

ON CONTACT MINERALS FROM PRE-CAMBRIAN LIMESTONES IN SOUTHERN NORWAY

BY
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Near the town Christiansand in southern Norway there are several occurrences of contact metamorphic limestones, which form a part of the Pre-Cambrian formation and are of certain sedimentary origin. The following groups of rocks constitute the geological structure of the area around Christiansand.

1. (Oldest) An old series of sediments including limestone.
2. Gneiss (foliated, with abundant plagioclase).
3. Granite (massive, with almost no plagioclase).

The contact metamorphism is evidently caused by the granite, shells of skarn rocks having been formed around the flakes or chunks of limestone which are found included in the granite.

The following contact minerals are found:

| | | |
|-------------|--------------|-------------|
| Graphite | Garnet | Quartz |
| Fluorite | Pyroxenes | Scapolite |
| Spinel | Amphiboles | Plagioclase |
| Pyrite | Biotite | Microcline |
| Limonite | Phlogopite | Epidote |
| Pyrrhotite | Muscovite | Zoisite |
| Magnetite | Chondrodite | Idocrase |
| Molybdenite | Titanolivine | Titanite |
| Zircon | Serpentine | Apatite |
| Rutil | Chlorite | Calcite |

An exact geological and mineralogical description of these occurrences will be given in an other paper. The present paper contains a description of the following five minerals, to which a special interest is attached: chondrodite, titanolivine, scapolite, plagioclase, and phlogopite.

I. Chondrodite.

Chondrodite, like phlogopite, is a fluorine bearing silicate of magnesia. It is not very frequently found, disseminated as it is in the limestone in small grains (about 0,5 mm.) often in contact with phlogopite, less frequently with spinel (pleonaste). The colour is sometimes dark brown, sometimes lighter with a yellowish tinge.

The chondrodite has no distinct cleavage, but it is traversed by many irregular cracks, which, however, generally are running approximately parallel to (103). It is often twinned according to the common law $\pm (001)$.

The pleochroism is $\alpha =$ yellowish brown.
 $\beta =$ light yellowish brown.
 $\gamma =$ white.

The pleochroism may also be absent.

The light and the dark chondrodite have the same indices of refraction. Determined by the immersion method in daylight they are:

$$\begin{aligned}\gamma &= 1,637 \\ \alpha &= 1,601\end{aligned}$$

$$\gamma - \alpha = 0,036$$

The dispersion of the optical axes is very small, nearly invisible $\rho < \nu$. $2V = 85 - 90^\circ$, optically positive. Extinction angle $\alpha : a = 27,2^\circ$.

The specific gravity was determined by Clerici's liquid and the westphalian scale: sp. g = 3,227.

The material for the chemical analysis was the one used in determining the specific gravity. The chondrodite grains were picked and carved out of the calcite, mechanically cleansed, and purified with Clerici's liquid. A portion was fused with

carbonate of soda, an other portion dissolved in HCl (in the following referred to as analysis I and II respectively). A third fraction was used for the determination of F which was determined as CaF_2 according to HILLEBRAND (8). TiO_2 and MnO_2 were determined by the colourimetric method. H_2O was directly determined according to PENFIELD (15).

The analysis gave the following result:

| | I | II | III | Average | Mol. numb. | IV |
|-------------------------------------|-------|-------|------|--------------|------------|--------|
| | % | % | % | % | | % |
| SiO_2 | 31,95 | 32,18 | -- | 32,07 | 0,5318 | 33,85 |
| TiO_2 | 0,25 | 0,22 | -- | 0,23 | 0,0028 | |
| Al_2O_3 | 1,14 | 1,11 | -- | 1,13 | 0,0111 | 1,23 |
| Fe_2O_3 | 0,35 | 0,35 | -- | 0,35 | 0,0022 | |
| FeO | 3,54 | 3,46 | -- | 3,50 | 0,0487 | 3,70 |
| MnO | 0,08 | 0,08 | -- | 0,08 | 0,0011 | |
| CaO | 0,20 | 0,28 | -- | 0,24 | 0,0039 | |
| MgO | -- | 53,26 | -- | 53,26 | 1,3210 | 55,21 |
| K_2O | -- | -- | -- | not. determ. | | |
| Na_2O | -- | -- | -- | not. determ. | | |
| F | -- | -- | 6,28 | 6,28 | 0,3358 | 4,50 |
| H_2O | -- | -- | 2,74 | 2,74 | 0,3044 | 2,90 |
| $\text{H}_2\text{O} \div 110$ | -- | -- | 0,28 | 0,28 | | |
| | | | | 100,26 | | 101,43 |
| O for F | | | | 2,68 | | 1,42 |
| Total | | | | 97,58 | | 100,01 |

The analysis gives the following molecular ratios:



The formula of the chondrodite requires: 2 : 5 : 2.

The large amount of water is due to the alteration of chondrodite to serpentine along several minute cracks.

