SVERIGES GEOLOGISKA UNDERSÖKNING

SER. **C.** Avhandlingar och uppsatser. N:o **304.**

ÅRSBOK 14 (1920) N:o 6

THE CERIUM MINERALS OF BASTNÄS AT RIDDARHYTTAN

BY

PER GEIJER

STOCKHOLM 1921
KUNGL. BOKTRYCKERIET. P. A. NORSTEDT & SÖNER
210566

CONTENTS.

Introduction.

The deposit of cerium minerals at Bastnäs is one of the more remarkable mineral localities in Sweden, although its number of mineral species is small, and well developed crystals are rare. It is probably the largest primary deposit of the cerium metals that has ever been discovered. Unlike other concentrations of the rare earths, it does not belong to any pegmatite rock. The metal cerium was discovered in ore from Bastnäs. Five minerals[1] have first been found there; for two of them it is the unique locality.[2]

The chemical composition of the Bastnäs minerals has been studied by a number of very able mineral chemists, and much work has been devoted to the search for crystals suited for goniometer measurements, but no study of the deposit as a whole has ever been undertaken, nor has its geological environment been satisfactorily described. A study of the mutual relations of the Bastnäs minerals is impossible without the aid of the petrographic microscope, because of their occurrence as finely crystalline aggregates. As yet, however, only one brief, although valuable note on the microscopical characteristics of cerium ore from Bastnäs has been published.[3]

An examination of the geology and ore deposits of the Riddarhyttan district, to which the Bastnäs mines belong, caused the writer to undertake a special study of the cerium minerals, the purpose immediately in view being to find in this unusual mineral association some clue to the process of ore deposition in the district in general. While thus the paragenesis of the cerium minerals formed the chief object of the study, some interesting optical and chemical data were also obtained, and a new mineral species was discovered. It seems justified, then, to publish the results of this examination as a special

---

[1] Cerite, bastnäsite, lanthanite, linnæite, and törnebohmite (a new mineral that is described in this paper).

[2] Cerite and törnebohmite.

[3] A. Lacroix, in Bull. Soc. Franc. Minéralogie, 1915, p. 121.

report.[1] As the results of older chemical and crystallographical investigations are generally to be found in well known works of reference, as DANA'S Mineralogy, HINTZE'S Handbuch der Mineralogie or DOELTER'S Handbuch der Mineralchemie, detailed reviews of these results are unnecessary.

No study of the cerium ore *in situ* is now possible, as the mines are idle and filled with water, after most of this ore had been taken out. Beside the detailed examination of the surface geology, both in the immediate surroundings of these mines and in the district as a whole, the writer's work has consisted in a thorough study of the dumps[2] and of specimens in mineral collections. Especially in the collections of the Mineralogical Department of the National Museum of Natural History there is a great number of specimens from Bastnäs, which were studied with advantage.

Situation, and history of mining.

The Riddarhyttan district is situated in the province of Västmanland, about 30 kilometer SW of Norberg, another mining centre in the same zone of ore-bearing rocks. Copper and iron ores had been mined at Riddarhyttan for several hundred years before the cerite was discovered at Bastnäs, about the middle of the eighteenth century. It was first observed in the S:t Göran copper mine. Later, in 1865, it was also encountered in a new shaft, a few meters West of this mine. Chemical examinations of the new mineral led to the discovery of the metal cerium, in 1804. Cerium ore, consisting of cerite and orthite, and probably on an average of a high grade, was mined in the period 1875—1888, the total production being 4 465 metr. tons.

Geological relations of the cerium ore deposit.

Like almost all other ore deposits in the Archaean of Central Sweden, those of the Riddarhyttan district occur in the supracrustal leptite formation, consisting in this district of leptites, mica schists with cordierite and often also andalusite, and subordinated limestone dolomite layers. The dip is always steep, as is generally the case in the leptite formation. There are several different types of ore deposits: quartz banded iron ore (magnetite and specular hematite); iron and copper ores with quartz and fluorite, partly fairly well banded; skarn ores[3] (magnetite and chalcopyrite) in the limestones, the skarn minerals being actinolite, diopside, garnet and fluorite; and finally magnetite ores with anthophyllite and accompanied by cordierite-anthophyllite quartzites. The first type exhibits a number of features pointing decidedly to a sedimentary origin, while the skarn ores are replacement deposits in the carbonate rocks. The study of the other types is not completed, and they need not to be considered here, as they do not occur within the Bastnäs field. It may be mentioned, however, that orthite is a rather widespread, although quite subordinated constituent in these two types, and also occurs in the skarn ores.

At Bastnäs, quartz-banded iron ore, mainly specular hematite, has been mined in a number of mines. Parallel to the hematite ore belt, and partly immediately adjacent to it, runs a zone of amphibole skarn. The amphibole varies from a tremolitic actinolite to a more deep green variety. Replacement relics of limestone are sometimes observed in the skarn. Magnetite ore occurs at several points in the skarn zone, and chalcopyrite has also been found in some quantity. The most important mine worked a magnetite ore with some pyrite, while copper ore was the chief product from some smaller workings. The cerite ore also belongs to the skarn zone, in which it is associated with the chalcopyrite.

