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Thermal expansion of some borate and borosilicate minerals (fluoborite, danburite, sinhalite, datolite, elbaite, dravite, kornerupine, dumortierite, ferro-axinite, and manganaxinite) between 25 and about 1200°C[1]

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[1] This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey editorial standards.

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Abstract

Thermal expansion data are presented for 10 borosilicate and borate minerals. Unit cell parameters are given at 25°C and at temperatures to 1200°C or the decomposition temperature. For a substantial temperature range, each mineral shows linear expansion.

Introduction

Thermal expansion data are rare for borosilicate and borate minerals. As part of a larger study of boron-bearing minerals (see Hemingway et al., 1990, and Mazdab et al., in prep.), we have determined the volumetric properties of several borosilicate and borate minerals as a function of temperature. These data will help define the stability fields of these minerals and their behavior in geologic processes, e.g., hydrothermal systems.

Samples

Chemical analyses for most of the samples studied here are given by Mazdab et al. (in prep.) who give complete details, but their results are also provided here in Table 1 for the convenience of the reader.

Fluoborite (ideal formula, $Mg_3BO_3F_3$) was separated from pieces of Franklin Marble from Crystal Springs Quarry, Rudeville, New Jersey (supplied by Dr. Paul Moore of the University of Chicago). The pieces of marble were dissolved in 1:1 HCl. Fluoborite was separated from the residue by heavy liquid and hand picking. Fluoborite shows a weak creamy yellow fluorescence under short wavelength ultra violet light (Paul Moore, personal communication) which aided the manual separation process. The fluoborite occurred as loose, buff-colored, hexagonal prisms up to 5 mm in length.

X-ray powder diffraction data were taken at 25°C for fluoborite at both the University of Arizona (UA) and the U.S. Geological Survey (USGS). The unit cell was refined from 37 reflections (silicon internal standard) by Mazdab (UA) who obtained a = 8.8398(9) and c = 3.1003(6) Å using the Appleman and Evans (1968) program. Evans (USGS) refined the unit cell from 39 reflections using the Guinier-Hägg method with silicon as an internal standard and found a = 8.8393(6) and c = 3.0997(4), V = 209.75(3) Å^3, and space group $P6_3/m$.

Danburite (ideal formula, $CaB_2Si_2O_8$) was separated from a large crystal aggregate donated by Dr. Peter Megaw, who collected the material from a skarn deposit located in Charcas, San Luis Potosí, Mexico. Inclusion-free crystal tips, gemmy and colorless, were separated and gently crushed. Small amounts of sphalerite and chalcopyrite were separated using heavy liquids and hand picking.

The unit cell of danburite was refined at 25°C from data collected at both UA and the USGS. Mazdab used 82 reflections with the Appleman and Evans (1968) program and reported a = 8.7641(9), b = 8.0438(9), and c = 7.7340(7) Å. Evans used the Guinier-Hägg method with silicon as the internal standard and reported a = 8.7641(10), b = 8.0466(9), and c = 7.7344(7) Å, V = 545.44(7) Å^3, and space group $Pbnm$.

Sinhalite (ideal formula, $MgAlBO_4$) was separated from pieces of Franklin Marble (not from the material from which the fluoborite was separated) by HCl dissolution of the marble. Pinkish-tan vitreous crystals up to 1 cm in length were hand picked from the coarse residue.

The unit cell of sinhalite was refined at 25°C by Evans using the Guinier-Hägg method for 31 reflections with silicon as the internal standard. The unit cell parameters were a = 9.877(1), b = 5.6781(7), and c = 4.3278(6)Å, V = 242.71(4) Å^3, and space group $Pnma$.

Datolite (ideal formula, $CaBSiO_4(OH)$) was obtained from the National Museum of Natural History (No. NMNH R3757) and was reported to be from the Lynn Quarry, Westfield, Massachusetts. Examination of the sample showed it to be mineral-inclusion-free. The sample was lightly crushed to a coarse grain size.

