markings is about that shown in figures 14A and B, a smaller type which often shows a radiate structure (figure 14C) also occurs.

Since the completion of this manuscript a definitive paper dealing with similar trace-fossils, which are collectively known as *Chondrites*, has been published (Simpson, 1957). They are apparently of widespread occurrence in sediments of a facies similar to that of the Cumberland Bay type.

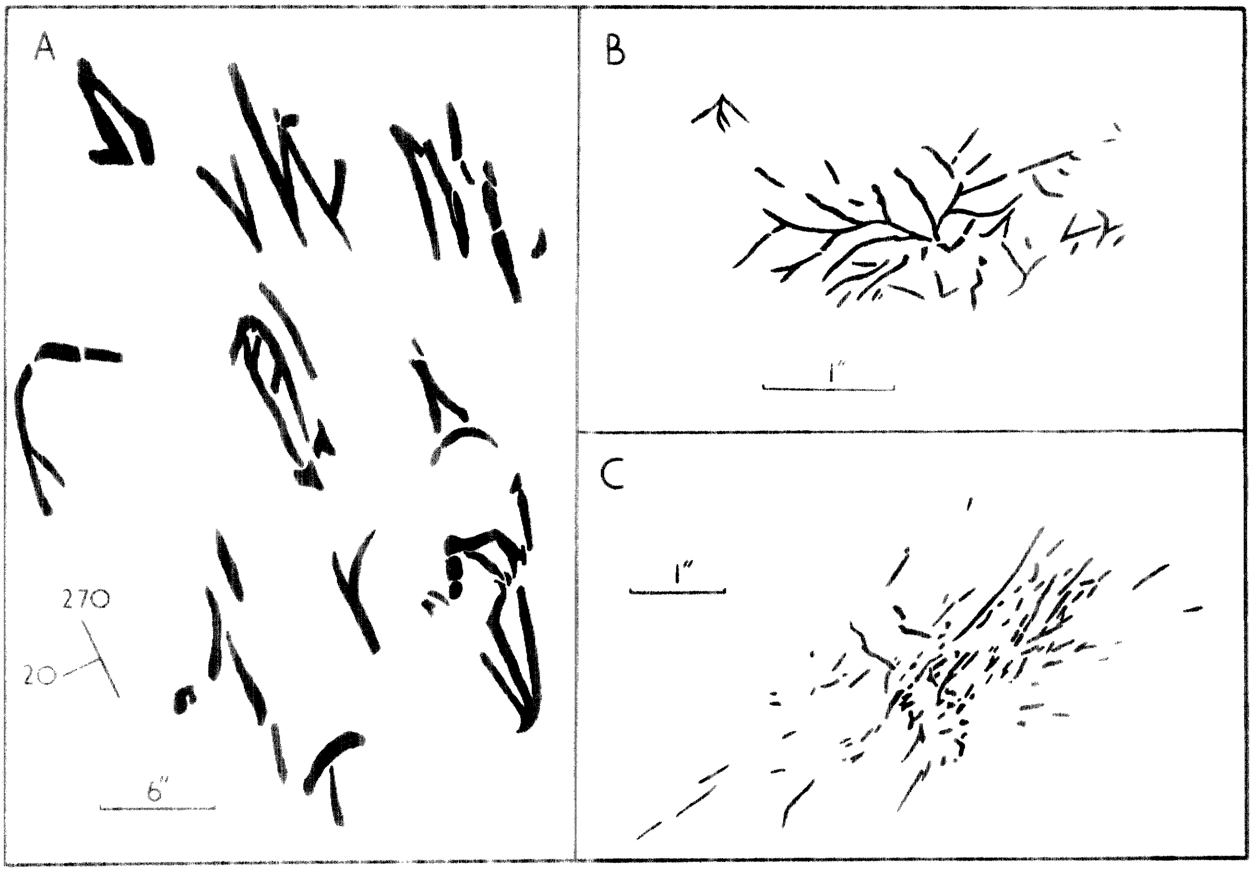

FIGURE 14

Trace-fossils.

A. Typical occurrence at Binder Beach, Right Whale Bay. The locally prevalent elongation in an east to west direction is probably due to tectonic distortion.

B. From near Grytviken, showing branching (specimen Nos. S.G. 195–6).

C. On a loose boulder from Right Whale Bay, showing a radiate cluster (specimen No. S.G. 193).

III. THE LAVAS

A. OCCURRENCE

THE positions of rocks examined and believed to be lavas are shown in figure 15, together with the orientation of the flow planes. The probable extent of the rocks between these exposures is indicated on the end folding map.

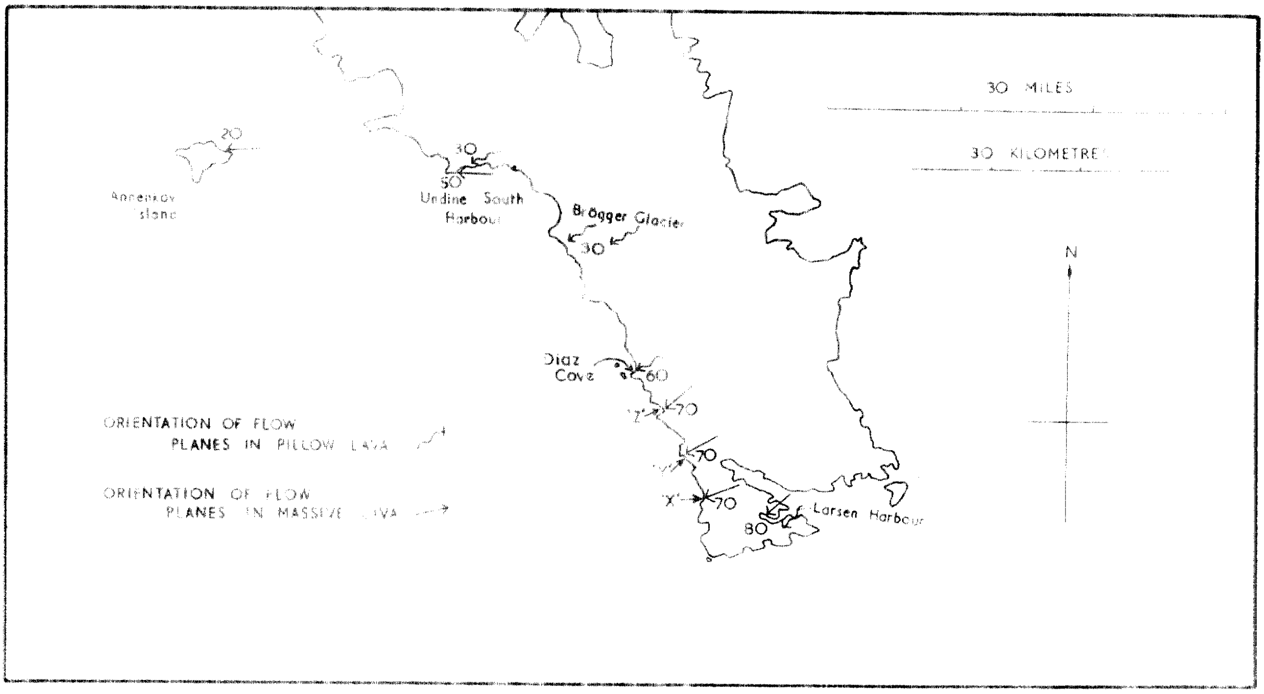

FIGURE 15

Map showing the nature and localities of the lavas examined, and the orientation of the flow planes.

B. RELATIONSHIP TO THE SEDIMENTS

It has already been noted (Trendall, 1953, p. 21) that along the south side of the Brögger Glacier "the rocks, for at least one and a half miles from the snout, consist of pillow-form lavas dipping normally and evenly at 30° to the south-west". The contact between these lavas and the similarly orientated adjacent sediments to the north-east was not seen. However, contacts between sediments and lavas have now been examined on the north coast of Undine South Harbour (see figure 15) and on Annenkov Island. At Undine South Harbour a band of fine-grained, dark sedimentary rock about 15 ft. thick dips at 50° to the west and is bounded on both sides by fine-grained, green lava having the same strike and dip. Both lines of contact are weathered throughout most of the exposure but at one point it is possible to discern a sharp contact between fine green material, which grades into definite lava, and fine brown material gradational into the quartzose siltstone. A short and typical length of this contact is shown in figure 16C. The absence of any evidence for the tectonic origin of this contact suggests that the lava is interbedded with the sediments; its precise mode of origin is unknown and is discussed elsewhere. At the landing beach on the north-eastern end of Annenkov Island amygdaloidal lavas alternate repeatedly with the tuffs. Although it was impossible to find and examine any contact, there is no indication that these alternations are of tectonic origin. Small scattered angular fragments (maximum length 3 in.) of recognisably bedded tuff were noted in one band of lava.

C. FIELD CHARACTERS

1. *Pillow Lavas*

Pillow lavas have been examined at Undine South Harbour, along the south side of the Brögger Glacier, at Diaz Cove and in Larsen Harbour. The pillows, green and fine-grained, are between a few inches and 6 ft. long. The flow planes are marked by the long axes of the larger pillows and by occasional thin continuous bands of fine-grained green material (ash?). The pillows are often vesicular and amygdaloidal, the vesicles being either spheroidal and arranged concentrically in one or more discrete bands, or tubular and arranged radially (figure 16B). The way-up of the lava is usually clear from the indented bases and rounded tops, particularly of the medium-sized pillows (figure 16A). The interstices between the pillows are filled by coarsely or finely crystalline epidote, calcite and quartz, and by amorphous jasper, which sometimes form strikingly coloured alternating bands.

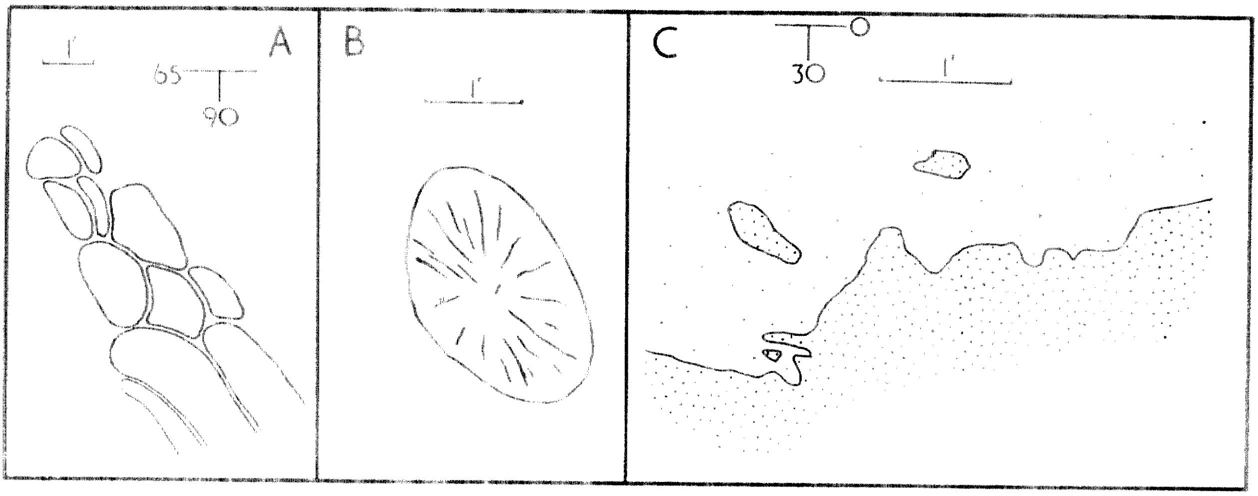

FIGURE 16

A. Pillow lava at Diaz Cove showing the rounded tops and indented bases of the pillows, which give a clear indication of the way-up.

B. Pillow at Larsen Harbour with radial tubular vesicles.

C. Contact between siltstone (above) and lava (below) at Undine South Harbour.

2. *Massive Lavas*

At Larsen Harbour pillow lava occurs in bands among massive, fine- or medium-grained green igneous rocks, in which various planar structures are parallel to the definite flow planes of the adjacent pillow lavas. These structures usually consist of poorly defined changes in the appearance of the rock which are caused by a change in grain size, an abundance of amygdales or porphyritic felspars, or a slight mineral or textural change. Occasionally the divisions are sharply defined and the direction may also be marked by a preferred long axis orientation of the amygdales. There is always marked jointing parallel to these structures which are of consistent orientation (see figures 15 and 20). At Larsen Harbour a careful distinction was made between such rocks and the abundant, similarly orientated dykes (figure 21), which are never amygdaloidal and which have chilled edges (except the edges of older parts of multiple dykes—see figure 30).

Similar massive green rocks, not associated with pillow lavas, and possessing a strong jointing parallel to indefinite banding, were examined at localities "X", "Y" and "Z", 3½ miles, 5 miles and 7½ miles north-north-west of Cape Disappointment respectively (see figure 1). At Undine South Harbour and on Annenkov Island the massive lavas are always fine-grained with less conspicuous banding. The form and type of the lavas at the eight localities visited is shown in Table I. The petrography is described in Section D below.

TABLE I. FORM AND TYPE OF LAVAS

Locality	Form	Type
Larsen Harbour	Massive	Spilite and basalt
	Pillow-form	Spilite
Locality "X"	Massive	Basalt
Locality "Y"	Massive	Basalt
Locality "Z"	Massive	Spilite and basalt
Diaz Cove	Pillow-form	Spilite
South Side of Brögger Glacier	Pillow-form	Spilite
Undine South Harbour	Pillow-form	Spilite
	Massive	Spilite
Annenkov Island	Massive	Spilite

D. PETROGRAPHY

1. *Spilite*

Albite or oligoclase is the dominant constituent of the spilites (approximately 60%). The felspar is always the low temperature form and normally occurs as laths less than 1 mm. long, either of uniform size or with a few crystals conspicuously larger than the rest. Both in the massive and pillow lavas they are mostly randomly orientated. The only exception to this is in a thin section of a massive spilite from Larsen Harbour. In this, the laths are arranged in a roughly tangential manner to the margins of the abundant, spherical, quartz-filled amygdales. In a section from the pillow lava at Diaz Cove, there are stumpy sub-hedral prisms of fresh augite, but elsewhere the mafic mineral is usually a pale or colourless amphibole in small elongate prisms. Many larger amphibole crystals are composed of numerous thin parallel needles. The amount of mafic minerals present varies; a thin section of massive lava from Larsen Harbour consists almost entirely of albite, which is black with evenly scattered small grains (0.002 mm. diameter) of an opaque mineral.

Abundant amygdales are commonly filled by epidote, chlorite, calcite or quartz, or by combinations of these minerals. Chlorite, probably replacing amphibole, is also a common secondary mineral and prehnite occasionally occurs within albite. Epidote is abundant but of variable occurrence; at Larsen Harbour entire pillows are formed of epidote while locally the mineral may be scarce or absent. A typical, but unusually coarse, spilite from locality "Z" is shown in plate IVe.

2. *Basalt*

The basalts are usually coarser than the spilites. Small plagioclase laths (An_{39-88}) are randomly arranged with the interstices filled by anhedral augite. Modal estimates of two thin sections, from Larsen Harbour and locality "Y", show 42% and 41% of plagioclase respectively. Normally the laths in any one thin section vary little in length but in a thin section from Larsen Harbour euhedral and equidimensional, porphyritic plagioclases 1 mm. in diameter are set in a matrix of random laths about 0.1 mm. long. All the plagioclases in this section have the same composition. Twinning is universal on albite, Carlsbad and pericline laws, in this order of abundance; in any one thin section there appears to be a tendency for either albite, Carlsbad or combined Carlsbad-albite twins to be most common. Zoning is usual and takes the form of a thin, evenly zoned margin with a composition of oligoclase or even albite at the rim.

The augite is often fresh but it may be altered either to amphibole containing small rounded augite cores or more commonly direct to chlorite with opaque grains. Chlorite is an abundant secondary mineral, which often occurs in small circular areas (diameter 0.5 mm.) probably representing amygdales. Epidote is less common than in the spilites. A thin section of a typical basalt is shown in plate IVf.

