GRØNLANDS GEOLOGISKE UNDERSØGELSE
BULLETIN No. 33

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BY

OEN ING SOEN

WITH 37 FIGURES AND 2 TABLES IN THE TEXT

Reprinted from
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CONTENTS

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Abstract.

Extensive zones of amphibolites and hornblendic rocks occur associated with biotite-plagioclase-quartz schists and garnet-biotite augen-gneisses, in the gneiss areas on NE. Tôrnârssuk and on the peninsula between Kuánit fjord and Tigssalûp ilua (Tigssaluk fjord) in SW. Greenland. Field and microscopic evidences show that these rocks have attained their present constitution mainly in the course of two metamorphic periods, referred to as the main and late-Ketilidian periods of metamorphism.

The first period of metamorphism took place under amphibolite facies conditions and is believed to have caused the formation of extensive hornblenditic and amphibolitic layers. Hornblenditic rocks are now only preserved as relics enclosed in rocks affected by the second period of metamorphism.

The second period of metamorphism in the Kuánit area and on NE. Tôrnârssuk occurred under epidote-amphibolite facies conditions. In the Kuánit area a metamorphic differentiation due to differential shearing took place within the hornblenditic layers and resulted in the formation of banded hornblendic rocks, consisting mainly of alternating bands of epidote-hornblende schists, quartz-hornblende schists, magnetite-hornblende schists, and amphibolites, while at places of strongest shearing biotite-plagioclase-quartz schists and tremolite schists were formed.

On NE. Tôrnârssuk biotite-plagioclase-quartz schists form more important zones or layers generally adjoining amphibolite horizons. Evidences are presented for the view that these schistose rocks are sheared and pegmatized, originally hornblendic rocks. The adjoining amphibolites are considered as feldspathized hornblendic rocks.

The garnet-biotite augen-gneisses and amphibolites in the area south of Tigssalûp ilua are believed to have a similar origin as, respectively, the biotite-plagioclase-quartz schists and amphibolites on NE. Tôrnârssuk. Mineralogical differences are due to the higher grade of the second metamorphism, which reached amphibolite facies conditions in the Tigsalluk area.

A third metamorphism during the Sanerutian period was apparently of a low grade or of a low intensity in the areas here under consideration, and it is not thought to have caused significant modifications in the rocks here described.

I. INTRODUCTION AND ACKNOWLEDGMENTS

In the years 1956, 1957 and 1958 a systematic mapping of the Ivigtut area, SW. Greenland, was undertaken by the Geological Survey of Greenland. Some results of this work has been reported by BERTHELSEN (1960), who is in charge of directing the geological work in that area. The island of Tôrnârssuk and the peninsula between Kuánit fjord and Tigssalûp ilua form parts of areas, which have been mapped, respectively by E. BONDESEN and N. HENRIKSEN. Due to these earlier works a good knowledge of the geology, and especially the chronological and structural relations, of the above-mentioned areas was already obtained before the author started his work. Zones of rusty coloured rocks, some of which contain disseminated ore minerals, have already been mapped on Tôrnârssuk and in the areas north of the Kuánit fjord and south of Tigssalûp ilua. In the summer of 1959 a geophysical team made an electrical survey of the rusty coloured zones and at the same time the writer was sent for one and a half months to study these rocks in three small areas indicated on fig. 1. In the Kuánit area the rusty coloured rocks consist of layers of banded hornblendic rocks[1]) containing magnetite- and iron-sulphide-bearing bands; on NE. Tôrnârssuk the rusty zones are made up of rusty coloured biotite-plagioclase-quartz schists, while in the area south of Tigssalûp ilua they are formed by layers of garnet-biotite augen-gneisses. Since these rusty zones appear closely associated and, in the author's opinion, genetically connected with the adjoining amphibolites and hornblendic rocks, the present study has been extended to include also the latter rocks.

The author is deeply indebted to Dr. A. BERTHELSEN, Mr. E. BONDESEN, Mag. scient., and Mr. N. HENRIKSEN for much valuable information, for stimulating and beneficial discussions as well as for their friendly and constructive critics, but especially for the generosity in allowing

[1]) In this paper the following terminology is adopted: Hornblendites – rocks consisting of 90 % or more hornblende; hornblendic rocks – rocks consisting of more than 70 % hornblende; they may include hornblendites and rocks approaching hornblendite in composition; amphibolites – rocks consisting essentially of hornblende and plagioclase, the amount of hornblende being less than 70 %.

him to make free and extensive use of their earlier, mostly still unpublished results. Without the latter the present study could not have been accomplished.

The author is indebted to the directors and other personnel of the Geological Survey of Greenland for providing the facilities, which have enabled him to carry out the present study. Special thanks are due to Mr. K. Ellitsgaard-Rasmussen, Mag. Scient., director of the Survey, and Mr. J. Bondam, Mag. scient., who were directing the Survey's field expedition in 1959, for an effective and pleasant field season.

Mr. J. Watterson, B.Sc. has kindly read through the manuscript.

The able assistance in the field of Mr. M. Ghisler is gratefully acknowledged.

II. SUMMARY OF THE GENERAL GEOLOGY OF THE AREA

Wegmann (1938) has laid the foundation of the presently adopted chronological division when he divided the Precambrian of southern Greenland into two main periods: the Ketilidian and the Gardar periods.

The Ketilidian period was initiated with the deposition of a thick geosynclinal pile comprising the lower, mainly sedimentary Sermilik group and the upper, mainly volcanic Arsuk group. In the course of Ketilidian orogeny this geosynclinal series were folded, migmatised and metamorphosed.

The Gardar period started with the deposition of the Igaliko sandstone on a peneplain, which truncated the deeply eroded Ketilidian mountain chain. Interstratified with the Igaliko sandstone are thick series of volcanic rocks. The alkaline batholiths in the Julianehaab district are considered to be of Gardar age. The whole Gardar series is traversed by dykes and faults of different generations. However, the Gardar sandstone and volcanic series have been preserved from erosion only in the graben zone around Igaliko; outside the latter area the Gardar period is represented only by faults, dyke rocks, granitic and syenitic intrusions.

Recent work (Berthelsen 1958; 1960) has led to a refinement of the chronological table by the introduction of the Kuanitic and Sanerutian periods. In the Ivigtut region the Kuanitic period was marked by the intrusion of several swarms of basic dykes after the consolidation of the old Ketilidian mountain chain. The Kuanitic dykes appear metamorphosed and deformed. A suite of granitic rocks appear to be younger than the Kuanitic dykes, but older than all Gardar dykes. The latter have after their intrusion not been subjected to transformations. The

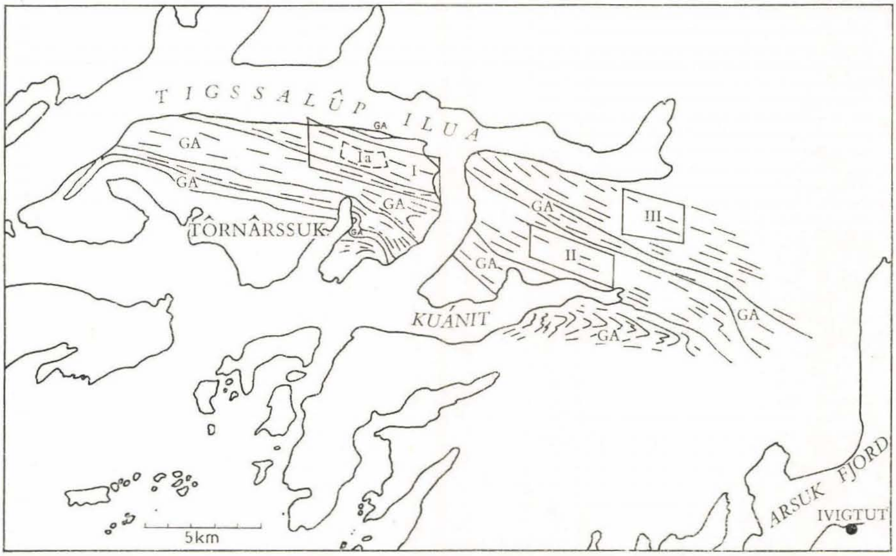


Fig. 1. Sketch map of the gneiss area NW. of Ivigtut with the locations of the investigated areas. I. NE. Tôrnârssuk, Ia. location of the map of Fig. 4; II. the Kuánit area; III. the area south of Tigssalûp ilua. GA. the "gabbro-anorthosite series". (After a map compiled by A. Berthelsen).

metamorphism and deformation of the Kuanitic dykes and the emplacement of the above-mentioned suite of granitic rocks are referred to the Sanerutian period, which covers the time interval between the Kuanitic and Gardar periods.

Finally, some olivine-dolerite dykes in the Ivigtut region are believed to be of Post-Gardar age (Henriksen 1960).

According to Berthelsen (1960) three different phases of Ketilidian folding have been discerned in the Ivigtut district. The oldest movements are pre-migmatitic and seem to have a NE.–SW. trend. The second phase is the main Ketilidian folding, which is more or less contemporaneous with migmatitization, gneissification and metamorphism. The axis of this folding trended in a NW.–SE. direction, the folds forming a large anticlinorium. During the third and last phase of Ketilidian folding, the earlier-formed structures were affected by semi-plastic refolding, twisting and bending. The originally NW.-trending synmigmatitic structures owe their present sinuous course to this deformation (see maps given by Berthelsen 1960). Connected with the latter deformation is a local refolding of older structures along an E.–W. to NE. axis.

The geological structure and chronology of events on Tôrnârssuk and in the area between Kuánit fjord and Tigssalûp ilua have become largely known by the works of Bondesen (1960) and Henriksen (1960;

1961). The isoclinal structures in these areas are due to the main Ketilidian folding. As a result of the regional twisting and bending of the last phase, the originally NW.–SE. structures were deflected and assumed an approximately N. 100–120 E. regional strike, the layers dip 40–70° towards the North on NE. Tôrnârssuk and are vertical or nearly so in the Kuánit and Tigssalluk areas.

A distinctive rock type in the above regions is formed by the "gabbro-anorthosite series", which consist of gneisses with a multitude of inclusions of gabbro-anorthositic and hornblendic composition. The structures, forms and alignment of the inclusions suggest their origin by boudinage of originally extensive layers. The concordant bands of the "gabbro-anorthosite series" indicate that the Ketilidian structures on NE. Tôrnârssuk continue in the Kuánit area (Fig. 1).

III. GENERAL FIELD ASPECTS

A. The region North of the Kuánit fjord.

The region North of the Kuánit fjord is composed of quartz-dioritic gneisses with intercalations of hornblendic rocks, amphibolites and talc lenses. The general strike of the isoclinally folded rock series is N. 95 –120 E.; locally the rocks may show variable dips, but in general they are vertical or nearly so. To the North the gneisses of the Kuánit area grade into those of the band of "gabbro-anorthosite series", which separate the Kuánit area from the area south of Tigssalûp ilua.

1. The gneisses and minor intercalations of amphibolitic and hornblendic rocks.

The fine- to medium-grained gneisses usually show a banded structure consisting of alternations of darker, more schistose, biotite-rich bands and lighter, more quartzo-feldspathic bands. In many horizons amphibole is an important constituent and the rock may then be termed an amphibole-gneiss. Concordant and discordant pegmatitic veinlets, often showing pinch-and-swell or ptygmatic structures, are common.

Concordantly intercalated as inclusions in the gneisses are bands, lenses, and streaks of amphibolitic rocks, the plagioclase and quartz content of which is often so small that transitions to hornblendites are common. The size of these inclusions ranges from a few cm or dm to about 15–20 meters. Locally swarms of smaller, irregularly shaped inclusions give the rock an agmatitic appearance. The contacts of the inclusions with the surrounding gneisses may be either sharp or of a

Fig. 2. Folded amphibole-gneisses with hornblendic rocks in the hinge zones of folds. Kuánit area.

gradational nature. In rare instances the amphibole-gneisses show folding on a small scale; in these cases hornblendic or amphibolitic rocks tend to occur especially along the crests of folds (Fig. 2). In fact, these small-scale folds have only been observed where thin intercalations of hornblendic or amphibolitic rocks occur and the presence of the latter seems to have facilitated the folding. The arrangements and shapes of the hornblendic and amphibolitic inclusions often give the impression of originally thin, extensive layers, which have been disrupted into boundins or of originally plastic beds, which during the folding have been migrating towards the hinges of folds (see p. 63).

2. The hornblendic layers.

Of a different magnitude than the hornblendic and amphibolitic inclusions are the concordant hornblendic layers, which are about 15–25 m thick and which extend for many kilometers beyond the investigated parts of the area. Three such parallel layers can be recognized in the Kuánit area, besides a smaller, more lens-shaped one. They are characterised in the field by the rusty colour of their outcrops, due to limonitic stains derived from the weathering of ore minerals. They differ in this respect from the hornblendic and amphibolite inclusions in the gneisses which do not contain any significant quantity of ore minerals.

The hornblendic layers are composed of a variety of related rock types, many of which can hardly be distinguished in the field. The following rock types are recorded:

a) hornblendites; rocks consisting of 90 % or more of hornblende,

b) pyroxenites and pyroxene-amphibole rocks; rocks consisting of 90 % or more of pyroxene or pyroxene and amphibole,

c) quartz-hornblende schists; rocks composed essentially of hornblende and quartz,

d) magnetite-hornblende schists; rocks composed essentially of hornblende, magnetite, and quartz,

e) epidote-hornblende schists; rocks composed essentially of epidote, hornblende and quartz,

f) epidote-diopside rocks; rocks composed essentially of epidote and diopside,

g) amphibolites; rocks consisting essentially of hornblende and plagioclase, sometimes with appreciable amounts of quartz,

h) tremolite rocks and tremolite-chlorite rocks; rocks consisting essentially of tremolite or of tremolite and chlorite,

i) biotite-hornblende schists and biotite-plagioclase-quartz schists; schistose rocks consisting for the major part of biotite accompanied by variable amounts of hornblende, plagioclase, quartz and sometimes garnet,

j) biotite rocks and biotite-hornblende rocks; massive rocks consisting mainly of biotite.

Varieties intermediate between the different rock types enumerated above may occur.

Hornblendites, pyroxenites and pyroxene-amphibole rocks.

The hornblendites and pyroxenites are fine-, medium-, or coarse-grained rocks, which sometimes show a faint foliation or lineation. True pyroxenites are rather rare and most diopside-bearing rocks have approximately equal amounts of diopside and hornblende. The hornblendites occur as lenses, bands, or streaks of variable size (ranging from less than 1 m to about 20 m long) intercalated between the other rock types. Smaller inclusions of hornblendic composition quite often occur as relic patches or thin streaks in all other rocks within the hornblendic layers. The pyroxenites and pyroxene-amphibole rocks occur as relatively thin layers within the hornblendite lenses and bands.

Quartz-hornblende schists and magnetite-hornblende schists.

The quartz-hornblende schists show a conspicuous banding due to alternations of thin quartz-rich bands with hornblende-rich bands. The magnetite-hornblende schists are essentially quartz-hornblende schists with regular intercalations of thin magnetite-rich bands. The magnetite-bearing rocks often show gentle folds and appear somewhat more deformed than the other rocks.

Epidote-hornblende schists and epidote-diopside rocks.

The epidote-hornblende schists and epidote-diopside rocks alternate with bands of quartz-hornblende schists. The epidote-hornblende schists usually appear finely banded by the alternation of epidote-hornblende bands with bands of more hornblendic or quartz-hornblendic composition. There are thus two kinds of banding; one is of the order of a few mm or cm and occurs within a certain rock type (e.g., the banded structure in the quartz-hornblende schists and epidote-hornblende schists), the other is of the order of a few dm or m and consists of an alternation of different rock types (e.g. the alternation of bands of quartz-hornblende schists with bands of epidote-hornblende schists).

Amphibolites.

The amphibolites sometimes occur as bands parallel to the quartz- and epidote-hornblende schists, but more often they form rather irregular patches within the hornblendic layers. Bands of quartz-hornblende schists, epidote-hornblende schists, etc., may grade laterally into amphibolites and locally the hornblendic layer is transformed into amphibolites over almost its entire width. The amphibolites may show a foliation caused by fine bands of more quartzo-feldspathic composition.

Tremolite- and tremolite-chlorite rocks, biotite-hornblende schists and biotite-plagioclase-quartz schists.

The light green, somewhat schistose tremolite and tremolite-chlorite rocks occur rather rarely as lens-shaped bodies at, or close to the contacts of the hornblendic layers with the surrounding gneisses. In this position they are often associated with lenses and bands of biotite-hornblende schists and biotite-plagioclase-quartz schists. The rocks along the contact zone of the hornblendic layers are often strongly contorted and plicated. Relic patches and streaks of hornblendic composition are very common in the tremolite- and biotite-rich rocks. At some places a hornblendic layer grades laterally over almost its entire width into schistose biotite-hornblende schist, biotite-plagioclase-quartz schists, and tremolite-chlorite rocks. Hornblendic rocks occur in these strongly schistose rocks as lenses, often bounded by sharp contacts. In these schistose rocks there is a greater abundance of pegmatitic veinlets. The field aspects of the schistose rocks described here show a close resemblance with those of similar rocks in NE. Tôrnârssuk.

Biotite rocks and hornblende-biotite rocks.

The biotite rocks and hornblende-biotite rocks occur locally as inclusions in the hornblendic layers. Some of the inclusions show conspicuous signs of deformation in the form of small plications.

Thus, the field relations suggest that in the hornblendic layers hornblendites, associated with minor amounts of hornblende-diopside rocks, occur as relic inclusions in more or less sheared and transformed, banded and schistose rocks.

3. The talc rocks.

Talc rocks are relatively rare in the area North of the Kuánit fjord. They occur generally as concordant lenses in the gneisses, 5 to 15 m long and 1 to 5 m thick. The foliation of the gneisses usually wraps around the lenses. Two or more lenses may occur close to each other but in general there is no apparent system in their distribution.

B. NE. Tôrnârssuk.

The geological structure of NE. Tôrnârssuk appears more complicated than that of the Kuánit area. The isoclinally folded rock series have in general strikes between N. 90 E. and N. 135 E. and dips between 70 N. and 40 N. Banded quartz-dioritic gneisses make up an important part of the area. Amphibolitic horizons appear several times in the rock series, indicating a more complicated folding than in the Kuánit area. A series of rusty coloured zones consisting mainly of biotite-plagioclase-quartz schists occur in and along the amphibolitic horizons. These rusty schists are well-developed on NE. Tôrnârssuk, but they seem less so on other parts of the island (unpublished map by E. BONDESEN). Hornblendites and hornblendic rocks are locally abundant as smaller inclusions and larger masses in the gneisses, amphibolites and rusty schists. Talc lenses occur mostly along amphibolite horizons. The presence of numerous faults make the picture still more complicated.

Fig. 3 gives a sketch map of a part of the area, which was investigated in greater detail. Variations in strike and dip of the isoclinal series suggest the presence of gentle NNE.-folds. The map is based on aereal photographs; the more outstanding topographic features have been sketched

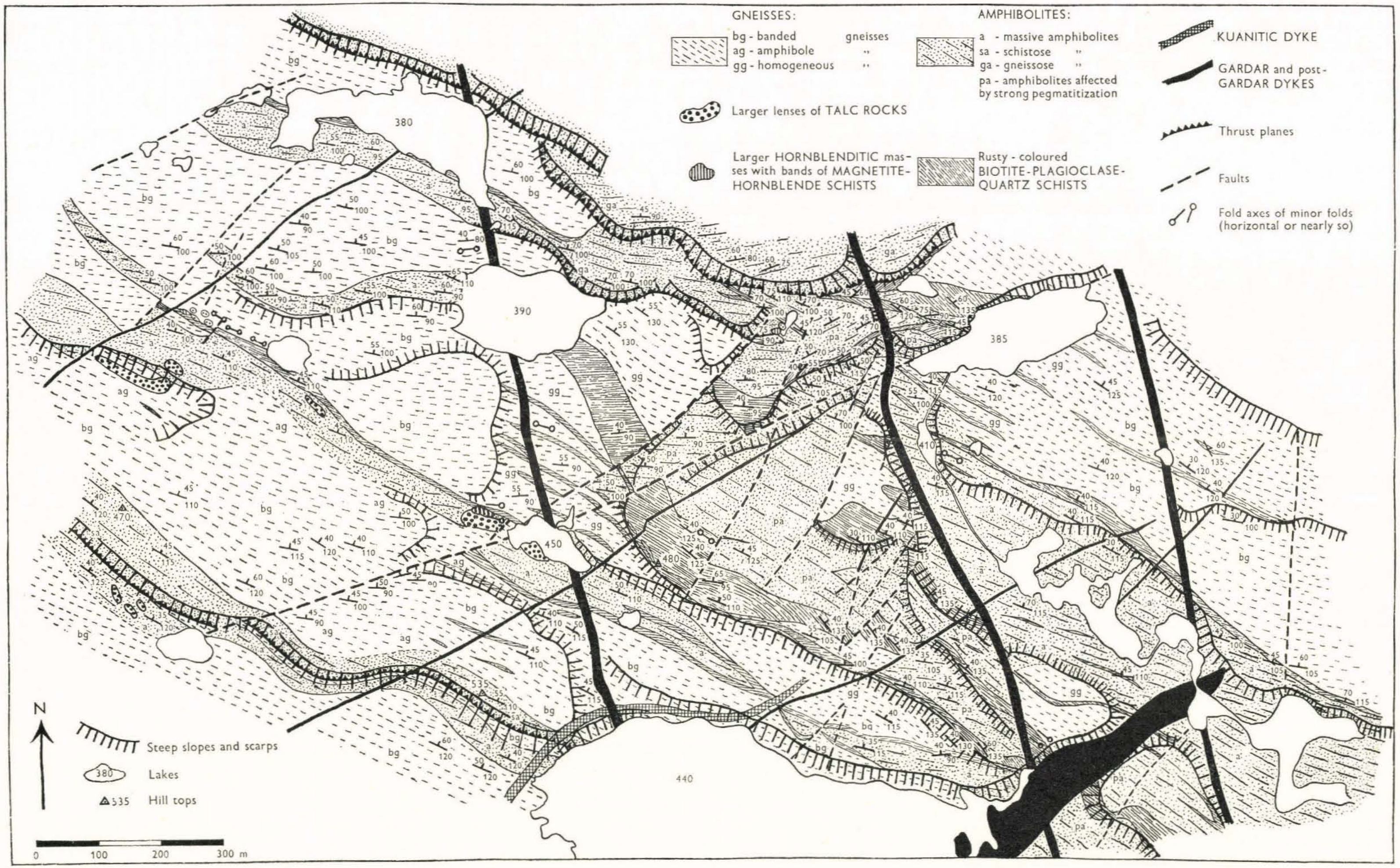


Fig. 3. Geological sketch map of part of NE. Tôrnârssuk; for location of the area see Fig. 1.

