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GRØNLANDS GEOLOGISKE UNDERSØGELSE

PLUTONIC DEVELOPMENT OF THE ILORDLEQ AREA, SOUTH GREENLAND

Part I:

CHRONOLOGY, AND THE OCCURRENCE AND RECOGNITION OF METAMORPHOSED BASIC DYKES

BY

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WITH 70 FIGURES IN THE TEXT
AND 9 PLATES

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Abstract.

Evidence is presented which shows the rocks of Ilordleq to be the products of two distinct episodes of plutonic (READ, 1957, p. 165) activity. In the first of these episodes the mise-en-place of a large area of synkinematic granitic rocks was effected. A NE striking belt of pre-granite supracrustal rocks is preserved in the north of the area, and isolated remnants of the supracrustal rocks remain as enclaves in the granite. Cutting the metasediments and metavolcanics of the supracrustal group are numerous basic dykes which pre-date the granite.

The first plutonic episode was followed by a further period of emplacement of basic dykes, which cut both supracrustal and granitic rocks. Indications of original chilled margins in these dykes, together with their regular form, suggest a marked change in conditions from those prevailing in the preceding plutonic episode.

The second period of plutonic activity which followed resulted in a reactivation of much of the granite previously formed, especially in the northern part of the area where basic dykes were deformed and became either disrupted or were migmatised by kinematically controlled metasomatism. The surrounding granite shows evidence of flow in the solid state and was evidently approaching a state in which diapiric movement was possible. In a less reactivated part of the area, porphyroblastic microcline augen granites were formed in those places where the supracrustal enclaves were most strongly deformed.

Deformation during each plutonic episode took place by homogeneous strain with resulting change in shape rather than tectonic transport; minor structures in supracrustal, granitic and dyke rocks are homologous. Principal stress axes were similarly oriented during both plutonic episodes.

A further period of emplacement of basic dykes took place in the closing stages of the second period of plutonic activity, while the country rocks were still at elevated temperatures and during the operation, at least intermittently, of compressive forces. A conjugate set of shear fractures controlled the emplacement of these dykes; movement along the fractures and emplacement of dykes were essentially contemporaneous and gave rise to 'differentiation by deformation' of the partially consolidated dyke magma, sigmoid foliation of the dykes, and other distinctive features.

Further swarms of basic dykes were subsequently emplaced during the Gardar volcanic episode (ca. 1150×10^6 years).

Reference is made to published criteria for the recognition of relict dykes, replacement dykes, and dykes emplaced in hot granite, and the possibility of confusion with dykes in reactivated granites is indicated.

The suitability of the orogenic cycle as the primary unit of Precambrian chronology is questioned and a less interpretative unit advocated.

The Ilordleq chronology is compared with those established by the writer's colleagues elsewhere in South Greenland and possible alternatives suggested to some current correlations.

The similarity of many features of the Ilordleq rocks to those of the Lewisian rocks of Scotland is referred to, and the concept of a migrating front of plutonic activity shown to be not applicable to Ilordleq.

PREFACE

Ilordleq lies on the west coast of the southern part of Greenland, some 40 km south of the mining settlement of Ivigtut. The location and extent of the area are shown in Plates VIII and IX.

The investigation of the Ilordleq area was carried out as a part of the G.G.U.[1]) programme of systematic mapping in South Greenland, which, starting in the Ivigtut district in 1956, has now been continued to the south and south-east into the Julianehåb area, and will soon be extended southwards to Kap Farvel. On completion of the mapping programme, carried out mostly on a scale of 1:20000, a considerable area of Precambrian crystalline basement rocks will have been investigated, and the results obtained from any one of the smaller areas, such as Ilordleq, will thus have more than a purely local application when considered in their regional context.

The Ilordleq area consists mainly of granitic rocks with some metasediments and metavolcanics and has been mapped by the writer on a scale of 1:20000. It occupies a crucial position on the southern boundary of an extensive area of gneisses and metamorphosed supracrustal rocks where these are bordered by the Julianehåb Granite, a mass of heterogeneous granitic rocks extending for nearly 200 km from Kobberminebugt in the west to the inland ice in the east: the southward extent of the Julianehåb Granite has not yet been determined.

The primary object of the mapping of the Ilordleq area was to establish a chronological sequence of events and determine the age relations of the rocks encountered; the purpose of this account is to present the information obtained and conclusions drawn which have a bearing on these problems. Other aspects of the geology of the area which are of more local interest will be described under the same general heading:–

Part II Late-kinematic amphibolite dykes.
Part III Deformation and the development of minor structures.
Part IV Petrography and metamorphic development.

A coloured geological map (scale 1:100.000) covering the Nunarssuit sheet area (60°30′ N–61°00′ N; 47°00′ W–47°30′ W) which includes

[1]) Grønlands Geologiske Undersøgelse (Geological Survey of Greenland).

Ilordleq, together with an accompanying memoir, will be published by G.G.U. in due course.

Field work: A total of five months field work was carried out during the summers of 1959 and 1960 and was facilitated by the excellent topographical maps available and by the use of air photographs.

The limits of the area were determined mainly on grounds of ease of ccmmunication rather than by geological considerations. Of the total area of 210 square km about half is occupied by either the sea or lakes, and although the terrain is very uneven the highest point reaches up to only 375 m and most places are easily accessible. The Kobberminebugt is noted for its inclement weather, and fog and rain are more frequent than in most parts of South Greenland; perhaps for this reason, the area is uninhabited, although offering good opportunities for hunting and fishing.

The only previous geological work in the area was a coastal reconnaissance of Nivâq and Sánerutip imâ carried out by A. BERTHELSEN in 1957, but WEGMANN's account of the geology of the surrounding region (WEGMANN 1938) provided a useful starting point for the present investigation.

All text figures are from the writer's photographs or field sketches, unless otherwise stated.

Acknowledgments: It is a pleasure to acknowledge the help and encouragement I have received from all members of G.G.U., and the many suggestions received in the course of numerous discussions with my geological colleagues. The G.G.U. photographer, Mr. POVEL POVELSEN, printed the photographs used for text-figures and has also prepared Plates I and II. Mr. LEE of the University of Liverpool prepared Plates III–VII.

For the opportunity of carrying out the work I am indebted to the board of G.G.U. and to the Mineralogical Museum of the University of Copenhagen for working facilities in Copenhagen. The maps used during the field work and in the presentation of this report were provided by courtesy of the Geodetic Institute, Copenhagen. Plate VIII is reproduced from HARRY and PULVERTAFT (1963) by kind permission of my colleague Mr. C. PULVERTAFT.

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INTRODUCTION

With the possible exception of the youngest dyke swarm, the rocks of South Greenland are of Precambrian age and consist mainly of a varied assemblage of gneisses, granites, and metamorphosed supracrustal rocks: smaller areas of unmetamorphosed intrusive and extrusive volcanics and continental sediments also occur.

Three petrologically distinct areas can be recognised in South Greenland. The *Ivigtut* area, extending northwards from Kobberminebugt, consists mainly of paragneisses and metamorphosed supracrustal rocks. A similar range of rocks is found in the Nanortalik area, which beginning at Sârdloq (15–20 km SE of Julianehåb), continues southwards to Kap Farvel. The area between Kobberminebugt and Sârdloq comprises mainly granitic rocks, collectively designated as the "Julianehåb Granite" (Ussing, 1912).

The current classification of these rocks owes much to the classic work of Wegmann (1938), although more recent work by G.G.U. has made it necessary to modify some of his conclusions (Berthelsen, 1960, 1961).

The major part of the South Greenland crystalline complex was interpreted by Wegmann as the product of what he designated the *Ketilidian cycle.* Beginning with the formation of geosynclinal sedimentary and volcanic rocks, this cycle continued with the folding, metamorphism, migmatisation and granitisation of these supracrustal formations during the Ketilidian orogeny. The gneisses occurring at Ivigtut and further to the north were the supposed basement rocks on top of which the Ketilidian supracrustal series was deposited; they thus represented the earliest, or *pre-Ketilidian period.* The post-Ketilidian unmetamorphosed volcanics and sediments were referred to the *Gardar period.*

More recent work has shown that some of the Ivigtut gneisses were formed from rocks of the same age as the overlying supracrustal rocks and they are therefore considered to be of Ketilidian age. Furthermore, basic dykes (*Kuanitic dykes*) which at Sermiligârssuk are only slightly metamorphosed, were found to become more intensely metamorphosed towards the SE, and in the areas between Ivigtut and Kînâlik are folded and in places migmatised. It was therefore evident that the gneisses had undergone a later metamorphism: the time during which the dykes were emplaced was accordingly called the *Kuanitic period* and the time during which they underwent metamorphism and deformation the *Sanerutian period* (BERTHELSEN, 1961).

The following chronology was therefore proposed in the Ivigtut area:–

4. Gardar period (volcanic activity and formation of continental deposits)
3. Sanerutian period (metamorphism, deformation)
2. Kuanitic period (intrusion of basic dykes)
1. Ketilidian cycle { Orogenesis / Supracrustal rocks }

Gardar intrusive rocks have been dated at about 1100 m and 1200 million years (MOORBATH, WEBSTER and MORGAN, 1960).

A regional swarm of coast-parallel dolerite dykes not affected by Gardar fault movements is thought to be of Tertiary age.

In the following account, the terms Ketilidian, Sanerutian and Gardar are used as in the table. In a concluding section (page 130), however, it is suggested that the use of these terms be revised and that the term Kuanitic no longer be used.

The greater part of Ilordleq is occupied by granitic rocks of the Julianehåb Granite formation but the oldest rocks encountered are represented by the NE striking band of a metamorphosed supracrustal series occurring in the north of the area: this has a migmatitic contact with the granitic rocks on either side and the boundaries as shown on the map are therefore arbitrary.

This juxtaposition of elements characteristic of both the Ivigtut and Julianehåb Granite areas affords a means of determining the chronological relationship of these two areas. This has accordingly been the main object of the work in Ilordleq.

All structures in both granitic and metamorphic rocks are dominated by a NE strike which is found to be characteristic of large areas of the Julianehåb Granite: planar structures usually dip steeply to the SE. The granitic rocks in the northern part of the area are usually strongly foliated and the banding of the gneisses is parallel to this foliation. In the S and SE of the area this foliation is rarely seen but on Qeqertaussaq a marked foliation of later date also strikes NE. Wherever the granitic rocks are foliated, the foliation is found to be parallel to the plane of flattening of triaxial enclaves of supracrustal rocks which are found in varying concentrations throughout the area, and wherever a linear structure is found in the granitic rocks, it is parallel to the longest axis of the enclaves. The NE trend of the belt of supracrustal rocks conforms with the regional strike direction, and within this belt bedding and foliation, except in a few isolated instances, are parallel to one another and to the foliation in the surrounding granitic rocks. Granite veins within the metamorphosed supracrustal rocks are in most cases parallel to bedding and foliation and are themselves foliated. Minor folds are uncommon except in the calcareous horizons and generally have axes parallel to the intense lineation found in the supracrustal rocks; this lineation is parallel to that found in the adjoining granitic rocks.

Cutting both the granitic and supracrustal rocks are numerous amphibolitic dykes, usually 1–2 m in width. These dykes can be separated into three groups, only two of which are found in the granitic rocks, the period of intrusion of each group being separated from that of each of the other groups by a sequence of plutonic events, and they are accordingly referred to as the first, second and third period amphibolitic dykes. These three periods are the basis of the chronology which is described in the following pages, and a large porportion of the time spent in the field was given to the examination of these dykes, particularly those which have been deformed and migmatised and therefore difficult to establish definitely as originally intrusive bodies. The recognition and chronological significance of such dykes is dealt with at some length in the following pages.

In this account the term synkinematic is used in its extended sense, including not only events taking place during deformation, but also those taking place during the static phase immediately following, in which the stress pattern was similar to that which operated during the preceding deformation.

The naming of structural axes which is shown in fig. 24, is descriptive only and has no genetic connotations. The concept of tectonic transport is not applicable to the type of deformation which affected the rocks of Ilordleq.

Section I

SUMMARY OF THE GEOLOGY OF THE AREA

Supracrustal Series.

This consists of interbedded metavolcanic and metasedimentary rocks, which each form bands from as little as one metre up to some hundreds of metres in width. Owing to the discontinuous nature of the exposure and considerable degree of migmatisation in many places, it has not been possible to establish a completely reliable stratigraphic sequence but the succession shown in fig. 1 is a fair indication of the relative amounts and thickness; those shown probably bear little relation to the original thickness. This succession has not been obtained from one single section across the area but is a composition of observations made at various localities within the supracrustal belt and in the adjacent areas of granitic rock where the original nature of the enclaves is apparent. It is almost certain that within the area covered by the succession shown in fig. 1, there is no major repetition of strata due to folding and that the supracrustal rocks form a part of the limb of a large structure of Ketilidian age, the disposition of which cannot be determined within the limits of the area under consideration.

The metasediments.

Rocks in which the detrital material is of pyroclastic origin are included under this heading; this has been found necessary because in many cases it cannot be ascertained whether the sedimented material is of volcanic origin or derived by weathering of consolidated country rock. Even in those cases where a volcanic origin is probable, it is not possible to distinguish between primary tuff deposits and those formed by erosion and transport of unconsolidated tuffs.

The metasediments are generally fine grained rocks in which the original banding is usually very well preserved; banding, the scale of which varies from a few mm up to 50 cm, is very regular and due to slight differences in grain size and composition and is accentuated by marked colour variation from bright green to grey.

Hornblende and oligoclase are the dominant minerals but biotite and epidote are rarely absent and predominate in some cases. Biotite

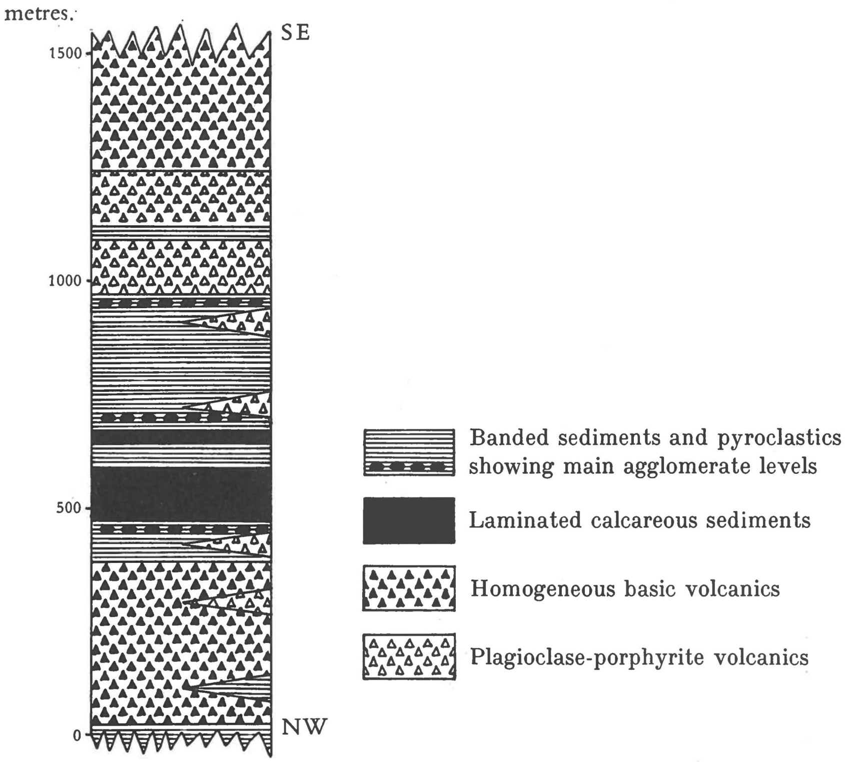

Fig. 1. Composite stratigraphic section of the supracrustal rocks in the northern part of Ilordleq.

schists are rare but semi-pelitic biotite granulites are common and comprise the major portion of the definitely non-pyroclastic sediments. Calcareous rocks are found only within two well defined horizons on the island of Sioragdlit and the smaller islands immediately to the west, and vary in composition from marls to almost pure limestone. A few thin quartzite bands occur, and zones containing many thin bands of magnetite up to 2 cm wide are found especially on Sioragdlit.

Agglomerates.

Lens shaped zones within the metasedimentary series contain abundant clastic fragments up to 50 cm in length, in a matrix of the usual finely banded sediment. The zones occur in many places rarely extending for more than 50 m laterally, but are up to 15 m thick in the centre. Although conclusive evidence is lacking, these zones are thought to be agglomerates. The fragments are evenly distributed and poorly sorted; a complete size gradation from the largest to fragments consisting of only a few mineral grains being evident in the most extensive of the

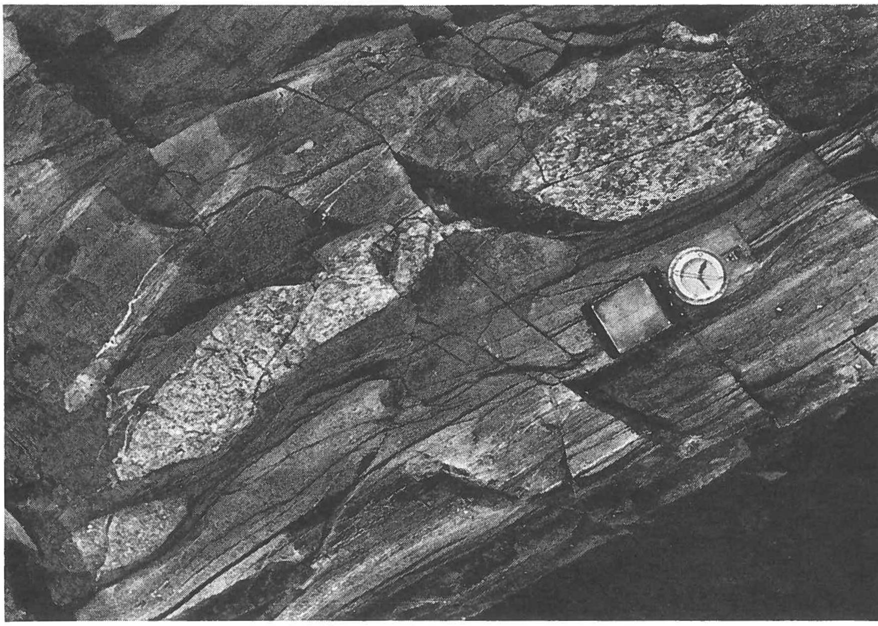

Fig. 2. Agglomerate with large fragments of porphyritic metabasalt, in finely banded pyroclastics. S.E. coast of Nivâq.

zones, on the tip of the large peninsula on the SW side of the Anchorage on the SE coast of Nivâq. Within this zone occur two large fragments of fine grained amphibolite with plagioclase megacrysts (fig. 2); this rock type is identical with that of the porphyritic metabasalt horizons described below and almost certainly derived from such an horizon. Derivation of these fragments by local subaerial weathering and subsequent transport would imply conditions unsuited to the deposition of the finely banded matrix.

One feature not fully consistent with a pyroclastic origin is the composition of the fragments; amphibolite is uncommon and most fragments are of granite, granite gneiss and quartzite. The comparative rariety of fragments of volcanic rock, except in the two instances described below, may be of some significance with regard to the chronology. The common occurrence of these plutonic rock types would not be expected if the larger part of the Ivigtut gneisses was Ketilidian and the great thickness of these formations lay between the agglomerates and the basement (see page 132).

Fig. 3 shows a distinctive rock type occurring at two localities on the east coast of Sãtukujôq, in both cases as a 1 m thick band within large remnants of supracrustal rock surrounded by granitic rocks. White 'augen' of quartz and microcline with subsidiary plagioclase are

Fig. 3. Strongly deformed felspathic fragments in agglomerate. Eastern end of Sâtukujôq.

set in a matrix of hornblende and plagoclase with some epidote. The rock bears a striking resemblance to some porphyroblastic rocks of migmatitic origin, but an important difference is the fine grain size of the quartz felspar patches in contrast to the medium or coarse grain of metasomatic augen. In the agglomerates containing the normal range of rock types some fragments are found identical with those of the rock in fig. 3 and it is likely that this too is an agglomerate. Probably the original fragments were of acid volcanic rocks and the rock of similar origin to the agglomerates with leptitic fragments described by ESKOLA (1914; 1950, fig. 1) from Orijärvi; here too, the certain identification of agglomerates causes difficulty (ESKOLA, 1950). Original shapes of the agglomerate fragments in both types of agglomerate have been obscured by later deformation, but it is probable that they were more or less rounded; measurement of the axes is, however, unlikely to give a reliable indication of the absolute deformation although the principal strain axes can easily be determined (fig. 4).

The pyroclastic rocks of Ilordleq are in many respects similar to those of the Søndre Sermilik region, between Julianehåb and Kap Farvel. In the latter area however, the supracrustal rocks have undergone less deformation and migmatisation and their original features are preserved sufficiently well for the origin of the various types to be more

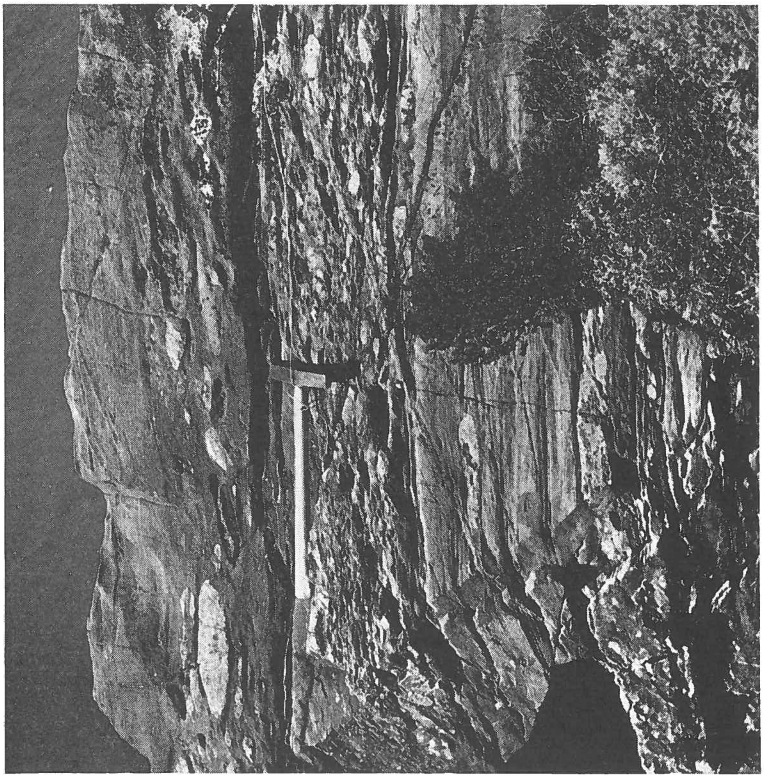

Fig. 4. Agglomerate zone in finely banded pyroclastics, showing a:c sections of deformed fragments which are flattened parallel to foliation and bedding of the host rock. S.E. coast of Nivâq.

easily determined. The agglomerates of Søndre Sermilik are very similar to those of Ilordleq, thus supporting the identification of the latter.

There is no evidence suggestive of a glacial origin for the deposits described above as agglomerates.

Evidence of 'way-up'.

'Way-up' criteria are rare: truncated current bedding was found at one locality in semi-pelitic biotite granulite, and one example of metamorphically reversed graded bedding (READ 1958, p. 96) was seen in the calcareous rocks. Both these indicated that the succession is younging towards the SE.

Epidote nodules.

These sometimes exceeded 1 m in length and are characteristic of much of the supracrustal series; although their origin is obscure it is certain that they are of metamorphic origin and do not represent pre-

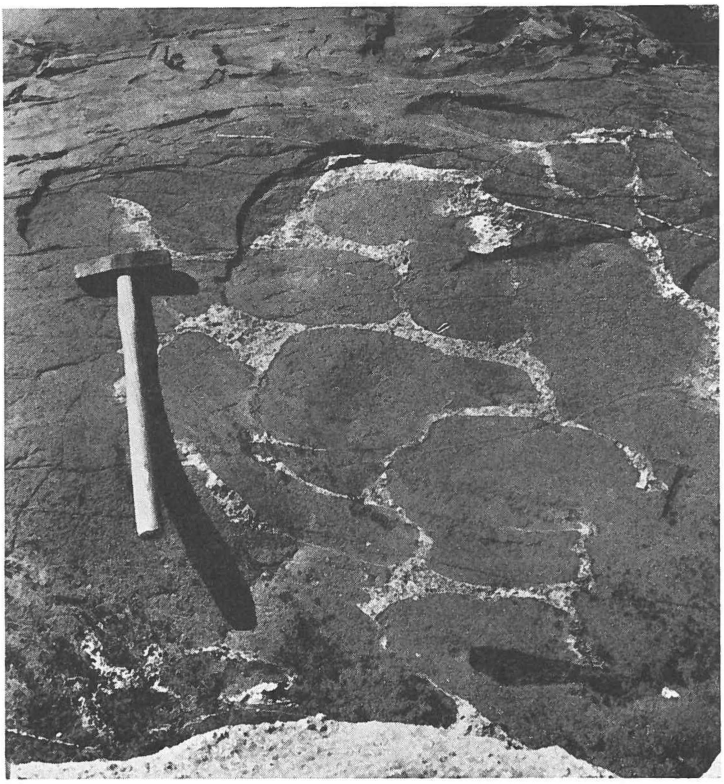

Fig. 5. Migmatised metavolcanics with neosome veins simulating pillow structure. Palaeosome is fine grained amphibolite. S. E. coast of Nivâq.

metamorphic sedimentary concretions. Part IV will contain details of the occurrence and petrographic features of these nodules. In the Søndre Sermilik region previously referred to, in a supracrustal series consisting of a wide variety of sedimentary and volcanic rocks, epidote nodules are almost confined to the pyroclastic group.

The metavolcanics.

As the pyroclastic rocks have already been described together with the sediments, only those volcanics originating as flows need be considered under this heading: although they form bands up to several hundred metres in thickness concordant with the bedding of the metasediments, no unequivocal evidence has been found to show that these rocks are of extrusive origin and it is conceivable that they were emplaced as sills. However, no discordant boundary between these rocks and the metasediments has been seen and on the basis of the evidence available, an extrusive origin seems to be the more likely. The meta-

Fig. 6. Typical porphyritic metavolcanic with both metamorphic foliation and flow orientation of phenocrysts parallel to hammer handle. S.W. tip of Ikerasârqap nunâ.

volcanics are derived from two fairly distinct types, the one a homogeneous basalt and the other a porphyritic basalt containing up to 50 % of felspar megacrysts.

The homogeneous metavolcanics are now fine grained black amphibolites with few notable features except in those places where they have been migmatised. The typical form of the neosome veining is shown in fig. 5 and as can be seen, there is a resemblance to a pillow-lava with the 'pillows' outlined by the granitic veins. These rocks are quite unlike undoubted pillow lavas on the nearby island of Sánerut (see Pl. VIII) which were however metamorphosed and deformed under conditions somewhat different to those which prevailed in Ilordleq. The characteristic pattern produced by migmatisation of the homogeneous metavolcanics is probably due to the greater homogeneity of these rocks compared to that of the other supracrustal rocks found in the area.

The porphyritic metabasalts (fig. 6) vary in the amount, size and shape of the felspar phenocrysts they contain, although each of these factors is constant within any one band when followed along the strike. Phenocrysts up to 4 cm in length are common and are usually tabular in habit, although equidimensional forms do occur. In nearly every case observed in which the phenocrysts are tabular, they have a marked flow orientation parallel to the bedding in adjacent sediments. No trace of subaerial weathering was found either between individuals flows or at the boundaries between the metavolcanics and metasediments. Although bands of metasediment are rare within the mainly volcanic horizons, narrow bands of metavolcanics frequently occur within the dominantly metasedimentary horizons.

Epidote nodules similar to those found in the metasediments occur in the porphyritic metabasalt but are found only very rarely in the homogeneous metabasalt.

Ketilidian Granitic Rocks.

These have been studied in most detail in the good coastal exposures, on the SE coast of Nivâq and on the off-shore islands.

Relations with the metamorphosed supracrustal rocks:

In all the many cases where contact relations have been observed, the supracrustal rocks are undoubtedly earlier than the granites. The boundary between the two is migmatitic and many granite veins are found in the supracrustal rocks, while numerous enclaves of the latter occur within the granite. In nearly every case individual contacts are sharp and there is little macroscopic evidence of felspathisation of the country rock. Nevertheless, whenever definite evidence has been found it shows the emplacement of the granite veins to have taken place by replacement of the country rock; such evidence can, however, only be found on the margins of the granite and is not necessarily valid for the main granite mass. An exception to this general rule is found in the vein shown in fig. 7 where the granite is almost certainly intrusive. The granite vein illustrated cuts a mass of coarse grained dark hornblendite, angular blocks of which are enclosed by the granitic material: the vein also contains blocks of a fine grained grey dioritic rock, which must have been carried into place by mobile granitic material. However, it is probable that granite formed by replacement of the normal range of foliated supracrustal rocks was intruded into fractures in the massive unfoliated hornblendite.

For chronological purposes the mode of formation and emplacement of the granite is only of secondary importance.

Good exposure is necessary for a reliable genetic interpretation of a granite to be made; as this condition is not fulfilled in Ilordleq the origin of the main mass of granitic rock must necessarily remain in doubt: the following points are, however, of some significance. On the margins of the granite, enclaves are found to be parallel to the NE strike direction and with their shapes and orientation determined by kinematically controlled replacement (see page 39); the enclaves

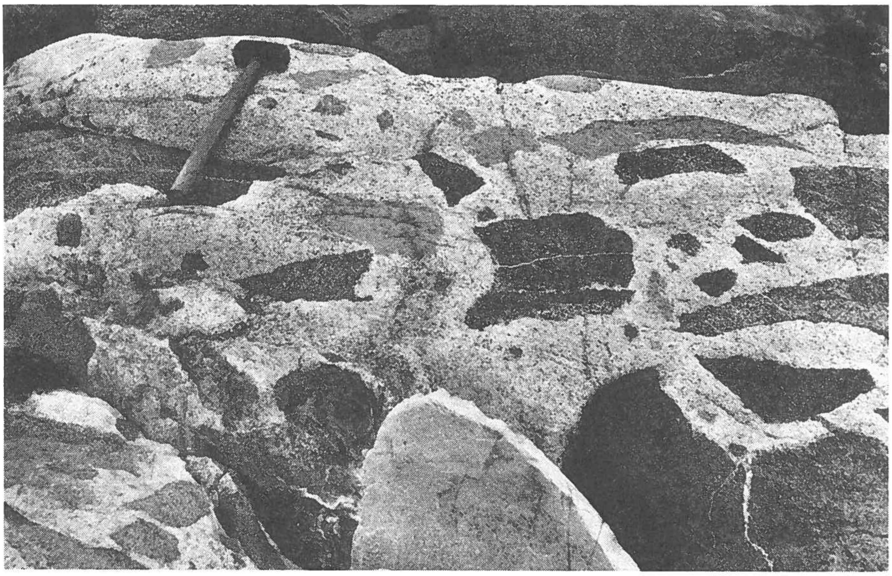

Fig. 7. Massive hornblendite with apparently intrusive vein of Ketilidian granite. Dark fragments enclosed by granite are of the coarse grained country rock while lighter fragments are fined grained diorite of a type not exposed elsewhere in the immediate neighbourhood. Island S.W. of Natsît iluat.

further away from the margins have similar shapes and orientation and it is reasonable to suppose them to have originated in a similar manner. However, enclaves of similar shape with constant orientation are known from granite masses which have been mobile in at least the final stages of emplacement, e.g. Thorr Granodiorite, Ireland (PITCHER, 1953).

Another feature which must be taken into consideration is the vast extent of the Julianehåb Granite, most of which was originally emplaced in Ketilidian time: the space problem which arises by supposing such a mass to be of intrusive origin is formidable, although of less account when the synkinematic nature of the granite is considered.

There is considerable variation in the rock type of the Ketilidian granite with regard to grain size and proportion of mafic material. From examination of the contact relations with the supracrustal series it is apparent that such variations do not reflect variation in the rock type from which the granite has been formed, and the variations are apparently fortuitous. A large proportion of the granites are medium grained with less than 15 % of mafic material, usually biotite, and little or no quartz visible in hand specimen. In the SE of the area, especially on Qeqertaussaq, quartz is more commonly seen, occurring in parallel sheet-like aggregates: the aggregation, and perhaps introduction, of the quartz post-dated the Ketilidian period of granite emplacement (see page 150).

Small amounts of fine grained aplitic leucogranite occur throughout the area in small veins and masses cutting the main granite; the largest of these masses is 2 km NE of the head of Natsît iluat. In the northern part of the area, where the granitic rocks are most strongly foliated, the leucogranite occurs in narrow veins which are usually parallel to the foliation; elsewhere the veins are more irregular.

Sanerutian Granites.

The so-called Sanerutian Granites are granitic rocks formed in Ketilidian time, but affected to such an extent by the subsequent Sanerutian plutonic activity that they can be considered as new rocks. Use of the term Sanerutian Granites therefore does not imply, in this case, a Sanerutian period of granitisation or granite intrusion but a 'reactivation' of pre-existing granitic rock. This is not to say that those rocks referred to as Ketilidian granites were unaffected by Sanerutian metamorphism and deformation, but rather that they did not undergo such a complete physical transformation as did the Sanerutian Granites. As there is a sharp boundary between those rocks strongly affected by Sanerutian events and those not so strongly affected, in Ilordleq it is relatively easy to separate the granitic rocks into the two groups which elsewhere may require arbitrary definition. Comparison of the relative effects of the Sanerutian on the various granitic rocks is greatly facilitated by the occurrence throughout the area of amphibolite dykes which are post-Ketilidian and pre-Sanerutian in age; these are the 2nd period dykes which are described in detail on a later page.

Sanerutian Hornblende Granite.

The most extensive area of Sanerutian granite, found in the NW of the area along the coast of Sánerutip imâ on the islands of Ikerasârqap nunâ, Sãtukujôq and Sioragdlit, differs from the Ketilidian granites in having a relatively uniform appearance. The characteristic features are a medium grain size, pale grey colour of both fresh and weathered surfaces, the presence of hornblende to the almost total exclusion of biotite, and the occurrence of the mafic material in crystals almost equal in size with those of felspar—a contrast with Ketilidian granites in which the mafic, whether biotite or hornblende, occurs in aggregates of very small crystals. As in the Ketilidian granites the colour index is variable but the amount of stubby black hornblendes is usually between 10 %

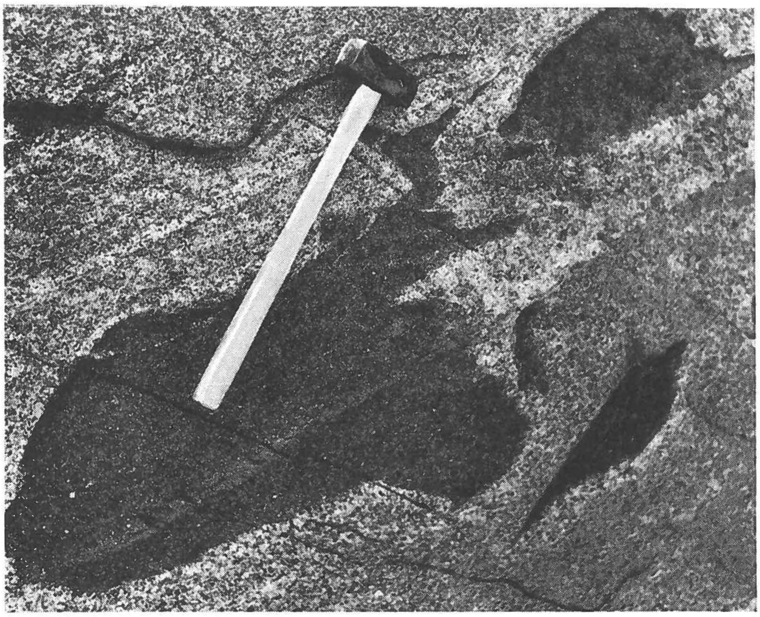

Fig. 8. Irregular amphibolitic enclaves, probably of metavolcanic origin, in Sanerutian hornblende granite. West coast of Ikerasârqap nunâ.

and 15 % of the rock: quartz is not seen in handspecimen. The concentration of large felspars in some places (see page 92) gives rise to a porphyroblastic phase of what will be referred to as the *Sanerutian Hornblende Granite.* Except at one locality on the western extremity of Ikerasârqap nunâ, the Sanerutian Hornblende Granite has a directional fabric which is expressed either as a planar foliation together with a linear structure, or as a more intense linear structure without foliation. At a few localities a banded structure is evident with alternating bands of light and dark granite from 1 cm to 5 cm in width: the light bands in places become so coarse grained as to be almost pegmatitic and although conclusive field evidence is lacking, the banding appears to be of metamorphic origin and not inherited from the supracrustal series.

As in the Ketilidian granites, remnants of supracrustal rock occur as enclaves, which are flattened within the plane of the foliation and elongated parallel to the lineation in the enclosing granite.

The only exposed contact between the Sanerutian Hornblende Granite and Ketilidian granite is found on the westernmost peninsula of Ikerasârqap nunâ. The few metres of the contact which are exposed show it to be knife-sharp but following an irregular course and cutting across the foliation of the Ketilidian granite: for a distance of 50 m or so from the contact the Sanerutian Granite has no foliation or linear structure and its enclaves, instead of having the regular shapes and orientations of those found elsewhere, have irregular forms such as that shown in fig. 8. At one point on the exposed contact, the Sanerutian Granite veins the Ketilidian granite. At this locality the Sanerutian Hornblende Granite appears to have been in a state of incipient diapiric movement, which would account for the disruption of enclaves and the contact relations with the Ketilidian granite.

Sanerutian Pegmatite Granite.

A small area of Sanerutian granite is found in the SW of the area, on the NW coast of Natsît iluat: the granite is almost free of mafic minerals; it is very coarse grained with a high proportion of quartz and is consequently referred to as the *Sanerutian Pegmatite Granite*: as in the case of the Sanerutian Hornblende Granite the age of this granite has been established on the basis of its relations with 2nd Period dykes.

Discordant Amphibolites.

The convenient field term 'discordant amphibolite' (DA) is used to refer to the numerous dykes in the area composed mainly of amphibole and felspar, and to the identifiable remnants of such dykes, in order to distinguish them from the fresh dolerite dykes on the one hand and dyke-like amphibolitic remnants of the supracrustal rocks on the other. As the origin of many of the amphibolite dykes was uncertain in the early stages of the field work, a non-genetic descriptive term was necessary and its usefulness justified its continued use in later stages of the work. There is, however, some risk of confusion with the 'amphibolite discordante' (AD) of earlier publications on South Greenland by members of G.G.U. (Ayrton, 1963; Weidmann, 1964). In these papers AD_1, AD_2, etc. refer to dyke generations within a single period, in contrast to the DA_1, DA_2, and DA_3 of the present account which refer to dykes of different periods without regard to the dyke generations within each period.

1st Period Discordant Amphibolites.

These are found only within the supracrustal rocks and are cut by the veins of Ketilidian granite which occur in the migmatised parts of the supracrustal series. The 1st period dykes have been divided into two subgroups, 1A and 1B, on the basis of age differences. The period 1A dykes are those which were emplaced before any deformation of the supracrustal rocks took place and are probably products of the same volcanic activity which gave rise to the supracrustal metavolcanics.

The period 1B dykes are identified as those which cut early folds in the supracrustal rocks but which are themselves cut by veins of Ketilidian granite. On only a few occasions can the distinction be made between 1A and 1B dykes because of the scarcity of early minor folds in the supracrustal rocks—this point is referred to in greater detail on a later page. It is possible that the emplacement of dykes took place throughout the initial folding phase, a situation apparently similar to that described by WHITE and BILLINGS (1951) from New Hampshire, in which case the distinction between 1A and 1B dykes must be regarded as the arbitrary chronological division of a single extended period of hypabyssal intrusion.

Many of the 1st period dykes were emplaced as sills and show only slight discordance (see fig. 10) and these are much better preserved than those emplaced as dykes, which are intensely sheared and have been broken up by displacement parallel to the bedding and foliation of the enclosing supracrustal rocks. Discordant amphibolites of all periods vary from 5 m down to a few cm in width but most are between 25 cm and 150 cm wide.

2nd Period Discordant Amphibolites.

These are found throughout the area in the supracrustal rocks and in both Ketilidian and Sanerutian granites.

In supracrustal rocks: unless the relationship to granite veins can be seen, the 2nd period dykes in the supracrustal rocks cannot with certainty be distinguished from dykes of the 1st period. Although less deformed than those of the 1st period, the discordant amphibolites of the 2nd period have been broken up in a similar manner, especially those in the metasediments where bedding-plane shear has caused large displacements.

In Ketilidian Granites: in these rocks the 2nd period dykes are best preserved and in most places retain their original trends and intrusive features. Fine grained margins are usual but in only a few cases can these be shown to be due to chilling of the magma against the country rock. In most of the dykes shearing has been concentrated along the dyke margins and no trace of the original texture is preserved; in a few discordant amphibolites however, the texture is sufficiently well preserved on the margins for the original outlines of felspar crystals to be seen in thin section and for a comparison to be made of the relative sizes of original felspars from the margin and centre of a single dyke (see page 114). In thin section all the 2nd period dykes, with the exception of the green type described on page 115, have strong directional fabrics, but this is not always evident in handspecimen owing to the fine grained nature of most of the dykes. When the foliation can be seen in the field it is either parallel to the foliation of the enclosing granite or is parallel to the dyke margins: the control of the foliation directions is described on a later page.

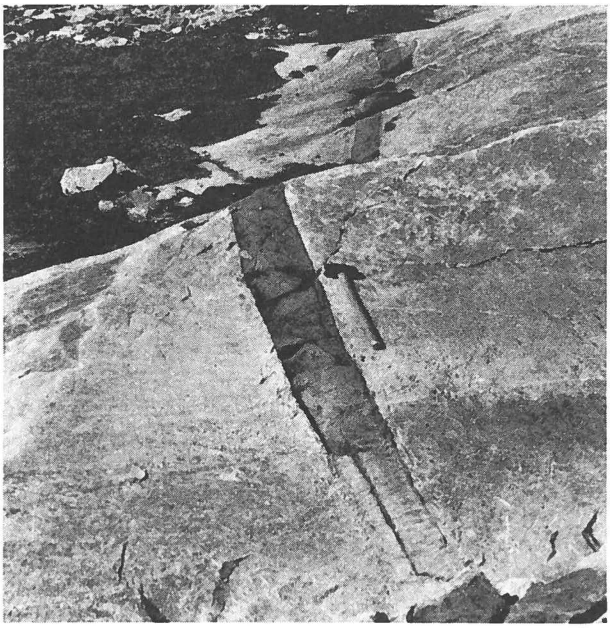

Fig. 9. Undeformed and unmigmatised 2nd period dyke in Ketilidian granite. S.E. coast of Nivâq.

In the NW part of the area of Ketilidian granite some 2nd period dykes have been shear folded; in this area too some felspathic veins in addition to occasional pegmatites can be seen cutting the 2nd period dykes.

In the neighbourhood of Natsît iluat, an area of locally intense Sanerutian activity, many 2nd period dykes are bordered on one or both sides by zones of fine grained leuco-granite. These so-called 'aplite-margins' are described in more detail on page 56. 2nd period dykes cut by pegmatites are also found in the Natsît iluat area.

In Sanerutian Hornblende Granite: the 2nd period dykes in this granite are strongly deformed and nearly all of them show some degree of replacement by granitic material. In some instances the granitic material has almost entirely replaced the amphibolite and in such cases it is often impossible to show that the remnants of amphibolite are in fact the remains of a dyke. However it is not necessary to prove the origin in the case of every supposed dyke, as a chronology can be established on the basis of those for which there is definite evidence available. It has been found that published criteria for the recognition of pre- and post-granitic dykes, as well as those supposedly emplaced contemporaneously with granite, are invalid. The results obtained by applying these criteria are inconsistent with those obtained from field observations in Ilordleq.

Accordingly, the problem of recognition of relict dykes is reviewed in a later section of this account.

3rd Period Discordant Amphibolites.