3. *Relationship between the Two Types*

A thin section of "spilite" from locality "X" with oligoclase laths lying at random in augite and amphibole contains scattered equidimensional porphyritic bytownite crystals (up to 3 mm. in diameter). This suggests a genetic relationship between the basalts and spilites, which are otherwise petrographically distinct. This distinction is emphasised by the histogram in figure 17 and the apparent connection is shown in figure 18, which is a different plot of the same material.

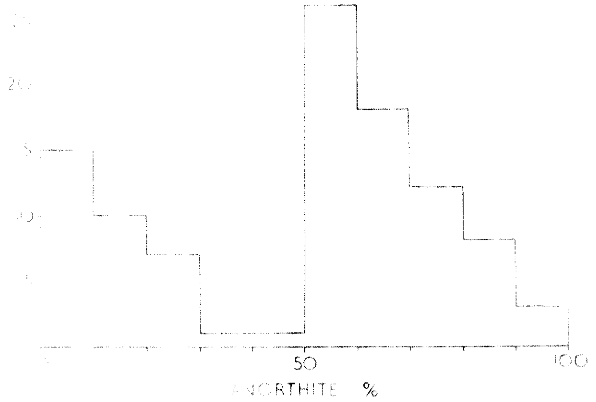

FIGURE 17

Histogram showing the compositions of 102 plagioclases from nine thin sections of lava. The localities are shown in figure 15.

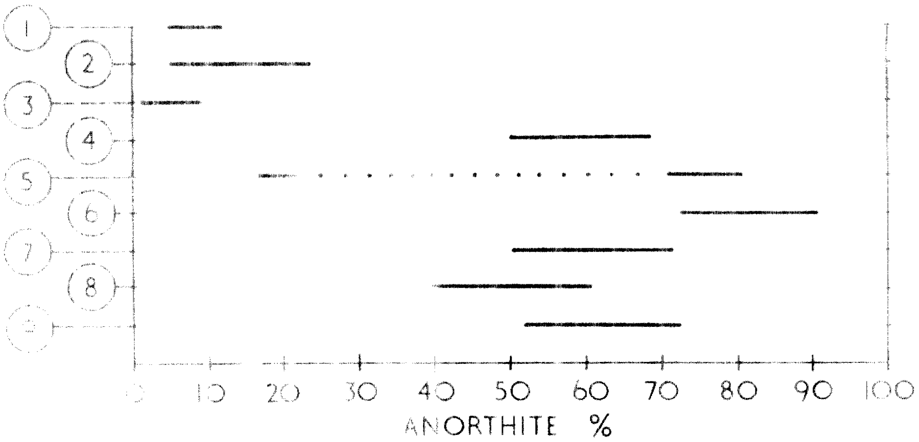

FIGURE 18

The range of plagioclase compositions in the nine thin sections used for figure 17. The ranges include an error which, as described in Appendix I, should be constant for each. 1 and 4. "Z"; 2. Annenkov Island; 3. Undine South Harbour; 5 and 8. "X"; 6 and 9. Larsen Harbour; 7. "Y".

IV. THE SOUTH-EASTERN IGNEOUS COMPLEX

A. INTRODUCTION

A TOPOGRAPHICAL map covering the area of the complex is given in figure 19. The geology of the same area is shown in figures 20 and 21 and is illustrated by the cross-section in figure 22. Plate IIa also shows a part of the complex.

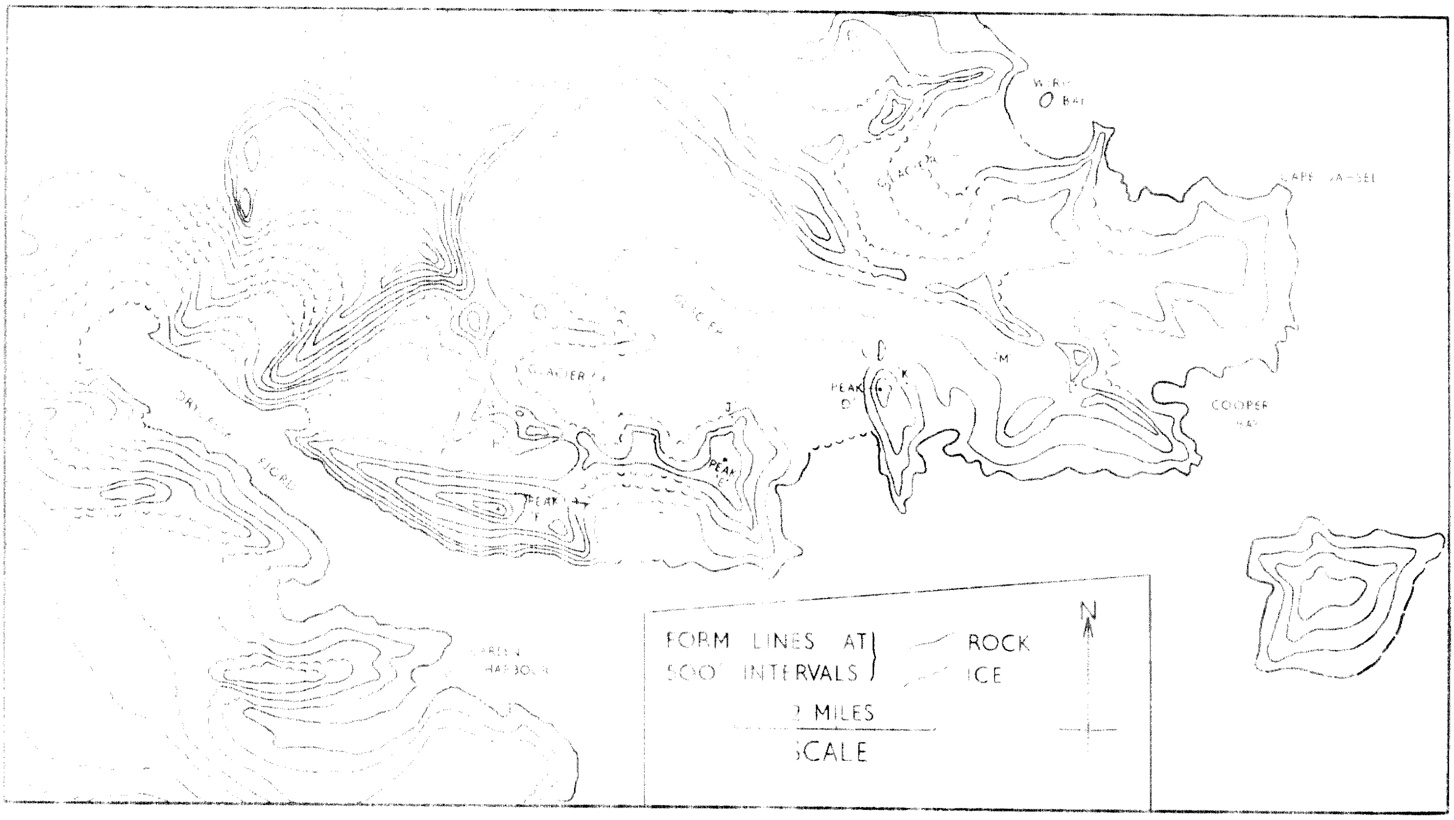

FIGURE 19

Map of part of the south-eastern end of the island (outline marked on the end folding map) showing topography, extent of glaciers and place-names. The letters A–F refer to glaciers and peaks which may ultimately receive an accepted name (see Appendix II). The letters G–M are used in the text to refer to localities of geological interest and do not indicate topographic features.

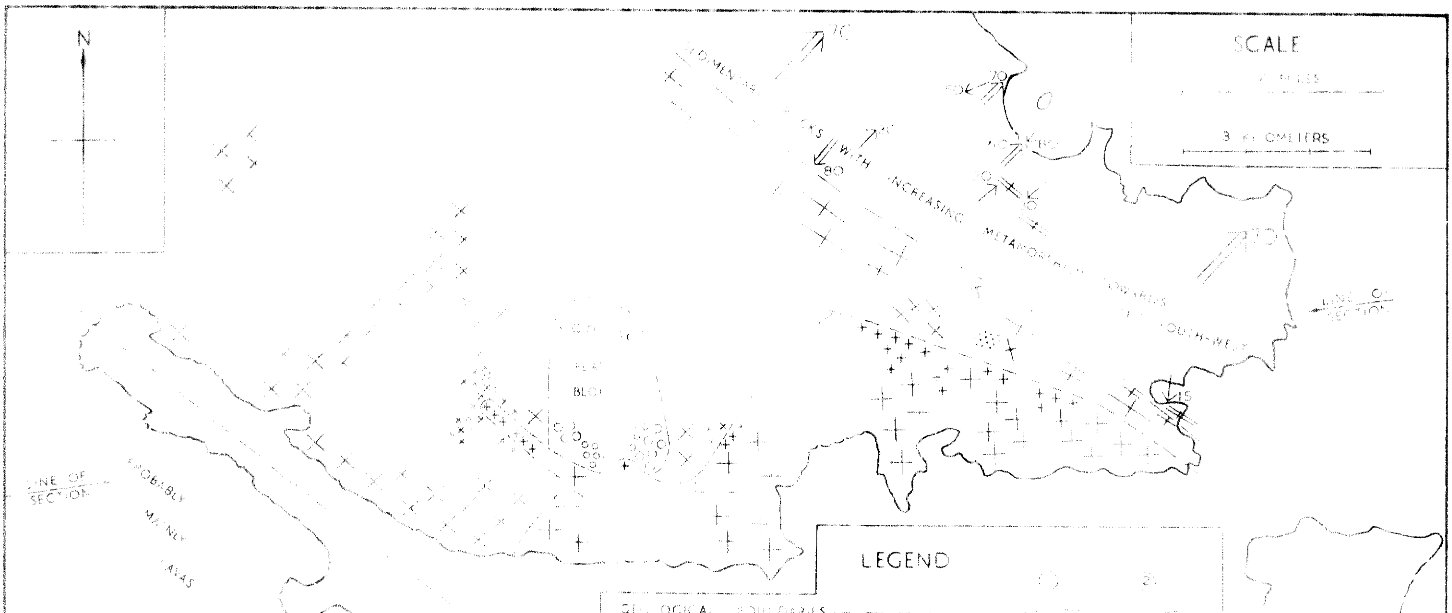

FIGURE 20

Geological map of the area shown in figure 19. The significance of columns "1" and "2" in the legend is described on page 28.

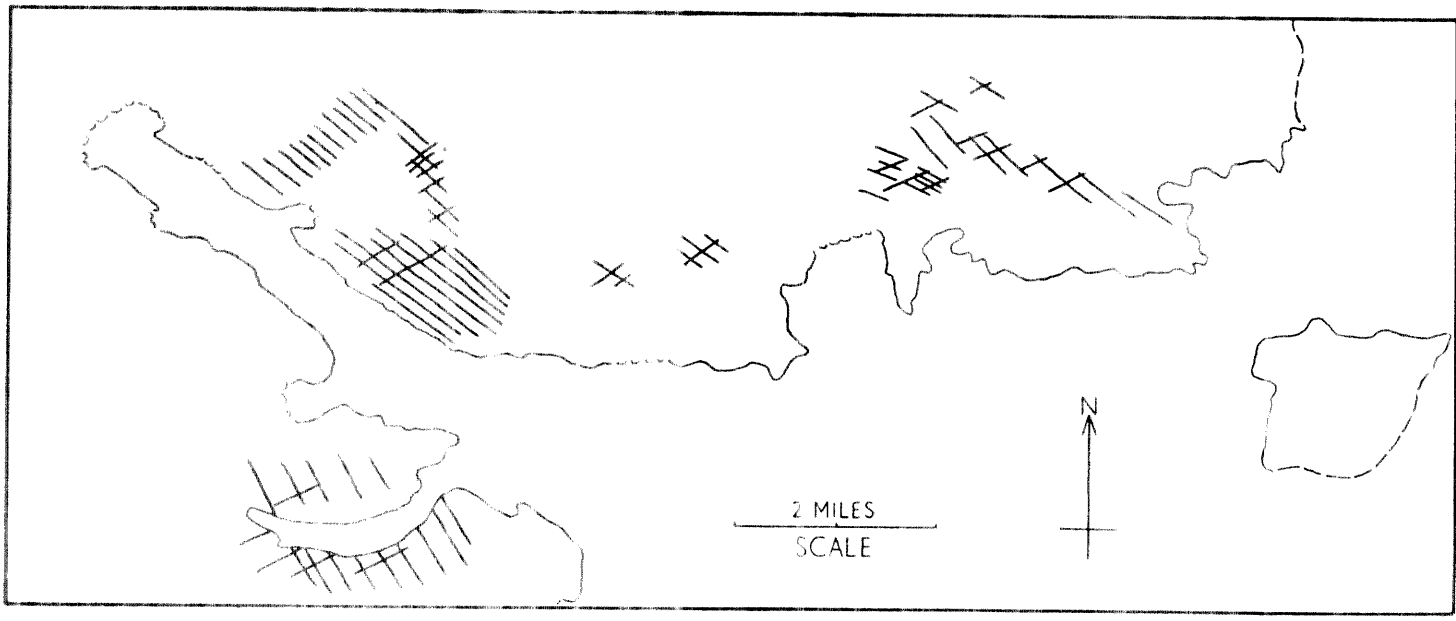

FIGURE 21
Map showing the directions of dykes (thin black lines) observed in the area shown in figures 19 and 20. The density of the dykes is indicated approximately by the spacing of the lines.

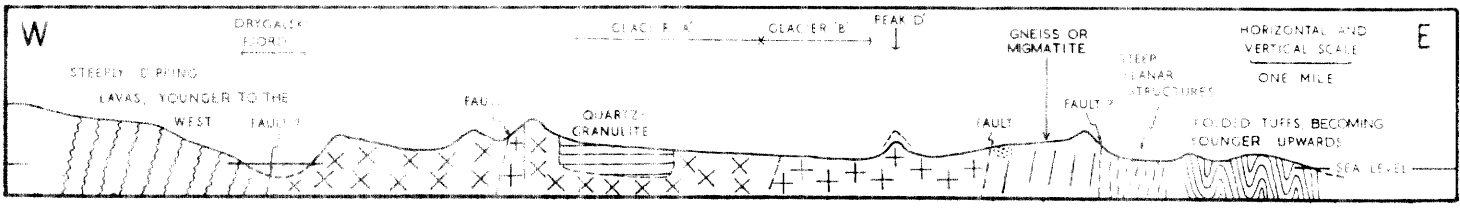

FIGURE 22
Vertical cross-section along the line marked in figure 20. Symbols not explained are those used in figure 20.

In 1954 it was possible to examine the rocks of the complex in a number of discrete areas, separated by stretches of glacier or by inaccessible country. These are:

(i) Between Cooper Bay and Glacier "B", ending to the north-west in Peak "D". Here, interbanded "migmatites", gneisses and intrusive quartz-diorites are separated from gabbros to the south-west by a major fault. This area is referred to in the text as "the area north-west of Cooper Bay" or by some similar phrase.

(ii) The north face of Peak "E" (figure 19), on which are exposed both gabbroic and granitic rocks.

(iii) A small area of quartz-granulite and gabbro on the south side of Glacier "A".

(iv) The area around the rock col at the head of Glacier "A", including a traverse into the deep valley to the south (plate IIa is a photograph taken looking across the area). The rocks include beautifully layered gabbro, granite and quartz-diorite. In the text the locality is referred to as "the area east of Drygalski Fjord".

In figure 20 all rocks and boundaries are shown by symbols of different size according to the "reliability". Rock types and boundaries actually examined in each of the four areas of the complex defined above are indicated by the symbols in column 1, whereas those seen from a distance or inferred are marked by the symbols in column 2. This second degree of reliability varies considerably. For example, there can be little doubt that the face of Peak "F", shown in plate IIa consists of dyked granite but, on the other hand, the extension of the gabbro boundary beneath Glacier "B" is purely hypothetical. More precise indications of the reliability of figure 20 are occasionally given in the text.

