KORNERUPINE: A MINERAL NEW TO NORWAY

DIRK VAN DER WEL

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The Bjordammen kornerupine (Bamble, south Norway) occurs in an anthophyllite-cordierite bearing gneissic rock. The mineral has hematite inclusions which are mainly confined to cleavage zones. In the same area we also find aventurine feldspar and hematite bearing cordierite. The physical and chemical properties of the Bjordammen kornerupine are discussed and listed below.

Dirk van der Wel, Mineralogisk-Geologisk Museum, Sars gate 1, Oslo 5, Norway.

In the autumn of 1971 a sample of gneissic rock with kornerupine crystals was found by Mr. O. Bjordammen near Hullvannet, Bamble, in southern Norway. This is the first report of kornerupine in Norway. The mineral is developed as green grey elongated crystals up to one centimetre in breadth (Fig. 1).

Kornerupine, $Mg_4Al_6[(O,OH)_2|BO_4|(SiO_4)_4]$ (Strunz 1966) occurs in high grade contact and regional metamorphic rocks high in Al, and low in Si. It is formed with, or instead of, tourmaline if sufficient boron is available. Cordierite, sapphirine, corundum and sillimanite are some of the minerals that may be found together with kornerupine (Trøger 1967).

Geology of the Bjordammen area

The Bjordammen area consists of Precambrian paragneisses with amphibolitic zones, some of which have been altered into anthophyllite-cordierite-phlogopite schist and scapolite-bearing amphibolite. During metamorphism these rocks were metasomatically altered by Mg bearing fluids, which possibly also supplied them with OH, B, and Cl (Divljan 1960). Tourmaline and kornerupine have been developed as a result of the introduction of boron.

Mineralogy of the sample from Bjordammen

The main minerals of the sample are quartz, phlogopite, cordierite (highly altered), and hematite. A quartz rich vein lying parallel to the foliation

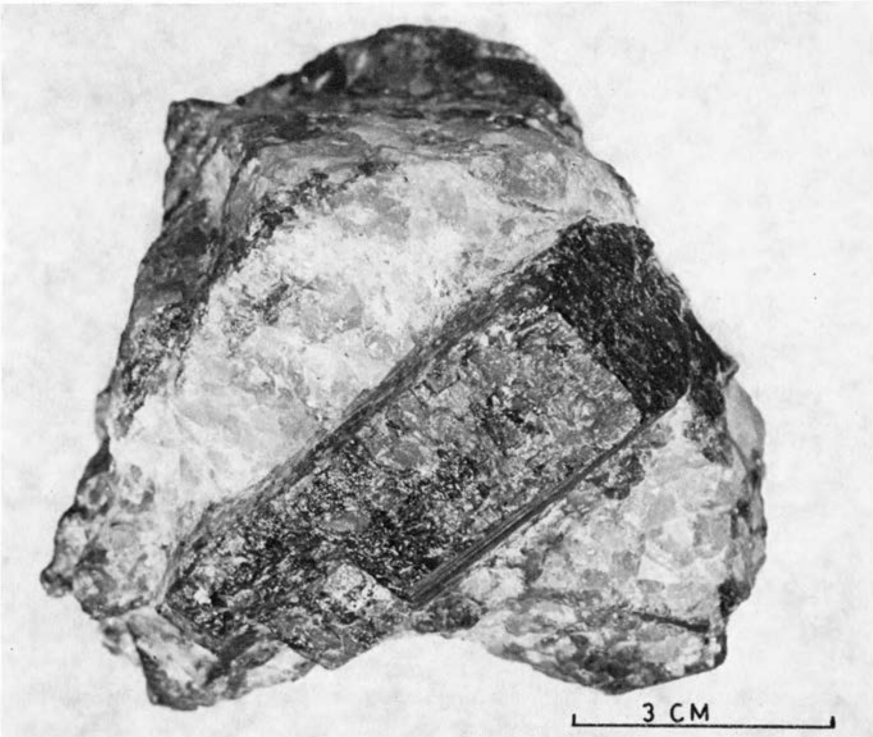

Fig. 1. Kornerupine crystal from pegmatoid in gneissic rock.

contains major amounts of phlogopite, kornerupine, and highly altered cordierite. The accessory minerals in this vein are tourmaline, zircon, and apatite.

Cordierite is almost completely altered into halloysite or chlorite (pennite) and hematite. The appearance of halloysite in thin sections is almost amorphous, sometimes it has colloform textures. It was identified by X-ray powder diffraction methods.