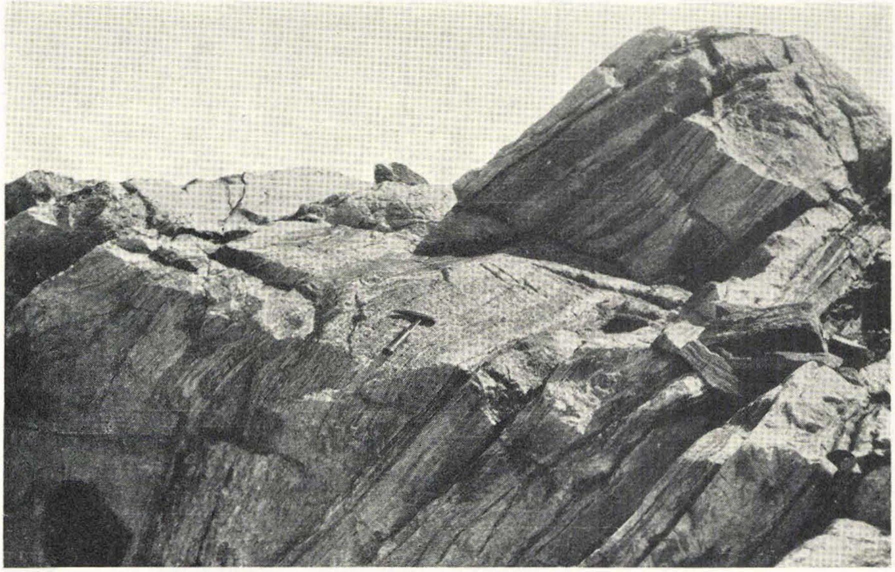


Fig. 4. Sedimentary features in the banded gneisses on NE. Tôrnârssuk (near lake 440).

in, but topographic details are not represented. As a result of topographic effects the trends on the map of some of the rusty schists and amphibolitic horizons may simulate westward plunging fold structures. Furthermore, the actual thickness of the layers of rusty schists varies between approximately 1 and 40 meters. However, where these layers form dip-slopes in the field their thickness appears exaggerated on Fig. 3.

1. The gneisses.

Quartz-dioritic banded gneisses are of widespread occurrence on NE. Tôrnârssuk. The ubiquitous occurrence of concordant pegmatitic veins accentuates the banded appearance of the rocks. In rare instances relic structures, reminiscent of sedimentary bedding features were observed (Fig. 4). The banded gneisses frequently show transitions into amphibole-gneisses, which again often grade into gneissose amphibolites. These transitions occur along as well as across the strike of the amphibolite horizons.

The banded gneisses and amphibole-gneisses often show transitions to more homogeneous gneisses, which show no conspicuous banding. The latter appear spatially associated with the rusty coloured zones of biotite-plagioclase-quartz schists. Several small horizons of rusty coloured, schistose biotite-rich rocks are found in the homogeneous gneisses. Furthermore, the rusty zones of biotite-plagioclase-quartz schists appear strongly pegmatized and often partly gneissified; in the latter case they usually grade into the homogenous gneisses.

Fig. 5. Folding along a zone of biotite-plagioclase-quartz schists. Partly biotitized hornblendic relics occur along the hinge zone of a fold in gneissified biotite-plagioclase-quartz schists. NE. Tôrnârssuk, north of hill 535.

2. The amphibolites.

Amphibolitic rocks occur in more or less parallel bands concordantly intercalated in the gneisses. Their structures show wide variations from almost massive to strongly gneissose. At places there are porphyroblastic varieties showing glomeroblastic plagioclase aggregates, 1–2 cm long, and oriented parallel to the strike of the rocks. Garnet-amphibolites occur locally. The different amphibolite varieties are not sharply separable and they show mutual transitions. Transitions to amphibole-gneisses occur, but sharp contacts between amphibolites and gneisses have also often been noticed. Hornblendic inclusions of different sizes are common. The amphibolites are commonly traversed by a network of discordant and subconcordant pegmatitic veinlets.

Some amphibolitic horizons rest with a structural unconformity on gneisses or other amphibolites. Along the unconformity plane the rocks appear transformed into fine-grained, schistose or gneissose mylonitic types. These unconformity planes are indicated on Fig. 3 as thrust planes.

3. The hornblendic rocks.

Most hornblendic inclusions in the gneisses and amphibole-gneisses are boudin-shaped and tend to occur in rows concordant to the strike of the rocks. Some of the boudins consist of hornblendite, but mostly there is some feldspar development and gradations to hornblendic rocks and amphibolites occur. Some of the boudins contain appreciable amounts of diopside. Besides the boudins there are also some irregularly shaped inclusions. The hornblendic boudins in the gneisses of NE. Tôrnârssuk may presumably be correlated with similar boudins in the gneisses of the Kuánit area. The thicker hornblendic layers in the latter area are represented on NE. Tôrnârssuk by the amphibolite horizons. In these amphibolites hornblendic inclusions are locally abundant, they are mostly of irregular shape and very often pass gradually into the surrounding rocks. Some boudin-shaped inclusions, surrounded by pegmatites, also occur (Fig. 36).

In the biotite-plagioclase-quartz schists hornblendic inclusions appear in general as rather small, contorted and deformed schlieren or drawn-out lenses. Where the schists show conspicuous small-scale folds, hornblendic rocks, usually partly transformed into biotite-rich rocks, tend to occur along the fold crests. These structures are also preserved in the gneissified parts of the rusty coloured schists zones (Fig. 5).

Larger masses of hornblendic rocks occur as irregularly shaped bodies, about 5 to 20 metres long, situated near the contacts or in the transition zone between amphibolitic rocks and biotite-plagioclase-quartz schists. The hornblendic rocks show gradual transitions into both amphibolites and biotite-plagioclase-quartz schists. Furthermore they occur conspicuously associated with lenses of talc rocks. Usually the hornblendic rocks are separated from the talc rocks by a small zone of amphibolitic rocks, which often contain appreciable amounts of biotite and sometimes also tremolite. Some of the larger hornblendic masses have banded structures and like similar rocks of the Kuánit area, they often consist of alternating bands of quartz-hornblende schists and magnetite-hornblende schists. The banding and other internal structures of these rocks often show conspicuous signs of deformation and they may appear unconformable to the strike of the surrounding rocks. In one instance it was observed that the magnetite-rich bands cut obliquely across the foliation of the rock, which is formed by the planar orientation of the hornblende (sample 42132). The magnetite bands are here thus clearly of later origin.

4. The rusty zones of biotite-plagioclase-quartz schists.

The rusty coloured zones on NE. Tôrnârssuk consist for the most part of biotite-plagioclase-quartz schists, sometimes containing garnet and/or hornblende. At several places of intense pegmatitization these rocks have become altered into chlorite- and muscovite-sericite-bearing quartzo-feldspathic rocks. Pegmatitic veins and veinlets are an important component in the zones of rusty schists. Minor rock types are formed by

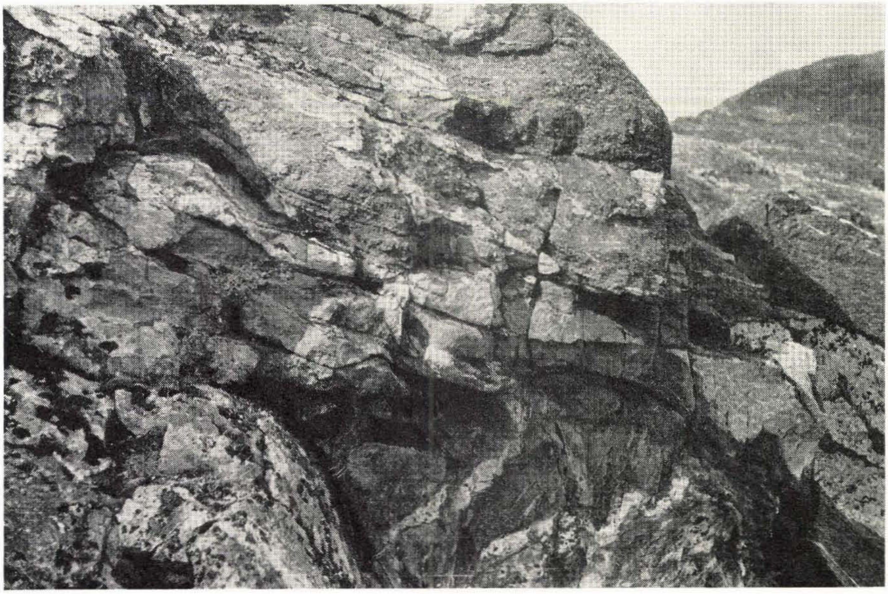


Fig. 6. Biotite-plagioclase-quartz schists thrusted upon amphibolites. The schists (upper and left hand part of picture) dip gently to the right and show concordant and subconcordant pegmatitic veinlets. The thicker subconcordant pegmatite with pinch-and-swell structures, and which is shown in the picture running almost diagonally from the upper left hand to the lower right hand corner, has developed partly along the thrust plane (as in the left hand side of picture) and partly just above this plane (as in the central part and lower right hand side of picture). The amphibolites (lower half of picture) dip steeply to the right and contain discordant pegmatitic veinlets, which are bent, broken, and cut off by the thrust plane. Near the thrust plane the amphibolites appear more schistose and they have apparently been subjected to strong shearing. NE. Tôrnârssuk.

epidote rocks, epidote-diopside rocks, hornblende-biotite schists, and garnet-quartz rocks. The rusty colour of all these rocks are mainly due to limonitic and hematitic coatings and crusts on rock surfaces and in fractures. Ore minerals are extremely rare; they occur locally in the form of fresh, euhedral pyrites.

There is a close spatial relationship between the rusty schists and amphibolite horizons (Fig. 3). In general the schists occur parallel to and adjoining the amphibolite horizons. In the gneisses they form only small and thin layers, which tend to fade away by grading into homogeneous gneisses.

Where the contact relations have not been blurred by the later gneissification, the schists generally rest with a sharp contact on the underlying gneisses or amphibolites. However, at its upper side the biotite-plagioclase-quartz schists, if bordered by amphibolites often grade into the latter rocks without sharp contacts.

Fig. 7. Rotated and drawn-out inclusions of biotitized hornblendic rocks in biotite-plagioclase-quartz schists. NE. Tôrnârssuk, NE. of hill 535.

The zones of rusty schists are in general concordantly intercalated between amphibolites and gneisses, but quite often they rest with a slight discordancy on the underlying rocks. The schistose nature of the rocks is most pronounced near the base of the zone. Fig. 6 shows a case where the schists rest with a marked discordancy on amphibolites; discordant pegmatitic veinlets in the amphibolite are bent, broken and cut off by the plane of discordancy, which is here apparently a thrust plane.

Amphibolitic and hornblendic inclusions are commonly found in the biotite-plagioclase-quartz schists. Some inclusions are 2–3 m long, but usually they are smaller and of the order of a few cm or dm only. Locally there are plenty schlieren-like hornblendic and amphibolitic inclusions showing unsharp contacts with the surrounding schists (Fig. 35). Especially near the base of the rusty zones deformed, rotated and drawn-out inclusions of partly biotitized hornblendic rocks are often found. The rotation of inclusions is demonstrated by S-shaped structures of pegmatitic veinlets in the inclusions (Fig. 7). Larger inclusions further away from the base of the zone were not rotated, but apparently acted as obstructions resisting movements, so that the surrounding schists were folded against them.

In and behind the zones of rusty schists small-scale folds with amplitudes of 1–10 m and horizontal or almost horizontal fold axes parallel to the strike of the rocks are often observed. The folds are often recumbent folds indicating a relative southward movements of the upper layers.

Fig. 8. Small-scale folds along a zone of biotite-plagioclase-quartz schists. The concordant pegmatites are affected by the folding and broken into pieces. The pieces in the limbs of the fold have been affected by shearing and were broken again into a series of smaller pieces. Further shearing will presumably result in the type of small, concordant pegmatites as shown in Fig. 9. NE. Tôrnârssuk.

Partly biotitized hornblendic rocks often occur along the hinge zone of the folds, while stronger biotitized hornblendic rocks or biotite rocks occur more along the limbs of the folds. Some NE. faults crossing the schist layers have broken and displaced the adjoining gneisses and amphibolites, while the schists have only been flexured by the same fault. Other faults cut and displace both the gneisses and schists.

5. Pegmatitization in and along the schistose zones.

The gneisses and amphibolites on NE. Tôrnârssuk are traversed by numerous pegmatitic veinlets, which presumably belong to different generations. However, in and along the zones of biotite-plagioclase-quartz schists there is a special abundance of pegmatitic material.

In the zones of rusty schists discordant pegmatitic veinlets are very rarely found and they appear younger than the very abundant concordant and subconcordant pegmatites. The latter occur in different forms:

a) Most abundant are thin (mostly between 1 and 10 cm), contorted and discontinuous strings and lenses, which appear drawn-out parallel to the schistosity of the rocks, and which seem never to cut one another (Fig. 9).

Fig. 9. Contorted, small, concordant pegmatites and large pegmatites with swell structures (right hand side of picture) in biotite-plagioclase-quartz schists. NE. Tôrnârssuk.

b) Another group of concordant and subconcordant pegmatites, often of appreciable thickness (10–50 cm) and extension, often cut through or distort the thinner veinlets of group a. In the folded parts of the zones of rusty schists these thicker concordant pegmatites are often characterized by fold patterns. In some instances it seems that they have been formed along the schistosity planes of an already folded rock (Fig. 34). In other instances they have clearly been affected by the folding and they appear broken along the fold axes (Fig. 8). Locally the pieces of the broken pegmatite in the fold limbs were apparently affected by continued shearing after the folding and broken again in a series of smaller pieces, arranged en echelon. Still further shearing may conceivably cause the broken pieces as seen in Fig. 8 to be further drawn out into a series of small concordant pegmatites of the type described under a (Fig. 9).

c) Also of frequent occurrence are large pegmatites with swell structures, which are mostly about 0.5–2 m thick and 2–8 m long (Fig. 9). Between the swells are pinches, in which the pegmatites are either very thin or disappear altogether. The pegmatites with swell structures do not appear deformed; they have pushed aside and distorted the schistosity of the surrounding rocks. These pegmatites have frequently developed along sub-concordant planes, which can be traced for several hundred metres, and which are often the contact

Fig. 10. Pegmatites in amphibolites. The pegmatites have developed along concordant planes and along sets of inclined diagonal joints. NE. Tôrnârssuk.

planes between zones of rusty schists and other rocks. They often contain relics of schistose material indicating an origin by replacement of the schists for at least a part of them.

The permeation with pegmatitic material is often so intense that the biotite-plagioclase-quartz schists appear partly gneissified and tend to assume the appearance of the homogeneous gneisses, into which they often grade without sharp contacts.

In the amphibolites and amphibole-gneisses adjoining the zones of rusty schists discordant pegmatitic veinlets are abundant. A system of older discordant pegmatites are often intersected by a younger generation of thicker (20–100 cm), more quartz-rich pegmatites, which have developed mainly along two sets of inclined diagonal planes, symmetrically arranged with regard to the foliation (Fig. 10). Locally the diagonal pegmatites are joined by concordant ones. Some of the larger of these pegmatites continue in the biotite-plagioclase-quartz schists as concordant pegmatites.

6. The talc rocks.

The larger lenses of talc rocks are elongated parallel to the strike of the surrounding rocks. The foliation in the surrounding rocks often wraps around the talc lenses. The latter show a tendency to occur near amphibolite horizons. The association of larger hornblendic masses with talc rocks have been noted.

Fig. 11. Hornblendic inclusions (Ho) in garnet-biotite augen-gneiss south of Tigssalûp ilua. The inclusions often occur in the hinge zone of folds.

Talc lenses in the strongly pegmatized zones are often surrounded by tremolite rims and traversed by undeformed, often straight tremolite veinlets.

C. The region south of Tigssalûp ilua.

In the area South of the Tigssalluk fjord zones of rusty coloured rocks extend eastward for several kilometers. The author has made only a few visits to the western parts of these zones and the following accounts must, therefore, be incomplete.

The rocks South of Tigssalûp ilua consist of a vertically folded isoclinal series, striking about N. 100 E., and composed of banded gneisses, amphibolites, and rusty coloured garnet-biotite augen-gneisses. The amphibolites form a series of subparallel bands, 15–100 m thick, intercalated in the gneisses. The garnet-biotite augen-gneisses form bands, 2–30 m thick, occurring in or alongside the amphibolite horizons.

1. The garnet-biotite augen-gneisses.

The field occurrence of these rocks has the following points of resemblance with the biotite-plagioclase-quartz schists on NE. Tôrnârssuk:

1) The spatial association of the augen-gneisses with amphibolite horizons.

Fig. 12. Slightly discordant contact between garnet-biotite augen-gneiss (lower left hand side of picture) and amphibolites (upper half of picture). South of Tigssalûp ilua.

2) The local occurrence of gradual transitions between garnet-biotite augen-gneisses and amphibolites.
3) The common occurrence of amphibolitic and hornblendic inclusions in the augen-gneisses. The inclusions occur as schlieren and streaks, not uncommonly along the hinge zone of small folds (Figs. 11 and 13).
4) The occurrence of discordant contacts between the augen-gneisses and surrounding rocks, and the stronger sheared appearance of the rocks near these contacts (Fig. 12).
5) The presence of small-scale folds in and along the zones of garnet-biotite augen-gneisses (Fig. 13).
6) Strong permeation with pegmatitic material in the zones of augen-gneisses and adjoining amphibolites.

As on NE. Tôrnârssuk the relative direction of movement of the upper blocks as deduced from small-scale folds and upthrusts is generally southward. However, along the northern contact of the layers of garnet-biotite augen-gneiss a northward directed folding, whereby the augen-gneisses have been warped upon amphibolites (Fig. 14), has locally been observed. These folds may be regarded as "plis en retour" or "Rückfalten".

The locally very abundant reddish brown garnets (about 0.5 cm diameter) are confined to the garnet-biotite augen-gneisses and immedi-

Fig. 13. Hornblendic inclusions in garnet-biotite augen-gneiss. Some of the inclusions are folded. The augen-gneiss is at the right hand side of the picture. The dark coloured rocks to the left are amphibolites. Pegmatites have developed along the contact plane between the augen-gneiss and the amphibolite. South of Tigssalûp ilua.

ately adjoining parts of amphibolites and banded gneisses. Amphibolitic and hornblendic inclusions in the garnet-biotite augen-gneisses are often surrounded by a rim of garnet-rich rocks (Fig. 37), while the inclusions are free from macroscopically visible garnets. This garnet-rich rim is somewhat darker coloured than the rests of the garnet-biotite augen-gneisses. The latter contain dark garnet-rich schlieren and spots, which may presumably be considered as relics of amphibolitic or hornblendic inclusions.

The augen structure is due to the abundance of quartz-feldspar lenticles, about 5–10 cm long and 1–3 cm thick, in a schistose, very biotite-rich matrix. The lenticles show transitions to concordant pegmatitic streaks and bands. Pegmatitic veinlets with ptygmatic structures and thicker concordant and swell pegmatites of the type found in the rusty schist zones on NE. Tôrnârssuk, are also present, though less abundantly than in the latter area. Some of the pegmatitic veinlets contain abundant euhedral garnets, while an ilmenite-rich pegmatite has once been observed. Pegmatitization has resulted in local transformation of the garnet-biotite augen-gneisses into homogeneous gneisses. The latter still contain relics in the form of schistose and garnet-bearing parts, fold structures and a rusty colour.

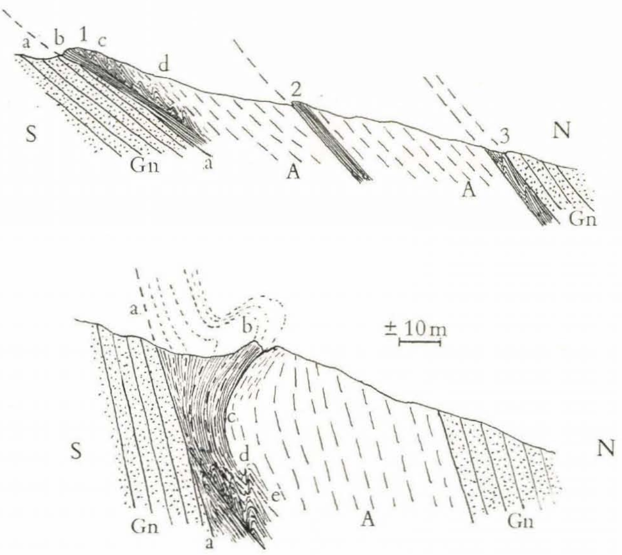


Fig. 14. Generalized diagrammatic representation of some field relations on NE. Tôrnârssuk and in the area south of Tigssalûp ilua. Upper figure: NE. Tôrnârssuk. 1. Zone of biotite-plagioclase-quartz schists on the foot wall side of amphibolitic layer; a-a, locally concordant and locally discordant contacts with the underlying gneisses (Gn), at places the contact appears to be a thrust plane (e.g. Fig. 6); b, strongly schistose zone showing microplications, rotated and drawn-out inclusions (Fig. 7), contorted pegmatitic veinlets (Fig. 9) and other signs of shearing movements; c, small-scale folds (Figs. 5 and 8), mostly southerly directed recumbent folds often with hornblendic relics in the hinge zones; d, gradual transitions of biotite-plagioclase-quartz schists into amphibolites (A). 2. Zone of biotite-plagioclase-quartz schists intercalated in amphibolites; the schists often show a slight discordancy with regard to either the underlying or overlying amphibolites. 3. Biotite-plagioclase-quartz schists on the hanging wall side of amphibolitic layer; sharp contacts between amphibolites and biotite-plagioclase-quartz schists.

