THORTVEITITE

A SILICATE OF SCANDIUM, $(\mathbf{Sc},Y)_2\,Si_2O_7$

BY

JAKOB SCHETELIG

Several years ago I published a preliminary paper[1] on a new mineral species from Sætersdalen in Norway, named thortveitite after my late friend Mr. OLAUS THORTVEIT[2]. The discovery of this mineral was important in as much as it is the first known to contain the rare element scandium as chief constituent. The formula of the mineral is $(\mathbf{Sc},Y)_2Si_2O_7$ with about 40 % Sc_2O_3.

The mineral was first found in a small feldspar quarry at Landsverk in the parish Evje, Sætersdalen, by the late Mr. PER SCHEI[3], who labelled it "epidot", the material being insufficient for a closer investigation. In 1910 a lot of fragmentary crystals of a grayish-green mineral was sent me from Mr. THORTVEIT, and my examination proved immediately, that the mineral was new and hitherto unknown. THORTVEIT discovered the mineral in a small feldspar quarry at the farm Ljosland in the parish Iveland, Sætersdalen. The specimen collected by SCHEI was afterwards identified as the same mineral species.

After the publication of my preliminary paper I have obtained an excellent material of thortveitite partly collected by myself and partly sent me from THORTVEIT. Many of my

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[1] J SCHETELIG. Ueber Thortveitit ein neues Mineral. Centr. Bl. f. Min. 1911 P. 721. (Prel. Pap.)

[2] † 1915.

[3] † 1905.

earlier statements have been modified especially through investigation of some splendid small crystals from a little feldspar quarry at the farm Eptevand in Iveland. This occurrence was also discovered by THORTVEIT. A fourth occurrence at the farm Unneland in Evje I have incidentally discovered myself.

My work on this mineral was finished in 1917, but the detailed paper is unpublished and may remain so for some time yet[1]. Meanwhile LACROIX's recent publication[2] of a note on thortveitite from Madagascar[3] makes it desirable to publish in advance the results of my own work on the mineral thortveitite. The present paper is in substance a brief extract from the manuscript of my final paper.

Occurrence and paragenesis. Four occurrences of thortveitite are known, all located in Sætersdalen:

(1) Ljosland and (2) Eptevand in Iveland,
(3) Landsverk and (4) Unneland in Evje.

The mineral belongs to the normal association of minerals of the granite pegmatites and always seems to occur in dykes of relatively small size but characterised by an abundance of rare minerals. The paragenesis is the same for all the four occurrences: *euxenite, monazite, alvite, ilmenorutile, thortveitite, beryl, magnetite, biotite, muscovite, oligoclase, microcline,* and *quartz.* The latter is partly simultaneous with the feldspars forming graphic granite both with oligoclase an microcline.

The crystals of thortveitite are comparatively large. In the feldspar quarry at Ljosland I have observed a crystal

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[1] The final paper is planned and written as part of a monograph on the rare earth silicates of the Norwegian granitic pegmatite dikes, which professor W. C. BRØGGER, Th. VOGT and I have been working on intermittently for some years. Other work have prevented us from completing this monograph but most of the work is now done and we expect to have it ready for publication in a near future.

[2] Compt. Rend. Acad. Sc. 171. Paris. Aug. 1920.

[3] Through the kindness of Mr. LACROIX I have got a fragmentary crystal of thortveitite from Befanamo, Madagascar. The mineral is in every respect identical with the thortveitite from Sætersdalen. The colour however is dark reddish brown due to intermixture with Fe_2O_3.

35 cm. long and as much as 4 cm. thick, of which fig. 1 shows the middle part. Fragments of crystals measuring 10 cm. × 2 cm. are very common. As a rule the crystals are badly developed with rough faces not fitted for goniometric measurements, partly due to polysynthetic twinning and partly due to development of vicinal forms or faces of deformation. The prismatic crystals with (110) predominating seldom show any terminal faces and without exception form complex multiple twins. The axial ratios are determined on two small crystals from Eptevand tabular // (110). The smaller one (fig. 3) is the only found single crystal, the other is a twin crystal after (110) and consists of two individuals. Fragments of other small tabular crystals with similar development of the forms were found at the same locality, but they broke during the preparation.

