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THE GEOLOGY OF SOUTH GEORGIA—I

By

A. F. TRENDALL, B.Sc., Ph.D.

Falkland Islands Dependencies Scientific Bureau

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Falkland Islands Dependencies Scientific Bureau
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I. INTRODUCTION

A. LOCALITY AND TOPOGRAPHY

SOUTH GEORGIA lies between latitudes 54° and 55° south, longtitudes 36° and 38° west, about 900 miles due east of Cape Horn. Its position in relation to the nearest lands is shown in figure 1.

The island is about 110 miles long, and has an average width of less than twenty miles. The axial mountain range, which rises to a height of 9200 ft. (Mount Paget), is traversed only by one glacier south-east of The Three Brothers, but is more broken towards the north-west. It separates two contrasting coasts. The north-east coast is deeply indented and has less permanent ice than the south-west coast, which has a comparatively smooth outline. All the features of a deeply dissected glaciated upland are present.

Along many stretches of coast recent uplift has produced a line of sea cliffs standing at the back of a low wave-cut platform. For a full account of the physiography the reader is referred to a well illustrated paper by Olaf Holtedahl (1929, pp. 58–82).

B. PREVIOUS INVESTIGATION

The chronological account of previous geological investigation below, is summarised in figure 2.

(i) Dr. Will (1884), of the German International Polar Year Expedition of 1882–3 made brief notes and brought back specimens of the rocks. These were described by H. Thurach (1890) as *Phyllitgneis, Phyllit, Kalkphyllit, Kornigen Kalk, Tonschiefer and Diabastuff* or *Schalstein.* He described a gradation from clay-slate to high grade paragneiss with sillimanite and andalusite.

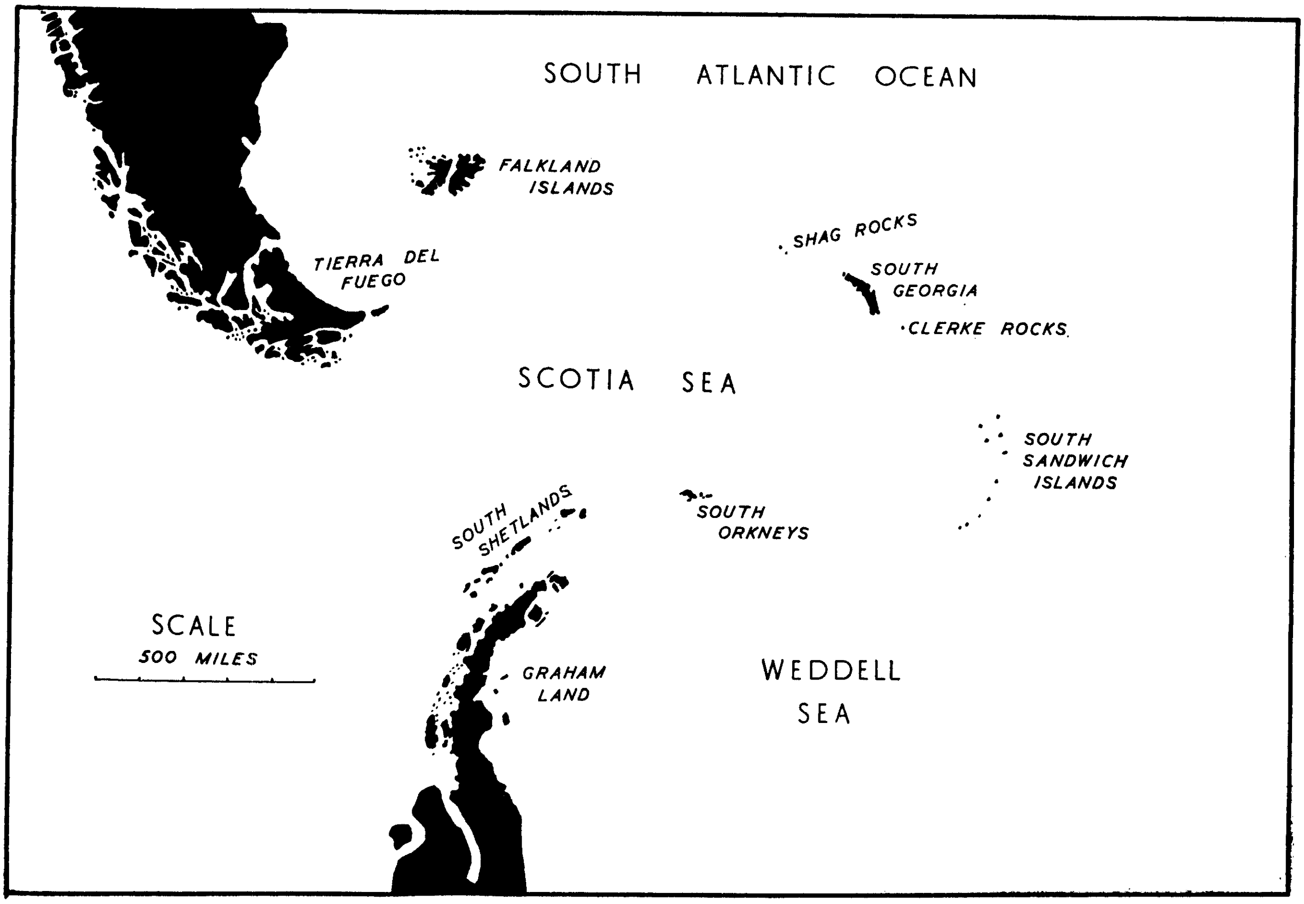

FIGURE 1
General map of the area of the Scotia Arc.

(ii) The Swedish Antarctic Expedition of 1901–3 was led by Otto Nordenskjöld (1905), who referred some of the gneissose sediments of Thurach to Porphyroid—a sheared porphyritic igneous rock. He confirmed the presence of abundant tuff. In a large tuff block in Moränen Fjord Nordenskjöld found a lamellibranch which J. G. Andersson (1907) described, on the authority of Professor Koken, as a *Posidonia* (*Posidonomya*) of late Palaeozoic or early Mesozoic age. Andersson noted that structural trend lines run parallel to the length of the island.

(iii) F. Heim (1912), of Filchner's German South Polar Expedition, visited South Georgia in 1911. He described the whole of the north coast, with the exception of Royal Bay and a part of Cumberland Bay, as consisting of dark to blue-grey shales and greenish tuffs. He also observed similar rocks on most of the south-western coast. Heim discovered that igneous rocks form the south-east corner of the island and Salomon found that they included diabase and melaphyre-like rocks. These rocks are described as "altvulkanischer", a term which has apparently puzzled all subsequent authors. König, the expedition zoologist, found an ammonite fragment which Pompeckj thought might be an Acanthoceratid, in a tough, compact shale at Prince Olaf Harbour. (Heim, 1912, p. 453–footnote by W. Salomon).

(iv) D. Ferguson (1915) visited the island in 1911–12 and attempted a stratigraphical division of the rocks. He divided a single conformable series of sediments on the basis of colour, into the Lower, Middle and Upper Cumberland Bay Series. This series rests uncomformably on the Cape George Series, an older folded and indurated series which is exposed at Godthul and Dartmouth Point. The Cumberland Bay Series is not folded and has a gentle dip, its strike is parallel to the length of the island and to the long faults which divide all the rocks into a number of fault blocks. G. W. Tyrrell (1915) examined the rocks of Ferguson's collection and found them to be sheared and slightly recrystallised tuffs, together with arenaceous

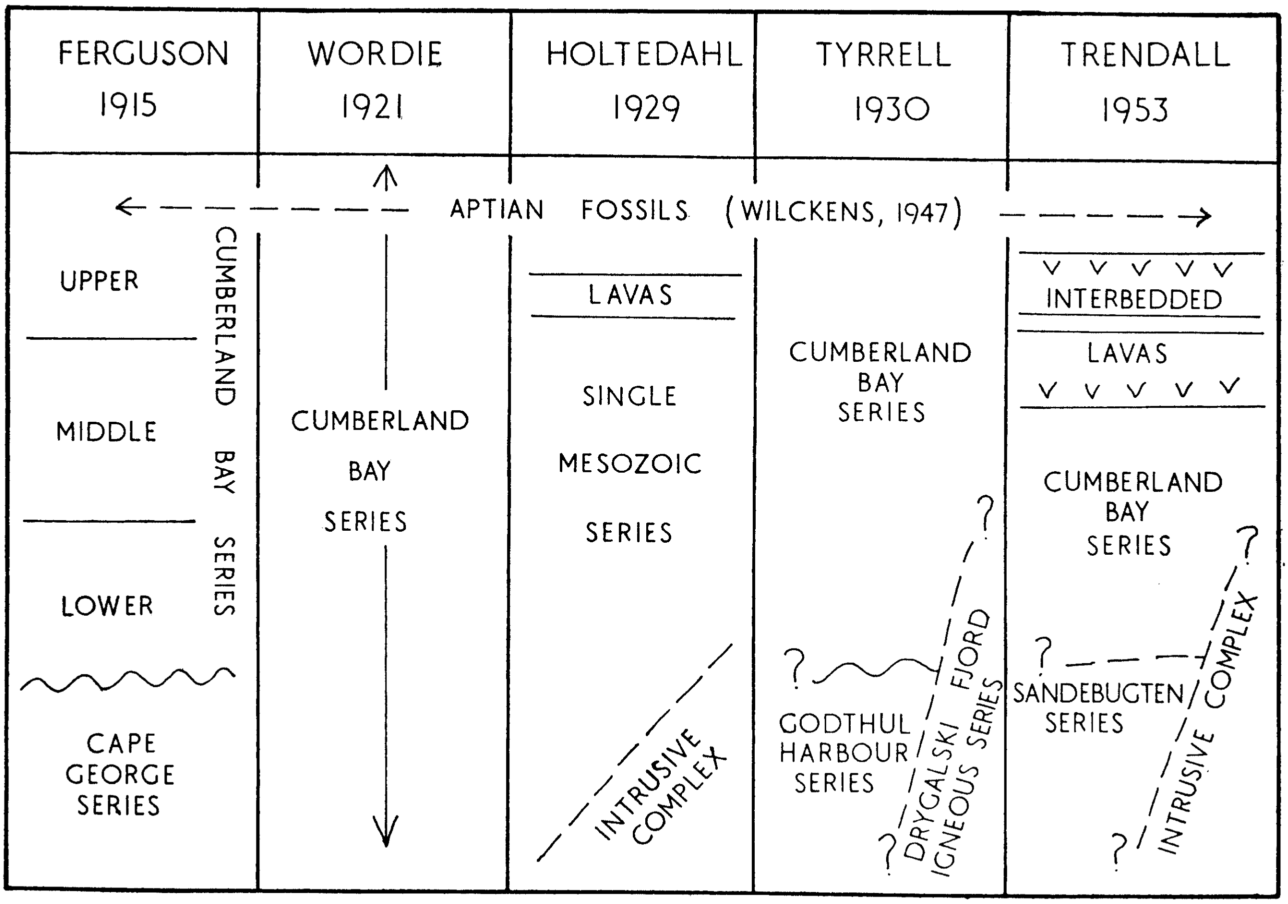

FIGURE 2
Table summarising the development of opinion concerning the geological relations of South Georgia.

and argillaceous sediments, typically fine-grained greywackes. He found little petrographic distinction between any of Ferguson's stratigraphical divisions.

Fossils collected by Ferguson near Leith Harbour were described by J. W. Gregory (1915). They include a possible *Omphyma*, doubtful sponges, and Camarocladoid organisms probably post-Cambrian and pre-Devonian in age. O. Wilckens (1930) regarded these organisms as Mesozoic. Radiolaria from various localities were examined by G. J. Hinde who thought that they were of Mesozoic age, probably between Triassic and Cretaceous. A collective preliminary paper was published jointly by Ferguson, Gregory and Tyrrell (1914).

(v) Later, Tyrrell (1916 and 1918) published further petrographic descriptions of rocks collected by whalers. This new material included spilites from Larsen Harbour.

(vi) J. M. Wordie (1921), the geologist of Shackleton's *Endurance* expedition, spent four weeks on South Georgia in 1914. He favoured the unity of all the sediments and thought that Ferguson was misled into the suggestion of an unconformity by the configuration of the folds, which are apparently overfolded from the south-west, the strike of the cleavage and fold axes running parallel to the axis of the island.

(vii) G. V. Douglas (1930), geologist of the Shackleton-Rowett *Quest* Expedition, of 1921–2, confirmed much of what was previously recorded. He agreed with Wordie's conclusions, except for suggesting the possibility of an unconformity near Prince Olaf Harbour. He also located a line of contact between sediments and igneous rocks running west and north-west from Cooper Bay. Douglas found a small piece of wood in a loose block of tuff on an island in the Bay of Isles. This tuff was lithologically identical with the country rock. W. T. Gordon (1930) identified the wood as *Dadoxylon* (*Araucarioxylon*). This indicated an age certainly not older than Carboniferous and probably not younger than Jurassic.

Tyrrell (1930) described the specimens collected by Douglas, which are similar to the collections previously described by him. On the basis of petrographical differences Tyrrell favoured Ferguson's division into an older series of quartzose greywackes, siltstones, slates and phyllites, and a younger consisting of shales, mudstones and tuffs. The older series he renamed the Godthul Harbour Series, the name Cumberland Bay Series being retained for the younger, tuff-bearing series. The relationship between the two series, and between these and the igneous rocks—the Drygalski Fjord Igneous Series—he considered to be uncertain.

(viii) In 1927–8 Olaf Holtedahl visited South Georgia with the *Norvegia* expedition, and has written an excellent summary of the geology (1929). With the help of specimens collected by Rustad, Holtedahl concluded that the island consists of a single sedimentary series of Mesozoic age, overfolded to the north-east and altered along the north coast. He described the lavas as belonging to the sediments and the remaining igneous rocks as post- and para-tectonic intrusions. At Annenkov Island Rustad collected an ammonite fragment from a pebble exactly similar to the country rock and in other specimens *in situ* from the same locality lamellibranchs were found. Wilckens (1932a) identified *Lima*, *Pecten* and *Oxytoma* among the lamellibranchs and referred the ammonite to *Holeodiscus*.

Rock specimens collected by Holtedahl were described by T. F. W. Barth and P. Holmsen (1939), who emphasised the metasomatic effects to be found throughout the sediments.

(ix) In the course of journeys made with mainly geographical interest during 1928–9 L. Kohl-Larsen (1930) noted a more widespread occurrence of lava than had been reported previously. From Annenkov Island he collected a group of fossils determined by Wilckens (1937 and 1947) as being Upper Aptian in age. They included *Puzosia*, *Tropaeum*, *Sanmartinoceras*, and a new ammonite genus—*Georgioceras*—as well as lamellibranchs, fish-scales, a cirripede and numerous "lebenspuren".

