GRØNLANDS GEOLOGISKE UNDERSØGELSE
BULLETIN No. 83

THE PETROGRAPHY AND ORIGIN OF GNEISSES, AMPHIBOLITES AND MIGMATITES IN THE QASIGIALIK AREA, SOUTH-WEST GREENLAND

BY

FEIKO KALSBEEK

WITH 18 FIGURES IN THE TEXT, 10 TABLES
AND 5 PLATES

KØBENHAVN
BIANCO LUNOS BOGTRYKKERI A/S
1970

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Abstract

The migmatites from a small area (approx. 200 km^2) in SW Greenland are described with special attention to the modal composition of the different rock types.

After a general introduction a description of the field relationships of the rocks is given. The leucosome of the migmatites consists of leucocratic veins which mostly have a quartz-dioritic to granodioritic composition; a typical melanosome has rarely been found. The paleosome consists of banded biotite gneisses, hornblende-biotite gneisses and amphibolites. In subordinate quantities occur anorthositic gneisses and garnet-rich gneisses and amphibolites. Spread throughout the area, homogeneous biotite gneisses occur, which locally form large masses, but generally occur as minor outcrops full of inclusions of banded gneisses and amphibolites. These homogeneous gneisses are generally hardly migmatized.

The different rock types are petrographically described. Histograms of measured An contents of plagioclase in the different rocks are given. It is shown from a large number of modal analyses that there is a gradual change in plagioclase and quartz content from the banded biotite gneisses via the hornblende-biotite gneisses to the amphibolites (in part). Some of the amphibolites do not fit into this pattern, these amphibolites are also in other respects different from the others, among others through the presence of garnet and/or diopside.

The homogeneous biotite gneisses may have a granodioritic composition, but the majority of the samples contain hardly any alkali feldspar and agree in modal composition with the banded biotite gneisses, but for a slightly higher amount of biotite in the latter. The leucocratic veins also have often a quartz-dioritic composition which agrees with most of the gneisses, but with a much lower content of dark minerals.

The paper is concluded with a discussion of the origin of the different rock types, based on the data collected. Most of the rocks are thought to be formed by isochemical metamorphism of geosynclinal sediments. The banded biotite gneisses probably represent original sediments of greywacke to arkose type. Part of the amphibolites probably represent original basic volcanic and tuffaceous rocks, which may have undergone erosion, transport and sedimentation. The hornblende-biotite gneisses are thought to derive from mixtures of normal sediment with varying amounts of tuffaceous material. Alternative interpretations of the gneisses and amphibolites are discussed.

The homogeneous gneisses may have formed from the metasediments by a process of homogenization and mobilization.

The origin of the leucocratic veins is discussed. The mineralogical composition of the veins and the An content of the plagioclase seem to exclude an origin by anatexis in situ of the gneisses, but the evidence is not conclusive.

CONTENTS

I. INTRODUCTION

During the summers of 1963 and 1964 the writer mapped an area of approx. 200 km² situated some 50 km SSE of Frederikshåb in South-West Greenland. This mapping formed part of the systematic mapping of South-West Greenland at present being undertaken by the Geological Survey of Greenland (Grønlands Geologiske Undersøgelse, GGU), and the writer is grateful to the Director of this Survey, K. ELLITSGAARD-RASMUSSEN, for permission to publish this paper.

The main part of the area consists of strongly deformed and migmatized gneisses and amphibolites, cut by large numbers of basic dykes. In an earlier paper (KALSBEEK, 1967 a) the writer described the complex pattern of folding found in the migmatites. In this paper a petrographic analysis of the rocks is given.

1.1. Geological setting of the area, outline of the main rock types, and aims of the investigation

The major part of SW Greenland consists of granites and gneisses which have undergone a long and complex geological history (ALLAART, BRIDGWATER and HENRIKSEN, in press). At a number of localities these rocks are discordantly overlain by low-metamorphic sediments and volcanic rocks of the Ketilidian geosyncline. Radiometric age determinations indicate ages of approx. 2500 m.y. for the 'basement' rocks, and an age of approx. 1750–1650 m.y. for the rocks belonging to the Ketilidian sequence (LARSEN and MØLLER, 1968; JØRGENSEN, 1968). Below the Ketilidian discordance low-metamorphic rocks have also been found for which a supracrustal origin is evident (HIGGINS and BONDESEN, 1966). These have been referred to as the Tartoq Group. The relationship between the rocks of the Tartoq Group (mainly metavolcanics) and the gneisses etc. are not clear. Locally the two are separated by a 'migmatite front', locally by thrust planes. The age of the rocks of the Tartoq Group is as yet not known.

Although a large number of papers dealing with the geology of SW Greenland have come forth as a consequence of the systematic mapping carried out by the Geological Survey of Greenland, petrographical descriptions of the gneisses and associated rocks are scarce, and numerical

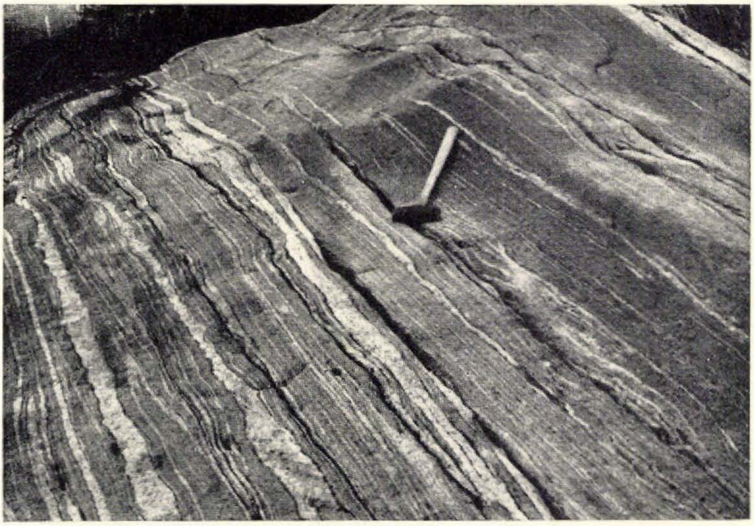

Fig. 1. Banded gneiss with concordant leucocratic veins. Note the narrow dark border zones of the veins. Locality: 66.2–171.3[1]).

data, for example on the mineralogical composition of these rocks, are almost completely lacking.

The first aim of the investigation described in this paper was to contribute to the petrographical knowledge of the gneisses, the amphibolites and a few other rock types, especially concerning their mineralogical composition. It was hoped that a better knowledge of the rocks in question would give some indication as to their origin, as will be discussed below.

In the investigated area different types of migmatites occur, grading between regularly banded gneisses, in which the leucocratic material occurs as concordant bands (fig. 1), and strongly veined to agmatitic gneisses and amphibolites in which most of the leucocratic material is present as discordant veins (fig. 2).

Apart from the leucocratic veins, the most important rock types in the area are biotite gneisses, hornblende-biotite gneisses and amphibolites, which, generally, form the dark component of the migmatites. Often these rock types occur together in the same outcrop interbanded with each other.

In the field one gets the impression that there is lithologically a gradational transition from the biotite gneisses via hornblende-biotite gneisses with increasing hornblende content to the amphibolites; *i.e.* in the different outcrops (and often in one outcrop) one can find bands of different hornblende content, and it is easy to make a collection of

[1]) Localities are indicated in coordinates according to the kilometre grid shown on the Greenland 1:20000 topographical maps (see plate 5).

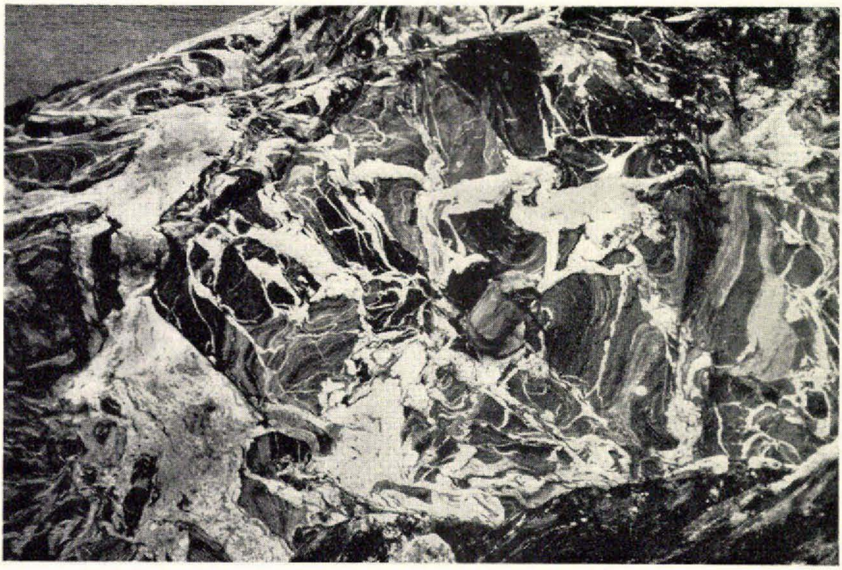

Fig. 2. Agmatitic gneisses and amphibolites, typical for large parts of the area. The banding of the gneisses and amphibolites is clearly visible. The rucksack in the centre gives an impression of the size of the outcrop. Locality: 62.4–178.4.

hornblende-biotite gneisses bridging the gap between the biotite gneisses and the amphibolites. It should be noted that, where the hornblende-biotite gneisses are interbanded with biotite gneisses and amphibolites, the boundaries between the different bands are as a rule sharp and do not show gradational transitions.

The author has earlier (Kalsbeek, 1962, 1965) investigated gneisses and amphibolites in part of the Belledonne Massif (French Alps) which in many respects resemble the rocks to be described in this paper. Since the conclusions arrived at for the Belledonne rocks have been used as a working hypothesis during the investigations reported in this paper, these conclusions will be discussed shortly below:

> Most of the gneisses from the Belledonne area have the chemical composition of greywackes and contain well-rounded accessory zircons. They are interpreted as having been derived from greywackes through isochemical metamorphism.
>
> The amphibolites in the Belledonne area have the chemical characteristics of basic igneous rocks. The field occurrence of the rocks however—they are banded and often interlayered on a fine scale with gneisses—and their content of well-rounded zircon grains indicate a sedimentary origin. The author has concluded that the amphibolites derived from disintegrated, transported and redeposited basaltic lavas and/or tuffs, mixed during the transport with a

certain amount of the normal greywacke sediment (to explain the zircons). In fact, the average chemical composition of the analyzed Belledonne amphibolites agrees very well with a mixture of 80 % of average basalt and 20 % of average greywacke.

The hornblende-biotite gneisses in the Belledonne area were not investigated in detail, since they occur only in subordinate amounts, but it seemed obvious that they also derived from mixtures of greywacke with basaltic material, but with a smaller amount of the basaltic component.

One of the aims of the investigation reported in this paper was to test whether the same hypothesis can be applied to the gneisses and amphibolites from the area the writer mapped in SW Greenland. In this case the banded biotite gneisses should be regarded as the equivalent of the original normal sediments, and the hornblende-biotite gneisses as mixtures of this sediment with basic tuffogeneous (or eroded lava) material.

As said before, biotite gneisses occur often as bands in the banded gneisses. In such cases one is inclined to interpret the rocks provisionally as paragneisses. In parts of the area, however, biotite gneisses (which generally are rather leucocratic) form fairly homogeneous, almost granitic looking masses, in which locally amphibolites and (hornblende-) biotite gneisses are enclosed as angular blocks. In this way beautiful agmatitic rocks can develop locally. The biotite gneisses from these homogeneous masses can not, in hand specimen, easily be distinguished from the biotite gneisses which occur elsewhere interbanded with hornblende-biotite gneisses and amphibolites. Also in the field the two types of biotite gneiss grade into each other. Large outcrops of homogeneous gneiss grade via inclusion-rich zones into banded gneisses, and one is often in doubt whether to regard an occurrence of biotite gneiss as part of the homogeneous gneiss or as a band in the banded gneisses.

Part of the investigation described in this paper is devoted to a comparison between the two types of biotite gneisses.

Finally, a number of leucocratic veins were studied to test the hypothesis that these rocks originated by local anatexis (VON PLATEN, 1965, WINKLER, 1967) of the gneisses encountered in the area.

1.2. Comments of the technique and reliability of the modal analyses; sampling procedure

The modal analyses made of a number of samples were carried out with a Swift point-counter. In most cases a point-counter analysis was made of two thin sections of the same hand specimen. Generally 800 points were counted in a thin section, but in those cases where only one thin section of a hand specimen was analysed, mostly 1000 points were taken. The points were spread as much as possible over the whole thin section.

Since the grain-size of the rocks does not permit the direct calculation of the accuracy of the point-counter analysis (VAN DER PLAS and TOBI, 1965), the counting was performed in groups of 50 points. For every group of 50 points, the number of points falling in quartz etc. were noted, *e.g.* 20, 24, 18, 21, . . . From the average of these numbers the (estimated) percentage of quartz etc. in the rock was calculated, and from the standard deviation of the numbers the (estimated) accuracy of the determination of the quartz content etc. was determined.

The accuracy of a point-counter analysis depends, among others, on the grain-size of the rock. The grain-size can conveniently be characterized by the 'number of points per crystal' found during the point counting. If during point counting one has to count 135 points to hit 100 crystals, the number of points per crystal is 1.35.

If now we wish to obtain a certain accuracy for a point-counter analysis, and VAN DER PLAS and TOBI's nomogram shows that, for example, 800 non-correlated points will give the desired accuracy, one has to count 800 points, multiplied by the number of points per crystal. For a rock with 1.35 points per crystal this will be 1080 points. During the counting of these 1080 points, 800 different crystals will have been hit, and therefore 800 non-correlated observations will have been made.

In the tables with the results of the point-counter analyses the number of points per crystal and the number of points counted are indicated for the rocks listed. With the help of these two values, the diagram of fig. 3 will give an estimate of the accuracy of the point-counter results. It can be shown that the accuracies calculated directly (see above) fit well with those obtained with the help of the diagram of fig. 3.

Of almost every thin section on which a point-counter analysis was made the two halves were counted separately and the results were compared. For example, if in one thin section 800 points were counted, 8×50 points were counted in one half of the slide and 8×50 in the other half. In this way one gets 8 different estimates for the amounts of the different minerals present in both sides, and this permits to test the homogeneity of the rock in thin section. A statistical test, WILCOXON's two-sample test, was used to see whether, for example, the quartz content in the one half of the thin section was significantly different from that in the other half. In 36 % of the thin sections inhomogeneity was found for one or more minerals. In a number of cases the inhomogeneity of the thin section is evident at a glance, e.g. through the presence of bands of a different colour, but in many cases the test revealed inhomogeneities that were not at first evident.

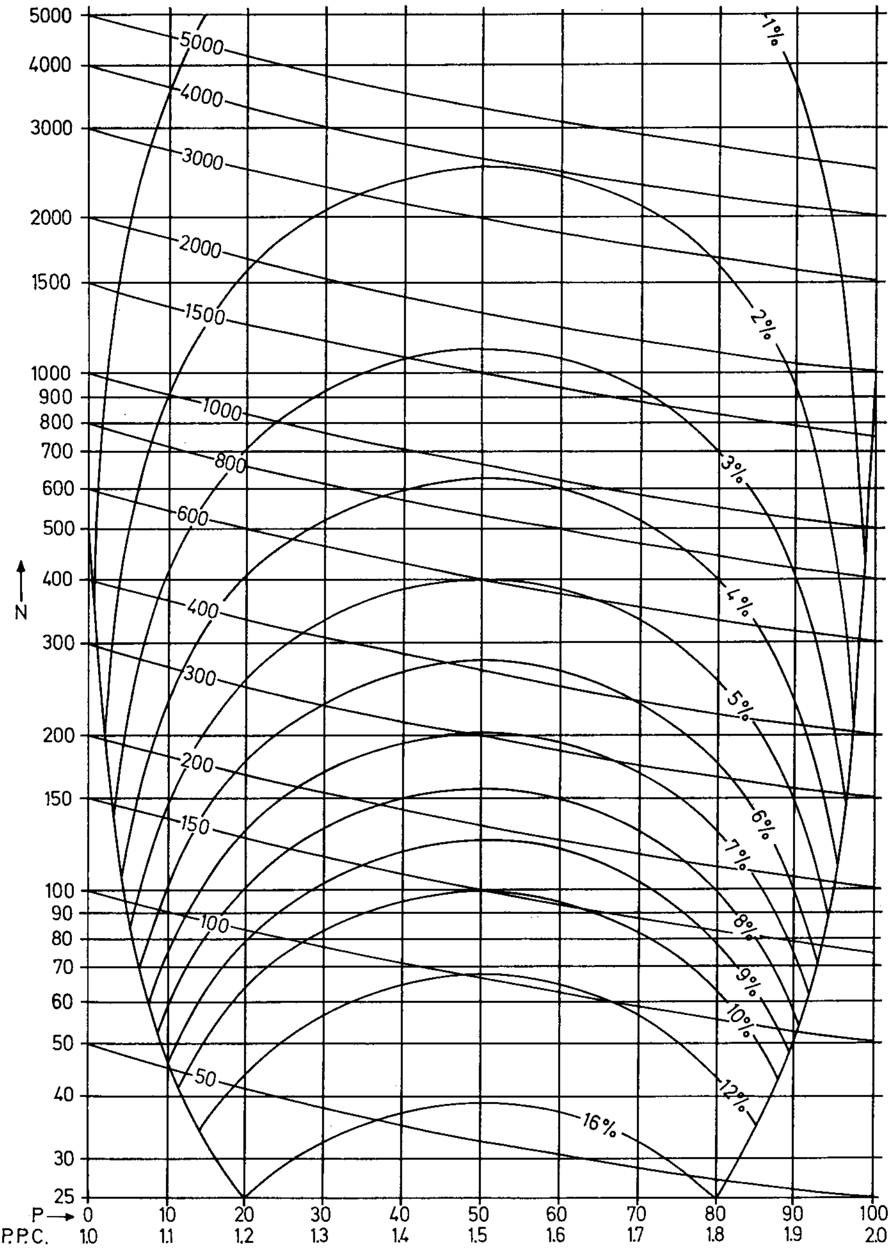

Fig. 3. Nomogram for estimating the maximum error (in 95 out of 100 cases) for point-counter results. The nomogram is composed of the chart of VAN DER PLAS and TOBI (1965) with superposed curves to show the influence of the grain size of the rocks. Example: For a rock with 1.3 points per crystal and a count of 600 points, the number of non-correlated points will be approx. 450. If 25 % of the points fell on quartz, the rock very probably contains 25 ± 4 % quartz. If 12 % of the points fell on hornblende, the rock very probably contains 12 ± 3 % hornblende. The nomogram is only valid for homogeneous rocks.

In those cases where two or more thin sections were counted of one hand specimen, it was tested with the standard statistical formulae whether significant differences were present. In 67 % of the cases two thin sections out of one sample had significantly different contents of one or more of the minerals. Again, in a number of cases the inhomogeneity of the specimen was obvious, but in many instances the inhomogeneity was only brought out by the point-counting.

It seems reasonable to conclude that the point-counter analyses give correct results (within certain limits of error) for the thin sections counted, but not necessarily for the samples from which the slides were made. Therefore, in a number of the diagrams which show the results of the point-counter analyses (section 4) the thin section, and not the specimen, was used as the unit to be plotted.

Another important point to be discussed is whether the point-counter results obtained for the rock samples are valid for the different rock types in the area. In order to obtain useful estimates for example of the average quartz content in a gneiss, the frequency distribution of hornblende in some amphibolites, etc., it is of utmost importance that the samples to be investigated are chosen in a statistically correct way. In homogeneous rocks (*e.g.* granites) random sampling schemes can be used, but in such very inhomogeneous rocks as migmatites it is hardly possible to devise a sampling scheme that is both satisfying from a statistical point of view and technically feasible (one of the limiting factors is the number of samples one can carry in a rucksack). The writer has not solved the sampling problem. The samples taken in the field are (subjectively) supposed to be representative for the rock types sampled. This has to be remembered in evaluating the results of the modal analyses. Some of the results probably are affected by the unsatisfactory sampling procedure, others probably are not. When discussing the results of the point-counter analyses (section 4) an attempt will be made to evaluate in several cases the influence of any bias during the sampling.

2. FIELD RELATIONSHIPS OF THE MAIN ROCK TYPES

2.1. Migmatites

Most of the area consists of strongly folded and migmatized gneisses and amphibolites. The degree of migmatization (here defined as the amount of leucocratic veins) varies from place to place. Locally one is dealing with regularly banded gneisses where the leucocratic material occurs as concordant veins and is of restricted importance. In other places up to 50 % of the total rock is made up of leucocratic veins, most of which cut discordantly through the foliation of the gneisses and amphibolites.

The different types of migmatites can only be mapped schematically. In the field they grade into each other, and it is impossible to map boundaries between 'banded' gneisses and 'veined' or 'agmatitic' gneisses (the terms 'banded', 'veined' etc. gneisses have been adopted from BERTHELSEN, 1960). As a rule, deformation and degree of migmatization seem to be related. Strong folding in the gneisses etc. occurs mostly in those parts of the area where migmatization was intense. Regular structures are more common in the 'banded' gneisses. There seems also to be a tendency that the hornblende-rich gneisses and amphibolites are more strongly migmatized than the more leucocratic gneisses. Migmatization and folding are intense in the central and western parts of the area. Here the rocks often make a very chaotic impression. In the eastern, and locally in the south-western part of the area, the rocks are less intensely migmatized and they show more regular structures.

The migmatites as a whole are often complex. In many outcrops several generations of leucocratic veins can be discerned. The banded gneisses (and amphibolites) often contain thin leucocratic bands that follow the isoclinal folds in the gneisses and seem to belong to the gneisses proper. These thin concordant leucocratic veins seem not to be related to the (later) large scale migmatization. Of the younger, discordant veins some are clearly tectonized, showing a foliation and a coarse lineation, locally they have been folded. Other veins seem not to be affected by tectonic forces. Intersections of veins are common (see fig. 4). Concordant veins are generally cut by discordant veins, but also discordant veins

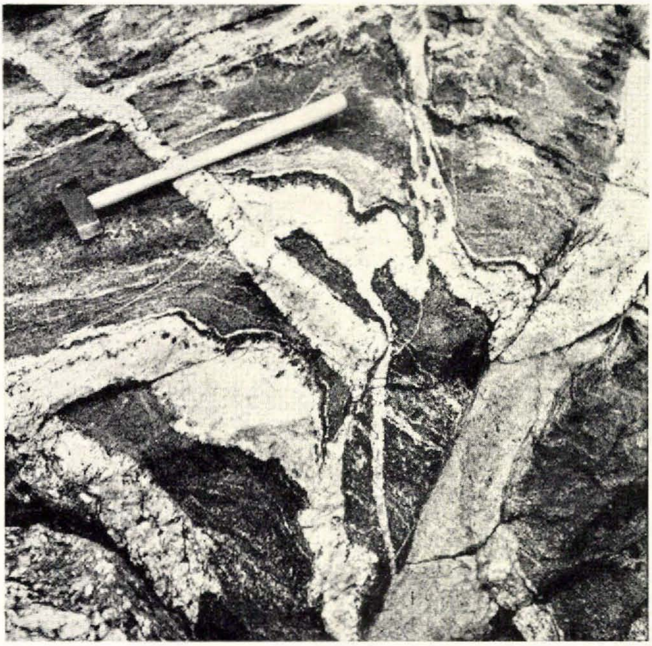

Fig. 4. Intersecting leucocratic veins in the migmatites. Veins of three ages can be recognized. The different veins have roughly the same mineralogical composition (see p. 35). Locality: 66.3–175.7

often intersect. Even intersections of strongly tectonized veins have been found. Samples of the different generations of pegmatites have been investigated, but no petrographical differences have been found (see p. 35). In a paper on the pattern of folding in the area (KALSBEEK, 1967 a) the author has suggested that the large scale migmatization of the rocks was more or less contemporaneous with one of the folding phases that affected the rocks. This would explain why some of the veins are strongly tectonized and others hardly or not.

