Bi-sulfosalts from Tokke, Telemark, Norway

Alf Olav Larsen[1] & Dan Topa[2]

[1]Bamseveien 5, N-3960 Stathelle, Norway (alf.olav.larsen@online.no)
[2]Naturhistorisches Museum, Burgring 7, A-1010 Wien, Austria (dan.topa@nhm-wien.ac.at)

Introduction

In the summer of 2017 a silvery mineral was found in an old copper ore prospect at the mountain Riplusdalsnuten in Tokke, Telemark by Mr. Jan Andersen, Dalen (Fig. 1). It was given to AOL for identification. Using PXRD technique the mineral was confirmed to be an aikinite-like species. In order to obtain a proper identification, a number of samples were handed over to DT for chemical analysis. Using electron microprobe several sulfosalts were subsequently identified. This paper describes the deposit and its mineral association of unusual sulfosalts.

Fig. 1. *The summit of the mountain Riplusdalsnuten in the distant, seen towards NW.*

The history

The mineralized veins in Telemark have been subject to extensive prospecting and mining. Some of the earliest mines date back nearly 500 years. A major boom, however, took place during the latter half of the 19th century, when many hundreds of localities were worked, often by local peasants. This was likewise the case with the deposit at Riplusdalsnuten.

As far as is known the copper ore deposit at Riplusdalsnuten was claimed in 1898 by farmer, postman and prospector Mr. Osmund Knutsson Kolkjøn. At the same time he also claimed an old adit located

50 m S of the first locality. The past history of this adit is, however, unknown. Mr. Kolkjøn maintained the two claims for the next seven years; thereafter they were abandoned. The deposits were re-claimed by Mr. A. Beck in 1905 and again by solicitor O. Chr. Berg in 1908. Some years earlier a mine workers log cabin was built near the southern foot of Riplusdalsnuten, 300 m SE of the summit. This construction was done on behalf of Supreme Court lawyer Hans E. M. Rolsted[5]. The cabin has locally been called "Gruvehytta" ("The Mine Cabin"). Later, the log cabin was dismantled. Its cornerstones, however, are visible still today (coordinates N59.41576°, E7.92467°). The cabin was rebuilt at the farm Viken in Skafså, about 4.5 km ENE of Riplusdalsnuten. In 2017 the cabin was again dismantled and rebuilt at the neighboring farm Døli.

