American Mineralogist, Volume 71, pages 188–193, 1986

Thalenite from Arizona

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Abstract

Thalenite occurs as a minor constituent of a single small pegmatite within an extensive area of granite a few miles south of Kingman, Arizona. Crystals are large but not faceted, and it is partly crystalline and partly metamict. The composition of this thalenite corresponds to $Y_3[Si_3O_{10}](OH)$, with extensive substitution of Y by RE elements, especially Dy, Er and Yb. Upon heating, even at moderate temperatures, both the crystalline and the metamict thalenite are converted to a phase with a structure corresponding to that of thortveitite, $Sc_2Si_2O_7$.

Introduction

Thalenite was first described from Österby in Dalekarlia, Sweden (Benedicks, 1898, 1900), and soon thereafter from Åskagen in Värmland, Sweden (Sjøgren, 1906). Vogt (1922) reported it from the island of Hundholmen in northern Norway, and later (Schetelig, 1931; Bjørlykke, 1939) it was recorded as occurring in half a dozen or more granite pegmatites in southern Norway. Finally, Griffin et al. (1979) described another occurrence in Reiarsdal, Vest-Agder, Norway. There is one occurrence in Finland, in the Pyörönmaa pegmatite (Vorma et al., 1966), and it has been reported from two vaguely described localities in Russia: "Eastern Siberia" (Skorobogatova et al., 1965) and the "northwestern rare-earth belt of the USSR" (Kornev et al., 1972). In Japan it has been found in Nosen Village, Yamanashi Prefecture (Nagashima, 1952) and at Suishoyama, Fukushima Prefecture (Nagashima and Kato, 1966). In the United States, thalenite has been reported from two localities in Colorado (Adams et al., 1962; Adams and Sharp, 1972) and from a locality near Kingman in Arizona (Pabst and Woodhouse, 1965).

The Arizona occurrence

The thalenite locality is in the NE¼ of the NW¼ of Sec. 15, R 17 W, T 20 N on the Kingman SE (1/24000) quadrangle, Mohave County, approximately 4½ miles (ca. 7.2 km) slightly W of S of Kingman, Arizona. It is indicated by a small *x* near the 3250 foot level on the topographic map and is designated "Prospect." This is in an area of "granite and related crystalline intrusive rocks" identified as "Older Precambrian" on the geologic map of Mohave County, Arizona, (1/375000) (Wilson and Moore, 1959).

At the time of the visit to the locality in 1970, the exposed pegmatite was about 24 meters long and 3 to 6 meters wide, trending N 33°E, fairly straight and not parallel to the general N–S lineation of the enclosing granitic rocks, which here is not prominent. The pegmatite was well-exposed by a trench, with claim stakes nearby. The surrounding granite is traversed by quartz veins, up to about a hundred meters in extent, parallel to the lineation. No other pegmatites were seen.

Associated minerals

The pegmatite is made up almost entirely of quartz and microcline; hematite, biotite and zircon are present in minor amounts. The zircon is anhedral and uniformly dark grey with a density of 4.2 and refractive index near 1.89. According to the table summarizing the properties of zircons given by Deer et al. (1962, vol. 1, p. 63), this is a "metamict" to "intermediate" zircon. No coarse thalenite was visible in 1970; presumably all easily recognizable thalenite had been removed. However, scanning by Geiger counter revealed an area of increased radioactivity at the south end of the trench. Material collected there was subsequently found to carry a small amount of fine-grained thalenite. No other minerals were seen in the pegmatite or identified in the material collected.

Benedicks (1900) and Vogt (1922) have described the morphology of thalenite from Österby, Sweden and from Hundholmen, northern Norway. Sjøgren (1906) mentions only that the thalenite at Åskagen in Värmland, Sweden, occurs in head-sized or larger crystals but makes no mention of morphology. Later workers have not described any well-formed crystals. However, thalenite is generally found as the large crystals characteristic of pegmatites, even though it may also be present in small grains, such as the thalenite remaining in place at the present locality.