Some of the leucocratic veins are clearly intrusive. An instructive example is given in fig. 5, which shows a large boulder of a gneiss dissected by leucocratic veins. Evidently the different pieces of dark gneiss fitted together before the pegmatitic material was intruded. Also fig. 6 gives an example of a dilatational leucocratic vein. In most cases, however, the writer has been unable to find evidence to show the mode of emplacement of the leucocratic veins. Since many leucocratic veins have been tectonized after their emplacement it is not surprising that most of the evidence has been destroyed. It is important to note that the clearly intrusive veins deviate from most of the leucocratic veins in that they contain albite, whereas the veins in general contain oligoclase or andesine. This means that the intrusive nature of these veins probably does not

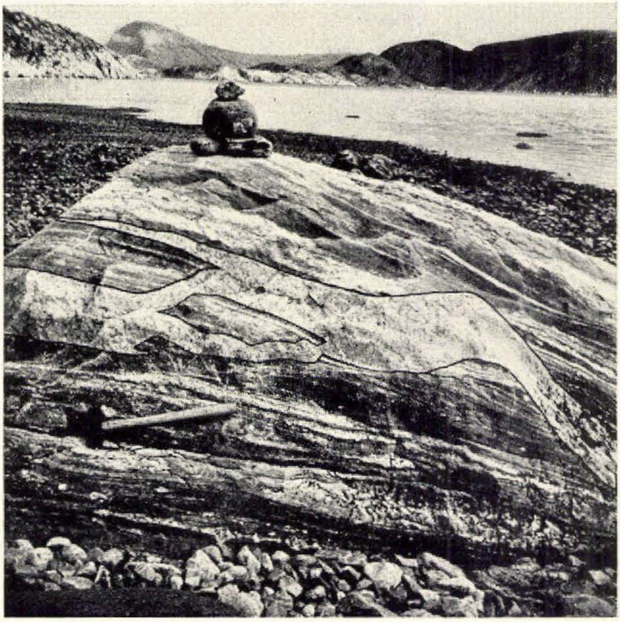

Fig. 5. Dilatational leucocratic vein in banded gneiss (The boundaries of the white veins have been accentuated on the photograph). Loose block at 50.2–175.6.

Fig. 6. Dilatational leucocratic vein in banded amphibolite. The amphibolite contains older concordant leucocratic bands. Loose block at 50.2–175.6.

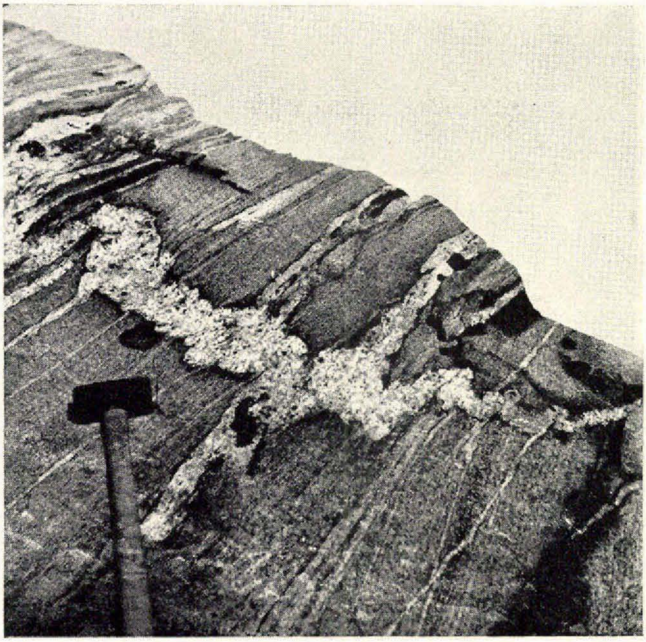

Fig. 7. Concordant and discordant leucocratic veins in banded gneisses. The concordant veins run without visible boundaries into the discordant veins; both have narrow dark rims. Locality: 66.2–171.3.

have any significance regarding the mode of emplacement of the majority of the leucocratic veins.

Almost without exceptions the boundaries between the leucocratic veins and the gneisses and amphibolites are sharp. Generally the dark rock does not visibly change in composition near the contact with the veins. Exceptions are sometimes found in the 'banded gneisses', where locally dark rims occur on both sides of the concordant white veins. This might indicate that (part of) the leucocratic material derived locally, leaving the dark material behind. Sometimes these concordant veins run into discordant veins with irregular boundaries, which seemingly consist of the same rock type (fig. 7). There are no visible boundaries between the leucocratic rock in the concordant and in the discordant veins. Also the discordant veins may have dark rims. A possible explanation of these features might be that the concordant veins originated by a process of exudation and that the more or less mobile felsic mass was pressed out into the discordant veins. One gets, however, the strong impression that the surplus of dark material in the dark rims of the veins is insufficient by far to balance the deficit within the veins.

As a rule the leucocratic veins consist of a medium-grained rock of quartz-dioritic to granodioritic composition. The grain size of the rock is generally of the order of $^1/_2$–1 cm. Rarely coarser grained veins, with crystals up to several cm in size, have been found. The leucocratic rock may contain some biotite or hornblende, but it is often almost devoid of dark minerals; locally a few grains of allanite or garnet have been found in the leucocratic veins, but typical pegmatite minerals do not seem to occur.

In a few outcrops very thin (several cm) young 'pegmatitic' veins have been found that cut through all the other rocks including the leucocratic veins of the migmatites. These veins consist of albite, quartz and subordinate microcline and may contain fairly large crystals of muscovite and beryl. It is possible that these veins are related with the clearly intrusive veins shown in figures 5 and 6.

2.2. Gneisses and amphibolites

The gneissic part of the migmatites (the paleosome) consists mostly of hornblende-biotite gneisses, which grade into amphibolites when the amount of hornblende increases and to biotite gneisses where the hornblende disappears. In the 'banded gneisses' the paleosome occurs as bands in between the concordant leucocratic veins; in the 'veined' and 'agmatitic gneisses' it occurs mostly as lenticular to angular blocks. There are no evident petrographic differences between the gneisses where they are weakly migmatized and where they are strongly migmatized. The angular blocks in the agmatitic gneisses consist mainly of the same hornblende-biotite gneisses that are found elsewhere hardly migmatized. One gets strongly the impression that the paleosome was hardly affected by the migmatization, *i.e.* that, when studying the gneissic part of the migmatites, one gets an insight into at least some of the properties (*e.g.* composition) of the rocks before they were migmatized.

The gneisses are generally clearly banded on all scales. This banding is often accentuated by the occurrence of thin pegmatitic bands. Amphibolite bands and thicker amphibolite horizons are of common occurrence within the hornblende-biotite gneisses. Attempts have been made to map such horizons, but this proved to be impossible. Firstly, the strong migmatization of the rocks makes such mapping difficult, and, secondly, the amphibolites mostly occur together with dark hornblende-biotite gneisses which are difficult to distinguish from the amphibolites proper. Under such circumstances mapping of thick homogeneous amphibolitic bands would probably still have been possible, but marker horizons of this kind do seemingly not occur in the area. The thinner (several metres, locally up to several tens of metres) amphibolitic bands, which are common, could not be followed over long distances. Often they proved to be discontinuous.

2.3. Homogeneous biotite gneisses (the 'white gneisses')

At many places throughout the area leucocratic homogeneous gneisses occur, which, during the field work, were called 'white gneisses' to distinguish them from the banded 'grey gneisses' (hornblende-biotite gneisses and biotite gneisses). The largest outcrops of these homogeneous gneisses have been indicated with I and II in the sketch map of plate 5. Locally the homogeneous gneisses contain numerous angular inclusions of amphibolite and grey gneiss, which moreover often are veined with leucocratic material which seemingly is identical with the white gneiss in which the inclusions swim.

In the western part of the area a several hundreds of metres thick band of leucocratic biotite gneiss can be followed as a 'stratigraphic' horizon for some 5 km. It is possible that the westernmost of the two large outcrops of white gneiss (I) is a comparable concordant mass, lying in the centre of a dome structure, but the evidence is not conclusive. For the easternmost of the large outcrops (II) there is no evidence that it is a more or less stratigraphically defined mass.

The large outcrops of white gneiss grade through wide inclusion-rich zones into banded gneisses. Often one finds in the transition zone white and grey gneisses interbanded, and since, moreover, lithologically there is little difference between the biotite gneisses from the banded rocks, and the biotite gneisses from the homogeneous masses, one is often in doubt how to classify a biotite gneiss. Generally the biotite gneisses from the banded rocks are somewhat darker than the homogeneous gneisses and show also in hand specimen a slight banding, but gneisses which are transitional between the two types are by no means rare, and during the field work the writer has often been unable to map the white gneisses.

Outside the two large outcrops mentioned above, the white gneisses do not form more or less well defined areas, but they are spread throughout large parts of the area as minor masses, full of inclusions of banded gneiss and amphibolite. This is especially the case along the central part of the north coast of the peninsula mapped. Here often only some 30 % of the terrain consists of homogeneous white gneiss and 70 % of bands and masses of strongly veined grey gneisses and amphibolites. Fig. 8 shows a large amphibolite inclusion in a homogeneous white gneiss. In this case part of the inclusion is rimmed by pegmatitic material. The writer does not know why. This feature has been observed on several localities but it is not common.

White gneisses, or at least rocks looking like white gneiss, have also been found locally as discordant dykes within grey gneiss or amphibolite. The dykes are generally in the order of 1–2 m thick.

Fig. 8. Banded amphibolite enclosed in homogeneous white gneiss. The inclusion is rimmed by pegmatitic material. Locality: 51.4–175.6.

The white gneisses are commonly hardly migmatized. They may contain leucocratic (pegmatitic) veins, but not nearly in the same amounts as the grey gneisses and amphibolites.

2.4. Other rock types

2.4.1. Anorthositic gneisses

On a number of small islands and on a small peninsula in the extreme western part of the area, leucocratic gneisses with anorthositic composition occur. Locally these gneisses are nearly pure plagioclase rocks, but often they contain varying amounts of hornblende and sometimes they even grade into dark amphibolitic rocks. These gneisses are generally clearly foliated and an indistinct banding is locally present. In one locality farther E (locality 62.8–172.0) lenticular inclusions of anorthositic gneiss occur in hornblende-biotite gneiss (fig. 9).

It has not been possible to study the contact relationships between the anorthositic gneisses and the other gneisses, since the anorthositic rocks only occur isolated on a number of islands, and on a peninsula where they have a fault contact with the other rocks.

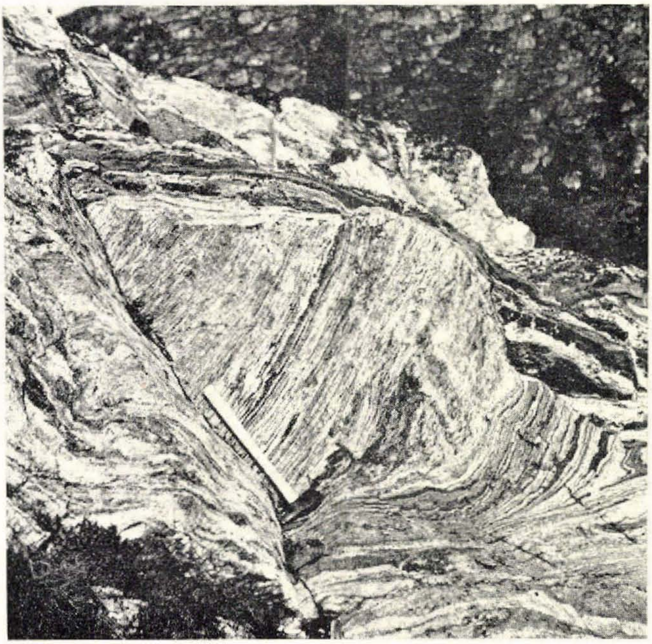

Fig. 9. Lense of anorthositic gneiss in banded gneiss and amphibolite. Locality: 62.8–172.0.

Comparable rocks occur in many localities in SW Greenland (BERTHELSEN, 1961, p. 332). They go under the name of 'gabbro-anorthosites'.

2.4.2. Garnet-rich gneisses and associated garnet amphibolites

In the extreme north-western part of the area a thick band of garnet amphibolites is found, which can be followed for several km over a number of islands, and which contains a number of lenses of ultramafic rock. Within these garnet amphibolites layers of very garnet-rich gneiss occur. These gneisses may have a bright red colour. They are often clearly striped, and consist mainly of garnet and quartz with subordinate amounts of plagioclase, hornblende and diopside.

Also elsewhere in the area garnet amphibolites have been found. As a result of the irregular and complex pattern of folding (KALSBEEK, 1967 a) it is impossible to prove or disprove that these occurrences could be stratigraphically related to the thick band of garnet amphibolite in the NW part of the area.

2.4.3. Ultramafic rocks

Scattered throughout the area lenses of ultramafic rock occur. Generally they are less than 10 m in length. The longest found has a length of at least 200 m. At several localities such ultramafic lenses lie in a row, which sometimes can be followed for several km along the strike of the foliation in the neighbouring gneisses and amphibolites.

Sometimes the ultramafic rock is so fresh that it has preserved large quantities of olivine. Often, however, they consist completely of secondary minerals such as actinolite/tremolite, talc or serpentine.

The ultramafic rocks are generally associated with amphibolites, *e.g.* the garnet amphibolites mentioned in the foregoing section contain many ultramafic lenses.

A few examples of ultramafic rocks cut by pegmatitic veins have been found. Locally, complex reaction zones between the ultramafic rock and the leucocratic veins have been observed (see section 3.5).

3. DESCRIPTION OF THE MAIN ROCK TYPES

In this chapter the main rock types will be briefly described. Some aspects of the quantitative investigations will be described in the next chapter.

Of the different rock types mentioned in chapter 2, the homogeneous biotite gneisses (white gneisses), the banded biotite gneisses and the hornblende-biotite gneisses have petrographically much in common. In many aspects the amphibolites (in part) and the pegmatitic veins resemble the gneisses. For these reasons the gneisses will be treated together in one section (3.1) and part of the information on the amphibolites and the leucocratic veins is incorporated in the section on the gneisses. Of course, differences between the different rock types will be emphasized.

In the sections 3.2 and 3.3 respectively the amphibolites and the garnet-rich gneisses and amphibolites will be described. The two rock groups have a number of features in common and it is therefore appropriate to describe them in two successive sections.

In section 3.4 the anorthositic gneisses will be described, and in section 3.5 the different types of ultramafic rocks. In section 3.6 a description is given of the leucocratic veins.

As a backbone for the descriptions, lists of the mineral contents of the different rock types are shown. The writer has devoted considerable time to prepare these tables, but still it is possible that in some cases accessories have been overlooked. Moreover, the tables are based on the study of thin sections (often one section of a sample was available) and, as every petrographer knows, it is not always certain that every mineral present in the sample occurs also in the thin section.

The tables showing the mineral contents of the various rocks are presented in the appendix. The chapter is concluded with a section (3.7) on the conditions of metamorphism of the rocks.

3.1. The gneisses

3.1.1. Mineralogical composition

Tables I a, b, II, III and V (see appendix) give the mineralogical composition of a number of gneiss samples. Plagioclase (oligoclase to andesine) and quartz are the most important light minerals. In a number of white gneisses microcline occurs, generally in small amounts, but in a few samples up to 30 % of microcline may be present. Biotite and, especially in the hornblende-biotite gneisses, hornblende are the normal dark minerals. In a number of white gneisses small amounts of white mica (probably muscovite, and henceforth called muscovite) are present. Possibly this is of secondary origin.

Epidote and, less commonly, chlorite occur as secondary minerals in nearly all the gneiss samples. In the hornblende-biotite gneisses, moreover, a light green amphibole (probably actinolite and henceforth called actinolite) and biotite occur commonly as secondary minerals after hornblende. Apatite, zircon and opaque minerals occur as accessory minerals in almost all thin sections. Sphene and allanite occur in many samples, sphene especially in the hornblende-bearing rocks. The accessory minerals generally occur in fairly large amounts, so that one hardly has to search for them and even so that they regularly are registered during the point-counting. Only the opaque minerals may occur in such small amounts that one has to search carefully to find a few grains. In the leucocratic ('pegmatitic') veins, described in section 3.6, generally the same accessoric minerals occur, but in much smaller amounts so that one has to be careful not to overlook them.

3.1.2. Grain size

Most of the gneisses and amphibolites are medium-grained rocks. The main minerals—quartz, feldspar, hornblende, biotite—range in size from a few tenths of a mm to a few mm. More coarse-grained gneisses, with grain sizes up to approx. 1 cm occur only exceptionally.

Although the largest crystals in the different rock types are often a few mm in diameter, the number of 'points per crystal' (see p. 9), when point-counting with a point distance of $^1/_3$ mm, is relatively low. Rarely values over 1.4 were found. This is due to the important variation in grain sizes encountered in the thin sections. The largest parts of the thin sections are occupied by the smaller crystals. Still, when looking subjectively at the thin sections, the rocks make a more or less even-grained impression.

3.1.3. Texture

In thin section the rocks appear as granular aggregates of irregularly shaped crystals of the main minerals. Only the biotite rather often has well developed basal planes; the other minerals (quartz, plagioclase and hornblende) are almost always quite irregular in outline. The quartz grains may show rounded shapes, especially where they are in contact with, or enclosed in, feldspar.

Generally a preferred orientation of biotite and hornblende is seen, but, especially in the leucocratic biotite gneisses, the preferred orientation of the minerals may be weak or even seemingly absent. In general there seems to be a positive correlation between the amount of biotite present in a gneiss sample and the degree of preferred orientation of the biotite, but also in fairly biotite-rich gneisses the preferred orientation may be poor.

The rocks show little evidence of postcrystalline deformation. The quartz mostly shows wavy extinction, but deformed biotite, feldspar or hornblende crystals are rare. Augen textures have not been found.

The anorthositic gneisses differ in texture from the other rock types in that the plagioclase and hornblende show relatively simple grain shapes (plate 1 c).

3.1.4. Notes on some of the minerals

Plagioclase. The composition of the plagioclase has been measured in all samples listed in the appendix, (except for those where the plagioclase was so altered that measurements were not possible) and in a number of additional samples. With few exceptions the measurements were made on crystals cut perpendicular to the crystallographic a axis. The angle $X' \wedge 010$ was measured, and the graph in Tröger (1956, p. 111) was used to read off the corresponding An content. These measurements are both simple and dependable. Often in one thin section four or five crystals could be measured. The results of the measurements are listed in the appendix; the range of the measured An contents is given for each sample, together with the number of crystals measured. The differences between the different measurements generally proved to be small (in the order of 2–3 % An). This means 1) that different plagioclase crystals in the same thin section have approximately the same An content and 2) that the measurements have a precision of at least $\pm$ 2 % An.

Fig. 10 shows histograms of the An content in samples of gneisses as compared with the other rock types. The average An content decreases from the amphibolites via the hornblende-biotite gneisses and the banded biotite gneisses to the white gneisses. The first most commonly contain andesine, the last generally oligoclase. It is seen, however, that the An contents in the different rock types overlap to a large extent. The leucocratic veins contain plagioclase with an An content which compares with the gneisses in general. The plagioclase in the leucocratic veins is distinctly more An rich than that in the white gneisses.

In a number of amphibolite samples the plagioclase is normally zoned; reversed zoning has only rarely been observed. The composition of the rims of a number of zoned plagioclase crystals is shown in fig. 10. In the gneisses the plagioclase is generally hardly zoned. Sometimes a

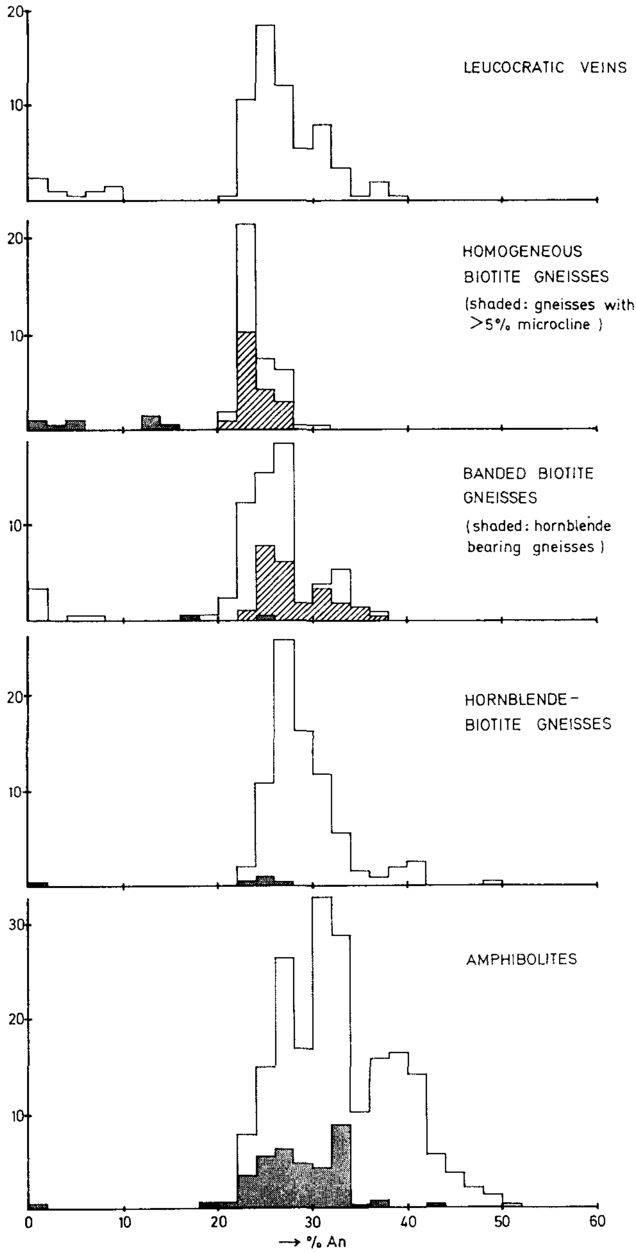

Fig. 10. Histograms of the An content in plagioclase of the different rock types. Each unit represents one plagioclase crystal of which the An content was measured. In general the An content was measured in the core of the crystals. An contents of the rims of zoned crystals are indicated in the grey histograms for the amphibolites and gneisses. For the homogeneous and banded biotite gneisses two histograms for the An contents are shown: The white histograms showing the composition of the plagioclase in all samples, and the ruled histograms showing the composition of the plagioclase in respectively the granodioritic homogeneous gneisses and the hornblende-bearing banded biotite gneisses alone.

normal zoning occurs, the cores of the crystals containing a few percent more An than the rims. Where the plagioclase is strongly altered the An content may be much lower. In the tables the An content of the fresh plagioclase is given, also in those cases where most of the plagioclase is altered to albite + sericite or albite + epidote.