Crystallographic and physical properties. Thortveitite crystalizises in the normal group of the *monoclinic* system[1].

The large crystals as a rule show only the unit prism (110), but sometimes also some vicinal unit pyramids (hhl) e. g. (551) and (552)[2]. One crystal shows the base (001). Plate I, fig. 1.

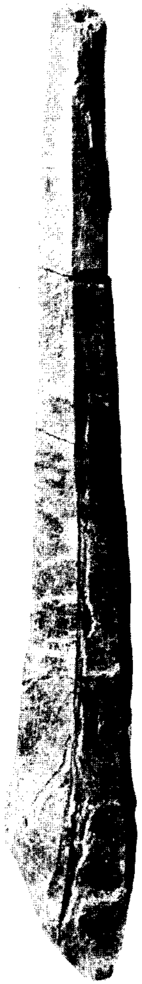

Fig. 1

The small crystals from Eptevand show the following forms:

m (110), p (111), o $(\bar{1}11)$, c (001), u $(\bar{1}31)$ and v (141).

The single crystal of which fig. 2, a. shows a projection $\perp$ c-axis is unique. The others are always twin-

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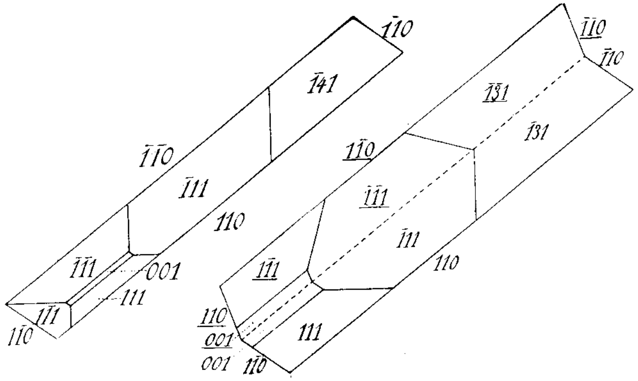
[1] In the Preliminary Paper it was described as belonging to the orthorhombic system. This statement was chiefly based upon an approximate determination of the optical properties in thin sections, the material available at that time not being sufficient for exact determinations of the optical or crystallographic properties,

[2] In Prel. Paper noted as resp. (221) and (111).

ned according to the law: *twinning axis normal to* (110), *twinning plane* (110), *composition plane* (110). Fig. 2 b shows a projection of the small twin crystal from Eptevand.



a. Fig. 2 a and b. b

As fundamental angles for calculation of the axial ratio I have chosen:

m : m'''	$(110):(1\bar{1}0)$	73° 38′	(±2′)
m : c	$(110):(001)$	80°	(±20′)
m′ : o	$(\bar{1}10):(\bar{1}11)$	53° 20′	(±10′)

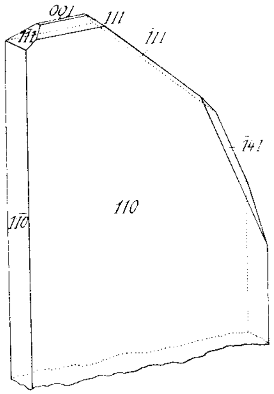


Fig. 3.

From these angles the axial ratios and the angle β were calculated as follows:

$$a : b : c \; 0,7674 : 1 : 0,5569, \quad \beta = 77° \, 28'$$

The angle β is directly measured to 78°.

The table on page 237 gives the measured and calculated angles.

Due to the imperfect development of the crystals the agreement between the measured and calculated angles is only approximate.

