Further Studies on Ultrabasic Rocks in Sukkertoppen District, West Greenland.

(On the Formation of Anthophyllite in Ultrabasic Rocks).

By

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Abstract.

Two occurrences of ultrabasic rocks of bronzitic composition are described and their retrograde transformation is discussed. It is concluded that anthophyllite in the outer parts of the ultrabasic rocks and scapolite in crossing pegmatites are formed in a comparatively late stage of the transformation.

During the field work of the Geological Survey of Greenland (Grønlands Geologiske Undersøgelse) in West Greenland in the summer of 1949, the writer had the opportunity of studying some occurrences of ultrabasic rocks in the Sukkertoppen district.

The ultrabasic rocks in the Isortok-Alangua region were briefly described in a previous paper (5). In the present paper, the petrography of one of these occurrences, namely the one called Ol.2 in the field, will be described in a more detailed way.

Ol.2 is situated on the west coast of the southern part of the peninsula west of the fiord Alangua and forms the north point of the westernmost part of this peninsula see 5, figs. 1 and 12).

The Ultrabasic Rocks at Ol. 2.

The ultrabasic body is conformably enclosed in a quartz-dioritic gneiss and is approximately 100 meters across. The northernmost part of the body forms a low cliff towards the sea, while the southernmost part is bounded by a steep gneiss-wall.

The ultrabasic rock is coarse-grained having bronzite prismae 2 centimeters in length or more. The central part of the body consists almost entirely of bronzite which poikilitically encloses small grains of a bright green hornblende. These hornblende grains have usually well-developed crystallographic outlines.

The bronzite is very fresh and has $n_\gamma = 1.685$ corresponding to 13% ferrosilite (fs) according to POLDERVAART (3). The bronzite prismae often have mutual boundaries but may in places be separated by hornblende, biotite and plagioclase.

The plagioclase grains are interstitial and have in some cases inclusions of hornblende. The composition varies from 35 to 45%. An, zonal structures being common. The light brown biotite, which is often associated with the plagioclase, has $n_\beta = n_\gamma = 1.599$.

The outer part of the occurrence has also large bronzite prismae ($n_\gamma = 1.690$ corresponding to 17 % fs), but hornblende and biotite have increased considerably in amount, growing at the expense of the bronzite. Anthophyllite is present in a few small, slender prismae. The scattered plagioclase grains seem to supplant all the above-named minerals.

The rock is crossed by microscopic crush-zones in which the biotite lamellae are bent.

In addition to the above-mentioned interstitial plagioclase grains, large plagioclase crystals (5 centimeter or more) occur throughout the ultrabasic body. This plagioclase has about 30 % An and is almost free from zoning. It is often altered to scapolite which can occur in fairly large grains. The larger grains of plagioclase are separated from the ultrabasic rock by a zone containing smaller plagioclase grains and large biotite flakes ($n_\beta = n_\gamma = 1.610$). This zone has in addition small grains of pyrite and iron ore.

In some cases these patches of plagioclase have replaced the primary ultrabasic minerals. The plagioclase is then slightly more basic (35—45 % An) and has zonal structure. Occasionally, plagioclases of different compositions are intergrown. The bronzite has most often sharp boundaries against the plagioclase, but locally intergrowths of a green hornblende, small fibres of anthophyllite ($n_\gamma = 1{,}642$), biotite, and possibly small flakes of talc occur between the bronzite and the plagioclase. The hornblende and anthophyllite replace the marginal parts of the bronzite grains. The plagioclase has bronzite inclusions and a few millimeter-size grains of a secondary scapolite. The latter has $n_\omega = 1.560$ and $n_\varepsilon = 1.546$, giving $n_\omega \div n_\varepsilon = 0.014$. This gives, according to WINCHELL (6) a dipyre of the approximate composition $Ma_{60}\ Me_{40}$.

The borders of Ol. 2.

The border relations of the ultrabasic body can be best studied towards the south and towards the west.

The southern part of the ultrabasic lens is a schistose, medium-grained bronzite-hornblende-biotite-rock. The bronzite here has $n_\gamma = 1.690$, giving 17 % fs. Biotite is the dominant mineral in the outermost part of the body. In addition, plagioclase (32 % An, no zoning), quartz, and hornblende are present. This rock is separated from the gneiss by a thin zone with hornblende and biotite. The gneiss is striated, hornblende-rich and has inclusions of ultrabasic origin.

The transition from the ultrabasic rock to the gneiss is fairly gradual in the western part of the body as a hybridization has taken place. The ultrabasic rock is surrounded by a hybrid zone having numerous inclusions of more or less altered ultrabasic rocks.