A few samples contain fresh almost pure albite (e.g. 70158). Here we are evidently dealing with rocks retrogradely metamorphosed under epidote-amphibolite facies conditions.

Almost all plagioclase shows lamellar twins. Both albite twins and acline/pericline twins are common, but albite twins more so than acline/pericline twins. Exceptionally Carslbad twins have been found.

Alteration of the plagioclase, both sericitization and saussuritization, is common.

Microcline. The alkali feldspar present in a number of gneisses always shows clear 'tartan' twinning, and is thus undoubtedly microcline. It is always microperthitic, mostly occurring as a string perthite.

Hornblende. The hornblende in the investigated samples has generally the following colours: X: pale yellow, Y: olive-green, Z: green with a bluish tinge. According to several authors (Turner, 1948, p. 98, Shidô, 1958, Miyashiro, 1958) the occurrence of bluish green hornblende indicates a relatively low degree of metamorphism. According to Turner (op. cit.) blue-green hornblende occurs preferentially in the epidote-amphibolite facies. A number of amphibolite samples contain brownish green (Z) hornblende which towards the rim changes in colour to bluish green. Also normal green hornblende has been found.

In a number of samples the hornblende is partly or strongly altered, actinolite, biotite and less commonly chlorite occurring as secondary minerals.

Biotite. The biotite ranges from normal brown biotite to very dark brown biotite, almost always with a greenish tinge. It seems that in the more leucocratic rocks the biotite is of a lighter colour than in the darker gneisses. Several interesting types of alteration of the biotite have been observed

1) replacement of biotite by chlorite
2) replacement of biotite by epidote
3) replacement of biotite by albite
4) replacement of biotite by actinolite.

The first type of replacement is relatively uncommon in the present area. Generally the biotite is replaced by epidote rather than by chlorite. Commonly one finds large epidote crystals as pseudomorphs after biotite. Replacement of biotite by feldspar has been described by Tobi (1959) from the Belledonne Massif. In the rocks from the area described here, this type of alteration is quite common. Where biotite is in contact with plagioclase (*e.g.* andesine) part of the biotite may be replaced by albite (plate 1 a). Sometimes only a 'ghost' of the original biotite crystal is left as tiny dust particles (sphene?) in the feldspar replacing the biotite. Replacement of biotite by actinolite is occasionally found where biotite is in contact with hornblende (plate 1 b).

In a few samples of the leucocratic veins in which the biotite is chloritized, the chlorite is again replaced by biotite (see plate 2 a). During the replacement of the original biotite by chlorite, titaniferous material is liberated, which is found a strings of tiny sphene crystals along the basal cleavage of the chlorite. The new-formed biotite, which again replaces the chlorite, lies with its cleavage roughly perpendicular to the cleavage of the old crystals, and in the new biotite one finds therefore the strings of sphene dust perpendicular to the cleavage of the new biotite. The new biotite crystals are of a lighter colour than the original biotite. They lie completely within the limits of the original (chloritized) biotite crystals

3.2. The amphibolites (see table VI)

Most of the amphibolites resemble the hornblende-biotite gneisses. Generally they contain more hornblende and less quartz, but the two rock groups overlap in these respects. It is therefore impossible to define a logical division between the amphibolites and the hornblende-biotite gneisses (see further section 4.6).

A number of amphibolite samples differ clearly from the above-mentioned group in that they contain diopside and/or garnet, some even in large amounts.

The clinopyroxene, which is present in a number of amphibolites, has not been studied in detail. It has in general a light green colour and a relatively large axial angle, and it is thus probable that one is dealing with a diopsidic pyroxene. In a few samples the pyroxene is more strongly, almost grass-green coloured; this might be due to a higher iron content.

The pyroxene is often irregularly intergrown with hornblende; one could get the impression that the pyroxene is partly replaced by hornblende, or that the two minerals crystallized side by side. In a number of pyroxene crystals a large number of irregular hornblende inclusions are present which all have the same optical orientation, and also often the same orientation as neighbouring larger hornblende crystals. Sometimes one finds the pyroxene enclosed in hornblende.

The hornblende in these diopside-bearing amphibolites is often very dark brownish green changing towards bluish green in the outer parts of the crystals. The garnet, present in a number of amphibolite samples, often has a distinctly reddish colour. It contains many inclusions of quartz and sphene. The garnet is often surrounded by rims of epidote which form myrmekite like intergrowths with quartz (?), the quartz (?) forming very narrow (approx. 0.01 mm) irregular, worm-like, inclusions in the epidote.

The same type of myrmekite has also been found surrounding plagioclase and hornblende, or occurring without a clear connection to one of these minerals. More rarely, myrmekites consisting of actinolite and quartz (?) (surrounding sometimes pyroxene and hornblende) and myrmekites of hornblende and quartz (?) have been found.

The pyroxene- and garnet-bearing amphibolites often contain relatively large quantities of sphene, which may have a distinct reddish colour.

It is possible that these amphibolites form a separate group, distinct from the normal amphibolites which grade into the hornblende-biotite gneisses, because of their peculiar properties described above: 1) the occurrence of garnet and/or diopside, 2) the occurrence of different types of myrmekite, 3) the dark colour of the hornblende, 4) the large amount of sphene. It is not, however, possible to classify all the amphibolites in one of the two contrasting groups because some of them look completely like the 'normal' amphibolites but contain some diopside or garnet, while others have garnet and epidote myrmekite, but contain a normal green hornblende, etc.

3.3. The garnet-rich gneisses and associated garnet amphibolites.

As described in section 2.4.2, a thick band of garnet amphibolites, with local layers of reddish garnet-rich gneisses, can be followed over a number of islands in the north-western part of the area. Some of the garnet- and/or diopside-bearing amphibolites described in the foregoing section are strongly reminiscent of the garnet amphibolites in this particular band, and possibly they are related to the rocks to be described in this section. In the following, however, only samples from this particular band will be described to be sure that the samples described belong to a genetically related group.

The rocks of this band of garnet amphibolites display many remarkable features that can only be briefly mentioned in this section. The rocks deserve a more complete description which the writer hopes to give in a later paper.

Table VII gives the mineral content of 10 samples of these rocks. In seven of those samples garnet is one of the major components. The content of garnet, the presence of fairly large amounts of sphene and opaque minerals, and the occurrence of the rocks in the same band, link them together. Petrographically, however, different samples of these rocks may show large differences. Sample 70030, for example, contains some 40 % garnet and six times more quartz than plagioclase. Only minor amounts of hornblende and diopside are present. The rock is distinctly red in hand specimen. Sample 71750 on the contrary consists for more than 50 % of dark green hornblende, it has much less garnet than 70030 and the amounts of quartz and feldspar are more or less equal. Diopside has not been found. The hand specimen is a very dark, almost black rock, speckled with dark red garnets.

Several features observed in the diopside- and/or garnet-bearing amphibolites are common also in some of the samples listed in table VII. Myrmekitic intergrowths of epidote, hornblende and plagioclase with quartz (?) have been found (plates 2b and 3a). The hornblende has generally a dark colour. The presence of relatively large amounts of sphene with in a few cases the same distinct reddish brown pleochroism, also links the garnet-rich rocks in the western part of the area with at least some of those in the rest of the area.

Most of the samples listed in table VII have very calcic plagioclase, An contents ranging up to approx. 80 %.

Except for sample 70201, in which the garnet is strongly chloritized, the garnet-rich rocks are very fresh. All the same there is much evidence of reaction between the different minerals. Apart from the occurrence of different types of myrmekites, replacement of diopside by bluish green hornblende, and strange intergrowths of hornblende and plagioclase which probably result from the replacement of hornblende by plagioclase (plate 3b) have been found.

A chemical analysis of the garnet from sample 70193 was made. It proved to be rich in almandine, but it contains also important amounts of grossular and pyrope (see table VII a).

3.4. The anorthositic gneisses

3.4.1. Mineralogical composition

Table VIII gives the mineral content of a number of anorthositic gneisses. Ca-rich plagioclase is by far the most important mineral — in several specimens it forms over 90 % of the rock. A more detailed description of the plagioclase is given below. Quartz occurs in minor amounts in a few samples, but is lacking completely in most of the anorthositic gneisses. Alkali feldspar has not been found.

Dark minerals are light green to green hornblende, locally grading into very light coloured amphibole, and light brown to light green biotite.

The colours of the hornblende and the biotite suggest that these minerals are relatively poor in iron. In some samples, however (70179, 70180), the hornblende is of a more intense colour, indicating a more normal iron content. Garnet occurs in a few samples.

Epidote and, in smaller amounts, chlorite are present almost without exception. The chlorite is clearly secondary after biotite. The epidote occurs in fairly large crystals, which seem to be in equilibrium with the plagioclase. The plagioclase does not change in composition where it borders an epidote crystal. Epidote may well border a homogeneous plagioclase crystal with, say 70 % An. Locally the epidote clearly replaces biotite, perhaps locally also hornblende. Only in a few samples is the plagioclase saussuritized; here of course the epidote minerals are partly derived from the alteration of the plagioclase.

Opaque minerals and sphene occur only in small quantities, or are totally absent. In 70180, a garnet-bearing anorthositic gneiss, sphene is more common. Apatite does not occur in most of the samples; it has only been found with certainty in a much altered anorthositic gneiss. Zircon has not been found with certainty. Some carbonate is present in partly saussuritized samples, probably it originated during the decomposition of the plagioclase.

3.4.2. Chemical composition

Two chemical analyses of anorthositic gneisses have been prepared. (tables VIII a & b). One of the two samples (70320) represents a typical leucocratic gneiss, the other sample (70196) is a more melanocratic type which in the field only occurs in subordinate amounts.

As the catanorms of the two samples show, the analyses agree quite well with normal anorthositic rocks. This means that the anorthositic gneisses could have been formed by isochemical metamorphism of igneous anorthosites.

The mesonorm of the two samples does not agree well with the mode. In both cases the calculated amount of hornblende is too low. Assuming that both the chemical and the modal analyses are more or less correct, this must be due to a real composition of the hornblende which deviates appreciably from the calculated one.

3.4.3. The plagioclase

Composition. The plagioclase in a number of samples of anorthositic gneisses has been studied in some detail. The An content of a number of crystals has been measured on the universal stage. The same method was used as described on p. 23 with the only difference that crystallographic a was made vertical with the help of the universal stage. The precision of the measurements is estimated to roughly ± 2 % An.

The results of the measurements are shown in fig. 11. The figure shows that the plagioclase in the anorthositic gneisses has a very variable composition. Not only may different samples have plagioclase of a very different composition (*e.g.* An 35–43 in 70196 against An 81–86 in 70334), but also within one sample a large range of compositions may be present (*e.g.* An 49–77 in 70038 and An 50–100 in 70186). Many crystals are not homogeneous in composition. Most of the crystals do not show regular zoning; an irregular distribution of more Ca-rich and more Na-rich patches within one and the same crystal is common. Zonary crystals are mostly more Ca-rich in the rim than in the core, but also the opposite has been found several times.

Twins. Lamellar twins occur almost in every plagioclase crystal. Albite twins are more common than acline/pericline twins. Simple twins, which are characteristic for plagioclase in basic igneous rocks, have not been found.

Lamellae. Many crystals of plagioclase show a peculiar type of lamellae, at an angle of approx. 20° with (010). The lamellae are closely spaced and very narrow (see plate 4a, b and c). From universal stage observations one gets the impression that the lamellae lie in the zone of (010) and (001). The constant angle of about 20° between the lamellae and (010), and the fact that the lamellae truncate the sharp angle between (010) and (001), indicate that they lie parallel with or nearly parallel with ($0\bar{5}1$). It is not certain, however, that the lamellae do correspond to a particular crystallographic direction; it is often seen that the lamllae in a crystal are not strictly parallel to each other. In a few plagioclase crystals a parting is visible which lies parallel with the lamellae.

Lamellae of this kind have never been observed in plagioclase with less than 70 $^0/_0$ An (see fig. 11). In many crystals of zoned or otherwise inhomogeneous plagioclase, the lamellae are only visible in those parts of the crystals where the An content is over 70 $^0/_0$. A number of crystals with An over 70 $^0/_0$, however, do not contain visible ($0\bar{5}1$) lamellae. It seems possible that in these crystals the lamellae are present, but too small to be visible under the microscope, since, apart from crystals in which the lamellae are clearly visible, there are also many crystals in which the lamellae are extremely narrow and only just visible.

It is not clear whether the lamellae described above represent inclusions of another mineral in the plagioclase, or plagioclase with a different composition, or some type of twinning. The lamellae are too narrow to permit reliable optical observations, but they seem to have a higher refractive index and birefringence than the host plagioclase, and a different optical orientation. Viewed with phase contrast optics, however, the contrast between the lamellae and the host plagioclase is so small that

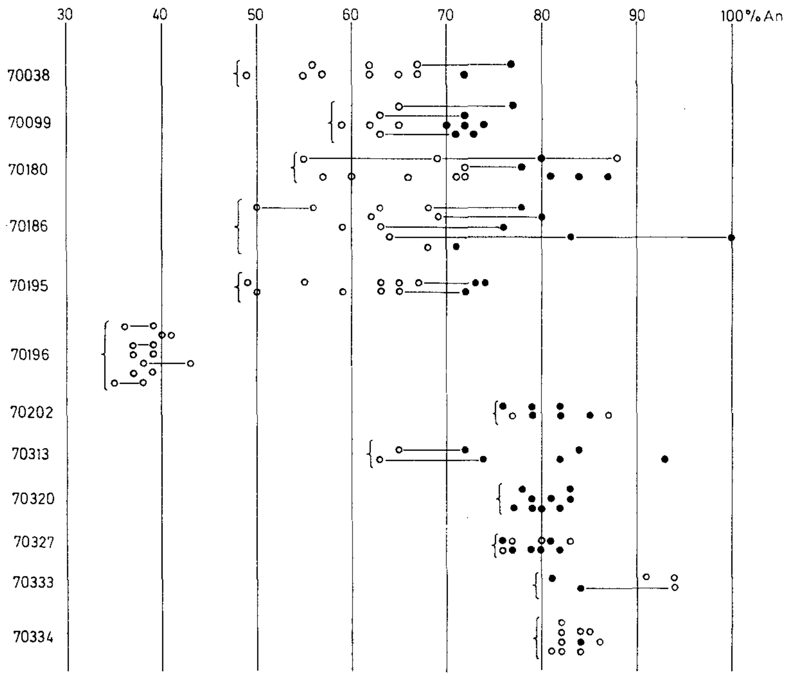

Fig. 11. Composition of the plagioclase in a number and anorthositic gneiss samples. Circles: plagioclase without visible lamellae. Dots: plagioclase with $(0\bar{5}1)$ lamellae. Circles and dots connected with a line indicate measurements on different parts of the same crystal.

probably the difference in refractive index between the two is less than 0.001.

Even the thickness of the lamellae is difficult to measure. Through optical effects along the lamellae they may look wider than they are in reality. The widest lamellae seem to have a width of approx. 1 micron.

An attempt was made to get more information on the lamellae with the help of electron microprobe investigations. The first trials were made by Dr. F. W. Warnaars with a Philips microprobe at the University of Utrecht (Holland). Later, through Dr. Warnaars, the lamellae were studied with an electron microprobe at the laboratories of N. V. Philips Gloeilampenfabriek at Eindhoven (Holland). Through Dr W. Tufar (the University of Aarhus) further measurements on the lamellae were made with a Siemens microprobe at the University of Heidelberg (Germany).

During these different investigations the distribution of a large number of elements (including calcium, silicium and barium) in plagioclase crystals with well developed lamellae was investigated, but for none of the elements investigated did the lamellae prove to have a different composition than the host crystal. This means either 1) that the lamellae have (very nearly) the same chemical composition as the host crystal, or 2) that the lamellae are too narrow to allow the detection of the chemical differences present. Both the Philips and the Siemens microprobe permit the analysis of areas with a diameter of approx. 1 micron, and, as mentioned above, it is not certain that the lamellae have a width of 1 micron.

Lamellae of the same type as those in the plagioclase of the anorthositic gneisses have been described by JÄGER and HUTTENLOCHER (1955) from gabbroic and kinzigitic rocks from the Ivrea zone in the Alps. Also these lamellae are restricted to plagioclase with over 70 % An. They are more or less parallel with $(0\bar{6}1)$, and make an angle of 17° with (010).

According to JÄGER and HUTTENLOCHER the chemically determined An content of the plagioclase is slightly higher than the optically determined An content of the host plagioclase alone, and it is therefore tentatively supposed that the lamellae consist of a slightly more calcium-rich plagioclase than the host. It is possible that this explanation also can be applied to the lamellae in the plagioclase described here, but in that case the difference in composition between the lamellae and the host plagioclase must be small, since otherwise a more distinct difference in refractive indices should be expected.

3.5. The ultramafic rocks

Table IX shows the mineral content of a number of samples of ultramafic rocks. In a number of samples olivine is one of the main minerals. Generally it is partly replaced by secondary minerals such as tremolite, serpentine and talc. In only one sample (70074) were large amounts of orthopyroxene (probably enstatite) found. The pyroxene is strongly altered to talc. Clinopyroxenes have not been found with certainty. Phlogopite occurs in several samples; it is restricted to those samples that are so well preserved that they also have retained their olivine.

Most of the samples listed in table IX only contain secondary minerals and also the better preserved samples contain generally large amounts of secondary minerals, and it is therefore difficult to ascertain the original composition of the rocks. The fact, however, that one sample (70056) almost exclusively consists of olivine, and that remnants of pyroxene only occur in large amounts in one sample, may indicate that one is dealing with originally pyroxene-poor ultramafics, such as dunites and some peridotites.

The most common secondary mineral in the ultramafic rocks is actinolitic amphibole. Both colourless amphibole (probably tremolite) and light green amphibole (probably actinolite) are present; often the two are present in the same thin section. Often the greenish amphibole forms the core of large crystals, whereas the colourless amphibole forms the rims, which usually have a sharp boundary with the core. In several samples (*e.g.* 70074) actinolite occurs side by side with olivine, as large crystals with the same size and simple outlines as the olivine, and it could be that these actinolite crystals are pseudomorphs after olivine. Only rarely, however, one can see that the amphibole really replaces olivine.

Several samples consist almost completely of actinolite and tremolite. In one sample (70073) a colourless amphibole with parallel extinction, probably anthophyllite, is found together with large amounts of actinolite and tremolite. A few samples in this group contain some biotite.

A few samples of serpentinite are present, the serpentine mineral is antigorite. In these, and in most of the other samples, some chlorite with a much lower birefringence and abnormal, generally brownish, interference colour is present. In the serpentinites this chlorite always is found around opaque ore minerals. In one sample of serpentinite (70344) sheaf-like aggregates of clinopyroxene (?) have been found. The mineral has the optical and crystallographic properties of a pyroxene, but the mode of occurrence makes the determination uncertain.

In several samples talc is the main secondary mineral. Whereas in the serpentinites actinolite/tremolite is rare, the talc-rich rocks contain large amounts of amphiboles. These amphiboles themselves are often partly or largely replaced by talc.

Of the accessory minerals, opaque ore grains are the most common. In the best preserved ultramafic rocks the ore crystals have the simple outlines of cubic crystals. Probably the ore mineral is chromite. In one sample (70074) the ore grains are associated with a dark green spinel. In the more altered rocks the ore minerals have irregular shapes; probably one is dealing with magnetite of secondary origin. Minor amounts of carbonate minerals have been found in a few samples. Sphene occurs in a few samples of amphibole-rich rocks. Apatite and allanite have been found in one sample each.

Most of the ultramafic rocks are of medium grain size. The olivine crystals in the best preserved rocks grade in size from about 1 mm to 1 cm. The amphiboles in the amphibole-rich samples occur generally as needles grading up to a few mm in length. Serpentine and talc are often very fine-grained, but crystals up to a few tenths of a mm have been found.

At a few localities ultramafic rocks are cut by pegmatitic veins. Locally, complex reaction zones have been formed between the pegmatitic material and the ultramafic rock. Directly outside the vein, coarse (several cm) biotite and tremolite crystals, sometimes still intergrown with the vein minerals (mainly quartz and feldspar), are found. Outside this coarse-grained rim there is a zone of fibrous tremolite, in which the amphibole needles are oriented perpendicular to the pegmatitic vein. This zone is followed outward by a zone of light gray talc-rich soapstone (71607) in which remnants of tremolite occur. This zone is followed by the fresh olivine-rich ultramafite (71606). The boundaries between the different zones are sharp. The zones are several cm wide.

Talc-rich soapstone has also been found along cracks in the ultramafic rocks which do not contain pegmatitic material.

3.6. The leucocratic veins

The leucocratic vein rocks are not really coarse-grained. Feldspar and quartz crystals are generally of the order of a few mm large and grade upward to approx. 1 cm. It would therefore be incorrect to call the rocks pegmatites, but on the other hand they are too coarse-grained to call them aplites. The writer thinks it best to talk neutrally about leucocratic veins.

Table X gives the mineral content of a number of samples of leucocratic veins. Quartz and plagioclase (mostly oligoclase to andesine) are in all cases the main minerals. Only in one of the investigated samples microcline occurs in large amounts, the other samples have a quartz-dioritic to granodioritic composition. Some samples have antiperthitic plagioclase, *i.e.* plagioclase containing regularly oriented inclusions of microcline. The feldspar crystals generally have irregular shapes, only rarely can rough crystal outlines be recognized. The quartz often lies as strongly deformed crystals with granulated boundaries in between the feldspars.

Dark minerals, generally biotite and sometimes hornblende, occur in small amounts, the maximum amount found is some 7–8 $^0/_0$. Often the biotite occurs as clusters of relatively small (0.1 mm) crystals.

As secondary minerals epidote, colourless mica and chlorite occur. Epidote is present in all samples. Generally it replaces biotite. Chlorite is less common, only in a few thin sections is the biotite clearly chloritized. It is interesting to note that in a few samples (71637) in which the biotite is chloritized, the chlorite again is replaced by biotite (see plate 2a and further description p. 26). White mica occurs in small amounts, less than 1 $^0/_0$, in a number of samples. Probably it is of secondary origin. The plagioclase in most of the leucocratic veins is partly sericitized, and it is possible that during this process also locally larger mica crystals formed. The latter are always relatively small, in the order of 0.1 mm.