Hematite occurs in two different ways. In small grains as a rock forming mineral and as veinlets and lamellae in, and between, quartz and kornerupine grains. Sometimes one can observe a distinct concentration of hematite with pennite in the alteration products of cordierite. In the thin sections from the quartz vein hematite is almost entirely confined to altered cordierite. It has been reactivated to a certain extent, one can for example see that small veins have been generated from preexisting hematite grains. These veins penetrate both quartz and kornerupine. The hematite lamellae in kornerupine are confined to fracture zones (Fig. 2), preferentially parallel to the (110) cleavage. They give the impression of having been introduced and not exsolved.

The phlogopite is a 3T phlogopite.

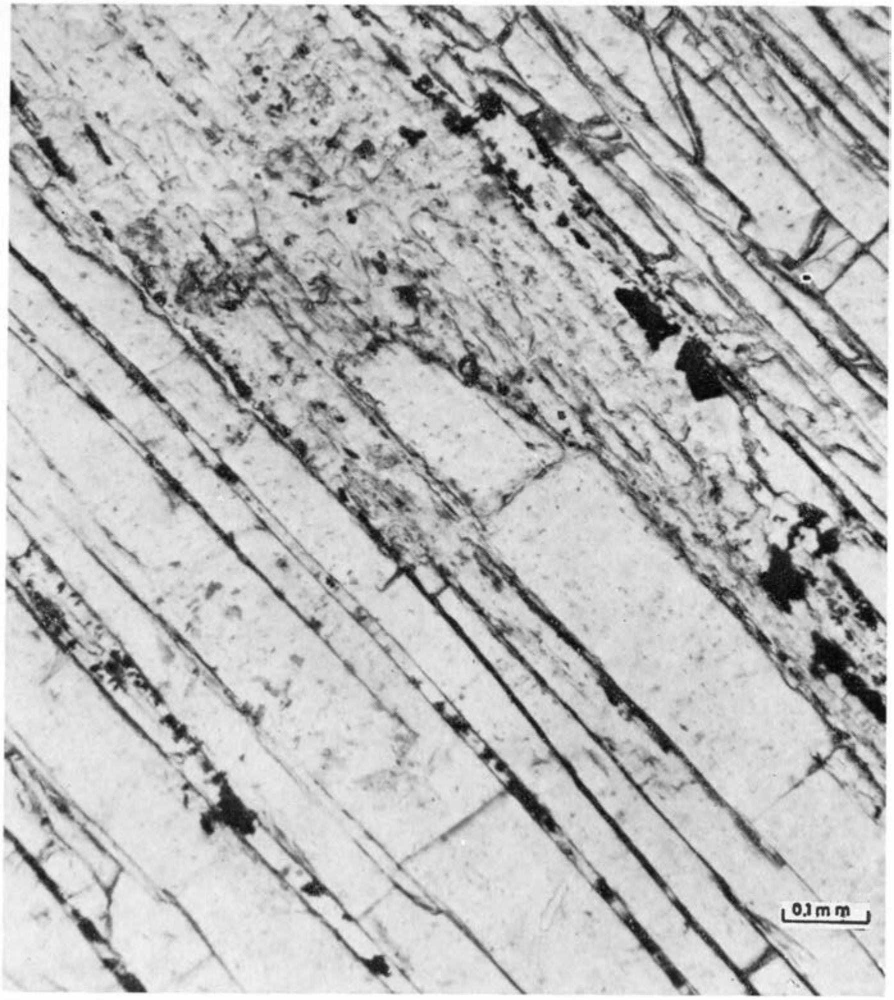

Fig. 2. The figure shows how the hematite lamellae are related to the cleavage in kornerupine (ca. 120 ×).

Physical properties

The physical properties of the Bjordammen kornerupine are listed in Table 1. The density has been determined on grains immersed in a calibrated clerici solution and a Westfahl balance. The distribution of the grains in the liquid showed that there is some variation in the density.

The calculated density from cell volume and chemical analysis (total oxygen equal to 22, Z equal to 4) (3.36) is 0.07 higher than the observed density (3.29).

The axial angle was determined with universal stage, measuring 2V directly (2V = 37°), and according to Tobi's method on an oriented section in sodium light (2V=38.5°).

Kornerupine has a moderately developed (110) cleavage and a poorly developed (001) cleavage.

Table 1. The physical properties of the Bjordammen kornerupine.

