GRØNLANDS GEOLOGISKE UNDERSØGELSE
BULLETIN No. 58

THE COMPOSITE NET-VEINED DIORITE INTRUSIVES OF THE JULIANEHÅB DISTRICT, SOUTH GREENLAND

BY

B. F. WINDLEY

WITH 27 FIGURES AND 2 TABLES IN THE TEXT
AND 1 PLATE

Reprinted from Meddelelser om Grønland,
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KØBENHAVN
BIANCO LUNOS BOGTRYKKERI A/S
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Abstract

Net-veined diorite intrusive are described from a plutonic environment of Precambrian granites in the Julianehåb district of S. Greenland. They are composite, minor intrusions consisting of a central diorite flanked by margins of aplitic granodiorite and they are characterised by the presence of pillow-shaped diorite blocks formed by granitic net-veins penetrating from the margins into the central diorite. The net-veins have not chilled the diorite, but along a few there are coarser grained margins in the diorite in which biotite, sphene and orthite have recrystallised.

A contraction crack – shear plane theory is proposed to explain the formation of the net-veins. The granite material was introduced along the walls of the bodies from where it penetrated inwards through a network of contraction cracks. It was also introduced through the central parts of bodies along a set of parallel sheet fractures formed by shearing and compression of the diorite.

The granitic material was produced by rheomorphism-at-depth from the recently reactivated granites of the Julianehåb district; it followed its basic parent to higher levels, where it penetrated the diorite at least partly by a process of recrystallisation and replacement.

CONTENTS

I. INTRODUCTION

The term "net-veined intrusives or bodies" is used in the following text to denote composite intrusions, the earlier basic member of which has been net-veined by granitic material, in such a way that the veins define a very characteristic rounded or pillow-shaped pattern. The general description of, and the genetic problems associated with the net-veined bodies described here appear to be similar to those recorded in many parts of the world; in particular, Maine, U.S.A. (CHAPMAN, 1962); Slieve Gullion, Ireland (REYNOLDS, 1951); Guernsey, Channel Islands (ELWELL, SKELHORN and DRYSDALL, 1962), and Ardnamurchan, W. Scotland (WELLS, 1954; SKELHORN and ELWELL, in press).

The net-veined intrusives form a spectacular event in the Precambrian chronology of S. Greenland. They are situated within the granitic rocks of the Julianehåb district, which is taken here to extend from Qagssimiut north-eastwards to Narssarssuaq (see the map, Plate 1). The writer's experience of the bodies concerned has been largely taken from a detailed investigation of those in the Sârdloq area, mapped in the summers of 1960–62 under the aegis of the Geological Survey of Greenland (Grønlands Geologiske Undersøgelse; hereafter termed GGU).

The author is indebted to the board of GGU and to its director K. ELLITSGAARD-RASMUSSEN for excellent facilities in the field and in the laboratory and for permission to publish this paper. The study at hand formed part of a doctorate thesis in the University of Exeter, England (WINDLEY, 1963). The author is grateful to Dr. K. COE for supervision and to Professor S. SIMPSON for use of the facilities at Exeter. The receipt of a studentship from the Department of Scientific and Industrial Research and of a Danish Government Scholarship issued by the British Council are gratefully acknowledged.

The purpose of the present paper is to describe the net-veined diorite intrusives concerned, to explain their mode of formation from their field and microscopic relations and to discuss their origin in the light of hypotheses proposed to explain the origin of similar bodies elsewhere.

General regional geology

S. Greenland is largely comprised of granitic rocks belonging to three plutonic periods within the Precambrian basement. WEGMANN (1938) made the first attempt to obtain a comprehensive picture of S. Greenland geology and this forms a sound basis for the present day views. As a result of the systematic mapping of S. Greenland by members of GGU since 1946, a very complex and detailed history of events has been established. BERTHELSEN (1960, 1961) has summarised the general geology of the area as far south as Julianehåb, and ALLAART (1964) has given a synopsis of the geology of the area between Kobberminebugt and Nanortalik. As a general background to the net-veined diorites, a short résumé of the geology is given.

During the Ketilidian a supracrustal series, intruded by basic dykes (1st period), and now preserved in the Ivigtut and probably in the S. Sermilik regions, was subjected to deformation, metamorphism and migmatisation, giving rise to a series of highly folded foliated granites and gneisses belonging to the amphibolite facies. Evidence has recently been brought to light establishing the existence near Ivigtut of pre-Ketilidian gneisses, which formed a basement to the Ketilidian supracrustal series (BONDESEN, 1962).

2nd period basic dykes were intruded in Kuanitic time under anorogenic conditions, marking a hiatus in plutonism (WATTERSON, 1965).

During subsequent Sanerutian time the earlier granites and gneisses in the Julianehåb district were reactivated under amphibolite facies conditions to form a new series of granitic rocks in which relics of the basic dykes are preserved. Megacrystic "New granites" formed in the area to the south-east partly by replacement and partly by intrusion, essentially at the same time as the reactivation (BRIDGWATER, 1963). During the Sanerutian there was a complex succession of events, such as late-plutonic intrusion of basic dykes (3rd period) and formation of homogeneous micrograniteS and of pegmatites and aplites; a further important event is marked by the intrusion of the net-veined diorite bodies.

In later Gardar time sandstones and lavas were deposited under continental conditions and a highly varied suite of igneous rocks, dominantly alkaline in composition, were emplaced in the form of dykes and layered igneous complexes such as Ilímaussaq, Kûngnât and Nunarssuit. Dolerite dykes were intruded in post-Gardar (Tertiary?) times.

For purposes of clarity and in order to see the correct chronological position of the net-veined bodies, the succession of events in the Julianehåb district is schematically represented as follows:

Post-Gardar (Tertiary ?)	Intrusion of basic dykes.
Gardar	Intrusion of basic dykes and layered complexes. Sedimentation and volcanism.
Sanerutian	Formation of pegmatites and aplites. Formation of homogeneous microgranites. Emplacement of composite, net-veined diorites. Syn-kinematic intrusion of basic dykes (3rd period). Regional reactivation of Ketilidian granites and gneisses; migmatisation and metamorphism of earlier basic rocks.
Kuanitic	Basic dyke intrusion under anorogenic conditions (2nd period).
Ketilidian	Orogeny, migmatisation and metamorphism. Intrusion of basic dykes (1st period). Sedimentation and volcanism.
Pre-Ketilidian	Basement gneisses.

It is important to note that the net-veined diorite bodies belong to a plutonic environment in the sense of Read (1957). This contrasts with those intruded in high-level volcanic environments, such as those of Slieve Gullion and Ardnamurchan of the British Tertiary Volcanic Province.

Previous investigations

Wegmann (1938) first noted the net-veined bodies in the Julianehåb district; Ayrton and Burri (1963) have studied some in the Qagssimiut area, Berrangé (in press) some in the Vatnahverfi area and Allaart (1964) has considered the chronological position of the bodies in the history of the Sanerutian period.

Wegmann (*op. cit.*) regarded the net-veined bodies to be pre-reactivated granite and thus correlated them with migmatised amphibolite bodies and the migmatised 2nd period amphibolite dykes. In discussing these pre-granitic basic rocks within the Julianehåb area, he stated (*op. cit.*, p. 28–29) "they are more or less brecciated, but these zones of breccia can be traced like stratigraphic horizons over wide stretches .... These horizons permit an investigation of part of the pre-granitic structure. In some areas these zones are on the whole more flatly undulating, in others they are steep." One such zone occurs "in the northeastern peninsula of the island Akkia, whence it extends across the island, to form flat-lying masses intersected by pegmatite sills in the southwestern part. In the Sârdloq archipelago the remnants become more distinct again: several basic masses, in part with relict structures, are found here." Some bodies on Hollænderø are described as "basic sills and dykes which are accompained by a margin of aplite, from which veinlets issue into the dyke."

It is clear that WEGMANN noticed several salient features of the net-veined bodies – their aplitic margins and veins, their form as flat-lying sheets and as dykes and their brecciated (net-veined) character. His observation that the sheets can be traced like stratigraphic horizons is due to their frequent occurrence at the present sea-level. However, as regards their age, he correlated them with other basic bodies that had been migmatised, such as the 2nd period basic dykes. He consequently considered that the "granitising" agent was the reactivated granite.

AYRTON and BURRI (1963) have largely arrived at the same conclusion as WEGMANN in so far as the bodies of the Qagssimiut area were veined by granitic material during a later period of reactivation.

Since WEGMANN, and AYRTON and BURRI arrived at a different conclusion from the author's regarding the age of the net-veined bodies, and since this necessarily concerns the genetic problem of the formation and origin of the acid veining, the age relations of the bodies in the rest of the Julianehåb district and in particular of those in the Sârdloq area will be examined in some detail.

Fig. 1. Upper, shallow-dipping contact of a net-veined diorite sheet with reactivated granite. A 2nd period amphibolite dyke, migmatised and internally folded, is cut by the diorite sheet. Island off W. Akia.

II. DESCRIPTION

Age relations

A great number of the net-veined bodies outcrop at the present sea-level, thus the polished coastal exposures have provided excellent opportunities for the study of age relationships between these and structures of earlier and later age, as well as features of genetic significance.

The net-veined intrusions are situated in both Ketilidian and Sanerutian granitic rocks, the foliations of which they truncate. Fig. 17 shows an inclusion of Sanerutian granite within a body off W. Akia. The sheets transect the migmatised amphibolite bodies of late Ketilidian age, truncating the migmatising veins and the foliation of the amphibolite. In a few places the bodies cut aplites and pegmatites, which probably belong to a late phase of the Ketilidian or an early phase of the Sanerutian. At least twenty intersections between the 2nd period basic dykes and the net-veined bodies have been observed, the latter being the younger in every case (fig. 1). The amphibolite dykes, which are migmatised and/or folded, end abruptly at the aplite margin of the bodies. The aplite margin clearly truncates the migmatising granitic veins of the dykes. In a body on an island off W. Akia there is an inclusion of migmatised, foliated, green amphibolite, which can be correlated with a nearby, truncated 2nd period basic dyke. The 3rd period basic dykes, intruded within the Sanerutian plutonic period, are also cut by the net-veined bodies, many intersections of which have been observed.

It is emphasized that there is good evidence that the net-veined bodies are later than the main Sanerutian reactivation. The contacts of the bodies cut the foliation or lineation of the reactivated granite: apophyses from the aplite margins as well as net-veined diorite apophyses extend from the bodies and truncate the granite structures: as mentioned above, there are inclusions of Sanerutian granite within the bodies. These age criteria not only show that the intrusion of the bodies was later than the main Sanerutian reactivation, but also that the aplitic margins are not genetically related to the wall rock granite.

The homogeneous microgranites, pegmatites, aplites and Gardar and Tertiary (?) dolerite dykes have been seen to cut and transect the net-veined bodies.

Form, attitude and internal structure

The bodies occur as intrusive dykes or sheets, which reach a maximum width of 40 m. Throughout most of the Julianehåb district flat-lying or shallow-dipping sheets predominate; these are generally more than 10 m wide. In a few areas such as just south of Sârdloq village they occur mostly as dykes between 30 cm and 10 m wide which have moderate to vertical dips. The dykes and sheets tend to form short and rather irregular bodies which pinch and swell or undulate and change attitude. Some horizontal sheets have been seen to pass laterally into vertical dykes, showing that they follow an earlier joint network. Contacts with the wall rocks are sharp and usually discordant to earlier structures. The flat-lying attitude of the sheets is expressed in places by their "caps" of country rock, as for example on Akia. Although they may be interconnected in a complicated network of dykes and sheets, at least 200 apparently separate bodies have been recognised.

All bodies are composite, being composed of a central component of diorite, which is flanked by a marginal component of aplitic granodiorite. A ramifying system of net-veins passes from the acid margin into the diorite forming a rounded or pillow-shaped framework, which is a characteristic of the bodies (fig. 2). In the larger sheets the net-veins may not extend far, so leaving the central dioritic component free of veining (fig. 2).

There are some isolated, thin net-veined dykes, less than 2 m in width, which may be apophyses of unexposed larger bodies. Apophyses commonly extend into the wall rocks. Like their parent bodies they consist of a central component of diorite and marginal zones of aplite from which veins penetrate the diorite.

Fig. 2. Upper, flat-lying contact of a net-veined diorite sheet with reactivated granite. Along the contact there is a thin pegmatitic seam (in the middle of the photo). Below the aplitic margin there is a zone, about 1 m wide, of perfectly pillow-shaped diorite blocks in an aplitic granodiorite matrix. Below this the diorite is free of granitic veining. Island off W. Akia.

Allaart (personal communication) has described some flat-lying sheets which lie at an altitude of 400 m just north of Igaliko Fjord. Below these there are some vertical net-veined dykes, which can be traced upwards as feeder dykes to the horizontal sheets. The acid margins and net-veins are equally present in the feeder-dykes and in the horizontal sheets.

The position of the bodies has been plotted as accurately as possible on the enclosed map. No doubt more exist than have been found. It should be noted that the same cross symbol has been used both for bodies of 20–40 m width and for smaller dykes of less than 10 m width. Furthermore, their distribution is imperfectly represented for the following reasons:

a) More bodies were naturally found on the polished and bare coastal exposures than on the lichen-covered inland outcrops.

b) In some areas the bodies have been obliterated by later Sanerutian microgranites and by Gardar igneous complexes or have been covered by Gardar sandstones and lavas. Their presence may also be obscured by talus, river gravels and Quaternary deposits.

