SVERIGES GEOLOGISKA UNDERSÖKNING

SER. C. Avhandlingar och uppsatser. N:o 343.

ÅRSBOK 20 (1926) N:o 4.

SOME MINERAL ASSOCIATIONS FROM THE NORBERG DISTRICT

BY

PER GEIJER

WITH ANALYSES BY ARTUR BYGDÉN

Pris 1 kr.

STOCKHOLM 1927
KUNGL. BOKTRYCKERIET. P. A. NORSTEDT & SÖNER
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CONTENTS.

Page

Introduction 3

Geological environment 4

Östanmossa 4

- General character of the deposit 4
- Orthite, and magnesium orthite 5
- Cerite 14
- Norbergite 16
- Unidentified minerals 17

Malmkärra 17

Geological aspect of the cerium associations 18

Tallgruvan 21

- General features 21
- Magnetite and spinel 22
- Ludwigite 22
- Fluoborite 26
- Other primary minerals 29
- Alteration products 29
- Paragenesis of the boron minerals 30

The rôle of $Mg(F, OH)_2$ 31

Introduction.

During work in the Norberg iron-mining district in Central Sweden, which has formed a preparatory stage for a planned comprehensive geological study of the district as a whole, certain peculiar mineral associations were encountered, immediately connected with the ore deposits and interesting both from a mineralogical and a geological point of view. As the geological survey of the district cannot be completed for considerable time, it has been deemed convenient to study and describe these mineral associations separately. A preliminary account of two new minerals, norbergite and fluoborite, has already been given.[1]

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[1] Per Geijer: Norbergite and Fluoborite, two new minerals from the Norberg mining district. Geol. Fören. Förh., Vol. 48, 1926, p. 84—85.

The necessary chemical analyses have been carried out by the chemist of the Survey, Dr. A. Bygdén. As will be seen from the following, the peculiar chemical character of several among the minerals made the analytical work unusually difficult, and, furthermore, the quantities at hand were sometimes exceedingly limited. Thanks to Dr. Bygdén's analytical skill, however, these difficulties were overcome.

Geological environment.

The general geology of the Norberg district is shown on the maps by Walfr. Petersson.[1] The main geological units are the same as in the majority of the ore-bearing areas in the Archean of Central Sweden: a band of leptite formation, which contains the ore deposits, is bounded on both sides by granites that are distinctly younger, but still belong to the older Archean. Besides quartz-banded ores, there are also replacement deposits in limestone and dolomite, partly accompanied by a silicate gangue (skarn) in large quantities. In their relations to the carbonate rock, and in their mineral composition, these skarn ore deposits, the iron ore mineral of which is invariably magnetite, are entirely similar to contact deposits. Those that will be considered here belong to this group. One of them is Östanmossa, a rather small mine in the very centre of the district. Besides containing, as a rarity, the new mineral norbergite, this ore deposit is remarkable by the occurrence in some quantity of a peculiar variety of orthite, and also of a little cerite. The association of cerium minerals recalls that of Bastnäs, at Riddarhyttan, but there are some important differences. Further, a similar occurrence was found at the Malmkärra mine, on the southern outskirts of the Norberg district, 5 km SW of Östanmossa. The third mine to be described here is called Tallgruvan (Pine Mine). It lies close to the railway line, between the stations Kallmora and Stripåsen, in the northeasternmost part of the district.[2] Tallgruvan shows a pronouncedly magnesian skarn association, and locally contains considerable quantities of the borate ludwigite, together with the new mineral fluoborite.

Östanmossa.

General character of the deposit.

The carbonate rock of Östanmossa is mainly dolomitic, with only subordinate portions of a purer limestone marble. The carbonate body is largely replaced by an association of magnetite and skarn silicates. The magnetite forms lumps and streaks of varying size within the skarn body, and in some places alternates stripe-wise with the silicates. The masses of almost pure magnetite are finely crystalline. The skarn generally consists of a fine felt of amphibole,

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[1] Geologisk Atlas öfver Norbergs Bergslag (Sveriges Geol. Undersökn., Ser. Bb, n:o 9). See also guide book no. 29, 11th internat. geol. congress, Stockholm 1910.

[2] Malmkärra and Tallgruvan fall a little outside the map that accompanies Petersson's guide book, but are shown on Pl. 1 in the Atlas quoted above.

ranging in colour from an almost colourless or very light green tremolite to a fairly deep-green actinolite, also the latter, however, being colourless in ordinary thin sections. Microscopic examination sometimes reveals numerous frayed fragments of a diopsidic pyroxene enclosed in the amphibole felt. Brown garnet of an andraditic aspect forms a considerable portion of the skarn in certain places but is, on the whole, much less important than the green silicates. Chondrodite, clinohumite,[1] and their serpentine alteration products are common, generally forming so-called ophi-calcite: scattered grains of chondrodite have developed in the dolomite and used up its magnesia, leaving the matrix a more or less pure calcite. Sulphide minerals are mainly represented by chalcopyrite and pyrite, generally rare, but locally more conspicuous. Molybdenite has also been noted in several places. One specimen in the museum of the Norberg mining administration shows bismuthinite associated with chalcopyrite. Together with pyrite, a little fluorite has been noted.

As to the relations of these minerals, the following features may be noted. The inclusions of diopside in the amphibole felt indicates that there has occurred, as in many other skarn deposits, a replacement of an earlier formed diopside by amphibole. There are some indications of actinolite replacement also in the garnet. There seems no reason to doubt that the magnetite and the skarn were essentially contemporaneous, but it is probable that the former antedated the development of the amphibole. This is inferred from the fact that the magnetite aggregates enclosed in tremolite show no relations to the cleavage planes of the amphibole, while the sulphides, both here and in a number of other deposits, are often seen to lie along the cleavage cracks. As to the chondrodite, its relations to the magnetite are partly analogous to those of the tremolite just mentioned, but less can be concluded from them. In other cases, when magnetite and chondrodite occur together as intersecting streaks in the dolomite, a contemporaneous deposition is indicated. Chondrodite is not often seen in the compact skarn masses. In one case it was observed to form a narrow veinlet, cutting a light green tremolite skarn. In another it encloses stalks of tremolite, an intergrowth that can be interpreted both ways.

The mineral association as now described is entirely normal for a Swedish skarn iron ore deposit, apart from the bismuthinite, perhaps. Besides those already mentioned, the following minerals have been noted, and will be described more in detail: cerite, orthite, magnesium orthite (a new variety of orthite), norbergite, and two unidentified, probably new minerals.

Orthite, and magnesium orthite.

Thin sections of ordinary skarn and ore from Östanmossa show scattered small grains of a perfectly unaltered, rather strongly pleochroic orthite. But

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[1] Measurable crystals have not been found. From the optical orientation, one specimen has been identified as clinohumite, but it is probable that chondrodite also occurs. In accordance with an inappropriate, but rather firmly rooted usage, the name chondrodite will here be used for both the monoclinic members of the humite group, when no further identification has been possible.

only rarely does this mineral occur in larger grains, visible to the naked eye. Most such cases are represented by lenses of coarsely crystalline calcite, that appear here and there in the tremolite skarn, as in many skarn deposits. In these lenses, the orthite occurs as thickly tabular crystals, generally 4 to 10 mm long. The crystals are extremely brittle, and it was not found possible to isolate them. Similar grains of orthite are also sometimes observed in the tremolite skarn, particularly near calcite segregations of the type mentioned. In both these types of occurrence, chondrodite has been observed together with the orthite.

Another occurrence of megascopically visible orthite is of a different type. It is a case of magnetite ore very rich in orthite, which encloses grains of cerite. There are large patches of green actinolite skarn in this ore.

The orthite is black, and brittle, with an irregular fracture, not the conchoidal fracture of the more or less altered pegmatite orthites. In these respects, it is similar to the orthite from Bastnäs.[1]

The orthite is always unaltered and vividly pleochroic. The colours are essentially the same as in the orthite from Bastnäs,[2] but not quite so strong, being, in a thin section of ordinary thickness: α light yellowish green; β reddish brown; γ reddish brown with a purplish tinge, or blood red; absorption $\gamma = \beta > \alpha$.

As to the refractive indices, I have only, by the immersion method, determined

$$\gamma, \beta > 1{,}78 > \alpha > 1{,}76 .$$

This shows a lower range of the refractive indices than in the Bastnäs mineral, where even α surpasses 1.78.[3]. No doubt this is due to the lower iron content in the orthite from Östanmossa (compare analysis in the following). The birefringence is high, but could not be determined with certainty, nor could a section be found that gave a satisfactory figure for the extinction angle. The optical character is positive, and the axial angle is large. In the rare case when the orthite is predominant in the ore, it is generally developed as radiating aggregates, sometimes with twinning.

An analysis of the orthite has been made by Dr. Bygdén. The results will be discussed in the following.

Orthite, Östanmossa.

	a	b	c	d	Average
SiO_2	31.85	—	—	—	31.85
Al_2O_3	10.06	10.12	—	—	10.09
Fe_2O_3	5.84	5.82	—	—	5.83
Ce_2O_3	(11.66)	11.66	—	—	11.66
$(La,Nd,Pr)_2O_3$ etc.	15.56	15.44	—	—	15.50

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[1] Per Geijer: The cerium minerals of Bastnäs at Riddarhyttan. Sveriges Geol. Undersökn., ser. C, n:o 304.