Lower figure: the area south of Tigssalûp ilua. a-a, Steeply northward dipping, locally concordant and locally discordant southern contact of garnet-biotite augen-gneisses resting on banded gneisses (Gn); b, "Rückfalte", the garnet-biotite augen-gneisses have been warped backwards upon amphibolites (A), a secondary schistosity has developed in the underlying amphibolites; c, the garnet-biotite augen-gneisses also occur as parallel stretches of concordant, non-folded bands; d, the garnet-biotite augen-gneisses locally show intricate folds and small thrust planes (Fig. 11), hornblendic relics are often preserved in the hinge zones of small folds; e, the garnet-biotite augen-gneisses locally show gradual transitions into amphibolites. Note also the varying thickness of the bands of garnet-biotite augen-gneisses.

2. The amphibolites.

The amphibolites South of Tigssalûp ilua show similar field characters to those of NE. Tôrnârssuk. Close to the augen-gneisses they are strongly affected by pegmatitization and subsequent gneissification; the resulting rocks are amphibolite agmatites and banded amphibole-gneisses. The latter may be indistinguishable in macroscopic appearance from other banded gneisses and amphibole-gneisses.

IV. PETROGRAPHY

A. Rocks from the Kuánit area.

1. Petrography of the hornblendic layers.

Hornblendites[1])

The hornblendites are composed of a green hornblende with accessory amounts of ore minerals and apatite.

The green hornblende ($2V\alpha = 80°$; $\gamma \wedge c = 28°$: γ and β green, α almost colourless) often shows narrow colourless rims with lower refractive indices and higher birefringence. The texture of the rock is equigranular,

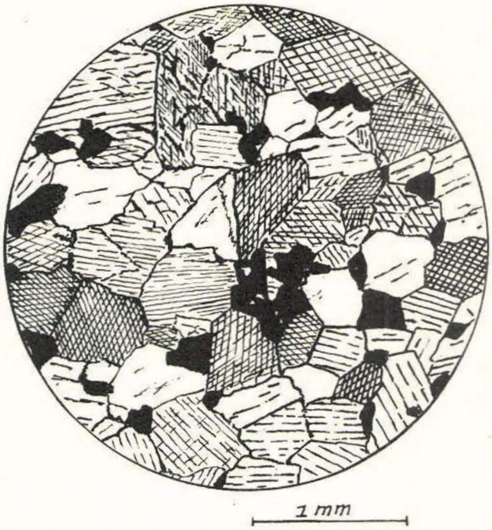


Fig. 15. Hornblendite, Kuánit area. The rock shows an equigranular, idioblastic texture. The ore grains are interstitial between the hornblende crystals. (46823).

idioblastic, often nematoblastic (Fig. 15). The prismatic crystals, mostly between 0.5 and 3 mm long, have their c-axes oriented approximately parallel to the strike of the rocks, causing a foliation and/or lineation, which is faintly visible in the hand-specimen.

[1]) Here and in the following pages numbers in footnotes or in parantheses refer to the investigated thin sections.

42334 A, 46821, 46823, 46824, 46825 B, 46830, 46833, 46846, 46855, 46918.

The rock shows in general no signs of cataclasis or recrystallization. However, a few specimens show incipient granulation and recrystallization of the green hornblende into a colourless, probably tremolitic amphibole ($2V\alpha = 78°$; $\gamma \wedge c = 22°$). The latter usually forms relatively broad rims around the green hornblende. The colourless amphibole tend to be fibrous and shows ragged outlines. At places there is an interstitial development of fine-grained colourless amphibole. Some apparently favourably oriented crystals have enlarged by the growth of the colourless rims in the direction of their c-axis; adjoining crystals are penetrated and intersected. These partly recrystallized hornblendites represent intermediate stages in the transformation of hornblendite into tremolite-rock.

Some hornblendites are devoid of ore minerals, whereas others may contain a few percents of them. Ilmenite occurs as interstitial grains (mostly smaller than 0.5 mm) and aggregates. The mineral appears homogeneous and no exsolution phenomena can be detected. Grains of magnetite often occur besides the ilmenite. The two minerals show "mutual boundary" relations, suggesting a contemporaneous formation. However, magnetite shows a stronger tendency to form idioblasts and it may sometimes show well-developed crystal faces against the ilmenite. Some magnetite grains contain a few ilmenite lamellae. The ilmenite and magnetite grains and aggregates are more or less equidimensional. Their distribution is controlled by the intergranular space between the amphiboles and they are mostly present in the places where three or more hornblende crystals meet each other. The ore minerals apparently have crystallized later than the hornblendes and in a stage when directed pressures were absent or not capable of exerting an orienting influence.

Pyrite, pyrrhotite, chalcopyrite, and pentlandite occur only in some hornblendite samples (Fig. 16). Well-developed crystals of pyrite occur sometimes between the hornblendes, but more often they appear surrounded by grains of pyrrhotite. Irregularly shaped grains of chalcopyrite always occur associated with the pyrrhotite. The amount of chalcopyrite is always only a small fraction of that of the pyrrhotite. Pentlandite occurs as typical pentlandite flames in pyrrhotite. The flames tend to segregate along crystal boundaries and locally they may form small granules. Since chalcopyrite rather often has developed along the grain boundary between pyrrhotite and idioblastic pyrite, it must be younger than this boundary and the idioblastic form of the pyrite may be ascribed to its earlier formation and not solely to its force of crystallization. By similar reasoning pentlandite seems to be later than chalcopyrite. The order of crystallization of the sulphides is thus pyrite-pyrrhotite-chalcopyrite-pentlandite. These sulphides form aggregates which only very rarely join the ilmenite-magnetite aggregates in the same rock. When

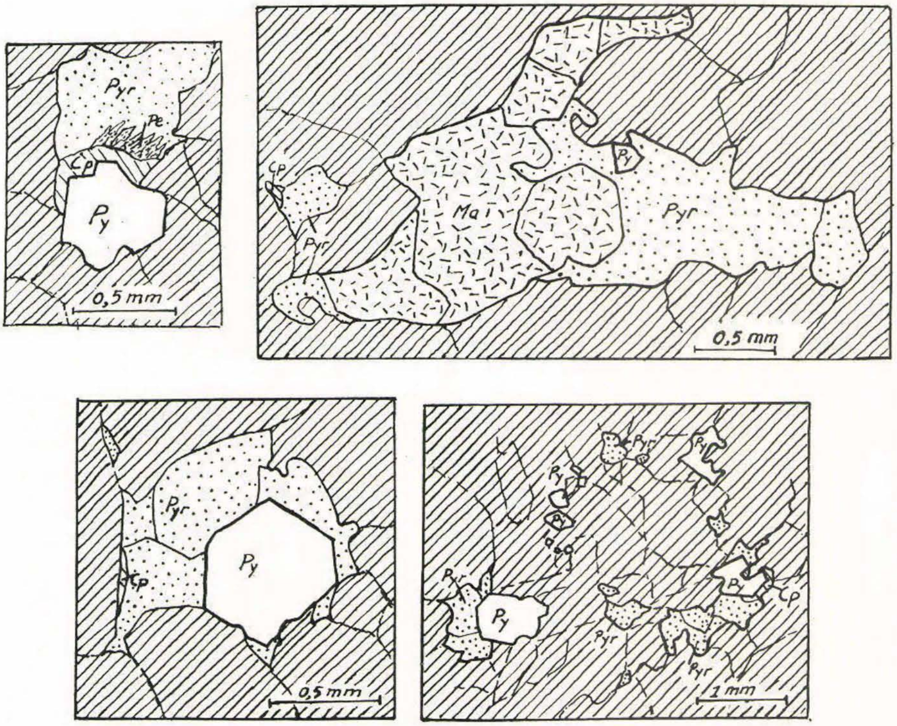


Fig. 16. Ore minerals in the hornblendites and epidote-hornblende schists. Pyrite (Py), pyrrhotite (Pyr), chalcopyrite (Cp), pentlandite (Pe), and magnetite (Ma).

they do so the ilmenite and magnetite show slightly rounded outlines against the sulphides, suggesting that the latter are younger (Fig. 16).

Supergene alterations of the ore minerals into limonite are common. The pyrrhotite often shows "birds eye" structures, which is commonly regarded as a result of supergene alterations of pyrrhotite into pyrite and marcasite (RAMDOHR 1955, p. 463). The pyrrhotite also shows alterations along cleavage planes into a brownish grey anisotropic substance with the same properties as the so-called "Zwischenprodukt" described by RAMDOHR (1955, pp. 463–464) and MARMO (1953).

By the development of quartz, biotite, epidote or plagioclase at the expense of the hornblende, the hornblendites pass into one of the various rock types described on pages 32–42.

Pyroxenites and pyroxene-amphibole rocks[1]).

In the pyroxenites a light green diopside forms stout, subhedral crystals, mostly between 0.5 and 2.5 mm long. There is no apparent

[1]) 42347, 46811, 46834, 46848, 46852.

crystal orientation and the rock has a massive texture. In a few specimen the diopside shows alterations into a fibrous, uralitic amphibole.

In most cases a hornblende is present besides the diopside. The idioblastic hornblendes are usually of somewhat smaller size than the pyroxene. Larger crystals of diopside often enclose small hornblende crystals, while inclusions of diopside in amphibole are occasionally noted.

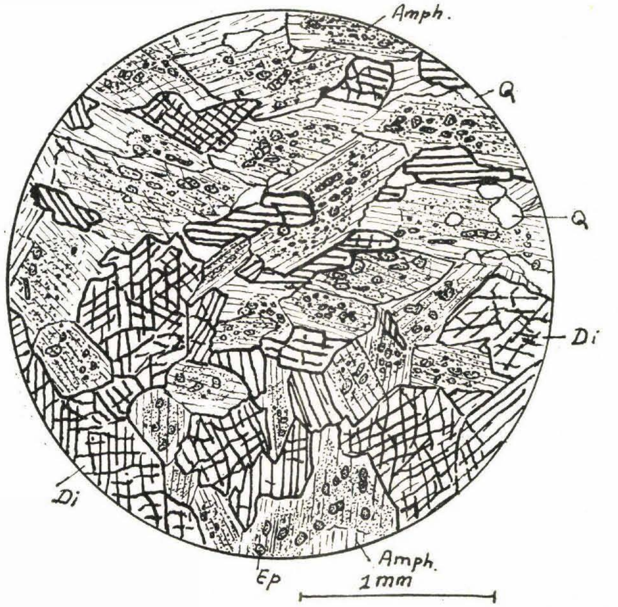


Fig. 17. Hornblende-diopside rock, Kuánit area. The amphiboles (Amph) have a core of bluish green hornblende surrounded by a rim of colourless, tremolitic hornblende. The bluish green core is replaced by epidote (Ep). Diopside (Di) appears quite fresh. Quartz (Q) is sparingly present. (46848).

Chondrodite is rarely present as xenoblasts reaching dimensions of 2 mm and more. It often contains small needle-like inclusions resembling rutile in a close triangular network. The mineral is often partly altered into a light greenish amphibole.

All diopside-bearing rocks show a more or less abundant development of epidote (pistachite). Whereas the diopside often appears quite fresh, the accompanying green hornblende has in general suffered metasomatic changes. Usually the amphibole has a bluish green core surrounded by a rim of a colourless, possibly tremolitic amphibole. Epidotization has selectively affected the bluish green cores, which are crowded by epidote microlithes, whereas the colourless rims are free of epidote (Fig. 17). By the development of more epidote, and of some quartz and plagioclase, transitional varieties to epidote-diopside rocks and epidote-diopside amphibolites are formed.

Idioblastic sphene is often associated with epidote masses.

Apatite is an accessory mineral.

The ore minerals consist of the same sulphides and their supergene alteration products as in the hornblendites. Epidote often forms around sulphide grains; the latter are apparently of earlier formation than the epidote. Ilmenite and magnetite have not been observed.

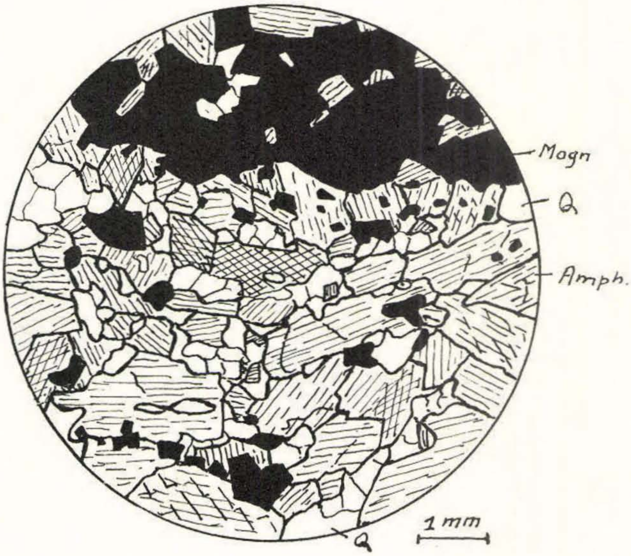


Fig. 18. Alternating bands of magnetite-hornblende schist and quartz-hornblende schist, Kuánit area. Quartz (Q) has developed interstitially between the amphiboles (Amph). Black is magnetite. (42351).

Quartz-hornblende schist[1]).

Compared with the hornblende in the hornblendites the amphibole in the quartz-hornblende schists is generally of darker, more bluish green colour ($2V\alpha = 68°$; $\gamma \wedge c = 21°$; γ bluish green, β green, α pale green to colourless).

Quartz has developed as finely-granular interstitial grains and aggregates between the amphiboles. When it is present in small amounts the equigranular, idioblastic texture of the hornblendites is still clearly recognizable (Fig. 18). When more quartz is present it forms larger grains (0.3–0.5 mm), gathered into more or less lenticular aggregates, bands and streaks. The amphiboles appear then in corroded aggregates, and the hornblendite textures are lost (Fig. 19). In the quartz-rich rocks the alternation of quartz-rich bands with hornblendic bands gives the rock a pronounced foliation.

[1]) 42351, 46856, 46859, 46925, 46927 B, 46933.

Magnetite occurs as well-developed crystals gathered in elongated aggregates parallel to the foliation. Ilmenite occurs very rarely as a few broad lamellae in magnetite. Sulphides are relatively rare, though in a few cases they may be as abundant as the magnetite. The sulphides consist of the same minerals in the same habits as in the hornblendites. Magnetite may sometimes appear corroded by the sulphides, but oc-

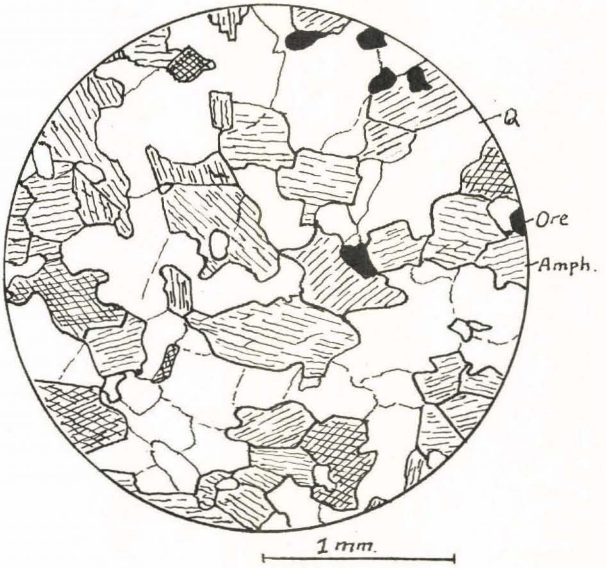


Fig. 19. Quartz-hornblende schist, Kuánit area. The hornblende (Amph) appears as corroded grains and aggregates in a quartz (Q) matrix. (46933).

casionally rounded inclusions of pyrrhotite are also found in the magnetite. The quartz-rich bands are relatively poor in ore minerals as compared to the hornblendic bands.

Apatite, sphene, epidote, plagioclase, and biotite figure as other accessory constituents.

Magnetite-hornblende schists[2]).

These rocks show an alternation of thin magnetite-rich bands (0.5–1 cm thick) with somewhat thicker magnetite-poor bands (Fig. 18). Hornblende, quartz, and magnetite are the essential constituents. The amphibole and quartz exhibit the same textures as in the quartz-hornblende schists, but the amphibole is usually of a pale green colour ($2V\alpha = 70°$; $\gamma \wedge c = 21°$; γ pale green, β pale green to almost colourless, α almost colourless). Polysynthetic twinning parallel to (001) is frequent.

[2]) 42362 A, 42362 B, 42351, 46927 A, 46934.

Some specimen show polysynthetic lamellar intergrowths of a green and a colourless, hornblende in the same fashion as found in similar rocks from NE. Tôrnârssuk (pp. 44–45). The quartz grains are as a rule more strongly undulose than in the quartz-hornblende schists. The stronger influence of shearing stresses also appears from the presence of concordant shear planes along which the amphiboles are broken and deformed, or have recrystallized into fine-grained aggregates of amphibole accompanied by finely-granular quartz. The magnetite-rich bands have apparently

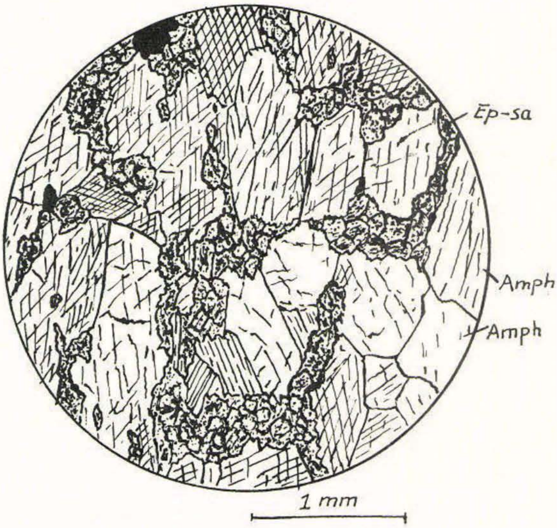


Fig. 20. Epidote-hornblende schist, Kuánit area. Intergranular development of fine-grained saussuritic material and epidote (Ep-sa) at the expense of hornblende (Amph). (46829).

also been affected by shearing movements; the magnetite grains are broken or have recrystallized as trains of minute grains parallel to the direction of shearing. However, larger and well-developed crystals (0.4 mm) and aggregates of magnetite also figure in the same sheared band. Shearing and formation of magnetite were probably more or less contemporaneous.

The elongated grains, aggregates, and bands of magnetite are of somewhat larger size than the equidimensional ore aggregates in the hornblendites. Whereas the ore minerals in the hornblendites are perfectly interstitial between unbroken hornblende crystals, the magnetite in the quartz-hornblende schists often penetrates along cracks into the amphibole and figure therein as secondary inclusions. The ore minerals often enclose corroded grains of amphibole and of quartz. No ilmenite and sulphides have been observed in the magnetite-hornblende schists.

Epidote-hornblende schists[1]).

The equigranular, idioblastic texture of the hornblende aggregates in most epidote-hornblende schists may be regarded as textural relics from hornblendites. The amphibole in the epidote-hornblende schists is generally of the same bluish green variety as in the quartz-hornblende schists.

The development of epidote minerals apparently has started with the appearance of an intergranular, fine-grained saussuritic substance corroding the hornblendes (Fig. 20). Eventually the relic hornblendite

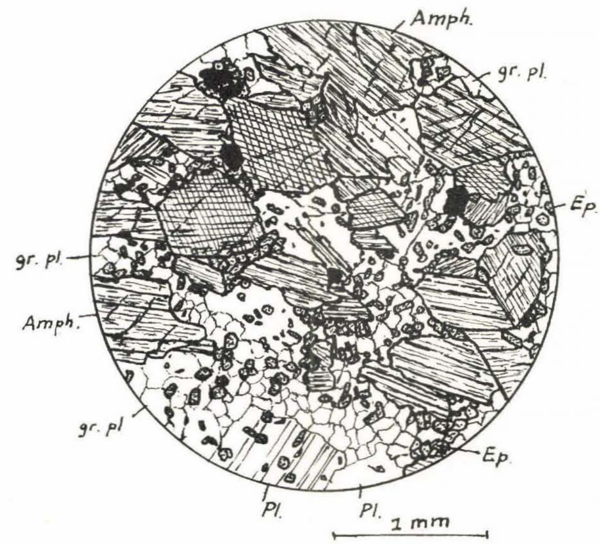


Fig. 21. Epidote-amphibolite, Kuánit area. Epidote granules (Ep) have developed interstitially between the hornblende crystals (Amph). Epidote and hornblende are replaced by granular plagioclase (gr. pl) aggregates, in which plagioclase porphyroblasts (Pl) have developed. (42332).

textures frequently have vanished. Small grains of recognizable mineral species have evolved from the saussuritic substance. They consist chiefly of granules of pistachite, accompanied by clinozoisite and an allanite mineral. The epidote minerals have often grown as a rim around ore grains. The saussuritic substance is also often replaced by finely-granular oligoclase aggregates in which some plagioclase porphyroblasts (An $_{10-30}$) of 0.3–0.5 mm size sometimes have developed. The epidote granules often have grown larger, forming idioblastic crystals up to about 0.3 mm in size. The result is often a plagioclase porphyroblast enclosing a few crystals or a number of microlithes of epidote. Locally, almost no epidote has developed and the saussuritic substance is directly replaced by oligoclase, sometimes in graphic intergrowth with some quartz. Thus,

[1]) 42370, 46812, 46824, 46825 A, 46829, 46853, 46856, 46918.

transitory varieties to amphibolites are formed (Fig. 21). In other instances, epidote and clinozoisite have developed with the exclusion of plagioclase. Carbonate material may then be present between the epidote minerals. In the latter rocks the epidote usually has developed as granules in the amphibole.

Quartz is usually scarce, but it is relatively abundant in some samples, which in fact consist of a finely banded alternation of quartz-hornblende schists and epidote-hornblende schists.