In spite of these difficulties it is clear that the bodies have an arcuate distribution, extending from Qagssimiut to Narssarssuaq. They are therefore confined to an area in which the effect of the Sanerutian reactivation has been most apparent.

Multiple dykes

On the northwesterly islands of the Ũmánaq group there is a swarm of multiple dykes, which warrant special mention. Ũmánaq is the only locality where multiple dykes have been recognised.

The dykes, which are steeply dipping to vertical, are composed of alternating layers of various types of diorite (fig. 3). The following types are present:

a) A medium-grained meladiorite which approaches a hornblendite in composition.

b) Three fine-grained porphyritic varieties of diorite.

   i) rich in hornblende aggregates, without plagioclase phenocrysts.
   ii) without – – , rich in – –
   iii) rich in – – , – – – –

   With increase in the amount of mafic aggregates, some varieties approach a meladiorite in composition. The phenocrysts and aggregates lie in a matrix of fine-grained diorite.

c) A fine-grained, non-porphyritic diorite. This is the type which is most commonly found in the net-veined bodies of the region and which in the multiple dykes is mostly later in age than the other varieties.

The multiple dykes at Ũmánaq have features illustrating the original igneous origin of the net-veined bodies. The layering, which is parallel to the dyke walls, reflects a mechanism of multiple injection. The mafic aggregates and phenocrysts are not always homogeneously distributed, but are commonly packed together to form concentrations within the layers and they are in places oriented parallel to the layers and walls of the dykes, defining by their parallelism the original flow orientation of the diorite. The layers are broadly continuous for several tens of metres, but locally they vary in width, as some, particularly those of the non-porphyritic diorite, penetrate and "cut out" others (fig. 3). The junctions between layers are therefore undulatory and rather irregular. As some layers are traced along their strike, they become fragmented, passing into a row of inclusions within an adjacent "penetrating" non-porphyritic layer (fig. 4). There is some evidence that the non-porphyritic diorite in the multiple dykes contains xenocrysts picked up from the porphyritic, more melanocratic layers. Although the contacts between

Fig. 3. Part of a multiple, net-veined diorite dyke. Dark meladiorite layers alternate with lighter and finer-grained diorite layers, which are spotted with hornblende aggregates also arranged in layers. Granitic material has penetrated along the dyke contacts and along the junctions between the layers, from where it has veined both the meladiorite and diorite layers. Island off N.W. Ũmánaq.

layers are usually sharp, in places they are gradational and here the non-porphyritic type contains xenocrystic aggregates concentrated near the gradational contact with a richly porphyritic layer. There are no mutual chilled margins between the layers and they do not seem to be symmetrically disposed with respect to each other within the dykes.

Within some bodies of fine-grained diorite on Ũmánaq and on Akia, there are irregularly arranged and shaped inclusions of fine-grained porphyritic diorite or meladiorite (fig. 5). The acid material has penetrated along the junctions, veins projecting into both types of diorite. These appear to be fragmented multiple dykes, in which the later, dominant, non-porphyritic diorite has penetrated, broken and included an earlier minor intrusion of porphyritic diorite or meladiorite. This represents an advanced stage of the fragmentation shown in fig. 4.

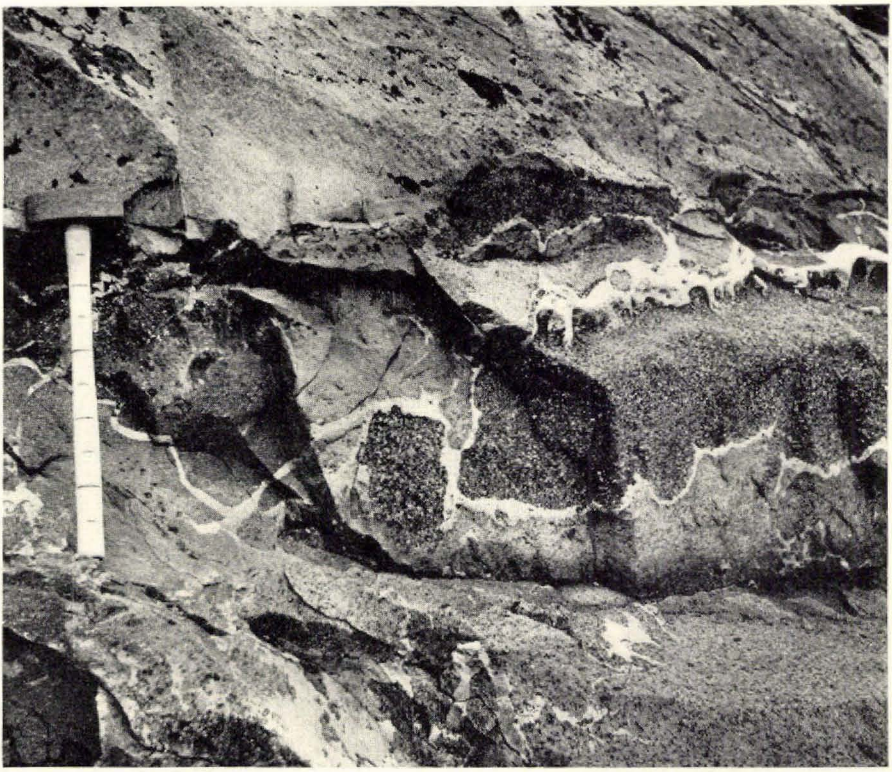

Fig. 4. Part of same multiple dyke as shown in fig. 3. The finer-grained and lighter diorite layer has penetrated and included an earlier darker meladiorite layer. Granitic material has penetrated between the layers from where it has extended into both types of diorite. Island off N.W. Ũmánaq.

The granitic component of the multiple dykes occurs as a mantle along the walls of the bodies, but it has also penetrated preferentially along the junctions between the different layers (fig. 3). From these junctions granitic veins extend outwards into the different types of diorite. The acid veins may be just short protuberances or may extend further into the basic component, linking with the acid veins from the next granitic layer and thus forming the typical pillow-shaped structures. The introduction of the acid material clearly took place after the intrusion of the various basic layers.

Within the chronology of the Sanerutian plutonic period in the Julianehåb district there is no major period of deformation following the net-veined bodies, thus they generally do not show any signs of deformation. However, in the Ũmánaq multiple dykes some evidence indicates a minor phase of later movements. Within the porphyritic layers the aggregates and phenocrysts are in places aligned, the resulting

Fig. 5. A fragmented multiple dyke in which there are relicts of dark meladiorite within lighter, finer-grained diorite. This represents a more advanced stage of fragmentation from that shown in fig. 4. Introduction of the granitic material post-dates the emplacement of both types of diorite. Island off N.W. Ũmánaq.

orientation lying oblique both to the walls and to the layers of the dykes. Furthermore, some aplitic veins, post-dating microgranite veins, are boudinaged within the dykes and the net-veins appear to be folded.

Aplite margins

The acid margins of the bodies are of saccharoidal, granodioritic aplite. It is significant that the width of the margin varies with that of the bodies themselves. It reaches a maximum width of 5 m in the largest, flat-lying sheets, but is only a few cm wide in some bodies (fig. 6) and in particularly thin dykes. The margin flanks the diorite on both sides, thus flat-lying sheets have a conspicuous upper and lower margin. The upper contacts of flat-lying sheets are sometimes undulatory, but whatever the contact's attitude the aplitic margin is almost always present. The upper margin is at times the wider, attaining its greatest width at the apex of some arched flat-lying sheets. However, in some bodies the lower margin is clearly the wider (fig. 7). The margin is remarkably continuous, thus it is not common for the diorite to come into contact with the wall rocks; in places it thins out for a distance of several cm or even a few metres (fig. 6). In whatever country rocks the bodies are situated, the aplitic margins are usually present. When they transect earlier amphi-

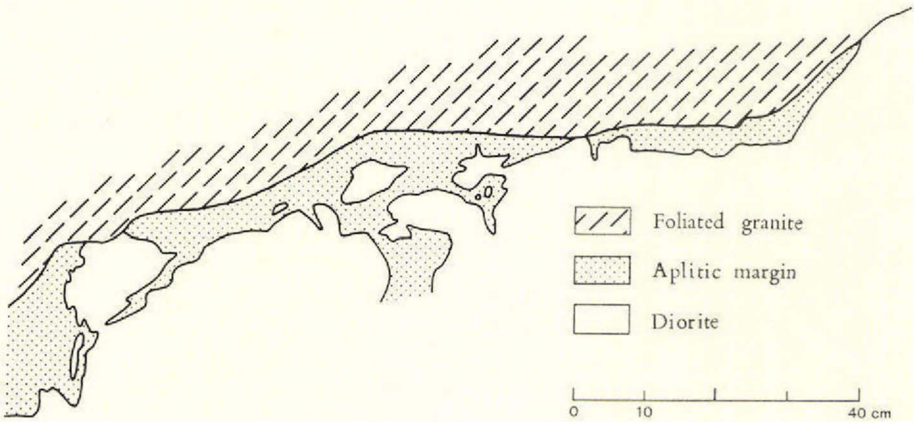

Fig. 6. Upper contact of a shallow-dipping net-veined sheet with granitic wall rocks. The granitic margin locally thins out, allowing the diorite to come into contact with the wall rocks. Island off W. Akia.

bolite bodies, the aplitic margins are as wide and as regular as when they transect granitic rocks (fig. 7). In the largest sheets the margin, where it is widest, may be layered with several units of aplite of variable grain size and mafic content.

It is very rare for apophyses to extend from the aplitic margin into the wall rocks. Only three such apophyses have been observed by the author; these were a few cm in width. The fact that they are noticeably straight (or planar in three dimensions) contrasts with the sinuous (curvi-planar) veins which extend inward from the margin into the diorite (fig. 8).

In some bodies there are inclusions of the diorite within the aplitic margins and occasionally within the net-veins. Where there are swarms of inclusions it is noticeable that they have not lost their orientation as indicated by their parallel alignment and matching walls. Their preferred orientation in the aplite indicates that the blocks are aligned and that they have undergone no appreciable movement during their inclusion. In most cases the inclusions are unaltered, but some have been partially transformed by the granodiorite. This transformation generally takes the

Fig. 7. Shallow-dipping net-veined sheet within an earlier amphibolite body. The lower granitic margin of the sheet is wider than the upper. The granitic net-veins are entirely confined to the diorite sheet. N. E. Akia.

form of an increase in the amount of granitic material and the appearance of leucocratic spots with cores of sphene (fig. 21).

Microscopically the texture of the margin is xenomorphic-granular-seriate; the grain size is less than 3 mm and the constituents are essential

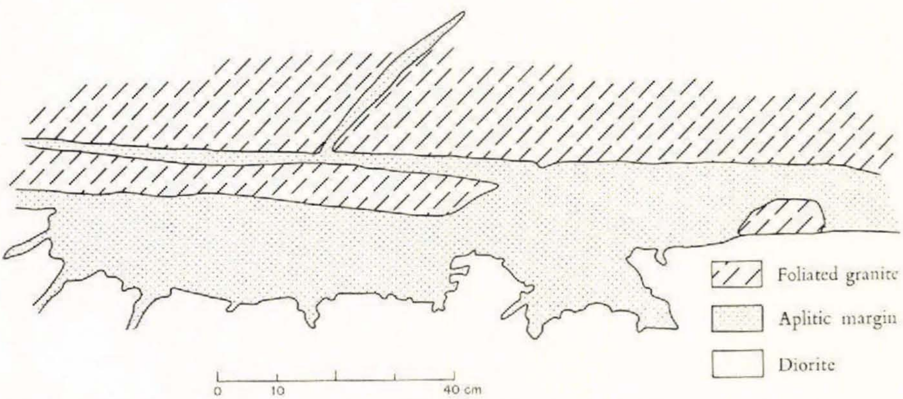

Fig. 8. Upper contact of a net-veined sheet with granitic wall rocks. Straight and parallel-sided apophyses extending into the wall rocks contrast with the sinuous and bulbous veins penetrating the diorite. Island off W. Akia.

plagioclase, quartz and potash feldspar with subsidiary rare biotite and chlorite.

Plagioclase (oligoclase) forms subhedral to anhedral grains which tend to be of the larger grain sizes. They have very irregular, indented grain boundaries, where they have been penetrated and replaced by quartz and microcline. Relict crystals of plagioclase are situated within the microcline and where these minerals are adjacent, separate "islands" of plagioclase within the microcline are in optical continuity with each other and with the adjacent plagioclase. Microcline has anhedral form and strong cross-hatch twinning. Its relationship with the earlier formed plagioclase has been described. Quartz occurs with anhedral shape and with slight to moderate strain shadows. Some grains have undergone partial recrystallisation (polygonisation) into sub-grains. Quartz crystallised after plagioclase as it penetrates along cracks and into the borders of the latter. There is little indication of the relative age between potash feldspar and quartz.

Mafic-bearing layers of the aplite margin

The aplitic margins of some larger bodies are layered, being composed of alternate mafic-bearing and mafic-free aplitic layers (the latter are described above). The mafic-bearing variety is compositionally a hornblende-biotite diorite, consisting of essential plagioclase, biotite and hornblende. There is only a little quartz and complete absence of potash feldspar. Apatite is an abundant accessory and ore and sphene are common. The texture is hypidiomorphic-inequigranular-seriate; the grain size is less than 3 mm. Both texturally and compositionally the rock is similar to the typical diorite itself.

Plagioclase is the dominant constituent forming a network of subhedral, randomly oriented, prismatic grains with extremely irregular margins due to penetrative growth of adjacent grains. Both twinning and zoning are common. Plagioclase is clearly the earliest of the primary constituents and bears evidence of heavy strain. Some grains have partly recrystallised, whilst some areas of plagioclase consist of amoeboid, interpenetrating grains, which represent the final stage in the recrystallisation of the earlier deformed crystals.

