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SOME INVESTIGATIONS INTO THE GEOLOGY AND PETROGRAPHY OF DRONNING LOUISE LAND, N.E. GREENLAND

BY

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WITH 21 FIGURES IN THE TEXT
AND 12 PLATES

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INTRODUCTION

Some time has passed since the writer published a general account of the geology of Dronning Louise Land (PEACOCK 1956a). The present paper, which is largely extracted from a thesis presented for the degree of Ph. D. in the University of Durham, deals with the petrography and petrology of some of the material brought back from Greenland by the writer and his co-geologist, P. J. WYLLIE. The results are discussed in the light of recent work in other parts of east and north Greenland.

The work of KOCH and WEGENER in Dronning Louise Land has already been referred to (KOCH and WEGENER 1930, p. 106, PEACOCK 1956a p. 8). At the time they crossed the Greenland ice-sheet in 1913, little was known about the geology of East Greenland. Between the two world wars, knowledge was greatly advanced owing to the activities of the Cambridge East Greenland Expedition (e. g. WORDIE 1927, WORDIE and WHITTARD 1930), and the numerous parties under the leadership fo Dr. LAUGE KOCH (KOCH 1955). It was established that a Caledonian mountain chain extended along the east coast from about lat. 70° as far north as lat. 75, and by implication to Kronprins Christian Land. In the south, the geosynclinal Eleanore Bay Formation, about 40,000 feet thick, was overlain by thinner Lower Palaeozoic. The extent to which the vast gneiss areas here were actually metamorphosed Eleanore Bay Formation was in doubt: at any rate the metamorphic rocks in the Dove Bugt area and northward were regarded as Archaean. In Kronprins Christian Land, Caledonian folding involving Silurian rocks was known (NIELSEN 1941).

Since the second world war, especially in the last seven years, geological mapping under the direction of Dr. LAUGE KOCH has been pressed vigorously, using the new topographical maps of the Danish Geodetic Institute. At the time of sailing of the British North Greenland Expedition, little of this new work was published, but it has since been coming out in a steady stream. In 1955, reconnaissance work was pushed forward to lat. 76°, and a geologist, John HALLER, visited Britannia Sø, and flew over Dronning Louise Land. Work farther south has indicated that no Archaean Gneiss is present in the Caledonian fold mountains. In the words of HALLER (1953, p. 190): "The several stratigraphical subdivisions, recognised in the Eleanore Bay Formation, can be traced also in the gneisses, schists, and marbles of the "Central Metamorphic Complex". The crystalline rocks of sedimentary origin represent members of the Groenlandium, metamorphosed and metasomatically altered during the Caledonian Orogeny," In Kronprins Christian Land, the equivalents of the Eleanore Bay Formation have been observed overlying the Thule Formation disconformably, and the western margin of the geosyncline observed—a margin hidden beneath the inland ice in East Greenland (FRÄNKL 1954). The geosynclinal sediments have been thrust westwards over the foreland, and subjected to low-grade metamorphism. Gneiss, regarded as Archaean, is pressed against the folded Thule Formation east of the thrust line (FRÄNKL, op. cit.). This gneiss, however, has not yet been investigated in the field.

Our fieldwork in Dronning Louise Land seemed at first to support the original idea that all the gneisses were indeed Archaean. In the west the red quartzites of the Trekant Series rest with great unconformity on metamorphic rocks, and these quartzites in turn are overlain unconformably by the Zebra Series, a thin series of grits, shales and quartzites (Plate 6). Thus the relationship of the sediments discovered by WEGENER to the basement rocks was found. I provisionally subdivided the metamorphic basement into the Western Gneisses, and the Eastern Schists and Gneisses; the latter mainly paragneisses, and the former "orthogneisses". It was evident that the Western Gneisses and associated intrusions had suffered retrograde metamorphism in all but a small area in the southwest, but this could easily be explained as the expression of a N.N.E.-fold system existing in the Trekant and Zebra Series. The Eastern Schists and Gneisses had not been affected by this diaphthoresis. I regarded a thrust at Durham Klippe (PEACOCK 1956a, p. 30) as possibly a local phenomenon only, since our fieldwork disclosed no further important dislocations.

The idea of an Archaean age persisted until the end of 1954, and seemed the best interpretation, although I had by this time discovered evidence of blastopsammitic structure in a quartzite from the Britannia Sø Group, and the existence of well-preserved current bedding in these rocks was suspicious. However, WYLLIE has always believed that the Durham Klippe dislocation and its northward continuation to Monumentet was of considerable importance. A consideration of all the petrological data has tipped the scales towards the idea of a "Caledonian" age for the Eastern Schists and Gneisses. The complete evidence also sugests that there is a considerable dislocation between east and west Dronning Louise Land. These matters are discussed in detail below.

The methods of research have been mainly petrographical, and most of the common techniques have been employed. Since the feldspars are of considerable interest, determinations have been made from the refractive indices of cleavage flakes in oils using sodium light, this being recommended by EMMONS 1953, e. g. p. 1. Where a measurement has not been made in oils owing to inclusions or alteration, recourse has been made to Universal Stage methods, as outlined by CHUDOBA and KENNEDY (1933). In some cases, staining has been carried out to discriminate potash feldspar (KEITH, 1939, p. 561).

Petrofabric studies have been made on a number of specimens, but the results have not justified the work done. The objectives in carrying out this work were (a) to see if a gradual change took place in the petrofabric diagrams from west to east, and (b) to see if petrofabrics would help to solve some structural problems in the Britannia Sø Area. The great variability in the diagrams makes interpretation speculative, and in Dronning Louise Land at any rate any such studies will have to be made in small areas on a more intensive scale.

The spot chemical analyses of the five rocks have been carried out using modifications of the methods of Shapiro and Brannock (1956). However, the silica determinations, in spite of repeated efforts over a long period of time, are only accurate to plus or minus one percent. Alumina has finally been determined using a normal gravimetric method. The results for the other fractions compare reasonably well with those achieved by SHAPIRO and BRANNOCK, though lime and magnesia are probably a little high. It should be emphasised that these analyses do not compare in accuracy with those obtained by classical methods.

A brief description of the topography of Dronning Louise Land was given in a previous publication (PEACOCK 1956a). In view of this and the much more detailed morphological account published by LISTER and WYLLIE (1957), further description is omitted.

London, January 1957.

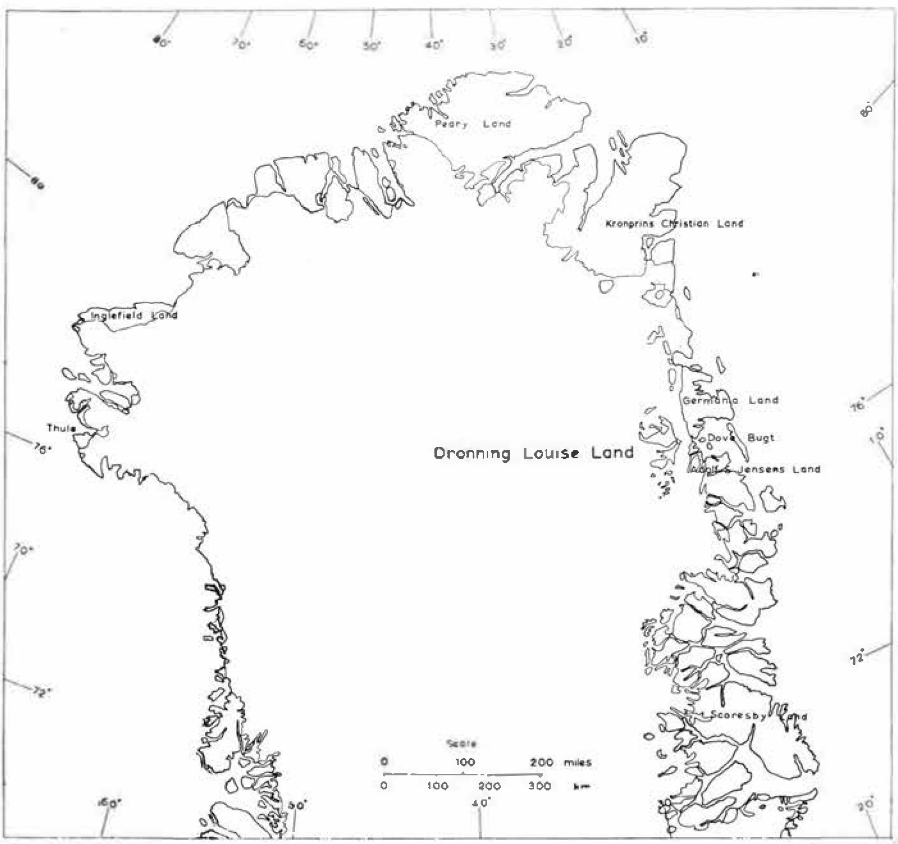

Fig. 1. Outline map of North Greenland.

SYNOPSIS OF STRUCTURE AND STRATIGRAPHY

The brief account given below partly foreshadows the results of detailed studies in succeeding chapters. For field details the reader is referred to previous papers (PEACOCK 1956a, 1956b).

1. West Dronning Louise Land.

Stratigraphy.

The dissected mountain and plateau area of the west is built of three formations, (a) the Western Gneisses, (b) the Trekant Series, and (c) the Zebra Series. Unconformities are present below (b) and (c). The Western Gneisses, Trekant Series, and possibly the Zebra Series are cut by minor intrusions. These are discussed under (d) below.

(a) The Western Gneisses. This is an exceedingly complex group of mainly acid gneisses derived in part from sediments and in part from rocks ranging from granite to granidorite. Subsidiary basic gneisses occur in the south. Two periods of metamorphism can be recognised. We can therefore subdivide the Western Gneisses into (1) rocks of the older metamorphism (2) intrusive rocks associated with the older metamorphism, and (3) rocks of the younger metamorphism (Table 1).

(1) The rocks of the older metamorphism, preserved mainly in S.W. Dronning Louise Land, comprise granitic gneisses and banded gneisses for the most part, with subsidiary basic gneisses, schists, and quartzites. It is difficult to generalize about the distribution of these rock types. Banded gneisses, with bands marked by more or less biotite, may be seen to advantage on the upper Budolfi Isstrøm; granitic gneisses are ubiquitous. The basic gneiss generally shows sharp boundaries gainst surrounding rocks, and there seem to be two types of occurrence. In the first, the basic gneiss is seen as flat bands of lenticles alternating with granitic rocks. In the second, very thick bands of the dark gneiss are cut by irregularly anastomosing veins of white granite or pegmatite. From a distance, the thick dark bands may simulate basic intrusions

Table 1. Classification of the Western Gneisses.

Rocks associated with the older metamorphism	Rocks of the younger ("Caledonian") metamorphism	
Paragneisses Banded gneisses (in part) Quartzite of Dickens Bjerg Schists (Curie Klippe)	Banded augen-gneisses (Eigil Sø) Quartzite (Regnbueklippe)	Crush Rocks
Basic gneisses (Budolfi Isstrøm)	Saussuritised basic gneiss (mid-Budolfi Isstrøm)	
Acid rocks of metasomatic or igneous origin Banded gneisses (in part) Porphyroblastic gneiss (Kamæleon)	Banded augen-gneisses	
Late- or post-tectonic intrusions Granite (Curie Klippe) Grandiorite (Cloos Klippe, Thomson Klippe) Adamellite (Cloos Klippe, St. Andrews Klippe) Granites associated with basic gneisses	Mortar-gneiss (Trefork Gletscher) Augen-gneisses (central Dronning Louise Land)	

(fig. 2). Quartzites are confined to thin bands at Dickens Bjerg and Regnbueklippe, and schists to Curie Klippe, and perhaps Thomson Klippe.

(2) The intrusive rocks associated with the older metamorphism are well seen in the extreme southwest (Wyllie's notes), at St. Andrews Klippe, and Cloos Klippe. At St. Andrews Klippe, a large mass of hornblende adamellite is intruded into a gneissic granite, and at Cloos Klippe a somewhat different adamellite is intruded into an earlier granodiorite the relations of which to the country rock are not clear—Cloos Klippe is an "enclave" of structurally unaltered rock in an area strongly affected by the younger metamorphism. Other intrusive rocks occur at Curie Klippe and Thomson Klippe. Pegmatite veins are widespread.

(3) The rocks of the younger metamorphism are widely-distributed over north Dronning Louise Land, and the easterly part of the outcrop in the south. They comprise augen-gneisses and mortar gneisses derived by the metamorphism of granitic gneisses, banded augen-gneisses, and saussuritized basic gneiss. Of these, augen-gneisses of various sorts are by far the most important, varying from very coarse material with a crude schistosity to schistose, almost phyllonitic rocks in crush bands.

(b) The Trekant Series. This is a series of continental red beds which overlies the Western Gneisses with great unconformity. The basal strata

Fig. 2. Basic and acid gneisses at the west end of Dickens Bjerg. Photo P. J. WYLLIE.

are breccias with fragments of the underlying gneiss, or conglomerates (e. g. Trekanten, Plate 11), the whole usually totalling less than 20 metres. In the south, for instance at Kaldbakur and Helgoland, only one band of fragmental material occurs, but further north at Trekanten and Newton Klippe, there may be several horizons. The overlying beds are quartzites which are dominantly red, but sometimes grey, green, or yellow. They are current-bedded, and some horizons are ripple-marked. In rare interbedded thin red or green mudstones, beautifully preserved desiccation cracks can be seen. While at Helgoland there are only 340 metres of Trekant Series, at Trekanten the thickness exceeds 500 metres, and there may be greater thickness as in the fold range of N.W. Dronning Louise Land.

(c) The Zebra Series. In contrast to the Trekant Series which outcrops, albeit patchily, from Ymer Nunataker in the north to the extreme south of Dronning Louise Land, the Zebra Series seems to be confined to isolated exposures in the southwest nunataks, and somewhat larger outcrops in the northwest of the country. The total measured thickness at Zebra Klippe is 100 metres, which is rather more than that remaining at Helgoland, and probably a little less than the maximum thickness in the fold range of the northwest. In lithology it is quite distinct from the Trekant Series, comprising beds of current-bedded white and purple grit and dark to light yellow-brown quartzite, alternating with green and purple-black mudstones or shales. At Suzanne Nunatak the rocks marked as ?BS (PEACOCK 1956a, Plate 1), which contain limestone, may well be rather higher beds in the Zebra Series. In the south, the Series appears conformable on the Trekant Series, but it is unconformable further north, overstepping onto the gneiss in places e. g. on the upper Admiralty Gletscher.

(d) Minor Intrusions. Three sets of minor intrusions have been found, these being (1) quartz-gabbro, (2) dykes of dioritic affinities, and (3) serpentine.

(1) The quartz-gabbro intrusions are by far the most important. Though true sills and dykes occur, the intrusions are often very irregular in attitude, fluctuating in dip and strike over short distances. Thus the terms "dyke-like" or "sill-like" are perhaps better from a descriptive point of view. The thickness of individual intrusions may reach 100 metres. Many of the dyke- or sill-like bodies show columnar jointing, and sometimes coarser and finer bands can be recognised. The rock itself is dark green or black when fresh, and weathers red or green. A grain size of 1–2 mm is usual, but apart from the variations noted above, vaguely-defined pegmatitic patches may occur.

Eastwards and north-eastwards from southwest Dronning Louise Land, lighter green colours and a greasy, yellowish appearance of the feldspars is associated with low-grade metamorphism. Among these intrusions, varieties with porphyritic feldspars or ophitic textures are preserved, but the margins are often schistose.

The quartz-gabbros are distributed throughout west Dronning Louise Land, penetrating the Western Gneisses, Trekant Series, and perhaps the Zebra Series. Cross-cutting dykes occur at three or four points e. g. at Zebra Klippe in the north, and St. Andrews Klippe in the south. It is not possible to say that these dykes were intruded at two distinct periods, as suggested by PEACOCK (1956a) nor is it possible to suggest the time interval between earlier and later intrusions. At Zebra Klippe, however, a later dyke has a chilled margin against an earlier intrusion.

(2) Dykes of dioritic affinities seem to be confined to north Dronning Louise Land, particularly the upper Admiralty Gletscher. They are dark, slightly schistose, and narrow, sometimes with traces of porphyritic feldspars. At Trekanten, dykes of this type are cut off by the unconformable Trekant Series, and at no place have they been observed to cut sedimentary rocks.

(3) At Regnbueklippe, there is a dyke of olivine-bearing serpentine, and similar rocks occur in the scree at other points in Dronning Louise Land. The relationship with a neighbouring dyke or quartz-gabbro is uncertain, and it is not known whether such dykes penetrate the sedimentary rocks.

Structure.

Three structural divisions can be recognised (Plate 7). They are as follows:

(a) An unfolded zone of sedimentary rocks. Unfolded strata are practically confined to the southwest nunatak zone and the string of outlying nunataks running south from Farvel Nunatak. These strata dip gently west.

(b) A N.N.E. fold system in N.W. Dronning Louise Land.

1. The Splinten Syncline. A major syncline in the Trekant Series can be traced from Splinten S.S.W. to within a few miles of the Admiralty Gletscher. The axis appears to rise southwards. A synclinal patch of sediments on the north side of the Admiralty Gletscher on almost the same line may represent a down-warping of the same fold axis. It is not quite certain to what extent the Zebra Series takes part in this structure, since although minor crumples in Zebra quartzites are on N.N.E. lines, the Series where it outcrops on Prins Axel Nunatak seems to step across what appears to be quite a large syncline in the Trekant Series. The structures on Prins Axel Nunatak do not, however, seem to appear on the south side of the glacier.

2. The Zebra Anticline. Rocks of the Trekant Series outcropping at Splinten reappear on the other side of the glacier (see map) in an anticlinal arch. Though not well defined at Zebra Klippe itself, this anticline is well seen in the mountains to the south and the axis appears to rise southwards like that of the Splinten Syncline. The west limb of the anticline is preserved as far south as Prinsessen.

No other fold structures can be traced for any distance with certainty in the sediments. N.N.E. folding occurs on Ymer Nunatak (WYLLIE's notes) and at Trekanten, and the various patches of sediments to the north and south of the Admiralty Gletscher are often almost flat-lying, but with sharply-upturned monoclinal limbs.

(c) A zone of easterly-dipping Western Gneisses. In the southern half of Dronning Louise Land, and to a lesser extent a far north as Admiralty Gletscher, the prevailing dip of the various types of gneiss is towards the east or southeast. Linear structures are poorly developed in the Western Gneisses here, and their significance obscure. Crush belts occur in the intrusive rocks of St. Andrews Klippe and Cloos Klippe, such belts running parallel to the planar elements in surrounding gneisses—striking N.N.E.—and also at an angle to this direction. It is reasonable to suppose that this area of Western Gneisses was formerly covered by the N.B.E. fold system preserved further north.

2. East Dronning Louise Land.

Stratigraphy.

The lower ground here is formed largely of paraschists and paragneisses apparently underlain in the north by a group with important quartzites and limestones. Thus two divisions can be recognized (a) the Eastern Schists and Gneisses, and (b) the Britannia Sø Group which is distinct from the Eastern Schists and Gneisses proper.

(a) The Eastern Schists and Gneisses. The leading rock types are schists in which plagioclase, quartz, biotite, and epidote play an important part, while green hornblende, microcline, muscovite, calcite, chlorite, and garnet are present in some beds. Calc-schists do not seem to be of great importance, and pure calcite-phlogopite limestones are very rare. Likewise quartzites and quartz-muscovite schists are uncommon. The schists are interbedded with gneisses which contain a higher proportion of feldspar, and in places, notably the Eastern half of Britannia Sø and parts of the lower Borgjøkel, there is granitic veining and development of porphyroblastic gneisses (see p. 72). Associated with the schists at Timeglasset and the lower Budolfi Isstrøm are almost concordant bands of white gneissose pegmatite.

Basic rocks were only recorded in one instance on the lower Budolfi Isstrøm, but cross-cutting or concordant intrusions of metagabbro and amphibolite occur further north in the cliffs flanking the lower Borgjøkel, and concordant bands of hornblendic schists are common in parts of the Britannia Sø area.

The thickness of the Eastern Schists and Gneisses is a matter of speculation, since at the best exposure (Durham Klippe), the base is cut off by a thrust. There is probably about 3,000 m of easterly-dipping schists here, though this figure may be too high because of possible repetition of beds, or too low as a guide to the total column because neither the top nor the bottom of the succession is seen.

(b) The Britannia Sø Group. The main features of this group are (1) the occurrence of thick beds of quartzite, often red-stained. Such quartzites often retain current-bedding. (2) Beds of quartz-magnetite rock. These are usually thin, less than 1 m in thickness, and may be interbedded with quartzites or schists. (3) Occurrence of metamorphosed limestones reaching many tens of metres in thickness (though the thickness of any one bed along the strike probably varies greatly owing to the movements during metamorphism). The Britannia Sø Group also contains beds of schists which appear to be more micaceous (or chloritic) than is usual in the Eastern Schists and Gneisses. The Group outcrops east of the Britannia Gletscher, in a narrow strip, and in the mountains southwest of Britannia Sø. What may be the base of the Group is seen at the snout of the Admiralty Gletscher, where quartzites overlie (in true succession) augen-gneisses possibly belonging to the Western Gneisses (Peacock 1956b, p. 210). On the east wall of the Britannia Gletscher, quartzites of the Britannia Sø Group are overlain by Eastern Schists and Gneisses, though it is not possible to say that the succession is not inverted. The hornblendic intrusions found in the Eastern Schist and Gneisses also cut the rocks of the Britannia Sø Group. Gneisses, which are undifferentiated on the sketch-map, but probably belonging to the Western Gneisses, outcrop S.W. of Gultop Gletscher. They are augen-gneisses, with occasional bands of dark, garnetiferous schists, and intrusions of hornblende-schist.

Structure.

Most of the area has a N.N.W.-running fold system, but N.N.E. or N.E. running folds occur in the extreme N.E. and also in the extreme east in places (as shown by aerial photographs). In the N.N.W. system, open folds can be recognised, sometimes with steep limbs, and many of the minor structures (corrugations, lineation) run parallel to these. In many places, minor folds with eastward-dipping axial planes may be observed. The N.N.E. fold system in the northeast is recognised by corrugations and lineations running in that direction.

3. Relations between east and West Dronning Louise Land.

At Durham Klippe, a thrust separates Eastern Schists and Gneisses from drag-folded quartzite and augen-gneisses. Elsewhere, the boundary between Eastern Schists and Gneisses and Western Gneisses has not been observed, but on stratigraphical and petrological evidence there may be a dislocation (p. 116).

THE WESTERN GNEISSES

This rock group outcrops in the western half of Dronning Louise Land from Ymer Nunatak in the north to at least as far south as the A.B. Drachmann Gletscher. In brief, the Western Gneisses may be described as a complex of banded granitic gneisses, augen-gneisses, and subsidiary basis gneisses, with intrusive rocks near adamellite in composition. Quartzites and schists to which an undoubted sedimentary origin can be assigned are rare. There is evidence of two periods of metamorphism; an older metamorphism of high grade, and a younger metamorphism of much lower, but eastwardly-increasing intensity.

The most extensive outcrops of these rocks are in S.W. Dronning Louise Land. A cross-section in the latitude of the Budolfi Isstrøm has the appearance of a gneiss dome, with even-grained rocks in the west followed to the east by steeply eastward-dipping augen-gneisses. This idea of a gneiss dome was used as a working hypothesis during the initial stages of research, but has been rejected in the light of evidence of increasing eastward metamorphism in this and other rock groups. The apparent mantle of augen-gneisses is, in fact, a phenomenon due largely to the younger metamorphism, though augen-gneisses (either due to cataclasis of porphyroblastic growth) may have been formed also during the older metamorphism and subsequent magmatic activity. There is insufficient evidence to decide what proportion of the oldest metamorphic rocks is of original igneous origin and what proportion (if any) represents original supra-crustal rocks.

S. W. Dronning Louise Land.

The broad outcrop of Western Gneisses cut through by the Budolfi Isstrøm shows the most complete transition between unaltered Western Gneisses and those affected by subsequent metamorphism, and the rocks here are described in detail.

A. PETROGRAPHY

1. Coarse-grained rocks of granite-like aspect.

(a) Hornblende-adamellite.

Much of Kamæleon and a large part of St. Andrews Klippe are formed of this rock. At both places it appears to have been intruded into pre-existing rocks, and it is probable that Kamæleon and St. Andrews Klippe are eroded from the same body. In hand specimen, the adamellite is notable on account of its porphyritic grey feldspars reaching up to 3 cm long, smaller quartzes, and clusters of dark hornblende and biotite. Where slightly weathered, there is a distinctive orange staining on some of the feldspars. A planar structure due to aligning of the feldspars is evident at some points, and at St. Andrews Klippe gradations occur to augen-gneiss with cataclastic structures. Thus the rock is a convenient datum in the Western Gneisses, being intruded into pre-existing rocks on the one hand, and being affected by the later metamorphism on the other. The rock showing the nearest approach to what was probably the original composition is that at Kamæleon. A slice from here (no. 191) shows approximately equal quantities of plagioclase, oligoclase and microcline (60 per cent) with hornblende, biotite quartz and accessory apatite and magnetite. The texture is xenomorphic granular.

Both the feldspars occur in very large crystals. The microcline is often fresh, with almost universal braid perthite in which the plagioclase shows strong cryptocrystalline alteration. In contrast, the plagioclase is usually strongly altered in patches or along cleavage cracks, though a little antiperthitic microcline remains unaltered. In places the alteration is to sericite, but is more usually in the form of brown cryptocrystalline aggregates. The minerals are markedly anhedral in many cases, but there is a tendency for the plagioclase to show form against microcline. Quartz-plagioclase myrmekitic growths occur at several points adjoining large microclines.

The quartz also occurs as very large grains, but with boundaries often rounded and embayed. Undulose extinction is slight to marked and widely-spaced cracks occur filled with a red-brown cryptocrystalline mineral, the cracks extending into the surrounding feldspar.

Hornblende and biotite occur in clusters of anhedral crystals, sometimes partly intergrown, up to 2 mm across. They are usually fresh, but the former shows slight alteration to pale green chlorite. Textural features of some interest are the sometimes almost myrmekitic intergrowths with small quartz grains, and frequent inclusions of quartz, apatite, and magnetite. Associated with the hornblende are a few large patches of fibrous colourless amphibole (tremolite), which may be another replacement product. Pleochroic halos in both hornblende and biotite are caused by small diamand-shaped zircons. Some optical properties of the hornblende, biotite, and plagioclase are as follows:—

Hornblende: α straw-yellow β green brown, γ green-brown. (–) 2 V very large.
Biotite: α pale brown, γ deep red-brown. (–) 2 V 0–10°, Nβ 1.67. Very small acicular inclusions at 60° in places.
Plagioclase: Extinction angles in section $\perp$ (010) very small. Refractive indices near balsam. Probably oligoclase.

A specimen from St. Andrews Klippe (no. 146) is mineralogically very similar to no. 191, but contains a greater proportion of mafic minerals and microcline. The feldspars, however, are strongly strain-shadowed, and contain cracks filled with fine granular quartz. Another feature is the development of extensive reaction rims around the biotite-hornblende-magnetite clusters, the rims overlapping into neighbouring minerals. Under high power, the pale reddish-brown material of which the rims are composed is resolved as tiny wisps and laths with parallel extinction, these probably being biotite. At one point, hornblende is partially replaced by epidote, quartz, and pale phlogopitic biotite. In this rock, the apatite-magnetite inclusions reach up to $^1/_2$ mm across, and can also be seen in the tremolite patches.

(b) Gneissic granite from St. Andrews Klippe.

The hornblende adamellite described above is intruded into a light grey slightly foliated granite composed of grey feldspar, quartz, and biotite, the latter occurring as thin lenticles 1 cm long. The foliation here is truncated by the boundary of the hornblende-adamellite.

This gneissic granite is itself intrusive into augen-gneiss, a rock into which it also appears to grade. Unfortunately, reconnaissance geology did not show the nature of its boundaries with other rock types, but it is mineralogically similar to the banded gneisses, as will appear in the subsequent descriptions.

In thin section (no. 144), the rock is seen to be a xenomorphic aggregate of microcline-microperthite, albite-oligoclase (An_8), quartz, sericite, and biotite, partly broken down by subsequent granulation. The potash feldspar, which forms about half the slice, shows characteristic twinning, and one or two sets of perthite braids in which albite twinning can sometimes be made out. Incipient granulation occurs around the margins, and some twins are fractured and warped. Plagioclase likewise shows signs of cataclasis, and a greater degree of alteration to sericite and fine epidote, while the quartz is considerably broken down into trails, with packet-structure in larger grains. The biotite is in the form of medium- to fine-grained laths arranged in irregular clumps (pleochroic red-brown to straw-yellow), and is often associated in winding sub-parallel trails with sericite, granular quartz (0.3 mm), feldspar, and epidote. The quartz forms about a third of the rock, and plagioclase 10 percent.

From this description it must be concluded that the planar structure visible in hand specimen is partly due to cataclasis, a cataclasis which can be matched in the St. Andrews Klippe specimen of adamellite. Since the planar structure is cut by the margin of the adamellite, it must be a composite feature.

2. Granitic rocks assosiated with basis gneisses.

Four specimens were obtained, these being nos. 174, 150, 469 and 398. The first two are associated with the basic gneiss at nunatak 3 (fig. 3); no. 469 was collected by WYLLIE from the west end of Dickens Bjerg, and no. 398 from the neighbourhood of the basic gneisses midway between Durham Klippe and St. Andrews Klippe.

No. 174 is a dark grey porphyritic microgranite with conspicuous pink feldspar both in the groundmass and as insets (2 cm). In section, highly sericitised plagioclase and microcline (70 per cent), quartz (20 per cent), epidote and chlorite, show a xenomorphic granular texture with slight cataclasis. The proportions of the two feldspars are difficult to make out: refractive index tests show that the plagioclase is about An_{10}, and unlike the microcline, it may contain fine-grained epidote inclusions. The epidote, apart from the inclusions, is colourless, and often occurs in association with less-strained quartz, while the clusters of small chlorite flakes (pleochroic dark to pale green, length slow) add to the dark appearance of the rock in the field.

A second light grey slightly foliated rock outcrops further up the small ridge, separating two outcrops of basic gneiss (no. 150). The rock is composed largely of medium- to coarse-grained white feldspar and quartz, the latter arranged in small parallel lenticles. The feldspars, which include both plagioclase (An_{17}) and smaller quantities of untwinned alkali feldspar, again show extensive cryptocrystalline alteration in which sericite and epidote can also be recognized. Braid perthite is present, and the plagioclase sometimes shows myrmekitic growths with quartz. Quartz forms up to half the rock, occurring as medium-grained anhedral forms among the feldspar, and very coarse-grained lenticles, often almost unstrained. A pale green variety of chlorite occurs in clusters of small laths, which are sometimes radiating.

The rock from Dickens Bjerg (no. 469) is similar. In this plagioclase (1.5 mm) is dominant, followed by quartz (1.5 mm), and microcline (0.5 mm), while a little skeletal iron ore occurs in addition to small amounts of chlorite and epidote.

No. 398 from the middle Budolfi has been affected by the younger metamorphism, and though in thin section it retains much of its original coarse-grained xenomorphic granular texture, at a number of points the minerals are separated by recrystallised quartz and a little phlogopitic biotite. The plagioclase is largely replaced by muscovite, biotite, and epidote, but shows clear rims against microcline, which is fresh excepting for the braid perthite. The quartz shows pronounced packet-structure and granulation.

The contacts in the regions from which nos. 174, 150, and 469 were collected (upper Budolfi Isstrøm) were not observed. The rocks represented by no. 398, (middle Budolfi Isstrøm) are, however, seen to be intrusive into the augen-gneisses. In view of this, it may be tentatively suggested that the material represented by all four rocks is younger than the foliation developed during the older metamorphism.

The mineralogy of all four rocks is not noticeably different from that of the gneissic granite at St. Andrews Klippe, though the proportion of plagioclase is greater in two specimens, and appears to be more calcic. Texturally, however, the four rocks in question differ from the gneissic granite in a generally smaller grain size, occurrence of isolated feldspar insets (no. 174), and parallel quartz lenticles (nos. 150 and 469), the comparison of course allowing for the cataclasis due to the later metamorphism in the granitic gneiss. These facts suggests a different mode of origin.

3. Banded gneisses.

In this account, the term is applied to rocks of granitic or granodioritic composition in which banding is developed due to differences in mineralogy. Such banding may vary from several centimetres in thickness to thin films surrounding eyes in porphyroblastic gneisses. Only three specimens were collected; no. 175 from Nunatak 1, no. 233 from Kamæleon, and no. 195 from the small nunatak between Kamæleon and its large neighbour to the S.S.W.

No. 175 from Nunatak 1, is a medium grey banded gneiss in which quartzo-feldspathic folia (grain size up to 2 mm) alternate with slightly finer grained quartz, feldspar, and aligned biotite. In section, microcline-microperthite and quartz each form about 30 per cent. of the rock, together with some albite and bleached biotite. The quartz, and to a lesser extent the feldspars, show strain shadows and granulation which are pronounced in more micaceous folia. The biotite is commonly partially or completely chloritised, and is arranged in irregular streaks and clusters with a rude parallel orientation, sometimes together with trails of granulated quartz and microcrystalline sericite. Alteration of the feldspars to sericite is slight in the microcline but marked in the plagioclase, both where it occurs as separate crystals and as perthitic intergrowths.

Rocks similar so this banded gneiss were observed by WYLLIE at the head of the Pony Gletscher, and probably form a larger part of the complex in the Budolfi area than direct observation has shown. Though now of a granitic composition, it is possible that these rocks are paragneisses which have undergone extreme metasomatism. In section, there is a tendency for plagioclase to be commoner in biotite-bearing bands, and reference must be made to the heterogeneous appearance of the gneiss at Helgoland and Dickens Bjerg. On the Pony Gletscher, and at the small nunatak east of Helgoland, rocks of this type are highly folded in a plastic manner, and in the latter case at least, there is a remarkable similarity to a photograph of granitization phenomena in Holmes "Physical Geology" (1946, Plate 11b).

The gneiss occurring as xenoliths in the hornblende adamellite of Kamæleon is composed of porphyroblastic single feldspars or aggregates up to 3 cm long, elongated in the direction of the foliation, and encased in discontinuous folia of medium- to coarse-even-grained quartz, biotite, hornblende and feldspar, with the dark minerals forming about 10 per cent of the whole (no. 233).

The hornblende (α yellow-brown, β brown-green, γ medium brown-green) occurs as large anhedral ragged crystals with good cleavage. There are numerous inclusions of euhedral to rounded apatites, and sometimes almost vermicular intergrowths with quartz. Biotite appears in intergrown clusters and bands with the hornblende, and shows a similar relationship with apatite and quartz. It is pleochroic in dark brown and straw-yellow, but basal sections have a marked red colour. Some crystals contain bundles of very fine inclusions arranged in three sets at 60°, and others show some alteration to pale chlorite. Feldspar forms a little over half the rock, being mainly antiperthite, with some oligoclase and microcline. The plagioclase is generally strongly altered preferentially along cleavages to microcrystalline sericite and epidote. Most of the feldspar is confined to feldspar-rich folia which also contain a little quartz. The quartz is medium- to coarse-grained (2 mm) with boundaries sutured or rounded, and often shows strain-shadows.

No. 195 from the nunatak between Kamæleon and the peak to the south is a light grey granitic gneiss with a greenish tinge. There is a rough foliation due to quartz-feldspar bands alternating with greenish streaks and patches. This rock, in section, is built up of perthitic microcline (40 per cent), sericitised albite (20 per cent), quartz (30 per cent), and altered biotite. The crude planar structure seems in part to be due to the elongated rounded quartz grains (5 mm) or lenticles. In the microcline (3 mm), braid perthite is particularly well shown, while the plagioclase, which is extensively sericitised, sometimes contains myrmekitic quartz. All the biotite is replaced, largely by iron ore, but with some sericite in addition. The replacement characteristics in thin section, and the greenish, weathered appearance of the rock at outcrop, suggest that we are dealing here with the weathered gneiss below the Trekant unconformity. No trace of sedimentary quartzite can be seen, however.

4. Augen-gneisses and Cataclasites.

Rocks in which penetrative movements subsequent to their original formation have played an important rôle form wide tracts of the cliff frontage of the Budolfi Isstrøm below St. Andrews Klippe. They also occur, according to WYLLIE's notes, overlooking the Pony Gletscher and in other areas south of the Budolfi Isstrøm. Though these rocks are uniform in field appearance over wide areas, they give valuable evidence about the degrees of metamorphism at different localities. It is covenient therefore to describe them on a regional basis.

(a) St. Andrews Klippe.

Four specimens (nos. 135, 148, 143 and 131) give a picture of the detailed variations at this locality. Nos. 135 and 148 were collected from crush belts in the hornblende-adamellite, and nos. 143 and 131 respectively from the north and extreme S.E. part of the cliff.

The two crush-gneisses are well-foliated with micaceous laminae completely or partially enclosing granular quartz-feldspar areas. No. 148 is the darker of the two, with lenticular augen (3 mm) and small glistening biotite flakes visible in the greenish micaceous folia.

Under the microscope, No. 135 appears as a strongly sheared aggregate of quartz, microcline-microperthite, albite-oligoclase and micas. While the feldspars, especially microcline, may reach 5 mm in length, the quartz rarely reaches 3 mm, and the micas are all fine-grained. The structure is characterised by strongly lenticular augen of quartz and feldspar enclosed by streams of granular quartz, feldspar, and micas. Mineralogically, the rock is similar to the gneissic granite from the same locality, excepting for the occurrence of muscovite and patches of green biotite. As in a number of other specimens, the potash feldspar is less altered than the plagioclase, which is sometimes crowded with flakes of sericite and cryptocrystalline material.

In the other specimen, the plagioclase porphyroclasts (30 per cent) show much cryptocrystalline alteration, and visible replacement by muscovite and biotite, while the lamellar twinning is often bent and fractured. The accessory microcline is much less altered. Here the quartz has been drawn out into large flat lenticles over 10 mm long, these being made up of long lenticular augen, with strongly developed strain-shadows, and separated by much granoblastic recrystallised quartz (0.3—0.7 mm). Biotite (up to .15 mm) is pleochroic dark brown to straw yellow and forms about 10 per cent of the rock. It is arranged in subparallel trains, sometimes accompanied by quartz, muscovite, and epidote. A little iron ore partially altered to cryptocrystalline very dark sphene is present.

Comparing these two rocks with the parent hornblende-adamellite, the more notable features are the absence of hornblende and red-brown biotite. In the adamellite, hornblende is mantled by brown biotite in places, and in others is replaced by phlogopitic biotite, epidote, and quartz. Since pale biotite is not present in the crush rocks, and epidote is present in small quantities only, it seems that the hornblende must have been largely replaced by the brown or green biotite.

Concerning the other two augen-gneisses, no. 143 is very like the granite into which it appears to grade (no. 144), but is distinguished from it by its distinct foliation and somewhat lenticular feldspar augen which reach 1 cm long. No. 131 bears a great resemblance to the crushed gneisses in the centre of St. Andrews Klippe, being finer in grain and containing, to outside appearances, a greater quantity of mica.

In both rocks, microcline-microperthite (50 per cent) predominates over plagioclase, this latter being albite in no. 143 and oligoclase (An_{17}) in 131. The potash feldspar also forms the larger porphyroclasts, and both feldspars show broken forms, with warped twinning and fractures filled with granulated material. Quartz is in large augen with packet structure, and trails of granoblastic grains (0.02 mm in 143; 0.1 mm in 131). Chlorite, epidote and sericite are accessory in 143, but in 131 muscovite (20 per cent), calcite (10 per cent), and fine-grained brown biotite are important.

(b) Midway between St. Andrews Klippe and Durham Klippe.

Two specimens were obtained from the material near the basic gneisses described on p. 27. No. 399 comes from the feldspathic gneiss which forms much of the cliff, while no. 398 belongs to one of the more-even-grained granitic masses which appear to cut the gneisses.