Unit cell (Å units):	Optical properties:
$a_0 = 13.80$	$2V_x = 37.5$
$b_0 = 16.05$	$N_x = 1.681 \pm 0.003$
$c_0 = 6.66$	$N_y = 1.695 \pm 0.003$
$V = 1476$ Å^3	$N_z = 1.695 \pm 0.003$
Density:	
D (obs) = 3.29	
D (calc) = 3.36	

Table 2. X-ray powder diffraction pattern for the Bjordammen kornerupine (abbreviated) and the Mautia kornerupine (McKie).

Bjordammen kornerupine				Mautia kornerupine		
hkl	dÅ(calc)	dÅ(obs)	I(obs)	dÅ(obs)	I(obs)	hkl
110	10.47	10.48	m	10.5	vf	110
020	8.03	8.06	f	8.06	vf	020
200	6.91	6.89	m	6.86	f	200
221	4.12	4.12	f	4.14	vf	221
040	4.01	4.02	m	4.03	vf	040
311	3.69	3.68	f	3.70	vf	311
041 400	3.44	3.44	m	3.45	f	400
410	3.38	3.36	s	3.37	s	002
112	3.17	3.16	f–m			
202 340	3.01	3.02	vs	3.03	vs	202
411						
032	2.83	2.84	f–s	2.85	vf	151,222
132	2.77	2.78	m	2.79	vf	132
302	2.70	2.71	m	2.716	f	510
024	2.63	2.630	vs	2.639	vvs	350
402	2.397	2.400	m	2.410	f	402
540	2.275	2.288	f–m	2.299	vf	152,600
203 123	2.113	2.112	m–s	2.137	f	203
213	2.095	2.105	m	2.118	s	460
				2.096	mf	550
–	–	2.071	f–m	2.079	vf	352
303	2.000	2.016	f–m	2.017	vf	080
313	1.984	1.995	m			
143	1.924	1.893	f			
333 403 243	1.873	1.876	m			
343	1.790	1.775	m			

McKie's crystallographic orientation of the Mautia kornerupine did not conform to the convention for orthorhombic minerals (c, a, b).
In this Table, McKie's hkl = khl, f = faint, m = medium, s = strong, v = very.

Table 3. Chemical analysis, and atomic-ratios calculated respectively relative observed density (D_{obs}) and calculated cell volume (V_{calc}), and relative to total oxygen 0 = 22.

Oxide	WTPCT*	Element	Atomic ratio: Formel Rel. D_{obs} and V_{calc}	Atomic ratio: Formel Rel. O = 22
SiO_2	31.06	Si	3.790	3.869
TiO_2	.25	Ti	.023	.023
B_2O_3	2.10	B	.442	.451
Al_2O_3	40.52	Al	5.828	5.948
Fe_2O_3	5.04	Fe^{3+}	.463	.472
FeO	.29	Fe^{2+}	.030	.030
MnO	.03	Mn	.003	.003
CaO	.08	Ca	.010	.011
MgO	19.96	Mg	3.631	3.706
H_2O	.38	H	.309	.316
Sum	99.71	O	21.555	22.000

*Analysis performed by Mr. B. Bruun.

X-ray powder pattern

The powder pattern was determined with both the Guinier camera (quartz monochromator, lead nitrate internal standard) and the 9 cm Debye-Scherrer camera (Mn filter). The cell dimensions were calculated from ten of the observed reflections. The three strongest reflections are 2.630, 3.02 and 3.26 Å. The powder pattern for the Bjordammen kornerupine is given in Table 2, together with published data for the Mautia kornerupine (McKie 1965). The calculated hkl values for the Bjordammen kornerupine show some deviation from the values for Mautia kornerupine.

Chemical composition

In order to determine the chemical composition, about 1.5 g of kornerupine was prepared by crushing a single crystal. The crushed material was sieved through 70 and 190 mesh sieves. The fraction between 70 and 190 mesh was passed through a Frantz isodynamic magnetic separator, in order to remove grains with hematite inclusions.

The analysis was performed by Mr. B. Bruun at Mineralogisk-Geologisk Museum in Oslo, and is listed in Table 3. The analysis has been recalculated to a chemical formula relative firstly to observed density (D) and cell volume (V), and secondly to total oxygen equal to 22. In both cases the number of formula-units per unit-cell (Z) is equal to 4. The formula based on D_{obs} and V shows an oxygen deficiency, which may indicate vacant oxygen sites.