In the S:t Göran mine, the cerium ore formed a narrow stripe that accompanied the copper ore and ended already at a depth of 30 meters. In the Cerite mine close by, there was one stripe of cerite ore, 0.3—0.6 meter in width and 6—7 meters in length, and a narrower one. Both ended at about 20 meters' depth.

The minerals of the cerium ore.

The following is a list of the minerals observed in the cerite deposit at Bastnäs. Those marked with an * have been observed by the writer at Bastnäs or in specimens known to have come from the cerite deposit. The others are quoted from the older mineralogical literature.

---

[1] The description of the general and mining geology of the Riddarhyttan district will appear later, and in Swedish.

[2] At least one of the dumps from the cerium mining seemed not to have been examined by any mineralogist.

Gold.
*Bismuthinite.
*Molybdenite.
*Chalcopyrite.
*Linnæite.
*Quartz.
? Cuprite.
*Magnetite.
*Bastnäsite.
*Lanthanite.
*Malachite.
*Fluocerite.
*Actinolite.
*Orthite (allanite, cerine).
*Cerite.
*Törnebohmite.
? Biotite.
*Talc.
Asphaltum.

Native gold is reported only once from Bastnäs. HISINGER[1] states that QVIST has found gold to a quantity of 0.1 lod (= 1.4 gram) »on cracks in a dark-green hornblende».

Bismuthinite is not rare It is generally associated with orthite (and primary bastnäsite), filling the interstices between orthite grains. The few crystals of cerite that are known occur embedded in bismuthinite, and also the best orthite crystals. BERZELIUS[2] found tellurium in a specimen of bismuthinite from Bastnäs, and thought the mineral tetradymite. However, a quantitative analysis, by G. LINDSTRÖM,[3] gave only 0.95 % tellurium, a percentage often found in bismuthinite.

Molybdenite is fairly common in association with the orthite, but rare in the purer cerite masses.

Chalcopyrite was the ore mineral mined in these mines before the discovery of the metal cerium. It occurs in moderate quantities in various associations, but particularly with orthite as an interstitial filling between the orthite grains.

Linnæite was first discovered at Bastnäs by BRANDT.[4] The material from this locality has recently been described in detail by FLINK.[5] It is one of the rarest minerals at Bastnäs, and occurs associated with chalcopyrite and green actinolite.

Chalcocite and bornite are also reported from Bastnäs, but have not been found in the mines containing cerium ore.

Quartz is found as small crystals in druses, and microscopically as occasional grains with cerite or orthite.

Cuprite is known from one specimen only.[6] I am not sure that it comes from the cerite deposit, as the cuprite coats one side of a piece of rich magnetite ore with only occasional radiating aggregates of the usual actinolite. In any case, the cuprite is a distinctly secondary mineral.

---

[1] Minerographie öfver Sverige, p. 66 (Stockholm 1790).
[2] K. Vetensk. Acad. Handl. 1823, p. 183 (Stockholm 1823).
[3] Geol. Fören. Förh., Vol. 28, 1906, p. 198.
[4] K. Vetensk. Acad. Handl., Stockholm 1746, p. 119
[5] Arkiv f. Kemi, Mineralogi, etc. III, n:o 11, p. 27 (Stockholm 1908).
[6] FLINK, in Arkiv f. Kemi, Mineralogi etc. III, n:o 11, p. 43 (Stockholm 1908).

Magnetite is rarely seen with the cerite. Besides microscopical grains, sometimes associated with chalcopyrite, I have not found more than one piece of ore, in which both magnetite and cerite occur. In this piece, there are two lumps of cerite, cut by orthite veinlets, and enclosed in actinolite skarn rich in orthite and carrying also chalcopyrite and some magnetite. Somewhat more often, *orthite* is found in magnetite ore of this character in the same mines.

Fluocerite.[1] This mineral has not before been observed at Bastnäs. I have found it as a subordinate constituent in several thin sections of cerite ore. The grains do not reach more than about 0.2 to 1.5 mm. in size. The fluocerite is identified through its birefringence and refraction,[2] its cleavage systems and parallel extinction, the occurrence of twinning lamellæ of the same character as in the fluocerite from Österby, and the fact that it is partly replaced by bastnäsite, which proves it to be a compound of cerium. These data are sufficient to show that the mineral must be fluocerite, although the material at hand did not give any decisive proofs of an optical uniaxial character. The replacement by bastnäsite often proceeds along the cleavage cracks, as shown in fig. 1. In one section, the fluocerite is largely altered to earthy products, probably of the same character as those found in the fluocerites from Broddbo and Österby.

