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The Precambrian Geology of the Sârdloq area, South Greenland

by

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With 13 figures and 1 map

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CONTENTS

Abstract

The geology of the Sârdloq area is divided on a chronological basis into two plutonic periods, preceded, separated and followed by periods of basic dyke intrusion.

During the Ketilidian plutonic period, veined, banded and homogeneous gneisses were formed, which were deformed in three periods of folding. The gneisses contain relicts of earlier, 1st period basic dykes. F_1 folds are relicts within the regional gneiss foliation (S_1); F_2 folds formed under syn-migmatitic conditions, giving rise to a major synform the axis of which plunges shallowly NE or SW and F_3 folds are represented by a post-migmatisation buckling of the foliation on axes trending NW-SE but with variable plunge.

Ultrabasic and basic intrusions are probably related to the 2nd period basic dykes intruded in the Kuanitic cratogenic period.

During the Sanerutian plutonic period the earlier gneisses were reactivated to form a new, more homogeneous granite, in which the Kuanitic basic dykes are preserved as undisturbed relicts. The intrusion of a swarm of basic dykes under late-plutonic conditions (3rd period) was followed by the intrusion of net-veined diorite sheets, emplacement of homogeneous microgranite bodies and tectonic emplacement of layered ultrabasic bodies. The formation of abundant dilatational pegmatites and layered aplite-pegmatites followed by a minor phase of basic dyking ended the second plutonic period.

During the Gardar period NE-SW and E-W trending dolerite dykes were intruded and followed by faulting and mylonitisation. A swarm of NW-SE trending dolerite dykes was intruded in post-Gardar time.

INTRODUCTION

This paper summarises the results of a doctorate thesis presented to the University of Exeter in August 1963 (Windley, 1963). The field work was carried out during the summers of 1960, 1961 and 1962 as a coordinated part of the systematic mapping of South Greenland by the Geological Survey of Greenland (Grønlands Geologiske Undersøgelse (GGU)). The mapping was carried out on 1:20,000 maps, assisted by aerial photographs, both of which were supplied by the Geodetic Institute, Copenhagen.

Acknowledgements

I am particular indebted to Dr. K. Coe of the University of Exeter for supervision of this research and to Professors S. Simpson and A. Noe-Nygaard for the use of facilities at Exeter and Copenhagen Universities respectively. I would also like to thank the director of GGU, mag. scient. K. Ellitsgaard-Rasmussen, for permission to use the Greenland material for the Exeter thesis. Dr. S. Watt kindly read the manuscript.

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Scope of the present study

In the Sârdloq area there are about 270 islands with a total length of about 320 km of ice-polished, lichen-free coast, presenting a remarkable opportunity for detailed observations which have enabled a complex picture of the structure and history of the area to be obtained without relying to any extent on the lichen-covered inland exposures.

In Precambrian terrains belonging to the infrastructure, like the Sârdloq area, which have been intensely deformed, migmatised, metamorphosed and intruded by acid and basic material, it is necessary to focus attention on the deformational history and chronological development. For this reason the development of the area has been worked out on a chronological basis and particular attention has been given to the structural complexities of the early gneisses. The following aspects were selected for detailed study: 1) The structure and petrology of the early gneisses. 2) The metamorphosed basic dykes and reactivated migmatising granite. 3) The composite, net-veined, diorite intrusives, which have been described together with those of the whole Julianehåb district (Windley, 1965). 4) The pegmatites and layered aplite-pegmatite sheets (Windley and Bridgwater, 1965).

Since more comprehensive publications on these topics are, or will shortly be, in press, they will only be summarised here, while other topics not to be studied in more detail at a later date (e.g. dolerite dykes), will be given a fuller presentation.

Previous work

The first geologist to visit the Sârdloq area was Giesecke in the early nineteenth Century, who made mineralogical notes on the gneisses, granites and dolerites (Giesecke, 1910). In 1876 Steenstrup and Kornerup recorded the presence of amphibolite (greenstone) dykes and Jessen (1896) first noted the numerous pegmatites with their dominant N-S trend.

Wegmann (1938) provided a general picture of the regional development of South Greenland which forms the basis of present day views. Berthelsen (1960) presented a summary of the geology of South Greenland, while the most recent review of the work done on the Precambrian basement rocks by members of GGU has been made by Allaart (1964).

For purposes of correlation with neighbouring areas the reader is referred to Berrangé (1966) and Persoz (in prep.).

Regional geological setting

Since the regional development has been so complex and the number of recognised chronological phases so numerous, no attempt will be made here to provide a synthesis of South Greenland geology. However, the chronology which has been established by members of GGU for the Ivigtut-Julianehåb region is given in table 1.

The broad chronological development of the Sârdloq area - early gneisses, basic dykes, reactivated granite, basic dykes and faulting, is in complete accordance with that of the Ivigtut-Julianehåb region and thus the four principal time divisions will be retained here.

The Sârdloq area lies astride the junction between the Julianehåb reactivated granitic block to the north and the earlier gneisses to the south

Table 1

Gardar	Faulting, sedimentation, intrusion of dolerite dykes and layered complexes
Sanerutian	Metamorphism, and reactivation of earlier gneissic rocks to form a new granitic series
Kúanitic	Intrusion of basic dykes
Ketilidian	Deformation, migmatisation, metamorphism Sedimentation

and thus forms a key area in the study of the relations between the two plutonic complexes. Important in this respect are the deformation and migmatisation of the Kuanitic basic dykes within the reactivated granite, as compared with the same dykes in the Ketilidian gneisses.

When studied in detail, each of the four main time periods is found to comprise several episodes, e.g. as well as the main reactivation in Sanerutian time, there was intrusion of syn-kinematic basic dykes, intrusion of net-veined diorites, and formation of microgranites, pegmatites and aplites. The establishment of an accurate chronology has been made easier by the presence of numerous episodes superimposed upon each other, since each can be used as a time marker in the classification of that period. By means of certain criteria, such as discordances, inclusions, migmatisation etc. the various episodes have been dated with respect to each other.

The chronology of the Sârdloq area is given in table 2.

For the purposes of conforming to a standard nomenclature it is necessary to make certain definitions concerning the various periods of basic dykes which are now in a metamorphic state. Watterson (1965) has classified the metamorphosed basic dykes of the Ilordleq area into 1st, 2nd and 3rd period DAs, which are respectively those intruded between the sedimentation and orogeny of the Ketilidian period, those intruded under stable (cratogenic) conditions in the Kuanitic period, and those intruded under synplutonic conditions in the Sanerutian period. These three terms will be retained for the metamorphosed basic dykes in the Sârdloq area, although "1st period DAs" is expanded in meaning to include some dykes that might be inter-Ketilidian in age. There are, moreover, a few basic dykes, now amphibolites, that post-date the net-veined diorites and pegmatites of the Sanerutian period and that do not have the characteristics of the 3rd period dykes; these will be referred to as "late Sanerutian DAs".

Table 2

Post-Gardar (Tertiary ?)	Intrusion of NW-SE trending dolerite dykes
Gardar	Faulting and mylonitisation Intrusion of SW-NE and E-W trending dolerite dykes
Sanerutian	Intrusion of basic dykes Formation of aplites, pegmatites and layered aplite-pegmatites Tectonic emplacement of layered ultrabasic bodies Emplacement of homogeneous microgranites Formation of the Iliverdleq granite Intrusion of net-veined diorites Intrusion of basic dykes under late-plutonic conditions (3rd period DAs) Reactivation and metamorphism under amphibolite-facies conditions: formation of the Akia granite
Kuanitic	Intrusion of basic and ultrabasic dykes (2nd period DAs) Intrusion of basic and ultrabasic bodies
Ketilidian	Orogeny comprising amphibolite-facies metamorphism, granitisation and three periods of folding. Intrusion of basic dykes (1st period DAs) Deposition of supracrustal series

GEOLOGICAL UNITS

Three geological units can be recognised, which structurally, mineralogically and chronologically are distinguishable from each other:

1) The early gneisses
2) The Akia granite
3) The Iliverdleq granite

The gneiss was formed in Ketilidian time, while the granites were formed by reactivation of the earlier gneisses in Sanerutian time.

One of the principal differences and means of distinguishing between the early gneisses and the later granites is the appearance of the 2nd period basic dykes. Where they are situated in the Ketilidian gneisses, they are migmatised yet have retained their continuity (i. e. they are unbroken) and are unfolded, whereas in the reactivated Akia granite they are not migmatised internally but occur as aligned blocks and in places are folded. The observed differences are due to the state of migmatisation, deformation and reactivation of the host rocks during Sanerutian time. Although unreactivated, the Ketilidian gneisses have been migmatised by granitic veins, whilst on Akia the early gneissic rocks have been almost entirely reconstituted into a new granite.

The gneisses occupy the ground between Sârdloq village and the north-east part of the area and comprise banded gneiss, veined gneiss and homogeneous gneiss. These rocks are characterised by their high degree of mobility, as evidenced by their intense plastic folding and so are easily distinguishable from the Sanerutian granitic rocks, which, albeit plutonic, bear little evidence of movement, on account of their essentially homogeneous character.

The following rocks are exclusive to the gneiss area: skarns, 1st period basic dykes and layered ultrabasic bodies. There are also a few, rare pinch-and-swell pegmatites of late Ketilidian age. There are no rock types which occur only in the granitic areas, although the net-veined diorites tend to be concentrated within the Akia granite.

The Akia granite forms the largest region of reactivated rocks in the Sârdloq area. On its southern side it grades via a conformable transition zone into the earlier, Ketilidian gneisses. There are xenoliths of gneiss in the granite, but far fewer than in the Iliverdleq granite. The net-veined diorites form a prominent feature on Akia as they appear to be confined to this most highly reactivated part of the area. The presence of the 2nd period DAs, which can be traced as aligned blocks through the granite, demonstrates that it has been reactivated. The granite has a linear/planar structure which is largely parallel to that in the surrounding Ketilidian gneisses.

The Iliverdleq granite is essentially homogeneous and differs from the Akia granite in its position chronologically within the Sanerutian. Both 2nd and 3rd period DAs are entirely lacking within it, suggesting a time of formation after the intrusion of these dykes, and megascopically it resembles a coarse-grained granite that cuts and agmatises the net-veined diorite bodies on the islands south of Tukingassoq. It is cut by the homogeneous microgranites and by the pegmatites and layered aplite-pegmatites and is therefore dated as late Sanerutian, having formed between the time of emplacement of the net-veined diorites and the homogeneous microgranites.

1st PERIOD AMPHIBOLITE DYKES

The term "1st period basic dykes" was originally applied to dykes intruded into the Ketilidian supracrustal rocks in the Nunarssuit region, where some of the supracrustals are preserved. During the Ketilidian orogeny and granitisation they were folded and broken into blocks within the Ketilidian granites and gneisses. In the Sârdloq area there is some evidence that there were dykes intruded during the Ketilidian period.

In this area it is impossible to distinguish with certainty dykes that might have been intruded into supracrustal rocks, since there are two complicating factors. Firstly, many dykes originally discordant might have been rotated parallel to the foliation during the plastic, syn-migmatitic, main, deformational phase. Secondly, many of the basic fragments and boudinés, basic bands that lie parallel to the Ketilidian foliation might originally have been calcareous or volcanic horizons. Due to inadequate criteria to separate these features, the origin of most of the parallel amphibolite fragments must be largely a matter of conjecture.

However, there are five dykes in the Ketilidian gneisses which have been distinguished as 1st period DAs. They cannot be relict supracrustal layers, neither can they be 2nd or 3rd period DAs. The general paucity of these early dykes prevents the establishment of any far reaching conclusions concerning the nature of such dyking, but the evidence available does indicate that there was at least a minor phase of dyking in the Sârdloq area during the Ketilidian period.