The following accessory minerals have been found: apatite, zircon and opaque minerals occur in almost all thin sections, but often in very small amounts. Sphene and allanite occur in a number of samples, sphene generally in those samples which contain some hornblende. Garnet has been found in one sample (71697). Two samples contain zircon in relatively large amounts as large crystals (70133, 71752) so that the mineral is readily visible in hand specimen and also was registered during the point-counting. In three thin sections of sample 71752, 1.2, 0.7 and 0.2 vol $^0/_0$ of zircon was found.

As described before (section 2.1), the leucocratic veins do not form a homogeneous family. There are clear differences in age between different veins. Some are tectonized, others are not; some are clearly intrusive, others are not. In most veins the plagioclase is oligoclase to andesine (see p. 24, fig. 10) but in some, especially the clearly youngest ones, the plagioclase is albite. The clearly intrusive veins depicted in figs. 5 and 6 have albitic plagioclase and contain some garnet.

Samples 71637, 71638 and 71639 are from three mutually intersecting pegmatites (see fig. 4) of which the older ones (71637 and 71638) are tectonized, the younger (71639) not. The three samples have more or less identical compositions and also the composition of their plagioclases is very much the same. Sample 71752 was taken from a thick vein cutting through an ultramafic body. This sample does not show any difference in mineralogical composition or An content of the plagioclase compared with most of the other samples.

The author concludes that the problem of subdividing the leucocratic veins is far too complex to be solved here. There are certainly different genetic groups of veins, but as yet it is not possible to separate them on a petrographical basis. Even the youngest ones (the albite-bearing ones) may be tectonized, as seen in thin section.

3.7. Conclusions regarding the metamorphism of the rocks

Obviously, the rocks of the area belong, with few exceptions, to the amphibolite facies. The association of hornblende with oligoclase or andesine and the presence of diopside prove that the rocks do not belong to the greenschist facies; the absence of hypersthene proves that they do not belong to the granulite facies. The presence of an orthopyroxene in one sample of the ultramafic rocks is of course insignificant in this respect. If we accept that the total absence of hypersthene in the gneisses and amphibolites proves that the rocks do not, and never did, belong to the granulite facies, the hypersthene in the ultramafic rock tends to indicate that the latter is of intrusive origin.

It is not possible to indicate with any certainty the subfacies to which the rocks belong since diagnostic minerals such as kyanite, andalusite, cordierite, etc. are totally lacking. The bluish-green colour of the hornblende, however, points to a relatively low temperature of formation of most of the hornblende (see literature cited on p. 25), and it is possible that the rocks belong to the low temperature part of the amphibolite facies. The presence of brownish-green cores in the hornblende in a number of samples may indicate that higher temperatures have been obtained in an early stage of the metamorphism.

In many samples traces of retrograde metamorphism have been observed. There is some evidence that locally recrystallization has taken place under epidote-amphibolite facies conditions. A few gneiss samples contain fresh, well crystallized albite + epidote + dark brown biotite + chlorite. The minerals seem to be in equilibrium with each other, indicating that equilibrium was reached under epidote-amphibolite facies conditions.

Further evidence of retrograde alteration of the rocks include the replacement of biotite by epidote, albite, actinolite and chlorite; the alteration of plagioclase, both sericitization and saussuritization; the local replacement of garnet by chlorite; the local replacement of diopside by hornblende and the replacement of hornblende by biotite. Some of these alterations (*e.g.* hornblende–biotite, diopside–hornblende) may have taken place under epidote–amphibolite facies conditions. Others (*e.g.* biotite–chlorite) are probably greenschist facies alterations.

The leucocratic veins generally contain biotite (locally hornblende) and oligoclase (–andesine). They formed therefore under amphibolite facies conditions, and are thus older than the retrograde metamorphism. The fact that in some of the leucocratic veins the biotite is chloritized and that new biotite has crystallized within this chlorite indicates oscillations in temperature after the emplacement of the veins. It is possible (but by no means sure) that this new biotite formed simultaneously with the epidote–amphibolite facies alteration in other rocks.

4. RESULTS OF THE MODAL ANALYSIS OF SAMPLES OF GNEISSES, AMPHIBOLITES AND LEUCOCRATIC VEINS

4.1. The division between the biotite gneisses and the hornblende-biotite gneisses

As previously stated, there is a gradual transition (not in the field but lithologically) from biotite gneisses over hornblende-biotite gneisses to amphibolites. The boundaries between the three rock groups are therefore more or less arbitrary.

Fig. 12 shows a histogram of the hornblende content of the point-counted gneisses and amphibolites. The value of the diagram is restricted because of the unsatisfactory sampling system (p. 11). The writer in 1964 specially collected amphibolites for a chemical investigation, and therefore the hornblende-rich rocks are certainly over-represented in the dia-

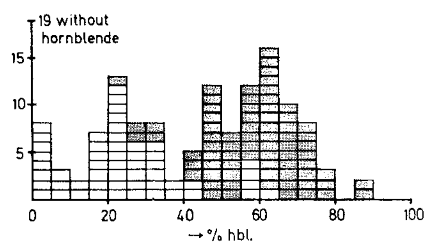

Fig. 12. Histogram of the hornblende content in the banded gneisses and amphibolites. Data from tables I , Ib, V and VI. The white part of the histogram shows the hornblende content in the gneisses; the shaded part the hornblende content in the amphibolites. Every sample is represented by two units. Where two thin sections of one sample were analysed the two hornblende contents were plotted. Where only one thin section was point-counted the same hornblende content was plotted twice. Where more than two thin sections were analysed (in a number of amphibolites), two averages were calculated and plotted, each for a homogeneous part of the sample.

gram. The diagram shows clearly a minimum between the hornblende-poor gneisses and the hornblende-biotite gneisses proper. The first group shows a Poisson like distribution of the hornblende content, the second group has a variable hornblende content.

The minimum in the diagram lies between 5 and 15 % of hornblende. In the two thin sections with hornblende content between 5 and 10 percent, 5.5 and 5.8 % of hornblende has been found (of one of these two samples only one slide was point-counted, this result is plotted two times in the diagram, see text to fig. 12). In one thin section that plots between 10 and 15 %, 12.3 % of hornblende was found, in the other 12.1 %. (In both cases a second thin section made of the same sample was found to contain more hornblende than the sections mentioned above). Since there is thus a clear gap in the diagram between the hornblende-poor and the more hornblende-rich gneisses, the gneisses with less than 6 % of hornblende will be regarded as hornblende-bearing biotite gneisses and those with more than 10 % of hornblende as hornblende-biotite gneisses proper.

4.2. Relation between biotite gneisses with and without hornblende

In the foregoing section it has been said that the gneisses with less than 6 % hornblende will be treated together with the biotite gneisses. This is of course only permissible if no other differences between the two rock groups are evident.

The mineral contents of a number of samples from both groups are listed in tables Ia and b. A statistical comparison (WILCOXON's two-sample test) shows that there is no significant difference (at 90 % probability level) between the quartz and plagioclase contents of the two groups of gneisses. The difference in biotite content, however, is highly significant, the hornblende-bearing gneisses having the higher biotite content.

This difference is probably only due to a higher content of iron and magnesium in the hornblende-bearing gneisses. When there is enough potassium present, all iron and magnesium will go into biotite. When, however, the amount of iron and magnesium increases, and there is not enough potassium present to form more biotite, some hornblende will form.

In fact, hornblende and microcline rarely occur together in the same sample, and when they occur together microcline is only present in very small amounts. Out of 68 point-counted gneiss samples 26 contain hornblende alone, 23 contain microcline alone, 11 contain neither hornblende nor microcline and 8 contain both. The maximum amount of microcline found together with hornblende is 1.8 % (sample 70226, table V).

It seems therefore justified to treat the gneisses with less than 6 % of hornblende as biotite gneisses. In the original material there must have been a certain spread in iron and magnesium content, and in those samples most rich in iron and magnesium some hornblende could develop.

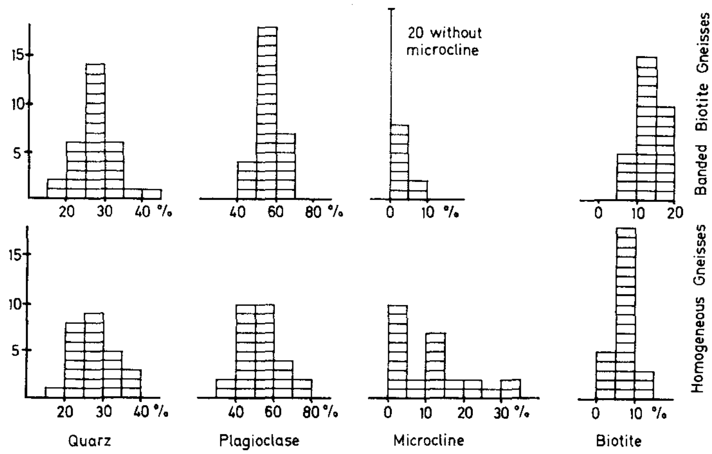

Fig. 13. Histograms of the quartz, plagioclase, microcline and biotite content in homogeneous and banded biotite gneisses. Every sample is represented by two units (se subscript of fig. 12). Data from tables I a, I b and II.

4.3. Relation between the banded and the homogeneous biotite gneisses

As described in chapter 2, biotite gneisses occur both as bands within the banded gneisses and as larger homogeneous masses. In hand specimen one can often not see to which groups a certain biotite gneiss belongs, and also in the field one may be in doubt how to classify a biotite gneiss, since the homogeneous white gneiss bodies often grade imperceptibly into the banded gneisses.

The samples listed in tables I a and I b come from the banded gneisses, the samples listed in table II are white gneisses from the homogeneous masses.

Fig. 13 shows the histograms of the amounts of the main minerals in the two groups of gneisses. The following features can be read from the diagrams:

1) In quartz content there is no clear difference between the two groups of samples.
2) The average plagioclase content in the banded biotite gneiss samples is slightly higher (55.4 %) than in the homogeneous white gneiss samples (52.6 %). The difference is significant, but the two groups show a considerable overlap in plagioclase content.
3) The average biotite content in the banded gneiss samples is much higher (13.3 %) than in the homogeneous gneiss samples (6.5 %). Even when we only consider the biotite gneisses without hornblende (which contain less biotite than the biotite gneisses with hornblende) the difference is highly significant.

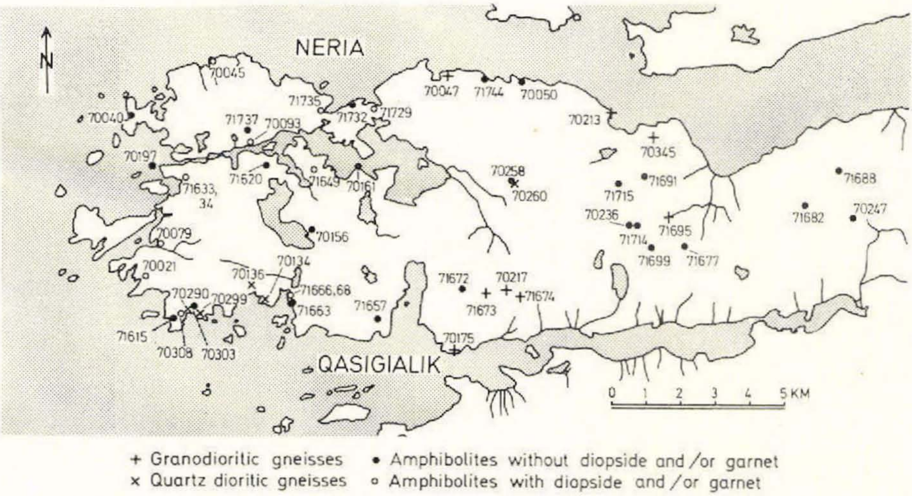

Fig. 14. Locality map of the analysed samples of homogeneous gneisses and amphibolites.

4) The microcline content in the banded gneiss samples suggests a Poisson distribution, whereas the microcline content in the homogeneous gneiss samples is bimodal. In the homogeneous gneisses two groups seem to be present, one with a Poisson like distribution of the microcline content and one with a normally distributed microcline content with average between 10 and 15 $^0/_0$. In petrographical terms this means that the samples from the banded gneisses have a quartz-dioritic composition, and that the homogeneous gneisses can be subdivided into a quartz-dioritic and a granodioritic group.

The difference between the two groups is even more pronounced than the diagram shows, since the highest microcline content in the 0–5 $^0/_0$ column is only 1.8 $^0/_0$, and the lowest microcline content in the 5–10 $^0/_0$ column is 8.6 $^0/_0$.

The large white gneiss outcrop II (see plate 5) is granodioritic in composition; the large outcrop I, in the western part of the area, is quartz-dioritic. Fig. 14 shows the field localities of the analysed biotite gneiss samples. It is seen that the granodioritic gneisses, analysed all come from the central part of the area.

4.4. Homogeneous gneiss in relation to amphibolite and gneiss inclusions

As stated in chapter 2 the homogeneous white gneisses often contain large amounts of angular inclusions of hornblende-biotite gneiss and amphibolite. In a large outcrop of white gneisses (around 65.5–171.8) a number of such inclusions are present within the very homogeneous gneiss. The inclusions are locally veined by leucocratic material which in appearance is identical with the white gneiss form the large mass. One gets in the field the impression that the white gneiss might be an originally igneous rock which also was intruded into the inclusions, especially along the cleavage planes of the 'xenoliths'. Moreover, rare discordant dykes of seemingly the same white gneiss occur in the amphibolites and gneisses which border the large white gneiss mass to the SW.

To test whether the white veins from the inclusions really consist of the same material as the white gneiss from the large mass, 6 samples from the mass and 4 samples from veins in inclusions were point-counted. Further, two white gneiss samples taken at the immediate contact with amphibolite and hornblende-biotite gneiss inclusions and a sample of a white gneiss dyke were analysed.

The results of these analyses are shown in table IV, and can be summarized as follows:

1) There are no significant differences between the amounts of the main minerals plagioclase, quartz and biotite in the two groups of rocks.
2) There is a significant but small difference in the amounts of microcline, the gneisses from the main mass containing some microcline, the veins often not.
3) The gneisses from the main mass contain some muscovite, the veins do not. The latter on the contrary may contain some hornblende, which is absent from the gneisses of the mass.

Although these differences are significant in a statistical sense, they are small. It seems not unreasonable to assume that the veins formed from the same material as the homogeneous gneiss, and that the small difference in composition is due to the influence of (contamination with) the material in the inclusions. In this connection it is interesting that also the gneiss at the contact with an amphibolite inclusion (70292) lacks microcline and muscovite.

4.5. The hornblende-biotite gneisses as a link between the biotite gneisses and the amphibolites

As stated in the introduction, one of the aims of the investigation was to test the following hypothesis: that the hornblende-biotite gneisses formed from mixtures of normal sedimentary material (now represented by the banded biotite gneisses) and basaltic, in part tuffaceous, material (now represented by the amphibolites). If this hypothesis is correct one would expect a gradual transition between the banded biotite gneisses and the amphibolites. The biotite gneisses in the area under discussion consist mainly of plagioclase, quartz and biotite. Amphibolites, all over the world, consist mainly of plagioclase and hornblende. Thus, for mixtures with increasing amounts of the basic igneous component one would expect in the metamorphic equivalents 1) a gradually increasing hornblende content, and 2) a decrease of the amount of quartz in relation to plagioclase.

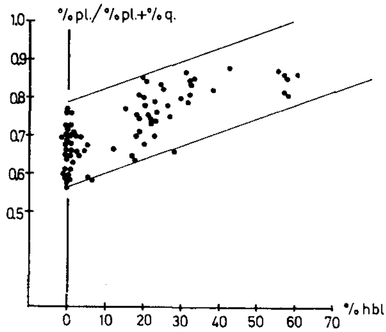

Fig. 15. Diagram showing the relation between the ratio % plagioclase/(% plagioclase + % quartz) and the hornblende content for the banded gneisses. The two parallel lines delimit the 95 % confidence belt within which most of the points fall. For further explanation see text. All the results from tables Ia, Ib and V have been plotted.

That gneisses with variable hornblende content occur in the area was known from the field work; this fact gave rise to the hypothesis mentioned above. The fact that with increasing hornblende content the amount of quartz would decrease could not be tested in the field, the rocks being too fine-grained. The change in quartz content with increasing hornblende content could therefore be used as an independent test for the correctness of the above-mentioned hypothesis.

In reality, the quartz content of the gneisses is not a priori independent of the hornblende content since the two form part of a total of 100 %. It is therefore better to plot as a variable against hornblende the ratio % plag/(% plag + % quartz) which is not a priori related with the hornblende content. The ratio % plag/(% plag + % quartz) may be expected to increase from approx. 0.66 (a value found for the biotite gneisses) with increasing hornblende content to approx. 1.0 (for amphibolites without quartz).

It must be emphasized that the working hypothesis and its consequences described above were not developed afterwards to fit the facts, but that they were formulated before the point-counting of the rocks started.

Fig. 15 shows a plot of the ratio % plag/(% plag + % quartz) against % hornblende for the banded gneisses (tables I a, I b and V). The diagram shows the expected trend for the ratio % plag/(% plag + % quartz).

The regression line of % plag/(%plag + % quartz) (Y) on % hornblende (X), was calculated (DIXON and MASSEY, 1957, chapter 11).

The denotation of the different statistics is taken from Dixon and Massey. Confidence intervals indicated are 95 % confidence intervals.

The following statistics were obtained:

$\overline{X} = 17.16 \quad \overline{Y} = 0.734$

$s_x = 17.3 \quad s_y = 0.084$

$b = 0.0037 \quad (0.0033 < B < 0.0041)$

$r = 0.76 \quad (0.63 < \varrho < 0.83)$

$s_{y.x} = 0.0556$

For the samples of which two thin sections were counted, the two values for % plag/(% plag + % quartz) and % hornblende were both used during the calculations. For the samples of which only one thin section was counted, the same value for % plag/(% plag + % quartz) was used two times. In total 78 pairs of observations were used in the calculations.

The correlation coefficient $r = 0.76$. This value indicates a highly significant correlation of % plag/(% plag + % quartz) and % hornblende. Even for $n = 39$ (the number of samples), $r = 0.76$ indicates a highly significant correlation.

The slope of the regression line $b = 0.0037$. This means that when the hornblende content increases with one percent, the factor % plag/(% plag + % quartz) increases with 0.0037. The regression line runs through $\overline{X}$, $\overline{Y}$, *i.e.* through the point % hornblende = 17.6, % plag/(% plag + % quartz) = 0.734.

With help of the regression line a prediction can be made of the ratio % plag/(% plag + % quartz) in the amphibolites. It may be expected that the corresponding point $\overline{X}$, $\overline{Y}$ of the amphibolites will fall upon or near the regression line calculated for the banded gneisses — if the working hypothesis is correct.

The statistic $s_{y.x}$ gives an impression of the spread of Y values for each X. In fig. 15 lines have been drawn through $Y_x \pm 2\, s_{y.x}$ for each X. In this way approx. 95 % of the plotted points will fall within the field bounded by the two lines, and it may be expected—if the working hypothesis holds—that most of the amphibolites also will plot in this field.

The fact that the samples were not taken according to a statistically sound system (p. 11) is, as far as the writer can see, hardly of influence in the diagram of fig. 15. The plotted ratio % plag/(% plag + % quartz) is not something one can see in a hand specimen, and therefore this ratio cannot directly influence the sampling. The hornblende content is something which is seen directly in the hand specimen, and may therefore introduce bias during the sampling. A bias, however, during the sampling, in favour of certain hornblende contents would not influence the regression coefficients in the diagram of fig. 15, but only the position of a number of points in the diagram.

4.6. The division between hornblende-biotite gneisses and amphibolites

There is no clear boundary between the hornblende-biotite gneisses and the amphibolites. As stated above, the writer made a special collection of 'real amphibolites' for a chemical investigation. These samples will be treated in this paper as amphibolites; the others (generally containing more quartz and less hornblende) have been treated as hornblende-biotite gneisses. This division, of course, is fully arbitrary, and the two rock groups grade into each other. It is, for example, evident in fig. 12 that there is a gradual increase in hornblende content from the gneisses to the amphibolites. During the investigations the hornblende-biotite gneisses were point-counted first, the series of amphibolite samples later.

4.7. The amphibolites – two types?

Since the amphibolites were investigated after the hornblende-biotite gneisses the writer expected the amphibolites to plot on the $^0/_0$ plag/($^0/_0$ plag + $^0/_0$ quartz) versus $^0/_0$ hornblende diagram in the field indicated by the hornblende-biotite gneisses. This proved not to be the case (see fig. 16 A). A number of amphibolites plot within the 'correct' field, but many of them do not.

This must mean either 1) that the hypothesis to be tested was wrong after all, or 2) that there are two essentially different groups of amphibolites of which one fits in the diagram and one does not.

The latter explanation seems to be the correct one. The amphibolites which plot clearly outside the expected field all contain either garnet or diopside. Fig. 16 B and C show the $^0/_0$ plag/($^0/_0$ plag + $^0/_0$ quartz) — $^0/_0$ hornblende plots for the amphibolites without diopside and garnet and for the amphibolites which contain diopside and/or garnet, respectively. The second group plots more or less at random in the diagram; the amphibolites of the first group all plot into or very near the expected field. (The four points between $^0/_0$ plag/($^0/_0$ plag + $^0/_0$ quartz) 0.7 and 0.8 and $^0/_0$ hornblende 70–80 come from four thin sections of one sample, 71657).

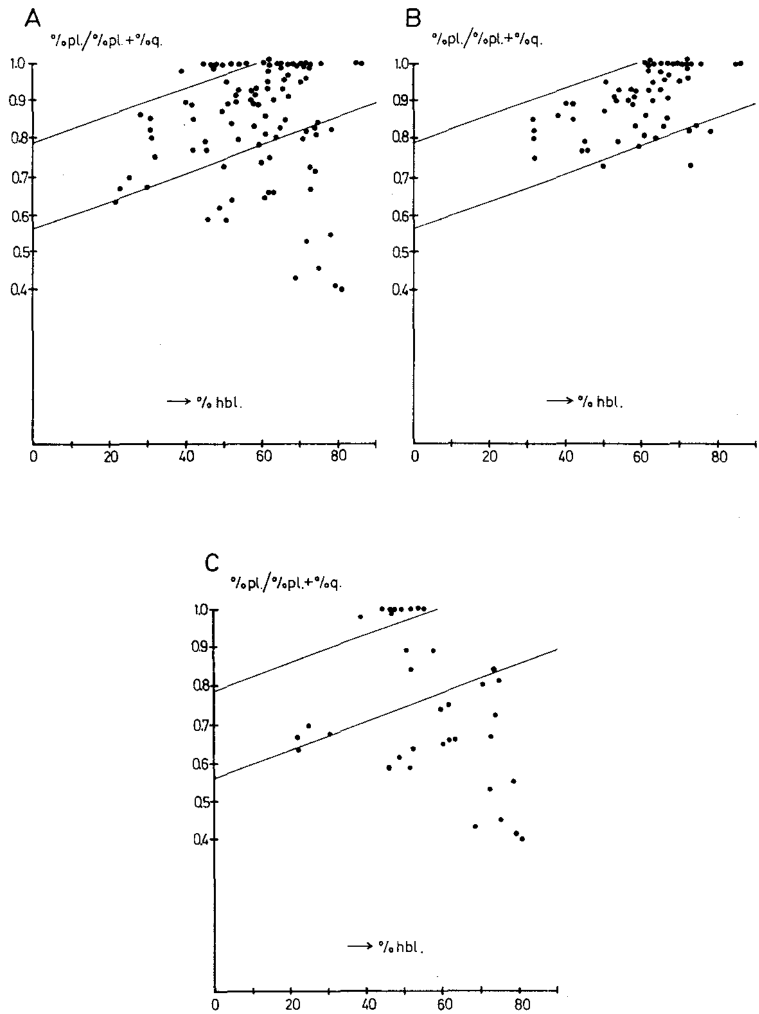

Fig. 16. Plots of the ratio % plagioclase/(% plagioclase + % quartz) against the hornblende content for the amphibolites.