In comparison is quoted analysis IV, a chondrodite from Mansjö, described by H. v. ECKERMANN (4).

The physical properties of this Mansjö chondrodite are the following:

$$\begin{array}{l|l} \alpha : a = 26^\circ 25' & \alpha = 1,607 \\ 2V = 72^\circ 14' & \beta = 1,620 \\ & \gamma = 1,643 \end{array}$$

The small amount of iron, which these two analyses give is not common. H. v. ECKERMANN'S opinion is that the small axial angle of the chondrodite from Mansjö is due to the small percentage of iron. This interpretation is not verified in the case of the chondrodite from Christiansand.

The chondrodite is strongly cracked, and the cracks are filled with foreign matter, very often with a powder-like opaque substance, perhaps graphite. The chondrodite is always altered to serpentine in the cracks.

A thin section of a dark brown, (not analysed) chondrodite has some varying optical properties:

The axial angle is somewhat smaller, 80° — 85° . The dispersion of the optical axes is distinct $\rho < \nu$ (green $<$ violet) with a suggestion of crossed dispersion. An easily visible dispersion of bisectrix in some sections, makes this evident.

The dispersion of the optical axes is anomalous, for in convergent light the hyperbolas do not show the ordinary coloured rims of blue and red, but on the convex side they are violet and on the concave side pure green.

This appearance of green instead of red is very interesting. It must depend upon the absence of the yellow and red rays. But these rays can not be absorbed by the crystal, as β in chondrodite has a light yellowish brown colour in consequence of an absorption of the blue rays. The cause is, that the axial angle has its greatest value at intermediate wavelengths (yellow and green). On *chrysoberyle* J. SCHETELIG (16) observed the same anomalies. He says: „Im konvergenten Licht, mit der Axenebene in 45° Stellung, war die Mitte des Gesichtfeldes, innerhalb der schwarzen Hyperbelen stark grün gefärbt, während die Felder außerhalb violett waren“.

SCHETELIG measured the axial angle at different wavelengths, and got a curve, showing how $2V\gamma$ at first increases with decreasing wavelengths, reaches a maximum between 0,6 and 0,5 μ , and than decreases.

2. Titanolivine.

In a thinsection of a garnet-scapolite bearing skarn, a mineral grain with the following properties is observed. The grain, which is about 0,7 mm. long, lies in contact with scapolite and has irregular outlines. It is traversed by irregular cracks, but is not altered; it is cut about normal to the positive bisectrix, and in this orientation it has a yellowish-green colour with no pleochroism between α and β .

The axial angle over the positive bisectrix is small, but the dispersion of the axes is very strong, $\rho < \nu$. Estimated from the interference colours in convergent light the birefringence is about 0,03. The mineral has much higher refractive indices than scapolite, and it has a very strong dispersion of bisectrix.

According to „Hülfstabellen zur mikroskopischen Mineralbestimmung“ in ROSENBUSCH u. WÜLFING: Mikroskopische Physiographie etc. Bd. 1, 2, this mineral can only be titanolivine.

Judging from the literature titanolivine may have varying physical properties.

LACROIX (10) gives the following data:

$$\left. \begin{array}{l} \gamma \\ \beta \end{array} \right\} \text{jaune claire}$$

$$\alpha \text{ jaune rouge foncé}$$

$$\alpha > \beta = \gamma; 2V = 61^{\circ}58'; \rho > \nu$$

BRUGNATELLI (3) states the same pleochroism as LACROIX. He finds further: $2V = 57^{\circ}56'$; crossed dispersion strong. Very strong dispersion of the bisectrices. These investigators, however, describe titanolivine from chloritic-amphibole shists, serpentines and similar rocks.

V. NOVARESE (14) has found titanolivine in crystalline limestone from the Pre-Cambrian formation of Calabria. He states the pleochroism:

$$\alpha = \text{golden yellow (giallo aureo)}$$

$$\beta = \text{pale yellowish green (giallo verdasto molto pallido)}$$

$$\alpha > \beta$$

He says, however, that the pleochroism is not of equal strength all over, but decreasing from the margin towards the centre which he ascribes to alteration, the unaltered specimens showing the weakest pleochroism. Concerning the occurrence he says, that in the limestone the mineral is met with as small irregular grains, without idiomorphic outlines. The mineral is amber coloured which sufficiently distinguishes it from olivine. It occurs with spinel and chondrodite.

All investigators state that titanolivine has high refractive indices and birefringence.

$$\begin{array}{r} \text{LACROIX states } \alpha = 1,669 \\ \beta = 1,678 \\ \gamma = 1,702 \\ \hline \gamma - \alpha = 0,033 \end{array}$$

The properties of the mineral from Christiansand thus agree with the corresponding properties of titanolivine. The perfect agreement between NOVARESE's description of titanolivine from Calabria on the one hand and the description of the mineral from Christiansand on the other, is especially noteworthy since the mineralogical occurrences and the association of minerals are exactly the same in both cases.