C. PRESENT WORK

The writer visited South Georgia in 1951 as geologist in a party of six whose main concern was with topographical survey. To provide a measure of the extent of his observations a time-table is given below:

- 1–11 November. Grytviken.
- 12–15 November. Part of east shore of East Cumberland Bay, and traverse thence to New Fortuna Bay.
- 16–19 November. Grytviken.
- 20–24 November. Coast between George Bay and Doris Bay (with sealers).
- 25 November. Landing in Fortuna Bay.
- 26 November. Grytviken.
- 27–30 November. Neumayer Glacier to col, and thence to Husvik.
- 1–8 December. Grytviken.
- 9–11 December. Circumnavigation of the island with brief landings at Wilson Harbour and Larsen Harbour.
- 11–31 December. Royal Bay (north side of Ross Glacier) and thence along the route shown.

Routes are marked on the end folding map.

Geological work was abruptly terminated on 1 January 1952, when the writer had the misfortune to fall into a crevasse, and had to return to the United Kingdom for medical treatment. It is hoped to be able to continue this investigation during the 1953–4 season.

This report deals in greatest detail with the structure of the sediments, most of the information concerning which is new. The petrography of the sediments is treated briefly, but that of the igneous rocks is omitted. Both are well described in the papers of Tyrrell (1915, 1916, 1918, 1930), which have been supplemented more recently by Barth and Holmsen (1939).

In Section III the evidence set out in Section II is discussed, particularly as a basis for the division of the sediments into two series. The present state of knowledge of the geology of South Georgia is summarised, with brief comments on such parts of the Scotia Arc as appear to concern South Georgia most directly.

The conclusions reached are recapitulated in Section IV and are summarised diagrammatically in the right-hand column of figure 2.

D. ACKNOWLEDGMENTS

The author wishes to thank his fellow members of the South Georgia Survey 1951–2 for their co-operation in the field, and also the various whaling companies without whose help the work could not have been accomplished. During the preparation of this report the advice of Dr. V. E. Fuchs was invaluable, and to Dr. R. J. Adie must go the credit for any merits of presentation it may possess. Professor H. H. Read kindly allowed some work to be carried out in the Department of Geology at the Imperial College of Science and Technology, London, and slides in the Department of Mineralogy and Petrology at Cambridge were examined with the permission of Professor C. E. Tilley.

II. THE NATURE OF THE ROCKS

A. INTRODUCTORY

TYRRELL'S petrographic work has shown that the area between Cumberland Bay and Royal Bay is formed mainly of sediments lacking igneous material, whereas the remaining sedimentary rocks are mainly tuffs. In this section the two groups are described separately, and form, after some discussion in the next section, a basis for the division of the sediments into two series. The rocks between Cumberland Bay and Royal Bay are given the name Sandebugten Series, and the remaining sediments are placed in the Cumberland Bay Series.

To avoid confusion it might be useful to explain briefly the rock names used in these descriptions. The terms greywacke, grit, silt, slate and tuff correspond to their field use, in which they tend to take on a significance not admissible by strict definition. Coarse greywacke, medium greywacke, fine greywacke, silt and slate here form a grade sequence in sediments of greywacke facies,* and have no other significance. The individual grains are indistinguishable in slate; in silt they can be made out with a lens; the largest can easily be seen with the naked eye in fine greywacke; in medium greywacke the largest can be recognised as round and clear, white and angular, etc., without a lens; when most of the grains can be easily distinguished the rock is coarse greywacke, the largest grains then being of the order of 3 mm. across the cleavage. "Grit" or "coarse grit" is used as a convenient alternative for coarse greywacke, and does not imply a smaller fine content. The term "tuff" may imply certain characters recognisable in the field rather than proven igneous content. Similarly a rock described as a "greywacke" may, in fact, be tuffaceous, unless it is specifically referred to as an arenaceous or argillaceous greywacke. Strictly the term "silt" should be used to describe unconsolidated sediment of a specific grain size, but here it is used as a convenient abbreviation of "siltstone". "Way-up" is used to denote the order of superposition of sediments, a "normal" bed being one rotated less than 90° from the horizontal and an inverted bed having been rotated more than 90°.

B. THE ROCKS BETWEEN CUMBERLAND BAY AND ROYAL BAY

(i) *General lithology*

These rocks consist of well-cleaved sediments of greywacke facies, varying in grade from dark structureless slate to a grit containing individual grains up to 5–6 mm. in diameter in a slightly finer matrix, with complete gradation between these two extreme types.

The rocks of finest grain are usually dark grey in colour or even black (graphitic). They are well but usually unevenly cleaved, with the bedding defined by lighter stripes. Sometimes they are very pale grey-brown with the bedding marked by narrow dark striping, as many as ten discrete narrow black stripes occurring in 1 cm. vertical thickness. As the grain size increases the rock becomes more massive in appearance, and the cleavage less well marked and more irregular. A broken surface then appears granular even before the largest grains become visible as small white streaks on the cleavage surface. With slightly coarser rock the individual grains can be clearly seen on surfaces perpendicular to the bedding, having their long axes arranged parallel to the cleavage and appearing white or light against the dark grey matrix. Depending

* A loose term. For a definition of greywacke in the sense intended see Pettijohn (1948, p. 244).

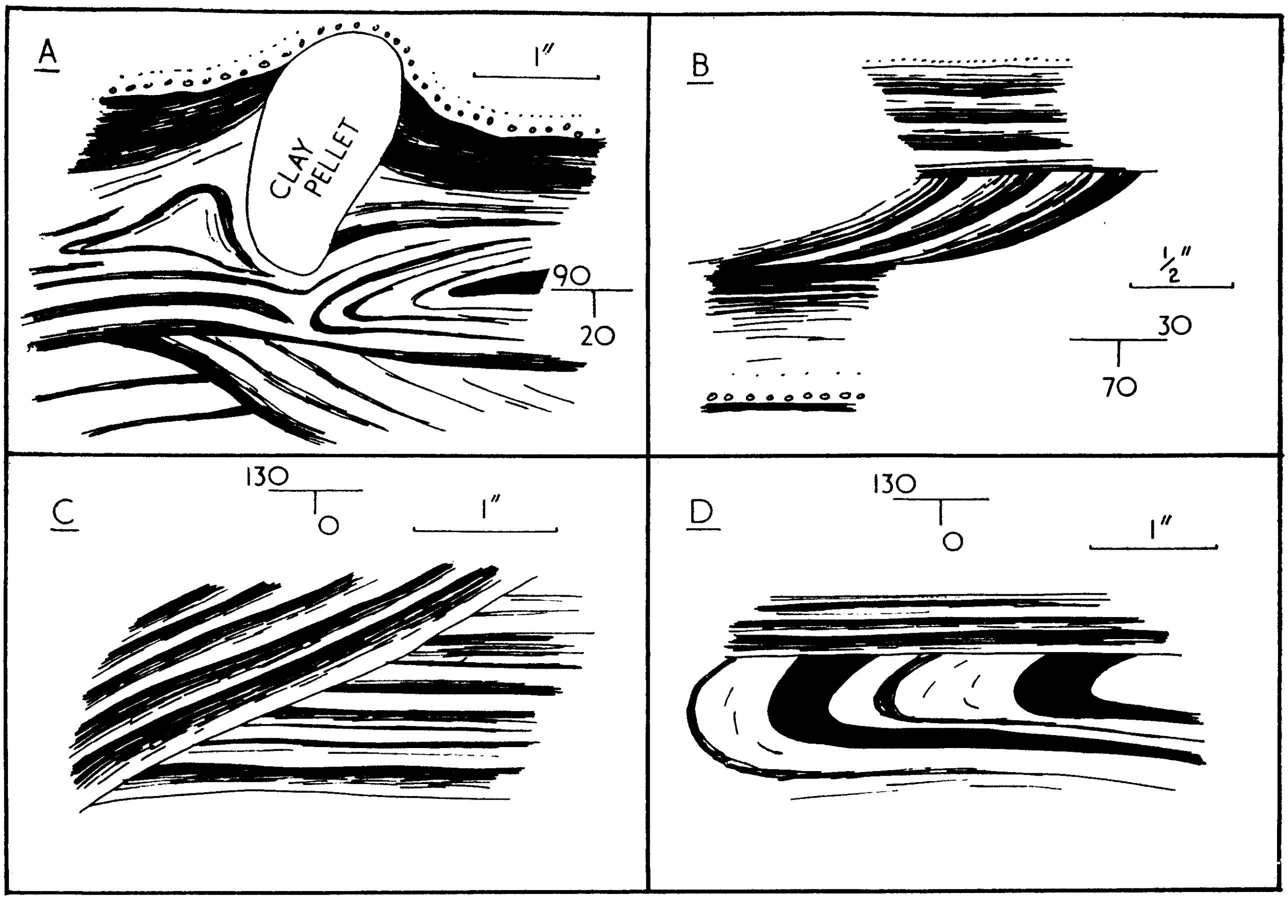

FIGURE 3

A. Cliff approximately two miles south-west of Cape Vakop. Current bedding and slumping in fine silt, with a large clay pellet disturbing the bedding. The grit at the top marks the base of a graded bed.

B. Cliff near the locality of "A". One inch thick bed graded from greywacke to slate succeeded by striped silt which is current bedded and graded, the coarse silt being darker than the fine.

C. George Bay. Graded bedding and current bedding seen together in striped silt.

D. George Bay. Incipient slumping in striped silt.

on the relative abundance of large grains, at about 2 mm. diameter the grains appear to have maintained their shape against the pressure in the matrix, and the lines of cleavage flow around them. In rocks with very little fine material only the largest grains retain their original shape, the smaller grains appearing lenticular. Throughout the series the relative proportion of coarse and fine material is very variable. In colour the coarser rocks are light or dark grey. All grades weather easily, especially along the cleavage, giving a brown staining.

The relative distribution of various grades follows no obvious rule; they occur apparently indiscriminately. There only appears to be regularity in a large-scale *gradual* change of grade. Slate may occur frequently in a visible thickness of up to 50 ft. of mainly coarse greywacke, and *vice versa*, but either coarse or fine rocks always predominate in sections of this thickness. Thus, very coarse grits never alternate repeatedly with slates in thin beds.

Considered in units of a foot or more the greywacke beds are fairly consistent laterally—the grade may change gradually or local thinning may be seen but the general impression of well exposed cliffs inspected from a short distance, is of massive, evenly bedded rock.

Graded beds are common, though they appear to vary in frequency of occurrence and may be absent from considerable thicknesses of rock, followed by an equal thickness in which they are strikingly abundant. The departures from an "ideal" gradation from coarse grit to slate in an even, unbroken bed are many.

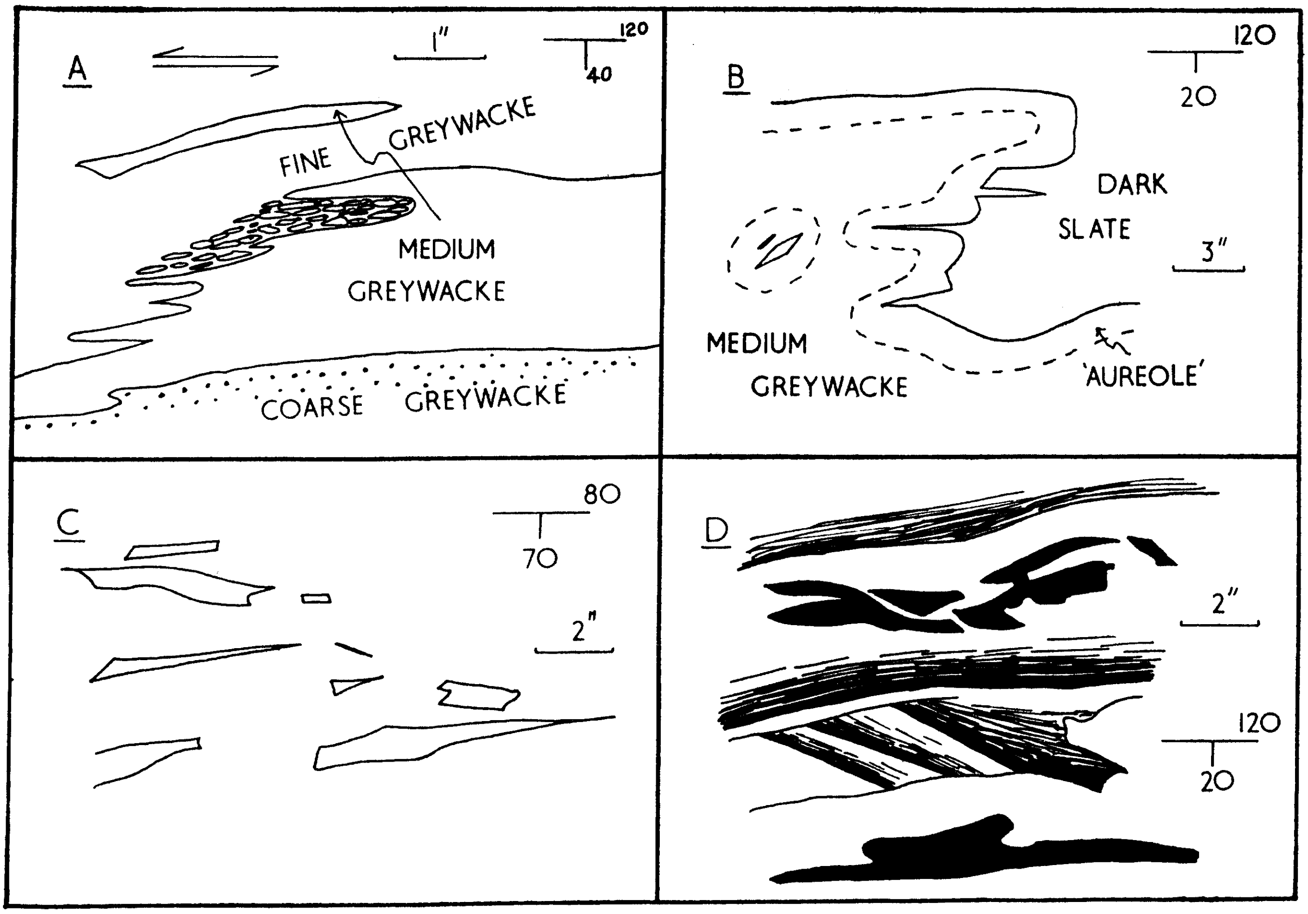

FIGURE 4

A. East shore of East Cumberland Bay. Irregular inverted greywacke beds with a pocket of coarse grit. There appears to be some indication of pressure in the direction shown by the arrows.

B. East shore of East Cumberland Bay. Irregular junction between slate and greywacke with the greywacke adjacent to the slate bleached to pale grey. Inverted beds. The projection of the slate into the greywacke appears to represent an antidune structure subsequently fractured, the cracks being filled in with greywacke.

