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Mineralogy and geochemistry of the Heftetjern granite pegmatite, Tørdal: a progress report

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Introduction

A large number of granite pegmatites are situated in the Nissedal volcano-sedimentary outlier (Fig. 1 of Juve and Bergstøl 1990). Both the outlier (1300-1200 Ma) and the basement (< 1500 Ma) are intruded by the Tørdal granite (960-850 Ma), which is regarded as the source of the pegmatite swarms (Bergstøl and Juve 1988, Juve and Bergstøl 1990).

The amazonite-cleavelandite pegmatites in Høydalen (upper and lower quarries) and at Skarsfjell were described by Oftedal (1942). These pegmatites are characterized by the elements lithium (lepidolite) and tin (cassiterite). Other noteworthy elements are beryllium (beryl, gadolinite), niobium, tantalum and rare earth elements (e.g. fergusonite, yttrotantalite, microlite, monazite, allanite, kuliokite), and fluorine (yttrian fluorite, tveitite, kuliokite, topaz).

Bergstøl et al. (1977) described the new mineral tveitite-(Y) from Høydalen and named it for the owner of the area at that time, John Peder Tveit (1909-1978). The mineral was subsequently redefined as a trigonal mineral with approximate formula $Ca_{14}Y_5F_{43}$, a complex, fluorite-derived structure (Bevan et al. 1982, Bevan and Lawton 1986).

The mineralogy of the Høydalen pegmatites was updated by Raade et al. (1993), who described kuliokite-(Y) and its alteration products kainosite-(Y) and kamphaugite-(Y). The latest survey of the Høydalen minerals was published by Kristiansen (1998).

The Heftetjern pegmatite is situated between Skarsfjell and Høydalen. Bazzite, scandian ixiolite and various minerals of the pyrochlore group were investigated and described by Bergstøl and Juve (1988). The bazzite was found to contain about 3 wt.% Cs_2O (Juve and Bergstøl 1990). It was shown that this pegmatite has tin, scandium, beryllium, and (to a lesser degree) lithium as characteristic elements.

Further work on the microminerals of the Heftetjern pegmatite by one of the present authors (RK) brought to light some interesting mineral phases and parageneses. The first author of this paper (GR) decided that it would be worthwile to undertake blasting in the Heftetjern pegmatite to secure mineral specimens for the Mineralogical-Geological Museum of the University of Oslo and to obtain material for continued scientific investigations. Hans Vidar Ellingsen was asked to negotiate with the owner of the Heftetjern area, Kaj Peder Tveit, to obtain the necessay permissions and work out an economic compensation.

Some members of Geologisk Museums Venner (Frode Andersen, Knut Eldjarn, Hans Vidar Ellingsen, Harald Folvik, Astrid Haugen, Roy Kristiansen) took part in the field work with blasting on 5-6 September 1998, together with Hans-Jørgen Berg from the Museum and the landowner. Costs were defrayed by Geologisk Museums Venner.

The purpose of the present paper is to sum up the mineralogical results so far. One paper, on the intergrowth of cascandite and scandiobabingtonite (Raade and Erambert 1999), has appeared already. Work is in progress and further publications are being planned.

Mineralogy of the Heftetjern pegmatite

The minerals identified from the Heftetjern pegmatite are shown in Table 1. The most interesting of these are briefly discussed below. Several phases are not finally identified; these are excluded from the table.

Ixiolite with a maximum of 18.80 wt.% Sc_2O_3 was reported by Bergstøl and Juve (1988). Having ideally a structure with disordered cations, this particular ixiolite has the following empirical formula: $(Sc_{1.46}Ta_{1.16}Nb_{0.76}Sn_{0.26}Fe_{0.24}Mn_{0.18}Ti_{0.03})_{\Sigma 4.09}O_8$ (the atomic proportions quoted by Bergstøl and Juve are slightly incorrect). Since scandium in the formula exceeds the other elements, this could in fact be a new species. Wise et al. (1998) have analysed two ixiolites from Heftetjern and found 13.56 and 15.17 wt.% Sc_2O_3. Their analyses also show 2.25 and 1.71 wt.% ZrO_2, which was not reported by Bergstøl and Juve (1988). A recent, unpublished refinement of the structure of scandian ixiolite from Heftetjern indicates that the structure is highly disordered and pseudo-orthorhombic, with a slight departure toward monoclinic symmetry; scandian ixiolite with Sc_2O_3 in excess of 8 wt.% was found to have a stoichiometry approaching $Sc(Nb,Ta)O_4$, with a structure related to wolframite (Wise et al. 1998). Whether scandium in ixiolite is disordered over all three cation sites or not is an interesting problem that needs further study.

