ON SAPPHIRINE FROM WEST GREENLAND

BY

HENNING SØRENSEN

WITH 2 FIGURES IN THE TEXT AND 2 PLATES

Abstract.

Two new occurrences of sapphirine from West Greenland are described. In the first of them (from Sukkertoppen District) sapphirine is present as rims of reaction around grains of corundum in patches of anorthite in small lenses of hornblendite. The hornblendites are found in a hydrid zone around a bronzititic ultrabasite. The second occurrence of sapphirine is a boulder of hornblendite found in the Qôrqut branch of the Godthaab Fiord. Sapphirine is here found in a similar way as in the first-mentioned occurrence, namely as rims between corundum/spinel and anorthite.

New observations from the Fiskenæsset occurrence are published. It is shown that the sapphirine-bearing rock has been formed by retrograde metamorphism of a spinel-bearing bronzitite. Sapphirine is formed at the expense of spinel; gedrite, hornblende and phlogopite at the expense of the bronzite. Corundum has also been found in this occurrence. Irregular replacement veins are found in the sapphirine-bearing rock. They consist of basic plagioclase, hornblende, biotite and cordierite. It is suggested that this cordierite (and possibly the kornerupine) has been formed at the expense of the sapphirine.

The occurrences of sapphirine at Sukkertoppen and at Auvaitsersarfik are briefly mentioned.

Corundum in ultrabasic rocks is discussed.

The parageneses with sapphirine mentioned in the literature are reviewed and the stability relations of sapphirine are discussed. It is concluded that sapphirine most often appears to be formed at the expense of spinel and corundum and that it often is associated with ultrabasic rocks.

Sapphirine is regarded to be formed where concentrations af Al in a milieu rich in Mg and poor in Si have been metamorphosed in a "closed system" under conditions of P,T corresponding to high amphibolite low granulite facies.

INTRODUCTION

Two new occurrences of sapphirine have been found during the expeditions of Grønlands Geologiske Undersøgelse (The Geological Survey of Greenland) to West Greenland, in 1949 and 1951, respectively.

In this paper these two occurrences will be described, mainly from a petrological point of view. No detailed mineralogical examination of the sapphirine from the two localities has been undertaken and the scarce material did not allow any chemical analyses to be carried out. The identity of the minerals have been checked by means of powder diagrams taken in the X-ray laboratories of the Geological Museum, Oslo. I wish to thank Dr. H. Neumann for this valuable help.

The new occurrences are compared with the occurrences of sapphirine to which references have been found in the literature. In this connection specimens from the classic locality at Fiskenæsset have been examined.

The examination has been based on material collected by the writer and on samples from the collections of the Mineralogical Museum in Copenhagen. I extend my sincere thanks to Professor A. Noe-Nygaard, Director of the Mineralogical Museum and leader of the mentioned expeditions to West Greenland.

Professor L. R. Wager, Oxford, supplied me in 1950 with information and samples of ultrabasic rocks from East Greenland and he has kindly allowed me to mention an interesting occurrence of corundum from this region. Samples of a possible occurrence of sapphirine from Ireland and of the sapphirine from Madura, India were made available for examination by Dr. S. O. Agrell, Cambridge. Mr. H. Pauly, mag. scient., has kindly placed a sample of corundum from Sukkertoppen at my disposal. I am most grateful for these valuable contributions.

Thanks are also due to Dr. Hans Ramberg for friendly criticism, to Mr. Chr. Halkier, Konservator at the Mineralogical Museum of Copenhagen for preparing the photographs for the paper and to Mr. P. Padget, M. Sc. for correcting the english of the manuscript.

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A NEW OCCURRENCE OF SAPPHIRINE FROM SUKKERTOPPEN DISTRICT

In the summer of 1949 sapphirine was found in a little fiord between the fiords Søndre Isortoq and Alangua at a place called Ol. 1 during the field work (see *24*, fig. 1 for the location of the occurrence).

The sapphirine was described by the writer in 1951 in an unpublished dissertation (kept at the University of Copenhagen) and it was later briefly mentioned in *25*, page 10). The locality Ol. 1 was treated in *24*, pp. 60—63.

At Ol. 1 several masses of ultrabasic rocks are found on a small peninsula. The masses may measure a few hundred metres across but are normally of a size of a few metres. They are enclosed in hornblende gneisses which in places may have very large garnet porphyroblasts. There are often pegmatites in the borders of the ultrabasites.

The largest of the ultrabasic masses is the one found on the most northerly point of the peninsula. It consists of large prismatic grains of bronzite (several centimetres long), a black hornblende, and biotite. Anthophyllite may be present and there are small patches of plagioclase and biotite scattered all over the occurrence. The texture is interlocking in the central parts of the mass but there may be a pronounced lineation with parallel prismae of bronzite in the marginal parts.

This northern ultrabasite is embedded in a strongly schistose, coarse-grained rock which is especially well studied in a zone about 200 metres thick to the northwest of the ultrabasite. Furthest away from the ultrabasite this zone is made up of a hornblende-biotite gneiss, but towards the ultrabasite there is an increasing amount of bronzite. This mineral is present: 1) in independent, strongly corroded grains (which may be divided into several fragments with common optical orientation), 2) in aggregates of several grains of bronzite and with the same texture as the ultrabasite. All transitions from such small ultrabasic lenses through bronzite gneisses to the hornblende-biotite gneiss may be seen in this zone and the main rock here, which from a magmatic point of view could be termed a norite with ultrabasic differentiates, is obviously as stated in *24*, page 62 a hybrid zone formed by *in situ* replacement of

Fig. 1. Corundum in hornblendite, Ol. 1. Two patches with red corundum are seen, one on each side of and slightly below the head of the hammer. To the left a good deal of smaller sapphirine-carrying patches. To the right veins of pegmatite in the hornblendite.

the ultrabasic rock. The hybrid zone may be folded and is rich in pegmatites.

The ultrabasic mass is conformably enclosed in the hybrid zone and is separated from the latter by a pegmatite.

South of this ultrabasic mass a great number of smaller masses occur. They are enclosed in hornblende gneisses of a hybrid character locally with large grains of garnet. The larger masses here are dunitic or peridotitic and they have been briefly described in (*24*). They will not be further treated in this paper being of secondary interest to the present problem.

To the east of the northern ultrabasite there is a great number of small masses of ultrabasic origin enclosed in hybrid gneisses with a good deal of pegmatitic material. Some of these masses are "outrolled" ultrabasites of the same type as the small lenses found in the hybrid zone to the west of the largest mass, while others are green hornblendites. These hornblendites are coarse-grained often with a pronounced lineation, or where rich in biotite with a distinct schistosity. Many of them have small white patches which on closer examination are seen to consist of a colourless corundum in the central parts and marginally of plagioclase. There is most often a thin bluish green rim of sapphirine between the corundum and the plagioclase. In one small mass (fig. 1) there are large (2 cm or more) grains of a red corundum enclosed in and intergrown by a white rock of plagioclase and biotite. The white rock is separated from the hornblendite by a zone rich in biotite. The largest grains of corundum have no rims of sapphirine, but around some of the smaller ones there are rims of the same type as those around the colourless corundum.

Petrography.

The ultrabasic rock. The northernmost mass of ultrabasic rock has bronzite $n\beta = 1{,}682$ as the main constituent (sample nos. **13536** and **13541**). It is present in somewhat irregular prismatic grains which may be mechanically deformed and even crushed. Hornblende (black in the handspecimen, faintly green under the microscope) is present in small grains. It is in part found as small euhedral inclusions in the bronzite (cf. *24*, plate 7, fig. 13), in part as interstitial, larger and more irregular grains. Between the latter and the bronzite there are often small fibres of anthophyllite (cf. *23*, page 240). A brown biotite is present in varying amounts, as is plagioclase in scattered, fairly large grains (often more than 1 cm across).