C. Cliff approximately two miles south-west of Cape Vakop. Elongate fragments of black slate in medium greywacke.

D. Cliff near the locality of "C". Fine greywacke, silt and slate, showing cross bedding and a fragmental slate band.

A thick bed of consistently coarse grit may grade suddenly to fine greywacke. Coarse grit may grade to medium greywacke, followed by a break in deposition above which slightly coarser greywacke grades to fine, above which the process is repeated, to give a series of "intra-grades",* each a single unit in a thick graded bed. A common feature is a sharp break at the top of the fine greywacke of an even gradation, followed by a small thickness of dark striped slates, which has sharp contacts with both the greywacke below and the coarse grit at the base of the succeeding grade. The base of graded beds is often extremely irregular in detail, frequently showing antidune ripple marking. The actual thickness varies from 3 ft. (usually intra-graded) downwards—a series of even grades from medium greywacke to slate on the east shore of East Cumberland Bay two miles north of the present position of the seaward termination of the Nordenskjöld Glacier were successively 6, 6, 12, 6, 2, 14, 4, 6, 9, and 12 inches in thickness. In the finer rocks, slates and silts, the grading can often be seen as grey to black colour banding; the coarser silt may be either lighter or darker than its finer top (figure 3, B and C). In an exposure at George Bay the grading in thinly bedded fine greywacke could be detected by cleavage curvature (such a curvature was never used as a criterion of way-up).

* See Figure 14. As there is no precise term at present to describe this character, the term "intra-grade" is used throughout this report.

Current bedding and minor slumping frequently occur in the dark striped slates (especially in those between graded beds) with or without colour grading in the stripes (figures 3 and 4, D).

A common feature in the greywackes is the occurrence of angular and usually elongated fragments of black slate. Their long axes are parallel to the bedding and they therefore lie close to the cleavage everywhere but in the crests of folds. Their abundance varies from a few isolated chips scattered along a bedding plane to what is virtually a loosely brecciated slate bed with the interstices filled by greywacke (figure 4, C and D). Such brecciation often appears to have taken place *in situ*. When coarse greywacke overlies slate (figure 4, B), isolated fragments are often found near the crests of antidune structures.

The slate fragments and, less conspicuously, some continuous slate beds, are sometimes surrounded by "aureoles" of bleached greywacke, formed by thin bands of lighter rock through which the changes of grade marking the bedding run uninterruptedly (figure 4, B). It is possible that the bleaching is associated with another character most easily seen on weathered surfaces of fine to medium greywackes—the occurrence of dark, slightly raised lenticular areas with indistinct boundaries. These lie with their long axes along the cleavage (mostly elongated about 4: 1) and vary in length from 1 inch to 6 ft. There is no apparent banding or irregularity in depth of colour within the dark areas. The dark colour was later determined to be due to the abundance of calcite in the matrix of the greywacke.

Quartz veining of varying abundance occurs throughout. A type of vein of possible tectonic significance is illustrated in figure 9, D.

As all the sedimentary structures are of necessity deformed by the general compression which caused the cleavage, the distinction between depositional and tectonic features is a matter of estimation. When minor folding is absent the deformation within an evenly bedded exposure can be regarded as homogeneous and the degree is indicated by the direction and intensity of the local cleavage. At fold crests the sedimentary details may be altered unrecognisably (figure 5, A, B, C, D).

(ii) *Structure*

The estimation of an intensity of deformation must be based on a synthesis of detail. Although there has been considerable deformation and recrystallisation, the general impression in the field is of cleaved sediments.

The main observable features relating to the structure are:

1. *Bedding, orientation and whether normal or inverted*

2. *Cleavage*

(a) Over the northern part of the area there is a strong slaty cleavage, gradational from fissility in the finest grades to a flattening of the individual grains where distinguishable. In the coarser grades there are usually unflattened grains around which the cleavage curves to give a small scale augen texture.

(b) In the exposures visited at and south of the snout of the large glacier flowing into St. Andrew's Bay* this cleavage is obscured by a later fracture cleavage, cutting across the direction of grain flattening. In the finer grades, where this fracture cleavage cannot be seen, the original cleavage is entirely obliterated by the later and coarser cleavage.

3. *Grain elongation*

In some of the greywackes of the northern part of the area there appeared, on the cleavage surfaces, to be an elongation of the grains as well as flattening. Where this was seen it was recorded and subsequent examination of two faces cut perpendicular to each other and to the cleavage in each of four specimens has confirmed the presence in them of a slight stretching.

4. *Plunge*

(a) The plunge of the main folding as defined by the orientation of the intersection of bedding and cleavage is normally in the general direction (see below) of:

(b) A faint "rippling" of smooth cleavage surfaces—the beginning of a phyllitic parting.

5. *Irregular planes of puckering*

*The glacier known locally as the "Cook Glacier": this is not an accepted name.

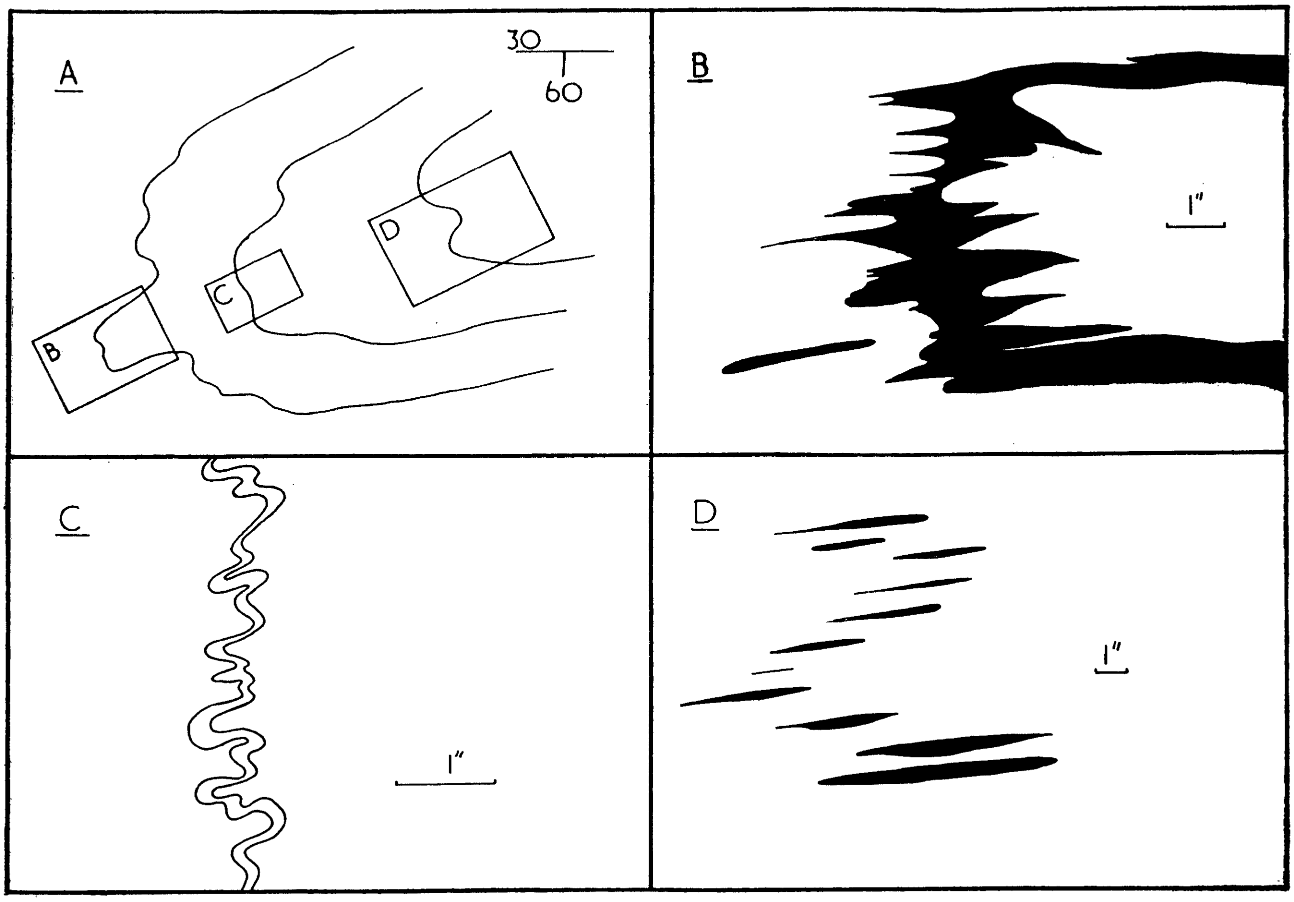

FIGURE 5

A. General form of small synform on the east shore of East Cumberland Bay at 30° to the fold axis. The positions of "B", "C", and "D" are outlined.

B. Deformed black slate band in greywacke.

C. Thin medium greywacke band in silt—the coarse grades tend to flow instead of shearing out into angular forms.

D. Continuous (on limbs) slate band in fine greywacke pulled out into lenticles at the crest of the fold.

In all the exposures visited north of Cape Vakop the tectonic orientation was consistent within narrow limits. Along the east shore traverse in Cumberland Bay the cleavage has an average dip of 40° to N.35°E.* Dip records range from 15° to 60° in directions N.20°–60°E. Most of the way-up evidence was seen in inverted beds, but from this it is difficult to estimate the actual proportions of normal and inverted beds. The average measured dip of inverted beds is 55° to N.30°E., with observations of dip varying between 30° and 70° to N.20°–50°E. Where normal bedding was found the cleavage was almost parallel to it, and was only distinguishable as dipping less steeply in good exposures. There is a slight easterly plunge of rippling and bedding/cleavage intersection. The direction of grain elongation plunges 40° to N.30°E.

In George Bay relations are similar, but the plunge is greater, giving a greater difference in orientation of the strike of normal and inverted beds. This information is summarised in figure 6.

Along the traverse at "A" (end folding map) the fold axes are at right angles to those of the exposures to the north and plunge at 50° in a direction N.10° W. A sketch map of a well exposed small fold along this traverse is shown in Figure 7. The rippling and grain elongation maintain the same orientations.

* All bearings are true.

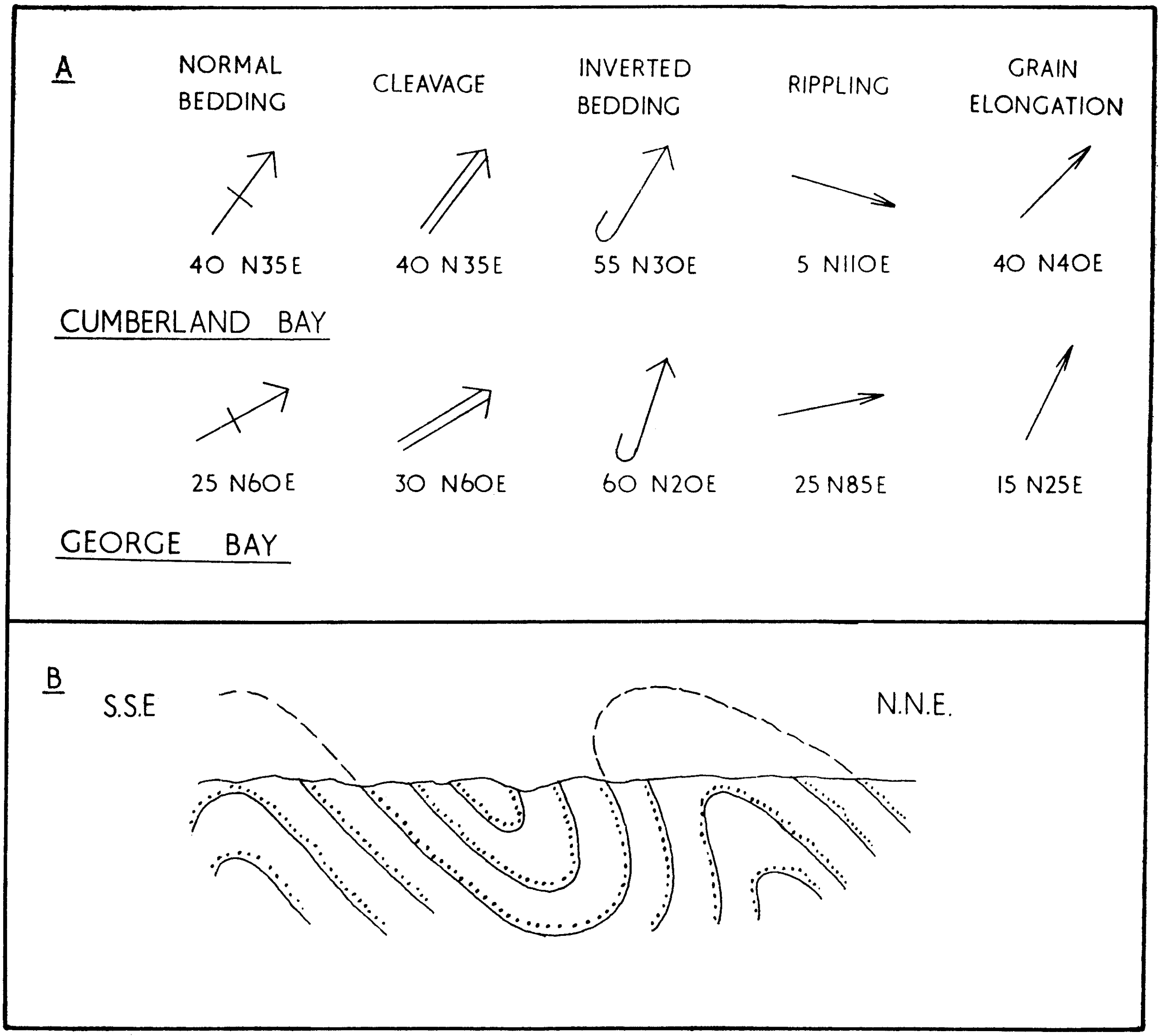

FIGURE 6

A. Summary of five structural features in Cumberland Bay and George Bay. Apart from "normal bedding" the values are averages of a number of scattered observations in each area. A value was taken for each structure at every observation point.

B. General form of folding suggested by the relations in "A".

Along the traverse at "B" (end folding map) the relations are again as in George Bay and Cumberland Bay, with minor plunge variations.

In the cliff immediately at the north end of the long beach along the snout of the large glacier flowing into St. Andrew's Bay, the whole appearance of the rock is different from exposures to the north. There the folding is on a large scale—that is, the limbs are massive, evenly bedded, and, as far as could be judged, of great thickness. In this cliff the beds are affected by the second cleavage, so that much haphazard crumpling and puckering, exceptionally abundant quartz veins, and many small folds and faults combine to give an impression of intense crushing at a time when the rock was not plastic. To illustrate this, the relations at a well exposed part of the cliff are shown in figure 8, the nature of the minor folding being shown in figure 9. The nature of the pressure causing the cleavage is not clear.