The unit cell of datolite was refined at 25°C by Evans using the Guinier-Hägg method for 52 reflections with silicon as the internal standard. The unit cell parameters were a = 9.6330(11), b = 7.6091(9), and c =

4.8363(6)Å, β = 90.175(10)°, V = 354.50(5) Å^3, and space group $P2_1/a$.

The elbaite sample was a large, nearly colorless (except for the outer rind), single crystal that appeared to be mineral inclusion free. The material was from Minas Gerais, Brazil. The sample was coarsely crushed to less than 1 cm. Material from the dark blue rind (iron-rich) was removed by hand picking the sample.

The unit cell for elbaite was refined at 25°C by Evans using the Guinier-Hägg method for 67 reflections with silicon as the internal standard. The unit cell parameters were a = 15.8466(6) and c = 7.1034(5) Å, V = 1544.6(1) Å^3, and space group $R3m$.

A large single crystal of dravite (ideal formula, $NaMg_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$) from Yinniethara, Western Australia, Australia, was crushed and sieved to various size ranges. Small inclusions of other phases were present in the dravite of all size fractions. Several inclusion-free fragments were hand picked from the 10-28 mesh fraction.

The unit cell for dravite was refined at 25°C by Evans using the Guinier-Hägg method for 51 reflections with silicon as the internal standard. The unit cell parameters were a = 15.926(1) and c = 7.186(1) Å, V = 1578.4(3)Å^3, and space group $R3m$.

Kornerupine is from Mt. Riddock Station, Harts Range, NT, Australia. The sample consisted of large porphyroblasts of kornerupine (up to 6 cm in length), rimmed by plagioclase and embedded in a coarse biotite gneiss. Individual crystals were removed from the matrix with a pneumatic drill. The material was crushed to less than 28 micrometers. Minor plagioclase and biotite were removed by floatation in heavy liquids and by hand picking the sample. Visual inspection showed the sample to have less than 1 percent, by volume, of impurities.

Kornerupine is a complex borosilicate with some samples B-free. Grew et al. (1996) have divided the kornerupine group into two compositional ranges. Boron is confined to the one **T3** site in the kornerupine structure. If boron is less than 0.5 per formula unit, Grew et al. (1996) suggest use of the name kornerupine. Samples with greater amounts of boron are labelled prismatine. In the nomenclature of Grew et al. (1996), this sample would be called prismatine.

The unit cell for kornerupine was refined at 25°C by Evans using the Guinier-Hägg method for 49 reflections with silicon as the internal standard. The unit cell parameters were a = 16.047(1), b = 13.733(1) and c = 6.7261(7)Å, V = 1482.3(2) Å^3, and space group $Cmcm$.

Dumortierite (ideal formula, $Si_3B[Al_{6.75}\square_{0.25}O_{17.25}(OH)_{0.75}]$) was a portion of the material used by Hemingway et al. (1990) who described the sample preparation. The sample was taken from a deep blue cube collected in the Indian Pass area of southeastern California and provided by a mineral collector, Brian Beck (Harding Lawson Associates, Phoenix, Arizona).

The unit cell for dumortierite was refined at 25°C by Evans using the Guinier-Hägg method for 59 reflections with silicon as the internal standard. The unit cell parameters were a = 11.816(2), b = 20.229(3) and c = 4.6975(6)Å, V = 1122.8(2) Å^3, and space group $Pmcn$.

Ferro-axinite (idealized formula, $Ca_2Fe^{2+}Al_2BSi_4O_{15}(OH)$) was a portion of a large, single crystal from New Melones, California, donated by Dr. Peter Megaw and Icon Mining. The crystal was coarsely crushed and hand picked to remove epidote.

The unit cell for ferro-axinite was refined at 25°C by Evans using the Guinier-Hägg method for 39 reflections with silicon as the internal standard. The unit cell parameters were a = 7.147(1), b = 9.189(2) and c = 8.959(2) Å, α = 91.77(2)°, β = 98.14(3)°, and γ = 77.10(2)°, V = 568.3(1) Å^3, and space group $P\bar{1}$.