0003–004X/86/0102–0188$02.00

Table 1. Early analyses of thalenite

1 Österby, Dalekarlia, Sweden		2 Askagen, Värmland, Sweden		3 Hundholmen, Northern Norway		4 Høgtveit Evje, Setesdalen Norway	
SiO_2	29.88	SiO_2	28.88	SiO_2	29.	SiO_2	29.4
Y_2O_3 (R_2O_3 = 245.3)	63.35	Y_2O_3 (at wt.106.6)	61.84	Y_2O_3 }		ΣY_2O_3	47.5
Fe_2O_3	0.30	Fe_2O_3, etc.	0.45	Fe_2O_3 }	64.34	Fe_2O_3	4.0
Al_2O_3 + BeO	0.45	La_2O_3, Di_2O_3, etc.	4.15	Al_2O_3 + BeO }		Al_2O_3	3.0
CaO	0.49	CaO	0.11			CaO	1.8
MgO	0.21	MgO	0.05			MgO	0.3
Na_2O	0.26	Na_2O	0.08			FeO	0.2
SnO_2	0.23	SnO_2	0.22			ThO_2	1.6
H_2O	2.08	ThO_2	0.18	H_2O	0.75	U_2O_3	1.0
CO_2	1.04	Ce_2O_3	0.83			MnO	0.3
N, He, etc.	1.40	ig. loss	3.33			Alk	0.2
						H_2O -110°C	2.3
						H_2O +110°C	6.8
						P_2O_5	0.7
						CO_2	0.7
	99.69		100.12				99.8
S.G	4.227		4.41		4.454		"G=3.4-3.5"

1. Benedicks (1900). 2. Sjögren (1906). 3. Vogt (1922). 4. Schetelig (1931).

Table 2. Yttrium and rare-earth-elements oxides only in six recently analyzed thalenites

R_2O_3	1 Eastern Siberia	2 Japan, Suishoyama	3 Norway, Reiarsdal	4 Colorado, Teller County	5 Colorado, South Platte area	6 Arizona, Mohave County
Y	41.62	49.57	38.6	32.6	44.0	44.53
Lu	0.55		6.7	0.83	0.8	
Yb	5.58	7.55	20.4	4.4	5.7	5.14
Tm	1.78		1.9	0.59	0.6	
Er	5.58	3.83	3.2	3.8	3.5	2.99
Ho	1.47		0.44	1.1	1.2	0.50
Dy	3.93	2.79	0.66	4.3	4.3	3.61
Tb	0.37	0.13	0.01	0.72	0.1	
Gd	0.68		0.03	2.8	1.7	
Eu			0.07	0.01	0.1	0.00
Sm	tr.	0.13	0.05	1.6	0.8	
Nd	tr.	0.19	0.00	2.0	1.1	0.40
Pr			0.00	0.42	0.2	
Ce	0.68		0.00	1.2	0.5	0.28
La				0.31	0.3	0.00
Σ	62.24	64.89	72.06	56.68	64.9	57.45

1 Skorobogatova et al., (1964); 2 Nagashima and Kato, (1966); 3 Griffin et al., (1979); 4 Adams and Sharp, (1972); 5 Adams et al., (1962); 6 Microprobe analysis by J. Fitzpatrick

Composition and formula

Analyses of the first known thalenites (Table 1) do not list the REE oxides; for comparison, in Table 2 are given the REE oxide contents only with totals thereof for several recently analyzed thalenites. Though there is wide variation of the substitution of REE for yttrium, the principal REE are the same; Dy, Er and Yb. Many different chemical formulas have been assigned to thalenite, but $Y_3Si_3O_{10}(OH)$ may now be considered as established, both by modern chemical analyses and by the determination of the crystal structure (Kornev et al., 1972).

Physical properties

Table 3 gives the refractive indices and 2*V*, cell dimensions or axial elements, and density for thalenite from various sources and for the Arizona thalenite. With the exception of the low values for density of the Setesdal thalenite (Schetelig, 1931, Table 1) and that reported by Skorobogatova et al. (1964, p. 112), there is little variation. The cell dimensions scarcely vary beyond the limits of error. β varies from 1.716 to 1.739 and the density ranges from 4.16 to 4.41. The lower densities referred to above seem to be anomalous, even lower than one would expect for metamict thalenite with high water content.

The axial elements given by Vogt (1922) correspond well to the cell dimensions reported by Kornev et al. (1972) and herewith. The optical orientation of thalenite is: acute bisectrix (neg), α, parallel to **b**; plane of optic axes very nearly normal to **c**.