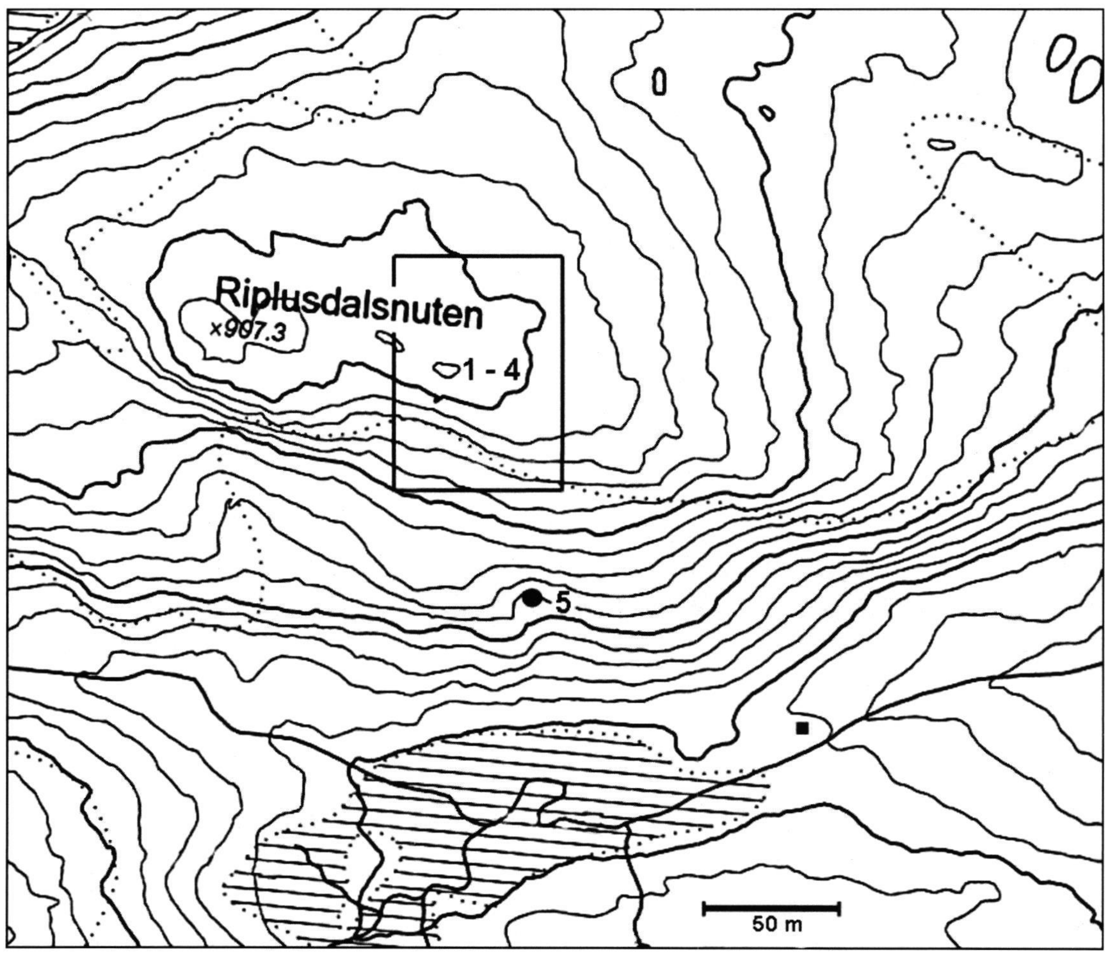

Fig. 2. Map of Riplusdalsnuten and its surroundings. The copper ore deposit (veins #1 - #4) occur within the quadrangel (see Fig. 4). The lower adit is shown as a black dot (#5), while the past location of the log cabin ("Gruvehytta") is shown as a black rectangle. Contour line interval is 5 m.

Geology

The Telemark Sector consists of Proterozoic supracrustals, which comprise an up to 7000 m thick sequence of felsic and mafic volcanics, quartzites, conglomerates, shists and marbles. Four main

[5] The history has been extracted from transcripts of prospecting letters housed at Norwegian Mining Museum, Kongsberg.

stratiform sequences are defined (Laajoki *et al.* 2002; Bingen *et al.* 2008, and references therein). The last, major geological event was the intrusion of a suite of granites during the period of 1050-930 Ma. Within the supracrustals of central Telemark Sector, especially within the upper volcanic sequence interlayered with metasedimentary units, are a large numbers of mineralized veins, notably quartz veins ± carbonates, sulfides and accessory minerals (Dons 1963; Nordrum 1972a; Nordrum & van der Wel 1981; Sandstad *et al.* 2012). The emplacement of these late stage veins was the result of regional tectonics combined with favorable host rock lithology, whereas the mineral assembly was controlled by the granite intrusions and probably with their interaction with the host rocks.