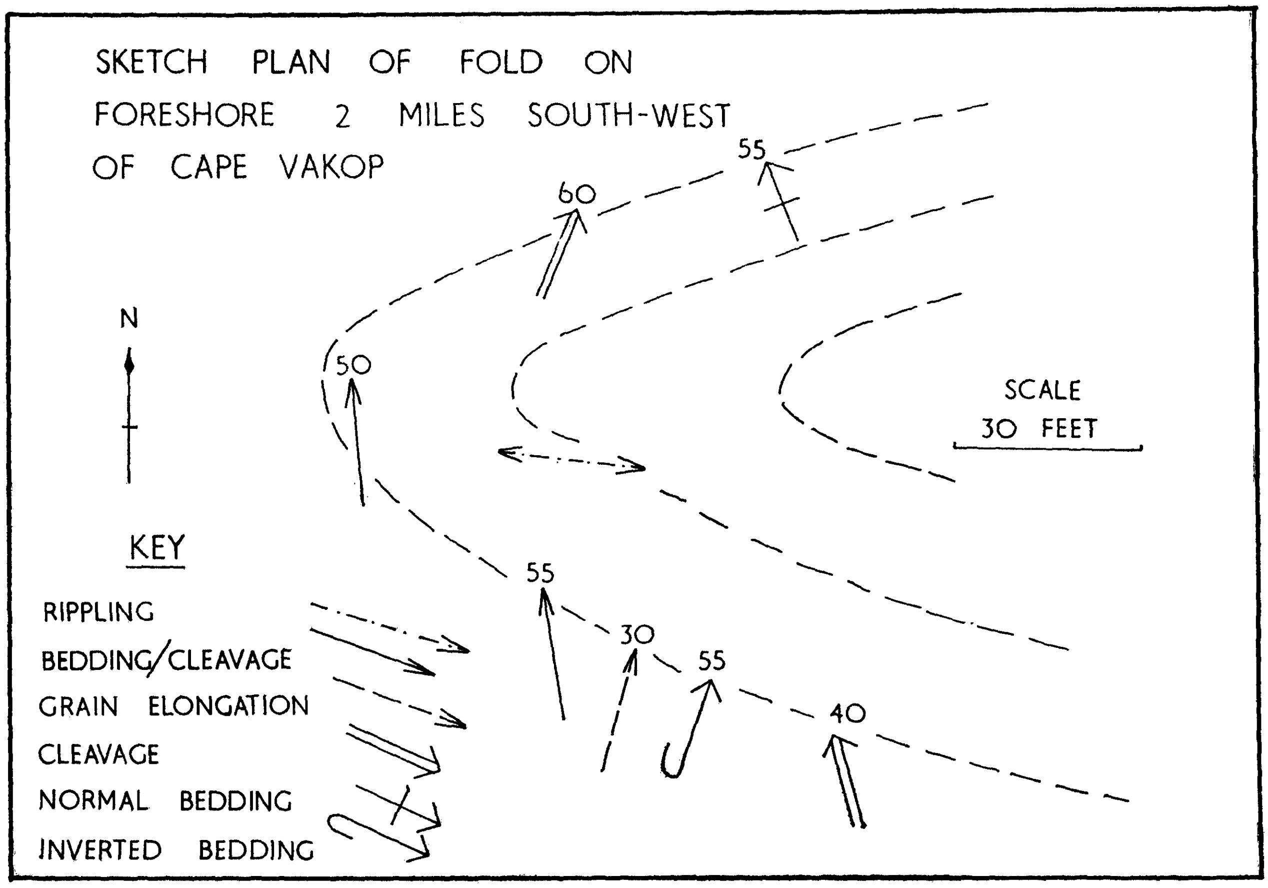

FIGURE 7
Fold in Sandebugten Bay Series with axis approximately parallel to the direction of pressure.

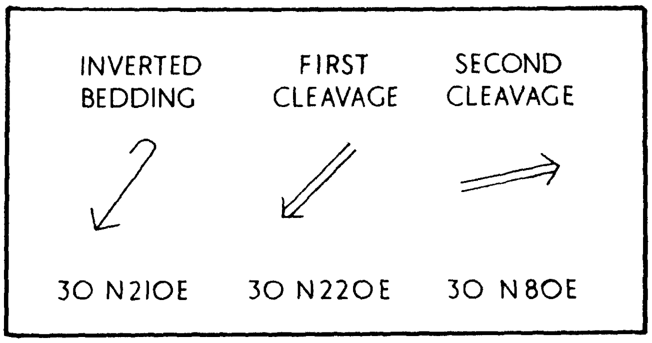

FIGURE 8

Along the traverse in Doris Bay the second cleavage affects the majority of the rocks seen, having a low dip (20° or less) to the north in the northern part and to the west in the southern part of the traverse. Exposures were in most places insufficient for a complete record of orientation and with a structure of this complexity unconnected records of bedding or cleavage dip are of little significance. The relations in a good exposure at the southern end of the traverse are shown in figure 10.

No grain elongation or proven original rippling could be distinguished here in the field. The rocks at the north end of the Ross Glacier snout in Royal Bay are also strongly affected by the second cleavage.

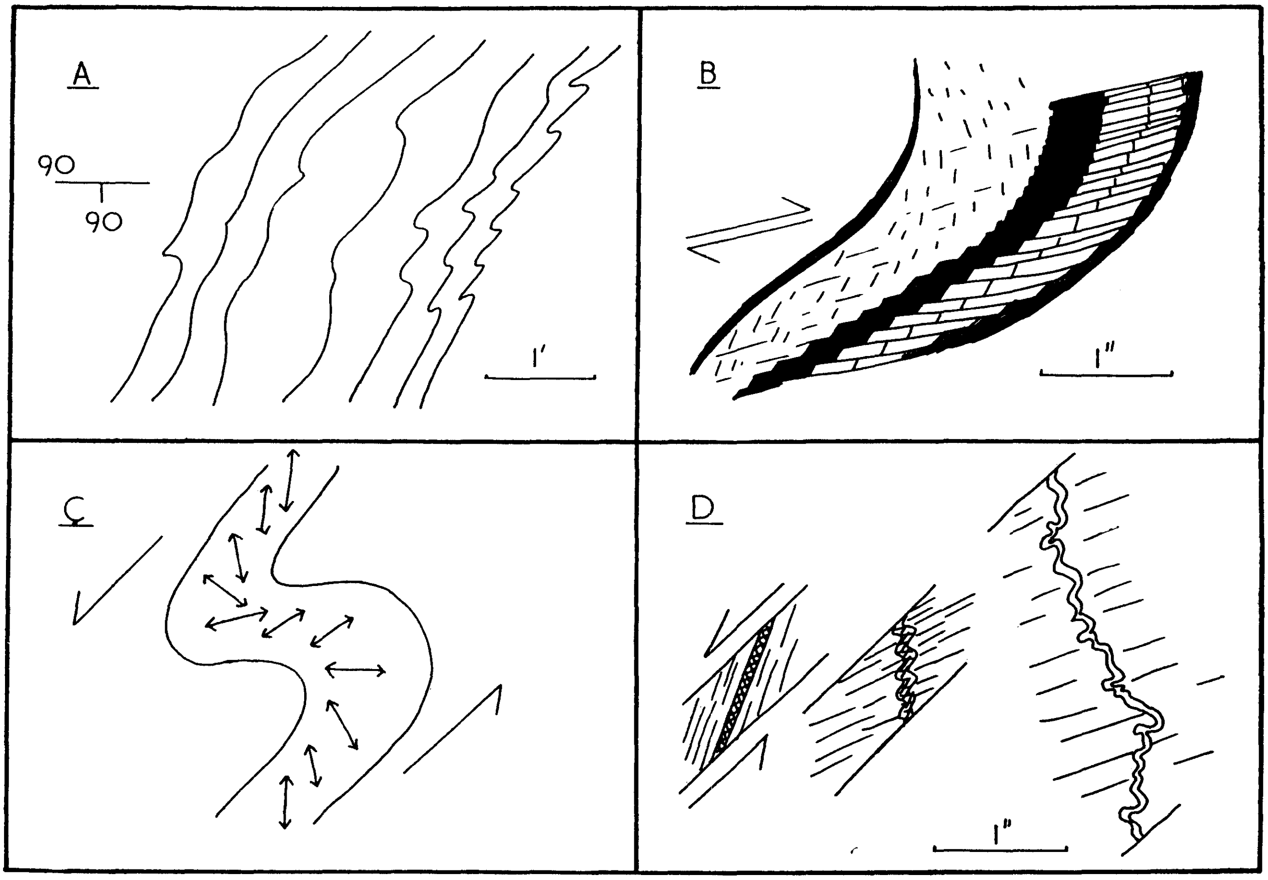

FIGURE 9

The effects of the second cleavage in the cliffs immediately north of the long beach along the snout of the large glacier flowing into St. Andrew's Bay.

A. Form of the minor folds, showing the general distortion of the bedding. (The orientation is the same for "B", "C", and "D".)

B. Detail of lower part of a fold of the type sketched in "C", showing direction of movement along the planes of fracture cleavage. Dark-slate; light medium greywacke.

C. Direction of grain elongation around a minor fold in medium greywacke, with arrows showing the supposed direction of stress causing the fold. This is in the opposite sense to the actual movement along the cleavage, shown in "B".

D. Left hand diagram: straight quartz vein along the original cleavage direction. Centre diagram: same vein distorted by pressure causing the second cleavage. Right hand diagram: sketch of a vein of a type common in the cliff, possibly originating in this way.

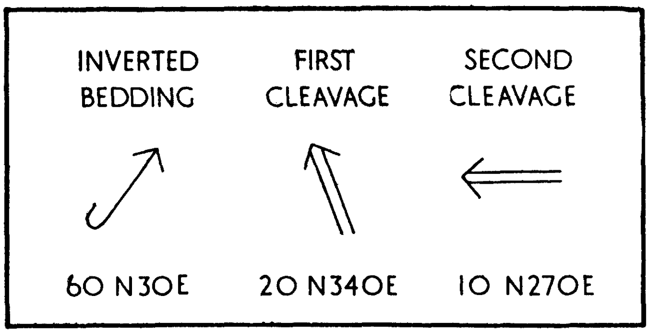

FIGURE 10

Anastomosing planes of puckering of the cleavage, illustrated in figure 11, are especially abundant north of St. Andrew's Bay. They are either vertical or steeply dipping, their strike being parallel to the general strike of the bedding and cleavage. They may show uplift of either north-east or north-west sides, and in one locality, in the traverse at "B" (end folding map), there are two distinct intersecting sets.

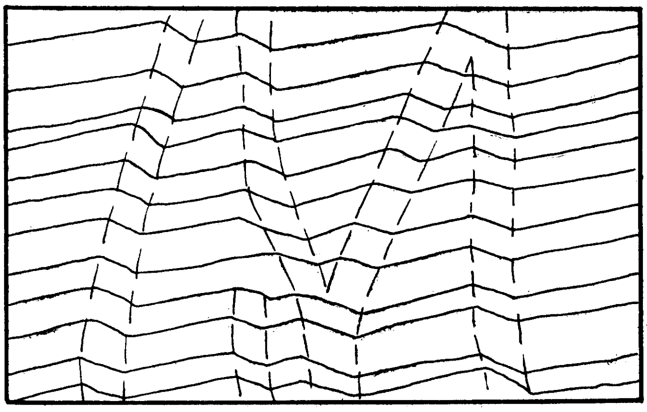

FIGURE 11
Appearance of anastomosing planes of puckering of the cleavage.

Some minor points concerning the interpretation of the structure may now be described:

Firstly, in the northern part of the area, the difference between bedding and cleavage dip of inverted beds is about 20°. In normal beds the dips are barely distinguishable. This would suggest a fold form as in figure 12, A (a modification of figure 7, B). If the abundance of inverted beds along the traverses made is of any significance the form of folding shown in figure 12, B is suggested rather than that of figure 12, C.

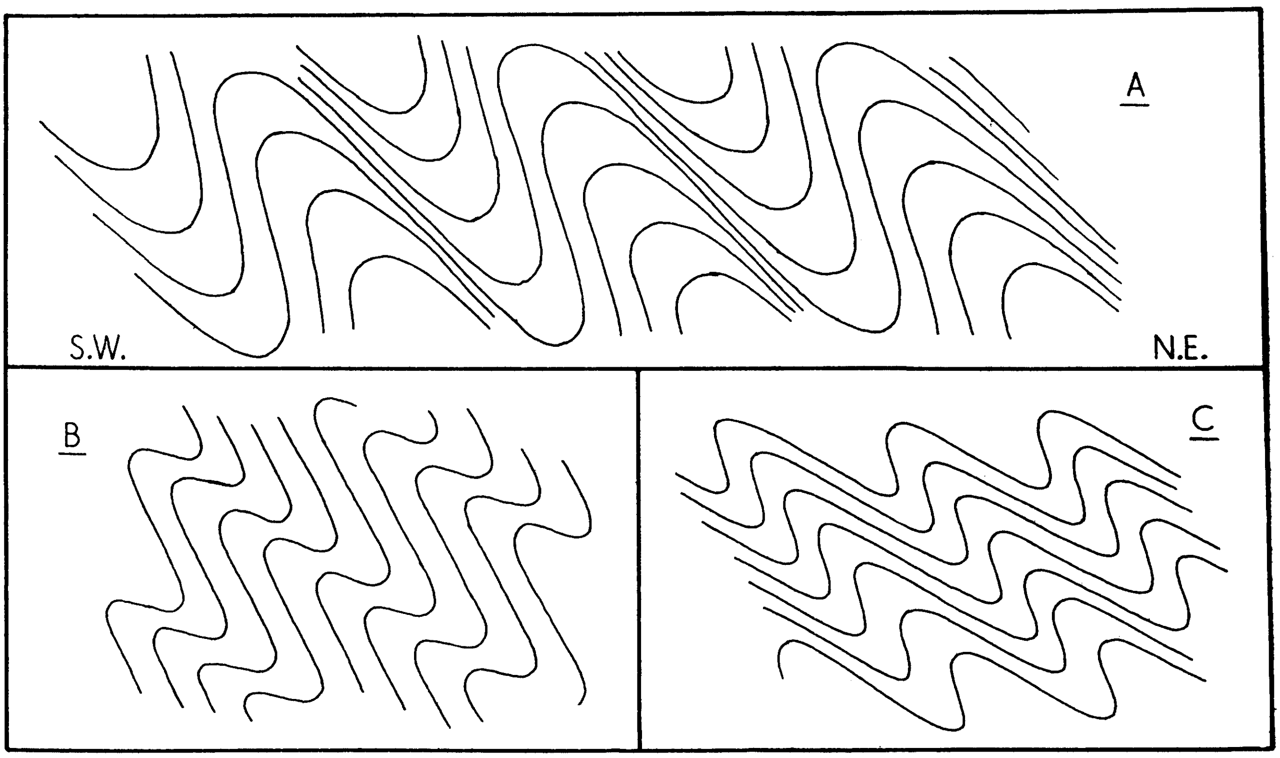

FIGURE 12
Folding of the rocks between Cumberland Bay and Royal Bay.

Secondly, in the Cumberland Bay traverse there was often a discrepancy between the orientation of the theoretical bedding/cleavage intersection and the rippling, and of the axes of the rare minor folds. The bedding/cleavage plunge is slightly anti-clockwise from that of the rippling.

A possible corroboration of the significance of this discrepancy lies in the folding in the traverse at "A" (end folding map) in which the fold axes are slightly more than 90° anti-clockwise from the rippling (figure 7), which maintains its orientation relative to the grain elongation. The orientation or rippling and grain elongation in the inverted limbs of the folds is shown in figure 13.