Bastnäsite. This mineral was discovered at Bastnäs by HISINGER,[3] in 1838; the name bastnäsite was given by HUOT.[4] The bastnäsite was regarded as a hydrous carbonate, until NORDENSKIÖLD[5] showed it to be a fluocarbonate, of the formula $RFCO_3$. NORDENSKIÖLD'S analysis gave:

Ce_2O_3	29.94
$(La, Di)_2O_3$	45.77
CO_2	19.50
F	7.42
	102.63
− O	3.11
	99.52

---

[1] About the identity of fluocerite and tysonite, compare the writer's paper in Geol. Fören. Förh., vol. 41, 1921, p. 19.
[2] The refraction could only be approximately estimated in the thin sections.
[3] K. Vetensk. Akad. Handl. (Stockholm), 1838, p. 187.
[4] Man. de Minéralogie, I, p. 269 (1841).
[5] Öfv. K. Vetensk. Akad. Förh. (Stockholm), 25, 1868, p. 399

Fig. 1. Microphoto of cerium ore from Bastnäs, magn. 45 times, nicols crossed. In the centre a grain of fluocerite (gray), partly replaced by bastnäsite (white). The surrounding mass is cerite (black or gray) with numerous patches of secondary bastnäsite (mostly white).

Later, the bastnäsite has been found in Colorado[1] and on Madagascar,[2] and (in microscopical quantities only) at Österby in Sweden,[3] in two cases as a pseudomorph after the fluoride of the same metals, fluocerite (tysonite), but on Madagascar replacing tscheffkinite.

Both HISINGER and NORDENSKIÖLD report that the bastnäsite is very rare at Bastnäs. I have, however, collected a number of specimens, in which it occurs as homogeneous grains, sometimes an inch or more across. In these cases, the bastnäsite is associated with orthite, which is idiomorphic against it. In none of my specimens there are any crystal faces on the bastnäsite, but in the National Museum collections there is one crystal with probably prismatic faces and idiomorphic against bismuthinite.[4] The two cleavage systems mentioned by NORDENSKIÖLD are probably the prismatic and basal ones that have been identified by DES CLOIZEAUX.[5] In the specimens I

---

[1] ALLEN and COMSTOCK, Am. Journ. Science, 19, 1880, p. 390.
[2] LACROIX, Bull. Soc. Franc. Minéralogie, 1912, p. 108.
[3] P. GEIJER in Geol. Fören. Förh., vol. 43, 1921, p. 20.
[4] FLINK, in Arkiv f. Kemi, Mineralogi. etc. III, no 35, p. 158 (Stockholm 1910).
[5] Man. de Minér. II, 1874, p. 165.

have studied, the prismatic cleavage is fairly well developed, but the basal system less so. The large grains are often composed of slightly divergent plates, 2 or 3 mm. thick, with their bounding planes more or less nearly coincident with the basis plane. The bastnäsite is honey yellow, entirely fresh and unaltered, translucent at the edges. It is optically uniaxial, positive, as has already been determined by LACROIX.[1] The refraction is strong and the birefringence very high. On prisms, cut parallel to the prismatic cleavage, the indices of refraction were determined by means of the method of the least deviation. As the orientation of the prism could not be made with quite satisfactory accuracy, the figures for ε and consequently also for $\varepsilon - \omega$ are minima, although probably not much too low. For Na light I obtained:

$\omega = 1.7225$ (average of determinations on 4 prisms); $\varepsilon' = 1.8242$; $\varepsilon' - \omega = 0.1017$.

On bastnäsite from Madagascar, LACROIX found $\omega = 1.7145$

Most of the bastnäsite at Bastnäs occurs in another way than has now been described. It is intimately mixed with the cerite, as an alteration product of cerite, fluocerite (see above), and, to some extent at least, also of törnebohmite. This metasomatic development of bastnäsite was first noted by LACROIX.[2] There is, in fact, hardly one thin section with any notable percentage of cerite that does not also contain bastnäsite, often making up one third or more of the cerite ore. The bastnäsite developing from fluocerite is often, but not always, oriented parallel to the latter. Also the microscopical grains are as a rule quite fresh. Only rarely there is seen a substance, supposed to be lanthanite, in such relations to the bastnäsite that it is probably an alteration product of the fluocarbonate.

Lanthanite. Also this mineral was first discovered at Bastnäs.[3] The chemical composition was definitely determined by G. LINDSTRÖM,[4] whose analysis gave:

$(La, Di)_2O_3$	28.34
Ce_2O_3	25.52
Y_2O_3	0.79
CO_2	21.95
H_2O	23.40
	100.00

The results correspond to the formula $(Ce, La, Di)_2C_3O_9 \cdot 8H_2O$.

---

[1] Bull. Soc. Franc. Minéralogie 1912, p. 109.
[2] Bull. Soc. Franc. Minéralogie 1915, p. 121.
[3] BERZELIUS, K. Vetensk. Acad. Handl. (Stockholm), 1824, p. 134.
[4] Geol. Fören. Förh., vol. 32, 1910, p. 206.

The crystallographic properties were determined by FLINK.[1]

The lanthanite is distinctly a secondary mineral. It occurs as a crystalline film coating on cracks in the cerium ore, and sometimes as small crystals in druses. Microscopically it has not been identified with certainty, but it is probably represented by very finely crystalline aggregates with a considerable refraction and high birefringence, which in some thin sections are seen to replace cerite and probably also bastnäsite.

Fig. 2. Microphoto. of cerium ore from Bastnäs, rich in orthite; ord. light, magn. 13 times. Dark areas and light areas marked O are orthite (note twinning), light areas marked C are cerite.