[2] Nils Zenzén: Determinations of the power of refraction of a number of allanites. Bull. Geol. Inst. Upsala, Vol. XV, 1916, p. 61. See also Per Geijer, op. cit.

[3] Zenzén, op. cit.

	a	b	c	d	Average
FeO	—	—	5·34	—	5·34
MnO	0.27	0.27	—	—	0.27
MgO	7·55	7·29	—	—	7·42
CaO	9·59	9·54	—	—	9·57
TiO_2	0.02	0.02	—	—	0.02
F	0.87	—	—	—	0.87
H_2O	—	—	—	1·79	1·79
					100.21
Spec. gravity 4.00				— O for F_2	0.37
					99·84

Air-dried sample lost 0.07 per cent in the H_2SO_4 exsiccator, and 0.01 per cent more at 105°. The analysis in calculated on substance dried at 105°.

a: 0.7154 g substance decomposed with $KNaCO_3$. Determination of fluorine after Berzelius.
b: 0.6524 g » » » HF + H_2SO_4.
c: 0.3120 g » » » »
d: 0.4646 g substance, heated in an electrical furnace (quartz tube) to c:a 1200°, with an absorption mass of $PbCrO_4$ and PbO heated to c:a 350°.

The mineral for which the provisional name magnesium orthite is here proposed, occurs at Östanmossa in greater quantities than the orthite, but with a more restricted distribution. It forms fine-grained aggregates that megascopically have a brown colour, rather similar to that of andradite garnet skarn, but without its luster. In the mine, I have encountered the magnesium orthite mainly in a drift on the 47 m level. This drift follows the contact of a body of magnetite and amphibole, outside of which is dolomitic limestone, with stripes and patches of a very light green tremolite skarn and the magnesium orthite, also some magnetite. The aggregates of the Mg-orthite — as the name may conveniently be written — are largely associated with the tremolite, in a way clearly showing that these two minerals together replace the carbonate rock (fig. 1). Besides there are streaks and lumps of Mg-orthite in the latter, without any noticeable accompanient of tremolite, just as tremolite may appear in aggregates free from Mg-orthite. The drift shows this association for a strike length of 20 m. On the dumps there is a considerable amount of material similar to that exposed in the drift, and probably deriving from there. The only other locality so far where I have observed this mineral *in situ* is in the southern end of the mine on the 24 m level, where small aggregates — mostly not over a few mm in length — are common in an almost white tremolite skarn with some stripes of rich magnetite ore.

Some thin sections of the Mg-orthite show the mineral developed as irregularly rounded grains, without idiomorphic outlines and generally without twinning. Most often, however, it forms radiating aggregates of thin laths that are simple twins (fig. 2), thus recalling a type that is often met with in orthite. In some specimens, the laths are so slender that they cannot be clearly discerned even with high magnifications, and the aggregate can be called a fibrous felt.

The colour of the Mg-orthite in ordinary thin sections is very light brown, with a pinkish tinge, and the pleochroism is weak. In thicker sections, however, the colours are practically the same that the ordinary orthite shows in a section of normal thickness, as described above. The optical character is positive.

A. Hj. Olsson photo.

Fig. 1. Specimen from Östanmossa, $^2/_3$ nat. size, showing dolomite (whitish, D), partly replaced by tremolite skarn (light gray, T) and magnesium orthite (dark gray, M).

Determination of the refractive indices, by the immersion method, gave, for the material used for the analysis:

$$\alpha = 1.715; \ \beta = 1.718; \ \gamma = 1.733;$$

The birefringence $\gamma - \alpha = 0.018$ was also determined directly. Abnormal bluish interference colours occur.

As some specimens megascopically show a slightly darker colour than the one that was chosen for analysis, it seemed possible that they represented intermediate stages between the ordinary orthite and the Mg-orthite. It turned out, however, that these specimens, too, had $\gamma < 1.740$. The slight difference in colour, then, must be due to other circumstances, and probably to the size of grain.

A. Hj. Olsson photo.

Fig. 2. Magnesium orthite, Östanmossa, microphoto., × 36, crossed nicols. Shows the radiating groups of twinned crystals.

The chemical composition of the Mg-orthite is shown in the analysis by Dr. Bygdén (next page).

Before discussing the chemical properties of the two minerals, it is necessary to consider the question whether the Mg-orthite really can be regarded as so closely related to the orthite and the epidote group in general as to justify the name that is here used for it. No crystallographic data are available that could prove an isomorphism with the epidote group, and the chemical formula shows very great deviations from the one that has been found for this group.

Magnesium orthite, Östanmossa.

	a	b	c	d	Average
SiO_2	31.39	—	—	—	31.39
Al_2O_3	8.09	8.00	—	—	8.05
Fe_2O_3	1.16	1.08	—	—	1.12
Ce_2O_3	(12.10)	12.10	—	—	12.10
$(La,Nd,Pr)_2O_3$ etc.	17.06	16.93	—	—	17.00
FeO	—	—	2.29	—	2.29
MnO	0.53	0.47	—	—	0.50
MgO	—	14.15	—	—	14.15
CaO	9.37	9.34	—	—	9.36
TiO_2	0.004	0.006	—	—	0.005
F	3.31	—	—	—	3.31
H_2O	—	—	—	2.02	2.02
					101.295
				— O for F_2	1.39
					99.905

Spec. gravity 3.90

Air-dried sample lost 0.07 per cent in the H_2SO_4 exsiccator, and 0.03 per cent more at 105°. The analysis is calculated on material dried at 105°.

a: 0.8502 g
b: 0.7053 g
c: 0.4553 g
d: 0.4726 g
The same methods were employed as in analysing the orthite.

No Y_2O_3, Sc_2O_3 or ThO_2 could be detected chemically.

The reasons that cause me to regard the mineral in question as a variety of orthite rather than as an entirely new mineral species are, besides the natural reluctance to establish a new species where its independence from known forms is questionable, the following facts. In its twinning growths and textural development, the mineral resembles orthite. The colours are the same as in the associated orthite, only that the intensity is weaker. All the deviations from the epidote formula appear already in the Östanmossa orthite. The Mg-orthite only represents a further step in the same direction.

I think, therefore, that the name magnesium orthite or, for the sake of brevity, Mg-orthite, ought to be used provisionally for this mineral. It is as yet impossible to decide, how fundamental for the mineral may be its content of fluorine. The name is therefore chosen to emphasize only the remarkable preponderance of magnesia in the RO group.

When it comes to comparing the above two analyses with other analyses of orthites, we face the difficulty to decide, which other analyses can be regarded as representative for fresh and unaltered orthite. Almost all the numerous orthite analyses published represent pegmatite minerals. These are generally somewhat altered. Zenzén's studies on the refraction of orthites from a number of localities[1] support the wide-spread belief that there is a progressive hydra-

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[1] Zenzén, op. cit.

tion, and that the water content above that required by the epidote formula is due to this hydration. It is possible that the process is accompanied also by other changes in the composition of the orthite. I think, therefore, that all orthites that show lower specific gravity and indices of refraction than the highest values found by Zenzén are strongly suspected of being altered, if the lower values cannot be explained by a lower content of iron oxides or other components with a high molecular refraction. To compare with the Östanmossa minerals, then, I take as the type of a normal and fresh orthite the mineral from Bastnäs, which among those studied by Zenzén shows the highest refraction and gravity, and at the same time has the chemical characters that are regarded as typical of orthite, corresponding fairly closely to the empirical formula $H_2O \cdot 4\,(Ca, Fe)\,O \cdot 3\,(Ce, Al, Fe)_2\,O_3 \cdot 6\,SiO_2$, the ratios being: 0.98 : 4.34 : 2.63 : 6.00. The analysis employed is Cleve's no. I from Bastnäs[1] with the figure for H_2O changed from 0.33 % to 1.52,[2] and fluorine according to Bygdén (compare below).

	Orthite, Östanmossa		Mg-orthite, Östanmossa		Orthite, Bastnäs	
	%	mol. prop.	%	mol. prop.	%	mol. prop.
SiO_2	31.85	0.5303	31.39	0.5226	30.99	0.5155
Al_2O_3	10.09	0.0989	8.05	0.0789	9.10	0.0892
Fe_2O_3	5.83	0.0365	1.12	0.0070	8.71	0.0544
Ce_2O_3	11.66	0.0821[3]	12.10	0.0879[3]	11.35	0.0826[4]
$(La,Nd,Pr)_2O_3$ etc.	15.50		17.00		16.08	
FeO	5.34	0.0742	2.29	0.0319	12.69	0.1762
MnO	0.27	0.0038	0.50	0.0070	traces	—
MgO	7.42	0.1840	14.15	0.3509	1.36	0.0340
CaO	9.57	0.1708	9.36	0.1669	9.08	0.1621
TiO_2	0.02	—	0.005	—	—	—
F	0.87	0.0458	3.31	0.1742	0.03	—
H_2O	1.79	0.0994	2.02	0.1121	1.52	0.0844
	100.21		101.295		100.91	
— O for F_2	0.37		1.39			
	99.84		99.905			

Let us first consider the ordinary orthite from Östanmossa. It shows very pronounced deviations from the normal (epidote) proportions between the chief groups. Further, iron is remarkably low, both in the ferric and the ferrous stage. In the latter, it is replaced by magnesia, which, if the molecular proportions are considered, forms the predominant member of the RO group. This relation has never been found in any other epidote mineral that has been

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[1] Öfv. K. Vetensk. Akad. Förh., 1862, p. 425 (Stockholm 1863).