A All amphibolites.
B Amphibolites without diopside and garnet.
C Amphibolites with diopside and/or garnet.

All the results from table VI have been plotted. The confidence belts shown are those calculated for the banded gneisses (see fig. 15).

For the amphibolites without diopside and garnet the regression line of $^0/_0$ plag/($^0/_0$ plag + $^0/_0$ quartz) (Y) on hornblende (X) was calculated and the following statistics were obtained.

$\bar{X} = 60.64$ $\bar{Y} = 0.912$
$s_x = 12.61$ $s_y = 0.081$
$b = 0.0035$ $(0.0019 < B < 0.0051)$
$r = 0.55$ $(0.33 < \varrho < 0.72)$
$s_{y.x} = 0.0682$

For every sample the results of two point-counter analyses were used. In total 48 pairs of observed values for $^0/_0$ hornblende and $^0/_0$ plag/($^0/_0$ plag + $^0/_0$ quartz) were used in the calculations.

The correlation coefficient $r = 0.55$. This value indicates a highly significant correlation of $^0/_0$ plag/($^0/_0$ plag + $^0/_0$ quartz) and $^0/_0$ hornblende, even for $n = 24$ (the number of samples).

The slope of the regression line $b = 0.0035$ is very nearly the same as calculated for the banded gneisses. The regression line runs through $X = 60.64$ and $Y = 0.912$, whereas the regression line for the hornblende-biotite gneisses cuts $X = 60.64$ at $Y = 0.894 \pm 0.034$.

As seen on fig. 16, most of the plotted points for amphibolites without diopside and garnet fall within the 95 $^0/_0$ confidence belt for the banded gneisses. A few fall outside this belt. In fact, the spread of the amphibolites in the diagram is slightly larger ($s_{y.x} = 0.0682$) than that of the hornblende-biotite gneisses ($s_{y.x} = 0.0556$).

The diopside- and/or garnet-bearing amphibolites often have a very low ratio $^0/_0$ plag/($^0/_0$ plag + $^0/_0$ quartz). In some cases they even contain more quartz than plagioclase. The writer supposes that these rocks are related to the garnet-rich gneisses and amphibolites described in sections 2.4.2 and 3.3. Also the latter have very much quartz in relation to plagioclase. Moreover the garnet-rich gneisses are found interbanded with garnet amphibolites. Some of the 'aberrant' amphibolites analysed come from these occurrences, but several others come from other parts of the area (see fig. 14).

4.8. The leucocratic veins in comparison with the biotite gneisses

The mineralogical composition of the leucocratic veins is shown in the quartz-plagioclase-alkalifeldspar diagram of fig. 17 B. For comparison the compositions of the different types of biotite gneiss are shown in fig. 17 A.

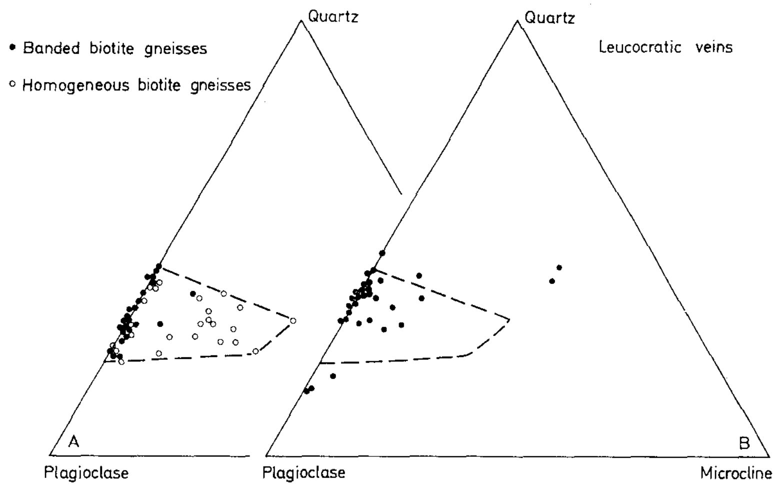

Fig. 17. Mineralogical compositions of the leucocratic veins (table X) as compared with those of the banded biotite gneisses (tables Ia and Ib) and the homogeneous gneisses (table II).

Most of the samples of white veins analysed plot within the field delimiting the compositions of the gneisses. The leucocratic veins, however, show a larger spread in composition. The two points falling far to the right in the diagram represent two thin sections from one sample (70164).

5. DISCUSSION OF THE RESULTS OF THE INVESTIGATIONS

5.1. The origin of the banded gneisses and amphibolites

According to the working hypothesis the banded biotite gneisses should represent the original normal sedimentary material in the area, the banded amphibolites should represent original basic lavas or tuffaceous material and the hornblende-biotite gneisses should represent mixtures of the two. On the basis of this working hypothesis a prediction about the relation of quartz and plagioclase contents in the hornblende-biotite gneisses could be made. This prediction was tested and proved to be correct (p. 43). It is therefore reasonable to accept the possible correctness of the working hypothesis, at least provisionally.

The question arises whether sediments of the type mentioned above do exist in an unmetamorphic state. Regarding basic sediments, formed by mixing of normal sedimentary and tuffaceous material, excellent descriptions of such rocks are given, *e.g.* by Edwards (1950, a, b). In the Aure Trough (Papua) about 15 000 feet of basic sediments occur which formed through the sedimentation of eroded andesitic tuffs. In general the chemical composition of these sediments is very close to that of andesitic rocks. A number of samples contain some quartz (up to 8 $^0/_0$) and sedimentary and metamorphic rock fragments (up to some 20 $^0/_0$); according to Edwards this is due to admixture of sedimentary material from a different source. In the Purari valley more than 5 000 feet of comparable sediments occur. The Purari rocks, however, contain a notable amount (5–15 $^0/_0$) of quartz; moreover they contain acid plagioclase and alkali feldspar. Edwards interprets the Purari rocks as mixtures of detritus coming from a granitic source area with some andesitic tuffaceous material.

That sediments of the mixed type postulated for the Greenland area do exist, and that sediments with an amphibolitic composition do occur, is thus beyond doubt.

The normal sedimentary component in the Greenland area should have had the composition of the banded biotite gneisses. A rough estimate for the chemical composition of such a sediment consisting, e.g. of 30 weight $^0/_0$ quartz, 55 weight $^0/_0$ plagioclase and 15 weight $^0/_0$ biotite gives:

SiO_2 68.5 % Al_2O_3 16.3 % Fe_2O_3 0.5 % FeO 2.7 % MgO 1.3 % CaO 3.6 % Na_2O 4.6 % K_2O 1.5 %. This composition agrees fairly well with some of the greywackes listed by PETTIJOHN (1957). According to PETTIJOHN's data, however, most greywackes contain more iron and magnesium than the investigated biotite gneisses.

The amphibolites in the area should, according to the working hypothesis, have a basic volcanic (tuffaceous) origin. It has been shown that probably two types of amphibolites occur, and that only one of these fits into the expected pattern. It is thus supposed that the amphibolites which do fit into the pattern are of volcanic origin. It must be possible to check this supposition whith a number of chemical analyses. A chemical investigation of the amphibolites is in progress[1]).

The origin of the diopside- and/or garnet-bearing amphibolites is not clear. They are often distinctly banded, and locally interlayered with garnet-rich gneisses (p. 19). They may thus be of sedimentary origin, but then the association of ultramafic rocks (which presumably are of an intrusive origin, see p. 35) with the garnet amphibolites becomes more difficult to understand. Moreover it is not clear which type of sediment may have given rise to the rocks in question. It is hoped that later investigations will help to solve the problem[1]).

The question may be raised whether the same relationships as described in the foregoing chapter can be explained in another way than by the working hypothesis used. Two possibilities may be mentioned:

1) Large scale metasomatic addition of, among others, silica and sodium could change originally basic rocks, such as amphibolites, into hornblende-biotite gneisses and biotite gneisses.

2) Anatectic processes, acting on rocks of intermediate composition (the hornblende-biotite gneisses) could, by melting away part of the light minerals, give rise to amphibolitic rocks.

These two hypotheses would explain the observed analytical data of section 4.6 as well as our working hypothesis. In all three cases we may describe the process in terms of a simple equation $a + b = c$. In the working hypothesis, the original normal sediment (a) + tuffaceous material (b) gives mixtures (c). In the metasomatic hypothesis metasomatizing agents (a) working on amphibolitic material (b) give 'granitized' amphibolite: hornblende-biotite gneiss (c). If the added material had the composition of the leucocratic veins in the migmatites, which in turn almost equals the composition of the biotite gneisses, the results

[1]) This investigation is now finished and confirms the igneous origin of the amphibolitic material. The diopside/garnet amphibolites rich in quartz may be late differentiates. (KALSBEEK and LEAKE, Medd. Grønland, in press).

of the two processes would be more or less the same. The fact that the biotite gneiss material contains more iron and magnesium than the leucocratic vein material would hardly be noticeable in mixtures with amphibolitic material. In the anatexis hypothesis hornblende-biotite gneiss (c) would, by partial melting, give rise to leucocratic material (a) + amphibolitic remnants (b). Again, analytically the result would be the same as for the other two hypotheses.

The three possible ways to explain the analytical results of section 4.6 (fig. 15) are shown schematically in fig. 18. It is evident that by the

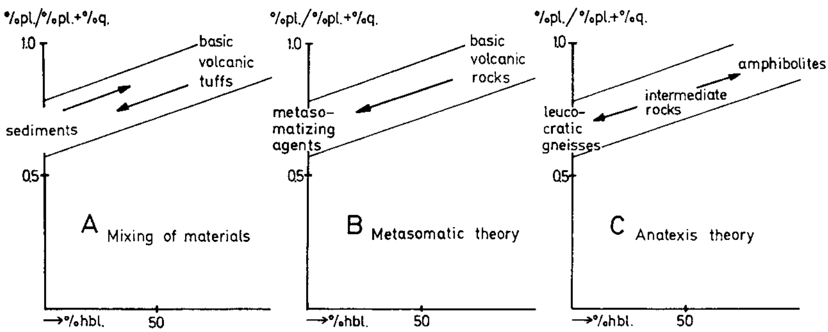

Fig. 18. Three possible explanations of the data shown in figs. 15 and 16.

analytical data alone no choice from the three hypotheses can be made. Another possibility to be kept in mind is the process of metamorphic differentiation. In an originally more or less homogeneous material, *e.g.* hornblende-biotite gneiss, by metamorphic differentiation alternating bands of amphibolite and biotite gneiss might result.

The different hypotheses are shortly reviewed below.

Metasomatism. Although the idea of large scale metasomatic changes in rocks seems to have lost most of its adherents, it is still met with in quite a number of papers on the basement rocks of SW Greenland. Very clearly the ideas are expressed by WINDLEY *et al.* (1966) who describe different types of border relationships between supracrustal and infracrustal rocks in SW Greenland. At several localities (Ravns Storø area, Sermiligârssuk region) the supracrustal rocks consist of basic metavolcanics (or greenschists) which, according to the authors, below the 'migmatite front' are 'gneissified' and 'quartz-dioritized' to give leucocratic biotite gneisses and hornblende-biotite gneisses. The latter often contain lenses and layers of amphibolitic material or greenschist which are supposed to be remnants of the original metavolcanics.

The authors of the above-mentioned paper were so kind to allow the present writer to inspect their thin sections for the presence of accessory zircon grains. The infracrustal gneisses proved to contain many, often well rounded, zircons whereas in the supracrustal volcanics (as in most basic volcanic rocks) hardly any zircons are found. On account of the great stability of zircon during metamorphic processes (see *e.g.* KALSBEEK (1967b) and MARSHALL (1967)) this seems to rule out the possibility that the gneisses represent quartz-dioritized pillow lavas and greenschists.

The field occurrence of the two rock types does not seem to rule out the possibility that one is dealing with original sediments of greywacke type with tuffaceous layers, overlain by a thick volcanic sequence. It would not then be surprising that during metamorphism the two rock series reacted in a completely different way, giving rise to a zone of complex contact phenomena which may be called a migmatite front. In fact, anatectic processes would occur in the quartzo-feldspathic rocks at temperatures where basaltic rocks are yet completely unaffected (WINKLER, 1967).

The writer discussed the paper of WINDLEY *et al.* at some length since it illustrates so clearly a possible alternative way to interpret the observations described in this paper. At least in the area under discussion this interpretation seems to be untenable because: 1) Amphibolites and gneisses occur interbanded on all scales. 2) The boundaries between the bands are sharp. 3) The gneisses contain numerous zircons, the amphibolites few or none. 4) The biotite gneisses, and even the leucocratic veins, which in the metasomatic hypothesis would represent the end products of metasomatism, border amphibolites with sharp contrast without intermediate rocks in between. 5) The hypothesis does not account for the gap in the histogram of fig. 12 between the hornblende-poor biotite gneisses and the hornblende-biotite gneisses.

Shortly, there are several arguments against and none in favour of a metasomatic interpretation of the rocks in question.

Anatexis. The question whether or not the leucocratic veins, which are ubiquitous in the area, formed by anatexis in situ of the gneisses is discussed in a later section. It will be shown there that there are several arguments against this hypothesis.

Another question is, whether the amphibolites can be regarded as the dark left-overs after the melting off of part of the light minerals in for example hornblende-biotite gneisses. This is very probably not the case because: 1) In the migmatites the amphibolitic lenses or angular blocks have always sharp contacts with the leucocratic veins. 2) Amphibolitic bands also occur in places where migmatization was not intense. 3) Also in the migmatites, blocks and bands of homogeneous amphibolite range up to many metres in width.

These features diverge very much from the normal mode of occurrence of a real melanosome in migmatites, *i.e.* as irregular dark schlieren in the leucocratic mass (MEHNERT, 1962).

Lastly, in the same migmatites in which the amphibolitic blocks and lenses occur, blocks of hornblende-biotite gneiss are found. The latter never seem to be in a state of partial melting. They show as regular and sharp contacts with the surrounding leucocratic rock as the amphibolites.

Metamorphic differentiation. Like anatexis, also metamorphic differentiation is a process in the scale of a few cm to a few dm, and therefore also this process can be excluded to explain the occurrence of many metres thick layers of amphibolite alternating with biotite gneisses and hornblende-biotite gneisses.

The writer concludes that, although definite proof is lacking, probably the gneisses and amphibolites derive largely from isochemically metamorphosed mixtures of greywacke-type sediments and basic tuffaceous material. It is probable that, locally, anatexis, metamorphic differentiation and metasomatic processes have played a role, so that the whole picture may be more complicated than the simple working hypothesis expresses. The effect of these processes, however, seems to have been of restricted importance, so that the evidence for the origin of the rocks is somewhat blurred, but not destroyed.

As described earlier (sections 3,2, 3.3 and 4.7) some amphibolites stand apart through a high quartz content and at the same time through the presence of diopside and/or garnet. The origin of these amphibolites is uncertain. They may be of igneous origin since they are associated with ultramafic rocks, but they are also associated with garnet-rich gneisses for which a sedimentary origin seems more probable.

5.2. The origin of the white gneisses (the homogeneous biotite gneisses)

The white gneisses display a number of 'igneous' features. They are often very homogeneous, lacking any banding. They are generally only faintly foliated. They often contain numerous angular inclusions, which themselves are dissected by veins of white gneiss. Even dykes of white gneiss occur.

For these reasons it would seem obvious to regard the white gneisses as orthogneisses. There are, however, a number of objections to this idea. 1) White gneisses often occur as layers in between other gneiss types, locally even as larger stratigraphic horizons. 2) There are gradual transitions between the larger white gneiss bodies and the country rock. 3)

Over fairly large areas the white gneisses form as it were a 'ground mass' in which hosts of gneiss and amphibolite bodies are enclosed. 4) Petrographically the differences between the white gneisses and the banded biotite gneisses are small and the two types of gneisses grade into each other.

These points do not exclude the possibility that the white gneisses have an igneous origin, but they are more easily explained if one assumes that the white gneisses had a local origin. The author thinks that the white gneisses formed from metasediments of roughly a white gneiss composition, and that these rocks became highly mobile during metamorphism. Possibly the process should be described as anatexis, but this is not sure. It seems that in nature there is a gradual transition between more or less solid rock via mobile, but not molten, rock material to really (partially) molten rock. This phenomenon has been described for example by ZWART (1965, section 3.4 and section 5). Many of the properties of the white gneisses would be easy to understand on the assumption that they formed in situ through mobilization of part of the metasediments.

5.3. The origin of the migmatites

The investigations of MEHNERT (1953a, b, 1962) in the Black Forest have shown that anatexis plays an important role for the development of migmatites. The experimental work of WINKLER (1967), VON PLATEN (1965), KNABE (1966) and others confirmed MEHNERT's field observations, and proved that in the high temperature part of the amphibolite facies anatexis should be expected. At this moment the interpretation of migmatites as the results of anatexis seems to be the only one well founded by experimental and quantitative petrographical experience. It is therefore appropriate to investigate in how far our data fit in with MEHNERT's and WINKLER's results. It will be shown that important differences between the experimental results and the observations occur.

5.3.1. The composition of the leucocratic veins

KNABE (1966) investigated experimentally the anatexis of rocks which, even under high grade metamorphism, do not contain alkali feldspar. He showed that, for 2000 bar H_2O pressure and temperatures between 690 °C and 720 °C, leucocratic granodioritic melts form with 10–25 % alkali feldspar. The potassium needed for the formation of the alkali feldspar derives from the incongruent melting of the biotite in the original rocks (which in KNABE's experiments contain 12–37 % biotite). One of KNABE's samples (Meta-Grauwacke II) contains quartz 45 vol %, plagioclase (An 21), 40 %, alkali feldspar 0.9 %, biotite 12 %, chlorite

0.9 %, muscovite 0.8 %, and compares well with our biotite gneisses. This sample gave rise to anatectic melts with 13 % alkali feldspar. With rising temperature, even over 800 °C, the composition of the melt remains granodioritic (10 % alkali feldspar being present in the melt of Meta-Grauwacke II) although more than half of the rock is molten (in Meta-Grauwacke II 85 %).

These results are in striking contrast with the data obtained from the Greenland area. Although a number of leucocratic veins contain alkali feldspar, the majority of the veins is quartz-dioritic. In outline, the leucocratic veins have the composition of the banded biotite gneisses and the white gneisses (see fig. 17), the only distinct difference being their lower content of dark minerals.

Also in the Black Forest the leucocratic veins (the leucosome) often are devoid of alkali feldspar (MEHNERT, 1962). MEHNERT explains this by the lack of alkali feldspar in the paleosome, but, since the latter is rich in biotite, alkali feldspar should have formed all the same, if in nature anatexis followed the same course as in the experiments.

5.3.2. The composition of the plagioclase in the leucocratic veins

WINKLER and VON PLATEN (1961) have shown that during melting experiments on natural rocks, the plagioclase behaves more or less according to BOWEN's (1913) well known phase diagram, but melting occurs at much lower temperatures. This means that the plagioclase in the melt is much more Na-rich (generally it is albite) than that in the crystalline rest or in the original rock.

Plagioclase in the investigated leucocratic veins from the area mapped is oligoclase to andesine. The histograms of fig. 10 show that there is a decrease in An content of the plagioclase from amphibolites over hornblende-biotite gneisses to the biotite gneisses, and that the leucocratic veins, with regard to the composition of the plagioclase, compare with most of the gneisses. The only leucocratic veins that do contain albite are those that clearly show dilatational effects on the country rock. These are rare. Probably they are the youngest pegmatitic veins.

Also in the Black Forest the plagioclase in the leucosome, the melanosome and the paleosome have more or less the same composition (MEHNERT, 1962), even so that a paleosome with andesine gives rise to andesine in the leucosome, and a paleosome with oligoclase gives oligoclase in the leucosome. MEHNERT assumes that, after the anatexis and after the solidification of the leucosome, an equilibrium was established between the plagioclase in the leucosome, in the melanosome and in the paleosome. The present writer thinks that this assumption is too speculative since it is not supported by petrographic observations. Differences in

An content, even in one and the same crystal, are very common, also in metamorphic rocks (see for example fig. 11). This means that even in a single crystal equilibrium was not attained. Moreover, a leucocratic vein in ultramatic rock (71752) also contains oligoclase (An 23–25).

5.3.3. The field relationships

The field characteristics of the migmatites described here are quite different from those in what one might call the type area of anatectic migmatites, the Black Forest. In the Black Forest there is a clear difference between the paleosome (mainly gneisses) the melanosome (mainly very biotite-rich schistose rocks) and the leucosome (the white veins). In the Greenland area a typical biotite-rich melanosome occurs only exceptionally. Generally the same gneisses and amphibolites which also may be found unmigmatized occur as the dark part of the migmatites. Seemingly almost only paleosome and leucosome occurs. In section 5.3.1 the possibility was discussed that the dark gneisses and amphibolites themselves could be a melanosome, but this seems very improbable.

5.4. Conclusions

The main rock types in the area are banded gneisses and amphibolites, which are strongly migmatized. Among the banded rocks a gradual transition has been demonstrated between biotite gneisses over hornblende-biotite gneisses to amphibolites. These rock types are interbanded on all scales. Most of the banded rocks are interpreted as metasediments. The biotite gneisses are supposed to derive from ancient greywackes or quartz-plagioclase arkoses, the amphibolites from basic tuffs and lavas, and the hornblende-biotite gneisses from sedimentary mixtures of these two materials (sections 4.5 and 5.1).

Two types of amphibolites seem to be present, one probably of tuffaceous origin, the other of unknown origin. The two types differ in plagioclase: quartz ratio and a number of other petrographic properties, among others the presence of diopside and/or garnet in the second type (sections 3.2, 3.3 and 4.7).

