Lithium mineralization in Norway: a review

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Introduction

Today lithium comprises 118 minerals world-wide containing essential lithium (Grew *et al.* 2018), while we only have 16 in Norway. Oftedal (1940) wrote "Minerals containing appreciable amounts of lithium appear to be particularly rare in Norway". However, he pointed out that a real lithium mica was described by Brøgger (1890) from Vesle Arøy in Langesundsfjord, but it was not analysed due to lack of material. Oftedal (1940) concluded that this must be polylithionite. Shortly after he analysed a number of differently colored micas from Høydalen and found a reddish violet lepidolite with 5.0 % Li_2O (Oftedal 1943). Oftedal (1950) briefly described multi-colored Li-tourmalines and spodumene from a pegmatite at Ågskardet in Holandsfjord, Nordland. Frigstad (1968) described small blue-green elbaite crystals from Iveland.

The diversity of lithium minerals in Norway are much less advanced than in Sweden and Finland. Generally, lithium occurs in tourmalines and micas in granitic pegmatites in Norway, with a few exceptions of some rare lithium bearing minerals in the syenite pegmatites in the Larvik Plutonic Complex (LPC) (Larsen 2010).

Lithium bearing tourmalines are restricted to a few occurrences in granitic pegmatites in northern Norway, in Iveland, southern Norway, and from Stord, western Norway. Lithium bearing micas are present in a few localities in southern Norway (Tørdal and Iveland), but rarely present in northern Norway. Rosing-Schow *et al.* (2018a, 2018b) have recently analysed the lithium content and classified a large number of micas from different granitic pegmatites in southern Norway.

The pegmatites in Høydalen are mixed LCT + NYF type pegmatite (Černý 1992) and not pure LCT pegmatites. There are two pegmatites with a modest evolvement of LCT-type pegmatite in northern Norway. One large pegmatite is situated at Ågskardet, close to the Svartisen glacier (Oftedal 1950), with abundant, multicolored fluor-elbaite and spodumene. Cookeite is rarely met with as an alteration product of tourmalines. Lithiophilite and ferrisicklerite are extremely rare (Kristiansen 1972), along with pollucite as the single Norwegian occurrence of this mineral (Kristiansen & Olsen 2019). In a small LCT pegmatite at Sandnessjøen, Nordland, fluor-liddicoatite and rossmanite occur, the former even of gem quality (Nordrum *et al.* 1999, 2003; Kolitsch *et al.* 2013). The rare beryllium mica bityite has been found in a granitic pegmatite in Iveland as an alteration product of beryl (Larsen /Corneliussen 2008).

The five lithium minerals in the syenite pegmatites in the LPC region are all very rare, except for the more common polylitionite, which have been found in several of the pegmatites both on the islands in the Langesundsfjord and on the mainland (Larsen 2010).

Lithium bearing micas

Rieder *et. al.* (1998) defined true micas with end-members and species name, and with permissible ranges of composition. They also included series names intended to designate incompletely investigated micas that are used by field geologists, petrographers and mineral collectors. The series names *lepidolite* and *zinnwaldite* are used in the present paper. More in-depth discussion has recently been published in an extensive paper on the lithium content of a number of micas from many pegmatites in southern Norway (Rosing-Schow *et al.* 2018a).

Lepidolite, $K(Li,Al)_3(Si,Al)_4O_{10}(F,OH)_2$

Lepidolite is a series name on trioctahedral, light, lithium rich micas on, or close to, the polylithionite – trilithionite join (Tischendorf *et al.* 1997; Rieder *et al.* 1998). The first Norwegian *lepidolite* was described by Oftedal (1943) from the granitic pegmatites in the Høydalen quarries in Tørdal. The mineral occurrs in rather large blocks attaining 15 -20 cm wide of bright reddish violet color in the upper quarry, and more greyish violet in the lower quarry. Rosing-Schow *et al.* (2018a) have classified the *lepidolite* from Høydalen as siderophyllite-polylithionite and polylithionite with up to 7.7 wt.% Li_2O. Other micas from Høydalen are less enriched in lithium and classified as trilithiolite or lithian ferroan muscovite.