All investigators maintain the relationship between titanolivine and the monoclinic humite minerals, especially chondrodite, from which titanolivine is distinguished by its stronger refraction and greater dispersion of bisectrix and optical axes.

LACROIX gives the following composition of titanolivine: $2(\text{MgO}, \text{FeO})(\text{SiO}_2, \text{TiO}_2)$. That is an olivine where the silicic acid is partly replaced by titanitic acid.

According to BRUGNATELLI, however, the chemical composition is more complicated. He has proved that water is a constant component (from 1,57 to 2,33 % H_2O); and this water is hard to drive out by ignition, in consequence of which he concludes, that it is bound as OH. Further he has determined traces of fluorine in one analysis. And lastly ZAMBONINI (22) has shown that the mineral specimen known as titanolivine is „une variété titanifère et glucinifère de clinohumite pratiquement sans fluor“.

In this connection attention is called to the chondrodite, previously described, which has a visible and anomalous, dispersion of the axes and of the bisectrices. One might suggest, that these particularities are due to an admixture of a component of titanitic acid, eventually titanolivine.

It is further very interesting, that SCHETELIG (see page 96) has found the same anomalous dispersion of the axes in a beryllium bearing mineral (chrysoberylle).

I conclude, that in the „chondrodite“ with the anomalous optical properties we have perhaps a link of an isomorphic series, which has chondrodite as the one extreme member, and titanhydroclinohumite¹ (with beryllium) as the other.

3. Scapolite.

I. Occurrence.

Scapolite generally occurs in the limestone as small prismatic crystals (2—3 mm. long) arranged as strings of pearls, with corroded borders and corners.

It is also very common in the contact-zone. It is the prevailing component in certain rocks, that may contain for instance $\frac{1}{4}$ quartz and $\frac{3}{4}$ scapolite. These rocks are white, sugar-grained (2—5 mm.) and show pavement structure. Sometimes rocks having the same colour and structure contain only scapolite.

In rocks, scapolite often resembles quartz so much, that one can not macroscopically distinguish the one from the other.

In the borders of the limestone, there is frequently observed a small rim containing scapolite and garnet intimately interwoven.

Scapolite occurs as a component in nearly all the skarn-rocks of the Christiansand district.

Scapolitebearing veins cutting the limestone are common. The scapolitecrystals here often have a size of 5 to 10 cm.

¹ This name is proposed by ZAMBONINI instead of titanolivine.

II. Physical properties.

Scapolite from Christiansand has not been described before¹. Specimens of scapolite from various localities were therefore collected, and examined with regard to the optical properties and specific gravity. They were all found to be identical.

The refraction was determined by the immersion method in day light:

$$\begin{aligned} \omega &= 1,582 \\ \varepsilon &= 1,545 \\ \hline \omega - \varepsilon &= 0,037, \quad \frac{\omega + \varepsilon}{2} = 1,564 \end{aligned}$$

The scapolite is uniaxial, optically negative. The specific gravity was determined by CLERICI'S liquid and the west-phalian scale:

$$\text{Sp. g} = 2,6902$$

III. Chemical composition.

The material for the analysis, and the determination of refractive indices was taken from some relatively big crystals, occurring in the limestone together with pyroxene and pyrite. The scapolite was picked and carved out of the calcite. The ground mineral was tested for purity under the microscope.

The CO₂-determination was made with a small admixture of HF, as the scapolite is dissolved very slowly in HCl. According to SUNDIUS (19) the result of the analysis is not changed by this procedure. The analysis gave:

| | | mol. numb. | B |
|---------|----------------------------------|------------|----------|
| | % | | |
| | SiO ₂ = | 44,64 | 0,7440 |
| | Al ₂ O ₃ = | 28,20 | 0,2765 |
| | CaO = | 17,42 | 0,3111 |
| | K ₂ O = | 1,31 | } 0,0704 |
| | Na ₂ O = | 3,50 | |
| Loss of | ign. { CO ₂ = | 3,54 | } 0,1634 |
| | | | |
| | Cl = | nil | |
| | SO ₃ = | nil | |
| | H ₂ O ÷ 110° = | 0,06 | |
| | | 100,17 | |

¹ See Lacroix: Bull. soc. min. 12, 1889, p. 357.

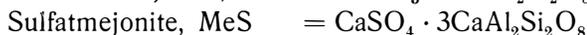
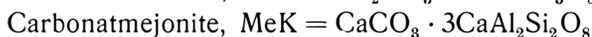
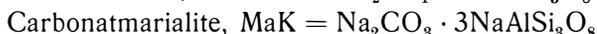
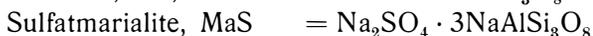
The amount of CO_2 was found to be 3,54 0/0. H_2O was calculated as the difference between the weight of CO_2 and the loss of ignition.