B. ACID AND ASSOCIATED ROCKS

1. *Granite and Granite-gneiss*

a. Note on Nomenclature

In this section the term "granite" is used in the sense of Turner and Verhoogen (1951, p. 259), who describe them as "holocrystalline coarse-grained rocks of plutonic aspect composed essentially of quartz, potash felspar and/or sodic plagioclase, and subordinate biotite, hornblende or pyroxene". Certain rocks, which are indistinguishable from granites in the field and which are encompassed by this definition, are included here although they are identical in composition with some of the quartz-diorites. Where quartz-diorites and granite-gneisses occur in juxtaposition north-west of Cooper Bay, the quartz-diorites have been isolated by virtue of their sharp distinction both in the field and in thin section and are described separately. Further comment on this nomenclature is included at the end of the section dealing with the quartz-diorites.

b. Occurrence and Field Characters

In the narrow strip of acid rocks running north-west from Cooper Bay (figure 20) coarse, light grey or brown, well-foliated gneiss is the most abundant rock. The trend of the foliation is approximately parallel to the margins of the strip and it usually dips steeply to the south-west. Xenoliths are of variable abundance. It was not possible to detect any linear structure on the foliation surfaces. On Peak "E" similar coarse-grained gneiss has a vertical foliation with a strike of 30° true. It is interbanded with a coarse granite showing no foliation and with a finer, pale, banded granulitic gneiss in which large angular basic xenoliths are conspicuously abundant (plate IIb). In the area east of Drygalski Fjord the massive, coarse pale granite has a weak foliation or none at all. When present, the foliation is defined by indistinct banding and by the orientation of sporadic, small dark xenoliths. The foliation in this area shows no consistent orientation.

c. Petrography

In thin section the acid gneisses of the area north-west of Cooper Bay are composed of felspar "augen", bounded by thin undulating bands and lenticles of quartz together with thin dark streaks mainly of biotite and amphibole. Muscovite, chlorite, apatite, zircon, epidote, clinozoisite and opaque minerals are also present in subsidiary quantities. Modal estimates of the mineralogical composition of six thin sections are given in figure 26.

A striking feature of these rocks is the intense cataclastic shearing which they have suffered. The direction of this is difficult to determine, since the vertical and horizontal sections in planes perpendicular to the foliation have a closely similar appearance. However, it is believed that this cataclastic deformation has been superimposed upon an original foliation.

The felspar, microcline or plagioclase (An_{13-14}), occurs mainly as conspicuous crystals up to 6 mm. long and which are either equidimensional or slightly elongate in the foliation. These crystals are sometimes broken up into several fragments separated by quartz-filled cracks. The proportion of potash felspar to plagioclase is variable and was not estimated. The plagioclases are invariably twinned on the albite, Carlsbad and pericline laws, and the twin lamellae are sometimes bent. In the more intensely crushed parts, plagioclases of normal appearance occasionally develop a vague obliquely cross-hatched structure resembling twinning; they sometimes show small (0.002 mm. thick), parallel, elongate, undulating lenticles which are optically continuous and distinct from the body of the plagioclase. The precise nature of these was not determined. Zoning is common and is always to a more sodic rim. All the felspars are cloudy and crowded with inclusions of recognisable clinozoisite, epidote and apatite as well as scattered indeterminate "dust" and needles. Small sub-parallel myrmekitic tubules of quartz are often present in the margins of the felspars.

The quartz is always intensely deformed and the lenticles in which it occurs are usually composed of a number of thinner streaks, each of which is made up of a finely sheared mosaic of crystals with undulating extinction. This structure is illustrated in plate Va. Biotite (often with sagenitic rutile), amphibole, muscovite and chlorite, all lie in thin streaks with their long axes parallel to the foliation. The mica cleavages are usually bent and the amphibole occurs as elongate masses of small parallel needles.

In the area east of Drygalski Fjord the granite has suffered no cataclasis and shows no orientation of the components. Large, subhedral crystals (up to 4 mm.) of andesine or oligoclase (An_{28-48}) are set in a coarse mosaic of quartz with subsidiary quantities of amphibole, biotite, and chlorite. Potash felspar is absent from the sections examined. Modal estimates are given in figure 26. The plagioclases, usually twinned on the albite, Carlsbad and pericline laws, are often zoned. Although in general the rims are more sodic, one thin section shows a number of crystals with oscillatory zoning.

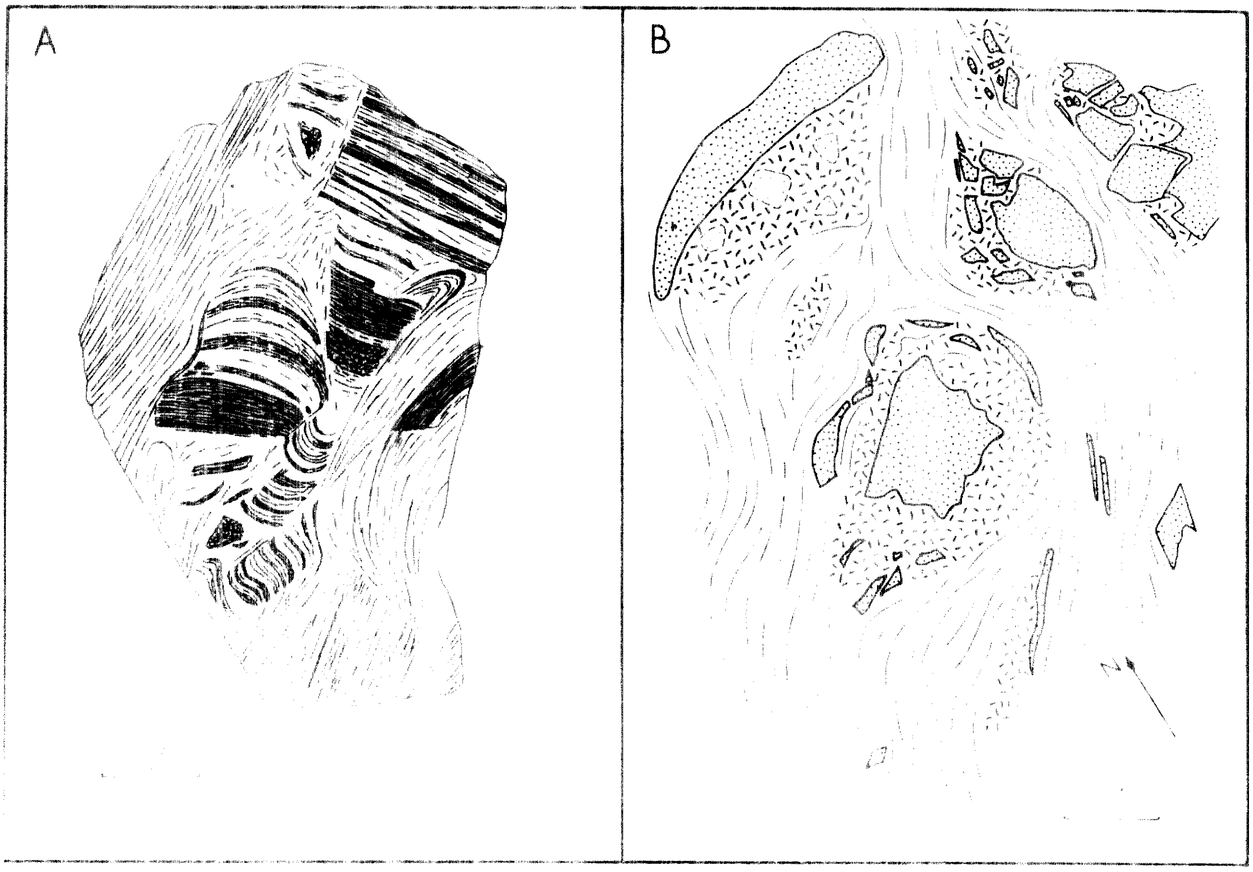

FIGURE 23

A. Vaguely defined banded xenoliths in the granulitic gneiss of Peak "E" (figure 19). The xenoliths are petrographically similar to the enclosing gneiss.

B. Angular basic xenoliths (stippled) in the granulitic gneiss of Peak "E" (figure 19). The xenoliths which are arranged in clusters are probably derived from the disintegration of larger blocks. The banding in the gneiss is shown by lines and the "dashed" areas represent lighter, homogeneous rock. Traced from a photograph.

The coarse acid gneisses of Peak "E" are similar in field appearance to those already described, but only thin sections of a pale grey granulitic gneiss were examined. Such a rock is shown in plate Vb, which is a photograph of part of a thin section cut from the specimen sketched in figure 23. The rock is composed of an evenly granular mosaic of quartz and felspar, in which are scattered plates and aggregates of red-brown biotite with the cleavages orientated approximately parallel to the foliation. The felspars are oligoclase and microcline and, although no precise modal estimate was made, quartz is the dominant constituent of the rock.

2. *Quartz-diorite*

a. Occurrence and Field Characters

In the strip running north-west from Cooper Bay a small area (about $\frac{1}{4}$ mile square around locality "M") of quartz-diorite was examined carefully. The central part of the mass consists of a fine-grained dark rock of which the most remarkable feature is the abundance of "xenolithic" structures defined by slight but abrupt petrographic changes. Sharply defined patches of light and dark rock are arranged in a variety of relationships, two of which are shown in figure 24. This structure is also illustrated in plate IIIb. Although these boundaries appear to be quite clear and definite, they are only discernible with difficulty in the thin section and are marked by no change of fabric.

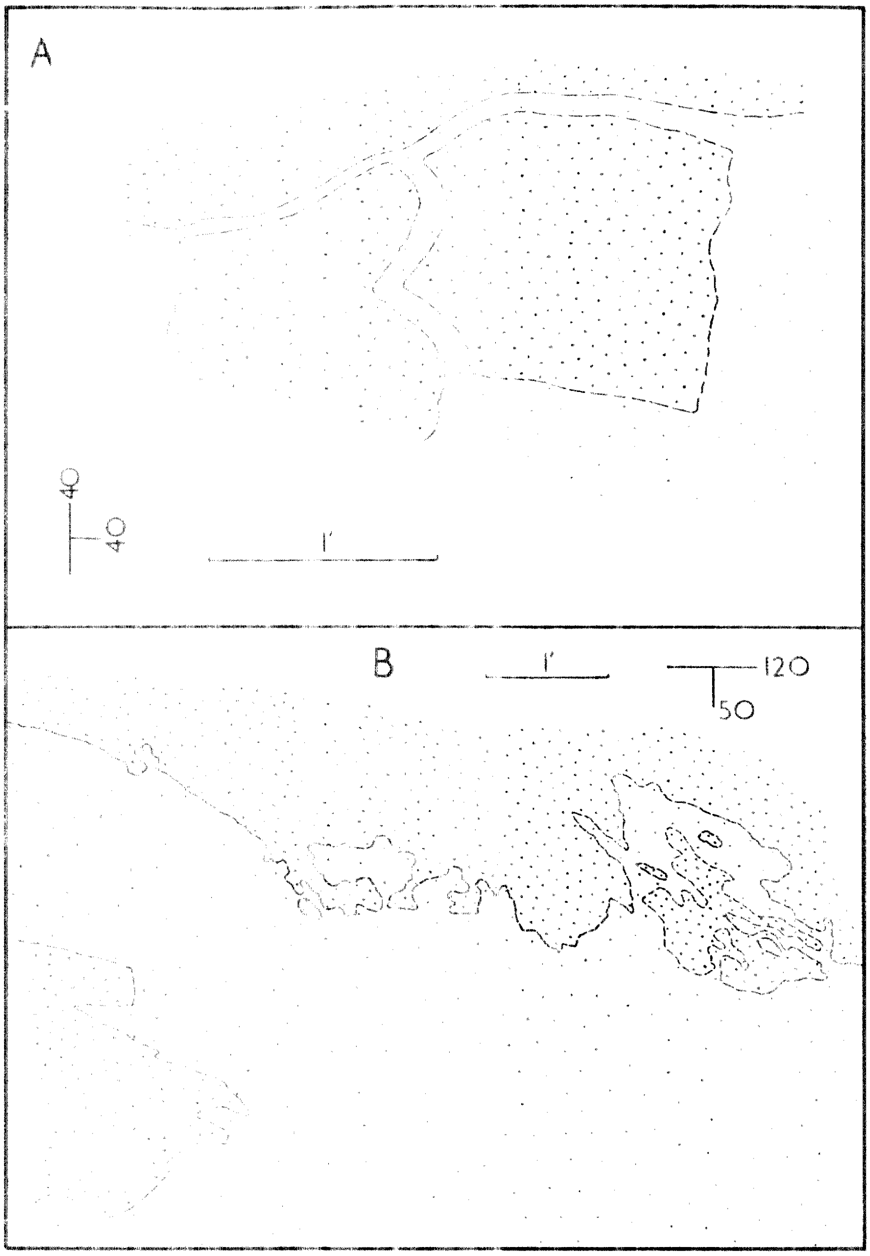

FIGURE 24

A. Darker (more closely stippled) areas of fine-grained dark quartz-diorite near locality "M" (figure 19). The block has the appearance of a stoped xenolith. Traced from a photograph.

B. Darker (more closely stippled) areas of fine-grained dark quartz-diorite near locality "M" (figure 19). The contact here is irregular and has the appearance of corrosion or replacement. Traced from a photograph.

In the area examined, the quartz-diorite possesses a locally distinct foliation parallel to that in the surrounding granite-gneiss. North-west of Cooper Bay thin "rafts" of quartz-diorite are surrounded by granite-gneiss and are concordant with the general foliation. At one locality, a raft of quartz-diorite 6 ft. thick had a foliation of increasing intensity towards the margins.

In the area east of Drygalski Fjord a similar quartz-diorite is present. It shows the characteristic patchiness of that north-west of Cooper Bay but is never foliated. It has a local occurrence among the coarser and lighter granites but no sharp junction between the two could be found.

b. Petrography

In thin section the quartz-diorites of the area north-west of Cooper Bay show clear evidence of severe cataclastic deformation, which is also common to the acid gneisses. The principal minerals are amphibole, plagioclase and quartz with subsidiary epidote, clinozoisite, micas and opaque minerals. A thin section of a typical quartz-diorite is shown in plate Vc. The modal estimates of eighteen thin sections, given in figure 26, show a wide variation which reflects the patchy structure visible in the field

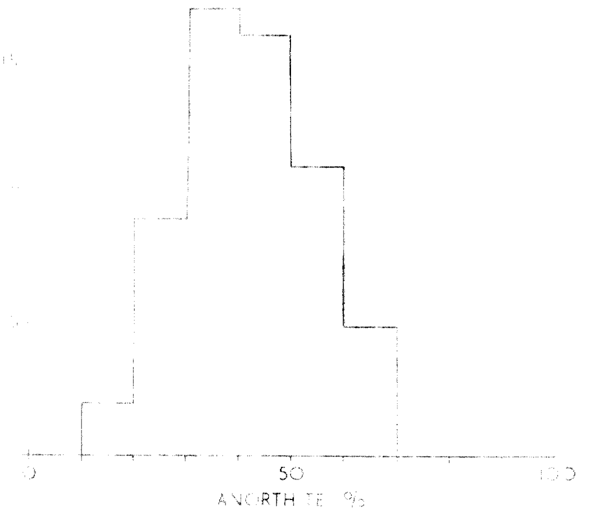

FIGURE 25

Histogram showing the compositions of 60 plagioclases from fifteen thin sections of quartz-diorite from near locality "M" (figure 19) and two thin sections from the area east of Drygalski Fjord.

In the less sheared rocks subhedral plagioclases (An_{11-67}; figure 25) up to 4mm. in diameter are equidimensional or in stumpy laths. Twinning on albite, Carlsbad and pericline laws is almost universal. The zoning from core to rim has been observed to cover a range of as much as 40% An; the rim is always the more sodic. Even in the diorite which has escaped shearing, secondary fine granular epidote and sericite are common within the felspars, which are also clouded with minute grains of indeterminate material.

Plagioclases are occasionally enclosed by large hornblende crystals (up to 1 cm. in diameter), which are easily distinguishable in the hand specimen, though more normally the subhedral hornblendes are of the same size order as the plagioclases. Quartz mosaic patches are also present. Where the rocks possess a foliation visible in the hand specimen, the cataclastic effects completely mask the original texture of the rock. Felspars and hornblendes form small "augen" around which "flow" wisps and streaks of intensely sheared quartz with chlorite and finely granular epidote. Both the hornblendes and the felspars are often fractured and bent.