Micas from Iveland in Setesdal have less lithium than the micas from the Tørdal pegmatites. They vary in their compositions and are classified as lithian muscovite - polylithionite (Rosing-Schow *et al.* 2018a). Most Li is found in mica from Skripeland (erroneously written as Skipeland by Rosing-Schow *et al.* 2018) with 2.75 wt.% Li_2O and classified as a trilithionite. Larsen & Erambert (2007), however, described *lepidolite* from Litjern in Iveland with 5.49 wt.% Li_2O. The mineral occurs as pale brownish «books» up to 8 cm across and 2 cm thick. As pointed out by Larsen & Erambert (2007) this may be the locality where Olaf Andersen collected a mica more than 100 years ago, and the same mica that Oftedal (1943) later analysed and described. It is strange that Rosing-Schow *et al.* (2018a) did not include this locality in their work on lithium in micas in southern Norway, but they did so in their summary paper (Rosing-Schow *et al.* 2018b).

Lepidolite of silvery-white color has been identified from the locality called "Tunnelen" (Birkeland 3) in Iveland (pers. comm. Larsen & Åsheim 1981). The mineral has 4.89 wt.% Li_2O, The sample was collected by the late Orest Landsverk. *Lepidolite* from Sandnesjøen occurs as pale violet, fine-grained masses. Singel flakes are less than 1 cm. *Lepidolite* is listed by Ihlen (2004) from the Ågskardet pegmatite, but with no further details. A flame test on a greyish violet mica was used on a sample collected by the author, and it indicated a lithium content. The mineral is associated with ferrisicklerite.

Polylithionite, $KLi_2Al(Si_4O_{10})(F,OH)_2$

Polylithionite is an end-member within the true micas and has the highest content of lithium. The mineral was first confirmed by Raade & Larsen (1980) from syenite pegmatite locations in the LPC; at Vesle Arøy and on the island Låven in the Langesundsfjord, and at Vøra, Vesterøya near Sandefjord. The mineral from the latter locality was fully analysed and contained 7.07 wt.% Li_2O. The Vøra polilithionite occurs as thick, irregular crystal blocks or aggregates with a pale yellowish green color.

Individual plates may attain 5- 6 cm across. Several other locations have been reported by Larsen (2010): Jahren, Buer, Vesle Arøya, Siktesøya, Sagåsen and Bratthagen. Li-bearing micas have later been recorded from approximately 30 localities in the LPC, but not all of them are confirmed by analyses (pers. comm. Svein Arne Berge 2018).

Zinnwaldite, $KLiFe^{2+}Al(AlSi_3O_{10})(F,OH)_2$

Zinnwaldite is a series name on trioctahedral, dark, lithium containing micas on, or close to, the siderophyllite – trilithionite join (Tischendorf *et al.* 1997; Rieder *et. al.* 1998). At Sandnessjøen, Nordland *zinnwaldite* occurs as aggregates to 7 - 8 cm very much alike biotite, but with a reddish tint (Nordrum *et al.* 1999). At Skarsfjell, Tørdal, *zinnwaldite* occurs as greyish brown to dark brown individuals up 10-15 cm across. Complete chemical analyses were perfomed on these two *zinnwaldites* and showed 2.48 wt.% and 4.18 wt.% Li_2O, respectively (pers. comm. Larsen & Åsheim 1982). *Zinnwaldite* is also identified from the Heftetjern pegmatite, Tørdal (Juve & Bergstøl 1997).

Lithium bearing tourmalines.

The first lithium bearing multicolored tourmalines in Norway were discovered in the Ågskardet lithium-pegmatite close to the Svartisen glacier, Nordland, briefly described by Oftedal (1950). He distinguished between three color types: black, yellowish brown, and colorless to pale red. Most of the tourmalines show zonation with a characteristic outer thin shell of greenish brown color.