Malachite in small quantities is seen on most pieces of cerium ore that have been exposed to the atmosphere for any longer period.

Actinolite. As already mentioned, the skarn silicate of the cerium ore is a light green actinolite, of the same type that accompanies the magnetite ore in the vicinity. It is generally developed in radiating aggregates, often built up of needles of an almost asbestos like fineness. The optical character is negative, the extinction angle $\mathfrak{c} : c = 17\frac{1}{2}^\circ$. By the immersion method, the maximum index of refraction was found to lie between 1.624 and 1.629. It is clear that this amphibole

---

[1] Arkiv f. Kemi, Mineralogi etc. III, n:o 35, p. 163 (Stockholm 1910).

belongs to the tremolite-actinolite series, and not to the Mg Fe amphiboles[1] (cummingtonite grünerite). Around minute inclusions of cerite, the amphibole shows light brown pleochroic halos.

Orthite (allanite, cerine). The orthite is one of the most common minerals of the cerium ore. Crystals are not common nor well developed, but are sometimes found, embedded in bismuthinite (NORDENSKIÖLD)[2] or in bastnäsite. The crystallographic properties have been described by NORDENSKIÖLD.[2]

The orthite is black, with an irregular fracture. Its specific gravity is very high, 4.10 to 4.20 (compare below). The optical properties have recently been studied by ZENZÉN.[3] The birefringence is high and the pleochroism very strong, with $\mathfrak{a}$ = light greenish yellow, $\mathfrak{b}$ = dark brown, $\mathfrak{c}$ = dark reddish brown, and the absorption $\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$. An idea of the strength of the pleochroism may be obtained from fig. 2, which shows a number of orthite grains, and some cerite, in a thin section of ordinary thickness and with one nicol only. ZENZÉN found the axial angle rather large, the optical character negative and the axial plane normal to the plane of symmetry. When studying the refraction by the immersion method, he found that even α surpassed 1.78; the specific gravity was determined to 4.15. According to a diagram drawn by ZENZÉN to illustrate the relation between specific gravity and medium refractive index in orthites, the β value corresponding to a weight of 4.15 ought to be about 1.80. Twinning along (100) is very common in the orthite (compare fig. 2).

The chemical composition of the Bastnäs orthite was studied by CLEVE;[4] older analyses by HISINGER and SCHEERER are unreliable. CLEVE found:

	I	II
SiO_2	30.99	31.12
Al_2O_3	9.10	8.73
Fe_2O_3	8.71	9.02
Ce_2O_3	11.35	12.90
$(La, Di)_2O_3$	16.08	14.46
FeO	12.69	12.29
MnO	traces	traces
CaO	9.08	9.74
MgO	1.36	1.12
H_2O	0.33	0.48
	99.69	99.86

Spec. gravity = 4.15

---

[1] Compare P. ESKOLA, Petrology of the Orijärvi Region (Bull. Comm. géol. Finlande, no. 40), on the refraction of cummingtonite.

[2] Öfv. K. Vetensk. Akad. Förh. (Stockholm). 1870, p. 551.

[3] Bull. Geol. Inst. Uppsala, Vol. XV, 1916, p. 67.

[4] Öfv. K. Vetensk. Akad. Förh., 1862, p. 425 (Stockholm 1863), and in »Undersökn. af några mineral, som innehålla sällsynta jordarter», acad. dissertation by N. ENGSTRÖM, Uppsala 1877.

A striking feature in these analyses is the very low figure for water. Of all other orthites, only that from Gyttorp in Sweden, which occurs associated with iron ore, as at Bastnäs, shows a similar low figure (0.67 %).[1] As these orthites are fresh and unaltered, while most analyzed orthites are more or less decomposed, one could suspect that the original orthite substance was free from water. This would, however, mean that the orthite is not built up according to the epidote formula. It was, then, much more probable that the water percentages just quoted were too low: older and imperfect analytical methods might have resulted in too low figures, which became conspicous only when there was no secondary water at hand to compensate and bring the percentage up to or above that required by the epidote formula. It was therefore necessary to have a new determination made of the water content of the orthite from Bastnäs. Such an analysis was made by Dr R. Mauzelius, of the Geological Survey, on material collected by the writer. The specific gravity was 4.20, the water content 1.52 %. If this figure is substituted for the one found by Cleve, the ratio $H_2O : RO : R_2O_3 : SiO_2$ in the average of his two analyses becomes 1 : 4.29 : 2.61 : 5.93, showing a fairly good agreement with the ratio 1 : 4 : 3 : 6 of the epidote formula.

A determination of the radioactive power of the orthite, by the electroscope method, gave a negative result. Mügge,[2] who studied the influence of orthite from Bastnäs on a photographic plate, obtained only a very weak impression.

Cerite. The cerite is interesting as being the mineral in which the metal cerium was discovered, and as occurring only at Bastnäs. There, however, it has been found in considerable quantities, as shown by the production figure quoted above.