No. 399 is an augen-gneiss in which a schistosity parallel to the foliation is developed by minute mica flakes (mainly biotite). The feldspathic material rarely reaches 5 mm in length, and much of the lighter part of the rock has a grain size of about 1 mm. The thin section shows rather isolated augen of microcline-microperthite, oligoclase with some antiperthite, and quartz, in a groundmass composed of biotite, quartz, epidote, with a little muscovite, chlorite, and iron ore. As is usual, the microcline is little altered, but the oligocalse is partially replaced by muscovite, phlogopitic biotite, and fine-grained epidote. Both minerals show evidence of fragmentation. The quartz augen are actually lenticles of granoblastic quartz (0.03–0.1 mm), sometimes drawn out into discontinuous folia, or retaining remnants of central strongly strained grains.

Surrounding the augen are swirling trails of granular quartz, ragged micas, and occasional feldspar fragments together with small granules of pale yellow epidote and rare green chlorite. The most interesting mineral is the biotite, which occurs in two sizes, both being pleochroic pale brown to colourless. The larger laths show oriented inclusions at 60°. Another feature is that the sparse small iron-ore flecks are surrounded by relatively broad coronas of cryptocrystalline sphene, in turn often mantled by biotite.

The more even-grained rock no. 398 has retained much of its coarse-grained xenomorphic granular texture as seen in thin section, but at a number of points the minerals are separated by recrystallised quartz (0.06 mm) and a little phlogopitic biotite. The plagioclase (4 mm) is largely replaced by muscovite, biotite, and epidote, but shows clear rims against microcline, which is fresh excepting for the braid perthite. The quartz shows pronounced packet-structure and granulation. A little calcite occurs at one point.

(c) Durham Klippe.

A hand-specimen from here (no. 130) is poorly foliated with knots or single feldspar eyes up to 3 cm long, but more usually 2–3 mm. Though much of the rock is quartzo-feldspathic, the micaceous folia show distinct small flakes of muscovite and biotite in which a poor lineation can be discerned, though the schistosity is most irregular. A neighbouring specimen shows few augen and a better developed foliation and schistosity, with a clear lineation due to parallel micas.

A slice from no. 130 shows that this rock is composed of scattered microcline augen set in a mainly medium-grained (0.1 mm) groundmass of quartz, microcline, brown biotite, muscovite, epidote, and a little plagioclase. The microcline is fresh, excepting for scattered flecks of sericite, and shows strain shadows. All gradations occur from 2 mm downwards to the groundmass.

In the groundmass, the quartz grains form a welded mosaic of varying size (0.02–0.2 mm), tending to be concentrated in patches, but also well distributed through the rock. Strain shadows are marked, but no "packet structure" and granulation can be seen. The microcline occurs as highly anhedral grains mixed with the quartz, and is accompanied by a little twinned (and probably more untwinned) albite. This plagioclase shows warped and fracture twinning in larger grains (0.5 mm). The biotite is a normal brown variety pleochroic dark brown to straw-yellow, and occurs in trails with epidote. Apart from its occurrence in trails, the epidote is concentrated in patches at one or two points, with quartz and micas, reminiscent of feldspar augen. A little calcite, apatite, and green chlorite are visible.

If this rock is compared with those further west, a considerable increase in the grade of metamorphism is apparent. The distinction between porphyroclasts and the recrystallised groundmass material is shadowy. Plagioclase appears to be partly recrystallised. Strain shadows are much less in evidence than in other augen-gneisses, and, neglecting porphyroclasts, there is a general increase in grain size of the rock. All these factors visible in thin section accompany the appearance of a marked lineation.

5. Basic Gneisses.

(a) Upper Budolfi Isstrøm.

Two specimens were obtained; no. 149 from Nunatak 2 (fig. 3) on the north side of the glacier, and no. 470 from the east end of Dickens Bjerg.

The material from the north side of the Budolfi is dark and dense, and the reddish weathered surfaces are mottled with grey feldspar laths. The thin section shows andesine, augite, hornblende, and actinolite, together with accessory magnetite and biotite, in a granular texture characterised by rounded and embayed forms. Andesine (An_{45}) occurs as rounded crystals averaging $^1/_2$ mm across and is frequently twinned on the albite law. Though the body of each crystal is generally fresh, there are narrow borders of uralite (parallel fibres at right angles to the edge), epidote, and sericite, and this material also occupies cracks running across the grains. The pyroxene is colourless, $+2V$ 60–70°, extinction $\gamma \wedge c$ about 45°, and generally reaches $^1/_2$ mm in length, though larger crystals also occur. It is often quite fresh, and is associated with magnetite and hornblende. Actinolite occurs as compact masses of parallel fibres in areas of the slide: at a few points there is evidence that it replaces pyroxene (alteration along cleavage cracks) but very few actinolites masses contain cores of pyroxene. The hornblende (α yellow-brown, β medium brown, γ deep brown) is fresh, and also bears a "subophitic" type of relation to the feldspar. Enclosures of magnetite are common in all ferro-magnesian minerals. The magnetite grains, which are small and rounded, sometimes show indefinite margins owing to a slight brownish cryptocrystalline corona. Biotite is comparatively uncommon, occurring as corroded laths up to 1 mm long, with a pleochroic scheme very dark brown to straw-yellow.

No. 470 shows basic gneiss interbanded with granular white andesine and quartz, the only other difference being the pronounced schistosity.

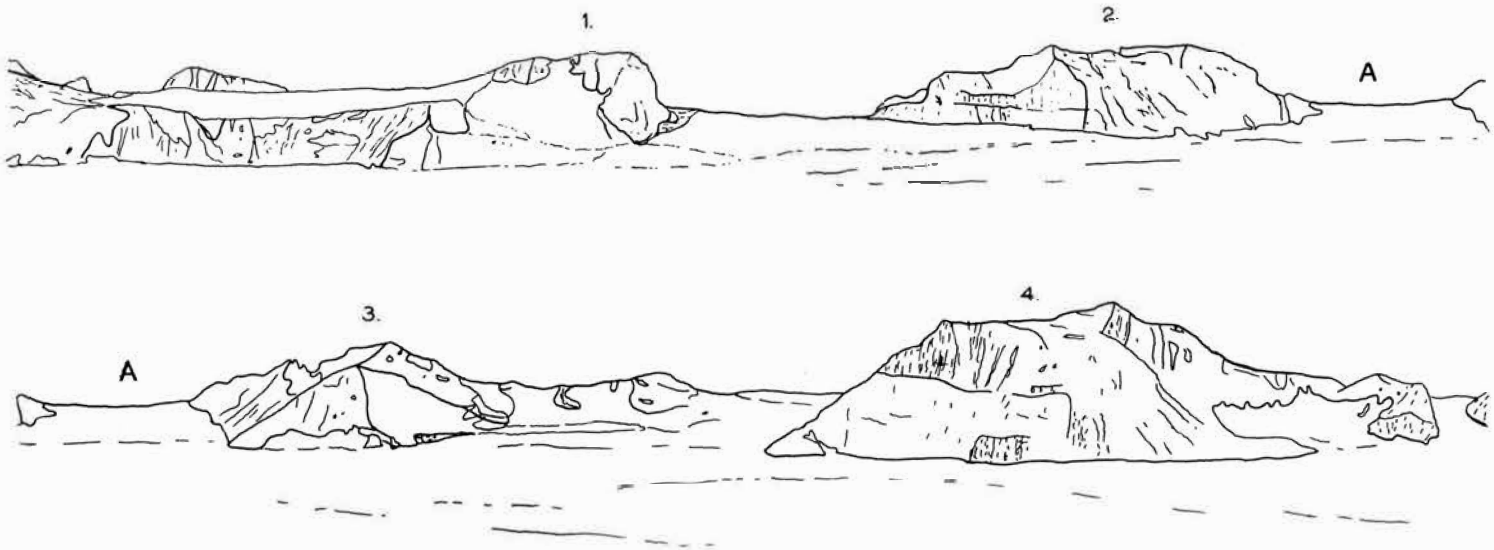

Fig. 3. Panorama of nunataks on the upper Budolfi Isstrøm. Figures refer to text.

(b) South St. Andrews Klippe.

At a point about 5 km south of St. Andrews Klippe proper, specimens of basic gneiss show perthitic microcline in addition to andesine. The pyroxene is almost entirely altered to actinolite; the andesine to epidote, sericite, and actinolite; while the magnetite is surrounded by coronas of fine-grained brown biotite. Hornblende, though usually fresh, also shows replacement by biotite.

(c) Basic gneiss midway between St. Andrews and Durham Klippe.

Not far east of the bend in the middle Budolfi Isstrøm, masses of dark rock appear in the cliff cut by anastomosing granitic veins. This rock is texturally similar to those described above, but is composed of brown hornblende, actinolite, zoisite, sericite, quartz, and pyrites. A little plagioclase remains, but most of it has been completely saussuritised.

B. PETROGENESIS

From the petrography and field relations, there are two distinct problems: 1. The original nature of the Western Gneisses; and 2. the degree to which they have been modified by later metamorphism.

1. In the Budolfi Isstrøm area, a consideration of the hornblende-adamellite of Kamæleon and St. Andrews Klippe is a good lead into discussion of the first problem. The evidence concerning its genesis may be summarized as follows—

(a) At St. Andrews Klippe, the rock shows cross-cutting relationships with the gneissic granite. However, there are no signs of chilled contacts, and at some points there is a complex streaky intermingling of the two rock types, with concentration of mafic minerals at the contacts.

(b) Orientated platy xenoliths occur at St. Andrews Klippe.

(c) At Kamæleon, the hornblende-adamellite shows intrusive junctions with a porphyroblastic augen-gneiss, and also cuts two generations of aplites in the gneiss.

(d) The mineralogy of the Kamæleon augen-gneiss is similar in many respects to that of the adamellite. Both contain associations of brown hornblende and reddish biotite, while the plagioclase is oligoclase. However, the big feldspars in the augen-gneiss are antiperthitic oligoclase and there is only a small proportion of microcline, thus contrasting with the adamellite where microcline is equivalent in quantity and grain size to the plagioclase.

(e) The hornblende-biotite association is absent from other acid rocks in the district.

It seems fairly certain that the adamellite is intrusive, but the nature of the boundaries suggests that the country rock was also at a high temperature at the same time. Platy xenoliths are a feature suggesting a magmatic origin for the adamellite.

The similarity of the adamellite to the porphyroblastic gneiss at Kamæleon is interesting, and there is a limited probability that the two rocks are related. Any explanation, however, must take into account the fact that the largest feldspars (antiperthitic oligoclase) in the augen-gneiss are absent in the adamellite, and that microcline crystals in the adamellite are equal in size or larger than their oligoclase companions. Direct incorporation of the feldspars of the augen-gneiss into the adamellite thus appears unlikely. A possible explanation is that the augen-gneiss with its aplite suite is the remains of a metasomatised aureole connected with the intrusion of the adamellite, such an aureole being largely submerged with the rise of the intrusion.

The second interesting problem is the origin of the basic gneisses in the complex. In many places they are associated with acid rocks which are intrusive both as regards the basic gneisses themselves, and the surroundings. The nature of these host rocks calls for comment. To review the several occurrences, at Nunatak 1 (fig. 3), the banded and streaky material in the cliff could be enclosed either in intrusive granite or the gneisses of the complex. The material on the small ridge running southeast from the nunatak is intruded by granitic rocks, but there is a possibility of a contact against banded gneiss at the southernmost end of the ridge. At the east end of Dickens Bjerg, the field evidence brought back by Wyllie suggests that the basic gneisses are riddled with granitic veins. On the middle Budolfi Isstrøm, granitic material surrounding another outcrop of basic gneiss appears to truncate the augen-gneiss. This latter is probably a "fossil" boundary, since the basic gneiss here has been affected by the later metamorphism as well as the augen-gneiss. At south St. Andrews Klippe, an outcrop of basic gneiss is enclosed by augen-gneiss.

There is a parallel here to the structures of the second metamorphism in the Lewisian of Scotland (e. g. Sutton and Watson 1950 p. 258), where the dolerite dykes have been completely transformed to meta-dolerite and amphibolite, rotated into conformity with the new foliation, and subjected to some degree of metasomatism. Here, however, there has been no actual mobilisation of the granitic rocks associated with the hornblende-gneisses. In Dronning Louise Land, besides occurrences similar to those in the Lewisian, some of the basic gneisses must have been moved as xenoliths in a granitic magma or mush.

The oldest parts of the complex appear to be the foliated gneisses and gneissic granite of St. Andrews Klippe. The gneissic granite might possibly be magmatic: the banded gneisses are possibly paragneisses, in part probably modified by metasomatism to a more granitic composition and appearance (compare SUTTON and WATSON, 1950, p. 250).

2. The problem of the later metamorphism of the Western Gneisses is treated as a whole subsequently, but it is of interest to bring together a few points:—

Quartz in augen-gneisses is strongly granulated, especially in the west, but the grain size of recrystallised material increases towards the east. At Durham Klippe the distinction between porphyroclasts and recrystallised quartz is shadowy. It is noticeable that the grain size of the broken-down quartz in one of the crush belts at St. Andrews Klippe is larger than in adjacent augen-gneisses.

Plagioclase disappears eastwards after undergoing extensive replacement, chiefly by muscovite and epidote, but albite is present in a recrycrysallised condition at the west end of Durham Klippe.

Microcline, whilst undergoing slight replacement, survives as porphyroclasts as far east as Durham Klippe, where it appears to be recrystallising, and the distinction between the original eyes and the groundmass is not sharply defined.

Iron ore, as in the basic rocks, shows an eastward development of sphene and biotite coronas.

In basic gneisses, pyroxene survives as far east as St. Andrews Klippe, but eastwards again feldspar is saussuritised and pyroxene has been completely pseudomorphed by actinolite.

The mineralogical changes and recrystallisation clearly indicate cataclasis and diaphthoresis followed by an increasing degree of metamorphism towards the east. It is noteworthy, however, that some of the granitic rocks associated with basic gneisses on the mid-Budolfi have retained much of their even-grained appearance in the field, though exhibiting a certain amount of recrystallisation when viewed in thin section. The cross-cutting relationship of these rocks with the augen-gneisses must be due to the fact that the latter have broken down more easily under the penetrative movements, possibly along a previous foliation or schistosity. In fact, the basic gneiss-granite complex in this area has probably retained much of its original structure, though suffering some mineralogical changes. The lack of marked recrystallisation of the quartz and epidote minerals, and survival of brown hornblende in the basic gneiss might be ascribed to a locally lower degree of metamorphism, possibly connected with the competency of the basic gneiss.

Another digression from the evenly-increasing degree of metamorphism is the disparity in the amount of recrystallisation in the two specimens from the crush-belts at St. Andrews Klippe. Sutton and Watson (1950 p. 256) have noted that the degree of metamorphism is higher in crush belts in the Diabaig area of the Lewisian Gneiss than in the enclaves of structurally unaltered rocks, and a similar state of affairs seems to exist in the Western Gneisses.

Central and Northern Dronning Louise Land.

In the Borgkjøkel area, the Western Gneisses are lithologically similar to those of the Budolfi Isstrøm. Rocks of granitic aspect are present at Trekanten, Cloos Klippe, and the north side of Eigil Sø. Of greater importance, however, are the augen-gneisses, derived from either banded gneisses or more uniform rocks. Some of these are very coarse-grained. The big feldspar gneisses at the east end of Eigil Sø (Peacock 1956a p. 13) are blastoporphyritic, with their present structure in part imposed by the younger metamorphism. Basic gneisses appear to be absent though there are platy xenoliths of biotite rock in the granodiorite at Cloos Klippe. No rocks which could definitely be called "paragneisses" were found, though, as on the Budolfi Isstrøm, it is not unlikely that some of the banded gneisses may have had a sedimentary parent.

Further north, true granite, intruded into schist bands, outcrops at Curie Klippe, and a rock approaching granodiorite at Thomson Klippe. Such rocks probably also form the foundations of the mountains around Prinsessen. Augen-gneisses in various forms are widespread, varying from texturally little-altered mortar gneisses (e. g. south of Bohr Bjerg) to slabby, phyllonitic rocks (Kelvin Klippe). Banded augen-gneisses, possibly of sedimentary parentage do not seem to be common, but an infolded quartzite at Regnbueklippe (fig. 4) points to formerly sedimentary material in the complex.

A. PETROGRAPHY

1. Coarse-grained rocks of granite-like aspect,

The rocks considered under this heading are as follows:—

Cloos Klippe: plagioclase-quartz-biotite-tremolite-granodiorite
microcline-plagioclase-quartz-biotite-adamellite.
Curie Klippe: granite.
Thomson Klippe: granodiorite.

At Cloos Klippe, the margin of the adamellite (which is porphyritic) truncates aplite veins in the granodiorite. Belts of augen-gneisses or crush rocks split up the various granitic outcrops, and gradations from granodiorite or adamellite to augen-gneiss can be seen. The Curie Klippe granite also shows intrusive relationships, sending tongues into narrow schist bands. Zenoliths occur in the granodiorite at Thomson Klippe.

The Cloos Klippe granodiorite contains a more basic plagioclase than is normal (An_{35}), and only a small proportion of untwinned alkali feldspar. Though texturally little altered, with a grain size between 2

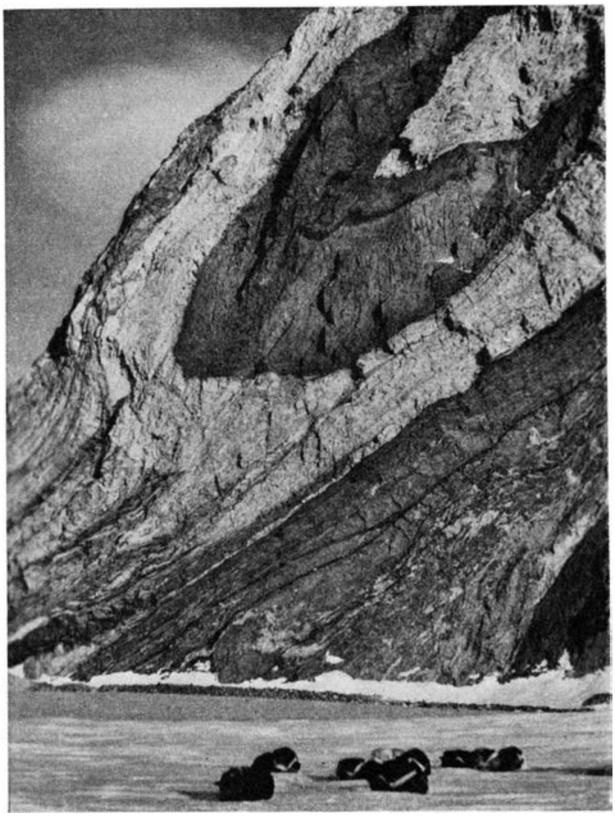

Fig. 4. Synclinal structure in quartzite and greenstone, Regnbueklippe.
Photo: P. J. Wyllie.

and 5 mm, the effects of the younger metamorphism can probably be seen in the turbidity of the feldspar, recrystallisation of the biotite, and coronas of sphene and pale biotite ($n\gamma = 1.64$) around iron ore grains. The platy tremolite may contain cores of brown hornblende. The adamellite is noteworthy on account of the phenocrysts (3 cm long) of microcline-microperthite. In it the quartz is partially granulated, and the brown biotite ($n\gamma = 1.65$) shows gradations from small decussate laths to larger plates (1 mm). Myrmekite bushes occur against alkali feldspar.

The granite and granodiorite outcropping on the upper Admiralty Gletscher are petrographically unremarkable, containing microcline and

Fig. 5. Migmatitic structure at Cloos Klippe cut by a metadolerite.
Photo: P. J. WYLLIE.

turbid albite-oligoclase in appropriate proportions, quartz, and chlorite. The younger metamorphism is most likely responsible for displacement and fracturing of twinning in the feldspars, intense undulation banding in the quartz, clouding of the plagioclase, and chloritisation of most of the biotite.

2. Quartzite.

A specimen from the fold at Regnbueklippe (fig. 4) contains porphyroclasts of quartz (0.5 mm) in a groundmass of tessellate and granoblastic quartz with clusters of parallel muscovite flakes which impart a schistosity to the rock. There is considerable variation in size of the quartz grains, but lenticles of granoblastic quartz show material averaging about 0.03 mm in diameter.

The quartzite therefore follows the augen-gneisses in the vicinity in so far as the texture is a product of the younger metamorphism, but there are no signs of relict sedimentary textures, though these are preserved in Trekant quartzites affected only by the younger metamorphism. The inference is that this rock was a metaquartzite before the younger metamorphism.

3. Mortar-gneisses.

According to BUDDINGTON (1939 p. 252) a mortar-gneiss can be defined as "a rock in which there has been only a little crushing, largely between and on the peripheries of grains, thus resembling stones in a wall with a mortar of comminuted material". Avoiding the direct genetic implications of this statement, some of the rocks forming the east wall of the Trefork Gletscher may be termed mortar-gneisses. Though these are marked as undifferentiated on the map, it seems reasonable from the field and petrographical evidence to place them with the Western Gneisses. An extended description is worth while, since these rocks are near neighbours of the much higher grade paragneiss complex exposed at Paradisklippe, and by implication on the south side of Trefork Sø.

Briefly, the rocks here (as observed in the field) are biotite-quartz-(feldspar)-gneisses, and coarse-grained, granitic-looking rocks with patches or veins of grey feldspar and quartz pegmatite. In places these rocks are traversed by gently-dipping bands of biotite-gneiss, which are concordant with any foliation in the lighter rocks.

A specimen from near the head of the glacier (no. 87) is a fairly even-grained foliated granitic gneiss composed predominantly of light grey feldspars up to 1 cm long, smaller quartzes, and small quantities of micaceous minerals. In thin section, porphyroclasts of microcline-microperthite predominate (40 per cent) with quartz (30 per cent) and a little acid plagioclase. Biotite, muscovite, and epidote build most of the remainder of the rock.

Microcline is fresh, and exceeds 3 mm in grain size. Boundaries are highly irregular, and usually mantled with granular quartz, micas, and epidote; and cracks running across the grains are filled with the same materials. Twinning is of the usual cross-hatched type, with carlsbad twins conspicuous in the larger grains. The plagioclase crystals (An_{12}) are smaller than the microclines, and are extensively altered to muscovite and epidote. Lamellar twinning is prominent in many cases, and is sometimes displaced and warped. Sometimes trains of plagioclase are obviously derived from one grain.

Quartz occurs largely in irregular areas. Much of it has recrystallised to a granoblastic aggregate (0.1–0.2 mm), though highly strained relics of larger grains occur here and there. The quartzitic areas tend to envelop the feldspars. Where mixed with other minerals, the grain size is much smaller.

The biotite is pleochroic from deep brown to straw-yellow, but there is often a pronounced green tinge, and in places true chlorite can be seen. Laths reach up to 0.3 mm long, and are arranged in small trains or clusters parallel to the margins of the feldspars. Muscovite (0.2 mm) builds rather thicker trains of laths, and is associated with granular epidote and a few grains of calcite.

No. 62, obtained from a feldspar-quartz vein, is similar to the above. The quartz, however, which forms half the rock in section, is all strongly strain-shadowed, though occurring in a similar grain size to that previously described. Plagioclase (An_{10}) is extensively altered to epidote, but tends to have clearer margins against microcline.

It is quite evident that the mortar-gneisses resemble the Western Gneisses in both field and laboratory characteristics. The influence of the younger metamorphism can be seen particularly in the recrystallized quartz (the mortar), and the replacement of the plagioclase by muscovite and epidote. This type of metamorphism is the same low-grade variety that occurs at Cloos Klippe, though possibly somewhat more intense. The amount of deformation, however, is small, and the rocks have retained their even-grained appearance in hand specimen.

4. Augen-gneisses.

In grain size and texture, the augen-gneisses show considerable variations at any one point, as indicated above. In general, however, the grain size decreases eastwards, and where very large feldspar porphyroclasts occur, as at Eigil Sø, there is an eastward decrease in number per unit area of rock face. On the Admiralty Gletscher, the grain size of the feldspars varies from up to 2 cm at the west end of Kelvin Klippe to 1–2 mm at Regnbueklippe. At Kilen, and also in the area northeast of Planck Klippe (on the N.W. side of Ad Astra Iskappe), a lineation has been imposed on the rocks, and the decreasing size of the porphyroclasts coupled with recrystallisation in the groundmass gives a more granoblastic appearance. These textural changes go hand in hand with mineralogical changes, which can be summed up as follows:—

Microcline. Generally one of the main components of the rock, microcline is at all stages fresher than plagioclase, and usually forms the larger porphyroclasts. Signs of stress are evident in the warping of crystals and the fractures filled with granular quartz. Sometimes the microcline eyes "float" in granulated microcline (Kelvin Klippe), and the perthitic component, where present, is extensively altered to muscovite and epidote. On the east side of Kilen, and also from Regnbueklippe eastwards, fresh granoblastic microcline is present and the distinction between porphyroclasts and groundmass is gradually lost.

Plagioclase. In the west, the albite-oligoclase of most augen-gneisses is rendered turbid by replacing muscovite, epidote, and sometimes chlorite. These replacing minerals increase in grain size towards the east. At Cloos Klippe, Planck Klippe, and Jaettebringen (Ymer Nunatak), some plagioclase porphyroclasts are rimmed by clear albite (An_3). Northeast of Planck Klippe, granoblastic albite is also visible in the groundmass of the rocks.

Quartz. At the west end of Eigil Sø, and at Kelvin Klippe, quartz forms flat porphyroclasts with tails of comminuted material. The grain size of the granulated quartz is very small (0.01–0.03 mm) but rises eastwards to 0.1 mm at Cloos Klippe and Planck Klippe. Though porphyroclasts become sparse, they do not quite disappear, but merge into granoblastic quartz as the grain size of the latter increases. On the ground west of Gultop Gletscher and N.E. of Planck Klippe, the quartz forms granoblastic crystals between 0.3 and 0.4 mm in diameter.

Other Minerals. Felts of muscovite, biotite, epidote, and sometimes chlorite and calcite are characteristic of many augen-gneisses, the grain size increasing from west to east. Northeast of Planck Klippe, the muscovite and biotite laths occur in strings of parallel well-formed laths more or less independant of the augen texture. Any iron ore is usually mantled by biotite and sphene. Actinolite is an important constituent in a rock collected by WYLLIE a short distance N.W. of Monumentet (Pony Gletscher), and hornblende (α pale yellow-brown, β pale brown, γ pale green, $\gamma \wedge$ c. 20°) in another from Regnbueklippe.

The biotite mentioned above is either a pale phlogopitic type, or a common brown variety. No regional grouping of these varieties can be made out. Common features of both are orientated sets of inclusions at 60°.

B. PETROGENESIS

It is self-evident that the Western Gneisses of central and north Dronning Louise Land have all been affected by the younger metamorphism to a greater or lesser degree. Nevertheless, enclaves of texturally and structurally little-altered rocks remain—the structures visible in fig. 5 taken at Cloos Klippe have little to do with the younger metamorphism. As in south Dronning Louise Land the complex associated with the older metamorphism includes a pre-existing series and intruded igneous rocks. The infolded quartzite at Regnbueklippe has been cited as evidence of a former sedimentary component in the country rock, and such evidence is supported by a find of blastoporphyritic quartzite at Jættebringen. It is unfortunate that no contacts of the old igneous (or partially migmatitic) complex at Cloos Klippe were found with the former country rock, since both here and at St. Andrews Klippe we have the interesting fact that an earlier igneous suite has been intruded by adamellite.

The younger metamorphism has produced a number of effects similar to those further south, with dominantly cataclastic action followed eastwards by recrystallisation and growth of new minerals. The Western Gneisses northeast of Planck Klippe and to the west and southwest of the Gultop Gletscher (rocks undifferentiated on the map) seem to reach a higher metamorphic grade than the others, if notice be taken of the comparatively large grain size of the quartz and recrystallised feldspar. This fact, supported by the state of the basic intrusions, suggests that these rocks are east of the presumed structural break running near the central meridian of Dronning Louise Land (see p. 116).

Conclusions.

We can conclude that the Western Gneisses are a complex rock group showing evidence of an earlier period of metamorphism and plutonic activity followed by a younger metamorphism. Two problems arise; firstly, the original nature of the Western Gneisses; and secondly, the degree to which they have been modified by the younger metamorphism.

1. The evidence put forward in the preceeding pages suggests that three different suites of rocks make up the unmodified Western Gneisses. These are (a) an originally sedimentary component, (b) acid plutonic rocks, and (c) basic gneisses.

(a) The sedimentary component in the Western Gneisses is represented by schists, metaquartzites, and banded gneiss, these latter probably being by far the most important. This series suffered a thoroughgoing metamorphism (the older metamorphism) eliminating all sedimentary structures. The state of the banded gneisses, with their almost granitic composition, suggests that metasomatic changes were important.

(b) Acid plutonic rocks varying from granite to granodiorite outcrop throughout all the exposed region of Western Gneisses. At some points, e. g. Curie Klippe, they are intrusive into the paragneisses. The evidence from the upper Budolfi Isstrøm and Cloos Klippe suggests two periods of intrusion of plutonic rocks separated by a short time interval. The lack of contact phenomena against earlier rocks suggests that the plutonic rocks were emplaced while the country rock was hot, leading to the idea that they may be contemporary with the later stages of the older metamorphism.

(c) The basic gneisses are confined to south Dronning Lonise Laud, though field evidence indicates that similar rocks may outcrop north of the Admiralty Gletscher (fig. 6). They are augite-hornblende-plagio-

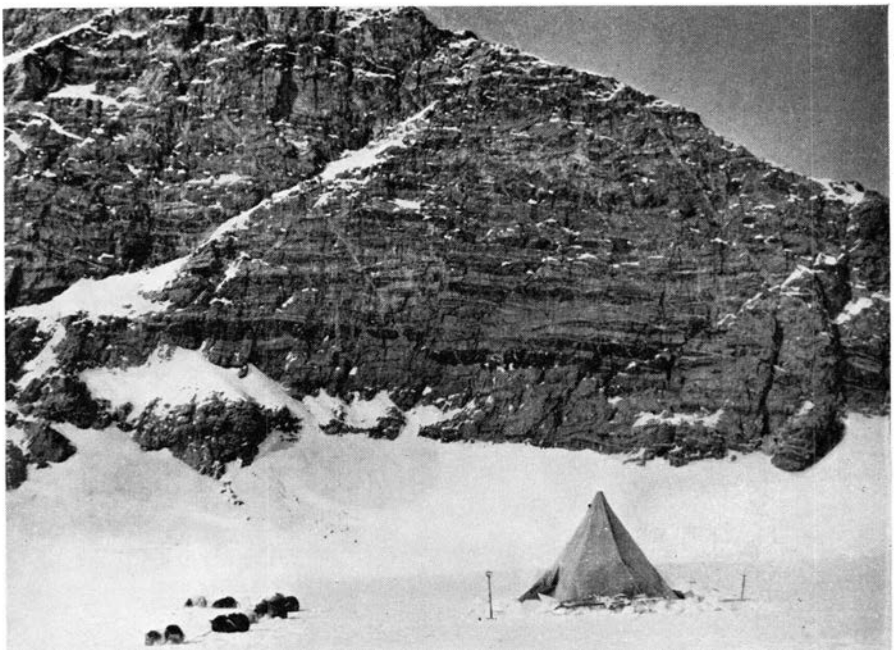

Fig. 6. Flat-lying Western Gneisses south of Prinsessen. Note the small thrust-faults dipping east. Photo: P. J. Wyllie.

clase gneisses, and occur either as lenticular streaky bodies in acid gneiss, or large masses seamed by granitic rocks. These are interpreted as meta-dolerites which have been brought into their present spacial and meta-morphic condition partly as a result of the older metamorphism and partly through being enclosed, disrupted, and bodily moved during the intrusion of granitic magma or mush.

The basic and acid gneisses are mineralogically similar to those found in other Archaean areas, e. g. the Lewisian, and like them have been subjected to deep-seated metamorphism and metasomatism. The preservation of augite and hornblende with andesine in the basic gneisses suggests the rocks are in the amphibolite facies. Gathering the various threads together, we may think of the plutonic, metamorphic, and metasomatic events as different stages in one large-scale orogeny.

2. We are now in a position to appreciate the effect of the younger metamorphism on the Western Gneisses in the whole of Dronning Louise Land. A rough zonal subdivision can be made as follows:—

(a) In the extreme southwest, west of St. Andrews Klippe, is a zone in which metamorphic effects are slight or absent. Quartz shows marked strain shadows in places, but mineralogical changes which can be directly attributed to the younger metamorphism are small. Plagioclase shows cryptocrystalline alteration and sericitisation, and biotite is sometimes bleached.

(b) A second zone of dominantly cataclastic metamorphism extends from north to south across the whole of Dronning Louise Land. We can trace this zone is the north from Ymer Nunatak to include the west side of Prins Axel Nunatak, Bohr Bjerg, and the upper Admiralty Gletscher. Southwards, the zone includes the west part of Eigil Sø, and passes across the upper Pony Gletscher. On the Budolfi Isstrøm, the area includes St. Andrews Klippe on the west side, and stretches eastwards to within a few miles of Durham Klippe. The western and eastern limirs are purely arbitrary, and reference must be made to other rock groups also affected by the younger metamorphism before coming to any firm conclusions.

In this second zone the rocks take on the habit of augen-gneisses where of appropriate composition. Quartz is granulated, and the larger grains pulled out into lenticular porphyroclasts. While microcline remains fairly fresh and remains as outstanding partially granulated and fractured eyes, the plagioclase is rendered turbid with replacing epidote and sericite and is much more broken down. These larger grains are wrapped by streaming fine-grained micas or chlorite, with epidote, calcite, sphene, and granulated material. The newly-crystallised minerals must derive their substance in part from the original biotite and iron ore in the rock, and in part from the replacement of plagioclase.

We can also distinguish all stages between augen-gneisses and rocks retaining their original textures. These latter have suffered much the same mineralogical changes as the augen-gneisses, but to a lesser degree. The place of hornblende appears to be partially taken by pale tremolite or actinolite (St. Andrews Klippe), but it also shows slight replacement by pale biotite, quartz, and epidote.

(c) In a third zone lying usually at the eastern limit of the outcrop of the Western Gneisses, the augen-gneisses are rather similar in appearance, but in places the eyes are much smaller. Here the quartz porphyroclasts are further broken down, but the granulated quartz is recrystallised, and in some rocks the distinction between porphyroclasts and newly-crystallised quartz is lost. Likewise, though microcline porphyroclasts are not notably replaced, they tend to be smaller, and there is freshly-crystallised microcline in the groundmass. Plagioclase porphyroclasts are not so common as in rocks further west, but there is sometimes recrystallised material in the granoblastic groundmass and occasionally recrystallised material mantling the porphyroclasts themselves. This new plagioclase is a pure albite (An_3), and differs from the older plagioclase, which is usually albite oligoclase.

The chief mafic mineral is biotite. Phlogopitic biotite is common in some rocks, but its place is taken in others by brown biotite of similar habit. The biotite often shows orientated acicular inclusions at 60°, possibly tremolite. Actinolite porphyroclasts are visible in one gneiss from the Pony Gletscher. Iron ore is surrounded by coronas of sphene and biotite.

Here again all stages can be observed through the series rocks with original textures—mortar gneiss—augen-gneiss. The mineralogical changes are the same as those in the augen-gneisses, but have often not proceeded so far.

In the basic gneisses of the Budolfi Isstrøm, the feldspar has been saussuritised, and the place of pyroxene taken by actinolite.

Superimposed on this general zonal scheme are local variations in metamorphism. The crush belts which are features of zones (b) and (c) may show evidence of greater recrystallisation than surrounding rocks (St. Andrews Klippe). On the other hand, mineral changes in texturally little-disturbed rocks are smaller than one might expect. The explanation of these facts would seem to be connected with variations in the stress factor of the metamorphism due either to the resistance of the rocks or to some other cause about which we know nothing. In any case, enclaves of texturally unaltered or little-altered rocks have survived as far east as Cloos Klippe.

It is difficult to generalize concerning the stability of minerals in the zone of cataclastic metamorphism, but we can say that, among acid rocks, epidote, muscovite, biotite (chlorite), sphene, and calcite are stable; possibly also microcline. In rocks of appropriate composition, actinolite accurs. Further east, where recrystallisation is taking place, the stable minerals in acid rocks are microcline, albite, epidote, muscovite, biotite (chlorite), sphene, calcite, and actinolite: in basic rocks, actinolite, epidote, and micas seem to be stable. Little more concerning the significance of these changes can be said until consideration has been given to other rock groups.

THE TREKANT SERIES

The Trekant Series, which rests with great unconformity on the Western Gneisses, is a group of quartzites or quartzitic sandstones with occasional thin intercalated siltstones or mudstones. The maximum observed thickness is 500 metres at Trekanten, though it is quite possible that greater thicknesses occur in the Splinten Syncline. There is a dominant red cast to all beds, especially those near the bottom of the series, but other colours are also present, e. g. yellow, green and purple in the quartzites, and bright green in the siltstones. As previously mentioned, we can trace the Series from the southernmost nunataks to Ymer Nunatak in the north. In the extreme west and southwest there are few signs of metamorphism, but further east there is increasing evidence of mineralogical and textural reconstitution. This eastwardly-increasing grade of metamorphism matches that in the underlying Western Gneisses, being the same as the "younger metamorphism" described from that rock group.

A. PETROGRAPHY

1. The Basement Rocks.

The rocks below the Trekant Series are the Western Gneisses, which have been described in a separate section. However, a description of the material immediately underlying the unconformity is of great interest, since it presents an extensively rotted appearance at most points where the junction of the two rock groups can be seen.

Two specimens of these rotted rocks (nos. 165 and 168) from Helgoland exhibit similar features. No. 165 is a coarse-grained rock in which pearly feldspar (10 mm) with numerous parallel cracks occurs in a purple matrix. In section, however, quartz (40 per cent) is quantitatively the most important mineral followed by potash feldspar (30 per cent). Much of the remainder of the rock is sericitised, with some hematite visible, and the remains of biotite and plagioclase. The quartz (4 mm) is in embayed crystals normally with sharp boundaries, but showing also minute serrations due to penetration by sericite laths. Much of it shows strong undulose extinction and sometimes slightly curved parallel lamellae. Potash feldspar is clouded and shows slight replacement along cleavages and parallel cracks by sericite, dusty hematite, and a little chlorite. The plagioclase is almost completely replaced by sericite, quartz, and a little dusty hematite, and patches of finely divided feebly birefringent material, probably cryptocrystalline silica. Bleached biotite forms 10 per cent of the rock with quantities of iron ore in the cleavage cracks.

No. 168 is composed of quartz (50 per cent), and the remains of potash feldspar and biotite. The unaltered rock probably had a poor graphic texture, but the feldspar is almost completely replaced by sericite with flecks of iron ore. Likewise the biotite is almost completely pseudomorphed by iron ore dust. In parts of the slide, the quartz also shows considerably replacement by sericite. The iron ore is largely opaque, but seems to grade to limonite which stains grain-margins and cleavage cracks.

In the above two specimens the replacing minerals are sericite, iron ore, and quartz or cryptocrystalline silica. A specimen of gneiss from Trekanten (no. 76) shows similar alteration, with exceedingly fine-grained quartz forming a larger proportion of the replacing minerals. The only new feature is the occurrence of scattered carbonate rhombs (0.2 mm) among the fine-grained quartz. The iron-ore which pseudomorphs biotite is finely-divided and semi-opaque. As in previous examples the original quartz is least attacked, and is strongly strain-shadowed, with lamellae of differing refractive index in some grains.

Another specimen from immediately below the unconformity at Trekanten (no. 59), in line with a very narrow basic intrusion in the fresher gneiss below, is composed largely of microcrystalline quartz (80 per cent), dusty clusters of iron ore, and sericite patches.

In summary, these rocks appear to have been subjected to a process involving substitution of sericite, quartz, iron ore, and rarely chlorite and calcite for the existing minerals, with quartz, potash feldspar, plagioclase, and biotite progressively and increasingly attacked in that order. Since chemical weathering is at a minimum at the present time, this process must be ascribed either to weathering of the old land surface, or some other chemical action connected with the laying-down or lithification of the Trekant Series.