Plumbomicrolite occurs as greenish to brownish octahedral crystals rarely exceeding 1 mm in size, often aggregated to larger units. Electron-microprobe analyses by GR (to be published separately) show that the mineral is typically zoned and has a heterogeneous composition within each zone. Specimen HF 53-98 (from RK) has the highest PbO content of 42 wt.%, grading down to 13 wt.%. A crystal taken from a specimen collected by Astrid Haugen has a core of microlite surrounded by plumbomicrolite with 33 wt.% PbO. The content of Ta is always much greater than the content of Nb. Scandium was not detected in plumbomicrolite. The scandian microlite minerals described by Bergstøl and Juve (1988) occur as an alteration product of scandian ixiolite.

Titanite is wide-spread as a micromineral in vugs and occurs with different colours and crystal habits. Significant amounts of Al, Ta, Nb, and Sn were detected (up to ~11 wt.% SnO_2).

A calcian ***hingganite-(Y)*** commonly occurs as aggregates of pseudo-hexagonal plates ~0.5 mm across or as blocky crystals to several mm. The mineral needs a closer chemical study. The possibility of intermediate compositions between hingganite-(Y), $Y_2Be_2Si_2O_8(OH)_2$, and minasgeraisite, $CaY_2Be_2Si_2O_{10}$, should be investigated.

Kainosite-(Y), as colourless, square prismatic crystals up to 2 mm long, is found embedded in pale violet fluorite.

In pegmatite vugs, ***milarite*** crystals up to 15 mm in length were found quite abundantly. These form colourless, slender hexagonal prisms. The mineral may also occur as whitish, sugary masses or as tan, irregular sprays. Most milarites have a normal chemical composition without any appreciable substitutions. A single sample of short-prismatic, greyish milarite crystals < 100 μm across, lining a small cavity in microcline, was found to contain 5-7 wt.% Sc_2O_3. Other samples are yttrian with ~5-7 wt.% Y_2O_3. Both varieties shall be studied in more detail.

Cascandite (Mellini et al. 1982) and ***scandiobabingtonite*** (Orlandi et al. 1998) are two relatively new scandium minerals. Both have pyroxenoid structures, cascandite with a *dreier* chain of SiO_4 tetrahedra (Mellini and Merlino 1982) and scandiobabingtonite with a *fünfer* tetrahedral chain. Both minerals have now been identified from the Heftetjern pegmatite, partly as fibrous intergrowths of areas exceeding 100 μm in length (Raade and Erambert 1999). Scandiobabingtonite also occurs as greenish, discrete crystals to 1 mm or as masses up to several mm.

Hellandite-(Y) was identified by Tomas Andersen. The mineral is found as pale red microcrystals with hingganite-(Y) in fluorite. A chemical composition that could well fit with hellandite-(Y) has been obtained by SEM-EDS on material collected by RK.

Helvite has been found in one sample as irregular masses several cm across in the vicinity of bazzite. The mineral also occurs as pinkish, irregular grains intimately associated with light blue bazzite. Electron microprobe analyses of the latter gave up to 1.7 wt.% Sc_2O_3. The Heftetjern helvites have a composition close to the danalite field and also with appreciable amounts of the genthelvite component (Bernhard and Raade, in prep.)

The most interesting and sensational new find in the Heftetjern pegmatite is certainly that of a new scandium mineral as sharp microcrystals, first observed and collected by RK. Its crystal structure is currently being investigated at the University of Torino. Electron-microprobe analyses (independently by GR and Franz Bernhard) give a nice stoichiometry and $Ca_2ScSnSi_4O_{13}(OH)$ as the probable formula. A calcium-scandium-tin-silicate, this is a most fascinating mineral.

Geochemistry of the Heftetjern pegmatite

The most striking geochemical feature of the Heftetjern pegmatite, already noted by Bergstøl and Juve (1988), is the high level of scandium. Four minerals with scandium as a major element are now known from the pegmatite: bazzite, cascandite, scandiobabingtonite, and the new Ca-Sc-Sn-silicate (thortveitite was erroneously reported from Heftetjern by Juve and Bergstøl 1997). In addition, several minerals contain scandium as a minor element at levels up to several weight percent (Table 2).