He also performed spectrographic analyses of the tourmalines, all characterized by a high lithium content except for the black type. They all have significant Na and Mn, while the brownish type contains considerably more Ca and Ti.

Almost 50 years later Larsen *et al.* (1999) published a large number of mostly partial analyses of tourmalines, which covered a large number of Norwegian localities, including tourmalines from the LCT-pegmatites at Ågskardet and Sandnessjøen. Their analysis no. 43 (from Sandnessjøen) was complete and showed that this is fluor-liddicoatite, se below.

Fluor-liddicoatite, $Ca(Li_2Al)Al_6(Si_6O_{18})(BO_3)_3(OH)_3F$

Besides dull blackish and brownish schorl, the most common tourmaline at the Sandnesjøen locality is olive green, well-developed crystals of liddicoatite. Many crystals are zoned and the purest part have 70 mol-% liddicoatite and 30 mol-% elbaite. The largest crystals were up to 13-14 cm in length, and often bent or fractured (Fig. 1). Nordrum *et al.* (1999) explained that the possible reason for the occurrence of fluor-liddicoatite may be caused by the surrounding calcium-rich skarn rocks. Some parts of the fluor-liddicoatite, up to 3.5 cm, were suitable for faceting and is illustrated by Nordrum *et al.* (2003). Zoned crystals of tourmalines from Ågskardet have a dark yellowish rim of fluor-liddicoatite.

Fig. 1. *Fluor-liddicoatite from Sandnessjøen. Fov 6 cm.*

Fluor-elbaite, $Na(Li_{1.5}Al_{1.5})Al_6(Si_6O_{18})(BO_3)_3(OH)_3F$

More than 60 years after Oftedal (1950) described the multicolored tourmalines from the Ågskardet Li-pegmatite, Kolitsch *et al.* (2013) finally investigated these tourmalines. The color zonation can be divided in to the following: 1) a thin brown yellow outer rim of fluor-liddicoatite, and 2) grading into a Ca-rich fluor-elbaite on a pale pink to almost colorless core of 3) fluor-elbaite. Sections of the outermost very thin rim (20-50 µm) is Na-rich and seems to correspond to **rossmanite,** ideally $\square(LiAl_2)Al_6(Si_6O_{18})(BO_3)_3(OH)_3(OH)$**,** along with Ca-rich fluor-elbaite, fluor-liddicoatite and Fe-rich fluor-elbaite.

Frigstad (1968) reported up to 5 mm long, blue-green, probably elbaite crystals from cleavelandite zoned pegmatites at Skripeland and Lauvland in Iveland. The few crystals were growing into beryl. The identification was based solely on the refractive indices.

From the Høydalen pegmatite in Tørdal two types of tourmalines were described and analysed by Raade & Kolitsch (2016). The two types are dark olive brown and bluish green and contains 0.19 wt.% and 0.47 wt.% Li_2O, respectively. They are rather poor in lithium, probably because the major part of lithium was consumed in the formation of *lepidolite*.

Significant amounts of a pink elbaite was found at Tindane, Fitjar, Stord, Hordaland, and first analysed by Larsen *et al.* (1999), and then briefly described by Raunholm & Bjugn (2000). The locality and minerals were further described Breivik (2018). The color varies from bright reddish pink to pale pink, while others are colorless, light yellow green, dark green, bluish violet and dark blackish

green. The aggregates of light pink elbaite attain a size of 10-15 cm in length, exceptions up to 20 cm, and are usually broken and bent. Most crystals are 4 - 6 mm in diameter (Breivik 2018). Based on the analyses by Larsen *et al.* (1999) the mineral is a OH-elbaite. Preliminary analyses and a structural refinement (R=1.76 %,) of a pink elbaite from the present author showed that it is either a OH-rich fluor-elbaite (F:OH = 0.6:0.4) or possibly a Li-rich olenite (pers. comm. Uwe Kolitsch 2016). The conclusion is still pending. Breivik (2018) recognized a number of color varieties and we can not exclude that other true tourmalines may exist in the locality.