The central parts of the larger inclusions are of the same appearance as the ultrabasic rock of the main body. They have the usual large bronzite grains (($\div$) 2V = 82°, $n_\gamma = 1.691$, giving about 18 % fs). The inclusions are crossed by thin pegmatitic veins (see 5, fig. 19) and from these, numerous light-coloured schlieren penetrate the rock between the bronzite porphyroblasts. The schlieren are composed of plagioclase (about 45 % An), hornblende (well-developed crystal faces, (÷) 2V = 80—88°, $c{:}\gamma$ = 20—16°), and biotite. (See 5, plate 8, fig. 15). Bronzite is not present in the schlieren. The reason for this is, as discussed in (5), that the reaction between the dispersed, pegmatitic material and the primary minerals took place under amphibolite-facies conditions, where bronzite is not stable in quartz-feldspar rocks.

Equilibrium has, however, not been reached in the marginal parts of the inclusions because of the hybridization. These parts have strongly corroded grains of bronzite, which may be divided into several small, irregular grains with the same optical orientation. The groundmass is composed of plagioclase (70—80 % An), green hornblende ((÷) 2V = 84—86°, $c{:}\gamma$ = 20—18°) and biotite. The biotite penetrates the bronzite along its cleavages (5, plate 8, fig. 16).

The marginal, hybrid rock has apparently bronzites of two compositions judging from the determinations of the axial angles. These determinations gave values about (÷) 79° (most common) and (÷) 67° respectively. n_γ was determined to be 1.689. The corresponding fs-values are 10 % and 25 %, respectively.

The gneiss around the inclusions is bronzite-bearing with a gradual transition to the rocks of the above-mentioned hybrid type. The smaller inclusions in this zone are more or less transformed to different types of hybrid rocks.

The hybrid zone is rich in pegmatitic veins.

Some inclusions in the hybrid zone are separated from the surrounding gneissic rocks by a rim rich in hornblende and biotite. These inclusions have the usual large bronzite porphyroblasts and contain in addition scattered interstitial lumps of quartz (dominant) and plagioclase up to 2 centimeters in size. Biotite is present in large flakes. A mass of fine anthophyllite fibres are locally present between the bronzite grains. The latter are to some extent transformed into hornblende and biotite along their cleavages. Anthophyllite is also found on the cleavages of the bronzite but has then cores of the green hornblende.

The hybrid rocks pass into a coarse-grained hornblende-gneiss which has numerous large garnet crystals (3 centimeters across, or more). The garnet has small inclusions of quarz, plagioclase, and bronzite in small amount. It is penetrated by hornblende and biotite. The garnet porphyroblasts are surrounded by a thin light-coloured zone composed of plagioclase, quartz, and apatite. Some of the garnets have a "rolled" appearance.

The groundmass of the gneiss consists of plagioclase, quartz, hornblende, biotite, garnet, and bronzite. The latter mineral occurs in small, corroded grains. Apatite is the most common accessory.

The garnet crystals and the orthorhombic pyroxene are only found in the above mentioned zone. 10 meters from the hybrid rock all traces of garnet porphyroblasts and pyroxene have disappeared. The gneiss is then the common quartz-dioritic gneiss, which encloses all the ultrabasic rocks examined so far in this region. The gneiss is composed of quartz, plagioclase

(25 % An, no zoning), hornblende, biotite, small garnet grains, and apatite. The gneiss has only faint traces of cataclastic deformation.

The Pegmatites in Ol. 2.

The ultrabasic body is penetrated by pegmatites varying in width from a few centimeters to a few meters.

The pegmatites can be more or less symmetric having narrow outer zones with quartz and plagioclase in the median parts. Some pegmatites also have a thin, central biotite zone. This symmetric arrangement is best developed in the smaller veins. The larger veins are usually of a more irregular development and the marginal zone of quartz is often lacking. On the other hand, a considerable amount of quartz may be present in the central parts of these veins.

The large plagioclase grains of the pegmatites have about 25 % An. They have very thin, indistinct twin lamellae and zonal structures can be observed in some sections.

The plagioclase has a somewhat antiperthitic appearance having small threads of a colourless mineral, the identity of which could not be established (see page 242).

Scapolite and quartz penetrates the plagioclase in a very irregular way. The border between plagioclase and scapolite is jagged and usually darkcoloured (plate IV, fig. 1). Small green flakes of a chlorite-looking mineral are present in the border zone. The birefringence of the scapolite is of the same order as that of quartz.

The scapolitization appears to proceed from irregular, pigmented fractures in the plagioclase. These fractures contain in addition small carbonate grains and small chlorite flakes.

The plagioclase is somewhat altered to sericite.

The plagioclase zone has quartz and biotite ($n_\beta = n_\gamma = 1.611$) in subordinate amounts.

The border between the plagioclase and the marginal quartz rim is irregular and it looks as if the quartz has grown at the expense of the plagioclase. Small grains of plagioclase in the quartz rim have the same orientation as the adjoining large plagioclase grains.

The very irregular quartz grains have a flashing extinction. An incipient granulation of the margins occurs in a few grains.

The quartz zone has "rolled-out" seams of small, bent biotite flakes, chlorite, and small fragments of anthophyllite.

