Crichtonite group minerals from Åmot quarry, Modum

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Sammendrag

Fra et nedlagt pukkverk nær Embretsfoss ved Åmot i Modum har det i mange år vært kjent et svart, massivt mineral som har vært omtalt som ”daviditt”, et mineral i crichtonittgruppen. Nye mikrosondeanalyser av en prøve fra Åmot pukkverk viser en sammensetning som passer med de data som er publisert i forbindelse med godkjenning av et nytt mineral: haitatitt-(La) (IMA 2019-033a), et uranholdig, lantan-dominant mineral i crichtonittgruppen fra en lokalitet i Kina. Tidligere SEM-EDS analyser har vist en varierende sammensetning av materialet fra Åmot i Modum, og det er sannsynlig at også daviditt-(La) forekommer der. Det er også funnet trigonale, omvandlede krystaller av et antatt crichtonitt-gruppemineral som nå består av en blanding av titanitt, ilmenitt og rutil. Dannelsen av crichtonitt-gruppemineraler på Åmot settes i sammenheng med at bergartene har vært utsatt for en omfattende retrograd omvandling med påfølgende albittisering som vises som årer og sprekkfyllinger både i amfibolitter og øvrige bergarter i området. Fraksjonering av de sjeldne jordartene (REE) i denne prosessen har resultert i La-dominante mineraler.

Introduction

The crichtonite group of minerals includes 20 approved mineral species plus 8 minerals not yet adequately described. The general formula for this complex group of oxides which composition is dominated by Ti and Fe can be written as $A(DE_2G_6J_{12})O_{38}$ where:
A = Pb, Ca, Sr, Ba, Na and LREE
D = U, Y, HREE, Fe, Mn, Zr, Ca
E = Mg, Fe^{2+}, Fe^{3+}, Zn
G = Fe^{3+}, Cr, V, Nb, Zr
J = Ti

Crichtonite group minerals are known to occur in many different geological environments and localities in Norway include granite pegmatites and other Precambrian rocks in southern Norway Selbekk (2010). In some cases these minerals have been described just as “davidite” without a proper identification. The crichtonite group minerals from pegmatites in the Iveland district and at the island of Hidra are proper davidites and in most cases clearly Ce-dominant. Neumann & Sverdrup (1960) described davidite-(Ce) from the pegmatite at Tuftane, Iveland. They also mentioned “davidite” in small amounts as an impregnation in a brecciated border zone between a pegmatite and amphibolites north of Bringebærkastet at Langøy in the municipality of Kragerø, as well as occurring in a brecciated rock at Åmot quarry in Modum. Although the mineral from the latter locality has been known for many years, the true identity of this mineral has been an enigma. This paper is a thorough investigation on the Åmot mineral.

Figure 1. *Åmot quarry 2022*

Occurrence and geological overview

The small, abandoned quarry (Fig.1) is located about 350 m west of Embretsfoss, on the western side of the river Drammenselva, north of Åmot in Modum (coordinates EU89 59.90087°N, 9.92016°E). The area belongs to the Kongsberg-Bamble formation of the Precambrian Baltic shield of Southern Norway. It is believed that this geological province was linked to the Grenville province of North America before the break-up of the supercontinent Rodinia. The high-grade metamorphic Precambrian basement in the Modum Complex was mapped and described by Jøsang (1966) and consists mainly of supracrustals (gneiss, mica schist, quartzite) and metagabbros/amphibolites. The gabbros were intruded at 1224 ± 15 Ma and experienced a high-grade metamorphism with alteration to amphibolites during the Sveconorwegian event (Munz & Morvik 1991). The area exhibits retrogradation and alteration due to late stage fluid infiltration with extensive alteration zones of albite- and calcite-rich veining especially within, and in the proximity, of the numerous metagabbros/amphibolites. Two generations of albite-rich rocks have been recognized; a fine grained, foliated type and a coarse grained crosscutting type. Both types pre-date the calcite veins. Age determination of these albite and calcite rich veins using U-Pb data from titanite indicates an age of 1080 ± 3 Ma (Munz *et al.* 1994). One such large metagabbro/amphibolite near Embretsfoss has been subject to quarrying, known as the Åmot quarry. The amphibolite and altered supracrustals in this area show extensive albite and calcite veining. The crichtonite group minerals ("davidite") occur in this assemblage, mostly in fine to coarse grained, foliated albite veins that may show a scattered red coloration, which, in part, could be caused by disseminated hematite (Fig. 2). However, an increased red colour around some of the crichtonite group minerals could also be a result of radiation. The mineral occurs in black, irregular masses to a few centimetres across with a vitreous to sub-metallic lustre and conchoidal to subconchoidal fracture (Fig. 3). In some samples there is a more pronounced red discoloration of the feldspar in the vicinity of the most glassy and metamict types indicating a higher uranium content. The same aspect is described by Wang *et al.* (2022) from the type locality of haitaite-(La) close to Haita village, Sichuan, China. The sample selected for this study was collected at the site by one of the authors (KE) in 1975 and represents the variety with the presumed highest U-content.