This general asymmetry of the folding may be connected with a third point, namely the tendency for the inverted beds of the Cumberland Bay traverse to appear when looking directly down the dip, as though their uppermost sides had been displaced from right to left, as shown in figure 4, A. This lateral stress appears to have been greater than would be expected to be caused by the effect of the slight easterly plunge on the normal (that is, in the *ac* plane) stress in fold limbs. This apparently anomalous stress is shown by the arrows in figure 13.

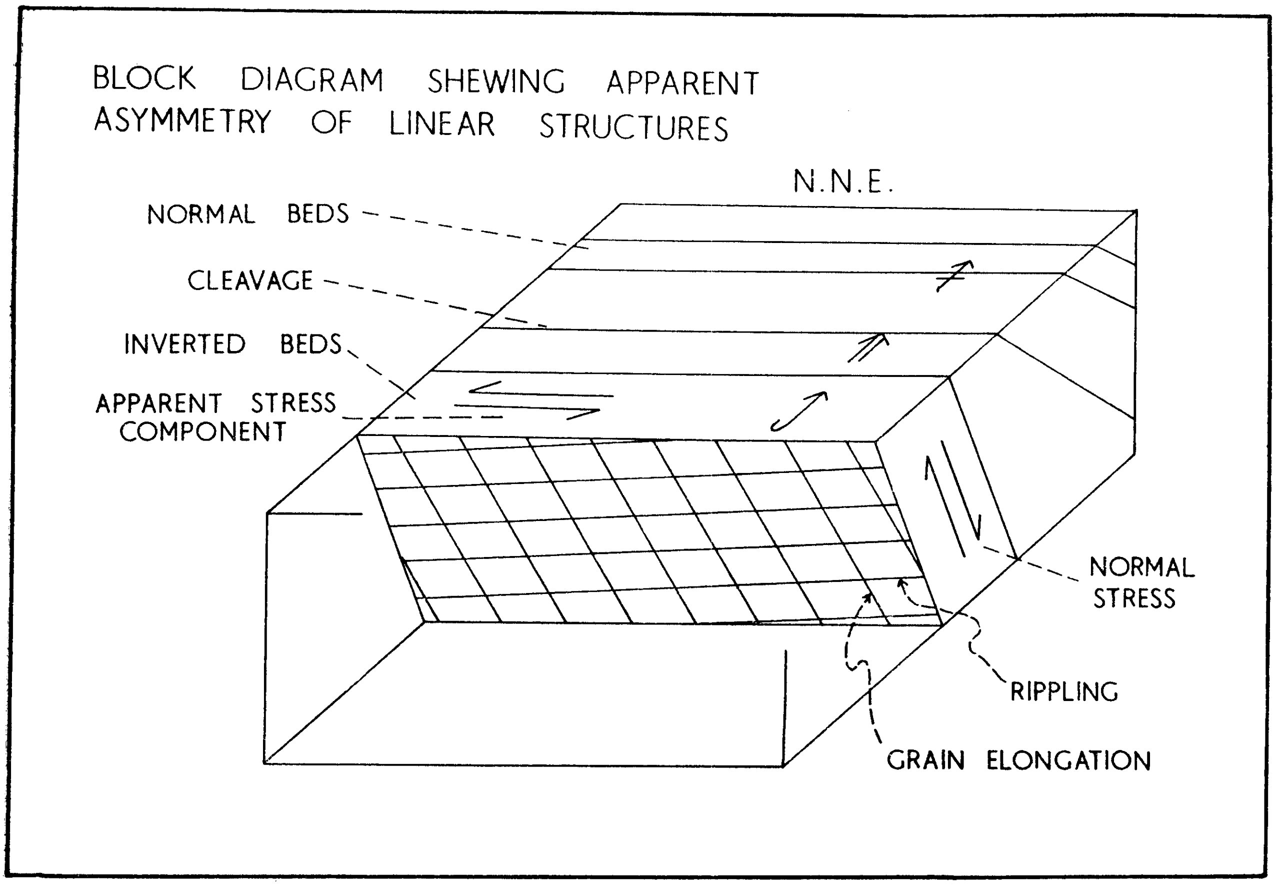

FIGURE 13

These three points are of doubtful significance. It may be that such structural asymmetry could be produced by a change in direction of movement after the original formation of a fold pattern in a series of sediments.

(iii) *Petrography*

The chief petrographic differences between the two groups of sediments are well reflected in their general lithology and field characters. Comparatively few thin sections were therefore used for the following petrographic description which is based on seven thin sections of specimens from the east shore of East Cumberland Bay, one from near New Fortuna Bay, two from George Bay, three from the coast between Cape Vakop and the large glacier flowing into St. Andrew's Bay, one from Doris Bay and two from a specimen from Royal Bay. None of the finer grades were chosen for sectioning, the finest having individual grains .8 mm. in diameter.

Quartz commonly occurs as angular grains, which always have their long axes oriented parallel to the foliation, but which have apparently retained their shape against the pressure. Strain shadows are usually present, and minor fractures with slight displacement are common. Two examples of fractured quartz grains slightly displaced along the foliation were seen, the space between being filled by a mosaic of quartz and sericite. In one slide the foliation is crossed at an angle of 80° by a series of narrow quartz-filled cracks which are parallel to strings of fine dust crossing the quartz grains. Less frequent are grains of *quartzite* which appear to have been elongated along the foliation. The identification of the quartzite is uncertain—one grain was seen in which a single large quartz grain had at one end been altered by pressure into a quartzite-like mosaic, and in this were scattered small flakes of sericite. The average size of individual grains in the quartzite mosaic, which often show strain extinction, is rather less than 1 mm., though in some specimens the grains are as fine as .01 mm. average grain diameter. Most abundant are angular fragments of *felspar*, chiefly oligoclase and usually showing albite twinning. The felspars, like the quartz grains are often crossed by fractures along which there is a slight displacement. The finer quartzite grains are difficult to distinguish from the grains of material which now appears as *slate*. These are normally elongated 3: 1 or more along the foliation, and are made up of cryptocrystalline quartz, felspar and sericite.

In three of the sections, one grain, and in another section, two grains of *lava* were found having small (generally about .05 mm. long and .01 mm. wide) flow-oriented laths of felspar with straight extinction, presumably oligoclase, in a cryptocrystalline matrix. One small grain of granophyric intergrowth of quartz and felspar was found.

These recognisably clastic constituents are easily identified in the larger grains but their nature becomes more obscure as the grain size decreases. In all the sections there is a complete downward variation of grain size until the individual grains cannot be distinguished from the finely intergrown quartz, felspar and sericite matrix. The cleavage direction is particularly well marked by the parallel orientation of the sericite, the long axis orientation of the clastic grains and by thin, undulating lines of indeterminate material possibly representing small pieces of graphitic slate squeezed out by pressure. The resistance of the grains to compression gives a schistose appearance to the rock, and the term "foliation" has been used in preference to "cleavage" in the description of thin sections.

Secondary minerals include sericite, clinozoisite, chlorite, biotite and muscovite. *Sericite*, in small flakes rarely exceeding .02 mm. in length, is particularly abundant in the argillaceous matrix, but occurs also scattered within clastic quartzite and felspar grains, as well as more rarely in quartz. In felspars the sericite can usually be seen to be oriented parallel to one or more cleavage directions. In the quartzite it may be oriented consistently parallel to, or at an angle of up to 45° to the general foliation. When it occurs within quartz grains it is often arranged parallel to the c-axis of the quartz, as shown by the strain shadows.

Clinozoisite occurs abundantly throughout the matrix in small prisms rarely larger than .01 mm. by .002 mm. These are oriented parallel to the foliation, as well as occurring as inclusions oriented at random within the clastic grains.

Biotite, *chlorite*, and *muscovite* occur sporadically in much larger plates than the sericite and lie at random in relation to the foliation.

Calcite occurs abundantly in association with quartz in veins. In two of the thin sections it occurs abundantly in the matrix, comprising an estimated 20% of the total volume. The distinction between primary and secondary carbonate material is difficult to make.

C. THE REMAINING SEDIMENTARY ROCKS—THE TUFF SERIES

(i) *General lithology*

These rocks, consisting principally of tuffs, are closely similar to the previous group in general facies and range of grade. The coarsest rock seen was a tuff with sub-rounded pebbles of average diameter 6–8 mm.

Typically, the finer grades are tough and compact, often with a cherty appearance. They may be dark grey-brown, black, cream or greenish in colour. This more compact appearance persists through all grades, the rocks being resistant to weathering, except along joint planes, to give abundant screes of sharply angular fragments. Often the rock has a characteristically shiny appearance on the weathered surface, and the individual grains tend to be less prominent, in relief and colour contrast, than in the previous group. The general colour of the rock is dark grey-brown, often with a green or red tinge. At the base of the cliffs immediately south of the Shackleton Memorial at Grytviken there are grey quartz-rich greywackes, but no other exception to the general lithology was seen.

Limestones are of irregular occurrence—most frequently as rounded or lenticular (elongated 2: 1 along the bedding) nodules of varying abundance along a bedding plane, but sometimes as continuous beds up to 2 inches thick. The rock is dark blue-grey and impure, with some carbon content.

Whenever well exposed, especially where they are not folded, the rocks of this series are remarkably well and evenly bedded (plate I, figure 1).

Typically the relative arrangement of grade is more regular than in the previous group. There appears to be, throughout great thicknesses of this series, a rhythmic sedimentary cycle, each unit of which shows a transition from grit to dark striped slaty tuff over a thickness of 1–5 ft., but most commonly between 2 ft. and 4 ft. Normally two or three graded beds, each slightly less coarse than the one below, are succeeded by a sharp break marking the base of a thin bed of fine dark tuff—identical to the intra-graded bed described as appearing in the previous group (p. 7).

It may be argued that there are no grounds for grouping the intra-grades into a single unit. In the course of precise measurements of beds at Grytviken and near the head of the Ross Glacier there was certainly a practical difficulty in doing this, and the distinction was often of doubtful validity, but over much of the thickness measured there was no difficulty in determining the rhythmic sequence shown diagrammatically in figure 14. A simple description of the rocks as having abundant graded bedding would not convey an impression of the regularity in the series.

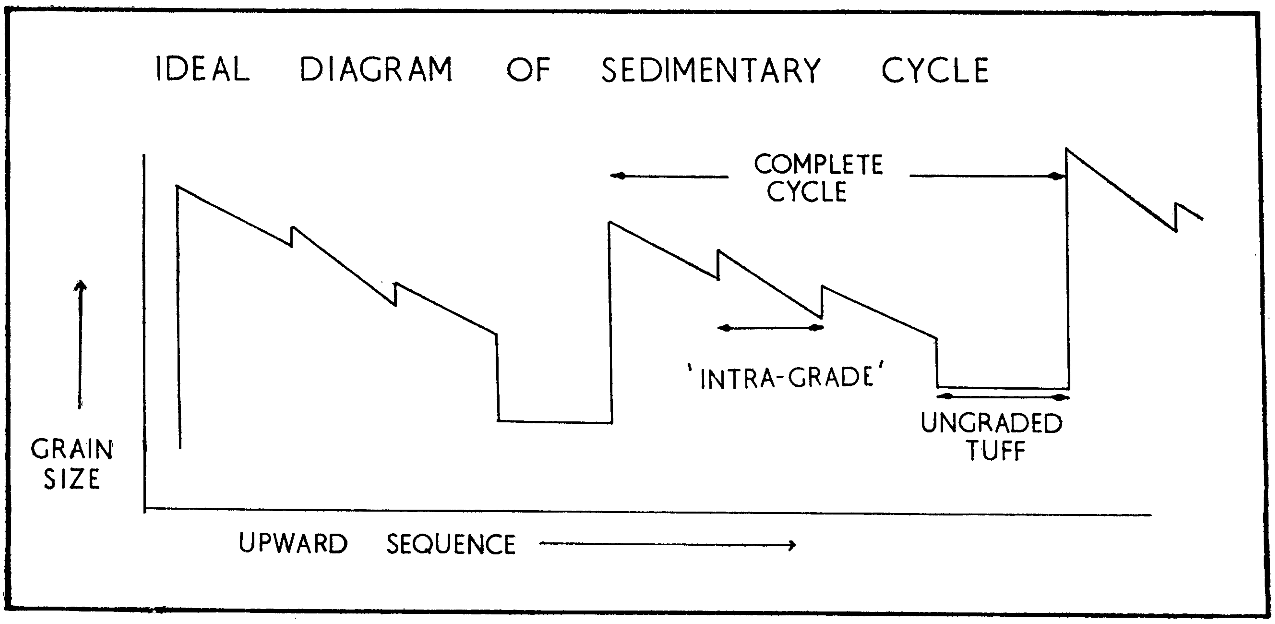

FIGURE 14

The depositional structures typical of greywacke facies of sediments described in the previous group, also occur in these rocks. Slump structures and current bedding in the fine tuffs are found in great variety. Rolled, rounded balls of coarse grit are found in the silts and angular fragments of fine rocks, as well as rounded mud pellets occur, in the grits. Antidune ripple-marks are common.

A curious point relating to the bleaching of greywacke around included black fragments noted on p. 8 is the occurrence of a structure in a large beach boulder at Grytviken in which both the light aureole and the dark fragment have withstood the pressure deforming the fine matrix. (Plate I, figure 2). Such structures are not uncommon in the Cumberland Bay Series, and it is not clear whether they are of depositional origin or formed by later leaching.

As in the previous group, depositional and tectonic structures are difficult to distinguish wherever there has been intense deformation. This difficulty is illustrated in figure 15.