Fig. 1 shows a 1st period dyke in hornblende-rich Ketilidian gneiss. The dyke is folded and has an axial plane foliation, which is orientated parallel to the regional foliation of the gneiss. The dyke fragments have been displaced by axial plane movements. The fact that the dyke trend was approximately normal to that of the gneiss has enabled the dyke to be folded and be foliated by the same stress components as gave rise to the foliation in the gneiss.

There is another dyke which pre-dates the Ketilidian folding, as some dyke blocks have been rotated by the plastic F_2 folds of the gneiss.

One xenolith has been found which megascopically is strongly porphyritic with randomly orientated plagioclase phenocrysts up to 2 cm long.

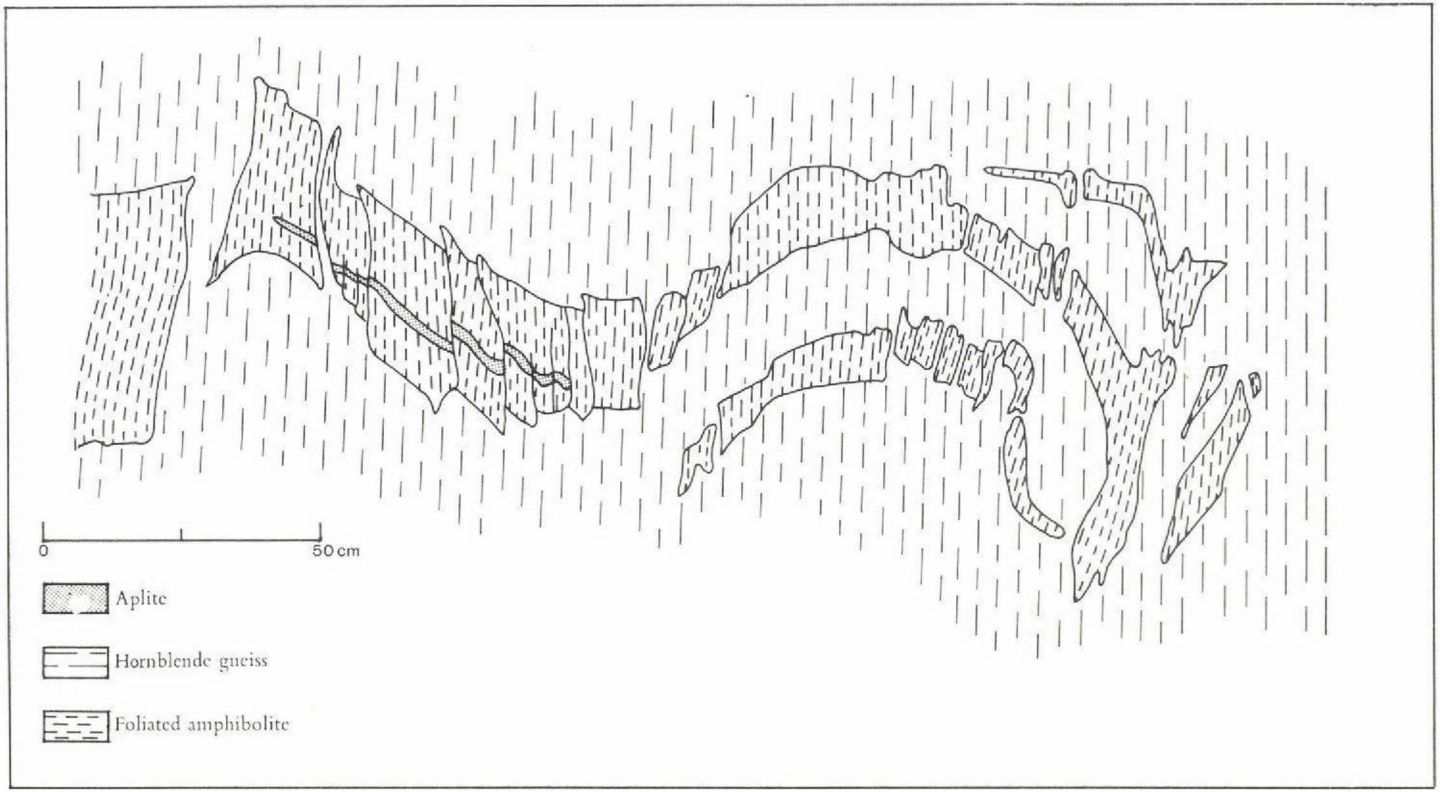

Fig. 1. A 1st period folded amphibolite dyke in hornblende-bearing homogeneous gneiss on the north coast of Qilungmiarssuq. The axial plane foliation in the dyke is parallel to the regional foliation of the gneiss.

This xenolith presents direct evidence of the existence of a basic, magmatic rock prior to the formation of the Ketilidian gneisses. It is not known however whether this was in the form of a sill, dyke or extrusive layer.

Microscopically the dykes are amphibolites with a plagioclase-hornblende-biotite assemblage. They vary from hornblende-rich to biotite-rich types, the biotite having grown retrogressively from the hornblende. There is no trace of relict pyroxene. Plagioclase is commonly sericitised.

KETILIDIAN GNEISSES

There are three types of gneiss of Ketilidian age in the Sârdloq area; banded gneiss, veined gneiss and homogeneous gneiss.

Banded gneiss

The banding forms a well-defined, planar structure which is composed of alternating basic and acid bands, which range in width up to 40 cm. The rock presents a very regular appearance due to the prevalent straightness and continuity of the bands.

The acid bands are composed of quartz, plagioclase (oligoclase) and microcline with a xenomorphic-granular texture. The rock is porphyroblastic with respect to plagioclase and microcline and these minerals tend to be concentrated in plagioclase-rich and microcline-rich bands; the plagioclase however tends to predominate in these banded gneisses.

The basic bands have a diopside-hornblende-biotite-chlorite-epidote assemblage with additional quartz, plagioclase and microcline. Accessory minerals, which are mostly confined to the basic bands, are sphene, apatite and ore.

Veined gneiss

The banding in the veined gneiss consists of alternate acid and basic bands which vary in width from a few cm to about 30 cm. These are discontinuous and thicken and thin over short distances which, together with the common plastic crumpling and folding, results in a very irregular appearance, which contrasts strongly with that of the banded gneiss.

The acid bands are made of plagioclase (oligoclase), quartz and microcline and the basic bands of biotite, muscovite, chlorite, epidote and hornblende (rare), together with plagioclase and quartz. Accessories are sphene and ore. The most conspicuous mineralogical features of the gneiss are the predominance of biotite and muscovite and the presence of plagioclase porphyroblasts. Chlorite is secondary after biotite.

Homogeneous gneiss

This is a granitic rock with no compositional banding, but with a foliation defined by the linear orientation of feldspar porphyroblasts and hornblendes and by the planar orientation of biotites. According to GGU terminology this is a homogeneous gneiss which "has no banding, but shows a preferred orientation of the mafics. Lithologically it is homogeneous" (Berthelsen, 1960, p. 71).

The rock displays a xenomorphic-granular texture with a plagioclase (oligoclase)-microcline-quartz-biotite-hornblende-muscovite-chlorite-epidote assemblage. Accessories include allanite, apatite, pyrite, haematite and ore. Chlorite has grown retrogressively from biotite.

Within the three types of gneiss described above there is evidence of two parageneses. Diopside has been partly altered to hornblende, hornblende to chlorite and epidote, plagioclase to epidote and sericite and biotite to chlorite. An originally high temperature amphibolite facies assemblage of diopside, hornblende and biotite has been altered retrogressively to a lower temperature hornblende, epidote, chlorite, sericite assemblage belonging to the quartz-albite-epidote-almandine subfacies of the upper greenschist facies according to the current nomenclature of Turner and Verhoogan (1960).

Succession

The three types of gneiss are intercalated to form a succession of horizons. The smaller horizons are only a few metres wide, while the wider are up to 1 km in width and can be traced along their strike for a distance of 20 km. There are no remnants of sedimentary rocks in the area.

The internal homogeneity of the three gneiss types has enabled them to be identified and traced over considerable distances, so that it has been possible to map a gneiss stratigraphy and consequently to unravel the Ketilidian structures in the Sârdloq area.

STRUCTURE

More than half of the Sârdloq area is underlain by gneissic rocks of Ketilidian age in which three phases of folding have been recognised. The first phase folds are in the form of relict, intrafolial folds, while the second and third gave rise to superposed fold structures. There is a single set of parallel, planar surfaces throughout the area (the regional foliation), which have a general north-easterly strike and a shallow to steep dip to the NW.

First phase folds

The first phase folds, F_1, occur in tectonic inclusions or as relics within the regional foliation, S_1 (fig. 2). They are asymmetrical "similar" folds with thickened hinges and attenuated, tightly appressed to isoclinal limbs. The axial planes have every possible attitude due to the effects of two later periods of folding. The length of the short limbs from closure to closure varies from 5 to 40 cm. However, many folds are merely single closures, so that their direction of vergence and fold size cannot be dis-

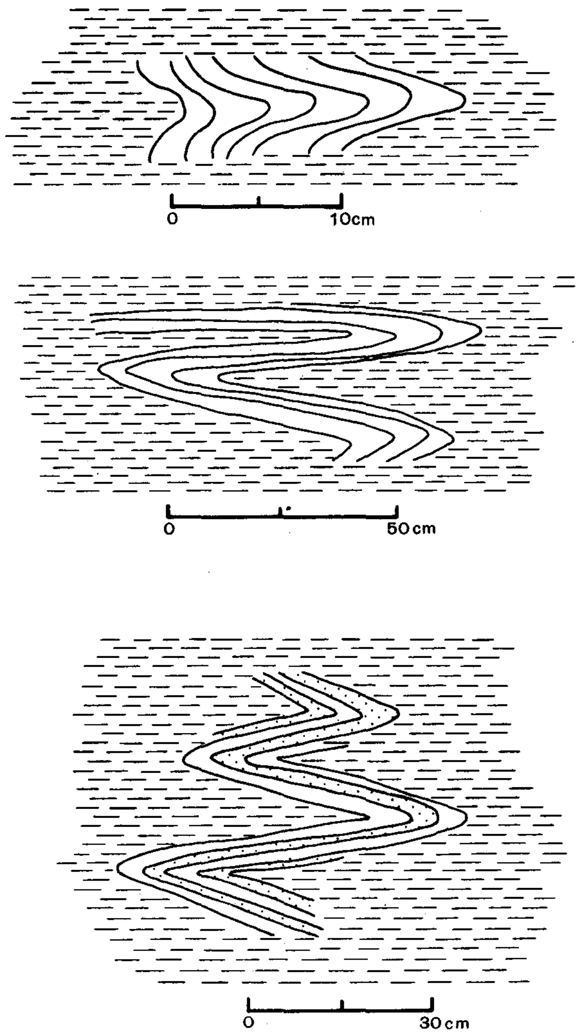

Fig. 2. Three examples of first phase folds, F_1, in homogeneous gneiss. The folds are relicts in the gneisses; their axial planes are parallel to the regional gneiss foliation, which may either truncate or be parallel to the fold limbs.

cerned. Fold axes vary widely in direction and amount of plunge. The surrounding regional foliation, S_1, has an axial plane attitude to the F_1 folds.

Second phase folds

Folds of the second phase, F_2, affect the regional foliation, S_1, Mesoscopic folds are asymmetrical with open to isoclinal limbs and are upright or overturned with axial planes vertical or dipping steeply to the NW. The short limbs range up to 1 m in length from closure to closure. Axes generally plunge shallowly to the NE or SW but, due to later refolding, their trend varies throughout the area from E-W to N-S.