Green hornblende and brown biotite occur as subhedral grains in mafic clusters. Some hornblendes have wavy extinction, but biotites are strain-free. There is much evidence that the biotite has grown retrogressively from the hornblende: there are seams of the former along the hornblende cleavages; parts of the hornblendes have been converted to biotite but have the original amphibole crystal form. Some hornblendes have begun to recrystallise into sub-grains with slightly different orien-

Fig. 9. A thin net-veined dyke in which granitic material, concentrated along the margins, has begun to penetrate a central diorite layer. N.E. Akia.

tation and a final stage in this process is seen in the hornblende clusters which consist of a mosaic of small sub-grains, each with slightly different orientation but with almost the same birefringence colours. Some hornblendes of the mosaics have been partly converted to biotite.

Quartz forms rare, anhedral grains in the smaller grain sizes. The crystals are strained with some development of sub-grains.

Net-veins

The most striking feature of these composite diorite bodies is the plexus of net-veins that penetrate the diorite. Very few veins extend from the aplitic margin into the wall rock, therefore it appears that the veins have a preferential affinity for the inner diorite rather than the outer wall rock. This relationship is more obvious when a dyke transects an earlier basic body. The acid veins project inwards into one basic rock but not outwards into the other (fig. 7).

The amount of penetration of the diorite varies in accordance with the size of the body. In the larger sheets veins extend inward for several metres, sometimes tapering out, so leaving the central core of diorite free of veining. In some narrow dykes only thin "fingers" of acid material penetrate a central diorite layer (fig. 9), but in others the veins completely segment the diorite into blocks (fig. 10). These figures demonstrate the progressive segmentation of the central diorite layer. In flat-lying sheets

Fig. 10. A narrow net-veined dyke representing a more advanced stage of fragmentation of the central diorite layer by the marginal granitic material than shown in fig. 9. The granitic material has sharp, discordant contacts with the granitic country rocks. N.E. Akia.

Fig. 11. Net-veining of the diorite showing the characteristic development of pillow-shaped diorite blocks within a plexus of granitic veins. Short granitic protuberances extending from the sheet-veins represent an incipient stage in the development of the net-veins and the formation of the pillows. Island N.E. of Ũmánaq.

Fig. 12. A flat-lying net-veined sheet in granitic country rocks. A narrow, upper, aplitic margin can be seen. The granitic veins in the diorite are in the form of parallel, planar sheet-veins from which cross-connections extend from both sides into the diorite. Akia.

Fig. 11.

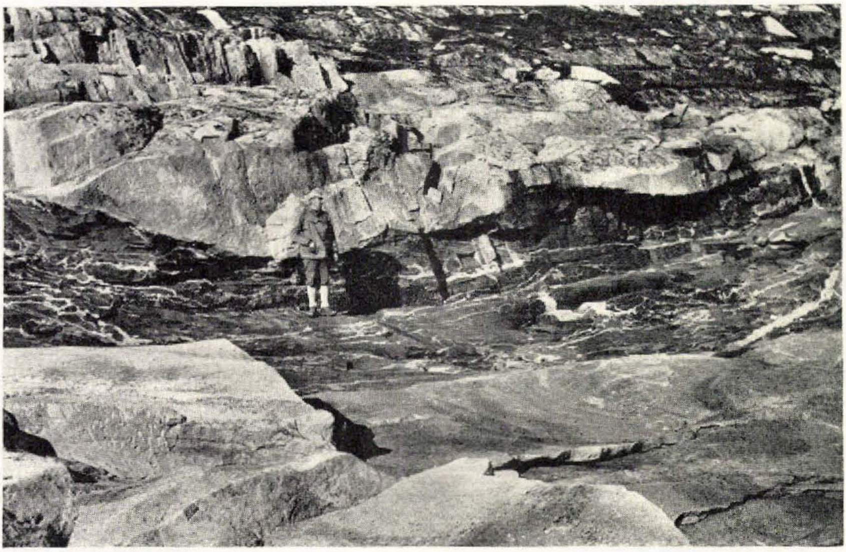

Fig. 12.

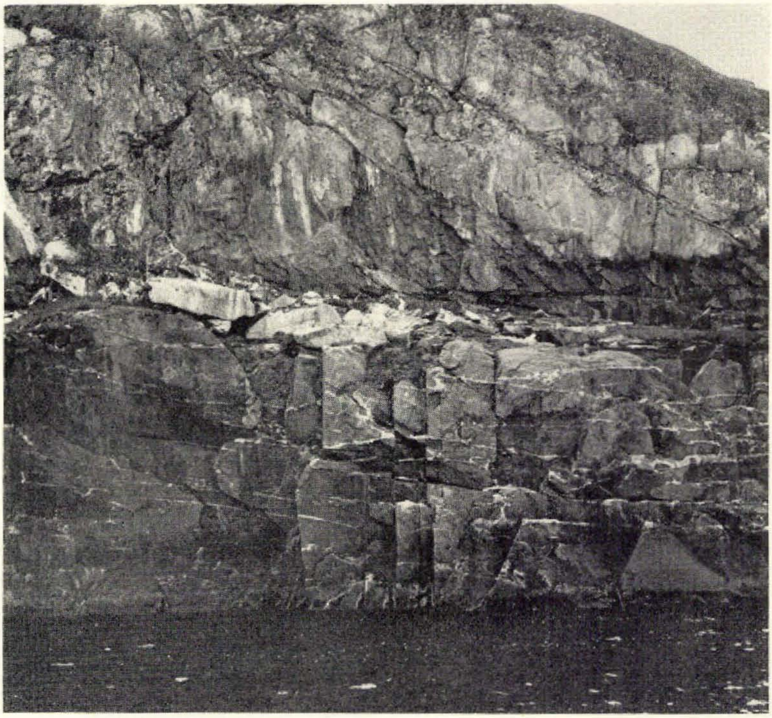

Fig. 13. Upper part of a wide, flat-lying diorite sheet. There is a 1 m wide, white upper aplitic margin just above the centre of the photo. Planar, parallel sheet-veins extend through the diorite parallel to the aplitic margin and contact of the sheet. There are short protuberances and cross-connections extending into the diorite from the sheet-veins. W. Akia.

the veins project as much downwards from the upper margin as upwards from the lower. In vertical dykes the veins extend horizontally.

The veins enclose masses of diorite that are ideally spherical in shape, thus circular forms are observable on all sections. Usually however, elongate "pillow-shaped" forms occur (fig. 11). The pillows are oriented with their longest dimensions parallel to the walls of the body.

Elwell *et al.* (1962) proposed the term "sheet veins" for the subhorizontal sheets of granitic material which lie parallel to the walls of the bodies and "cross-connections" for the short projections which extend from the sheet veins into the diorite on either side. Both of these features are well developed in the net-veined bodies of the Julianehåb district (fig. 12), for which the same terminology will be adopted. Cross-connections from adjacent, parallel sheet-veins join together, so enclosing rounded or pillow-shaped masses of diorite. Fig. 13 shows thin, fingerlike extensions from the sheet-veins which seem to represent the incipient stage in the formation of the cross-connections. Within a small area all

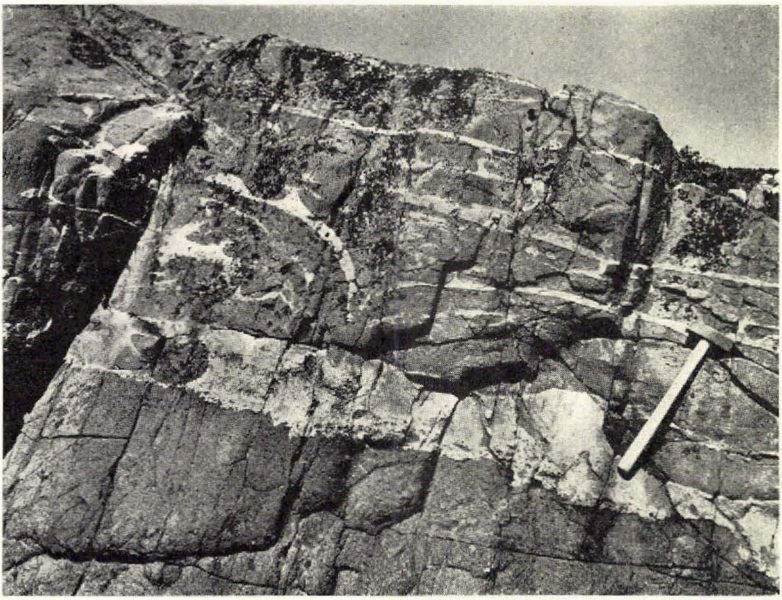

Fig. 14. Parallel granitic sheet-veins cutting diorite. The lowest sheet-vein has a smooth, planar upper surface but an irregular, digitate, lower surface. Island off W. Akia.

stages can frequently be traced in the formation of the pillows from the incipient fingers to the linking together of the cross-connections. The rounded or pillow-shaped framework is the final product in the development of the vein system. Further development appears to take place in the form of widening of the marginal zones and veins.

Where sheet-veins bifurcate or merge with cross-connections, there is generally a thickening of the granitic material at the convergence point (fig. 11).

In the smallest dykes sheet-veins are uncommon, as cross-connections from both margins link together, so dividing the central diorite into rounded segments (figs. 9 and 10).

Both surfaces of the sheet-veins are usually planar. In the flat-lying sheets, however, some have planar upper, but digitate lower surfaces (fig. 14): along the lower part of this sheet there are inclusions of the diorite. This relationship is the reverse of that described by Elwell *et al.* (1962) from the Guernsey net-veined bodies.

Within a body in the Ũmánaq island group an inclusion of foliated amphibolite has been observed and the pillow-shaped masses of diorite decrease progressively in size towards the contact of the inclusion (fig. 15). This is considered to be an important feature, the significance of which will be discussed later. Within the same body adjacent to the lower

Fig. 15. Spherical and pillow-shaped blocks of diorite within a granitic matrix. The large amount of granitic material in this body has cut the diorite into separate blocks, giving the appearance of inclusions of diorite in a body of aplite. This represents an advanced stage of granite penetration from that shown in fig. 11. In the lower part of the photo there is a xenolith of foliated amphibolite. Note that the elongate diorite blocks decrease in size towards the contact of the xenolith. Island off N.E. Ũmánaq.

margin there is a myriad of minute diorite blocks situated interstitially between larger diorite blocks (fig. 16). The smaller blocks are confined to a zone adjacent to the aplite margin; further within the body the included blocks of diorite are mostly of the larger size.

No evidence has been found to suggest flow of the diorite in its marginal zones against the veins. On the other hand, the vein material locally has a preferred orientation. The quartz and feldspar grains are aligned parallel to the walls of the veins.

As they pass further into the larger bodies, the acid veins, fine-grained and leucocratic in the marginal zones, in places become coarser-grained and more rich in mafic material.

The acid material is not always homogeneously distributed between pillow-shaped blocks throughout the bodies. Locally it appears in larger masses occupying considerable volumes of the bodies; within these more extensive granodioritic parts there are relict inclusions of the diorite.

Fig. 16. Spherical and pillow-shaped diorite blocks in granitic material similar to that shown in fig. 15. The lower aplitic margin of this flat-lying sheet is seen at the foot of the photo. There is a myriad of minute diorite blocks situated between larger blocks in a zone which is nearest to the aplite margin. Island off N.E. Ũmánaq.

When considered collectively the bodies display a great variation in their amount of acid veining. At one extreme some bodies have very little veining (only thin aplitic margins and short "finger-like" net-veins) (fig. 6), and some bodies locally have stretches of unveined diorite, where the granitic material has not penetrated. The intermediate and most typical stage is that of the net-veined framework already described, in which the acid veins extend from the margin into the diorite enclosing pillow-shaped blocks of diorite. At the other extreme, some bodies contain a great deal of acid material, and here the diorite appears as inclusions within a body of granodioritic aplite (fig. 15). There are, moreover, all transitional stages in different bodies between these extremes.

Table 1. *Modal analyses of some granitic rocks from net-veined bodies.*

	1	2	3	4	5	6	7
Quartz...........	23.41	30.68	26.94	28.86	33.07	3.18	33.91
Microcline........	21.48	21.73	22.82	25.09	14.87	– – –	10.28
Plagioclase	51.83	44.23	46.37	43.62	48.18	54.67	44.00
Biotite...........	2.31	2.83	2.96	2.14	2.44	21.55	10.28
Hornblende.......	– – –	– – –	– – –	– – –	– – –	16.15	– – –
Accessories	0.96	0.55	0.91	0.30	1.46	4.44	1.54
Total	99.99	100.02	100.00	100.01	100.02	99.99	100.01

1. 57301. Aplite margin. Granodiorite. N. W. Akia
2. 57301. – – – Island off W. Akia
3. 62088. – – – Island between Ūmánaq and Ūmánalik
4. 62305. Net-vein. – S. E. Ūmánaq
5. 62306. – – – S. E. Ūmánaq
6. 62093. Mafic-bearing aplite margin. Diorite. N. E. Ūmánaq
7. 41225. Mafic-rich part of a net-vein. Biotite granodiorite. N. E. Kangeq

All stages can sometimes be traced along the strike of a dyke from a diorite to a granodiorite. The acid material may increase in amount and the size and number of diorite blocks decrease until the dyke consists wholly of granitic material. It is important to note that the width of the dyke is the same throughout, thus a dilatational mechanism of granitic "intrusion" cannot have taken place. Within the final granodiorite dyke there are usually a few inclusions of diorite, and rarely small relicts of the wall rock granite, representing unreplaced inclusions.

