Prismatine: revalidation for boron-rich compositions in the kornerupine group

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Abstract

Kornerupine and prismatine were introduced independently by Lorenzen in 1884 (but published in 1886 and 1893) and by Sauer in 1886, respectively. Ussing (1889) showed that the two minerals were sufficiently close crystallographically and chemically to be regarded as one species. However, recent analyses of boron using the ion microprobe and crystal structure refinement, indicate that the boron content of one tetrahedral site in kornerupine ranges from 0 to 1. Kornerupine and prismatine, from their respective type localities of Fiskenæsset, Greenland and Waldheim, Germany, are distinct minerals, members of an isomorphic series differing in boron content. For this reason, we re-introduce Sauer's name prismatine for kornerupines with B > 0.5 atoms per formula unit (p.f.u.) of 22(O,OH,F), and restrict the name kornerupine *sensu stricto* to kornerupines with B < 0.5 p.f.u. Kornerupine *sensu lato* is an appropriate group name for kornerupine of unknown boron content. Kornerupine *sensu stricto* and prismatine from the type localities differ also in Fe^{2+}/Mg ratio, Si – (Mg + Fe^{2+} + Mn) content, Al content, F content, colour, density, cell parameters, and paragenesis. Both minerals formed under granulite-facies conditions with sapphirine and phlogopite, but kornerupine *sensu stricto* is associated with anorthite and hornblende or gedrite, whereas prismatine is found with oligoclase (An9–13), sillimanite, garnet, and/or tourmaline. Occurrences at other localities suggest that increasing boron content extends the stability range of prismatine relative to that of kornerupine *sensu stricto*.

KEYWORDS: prismatine, kornerupine, boron, Waldheim (Germany).

Introduction

MINERALOGISTS have been slow to recognize the role of boron in kornerupine (Lorenzen, 1886, 1893) and prismatine (Sauer, 1886), largely because of the difficulty in analysing this constituent in refractory silicate minerals, whether by wet chemistry (e.g. Hey *et al.*, 1941) or by microprobe methods. As a result of recent advances in the technology of ion- and electron-microprobe analysis and of crystal-structure refinement, accurate measurement of boron in silicate minerals has become more feasible. New data on the boron contents of kornerupine, including specimens from the type localities of Fiskenæsset, Greenland (kornerupine) and Waldheim, Germany (prismatine), show that kornerupine and prismatine are distinct minerals.

In the present paper, we revalidate the name prismatine for boron-rich kornerupine (B > 0.5 atoms per formula unit of 22(O,OH,F), i.e. > 50% B at the *T*3 site, which is the only tetrahedral site occupied by boron (Moore and Araki, 1979, whose terminology is used for the irregular cubic site *X*, five octahedral sites *M* and three tetrahedral sites *T*):

$${}^{X}(\square,Fe,Mg)^{M1,2,4}(Mg,Al,Fe)_5{}^{M3,5}Al_4{}^{T1}Si_2{}^{T2}(Si,Al)_2{}^{T3}(B,Si,Al)(O,OH,F)_{22},$$

This paper is dedicated to the memory of Gerhard Mathé, who contributed so much to the study reported in this paper.
Diese Publikation ist dem Andenken an Gerhard Mathé gewidmet, der viel zum Gelingen dieser Studie beigetragen hat.

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the formula for prismatine. Kornerupine *sensu stricto* applies to kornerupine with B < 0.5 p.f.u., whereas kornerupine *sensu lato* is the group name for a kornerupine-structure mineral of unspecified boron content. This revision in the nomenclature has been approved by the Commission on New Minerals and Mineral Names of the International Mineralogical Association. In addition, we concur with Friend (1995) that the term boron-free kornerupine *sensu stricto* be restricted to kornerupine analysed for boron and found not to contain it.