F_2 folds are characterised by their high degree of plasticity; both disharmonic and conjugate folds are common (fig. 3), fold limbs are attenuated and hinges thickened. In places there are arrow head structures in migmatised basic bands which are indicative of an extreme stage of plastic deformation.

S_2 axial planes are rarely developed. In one micaceous layer they are of the strain-slip type and in more competent banded gneiss, they are in the form of a fracture cleavage. Axial surfaces are commonly non-parallel and curviplanar (fig. 3). In most F_2 folds there is no trace of a planar structure parallel to the axial plane. The last stage of crystallisation usually outlasted the formation of F_2 i.e. post-tectonic crystallisation. The F_2 folds formed under syn-migmatitic conditions preferentially in the highly deformed, veined gneiss horizons which acted as incompetent units during the deformation.

There is a major overturned F_2 synformal fold closure under the sea not far to the south of Sârdloq village. The axis trends NE-SW and the axial plane dips steeply to the NW. The presence of the fold closure is demonstrated by the opposing sence of vergence of the asymmetrical, mesoscopic F_2 folds on the two fold limbs and by the large-scale strike convergence across the area.

Third phase folds

The folds of the third generation, F_3, are symmetrical with vertical axial planes. They are flexural slip folds with axes plunging shallowly to steeply to the NW, the amount of plunge depending on their position on the F_2 fold limbs. No axial planar structures are developed, as the F_3

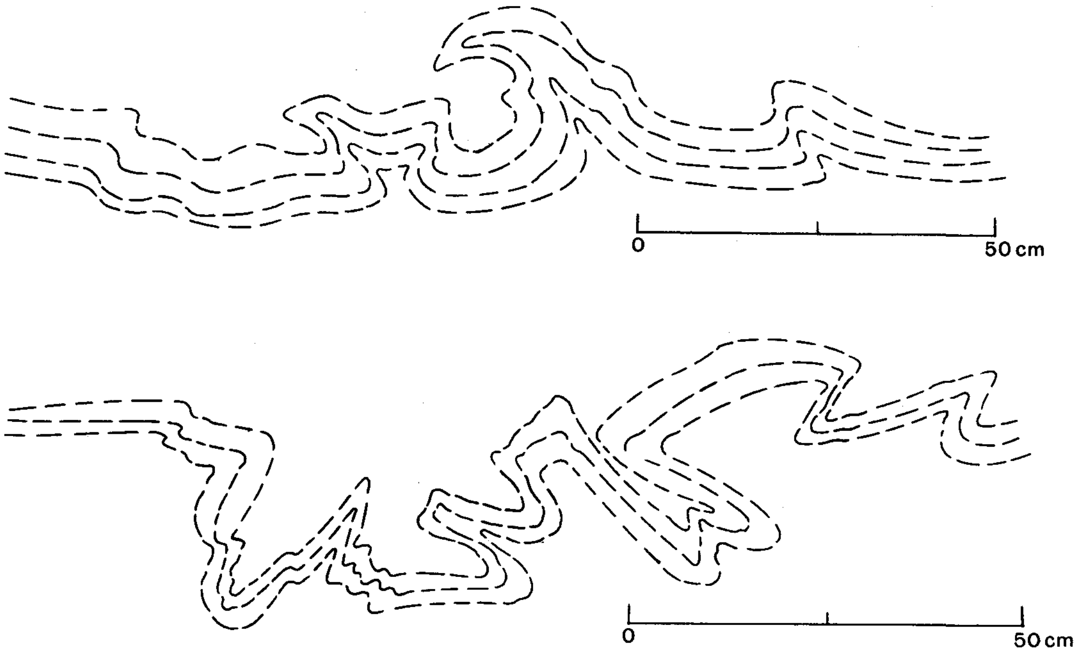

Fig. 3. Two groups of F_2 folds in veined gneiss from the same locality near Sârdloq village. The folds have curviplanar, non-parallel axial planes and parallel axes - they are non-plane, cylindrical folds. In both examples there is a conjugate fold.

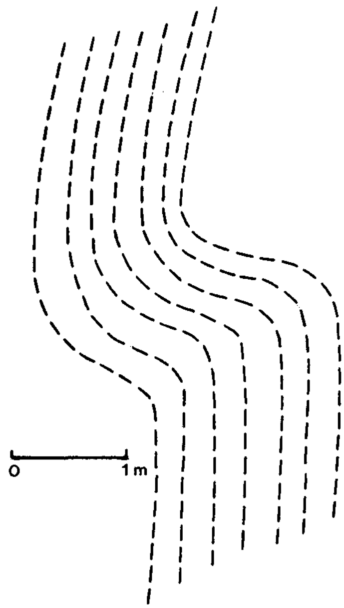

Fig. 4. An open, concentric F_3 fold in homogeneous gneiss.

folds were formed under post-migmatisation metamorphic conditions. Very few mesoscopic F_3 folds have been observed (fig. 4); mostly they are in the form of macroscopic, open, warpings of S_1 observable on the map with the distance between closures ranging from 4 to 10 km. They are developed in the north-east of the area.

Summary of structural development in relation to migmatisation

The first period of movements probably began in a premigmatitic stage. Granitisation occurred in connection with axial plane recrystallisation of F_1, giving rise to the present regional foliation (S_1). The relict F_1 folds, often in tectonic inclusions, provide the only remaining evidence of this folding episode.

The second period of folding (F_2) took place under syn-migmatitic conditions, resulting in plastic and disharmonic folds. A major synform was formed in the area, the axis of which trends NE-SW with a shallow plunge.

The third and last period of folding took place under postmigmatisation conditions. The foliation with an already variable attitude was folded by compression acting along this plane, giving rise to fold axes with variable plunge. The deflection of strike from the regional NE-SW attitude is a result of the third phase of folding (F_3).

BASIC AND ULTRABASIC BODIES

In the Sârdloq area there are 39 bodies of basic or ultrabasic composition. Two mineralogical types can be distinguished;a) a fine- to coarse-grained, blue amphibolite containing a small amount of feldspar and variable amounts of biotite. There are 35 bodies of this type. b) a coarse-grained, green hornblendite consisting of blunt hornblendes with some biotite. Feldspar is absent.

There is one composite body in the north-east of Nunarssuaq with a core of amphibolite and a marginal zone of hornblendite.

The bodies have either elliptical or circular cross-sections on a near-horizontal surface and they vary in size from 10 m to 3.5 km in diameter.

In two intrusions there has been found relict pyroxene and blasto-ophitic textures are visible in places. There has been an almost complete, mineralogical reconstitution of the original, primary basic and ultrabasic assemblages. The mineral paragenesis in these bodies now provides an excellent example of a disequilibrium assemblege. Constituent minerals include primary pyroxene and apatite, two generations of recrystallised hornblende and biotite, secondary plagioclase and quartz, retrogressive chlorite and introduced microcline and quartz.

The bodies have undergone two migmatisations. The first has a plastic style and is in the form of sinuous, coarse-grained granitic veins that swirl through the rock, enclosing rounded and lens-shaped inclusions. The second takes the form of homogeneous microgranite veins with sharp, straight and parallel walls, which contain angular-shaped inclusions, giving rise to agmatites. These regular, angular veins post-date the first irregular, sinuous veins. The two migmatisations can be correlated respectively with the reactivation and the emplacement of the microgranites in the Sanerutian period.

When situated in Ketilidian rocks the contacts of the bodies usually cross-cut the gneiss foliation. They pre-date the 2nd period DAs and have undergone two periods of migmatisation. They can therefore be dated as either late Ketilidian or early Kuanitic in age. Some bodies are situated in the Akia reactivated granite, where they occur as relicts and have been more intensely migmatised than have those in Ketilidian rocks.

The bodies are widely scattered throughout the whole area. There is a noticeable concentration of eight bodies in the vicinity of Sârdloq village.

2nd PERIOD AMPHIBOLITE DYKES

About 200 2nd period DAs have been examined on the well-exposed coasts of the Sârdloq area. Many have been seen and no doubt hundreds exist inland, but the heavy cover of lichen prevents detailed examination.

The dykes are mostly between 30 cm and 1 m wide and have a predominant NE-SW trend throughout the area. N-S trends are common on N. Akia and E-W trends on N. Kangek.

All the dykes are foliated with a planar, parallel fabric. The foliation is parallel to the walls or extends obliquely across the dykes. No curviplanar, "S-shaped" foliation, characteristic of the 3rd period DAs, has been observed. Aphanitic chilled margins are present in dykes in both Ketilidian and Sanerutian country rocks. The dykes can be divided into two mineralogical types: 1) a fine- to medium-grained, blue amphibolite containing hornblende, biotite and feldspar. This is by far the predominant type. 2) a coarse-grained, green hornblendite which is composed essentially of hornblende, but with some biotite and only a little feldspar.

Plagioclase phenocrysts are present in some dykes. They reach

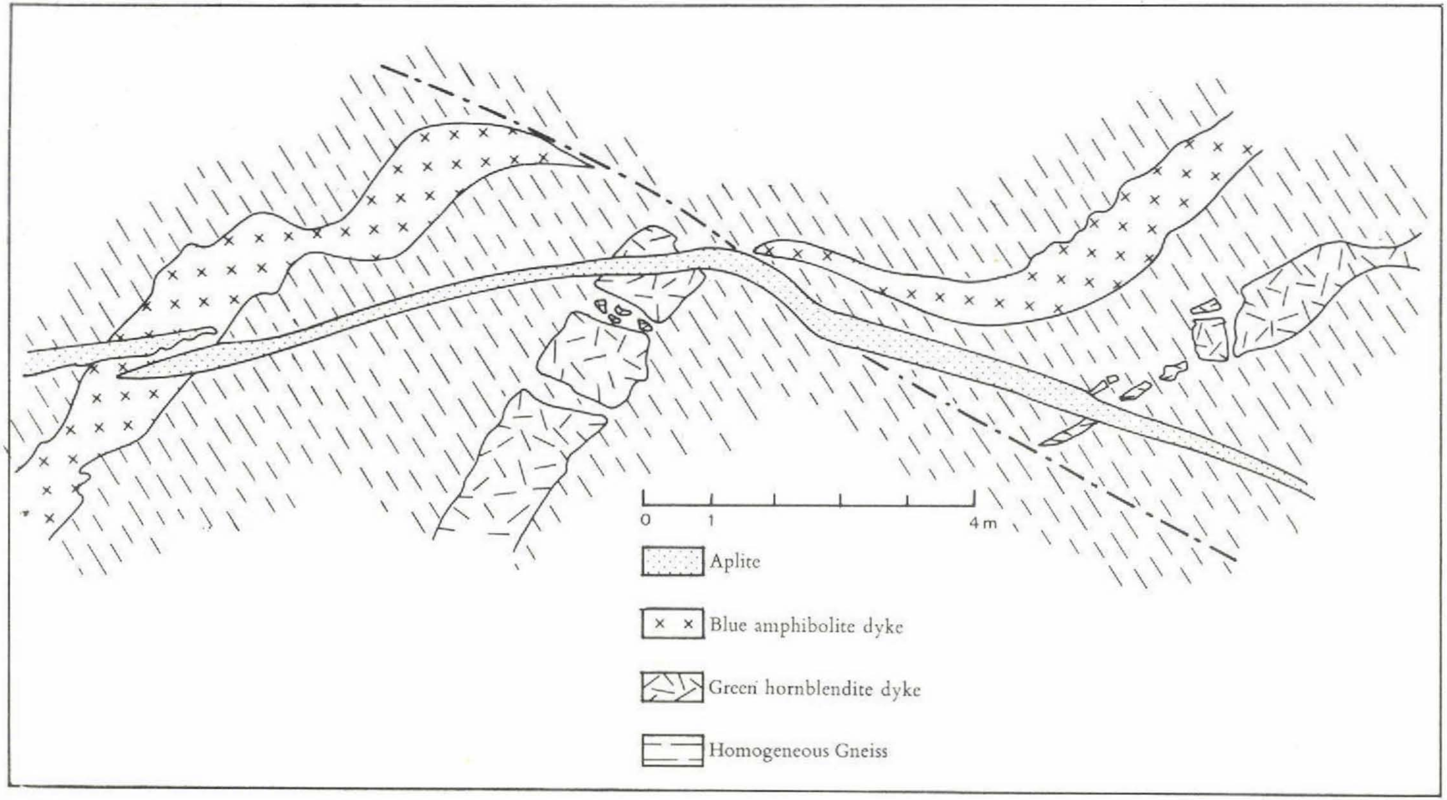

Fig. 5. Two types of 2nd period dykes in homogeneous gneiss from NW Kangek. The one, which has a basic composition (amphibolite), has been veined internally by granitic material but is unbroken, whilst the other, which is of ultrabasic hornblendite, is not veined but has been broken into blocks. This demonstrates that the type of migmatisation and deformation of the dykes is dependent on their composition and degree of competency.