Modal estimates of two fine-grained, dark rocks from the area east of Drygalski Fjord are given in figure 26. These rocks are even-grained (0.5 to 2.0 mm.) and are composed of andesine laths and hornblende with quartz mosaic patches. They are dark, compact and of quite a different appearance in the hand specimen from the coarse light granites of the same area which are described above. However, it is clear from figure 26 that:

(i) No distinction can be made on modal estimates (or, in fact, by plagioclase composition) between these fine-grained, dark quartz-diorites and the coarse light granites in the area east of Drygalski Fjord.

(ii) In the strip running north-west from Cooper Bay there is a clear distinction, both in the field and in the average modal estimates, between the quartz-diorites and the granite-gneiss.

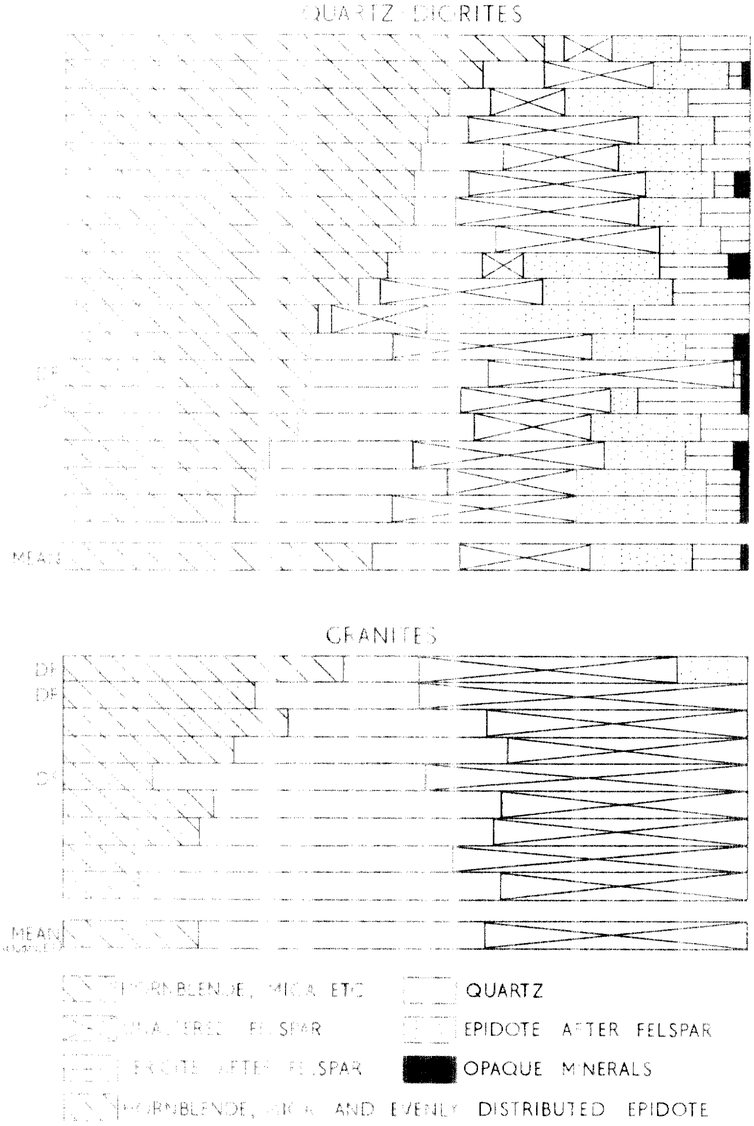

FIGURE 26

Modes estimated from eighteen thin sections of quartz-diorite and nine thin sections of granite. Those marked "DF" are from the area east of Drygalski Fjord; the remainder are of rocks from the area north-west of Cooper Bay. The lower mean is of the six rocks from the area north-west of Cooper Bay.

(iii) There is no modal difference between the granite-gneisses of the area north-west of Cooper Bay and a rock such as the most acid granite from the area east of Drygalski Fjord shown in figure 26.

3. *Migmatite*

a. Occurrence and Field Characters

The term "migmatite" is applied here to various cataclastically deformed gneisses occurring in the area north-west of Cooper Bay. Some are of definite sedimentary and others of definite igneous derivation but most are of mixed or doubtful origin. They all have a clear planar structure (shearing, foliation or colour-banding), the strike of which is sub-parallel to the boundaries of the area of acid rocks and is either vertical or steeply dipping to the south-west. There are several varieties, any one of which can be gradational into another. It is only possible to distinguish the varieties described below and, of these (iv) and (v) are gradational into the two distinct rocks, granite-gneiss and sheared quartz-diorite, already described from the area.

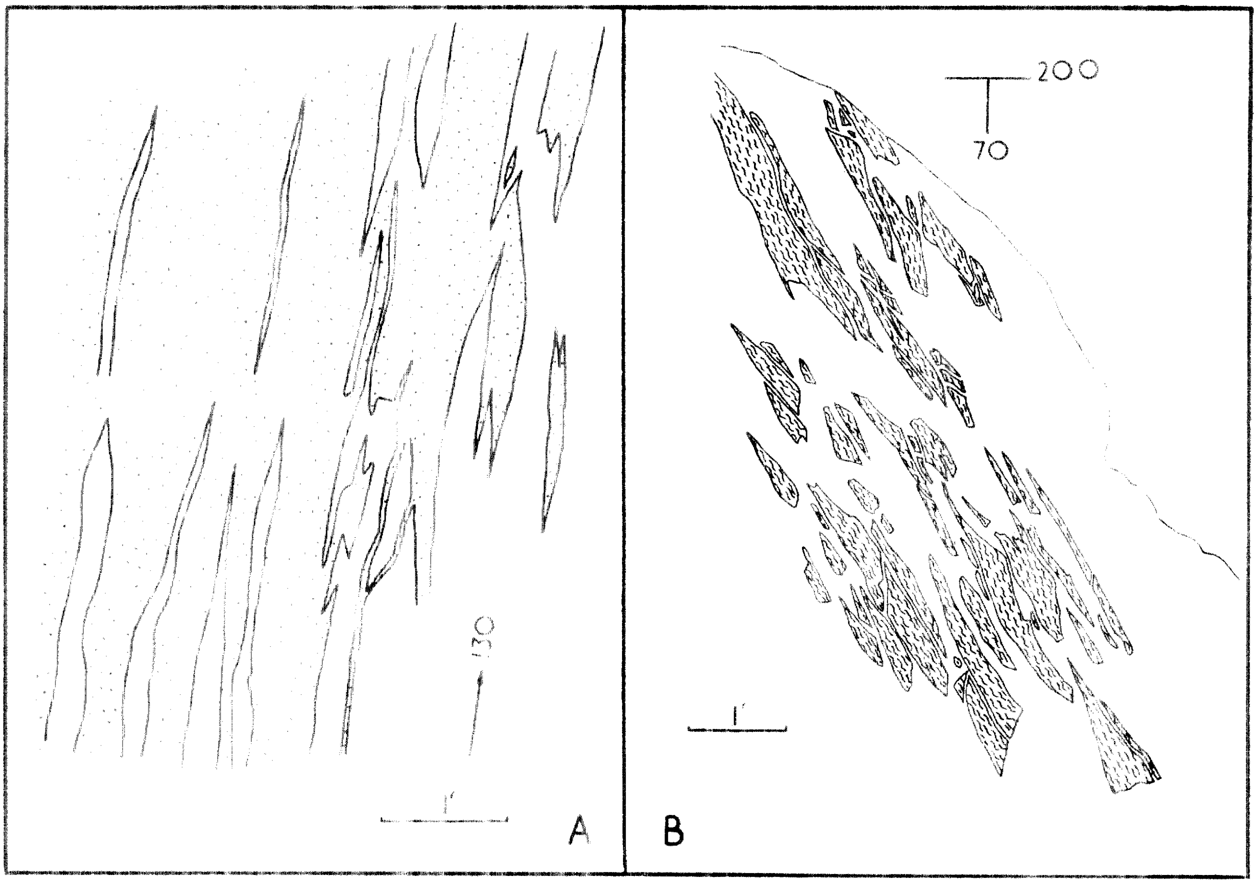

FIGURE 27

A. Horizontal surface of migmatite in the area north-west of Cooper Bay with the strike bearing of the vertical foliation marked. The areas left blank are of fine dark homogeneous gneiss (type (ii), p. 34) while the stippled parts represent similar gneiss but with conspicuous porphyritic felspars (type (iii), p. 34). Traced from a photograph. B. Vertical face showing bodies of sheared hornblendic gneiss (type (v)) in quartz-bearing gneiss (type (iv)).

(i) Massive fine-grained rock of cherty appearance with fine banding in shades of pale grey which occurs in sheets between 2 and 20 ft. thick and is usually in sharp contact with a coarse granite-gneiss.

(ii) Massive, fine, dark homogeneous gneiss.

(iii) Similar to (ii), but with abundant, small conspicuous porphyritic felspars giving a speckled appearance to the rock. The dark groundmass is fine- or medium-grained. Although the boundaries of the bands containing porphyritic felspars are usually poorly defined, a surface with interdigitated bands is shown in figure 27A.

(iv) Similar fine-grained gneisses with porphyritic felspar but containing conspicuous quartz.

(v) Fine-grained, dark gneiss rich in hornblende. A face showing isolated sheared bodies of hornblendic gneiss in contact with the quartz-bearing gneiss (type (iv)) is shown in figure 27B.

b. Petrography

Microscopic examination of a thin section from a pale cherty "raft" 10 ft. thick in the granite-gneiss shows it is clearly an altered sedimentary rock. Small (0.2 mm.) clastic grains of quartz with subsidiary albite and oligoclase occur in a matrix of very fine (0.005 mm.) mosaic quartz in which are abundant strings and lenticles of equally fine granular epidote. A section of a smaller patch of similar rock shows it is a quartz-epidote rock with the two minerals arranged in alternating finely granular bands.

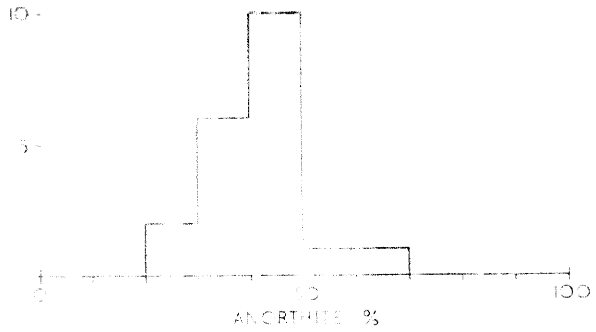

FIGURE 28
Histogram showing the compositions of 20 plagioclases from twelve thin sections of migmatite (mainly type (v), p. 34).

The remaining types of gneiss listed above consist principally of varying proportions of quartz, plagioclase (figure 28) and hornblende. The sheared appearance and arrangement of these minerals is similar to that in the granite-gneisses already described. The plagioclases, always twinned and zoned, are often fractured and separated. Quartz occurs in streaks of fine mosaic flowing around the plagioclase. Biotite, chlorite and amphibole are similarly arranged in undulating bands, parallel to which the individual crystals are elongated. Secondary epidote and clinozoisite are abundant with minor quantities of calcite, apatite and opaque minerals.

4. *Xenoliths*

a. Occurrence and Field Characters

In the coarse granite-gneiss of the area north-west of Cooper Bay xenoliths are locally abundant. They are usually between 1 in. and 1 ft. long, elongate and fine-grained. There is often a rough banding parallel to the long axes of the xenoliths but they have a random relationship to the foliation in the surrounding gneiss.

In the acid gneisses of Peak "E" xenoliths are often conspicuously abundant (figure 23 and plate IIb); they vary in size from 3 ft. downwards and are usually dark and homogeneous. A common feature is the disintegration of individual xenoliths into a cluster of angular fragments which appear to be slightly displaced (figure 23B). The xenoliths of figure 23A are banded and vaguely defined but neither of these features is common. In the gneiss with packed xenoliths it is always possible to distinguish a plane of flow banding defined either by the long axes of the xenoliths or by a roughly parallel streaking in the surrounding gneiss, or by both.

b. Petrography

In thin section the xenoliths of the area north-west of Cooper Bay are similar to certain of the migmatites, particularly to those of sedimentary origin. Plagioclase (An$_{23-41}$), quartz and amphibole are the major constituents. When the banding in the xenoliths (presumably relict bedding) is not parallel to the foliation of the surrounding gneiss it is crossed by the cataclastic shearing. In the thin sections examined, the plagioclases never exceed 0.2 mm. in diameter and are arranged in a fine sheared quartz mosaic with elongated lenticles of amphibole, biotite and chlorite parallel to the direction of shearing. Epidote is an abundant accessory mineral.

The dark xenoliths from Peak "E" are entirely different. The principal constituents are plagioclase (An$_{66-87}$) together with amphibole, pyroxene, biotite, or various combinations of these three minerals. In the thin section shown in plate Vd, which is typical of those examined, laths of fresh plagioclase about 0.5 mm. long and with an elongation of 5–6:1 are randomly orientated and are evenly distributed through the rock. The cores of the plagioclase laths are bytownite (An$_{80-87}$) zoned down to An$_{66}$ at the edges. The plagioclases almost invariably show combined lamellar albite and simple Carlsbad twinning, while lamellar pericline twinning is rare. The sides of the laths are irregularly embayed by the rounded outlines of the fresh pyroxene crystals. The latter may be equidimensional, elongate or irregular and they fill most of the interstices in the continuous network of plagioclase. Small groups of slightly separated, rounded pyroxenes are sometimes optically continuous. Elongate areas with widely scattered, optically continuous, irregular patches of red-brown biotite up to 3 mm. in length are present. Subsidiary amounts of hornblende, the occurrence of which is similar to that of the pyroxene, and small opaque grains are evenly scattered through the section.

C. THE CENTRAL QUARTZ-GRANULITE

1. *Occurrence and Field Characters*

The origin of these rocks is doubtful and, although they were visited in several places, much of the contact is hypothetical (figure 20). In field appearance this rock resembles a sedimentary quartzite. It is a hard, pale green, grey or brown rock, and the close conspicuous planar structures and very regular striping in shades of these colours facilitates its recognition from a distance. On the south side of Glacier "A", in places where it could be examined closely, the striping dips at between 10 and 20° to the north-west, but in the cliffs on the north side of the same glacier the striping appears to be almost horizontal. In figure 20 the rock has been marked "flat block". The rock breaks easily along the direction of striping and in the unweathered central part is a distinctive pale purple. Elongated flecks of dark mica are easily visible on broken surfaces and their long axes have a consistent orientation, which is almost horizontal and strikes 220° true. This orientation is consistent over the whole area examined. The only disturbance in the extreme regularity of the striping is caused by thin lenticular quartz veins, which occur in the plane of the striping and are elongated parallel to the lineation of the mica. This lineation is marked by no other structure in the hand specimen; minor folds on any scale are absent.

2. *Petrography*

The rock is composed principally of quartz, which in thin section forms an even mosaic of slightly elongate individuals, varying in diameter from 0.2 mm. downward. Thin sections were cut from one specimen in vertical planes parallel and perpendicular to the lineation. The quartzes of the mosaic in the section parallel to the lineation are slightly more elongated (2:1) than those in the section perpendicular to the foliation (3:2). The elongation is always in the plane of the striping. A more striking feature of the section parallel to the foliation is the tendency for the larger quartz grains to be arranged in strings, end to end, and one individual thick. Scattered equigranular grains of oligoclase occur in the quartz mosaic.

Small (less than 0.2 mm.) flakes of biotite or muscovite are scattered throughout the mosaic and they are also arranged more commonly in strips which define the macroscopic striping. It is clear that the flecks of mica visible in the hand specimen are in fact elongated aggregates of such small flakes. The cleavages in all the micas are conspicuously parallel to the striping and it is estimated that in the section parallel to the lineation no biotite cleavage departs more than 10° from the plane of striping. The orientation is slightly less consistent in the section perpendicular to the lineation. There is a small quantity of chlorite and sericitised plagioclase in one section. Small apatite grains and opaque minerals are also present. These granulites are remarkably similar *in thin section* to the granite-gneisses described above (pp. 29–30) and figured in plate Vb.