The results of this analysis show several interesting features. The total absence of Cl' and SO_4'' is especially worthy of notice. TSCHERMAK in his publication of 1883 (21) regarded the scapolite as a mixture of the following two extreme members:



Afterwards BORGSTRÖM (2) stated, that CO_2 and SO_8 enter into the constitution of scapolite.

In accordance with his analyses he gives the following 5 components:



Subsequent investigations of SUNDIUS (20), have proved that the following formula is more correct:



SUNDIUS agrees with BORGSTRÖM as far as the other formulae are concerned. Under B (page 100) I have used the formulae of SUNDIUS, and calculated the molecular ratios of a scapolite of 28,57 0/0 MaK, and 71,43 0/0 MeK (or $2/7$ MaK, $5/7$ MeK). As shown above, the scapolite from Christiansand has about that composition.

IV. Relation between the physical properties and chemical composition.

a. Optical properties.

The following diagram shows the relation between the chemical composition, and the refractive indices of scapolite according to SUNDIUS (20), see fig. 1.

It will be observed, that the scapolite from Christiansand does not agree with the diagram. The refraction $\frac{\omega + \varepsilon}{2}$ is too

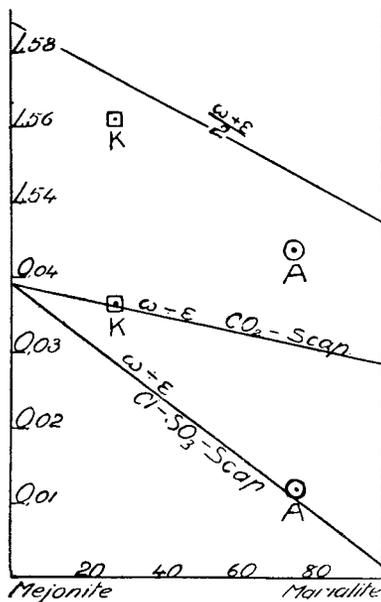


Fig. 1.

K = Scapolite from Christiansand.

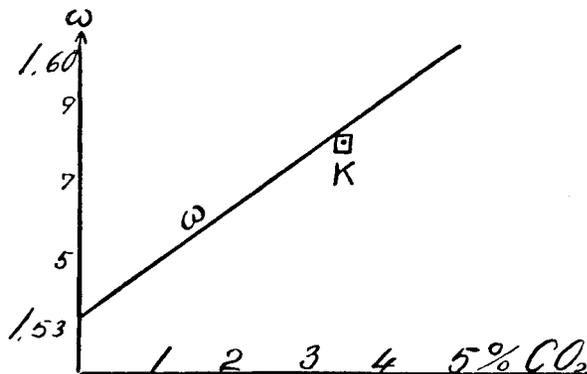
A = Scapolite from Aarvold.

1,2 pct. in excess of the theoretical amount, calculated from the formula of SUNDIUS. At the same time the analysis shows 1,2 pct. CO_2 less than calculated. In attempting to explain these discrepancies between the analysis and the accepted

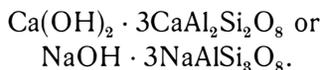
low, compared with the high birefringence. It is generally supposed that the amount of CO_2 fixes the birefringence. This is seen in a diagram of BORGSTRÖM, fig. 2.

The refractive indices of scapolite from Christiansand are plotted against the carbon dioxide in the diagram, and it is seen, that ω is normal. Consequently ϵ is too low.

It must be concluded, therefore, that the scapolite contains constituents which tend to lower the refraction. One of these constituents may be potassium which is present in rather large amounts. It is more important, however, that the amount of water is exceptionally large, about

Fig. 2. ω increases proportional to CO_2 , but ϵ is not affected.

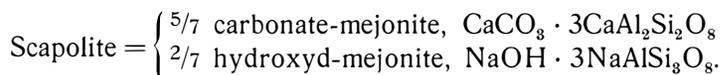
formulae the first natural suggestion is that a part of the water, somehow replaces the carbon dioxide. It might be thought possible, for instance, that the carbon dioxide entered into a hydrated compound $[\text{Ca}(\text{HCO}_3)_2 \cdot 3\text{CaAl}_2\text{Si}_2\text{O}_8]$ also in MeK. Calculation shows, however, that while this formula leads to a larger amount of water, it also demands more carbon dioxide than the formula of Sundius. Thus it is not in agreement with the analysis. The only possible explanation, then, is that water replaces the carbon dioxide directly, forming



This is a hydroxylmejonite, closely related to the oxide mejonite proposed by TSCHERMAK, but rejected by BORGSTRÖM.

If this formula is used together with the corresponding carbon dioxide-formula, about 0,5% water should enter instead of the missing carbon dioxide. This will leave about 0,7% H_2O of the analysis in excess of the amount demanded by the formula.

It is not necessary to accept hydroxyl as a component both in marialite and mejonite. The mejonite component is sufficient for the saturation of the existing carbon dioxide. Disregarding the little excess of water, we get:



b. Specific gravity.