The tabular crystals were measured on a Fuess goniometer furnished with a theodolitic suffix according to professor V. M. GOLDSCHMIDT, Kristiania. It is worth being noticed that the angle of the unit prism — 73$^1/_2$° — is characteristic of thortveitite but otherwise seldom observed.

Table of angles on thortveitite.

		Measured	Calculated
m : c	$(110):(001)$	*80°	—
m : m'''	$(110):(1\bar{1}0)$	*73° 38	—
m : m′	$(110):(\bar{1}10)$	106° 24′	106° 22′
m (I) : m''' (II)	$(110):(1\bar{1}0)$	32° 42$^1/_2$′	32° 44′
m′ : o	$(\bar{1}10):(\bar{1}11)$	*53° 20′	—
m : p	$(110):(111)$	43° 39′	43° 6′
m'' : o	$(\bar{1}\bar{1}0):(\bar{1}11)$	85° 43′	86° 12′
m'' : u	$(\bar{1}\bar{1}0):(\bar{1}31)$	106° 7′	106° 54′
m'' : v	$(\bar{1}\bar{1}0):(\bar{1}41)$	112° 30′	111° 38′
p : p′	$(111):(1\bar{1}1)$	44° —	42° 52′
p : o	$(111):(\bar{1}11)$	63° 42′	62° 40′
p : o′	$(111):(\bar{1}\bar{1}1)$	82° 58′	83° 34′
m : t	$(110):(211)$	37° —	36° 35′
m : δ	$(110):(551)$	11° 30′	12° 28′
m : ϱ	$(110):(552)$	21° 57′	21° 52′
m : π	$(110):(332)$	32° 54′	32° 40′
m : q	$(110):(335)$	55° 30′	54° 30′
m : r	$(110):(113)$	64° 55′	64° 0′

Cleavage seems to be distinct // (110) and cleavagetracks are easily shown in thin sections ⊥ c-axis. Perhaps it is more correctly interpreted as a pseudocleavage due to twinning lamellæ // (110).

Fracture uneven to conchoidal. The mineral is very brittle, and the crystals show innummerable cracks and are therefore easily broken to pieces.

Hardness is between 6 and 7.

The specific gravity is 3,57, mean of two determinations with the pycnometer at 25° C.

Etchingfigures produced on (110) with hydrofluoric acid have unsymmetrical triangular outlines in agreement with the monoclinic symmetry. *Luster* vitreous to subadamantine.

Streak nearly white to light grayish green.

Radioactivity. Radiation of α- and β-rays not measurable, in agreement with the absence of uranium and the presence of nothing but traces of thorium.

The small crystals from Eptevand are transparent, of pure green colour and show distinct pleochroism: $\alpha > \beta = \gamma$, α is deep and pure green, β and γ are yellow to brownish yellow. The pleochroism is too weak to be noticed in thin sections of the usual thickness. Therefore I have earlier described the mineral as not pleochroic. The large crystals are subtranslucent to opaque. The colour is grayish green to gray for subtranslucent substance, and grayish white to reddish white for opaque.

Thortveitite itself is always fresh and never show any trace of alteration to the amorphous condition, usually met with in minerals containing rare earths and at the same time radioactive elements. The explanation of this fact I think is found in the absence of the radioactive elements uranium and thorium. On the other side indications of an initial alteration of this kind are met with when the thortveitite contains included crystals of radioactive minerals such as euxenite and monazite, the altered sustance then forming narrow rims around the minute inclusions.

Optical properties. Thortveitite is optically negative. The plane of the optic axes is (010), $\beta = b$, the angle $c : \alpha = 4° - 6°$, in the obtuse angle β. In thin sections // (010) the observed angle of extinction is very small.

The principal refractive indices are determined on three prisms cut with their refractive edges // respectively to α, β and γ. The table shows the results.

Table of refractive indices.

	α	β	γ
Red light	1,7521	1,7886	1,8055
Na „	1,7561	1,7926	1,8093
Green „	1,7617	1,7980	1,8151
Blue „	1,7728	—	1,8293

Table of birefringence.