D. GABBRO

1. *Occurrence and Field Characters*

a. General

Parts of large gabbroic bodies were examined in the area north-west of Cooper Bay, on Peak "E", on the ridge south of Glacier "A" and in the area east of Drygalski Fjord. The areas shown as gabbro by the appropriate symbol of column 2 in figure 20 are almost certainly underlain by this rock. It is usually massive, coarse- and even-grained, varying from pale green or cream to dark grey or purplish black in colour. Although it is mostly homogeneous two locally developed structures were observed and are described below.

b. Inclusions

In a small area immediately east of Peak "D" the gabbro commonly contains dark masses of "pyroxenite". These inclusions, which vary both in size and shape, are coarsely granular and dark in colour with no felspar. They may be up to 100 ft. long and are either tabular, equidimensional or irregular in form. The edges of all the observed masses were "stoped" and veined by the surrounding gabbro. This is shown in plate IIIa.

c. Banding and Layering

The gabbro of the area, where the inclusions occur, possesses a banding which is defined by abrupt or gradational changes in the proportions of light and dark minerals. The characteristic appearance of this is shown in plate IIIc. Such banding may die away laterally and give place to (as far as can be seen in the field) structureless gabbro. Wherever banding is visible it continues for some distance (up to 300 ft.) and is of strikingly consistent orientation in any one locality. In a traverse of about half a mile through the gabbro, however, twelve areas of locally consistent bands were found to be randomly orientated in relation to one another, though most of the banding dipped steeply. No clear curving of this banding was observed.

In the area east of Drygalski Fjord, a part of the gabbro shows rhythmic layering of a type quite distinct from the banding described above. This structure can be seen in plates IIa and IIId. The layers dip at 40° to the south-south-west and are 2–5 ft. thick. Although there is no gradation of colour through each layer, the lower part of each is distinctly darker; modal estimates of upper and lower parts of a single layer are given below. The exact nature of the contacts between layers cannot be seen in the field but they appear as poorly defined planes of weakness resembling joints.

2. *Petrography*

Part of a thin section of the layered gabbro from locality "H" is given in plate Ve. The rock consists principally of coarsely (1–2 mm.) crystalline plagioclase and pyroxene with minor amounts of hornblende, chlorite, and opaque minerals. In the following table thin sections of specimens taken 6 in. and 4 ft. from the base of a layer 5 ft. thick are compared:

	Plagioclase	Mafic minerals	Opaque minerals
4 ft. from base of layer	50	48	2
6 in. from base of layer	34	60	6

The plagioclase, in the form of subhedral equidimensional grains or stumpy laths, varies in composition from An_{78} to An_{85}. Twinning in broad lamellae on albite and Carlsbad laws is usual and zoning is absent. The compositions of plagioclases in gabbros from various localities are given in figure 29. Similar rocks which have up to 15% of olivine in some sections constitute the gabbro on the south side of Glacier "A" and on Peak "E".

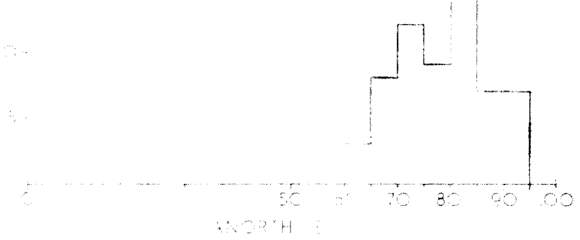

FIGURE 29

Histogram showing the compositions of 66 plagioclases from eight thin sections of gabbro from the area east of Drygalski Fjord, Peak "D" and near locality "K" (figure 19).

In the area north-west of Cooper Bay the gabbro is uniformly altered, the felspar being almost completely converted to saussurite with amphibole and chlorite replacing the pyroxene. Epidote granules and patches of prehnite are abundant. In thin section the "pyroxenite", which in the field appears to be quite fresh, is composed of chlorite and thinly prismatic amphibole with occasional, irregularly rounded remnants of pyroxene. Serpentine pseudomorphs after olivine are also present. To the north-east of Peak "D", along the fault separating the gabbro from the acid rocks, the gabbro is intensely sheared parallel to the fault, and in thin section the only mineral which never appears to be fractured is epidote.

V. THE DYKES AND OTHER MINOR INTRUSIONS

A. THE DYKES

1. *Distribution*

THE distribution and directions of dykes in, and adjacent to, the south-eastern igneous complex are shown in figure 21. Outside the area of this map dykes of both principal directions have been observed along the south-east coast at localities "X", "Y" and "Z", at Diaz Cove, and inland in a small area south of the Ross Pass. No dykes have been found in the sedimentary rocks to the north-east of the igneous complex in the area of figure 20, nor have any been recorded elsewhere in the folded sedimentary rocks.

2. *Field Characters*

The dykes are of a uniform dark colour and are usually fine- or medium-grained. The thicknesses of the dykes examined vary between a few inches and nearly 20 ft., the dip always being within 30° of the vertical. Vertical dykes cutting the granite of the south-eastern igneous complex are well illustrated in plate IIa. In two areas dykes trending approximately north-west to south-east have been intruded along original structures in the rocks. Chilled edges are the only reliable field criteria for the recognition of dykes in these areas. The structures are:

(i) The foliation of the granite-gneiss in the area north-west of Cooper Bay.

(ii) The flow planes of the lavas at Larsen Harbour, localities "X", "Y", "Z" and Diaz Cove.

In the areas north-west of Cooper Bay and east of Drygalski Fjord, the dykes with a consistent north-east to south-west trend traverse those trending north-west to south-east. North-west of Cooper Bay, the north-west to south-east dykes are sometimes affected by the cataclastic shearing prevalent in the intruded rocks. In the field the north-east to south-west dykes do not appear to be affected but a thin section of a specimen taken near locality "M" reveals distinct shearing.

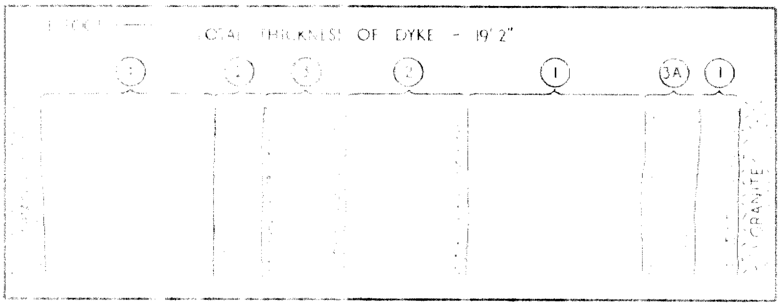

FIGURE 30

Scale section of a vertical multiple dyke of quartz-dolerite, near locality "G" (figure 19). The successive intrusions are numbered and chilled edges are stippled.

East of Drygalski Fjord, many of the larger dykes are multiple, and a measured section of one such dyke with a strike of 130° true is given in figure 30.

3. *Petrography*

The dyke rocks can be broadly divided into two groups—basic rocks (dolerite, quartz-dolerite and olivine-dolerite) bearing labradorite and bytownite and similar rocks bearing sodic plagioclase (figure 31).

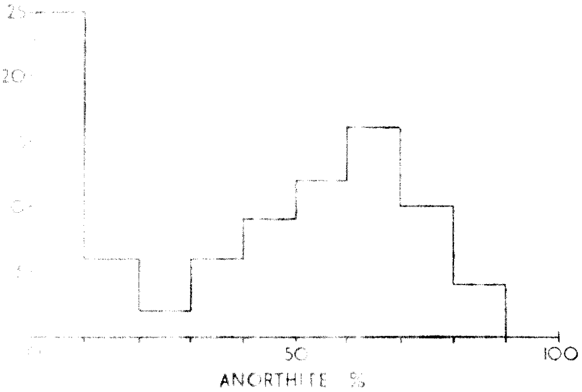

FIGURE 31

Histogram showing the compositions of 90 plagioclases from seventeen thin sections of dyke rocks.

a. Dolerites with Sodic Plagioclase

The only dyke rocks in which the plagioclase is of definite primary origin occur at Diaz Cove and locality "Y", where the dykes strike 140° and 60° true respectively. Although there are albite-bearing dykes containing fresh pyroxene in the area around Peak "D", it is not certain whether the albite is of primary origin. These dykes are associated with others in which the albite is packed with epidote inclusions and in which all the associated minerals show evidence of decomposition. The principal constituents of a thin section from Diaz Cove (plate VI) are albite and pyroxene with subsidiary chlorite and opaque minerals. The plagioclase in two sections consists of small (less than 0.5 mm.) laths of albite (An_{3-10}) or oligoclase (An_{8-25}). Simple twinning is usually on the albite law and the laths are arranged at random in a pyroxene matrix. The pyroxenes are up to 2 mm. in length and their subhedral outlines disregard the network of plagioclase laths which are frequently totally enclosed to give an ophitic texture. Probable secondary chlorite occurs in irregular, finely crystalline patches. Although the pyroxene is fresh the rock is given a "dirty" appearance by abundant indeterminate "dust". Modal estimates of two thin sections gave the following results:

Locality	Pyroxene	Plagioclase	Chlorite	Opaque minerals
"Y"	45	30	19	6
Diaz Cove	34	37	23	6

b. Dolerites

Thin sections of these rocks have been examined from many localities within the south-eastern igneous complex and also from Larsen Harbour. They are composed essentially of calcic plagioclase and pyroxene or hornblende. Representative modal estimates are given in Table II.

In texture these rocks are similar to the basalts. Twinned laths of plagioclase (figure 31) are set in a matrix of pyroxene or amphibole. Zoning with a range of up to 10% An at the edge of the laths is usual. Fine mosaic quartz sometimes occurs in patches. Olivine was found in a single dyke with a north-east to south-west trend.

TABLE II. MODAL ESTIMATES OF DOLERITES

Locality	True bearing of dyke	Mafic minerals	Quartz	Felspar and alteration products	Opaque minerals
Area east of Drygalski Fjord	150°	48	8	44	—
	135°	59	11	30	—
	115°	60	5	34	1
	60°	57	—	42	1
Larsen Harbour	170°	57	—	37	6
	80°	42	—	53	5
Ridge south of Glacier "A"	120°	64	—	36	—
Area north-west of Cooper Bay	110°	55	—	40	5
	140°	37	9	48	6
	130°	56	—	41	3
	125°	59	4	36	1
	105°	51	—	47	2
	30°	68	—	32	—
	40°	58	2	40	—
	90°	57	—	39	4

B. OTHER MINOR INTRUSIONS

1. *Wirik Bay*

In the cliffs on the north-west side of Wirik Bay and in the central islet vertical stripes of light-coloured rock are prominently intercalated with the dark, fine-grained tuffs. These bands are never thicker than 10 ft. and are sub-parallel to both the bedding and cleavage. It is certain that they are intrusive, since there are chilled edges on both sides and small apophyses at the edges. The intense local shearing of the rocks (especially in the fine-grained dolerites) suggests that they represent pre-tectonic sills. Coarse-grained, pale green, highly sheared dolerite was found in a cliff at the head of the bay, but its relationship to the sedimentary rocks was not seen.

2. *Gold Harbour*

At Gold Harbour Tyrrell (1916, p. 437) recorded the presence of a coarse ophitic dolerite, through which pass strong lines of shearing. From an examination of the outcrop of this intensely sheared rock, it was not possible to ascertain its relationship to the neighbouring sediments, but the degree of shearing suggests that it, too, is a pre-tectonic sill.

3. *Moraine Fjord*

Tyrrell (1915, p. 830) also recorded the discovery by Ferguson of a coarse dolerite sill in Moraine Fjord, but it was not located during the recent journeys.

VI. GEOLOGICAL RELATIONS

A. THE TWO GROUPS OF SEDIMENTARY ROCKS

THE approximate areas covered by quartzose greywackes and tuffaceous greywackes are marked on the end folding map. These two groups of sediments, previously referred to as the Sandebugten Series and Cumberland Bay Series (Trendall, 1953, p. 22), are both included here in the Cumberland Bay Series and are referred to in this paper as the Sandebugten type and the Cumberland Bay type respectively. This modification of nomenclature corresponds to a change of opinion concerning the quartzose greywackes. The evidence, on which it was previously argued that the quartzose greywackes were involved in a distinct folding earlier than that which affected the tuffaceous greywackes and possibly of Palaeozoic age, is set out below:

(i) There was (in spite of some exceptions) a clear difference in petrography between the two types and each had a discrete area of outcrop.

(ii) There appeared to be a distinct type of structure confined to each type of rock. These were an axial plane cleavage dipping north-north-east in the quartzose greywackes and south-westwards in the tuffaceous greywackes, and the presence of fracture cleavage in the quartzose greywackes.

(iii) The quartzose greywackes are very similar to the quartzose greywackes of the South Orkneys and the rocks of both areas contain occasional grains of lava.

The evidence in (i) and (iii) is still relevant to the problem of the relationship between the two groups, but further field observations have revealed that (ii) is no longer valid for the following reasons: the axial plane cleavage in both groups is probably contemporaneous (p. 20) and fracture cleavage is not confined only to the quartzose greywackes. On the Cape Charlotte peninsula and in the Wirik Bay–Cooper Bay area, fracture cleavage affects tuffs of Cumberland Bay type.

The following entirely new evidence relevant to the problem of the age and structural position of the quartzose greywackes has also been found

(i) The current directions in the Cumberland Bay type, indicated by the orientation of cross-bedding, are consistent over a wide area (figure 4), whereas a small area of the Sandebugten type has currents from a different direction.

(ii) Grains of sandstone in the quartzose greywacke near Rookery Bay (p. 10) have never been found in the Cumberland Bay type.

(iii) Grains of low temperature albite present in the Sandebugten type are comparable to those in the Cumberland Bay type (figure 6), but the samples studied so far are too small for any definite conclusions to be reached.

Taking into account new evidence, the state of the problem may be summarised as follows:

The Sandebugten type quartzose greywackes are *similar* to the Cumberland Bay type tuffaceous greywackes in the following respects:

(i) The facies of both groups suggests they are essentially turbidity current deposits.

(ii) The structural evidence at Dartmouth Point suggests that (at least in part) the deformation of the two groups was contemporaneous. The distribution of fracture cleavage is of no direct use in considering the relationship between two groups.

The Sandebugten type quartzose greywackes *differ* from the Cumberland Bay type tuffaceous greywackes in the following respects:

(i) Although there are local exceptions, there is a clear petrographic distinction between the two groups. In the Cumberland Bay type there is *no* debris which could not have been derived from a volcanic terrain. The presence of quartzite and sandstone grains in the Sandebugten type shows that at least part has been derived from a land surface with metamorphic rocks and unmetamorphosed sediments. Some lava is also present; it is not known whether the low temperature albites associated with the lava grains were derived from volcanic or plutonic rocks. No microcline or other potash felspar has been found, so that good evidence would be required in order to postulate a plutonic (granitic origin) for the albite.

(ii) The current directions support the petrographic evidence that, whatever the similarities between the two groups, palaeogeographic conditions were dissimilar during their deposition.

(iii) Although the main axial plane deformation of the two groups cannot be separated there appears to be some structural difference between them. The Sandebugten type is found in either of the two tectonic orientations shown in figures 12A and B, while those of the Cumberland Bay type are shown in figures 12D and E. The folding in the Cumberland Bay type of the Wirik Bay–Cooper Bay area is shown in figure 22 but this may be related to the neighbouring igneous complex. Although the deformation is contemporaneous, the type of deformation in each group is therefore related to the petrography. The two possible interpretations of the structure shown in figure 12 are described in the next section.

Although the Cumberland Bay type is known to be Cretaceous in part, the age of the Sandebugten type is still a matter for speculation. From the differences and similarities set out above it is believed that:

1. The Sandebugten type underlies the Cumberland Bay type and a major regional palaeogeographic change (but not of orogenic proportions) occurred before the deposition of the latter.