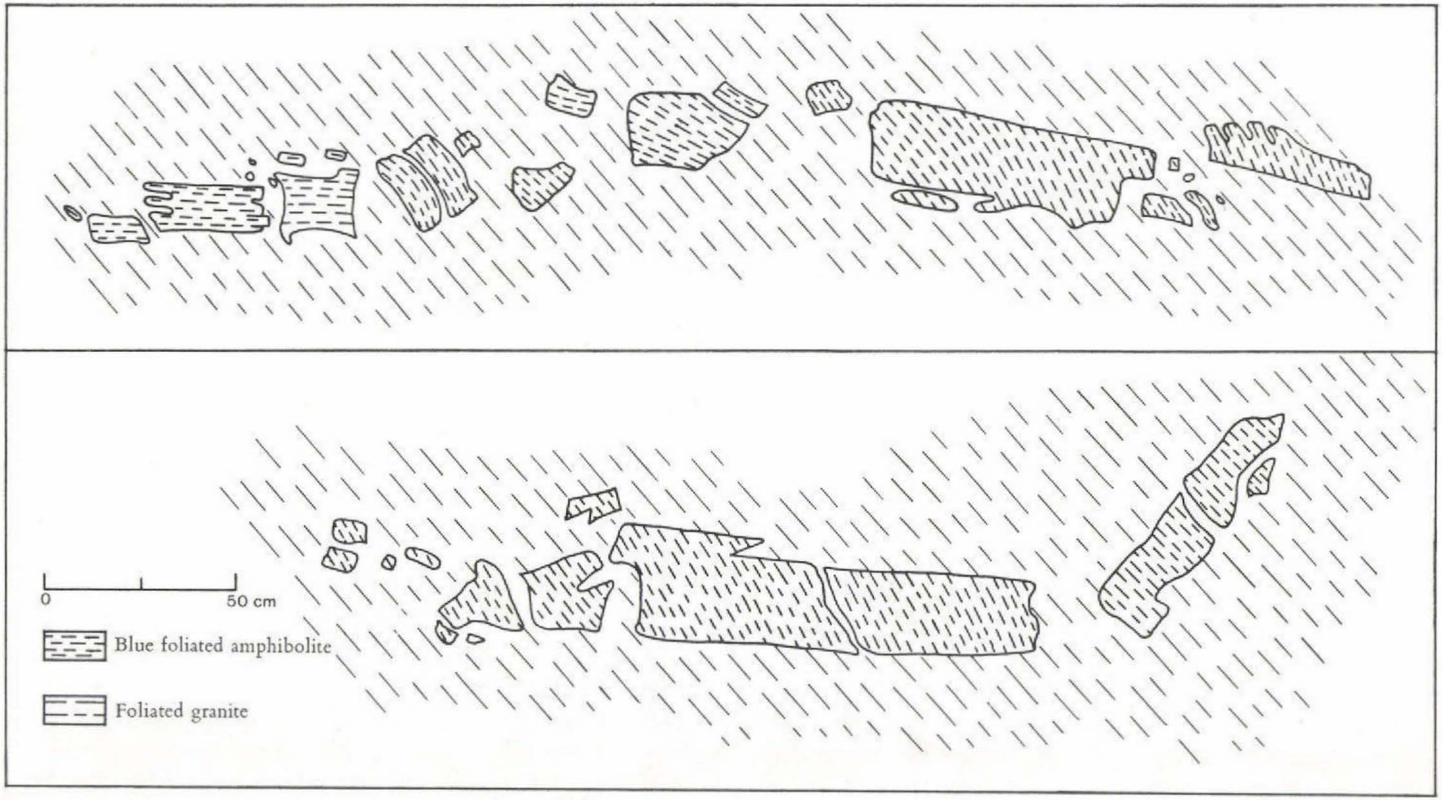

Fig. 6. A 2nd period amphibolite dyke in reactivated foliated granite from SE Akia. The dyke has been broken into numerous blocks separated by the reactivated granite, their parallel alignment indicating the trace of the dyke. The dyke blocks truncate the granite foliation reflecting the discordance of the original dyke.

up to 10 mm in length, are randomly orientated and entirely sericitised. Relict ophitic texture can sometimes be discerned, reflected by plagioclase laths with ragged boundaries. They have a random orientation and interlock with each other. Relict, primary pyroxene has not been seen.

No dykes representing transitional stages between the amphibolitic and hornblenditic types have been found. Both types occur together in the same area and pairs of dykes, one from each type, are extremely common (fig. 5). At intersections it has been observed that the blue amphibolites are younger than the green hornblendites.

One of the most interesting features of the 2nd period DAs is their variable states of migmatisation. Where they are situated in Ketilidian rocks, they have been migmatised internally by penetrative granitic veins, which either form an anastomising network or occur as parallel bands along the oblique or parallel dyke foliation. The essential point to note is that the dykes in this area have not been broken into blocks, but rather have been veined internally. Where fracturing or boudinage has occurred, it is a local feature and is subordinate to the veining. However, a different picture is presented in the Akia reactivated granite, where the dykes have been broken into numerous blocks separated from each other by the granite itself, but their parallel alignment outlines the trace of the original dyke (fig. 6). In this granite the dykes are not veined by granitic material, but are only broken into blocks. It appears, as it were, that once the dykes break into blocks, the latter are able to "float" in this reactivating granite without penetration by granitic material. A similar phenomenon has been observed by Watterson (1965) in the Ilordleq area.

Within the reactivated granite there are folded 2nd period DAs. The fold axes vary in plunge from shallow to vertical. The host rock and dyke foliation lie approximately parallel to the axial plane of the folds. The variation in plunge of the fold axes is the result of the folding of already shallow- or steeply-dipping dykes. This is comparable to the variably-plunging fold axes produced by a second period of folding of an already folded series of beds. Since the linear/planar orientation in the granite lies in an axial plane position in relation to the folds, it was formed under the same stress system as the folding. In some folded dykes the migmatising granitic veins are folded with the dyke, demonstrating that the folding post-dated the migmatisation.

There is a marked similarity in mineralogy between the 2nd period

DAs and the basic and ultrabasic bodies described in the last section. In both groups of rocks there is a blue amphibolite, which is the predominant type, and a green hornblendite. In the chronological seccession the intrusion of the dykes followed immediately after that of the larger bodies. The closeness in their mineralogy and their time of intrusion suggests that the two forms of intrusion are cogenetic, the dyking forming a late phase of the intrusion of the larger bodies. This conclusion is in disagreement with that of Watterson - that the dykes of hornblendite are derived from the amphibolitic type by decrease in the feldspar content during the reactivation (Watterson, 1965).

It is significant that the number of 2nd period DAs increases considerably from the south to the north of the area. As fewer dykes would be expected to survive in the reactivated granite area, this increase must indicate that there were more dykes intruded in the Akia area than farther to the south.

THE REACTIVATED GRANITES

The coarse - grained reactivated granites are younger than the Ketilidian gneisses and 2nd period DAs and are older than the late Sanerutian homogeneous microgranites. The principal body, the Akia granite, is a continuation of the granites of similar appearance and age on the north side of Julianehåb fjord and therefore it forms the southern limit of the Julianehåb reactivated block. The remaining granites form outlying masses within the earlier Ketilidian rocks. Whereas the Akia granite pre-dates the net-veined diorites and 3rd period DAs, there is some evidence that the Iliverdleq granite is younger than these rocks. Nevertheless, all granites have the same field relations and will be treated together in the ensuing description.

They are coarse - grained, porphyroblastic, hornblende - biotite granites with a weak structure. In places there is a lineation due to the linear parallelism of hornblende crystals, whilst elsewhere there is a foliation due to the planar parallelism of hornblende and biotite. Locally, all structure is lost and the granite appears megascopically homogeneous.

The composition of the granites is variable, but they are all rich in strongly perthitic microcline. Additional, essential constituents are plagioclase (oligoclase), quartz, hornblende and biotite. Accessories include sphene, apatite, zircon, allanite, epidote and ore. The quartz-feldspar ratio varies considerably so that the rocks range from adamellites to alkali granites; the latter predominate.

The density and distribution of the potash feldspar porphyroblasts is variable; in places they are abundant, in others they are sparse and locally they are absent. The porphyroblasts can be used as a time marker. On Akia the 2nd period DAs have been broken into blocks between which there are feldspar porphyroblasts in the reactivated granite. The feldspar growth occurred subsequent to the fracturing of the dykes. In contrast to this the 2nd period DAs in the Ketilidian gneisses have no porphyroblasts between broken blocks, as the boudinage of the dykes took place after the porphyroblastesis in the gneisses. Two periods of porphyroblast growth can thus be recognised.

Whereas the feldspar porphyroblasts in the Ketilidian gneisses have a linear, dimensional orientation in the plane of foliation, those of the Sanerutian reactivated granites are randomly orientated.

On W. Iliverdleq the contact of the granite follows conformably the boundary of the banded gneiss horizon, but it cross-cuts it at one point. The lineation in this granite has an arcuate trend which reflects that of the surrounding Ketilidian gneiss. This granite is situated in the core of the Ketilidian, major F_2 synform. The linear/planar structure of the Akia granite has a NE-SW trend parallel to the adjacent, prevailing Ketilidian trend. It is clear that the reactivated granites have inherited the structural trend lines of the Ketilidian rocks.

There is a noticeable lack of inclusions of Ketilidian rocks in all the granites except that of Iliverdleq. This granite contains innumerable inclusions of all sizes up to 1 km in length. Around the margins of the larger inclusions there are agmatites composed of inclusions which decrease in size away from the contact. The inclusions are of fine- or coarse-grained, homogeneous gneiss and banded gneiss. The linear/planar structure of the granite is parallel to the walls and internal foliation of most of the inclusions. Local mobility of the reactivated granites is evidenced by clusters of disoriented inclusions. The present position, however, of some of the largest inclusions in the Iliverdleq granite (pairs of sheets which consistently dip towards each other) suggests that they occupy a synform and that they were not disturbed from their original, folded attitude during the reactivation.