The scandium-bearing minerals in the Heftetjern pegmatite seem to be confined to a certain phase of the pegmatite formation. Closer paragenetic studies and determination of the scandium content of most of the minerals are needed to substantiate this view. It is interesting to note that Oftedal (1943) in the Høydalen pegmatite found less scandium in the younger, pale pink beryl than in the older, blue or yellow beryls, and less scandium in the younger lepidolite and pink muscovite than in the older, greyish muscovite (Table 2). Oftedal concluded that the main reason for the low level of scandium in the youngest micas and beryls is probably that no more scandium was available during their crystallization.

Bergstøl and Juve (1988) have shown that some of the tin and a major part of scandium in the amazonite-cleavelandite pegmatites of the area may have their source in volcanogenic rocks of the Nissedal outlier, which were penetrated by the pegmatitic fluids. The Heftetjern and Høydalen pegmatites are situated no more than 1 km apart and yet there are major differences in their geochemistry, the former showing a remarkably strong concentration of scandium and the latter being enriched in lithium and fluorine, elements that are typically concentrated in fluids derived from granitic magmas.

The Tørdal pegmatite area can generally be classified as a lithium-scandium-tin province. Oftedal (1956) has discussed the behaviour of certain elements during the replacement of amazonite pegmatite by cleavelandite pegmatite in the Tørdal area. Following Černý (1992), the Tørdal pegmatites are of a mixed LCT-NYF family. The LCT family typically carries <u>L</u>i, Rb, <u>C</u>s, Be, Sn, Ga, <u>T</u>a>Nb, (B, P, F) and the NYF family is marked by a <u>N</u>b>Ta, Ti, <u>Y</u>, Sc, REE, Zr, U, Th, <u>F</u> signature.

Collecting in the Heftetjern pegmatite

It must be emphasized that any collecting in the Heftetjern pegmatite can only take place with permission from the landowner, who has posted a sign with the following text at the site:

WARNING !!!
Removing of minerals and rocks without the landowner's permission will be reported to the authorities.
Fjerning av mineraler uten grunneiers tillatelse vil bli påtalt/anmeldt.
Kaj Peder Tveit (tlf. 35998221)

Acknowledgements

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Table 1. Minerals from the Heftetjern granite pegmatite, Tørdal, Telemark, Norway.

Mineral	Formula	Variety	Identification
Sulphides			
Galena	PbS		visual
Pyrite	FeS_2		visual
Halides			
* Fluorite	CaF_2	yttrian	FB
Oxides			
* Quartz	SiO_2	partly smoky	
Opal	$SiO_2 \cdot nH_2O$		visual
** Magnetite	Fe_3O_4		
Ferrotantalite	$FeTa_2O_6$	scandian	EX
* Ixiolite	$(Ta,Nb,Sn,Fe,Mn)_4O_8$	scandian	
Anatase or brookite	TiO_2	scandian	FB
* Cassiterite	SnO_2		XRD 129
* Yttropyrochlore-(Y)	$(Y,Na,Ca,U)_{1\text{-}2}(Nb,Ta,Ti,)_2(O,OH)_7$	scandian	
* Microlite	$(Ca,Na)_2(Ta,Nb)_2O_6(O,OH,F)$	scandian/uranian	
Plumbomicrolite	$(Pb,Ca,U)_2(Ta,Nb)_2O_6(OH)$		FB, EPMA
* Yttrobetafite-(Y)	$(Y,U,Ce)_2(Ti,Nb,Ta)_2O_6(OH)$		
Ilmenorutile	$(Ti,Nb,Fe)_3O_6$	scandian	EX
Yttrotantalite-(Y)	$(Y,U,Fe)(Ta,Nb)O_4$		EX
Phosphates			
** Monazite-(Ce)	$CePO_4$		XRD 246, 247; X-ray 29947, 29989
Apatite	$Ca_5(PO_4)_3(F,OH)$		XRD 246
Carbonates			
Calcite	$CaCO_3$		visual, chemical test
Cerussite	$PbCO_3$		FB, chemical test
Silicates			
* Spessartine	$Mn_3Al_2(SiO_4)_3$	scandian	FB
* Zircon	$ZrSiO_4$		FB
Titanite	$CaTi(SiO_4)O$	stannian	FB, EX
* Gadolinite-(Y)	$Y_2FeBe_2Si_2O_{10}$		