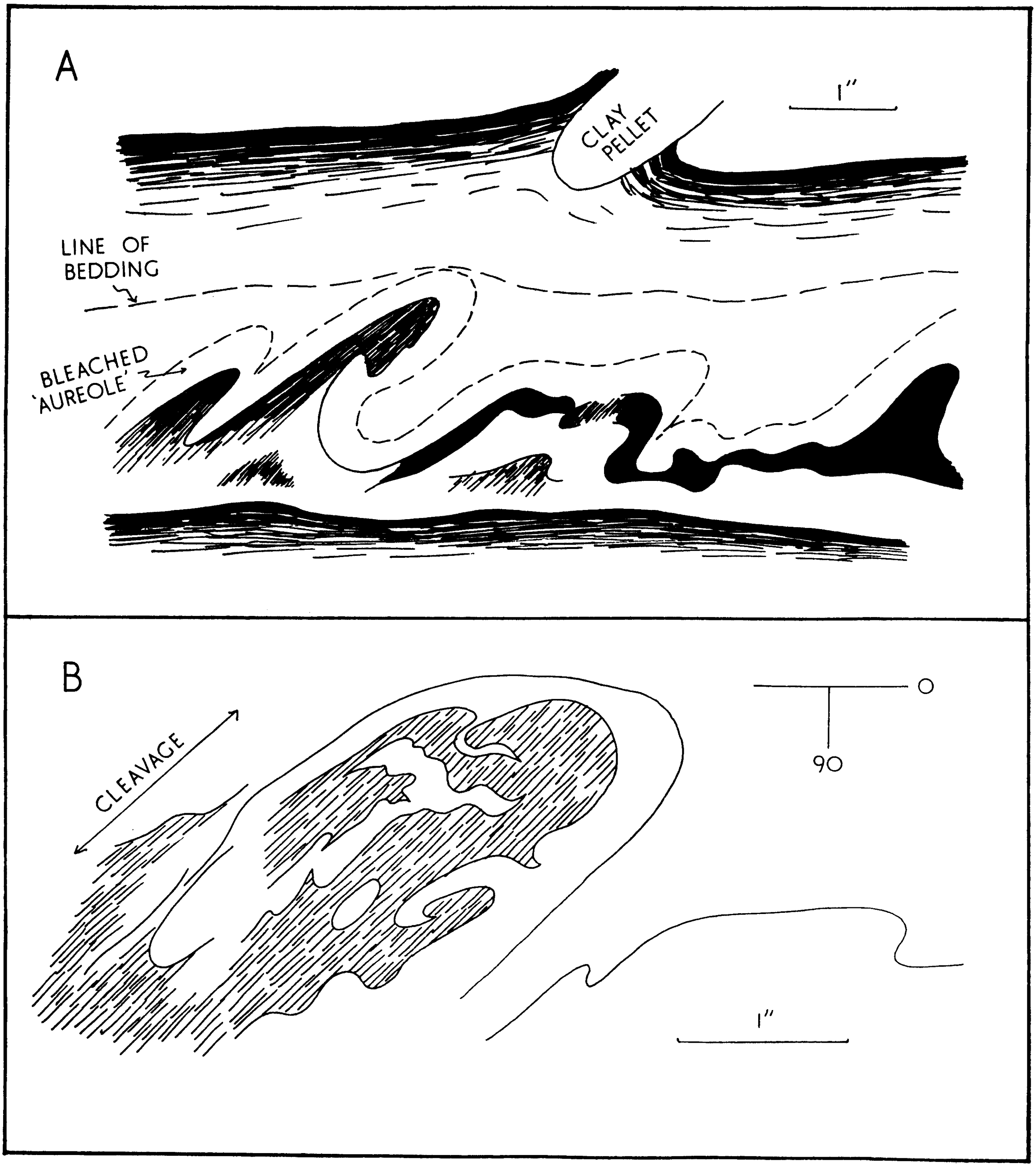

FIGURE 15

Distortion of sedimentary structures by pressure.

A. Fine dark tuff (black) interbedded with and grading into (shaded) gritty tuff. The slumping has been emphasised by the distortion producing the cleavage, which is in the direction indicated in "B".

B. Slumped (?) projection of fine tuff into gritty tuff, which has flowed into the fine tuff along later cracks. The whole structure has subsequently been elongated by the pressure causing the cleavage.

Where the tuffs have not been deformed they have the appearance of normal marine sediments of greywacke facies. Petrographically (p. 15) they consist of intimately mixed fragments of well rounded lava and sharply angular crystals. No evidence was found explaining this anomalous mixing of rounded and angular fragments in the same sediment. The angular fragments may have settled directly from erupted ash into a marine deposit of lava fragments derived by erosion of the associated cone and its surrounding flows. Alternatively the angular crystals may have been subjected to little abrasion when carried for some distance in suspension in a turbidity current whereas the original weathering of the lava may have tended to form it into rounded grains before transport.

(ii) *Structure*

The observable structures are:

1. *Bedding, including way-up*
2. *Cleavage—a single slaty cleavage*
3. *Grain elongation*
4. *Plunge of bedding/cleavage intersection or rippling*

Planes of puckering are absent in the tuff series.

The intensity of cleavage varies according to the extent to which the beds are locally folded. Cleavage is virtually absent in areas where the rocks are gently dipping and evenly bedded. Related structures such as grain elongation and rippling are similarly variable—as also are some minor features such as the abundance of quartz veining.

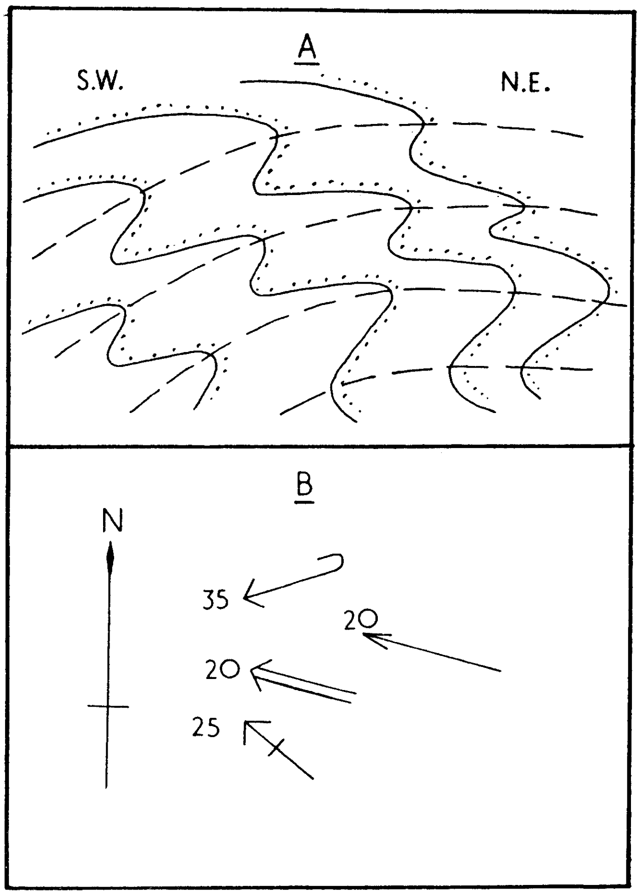

FIGURE 16

A. General cross-section showing the overfolding of the rocks between Moränen Fjord and Fortuna Bay.

B. Typical relations found in the field between Moränen Fjord and Fortuna Bay.

In the exposures examined between Grytviken and Fortuna Bay this series is strongly folded and cleaved, cleavage in the coarser grades being marked by flattening of grains (often as much as 3: 1), with a slight elongation. The nature of the folding can be seen in many large exposures, notably on the mountain face immediately west of Busen Point on the south side of Stromness Bay (plate II, figure 2).

The rocks are apparently overfolded from the south-south-west, the axial planes of the folds having been originally inclined between 30° to the south-south-west and a few degrees to the north-north-west. A west-north-westerly plunge of 10° to 20° as shown by the bedding/cleavage intersection, causes the expected deviation of individual dip and strike measurements of bedding and cleavage from a direction perpendicular to the direction of movement. The grain elongation lies in the plane of the cleavage in a south-south-west to north-north-east direction. This structure is summarised in figure 16. Figure 16, A is intended as a diagrammatic vertical cross-section; for the approximate scale of the folding see plate II, figure 2.

In the exposures along the Neumayer Glacier traverse even dips of 30° to S.80°W. were observed. Cleavages dip at 25° to S.70°W. The cleavage is marked by a flattening of the grains in the coarse grades as well as by fissility in the finer rocks but is not so intense as in the beds around Grytviken. The general impression of the rocks from a distance is of an evenly dipping series, slightly puckered by occasional folds. The sense of these was not established.

Along the route followed inland from Royal Bay the rocks dip evenly and consistently at about 30° to the south-west. Occasionally the even bedding is disturbed by an isolated fold apparently having the proportion shown in figure 17—a large-scale pucker which is quite different from the intense folding in the rocks between Grytviken and Fortuna Bay. At and westward of the col at the head of the Ross Glacier the cleavage is barely discernible, there being no grain flattening in the coarse grades. There is a very faint horizontal rippling parallel to the strike.

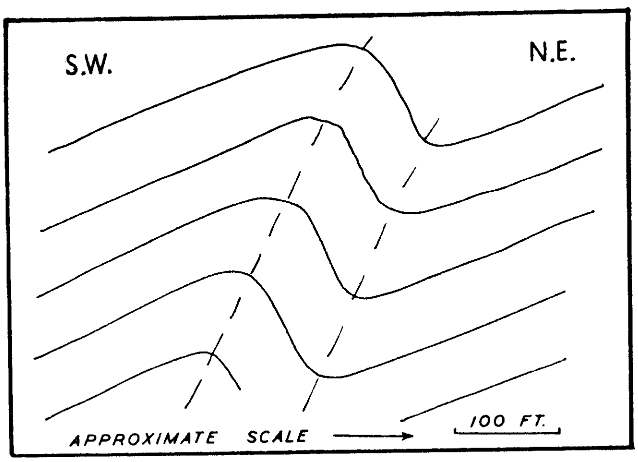

FIGURE 17

In many places where the rocks of this group were not actually visited the bedding could clearly be seen from a distance, in sea cliffs or mountain faces. From such exposures it seems probable that the westerly pitch at Fortuna Bay persists westward, giving a steady upward stratigraphical succession in that direction. An observation of the bedding/cleavage/way-up relationship at Wilson Harbour, where the cleavage is well developed, is consistent with that at Fortuna Bay. South-east of the Three Brothers a general south-westerly dip of about 30° is clearly visible (plate I, figure 1). In the central part of the island this steady dip persists as far north-eastwards as Moränen Fjord.

(iii) *Petrography*

As in the previous group the petrography is well reflected in the general lithology and field appearance of the rocks. Taking this into consideration, the comparatively few sections used for this account of the petrography are sufficiently consistent to justify their acceptance as a representative sample. The following description is based on two thin sections of specimens from Fortuna Bay, eight thin sections of rocks from

Grytviken, six thin sections of rocks from the area around the col at the head of the Ross Glacier, one section from Wilson Harbour and one from the cliffs on the south side of the Neumayer Glacier, about two miles from the snout.

The rocks in the area around the col at the head of the Ross Glacier have not undergone shearing. They consist principally of igneous material.

Most conspicuous in thin section are fragments of lava which vary in diameter from 6 mm. downwards, according to the general grade of the rock. They are sub-rounded to sub-angular, having a ratio of length to width of about 3: 2 and mostly lie with their long axes along the bedding. The majority are fragments of andesite having flow oriented laths of twinned oligoclase of average length .05 mm., closely packed in an aphanitic matrix. Large (up to .1 mm. diameter) idiomorphic crystals of augite are occasionally present, and augite is sometimes also scattered as abundant small granules in the matrix. Felspars may be present as phenocrysts, up to .2 mm. diameter, consisting of either orthoclase, albite or oligoclase, the plagioclase invariably showing irregular combinations of albite and Carlsbad twinning. Some pyroxene-free grains having abundant orthoclase may be described as trachyte.

The direction of flow orientation of the felspar laths is often parallel to the long axis of the cross-section of the grain, though this is not an invariable rule, the two directions in some grains being perpendicular. Even in the most rounded grains the direction of the flow orientation bears no relation to the boundary of the grain, individual laths being abruptly terminated by the margin.

Such fragments of lava make up an estimated 40% of the total bulk of the rock. Most of the remainder of the recognisable constituents consist of single crystals of the (presumed) constituents of the lavas. In shape these are strikingly more angular than the sub-angular to sub-rounded lava grains, normally they have sharp (cleavage) angles and are sometimes idiomorphic. This angular shape is not universal; some of the crystal fragments have slightly rounded corners, but no more so than the corroded phenocrysts of the lava fragments. The most abundant felspar occurring in this way is oligoclase, with less abundant andesine, albite and orthoclase. Felspars make up an estimated 90% of these crystal fragments, the remaining 10% consisting of appproximately equal amounts of quartz (clear, unstrained and sometimes as corroded idiomorphic crystals), and augite, with rather less abundant hornblende.

Olivine was not seen in any of the sections examined.

In thin section these clastic constituents are closely packed in a fine dark matrix which is almost isotropic, showing only a faint speckling as the stage is rotated.

The original structure of the rocks is obscured by the presence of abundant secondary minerals. Prehnite is abundant, with little apparent regularity in its mode of occurrence. A single (presumed) felspar crystal may be completely replaced by either one crystal of prehnite or an aggregate of small crystals. Some of the adjacent matrix may be included within the area of alteration. Sometimes a group of slightly separated but optically continuous blotches of prehnite may cover parts of lava grains, matrix and felspar crystals.

Calcite also replaces grains of lava, crystals and matrix, in one section constituting about 20% of the bulk of the rock. Magnetite occurs often as large irregular areas fringed by chlorite, and also as small grains scattered in the matrix of lavas; both types are of doubtful origin.

The remaining thin sections are of similar rocks which have suffered considerable deformation.

The lava fragments are considerably elongated along the direction of cleavage, the ratio of length to breadth being sometimes as much as 5: 1. Some fragments have even been pulled into two or three separate lenticles between which scattered laths of felspar demonstrate the previous continuity. Many of the smaller crystal fragments have been rotated so that their long axes lie along the cleavage; these, too, are often separated, the felspars fracturing easily into three or more pieces along their cleavages. The intervening spaces are normally filled with calcite. The felspar crystals appear to be slightly less angular than those in the unsheared rocks; this is probably a result of the shearing, as the occasional harder angular quartz grains appear as sharply angular as the quartz of the unsheared tuffs.

Examination of sections of the Grytviken-Fortuna Bay rocks shows that calcite is the predominant secondary mineral, with prehnite rather less abundant and more sporadic in its occurrence.

D. THE IGNEOUS ROCKS

As the writer only examined igneous rocks at Larsen Harbour and in a small area south of the col at the head of the Ross Glacier, there is only one significant note to be added to the existing descriptions.

Along the south side of the glacier flowing westward into Undine South Harbour 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 (plate I, figure 3; plate II, figure 1). The actual contact with the sediments was not seen but the abundance of volcanic material in the sediments closest to the lava, and the fact that they have the same orientation, suggests that the lavas are a conformable part of the sedimentary series.

III. GEOLOGICAL RELATIONS

AT the time of writing, the knowledge of the geology of South Georgia is in a state where investigation of individual rocks has far outstripped the information concerning their field relations. The questions of the relationship between igneous rocks and sediments, and between the two sedimentary types, are still undecided, and are discussed below. The relevant evidence comes mostly from South Georgia itself, but the geology of some parts of the Scotia Arc which seems to concern South Georgia directly is also described.

A. THE SEDIMENTARY ROCKS

In Section II the sedimentary rocks were described under two sub-headings as a matter of convenience. Whether this division is of any significance is a matter on which both structural and petrographic evidence have some bearing.

Temporarily disregarding the minor structural features of the sediments one point seems indisputable: wherever their structure can be clearly seen the rocks between Cumberland Bay and Royal Bay appear to have been overfolded from the north-north-east. The remaining sediments appear to have been overfolded from the south-south-west. The relationship between the two types was not conclusively proved, but some evidence was found in Cumberland Bay.

During a brief ascent of a small hill about one and a half miles south of Dartmouth Point for survey purposes two observations were made. At and immediately below the summit there is intensely crushed and folded tuff lithologically identical with that of Grytviken. It contains exceptionally abundant quartz and calcite veins. The folds plunge 20° westward. At a point threequarters of a mile due north of the summit a normal graded bed dipping at 30° in a direction N.30°W. is crossed by cleavage dipping at 20° to N.70°W. These relations are typical of the country between Grytviken and Fortuna Bay. A small cliff by one of the lateral moraines on the east side of Moränen Fjord consists of arenaceous and argillaceous greywackes similar in appearance to those of the east shore of East Cumberland Bay. A series of inverted beds dipping at 60° to N.30°E. is crossed by cleavage dipping 35° in a direction N.60°E.