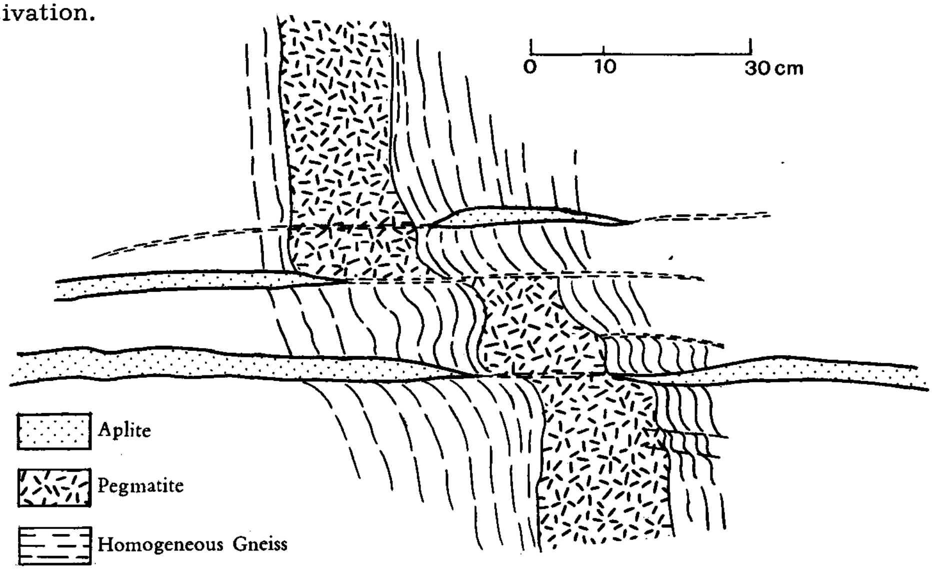

Fig. 7. A conformable pegmatite together with aplites formed in recrystallised shear zones in homogeneous gneiss. This is in an inclusion of Ketilidian gneiss in the Iliverdleq granite. 2 km SE of Ilivercleq.

Associated with the reactivated granites are aplites and pegmatites formed in recrystallised shear zones (fig. 7). The aplites and pegmatites, which are up to 1 m wide, range from mere discontinuous films to complete dykes. In places the sigmoidal foliation of the shear zones has been taken over by the aplites. These partly recrystallised shears are abundant in the inclusions of Ketilidian rocks in the reactivated granites. In the Ketilidian gneisses they significantly increase in number towards the main contact of the Akia and Ilivercleq granites, indicating that the reactivation was associated with a period of shearing.

3rd PERIOD AMPHIBOLITE DYKES

Watterson (1965) has described basic dykes from the Ilordleq area that were intruded under late plutonic conditions; these were termed 3rd period DAs. In the Sârdloq area there is a swarm of NNE-trending dykes of this type. The swarm dies out northwards and at its southern end it contains at least a hundred dykes, which are well exposed on the islands near Sârdloq.

The dykes have a variable composition and reach up to 1 m in width. For descriptive purposes the dykes can be divided mineralogically into two types. There are however dykes with all transitions in composition between these two extremes.

Acid dykes have a granodioritic composition with a plagioclase - quartz - hornblende - biotite assemblage with accessory sphene, epidote, apatite and ore. Microcline is a rare subsidiary. The quartz and plagioclase crystals have a polygonal form and intercrystal boundaries are planar meeting at triple junctions at 120^{o}. The dykes are porphyritic with respect to plagioclase phenocrysts which are bent, fractured, have strain shadows and displaced twin lamellae and some have started to recrystallise into subgrains. The matrix grains have penetrated between the broken crystal fragments, demonstrating that the phenocrysts belong to an early phase of the crystallisation history of the dykes. In many dykes there are elongate aggregates composed of randomly oriented hornblendes. The alignment of the aggregates defines the dyke foliation.

Basic dykes vary in composition from quartz diorites to meladiorites. Where the basic dykes predominate, the basic material is penetrated by an anastomising network of leucocratic veins, forming a "differentiation texture". Where acid dykes occur together with basic dykes, it was found that the basic dykes did not contain the "differentiation texture". The basic material of the dykes is composed of hornblende, biotite and plagioclase. The leucocratic veins vary in composition from trondjemites, through tonalites to diorites, and have a planar, granular fabric of equant grains. Clinopyroxene forms subhedral granules with planar boundaries, post-dates hornblende, and occurs in reaction rims between the quartzo-feldspathic veins and the basic material.

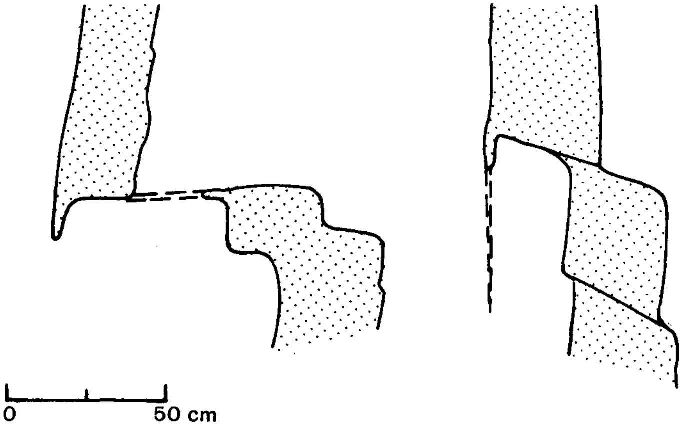

Fig. 8. Two 3rd period amphibolite dykes. The first has an apophysis situated in a transverse shear zone, and the second has one in a longitudinal shear zone.

The dykes are closely associated with shear zones in the granitic country rocks, which form the principal feature of genetic significance in this area (fig. 8). The shears can be divided into two sets:

Transverse shears lie normal to the trend of the dykes, and are associated with the following features: the shears frequently offset the dykes; apophyses extend from the faulted walls of the dykes; fine-grained border zones are present along the fault walls; there are shears between displaced blocks at dyke offsets; some apophyses turn sharply when they come into contact with the shears and some apophyses have been torn from the dykes by the shears.

Longitudinal shears are roughly parallel to the dykes; they extend into the granite from the ends of apophyses; some apophyses occur as rows of broken fragments within the shears and some shears have caused drag of the gneiss foliation against the dykes.

The internal foliation of the dykes is in places parallel to their walls. Where the dykes have been affected by the transverse shears, they are more strongly foliated near the offsets. Apophyses that extend from the faulted walls also have a transverse foliation.

A sigmoidal (curviplanar) foliation is characteristic of many dykes, particularly those at the southern end of the swarm (fig. 9). All dykes display the same sense of movement as indicated by the sigmoidal foliation, and the sense of displacement shown by the longitudinal shears in the country rocks is in accordance with that shown by the sigmoidal foliation of the dykes.

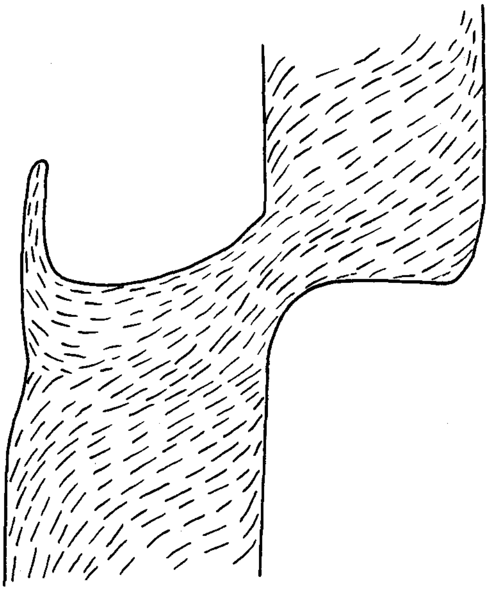

Fig. 9. A 3rd period amphibolite dyke, about a metre thick, showing the curviplanar, sigmoidal foliation which is characteristic of this period of late plutonic dykes.

Where there are irregularities in the shape of the dykes e.g. apophyses, faulted blocks, constrictions etc., it is characteristic for the foliation to follow faithfully the dyke walls around all the irregularities.

At intersections of 3rd period DAs the foliation of the later dyke clearly transects that of the first.

The irregularity in shape of the 3rd period DAs is particularly striking. This is expressed by their sinuous course, which is a combined result of the frequent constrictions, abundant apophyses and sheared offsets. The large number of inclusions, which is typical of the 3rd period DAs, is a result of the rejoining of the many apophyses to the main dykes.

Along the walls of some dykes there are border zones, a few centimetres wide, composed of discontinuous, shred-like wisps of granitic material.

Some dykes have been internally folded with development of an axial plane cleavage. The dyke foliation has been crumpled into small folds, the amplitudes of which never exceed 10 cm. Axial planes are commonly not parallel. The folding post-dates the formation of the leucocratic veins. In thin section it can be seen that the folds formed during a paracrystalline deformation, in which the folding movements kept apace with the crystallisation of hornblende and biotite.

The presence of "hot shears" in the country rocks indicate that they were at a sufficiently high temperature to recrystallise during the period of dyking. The dykes were thus intruded under late syn-plutonic conditions of intermittent stress into hot country rocks. From the microscopic evidence described above it is concluded that a high wall-rock temparature prevented escape of heat from the intruded liquid, which therefore cooled slowly over a lengthened period of time, giving rise to an equilibrium fabric in which planar grain boundaries meet at stable triple points at 120^{o}.

Watterson (1965) has shown that the network of penetrative, leucocratic veins was formed by "differentiation during deformation", and that the granitic border zones formed as a result of shearing movements along the dyke walls with consequent recrystallisation under stress.

NET-VEINED DIORITE INTRUSIVES

There are at least 70 net-veined diorite bodies in the Sârdloq area. They occur either as flat-lying sheets, ranging up to 40 m in width, or as dykes between 30 cm and 10 m wide. Some sheets pass into dykes.

All bodies are composite, being composed of an inner zone of diorite which is surrounded by a marginal zone of aplitic granodiorite, from which extend net-veins into the diorite, forming bulbous shapes (fig. 10), which are a characteristic feature of net-veined bodies (Chapman, 1962).

On NW Umanaq there is a swarm of multiple dykes in which several varieties of basic material have been intruded into the same dyke fissures. These vary from fine-grained, non-porphyritic quartz diorite or diorite to coarse-grained meladiorite, rich in plagioclase phenocrysts and aggregates of hornblende. Potash feldspar never exceeds 5% of the rock.