Lithiophilite, $LiMn^{2+}PO_4$

Lithiophilite is a typical mineral in LCT type pegmatites in many localities worldwide, often in very nice crystals. On his first visit in 1971 the author found the mineral in the Ågskardet pegmatite as an irregular crystalline, 2 cm nodule of pinkish salmon color (Fig. 2). The nodule is surrounded by colorless transparent aggregates of hureaulite $(Mn,Fe)_5(PO_4)_2(HPO_4)_2 \cdot 4H_2O$, partly stained by Mn-oxides. The sample contains very small amounts of a brown unidentified mineral, perhaps bermanite, which use to be an altration product of hureaulite. Lithiophilite and hureaulite are still the only findings in Norway.

Fig. 2. *Lithiophilite from the Ågskardet, Meløy, Nordland. Fov 3 cm.*

Ferrisicklerite, $Li_{1-x}(Fe^{3+}_{x}Fe^{2+}_{1-x})PO_4$

This was a new mineral to Norway, and found together with lithiophilite in 1971 in the Ågskardet Li-pegmatite. It occurs in a 4 x 6 cm sample of feldspar, and ferrisicklerite appears as a 3 x 7 mm large, irregular, prismatic, altered crystal of rusty brown color associated with heavily altered spodumene, cookeite, apatite, and dull greyish violet flakes of lepidolite. Ferrisicklerite could well be an alteration product of triphylite.

Spodumene, $LiAlSi_2O_6$

The very first finding of spodumene in Norway was reported by Oftedal (1950) from the Ågskardet pegmatite. The mineral occurs as incomplete platy crystals, 4-5 cm in length and 5 mm thick (Fig. 3). Most of the material is turbid and only partially transparent. The mineral is dull whitish to pale brownish in color. It shows a dull, very pale orange fluorescence in SW-UV light. Many crystals shows a pinkish or rose color which indicate an incipient alteration towards cookeite/montmorillonite. Oftedal (1950) analysed the mineral with a quartz-spectrograph combined with optical examination and thereby verified the mineral as spodumene. Besides the main components he also found small amounts of Mg, Fe, Mn, Ca. Na, and traces of Sn. A white crust or rarely some lath-like crystals, sometimes covering the altered surfaces, turned out to be laumontite, previously reported by Ihlen (2004).

Fig. 3. *Spodumene from Ågskardet. Fov 3 cm.*

Spodumene was identified from the lithium-pegmatite at Sandnessjøen, in Nordland, where the mineral occurs as transparent, pale violet cleavage plates to 2 cm with no trace of alteration. The

mineral shows a red fluorescence in SW-UV light. The spodumenes from Ågskardet and Sandnessjøen have not been examined for inclusions.

Gunnar Raade (pers. comm. 1981) visited the collections of École de Mines in Paris in 1980, and observed on exhibition a sample labelled "*Pegmatite & tourmaline á triphane, Bamble, Norvégé*" *Triphane* is an old synonym for spodumene, and the mineral occurs as centimeter large areas in quartz associated with black tourmaline. Later, he obtained a small, sawn piece from the sample. PXRD analysis confirmed the identity. Unfortunately, we do not know the exact locality.

Cookeite, $(Al_2Li)Al_2(AlSi_3O_{10})(OH)_8$

Neumann (1959) first reported the identification of cookeite from Holandsfjord, but without any description. The precise locality is the Ågskardet pegmatite, Meløy, Nordland where the mineral occurs in two main varieties:

- As colorless or yellowish globules in aggregates to several centimetre (Fig. 4a). Single globules are less than 1 mm in size, and composed of hexagonal flakes projecting out of a flaky matrix of the same material (Fig. 4b). It is either found together with well-developed albite crystals as a replacement of muscovite plates or together with quartz crystals replacing multicolored tourmaline. The crystal shape of tourmaline is often well preserved.
- As violet to rose colored dense masses mixed with quartz and clay minerals occurring as fracture fillings or coatings on feldspar.