From these observations it appears that the tectonic orientation of the tuff series is consistent from Dartmouth Point westwards at least as far as Fortuna Bay, and that the arenaceous and argillaceous greywackes have a consistent orientation from the same locality certainly as far eastwards as Cape Vakop. With such consistency it seems unlikely there can be any gradual change of tectonic orientation in the vicinity of Cumberland Bay. Structures such as a transition in dip of the axial planes of the folds from north-north-east to south-south-west through the vertical must be regarded as improbable, and any structure suggested should be able to account for this sudden change.

There are three main possibilities. All the sediments may form a continuous conformable series, the junction between the two types of structure representing a plane of movement separating two blocks in which different stresses have operated. The second possibility is that the tuff series was laid down unconformably upon the older folded greywackes, and was later pushed to the north-north-east over these. The third possibility is that the two groups represent sediments differing widely in age and original position, brought into apposition by movements which simultaneously folded them.

Any theory involving the idea of a continuous series of sediments must account for the presence of two distinct and apparently mutually exclusive rock types and structural orientations. That two types of structural orientation are present there can be little doubt. The extent to which the two sedimentary types are confined each to one type of structure, as well as the extent to which they differ from each other, have yet to be discussed.

The lithological, structural and petrographic evidence is clear. On the folding map at the end of this report the pecked line from Cumberland Bay to Royal Bay separates two areas having distinct structures and (with one exception—p. 16) distinct rock types. The two groups of sediments are in many ways similar. They have, for example, a similar range and distribution of grade, and also many depositional features in common. Their distinction lies in the nature of the material composing them, which differs widely and consistently, as has already been shown in Section II.

Previous petrographic evidence suggests that this division found by the writer has other exceptions. Tyrrell (1915, p. 832) records twenty-three out of thirty-five specimens from the "Middle Cumberland Bay Series" (Ferguson, 1915), which covers much of the area of the tuff series described in Section II, as being arenaceous and argillaceous sediments. Holtedahl (1929, p. 54) describes arenaceous rocks among a collection from the south-west coast. Barth and Holmsen (1939, p. 51) record "relatively pure argillite" from Leith Harbour, Prince Olaf Harbour and Sandefjord, as well as (p. 58) tuffs with quartz fragments from Leith Harbour and from the south-west coast. The extent to which argillaceous and arenaceous rocks occur outside the area between Cumberland Bay and Royal Bay has yet to be determined. Tyrrell (1930, p. 43) describes Douglas as having found a tuff *in situ* at Barff Point, and a rock collected by Ferguson at Godthul was "a limestone containing angular quartz grains, with fragments of keratophyric lava and black slate" (Tyrrell, 1930, p. 46). Apart from these records of volcanic material in the rocks between Cumberland Bay and Royal Bay the writer (p. 15) found five small grains of a trachytic lava in otherwise arenaceous greywacke on the east shore of East Cumberland Bay and at George Bay. The significance of these as evidence for or against a two-fold division of the sediments requires some digression in the discussion.

The successive discoveries of fossils from South Georgia are described in the introduction. The reliable palaeontological evidence comes from the tuff series and mainly indicates a definite Mesozoic age. A *Posidonomya* from Moränen Fjord (Andersson, 1907, p. 725) could be of early Mesozoic or late Palaeozoic age. Heim (1912, p. 453) recorded an ammonite from Prince Olaf Harbour. From Annenkov Island Wilckens (1932) has described an ammonite fragment and lamellibranchs collected by Rustad (Holtedahl, 1929, pp. 54–55). He also described (Wilckens, 1937 and 1947) ammonites and lamellibranchs collected by Kohl-Larsen which indicate an Upper Aptian age.

The available structual evidence suggests that the sediments between Moränen Fjord and Annenkov Island are comparatively little folded and probably dip evenly south-westward at about 30°. The arenaceous and argillaceous greywacke series crops out three miles north-north-east of evenly south-westerly dipping rocks in Moränen Fjord. If these are regarded as a part of the tuff series they should not be older than Mesozoic. A conformable succession from Palaeozoic to Upper Aptian is not impossible, but certainly exceptional. Small scattered grains of lava are occasionally present (see pp. 24, 25) in the arenaceous greywackes of the Trinity Peninsula Series of Graham Land and in the greywackes of the South Orkneys. The age of the Trinity Peninsula Series is certainly pre-Jurassic and probably Palaeozoic. Evidence from the South Orkneys suggests that the greywackes there are of Palaeozoic age (Pirie, 1906). The arenaceous greywacke series of South Georgia, which is closely similar petrographically to these rocks, may be of the same series, and age. It is at least certain in Graham Land that the presence of small scattered lava fragments in arenaceous greywacke is no criterion for connecting them with neighbouring sediments containing abundant volcanic material.

Although not conclusive, the evidence discussed so far does suggest that the two groups of sediments in South Georgia are not parts of a single series and evidence to the contrary is lacking. If the two groups are distinct there still remains the question of their structural relationship. In subsequent discussion the tuff series will be alternatively referred to as the Cumberland Bay Series (Ferguson, 1915, p. 802; Wordie, 1921, p. 19; Tyrrell, 1930, p. 48). The rocks between Cumberland Bay and Royal Bay will be referred to alternatively as the Sandebugten Series. This new name is thought justifiable on the grounds that previous two-fold divisions have been made on less convincing evidence. The Cape George Series (Ferguson, 1915, p. 802), subsequently renamed the Godthul Harbour Series (Tyrrell, 1930, p. 48) was established on mistaken structural relations and purely petrographic evidence.

If the Sandebugten Series was already folded, forming a stable block at the time of overthrusting of the Cumberland Bay Series, some signs of a later stress should be present. Physical conditions within sediments at the time of folding are not well known, but a pressure sufficient to flatten grains at Grytviken to a 3: 1 elongation may be expected to have some effect on the underlying basement. It is possible, though it seems unlikely, that features such as the greater incidence of fractured grains in the Sandebugten rocks, the abundant lines of puckering (p. 13) or the second cleavage in the St. Andrew's Bay—Royal Bay area may represent the result of such effects. Small-scale fracturing of grains would be expected in a rock consisting of quartz and felspar, compared with a tuff with constituents capable of being plastically deformed. The second cleavage is absent in the Sandebugten Series one and a half miles south of Dartmouth Point within a few hundred feet of the overlying Cumberland Bay Series, where the only exceptional feature of either is the intense folding and fracturing of the overlying tuffs. This absence might be explained by the suggestion that the later north-north-eastward pressure only produced a fracture cleavage in the stable block within narrow limits of depth (and pressure).

Such refinement of argument is out of place in a little-known area. Any structure, in either series, formed by the movement of the Cumberland Bay Series over the Sandebugten Series should be found near the junction between the two and decrease in intensity away from it. Exposures south of Royal Bay were not visited. The pecked line, on the end folding map, separating the two series has been drawn passing out of the mouth of the bay partly on previously published evidence and partly on a general impression of the structure as seen from the sea. Tyrrell (1930, p. 44) describes the rocks of Gold Harbour as belonging to the "shale-tuff" series, with "highly-sheared and mylonised tuff and tuffaceous slate" at Wirik Bay ("Verik Harbour" of Tyrrell). Possibly the junction between the two series is at Gold Harbour, since Tyrrell (1918, p. 487) describes argillaceous and arenaceous greywackes there as having a structure similar to that described by him from Royal Bay (1915, p. 826, plate XCIV, figure 1). The writer believes this to be evidence of the presence of the two cleavages described as locally present in the Sandebugten Series. Barth and Holmsen (1939, p. 57) record a limestone from Wirik Bay which suggests the presence of the Sandebugten Series there.

Having visited relatively few separate exposures of the Cumberland Bay Series, none of which are south of Royal Bay, it is difficult for the writer to estimate the distribution of the intensity of folding (and cleavage) and its relation to the contact with the Sandebugten Series, having due regard to the possible effects of plunge and to the unknown orientation of the contact. It is certain that the intensity generally increases north-eastwards. Holtedahl (1929, p. 55) describes specimens from Annenkov Island as having "a practically unaltered character". The writer found cleavage difficult to detect in the exposures west of the Ross Glacier, and the rocks along the south side of the upper part of the Ross Glacier are poorly cleaved. On the other hand the cleavage is strongly developed at Wilson Harbour. As noted above, the Cumberland Bay Series dips evenly to the south-west three miles south-south-west of the junction at Dartmouth Peak (Wordie, 1921, plate II, figure 2). While recognising the difficulty of arbitrary estimation of cleavage intensity there appears to the writer to be no obvious correspondence between the structures of either sedimentary series and the probable line of the junction between them.

The presence of an unconformable junction, over which the Cumberland Bay Series has been relatively little displaced, might demand less correspondence than if there were a thrust in a conformable series. However, there seems to be no evidence for this belief, and the intensity of folding and pressure in the country between Grytviken and Fortuna Bay seems inconsistent with any small-scale movement possibly gravitational in origin. Any suggestion of an unconformable junction should be supported by the presence of a basal conglomerate, or at least the presence of some greywacke fragments in the lower part of the Cumberland Bay Series.

If the folding of the two series took place simultaneously the junction between them would represent a plane of movement separating upper and lower blocks in which overthrusting of normal sediments in opposite directions occurred. This seems unlikely, and is certainly unusual, but the writer does not at present wish to discuss its probability in detail. At present it is difficult to favour any one of the possible structural theories which do not conflict with the scanty factual evidence available.

B. THE IGNEOUS ROCKS

Little new evidence concerning the relationship between sedimentary and igneous rocks was found, and the writer can do no more than review the present state of the problem.

The presence of bedded lava, of similar orientation to the nearby tuffs of the Cumberland Bay Series east of Undine South Harbour (p. 21) suggests that some of the lavas recorded from the south-east corner of the island may also be interbedded with the tuffs. Tyrrell (1916, p. 436) records sediments from between "Slosarczyk Bay"* (either Doubtful Bay or Smaaland Bay) and Cape Disappointment. Kohl-Larsen (1930,

p. 344) records andesite (on the authority of Chudoba) on Annenkov Island and (p. 347) a junction between igneous and sedimentary rocks at "Zuckerspitzen Bucht"* (the north arm of Newark Bay), as well as at "Johannensson Bucht"* and Undine South Harbour (Wilckens, 1947, p. 13). Holtedahl (1929, p. 56) states that Rustad found sediments occurring between lavas along the south-west coast between Undine South Harbour and Cape Disappointment. It seems probable that in the country between Drygalski Fjord and Undine South Harbour the lavas are interbedded with the tuffs, rather than intrusive into them, as suggested by Holtedahl (1929, p. 56). Ferguson (1915, p. 804) found an intrusive sill in Moränen Fjord (Tyrrell, 1915, p. 830).

The occurrence of definitely intrusive igneous rocks on a large scale is uncertain. The contact between gneissose dioritic rocks and sediments, with their foliations (or bedding?, in the sediments) parallel has been described by Holtedahl (1929, p. 56), who also obtained a true granite from Clerke Rocks (Holtedahl, 1929, p. 102; Barth and Holmsen, 1939, p. 58). No further field relations of this intrusion are known. It might, however, be assumed to be the source of the secondary mineralisation of the sediments, and therefore para-tectonic. Since it is foliated it cannot be post-tectonic, and as the secondary minerals are never broken it is not pre-tectonic. If there were two tectonic episodes the question remains, with which was it associated?

C. REGIONAL GEOLOGY

The development of opinion on the Scotia Arc is described by Wilckens (1932b and 1933) and has recently been well summarised by Wordie in a foreword to a paper by Tyrrell (1945) which contains much recent petrographic work. Recent information concerning the form of the ocean floor in the area of the Scotia Sea (Herdman, 1948) has demonstrated the connection between the constituent islands of the arc, and the mainlands of South America and Graham Land. A detailed discussion of the problem of the origin and relations of the structure is outside the scope of this report, but it may be useful to discuss some features concerning the interpretation of the geology of South Georgia.

Tilley (1935) divides the rocks of the South Orkneys into an older metamorphic series, occurring in the western islands of the group (Signy, Coronation and Larsen Islands), and a younger series of quartzo-felspathic greywackes and interbedded shales, occurring in the eastern part (Michelsen, Powell, Fredriksen and Laurie Islands). Resting unconformably upon these are much younger conglomerates. The metamorphic rocks comprise schists with hornblende, garnet, mica and albite, and are associated with marbles. Some information concerning the orientation of the greywacke beds is given by Pirie (1904, 1906 and 1913) who described the rocks as folded along north-north-west to south-south-east axes. Pirie (1913) has also recorded the presence of greywackes on the south side of Coronation Island. The general strike of the metamorphic rocks is not given, but Holtedahl (1929, p. 99) describes the rocks of Signy Island as striking north-south. Thus a hypothetical junction between the greywackes and the metamorphic rocks could be drawn parallel to the strike, and it seems likely that the two groups are parts of a single metamorphic series. A similar change in grade and petrography occurs within a comparable distance across the strike in, for example, the Dalradian rocks of the Scottish Highlands.

In sections of the greywackes of Michelsen Island and Laurie Island (Nos. 36059 and 36002 in the Harker collection, Department of Mineralogy and Petrology, Cambridge; Nos. 1095/23 and 1089/29 of Discovery Report, vol. 10—Tilley, 1935) the writer noticed two small grains of lava having flow-oriented laths of felspar with straight extinction. Petrographically these rocks are indistinguishable from those of the Sandebugten Series of South Georgia.

Pirie (1906 and 1913), also describes probable Palaeozoic fossils from the greywackes.

Tilley (1935, p. 390) has suggested a connection between the metamorphic rocks of the South Orkneys and those of the Elephant and Clarence group of the South Shetlands. The rocks of this group have been described by Wordie (1921, with petrography by Tyrrell), Tilley (1930) and Holtedahl (1929, p. 48), and the information has been summarised by Tyrell (1945, pp. 76–83). They are low-grade metamorphic rocks—garnet-hornblende-albite schists, amphibole-bearing marbles and para-amphibolites which are remarkably similar to the schists of the South Orkneys. Their general strike is parallel to the trend of the submarine ridge on which the South Shetlands lie.

* The names "Slosarczyk Bay", "Zuckerspitzen Bucht" and "Johannesson Bucht" are not accepted names. The correct names, if known, are given in brackets.

The Trinity Peninsula Series of Graham Land, previously known as the Greywacke-Shale Series (Adie, in a F.I.D.S. Scientific Report to be published later) consists of folded and cleaved sediments of greywacke facies. In three of the thin sections from this series examined by the writer there were five small grains of lava with flow-oriented laths of felspar having straight extinction. The rocks are slightly altered greywackes from the following localities:

E. 32/3—69° 30′ S., 62° 30′ W.
E. 27/2—South side Mason Inlet, 73° 10′ S., 60° 42′ W.
D705/7—Just inland from Crystal Hill 63° 37′ S., 57° 46′ W.