The boron and the total-iron contents are low, but the ratio of Fe^{3+}/Fe^{2+} (= 15.4) is high compared to other analyses, which usually show a ratio lower than 0.5 (see analyses tabulated in McKie 1965). In a (Mg,Fe)O − $(Al,Fe)_2O_3 - SiO_2$ triangular diagram (Fig. 3), the Bjordammen kornerupine

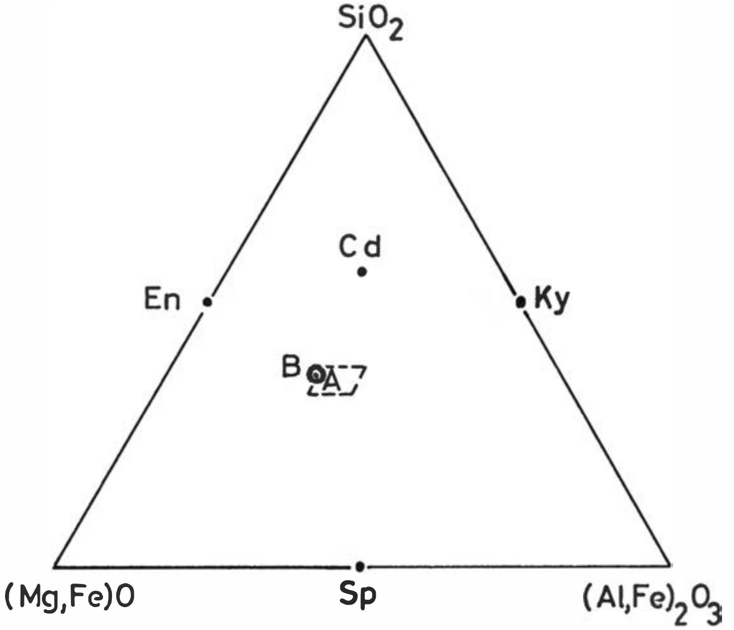

Fig. 3. Diagram of kornerupine compositions in terms of (Mg,Fe)O — $(Al,Fe)_2O_3$ — SiO_2 molecules.
A: compositional field of nine different kornerupines (after McKie).
B: composition of the kornerupine from Bjordammen.
En = Enstatite, Cd = Cordierite, Ky = Kyanite, Sp = Spinell.

plots in the upper-left corner on the SiO_2-rich side of area A in Fig. 3 in which nine other kornerupines have been plotted by McKie (1965).

Kornerupine's general formula as proposed by McKie is:

$$R_{<2}^{[8,6]}\ R_4^{[6]}\ Al_5^{[6,4]}\ (Al,Si)_4^{[4]}\ (Si,B)^{[4]}\ (O,OH)_{22}$$

$R^{[8,6]}$ represents larger cations like Na in eight- or six-fold coordination. $R^{[6]}$ represents mainly Mg, but also Al,Fe^{3+}, and Fe^{2+} may go into this position (Bartl 1965, McKie 1965).

According to this we can write for the Bjordammen kornerupine:

$$(Ca,Mg)_{.21}(Mg,Fe^{\cdot\cdot},Fe^{\cdot\cdot\cdot},Al)_4(Al,Fe^{\cdot\cdot\cdot})_5(Si,Al,Ti)_4(Si,B)_1(O,OH)_{21.56}$$

Moore & Bennett (1968) have made an extensive study of the structure of kornerupine, and the crystallochemical formula that resulted from it is written as follows:

$$Mg_2^{[6]}Mg^{[6]}Al_6^{[6]}[Si_2O_7]\,[(Al,Si)_2SiO_{10}]O_4(OH).$$

According to this the crystallochemical formula for the Bjordammen kornerupine is

$$(Mg,Ca)_2Mg(Al,Fe^{\cdot\cdot\cdot},Fe^{\cdot\cdot},Mg)_6[Si_2O_7]\ [(Al,Si,Ti)_2(Si,B)_{1.21}O_{10}]O_4(O,OH)_{0.56}$$

The excess of 0.21 cations may indicate the position proposed by McKie R[8,6] filled up with Ca and Mg ions.

Discussion

The Bjordammen area seems to be of special interest. This is so, not only because of the mineral species found there, but also because of the hematite content of rock and minerals occurring there. Andersen (1915), Divljan (1960), and Neumann & Christie (1962) have made studies on the hematite bearing minerals of this and other districts.