2. The tectonic disturbance connected with this change probably initiated the folding in the Sandebugten type, which was still "plastically deformable" at the time of the main orogeny which folded the Cumberland Bay type.

3. It therefore seems probable that the Sandebugten type is also of Mesozoic age, though there is still the possibility that it is Palaeozoic.

B. THE POSITION OF THE LAVAS

It is generally accepted that pillow lavas belong to a subaqueous environment. At Undine South Harbour spilitic pillow lavas and massive lavas occur together. The massive lavas of Annenkov Island are also spilitic and may be of a subaqueous extrusive origin. They are certainly interbedded with sediments which were deposited in deep water (pp. 9–10) and therefore any hypothesis inferring that the massive spilites are of subaerial origin is untenable. It is more likely that they were intruded as sills along the flow planes of previously extruded pillow lavas.

The basaltic lavas are also massive and it is equally unlikely that they were extruded subaerially, since they are also interbedded with deep water sediments. Although they may be sills as suggested by Holtedahl (1929, p. 57), the petrographic connection (figure 18) and close field association of the two lava types support the idea of a common origin. It is suggested that the rocks described as lavas in Section III (p. 23) comprise a group of related rocks, some of which were extruded subaqueously and some of which may have been intruded as sills close to the submarine surface.

C. THE SOUTH-EASTERN IGNEOUS COMPLEX

1. *Relationship to the Sediments and to the Folding*

Holtedahl (1929, p. 56) was the first to recognise that the igneous rocks forming the south-eastern end of the island are not an "older basement complex of igneous rocks, on which the sediments rest *in situ*". The increasing metamorphic grade in the Cumberland Bay type tuffs towards the contact with the marginal granite-gneiss (figures 20, 22; pp. 27–28) shows that the south-eastern igneous rocks are intrusive. The precise time and nature of the intrusion is more difficult to determine and the relevant evidence is as follows:

(i) The acid rocks are strongly foliated near the north-east edge of the complex. Although this foliation is due in part to late cataclastic shearing connected with the fault separating the granite-gneiss from the gabbro to the south-west, it is probable that this shearing took place along an existing foliation direction. The evidence for this is the direction of the "pre-shearing" dykes in the granite-gneiss, which are close to the direction of shearing but are of slightly different orientation to the dykes of similar trend in the nearby gabbro. The orientation of these dykes is probably controlled by a "pre-shearing" structure in the gneiss. This marginal foliation therefore suggests para-tectonic intrusion of these acid rocks.

(ii) In the chloritic phyllites near the contact (e.g., plate IVd) some chlorite is bent and some is not, although it is tangential to the puckering. Thus there were suitable pressure and temperature conditions in these rocks for the crystallisation of chlorite both before and after the movement causing the puckering. If the presence of the intrusives was necessary for these conditions (as it appears to have been, since they are only found near the intrusives), then there has been some movement since intrusion but prior to the cooling of the igneous rocks. Some of the intrusive rocks must therefore be para-tectonic.

(iii) Unfortunately the nature of the marginal contacts of the granite or granite-gneiss with the nearby sediments or lavas has not been seen but it is possible to infer from the straightness of the north-east margin and of Drygalski Fjord itself (along which the south-western contact lies) that both edges are faulted, particularly because there are parallel faults visible within the complex (figures 20, 22). In any case the throw of a fault on the north-east side of the intrusion cannot be large, because of the degree of metamorphism in the sediments. As the intrusion was para-tectonic ((i) and (ii) above), it is reasonable to suppose that the strike of all the structures in the intruded rocks was the same at the time of intrusion as at present. Either stoped or replaced margins would then tend to be straight. The presence of parallel "rafts" of sedimentary origin within the marginal granite-gneiss appears to support a hypothesis of normal (that is, non-tectonic) contacts for the whole complex.

2. *Order of Intrusion within the Complex*

There is little evidence for the order of intrusion since the only contacts examined between gabbro and granite were the faulted ones in the areas north-west of Cooper Bay and east of Drygalski Fjord (plate IIa). The gabbros near Peak "D" (figure 19) are affected by the cataclastic shearing, which is particularly common in the acid rocks to the north-east, but this is probably a very late structure. Apart from this the gabbro is never seriously deformed and, if the local presence of rhythmic layering suggests a fairly stable magma chamber, it is reasonable to suppose that the gabbros were intruded after the main period of tectonic activity. Unfortunately, there is no evidence of contact metamorphism to prove or disprove this hypothesis.

3. *The Central Quartz-granulite*

The ovoid boundary of the quartz-granulite shown in figure 20 and the extension in depth illustrated in figure 22 are both hypothetical. It has been assumed that the whole block is a vast xenolith "floating" in the granite. This rock is remarkable in that, although it is recrystallised and has been subjected to intense pressure, the striping is quite flat and even. Although no rock as quartz-rich as this exists in either the Sandebugten or the Cumberland Bay types, the above hypothesis appears to be the most likely explanation of the presence of this rock.

D. THE DYKES

Although they are partly affected by some of the later faulting and associated cataclastic shearing in the area north-west of Cooper Bay, the dykes are post-tectonic and the ones trending north-east to south-west are later than those trending north-west to south-east. It is therefore surprising to find that the petrography of the dykes is comparable to that of the pre-tectonic lavas. A comparison of figure 17 with figure 31 indicates there is a similar division within each group into sodic and calcic types. It is noteworthy that in both the lavas and dykes these two types appear together in the field, but the lavas are pre-tectonic and the dykes are post-tectonic.

It should also be noted that the dykes are present only in the less deformed rocks, so that dyke injection and deformation by folding appear to have been mutually exclusive. The possible significance of this is discussed on p. 47.

VII. STRUCTURAL EVOLUTION

A. INTRODUCTION

A THEORETICAL synthesis of the factual evidence set out above is presented in this section. In Section "B" the depositional conditions for the Cumberland Bay type are reconstructed in detail, but for the later sections it has been impossible to do this. Especially in Section "E" the hypothetical reconstruction of the orogeny (figure 33) goes well beyond the evidence from South Georgia and is influenced by the literature of tectonically comparable regions.

B. DEPOSITION OF THE CUMBERLAND BAY TYPE

Some of the inferred conditions prevailing during deposition of the Cumberland Bay type tuffs have already been noted (pp. 9–10). They are:

1. A constant direction of the turbidity currents throughout the series, parallel to,

2. A slight bottom slope;

3. A consequent slope of 3½ km. per 100 km. from south to north.

Other features of the sediments relevant to this palaeogeographical reconstruction are:

1. The Cumberland Bay type is unlikely to be less than 10 km. (~33,000 ft.) thick. Allowing two graded beds per metre the entire succession should contain about 20,000. The palaeontological and stratigraphical evidence (Trendall, 1953, p. 22), though slight, suggests a time range from early Mesozoic to Cretaceous. It is likely that the graded beds are of catastrophic origin, the movement being initiated abruptly by earthquakes. Kuenen (1953, p. 1046) estimates intervals of between 100 and 100,000 years between successive graded beds of various basins.

2. It has already been noted (p. 12; Trendall, 1953, p. 15, 18) that the tuffs contain both rounded grains and angular fragments of lava (plate IVb). If it is accepted that turbidity currents resulted from the sudden collapse of offshore sediments, which were accumulating during a period of quiescence, then the rounding of the lava grains by normal marine erosion can be accounted for. It is possible that the angular fragments represent the debris of volcanicity which was associated with, and occurred immediately before, the earthquakes which caused the collapse.

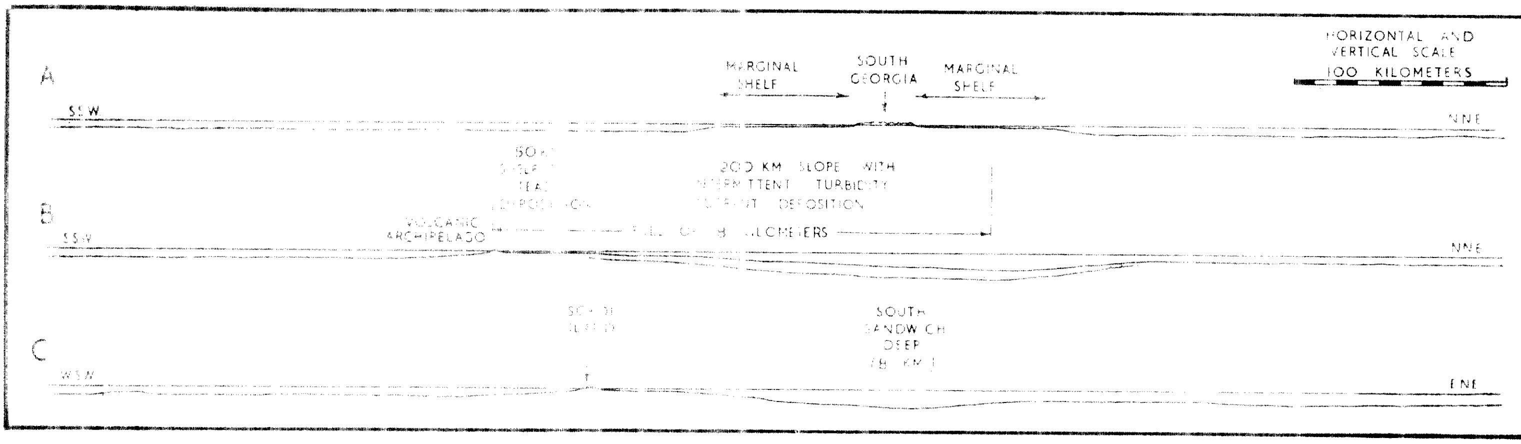

FIGURE 32

A. Cross-section from S.S.W. to N.N.E. through South Georgia. Drawn from the map by Herdman (1948).

B. Hypothetical cross-section during Mesozoic times; along the same line as "A". Five kilometers of the Cumberland Bay type (stippled) have already been deposited.

C. Cross-section from W.S.W. to E.N.E. through a part of the South Sandwich Islands group at the present day. The similarity to "B" is striking.

The features already described are illustrated in the cross-section of figure 32B. The main characters of this reconstruction, together with the evidence for each, are summarised below:

1. A slope of 200 km. at 2°, on which the graded beds were laid down. On p. 10 the distance of 100 km. used represents the length of the projection of the outline of the present island on a line parallel to the current direction. There is, however, no reason to suppose that the original basin was confined within these limits and 200 km. has been arbitrarily chosen for the construction of figure 32B.

2. A slope 50 km. in width adjacent to the land. If the fall over this distance is assumed to be 1 km. then (a) the top of the 200 km. slope would already be deep enough for the accumulation of typical graded deposits, and (b) the slope of just over 1° provides a platform for the accumulation of sediments representing potential turbidity current material. The width of this platform is of necessity hypothetical. If there were any evidence of the shape in plan of graded beds then it would be possible to estimate their absolute volumes and subsequently the width of shelf required to produce the necessary material.

3. A volcanic archipelago from which the material came. The reasons necessitating the existence of an archipelago are: (a) the constructed section with a slope of 8 km. in 250 km. is comparable to the present

South Sandwich arc and deep, in which a depth of 8 km. is attained in 150 km. (figure 32C). The association of a volcanic (dormant or active) arcuate island chain with a slope leading to a deep, exists not only in the South Sandwich Islands but also in the East and West Indies. Eardley (1951, p. 13, 14) has suggested the presence of similar volcanic archipelagos on the Pacific side of the Cordilleran geosyncline. (b) The complete absence of material other than of volcanic or possible volcanic origin suggests that the land was not extensive.

C. THE AXIAL DIRECTION OF THE BASIN

In the north-west part of South Georgia the present structural strike is almost perpendicular to the direction of the original bottom slope and the turbidity currents (figure 4). Although the strike of the structures swings clockwise towards the south-east, the current direction remains constant. Evidence from

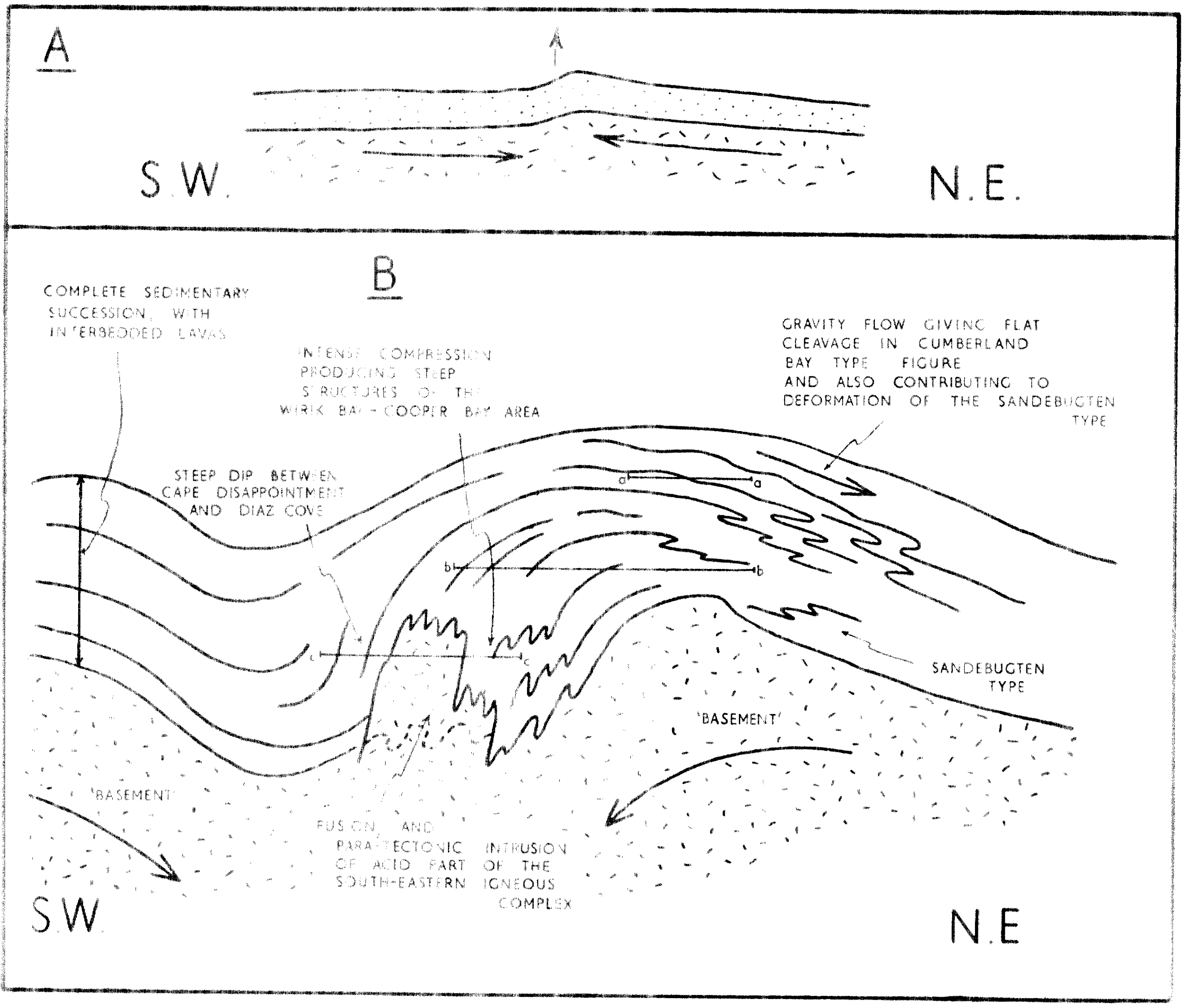

FIGURE 33

Cross-sections illustrating the major period of folding.

A. The complete sedimentary succession (stippled) lying on "basement" rocks, showing the direction of the supposed forces with the north-east side being thrust over the south-west side, combined with an upward movement.

B. Details of the central buckle of "A" towards the end of the movement. The lines a–a, b–b, and c–c show the approximate positions of the three cross-sections indicated on the end folding map.

other localities has suggested that turbidity current directions are often parallel to the length of the basins into which they flow, but in South Georgia the confirmatory evidence of slumping indicates that the currents were, in fact, approximately normal to the axis. This hypothesis is supported by the fact that the trend of the Scotia Arc runs obliquely through South Georgia in an east to west direction.