Olivine is not present in the specimens from this mass but is prominent in the most southerly masses.

Spinel has not yet been observed in this occurrence.

Corundum-anorthite-biotite rock (nos. **13531 a** and **b**). This rock shows in the handspecimen large red grains of corundum in a matrix of plagioclase and biotite. The biotite often penetrates and surrounds the corundum.

Under the microscope large, irregular grains of corundum with twin lamellae are seen. They are intergrown with plagioclase which according to the REINHARD method (*22*) has a content of anorthite of about 95 %. $n\beta$ has been determined to be 1,580, (—) $2V = 77°$, and there are albite and pericline twins. The plagioclase is turbid and has zonal structure. Biotite also penetrates the corundum so that the latter appears to be corroded by anorthite as well as by biotite.

This rock greatly resembles the corundum-bearing sakénites described by LACROIX (*13*) from Madagascar.

There is no sapphirine in this sample, but another sample taken about 10 centimetres from nos. 13531 a and b contains a good deal of sapphirine, especially along the margins of the corundum. This rock was not examined in thin section since it greatly resembles no. 13532 a which is a white patch in the hornblendite.

No. **13532 a** has an equigranular white groundmass consisting of irregular grains of plagioclase with few and fairly broad twin lamellae (albite and pericline twins). It has an anorthite content of about 95 $^0/_0$, zoning is inconspicuous, so is a dark pigmentation. There are a few grains of a faintly green hornblende intergrown with biotite.

Scattered over this rock are a good deal of small grains of corundum. Adjacent grains often have a common optical orientation and it may therefore be concluded that corundum has originally been present in much larger grains. There is almost always a rim of sapphirine between corundum and plagioclase although direct contact between these two minerals may be seen. Inclusions of plagioclase in the corundum have also sapphirine against the latter (this is most probably caused by the cutting of the section, the corundum having very irregular outlines).

The sapphirine is clearly formed at the expense of the corundum, all transitions from thin rims on the latter to independent grains with small inclusions of corundum may be seen. There is a tendency to a development of elongated crystals of sapphirine resembling the plates of sapphirine in the Fiskenæsset occurrence. Tiny grains of a green spinel are enclosed in the sapphirine and they may also be seen in the anorthite.

The sapphirine is strongly pleochroic with γ blue, β blue, and α colourless. (—) 2V is about 60°, $v > r$. Twinning has been observed.

Hornblendite with corundum and sapphirine (no. **13532 b**). The main component of this rock is a bluish-green hornblende in prismatic grains of about $^1/_2$ cm arranged in subparallel layers. Between the prismae of hornblende are small patches of anorthite, corundum and sapphirine. These patches may be as much as 1 cm across. The corundum is generally colourless, but it may be red in restricted areas. It is then associated with a good deal of biotite and sapphirine is often lacking.

Under the microscope it is seen that the hornblende is faintly green (edenite) and with well-developed prismae faces when bordering on hornblende and very irregular outlines where bordering on anorthite. The prismae of hornblende are arranged parallel to two mutually perpendicular directions. Biotite penetrates the hornblende and there are a few interstitial grains of anorthite.

The white patches have in their central parts corundum in very corroded grains as in 13532a, but it is never seen in contact with plagioclase in this thin section, being separated from the latter by a rim of sapphirine (as mentioned above there are a few patches with red corundum and without sapphirine). The sapphirine is also here replacing the corundum and may occur in grains free from inclusions of the latter. There may be small grains of green spinel between corundum and sapphirine and spinel is also present as inclusions in the sapphirine, where all traces of corundum have disappeared (plate 1, fig. 1).

Also this rock bears a certain resemblance to the sakénites from Madagascar. The genesis of these rocks will be discussed below.

BOULDER WITH SAPPHIRINE AND CORUNDUM FOUND IN QÔRQUT, THE GODTHAAB FJORD

In the summer of 1951 a boulder of hornblendite with sapphirine and corundum was found by Dr. H. RAMBERG, Mrs. M. L. RAMBERG and the writer in Qôrqut which is the south eastern branch of the Godthaab Fiord.

The boulder consists of green, coarse-grained hornblendite which has a good deal of biotite and anthophyllite in restricted areas. There are a great number of white patches varying in size from very small to several centimetres across.

The patches may have a thin marginal rim of red garnet, but this rim is often incomplete and may be totally absent. The white rock is mainly made up of anorthite, but there is often a central spot of a bluish-black colour which under the microscope is seen to consist of corundum, spinel and sapphirine. Scattered over the white rock biotite and hornblende occur and anthophyllite may rarely be seen along the margins of the patches. The white patches are apparently formed at the expense of the hornblendite.

The white patches were examined in the thin sections nos. **13732 a** and b (plate 1, fig. 2).

Strongly corroded grains of corundum are present in the central parts of these two patches. The corrosion may be so advanced that the grains are divided into several fragments of common optical orientation. The corundum is embedded in a scaly and fibrous matrix in which the following components have been definitely identified: basic plagioclase, chlorite (faintly green, lengthfast, optically positive), muscovite and clinozoisite. Tiny scales in the interior parts of the corundum (or rather in holes in the corundum) have weak birefringence and are very likely margarite.

Outwards the lobed grains of corundum are surrounded by green spinel and this again by sapphirine. This green and blue rim is surrounded by the plagioclase matrix of the patches. The coloured rim may be absent, the corundum is then separated from the plagioclase by a thin rim of tiny scales of chlorite.

The sapphirine is pleochroic: γ blue, β blue, and α faintly reddish. (—) 2V is about 60° and $v > r$. The sapphirine has most often inclusions of spinel, but it may be seen in pure grains of an elongated habit like the sapphirine from the Fiskenæsset occurrence. There is often a thin rim of chlorite between sapphirine and plagioclase.

A symplectite is occasionally associated with the spinel. It is made up of tiny grains of spinel, of ore and probably also of corundum. It is separated from the plagioclase by sapphirine and often also by chlorite.

The plagioclase of the matrix is present in irregular grains with zonal structure. The content of anorthite is about 95 $^0/_0$, twinning according to the albite and pericline laws has been noted. This plagioclase is less altered than that found in association with the corundum; but there is nevertheless a good deal of muscovite and clinozoisite (the latter is present in irregular aggregates of small grains). Some grains crowded with scaly material might be cordierite, but this mineral has been seen neither in section nor in powder.

The rim of garnet around the plagioclase is as mentioned above often incomplete. The garnet occurs in small grains with biotite and secondary chlorite. There may be inclusions of hornblende.

The hornblendite outside the garnet is made up of a faintly green hornblende, plagioclase and biotite. Anthophyllite is not found in the sections, but it has been seen in the hand specimens. The white patches appear to grow at the expense of the hornblendite where the garnet is absent.

REMARKS ON THE SAPPHIRINE FROM FISKENÆSSET, WEST GREENLAND

In 1949 the writer paid a short visit at Fiskenæsset but having only a late evening at my disposal I have not much to add to the description of the locality.

The sapphirine is found in a strongly altered ultrabasic mass. The original ultrabasite appears to have been made up of rocks rich in olivine, bronzite and spinel. The main rock in the occurrence is now a light-coloured rock with the components: gedrite, biotite, hornblende and sapphirine.

There are small patches with corundum and the sapphirine-bearing rocks are cut by thin pegmatitic veins. Zones of crushing are also present.

The enclosing rock is a hornblende gneiss with recrystallized mylonites.