2. Conglomerates and Breccias.

With the exception of Trekanten, the material collected from these was obtained from the basal beds of the succession. On the whole, in the south, the conglomerates or breccias are restricted to the lowermost few metres of the succession. Northwards, however, there may be several horizons of conglomerate or breccia within the first hundred metres, for instance at Trekanten and Newton Klippe.

A survey of sections, together with the field data, suggests that in nearly all cases there are at least two size-classes in the clastic material, and also that there are few gradations between the two. We may therefore treat the rock fragments separately from the material of the matrix.

(a) Rock fragments.

The most complete record of the phenoclasts in the conglomerates or breccias was obtained at Trekanten (Plate 11). In summary, the content of the bands is as follows:

Basal breccia:	Blocks of the underlying gneiss (up to 40 cm). Red and purple shale (4 cm average). Quartz and feldspar.
Red and purple breccia:	Green gneiss (up to 10 cm) from below unconformity. Red quartzite (15 cm or less).
Conglomerate group:	White quartz. Dark purple quartzite. Green gneiss. Red quartzite and shale. Red jasper. Grey feldspar.

In the conglomerate groups, the well-rounded pebbles reach 10 cm across.

A specimen of a gneiss fragment (no. 73) from the basal breccia is an even-grained rock with an average grain size of about 2 mm. In section it resembles no. 168 above in texture, but the remaining alkali feldspar shows pronounced cross-hatching. The replacing minerals, forming about 30 per cent of the rock, are sericite, hematite, and microcrystalline quartz, the hematite occurring as patches or trails of tiny flecks which are bright red in reflected light.

No. 72 from the red and purple breccia is a chocolate-brown and yellow-green rock in which there are numerous feldspar fragments up to 8 mm, smaller quartzes, and indistinct pebbles of red quartzite. In section, the red quartzite is confirmed as the same type as in the underlying bed (see later section p. 46). The quartz fragments (strain-shadows) reach 3 mm across, and are either well rounded or angular, whilst the feldspar is clouded microcline showing some patchy replacement by sericite. One or two small fragments of sericitised gneiss are also visible. This rock is exceptional in that there appear to be a gradation between the large and small quartz clastics. The groundmass is described in the next section.

Several pebbles were obtained from the conglomerate group. Two pebbles of jasper-like material are composed of fine-grained quartz (0.02 mm) and dusty hematite (30 per cent). Indistinct worm-like trails or blebs of quartz, with mantles of hematite are characteristic, and one gets the impression that the material was once truly cryptocrystalline (nos. 74e and 74f). A section from a pebble which in the field was identified as vein quartz (no. 74b) is made up of microcrystalline quartz with lenticles or veins of strongly sutured coarser quartz with marked strain-shadows.

Two more pebbles (not. 74a and 75) macroscopically appear to be of dark grey quartzite. Under the microscope, however, there is little to differentiate them at first glance from fine-grained gneiss. The quartz is in irregular clusters of welded grains (0.1–0.3 mm), making up about 40 per cent of the rock. However, traces of original grain boundaries are visible in places outlined by iron staining or cryptocrystalline dust, and these original boundaries rarely coincide with present crystal boundaries. The original clastic grain size appears to have been 0.2 mm. Feldspar (10 per cent) is fresh-looking microcline in subangular grains showing considerable replacement by the groundmass. Much of the remainder of the rock is finely divided sericite with clusters of microcrystalline quartz and flecks or groupings of iron-ore.

From Trekanten, therefore, we can distinguish among the fragmental material (1) gneiss of a type similar to that immediately below the unconformity, (2) slightly recrystallised chert and jasper, (3) quartzite or siltstone derived from erosion of an underlying bed, and (4) quartzite or sandstone derived from a pre-existing sedimentary sequence.

A selection of pebbles from the basal conglomerate at Kaldbakur consists of recrystallised chert jasper, red shale, dark red quartzite and gneiss.

A section of gneiss (200d) reveals quartz (40 per cent), untwinned alkali feldspar (30 per cent), together with bleached biotite, iron ore (10 per cent), and sericitic alteration (20 per cent). The texture is xenomorphic with a tendency towards graphic intergrowths between quartz and felspar. The exceedingly fine-grained alteration material is chiefly sericite with microcrystalline quartz and chlorite.

No. 200a is a specimen of the dark red quartzite. In section this is immediately resolved as a sedimentary rock. The original clastic quartz grains are visible, often surrounded by much secondary silica, or outlined by dust in groups of welded crystals. These clastic forms are subrounded, and are often well flattened with longer axes (0.3 mm) parallel. Quartz forms about 60 per cent of the rock. Feldspar is clouded microcline (10 per cent) with a similar form to the quartz, but more angular. As before, the groundmass is largely microcrystalline sericite, with some finely-divided quartz, and irregular concentrations of hematite dust (10 per cent). A grain of apatite (0.1 mm) is also visible in section.

A pebble identified in the field as "vein quartz" is an aggregate of microcrystalline granoblastic quartz with patches of larger grains. The boundaries are usually of the straight welded type. It seems reasonable to suppose that this material is recrystallised cryptocrystalline silica, and that the original material was chert like the example from Trekanten.

(b) The cement.

In the basal breccia at Trekanten (no. 73), the matrix is formed of clastic quartz (60–70 per cent) and feldspar, in a ground of sericite, microcrystalline quartz, and hematite. The quartz grains are markedly angular, and vary considerably in grain size, with about 0.2 mm as a mean. Both it and the microcline show signs of replacement by the groundmass, slight in the case of the quartz, but marked in the case of microcline. The microcline is often in rather larger grains than the quartz, and is largely untwinned. Hematite is an important part of the groundmass, forming dusty skins on clastic grains, and also larger grains which replace quartz in some instances, but for others their rounded form and situation suggests a clastic origin. The sericite as usual is microcrystalline and mixed with fine quartz.

In the red and purple breccia (no. 72), the proportion of clastic quartz in the matrix is low, being commonly only about 20 per cent, and showing much replacement by the groundmass. The grain size is very variable. Apart from a little microcline, the clastics also include grains composed entirely of microcrystalline granoblastic quartz—evidently formerly chert. The groundmass is largely sericite with a little quartz. In some parts of the slide, however, the matrix is hematite-rich, and in these parts the amount of clastic quartz is much greater. The contact between the hematite-rich and sericite-rich parts is sharp and irregular, and "pebbles" of the dark material are enclosed in the lighter.

Regarding the conglomerate, a sample of the cement (no. 75) is composed of much-replaced clastic quartz of variable grain size (generally 0.2 mm) opaque iron ore flakes (0.1 mm), and traces of feldspar in a groundmass with sericite, fine-grained quartz, and a little hematite. In this slice, as well as no. 72, there are signs of orientation in the sericite.

Further evidence concerning the basal breccia comes from Helgoland (no. 167). The matrix here is banded: some bands contain clastic quartz and feldspar in abundance; others have an abundance of sericite or hematite. The grain size of the clastic quartz in most cases is approximately 0.5 mm, and in some bands it forms about half the rock material. In the same bands, the feldspar is largely replaced by sericite and chlorite, and the ground contains a higher percentage of finely-divided quartz than micaceous minerals. A few fragments of material with finer-grained clastics and a somewhat larger proportion of iron ore occur in a quartzose band, obviously of clastic origin. The gradation into iron-rich bands is sharp, or takes place through a zone where clastic grains are mantled in ore. One such band is almost pure iron ore.

Finally, a section from the breccia matrix at Dickens Bjerg (no. 171) is formed of clastic quartz (30 per cent), with muscovite, sericite, iron ore, and microcrystalline quartz. Here the clastic quartz (0.2 mm) is even-grained, though subangular, even sharply angular in some cases, and often with indistinct boundaries due to attack by the groundmass. The muscovite is in parallel laths (10 per cent), and is evidently of clastic origin. However, the finely-divided sericite, which tends to congregate into lenticles and which also shows some orientation, is part of the cement. Both translucent and opaque hematite occur as rounded clastic grains, and dusty material scattered in the groundmass. One or two small rounded grains of rutile and zircon are present, and tourmaline was noted in a heavy mineral separation.

Thus in the fragmental rocks, the cement contains clastic grains of quartz, microcline, recrystallised chert, muscovite in some rocks, and iron ore. The high angularity of the quartz-grains in one specimen may put them into a different category from that of the quartzites described below: they have either been subjected to corrosion, or they have been derived locally. Likewise the potash feldspar is in two classes: untwinned grains, rather large, derived from the local gneiss; and cross-hatched microcline of the same type as in the succeeding quartzites. The clastic opaque iron ore appears to be hematite because there are no strongly magnetic minerals in heavy separations, The groundmass is hematite, finely-divided quartz, and sericite.

3. Quartzites and Quartzitic Sandstones.

Since they are in most cases metamorphosed, or at least strongly lithified, the nomenclature of the rocks with sand-grade clastic material is doubtful. In the field many such rocks behave like quartzites: in the laboratory they may contain only 70 or 80 per cent of clastic quartz, and an indefinite, though often small percentage of micro-crystalline quartz. In the broader and looser terminology of a metamorphic geologist such rocks would be quartzites: to the sedimentary petrologist they are sandstones, or quartzitic sandstones. Since the distinction is academic in this case, I have made free use of both names in the following account.

Sufficient specimens were collected at Trekanten and Helgoland (PEACOCK 1956a pp. 20–22) to illustrate the variations encountered in these rocks, and the material from these two localities is described first.

(a) Trekanten (Nos. 65, 70, 72, 79).

The clastic grains in the quartzites here are quartz, microcline, chert (microcrystalline quartz), quartzite, muscovite, iron ore, mudstone fragments, and rare rounded fragments of matrix.

Quartz in subrounded or subangular grains varyies from almost spherical in shape to tabular with a ratio of maximum to minimum diameters as much as 4 to 1. In size, the more usual range is 0.2 to 0.3 mm, though occasional larger fragments are present, perhaps consisting of several crystals. In one specimen (No. 79), however, the average grain size is 0.6 mm. Most of the grains are strain-shadowed to some degree. A feature of the grains is the coatings of iron ore, generally hematite or yellowish iron stain, such coatings being either broad and well seen, or grading down to microscopic thicknesses. Growths of secondary silica are present on many grains, generally as a thin growth on the hematite skins, and in no. 79, the secondary silica is pronounced to the extent that several welded grains may have formed, the crystal interfaces cutting across the original clastic grains. One can see replacement by the groundmass on most grains, this replacement attacking the secondary silica as well. The percentage of quartz sand varies from 50 to 80, and the grains may thus be frequently or infrequently in contact.

Microcline. Like the quartz this mineral is in subrounded or subangular grains, but the original shape is often lost due to the partial replacement by the groundmass. The grain size in the original state appears to be somewhat smaller than that of the quartz. Two varieties of the mineral are present—(1) fresh, and (2) clouded with cryptocrystalline dust—but both show similar frequent twinning and replacement. The proportion is generally up to a quarter of the total clastics.

Chert—microcrystalline quartz. Grains of this material are uncommon, and sometimes difficult to distinguish from the groundmass quartz. Where present, the grains are well rounded, and consist of aggregates of microcrystalline quartz, usually less than 0.2 mm across.

Quartzite. Again this material is rare, and forms grains externally similar to the ordinary quartz clastics, but composed of a number of crystals with tessellate borders. They could have been derived from metaquartzite, chert, or the partially granulated quartz grains found in any rock subject to stress.

Muscovite. In one or two rocks, a few parallel flakes of this mineral are visible.

Iron ore. Sparse, well-rounded grains of opaque iron ore are present, the grain size being about 0.05–0.1 mm.

Fragments of matrix. These are present in no. 70 only (the red quartzite between the basal and upper breccias at Trekanten). Of similar size and shape to the quartz clastics, they are composed of sericite flakes with a thick outer coating of hematite giving the form to the grain.

Mudstone fragments. One specimen (no. 79) with an included mudstone fragment was sectioned. Part of the material is entirely exceedingly fine-grained sericite and disseminated hematite dust with very small amounts of quartz and rare muscovite flakes. The remainder includes the remains of scattered quartz and feldspar clastics (0.2 mm) in a matrix with a larger quantity of hematite.

The groundmass of these rocks invariably includes micro-crystalline sericite, quartz, and iron ore. Of these, the sericite is usually the most important, but quartz may be present in large amounts. Iron ore is usually accessory.

The sericite, though commonly mixed with quartz, tends to form ill-defined patches which alternate with quartz-rich areas, and a certain degree of alignment of laths is evident in some cases. Iron ore is hematite (red in reflected light) and opaque ore, probably also hematite. The red hematite occurs as microcrystalline dust, while the other forms well-defined round grains (clastic) mentioned above. Accessory minerals visible in thin section are zircon and rutile, the former being the more common.

Looking at the specimens from the point of view of distribution in the succession, little variation is evident from bottom to top, excepting perhaps a falling-off in the proportion of iron ore.

(b) Helgoland.

As before, the clastic grains in the quartzites are quartz, microcline, quartzite, and recrystallised chert in a groundmass of sericite, microcrystalline quartz, and a little iron ore (Plate 3 a).

In two specimens from the normal quartzites (nos. 157 and 160), the grain size of the clastic quartz varies from 0.2 mm in the upper rose quartzite to 0.6 mm in the lower dark quartzite. The packing is noticeably higher than at Trekanten, with a greater frequency of welded boundaries due to pressure welding or interfaces between growths of secondary silica. The degree of sorting is much higher in the upper rose quartzite, with a diminution in numbers of tabular forms among the subangular grains. Strain shadows are more marked in the lower example (no. 160).

The feldspar is twinned microcline, the two varieties (clouded and clear) present at Trekanten again being present. Replacement by the groundmass is slight to considerable, contrasting with the little-altered quartz. Chert and quartzite fragments resemble the quartz clastics in form, and jointly make up about 10 per cent of the clastics while the feldspar makes up about 20 per cent.

A feature of the groundmass (10–20 per cent) of the two specimens is the dominance of sericite over microcrystalline quartz. The grain size tends to be smaller than at Trekanten. The iron ore in the two rocks is very small in amount, forming exceedingly thin diffuse coatings on the original quartz grains, inside the skin of secondary silica, where this is present. Some scattered diffuse ore, gathered into small flecks here and there, is present in the groundmass proper: some of this may be clastic. Examination of the iron ore under reflected light indicates that it takes three forms: hematite; opaque black, lustrous material (probably also hematite); and a form giving a matt-white reflection (probably ilmenite). Minor accessories are zircon and euhedral epidote.

No. 159, from a gritty band in the rose quartzite, differs from the more normal quartzites in several features. Most of the cementing material is secondary silica, so a welded appearance is characteristic. The sericite forming the remaining cement is very patchy. The quartz (0.6 mm) is well sorted, and shows a much higher degree of rounding and sphericity than normal. Much of the microcline is unaltered, though slightly clouded, but some grains show partial or complete replacement by calcite. No secondary growths occur on either microcline or chert, and their sphericity is variable. There appears to be a gradation between the recrystallised chert and quartzite fragments.

(c) Comparison with other areas.

A specimen from Dickens Bjerg (no. 173), is a buff quartzite, very similar in thin section to the average material at Trekanten, though the iron ore content is negligible. The clastic quartz grains (0.3–0.4 mm) and partially sericitised microcline form about 70 per cent of the rock, and individual grains are rarely in contact, being separated by a mantle of sericite. The ground of cryptocrystalline quartz and sericite shows slight orientation of the sericite laths in places, especially as outgrowths on some quartz grains.

Feldspar-free quartzites come from Poulsen Nunatakker and Farvel Nunatak, both specimens (nos. 204 and 51) being fine-grained red quartzitic sandstones with bedding outlined by darker bands between 1 and 10 mm thick and 3 to 10 mm apart. In section, the clastic quartz grains are of variable sphericity and arranged with longer axes parallel to the bedding. The grains are frequently in contact, partly owing to a growth of secondary silica, and there is usually a thin coating of hematite. Chert (microcrystalline silica) is the only other clastic, and is sparsely distributed. The cement is almost entirely sericite in larger flakes than usual, together with a few specks or flecks of hematite and opaque ore. The only accessory mineral in either of these rocks is a grain or two of epidote.

The chief interest in these latter two rocks in the fact that they are completely feldspar free: in all other respects they are typical Trekant quartzites. The two rocks probably outcrop only a short distance from the basement gneiss, as indicated by boulders of pegmatite and gneiss. Again, none of the other quartzites picked up loose in the moraine, quartzites which probably belong to the Trekant Series, contain feldspar. The inference is that no feldspar was deposited with the lowermost Trekant Series (excluding basal beds proper) on the submerged mountain range between Poulsen and Farvel Nunatakker.

4. Mudstones and Siltstones.

A mudstone from Helgoland (no. 155) is a dull red compact rock with a splintery fracture, but little sign of fissility. Very fine parallel muscovite flakes are the only visible minerals. The section shows it to be an exceedingly fine-grained rock in which quartz, sericite, and iron ore take part. An alignment of the sericite is the only marked structure, the remainder of the rock being micro-crystalline quartz, and hematite dust or flecks. It is probable that quartz is the most important mineral, followed by sericite, and the percentage of hematite is very small. One or two ovoid concretionary bodies occur with the plane of flattening parallel to the bedding: in these hematite is the principal mineral, though there is a tendency for there to be a quartz rich core.

A siltstone (no. 77) from Trekanten is somewhat similar in composition, but shows about 30 per cent of angular quartz grains up to 0.1 mm in addition. The iron ore forms about 10 per cent of the rock, occurring as wisps, lath forms, small flecks, and finely-divided material. Most of it is hematite, but some magnetite is present. Some original banding is hematite-rich with few clastics, but there are signs that clastics were once present and have been replaced by the remainder of the groundmass.

No comment is required at this stage on these rocks beyond remarking the peculiar mineralogy, the notable absentee being chlorite.

5. Metamorphosed Trekant Series.

From what has gone before, it is evident that the beds of the Trekant Series have undergone slight metamorphism at Dickens Bjerg, and at Trekanten itself. This metamorphism here expresses itself in a tendency to alignment of the sericite, an increase of strain shadows in the quartz, and a certain increase in the groundmass silica coinciding with a decline in the area occupied by quartz clastics. The metamorphism becomes much more pronounced in the folded belt of N.W. Dronning Louise Land, though remaining slight to the extreme west.

A specimen of dark brown-grey fine-grained quartzite (no. 52) from Newton Klippe contains about 70 per cent sand grains (quartz and microcline) in a matrix of sericite, quartz, and minor iron ore, approximating to the commoner type of quartzite described above. However, where grains are in contact, a serrated margin and traces of granulation can be seen, and penetration of the margins by sericite laths is in evidence at contacts with the groundmass. Both the sericite and fine-grained groundmass quartz show some orientation. The iron ore is in the form of minute red-brown scales sparsely distributed through the rock. One or two tiny grains of zircon are visible in the section.

From Regnbueklippe, a specimen of the unconformable quartzite (no. 330) obtained by WYLLIE shows a higher degree of metamorphism. Though the clastic microcline here (clear and clouded) is little altered and retains its sub-rounded form, the quartz has undergone a marked degree of recrystallisation. Though some of the quartz sand grains retain their original shape, much is granulated, recrystallised, and spread into the groundmass. This recrystallised material has a grain size of about 0.03 mm. The sericite shows some alignment. Quartz in mica-rich areas is much less recrystallised.

A similar sequence of metamorphism can be made out in north Dronning Louise Land. WYLLIE gathered a specimen from the brown Trekant quartzite below the Zebra Series at the west end of Zebra Klippe (no. 282). Here the section shows that while the margins of the quartz sand grains have been little disturbed (excepting for slight replacement), the sericite of the groundmass is strongly orientated. The iron ore is in brown specks, which are white under reflected light (probably partly ilmenite; partly hematite). One or two grains of chert are visible, with irregular boundaries, and the usual percentage of microcline is present showing some replacement by the groundmass.

No. 230 was obtained from the main cliff on the S.W. face of Prins Axel Nunatak. This is a grey-green quartzite, in which a preferred mineral orientation can be seen in hand specimen. In section, the quartz sand grains have assumed a dimensional orientation, and are in fact porphyroclastic and show much granulation. The feldspar, however, remains unmortared. Sericite forms about 20 per cent of the rock, and shows a considerable tendency to wrap around the clastics and form trails parallel to the preferred orientation of the quartz. There is much fine-grained quartz derived from the quartz sand, with a grain size of 0.01–0.02 mm. Minor accessories are zircon and leucoxene flecks.

An extreme example of mortaring comes from the S.W. side of Rutherford Bjerg (no. 229). Here isolated quartz porphyroclasts up to 4 mm long, with strong undulose extinction and mortaring, are embedded in a groundmass of foliated muscovite and quartz. The quartz folia are long and lenticular, with a grain size of about 0.01 mm, and have obviously been derived from porphyroclasts, whilst the muscovite (0.1 mm) is derived from the original sericite. A little iron ore is arranged in trails of granules, together with one or two rounded apatites.

Wyllie obtained a specimen of red quartzite not far above the unconformity on the south side of Rutherford Bjerg. In this rock recrystallisation has proceeded further, but deformation is less intense. The clastic quartz sand grains show all stages of breaking down and recrystallisation, the recrystallised grains reaching a size of 0.03 to 0.04 mm. Some of the feldspar is almost replaced by sericite, but some remains fresh and undeformed. The sericite shows little growth, though some of it is re-orientated parallel to a dimensional elongation of the quartz.

Below the quartzite here there is an arkose which grades down into the gneiss below and to the east. In this arkose (no. 474) the quartz and microcline form large porphyroclasts separated by fine-grained muscovite and granular quartz (0.05 mm). Though the microcline here shows much patchy replacement by the muscovitic ground, the untouched parts are notably fresh and beautifully twinned. Minor accessories are zircon and one or two irregular grains of tourmaline.

B. PETROGENESIS OF THE TREKANT SERIES

The basement rocks immediately beneath the unconformable Trekant Series have been subject to chemical alteration resulting in progressive replacement of the minerals by sericite, quartz, and iron ore. In addition, a little chlorite and carbonate may also be present. The quartz grain in the gneiss show slight replacement, the potash feldspar much more, and plagioclase and biotite are often totally converted.

In the overlying Trekant Series, the basal fragmental deposits contain material derived from the weathered gneiss, and sandstone and mudstone fragments derived from reworking of sediment which had recently been laid down. A second group of pebbles are of recrystallised chert and jasper, and more indurated quartzites. In these latter (sedimentary) quartzites, the large proportion of matrix compared with the normal Trekant quartzites suggest they belong to an older sedimentary group which suffered the same chemical alteration as the gneiss below the unconformity.

The cement of the fragmental deposits varies from quartzite (originally sandstone) to a material composed of sericite and microcrystalline quartz, and iron ore. The small clastic grains in the cementing material are quartz and microcline of local derivation, quartz and microcline from more distant sources, muscovite, and iron ore. Rutile, zircon, and tourmaline may be present as minor accessories.

In the quartzites, the amount of clastic material varies between 70 and 90 per cent, and consists of quartz and microcline in the ratio of about 4:1, with very subsidiary recrystallised chert and iron ore. A few quartzite fragments might equally well be recrystallised chert with a higher degree of crystallinity. The average grain size is 0.2 to 0.3 mm, though there is some variation in each section, and coarser beds occur. The roundness and sphericity are moderate, and tabular sand grains are quite common: in coarser beds, the roundness and sphericity, and the degree of sorting, are very high.

Secondary silica growth on the quartz is characteristic, often separated by a thin skin of iron oxide from the sand grain proper. The secondary silica and original quartz grains show a varied degree of attack by the groundmass, a feature partially bound up with metamorphism. Thus a sequence of genetic interest can be built: shaping of the sand grains; the obtaining of a ferruginous coating: the deposition of secondary silica: partial replacement by the groundmass.

The feldspar clastics are all microcline, and can often be divided into clouded and clear varieties. Secondary growths are absent, and replacement by the groundmass sericite is often marked. Replacement by calcite was noted in only one specimen, this being a gritty band in the rose quartzite of Helgoland. There appears to be no regular variation of feldspar content from bed to bed: the absence of feldspar in specimens from the Outer Nunataks can be put down to non-deposition of the mineral in the lower Trekant Series.

An interesting feature of the recrystallised chert clastics is that there are no growths of secondary silica on them. This implies that the silica of the chert must have been in a different crystalline condition to that of the clastic quartz during the period of deposition of secondary silica. This, then, is further evidence that the secondary silica deposition took place before any metamorphism of the beds.

Clastic iron ore is in rounded grains, smaller than those of quartz and feldspar. It is opaque in transmitted light. However, heavy separations failed to yield any strongly magnetic material, though it is not impossible that such might be present in a very finely-divided state attached to other minerals. This suggests that this clastic ore is hematite.

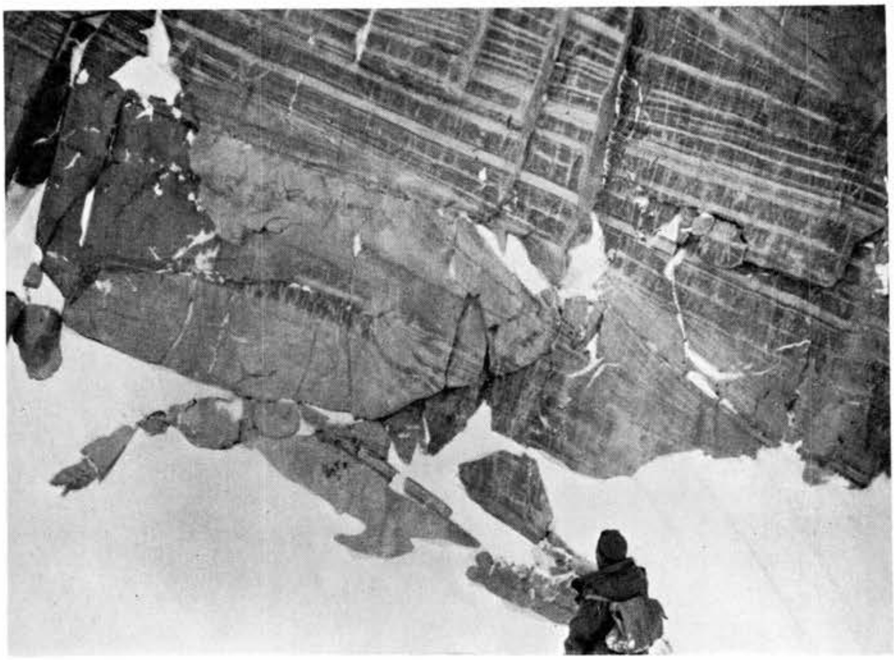

Fig. 7. Current-bedding and fracture cleavage at Trekanten. Photo: P. J. Wyllie.

The iron ores of the cement are hematite, ilmenite, and "limonite". Their habits are as follows:—

Hematite:—	Coating on quartz grains. Also flecks and fine dust.
Ilmenite:—	Clusters of flecks with a matt-white reflection.
"Limonite":—	A staining on some quartz grains.

Apart from the subsidiary iron ore, the cementing materials in the quartzites are sericite and microcrystalline quartz. Where the clastic grains are closely spaced, as at Helgoland and the outer nunataks, sericite is almost the only constituent (other than secondary quartz growths and iron ore). At Trekanten, however, a considerable proportion of microcrystalline quartz makes its appearance, and the percentage of quartz clastics diminishes. Here also there is penetration of quartz grains by sericite laths, and a tendency to parallelism of these latter also. These facts suggest that the groundmass quartz is largely re-precipitated silica derived from the clastic quartz, and is a phenomenon due to metamorphism.

Among the pelitic beds, the siltstones carry a proportion of small angular clastic quartz grains together with exceedingly fine-grained quartz, sericite, and hematite. Here the iron ore is all finely-divided.

The colour of all the Trekant beds seems to be controlled by (a) the sericite and (b) the types and relative proportions of iron ore. Thus sericite as almost the sole cement in a rock gives rise to a yellow or greeny-yellow shade. A small to large proportion of finely-divided hematite gives a dominant red cast, but if the hematite is in larger grains, the rock has a purple appearance.

Decolourization of red quartzites in current-bedding units, in isolated spots, and also adjacent to fracture cleavage and joints, is a widespread phenomenon in the basal beds (fig. 7). In the case of the current-bedding, light and dark colouring is probably depositional, since it can commonly be seen in many red sandstones. The decolourization adjacent to joints and fracture cleavage can most readily be explained by movement of iron during the incipient metamorphism which most of the rocks have undergone. A similar phenomenon has been described from the Thule Formation of N.W. Greenland (KURTZ and WALES 1950) where it is attributed to solutions from basic intrusions moving along many minute fractures in the rock, reducing the iron, and eliminating the red coloration.

Concerning the metamorphism of the Trekant quartzites, the changes may be tabulated as follows:—

Original State		Stage 1		Stage 2
feldspar	→	no change	→	no change
quartz	→	attack by groundmass	→	granulation and breakdown
ground quartz +		contribution from clastics	→	recrystallisation
sericite	→	slight orientation	→	marked orientation, some recrystallisation
hematite	→	no obvious change	→	no obvious change
ilmenite	→	no change	→	sphene

In this scheme, stage 1 has been reached at Trekanten, and stage 2 is confined to N.W. Dronning Louise Land, particularly in the Splinten range and Prins Axel Nunatak. The evidence regarding associated changes in the pelitic interbeds is lacking, but it seems that a similar scheme could be built up for the fragmental deposits and altered gneiss beneath.

Not much direct evidence is available concerning the character of the surface on which the Trekant Series was laid down. At Helgoland and Dickens Bjerg, the beds appear to lie on a planned-off surface of Western Gneisses. Further north, at Trekanten, however, there is a relict hill standing 70 metres above the surrounding gneiss, and at Newton Klippe, the truncation of bedding structures by the underlying gneiss suggests some range of relief. The surface at Thomson Klippe appears to be level. We can therefore imagine a surface of low relief, broken here and there by monadnocks.

That the Trekant Series is water-deposited is evidenced by the constant occurrence of ripple-marking and current-bedding. Evidence for very shallow water conditions is provided by the rare, discontinuous layers of mudstone, often with desiccation cracks which may be deep. Current-bedding is characteristic of both continental and shallow marine deposits, but the thinness and other characteristics of the mudstones point to deposition in temporary lakes, and this, together with the red bed nature suggests continental deposition (e. g. PETTIJOHN 1948 p. 172).

Before seeing whether the petrography gives any further lead regarding conditions of deposition, we must consider whether a line can be drawn between strong lithification and the beginnings of metamorphism. The nearest approach to the pre-metamorphic mineralogy is in the S.W. Nunataks, and the outer nunataks. Here the quartzites contain quartz and microcline clastics in a cement of sericite, with a little microcrystalline quartz and iron ore. Does this sericite approximate to muscovite, or does it lean towards the clay minerals?

The optical data suggests mica-like material with a birefringence of at least 0.3, and we can eliminate such minerals as kaolinite, and allophane. Both indices of refraction appear to be greater than 1.53, and there is no pleochroism. The best fit among the clay minerals is the illite group (GRIM 1953 p. 279).

X-ray diffraction work on clay minerals usually required special techniques (GRIM 1953 pp. 84–86). However, the Dept. of Physical Chemistry at King's College very kindly took a powder photograph of a mudstone specimen, and although no special methods were employed, a pattern near that of muscovite was obtained.

In a study of the effects of temperature and acidity on the alteration of feldspars, FOLK (1950) indicates that under laboratory conditions, sericite and muscovite do not crystallise below a temperature of 200° C. On the other hand, sericite is a common constituent of Precambrian sandstones in unmetamorphosed areas of North Greenland (FRÄNKL 1954 p. 34). This conflict of evidence is probably because laboratory experiments cannot imitate the geological time factor. The best that can be said is that the Trekant Series has probably been slightly affected by metamorphism nearly everywhere in Dronning Louise Land, with the proviso that some of the effects might be due to diagenesis.

The next problem is to account for the alteration of the gneiss below the Trekant Unconformity. The agencies responsible for such alteration could be pre-Trekant weathering of the gneiss surface, or attack by circulating waters during or after the deposition of the Trekant Series. Relevant points are summarised below:—

(1) The replacing minerals in the gneiss are the same as those in the cement of the quartzites, and for that matter are the same as the minerals in the mudstones.

(2) In a few places, e. g. Trekanten and Rutherford Bjerg, a regolith of gneiss fragments overlies the gneiss surface.

(3) Pebbles of underlying quartzites occur in overlying beds. This means that some form of cementation must have taken place immediately after deposition.

(4) Quartz sand grains in the quartzites are sometimes entirely mantled by iron ore. This suggests that such a mantle must have been acquired after transportation and during deposition. There was then accretion of secondary silica, followed by partial replacement of this and the quartz sand grains by sericite.

(5) The feldspar in the quartzites is much less replaced by sericite than similar feldspar in the gneiss.

(6) Gneiss pebbles in quartzites are in the same state as the gneiss immediately below the unconformity. Older quartzites as pebbles show much more replacement than Trekant quartzites.

Of these, point (1) is in accord with the idea that replacement was due to circulating waters. Points (3), (4) and (6) are neutral in this discussion. Some form of cementation after deposition certainly does not preclude later changes due to ground water. It is quite conceivable that secondary silica can grow on quartz grains while a cement is present, or at least while a cement is being introduced. Nevertheless, no cement seems to be entrapped between the secondary silica and the host quartz grain. We know that pebbles of quartzite and mudstone of an underlying rocks occur in overlying beds, suggesting rapid cementation. To reconcile this with the evidence of the secondary silica, it seems that the latter must have started growing from the time of deposition onwards. The sericitic replacement of the quartz could therefore have begun at any time between a geologically short period after deposition, and the later metamorphism, though the association with metamorphism is marked, as shown above.

Point (5) seems to effectively kill any argument for large-scale post-depositional circulation of ground water. It is not conceivable that such ground water would discriminate between microcline in the quartzites and microcline in the geniss beneath. Since the gneiss pebbles in the quartzites are in the same state as the gneiss below, we must conclude that they were derived from a weathered gneiss surface. The regolith (point (2)) must be due in part at least to deep weathering of the old gneiss surface, and not entirely to the erosional action of the streams which laid down the Trekant quartzites.

A comparable description of a Precambrian weathered surface is given by Sharp (1940, pp. 1245–1279). In this case the deepest parts of the weathered gneiss show chloritisation of the biotite and kaolinisation of the feldspar. At 3 ft. below the unconformity, the biotite, chlorite, and feldspars have disappeared and the rock consists of quartz, muscovite, and iron oxides. Near the surface, there is an increase in iron oxide content. This uppermost zone is similar to the weathered gneiss below the Trekant Series, but comparison cannot be taken further since no profile from unweathered gneiss to the base of the unconformity was collected in Greenland.

The question of sericite versus muscovite has already been discussed to some extent, and it has emerged that the Trekant Series has probably suffered at the very least a slight metamorphism. However, we must now try to account for the fact that these rocks appear to be high in potassium (possibly sodium also), and low in carbonate. Large-scale circulation of ground water seems to be inadmissable as an agency for the transfer of ions, and therefore the present chemical composition of the cement must have been almost fixed shortly after the sandstones and shales were laid down. The chemical composition of the cement is a function of the conditions of deposition.

Correns (1950, p. 51) gives solubility curves of SiO_2 gel and calcium carbonate in fresh water and seawater. While the solubility of calcium carbonate falls off very rapidly between pH 6.5 and 7.5, that of silica shows a gradual increase. The intersection of the curves is at pH 7.4 for freshwater, and pH 7.1 for seawater. We know that carbonate was sparsely deposited in some beds, and also that secondary silica was precipitated shortly after deposition. This might suggest slightly acid conditions. However, we have no means of knowing how much silica was available for precipitation, or for that matter how much carbonate though there is an obvious source for both in the gneiss. The solubilities must also vary with temperature.

It is unlikely that potassium was fixed initially in sericite. Probably a clay mineral was precipitated with the sand grains or introduced shortly afterwards into the unconsolidated sediment. Clay minerals, e. g. illite, may contains potassium in their structure, and more potassium ions could be adsorbed from groundwater. According to Grim (1953, p. 342) fixation of potassium would seem to exclude a climate with dominant leaching.

Iron ore is present both as clastic grains and as part of the cement in the Trekant Series. Commenting on skins of iron ore on sand grains in the Penrith Sandstone, Dunham (1953, pp. 27–28) suggests that finely divided iron oxide was in suspension in the lagoon waters in which the sandstone accumulated, and that each grain became coated during sedimentation. However, there are no means of knowing whether the iron in the Trekant Series was carried in the ferrous or ferric state, or whether organic matter played any part in its precipitation. Simple algae were present in the Precambrian, in sea water at any rate, as is evidenced by the occurrence of algal limestones.

The conclusions which can be drawn are few. The Western Gneisses were subjected to extensive subaerial erosion leaving a surface of low relief broken by a few monadnocks. Deposition took place under continental conditions on a surface on which some of the weathered regolith-remained. Some of the regolith was reworked and redeposited as basal breccias and arkoses, and at the same time pebbles of chert, jasper, and quartzite brought in from some distant source. Silts and muds were laid down in temporary lakes, but most of the clastic material was quartz sand with microcline and chert brought from some distant source. Cementation probably took place almost immediately under conditions in which there was enough groundwater to facilitate rapid precipitation of secondary silica on quartz grains, but not enough movement of such groundwater to promote dominant leaching. The climatic conditions under which deposition took place were probably not much different to those obtaining during the weathering of the old gneiss surface.

THE ZEBRA SERIES

Unlike the Trekant Series, which can be traced along the whole west line of Dronning Louise Land, the Zebra Series outcrops in two separated areas, i. e. north of the Borgjøkel, and in the S.W. nunataks. In the S.W., the thickness approaches 70 metres, and at Zebra Klippe the thickness probably does not exceed 100 metres. Thus only the basal beds of the series are generally preserved (coarse, light and dark, gritty quartzitic sandstones with occasional beds of green and purple siltstones or shales). Light yellow cross-bedded quartzitic sandstones appear to be more important higher in the succession, and at Suzanne Nunatak limestone is present in beds which probably belong to the Zebra Series. The series seems conformable on the Trekant Series in the south, but is unconformable on Trekant Series and Western Gneisses further north.

A. PETROGRAPHY

(a) S.W. Nunataks.

As with the Trekant Series, the Zebra Series shows slight metamorphism in the folded areas of N.W. Dronning Louise Land, and in a consideration of the petrography, the S.W. nunataks afford the nearest approach to the original lithology. At Helgoland and Falkonerklippe specimens were obtained from fallen blocks.

No. 169 is a white, gritty quartzitic sandstone composed chiefly of fine sand with bands of somewhat coarser material (1 mm) and scattered bluish quartzes up to 1 cm across. In hand specimen, there is a strong resemblance between this rock and the lowermost quartzite of the Cambrian succession in the N.W. Highlands of Scotland. In thin section it is largely a mosaic of welded quartz grains between 0.5 mm and 1 mm across with a few larger grains. The outlines of the original quartz sand grains are not always easy to make out, but where preserved as trails of fine dust it can be seen that they are rounded to sub-rounded, with variable sphericity. Some dust trails also cross the quartz grains. Apart from the secondary silica, the only other minerals are a few sericite laths and flecks of hematite. Minor accessories are rutile and tourmaline (a tiny grain of each).

A representative of the dark beds, no. 170, is a sandy quartzite with impersistant bands of coarse gritty quartz (grain size 2 mm). The coloration is purple to light grey according to the amount of dark matrix. The clastic quartz, which forms 70–90 per cent of the rock in different bands, occurs substantially in two grain sizes. Of these the larger (up to 2 mm) show a much higher degree of sphericity and rounding, and where bands of this one size occur, much secondary silica welds the grains. The smaller grains (0.2 mm) are angular and show great variation in form. However, the grain boundaries of both grain sizes are serrated in detail due to attack by the iron ore and sericite cement. As in the previous specimen in the grains show dust inclusions and undulose extinction.

