

Dravite, schorl and axinite-(Fe) from Mule, Porsgrunn, Telemark, Norway

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Introduction

During building of a new nursing home at Mule, Porsgrunn, in the autumn of 2017, the mineral collector Vegard Evja, having the construction site as his working place, noticed peculiar mineralisations in a rock wall that was recently exposed by blasting (Fig. 1, coordinates EU89: 59.10256° N, 9.69635° E). Fortunately, he kept most of the material. When studying the samples he observed small amounts of a pale bluish, radiating mineral along with masses of beige to pale violet, coarse crystals. The minerals were identified by the authors as tourmaline (both dravite and schorl) and axinite-(Fe), respectively. This paper documents the locality and its mineralogy, unparalleled in the southern part of the Oslo Region.

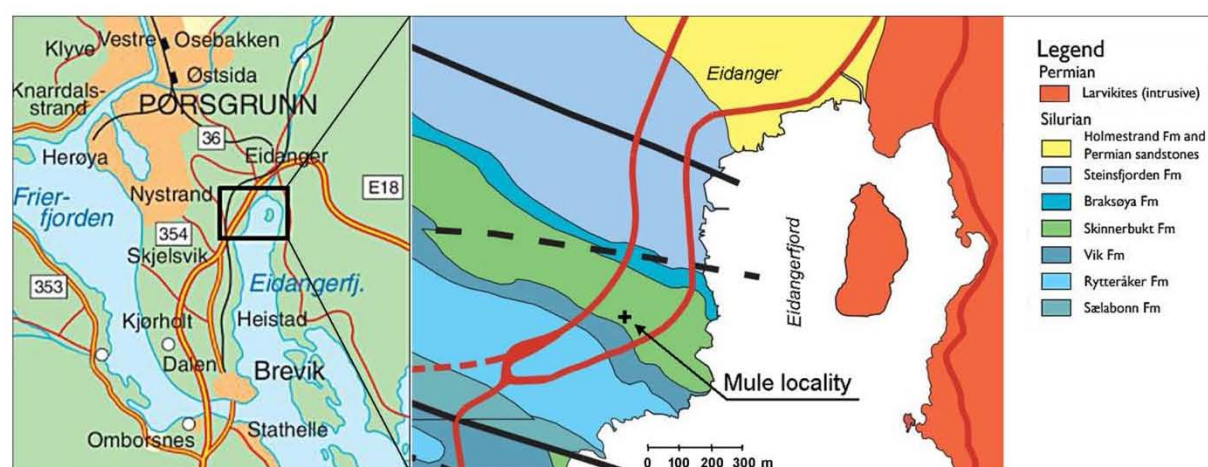


Figure 1. The location (left) and geology of the Eidanger district (right), with the Mule locality marked with a cross (excerpt from Schovsbo et al. 2018).

The locality and its geology

The Lower Palaeozoic sedimentary rocks in the Grenland district (from Langesund in the south to Skien in the north) form one of many regions of similar rocks scattered throughout the Oslo Region. The sediments were preserved due to the formation of a rift valley during episodes in the late Carboniferous and early Permian. The sedimentary succession subsequently was greatly affected by heat from the intrusion of plutons of Permian age, resulting in contact metamorphism and

hydrothermal alteration. The Silurian succession of the Oslo Region was defined by Worsley *et al.* (1983). The Mule locality is found in the lower part of the Skinnerbukta formation, which is an approximately 80 m thick section of grey, graptoliferous shales (Fig. 1). The locality is situated about 500 m west of the border towards the igneous rocks of the Larvik Plutonic Complex (LPC).



Figure 2. Vegard Evja pointing at an axinite-rich nodule in the wall rock at Mule, Porsgrunn. Note the brown, recent clay and soil overlying the pale Silurian rocks.

The exposed wall of contact-metamorphosed and hydrothermally altered Silurian sedimentary rock at Mule was up to a metre high (Fig. 2). Several mineralised, irregular, brownish nodules up to several centimetres across were observed along a short distance, 20 to 40 centimetre below the present rock surface. The largest, nearly fist-sized nodule showed the most diverse mineralogy, including borosilicates. The total extent of boron mineralisation at Mule is unknown due to the limited rock exposure. The locality is now reclaimed and covered by gravel and soil.

Minerals

Axinite-(Fe), $Ca_2Fe^{2+}Al_2BSi_4O_{15}OH$

Axinite-(Fe) is the principal mineral in the mineralised nodules and represents the first crystallised mineral phase in them. It occurs as coarsely crystalline masses. Crystal faces up to 1-2 cm across are observed. Well-developed crystals up to 3-5 mm occur in small vugs. The colour of the Mule axinite-(Fe) is pale violet-grey with transitions to pale greyish-brown. A bulk XRF analysis on the mineral showed 10 wt.% FeO, 1.2 wt.% MnO and 1.6 wt.% MgO, thus confirming the Fe²⁺-dominant member of the axinite group.

Dravite, $\text{NaMg}_3\text{Al}_6(\text{Si}_6\text{O}_{18})(\text{BO}_3)_3(\text{OH})_3(\text{OH})$, and *schorl*, $\text{NaFe}^{2+}_3\text{Al}_6(\text{Si}_6\text{O}_{18})(\text{BO}_3)_3(\text{OH})_3(\text{OH})$

A tourmaline-group mineral occurs sparingly as pale bluish, radiating aggregates up to 4-5 mm across (Fig. 3). Small fragments, composed of subparallel, very thin prisms, show slight variations in colour when observed under a binocular at high magnification: (i) from nearly colourless to pale blue, sometimes with a very faint greenish tint; (ii) from pale bluish to pale brownish, with a fairly sharp boundary between the two hues.