These dykes occur throughout the area and, in contrast to the 'anorogenic' 2nd period dykes, are thought to have been emplaced during the closing stages of the Sanerutian plutonic period while the country rocks were still at an elevated temperature and during the operation, at least intermittently, of strong compressive forces. The dykes were emplaced not in tensional fractures, but along compressional shear zones; in many cases this resulted in the separation of the early formed minerals from the remaining magma in a manner similar to the 'filter pressing' described from some cratogenic volcanic rocks. This has resulted in the dykes having an original foliation with a characteristic pattern reflecting the relative movement of the wall rocks, and from which an indication of the regional stress pattern can be obtained. Further information regarding these dykes is given in section II and a complete description and discussion comprises Part II of this series. Like the 1st and 2nd period dykes, the 3rd period dykes consist mainly of hornblende and plagioclase but have textural features quite unlike those found in the dykes from earlier periods.

Unmetamorphosed Basic Dykes.

Unmetamorphosed dykes are found throughout the area but are especially common on the N coast of Tarajornitsoq and on Qeqertaussaq where a dense swarm of NE striking dolerites, with individual dykes up to 150 m in width, must have caused a widening of at about 15 % within a zone 5 km in breadth. Six dykes belonging to the suite of what are known as 'big-felspar' dykes occur, and are characterised by the large amounts of xenolithic felspar which they contain in the form of both individual crystals and blocks of anorthosite. Most of the dykes were emplaced during the Gardar period but the youngest dyke generation, which post-dates all fault movements, is perhaps of Tertiary age.

Outline of the Structural History.

The structural features of the area were produced during two main deformation episodes which, although sharing a common pattern of principal stress axes, were nevertheless separated by a tensional period during which the intrusion of basic dykes (2nd period dykes) took place.

The first period of deformation (Ketilidian) took place before and during the arrival of the granitic rocks and thus gave rise to fold structures in the layered sequence of supracrustal rocks. The later deformation (Sanerutian), acting mainly on an unlayered granitic mass, gave rise to fold structures only in suitably oriented discordant bodies within the granites and supracrustal rocks. Thus the different styles of the structures produced by the two deformational episodes should be regarded as due to the different material undergoing deformation, rather than to more fundamental differences in the plutonic environment.

The narrow strip of supracrustal rocks, bounded on either side by massive granitic rocks as it was during the Sanerutian deformation, forms an ideal site for the examination and interpretation of structures which are known to have formed as a direct result of compression without possibility of flexural slip; the calcareous rocks are exceptional in this respect. The minor structures in the area are therefore treated in some detail in Part III and the structural evidence presented in this account will be confined to that necessary for a chronologic interpretation of the area.

The first recognisable structural event is the large scale folding of Ketilidian age, probably during which the present disposition of the supracrustal rocks was established. No structural evidence is available which enables the initial phase of deformation, separating the 1A and 1B dykes, to be distinguished from the main Ketilidian deformation. The axis of folding was essentially horizontal along a NE–SW axis, as is shown by minor folds and linear structures. Minor folds are rather uncommon except in the calcareous rocks; the foliation of the supracrustal rocks, normally parallel to the bedding, is parallel to the axial planes of the minor folds where these occur. Linear structures are found throughout the supracrustal series, usually as a mineral orientation parallel to the longest axes of agglomerate pebbles and epidote nodules where these are found. Emplacement of the Ketilidian granite took place during this first deformation episode but probably after the formation of the major structure. Granite veins follow the axial planes of Ketilidian minor folds and are themselves unfolded, showing that deformation involving flexuring of the layered rocks, if it occurred at all, had ceased by the time the granite was emplaced. The calcareous rocks are an exception also in this respect since they contain flexural folds formed after the emplacement of axial plane granitic veins. Minor folds in the calcareous rocks have constant axial directions but chaotic axial planes, unlike the minor folds of Ketilidian age elsewhere in the supracrusta-series which invariably have axial planes parallel to the regional foliation, i.e. striking NE and dipping steeply to the SE.

The intrusion of numerous basic dykes (2nd period dykes) besides bearing witness to a marked change from the conditions prevailing during the period of Ketilidian plutonism, provides in addition a useful means of distinguishing between Ketilidian and Sanerutian structures.

The intrusion of the 2nd period dykes was followed by a return to plutonic conditions and the renewal of deformation during the Sanerutian period. The Sanerutian deformation resulted in the intensification of earlier linear and planar structures and in the shear-folding of discordant bodies emplaced after the completion of the Ketilidian deformation, e.g. 2nd period dykes, epidote veins and some granite, aplite and pegmatite veins. That the Sanerutian structural features were developed independently of the Ketilidian structures, although parallel to them, is shown particularly clearly by the structural pattern of the Sanerutian granitic veining in the 2nd period dykes.

The Sanerutian deformation is most intense in the N and NW of the area and corresponds closely to the higher degree of reactivation there than elsewhere in the area. In the central part of the area, Ilordleq proper, there is little evidence of Sanerutian deformation except for some NE striking mylonite bands, but in the SE a brittle shearing has taken place along closely spaced shear planes giving rise to a new shear-foliation in the granitic rocks and to shear folding of 2nd period dykes, but of a less plastic type than is found in the N of the area. The NE striking shear foliation dips steeply to the SE and is frequently accentuated by flat lenses of quartz which lie parallel to it. No field evidence is available to show whether the brittle deformation which took place in the central and SE parts of the area was contemporaneous with the more intense deformation in the north or whether it represents a widespread early Sanerutian brittle deformation. Petrographic evidence however suggests that the differences described represent a variation in space rather than in space and time: there is no evidence of a 'frontal' migration of the plutonic activity.

The final phase of the Sanerutian deformation throughout the area consisted of the development of a conjugate set of almost vertical fractures striking NNW and ENE, the former being more strongly developed, and along many of which there was a relative horizontal movement. The 3rd period dykes were emplaced along the fractures of this conjugate system while the movement was still taking place, resulting in the 'differentiation by deformation' shown by many of these dykes.

Metamorphism.

The mineralogical constitution of the metamorphosed supracrustal and basic intrusive rocks throughout the area corresponds to that of the epidote-amphibolite facies. The variation in intensity of the plutonic processes operating during the Sanerutian thus finds no parallel in mineral facies variation. The mineral assemblages produced by the Ketilidian metamorphism can be inferred only from indirect evidence. The total absence of relict metamorphic minerals and textures suggests that mineralogically the Ketilidian metamorphism was similar to that of the Sanerutian and this is confirmed by the development of epidote nodules during the Ketilidian.

Evidence of a slight retrogressive metamorphism is provided by thin sections of rocks from all parts of the area which show the development of chlorite and epidote from biotite and iron-ore, and the alteration of felspar, concentrated along narrow bands parallel to the foliation in the host rock.

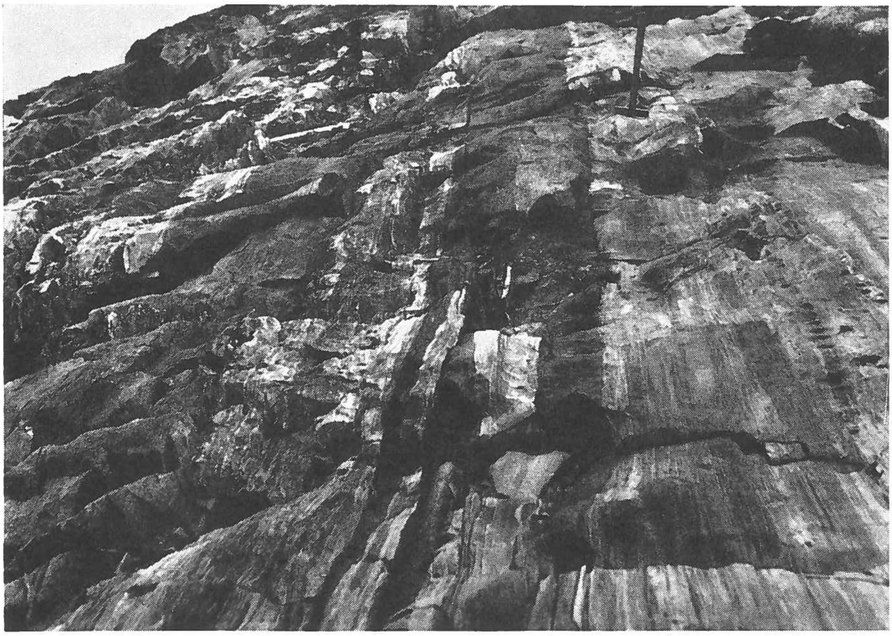

Fig. 10. Banded epidote-rich rocks of pyroclastic origin, with impersistent sills (dark) of 1st period dyke age. Island at western end of Nivâq.

Section II
CHRONOLOGICAL DESCRIPTION OF THE AREA

In this section the various events which have taken place in the area are described, in so far as it is known in the order in which they occurred, together with the field evidence by which their relative order has been established. An attempt to satisfy the sometimes conflicting requirements of objectivity and clarity has led to some repetition of the previous section.

Ketilidian Period.

The formation of the supracrustal rocks, defined by Wegmann (1938) as the beginning of the Ketilidian, has been referred to in the previous section, together with the clear evidence regarding the age of these relative to the granitic rocks. Apart from granitic agglomerate pebbles, no trace of the pre-Ketilidian basement is found in the area.

Fig. 11. Migmatised 1st period dyke (above) cutting finely banded semi-pelitic sediments. Concentration of neosomatic material in dyke is due to inhomogeneous deformation of discordant dyke rock, in contrast to homogeneous deformation of metasediments. Nearby 2nd period dykes (see fig. 9) are unmigmatised. S.E. coast of Nivâq.

1st Period Discordant Amphibolites.

The 1A and 1B dykes will be described together as they can be distinguished in the field in only very few instances. These dykes are found only within the supracrustal series, and in areas with granitic veining are cut by veins (fig. 11, 12, 13). Even in those places where the granite veins may be interpreted as having been formed by replacement, the veins continue without interruption across the dykes which in no case appear more resistant to replacement than the surrounding supracrustal rocks. Indeed many examples have been seen in which the dykes are more intensely veined than the country rock, as in that shown in fig. 11. The dyke shown in the upper part of the figure is ca. 1.5 m wide and medium grained, and is found cutting only slightly migmatised banded metasediments: in contrast to the metasediments the dyke is intensely agmatised. This may be interpreted as being due to the finely laminated sediments deforming in a more regular manner than the cross-cutting massive dyke, and consequently being less easily

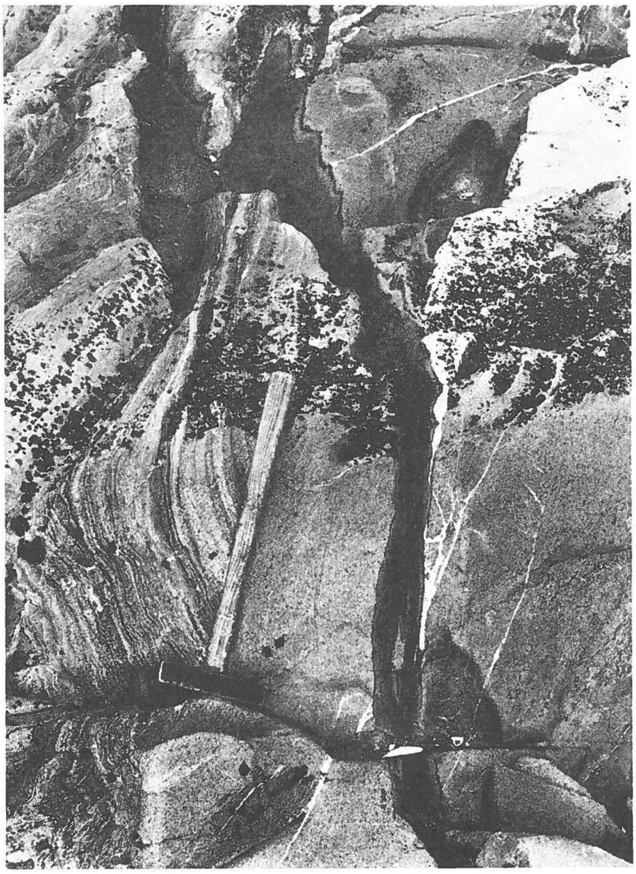

Fig. 12. 1st period dyke (right) in metasediments (left), cut by veins of Ketilidian age which are in turn cut by 3rd period dyke (dark). Movement along contact between metasediments and 1st period dyke (along hammer handle) has folded 3rd period dyke. S.E. coast of Nivâq.

penetrated by the migrating material. The possibility that the neosome veins in the dyke were derived by metamorphic differentiation of the dyke material cannot be excluded, and is considered with reference to this and other occurrences in Part IV.

The fact that the pre-granite dykes do not behave as resisters is emphasised in view of its bearing on the origin of dyke remnants in the Sanerutian granites.

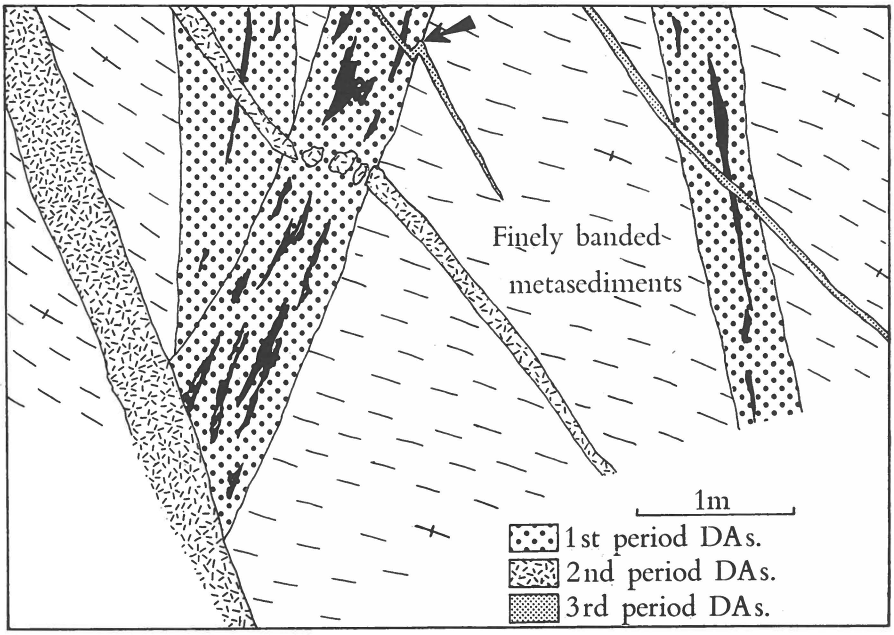

Fig. 13. Migmatised 1st period dykes cutting Ketilidian supracrustal rocks. Neosome is earlier than 2nd and 3rd period dykes. Narrow 2nd period dykes broken up by movement within large 1st period dyke (same as in fig. 11). Arrow indicates 3rd period dyke shown in figure 12. S.E. coast of Nivâq.

The 1st period dykes are from 25 cm up to 5 m in width and include a variety of rock types which probably represent different dyke generations. The number of intersections found is not sufficient to establish the relative order of emplacement of the various generations of pre-granite dykes, and the present irregularity of the dykes prevents recognition of dyke generations based on differences in strike direction. The best preserved 1st period dykes are those emplaced as sills parallel to the bedding planes of the metasediments and now forming 25 cm–1 m bands of amphibolite, which can be identified as intrusive only in those places where they are locally discordant, or interdigitate with the metasediments as shown in fig. 10. 1st period dykes emplaced as dykes intersecting bedding planes at high angles are often hardly recognisable as such, due to intense shearing movements parallel to the bedding planes. A further difficulty is that 1A dykes, emplaced vertically in flat-lying and unmetamorphosed sediments, are now in many cases almost horizontal and this coupled with the mainly horizontal exposure surfaces, makes outcrop patterns of these dykes difficult to interpret. It is clear that vertical dykes emplaced in an unfolded supracrustal series have little chance of remaining vertical during subsequent large scale folding of the supracrustal rocks; the relevance of this point to the interpretation of relic dykes in granitic rocks is referred to on a later page. The 1A and 1B dykes cannot be distinguished on the degree of deformation as this depends to a large extent on the attitude of the dyke relative to the direction of bedding and foliation in the enclosing rock: of two dykes occurring at the same locality the later one may be more strongly deformed if it cuts the bedding at a greater angle than does the earlier dyke. The 1B dykes can therefore only be distinguished from the 1A dykes where the former are seen cutting structures produced during the first phase of Ketilidian deformation; two criteria must thus be satisfied before a 1B dyke can be recognised as such—it must cut the structures referred to above and must itself be cut by veins of Ketilidian granite. These conditions are met with only at the locality illustrated in fig. 13. The sketch shows two dykes emplaced in finely banded metasediments of semipelitic composition which at this locality form a gently curving arch: granite veins cut straight across this structure which can thus be identified as being of pre-granite age. The two dykes also cut straight across the structure and are themselves cut by granitic veins. The 2nd and 3rd period dykes shown in fig. 13 are referred to elsewhere.

The ages of 1st period dykes relative to the formation of certain epidote rich zones in the supracrustal rocks could possibly be used to distinguish 1A and 1B dykes. One example has been seen in which a diffuse epidote rich patch, some few metres in extent, continued without interruption through one 1st period dyke but was cut by another 1st period dyke.

The distinction between 1A and 1B DAs of Ilordleq is of little practical value at present but may possibly be of use in the future when correlation can be made with areas in which the differences are more clear, and thus assist in the more exact chronological positioning of the Ketilidian granite relative to, for example, the gneisses of the Ivigtut area.

Metagabbros.

The five areas of metagabbro shown on the map (Plate IX) are probably the remnants of coarse grained basic intrusions, which because of their massive nature resisted the granitisation which gave rise to the Ketilidian granites. The original textures are in many places well preserved and the rocks are in general unfoliated; relict igneous banding was seen in the metagabbro on the island between Avssãnguit and Ikerasârqap nunâ. The original contacts of these basic masses have not been seen; they are undoubtedly earlier than the Ketilidian granites, being cut by veins which differ from the granitic veins in the supra-crustal rocks in being irregular in form and frequently forming agmatites. The amount of veining in the metagabbros is relatively small and in addition, the veins are of a more leucocratic nature than the surrounding granite.

A clue as to the cause of the resistance of these bodies to the granitisation is found by examination of thin sections, which show that microscopic veinlets of microcline are found only along micro shear fractures which disturb an otherwise well preserved igneous texture. Thus the behaviour of these bodies as 'resisters' can be ascribed to their original form and texture and consequent resistance to deformation, rather than to their chemical composition.

As the age of the metagabbros relative to the 1st period dykes is uncertain, their exact chronological position remains in doubt.

Ketilidian Plutonic Period.

The intrusion of the 1st period dykes was followed by a period characterised by intense deformation and metamorphism together with the mise-en-place of large amounts of granite. The granite occupied not only those areas now occupied by Ketilidian granite but also those now occupied by Sanerutian granite (Plate IX).

Description of the Ketilidian deformation and metamorphism is somewhat complicated by the difficulties of distinguishing between the effects of these events and the effects of similar events which took place in the Sanerutian period. The fixed point in the chronology at this stage may be taken as the formation of the Ketilidian granite; as the 2nd period dykes can be shown to be later than the Ketilidian granite but earlier than the Sanerutian, these too can be used for the recognition of Ketilidian effects. Accordingly the following scheme seems best suited to the investigation and description of the events which took place during the Ketilidian plutonic period.

(1) Determination and description of those areas of granitic rock which may be classed as Ketilidian. The 2nd period dykes are very useful for this purpose; in those areas where 2nd period dykes are undeformed and unmigmatised, the effects of the Sanerutian may be assumed to have been no more than slight and the granite therefore classed as Ketilidian.

(2) Recognition and description of structural features which are either earlier than or contemporaneous with the Ketilidian granite, or which are earlier than 2nd period dykes.

(3) Recognition and description of metamorphic features which can be shown to be (a) earlier than or contemporaneous with the Ketilidian granite, (b) earlier than 2nd period dykes, or (c) earlier than or contemporaneous with the Ketilidian deformation.

The Ketilidian Granite.

Most information regarding the relations of the granite with other rocks has been obtained on the well exposed coastlines on either side of Nivâq where the occurrence of both supracrustal and granitic rocks, together with dykes from each period, afford ideal conditions for establishing relative ages.

The granitic rocks along these coastlines, although varying somewhat in detail, have so many features in common that they may reasonably be regarded as one unit and of the same age. These features include both relationships with other rocks and petrological characteristics.

In the supracrustal series the granitic veins are almost always conformable with the steeply dipping bedding and foliation planes, and vary from a few cm up to several metres in width. Macroscopic evidence of felspathisation of the country rocks adjacent to granite veins is found in only a few places, but examination of thin-sections has shown that felspathisation is rather widespread and intense in some places. The granitic veins in general exhibit features very similar to those of the main granite mass and are indubitably of the same age. The principal features are a medium to coarse grain-size, quartz visible only in thin-section, and 5–15 $^0/_0$ of biotite occurring in aggregates of crystals which are very much smaller in size than those of the felspar. Large crystals of felspar may either occur as porphyroblasts in a groundmass of finer-grained felspar, or may so predominate as to form a coarse grained rock, such as that shown in Plate I (a). A description of the microscopic features of this rock is given on page 105.

The Ketilidian granite veins along the SE coast of Nivâq, although usually with a strong foliation as a result of the elongation and alignment of the biotite aggregates, show no sign of cataclasis. As the granite in this area has certainly not been completely recrystallised since its formation (specimen 31534, page 105), the absence of cataclasis suggests that the foliation in the veins dates from the time of emplacement of the veins, although it may have been intensified by the partial recrystallisation which took place during the Sanerutian.

The strike of the veins is parallel to the foliation within them, which is in turn parallel to both foliation and bedding of the adjacent supracrustal rocks; the parallelism of veins and both foliations is, however, maintained within the unbedded porphyritic metavolcanics and so is not due to bedding-plane control of any of these structures. Small amounts of a leucocratic granite are found as discordant veins from 1–5 cm in width cutting the more common granite type with sharp contacts. The foliation continues without interruption across the boundary between the two granite types. These features suggest that the granite foliation is not a structure inherited from the foliated supracrustal rocks but a structure produced in response to the same forces which produced the foliation in the supracrustal rocks, and is an indication of the synkinematic nature of the granites. The concordance of foliation in the granites and in their country rocks clearly does not constitute evidence for the granite foliation being an inherited structure, or for the replacive origin of the granite.

Aplite veins commonly occur in the granites in the Nivâq area and, as they are cut by 2nd period dykes, are of Ketilidian age. Most of the aplites, forming veins 5–25 cm in width, are parallel with the host rock foliation and are unfolded. Others, however, lie at an angle to the host rock foliation and are then usually folded, the axial planes of the folds being parallel to the foliation. As will be emphasised elsewhere, the foliation is a first order structure produced in direct response to the deforming forces.

Ketilidian Structures.

a) in the supracrustal rocks:

The structures may be divided into the three following groups:–

1) Bedding and foliation
2) Minor folds
3) Linear structures.

1) The coincidence of bedding and foliation has already been referred to in addition to the evidence against the foliation being an inherited or palimpsest structure, further evidence for which is found in the minor folds described below.

2) Minor folds: as mentioned previously these are uncommon except in the calcareous rocks which are intensely folded. A few of the folds which have some relevance with regard to the chronology are described below.

Figure 14 shows a part of the limb of a minor fold in finely banded pyroclastic rocks occurring on the SW extremity of Ikerasârqap nunâ, the exposed surface being normal to the fold axis which plunges at a low angle to the SW. The foliation is everywhere parallel to the granite veins which maintain a constant attitude. In that part of the fold shown in fig. 14 the plane of flattening of the agglomerate pebbles, with only rare exceptions, is parallel to the foliation and to granite veins which are parallel to the axial plane of the fold. On the turnover of the fold (not shown) flattening of the pebbles appears to be parallel to the bedding although the foliation and granite veins maintain their alignment parallel to the axial plane. Although no certain interpretation of these relationships is justified without further evidence, it appears that the folding

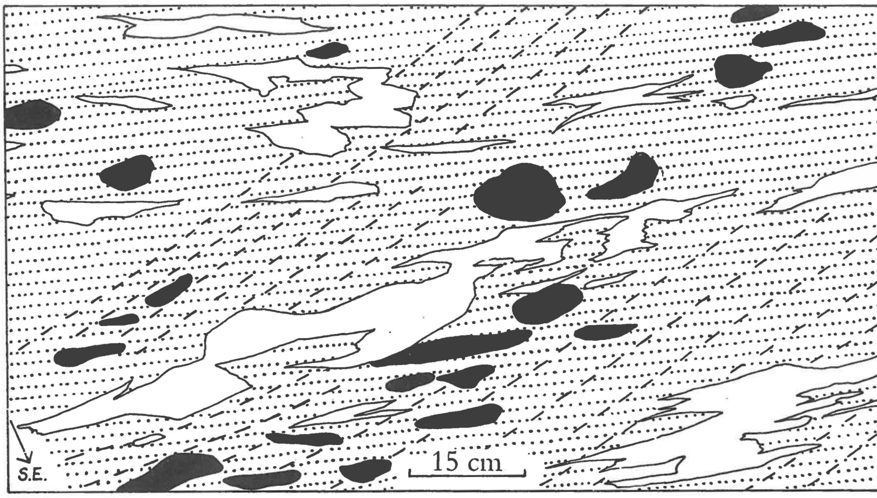

Fig. 14. Deformed agglomerate fragments (black) in folded finely banded pyroclastics. Shows a:c section with foliation (dotted) diverging from bedding (broken lines) near turnover of small fold. Symmetry of agglomerate fragments and granite veins (plain) described in text. Peninsular at S.W. corner of Ikerasârqap nunâ.

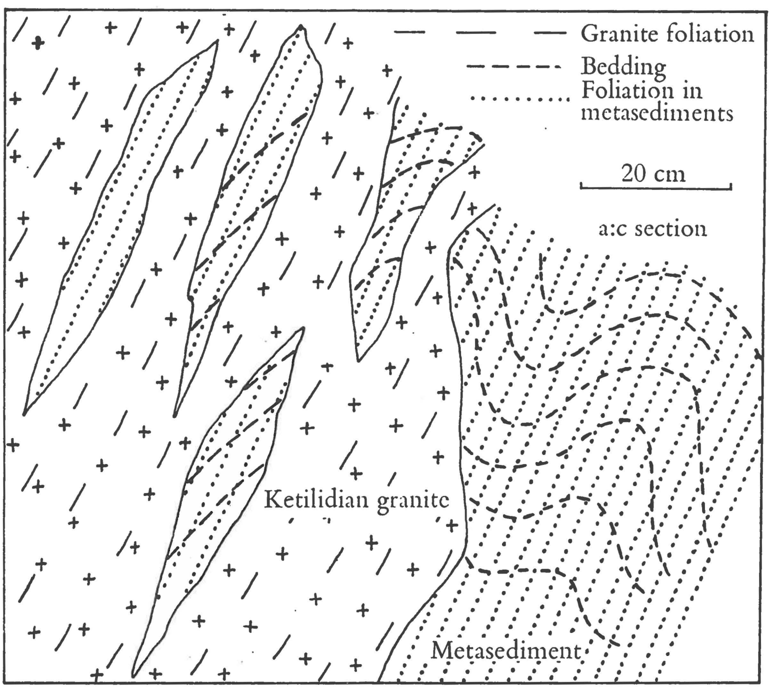

Fig. 15. Fold in banded supracrustal rocks on S.W. border of Ketilidian granite of Ikerasârqap nunâ. Foliation (dotted) and bedding (broken lines) diverge; apparently unmoved enclaves of supracrustal rock in granite (crosses) represent a further stage in formation of granite than that shown in fig. 14. S.E. coast of Ikerasârqap nunâ.

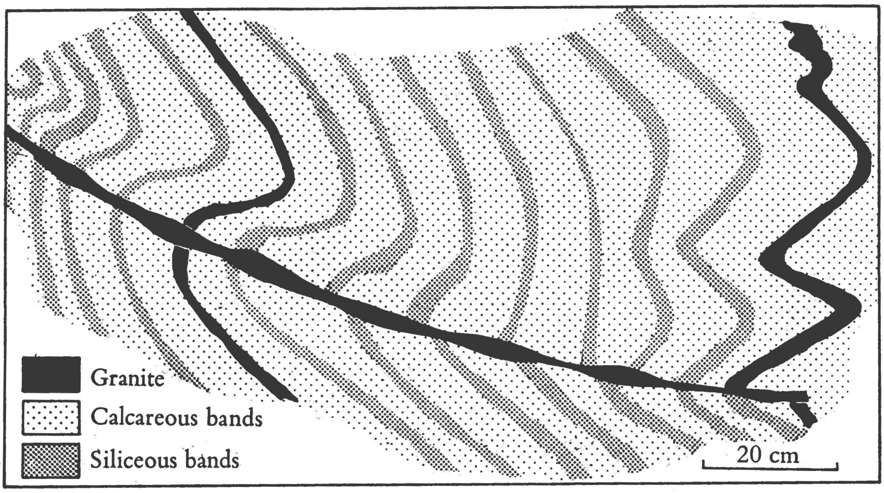

Fig. 16. Interbedded siliceous (heavily dotted) and calcareous (lightly dotted) bands in the calcareous horizon on island between Sioragdlit and Sãtukujôq, showing age of granite veining (black) relative to deformation (see text).

and some flattening of the pebbles took place before the formation of the foliation and emplacement of the granite veins. Whether this is correct or not, it is quite clear that the foliation is quite independent of the bedding plane and that the granite veins, which have their greatest length in the direction of the fold axis, were emplaced under the influence of the same forces which produced the folding, pebble deformation, and foliation.

A further example of a minor fold with axial plane foliation, which is shown in figure 15, is from a contact between granite and metasediment in the SW of Ikerasârqap nunâ. In this case the alignment of the granite, and the foliation within it, are parallel to the foliation of the country rock which in turn is parallel to the axial plane of the minor fold. The enclaves of country rock remaining in the granite are typical of those found throughout the Ketilidian granites and it is apparent that their shapes and orientation are a direct reflection of the forces which were maintained during the Ketilidian deformation. A replacive origin for the granite shown in figure 15 would best account for the apparently undisturbed enclaves and for their regular shapes, and thus the granite at this locality may reasonably be considered to have been formed by kinematically controlled replacement.

A further illustration of the relationship between deformation and granite emplacement is given in figure 16. The country rock in this case consists of alternating laminae of calcareous and siliceous metasediment and has been strongly folded, but is unfoliated; the folding continued

Fig. 17. Asymmetric folding of interbedded siliceous and calcareous (deeply eroded) bands. Incipient cleavage in siliceous bands is parallel to regional foliation, and pencil structure of same bands is parallel to fold axes and to regional lineation. Island between Sioragdlit and Sãtukujôq.

over a longer period in these rocks than elsewhere and it is probable that some folding also took place during the Sanerutian. In the fold shown in figure 16 a granitic vein has been emplaced parallel to the axial plane of the fold, a situation similar to that already described from figures 14 and 15. In this case, however, an earlier granite vein emplaced parallel to the bedding has been folded together with the bedding, a clear indication that the period during which the granite veins were emplaced overlapped with the period of active deformation, and that the parallelism of granitic veining and country rock foliation which is usually found elsewhere, is not the result of static control of the former by the latter. The two features, foliation and alignment of granite veins, are independent products of the same stress system.

3) Linear structures: the principal linear structure which is found throughout the area of supracrustal rocks, except for certain parts of the calcareous series, is the orientation of the long axes of amphibole

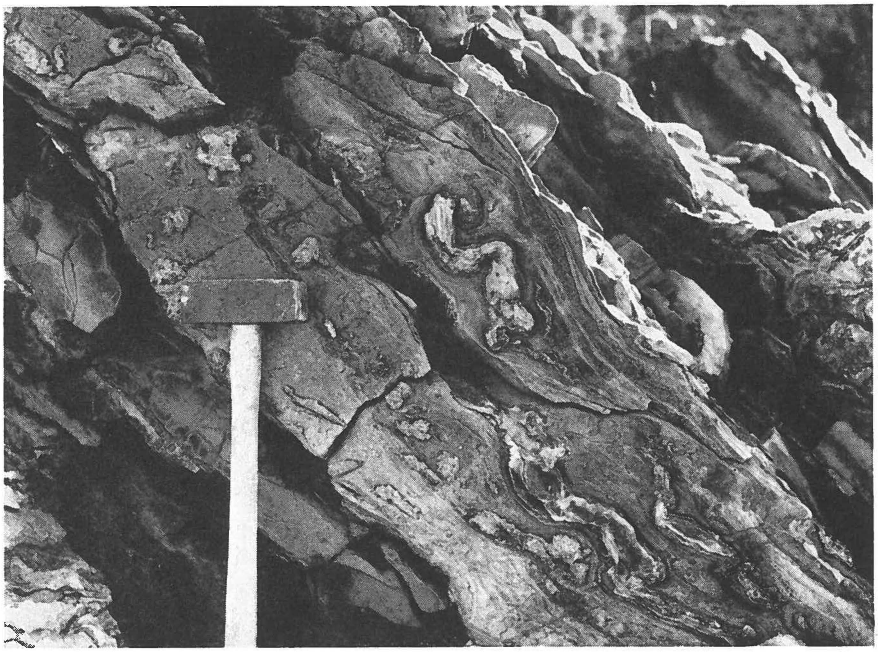

Fig. 18. Fragmented siliceous bands in calcareous horizon. Siliceous remnants are strongly rodded parallel to fold axes which have constant direction. Axial planes are rotated about axial direction as a result of "progressive" deformation. Island between Sioragdlit and Sâtukujôq.

crystals which invariably lie within the foliation. This lineation is easily measured on foliation surfaces in rocks of suitable mineral composition and grain size, and even in rocks too fine grained for the orientation of individual mineral grains to be seen, is evident as distinct lines and in micaceous rocks as a slight corrugation. The lineation is not often visible in the fine grained metavolcanics but in the porphyritic metabasalts is occasionally seen as a stretching of the blastoporphyritic felspars. The longest axes of deformed agglomerate pebbles are parallel to the mineral lineation in surrounding rocks and, as mentioned in reference to figure 14, parallel to the axes of minor folds of Ketilidian age. In the minor folds the intersection of foliation and bedding gives rise to a linear structure parallel to those described above and parallel to the fold axes. In the calcareous rocks (fig. 17) foliation is uncommon, but in the laminated types the corrugation of the siliceous bands has given rise to an intense rodding or 'pencil' lineation parallel to the fold axes. Isolated siliceous bands enclosed in calcareous horizons are completely disrupted and form rods parallel to fold axes (see fig. 18).

The attitude of the lineations described varies within the belt of supracrustal rocks. In the NE part of the supracrustal belt lineations and minor fold axes plunge to NE, the plunge becoming less steep and eventually horizontal with progress toward the SW, and at the SW end of the supracrustal belt these structures plunge 15° SW. This variation is probably best accounted for by later flexuring rather than by original differences in the attitude of the structures. Evidence will be given in a later section which shows that it is probable that the Ketilidian structures have been intensified by the Sanerutian deformation.

An apparently anomalous lineation direction is found within the flexure mentioned in reference to figure 13; on the evidence of the 1B dykes this flexure was formed earlier than the main Ketilidian deformation phase. The lineation in this case is formed by the intersection of bedding and foliation and plunges steeply to the S. The foliation in the rock conforms to the regional pattern, as does the elongation of small pebbles which it contains and the amphibole lineation on foliation surfaces. The direction of the intersection lineation here is apparently due to the anomalous attitude of the bedding here with respect to that elsewhere in the area at the beginning of the main Ketilidian deformation phase, due to earlier flexuring. As this steeply dipping intersection lineation is not found elsewhere, it may be assumed that the pre-1B dyke flexuring was of little significance in this area.

b) Structures in the Ketilidian granitic rocks.

Evidences of Ketilidian deformation within the granitic rocks of this age are similar to those found in the supracrustal rocks and there is complete structural conformity between the two. The foliation in the granitic rocks has been referred to previously together with the evidence for it being an original feature of the rock; it is everywhere conformable with that of the nearby supracrustal rocks. A linear structure is also found within the foliated granitic rocks and can be seen on foliation surfaces as elongate mafic aggregates which are flattened within the plane of foliation; the lineation too is everywhere conformable with that in that nearby supracrustal rocks.

Enclaves of the supracrustal rocks found within the granites are similar in shape to the deformed agglomerate pebbles found within the pyroclastic rocks. The long and intermediate axes (b and c axes) lie within the plane of foliation with the b axis parallel to the lineation. When bedding can be seen in the enclaves it lies within the plane containing the b and c axes of the enclaves. The strict conformity between structures in the granitic rocks and those in the supracrustal rocks, together with the evidence concerning the age relationships of the granites and the structures they contain, may be regarded as evidence, albeit inconclusive, for the replacement origin of these rocks.

Kuanitic Period.

By analogy with the Ivigtut area (Berthelsen 1961, see page 131) the period during which the 2nd period dykes were emplaced is at present referred to as the Kuanitic. In Section V it is suggested that the term Kuanitic is unsuitable in this context, but it is retained in this account because no suitable alternative has yet been agreed upon

In contrast to the conditions prevailing during the plutonic phase of the Ketilidian, conditions during the Kuanitic were such as to allow the intrusion of normal basaltic dykes into probably tensional fissures in the cool country rock. The original features can be recognised with some certainty in those dykes found in the Ketilidian granites which have not been strongly sheared. The fissures into which the dykes were emplaced were of a regular nature and the dyke margins are sharp and straight (fig. 9). In some cases it can be established that the fine grained borders of the dykes are due to chilling against the country rock (see page 24); this in itself does not constitute evidence that the country rocks were cool at the time of intrusion of the dykes (see page 126). The 2nd period dykes are distributed fairly evenly throughout the whole area and, unlike the 3rd period dykes, are not noticeably concentrated in swarms. The dykes are in most cases vertical although a few occur as almost horizontal sheets. As most of the dykes have been seen on coastal exposure and not traced inland it is not known how persistent they are, but one 4 m dyke has been followed for over 1 km within the Ketilidian granite and several others for distances of 50–300 m. Not all the 2nd period dykes belong to the same generation but insufficient intersections have been found to enable them to be divided into distinct generations based on strike directions. Dykes with a NE strike are the most common, however, and figure 19 shows the strike distribution of 50 2nd period dykes. The diagram has been compiled from strike readings of dykes which have not been folded subsequent to their intrusion and includes only those dykes identified with certainty as belonging to the 2nd period; this was possible only during the later stages of the field work when the chronology as presented in this account had been established. During the field work over 350 discordant amphibolites were recorded, probably over half of which were 2nd period dykes. The strike distribution diagram shows that the majority of the 2nd period dykes have a strike almost parallel to that of the foliation produced during the Sanerutian period, i.e. the dykes are normal to the axis of maximum Sanerutian compressive stress; this point is of some significance when the effects of Sanerutian deformation are considered.

Petrologically the 2nd period dykes can be divided into two distinct groups, the one group being distinguished by a grey colour on weathered surfaces and the other by less common dykes which have a green colour. The green type are formed from dykes of a more basic composition. In those parts of the area where the effects of the Sanerutian deformation have been comparatively slight, the differences between the two types is not very great. With increasing deformation the differences become more marked due to the very different behaviour of the two types when subjected to stress. The less competent grey type deformed by shear

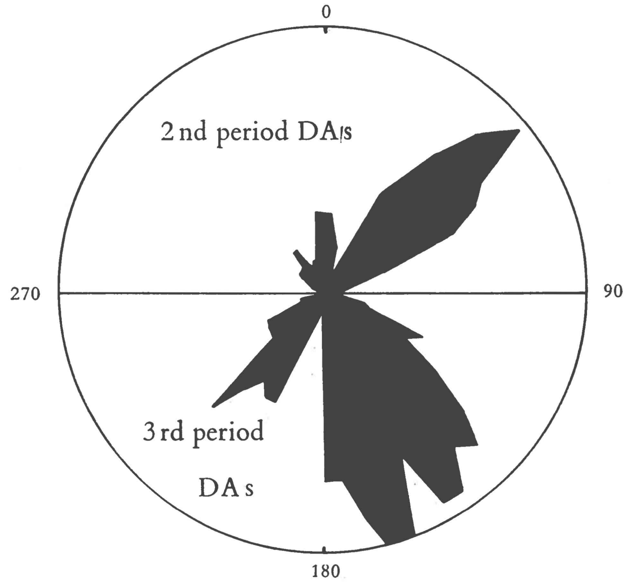

Fig. 19. Diagram showing preferred strike directions of 50 2nd period dykes and 70 3rd period dykes in least deformed parts of the area. Note commonest direction of 2nd period dykes (NE-SW) is parallel to strike of regional foliation.

along closely spaced foliation planes while the competent green type deformed by fracture in the dykes, into which the felspar of the dyke material migrated. The remaining dyke material thus becomes even more basic than before, giving rise to dykes consisting only of bright green amphibole cut by veins of felspar or scapolite. The different effects of deformation and migmatisation on the two types of 2nd period dykes are described in detail on pages 67–70 and the microscopic evidence for the progressive metamorphic differentiation of the green dykes is given in Part IV of this series.

The grey type of 2nd period dykes generally have even textures but a few dykes have evenly distributed small blastoporphyritic felspars up to 5 mm in size while others have large irregularly distributed blastoporphyritic felspars up to 5 cm in size. Relict doleritic textures can be seen in thin sections of the better preserved grey 2nd period dykes.

Sanerutian Period.

The intrusion of 2nd period dykes of the Kuanitic period was followed by a return to plutonic conditions, resulting in further metamorphism and deformation of the Ketilidian rocks and local reactivation of the granites, together with the metamorphism, deformation and in some places migmatisation of the 2nd period dykes. The nature of this further period of plutonic activity is well demonstrated in Ilordleq because of the wide variation in the plutonic effects within the area. The similarity between the Ketilidian and Sanerutian stress patterns makes distinction between the effects of these two periods difficult in many cases.

For the purposes of description it will be convenient to divide the whole area into five sub-areas, within each of which the Sanerutian effects were of similar intensity and type.

1. The main area of Ketilidian granite occupying almost the whole of the area of Ilordleq s.s., the *central* sub-area.

2. The *Qeqertaussaq* peninsula together with the extreme SE part of Ilordleq s.s.

3. The area around *Nivâq* consisting of the Ketilidian granite on the SE shores of the islands Ikerasârqap nunâ and Sãtukujôq, the supracrustal rocks and a small area of Ketilidian granite on Itivdliatsiaup kangia.

4. The peninsula on the SE side of *Natsît iluat* together with the NE and NW coasts of this inlet.

5. The area of Sanerutian Hornblende Granite on the islands Ikerasârqap nunâ, Sãtukujôq and Sioragdlit, make up the *Sánerutip imâ* sub-area.

Central sub-area.

The only Sanerutian effects which can be detected here by field observations are the formation of NE striking mylonite zones and the metamorphism, foliation and local shearing of the 2nd period dykes. Under the microscope, partial recrystallisation of the granitic rocks outside the mylonite zones can be detected, but the Sanerutian age of this recrystallisation cannot be proved.

Mylonites: these mostly occur as narrow shear zones about 1–5 m in width which have not been followed for more than a few metres along their strike. They are concentrated in the northern part of the central sub-area where are also found some broader mylonites, one of which is 100 m wide and has been followed for 2 km. A narrow mylonite about

10 m broad, occurs on the coast a little to the south of Itivdliatsiaup kangia; a 2nd period dyke within this mylonite is sheared and disrupted and this, together with similar less well exposed occurrences inland, establishes the age of the mylonites as being post-Kuanitic. The upper age limit of the mylonites is established by the occurrence of 3rd period dykes cutting them without being disrupted and the mylonites must therefore have been formed within the earlier part of the Sanerutian. It is possible that of the numerous mylonites for which there is no definite evidence to establish the relative age, some may have been formed in either late Ketilidian or post-Sanerutian time.

The mylonite zones strike parallel to the usually indistinct foliation in the surrounding granite, 050°–060°, and are themselves very strongly foliated parallel to the margins (and have an intense sub-horizontal elongation lineation). They are fine grained and have a somewhat darker appearance than the coarser grained country rock from which they have been formed; many have a laminated structure with alternating folia of quartz and felspar up to 3 mm in width. It is apparent from the textures and mineral assemblages of the mylonites that the deformation by which they were formed took place at elevated temperatures and while the surrounding rocks were undergoing regional metamorphism. The mylonitisation may therefore be regarded as taking place in the central sub-area more or less contemporaneously with processes of a more obviously plutonic nature in the Nivâq and Sánerutip imâ sub-areas.