[2] Per Geijer: The cerium minerals of Bastnäs, p. 14.

[3] The molecular weight was taken as 331, because of the high proportions of Nd.

[4] The molecular weight used is 332, the one employed by Mauzelius for the törnebohmite from Bastnäs.

analysed quantitatively, although Damour and Des Cloizeaux have described as »picro-epidote» a mineral from the region of the Baikal Lake, which is said to have shown only silica, alumina, and magnesia in the qualitative analysis, and therefore is interpreted as a magnesia epidote.[1] In the R_2O_3 group, on the other hand, the decrease in the iron has not been counterbalanced by an increase in the other oxides (Al_2O_3 and the ceria oxides). Thus the abnormal $RO : R_2O_3$ ratio, about 4 : 2 instead of 4 : 3, seems to depend largely upon the low content of iron. Also, the ratio $RO : SiO_2$ is too high. Finally, the content of fluorine is considerably higher than previously recorded in any mineral of the epidote group, the previous maximum seeming to be 0.35 %.[2]

Turning then to the Mg-orthite, we encounter all the same kinds of deviations from the accepted formula, only much stronger. The fluorine rises up to 3.31 % by weight, and must be accounted for in the formula. Apparently, it increases with the magnesia, and, further, it does not replace the water. From the fact that it increases with the magnesia, and from the association with chondrodite and norbergite, both of which contain the group MgF_2, it seems probable that this group appears also in the orthites. When comparing the analyses, MgF_2 is therefore treated as a separate unit, but it must be left an open question whether it occurs in stoechiometrical relations to the silicate, or not. The former seems highly probable in the Mg-orthite, where the relation is exactly 1.00 MgF_2 for 6.00 SiO_2, the latter in the ordinary orthite from Östanmossa.

The suspicion was near at hand that also the Bastnäs orthite contained some fluorine. A sample was therefore analysed by Dr. Bygdén, who proved the presence of fluorine, but only to the amount of 0.03 per cent, which may either belong to the orthite, or derive from a slight admixture of bastnäsite, a mineral that is often found with the orthite of Bastnäs.

It must be pointed out that certain other tendencies exhibited by the Östanmossa minerals can be traced also in the Bastnäs orthite, but on so small a scale that they may fall within the limits of possible analytical errors. Thus the ratio $RO : R_2O_3$ is 4.34 : 2.63 (taking $SiO_2 = 6.00$) instead of 4 : 3.

If, on the other hand, we consider RO ($-$ Mg/F_2) and R_2O_3 together, the deviations from the epidote formula become small, in that we obtain the following relations:

	Orthite, Östanmossa	Mg-orthite, Östanmossa	Orthite, Bastnäs	Epidote
H_2O	1.07	1.29	0.98	1.00
$RO + R_2O_3$	7.10	7.39	6.97	7.00
SiO_2	6.00	6.00	6.00	6.00

The ratios obtained show clearly that although the orthites differ from the epidote group proper in the way that the relation $RO : R_2O_3 = 4 : 3$ is not kept, they still conform to the ratio $H_2O : (RO + R_2O_3) : SiO_2 = 1 : 7 : 6$, if

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[1] Damour et Des Cloizeaux: Sur une épidote à base de magnésie. Bull. Soc. minéral. de France, VI, 1883, p. 23.

[2] U. S. Geol. Survey, Bull. 419, p. 272.

deduction is made for the RO equivalent to the fluorine. The deviation seems only to take place in the direction of increasing RO. It is possible that some OH occurs in the same way as the fluorine. If so, the slight excess of H_2O and RO + R_2O_3 in the Mg-orthite may be explained.

The material at hand gives little foundation for further discussion, but some features may be pointed out, as they seem to shed some light upon the limits of variability in the orthites.

Comparing the three analyses, one observes that CaO is nearly constant, with the molecular ratio of 2. Thus MgO replaces FeO and not CaO. This is in accordance with the isomorphism relations of these oxides in many other minerals. Further, the sum of the molecular ratios of Al_2O_3 and the ceria oxides is almost constant, and also very near 2 (resp. 2.05, 1.91 and 2.00), and the variations within it are limited. Thus, Fe_2O_3 is practically the only one of the R_2O_3 oxides that varies, and this is, like FeO, replaced by MgO, not by an increase in Al_2O_3 or the rare earths. One is tempted to return to old interpretations of the epidote analyses, by regarding all Fe_2O_3 as oxidised FeO, but this is not corroborated by the figures one obtains by recalculating it as FeO and adding it to the RO group, for in this way the sum RO + R_2O_3 becomes 8 instead of 7.

It seems most probable that these almost constant proportions mark the limits of miscibility, and the simple ratios found may be accidental, although this is not necessarily the case.

Summarising this discussion, we find that the following new points in the chemistry of the orthites have been found:

With high magnesia, fluorine is found to enter in considerable quantities. It is impossible to find a common formula for the orthites without first putting apart the fluorine and an equivalent amount of RO.

Having done this, the ratio $H_2O : (RO + R_2O_3) : SiO_2$ is found to be 1 : 7 : 6, but the ratio $RO : R_2O_3 = 4 : 3$, which is postulated by the epidote formula, is not kept. The variations in this ratio are in the way of increasing the proportion of RO, replacing Fe_2O_3, while Al_2O_3 and the ceria oxides are almost constant.

The increase in RO is in the form of MgO. The fact that CaO does not increase may possibly be due to local factors in the concentration CaO : MgO. On the other hand, CaO seems not to be reduced below a molecular ratio of approximately 2.

The group MgF_2 has been found to be present in the Mg-orthite in the simple proportion of one molecule fluoride for one molecule silicate, but seems to occur also in smaller amounts. It has not been possible to determine the crystallographic influence of the addition of this group.

As the orthite minerals of Östanmossa represent a new example of the rare type of paragenesis previously known only from Bastnäs and vicinity, it seemed interesting to obtain a more definite idea of their contents of rare earths than was possible with the chemical analysis. Fil. kand. B. Broomé kindly undertook an X-ray spectroscopic examination of the isolated rare metal oxides, in the laboratory of the Mineralogical Department of the Museum of Natural History, Stockholm.

The examination was carried out on a vacuum spectrograph of Siegbahn's construction, with calcite crystal. The exposures covered the range 2,700—1,700 X. E. The position of the lines on the photographic plate could be determined with a precision of 0.1 mm for good lines, corresponding to 2 X. E. in wave length. For the identification, Siegbahn's tables were used.[1] The observed wave lengths differed from Siegbahn's values with ≤ 2 X. E., with a few exceptions. The intensity was graded subjectively within each sample in the way indicated in the table. The steps between the various grades are not comparable. Where coincidences may occur, the distribution of the observed intensities on the various lines has been made as seemed most probable with regard to the intensities observed for other lines.

The results show a general similarity to those obtained by Goldschmidt and Thomassen[2] on cerite and törnebohmite from Bastnäs. Thus, metals with uneven numbers above 59 (Pr) are absent, apart from dubious lines for 61 (Il) and possibly also 63 (Eu) in the ordinary orthite. A remarkable result is the very distinct difference between the two orthites from Östanmossa, the ordinary and the magnesian form. This is particularly striking in the proportion between Ce and Nd, the former being higher in the ordinary orthite, the latter in the Mg-orthite.[3] Further, both Sm and Gd are decidedly stronger in the Mg-orthite.

Cerite.

Previous to its discovery at Östanmossa, the mineral cerite was known only from two mines at Bastnäs and Storgruvan, both in the Riddarhyttan district, 30 km SW of Norberg.[4] Quite recently, Dr. Alvar Högbom, of the Geol. Survey, found some cerite also in the Högfors mines in the same district.[5] At Östanmossa, cerite is found in some quantity in the association that carries the Mg-orthite, but as a rule only in microscopical grains. It occurs in the carbonate rock, in the interstices between the aggregates of Mg-orthite, and is generally accompanied by some tremolite and the unidentified mineral mentioned below as »Östanmossa A».

As already described, some cerite, associated with orthite in magnetite ore, occurs as megascopically visible grains. Thin sections of this aggregate of cerite and orthite have the same aspect as sections from Bastnäs.

I have also found some specimens showing larger grains of cerite. In one of them, taken in the drift on the 47 m level, cerite to the amount of about 30 g occurs as a few large grains, together with some tremolite, in a vein of coarsely

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[1] Spektroskopie der Röntgenstrahlen, Berlin 1924.

[2] Geochemische Verteilungsgesetze der Elemente III. Röntgenspektrographische Untersuchungen über die Verteilung der seltenen Erdmetalle in Mineralen. Videnskapsselsk. Skrifter, I, 1924, N:o 5. Kristiania 1924.

[3] A similarly high content of Nd was found by Goldschmidt and Thomassen in rare earths isolated from orthite from Hundholmen (op. cit).

[4] Per Geijer, in Riddarhytte malmfält (Beskrivningar över mineralfyndigheter, n:o 1. Stockholm 1923), and op. cit.

[5] Personal communication.

Östanmossa orthites, X-ray spectrography.