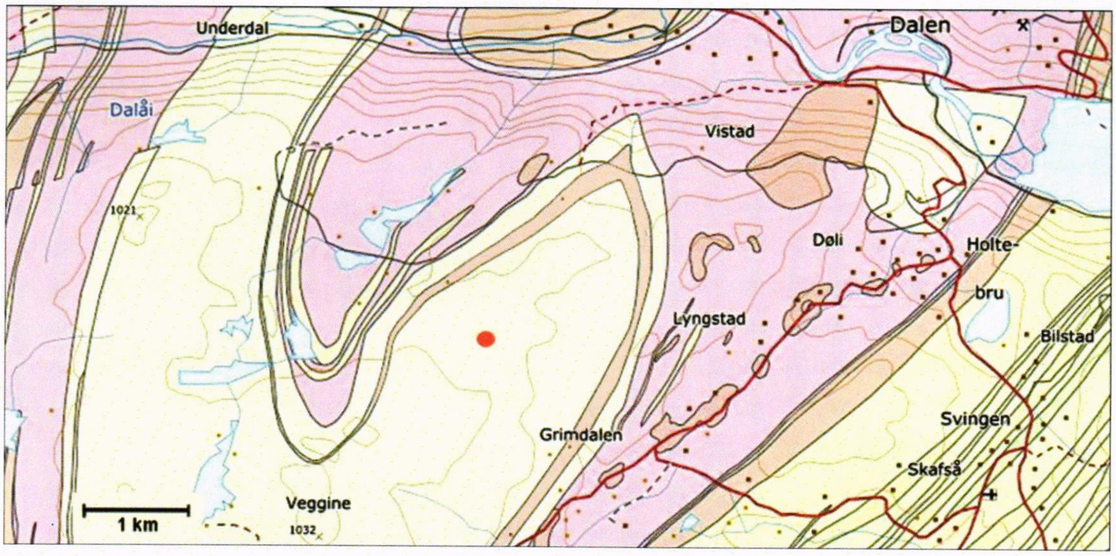

Fig. 3. Geological map of the Skafså area with location of Riplusdalsnuten shown as a red dot. Yellow colours indicate metasandstones, violet colour indicates amphibolite, brown colour indicate greenstones. From Sigmond et al. (2015), downloaded from www.ngu.no.

The sulfides in the quartz veins are typically chalcopyrite, bornite and chalcocite/djurleite. Some veins show abundance of pyrite, molybdenite or galena. Less abundant are gold/electrum, silver, bismuth and various Bi-minerals (Nordrum 1972b; Cook *et al.* 2010; Larsen & Topa 2015), hessite, tetrahedrite, digenite, mackinawite, sphalerite, arsenopyrite, scheelite, hematite and magnetite.

The Riplusdalsnuten deposit is situated in the Veggine-Skorvi anticlinal fold (Fig. 3), which is composed mainly of metasandstone with interlayers of metabasalt (greenstone). These units belong to the Bandak group of the Telemark supracrustals. The mineralized quartz veins at Riplusdalsnuten are situated within one of the greenstone layers, which is, however, too narrow to be shown on the general, geological map (Sigmond *et al.* 2015). The quartz veins strike approximately 60° N (Fig. 4) and show a nearly vertical dip.

The prospects

The following five locations have been worked (shown as **1 - 4** in Fig. 4, and **5** in Fig. 2):

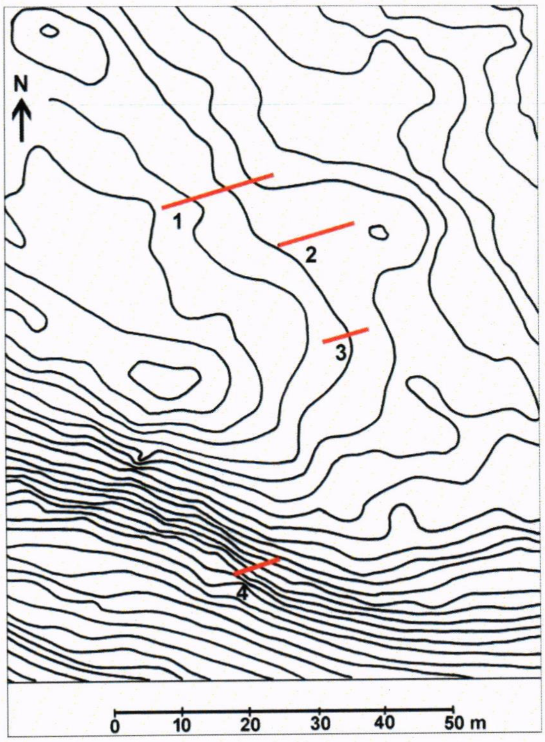

Fig. 4. Location of the quartz veins with ore mineralization. The numbers refer to the descriptions in the text. Contour line interval is 1 m.