	$\beta - \alpha$	$\gamma - \beta$	$\gamma - \alpha$
Red	0,0365	0,0169	0,0534
Na	0,0365	0,0167	0,0532
Green	0,0363	0,0171	0,0534
Blue	—	—	0,0565

The mean refractive index β is high: 1,793 and the birefringence $\gamma - \alpha$: is high: 0,053.

The axial angle $V\alpha$ is calculated from the refractive indices for Na-ligth:

$V\alpha = 32° 45'$ $2 V\alpha = 65° 30'$[1] $2 E\alpha = 152°$.

The axial angle is also determined directly in a thin section cut approximately ⊥ one optic axis. The direct determination has given $2 V\alpha = 66°$ in good agreement with the calculated value.

Chemical composition of thortveitite. The ground mineral has a grayish green colour, changing to reddish white by strong ignition, (probably due to oxidation of FeO to Fe_2O_3). The powder is partially decomposed by conc. HCl but without gelatinizing. The hydrochloric solution contains FeO.

A preliminary examination made by me at Vienna in 1910 has shown that the mineral chiefly was a silicate of rare earths. A spectrographic examination of the solution of the contained earths kindly made by professor EXNER, director of the physical laboratory at Vienna, at my request, has given the following result.

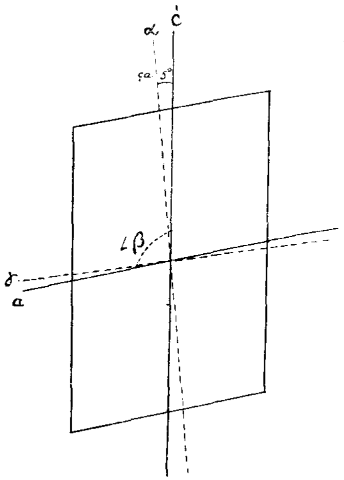


Fig. 4.

Present:	*bulk:*	*Sc*
	very strong:	Y
	strong:	Dy, Er
	distinct:	Ad, Cp, Tm
	traces:	Gd, Nh, Th
Absent:	Be, Eu, Pr, Nd, Sa, La, Ce, Zr.	

Later G. EBERHARD, Astrophysical Institute at Potsdam has repeated the spectrographic examination of thortveitite from Ljosland, the results being identical with those of EXNER. EBERHARD has also kindly made spectrographic examination of thortveitite from two of the other known localities: Eptevand and Unneland. According to a letter from EBERHARD[2] the com-

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[1] In my Prel. Paper 2 V is erroneously stated to be about 80°.

[2] The letter is to be printed the final paper.

position of the mineral from all these three occurrences is quite identical.

The chief result of the spectrographic examination is that the bulk of the oxides consists of scandia, Sc_2O_3 and that the whole series of the rare elements of the yttrium group (incl. ThO_2) are present. Highly interesting is also the absolute absence of the elements of the cerium group.

The quantitative analysis of thortveitite has presented considerable difficulty, chiefly because the analytical methods for separation of Sc fail in this case, when scandium is met with as chief constituent of a complex silicate. In the final paper I have discussed the different analyses of thortveitite at some length. On this occasion only the results are given with some critical remarks added for closer information.

The following table shows the results of two analyses of thortveitite. For both analyses I have chosen well selected fresh material, and the close agreement between the two independent determinations of the spec. gravity proves the identity and the purity of the material in both cases.

Analyses of thortveitite.