After much searching, Nordenskiöld found measurable crystals of cerite,[3] and could prove that the mineral is orthorhombic, the axial ratio a : b : c : being 0.9988 : 1 : 0.8127. These crystals have a light red colour. This is the normal colour of the cerite, but grayish red hues are also seen.

Many analyses of cerite have been published, but they give rather divergent pictures of the chemical composition of this mineral. This must be due to the use of impure material. In almost all specimens, the cerite occurs as fine grained aggregates. The microscopical examination reveals an always considerable, sometimes even high content of various other minerals with the cerite, above all of bastnäsite.

---

[1] G. Nordenström, in Geol. Fören. Förh., vol. XII, 1890, p. 540.

[2] Centralbl. f. Mineralogie. etc., 1909, p. 148.

[3] Öfv. K. Vetensk. Akad. Förh., 1873, n:o 7, p. 13 (Stockholm 1873).

Lacroix has already pointed out that admixture of this mineral, and not of lanthanite as previously supposed, is probably the cause of the high CO_2 in several analyses. Nordström's analysis on the crystal material described by Nordenskiöld is the only one, where, so far as I know, there is no *a priori* reason to doubt the purity of the cerite. The admixture of sulphides is of little consequence, as the errors introduced in this way are easily computed and eliminated.

Nordström's analysis gave:

SiO_2	22.79
Ce_2O_3	24.06
$(La, Di)_2O_3$	35.37
Al_2O_3	1.26
FeO	3.92
CaO	4.35
Bismuthinite	3.58
Chalcopyrite	0.75
Loss at ign.	3.44
	99.52

The specific gravity of fragments fairly free from sulphides was 4.86.

Unfortunately, Nordström does not tell whether the ferrous iron was determined as such. The results of the analysis correspond to the formula $2(Ca, Fe)O.\ 3Ce_2O_3,\ 6SiO_2,\ 3H_2O$. It is to be added that Nordström found some fluorine, which was not quantitatively determined. Later, Muthmann and Stützel[1] have spectroscopically determined the relation between Pr_2O_3 and Nd_2O_3 in cerite, finding respectively 8.45 and 16.49 p. c. Small quantities of other elements have also been found. St. Claire Deville[2] has reported Va, Ti and Ta. Krüss and Nilsson found Sm.[3] The varying water content has led Nordenskiöld to suppose that the cerite originally is free from water. It is possible, however, that the higher figures for the loss at ignition may be due to CO_2 in admixed bastnäsite.

The cerite is optically uniaxial, or biaxial with a very small axial angle, and positive.[4] The uniaxial character and the axial ratio point to the possibility that the mineral is tetragonal. Nordenskiöld has discussed this possibility in his paper on the crystallographic properties of the cerite, but points out that the habit of the crystals is

---

[1] Ber. Dtsch. Chem. Ges., 32. 1899, p. 2675. In Doelter's Handb. d. Mineralchemie, this analysis is cited as having given 16.36 p. c. Y_2O_3 but no La_2O_3, while the original has »La_2O_3, incl. yttria earths = 16.36».

[2] Ann. chim. phys., 6 1861, p. 344.

[3] Öfv. K. Vetensk. Akad. Förh., 44, 1887, p. 371 (Stockholm 1887).

[4] Lacroix, Bull. Soc. Franc. Minéralogie, 1915, p. 121.

decidedly orthorhombic. No sign of any regular cleavage can be discerned. Instead, the mineral is cut by irregular cracks in all directions. The birefringence is very low, about 0.002. The refraction is high. An attempt was made to determine it by the method of the least deviation, but the cracks in the cerite blurred the image. The figure obtained was 1.81 (for Na). The cerite is very weakly pleochroic in light rosa tints.

The existence of a weak radioactive power in cerite is proved by the pleochroic halos that have already been mentioned. A determination with the electroscope gave < 0.0005 uranium units, however, that is, practically no activity. This result agrees with that previously obtained by PISANI[1] who tested the influence of »cérérite» on a photographic plate, and found no influence from a 12 hours' exposition. BARDET,[2] on the other hand, who used a similar method but developed so that the results could be compared quantitatively, reports that the active power of cerite is 5 p.c. of that of pechblende.

The cerite is replaced by orthite and bastnäsite, and more rarely by lanthanite.

Törnebohmite. The first to notice the mineral which will now be described, was probably COSSA,[3] who studied the absorption spectrum of cerite in a section 0.09 mm. thick. COSSA mentions a pleochroic mineral associated with the cerite.[4] Later, LACROIX[5] has given some characteristics of it: »Il existe aussi un mineral vert clair, très faiblement polychroique, biaxe, optiquement positif, avec 2 V petit et forte dispersion. Il est incolore en lames minces et ne se distingue de la cérite que par sa forte birefringence».

This mineral is seen in many specimens of cerite ore, as light green to olive-coloured grains disseminated in the cerite or gathered in patches, particularly in the neighbourhood of orthite veinlets. Its hardness is about 4.5.