Small, often idioblastic crystals of sphene are always present.

A pale green chlorite showing anomalous blue interference colours has locally developed at the expense of the amphiboles.

Small flakes of phlogopite have rarely been observed.

Apatite is a regular accessory constituent.

The ore minerals consist exclusively of sulphides and their supergene alteration products. Pyrite, pyrrhotite, pentlandite, and chalcopyrite occur in the same forms and habits as described before in the hornblendites (Fig. 16). The epidote-hornblende schists are the richest in sulphides when compared with all other rocks in the hornblendic layers. The sulphides occur in disseminated aggregates, but in specimens with pronounced banding, the aggregates tend to be aligned parallel to this banding.

Epidote-diopside rocks and epidote-diopside amphibolites[1]).

In the diopside-bearing rocks hornblende is first selectively replaced by epidote, while the diopside remained stable for a longer time. Again, the earliest stage in the epidote formation seems to be represented by fine-grained, interstitial masses of saussuritic substance, which have apparently enlarged by corroding the hornblende, and to a lesser extent the diopside. The corroded hornblendes have often become poikilitic by the development of epidote granules in the amphibole (Fig. 17). From the saussuritic mass granular aggregates of epidote, sometimes accompanied by a little quartz, have developed. As the epidote granules have grown larger, they tend to coalesce and assume an uniform orientation. At last epidote porphyroblasts or poikiloblasts, reaching 2 mm or more in lengths, and enclosing diopside crystals and patches of saussurite or granular epidote masses, may have formed. The origin of these porphyroblasts by growth and coalescence of several smaller grains is discernible by the form of the relic saussuritic inclusions and by the fact that the coalescing grains maintain slightly different orientations, so that the

[1]) 42327, 42332, 42357, 46834, 46848, 46852.

resulting porphyroblasts show irregular, patchy extinctions (Fig. 22). The hornblende may have become almost completely eliminated by epidote and the rock may properly be named an epidote-diopside rock.

In some specimens granular quartz aggregates occur in addition to the epidote. In others the epidote is replaced by oligoclase. The latter mineral has also developed from the interstitial saussuritic mass. In

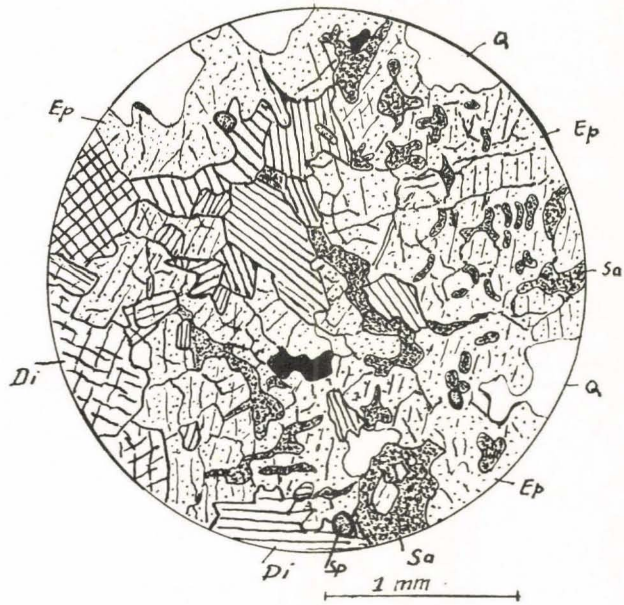


Fig. 22. Diopside-epidote rock, Kuánit area. Epidote (Ep) porphyroblasts have formed by the coalescence of several smaller grains. The saussuritic inclusions (sa) in the epidote separate parts of the porphyroblasts with slightly different extinctions. Diopside (Di) is sometimes found enclosed in the epidote. Other minerals present are quartz (Q) and sphene (Sp). (42357).

some samples albitic patches have become recognizable in the still predominantly saussuritic aggregates, in other ones the albitic areas have enlarged, and eventually oligoclase grains, reaching lengths of about 0.4 mm, have formed. The latter mostly show patchy extinctions; their central parts contain relatively few epidote inclusions, but their rims have remained crowded with epidote and saussuritic patches. The oligoclase-rich rocks may be described as epidote-diopside amphibolites.

The epidote-diopside rocks are often as rich in sulphides as the epidote-hornblende schists. The ore minerals are the same as in the latter rocks.

Amphibolites[1]).

Intermediate varieties between epidote-hornblende schists, epidote-diopside rocks, and amphibolites have been described before. There are also varieties intermediate between hornblendite or quartz-hornblende schist and amphibolite.

In the latter-mentioned varieties the bluish green hornblende figures in aggregates with embayed and ragged outlines in a more or less inter-

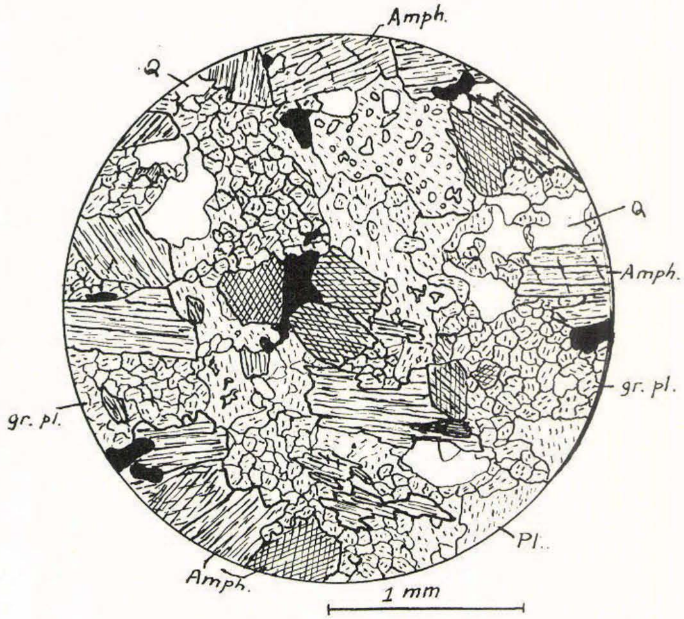


Fig. 23. Amphibolite, Kuánit area. Corroded hornblende (Amph) aggregates figuring in a matrix of granular plagioclase (gr. pl) and quartz (Q). Some plagioclase porphyroblasts (Pl) showing graphic intergrowths with quartz have developed in the granoblastic groundmass. (46858).

granular matrix of fine-grained (grain size less than 0.1 mm) granoblastic oligoclase (An $_{10\text{-}30}$) and some quartz. Xenoblasts (up to 1.5 mm in length) of oligoclase have developed here and there in the granoblastic mass. The xenoblasts locally still enclose granules and aggregates of the matrix plagioclase and quartz. These inclusions seem to have gradually faded away, resulting in xenoblasts and porphyroblasts showing irregular, patchy extinctions and graphic intergrowths with quartz (Fig. 23). The quartz is also often present as rounded inclusions in the plagioclase and as interstitial grains between the xenoblasts. It can be observed within the limits of a thin section that in a certain direction the plagioclase porphyro-

[1]) 42333, 42339, 42354, 42356, 42367 B, 42380, 42392, 46839, 46842, 46844, 46849, 46858, 46866, 46921.

blasts become more numerous at the expense of matrix plagioclase. The latter is eventually reduced to interstitial parties between the porphyroblasts.

However, in most of the amphibolites the plagioclase (An $_{15\text{-}30}$) is relatively coarse-grained (0.5–1.5 mm), generally polysynthetically twinned, and usually of homogeneous extinction. Zonal textures with more An-rich outer rims have occasionally been observed. Corroded

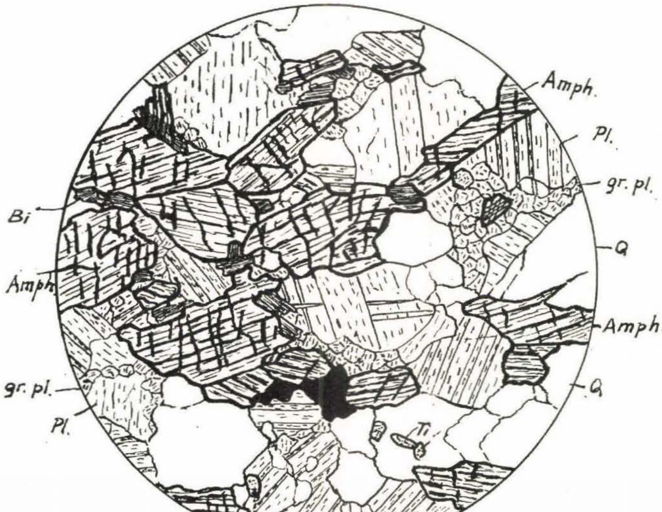


Fig. 24. Amphibolite, Kuánit area. Corroded hornblende (Amph) aggregates figuring in a matrix of coarse-grained plagioclase (Pl) and quartz (Q). Finely granular plagioclase is locally present (gr. pl). Some biotite (Bi) has developed interstitially between the amphiboles. Sphene (Ti) is an accessory mineral. (46842).

amphibole fragments are frequently present as inclusions in the plagioclase. Quartz is present as xenoblastic, undulose grains, interstitial between the plagioclases and amphiboles. Patches of granoblastic plagioclase and quartz still persist locally. The bluish green hornblendes always appear strongly corroded and reduced in size and amount (Fig. 24).

Biotite is an accessory constituent occurring as small flakes between the amphiboles and along the amphibole-plagioclase boundaries. In some specimens the biotite flakes are larger (up to 1.5 mm) and more numerous; they often form aggregates enclosing relic grains of hornblende. Occasionally narrow bands consisting only of biotite may occur.

Sphene is commonly found as idioblastic grains.

Epidote granules are frequently present in the plagioclase porphyroblasts.

A carbonate, tourmaline, and apatite are relatively rare accessories.

The amphibolites are relatively poor in ore minerals. Pyrite, pyrrhotite, pentlandite, and chalcopyrite occur in the same way as in the epidote-hornblende schists. Some samples are rich in a pyrite belonging to a later generation. This pyrite is not accompanied by other sulphides, it is often irregularly shaped and has inclusions of silicates.

Tremolite rocks and tremolite-chlorite rocks[1]).

It has been described before that by partial recrystallization of the hornblendites a transitional variety to a tremolite-rock may have been formed. The tremolite rocks are apparently completely recrystallized hornblendites. They consist principally of long (up to 2.5 mm), slender tremolite crystals with a more or less fibrous habit. Clinochlore often forms a groundmass of interstitial flakes. A few small flakes of phlogopite, and rarely grains of magnetite are present as accessories.

Biotite-hornblende schists and biotite-plagioclase-quartz schists[2]).

Biotite, plagioclase, and quartz are the essential constituents of these schistose rocks. Hornblende, garnet, and epidote are regularly present. Tourmaline, orthite, apatite, and ore minerals are accessory constituents.

The hornblende is usually of the same bluish green variety as in the hornblende schists and amphibolites. It appears replaced by biotite and strongly corroded by plagioclase and quartz. Locally the hornblende is practically eliminated and the rock is a garnet-bearing biotite-plagioclase-quartz schist, strongly resembling similar rocks on NE. Tôrnârssuk. However, in some places the amphibole has apparently recrystallized as a stable mineral alongside the biotite. The newly formed amphibole figures as skeletal crystals (mostly between 0.1–0.5 mm long) consisting of intergrowths of a colourless, probably tremolitic amphibole ($2V\alpha = 95°$; $\gamma \wedge c = 19°$) with a bluish green one ($2V\alpha = 80°$; $\gamma \wedge c = 16°$; γ bluish green, β green, α colourless). The two amphiboles are homoaxially intergrown and mutually polysynthetically twinned on (100), so that lamellae of colourless and bluish green amphibole alternate with each other (Fig. 25). A narrow outer rim of the crystals usually consists entirely of the colourless amphibole, while the inner parts consist of intergrowths of the two amphiboles. There are also very small (smaller than 0.1 mm) idioblasts of colourless amphibole. The skeletal appearance is due to trains of minute quartz inclusions along the planes of polysynthetic twinning. The colourless rims and small crystals of colourless amphibole do not show these inclusions. In spite of this skeletal appearance and of some corrosion by

[1]) 46828, 46883.

[2]) 42361, 42367, 42369, 42381, 46806, 46808, 46841, 46845, 46929.

plagioclase and quartz, the crystal outlines of the amphibole are generally easily discernible. The amphibole has often become partly enclosed in biotite aggregates without being significantly corroded. The c-axes of the newly formed amphiboles have produced a lineation within the plane of schistosity; sections perpendicular to this lineation show basal sections for about 80–90 % of the amphiboles (Fig. 25). The rock has apparently recrystallized under relatively strong directed pressures and presumably

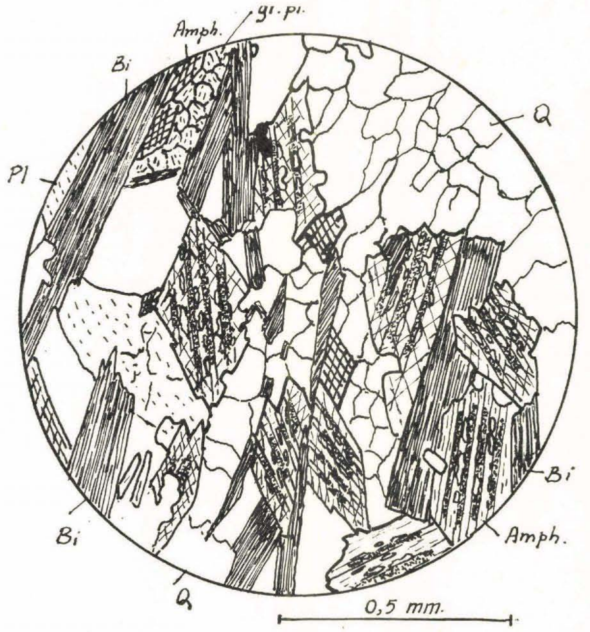


Fig. 25. Biotite-hornblende schist, Kuánit area. The idioblastic amphiboles (Amph) consist of a colourless, probably tremolitic amphibole with lamellae of blue green hornblende in the central parts of the larger crystals; parallel to the lamellae are trains of quartz inclusions. Quartz (Q) forms a granoblastic groundmass. Plagioclase (Pl) is present as porphyroblasts and in fine-granular aggregates. Biotite (Bi) forms relatively large subhedral flakes. (46845).

under the latter conditions the two mutually intergrown amphiboles were immiscible and could form beside each other. A similar case in magnetite-hornblende schists from NE. Tôrnârssuk will be described on a later page (see pp. 44–46).

The larger flakes of biotite are usually oriented parallel to the schistosity of the rock. Bending and undulatory extinction of the flakes are common. Aggregates of smaller biotite flakes tend to gather around and between the amphiboles and garnets. Biotite is corroded by plagioclase and quartz and the latter minerals contain numerous small inclusions of biotite.

Oligoclase (An_{10-30}) forms granoblastic aggregates and xenoblasts (up to 1 mm in size). The latter commonly show irregular, wavy extinctions and graphic intergrowths with quartz.

Quartz occurs in lenticular or streaky aggregates between the other minerals.

Garnet is regularly present as skeletal crystals, up to 1.5 mm in size. It is often partially replaced by plagioclase, biotite, and quartz.

Epidote granules are often present in the plagioclase.

A few small grains of magnitite, usually associated with the biotite, are found. Chalcopyrite is occasionally found as interstitial grains, presumably belonging to a later generation than the chalcopyrite in the hornblende schists.

Biotite-hornblende rocks and biotite rocks[1]).

These rocks consist chiefly of biotite developed as rather large flakes, mostly between 2 and 3 mm long, and often strongly bent and twisted. Their derivation from hornblendites is indicated by the occurrence of intermediate varieties consisting of biotite rocks with relic bands or streaks of hornblendite. Flakes of biotite have developed in and between the hornblendes.

Oligoclase is present in granoblastic masses, which have mainly developed at the expense of biotite. Porphyroblasts of oligoclase frequently have grown in the granoblastic masses. Biotite and hornblende appear corroded and the plagioclase often contains many inclusions of them.

A carbonate is often present interstitially between the biotites.

Epidote often occurs as swarms of microlites, usually enclosed in oligoclase.

Some samples contain granoblastic aggregates of quartz.

Accessory pyrite and chalcopyrite occur as interstitial fillings. Their habit is different from that in the hornblende schists and other rocks. The pyrite is usually irregularly shaped and has many inclusions of the silicates, and occasionally of corroded pyrrhotite and magnetite grains. The pyrite and chalcopyrite in these rocks belong presumably to a later generation of sulphides.

2. The gneisses of the Kuánit area[2]).

The gneisses consist predominantly of oligoclase (An_{15-30}) and quartz, with minor amounts of biotite, and accessory potash feldspar. A bluish green hornblende and epidote are often present. Sphene, apatite, and a

[1]) 42334 B, 42355, 42386, 46836.

[2]) 42325, 42341, 42350, 46840, 46851.

zircon-like mineral are regular accessories. The rocks have a schistose, often finely banded structure. Their texture is granoblastic, fine- to medium-grained.

In the finer-grained varieties oligoclase occurs predominantly in granular aggregates. Potash feldspar, sometimes showing microcline twinning, is found interstitially between the plagioclase granules. Some of the larger potash feldspar grains are perthitic. Quartz usually forms relatively coarser-grained aggregates and grains between the feldspars.

In the granoblastic feldspar-quartz groundmass there is always some development of oligoclase porphyroblasts (up to 1 mm long and more). Often the porphyroblasts show irregular, patchy extinctions, reminiscent of an original granular texture. Some of them contain numerous biotite inclusions, apparently inherited from the groundmass. Epidote inclusions are rather rare. Very distinctive are small inclusions of potash feldspar and quartz. The potash feldspar inclusions are sometimes of irregular shape and random distributions, but more often they tend to be rectilinear and arranged parallel to (010) of the plagioclase. All potash feldspar inclusions in one plagioclase crystal show an uniform optical orientation. Quartz inclusions, if present, often tend to form elongated grains of uniform extinction parallel to (001) of the plagioclase. During the growth of the oligoclase porphyroblasts in a groundmass of granular oligoclase, quartz, and potash feldspar, an excess of the latter two minerals was in the first instance presumably taken up by the porphyroblasts; this excess material was more or less immediately thereafter released again as oriented inclusions. In a few instances inclusions of small biotite flakes also show a tendency for an orientation according to crystallographic directions of the plagioclase.

The darker components, predominantly biotite, occur as patchy or streaky aggregates amidst the granoblastic quartz-feldspar mass. The biotite flakes appear in general strongly corroded and sometimes partly chloritized. Biotite-quartz symplectitic intergrowths have sometimes developed along the rims of corroded biotite. When hornblende is present it is always found as relic grains, enclosed or partly enclosed in the biotite aggregates. Epidote granules, sometimes forming crystals of about 0.2 mm length, have developed preferably near and in the biotite aggregates. Near these aggregates trains or patchy concentrations of epidote granules are often found in the granular quartz-feldspar groundmass. They are always accompanied by flaky fragments of corroded biotite and occasionally also by hornblende. It seems that the leucocratic granoblastic groundmass has partly replaced the darker components.

In the coarser-grained gneiss varieties the dark minerals are present in the same fashion as in the finer-grained varieties. However, instead of the fine-granular feldspar-quartz groundmass, a coarser-grained (average grain size about 1 mm), equigranular, xenoblastic mass of oligoclase and quartz occurs. The amount of potash feldspar is mostly reduced to nil. The irregular, patchy extinction of the oligoclase has mostly given way to an uniform extinction and twinning has become common. However, not infrequently the plagioclase contains potash feldspar and quartz inclusions in the same fashion as the porphyroblasts in the finer-grained gneisses.

B. Rocks from NE. Tôrnârssuk.

1. The gneisses[1].

The banded gneisses and amphibole gneisses of NE. Tôrnârssuk have the same composition and textures as those of the Kuánit area. It may only be remarked here, that on NE. Tôrnârssuk the majority of the gneisses are of the coarser-grained variety.

The homogeneous gneisses, i. e. gneisses without conspicuous banding, are equigranular rocks of varying grain size. They are usually more quartz-rich than the other gneisses. Some varieties may consist of quartz, oligoclase, some potash feldspar, muscovite, and sericite, and accessory biotite and chlorite. Other varieties may contain important amounts of biotite. Epidote is also often present. Graphic intergrowths consisting of oligoclase grains containing small inclusions of quartz showing uniform optical orientation are common.

2. Hornblendites and related rocks[2].

The hornblendic rocks occurring as relatively small inclusions in the amphibolites, gneisses, and biotite-plagioclase-quartz schists on NE. Tôrnârssuk resemble exactly similar rocks from the hornblendic layers in the Kuánit area. Some larger hornblendic masses, occurring associated with talc lenses, consist of alternating bands of hornblendites, diopside-hornblende rocks, quartz-hornblende schists, and magnetite-hornblende schists. In the following only some additional remarks on the amphibole in the magnetite-hornblende schists are given.

In the magnetite-hornblende schists the amphibole consists of homoaxial intergrowths of alternating lamellae of a blue green hornblende ($2V\alpha = 67°$; $\gamma \wedge c = 19°$; γ blue green, β green; α colourless) and a colourless, probably tremolitic hornblende ($2V\alpha = 89°$; $\gamma \wedge c = 20°$), polysynthetically twinned on (001) (Fig. 26). A crystal frequently consists partly of blue green hornblende with fine lamellae of colourless amphibole, and partly of a colourless amphibole with equally fine lamellae of blue green

[1] 42002, 42042, 42089, 42186, 42215, 42222 A, 42222 C, 42289.
[2] 42021, 42105, 42114, 42132, 42175, 42189, 42190, 42221, 422221, 42251.

hornblende. The colourless lamellae in the blue green part of the crystal often continue as blue green lamellae in the colourless part of the crystal. The boundary between the two amphibole varieties is always sharp.