The optical effect caused by flaky minerals like hematite and biotite in other minerals is called aventurization. Aventurization has been observed hitherto in quartz, plagioclase, alkali feldspar, cordierite, cancrinite, and carnallite. In quartz and cordierite the effect is due to mica inclusions, in the other minerals to hematite inclusions (Neumann & Christie 1962). Recently it has been found that cordierite may also contain hematite lamellae (H. Neumann, pers. comm.). The study of the Bjordammen kornerupine has now revealed that this mineral also has inclusions of hematite lamellae. In this kornerupine the inclusions are concentrated along zones of fracturing, usually parallel to the (110) cleavage lamellae. Neumann & Christie suggested that the effect in feldspars is due to an exsolution phenomena at lower temperatures of an originally more ferric rich feldspar formed at high temperatures and moderate water activity. Divljan, however, regards the effect to be a direct result of the metamorphic-metasomatic processes in the area. This process introduced ferric ions into the crystal lattice of the feldspars.

The way in which hematite occurs in kornerupine supports introduction from outside. As noted previously hematite preferentially occurs along fracture zones and grain borders. One can also observe hematite zones crossing grain boundaries. These zones are frequently defined by a succession of hematite lamellae, but sometimes they are developed as continuous hematite veins. The ferric content of the rock seems to have been high before the formation of the veins and lamellae. This may be deduced from the fact that one can observe that the veins have formed from preexisting hematite grains. A part of the hematite is a breakdown product of cordierite, it is frequently associated with the alteration products of cordierite.

Kornerupine and tourmaline are confined to a quartz vein in the sample studied. This indicates low temperature formation for these minerals, which again suggests that the even later hematite lamellae are more likely to have been formed by metasomatism than by exsolution from a metastable phase.

A plot of the optical data and the observed density in Girault's diagram (Fig. 4) shows an inconsistency in the Mg/Fe^2 ratios relative to optical constants and density. The fact that the Mg/Fe ratio obtained from the optical data is lower than the ratio obtained from observed density supports dif-

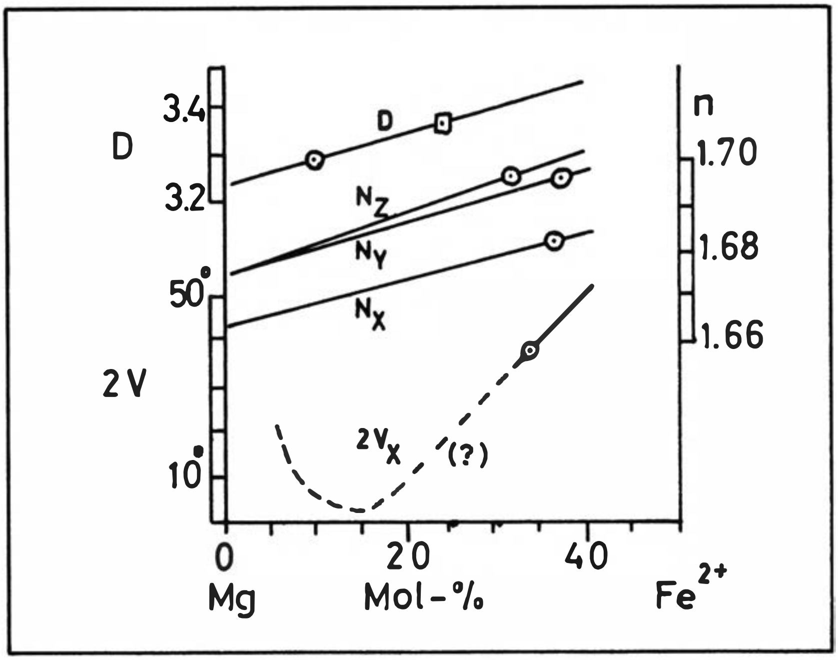

Fig. 4. Plot of physical data against chemical composition for kornerupine (a Girault diagram). The observed optical data and the observed density give different values for the Fe content.
⊙ = Observed data.
⊡ = Calculated density from chemical composition.

fusion of ferric iron out of the lattice. In this case the optical data reflect the initial ratio, and indicate vacant Fe sites.

The thin sections studied indicate that at least part of the hematite has been introduced from outside. From the optical constants, density and chemical formula relative to $D_{(obs)}$ and V one may find an indication of diffusion of Fe and O out of the crystal lattice of kornerupine. At this stage it seems not yet possible to come to some conclusive idea about the formation of the lamellae. As already noted the presence of kornerupine within the quartz vein indicates low temperature formation and so it may probably be concluded that the hematite has been introduced from outside.

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