Brief history of the name prismatine

Sauer (1886) proposed the name prismatine for a prismatic mineral from a cut near the Waldheim railroad station, Saxony, Germany. This mineral resembled sillimanite and andalusite in appearance and staurolite in composition. At that time Sauer was presumably unaware of Lorenzen's (1886) name kornerupine for a mineral from Fiskenæsset, Greenland, of composition $MgAl_2SiO_6$ and resembling kyanite and sillimanite.

Ussing (1889) compared Sauer's prismatine with Lorenzen's kornerupine and concluded that they were the same mineral on the basis of symmetry, cleavage and optical orientation; differences in optic angle, colour and specific gravity were presumed to be within the ranges found in isomorphic minerals. The name kornerupine has been given priority because Lorenzen's report was due to be published in 1884, but was delayed until 1893 (see Lorenzen, 1886; Grew *et al.*, 1987). Compared with kornerupine, prismatine was found to contain less Al, more Fe and substantially more alkalis (Table 1). Uhlig (1910) cited the alkali content as being sufficient to define prismatine as a distinct species linked in an isomorphic series to kornerupine through the substitution NaH $\rightleftharpoons$ Mg:

Prismatine: $(NaH)H_2Mg_6Al_{12}Si_7O_{40}$
Kornerupine: $(Mg)H_2Mg_6Al_{12}Si_7O_{40}$

Goβner and Muβgnug (1928) referred to the mineral as prismatine and cited X-ray data as evidence that kornerupine and prismatine were virtually identical. A few authors have applied the term prismatine to material from localities other than Waldheim (e.g. Kuryleva, 1960). However, since 1928, most authors have only used the term specifically for the Waldheim mineral (e.g. Hey *et al.*, 1941, p. 122, wrote "...a prismatine from Waldheim, Saxony,..."). Scheumann (1960) concluded that prismatine was an intermediate member in the isomorphic kornerupine series, and suggested that the term prismatine should be used only in reference to material with the distinctive prismatic habit. Nonetheless, even relatively recently, Seifert (1975, p. 81) referred to the "sodium-rich variety prismatine" linked to kornerupine through the substitution Na + (Mg,Fe) = Al. Thus, the name prismatine has persisted in the literature for nearly 100 years after its introduction.

Relation of studied samples to type material

We have analysed four prismatine specimens using crystal-structure refinement (Hawthorne *et al.*, 1995) and electron-microprobe analysis. Specimen no. 5105x (our number) was provided by K. Hoth,

TABLE 1. Wet-chemical analyses of prismatine from Waldheim, Germany (in wt.%)

	Sauer (1886)	Uhlig (1910)	Goβner and Muβgnug (1928)	Hey *et al.* (1941)
SiO_2	30.89	30.61	33.20	30.5
TiO_2	–	0.30	–	–
B_2O_3	–	–	–	3.0
Al_2O_3	43.06	42.11	42.36	35.8
Fe_2O_3	–	2.21	0.30	3.2
FeO	6.28	4.51	5.81	9.1
MgO	15.08	15.23	11.76	17.6
Na_2O	2.04	1.85	5.07	1.6
K_2O	0.79	0.85	0.83	trace
H_2O	1.36	1.94	1.60	–
Moisture	–	0.14	–	–
Total	99.50	99.75	100.97*	100.8

*Total as given. The reported values sum to 100.93%.

Vice-President of the Sächsisches Landesamt für Umwelt und Geologie, Bereich Boden und Geologie, which is the successor to the Geologische Landesuntersuchung Sachsen, where Sauer was working when he discovered prismatine. Hoth (pers. comm. to E. Grew, 1994) wrote that this specimen is "a piece of Prismatingranulit, which belongs to the material studied by A. Sauer and had been collected by him from the classic locality at the exposure near the Waldheim Bahnhof (Sauer, 1886)". The specimen was collected in 1885, when the outcrop of granulite was first exposed by construction at the Waldheim railroad station (Purgold, 1886, 1887).