Manganaxinite (idealized formula, $Ca_2Mn^{2+}Al_2BSi_4O_{15}(OH)$) was a portion of material provided by the National Museum of Natural History (No. NMNH C3145). The material was orange-yellow and was reported to have come from the

metamorphosed, manganiferous, zinc orebody at Franklin, New Jersey. The material was crushed, sieved, and separated by floatation in heavy liquids.

The unit cell for manganaxinite was refined at 25°C by Evans using the Guinier-Hägg method for 41 reflections with silicon as the internal standard. The unit cell parameters were a = 7.170(2), b = 9.199(2) and c = 8.967(2) Å, α = 91.77(2)°, β = 98.14(3)°, and γ = 77.10(2)°, V = 570.7(1) Å^3, and space group $P\bar{1}$.

Experimental results

Unit cell parameters determined by the Guinier-Lenné method (Lenné, 1961) by Evans are presented as a function of temperature in Table 2. For all or a substantial portion of the temperature range studied, the expansion of each phase was linear. In Table 3, we present the linear expansion coefficients (α) calculated in this study and the temperature range over which they are valid. In Table 4, we present the value of the parameter (p_0) calculated at 0°C from the equation of the form $p_t = p_0 + \alpha t$ fit to the data for each phase, where p_t is the value of the parameter at temperature t (t in °C). A brief discussion of the thermal history of each phase follows.

Two sets of thermal expansion measurements were made for fluoborite, one using fluorophlogopite as the supporting medium and the other using silica glass. In both cases, fluoborite showed linear expansion to 780°C where decomposition produced an axinite-like phase, likely from a reaction with silica in the supporting medium. A portion of the fluoborite sample was heated in a platinum crucible to 950°C where no change was observed, and then to 1050°C where it was seen to have decomposed to kotoite ($Mg_3(BO_3)_2$) and periclase (MgO). The orthorhombic cell of kotoite (Pnmn, Guinier-Hägg) was a = 5.4002(7), b = 8.4183(10), and c = 4.5043(6) Å, and the cubic cell of periclase (Pm3m) was a = 4.211 Å.

Danburite decomposed in air at 950°C to an unknown phase. Brun and Ghose (1964) propose that danburite decomposes into cristobalite, B_2O_3 vapor and wollastonite. Linear expansion was seen to 950°C. Sugiyama and Takéuchi (1985) reported thermal expansion data for a sample from the Toroku mine, Miyazaki Prefecture, Japan. Their results for the volume expansion are in good agreement with the values presented here, being 0.4 percent smaller at 25°C and 0.2 percent larger at 900°C.

Sinhalite transformed at 1010°C to a spinel phase with a = 8.101 Å and V = 533.4 (2x266.7) Å^3 (at 25°C). Linear expansion was seen to 1010°C.

Datolite shows linear expansion to about 700°C. The datolite sample decomposes in air at 700°C to an unknown phase that exhibits diffuse X-ray data. A third phase with sharper X-ray data appears at 900°C. A subtle shift of volume to a higher value is seen at 50°C, but the change could not be measured precisely. Tarney et al. (1973) have shown that dehydroxylation of datolite occurs very rapidly above 700°C in air, and a boron-containing analogue of the melilite structure forms. Through synthesis experiments, Tarney et al. (1973) have shown that the boron-containing melilite is metastable, being formed only through dehydroxylation of datolite.

Normal linear expansion is seen for elbaite to 480°C where a increases abruptly and c slows. The expansion of a and c are still linear to 850°C. At this temperature, a jumps and c declines, and V remains constant. The decomposition product at 940°C is cordierite. According to Kurylenko (1950), H_2O is lost over the temperature range of 480° to 850°C, and boron is lost at temperatures above 850°C.