The converse situation to that described above is sometimes found. By decrease in the quantity of granitic material some net-veined diorite dykes pass laterally into ordinary diorite dykes. The net-veins decrease in size and extent and the acid margins become narrower, until the dyke consists wholly of diorite.

The texture and composition of the net-veins do not differ significantly from those of the aplitic margins. The veins have a granodioritic composition (see table 1) and a xenomorphic-granular-inequigranular-seriate texture, and are composed of essential plagioclase, microcline and quartz with a trace of biotite. The grain size is less than 2 mm. All grains are irregularly shaped and have sutured boundaries. A microporphyritic texture is apparent in some veins. Plagioclase is commonly replaced by microcline; relict "islands" of the former are in optical continuity with surrounding plagioclases. Larger plagioclases are zoned and have irregular boundaries, having been "nibbled" by adjacent, smaller quartz and feldspars. These are reckoned to be relict phenocrysts from the diorite. Micrographic intergrowths between quartz and either plagioclase or microcline are common. The "sets" of graphic quartz rods spread across several crystals of feldspar, the intergrowth representing a late crystallisation of quartz. Myrmekite is also present, occurring where plagioclase lies adjacent to microcline. Subhedral sphene forms a rare accessory.

The meladiorites, diorites and quartz diorites

Several varieties of diorite form the inner component of the net-veined intrusions. The mafic content varies from body to body with concomitant variation in the plagioclase or quartz content giving rise to quartz diorites, meladiorites or diorites. The hornblende/biotite ratio varies considerably (see table 2). Some types are fine-grained, some are medium- or coarse-grained, some are non-porphyritic, some are plagioclase-phyric; in most there are hornblende aggregates and a few contain hornblende phenocrysts. Most of the bodies are of the fine-grained, non-porphyritic variety of diorite. These compositional varieties are the same as those occurring in the multiple dykes.

Some diorites display a weak to strong directional fabric expressed by the dimentional orientation of matrix hornblende and biotite and by hornblende aggregates; this is interpreted as a primary flow orientation. The oriented matrix grains are commonly deflected by the plagioclase phenocrysts. There are some bodies, however, which are homogeneous with no directional fabric.

There are also inclusions of the country rocks within the diorite of some bodies. The petrographic nature of the inclusions correlates well with that of the adjacent wall rock suggesting local derivation. They are mostly angular blocks of foliated or lineated granite, which are between a few cm and about 3 m long, and which have sharp and planar boundaries. It appears that the net-veins have an affinity for the blocks, as they are invariably surrounded by a sheath of granitic material (fig. 17); thus the inclusions seldom come into contact with the diorite. The inclusions only occur within the net-veined outer zone of the bodies i.e. they are absent from the central diorite zone of the largest bodies. They may occur as isolated blocks or in clusters. Since the granite usually has a penetrative fabric, the orientation of the inclusions can be determined relative to each other and to the nearby wall rocks. This shows that, where they are within the diorite, they have been disoriented relative to the wall rock orientation. Within the aplitic margin of one body, how ever, a cluster of thirteen blocks has been observed and not one of them had been disoriented with respect to each other. Their common orientation is different, however, from that of the wall rock.

As mentioned previously, in a body off W. Akia there is an inclusion of green, migmatised, folded and lineated amphibolite that has come

Fig. 17. Xenolith of lineated reactivated granite within a net-veined diorite body. The xenolith is surrounded by a sheath of aplitic granodiorite, which connects with the net-vein material. Island off W. Akia.

from a nearby 2nd period basic dyke of similar type, which has been cut by this body.

Table 2. *Modal analyses of some basic rocks from net-veined bodies.*

	1	2	3	4	5
Quartz	0.56	---	0.51	9.40	18.48
Microcline	---	---	0.29	0.43	2.70
Plagioclase	15.03	43.16	71.12	54.14	38.76
Biotite	51.13	32.28	18.32	21.72	13.89
Hornblende	32.91	23.82	9.16	7.19	23.87
Accessories	0.38	0.75	0.59	7.13	2.30
Total	100.01	100.01	99.99	100.01	100.00

1. 62104. Mela-diorite. S. W. Ūmánaq
2. 62105. – – S. W. Ūmánaq
3. 62185. Diorite. W. Qilungmiarssuit
4. 62096. Quartz-diorite. Island between Ūmánalik and Ūmánaq
5. 62098. – – N. W. Ūmánaq

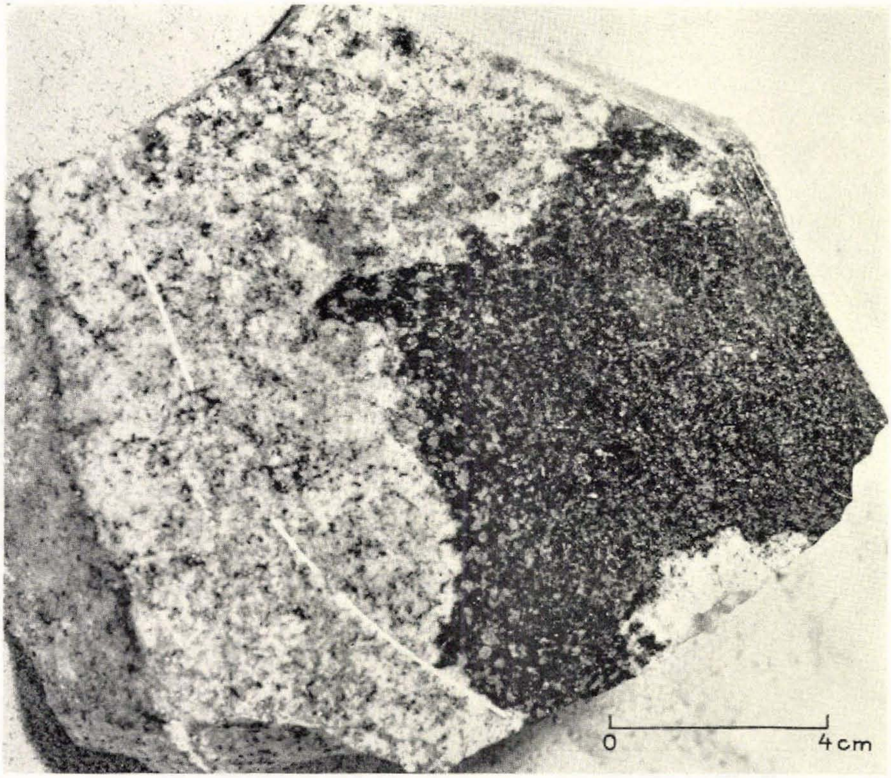

Fig. 18. Contact of diorite with a granitic net-vein. The diorite has a coarse-grained, recrystallised margin in which leucocratic spots with cores of sphene increase in size towards the contact of the net-vein. N. E. Kangeq.

The granitic inclusions do not seem megascopically to have been affected by the granodioritic material. Microscopically they can be seen to have undergone very little alteration. In some no alteration has taken place. However, in others there has been a retrogressive transformation; hornblende and biotite have been entirely replaced by penninite and the plagioclase has been entirely sericitised. Others show an intermediate stage in this alteration.

Modal analyses of the different types of diorite are given in table 2 and of the granodioritic margins and net-veins in table 1. In the meladiorites and diorites the potassium feldspar content does not exceed 3 %. The total mafic content rises to 84 % in the meladiorites with a minimum of 50 %. The quartz content is low, less than 1 % in the meladiorites and diorites and rising to 18 % in the quartzdiorites.

In the leucocratic margins and net-veins (table 1) the microcline content lies between 15 and 25 %, near the limit of one third of the total feldspar content. There is between 20 and 35 % of quartz. The plagioclase content is not significantly different from that in the diorites, but hornblende is absent and biotite does not exceed 3 %.

Some varieties of the diorites approach a granodiorite in composition and the more mafic-bearing layers of the net-veins (fig. 18) and the mafic-bearing layers of the aplite margins approach a diorite in composition. In this way there is a compositional gradation between the meladiorites and diorites and the granodiorite of the margins and veins.

Groundmass

Microscopically the texture is hypidiomorphic-equigranular (grain size less than 0.3 mm), hiatal with respect to the phenocrysts and aggregates. It is composed of essential plagioclase, hornblende and biotite with subsidiary quartz. Pyroxene is entirely absent and potash feldspar is extremely rare. Sphene and apatite are abundant accessories in the diorites of all bodies; there is a little ore.

Plagioclase (olig.-and.)–other than phenocrysts–forms unaltered sub- to anhedral grains with jagged outlines.

Hornblende (pale green to green) and biotite (pale to deep straw brown) occur as short, sub- to anhedral grains. Biotite often interlocks with hornblende but in many cases it replaces it as seams along the hornblende cleavages. In places there are gradational transitions between these minerals and some biotites have grown across hornblende cleavages and twin planes. Quartz is a subsidiary constituent, being entirely absent in the meladiorites. It forms anhedral granules, which sometimes occur in clusters forming an amoeboid mass of quartz. The plagioclases and mafics of the groundmass commonly have a parallel orientation, defining a pilotaxitic texture.

Plagioclase phenocrysts

Most of the meladiorites are porphyritic, the plagioclase phenocrysts (olig.-and.) occurring as subhedral crystals with random orientation, and reaching a maximum length of 7 mm but with an average of 1–2 mm. They are strongly zoned and they commonly deflect the groundmass grains. Some phenocrysts have formed by multiple growth, as they contain cores of partially replaced plagioclase, which are in optical continuity with the outer crystal. Some, moreover, have formed by coalescent growth of smaller plagioclases to form glomeroporphyritic phenocrysts. Euhedral zoning is present, the zones having incorporated all the crystals to form a "composite shell". The individual crystals have irregular, mutual, interpenetrating boundaries which are discordant to the cleavages planes of both grains and they have polysynthetic twin lamellae which do not continue across crystal boundaries. These features are similar to those recorded by VANCE (1957), who considered that they are "compatible only with crystallisation from a magma".

The phenocrysts have been heavily deformed. They commonly have fractures along which partial recrystallisation has taken place to form smaller sub-grains or complete crystals are in places segmented into several parts with slightly different orientations. Twin lamellae are bent and offset by microfractures. The crystals have very indented margins due to penetration by the matrix grains; the mafic matrix minerals have grown along microfaults and along twin lamellae. In a few instances deformed parts of a crystal have become separated and the matrix grains have grown in the space between them. All the phenocrysts have undergone sericitisation, although the degree of alteration is variable in different bodies.

The above mentioned features of the plagioclases–their complex twinning and zoning, fragmental and deformed nature, penetration by the groundmass, and the presence of multiple and coalescent glomero-phenocrysts-indicate that they are in no way porphyroblastic but are true phenocrysts of intratelluric origin, which pre-date the matrix grains.

Hornblende phenocrysts

These are rather sparse, occurring only in rocks with hornblende aggregates. The colour of the mineral is the same as that of the aggregates and in the groundmass. The sub- to anhedral crystals have ragged boundaries, are from 1 to 5 mm long and are strongly poikilitic with respect to quartz and ore. The quartz inclusions and ore granules often define a zoning of the hornblende, as they tend to concentrate in the crystal cores or marginal zones.

Frequently the phenocrysts contain partially replaced cores of hornblende–a situation similar to that already described for the plagioclase multiple phenocrysts. In one crystal three stages of growth have been observed: but, although it appears that the later crystals are replacing the earlier, each hornblende is in optical discontinuity with its antecedent. There were presumably external forces with respect to the crystal, which changed its orientation during growth.

The phenocrysts are usually divided into several sub-grains with almost the same interference colours but with different orientations; this is the first stage of recrystallisation. A more advanced stage is represented by crystals, the external outlines of which are still visible, but which now consist of several, smaller hornblendes with quartz inclusions situated along the intercrystal grain boundaries. It will be argued later that these represent the transitional stages in the formation of the hornblende aggregates.

Aggregates of hornblende

The aggregates are spindle-shaped with an average length of 1–6 mm. By their dimensional orientation they form the principal expression of the penetrative linear structure in the typical diorite. They are composed of short hornblendes, ranging from 0.05–0.3 mm, which are densely packed together with no preferred orientation. The hornblende has the same colour as that already described, is commonly zoned and bears no sign of strain or recrystallisation. The aggregates frequently contain a few quartz grains (averaging 0.1 mm) and ore grains (0.3–0.6 mm).

Biotite forms a subsidiary constituent of all aggregates but is of variable amount in different bodies. The euhedral biotites, 0.3–0.6 mm long, are slightly larger than the hornblendes of the aggregates. They interlock with the hornblendes, but frequently biotite replaces the latter along (110) cleavage planes and intercrystal boundaries. It is common for the aggregates to be rimmed with a sheath of biotite flakes, some of which have grown retrogressively from the hornblende.

The formation of the aggregates post-dates that of the plagioclase phenocrysts, as the aggregates contain inclusions of the latter. The textural appearance of the aggregates conforms with the "synneusis texture" of VOGT (1921) defined by JOHANNSEN (v. 1, 1939, p. 234) as "a texture in which the individual crystals of some mineral swam together in the magma to form groups of aggregates".

Origin of the aggregates

There are two possible mechanisms for the origin of the aggregates:

1. That of JOHANNSEN, mentioned above.
2. Formation by recrystallisation of hornblende phenocrysts.

1. If JOHANNSEN's hypothesis is correct, the aggregates represent accumulated phenocrysts. However, firstly, the unstrained grains of the aggregates are very different from the poikilitic and deformed hornblende phenocrysts. Secondly, if the hornblendes had been compacted together into clusters in an intratelluric stage, one would expect them to show signs of strain in common with the plagioclase phenocrysts. These objections make JOHANNSEN's hypothesis untenable.