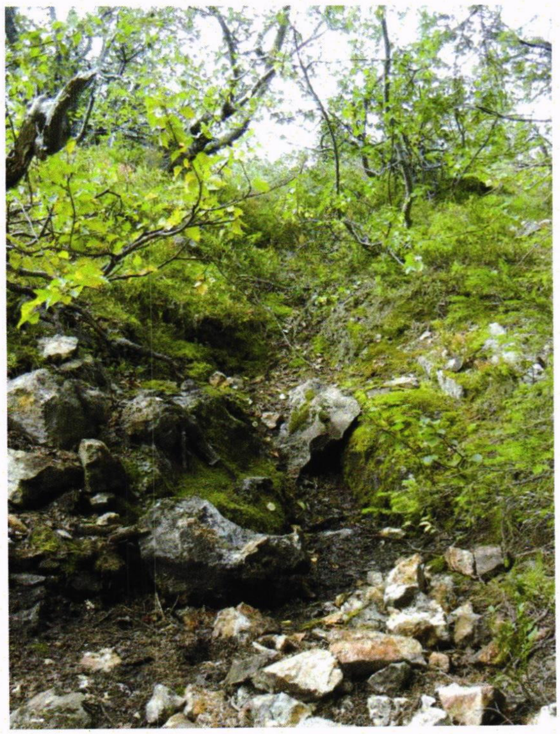

Fig. 5. The shallow ditch following vein #1, seen towards W.

Vein #1. Location: Coordinates N59.41716, E7.92177. About 90 m E of the Riplusdalsnuten summit. A quartz vein, generally 20 cm wide, rich in ore minerals (Fig. 5). The vein widens to 1 m in the last 4 m of its western end, but here with less ore minerals. The vein shows a symmetrically zonation with abundant pyrite in the central part, scattered masses of chalcopyrite in the major quartz mass, and hematite and ankerite along the border zone (Fig. 6). Bi-sulfosalts have been observed as minor aggregates both with chalcopyrite and pyrite. The vein has been exposed through digging and shallow

Fig. 6. A complete cross-section of quartz vein #1, approximately 20 cm wide (shown by arrow).

blasting for 16 meters in length. It should be mentioned that the complete length of the different veins are unable to assess due to overburden.

Vein #2. Location: 10 m S of vein #1. A quartz vein, 15-20 cm wide, with zonation as in vein #1, but no visible Bi-sulfosalts. The vein has been exposed through digging and shallow blasting for 12 meters in length.

Vein #3. Location: 15 m S of vein #2. A quartz vein, 10 cm wide, with zonation as in vein #1, but no visible Bi-sulfosalts. The vein has been exposed through digging and shallow blasting for 7 meters in length.

Vein #4, upper adit. Location: Coordinates N59.41668, E7.92205. About 25 m S of vein #3, and 10-12 m lower, down the steep hillside. A vertical, 10-15 cm wide quartz vein with locally abundant chalcopyrite and ankerite plus minor pyrite. The vein has been followed by a 6 m long, horisontal adit.

Working #5, lower adit. Location: Coordinates N59.41616, E7.92255. In the steep, southern hillside, 150 m SE of the Riplusdalsnuten summit, about 30 m above the moor at the foot of the hill. The mine consists of a 6 m long trench followed by a 14 m long, horisontal adit. Its direction is 170° N. The bedrock is metasandstone, locally transected by minor quartz lenses. No ore mineralization is observed. Maybe it was worked hoping to intersect the ore bearing quartz veins (#1 - #4) at a lower elevation? In that case, the adit must have been driven at least 50 - 100 m.

Mineralogy

White quartz is the main mineral in veins #1 - #4. Ankerite makes up the border zone with varying thickness towards the wall rock. Hematite and muscovite occur as fine-scaly masses, mostly confined to the ankerite zone. The central zone in the quartz veins are pyrite (Fig. 6), which occurs as masses

Table 1. *The chemical composition (in wt.%) of sulfosalts from sample A.*

No.	S	Fe	Cu	Ag	Sb	Pb	Bi	Total
1	17.42	0.01	8.07	0.03	0.02	24.84	50.85	101.23
2	17.52	0.00	8.19	0.00	0.00	24.42	50.30	100.43
3	17.38	0.03	9.27	0.03	0.11	28.42	46.42	101.66
4	17.49	0.03	9.31	0.08	0.02	28.09	46.30	101.32
5	17.75	0.01	7.42	0.00	0.00	22.99	52.91	101.08
6	17.79	0.01	7.11	0.09	0.03	21.55	54.00	100.57
7	17.89	0.04	6.94	0.02	0.02	21.29	55.01	101.21
8	17.87	0.04	7.64	0.04	0.03	23.29	52.25	101.15
9	17.74	0.02	7.75	0.00	0.02	24.11	51.54	101.17
10	17.79	0.04	7.68	0.02	0.00	23.58	51.65	100.76
11	17.48	0.03	10.04	0.00	0.04	30.17	43.51	101.26
12	17.47	0.05	10.08	0.00	0.00	30.57	42.16	100.33
13	17.40	0.01	9.66	0.00	0.05	29.46	44.07	100.65
14	17.71	0.03	8.07	0.02	0.00	25.01	50.32	101.16
15	17.85	0.02	7.84	0.00	0.05	23.91	51.27	100.93
16	17.82	0.03	7.77	0.22	0.05	24.04	51.52	101.46