A = Ord. orthite; B = Magnesium orthite. Intensity grades:

+	–	—	— —	— — —	— — — —	— — — — —

← weakest strongest →

L series Intensities[1]		α_2 3	α_1 10	β_4 2	β_1 8	β_3 3	β_6 —	β_2 6	γ_1 3	γ_2 1	γ_3 1	γ_4 —	γ_9 —
57 La	A	–	— — —	–	— — —	—		– — —	– —	?			
	B	–	— — —	+	— — —	—		– — —	— —	?[2]			
	Coincidences						Nd Lα_2						
58 Ce	A	—	— — — — —	—	— — — — —	— —	?	— — —	— —	+	—?	+	
	B	+	— — —	+	— – —	–		— —	—[3]				
	Coincidences						Il Lα_1	Sm Lα_2		Pr L γ_1	Il Lβ_2		
59 Pr	A	–	– —		— —	+		—	+				
	B	+	– —		– —			–					
	Coincidences							Eu Lα_1	Ce L γ_2				
60 Nd	A	—	– — — —		– — — —	—		— —	—	–			
	B	—	— — — — —		— — — — —	—		– — —	–	+			
	Coincidences	La Lβ_6							Sm Lβ_2				
61 Il	A		–?										
	B												
	Coincidences		Ce Lβ_6					Ce Lγ_3					
62 Sm	A	–	— —		—			–					
	B	–	— — —		— —			–					
	Coincidences	Ce Lβ_2						Nd Lγ_1					
63 Eu	A		+ ?										
	B		?										
	Coincidences		Pr L β_2										
64 Gd	A		–		–			–					
	B	–	— —[4]		— —			–					
	Coincidences				Ho Lα_1								
65 Tb	A												
	B												
66 Dy	A		+										
	B		–		+								
67 Ho	A		?										
	B		?										
	Coincidences		Gd Lβ_1										
68 Er	A												
	B												
69 Tu	A												
	B												

Limit of exposures

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[1] P. Günther, Tabellen zur Röntgenspektralanalyse. Berlin, 1924.

[2] Ce L γ_1, Gd L α_1

[3] La L γ_2; Gd L α_1

[4] La L γ_2; Ce L γ_1

crystalline calcite that cuts at right angles across the stripes of Mg-orthite in tremolite skarn.

The cerite is identified from its colour, lustre, and degree of hardness, the presence of an irregular cracking instead of cleavage, the high refraction and very low birefringence, the small angle of the optical axes and the positive character; finally, chemical tests showed the presence of a high percentage of cerium. The identity with the original cerite from Bastnäs is thus clearly established.

Norbergite.

Of this mineral, already preliminary described (compare above), only two specimens have been found. One of them shows a couple of irregular grains, each some mm in size. This specimen was taken in situ on the 47 m level, in the area that is rich in Mg-orthite. This mineral and tremolite accompany the norbergite in the dolomite. The other and larger specimen was found on the dumps. There, too, the norbergite is associated with the minerals just mentioned. Apparently, this specimen must come from the same part of the mine, or from an identical association.

The norbergite occurs in massive aggregates. Its colour is pink (with a purplish shade) to whitish, translucent in thin edges. The hardness is $6^{1}/_{2}$, the specific gravity 3.13—3.15. The mineral is optically biaxial, positive, with $2\,E = 82^\circ$ (measured, drawing table method). With the determination of $\beta = 1.567$ this gives $2\,V = 49^\circ 30'$. The refractive indices are $\alpha = 1.563$, $\gamma = 1.590$ (immersion method), $\beta = 1.567$ (from determinations of α and $\beta - \alpha$).

Thin sections of the norbergite show that it is developed as somewhat rounded grains, without any crystal faces. No cleavage has been observed, and no twinning.

An analysis of the norbergite has been made by Dr. Bygdén:

Norbergite, Östanmossa.

	a	b	c	d	Average	Mol. prop
SiO_2	28.54	—	—	—	28.54	0.4757
Al_2O_3	0.09	0.09	—	—	0.09	—
Fe_2O_3	0.69	0.69	—	—	0.69	0.0043
FeO	—	—	0.82	—	0.82	0.0114
MgO	56.39	56.51	—	—	56.45	1.4000
CaO	1.01	1.01	—	—	1.01	0.0180
MnO	0.17	0.18	—	—	0.18	0.0025
F	13.70	—	—	—	13.70	0.7210
H_2O	—	—	—	2.90	2.90	0.1611
CO_2	—	—	—	1.21	1.21	0.0275
					105.59	
— O for F_2					5.77	
					99.82	

Spec. gravity 3.13—3.15

Air-dried sample lost 0.08 per cent in the H_2SO_4 exsiccator, and 0.06 more at 106°. The analysis is calculated on material dried at 106°.

a: 0.5168 g substance decomposed with $KNaCO_3$. Determination of F after Berzelius.
b: 0.5128 g substance decomposed with $HF + H_2SO_4$.
c: 0.5132 g » » » »
d: 0.4033 g » . Long-continued heating in an electrical furnace at c:a 1200°, with absorption mass of $PbCrO_4$, PbO and PbO_2 heated to c:a 350°.

The mineral is soluble in warm HCl, with segregation of silica. No Cl, SO_3, P_2O_5 or TiO_2 was found. There is possibly a trace of boron.

If one detracts Fe_2O_3 and an equivalent amount of FeO for magnetite, and CO_2 with CaO and MgO for dolomite, the remaining ratios are SiO_2: RO : (F, OH) $= 1 : 2.92 : 2.19$, which probably means $1 : 3 : 2$. The formula, then, becomes $2\ MgO\ .\ SiO_2\ .\ Mg\ (F, OH)_2$, in which Mg may to some extent be replaced by other bivalent metals.

This formula places the norbergite in the humite group. The place was already occupied by the prolectite of Hj. Sjögren, but, as shown by the writer,[1] it is highly dubious that the crystals named prolectite really have this composition. The question whether the crystallographic properties of the norbergite also place it in the humite group cannot be determined until measurable crystals have been found, or the structure investigated together with that of the humite group.

Unidentified minerals.

»Östanmossa A». This mineral is known only in microscopical grains, associated with the cerite in the interstices between the aggregates of Mg-orthite. It forms elongated grains with a decided cross parting but no cleavage, and is optically uniaxial, positive. Immersion tests give $\omega < 1.74 < \varepsilon$. The birefringence is very high, $\varepsilon - \omega = 0.075$. Specific gravity > 3.30 (methylene iodide). The mineral is not dissolved by a 36 % hydrochloric acid. Chemical tests show that it is not a phosphate. Unfortunately it seems a hopeless undertaking to try to isolate material for an analysis, especially since the mineral is so closely associated with cerite. It cannot be identified with any known mineral, although it resembles the fluo-carbonates of cerium in several properties. To judge from its light colour, high refraction and specific gravity, and from the associated minerals, it is probably a compound of cerium.

»Östanmossa B», which has been found as a couple of yellowish brown grains in limestone, is also uniaxial, but negative, with $\omega > 1.74 > \varepsilon$, and, like »Östanmossa A», a specific gravity higher than 3.30.

Malmkärra.

The Malmkärra mine works a series of magnetite lenses which occur immediately upon the foot-wall in a steeply pitching syncline of dolomitic limestone The foot-wall rock is a sodic leptite. The magnetite is accompanied by skarn — chiefly tremolite — in rather small quantities. Pyrite and chalcopyrite ap-

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[1] Per Geijer: Notes on the crystals described as »prolectite». Geol. Fören. Förh., 1926, p. 86.

pear locally, and are accompanied by a gray amphibole, presumably a more magnesian variety. Chondrodite[1] is often abundantly developed in the limestone immediately above the ore zone.

So far, the writer has not had the opportunity to pay more than a short visit to this mine. During this brief examination, mainly devoted to a study of the structure of the deposit, cerium minerals were, in several places, found to form a band between the iron ore and the zone of ophicalcite in the limestone. There was seen grayish red cerite in a fine-grained aggregate, with patches and veinlets of blackish orthite, and also an ore formed by a more even mixture of these two minerals, together with scattered stalks of tremolite.

Microscopic examination shows that the cerite is essentially like that of Bastnäs. The orthite does not show any twinning. Its absorption colours are the same as in the orthite minerals from Östanmossa, and the intensity is intermediate between those of the Mg-orthite and the ordinary orthite from that locality. An intermediate position is also indicated by other properties: there are seen abnormal interference colours, as in the Mg-orthite, but the refraction is higher than in this mineral, with $\alpha > 1.770$, thus near to that of the ordinary orthite of Östanmossa. The discovery of this orthite variety makes it still more probable that there is a series of variations from the normal orthite of Bastnäs, through the Östanmossa and Malmkärra orthites, to the Mg-orthite. For lack of chemical data concerning the Malmkärra mineral we cannot prove definitely whether there is such a close relation between the magnesia and the fluorine in this series as seems probable from the Östanmossa and Bastnäs analyses.

Neither the cerite nor the orthite shows any distinct crystal outlines. The associated minerals are tremolite, as already mentioned, a little pyrite, and sometimes much chondrodite, irregularly intergrown with the cerium minerals.

Geological aspect of the cerium associations.

The writer's study of the deposit of cerium minerals at Bastnäs[2] gave the result that it is a variety of skarn ore, formed by complete replacement of a carbonate rock. This conclusion was corroborated through the subsequent discovery of a similar but much smaller deposit at Storgruvan, about 800 m NE of Bastnäs,[3] which lies in a dolomite body that is replaced only in part. The wide distribution of orthite in the iron ores of the district, and particularly in the most magnesian types, was also recorded. The conclusion was reached that the cerium compounds had been introduced, together with the other material forming the replacement ore bodies of the district, during the period when the leptite formation was folded and the older Archean granites intruded into it.