In thin sections, the mineral shows the same irregular cracks as the cerite, without any regular cleavage directions. The refraction is of approximately the same magnitude as in the cerite. The birefringence is much higher, however, amounting for $\gamma - \alpha$ to 0.028—0.030, while $\beta - \alpha$ does not reach more than about 0.001. It is biaxial with a moderate axial angle, $2\,E = 49°$, which, if β is assumed to be the same as in cerite (1.81), means $2\,V = 26°30'$. The dispersion is very strong, $v > \varrho$. The optical character is positive.

---

[1] Bull. Soc. Franc. Minéralogie, 1904, p. 58.

[2] Ibid., p. 63.

[3] Trans. Real. Acc. Lincei, II, 1877—1878, p. 191—192.

[4] Orthite is here excluded, as hardly translucent in a section of this thickness.

[5] Bull. Soc. Franc. Minéralogie, 1915, p. 121.

The most remarkable property of this mineral is its pleochroism. I cannot agree with LACROIX, who calls it »very weakly pleochroic», and will characterize it as moderately so. The absorption scheme is the following:

$\mathfrak{a}$ = light rosa to greenish yellow
$\mathfrak{b}$ = bluish green
$\mathfrak{c}$ = light rosa
$\mathfrak{b} > \mathfrak{a} = \mathfrak{c}$.

The striking feature is the very marked difference in absorption in directions ($\mathfrak{a}$ and $\mathfrak{b}$) that differ only very slightly in refraction.[1] Thus sections with a very low birefringence exhibit a fairly strong pleochroism when viewed with only one nicol, while those with high birefringence may show no appreciable pleochroism at all.

The mineral does not show any crystal forms. It is often developed in elongated grains, however, with the optical axial plane at right angles to the longer axis. In two specimens, a remarkable intergrowth with orthite has been found. These minerals are often associated and intergrown, but only in these cases is there any regularity in their relations. In thin sections of these specimens, the new mineral is seen to contain numerous parallel narrow lamellæ of orthite. Apparently, each compound grain is built up of alternating shells of the two minerals, the layers of each being oriented crystallographically parallel to each other. Fig. 3 illustrates this phenomenon.

The selection of material for analysis presented considerable difficulties. Particular care was taken to avoid admixture of cerite, orthite, and bastnäsite. The sample could not be entirely freed from chalcopyrite, however, and there were also some foils of molybdenite, but these were too small to have any influence on the analysis. The analysis was made by Dr R. MAUZELIUS, who communicates the following:

»The mineral is slowly dissolved by hot, concentrated HCl. On account of the scant material at hand (1.7 grams), the analysis could not be made so complete as was desirable. For water, the loss at ignition had to be given, although this is justified only by the fact that errors due to the presence of sulphides and fluorine, and of lower oxides of cerium and iron, compensate each other. An attempt to determine the water directly, by the method of Brush Penfield, gave only 0.99 p.c., but it is probable that the temperature was not high enough to drive out all the water. All iron that does not

---

[1] Compare CORNU's observations on blue rock salt (Centralbl. f. Mineralogie, etc., 1907, p. 166), which under pressure shows a marked pleochroism, already when no birefringence could be observed between crossed nicols.

Fig. 3. Microphoto. of cerium ore from Bastnäs, showing intergrowths of orthite and törnebohmite; ord. light, magn. 10 times. The orthite is mostly dark, the törnebohmite white.

belong to the chalcopyrite (calculated from 0.42 p.c. CuO) has been computed as FeO, although a direct determination gave only 1.22 p.c. FeO, as this figure is evidently too low, part of the material remaining undissolved. A small quantity of molybdenite has not been determined. The material did not allow any direct determination of the sulphur. Yttria earths could not be detected with certainty. The average atomic weight of the ceria oxides has been assumed to be 142.

SiO_2	22.05	0.367
Ce_2O_3	27.52	0.084
$(La, Di)_2O_3$	34.85	0.106
Al_2O_3	8.55	0.084
FeO	1.91	0.027
MnO	0.05	0.001
MgO	0.49	0.012
CaO	0.23	0.004
F_2	0.29	0.007
Loss at ign.	1.70	0.094
Chalcopyrite	0.96	
Molybdenite	not det.	
Insoluble	0.95	
	99.55	

Specific gravity = 4.94

If the small amount of RO is recalculated as R_2O_3,[1] one obtains

$$SiO_2 : R_2O_3 : H_2O = 0.367 : 0.289 : 0.101 = 4 : 3.15 : 1.10,$$

which may also be written

$$SiO_2 : R_2O_3 : 2\overset{III}{RO} \cdot OH = 4 : 2.05 : 1.10, \text{ or } R_2 \cdot ROH\ (SiO_4)_2.$$

This result places the mineral in the andalusite topaz group.