Outside the quartz, there is a narrow zone consisting of a brown biotite ($n_\beta = n_\gamma = 1.603$), which may have its cleavages bent. A few small anthophyllite fibres are also present.

Small, well-developed crystals of zircon and monazite occur in all the above-mentioned zones of the pegmatites.

The zircon is present in a very insignificant amount in prismatic crystals about 0.5 centimeters long.

The monazite occurs in larger crystals (up to 1 centimeter) in a slightly larger amount than the zircon.

Monazite has been described so far from only one locality in Greenland (O. B. BØGGILD, 2, page 202).

The monazite from Ol.2 is bright red with a faint, yellowish tinge. It is very fresh in the central parts of the crystals, but the margins are usually somewhat altered. It has twinning on 100 and a well-pronounced parting

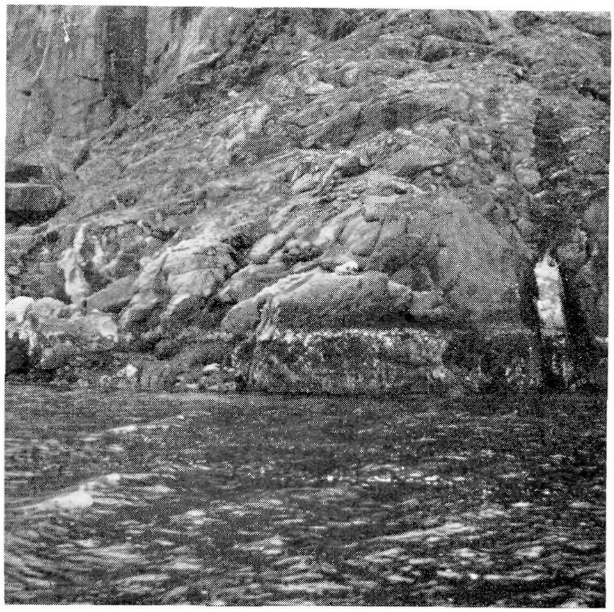


Fig. 1. Pegmatites in Ol.2.
In the background (top left) steep wall in gneiss.

parallel to this direction. In addition it cleaves along 001 planes.

Under the microscope, the mineral is colourless and has a small positive axial angle.

A spectrographic examination was carried out by Mr. S. RUTLIN, civil engineer, in Statens Råstofflaboratorium, Oslo. La, Ce, P, and traces of Cr and Y were found.

A powder-diagram taken in the X-ray laboratory of Geologisk Museum, Oslo showed the usual monazite pattern.

The ultrabasic rock is usually altered into an anthophyllite-rich rock close to the pegmatites.

The anthophyllite (optically positive, $n_\gamma = 1.640$, $n_\beta = 1.630$) occurs partly in long, bent, fibrous crystals (attaining a length of 0.5 to 1 centimeter), and partly in aggregates of tiny fibres. The longer prismae are mostly arranged in parallel layers with the individual prismae contiguous.

The anthophyllite is homoaxially intergrown with a faint green, monoclinic hornblende, which forms the highly corroded cores of a great deal of the anthophyllite prismae.

A yellowish brown biotite is present in large flakes. These are often bent and are occasionally broken in such a way that the fragments are separated by a fine-grained anthophyllite aggregate, the larger fibres of which embrace the biotite (plate IV, fig. 2). On the other hand, some of the biotite flakes enclose corroded anthophyllite grains of common optical orientation.

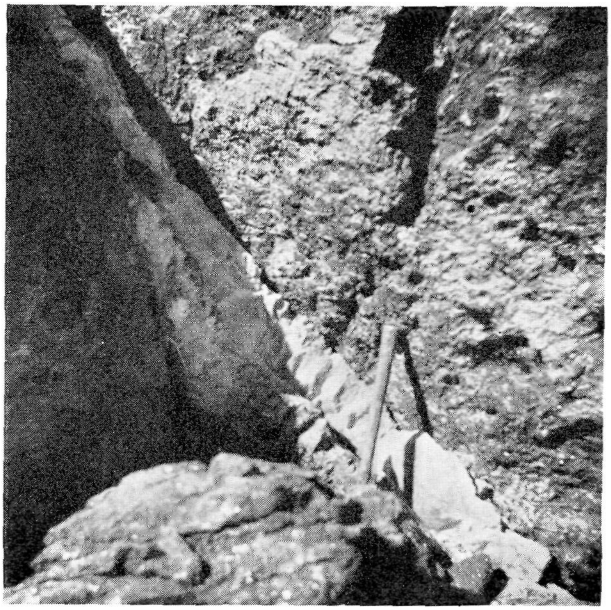


Fig. 2. Ol.2. Pegmatite with a thin layar of biolite in its central part.

A few plagioclase grains enclose corroded fragments of all the other minerals of the rock.

A Small Ultrabasic Body South of Ol. 2.