The amphiboles form equigranular (grain size about 1 mm) aggregates. Signs of deformations such as deformed cleavage planes and undulatory extinction are common in addition to the ubiquitous twinning. The rocks show a number of cracks, which may cut through the

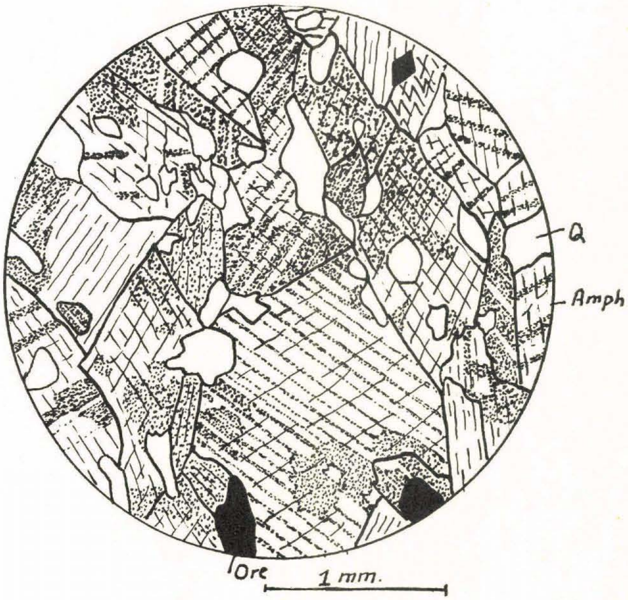


Fig. 26. Magnetite-hornblende schist, NE. Tôrnârssuk. The amphiboles (Amph) consist of homoaxial intergrowths of alternating lamellae of a colourless, probably tremolitic amphibole and a blue green hornblende, polysynthetically twinned according to (001). The amphiboles are corroded by quartz (Q). Black is magnetite. (42132).

amphibole crystals. The cracks are filled with fine-grained quartz and magnetite, while often there is also some granulation of the amphibole. Along such cracks the colourless amphibole has often developed blue green rims. Where the colourless amphibole is corroded by interstitial quartz a similar blue green rim is also frequently observed along the corrosion boundaries. Except for these secondary rims of blue green hornblende, no other replacement relationships between the two amphibole varieties can be deduced from the observed textures.

The occurrence of blue green amphibole in the quartz-hornblende schists and amphibolites surrounding the bands of magnetite-hornblende schists indicates that this amphibole was apparently the stable one that was formed under the regional PT-conditions of the epidote-amphibolite facies. Stronger shearing stress in some particular bands within the hornblendic masses have caused deformation by differential gliding movements in crystals, resulting e.g. in twinning of the amphiboles, and by intergranular movements. It is thought that under the latter conditions a colourless, presumably tremolitic amphibole has become stable besides the blue green one, and that intergrowths of the two immiscible amphiboles were then formed. Statistical studies by SHIDÔ (1958, pp. 183–184) have shown that under certain conditions, presumably intermediate between those of the epidote-amphibolite and green schist facies, a miscibility gap might exist between actinolitic amphiboles and common hornblende. Since the allegedly tremolitic amphibole presumably could not take up as much iron as the blue green hornblende, the formation of magnetite as a new phase in the bands under stronger stress is promoted. With the decline of differential stresses the blue green hornblende again became the stable one and the colourless amphibole is replaced along grain boundaries by blue green amphibole. The formation of the magnetite-rich bands seems to have been restricted to periods of active deformation during which differential shearing stresses exert a controlling influence on the processes of metamorphic differentiation.

3. Biotite rocks and biotite-hornblende rocks[1]).

Biotite rocks and biotite-hornblende rocks of the same composition and texture as similar rocks found in the hornblendic layers in the Kuánit area occur as relatively small inclusions in the biotite-plagioclase-quartz schists and amphibolites on NE. Tôrnârssuk. They are often found as rotated inclusions and drawn-out schlieren in the limbs of the folds in the zones of biotite-plagioclase-quartz schists. The biotite rocks may be regarded as strongly sheared and totally reconstituted hornblendites. The biotite-hornblende rocks, in which hornblende figures as relictic grains in a biotite mass, form a transitional variety. The latter are usually found along the crests of folds, whereas the biotite rocks in general occupy a place along the fold limbs.

4. The amphibolites[2]).

Transitional types between hornblendites and amphibolites are represented by amphibolitic rocks surrounding hornblendic inclusions. The blue green hornblende ($2V\alpha = 75°$; $\gamma \wedge c = 20°$; γ blue green, β green, α almost colourless) is corroded by finely granular oligoclase and quartz. Oligoclase porphyroblasts and coarser-grained quartz have often developed in the granular quartz-plagioclase mass. The corrosion of the horn-

[1]) 42131, 42185, 42187, 42224A, 42224B, 42301.

[2]) 42035, 42048, 42067, 42086, 42088, 42094, 42110, 42115, 42118, 42184, 42222B, 42234, 42253, 42254, 42288, 42131.

blende has frequently been preceded by incipient biotitization and, sometimes, chloritization. Biotite is often present along the corrosion boundaries between the plagioclase and amphibole, giving the impression that it represents a kind of reaction zone between the two minerals (Fig. 27). The hornblende usually does not contain any biotite inclusions, whereas the plagioclase always contains numerous small corroded flakes of biotite. In some instances the biotite is replaced by a finely-granular

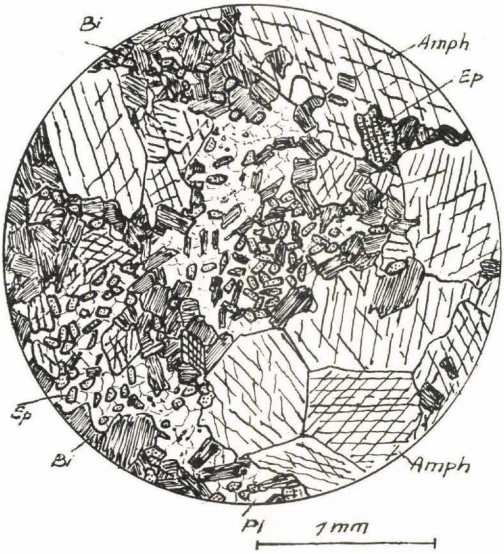


Fig. 27. Epidote-amphibolite, NE. Tôrnârssuk. Biotite (Bi) has formed at the expense of hornblende (Amph). Epidote (Ep) has developed as interstitial grains in the biotite aggregates. Granular plagioclase (Pl) has replaced much of the biotite and epidote; the latter minerals often figure as inclusions in the plagioclase aggregates. (42035).

plagioclase aggregate, in which fine trains of black ore substance still persist as a relic of the biotite. In other cases the hornblende is traversed by a crack along which a biotite veinlet has developed; the hornblende was later corroded by plagioclase and quartz, but the biotite veinlet remained as a relic in the plagioclase-quartz mass (Fig. 28).

In some hornblendic rocks (42131) the amphiboles appear replaced by subhedral oligoclase crystals, which tend to gather in glomeroblastic aggregates, and which often contain numerous inclusions of recrystallized amphibole needles and chlorite aggregates. These rocks may be regarded as a transitional type between hornblendites and the porphyroblastic amphibolites to be described below. In the latter rocks replacement relics are not so conspicuous and the later origin of the oligoclase can often only be indirectly inferred from its association with plagioclase of clearly later origin.

Where the fine-grained, granoblastic quartz-feldspar mass between the amphiboles has been entirely replaced by oligoclase xenoblasts (0.5–1 mm) and by coarser-grained quartz, it may appear difficult to discern the derivation of the amphibolite from a hornblendic rock. The plagioclase (An $_{15\text{-}35}$) often exhibits polysynthetic twinning. Some grains are zonal with more basic central parts, others show a patchy extinction due to the presence of patches of more basic composition. Crystals of blue

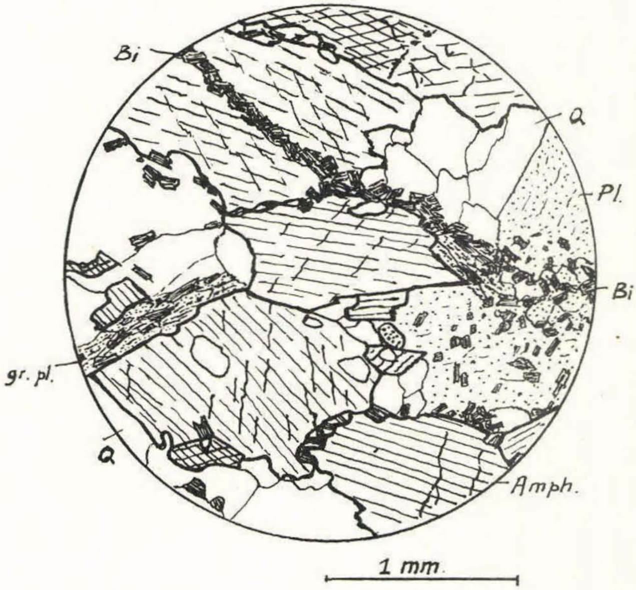


Fig. 28. Amphibolite, NE. Tôrnârssuk. Interstitial development of biotite (Bi) between the hornblendes (Amph) and along a crack in the rock. Biotite and hornblende are replaced by plagioclase (Pl) and quartz (Q). The biotite veinlet traversing the hornblende crystals is still recognizable in the plagioclase, although in the latter mineral it appears to have been disordered. Granular plagioclase (gr. pl) have locally replaced biotite aggregates. (42115).

green hornblende in mutual contact show idioblastic crystal outlines, but where they are in contact with plagioclase or quartz they appear corroded and show embayed and ragged outlines. However, these relatively coarse-grained amphibolites composed only of amphibole, plagioclase and quartz are rare. Most amphibolites on NE. Tôrnârssuk are biotite-bearing epidote-amphibolites and garnet-amphibolites, in which the plagioclase has replaced epidote, garnet, and biotite. The latter minerals have developed at the expense of hornblende. From this mineral sequence the derivation of the rock from a hornblendic rock can be made reasonable.

In the epidote-amphibolites idioblastic aggregates of blue green hornblende figure as textural relics in a xenoblastic groundmass of biotite, epidote, plagioclase, and quartz. The latter minerals may only form a fine-grained interstitial mass between the amphibole aggregates, but they may also form a coarser-grained matrix in which strongly corroded hornblende crystals and aggregates are embedded.

Biotite has developed interstitially between the amphiboles. It often penetrates into and replaces the amphiboles along cracks and cleavage directions. Some larger biotite flakes and biotite aggregates, often enclosing relic fragments of hornblende, have been regularly observed.

Epidote granules (smaller than 0.1 mm) are concentrated in and around biotite aggregates. Occasionally larger crystals (0.5 mm) of epidote have developed. Another part of the epidote has formed from saussuritic masses, which are present as interstitial aggregates and intergranular veinlets between the amphiboles and biotites. Some sericite and calcite are associated with the saussuritic substance. Most of the epidote is present as small granules or microlite swarms surrounded by or enclosed in plagioclase.

Finely-granular oligoclase aggregates occurring as interstitial masses between the hornblende and biotite usually enclose numerous flakes of corroded biotite and many epidote granules. This is especially so near epidotized and corroded biotite aggregates (Fig. 27). Here the epidote granules replacing the biotite often form a dense aggregate of small crystals between which the oligoclase occurs interstitially. Some of these fine-grained epidote-oligoclase-biotite aggregates show approximately straight boundaries towards the amphiboles and in these cases they are believed to have pseudomorphically replaced larger biotite flakes or biotite aggregates. Porphyroblasts of oligoclase have frequently formed in the finely-granular plagioclase mass, which latter often appears eventually replaced by a coarser-grained (0.5 mm) xenoblastic oligoclase aggregate. The coarser-grained plagioclase crystals are commonly crowded with epidote microlites, which either show a random distribution, exhibit a tendency to a radial arrangement, or are arranged along crystallographic directions in the plagioclase. A densely crowded grain may be adjoined by one devoid of epidote. The microlites are often restricted to that part of a plagioclase crystal that adjoins epidotized biotite and hornblende aggregates. The plagioclase ($An_{15\text{-}30}$) very often show an inhomogeneous extinction due to the presence of more basic or more albitic patches. The latter are quite often found surrounding aggregates of epidote microlites. Graphic intergrowths consisting of plagioclase containing quartz inclusions showing uniform optical orientations sometimes occur.

The later formation of the plagioclase is also well demonstrated in an amphibolite sample very rich in epidote and biotite, and which is traversed by a thin (1 mm), subconcordant quartz-oligoclase veinlet (Fig. 29). The quartz grains in this veinlet contain some inclusions of replaced epidote and biotite. The oligoclase crystals contain numerous epidote granules, often arranged along crystallographic directions and sometimes in radial aggregates. These textures have presumably originated by the replacement of epidote aggregates by oligoclase, whereby part of the epidote recrystallized as arranged inclusions in the plagioclase. Another example shows epidote aggregates in dense bundles of trains of small, prismatic crystals, not unlike the wellknown fibrolite or sillimanite bundles in

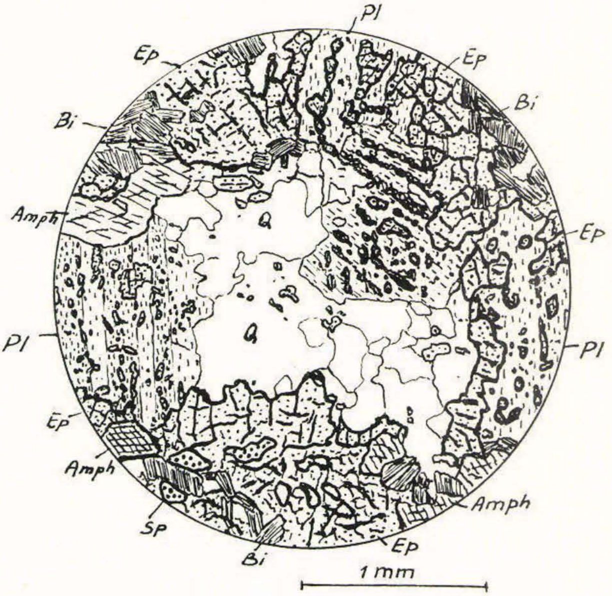


Fig. 29. Quartz-feldspar veinlet in epidote-biotite amphibolite, NE. Tôrnârssuk. Hornblende (Amph) figures as corroded grains in a mass of biotite (Bi) and epidote (Ep). Plagioclase (Pl) and quartz (Q) form a veinlet in the rock. Corroded epidote inclusions are present in the quartz grains and plagioclase crystals. In the latter mineral the numerous inclusions tend to become arranged parallel to certain crystallographic directions. (42088).

appearance. The bundles are enclosed in several randomly oriented oligoclase grains and the individual trains traverse the crystal boundaries of the plagioclase. The epidote bundles seem to have been formed before the enclosing plagioclase, probably at the expense of biotite (42110). Also a noteworthy feature in the epidote-amphibolites is the tendency of the larger oligoclase grains to contain less and smaller epidote inclusions than the smaller grains of plagioclase. The same tendency is reflected by the close association of amphibolites containing coarser-grained, fresh oligoclase, few biotite and few or accessory epidote with amphibolites containing finer-grained oligoclase and abundant epidote and biotite.

In the epidote-amphibolites quartz is present in moderate amounts. Apatite, tourmaline, sphene, orthite, and ore minerals are common accessories. Some samples contain radially arranged tourmaline needles enclosed in plagioclase or quartz.

The garnet-amphibolites are essentially epidote-amphibolites containing poikiloblasts of a brownish red garnet. Biotite is usually rather abundant in the garnet-amphibolites. The skeletal crystals of garnet (1–2 mm) frequently enclose hornblende fragments. The biotite flakes surrounding the garnet often appear bent and show undulatory extinctions. The garnet is often replaced along cracks by biotite, quartz, and plagioclase. A fine-grained aggregate consisting of the three latter minerals have often pseudomorphically replaced the garnet.

The porphyroblastic amphibolite varieties, to which reference has been made earlier, contain glomeroblastic aggregates (1–2 cm) of xenoblastic to idioblastic oligoclase crystals (0.2–0.6 cm). Corroded hornblende and biotite are commonly found enclosed in the glomeroblasts, which usually occur aligned parallel to the foliation of the rock.

5. The rusty zones of biotite-plagioclase-quartz schists.

A garnet-bearing biotite-plagioclase-quartz schist[1]), often containing some epidote and hornblende, is the most common rock type in these zones.

Biotite is the most prominent mineral. It occurs both as bands of larger flakes (up to 3 mm long) oriented parallel to the schistosity, and as aggregates of smaller, randomly oriented flakes. Deformation of the larger flakes is common. Incipient chloritization and sericitization is often observed.

Oligoclase forms xenoblastic to idioblastic crystals, which have corroded and replaced the biotite. Locally finely-granular aggregates of oligoclase occur.

Biotite, and to a less degree also plagioclase, appears corroded by quartz. The latter mineral occurs as interstitial grains and in lenticular aggregates, bands, or streaks consisting of quartz grains showing a pronounced undulatory extinction.

Epidote is commonly present and in some samples even abundantly. However, taken as a whole the mineral is not so common as in the amphibolites. Epidote has developed interstitially in the biotite masses, while it is also commonly found as microlites in oligoclase.

Blue green hornblende is only found as strongly corroded relic grains in the biotite aggregates, and occasionally as small fragments enclosed in plagioclase or quartz.

The garnets apparently have deformed the surrounding biotite

[1]) 42007, 42018, 42029, 42102, 42163, 42168 A, 42168 B, 42192, 42222 H, 42222 D, 42250, 42255, 42254 B.

flakes, which appear bent and show undulatory extinctions (Fig. 30). The garnets have often been replaced by pseudomorphic aggregates of biotite, quartz, and plagioclase.

Sphene, apatite, tourmaline, orthite, rutile, and ore grains are common accessories.

At many places the biotite-plagioclase-quartz schists have been modified by metasomatism accompanying pegmatitization. In the rocks

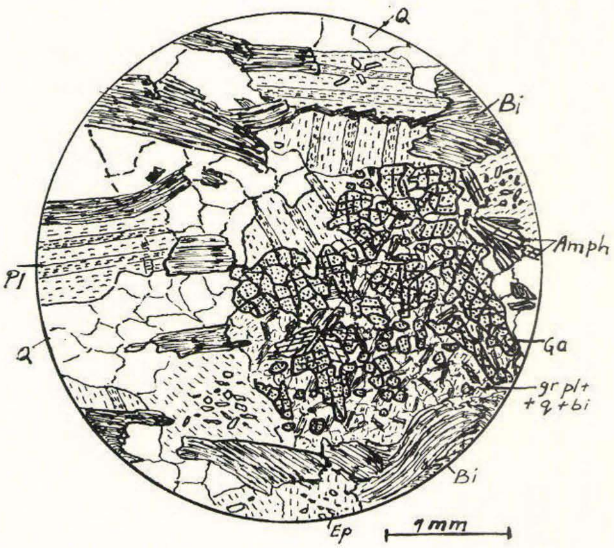


Fig. 30. Garnet-bearing biotite-plagioclase-quartz schist, NE. Tôrnârssuk. The garnet (Ga) porphyroblasts have deformed the biotite (Bi) flakes. Some relic grains of amphibole (Amph) are enclosed in the garnet. The garnet is partly replaced by a fine-grained aggregate of granular plagioclase (gr. pl), biotite, and quartz. Plagioclase porphyroblast (Pl) sometimes contain inclusions of epidote (Ep) granules. (42250).

affected by pegmatitization, sericite, muscovite, chlorite, and potash feldspar have commonly formed, while there is often also an enrichment in plagioclase and quartz. Some rock types, which have originated in this way, will be briefly described below. Sphene, apatite, tourmaline, rutile, orthite, and ore minerals are common accessories in all these rocks.

Quartz-sericite rocks[1]). These rocks consist predominantly of a fine-grained sericite-muscovite mass in which patches of chlorite, apparently pseudomorphic after biotite, are embedded. Trails of black, dusty ore material, partly altered into limonitic substance, indicate the former presence of more biotite and chlorite. Quartz occurs in grano-

[1]) 42106, 42259 A.

blastic aggregates and streaks composed of strongly undulatory grains, which are often broken and traversed by series of fine cracks along which trails of sericitic substance have formed. Xenoblastic oligoclase occur locally.

Plagioclase-quartz-sericite rocks[1]). These rocks are essentially the same as the quartz-sericite rocks but they contain appreciable amounts of oligoclase, which occurs as xenoblasts in thin quartzo-feldspathic streaks or augen (up to 5 cm long). Some potash feldspar is present interstitially between the plagioclase and quartz. The feldspars appear somewhat sericitized.

Biotite-sericite-chlorite schists[2]). The biotite flakes in these rocks are strongly corroded and partly altered into chlorite. The biotite is replaced by a fine-grained aggregate of chlorite, sericite, and muscovite. Small grains of magnetite, partly altered into limonitic substance are common in the micaceous aggregates. This ore substance apparently originated as a result of the replacement of biotite and chlorite by sericite and muscovite. Xenoblasts of oligoclase and lenticular aggregates and streaks of granoblastic quartz frequently occur. Potash feldspar is an accessory constituent. Some samples contain augen, streaks or bands of coarser-grained, xenoblastic aggregates of oligoclase with interstitial quartz and potash feldspar. Graphic intergrowths consisting of plagioclase containing quartz inclusions of uniform optical orientation are common.

Micaceous schlieren[3]). They consist predominantly of muscovite with subordinate biotite and minor amounts of epidote. The muscovite flakes are usually rather large (up to 3 mm long) and often contain inclusions of biotite, epidote, and very small ore grains. Biotite is apparently replaced by muscovite and the ore grains are a by-product of this process.

Quartz-feldspar rocks[4]). These medium-grained, leucocratic rocks represent more strongly gneissified varieties and they show transitions to coarser-grained pegmatitic veinlets. Oligoclase and quartz, occurring as xenoblastic grains, are the main constituents. Some potash feldspar, sometimes exhibiting the microcline cross-hatch twinning, is usually sparingly present as interstitial grains between oligoclase and quartz. Occasionally the potash feldspar is perthitic. Graphic intergrowths of plagioclase and quartz are common. The feldspars mostly show inci-

[1]) 42039, 42054, 42055.
[2]) 42030.
[3]) 42079.
[4]) 42040.

pient sericitization. Relic patches of biotite, or chlorite, partly replaced by muscovite or sericite, are regularly found accompanied by small grains of dusty ore substance. Pyrite is locally abundant.