2. It has already been shown that the hornblende phenocrysts have partially recrystallised into smaller sub-grains. The final stage of this process is an aggregate of small hornblende prisms. It may be that the aggregates are recrystallised products of earlier deformed mafic phenocrysts (see also MOORE and HOPSON, 1961, p. 250). If recrystallisation were responsible for the formation of the aggregates one would expect the aggregate hornblendes to be less deformed than the plagioclase and hornblende phenocrysts. This is the case. It is suggested that the strained

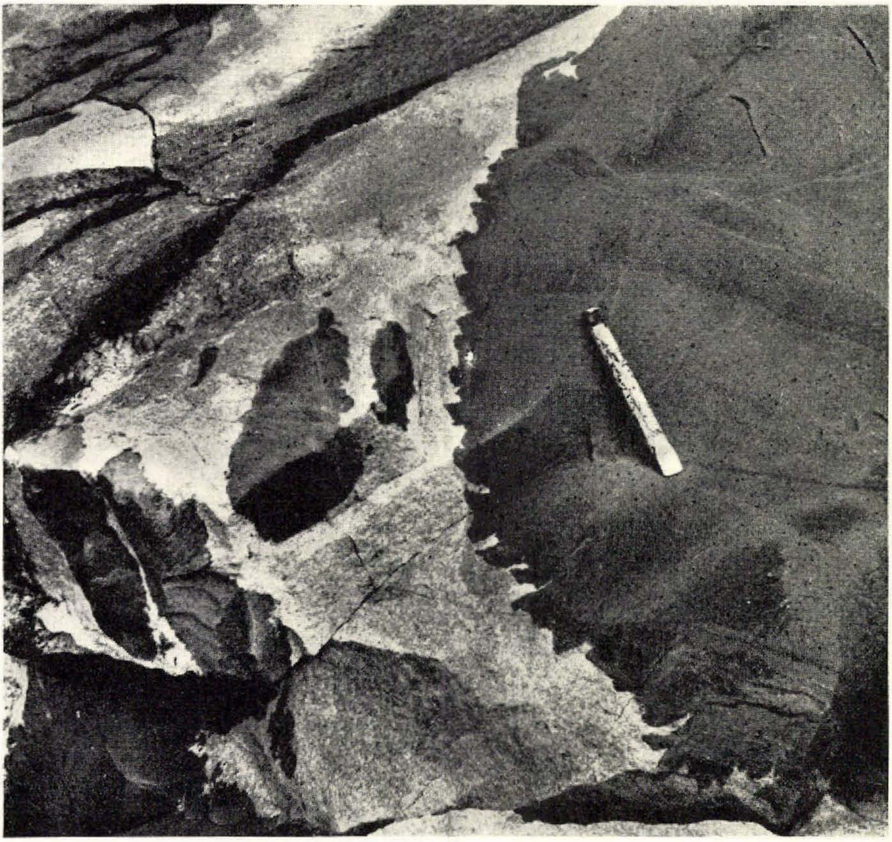

Fig. 19. Detail of diorite blocks in granitic vein material. The largest block has a dentate contact. This is the only dentate contact observed, the diorite blocks normally having smooth and rounded contacts such as those seen to the left. Island off N. E. Ũmánaq.

and partly recrystallised hornblende phenocrysts provide the clue to the origin of the aggregates. If this hypothesis is accepted, the quartz grains and large ore grains within the aggregates are satisfactorily explained as the recrystallised poikilitic quartzes and smaller ore granules from within the pre-existing hornblende phenocrysts. It furthermore follows that the scarcity of hornblende phenocrysts in most bodies indicates widespread recrystallisation of the hornblende.

Contact relations between the diorite and the net-veins

Ordinarily the contact is smooth and planar (or curviplanar), but locally dentate junctions occur (fig. 19). The contact may be parallel or discordant to the linear orientation in the diorite.

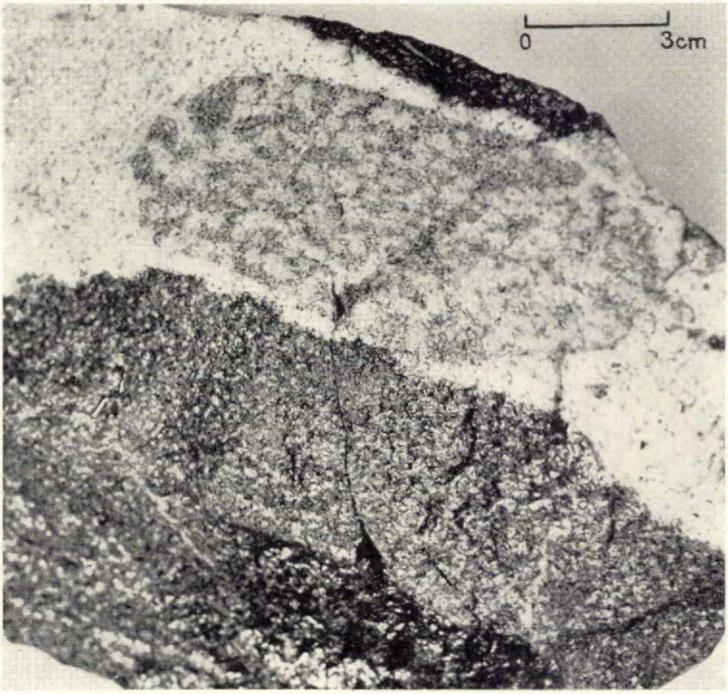

Fig. 20. Within a granitic net-vein there is an inclusion of diorite which has been partly transformed to granite. Within the inclusion there are leucocratic spots some of which have cores of sphene. Within the diorite in the lower part of the specimen there are smaller spots with sphene cores, representing an initial stage in the transformation of the diorite. Island off W. Akia.

A genetically significant, albeit negative, feature of all the bodies is the absence of fine-grained margins in the diorite against the veins. There is no visible change in grain size, texture or composition of the

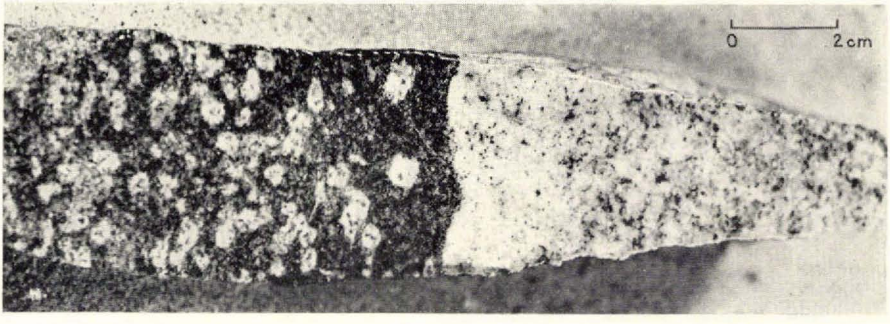

Fig. 21. Contact of diorite with a granitic net-vein. The diorite contains leucocratic spots with cores of sphene which increase in size towards the contact. Within the net-vein there is a leucocratic zone poor in mafic minerals against the contact. N.E. Kangeq.

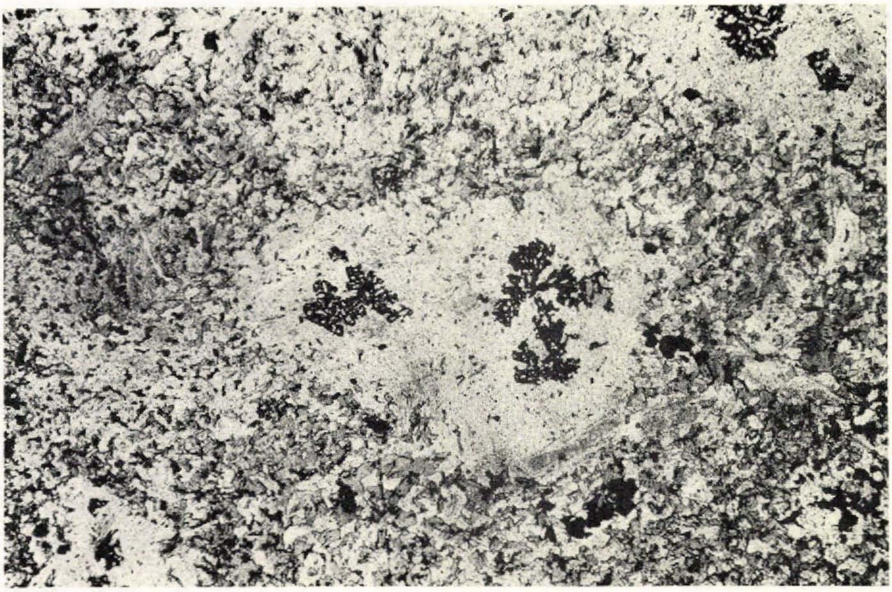

Fig. 22. Photomicrograph of a typical leucocratic spot with a core of skeletal sphene. Within the halo of the spot the chlorite and biotite of the diorite are absent.

diorite, either megascopically or microscopically, in the vicinity of most of the net-veins. No chilled zones have been found in the aplitic vein material against the diorite.

However, along some net-veins there is a recrystallised contact zone. This may be represented by the following mineralogical changes:

a) There is appreciable change in the hornblende/biotite ratio. Both the amount and grain size of the biotite increase towards the contact at the expense of the hornblende, so that at the contact itself the mafic material consists entirely of biotite,
b) In association with this retrogression there is an increase in size of orthite crystals at some contacts,
c) A more conspicuous mineralogical change is presented by the leucocratic "spots" occurring in the diorite adjacent to some net-veins (fig. 18). This spotted contact zone may be up to 30 cm wide. Moreover, some inclusions of diorite within the aplitic margins and net-veins are spotted throughout (fig. 20). Fig. 21 shows that the spots *increase* in size towards the veins. This increase in grain size contrasts with the decrease observed in the chilled margins in net-veined bodies elsewhere. Microscopically a typical spot consists of a core of anhedral to subhedral, skeletal sphene up to 2 mm in size, which is surrounded by a leucocratic rim composed of quartz and feldspar, in which the mafic minerals of the surrounding diorite are absent (fig. 22). This rock

Fig. 23. Handspecimen of a granitic net-vein bearing leucocratic spots with cores of sphene. This represents the final stage in the transformation of the diorite to a granodiorite. A sequence of stages can be followed in this transformation through figures 18, 20 and 23. S.E. Ũmánaq. Natural size.

is similar to the "titanitfleckengesteine" recorded in many parts of the world (Osann, 1923; Fromm, 1943).

d) There is a zone of quartz enrichment in the veins along some contacts. The quartz are in places graphically arranged passing across several feldspars of the granodiorite, indicating that this is a late stage crystallisation of quartz.

The diorite-vein contacts are usually sharp, but along some there is a transitional zone, in which crystals are shared and the rocks merge into each other, so that the line of the contact cannot be accurately defined. In some net-veins there is a transition between the diorite and the granodiorite through a mafic-rich aplite. Where this forms the transition between the sphene-spotted diorite and the granodiorite, it contains the sphene spots (fig. 18). In places the aplitic net-veins, which have only a small amount of mafic material, bear the leucocratic spots (fig. 23). The net-veins commonly contain large crystals of euhedral sphene.

Granite pipes and pods

Granite pipes are present in some net-veined bodies in the Julianehåb district. The pipes extend from, and appear to be a local modification of, the net-veins. They have circular cross-sections with a diameter of between 5 and 10 cm (fig. 24). They are generally parallel, are inclined

Fig. 24. Granitic pipes in the diorite representing a local modification of the net-veins. The pipes with perfectly circular cross-sections are inclined only a little from the vertical. Island off N.W. Ũmánaq. Photo: J. H. ALLAART.

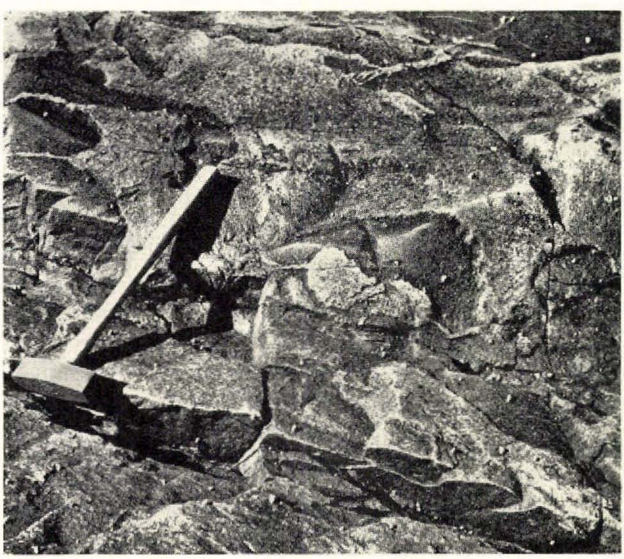

Fig. 25. Net-veined diorite showing a granitic pod (to the right of the hammer handle) connected by thin "strings" to the net-vein material. N.W. Kangeq.

Fig. 26. Granitic pods in diorite. The pods are aligned in a row and one has a remnant granitic "string" which once may have been connected with a net-vein as shown in fig. 25. The pods have spherical or ellipsoidal shapes and do not connect with any other granitic material. N.W. Kangeq.

a little from the true vertical, and in form are cylinders or pipes. Similar granite pipes have been described from net-veined basic rocks in Guernsey (ELWELL *et al.*, 1960) and in Slieve Gullion (ELWELL, 1958).