It is apparent, however, that it is chemically similar to the cerite. The main differences are its lower figures for CaO and RO in general and for H_2O, and higher for Al_2O_3. Also in several physical qualities does it approach the cerite. The medium refraction, the irregular cracks, and the light rosa colour make it in certain positions almost impossible to distinguish it from the cerite in a thin section in ordinary light. These facts make it necessary to consider the possibility that it may represent an original, unaltered form of cerite, which would be a hydrated product. Those properties that show the greatest difference are the birefringence and the size of the optical axial angle. Since a sinking of the birefringence down to isotropism, accompanied by increase in the water content, is a common feature in several minerals that contain rare earths, the birefringence could not alone prove any difference between cerite and the new mineral. There are other facts, however, which show that the supposed relation between cerite and the new mineral is impossible. There are no intermediate stages in birefringence between the two, nor is the birefringence of the cerite variable. Further, a sinking of the birefringence due to hydration, as often in orthite, is also accompanied by a sinking of the medium refraction, which is not proved in this case. The cerite never surrounds the other mineral as a mantle, as could be expected if it was a product of hydration. If hydration has taken place, it has affected most grains, and changed them completely without leaving any cores, but has left a great number of other grains untouched, which is improbable. It is also to be remembered that the orthite is quite fresh. The elongated form, often observed in the new mineral, is rare in the cerite. Finally, the intergrowth with orthite, and the fact that the new mineral is much more closely associated with orthite than with cerite, in other words, is somewhat *later* than the cerite, decisively prove it to be different from cerite. The intergrowth with orthite points to a similarity in crystal symmetry. The position of the optical axial plane perpendicularly to the elongation is a feature that the new mineral shares with the orthite.

---

[1] Compare ZAMBONINI in Bull. Soc. Franc. Minéralogie, 1915, p. 106.

Neither the chemical nor the physical properties of the new mineral suggest any name for it, and the name of the locality is already used for another mineral species. It therefore ought to be named for some investigator in the field of mineralogy and related sciences. If so, no one is nearer at hand than the late A. E. TÖRNEBOHM, the pioneer in the geological study of the Archæan of Central Sweden and in the use of the microscope in this work. I therefore propose the name *törnebohmite*.

In one thin section, there is observed a mineral that is similar to the törnebohmite in refraction and birefringence, but differs by its greenish yellow colour without any pleochroism, and by its large axial angle.

Biotite. »Mica» or biotite is mentioned in most textbooks as one of the more important minerals of the cerite association. I have never observed it there, however, and although it may occur, it must be very rare. Probably the note in the textbooks has its source in HISINGER's note[1] that »mica» occurs at the *Old* Bastnäs Mine, which is not the cerite locality.

Talc in thin plates, sometimes a centimeter in diameter, is often observed in the orthite veins. There are very strong reasons to believe it to be secondary, pseudomorphous after some other mineral, but the character of this original mineral is unknown.

Asphaltum. »Mineral pitch» is mentioned by HISINGER.[2] It probably occurs in druses, as in so many other mines in Central Sweden.

Paragenesis; textural relations of the minerals; origin of the deposit.

Among the minerals enumerated and described above, the malachite is a product of weathering, partly, at least, formed since the ore blocks were brought to the surface. The asphaltum is a secondary infiltration without any original connection with the deposit. The cuprite, if at all belonging to this locality, in any case is secondary. The lanthanite is an alteration product, showing by its occurrence in cracks and fissures that is was formed much later than the other cerium minerals. The talc is probably pseudomorphous.

If we leave aside the rare linnæite and gold, there remain to be considered the following primary minerals of the deposit: bismuthinite, molybdenite, chalcopyrite, magnetite, quartz, bastnäsite, fluocerite, actinolite, orthite, cerite and törnebohmite. Three paragenetical types can be discerned: the cerite ore, the orthite veinlets, and the actinolite orthite rock, but there are no sharp distinctions between them.

---

[1] L. c.

[2] L. c.

The cerite ore is a fine grained aggregate of equidimensional cerite grains, mostly 0.2 to 1.0 mm. in size, with bastnäsite and generally also with some törnebohmite and a little orthite. The törnebohmite is developed in grains of the same magnitude as the cerite grains, the outlines are irregular in both minerals. The orthite often forms branching, poikilitical individuals, and is more often associated with the törnebohmite than with the cerite. The bastnäsite forms irregular patches in the cerite (compare fig. 1). Only where there are larger areas of bastnäsite one may see it developed as aggregates of prismatic crystals. The törnebohmite seems to be less easily altered than the cerite, as elongated grains of it are often enclosed in bastnäsite

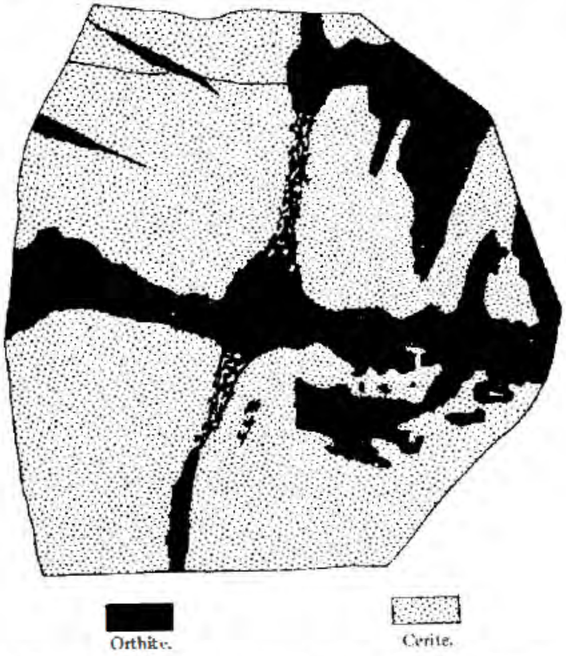

Fig. 4. Cerite ore with replacement veins of orthite. Nat. size. (Drawn from a photograph of a hand specimen).