Metamorphism and foliation of 2nd period dykes: in the central sub-area the amphibolitised dykes although undeformed are invariably foliated, but owing to their usually fine grained nature this foliation is often indistinct or invisible in the field. The foliation, although constant within any one dyke, varies from one dyke to another; in some dykes it is parallel to that in the country rock, while in others it is parallel to the margins of the dyke. It appears that those dykes with a strike similar to that of the foliation in the country rock granite most often are foliated parallel to their margins, while those striking at a large angle to the granite foliation have a foliation parallel to that in the country rock. This is thought to be due to the stress operating in Sanerutian time normal to the Ketilidian foliation of the granitic rocks, being accomodated in different ways depending on the orientation of the dyke relative to the principal stresses. The behaviour of the dykes under these conditions is illustrated in figure 20. Where the angle between the strike of a vertical dyke and the nearly horizontal maximum principal stress axis is large, i.e. the dyke is nearly parallel to the minimum stress axis, fig. 20 A, B and C, the stress is accommodated by shearing along the dyke resulting in a foliation parallel to the dyke

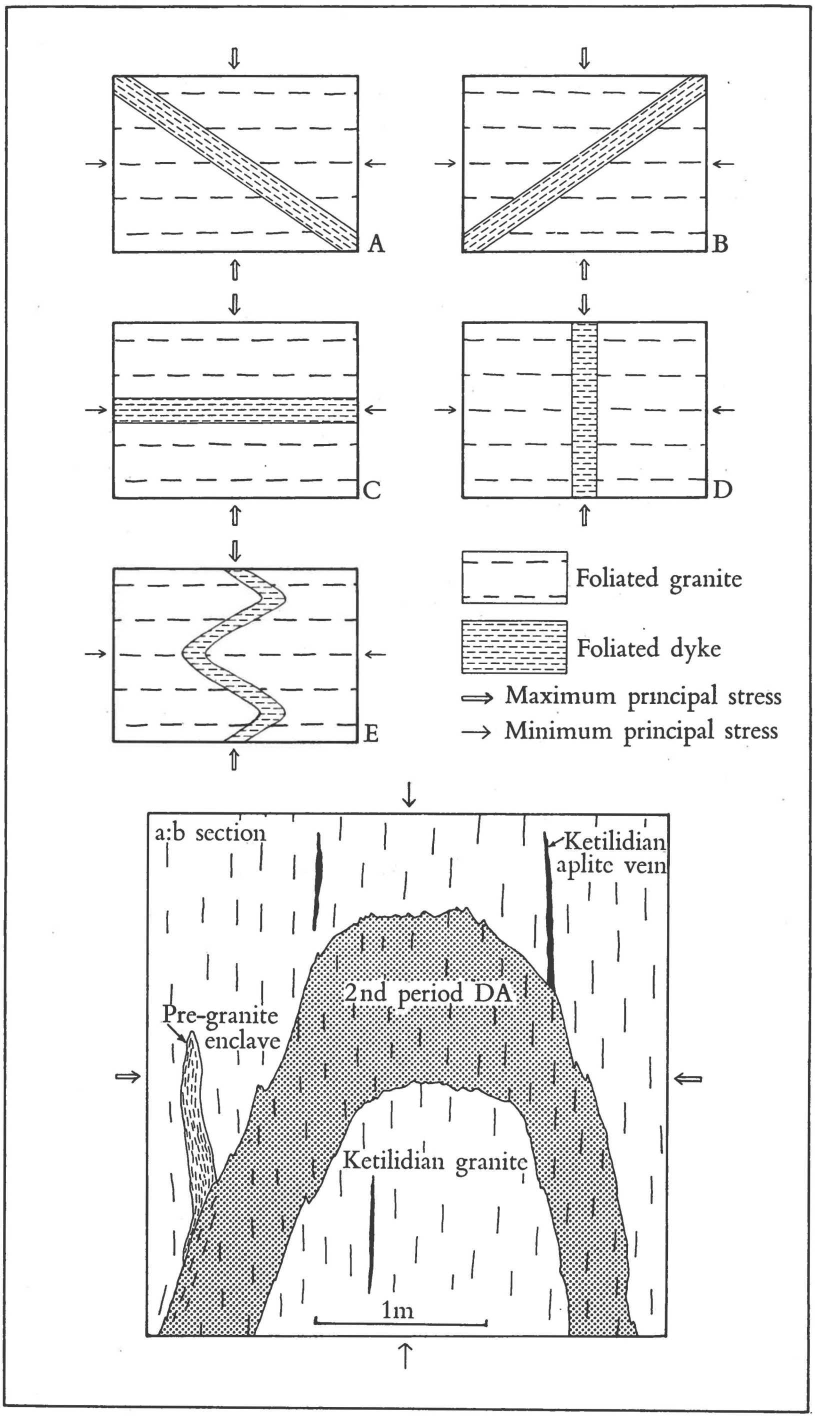

Fig. 20. A-E show orientation of superimposed Sanerutian foliation in Ketilidian granites in the central, Nivâq and Qeqertaussaq sub-areas; and direction of foliation in variously oriented 2nd period dykes relative to supposed principal stress directions. Large sketch shows field example of E (see also figs. 19 and 22).

Fig. 21. Folded 2nd period dyke in Ketilidian granite (see figs. 20 and 23). Foliation in dyke and granite is parallel to hammer handle. Note shearing of enclave parallel to dyke margin, lower left. Western peninsular of Itivdliatsiaup kangia.

margins. In the case of a dyke lying nearly parallel to the maximum principal stress axis, figure 20 D, the potential shear movements cannot be accommodated by movement parallel to the dyke margins and the foliation in the dyke is parallel to that induced in the country rock. The coincidence of Ketilidian and Sanerutian foliation in the country rocks in this area makes it difficult to demonstrate the formation of a Sanerutian foliation in the granitic rocks of the Central sub-area.

Figure 20 E shows a further development of D, as found in dykes in the Nivâq sub-area (figures 21 and 23) where the higher degree of deformation has resulted in shear folding of dykes striking nearly parallel to the maximum principal stress axis. Figure 20 (bottom) is from a field sketch of a folded 2nd period dyke in the Nivâq sub-area (see page 50 and fig. 21). Dykes in the Nivâq sub-area striking at a large angle to maximum principal stress axes show similar features to similarly oriented dykes in the central sub-area.

Similar structural patterns to those described above have been described by ESKOLA (1914), MILLER (1945) and JONES (1959).

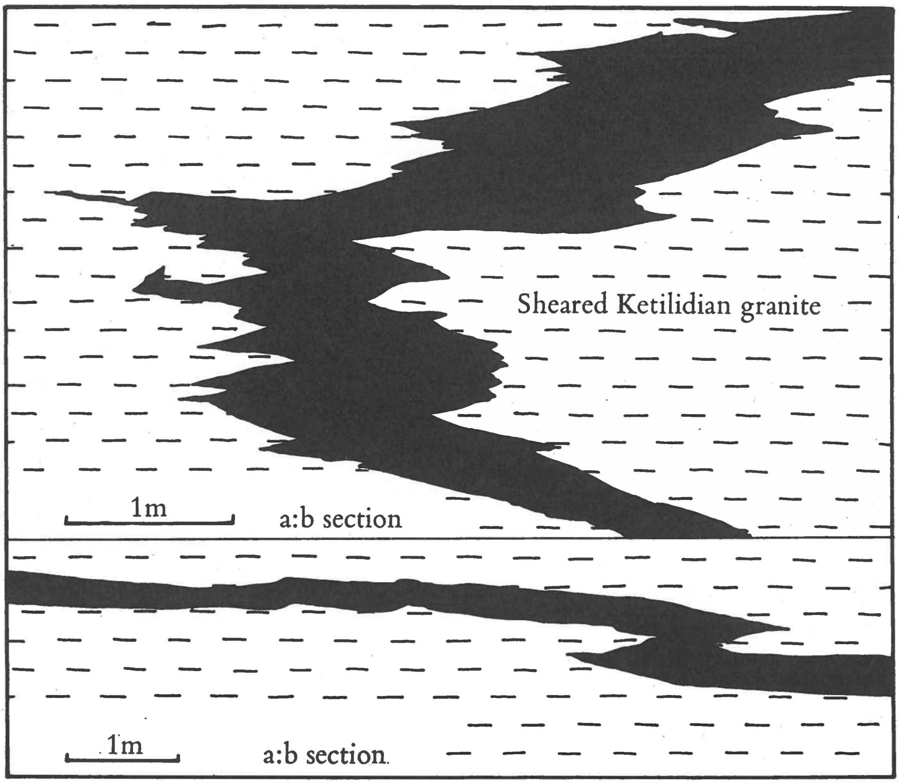

Fig. 22. Deformed 2nd period dykes in Ketilidian hornblende granite of Qeqertaussaq sub-area. Lower dyke emplaced almost parallel to direction of subsequent Sanerutian movement appears only slightly deformed in contrast to upper dyke which strikes almost at right angles to movement direction. Degree of internal deformation is, however, probably much the same in each case. N. coast of Tarajornitsoq.

Qeqertaussaq sub-area.

Sanerutian effects in this area are again rather slight but nevertheless distinct from those of the central sub-area. The effects which can be seen in the field are 1) imposition of shear foliation in the granitic rocks with migration and possible introduction of quartz, 2) amphibolitisation and foliation of 2nd period dykes, 3) formation of NE striking mylonitic shear zones in which 2nd period dykes are shear-folded.

1) The characteristic feature of the area is a strongly developed NE trending shear foliation, which is quite distinct from both Ketilidian and Sanerutian recrystallisation foliations found throughout the rest of the area. Although the shear foliation has been formed after the formation of the granites it is probably parallel to the original foliation of these rocks, as in a migmatitic part of the granite relict supracrustal

folds are found with axial planes parallel to the shear foliation. The shear foliation in the granite is emphasised by thin quartz folia, similar but not as intensely developed as those in the mylonites of the central sub area. 2nd period dykes are undoubtedly earlier than the imposition of the shear foliation as they themselves are strongly foliated and in places cleaved, with quartz veining parallel to the foliation in some cases.

The relationship between the mylonitic shear zones and the 2nd period dykes is shown in figure 22, which shows two dykes emplaced in the Ketilidian hornblende granite on the north coast of Tarajornitsoq. The dykes are about 10 m apart and both within mylonitic shear zones, which here form bands from a few cm up to several metres in width alternating with the un-mylonitised country rock granite. The original strike of the upper dyke (fig. 22) was nearly at right angles to the strike of the shear zones and the dyke has consequently been strongly folded. The original strike of the lower dyke was nearly parallel to that of the shear zones and this dyke is therefore less folded although subjected to exactly the same type and degree of stress as dyke A. The dykes have, however, both undergone a similar degree of *internal deformation*, as opposed to folding (compare for example, fig. 39). The relationship between these two dykes illustrates very well the importance of original orientations in the interpretation of folded structures in the area and also gives a useful indication of the stress field by which the structures were produced. Many structures similar to those shown by these dykes are found in the Nivâq and Sánerutip imâ sub-areas where the deformation is not localised within shear zones but distributed evenly throughout the granitic rock masses.

Nivâq sub-area.

In this area the effect of the Sanerutian deformation has been sufficiently intense to produce a variety of new structures and to intensify many of the Ketilidian structures. The deformation was accompanied by a limited amount of migration of granitic material. The structures most readily recognisable as being of Sanerutian age are those produced by the deformation of 2nd period dykes and immediately adjacent rocks, and these will accordingly be described first.

On the NW corner of Itivdliatsiaup kangia, within the main body of granite but close to its contact with the supracrustal rocks, is found the folded 2nd period dyke shown in figures 21 and 23, and also in figure 20. It is apparent that this dyke has been deformed by movement in the granite and within the dyke, along planes parallel to the foliation in the granite. The nature of the deformation is clearly shown by aplite veins within the granite and parallel to the foliation, which are cut by

Fig. 23. Detail of contact between 2nd period dyke shown in figs. 20 and 21, and surrounding Ketilidian granite. Foliation in both granite and dyke is parallel to hammer handle. Western peninsular of Itivdliatsiaup kangia.

the dyke (top right, figure 21), but are nevertheless unfolded. Supracrustal enclaves within the granite, which lie parallel to the granite foliation, are also unfolded. The direction of both the pre-dyke aplite veins and the enclaves shows that the Sanerutian foliation is parallel to the earlier Ketilidian foliation on which it has been superimposed. The effect of the Sanerutian deformation on the granite has clearly been an intensification of the Ketilidian structure but the foliation within the 2nd period dyke is due entirely to the Sanerutian deformation. An important and expected feature is that the axial plane of the dyke fold is parallel to the foliation in the enclosing granite; the axis of the fold lies within the foliation plane but its plunge is controlled by the original attitude of the dyke. The folding of discordant bodies and the attitude of the resulting structures is described in Part III. The stretching lineation found within the dyke is parallel to that in the granite and plunges at a shallow angle to the SW.

The enclave in the granite which is intersected by the dyke (left side of figure 21) is regular in appearance and parallel to the granite foliation, like other enclaves, except for the few cm closest to the dyke. Here, both the enclave and the granite foliation are swung round parallel to the dyke contact. The foliation in the marginal part of the dyke at this point is also swung round parallel to the contact, and it is apparent that there has been movement parallel to the granite-dyke contact at this point and not, as elsewhere, parallel to the granite foliation. At this point, the granite dyke contact most nearly approaches the direction of the granite foliation, thus allowing the stress to be accommodated by slip along the contact as shown in figure 20B. Where the granite-dyke contact makes a large angle with the granite foliation, the stress has been accomodated entirely by internal deformation within dyke and granite and the regularity of the foliation is undisturbed (see figure 20D). 2nd period dykes folded in a similar way are found on the south coast of Sãtukujôq and on the small island off the easternmost point of Sãtukujôq. No other folded 2nd period dykes are found within the granite of the Nivâq sub-areas as all other 2nd period dykes found are more or less parallel to the strike of the granite foliation, i.e. at 90° to the maximum principal stress axis.

Within the supracrustal rocks of the Nivâq sub-area the 2nd period dykes are found to be generally less deformed than the 1st period dykes, but where no granite veins are found the dykes of these two periods cannot be distinguished with any certainty. The deformation of the 2nd period dykes within the metasediments again is controlled to a large extent by their strike relative to the foliation of the country rock. Dykes which cut the foliation, and hence the bedding, at a high angle, instead of being folded like those in the granite are broken up by shears parallel to the bedding and foliation of the host. This difference may be attributed to the inhomogeneity of the metasediments when compared with the granites, which has resulted in concentration of movement along a few widely spaced shear planes in the former as opposed to the many closely spaced planes within the granite. Dykes emplaced parallel to the foliation and bedding of the metasediments show pinch and swell structure, with a distance of 2–4 m between crests of successive swells.

Development of Augen Granite in the Nivâq sub-area.

A gradual increase, from SW to NE, of the Sanerutian deformation within the Nivâq sub-area is shown in plate IX. The evidence for this is found in the progressive variation in the shape of the enclaves within the granitic rocks; it has been found that the deformation of the supracrustal enclaves is analogous to the deformation of conglomerate pebbles and allows similar conclusions to be drawn regarding relative intensity and orientation of the forces giving rise to the deformation.

The enclave cross-sections shown in figure 24 (left inset) are typical of those found within the Ketilidian granite throughout the central sub-area. Within the Nivâq sub-area, however, there is a gradual increase in the b:a and c:a axial ratios, as a consequence of the progressive

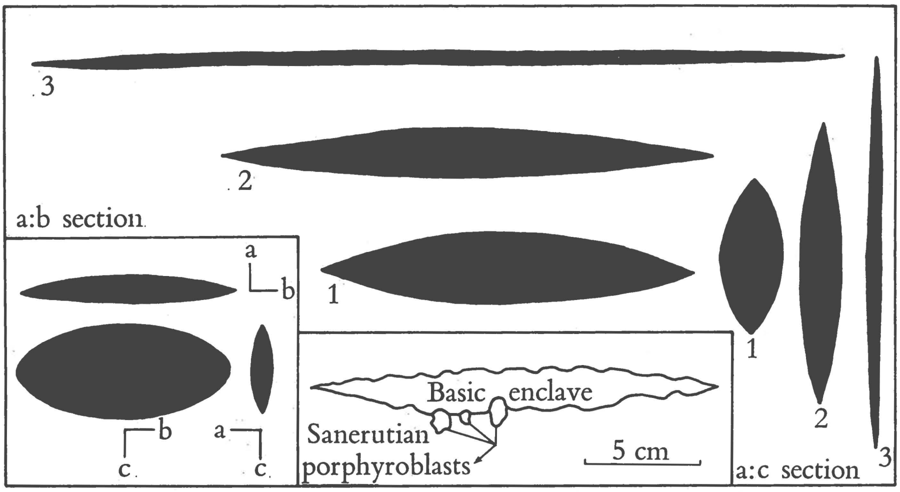

Fig. 24. Lower left inset: shows descriptive nomenclature of axes for triaxial enclaves, pebbles etc. Regional foliation lies in b:c plane and lineation is parallel to b. Central inset: felspar porphyroblasts growing along boundary of deformed enclave in augen granite—see text.

1, 2 and 3 show successive degrees of Sanerutian deformation of enclaves on N.W. coast of Nivâq. See text for explanation.

flattening of the enclaves due to a relative increase in deformation parallel to the axis of maximum principal stress which is normal to the granite foliation, i.e. parallel to the a axis of the enclaves. Figure 24, 1, 2 and 3 shows the effects of this progressive increase in deformation on the a:b and a:c sections of the enclaves at various localities (see Plate IX) on the NW coast of Nivâq. The enclave of locality 1 is of similar shape to the enclaves in the Ketilidian granite throughout the central sub-area, and may be taken as representing the original shape of all enclaves. The shape of enclaves to the NE of locality 3 is not indicated in fig. 24 because the deformation has been so extreme; a:b ratios at specimen locality E are of the order of 1:400.

It can be seen from figure 24 that there is little change in the b:c axial ratios of the enclaves with increasing Sanerutian deformation. This suggests that the Sanerutian deformation of the Ketilidian granite, at least in the Nivâq sub-area, was essentially a flattening, such as could be represented by an oblate strain ellipsoid; or in the terminology of Flinn (1962), homogeneous strain with deformation path $k = 0$. This contrasts with the deformation of the Hornblende Granite on Sãtukujôq in which an intense linear structure is developed and the deformation path approached $k = \infty$, i.e. a stretching which can be represented by a prolate strain ellipsoid. Both these cases differ from the Ketilidian deformation which, to judge from the shapes of agglomerate fragments, enclaves in granite and other lines of evidence, seems to have resulted in approach to deformation path k = 1, represented by a triaxial strain ellipsoid in which the length of the intermediate axis remains unchanged throughout the deformation. These differences will be considered in more detail in Part III.

With the progressive deformation of the enclaves there is a concomitant change in the enclosing granite, leading to the formation of an augen granite from the original even textured rock. The progressive change in the granitic rocks is illustrated in Plates I and II which show the successive stages in the development of the augen granite which is fully developed in the extreme NE part of the Nivâq sub-area. The time relations between deformation and growth of the felspar in these rocks show an interesting variation: in the early members of the series the felspar recrystallisation is dominantly synkinematic, but in the fully developed augen granite the more intense deformation resulted in an almost complete cataclasis of the rock before the post-kinematic porphyroblastic growth of felspar took place. A description of the changes taking place within these rocks is given in the petrographic section. The increase in deformation toward the NE is not completely regular and at all points on the NW coast of Nivâq, narrow concordant mylonite zones are found, usually only a few decimetres in width, in which the granitic rocks have been finely granulated to produce bands of fine-grained quartzo-felspathic rock with a strong superficial resemblance to remnant sedimentary horizons. Not all these mylonites are of Sanerutian age however, as intersections with 2nd period dykes show some of them to have been formed in the Ketilidian. That growth of the felspar augen took place after the formation of the mylonites, is shown at the numerous localities where undeformed porphyroblasts are found both within the mylonites and along their contacts with the surrounding granite. The post-kinematic nature of the augen is further shown by the relationship of undeformed augen to the deformed enclaves (fig. 24, inset). The non-cataclastic microscopic features of such porphyroblasts show that their growth along the margins of the enclave could have taken place only after deformation of the enclave had ceased.

An increase in the intensity of linear structures and boudinage within the supracrustal rocks with progress toward the NE part of the Nivâq sub-area, is probably equivalent to the increase in Sanerutian effects noted in the granitic rocks; however, critical evidence by which these features could be dated is lacking.

It can be seen from the descriptions given above, that movements due to the Sanerutian deformation in the Nivâq sub-area took place by translation of individual rock particles within the plane of the Sanerutian foliation, which is parallel to that of the earlier Ketilidian foliation.

Thus any pre-Sanerutian structures which were parallel to the Ketilidian foliation, remained unfolded during the Sanerutian deformation; these structures include bedding except in isolated cases, concordant granite veins in the supracrustal rocks, enclaves of supracrustal rock within the granite, concordant aplites in the granite, deformed agglomerate pebbles, and those 2nd period dykes emplaced parallel to the Ketilidian foliation. The folding of discordant structures has been illustrated by reference to one of the 2nd period dykes, but folds are also found where discordant granite, aplite and epidote veins occur, and in those places where the bedding direction deviates from the regional trend. The effects of the Sanerutian deformation on the calcareous rocks may be summarised as a tightening of Ketilidian folds, and in some cases refolding of these folds about their original axes.

The overall picture of the Sanerutian deformation is of a strong NW–SE compressional force acting normal to the earlier Ketilidian foliation, with an approximately horizontal NE–SW stretching giving rise to a Sanerutian elongation lineation parallel to that formed in Ketilidian time. The detailed structural evidence on which these conclusions are based is given in Part III.

Other Sanerutian effects in the Nivâq sub-area.

A limited amount of migration of material took place within the supracrustal rocks. This material consisted mainly of alkali felspar together with small amounts of hornblende, calcite, quartz, haematite, flourite and larger amounts of epidote. Favourite sites for the localisation of the migratory material were fractures in epidote nodules and tension openings between boudins in competent layers of the metasediments. Flat-lying veins of black hornblende were evidently formed after the main phase of Sanerutian deformation, as the shear zones along which they are emplaced cut the granite foliation but are unfolded. It is probable that both these hornblende veins and later quartz veins which cut them were more or less contemporaneous with the 3rd period dykes and represent a stage in the gradual decrease in Sanerutian plutonic activity.

Natsît iluat sub-area.

Sanerutian time in the area immediately surrounding Natsît iluat was marked by the formation of pegmatites and small patches of coarse grained pegmatitic granite, in addition to small bodies of aplite which have a close spatial relationship to 2nd period dykes. Deformational effects are slight.

A few small pegmatite veins are found cutting 2nd period dykes on the peninsula to the SE of Natsît iluat, and many of the dykes here, unlike those in the sub-areas described previously, contain scattered grains of microcline. The pegmatites strike more or less parallel to the foliation of the country rock granite but have dip surfaces discordant to the granite foliation; slight shear folding of the pegmatites has taken place by movement parallel to the foliation of the granite in some cases. The 2nd period dykes here, all of which have a NE strike, are not folded but streaks of granitic material occur along the sheared margins of some of them.

On the same peninsula many discordant amphibolites are found which show a curious association with an aplitic granite. The aplite veins found in the country rock immediately adjacent to the dykes, on one or both sides, are up to 2 m in width but are impersistent and have very irregular outer margins. The inner margins of the aplites, on the contrary, are straight and abut against the dykes. It appears that the present contact between dyke and aplite marks the original boundary of the dyke. In two cases veins of marginal aplite have invaded the adjacent dyke and are folded along axial planes parallel to the dyke foliation. Narrow pegmatitic veins parallel to the dyke foliation are unfolded although cut by the aplite.

On the NE shore of Natsît iluat a narrow 2nd period dyke (see fig. 25) emplaced in fine grained Ketilidian granite is enclosed by unusually regular borders of aplite which appear to have been formed from the country rock granite; small remnants of the surrounding granite are found within the aplite and are elongated parallel to the strong foliation found in both the dyke and aplite.

It is very difficult to account for the origin of the aplites described, but it is provisionally suggested that they have been formed by the localisation of potash metasomatism along shear zones in the country rock adjacent to the dykes. However, there is good evidence elsewhere in the Ilordleq area that shearing is normally concentrated within the dykes rather than in the country rock immediately adjacent to them. An interesting parallel to these aplite margins is described by RAMSAY (1958) from Glenelg in the NW Highlands of Scotland. At Glenelg, the concentration of deformation at the edges of the thickest and most persistent sheets of basic rock, transformed the adjacent rocks into microgranulitic types resembling mylonites (loc. cit., p. 495). Occasional veins coming from the marginal aplites and cutting the associated amphibolite dykes, referred to above, suggest that the aplite although formed by the localisation of metasomatism along zones of inhomogeneous deformation, may have been capable of intrusion at some stage. This conclusion is reinforced by evidence from similar occurrences elsewhere in South Greenland and comparable occurrences in the Sánerutip imâ sub-area. The aplites may be considered as the plutonic equivalents of the pseudotachylite veins found in zones of dislocation (inhomogeneous deformation) at higher structural levels (see PARK, 1961).

On the NW shore of Natsît iluat two small bodies of pegmatite granite occur, which on the basis of their relations with 2nd period dykes,

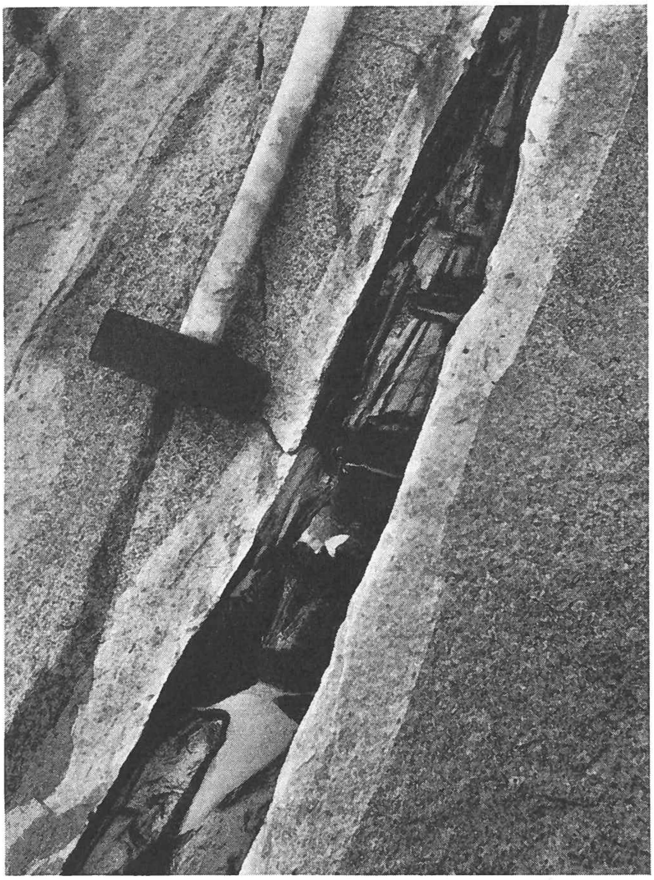

Fig. 25. Narrow 2nd period dyke in fine grained Ketilidian granite on the N.E. coast of Natsît iluat. Dyke is bordered by aplite which is strongly foliated parallel to dyke margin, and contains elongate enclaves of country rock granite from which it appears to have been formed.

are considered to be of Sanerutian age. The larger of the two bodies, which outcrops for 100 m along the coast, has no dykes either within it or within the porphyritic Ketilidian granite immediately surrounding which is veined by the pegmatite granite. Within the smaller body of pegmatite however are remnants of at least one, and possibly two dykes which can be traced into the surrounding porphyritic and aplite granites of Ketilidian age. Fig. 26 shows the disposition of outcrops of the three

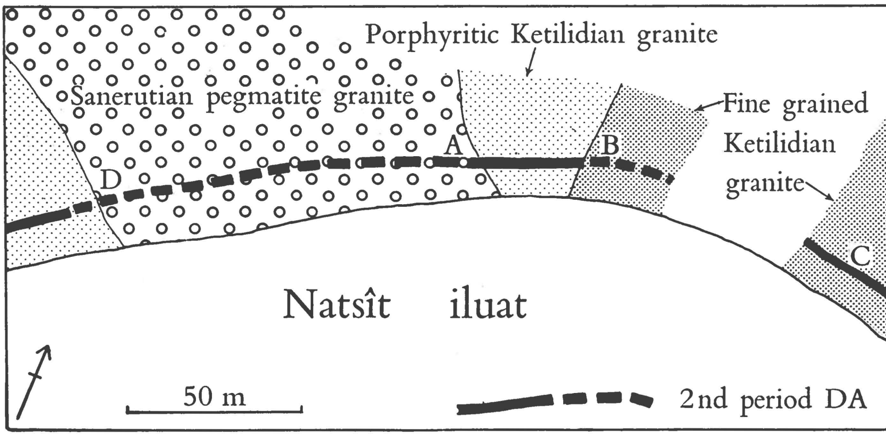

Fig. 26. Northern coast of Natsît iluat showing diagrammatically the distribution of granitic rock types and course of the 2nd period dyke shown in figs. 27–34.

granite types and a 2nd period dyke along a 250 m stretch of coastline. Figure 27 shows two relict dykes in the pegmatite granite at point A, one of which has been almost completely digested and is referred to as a relict dyke only because of its occurrence adjacent to an undoubted relict dyke: no other enclaves of any type are found in the pegmatite

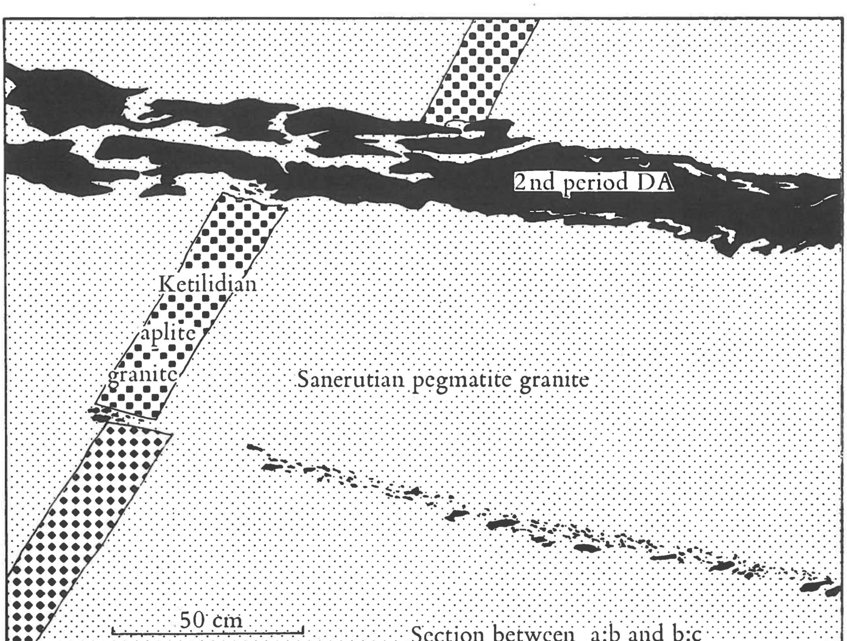

Fig. 27. Remnants of one, and possibly two 2nd period dykes in Sanerutian pegmatite granite (see fig. 26). See text.

Fig. 28. 2nd period dyke at locality B of fig. 26. Dyke cuts across contact between porphyritic granite (left) and fine grained granite (right), both of Ketilidian age. Material replacing dyke is indistinguishable from Sanerutian pegmatite granite.

granite. The vein of aplite shown in figure 27 is clearly older than the dykes and is almost certainly related to the larger outcrop of Ketilidian aplite granite nearby (fine-grained Ketilidian granite of fig. 26). It is suggested that the pegmatite granite has itself been formed from the original porphyritic granite into which both the dykes and aplite vein were emplaced. Unlike the porphyritic granite, and to a lesser extent the mafic dykes, the aplite has not been attacked and transformed to pegmatite granite; this is attributed to the different structural properties of the very fine grained aplite vein. The relationship of one of the dykes at the margins of the pegmatite granite body confirms the interpretation suggested above. East of point A (fig. 26) the dyke passes from pegmatite granite in which it is digested, into porphyritic granite in which it is unadulterated, as shown in figure 26 and on the left of

Fig. 29. 2nd period dyke at locality A (fig. 26), here emplaced in porphyritic Ketilidian granite and replaced by Sanerutian aplite granite. See fig. 30.

figure 28. Passing through the porphyritic granite the dyke enters the Ketilidian aplite granite within which it is again digested (figure 28) but in this case *the replacing material is again pegmatite granite* and not the enclosing aplite granite. On the other margin of the pegmatite granite body the same dyke crosses the contact and passes into the Ketilidian porphyritic granite: for the first 15 m of its course in the porphyritic granite it is veined and digested after which it continues in an unadulterated state (see figure 26). However, the veining material in this case is again pegmatite granite as shown in figures 29 and 30 (from just to the west of point D). Thus in every case the material veining the dyke is pegmatite granite while the porphyritic and aplite granites everywhere appear to be older than the dyke. This conclusion is further confirmed by the relationships shown at a point just to the east of the area in fig. 26, where there is a sharp contact between porphyritic and aplite granites (fig. 31), both believed to be of Ketilidian age: the dyke here, very probably the same as that seen elsewhere, cuts cleanly across

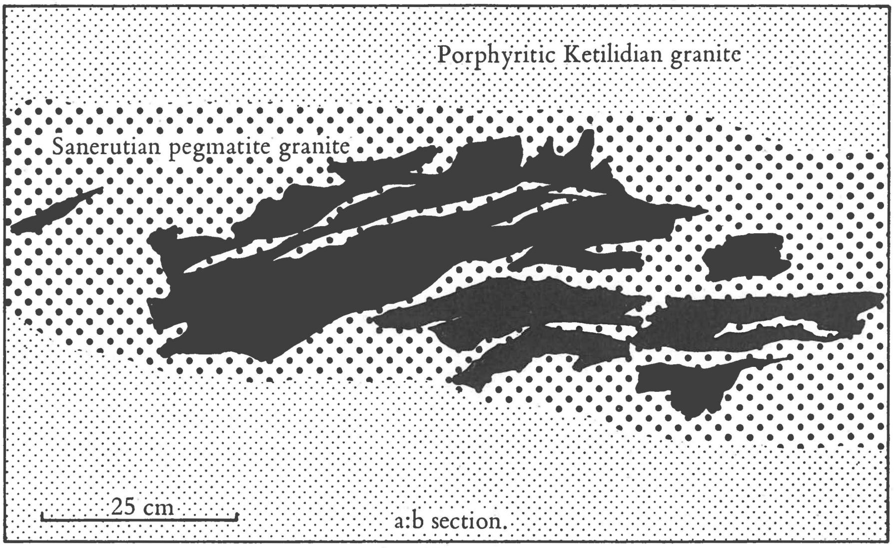

Fig. 30. Sketch of 2nd period dyke from exposure immediately adjacent to that shown in fig. 29.

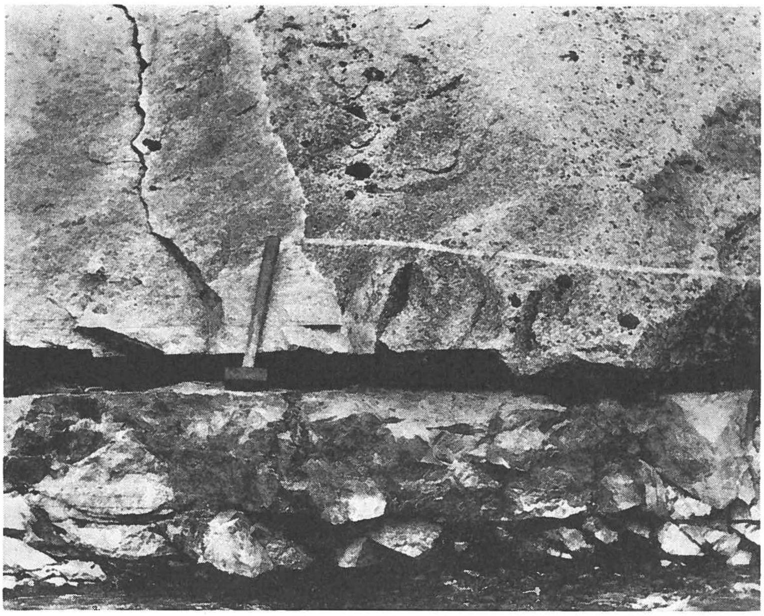

Fig. 31. Contact between porphyritic (right) and fine grained (left) granite, both of Ketilidian age, cut by unmigmatised 2nd period dyke. From exposure 100 m east of locality C, fig. 26.

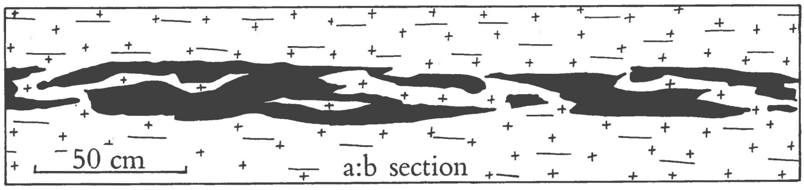

Fig. 32. Sketch of 2nd period dyke surrounded and partly digested by Sanerutian pegmatite granite, showing neosome and basic remnants parallel to foliation in granite. Note orientation of section.

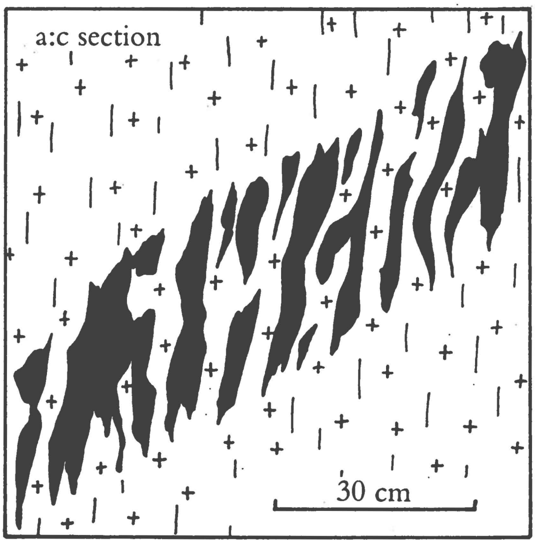

Fig. 33. As for fig. 32 but a:c section; preserved fragments form sheets parallel to foliation but are elongated in b direction (see fig. 32), forming linear structure which cannot be seen in pegmatite granite. See also fig. 34.

this contact and is clearly later than both granite types, as shown in figure 31. The age relationships determined on the basis of field evidence described above may with some confidence be set out as follows:–

pegmatite granite (formed from earlier granites)	Sanerutian
basic dykes	Kuanitic
aplite granite porphyritic granite	Ketilidian

No folding or shearing effects have been noted as accompanying the formation of the pegmatite granite but there is nevertheless clear evidence that this granite is of synkinematic origin in the sense defined on page 11. The pattern shown by the introduced material in the digested

Fig. 34. Photograph showing same section of digested 2nd period dyke as fig. 33. Aplitic vein seen below line of amphibolite fragments may have similar origin to aplite margins shown in fig. 25.

2nd period dykes indicates that the orientation of the stresses operating during the formation of the pegmatite granite were similar to those giving rise to the Sanerutian deformation elsewhere in Ilordleq. Foliation and lineation in the pegmatite granite are weak and often absent, probably due to the coarse grain and leucocratic nature of the rock. Where present they conform to usual pattern of steeply dipping NE foliation and sub-horizontal lineation. Figures 32, 33, and 34 show veining of the 2nd period dyke by pegmatite granite on two different surfaces, both at right angles to the weak foliation referred to. Figure 32 shows a surface parallel to the lineation direction (a:b section) while figs. 33 and 34 show the surface, normal to the lineation direction. It is apparent that in the case of this particular dyke no foliation was induced by shearing parallel to the dyke margins and that the veining is a direct reflection of the regional stress pattern under conditions corresponding to those of homogeneous deformation. It is difficult to conceive of any process other than that of metasomatic replacement, by which the granitic material invading the dyke would preserve such clear evidence of its synkinematic origin.

Discussion of the actual processes by which the pegmatite granite was formed is more appropriate to Pt. IV.

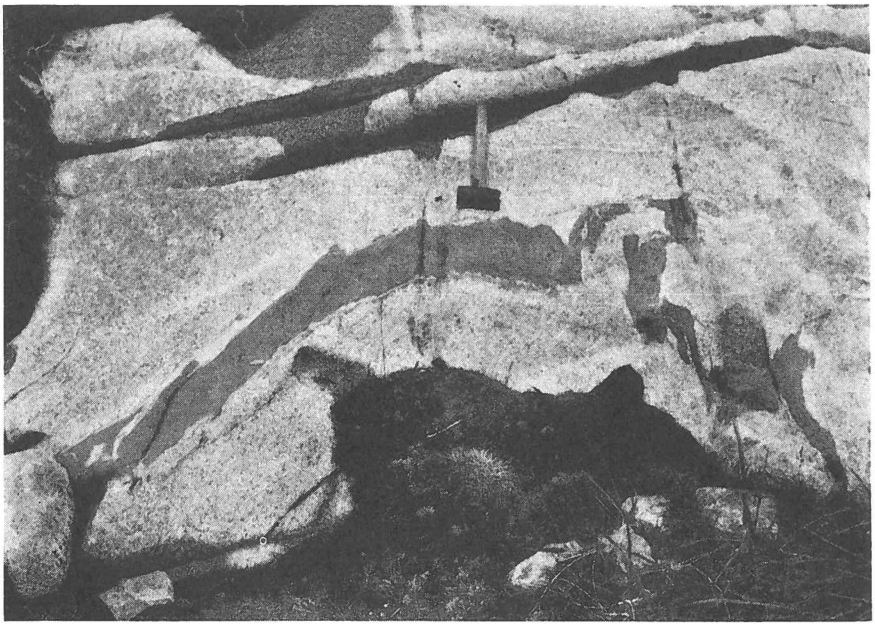

Fig. 35. Folded grey 2nd period dyke in Sanerutian hornblende granite, intruded and broken by mobile country rock. Granite has strong planar (parallel to hammer handle) and linear (normal to plane of paper) structures. Folding slightly exaggerated due to orientation of exposure. N.W. coast of Ikerasârqap nunâ.

The Sanerutian effects in the Natsît iluat sub-area may be summarised as the synkinematic formation of small bodies of pegmatite granite, and aplites marginal to some 2nd period dykes.

Sánerutip imâ sub-area.

This area is distinguished from the other four sub-areas by the very high degree of Sanerutian activity which led to complete reactivation of the granitic rocks and folding, breaking and migmatisation of the 2nd period dykes. The high degree of reactivation of the granite in this area leading to the formation of the Sanerutian Hornblende Granite, is shown by the response to the Sanerutian deformation; in the Nivâq sub-area, Sanerutian deformation took place by means of discrete movements parallel to foliation planes together with recrystallisation, whereas all deformation of granitic rocks in the Sánerutip imâ sub-area appears to have taken place completely by recrystallisation. In this sense the Hornblende Granite may be said to have flowed and indeed in some places the Sanurutian Hornblende Granite is found intruding 2nd period dykes (figures 35 and 36); however, this flowage took place

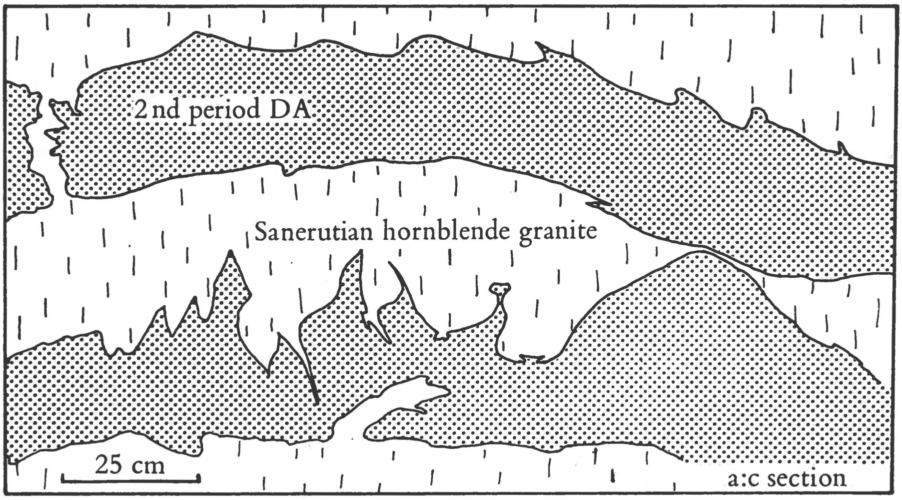

Fig. 36. Green 2nd period dykes intruded by Sanerutian hornblende granite. Lack of separation of blocks is due to orientation relative to main stretching i. e. lineation direction, which is normal to section shown. N. coast of Sătukujôq.

largely in the solid state and Sanerutian structures in the Sánerutip imâ sub-area are homologous with those elsewhere in Ilordleq.