The region in question is made up of gneisses belonging to the transition zone between amphibolite and granulite facies.

Petrography.

This chapter is based on samples collected by K. J.V. Steenstrup in 1877 (kept in the Mineralogical Museum of Copenhagen) and by the writer in 1949. I have also had the opportunity of studying some of the rocks and thin-sections examined by Ussing (*29*).

The ultrabasic rocks. One type of rock has elongated grains of black spinel (1 cm long, or more) in a fairly equigranular matrix of hornblende, olivine and bronzite. The rock is of a foliated appearance because of the parallel arrangement of the prismatic grains of hornblende and the grains of spinel have their longest direction parallel to this foliation.

Under the microscope this rock is seen to be made up of parallel prismae of a faintly green hornblende and of equidimensional grains of olivine and bronzite. The amount of spinel (green in thin section) is considerable. Chlorite and carbonate minerals are present in minor amounts. Sapphirine has not been observed.

This rock greatly resembles the ultrabasites associated with dolomitic limestones at Grønøy, Northern Norway (see *26*).

Another of the samples from the collections of the Mineralogical Museum is a black hornblendite with grains of spinel. It is cut by thin (1 cm) veins of plagioclase.

This rock is made up of long prismae of hornblende (faintly green in thin section) which have numerous inclusions of small grains of spinel (green). Spinel is also found in large grains as in the rock described above.

The thin, parallel veins of plagioclase (about 100 $^0/_0$ anorthite) have fragments of hornblende and of spinel.

Sapphirine is rarely present on the borders of the spinel, but it is also seen as small grains in the hornblende and in the plagioclase. These small grains have most often inclusions of spinel.

Secondary minerals are chlorite and carbonate and there are zones of crushing.

This hornblendite is by analogy with similar rocks in other localities in West Greenland interpreted as having been formed through reactions along fractures in the ultrabasite.

The bronzitite. No. **13370 b** collected by the writer in 1949 is made up of prismatic grains of bronzite (2 cm long or more) and contains a good deal of spinel (the grains and aggregates of spinel may be several centimetres across. Biotite is present in large flakes. Small bluish-black grains of sapphirine most often in association with spinel may be seen by the naked eye.

The prismae of bronzite have rather irregular outlines. The bronzite is optically positive and has according to USSING (*29*, page 615) 5.71 $^0/_0$ FeO.

The spinel is present in irregular grains or in aggregates of many small grains. It is faintly green in thin section.

In this rock the spinel is associated with an almost colourless sapphirine which is most often found along the margins of the spinel and it has very often inclusions of spinel when present in independent grains (fig. 2). The sapphirine is found in irregular grains and its mode of occurrence indicates that it is formed at the expense of the spinel.

Phlogopite is an important constituent of this rock. The following minerals are present in subordinate amounts: gedrite, chlorite and carbonate.

This rock belongs to USSING's "second type" (op. cit. page 597). It has been examined in one more thin section (**U 200**). This sample

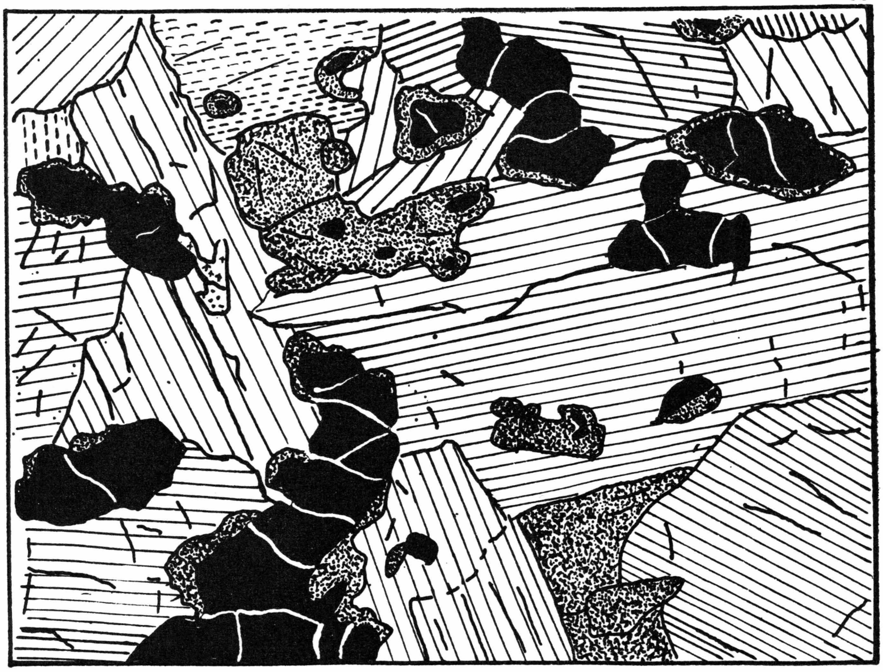

Fig. 2. No. **13570 b.** 30 ×. Bronzitite from Fiskenæsset. The components are: bronzite, spinel (black), sapphirine (dotted), chlorite (broken lines) and carbonate (crosses). Compare the corresponding microphoto plate 2, fig. 1.

resembles no. 13570b but the spinel has disappeared, sapphirine is present in larger grains, and the bronzite is clearly being replaced by gedrite and hornblende (colourless).

Some bronzite-bearing rocks have a considerable quantity of sapphirine.

The gedrite-bearing rocks. This type of rock has been examined in four thin sections, no. **13570 a** collected by the writer and three sections from the collections of the Museum.

This type of rock has sapphirine of a pale blue colour occurring in thin plates or in aggregates of plates so that grains more than one centimetre across may be seen. An almost colourless gedrite, phlogopite and a faintly green hornblende are the remaining components.

Under the microscope the groundmass of the rock is seen to be made up of phlogopitic mica and of prismae of gedrite and hornblende. A few small corroded remnants of bronzite may be seen, adjacent grains often with common optical orientation so that is appears as if larger grains of bronzite have formerly been present (plate 2, fig. 2).

The platy crystals of sapphirine may as mentioned by USSING have very regular outlines. Such plates may combine to form aggregates made up of several almost parallel individuals in a way resembling twinning (cf. USSING, op. cit. page 599). The sapphirine has prominent cracks and is colourless in thin section.

The monoclinic hornblende is colourless in thin section and it has therefore not been possible to undertake any detailed examination of the relations between bronzite and the two amphiboles. It is, however, likely that the relations are similar to those described in (*23*).

This spinel-free rock is the "type number one" of USSING.

In some parts of the occurrence there are rocks very rich in biotite but still with large aggregates of the blue sapphirine. Gedrite is a more scarce component than in the rocks mentioned above and it may be totally lacking. It is clearly in a process of dissolution.

One of these rocks examined in thin section had the components biotite, sapphirine, basic plagioclase (almost pure anorthite), cordierite, chlorite, tiny grains of corundum and a few small spots of ores.

The sapphirine occurs in part in big crystal plates, in part in aggregates made up of several small plates. The crystallographical outlines are often well-developed, but the grains may also be lobed and full of holes. Parallel intergrowths of biotite and sapphirine are common and the biotite may even penetrate the sapphirine. There is then a separation of small grains of corundum and aggregates of biotite and corundum may be observed in continuation of the plates of sapphirine with the original shape of the sapphirine crystals preserved. Corundum is moreover present in many of the sapphirine grains. Biotite is obviously replacing the sapphirine and there is a simultaneous separation of corundum corresponding to the features described by CORNELIUS and DITTLER (*5*) (compare page 24).