Locally in the area homogeneous, leucocratic biotite gneisses occur with almost granitic textures. They agree in mineralogical composition rather well with the banded biotite gneisses, but they contain less biotite, and locally more microcline. The origin of these rocks is not quite clear. Locally they seem to have been highly mobile and able to intrude into the banded rocks. They are tentatively supposed to be formed by mobilization of leucocratic metasedimentary gneiss (sections 2.3, 4.3, 4.4 and 5.2).

Leucocratic veins occur as a major rock type throughout most of the area. Several types of veins can be discerned. There are thin white veinlets parallel with the banding of the rocks, which seem to belong to the gneisses proper, and thicker concordant and discordant veins which do not seem to have affected the gneisses and amphibolites appreciably (section 2.1).

The origin of the leucocratic veins is discussed. Their petrographic properties seem to rule out the possibility that they originated by anatexis in situ — if the experiments of WINKLER, VON PLATEN, KNABE and others (WINKLER, 1967) adequately illustrate natural anatexis. This, however, is not necessarily the case, since also in the Black Forest, where anatexis seems to be convincingly demonstrated in the field, the results do not agree with the experimental findings (MEHNERT, 1962).

The rocks in the area described here have much in common with those recently described by MISCH (1968) from the Cascade Mountains. Also in the Cascade Mountains the composition of the leucocratic veins and the composition of the plagioclase they contain are in contradiction with what one would expect on the base of the experiments. The present writer, however, does not think that these facts alone (sections 3.1.4 (plagioclase) 4.8, 5.3) exclude the possibility that the veins originated by anatexis.

The most important argument against the origin of the migmatites by anatexis in situ is that they do not in the field look like typical anatectic migmatites (compare section 2.1 with the description of the Black Forest migmatites by MEHNERT, (1953a, b).

It is possible that the thin concordant veinlets in the gneisses originated by anatexis in situ, and that the majority of later, mostly discordant, leucocratic veins originated by anatexis at greater depth and emplacement of the material at a higher level. This would also be better in accordance with the degree of metamorphism of the rocks, anatectic processes being most characteristic for the high temperature part of the amphibolite facies, whereas the gneisses and amphibolites here probably belong to the lower temperature part of the amphibolite facies (section 3.7)

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APPENDIX

Tables I–X

The tables are built up in the following way:

First is given GGU's sample reference number. Then the locality is given in coordinates according to the kilometre grid shown on the Greenland 1:20000 topographical maps. This grid is indicated on the map (plate 5).

The mineral content of most samples is determined with the help of a Swift point-counter. The reliability of the results can be judged with the help of the diagram fig. 3, when using the number of points counted (N) and the average number of points per crystal (p.p.c.) as given on the right hand side of the tables. For non-homogeneous thin sections (for example showing bands with variable mineral content) no p.p.c. number is given. These samples are indicated by n.h. (non homogeneous) in the p.p.c. column. Minerals present in the samples, but not hit during the point-counting have been indicated with +.

In the column showing the An content of plagioclase, the whole range of measured An contents is given with, between parentheses, the number of measurements. Most measurements were made on homogeneous crystals. For zoned crystals the An contents in the cores is indicated with c, those in the rims with r. The An contents shown in table X have been determined in the different thin sections present for each sample.

Generally, secondary minerals have not been point-counted separately. For example, chlorite was counted either as biotite or as hornblende. The presence of chlorite in the sample is in those cases indicated with +. Actinolite in a number of samples is secondary after hornblende. In a number of samples of amphibolites, the amount of hornblende replaced by actinolite is indicated as for example 51.4 + (4.0). In this case, of the original 55.4 % of hornblende, 4.0 % is replaced by actinolite. Also in other samples, in which it is not indicated, minor parts of the hornblende may be replaced by actinolite. Epidote is counted apart, since it is often not clear which mineral it replaces. All saussurite is counted as plagioclase.

In tables VII and IX the mineral content of a number of samples is visually estimated. The following symbols have been used: • very small amounts, + small amounts, x important amounts, xx large amounts.

In table VIII combined point-counter results of several thin sections of the same sample have been shown. The following notation is used: N 2000/8 means 2000 points counted, spread over 8 thin sections, p.p.c. 1.63/2 means that the p.p.c. number is an average of two determinations in two different slides.

Table I a. Mineral content of banded biotite gneisses without hornblende

number	locality	quartz	plagioclase	microcline	hornblende	biotite	white mica	chlorite	epidote	opaque	sphene	apatite	allanite	zircon	garnet	% An in plag.	N	p.p.c.
70008	68.2–174.3	27.4	60.5	..	..	11.4	..	+	0.5	0.1	+	0.1	+	+	..	31–33(5)	800	1.10
—	—	30.1	56.0	..	..	12.4	..	+	0.9	0.1	0.1	0.2	+	+	..	32–36(4)	800	1.15
70035	66.8–177.1	25.4	56.7	1.4	..	14.1	+	..	2.0	0.1	0.3	0.1	..	+	..	20–21(3)	1000	1.24
70052	64.3–171.2	25.3	59.9	..	..	13.4	+	+	1.0	0.1	0.1	0.4	+	+	..	19–22(3)	800	1.31
—	—	26.0	57.6	..	..	12.4	1.0	+	2.0	0.5	+	0.3	+	+	..	21–22(5)	800	1.17
70064	66.8–171.8	35.1	47.3	..	..	13.6	..	+	3.8	0.1	..	0.1	..	+	..	24–27(4)	800	1.11
—	—	34.3	47.1	..	..	12.4	..	+	4.6	+	..	0.1	..	+	1.5	25–27(5)	800	1.08
70126	64.1–179.2	22.9	58.8	0.9	..	16.5	+	..	0.3	+	0.4	+	0.3	+	..	26–27(5)	800	1.23
—	—	24.3	59.0	0.5	..	14.6	+	..	0.6	+	0.4	0.1	0.5	+	..	23–26(5)	800	1.29
70128	65.2–177.2	37.0	53.2	..	+	7.7	0.4	+	1.4	+	0.1	0.1	+	+	0.1	c 24–27(5) r 16(1)	800	1.21
—	—	29.9	56.3	..	+	9.5	+	+	4.3	+	0.1	+	+	+	+	26–27(8)	800	1.13
70239	49.9–173.1	33.8	49.1	9.0	+	8.0	..	..	+	+	0.1	+	+	+	..	23–25(5)	800	1.19
—	—	27.3	57.1	6.3	+	9.0	..	..	0.1	0.3	+	+	+	+	..	23–25(6)	800	1.11
70269	48.4–176.1	34.1	53.1	0.8	..	11.3	+	+	0.5	0.1	..	0.1	+	+	..	c 23–27(5) r 24(1)	800	1.26
70343	51.0–176.3	26.9	61.6	..	..	10.7	..	..	0.2	+	0.1	0.4	+	+	..	22–23(4)	800	1.17
—	—	26.5	63.4	..	..	9.5	..	..	0.4	+	+	0.3	+	+	..	22–23(4)	800	1.25

Table I b. Mineral content of banded biotite gneisses with some hornblende

number	locality	quartz	plagioclase	microcline	hornblende	biotite	white mica	chlorite	epidote	opaque	sphene	apatite	allanite	zircon	garnet	% An in plag.	N	p.p.c.
70011	68.2–174.3	23.3	50.4	..	5.5	16.6	..	+	4.0	0.1	+	0.1	+	+	..	29–36(6)	800	1.05
—	—	20.5	66.3	..	0.4	11.6	..	+	0.9	0.1	0.2	+	+	+	..	30–35(6)	800	1.11
70109	65.8–178.7	31.9	45.8	..	5.8	15.3	..	+	1.0	+	0.1	0.3	+	+	..	24–26(5)	800	1.20
70157	62.8–172.7	26.5	50.4	..	2.4	16.0	..	+	3.6	+	0.8	0.1	..	0.1	0.1	25–27(3)	800	1.07
—	—	29.8	50.6	..	1.4	14.0	..	+	3.9	+	0.1	0.3	..	+	..	25–27(4)	800	1.11
70160	60.8–176.0	23.0	53.6	..	2.2	19.6	..	+	1.6	+	..	0.1	+	+	..	27–31(5)	1000	1.17
70254	53.5–177.2	19.1	64.0	1.0	0.8	13.9	..	..	0.3	0.1	0.3	0.1	0.5	+	..	24–27(5)	800	1.22
—	—	19.1	62.1	1.8	..	15.9	..	..	0.3	0.1	0.4	0.3	0.1	+	..	23–25(5)	800	1.20
70268	48.0–176.6	28.1	54.0	..	0.8	16.6	..	+	+	0.5	+	+	+	+	..	25–28(5)	800	1.25

Table II. Mineral content of white gneisses from the homogeneous masses.

number	locality	quartz	plagioclase	microcline	hornblende	biotite	white mica	chlorite	epidote	opaque	sphene	apatite	allanite	zircon	% An in plag.	N	p.p.c.
70047	58.2–178.6	28.5	51.3	13.8	..	5.9	0.1	..	+	0.3	+	0.3	..	+	22–23(5)	800	1.15
—	—	32.5	43.9	20.4	..	2.8	+	..	0.5	+	+	+	..	+	22–23(7)	800	1.13
70134	63.6–172.0	22.4	69.5	1.0	..	6.3	+	..	0.6	+	..	0.3	..	+	c22–23(5) r13(1)	800	1.14
—	—	24.5	67.3	1.3	..	6.9	+	..	0.1	+	..	+	..	+	22–23(5)	800	1.20
70136	64.0–172.5	22.9	72.5	0.3	..	3.4	0.3	+	0.6	..	..	+	+	+	23–26(4)	1000	1.22
70175	58.0–170.6	22.1	43.7	26.9	..	6.3	..	+	0.1	..	0.3	0.1	0.3	0.1	21–24(5)	900	1.14
—	—	24.0	49.8	19.4	..	5.8	..	+	0.5	..	0.1	0.4	+	+	23(3)	1000	1.16
70213	53.4–177.4	30.0	46.8	13.3	..	6.1	3.1	..	0.4	+	+	0.1	0.3	+	c21–22(4)r1-15(3)	800	1.16
—	—	26.5	45.9	13.4	..	8.5	3.9	..	0.9	0.3	0.1	0.3	0.1	0.1	c20–22(3) r0–4(2)	800	1.17
70217	56.5–172.5	32.6	47.4	11.7	..	5.9	1.4	..	0.4	+	+	0.3	0.4	+	24–25(5)	800	1.36
—	—	34.1	43.1	14.5	..	6.1	1.3	..	0.2	+	0.1	0.4	0.1	+	23–24(4)	800	1.38
70260	56.3–175.5	36.6	55.9	1.8	+	5.3	+	..	0.1	+	+	0.3	0.1	+	25–27(6)	800	1.76
—	—	31.8	58.5	0.4	0.1	8.8	+	..	0.4	0.1	+	+	+	+	25–26(3)	800	1.58
70290	65.8–171.8	37.3	57.5	0.6	..	1.3	2.7	..	0.4	+	..	+	..	+	20(2)	1000	1.35
70299	65.3–171.7	26.5	63.4	1.1	..	5.2	3.6	..	+	+	..	0.1	..	+	22–24(4)	1000	1.26
70345	52.2–176.9	23.1	52.7	8.7	..	12.3	0.6	..	1.0	0.1	1.1	0.2	0.1	+	22–23(3)	1000	1.20
—	—	19.9	55.9	8.6	..	11.5	1.8	..	0.4	0.1	1.6	0.1	0.1	+	21–23(2)	800	1.17
71673	57.1–172.4	25.9	43.0	19.4	..	0.1	1.3	..	0.1	0.3	0.3	0.4	0.3	0.1	22–25(3)	800	1.27
—	—	22.4	42.3	20.1	..	8.3	0.9	..	+	0.4	0.1	0.1	0.5	+	25–26(3)	800	1.30
71674	56.1–172.3	26.3	45.3	14.4	..	11.1	1.3	..	+	+	1.0	0.3	0.5	+	23–26(3)	800	1.24
—	—	24.1	50.3	13.4	..	9.4	1.8	..	0.1	0.1	0.6	0.3	+	+	23–27(4)	800	1.20
71695	51.7–174.4	28.9	33.9	30.8	..	6.1	..	+	0.1	+	..	0.1	0.1	+	25–26(2)	1000	1.19

Table III. Mineral content of other biotite gneisses (among others white gneisses from bands in the banded gneisses and amphibolites).

number	locality	quartz	plagioclase	microcline	hornblende	biotite	white mica	chlorite	epidote	opaque	sphene	apatite	allanite	zircon	carbonate	% An in plag.	N	p.p.c.
70026	66.6–173.5	28.8	61.9	..	..	7.9	..	+	1.3	+	0.3	+	+	+	..	25–26(5)	800	1.19
70034	79.4–175.3	36.3	59.8	..	..	1.5	+	+	2.5	..	..	..	..	+	..	26–28(3)	800	1.23
70065	66.9–171.7	37.9	57.5	1.0	..	1.4	0.1	..	2.1	..	..	+	..	+	..	18–21(4)	1000	1.13
70163	60.6–175.8	33.9	60.5	0.4	..	4.9	..	+	0.1	0.1	..	0.1	+	+	..	c 31–33(5) r 20(1)	1000	1.15
—	—	30.4	60.9	1.1	..	7.2	..	+	0.3	+	..	0.1	+	+	..	31–33(5)	1000	1.14
70244	46.6–175.3	22.6	65.6	..	0.1	11.5	..	+	+	+	..	0.1	+	+	..	32–35(6)	800	1.20
—	—	20.0	67.1	..	..	12.9	..	+	+	+	..	+	+	+	..	32–37(4)	800	1.19
70340	66.2–177.2	33.0	52.5	..	..	11.6	..	..	2.3	+	..	0.4	0.1	0.1	..	25–28(6)	800	1.26
70311	65.9–171.8	38.0	51.9	..	..	7.4	1.6	..	0.6	+	+	0.2	..	+	0.3	25–28(6)	1000	1.21

70026 Fine grained gneiss, discordant band in the surrounding rocks, possibly recrystallized crush zone.
70034–70340 Gneisses intermediate between the typical banded gneisses and the typical homogeneous gneisses, generally occurring as bands of homogeneous gneiss between banded amphibolites and gneisses.
70311 Homogeneous gneiss from a discordant dyke.

Table IV. Mineral content of the white gneisses and leucocratic veins compared in section 4.4.

number	locality	quartz	plagioclase	microcline	hornblende	biotite	white mica	chlorite	epidote	opaque	sphene	apatite	allanite	zircon	carbonate	% An in plag.	N	p.p.c.
70290	65.8–171.8	37.3	57.5	0.6	..	1.3	2.7	..	0.4	+	..	+	..	+	+	20(2)	1000	1.35
70296	65.4–171.9	20.8	70.9	2.5	..	4.6	0.2	..	1.0	..	..	+	+	+	..	22–23(4)	1000	1.16
70299	65.2–171.8	26.5	63.4	1.1	..	5.2	3.6	..	+	+	..	0.1	..	+	..	22–24(4)	1000	1.26
70300	65.2–171.8	25.9	66.5	0.2	..	4.0	2.8	+	0.4	0.1	..	0.1	..	+	..	22(3)	1000	1.44
70301	65.7–171.8	22.6	68.7	0.4	..	4.5	3.1	+	0.6	+	..	0.1	..	+	..	23–24(3)	1000	1.09
70305	65.3–171.7	28.7	64.9	1.4	..	1.6	2.9	+	0.5	+	..	+	..	+	..	22(1)	1000	1.33
70292	65.8–171.8	25.8	71.0	..	..	2.0	..	+	0.9	+	..	0.2	..	+	+	23–24(3)	1000	n.h.
70295	65.4–171.7	24.6	68.6	0.5	..	4.2	1.1	..	1.1	..	..	0.1	..	+	..	21–23(3)	1000	1.15
70293	65.8–171.8	34.6	58.5	..	..	6.0	..	..	0.1	..	0.3	0.5	..	..	..	25–26(5)	800	1.10
70297	65.4–171.7	26.5	68.8	0.1	0.8	2.9	..	..	0.8	+	+	+	..	0.1	..	23–25(3)	1000	1.24
70298	65.4–171.7	25.9	67.9	..	1.4	3.6	..	..	1.0	..	..	0.2	..	+	..		1000	1.22
70304	65.3–171.7	27.1	66.6	..	1.9	2.3	..	+	1.8	+	+	0.4	..	+	..	22–23(5)	800	1.43
—	—	26.0	68.5	..	0.8	2.1	..	+	2.5	+	+	0.1	..	+	..	22–23(5)	800	1.52

70290, 70296, 70299, 70300, 70301, 70305 are samples from the homogeneous gneiss mass.
70292 is a gneiss sample in direct contact with an amphibolite inclusion.
70295 is a gneiss sample in direct contact with an inclusion of hornblende-biotite gneiss.
70293, 70297, 70298 and 70304 are thin (several cm) veins in amphibolite inclusions.

Table V. Mineral content of hornblende-biotite gneisses.

number	locality	quartz	plagioclase	microcline	hornblende	biotite	clino-pyroxene	white mica	chlorite	epidote	opaque	sphene	apatite	allanite	zircon	garnet	carbonate	% An in plag.	N	p.p.c.
70010	68.2–174.3	10.2	56.4	..	20.2	10.3	..	..	+	1.4	0.2	0.9	0.3	0.1	+	..	..	30–33(5)	1000	1.10
70019	67.2–173.1	14.4	51.5	..	21.0	9.6	..	..	+	2.4	0.1	0.8	0.3	+	+	..	..	25–28(4)	800	1.15
—	—	12.9	50.4	..	20.8	12.3	..	..	+	2.9	+	0.8	+	+	0.1	..	..	26–27(5)	800	1.08
70020	67.2–173.1	9.6	48.0	..	25.0	11.0	..	..	+	2.2	0.6	3.0	0.6	+	..	..	..	25–27(5)	500	1.09
70022	67.1–172.7	22.4	46.0	..	12.3	13.8	..	..	+	4.4	0.4	0.4	0.5	+	+	..	..	29–32(4)	800	1.25
—	—	15.5	51.6	..	15.4	12.6	..	..	+	3.4	0.1	1.0	0.5	+	+	..	..	28–29(6)	800	1.14
70027	66.6–172.5	16.0	47.7	..	27.4	6.9	..	..	+	0.1	1.2	0.4	0.3	+	+	..	..	27–30(5)	1000	1.18
70037A	67.5–176.1	5.1	31.3	..	56.9	4.4	..	..	+	+	1.4	0.9	0.1	..	..	..	..	c26–28(5)	800	1.31
																		r23–26(3)		
— B	—	32.0	52.5	..	12.1	2.4	..	..	+	0.3	0.4	0.1	0.3	..	+	..	..	25–28(8)	800	n.h.
70054	60.0–171.1	8.8	50.1	..	32.5	8.0	..	..	+	0.3	+	0.1	0.2	..	..	..	..	28–31(4)	800	1.26
—	—	14.1	50.9	..	26.6	7.3	..	..	+	0.4	0.3	0.4	0.1	..	..	..	..	27–29(6)	800	1.27
70077	64.0–173.2	21.3	51.9	..	18.0	7.0	..	..	+	1.5	+	0.3	0.1	+	+	..	..	26–27(4)	800	1.06
70091	63.8–176.5	11.1	48.3	..	32.3	6.9	..	..	+	1.2	+	0.1	0.1	..	+	..	..	26–27(3)	800	1.24
—	—	13.1	47.9	..	31.8	5.4	..	..	+	1.3	+	0.4	0.3	..	+	..	..	27–28(2)	800	1.14
70107	65.5–177.7	11.4	48.3	..	19.1	14.5	..	..	+	4.5	0.1	2.1	+	+	+	..	..	27–28(4)	800	n.h.
—	—	16.1	45.8	..	23.0	10.5	..	..	+	2.3	0.3	2.1	+	+	+	..	..	27–29(4)	800	n.h.
70111	65.8–178.9	17.9	53.8	..	18.7	8.0	..	..	..	0.5	..	0.7	0.3	+	0.1	..	..	25–26(6)	1000	1.15
70117	64.2–176.8	9.0	35.4	..	30.0	25.5	..	..	+	+	+	..	0.1	+	+	..	..	25–28(4)	800	1.24
—	—	5.0	33.4	..	31.9	29.3	..	..	+	0.5	+	..	+	+	+	..	..	26–28(4)	800	1.19
70119	64.8–177.6	26.4	47.6	..	17.5	7.7	..	..	+	0.6	+	+	0.2	+	+	..	..	29–32(7)	1000	1.12
70172	53.7–177.7	6.0	42.1	0.4	42.8	..	4.9	..	..	2.5	..	1.0	0.4	+	+	..	..	25–27(4)	800	n.h.
70216	57.2–172.8	21.6	42.7	+	28.4	5.3	..	..	..	1.2	0.1	0.5	0.1	+	+	..	..	28–31(5)	750	1.17
—	—	22.1	46.5	0.3	20.1	9.0	..	..	..	1.1	+	0.5	0.4	+	+	..	..	28–32(4)	800	n.h.
70226	51.6–172.5	9.8	50.6	1.8	32.3	2.1	..	..	+	2.9	+	0.6	+	..	..	..	..	23–25(5)	800	n.h.
—	—	7.4	50.1	0.5	28.1	8.0	..	..	+	5.0	+	0.6	0.1	..	..	..	..	24–26(5)	800	n.h.
70233	53.0–174.0	10.0	45.8	..	38.2	2.3	..	+	..	3.5	..	0.3	+	+	..	..	..	23–26(5)	1000	1.19
70241	48.5–173.6	18.4	54.0	..	21.6	4.8	..	..	+	0.4	0.5	0.3	0.3	..	+	..	..	32–36(5)	1000	1.23
70243	47.0–174.6	17.1	49.1	0.1	22.6	10.0	..	..	..	0.2	+	0.4	0.2	0.1	..	..	..	c25–30(5)	800	1.12
																		r25(1)		
—	—	20.9	48.0	0.1	23.1	7.3	..	..	..	0.1	+	0.1	0.4	+	..	..	..	25–27(5)	800	1.16
70277	66.0–171.3	14.5	55.8	..	23.0	4.8	..	..	+	1.6	+	0.4	+	..	+	..	..	30–33(5)	800	1.32
—	—	17.1	54.4	..	23.9	3.1	..	..	+	1.1	+	0.1	0.3	..	+	..	..	29–32(6)	800	1.30
70306	65.8–171.7	4.9	26.4	..	57.6	2.7	..	..	+	+	1.3	+	0.2	..	..	6.4	..		550	1.13
—	—	6.3	27.2	..	56.8	3.1	..	..	+	0.3	1.0	+	0.3	..	..	4.5	..		500	1.13
70307	65.8–171.7	5.1	23.8	..	55.5	+	+	..	..	3.9	0.3	0.9	0.3	..	..	..	+	37–50(6)	800	1.20
—	—	5.1	30.1	..	60.5	+	+	..	..	3.4	0.3	0.1	0.3	..	..	..	+	38–41(5)	800	1.20