In some bodies, often in association with the pipes, there are peculiar, bulbous masses of granitic material. These mostly appear as pods which are connected by a thin "arm" to a sheet-vein or cross-connection (fig. 25). In places there are several pods strung together and connected by a thin "string" of granitic material, thus simulating "beads on a string". Some pods are isolated and seem to have become separated from their "mother" vein; these may be aligned in a row (fig. 26). These have a spherical or ellipsoidal shape and are discontinuous, not connecting downward with any net-veins.

Metamorphism

Most of the net-veined bodies are situated in granitic rocks or earlier basic rocks belonging to the amphibolite facies. There is little discernible contact metamorphism by the bodies on these wall rocks. However, BERRANGÉ (in press) has described a body from the south shore of Igaliko Fjord, which has transected an olivine norite pluton. A zone of contact metamorphism was found in the norite, which was downgraded from an olivine-hypersthene-augite-andesine-phlogopite-hornblende assemblage to a hornfels with a biotite-hornblende-plagioclase assemblage.

The transformation of granite inclusions with a plagioclase + hornblende + biotite assemblage to a sericite + penninite assemblage can be ascribed to hydrothermal alteration at a late stage in the cooling history of the bodies.

III. CONCLUSIONS

There are several features which indicate the primary igneous origin of the basic components of the net-veined bodies. The presence of the layering in the multiple dykes is particularly important in this connection, as this directly reflects the original multiple injection of various types of diorite into the same dyke fissures. Later injections locally fragmented and included earlier layers. Furthermore, the feeder dykes to horizontal sheets demonstrate the intrusive nature of the bodies.

The central basic member of the bodies is composed essentially of plagioclase, hornblende and biotite. Only part of the biotite is after hornblende; much of it appears as a primary mineral and it commonly predominates over hornblende. No trace has been found of relict pyroxene or olivine. There are plagioclase and hornblende phenocrysts which are strongly zoned, fragmentary and pre-date the matrix grains. Some glomero-porphyritic types of plagioclase have formed by coalescent growth; similar features have been considered by VANCE (1957, p. 1849) as "a criterion of igneous origin". The matrix grains often have a pilotaxitic texture and are deflected by the plagioclase phenocrysts. This is clearly a primary flow orientation. From the textural evidence it is concluded that the present mineral assemblage largely constitutes a primary diorite assemblage. In this connection it should be remarked that AYRTON and BURRI (1963) have termed these rocks "amphibolites".

Many of the plagioclase and hornblende phenocrysts have been deformed and have undergone partial to complete recrystallisation. A final stage in this process has been the formation of aggregates of hornblende and mosaics of plagioclase grains. Retrogressive crystallisation has taken place; some biotite has formed after hornblende, plagioclase has been sericitised and some biotite and hornblende has been altered to chlorite.

The net-veined diorite bodies were intruded during the Sanerutian plutonic period. It might therefore be expected that movement of the wall rocks took place during their emplacement and crystallisation, thereby causing strain and recrystallisation of the phenocrysts. The retrogressive crystallisation of some of the biotite may have taken place during the waning stages of the Sanerutian period or equally well it may have been caused by autometamorphism or by the penetrating granodioritic net-veins (such a retrogression has been established in the vicinity of some net-veins). There is in other words no evidence that the net-veined bodies were followed by a period of metamorphism or deformation.

With regard to the internal structures of the bodies the following critical features should be noted, from which conclusions of genetic significance can be drawn:

a) In the typical net-veined bodies the net-veins separate rounded or pillow-shaped masses of diorites. Due to the non-congruence of the rounded blocks, they cannot be refitted together to form a complete diorite body. If it is assumed that the diorite was crystalline, the veins cannot have dilated the blocks; the granitic material can only have replaced the diorite.

b) It has been shown that the acid material in some dykes increases laterally in amount, with a concomitant decrease in the number and size of diorite blocks, until a complete granodiorite dyke is produced, which may contain a few relict inclusions of diorite. Conversely, net-veined dykes pass into ordinary diorite dykes by lateral decrease in the quantity of acid material. It is significant that a dyke has the same width both where it is the original diorite dyke and where it has been entirely made over into a granodiorite dyke. This demonstrates that the acid material has transformed the diorite with no resultant dilatation of the dyke.

c) In some bodies there are inclusions of wall rock which are not disoriented with respect to each other. A cluster of thirteen inclusions of lineated granite in one body showed no disorientation showing that they originally belonged to a single block. It is most likely that the granodioritic material of the net-veined body replaced the granitic material originally between the inclusions. It has been shown that within the aplitic margins there are occasionally relict inclusions of partially "granitised" diorite. Clearly the granodioritic material of the margins has partly replaced the diorite. The thirteen wall rock inclusions referred to above have a different orientation from the nearby wall rock granite. Thus it can be established that a large block of wall rock lost its orientation when included in the diorite body. During the formation of the aplite margin the granodiorite material replaced both the diorite and part of the granitic inclusion.

d) In many net-veined bodies described elsewhere (Slieve Gullion, Ardnamurchan, Guernsey, and Maine, U.S.A.) fine-grained margins occur in the basic rock adjacent to the net-veins. These have formed the focal point of interest in the interpretation of the mode of formation of the net-veins. Such "chilled" or "pseudochilled" margins are entirely absent in the bodies of the Julianehåb district.

Although at most contacts there are no textural or compositional changes, at some there are features providing evidence concerning the origin of the net-veins. The diorite-vein contacts provide no features which could be interpreted as a result of the action of an acid magma on a basic magma. The contact features previously described are secondary phenomena resulting from recrystallisation and replacement. The increase in quantity of biotite, orthite and sphene spots towards the contacts is evidence of recrystallisation of the diorite. The sphene spots are a metamorphic segregation feature similar to those recorded by KNILL (1959) from Rosguill, Eire. The interlocking of grains and the blending of rocks across the contacts, and the relict, partly transformed diorite xenoliths within the aplitic margins and net-veins are evidence that the diorite has been replaced by the acid material. In places the net-veins become richer in mafics as they proceed farther into the diorite. This was due to contamination of the granitic material.

A sequence of mineralogical stages can be appreciated in the progressive recrystallisation and replacement of the diorite by the net-veins:—

1) The incipient stage is marked by the recrystallised margins with the leucocratic spots with cores of sphene (fig. 18).
2) Diorite inclusions within the net-veins have been partly transformed into granite and these bear the sphene spots throughout (fig. 20). It is important to note that the sphene spots *increase* in size towards the vein contacts (figs. 18 and 21).
3) Within the net-veins there are mafic-rich areas which contain the sphene spots (fig. 18).
4) The final stage is represented by the aplitic net-veins which have only a little mafic material, but in which the sphene spots are in places still present (fig. 23). Finally the net-veins commonly contain large, euhedral sphene crystals.

Chilled or recrystallised margins are indicative of a temperature difference between the acid and basic materials. On the other hand, widespread absence of these features may suggest a state of equilibrium, the acid and basic parts of the bodies being at approximately the same temperature. However, the formation of local segregation sphene spots and biotite from hornblende indicate that at least in part the diorite was crystalline at the time of the advent of the granitic material. It is difficult to know to what extent this conclusion can be applied to the rest of the diorite, but there is no reason to suspect that it was in a different state. Furthermore, even if this was crystalline, there is no positive evidence to indicate whether it was cold or still hot on the advent of the net-veins. There is, however, some circumstantial evidence bearing on the problem: from the intimate association between the two materials and the preferential veining of the diorite by the granitic material (even when the dykes are situated in similar basic rocks), it can be inferred that the diorite was not completely cold, but rather at an elevated temperature when acid material was introduced, thereby facilitating its penetration and replacement of the diorite.

If the diorite was crystalline but hot on the introduction of the granitic material, the granitic pipes cannot be explained by the gravitative rise of one liquid through another. Rather the formation of the pipes can be best ascribed to density differences between two materials that were largely in a crystalline, mushy state, as suggested by BISHOP (1963). "A dense crystal mush could be capable of penetration by a lighter, more mobile crystal mush from below".

Granitic pods and droplets with attached arms and stringers, similar to those described above, have been produced experimentally by GROUT (1945, p. 263). They were formed by rise of lighter material into a more dense medium.

It is likely that density differences between the acid and basic materials, which were largely in a crystalline, mushy state, were responsible for the formation of the granitic pipes and pods. In summary: from each of the above lines of evidence it has been concluded that the diorite was replaced by the granodioritic material of the net-veined bodies. The sequence of stages in the progressive transformation of the diorite to the granodiorite can be traced both megascopically and microscopically. Granitic penetration took place by a process of recrystallisation and replacement of the diorite. This process proceeded to such an extent in some bodies that the dioritic component forms a minor constituent, and it proceeded to completion in some dykes which have been entirely transformed to granodiorite. The outlines of the original dyke walls have been perfectly preserved, so that it is impossible to distinguish these transformed "secondary" granite dykes from ordinary "primary" granite dykes.

It has been established by a large number of GGU investigators that in the chronology of events in the Julianehåb district there is not a period of reactivation after the intrusion of the net-veined diorites. Indeed the intrusion of the 3rd period basic dykes separates the period of regional reactivation of the Julianehåb granite from the later net-veined diorites. The 3rd period dykes are not veined by any granitic material that could have been caused by reactivation and therefore there is no evidence that the net-veined diorites were followed by any reactivation or granitisation. This makes it impossible for the penetration by the granitic component of the bodies to have been caused by regional migmatisation during a later reactivation period. Moreover, the bodies truncate with sharp contacts the structures of the reactivated granitic host rocks, establishing a clear age relationship.

There is indeed considerable evidence from the bodies themselves which indicates that the granitic material was genetically related to the dioritic component. In whatever rock the bodies are situated – gneisses, amphibolite bodies, Ketilidian or Sanerutian granites – and whatever the attitude or orientation of the bodies, either as dykes or sheets, the aplitic margins and net-veins are constantly present to the same degree and with the same relationships. This is particularly striking when they are situated entirely within amphibolite bodies, which megascopically are hardly distinguishable from the diorites. The aplitic material is present here as much as in those bodies in granitic host rocks and the net-veins penetrate mostly inwards to the diorite and hardly ever outwards to the amphibolite. Altogether the impression is gained that the granitic material is intimately related to the dioritic component. Since the granitic material cannot be derived by external migmatisation from the adjacent host rocks even when the latter are granitic, it can only be concluded that it was genetically connected in some way with the dioritic material. This conclusion differs from that of WEGMANN (1938) and AYRTON and BURRI (1963), who, in the author's opinion confused the net-veined diorites with migmatised basic dykes which are common in the Julianehåb district, and therefore regarded the penetration by the granitic material to be caused by later reactivation. It is considered by the author that there is little or no evidence for this conclusion and it is stressed that the net-veined diorites are composite intrusives, which must be distinguished from basic dykes migmatised by a later period or reactivation or granitisation. There are several ways in which the granitic material might have been derived; differentiation, rheomorphism, anatexis, etc. This question warrants attention. Crystallisation differentiation has long been disregarded as a mechanism for the production of granitic magma from basic magma, excepting in layered plutons and igneous batholiths. The vast quantity of granites and granodiorites and the paucity of gabbros and their deep-seated equivalents in batholiths are incompatible with the principles of fractional crystallisation, according to which a basic magma can only give rise to about 5 % of residual granitic magma (BARTH, 1952, p. 234–7). As the granodioritic material amounts to more than 50 % of many net-veined bodies and in some approaches 100 %, this process will not be considered further.

HARKER (1904) was one of the first who adduced the idea that the acid material of composite intrusions was derived by melting of the country rocks. REYNOLDS (1937 and 1951) demonstrated that the Caledonian Newry granodiorite was rheomorphosed during Tertiary times, causing the net-veining of the dolerites of the Slieve Gullion complex. BAILEY and MCCALLIEN (1956) followed REYNOLDS in the derivation of the granodiorite of Slieve Gullion and BAILEY (1959) ascribed the net-veining of the Tertiary dolerites of the Carlingford Complex to a rheomorphic process. As a result of his review of the problem HOLMES (1931, p. 243) subscribed to "the hypothesis that in acid-basic associations the acid magma is essestially the product of the partial or complete refusion of the granitic rocks locally available".

It is thought that rheomorphism is the most likely mechanism for the derivation of the acid material of the net-veined bodies of the Julianehåb district and there is one piece of evidence which strongly favours this view. The distribution of the bodies conforms fairly accurately to the limits of the Ketilidian granitic rocks that were reactivated during the early Sanerutian. From the map it can be seen that the bodies occur in a roughly west to north-east belt which extends from Qagssimiut to Narssarssuaq, thus their distribution is confined to the area where the Sanerutian reactivation had been most apparent.

The net-veined bodies were intruded during the waning stages of the Sanerutian plutonic period and it can be reasonably assumed that the recently reactivated granitic rocks were still at an elevated temperature when the bodies were intruded. Rheomorphism of cold country rocks is an established process, but an elevated temperature of the wall rocks would greatly facilitate the rheomorphic process giving rise to greater amounts of granitic material. It should be added that there is a precedent to this view: "It is quite possible that the granophyre of Slieve Gullion had not thoroughly cooled before the intrusion of the dolerites, and that this contributed to the remelt effects" (BAILEY and MCCALLIEN, 1956, p. 498). If this effect is possible in high-level, volcanic associations, it is even more likely in deep-seated plutonic environments.