Specimen no. 1892.1438 from the Geologisk Museum (Copenhagen) was used by Ussing (1889) to demonstrate that prismatine and kornerupine were identical. The museum label reads 'A. Sauer leg.', that is, collected by Sauer; Ussing (1889) reported that the specimen had been given to him by H. Rosenbusch.

Specimen no. 5105M (Grew's number) is from the collection of the 'Mineralogische Schausammlung', Technische Universität Berlin. The museum label reads 'Credner leg. 1898', that is, it was collected by H. Credner, who was director of the Royal Geological Survey of Saxony.

Specimen 12567 is from the American Museum of Natural History, which acquired it in 1908.

Strictly speaking, none of the analysed samples is holotype material. Specimens 5105x and 1892.1438 could be co-type. In any case, there is a close correspondence between our samples and Sauer's (1886) description. We have no doubt that all four samples come from the same lens of granulite exposed in a roadcut near the railroad station, and reported to be only some 3 m thick and to extend 15 m (Kalkowsky, 1907). No other exposure of kornerupine- or prismatine-bearing rock was discovered in Waldeim until the 1980s (Grew, 1989). Differences in the compositions reported by Sauer and by us can be attributed to variations in Fe^{2+}/Mg ratio from sample to sample, to possible plagioclase impurities in Sauer's material, and to Sauer having overlooked the presence of boron.

Rationale for reviving the name prismatine

More recent analyses of kornerupine *sensu stricto* and prismatine have confirmed the differences in Al and Fe discussed by Ussing (1889). However, no electron-microprobe analysis of prismatine from Waldheim has shown more than 0.2 wt.% Na_2O (Schreyer *et al.*, 1975; Grew, 1986; Grew *et al.*, 1990; this report, Table 2); thus prismatine is not a sodian variety of kornerupine (Schreyer *et al.*, 1975). Lacroix and de Gramont (1919) first reported that prismatine contained substantial boron, which was shown to be in tetrahedral coordination from infrared data (Moenke, 1962; Povarennykh, 1970). However, the data available to Scheumann (1960) were insufficient for him to distinguish prismatine and kornerupine *sensu stricto* on the basis of boron content.

Distinguishing kornerupine *sensu stricto* and prismatine on the basis of boron content was really not possible until crystal-structure refinements showed that the B content at *T*3 was highly variable (e.g. Moore and Araki, 1979; Klaska and Grew, 1991). Recent analyses, including 40 compositions determined by electron-microprobe analysis, ion-microprobe analysis (SIMS), site-scattering refinement and stereochemical analysis (Hawthorne *et al.*, 1995; Cooper and Hawthorne, unpub. data), show that there is continuous variation in composition and structure between prismatine and kornerupine *sensu stricto* (Fig. 1).

Crystal-structure refinements of three prismatines from Waldeim confirm ion-microprobe data indicating that these contain more B than Si or Al at the *T*3 site (i.e. 0.73–0.84 B, Table 2); an exception is 0.45 B measured on fine-grained material in one sample (Grew *et al.*, 1990; Fig. 2, this paper). Electron-microprobe analyses of three prismatine grains in a sample from Sauer's collection (#5105x, Table 2) are consistent with comparably high boron content. On the other hand, wet-chemical analysis, ion-microprobe analyses, and a combination of site-scattering and mean bond-lengths on Fiskenæsset kornerupine *sensu stricto*, including the type

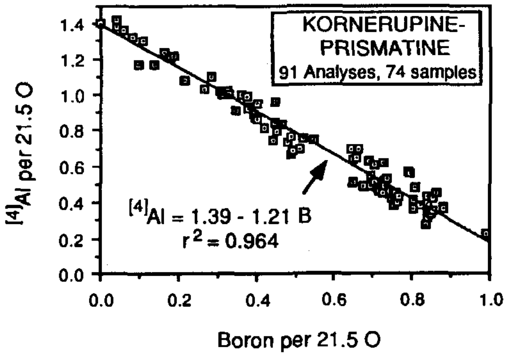

FIG. 1. Plot of 91 kornerupine (here *sensu stricto*) and prismatine compositions obtained on 74 samples in terms of boron and $^{[4]}$Al (calculated from 5 - Si - B - Be) per formula unit of 21.5 oxygens. Sources of data are Table 2; Grew *et al.* (1987, 1990); Friend, 1995; Cooper and Hawthorne, unpublished data; and the literature cited in Grew (in prep.).