Figure 3. Radiating aggregates of pale blue tourmaline (*dravite*, *schorl*) from Mule, Porsgrunn. FOV 9 mm. Collection: A.O. Larsen. Photo: OT. Ljøstad.

SEM-EDS analyses of several carbon-coated prismatic fragments, both pale bluish and pale brownish, were carried out using a JEOL JSM-6610LV scanning electron microscope equipped with an energy-dispersive X-ray spectrometer (Bruker e-FlashHR+) and Bruker Esprit 2.0 software at the Natural History Museum Vienna (measurement conditions: 15 kV, 60 s per spot analysis). These EDS analyses showed a variable composition of the tourmaline. Both Fe-bearing dravite and Mg-bearing schorl were identified. The Mg:Fe ratio ranged between 2.6:1 and 0.5:1. In all analyses, very minor amounts of Ca were detectable (Na:Ca ~ 8:1). The measured Al:Si ratio showed that about 1-1,5 at.% Al is located on the Y site (which hosts Mg and Fe). Any amounts of K, Ti and F were all below the respective detection limits.

A crystal-structure refinement was carried out on a pale bluish, tiny prismatic fragment using SHELXL-97 (Sheldrick 2015). The dataset was measured at ambient temperature with a Bruker ApexII single-crystal X-ray diffractometer (MoK α radiation). The intensity data were processed in a

standard way, including multi-scan absorption correction. The refined unit-cell parameters are $a = 15.936(2)$, $c = 7.182(1)$ Å, $V = 1579.6(4)$ Å³. The refined structure model [$R(F) = 4.3\%$; the relatively high value is due to imperfect crystal quality] corresponds to an Fe-rich and ^YAl-bearing, practically F-free dravite. The simplified refined formula is $\sim^X(\text{Na}_{0.70}\text{Ca}_{0.02}\square_{0.18})^Y(\text{Mg}_{0.62}\text{Fe}_{0.28}\text{Al}_{0.10})_3^Z(\text{Al}_{0.98}\text{Fe}_{0.02})_6\text{Si}_6\text{O}_{18}(\text{BO}_3)_3(\text{OH})_3(\text{OH})$. There might be minor Mg on the Z (Al) site. Average Y-O, Z-O and Si-O bond lengths are 2.009, 1.926 and 1.618 Å, respectively.

Studies by Fritsch *et al.* (1990), Rossman *et al.* (1991) and Laurs *et al.* (2008) have shown that blue colour in elbaite is controlled mainly by Cu. The colour may be modified, however, by the combination of the concentrations and oxidation states of Mn, Fe and Ti. A SEM-EDS analysis on a pale blue Mule tourmaline aggregate (Fig. 3) was carried out using a JEOL JSM-IT700HR scanning electron microscope equipped with an energy-dispersive X-ray spectrometer (measurement conditions: 15 kV, 200 s counting time). The analysis shows that the tourmaline contains 0.5 wt.% CuO and 0.2 wt.% MnO. Based on these results, there is reason to assume that Cu is one of the chromophore elements in the pale blue Mule tourmaline.

Actinolite, Ca₂(Fe²⁺,Mg)₅Si₈O₂₂(OH)₂

Myriads of tiny (< 1 mm), greenish, interlocking acicular crystals of actinolite form fragile masses up to 1-1.5 cm across. The mineral also occurs as aggregates of intergrown prismatic crystals up to 2 mm in length.

Chalcopyrite, CuFeS₂

Small amounts of chalcopyrite occur in the border zone of the mineralised nodules and in interstitial voids of the axinite-(Fe).

Calcite, CaCO₃

White calcite occurs as a late-stage mineral filling voids in the mineralised nodules.

Malachite, Cu₂CO₃(OH)₂

Malachite occurs as tiny spherulites scattered in vugs. The mineral is the result of supergene weathering and oxidation of the chalcopyrite, due to the fact that the mineralised nodules occur close to the present surface of the bedrock.

Rozenite, Fe²⁺SO₄·4H₂O, and melanterite, Fe²⁺SO₄·7H₂O

Rozenite and melanterite were identified by powder X-ray diffraction in a dark brown, rusty aggregate of decomposed chalcopyrite.

Discussion

Aqueous fluids released during crystallization of the Permian intrusion, known as the Larvik Plutonic Complex (LPC), resulted in hydrothermal activity leading to formation of contact-metamorphic mineral assemblages in the contact aureoles. The present surface is 1 to 3 km lower than the Permian erosion level. Along the SW area of the Oslo Rift (*i.e.* close to the LPC), contact-metamorphism of the Palaeozoic succession was mainly governed by an increased permeability by devolatilization reactions and migration of meteoric fluids (Jamtveit *et al.* 1991). Marine sediments, and rocks derived from them, are generally rich in boron (Harder 1975). Fluids from the intrusion and also from the country rocks mobilised boron from the Palaeozoic sedimentary series and made it available for formation of contact minerals like the borosilicates axinite and tourmaline. The mobility of boron is demonstrated by the study of Sunde *et al.* (2020) who investigated the source of boron isotopes in tourmaline and hambergite from the LPC pegmatites. They proposed that the observed heavy boron isotopes were introduced by fluids derived from thermal metamorphism of Paleozoic sediments that host the LPC.

The boron content of the sediments, however, are highly dependent on the character of the rocks (shale, limestone, sandstone). During contact metamorphism the possibility of boron mineral formation along the contact will therefore show wide variations. On the whole, axinite and tourmaline are relatively rare as contact metamorphic minerals in the Oslo Region and known from just a few localities (Goldschmidt 1911).

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