Even in the classical papers of TSCHERMAK (21) it is pointed out, how the specific gravity of the scapolite series increases from marialite to mejonite.

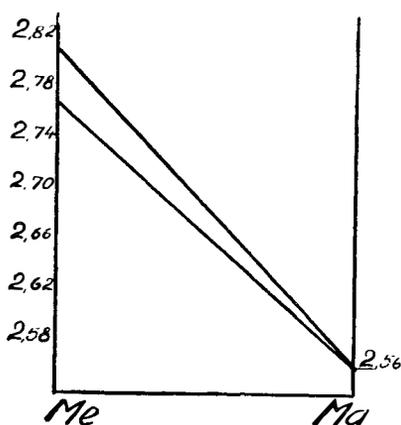


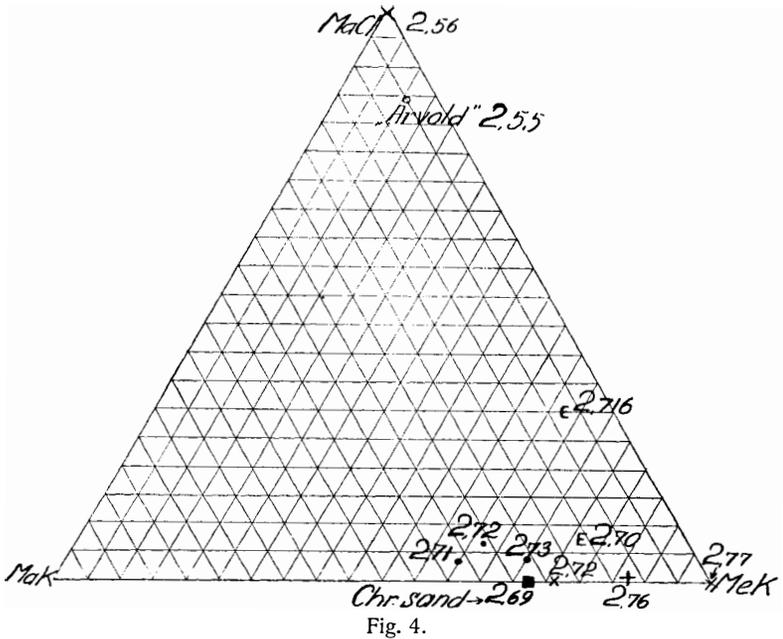
Fig. 3. SUNDIUS' diagram is the upper curve, taken from HIMMELBAUER'S (9) values. The lower curve is plotted from the figures of BORGSTRÖM.

SUNDIUS (18) also mentions this, and gives the following diagram (fig. 3).

BECKE (1) has also determined the specific gravity of the extreme members of the scapolite series.

He states: Sp. g. of mejonite = 2,737

Sp. g. of marialite = 2,566



| | | |
|--------|-------------------|-----------------------|
| × | Data according to | BORGSTÖM (2). |
| E | " | — " V. ECKERMANN (4). |
| + | " | — " LAITAKARI (11). |
| ● | " | — " SUNDIUS (20). |
| Årvold | " | — " GOLDSCHMIDT (6). |

It is seen, that the figures arrived at by the different writers vary considerably. This is due to the fact, that all the calculations are based on the old formulae of TSCHERMAK which recognize only one variety of marialite, and one of mejonite, no distinction being made between the different varieties of molecules now known to enter into scapolite.

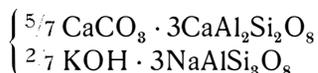
Scapolite is now supposed to contain five components, two of which are sulfate bearing. A scapolite containing no sulfate, therefore generally consists of three components only, and its properties may be easily plotted in a ternary diagram.

Among the varieties of scapolite of which recent analyses and determinations of specific gravities are available, I have selected those which contain no sulfate. In the diagram, fig. 4, eight analyses of this kind are plotted with their corresponding specific gravities.

The great irregularity of the specific gravity is to be noticed. It will be observed, however, that the specific gravity has a maximum at MeK, and decreases towards the other two components. The scapolite from Christiansand, which is included in the diagram shows quite anomalous properties; it is too light for the formula ascribed to it, which would place it among heavier scapolites only. This is explained by its large contents of water.

It is of interest to notice, that the scapolite from Aarvold, which is described by V. M. GOLDSCHMIDT (6) shows the same anomalies, namely: 1. The indices of refraction are not high enough, compared with the birefringence. (see fig.1 page 102, where its approximate position is plotted) 2. The specific gravity is too low (see last diagr.). 3. It contains potassium and much water.