Since pegmatitization is very common in the zones of biotite-plagioclase-quartz schists the above rock types are of widespread occurrence. They occur intermingled with each other and with the biotite-plagioclase-quartz schists. In all these rocks the replacement of biotite and chlorite by sericite and muscovite, and also by feldspars and quartz, has apparently led to a liberation of iron and the formation of small particles and dusty aggregates of ore substance. Oxidation of these ore substances and subsequent enrichment of iron oxides and hydroxides by supergene processes is apparently the cause of the rusty colour of these zones.

Besides the more common rock types in the zones of biotite-plagioclase-quartz schists there are also a number of less common ones. These will also be described briefly.

Hornblende-biotite rocks[1]). These rocks occur as concordant bands or schlieren and usually show a banded structure of biotite-bands alternating with hornblende-biotite bands. The latter consist of relatively large hornblende relics embedded in a matrix of biotite. The biotite bands are composed of biotite flakes (up to 2 mm long), oriented parallel to the schistosity of the rock, and often showing bent cleavage planes and undulatory extinction. Small hornblende fragments are often found in the biotite bands. Like the rotated and drawn-out inclusions of biotite- and biotite-hornblende rocks (p. 20), these banded hornblende-biotite rocks may be considered as relics of hornblendic rocks.

Garnet-quartz rocks[2]). The garnets are visible in the handspecimen as reddish brown crystals of about 0.5 cm diameter. The poikiliblastic crystals have inclusions of quartz, blue green hornblende and some ore. The garnets tend to gather together to form clusters. Replacements of the garnets by biotite and epidote occur along cleavage planes and around hornblende inclusions. The poikiloblasts occur in a groundmass of a granoblastic quartz mosaic with sutured outlines. Sphene is an accessory constituent.

Epidote rocks[3]). These rocks consist predominantly of minerals of the epidote group. Diopside, hornblende, garnet, and quartz are usually present. Sphene, apatite, and ore minerals are accessories.

[1]) 42145, 42222 F.
[2]) 42120.
[3]) 42260 A, 42261.

Diopside, if present, appears partly or completely replaced by a somewhat fibrous, pale green amphibole, which in its turn may appear replaced by epidote minerals. The originally idioblastic forms of the pyroxene is often still recognizable.

Some samples contain an almost colourless, amphibole which does not appear attacked by epidote. Granular quartz has developed along the cleavage planes of the amphibole and along its boundaries with the surrounding epidote minerals, but in spite of this skeletal habit, the idioblastic forms of the amphibole are usually well pronounced.

Garnets are present as skeletal crystals, which appear partly replaced by epidote and quartz.

The epidote minerals form xenoblastic aggregates consisting of intergrowths of different epidote minerals. The core of the crystals usually consist of uniformly oriented relic fragments of iron-free or α-zoisite (WINCHELL 1951, p. 446). This α-zoisite is replaced by iron-bearing or β-zoisite. In the intergrowths n_α of α-zoisite is parallel to n_β of β-zoisite. The transition zone between α- and β-zoisite is marked by zonal textures due to differences in birefringence between the two zoisite varieties. Pistachite, and sometimes clinozoisite, form rims around ore grains and garnets. This rim has often enlarged and replaced the surrounding zoisite minerals. The enclosed ore grain is often totally consumed, and eventually the pistachite has assumed idioblastic forms.

The epidote-rocks may be regarded as the altered representatives of diopside-bearing intercalations in the hornblendic layers (compare with the hornblendic layers in the Kuánit area).

6. Talc rocks[1].

The talc rocks are made up of dense aggregates of talc flakes of varying grain size (usually between 0.1 and 1 mm long).

A chlorite with anomalous blue interference colours is commonly found embedded in the talc masses. It is often partially replaced by talc, which may form pseudomorphs after chlorite. In some chlorite-rich samples the chlorite flakes have a distinct orientation, revealing a relic schistosity with microplications.

A carbonate, presumably calcite or dolomite, forms irregular veinlets and interstitial aggregates and nests. Chlorite is often conspicuously surrounded by carbonate matter.

Magnesite is often visible as large brown porphyroblasts attaining lengths of 1 cm or more. It is distinguished from the other carbonates by its higher refractive indices and stronger birefringence. The well shaped porphyroblasts have inclusions of talc flakes.

[1]) 42005, 42093, 42104, 42109, 42222 K, 42252, 42295, 42310.

Small grains of magnetite are often conspicuously associated with partially replaced chlorite.

A few samples contain aggregates of fibrous serpentine, presumably pseudomorphs after a completely replaced mineral.

Small needles of a colourless tremolite are sometimes found in the talc masses.

Some talc lenses are surrounded by rims of tremolite rocks. The tremolite rocks also occur as veinlets in the talc lenses. The tremolite in these rocks forms dense aggregates of prismatic crystals (0.5–1 cm long), which are mostly partially replaced by interstitial chlorite and talc. The chlorite also appears replaced by talc. The tremolite rocks presumably represent alterations of the talc lenses due to pegmatitic solutions. The chemical composition of the talc mass was unsuitable for the formation of quartzo-feldspathic pegmatites and tremolite veinlets were formed instead. With decreasing temperatures the tremolite is replaced by chlorite and talc (see e.g., HESS 1933, ROST 1949).

C. Rocks from the area South of Tigssalûp ilua.

1. Hornblendic rocks[1]).

Hornblendic rocks occur in the area south of Tigssalûp ilua only as inclusions in the amphibolites and garnet-biotite augen-gneisses.

The rocks consist predominantly of a deep blue green hornblende. The crystals clearly have been subjected to strong stresses and they show many cracks, undulatory extinction, and incipient recrystallization. The hornblende is corroded by a fine-grained interstitial mass of sericitic and saussuritic substance, in which zoisite granules, flakes of a colourless mica, or grains of andesine have developed. Garnet poikiloblasts (1–3 mm), containing inclusions of hornblende and quartz are not uncommon in the hornblendic inclusions in the garnet-biotite augen-gneisses. Ilmenite, rutile, and apatite are accessories.

2. Amphibolites[2]).

The blue green hornblendes exhibit the same textural characteristics as those in the amphibolites on NE. Tôrnârssuk, but it has generally a somewhat darker colour ($2V\alpha = 80°$; $\gamma \wedge c = 21°$; γ deep blue green, β green, α pale green).

Biotite is usually rather scarce; the mineral has developed interstitially between the hornblendes.

[1]) 42313, 46881, 46882.

[2]) 42517, 42393 B, 42395, 46803, 46880, 46903.

Garnet is sporadically present as porphyroblasts or poikiloblasts, often partially replaced by biotite, plagioclase, and quartz.

Epidote has not been observed.

The plagioclase is an andesine (An_{30-50}) occurring as more or less interstitial granular aggregates and as small xenoblasts (1–2 mm long). The latter often contains biotite inclusions or occurs in graphic intergrowths with quartz inclusions of uniform optical orientation.

Quartz is present as interstitial grains and in granoblastic aggregates between the other minerals.

Apatite, sphene, and ore minerals are accessories.

Close to the garnet-biotite augen-gneisses the amphibolites frequently appear schistose and more fine-grained. These rocks may be regarded as transitory varieties between the amphibolites and the garnet-biotite augen-gneisses. They are often almost completely recrystallized and consist of a fine-grained matrix of quartz-andesine-biotite aggregates, in which corroded grains of hornblende are found.

3. Garnet-biotite augen-gneisses[1].

The garnet-biotite augen-gneisses locally contain sillimanite, staurolite, or anthopyllite and cummingtonite.

Biotite is very abundantly present; often it forms the only essential component in the schistose matrix of the augen-gneisses. The mineral forms flakes up to 2 mm length, arranged parallel to the schistosity. The flakes are gathered in biotite bands, streaks, or aggregates. Undulatory extinction and bending and twisting of biotite flakes are frequent. Besides the larger flakes there are also aggregates of smaller usually randomly oriented biotite flakes, which occur interstitially between the larger, parallelly oriented biotite flakes and plagioclase-quartz aggregates. The staurolite- and the anthophyllite-bearing rocks often contain large (2–3 mm), well developed poikiloblasts of apparently late biotite. These poikiloblasts have quartz inclusions and show a random orientation.

Garnet is often abundantly present as large (up to 1 cm), reddish brown crystals. The larger, parallelly oriented biotite flakes have apparently been pushed aside by the growing garnets, and the biotite flakes wrapping around the garnets often appear bent and show undulatory extinction. Replacement of garnet by quartz, biotite, and andesine is common and often the garnet is only observed as relic fragments embedded in a fine-grained pseudomorphic aggregate of the replacing minerals. In some specimens the garnet is replaced by late albite.

The plagioclase is commonly an andesine (An_{25-45}). It forms either

[1]) 42312, 42314, 42321, 42322, 42393, 42396, 42398, 46801, 46883, 46884, 46886, 46892, 46900.

finely-granular masses, often associated with quartz, or coarser-grained xenoblastic crystals. The latter often show uneven extinction and quartz inclusions of uniform optical orientation. Biotite and garnet are corroded by the plagioclase. Very often lenticles consisting of an xenoblastic aggregate of feldspars and quartz have formed. The augen structure of the rocks is due to these lenticles. The lenticle may contain corroded biotite flakes. Granulation and recrystallization of the earlier formed plagioclase have often been observed.

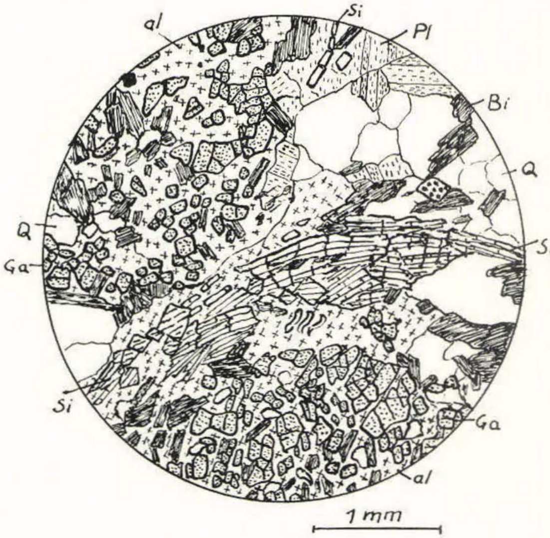


Fig. 31. Garnet-sillimanite-biotite augen-gneiss, South of Tigssalûp ilua. The dense aggregates of sillimanite (Si) contain some relic biotite (Bi) flakes. The sillimanite needles are bent and broken by the garnet (Ga) porphyroblasts. The garnets have been partly replaced by biotite. Late albite (al) occurs as large grains replacing sillimanite, garnet, biotite, andesine (Pl), and quartz (Q). (46884).

Late albite (about An_5) is often developed as large grains of uniform extinction enclosing and replacing the garnets, and often also sillimanite aggregates. Prior to its replacement by late albite the garnet was apparently already partly replaced by biotite, quartz, and andesine, for the latter minerals are also enclosed in the late albite together with relic garnet fragments. Late albite is frequently developed interstitially between andesine crystals. Very often it forms graphic intergrowths with quartz.

Quartz is present in varying amounts. It occurs as interstitial grains which have corroded biotite, garnet, or andesine. Granoblastic quartz aggregates occur in the form of streaks, lenses, and bands.

Sillimanite is not a common mineral, but it occurs abundantly in some specimens (Fig. 31). Tourmaline, apatite, and late albite are common associates of the sillimanite. The mineral has a prismatic habit and it occurs as aggregates of relatively coarse-grained needles (1–2 mm long), mostly embedded in biotite. The sillimanite has clearly developed from the biotite and relic patches of biotite may still be present in the sillimanite aggregates. The surrounding biotite has often been replaced by andesine, quartz, or late albite, and the sillimanite is often found enclosed in these minerals. The bundles of sillimanite needles have frequently been deformed by growing garnet porphyroblasts. Adjacent to garnets

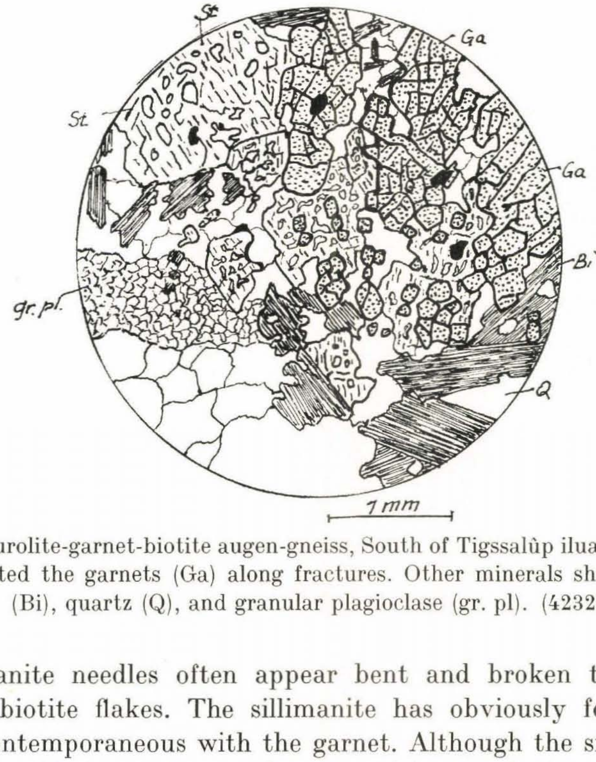


Fig. 32. Staurolite-garnet-biotite augen-gneiss, South of Tigssalûp ilua. Staurolite (St) has penetrated the garnets (Ga) along fractures. Other minerals shown are biotite (Bi), quartz (Q), and granular plagioclase (gr. pl). (42321).

the sillimanite needles often appear bent and broken together with enclosing biotite flakes. The sillimanite has obviously formed earlier than or contemporaneous with the garnet. Although the sillimanite has formed from biotite, it has not been found in association with the later biotite, which has replaced the garnets. The sillimanite aggregates are often joined by crystals of tourmaline and apatite. The latter minerals are also often observed in the shadow zones of large garnet porphyroblasts. From the presumed contemporaneity of sillimanite, tourmaline, and apatite on the one hand, and of garnet, tourmalíne and apatite on the other hand it seems probable that sillimanite and garnet have formed approximately at the same time.

Staurolite is of more widespread occurrence than sillimanite. The mineral is often present as large poikiloblasts. The inclusions consist commonly of quartz, but some biotite may also be included. The staurolite crystals have often penetrated the garnet along fractures in the latter mineral (Fig. 32); they have frequently corroded the garnet and they sometimes contain garnet inclusions. The staurolite is clearly later than the garnet. Small flakes of muscovite sometimes partly surround staurolite crystals. Many staurolite-bearing rocks contain biotite poikiloblasts associated with the staurolite.

A pale green to colourless anthophyllite ($2V\alpha = 100°$; $\gamma \wedge c = 0°$) occurs in some specimens as idioblastic crystals forming long needles (up to 5 mm long). It is usually intergrown with a colourless cummingtonite ($2V\alpha = 104°$; $\gamma \wedge c = 18°$), which occurs as very fine lamellae parallel to (100) in the anthophyllite. When the cummingtonite lamellae are somewhat broader, they can often be seen to be finely polysynthetically twinned. The amphiboles are often elongated transverse to the schistosity of the rock, and they often cut through flakes of early biotite. Sillimanite and staurolite have not been found in the anthophyllite-bearing rocks. However, the anthophyllite is often accompanied by poikiloblasts of late biotite, which are also typically found in the staurolite-bearing rocks. It is suggested that anthophyllite and staurolite are approximately of the same age, the first mineral is present in more Mg-rich rocks, whereas the latter mineral has developed in more Fe- and Al-rich rocks.

Tourmaline, apatite, epidote, magnetite, and orthite are accessory constituents in the garnet-biotite augen-gneisses.

The later pegmatitization has mainly involved the introduction of quartz and plagioclase, some muscovite and sericite, and rarely potash feldspar. The rocks appear locally transformed into a gneiss consisting of thin bands of a granoblastic quartz mosaic with sutured outlines, alternating with equally thin bands of a granoblastic quartz-plagioclase aggregate. Streaks of micaceous material, accompanied by aggregates of dusty ore substance, occur in the quartz and quarts-plagioclase bands. Cataclastic effects, such as granulations and mortar structures are rather common. Strongly corroded grains of garnet are sometimes found.

V. PETROLOGICAL CONSIDERATIONS

A. The originally widespread occurrence of hornblendic rocks.

In the investigated areas hornblenditic or highly hornblendic rocks, associated with minor amounts of diopside- and diopside-hornblende rocks, occur commonly as bands, streaks, lenses and other inclusions in amphibolites, quartz-, epidote-, magnetite-hornblende schists, and associated biotite-plagioclase-quartz schists and garnet-biotite augen-gneisses. Under the microscope hornblendites may pass through every gradation of intergranular development of new minerals, corrosion of older minerals, and subsequent blastesis into amphibolitic rocks or into foliated, banded or schistose rocks. Amphibolitic rocks, which by their gradation into hornblendic rocks in the field have presumably originated in this way, show characteristic textures and sequences of mineral developments that are also found in most of the other investigated amphibolitic rocks of the area. Therefore, it may be suggested that hornblendites or highly hornblendic rocks were originally of widespread occurrence in the investigated areas, but that they are now mostly represented by amphibolites, banded hornblende-schists, and associated rocks. (However, see also p. 77).

The metamorphism leading to the formation of the hornblenditic rocks is believed to be, broadly speaking, contemporaneous with gneissification, migmatitization, and the main Ketilidian folding (pp. 9–10). Its metamorphic degree presumably corresponds to the amphibolite facies. In the Kuánit area and on NE. Tôrnârssuk inclusions of hornblenditic rocks, consisting predominantly of a green hornblende, may be regarded as amphibolite facies relics in epidote-amphibolite facies rocks. The green hornblende in some of these inclusions tends to recrystallize or to be altered into a deep blue green, perhaps more actinolitic, or into a light coloured, perhaps more tremolitic amphibole. The latter amphiboles are also the common modification of the mineral in the surrounding amphibolites and banded hornblende schists. The occurrence of oligoclase and epidote in the latter rocks indicate that they are in the epidote-amphibolite facies. Thus, at least two phases of metamorphism can be recognized in the Kuánit area and on NE. Tôrnârssuk. In the area south of Tigssalûp ilua the amphiboles in the hornblendic inclusions and surrounding amphibolites consist seemingly of the same deep bluish green variety. The amphibolites contain andesine instead of epidote and oligoclase and they are apparently in the amphibolite facies. These conditions may be so interpreted that the second metamorphic period, being of a higher grade in the area south of Tigssalûp ilua than in the Kuánit area and NE. Tôrnârssuk, has also caused the recrystallization or transformation of the amphiboles in the hornblendic relics, so that they assumed the same composition as those in the surrounding rocks (see also pp. 78–79).

The pre-metamorphic materials of the hornblendic rocks are unknown. They could have been marly or calcareous sediments and/or basic or ultrabasic intrusive or extrusive rocks, which are all represented in the low-metamorphic Ketilidian series preserved within the Arsuk bassin and other parts of the Ivigtut region. An indication, unreliable as it may be, is afforded by the relatively high content in Cr, Ni, Cu, and Ti (Fig. 33). Amphibolitic rocks rich in these elements have often been referred to as probably of igneous derivation (Engel and Engel 1951; Goldschmidt 1954, pp. 548, 676).

However, the products that are to be expected of medium- to high-grade metamorphism in the amphibolite facies of marly, ultrabasic and basic complexes, will presumably consist mainly of amphibolites, possibly with subordinate hornblendites and pyroxenites. Such rock assemblages of different geological ages are of common occurrence, whereas extensive complexes consisting predominantly of hornblendites of apparently metamorphic origin seem to have been rather rarely described, mostly, if not exclusively, from Precambrian areas. The formation of the hornblendic layers in the areas presently under consideration was presumably accompanied by migmatitization and gneissification, which most probably involved important metasomatism. The author believes that in an open system where elements as Na, Ca, Si, and Al are available and can migrate freely, the ensuing rocks on ordinary regional metamorphism in the amphibolite facies of marly or calcareous sediments and basic or ultrabasic rocks would consist of the assemblage hornblende-plagioclase (i.e. amphibolites) rather than of hornblende alone. Some additional controlling factor must seemingly be assumed to explain the occurrence in the considered areas of extensive layers, thought to be of formerly hornblenditic composition. These layers have thicknesses varying from few meters to more than 100 meters; they occur intercalated in the banded gneisses and they extend for at least 20 km along the strike of the rocks.

The author would suggest a kinematically controlled metamorphic differentiation related to folding in the sense as proposed by TUOMINEN and MIKKOLA (1950) and MIKKOLA (1955) as a possible explanation for the presumed widespread occurrence of hornblendic rocks within the areas here considered. It is suggested that at an early stage a kinematically controlled metamorphic differentiation might result in the formation of bands of highly chloritic composition in layers of suitable chemical and mechanical properties. This stage of synorogenic metamorphism presumably involved extreme deformation and intense gliding and penetrative movements in layers of suitable properties; these conditions are to be expected during the orogeny in the inner portions of a geosyncline. The actual composition of the hornblendic rocks is thought to be the result of a subsequent recrystallization in the amphibolite facies of the highly chloritic material. The early, sometimes seemingly anomalous production of hornblende in highly chloritic rocks has been noted by HARKER (1939, pp. 266, 280). The later high-grade recrystallization may presumably be linked with widespread plutonic activity (the main Ketilidian granitizations and migmatitizations) and when it took place under approximately static conditions and with the possibility of migrations of material, the resulting rocks would probably be amphibolites rather than hornblendites. Therefore, in our area a rather intimate relationship between orogenic and plutonic metamorphism (READ 1957, p. 389) has to be assumed and the subsequent stages should rather be regarded as overlapping phases. Such a relationship might be expected to have prevailed in the deeper levels of folded mountain chains, such as are many of the Precambrian terrains (compare READ, loc. cit.). However, the latter areas are often polymetamorphic and hornblendic rocks may be transformed into amphibolites in the course of a later metamorphic period, or even a later metamorphic stage.