The sapphirine is also enclosed in and penetrated by plagioclase and cordierite, and is no doubt in a process of replacement by these minerals. The cordierite is pale red and occurs in equidimensional grains almost free from twinning. There are no pleochroic rings. (+) 2V is about 78°, the refractive indices close to that of Canada balsam. The small grains of cordierite form aggregates of the same size as the original grains of sapphirine and with remnants of the last-named mineral.

Patches with corundum. Corundum has not previously been mentioned in the literature on the Fiskenæsset occurrence, but it was found in 1949 (no. 13569). This mineral occurs in white to brown, barrel-shaped crystals of $^1/_2$ cm or more. The corundum is present in a small white patch and is embedded in a matrix of anorthite and biotite. Cordierite has been identified in powder from the outer part of the white patch so that it appears as if the corundum-plagioclase rock is separated from the sapphirine-bearing complex by cordierite and biotite.

The narrow, light-coloured veins in the sapphirine-bearing complex are apparently free from sapphirine and are separated from the sapphirine rock by gedrite and plagioclase. Sapphirine may rarely be seen in the irregular borders of the veins. The veins consist of basic plagioclase (about 95 $^0/_0$ anorthite), gedrite, a green hornblende, biotite, and cordierite. A small amount of carbonate is present.

The sapphirine in the border rock is enclosed by plagioclase and the grains have a corroded appearance.

The gedrite of the veins is also highly corroded and may be divided into several fragments of common optical orientation. It is therefore reasonable to assume that the irregular veins are formed through replacement of the sapphirine-bearing rock and the grains of cordierite may in this case mark the former site of the grains of sapphirine.

The kornerupine found in this locality is most probably associated with these veins. It is found in association with phlogopite, plagioclase and cordierite. The relationship between sapphirine and kornerupine is still uncertain. The writer did not examine this problem when visiting the occurrence in 1949.

SAPPHIRINE AS A CONSTITUENT OF ROCKS

The stability relations of sapphirine have recently been treated by VOGT (*30*) and by RAMBERG (*21*). It was concluded that the sapphirine has a narrow field of stability in the high amphibolite- and low granulite facies region. Experimental work by FOSTER (*7*) and by KEITH and SCHAIRER (*10*) has shown that sapphirine has a primary field of crystallization on the liquidus surface of the system $MgO - SiO_2 - Al_2O_3$. The present examination indicates that it, if stable, has a very narrow field of stability.

In the three localities in Greenland mentioned above sapphirine is found in rocks of ultrabasic origin, an origin which is apparent in Fiskenæsset and in Ol. 1. The ultrabasic origin of the boulder in Qôrqut is almost indisputable.

Two other occurrences of sapphirine have been described from West Greenland. The first in Avatsissarfik (Auvaitsersarfik) (BØGGILD, *4*) recalls much of the boulder from Qôrqut and they may in fact both belong to one and the same complex, since Avatsissarfik is situated at the bottom of the Ameralik Fiord not far to the east of Qôrqut.

The paragenesis is: gedrite, phlogopite, corundum, sapphirine and spinel.

The corundum is according to BØGGILD (op. cit. page 107) present in large grains which may be divided into several smaller ones of common optical orientation. The sapphirine forms according to RAMBERG (op. cit. page 20) rims of reaction between gedrite and corundum/spinel. The resemblance to Qôrqut is thus pronounced.

The second occurrence is that at Sukkertoppen described by RAMBERG (*21*). The writer visited the occurrence in 1953 and found great similarities with Ol. 1 (*25*, page 9). RAMBERG has interpreted the occurrence as a metamorphosed ultrabasic complex, the present writer is of the same opinion. Small green masses of hornblendite and small lenses of various types of ultrabasic rocks are enclosed in a strongly lineated hypersthene-bearing gneiss which may be best interpreted as a hybrid rock formed at the expense of the original ultrabasic mass.

The sapphirine is most often associated with a bluish-black spinel (green in thin section), which is present either as large porphyroblasts or as small grains in the ultrabasic masses. Thus a thin section of a hornblendite (no. 18333) had as its components, a faintly green hornblende, small grains of bronzite, small grains of anorthite, sapphirine and spinel. A few interstitial grains of spinel are seen, but the mineral is most often found as inclusions in the sapphirine (more rarely as tiny spots in bronzite and hornblende). To the writer this rock is a metamorphosed spinel-bearing bronzitite with hornblende formed at the expense of the bronzite and with sapphirine replacing the spinel.

In 1950 Mr. H. Pauly, mag. scient. found corundum in this locality. A faintly red grain of corundum, $^1/_2$ cm across was found in the central part of a spinel porphyroblast enclosed in an intergrowth of the spinel and sapphirine. The spinel is enclosed in a rock with plagioclase, bronzite and phlogopite.

In the occurrences of Ol. 1, Qôrqut, and Avatsissarfik the sapphirine is found as reaction rims around corundum/spinel, and more rarely as independent grains. In Fiskenæsset and in Sukkertoppen sapphirine appears to be a true component of the rocks.

The examination of the rocks from the three first-named localities shows that the corundum was formed earlier than the sapphirine and it may therefore be useful first to discuss the appearance of the corundum.

Corundum associated with ultrabasic rocks.

Corundum is as mentioned above found in white patches in the ultrabasic rocks in association with basic plagioclase and biotite. The white patches are surrounded by biotite or garnet.

The white rocks resemble, as will be mentioned below, the sakénites from Madagascar (Lacroix, *13*, *14*) and they also recall the plumasites which are always associated with ultrabasic rocks as has been emphasized by E. S. Larsen (*15*).

The plumasites are most often found as dykes or irregular veins in ultrabasic rocks from which they are separated by zones of biotite, vermiculite or chlorite. They are made up of sodic plagioclase and of corundum. The difference in composition between the plagioclase of the plumasites and that of the rocks from Greenland (and Madagascar) may be a result of the deep-seated origin of the last-mentioned rocks, while at least some plumasites are formed in higher levels of the crust.

Du Toit (*27*) has interpreted the plumasites as products of reaction between pegmatites and ultrabasites with a transportation of Si towards the ultrabasite and with a resulting deficiency of Si in the pegmatite in which corundum consequently appears.

E. S. LARSEN (op. cit.) considers the plumasites as formed through replacement processes at conditions of P,T approaching pegmatitic or hydrothermal contact metamorphism. The solutions moved along channels depositing only a part of the dissolved material and at the same time removing material from the surroundings.

The writer agrees in principle with the explanation of E. S. LARSEN. It is a well known fact that the composition of the pegmatites often depends on the enclosing rocks. Thus kyanite or sillimanite may be found in pegmatites cutting rocks containing these minerals, graphite may occur in pegmatites in graphite schists, and pegmatites may change in composition where they cut bands of different rocks. It is not uncommon in West Greenland to see pegmatites red (with microcline) in gneiss become white (with plagioclase) when they cut bands of amphibolite. Similarly DU TOIT (*27*) has described pegmatites from Natal which are normal in gneiss, but plumasitic when penetrating ultrabasites.

These features may be best explained by considering the pegmatites as products of replacement processes. "Dispersed" material migrating through fractures in the rocks reacts with the latter resulting in the replacement of the original rocks and in a simultaneous dissolution and removal of material. There is a change in chemical composition but primary structures are often preserved. The dispersed material is of the same composition in the same fracture, but the rocks formed through the replacement processes depend on the material present before the replacement and the recrystallization commenced.

The white patches described in this paper are then, if this point of view is taken, formed by pegmatitic replacement at favourable places in the ultrabasic bodies.