However, remelting of the immediately adjacent granitic wall rocks is out of the question. The aplitic margins and the dyke apophyses transect discordantly the granitic wall rock structures. Also, when the net-veined bodies are situated within earlier amphibolite masses, the aplitic margins are as wide and continuous as when they are outside in granitic host rocks. Therefore it is concluded that the granitic material of the marginal zones was introduced from depth, and rheomorphism-at-depth can be regarded as equivalent to anatexis. It is envisaged that the dioritic magma remelted the granitic rocks at depth and the resulting granitic material followed its parent to higher levels where it was introduced along the walls of the bodies.

A further factor bearing on the mode of formation of the bodies is the constancy in composition of the granodioritic margins and net-veins (table 1) which is particularly striking and requires explanation. The following conclusions can be made: – Firstly, a derivation by differentiation from the original basic magma cannot be accepted. Secondly, it is impossible for a granodioritic magma with a constant composition to be produced by rheomorphism of a variety of granitic country rocks that vary in composition from potassic granites to granodiorites. Therefore, it is concluded that the rheomorphically produced granitic material reacted with the dioritic material to give rise to the granodioritic margins and net-veins. The presence of relic diorite blocks, partly made over to granodiorite and of dioritic patches in the net-veins corroborates this conclusion.

The question now finally arises of the relative roles played by intrusion and replacement in the net-veined bodies. The granitic material, generated rheomorphically at depth, may be regarded as having been in a magmatic state when it was introduced along the walls of the bodies. As it penetrated inwards, this magma interacted with the recently crystallised dioritic material, which was probably still at an elevated temperature, and thus it partly recrystallised and replaced the diorite. It is important to appreciate that magmatic intrusion and metasomatic recrystallisation and replacement are not incompatible in rocks in plutonic environments, as it is here that the two phenomena converge. Thus the granitic material was magmatic in the sense that it was mobile and that it was above its crystallisation temperature, but being in a plutonic environment its cooling was slow with the result that it was able to remain active long enough to recrystallise, react with and replace the diorite.

IV. INTERPRETATION AND DISCUSSION

There have been several hypotheses proposed to explain the origin and mode of emplacement of the net-veins of basic bodies and they differ in particular concerning two questions:

a) The mode of formation of the net-veins.

b) The provenance of the granitic material.

Whatever the mechanism responsible for the formation of the net-veins, the ubiquitous granitic material has more or less obliterated and obscurred the original relationships and therefore the mode of formation of the net-veins is a particularly moot question. It is necessary to take account of the various proposed possibilities and to consider all aspects of the problem before reaching a solution concerning the origin of the net-veined bodies under discussion.

Fluidization

To explain the origin of the net-veined dolerite intrusions of the Slieve Gullion complex, Ireland, REYNOLDS (1954, p. 596) proposed the fluidization process, which accounted for the granitic veins as "products of metasomatic transformation of Caledonian granodiorite emplaced as fluidized systems". CHAPMAN (1962, p. 560) described such a fluidization system as an "intensive flow of volcanic gas carrying sufficient tuff size particles to abrade and gradually wear away the diabase .... Although dilatation of the entire dyke would be nil, much diabase might be stripped away along fractures and the space thereby created filled with acidic tuff" which recrystallised to form the granitic material.

The fluidization process is inadequate for the Julianehåb district bodies for the following reasons:

a) Neither the regular planar walls of the bodies nor those of the granitic inclusions show any signs of abrasion. If the diorite bodies were penetrated by streams of fluidized gas, it would be expected that the walls of the bodies and of the inclusions would have been abraded. The absence of such critical features negates a formation by fluidization.

b) Narrow net-veined dykes can be seen to have formed by a dilatational mechanism by means of intersections with earlier oblique structures.

c) The intricate plexus of net-veins could not have formed by a unidirectional stream of gas. Moreover, the flat-lying attitude of the bodies would necessitate a horizontal flow of gas which is unlikely.

The theory of two contemporaneous magmas

The intimate association of acid and basic materials within the same dyke was recognised by HARKER (1904) from the Tertiary igneous rocks of Skye, N.W. Scotland. RICHEY (1961, p. 59) stated that in the composite cone-sheets the acid magma "intruded itself along the centre of the basic injection before the latter had completely consolidated, or at any rate before it had become cold. The internal contacts between basic and acid portions are therefore unchilled and often one rock merges into the other or else the acid rock is flanked on either side by a hybrid zone formed by its admixture with basic materials". HARKER (1904) was of the opinion that the basic and acid magmas must have coexisted in the magma reservoir from which they were both derived.

The two magma theory was proposed by WELLS (1954) to explain the formation of the Ardnamurchan net-veined ring-dyke. The veining was accordingly formed by the intrusion of an acid residual magma that had separated from its basic parent. "The granophyric material was emplaced in some form essentially at the same time as the main quartz doleritic magma was intruded" (*op. cit.*, p. 302).

The first observation of features regarded as the result of chilling of basic magma by acid magma was made by WAGER and BAILEY (1953) from Slieve Gullion and St. Kilda. "Since the temperature range of crystallisation for basic magma is a hundred or so degrees higher than that for acid magma, it is not unreasonable to postulate chilling of basic magma against the cooler, but still liquid, acid magma" (*op. cit.*, p. 68). Essentially contemporaneous veining of "partially consolidated" basic magma by acid magma was advanced by BAILEY and McCALLIEN (1956 for the net-veined intrusives of the Slieve Gullion complex and by BAILEY (1959) for those of the Carlingford complex, N.E. Ireland.

Simultaneous emplacement of acid and basic lavas was proposed by WILCOX (1944) for the Gardiner River, Tertiary basalt-rhyolite flow and by GIBSON and WALKER (1963) for some composite lavas in E. Iceland.

In 1962 ELWELL *et al.* suggested a variation of the two magma theory. They proposed that a "prolonged blast of gas" split the diorite of the Guernsey complex while it was still hot. Acid magma was then introduced along the sheet-vein fissures and the vein projections were formed by a process of channelling and wedging into the diorite.

Blake, Elwell, Gibson, Skelhorn and Walker (in press) have recently reviewed the information concerning the relationships resulting from the intimate association of acid and basic magmas, mostly from volcanic environments.

There is evidence in the Julianehåb district net-veined bodies to suggest that the simultaneous emplacement of two magmas was not responsible for their formation. The presence of coarse grained recrystallised margins in the diorite pillows against the net-veins demonstrates that the diorite was crystalline when the granitic material was introduced. Although this is a local and rather rare feature, there is no evidence to suggest that the diorite elsewhere was in a different state. The conclusion is made that although there were two magmas, they were not simultaneously emplaced.

The contraction crack theory

Chapman (1962) applied a contraction crack theory to the net-veined diabase dykes of Maine, U.S.A., which in outline is as follows: After solidification the dykes were autometamorphosed. Rapid cooling and contraction of the diabase produced a myriad of pillow-shaped or spheroidal cracks. Subsequently granitic material was introduced metasomatically "in regions of intense fracturing, as, for example, near dyke walls" to form the net-veins, which were widened by recrystallisation and replacement of the diabase.

It should be noted that there is precedence for the view that granitic material entered a system of spheroidal cooling cracks; Smellie (1915) proposed this idea for the net-veined composite sheet at Bute, Scotland and similarly Kahma (1950) for the rheomorphically-veined diabase dyke at Satakunta, Finland.

Evidence in favour of Chapman's cracking theory is shown in fig. 15 in which rounded diorite pillows decrease in size towards the contact of an included amphibolite block, which can be presumed to have been cool when derived and included from the wall rocks. Cooling cracks, formed in the fine-grained contact zone, would be expected to be smaller and more numerous than those further into the diorite. A decrease in size of the pillows might well be expected to result from granitic material penetrating along these cracks.

It is possible that the features shown in fig. 16 were formed in a similar manner. The clusters of small diorite blocks situated between the larger blocks occur only in a zone immediately adjacent to the aplitic margin of the body. A marginal zone of cooling cracks could also have controlled the formation of these features.

CHAPMAN (1962, p. 562) suggested that "more extensive replacement at fracture intersections and junctions gradually transformed more angular blocks .... to rounded or pillow-shaped blocks". Evidence in favour of this is the widening of the granitic veins at convergence points (figs. 5 and 11).

A contraction crack – shear plane theory

For the purposes of genetic classification two types of granitic veins can be distinguished:

a) net-veins occurring throughout dykes as narrow as 30 cm and extending inwards from the aplitic margins of larger bodies,

b) parallel sheet-veins extending through the central parts of bodies.

CHAPMAN's contraction crack theory cannot explain the formation of the parallel sheet-veins and their associated net-veins (cross-connections), although it is applicable to the formation of the net-veins in the marginal parts of bodies and in narrow dykes. Therefore a combined contraction crack–shear plane theory is proposed to explain the formation of the entirety of net-veins in these net-veined bodies, as it is considered important to specify separately the two types of veins.

a) Net-veins in the marginal parts of bodies and in narrow dykes.

Net-veins enclosing pillow-shaped blocks of diorite occur throughout narrow dykes and in the marginal parts of larger bodies. In the wide flat-lying sheets the upper and lower net-veins commonly die out inwards, leaving a central zone of diorite free of veining. CHAPMAN's contraction crack theory satisfactorily explains the formation of these net-veins. It is a reasonable inference that the marginal zones of net-veins reflect the marginal cooling zones with contraction cracks.

Recently the author (in press) has outlined the role of cooling cracks formed at high temperatures in the formation of marginal net-veins. In his study of the cooling of intrusive bodies JAEGER (1961) stated that cooling cracks can form in the recently crystallised material in the marginal zone of an intrusion at a temperature between 600 and 700°C. TOMKEIEFF (1940), from his investigation of the Giant's Gauseway basalts, concluded that the lavas cracked at about 900°C. According to CHAPMAN's contraction crack theory granite veining "proceeded most readily in regions of intense fracturing, as, for example, near dyke walls" (p. 562) when the basic material was almost cold. However, if cooling cracks can form at the high temperatures given by JAEGER and TOMKEIEFF, it is not unreasonable to postulate that granitic material penetrated hot, crystalline basic material along a marginal network of cooling cracks.

In narrow dykes where the rate of cooling and the heat loss were greater, contraction cracks and consequent net-veins extended across the entire dykes.

b) Sheet-veins through the interior of bodies.

Through the inner parts of bodies, which reach up to 40 m in width, there are parallel sheet-veins from which cross-connections extend outwards. Where the cross-connections join together or where they meet cross-connections from neighbouring sheet-veins, the typical pillows are formed.

If the cross-connections were situated in contraction cracks, the latter must have been formed either by the cooling effect of the granitic sheet-veins or by the marginal cooling of the diorite bodies.

The cooling effect of the thin, acid sheet-veins could not have been sufficient to cause the formation of extensive cooling cracks, and thus the cross-connections extending from the sheet-veins are not likely to be situated in a pre-existing crack network.

Some bodies have 20 or more parallel sheet-veins. It is unlikely for the marginal cooling of the diorite to have given rise to so many parallel fractures throughout the central parts of the bodies. Such an abundance of parallel fractures is not common in recently cooled basic dykes or sills. Therefore it is concluded that the formation of the sheet-veins and their associated net-veins was controlled by some mechanism other than contraction cracking.

The presence of planar sheet-veins that occur as parallel layers throughout the bodies necessitates the prior existence of a system of parallel fractures. The granitic veins that occur along the junctions of the layers in the multiple dykes described in section II simulate the sheet-veins and it is clear here that their presence was controlled by the planes of inhomogeneity and weakness between the layers. However, there is no evidence suggesting the presence of layering in the remainder (the majority) of net-veined diorite bodies. Thus it is necessary to postulate the existence of a system of parallel, planar fractures into which the granitic material was introduced. There is evidence that some of the net-veined diorites were subjected to a minor phase of deformation during their formation—oblique and sigmoidal (curviplanar) foliation, boudinaged aplite veins and folded net-veins. Moreover, evidence has been presented demonstrating that the plagioclase and hornblende phenocrysts were strained and consequently recrystallised to mosaics and aggregates of subgrains. It is suggested that this minor phase of deformation was responsible for the formation of the sheet-vein fractures.

It is envisaged that the bodies were sheared and thus the crystalline diorite was split along parallel fractures into which granitic material was later introduced. Since these are composite intrusions, there was only a short time interval between the emplacement of the acid and basic magmas and therefore it may be that the emplacement of the granitic magma was associated with and may have been responsible for the compression and shearing of the dioritic material.

Cross-connections commonly extend from the sheet-veins. It is likely that there were sufficient irregularities and fractures in the diorite on either side of the parallel sheet-veins following the shearing to allow penetration by the granitic material to form the cross-connections.

c) Discussion.

So far, for the purposes of the contraction crack theory, it has been assumed from the evidence of the recrystallised margins that the diorite was crystalline when the granitic material entered. Nevertheless, it is possible that some of the diorite was only partially consolidated at that time.

It is striking that all the net-veined bodies recently described from Ardnamurchan, Slieve Gullion, Guernsey and Maine are characterised by the presence of pillow-shaped blocks of basic material within a plexus of net-veins. It is also significant that many, if not the majority, of the investigators of these bodies – WELLS, BAILEY and McCALLIEN, ELWELL, SKELHORN and DRYSDALL – came to the conclusions firstly that the basic material was able to crack when its crystallisation was not far advanced, and secondly that the granite entered when the basic material was still hot. CHAPMAN (1962, p. 563) also stated that "if replacement followed closely the solidification of the diabase, the dike may have been slightly hotter than the gabbro" wall rock. Furthermore, it is interesting that granitic pipes, agreed by the investigators to have resulted from gravity differences between two materials either in a liquid or mushy state, are associated with the granite veins in most of the described net-veined bodies. It appears therefore that the problem of net-veined basic intrusives is the problem of the association of acid magma with a basic body which was in an intermediate state between full liquidity and complete solidification. The dioritic material in the bodies under discussion appears to have been in a more crystalline state than most of the examples described.