2nd period dykes.

In the Sánerutip imâ sub-area the 2nd period dykes are of two distinct types, one type consisting almost entirely of green amphibole while the other type contains appreciable amounts of felspar; these will be referred to as the green type and the grey type 2nd period dykes or discordant amphibolites. Recognition of the two types in the Sánerutip imâ sub-area caused some difficulty during the field work because 2nd period dykes elsewhere had not been seen to show such marked differences. A re-examination of the 2nd period dykes in the granitic and supracrustal rocks of the Nivâq sub-area confirmed that such distinct petrological differences as were found in the Sánerutip imâ sub-area were not evident in Nivâq. However, it was evident that some of the 2nd period dykes in the Nivâq sub-area are slightly more mafic and coarser grained than the others which were of a more typically metabasaltic type, and tended to become boudiné more easily than the latter. Whereas the 'metabasaltic' dykes in the Nivâq sub-area had undergone a homogeneous type of deformation the more mafic types were typically fractured and contained irregular leucocratic veins (fig. 37). There appeared to be a transition from the mafic types of the Nivâq sub-area to the ultrabasic green types of Sánerutip imâ which could best be accounted for by progressive metamorphic differentiation and loss of fel-

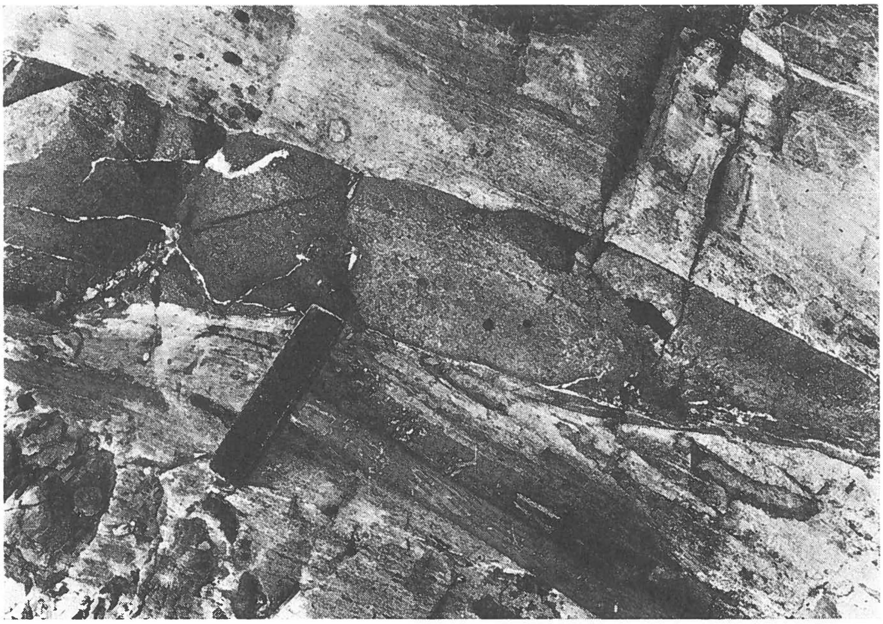

Fig. 37. Green 2nd period dyke in banded supracrustal rocks. Dyke shows pinch and swell structure, and scapolite veins probably derived from dyke by metamorphic differentiation. Island in centre of Nivâq.

spar from the original mafic dykes. This interpretation received some support by the discovery that the leucocratic veins in these dykes consisted of either plagioclase or scapolite and not alkali felspar. The cause of the differentiation is thought to be the migration of the most mobile constituents to the low pressure zones in the fractures forming in the relatively competent green dykes. The grey dykes containing initially slightly less hornblende than the green dykes deformed by slip along closely spaced foliation planes and show no tendency to boudinage or fracture, and hence no tendency to metamorphic differentiation. The differences between the green and grey dyke types is increased further by migmatisation of the latter in the Sánerutip imâ sub-area; by introduction of alkali felspar and quartz along foliation planes the composition of the grey dykes changes from that of metadolerite to dioritic or monzonitic. The amphibole rich green dykes showing no foliation or linear structure are not affected by this migmatisation. Originally small differences in dyke composition have thus given rise to two very different rock types; the one type becoming more basic by metamorphic differentiation, the other becoming less basic by addition of granitic material. Many green type 2nd period dykes are found which dip at angles as low as 30°, usually to the ESE.

It is of some interest to note that WEGMANN (1938) referring to what he called pre-granitic basic dykes on the south side of Kobberminebugt, concluded that (p. 27) "The differences in the rocks of the dykes seem often to become more distinct through the metamorphism since dykes with comparatively small differences behave differently on recrystallisation". The interpretation outlined above regarding the metamorphic differentiation of the green dykes is considered in more detail in Section IV.

Grey 2nd period dykes.

In the Sánerutip imâ area these dykes have been both deformed and migmatised; the degree of deformation increases with the intensity of lineation in the enclosing granite and both increase fairly regularly toward the NE (page 91). The degree of migmatisation does not vary so regularly, but nevertheless, offers an interesting demonstration of the kinematic control of metasomatism. All stages have been found between dykes in which there has been no metasomatic alteration, and those which have been almost completely replaced by granitic material and whose dyke origin would be difficult to appreciate if it were not for the intermediate stages shown by their less altered counterparts. The criteria used in distinguishing dyke remnants from pre-granite amphibolitic enclaves are described in Section IV.

The granitic material which migmatises and replaces the dykes is more leucocratic and finer grained than the surrounding Hornblende Granite, and is strongly selective in its action; leucocratic veins are only rarely found to extend outside the original limits of the basic dykes. The progressive replacement of the dykes is best demonstrated by describing a few individual dykes representing the various stages. The intensity of the migmatisation varies capriciously within small areas and even within individual dykes, but in view of the highly selective nature of the process this is not surprising.

Figure 38 shows a grey 2nd period dyke on the north coast of Ikerasârqap nunâ, 2 km SW of the Anchorage. This dyke has similar characteristics to those found in the Ketilidian granite in the Nivâq sub-area, and at this point contains only very small amounts of granitic material (along the right hand margin). The foliation in the dyke is parallel to that in the country rock, except within narrow zones adjacent to the margins where the foliation is parallel to the strike of the dyke. In the figure the foliation in the Hornblende Granite is evident, as also are the small pre-granite enclaves which appear as dark streaks parallel to the foliation and which quite clearly are unrelated to and earlier than the discordant post granite dyke. As the strike of the dyke makes only a small angle with the granite foliation it has not been strongly deformed, but that there has been intense deformation subsequent to the emplacement of the dyke can be seen from figure 39. This shows the same dyke as in the previous figure and at only a few metres distance, where it has been cut by a discordant aplitic vein of presumed early

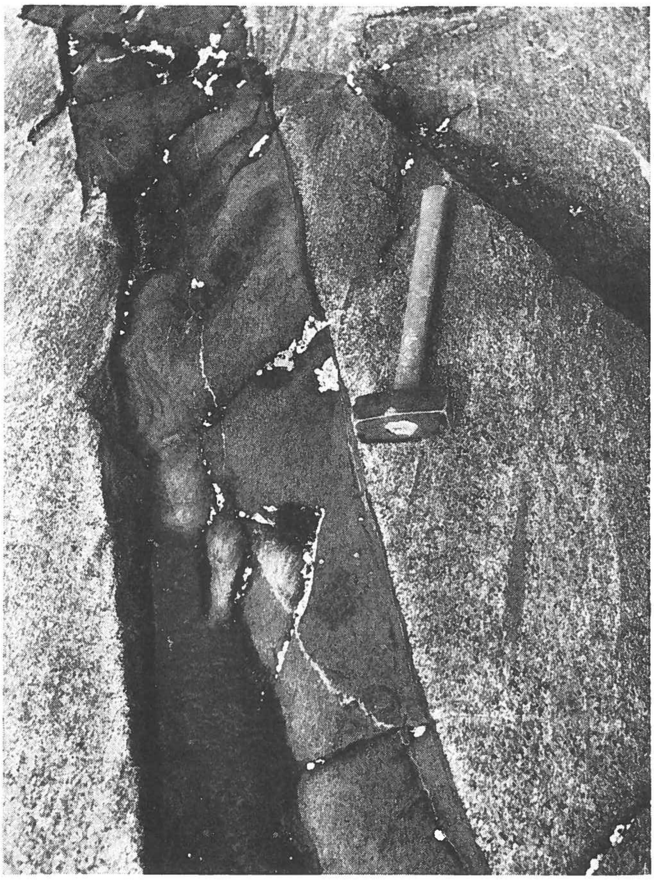

Fig. 38. Grey 2nd period dyke in Sanerutian hornblende granite. Only slightly discordant to granite foliation and trend of enclaves (parallel to hammer handle), the dyke is not folded. Foliation in the dyke is mostly parallel to that in surrounding granite, except along the margins where it is parallel to the margin. Small amounts of neosome along the dyke margin (next to hammer head) show earliest stages of replacement of 2nd period DAs. N. coast of Ikerasârqap nunâ, 1200 m W. of Anchorage.

Sanerutian age. The axial planes of the folds of the vein are parallel to the foliation in the dyke, which in turn is parallel to that in the granite country rock (parallel to hammer handle). The aplite is more intensely deformed in the dyke than in the granite.

A comparatively early stage in the replacement of a grey dyke is shown in figure 40, in which a vertical 2nd period grey dyke is seen

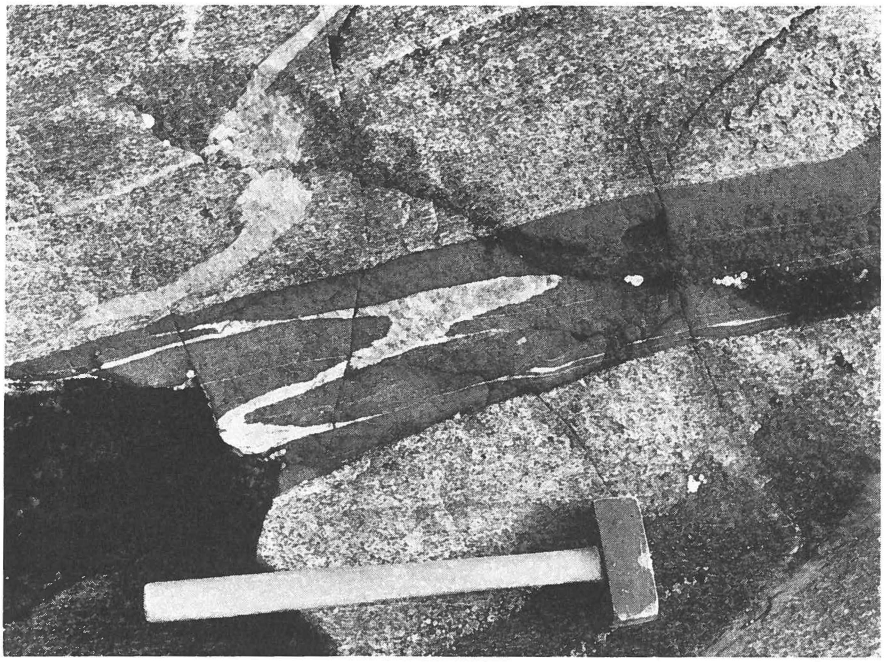

Fig. 39. Same 2nd period dyke, and on same exposure as that shown in fig. 38. Folding of discordant Sanerutian aplite shows high degree of internal deformation in dyke relative to that in adjacent granite.

intersecting a gently dipping green dyke of the same period, at a locality a few hundred metres NE of the dyke shown in figures 38 and 39. In figure 40 the different behaviour of grey and green dykes can be easily seen, and it is clear that both have been intruded into granitic rock and affected by subsequent metamorphism and deformation. Both dykes are discordant to the steeply dipping foliation in the country rock which can be seen on the left hand side of the figure; a : c sections of the ellipsoidal enclaves are aligned parallel to the foliation. The grey dyke, which is also shown in figure 41, is replaced by a fine grained leucogranite which is evenly distributed throughout the dyke and not concentrated on the margins. Just above the intersection shown in figure 40 the grey dyke is almost whole and separated from the country rock only by a narrow strip of leucogranite or not at all. Where the replacement has proceeded further, as in figure 41, the amphibolitic remnants of the dyke are nowhere in contact with the country rock but everywhere surrounded by leucogranite. The surface shown in figure 41 is more or less horizontal and in that plane the dyke is almost parallel to the strike of the country rock foliation, and has been stretched and broken in the direction of the lineation (shown by the alignment of the hammer handle). Where the dyke has been stretched and broken, the individual pieces are sepa-

Fig. 40. Remnants of grey 2nd period dyke (vertical) cutting gently dipping green 2nd period dyke. View is almost parallel to lineation and main stretching direction and hence no boudinage effects can be seen in green dyke (see fig. 55). Foliation in granite and flattening of enclaves (upper left) are parallel to hammer handle. Grey dyke partially replaced by fine grained granite (see fig. 41), the veins of which have directional features homoaxial with planar and linear structures in country rock granite. Anchorage, N. coast of Ikerasârqap nunâ.

rated by normal Hornblende Granite containing no leucogranite. The synkinematic nature of the replacement of the dyke is shown by the veins of leucogranite which form sheets within it (fig. 41) which are parallel not to the walls of the dyke, but to the foliation within it which is parallel to that in the country rock. The sheets of leucogranite are irregular because of a tendency to form rods parallel to the country rock lineation; as a result of this the amphibolitic dyke remnants are also elongated parallel to the lineation in country rock and, where replacement has been extensive, form triaxial ellipsoids elongated parallel to the lineation and flattened parallel to the foliation of the country rock granite. This effect can be seen on irregular surfaces shown in the foreground of figure 41, but it is more clearly shown in figure 42 which is a diagrammatic sketch of a handspecimen from the same dyke. In the specimen shown in the sketch, the amount of amphibolite is still greater than that of leucogranite which appears as sheets or rods within it. There can be little doubt that the arrangement shown is an original feature of the leucogranite and not a relationship induced by deformation sub-

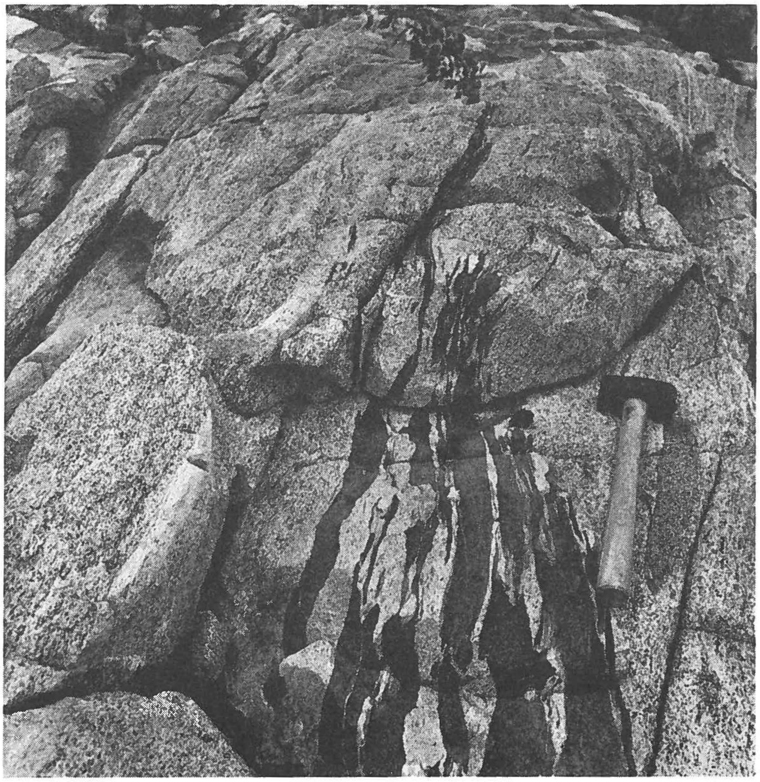

Fig. 41. Remnants of same grey 2nd period dyke as shown in fig. 40. Hammer handle is parallel to lineation and dyke is discontinuous on surface parallel to this direction. Foreground shows section normal to lineation on which the forms of both replacing fine grained granite and basic remnants show as discontinuous sheets parallel to foliation of surrounding granite.

sequent to the formation of the leucogranite. Similar evidence of the synkinematic nature of the replacement of the 2nd period dykes and of the homology of Ketilidian and Sanerutian structures is shown by a dyke on the extreme NE peninsula of Ikerasârqap nunâ, illustrated in figures 43 and 44. Figure 43 shows an a:c section of a digested dyke which contrasts strongly with the b:c section of the same dyke shown in figure 44. The rod-like form of the dyke remnants is very marked and this rodding is parallel to the lineation in the enclosing granite and to the b direction of Ketilidian structures. In this example the difference between a and c directions is not very obvious although still identifiable in the outcrop, where the c direction (shown by direction of hammer handle in both figures) lies within the plane of foliation of the surrounding granite (parallel to hammer handle in fig. 43).

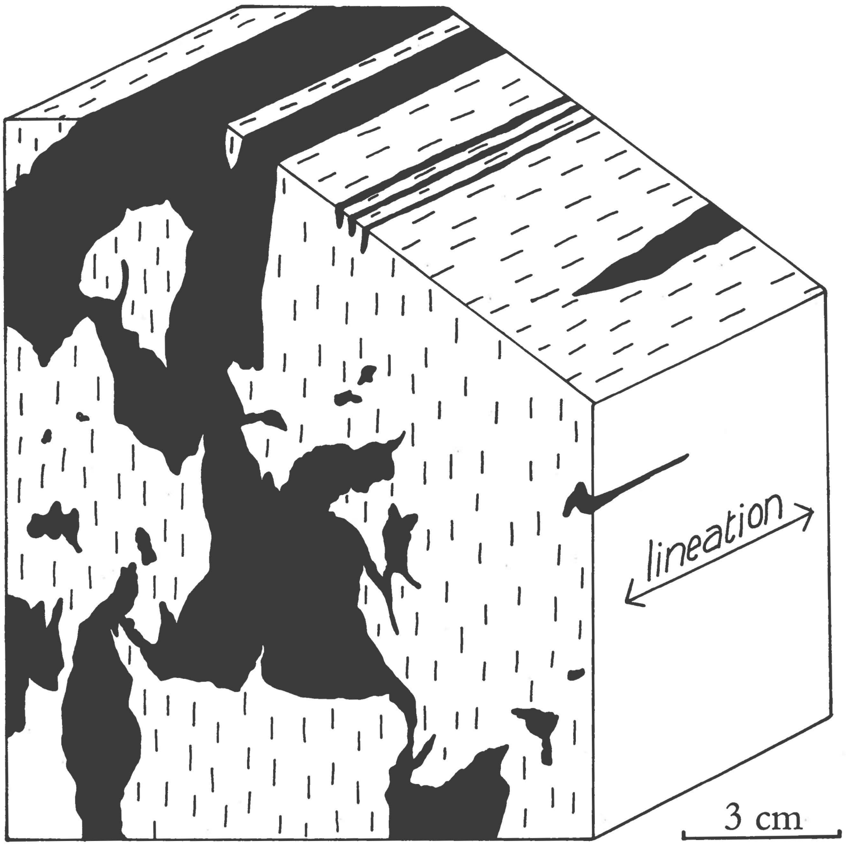

Fig. 42. Sketch from handspecimen showing form of replacing fine grained granite veins (black) and their disposition relative to foliation and lineation in grey 2nd period dyke host rock (same as that in figs. 40 and 41).

Part of another grey 2nd period dyke from close to the SW corner of Ikerasârqap nunâ, which shows a similar degree of replacement, is shown in figure 45. In this case there was a large angle between the original strike of the dyke and the strike of the country rock foliation, which resulted in the dyke being folded during the Sanerutian deformation. The closure of the fold is shown in the photograph and, although the fold is somewhat exaggerated because of the orientation of the outcrop surface, it can be seen that the sheets of replacing leucogranite are parallel to the axial trace of the fold and to the country rock foliation. In the figure the hammer handle is approximately parallel to the lineation in the Hornblende Granite, and here too the leucocratic nature of the replacing granite and its sharp contacts with both the dyke remnants and the country rock granite can be clearly seen.

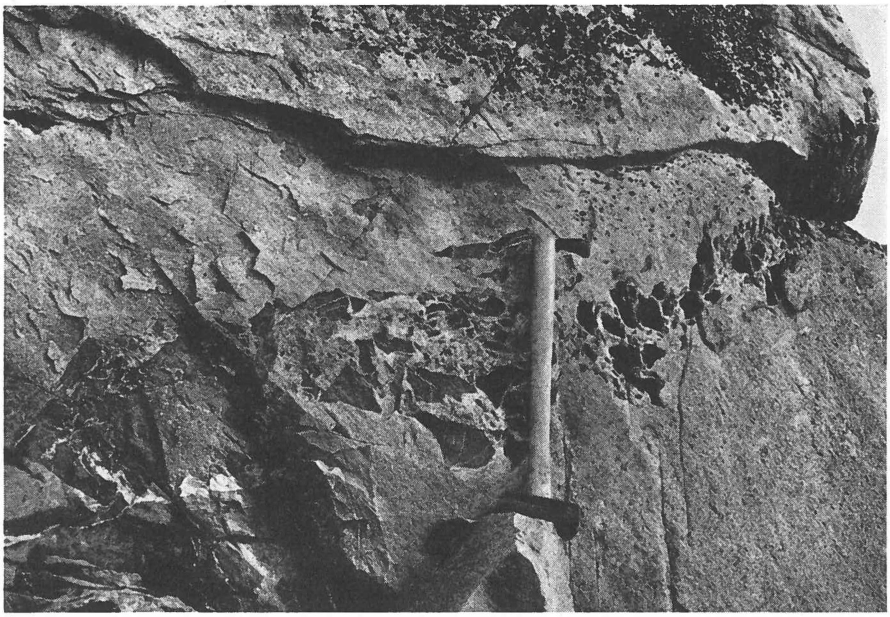

Fig. 43. a:c section of green 2nd period dyke broken up by reactivation of granite (see fig. 44).

Fig. 44. b:c section of dyke shown in fig. 43 showing strong kinematic control of the form and disposition of the veining material. The strong rodding of the dyke remnants is parallel to the lineation in the enclosing Sanerutian hornblende granite. North coast of Ikerasârqap nunâ, 1 km E. of Anchorage.

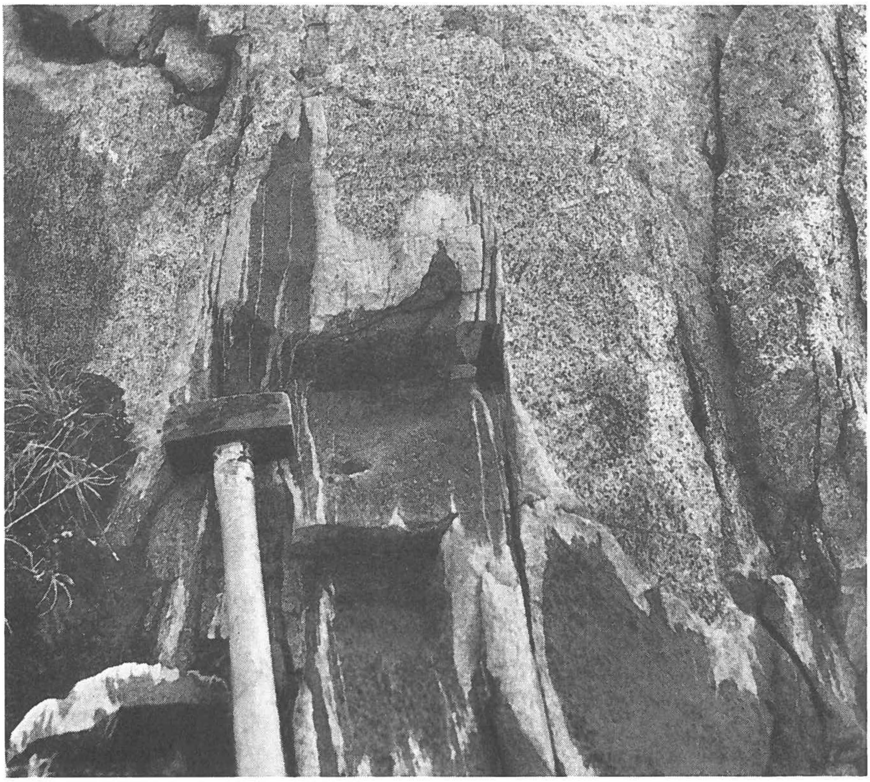

Fig. 45. Folded and partially replaced grey 2nd period dyke in Sanerutian hornblende granite. The leucocratic veining material has similar directional features to those shown by the dyke in figs. 40–42. Linear structure parallel to hammer handle; folding slightly exaggerated due to shape of outcrop. N.W. coast of Ikerasârqap nunâ, 3 km W. of Anchorage.

Two further stages in the replacement of grey 2nd period dykes are shown in figures 47 and 48, from a locality close to that of figure 45. In figure 47 the amount of replacing leucogranite is greater than that of the dyke remnants which remain as enclaves within it. These enclaves are triaxial ellipsoids with their greatest lengths parallel to the country rock lineation and are flattened parallel to the plane of foliation; they may thus be considered as the Sanerutian analogues of the elongate flattened enclaves of supracrustal rocks within the Ketilidian granites and which are also preserved within the Sanerutian Hornblende Granite. There are thus two almost identical sets of enclaves within the Sanerutian granite which are of very different ages. Distinction of the two types is further complicated by their identical orientation, a result of and testimony to the homology of the principal stress axes in Ketilidian and Sanerutian time.

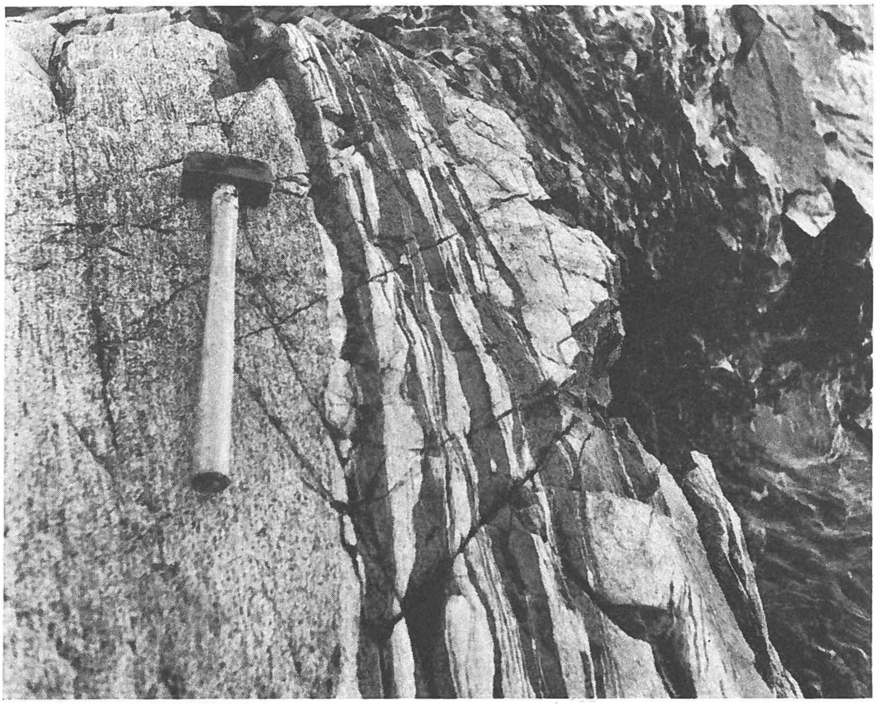

Fig. 46. Strongly veined 2nd period dyke in Sanerutian hornblende granite. Hammer handle parallel to linear structure in both dyke and country rock. Dyke is nowhere in direct contact with country rock as margins are completely replaced by aplite. N. coast of Ikerasârqap nunâ, 1 km E. of Anchorage.

Figure 48 shows part of a replaced grey 2nd period dyke in which the proportion of leucogranite is greater than in any of the previous examples, but with the sharp contact against country rock granite still preserved. The irregular appearance of the boundary between the two granite types is partly due to folding of the dyke, and partly to a later fault which has also displaced a pegmatite vein which cuts both the replaced dyke and the Hornblende Granite country rock. As the pegmatite is slightly discordant to the foliation and yet is not folded, it must be of late or post kinematic origin with respect to the Sanerutian deformation.

In both figure 47 and figure 48 the remnants of amphibolite are of all sizes from 30 cm down to a few mm. The preservation of so many of the smaller remnants appears to be characteristic of the most replaced dykes: in the less replaced dykes the leucogranite sheets are completely free of any small remnants of amphibolite (see, for example, fig. 46). It must therefore be assumed that, at least in most cases, the most completely replaced dykes have not passed through all the stages represented

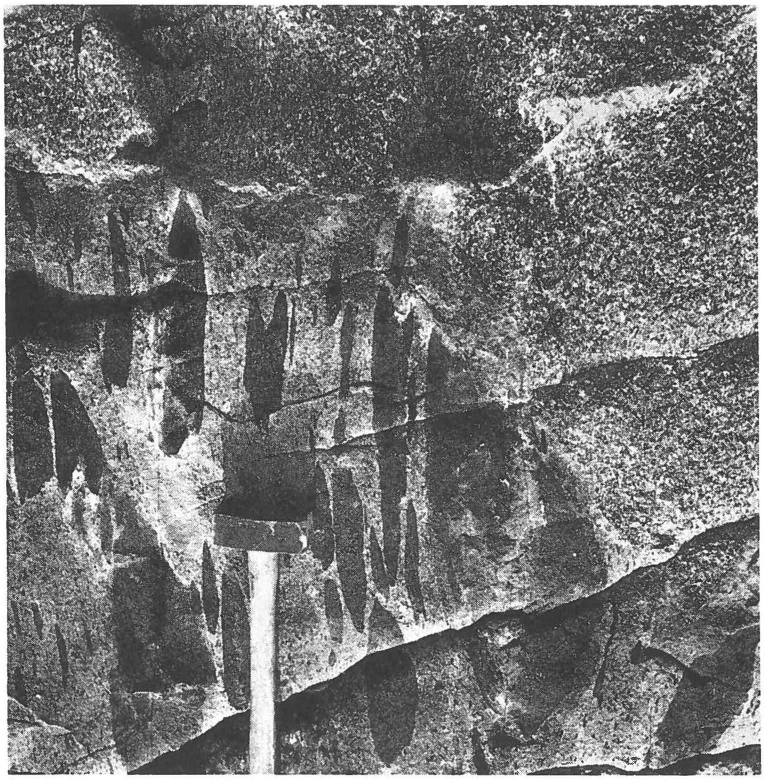

Fig. 47. Advanced stage of replacement of grey 2nd period dyke by fine grained granite (lower part of figure) which does not extend into the country rock of Sanerutian hornblende granite (upper part of figure). a:b section with hammer handle parallel to b. Basic remnants of dyke now most clearly show directional features, and have forms similar to those of enclaves of pre-granitic rocks found throughout the area (compare with figs. 45 and 48). N. coast of Ikerasârqap nunâ, 2 km W. of Anchorage.

by their less replaced counterparts; the sequence described above thus shows only successive *degrees* of replacement and not successive *stages* of replacement.

Figure 48 shows the highest degree of replacement of a grey 2nd period dyke by which the original presence of a basic dyke can be inferred. Only small amounts of the original basic material remain in what is now a dyke of fine grained leucogranite with sharp contacts against the country rock granite. Dykes of leucogranite or aplite have been found for which there is no way of definitely establishing whether or not they represent originally basic dykes. There can be no suggestion that all leucogranite or aplite veins are formed from basic dykes.

Fig. 48. Furthest stage of replacement from which the original presence of a basic dyke can be inferred. Hammer head rests on Sanerutian hornblende granite country rock; contact between this and microgranite replacing dyke is irregular due to folding of dyke and later shearing, which also displaces slightly discordant late Sanerutian pegmatite. Note wide range of sizes of basic remnants. Hammer handle parallel to b direction. N. coast of Ikerasârqap nunâ, 2 km W. of Anchorage.

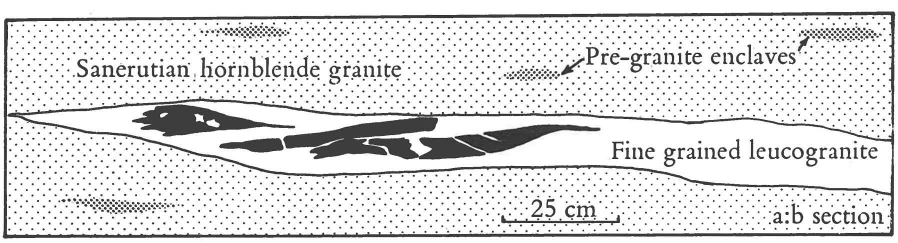

Fig. 49. Vein of fine grained leucogranite containing a few fragments of dark amphibolite which are quite distinct from enclaves in surrounding granite. Leucogranite possibly occupies site of what was originally a basic dyke. W. coast of Ikerasârqap nunâ.

Figure 49 shows an aplite vein which may be considered typical of those for which no definite interpretation is justified. The vein occurs in the W part of Ikerasârqap nunâ within Sanerutian Hornblende

Granite and is 30 cm wide, striking nearly parallel to the strike of the country rock foliation. Although the vein is discontinuous it can be followed for 40 m along its length on continuous coastal exposure: in one place only, that shown in the figure, does it contain enclaves of amphibolite. The enclaves are black in colour and show no sign of felspathisation, unlike the more shadowy grey enclaves in the surrounding granite; in this respect the former resemble the remnants of replaced dykes found elsewhere. For these reasons, the possibility that the aplite vein represents an original basic dyke which has been almost entirely replaced cannot be discounted. This is altogether in keeping with the views of CHAPMAN (1955) who concluded (p. 123) "Particularly in metamorphic and metasomatic terrains, old basic dykes may have been pseudomorphed by granite or pegmatite in great numbers, and so completely as to almost defy detection."

Palingenesis of replaced grey 2nd period dykes.

On the north coast of Ikerasârqap nunâ, where replaced grey 2nd period dykes are most frequent, occur a few small apparently intrusive patches of aplitic granite containing numerous small enclaves of un-

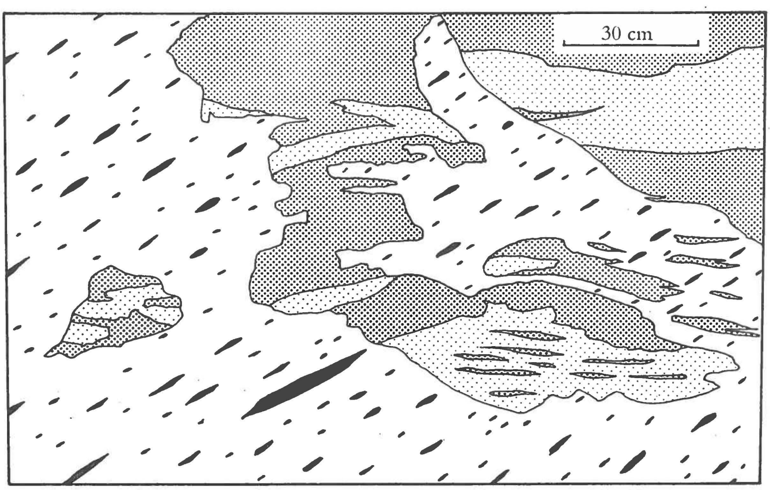

Fig. 50. Migmatite with Sanerutian hornblende granite (lightly dotted), neosome and metavolcanic palaeosome (heavily dotted), cut by microgranite (plain) containing numerous small fragments of dark amphibolite. The micrograniteand its basic enclaves closely resemble a replaced 2nd period dyke but are here intrusive into earlier migmatite. Anchorage, N. coast of Ikerasârqap nunâ.

felspathised, dark, fine grained amphibolite. These aplites are in many respects identical with the replaced 2nd period dykes which have been described, but unlike these do not have a regular and persistent dyke

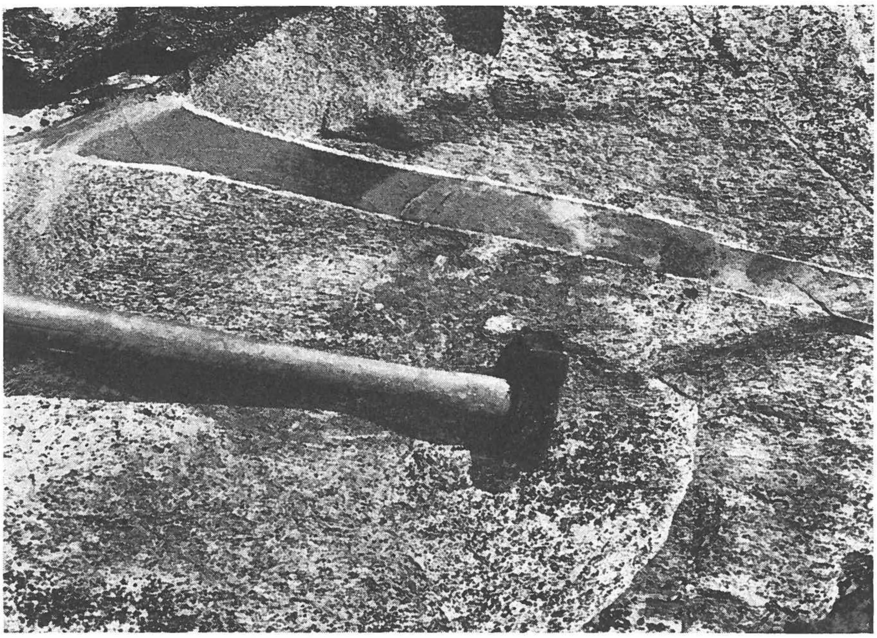

Fig. 51. Narrow grey 2nd period dyke in Sanerutian hornblende granite, with well developed aplite margins; a:b section in which dyke is not folded (see figs. 52 and 53). Western peninsular of Sãtukujôq.

form and instead occur as small irregular masses a few metres in extent. Another important difference is that the orientation of the small enclaves of amphibolite, although regular, does not conform with the foliation and linear structures in the surrounding Hornblende Granite. Figure 50 shows a part of one of the larger of these masses emplaced in a migmatitic part of the Hornblende Granite in which the palaeosome is amphibolite, probably of metavolcanic origin, and of a paler colour than the dark enclaves in the later aplite.

The enclaves in the aplite strike NNE; a similar direction has been noted in other similar occurrences, but these aplites are not sufficiently numerous for this similarity to be of much significance. No conclusive evidence has been found by which the origin of these aplites can be determined, but on account of the similarity to the replaced grey 2nd period dykes it is suggested that they represent replaced grey 2nd period dykes which have become intrusive into the surrounding rocks. There is some evidence of a more definite nature indicating that replacive aplite granite formed within an earlier basic dyke can become sufficiently mobile so as to vein the surrounding granite. One such vein can be seen in figure 40 immediately behind the hammer handle: to the right of the hammer it continues towards the replaced grey dyke where it merges with the aplite actually within the dyke. To the left of the hammer it continues horizontally for a short distance before turning upwards and cutting through the green dyke, above which it thins out and disappears. As the vein is discordant to the country rock structures and is unfolded, its emplacement must have been late or post kinematic with respect to the Sanerutian deformation. The possibility that aplitic rocks initially

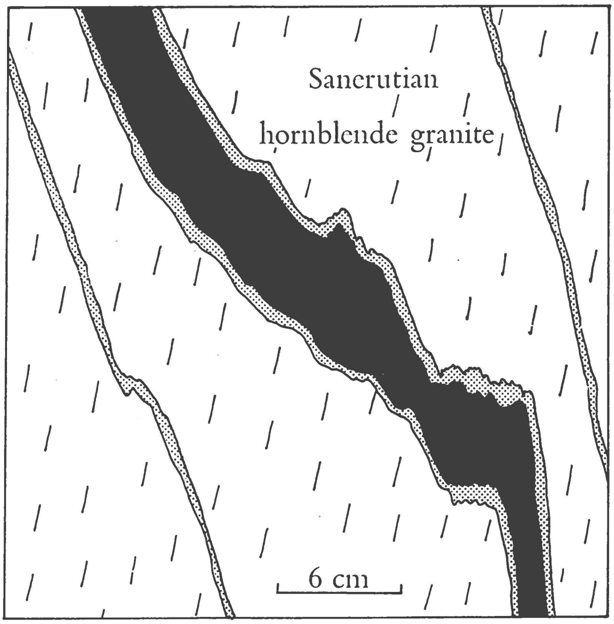

Fig. 52. a:c section of 2nd period dyke (black) shown in figs. 51 and 53, showing folding of dyke along plane of country rock foliation. Folding post-dates emplacement of neosome (dotted) along dyke margins and veins in country rock granite.

formed by replacement may become mobile has already been suggested in connection with the aplite margins to dykes in the Natsît iluat area (page 56).

Grey 2nd period dykes become fewer towards the NW along the coast of Sánerutip imâ and only one has been recognised on the north coast of Sãtukujôq. Whether this is because they have become unrecognisable or because none were emplaced here is not known, but the latter seems the more likely in view of the one small grey dyke which has been found. This dyke is only a few cm wide and has been folded; although not typical of the grey 2nd period dykes in the Sánerutip imâ sub-area, it is of interest on account of the evidence it provides of the formation of aplite margins to basic dykes. Nearby 2nd period dykes of the green type do not show evidence of much metasomatic activity and this, together with the small size of the grey dyke, probably accounts

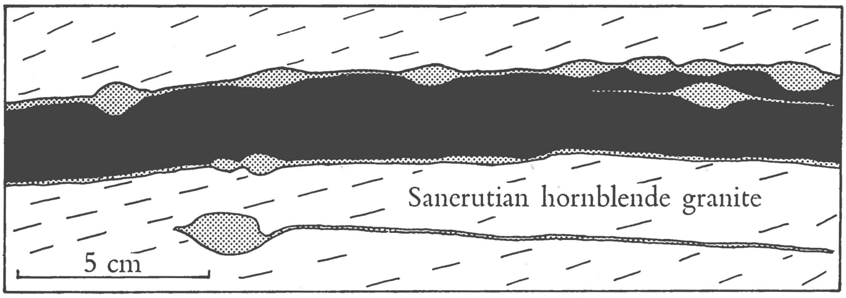

Fig. 53. Sketch from same exposure as that shown in fig. 51. Dyke (black) is rimmed by quartz-felspar material (dotted) which contains large porphyroblastic felspars; veins of similar material are also rarely found within the dyke and in the country rock. Individual porphyroblastic felspars of the same age are found in the surrounding granite. a:b section.

for its preservation almost intact. Figure 51 shows this dyke on a horizontal surface where it appears to be almost concordant with the country rock foliation. Narrow felspathic margins separate the dyke from its country rock and are of very regular form. Figure 52 shows the same dyke on a vertical surface normal to the foliation and lineation of the host rock, where its discordant nature can be clearly seen. Slight folding of the dyke has taken place by movement parallel to the foliation of the host rock. The felspathic borders have also been folded and are thus of pre- or syn-kinematic age with respect to the Sanerutian deformation. In the Hornblende Granite surrounding the dyke a few felspathic veins identical with those bordering the dyke are also slightly folded; two of these veins are shown in figure 52 and it is most probable that both types of vein are of the same age and origin. A clue to this origin is found in the same exposure (fig. 53) where the aplite veins marginal to the dyke are attenuated and discontinuous: here the veins have large porphyroblastic microclines situated at irregular intervals along their lengths, and similar porphyroblasts occur in the individual veins in the country rock and in a single vein within the dyke (fig. 53). The porphyroblasts are indistinguishable from those which occur singly within the Hornblende Granite both at this locality and many others on Sãtukujôq and Ikerasârqap nunâ (page 92); the metamorphic origin of the porphyroblasts thus seems to be beyond reasonable doubt.