There is, however, another possibility. As described in (*23*) small patches of pegmatitic material are often found in the ultrabasic bodies and they are also present in Ol. 1 in the larger ultrabasic masses. They consist most often of an intermediate to basic plagioclase and of biotite. If an ultrabasite containing such pegmatitic spots is deformed and fractured, the fragments will gradually change their composition and may for instance be transformed into hornblenditic rocks. There may in this stage of the metamorphism be a neomineralization within the rock and Si may migrate from the pegmatitic patch into the ultrabasic rock so that the appearance of corundum is explained. Pegmatitic veins in the ultrabasite might be altered in a similar way so that plumasites could be formed.

The writer considers both explanations possible and in both cases the corumdum-bearing rocks are to be regarded as intermediate stages in the transformation. The corundum is an unstable mineral a view which is supported by the corroded appearance of the grains of this mineral and by the rims of reaction of sapphirine. Corundum is never found in the rocks from West Greenland in direct contact with hornblende, but is always enclosed in a rock of plagioclase and biotite.

Corundum may, however, also occur in contact with hornblende as is the case on an islet off Ingmikêrtoq, south of Nagssivit, Súportôq (Watkins Base Fjord), the Angmagssalik District in East Greenland (WAGER, *31*). Professor L. R. WAGER, Oxford has kindly furnished me with information about this discovery and has placed a sample of the rock at my disposal. The sample was taken from the central (10 cm or so) part of a zone of alteration cutting an ultrabasic mass included in the general grey gneiss of the region. As mentioned in (*24*, page 67) there are great similarities between the rocks in East Greenland and the rocks in Sukkertoppen District, the ultrabasic rocks are almost identical in the two areas and they are in both places enclosed in hornblende-bearing, often quartz-dioritic gneiss with bands of amphibolite.

During my visit to Durham in 1950 Professor WAGER kindly placed his collections and field notes at my disposal. The ultrabasic rock cut by the zone of alteration is made up of bronzite, hornblende, biotite, chlorite, carbonate and anthophyllite. Towards the zone of alteration there is first a rock rich in anthophyllite and biotite, then a zone rich in green amphibole, then a thin chloritic zone and in the central part of the zone a hornblenditic rock with biotite and with large grains of corundum.

The hornblenditic zone may be regarded as an incipient pegmatitic formation along fractures in the ultrabasite (cf. veins of enstatite in the dunite at Siorarssuit, *26*). The ultrabasite has been altered into hornblenditic rocks along the fracture, salic minerals have not yet appeared. The corundum may then as in the rocks discussed above be regarded as a metastable mineral formed in an intermediate stage of the formation of the pegmatite. It is, however, difficult to say why corundum and hornblende have not reacted in the East Greenland rock.

In this connection is should be pointed out that the retrograde metamorphism of the ultrabasic rocks took place at lower temperature in the Angmagssalik District than in the Sukkertoppen District (*24*, page 67). The rocks from East Greenland are rich in serpentine and chlorite while these minerals are almost totally lacking in the rocks from the Sukkertoppen District. The temperature of metamorphism may therefore have been so low that the corundum once formed may survive the metamorphism because of too slow rate of reaction.

Reference should also be made to the following statement by YODER (*35*, page 603): "It is well known that corundum is extremely slow to react in the laboratory experiments. Moreover it crystallizes metastably readily and is resorbed at an extremely slow rate, if at all."

Finally should be mentioned that corundum may be formed as a secondary product in the sapphirine where this mineral is replaced by biotite. The considerable amount of Al_2O_3 thereby released is responsible for the formation of corundum. Secondary corundum has so far only been observed in Fiskenæsset (page 16) and in Val Codera (page 24). The patches with large crystals of corundum discussed above are clearly of a different origin.

Parageneses with Sapphirine.

Sapphirine in the Greenland occurrences is found as a true component of the rocks in Fiskenæsset and in Sukkertoppen. In Ol. 1 and Qôrqut independent grains of sapphirine may be found so that this mineral appears as a true constituent of the rocks in very restricted areas.

The parageneses including sapphirine from the occurrences in Greenland and from the occurrences in other parts of the world are given below.

1) **Fiskenæsset:** sapphirine, gedrite, hornblende, biotite, anorthite, cordierite (spinel, bronzite and possibly kornerupine).

2) **Sukkertoppen:** sapphirine, hornblende, anorthite, biotite, (spinel and bronzite).

3) **Ol. 1:** sapphirine, hornblende, anorthite, biotite, (corundum and spinel).

4) **Qôrqut:** sapphirine, anorthite, garnet/biotite, (corundum and spinel).

5) **Avatsissarfik:** Sapphirine only observed in rims of reaction.

6) **Dangin. Western Australia** (PRIDER, *20*): Sapphirine is found in a biotite schist either in a) small lenticles with orthoclase (no sapphirine is observed outside these lenses) or in b) with biotite, orthoclase, plagioclase (Ab_7An_3), zircon and corundum). PRIDER has interpreted these rocks as formed at the expense of spinel-bearing hypersthenites.

7) **Guinea, West Africa** (JEREMINE, *9*): Sapphirine is described from a schist with hypersthene, biotite and basic plagioclase. The sapphirine has inclusions of a green spinel.

8) **Madagascar:** (LACROIX, *11*, *12*, *13*, *14* and, BESAIRIE, *2*):

a) *Itrongay*, sapphirine is found in soil,

b) *Sakena*, sapphirine is here found in the suite of rocks which has been termed sakénites by LACROIX (*13*, *14*). They are white, sugary-grained with anorthite, sapphirine, spinel and corundum as the main components. These rocks are associated with paragneisses (containing sillimanite, cordierite and almandine) and with pyroxenites and amphibolites. LACROIX has described sapphirine from the following rocks: sapphirine-sakénites (anorthite, sapphirine and small amounts of augite), sapphirine-spinel-sakénites, sapphirinite (sapphirine and spinel), spinel-sapphirine-pyroxenite (augite, spinel and sapphirine), and sapphirine amphibolite (edenite and sapphirine). There are also rocks with anorthite and corundum and/or spinel. In the collections of the Mineralogical Museum of Copenhagen there is a pyroxenite from Vorokufotra, Betroka which resembles the bronzitite from Fiskenæsset being made up of bronzite and large grains of sapphirine.

The sakénites resemble the anorthite, corundum, spinel rocks from Greenland and since they are associated with pyroxenites it is very likely that they are of ultrabasic origin. In this connection it is worth noting that BESAIRIE (*2*) has described inclusions of sapphirinite in pyroxenite (with spinel) which also has inclusions of limestone.

BARLOW (*1*, page 65) has described rocks resembling some of the types of sakénite from Canada.

9) **India:**

a) *Hill Tracts*, *Vizagapatam* (MIDDLEMISS, *17*, WALKER and COLLINS, *33*, and CROOKSHANK, *6*): Sapphirine forms, according to CROOKSHANK, rims around grains of hercynite and separates this mineral from hypersthene of which the bulk of the rock is composed. According to WALKER and COLLINS the sapphirine is found in the border zone between ultrabasites and khondalites and it is formed at the expense of spinel. The presence of sillimanite in the sapphirine-bearing rock has been questioned by LACROIX.

b) *Ganguvarpatti*, *Madura* (MUTHUSWAMI, *19*): Sapphirine is found in bands of hypersthene granulite consisting of hypersthene, cordierite, spinel, garnet, biotite, and anthophyllite. MUTHUSWAMI mentions 6 modes of occurrence of the sapphirine, the most important ones being in symplectites with hypersthene, in myrmekites with cordierite and finally replacing spinel. It is thus present in symplectites of hypersthene and spinel around porphyroblasts of garnet, the spinel being in part replaced by sapphirine. Dr. S. O. AGRELL, Cambridge has kindly sent me samples of these rocks for examination.