Linear expansion of dravite was evident to about 910°C where dravite decomposed to a cordierite structure. The mechanism of this transition is not clear, however, both structures are based on an assemblage of 6-fold (Si_6O_{18}) rings. Kurylenko (1950) shows evidence for water loss from dravite by 240°C, and loss of boron beginning near 910°C.

The thermal expansion of kornerupine was linear and normal to 1000°C, the highest temperature for which data were collected.

Linear expansion of dumortierite was disrupted at about 620°C by the

onset of some sort of internal structural rearrangement. The values for *a* and *b* decreased, and those of *c* increased more rapidly. The cell volume increased at about the same rate as at lower temperatures, except for a slight shift near 600°C. At 1130°C, the dumortierite structure decomposes completely to an unknown phase.

Ferro-axinite shows linear expansion to 620°C where expansion increases suddenly. The triclinic angles do not change significantly below 620°C, but enlarge significantly above 620°C. Expansion remains linear to 890°C where decomposition produces an unknown phase. The sudden change in expansion at 620°C may be related to the onset of oxidation of iron to Fe^{3+} with concomitant loss of hydrogen (from OH).

Manganaxinite shows linear expansion to about 830°C where the structure expands rapidly and shows evidence for poor crystallinity. Unit cell parameters *a* and *c* remain linear to about 830°C, but *b* begins to expand rapidly above 600°C. At 930°C, the structure transforms completely to an unknown phase. As with ferro-axinite, the sudden expansion is probably related to oxidation of Mn and Fe in the structure.

Acknowledgments

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Table 1. Chemical analyses[1] of selected boron-bearing phases.

	Fluoborite	Danburite	Sinhalite	Datolite	Elbaite	Dravite	Kornerupine
SiO_2		48.54(27)		37.41(21)	36.55	36.82(23)	30.1328
TiO_2					0.003	1.16(6)	0.1607
Al_2O_3		0.14(14)	40.21(24)		41.73	32.32(14)	38.1981
B_2O_3	[18.42]	28.31(138)	27.02(54)	21.88(76)	10.59	10.15(43)	4.3537
Cr_2O_3					0.01		0.0616
Fe_2O_3			[0.68]				11.4399
FeO	0.45(7)		0.92(6)		0.26	0.50(6)	
MnO			0.05(5)		1.72		0.0413
MgO	63.62(65)		31.15(36)		0.004	11.16(16)	15.4075
CaO		22.68(22)		34.88(17)	0.15	0.46(6)	0.0095
Na_2O					1.96	2.71(10)	0.1544
Li_2O					n.a.		
K_2O					0.02		
ZnO		n.a.	n.a.	n.a.	0.23	0.05(6)	
CuO	0.05(6)	n.a.	n.a.	n.a.			
PbO	0.07(6)	n.a.	n.a.	n.a.			
V_2O_3					0.003		
F	22.15(73)	0.05(6)		0.04(4)	0.85	0.18(8)	0.2736
Cl					0.003		0.0097
H_2O^+	[3.81]			[5.54]		[3.58]	1.0500
other							
subtotal	108.57	99.72	100.03	99.75	94.08	99.09	101.3036
O=F,Cl	-9.33	-0.02		-0.02	-0.36	-0.08	-0.1174
total	99.24	99.70	100.03	99.73	93.72	99.01	101.1862

No. cations	4	5	3	3	19	19	
Si		1.99		1.00	6.00	6.00	3.68
Ti						0.14	
Al		0.01	1.00		8.07	6.21	5.49
B	1.00	2.00	0.99	1.01	3.00	2.85	1.05
Fe^{3+}			0.01				1.05
Fe^{2+}	0.01		0.02		0.04	0.07	
Mn^{2+}			<0.01		0.24		
Mg	2.99		0.98			2.72	2.80
Ca		1.00		0.99	0.03	0.08	
Na					0.62	0.86	
Li					0.62		
Zn					0.03	0.01	
Cu	<0.01						
Pb	<0.01						
F	2.20	0.01		<0.01	0.44	0.10	0.08
OH	0.80			0.99	2.42	3.54	0.84
O	3.00	7.99	4.00	4.01	28.14	27.36	21.00
other						0.06[2]	

Table 1. Continued.