From the arcuate strike of the structures of the island it can be inferred that the lateral forces leading to the deformation may not have been perpendicular to the axis of the trough. If the trough was formed originally by similar forces in a way such as that postulated by Hess (1938), then this is unexpected. The reconstructed section given in figure 33 has been drawn in a north-east to south-west direction (perpendicular to the general structural trend of the island) but it should be remembered that the trough of deposition probably ran east–west and that the regional trend of deformation may also have been in the same direction. It is in fact possible that the axial line of deformation was arcuate, a possibility which is referred to below.

D. THE SANDEBUGTEN TYPE

It was suggested above (p. 41) that a major regional palaeogeographical change separates the Sandebugten and Cumberland Bay types. Two mechanisms, both of which would be capable of producing the structural relationship between the two types shown in figure 12, are therefore suggested:

1. If the Sandebugten type had already been deposited before the formation of the basin in which the Cumberland Bay type was laid down, it is possible that there was large scale movement down the north-east slope of the trough, thus initiating the folding of the type shown in figure 12. It is also possible that, once formed, these folds with axial planes dipping north-eastwards were emphasised by the weight of the overlying Cumberland Bay type, even when the Cumberland Bay type itself flowed north-eastwards under the action of gravity during the major folding (figure 33).

2. It is possible that folding of the Sandebugten type, in the sense illustrated in figure 33B and in the tectonic position shown, could have been caused by the lateral compression indicated by the two lower arrows in figure 33A; that is, with axial planes dipping north-eastwards and the anticlines becoming younger towards the south-west. The folds of the Cumberland Bay type immediately overlying the Sandebugten type in the position shown in figure 33B would have axial planes dipping gently to the south-west with anticlinal crests becoming younger towards the north-east.

Either of these two hypotheses are tenable, but until further evidence becomes available the exact structural relationship between the Sandebugten and Cumberland Bay types must remain unsolved.

E. THE MAJOR PERIOD OF FOLDING

The age of the major period of folding is unknown, except that it is post-Aptian. The Cumberland Bay type tuffs of Annenkov Island are known to be Aptian (Wilckens, 1947). A reconstruction of the area of South Georgia towards the end of the folding is shown in figure 33, which is not drawn to scale. The following notes are given to amplify various features of this text-figure:

1. Lateral compression is assumed and it is not intended to discuss causes of crustal stress. It is supposed that the sediments of the basin (5 km. of which are shown to scale in figure 32) were locally buckled by compression and that there was a regional upward movement. The form of this buckle and the nature of the compressing forces are illustrated in figure 33A, where the north-east side is thrust over the south-west. Figure 33B shows the details of the central buckle.

2. The approximate positions of the three sections (a–a, b–b, and c–c) in figure 33B are indicated on the end-folding map. The westerly plunge north-westwards from Cumberland East Bay makes the relationship between a–a and b–b definite but there is little evidence for the position of c–c. It is possible for there to be an actual plunge of the structures with no clear lineation to be seen in the field; the very presence of the south-eastern igneous complex suggests a lower tectonic position for section c–c.

3. It was noted on pp. 21–22 that there is a flattening of grains in the Sandebugten type and in part of the Cumberland Bay type which is equivalent to an elongation in both *b* and *c*. In the diagrammatic section of figure 33 the mechanism of the elongation in *c* can be explained by lateral expansion of the sedimentary rocks overlying the compressed rocks below. An overall elongation of the whole sedimentary mass along the axis of the belt of folding is more difficult to visualise but it is not certain that a grain elongation in *b* necessitates this. The concept of a general crustal elongation along the axis of the geosyncline is easier to reconcile with an arcuate axis of the folding but, if an arcuate fold belt moves outwards from the centre of the arc, then crustal elongation (at least of the sediments) becomes essential. In this connection some elongation is suggested by the presence *either* of dykes *or* of deformation in the sedimentary rocks. In the granite face shown in plate IIa dykes occupy 60% and granite 40% over a distance of about 1 km. Although these dykes are parallel to the structural trend, dykes perpendicular to that trend are locally abundant. Unfortunately there is insufficient information to make a reliable estimate of their total thickness.

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APPENDIX I

PLAGIOCLASE DETERMINATIONS

During the examination of thin sections for the preparation of this report the compositions of 425 plagioclases were determined by Köhler's method (Köhler, 1942). The indicatrices of both halves of a twinned crystal were plotted and the angles α, β and γ were used (for albite, Carlsbad and combined Carlsbad-albite twins) in conjunction with the tables given by Tröger (1952). By this method it is theoretically possible to determine whether each plagioclase crystal has low or high temperature optics, but it was found that the error in determining these three angles (by plotting the results from a Leitz three-axis stage on a Wolff net) was often too large to allow this. In such cases the plagioclases were assumed to have the optics appropriate to the rock and the mean of the three values was used. If the method is used quickly (about seven complete plots in an hour), it is believed to be reliable within ± 5% An, and this error is implicit whenever An values are quoted to 1% in the text. Apart from some albites, which can be reliably checked by 2V determination, no plagioclases have been described as having low or high temperature optics as they will be studied further.

If all the plagioclases of a thin section have the same composition, the error of the method can be reduced by examining a larger number. If the range of composition is required, the range of determinations will be greater but the ranges in different thin sections will be equally affected, since the error remains the same.

APPENDIX II

PLACE-NAMES

1. Since the publication of *The Geology of South Georgia—I* a gazetteer for the Falkland Islands Dependencies has been prepared by the Antarctic Place-Names Committee and some names used in that report have been changed. The following substitutes have been used in this paper:

Trendall, 1953	*Equivalent accepted name in Gazetteer, 1955.*
East Cumberland Bay	Cumberland East Bay
George Bay	Hound Bay
Moränen Fjord	Moraine Fjord
New Fortuna Bay	Ocean Harbour
Doubtful Bay	Smaaland Cove
Smaaland Bay	Doubtful Bay
"large glacier flowing into St. Andrews Bay"	Cook Glacier
"glacier flowing westward into Undine South Harbour"	Brögger Glacier

2. Figure 19 is a preliminary modification of parts of F.I.D.S. 1:100,000 Sheets 54 36 SE and 54 34 SW, based on a survey carried out by the South Georgia Survey 1953–4, and drawn and supplied by G. Smillie. It is expected that further modifications to place-names in this area will be made shortly. Various features that may ultimately bear a name accepted by the Antarctic Place-Names Committee have therefore been marked by letters for descriptive convenience in the text, and their positions are shown in figures 1, 15 and 19.

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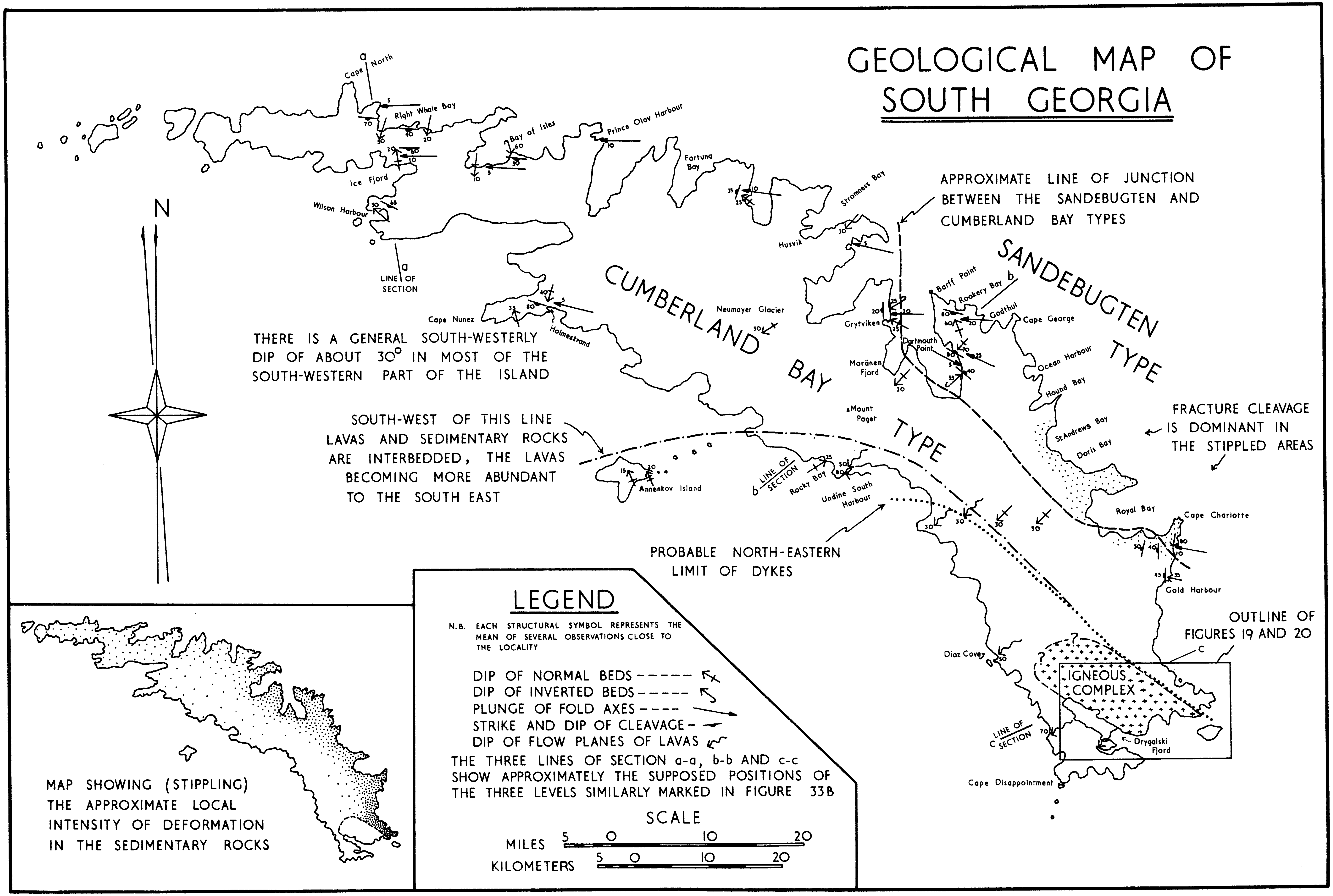
GEOLOGICAL MAP OF SOUTH GEORGIA



LEGEND

N.B. EACH STRUCTURAL SYMBOL REPRESENTS THE MEAN OF SEVERAL OBSERVATIONS CLOSE TO THE LOCALITY

DIP OF NORMAL BEDS
DIP OF INVERTED BEDS
PLUNGE OF FOLD AXES
STRIKE AND DIP OF CLEAVAGE
DIP OF FLOW PLANES OF LAVAS

THE THREE LINES OF SECTION a-a, b-b AND c-c SHOW APPROXIMATELY THE SUPPOSED POSITIONS OF THE THREE LEVELS SIMILARLY MARKED IN FIGURE 33B

SCALE

MILES 5 0 10 20

KILOMETERS 5 0 10 20

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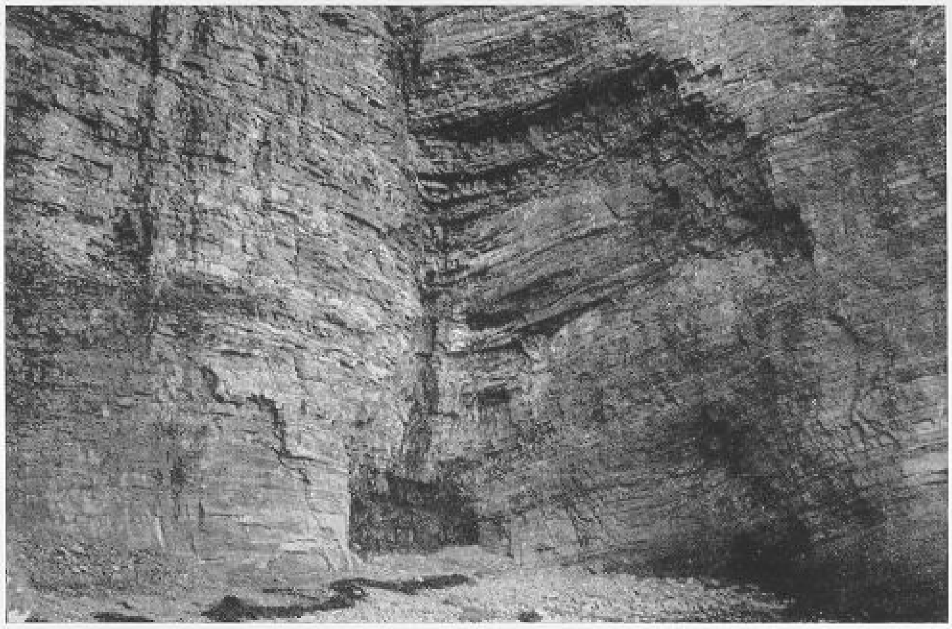
PLATE I

a. Cliff 40 ft. high at the west end of the north-eastern landing beach on Annenkov Island, showing thin even bedding in gently dipping tuffs of Cumberland Bay type.

b. Cliff on the west coast of Right Whale Bay, illustrating typical graded beds of Cumberland Bay type tuffs. The boundaries between complete graded beds are marked by solid white lines with pecked white lines marking the divisions between upper and lower parts.

c. Dyke of coarse tuff cutting Cumberland Bay type tuffs in Right Whale Bay. The bedding of the tuffs can be seen sloping downwards from left to right. The shaft of the hammer is 1 ft. long.

PLATE I



a

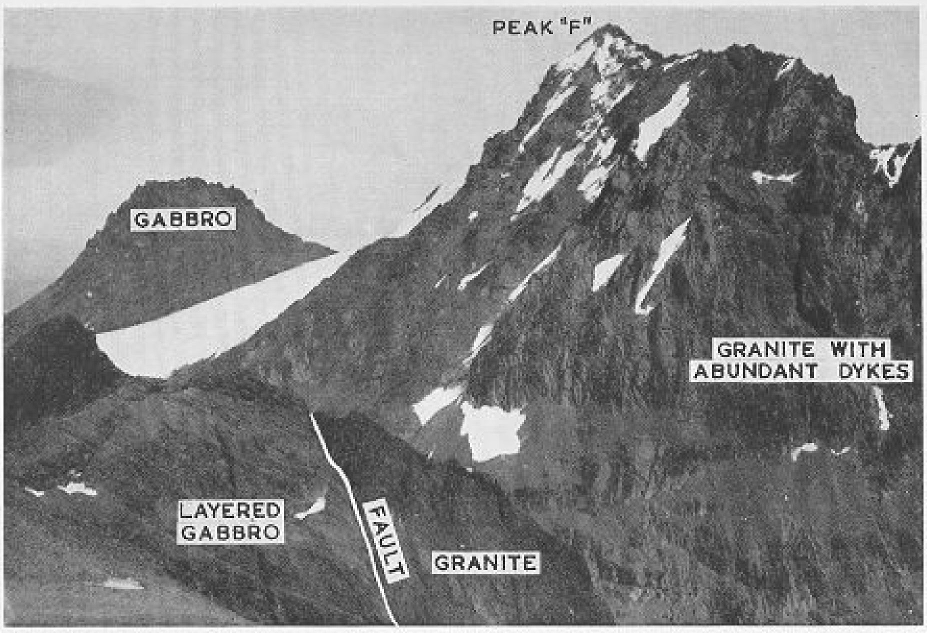
b

c

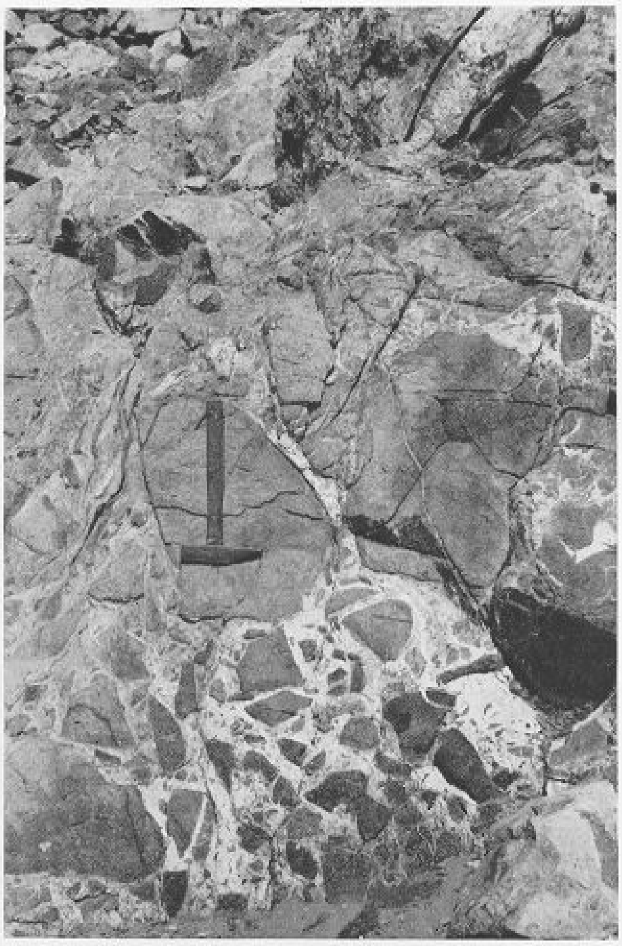
PLATE II

a. Part of the south-eastern igneous complex. The photograph was taken from the point marked "G" in figure 19 towards the south-east. A closer view of the clear rhythmic layering in the gabbro is shown in plate IIId, which was taken to the left of the fault and a little below the lowest part of the cliff visible here. Note the abundance of dykes in the granite. A measured section of one such dyke is given in figure 30.

b. Light-coloured granulitic gneiss packed with dark basic xenoliths at the locality marked "J" in figure 19. The brecciation of some of the xenoliths is comparable to that shown in figure 23B. The appearance in thin section of the xenolith material at this locality is shown in plate Vd. A rock from a nearby locality which is closely similar to the gneiss is illustrated in plate Vb. The hammer shaft is 1 ft. long.