TABLE 2. Compositions and cell parameters of kornerupine *sensu stricto* and prismatine from Fiskenæsset, Greenland and Waldheim, Germany

	Kornerupine 31498 Fiskenæsset	Prismatine 5105C Bahnhof	Prismatine 12567 Bahnhof	Prismatine 5105M Bahnhof	Prismatine 1892.1438 Bahnhof	Prismatine 5105x Bahnhof	Prismatine 5126AA Eichberg
			Electron Microprobe Analyses – wt.%.				
SiO_2	29.78	29.97	30.26	30.85	31.06	30.38	30.74
TiO_2	0.08	0.27	0.23	0.21	0.21	0.23	0.21
Al_2O_3	45.72	42.01	41.67	41.61	41.62	42.23	41.42
Cr_2O_3	0.02	0.07	0.12	0.12	0.19	0.11	0.12
V_2O_3	b.d.	–	0.10	0.12	0.14	0.11	0.11
FeO	1.38	6.40	8.44	5.74	4.91	6.65	5.77
MnO	b.d.	0.09	0.09	0.05	b.d.	0.08	0.06
MgO	19.45	15.36	13.03	15.18	16.21	14.41	15.39
CaO	0.08	0.03	b.d.	b.d.	b.d.	b.d.	b.d
Na_2O	b.d.	0.14	0.07	0.10	0.14	0.08	0.09
K_2O	b.d.	b.d.	b.d.	b.d.	–	–	b.d.
F	b.d.	–	0.76	0.76	0.89	0.60	0.78
			Crystal Structure Refinement – wt.%.				
B_2O_3	1.47	–	3.94	3.75	3.59	–	3.92
			Ion Microprobe Analysis – wt.%.				
B_2O_3	1.35**	3.40	3.98**	3.70**	–	–	4.05**
F	–	0.73	–	–	–	–	–
			Calculated – wt.%.				
H_2O	1.22	0.86	0.84	0.85	0.79	–	0.84
-O=F	0	−0.31	−0.32	−0.32	−0.37	−0.25	−0.33
Total	$99.18^{\$}$	99.15	$99.23^{\$}$	$99.02^{\$}$	$99.37^{\$}$	94.64	$99.12^{\$}$
			Formulae per 21 O + 1 (OH,F)				
Si	3.668	3.741	3.791	3.831	3.836	–	3.813
B	0.313*	0.733	0.852*	0.804*	0.764*	–	0.839*
Al	6.637	6.180	6.152	6.090	6.058	–	6.055
Ti	0.007	0.025	0.022	0.020	0.020	–	0.020
Cr	0.000	0.007	0.012	0.012	0.019	–	0.012
V	0.000	–	0.010	0.012	0.014	–	0.011
Fe^{2+}	0.142	0.668#	0.884#	0.596#	0.507#	–	0.598
Mn	0.000	0.010	0.010	0.005	0.000	–	0.006
Mg	3.572	2.858	2.433	2.810	2.984	–	2.846
Ca	0.011	0.004	0.000	0.000	0.003	–	–
Na	0.000	0.034	0.017	0.024	0.034	–	0.022
Total	14.350	14.321	14.183	14.203	14.234	–	14.220
			*T*3 occupancies (combined site-scattering and mean bond-lengths)				
Si	0.44	–	0.08	0.12	0.12	–	0.10
Al	0.24	–	0.08	0.08	0.12	–	0.06
B	0.32	–	0.84	0.80	0.76	–	0.84
			Anions				
F	0.000	0.288	0.301	0.298	0.348	–	0.306
OH	1.000	0.712	0.699	0.702	0.652	–	0.694