	Dumortierite	Ferro-axinite	Manganaxinite
SiO_2	29.3	42.14(24)	40.73(34)
TiO_2	1.36		
Al_2O_3	62.8	17.88(27)	17.41(15)
B_2O_3	[5.00]	6.30(9)	6.25(19)
Fe_2O_3		[0.85]	0.38(21)
FeO	0.55	7.50(48)	
MnO		0.86(14)	9.94(60)
MgO	0.01	2.53(14)	0.25(7)
CaO	0.01	19.40(24)	18.09(44)
Na_2O	0.01		0.08(7)
ZnO			1.96(24)
CuO			
PbO			0.15(13)
F			0.05(5)
H_2O^+		[1.59]	1.50
other			2.18[3]
subtotal	99.04	99.05	98.97
O=F,Cl			-0.02
total	99.04	99.05	98.95

No. cation	10	10	10
Si	3.00	3.97	3.92
Ti			
Al	6.75	1.98	1.97
B	1.00	1.02	1.04
Fe^{3+}		0.06	0.03
Fe^{2+}		0.59	
Mn^{2+}		0.07	0.81
Mg		0.35	0.04
Ca		1.96	1.87
Na			0.02
Zn			0.14
Cu			
Pb			<0.01
F			0.02
OH	0.75	1.00	0.96
O	17.25	15.00	15.02
other	0.25[2]		0.16[3]

[1] Data are normalized to the appropriate number of cations. Precision of the data is given in parentheses as ± 1σ of the sample (n-1). All Fe originally measured as Fe^{2+}. Where calculated, values for Fe^{3+} are based on charge balance and site occupancy considerations. No value indicates below 0.03 wt.% (except for dumortierite). Ba, K, Sn, and Cl were sought but not detected. n.a. = not analyzed or calculated; [ ] indicate a value has been calculated. See Mazdab et al., 1995, for details, except for dumortierite see Hemingway et al. (1990).

[2] For dravite and dumortierite, an estimate of vacancies is included in the normalization.

[3] For manganaxinite, "excess" Mn has been assigned to Mn^{3+} (2.18 = Mn_2O_3 wt. %, 0.16 = normalized Mn_{3+}).

Table 2. Thermal expansion of some boron-bearing phases (Guinier-Lenne method).

t/°C	a	b	c	β	V	$V^{1/3}$
			Fluoborite			
25	8.839(1)[1]		3.100(1)		209.7	5.942
100	8.845(3)		3.101		210.1	5.945
200	8.849(2)		3.104		210.5	5.949
300	8.853(3)		3.111		211.2	5.955
400	8.859(3)		3.116		211.8	5.961
500	8.867(3)		3.130(2)		212.7	5.969
600	8.876(2)		3.130		213.6	5.978
700	8.880(3)		3.138		214.1	5.982
800	8.893(3)		3.145(2)		215.4	5.994
			Danburite			
25	8.763(2)	8.049(2)	7.733(2)		545.4(2)	8.171
200	8.772	8.058	7.741		547.2	8.174
300	8.776	8.064	7.746		548.1	8.184
400	8.779	8.066	7.750		548.8	8.187
500	8.783	8.071	7.757		549.9	8.193
600	8.788	8.076	7.762		550.8	8.197
700	8.794	8.083	7.768		552.1	8.204
800	8.797	8.087	7.773		553.0	8.208
900	8.798	8.094	7.779		554.0	8.213
			Sinhalite			
25	9.878(3)	5.679(2)	4.325(1)		242.8(1)	6.238
200	9.897	5.683	4.329		243.5	6.244
300	9.890(5)	5.690	4.335		244.0	6.249
400	9.921	5.694	4.337		245.0	6.257
500	9.936(2)	5.701	4.342		245.9	6.265
600	9.947	5.706(1)	4.342(3)		246.4	6.269
700	9.962(2)	5.705	4.356		247.6	6.279
800	9.979	5.716	4.362		248.8	6.290
900	9.997	5.719	4.366		249.6	6.296
1000	10.009	5.723	4.373		250.0	6.300