It is suggested that the felspathic veins were formed by localisation of metasomatism in shear zones along the margins of the dyke, at a comparatively early stage of Sanerutian plutonic activity when the country rock granite was sufficiently brittle for small parallel shears to develop within it, along which the other felspathic veins were formed.

This interpretation is similar to that advanced for the origin of marginal aplites in the Natsît iluat area (page 56) and suggests that at an early stage of the Sanerutian, conditions in the Sánerutip imâ sub-area were similar to those which characterised the Sanerutian in the Natsît iluat sub-area.

Green 2nd period dykes.

The formation of green discordant amphibolites, with compositions approaching ultra-basic, by metamorphic differentiation of originally less basic dykes, has already been referred to (page 65). The competent nature of the original dykes was put forward as the reason for this differentiation, and many characteristics of the green dykes in the Hornblende Granite of Sánerutip imâ can be shown to be direct consequences of their highly competent nature compared with that of the surrounding granitic rocks. Unlike the grey 2nd period dykes, the green dykes are found throughout the Sánerutip imâ sub-area, allowing a more comprehensive study of their behaviour in response to the Sanerutian plutonic activity and of variations in the intensity of this activity.

The green 2nd period dykes found in the Sanerutian Hornblende Granite consist mainly, and in some cases entirely, of fibrous green amphibole. Plagioclase and epidote are the other minerals which occur It is quite clear that such rocks will respond to deforming stresses in quite a different way to amphibolites containing appreciable amounts of felspar, such as the grey 2nd period dykes. The green dykes are found to deform mainly by boudinage and fracture rather than by the homogeneous deformation characteristic of the grey dykes.

The degree of deformation of the green dykes is found to be greater toward the NE end of the Sánerutip imâ sub-area and this change confirms conclusions drawn from other lines of evidence concerning variation in the intensity of the Sanerutian deformation (page 90). In the Hornblende Granite on Ikerasârqap nunâ the green dykes show pinch and swell structures parallel to direction of lineation and stretching in the country rock, but only rarely has the deformation proceeded sufficiently far for the dykes to become broken and the fragments separated. On Sãtukujôq however, the green dykes are completely broken up and small fragments of the original dykes are found completely surrounded by the country rock granite; the distance between neighbouring fragments may be up to many metres. Apart from providing information concerning the green dykes themselves, such relationships provide very useful evidence regarding the physical characteristics of the Hornblende Granite at the time the deformation took place.

Migration of granitic material, such as that found in connection with grey 2nd period dykes, is not found to such a high degree in the vicinity of green dykes and then only in association with those dykes which have *not* been completely broken up. It must be imagined that migration of granitic material only took place when suitable pathways were afforded in zones of inhomogeneous movement or fracturing. Continuous septae of competent material within a mass of deforming incompetent material, as were the 2nd period dykes within the reactivated granite of Sánerutip imâ, are obvious sites for inhomogeneous defor-

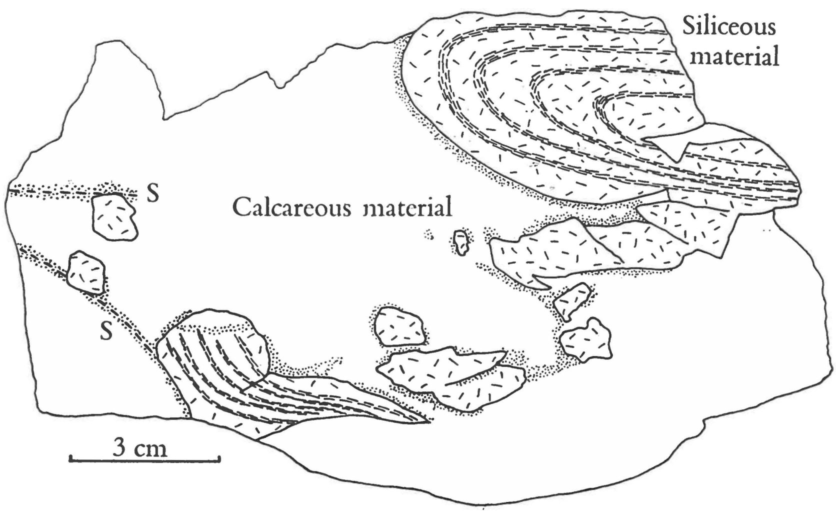

Fig. 54. Sketch of handspecimen from calcareous horizon on small island between Sioragdlit and Sãtukujôq. The kinematic environment of the fragmented siliceous bands (ornamented) in calcareous matrix (plain) is similar in many respects to that of basic dyke in deforming granite. Mobile material or neosome, in this case pyrites (dotted), is concentrated along contact between siliceous and calcareous material and along visible shear planes (S).

mation and excessive shearing and fracture, and hence become loci for preferred concentration of mobile material. On the other hand, when such dykes become broken into relatively small fragments they may be considered as floating in the granitic material, and offering no resistance to the homogeneous deformation of the latter: in such circumstances the dyke rock is no longer a metasomatic sink and may thus survive indefinitely without mechanical breakdown and chemical alteration or 'granitisation'.

Isolated fragments of disrupted dykes are usually surrounded by leucocratic felspathic zones interposed between the fragments and their granitic host rocks. This is especially evident in the case of fragments of green dykes (see figs. 58, 60, 62) and appears to be the result of relatively slight frictional drag between deforming granite and passive inclusion. In rare instances similar felspathic zones surround enclaves of supracrustal rocks in the Hornblende Granite of Sánerutip imâ. A similar circumstance is found in the calcareous rocks of Nivâq where competent siliceous bands are surrounded by an incompetent calcareous matrix. Inhomogeneous deformation is concentrated along the boundary between the two rock types and this boundary is a preferred site for pyrite mineralisation; pyrite is also concentrated along recognisable shear zones (see fig. 54). A close parallel to isolated fragments of dyke rock is found in comparatively large crystals or rock fragments found in mylonitic rocks, which are protected from further mechanical break-down by the fine grained, plastically deforming matrix in which they are enclosed. If the matrix is able to deform sufficiently rapidly, the porphyroclasts are subjected only to hydrostatic rather than shearing stresses, and under such conditions will survive indefinitely. Porphyroclastic textures analogous to those formed by the green dyke fragments in Sanerutian granite, but on a different scale, are described and figured by SUTTON and WATSON (1959).

It is of interest to note that kinematically controlled metasomatic replacement of bodies such as *unbroken* discordant amphibolites in granitic rocks has been forecast on theoretical grounds by RAMBERG (1956). "Now if relatively competent rocks are interlayered with incompetent rocks and exposed to compressive stresses, the "secondary" tensile stress created in the competent layers need not cause distinct macroscopic fracturing or breaking down. Instead, the tension could affect the whole body, and nucleation of new minerals (neosomes) would be favoured at countless points throughout the competent rock. The stressed competent rock could then be elongated uniformly and without loss of cohesion, because the growth of the introduced metasomes keeps pace with the elongation" (loc. cit., p. 520).

The following descriptions of green 2nd period dykes indicate the evidence cn which the above proposals are based.

The green dyke shown in figure 40 is one of those which is comparatively slightly deformed and shows pinch and swell structure in sections parallel to the lineation in the country rock. A complete separation of fragments is found in only one place but at all 'pinches' large amounts of leucocratic veining material are found (figure 55). It is probable that the veining material is a mixture of material introduced from external sources and material derived by metamorphic differentiation of the dyke. The large vein shown in figure 55 consists of plagioclase and quartz with only small amounts of microcline which is elsewhere the normal felspar of the neosome. Apart from the irregular veining, the dyke illustrated consists entirely of acicular pale green amphiboles which form a felted aggregate. It is evident from the illustration that the leucocratic veins within the dyke do not extend for more than short distances

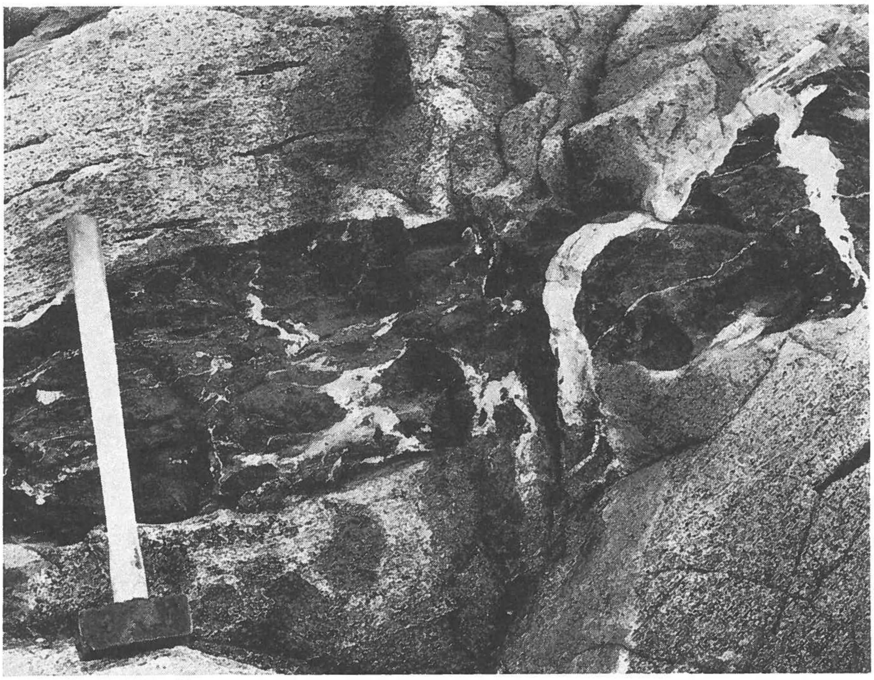

Fig. 55. Section between a:b and b:c of green 2nd period dyke shown in fig. 40. Main stretching direction is at right angles to hammer handle. Dyke shows pinch and swell structure but is broken only at one place (not shown). Leucocratic neosome is concentrated in 'pinches' but is also found elsewhere in the dyke where its agmatitic form is distinct from that of the strongly oriented neosome in grey 2nd period dykes. N. coast of Ikerasârqap nunâ, 1200 m W. of Anchorage.

into the surrounding granite. The contrast between the irregular veining of this dyke and the remarkably regular orientation of veining in the adjacent grey dyke is most striking and affords an excellent illustration of the important differences in structural behaviour of the two rock types.

An example of a green 2nd period dyke which has been completely brecciated is shown in figure 56. Elongation parallel to the lineation in the country rock is not evident in this dyke which occurs on the peninsula NE of the Anchorage on the north coast of Ikerasârqap nunâ. On the surface illustrated the dyke appears to be concordant to the structure in the granitic country rock but in vertical sections clearly is discordant —a similar relationship is seen in the green dyke shown in figure 67. The granitic material veining the dyke (fig. 56) appears to have occupied fractures and spaces between fragments of the brecciated dyke, but examination of the individual fragments shows that some replacement must also have taken place. It is apparent from the photograph that a

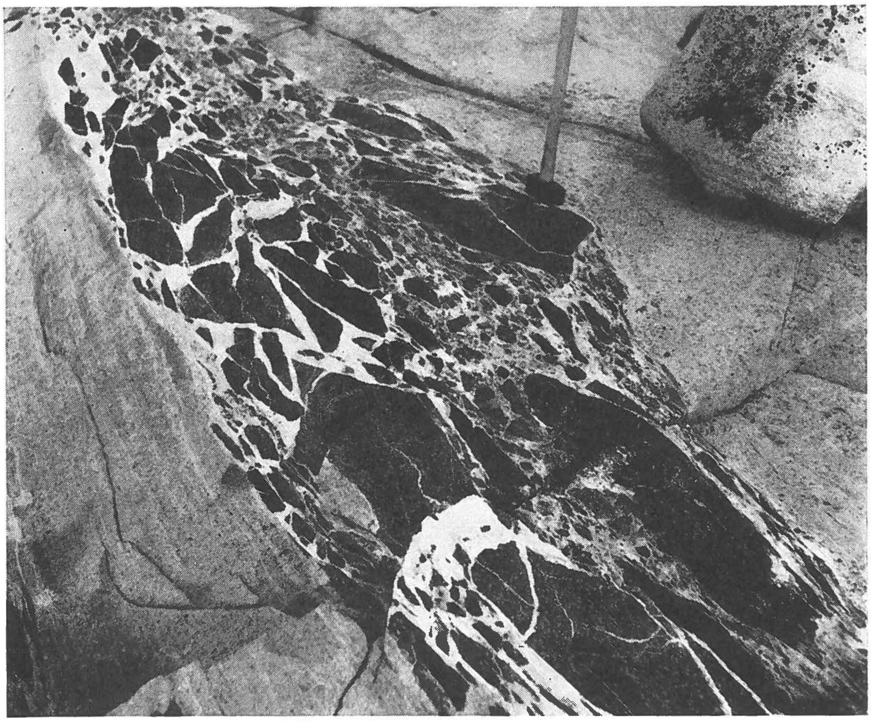

Fig. 56. Green 2nd period dyke in Sanerutian Hornblende Granite, agmatised by leucocratic neosome with movement of palaeosome fragments. The neosome appears to have been introduced into fractures in the brecciated dyke, but some replacement of the palaeosome has also taken place. N. coast of Ikerasârqap nunâ, 1 km E. of Anchorage.

large amount of relative movement has taken place between some of the fragments and it seems likely that the whole dyke was at one time in a state of incipient flow movement. It might be expected that had the potential mobility been fully realised, the material would have become one of the palingenetic dykes described earlier (page 80). In fact no palingenetic dykes have been found in which the basic fragments resemble the green dyke rock type. The amount of granitic material within the dyke shown is too great for it all to have been derived by metamorphic differentiation of the original dyke, and it must be assumed that appreciable amounts were introduced from external sources.

Figure 57 shows a 2nd period green dyke similar to that described above but less brecciated and containing smaller amounts of granitic veining. The type of veining is different however in that the granitic material contains appreciable amounts of hornblende and in places is indistinguishable from the Hornblende Granite country rock. This may represent a preliminary stage of a feature which is generally more

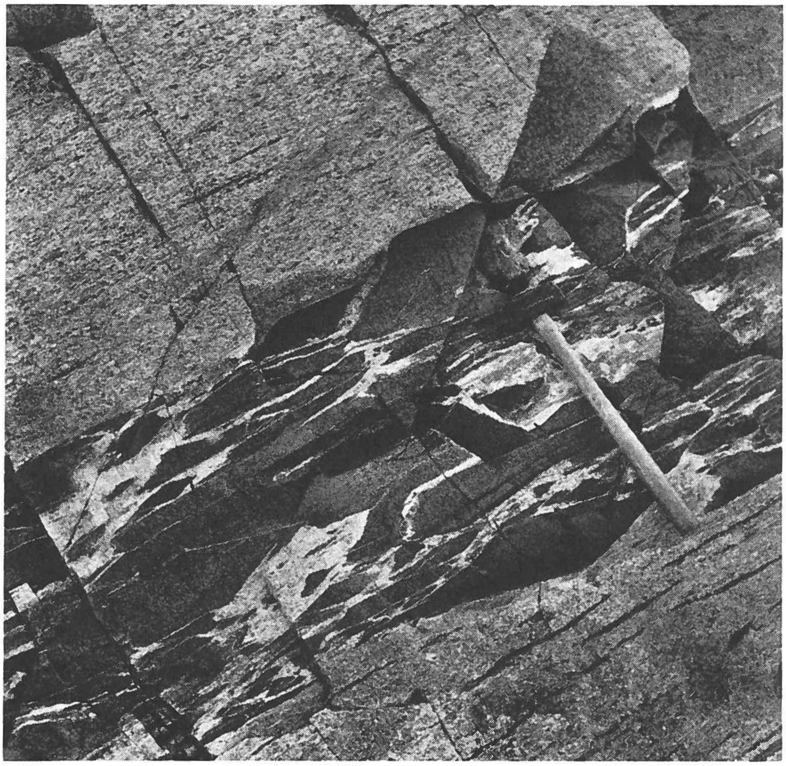

Fig. 57. Green 2nd period dyke agmatised by usual leucocratic neosome and also by veins identical with the Sanerutian Hornblende Granite country rock; unlike other cases illustrated (figs. 35 and 36) the country rock does not appear to be intrusive into the dyke. N. coast of Ikerasârqap nunâ, 1 km E. of Anchorage.

characteristic of Sãtukujôq, namely the extreme mobility of the Hornblende Granite country rock resulting in the fragmentation of green dykes: evidence is adduced elsewhere that this mobility is consistent with deformation in the solid state (page 91).

The mobility of the granite is shown by the manner in which separated fragments of a dyke become displaced relative to one another. Figure 58 shows separated blocks of a green 2nd period dyke on the SE coast of Sãtukujôq. The section is normal to both lineation and foliation directions in the granite and is that in which displacements are usually least, as the principal stretching axis is parallel to the lineation. In this case the absence of fracturing and veining of the dyke distinguishes it from these described earlier and the only sign of chemical activity is the leucocratic nature of the granite immediately adjacent to the dyke blocks. The suggested explanation for this has been given earlier (page 84) and it appears that the mobility of the granite here was sufficient to separate the dyke blocks before extensive fracturing had taken place.

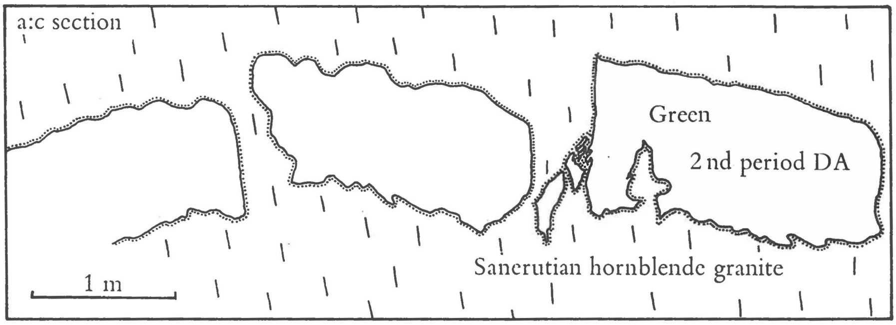

Fig. 58. Separated blocks of flat-lying green 2nd period dyke in Sanerutian Hornblende Granite. Blocks are surrounded by narrow felspathic rim. Foliation and lineation in country rock are undisturbed. Southern peninsular of Sãtukujôq.

Further stages in the disruption of green 2nd period dykes are shown in figures 59 and 60. In both cases the fragments illustrated can be interpreted as dyke remnants only because the excellent coastal exposure enables the trail of fragments to be followed for over 50 m in each case. Narrow leucocratic zones surrounding the dyke fragments can be seen in figure 60 and the similarities with figure 54 are quite clear.

On the SE coast af Sãtukujôq is a coastal exposure in which three types of dyke occur together; these are two 2nd period dykes, grey and green respectively, which are cut by a 3rd period dyke. The relationships are illustrated in figure 61. Both of the 2nd period dykes have been fragmented and folded by movement within the 'mobile' granite, and

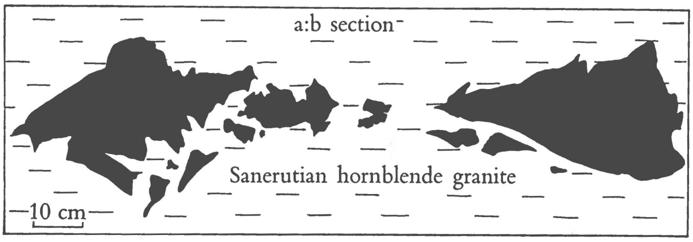

Fig. 59. Fragments of green 2nd period dyke in Sanerutian Hornblende Granite. The course of the original dyke can be followed for 100 m on good coastal exposure (see fig. 60). N.W. coast of Sãtukujôq.

the fragments drawn apart. The grey dyke remnants contain a few granitic veins. The granitic rock in the vicinity of the dyke fragments is in many places finer grained than elsewhere (without ornament in fig. 61); it seems that the concentration of movement within the granite in the vicinity of the dykes has resulted in granulation of the granite which outside this zone was undergoing slower viscous deformation. The 3rd period dyke illustrated quite clearly was emplaced after com-

Fig. 60. Fragments of green 2nd period dyke shown in fig. 59. Original dyke was gently dipping and has been folded. Fragments of same dyke can be seen top centre. N.W. coast of Sãtukujôq.

pletion of the movements by which the 2nd period dykes were disrupted. There is, however, no *conclusive* evidence that the fragments illustrated ever were 2nd period dykes. Similarities of rock type cannot be considered a diagnostic feature in such an area. However, the contact with genuine pre-granite enclaves at the same locality is significant, as also is the discordant trend of the lines of fragments. Figure 61 (inset) shows the same 3rd period dyke (without ornament) as in the previous figure but a few metres further along its strike; it is seen to cut what is apparently another grey 2nd period dyke which is better preserved than that shown in the larger sketch. The discordance of this dyke to the trend of enclaves and foliation in the granite leaves little room for doubt that it was originally an intrusive basic dyke.

Numerous green 2nd period dykes occur on the eastern extremity of Sãtukujôq and are broken and drawn out parallel to the lineation direction of the country rock. Internal fracture and veining effects have been only slight and leucòcratic zones in the immediately adjacent granite (figure 62) are the only signs of chemical activity. No sign of discontinuity can be seen in the granite between separated fragments

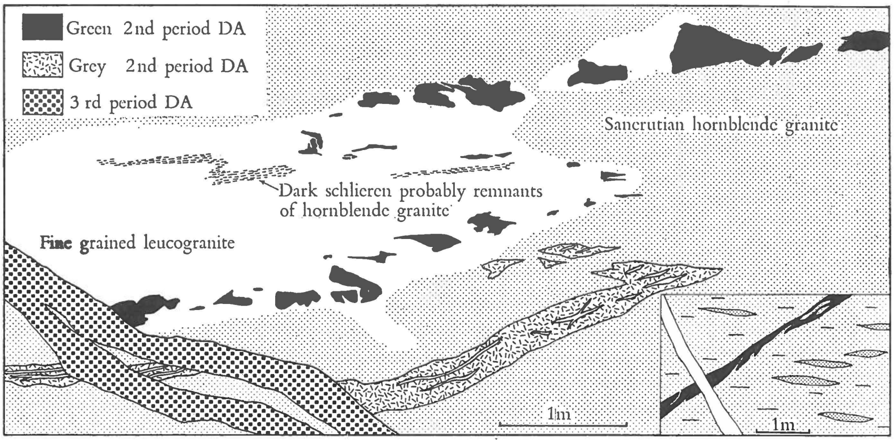

Fig. 61. Remnants of green and grey 2nd period dykes in Sanerutian Hornblende Granite; both dykes have been folded and the axial planes of the folds are parallel to country rock foliation. Both 2nd period dykes and their neosome veins are cut by undeformed and unmigmatised 3rd period dyke. Inset shows continuation of 3rd period dyke (white) cutting unbroken 2nd period dyke which is discordant to foliation and trend of enclaves (closely dotted) in country rock granite. S.E. peninsula of Sãtukujôq.

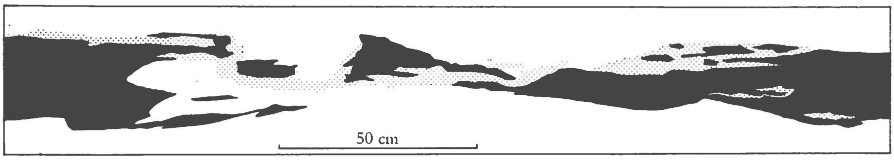

Fig. 62. Typical broken up green 2nd period dyke (black) from E. Sãtukujôq. Discontinuous leucocratic rim (dotted) separates dyke from enclosing Sanerutian Hornblende Granite and is also found in veins within the fragments of dyke.

of these green dykes and it is clear that at the time the dyke was disrupted, the granite was deforming viscously and undergoing a thorough recrystallisation.

Granitic rocks of the Sânerutip imâ sub-area.

It has been suggested that the granitic rocks of the Sánerutip imâ sub-area underwent profound changes during the period of Sanerutian plutonic activity, resulting in the formation of the Hornblende Granite. It is apparent, from the descriptions given of the 2nd period dykes, that the granite in which they are found must have been strongly influenced by the processes which effected such marked physical and chemical transformations of the dykes. With large masses of more or less homogeneous rock such as granite, it is difficult to establish precisely what changes were effected; microscopical evidence (page 117) is of little use as it indicates that the Hornblende Granite, unlike the Ketilidian granites, was completely reconstituted during the Sanerutian. Information regarding the state of the Hornblende Granite must therefore be inferred from the evidence afforded by the present fabric of the rock and its physical relations with dykes and enclaves of supracrustal rock.

The main petrologic features of the Hornblende Granite have already been briefly described, as also has the remarkable conformity of structures in the Sánerutip imâ sub-area with the identifiable Sanerutian structures elsewhere in Ilordleq.

The pronounced foliation and linear structure in the granitic rocks of the Nivâq sub-area are equally well developed in the SW part of the Sánerutip imâ sub-area. However, with progress toward the NE, along the NW coast of Ikerasârqap nunâ, the linear structure becomes increasingly strongly developed and there is a corresponding weakening in the intensity of the foliation. Throughout much of Sãtukujôq the foliation is either absent or very weak but the linear structure is everywhere strongly developed; such a rock is commonly called a pencil gneiss. It is apparent from the degree of deformation of the dykes in both the Sánerutip imâ and Nivâq sub-areas, and degrees of deformation of enclaves in the latter sub-area, that the areas where the lineation is most intense are those areas where deformation has been strongest. In Pt. III an attempt is made to account for these observations by the theory of viscous flow and variations in the effective viscosity of the granitic rocks. However, it is sufficient for the purposes of this account to show that the Hornblende Granite was capable of flow in the solid state. The presence of such a marked directional fabric, in the Hornblende Granite, homologous with that in the Ketilidian granites, shows that a liquid or magmatic state was never achieved, except possibly in one small area (page 23). The separation of fragments of broken dykes is a clear indication that flow occurred: even better evidence of flow is provided, however, by dykes which were not fragmented but invaded by the granite. Two such examples are available, the first of which, shown in figure 35, is a narrow grey 2nd period dyke occurring near the northern extremity of Ikerasârqap nunâ. At this point the effective viscosity of the granite must have been relatively slight and the shearing effects on the dyke correspondingly small, with consequently only little metasomatic activity. The granite within and surrounding the dyke has the same marked fabric as elsewhere. A similar case is found near the westernmost part of Sãtukujôq, where a green 2nd period dyke, figure 36, is invaded by tongues of granite. It is clear that only those dykes retaining their dyke or sheet forms are likely to show such features as they, unlike the fragmented dykes, obstruct the homogeneous 'flow' of the granite.

Porphyroblasts of microcline, 5–10 mm in size, in the Hornblende Granite occur at scattered localities on Ikerasârqap nunâ but are most widespread on Sâtukujôq and Sioragdlit. They are clearly of Sanerutian age as they show no sign of cataclasis and in one case have been found to be later than a 2nd period dyke (page 81). It is probable that they are of similar age to the felspar porphyroblasts in the augen granite bordering Nivâq. A number of small pegmatites and aplites are found throughout the Sánerutip imâ sub-area; they are frequently discordant to structures in the country rock but are themselves undeformed and may thus be regarded as late or post kinematic with respect to the Sanerutian deformation. There is a notable absence in the Hornblende Granite of the mylonitic zones which frequently occur in the Ketilidian granitic rocks.

Enclaves in the Sanerutian Hornblende Granite.

Enclaves of supracrustal rocks are of similar shape and orientation relative to foliation and lineation, as those found in the Ketilidian granites in the SW part of the Nivâq area. In view of the metasomatic replacement of the 2nd period dykes in the Hornblende Granite, the preservation of enclaves of similar composition at the same localities at first appears somewhat anomalous. In only a few cases have enclaves of pre-granite supracrustal rocks been affected by Sanerutian migmatisation. Figure 63 shows one such case from a migmatic part of the Hornblende Granite close to the anchorage on the NW coast of Ikerasârqap nunâ. The amphibolite palaeosome contains irregular felspathic veins which are later than the country-rock granite and without its strong directional features; the form and occurrence of the felspathic veins are very similar to those in nearby green 2nd period dykes (compare figure 56) and they are probably of Sanerutian age. In figure 64 another part of the same migmatite outcrop is shown; in this case the palaeosome is similar to the coarse grained green variety of 1st period dykes although in this case it cannot be shown to have been one. Here, too, the mantling and veining by the felspathic material is very similar to that seen in some green 2nd period dykes and is of Sanerutian origin. The migmatite is cut by a narrow 3rd period dyke (page 95). Another apparently anomalous feature of the enclaves in the Hornblende Granite is the relative constancy of their axial ratios even where the surrounding granite and adjacent dykes can be shown to have undergone intense deformation during Sanerutian time. In view of the extreme flattening and elongation shown by enclaves in the augen granite of the Nivâq sub-area, a similar flattening and elongation might be expected in the enclaves of the Hornblende Granite, especially in the NE part of the Sánerutip imâ sub-area.

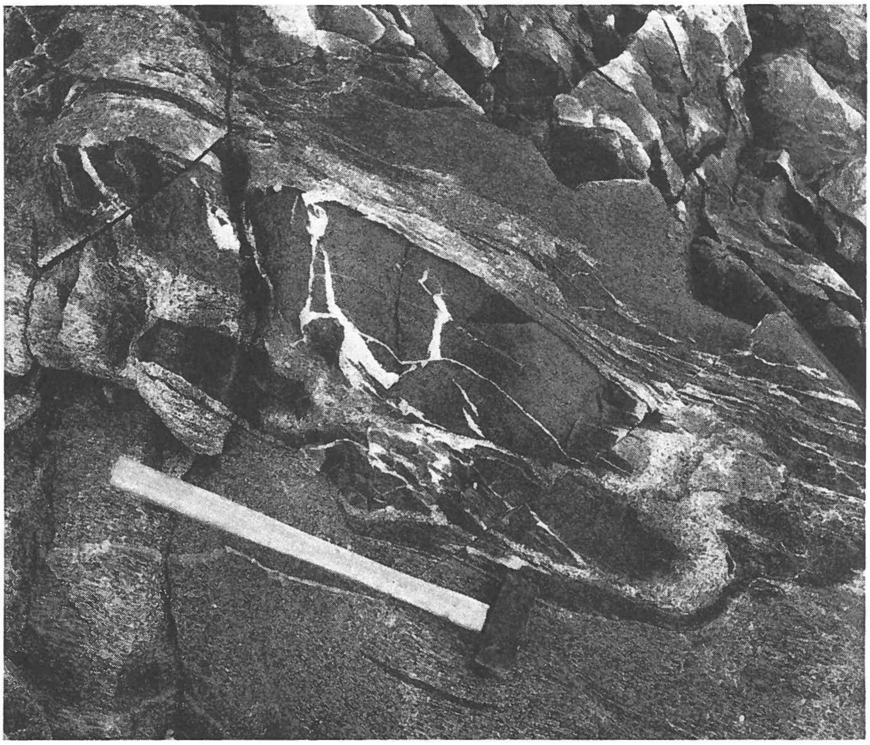

Fig. 63. Migmatite with metavolcanic palaeosome and nesosome of what is now Sanerutian Hornblende Granite. Agmatitic felspathic veins are probably Sanerutian in age, corresponding to similar veins in some green 2nd period dykes which provide a similar kinematic environment (see figs. 55 and 56). Anchorage on N. coast of Ikerasârqap nunâ.

A suitable explanation of these apparent paradoxes can be found by comparing the enclaves in the Hornblende Granite, not to the 2nd period dykes as a whole, but to individual fragments of broken up dykes which, as has been suggested previously, may be considered as floating in the viscously deforming matrix. Under such circumstances small bodies such as the enclaves would be subject only to hydrostatic pressure and not shearing stresses. The stresses exerted on a body enclosed in a viscously deforming granitic mass will depend on the size of the enclosed body, the relative viscosities of the body and enclosing granite and the rate of strain of the granite. The different behaviour of the enclaves in different localities may thus be used to compare the effective viscosities of the granitic rocks throughout the area; the viscosity of the granite depends to a large extent on the rate of recrystallisation, which in turn may be used as a measure of the intensity of the plutonic activity. "Intensity of plutonic activity" is a somewhat imprecise term but of

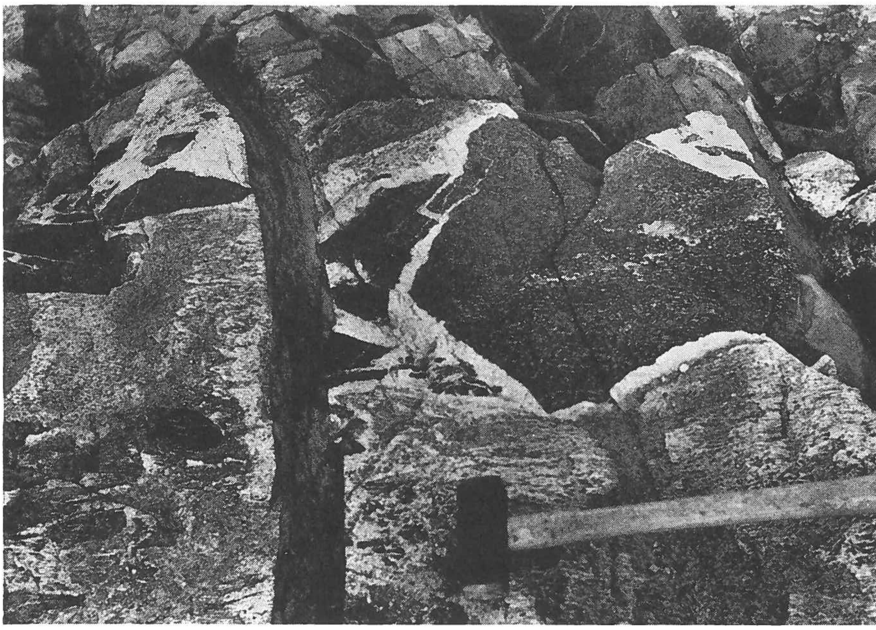

Fig. 64. Migmatite with neosome of Sanerutian Hornblende Granite. Rock type of palaeosome is similar to that of some 1st period dykes. Leucocratic material rimming and veining palaeosome is probably of Sanerutian age and corresponds to leucocratic veining of green 2nd period dykes. Cross cutting 3rd period dyke post-dates all migmatisation. Anchorage on N. coast of Ikerasârqap nunâ.

more practical use in basement complexes than the terminology of metamorphic facies; an area with crystalline rocks of a single metamorphic facies, such as Ilordleq, may show considerable variation of "plutonic facies".

Migmatisation in the Sânerutip imâ sub-area.

Migmatisation of many of the 2nd period dykes during the Sanerutian affords clear evidence of the migration of granitic material but gives no indication as to where this material was derived from. The amount of metasomatic material is sufficiently small for it to have been derived from the country rock granite without changing the overall composition of the latter to any noticeable degree. The material forming the Sanerutian pegmatites and porphyroblasts in the Hornblende Granite could be derived from the same source. However, the possibility that some granitic material was introduced from external sources cannot be ignored and, as with the possibility of introduction of quartz in the Qeqertaussaq sub-area, there is no justification for deciding one way or the other.

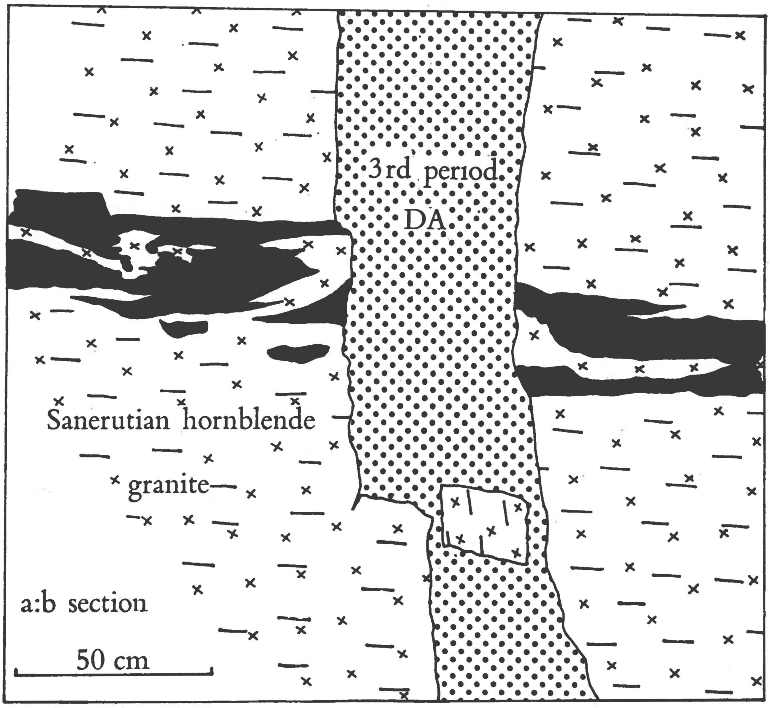

Fig. 65. Remnants of 2nd period dyke (black) cut by 3rd period dyke with xenolith. N.W. coast of Sãtukujôq.

If the neosomatic material was of relatively local origin, a change in composition of the Sanerutian granitic rocks would be expected. Such changes would be so small, however, that they could not be established quantitatively in an area in which the granites are known to have been originally inhomogeneous. The fact that the Sanerutian granite of Sánerutip imâ is hornblende bearing, as opposed to the dominantly biotite bearing Ketilidian granites, may appear to suggest that it has undergone some degree of 'degranitisation'. An introduction from external sources does not seem unlikely in view of the amount of Sanerutian migmatisation in both the Sánerutip imâ and Natsît iluat sub-areas, but the significance of such isolated observations must await a regional account and synthesis of observations concerning the Sanerutian plutonic period.

3rd Period Discordant Amphibolites.

Throughout Ilordleq occur swarms of distinctive amphibolitic dykes, the 3rd period dykes, which clearly post-date the plutonic events giving rise to the Sanerutian features described in the previous pages. This is

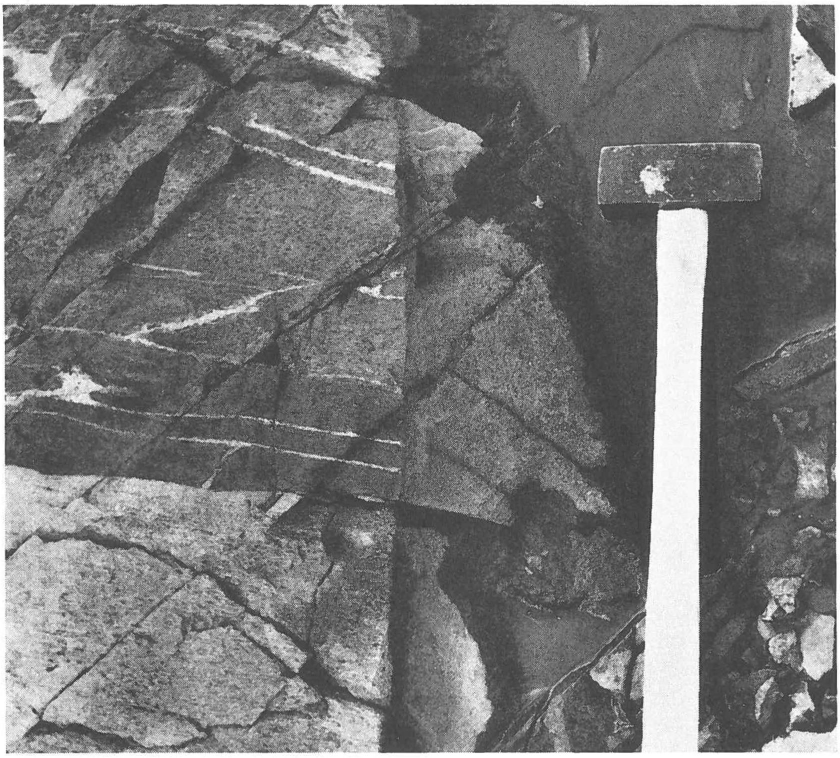

Fig. 66. Migmatised 2nd period dyke (upper left) in Sanerutian Hornblende Granite (lower left), cut by unmigmatised 3rd period dyke (right) which is clearly later than neosome in 2nd period dyke. The same 2nd period dyke is shown in fig. 67.

perhaps best seen in the Sánerutip imâ sub-area where the migmatitic veins which cut the 2nd period dykes are themselves cut by the 3rd period dykes which are unmigmatised and show clear evidence of having been intruded into a country rock capable of sustaining fractures. Figures 64, 65 and 66 show 3rd period dykes which clearly post-date the reactivation phase of the Sanerutian. Figure 66 shows a detail of the intersection of a 3rd period dyke and a veined green 2nd period dyke in the Hornblende Granite of the Sánerutip imâ sub-area; a more general view of the 2nd period dyke is shown in figure 67 in which the dyke origin of the amphibolite is evident. From this exposure therefore the following sequence can be established:-

(4) Intrusion of later basic dyke	(3rd period dyke)
(3) Veining of the basic dyke	(Sanerutian reactivation)
(2) Basic dyke	(2nd period dyke)
(1) Granite	(Ketilidian).

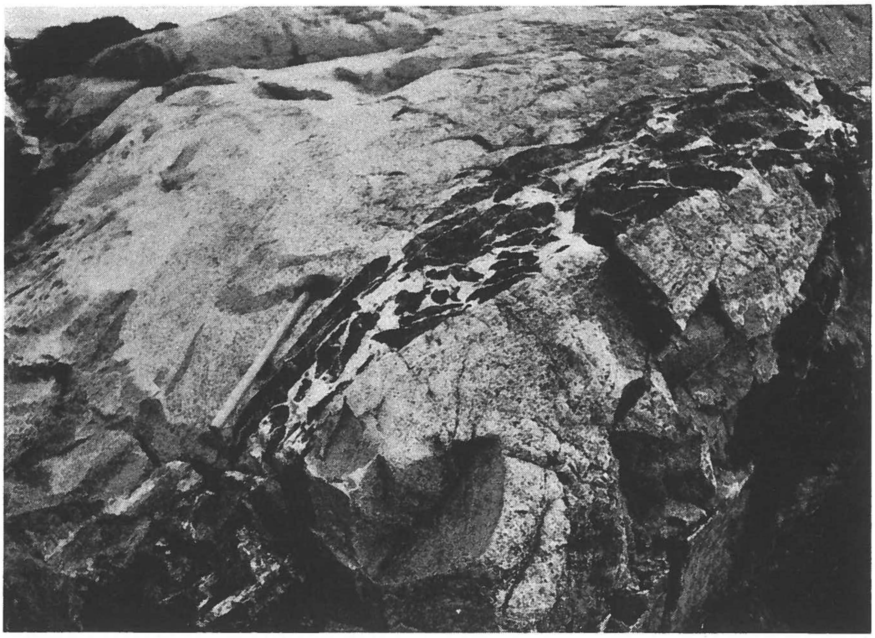

Fig. 67. Agmatitic leucocratic neosome in green 2nd period dyke in Sanerutian Hornblende Granite (see also fig. 66). 500 m E. of Anchorage, N. coast of Ikerasârqap nunâ.

The 3rd period dykes have many unusual characteristics and warrant a detailed description which will be presented as Pt. II of this series. The following account is therefore limited to a description of those features of the dykes, and their interpretation, which have a bearing on the chronology of the area. The main conclusion is that the 3rd period dykes were emplaced during the closing stages of the Sanerutian period, at a time when compressional conditions still prevailed and while the country rocks were still at an elevated temperature: accordingly their intrusion does not indicate a break in the plutonic development such as is indicated by the intrusion of the 2nd period dykes in accordance with SEDERHOLM's method of basic dykes. A summary of the evidence for this interpretation is given below.

Swarms of 3rd period dykes occur throughout Ilordleq, the strike and hade of dykes usually being constant within any one swarm. The direction of the swarms is WNW-NW but a few dykes, usually occurring singly, strike NE-ENE. The dykes are fine grained and consist principally of green hornblende and oligoclase which occur in varying proportions both within individual dykes and from one dyke to another: biotite and epidote are present in appreciable quantities in some dykes. Relict ophitic textures such as are found in 2nd period dykes, do not occur in the 3rd period dykes which have primary 'metamorphic' textures.