MUTHUSWAMI states that sapphirine occurs in rocks intimately associated with hypersthene spinellites. It is always associated with biotite. Of interest is the intergrowth between cordierite and sapphirine. MUTHUSWAMI regards the sapphirine as due to metasomatic metamorphism.

10) **Alpe Brasciadega in Val Codera, Italy** (CORNELIUS and DITTLER, *5*): Sapphirine is found in blocks in the scree below a steep wall. There are two types of sapphirine-bearing rocks. In the first type sapphirine is found in the following parageneses: a) biotite, cordierite, hypersthene, sapphirine and in some cases garnet, b) sapphirine, sillimanite, cordierite and in some rocks biotite. The sapphirine is usually enclosed in cordierite but may also be seen in contact with garnet, hypersthene and biotite. It is always separated from veins of orthoclase by cordierite. The sillimanite is surrounded by sapphirine and this again by cordierite.

The second type has the constituents: biotite, sapphirine, cordierite, garnet, amphibole (orthorhombic as well as monoclinic). The sapphirine is present in small tabular grains which may be transformed into corundum and biotite. Sapphirine is also enclosed by cordierite in this rock.

CORNELIUS and DITTLER conclude that sapphirine is formed by subtraction of K_2O and SiO_2 from a biotite-mica-schist. This interpretation is not in the best agreement with the pegmatitic veins rich in orthoclase in the schist, since these veins according to the description are introduced into the sapphirine-bearing rock. The origin of this rock still seems to be uncertain.

11) **Stallen, Kartenblat Drosendorf,** Austria (WALDMANN, *32*): A large, heterogeneous mass of amphibolite is found in the Moldanubian zone and at Stallen an olivine gabbro occurs. This rock has large laths of plagioclase and prismae of diallage in a groundmass with olivine and hypersthene and in addition hornblende, spinel and sapphirine. The sapphirine is found in a kelyphitic zone between the hypersthene and the secondary plagioclase of the rock. The transition is: olivine (enclosed in the hypersthene) — hypersthene — diopside — hornblende — hornblende + spinel — hornblende + sapphirine + spinel — plagioclase.

12) **Cortland, New York** (FRIEDMAN, *8*): In the endogenic border of a norite enclosed in mica schist there is a development of emery (consisting of corundum, titanomagnetite and spinel). Where this rock is cut by veins of quartz, sapphirine appears. The transition is: quartz — garnet — sillimanite — sapphirine + spinel — emery (corundum, magnetite and spinel). The mica schist is transformed into a sillimanite-cordierite-magnetite-hornfels which in a narrow zone close to the norite (emery) has sapphirine and relics of spinel.

FRIEDMAN regards the sapphirine as formed at the expense of spinel.

13) **St. Urbain, Quebec** (WARREN, 34): Sapphirine is found in ilmenite-rutile-masses in anorthosite. The paragenesis is: ilmenite, rutile, andesine, biotite, spinel and sapphirine. The sapphirine is especially found on

the borders of the andesine. WARREN believes that the sapphirine is of magmatic origin but mentions the possibility of its being formed through replacement of spinel.

14) **Blinkwater, Transvaal** (MOUNTAIN, *18*): Sapphirine is here found in a coarse-grained granite enclosed in brown mica and associated with prismatic crystals of corundum.

15) **Tievebulliagh, Co. Antrim, Ireland** (Dr. S. O. AGRELL, personal communication): Small spots of a blue mineral are found in one slice of one specimen from this locality and Dr. S. O. AGRELL, Cambridge has kindly lent me this thin section. The rock is very fine-grained and is made up of a felt-like mass of small crystals. The blue mineral is found in the mullite-cordierite-hercynite portions of this hornfels (metamorphosed laterite). There are very few blue grains and a closer study is made very difficult because of their smallness. The mineral has a weak birefringence and Dr. AGRELL has determined the index of refraction to be about 1.72. It is therefore very likely that the mineral is sapphirine. (The Tievebulliagh area has been described by TOMKEIEFF (*28*)).

On the Stability Relations of Sapphirine.

In the preceding chapter all the parageneses of sapphirine known to the writer are presented. In many the sapphirine is found in ultrabasic rocks where it is formed at the expense of spinel and/or corundum. This is valid for the occurrences in Greenland, Australia, Madagascar, Guinea (?) and in Vizagapatam.

In Ganguvarpatti and in Stallen sapphirine replaces spinel in rims of reaction. The sapphirine in Cortland and the possible sapphirine in Tievebulliagh are found in hornfelsic contact zones of basic rocks, but the occurrence in Cortland is most probably to be regarded as a sort of reaction rim. The occurrence in Val Codera may also belong to a contact zone where mica schists are metamorphosed by the Bergeller granite, but an ultrabasic origin of this rock cannot be excluded. Only further field studies can answer this question.

At St. Urbain the sapphirine is apparently also a product of reaction between incompatible minerals and the sapphirine is in part formed at the expense of spinel.

The occurrence in Transvaal may be of ultrabasic origin but nothing definite can be said on the basis of the description of this rock.

Sapphirine is as mentioned above found in rims of reaction in many of the occurrences and it is clearly not a stable component of these rocks. Under the description of Ol. 1 and Qôrqut it was suggested that these reactions might run until an equilibrium was established since there is a tendency for the development of crystals of sapphirine in these two places. There might then be a transition to the rocks in which sapphirine appears to be a true component.

Crystals of sapphirine in the occurrences mentioned in the preceding chapter have been found associated with the following minerals: anthophyllite, hornblende, biotite, (garnet), cordierite, anorthite, orthoclase, rutile, ilmenite, magnetite and possibly sillimanite and mullite. Spinel, corundum, bronzite, (and sillimanite) may be present where the reactions are incomplete.

According to VOGT (*30*) sapphirine-bearing rocks belong to the undersaturated region of a special facies: the sakenite facies, which is related to the amphibiolite facies from which it differs in having gedrite, augite and sillimanite instead of anthophyllite, diopside, and andalusite. He states that sapphirine is not yet known from the amphibolite facies.

RAMBERG (*21*, page 21) concluded that the physical stability field of sapphirine is confined to a narrow P,T—field situated between granulite facies and amphibolite facies. He further states (op. cit. page 20) that sapphirine will appear in rocks with considerable chemical variations, i.e. its chemical stability field is rather large. The sapphirine may according to RAMBERG be formed either by interaction between minerals lying intimately intermingled or by help of the transfer of Si and K towards the spinel-rich parts of an ultrabasic complex.

The results of the present examination show that sapphirine is found in associations typical for the low granulite- or the high amphibolite facies. It is therefore not necessary to establish a new facies (or sub-facies) in order to place sapphirine in the facies classification. It should, however, be pointed out that ultrabasic rocks may exist as "armed relics" (*25*, page 34), since their parageneses often correspond to conditions of P,T higher than those prevailing during the metamorphism of the country rocks. Equilibrium is only established along the borders and the fractures of the ultrabasic masses. The co-existence of bronzite, spinel and sapphirine should most probably be seen in the light of this statement.

In most occurrences sapphirine is seen to be formed around centres of spinel and/or corundum. Spinel is a common constituent of ultrabasic rocks and spinel-bearing ultrabasic rocks are furthermore very common in many of the regions in which sapphirine has been found. These ultrabasic rocks are formed at a fairly high temperature and if sapphirine had a field of stability, it should be expected to be a common constituent of such ultrabasic rocks, being formed during the retrograde metamorphism of the ultrabasites. In favour of this view is the fact that sapphirine is found in rocks of very varying chemical compositions.