V. M. GOLDSCHMIDT also mentions, that the low refraction is well explained by the acceptance of a potassium and hydroxyl bearing component. It is worth being noticed, that in both these scapolites (from Aarvold and from Christiansand) the large amount of potassium is accompanied by a large water-contents. The cause of this may be that a component $KOH \cdot 3NaAlSi_3O_8$, containing both potassium and water is able to enter into the constitution of scapolite. Calculated with this components, the scapolite from Christiansand has the following composition:



This agrees well with the result of the analysis:

| Calculated | Found |
|--|-------------------------|
| SiO ₂ = 45,91 0/0 | 44,04 0/0 |
| Al ₂ O ₃ = 27,63 „ | 28,80 „ |
| CaO = 17,33 „ | 17,42 „ |
| K ₂ O = 1,58 „ | 1,31 „ |
| Na ₂ O = 3,14 „ | 3,50 „ |
| CO ₂ = 3,36 „ | 3,54 „ |
| H ₂ O = 1,05 „ | 1,50 „ |
| 100,00 0/0 | 100,17 0/0 ¹ |

V. The Origin of Scapolite.

The scapolite contains only the elements which occur in the limestone and the granite. It has, consequently, not originated as a pneumatolytic mineral, but is to be regarded as a simple reaction product between limestone and the adjacent granite.

When scapolite occurs in the skarn-rocks, it has often irregular crystal outlines and symplectitic intergrowths. Some of these phenomena will be described in the following.

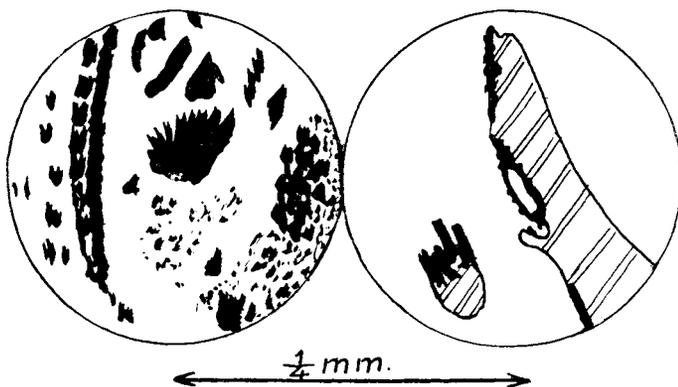


Fig. 5.

Scapolite (solid black) originated in a matrix of plagioclase (white); and on the contact between calcite (lined) and plagioclase.

¹ With 0,06% H₂O ÷ 110°.

From fig. 5 and 6 is observed that scapolite originates within plagioclase, and on the contact between calcite and plagioclase, which shows that scapolite has originated through a reaction between calcite and plagioclase.

It is further of some interest to note, that quartz so frequently occurs as small drops, within the scapolite grains.

The composition of the plagioclase is about 30% An, i. e. about $\frac{1}{3}$ An, $\frac{2}{3}$ Ab. We thus have the following equations of the origination of scapolite:

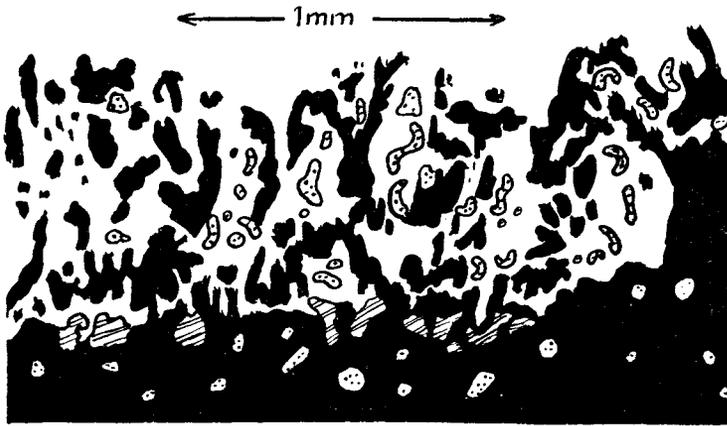
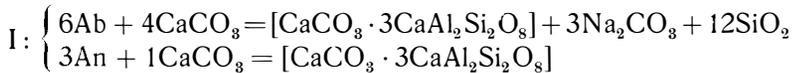
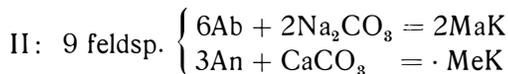


Fig. 6.

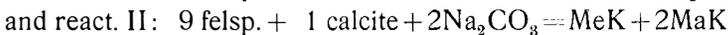
The contact between scapolite and plagioclase. Scapolite = solid black.
Plagioclase = white. Calcite = lined. Quartz = dotted.



Some of the Na_2CO_3 will enter into a marialite-molecule:



If reaction I is doubled, we have:



If the originated Na_2CO_3 reacts with SiO_2 and escapes as water-glass and carbondioxide, we obtain as rest:



Or translated to words:

During the metamorphism the plagioclase of the granite (partly originated by replacment of microcline) was dissolved by aqueous, calciumcarbonate bearing solutions, with scapolite at the same time crystallizing out.

In reality the scapolite also contains water; but this only means, that the water has taken part in the reaction, in the same way as the carbon dioxide.