The cement forms up to 30 per cent of the rock, the proportions being greater in finer-grained areas. Sericite (muscovite) tends to form rounded patches in which some orientation of laths at right angles to each other can be seen, giving the impression of a grid. Both opaque iron ore and blood red hematite are present, and form over two thirds of the cement in places. The fact that the muscovitic areas generally contain little iron ore, and are sharply delineated, suggests that the iron ore is a replacement phenomenon. There are no obvious skins of iron ore on the original clastic quartz boundaries.

A fallen fragment of hard purple and bright green shale presumably derived from the Zebra Series (no. 187) shows numerous small flakes of muscovite on the bedding planes. In section it is composed of angular clastic quartz grains up to 0.15 mm, parallel flakes of clastic muscovite (0.2 mm) in a cement of microcrystalline sericite and variable quantities of iron ore. The clastic quartz shows marginal replacement to sericite, a feature well shown in iron-rich areas where the original outline of the grains are retained. Where the iron ore is absent, the amount of quartz diminishes, and the sericite areas contain dusty trails parallel to the bedding. As before, both opaque ore and red hematite are present, being in a finely-divided state, or in larger flecks. In this rock, relations of the cement to the clastics suggest that the replacement of the quartz by sericite took place after the introduction of the iron ore.

(b) Zebra Klippe.

WYLLIE collected two specimens from Zebra Klippe. One (no. 281), from the white gritty quartzite, is composed of quartz (0.4 mm) with a few larger grains (3 mm) in a matrix of sericite (10–20 per cent). The quartz shows some dimensional orientation and in places where the grains are not mantled in sericite, the contacts tend to be serrate, and sometimes granulated. The sericite is partially orientated, and infiltrates through the boundaries of the quartzes. A grain of tourmaline (0.2 mm) is the only accessory.

The other specimen (no. 280) is from a darker band. This is similar to 281 excepting in the occurrence of a small proportion of dusty iron ore and some exceedingly fine-grained quartz with the sericite. Strain shadows are marked in the quartz.

There is no doubt that these rocks are petrographically closely similar to those on Helgoland some 30 miles to the south, excepting that they have undergone slight metamorphism.

(c) Prins Axel Nunatak.

Two specimens gathered from Kap Trekløver illustrate the nature of the Series here. No. 489 is a white gritty quartzite which in section shows blastopsammitic quartz grains (1.5 mm) separated by films of granular quartz and a little muscovite. The granular quartz grains average about 0.02 mm across and form about 20 per cent of the rock. No. 491 from a white and purple banded quartzite shows stronger orientation of the original quartz sand grains, and orientated trains of disseminated iron ore in parts of the groundmass (Plate 3b).

Wyllie obtained two more specimens from the quartzites on the south east side of the nunatak. The white quartzite (no. 337) is composed of quartz porphyroclasts (1.5 mm) in a granoblastic quartz groundmass with a grain size of about 0.5 mm, but there is considerable gradation between the two forms. The larger quartzes especially have strong undulose extinction, with formation of curved lamellae of differing refractive index, and Boehm lamellae marked by opaque dust. Holmquist among others has differentiated between Boehm lamellae and lamellae of differing refractive index (1926). Weiss, from petrofabric studies believes that during the first stages of quartz deformation ruptures are formed parallel to (0001) and deformation lamellae by bend gliding on the basal pinacoid and rhombohedron (1954, p. 73), these presumably accounting for the "packet structure" of Holmquist (op. cit.), a feature present in an imperfect state in many deformed rocks in west Dronning Louise Land. Sander figures a quartzite with lamellae similar to those in no. 337 (1950, p. 141, Abb. 41).

A white and purple quartzite, no. 482, is also blastopsammitic with the outlines of the original clastic quartz grains clearly preserved by iron ore dust even where complete recrystallisation has taken place (Plate 4a). The porphyroclasts (0.5 mm) below all stages of breaking up, and as in no. 337, are strongly affected by undulose extinction with the formation of lamellae. In places, the iron ore dust marking clastic grain boundaries passes through the porphyroclasts, indicating either original secondary silica growths or accretion during metamorphism: in places also, some of the iron ore dust seems to mark boundaries of such secondary silica growths rather than clastic grain boundaries. The grain size of the granular quartz in the matrix is about 0.05 mm.

The iron ore (5 per cent), apart from the dust, is in numerous, partly-coelesced, tiny flecks showing some degree of alignment, and is accompanied by a little leucoxene. Minor accessory minerals in the groundmass are zircon and blue-green tourmaline.

The field appearance of the quartzites at the southeast side of Prins Axel Nunatak resembles that of the Zebra Series, and allowing for the greater degree of metamorphism, other similarities also occur in thin section. The quartzites can therefore be assigned to the Zebra Series with a fair degree of certainty, though a case can also be made out for placing them with the Britannia Sø Group. If the Zebra Series equates with the Britannia Sø Group as I shall try to show in another section, then, of course, the need for argument disappears.

(d) Vinkelklippe.

Two more specimens collected by WYLLIE illustrate the character of the light and dark beds here. No. 326 from the white quartzite is blastopsammitic, composed almost entirely of welded quartz grains. The larger grains (up to 1 mm across) show some strain-shadows, and have irregular serrated margins: their outlines, however, suggest that they are the remains of original sand grains. There is a gradation to the smaller grain sizes, which no doubt represent recrystallised material (0.1 mm). The degree of strain-shadowing here is much the same, as in the larger quartzes. Minor accessory minerals are green tourmaline, epidote (recrystallised), and zircon.

No. 328 from the dark quartzite, is definitely allied to the more normal quartzitic sandstones, containing recognisable quartz sand grains (0.4 mm) in a matrix of recrystallised muscovite (0.02 mm) and fine granular quartz. The quartz sand grains are not markedly strain shadowed. The dark colour is given by scattered clusters of magnetite euhedra (1 mm) which replace the other minerals in entirety. There is also a little dusty finely--divided iron ore.

Interesting features of the quartzite here are pockets of green material, which in thin section are seen to be of yellowish epidote (0.5 mm) with a minor amount of poikiloblastic quartz and a little sphene.

(e) Suzanne Nunatak.

WYLLIE's notes on the beds at Suzanne Nunatak suggest great resemblances to the Britannia Sø Group and Zebra Series. However, two sections of quartzite (kindly lent by WYLLIE) indicate a low degree of metamorphism. No. 320 from a rusty stained bed is blastopsammitic, with somewhat flattened clastic quartz grains (0.6 mm) in a ground of mortar quartz with a rather variable grain size. A few parallel wisps of muscovite are scattered here and there, and there are sparse granules of opaque iron ore. The colouring of the rock is derived from yellow limonitic staining between some of the quartz grains.

No. 321 was taken from a grey-green quartzite, and unlike no. 320 contains feldspar, and a considerable proportion (30 per cent) of aligned fine-grained muscovite. The original clastic quartz grains are considerably granulated, but probably varied in grain size from 0.2 mm (the majority) to 0.6 mm. However, the feldspar (microcline), which forms about a third of the clastic grains, though much replaced by the groundmass, is but little granulated.

To sum up, the petrographic features of the Zebra Series parallel those of the Trekant Series in many respects, particularly in the similarity of the cementing materials. However, there is evidence for diagenetic changes in the iron ore/sericite content of the material. In all the basal beds examined skins of iron ore on the sand grains are absent, and there is no feldspar. If the beds on Suzanne Nunatak are Zebra Series, then the incoming of feldspar in the quartzites together with the occurrence of limestone indicates that they must be higher in the succession than the other rocks examined.

B. PETROGENESIS

The metamorphism of the Zebra Series follows much the same lines as that already described in the Trekant Series, and is carried a stage further in the specimens from the southeast side of Prins Axel Nunatak, and in one specimen from Vinkelklippe. These quartzites are either blastopsammitic with a structure like that of a mortar gneiss (Buddington 1939, p. 252) or completely recrystallised. The recrystallised quartz has maximum grain size between 0.5 mm and 0.1 mm (nos. 337 and 326).

An interesting commentary on the apparent variability of metamorphism is the occurrence of completely recrystallised quartzite and less affected quartzite in adjacent beds as Vinkelklippe. This latter rock (no. 328), however, contains idioblastic magnetite crystals in contrast to the more usual dusty iron ore of the more recrystallised quartzites mere and at Prins Axel Nunatak. This divergence could be ascribed to (a) differential porosity, (b) the inhibiting effect of muscovite on the recrystallisation of quartz, (c) variation in shearing stress, or (d) presence of a crush belt in the gneiss beneath. Without having visited this particular exposure it is impossible to choose between the various possibilities.

With regard to *conditions of deposition* there is not much evidence. In the south of Dronning Louise Land, the Zebra Series of

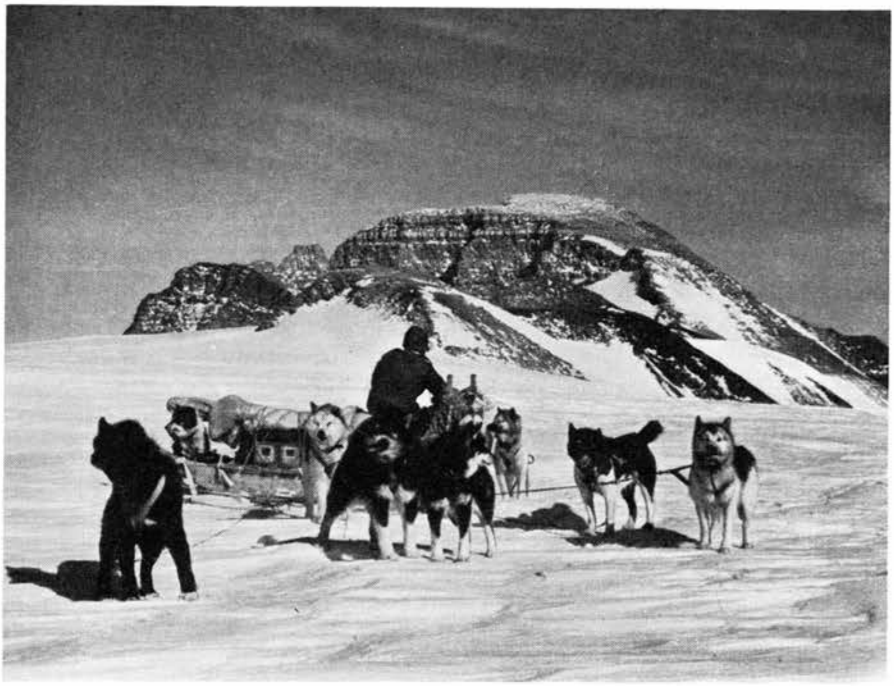

Fig. 8. Helgoland from the south-east. Beds of the Zebra Series resting with apparent conformity on the Trekant Series. Photo: R. Brookes.

the S.W. Nunataks lies apparently conformably on the Trekant Series (fig. 8). Further north, however, the Trekant Series was folded and eroded, and the Zebra quartzites laid down on a surface either of Trekant Series or Western Gneisses. The actual line of unconformity was observed at Zebra Klippe, where the angular difference between the Zebra and Trekant Zeries is small (fig. 9), and at Prins Axel Nunatak, where the divergence increases markedly from west to east. The relations between the two series on the upper Admiralty Gletscher can only be explained by a marked unconformity. At all these exposures, if one endeavours to visualise conditions before the later folding, the surface on which the Zebra Series was laid down appears to have been nearly level.

Though conglomerates of the type associated with the basal Trekant Series are absent, the Zebra quartzites are often very coarse, with sand grains up to 5 mm across. A specimen of the Zebra/Trekant contact obtained by Wyllie from Kap Trekløver (Prins Axel Nunatak) shows fine conglomerate composed of rounded quartz grains up to 1 cm across overlying fine-grained sheared Trekant quartzite. A leaf of the quartzite has been partially detached and incorporated into the conglomerate.

Fig. 9. Western end of Zebra Klippe. Crumpled Zebra Series unconformably overlying massive Trekant quartzite. Photo: P. J. Wyllie.

The overlying beds, with rapidly alternating quartzites, grits, iron-rich rocks and shales contrast with the more even appearance of the Trekant rocks. Mr. Campbell of the Chemistry Department, Kings, College, kindly analysed one of the dark grits and found ferric iron only, with no trace of ferrous iron or manganese. Thus the opaque ore in these rocks is probably hematite, as is likely also in the Trekant Series. Unlike the Trekant Series, ferruginous coatings on the clastic grains are uncommon or absent. The coarser, variable grain sizes, and occurrence of cross-bedding point to rapid, if spasmodic, deposition. The absence of feldspar in the lower beds at least suggests that the basement gneisses did not contribute much to the detrital material, and a more distant source must be invoked for this.

There is some fragmentary information about the upper beds. Light yellow quartzites become increasingly frequent higher in the succession at Zebra Klippe, with cross-bedding and ripple-marks. At Thomson Klippe, fallen blocks occur of yellow, strongly cross-bedded quartzite, and at one of the nunataks in S.W. Dronning Louise Land (Nunatak 3, Plate 9) there is an outcrop of cross-bedded quartzitic sandstone and shales presumably belonging to the Zebra Series. Thus it appears that somewhat quieter, possibly shallow water conditions ensued.

If we regarded the Suzanne Nunatak beds as being Zebra Series, we see a satisfying gradation from coarse basal beds to finer quartzitic sandstones and limestones. It should be mentioned here that a boulder of black limestone was found in the moraine on the S.E. side of Prins Axel Nunatak among rocks which could be matched in the Trekant

Series, Zebra Series, and Western Gneisses. Another erratic of similar material was discovered east of Dryasdal near Britannia Sø, this specimen containing intraformational conglomerate.

Whether the Zebra Series is a marine or continental deposit is open to argument. It is probable that it is at least partly marine because of (a) the similarity of the basal beds to marine quartzites overlying unconformities elsewhere, e. g. the Cambrian quartzite of the N.W. Highlands of Scotland; (b) the absence of coated clastic sand grains, and (c) the possible upward passage into limestone.

THE BRITANNIA SØ GROUP

Apparently underlying the Eastern Schists and Gneisses proper in the Britannia Sø area is a group of quartzites, limestones, and schists, with subordinate quartz-magnetite rock. Though in a thoroughly metamorphosed state like the Eastern Schists and Gneisses, they are lithologically distinct, and merit separate treatment. Since the area of outcrop seems to be restricted to the western half of Britannia Sø and the mountains to the south, it is appropriate to call them the Britannia Sø Group. Some of the field detail has been recorded elsewhere (PEACOCK 1956b, 1956c).

A. PETROGRAPHY

1. Quartzites.

These rocks range from almost pure quartz to those with a considerable variety of accessory minerals.

Feldspar-free quartzites with few accessory minerals outcrop S.E. of the junction of the Admiralty Gletscher and Gultop Gletscher, at the corrie N.W. of H.A. Jensen Bjerg, on the summit of Gultop, and probably at many other points (specimens 23, 500 and S. 11). Interlocking quartz grains between 0.3 and 1.0 mm across form the majority of the rocks in thin section, becoming finer in grain size where there is an appreciable quantity of lineated muscovite. The iron ore is either magnetite in very isolated wisps, or occasional clots of blood-red hematite. Minor accessory minerals are zircon and tourmaline.

Quartz-magnetite rocks are subsidiary but distinctive rocks in the succession. A specimen from Hvalryggen (no. 210) in a Dollar Stage measurement, has 67 per cent quartz, 22 per cent magnetite and 10 per cent apatite and muscovite. The quartz, with an average grain size of 0.2 mm, is in a granoblastic aggregate more or less independent of a blastopsammitic structure made visible through the outlining of the original sand grains by muscovite, apatite, and sometimes magnetite. These sand grains have a diameter of about 0.3 mm. The magnetite itself is partially fine-grained, and partially in euhedral crystals up to 0.4 mm in diameter. While apatite occurs in tiny grains of random orientation, the muscovite laths, which reach 0.1 mm in length, show considerable alignment.

Only one specimen of feldspathic quartzite was obtained, this being from the grey banded quartzite which outcrops near the base of the observed succession at Hvalryggen. The slice shows that some microcline (20 per cent) is present in addition to the quartz, which forms and interlocking aggregate of strained grains with greater axes (0.3 mm) parallel to the schistosity. A little magnetite is visible as shapeless flecks which are often included in the quartz grains, this mineral giving the darker banding visible in hand specimen. The feldspar, which is largely untwinned, is in xenoblastic grains, sometimes with slight dusty alteration.

A fine-grained quartzite (no. 215) among the schists at the east end of Støvdal consists of quartz (0.1 mm) with 20–30 per cent of muscovite, apatite, sphene, calcite, and pale brown biotite.

The specimens of feldspar-free quartzites could easily have been derived from the metamorphism of Zebra-type quartzites, and the preservation of blastopsammitic structure with few signs of deformation in the quartzmagnetite rock brings to mind the purple quartzites at the southeast side of Prins Axel Nunatak. Future collection of quartzite specimens might enable a distinction to be made in the distribution of feldspar-bearing and feldspar-free quartzites. Such a distinction might be of great stratigraphical value, and aid correlation among local horizons, and perhaps in more general terms correlation with the Zebra Series farther west.

2. Limestones.

Specimens from Hvalryggen and the east end of Støvdal consist largely of interlocking calcite crystals (0.5–1.0 mm) with small amounts of quartz in single crystals or clumps, and parallel laths of phlogopite. The phlogopite ($n\gamma = 1.59$) is pleochroic with α colourless, γ pale yellow, and individual laths reach 1 mm in length. Pyrites in euhedral crystals is a minor accessory mineral in the limestones themselves, but is of greater importance in cross-cutting calcite veins.

3. Calc-silicate rock.

One outcrop only of this was found, though the occurrence of calcite in one of the quartzites described above shows that lime-bearing schists may be quite common. This particular specimen (no. 219) was taken from a narrow band of schist spotted with radiating fibrous pale green amphibole, the spots being about 2 cm. broad and elongated along the schistosity. The remainder of the schist is even-grained, speckled with biotite and pyrites.

In section, the schistose part of the rock is composed of calcite, biotite, quartz, and a little pyrites. The calcite (0.4 mm) forms interlocking anhedral grains, xenoblastic against the biotite, which is a pale brown variety. The quartz (0.15 mm) is scattered grains with a dirty appearance due to cryptocrystalline dirt. The spots seen in hand specimens are of very pale, almost non-pleochroic amphibole in radiating fibres averaging about 1 mm long. An extinction angle $\gamma \wedge c$ of about 23° suggests tremolitic hornblende.

4. Mica-schist.

A lustrous muscovite-schist was collected from between the two red-stained quartzite beds at the waterfall N.W. of H.A. Jensen Bjerg.

In section, some quartz lenticles consist of interlocking strongly strain-shadowed grains (with packet structure) in which the grain size reaches over 10 mm. Other parts of the rock are composed of plicated muscovite (0.5 to 1.0 mm) with varying small quantities of red-brown biotite, quartz, and idioblastic tourmaline needles (0.2 mm). Some magnetite is present at a few points, separating quartz lenticles from the schist proper.

Beds of micaceous schist with biotite, muscovite, and probably chlorite are of much greater importance in the Britannie Sø Group than the collection of one solitary example indicates. They are quite different from the schists in the Eastern Schists and Gneisses proper, and from memory seem much more like Dalradian schists, for example those in the neighbourhood of Pitlochry, Scotland.

B. PETROGENESIS

The Britannia Sø Group contains the metamorphosed representatives of pure quartz sands, iron-rich beds, limestones, shales, and calcareous shales. The Group appears to pass rather rapidly into Eastern Schists and Gneisses, though whether this transition takes place in an upward or downward stratigraphical succession is not clear. At the snout of the Admiralty Gletscher, augen-gneiss is exposed overlying inverted quartzites and quartz-magnetic rock. This may actually be the base of the Britannia Sø Group. The augen-gneiss here possible belongs to the Western Gneisses.

The affinity of the Britannia Sø Group with the Zebra Series is a matter of considerable importance, since this seems to be the only possible stratigraphical connection of a rock group in west Dronning Louise Land with one in the east. There are four possibilities (a) the Britannia Sø Group is pre-Trekant Series, (b) that it is equivalent to the Trekant Series, (c) that it is equivalent with the Zebra Series, and (d) that it is post-Zebra Series.

(a) Since the Britannia Sø Group quartzites have retained current-bedding as well as blastopsammitic structure in at least one instance, it is highly unlikely that they have undergone more than one period of metamorphism. Since the Trekant Series is probably part of the Thule Formation of North Greenland, and no pre-Thule rocks retain undoubted current-bedding (L. Koch, 1929a and 1929b), it is improbable that the Britannia Sø Group is post-Western Gneisses and pre-Trekant Series.

(b) The uniform lithology of the Trekant Series is in striking contrast to the varied aspect of the Britannia Sø Group. The quartzites of the Britannia Sø Group are pure and do not often contain feldspar: those of the Trekant Series are muscovite-rich and usually contain feldspar. No limestone seems to be present in the Trekant Series, and there are no beds of shale which could compare in thickness with those in the Britannia Sø Group. Thus correlation of the Trekant Series with the Britannia Sø Group is improbable.

(c) Pure quartzites and iron-rich rocks occur in both Zebra Series and Britannia Sø group. Slightly metamorphosed Zebra Series resembles the Britannia Sø Group in field appearance. Limestone, though absent in undoubted Zebra rocks, occurs at Suzanne Nunatak among partially metamorphosed rocks which resemble the nearest outcrops of the Zebra quartzites. The Zebra Series oversteps onto Western Gneisses in places: the Britannia Sø Group may rest on Western Gneisses.

(d) No Lower Palaeozoic rocks have undergone extensive metamorphism in East and North Greenland (L. Koch 1929a, Fränkl 1954). Only two late Precambrian groups are known in Greenland, these being the Thule Formation and Eleanore Bay Formations. Since the Trekant Series and Zebra Series are both presumably Precambrian, to postulate that another Precambrian formation overlies the Zebra Series is pure speculation.

Work in the Eastern Schists and Gneisses suggests that great thicknesses of quartzite or limestone do not occur, and we are left with the alternatives that the Britannia Sø Group either overlies or underlies the paraschists. In the absence of conclusive structural evidence regarding top and bottom relations at Britannia Sø (Peacock 1956b) the latter alternative would appear more likely.

Concerning the metamorphism, the Britannia Sø Group is in a completely crystalline condition, and the grain size of the quartz in the quartzites is much larger than in any rocks further west. Mineralogically, however, there is little to aid the determination of the metamorphic grade. In the calc-silicate rock, the assemblage calcite-quartz-phlogopite is stable into the amphibolite facies (Ramberg 1952, p. 150). Reliance must be placed on the associated basic rocks, which are described in another section.

The style of the metamorphism in the Britannia Sø Group is dominated by the thick quartzites. In many cases these have been little deformed, though totally recrystallised. Probably much of the stress has been dissipated in the limestones and schists, which show evidence of much minor crumpled folding.

THE EASTERN SCHISTS AND GNEISSES

This rock group, which is mainly a metamorphosed sedimentary series, extends from Søstersøer in the north, to south of the A. B. Drachmann Gletscher. The eastward extent is defined by the eastern edge of the land, but the western margin is against the Britannia Sø Group in the north, and the Western Gneisses farther south. Specimens were collected from the region of the Borgkjøkel and lower Budolfi Isstrøm during the various sledging journeys, and a more representative selection from the accessible Britannia Sø area. These latter form the framework of the following account.

A. PETROGRAPHY

1. Paragneisses and Paraschists.

The leading rock types of the Britannia Sø area show considerable resemblances in field appearance to the grey speckled schists which form a large part of the succession at Durham Klippe (Peacock 1956a, p. 15; 1956b, p. 211). Feldspar porphyroblasts are developed in the gneisses at Timeglasset, while granitic banding occurs east of a meridian dividing Britannia Sø. These feldspathised rocks are described subsequently, though all gradations occur between them and the paragneisses.

In hand specimen, the paragneisses and paraschists show varying degrees of schistosity due to the degree of orientation and proportions of biotite or hornblende. The grain size, too, varies greatly: as a general rule it increases eastwards, and this fact is brought out in the descriptions below. The following rocks are described:—

From Timeglasset:—	Plagioclase-quartz-biotite-epidote-(hornblende)-schist (no. 248)
	Plagioclase-quartz-microcline-biotite-gneiss (no. 311)
	Quartz-microcline-oligoclase-biotite-epidote-schist (no. 34)
From Kap Bellevue:—	Plagioclase-quartz-biotite-schist
	Plagioclase-quartz-biotite-gneiss (no. 31 and 246)

Plagioclase-quartz-biotite-(microcline)-gneiss (S. 2)

From Stranddal:— Plagioclase-quartz-biotite-gneiss (S. 3)

From N.W. of H.A. Jensen Bjerg:— Plagioclase-quartz-biotite-muscovite-epidote-(microcline)-schist (no. 237)
Quartz-microcline-plagioclase-(biotite, epidote)-schist (no. 505)
Biotite-quartz-epidote-(calcite)-schist (No. 506)

From east of Dryasdal:— Quartz-plagioclase-microcline-biotite-schist (no. 503)

Quartz. The percentage of quartz varies from almost nothing in hornblende-bearing bands e. g. of no. 248, to almost half the rock. In the material from Kap Bellevue, the grain size usually reaches 1.5 mm, and these values are reached in quartzo-feldspathic bands or lenticles elsewhere. However, in the schists N.W. of Britannia Sø, grain sizes vary between 0.3 and 0.5 mm. The quartz often builds a granular mosaic with feldspar, and in some rocks shows dimensional orientation with the longer axes garallel to the schistosity. Strain-shadows are universal, but undulation banding is absent.

Plagioclase. In most rocks, the plagioclase tends to have much the same grain size as quartz, but in some rocks (e. g. S. 2 and 248) it is sometimes porphyroblastic, with crystals reaching 5 mm long. Where plagioclase is the principal mineral, as in the plagioclase-quartz-biotite-gneisses (with or without epidote) it usually forms about 40 per cent of the rock. In contrast with the quartz, which is always anhedral, plagioclase occasionally shows subhedral forms, especially in feldspar-rich lenticles, or where it is aggregated with quartz. While generally fresh, the plagioclase sometimes contains fine inclusions of epidote, and in one case (no. 237) there is extensive cryptocrystalline alteration to an opaque dust, though the margins of grains sometimes remain clear. Inclusions of muscovite and biotite are present in a few cases.

The composition of the feldspar N.W. of Britannia Sø is albite, sometimes approaching An_{10}. On Timeglasset, measurements of maximum symmetrical extinction angles and refractive indices show albite-oligoclase (An_{10}). East of Dryasdal, a solitary specimen (no. 503), contains oligoclase (An_{25}), while) east of the outflow from Britannia Sø, a number of measurements give compositions between An_{24} and An_{40} with a maximum at An_{30}. A rock from this neighbourhood, in which epidote inclusions occur, has oligoclase An_{20}. Some rocks show evidence of both normal and inverse zoning, but in others what appears to be zoning at first glance is due to strain-shadows.

Twinning is uncommon in albitic feldspars, and where present, appears to be on the albite law only. As the anorthite content increases, twinned crystals become more common, and pericline lamellae occur in addition to repeated twinning on the albite law. Gorai's twin studies only refer to amphibolite facies rocks but in these he finds no correlation of amount of twinning with anorthite content (1951, p. 894, fig. 9).

Microcline is present as an important accessory in many rocks, usually as anhedral crystals occupying interstices among the quartz and plagioclase. The grain-size is often smaller than that of the other feldspar. Strain-shadowing is slight where present. Twinning of the usual cross-hatched type is common in most sections.

Antiperthite occurs in two of the rocks mentioned above (S. 2 and 31), both these rocks being from the Kap Bellevue Area. The microcline in the antiperthitic crystals is patchy in occurrence, and shows typical cross-hatching.

Myrmekite (plagioclase-quartz intergrowths) is often associated with microcline grains. Bushy forms, with the top of the bushes occupying crenulate embayments in the microcline, are characteristic. Plagioclase always predominates over quarts in these intergrowths.

Biotite. A proportion of biotite occurs in most specimens, commonly about 10–20 per cent. The pleochroism is always straw yellow to deep brown, though a reddish tinge appears in one specimen from Kap Bellevue. In two specimens from Kap Bellevue, the R. I. of the slow ray is 1.64. As in the minerals described above, the grain size increases from west to east, varying from 0.1–0.5 mm to over 1.5 mm. There is a tendency also for the laths to be stouter and better-shaped with the larger grain sizes. Where present in significant amounts, the biotite always shows a strong preferred orientation.

Epidote. As an essential mineral, epidote is confined to areas west of Timeglasset. Here it forms 10 per cent in plagioclase-schists and gneisses, and may be an important accessory in other rock types. The grain size is always small, of the order of 0.1 mm, and clusters of such grains strewn along foliation planes are characteristic. In section, the colour varies from apple yellow to colourless. The coloured varieties are slightly pleochroic, but there appears to be no significant difference in the birefringence of the two types, and the distribution is random. In one specimen (no. 311), the accessory epidote occurs in clusters with feebly birefringent, brownish, fine-grained cores (possibly allanite).

Hornblende. Only one rock (no. 248) contains any hornblende. Here it is in idioblastic crystals (0.5 mm) aligned along the foliation (in one band only). The pleochroism is α yellow-brown, β dark green-brown, γ deep sea-green.

Calcite. This mineral is an uncommon accessory occupying interstices between quartz grains.

Garnet occurs in the schist no. 34 as an accessory. The grains, which reach 0.5 mm across, are idioblastic, but show numerous inclusions of very fine quartz and epidote, and replacement by a carbonate.

Other accessories are sphene (usually associated with biotite), muscovite, magnetite, apatite, and zircon.

2. Feldspathised Gneisses and Granitic Gneisses.

The areas in which these rocks occur, as noted before, are east of a meridian dividing Britannia Sø for the most part, though there are indications that migmatites form part of the debris-covered land near H.A. Jensen Bjerg. At Timeglasset increase in the quantity of porphyroblastic feldspars both along across the strike gives rise to granitic gneisses of a type which can also be found as discrete bands interbedded with the other rocks. Similar phenomena occur north of Dryasdal and in the Stranddal area. At Kap Bellevue, one body of granitic gneiss is crossed by aplite veins.

Nos. 35 and 37 are representatives of a wide variety of gneisses with porphyroblastic feldspars. In the field, no. 37 is a rather dark coarse-grained rock with numerous pinkish feldspar eyes averaging about 3 mm long in a matrix of hornblende, biotite, and quartzo-feldspathic material. No. 35 is a variety in which the pink eyes have almost coelesced, and the quartz and feldspar forms ill-defined areas with micaceous layers winding between them.

In thin section, about half the mineral substance of both is microcline either in the form of porphyroblasts (3 mm) or subhedral grains (0.3 mm), these latter forming agglomerations or being scattered throughout the rock. Plagioclase (An_{10}) only makes up about 10 per cent, and is often in the form of myrmekite bushes around the microcline. The well-developed cross-hatching of the microcline is in striking contrast to the rarity of twinning in the plagioclase, and this feature shows up well also in rare porphyroblastic antiperthite crystals. Quartz (0.5–2 mm) tends to build parallel folia, and is the only other essential mineral in no. 35. In no. 37, idioblastic hornblende (α straw yellow, β green-brown, γ deep green, $\gamma \wedge c$ 20°) seived with quartz bulks as an essential mineral, and is accompanied by a little brown biotite and sphene. Other accessories here are calcite and a little epidote; and in no. 35 skeletal muscovite, brown biotite, and green chlorite (length slow).

No. 37 has probably been formed by the metasomatism of rocks similar to no. 248 or S.3, where ferromagnesian minerals form between 20 and 40 per cent of the rock substance. No. 35 was collected from a granitic band which grades into a biotite-bearing quartzite across the strike. The mineralogical convergence of the two rocks is striking.

A further stage in metasomatism is illustrated by a specimen from a granitic band at the knee-bend in Strandal (Plate 4b). Here there are no traces of porphyroblastic structures, and most of the section is taken up with coarse, exceedingly well-twinned microcline. The remaining albite, slightly myrmekitic and much embayed, has a brown clouded core mantled by fresh material of lower refractive index.

No. 247 from the granitic gneiss at Kap Bellevue bears some resemblance in hand specimen to the plagioclase-gneisses of the area, but differs in its pinkish colour and poorer schistosity. The plagioclase (An_{24}) here forms 20 per cent of the rock, and quartz (40 per cent) and microcline (30 per cent) are more important. In places the plagioclase bordering microcline is rimmed by a clear zone with higher birefringence and markedly lower refractive index—albite:— as usual it tends to be myrmekitic. The biotite is pleochroic straw-yellow to deep brown, and shows slight enhancement of the cleavages by inclusions of magnetite granules. The laths are the stout variety noted before from this district, and are associated with occasional granules of sphene and yellowish epidote.

3. Gneissose pegmatite.

The gneissose pegmatites outcropping on the west side of Kap Bellevue are white, coarse-grained rocks with discontinuous folia of pegmatitic white feldspar (2 cm) and quartz. Lineated muscovite (3 mm) is prominent, and there is a sprinkling of blood-red garnets which reach 2 cm across, though usually much less.

A sliced specimen (no. 242) shows that microcline (30 per cent), quartz (40 per cent), plagioclase (10 per cent), and muscovite (10 per cent) are the chief minerals, with accessory garnet and apatite. The microcline is porphyroblastic in some cases, and reaches 4 mm across, but is embayed by large quartz-plagioclase bushes. Plagioclase (An_{24}) is almost restricted to myrmekite, but may form part of the granoblastic quartz-feldspar aggregate. The quartz varies considerably in grain size, from very small to 2 mm, and shows strain shadows like the quartz of the granitic gneisses. Muscovite is in the form of broad subparallel laths which tend to be segregated into folia. A single porphyroblastic garnet in the section contains inclusions of quartz and muscovite. The refractive index of garnets collected from the pegmatites (1.80), the red colour, and their isotropic nature suggest common almandine.

Fig. 10. North face of Rosmule, lower Borgjøkel. Dyke of metagabbro cutting gneisses. Photo: P. J. WYLLIE.

Petrographically, no. 242 shows similarities to the feldspathised gneisses, but differs from them in that it contains large flakes of mucovite, large garnets, and no biotite. Porphyroblastic microclines also spread into surrounding schists in one or two cases. The genesis of the gneissose pegmatites would appear to be bound up with metasomatism of a slightly different kind to that associated with the gneisses farther west.

4. Comparison with other parts of Dronning Louise Land.

(a) Borgjøkel. The grey schists found at Britannia Sø also outcrop in force here. In the absence of specimens, it can be assumed that the mineralogy is not notably different. At Rosmule, there are concordant dark bands (fig. 10) among the grey schists from which specimens of fine-grained quartz-hornblende-biotite-schist and quartz-microcline-biotite-schist were collected. The first of these contains accessory garnet. From their field relations, these two schists could be either metamorphosed basic sills, or varieties of paraschist. The high quartz content suggests the rocks were originally sediments. A specimen of quartz-plagioclase-microcline-biotite banded gneiss, also obtained from Rosmule, is evidently related to the paraschists.

Fig. 11. Durham Klippe. Eastern schists and Gneisses thrust over quartzite and augen-gneiss (left). Photo: J. D. P.

Porphyroblastic gneisses similar to those described from Timeglasset outcrop at Rosmule, and a hornblende-microcline-plagioclase-biotite-gneiss collected from Paradisklippe is mineralogically similar to a hornblendic porphyroblastic gneiss already described above (no. 37 p. 75). The example from Paradisklippe is a medium-grained rock with continuous or discontinuous bands of pink-weathering quartz and feldspar. In it the common green hornblende sometimes merges into fibrous or platy pale green actinolitic amphibole, and contains apatite inclusions.

Recrystallised limestone or marble collected from a narrow band at Paradisklippe is composed of calcite with some phlogopite, and a little tremolite in veins. Such a rock is similar to the Britannia Sø limestones.

(b) Budolfi Isstrøm. In a preliminary publication (Peacock 1956a), no mention was made of plagioclase, but consideration of all the specimens suggests this is an essential mineral in many rocks. Examples of schists follow:—

Plagioclase-quartz-epidote-biotite-hornblende-schist
Plagioclase-quartz-epidote-biotite-schist
Quartz-epidote-biotite-calcite-schist
Plagioclase-quartz-epidote-muscovite-hornblende-(garnet)-gneiss.

The first two of these, which form the majority of the succession, are evidently similar to specimens from Britannia Sø. The plagioclase (An_{22} in the hornblende-bearing schist and An_{15-20} in the other) is often almost indistinguishable from quartz, both being of similar grain size (0.1–0.5 mm) and the former showing only rare lamellae, and no simple twinning. The amber epidote, corresponding to pistacite ($HCa_2 Fe_3Si_3O_{13}$ about 20 per cent according to WINCHELL 1951, p. 449), varies between 10 and 30 per cent. Pyrites is a common accessory mineral in many beds, and its reddish weathering gives it a superficial resemblance to garnet. The third rock (no. 231) is a calc-schist. The gneiss is coarser-grained than any of the foregoing (0.5–1.5 mm), and comes from a thick bed at the east part of Durham Klippe: it is not clear whether it is a paragneiss or an orthogneiss.

Apart from such rocks there are also narrow bands of muscovite-biotite-hornblende-schist, some beds of garnetiferous augen-gneiss, and intercalated gneissose pegmatites like those outcropping at Britannia Sø.

It seems reasonable to suppose that the majority of the schists were derived from argillaceous or near-argillaceous sediments. The grain size, presence of biotite and almandine, and the absence of pure albite suggest that a moderate stage of metamorphism has been reached.

In a slightly different catagory are the quartzites below the thrust at Durham Klippe. Their position overlying the Western Gneisses, but structurally separated from the schists farther east makes their stratigraphical position doubtful, but they may well be considered at this stage. No. 128A from about 40 m below the thrust on the west side of the large drag fold (fig. 11) is a lineated light grey rock composed mainly of granoblastic quartz (0.2–0.3 mm) and a little muscovite. The grain size is notably less than in other rocks from Durham Klippe. A black quartzite from about 4 m below the thrust is finer grained with muscovite bands, and shows fracturing and general cataclasis which might be ascribed to the nearby thrust.

B. PETROGENESIS

We may consider the problems arising in connection with the Eastern Schists and Gneisses under the following headings:—

1. The original nature of these rocks.
2. The effects of the metamorphism.
3. Introduction of new material.

1. Original Nature of the Rocks.

The leading rock types are monotonous grey schists made up in detail of beds of differing composition varying from a few centimetres to many metres in thickness. Since there are occasionally interbedded thin quartzites and limestones, there can be little doubt that most of the banding in the schists is a sedimentary feature.

Regarding the quartzites, such rocks must be the representatives of pure quartz sands like those of the Britannia Sø Group, and by analogy, the Zebra Series. The rare limestones are also mineralogically similar to those in the Britannia Sø Group, and may reflect similar conditions.

Calc-silicate rocks are probably of greater importance than either limestones or pure quartzites, and the mineralogy of one (no. 231—quartz, epidote, biotite, and calcite) suggests derivation from a calcareous siltstone.

The majority of the schists, however, approximate to nos. 123 and 31, i. e. plagioclase-quartz-(epidote)-biotite-hornblende-schist, and plagioclase-quartz-(epidote)-biotite-schist. This mineral composition is in accordance with a derivation from pelitic or semipelitic rocks, but it is noteworthy that aluminium silicates have not been found. Detailed modal compositions are as follows:—

	No. 123 (Lower Budolfi)	No. 31 (Kap Bellevue)
Plagioclase	47.1 per cent	49.8 per cent
Quartz..............	14.9 —	26.9 —
Biotite..............	14.9 —	23.0 —
Hornblende	12.7 —	..
Epidote.............	10.3 —	..
Muscovite...........	..	0.1 —
Apatite	—	0.2 —

The presence or absence of epidote can in part at least be ascribed to the metamorphic grade, and is discussed below.

Several interesting conclusions emerge when we compare these schists with Moine pelites and a composite analysis of shales (Table 2).

(a) In both no. 123 and 31, lime and soda are considerably higher than in the other shales and schists, while potash is correspondingly low. This is reflected in the dominance of plagioclase and epidote in the one, and plagioclase alone in the other.