Outside the hybrid zone around Ol.2, the gneiss is, as mentioned above, of a quartz-dioritic composition. This gneiss encloses conformably several small lenses of ultrabasic rocks south of Ol.2. One of these, which is approximately 15 × 20 meters in size, is situated 2–300 meters southwest of Ol.2 in a creek on the westcoast of the peninsula (5, fig. 12). Its southern part is covered by vegetation and the northern end is covered by the sea at high tide.

The almost monomineralic central part of this lens is composed of large bronzite prismae which are 5 centimeters in length or more. $n_\gamma = 1.680$ gives 9 % fs. The bronzite has small inclusions of a green hornblende and biotite which are present in considerable amounts in some parts of the body. This is the case in the marginal zone of the lens where the three above-mentioned minerals occur in equal amounts. The bronzite in this zone has $n_\gamma = 1.685$, corresponding to 13 % fs, and is often separated from the green hornblende by a fibrous mass of anthophyllite. The latter mineral is intergrown with the green hornblende.

The ultrabasic rock has, in its eastern border, a one meter thick biotite- and hornblende-rich zone which is separated from the gneiss by a pegmatite. This is the usual border-type in this district (see 5).

The western border is somewhat different. The outer part of the ultrabasic body is, as usual, rich in hornblende and biotite. Outside this rock there is a zone a few centimeters thick of fibrous anthophyllite crystals which may be separated from the ultrabasic rock by a thin zone of pegmatitic material. A similar light-coloured zone separates in places the anthophyllite from the adjacent hornblende gneiss, which is rich in large biotite-flakes close to the ultrabasic rock. The border-zone is very irregular. Thus, the anthophyllite is lacking in some places, while it penetrates the outer part of the ultrabasic rock at others.

The border relations were studied in thin sections. The outer part of the ultrabasic rock consists mainly of large grains of a faint green hornblende which are intergrown with (and replaced by) biotite, plagioclase and quartz. Locally, scapolite occurs in small grains.

The hornblende has, especially in the outer part of the border zone, colourless, anthophyllite-looking parts, which have the same oblique extinction as the "enclosing" green hornblende.

The thin pegmatite, adjacent to the hornblende border, has strongly corroded hornblende-grains and, in addition, fibres of anthophyllite which may have inclusions of the green hornblende. The groundmass is composed of plagioclase and quartz. The plagioclase has zonal structure, wavy extinction and is somewhat transformed into sericite and carbonate. It has, like the quartz, a good deal of dark pigmentation. Rutile, pyrite, and a colourless, isotropic mineral (garnet?) are accessories. Biotite is present in subordinate amount. Granulitic zones are occasionally found around the plagioclase.

The anthophyllite zone, which follows the pegmatite, is in places in contact with the hornblendic border of the ultrabasic rock. The anthophyllite has $n_\gamma = 1.644$ and occurs in more or less bent fibres which may have cores of the green hornblende. The anthophyllite has not the corroded appearance of the hornblende of the inner zone, although a few grains have numerous plagioclase-filled holes. Biotite is present in a very subordinate amount in the anthophyllite zone.

The fibres of the anthophyllitic zone and the hornblende prismae of the inner hornblendic zone are, on the whole, parallel with the border. On the other hand, the bent fibres of anthophyllite in the pegmatite, between the two zones in question, may be perpendicular to the border. The few hornblende grains in this zone are arranged in a similar way. The pigmentation lines in the plagioclase are curved in such a way that they are parallel with, or are arranged in continuation of the anthophyllite fibres. The subparallel crystals of hornblende and anthophyllite of the two above-mentioned zones are thus connected in a sinuous fashion by the fibres of anthophyllite and the pigmentation-lines of the pegmatite (plate V, fig. 1). This means that the pegmatite is a recrystallized displacement zone. As the twin lamellae of the plagioclase are not bent, it is evident that the plagioclase was formed after the deformation ceased.

The garnet-looking mineral mentioned above is clearly pre-pegmatitic as it occurs in corroded grains arranged in continuation of each other in the direction determined by the bend of the anthophyllite fibres.

Outside the anthophyllite there is a granulated zone, where larger plagioclase grains are embedded in a very fine-grained matrix of quartz. The plagioclase has zonal structure and wavy extinction. This cataclastically deformed zone has fragments of anthophyllite in some parts, while tiny biotite fragments occur in others.

Corresponding to this distribution of anthophyllite and biotite, the next zone has larger, corroded anthophyllite fibres and grains of green hornblende adjacent to the anthophyllite-bearing granulated zone. The hornblende has, as in the inner zone, colourless parts. The plagioclase here is very altered. Where this zone adjoins the biotite-bearing granulated rock, the anthophyllite disappears and its place is taken by bent flakes of a reddish brown biotite. This rock has in addition small grains of the green hornblende, plagioclase (less altered than in the anthophyllite part of the zone), quartz and very few small grains of anthophyllite and garnet.

The anthophyllite-biotite layer has a winding course and is embedded in the outer part of the cataclastically deformed zone. The biotite-rich part of the layer is separated from the gneiss by a thin zone of biotite, plagioclase and quartz, while the anthophyllite-bearing part borders directly on the gneiss.