	I		II	
	J. Schetelig.		J. Sterba, Prague.	
	$^0/_0$	Mol. numb.	$^0/_0$	Mol. numb.
SiO_2	42,9	0,710	45,45	0,752
Sc_2O_3	37,6	0,272	42,06	0,309
$(Y, Dy, Er,)_2O_3$	17,7 (270)[1]	0,065	8,89 (320)	0,028
Fe_2O_3	2,1	0,013	2,83	0,018
FeO	0,8	0,011	—	—
BeO	—	—	0,51	0,020
Ign.	0,4		0,54	
	100,9		100,28	
	G = 3,57		G = 3,566	

As my experience in the difficult work of analysing rare earth minerals is rather limited I can claim no more than approximate accuracy for the results of analysis I made by

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[1] Calculated from the values of mol. weight for Y_2O_3 determined by dr. Tauchert, Munich. Cfr. p. 242.

myself in 1911[1]. Nevertheless the recalculation of these results to molecular ratios, as shown below, gives very reasonable figures which may indicate that the analysis is not far from being correct.

$$SiO_2 : R_2O_3 = 0{,}700 : 0{,}350 \text{ or } 2 : 1$$
$$SiO_2 : FeO = 0{,}010 : 0{,}011 \text{ or nearly } 1 : 1$$

The thortveitite may therefore be considered a diorthosilicate of Sc, Y, Dy, Er, . . . and Fe‴. The small amount of FeO is possibly present as metasilicate.

The analysis II, kindly made at my request by professor dr. JAN STERBA-BÖHM, Prague, in 1915, shows figures, that differ considerably from those of analysis I. STERBA has found BeO, but EXNER and EBERHARD have independently stated that the lines of the element Be are absent in the spectrogramme of thortveitite. The only possible explanation of this discrepancy is, that the material analysed by STERBA may have been accidentally intermixed with a small quantity of beryl. But the material was selected by myself with all possible care, and I think this possibility should be excluded, the more so because the spec. gravity of the material used for both analyses is quite identical as mentioned above.

If the different compounds are calculated as diorthosilicates, the following results are obtained:

$$Sc_2O_3 : 2SiO_2 = 0{,}309 : 0{,}618$$
$$\Sigma Y_2O_3 : 2SiO_2 = 0{,}028 : 0{,}056$$
$$Fe_2O_3 : 2SiO_2 = 0{,}018 : 0{,}036$$
$$\overline{R'''_2O_3 : 2SiO_2 = 0{,}355 : 0{,}710}$$

If the amount of BeO is also calculated as diorthosilicate, it requires 0,014 SiO_2. The amount of SiO_2 necessary to saturate the total amount of oxides is 0,724, (expressed in molecular numbers). The calculation gives an excess of 1,69 $^0/_0$ SiO_2, and I think therefore, that the figure in analysis II is too high. The analysis I shows no deficit of SiO_2 or, if FeO is calculated also as diorthosilicate, a deficit of only 0,7 $^0/_0$ SiO_2, and is therefore probably more correct.

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[1] The methods used are mentioned in my Prel. Paper of 1911.

The analysis II shows 5 % more Sc_2O_3 than the analysis I and this difference is more difficult to explain. The lower figure of anlysis I is corroborated by an incomplete analysis, made by dr. TAUCHERT, assistant to the late professor MUTHMANN, Munich.

Incomplete analysis of thortveitite.
Analyst: dr. Fr. Tauchert, Munich.

SiO_2	(45,55)[1]	(0,721)
Sc_2O_3	38,61	0,283
Y_2O_3	10,47 (226)	0,046
$(Dy, Er,)_2O_3$	4,26 (380)	0,011
Fe_2O_3	3,13	0,020
	100,02	

The figures for Y_2O_3 and $(Dy,Er)_2O_3$ determined by dr. Tauchert, show good agreement with the spectrographical results. STERBA on the other hand has determined the bulk of $(Y, Dy,Er)_2O_3$ to 8,89 % with molecular weigth 320, indicating that the amount of Y_2O_3 is smaller than the amount of $(Dy, Er)_2O_3$. This is opposite to the results obtained by EXNER and EBERHARD.