A stage intermediate between liquid and solid may be represented by a crystal mush. The cooling basic material reaches a point when it is "sufficiently crystallised to behave in many respects as a solid – weak and mushy, but solid in that crystals in contact offer resistance to shearing stresses" (EMMONS, 1940, p. 2), the transmission of which are necessary for the formation of contraction cracks and shear planes.

The relationships between two intruded magmas will depend on the state of the basic when the acid was introduced. This in turn will depend on the nature of the country rocks, the size of the body, the distance from the centre of granitic activity, and the relative time of emplacement of the two magmas. Thus some basic bodies may have reached a more advanced state of crystallisation than others by the time the acid magma was introduced.

In particular, there can be a considerable difference in time between the emplacement of the two magmas in different bodies and in different areas. The granitic material in composite intrusions can be introduced almost simultaneously with the basic material (WELLS, 1954), or it can be introduced a short time (ELWELL *et al.*, 1962) or a long time (CHAPMAN, 1962) after the basic material was intruded. It is likely, moreover, that even within any one region, such as the Julianehåb district, in which bodies in a variety of attitudes are situated in a variety of host rocks and in an area approximately 100 km across, the introduction of the two magmas was diachronous; that is, some bodies of diorite had reached different stages of crystallisation from others on the advent of the granitic material.

With these considerations in mind, the significance of many of the anomalous features and contradictory conclusions from the bodies under discussion can be more easily appreciated: – the local presence of recrystallised margins indicates that the diorite had reached a crystalline state; the presence of granitic pipes suggests that the diorite was in a mushy state; the presence in flat-lying sheets of a wider, upper aplitic margin can be best ascribed to the rise of lighter acid material (WELLS, 1954); in some sheets the lower margin is the wider (fig. 7); sheet-veins with upper digitate surfaces have been interpreted by ELWELL *et al.* (1962) as due to the rise of lighter acid material; however, there are some sheet-veins with digitate lower and planar upper surfaces (fig. 14). The conclusion is made, therefore, that the Julianehåb district bodies of diorite were largely in a crystalline state, but in places still in a semi-crystalline mushy state, at the time of entry of the acid material. Only this conclusion can account for all the features described.

The problems of correlation

On the whole there has been good agreement amongst GGU investigators concerning the recognition and correlation of the net-veined diorite intrusives of the Julianehåb district. Particular mention must be made of J. Allaart, J. Berrangé, S. Watt, H. Scharbert, E. Breval, D. Bridgwater and S. Andersen, to each of whom the author is grateful for permission to describe the net-veined diorites comprehensively.

The bodies in Ayrton's ground near Qagssimiut (Ayrton and Burri, 1963) have proved difficult to correlate, because the 3rd period basic dykes are absent in this area, thereby making it difficult to distinguish between migmatised 2nd period basic dykes and net-veined diorites.

In S. Greenland there are a few remaining, scattered net-veined basic intrusives. Watterson (personal communication) and Ayrton (personal communication) have reported the presence of some net-veined bodies in areas to the S. E. and N. W. of Søndre Sermilik fjord respectively. These appear to have undergone some late deformation. It should be remembered that the multiple dykes on Ũmánaq have been subjected to late movements. If the bodies from these areas are the same age as those of the Julianehåb district, it can be presumed that the late movement phase increased in intensity towards the E. and S. E.

Correlation of the Julianehåb district net-veined bodies is difficult in the area north of Narssarssuaq, where there are two types of diorites (Walton, in press):

a) The net-veined bodies of the Julianehåb district may be represented north of Narssarssuaq by dioritic intrusions, which are net-veined by acid material derived from the wall rock granites during their reactivation. These diorites, which texturally are quite different from those of the Julianehåb district net-veined bodies, are roughly equivalent in age to the 2nd period basic dykes.

b) The Julianehåb district net-veined bodies may be equivalent to some diorites north of Narssarssuaq which post-date the above-mentioned reactivated granite. The diorites are equivalent in age and texturally identical to the net-veined bodies of the Julianehåb district. However these diorites are not veined by acid material.

Although it is difficult to make an unequivocal correlation, it appears more likely that the second unveined diorites are equivalent to the net-veined diorites of the Julianehåb district. It is these that have been marked on the enclosed map. This means that the acid veining did not take place in this area. This however is not difficult to envisage, since throughout the Julianehåb district several net-veined dykes have been seen to pass along their strike into ordinary diorite dykes by means of a lateral decrease in the amount of acid material.

Some interesting bodies have been described by Dawes (personal communication) from the Tasiussaq area, near Nanortalik. These are distinctive in having fine-grained margins in the doleritic material

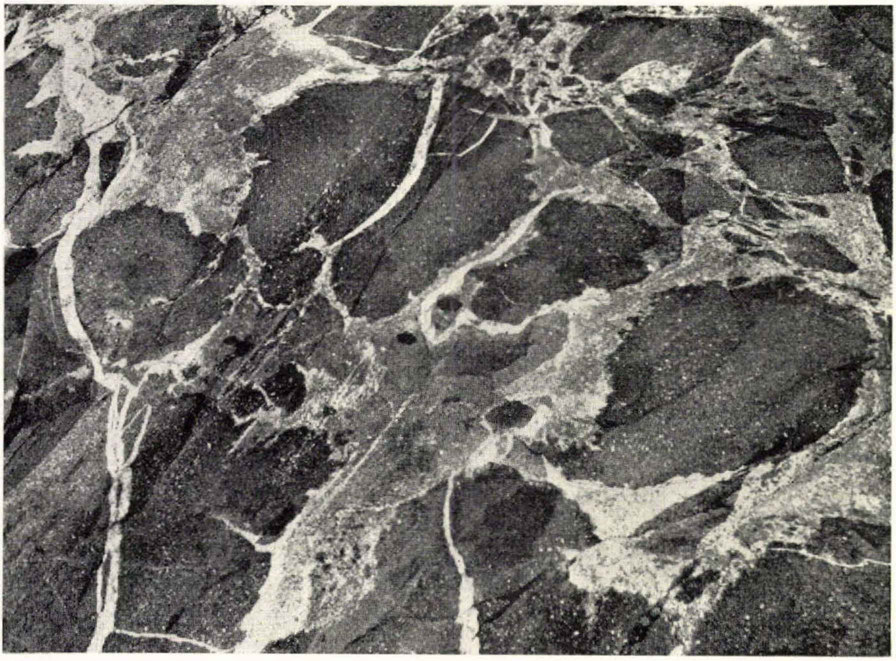

Fig. 27. 2nd period amphibolite dyke that has been migmatised during the later Sanerutian period of reactivation. The presence of rounded and pillow-shaped basic blocks simulates that in the net-veined diorites. Island S.W. of Pârdlît. Photo: J. H. Allaart.

adjacent to the net-veins. Since the presence of the fine-grained margins implies slightly different conditions of formation from those in the Julianehåb district and since they are situated about 80 km to the south, they have been excluded from the present account.

Convergence phenomena

In high-level, volcanic environments it is easy to appreciate the significance of the acid veining of composite net-veined bodies, the acid material being assigned either to a magmatic or a rheomorphic origin. In those in deep-seated, plutonic environments, however, the acid material may be confused with the granitic veins caused by granitisation and migmatisation during a later plutonic period. In S. Greenland the 2nd period basic dykes were penetrated by granitic veins during the Sanerutian period. Although the rounded, pillow-shaped veins characteristic of the net-veined bodies are generally easy to distinguish from the more irregular, anastomising veins of the migmatised basic bodies, it is quite likely that there is a point when the two appear similar. In this way WEGMANN (1938) confused the composite net-veined bodies with the migmatised basic bodies of the Julianehåb district. Fig. 27 is of a migmatised basic dyke, the veining of which appears similar to that in the net-veined bodies.

ESCHER (in press) has described from the Nanortalik area some basic dykes almost completely replaced by granitic material during a later period of reactivation. The original dyke walls are entirely preserved in the resultant granitic dykes, thus this is a type of "internal migmatisation" similar to that operating in the net-veined diorite dykes. However it is more common for "external migmatisation" of basic dykes to take place during later periods of reactivation or granitisation, when the penetrative granitic material is derived from the immediately adjacent country rocks.

SUMMARY OF CONCLUSIONS

The following conclusions have been made concerning the mode of formation of the net-veined diorite intrusives of the Julianehåb district:

1) Rheomorphism-at-depth of granitic rocks, occasioned by the passage of dioritic magma, gave rise to granitic magma which followed its parent to higher levels.
2) The granitic material was introduced along the walls of the bodies from where it penetrated inwards through a network of contraction cracks in the diorite. It was also introduced through the central parts of bodies along a system of parallel, planar fractures formed by shearing and compression of the diorite possibly in connection with the emplacement of the granitic material.
3) The formation of the aplitic granodiorite veins took place by a process of reaction of this granitic material with the diorite and consequent replacement of the latter while it was largely in a crystalline state. In places, however, it was still in a semi-crystalline, mushy state when the granitic material was introduced.

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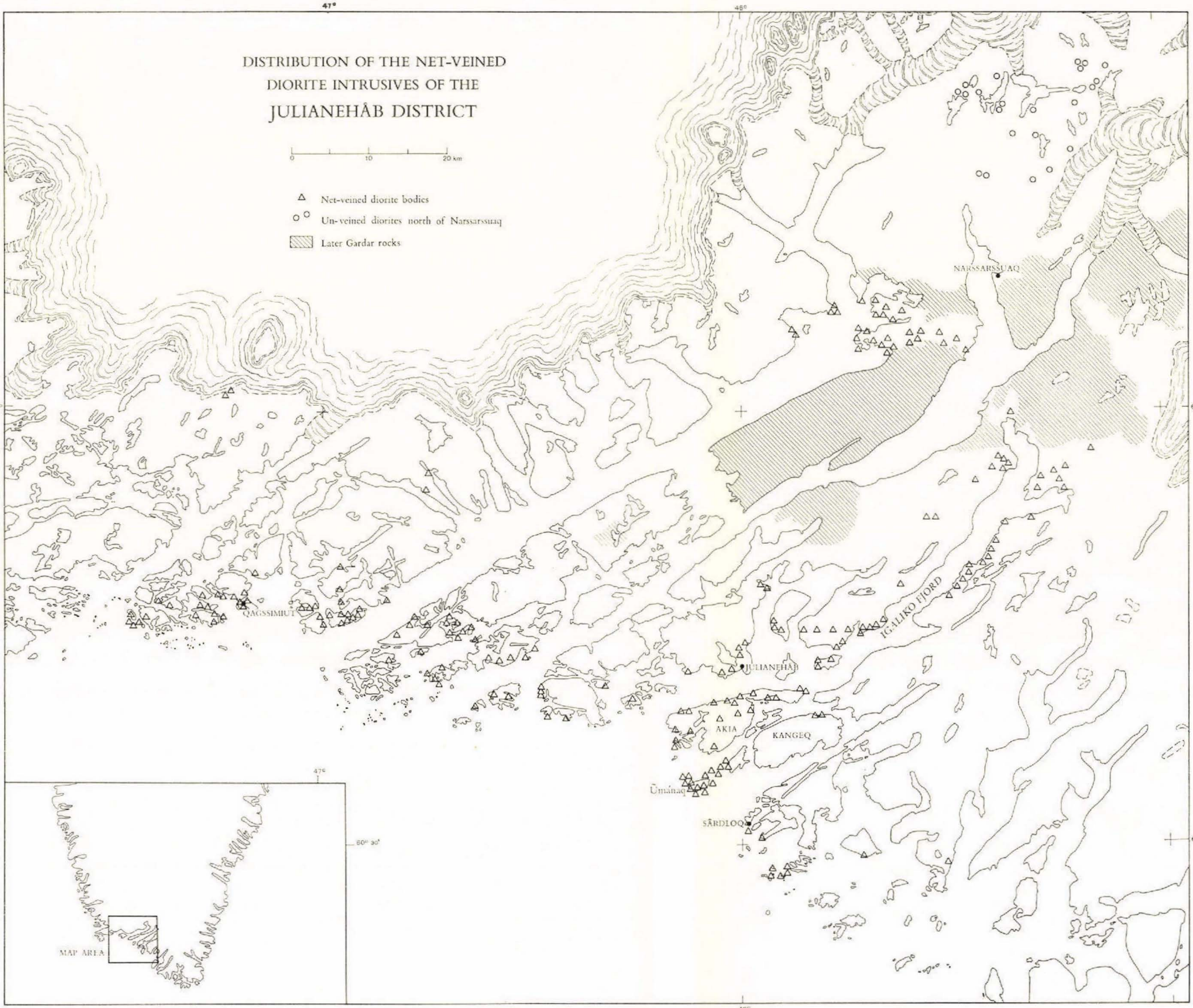
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46°
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DISTRIBUTION OF THE NET-VEINED
DIORITE INTRUSIVES OF THE
JULIANEHÅB DISTRICT
0
10
20 km
Net-veined diorite bodies
Un-veined diorites north of Narssarssuaq
Later Gardar rocks
NARSSARSSUAQ
QAGSSIMIUT
IGALIKO FJORD
JULIANEHÅB
AKIA
KANGEQ
Ũmánaq
SÂRDLOQ
47°
60° 30'
MAP AREA