The first few centimeters of the gneiss are rich in large biotite flakes which have numerous small pleochroic halos around tiny grains of zircon (?). The biotite replaces the hornblende so that the latter occurs in small, corroded grains. These may have colourless, anthophyllite-looking parts. Plagioclase occurs in strongly zoned grains and is often somewhat altered, especially in the cores of the zoned grains. The alteration-product has aggregate-extinction and seems, at least partly, to be composed of scapolite. Quartz and apatite are present in subordinate amounts.

The surrounding gneiss is still biotite-rich and has bent and somewhat "rolled-out" biotite layers. Its plagioclase has only faint traces of zonal structure.

The ultrabasic rock has a zone about one meter thick which is rich in hornblende and biotite towards a crossing pegmatite. It is separated from the latter by a layer 0.25 meter thick, composed of large prismae of a dark green hornblende which are intergrown with biotite. The hornblende has scattered inclusions of bronzite. In addition grains of plagioclase and quartz occur in this zone.

Under the microscope the hornblende-grains are seen to be very corroded having irregular outlines and being full of plagioclase- and quartz-filled holes. The few bronzite-grains ($n_\gamma = 1.693$, corresponding to 20 % fs) are highly transformed into an aggregate of small green scales, probably of a chloritic mineral. They are always separated from the adjacent hornblende by a fibrous mass of anthophyllite. The latter mineral seems preferably to grow at the expense of the hornblende which is replaced along its cleavages. The anthophyllite has $n_\gamma = 1.639$, the green hornblende $n_\gamma = 1.654$. Occasionally the anthophyllite grows into the bronzite.

The pegmatite is composed of the following minerals: plagioclase in large, dark crystals (about 30 % An), large prismae of a dark green hornblende ($n_\gamma = 1.650$), scapolite in rosettes of long, light-brown prismatic crystals ($n_\omega = 1.562$, $n_\varepsilon = 1.547$, $n_\omega - n_\varepsilon = 0.015$, corresponding approximately to the composition Ma_{60} Me_{40}), biotite and quartz.

The hornblende is intergrown with biotite, plagioclase and quartz as in the hornblendic border of the ultrabasic rock. Some of the hornblende grains have lighter coloured parts consisting of a fainter green, monoclinic hornblende and anthophyllite ($n_\gamma = 1.639$). The hornblende is occasionally separated from the adjoining pegmatitic minerals by a zone rich in scapolite and quartz. The scapolite penetrates the outer part of the hornblende and has inclusions of hornblende, plagioclase (in strongly corroded grains) and calcite, (plate V, fig. 2).

The large plagioclase grains have zonal structure and are often altered into scapolite (in large crystals) and calcite to some extent. The twin lamellae are slightly bent in some of the grains.

The quartz is present in smaller grains which have undulatory extinction. Locally, some granulation has taken place in the outer parts of the grains.

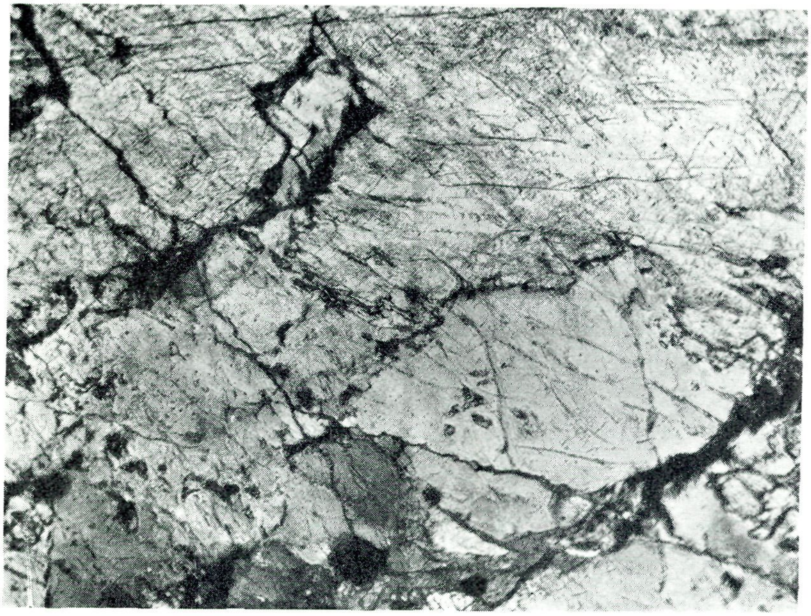
The few biotite flakes are bent and are strongly corroded. They may have inclusions of hornblende and chlorite.

Summary and Conclusions.

The two occurrences of ultrabasic rocks described in this paper are of a bronzitic composition in their central parts. Rocks of this type are very common as transformation-products of dunitic- and peridotitic rocks in orogenic zones. Thus a good deal of the caledonian peridotites of Northern Norway, which the writer studied in the summer of 1952, have rosettes of large, secondary crystals of bronzite. This transformation begins from the margins of the masses and from traversing fractures, resulting in peridotitic bodies with bronzititic marginal facies and crossing "bronzitite dykes". The transformation may be complete in which cases large bodies of bronzitite, sagvandite, etc. are formed.