Table VI. Mineral content of amphibolites.

number	locality	quartz	plagioclase	microcline	hornblende (+actinolite)	diopside	garnet	biotite	chlorite	epidote	skapolite	opaque	sphene	apatite	allanite	zircon	carbonate	% An in plag.	N	p.p.c.
70021	67.1–172.7	..	32.9	..	54.4	8.9	..	0.1	..	3.7	..	+	+	+	..	..	..	46–50(5)	800	1.40
—	—	..	34.2	..	51.4 (+4.0)	3.9	..	0.5	..	5.6	..	+	0.2	0.1	..	..	..	42–60(5)	800	1.38
70040	67.4–177.4	..	3.6	..	85.9	..	..	6.1	..	2.4	..	+	1.1	0.9	+	+	..	37(1)	800	1.46
—	—	..	5.5	..	85.5	..	..	5.6	..	1.9	..	0.1	0.6	0.8	+	+	..	40(1)	800	1.29
70045	65.1–179.0	22.6	45.2	..	22.2	..	2.0	+	..	+	..	1.0	+	0.7	+	+	..	29–32(6)	800	1.24
—	—	19.7	41.1	..	30.1	..	0.7	6.6	..	+	..	1.0	+	0.2	+	+	..	30–31(6)	800	n.h.
—	—	26.4	46.0	..	21.2	..	1.2	4.1	..	0.5	..	0.2	+	0.2	+	+	..	30–31(5)	800	n.h.
—	—	19.0	44.6	..	24.9	..	1.2	8.5	..	0.2	..	1.2	+	0.2	+	+	..	29–31(5)	800	n.h.
70050	56.3–178.5	3.7	30.7	..	57.9	..	..	6.6	..	0.9	..	+	+	0.1	+	..	+	—	800	1.55
—	—	5.1	33.2	..	49.6	..	..	10.2	..	1.5	..	+	0.2	+	+	..	0.1	—	800	1.44
70079	66.6–173.7	14.7	23.9	..	49.0	2.1	0.7	+	..	5.2	..	0.7	2.6	0.9	..	..	..	42–46(3)	800	1.08
—	—	19.2	28.1	..	46.0	..	1.0	+	..	0.9	..	1.1	3.4	0.2	..	..	..	42–48(4)	800	1.18
70093	63.8–176.5	8.5	17.6	..	73.1	0.1	..	+	..	0.1	..	0.2	+	0.2	+	+	..	37–40(4)	800	1.28
—	—	19.7	28.8	..	50.6	+	0.6	+	..	+	..	0.4	+	+	+	+	..	c32–35(5) r29(1)	1000	n.h.
—	—	9.4	11.4	..	78.5	+	..	0.5	..	+	..	0.1	+	0.1	+	+	..	c35(4) r27–29(2)	800	1.38
—	—	16.9	30.6	..	52.1	+	..	+	..	+	..	0.2	+	0.1	+	+	..	c28–40(9) r28(1)	800	n.h.
70156	62.2–174.1	6.4	50.7	..	41.4	..	..	+	..	1.5	..	+	+	+	+	+	..	30–32(6)	800	1.25
—	—	3.0	38.7	..	53.9	..	..	1.0	..	2.5	..	0.2	+	0.6	+	+	..	30–32(5)	800	1.23
—	—	2.6	45.8	..	50.5	..	..	0.6	..	0.2	..	+	0.1	0.1	+	+	..	c32–36(2) r31(1)	800	1.25
—	—	6.4	51.6	..	40.4	..	..	+	..	1.6	..	+	+	+	+	+	..	31–32(4)	800	1.24
70161	60.8–176.0	1.0	30.1	..	66.9	..	..	1.5	..	0.2	..	0.2	+	+	..	..	..	c32–35(4) r28(1)	800	1.16
—	—	..	27.1	..	56.5 (+7.2)	..	..	+	..	8.1	..	+	0.5	0.1	..	..	..	37–45(2)	800	1.16
70197	66.7–175.9	7.0	28.6	..	63.6	..	..	0.5	..	..	..	0.1	..	0.1	+	+	..	c37–41(5) r28–31(3)	800	1.14
—	—	8.2	29.6	..	59.2	..	..	0.6	..	..	..	1.6	..	0.4	0.1	0.1	..	c37–42(5) r18–28(2)	800	1.20
—	—	5.7	27.6	..	65.4	..	..	0.1	..	..	..	1.0	..	0.1	+	+	..	c39(3) r27–28(2)	800	1.20
70236	53.0–174.3	..	13.2	..	71.9	..	..	14.9	..	+	..	+	+	+	..	..	..	26(1)	800	1.30
—	—	..	4.4	..	75.5	..	..	18.4	..	1.5	..	+	+	0.2	..	..	..	27(1)	800	1.68
—	—	..	6.1	..	71.5	..	..	21.1	..	1.1	..	+	0.1	+	..	..	..	—	800	1.50
—	—	..	12.7	..	71.1	..	..	16.1	..	+	..	+	+	+	..	..	..	26(1)	800	1.48
70247	46.2–174.4	12.3	54.6	..	30.5	..	..	+	..	0.4	..	+	0.9	0.4	+	..	..	27–30(4)	560	n.h.
—	—	16.0	48.4	..	31.5	..	..	0.3	..	3.0	..	0.1	0.4	0.1	0.1	..	..	26–29(5)	800	n.h.
—	—	12.2	48.5	..	31.2	..	..	+	..	6.9	..	+	0.5	0.4	+	..	..	c30–32(4) r27(1)	800	1.04
—	—	10.7	55.2	0.2	30.6	..	..	0.2	..	2.6	..	+	0.5	+	+	..	..	c27–30(5) r26–27(2)	800	n.h.

(continued)

Table VI (continued)

number	locality	quartz	plagioclase	microcline	hornblende (+actinolite)	diopside	garnet	biotite	chlorite	epidote	skapolite	opaque	sphene	apatite	allanite	zircon	carbonate	% An in plag.	N	p.p.c.
70258	56.3–175.5	0.6	37.3	0.4	38.7	18.2	..	..	..	2.0	..	0.5	1.4	0.1	..	..	..	c31–35(4) r3(1)	850	n. h.
—	—	+	38.4	+	44.6	12.7	..	..	..	2.5	1.2	0.4	1.1	0.1	..	..	..	c32–36(5) r27–32(3)	800	n. h.
—	—	+	32.1	+	51.7	13.4	..	..	..	1.7	..	+	0.9	0.1	..	..	..	c27–33(4) r24(1)	800	1.13
—	—	0.1	32.4	0.9	46.5	12.9	..	..	..	5.2	1.2	0.2	0.5	+	..	..	..	c31–36(5) r31–32(2)	800	n. h.
70303	65.7–171.8	6.9	26.0	..	53.6	..	..	10.6	+	1.4	..	0.1	1.4	+	+	..	..	24–26(6)	800	1.30
—	—	5.4	26.4	..	57.7	..	..	7.4	+	0.4	..	0.4	2.2	0.1	+	..	..	24–26(5)	800	1.26
70308	65.8–171.7	9.9	19.6	..	63.0	..	7.5	..	..	+	..	+	+	+	..	..	..	c38–40(4) r32–33(2)	800	1.12
—	—	11.5	21.6	..	60.5	..	5.4	..	..	+	..	1.0	+	+	..	..	..	38–42(6)	800	1.15
—	—	10.5	20.7	..	62.2	..	6.2	..	..	+	..	0.2	+	+	..	..	..	c39–45(5) r32–37(3)	800	1.24
71615	63.5–176.0	0.7	34.2	..	64.9	..	..	+	..	+	..	0.1	+	+	..	..	..	c37–41(5) r23–33(2)	800	1.19
—	—	1.5	31.9	..	66.0	..	..	+	..	0.2	..	0.1	0.2	+	..	..	..	c20–45(6) r25–32(4)	800	1.14
71620	63.5–176.0	2.4	32.0	..	59.5 (+2.1)	..	..	0.1	+	3.4	..	+	0.1	0.2	..	..	..	c28–36(5) r23–29(2)	800	1.25
—	—	2.7	28.2	..	64.7 (+2.2)	..	..	0.1	..	1.7	..	+	0.1	+	..	..	..	c28–32(5) r33(1)	800	1.31
—	—	3.2	30.9	..	63.0	..	..	0.1	..	2.5	..	+	0.1	0.1	..	..	..	c27–32(6) r29(1)	800	1.20
—	—	3.0	30.1	..	53.0 (+5.9)	..	..	0.2	..	8.2	..	0.2	0.2	+	..	..	..	c28–35(5) r24–27(2)	800	1.26
71633	65.8–175.6	4.1	31.9	..	57.7	4.7	0.1	..	..	0.9	..	0.4	0.1	+	..	..	..	c40–45(4) r32–35(4)	800	1.20
—	—	4.4	37.2	..	50.7	5.7	+	..	..	0.6	..	0.7	0.5	+	..	..	..	39–43(4)	800	1.09
71634	—	0.2	35.5	..	47.1	16.1	..	+	..	0.4	..	+	0.4	+	..	+	..	38–40(4)	800	1.14
—	—	5.7	30.2	..	52.1	10.6	..	0.1	..	0.7	..	0.1	0.1	0.1	..	+	..	c36–38(5) r33(1)	800	n. h.
71649	62.3–175.9	7.9	24.1	..	62.2	5.4	..	..	..	+	..	0.1	+	0.2	..	..	..	32–36(5)	800	1.69
—	—	9.6	27.1	..	60.1	2.9	..	..	..	+	..	+	0.1	0.1	..	..	..	33–36(5)	800	1.67
71657	60.3–171.6	3.0	13.2	..	72.6	..	..	11.1	+	..	..	+	+	+	..	..	..	30(3)	800	n.h.
—	—	2.6	11.6	..	78.2	..	..	7.4	+	..	..	0.1	+	+	..	..	..	c30–31(6) r24–27(3)	800	n.h.
—	—	3.2	15.6	..	74.0	..	..	7.0	+	..	..	0.1	+	+	..	..	..	c29–31(4) r7(1)	800	n.h.
—	—	4.9	13.5	..	72.7	..	..	8.6	+	..	..	0.2	+	+	..	..	..	29–31(5)	800	n.h.
71663	62.8–172.0	0.1	33.4	..	61.6	..	..	4.9	..	+	..	+	..	+	..	?	..	30–36(5)	800	1.22
—	—	+	25.5	..	68.2	..	..	6.2	..	+	..	+	..	+	..	..	..	c40(3) r37(1)	800	1.19
71666	62.8–172.3	..	42.0	..	47.4 (+0.1)	8.9	..	+	..	1.1	..	0.4	..	0.1	..	..	..	38–45(5)	800	1.18
—	—	..	43.0	..	48.9 (+0.7)	5.7	..	+	..	1.4	..	0.1	..	0.1	..	..	..	38–42(7)	800	1.42

(continued)

Table VI (continued)

number	locality	quartz	plagioclase	microcline	hornblende (+actinolite)	diopside	garnet	biotite	chlorite	epidote	skapolite	opaque	sphene	apatite	allanite	zircon	carbonate	% An in plag.	N	p.p.c.
71668	62.8–172.3	12.4	41.0	..	45.4	..	..	+	..	1.0	..	0.1	+	+	+	0.1	..	27–33(5)	800	n.h.
—	—	12.5	41.6	..	39.2 (+4.4)	..	..	+	..	2.2	..	+	+	+	+	+	..	c27–33(5) r28(1)	800	n.h.
71672	57.7–172.8	+	29.6	..	69.9	..	..	+	..	0.4	..	+	+	+	..	..	..	28–30(5)	800	1.14
—	—	0.9	37.0	..	61.6	..	..	0.4	..	0.1	..	+	+	+	..	..	..	27–28(3)	800	n.h.
71677	51.4–173.8	3.9	38.2	..	53.2	..	..	3.5	+	0.1	..	+	0.9	0.1	+	..	..	27–28(4)	800	1.32
—	—	9.2	54.7	..	28.1	..	..	6.2	+	0.9	..	+	0.7	+	+	..	..	28–29(4)	800	1.10
—	—	2.6	33.6	..	58.2	..	..	4.6	+	0.5	..	+	0.4	+	+	..	..	24–29(4)	800	1.33
71682	47.7–174.8	..	26.5	..	61.3	..	..	12.1	+	+	..	+	+	0.1	+	..	..	c32–39(4) r30–32(3)	800	1.36
—	—	..	27.6	..	61.7	..	..	10.6	+	+	..	+	+	+	+	..	..	c32–36(4) r31–32(2)	800	1.32
71688	46.6–175.7	1.4	25.1	..	69.7	..	..	2.2	+	0.1	..	0.1	1.1	0.1	..	..	..	—	800	1.31
—	—	2.1	28.4	..	65.4	..	..	1.7	+	0.2	..	0.2	1.7	0.1	..	..	..	c27–29(3) r25(1)	800	1.34
71691	52.5–175.5	7.0	29.2	..	61.2	..	..	0.7	..	0.4	..	0.1	1.0	0.2	+	..	..	24–27(5)	800	n.h.
—	—	5.2	31.1	..	60.7	..	..	1.2	..	0.4	..	+	1.2	+	+	..	..	c24–26(5) r22(1)	800	1.27
71699	52.4–173.8	1.0	25.2	+	71.6	..	..	1.6	+	0.2	..	0.2	+	+	..	..	..	c24–29(3) r22(1)	800	n.h.
—	—	4.9	27.9	0.1	66.4	..	..	0.1	..	0.4	..	0.1	0.1	+	..	..	..	c23–25(4) r22(1)	800	1.08
71714	52.9–174.3	..	34.2	..	64.7	..	..	+	+	0.5	..	+	0.2	0.1	..	..	..	c36–40(6) r32(3)	800	1.23
—	—	..	31.4	..	67.1	..	..	0.4	+	0.9	..	0.1	+	0.1	..	..	..	36–40(6)	800	1.16
71715	53.3–175.4	..	30.6	..	69.0	..	..	+	+	0.4	..	+	..	+	..	..	..	c65–86(3) r68(1)	800	1.17
—	—	..	28.5	..	71.5	..	..	+	+	+	..	+	..	+	..	..	..	—	800	1.20
71729	60.2–177.5	2.9	15.1	..	74.3	7.7	..	+	..	+	..	+	+	+	..	..	..	22–24(5)	800	1.19
—	—	4.4	17.2	..	70.9	7.2	..	+	..	+	..	+	0.2	+	..	..	..	22–23(5)	800	1.23
—	—	3.6	15.5	..	73.7	6.7	..	+	..	+	..	+	0.1	0.2	..	..	..	23–25(4)	800	1.30
—	—	4.9	12.6	..	74.2	7.4	..	+	..	0.7	..	0.1	+	+	..	..	..	23–25(4)	800	1.30
71732	60.9–177.8	1.5	31.1	..	63.1	..	..	1.2	..	0.6	..	+	2.4	+	..	..	..	25–27(4)	800	1.26
—	—	2.5	32.7	..	57.6	..	..	3.2	..	1.6	..	0.2	2.0	+	..	..	..	c24–26(5) r25(1)	800	1.34
71735	61.8–177.5	16.9	12.9	..	69.2	0.2	..	0.5	..	0.1	..	+	..	0.1	..	..	..	26–27(3)	800	1.18
—	—	10.2	6.7	..	81.0	0.4	..	1.2	..	0.1	..	0.2	..	+	..	..	..	25–27(6)	800	1.45
—	—	11.1	12.4	..	72.4	..	..	4.1	..	+	..	+	..	+	..	..	..	c27–28(3) r24(3)	800	1.30
—	—	10.9	7.6	..	79.5	1.1	..	0.6	..	+	..	0.2	..	+	..	..	..	25–27(4)	800	1.50
—	—	12.1	9.9	..	75.4	..	..	2.6	..	+	..	+	..	+	..	..	..	25–28(4)	800	1.44
71737	63.8–177.0	9.4	35.9	..	45.0	..	..	4.7	0.2	2.7	..	0.1	0.5	+	..	..	1.4	c32–35(5) r27–30(2)	800	1.28
—	—	8.0	44.6	..	42.1	..	..	2.1	0.6	1.6	..	0.1	0.2	0.1	..	..	0.4	31–35(6)	800	n.h.
—	—	10.5	35.5	..	50.1	..	..	2.6	+	1.0	..	+	+	+	..	..	0.2	30–33(6)	800	1.38
71744	57.0–178.5	4.1	36.7	..	53.5	..	..	4.6	+	0.6	..	+	0.4	+	..	..	..	25–28(2)	800	n.h.
—	—	3.9	35.1	..	57.2	..	..	2.6	+	0.9	..	+	0.2	+	..	..	..	c25–26(3) r23(1)	800	1.35

Table VII. Mineral content of garnet-rich gneisses and amphibolites.

number	locality	quartz	plagioclase	diopside	hornblende	biotite	garnet	epidote	light green amphibole	chlorite	opaque	sphene	apatite	zircon	allanite	% An in plag.	N	p.p.c.
70030	68.5–176.1	46.1	7.8	1.5	2.1	..	40.1	..	..	..	0.4	2.0	•	..	..	c45–50(3) r60–70(3)	1000	1.80
70079	66.6–173.7	x	xx	+	xx	•	x	x	..	..	+	+	+	..	..	c46–50(4) r55(1)		
70181	69.2–175.5	x	xx	..	xx	+	xx	•	..	•	+	..	+	•	..	21–22(3)		
70193	66.7–175.6	xx	x	xx	xx	..	xx	..	..	..	x	+	+	?	..	c60–80(3) r85(1)		
70201	67.2–177.4	xx	xx	x	xx	..	x	+	x	+	+	•	•	•	..	36(2)		
71747	66.7–175.5	34.2	8.0	9.1	8.7	..	37.1	1.4	+	..	0.6	0.8	•	•	..	c42–45(2) r58–62(2)	800	n.h.
—	—	45.6	11.9	3.1	3.7	..	32.9	0.7	+	..	0.9	1.0	0.1	•	..	c42–50(3) r65–70(3)	800	1.64
71748	66.7–175.5	xx	x	xx	xx	..	xx	•	x	..	+	+	+	•	..			
71749	66.7–175.5	xx	xx	xx	xx	..	xx	..	+	•	+	•	+	..	•	45–70(3)		
71750	66.7–175.5	13.1	11.9	..	60.1	..	11.6	..	..	•	2.8	0.2	0.2	?	•	c55 r82(1)	800	n.h.
—	—	14.9	11.9	..	50.1	..	20.1	..	..	•	2.8	0.1	0.1	?	•	60–80(4)	800	1.32
71761	68.5–176.2	xx	xx	..	xx	•	x	..	..	..	+	+	..	..	..	c48–53(3) r60(1)		

Table VII a. Chemical composition of the garnet from a garnet-rich amphibolite (sample no. 70193).

A		B		C	
SiO_2	38.21	6.069	6.069	almandine	55.6
TiO_2	0.48	0.057	4.038 (sum of TiO_2, Al_2O_3, Fe_2O_3)	spessartine	1.7
Al_2O_3	19.70	3.688		pyrope	15.0
Fe_2O_3	2.45	0.293		andradite	7.6
FeO	24.18	3.211	5.776 (sum of FeO, MnO, MgO, CaO)	grossular	20.0
MnO	0.75	0.101			
MgO	3.67	0.868			
CaO	9.38	1.596			
Na_2O	0.07				
K_2O	0.0				
P_2O_5	0.15				
H_2O^+	trace				
total	99.04				

A Chemical composition in weight %.
B Number of cations per 24 oxygens.
C Calculated composition in the different end-member molecules.

Table VIII. Mineral content of anorthositic gneisses.

number	locality	quartz	plagioclase	hornblende	biotite	garnet	epidote	chlorite	white mica	opaque	sphene	apatite	carbonate	% An in plag.	N	p.p.c.
70180	69.2–175.5	1.7	80.8	11.6	0.3	2.3	2.6	+	+	+	0.4	0.1	..		2000/8	1.63/2
70186	67.8–176.6	..	69.9	25.5	0.6	..	3.0	0.8	0.1	+	..	..	..		2000/8	1.48/2
70196	66.7–175.9	..	56.2	38.3	5.5	..	+	..	..	+	..	..	..	see	1000/1	1.58
70202	67.5–178.0	..	84.6	13.9	0.5	..	0.7	0.3	+	..	+	..	+	fig. 11	2000/8	2.18/2
70313	67.5–178.1	..	93.3	..	+	..	4.1	1.6	0.5	+	+	..	0.4		1400/4	1.85/2
70320	67.5–178.1	..	88.7	9.7	0.4	..	1.2	+	+	..	..	..	..		2000/5	2.02/2
70327	67.5–178.1	..	83.0	14.5	0.2	..	1.4	0.7	0.1	+	+	..	..		2000/5	1.53/2

Table VIII a. Chemical composition of an anorthositic gneiss, sample 70320.

	Weight %	Cation %	Catanorm		Mesonorm			Modus
SiO_2	49.45	45.0						(5 thin sections,
TiO_2	0.07	0.0	or	1.0	ab	26.4	plagioclase 91.9	total 2.000 points)
Al_2O_3	29.58	32.0	ab	27.0	an	65.5	with An 71	
Fe_2O_3	0.48	0.3	an	65.5				Plagioclase 88.7
FeO	1.29	1.0	ne	0.6				(An 77–83)
MnO	0.03	0.0						
MgO	1.23	1.7	di	2.8	bi	1.6		Biotite 0.4
CaO	14.08	13.8	ol	2.7 (fo 65%)	akt	0.3		
Na_2O	3.15	5.6			ed	5.2	hornblende 6.1	Hornblende 9.7
K_2O	0.20	0.2	mt	0.4	hy	0.6		Epidote 1.2
P_2O_5	0.02	0.0			mt	0.4		
H_2O	0.44	not calc.						
total	100.02	100.0			Niggli values			
					al	45	si 127	
					fm	8	k 0.04	
					c	39	mg 0.56	
					alk	8	qz ...... −5	

Table VIII b. Chemical composition of an anorthositic gneiss, sample 70196.