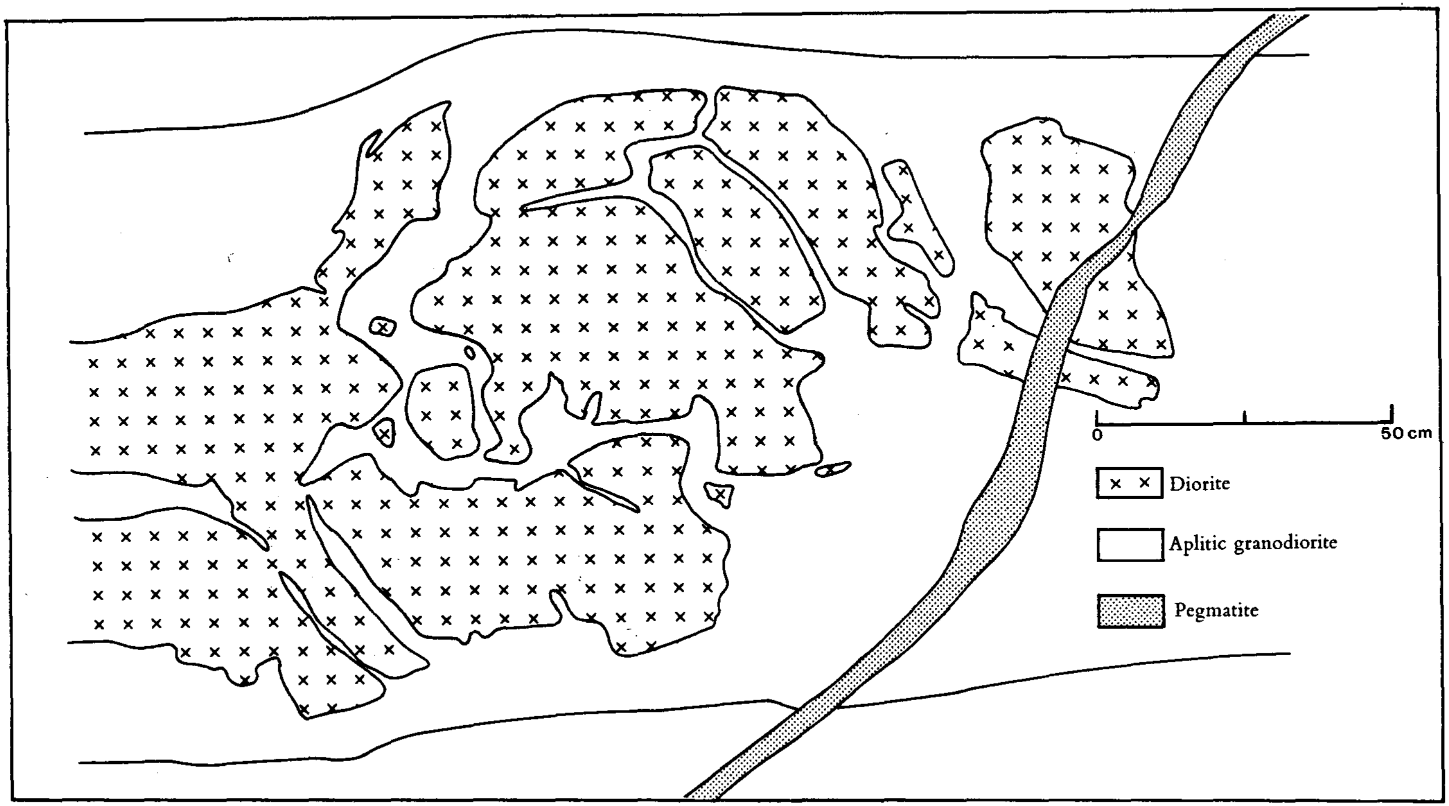

Fig. 10. A net-veined diorite dyke with rounded, pillow-shaped diorite blocks in an aplitic granodiorite matrix. This feature is typical of the net-veined diorites. The dyke is cut by a replacive non-dilatational pegmatite dyke. N coast of Akia.

The aplite margin has a maximum width of 5 m in the largest sheets and surrounds the diorite of all sides. The most striking feature of these rocks is the plexus of net-veins that extend into the diorite from the aplite margins. The veins enclose masses of diorite that are ideally spherical in shape, but pillow-shaped forms are usually present. Sheet-veins of granodioritic material pass through the central parts of the diorite and from these there extend cross-connections. Rejoining of the cross-connections with those from neighbouring sheet-veins gives rise to additional pillow-shaped forms. Similar features have been described from the net-veined diorites of Guernsey by Elwell, Skelhorn and Drysdall (1962).

An important, although negative, feature of all the bodies is the absence of chilled margins in the diorite against the veins. Mostly there is no observable change at the contact, but in places the biotite content increases (with increase in grain size) towards the contact at the expense of hornblende and against some veins there is a zone of leucocratic "spots" with cores of sphene, which increase in size towards the contact.

It is concluded that the acid material was generated by rheomorphism at depth and followed its basic parent to higher levels, where it penetrated it to form the net-veins. A retrogressive, contact metamorphic effect was caused by some net-veins. For a more comprehensive description and discussion of the mode of origin of these rocks the reader is referred to Windley (1965).

HOMOGENEOUS MICROGRANITES

In the Sârdloq area there are some 22 bodies of homogeneous microgranite ranging in size up to about 5 km. They are distributed throughout the whole area, but they increase in number towards the north and especially the north-east. They are all megascopically similar in their field relations, grain size, composition, texture and age and thus it is considered that they are genetically connected and can be included together for purposes of description and genetic discussion.

Typically the granites have a mosaic texture with no trace of a linear or planar fabric and are entirely non-porphyroblastic. The essential constituents are plagioclase (oligoclase), quartz, microcline, biotite, hornblende, muscovite and chlorite. Accessories, which are rare, include sphene, epidote, zircon, allanite and ore. The mafic content amounts to less than 5 % by volume, and their plagioclase/microcline ratio varies considerably, so that they range from alkali granites through adamellites to granodiorites. All rocks have a xenomorphic-granular texture. The average grain size is less than 4 mm. Plagioclase has been replaced extensively by microcline, and both of these minerals have been partly replaced by skeletal muscovite, which sometimes extends across several feldspars.

In the field the two most striking characteristics of the microgranites are their extreme homogeneity and their lack of xenoliths of earlier rocks. They thus contrast markedly with the Ketilidian and early Sanerutian granites. Remnants of basic rocks are noticeably absent. It is genetically significant that the few xenoliths that have been observed are typically disoriented in both the contact zones of large bodies (fig. 11) and in narrow dykes and sheets (fig. 12). The bodies have sharp contacts which cross-cut the structure of both the Ketilidian and early Sanerutian granitic rocks.

The microgranites send many apophyses into their surrounding rocks. These apophyses appear identical in composition and texture etc. to their parent bodies, forming parallel-sided sheets which transect all earlier rocks. At oblique intersections the sheets visibly dilate earlier structures.

The relative age of the microgranites is provided by numerous intersections especially of the narrower sheets, which cut both the net-veined diorites and the 3rd period DAs as well as earlier rocks. In several localities it was seen that microgranite sheets were situated in the cores of F_3 folds in the Ketilidian gneisses, indicating structural control of granite emplacement (fig. 13).

The layered aplite-pegmatite dykes are concentrated within some bodies especially in the Ivnarssup qava area. A swarm of dykes confined to one microgranite body stops abruptly at its contacts.

Although being abundant in the area immediately surrounding the

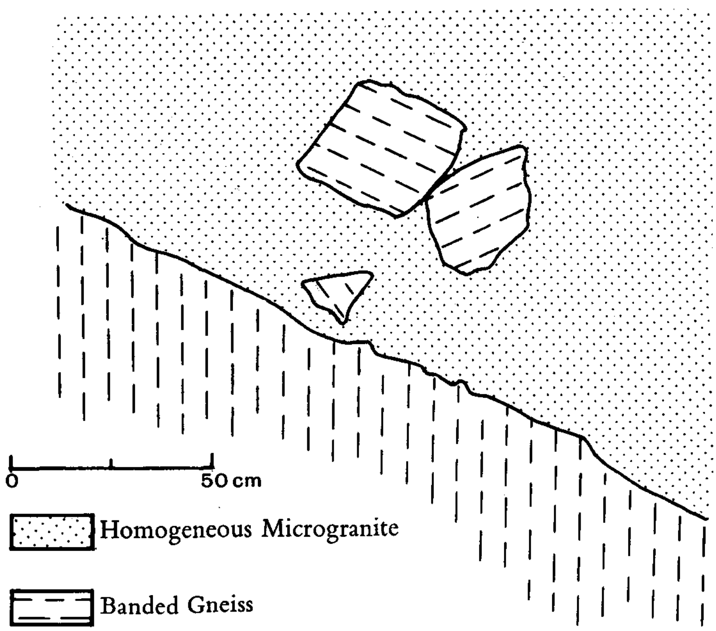

Fig. 11. Contact of a body of homogeneous microgranite with its country rock of banded gneiss. There are three disoriented inclusions of gneiss within the microgranite suggesting movement during its formation. 4 km NE of Sanerut.

large microgranite bodies, thin dykes and sheets of microgranite are common throughout the whole area. On Quvssagssat island they amount to 50 % of the rock.

The main problem of these granites is their mode of origin. The sharp, discordant contacts afford little genetic information, as it is well known that replacement granites have these types of contacts as well as intrusive bodies. The fact that they contain few or no basic inclusions or remains of basic dykes or relict structures indicates either that they represent an intense homogenisation of pre-existing granitic rocks by reactivation or that xenolith-free granitic material (magma) was intruded from below. It is significant that almost all the xenoliths observed have been disoriented, from which it is concluded that some movement accompanied their formation. At intersections the dyke-like apophyses dilate earlier structures, which shows that the granite was not formed by replacement processes, but by introduction of material in dilating fissures. Furthermore, it seems difficult to imagine that the bodies, especially the smaller ones, could be the result of an intense homogenising reactivation within such small areas. It is considered that the available evidence leads only to the conclusion that the micrograntes were formed by emplacement of mobile granitic material. However, this does not necessarily mean that there was intrusion of a deep-seated, crustal magma, as the granitic material could easily be palingenic in origin, formed by remobilisation of the earlier granitic rocks.

The common presence of muscovite and chlorite as late minerals in the microgranite paragenesis indicates that in their late stages the granites crystallised under greenschist facies conditions.

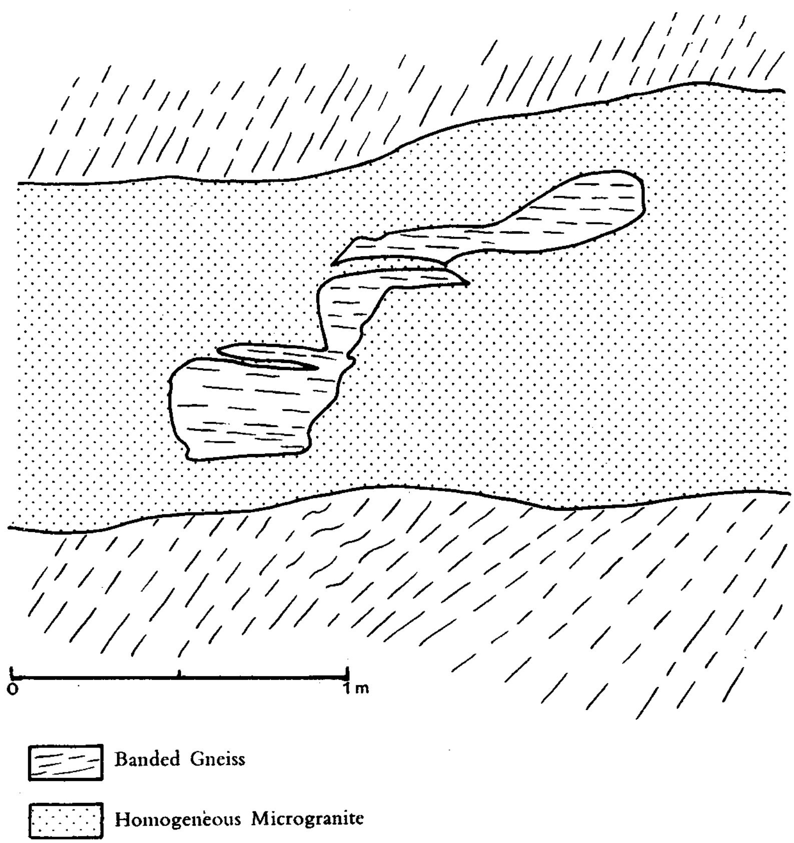

Fig. 12. A dyke of homogeneous microgranite with a disoriented inclusion of banded gneiss. 5 km SSW of Iliverdleq.