Table 2 (*cont.*)

	Kornerupine 31498 Fiskenæsset	Prismatine 5105C Bahnhof	Prismatine 12567 Bahnhof	Prismatine 5105M Bahnhof	Prismatine 1892.1438 Bahnhof	Prismatine 5105x Bahnhof	Prismatine 5126AA Eichberg
Cell Parameters (Space group *Cmcm*)							
a (Å)	16.050(6)	–	15.938(3)	15.949(2)	15.980(3)	–	15.938(2)
b (Å)	13.742(4)	–	13.673(3)	13.669(2)	13.697(2)	–	13.670(3)
c (Å)	6.728(2)	–	6.693(1)	6.692(1)	6.696(2)	–	6.690(1)
V (Å^3)	1483.7(2)	–	1458.5(5)	1459.0(4)	1465.5(5)	–	1457.6(4)

Notes: Sources of data by column. 1 and 3 to 7 – Mark Cooper and F. C. Hawthorne, unpub. data; 2 – Grew (1986), Ba and Sr below detection. Totals include BeO 0.007 and Li_2O 0.12 wt.%, and Be 0.002, Li 0.060. Column 6 is average of 3 grains for which FeO varies 6.54–6.82 wt.%, MgO 14.26–14.54 wt.%, and Al_2O_3 41.78–42.87 wt.%. Bahnhof refers to the type locality at the railroad station in Waldheim. Eichberg is situated in Waldheim, 800m from the type locality (Grew, 1989). *B values from crystal structure refinement. #Mössbauer spectroscopy of another sample from Waldheim Bahnhof shows that <1% of the Fe is Fe^{3+} (Grew, Redhammer and Amthauer, unpub. data). $^\$$Does not include ion microprobe B_2O_3 contents. b.d. below detection. **Values from Hawthorne *et al.* (1995).

specimen (no. 1883.754), consistently give less than 0.5 B p.f.u. (Grew *et al.*, 1987, Table 1; this paper, Table 2). The difference in *T3* composition between the type kornerupine *sensu stricto* (Al < B < Si) and prismatine (B $\gg$ Si and Al) is sufficient to recognize prismatine and kornerupine *sensu stricto* as distinct isostructural species. That is, *T3* compositions (see structural formula above) are (B,Si,Al) in prismatine, (Si,B,Al) in borian kornerupine *sensu stricto*, and (Si,Al) in boron-free kornerupine *sensu stricto* (Klaska and Grew, 1991; Friend, 1995).

For this reason, we re-introduce Sauer's (1886) name prismatine for a kornerupine-structure mineral with B > 0.5 atoms per formula unit (p.f.u.) of 22(O,OH,F), and restrict the name kornerupine *sensu stricto* to kornerupine with B < 0.5 p.f.u. Kornerupine *sensu lato* is an appropriate group name for kornerupine-structure minerals of an unknown boron content. We recommend referring to kornerupine *sensu lato* simply as kornerupine, and will do so in the remainder of the present paper. Thus, use of the names kornerupine and prismatine would be analogous to the accepted use of the names spinel and hercynite for the group or Mg-dominant member and Fe-dominant member, respectively, of the $MgAl_2O_4$ – $FeAl_2O_4$ series, except that we make a clearer distinction between kornerupine *sensu stricto* and *sensu lato*. The modifier 'boron-free' should be applied only to kornerupine *sensu stricto* with B = 0 (Friend, 1995), and the modifier 'boron-poor' is a reasonable term for kornerupine *sensu stricto* with B < 0.2, a usage also recommended by Friend (1995). Strictly speaking, the distinction should be B > (Si + Al) (prismatine) and Si > (B + Al) (kornerupine *sensu stricto*). However, the amount of Al at *T3* can only be ascertained by crystal-structure refinement, so that including Al in the definition is not practical.