The bronzitite at Ol.2 originated probably from an olivine-rich rock. In support of this view it should be mentioned that olivine rocks occur in the Isortok-Alangua-region as for instance at Ol.1 and in Amitsuarssoralak (see 5), where the formation of the secondary bronzite can be studied.

It is important to note that the bronzites of the central parts of the two occurrences described in this paper are more Mg-rich than those of the marginal parts. This is best explained by assuming that there was, during the transformation of the original olivine-rich rock, a "composition-gradient" along which the exchange of material between the Mg-rich



(B. Mauritz phot.).

Fig. 1. Pegmatite in Ol.₂ (no. 13512). 32×, +nic. Plagioclase (top) being replaced by scapolite (below), which has small inclusions of plagioclase. Note the black border between plagioclase and scapolite. A few grains of calcite are seen in fractures bottom right.

(B. Mauritz phot.).

Fig. 2. Pegmatite in Ol.₂ (no. 13512). 32×, 1 nic. A bent and fractured flake of biotite in a matrix of anthophyllite.

rock and the surroundings took place. The biotites of the central parts of the ultrabasic bodies are for the same reason of a lighter colour and have lower indices of refraction than the biotites of the outer parts, the pegmatites and the gneiss.

In the subsequent stages of deformation the ultrabasic rocks are altered in various ways. If the surroundings are granitized, as it is the case in the caledonian zone of Northern Norway and in the Godthaab fiord-area in West Greenland (see 5), the rocks are changed into aggregates composed of one or more of the following minerals: anthophyllite, actinolitic hornblende, talc, serpentine, chlorite and carbonates, the trend of the deformation is in part determined by the amount of olivine in the rock.

In the Isortok-Alangua-area the milieu was fairly "dry" and common metamorphic hornblende and biotite were formed at the expense of the bronzite. The olivine-rich rocks in this area have some serpentine.

The transformation of the central parts of the bodies is usually not very pronounced as they were incapsulated by reaction rims which to some extent protected the ultrabasic rocks. This is the normal type of transformation in this area. The hornblende-biotite-rim of the small lens south of $Ol._2$ was formed in this way and so were the rims of hornblende and biotite between the ultrabasic rocks and the pegmatites, where the latter invaded the former along fractures.

Where the marginal parts of the ultrabasic bodies were fractured, these parts were soaked through with dispersed, pegmatitic material. If the reaction between the original minerals and this material was on a small scale, as for instance in the tiny schlieren between the bronzite-porphyroblasts (see page 231), equilibrium was reached and the minerals stable at the given P,T-conditions were formed. Where larger quantities of material were involved in the reactions, equilibrium was not established because of the slowness of the diffusion processes, and therefore the hybrid rocks were formed. The basic composition of the plagioclase in the hybrid rock is the result of unfinished diffusion processes (composition gradient).

The anthophyllite-rich rocks were, as proved by the examination of thin sections, formed later than the rims of hornblende and biotite around the ultrabasic bodies. The difference of age of formation need not be large, the anthophyllite may have replaced the hornblende without interruption of the processes or may be of a later date. All we know is that the rims of hornblende and biotite were deformed during the formation of the anthophyllite and that the latter mineral was formed at conditions corresponding to the amphibolite facies (i. e. in the same facies as the reaction rims). The change in the physico-chemical conditions responsible for the formation of the anthophyllite will be discussed below. We note here that the anthophyllite is always associated with pegmatitic material and is invariably formed at the expense of the green hornblende.

The writers interpretation of the transformation of the ultrabasic rocks is the following:

The ultrabasic rocks were, as discussed in (5), formed in amphibolites in the first tension stages of deformation. The original ultrabasic rock, which was stable only at the most extreme conditions of strain, was soon transformed into the more stable bronzitites. When the tension was relieved, i. e. when the cohesional attraction of the amphibolite was exceeded, the latter rock was sliced and the slices were incorporated in and digested by the surrounding gneissic rocks which were plastically deformed. During this stage of intense deformation the ultrabasic masses were boudined and their outer parts could be folded (e. g. Ol.3) or fractured (see above page 231). Pegmatites pervaded fractures in the ultrabasic rocks.

In a later stage of intense deformation, stress was accumulated in zones of discontinuity which had an adequate orientation in relation to the forces at work. This happened along the pegmatites described in this paper and also in the western border of the smallest lens. The writer believes that the rims rich in anthophyllite were formed in this period.