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[1] Compare foot-note p. 5.

[2] Compare foot-note p. 6.

[3] Riddarhytte malmfält (Beskrivn. över mineralfyndigheter n:r 1. Stockholm 1923).

It has been verbally pointed out to the author that such a concentration of the cerium metals could only be brought about by a pegmatitic differentiation and that, therefore, the deposit of Bastnäs would probably be due to an accidental meeting of a pegmatite magma extremely high in cerium compounds, and a limestone. This interpretation, for which no arguments could be found at Bastnäs or elsewhere in the Riddarhyttan district, is now definitely eliminated. The appearance of similar mineral aggregates at Östanmossa and Malmkärra gives ample proof of the correctness of the writer's interpretation, and illustrates the preference for magnesian associations.[1]

There are some more points to consider, however. The writer's results from Riddarhyttan, according to which all the skarn ores were formed during the period indicated, are not corroborated by writers who have later described other portions of the ore-bearing formation of Central Sweden. There is practically a consensus of opinion so far as the sulphidic ores are concerned, but the view is expressed that the iron ores of every type should be of a much earlier date and contemporaneous with the containing leptite formation.

I do not intend to discuss here this important and much debated problem, particularly as new material to its solution is being rapidly accumulated by several observers, promising a better foundation for a discussion, but I cannot avoid touching it, as the paragenesis of the minerals that have been described here cannot be understood without giving due consideration to these various possibilities. Of the other interpretations offered I shall, however, only consider the one advanced by Magnusson,[2] who studied the Persberg district, the classical skarn ore region. According to Magnusson, the iron ores were formed at low temperatures during the building up of the leptite formation; beginning folding and metamorphism caused important re-arrangements and determined the present mineral composition, magnetite with skarn of garnet and pyroxene; later, addition of material from the rising granite intrusions, especially magnesia, gave parts of the deposits an entirely new stamp by the development of magnesian skarn silicates, largely at the expense of the older, more calcic minerals; lastly, emanations from the immediate granite contacts gave some further additions. Important arguments for this view are presented. It is worthy of note that Magnusson found some orthite associated with the most pronouncedly magnesian skarn.

Leaving aside the general problem involved, we shall now consider only the Östanmossa and Malmkärra mines. It seems clear that the cerium associations of these two mines, like that of Bastnäs, must have been formed during that stage in the geological history of the district when solutions, high in magnesia and iron and emanating from the rising granite masses, pervaded the leptite formation. The high magnesium content of the orthites suggests an unusually

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[1] The rather small quantity of cerite (with orthite) found by Dr. Högbom in the Högfors mines occurs with tremolite in a quartz-banded iron ore, presumably replacing a narrow band of limestone interstratified in it. Such ore is also closely associated with the cerite deposit at Bastnäs, and it is probable that the Högfors mines form a direct continuation of these deposits.

[2] Persbergs malmtrakt (Beskrivn. över mineralfyndigheter, n:r 2. Stockholm 1925).

high proportion of magnesia to iron. The absence of similar orthite varieties in pegmatites is probably explained by the lower magnesia ratio in these rocks. The development of norbergite and fluoriferous orthites may have been determined by the presence of an unusually great concentration of fluorine, although other factors may also have played a part.

It is a remarkable feature in this geological process that compounds of the rare earths have been concentrated on a scale comparable to, or even surpassing, that shown by pegmatitic differentiation. As already pointed out by the writer,[1] the conclusion seems unavoidable that there was a pronounced differentiation in the volatile emanations that brought about the replacement.

Among the cerium minerals, the following relative ages have been observed at Östanmossa. The microscopical cerite grains that are associated with the Mg-orthite are probably very closely connected in time with it, but may be a little later. On the other hand, the cerite in a cross-cutting calcite veinlet is decidedly later than the Mg-orthite. As to the two varieties of orthite, the ordinary orthite is in part distinctly later than the magnesian variety, as it occurs in the calcite veins. The textural relations between the ordinary orthite and the cerite give the same impression, for they are analogous to those observed at Bastnäs, where the orthite is later than the cerite. If the chemical gap between the two orthite varieties is not determined by stoechiometrical proportions of MgF_2, it is probably due to deposition in two periods, there having been a higher concentration of iron in the later stage. At Malmkärra, the orthite seems to be, in part at least, somewhat later than the cerite (compare above), just as it is at Bastnäs. The association of cerium minerals and chondrodite in both Östanmossa and Malmkärra is significant.

If we try to ascertain the relations between the deposition of the cerium minerals on one hand, and the iron ore on the other, we encounter very great difficulties. The former was undoubtedly a phase of the process which, with somewhat too much emphasis on the quantitative importance of the magnesia, is spoken of as the magnesia metasomatism, and which is clearly a consequence of the intrusion of the older Archean granites. But what about the iron ore? Nothing observed at Östanmossa excludes the possibility that the whole iron ore deposit was produced by the same general processes that also contributed the cerium metals. But it is necessary to admit, here as in most similar cases, that a complete metasomatic re-arrangement of a previously existing deposit may have formed an important phase, also quantitatively speaking, of this process.

At Malmkärra, the room relations of magnetite, cerium ore, and chondrodite zone suggest deposition in one series, without any large gaps.

We shall encounter the same problem at Tallgruvan.

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[1] Processes in contact metasomatism, Econ. Geology, 1925, p. 687.

Tallgruvan.

General features.

This mine has not been worked for some decades, and the shaft has filled with water. There are dumps containing probably a thousand tons or so of lean ore and waste rock, and from these most of the material for the present study has been collected. Some of it, however, comes from a number of small prospecting pits west of the shaft.

Tallgruvan lies close to the granite boundary. Drift and moss covering make it impossible to fix exactly the position of the contact at this place. From its direction in the neighbourhood it seems probable that the distance from the shaft is not more than about 50 m. The nearest granite outcrop is 90 m S of the mine, and shows a light red, fine-grained rock, consisting, as the microscopic examination reveals, of a highly perthitic microcline, albitic plagioclase, and quartz. A pronounced »mortar structure» indicates that the rock has undergone considerable deformation by pressure. About 500 m ENE of Tallgruvan, a railway cut shows a white albite granite. A similar rock has been found as a border phase of the same granite in the centre of the Norberg district, and it is probably represented also at Tallgruvan, but falls in the covered stretch between the mine and the outcrop of reddish granite.

The ore body at Tallgruvan and the neighbouring prospects replaces, to a larger or smaller extent, a narrow layer of dolomite that runs nearly parallel to the granite contact. The ore mineral is magnetite. The associated skarn is generally pronouncedly magnesian. The most common type is a brownish gray mass of chondrodite, with small patches of light green chlorite.

Further there is skarn of tremolite, or green actinolite. Phlogopite is also noted. Skarn of garnet (presumably andradite) and diopside is seen in some quantity on the dumps at Tallgruvan. Magnetite is associated with all these types of skarn. One of the prospecting pits, however, shows diopside skarn entirely without magnetite. Replacement remnants of dolomite marble are often seen. In one prospect close by the mine, the dolomite predominates, and only streaks and isolated grains of magnetite and the skarn minerals occur.

The boron minerals, which give to this deposit its particular interest, mineralogically and geologically, have been noted in two slightly different associations. One is represented by a number of blocks on the dumps at the shaft. It shows a magnetite ore mixed with a grayish black mass, largely consisting of serpentine and talc. Small colourless stalks, white on weathered surfaces, are also noted. The microscope reveals the following combination of primary minerals: magnetite, ludwigite, chondrodite, fluoborite (the colourless stalks), and very rarely spinel. As secondary products, serpentine, talc, chlorite, and possibly others appear, derived mainly from chondrodite and ludwigite.

The other boron association is found in the prospect just mentioned, where a dolomite marble is partly replaced by magnetite and skarn. The minerals accompanying the magnetite are ludwigite, chondrodite, spinel, and chlorite. The alteration products are little conspicuous and generally limited to direct pseudomorphs after ludwigite.

The only differences between the two associations lie in the facts that at the prospect the replacement of the dolomite is less advanced, and the metacrysts often lie isolated in the carbonate mass, while the other association represents a complete or almost complete replacement; further, the fluoborite is lacking in the prospect but common in the other association, while spinel, and chlorite in large plates, are much more common in the former.

Magnetite and spinel.

The magnetite always shows a very pronounced octahedral parting. This phenomenon is not restricted to the boron association, but is sometimes observed also in other specimens. Otherwise the magnetite at this mine exhibits entirely normal characters, alike when occurring with garnet, tremolite or chondrodite skarn. The magnetite with the well-developed parting has a peculiar dull lustre which, together with the parting, makes it difficult to recognize the mineral at first glance as magnetite.

The spinel, which is common at the prospect, generally occurs as isolated grains in the dolomite, mostly about 5 mm in size. The octahedral shape may sometimes be discerned. The colour is brownish green. The refraction is $1.755 > n > 1.740$. The spinel is partly replaced by serpentine.

Ludwigite.

It is impossible to recognize the ludwigite as such in hand specimens of the magnetite ore. This is largely due to the character of the magnetite. When there is much ludwigite in the ore, however, this is apparent from a decidedly dullish black colour.