Comparison of prismatine and kornerupine *sensu stricto*

Type kornerupine *sensu stricto* and prismatine differ not only in B content of the *T3* site, but also in Fe/Mg ratio, Si - (Mg + Fe^{2+} + Mn) content , Al content, F content, colour, density and cell parameters (Fig. 2; Tables 2, 3; no optical data were reported for kornerupine *sensu stricto* except for −2E = 14–32.5° by Ussing, 1889). Of the above listed chemical and physical properties, the cell volume, a and c parameters are most clearly related to the B content; the b parameter is sensitive to other compositional variables. In principle, the a and c parameters could be used as criteria to distinguish prismatine from kornerupine *sensu stricto* because all three decrease with B content (e.g. Werding and Schreyer, 1978; Grew *et al.*, 1990). Al content varies inversely with B by virtue of the coupled substitution ${}^{[T3]}B + {}^{[T2]}Si \rightleftharpoons {}^{[T3]}Si + {}^{[T2]}Al$, which sums roughly to B for Al substitution (Fig. 1); thus Al content could be used to estimate B content. However, Al also varies inversely with Mg + Si (Tschermak substitution) and with Fe^{3+} (e.g. Klaska and Grew, 1991), and thus Al content must be used with caution. Colour and refractive indices vary with Fe/Mg ratio, but little, if at all, with B content (e.g. Waters and Moore, 1985).

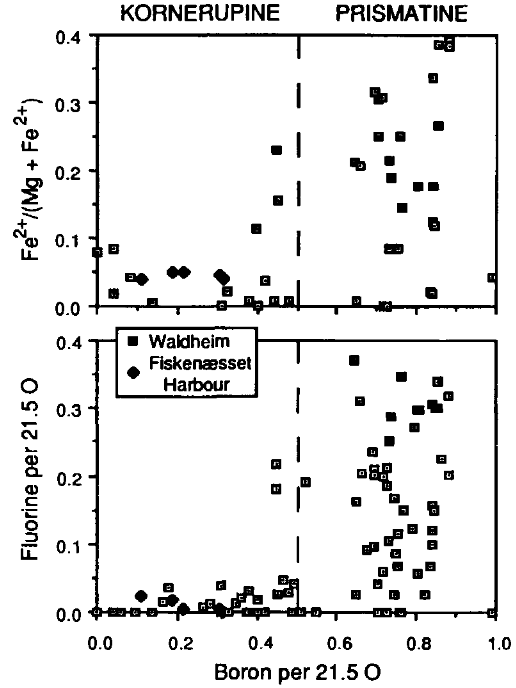

FIG. 2. Plot of kornerupine (here *sensu stricto*) and prismatine compositions in terms of B, Fe^{2+}/(Fe^{2+} + Mg) ratio (47 compositions) and F (87 compositions). The 49 compositions are those in which Fe^{3+}/Fe^{2+} ratio have been estimated from crystallographic, wet-chemical, or Mössbauer data, or in which Fe as FeO < 2 wt.%. Cooper and Hawthorne's electron microprobe F values of 0.2 wt.% or less are plotted as F = 0. Sources of data are the same as for Fig. 1.

The minor-element signature of the Waldheim prismatine is distinctive in that Na, Ti, Cr, and V are present in amounts exceeding 0.1 wt.% oxide. None of these constituents, except Ti, reach 0.1 wt.% oxide in kornerupine *sensu stricto* from the type locality, although chromian kornerupine *sensu stricto* is found elsewhere in the Fiskenæsset complex (Cooper and Hawthorne, unpub. data). The V content of prismatine is exceeded only by green and blue vanadian prismatine and kornerupine from Kenya and Tanzania (to 0.78 wt.% V_2O_3, Girgis *et al.*, 1976; Schmetzer *et al.*, 1979).