The occurrence Ol.3 just south of the two occurrences described in this paper gives additional information about the formation of the anthophyllite. The northern end of Ol.3 is traversed by thin displacement zones (5, fig. 17) which slice all the minerals of the rock including the small grains of pleonaste which occur as parallel rods in the zones in question. Originally, the zones were granulated, but later recrystallization obliterated most traces of cataclastic deformation. The recrystallization-products are different in the different minerals of the ultrabasic rock. The olivine, bronzite and spinel have the crush-zones filled with carbonate minerals and platy minerals, of which a part, at least, consists of talc. The hornblende grains have, however, anthophyllite-fibres in the displacement zones.

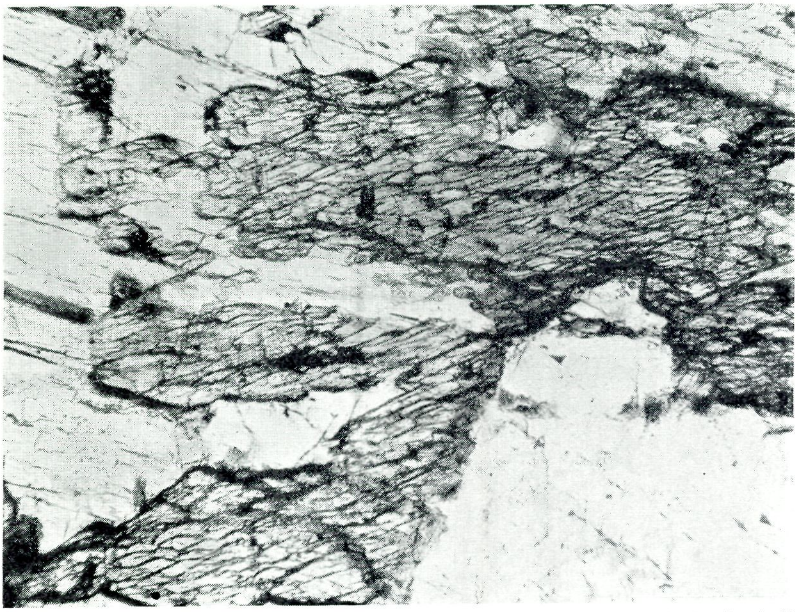
The observations from Ol.3 combined with the features described above make it clear that the anthophyllite only grows where grains of related structure (i. e. the green hornblende) are present. In spite of similarity in composition, the anthophyllite seems not to be able to grow directly on the bronzite, although the material of the latter undoubtedly to a large extent enters the anthophyllite. This is seen in the example on page 232 where anthophyllite, growing along the cleavages of the bronzite, has inclusions of green hornblende.

The incipient formation of the anthophyllite can be studied best in the western border of the small lens south of Ol.2. At first, colourless parts with the same optical orientation as the green hornblende are formed in the latter. The colourless parts are clearly composed of a monoclinic hornblende, perhaps of tremolitic or cummingtonitic composition. Outside the hornblende-rim, fibres of anthophyllite begin to appear until in the anthophyllite zone there are well-developed prismae of anthophyllite which have cores of the green hornblende. Thus, there seems to be a gradual transition from the monoclinic hornblende to the anthophyllite. The green hornblende in the surrounding gneiss has also colourless parts which means that the formation of the anthophyllite proceeded from the border between the ultrabasic rock and the gneiss (i. e. from the crushed discontinuity zone).

The bent fibres of anthophyllite in this border shows that deformation continued during the formation of the fibres.

(B. Mauritz phot.).

Fig. 1. Border of small ultrabasic lens (no. 13503). 32×, 1 nic. Prismae of anthophyllite in a groundmass of plagioclase. Note the lines of dark pigmentation in the latter mineral.



(B. Mauritz phot.).

Fig. 2. Pegmatite in small ultrabasic lens (no. 13505). 48×, 1 nic. Green hornblende being replaced by scapolite (white).

Anthophyllite seems to be formed in a similar way in the pegmatite borders in Ol.2. In the pegmatite border in the small lens south of 01.2 the formation of anthophyllite is not very advanced.

The bending of the anthophyllite was in both localities followed by a period of recrystallization, during which plagioclase, quartz and biotite were formed. The development in the western border of the small lens was described on page 236. It is worth noting that the plagioclase of the gneiss has strong zonal structure close to the anthophyllite zone, while it is unzoned further out. The plagioclase rims were probably formed at the same time as the plagioclase of the zone with bent fibres of anthophyllite. This cannot be proved until the plagioclases here have been examined by means of the universal stage. The writer hopes to return to the mineralogy of the plagioclases of this area in a later publication.

The marginal rims of quartz of the pegmatites in Ol.2 seem to be formed in the same period of recrystallization as the quartz grains enclose the "rolled-out" layers of anthophyllite and biotite.

The zone between the anthophyllite rim of the small lens and the gneiss was crushed in a still later period. No recrystallization has concealed the crushing (see page 237). The crushing of pegmatites in and gneisses around Ol.5 and the ultrabasic rock in Amitsuarssoralak may be of the same age.