The most striking feature of the dykes is the extreme textural variation due to separation of the light and dark material. Aggregates of small amphiboles vary from a few mm up to many cm in size and may be gradational into or sharply differentiated from the groundmass consisting of approximately equal amounts of oligoclase and amphibole. Individual amphiboles, which are prismatic or acicular in form, are aligned parallel to the strong foliation present in many of the dykes. Aggregates of amphibole are elongated and are also parallel to the foliation, and concentrations of both light and dark material are streaked out parallel to the foliation in many cases.

The foliation is generally S shaped and in the border zones of the dykes is almost parallel to the dyke margins (fig. 68). The foliation appears to be due to horizontal movement along the dyke fissure, with the direction of relative movement shown by the asymmetry of the foliation. Thus, on a horizontal surface, an S foliation shows dextral movement and a Z foliation shows sinistral movement. That movement has actually taken place along dyke fissures has been confirmed in many cases by the offset of structures on either side of a dyke; the maximum displacement recorded is 5 m and this on a 1 m dyke.

There is convincing evidence that these unusual features are due to movement, not subsequent to the emplacement of the dykes, but at the time of dyke emplacement. Displacements and en echelon effects of the dykes are frequent and where such offsets occur the foliation is not cut abruptly but swings round to conform with the irregularities in the outcrop pattern. It is thus apparent that the foliation was formed at the same time as the offsetting of the dykes took place. Evidence that the offsetting took place at the time of dyke intrusion is shown by apophyses which continue without interruption across the 'faults' along which the dykes are displaced. Such relationships, which are illustrated in figure 68, can be due only to displacement taking place before consolidation of the dyke magma. The separation of light and dark material in the dykes can be adequately accounted for by differentiation by deformation (BOWEN, 1926) during crystallisation of the magma within the dyke fissure. Other processes which have been considered, but which seem inadequate to account for the observed textural features are metamorphic differentiation, metasomatic alteration, liquid immiscibility, and multiple intrusion.

The original nature of the various features described is clearly demonstrated in the rare instances when two 3rd period dykes in the same swarm intersect one another. The foliation and textural pattern of the earlier dyke are cut by the later dyke.

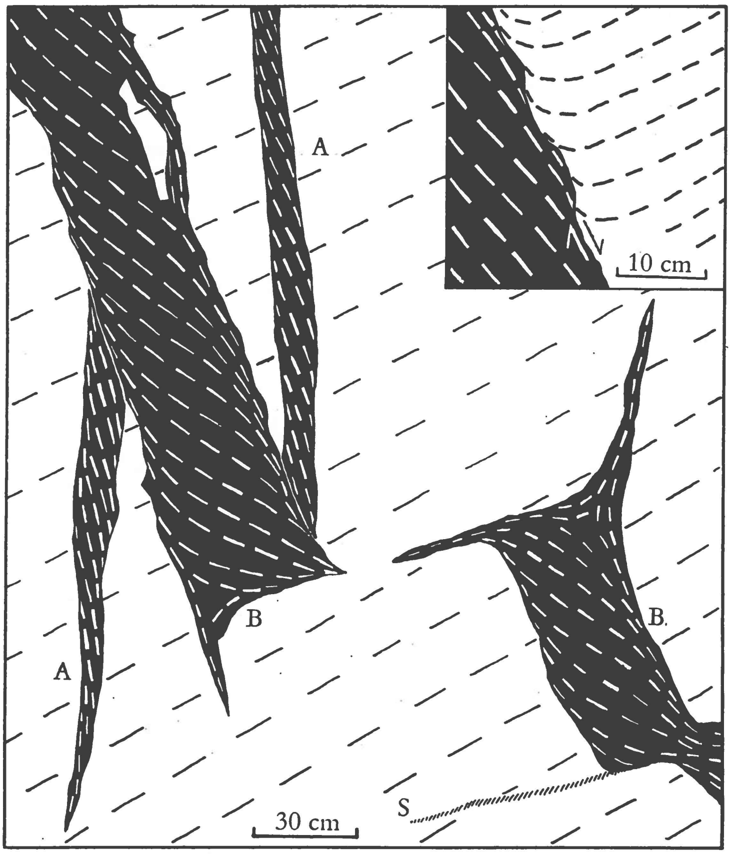

Fig. 68. Diagrammatic sketch showing principal features of 3rd period dykes (black). For explanation see text.

It seems likely that the 3rd period dykes were emplaced along shear fractures in the granitic country rock; a conjugate set of shear fractures has been identified (WNW and NE) and their orientation and the relative movement along each direction is consistent with their having been formed by a NNW-SSE compression. As this direction is similar to the direction of the maximum principal stress during the Sanerutian reactivation it is likely that the 3rd period dykes were emplaced during a later 'brittle' stage of the Sanerutian deformation. This proposal finds support in the evidence concerning the physical state of the country rocks at the time of dyke emplacement. Where apparent offsets of the dykes are found, no corresponding break or fracture is usually evident in the country rock granite; in some cases this could possibly be accounted for by the apparent offsets being due to original irregularities of the dyke fissure, as described by KAITARO (1952). In other cases, however, the irregularities can only be explained as being due to faulting with subsequent healing of the fractures in the country rock; in a few cases the fractures in the country rock have been only incompletely healed and it can be seen that the country rock foliation has been plastically deformed and drawn out adjacent to the plane of movement. The foliation in the country rock immediately adjacent to the dykes is sometimes dragged into parallelism with the dyke margins (fig. 68, inset) and in these cases forms a continuance of the S foliation within the dykes. All these features indicate that at the time of dyke emplacement, the country rock granite, although sufficiently brittle to fracture, was nevertheless still capable of a certain degree of plastic deformation and recrystallisation. It may thus be concluded that the 3rd period dykes were emplaced not only during compressional stressing of the country rocks but also while these country rocks were at moderately elevated temperatures. This conclusion is of some importance as it shows that the 3rd period dykes do not represent a significant break in the plutonic activity but rather were emplaced during a period of declining plutonic activity. Such dykes do not of course invalidate SEDERHOLM's method of basic dykes but merely indicate that the method cannot be applied when dealing with dykes of this type. Dykes very similar to the 3rd period dykes have been described from the Åva area, SW Finland, by SEDERHOLM (1934) and by KAITARO (1953) and have been interpreted by the latter in much the same way as is proposed for the Ilordleq dykes.

One result of the recognition of the 3rd period dyke type is the extra credence provided for the view that dykes which do not show such features, i.e. normal metabasaltic dykes such as the 2nd period dykes, have been emplaced during periods of crustal tension and thus represents a complete and significant break in plutonic acitivty.

Gardar Period.

Large numbers of unmetamorphosed dolerite dykes occur especially in the S and SE parts of Ilordleq, where dyke widths of 50 m are common and exceptional dykes are up to 150 m in width. The Gardar, so named by WEGMANN (1938), was a period of intensive volcanic activity and rocks of this age are found throughout South Greenland; they include the intrusives of the South Greenland alkaline volcanic province and extrusive volcanic rocks interbedded with continental sandstones (see map, Plate VIII).

The scores of Gardar dykes occurring in Ilordleq have not been included on the map (Plate IX) but will be shown on the geological map of the Nunarssuit map area, which is in the course of preparation, where their density and structural relations with the Nunarssuit intrusive complex (HARRY and PULVERTAFT, 1963) will be apparent.

An attempt has been made to subdivide the dykes on the basis of strike directions and relative ages but the comparatively small number of well exposed intersections has prevented resolution of some apparent anomalies due to deviations from the following sequence:–

(7) Black, porphyritic	NNW	
(6) Brown	NW	Relative ages not known
(5) Brown	ENE	
(4) Brown coarse grained	ENE	Main dyke swarm.
(3) Brown medium grained	NE	
(2) 'Big Felspar' and related dykes	NE-ENE	
(1) Brown	ENE	

The vast majority of the dykes are of brown-weathering dolerite and in all dykes phenocrysts (or xenocrysts) of felspar, up to 20 cm in size, may be found. Six distinctive and persistent ENE dykes, which in places attain widths of up to 150 m, are characterised by an abundance of xenoliths of anorthosite and xenocrysts of felspar or, less commonly, xenoliths of granite. In places these dykes are composite and then consist of a variety of rock types including granophyre, granite and syenite. These dykes form part of a swarm of 'Big Felspar' dykes extending from Kobberminebugten in the west to Julianehåb in the east.

The main dyke swarm is concentrated in the S and SE of Ilordleq and is responsible for a crustal widening of 10–20 % within a zone approximately 5 km in width. In the south-west the dykes of the main swarm form an irregular anastomosing network with numerous confluences and bifurcations, but when traced along their strike in a NE direction become more regular. The emplacement of this swarm had an intimate structural connection with the emplacement of the extensive Nunarssuit intrusive complex which is slightly younger than the dykes.

The few narrow trachytic dykes which occur in Ilordleq are probably related to the alkaline rocks of the Nunarssuit complex.

Extensive faulting took place during Gardar time but only a few of the more important faults are shown on the map (Plate VIII). It is apparent that many of the faults by which Gardar dykes have been displaced were active during earlier periods and examination of aerial photographs suggests that the most intense faulting took place before the emplacement of the Gardar dykes. There is too evidence of both sinistral and dextral movements at different times on the same fault and in view of the undoubted complexity of the faulting, no systematic account will be attempted. Only horizontal components of fault movements can be detected.

Rock surfaces within fault zones are frequently coated with epidote and in the SE of Sãtukujôq an ENE crush zone contains quartz veins with small amounts of galena and chalcopyrite.

No metamorphism of rocks of Gardar age has been detected anywhere in South Greenland and the Gardar intrusions at Kûngnât and Ilímaussaq have been dated at 1240 and 1086 million years respectively (MOORBATH, WEBSTER and MORGAN, 1960).

Post-Gardar.

Three NNW striking dolerite dykes occur in Ilordleq and postdate all fault movements. These form a part of a coast-parallel swarm of regional extent in which individual dykes are extremely persistent, although the number of dykes is relatively small. A Tertiary age has been suggested for these late dykes (BERTHELSEN, 1961).

Ilordleq contains no features of outstanding interest with regard to the development of South Greenland during the Quaternary (WEIDICK, 1959, 1963).

SECTION III
PETROGRAPHY

Sanerutian Development of Augen Granite in the Nivâq sub-area.

The development of augen granite in the Nivâq area during the Sanerutian has been referred to previously (page 52). The degree of augen development is closely correlated with the degree of Sanerutian deformation of Ketilidian enclaves (page 52 and figure 24). The granitic rocks described below have been selected as representative of the gradation observed in the field from more or less unchanged Ketilidian granite (A) to Ketilidian granite strongly affected by the Sanerutian activity (E) in which most of the original Ketilidian features are obscured by those of Sanerutian age; in the field the most obvious change is the development of large porphyroblasts of microcline, and the appearance of handspecimens representative of the various stages is shown in Plates I and II. The cut specimens illustrated all show surfaces normal to the lineation direction, i.e. a:c sections, except for specimen A in which no lineation can be seen in handspecimen. The photographs give a somewhat misleading impression of the actual rocks, as the contrast has been exaggerated in order to emphasise the textural variation. The location of the specimens is shown on Plate IX.

The purpose and results of the microscopic investigation may be summarised as follows. The broad significance of the changes shown having been determined from field evidence, thin sections were examined in order that the microscopic features might be interpreted in the light of the conclusions based on such evidence; petrographic interpretation of granitic rocks is not sufficiently reliable to justify significant amendments to conclusions based on field evidence. The following descriptions are therefore presented not as the only possible interpretation of the observed microscopical features but as one which accords with the conclusions based on field evidence.

In the first member of the series (A), in which Sanerutian effects have been least, certain microscopic features of the original Ketilidian granite can be recognised. Most important of these is the presence of megacrysts of microcline and plagioclase. The microcline megacrysts appear to have formed by replacement of original plagioclase: all stages are found between unreplaced plagioclase and plagioclase preserved only as optically continuous skeletal remnants in a microcline porphyroblast (Plate IIIb). This structure is quite distinct from that produced by exsolution and is typically the result of potash metasomatism in syn- and late-kinematic granites (MARMO, 1955). It is unlikely that significant amounts of potassium were introduced into the granite of the central sub-area during the Sanerutian and isochemical recrystallisation is unlikely to produce such textural relationships. These 'old' felspars may thus be regarded as being of Ketilidian age, and can be distinguished from 'new' Sanerutian porphyroblasts which are found in other members of the series (C, D, E). In the new microclines no skeletal remnants of plagioclase are found but they are instead poikilitic with randomly oriented inclusions of quartz, plagioclase and microcline (Plate V d). Carlsbad twinning is common in the old microclines (Plate III d) and seems to be inherited from the replaced plagioclase; such twinning is rare in the new microclines which are also distinguished by small amounts of flame perthite. Flame perthite is a usual feature of microcline porphyroblasts in the Sanerution Hornblende Granite (page 117). Myrmekite is usual on the margins of 'old' felspars in rocks of the augen granite series, but is rarely found bordering new microclines.

Microscopic development of the augen can be summarised as follows:–

A. 'Old' felspar porphyroblasts fractured and replaced by cross-cutting veins and along margins by fine grained groundmass (Plate III b).

B. First appearance of polycrystalline augen which consist of fine grained mafic-free areas centred on relics of 'old' felspar (Plate III c and d). No post-kinematic changes.

C. Two types of augen apparent: the first type is a further development of those in B, consisting of quartz-felspar mosaic formed by degradation of old porphyroblasts (Plate IV a and b). The second type consists of old felspar porphyroblasts (Plate IV c and d); these Ketilidian porphyroblasts are better preserved than any in A or B, showing that C has not passed through the stages represented by A and B. These rocks therefore show a spatial rather than genetic series of changes. The preservation of the 'old' porphyroblasts in C is accompanied by a more intense granulation and increase in proportion of the groundmass. It seems that by concentration of movement in the recrystallising groundmass, opportunity is afforded for preservation of some large felspars as porphyroclasts (see also page 84).

D. Two types of augen still apparent: polycrystalline augen of C are centres for porphyroblastic growth of 'new', i.e. Sanerutian, microcline (Plate V a and b), while other augen contain porphyroclasts of Ketilidian felspar which show some fracturing and distortion. Sanerutian microcline porphyroblasts are undeformed and post date the syn-kinematic granulation stage.

E. Two types of augen still in evidence: those consisting of new microcline (Plate V c and d) are dominant and much larger than the porphyroclastic augen (Plate VI a); the latter too are always aligned parallel to the foliation whereas the former intersect the foliation but are undeformed (Plate II b). Old porphyroclastic microclines have features very similar to those in A (compare Plates III b and VI a). The two types of augen can also be distinguished in Plate II a and b, where smaller concordant augen contrast with larger discordant post-kinematic porphyroblasts.

It is unlikely that the rocks described below were identical before their Sanerutian transformation, but any differences which existed were probably small compared with changes which the rocks underwent during the Sanerutian.

Granite A. (GGU 31534) Plates I and III b.

Foliation not evident in handspecimen but visible on outcrop surfaces; contains felspar porphyroblasts up to 1.0 cm in size, surrounded by a fine grained groundmass, the whole comprising 50 % microcline, 20 % plagioclase, 20 % quartz, 5 % biotite and small amounts of chlorite, sphene, orthite, muscovite and ore.

Porphyroblasts of microcline and plagioclase are contained in a granoblastic groundmass, which forms half the rock. The microscopic appearance is dominated by microcline porphyroblasts up to 1 cm in size which have been formed by the replacement, incomplete in most cases, of earlier plagioclase porphyroblasts to form replacement perthites. The 'skeletons' of relict plagioclase remaining within the microclines are optically continuous. The outer parts of the microcline porphyroblasts often are without plagioclase relicts and replacement of the original plagioclase porphyroblasts appears to have been followed by further outward growth of the microcline; the microclines have subhedral forms. Every gradation can be found between rare plagioclases which have suffered no replacement to microclines with only a few small and scattered inclusions of plagioclase. The original plagioclase shows very fine albite twinning and often carlsbad twinning too; preservation of the carlsbad twinning by the replacing microcline is found both here and in many other rocks from Ilordleq. The old plagioclases are turbid and compositions fall within the range oligoclase-andesine.

The replacement perthite porphyroblasts described above are fractured and penetrated by veins of the small (0.1 mm) saccharoidal microclines and plagioclases which, together with quartz, form most of the groundmass. The groundmass minerals also embay the margins of the porphyroblasts which are clearly of earlier origin than the smaller grains. Little internal migration was involved in the recrystallisation of the porphyroblasts as the small new microclines are concentrated in those parts of the rock where microcline porphyroblasts predominate, and small new plagioclases in those parts where the relict plagioclases are most frequent. The new plagioclases are only slightly turbid and are rarely twinned, but refractive indices are similar to those of the older plagioclase. The new grains of plagioclase are invariably myrmekitic, unlike the old plagioclase in which myrmekite is rarely developed. The myrmekite in the new plagioclase is not confined to those grains adjacent to potash felspar.

The small amounts of mafic minerals are found in irregular aggregates, with sphene rimming the ore grains. The flakes of brown biotite are deformed and show varying degrees of alteration to chlorite.

It is probable that the porphyroblasts are Ketilidian relicts and that most of the groundmass material crystallised during the Sanerutian. Replacement of the plagioclase by microcline on the scale observed must have been accompanied by introduction of large amounts of potash; there is no indication that this could have occurred during the Sanerutian. The potassic nature of the Ketilidian granite is in keeping with its synkinematic origin, inferred from structural evidence.

Granite B. (GGU 47234) Plates I, III c and d.

Strongly foliated medium grained rock containing 50 % microcline, 20 % plagioclase, 15 % quartz, 10 % biotite and small amounts of sphene, ore, chlorite and muscovite. Petrographically similar to 31534 but with a smaller proportion of porphyroblastic felspar and with felspar aggregates surrounded by sheaths of biotite.

The replacement perthite porphyroblasts are similar to those in 31534 and clearly are relics older than the groundmass minerals, but differ from those in 31534 in being replaced by the groundmass minerals to a higher degree and consequently are smaller in size (up to 3.0 mm). Formation, or accentuation, of the foliation took place at the same time as the crystallisation of the groundmass minerals and postdates the relict porphyroblasts which are fractured. The lenses of felspar which define the foliation consist mainly of fine grained groundmass minerals, frequently with a relict phenocryst in the centre. The best developed lenses, i.e. those with the most regular shapes and with a complete sheath of biotite, are those in which the proportion of newly recrystallised felspar is highest and in which only small relicts of the old phenocrysts are preserved (Plate III d). It seems likely, but cannot be demonstrated beyond doubt, that each felspar lens has been formed by recrystallisation of an old porphyroblast.

The groundmass felspars form small (0.1–0.2 mm) equant grains and the only groundmass plagioclases which are myrmekitic are those adjacent to relict microclines. Individual quartz grains are somewhat larger than those of the groundmass felspars, and form aggregates of size similar to that of the smaller relict porphyroblasts (ca. 1.0 mm) and elongated parallel to the foliation; grain boundaries of the quartz are interlobate and a slight degree of undulatory extinction is usual.

Flakes of brown biotite (0.3–0.5 mm) are aggregated and form sheaths around the felspar lenses giving rise to the first stages of an augen structure. Individual flakes are subhedral to anhedral and a high proportion are parallel to the foliation. None of the biotite flakes is fractured and it appears that although the formation of augen was probably initiated while the rock consisted mainly of old porphyroblasts, the biotite continued to recrystallise for as long a time as the groundmass felspar. The biotites have interlocking relationships with the groundmass felspars but intersect the relict porphyroblasts. Rare biotites are replaced by chlorite and ore and sphene occur within the biotite aggregates; ore grains are only rarely rimmed by the sphene.

Granite C. (GGU 47208) Plates I and IV a–d.

Strongly foliated augen granite with concordant augen; the rock consists of 45 % microcline, 25 % plagioclase, and 15 % quartz while hornblende and chlorite together make up 10 % and epidote, sphene and ore are present as accessories. The chlorite is derived from biotite of which a few remnants can be seen.

There is a marked differentiation of groundmass and augen material. The characteristics of the groundmass minerals are similar to those in earlier members of the series; a fine-grained granoblastic aggregate of small (0.1–0.2 mm) more or less equant grains of microcline, usually untwinned plagioclase, and quartz with interstitial chlorite. A few relicts of somewhat larger and very irregular microclines and plagioclase correspond to the relict porphyroblasts in granites A and B, and these are in the course of replacement by the groundmass material. The characteristics of the augen material are, however, quite different from those in rock B. Two types of augen can be distinguished (Plate IV), the one type consisting essentially of groundmass material but somewhat coarser grained, while the other type consists of single crystals of either plagioclase or microcline which are similar in every respect to the relict porphyroblasts in rocks A and B, but which show no sign of being broken down to form fine grained groundmass material.

Augen of the first type, illustrated in Plate IV a and b, are larger, and consist of crystals varying in size from those of the groundmass (0.1–0.2 mm) up to 3 mm, and contain only microcline and quartz. The larger microclines, which occupy the centres of the augen have complicated interlocking boundaries and appear to have grown at the expense of their smaller neighbours; features in keeping with this suggestion are the presence of small disoriented inclusions of both microcline and quartz within the larger microclines and the total absence of the skeletal relics of plagioclase which are characteristic of the old older generation of microcline porphyroblasts. Small patches and stringers of groundmass material are trapped between the large microclines, the margins of which are not embayed by the groundmass crystals (cf. Plates III d and IV d). The larger microclines in these augen thus appear to represent the first stage of porphyroblastic growth which can be ascribed to *Sanerutian* activity.

The second, smaller type of augen are clearly formed from *Ketilidian* porphyroblasts which, unlike the old relicts in the groundmass, have to a large degree resisted granulation and recrystallisation. That this resistance was not complete is shown by the smaller crystals surrounding and embaying them; quartz is not found in augen of this type. The identification of these large crystals as relict Ketilidian porphyroblasts is confirmed by the occurrence of skeletal remnants of plagioclase in the microcline and the saussuritisation and fine lamellar twinning of the plagioclase, and the absence of other types of inclusions. Unlike the large crystals in the first type of augen, those in the second type sometimes show slightly deformed twin lamellae. There is no evidence that crystalloblastic extension of any of these well preserved relicts took place after initiation of the augen, i.e. in Sanerutian time. The small amount of deep green hornblende occurs as small anhedral crystals which are found mainly on the borders of the augen. Chlorite laths which parallel the foliation are found both bordering the augen and in the groundmass.

Only a few small granules of ore are found and these are rimmed by sphene which also occurs as large (3.0 mm) subhedral wedges. Epidote is found in relict Ketilidian porphyroblasts both within the groundmass and in the second type of augen.

Granite D. (GGU A7224) Plates II, V a and b.

The principal macroscopic difference between this rock and earlier members of the series is that the felspar lenses or augen are not so clearly aligned parallel to the foliation and do not have regular elliptical outlines (see Plate II). The rock contains 50 % microcline, 20 % plagioclase and 20 % quartz with hornblende, biotite and chlorite together making up 10 % and sphene, ore, and orthite occurring in small quantities. Notwithstanding the large size of some of the porphyroblasts, there is not such a clear distinction between porphyroblasts and groundmass material as in specimens B and C because of the higher proportion of relict microcline and plagioclase. The relict felspars are of all sizes and have characteristics similar to those described from previous specimens, i.e. skeletal remnants of plagioclase in microclines, both types of felspar with deformed twin lamellae in some cases, and fine lamellar twinning in the plagioclase which contains numerous grains of epidote.

The new microcline porphyroblasts are poikilitic and further distinguished from relict microclines by the occurrence of exsolved albite in the form of flame perthite; the new microclines and relict plagioclases form the largest porphyroblasts in the rock. There is no sign that porphyroblastic Sanerutian growth of plagioclase took place, as all the latest generation of plagioclase occurs in small equant grains similar to those in the groundmass of the other rocks. Myrmekite is very rare. Mafic material is mostly in the form of chlorite derived from biotite; this late stage alteration also resulted in sericitisation of much of the plagioclase, including that exsolved from the new microcline. In both hand specimen and thin section the strong directional texture is less evident than in B and C; this is so however, only on surfaces and in sections normal to the lineation: on a:b sections the porphyro blasts are aligned parallel to the b (lineation) direction. The lack of planar structure appears, however, to be due at least in part to post-kinematic growth of most of the new microclines; these crystals usually have a close spatial association with quartz-microcline stringers which are parallel to the foliation and are evidently of syn-kinematic origin. These stringers cut across and displace both microcline and plagioclases of Ketilidian age whereas the Sanerutian microcline porphyroblasts, although often found within the stringers, are undeformed.

Granite E. (GGU 47314) Plates II, V c and d, VI a and b.

A strongly foliated rock in which the foliation is somewhat obscured, especially in sections normal to the lineation, by large unoriented porphyroblasts of microcline. The principal constituents are 45 % microcline, 20 % plagioclase (oligoclase), 20 % quartz and 10 % biotite which are accompanied by minor amounts of apatite, chlorite, sphene and ore.

The texture is more clearly porphyroblastic than in early members of the series but the heteroblastic groundmass is similar to that in the other rocks.

The large porphyroblasts of microcline are the most notable feature both in the field and in thin section. Whereas in previous members of the series both old and new felspars formed the porphyroblasts, in this rock the largest and most evident porphyroblasts all consist of the "new", i.e. Sanerutian microcline. These contain no skeletal remnants of plagioclase and have markedly a poikiloblastic habit with inclusions mainly of quartz but with some of microcline towards the margins. The boundaries of the poikiloblasts against neighbouring groundmass crystals show evidence of expansion, as opposed to the boundaries of the relict felspars which show evidence of replacement by groundmass crystals (compare Plates V d, and VI a and b). The poikiloblasts are too often subparallel or discordant to the foliation whereas the larger relics of old felspar invariably parallel the foliation.

Growth textures are also in evidence in the groundmass, quartz for the first time forming crystals considerably larger (0.5 mm) than those of the groundmass felspar (0.1–0.2 mm) and elongated parallel to the foliation. Fairly large relict plagioclase, and more rarely microcline, form some of the smaller felspathic nodules or augen which can be seen in Plate II but some microclines of similar size have characteristics similar to those of the large poikiloblasts. A small amount of myrmekite is found on the margins of relic microclines, where it appears to have been formed by crystalloblastic extension of the groundmass, but is not found bordering new (poikiloblastic) microclines. Biotite flakes have an interlocking relationship with the poikiloblastic microcline and with the recrystallised felspar of the groundmass, whereas they cut across identifiable relics of both microcline and plagioclase. As in granite D exsolution perthite is a feature of many of the poikiloblastic microclines. It seems evident from the textural relationships that the poikiloblastic microclines were formed by late or post kinematic growth from groundmass material whereas recrystallisation of the early (Ketilidian) felspar to form the groundmass took place synkinematically and that the formation, or accentuation, of the foliation and lineation also took place at this time. The deformation of the enclaves (page 52) must also have taken place at this time, i.e. before the main stage of poikiloblastic microcline growth.

Petrographic descriptions of principal rock types in the area.

Homogeneous metavolcanic (GGU 31645) Plate VI c.

From the SE coast of Nivâq, some 500 m from the main granite contact and possibly a pillow lava. The rock is a fine grained, homogeneous, dark grey amphibolite with only indistinct foliation. Although one of the oldest rocks in the area, under the microscope it shows a remarkable degree of structural preservation; this must be attributed to the massive nature of the metavolcanic layers. 50 % plagioclase, 35 % hornblende, 10 % biotite, together with appreciable amounts of ore are the main consituents. A few grains of microcline are found but epidote is absent. The composition of the plagioclase is An 45–55 but less calcic margins are usual.

The felspar laths of an original sub-ophitic texture are well preserved and retain original shapes and twinning in most cases, but irregular zoning shows that they are not chemically unchanged. Only few felspar crystals are bent or broken, and these are generally the larger ones which are up to 2 mm in length (see Plate VIc). Biotite and hornblende are generally interstitial in the felspars except where the latter have been deformed, in which case the mafic minerals encroach upon original felspar sites.

The hornblende is of two generations: the earlier type is evidently uralitic and occurs in large crystals with irregular margins, patchy pleochroism, and rather pale colours. The later hornblende has an even sea-green colour and occurs in smaller crystals which are anhedral but tend to have rounded outlines; the later hornblende frequently forms an irregular rim around the earlier type. Biotite occurs in patches which are capriciously distributed and neither these patches nor individual crystals show any tendency to preferred orientation. Biotite is intergrown with and apparently the same age as the later hornblende. Ore occurs only in and around the biotite, in the form of numerous small grains, and rutile occurs as elongate blobs within the biotite. The original rock was clearly a sub-ophitic dolerite probably with titaniferous augite.

Plagioclase Porphyrite Metavolcanic (GGU 31461).

The specimen is from the migmatic border zone of the Ketilidian granite on the SE coast of Nivâq. The rock is massive and unfoliated in handspecimen and relict felspar phenocrysts and groundmass material are present in about equal amounts. The phenocrysts are from 0.5–2.0 cm in size, euhedral to subhedral and with equidimensional or short rectangular forms. The grey groundmass is fine grained and contains 50 % plagioclase, 20 % microcline, 10 % green hornblende, 5 % each of epidote, sphene, and ore, together with lesser amounts of scapolite, apatite, and biotite.

The homeo-granoblastic groundmass, with average grain size of less than 0.2 mm, consists mainly of equant pellucid grains of plagioclase and microcline; a few 1.0 mm laths of turbid and strongly zoned plagioclase occur and probably are relics of the original volcanic rock. The new plagioclases are also zoned and compositions determined varied from An_{22}–An_{35}. Anhedral grains of hornblende are distributed throughout the groundmass and are noticeably embayed by microcline. No directional structure is evident in thin section. Scapolite occurs in large (0.5 mm) very poikilitic crystals within the groundmass and as smaller anhedra within the plagioclase phenocrysts.

The relict phenocrysts are almost completely obscured by sericite and contain numerous granules of epidote in addition to the scapolite. Some recrystallisation to small pellucid grains of plagioclase has taken place along fractures in the larger crystals but in other cases a homoaxial recrystallisation has taken place next to fractures or on the borders of the phenocrysts. Where such homoaxial recrystallisation has taken place, concentrations of scapolite are found and it may be supposed that the new felspar is less calcic than that from which it is derived. Most interesting are the few cases where homoaxial extension appears to have taken place on the borders of the phenocrysts; such rejuvenation of early phenocrysts during later metamorphism is also found in the Sanerutian development of augen granite; elsewhere the borders of the phenocrysts are replaced by small plagioclases and microclines of the groundmass.

The composition of the unfelspathised plagioclase porphyrites is similar to that of the gabbro anorthosite layers which are found as distinct horizons in the gneisses of the Ivigtut district and at many other localities in western Greenland (BERTHELSEN, 1960); the frequent occurrence of scapolite is another feature which the metavolcanics and 'gabbro anorthosites' (BERTHELSEN, 1962) have in common. Although the similarity in composition may point to a common type of origin, it does not of course indicate a similarity in age.

Finely banded Pyroclastic (GGU 31653).

The specimen is taken from the agglomerate zone shown in figure 4, where granitic veins are very infrequent. The bands are less than 1 cm in width. The grain size varies from fine to medium, but is constant within individual bands which are usually less than 1 cm in width. Hornblende, 40 %, and plagioclase, 45 %, are accompanied by small amounts of potash felspar, epidote, ore, sphene, and apatite. Lapilli, which are distinct in the handspecimen, are less obvious in thin section. That part of the rock in which lapilli cannot be recognised has a heteroblastic texture with granoblastic plagioclase and lepidoblastic hornblende; the marked foliation and lineation of the handspecimen are not evident in thin section. Large (0.5 mm) irregular, turbid, finely twinned plagioclases containing granules of epidote evidently represent original detrital grains and are surrounded by much smaller polygonal untwinned grains of metamorphic origin. Most of the amphibole is uralitic, with pale colours, patchy pleochroism, and a close association with ore grains and iron rich epidote. Crystal tuffs with hornblende pseudomorphs after euhedral pyroxenes have been found at many localities and it is possible that pyroxene was a common constituent of the pyroclastic deposits. The remainder of the hornblende occurs in small grains with deeper and more even colouring than the uralite and is not associated with granules of either ore or sphene.

The lapilli can be distinguished by their comparative lack of mafic minerals and what appear to be original grains can be distinguished in most of them. Potash felspar is a common consitutent of the lapilli and the original perthitic untwinned grains are now surrounded by smaller polygonal grains of twinned microcline.

Calcareous Metasediment (GGU 52493).

From the horizon of mixed calcareous rocks on the island of Sioragdlit. A very fine grained buff coloured *Hornblendegarbenschiefer* with numerous acicular amphiboles arranged in stellate aggregates and lying within a plane parallel to the bedding; there is a notable lack of alignment of the amphiboles. Some narrow greenish bands, a few mm in width, are coarser grained. Under the microscope nematoblastic actinolites (20 %) are seen to lie in a granoblastic groundmass of biotite (25 %) and albite (55 %). The section is cut normal to a linear structure which can be seen in the groundmass in handspecimen. Perfectly shaped six sided basal sections of actinolite are frequent and aligned with 100 parallel to an indistinct foliation seen in handspecimen which is parallel to the bedding. The greatest dimension of the basal sections averages 0.5 mm while the few longitudinal sections are up to 1 cm in length. The actinolites are poikiloblastic, containing numerous inclusions of albite but none of biotite, and have not been deformed.

Albite and biotite have an interlocking relationship and both occur with a rather constant grain size .02–.03 mm. The biotite flakes are distinctly aligned along preferred directions at 45° to the bedding and apparently intersecting in a line parallel to the linear structure observed in hand specimen. The only other rocks in the area which show a similar biotite fabric are the biotite bearing types of Sanerutian granite on Sãtukujôq in which the linear structure is dominant and which, on the evidence of the 2nd period dykes, were deformed by viscous flow. Biotite is evenly distributed and pleochroic mid-brown to almost colourless; no relict textural features can be seen and both biotite and amphibole are fresh and unaltered.

The coarser grained bands seen in handspecimen contain no biotite but up to 20 % quartz is found; these probably represent original sedimentary bands. A few grains of microcline occur. Although classed as a metasediment this rock is equally likely to be of pyroclastic origin.

Of all the rocks in the area, those from the calcareous horizons most regularly show no textural evidence of mineralogical disequilibrium. They are also the most highly deformed rocks.

Meta-gabbro (GGU 52472) Plate III a.

From a small mass of coarse grained amphibolite, showing probable relict igneous banding, on the westerly extremity of Ikerasârqap nunâ. The rock is coarse grained, unfoliated and contains 50 % plagioclase, 35 % green hornblende, 5 % each of biotite and ore, and lesser amounts of quartz, sphene and apatite.

Plagioclase forms anhedral and subhedral crystals up to 6 mm in length, usually 2–3 mm, strongly twinned and showing moderate to strong normal zoning. The zoning is generally a smooth transition although sharp breaks between zones do occur, but not more than two or three in any one crystal; the crystals are not obscured by the small amount of sericite which occurs, but are turbid. Some crystals have a rim of untwinned plagioclase, the outer boundary of which defines a subhedral outline, while the inner boundary embays the enclosed plagioclase which has only a slightly higher refractive index. Twin lamellae are frequently warped and some crystals are fractured (see Plate III a). On boundaries between some of the larger crystals a thin stringer of small and later grains occurs—these have equant shapes, are 0.1–0.2 mm in size, are pellucid and rarely twinned. This new plagioclase is evidently of metamorphic origin and forms only 10 % of the total felspar; the refractive index is only slightly lower than that of the early plagioclase which varies in composition from andesine to labradorite.

Hornblende has a typically uralitic appearance and crystals, occurring either singly or in small aggregates, cut across felspar boundaries. Biotite apparently replaces the hornblende with which it is in close association, and penetrates along the amphibole cleavages. Grains of ore and sphene are closely associated with biotite and hornblende and in the vicinity of biotite flakes sphene is found rimming the ore. Epidote is not found.

The rock has evidently been little affected by the two periods of metamorphism to which it has been subjected. This must once again be attributed to the massive nature of the rock and clearly shows that an elevated temperature is not synonymous with plutonic activity.

1st Period Discordant Amphibolite (GGU 31514) Plate VII a and b.

Specimen from a coarse to medium grained variety of 1st period dyke emplaced in banded metasediments on the SE coast of Nivâq (see figure 11). The dyke is agmatised and has only an indistinct foliation and lineation. The section is cut normal to the lineation and shows the foliation to be the result of mineral distribution rather than mineral orientation. The rock contains 55 % hornblende, 35 % plagioclase, 5 % biotite, 5 % epidote, and small amounts of sphene and apatite. Ore minerals are not present.

Two types of hornblende occur, the earlier type in large (up to 3.0 mm) irregular crystals with pale colours and patchy pleochroism, and containing numerous small granules of sphene, small hornblendes and less commonly quartz; this type is a typical uralite. The uralite is often surrounded by the later type which occurs in small (.01 mm) well formed subhedral grains with deeper and more even colouring. The second type also occurs together with equant plagioclase (andesine) grains of similar size, the two minerals forming a granoblastic groundmass around the early hornblendes. The small plagioclases are pellucid and rarely twinned, and are distinct from rare remnants of an early generation of plagioclase which occur as corroded grains up to 1.0 mm in size, turbid in appearance and invariably twinned although the twin lamellae are not sharply defined. Rectangular areas containing no hornblende but numerous small biotite flakes, and frequently with centres of epidote and sericite, are occupied by hundreds of grains of groundmass plagioclase; these areas represent sites of original plagioclase which have now been completely recrystallised to the new generation of plagioclase (see Plate VII). The plagioclase which originally occupied these sites and the few remnant plagioclases found were almost certainly the original magmatic felspars. In the majority of 1st period dykes no trace of the original minerals remains; the dyke from which the described specimen was taken is however broader than most and is also more mafic, and these factors together with the nearly concordant nature of the dyke, contributed to minimising the internal deformation and thus preserving relict minerals.

2nd Period dyke (GGU 31529 (margin) and 31530 (centre)).

The 4 m wide dyke occurs in Ketilidian granite at the western end of the SE coast of Nivâq, and has been followed inland for about 1 km. A relict ophitic texture is macroscopically visible in the medium grained centre of the dyke but not in the fine grained margins.

The medium grained rock consists of equal amounts of plagioclase and hornblende with only traces of ore. Green hornblende occurs as discrete grains with uralitic characteristics; the grains are prismatic, subhedral and have a marked preferred orientation which is barely visible as a macroscopic foliation. Two types of plagioclase can be distinguished, the older of which is strongly sericitised and comprises relics of euhedral laths which are partly replaced by smaller, equant, rarely twinned grains of a later generation of plagioclase. The earlier plagioclases are often fractured and have indistinct twinning, and appear to have undergone chemical change during metamorphism; the composition of both old and new generations of plagioclase is An_{25}–An_{35}. Relict euhedral plagioclase phenocrysts up to 15 mm in size occur, and have features similar to those of the early generation of groundmass plagioclase; they thus confirm that the relict texture seen in thin section is that of the original intrusive dyke. Relict phenocrysts in the marginal parts of the dyke are of similar size to those found in the central part. The minerals and texture of the marginal rock type are the same as those of the central type, and the only significant difference is in the grain size; the maximum length of early plagioclase laths in the central part of the dyke is 3 mm but only 0.5 mm near the margins. Grains of the new generation of plagioclase are rarely greater than 0.1 mm in size in both central and marginal parts of the dyke. There can be little doubt that the margins of the dyke were originally finer grained than the central part and this may reasonably be interpreted as due to chilling of the magma against the country rocks.

Fine grained margins are common features of 2nd period dykes but in most cases shearing has destroyed all evidence of *original* grain size; in such sheared margins biotite occurs, often to the exclusion of hornblende.

Green 2nd Period Dyke (GGU 32184) Plate VII c and d.

From a 1.5–2 m dyke on the small island in Nivâq, cutting supracrustal rocks and itself cut by veins of scapolite and sphene and similar to dyke shown in figure 37. This is the parent type from which the green ultrabasic 2nd period dykes in the Sanerutian granite have been formed. The rock is fine grained with indistinct foliation and lineation, and consists of 60 % amphibole, 10 % biotite, 25 % plagioclase (andesine), 5 % scapolite (meionite) and small amounts of apatite. In thin section mafic aggregates are seen in a groundmass of plagioclase and hornblende. Little or no felspar occurs in the mafic aggregates. The usual lengths of the hornblendes and biotites is about 0.3 mm while the aggregates are 3–5 mm in size and elongated parallel to the foliation—it is mainly the elongation of the aggregates which defines the foliation. Felspar crystals are usually less than 0.1 mm in size. The mafic aggregates make up over half the rock and in most of the groundmass hornblende and felspar occur in equal amounts.

Within the mafic aggregates the amphibole shows no preferred orientation but towards the margins of the aggregates and in the groundmass, most amphiboles parallel the foliation. Some larger amphiboles up to 1.0 mm in length occur in some aggregates, in one case with stellar arrangement. These larger crystals are clouded with minute ore grains and have patchy pleochroism with areas of colourless tremolite. Biotite is concentrated in the centres of mafic aggregates.

Plagioclase occurs in small, pellucid, polygonal grains with concentrations of fine grained alteration material in some crystals; these are typical of the felspars in the metamorphosed basic rocks of Ilordleq. The only evidence of an earlier generation of felspar is found in rectangular patches, 0.6–0.7 mm in length, containing numerous plagioclase crystals with some biotite. The centres of these patches (see Plate VIIc and d) contain concentrations of sericitic material with small amounts of epidote; the outlines of these patches of alteration material are often parallel to the margins of the rectangular felspar aggregates and occur without regard to the boundaries of the small crystals in these aggregates. The aggregates are thought to represent the sites of felspar phenocrysts in the original dyke and the sericite and epidote the products of saussuritization in the early stages of metamorphism.

Scapolite occurs as large crystals up to 1 mm in size, which are intensely poikilitic; inclusions occupy 60–70 % of the roughly rectangular crystals, some of which are altered to fibrous aggregates.

Narrow veins cutting the dyke consist of scapolite and sphene.

Partially Digested Grey 2nd Period Dyke (GGU 32110).

This dyke is shown in figures 40 and 41. The granitic neosome is described below (specimen 32111). The remnants of the 2nd period dyke consist of fine grained foliated amphibolite with numerous relict felspar phenocrysts up to 5 mm in size. The rock consists of 55 % oligoclase, 15 % green hornblende, 15 % olive-green biotite, 10 % epidote and small amounts of sphene, ore, apatite, and muscovite.

About 15 % of the felspar present is in the form of relict phenocrysts, the original size of which was 2–5 mm. The sites of these originally lath shaped felspars are now largely occupied by flakes of muscovite, sometimes in aggregates of minute flakes but sometimes recrystallised to crystals of identifiable size. The relict phenocrysts are often almost surrounded by large (up to 2 mm, usually 0.5–1.0 mm) crystals of epidote; only few small epidote grains occur within the sites of the relict felspars. The volume of epidote associated with any one relic is about half that of the original felspar. The felspar now occupying the relict sites is pellucid and sometimes still remains as a single crystal. Usually some smaller felspar grains similar to those in the groundmass occur within the relics and in some cases these are the only felspars occupying the site of the original phenocryst. Even in these cases, the original outlines of the phenocrysts are easily identified by the distribution of muscovite and epidote, and the rarity of biotite and absence of hornblende within the relict sites.

The groundmass felspar is in the form of more or less equant grains with fairly constant grain size of 0.1–0.2 mm; about a quarter of these grains have distinct twinning. The groundmass felspar grains are pellucid and free of inclusions except for some apatites; these felspars are evidently of metamorphic origin. Also in the groundmass occur some rather larger felspars (0.4–0.8 mm) with irregular shapes determined mainly by the surrounding smaller crystals, and containing patches of sericite with grains of epidote; they are intersected by biotites and all have indistinct twinning. These felspars probably represent remnants of the groundmass crystals of the original dyke.

Biotite is distributed throughout the groundmass as well oriented flakes, 0.2–0.3 mm in size and of regular shape; they are interstitial with respect to the metamorphic felspars of the groundmass but are not corroded by them. Hornblende occurs in 0.1 mm anhedral grains with regular margins. No relative age difference is apparent between biotite and hornblende, the proportions of which vary throughout usually with one or the other markedly predominant. Larger (0.5 mm) hornblendes occur, tightly packed in aggregates elongated parallel to the foliation in sections normal to the lineation. These hornblendes are well crystallised with no inclusions; the aggregates are surrounded by small granules of sphene and may represent the sites of original pyroxenes.