The compositional differences between type prismatine and type kornerupine *sensu stricto* characterize these minerals from other localities (Fig. 2). On the one hand, in kornerupine *sensu stricto* with B $\leqslant$ 0.4 atoms p.f.u., F contents are negligible and Mg$\gg$Fe^{2+}. Variations among the major constituents can be largely expressed by a Tschermak-type substitution involving boron (horizontal line marked MgSiAl$_{-2}$ in Fig. 3), that is, Si $\approx$ Mg + Fe^{2+} + Mn. On the other hand, prismatine (and kornerupine *sensu stricto* with B > 0.4 p.f.u.) can contain substantial F and Fe^{2+}. Prismatine compositions define a trend in Fig. 3 clearly at variance with a Tschermak-type substitution. Another substitution, possibly acting in tandem with a Tschermak-type substitution, is needed to explain compositional variations in prismatine. Two possible alternatives are indicated in Fig. 3; these involve the region around the partially occupied *X* site. Charge balance for the substitution $^{[M4]}$Mg = $^{[M4]}$(Al,Fe^{3+}) is attained either by filling the *X* site itself with a divalent cation (MgAl$_{-0.67}$, Fig. 3) or by adding a proton to the nearby *H* site (HMgAl$_{-1}$, Fig. 3). The distinction between the trends for prismatine and kornerupine *sensu stricto* in Fig. 3 clearly illustrates the effect of boron on other cations.

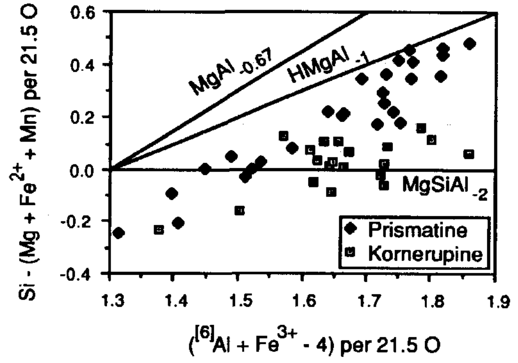

FIG. 3. Plot of the 47 kornerupine (here *sensu stricto*) and prismatine compositions of known Fe^{3+}/Fe^{2+} ratio in terms of Si - (Mg - Fe^{2+} + Mn) and $^{[6]}$Al + Fe^{3+} + (Cr + V) - 4 per formula unit of 21.5 oxygens. Possible substitutions (site terminology of Moore and Araki, 1979) are $^{[X]}$Mg + 2$^{[M4]}$Mg = 2 $^{[M4]}$(Al,Fe^{3+}) (MgAl$_{-0.67}$), H + $^{[M4]}$Mg = $^{[M4]}$(Al,Fe^{3+})(HMgAl$_{-1}$), and Si + $^{[M4]}$Mg = $^{[T]}$(Al,B) + $^{[M4]}$(Al,Fe^{3+}) (MgSiAl$_{-2}$). Sources of data are the same as for Fig. 1.

The parageneses at the type localities are different. Kornerupine *sensu stricto* occurs with phlogopite, anorthite, sapphirine, hornblende, gedrite, spinel, corundum, chlorite and pinite; inferred equilibrium mineral assemblages are kornerupine *sensu stricto* + hornblende, kornerupine *sensu stricto* + gedrite, and kornerupine *sensu stricto* + sapphirine (all with anorthite + phlogopite; Grew *et al.*, 1987). Minerals associated with prismatine are sodic oligoclase (An9–13), kyanite, sillimanite, andalusite, tourmaline, dumortierite, biotite, sapphirine, garnet, corundum, quartz, rutile, muscovite and chlorite,

TABLE 3. Comparison of the optical, physical, and crystallographic properties of kornerupine *sensu stricto* and prismatine from Fiskenæsset, Greenland and Waldheim, Germany