	Weight %	Cation %	Catanorm		Mesonorm			Modus
SiO_2	51.92	48.1	or	4.5				(1 thin section
TiO_2	0.17	0.1	ab	36.0	ab.–	34.0	plag. 67.2[5]	1.000 points)
Al_2O_3	19.57	21.4	an	33.2[5]	an	33.2[5]	with An 49%	
Fe_2O_3	1.91	1.3						Plagioclase 56.2
FeO	5.09	4.0	di	10.6	bi	7.2		(An 35–41%)
MnO	0.12	0.1	hy	4.7 (en 69%)	hy	3.6	hbl.	Biotite 5.5
MgO	5.42	7.5	ol	8.7 (fo 69%)	act	13.2	23.2	Hornblende 38.3
CaO	9.38	9.3			ed	6.4		
Na_2O	4.03	7.2	il	0.2	ti	0.3		
K_2O	0.82	0.9	mt	1.9[5]	mt	1.9[5]		
P_2O_5	0.04	0.0						
H_2O	1.44	not calc.						
total	99.91	99.9						

Niggli values

al	29	si	130
fm	35	k	0.12
c	25	mg	0.58
alk	11	qz	−14

Table IX. Mineral content of ultrabasic rocks.

number	locality	olivine	ortho-pyroxene	clino-pyroxene	phlogopite	colourless amphibole	light green amphibole	antho-phyllite	talc	serpentine	chlorite	biotite	opaque	spinel	carbonate	sphene	apatite	allanite
A 70074	64.9–172.4	xx	xx	..	+	..	xx	..	x	•	..	..	+	•	..	..	..	..
70150	60.6–171.6	xx	• or	•	x	x	..	..	+	+	..	..	+	..	•	..	..	..
70056	60.1–171.3	xx	..	..	x	+	..	..	+	..	+	..	+	..	+	..	..	..
70068	67.6–173.1	xx	..	..	•	+	..	..	•	xx	x	..	+	..	..	..	..	..
70190	66.8–175.4	xx	..	..	..	x	..	..	..	x	x	..	+	..	..	..	..	..
71606	67.3–173.4	xx	..	..	..	xx	..	..	•	..	+	..	+	..	..	..	..	..
B 71607	67.3–173.4	..	..	..	..	x	..	..	xx	..	+	..	+	..	..	..	..	..
70036	67.0–177.2	..	..	..	..	xx	+	..	xx	..	x	..	+	..	..	..	..	..
70053	64.4–172.0	..	..	..	..	x	xx	..	xx	..	+	..	+	..	..	..	..	..
C 70003	67.2–173.6	..	..	..	..	x	..	..	..	xx	+	..	x	..	•	..	..	..
70344	51.9–177.0	..	..	?	..	+	..	..	+	xx	..	..	+	..	..	..	..	..
D 70073	65.0–172.3	..	..	..	..	x	xx	x	..	..	x	..	+	..	..	..	..	..
70088	65.8–171.7	..	..	..	..	xx	..	..	+	..	+	..	•	..	..	..	..	..
70090	65.6–176.4	..	..	..	..	x	xx	..	..	..	x	..	+	..	..	+	..	..
70147	61.7–171.7	..	..	..	..	xx	xx		+		xx	•	•			+	•	..
70149	60.6–171.6	..	..	..	..	..	xx	..	..	..	..	x	•	..	..	..	..	•
71611	67.3–173.4	..	..	..	..	xx	xx	..	•	..	x	..	+	..	..	+	..	..

A. Olivine-rich samples. B. Talc-rich samples. C. Serpentine-rich samples. D. Actinolite/Tremolite-rich samples.

Table X. Mineral content of leucocratic veins.

number	locality	quartz	plagioclase	microcline	hornblende	biotite	white mica	actinolite	chlorite	epidote	opaque	sphene	apatite	allanite	zircon	garnet	% An in plag.	N	p.p.c.
70132	63.6–172.0	18.4	76.9	4.2	..	+	0.2	..	..	0.1	+	..	0.1	..	+	..	23–25(5)	800	1.53
—	—	36.7	60.5	2.0	..	+	0.2	..	..	+	+	..	0.5	..	+	..		800	n.h.
70133	63.6–172.0	13.7	76.0	0.9	..	8.2	..	..	..	0.1	..	..	0.9	+	0.1	..	23–25(5)	800	n.h.
—	—	13.7	77.1	1.2	..	7.1	..	..	..	0.2	..	..	0.5	+	+	..		800	n.h.
70164	60.6–175.8	42.2	19.6	35.9	..	0.9	+	..	+	+	1.4	..	+	..	+	..	22(1)	800	n.h.
—	—	39.6	23.4	36.5	..	0.5	+	..	+	+	+	..	+	..	+	..		800	n.h.
70174	53.8–177.7	39.0	56.5	3.1	..	1.4	+	..	+	+	+	..	+	+	+	..	24–25(3)	800	1.43
—	—	28.0	59.4	9.0	..	2.7	0.1	..	+	0.5	+	..	0.2	+	+	..		800	1.22
71605	67.6–173.3	38.2	59.4	0.2	1.6	+	+	+	..	0.1	0.1	0.1	0.1	..	+	..	30–31(5)	800	n.h.
—	—	34.5	63.5	+	1.4	+	+	+	..	0.5	+	0.1	+	..	+	..		800	n.h.
71637	66.3–175.7	34.7	57.5	..	..	7.4	+	..	+	0.1	0.1	0.1	+	+	+	..	30–32(6)	800	n.h.
—	—	42.2	49.6	..	..	8.1	+	..	+	+	+	+	+	+	+	..		800	n.h.
71638	66.3–175.7	35.9	62.6	..	1.2	+	+	..	+	+	+	0.2	+	+	..	..	33(1)	800	n.h.
—	—	39.1	60.6	..	0.1	+	+	..	+	+	+	0.1	+	+	..	..		800	n.h.
71639	66.3–175.7	33.6	62.8	..	+	2.6	..	..	+	1.1	..	0.1	+	+	+	..	32(1)	1000	1.52
—	—	29.2	63.9	..	+	5.1	..	..	+	1.5	..	0.1	+	0.1	+	..		800	1.75
71669	62.8–172.3	42.2	57.4	..	0.1	0.1	+	..	..	0.1	+	..	+	..	+	..	27–33(6)	800	2.44
—	—	37.4	62.4	..	..	0.1	+	..	..	+	+	..	0.1	..	+	..		800	1.85
71670	59.3–173.3	35.2	58.4	4.2	..	1.2	0.1	..	+	0.8	+	..	..	..	+	..	23–24(2)	800	n.h.
—	—	30.9	63.9	4.7	..	0.1	0.1	..	+	0.2	+	..	..	..	+	..		800	n.h.
71680	48.5–173.5	39.9	55.1	..	4.4	0.1	..	..	+	0.4	0.1	..	+	..	+	..	36–37(3)	800	n.h.
71694	51.7–174.4	36.5	61.2	1.4	..	0.4	+	..	+	0.5	+	..	..	..	+	..	25–26(4)	800	n.h.
—	—	40.5	48.2	10.4	..	0.1	+	..	+	0.8	+	..	..	..	+	..		800	n.h.
71697	51.7–174.4	33.1	56.5	7.7	..	1.5	..	..	+	1.0	+	..	+	0.1	+	..	24–25(3)	800	n.h.
—	—	35.4	49.6	12.7	..	1.5	..	..	+	0.8	+	..	+	+	+	..		800	n.h.
71704	50.2–175.6	37.6	61.6	0.4	..	..	..	..	+	0.2	+	+	..	+	..	0.1	0–6(4)	800	2.68
71705	50.2–175.6	30.0	58.0	11.6	..	0.2	+	..	+	0.1	+	+	..	..	+	..	6–9(4)	800	1.69
—	— —	28.9	63.0	3.2	..	0.4	0.2	..	+	0.6	3.2	+	..	..	+	..		800	n.h.
71752	66.8–175.3	32.0	64.7	..	..	1.5	0.4	..	..	0.1	..	..	..	..	1.2	..	23–25(9)	800	n.h.
—	—	29.9	67.1	..	..	1.2	1.0	..	..	+	..	..	..	..	0.8	..		800	n.h.
—	—	33.5	59.9	..	..	6.4	+	..	..	+	..	..	..	..	0.2	..		800	n.h.

Samples 71637, 71638 and 71639 represent three intersecting veins in one outcrop, see fig. 4.
Sample 71752 is a leucocratic vein in ultramafic rock.

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Færdig fra trykkeriet den 16. januar 1970.

PLATES

Plate 1

a. Biotite, partly replaced by albite. The twins in the large plagioclase (andesine) crystal run through in the albite bordering the biotite. Due to the different optical orientations in andesine and albite, the lamellae that appear light in the andesine are almost in extinction position in the albite and vice versa. Crossed polars. No. 70054, hornblende-biotite gneiss. Locality: 60.0–171.1.

b. Biotite, in contact with hornblende, partly replaced by actinolite. Crossed polars, No. 70121, hornblende-biotite gneiss. Locality: 65.0–178.2.

c. Anorthositic rock. Crossed polars. No. 70099. Locality: 67.2–177.6.

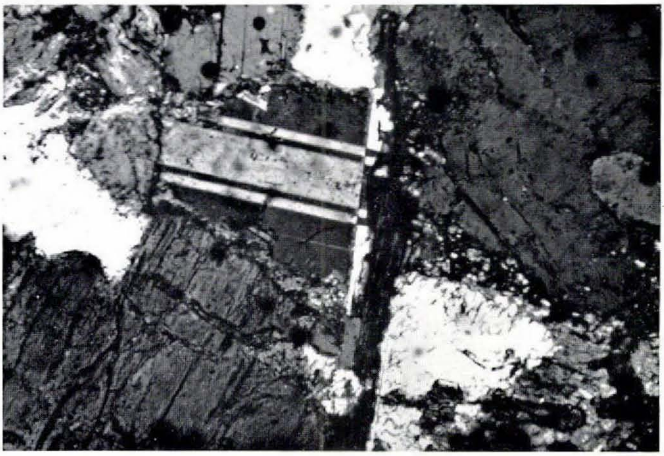


Plate 1 a

Plate 1 b

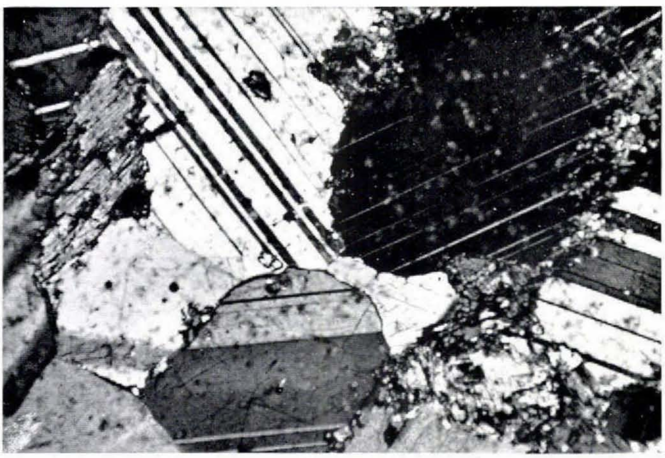


Plate 1 c

Plate 2

a. Biotite replacing chlorite, which itself is secondary after biotite. One polar. The countours of the biotite crystals have been accentuated with ink on the photograph. Due to the strong pleochroism of the biotite, some of the crystals appear dark and some light against the greyish tone of the chlorite. Due to trains of dust particles the cleavage of the old, chloritized biotite can faintly be followed through the new formed biotite. No. 71637, leucocratic vein. Locality: 66.3–175.5.

b. Myrmekitic intergrowths of epidote and quartz (?) Crossed polars. No. 70079, garnet amphibolite. Locality: 66.6–173.7.

Plate 2 a

1 mm

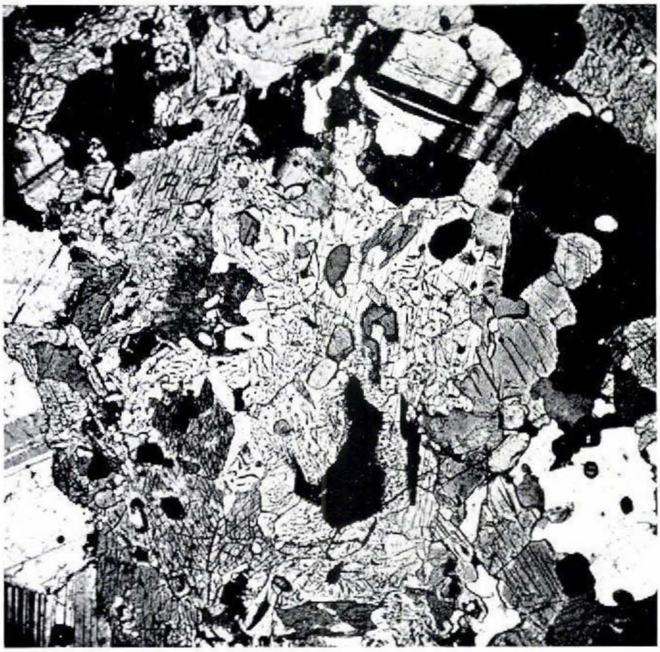


Plate 2 b

1 mm

Plate 3

a. Myrmekitic intergrowths of plagioclase and quartz (?) Crossed polars. No. 71747, garnet-rich gneiss. Locality: 66.7–175.5.

b. Hornblende, partly replaced by plagioclase. One polar. No. 71750, garnet amphibolite. Locality: 66.7–175.5.

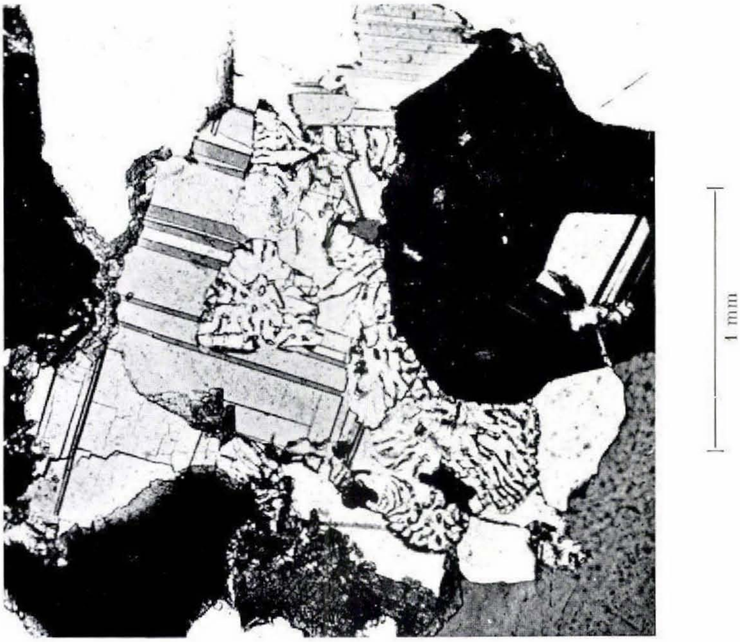


Plate 3 a

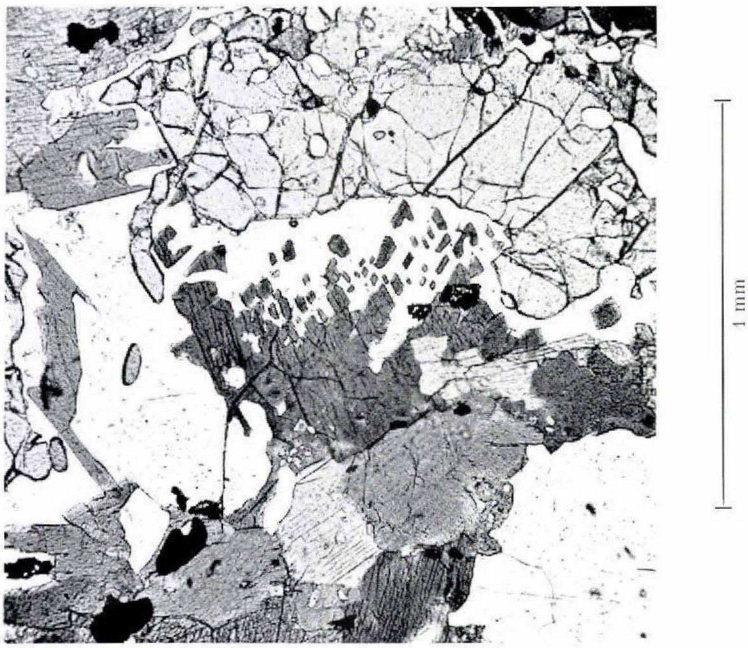


Plate 3 b

Plate 4

a. $(0\bar{5}1)$ lamellae in plagioclase from an anorthositic gneiss. In the upper part of the photograph the lamellae disappear, the An content of the plagioclase here being below 70 %. Crossed polars. No. 70099. Locality: 67.2–177.6.

b. As plate 4a. One polar.

c. $(0\bar{5}1)$ lamellae in plagioclase from an anorthositic gneiss, showing their relation with (010) and (001) directions. No. 70099.

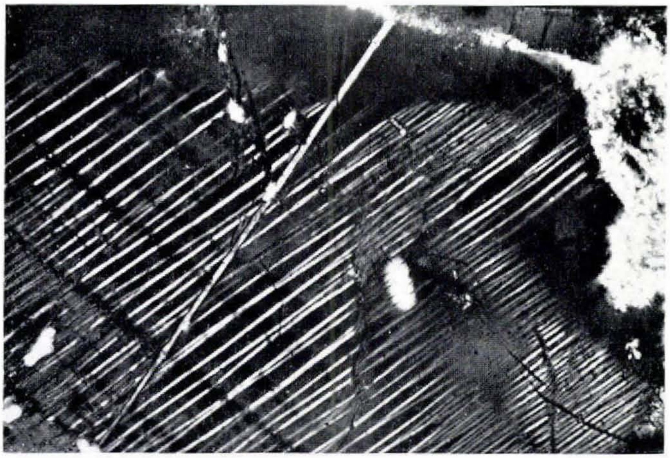


Plate 4 a

0.1 mm

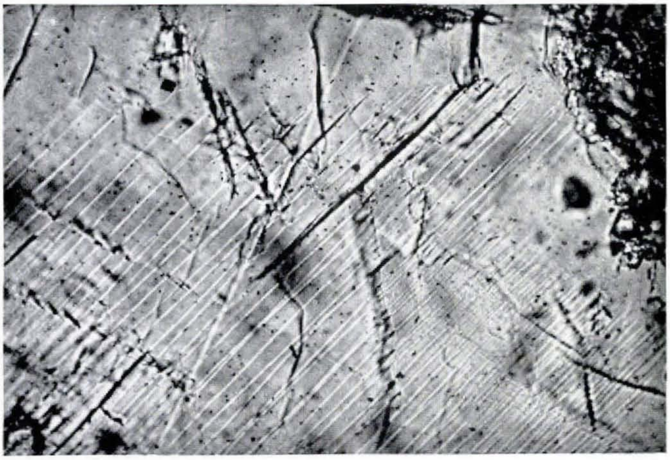


Plate 4 b

0.1 mm

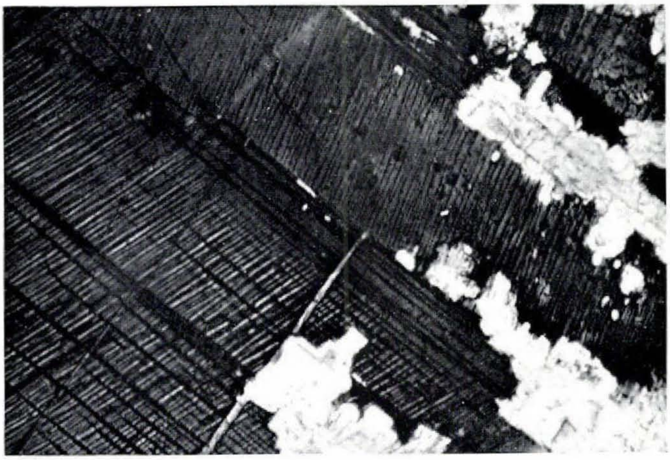


Plate 4 c

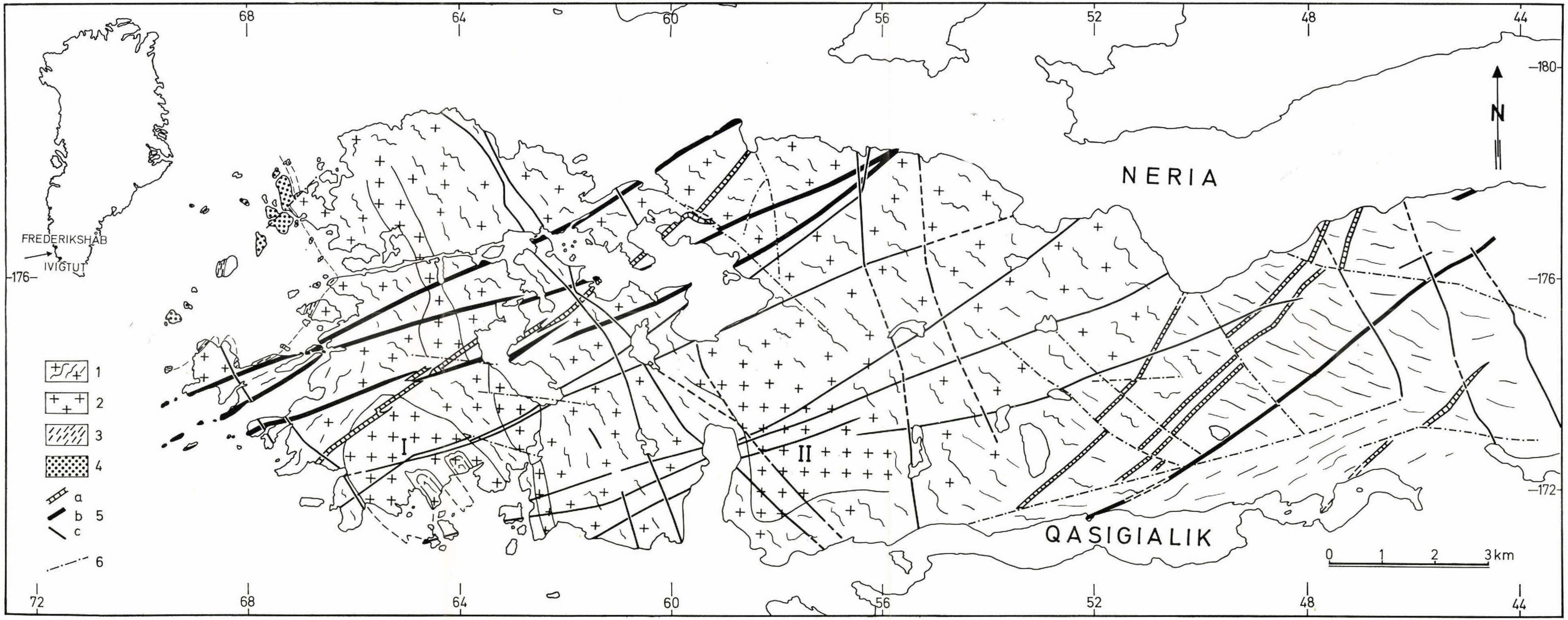
0.1 mm

Plate 5

Geological sketch map of the area between Neria and Qasigialik fjords, south-west Greenland.

1. Gneisses and amphibolites. The direction of the stripes roughly indicates the strike of the foliation. The density of crosses roughly indicates the degree of migmatization (the amount of leucocratic veins).
2. Homogeneous leucocratic biotite gneisses.
3. Garnet-rich gneisses and amphibolites with local ultramafic lenses (in the western part of the area).
4. Anorthositic gneisses (in the western part of the area).
5. Dolerite dykes of different ages.
6. Faults.

The Roman numbers I and II indicate the largest outcrops of homogeneous leucocratic gneiss, referred to in the text.


FREDERIKSHÅB
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QASIGIALIK
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176
172

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