Thalenite is often metamict, and both metamict and non-metamict thalenite may exist together, as in the Arizona and Iveland occurrences (Fig. 1). The metamict character is caused by the radiation from uranium and thorium which occur in small amounts (up to one or two weight percent) in most analyzed thalenites. Due to the U and/or Th, it is possible to obtain excellent autoradiographs of thalenite cut to provide a plane surface. Figure 2 shows an autoradiograph of a small slab of thalenite weighing about 75 g, together with a parallel photograph of the same specimen. The close correspondence of the two pictures, even in the leached crust, is striking.

X-ray data

Cell dimensions of the thalenite from near Kingman, Arizona, and from Österby, Dalekarlia, Sweden (Table 3), were determined from single-crystal X-ray diffraction data. These dimensions are in close agreement with those reported by Kornev et al. (1972) and Bataliyeva et al. (1967) for thalenite from unspecified localities in the USSR. Unfortunately, these authors reported no powder diffraction data. Adams et al. (1962, table 121.1) gave unindexed, powder diffraction data for thalenite from Teller County, Colorado, and from Österby and similar measurements were carried out for the Arizona thalenite. These powder patterns are compiled in Table 4.

Table 3. Numerical data for Arizona thalenite and from the literature

	Locality	α	β	γ	2V	a	b	c	β	a:b:c	S.G.
1.	near Kingman, Arizona	1.716	1.723	1.729	-69±2°	10.38Å	11.16	7.319	97°14'	0.9301:1:0.6558	4.41±0.05
2.	Teller County, Colorado	1.719	1.739	1.748	-67°30'						4.396
3.	Österby, Dalekarlia, Sweden	1.725	1.733	ca.1.738		10.38	11.22	7.33	97°20'	0.9251:1:0.6533	4.35±0.05
4.	Österby, Dalekarlia, Sweden	1.7312	1.7375	1.7436	67°35'				60.2°	1.154:1:0.602	4.227
5.	Hundholmen, northern Norway										4.45
6.	Setesdal, southern Norway										3.28-3.62
7.	Suishoyama, Japan	1.709	1.716	1.723	~79°						4.16
8.	"Eastern Siberia" U.S.S.R.	1.730		1.744	-70°						3.64-3.72
9.	U.S.S.R. locality not reported	1.717	1.736	1.746	-68	10.343	11.093	7.294	96°55'	0.9324:1:0.6575	4.34
10.	U.S.S.R. no locality reported					10.35	11.22	7.31	96°55'	0.9225:1:0.6515	

1. this study 2. Adams et al.(1962) 3. this study 4. Benedicks (1900) 5. Schetelig (1931) 6. Schetelig (1931) 7. Nagashima and Kato (1966) 8. Skorobogatova et al. (1964) 9. Kornev et al. (1972) 10. Bataliyeva et al. (1967)

Metamict thalenite cannot be reconstituted to its original structure by heating. This is due to the fact that heating dehydrates the metamict thalenite and converts it to $Y_2Si_2O_7$ with thortveitite-type structure. Attempts to synthesize $Y_2Si_2O_7$ under hydrothermal conditions at 330°C, 1866 psi and at 500°C ca. 15000 psi from the mixed oxides gave only the thortveitite-like phase.

Sintering mixtures of the component oxides at 1170°C and at 1300°C with and without borax flux produced little reaction and no indication of thalenite or any $Y_2Si_2O_7$.

Related phases, crystal data

Felsche (1970, 1970a) listed four distinct crystal structures of $Y_2Si_2O_7$ in the space groups $P1$, $C2/m$, $P2_1/a$ and $Pna2_1$, and designated them the α, β, γ, and δ types (1970). Smolin and Shepelev (1970) also listed four types of REE pyrosilicates, not including the triclinic type but including a second orthorhombic type in the space group $P2_12_12_1$. Five structure types are known for the REE pyrosilicates, and one of these, the thortveitite type ($C2/m$), occurs in nature as $Sc_2Si_2O_7$, not a rare-earth silicate.

Bataliyeva et al. (1967) claim to have identified three phases within a nonmetamict thalenite from Österby, Sweden, the γ type, the β type corresponding to thortveitite and thalenite. It seems strange that three phases should exist within a single crystal, especially as the material examined was from the type locality and may be presumed to have corresponded to the fine, form-rich crystals described by Benedicks (1900). No other observers have reported comparable composite material.