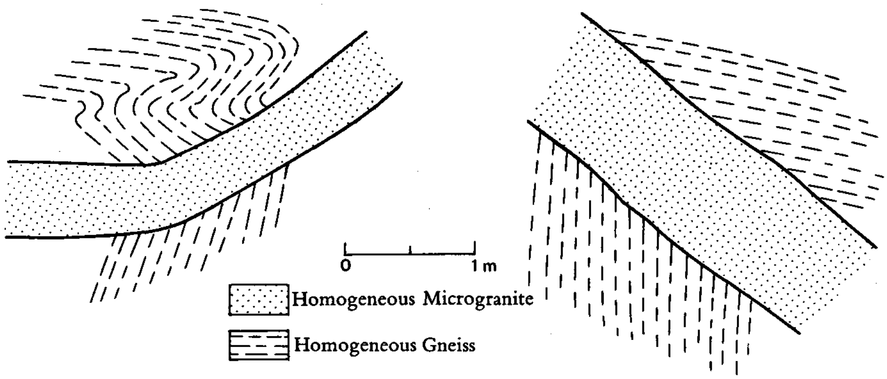

Fig. 13. Two examples of sheets of homogeneous microgranite situated in fold cores in homogeneous gneiss, indicating structural control of granite emplacement. Sanerut.

LAYERED ULTRABASIC BODIES

Three bodies of a layered ultrabasic rock are situated in the Ketilidian hornblende gneiss on the islands 2 km west of Quvssagssat. The bodies are 100 x 100 m, 70 x 10 m and 25 x 10 m in size. The layering consists of three components: a magnetite-rich olivine-garnet rock is interlayered with syenite and hornblende-magnetite granitic layers. These granitic layers are themselves intensely layered, displaying features similar to current bedding, trough banding and graded bedding. This igneous layering is generally discordant to the contacts of the bodies.

The ultrabasic component is a magnetite-rich olivine-garnet rock with orthite, zircon, quartz and sulphide minerals.

The contacts of the bodies vary considerably in attitude from vertical to horizontal. There is commonly a skin of magnetite-garnet bearing granite along the contacts between the ultrabasic rock and the wall rock gneiss. Garnet is particularly concentrated in a transition zone between the granitic skin and the ultrabasic layers, but also occurs in the granitic layers where it is particularly associated with the magnetite-rich layers. Where the granite contains less magnetite and garnet, it is similar to the leucocratic microgranites which are common in the area.

The bodies are older than the zoned pegmatite sheets of late Sanerutian age and are later than the Ketilidian gneisses. These are the only positive age relations known, but they do demonstrate that these are not layered intrusions of Gardar age. As a magma chamber of considerable size is necessary for the development of magmatic currents (Walker, 1956, p. 440), it is suggested that there was a larger layered igneous body at depth which was segmented into fragments and tectonically emplaced to the present level (cf. Bowes, Wright and Park, 1964). The skin of granite surrounding the bodies may have been formed by recrystallisation during the tectonic emplacement of the bodies.

PEGMATITES AND APLITES

The following types can be distinguished:

a) Replacement pegmatites and aplites
b) Layered aplite-pegmatites
c) Dilatational pegmatites and aplites. These can be subdivided into single and complex types.

At least 6000 pegmatites have been recorded on the well-exposed coast lines of the Sârdloq area. As these represent only a small fraction of the total, it is estimated that there are more than a hundred thousand pegmatites in the area. The pegmatisation is best developed in the southern part of the area reaching a maximum on the islands around Sârdloq village. Layered aplite-pegmatites and simple and complex dilatational types are commonest. The replacement types are only locally developed.

Replacement pegmatites may have straight, parallel walls or irregular margins. The dyke-like bodies vary from 10 to 40 cm in width. At intersections it can be seen that they have not dilated earlier structures. One of the most common features is the presence of undisturbed, only partly digested fragments of country rock. There may be a central zone or parallel strips of relict country rock granite, in which the original foliation can be still discerned. Basic fronts are usually present. There is no preferred orientation of growth or zoning of the constituent minerals. These pegmatites formed by replacement processes and are similar to some of those described from West Greenland by Ramberg (1956).

The orientation of the remaining groups of pegmatites is particularly significant. They fall into major sets. There is a N-S trending set consisting of abundant pegmatites that are mostly vertical, and that vary between 10 and 30 cm in width. This set includes the dilatational, simple pegmatites and the layered aplite-pegmatites. The pegmatites of the second group are fewer in number, trend roughly E-W, vary irregularly between 1 and 15 m in width and dip shallowly to the N or S. These are the graphic, complex dilatational pegmatites.

Layered aplite-pegmatites. Dykes and sheets of interlayered aplite and pegmatite are abundant in the Sârdloq area. The two rock types may be regularly intercalated with up to 15 layers lying parallel to the walls of the sheets. The aplite is itself layered and locally is truncated by the pegmatite layers. Occasionally there are layers of garnet in the aplite. The most common feature of these rocks is the presence of parallel, relict strips of aplite within pegmatite layers and within bodies consisting almost entirely of pegmatite. A general trend of crystallisation can be distinguished from an early layered aplite to a late pegmatite, with pegmatite replacing part of the already crystallised layered aplite. Some intensely layered, garnet-bearing aplite-pegmatites have been described from Kînâlik in the neighbouring area by Windley and Bridgwater (1965). A review and petrogenetic discussion of similar rocks, mostly from America, has been made by Jahns and Tuttle (1963).

Simple, dilatational pegmatites occur as dykes with a marked N-S trend. Within a 2.5 km length of coast 2 km to the south-west of Iliverdleq there are at least 400 parallel pegmatites of this type. They are composed of essential microcline, plagioclase and quartz with subsidiary biotite and hornblende and accessory magnetite and garnet. The cafemic minerals are extremely rare. Almost all dykes are symmetrically zoned with a quartz core and quartz-feldspar margins.

Complex, dilatational pegmatites have a dominant E-W trend and are composed essentially of microcline, plagioclase and quartz. In addition they contain magnetite, garnet, biotite, muscovite, beryl, orthite, monazite, ilmenite and fergusonite. Their most outstanding feature is the presence of abundant graphic intergrowths of quartz and feldspar. The bodies are symmetrically zoned with a quartz core, potash feldspar pegmatoid zones, intermediate graphic intergrowth zones and wall zones of plagioclase, microcline and quartz. Both types of dilatational pegmatites crystallised from intruded fluids.

LATE SANERUTIAN AMPHIBOLITE DYKES

Only four, unequivocal examples of these late Sanerutian basic dykes have been found in the Sârdloq area. More may be presumed to exist in the poor inland exposures. Their position in the chronology has been established by the fact that they transect the net-veined diorites and the pegmatites and aplites. The dykes trend E-W and vary in width from 20 to 60 cm. The principal, megascopic feature of the dykes is that their constituent minerals have very little preferred orientation. The marked foliation, common in the 1st, 2nd and 3rd period DAs is absent; they only locally display a faint, linear mineral orientation. The second conspicuous feature is that they have undergone only partial recrystallisation. They contain plagioclase phenocrysts with very ragged boundaries which are clearly relict crystals in a recrystallised matrix, which largely consists of biotite. There are also matrix plagioclases with embayed boundaries, which locally have a preferred orientation, representing a remnant flow texture.

The metamorphism which caused partial recrystallisation of these basic dykes represents the last phase of plutonic activity in the area.

GARDAR DOLERITES

There are about a hundred dolerite dykes belonging to the Gardar period in the Sârdloq area. They occur in two swarms, which are distinguishable in trend from the post-Gardar dykes. It is unfortunate that there are very few visible intersections between different dolerite dykes in the Sârdloq area; either they exist, but are unexposed, or the different dyke swarms occur in different areas. The principal means of distinguishing between the Gardar and post-Gardar dykes is that the former show evidence of shearing and faulting, whilst the post-Gardar dykes either transect the fault and mylonite zones or lack evidence of cataclastic deformation.

The two swarms are as follows:

1) NE-SW trending dykes
2) E-W trending dykes

It has not been possible to date these relative to each other.

1) NE-SW trending dykes vary between 30 cm and 10 m in width, dykes less than 2 m in width being most common. Most are vertical but some dip steeply. There are only about 23 dykes with this trend, which are scattered sporadically throughout the area. They form short dykes which in places have been deeply eroded, leaving only a clean-cut gully with a few scattered remnants of dolerite attached to the walls. In several places e. g. NE Akia, they have been heavily mylonitised, whilst in others e. g. central Kangek, they have been displaced by faults.

2) An E-W swarm of dykes, members of which vary between 30 and 127 m in width; most dykes are between 10 and 60 m. There are at least 70 dykes in a pronounced swarm which traverses SW Akia, SE Kangek and N Iliverdleq. Characteristically the dykes can be followed for long distances, but only the largest dyke of the swarm can be traced continuously across the area. The dykes are frequently faulted and sheared. Some faults have caused visible drag of the dykes e. g. on Umánalik and 3 km south-west of Nunarssuaq. The wider dykes contain pegmatitic dolerite either as irregular patches reaching 30 cm or as 15 to 30 cm thick veinlets which penetrate the dolerite often close to and parallel to the dyke walls.

There are two features of the Gardar dykes which warrant a more detailed description as they provide evidence bearing on the mode of intrusion:

a) Two dykes (120 m and 10 m) of the E-W swarm on SW Akia contain abundant feldspar and anorthositic xenocrysts. It is interesting that the larger dyke has also been reported to contain abundant xenocrysts near Lichtenau about 24 km to the E (Bridgwater, personal communication). The feldspars are mostly euhedral, with an average length of 2-5 cm reaching a maximum of 7.5 cm. They are packed into two zones about 1-2 m from the dyke walls. Within these zones the feldspars may occupy up to 80% of the rock. Within the central part of the dyke between the two zones there are no xenocrysts. Between the zones and the dyke walls there are a few large feldspars, some of which lie against the contact. There are several well exposed apophyses which contain numerous xenocrysts. Within the concentrated zones most of the feldspars are aligned with their longest axes in a horizontal position parallel to the dyke walls; only a few lie normal to this direction. Frequently aggregates of feldspar occur, the individuals of which are interlocked. In places a lamination of the crystals can be seen parallel to the walls. Many crystals are cracked and veins of dolerite penetrate the crystals. There are a few blocks of pyroxene anorthosite, reaching about 10 cm in size. The fragmented nature of many crystals suggests that they are the remnants of larger, anorthosite blocks, which have been mechanically broken into single crystals or aggregates of feldspar.

Dolerite dykes carrying innumerable blocks of anorthosite are common to the NW of the Sârdloq area, thus there is a possibility that the xenocrysts described above were derived from a source to the north-west (at depth) where they are abundant. The evidence favours this suggestion. Where the dyke is widest (120 m) it has split into three smaller dykes, only the larger (65 m) of which continues to the east. The xenocrysts are conspicuously packed together at the point where the dyke is widest and has forked, but they are mostly concentrated within the eastward extending apophysis. This indicates that the xenocrysts were transported from the west.

b) A 3 m NE-SW trending, multiple dolerite dyke on an island 4.5 km south-west of Quvssagssat contains abundant xenoliths which are concentrated within the central zone of the dyke: there are none in the marginal zones. The xenoliths are of aplite, pegmatite, graphic feldspar, blocky quartz and layered aplite-pegmatite. Only one xenolith was observed to be of gneiss representing the country rock of the layered aplite-pegmatites. The pegmatite contains a great deal of magnetite and a little biotite and beryl. The xenoliths occupy about 40% of the volume of the central zone of the dyke. They vary in size from microscopic fragments to blocks 1 m across. There is a pronounced tendency for the largest blocks to occur along the central part of the zone. Although most blocks are angular, many are elongate or lens-shaped with their longest axes mostly aligned parallel to the dyke walls. There are several other parallel, dolerite dykes in the vicinity, none of which bears any trace of xenoliths. Also nearby there are innumerable pegmatites and layered aplite-pegmatites which contain magnetite, biotite and beryl. Graphic feldspars and core quartz are well developed. There are no garnets in these pegmatites and neither are there in the xenoliths-

Megascopically there appears to have been no appreciable effect on the xenoliths caused by the dolerite. Microscopically it can be seen that the feldspar xenocrysts have been extensively replaced by calcite, which is abundant in the dolerite: the quartz xenocrysts on the other hand have been little affected. Calcite has penetrated along cracks in the quartz and along mutual quartz grain boundaries. Quartz xenocrysts are rimmed with calcite and biotite.