Table 2. Continued.

t/°C	a	b	c	β	V	$V^{1/3}$
			Datolite			
25	9.663(11)	7.610(5)	4.828(4)	90.19(4)	355.0(4)	7.081
100	9.684	7.626	4.831	90.09	356.8	7.093
200	9.679	7.635	4.840	90.10	357.7	7.099
300	9.693	7.644	4.842	90.09	358.7	7.105
400	9.695	7.653	4.836	90.21	358.9	7.106
500	9.697	7.659	4.854	90.10	360.5	7.117
600	9.704	7.669	4.859	90.10	361.6	7.124
700	9.717	7.682	4.863	90.08	363.0	7.134
			Elbaite			
25	15.846(2)		7.103(2)		1544.5(4)	11.559
100	15.849		7.108		1546.2	11.564
200	15.855		7.114		1548.6	11.570
300	15.861		7.121		1551.5	11.577
400	15.870		7.128		1554.6	11.584
500	15.878		7.136		1558.0	11.593
600	15.882		7.146		1561.0	11.600
700	15.888		7.157		1564.6	11.609
800	15.890		7.166		1566.9	11.615
850	15.893(3)		7.175		1569.9(6)	11.622
940	15.867(4)		7.198(3)		1569.5(8)	11.621
			Dravite			
25	15.918(7)		7.190(5)		1577.(1)	11.64
200	15.930(6)		7.199		1582.	11.65
400	15.937(8)		7.208		1585.	11.66
600	15.955		7.216(6)		1591.	11.67
800	15.967(8)		7.234		1597.	11.69

Table 2. Continued.

t/°C	a	b	c	β	V	$V^{1/3}$
			Kornerupine			
25	16.073(5)	13.733(4)	6.734(2)		1486.5(6)	11.413
100	16.086(7)	13.743(6)	6.742(3)		1490.4(9)	11.423
200	16.100(6)	13.754(5)	6.741		1492.8(7)	11.429
300	16.111	13.766(5)	6.745		1495.9(7)	11.437
400	16.121(7)	13.766(5)	6.747(3)		1498.2(8)	11.443
500	16.134(7)	13.786(6)	6.748(3)		1501.0(9)	11.450
600	16.143(7)	13.796(6)	6.751(3)		1503.6(9)	11.456
700	16.157(6)	13.807(5)	6.754(3)		1506.6(8)	11.464
800	16.171(7)	13.818(6)	6.759(3)		1511.5(9)	11.476
900	16.186(8)	13.825(7)	6.766(3)		1514.2(10)	11.483
1000	16.189(8)	13.837(7)	6.773(3)		1517.3(10)	11.491
			Dumortierite			
25	11.824(5)	20.225(14)	4.698(4)		1123.5(7)	10.396
100	11.827	20.227(11)	4.702(3)		1124.9(6)	10.400
200	11.829(6)	20.242	4.704		1126.2(8)	10.404
300	11.837(4)	20.244(11)	4.706(3)		1127.8(6)	10.409
400	11.844	20.252	4.709		1129.5	10.414
500	11.850(6)	20.262(15)	4.713		1131.7(8)	10.421
600	11.857(6)	20.278(17)	4.715		1133.7(9)	10.427
700	11.854(7)	20.254(18)	4.725(6)		1134.4(11)	10.429
800	11.847(9)	20.263(23)	4.742(8)		1138.4(14)	10.442
900	11.836(9)	20.231(20)	4.770(9)		1142.0(15)	10.452
1000	11.834(10)	20.229(22)	4.779(10)		1144.1(16)	10.459
1100	11.831(10)	20.238(21)	4.778(9)		1144.2(16)	10.459