(b) Alumina is present in about the usual amount for pelitic rocks.

(c) Total iron is rather low in both schists, and ferrous iron is low in no. 123.

The absence of staurolite ($HFe_2Al_9O_8Si_4O_{16}$) might therefore be due partly to the low iron, and partly to the excess of lime and soda. Since there is no deficiency in alumina, the non-appearance of kyanite in the higher grade rocks seems also to be related to the excess of lime.

In silica content, no. 123 compares with the Palaezoic shales (Table 2, no. 1), but no. 31 approaches average greywacke (Table 2, no. 6) or a garnetiferous mica gneiss. Regarding the latter rock, CHENG

Table 2. Chemical Composition of Paraschists.

	1.	2.	3.	4.	5.	6.
SiO_2	60.15	64.83	63.98	60.1	65.6	64.2
Al_2O_3	16.45	16.97	17.68	18.1	16.95	14.1
Fe_2O_3	4.04	0.63	2.23	1.14	0.55	1.0
FeO	2.90	5.64	4.76	3.58	4.53	4.2
MgO	2.32	1.94	3.18	3.83	1.92	2.9
CaO	1.41	2.76	1.05	6.16	3.43	3.5
Na_2O	1.01	2.48	1.10	4.28	4.05	3.7
K_2O	3.60	3.05	4.16	1.52	2.45	2.0
TiO_2	0.76	0.87	0.85	0.73	1.40	0.5
P_2O_5	0.15	0.34	0.08	0.31	0.27	0.1
MnO	Tr.	0.12	0.05	0.18	0.25	0.1
CO_2	1.46	Nil	..	No Analysis		1.6
H_2O^+	3.82	1.36	0.10			2.1
H_2O^-	0.89	0.87	1.18			0.1
Others	1.50	..	0.01			..
	100.46	100.17	100.41			100.0

1. Composite Analysis of 51 Palaeozoic Shales by N. H. STOKES. Bull. 695 U.S. Geol. Survey 1920, p. 544.
2. Garnetiferous mica gneiss. Anal. W. H. Herdsman. CHENG 1943, p. 115, Table 2 A.
3. Staurolite garnet schist. READ 1931, p. 40.
4. Schist, Lower Budolfi (Specimen 123).
5. Schist, Kap Bellevue (No. 31).
6. Average greywacke. PETTIJOHN 1949, p. 250, Table 64 G.

(1943, p. 115) states that it has been slightly metasomatised, and this might also be the case with no. 31, since it outcrops in an area of gneissose pegmatites, not far from a body of granitic gneiss. Nevertheless, the comparison with greywacke is heightened when one considers the alkalis and lime in the two rocks—the proportions are very similar. Chemically then, the Greenland rocks could be metamorphosed slightly calcareous shales, or in one case metamorphosed greywacke.

ENGEL and ENGEL have described paragneisses rich in soda from the Grenville Series, Northwest Adirondacks. These gneisses, with quartz, plagioclase, and biotite as principal minerals are remarkably like the Dronning Louise Land schists in some respects, but differ in being more siliceous, and relatively deficient in lime, (1953, p. 1063). The interpretation is in some doubt, and the alternatives of zeolitic rocks as parent material or sodic clays formed in a sea abnormally warm and rich in soda are suggested (e. g. p. 1030). A greywacke environment is ruled out because of association with pure quartzites and marbles, and absence of tuffs.

In Dronning Louise Land there appear to be no cases in which sedimentary structures other than bedding have been preserved in the schists. If there had been deposition of a greywacke type, one would have expected to find evidence of coarser fragments either in the field or under the microscope. Under favourable circumstances, graded bedding might have been preserved. No features of this type have been seen in the schists, and we may conclude that they were originally laid down as fine-grained material of shale or siltstone grade. It may be remarked also that the associations of the schists (occasional quartzites

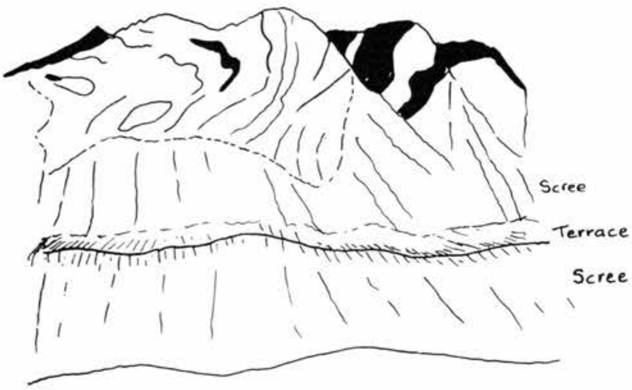

Fig. 12. Mountain on the south side of Trefork Sø. Recumbent migmatitic fold in Eastern Schists and Gneisses.

and limestones: absence of volcanic rocks) do not suggest deposition under the same conditions as greywacke (compare the Grenville Series op. cit.).

Apart from the rocks hitherto mentioned, there are thin intercalations of more micaceous schists in places, presumably representing slightly different pelitic parents. If the two dark schists collected at Rosmule (p. 77) are paraschists as is supposed, then the divergences in composition among such schists might be quite marked.

The gneisses are a difficult problem. Some of them are undoubtedly paragneisses allied to the schists, others might be metamorphosed intrusions, and others are products of metasomatism. The garnetiferous augen-gneisses among the paraschists of the lower Budolfi look suspiciously like the Western Gneisses, but in the absence of specimens no conclusions can be drawn. A further problem is the gnesis of the gneissose pegmatites of the Budolfi Isstrøm and Kap Bellevue, rocks in which metasomatism also appears to have taken part.

If the succession at Durham Klippe is uninterrupted, a thickness of about 3,000 metres of Eastern Schists and Gneisses is present at

Fig. 13. Tight folds outlined by quartzite bands in schists at the east end of Britannia Sø not far from Dryasdal. Photo J. D. P.

this one point. The total thickness of schists must therefore be very great. One is left with the impression of deposition under quiet conditions in a continuously subsiding basin with only the finer grades of sediment being brought in. The rare limestones and quartzites mark slightly different conditions, the former being associated with a lack of clastic material, and the latter with an influx of well-sorted sands.

2. Effects of the Metamorphism.

All the rocks in the Eastern Schists and Gneisses, with one or two doubtful exceptions, have been completely recrystallised, and all sedimentary structures except bedding obliterated. Compared with the Britannia Sø Group, where the thick quartzites have resisted the stress factor to some extent, the schists differ in that their fabric is the result of thorough-going deformation. Though bedding is retained in many cases, the schists usually show all degrees of plication and in places larger fold structures (figs. 12, 13, and 14).

The best evidence concerning metamorphic grade is from the Britannia Sø area, and may be summarised as follows:—

Fig. 14. Folded feldspathised schist, Timeglasset. The dark rock is quartz-amphibolite. Photo: J. D. P.

Garnet occurs sporadically throughout the area north of Britannia Sø, and also on Timeglasset. It becomes more common at Kap Bellevue. All observations indicate that it is almandine.

Epidote is common as far east as Stranddal but is present only in accessory proportions on Kap Bellevue.

Plagioclase in microcline-free schists varies from albite-oligoclase in the western part of the area to oligoclase-andesine at Kap Bellevue (fig. 15). The change seems to be regular from the few available specimens, and there does not seem to be an abnormally wide scatter at any one point.

Brown biotite occurs at all points, while chlorite, if present, is an accessory.

The assemblages with epidote (plagioclase-quartz-biotite-epidote) correspond with the albite-epidote-amphibolite facies of Turner (1948, p. 90), except that the feldspar is usually albite-oligoclase. Turner prefers the term "albite-epidote-amphibolite facies" since epidote-amphibolites with oligoclase or andesine are apparently stable throughout much of the range of the amphibolite facies (1948, p. 89). Ramberg, however, states that rocks recrystallised at a somewhat higher grade of metamorphism than the green schists and their facies equivalents often contain common green hornblende, spessartite-free garnet, and oligoclase (1952, p. 145). Both authors agree that the upper limit of the greenschist facies might be defined by the incoming of almandine garnet. We can therefore be fairly certain that the Britannia Sø rocks with essential epidote crystallised under pressure/temperature conditions above that of the greenschist facies, though YODER's findings that some critical assemblages at present used to define metamorphic facies can be experimentally produced under the same pressure-temperature conditions may have some bearing on the matter (YODER 1952, 1955).

RAMBERG gives two equations relating the composition of the plagioclase with epidote. These are:—

$$\text{epidote} + \text{kyanite} \gtrless \text{anorthite} + H_2O$$
$$\text{muscovite} + \text{epidote} \gtrless \text{anorthite} + \text{potash feldspar} + H_2O$$

Neither of these equations (RAMBERG 1952, p. 147) satisfies the mineral conditions in typical schists from Britannia Sø, nor do similar equations for rocks with excess of calcite (1952, p. 53). In the Britannia Sø rocks, a large proportion of potash feldspar may be connected with metasomatism, since muscovite is not a common mineral, and the higher anorthite contents of some schists is in rocks in which potash feldspar is absent (fig. 15, see discussion below).

A more hopeful prospect of a link-up with previous work on pelites is given by a consideration of a paper by ROSENQUIST (1952). He believes (p. 37 et seq.) that the reaction oligoclase + water $\lesseqgtr$ albite + zoisite most likely depends on temperature and pressure in much the same way as hornblende + water $\gtrless$ chlorite. The advantage of the oligoclase reaction is that minerals on both sides of the equation are definable; in the other they are not. From experimental work, he is able to conclude that plagioclase with 10 per cent An. does not undergo saussuritization above 260–300° C, and that plagioclase with 25 per cent An. does not undergo saussuritization above 300–350° C (p. 57).

We know that in many Britannia Sø rocks the anorthite content of the plagioclase varies inversely with the epidote content as a general rule, in line with the sort of reactions envisaged by Rosenquist. Allowing for any anomalies due to the Fe/Al ratio of the epidote and associated plagioclase (ROSENQUIST, p. 45–46), all the schists west of Kap Bellevue may be placed in the epidote-amphibolite facies of RAMBERG (1952, p. 137.

The status of the Kap Bellevue rocks is more difficult. RAMBERG (p. 149) states: "It is evidently not always easy to decide whether the common gneisses belong to the epidote amphibolite facies or to the amphibolite facies, because the association of quartz, potash feldspar, acidic plagioclase (An_{30}), and micas or hornblendes is stable in either facies". However, as already stated, the epidote/plagioclase reactions in

Dronning Louise Land appear to be independent of potash feldspar, and therefore the conditions of Ramberg's equations given above do not apply. On the other hand, the quantity of epidote is limited, and it may all have reacted to form the anorthite in the plagioclase before temperatures and pressures appropriate to the amphibolite facies were reached. Also, Rosenquist's experiments do not extend to feldspars with more than 35 per cent An. The best that can be said is that the rocks at Kap Bellevue are high epidote-amphibolite, or low amphibolite facies.

Following on from these speculations, the schists exposed on the lower Borgjøkel, which contain garnet, green hornblende, albite or oligoclase, and only accessory epidote must belong to the epidote-amphibolite facies at least. Unfortunately, the paragneisses here appear to have been affected by metasomatism to some extent.

The schists of Durham Klippe (plagioclase, epidote, quartz, biotite, hornblende) on similar reasoning are probably epidote-amphibolite facies.

3. Introduction of new material.

The problem to be considered under this heading are (a) the feldspathisation phenomena and granitic veining on Timeglasset and elsewhere, (b) gneissose pegmatites of Kap Bellevue and Durham Klippe.
(a) Feldspathisation and granitic veining. The main evidence concerning these features comes from the Britannia Sø area. To recapitulate, on Timeglasset, porphyroblastic microclines are developed in rocks varying from normal plagioclase-schists to quartzite. The feldspathisation seems to be restricted to certain horizons, and within these, there is considerable variation in the quantity of porphyroblasts both along and across the strike, giving gradations between schists with porphyroblasts and granitic-looking rocks.

In thin section it can be observed that the porphyroblasts may in reality be clumps of slightly perthitic microcline crystals or single large crystals, sometimes with antiperthite. Myrmekite (quartz-plagioclase intergrowths) borders the porphyroblasts where these are in contact with plagioclase. In a specimen from a granitic-looking rock from Stranddal, the plagioclase appears to be undergoing resorption by microcline, and has outer clear rims richer in albite than the bodies of the crystals.

Turning to Kap Bellevue, the granitic gneiss collected from a body of that material differs in that it is not porphyroblastic, and contains more quartz than the usual plagioclase gneiss. Also, in the field, it is criss-crossed by aplite veins apparently of similar composition. However, the microcline-plagioclase-quartz relationships are the same, and the differences between centres and exteriors of plagioclase crystals is even more marked than at Timeglasset. The turbidity of the plagioclase due to brown dust, and inclusions of epidote and muscovite granules are noticeable, though similar features can be seen in other rocks without microcline.

The third line of evidence is that schists or gneisses with microcline almost always contain a more acid plagioclase than the surrounding schists (fig. 15). This is especially well seen where the anorthite-content of the schists is normally about 30 per cent; that of microcline-bearing rocks is An_{20}–An_{24} or less.

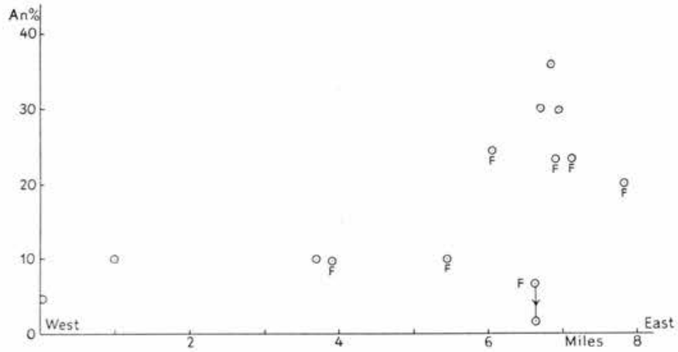

Fig. 15. Anorthite content of plagioclases from the Britannia Sø area. F = schists or gneisses with essential microcline.

Similar quartz-plagioclase myrmekite and porphyroblast features have been described from many places e. g. the granitic gneisses of western Ardgour, Scotland (HARRY 1953, p. 296), and in a more exhaustive fachion by DRESCHER-KADEN (1948). They resemble Dresher-Kaden's Type 1 pre-microcline myrmekite (1948, p. 104), to which is ascribed a metamorphic origin. The quartz stems in the plagioclase are regarded as being produced by variable solution principally through discontinuities of the texture, the silica being left in place, and the cations moved to other parts of the structure. The conclusion is that myrmekite belongs to a period of metasomatic textural alteration of granitic rocks.

In the Britannia Sø rocks we may carry these suppositions a stage further by noting first of all that plagioclase shows evidence of replacement by microcline in at least one rock. Since plagioclase in granitic rocks has clear borders of more albitic composition, we may postulate some sort of metasomatism after the main phase of metamorphism. Since clear borders are always associated with microcline, such metasomatism is connected with microcline. It seems logical to believe that the incoming of microcline and the alterations in the plagioclase are part of the same process, both taking place at a late stage in the metamorphism. By analogy, this idea is supported by Drescher-Kaden's work (p. 104, para. 6) where he finds that the quartz in myrmekite is later than the plagioclase, and in a few cases earlier than potash feldspar. We may therefore conclude that porphyroblastic schists and other granitic phenomena in the Timeglasset area are the result, in part at least, of potash metasomatism after the main phase of metamorphism.

On Kap Bellevue, the granitic phenomena take a slightly different form, in that aplite veins are present and there is an increase in silica. It seems reasonable to suppose that similar metamorphic and metasomatic reactions took place here, but little further can be said excepting to speculate that the higher grade of metamorphism had something to do with a somewhat different metasomatic style, and that it is quite possible that much more movement took place in the softened rocks giving opportunities for the formation of local segregation or intrusive aplites.

The fact that the anorthite-content of the plagioclase is less in all rocks with microcline is difficult to explain. Perhaps the specimens could have been picked from rocks which were originally rich in potash, and the reactions have followed the lines indicated by Ramberg (op. cit.). On the other hand, one of the specimens showing this phenomenon is the granitic gneiss at Kap Bellevue, which is probably metasomatised. It is quite a different phenomenon from the sodic borders on certain feldspars, because the whole plagioclase crystal is involved. A parallel occurrence is the transition between paragneiss and granitic rock described by Engel and Engel in the Grenville Series of the Northwest Adirondacks. Here they are able to plot a decline in the anorthite molecule against increasing potash feldspar. This is interpretated as being due to interaction with, or replacement by granitic fluids (1953, pp. 1064–1065).

Now, excepting for a schist (no. 505) from N.W. of H.A. Jensen Bjerg, in all instances where microcline is in a rock, it seems to have taken part in plagioclase-microcline border reactions, and also tends to be porphyroblastic. Thus one must conclude that whatever the ultimate origin of the potash, it has been involved in two distinct processes (a) a tendency to move towards albite as a result of differing temperature/pressure/chemical conditions during metasomatism, and (b) marginal effects due to the growth of microcline porphyroblasts. As a result of (a) one would expect to find evidence of instability, and in fact, in at least one rock from Kap Bellevue, a rock with An_{20} has epidote inclusions in the plagioclase, accounting for part of the unstable calcium at least. If the Rosenquist reaction oligoclase + water $\gtrless$ albite + zoisite is followed, then water must also be added as part of the metasomatic process.

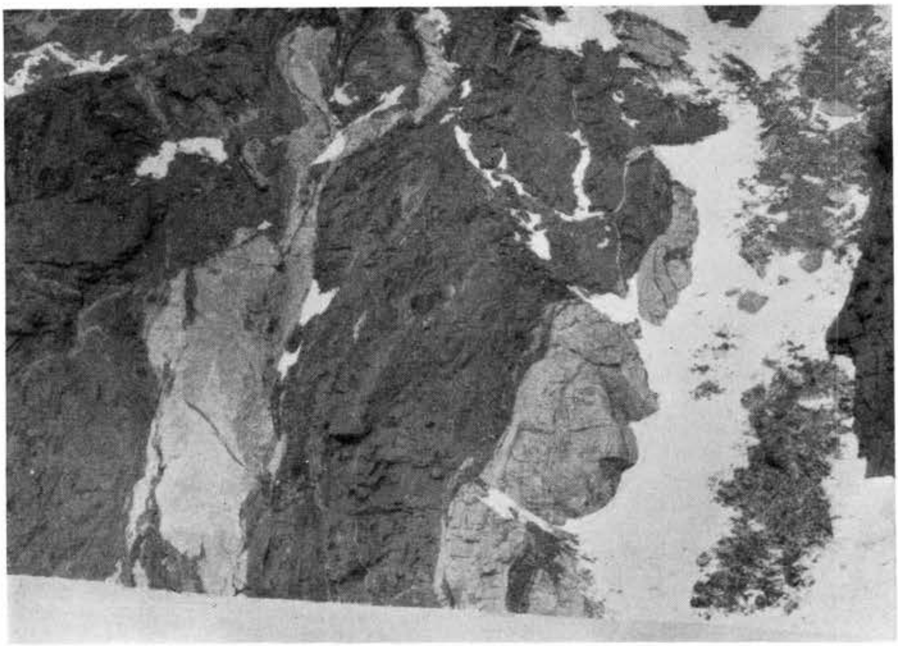

Fig. 16. Gneissose pegmatites at Durham Klippe. Photo J.D.P.

One of the difficulties in proposing any sort of metasomatism is in finding a repository for the ions which have been replaced. In the Britannia Sø area, we must account for a loss in calcium, and to a lesser extent sodium, and probably minor quantities of iron and magnesium due to a tendency for ferromagnesian minerals to decrease as a more granite-like appearance is gained. The only positive piece of evidence is the occurrence of minor calcite in some of the gneisses, accounting for some calcium, and there is nothing to suggest that other awkward ions could be conveniently disposed of in such a thing as a "basic front". This sort of problem can only be overcome by further field- and laboratory work concerning the chemical composition of the complex as a whole.

From field evidence, and the fact that all relevant specimens contain microcline and acid plagioclase, the Eastern Schists and Gneisses in the Borgjøkel area have suffered varying degrees of metasomatism of the same nature as regions further north. Southwards, however, Durham Klippe has largely escaped, as have the rocks around Vedel Sø.

(b) We must now consider the genesis of the gneissose pegmatites of Kap Bellevue and Durham Klippe (fig. 16). On the whole they are concordant bodies of rock, but in detail they may cut the schistosity of surrounding rocks, or the porphyroblastic microclines associated with the pegmatites may be seen in schists at the contact (Kap Bellevue). They appear therefore to have been formed later than the schists. On the Budolfi, the gneissose pegmatites seem to be related to ptygmatic quartz-feldspar veins, and in places contain hornblende, thus seemingly linking them with a garnetiferous plagioclase gneiss described from the same area. However, this latter rock is free of microcline, which is of great importance at Kap Bellevue, and the likeness must be superficial only.

Petrographically, the specimen from Bellevue shows similarities to the granitic gneisses described above, in that microcline with myrmekite bushes is a major component of the rock. This suggests that some sort of metasomatism (vide DRESCHER-KADEN, op. cit.) was involved during formation or during intrusion, an idea supported by the feldspathisation of associated schists. The cross-cutting relationships could be due to magmatic intrusion, differential movement, or a replacement front—there is no evidence to decide which is right. Large flakes of muscovite, and large garnets do not, however, occur in the other granitic gneisses. This suggests that if metasomatism played a part in the formation of the gneissose pegmatites, it was of a different type, a point of view further supported by the absence of feldspathisation among schists at Durham Klippe. The two phenomena would appear to be unrelated.

MINOR INTRUSIONS

In west Dronning Louise Land, the Western Gneisses, Trekant Series, and possibly the Zebra Series also, are traversed by dykes and sometimes sills of quartz-gabbro. Such intrusions vary from a few metres to over 100 metres across, and frequently show columnar jointing, usually at right angles to the margins. Eastwards, the dykes are metamorphosed by the pressure and temperature conditions which imposed the younger metamorphism on the Western Gneisses.

Apart from the quartz-gabbros, which show evidence of at least two periods of intrusion, a number of narrow, dyke-like bodies occur in the Western Gneisses north of Eigil Sø, and at no point can these be seen to penetrate the sedimentary rocks. These older intrusions seem to have dioritic affinities. Metamorphosed dykes of doubtful affinities occur along Eigil Sø, and an ultrabasic dyke at Regnbueklippe.

In east Dronning Louise Land, a series of dykes varying from metagabbro to amphibolite outcrops in the region of the lower Borgjökel, cutting the Eastern Schists and Gneisses. Concordant or cross-cutting intrusions of hornblende-quartz schist or metagabbro can be found farther north both in the schists, and in the Britannia Sø Group.

1. Quartz-gabbros.

A. PETROGRAPHY

The unmetamorphosed quartz-gabbros show considerable variation in hand specimen, though for the most part they are dark and fairly coarse-grained, with a grain size of 1–2 mm. The feldspar is visible as dark grey or sometimes faintly reddish laths, and a dark speckled appearance in some rocks can be traced to iron-ore crystals. In two examples (no. 196 from Kaldbakur, and no. 362 from the head of the Pony Gletscher), however, patches of coarser material occur in which dark green pyroxene needles reach a length of two centimetres with interstices occupied by feldspar. In some dykes, e. g. at Helgoland, there is an interleaving of fine-grained gabbro with the more usual rock, and at Kaldbakur chilled facies can be seen within the dyke. Chilled dyke margins are a common feature, and sometimes show cleavage.

Two specimens from one intrusion (nos. 163 and 158) at Helgoland serve to illustrate the more usual type of texture. A pyroxene is seen in subophitic relationship with plagioclase, these two minerals forming about sixty to seventy per cent of the rock. They are accompanied by micropegmatite, which is interestitial to the plagioclase, and a small proportion of iron ore and brown hornblende. There is considerable alteration of the pyroxene to chlorite and pale green amphibole. A Dollar Stage measurement of no. 163 gave pyroxene 28 per cent, plagioclase 39 per cent, hornblende and chlorite 9 per cent, micropegmatite 15 per cent, magnetite 6 per cent, and quartz 3 per cent.

In no. 163, the pyroxene is relatively fresh, and forms large subhedral sub-ophitic crystals (2 mm), often twinned, of a very pale greeny-brown colour. However, there is much alteration at some points to a pale green fibrous actinolitic amphibole, and a similarly-coloured chlorite, which are often difficult to separate. At one or two points brown hornblende is moulded on to the pyroxene in a manner suggesting replacement. There is a tendency towards hourglass structure. A determination of $n\beta$ using (100) parting tablets (Hess 1949) gives an approximate value 1.685, and 2V varies between 58 and 44 degrees in the same crystal in different parts of an "hourglass". This suggests an augite with composition somewhat below that given by reference to the "normal curve of crystallisation" of Hess ($Fe_{14}Mg_{44}Ca_{42}$).

The plagioclase is in idiomorphic rectangular plates and laths up to 3 mm long with a random orientation. It is strongly zoned (An_{60} to An_{25} at the margin), and is usually well twinned on both simple and complex laws. Though many crystals are fresh, there is patchy alteration to muscovite and chlorite. The rock is remarkable for its beautiful graphic intergrowths of orthoclase and quartz, which are sometimes orientated around plagioclase laths. Though generally fresher than plagioclase, the orthoclase is sometimes intergrown with chlorite.

Of the accessories, the iron ore forms large skeletal crystals, anhedral to euhedral, with inclusions of other minerals. The hornblende (α straw yellow, $\beta = \gamma$ medium brown) is in small subhedral crystals usually attached to pyroxene grains. One or two grains show bluish terminations against chlorite. At various points in the rock, very narrow apatite needles (0.5 mm long) can be observed crossing contiguous grain boundaries.

The other section (no. 158) from the same intrusion is somewhat finer grained and more altered. Much of the pyroxene has been replaced by greenish fibrous amphibole or chlorite, and the iron ore (1 mm) shows a greater degree of association with the dark minerals. A little free quartz in clusters of small grains occurs apart from the graphic intergrrowt, and some epidote in irregular grains is associated with the chlorite.

Of the specimens showing the coarser facies seen in the dykes, the fresher (no. 362) comes from the Pony Gletscher. Here pyroxene is very variable in grain size, and is usually fresh, but some grains are replaced by platy or fibrous very pale green amphibole and a little magnetite. Incomplete replacement sometimes results in a schiller effect. As in no. 163, the pyroxene shows hourglass structure and zoning. The plagioclase is of much the same composition as that of 163, but displays even better zoning phenomena in which at least two slight reversals can be made out. There is a patchy development of muscovite, pale amphibole and fine-grained epidote along cracks in this feldspar. Magnetite is small in amount, and again tends to be skeletal. The major difference between this rock and the others described is the absence of quartz and orthoclase. As before, however, the texture is subophitic, and resembles that of a dolerite rather than a gabbro.

The Kaldbakur example (no. 196) differs little from this excepting for the long needle-like twinned pyroxenes in some places. A little interstitial quartz is present also. Plagioclase here, however, is strongly replaced by blebs of muscovite and patches of cryptocrystalline dust, particularly near the corse of the grains, while the pyroxene is relatively fresh. The composition by measurement is augite 36 per cent, plagioclase 52 per cent, chlorite 9 per cent, magnetite 4 per cent, quartz 2 per cent.

In grain size (greater than 1 mm), these intrusives must be classed as gabbros. Texturally, mineralogically, and from their field occurrence, they are allied to quartz-dolerites.

Metamorphosed quartz-gabbros are more widely-distributed than the little-altered rocks described above, and the degree of metamorphism increases towards the east in accordance with observations on other rock groups in west Dronning Louise Land. In the field, the rocks become a ligher green, and the distinction between feldspar laths and ferromagnexian material diminishes. The feldspathic material become yellowish and greasy in appearance. Though the interiors of the intrusions retain their igneous texture, the exteriors become schistose and darker in colour.

A typical thin section is from specimen no. 366, which Wyllie collected not far from Monumentet. The conclusion reached from external appearance that this rock is of quartz-gabbro type is supported by the relict igneous (doleritic) texture seen in the slice. The plagioclase is highly altered to semi-opaque material, among which zoisite, sericite, and possibly chlorite laths can be made out. The pyroxenes have been entirely replaced and are represented by small plates and sheaves of pale amphibole ($\gamma \wedge c$ about 15 degrees, γ very pale green) together with a little pale brown biotite. Mineral boundaries are obscure, and the amphibole trespasses into the original feldspars in many cases. A few small patches of coloured hornblende (α straw, β brown, γ green) are intergrown with the other amphibole in optical continuity. While there is a little recognisable micropegmatite, the iron ore has been largely converted to pseudomorphs of leucoxene or brown sphene surrounded by an ill-defined corona of fine-grained pale biotite with a little greenish amphibole.

Though many sections resemble the one described in the last paragraph, there are quite a few variations in the replacing minerals, and it is worth while giving a little consideration to these.

Amphibole. The greenish amphibole replaces pyroxene in all rocks, either as small plates or laths, or one large plate pseudomorphing the entire pyroxene grain. A good example of this latter type is in no. 78 from Newton Klippe (Admiralty Gletscher) where much of the rock consists of ophitic plates of the amphibole 3 to 4 mm across, with numerous inclusions of altered feldspar laths (1 mm). There are traces also in this rock of very large original plagioclase laths (4 mm), and we must conclude that the original rock here had a texture differing markedly from the two described unmetamorphosed types of the S.W. nunataks.

The pleochroism of the replacing amphibole ranges from α pale green to colourless; β pale green to colourless, and γ medium green to almost colourless; while the extinction angles $\gamma \wedge c$ range from 15 to 20 degrees in paler varieties to 13 degrees in those with greater pleochroism. In one rock (no. 140) from near the west end of Eigil Sø, there is a partial mantling of the pale amphibole by vary variable blue-green hornblende in larger plates (0.5 mm), with an extinction angle $\gamma \wedge c$ of about 18 degrees. In some cases also the marginal amphibole is a rather darker green than the central material. The birefringence usually varies between about .02 and .03, and 2V is large and negative. Thus much of the amphibole lies in the tremolite-actinolite range, though some of it may be like those described by Eskola in his studies of Finnish amphibolites (1925, p. 41) . . . "The greenstone amphiboles are mostly nearly colourless in thin sections, and in thicker sections their pleochroism is feeble, the green colour of γ being of the emerald green shade known in actinolites, though more greyish, as though dirty. Its birefringence is remarkably low, for the interference colour generally does not pass, in usual thin sections, orange or red of the first order, which should indicate $\gamma - \alpha = 0.015$ approx. Such low birefringences are sometimes observed in common hornblendes, but have not been recorded from actinolites. The optical character is negative with large axial angle."

From the east end of Eigil Sø, an actinolite has $\gamma \wedge c$ 16°, $\gamma - \alpha$ c. 0.025, and $n\beta = 1.632$.

While in some cases the boundary between the amphibole and altered feldspar is quite well marked, in other cases shreds of amphibole push across the borders and may form a large part of the feldspar replacement. Another feature in some cases is the occurrence of numerous inclusions of fine-grained quartz in the amphibole plates.

Biotite. There is nearly always a certain amount of biotite associated with the amphibole, sometimes as patches within plates or bundles of fibres, and sometimes as a partial mantle. In some places it seems to have a replacement relationship with amphibole, but in view of its widespread occurrence, this sort of feature must be due to simultaneous growth. In fact, pyroxene goes over to actinolite + biotite + (quartz). Much of the biotite has a pleochroism pale brown to straw, and this together with the R.I. ($n\gamma$ about 1.62) indicates a composition approaching phlogopite. Besides its association with actinolite, the biotite can often be seen replacing the orthoclase in the micropegmatite, and in one rock in which this occurs it assumes a reddish tinge (no. 40). The fact that biotite is a constituent of coronas around iron ore has already been mentioned, and in no. 40 the absorption of γ may be a dark brown, and the larger biotite laths (0.5 mm) show orientated sets of inclusions at 60°.

The plagioclase in the quartz-gabbros shows varying degrees of replacement, generally by colourless epidote, zoisite, or sericite, with some amphibole and quartz. In specimens from the west end of Trekanten (nos. 64 and 66), most of the feldspar is replaced by yellow epidote and calcite in quite large grains, and the rock generally seems to have been chemically altered. Very pale green chlorite is a replacing mineral in a rock from Newton Klippe (no. 78) and Ymer Nunatak, and the pale biotite referred to above also plays a part in rock from Planck Klippe. Where replacement is incomplete, the original twinning and sometimes zoning can be made out. Even as far east as Planck Klippe, the remaining feldspar may be quite basic, a composition of An_{40} being recorded from here. In most places, however, the feldspar approaches albite, though there are no obvious signs of recrystallisation.

Micropegmatite preserves its identity farther east than the other constituents, and the orthoclase may remain unaltered where plagioclase is completely replaced. However, in some rocks the potash feldspar is replaced by biotite, as noted above, and in one (no. 88 from Cloos Klippe) the quartz has been largely recrystallised into granular pockets in which a little microcline is sometimes visible.

Iron ore may be completely pseudomorphed by leucoxene (e. g. the west end of Eigil Sø), or surrounded by sphene, in turn mantled by a corona of biotite, sometimes with greenish actinolite or hornblende in addition. The presence of leucoxene or sphene suggests that such iron ore was formerly titaniferous.

So far these mineralogical changes have referred only to dykes which have more or less retained their former igneous texture. Some dykes are slightly schistose even at the centre, while the dyke margins are always schistose. One example of a dyke on which a schistosity has been imposed is no. 13 from Regnbueklippe. Here the greater part of the rock is built of very pale green biotite. Very fine granular epidote and a little quartz make up most of the remainder, together with scattered parallel streaks of leucoxene. A somewhat similar rock comes from the margin of a large intrusion on the east side of Kilen (no. 45). It is a light green schistose rock with a distinct lineation. In section, the almost colourless amphibole forms subidioblastic rounded plates or fibres which are markedly orientated, and associated with pale biotite. Much of the rest of the rock consists of trails of fine-grained epidote, quartz, and albite, and rare granular patches of sphene are associated with the amphibole.

Other dyke margins are much finer-grained. The margin of a dyke at Regnbueklippe (no. 11) is a very fine compact pale green rock, which is resolved under the microscope as a biotite-epidote-quartz-sphene-schist with a grain size of less than 0.02 mm. The biotite is pale, though darker than the phlogopitic type hitherto described, and a little plagioclase is probably present, though identification is uncertain. A slightly different rock (S. 25) from here shows small elongated porphyroclasts of turbid feldspar (near albite) up to 0.5 mm long in a schistose groundmass of biotite, epidote, sphene, quartz, and albite. In small quartz-rich lenticles, the recrystallised quartz reaches 0.04 mm. The biotite is again darker, and is pleochroic medium brown to straw.

B. PETROGENESIS

From what has been said above, the quartz-gabbros in their unmetamorphosed state must have shown more textural variations than are preserved at Kaldbakur and Helgoland. Apart from the dykes with normal doleritic texture, there is the rather variable, almost pegmatitic facies as seen at Kaldbakur, the ophitic texture pseudomorphed at Newton Klippe, and a fourth type with scattered plagioclase phenocrysts, of which a metamorphosed example was collected from Ymer Nunatak.

The rocks can be compared with gabbros and quartz-dolerites. In grain size they are doubtless gabbroic, but mineralogically and in the

Table 3. Chemical composition of basic intrusions.

	1.	2.	3.	4.
SiO_2	50.52	52.8	51.7	49.8
Al_2O_3	13.76	15.7	17.47	16.2[1]
Fe_2O_3	3.87	4.0	2.3	4.8
FeO	8.50	7.7	7.1	10.0
MgO	5.42	5.3	5.5	6.2
CaO	9.09	8.8	9.2	10.4
Na_2O	2.42	2.1	3.3	2.0
K_2O	0.96	1.3	1.4	1.7
TiO_2	2.39	1.2	1.4	1.6
P_2O_5	0.26	0.3	0.6	0.2
MnO	0.16	0.4	0.3	0.5
CO_2	0.58	..	..	..
H_2O^+	1.51	1.6 (both)	2.36 (both)	..
H_2O^-	0.76			..
Others	0.14	..	..	..

[1]) Probably high.

1. Whin Sill. Holmes and Harwood 1928, p. 530.
2. No. 163. Quartz-gabbro, Helgoland.
3. No. 85c. Metagabbro, Rosmule.
4. No. 26. Metagabbro, Britannia Sø.

mutual relations of the minerals they lean towards the quartz-dolerites. The partial chemical analysis of no. 163 from Helgoland compares with that of the Whin Sill of the north of England (Table 3). Silica is higher, but is compensated for by a slight decrease in total iron and lime. The prominence of micropegmatite in no. 163 is reflected in the relatively high potash; in fact, this proportion of micro-pegmatite corresponds with that in the pegmatoid facies of the Whin Sill (Holmes and Harwood 1928, p. 510). The variability of pyroxene and micropegmatite

	no. 163 (Helgoland)	no. 158 (Helgoland	no. 196
Pyroxene etc.	36.8 per cent	29.9 per cent	42.1 per cent
Plagioclase	39.4 —	39.7 —	51.7 —
Micropegmatite	15.2 —	21.6 —	..
Iron Ore	6.2 —	6.3 —	4.3 —
Quartz	3.3 —	2.5 —	1.9 —

are of interest in the rocks from the same dyke (nos. 163 and 158), but this could well be a chance variation in the specimens selected.

As previously stated, multiple intrusions can be recognized. At St. Andrews Klippe, an earlier sheared dyke is cut by a later dyke-like body (fig. 17), and at Zebra Klippe Wyllie noted that one large quartz-gabbro body was intruded by another which has chilled contact against the earlier rock.

Fig. 17. St. Andrews Klippe. Note the later quartz-gabbro dyke cutting an earlier dyke of the same type. The later dyke is affected by a fault to the right of the picture. Photo: J. D. P.

The quartz-gabbros definitely cut the Western Gneisses, and Trekant Series (fig. 18). Though the centre of the Prins Axel sill is metamorphosed quartz-gabbro, the upper margin (no. 488) has been transformed to sericite-quartz-magnetite-schist, a feature which could be explained either by pre-Zebra weathering, or movement of solutions between quartzite and gabbro during metamorphism. However, no pebbles of quartz-gabbro have been found in the grits of the Zebra Series at this or other localities.

The only other lines of evidence of age relative to Zebra rock are (a) that a dyke of quartz-gabbro type occupies a fault adjacent to presumed Zebra quartzites at S.E. Prins Axel Nunatak, and (b) a body of this nature outcrops on Suzanne Nunatak among rocks presumed to be higher beds of the Zebra Series. That quartz-gabbro intrusions cut the Zebra Series is therefore likely, but not proven.

The metamorphic effects on the quartz-gabbros are summarised below. From a progressive point of view, we can distinguish three zones (1) A region in which metamorphism is slight or absent, (2) a zone in which pyroxene shows partial replacement by actinolite, and (3) a broad area in which pyroxene is completely replaced, and feldspar is usually extensively saussuritised.

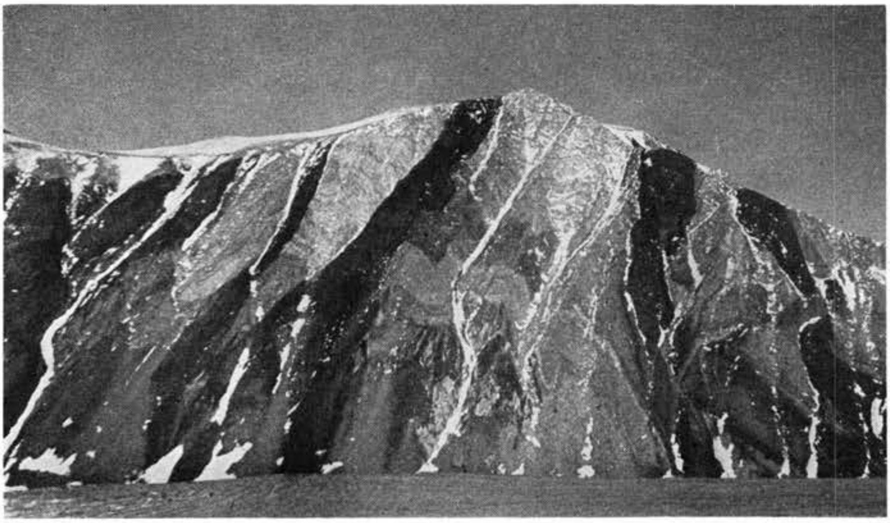

Fig. 18. Quartz-gabbro intrusions cutting Trekant quartzites at Krebs Bjerg. Photo: P. J. WYLLIE.