Relation of yttrialite to thalenite

Yttrialite was named by Hidden and Mackintosh (1889) eleven years before Benedicks named thalenite. They gave the formula as "R_2O_3,$2SiO_2$, in which R_2O_3 may be replaced by its equivalent RO, RO_2 or RO_3." Benedicks gave the formula of thalenite as $H_2Y_4Si_4O_{15}$ when he described and named the new mineral. Strunz and Tennyson (1970, p. 387, 388) assign the formula $Y_2Si_2O_7$ both to yttrialite and to thalenite. Fleischer (1983, p. 163, 183) assigns thalenite the formula $Y_3Si_3O_{10}(OH)$ based on the structure determination of Kornev et al. (1972) but appendix a question mark, (?), and gives the formula $(Y,Th)_2Si_2O_7$, hex.(?) for yttrialite. From this it may seem that the difference is in the water content and in the higher thorium content of yttrialite.

Earlier, Frondel and Fleischer (1952) had stated that yttrialite is "possibly thalenite with much Th," that thalenite is "related to yttrialite" and that rowlandite is "possibly a metamict thalenite." However, Frondel (1961) later showed that rowlandite is a valid species. Yttrialite is known only as a metamict material. None of the later

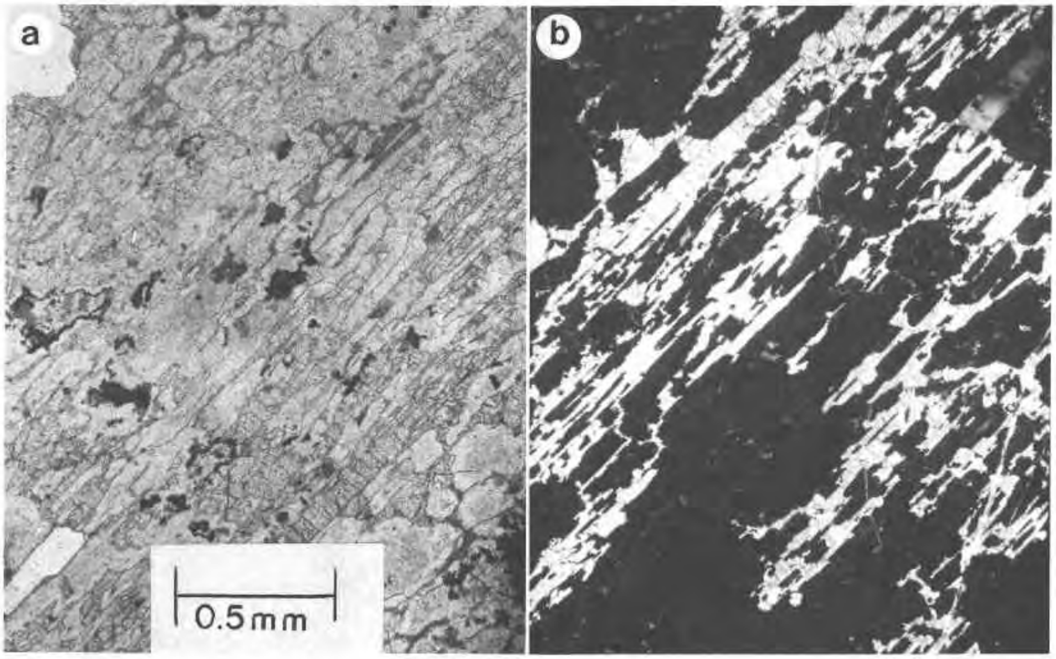

Fig. 1. Thin section of thalenite from Iveland, Setesdal, Norway. A. Left; in polarized light; B. Right; polars crossed, section *not* in "extinction" orientation; dark portions are isotropic thalenite, light portions are anisotropic thalenite, nearly all in parallel orientation.

writers on "yttrialite," Omori and Hasegawa (1953), Takubo et al. (1953), Ueda and Nishimura (1954), Proshchenko (1962), Ito and Johnson (1968), Bataliyeva et al. (1969), Nilssen (1971) or Ewing and Ehlmann (1973) have reexamined type material and most have not even referred to the initial description.