	Kornerupine Fiskenaæsset	Prismatine Waldheim (Bahnhof)
	Optical properties	
α	–	$1.669-1.671^{2,3}$
β	–	$1.681-1.683^{2,3}$
γ	–	$1.682-1.684^{2,3}$
$2V_\alpha$	$8-19^{\circ 2*}$	$28-38^{\circ 2,3}$
Dispersion	None^{2}	r<v, weak^{2,3}
Colour (hand sp.)	White^{1}	Gold-brown^{2,3}
Colour (thin sect.)	Colourless^{2}	Colourless^{3}
Colour (sections of greater than standard thickness)	–	Pleochroic: colourless to greenish, reddish, yellow, and yellow-brown^{2,3}
	Physical properties	
Density (g/cm^3)	3.23^{1},3.273^{2}	$3.341-3.345^{2,3}$
Hardness	$6.5^{1,2}$	$6.5-7.0^{2,3}$
Cleavage	$\{110\}^{2}$	$\{110\}^{2}$
	Crystallographic properties	
a : *b* : *c* (morph.)	$1:0.854:-^{2}$	$1:0.862:0.4345^{3}$
a : *b* : *c* (X-ray)	$1:0.856:0.419^{4}$	$1:0.857:0.420^{5}$

Sources: 1. Lorenzen (1886), 2. Ussing (1889), 3. Uhlig (1910), 4. This report, sample 31498. 5. This report, average of the three prismatines from Waldheim Bahnhof in Table 2.
* 2V calculated from the relation sinV = sinE/β (Uhlig, 1910) and Ussing's (1889) 2E = 14–32.5° and assuming β = 1.68. Refractive indices were not reported for Fiskenæsset kornerupine *sensu stricto*.

and the inferred equilibrium assemblage at the type locality is prismatine + biotite + sapphirine + corundum + sillimanite ± garnet ± tourmaline (Schreyer *et al.*, 1975; Grew, 1986). Prismatine + quartz is a rare assemblage at the type locality, but is common at a second Waldheim locality, Eichberg, situated 800 m to the east (Kalkowsky, 1907; Grew, 1986, 1989); one prismatine from Eichberg contains 0.84 B p.f.u. (Table 2). Kornerupine *sensu stricto* and prismatine are granulite-facies minerals; at the type localities, estimated conditions of formation are 700–830°C, 5–10 kbar (Grew *et al.*, 1987; Riciputi *et al.*, 1990) and 750–850°C, 5–12.5 kbar (Grew, 1986, Rötzler, 1992), respectively. More recent data on the Saxony granulites, including the Waldheim area, suggest that temperatures and pressures during early stages of prismatine formation could have been as high as 1050°C and 20–23 kbar (e.g. Rötzler *et al.*, 1995). Prismatine is inferred to have formed during decompression in close association with anatexis.

Kornerupine *sensu stricto* with B < 0.4 p.f.u. is found in Mg-Al-rich, silica-undersaturated rocks metamorphosed under upper amphibolite or granulite-facies conditions, of which the sapphirine-kornerupine *sensu stricto* rocks associated with the Fiskenæsset Complex are a prime example (e.g. Friend, 1995). Many prismatine-bearing rocks are similar in being Mg-Al-rich and silica-undersaturated; indeed, both minerals have been found at one locality, or even in a single specimen in which B contents vary markedly. However, prismatine parageneses are more diverse, and include assemblages with quartz, andalusite, K-feldspar or grandidierite (e.g. Grew *et al.*, 1990), and host rocks for prismatine are closer to average metapelites at some localities. Other than Waldheim, prismatine is reported to be stable at *T–P* conditions as extreme as 900°C, 6.5 kbar (Paderu, India, Lal *et al.*, 1987) and $\geqslant$ 540°C, $\leqslant$3 kbar (Homagama, Sri Lanka; Grew *et al.*, 1995). The latter conditions are outside those determined experimentally for B-free kornerupine *sensu stricto* ($T \geqslant 735°C$, $P_{H_2O} \geqslant 4.5$; Seifert, 1975), implying thereby that increasing boron content extends the stability range of prismatine relative to that of kornerupine *sensu stricto*.

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