Of these zones, (1) is confined to the S.W. nunataks, the inflow of the Pony Gletscher, and (on the evidence of hand-specimens) Poulsen and Farvel Nunatakker. Zone (2) runs N.E. from St. Andrews Klippe, skirts the Revaltoppe and runs thence just east of Prinsessen to Zebra Klippe.

The third zone is bounded to the east by Monumentet, Kilen, Planck Klippe, Vinkelklippe, S.E. Prins Axel Nunatak (field evidence), Suzanne Nunatak (field evidence), and Jættebringen. This zone has the following mineralogical characteristics:—

(The symbol (→) here does not indicate chemical equality. Material has probably been added or subtracted).

Metagabbro.

Pyroxene →	Actinolite + phlogopitic biotite + (quartz) + (hornblende)
Iron ore →	Sphene + biotite + (actinolite, hornblende)
Micropegmatite →	Quartz + biotite
Plagioclase →	Epidote (zoisite) + albite + (sericite) + (chlorite) + (actinolite).

Schists.

Quartz-gabbro →	Actinolite-phlogopitic biotite-quartz-epidote-albite-sphene
	Biotite-epidote-quartz-sphene-(albite)

Of these two groups of rocks, the minerals is the textural unchanged metagabbros have been developed under different conditions from those in the schists, and it is unlikely that the stress conditions operation in them were the same. In view of the textural and mineralogical relics, they certainly have not reached the stable conditions appropriate to the metamorphic grade. The schists on the other hand are thoroughly recrystallised, and their mineral assemblage probably gives a better comparison with metamorphic facies in other areas of basic rocks.

It is difficult to say to what degree chemical changes have taken place in the metagabbros. In all rocks, the appearance of epidote and actinolite involves the adition of water. Considerable mobility of some ions is shown by the growths of amphibole in plagioclase, and also by the biotite growths around iron ore. These latter are not reaction rims in the strict sense, since they are not confined to iron ore and any one other mineral. At Trekanten, two specimens show intense epidotisation, but these seem to be exceptions. Against this sort of evidence, suggesting as it does mobility of ions and possibilities of changes in chemical composition, is the partial or complete pseudomorphing of pyroxene by amphibole and biotite, and the preservation of a little of the original feldspar at Regnbueklippe.

Metamorphic trands in basic rocks have been studied by a number of authors, and the accounts by Wiseman (1934), Read (1923), and Sutton and Watson (1951) seem to be particularly useful in a discussion of the Dronning Louise Land quartz-gabbros. In the Loch Torridon dykes (Sutton and Watson, 1951, p. 28), pyroxene is replaced by quartz-hornblende aggregates, in which the central grains are smaller and paler than those on the rim. This can be paralleled in Dronning Louise Land where quartz is sometimes associated with the replacing amphibole, and rims of slightly darker amphibole mantle paler areas. A similar origin might be postulated, in that the darker amphibole represents the initial stage of alteration of the pyroxene, preserved when the remainder of the pyroxene was replaced.

In Eastern Scotland, Read notes that the pyroxene is replaced by either of two amphiboles, of which the paler variety is associated with red-brown biotite (op. cit. p. 91) which also seems to be derived from the pyroxene. The parallel with Dronning Louise Land is again obvious, but for the differences in pleochroism of the biotite. Read also indicates that the feldspar is saussuritised at the lower grades of metamorphism, and that iron ore is occasionally bordered by leucoxene and associated with biotite (p. 93).

In a study of the epidiorites of the central and S.W. Highlands, Wiseman shows that the typical low-grade mineral assemblage is chlorite-(biotite)-epidote-albite-amphibolite (p. 410). However, the chlorite here is regarded as due to the reaction of pyroxene with feldspar, and its refractive index together with that of the amphibole is an index of metamorphic grade, whereas in West Dronning Louise Land chlorite appears only sporadically. The place of this chlorite in epidiorite is taken, in a sense, by pale biotite. Without detailed collecting and a number of analyses, however, it would be unwise to press conclusions farther than to say that the metagabbros compare with those of the chlorite and biotite zones of the Highlands in metamorphic grade.

2. Dykes of dioritic affinities.

In the field, these are dark rocks, usually very fine-grained in appearance, showing cleavage or schistosity. The fine-grained look is not maintained in thin section, and might be attributed to the extensive alteration of many of the minerals, an alteration illustrative of the metamorphism which has affected all other rock groups in West Dronning Louise. There are only two specimens available of these dykes, both from Thomson Klippe.

No. 3 is a fine-grained grey-green rock with a very slight cleavage. The section shows it to be composed of albite (60 per cent), chloritised biotite (20 per cent), and epidote, together with a little quartz and iron ore. The plagioclase (0.5 mm) is uniform in size, but shows signs of crushing with bent or displaced twins. Twinning is frequent on the albite law, and the maximum symmetrical extinction angle of 16 degrees, together with the relatively low refractive indices indicate a composition of about An_3. Apart from a persistant turbidity due to very fine dust, the plagioclase shows some alteration to fine-grained epidote, chlorite, and calcite. A phenocryst of plagioclase seems to be of similar composition. The random chlorite sheaves (0.5–1.0 mm) are accompanied by a dusting of magnetite, and this, together with relict cores of biotite (pleochroic pale brown to straw) suggests it is pseudomorphous after the mica. This chlorite, with length show, and ultrablue polarization colours is probably penninite. Epidote occurs as isolated granules or patches of granules scattered fairly evenly through the rock.

A second specimen (no. 5) also consists largely of extensively sericitised albite (70 per cent), chlorite (20 per cent), with a little biotite and quartz. The texture is cataclastic to come extent, and there is a distinct schistosity. The chlorite is very pale green, length fast, and shows anomalous brown polarization colours. It forms sheaves of small laths occupying interstices between feldspars, and is mixed with a little fine-grained quartz. The biotite is a medium brown variety, and forms occasional laths up to 1 mm long parallel to the schistosity. There is a partial chloritisation to the same type of chlorite as in the remainder of the rock.

From their former mineralogy, differing products of metamorphism, and lack of typical quartz-gabbro texture these rocks evidently do not belong to the quartz-gabbro suite. Before metamorphism, they must have been biotite-plagioclase diorites, or microdiorites.

3. Ultrabasic Rocks.

A specimen of serpentine was obtained from Planck Klippe (no. 14), where a dyke of this material outcrops near a quartz-gabbro intrusion. It is a dense, massive dark rock, with traces of poikilitic crystals visible in hand specimen. In section, these poikilitic crystals are the larger of two sizes of olivines, the smaller (0.3 mm) being enclosed in the larger (3 mm). The olivines, which show much dusty alteration along cleavages, are marginally replaced by fibrous tremolite (colourless, $\gamma \wedge c$ 15 degrees), the fibres being perpendicular to the crystal surface. Much very fine-grained magnetite is also associated with the olivine, which has 2V approximately 90° and is probably near forsterite in composition. The serpentinous ground forms about 70 per cent of the rock. Some of it is nearly isotropic, but shadowy olivine pseudomorphs are outlined in feebly birefringent antigorite. The quasi-isotropic material is probably largely chrysotile.

Wyllie discovered one or two loose blocks of serpentine at various points in west Dronning Louise Land, thus a search would probably disclose one or two more occurrences of this sort of intrusion. Though it is adjacent to a quartz-gabbro dyke, the age of the Planck Klippe dyke could not be ascertained. The preservation of much of the olivine, however, suggests that it post-dates the metamorphism which has affected the neighbouring basic dyke. On the other hand, the occurrence of replacing tremolite would be in accord with the idea that the serpentine had also been affected by the metamorphism.

4. Eigil Sø Dykes.

Apart from the normal quartz-gabbros, a number of usually narrow, dyke-like bodies cut the gneisses at various points. They are almost completely metamorphosed, and on the basis of field appearance alone it is difficult to fit them in with the other categories of minor intrusions. Petrographically, some of them appear to have been porphyritic quartz-dolerites; others may be allied to the dioritic dykes discussed above.

(a) Porphyritic quartz-dolerites (nos. 30 and 33). These are finer grained and darker than the metamorphosed quartz-gabbros, and show tabular feldspar insets in a schistose groundmass. No. 30 from 2 km N.E. of the west end of the lake as been converted into a fine-grained epidote-albite-actinolite-schist with some sphene, quartz, muscovite and phlogopitic biotite. A higher grade of metamorphism is shown by No. 44 a few kms. further east in which albite phenocrysts riddled with epidote and biotite, are enclosed in a medium-grained (0.5–1.0 mm) biotite-epidote-quartz-albite-sphene-schist. The mineralogy of this latter specimen is the same as that of a quartz-gabbro dyke margin at Regnbue-klippe.

(b) Of the other dykes, no. 19 from near the west end of Eigil Sø shows phenocrysts of quartz and altered plagioclase in an exceedingly fine matrix of quartz-biotite, calcite, and muscovite. It evidently does not belong to the quartz-gabbro suite.

Another rock difficult to classify is a biotite-epidote-sphene-quartz-schist with former phenocrysts entirely replaced by zoisite, muscovite, phlogopitic biotite and colourless amphibole; this dyke-rock was collected from close to no. 44 above.

More detailed field and laboratory work is needed before such rocks can be satisfactorily classified.

5. Cloos Klippe.

A number of dykes of dark green schist outcrop here, apparently in places marginal to the texturally little-altered parts of quartz-gabbro dykes. No. 9, collected from one of these dykes, is an olive green unlineated schist composed of plagioclase (40 per cent), epidote (10–20 per cent), pale green amphibole (10–20 per cent), and quartz, with accessory phene, magnetite and biotite.

The plagioclase occurs in tabular crystals often with ragged or splintery margins, and fracturing and warping of twin lamellae. There are inclusions of tiny epidote, biotite, and amphibole crystals, and most grains are rendered turbid with crystocrystalline matter, though the margins are clear in some cases. Determination in oils gives a composition of An_{15} for the clouded portions, and An_7 for the clear margins. The grain size (1.0 mm), strain shadows, and splintered or granulated margins indicate that these are porphyroclasts.

As in quartz-gabbros, the amphibole, which is a pale green actinolite, is mixed with a small proportion of medium brown biotite, and the iron ore is enclosed in sphene. Quartz (0.1 mm) is in rather inconspicuous flat lenticles, accompanied by much fresh, clear, partially twinned albite.

One must conclude that this particular dyke at any rate is one of the quartz-gabbro group of rocks, since the mineralogy is exactly as one might except. It is of interest too in that it shows direct evidence both of albitisation of the porphyroclasts, and the crystallisation of albite in the groundmass.

6. Intrusions of the lower Borgjøkel.

The schists at Rosmule are cut by dyke-like bodies of hornblende-schist and igneous-looking metagabbro (fig. 10), and there is a large, complex body of metagabbro and amphibolite on the opposite side of the glacier at Paradisklippe. Four specimens (one from Rosmule and three from Paradisklippe) show all gradations between metagabbro with igneous texture and amphibolite.

No. 85c from Rosmule is a coarse-grained green igneous-looking rock composed predominantly of dark minerals set about with narrow grey feldspar laths (4 mm). The thin section is striking, showing pseudomorphs after pyroxene (4 mm), and iron ore with coronas among interlocking plagioclase laths with a little interstitial quartz (Plate 5 a).

The pyroxene, (20 per cent), which previously had a sub-ophitic relationship with plagioclase, is now represented by pale actinolite ($\gamma \wedge c$ 17–19°) with a narrow rim of green hornblende ($\gamma \wedge c$ 19–21°). Though more usually in flakes, the actinolite sometimes forms plates in which there is schiller structure due to needles or a dusting of iron ore. The mantle of darker hornblende (α straw yellow, β pale brown, γ emerald green) is nearly always in the form of flakes with marked orientation.

Iron ore, which reaches 0.5 mm in crystal diameter, is strongly replaced by sphene and biotite, the sphene generally forming a very narrow rim against the relict magnetite core. The biotite areas, on the other hand, have a radius approximately twice that of the larger magnetite cores, this biotite occurring as poorly-formed laths (pleochroic medium red-brown to straw yellow). The outer parts of the biotite mantles and also the surrounding feldspars are studded with pale pink garnets (0.3 mm), the refractive index of which (1.794) together with the colour suggest almandine. Apatite (0.2 mm) is scattered in the corona, sometimes in well formed needles.

The plagioclase is in the form of very large laths in which lamellar twinning on pericline and albite laws is common, often in the same crystal. There are numerous tiny inclusions, probably epidote, and these prevent a very accurate determination in oils, though a composition between An_{50} and An_{55} is indicated, which is confirmed by a maximum symmetrical extinction angle approaching 30 degrees. Some replacement by calcite can be seen at one point, and edges are blurred owing to penetration by needles of hornblende. The quartz is largely interstitial, and is occasionally intergrown with a little orthoclase.

From its original mineralogy (pyroxene, labradorite, iron ore, accessory quartz and orthoclase) there is little doubt that this rock was a quartz-gabbro. The metamorphic effects belong to a higher grade than those in the quartz-gabbros to the west, though the preservation of the original igneous feldspar seems to be nearly complete. Dodge (1942) in a study of the amphibolites of the Lead region, South Dakota, figures a few coarse-grained rocks with what appear to be the original igneous feldspars, and also refers to brightly-coloured rims surrounding pale hornblende—these occurrences seem to be very similar to those here, but occur in very large masses of amphibolite, contrasting with the minor intrusion habit of the metagabbros in Dronning Louise Land.

No. 9 from Paradis Klippe is similar to the above in hand specimen except that it contains a smaller proportion of feldspar. The section also shows many similarities. The same hornblendic pseudomorphs occur, forming about 60 per cent of the rock, but they differ in the greater proportion of green hornblende, and its larger grain size (up to 0.2 mm). Iron ore is largely replaced by granular sphene, which may in turn be mantled by a broad rim of green hornblende flakes. The original igneous plagioclase laths are still present, but often show granular fresh, more acid, margins (0.05 mm) and enclosures, and contain numerous epidote inclusions. Another interesting feature is the development of a network of veins of clear feldspar in the slightly turbid igneous plagioclase, this feldspar being a slightly more acid variety. The network is related to cleavage directions. The larger epidotes (which are randomly orientated within the original feldspar) may be surrounded by the more acid plagioclase. Numerous small garnets are scattered in the plagioclase crystals and tend to congregate as an external rim around iron ore/sphene/hornblende coronas. The quartz (0.2 mm) forms small aggregates among the plagioclases. There is no trace of orthoclase.

The growth of almandine garnets within the plagioclase itself, and not only in the coronas against iron ore, is similar to phenomena commented on by Poldervaart and Gilkey with respect to clouded plagioclase (1954, p. 87). They believe that since enclosures in clouded plagioclase, when recognisable, are of the same minerals as those outside the plagioclase crystals, there must be some degree of equilibrium between exterior and interior of the crystals. This state of equilibrium means that the crystals are open to diffusion. Gjelsvik (1952) has described metamorphosed dolerites from Sunnmøre on the west coast of southern Norway. He notes that in the Middle Stage of dolerite alteration, plagioclase is replaced by granoblastic more acid plagioclase, and that garnet grows in cracks or interiors of plagioclase. However, in these rocks, the reaction coronas around the ferromagnesian minerals are usually of anhydrous minerals such as diopside, plagioclase, and garnet, whilst in the metagabbros from the Borgjøkel the occurrence of actinolite and epidote point to the addition of water.

No. 86, also from Paradisklippe, is a third variety of these igneous-looking rocks. In hand specimen, the dark minerals (hornblende and biotite) are clotted, and form only about 30 per cent of the rock.

The section shows a hornblende similar to that described above (α yellow-brown, β green-brown, γ sea green, 2V very large and negative) in grains up to 3 mm long. This amphibole occurs in clumps with biotite (γ dark brown, α straw-yellow). Some of the larger hornblende plates show traces of schiller, and there is also a tendency for the hornblendes at the centres of the clumps to be seived with quartz (0.05 mm). The biotite is partly intergrown with hornblende, but also is in well-formed laths (1 mm), and, like the hornblende, shows occasional inclusions of magnetite. A few crystals of epidote and apatite are scattered here and there. The plagioclase (An_{44}) is crystalloblastic and reaches 1 mm. in grain size, containing occasional includions of garnet, epidote, and biotite. One part of the slide shows much spherulitic green chlorite (length fast, anomalous polarization colours), large masses of sphene, and shapeless calcite replacing feldspar, the grain size of the feldspar here is smaller and it is associated with much quartz.

The amphibolite, no. 47 from Paradisklippe is a dull green rock with linear and plane schistosity. A foliation is developed with segregation of light minerals into thin bands alternating with biotite and hornblende-rich portions. In thin section, however, it greatly resembles no. 86. The hornblende is again a green variety with $\gamma \wedge c$ about 24 degrees, and $-2V$ approaching 90 degrees. The biotite also is similar, but with more red in the pleochroism and occasional pleochroic halos around tiny zircons. A measurement of the extinction angles in the plagioclase give a composition of An_{40}–An_{45}. Some quartz (10 per cent), garnet, and apatite, are present, and a little sphene is associated with the iron ore.

PETROGENESIS

There can be little doubt that these rocks have been formed by the metamorphism of quartz-gabbros. This view is supported by the partial chemical analysis of no. 85c given in Table 3. The proportion of silica falls within the expected range, but the ferric iron is rather low. However, there is quite a mineralogical variation from rock to rock among this basic material, and any chemical differences seem to be well within the range of variation which is to be expected.

Not only is the ancestry of the metagabbros reasonably certain, but it is reasonable to suppose that they belong to the same suite of quartz-gabbros that is intruded into the Western Gneisses and Trekant Series. The full stratigraphical implications of this can only be discussed in a later section, but to anticipate, if the Britannia Sø Group equates with Zebra Series, and the Eastern Schists and Gneisses lie stratigraphically above the Britannia Sø Group, then the Zebra Series must lie within the time range of intrusion of the quartz-gabbro suite.

It seems likely that the amphibolite in the above series reached equilibrium in the temperature and pressure conditions prevailing during metamorphism. Here andesine, green hornblende, and accessory almandine are found together, an assemblage characteristic of the amphibolite facies (e.g. RAMBERG 1952, p. 150). The small quantities of epidote in the schists and gneisses of the area support this view.

The metagabbros, outcropping as they do in a small area, must therefore have been at least partially subjected to the conditions of the amphibolite facies. Since an igneous mineral has survived in one of them (labradorite in 85c), the metamorphic processes evidently were unable to bring the appropriate chemical reaction to completion, and in view of the high grade of such processes, the time of operation must have been short. The preservation of igneous textures also supports this idea, but, this of course, can also be put down to the greater competency of basic rocks in the prevailing conditions. Preservation of igneous textures in garnet-grade epidiorites has been noted elsewhere, e. g. by WISEMAN (1934, Plate 12, figs. 1 and 4).

In the metagabbros, the mode of replacement of the original pyroxene and iron ore is similar to that described in the minor intrusions of west Dronning Louise Land, excepting that the place of actinolite is largely taken by hornblende, and that garnets appear in the iron ore coronas. These facts might be correlated with the higher grade of metamorphism.

Likewise, feldspar is never completely saussuritised. We can put down the stages of replacement as follows:—

—Clouding of labradorite. This is exceedingly fine-grained, and is more like the true clouded feldspar described by POLDERVAART and GILKEY (op. cit. 1954, p. 87) than the general turbidity in the quartz-gabbros of the west.

—Replacement of labradorite by epidote + andesine. The andesine grows as crystalloblastic grains from centres usually on the peripheries of original labradorite grains, and also as a network along the cleavages of the feldspar. Epidote grains cluster near the centres of the old labradorite crystals, and may be surrounded by a "bleached" zone of andesine.

—Crystalloblastic growth of andesine. Since the proportion of epidote at this stage is very small, most of the "potential epidote" must have been taken up in hornblende.

These stages have all taken place under the same general metamorphic conditions, and certainly do not represent a progressive sequence of events as regards temperature and pressure. Two conclusions may be drawn, firstly that the metagabbros, were subjected to maximum metamorphism for a relatively short time, and secondly that such maximum conditions were reached very quickly allowing no time for changes to take place under lower grades of metamorphism.

7. Intrusions of the Britannia Sø Area.

Both the schists and gneisses and the quartzites of the Britannia Sø Group are penetrated by intrusions of hornblende-quartz-schist, and metagabbro, the latter being found only in one sill on the south bank of Britannia Sø. True plagioclase-amphibolite outcrops in the Kap Bellevue area. Though concordant on the whole, the hornblendic rocks may be cross-cutting in detail, and one body at least is sharply cross-cutting.

(a) *Metagabbro.*

This outcrops as a sill-like rock on the lower N.W. slopes of Hvalryggen. It is massive, composed chiefly of radiating dark green hornblende crystals up to 3 mm long together with minor light minerals. The mineral composition, as shown in section (no. 26), is hornblende, quartz, epidote, plagioclase, and biotite, together with a little sphene and apatite.

The texture of the rock is largely controlled by the porphyroblastic clumps of hornblende, which are idioblastic against the other components. This hornblende, which forms up to 60 per cent of the rock, is pleochroic sea-green, brown and yellow, nβ is approximately 1.68, and $\gamma \wedge c$ is approximately 20°. (See discussion below). Some grains are riddled with small includions of quartz. The biotite (up to 0.5 mm) is pleochroic red brown to straw, and is in well-formed laths which are clumped together at the margins of the hornblende crystals. The centres of the clumps often contain granular sphene, this latter mineral sometimes surrounding (and replacing) small iron ore flecks.

The remaining third of the rock is formed largely of quartz and plagioclase together with epidote (10 per cent). The plagioclase crystals are plate-like, and twinning is very rare; this fact, together with the numerous epidote inclusions, make determination difficult. Universal Stage measurements give a composition of about An_{20}. One of the interesting features of the rock is the graphic intergrowths of quartz with plagioclase, surrounding plates of original plagioclase (Plate 5 b). The quartz (0.2–0.5 mm) also forms granular areas, sometimes with subhedral grains. Apart from visible inclusions in feldspar, the epidote forms granular patches of coarser grain mixed with quartz, the patches often being reminiscent of former feldspars with epidotised cores. The quartz-feldspar areas contain numerous acicular apatite needles, which may lie across quartz grain boundaries.

The spot analysis of this rock (Table 3, no. 4) suggests it is high in total iron, and a little higher in lime and magnesia than other rocks in the table. A norm of the rock is as follows:—

1.		2.		3.	
Quartz	2.82 %	Quartz, Feldspar	24.3 %	Quartz	1.9 %
Orthoclase	3.90 -			Plagioclase	51.7 -
Albite	17.30 -				
Anorthite	28.60 -	Hornblende	68.4 -	Pyroxene	42.1 -
Diopside	18.08 -			Iron ore	4.3 -
Hypersthene	20.19 -	Epidote	3.8 -		
Magnetite	4.40 -	Biotite	2.2 -		
Ilmenite	3.65 -	Sphene, Iron ore	1.3 -		
Apatite	0.34 -				

1. Norm of no. 26. 2. Mode of no. 26. 3. Mode of no. 196 (Kaldbakur).

It can be seen that the norm of no. 26 resembles the mode of no. 196 in the small amount of quartz and the proportion of normative feldspar. The percentage of iron ore differs little from that of other quartz-gabbros (p. 97), but is considerable greater than in no. 196. However, the normative plagioclase is roughly An_{66} compared with a maximum anorthite content of about 60 per cent in the Kaldbakur rock, and if no. 26 is to be compared farther with the quartz-gabbros this must be accounted for.

Now total normative mafic minerals total roughly 46 per cent compared with 68.4 per cent hornblende in the mode of the same rock. This suggests than, even on allowing the volume difference between pyroxenes and amphiboles, the hornblende has encroached somewhat on the original feldspar areas. On the petrographic evidence (which is unsatisfactory owing to great difficulty in differentiating between crystalloblastic quartz and feldspar, even when some means to accentuate the relief of the latter is used), there would seem to be a greater percentage of quartz in the rock than in the norm, suggesting that it is one of the products of a metamorphic reaction. Such a reaction could be (1) the conversion of pyroxene to amphibole, (2) Conversion of part of the original feldspar substance to hornblende (among others), and (3) a combination of (1) and (2).

(1) The conversion of pyroxene to amphibole. Combining the results of the modal and chemical analysis (Table 3, no. 4), it seems reasonable

to suggest that the hornblende is a moderately aluminous and iron-rich variety. This agrees with results from comparable rocks. TILLEY (1923, pp. 185–187) notes that aluminous iron-rich hornblende in Start Point hornblende-epidote-albite-schists is pleochroic in pale green tints. A brown hornblende from Mysore amphibolites (NAIDU M.G.C. 1949 quoted in Mineralogical Abstracts 1950–52) has $n\beta = 1.69$ and 15.68 per cent alumina. NICHOLLS (1950–51, p. 331) reports a deep green hornblende with 10.17 per cent alumina and 11.42 per cent ferrous iron from a diorite. The refractive indices ($n\gamma = 1.689$, $n\alpha = 1.666$) suggest that the intermediate index $n\beta$ is comparable with that in no. 26, i.e. about 1.68. The optic axial angle, of 65° is small compared with that of the Dronning Louise Land specimen, where the angle is nearer 90°. Nicholls' hornblende contains 41.96 per cent silica. Hornblendes of similar composition cited in IDDINGS (1911, p. 352) have silica percentages between 39 and 41. On the other hand, most aluminous augites have silica percentages between 46 and 52 (IDDINGS, op. cit., p. 310). Thus there seems to be some chance of release of silica on the conversion of pyroxene to hornblende.

(2) If the feldspar of the norm of no. 26 be anywhere near the true original feldspar in amount, then, as suggested above, hornblende has transgressed into such feldspar areas. The theoretical silica percentage in plagioclase varies between 43.2 per cent in pure anorthite and 64.7 per cent in pure albite. Thus if moderately basic plagioclase moved during metamorphism to oligoclase with release of lime, alumina and some soda for incorporation in hornblende and epidote (silica < 40 per cent), one would expect some release of silica to form free quartz. Nicholls's hornblende contains 1.67 per cent soda, and other common hornblendes contain between 1 and 3 per cent soda (IDDINGS 1911, p. 352).

(3) It seems from the above discussion that there are possibilities of deriving the free quartz in the metagabbro from a pyroxene — amphibole reaction, together with alteration of feldspar.

We can conclude that the metagabbro could have been derived from an igneous rock without bulk changes in chemical composition (excepting, of course, the addition of water). The igneous parent was an oversaturated rock with respect to silica, possibly, but not necessarily, belonging to the quartz-gabbro suite.

(b) *Hornblende-quartz-(plagioclase)-epidote-schist.*

Mineralogically schists of this type are similar to the metagabbro, but the quantities of the various minerals varies greatly. A specimen from the cross-cutting intrusion at Hvalryggen (no. 212) is a bottle-green schist in which fine-grained lineated hornblende forms the majority of the rock. The section shows it to be a hornblende-quartz-epidote-schist, with small quantities of sphene, biotite, chlorite, and magnetite.

The hornblende, which has a grain-size between 0.1 and 1 mm in a section cut perpendicularly to the schistosity, is seived with quartz and epidote, and shows some dimensional orientation. It is pleochroic α yellow brown, β brown, and γ sea green, and $\gamma \wedge c$ is about 22 degrees. There is a tendency towards segregation with the granular sphene and small amounts of medium-brown biotite (0.05 mm). The colourless epidote too is very fine-grained, and tends to form masses elongated along the schistosity, generally being associated with quartz. Strain shadows are present in the quartz, which has a grain size in more quartz-rich parts of about 0.15 mm. Chlorite forms occasional patches of laths with feeble birefringence and negative elongation.

On the south side of Britannia Sø, similar rocks can be found as far southwest as the ground on the west side of Adastra Iskappe. S22 collected by Simpson from here, is similar in many respects to no. 212. However, the extinction angle of the hornblende is below 20 degrees, and some plagioclase (probably oligoclase) with strain-shadows accompanies the quartz. Another schist obtained from near the summit of Gultop also contains a little plagioclase (An_{37}) which is partially epidotised, and the amphibole ($\gamma \wedge c$ 16 degrees) is paler than in previous examples. There is a suggestion in this rock of a former igneous texture, deformed by being drawn out along the schistosity.

Another of Simpson's rocks, (S9) from the southeast side of Hvalryggen contains about 20 per cent of fresh plagioclase (An_{28}) forming a granular mosaic with quartz. The hornblende (40 per cent) is the same type as in no. 212, and likewise is seived with quartz and epidote. It is perhaps significant that this specimen outcrops to the east of most of the remainder, and is approaching the plagioclase amphibolites in mineralogy.

A specimen (no. 238) from S.W. of Søstersøer carries a comparatively high proportion of epidote (30–40 per cent), quartz (30–40 per cent), hornblende (20 per cent), biotite (10 per cent), and a little chlorite, sphene, and magnetite. In this rock there is a strong schistosity due to the alignment of the micaceous minerals and hornblende. Another variant is no. 235 from the corrie west of H. A. Jensen Bjerg. Here the rather pale hornblende ($n\beta = 1.656$, $\gamma \wedge c$ 20°) is accompanied by, and is intergrown with light green chlorite (length fast, $n\beta = 1.614$, birefringence .005), while biotite is small in amount. The hornblende forms about 40 per cent of the rock, and its grain size (1.5 mm) compares with that of no. 212. No feldspar is present in either 235 or 238.

According to Winchell's diagram (1951, p. 383), the chlorite with $n\beta = 1.614$ and $\gamma - \alpha = .005$ would fall into the diabantite group.

This also occurs if Hey's revised classification is followed (Hey 1954, figs. 1a and 4, pp. 280–284). The refractive index of this chlorite and that of the associated hornblende do not fall on to either of Wiseman's curves relating the indices of the two minerals (Wiseman 1934, p. 364 and p. 404). A detailed study would be needed to find if there was a similar hornblende-chlorite relationship in the Dronning Louise Land rocks.

It seems reasonable to suppose that the hornblendic schists have followed a similar course of metamorphism to that described from the metagabbro. The variations in the amounts of ferromagnesian minerals might be a function of the original variations in pyroxene.

Where plagioclase remains, over most of the area it contains between 20 and 37 per cent anorthite. In one rock, towards the east, fresh plagioclase has 28 per cent anorthite. One would suggest that as regards the plagioclase relics, those with the lower anorthite content might be nearer equilibrium under the conditions of metamorphism. The association of oligoclase and green hornblende is characteristic of the epidote-amphibolite facies (Ramberg, op. cit., p. 145). Noble and Harder (1948, Table 1, p. 967) in summarising metamorphism in Dakota amphibolites correlate oligoclase and hornblende ($n\beta = 1.670$) with the biotite, and part of the garnet zone of regional metamorphism.

(c) *Garnetiferous hornblende-schist.*

An outcrop north of Dryasdal consists of granitic gneiss and garnetiferous hornblende-schist. Since I examined it by torchlight on a November day, conditions were not good enough to study the relations of the two rock types. A specimen of the schist (no. 312) is well-foliated, and lineated hornblende and biotite are identifiable, with a few red garnets reaching 2 mm across. In slice, it proves to be a plagioclase-quartz-hornblende-biotite-schist, with pink garnet, magnetite, chlorite, calcite, and apatite in addition. This plagioclase has an anorthite content of 23 per cent, and the garnets are seived with quartz, feldspar, biotite, hornblende, and magnetite. The hornblende is a common green type; the associated biotite is medium brown; and the chlorite, also associated with hornblende, is probably penninite. The association of green hornblende, garnet, and oligoclase again suggests the epidote-amphibolite facies.

(d) *Plagioclase-amphibolite.*

The three available specimens (S. 1, S. 13, and S. 4) were collected by Simpson. Of these, only one is a "normal" amphibolite.

S. 1 comes from the riverside due south of the highest point of Kap Bellevue. It is a dark, lineated schist, which in section proves to be a plagioclase-hornblende-biotite-quartz-schist with a little accessory sphene and epidote. The hornblende is in the form of large subidioblastic plates (2 mm long), often enclosing feldspar and quartz. An extinction angle ($\gamma \wedge c$ 20°), and the pleochroism (α yellow brown, β dark brown-green, γ sea green) show it differs little from that recorded further west. Plagioclase (An_{37}) is distinctly larger in grain size (0.3–0.4 mm), and the grains form a crystalloblastic background to the more idioblastic ferromagnesian minerals. Twinning on the albite law is frequent, and pericline lamellae are also present in a few grains, Strain-shadows occur in many grains, though in some cases are confined to one set of twins. The proportion of plagioclase is about 40 per cent, and that of hornblende 20 per cent. Biotite (pleochroic deep brown to straw) occurs as stout laths with a subparallel arrangement, giving a planar schistosity to the rock. It is idioblastic against the hornblende with which it is commonly associated in about equal quantity. Quartz is anhedral, and somewhat finer-grained than the feldspar, with marked undulose extinction.

S.4 is from the knee-bend in Stranddal, just above the waterfall. It differs from S.1 in that the plagioclase (An_{30}) has albitic, altered, margins and some bundles of green chlorite (length fast), of rather higher birefringence than usual, are associated with the hornblende. Since the specimen is weathered, the significance of the feldspar alteration is doubtful. The accessory minerals here are magnetite, epidote, and a few grains of rutile.

The third specimen, S.13, Simpson collected from a hill about 5 km south of Stranddal. It is poorly schistose, with some segregated grey feldspar as discontinuous bands or lenticles. The slice shows hornblende and biotite in much the same proportions as in the fore-going, but the plagioclase (An_{37}) is accompanied by a little potash feldspar, and there is a greater proportion of quartz (20 per cent). The interest lies in the fact that most of the potash feldspar, which is untwinned, occurs as strips in the plagioclase, or simulates graphic growth, whilst the remainder shows up a small xenoblastic crystals associated with a little myrmekite. Also, the epidote (0.2–0.3 mm) has an embayed appearance against quartz and plagioclase, seemingly due to replacement by these minerals.

The mineralogy of the plagioclase amphibolites confirms the evidence of the paragneisses concerning the high grade of metamorphism in this part of Dronning Louise Land. The co-existence of hornblende with andesine suggests the lower part of the amphibolite facies. Noble and Harder (op. cit., p. 967) suggest that hornblende ($n\beta = 1.680$), andesine (oligoclase) and biotite in Dakota amphibolites can be correlated with the upper garnet and staurolite zones in pelitic schists.

THE GEOLOGY OF DRONNING LOUISE LAND IN RELATION TO OTHER PARTS OF EAST GREENLAND

1. Aspects of the Geology of Dronning Louise Land.

Before widening the area under consideration, it is necessary to bring together some of the conclusions, explicit and implicit in the previous chapters. Of particular interest are (a) the younger metamorphism, and (b) the relationship between west and east Dronning Louise Land.

(a) The younger metamorphism. In previous sections, I have tried to show that all rock groups have been affected by a metamorphism later in age than the Zebra Series, a metamorphism which overprints evidence of an older, pre-Trekant, metamorphism retained in the Western Gneisses. The accompanying Table 4 summarises the metamorphic conditions discovered in the different rocks, and relates them one with another in a general way. Greenschist, epidote-amphibolite, and amphibolite facies are all present, yet there is a distinct break near the central meridian of Dronning Louise Land. This is more noticeable in the sequence of events recorded in the minor intrusions rather than in the other rocks: e.g. the transition between actinolite and gren hornblende has not been observed. One can also see from the table that the greenschist facies as based on the minor intrusions is probably capable of further subdivision when other rock types are taken into consideration. To plot such subdivisions on a map is, however, not possible using the available specimens.

An attempt has been made to plot the distribution of the metamorphic facies on a map (Plate 8). This shows that the almost unmetamorphosed cover of Trekant and Zebra Series (associated with a high metamorphic facies in the underlying Western Gneisses) is confined to the area of flat-lying sedimentary rocks of the southwest. Nevertheless, it seems possible that this relatively untouched area might extend northwards a short distance to the west of the line marked "east limit of pyroxene". The greenschist facies area seems broad in the north, but is

Table 4. The younger metamorphism in Dronning Louise Land.

		West Dronning Louise Land		East Dronning Louise Land	
Western Gneisess	Acid Gneiss and Intrusions	Zone of cataclastic metamorphism. Granulation and partial recrystallisation of quartz. Breakdown of feldspars especially plagioclase.	Recrystallisation of feldspars (albite and microcline). Marked recrystallisation of quartz. Growth of sphene and biotite and expense of iron ore. Actinolite stable.		
	Basic gneiss	Pyroxene undergoes replacement by actinolite. Feldspar saussuritised.	Actinolite, brown hornblende, zoisite, epidote		
Trekant/Zebra Series	feldspar →	no change →	no change	Metaquartzite, muscovite-schists, {calcite-phlogopite marbles (Britannia Sø Group)	
	quartz →	attack by groundmass →	granulation and breakdown		
	ground quartz	+ contribution from clastics →	}marked recrystallisation		
	sericite →	slight orientation →	{marked orientation recrystallisation		
	hematite →	no obvious change →	{no obvious change ? magnetite		
	ilmenite →	no change →	sphene		
Minor Intrusions	quartz-gabbro	*Limit of pyroxene* Greenschist Facies (biotite, actinolite, epidote, quartz, albite, (chlorite))		Epidote-amphibolite Facies (Green hornblende, epidote, quartz, biotite, oligoclase).	Lower Amphibolite Facies (Green hornblende, andesine, garnet).
8* Eastern Schists & Gneisses				Epidote-amphibolite Facies (Albite-Oligoclase, quartz, epidote, biotite, garnet)	Lower Amphibolite Facies (Andesine, quartz, biotite, garnet).

reduced in width particularly along the line of the Pony Gletscher farther south. This fact no doubt is associated with the upward jump in grade east of the Durham Klippe thrust and its northward extension. The juxtaposition of low- and high-grade rocks on the middle limb of the Borgjøkel might well be due to a northward extension of this dislocation or zone of dislocation (see discussion below).

That the low grade metamorphism of the west is of the same age as the much higher grade of metamorphism in the east can be inferred from the fact (1) that the metamorphism increases towards the east in both cases, (2) there is a continuity in the metamorphic changes in rocks belonging to, or resembling the Western Gneisses and (3) structural and mineral changes are of the same order, depending, of course, on metamorphic grade (e. g. the metagabbros pp. 93–113).

So far, I have referred to the distribution of the younger metamorphism only in regard to a horizontal surface. However, the field studies suggest that metamorphism increases downwards as well as laterally. For instance, fracture cleavage is evident at Dickens Bjerg, but is much less evident at Helgoland or Kaldbakur which stand higher above sea-level. The much greater degree of metamorphism in the mountain range running southwards from Splinten compared with that in the mountains in the neighbourhood of Prinsessen could also be due in part to a vertical increase in metamorphic grade.

(b) The relationship between west and east Dronning Louise Land. We can summarise the stratigraphy as follows:—

West D.L.L.		East D.L.L.
Zebra Series		Eastern Schists & Gneisses
Unconformity	— — — ? —	? Britannia Sø Group
Trekant Series		? Western Gneisses
Unconformity		
Western Gneisses		

From consideration of lithology the Britannia Sø Group could be equated with the Zebra Series. On slender evidence also the Britannia Sø Group might overlie the Western Gneisses (the inverted succession at the snout of the Admiralty Gletscher where augen-gneiss is in contact with quarzites). However, since undoubted top and bottom criteria have yet to be discovered at the contact of the Britannia Sø Group and Eastern Schists and Gneisses (Peacock 1956 b, Haller 1956), it is quite possible that the Britannia Sø Group overlies the paraschists. The writer believes that this problem can be solved by patient searching for current-bedding at vital contacts, since such current-bedding undoubtedly exists at Britannia Sø.