This reaction gives an explanation of the myrmecite-like structures which occur. When myrmecite-like structures occur in a matrix of scapolite, the quartz will have drope-like forms. The wellknown vermicular myrmecitegrains, on the contrary, occur in a matrix of plagioclase (see e. g. fig. 6, where myrmecite quartz occurs both in scapolite and plagioclase). In the whole of the thin section from which this illustration (fig.6) is taken, no microcline occurs, and there is nothing to show, that there has ever been potassium-feldspar present. The myrmecite, consequently, has not originated through a replacement of potassium-feldspar. It seems evident, however, that it has originated through the reaction between calcite and plagioclase, simultaneously with scapolite.

SEDERHOLM (17) has also observed symplectites of scapolite and quartz in crystalline limestone.

VI. „Hydroxyl scapolite“.

It looks as if little by little the opinion has arisen, that a hydroxyl component enters into the constitution of scapolite.

The former theory was, that no hydroxyl bearing constituent existed. BORGSTRÖM was of this opinion in 1914. SUNDIUS later maintained, that a little hydroxyl was able to enter into the scapolite. He proposed the following formula:



As far as the scapolites from Aarvold (described by V. M. GOLDSCHMIDT) (6), and from Christiansand, are concerned, the formula of SUNDIUS do not suffice. The large amount of hydroxyl is not in correspondence with this formula.

The theory suggested on pag. 105—106, postulates the existence of an idiomorphic series, derived from the normal scapolites by increasing water-contents. An important problem, then, is to find out to what extent this hydroxyl bearing constituent may enter into the scapolite.

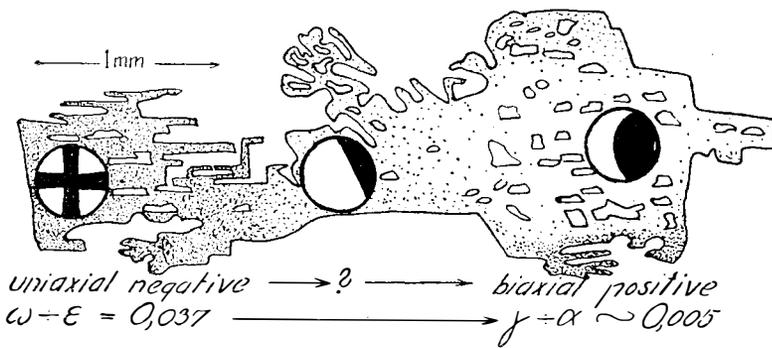


Fig. 7.

Mineral with varying birefringence light parts indicate low birefringence and shaded parts high birefringence.

The analysed scapolite from Christiansand does not represent the extreme member; for the scapolite from Aarvold contains a larger amount of water.

On examining the thin sections, I further observed a mineral which resembles scapolite, but has a lower birefringence. It always occurs either in contact with normal scapolite or with zoisite forming small grains and symplectites in these.

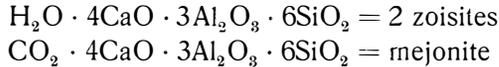
The birefringence is varying, and when it is very low the mineral is anomalous biaxial (fig. 7).

This is explained by assuming that the mineral has started to crystallise as a CO_2 scapolite, but during the growth little by little has been transformed to a hydroxyl scapolite, thereby obtaining different optical properties.

This mineral occurs frequently in contact with zoisite and penetrates it. Normal scapolite and zoisite also frequently occur in contact with each other.

In the description of the alteration of plagioclase it will be brought out, that scapolite and zoisite have originated in quite the same way.

Zoisite and scapolite are crystallographically very different, but chemically closely related :



In scapolite from Christiansand water directly replaces the carbon-dioxide; and it is seen from the preceding formulae, that if hydroxyl enters into the mejonite component, we may get zoisite i. e.: An eventual hydroxyd mejonite is nothing but zoisite.

It is perhaps more reasonable to suppose that hydroxyl enters into the marialite component. In this case, we get no series from scapolite to zoisite, but a basic hydroxyl scapolite, is chemically very much related to zoisite.

It might be tempting to say, that a part of such a scapolite-molecule was isomeric with zoisite.

As an other example of the close relationship between scapolite and zoisite, it may be mentioned that H. v. ECKERMANN (5) has described a transformation of clinozoisite to carbonate mejonite in the contact between limestone and granite.

It is mentioned before that scapolite has originated as a contact mineral without addition of foreign substance. SUNDIUS (20) discusses the origin of these contact and regional metamorphic CO_2 scapolites, and his opinion is, that they are formed at relatively high temperatures and pressures. But he adds, that if scapolite occurs with albite, and the calcium contents of the rock for the greatest part occur in scapolite, we approach the upper zone of GRUBENMANN (7).

The metamorphism at Christiansand has taken place at relatively low temperatures and pressures. The formation of the hydroxylscapolite therefore belongs to the a upper zone of

GRUBENMANN. (This was also a priori to be expected, cfr. e. g. the low specific gravity.)