Optical spectrography of the first variety showed ~0.3 wt.% B_2O_3, minor amounts of Fe, Mn, Mg, and traces of Be, probably ~0.1 wt. %, as well as a few hundred ppm of Ti and Sn (pers. comm. Ivar Oftedal 1972). The mineral was briefly mentioned and pictured by Kristiansen (1994).

Most cookeites contain very little or no boron, but shows large variations in chemistry (Černý 1970). Boron-containing cookeites occur in some pegmatites abroad, and the new mineral borocookeite was described from boron-rich pegmatites in Russia (Zagorsky *et al.* 2003).

Fig. 4a (left). *Cookeite from the Ågskardet pegmatite, Meløy, Nordland. Fov 3 cm.*
Fig.4b (right). *SEM photo of crystal aggregates of cookeite from Ågskardet. Fov 1 mm.*

Bityite, Li Ca $Al_2(AlBeSi_2O_{10})(OH)_2$

The Li-Be-mica bityite was identified from Tveit 3 in Iveland by Alf Olav Larsen in 2008 by PXRD analysis. The sample was supplied by the late Andreas Corneliussen. It is a rather massive sample with no distinct crystals. Associated minerals include muscovite-$2M_1$, quartz, bertrandite, and beryl. Bityite seems to be an alteration product of beryl. This is the first record of the rare mineral bityite in Norway. Lahti & Saikkonen (1985) gives a detailed description of bityite from Eräjärvi, southern Finland, where it occurs in pseudomorphs after beryl or in cavities with bertrandite.

Lithium minerals in the Larvik Plutonic Complex

Zektzerite, $NaLiZrSi_6O_{15}$

The mineral was first found at Virikkollen, Sandefjord, in a small syenite pegmatite, as the first finding in Norway (Larsen & Kolitsch 2012). It occurs as vitreous, strongly hydrothermally etched crystals, up to 1 cm in size (Fig. 5). The mineral is colorless, transparent with a slightly pinkish hue and shows a light yellow fluorescence in SW UV light. Zektzerite occurs in vugs in quartz together with zircon, opal, bertrandite and aegirine.

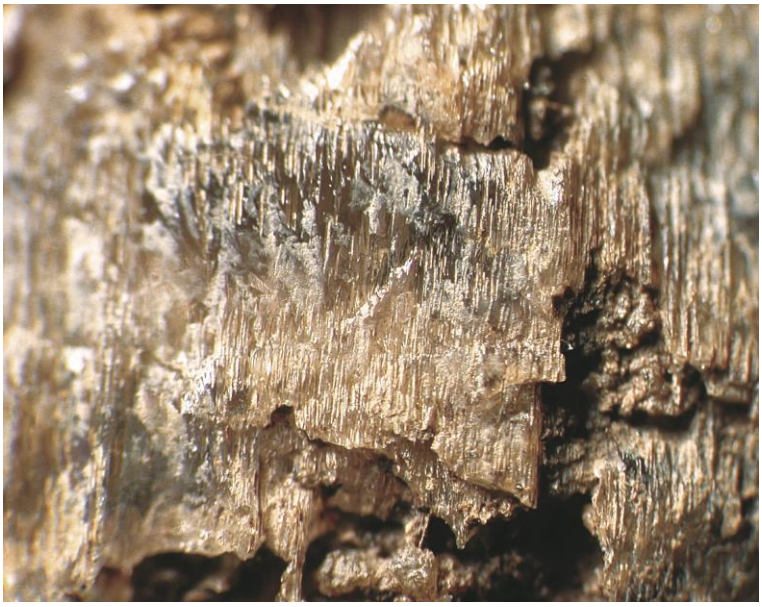

Fig. 5. *Zektzerite from Virikkollen, Sandefjord, showing the etched surface. Fov 1 cm.*

In 2017 zektzerite was found in the Jahren pegmatite, Stavern, Larvik (Kjærnet 2018). The mineral occurs as a rather common mineral in the locality as irregular masses of colorless to pale brownish color up to several centimetres in size. Crystals up to 1 cm are rare. The mineral shows yellowish to whitish bluish fluorescence in SW UV light (Fig. 6). A third locality was discovered at Fuglevik feldspar quarry, about 1 km SW of Jahren, where it occurs as sugary aggregates up to 1 cm. All findings occur in the Stavern-type of pegmatites. (Kjærnet 2018) pointed out that further findings could be expected in other locations in the LPC, especially in pegmatites carrying Li-minerals as polylithionite.