At present I think a further discussion about the real composition of thortveitite is purposeless. At my request A. RØDLAND, chief chemist of the Mineralogical Institute, Kristiania, (director professor dr. V. M. GOLDSCHMIDT) has undertaken on broad base a new investigation of thortveitite, including a critical revision of the analytical methods for determination of Sc_2O_3. The results will be published by RØDLAND.

In short summary the results of the chemical and spectrographical investigations are, that *thortveitite is a diorthosilicate of scandium and the other elements of the yttrium group,* connected with a small amount of Fe_2O_3 and FeO, and that *the amount of Sc_2O_3 is about 40 %.*

Thortveitite is chemically closely related to the mineral *thalenite* (C. Benedicks), a diorthosilicate of yttria: $(Y, Er)_2Si_2O_7$,

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[1] The amount of silica is only calculated, as the material used for the analysis contained quartz as impurity, being decided only for preliminary experiments.

but the axial ratios and the optical properties differ from those of thortveitite. The minerals *yttrialite* and *rowlandite* are also chiefly diorthosilicates of yttria, but only known in altered and amorphous condition. The other known silicates containing rare earths of the yttrium group: *kainosite, hellandite* and *gadolinite* have a more complex chemical composition and are neither geometrically nor optically related to thortveitite.

I have recently noticed that E. ARTINI during the war time published a short paper[1] on a new scandium mineral, *bazzite,* occurring in minute crystals on quartz and red orthoclase in druses in the granite from Baveno, Italy. A qualitative chemical test has shown, that the mineral is a silicate of scandium and other rare earths with Fe and a small amount of Na. The mineral occurs in small hexagonal crystals of prismatic habit, the colour is skye blue. The mineral is opt. negative, uniaxial and strongly dichroïc. According to the physical properties the new scandium mineral *bazzite,* shows no relationship to thortveitite.

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[1] Rend. Acc. Linc. 1915. 24 (1) 313.

List of illustrations.

Fig. 1. A fragment of the biggest known crystal of thortveitite from Ljosland. 2/3 of natural size.
Fig. 2 a) Projection $\perp$ c-axis of the single crystal from Eptevand.
" b) Projection $\perp$ c-axis of the twin crystal from Eptevand.
Fig. 3. Drawing of the single crystal forom Epteland.
Fig. 4. Section // (010) showing the optical orientation.
Plate I. 1. Crystal in of thortveitite in matrix showing (110) and (001). Natural size.
2. Crystal thortveitite in matrix. Natural size.
Plate II. Group of crystals of thortveitite in pegmatite (quarz and feldspar from Ljosland). 2/3 of natural size.

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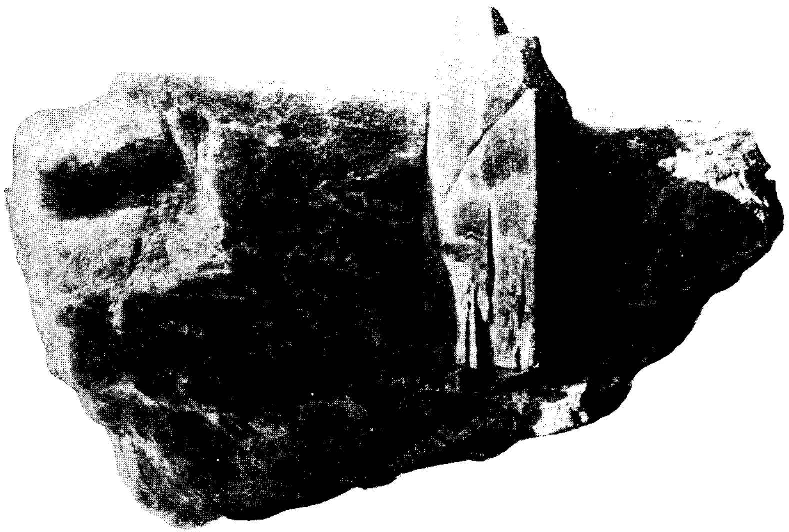

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Fig. 1.

ca. 1/1

Fig. 2.