	Hingganite-(Y)	$(Y,Yb)_2Be_2Si_2O_8(OH)_2$	calcian	XRD 152, 273; X-ray 29887, 29922, 29952
*	Bertrandite	$Be_4Si_2O_7(OH)_2$		XRD 257
	Epidote	$Ca_2(Fe,Al)_3(SiO_4)(Si_2O_7)O(OH)$	cerian/scandian	FB
*	Allanite	$(Ce,Ca,Y)_2(Al,Fe)_3(SiO_4)(Si_2O_7)O(OH)$		XRD 153, 254, X-ray 30131
	Kainosite-(Y)	$Ca_2(Y,REE)_2Si_4O_{12}(CO_3)\cdot H_2O$		XRD 174, EX, FB
*	Beryl	$Be_3Al_2Si_6O_{18}$		XRD 274
*	Bazzite	$Be_3(Sc,Al)_2Si_6O_{18}$	in part cesian	XRD 242; X-ray 29848
	Schörl	$NaFe_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$		FB
	Milarite	$KCaAlBe_2Si_{12}O_{30}\cdot 0.5H_2O$		XRD 149, 179, 248, 256, 257
	do.		yttrian	FB
	do.		scandian	FB
	Augite	$(Ca,Na)(Mg,Fe,Al)(Si,Al)_2O_6$		XRD 445
	Actinolite	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$		XRD 445
	Cascandite	$Ca(Sc,Fe)Si_3O_8(OH)$		cf. Raade and Erambert (1999)
	Scandiobabingtonite	$Ca_2(Fe,Mn)ScSi_5O_{14}(OH)$		XRD 332; cf. Raade and Erambert (1999)
	Hellandite-(Y)	$(Ca,Y)_6(Al,Fe)Si_4B_4O_{20}(OH)_4$		X-ray 29924
**	Bavenite	$Ca_4Be_2Al_2Si_9O_{26}(OH)_2$		XRD 245
	Muscovite	$KAl_2(AlSi_3)O_{10}(OH,F)_2$		visual, FB
	Biotite	$K(Mg,Fe)_3((Al,Fe)Si_3)O_{10}(OH,F)_2$		visual
**	Zinnwaldite	$KLiFeAl(AlSi_3)O_{10}(F,OH)_2$		
	Clinochlore	$(Mg,Fe)_5Al(AlSi_3)O_{10}(OH)_8$		XRD 154, FB
	Stilpnomelane	$K(Fe,Mg,Fe)_8(Si,Al)_{12}(O,OH)_{27}$		XRD 243, 244
*	Microcline	$KAlSi_3O_8$		visual
*	do.		amazonite	visual
*	Albite	$NaAlSi_3O_8$	cleavelandite	visual
*	Albite-oligoclase	$(Na,Ca)Al(Si,Al)Si_2O_8$		
	Helvite	$(Mn,Fe,Zn)_4Be_3(SiO_4)_3S$	scandian	XRD 255, FB

* noted by Bergstøl and Juve (1988).
** noted by Juve and Bergstøl (1990).
X-ray: 9 cm Debye-Scherrer camera (MGM, Oslo).
XRD: Siemens D 5000 diffractometer (MGM, Oslo).
EPMA: Electron-probe microanalysis (MGM, Oslo).
EX: SEM-EDS (Excalibur Mineral Co., USA).
FB: SEM-EDS (Franz Bernhard, Univ. Graz).

Table 2. Scandium in minerals from granite pegmatites of the Tørdal area.

Mineral	Sc ppm	Sc_2O_3 wt.%	Ref.
Heftetjern			
Ferrotantalite		~ 7	
Ixiolite		1.70-18.80	1
Brookite or anatase		~ 0.5	
Yttropyrochlore-(Y)		6.0	1
Microlite		0.2-3.9	1
Yttrobetafite-(Y)		1.0	1
Ilmenorutile		~ 1.6	
Spessartine		~ 0.5	
Epidote		~ 3.0	
Milarite		5-7	
Helvite		~ 1.7	
Høydalen			
Muscovite, greyish, rich in Li	700		2
Lepidolite, reddish violet	5		2
Muscovite, pink	<3		2
Beryl, yellow	300		2
Beryl, pale blue	100		2
Beryl, pale pink to colourless	3		2
Beryl, light red	20		3
Cassiterite	100		2
Ixiolite(?), incl. in cassiterite		1.03-1.69	4
Skarsfjell			
Biotite from bedrock contact	100		2
Muscovite, yellow	500		2
Muscovite, greyish, rich in Li	400		2
Zinnwaldite(?), brown	2000		2
Topaz	3		2

1. Bergstøl and Juve (1988). 2. Oftedal (1943). 3. Neumann (1961). 4. Raade et al. (1993).