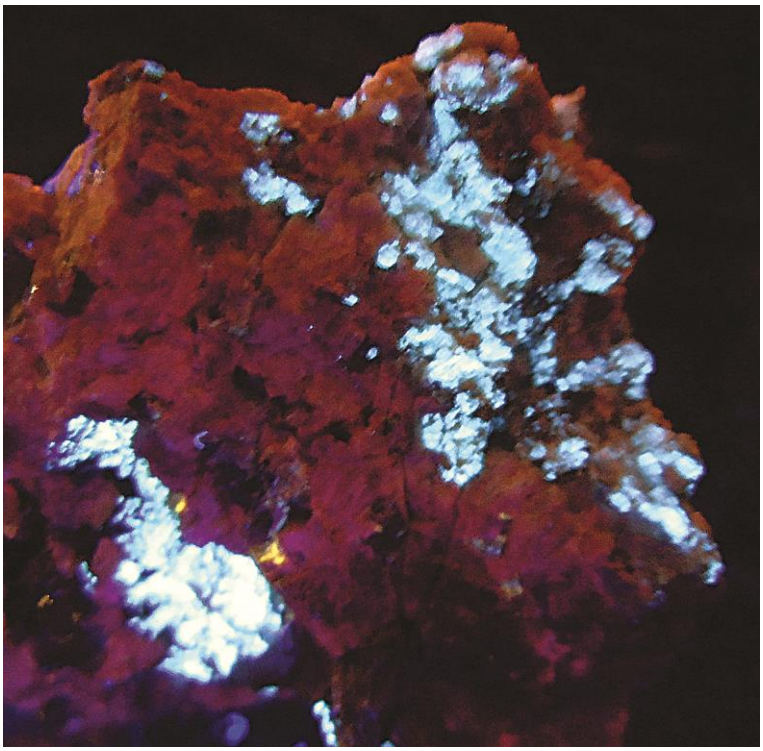

Fig. 6. *Zektzerite from Jahren, Larvik, showing bluish white fluorescence in short-wave UV light. The feldspar fluoresces dark red. Fov 6 cm.*

Ephesite, $LiNaAl_2(Al_2Si_2O_{10})(OH)_2$

The rare mica group mineral ephesite was first reported from LPC by Andersen *et al.* (1996) after the mineral was identified by Uwe Kolitsch. The mineral occurs as colorless to white, thin, pseudohexagonal platy crystals to 1 mm across in vugs in natrolite associated with böhmite, diaspore, amesite and berborite at Saga I quarry, Mørje, Porsgrunn. SEM photos are shown by Larsen (2010).

Tainiolite , $KLiMg_2(Si_4O_{10})F_2$

Tainiolite was first found by Frode Andersen in 1998 in a syenite pegmatite at Tangane on the southern part of Siktesøya in the Langesundsfjord. The mineral occurs very sparingly as a late hydrothermal mineral in vugs associated with aegirine, astrophyllite and analcime. It appears as pseudohexagonal, thin tabular crystals up to 0.2 mm across, but also as intergrown masses up to 1 cm. The mineral is also found as colorless flakes to 1 cm across in syenite pegmatite material at Valleråsen, Porsgrunn (Larsen 2010).