Some observations which are consistent with the above hypothesis may be cited below in support of it. In an earlier stage the material recrystallizing into hornblenditic rocks (presumably highly chloritic schists) apparently had behaved as relatively incompetent with regard to the gneisses, and thin incompetent beds were squeezed from the limbs towards the crests of folds (Fig. 2). These structures should not be confused with the hornblendic relics in folds in the biotite-plagioclase-quartz schists and garnet-biotite augen-gneisses. In the latter rocks the hornblendic relics generally appear partly transformed into biotite-rich rocks, whereas in the present case no such transformations occur. In a more advanced stage the hornblendic layers may gain in relative competency and be subjected to boudinage. Similar changes in relative competency in amphibolitic and ultrabasic rocks have been observed by BERTHELSEN in the Tovquassaq region, West-Greenland (BERTHELSEN 1957, p. 181).

With regard to the close association in the present area of lenses of talc schists, often containing chlorite relics, with hornblendic rocks, attention may be drawn to those hypotheses attributing a metamorphic origin by tectonically controlled differentiation processes to talc and other ultrabasic rocks (SØRENSEN 1953; MIKKOLA 1955; BENNINGTON 1956). The talc rocks might well be considered as very Mg-rich differentiates resulting from the same processes that caused the formation of the hornblendic layers.

B. Metamorphic differentiation due to differential shearing in the hornblendic layers of the Kuánit area.

It has been assumed that hornblenditic inclusions in the hornblendic layers in the Kuánit area form amphibolite facies relics enclosed in epidote-amphibolite facies rocks. The latter consist of a banded series of mainly epidote-hornblende schists, quartz-hornblende schists, and magnetite-hornblende schists. By the development of oligoclase in these rocks transitions into amphibolitic bands and layers occur. Hornblende-biotite schists, biotite-plagioclase-quartz schists and tremolite-chlorite rocks occur at places where the rocks have seemingly been affected by stronger shearing, mostly along the contacts of the hornblendic layers with the surrounding gneisses. Disseminated iron sulphides occur in diopside and epidote-rich bands. The thicknesses of the different bands within the banded layers vary from place to place, but the total thickness of the layer is approximately constant. These relations suggest that the banded rock series may have originated from originally hornblenditic layers by a process of metamorphic differentiation in the epidote-amphibolite facies. The observation that magnetite bands in similar magnetite-hornblende schists on NE. Tôrnârssuk occasionally cut obliquely across an older foliation formed by the amphiboles, clearly indicates the later origin of the banding in these rocks (see p. 18).

Textural studies have indicated that the transformation of hornblendite into quartz-hornblende schist involved a volume by volume replacement of hornblende by quartz. Evidently this process involved the expulsion of Ca, Mg, Fe, Al, Na, and possibly other elements contained in the hornblende, and a corresponding introduction of Si in the bands of quartz-hornblende schists.

The quartz-hornblende schists alternate with epidote-hornblende schists, epidote-bearing diopside-hornblende rocks, and epidote-diopside rocks. The possible chemical changes attending the replacement of hornblende by epidote may be depicted by considering the respective formulas and corresponding molecular volumes:

1 mol (898 gr) $\underset{\text{(hornblende)}}{NaCa_2(Mg,Fe)_4Al_3Si_6O_{22}(OH)_2}$ occupies a volume of 281 cc,

1 mol (399 gr) $\underset{\text{(pistachite)}}{Ca_2(Al,Fe)_3Si_3O_{12}(OH)}$ occupies a volume of 111 cc.

The dissolution of 1 mol hornblende will furnish enough Ca and Al for 1 mol of epidote, but to maintain constant volume more epidote has to be formed and, therefore, Ca, Al, and Si have to be introduced, while Mg, Na, and probably Fe will be removed. Most of the Fe may be retained in the rock in sulphides and as a substitute for Al in the epidote. The formation of plagioclase at the expense of epidote needs an excess of Al_2O_3 and SiO_2 over CaO; the elements in excess combine with Na_2O to form albitic plagioclase. The presence of oligoclase and quartz in most epidote-bearing rocks indicate that in most cases Si and Al were indeed introduced. On the other hand, if CaO is in excess plagioclase will not form and calcite may figure in addition to epidote. Enrichment in epidote occurs especially in the diopside-rich bands, i.e., in those bands which were originally already richer in lime. Ti apparently also migrated to the lime-rich bands to form sphene.

The magnetite bands in the magnetite-hornblende schists represent concentrations of Fe, presumably mainly derived from the surrounding quartz-hornblende schists.

The formation of plagioclase and quartz at the expense of hornblende in the amphibolites involves probably an increase in Na and Si, and a corresponding decrease in Ca, Mg, and Fe. Ca may be partially retained in epidote, but the replacement of epidote by plagioclase indicates that this might be only temporarily. The development of biotite in many amphibolites requires the addition of some K.

The conversion of hornblendite into hornblende-biotite schists and biotite-plagioclase-quartz schists requires the availability of K, which has to be introduced. A gain in Mg and Fe and a loss in Na and Ca at the time of biotite formation seems obvious. However, the formation of epidote, plagioclase and quartz at the expense of biotite indicates that at a later stage the processes were reversed, resulting in a regain in Na, Ca, Al, and Si, and a loss in Mg, Fe, and K.

The formation of tremolite-chlorite rocks from the hornblendites presumably implies an enrichment in Mg and Fe, and a corresponding loss in Na and other elements.

Thus, it appears that in the course of the transformation of the hornblendites into a banded rock series a metamorphic differentiation has taken place; certain elements were expelled from certain bands and became concentrated in other bands. However, the above considerations neglect several factors. The composition of the mineral species can only be approximated and no account has been taken of the fact that their compositions are subjected to changes in the course of metamorphism. Furthermore, the recrystallization of the hornblendites into the stronger sheared and schistose rocks may not have taken place at constant volume. The results summarised in Table 1 represent, therefore, only a rough quantitative approximation.

Taking into account the relative abundances of the different rock types, a few estimates regarding the overall chemical changes in the hornblendic layers during the later metamorphism may be made from Table 1. An introduction of Si seems clear since all the more abundant rock varieties are enriched in it. K seems also to be introduced since the original potash content of the hornblendites was presumably too low to form all the biotite. The presence of sulphides, tourmaline, and orthite indicates an introduction of S, B, and other less common elements. Mg seems to be the principal element that is removed. Ca may be temporarily retained in epidote, but with the replacement of epidote by plagioclase Ca is expulsed and Na introduced. Other changes undoubtedly have taken place but the available data do not permit further discussion.

TABLE 1.

Metamorphic differentiation in the polymetamorphic hornblendic layers in the Kuánit area.

Rock types in the order of their estimated relative abundances	Relative influence of shearing stress	Elements presumably enriched	Elements presumably expelled	Uncertain
epidote-hornblende schists	weak to moderate	Ca, Al, Si, Ti, S	Mg, Na	Fe
quartz-hornblende schists	moderate	Si	Ca, Mg, Fe, Al, Na, Ti	
amphibolites	moderate	Si, Na, K	Ca, Mg, Fe	Al, Ti
magnetite-hornblende schists	moderate to rather strong	Si, Fe	Ca, Mg, Al, Na, Ti	
hornblendites and associated diopside rocks	absent to very weak	–	–	
epidote-diopside rocks	weak to moderate	Ca, Al, Si, Ti, S	Mg, Na	Fe
hornblende-biotite schists and biotite-plagioclase-quartz schists	strong to extremely strong	Mg, Fe, K	Ca, Ti	Si, Al, Na
tremolite-chlorite rocks	strong to extremely strong	Mg, Fe	Na, Ti	Si, Al, Ca

The metasomatising solutions were apparently introduced partly along discordant fractures, now filled with pegmatitic material. However, migration of material along planar features parallel to the present banding seems to have been the more important. These planar features are presumably shear planes (BARTH 1952, p. 305). In Table 1 the relative influence of shearing stress in different bands as deduced from observed macro- and micro-deformations are given for the various rock types. It appears that Mg and Fe are enriched in the strongest sheared and more or less completely recrystallized rocks. In the less intensely sheared rocks shearing stress did not cause the total recrystallization of the rock, but it resulted in the development of planar features along which the predominantly siliceous metasomatising solutions were squeezed in. Replacement proceeded by corrosion of older minerals, volume by volume. The resulting banded rocks show in general a loss in Mg and Fe, and a gain in Si. The rocks not significantly affected by shearing stress may survive as unaltered hornblenditic relics in the banded rock series.

C. The origin of magnetite- and sulphide-bearing bands in the hornblendic layers.

After the above considerations on metamorphic differentiation the present topic needs only few comments.

Ilmenite and magnetite were presumably original accessory constituents in the hornblendites. Metamorphic differentiation has resulted in the liberations of Fe and Ti, mainly derived by the dissolution of hornblende and ore minerals in certain bands, and in their migration to and concentration in other bands. A similar differentiation under dynamometamorphic conditions of the epidote-amphibolite facies has been assumed for the ilmenite-magnetite ores of OTANMÄKI, Finland (PÄÄKKÖNEN, 1956). However, in the present case Ti was not redeposited as ilmenite, but it migrated towards the Ca-rich diopside- and epidote-bearing bands and formed sphene.

The magnetite-hornblende schists appear relatively more strongly deformed than the surrounding quartz-hornblende schists. Presumably due to higher pressures or shearing stress the amphibole in the magnetite-hornblende schists is different from that in the quartz-hornblende schists. In the former rocks the amphibole is either a pale green variety or it consists of intergrowths of a colourless and blue green hornblende (NE. Tôrnârssuk). The lighter coloured, presumably tremolitic hornblende can apparently take up less Fe than the blue green hornblende of the quartz-hornblende schists. This condition may have favoured the appearance of magnetite as a new phase. Enrichment in magnetite occurred as long as these conditions prevailed and the formation of magnetite bands seems restricted to periods of active deformation and controlled by the existence of differential stresses.

In the more Ca-rich, diopside- and epidote-bearing bands magnetite is not formed, but the Fe, together with some Ni and Cu, is bound in sulphides. The sulphur was apparently introduced. The sulphides formed in a definite order: pyrite, pyrrhotite, chalcopyrite, and pentlandite, locally followed by a later generation of pyrite and chalcopyrite. The early crystallization of pyrite before pyrrhotite indicates that the partial

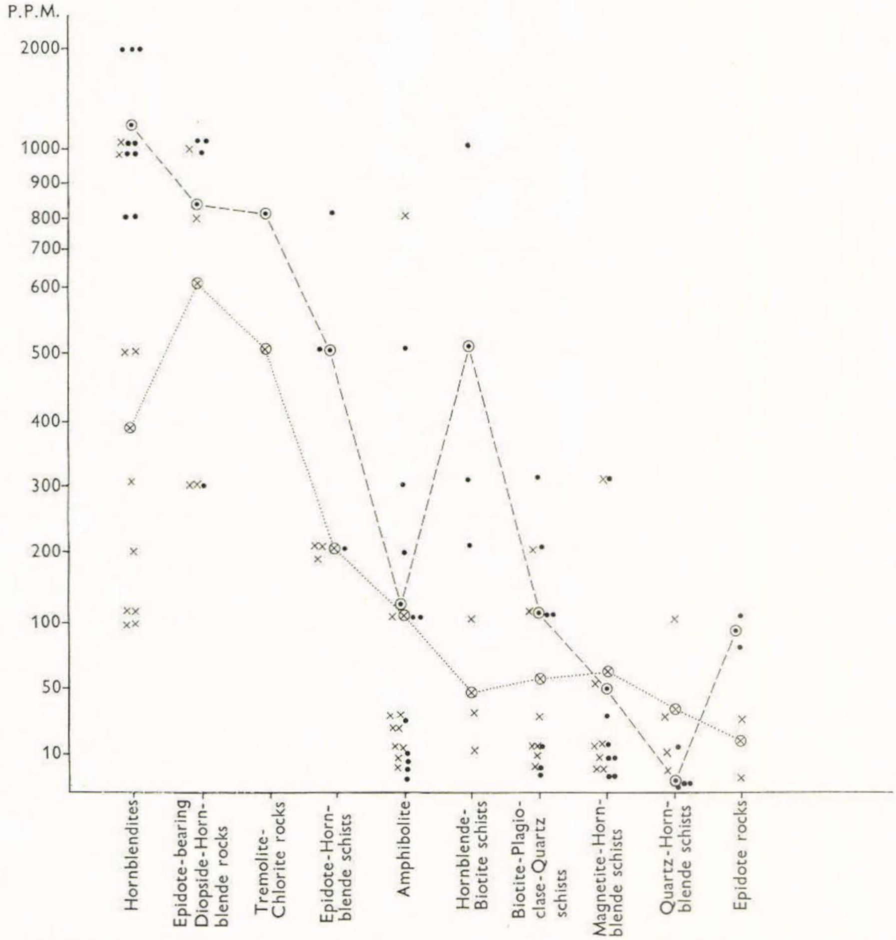


Fig. 33. Results of semi-quantitative spectrographic analyses for Cr and Ni in hornblendic rocks and their polymetamorphic derivatives from NE. Tôrnârssuk and the Kuánit area. Dots represent Cr-values; crosses Ni-values; average values are circled. Analyst Mr. IB SØRENSEN.

vapour pressure of sulphur or the S-content of the ore-bringing solutions must in the early stages have been high (KULLERUD and YODER 1959). Yet, the sulphides were not distributed evenly throughout the rock, which suggests that the sulphide formation was contemporaneous with metamorphic differentiation.

The results of a series of semi-quantitative spectographic determinations of the Ni- and Cr-contents of different rock types from the hornblendic horizons in the Kuánit area and NE. Tôrnârssuk are given in Fig. 33. The highest Ni-contents are found in the unaltered hornblendites and related diopside-bearing varieties. The epidote-hornblende schists show intermediate values, while all other polymetamorphic derivatives of the hornblendites have lower values. However, the richest concentrations in nickeliferous sulphides (pyrrhotite and pentlandite) occur in the epidote-hornblende schists. Therefore, the Ni-content in the relatively sulphide-rich bands is rather to be considered as a residual concentration.

The Cr-content is also the highest in the untransformed hornblendites and diopside-bearing rocks. The main Ketilidian metamorphism, which has resulted in the formation of ferro-magnesian rocks may apparently not have resulted in reduction of the initial Cr- and Ni-concentrations (Engel and Engel 1951). However, the later metamorphism, which has involved considerable breakdown of the ferro-magnesian minerals and their replacement by quartzo-feldspathic material, has removed much of the latter elements.

Finally, it may be noted that metamorphic differentiation occurred only in the thicker hornblendic layers and lenses and not in the thinner intercalations in the gneisses. This explains why ore-bearing bands are only found in the thicker hornblendic horizons.

D. The rusty-coloured zones of biotite-plagioclase-quartz schists on NE. Tôrnârssuk.

The field observations summarized below offer ample evidence that in and along the zones of biotite-plagioclase-quartz schists on NE. Tôrnârssuk important deformations and shearing movements have taken place.

a) The pronounced schistose and sheared appearance of the rocks (Fig. 9), which is generally most pronounced near the base of the rusty horizons, already suggests shearing as an important factor.

b) The preservation of hornblendic relics along the hinge zone of folds in the rusty schists may well be explained by the operation of shearing stresses, which are most intense along the limbs and less so along the hinge zone of the folds.

c) The schists generally rest with a sharp, often slightly discordant contacts on the underlying rocks; in some instances the discordancy is more pronounced and the contact plane is apparently a thrust plane (Fig. 6).

d) Deformed, rotated, and drawn-out inclusions of biotitized hornblendic rocks (Fig. 7) and the folding of the schists against larger obstructing inclusions indicate that differential movements within the schist layers have taken place.

e) In and behind the schist zones small-scale folds with amplitudes of 1–10 m and axes parallel to the strike of the surrounding rocks are

Fig. 34. Pegmatites in the transition zone between amphibolites and biotite-plagioclase-quartz schists. The rocks are amphibole-bearing biotite-plagioclase-quartz schists. The pegmatite in the center of the figure is seemingly younger than the small-scale folding and has partly formed along the schistosity planes of the already folded rock (left hand side of picture; note also schist inclusions in the pegmatite) and partly along discordant fractures. The pegmatite is a coarse-grained massive rock, which shows no signs of shear-folding. NE. Tôrnârssuk, near lake 450.

often observed. The folds are often recumbent folds indicating a southward movement.

f) The abundant small, concordant, contorted and drawn-out pegmatitic veinlets in the schists (Fig. 9) form a strong contrast to the often undeformed and discordant, intersecting veinlets in the surrounding rocks. Thicker concordant pegmatites are younger than the abovementioned contorted and drawn-out veinlets; they frequently appear later than the small-scale folds (Fig. 34), but also often they still appear affected by folding and local shearing (Fig. 8). Finally, an apparently still later generation of pegmatites showing swell structures (Fig. 9) do not appear deformed and they were presumably formed at a time when the shearing movements were dying out. Pegmatitization and shearing appear as overlapping, alternating and mutually facilitating processes. An estimate of the relative abundance of pegmatites in the schists and in the surrounding rocks suffices to make it a reasonable supposition that pegmatitic material was introduced in the schist zones during the period of shearing.

A generalized diagrammatic representation of the zones of biotite-plagioclase-quartz schists on NE. Tôrnârssuk is given in Fig. 14.

The possibility that the schists represent layers of pelitic or kindred sediments, which during folding and metamorphism became stronger sheared than the surrounding rocks because they behaved as incompetent beds intercalated between more competent ones, must be considered and can not be entirely ruled out. An alternative possibility, which in the author's opinion is more probable, is that the schists represent sheared and pegmatized hornblendic rocks. Some considerations, regarded as in favour of or at least consistent with the latter possibility are summed up below.

1) There is a close spatial relationship between the schists and amphibolitic or hornblendic horizons (Fig. 3). Some small, discontinuous streaks of biotite-plagioclase-quartz schists occur in the gneisses close to the amphibolitic horizons, but they do not occur farther away from the latter rocks.

2) The amphibolites on NE. Tôrnârssuk presumably form the westward prolongation of the hornblendic layers in the Kuánit area. Bodies of banded hornblendic rocks, comparable in their petrological and mineralogical aspects with similar rocks of the Kuánit area, occur on NE. Tôrnârssuk as rather large inclusions in and between the amphibolites and biotite-plagioclase-quartz schists. In the field they often grade into both the latter rock types. Since there are strong indications that within the hornblendic layers of the Kuánit area metamorphic differentiation due to differential shearing has resulted in the local formation of, among others, amphibolitic rocks and, apparently at places of stronger shearing, biotite-plagioclase-quartz schists, the inference seems reasonable that shearing operating more intensively along certain zones on NE. Tôrnârssuk, may also have caused the transformation of hornblendic layers in the latter area into a series of mainly amphibolites and biotite-plagioclase-quartz schists. It is remarkable that where larger bodies of banded hornblendic rocks occur enclosed or partly enclosed in the biotite-plagioclase-quartz schists, they almost always adjoin lenses of talc schists (Fig. 3). The latter fact may be so interpreted that, due to the greater liability to shearing of the talc schist, shearing movements became concentrated in the talc schists and the adjoining hornblendic rocks may escape intense shearing and transformation into schistose rocks.

3) Amphibolitic and hornblendic inclusions of smaller size are commonly found in the schists (Fig. 35). They often show unsharp contacts with surrounding rocks. Gradual transitions between schist and amphibolite layers have also frequently been noted. Under the microscope the transitions appear to be caused by the progressive elimination of hornblende, which gives way in the first place to biotite.

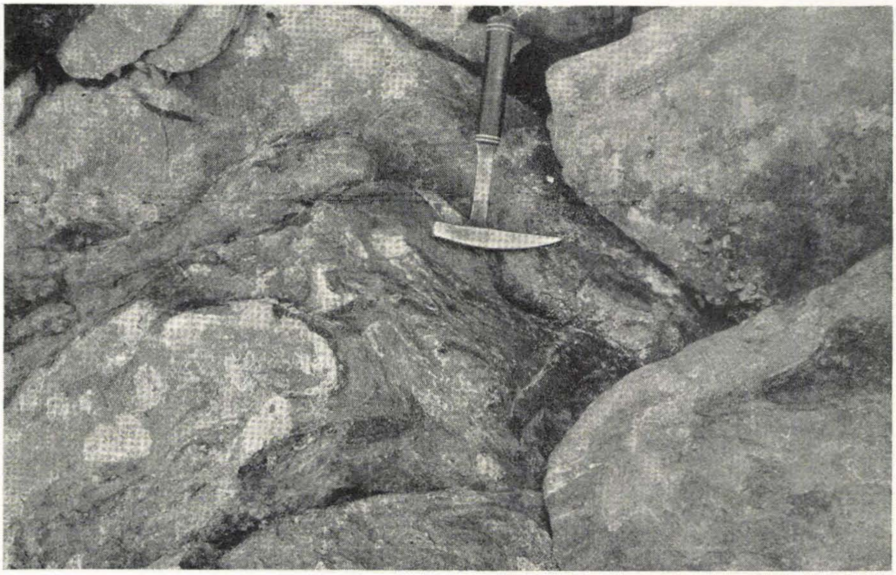


Fig. 35. Hornblendic schlieren in biotite-plagioclase-quartz schists. The hornblendic inclusions tend to be preserved along the hinge zone of small folds and appear in different stages of transformation into biotite-plagioclase-quartz schists. The darkest inclusions in the center of the picture consist of slightly biotitized and feldspathized hornblendic rocks (note association with pegmatites). At the left hand side and upper part of the picture the hornblendic schlieren have been transformed into hornblende-biotite-plagioclase-quartz schists and are only faintly visible on the picture. NE. Tôrnârssuk, N. of hill 510, north of the area of Fig. 3.