without exhibiting any signs of replacement. The orthite is not attacked at all. The rare fluocerite also belongs to this association. It is probably formed slightly later than the cerite. Its alteration to bastnäsite has already been described. Much of the cerite ore is almost free from actinolite, but there are also varieties that are very rich in it. It is always developed as radiating aggregates of fine needles. Sometimes these acicular actinolite individuals penetrate orthite and cerite, but more often they show irregular, corroded outlines, and are probably partly replaced by the cerium minerals. Therefore, it is assumed that actinolite was the first mineral to develop, among those now considered. Small interstitial patches of quartz are observed in the cerite aggregates. Sulphides are rare, on the whole. Chalcopyrite is probably most common. It occurs in patches that send out short veinlets between the surrounding grains of cerite, which appear to be to some extent corroded by it. With the chalcopyrite, some magnetite has also been observed.

The cerite ore is interwoven with more or less irregular, often very vaguely defined veinlets of orthite, grading into isolated streaks and patches. These veins vary in width from a fraction of one millimeter up to 5 centimeters, or locally more. Their relations to the cerite show them to be later than this mineral, and at the same time no fissure fillings, consequently they are replacement veins (figs. 4 and 5). It is very probable that the orthites occurring scattered in the cerite are also of this origin. The törnebohmite is also suspected of a similar origin, because of its intimate relations to the orthite.

With the orthite of the veins there is much sulphides, bastnäsite, and talc. Irregular intergrowths of orthite and bastnäsite are sometimes observed under the microscope. In one very narrow vein, the bastnäsite is developed as prismatic grains with idiomorphic contours against the orthite. These grains may be pseudomorphs after fluocerite; but it is more probable — considering the absence of the fluocerite from this association — that they are original bastnäsite. With this exception, the bastnäsite is always later than the orthite. The hexagonal form observed on one grain of bastnäsite, idiomorphic against bismuthinite (see above), is probably the bastnäsite's own. In other cases, the bismuthinite appears to be the older of the two, while mostly their relations suggest a practically contemporaneous development.

All the sulphides are much more common with the orthite than with the cerite. They are later than the orthite, occupying the interstices between grains of this mineral. The orthites enclosed in chalcopyrite are generally somewhat corroded, while those in bismuthinite have their crystal faces intact.

There is seen on the dumps a considerable amount of material containing only orthite and actinolite, with some chalcopyrite. There is no sharp limit between this association and the cerite ore with some orthite on one hand, the actinolite bearing magnetite ore on the other. As lumps of cerite ore with veins of orthite are found enclosed in actinolite skarn with orthite and some chalcopyrite and magnetite, it is probable that the cerium ore is, on the whole, somewhat older than the skarn magnetite ore.

When considering the origin of this unique mineral deposit, two significant facts must be kept in mind: the analogies between this deposit and others in the immediate neighbourhood, which show themselves to have been formed through metasomatic processes in limestone, and the mineral association, which includes minerals characteristic of granite pegmatites and of deposits originated through pneumatolytic replacement at igneous contacts. The fluocerite is a pegmatite mineral, molybdenite and bismuthinite are relatively often observed both in pegmatites and in contact deposits, chalcopyrite is rare in pegmatites but a common mineral in contact ore deposits, and the orthite is rather common in pegmatites and not rare in contact deposits. The actinolite is very often found in contact deposits.

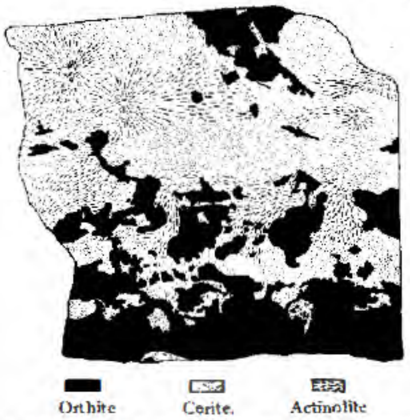

Fig. 5. Cerite ore with actinolite aggregates, and replacement veins of orthite. Nat. size. (Drawn from a photograph of a hand specimen.)

We can therefore conclude that the cerium ore deposit of Bastnäs was formed through processes of the same nature that are active at the building up of a typical contact ore deposit: metasomatic replacement of limestone at a high temperature through compounds that were probably carried in a gaseous state.

The question of the source of these substances raises a geological problem of wide reach. and the discussion must be deferred until the study of the geology of the district is completed.

The Gyttorp mine near Nora[1] is the only ore deposit in Central Sweden outside the Riddarhyttan district that shows any important analogies to the cerium deposit of Bastnäs. In this mine, orthite has been found in considerable quantities, associated with skarn bearing magnetite ore. Biotite, actinolite and molybdenite are important members of this mineral association.

---

[1] G. NORDENSTRÖM, l. c.