Farther south there are one or two indications that rocks resembling the Britannia Sø Group or metamorphosed Zebra Series rest on Western Gneisses. At Eigil Sø, metamorphosed quartzite and marble lie above the gneisses at the east end of the lake (fig. 19), and at Durham Klippe, the gneisses at the west end of the exposure are overlain by red-stained metaquartzites. HALLER, from aerial reconnaissance has traced rocks which he equates with the Britannia Sø Group proper southeastwards

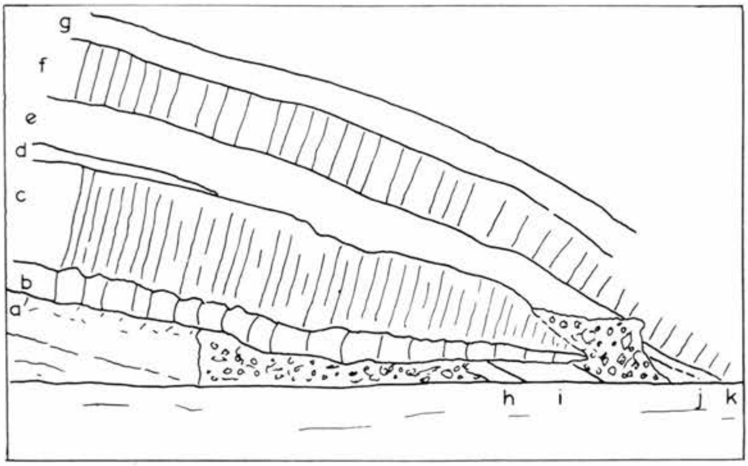

Fig. 19. Sketch of west face of Kilen, overlooking Eigil Sø.
a. Augen-gneiss, fractured at the top; b. Dark rock with widely-spaced joints; c. Green dyke with close columnar jointing; d. Light coloured rock; e. Probably augen-gneiss; f. Green intrusions; g. Quartzite; h. Augen-gneiss; i. "Quartz-schist"; j. Augen-gneiss; k. "Quartz-schist".

across Dronning Louise Land (1956, p. 14). The possibility exists, therefore, that quartzites and limestones occur at the base of the Eastern Schists and Gneisses whatever the stratigraphical position of the Britannia Sø Group.

A clear thrust brings the Eastern Schists and Gneisses at Durham Klippe over Western Gneisses (fig. 11). A similar state of affairs can be inferred on the Pony Gletscher, and in addition, WYLLIE found dislocations in the gneiss west of Monumentet. The thrust appears to separate rocks of low metamorphic grade from those of considerably higher grade (plate 8). A close juxtaposition of rocks of differing metamorphic grade occurs along the mid-meridian of Dronning Louise Land at many points farther north, suggesting an extension of dislocations in this direction. It follows from postulating a similar age for the metamorphism on both sides of this dislocation that such a dislocation must be later than the metamorphism.

Mylonite occurs on the thrust plane at Durham Klippe, but the quartzite which immediately underlies it has been drawn into a large drag fold without large-scale fracturing (fig. 11). Elsewhere at Durham Klippe, some beds among the schists have been folded and fractured. We can conclude that the thrusting here probably took place when the rocks were cool relative to conditions during metamorphism, but that P,T conditions allowed drag-folding in usually competent rocks in places, at least along the line of the break. The fact that we can reasonably infer (1) that the Durham Klippe thrust is later than the metamorphism, and (2) that a postulated dislocation which appears to be a northward extension of this thrust also appears to be later than the metamorphism, is in favour of them being the same age, though allowing for many loopholes.

As mentioned in the Introduction, the geologist John HALLER has made several flights over Dronning Louise Land, and believes that a thrust separates the Western Gneisses from the schists to the east (1956, p. 15 and earlier personal communication). The line I have drawn, based on the evidence in previous pages, is roughly in accord with this. Though the thrust at Durham Klippe is a simple break, WYLLIE's evidence from the Pony Gletscher indicates that there is probably more than one dislocation at that point. Farther north, the non-appearance of the quartzite-limestone succession mentioned above at the north tip of Kilen, and the difference in appearance of the Western Gneisses to west and east of this point suggest more complexities. The inferred N.N.E.—trending faults and folds at Prins Axel Nunatak (PEACOCK 1956a, p. 33) might be due to part of a thrust system.

2. Synopsis of the Geology of North-east Greenland.

To summarise briefly the literature of the geology of the eastern half of Greenland would be an impossible task, and even in confining attention to rocks from Devonian and downwards in the stratigraphical column, volumes might be written. This applies especially to the Fjord region of East Greenland in the latitudes of 73° and 74° north which is the first area I shall consider. The literature concerning North Greenland (Kronprins Christian Land fig. 1) is small, the ground coverage less intense, and the assumptions correspondingly greater.

(a) The Fjord region of East Greenland. The most recent comprehensive account of the geology is by HALLER (1955) with full references. His views may be summed up in a quotation:— "The central part of the mountain range is about 2,500 m high and consists of a zone of uplift 60 km wide and 500 km long, of crystalline rocks, the so-called

"Central Metamorphic Complex"... which represents the metamorphic basal part of the Caledonides. In its care a large portion of the orogenic segments has been transformed through migmatisation and granitisation. To the west and east continuous transitions lead to the sedimentary upper part of the Caledonian structure. The series of sediments affected by the Caledonian movements attains a thickness of over 16,000 m. It consists largely of young pre-Cambrian rocks (Greenlandian) to a less extent of early Palaeozoic (Cambro-Ordivician) formations." (1955, p. 156).

The lower Greenlandian sediments are geosynclinal shales and quartzites totalling some 6,500–9,000 m in thickness, while the upper beds (quartzite, multicoloured, and limestone-dolomite series), which are much more constant in detailed lithology, reach about 1,500 m. The Lower Palaeozoic limestones and dolomites (2,000 m) range from Lower Cambrian to Ordovician, and were deposited in shallow seas. Thereafter there is no record of deposition until Devonian times.

Though movements occur in these geosynclinal deposits from Tillite times onwards, the main orogeny represented by the granitisation and migmatisation of the deeper-lying sedimentary series, and the associated initiation of the north-south fold system took place between mid-Ordovician and Middle Devonian (HALLER 1955). Thus the interval of time allowed for this "Caledonian" orogeny is extremely large, and the term "Caledonian" sensu late according to HALLER denotes the major orogenic phase of the early Palaeozoic (footnote 1955, p. 160). BÜTLER (1954) would extend the meaning of the term to include Middle Devonian to Carboniferous movements. The metamorphism has not so far been found above the Multicoloured Series (HALLER 1953).

Much of the coastal region of East Greenland is affected by block faulting, the individual blocks dipping gently westward. The inner Caledonian mountain structures also show complex block faulting in which an older N.N.W.-striking series can be recognized, due to expansion immediately subsequent to the main orogeny: and later series of "late-Caledonian" N–S to N.N.E.–S.S.W. running faults (HALLER, p. 162–164).

The transitional zone of shearing between the migmatitic basal part and the non- to slightly metamorphic mantle of the main orogenic phase (HALLER 1955, fig. 11 p. 43) was a weak zone which determined to a great extent the emplacement of late- to post-orogenic granite intrusions (op. cit., p. 169). The late- and post-orogenic shearing and faulting took place mainly in peripheral regions. The N–S fold system along the eastern margin of the Caledonides were accentuated by thrusting from the east during later Middle Devonian to early Carboniferous time.

(b) Kronprins Christian Land. Almost all the theoretical work here is due to FRANKL (1954, 1955), with other details in ADAMS and COWIE (1953), and NIELSEN (1941). The following stratigraphical table is condensed from FRÄNKL 1955, p. 13. The Hekla Sund Succession is on a nappe, and that at Danmark Fjord on the autochthon to the west.

	Danmark Fjord	*Hekla Sund*
Silurian (Niagaran		Profilfjeldet shales Drømmebjerg limestone
Ordov. (Canadian)	Centrum limestone Danmark Fj. dolomite	Centrum limestone Danmark Fj. dolomite
Cambrian ? ?	Kap Holbæk Sst.	Kap Holbæk Sst.
? ?	Fyns Sø dolomite Campanuladal 1st	Fyns Sø dolomite Campanuladal 1st
Greenlandian	Campanuladal sst.	Ulvebjerg sst. and tillite Rivieradal sst. Taagefjeldene greywacke Sydvejdal marble Stenørkenen phyllite
Keweenawan	Thule Formation	Thule Formation Gneiss

Though the Thule Formation is known to overlie gneiss with great unconformity in regions well to the west of Kronprins Christian Land (e.g. KOCH 1929b), the gneiss in this case is that lying east of the dislocations and pressed against the Thule Formation. The red sandstones and quartzites, of the Thule Formation itself reach a thickness of 300 m with base unknown at Danmark Fjord (FRÄNKL 1954, ADAMS and COWIE 1953), and 200 m was measured on the gliding nappe (FRÄNKL 1954, p. 28), also with the base not seen. Correlation of this formation with the type area in N. Greenland (Peary Land) is lithological only af the moment, though quartz-dolerite or diabase dykes occur in both areas, and porphyrite dykes as well in Kronprins Christian Land.

The Greenlandian is represented by about 250 m of sandstone and shales (Campanuladal sst.) at Danmark Fjord, but near Hekla Sund there are some 3,000 m of sediments below the Campanuladal limestone which is found in both areas. The base of the Stenørkenen Phyllite is unknown, and there is a gap between it and the Thule Formation, such a gap probably being small (FRÄNKL 1955). The tillite itself is only a metre thick, and is in the form of a fine conglomerate (pebbles of quartzite and porphyry in a groundmass of calcite and red-brown ore), and can be correlated on lithology and approximate stratigraphical position with tillites in Peary Land (FRÄNKL 1954, p. 56). The Kap Holbæk Sandstone, 130 m thick at Danmarks Fjord, thins to 2–5 mm of quartz-sandstone with a deeply eroded surface farther east, and in this latter area is transgressive on to the Fyns Sø Dolomite.

The Centrum Limestone, closely linked with the Danmark Fjord Dolomite is 2,500 metres thick at Danmark Fjord, but thins rapidly eastward (op. cit. 1955, p. 23) and near Hekla Sund is 250–300 m thick. It is the first fossiliferous and therefore dateable horizon. The Drømmebjerg limestone contains a Silurian fauna.

The tectonics are summed up in Fränkl 1955, p. 26 fig. 12. In brief there are, from west to east, (a) the autochthon, (b) a gliding nappe (Vandredalen Syncline), (c) a thrust nappe (Prinsesse Caroline-Mathildes Alper), (d) a root zone, (e) imbricated Thule Formation, (f) older gneisses pressed against the Thule Formation. The post-Thule rocks west of the root zone were laid down in shallow basins separated by a ridge from the geosynclinal basin proper to the east (1954, p. 72). The age of the thrust movements is post-Niagaran and took place after formation (or re-activation) of the Vandredalen Syncline and Prinsesse Caroline-Mathildes Alper Anticline (1954, p. 73).

The lower beds in the thrust nappe have been subjected to low grade metamorphism, and other beds coming against the dislocation zones are sheared. Nielsen (1941, p. 17) reported metamorphosed sediments (Thule Formation) and amphibolite in the Prinsesse Caroline-Mathildes Alper. Nothing is known about the age of the metamorphism or relationship of the metamorphism with the thrust movements. Fränkl believes that the thrusting took place shortly after the deposition of the Profilfjeldet shales (1955, p. 28). Post-Devonian sediments probably overlie the thrust structures in the north and this seems to be the only datum line for an upper limit to the age of the movements.

There does not seem to be much doubt that we are dealing with the same series of movements that occurs in East Greenland, but we are confined to postulating a pre-Carboniferous age for the major movements in Kronprins Christian land and a pre-Middle Devonian age for the metamorphism in East Greenland. A range of movements from post-Ordovician to Middle Devonian on the one hand, and post-Silurian to pre-Carboniferous on the other, though possibly belonging to one orogenic cycle, makes it impossible to date the movements as Taconian, Caledonian sensu stricto, or Acadian, at Fränkl rightly states (p. 34). On the other hand, the term "Caledonian" has long been entrenched in Greenland literature for just this orogenic cycle, and would be difficult to eradicate at this stage.

3. Stratigraphical Setting of Dronning Louise Land.

(a) The Western Gneisses. The dating of the older metamorphism of the Western Gneisses is conjectural. We know that it was pre-Trekant Series, and that a very long period of denudation separates the two formations. Since a detailed search of both the Trekant and Zebra Series failed to yield fossils, and in view of the time interval which probably separates events recorded in the Western Gneisses and Trekant Series, there are reasonable grounds for referring the Western Gneisses to the Archaean.

(b) The Trekant Series, which are red beds probably belonging to a continental environment, overlie the Western Gneisses with great unconformity, and in turn are overlain with probable disconformity and in places angular unconformity by the Zebra Series. Cutting the Trekant Series and underlying gneisses are minor intrusions of quartz-gabbro. In general terms, one can say that the Trekant Series resembles the Thule Formation in stratigraphical relations.

We can examine this tentative conclusion by referring to the lithology of the Thule Formation and the overlying Greenlandian. Fränkl has described a few specimens of Thule sandstones and quartzites from Kronprins Christian Land (1954, p. 34), and compared them with the type area of that formation in N.W. Greenland (Munck 1941). In Hekla Sund (fig. 27), the usual composition is some 80–90 per cent of sand material in a fine-grained ground-mass of sericite, quartz, and perhaps hematite as rounded particles or dust. Carbonate may also occur in the cement in places. In the sandy material, the ratio of quartz to feldspar (microcline) is about 3:1. To the west in Danmark Fjord, feldspar seems to be absent, a fact due either to different environment or to stratigraphical position. Albite has only been uncertainly identified in one specimen.

This description of Thule sandstones might be applied to many of the little-metamorphosed Trekant specimens which I have observed: in facts it is an interesting parallel that feldspar is absent in the outer nunataks though present where the Trekant Series outcrops in Dronning Louise Land proper. A notable absentee is albite. However, we must sum up, in very general terms, the lithology of Greenlandian sandstones and quartzites in Rast and North Greenland, before concluding that this lithological similarity is of any consequence.

At Danmark Fjord, the Campanuladal Sandstone is a thinly-bedded, fine-grained calcareous sandstone with glauconite. On the gliding nappe, the Rivieradal Sandstone is almost feldspar-free as is the Taagefjeldene Greywacke (Fränkl 1954, pp. 38–40; 1955, p. 16).

The sediments in Kronprins Christian Land are correlated with the Greenlandian of East Greenland mainly on the occurrence of tillites (Fränkl 1954, p. 56). Little detailed petrographical work seems to have been done on the Greenlandian, and we must turn to the Petermann Series of Wordie and Whittard (1930) which are correlated with parts of the Lower Greenlandian (Wenk and Haller 1953). The lowest beds of the Petermann Series in the type area reach biotite grade (Odell 1944), but the upper beds of similar composition contain quartz sand grains with a little plagioclase in a cement of fine-grained quartz, sericite, and chlorite. Wenk and Haller record ferruginous quartzites at some levels, and shales, slates, or pelitic schists are common, with calcareous or dolomitic horizons. In the upper Eleanore Bay Formation (Greenlandian), the Quartzite Series with its grey, and greenish quartzites contains microcline and plagioclase grains among the quartz clastics in a cement of mortar quartz and sericite. Grains of detrital garnet have been observed, and the groundmass is sometimes hematitic (Fränkl 1953, pp. 26–28).

There is little basis for discussion here, excepting that plagioclase seems to be a constant constituent of the Greenlandian whereas it is absent in Trekant rocks. The Greenlandian sediments are conceived as having been deposited in a subsiding trough presumably under marine conditions (Haller 1955). Glauconite is essentially a mineral of marine environment (Hatch and Rastall 1938). Correlation of the Trekant Series with the Thule Formation seems to be more likely than correlation with the Greenlandian.

(c) The Zebra Series. The strongly contrasting light and dark grits, quartzites, and shales which form the lower beds of the Zebra Series present an entirely different appearance to the underlying Trekant Series. The Series is probably disconformable on Trekant beds in the south and certainly strongly unconformable in the north. In stratigraphical relationships, the Zebra Series compares with the Greenlandian sediments on the nappe in Kronprins Christian Land (possible marine conditions, apparently unfossiliferous nature, position above Trekant Series). We may note, however, that they may be penetrated by quartz-gabbro intrusions, whereas in Kronprins Christian Land no basic intrusions penetrate the Greenlandian.

From the foregoing descriptions, it is evident too that the Zebra rocks only compare in a general way with the arenaceous beds of the Greenlandian. The lower quartzite/shale beds of the Zebra Series, possibly overlain by quartzite and limestone might be compared with the Campanuladal sandstone and limestone of Danmark Fjord, but comparison with Hekla Sund does not yield anything positive. Obviously in the distance of some 300–400 km between Kronprins Christian Land and Dronning Louise Land there is room for great lithological change. The reported ferruginous horizons in the Petermann Series resemble those in the Zebra Series rather than anything in the Trekant Series. Unfortunately the base of the succession is unknown in East Greenland.

(d) The Eastern Schists and Gneisses. The discussion in earlier pages suggests it is conceivable that the Zebra Series might be correlated with the Britannia Sø Group and that the Eastern Schists and Gneisses follow in stratigraphical order. The strongest representatives of the latter are what have been slightly calcareous shales, but calc-schists, semi-peltic schists, quartzites, and limestones are known.

Now upper Greenlandian sediments, overlying rocks affected by the post-Ordovician metamorphism, can be traced nearly as far north as latitude 76° on the east coast of Greenland (L. KOCH 1929a, TEICHERT 1933, p. 30 et seq.), and metamorphic rocks presumably affected by the same sequence of movements outcrop in Bessels Fjord (TEICHERT op. cit.). There seems reason to believe, therefore, that the Eastern Schists and Gneisses which outcrop a relatively short distance northwest of Bessels Fjord have been metamorphosed by the same set of precesses as those in East Greenland, though whether during exactly the same interval of time it is impossible to say (see HALLER 1956). On the grounds that (a) unmetamorphosed Greenlandian is present so far north, and (b) the uppermost Eleanore Bay Formation of the Fjord region of East Greenland is not affected by the metamorphism (p. 119), it is a strong speculation that the Eastern Schists and Gneisses are Greenlandian. Thus—on the very slender evidence of possible equation of the Zebra Series = Britannia Sø Group, = Greenlandian on comparison with Kronprins Christian Land; and Eastern schists and Gneisses = Greenlandian on comparison with East Greenland—it would seem reasonable to pay special attention to that part of the sequences of East and Northeast Greenland below the Lower Palaeozoic and above the Thule Formation.

The lowest Greenlandian beds in Kronprins Christian Land are phyllites, a marble, and the greywackes, together with a bed of alum shale. The so-called greywackes are quartzite fragments sometimes with chlorite schist fragments in a silty groundmass which is iron-rich and apparently dolomitic and sometimes carbonaceous (FRÄNKL 1954, p. 38). The lithology and associations appear to be more those of the sub-greywackes (e. g. PETTIJOHN 1949, p. 245, p. 255), and are not inconsistent with deposition in a shallow sea. The overlying Rivieradal Sandstones are interbedded with shales, and differ little in lithology from the groundmass of the greywackes, being composed of quartz sand grains with rare feldspar in a groundmass of sericite calcite, dolomite, chlorite, and iron ore (FRÄNKL 1954, p. 40). There is a conglomeratic horizon at about 1,000 m in a total thickness of some 1,500 m. A quite small lithological change would bring these sediments to the chemical composition of parts of the Eastern Schists and Gneisses. A like conclusion can be reached in comparison with the Lower Greenlandian succession of East Greenland, though here a rather greater lateral change would be necessary. It might be as well to note, nevertheless that we do not know the lithology of the base of the Greenlandian in the geosynclinal deposits either of Kronprins Christian Land or East Greenland.

In view of the distances involved in correlation with both areas (over 2 degrees of latitude), one may conclude that the stratigraphical position and the lithology of the Eastern Schists and Gneisses are not inconsistent with a Greenlandian age.

(e) Before passing on to the next section, a word is necessary about the geological conditions to the east of Dronning Louise Land. TEICHERT (op. cit.) makes brief reference to quartzites and phyllitic rocks dipping steeply S.S.W. in the Bessels Fjord area (S.E. of Dronning Louise Land), overlain eastwards by gneiss (p. 30), and MITTELHOLZER observed high grade metamorphic rocks and migmatities during a sledge trip through the islands in Dove Bugt (1941). BRONNER of the LOUISE A. BOYD expedition found paraschists and quartzites which from the account seem similar to the Eastern Schists and Gneisses (BRONNER in BOYD 1948). All these rocks might well belong to the "Caledonian" cycle of East Greenland on the rather flimsy grounds presented on p. 124, and this supposition seems to be axiomatic in ideas of Greenland geologists from 1929 onwards (e. g. KOCH 1929a, p. 286). In Germania Land, east of the northern half of Dronning Louise Land, WYLLIE (1957) comes to the conclusion that the high grade schists and gneisses are metamorphosed greywackes. Limestones are absent in this area, a fact which is against direct correlation of these rocks with the Eastern Schists and Gneisses, though the 30 km width of the Storstrøm would allow ample room for facies change. From recent reconnaissance work in Dove Bugt, HALLER (1956) believes that some of the structures, including the N.N.W.-striking group in Dronning Louise, belong to an earlier period than the main phase of the "Caledonian" metamorphism of East Greenland.

4. Tectonic Setting of Dronning Louise Land.

In reconnaissance geology, the data for tectonic style are necessarily incomplete, and the most that can be done is to discuss some of the phenomena mentioned in preceeding pages. For the purposes of discussion, one can distinguish three areas in Dronning Louise Land (a) the zone of almost unmetamorphosed sediments to the west, (b) the region indicated as greenschist facies, and (c) the region east of the line of dislocation.

(a) In the area of unmetamorphosed sediments, one can find no evidence in the Trekant or Zebra Series of folding. Faulting on any scale is at a minimum. A fairly regular system of joints appears in the

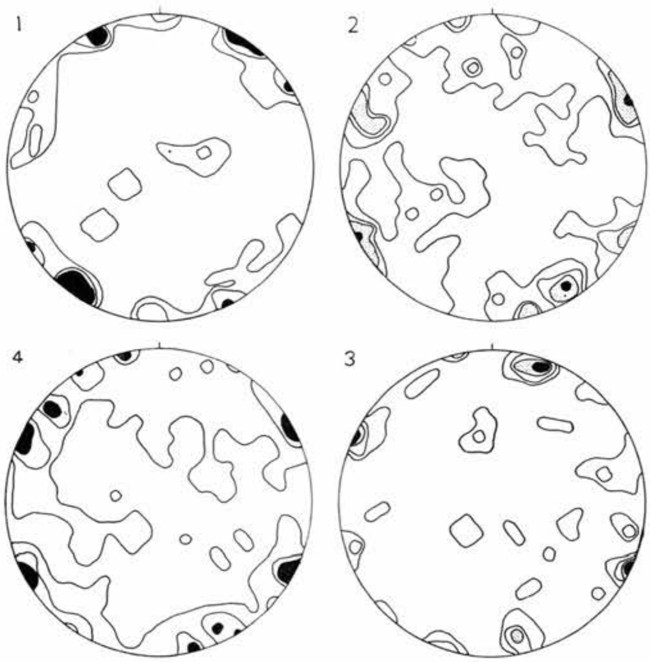

Fig. 20. Stereographic projections of joints, upper hemisphere, (after WYLLIE).
1. Sediments, 32 joints, contours 3, 6, and 9 per cent.
2. Western Gneisses, 170 joints, contours 1, 2, 3, and 4 per cent.
3. Eastern Schists and Gneisses, 77 joints, contours $2^1/_2$, 4, 5, and 6 per cent.
4. All joint measurements, contours 1, 2, and 3 per cent.

sediments in any one small area—generally two vertical systems inclined at about 60°,—but when larger areas are taken into consideration the position is more complex. From fig. 20 it can be seen that a number of joints strike W.N.W.; others run E.N.E.; and a smaller number N.N.W., but no firm conclusions can be drawn because of the small number of observations. Fracture cleavage, no doubt related to incipient metamorphism can be seen in sediments at Dickens Bjerg.

(b) The region marked as greenschist facies corresponds very well with the N.N.E. fold system in the sedimentary cover of the north, and with the N.N.E. strikes in the augen-gneisses further south. We can regard these two structural divisions as a tectonic unit.

The form of the major folds is difficult to follow excepting where down-cutting glaciers give a good vertical profile. The best example is the Admiralty Gletscher, and it can be seen from a natural cross-section (Plate 10) that the folding is almost monoclinal, with flat regions, and sharply turned-up limbs. How much of this folding is due to pre-Zebra movements is difficult to say, but at Kelvin Klippe, both Trekant and Zebra Series are involved in one of these sharp folds. At Prins Axel Nunatak, however, the Zebra Series ignores what appears to be a tight syncline in the Trekant Series (Peacock 1956a), so there is indirect evidence for considerable folding before the Zebra Series was laid down. The western boundary of such pre-Zebra folding, as at present observed, would seem to coincide in a remarkable manner with the western boundary of the later movements. One might suppose that the style of folding shown on the Admiralty Gletscher is consistent with it being produced by the same movements which produced the crush zones in the Western Gneisses.

On a minor scale, the Trekant and Zebra quartzites have yielded by flowage rather than by fracturing. Thus at Zebra Klippe (fig. 9) and Prins Axel Nunatak, the interbedded grits and shales which constitute the Zebra Series are thrown into corrugations. Likewise, the more massive Trekant rocks at Newton Klippe contain stretched pebbles, and are cleaved in addition. Hills believes that strong folding of many sedimentary successions took place before complete lithification and thus under conditions in which the rocks must be regarded as more or less loose granular aggregates rather than solid bodies (1953, p. 43). However, the association with metamorphism in the case under consideration makes this unlikely.

Other minor structures shed a little more light on the tectonic style in the sedimentary rocks. Cleavage at Trekanten and Newton Klippe is consistent with axial plane cleavage in some cases (e. g. Wilson, p. 264 et seq.), but in others is true mechanical fracture cleavage (for instance the decolourised streaks on joint faces). The slaty cleavage is illustrated by that passing from conglomerate to gneiss at Newton Klippe. At this latter point, the directions of deformation of desiccation cracks are consistent with normal bedding slip during folding (fig. 21). At Splinten, however, and Rutherford Bjerg the less massive quartzites of the Trekant Series have been broken down into schists, and the rocks themselves show evidence of penetrative movements side by side with recrystallisation. The extreme case is at the east side of Prins Axel Nunatak, where a lineation is developed, though this appears unrelated to the corrugations at this point.

Fig. 21. Desiccation cracks in Trekant quartzites and mudstones at Newton Klippe.
Photo: J.D.P.

In the less metamorphosed areas (e. g. Trekanten, Newton Klippe), it seems reasonable to suppose that the sedimentary cover has been subjected to normal folding processes, at testified by evidence of structures in the same sense as the "dependent" drag folds of Derry (1939, p. 129). Such folding would not be produced by vertical movements in the crush zones of the underlying gneiss, and it is therefore unlikely that such crush zones have operated like faults in less deformed strata. Though the form of the major folds would be consistent with production by movements with a strong vertical component, the minor structures suggest such was not the case. Thus we are left with the conclusion that although the crush zones and folding were probably developed at the same time, the former were not the cause of the latter, and are different expressions of the same series of physical conditions in mineralogically unlike rocks.

The tectonic style in the Western Gneisses has been dealt with in some detail in an earlier section. Noteworthy points are the predominance of steep easterly dips, presence of crush zones, large areas of augen-gneisses with evidence of thorough-going penetrative metamorphism, and "enclaves" of rocks structurally little affected by the surrounding movements. A diagram of the joints (fig. 20) shows a major set striking N.N.W., with less well-defined sets striking N.N.E. and E.N.E., but it is difficult to relate such joints to the other minor structures such as the schistosity.

The nearest analogues of the Caledonian metamorphism of the Western Gneisses are in those Adirondack igneous rocks described by BUDDINGTON (1939) and the second metamorphism of the Lewisian Gneiss (SUTTON and WATSON 1950). In the former, BUDDINGTON concludes (p. 306) that "The hypothsis that most of the Adirondack igneous rocks have undergone plastic flow while still effectively solid appears to necessitate that at one extreme units of one type of country rock have locally moved as rigid blocks with respect to dikes and veins at an angle to the foliation of the country rock so as to induce in the cross bodies a foliation parallel to their walls; and at the other extreme delicate differences in plasticity and in the local dynamic forces have been such as to leave essentially unaffected an included block of one the type of anorthosite . . . and at the same time permit flowage of the groundmass anorthosite at an angle to the foliation of the included block." In the Western Gneisses, the variations in schistosity due to the preservation of rigid blocks are not so evident, and on the whole the penetrative movements must have been stronger. Likewise the metamorphism in the Western Gneisses differs from that described in the Adirondacks because pyroxenes are stable in the metagabbros of the latter area under conditions of cataclastic deformation (p. 254). The possible analogy of the metamorphism in the Western Gneisses to the second metamorphism in the Lewisian has already been commented on (p. 30); here again there are structural similarities in the retention of enclaves of texturally unaltered rocks bounded by broad crush belts.

(c) The area east of the line of dislocation is characterised by two sets of folding, one on N.N.W. lines, and the other on N.N.E. lines. In the first of these, broad synclines and anticlines can be recognised, but there is evidence of overturning towards the west. Folding of a more plastic nature also seems to have taken place. Small scale folding frequently shows eastward-dipping axial planes suggesting movement of the upper beds towards the west. The lineation produced by orientation of minerals is parallel to the axes of major and minor folds in most cases (PEACOCK 1956a), but in the Britannia Sø area, northeasterly strikes in the Britannia Sø Group in an area with N.N.W. lineation might be connected with the N.N.E. folding farther east (PEACOCK 1956b). The joint pattern is roughly symmetrical with regard to the fold axes directions. The fold style and lineation suggest a monoclinic symmetry, with the lineation in 'b' (KNOPF and INGERSSON 1938, p. 43). With regard to the N.N.E. folding, the aerial photographs suggest a predominance of high dips in the south, but there seem to be considerable variations in the Britannia Sø area. No major fold axes were located. Here again there is a marked lineation due to elongation of minerals parallel to the axes of small folds.

The relationship between the two fold areas was not observed, but from work in Dove Bugt, HALLER (1956) finds the N.N.E. system to be younger. Thus we are not dealing with simultaneous "cross-folds" as in the Scottish Caledonian (PEACH et al 1907, KING and RAST 1956). It may be noted in passing, however, that the tectonic style depicted in fig. 13 resembles the Moine style of folding (op. cit., 1956, p. 247), though on the whole schistosity seems parallel to bedding planes. Also, there is no conjugate folding of the type observed by JOHNSON from the vicinity of the Moine Thrust (1956, p. 345).

Perhaps the most difficult point is to decide to what extent the minor folding is connected with the original metamorphism, and to what extent it originated with the movements which produced the line of dislocation. Until further evidence is made available it is perhaps best to leave the issue unresolved, though it might be pointed out that the age of the N.N.W. folding elsewhere and the coincidence of the minor structures with such folding suggest that the minor folding in part antedated the dislocation.

Turning to tectonic style as a whole, the fold style in the Eastern Schists and Gneisses is in accord with a suggestion that they have been pressed from the east against the rigid Western Gneisses (WYLLIE 1956, in press), such style being imposed in part at the time of metamorphism. WYLLIE suggests that the difference in tectonic style is due to movements and metamorphism under shallow cover to the west, and under geosynclinal conditions to the east. READ, however, has indicated that the word "depth" might be taken to mean geosynclinal depth, magmatic-migmatitic depth, and tectonic depth (1948, p. 167). He defines geosynclinal depth as true depth; magmatic-migmatitic depth is determined by the height reached by igneous intrusions or by the migmatite front; and tectonic depth is due to the piling of higher tectonic elements on lower to produce a blanket.

The style of folding suggests that in most of Dronning Louise Land tectonic depth is unimportant. Nappe-like structures might be fitted into the Britannia Sø area on the available very incomplete results and folds overturned towards the west can be seen on the south side of Trefork Sø (fig. 12) and very doubtfully inferred at Paradis Klippe. Elsewhere the greater part of the folding seems to be open in both the eastern and western blocks. The question of geosynclinal depth versus magmatic-migmatitic depth is more difficult. We have little direct evidence from stratigraphy regarding any lateral variations of a major sort. Indeed, if the supposition that Zebra Series = Britannia Sö Group = limestone-quartzites in Dove Bugt is correct, the lowermost beds of the geosynclinal cycle seem to be fairly constant over a great distance. This is in contrast to conditions in Kronrpins Christian Land (Fränkl 1954, 1955) referred to previously. In this latter area, the shelf sediments bear little relationship to those of the geosyncline in thickness, and there are considerable changes in lithology.

Wegmann and Backlund, followed by Haller have shown that in East Greenland, the metamorphosed sedimentary cover is a function of the rise of the infrastructure beneath (1935, 1932, and 1955). This migmatitic infrastructure not only gives rise to the metamorphism in the overlying beds, but crosses stratigraphical boundaries. Thus here magmatic-migmatitic depth is not the same as geosynclinal depth.

In Dronning Louise Land the area of thoroughly migmatised rocks is probably small compared with those subject only to regional metamorphism, and little evidence is forthcoming as to whether stratigraphical boundaries are actually crossed. On Timeglasset, the granitisation seems to be confined to certain stratigraphical horizons in the schists. Wyllie believes that synorogenetic granitic activity in Germania Land is confined mainly to a broad area or strip (op. cit.) which is of high amphibolite or granulite facies. In view of the fact that potash metasomatism or granitic intrusion seems to have taken place under conditions varying from granulite to epidote- amphibolite facies along a belt from Dronning Louise Land to Germania Land, direct correlation of migmatitic-magmatic activity with metamorphism is unlikely, and the conditions appear more like the Scottish Highlands where recent opinion would put the metamorphism earlier than the "Older Granite" (e. g. Read 1948, p. 164). This idea is supported by the hypothesis already put forward that the metasomatism in Dronning Louise Land is later than the main phase of metamorphism. It seems that if rise of the migmatite is not the direct cause of metamorphism in this particular cross-section of the Caledonian geosyncline, geosynclinal depth might be a controlling factor, as seems implicit in Wyllie's account. This idea, of course, depends on a similar age for the metamorphism along the cross-section. Support for this is that metamorphism increases eastwards in West Germania Land as in Dronning Louise Land (Wyllie op. cit.), though there is a present a conflict of evidence here if Haller's tentative structural synthesis is followed (Haller 1956).

The contrast in tectonic style between the Western Gneisses and the Eastern Schists and Gneisses is a function not only of the metamorphic grade but of the differences in rock type. A scale of comparison is provided by the preservation of the Carn Chuinneag pre-foliation granite among Moine rocks deformed by regional metamorphism.

Table 5. Stratigraphical Correlation.

	Kronprins Christians Land	West Dronning Louise Land	East Dronning Louise Land	East Greenland
Greenlandian	Ulvebjerg sst. & tillite			Tillite Formation
	Rivieradal Sst.			Upper Eleanore Bay Form.
	Taagefjeldene Greywacke		E. Schists and Gneisses	
	Sydvejdal marble			Lower Eleanore Bay Form.
	Stenørkenen phyllite			
	?	Zebra Series	Britannia Sø Group	?
Thule Formation	Thule Formation	Trekant Series		?
Archaean		Western Gneisses	Western Gneisses (?)	?

(PEACH et al. 1912). Though the Eastern Schists and Gneisses have been pressed against the relatively rigid block of the Western Gneisses, the eastern flank of the block has suffered thorough-going penetrative metamorphism. The style of metamorphism in both the Western Gneisses and overlying sedimentary cover suggests that it took place under a considerable load, though such a load could be less than that affecting the higher grade schists to the east. Since we are no doubt looking at the "roots" of a geosyncline, the true shelf area lies in the extreme west, at least in the western nunataks, and possibly entirely beneath the inland ice. Of these two suppositions, the lack of folding supports the former, and incipient metamorphism or strong diagenesis in the sediments the latter.

It is not possible at present to achieve a satisfactory structural synthesis with Kronprins Christian Land because of the distance involved and the very fragmentary evidence for dating the movements.

5. Conclusions.

We can sum up the stratigraphical setting of Dronning Louise Land as follows in Table 5, realising of course, that much of this is little more than intelligent guesswork. The tectonic setting fo Dronning Louise Land might be thought of as a position at or near the western edge of the so-called "Caledonian" structures of East and Northeast Greenland. The cross-section of "Caledonian" structures from Dronning Louise

Land to Germania Land shows evidence of thorough metamorphism probably controlled to a great extent by geosynclinal depth, closely followed by a magmatic-migmatitic phase. These features are comparable in some respects with events in East Greenland, but might differ in age. At an unknown, but later period, the eastern block of Dronning Louise Land was thrust westwards over the western block.

It is evident that there is scope for a large research programme in Dronning Louise Land. The structural problems could all be tackled by an expedition based on Britannia Sø. On the petrological side, the problems connected with the metamorphism of the minor intrusions and the large-scale cataclastic metamorphism of the Western Gneisses have barely been touched on in the above account. Many of these too could be approached by an expedition based on north Dronning Louise Land.

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ABSTRACT

Dronning Louise Land, some 110 km long and 60 km broad, is situated about midway between the intensively studied Fjord region of East Greenland, and the less well known Peary and Kronprins Christian Lands.

In the west, the presumably Archaean Western Gneisses are unconformably overlain by the Trekant Series. These are overlain unconformably or disconformably by dark- and light-banded quartzites and shales of the Zebra Series. The petrogenesis of these rock groups is discussed, together with that of the Eastern Schists and Gneisses, a group of paragneisses and schists building the east half of the country.

The sediments are flat-lying in the southwest and extreme west, but folded on N.N.E. lines towards the north. Such folding is associated with mainly low grade cataclastic metamorphism. The eastern schist sequence is folded mainly on N.N.W. lines.

From the petrography of minor basic intrusions, paraschists, and gneisses, four metamorphic zones are tentatively drawn, the metamorphic grade rising from low or neglegible in the west, to lower amphibolite facies in the east. A petrographical discontinuity roughly coincides with westward-thrusting observed in the schists of south-central areas, and it is inferred that a dislocation zone extends from north to south across mid-Dronning Louise Land.

Correlations with other areas of Northeast Greenland are examined. It is concluded that only Archaean and late Precambrian rocks are present, such rocks having been affected to a greater or lesser degree by earth movements and metamorphism of so-called "Caledonian" age. Structural and stratigraphical considerations suggest a position near or on the western border of the East Greenland "Caledonian" geosyncline.

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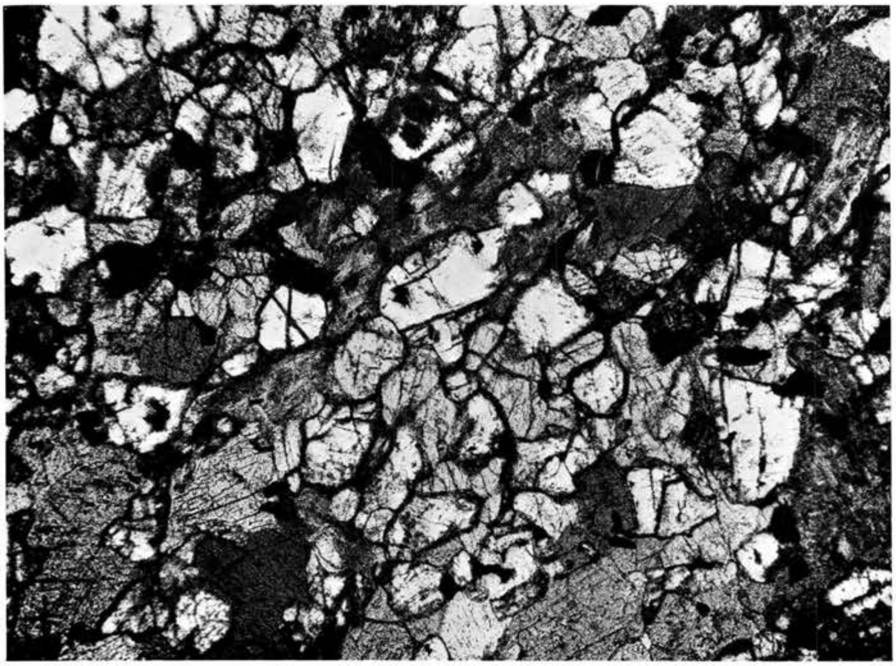
Færdig fra trykkeriet den 3. juni 1958.