If a derivation of the schists from pelitic sediments is presumed, the hornblendic inclusions may be considered as pieces of intercalated competent layers, which on deformation together with the surrounding incompetent pelites were disrupted into fragments or boudins. GAVELIN (1960) has described such a case from the Stockholm area, where metabasite inclusions in veined gneisses are surrounded by thin reaction zones of biotite, plagioclase and quartz. These reaction zones are ascribed to the action of "kinetometamorphism" connected with the plastic flow of the incompetent gneiss mass surrounding the metabasite inclusions. GAVELIN (1960, pp. 254, 256) also cited similar examples from Finland described by HÄRME and LAITALA (1955) and stated that the most conspicuous feature in the reaction zones is that the amphiboles have been completely replaced by biotite. If in the present case the inclusions are considered as fragments of disrupted hornblendic intercalations in the schists, the replacement of amphibole by biotite and the transition into biotite-plagioclase-quartz schists occurring around the inclusions may be considered as reaction zones. It should be noted then, that the reaction zones are rather broad and that no sharp boundary exists between the reaction zone and surrounding schists. Locally the inclusions are so abundant that if allowance is made for reaction zones, not much space is left over for originally pelitic material. Therefore, the author thinks that original pelitic material, if ever present at all, is of subordinate importance; the schists are believed to be derived from hornblendic rocks by metamorphic transformations involving important shearing and pegmatitization. In principle this process is similar to that leading to the formation of biotite-plagioclase-quartz reaction zones in the metabasite inclusions in gneiss described by GAVELIN, the difference lies mainly in the fact that in the present case biotite-plagioclase-quartz schists are formed in broader zones of shearing and pegmatitization situated along the contacts of hornblendic and gneiss layers.

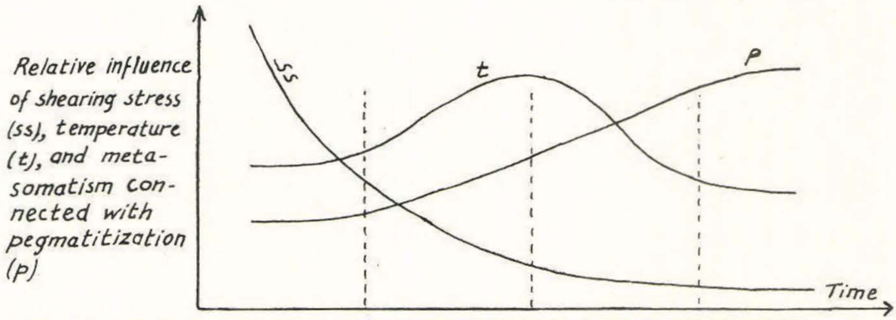
4) The schists are epidote-amphibolite facies rocks characterized by the assemblage epidote-oligoclase. If they were originally present as pelitic material they must have been affected together with the surrounding hornblendic rocks by the earlier gneissification and amphibolite facies metamorphism. They would either have been gneissified or metamorphosed in garnet-, staurolite-, kyanite-, or sillimanite-bearing schists. These typomorphic minerals, except perhaps sillimanite, might be expected to persist at least locally as stable relics during a subsequent period of metamorphism in the epidote-amphibolite facies, even when the effects of shearing are taken into account. No mineralogical or structural relics pointing to such a previous state have been found in spite of a search in a sufficient number of sections; instead relics of hornblendic rocks have been commonly observed. It is true that garnets are sporadically found in the schists, but their habit and textures indicate a post-kinematic origin, so that they cannot be considered as relics of a previous metamorphism. The same applies to the garnet, staurolite, and sillimanite in the garnet-biotite augen-gneisses south of Tigssalûp ilua (see also pp. 78–80).

The textural and mineralogical evolution of the biotite-plagioclase-quartz schists, as studied under the microscope, is in agreement with the views expressed in the foregoing.

Biotite is the first mineral that has developed abundantly at the expense of amphibole. This early biotite forms large flakes parallel to the schistosity which often shows micro-plications. The biotite often shows conspicuous signs of deformation. The early biotite is presumably synkinematic, and under the prevailing conditions of intense shearing and availability of potash, a hornblendic rock will probably in the first instance be transformed into a biotite rock. This is suggested by rotated and drawn-out inclusions, which often consist essentially of biotite with some relic hornblendes, and by concordant layers or schlieren of

TABLE 2.

Mineralogical developments in the biotite-plagioclase-quartz schists on NE. Tôrnârssuk and in the garnet-biotite augen-gneisses South of Tigssalûp ilua.



Metamorphic stages	dislocation metamorphism I	main stages of metamorphism II	III	late metasomatic effects IV
Garnet-bearing biotite-plagio-clase-quartz schists, NE. Tornarsuk (Epidote-amphibolite facies).	biotite	epidote garnet biotite oligoclase (quartz)	oligoclase quartz (biotite) (tourmaline) (orthite) (apatite)	oligoclase quartz chlorite sericite muscovite (potash feldspar) (tourmaline) (orthite) (apatite) iron oxides and sulphides
Garnet-biotite augen-gneisses, Tigsalluk area (Amphibolite facies)	biotite	garnet biotite andesine (quartz) (sillimanite) (tourmaline) (apatite)	andesine quartz staurolite (anthophyllite) (cummingtonite) (biotite) (tourmaline) (orthite) (apatite)	andesine quartz muscovite sericite late albite (potash feldspar) (tourmaline) (orthite) (apatite) iron oxides and sulphides

The minerals underlined have developed abundantly; the minerals in parentheses are the quantitatively less important ones. In the course of the successive stages hornblende is progressively eliminated.

banded hornblende-biotite rocks occurring intercalated in the schists (pp. 20–54).

Epidote and garnet have developed mainly at the expense of biotite and hornblende, which latter mineral was then already strongly reduced in amount. The garnet porphyroblasts have pushed aside biotite flakes, but rotation structures, so common in garnets grown under dynamometamorphic conditions, have not been observed. Biotite continued to form in this stage as nests, bands, or streaky aggregates of randomly oriented flakes. Epidote is commonly found as interstitial masses and granules between the biotites and relic hornblende. These textures suggest that with the formation of garnet and epidote, strong differential movements were already declining.

Fine-granular interstitial aggregates of oligoclase and quartz, which have exerted strong corrosive actions against all earlier minerals, formed as the last essential minerals. Frequently, the oligoclase has eventually grown to small porphyroblasts. The garnets have often been replaced by quartz-biotite-oligoclase aggregates. These latter stages are characterized by a decreasing influence of shearing and an increasing manifestation of metasomatic changes connected with pegmatitization.

The modifying influences of pegmatitization remained effective after the relatively high temperatures reached during the main stages of metamorphism were already declining. They consist mainly of chloritization of biotite and the replacement of important amounts of biotite and chlorite by sericite, muscovite, alkali feldspars, and quartz. As a result of these replacements, Fe of the biotite was apparently set free. It may have remained as magnetite or pyrite in the rocks, but at present it is mainly found as iron-oxides and -hydroxides, which lend the rocks a pronounced rusty colour. In an advanced stage of pegmatitization the rock may locally become transformed into homogeneous gneisses.

The formation of the biotite-plagioclase-quartz schists may be conceived as involving four stages, in the course of which the relative importances of shearing stress, temperature, and metasomatism connected with pegmatitization gradually changed (Table 2).

E. The amphibolites on NE. Tôrnârssuk.

Arguments for the suggestion that the amphibolites adjoining the zones of biotite-plagioclase-quartz schists on NE. Tôrnârssuk have originated from hornblendic rocks have already been put forward (p. 71). This suggestion is well supported by the mineralogical and textural relations observed under the microscope.

The formation of biotite in the earlier stages of the second metamorphic period was restricted to an interstitial development between hornblende crystals, along cleavage planes and cracks in the latter mineral, and along small shear planes in the rock. The hornblende aggregates remain recognizable as textural relics of hornblenditic rocks. In the subsequent stages garnets developed sporadically in the more biotite-rich rocks, while abundant epidote formed partly at the expense of biotite and partly from saussuritic masses, which have developed interstitially between the amphiboles. Garnet and epidote were followed

Fig. 36. Hornblendic inclusions in amphibolites. The inclusions are entirely surrounded by pegmatites, which have formed along sets of inclined, diagonal planes. NE. Tôrnârssuk.

by strongly corrosive oligoclase and quartz, which occur as interstitial, fine-granular aggregates, anhedral porphyroblasts, or glomeroblastic aggregates.

The feldspathization of the hornblendic layers was presumably accompanied by the formation of a generation of pegmatitic veinlets, which have formed along concordant and diagonal shear planes (p. 23, Fig. 10), and which intersect an older set of discordant pegmatitic veinlets. Lensoid or boudin-shaped hornblendic masses, which in an early stage have become entirely surrounded by pegmatitic veinlets, may apparently become protected against further feldspathization, so that they appear now as hornblendic inclusions in amphibolites (Fig. 36). At other places the prolonged action of pegmatitization has resulted in the formation of amphibole-gneisses and amphibolite pegmatites. Some of the concordant and diagonal pegmatites in the amphibolites continue in the biotite-plagioclase-quartz schists, where pegmatitization was contemporaneous with shearing (p. 70) and the alleged transformation of hornblendic rocks into schists. The transformations of hornblendic rocks into amphibolites and biotite-plagioclase-quartz schists, both of the epidote-amphibolite facies, appear as contemporaneous processes, presumably controlled by the same conditions. Except for the absence of an initial period of strong biotitization connected with dislocation metamorphism, the mineralogical and textural developments in the amphibolites follow the same lines as those in the biotite-plagioclase-quartz schists. Apparently due to the absence of strong penetrative movements, and contrary to the conditions in the schists, the transformation into amphibolites took place without the complete recrystallization and reconstitution of the rock. The amphiboles have undergone metasomatic changes, but the amphibole aggregates may still preserve the textures of the parent hornblendite. The new minerals started to develop along shear planes and in the intergranular space, and from these foci proceeded to grow by corroding older minerals. A somewhat similar mode of formation has been put forward by FRANCIS (1958) for the banded amphibolite of Doir'a'Chata (Durcha), Sutherland. The quartzo-feldspathic bands in these amphibolites are thought to have originated by lit-par-lit injections along a closely-spaced and parallel set of S-planes in hornblende-rich rocks.

Finally, it should be noted that the investigated amphibolites form only three or four out of several amphibolitic horizons on Tôrnârssuk. They are characterized by their association with rusty schists and a multitude of hornblendic inclusions and they are thought to form the prolongation of the hornblendic horizons in the Kuánit area. Amphibolitic intercalations in the "gabbro-anorthosite series" show different textures with two or more plagioclase generations, differently related to an intervening saussuritization or epidotization. The older plagioclases have a composition near calcic andesine and these amphibolites, which have presumably been formed as a result of the first metamorphism in the amphibolite facies, are apparently different from the epidote-oligoclase amphibolites described here. Therefore, the conclusions that certain amphibolitic bands have originated by later feldspathization of hornblendic rocks may not without more be extrapolated to include other amphibolites on Tôrnârssuk and neighbouring regions. The two kinds of amphibolites may presumably be distinguished by their textural characteristics. Amphibolites derived from originally hornblendic rocks form the predominant type and occur in extensive layers in the areas investigated by us, but this may not be the case in other parts of the region[1]). Considered from a more regional point of view, the first metamorphism in the amphibolite facies has presumably given rise to the formation of both extensive hornblendic and amphibolitic layers, and lateral transitions between the two may well occur.

[1]) It should be stated that according to BONDESEN (1960) and HENRIKSEN (1961), the amphibolites on Tôrnârssuk and in the region between Arsuk and Tigssalluk fjords commonly contain partially recrystallized or saussuritized plagioclases of a composition varying between andesine and labradorite. This feature has not been noted in the oligoclase-amphibolites here under consideration, but it may be reemphasized that the investigated samples are provided by only a limited number of amphibolitic horizons.

F. The amphibolites and garnet-biotite augen-gneisses in the area south of Tigssalûp ilua.

In the amphibolites and garnet-biotite augen-gneisses south of Tigssalûp ilua epidote occurs in very insignificant amount and andesine takes the place of the combination epidote-oligoclase. Since epidote is regarded as still a stable mineral in the lower temperature range of the amphibolite facies (e.g., BARTH 1952, p. 341), its disappearance indicates that metamorphism has proceeded well within the amphibolite facies. The occasional occurrence of sillimanite and the abundant development of large garnets in the augen-gneisses may also be considered as an expression of the higher facies conditions. On the other hand, staurolite is not believed to be a common mineral in the amphibolite facies when the lower boundary of this facies is defined by the stability relation epidote $\rightleftarrows$ oligoclase (An_{30}) (RAMBERG 1952, pp. 150–151; FRANCIS 1956, p. 356). However, as the staurolite formed later than the garnets, it may have developed at a late stage when temperatures were already declining (Table 2). Anthophyllite and cummingtonite are thought to have developed in more Mg-rich layers during the same stage as staurolite.

In the Kuánit area and on NE. Tôrnârssuk the amphibole produced in the hornblendic rocks during the first period of metamorphism and preserved as relics in some hornblenditic inclusions is a green hornblende, which as a result of a subsequent metamorphism in the epidote-amphibolite facies tend to break down to yield biotite and epidote or to be transformed into blue green or nearly colourless amphiboles. In the Tigsalluk area the amphibole in the amphibolites and hornblendic rocks is a deep blue green one and it seems reasonable to assume that the rocks in the area south of Tigssalûp ilua were also affected by a second metamorphism, in the course of which the amphiboles were transformed into the present blue green variety. This view is supported by the observation that hornblendic inclusions in the amphibolites and augen-gneisses commonly show cataclastic effects, incipient recrystallizations, and some development of garnet, andesine, zoisite, saussurite and sericite, all at the expense of hornblende (pp. 56–57). The locally abundant occurrence of idioblastic garnets in the augen-gneisses as well as in some concordant pegmatites in these gneisses suggest that pegmatitization and garnet formation were about contemporaneous. The field aspects of this pegmatitization and the subsequent gneissification strongly resemble those observed in and along the zones of biotite-plagioclase-quartz schists on NE. Tôrnârssuk. In the latter schists garnets are sporadically found, while garnet-quartz rocks of pegmatitic habit have occasionally been observed. It may be supposed that pegmatitization in and along the schistose zones on NE. Tôrnârssuk is contemporaneous with those in

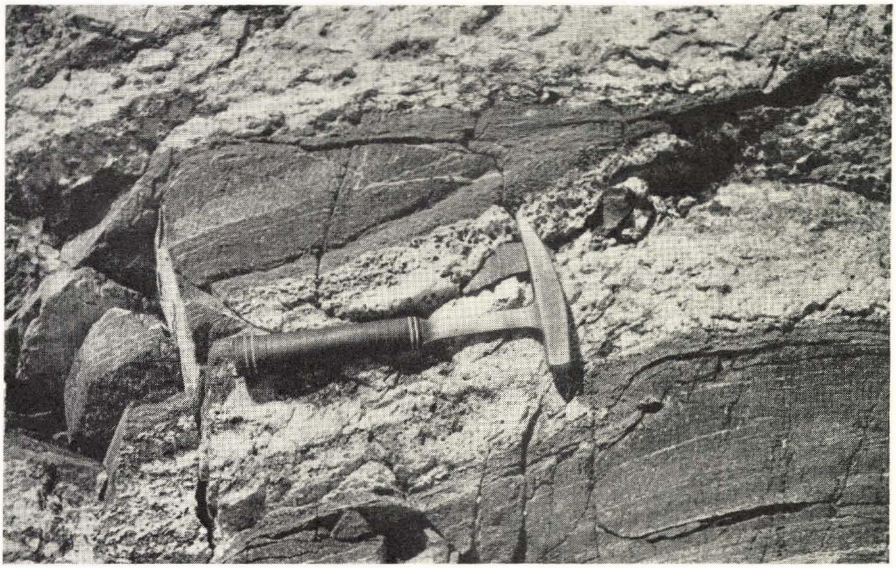


Fig. 37. Hornblendic inclusions surrounded by garnet-rich rims in garnet-biotite augen-gneiss. The big garnets are most clearly visible in the pegmatitized part of the rock, e.g., near the point of the hammer. South of Tigssalûp ilua.

and along the augen-gneisses south of Tigssalûp ilua. The second metamorphism in the latter area is then correlatable with those on NE. Tôrnârssuk and the Kuánit area. Since the garnets, by their association with the pegmatitic veinlets and by their occurrence in reaction zones around hornblendic inclusions, are presumably products of the second metamorphism, it follows from the relations between the other typomorphic minerals and the garnets (Table 2) that the present amphibolite facies assemblage in the augen-gneisses, and presumably also in the adjoining amphibolites, is a result of the second metamorphism. The latter may have passed through a stage of epidote-amphibolite facies conditions to reach those of the amphibolite facies and the resulting amphibole may well appear adapted to both these facies. In the latter case the rocks might survive a later metamorphism (the Sanerutian metamorphism, see below) in the amphibolite or epidote-amphibolite facies without apparent modifications.

The occurrence of many hornblendic inclusions (Figs. 11, 13 and 37), the development of dark garnet-rich zones as a kind of reaction zone around these inclusions (Fig. 37), and the common occurrence of dark garnet-rich spots and schlieren regarded as relics of hornblendic inclusions in the garnet-biotite augen-gneisses, suggest that the latter rocks may have originated, for an important part at least, by transformation of hornblendic rocks. This suggestion is in line with the general resemblance in field aspects with the biotite-plagioclase-quartz schists on NE. Tôrnârssuk (pp. 24–25). A difference is given by the vertical or nearly vertical attitude of the layers south of Tigssalûp ilua, which locally may have given rise to "Rückfalten" (Fig. 14). As in and along the schistose zones on NE. Tôrnârssuk, deformation and shearing phenomena are well displayed in and along the augen-gneisses in the area south of Tigssalûp ilua; pegmatitization is contemporaneous with deformation and followed by local gneissification of the adjoining amphibolites. Under the microscope the textural and mineralogical developments in the augen-gneisses follow the same lines as those in the biotite-plagioclase-quartz schists (Table 2): a first stage of abundant formation of synkinematic biotite was followed by the post-kinematic crystallization of the other components. Comparable textural relations are also shown by the amphibolites south of Tigssalûp ilua and those of NE. Tôrnârssuk.

From these considerations the author believes that the metamorphic history of the area south of Tigssalûp ilua is comparable with those of NE. Tôrnârssuk and the Kuánit area. A first metamorphism in the amphibolite facies resulted in the formation of extensive hornblendic layers in the area considered. A second metamorphism, which also reached amphibolite facies conditions, involved important shearing and pegmatitization in zones along or within the hornblendic layers. In these zones hornblendic rocks were transformed into garnet-biotite augen-gneisses, while pegmatitization in the hornblendic rocks adjoining the zones of augen-gneisses resulted in their alteration into amphibolites and eventually amphibole-gneisses.

G. Concluding remarks.

Two periods of metamorphism have been recognized. The first metamorphism in the amphibolite facies is presumed to have been in a broad sense contemporaneous with the main Ketilidian folding (BERTHELSEN 1960; BONDESEN 1960; HENRIKSEN 1961), and is believed to have resulted in the formation of extensive hornblendic layers within the areas considered, while outside the latter areas equally extensive amphibolitic layers may have been formed besides hornblendic ones. In the investigated areas hornblenditic rocks are now only found as relics enclosed in rocks affected by the second metamorphism, which has been of the epidote-amphibolite facies in the Kuánit area and on NE. Tôrnârssuk, but has reached amphibolite facies conditions in the area, south of Tigssalûp ilua.

The second metamorphism is characterized by deformational movements, pegmatitization and subsequent gneissification in and along the zones of biotite-plagioclase-quartz schists and garnet-biotite augen-gneisses. NE.–SW. and NNW.–SSE. Kuanitic dykes on NE. Tôrnârssuk and south of Tigssalûp ilua transect the zones of biotite-plagioclase-quartz schists and augen-gneisses without being deformed or pegmatized. Therefore, the second period of metamorphism is most probably late-Ketilidian. The existence in the investigated areas of a metamorphic period in late-Ketilidian times, subsequent to the main Ketilidian metamorphism, has already been inferred by BONDESEN (1960) and HENRIKSEN (1961) from their earlier studies.

The deformation and shearing along the schist zones and augen-gneisses during the late-Ketilidian metamorphism may conceivably be regarded as comparatively local effects accompanying the large-scale twisting and bending of the main Ketilidian structures during BERTHELSEN's (1960) third phase of Ketilidian folding. The intensity of the late-Ketilidian metamorphism might eventually appear to be enhanced along localized zones of stronger deformation, pegmatitization and subsequent gneissification and this might perhaps cause its significance being differently evaluated by others. The behaviour of some inclusions as obstructing masses to movements in the biotite-plagioclase-quartz schists, the development of pegmatites along diagonal joints or shear planes in the amphibolites adjoining the schist horizons, and the "Rückfaltung" in the Tigsalluk area, suggest that while the schistose rocks and augen-gneisses were deformed, the adjoining rocks behaved as relatively stable and brittle masses, so that a certain degree of consolidation of the rocks before the late-Ketilidian metamorphism set in may be assumed; a conclusion, which has also been reached earlier on other grounds by BONDESEN (1960).

With the assumption that the second metamorphism is late-Ketilidian, it follows that the rocks must have been affected by a third, the Sanerutian, period of metamorphism, which has affected the Kuanitic dykes in the region (BERTHELSEN 1960; BONDESEN 1960; HENRIKSEN 1960, 1961). The latter metamorphism has been most intense in the areas SW. of Ivigtut and around the Arsuk fjord, and its effects are decreasing towards the West. According to HENRIKSEN (1961) the Kuanitic dykes in the area between Tigssalûp ilua and Arsuk fjords have been recrystallized in the amphibolite facies, while BONDESEN (1960) has found those on Tôrnârssuk to have been altered in the epidote-amphibolite facies. The rocks described in this paper have apparently not been significantly modified by this Sanerutian metamorphism, which is to be expected, at least for the area south of Tigssalûp ilua and NE. Tôrnârssuk, since the rocks on the last-mentioned island were then already adapted to the epidote-amphibolite facies, while those south of Tigssalûp ilua may already have been stable in both the epidote-amphibolite and amphibolite facies. HENRIKSEN (1961) has argued that in the western parts of the region between Arsuk fjord and Tigssalûp ilua the Sanerutian metamorphism has been of comparatively short duration as compared with the areas more to the East, so that in the western areas (including the Kuánit area) the late-Ketilidian epidote-amphibolite facies assemblages may still prevail in spite of the amphibolite facies conditions reached during the Sanerutian metamorphism.

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