Ferri-fluoro-leakeite, $\{Na\}\{Na_2\}\{Mg_2Fe^{3+}{}_2Li\}(Si_8O_{22})F_2$

This is a very rare amphibole originally described from Kazakhstan by Camara *et al.* (2010). Norwegian material was collected by the author in 1978 at the Bratthagen nepheline syenite pegmatite in Lågendalen, Larvik (Larsen 2010). The sample containing ferri-fluoro-leakeite is 6 x 5 x 4 cm in size, and contains anorthoclase and broken crystals of aegirine as major constituents, with minor catapleiite, a pyrochlore group mineral, pyrophanite and zircon (Fig. 7). Ferri-fluoro-leakeite, about 8 x 4 mm in size, occurs as an elongated striated crystal of mustard yellow to brownish yellow color,

growing parallel to a broken aegirine crystal. The mineral has a relatively high content of Zn. A tiny crystal fragment was selected for data collection and structure analysis, and was fully characterized by Oberti *et al.* (2014). The Norwegian material is even closer to the ideal composition than the type material from Kazakhstan (Camara *et al.* 2010).

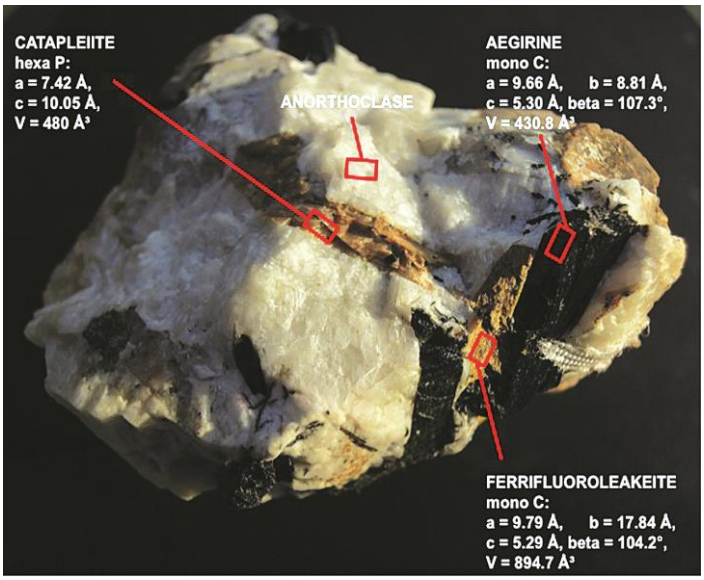

Fig. 7. *The sample from Bratthagen from which ferri-fluoro-leakeite was identified. Fov 6 cm.*

Discusion and comments

Why are lithium minerals so rare in Norway? The explanation may be the different geological settings in Norway compared to the wide distribution of LCT-pegmatites in Sweden and Finland. Looking at a simplified geological map of the Fennoscandian peninsula (the Baltic shield) one observes that the geology is of Paleoproterozoic origin in large part of Sweden and Finland, or socalled Svecofennian origin, 1750 - 2500 Ma. This has favored the evolvement of several LCT pegmatites with petalite, amblygonite-montebrasite, spodumene, eucryptite, pollucite, holmquistite, and extensive assemblages of secondary phosphates, including beryllium phosphates. The latter is completely absent in Norwegian pegmatites (Kristiansen 2016). We can not exclude that amblygonite and petalite may have escaped attention, because of the difficulty to visually distinguish these minerals from feldspar or quartz.

Ihlen (2004) listed 54 different minerals from the Ågskardet pegmatite, including the Li-minerals amblygonite, petalite and triphylite. We have not been able to confirm these three minerals. Pollucite were also listed, although more than 200 samples had been tested with negative results using a chemical reaction. However, pollucite was in fact collected by Hans Chr. Olsen already late in the 1960's and identified by Per Chr. Sæbø, confirmed by Alf Olav Larsen (pers. comm. 2018), and briefly described by Kristiansen & Olsen (2019).

The granitic pegmatites with lithium mineralization in southern Norway are of Proterozoic origin, 900 - 1700 Ma, while the LPC region are dated to < 300 Ma.

In northern Norway all locations with lithium mineralization are within the Caledonian belt, and the Ågskardet pegmatite are of Devonian age, dated to 402 - 409 Ma (pers. comm. Peter Ihlen 2018).

A short, summarized version of the present paper was presented by the author in Stockholm 2018 during the anniversary conference “Lithium 200 years" (Kristiansen 2018).

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