The Trinity Peninsula Series is certainly pre-Jurassic, as it is overlain by the Jurassic sediments of Mount Flora at Hope Bay. Plants collected from this series in the Hope Bay area by W. N. Croft showed it to be late Palaeozoic in age.*

This close petrographic similarity suggests the correlation of the Trinity Peninsula Series with the greywackes of the South Orkneys and Sandebugten Series of South Georgia. It is also suggested that the metamorphic rocks of the South Orkneys and the South Shetlands form part of the same series. The correlation between the greywackes of the South Orkneys and South Georgia has already been suggested by Tyrrell (1930, p. 53).

Such a correlation supposes a geological connection between the two topographically distinct ridges (Herdman, 1948) of which the South Orkneys and the South Shetlands form parts, and leads to a consideration of the actual structure of the ridge, or ridges, of the arc and the nature of the relationship between topography and geology. So far this has only been treated briefly by Holtedahl (1929, p. 111) and Joyce (1952). It seems that much evidence for the solution of the problem lies in the investigation of the individual islands of the Scotia Arc.

IV. SUMMARY AND CONCLUSIONS

THE following summary is a brief recapitulation of the results to be inferred from the discussion in Section III.

The sedimentary rocks of South Georgia are divisible into two groups.

(i) The rocks in the area between Cumberland Bay and Royal Bay consist of well cleaved grits and shales of greywacke facies. They are strongly folded, the axial planes of the folds dipping steeply to the north-north-east. Correlation with other parts of the Scotia Arc suggests a Palaeozoic age. The name Sandebugten Series is proposed for this group.

(ii) The remaining sediments consist predominantly of tuffs of greywacke facies. In the north-east they are strongly cleaved and overfolded from the south-west, but towards the south-west the folding rapidly becomes less intense, the beds dipping evenly to the south-west. Fossils from the upper part of this series are of Aptian age. The name Cumberland Bay Series is retained for this group.

The junction between the two series is probably tectonic, though the Cumberland Bay Series may originally have lain unconformably on the Sandebugten Series.

The igneous rocks are also divisible into two groups:

(i) Interbedded with the tuffs of the upper part of the Cumberland Bay Series are spilitic lavas, sometimes pillow-form.

(ii) A foliated grano-diorite intrusion probably represents a late plutonic rock associated with the metasomatic recrystallisation and alteration found throughout the sediments and lavas.

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* Verbal communication from R. J. Adie.—See also footnote p. 393, Adie 1952.

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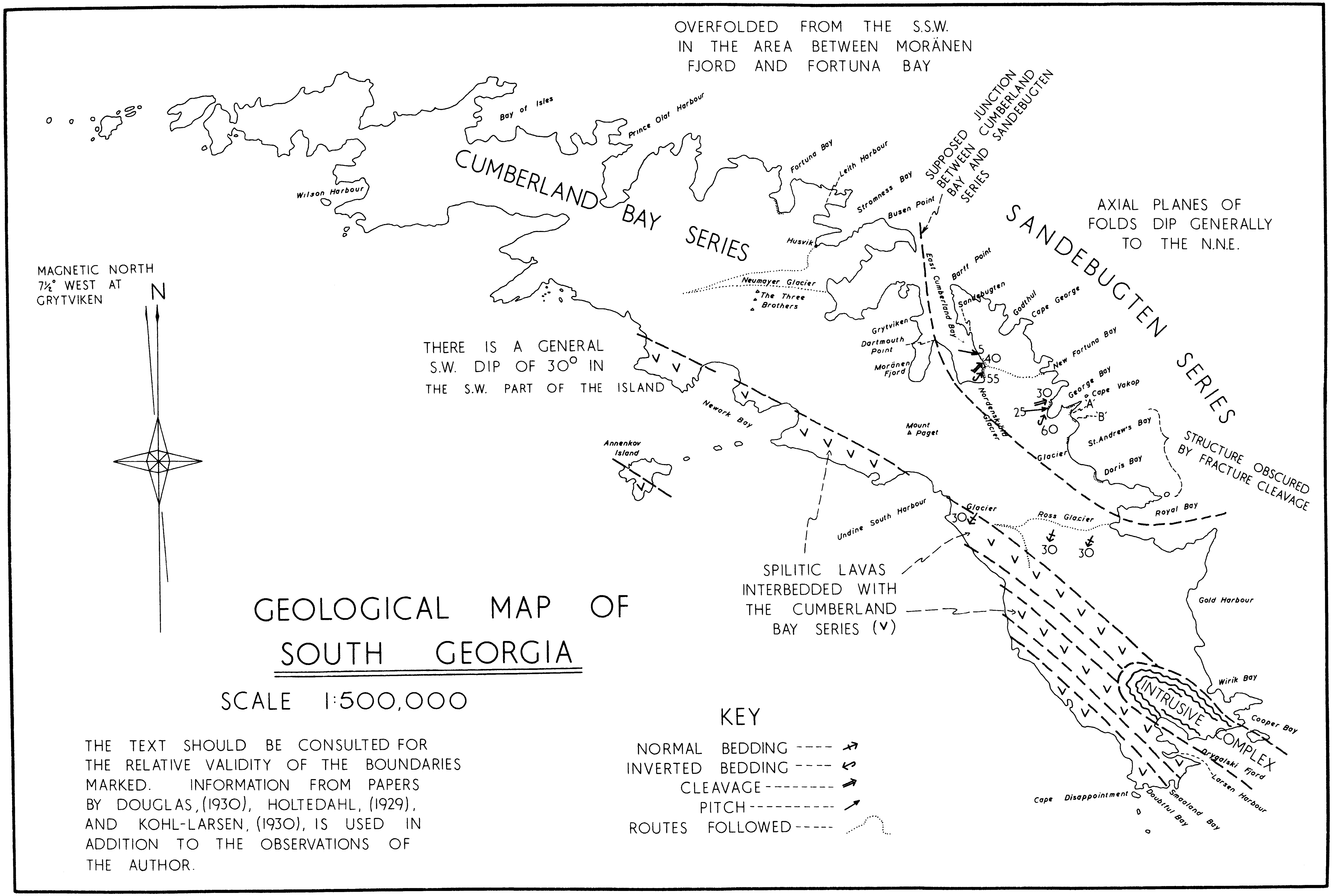

GEOLOGICAL MAP OF SOUTH GEORGIA

SCALE 1:500,000

THE TEXT SHOULD BE CONSULTED FOR THE RELATIVE VALIDITY OF THE BOUNDARIES MARKED. INFORMATION FROM PAPERS BY DOUGLAS, (1930), HOLTEDAHL, (1929), AND KOHL-LARSEN, (1930), IS USED IN ADDITION TO THE OBSERVATIONS OF THE AUTHOR.

FIGURE 1

Cumberland Bay Series dipping evenly to the south-west in the cliffs along the south side of the Ross Glacier. Photograph taken from below the "G" in "Ross Glacier" (end folding map) looking south-east.

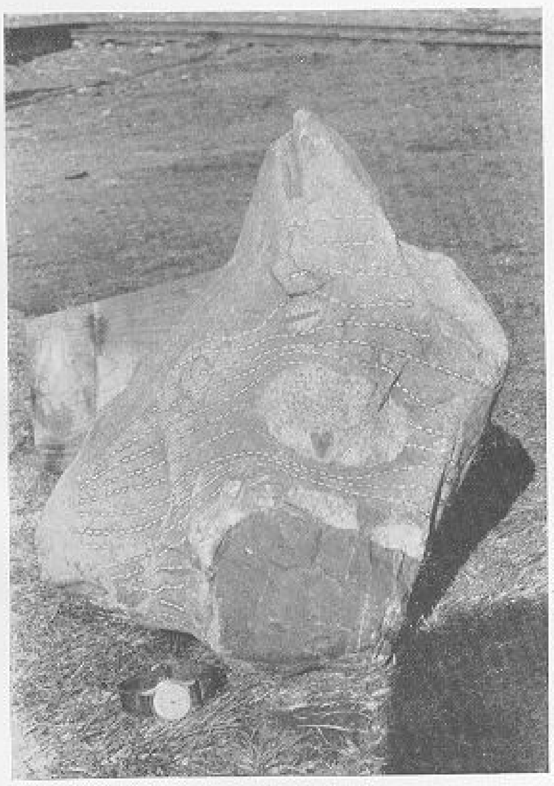

FIGURE 2

Lines of grain flattening, picked out in white paint, "flowing" around dark tuff fragments and their surrounding aureoles. The formation of the aureoles is evidently pre-tectonic. Beach boulder at Grytviken.

BOTTOM

TOP

FIGURE 3

Pillow lava at the south side of the glacier flowing westward into Undine South Harbour, one and a half miles from the snout. The planes of flow of the lava run from top left to bottom right. The area photographed is approximately 3 ft. by 4 ft.

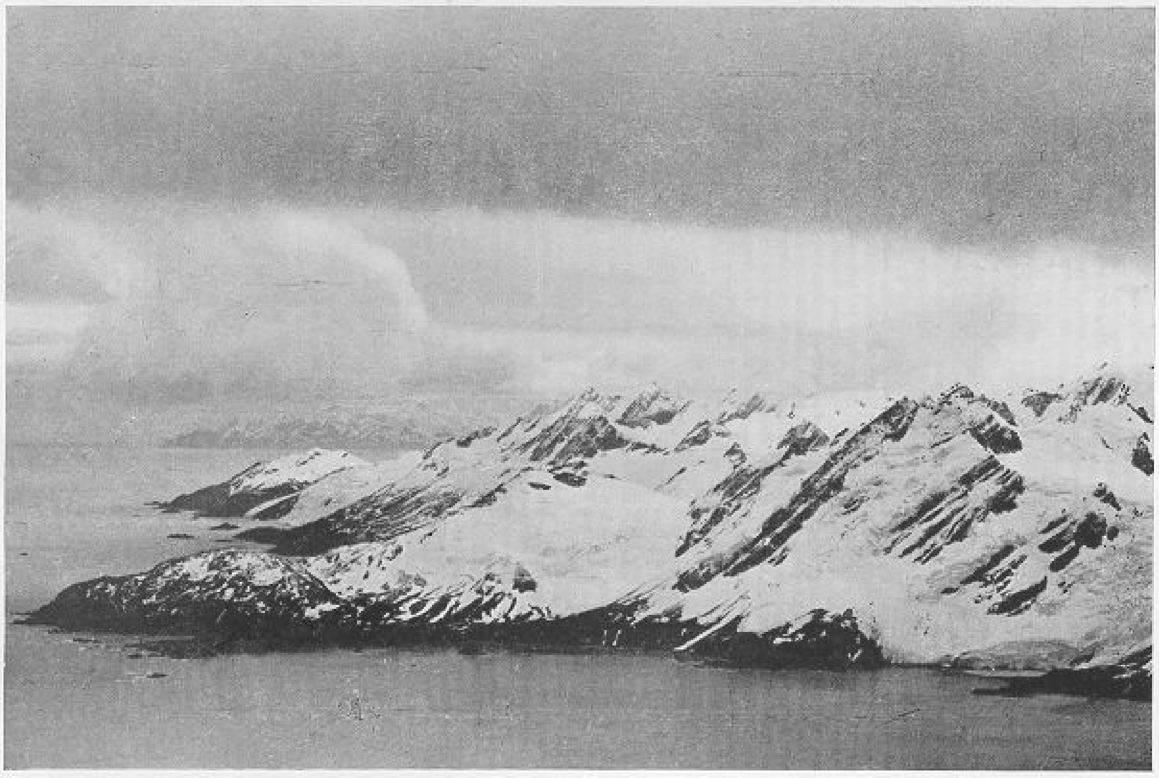

FIGURE 1

Lavas of the Cumberland Bay Series dipping evenly to the south-west. Photograph taken from the centre of the "O" in the figure "30" by Undine South Harbour (end folding map), looking north-west. These rocks were not visited and continuity along the strike is assumed.

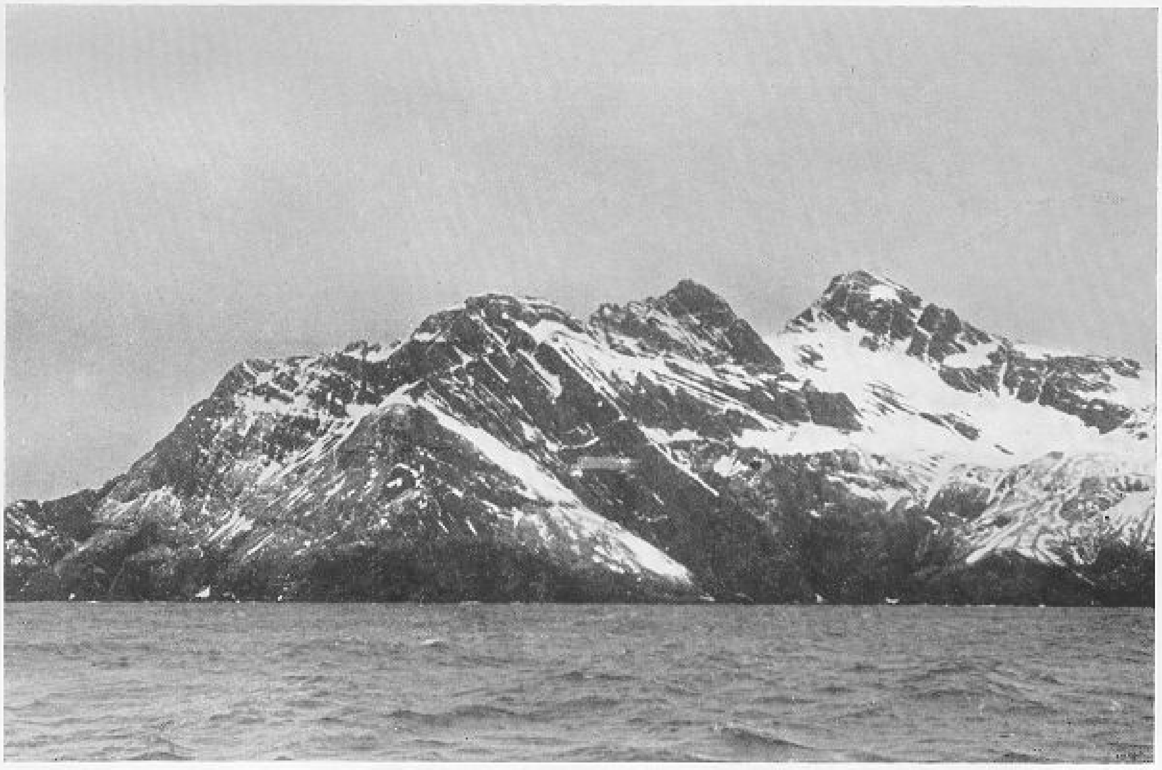

FIGURE 2

Folding in the Cumberland Bay Series near Busen Point. Photograph taken from the "O" in "Stromness Bay" (end folding map), looking south-east.