Lacking morphology and optical properties by which yttrialite might be defined, there remain only X-ray diffraction data for its characterization. However, yttrialite is known only as a metamict mineral. Bataliyeva et al. (1969) have published powder patterns of natural yttrialite from Yakutia heated to 900°C, and "synthetic yttrialite" ($Y_2Si_2O_7$ + 4% ThO_2) indexed on the basis of a monoclinic cell: $a = 7.34$, $b = 8.06$, $c = 5.02$ Å, $\beta = 108° 30'$, markedly

Fig. 2. Cut slab of thalenite from near Kingman, Arizona, natural size. Left: photograph; right: autoradiograph; note the effects of radiation from the sides of the specimen.

Table 4. Powder diffraction data for thalenite

		1 near Kingman Arizona		2 Teller County Colorado		3 Eastern Siberia		4 Åskagen Sweden	
hkl	d calc.	I	d obs.	I	d	I	d	I	d
$10\bar{1}$	6.321	w	6.32	5	6.3				
011	6.086	vw	6.11	4	6.07	2	6.11	-	-
020	5.580			2	5.57				
$11\bar{1}$	5.500	m	5.52	20	5.50	5	5.51	3	5.41
200	5.150	w	5.16	3	5.16				
120	4.906			1	4.98				
210	4.676	vvw	4.67	½	4.67	-	-	1	4.77
021	4.424	w	4.43	5	4.44	1	4.33	-	-
$12\bar{1}$	4.163	w	4.17	4	4.17	3	4.14	2	4.20
121	3.958			1	3.95				
220	3.786	m	3.79	25	3.79	5	3.74	3	3.76
002	3.630	w	3.625	5	3.63				
$22\bar{1}$	3.492	w	3.493	4	3.51	-	-	5	3.49
012	3.453	mw	3.453	11	3.44	2	3.29	2	3.29
				2	3.31				
$30\bar{1}$	3.267	m	3.276	18	3.27				
$20\bar{2}$	3.161	m	3.159	18	3.16				
$31\bar{1}$	3.136			11	3.13				
131	3.101	vs	3.104	100	3.10	10	3.08	10	3.09
022	3.044	vw	3.048	4	3.05	-	-	2	3.03
$21\bar{2}$	3.042								
301	2.962	vw	2.959	1	2.96				
311	2.864	w	2.868	6	2.86				
202	2.806	m+	2.808	40	2.81	8	2.800	7	2.814
040	2.790								
$22\bar{2}$	2.750	mw	2.753	30	2.75	-	-	2	2.736
212	2.722								
321	2.617	vvw	2.610	2	2.71				
400	2.575	w+	2.581	6	2.57	2	2.580	2	2.580
222	2.507	w	2.522	4	2.51				

1. This study; 2. Adams et al.(1962); 3 and 4. Skorobogatova et al.(1965). (JCPDS, 19-1450)

different from any of the types recognized by Felsche (1970, 1970a). An unindexed JCPDS card, 18-1469, for "Yttrialite (Ignited 770°C 24 hours)" records a closely similar set of lines.

When yttrialite is heated to higher temperatures, 1000°C or more, another phase is formed. This is represented by JCPDS card 24-1427 (unindexed) which gives data for "Natural yttrialite, Yakutia" heated to 1000°C, taken from Bataliyeva et al. (1969, Table 2) and by card 21-1457 for "α-$Y_2Si_2O_7$," "synthetic, by fusion at 1190°C in air," which carried a reference to Ito and Johnson (1968), data on the card having been taken from table 3, column 1, of these authors. Similar data have been reported by Lima de Faria (1964, table 4) that he attributed to two (or more) phases, an isometric phase, a = 5.41 Å (possibly 10.82 Å) and α-$Y_2Si_2O_7$. Vorma et al. (1966, table 7, columns 2 to 5) simply copy from Lima de Faria. Column 1 of that table shows that thalenite heated to 1000°C yields a pattern similar to those from yttrialite heated to the same temperature. This suggests that yttrialite may be identical with metamict thalenite.

Acknowledgments

Thanks are due to the late C. D. Woodhouse of Santa Barbara, California, for most of the specimens on which this study is based, to Mr. Dwight Sawyer of Henderson, Nevada, for transportation and assistance in the field, to Professor Chr. Oftedahl of Trondheim, Norway, for information and for valuable specimens of thalenite from Norway, to Mr. Robert Jack for the initial X-ray spectrographic examination and to Mr. Joachim Hampel for photography. The facilities of the Department of Geology and Geophysics, University of California, Berkeley, were available to the senior author throughout the long years of this study.

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Manuscript received, February 12, 1985;
accepted for publication, September 16, 1985.