Figure. 2. *Amphibolite with a vein of albite including black crichtonite group minerals from Åmot quarry. Specimen 15 x 10 cm.*

Figure 3. *Sample from Åmot quarry showing the analyzed crichtonite-group mineral, haitaite-(La), about 2 cm across.*

Chemical composition

A fragment of 3 mm coming from a 1 cm large mass of the mineral was mounted in epoxy, polished and carbon coated. The analyses were done using a Jeol 8200 Superprobe at the Earth Sciences Department of the University of Milano. The microprobe was operated in wavelength dispersive mode at 20 kV, 5 nA and with a beam diameter of 1 μm. The following minerals, synthetic compounds and pure metals were used as standards: Ilmenite for Ti, fayalite for Fe, forsterite for Mg, grossular for Ca, rhodonite for Mn, K-feldspar for K and albite for Na; pure metals (99.99 %) for Cr and V; synthetic UO_2 and PbO for U and Pb, respectively; synthetic Y_2O_3 and REE_2O_3 for Y and REE, respectively (Jarosewich & Boatner 1991). The obtained data are summarized in Table 1.

Table 1. *Electron microprobe analysis of haitaite-(La) from Åmot quarry.*

	Average of 4 points weight-%	Standard deviation	Number of atoms based on 38 O	
TiO_2	49.12	0.52	Ti	11.949
Cr_2O_3	1.49	0.01	Cr	0.381
V_2O_3	1.38	0.08	V	0.358
Fe_2O_3	21.78	0.25	Fe^{3+}	5.300
			Total	17.988
MgO	0.08	0.02	Mg	0.039
Fe_2O_3	6.20	0.25	Fe^{3+}	1.509
MnO	0.17	0.02	Mn	0.047
CaO	0.62	0.05	Ca	0.215
			Total	1.809
Y_2O_3	1.05	0.03	Y	0.181
UO_2	6.67	0.22	U	0.480
Eu_2O_3	0.04	0.07	Eu	0.004
Gd_2O_3	0.15	0.07	Gd	0.016
Ho_2O_3	0.04	0.06	Ho	0.004
Yb_2O_3	0.30	0.06	Yb	0.030
			Total	0.715
Na_2O	0.01	0.02	Na	0.006
K_2O	0.03	0.01	K	0.012
SrO	0.21	0.06	Sr	0.039
PbO	1.01	0.12	Pb	0.088
La_2O_3	3.32	0.03	La	0.396
Ce_2O_3	2.33	0.15	Ce	0.276
Nd_2O_3	0.11	0.07	Nd	0.013
Sm_2O_3	0.03	0.05	Sm	0.003
Total*	96.14		Total	0.834

Notes: Ba, Pr, Tb, Dy and Er were below detection limits in all analyzed points.
* The low total can be due to the presence of Nb and Zr that were not analysed.

The molar formula was normalized to 38 oxygens in the stoichiometry (Table 1). The cation distribution, following the general formula of the crichtonite group described in the introduction, gives the following empirical formula:
$(La_{0.40}Ce_{0.28}Nd_{0.01}Pb_{0.09}Sr_{0.04}K_{0.01}Na_{0.01})_{\Sigma 0.84}(U_{0.48}Y_{0.18}Yb_{0.03}Gd_{0.02})_{\Sigma 0.72}(Fe^{3+}_{1.51}Ca_{0.22}Mn_{0.05}Mg_{0.04})_{\Sigma 1.82}$ $(Fe^{3+}_{5.30}Cr_{0.38}V_{0.36})_{\Sigma 6.04}Ti_{11.95}O_{38}$.The empirical formula is in fairly good agreement with the formula of the recently approved (2021), but not yet published mineral haitaite-(La) (IMA 2019-033a) from Haita village, Miyi county, Panzhihua, Sichuan, China. The formula is presented as $LaU^{4+}Fe^{3+}_2(Ti_{13}Fe^{2+}_4Fe^{3+})O_{38}$ (Wang *et al.* 2021).

Discussion

The exact characterization of the minerals belonging to the chrictonite group can be challenging due to the extremely complex chemical composition of this group. Nevertheless a complete chemical analysis can be conclusive for the adequate characterization of these minerals. Regarding haitaite-(La), the crystallographic characterization is quite difficult since the mineral is almost completely metamict, as described by Wang *et al.* (2022). For this reason we can define the mineral from Åmot as haitaite-(La) using only electron microprobe analysis and its aspect. Compared to the analyses shown by Wang *et al.* (2022), the mineral from Åmot differs only by a lower content of U^{4+} of 10 % in terms of mol- % in the *D* site. Nevertheless the strong predominance of U^{4+} in the *D* site allows classifying the mineral as haitaite-(La) rather than davidite-(La). Minor differences are due to the complete lack of Al in the specimen studied in this work.