PLATES

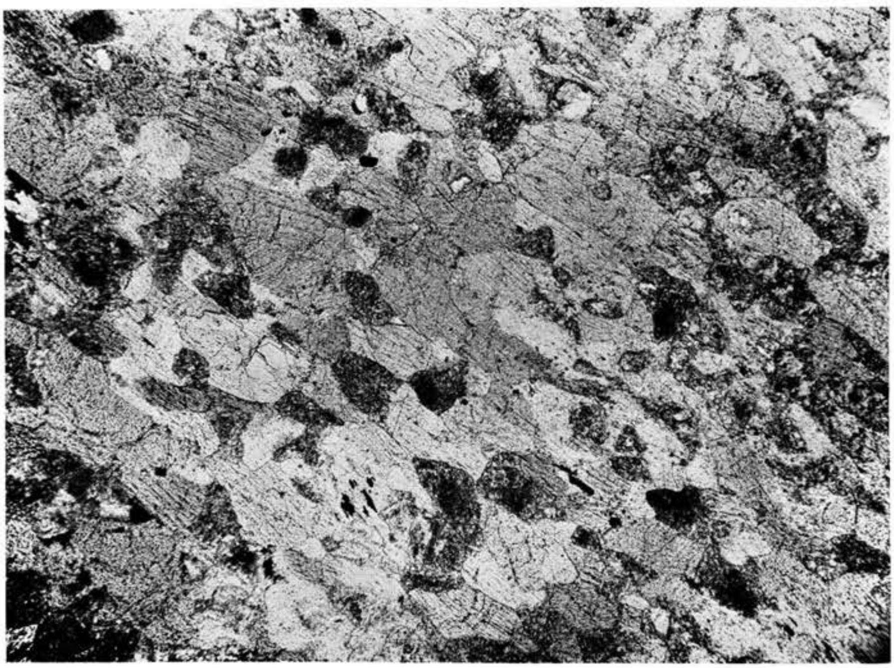
Plate 1.

a. Basic gneiss, upper Budolfi Isstrøm. Plagioclase, hornblende (dark), pyroxene, and magnetite. Crossed nicols. × 30.

b. Basic gneiss, middle Budolfi Isstrøm. Brown hornblende, actinolitic amphibole, saussuritized feldspar. Ord. light. × 30.



1 a.

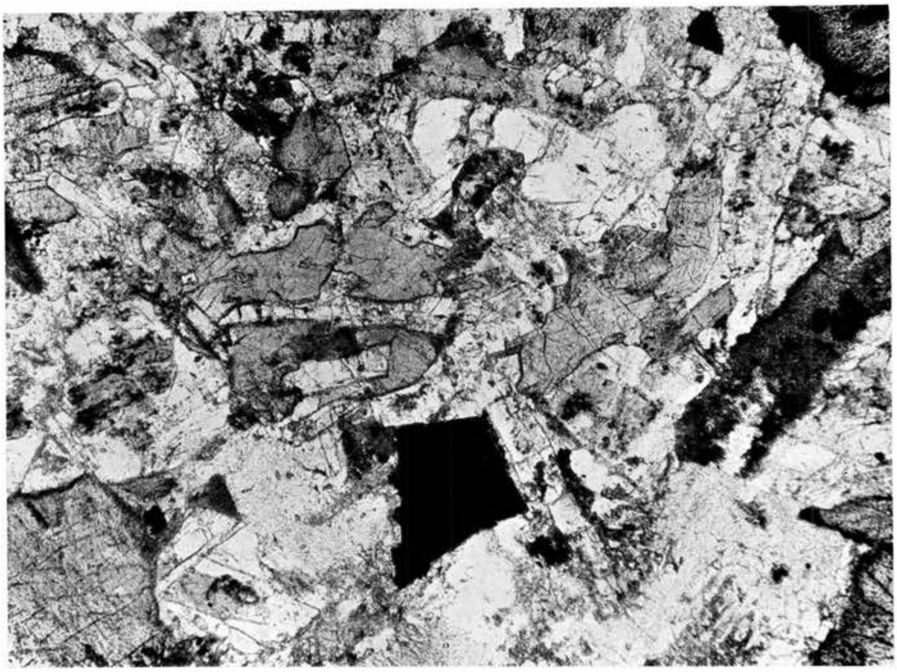


1 b.

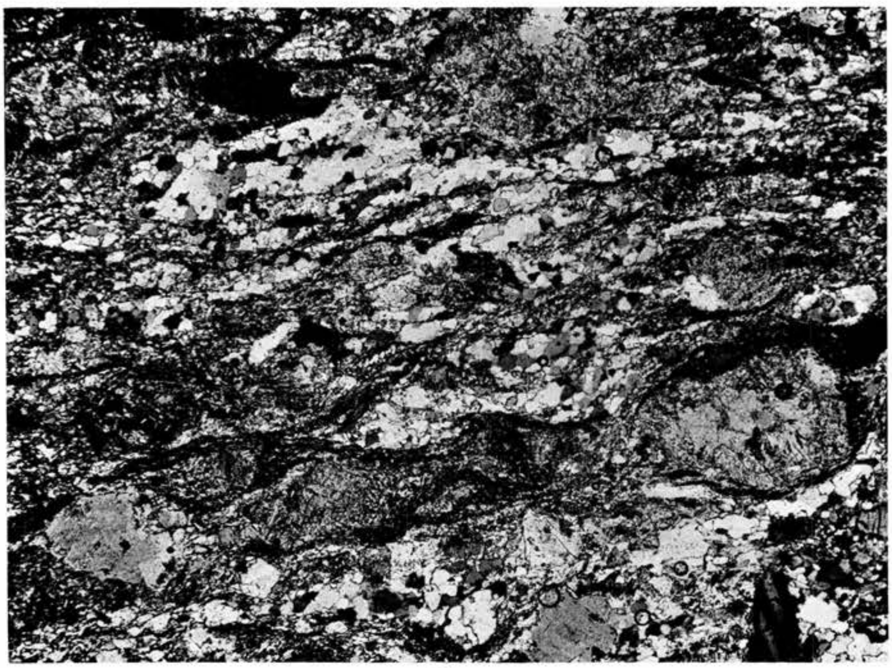
Plate 2.

a. Quartz-gabbro, Helgoland. Augite, plagioclase (partly altered), and magnetite. Ord. light. × 30.

b. Augen-gneiss, middle Budolfi Isstrøm. Altered feldspars, partly recrystallised quartz, trails of micas and epidote. Crossed nicols. × 30.



2 a.

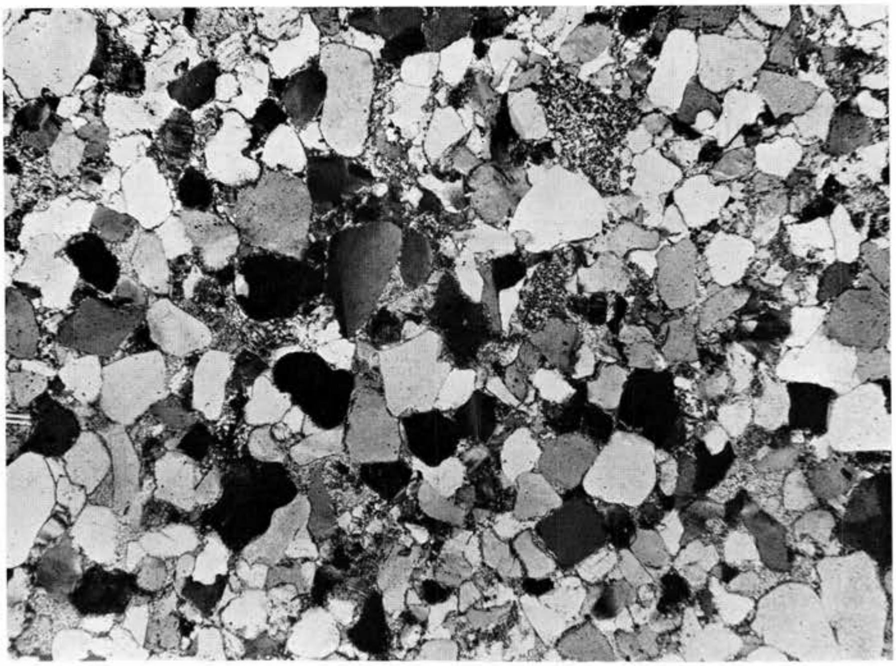


2 b.

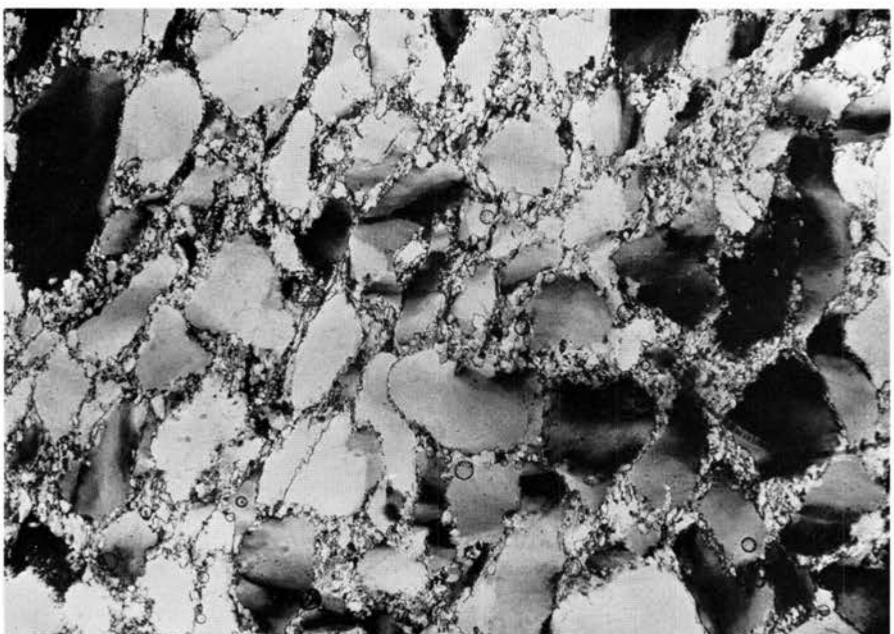
Plate 3.

a. Trekant quartzite, Helgoland. Quartz grains with iron ore coatings; turbid microcline. Crossed nicols. × 30.

b. Zebra quartzite, N.W. Prins Axel Nunatak. Sutured blastopsammitic quartz in a slightly-recrystallised groundmass. Crossed nicols. × 30.



3 a.

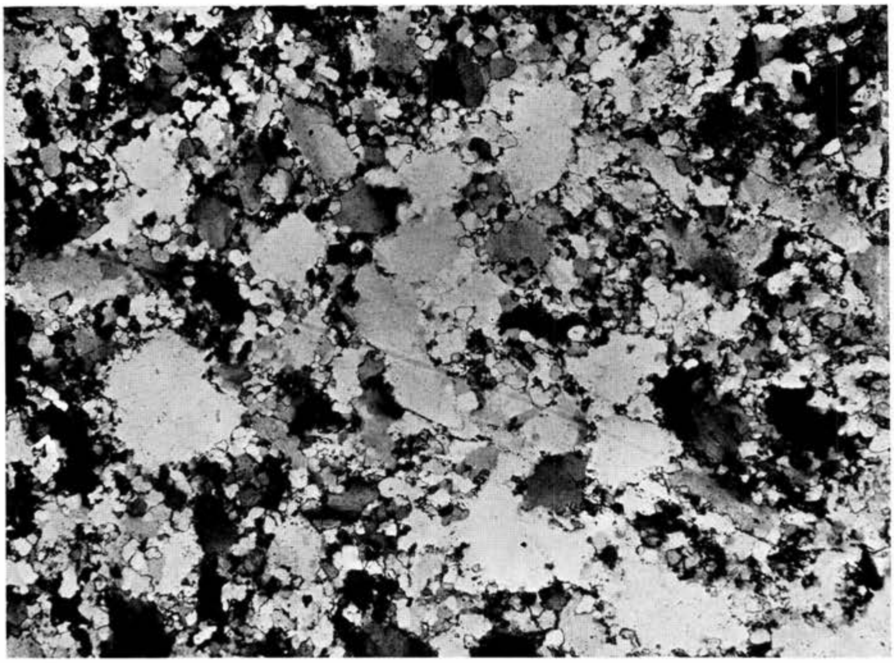


3 b.

Plate 4.

a. Quartzite, S.E. Prins Axel Nunatak. Metaquartzite with blastopsammitic structure. Crossed nicols. × 30.

b. Granitic gneiss, Timeglasset. Turbid plagioclase with clear rims of lower refractive index in a replacement relationship with microcline. Quartz and feldspars with lines of dust inclusions. Crossed nicols. × 30.



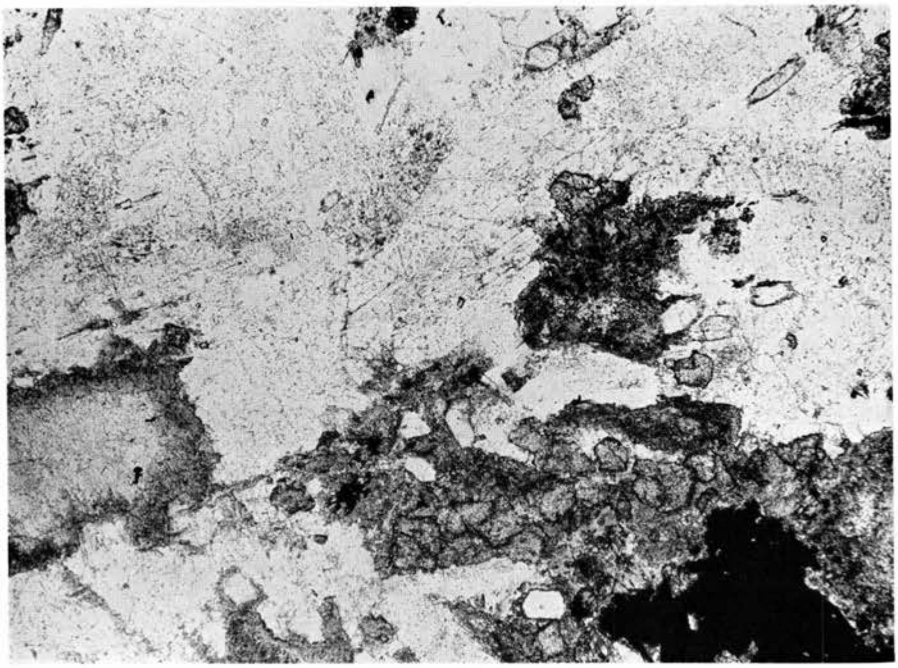
4 a.

4 b.

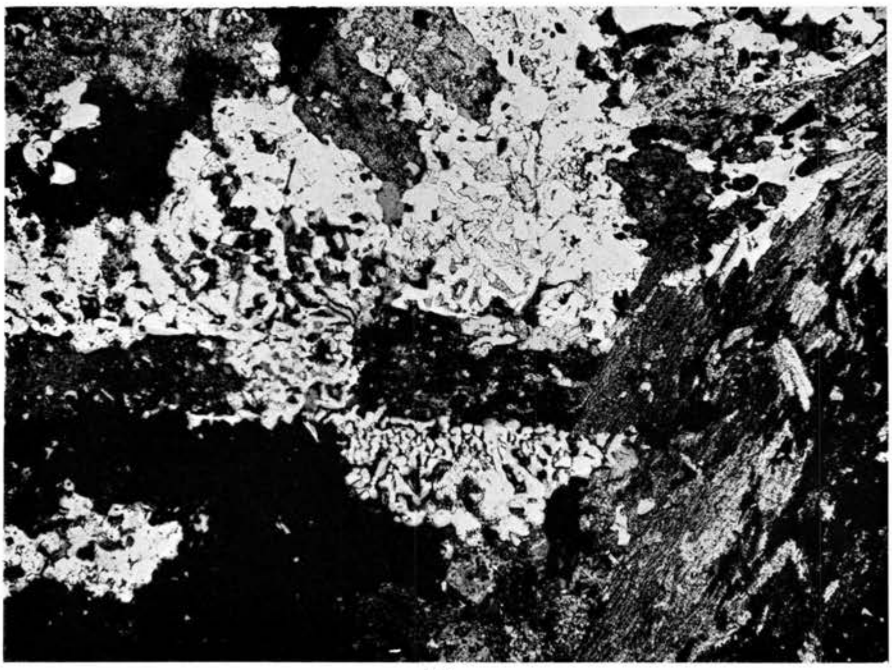
Plate 5.

a. Metagabbro, Rosmule. Original igneous feldspar (turbid); pseudomorph after pyroxene (left). Corona of biotite, garnet, and apatite around magnetite. Ord. light. × 30.

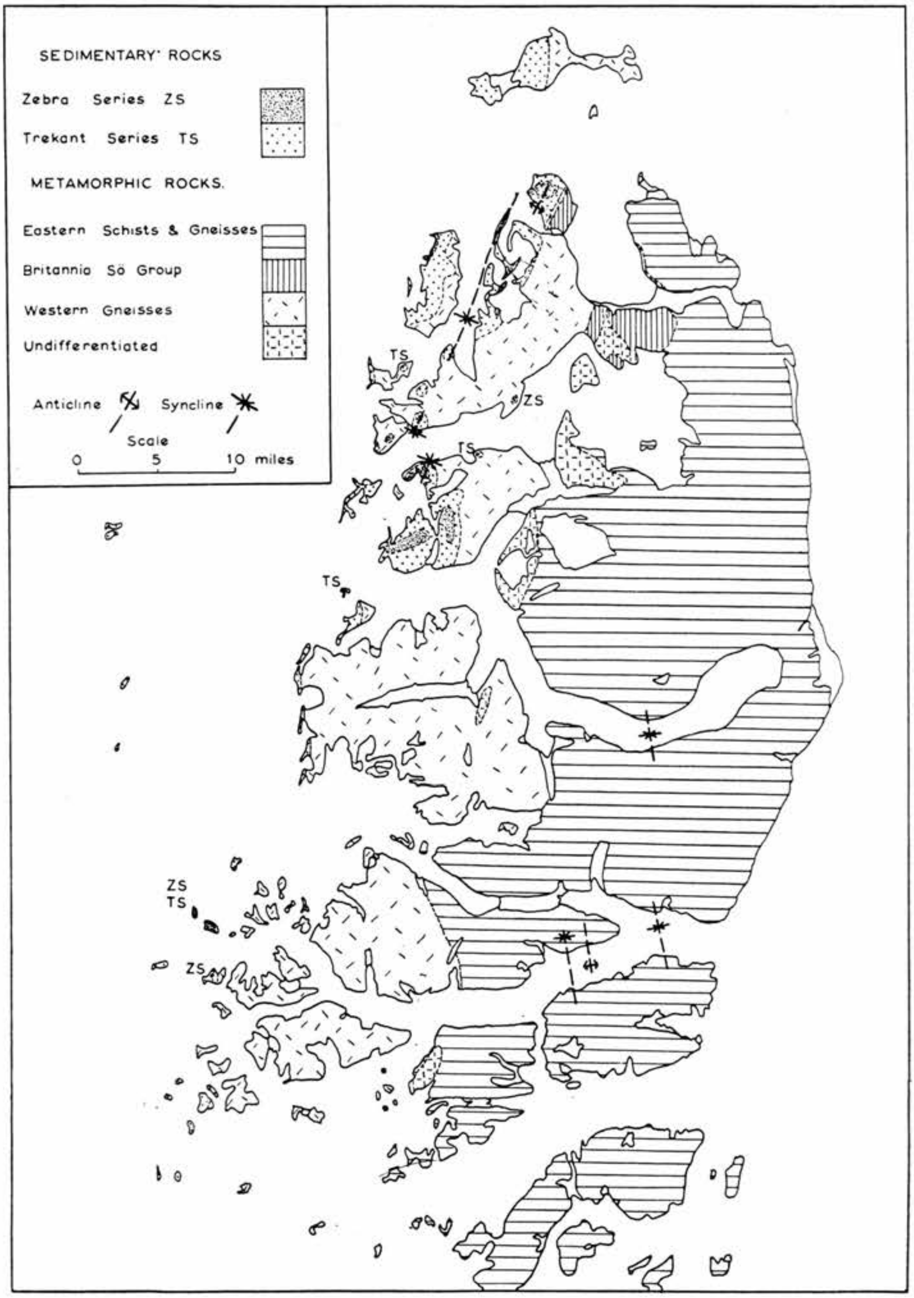
b. Metagabbro, Britannia Sø. Turbid igneous plagioclase with interlocking plagioclase-quartz replacement. Crossed nicols. × 30.



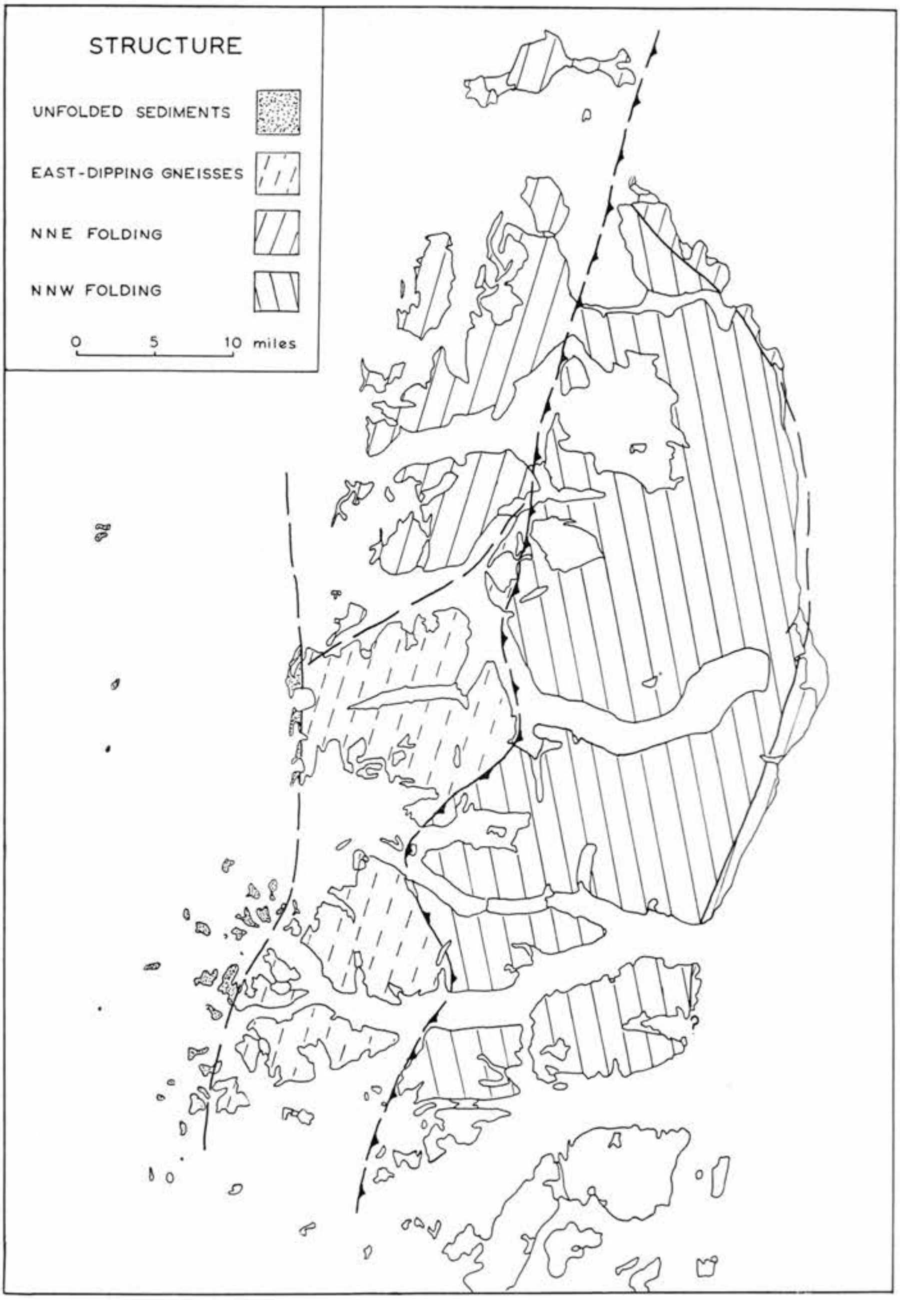
5 a.



5 b.



Geological Sketch-map of Dronning Louise Land.

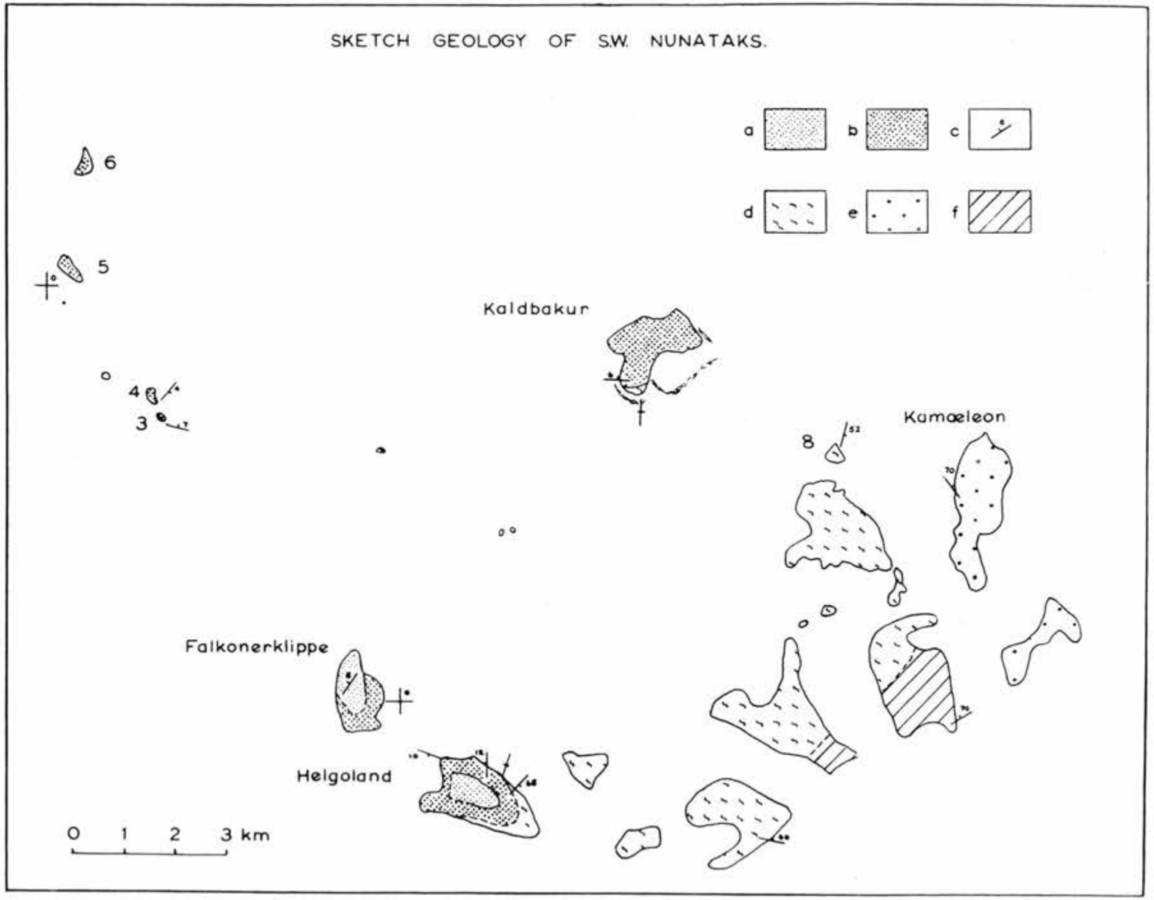


Structure of Dronning Louise Land.
The heavy line dividing east from west Dronning Louise Land is the approximate line of a major dislocation.

Metamorphic zones of Dronning Louise Land.

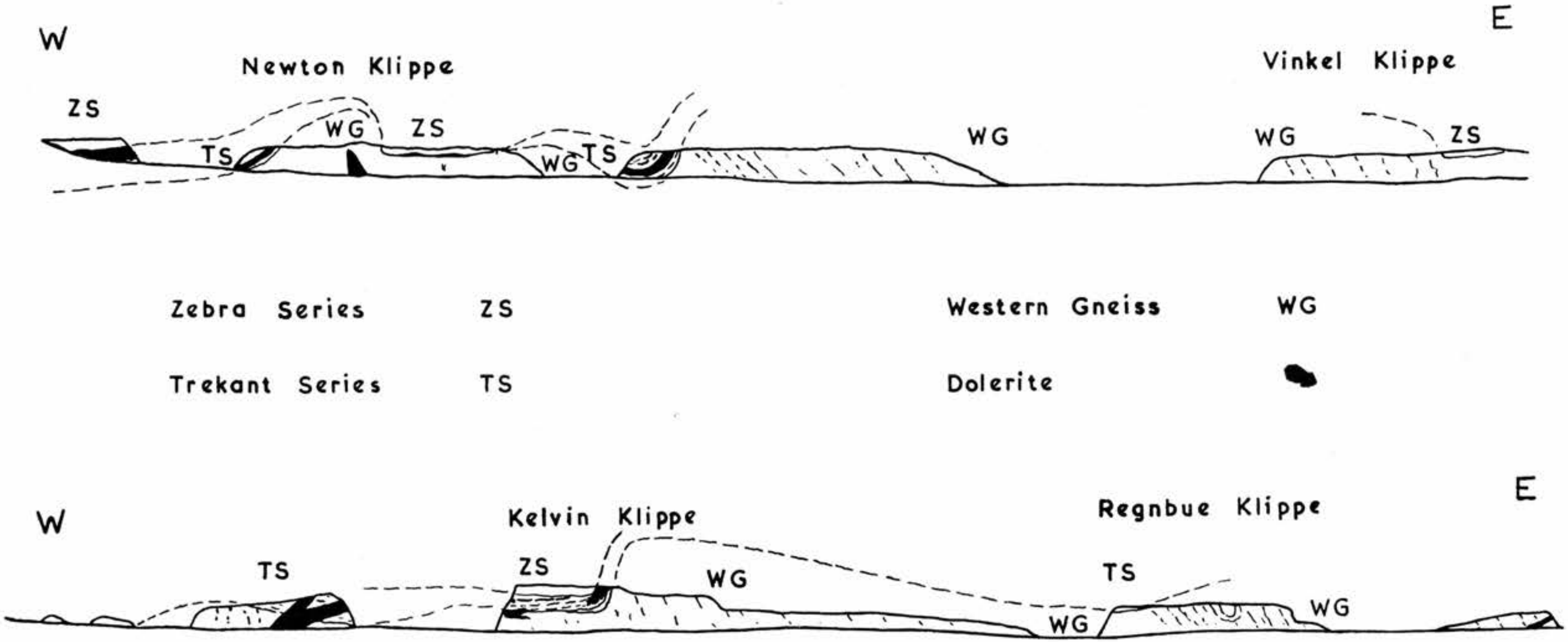
1. Almost unmetamorphosed sediments. Western Gneisses affected only by the older metamorphism.
2. Greenschist to (?) lower epidote-amphibolite facies.
3. Epidote-amphibolite a facies.
4. Upper epidote-amphibolite facies—lower amphibolite facies.

The dashed line marks the eastern limit of pyroxene in basic rocks.



Geology of the S.W. Nunataks.

a. Zebra Series.
b. Trekant Series.
c. Dip with amount in degrees.
d. Gneiss.
e. Hornblende-adamellite.
f. Basis gneiss and associated rocks.

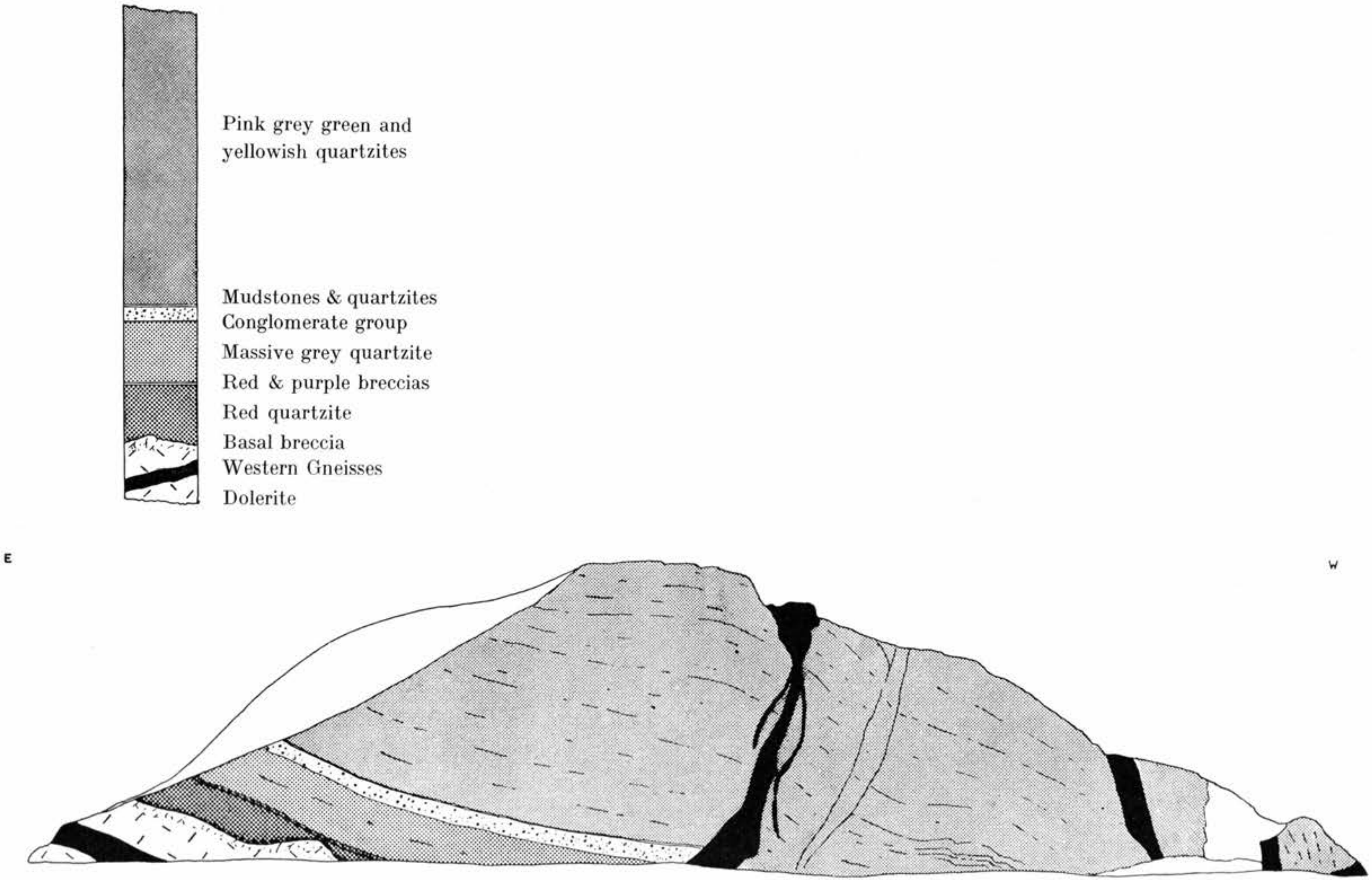


a. Section along N. side Admiralty Gletscher.

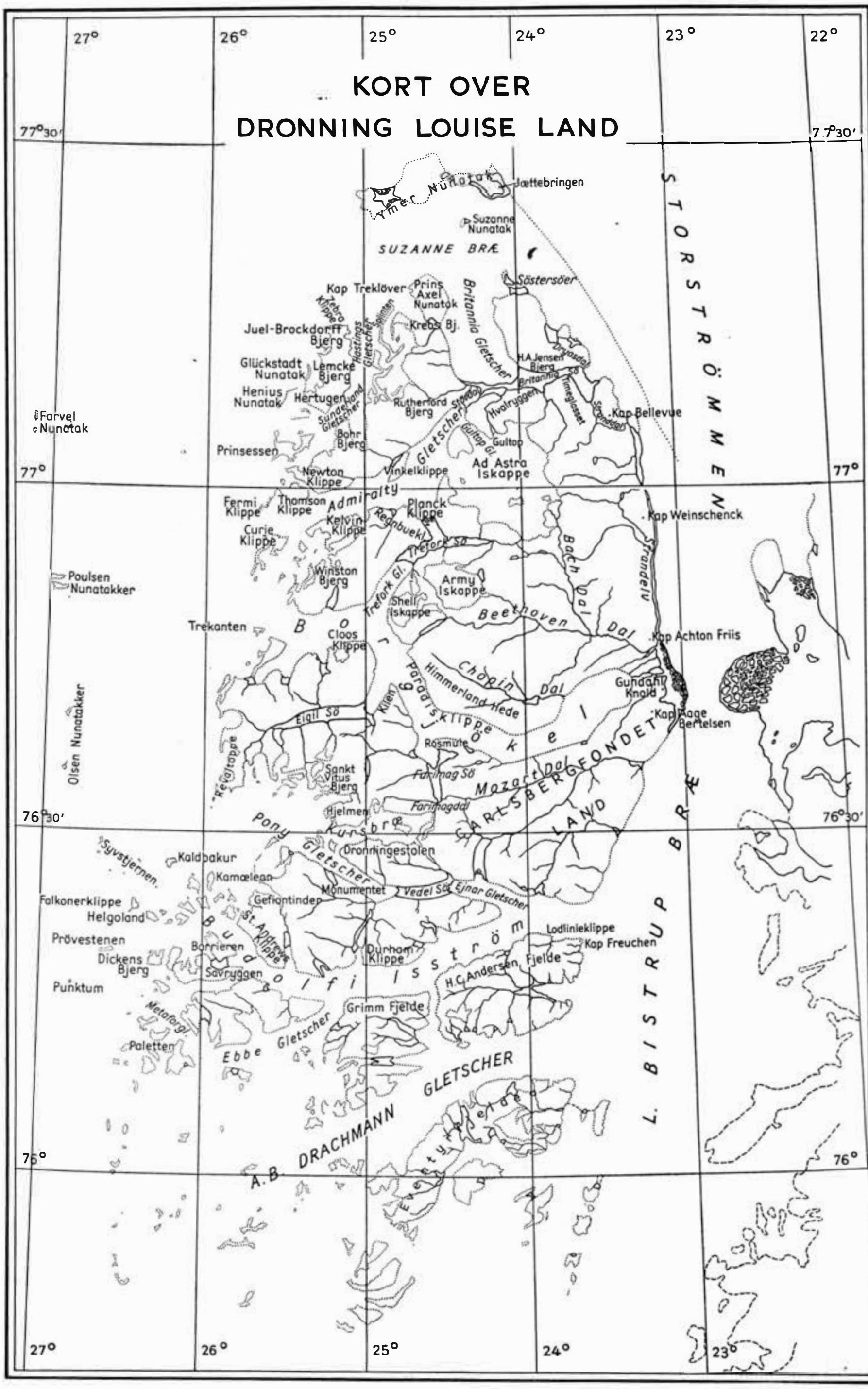
b. Section along S. side Admiralty Gletscher.

Cross sections on Admiralty Gletscher.

Top: along the north side, bottom: along the south side of the glacier.



Trekanten. Scale: 1 cm approximately 70 metres.



Outline map of Dronning Louise Land. Scale approximately 1:1,200,000.