As to the interstitial plagioclase of the ultrabasic rocks and the associated anthophyllite it cannot be decided at the moment whether these minerals were formed in the first period of pegmatitic infiltration (when the ultrabasic bodies were boudined and the hornblende rims were formed) or in the second period (the period of crushing and formation of the rims of anthophyllite) or whether the anthophyllite was formed during one long, continuous period. It may be most reasonable to assume that the interstitial minerals were formed, preferably, in the second period. If this be the case the anthophyllite between the plagioclase and the bronzite was formed, where the migrating material, which was responsible for the formation of the anthophyllite rims, penetrated into the ultrabasic rocks. As the plagioclase is partly transformed into scapolite, we may state that the latter mineral was formed in the same period.

The presence of scapolite in the cores of the zoned grains of plagioclase in the gneiss outside the anthophyllite rim of the small lens shows that the scapolite was older than the last period of recrystallization.

This interpretation is in agreement with the observations in the pegmatites. The migrating material, which penetrated the crushed zones between pegmatite and ultrabasic rock, transformed the outer part of the latter into anthophyllite, while the plagioclase of the pegmatite was transformed into scapolite.

The scapolite replaces the plagioclase as well as the hornblende. This is in agreement with SUNDIUS's observations in the Kiruna area. (4, page 59). SUNDIUS states that the Mg-Fe released, when the hornblende was replaced, is bound in biotite. In the present case there is nothing to indicate that biotite was formed at the same time as the scapolite.

The chemical composition of the scapolites has not been examined so far. As sulphide ores are very rare in the pegmatites, it seems very unlikely that sulphur plays any rôle in the scapolite. The association of scapolite and small carbonate grains, on the other hand, makes it probable that the scapolite is CO_2-bearing. As to chlorine nothing definite can be stated at the moment, but the presence of apatite in all the gneisses of the area supports the view that chlorine may be of some importance in the scapolite.

The birefringence of the scapolite indicates that the mineral has about 40 % of the meionite-component. The coexisting plagioclase has 30–40 % An, i. e. the two minerals have corresponding amounts of Na and Ca. It is interesting to note that the most albite-rich plagioclase examined, namely the one in the pegmatites in Ol.2, is being replaced by a scapolite, the birefrigence of which is of the order of that of quartz, thus indicating a larger proportion of the marialite-component in the scapolite.

SUNDIUS explained the scapolitization in the Kiruna area as a result of regional pneumatolysis (op. cit. page 206). He believed that the emanations originated from deep-seated magmas, in spite of the fact that no magmatic rocks of the appropriate types and of the proper age are found in the region.

The scapolitization in the Isortok-Alangua-region is best explained in a somewhat different way.

When the crush-zones were formed in the rigid ultrabasic rocks, the surrounding gneissic rocks were deformed in a more plastic way. That means that the rigid rocks were the only places, where "open fractures" could be formed. These fractures were places of low mechanical pressure and acted as migration channels for the material driven out of the underlying rocks. Therefore, the scapolite, zircon and monazite were formed in these places, representing remnants of the material which passed through the fractures. The antiperthitic appearance of the plagioclase in some of the pegmatites is probably a result of unfinished diffusion processes. That anthophyllite was formed in this "hydrothermal" milieu is in close agreement with the experiments of BOWEN and TUTTLE (1, page 457).

The extension of the scapolitization in the Isortok-Alangua region cannot be established as long as the geological mapping of the region is in a preliminary state. Scapolite has been observed so far in a few localitites, among which a scapolite-bearing pegmatite on the west coast of Alangua is the most important.

The problems discussed in the present paper cannot be solved until the tectonic analysis of the region has been concluded. It will then be possible to discuss the location of the pegmatites and the crush zones in the ultrabasic rocks in a more satisfactory way.

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DANSK RESUME

To forekomster af ultrabasiske bjergarter i Sukkertoppen distrikt beskrives. De centrale dele af disse består overvejende af bronzit, medens hornblende og biotit spiller en vigtig rolle i de marginale dele. De ultrabasiske linser er adskilte fra den omgivende hornblende-gnejs af reaktionsrande af biotit og hornblende. Den ene forekomst har en hybrid, bronzit-førende bjergart mod gnejsen.

Begge forekomster gennemsættes af pegmatiter. Disse har rande af hornblende og biotit mod den ultrabasiske bjergart og består af plagioklas, kvarts, biotit (og hornblende). Nogle pegmatiter har desuden monazit og zircon. I alle pegmatiter er plagioklasen mere eller mindre omdannet til skapolit, der kan optræde i store krystaller.

Anthophyllit optræder i visse pegmatitgrænser og findes desuden knyttet til interstitielle plagioklasklumper i den ultrabasiske bjergart.

Det konkluderes, at anthophyllit og skapolit er dannet i et forholdsvis sent trin af deformationen af området, hvor pegmatitisk materiale har migreret gennem knusningszoner i ultrabasiterne og har reageret med den ultrabasiske bjergart og med pegmatiterne.

Anthophylliten dannes overvejende på bekostning af bronziten men vokser på hornblenden, der har en struktur, som er nært beslægtet med anthophyllitens.