The formation of the crichtonite group minerals at Åmot quarry is clearly related to retrograde fluid infiltration with extensive albitization and alteration of the high grade metamorphic rocks of the Modum Complex as described by Munz *et al.* (1994). Such retrograde fluids may result in the redistribution of many elements including Ti, U, REE. Albitization in the Kongsberg-Bamble formation is typically accompanied by enrichment in Ti forming abundant titanite and rutile which have also been found at Åmot quarry. Surveys by NGU have disclosed radioactive anomalies mostly caused by the presence of small amounts of uraninite in many areas of the Modum sector both related to the Co-bearing veins near Skuterud and in veins in amphibolites and altered supracrustals (Sverdrup *et al.* 1957).The U and Ti bearing mineral brannerite has been identified in thin albite veins in a brecciated greenschist 300 m W of Haugfoss bridge near Åmot (van Autenboer & Skjerlie 1957). The introduction of REE with uranium is known from other similar geological environments. Lobato *et al.* (1983) described a uranium mineralization within shear zones transecting Archean basement gneisses at Lago Real in Brazil where LREE were introduced with U from hypersaline CO_2 rich fluids in oxidizing condition. Fractionation of REE is common as a result of such processes. The La-dominance in the crichtonite group minerals at Åmot quarry could be a result of the composition of the fluids that leached and transported the REE. A mildly oxidizing environment could partially oxidize Ce to Ce^{4+} rendering it less mobile than *i.e.* La. This is, however, just one possible explanation for the REE-pattern observed in haitaite-(La) in the present study.

Previous studies

In 2005/2006 one of the authors (KE) collaborated with Andrew G. Christy (presently senior curator at Queensland museum in Australia) on preliminary studies of samples of the "davidite" mineral and other minerals from Åmot quarry with SEM/EDS. The results indicated that the most metamict and glassy material was a La-dominant crichtonite group mineral with a composition similar to what has been found in this study with U > Y. The data did not match any known mineral at the time, but the metamict nature of the material complicated further studies. Other dull black samples with a more sub-metallic lustre and less pronounced conchoidal fracture lacking the red discoloration of the adjacent feldspar showed Y > U. It is therefore likely that also davidite-La occurs at Åmot quarry, but this has not been confirmed in the present study where only the presumed most U-rich variety of the crichtonite group mineral has been analysed.

Other minerals occurring at Åmot quarry

The studies in 2005/2006 also included samples of other black minerals from Åmot quarry. One such sample contains greyish-black, thick, platy, trigonal crystals to 2 cm that resemble crystals of minerals in the crichtonite group. SEM-EDS studies revealed a mixture of titanite, ilmenite and subordinate rutile. The crystals occur with coarse grained albite and calcite. It could be from a younger generation of veins. There are no discoloration or alteration products that could indicate a U-bearing precursor mineral. These samples are believed to be pseudomorphs after an unknown crichtonite group mineral, possibly davidite-(La). Another sample showed a complex intergrowth of multiple phases, mostly rutile and titanite with about 6 % finely dispersed UO_2 possibly as micron-sized grains of uraninite. This sample could represent an altered haitaite-(La). Black plates to a few centimetres of hematite also occur at the locality. Dons (1956) reported “coal blende” from the locality, but no hydrocarbon has been observed in the rocks at the locality by the present author (KE). Large crystals of titanite, cleavages of a green to black amphibole, small masses of rutile and minor epidote and pyrite have also been observed in the albite veins. A mineral occurring as reddish brown, distorted crystals with a glassy lustre and fracture was found in 1975 and erroneously reported as zircon in 1982 by one of the authors (KE). The mineral was visually identified with the support of a yellow fluorescence. Recent XRD analysis has shown the mineral to be titanite. The fluorescence could be resulting from a sub microscopic coating of a U-bearing mineral and illustrates the pitfalls when using fluorescence as an aid in identifying minerals.

Conclusion

An unidentified crichtonite-group mineral (“davidite”) has for more than half a century been known to occur at Åmot quarry in Modum. The present study on a sample of this mineral concludes that the composition is similar to the newly IMA approved mineral haitaite-(La) (IMA 2019-033a) from the Haita village in Sichuan, China. The Åmot quarry represents the second documented locality in the world for haitaite-(La) that can be considered as the U-analogue of davidite-(La). Previous studies with SEM-EDS have shown a variable U/Y-ratio. In some samples, Y>U indicates that also davidite-(La) occurs at the locality.

Locality access

Åmot quarry is now completely overgrown and is used as a sand silo by Brevik farm, from where permission to visit the site should be obtained.

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