Furthermore scapolite occurs in contact with and symplectitically intergrown with chlorite.

This is, as far as I know, the first time the paragenesis scapolite and chlorite is observed.

Feldspars.

The feldspar in the typical granite is a completely unaltered microcline. The plagioclase is very rare, but occurs as myr-

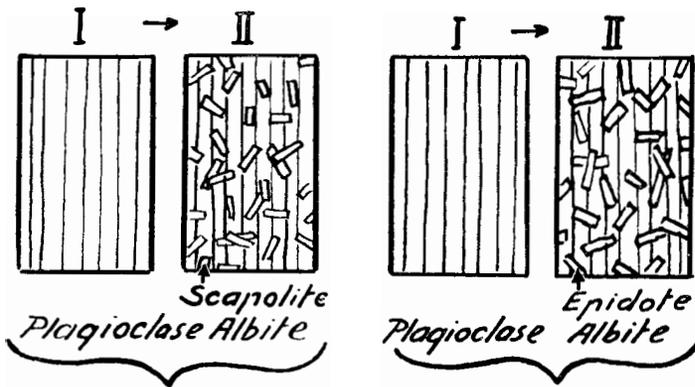


Fig. 8.

Schematic picture of scapolitizing and saussurization.

mecite or small grains with a composition of about 20% An. (The extinction angle \perp MP $\sim 0^\circ$). The plagioclase is often zoisitized. Towards the limestone contact, however, a relative enrichment of plagioclase takes place. The microcline is replaced, and „schackbrett” albite occurs. An absorption of CaO takes place, and the plagioclase is transformed to a more basic feldspar, reaching a composition of about 30% An. As a rule, it is homogenous, but not unfrequently a zonal structure is found. In fig. 6, page 107 the whole of the plagioclase which is filled with scapolite and quartz, is more acid than the rest.

This zonal structure depends upon the reaction between plagioclase and calcite with formation of scapolite and myrmecite (according to the equations suggested on page 107). This illustration might be multiplied. The feldspar is always

more acid near the contact against scapolite, because the calcite has reacted especially with the anorthite component.

Where the plagioclase is intensively scapolitized, albite has been formed.

The chemical analogy between zoisite and scapolite should be born in mind. The scapolitizing is to be regarded as a process analogueous to the well-known reaction, according to which, the plagioclase in the upper zone of the crystalline shists

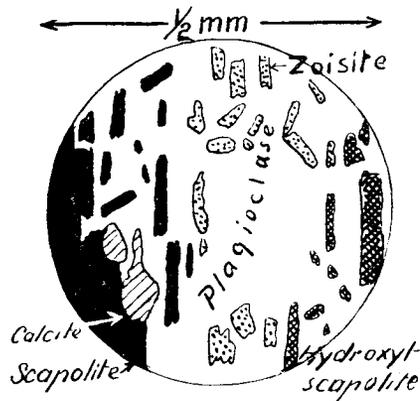


Fig. 9.
Zoisitized and scapolitized plagioclase.

is transformed to albite and zoisite by means of circulating aqueous solutions. In the same manner the plagioclase round the limestone is transformed to albite and zoisite by means of carbonatiferous solutions, see fig. 8 and 9.

Phlogopite.

Phlogopite is found in the limestone, near the contact against the granite. The mineral is interesting because of the low indices of refraction. These were determined by the immersion method.

| | |
|--------------------------------------|----------------------|
| I. | II. |
| $\alpha = 1,539$ colourless | $1,562$ brun pâle |
| $\beta = 1,561$ } yellowish brown | $1,606$ } brun foncé |
| $\gamma = 1,562$ } | $1,606$ } |
| <hr style="width: 50%; margin: 0;"/> | |
| $\gamma - \alpha = 0,023$ | |
| optically negative. | |

II are the data of MICHEL LEVY and LACROIX (13).

In ESPER LARSENS: "Tables for Determination of Minerals" (12) no mineral of the mica-group with such low indices of refraction is quoted. According to these tables the mica-mineral with the lowest refractive indices is the following biotite.

$$\begin{array}{r} \alpha = 1,541 \\ \beta = 1,574 \\ \gamma = 1,574 \\ \hline \gamma - \alpha = 0,033 \end{array}$$

No analysis has been made of the phlogopite, nor an exact determination of the axial angle. But when the mineral is examined through a microscope with great aperture, it is apparently uniaxial. When using a small aperture, the greatest observed axial angle was about $2E = 20^\circ$, consequently $2V \sim 13^\circ$. $c : \gamma \sim 0^\circ - 2^\circ$.

While this paper was in print, a work discussing the mica groups has been published by W. KUNITZ: Die Beziehungen etc. innerhalb der Glimmergruppe (Neues Jahrb. für Min. etc., Beilag. Bd. L, 1924). According to his data the phlogopite from Christiansand with the extrem low indices of refraction represents a normal phlogopite with approximately 6 Mol % F.

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