Granite veining 2nd period dyke (GGU 32111) Plate VI d.

From the grey 2nd period dyke shown in figures 40 and 41. The rock is fine to medium grained with porphyroblastic felspars. The foliation, which has a marked linear element, is defined by discontinuous quartz-felspar and biotite rich folia, 0.5–2.0 mm wide and 1–4 cm long. Concordant amphibolite enclaves up to 5 cm wide emphasise the foliation.

The rock contains 20 % microcline, 40 % oligoclase, 25 % quartz, 5–10 % biotite and small amounts of sphene, ore, apatite, epidote, and muscovite. In thin sections normal to the lineation, the foliation is indistinct. Three types of felspar occur, namely old plagioclase, new plagioclase and microcline. The outlines of the old plagioclases are now irregular due to replacement by later minerals (Plate VI d); they appear to have been originally rectangular, 2–3 mm in length, and contain numerous small granules of epidote and flakes of muscovite; some crystals show a regular normal zoning. Small rounded quartzes are found in some crystals of old plagioclase and in some cases have a myrmekitic development: twinning is well preserved in the centres of some crystals which contain larger amounts of alteration products than is usual. Remnants of all sizes of old plagioclase occur, the smaller ones with rounded shapes and often enclosed by microcline.

The new plagioclase is of the same composition as the old but occurs as polygonal grains, 0.1–0.2 mm in size, aggregated often on the borders of an old plagioclase; unlike the latter they are not replaced by microcline. Both types of plagioclase often have albitic border zones. Microcline occurs in anhedral, irregular crystals of all sizes up to 2 mm; good microcline twinning is rare. Microclines without twinning are usually perthitic, with the exsolved albite in optical continuity with surrounding or adjacent plagioclase which the microcline appears to replace. The largest microclines appear to be formed by the replacement of the largest old plagioclases, as they contain scattered remnants of optically continuous plagioclase.

Quartz has transgressive boundaries against all other minerals and, like the microcline, occurs in a wide variety of grain sizes up to 0.5 mm. Grain boundaries are regular or interlobate and strain extinction usually weak.

Biotite is corroded by all minerals except the old plagioclase which it transects and is later than, and occurs as anhedral flakes with embayed margins, many of which are either fractured or have been distorted by the growth of adjacent microclines. Biotite, plagioclase, and the accessory minerals, occur together in distinct bands which alternate with quartz-microcline lenses around which the biotites are wrapped.

Sanerutian Hornblende Granite (GGU 32130).

From the hornblende granite on the western end of Ikerasârqap nunâ, in the Sánerutip imâ sub-area.

The medium grained rock has a well-marked foliation and a strong linear structure, both defined by the shape and orientation of mafic concentrations. Amphibole is the dominant mafic, appearing in hand specimen as stubby black prisms which are of similar size to the majority of felspars. Rare porphyroblastic felspars occur and intersect both foliation and lineation which do not swing round the porphyroblasts as would be the case with augen. The porphyroblasts are fewer and smaller than those in the hornblende granite further to the NE.

The rock is of adamellitic composition with 45 % microcline, 30 % plagioclase (oligoclase), 10 % quartz, 10 % hornblende, and lesser amounts of biotite, sphene, epidote, and apatite. The texture is markedly heteroblastic and primarily determined by ragged anhedra of microcline, plagioclase (oligoclase) and quartz, from 0.5–2.0 mm in size. No time relations can be established from the extremely irregular interpenetrating boundaries of these minerals, and there are no identifiable relics of earlier generations of either microcline or plagioclase. No relics of plagioclase are found within any microcline; myrmekite is a common feature although irregularly distributed. The porphyroblasts of microcline (up to 6 mm in size) differ from the groundmass microclines only in their larger size and in being more commonly perthitic. About half the microcline has only poorly developed or no cross-hatch twinning; twinning is most often absent from crystals or parts of crystals which are perthitic. No crystals are fractured or show other signs of deformation. Green amphibole occurs as subhedral crystals up to 3 mm in size, usually separate from one another but concentrated along bands which parallel the foliation (in section normal to lineation). Concentrations of accessory mafic minerals surround the amphiboles.

All minerals appear to be of similar age to the microcline porphyroblasts; from field evidence it is apparent that all minerals now present are of Sanerutian age and that the rock was completely reconstituted by the Sanerutian plutonic activity. This conclusion is in keeping with the field evidence of extreme mobility of the hornblende granite during the Sanerutian.

Ketilidian Hornblende Granite.

The small area of hornblende granite (of granodioritic composition) occurring on the northern coast of Tarajornitsoq is cut by numerous narrow NE shear zones. Within these zones 2nd period dykes are strongly deformed (figure 22). The rocks described are from the same locality as the dykes illustrated; one specimen (52453), although a tectonite, has not been affected by the shearing which is later than the dykes and some of its petrographic features may be expected to be of Ketilidian origin. The other specimen (52454) is taken from a shear zone adjacent to the deformed dykes and is thus a further development of the type exemplified by 52453.

Hornblende Granite (GGU 52453).

A medium-grained strongly foliated granite with a linear structure which is indistinct in hand specimen. 60 % of the rock consists of felspar, this amount including a considerable quantity of sericite. 15 % of green hornblende and 20 % of quartz are the other main consistuents and ore, sphene, biotite and zircon occur in minor amounts.

The plagioclase is very strongly altered and the sites of most crystals are almost completely occupied by sericite although epidote is uncommon. Less altered crystals show fine lamellar twinning which is invariably distorted. The original plagioclases were up to 5 mm in size but most have been recrystallised to smaller grains 1–2 mm in size. This recrystallisation took place at an early stage and the later generation of plagioclase pre-dates all other minerals present.

Quartz occurs in aggregates between larger aggregates of felspar; crystals are similar in size to those of the later felspar; grain boundaries are smooth and strain extinction not pronounced.

Hornblende occurs in aggregates of anhedral grains; grain shapes are most irregular and sizes up to 5 mm although more usually 2–3 mm. Notable features of the hornblendes are the fresh appearance and the poikilitic habit. Inclusions are nearly always of quartz, occurring as small granules or in rounded blebs elongated parallel to the cleavage of the host. The quartz inclusions within any one hornblende are not in optical continuity although only about a twentieth the size of other quartzes in the rock; the inclusions are concentrated in the cores of the host crystal and increase in size toward the margins of the latter. As external quartz grains embay the hornblendes these relations may have some time significance. Felspar is not found as inclusions within the hornblende although cut by it. The described features of the hornblende are similar to those of the occasional hornblendes in the augen granites in the Nivâq sub-area; in the latter area, however, the hornblende also contains inclusions of microcline. It appears likely that hornblende contains inclusions only of minerals undergoing recrystallisation at the time of hornblende growth; in the rock under consideration this would indicate a recrystallisation of quartz and hornblende subsequent to felspar crystallisation, and possibly therefore during the Sanerutian. Such a proposal is supported by the appearance of the hornblende in the sheared equivalent (52454) of this rock in which all minerals were recrystallised during the Sanerutian; the hornblendes although much smaller than those in 52453 show poikiloblastic features and contain inclusions of both quartz and felspar. Such a time relation between crystallisation of hornblende and minerals included within it is not suggested as a general rule; however, it is sufficient to show that hornblendes containing quartz inclusions can be derived in other ways than by uralitisation. The hornblendes with quartz inclusions, derived by alteration of pyroxene during retrogressive metamorphism of granulite facies gneisses cannot be considered diagnostic for a retrogressive development.

Sheared Hornblende Granite (GGU 52454).

A finely banded, fine grained, strongly tectonised rock containing 50 % albitic plagioclase, 40 % quartz, 10 % hornblende and small amounts of epidote, sphene, and ore. Under the microscope a blastocataclastic texture is apparent with fine alternating bands, 0.2–3.0 mm in width, of quartz and felspar. The banding is very marked although individual bands are neither regular in width nor persistent along their lengths; the section described is normal to the lineation. The felspar is almost completely sericitised but twinning can occasionally be seen. The hornblende occurs in elongate aggregates within the felspar bands; crystals are small and irregular in shape, many of them containing irregular inclusions of plagioclase and quartz. The grain size of all minerals seldom exceeds 0.3 mm and no deformed crystals occur; the margins of the quartz crystals are irregular but not interlocking, and undulose extinction not very marked. The quartz grains have a marked shape orientation. Ore grains have hornblende rims and epidote granules occur within the felspars. It is apparent that the post 2nd period dyke shearing which affected the rock resulted in a complete recrystallisation. No significance can be attached to minor compositional variations in such an area but the high percentage of silica in this rock suggests that quartz may have been introduced during the Sanerutian plutonism; the relative proportions of felspar and hornblende in this rock are similar to those in 52453.

Section IV

RECOGNITION OF METAMORPHOSED BASIC DYKES IN REACTIVATED BASEMENT AREAS

In previous sections a great deal of significance has been attached to what have been interpreted as relict dykes, originally emplaced during the interval between two separate periods of plutonic activity. As these dykes are similar in many ways to what have been described elsewhere as pre-granite relics or dykes emplaced in hot granite, it is necessary to justify the interpretation given in the earlier pages, especially as the dykes show features which some others have considered diagnostic of pre-granite remnants or dykes emplaced in hot granite.

Some confusion in terms may arise in referring to dykes such as the 2nd period dykes in the Sanerutian Hornblende Granite. Such dykes will be referred to as post-granitic or relict dykes, as the term pre-granitic has been used extensively in the literature for dykes emplaced in non-granitic rock which was subsequently granitised, the dykes remaining as resisters to the granitisation.

Distinction from pre-granitic dykes and other pre-granite remnants.

During the mapping of Ilordleq, an intensive search was made for conclusive physical evidence by which the age of the relict dykes could be established. This physical evidence is distinguished from the more circumstantial type of evidence, which although showing which is the most likely age, is nevertheless inconclusive.

Physical evidence: 1) Dykes cutting enclaves in the granite. This was accepted as conclusive evidence of a post granitic age even in those dykes affected by later migmatisation. The shapes of enclaves has been shown to be due to a marked kinematic control and so there is no reason to suppose that if the dykes were pre-granitic they would cut enclaves as in the case shown in figure 69. Even better is the case where separated pieces of the intersected enclave can both be seen, as in figure 70. This criterion does not show that the dyke was not emplaced in hot or only partially consolidated granite, but it is of interest to note that dykes

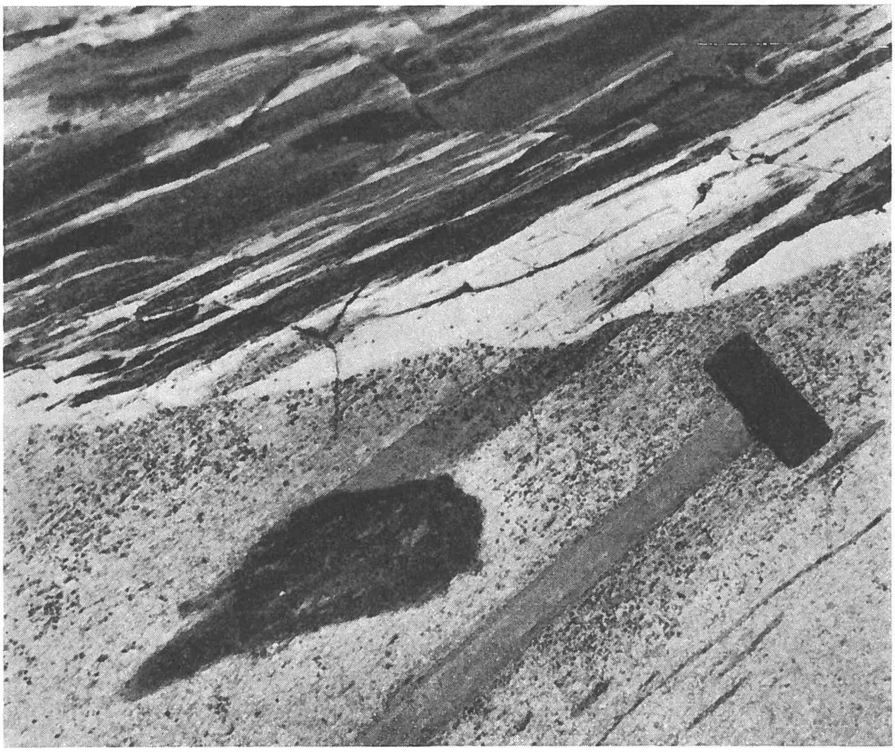

Fig. 69. Detail from margin of 2nd period dyke in Sanerutian Hornblende Granite showing dyke margins intersecting pre-granite enclave (parallel to hammer handle). Dark patch in lower half of picture is water filled glacial chatter mark. Leucocratic neosome in dyke does not extend into country rock. N. coast of Ikerasârqap nunâ, 1 km W. of Anchorage.

emplaced in the Main Donegal Granite before its final consolidation, are threaded between the semi-pelitic enclaves (Pitcher and Read, 1960). 2) Dykes cutting post-granitic structures such as aplite veins or re-crystallised shear zones. An example of the use of an aplite vein has been given earlier in the description of the Natsît iluat sub-area, and is shown in figure 27. An example of the use of shear zones can be given from a locality on the NE end of Sãtukujôq where most of the dykes are very much broken up and their true nature not always evident. The Sanerutian granite here contains some fine grained mylonitic bands, which probably represent a stage in the formation of concordant aplite veins. Some of these mylonites are cut by large remnants of a green 2nd period dyke, similar to that shown in fig. 62. Five of these dykes occur within a 50 m stretch of coastline and are in various stages of fragmentation and were it not for the evidence afforded by the earlier mylonite bands could easily be mistaken for pre-granite relics.

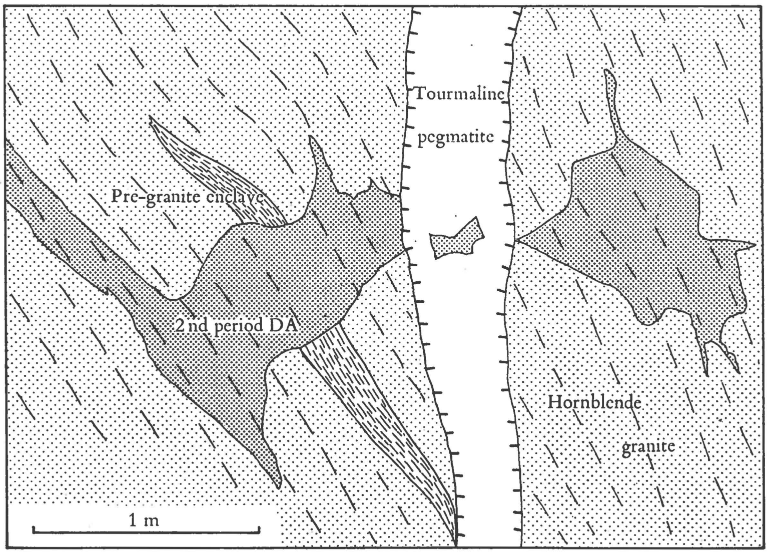

Fig. 70. 2nd period dyke deformed by shearing and partly fragmented. Intersection with pre-granite enclave shows original intrusive nature of dyke. Tourmaline pegmatite appears in the field to be of replacive origin, with large prismatic tourmalines oriented normal to margin of pegmatite. N. coast of Ikerasârqap nunâ, 300 m W. of Anchorage.

Restricted exposures in which amphibolitic relicts apparently cut earlier structures can, however, be misleading. Many cases were seen in Ilordleq, in which considerable displacements have taken place by movement along the contact between amphibolite and granite; in some cases veins in the granite which are younger than the amphibolite dykes end abruptly at the amphibolite granite contact and thus appear to be older than the amphibolites.

3) Dykes containing xenoliths of country rock. This criterion was of little use as xenoliths are rare in 2nd period dykes. One confusing case was recorded, however, in which movement within a 2nd period dyke had resulted in the shearing out of a xenolith of country rock granite which looked very similar to a post-dyke granite vein.

The remaining lines of evidence are those which although not individually conclusive, when considered together, are highly suggestive of a post-granite origin rather than a pre-granite origin, even in those cases in which the dykes have been migmatised. It is recognised, however, that the value of each criterion is to a certain extent dependant on the preconceptions of the individual observer.

a) Discordance to granite foliation. As the strike direction of the majority of 2nd period dykes is almost parallel to that of the foliation of the surrounding granite, many of them resemble concordant enclaves when viewed on horizontal exposure surfaces which are the most common. On vertical surfaces normal to the foliation, however, such dykes in nearly every case can be seen to be discordant to the foliation in the granite. The two dykes shown in figure 40 are typical examples of the many occurring in the Sanerutian granite. When the dykes are folded with axial planes parallel to the granite foliation, this criterion cannot be applied, nor can it be applied in other cases in which there is a possibility that the foliation is later than the dyke. Where a gneissic structure is preserved within the granite and cut by the dyke, the relations are quite clear, as with the dyke shown in figure 38.

b) Discordance to the trend of enclaves. This is similar in many ways to (a). The orientation of the enclaves has been shown to have been determined in the Ketilidian. Cases in which imposition of a later foliation in a different direction has caused disruption of the enclaves have been referred to (fig. 8). Where the enclaves have a regular shape, it is reasonable to assume that they maintain their original Ketilidian trend and that any body cutting across this direction is of later origin.

c) The supracrustal rocks which have been replaced by the granites have in many cases a composition not far removed from that of a basaltic dyke; in the case of some of the metavolcanics the composition is almost identical. There is thus no reason for assuming selective replacement of the supracrustal country rocks with basaltic dykes remaining as resisters to the granitisation.

d) Where contacts between 1st period dykes and granite are found, the dykes show no sign of being more resistant to the granitisation than any of the surrounding rocks of the supracrustal series.

e) The migmatised and deformed 2nd period dykes in the Sanerutian granites can be correlated with dykes in the Ketilidian granites which can be shown to be post – Ketilidian in age, cutting migmatites and other Ketilidian structures. If the migmatised dykes in the Sanerutian granite were in fact of pre-Ketilidian granite age, some reason would have to be found to account for the lack of 2nd period dykes in the Sanerutian granite areas.

f) Porphyroblastic felspars comprise a high proportion of the granitic rocks and are frequently found in enclaves; in only two cases have isolated felspar porphyroblasts been found within a 2nd period dyke.

Previous literature: The preservation of basic dyke rocks when the surrounding supracrustal rocks have been granitised is a process the validity of which is rarely questioned, especially in transformist literature. A search, albeit incomplete, of the literature shows that substantiated examples are not so common as would be suggested by the frequent references to them (POLDERVAART, 1953; READ, 1957; WEGMANN, 1938). Four detailed studies of progressive migmatisation of supracrustal rock series (CHENG, 1943; HARRY, 1953; PITCHER, 1952; GINDY, 1952) have demonstrated that although pre-migmatitic basic intrusives show, as do limestones and quartzites, a greater resistance to migmatisation than associated pelitic rocks, they do not do so to such an extent that there is any likelihood of them remaining as recognisable relict dykes in a relatively homogeneous granitic mass. GINDY's account (loc. cit.) is of especial interest as it concerns originally doleritic rocks which occur as sills or mildly transgressive sheets in a metasedimentary series, with foliation more or less concordant with the bedding; these are the most favourable conditions for preservation of the metadolerite. GINDY's map shows, however, that the elongate enclaves of metadolerite are no more elongate or dyke-like than the pelitic or semi-pelitic enclaves. Had these metadolerites originally cut the bedding of the metasediments at an oblique angle, it seems likely that they would have been preserved only as isolated, more or less equi-dimensional fragments. Such examples are of course no proof that more selective preservation of basic dykes cannot occur but it seems likely that in cases of synkinematic granitisation, discordant dykes are likely to be fragmented beyond recognition. The fragmentation of the 1st period dykes in the supracrustal rocks of Ilordleq is probably the almost invariable fate of discordant dykes. In cases of completely static granitisation basic dykes would be more likely to be preserved. Such a case has been described by KING (1953) who has described basic dykes which were preserved while the surrounding sandstone was transformed to granite. However, the scale of granitisation is relatively small and the dykes show considerable marginal acidification and granite veining. In this case too the granitisation was a result of volcanic processes and the conditions quite unlike those found in basement terrains. The static granitisation described by MISCH (1949) is one of the few described examples of large scale static granitisation; in this case the compositional change was relatively small and it might be expected that had pre-granitisation basic dykes been present, they would have been preserved.

The most detailed description known to the writer of supposedly pre-granitic basic dykes is that of GOODSPEED (1955) who lists criteria by which such dykes may be identified. The criteria are (1) Pre wall-rock age shown by transecting veinlets of granitic wall rock and crystalloblastic extension of wall rock into relict dyke, (2) Wall rocks are always granitic with sharp or gradational contacts, (3) Composition will indicate either a magmatic or replacement dyke, (4) Relict appendages may look like apophyses and may also become detached inclusions in the granitic rock, (5) In general, uniform widths are characteristic. Irregularities are usually caused by later metasomatic action.

All of the above features may be found in the 2nd period dykes of Ilordleq and all were recorded by SEDERHOLM in his descriptions of the metabasaltic dykes of S and SW Finland (SEDERHOLM 1923, 1926, 1934). It is of interest too that some of the dykes described by GOODSPEED have narrow leucocratic border zones.

Dykes in reactivated granitic rocks must not only be distinguished from pre-granitic dykes but also from dyke-like remnants of other pre-granitic rocks. As criteria for the recognition of dyke-like remnants of pre-granitic rocks have been put forward, it is necessary to examine these and see how distinction can be made from relict dykes.

MILLER (1945) has pointed out some of the difficulties which arise in distinguishing between elongate xenoliths (or enclaves) and dykes in granitic rocks. However, the criteria which he suggests for the identification of elongate xenoliths must be considered unacceptable for all areas except those in which the possibility of polymetamorphism can be definitely discounted—a condition which is met in very few Precambrian areas.

In giving examples of 'pseudo-dykes' (i.e. elongate xenoliths), MILLER (1945, p. 182) describes the following "... several interesting pseudo-dikes, forming a parallel group in an outcrop near Molde, Norway. These are fine-grained, strongly foliated metadiorite, with sharp, somewhat irregular, boundaries, in pink, impure, pre-Cambrian granite. Foliation of pseudo-dike and granite are parallel. The smaller pseudo-dikes are seen to pinch out at each end. The largest one, exposed for 40 feet, is $1^1/_2$–2 feet in width. A small pegmatite dike, derived from the granite magma, cuts this pseudo-dike very sharply; but the pegmatite is not sharply separated from the granite. Sharp contacts of the metadiorite against both the granite and the pegmatite and the highly foliated and sheared structure of the metadiorite rule out the possibility that we are here dealing with a true dike—even one which could have intruded the granite before final consolidation of the latter." This example may well be a pre-granite xenolith, but the description given would be equally suitable for many of the metamorphosed dykes in Ilordleq, not to mention the innumerable metamorphosed dykes in Fennoscandia. Other examples given by MILLER are similarly ambiguous.

GOODSPEED (1955) gives a table of criteria for distinguishing between pre-granite dykes and pseudo-dykes (elongate enclaves of pre-granite country rock). The diagnostic features given for the recognition of pre-granitic pseudo-dykes in granitised rock are as follows: (1) contain transecting replacement veinlets of the surrounding granitic rock, (2) irregular cusp-like embayments of the granitic rock into the relics, (3) formation of irregular appendages or thin elongated ancillary inclusions in the granitic rock, (4) shadow-like borders and locally gradational contacts between the 'dyke' and the granitic rock, (5) crystalloblastic extensions of the granitic rock into the dykes. With the possible exception of (3), all these features are just as likely to be found in dykes emplaced in subsequently reactivated granite and therefore cannot be considered diagnostic of inclusions of pre-granitic country rock.

Distinction from dykes emplaced in hot granite.

This distinction is more difficult than those previously considered. The difficulty is inherent in the nature of all metamorphosed dykes because it will be agreed that the dykes assumed their metamorphic characteristics when the country rocks were hot; it thus becomes more difficult to prove that the country rocks were at normal temperatures when the dykes were emplaced.

A line of evidence which is commonly offered is the fine grained nature of dyke margins. Such a feature cannot, however, be seen if the dykes have been migmatised and in any case is not indicative of cold country rock. The temperature difference between an intrusive basic dyke magma and cold country rocks may be as high as 1000°C, but the temperature difference between an intrusive basic magma and country rock at the temperature of amphibolite facies would then be 500°C; this is certainly sufficient for the formation of chilled margins as can be seen in the case of dilation dykes of granitic composition. As has been pointed out by POLDERVAART (1953), a fine grained margin to an amphibolite dyke is not evidence of an original chilled margin but may be due to metamorphic or shearing effects. This would not apply, however, in those cases where traces of the original magmatic texture can be identified, as in some of the 2nd period dykes in the Ketilidian granite of Ilordleq.

A more fruitful line of enquiry concerns features which indicate a marked kinematic control of the metasomatism of dykes in the Sanerutian granite, especially those on the NW coast of Ikerasârqap nunâ. The neosomatic material in the dykes shows exactly the same intense linear structure as that of the country rock granite, and can be seen to be an original feature and not imposed by later deformation (page 71). The operation of the forces responsible for this structure is inconsistent with the conditions under which intrusion of basic magma and the formation of dykes could take place. Strong compressive forces and elevated temperatures are the antithesis of conditions under which basic dykes are normally emplaced. It is also of some significance that the foliation of the majority of the dykes in the Sanerutian granite is parallel to that produced in the country rock by the deforming forces. The intrusion of flat-lying or gently dipping sheets seems even more improbable under these conditions than the emplacement of vertical dykes, and yet some of the 2nd period dykes were emplaced as gently dipping sheets.

The possibility of emplacement in hot granite applies of course only to those 2nd period dykes in the Sanerutian granite; there is no reason to suppose that 2nd period dykes elsewhere were emplaced as anything other than normal basic dykes.

The contrast between the intrusive features of the 2nd and 3rd period dykes is again highly suggestive of tensional conditions and relatively cool country rocks during emplacement of the 2nd period dykes. The 3rd period dykes can be seen to have been emplaced while the region was still under stress, and have very characteristic features (page 95), which are entirely lacking in the 2nd period dykes. Other instances of dykes emplaced under conditions of stress and elevated temperatures show many of the features of the 3rd period DAs to be typical of such dykes (Kaitaro, 1953; Pitcher and Read, 1960).

Use of the terms hot and cold to describe temperatures of country rocks during dyke emplacement may in fact be rather misleading. Elevated temperatures and high load pressures are not necessarily accompanied by metamorphism and we should perhaps distinguish between country rocks in which plutonic processes are not active, even though the rocks may be at moderately high temperatures, and with high load pressure, and those country rocks in which plutonic processes are active. Following Roddick and Armstrong (1959), the term synplutonic may be applied to dykes emplaced in country rocks in which the plutonic processes are operating. High temperature of the country rocks during dyke emplacement, due either to depth of burial or to a local rise of the thermal front around swarms of dykes (Wegmann 1938, p. 138), may result in slow cooling and perhaps autometamorphism within the dykes. The autometamorphic garnet-amphibole assemblages in border zones of the Scourie dyke, Sutherland, (O'Hara, 1961) appear to be the result of such effects. Such dykes are in no way comparable with synplutonic dykes and may thus be taken as an indication of a break in plutonic activity.

Roddick and Armstrong (1959) describe dykes from the Coast Mountains, British Columbia, which have a striking resemblance to some of the 2nd period dykes of Ilordleq. Conflicting age relations with the enclosing granitic rocks, leucocratic margins and metasomatism of the dykes are features particularly reminiscent of the Ilordleq dykes. These dykes had previously been described by Phemister (1945) who concluded that an invading granite magma stoped away the supracrustal country rocks into which the dykes originally had been emplaced, leaving behind the dykes which behaved as barriers to the incoming magma. RODDICK and ARMSTRONG disagree with PHEMISTER's conclusion, as they consider the granitic rocks to have been formed by metamorphic transformation of earlier supracrustal rocks, and with regard to the problem of the relict dykes they add that "magmas seem to be crude mechanisms, too lacking in possibilities for refinement to provide a satisfactory solution to the problem" (p. 608). They then go on to consider what might be referred to as the orthodox transformist solution, in which the dykes are considered as pre-granitic and to have behaved as resisters during the granitisation of their country rocks. Such an explanation had indeed been proposed for the British Columbia dykes by H. H. READ in the discussion of PHEMISTER (1945). RODDICK and ARMSTRONG consider this explanation inappropriate to the relict dykes which they describe and conclude "if the partly replaced dikes existed only in plutonic rock containing many inclusions, replacement processes might logically account for the phenomena, but they are, in fact, common in biotite rich plutonic rocks, where the replacement processes were so vigorous as to remove almost completely the country rock. Under such conditions no dike, regardless of its composition, is likely to remain as immune as some of those seen in the field" (p. 609). With this moderate statement the present writer would agree, but as RODDICK and ARMSTRONG point out, replacive processes can be very selective in their operation, as for instance in the formation of sulphide deposits. A strong dynamo-structural control can also lead to a considerable selectivity of metasomatic processes, as is shown by replacement of the 2nd period dykes of Ilordleq, and previously emphasised especially by RAMBERG (1952) and GAVELIN (1960). The solution finally put forward by RODDICK and ARMSTRONG is that the dykes intruded the granitic country rock while the latter was still chemically active and "still evolving by recrystallisation and metasomatism". The absence of chilled margins in many of the dykes is accounted for by the high temperature of the rocks into which the dykes were intruded. Consequent on this interpretation, they suggest the term synplutonic to describe such dykes.

There is, however, one striking inconsistency which is not satisfactorily resolved by such an interpretation. Supracrustal rocks, of volcanic and sedimentary origin, equivalent in age to the 'synplutonic' dykes, also show conflicting age relations with the granitic rocks. On the one hand conglomerates contain pebbles of the underlying granite and the same granite veins the conglomerates; this is explained by the authors as a result of the 'essential contemporaneity' of the dykes, associated effusives and *the plutonic granitic rocks.* Such an explanation runs counter to all established concepts concerning the nature and formation of plutonic rocks.

In view of the fact that three quite different interpretations of the dykes in British Columbia have already been put forward, it seems that a fourth interpretation would not be entirely unjustified. The situation described by RODDICK and ARMSTRONG is entirely analogous with features described by ESKOLA (1948) as being characteristic of the mantled gneiss domes, and it therefore seems likely that the interpretation put forward to account for the 2nd period dykes in Ilordleq would be equally suitable for the dykes in British Columbia. Of some significance is the fact that of the dykes described by RODDICK and ARMSTRONG, those showing the highest degree of recrystallisation (dykes with granulitic texture) and penetration by the country rock, characteristically occur in one particular type of plutonic rock, i.e. the biotite rich variety, while those dykes retaining fine grained margins (PHEMISTER 1945, p. 59) are found within the Caulfield gneiss, which may thus be interpreted as the parent of the rocks of the 'batholith'. If analogy with Ilordleq be allowed, the biotite rich plutonic rock would be equivalent to the Sanerutian granite, while the Caulfield gneiss could be compared with Ketilidian granite. Such proposals would not be justified if it were not for the excellent descriptions and photographs given by the authors concerned, and the striking similarity between both individual features and the regional setting of the dykes in British Columbia and South Greenland.

In view of the fact that both dykes and plutonic rocks appear to occur throughout the Coast Mountain belt, ESKOLA's view that mantled gneiss domes formed only in areas which have undergone two orogenic revolutions may have some application in British Columbia. Evidence for multiple orogenic events in the mobile belt of the Western Cordillera has recently been put forward by DOTT (1961).

Section V

REGIONAL SETTING AND CORRELATION

A brief reference was made in the introduction to the three petrologically distinct regions of South Greenland, viz. the Ivigtut region, extending north from Kobberminebugt, characterised by gneisses and metamorphosed supracrustal rocks; the Julianehåb region extending from Kobberminebugt in the west to the margin of the inland ice 150 km to the east, consisting mainly of granitic rocks; the Nanortalik region beginning some 30–40 km south of Julianehåb and consisting mainly of gneisses and supracrustal rocks.

The aim of the present systematic work being undertaken by G.G.U. must be to relate these divisions on a chronological basis and thus prepare the way for a genetic interpretation of the whole area. The results of investigations in Ilordleq may be used in establishing a necessary link between the Ivigtut and Julianehåb regions and the following remarks will be confined to these two regions. Work in the Nanortalik region is not yet sufficiently advanced to enable correlations to be made with any degree of confidence.

Ivigtut Region.

To correlate the chronologies which have been established independently in the Ivigtut and Julianehåb regions, a datum must be found which is common to both sequences. The only feature sufficiently distinctive to be used for this purpose is the supracrustal series, which can be traced from Kobberminebugt northwards along the eastern boundary of the Ivigtut gneisses (see Plate VIII). The supracrustal rocks along the margin of the inland ice north of Arsuk Fjord consist of metasediments of the *Vallen* group, overlain by volcanics of the *Sortis* group (Bondesen, 1962). Metasedimentary rocks in the upper part of the Sortis group can be correlated with the metasediments occurring on the mainland NE of Sánerut, which appear to pass upwards into the supracrustal rocks of Ilordleq. Although a precise stratigraphical correlation cannot be made, it is clear that the supracrustal rocks found to the north of Arsuk Fjord were formed during the same depositional period during which the Ilordleq supracrustal rocks were formed and may be considered as being of the same age.

The Precambrian chronology of the Ivigtut region has been given by BERTHELSEN (1960) as follows:

(4) Gardar	Faulting, dyking, intrusive centres
(3) Sanerutian	Reactivation (SE of Arsuk Fjord)
(2) Kuanitic	Intrusion of doleritic dykes
(a) Ketilidian	Orogeny
	Arsuk, Sermilik } supracrustal groups

On this basis the supracrustal rocks, found mainly at Sermiligârssuk, Arsuk Ø, and along the margin of the inland ice, are of Ketilidian age, following the usage of WEGMANN (1938). The supracrustal rocks are interpreted as belonging to the same depositional cycle as the supracrustal rocks from which the large area of gneisses has been formed. The separate development of the supracrustal remnants and the underlying gneisses is interpreted as being due to a differentiation into superstructural and infrastructural elements during the Ketilidian orogeny. The structural style of the infrastructural gneisses, developed during three folding phases, contrasts with that of the supracrustal superstructure.

After the Ketilidian plutonic activity had ceased, regional swarms of basic dykes were emplaced in tensional fissures. This dyke phase is especially well developed at Kuánit (between Tôrnârssuk and Kungnât) and the period during which the dyking took place therefore referred to as the Kuanitic period.

Metamorphism, and in places migmatisation of the Kuanitic dykes, was accompanied by reactivation of the gneisses; this plutonic activity was especially severe to the SE of Arsuk Fjord, but to the north in the Tôrnârssuk area, the Kuanitic dykes are scarcely metamorphosed and only slightly deformed. The time after the emplacement of the Kuanitic dykes and before the Gardar is referred to as the Sanerutian period. The metamorphism of the Kuanitic dykes therefore took place during the Sanerutian.

A correlation of the above sequence of events with that determined for Ilordleq is fairly straightforward and justifies the use of the terms Ketilidian and Sanerutian in this account of Ilordleq. The 2nd period dykes of this account would therefore correspond to the Kuanitic dykes of the Ivigtut region.

Recent work in the Ivigtut area, however, has shown that some revision of the above chronology may be necessary. A distinct unconformity with basal conglomerate has been found separating supracrustal rocks from underlying gneiss, north of Arsuk Fjord (BONDESEN, 1962). It has been suggested that this discrepancy be circumvented by assuming that a small thrust wedge of pre-Ketilidian rock is confined to the area immediately underlying the observed unconformity (BERTHELSEN, 1962, Table 7). However, the possibility arises that the apparent conformity elsewhere of the supracrustal rocks and gneisses is due to the unconformity being obscured by reactivation of the underlying gneisses. Confirmation of this proposal probably must await the results of investigations north of Sermiligârssuk which will be carried out in the next few years. However, if the proposal is correct, the Kuanitic dykes may be equivalent in age, not to the 2nd period dykes of Ilordleq, but to the 1st period dykes. This does not mean, however, that the supracrustal rocks of Ilordleq, being of the same age as the 1st period dykes, should then belong to the Kuanitic period. Following WEGMANN (1938), the supracrustal rocks are defined as Ketilidian and thus it is the status of the Kuanitic period in the Ivigtut region which may be in doubt. The status of the Sanerutian also becomes doubtful, this period having been established as that following the Kuanitic. The possibility of confusion in the future might be most easily avoided by redefining Sanerutian as the plutonic episode during which 2nd period dykes in Ilordleq and other areas of the Julianehåb region (see below) were metamorphosed and deformed and their granitic country rocks reactivated.

It will be noted that in the suggested new definition, Sanerutian is described as a plutonic episode rather than either a period of time or a cycle. At the moment there is confusing inconsistency in the units used in the chronological subdivision of South Greenland, similar to that which appears to have led to chronological misunderstanding elsewhere (BROWN 1962). According to BERTHELSEN (1961, p. 333) the Ketilidian *cycle* is followed by the Kuanitic and Sanerutian *periods* which are in turn followed by the Gardar *cycle*. Periods of time and cycles of events are somewhat different concepts which need to be clearly distinguished; neither, however, is suitable for use as the basic unit of Precambrian chronology.

The advantages of defining Sanerutian as an event can be most clearly recognised when similar and more or less synchronous events elsewhere are considered. Laxfordian (SUTTON and WATSON, 1951), Nagssugtoqidian (NOE-NYGAARD, 1952), Hudsonian (STOCKWELL, 1961) and Sanerutian plutonic activity took place at approximately the same time (1650–1700 million years); Sanerutian is at present defined as a time span, Laxfordian as an event, Nagssugtoqidian and Hudsonian as orogenies and, by implication, cycles. Only by restricting the terms to single events can correlations be made without ambiguity.

The difficulties which arise when primary subdivision is made on an interpretative or cyclic basis are well illustrated in the literature on the Fennoscandian shield, especially that in which the relationship of the Svecofennian and Karelian cycles is considered. Suggestions that "Precambrian stratigraphy should be based on the "recognition of geological cycles" (QUENNELL and HALDEMANN, 1960) and that "subdivision and correlation of the Precambrian is most logically effected by reference to cycles of events" (HARPUM, 1960) assume a knowledge of, and agreement upon, Precambrian cycles which does not exist. Such a classification tends also to obscure differences between cycles which although possibly synchronous, are of different types (WEGMANN, 1961).

The procedure of recognising orogenic cycles by a combination of mapped structural trends, and isotopic age measurements (STOCKWELL, 1961) is prone to misinterpretation; the age calculated from a metamorphosed supracrustal rock may reflect plutonic activity in a cycle much younger than that in which the supracrustal series was formed; metamorphism and reactivation of granitic rock pose similar problems. For these reasons misinterpretation of isotopic ages may well prove to be the case in Fennoscandia (ESKOLA, 1960), and until isotopic age studies are able to provide a more sophisticated analysis of the evolution of a rock, the methods of SEDERHOLM remain indispensable.

The requirement is thus for a local definition and naming of certain events in the order of their occurrence: the time accounted for by these events may be considerably less than the elapsed time. This being done, the essentially interpretative proposals of cycles can be carried out quite separately and without affecting established chronologies or nomenclature. In this way, the widely different uses of the term orogeny would be more clearly recognised; examples of different opinions regarding the nature of Precambrian cycles are referred to in the section dealing with the significance of metamorphosed basic dykes. The term orogeny is used by some authors to refer not to a cycle of events but only to a plutonic episode; "a period of mountain building accompanied by folding and commonly by metamorphism and granitic intrusion" (STOCKWELL, 1963, p. 124) The reference to "a period of mountain building", however, is an interpretative extrapolation inappropriate to a primary chronological subdivision. It should be noted that the procedure proposed is very similar to that employed in the description and *subsequent* correlation and interpretation of normal stratigraphic sequences.

In applying these principles to the chronological subdivision of South Greenland, it becomes necessary also to reconsider the term Ketilidian, which was originally defined as an orogenic cycle (WEGMANN, 1938). The shortcomings of this usage are illustrated by BERTHELSEN (1961), who in pointing out that the significance of the Sanerutian was not yet understood, thereby implied that it was not yet known whether or not the Ketilidian cycle included the Sanerutian episode of plutonic activity. The term Ketilidian may therefore be retained for a cycle, or alternatively applied to either an episode of supracrustal deposition and volcanic activity, or to an episode of plutonic activity.

The following table summarises the suggestions put forward above. Brackets enclose interpretations which are suggested as *possible* alternatives to current correlations. Possible absolute dates are also given.

	Episode		characterised by:–
(7)	Gardar	(ca. 1150×10^6)	intrusive and extrusive vulcanicity, faulting, continental sandstones.
(6)	Sanerutian	(ca. 1590×10^6)	plutonic activity, emplacement of 3rd period dykes.
(5)			intrusion of 2nd period dykes [supracrustal rocks, including Sermilik group ?].
(4)	Ketilidian	(ca. 2400×10^6)	plutonic activity [only S and SE of Arsuk Fjord ?].
(3)			supracrustal rocks, 1st period dykes.
(2)		(ca. 2700×10^6)	plutonic activity [formation of Ivigtut gneisses from supracrustal series ?].
(1)			(supracrustal rocks).

Julianehåb Region.

Within the last few years almost the whole of this region has been surveyed, and it is apparent that the sequence of events which can be demonstrated in Ilordleq is repeated with only minor variations throughout the whole region. The sequence granite—basic dykes—reactivation is recognisable in all areas. The reactivation is generally more intense in the eastern part of the region, and Ketilidian granite, in the sense used in Ilordleq, is only rarely found east of Qagssimiut. In view of this it seems likely that the age of 1590 ± 70 million years of a biotite from a granite collected at Julianehåb (Moorbath, Webster and Morgan, 1960) gives the approximate age of the Sanerutian reactivation in Ilordleq.

Isotopically anomalous lead associated with Gardar intrusives in the Ivigtut area, possibly representing lead remobilised from rocks approximately 2400 million years old (Bate and Kulp, 1956), may therefore give an approximate indication of the date of the Ketilidian plutonic activity. The age of pre-Ketilidian basement, represented in Ilordleq only by clastic fragments in agglomerates but perhaps occurring more extensively in the Ivigtut region, is possibly indicated by a date of 2710 ± 130 million years of biotite from a gneiss at Godthåb (ARMSTRONG, 1963), about 400 km to the north of Ilordleq.

Supracrustal rocks of the same age as the 2nd period dykes have not yet been identified and thus the full significance of the Sanerutian reactivation is difficult to evaluate. WEGMANN (1938) already recognised the reactivated nature of much of the Julianehåb granite, and it is apparent (loc. cit. p. 55) that he regarded the reactivation to have taken place at the same time as the folding and migmatisation of the supracrustal rocks of the Nanortalik region. The supracrustal rocks of the Nanortalik region would on this basis be the same age as the 2nd period dykes of Ilordleq. No evidence has been found during more recent investigations which shows that this suggestion is incorrect. Thus it is possible that the Ketilidian granite of Ilordleq and neighbouring areas formed the basement for a supracrustal series now preserved only in the Nanortalik region, and that the orogenic folding and migmatisation of the supracrustal series found expression in the basement rocks as the Sanerutian reactivation. In view of this the continued correlation of supracrustal rocks occurring in the widely separated Ivigtut and Nanortalik regions would seem unwise, although by no means definitely incorrect. A necessary precaution, however, appears to be restriction of the term *Sermilik group* (WEGMANN, 1938; BERTHELSEN, 1961) to metasediments in the Nanortalik region, and discontinuance of use of the term for metasedimentary rocks in the Ivigtut region.

Dykes showing features similar to those of the 3rd period dykes have been found in other areas of the Julianehåb region and appear to occupy a similar chronological position relative to the Sanerutian reactivation. Synkinematic basic dykes, which may well be of the same age as the 3rd period dykes of Ilordleq, have recently been found in the Nanortalik region where they are closely related in both space and time with discordant granite masses.

Section VI
CONCLUDING REMARKS

Significance of Metabasaltic Dykes.