The ludwigite was first identified optically in thin sections from its prismatic or fibrous habit, high refraction, parallel extinction and very strong pleochroism with characteristic absorption colours. A sample containing chiefly ludwigite was tested chemically by Dr. Bygdén, who found mainly iron, magnesia, and boracic acid, thus corroborating the optical determination. It would have been very difficult to isolate material for a quantitative analysis, moreover, the composition of the ludwigite minerals seems clearly established through recent analytical work by Schaller,[1] Shannon,[2] and Eakle.[3]

The ludwigite appears in two distinctly different shapes, which are often immediately associated. The finely fibrous aggregates that are the common development of this mineral at most other localities appear also at Tallgruvan,

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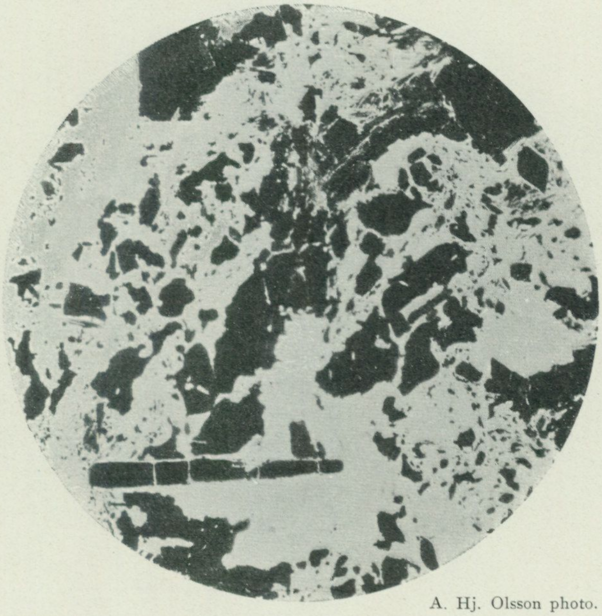
[1] Mineralogical notes (U. S. Geol. Survey, Bull. 490) p. 28, and B. S. Butler and W. T. Schaller, Magnesioludwigite, a new mineral. Journ. Wash. Acad. Sciences, VII, 1917, p. 29.

[2] Ludwigites from Idaho and Korea. Proceed., U. S. National Museum, 59, 1922, p. 667.

[3] Vonsenite, a preliminary note on a new mineral. Amer. Mineralogist, 5, 1920, p. 141.

but as much, or probably a good deal more, of the ludwigite exhibits the form of moderately thick isolated prisms. Fig. 3 shows a typical length section of one of the larger prisms, and also a cross section. The size is widely varying, even among crystals that lie close to each other. The shape is always distinctly rectangular in length sections, indicating the presence of a terminal pinacoid. Cross sections give rhomboidal shapes. Under the microscope, the prism angle has been measured to 60°. No cleavage is observed, but the prisms often show a sparsely spaced parting at right angles to their elongation (fig. 3).



A. Hj. Olsson photo.

Fig. 3. Ludwigite-bearing ore, Tallgruvan, microphoto., ord. light, × 75. Ludwigite and magnetite black, serpentine etc. white. A long ludwigite prism in the lower part of the field, a cross section in the upper right part.

It is known that the ludwigite belongs to the orthorhombic crystal system, but the axial ratio is not known with certainty. Mallard[1] measured the angles:

$$(110) : (1\bar{1}0) = 89^\circ 20'; \; (110) : (310) = 27^\circ 4'; \; (110) : (120) = 17^\circ 4',$$

and calculated the axial ratio a : b = 0.988 : 1. The same value Mallard also obtained on Ebelmen's synthetic ludwigite. Instead, if the angle of ~ 60° found by the writer in the ludwigite from Tallgruvan is regarded as representing $(110) : (1\bar{1}0)$ — which is probable from the morphological development of the mineral, and its optical properties — the ratio a : b becomes 0.58 : 1. This corresponds to the ratio 0.5881 that Brögger[2], using another position than

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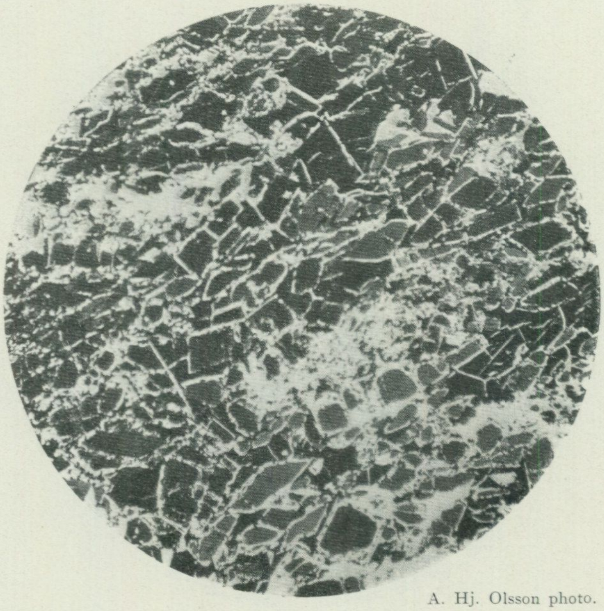
[1] Examen de diverses substances cristallisées. Annales des Mines, 1887, p. 427.

[2] Über die morphotropischen Beziehungen des Pinakiolith und des Trimerit zu verwandten Mineralien. Zeitschr. f. Kryst., 18, 1890—1891, p. 377.

Flink,[1] found for the pinakiolite, which one has all reasons to expect of being isomorphous with ludwigite. The c ratio found by Brögger, 0.469, is therefore probably also approximately that of ludwigite.

More rarely, the ludwigite is developed as short and thick prisms (fig. 4).

For ludwigite from various localities, the absorption colour for α and β is given as green, while γ (parallel to the elongation) is brown or completely absorbed.[2] In very thin sections of the ludwigite from Tallgruvan, γ is brown, otherwise opaque. The two other rays, which are observed in the rhomboidal cross sections, are green (bottle green to moss green), the one parallel to the longer diagonal being appreciably more absorbed than the other. In sections of ordinary thickness, about 0.025 mm, light vibrating parallel to the shorter diagonal is deep green, and the other ray is completely absorbed. This difference in the absorption of α and β appears not to have been noted elsewhere in ludwigite, but is reported by Flink[3] for pinakiolite.



A. Hj. Olsson photo.

Fig. 4. Ludwigite, Tallgruvan, microphoto., ord. light, × 75. The ludwigite is gray in various shades (due to pleochroism), the magnetite pure black, chondrodite and alteration products are white.

Larsen, who examined ludwigites from Hungary, Utah, and Montana,[3] found the optical axial angle to be small in ordinary ludwigite, and very small

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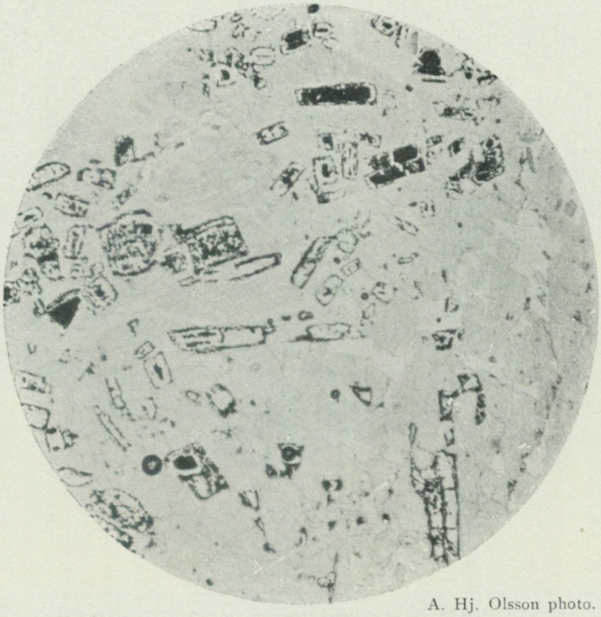
[1] Über Pinakiolith und Trimerit, zwei neue Mineralien aus den Mangangruben Schwedens. Zeitschr. f Kryst., 18, 1890—1891, p. 361.

[2] Esper S. Larsen: The microscopic determination of the non-opaque minerals (U. S. Geol. Survey, Bull. 679).

[3] Op. cit.

in magnesioludwigite, with extreme dispersion, $\varrho > \nu$, and positive character. In the mineral from Tallgruvan, the axial angle is rather small, $2\,E = 75^\circ$ in sodium light (drawing table method), which, using Larsen's figure $\beta = 1.85$, gives $2\,V_{Na} = 38^\circ$. Like the strength of the absorption, this angle points to an ordinary ferroludwigite. The dispersion is extremely strong, with $\varrho > \nu$. Thin sections cut nearly at right angles to the optical axes show very little variation in the intensity of transmitted light when rotated between crossed nicols.



A. Hj. Olsson photo.

Fig. 5. Ludwigite pseudomorphs in dolomite, Tallgruvan; microphoto., ord. light, × 45. Remnants of ludwigite are seen as black kernels in some grains.

The ludwigite is often altered, in fact, few grains are entirely intact. The alteration starts from the sides of the prisms, and from the parting cracks, and generally proceeds so regularly that the contours of the unaltered remnants are very nearly parallel to those of the original grain. The most complete alteration was observed in the scattered ludwigite prisms in the dolomite, where remnants of the borate are not common (fig. 5). The pseudomorphs have black rims of hematite where the alteration started (along the crystal faces and parting cracks), the rest is made up of plates of a mineral that is probably serpentine. The same alteration products develop in the fibrous aggregates of ludwigite, generally growing along the fibres.