In view of the similarity of the aplite-pegmatite xenoliths to aplite-pegmatite dykes in the immediate vicinity, it can be presumed that they were derived from no great depth. The mineralogy of pegmatites at considerable depths would be different from that of pegmatites at the present erosion level. The absence of xenoliths of gneiss suggests that the xenoliths were derived from a single body of aplite-pegmatite. It is envisaged that the path of the uprising doleritic magma was blocked by a large layered aplite-pegmatite sheet and that the pressure of the magma increased to such an extent that the pegmatite was finally shattered.

FAULTS AND MYLONITES

Faults and mylonite zones are variably developed throughout the Sârdloq area. They can be divided into four sets:

E-W; N-S; NE-SW; NW-SE

The largest and greatest number of faults belong to the NE-SW set. They have formed parallel to the foliation of the Ketilidian and Sanerutian granitic rocks. The faults have displaced earlier structures e.g. dolerite dykes, and are characterised by mylonite zones. The width of a mylonite zone depends on the size and length of a fault; the maximum width attained in the Sârdloq area is about 200 m on NE Akia. Recrystallised banded mylonites occur in places. In many zones the rocks have been cataclastically deformed to a fine-grained mylonite, which megascopically appears like a "quartzite". In this rock the mafic constituents have been transformed into chlorite and the quartzo-feldspathic minerals have been reduced to a fine-grained "powder". This corresponds to the "roche broyée" of Raguin (1957, p. 143). Less deformed types have relict fragments of the original rock surrounded by comminuted material, giving rise to typical "mortar texture".

Offset structures indicate that lateral or oblique movements have taken place along the fault planes. The amount of vertical displacement is difficult to assess. The largest transverse displacement in the area is 1.5 km along a fault in the NE corner of the area and there is another of this size 3 km south-west of Nunarssuaq.

The age relations between faults and dykes in the last-mentioned area are instructive with respect to the fault movements. A 96 m dolerite dyke has been titled from 80 to 58 degrees by a NNE trending fault which had a scissor movement.

It is probable that many of the NE trending fjords owe their origin to the NE-SW faults. That there is a fault along the east end of Kangerdluarssorojuk fjord is indicated by the presence of abundant mylonites in the gneiss parallel to the fjord on its south side and by the absence of a 96 m E-W dolerite dyke on the south side of the fjord. A 20 m mylonite zone on the neck of land at the end of Sangmissoq indicates that the fjord occupies a fault zone. Other NE-SW faults trend parallel to the fjord.

POST-GARDAR (TERTIARY ?) DOLERITES

There are about 60 dykes of possible Tertiary age in the Sârdloq area. They can be divided into two types:

1) There is a pronounced swarm of vertical NW trending dykes traversing N. Iliverdleq and central Kangek. They transect both faults and mylonite zones and are mostly between 10 and 20 m in width, although a few are thinner. They are conspicuous on account of their layering, which is vertical, parallel to their contacts and which forms in zones adjacent to the dyke walls. The layers are of fine- to medium-grained dolerite and there

are chilled margins along the junctions of most of the layers. The latter fact indicates that the layering has been caused by multiple injection of thin units during the initial stages of intrusion. There are other dykes with central and marginal units of different types of dolerite, which are more obvious examples of multiple intrusion. The presence of this layering distinguishes the post-Gardar from the Gardar dykes in the Sârdloq area.

2) On W. Akia there is a swarm of shallow-dipping dolerite sheets, which post-date the faults and cross-cut the E-W trending Gardar dykes. They vary between 0.5 and 4 m in width, trend either N-S or E-W and have shallow dips of 10 to 30°. They are also conspicuously layered parallel to their walls. The layers are of fine- to medium-grained dolerite and chilled margins are common to all junctions. It is likewise concluded that the layering was formed by multiple injection of doleritic magma into shallow-dipping fissures.

Some of the sheets have a lamprophyric composition. They are composed of euhedral phenocrysts of olivine, pyroxene and plagioclase in a microcrystalline mesostasis. Calcite forms a major constituent; it has replaced phenocrysts which may have been olivines and it has crystallised in vugs which form a noticeable feature of the sheets.

The doleritic sheets are very similar to the vertical dykes described above with respect to their brownish colour, rubbly, desert weathering, and abundant layering. It seems likely that they were cogenetic and simultaneous intrusions, but lack of intersections, due to their occurrence in different areas, makes precise age correlations impossible.

CORRELATION WITH NEIGHBOURING AREAS

The Sârdloq area lies astride the junction between the Julianehåb granite to the north and the gneisses to the south-east.

Nesbitt (1961) has described the neighbouring Julianehåb area to the north where there is a reactivated granite similar to that on Akia. Within the Julianehåb granite there is a relict strip of banded gneiss 18 km long. It should be remembered that the whole of W. Kangek is of banded gneiss which grades transitionally into the Akia reactivated granite. Nesbitt's gneiss xenolith may represent an unreactivated segment of the earlier gneiss series.

To the north-east of the Sârdloq area lies the Vatnahverfi area described by Berrangé (1966). The gneiss-granite boundary of S. Akia can be followed along its strike into and through the Vatnahverfi area. In the Ketilidian gneisses there is a major antiform trending NE-SW, which lies on the north-west flank of the Sârdloq, major F_2 synform. The net-veined diorite intrusives, prominent in the reactivated granite area of Akia, are also confined to the reactivated granite of Vatnahverfi.

Persoz (personal communication) has described the Akuliaruseq area, which lies to the east of the Lichtenau/Sydprøven area. Here there is an F_2 antiform trending NE-SW in the Ketilidian gneisses. This major antiform structure is probably complementary to the Sârdloq F_2 synform. Between these structures there is only a minor antiform and synform. The Akuliaruseq antiform has been refolded by F_3 open folds, the axes of which trend NW-SE, which can be correlated with the Sârdloq F_3 folds. The third phase folds have the same axial trend and age relations to F_2 structures in all the neighbouring areas where they have been identified.

CONCLUSIONS

The geological history of the Sârdloq area has been divided on a chronological basis into three periods of granite formation preceded, separated and followed by periods of basic dyke intrusion. Conditions in the crust alternated between cratogenic and plutonic on several occasions.

The Ketilidian gneisses were autochthonous, the early Sanerutian reactivated granite was formed in situ but with local mobilisation (parautochthonous) and the late, homogeneous microgranites were allochthonous.

This picture of the variation in the mode of formation of the granites of the Sârdloq area with time is in accordance with the idea of the "granite series" of Read (1957, p. 335).

Basic dyking has played a major role in the development of the Sârdloq area. In total there were eight generations of basic dyke intrusion, only the last three of which are unmetamorphosed. By means of "the method of basic dykes", originally proposed by Sederholm (1962), first applied to South Greenland by Wegmann (1938) and refined and applied to the Ilordleq area, South Greenland, by Watterson (1965), it has been possible to separate the reactivated granites from the earlier gneisses. Basic dykes intruded under cratogenic conditions (2nd period DAs, Gardar and post-Gardar dykes) were unaffected by their wall rocks on intrusion. However, basic dykes intruded syn-kinematically under late plutonic conditions (3rd period DAs) bear critical evidence of this special mode of intrusion, as they were directly affected by the temperature and movements of their wall rocks.

Acid intrusions have also played an important role in the development of the Sârdloq area. Mobile, quartzo-feldspathic material was intruded in the form of microgranites, margins to net-veined bodies, dilatational pegmatites and layered aplite-pegmatites. No acid intrusion took place under cratogenic conditions.

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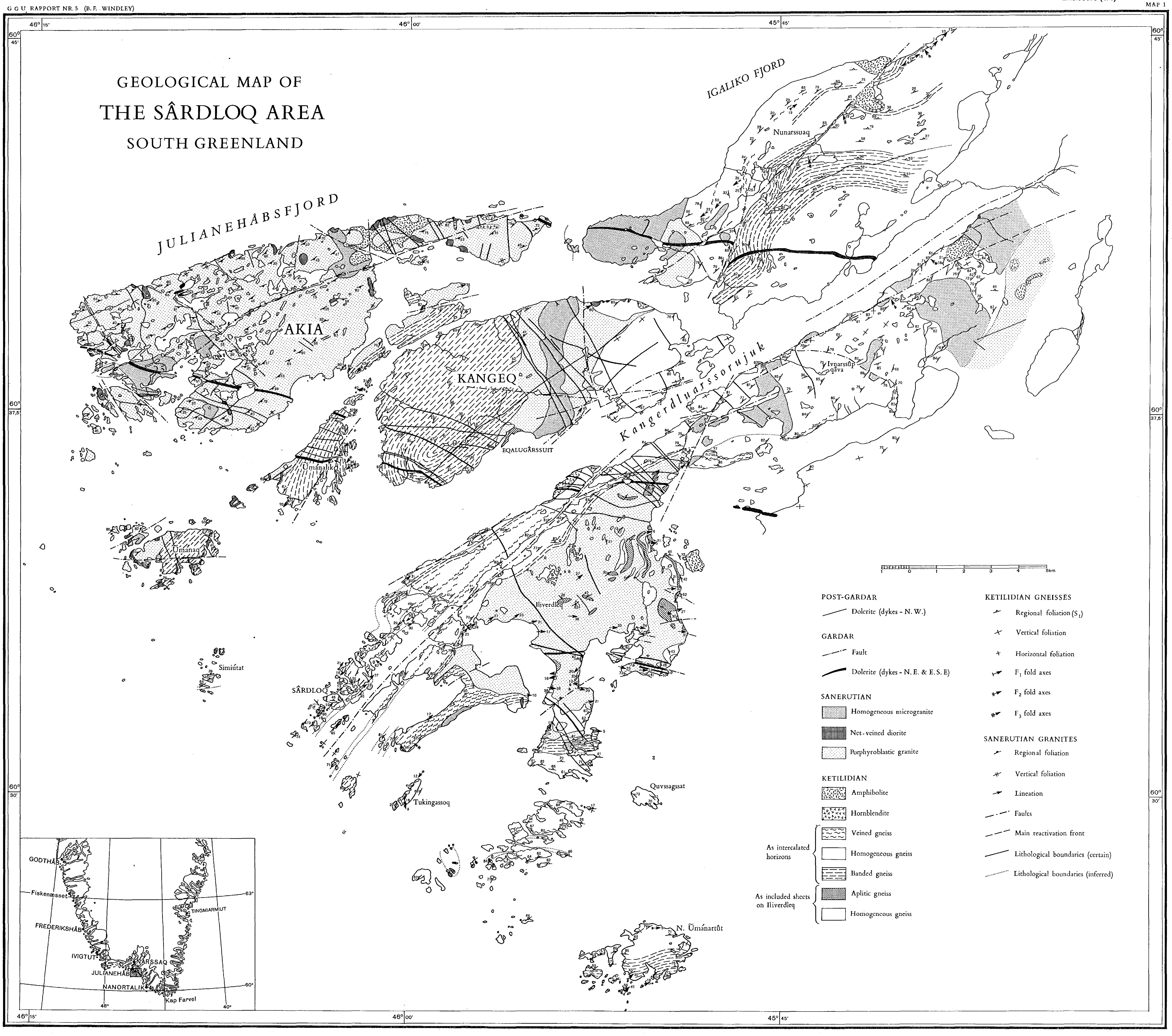

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