The use of metabasaltic dykes in the chronological subdivision of areas of plutonic rocks was initiated by Sederholm in his investigations of the migmatitic rocks of S and SW Finland. Sederholm's views regarding the significance of the metabasaltic dykes were unequivocal, and the sequence granite—basic dykes—reactivation was taken as a clear indication that rocks in which this sequence was observed were products of two distinct orogenic periods. This view was to some extent influenced by, but clearly not dependent on, the occurrence of a series of metamorphosed supracrustal rocks which Sederholm regarded as equivalent in age to the hypabyssal basic intrusives. These supracrustal rocks of the Tampere schist belt were later shown to be earlier than the granitic rocks in which the basic dykes were emplaced. Many later workers, both in Finland and in similar areas elsewhere, have not followed Sederholm's lead and at the moment a wide divergence of opinion is evident regarding the significance of metabasaltic dykes, so much so that Berthelsen (1955) was led to conclude "opinions differ as to the importance of the hiatus marked by basic dykes . . . it seems a matter of traditional or personal conviction . . ."

It seems that there are two reasons for this disagreement. The first of these is the failure to distinguish between metabasaltic dykes of the type described by Sederholm, represented in Ilordleq by the 2nd period dykes, and basic dykes which are of syn- or late-kinematic origin. The late-kinematic type, represented in Ilordleq by the 3rd period dykes, clearly do not separate two periods of plutonic activity, and if not distinguished from the metabasalts lead to doubts about the geological significance of the latter. This appears to be the case in a recent account of basic dykes reminiscent of the 3rd period dykes of Ilordleq rather than metabasalts, and which clearly do not separate two plutonic periods (Moore and Hopson, 1961).

The distinction of the two types of dyke will be described more fully in Part II of this account.

A second reason for the diversity of opinion regarding the significance of basic dykes arises from the several usages of the term orogeny. Reference should here be made to the four distinct cases which can be recognised in the occurrence of metabasaltic dykes in basement complexes:–

i) Metamorphosed dykes which are related to and equivalent in age with supracrustal rocks lying unconformably on the plutonic rocks into which the dykes were emplaced. Examples of this situation are known from mantled gneiss domes of Finland (Eskola, 1951; Preston, 1954) and North America (Bloomer and Werner, 1955) and if the writer's suggestions are correct, the coast ranges of Western North America (Roddick and Armstrong, 1959). This situation may also occur in S. Greenland if the first period dykes are equivalent in age to the Kuanitic dykes (page 132).

ii) Metamorphosed basic dykes in reactivated basement rocks, which can be traced into areas where no post-dyke reactivation has taken place. Examples have been described from Scotland (Sutton and Watson, 1951), West Greenland (Noe-Nygaard, 1952; Ramberg, 1948) and South Greenland (page 131).

iii) Metamorphosed basic dykes which have not been traced into areas in which they are unmetamorphosed, and for which no related supracrustal rocks are known. Very many examples have been described (e.g. Eckelmann and Poldervaart, 1957; Eskola, 1914; Lund, 1956; Gjelsvik, 1952; Dietrich, 1954; White and Billings, 1951; Hunter, 1957; Wegmann, 1962). The 2nd period dykes of Ilordleq fall into this category, unless it is found that they can be correlated with the Kuanitic dykes of the Ivigtut area.

iv) A further possibility is a combination of (i) and (ii), but no certain example of this is known to the writer; further work on the Lewisian rocks of Scotland may, however, show such a relationship.

There is, however, no fundamental difference between the four categories (cf. Berthelsen, 1955); in each case a break in plutonic activity is indicated, and the occurrence of dykes implies at least the possibility of effusive volcanic activity and the formation of supracrustal rocks. Although there is fairly wide agreement that the emplacement of basic dykes evidences a change in conditions, there is less agreement on the significance of such a change. Views expressed can be divided into those in which metabasaltic dykes are regarded as intra-orogenic (e.g. Simonen, 1960 b; Vilcox and Poldervaart, 1956; Wahl, 1936; Seitsaari, 1951; Magnusson, 1936; Hunter, 1957; Eskola, 1914) and those in which the occurrence of the dykes is regarded as indicating an interorogenic interval (SEDERHOLM, 1926; NOE-NYGAARD, 1952; RAMBERG, 1948; SUTTON and WATSON, 1951; READ, 1957; WEGMANN, 1938; KRANCK, 1935). Such a simple division is rather misleading however, as it conceals wide differences of opinion regarding the nature of an orogenic period or cycle, and this indeed appears to be a problem of some importance. The problem is illustrated by the following examples of uses made of the term orogeny.

The complex tectonic pattern of the western United States is interpreted by GILLULY (1963) as the product of a large number of orogenic events which took place between Early Mississippian and Miocene time; there is "clear evidence of several large scale orogenic episodes in Mississippian, Pennsylvanian and Permian times" (loc. cit. p. 164). The duration of these periods is thought to be 130×10^6 years (KULP, 1960).

Recent work (HALLER and KULP, 1962) indicates that the Lower Palaeozoic orogenic cycle of East Greenland extended over a time span of 150×10^6 years, although the main orogenic activity lasted for a much shorter time. In Finland, a time of 230×10^6 years elapsed between the beginning and end of the Svecofennian orogeny (SIMONEN, 1960 a), the synorogenic intrusions being emplaced during a period of 100×10^6 years.

These differences could reflect a genuine progressive change in the duration of orogenic cycles; on the other hand, it has been suggested that Precambrian mountain building episodes were more frequent and shorter lived than in Phanerozoic time (GILL, 1952). It seems more likely, however, that the differences should be accounted for by the different usages of 'orogeny', resulting mainly from the different methods employed in the investigation of the regions concerned. In the Upper Palaeozoic, Mesozoic and Tertiary rocks of Western North America the approach is dominantly a stratigraphic-structural one in which plutonic activity is of secondary importance; in such circumstances it is reasonable to conclude that "plutonism is indeed associated with orogeny, but the converse is quite as certainly not true" (GILLULY, 1963, p. 166).

In East Greenland, a concentration on structural and metamorphic events leads to a somewhat different concept of orogenesis, and one in which systematic changes are apparent throughout the orogenic period; a cyclic interpretation becomes necessary.

In the Finnish Precambrian, a petrological emphasis together with the magmatectonic concept has resulted in even greater emphasis on systematic changes during orogenesis. "Every orogenic cycle is associated with intrusions of different kinds of granitic rocks" (SIMONEN, 1953, p. 12). The Svecofennian orogeny thus bears little relation to, for example, the Antler orogeny of Nevada (GILLULY, 1963, p. 138).

It is evident that the meaning given to orogeny is largely dependent on the depth of erosion reached in any particular area under discussion, the depth of erosion more or less determining the method of investigation. If the orogenic cycle or period must be defined so subjectively, it is clearly unsuitable as the primary chronological unit in the subdivision of Precambrian areas: furthermore, its use for this purpose will continue to obscure possible progressive changes which have taken place in the scale, nature and duration of continental processes throughout geological time.

Although the main geological events of Phanerozoic times are already fairly well established, an evolutionary interpretation of these events is not yet agreed on. On the other hand, our knowledge of Precambrian events is very incomplete and it is inevitable that no agreement can yet be reached on an evolutionary interpretation. However, it is unlikely that these events could ever be represented in terms of a simple repetition of similar cycles of events—"uniformitarianism cannot be eternally true" (Read, 1957, p. 263).

To speculate further upon, or assume a knowledge of, the significance of metabasaltic dykes in regard to genetic cycles of events seems unjustified at the present time; they remain an invaluable means of recognising important changes of conditions during the development of particular areas, and provide opportunity for a standardised chronological subdivision of Precambrian areas in which the interpretative element is kept to a minimum. If, as seems likely, the intrusion of these dykes takes place more or less contemporaneously at all levels in the crust, they will provide a method of relating synchronous events at the different levels.

It is useful, however, to remember the distinction between ophiolitic dykes, i.e. those associated with the ophiolitic effusive volcanic rocks in mobile belts, and cratogenic dykes related to effusive vulcanicity of the plateau basalt type and often too with alkaline intrusive rocks. Ophiolitic dykes may be expected to be emplaced only in basement rocks in areas destined as sites of plutonic activity; unmetamorphosed representatives of this type may therefore be rather uncommon in the shield areas. The cratonic type on the other hand is likely to be emplaced in many basement areas not subjected to later reactivation and a large proportion of the unmetamorphosed dykes in shield areas should be of this type. The suggestion that dyke emplacement may be expected in the later stages of chelogenic cycles during the break-up of continents (Sutton, 1963), would thus refer to the cratogenic rather than ophiolitic dykes.

The Gardar volcanic rocks in S. Greenland, intrusive representatives of which are dominantly alkaline, provide an example of the cratogenic type of vulcanicity; on the basis of the chelogenic hypothesis, both these rocks and the volcanic rocks of similar age and type in the Canadian

Shield would have been emplaced during the break-up stage of the Svecofennian chelogenic cycle.

The profusion of alkaline rocks of Upper Phanerozoic age would have a similar relationship to the Grenville chelogenic cycle, and indicates the possibility of a connection between the late stages of chelogenic cycles and the supposed tectonic control of alkaline rocks (TILLEY, 1957).

Comparison with similar areas.

Ilordleq is of some interest as an example of the reactivation of a basement complex. Apart from the allochthonous Hercynian massifs in the European Alps, comparatively few such areas have been examined in detail and of these the Lewisian rocks of the N.W. Highlands of Scotland (SUTTON and WATSON, 1951) are probably the best known. The broad similarity between the development of the Lewisian rocks and those of Ilordleq is quite clear and the distinctive behaviour of basic rocks a notable feature of both areas. The following comparable features are of particular interest:–

i) The preferential migmatisation of basic rocks in Ilordleq in certain kinematic environments is paralleled by the pegmatisation of basic Scourian gneisses (loc. cit. p. 266) and metadolerites (loc. cit. p. 276).

ii) The association of pods or fragments of hornblendite with particularly leucocratic parts of their host rocks of acid gneiss (page 88, fig. 61, loc. cit. p. 259) is common to both areas and a similar interpretation appears applicable in both cases.

iii) The metamorphic differentiation of metabasaltic dykes into hornblende rich rocks and acid veining material, giving rise to venites; best seen in Ilordleq in the green 2nd period dykes and possibly also 1st period dykes (fig. 11), as well as in the Scourian dykes (loc. cit. pp. 253 and 276).

iv) The preservation of earlier textures to a much higher degree in some basic rocks than in adjacent acid rocks. In Ilordleq this feature is considered mainly a function of the kinematic environment of the rock, in which the shape, size and attitude of the basic body is of primary importance and the mineralogy a secondary factor.

v) The very close relationship between metasomatism and inhomogeneous deformation, e. g. in shear belts (page 56, loc. cit. pp. 255, 261, 278, 290).

vi) The structural distinction between the plastic deformation of the Laxford zone and brittle deformation elsewhere is closely parallelled by the structural differences between the Sânerutip imâ and other sub-areas to the S.E. Following WEGMANN (1935) and READ (1957), SUTTON and WATSON appear to regard the plasticity as a result of the concomitant migmatisation. In the Sânerutip imâ sub-area this cannot be the case as no granitisation or migmatisation took place during the reactivation, and indeed it seems that potash may have been removed during this time. The migmatisation of the discordant amphibolites shows at least the mobility of potash within the sub-area.

vii) No evidence has been found in Ilordleq for a 'diachronous metamorphic front' (SUTTON and WATSON, 1951, p. 288). As far as the Central and Nivâq sub-areas are concerned this may well be due to lack of sufficiently detailed observations, but it is quite clear that the rocks of the Sânerutip imâ sub-area did not pass through the stages represented by the less intensely reactivated areas. This is also the case with the Laxford zone (loc. cit. p. 290). The important point that highly metamorphosed rocks do not usually pass through the stages represented by associated less metamorphosed rocks, i.e. are members of a spatial series (page 104), has been emphasised by READ (1957, p. 24). In Søndre Sermilik fjord, between Julianehåb and Kap Farvel, where supracrustal rocks are intensely migmatised, the writer has found no evidence for either the advance or retreat of the migmatite front; the minor structures and age of the migmatisation relative to those structures, indicate that the position of the clearly defined migmatite boundary was established not during the climax of migmatisation but at an early stage. The latest migmatitic activity also occurred in the vicinity of this boundary and shows no signs of a progressive retreat. It is apparent that the concept of a migrating front of migmatitic or plutonic activity, although applicable in some areas, is not suited to every case.

Remarks on some structural features of the area.

The coincidence of principal strain axes of the Ketilidian and Sanerutian deformations is a feature of some importance and although no detailed structural evidence has been presented, some comment is required on the chronological significance of such coincidence. Were it not for the occurrence of the 2nd period dykes, there would be little reason for supposing that two different episodes of deformation had affected the area (cf. REID, 1963). The remarkable concordance between structures in reactivated basement rocks and those in deformed mantling rocks has been referred to by SUTTON (1962) and is a marked feature of the mantled gneiss domes.

The recognition of age differences between Precambrian formations is one of the outstanding problems of basement geology, not least in South Greenland. The relationships shown by the Ilordleq rocks add to the considerable body of evidence, indicating that structural homology may disguise important time breaks.

The trend of the Sanerutian structures in Ilordleq appears to be parallel to that of Sanerutian structures elsewhere in South Greenland and it is therefore unlikely that the trend in Ilordleq was controlled by the pre-existing Ketilidian structures. What may be a related feature is the parallelism of the majority of 2nd period dykes to the Sanerutian foliation, especially in the areas of most intense Sanerutian deformation. It is unlikely that the dykes were of sufficient size to influence the deformation to any large extent, although such a circumstance is known (NOE-NYGAARD, 1952). Rather the dykes appear to have been swept into near concordance with the country rock structures in a manner similar to the Scourian dykes of N.W. Scotland (CLOUGH 1907, p. 205; SUTTON and WATSON, 1951). It would be difficult to understand how such a re-orientation could take place, were it not for the analysis of finite homogeneous strain by FLINN (1962). In a previous section it has been suggested that the Sanerutian deformation could be regarded as a homogeneous strain with deformation paths varying from $k = 0$ to $k = \infty$.

The tendency for planes (in this case dykes) to migrate and become aligned parallel to the direction of extension is very marked (FLINN, loc. cit., fig. 4). With deformation less than that which is thought to have occurred in parts of Ilordleq during the Sanerutian ($a/c = 10$), and with a flattening-type (oblate) deformation ($k = 0$), the attitudes of originally randomly orientated planes (dykes) can be calculated, and it is found that half will be inclined at no more than 10° (FLINN, loc. cit., p. 399).

A discordance less than 10° is very difficult to detect in the field and allowing for a non-random original orientation of 2nd period dykes, it is clear that no problem is posed by the apparent conformity of many of the dykes. The parallelism of Ketilidian and Sanerutian planar and linear structures also appears to be less remarkable when the possible effects of Sanerutian homogeneous strain are considered.

In those parts of the area with Sanerutian deformation paths of $k = 0$, all planes originally inclined at 40° to the Sanerutian foliation direction would have migrated and now be inclined at only about 10° (as before, assuming $a/c = 10$). However, with deformation path $k = 0$, Ketilidian linear structures would not have been rotated into parallelism with the Sanerutian b direction, and so it must be assumed that the sub-horizontal character of the linear structures has remained unchanged. Some rotation of the Ketilidian strike direction seems possible, however, although not as much as 40° as the degree of deformation in the central part of the area is less than that represented by $a/c = 10$.

Consideration of the effects of finite homogeneous strain in similar situations elsewhere may assist in resolving difficulties posed by the apparent structural conformity of originally unconformable junctions.

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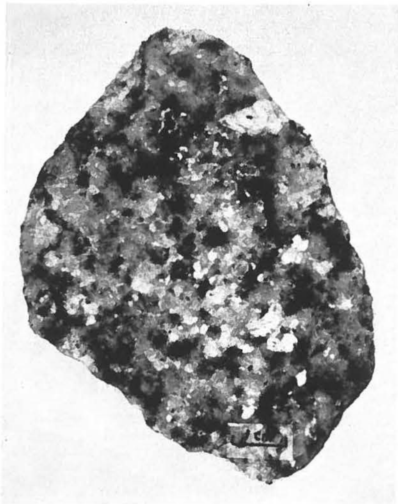
Færdig fra trykkeriet den 17. maj 1965.

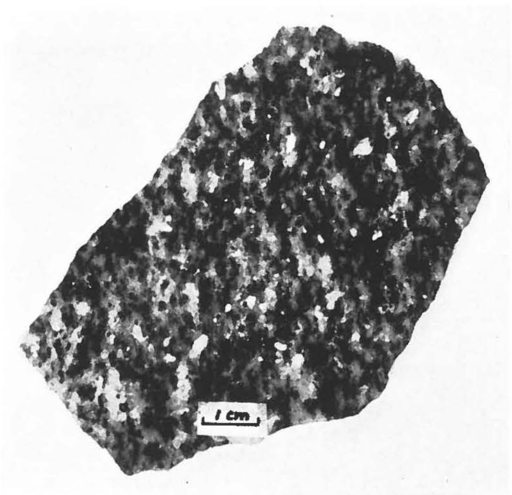
PLATES

Plate I.

Members A, B, and C of the augen granite series. A is only slightly modified Ketilidian granite. Sections of B and C are normal to foliation and lineation. Text reference pages 105—107.



A

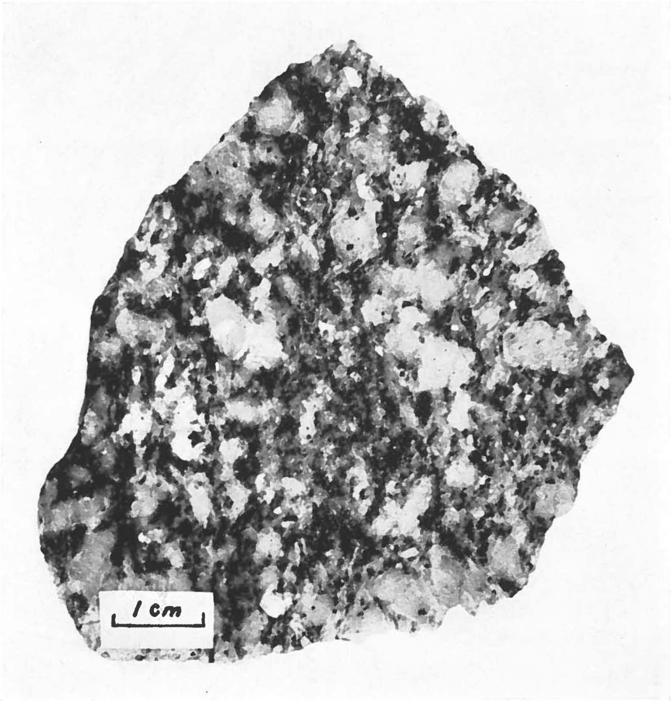


B

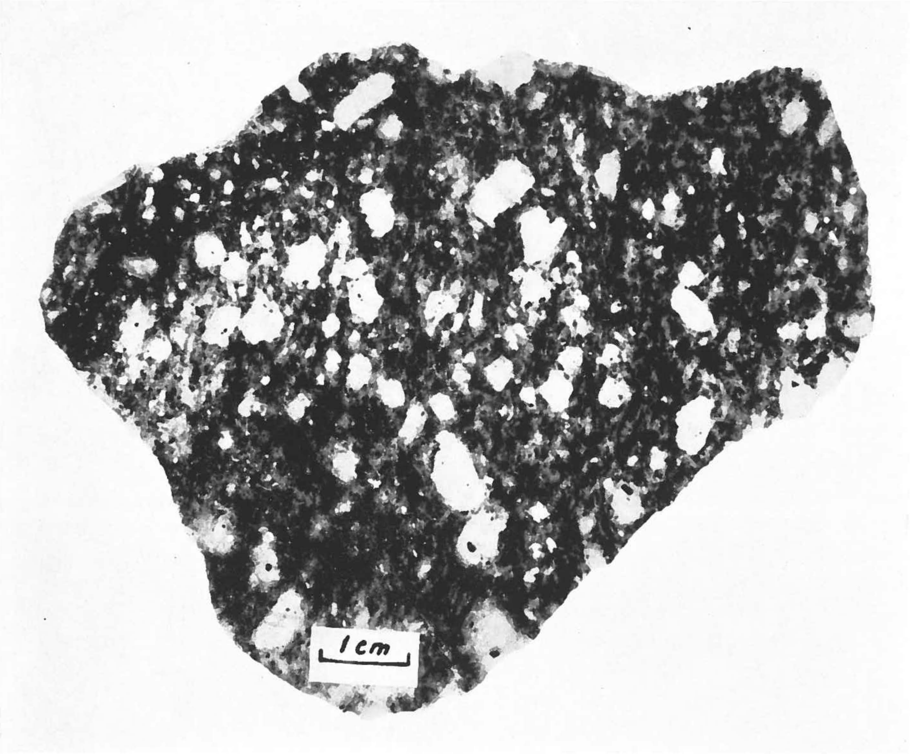
C

Plate II.

Members D and E of augen granite series. Discordant nature of largest microcline porphyroblasts is evident in each rock; both sections are normal to foliation and lineation. Text reference pages 108 and 109.



D



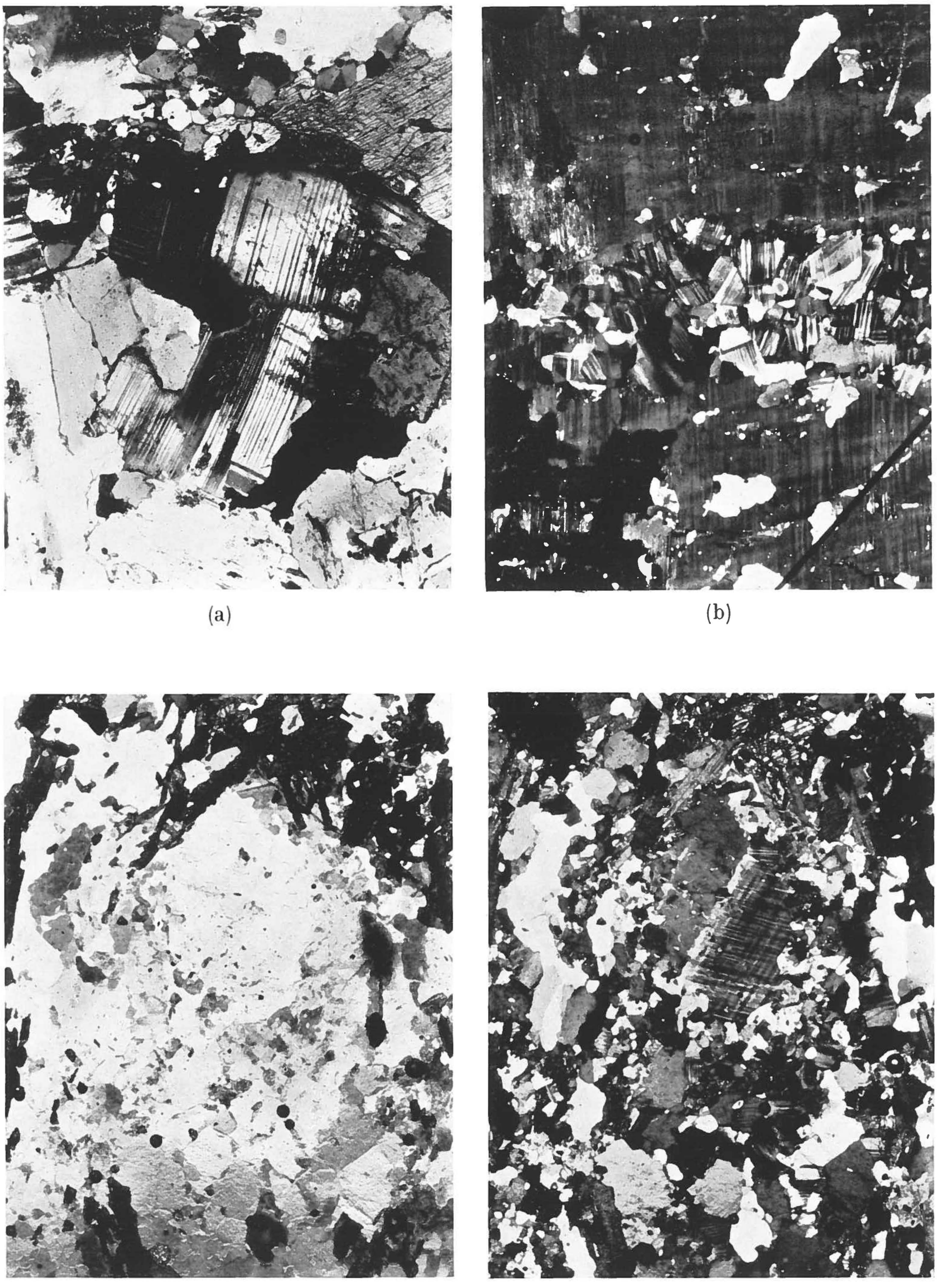
E

Plate III.

(a) Metagabbro (G.G.U. 52472) with original igneous texture well preserved. Finely twinned igneous felspar is distorted, and recrystallised to smaller polygonal grains (top centre) of metamorphic felspar which have either simple twinning or are untwinned. ×23. crossed nicols. Text reference page 113.

(b) Granite A of augen granite series (G.G.U. 31534). Large microcline (Ketilidian) with optically continuous skeletal remnants of altered plagioclase, replaced by cross-cutting aggregate of small equant grains of microcline (Sanerutian). ×17. crossed nicols. Text reference page 105.

(c) and (d). Granite B of augen granite series (G.G.U. 47234). Quartz-felspar lens centred on core of Ketilidian microcline megacryst showing carlsbad twinning inherited from replaced plagioclase. Corroded megacryst contains skeletal remnants of plagioclase. ×23. plain light (c), crossed nicols (d). Text reference page 106.

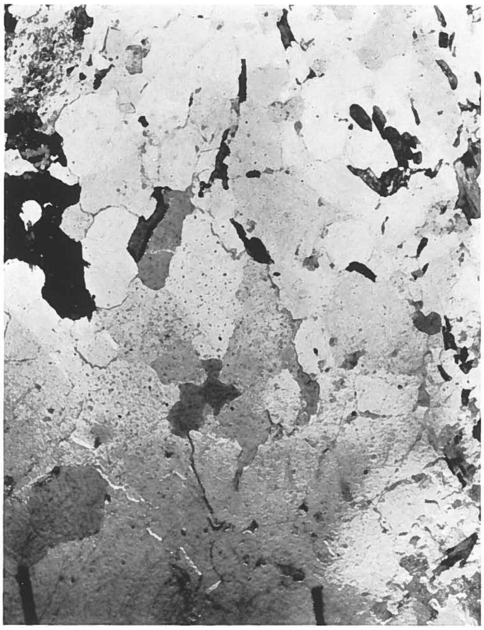


(a) (b) (c) (d)

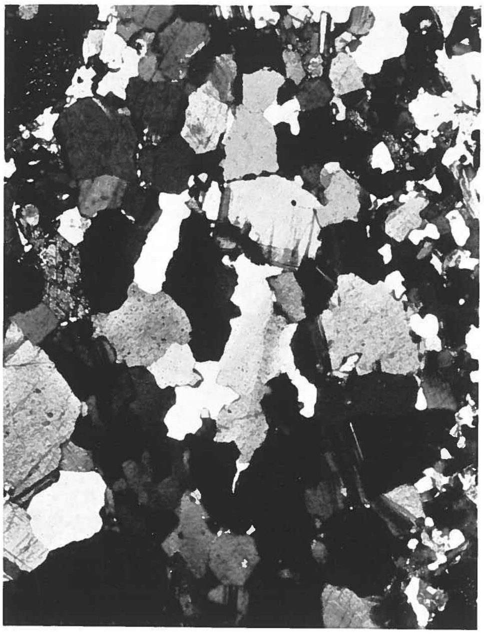
Plate IV.

(a) and (b). Granite C of augen granite series (G.G.U. 47208). Quartz-felspar lens without core of earlier felspar, and of grain size significantly larger than that of groundmass. ×17. plain light (a), crossed nicols (b). Text reference page 107.

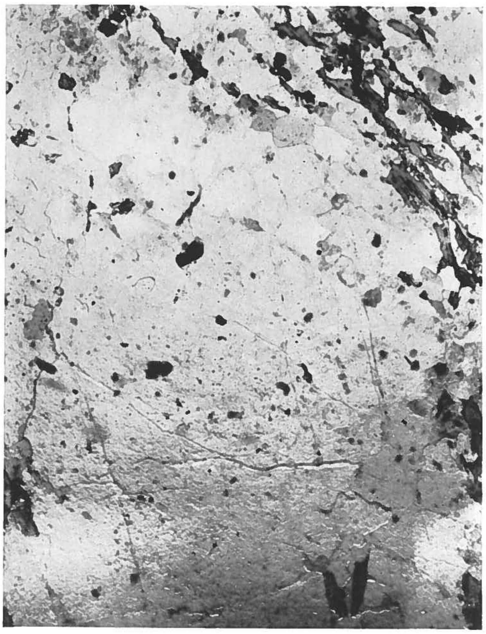
(c) and (d). Granite C of augen granite series (G.G.U. 47208). Augen composed mainly of Ketilidian microcline megacryst which shows relatively small amount of corrosion. ×23. plain light (c), crossed nicols (d). Text reference page 107.



(a)



(b)



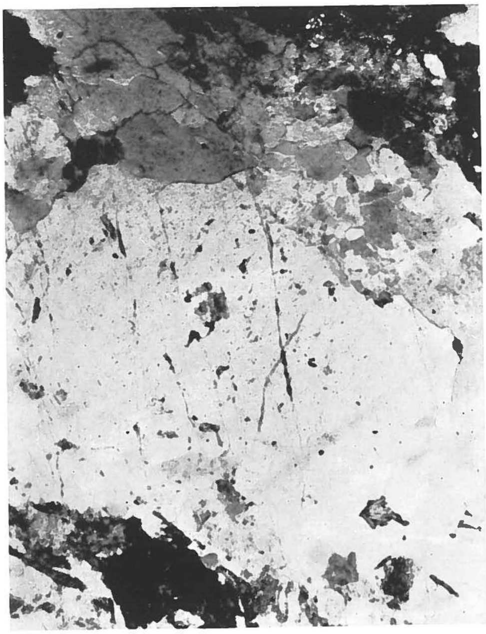
(c)

(d)

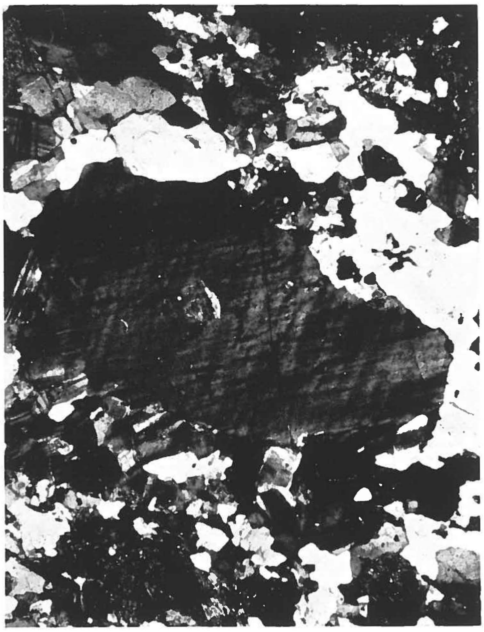
Plate V.

(a) and (b). Granite D of augen granite series (G.G.U. 47225). Relatively early stage of growth of 'new' (Sanerutian) microcline in polycrystalline augen. Microcline contains unoriented inclusions but no skeletal remnants of plagioclase. ×17. plain light (a), crossed nicols (b). Text reference page 108.

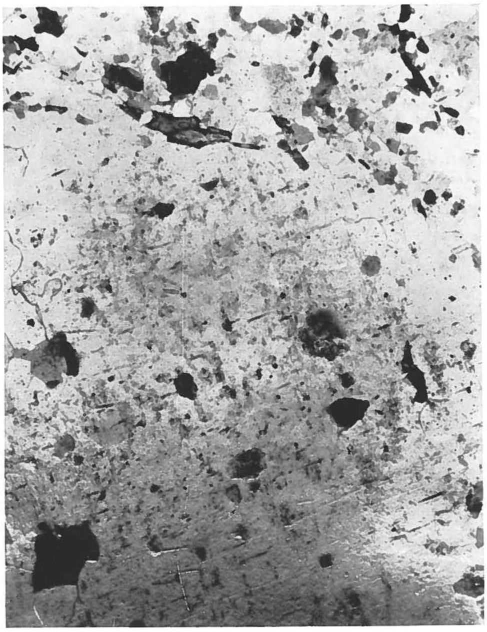
(c) and (d). Granite E of augen granite series (G.G.U. 47314). Poikilitic microcline porphyroblast of Sanerutian age, of the discordant postkinematic type. Although lying oblique to the foliation, the porphyroblast is undeformed. ×17. plain light (c), crossed nicols (3). Text reference page 109.



(a)



(b)



(c)

(d)

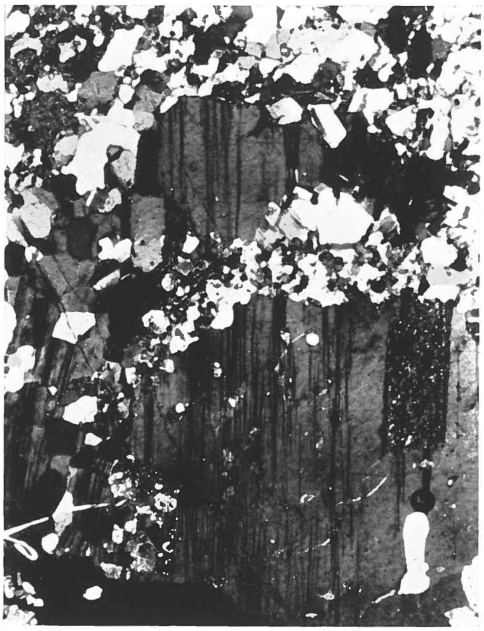
Plate VI.

(a) Granite E of augen granite series (G.G.U. 47314). 'Old' porphyroclastic microcline of the type found in concordant augen and interpreted as Ketilidian relic. Skeletal remnants of altered plagioclase and cross-cutting vein of fine-grained groundmass material are features typical of these 'old' felspars, and contrast markedly with those of the 'new' felspar of the type shown in Plate Vd. ×20. crossed nicols. Text reference page 109.

(b) Granite E of augen granite series (G.G.U. 47314). Deformed and corroded Ketilidian microcline preserved in concordant augen. ×70. crossed nicols. Text reference page 109.

(c) Homogeneous metavolcanic (G.G.U. 31645) with well preserved remnants of original igneous felspars. One such crystal (upper centre) is only slightly deformed but broken up by encroachment of metamorphic groundmass minerals, while another (lower centre) is replaced to a lesser degree but twinning is displaced along fracture. ×50. crossed nicols. Text reference page 110.

(d) Fine grained granite replacing grey 2nd period dyke (G.G.U. 32111). Relict igneous plagioclase (dark) with patches of fine grained alteration material (upper right), corroded by small crystals of introduced microcline. Original plagioclase crystal is now broken into three pieces which remain in optical continuity. ×80. crossed nicols. Text reference page 116.



(a)

(b)

(c)

(d)

Plate VII.

(a) and (b) First period dyke, showing site of original igneous felspar now occupied by polycrystalline aggregate of small plagioclases with intergranular biotite. Dark centre of aggregate is concentration of sericite and epidote, which is produced by saussuritization of original felspar. ×35. plain light (a), crossed nicols (b). Text reference page 113.

(c) and (d) Green second period dyke showing site of original igneous felspar now occupied by polycrystalline aggregate of metamorphic plagioclase and biotite. Concentration of sericite (upper part of aggregate in (c)) formed by alteration of original felspar. Original felspar site is outlined by dark groundmass consisting mainly of amphibole. ×50. plain light (c), crossed nicols (d). Text reference page 115.

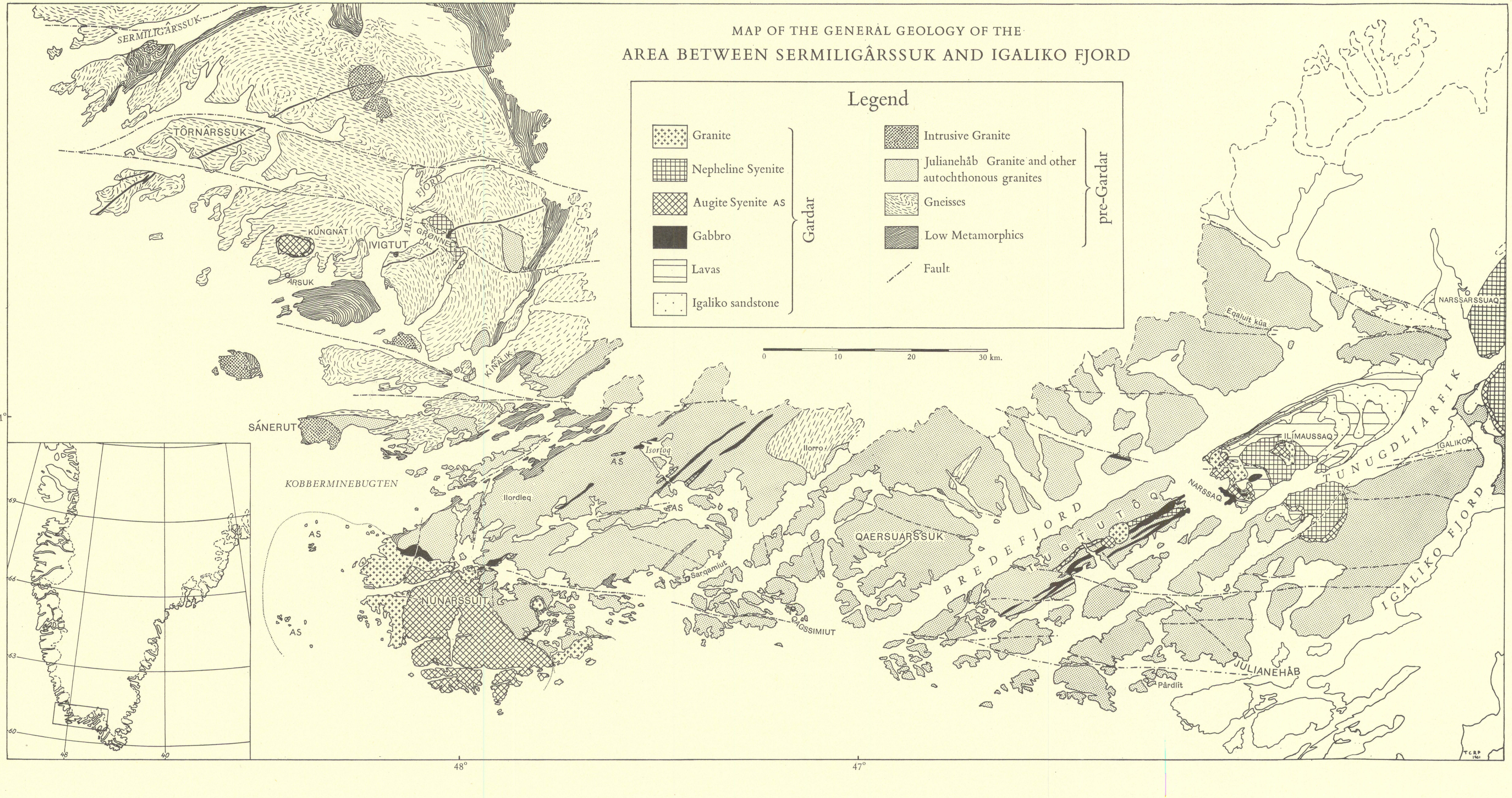
(a)

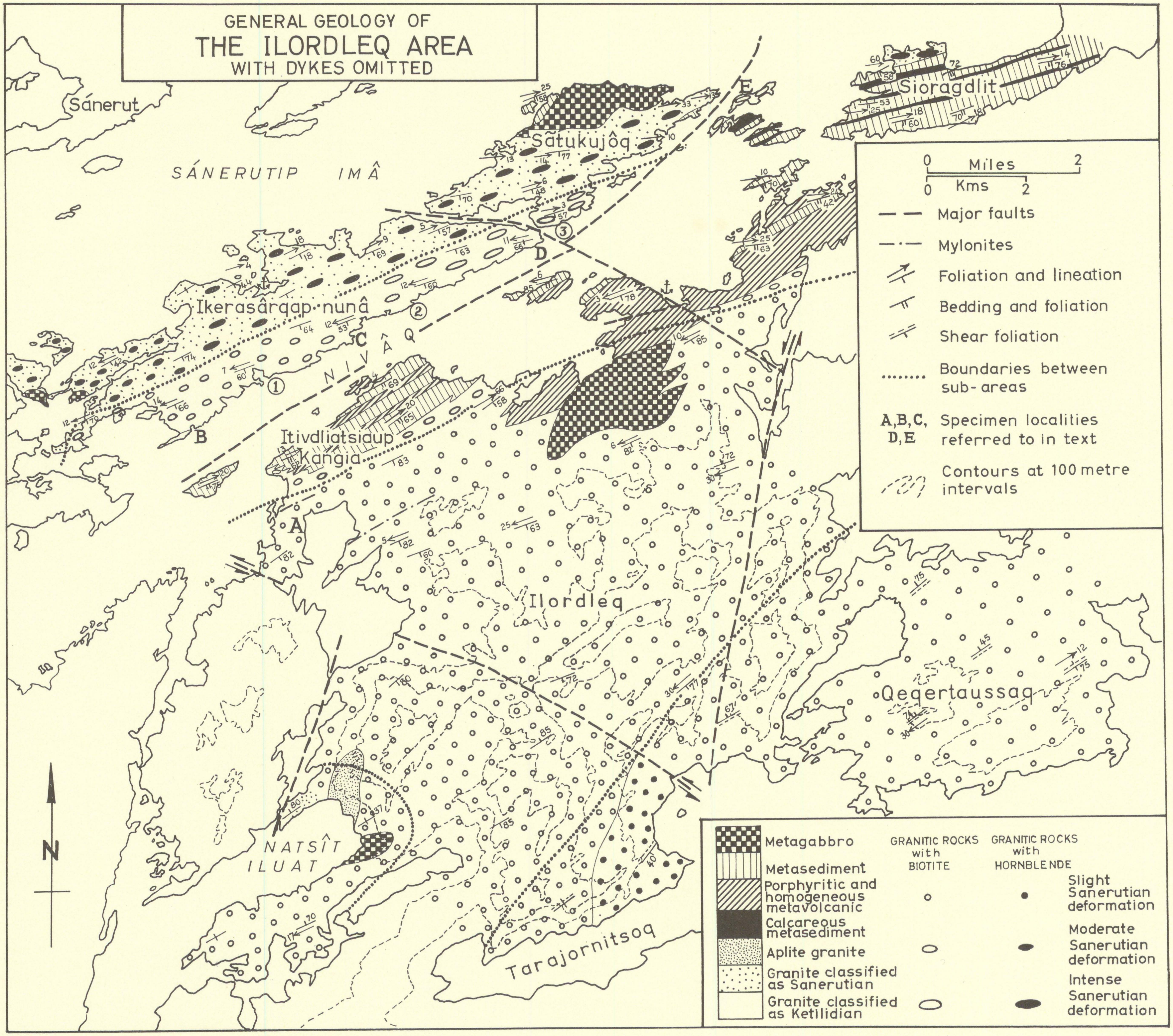
(b)

(c)

(d)

GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND




GENERAL GEOLOGY OF
THE ILORDLEQ AREA
WITH DYKES OMITTED
Sánerut
SÁNERUTIP IMÂ
Sâtukujôq
Sioragdlit
Ikerasârqap nunâ
NIVÂQ
Itivdliatsiaup Kangia
Ilordleq
Qeqertaussaq
NATSÎT ILUAT
Tarajornitsoq
A
B
C
D
E
N
0 Miles 2
0 Kms 2
Major faults
Mylonites
Foliation and lineation
Bedding and foliation
Shear foliation
Boundaries between sub-areas
A, B, C, D, E Specimen localities referred to in text
Contours at 100 metre intervals
Metagabbro
Metasediment
Porphyritic and homogeneous metavolcanic
Calcareous metasediment
Aplite granite
Granite classified as Sanerutian
Granite classified as Ketilidian
GRANITIC ROCKS with BIOTITE
GRANITIC ROCKS with HORNBLENDE
Slight Sanerutian deformation
Moderate Sanerutian deformation
Intense Sanerutian deformation