PEAK "F"
GABBRO
GRANITE WITH ABUNDANT DYKES
LAYERED GABBRO
FAULT
GRANITE

a



b

PLATE III

a. Angular mass of dark "pyroxenite" in coarse-grained, light-coloured gabbro showing apparent brecciation. The photograph was taken near the point marked "K" in figure 19 and the face shown is 6 ft. wide.

b. Dark- and light-coloured quartz-diorite at the locality marked "M" in figure 19. Although the dark patches sometimes resemble xenoliths it appears from the irregular tongue of lighter material on the right that some assimilation or replacement has occurred. The isolated central patch is 1 ft. wide.

c. Striping in gabbro near the locality marked "K" in figure 19. The streaky appearance is quite different from the layering shown in plate IIId. Part of a dyke is visible at the left-hand edge. The hammer shaft is 1 ft. long.

d. Rhythmic layering at the locality marked "H" in figure 19. The scree in the right foreground lies in the lowest exposed part of the fault cleft in plate IIa. A thin section of the gabbro is shown in plate Ve and modal estimates of thin sections from the lower and upper parts of the thickest visible layer (8 ft.) are given on p. 37. The photograph was taken from the granite looking east-north-east.

a

b

c

d

PLATE III

PLATE IV

a. Intensely deformed tuff from the Cumberland Bay type near Grytviken (S.G. 201; ordinary light; × 37).

b. Cumberland Bay type tuff from the cliff on the south-east side of the Ross Pass. Note the large rounded grains of lava with interstitial debris including an angular crystal of albite (S.G. 81; ordinary light; × 37).

c. A slightly deformed, small rounded grain of sandstone in Sandebugten type greywacke. Part of another sandstone grain appears at the edge of the photograph. Most of the matrix is finely crystalline calcite (S.G. 199; X-nicols; × 35).

d. Intensely deformed tuff (?) from the ridge on the north side of Glacier "C" (figure 19). The lines of dark material probably represent the original bedding of the rock (S.G. 219; ordinary light; × 35).

e. Massive spilite from locality "Z" (figure 15). Laths of albite in a matrix consisting mainly of pyroxene (S.G. 367; partly X-nicols; × 37).

f. Basalt from locality "Y" (figure 15). Laths of plagioclase (An_{68-76}) in a matrix mainly of pyroxene (S.G. 365; ordinary light; × 37).

PLATE IV

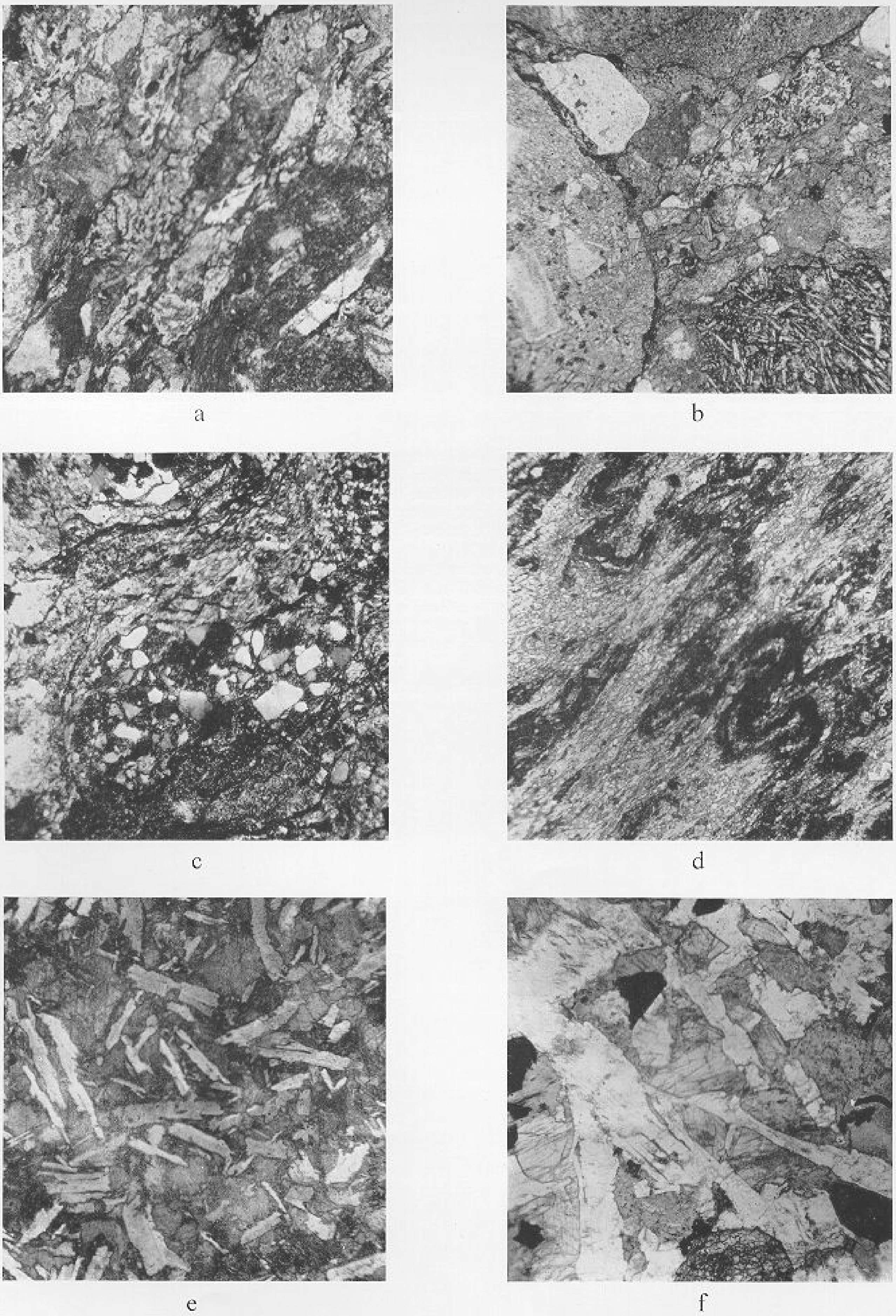


PLATE V

a. Sheared granite-gneiss from the area north-west of Cooper Bay. Note the microcline and fine sheared quartz mosaic (S.G. 250B; ordinary light and X-nicols; × 32).

b. Granulitic gneiss from near locality "J" in figure 19. Quartz is the most abundant mineral with biotite defining the foliation. A rock similar to this forms the light-coloured matrix between the xenoliths in plate IIb (S.G. 349; ordinary light and X-nicols; × 37).

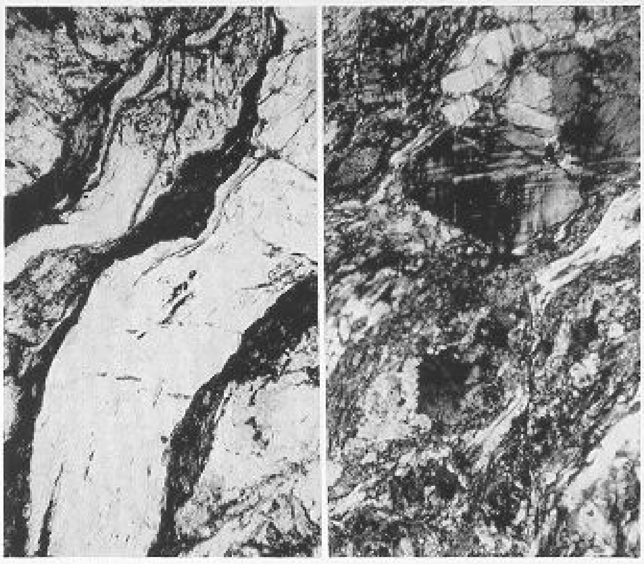
c. Quartz-diorite from near locality "M" in figure 19. Hornblende and andesine are the principal constituents with subsidiary quartz (S.G. 303; ordinary light and X-nicols; × 32).

d. Material from a xenolith in the face shown in plate IIb. Basic plagioclase (An_{80-87}) and pyroxene are the principal constituents (S.G. 348; partly X-nicols; × 37).

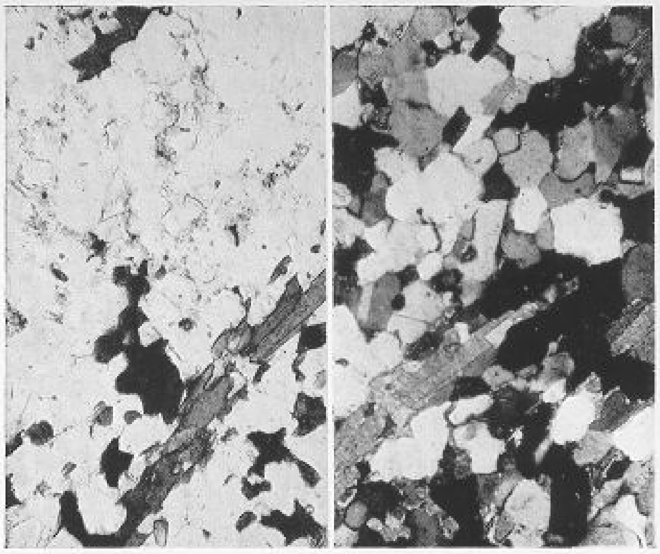
e. Gabbro from locality "H" in figure 19 with pyroxene (centre), hornblende, chlorite and calcic plagioclase. The mode of this rock is given on p. 37 (S.G. 330; ordinary light and X-nicols; × 37).

f. Laths of albite enclosed by a large augite crystal in a sodic dyke from Diaz Cove (figure 15) (S.G. 376; X-nicols; × 85).

PLATE V



a



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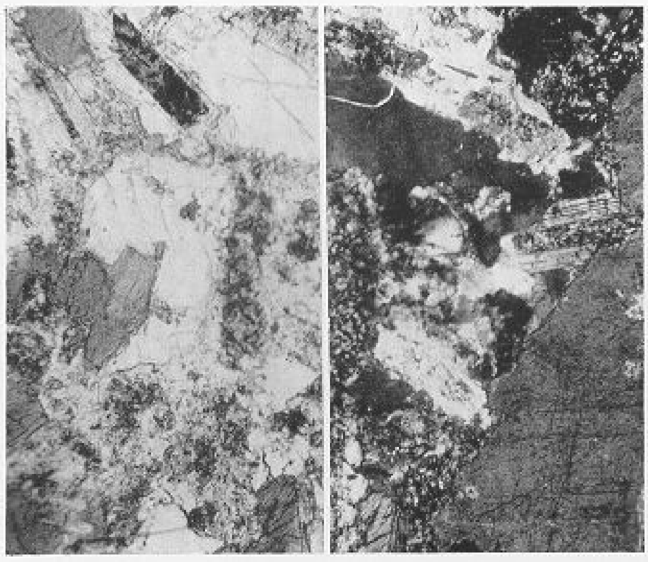

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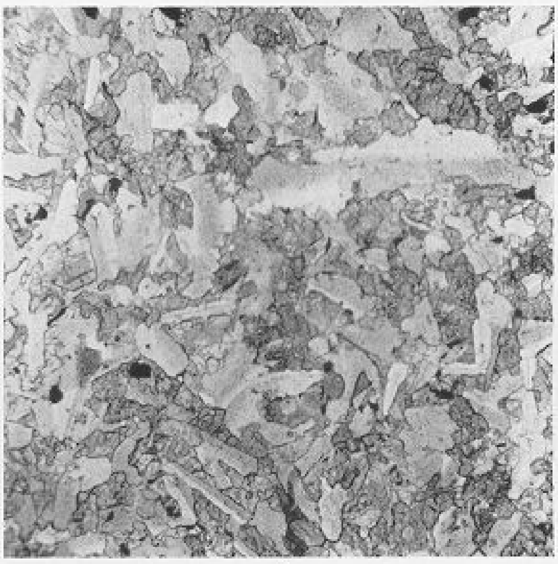

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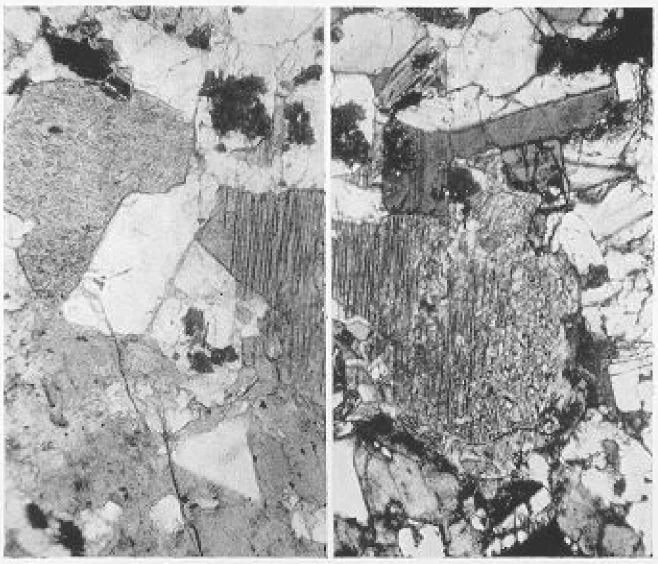
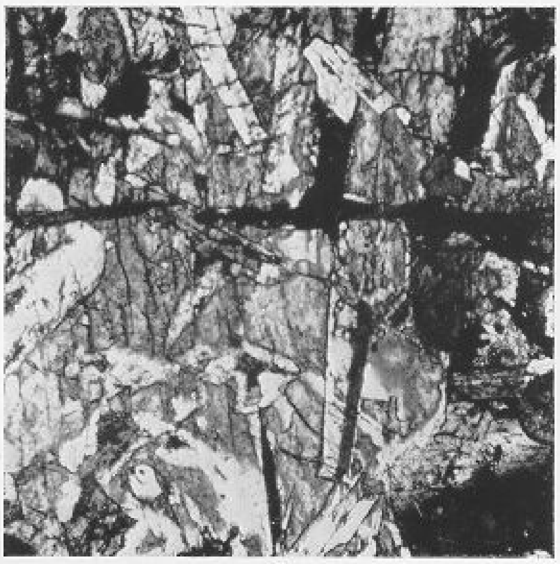


e



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