The writer has studied a great number of ultrabasic rocks from Greenland and if the above-mentioned statement be correct, sapphirine should be a very common constituent of these rocks which have been exposed to metamorphism of the same degree as the sapphirine-bearing complexes. Sapphirine has been searched for, but was never found in the examined rocks.

If it is assumed that sapphirine is formed within a very narrow field of P,T the missing sapphirine in these ultrabasic rocks may be due to a too rapid cooling which did not allow the formation of this mineral. But even then sapphirine should be expected to be much more common than it really is.

A few examples may elucidate this. In the writers opinion olivine and spinel are the first minerals to be formed where amphibolitic (or dolomitic) rocks are exposed to "ultrabasification", i. e. where ultrabasic rocks are formed through metasomatic processes. This has been described from Tovqussaq (*24*, page 48) and is most probably also the case in Grønøy, Northern Norway (*26*) where ultrabasic rocks are formed at the expense of calcareous (dolomitic) sediments. The first minerals to be formed are olivine and spinel.

The retrograde metamorphism of the ultrabasic rocks from Tovqussaq has been described in (*24*). The rocks consist of (olivine), bronzite, hornblende and spinel, i. e. a composition corresponding to that of the primary rocks in Fiskenæsset. The transformation has taken place at low granulite facies conditions, hornblende is formed at the expense of the bronzite and the spinel is dissolved in the hornblende (op. cit. page 28).

The ultrabasite at Ol. 3 (*24*, fig. 14, and *23*, page 240) is cut by zones of crushing along which a certain recystallization has taken place. Where grains of spinel are situated in these zones they may be sliced into parallel rods, the crushed hornblende is recrystallized into anthophyllite. There is not the slightest trace of sapphirine around the sliced grains of spinel, the spinel is on the contrary altered into a scaly matrix. The transformation has taken place at amphibolite facies conditions.

These two examples are typical for the retrograde transformation of ultrabasic rocks at conditions of P,T corresponding to the assumed stability field of the sapphirine. The spinel is resorbed by hornblende as it has been described by Brøgger (*3*, page 89) from Southern Norway, where spinel in symplectitic intergrowth with hornblende in the outer zone of a corona around olivine is resorbed in the hornblende in the later stages of the transformation.

If sapphirine has a field of stability the writer believes that it ought to be much more common than is in fact the case. A somewhat different explanation will therefore be advanced in the following pages.

Sapphirine is formed in restricted Al-rich areas in rocks rich in Mg and poor in Si, e.g. around concentrations of spinel in ultrabasic rocks. This is seen especially well in Fiskenæsset where there is an incipient formation of sapphirine around the spinel of the bronzitite. At the same time the bronzite is replaced by gedrite, hornblende and phlogopite. The spinel may be entirely replaced by the sapphirine and since the distribution of sapphirine within the rock resembles the distribution of spinel in the original rock it is reasonable to believe that sapphirine is only formed where there are original grains of spinel.

The formation of sapphirine may then be regarded as an intermediate stage in the dissolution of the spinel, the latter process being very slow because of the low rate of migration of material in the fractures in the rock and along the grain boundaries so that it takes a long time to "wipe out" the original concentrations of Al.

The correctness of this interpretation is supported by the veins of plagioclase described on page 14. These veins were formed along fractures in the original rock which was transformed into a hornblendite, hornblende being formed at the expense of the bronzite. As to the primary grains of spinel they are clearly strongly corroded and divided into numerous fragments, being replaced by hornblende and plagioclase. There has been free access to the rock along the fractures and there is therefore a very insignificant formation of sapphirine (which occurs in a few irregular grains).

Further proof is found in the irregular, light-coloured veins described on page 17. This rock is clearly formed by replacement of the gedrite-sapphirine rock and nothing speaks against the assumption that these veins were formed at the same conditions of P,T as the sapphirine was. (Thus the plagioclase is extremely rich in anorthite in all these rocks). The veins were formed where migrating material from the surroundings was introduced into the rock. This results in the formation of a basic plagioclase, cordierite, green hornblende and carbonate at the expense of sapphirine and gedrite. In the biotite-rich portions of the Fiskenæsset locality the sapphirine is replaced by cordierite/anorthite and by biotite/corundum. In Ganguvarpatti and in Val Codera cordierite also appears to replace the sapphirine.

Kornerupine may be formed at the expense of sapphirine, it is most probably a constituent of the light-coloured veins, as it has been suggested on page 17.

According to this interpretation sapphirine is formed through reactions starting at the boundaries of the grains of spinel. Mg and Si from the bronzite migrate, towards the spinel, while Al migrates the opposite way. The spinel is then replaced by sapphirine; an aluminous anthophyllite (gedrite) takes the place of the bronzite. The appearance of gedrite is thus a result of the high content of Al in the original rock, it is not necessary to explain the formation of gedrite as a result of high pressure and temperature as Vogt did (op. cit. page 23). The chemical changes may be seen in the table where the analyses of bronzite, gedrite, sapphirine and spinel from Fiskenæsset are quoted from Lorenzen (*16*) and Ussing (*29*). For comparison analyses of kornerupine (from Ussing, op. cit.) and cordierite (ideal) are given.

	Spinel	Sapphi-rine	Gedrite	Bronzite	Korne-rupine	Cordie-rite
	%	%	%	%	%	%
SiO_2	0.23	12.83	46.18	55.04	30.90	51.40
Al_2O_3	70.05	65.29	21.78	3.35	46.79	34.85
Fe_2O_3	..	0.93	0.44	..	2.02	..
FeO	9.86	0.65	2.77	5.71	..	..
MgO	21.25	19.78	25.05	33.98	19.46	13.75
Na_2O	..	..	2.30	..	..	..
H_2O	..	..	1.37	..	..	..

The analyses show a decreasing amount of Al from spinel over sapphirine and gedrite to bronzite and increasing amounts of Si and *Mg* in the same direction. It is not apparent what has happened to the Fe of the spinel. A possible explanation is that the spinel becomes richer and richer in Fe as the reaction progresses. It should also be remembered that the sapphirine found in association with spinel is of a more intense blue colour (and probably more rich in Fe) than the analyzed sapphirine of the gedrite-bearing rock.

There is an increase in Si and a decrease of Al from sapphirine over kornerupine to cordierite. Sapphirine and kornerupine have corresponding amounts of Mg, while cordierite has a lower amount. The content of boron in the kornerupine should be seen in connection with the possible pegmatitic rôle of this mineral.

Sapphirine is thus in the writer's opinion a mineral which is formed where "stirring" has been too slow to dissipate concentrations of Al in a milieu rich in Mg and poor in Si. The sapphirine is formed through reaction between adjacent minerals and the scarce amount of dispersed ions available. This explanation may account for all known occurrences since one of the characteristics of sapphirine is that it first appears as rims of reaction around minerals rich in Al. This reaction may be restricted to a narrow field of P,T. It is to be hoped that experimental studies may be undertaken in the appropriate part of the system MgO-SiO_2-Al_2O_3-H_2O and at the temperatures (400—700° C) at which sapphirine might be expected to be formed. KEITH and SCHAIRER (*10*, page 185) have announced such a discussion.

It appears as if sapphirine is fairly resistant when formed as long as it is protected against the dispersed phase (by dispersed phase is here understood migrating ions, vapours and solutions).

Sapphirine might perhaps be regarded as a stable mineral in undersaturated rocks rich in Al being formed at conditions of P,T corresponding to the amphibolite-granulite facies region. The present examination has, however, shown that sapphirine only is stable in the "closed system", it disappears soon when exposed to the dispersed phase. If sapphirine should be regarded as a stable mineral under these conditions, one might as well regard olivine as a stable mineral of the green schist facies where "armed relics" of dunite are enclosed in gneisses belonging to this facies.