Fluoborite.

The fluoborite occurs in the ludwigite-bearing blocks on the dumps, where it generally seems to make up several per cent of the rock. It forms slender prisms, mostly 2 to 8 mm in length, sometimes arranged in fan-shaped groups or stellate clusters (fig. 6). The mineral is colourless, but becomes whitish on

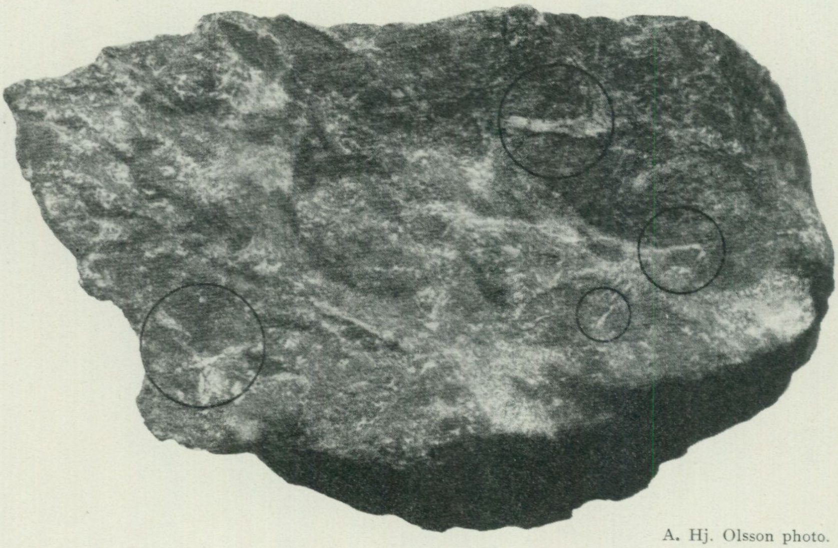

A. Hj. Olsson photo.

Fig. 6. Fluoborite-bearing ore, Tallgruvan, weathered surface. 2/1 nat. size. White prisms of fluoborite are seen within the circle marks.

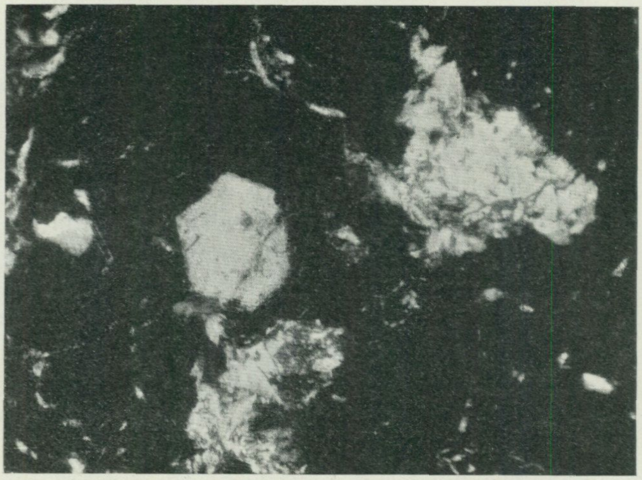

A. Hj. Olsson photo.

Fig. 7. Hexagonal cross section of fluoborite in magnetite ore, Tallgruvan; microphoto., × 45, cr. nic. Magnetite and ludwigite black; fluoborite, chondrodite, and serpentine white.

weathered surfaces. The form is very distinctly hexagonal (fig. 7). No terminal faces have been observed. There are no signs of any cleavage. A peripherical alteration is often seen, resulting in a finely fibrous or scaly mass, the identity of which could not be fixed (compare discussion of the analysis, below). The hardness is low, below 5 and probably about $3^1/_2$. The determination is difficult because of the small width of the prismatic crystals. The specific gravity is 2.89 (at 15°). As stated in the writer's preliminary description, the fluoborite is probably identical with an unidentified mineral mentioned by Gillson and Shannon.[1]

The fluoborite is optically uniaxial, negative, with $\omega = 1.566$, $\varepsilon = 1.528$ (immersion method).

The task of isolating material for a chemical analysis was rendered very difficult by the small size of the crystals and the degree of hardness, which is lower than that of the associated magnetite. Separation by gravity proved impossible, as fine-grained mixtures of talc or serpentine with magnetite or ludwigite occur in such proportions as to have practically the same gravity as the fluoborite. Therefore, picking under the lens was the only possible way. Most of this work was carried out by Mr. G. Larsson, preparator of the Survey, who by very careful work succeeded in isolating a quantity of 0.58 g.

The analysis also presented great difficulties, as only this small quantity was available, and the combination boron, fluorine, carbonic acid, and water had to be determined. Concerning the analysis and the methods employed, Dr. Bygdén has given the following account.

Fluoborite, Tallgruvan.

	a	b	c	d	e	f	Figures used in calculation	Mol. prop.
SiO_2 . . .	0.45	—	—	—	—	—	0.45	0.0074
Al_2O_3 . .	0.88	0.92	—	—	—	—	0.90	0.0087
Fe_2O_3 . . .	0.83	0.80	—	—	—	—	0.81	0.0051
MgO . . .	61.44	61.65	—	—	—	—	61.65	1.5290
MnO . . .	—	0.05	—	—	—	—	0.05	0.0007
F	9.30	—	—	—	—	—	9.30	0.4894
B_2O_3 . . .	17.88	—	17.91	—	—	—	17.90	0.2570
H_2O . . .	—	—	—	10.94	10.61	13.03	10.78	0.5989
CO_2 . . .	—	—	—	1.34	1.37		1.36	0.0309
							103.20	
Spec. gravity	2.89					— O for F_2	3.92	
							99.28	

Air-dried material loses 0.07 per cent in the H_2SO_4 exsiccator, and 0.13 per cent more at 105°. The analysis is calculated upon material dried at 105°.

a: 0.1999 g subst. decomposed with $KNaCO_3$. Determination of F after Berzelius, of B_2O_3 after Rosenbladt and Gooch.

b: 0.1509 g » » » HF + H_2SO_4.

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[1] Szaibelyite from Lincoln County, Nevada. Amer. Mineralogist, 10, 1925, p. 137.

c: 0.1297 g subst. decomposed with K_2CO_3. Determination of B_2O_3 after Marignac, Bodewig and Jannasch.
d: 31.114 mg subst. } heated in electrical furnace (quartz tube) to c:a 1200°, with absorption
e: 31.582 » » } mass of $PbCrO_4$ and PbO heated to c:a 350°.
f: 28.142 » » Loss at ignition with CaO.

The rest after ignition showed no sign of melting or sintering. Because of the scant material at hand, and the difficulty of determining F, B_2O_3, H_2O and CO_2 together, the figures obtained are not entirely reliable.

When calculating the formula, SiO_2 is left out (serpentine or talc?) and likewise Fe_2O_3, which is probably present in impurities (magnetite or ludwigite). It seems improbable that CO_2 belongs to the mineral itself. Presumably it is present in alteration products, either magnesite or hydromagnesite, both of which are known from similar parageneses. The hydromagnesite, in particular, may be present among the unidentified alteration products.

One has, then, $MgO : B_2O_3 (+ Al_2O_3) : F_2 : H_2O = 6.00 : 1.04 : 0.96 : 2.35$. It is probable that F_2 and H_2O replace each other, especially since the mineral must have been formed at a high temperature. Although the sum $F_2 + H_2O$ becomes 3.31, the ratio is probably $MgO : B_2O_3 : F_2, H_2O = 6 : 1 : 3$, therefore the formula may be written $3\ MgO . B_2O_3 + 3\ Mg\ (F, OH)_2$, that is, as a combination of the borate member in ludwigite and the molecule $Mg\ (F, OH)_2$. If CO_2 is regarded as occurring as hydromagnesite, the surplus of H_2O is also somewhat reduced, the ratios being 6.00 : 1.08 : 3.24. The formula found has a molecular weight of 374, showing a fairly good correspondance with the value 384 calculated from the X-ray examination (compare below).

Since well-developed hexagonal prisms could be isolated, it was thought possible to undertake a structural determination by X-ray rotation spectrograms. Prof. G. Aminoff, of the Mineralogical Department of the Museum of Natural History, Stockholm, kindly took the photograms, using for the orientation the device described in his study of the trimerite,[1] and obtained good results. The rotation axes were parallel to the edges $(10\bar{1}0) : (01\bar{1}0)$, which gave one pair of interference spot lines, and $(0001) : (10\bar{1}0)$, which gave three. An anticathode of iron was used ($FeK\,\alpha = 1.394$ Å), the radius of the camera was 28.6 mm. From the distances measured from the »equator» line, respectively 23.0 and 6.25 mm, one obtains

$$c = 3.09\ \text{Å};\ a = 9.05\ \text{Å};\ c : a = 0.341.$$

The molecular weight M is determined from the identity

$$N \cdot M \cdot 1.65 \cdot 10^{-24} = \frac{a^2 \cdot \sqrt{3} \cdot c}{2} \cdot \delta \cdot 10^{-24}.$$

As already mentioned, δ is 2.89, thus $M = \frac{384}{N}$, N being the number of chemical molecules within the cell.

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[1] G. Aminoff; Zur Kristallographie des Trimerits. Geol. Fören. Förh., 1926, p. 19.