Table 2. Continued.

t/°C	a	b	c	α	β	γ	V	$V^{1/3}$
				Ferro-axinite				
25	7.153(5)	9.182(8)	8.961(8)	91.83(8)	98.15(8)	77.44(6)	568.6(6)	8.285
100	7.156	9.192(5)	8.957	91.81	98.08	77.44	569.4	8.288
200	7.165(3)	9.199(4)	8.977(6)	91.75(5)	98.18(6)	77.41(4)	571.6(4)	8.299
300	7.173	9.218(5)	8.979	91.81(6)	98.24	77.39	573.3	8.307
400	7.177(4)	9.225(4)	8.990(7)	91.81(6)	98.24(7)	77.37(5)	574.1(5)	8.311
500	7.185(2)	9.229(2)	8.982(3)	91.83(3)	98.26(3)	77.32(3)	575.0(6)	8.316
600	7.184(6)	9.239(4)	8.988(7)	91.78(7)	98.17	77.38(7)	576.2(5)	8.321
700	7.218(8)	9.247(6)	9.024(7)	91.93(7)	98.58	77.73(13)	581.9(6)	8.349
800	7.273(8)	9.252(7)	9.060	92.06	99.10(9)	77.88(14)	588.5(6)	8.380
				Manganaxinite				
25	7.170(4)	9.203(6)	8.964(6)	91.81(8)	98.24(5)	77.15(6)	570.8(5)	8.295
200	7.180(3)	9.207(5)	8.977(5)	91.79(6)	98.25	77.14(5)	572.4(4)	8.303
400	7.191(3)	9.225(4)	8.984(4)	91.77(5)	98.21(4)	77.19(4)	575.1(3)	8.316
600	7.204	9.241	9.001	91.70(7)	98.21	77.26	578.4	8.332
800	7.218(5)	9.277(8)	9.005(8)	91.86(10)	98.23(7)	77.27(8)	582.0(6)	8.349

[1] Uncertainties are given in parentheses at 25°C, and at higher temperatures if different from the value at 25°C.

Table 3. Linear expansion coeficients ($x10^5$) for a, b, c, and V for selected boron-bearing minerals.

Phase	α(a)	α(b)	α(c)	α(V)	Temp. Range
Fluoborite	6.92		6.60	671.	25° to 800°C
Danburite	4.26	5.02	5.09	960.	25° to 950°C
Sinhalite	14.7	5.0	5.1	850.	25° to 1010°C
Datolite	6.45	9.70(β 0)	5.26	940.	25° to 700°C
Elbaite(1)	6.35		6.64	2691.	25° to 480°C
Elbaite(2)	5.30		10.10	3030.	500° to 850°C
Dravite	6.31		5.39	2510.	25° to 910°C
Kornerupine	12.3	10.5	0.34	3110.	25° to 1000°C
Dumortierite	5.9	8.8	2.8	1744.	25° to 600°C
Ferro-axinite	6.3	9.0	6.3	1250.	25° to 620°C
Ferro-axinite	79.	33.	62.	3750.	620° to 890°C
Manganaxinite	5.55	6.5	5.55	1200.	25° to 600°C

Table 4. Values of unit cell parameters (p_0) calculated from the fitting equation for each phase at 0°C.

Phase	a_0	b_0	c_0	V_0
Fluoborite	8.841		3.098	209.2
Danburite	8.763	8.047	7.730	545.10
Sinhalite	9.864	5.674	4.312	241.8
Datolite	9.669	7.613	4.827	90.11
Elbaite(1)	15.432		7.1012	1576.
Elbaite(2)	15.851		7.086	1543.
Dravite	15.961		7.208	1576.
Kornerupine	16.071	13.733	6.734	1486.4
Dumortierite	11.820	20.273	4.698	1122.9
Ferro-axinite	7.153	9.186	8.959	
Manganaxinite	8.966	9.200	7.169	