In this connection reference may be made to YODER's discussion of the "water-deficient region" (*35*, page 615) and to his examination of the stability relations of anthophyllite. Anthophyllite (op. cit. page 609) is shown to lie in the water deficient region. It is not stable in the presence of an excess of water. This is a further corroboration of the views expressed above since anthophyllite (gedrite) is formed together with sapphirine in the spinel-bearing bronzitites of Fiskenæsset.

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PLATES

Plate 1.

Plate 1, fig. 1. No. **13532 b.** 30 ×, 1 nic. Hornblendite, Ol. 1. At the top and at the bottom: hornblende. Between these two layers: white patches of anorthite with corundum surrounded by sapphirine. The black mineral in the sapphirine is spinel. (CHR. HALKIER phot.).

Plate 1, fig. 2. No. **13732.** 30 ×, 1 nic. Hornblendite, Qôrqut. From top to bottom: hornblende, garnet, anorthite with alteration products (to the right a cluster rich in clinozoisite), and at the bottom spinel surrounded by sapphirine. At the extreme bottom a few small grains of corundum. (CHR. HALKIER phot.).

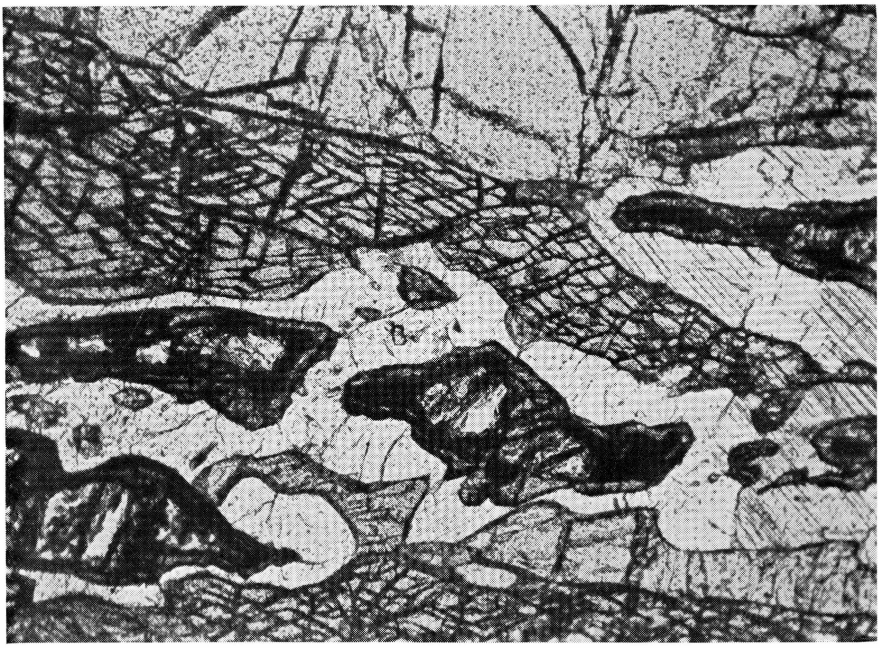

Fig. 1.

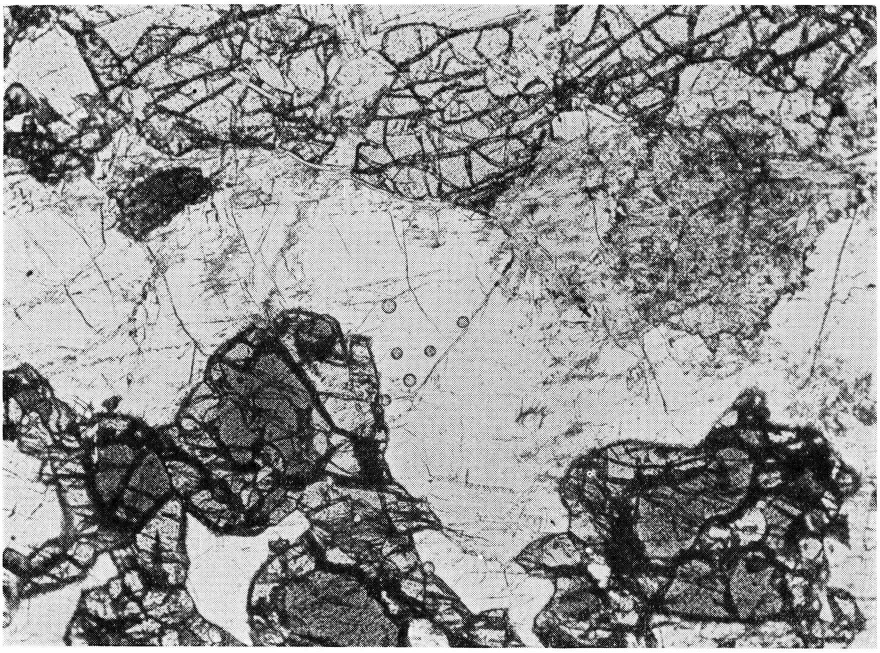

Fig. 2.

Plate 2.

Plate 2, fig. 1. No. **13570 b.** 30 ×, + nic. Bronzitite with spinel and sapphirine, Fiskenæsset. For explanation see fig. 2, page 15. (CHR. HALKIER phot.).

Plate 2, fig. 2. No. **13570 a.** 30 ×, 1 nic. Crystals of sapphirine in a matrix of phlogopite and gedrite, Fiskenæsset. Top centre and top left: two small grains of bronzite. (CHR. HALKIER phot.).

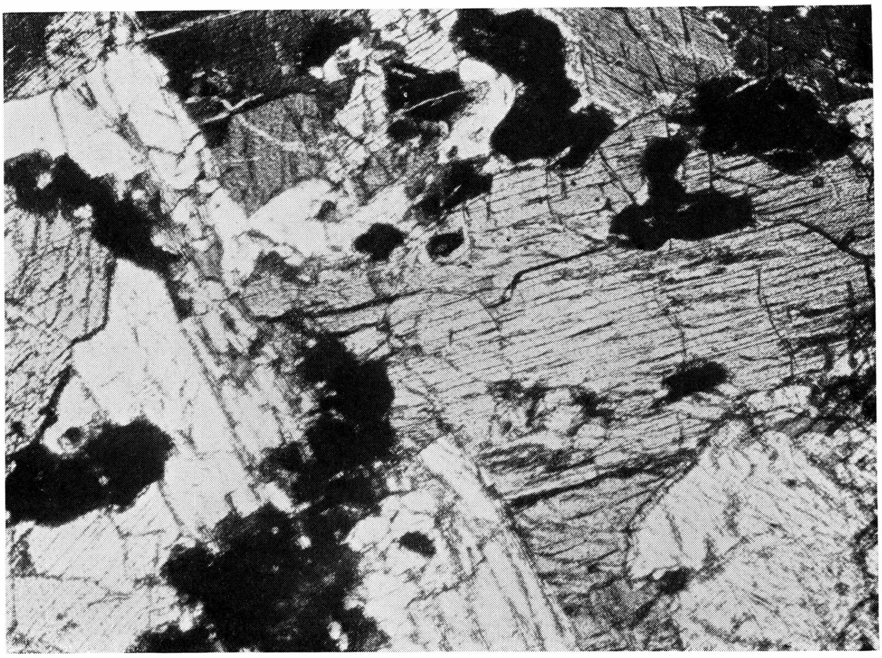

Fig. 1.

Fig. 2.