At first glance, the composition found for the fluoborite may seem to place it entirely apart from all other known borates. However, several other minerals have a composition that can be interpreted as analogous to that of the fluoborite, except that they lack the fluorine. Thus, the formula for the hambergite can be written $3\ BeO \cdot B_2O_3 + Be\ (OH)_2$, and that of the sussexite $RO \cdot B_2O_3 + + R\ (OH)_2$, where R stands for Mg, Mn, and some Zn. It is possible that also the szaibelyite has a similar structure: while older analyses give no decided guidance, that by Gillson and Shannon[1] corresponds fairly well to the proportions $MgO \cdot B_2O_3 + Mg\ (OH)_2$, that is, a purely magnesian sussexite. This formula cannot be regarded as so clearly established as the others, however, as the material used for the analysis was rather unsatisfactory. Also, the optical properties reported for sussexite and szaibelyite do not indicate any close relations between these species. As to the lack of fluorine in hambergite, there may possibly be some significance in the fact that those varieties of humite that contain an appreciable amount of beryllium are also the only ones in which the fluorine seems to be completely lacking, being entirely replaced by hydroxyle.

Other primary minerals.

Szaibelyite. There have been observed under the microscope two or three grains of a mineral that resembles fluoborite but has a higher refraction. From the data for szaibelyite that are reported by Gillson and Shannon, it seems probable that they belong to this mineral.

Chondrodite. This is the only silicate among the primary minerals of the boron association. It is mostly unaltered or only partly serpentinized. Lamellar twinning is very common. In sections perpendicular to the acute bissectrix, the extinction angle, measured against the twinning boundaries, is 20°. The determination as chondrodite is therefore somewhat doubtful, for, although this mineral is known to show a variation in the said angle down to about 26°, lower values seem not to be recorded, while clinohumite may reach up to 15°.

In one specimen, not containing any boron minerals, there is a mineral that is probably *olivine*. *Phlogopite* and *tremolite,* although high in magnesia, have not been noted with the borates. The distribution of the more calcic skarn minerals, *garnet* and *diopside,* has already been mentioned.

Alteration products.

The most common products of the alteration of the magnesian minerals is a set of lamellar minerals with the optical properties of serpentines or »colourless» chlorites. No detailed study of these minerals has been undertaken, but a few observations may be recorded. The minerals show one cleavage system and parallel extinction, positive optical character with a small axial angle, down

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[1] Op. cit.

to zero, a birefringence varying from about 0.007 in the most common form to considerably higher values in the pseudomorphs after ludwigite prisms. In one specimen, abnormal, reddish brown interference colours were noted. The refraction is generally considerably higher than that of the Canada balsam, but in the aggregates that develop from the fibrous ludwigite it is lower.

There are also sometimes seen finely felted aggregates of talc, and it is possible that more mineral species are present among the alteration products, as already indicated.

Paragenesis of the boron minerals.

The sharply idiomorphic prisms of fluoborite and ludwigite were certainly formed before the magnetite. Their age relations to the chondrodite are less clear. This silicate is also often enclosed in the magnetite, and clearly older, although is does not show so well developed crystal faces as do the borates. The fibrous aggregates of ludwigite, on the other hand, have the appearance of being contemporaneous with the magnetite, or possibly somewhat later. It is to be noted that in the first stages of replacement, when most of the dolomite is still unreplaced, the ludwigite appears only as thick prisms (fig. 5). It therefore seems as if this mineral had been formed during two stages of the mineralizing process. This is also indicated by the not unusual sight of a well-developed prism of ludwigite, surrounded by a finely fibrous mass of the same mineral. These felty aggregates are also very clearly later than the fluoborite.

Ludwigite, including magnesioludwigite and vonsenite, is previously known from a rather limited number of places:[1] besides the original locality at Moravicza (then in Hungary, now in Roumania), it has been identified in a number of ore deposits in western North America (several localities in Utah, and one in each of Montana, Idaho, Nevada, and California), at one in Peru and one in Korea. In all these cases, it is a contact mineral in dolomite or limestone, associated generally with magnetite, but sometimes rather with sulphide ores. Among the accompanying skarn silicates, compounds of magnesia often predominate. Shannon has pointed out that the appearance of ludwigite instead of tourmaline may be due to deficiency in silica. This seems indeed probable in view of the association mainly with orthosilicates, but the rarity of tourmaline in general in replacement deposits in carbonate rocks indicates that other factors than the supply of silica also count.

Ludwigite is exclusively a mineral of the contact replacement deposits, and it is doubtful whether any other mineral is so completely restricted to this type of paragenesis.[2] Therefore, the identification of ludwigite in an otherwise entirely typical deposit of skarn iron ore in Sweden is of particular interest.

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[1] Compare survey in Earl V. Shannon: Ludwigites from Idaho and Korea (Proc. U. S National Museum, 59, 1922, p. 667), and, for the Nevadan locality, Gillson and Shannon, op. cit.

[2] It may be remarked that the corresponding manganese mineral, pinakiolite, occurs in an association where the temperature may perhaps not have reached the range of the typical contact deposits, but this does not necessarily contradict the above statement: it is sufficient to recall that manganese pyroxenes and garnets often enter into mineral aggregates formed at lower temperatures than the corresponding iron and magnesia compounds.

As to Tallgruvan, there seems little room for doubt that the boron and the other substances added through metasomatism were contributed by emanations from the neighbouring granite. That this intrusive has carried boron is well illustrated by the common occurrence of tourmaline seams in the sodic border phase of the granite in the Bergenschiöld shaft in Norberg. The added substances and their mineral forms are seen from the following table:

Boron	in ludwigite and fluoborite.
Silica	» chondrodite.
Magnesia	» chondrodite, ludwigite, fluoborite.
Fluorine	» chondrodite and fluoborite.
Iron	» magnetite and ludwigite.

Some uncertainty relates to the quantitative importance of magnesia and iron in the emanations from the granite. Magnesia was present as dolomite before the high-temperature mineral association was formed, but it seems impossible to explain this very pronouncedly magnesian association, entirely free from calcium minerals, simply as the result of a concentration of the magnesia previously present as dolomite. It is therefore concluded that a great amount of this element was added.

As to the iron, a similar conclusion is difficult to escape. The magnetite associated with the chondrodite skarn cannot very well be derived from iron compounds that were present before the contact metasomatism. A development of magnetite by the splitting up of iron-containing silicates under the influence of granitic emanations has, according to Magnusson, been a process of quantitative importance in the Persberg district (compare above). Such a process, however, could not possibly change an andradite-diopside skarn into an ore composed of magnetite and an orthosilicate (chondrodite), if no silica was detracted. The textural relations between the borates and the magnetite, already referred to, show conclusively that the magnetite did not crystallize until the boron minerals were formed. I think, therefore, that iron must have been present in great amounts among the substances that were contributed by the granite. It must remain for the further study of the region to find an answer to the question whether all the iron in the deposit is of this age, or perhaps a large quantity is older. The presence of andradite-diopside skarn is noteworthy in this respect, although these minerals are also known from ludwigite-bearing associations elsewhere.

The rôle of $Mg(F, OH)_2$.

The mineral associations that have been described in this paper have that in common that they are all formed by high-temperature replacement in carbonate rocks, and that magnesia and fluorine have been prominent among the substances that were added. On the other hand there is a very marked difference, inasmuch as cerium is fixed in considerable quantities at Östanmossa and Malmkärra, but boron at Tallgruvan. It is not clear, how close has been the relation between the emanations that built up these different deposits. They must all belong to the epoch of the older Archean granites, but it is quite possible that the minerals at Tallgruvan were formed in a more immediate connection with the granite than the rest.

Just as the addition of magnesia and fluorine has been a conspicuous feature of the mineral-forming processes, the presence of the group $Mg(F,OH)_2$ is characteristic for all the three new species or varieties of minerals that have been found. As already indicated when discussing the Östanmossa paragenesis, an unusually high concentration of magnesia and fluorine seems to be indicated by the presence of norbergite and Mg-orthite.

The minerals of the humite group have long been regarded as a series of molecular combinations of Mg_2SiO_4 with $Mg(F,OH)_2$ in varying, but always simple, molecular proportions. The discovery of the norbergite completes the picture.

As to the orthite minerals so much is clear, in spite of all the still remaining uncertainty regarding their chemical constitution, that the fluorine does not enter into the silicate molecule but is added in the form of $Mg\,F_2$, or possibly $Mg\,(F, OH)_2$. The magnesium orthite, therefore, has a similar chemical relation to an ordinary orthite as norbergite has to olivine (forsterite).

Again at Tallgruvan, the individuality of this molecule is strikingly illustrated, if the minerals of the boron association are written in the following way:

Chondrodite : $2\,Mg_2SiO_4 + Mg\,(F, OH)_2$
Fluoborite : $3\,MgO \,.\, B_2O_3 + 3\,Mg\,(F, OH)_2$
Ludwigite : $3\,MgO \,.\, B_2O_3 + Fe_3O_4$
Magnetite : Fe_3O_4

The paragenesis suggests that not only the chondrodite, but also the fluoborite and the ludwigite are to be interpreted as molecular compounds.

It seems probable that in many cases where fluorine is found in smaller quantities in minerals, particularly in silicates, it is combined with magnesia. The ordinary orthite from Östanmossa is particularly remarkable in this connection.

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