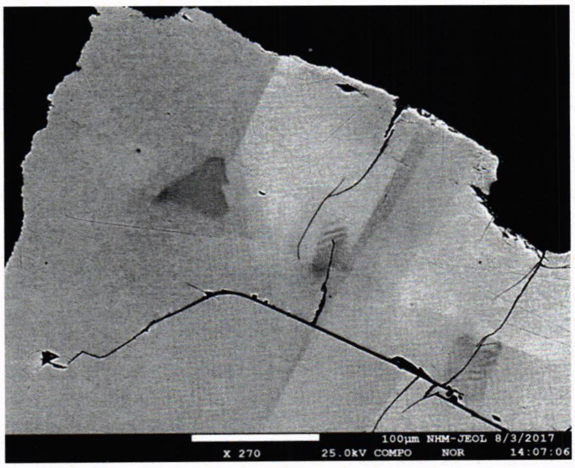

Fig. 7. Electron microprobe backscatter image of sample A showing various species within the aikinite-krupkaite series (see Table 2), revealed by different shades of grey.

The aikinite-bismuthinite series	*Chemical formulae*
Aikinite	$PbCuBiS_3$
Friedrichite	$Pb_5Cu_5Bi_7S_{18}$
Emilite	$Pb_{2.7}Cu_{2.7}Bi_{5.3}S_{12}$
Hammarite	$Pb_2Cu_2Bi_4S_9$
Lindströmite	$Pb_3Cu_3Bi_7S_{15}$
Krupkaite	$PbCuBi_3S_6$
Paarite	$Pb_{1.7}Cu_{1.7}Bi_{6.3}S_{12}$
Salzburgite	$Pb_{1.6}Cu_{1.6}Bi_{6.4}S_{12}$
Gladite	$PbCuBi_5S_9$
Pekoite	$PbCuBi_{11}(S,Se)_{18}$
Bismuthinite	$[Pb_0Cu_0]\ Bi_2S_3$

***Table 2.** The complete aikinite-bismuthinite series. The minerals that are covered by the analyses in Table 1 are highlighted in yellow.*

and more or less well developed, small crystals, usually octahedron {111} modified by cube {100}. Irregular masses of chalcopyrite are common in the quartz veins.

Vein #1 at the Riplusdalen deposit is relatively rich in Bi-sulfosalts, which occur as silvery masses up to 1 cm across. Two random samples of sulfosalts (sample A and sample B) from vein #1 were analyzed using a JEOL Hyperprobe JXA-8530F electron microprobe (installed at Natural History Museum, Vienna). Individual sulfosalt aggregates are inhomogeneous (Fig. 7 and Fig. 8) and show a mosaic of various species. The chemical compositions on 16 spots in sample A are given in Table 1.

The results show that the Bi-sulfosalts in sample A may be interpreted as different species within the aikinite-krupkaite subseries, a part of the aikinite-bismuthinite series, which form a group of 11 species (Table 2). The species are distinguished on the basis of structural changes associated with dominant substitution within this group, *i.e.* Cu + Pb = □ + Bi. The essential equation of this division, (Cu + Pb)/2 + Bi = 8, gives the following general formula for the compositions of the whole series: $Cu_xPb_yBi_{8-0.5(x+y)}S_{12}$, where the x value should be equal to y, and both can change continuously between 0 and 4. Friedrichite, emilite, hammarite and lindströmite have not previously been described from a Norwegian locality.

Sample B shows a very complex pattern of two exsolved phases on a micrometer scale (Fig. 8). The chemical compositions on 22 spots given in Table 3 indicate that the minerals can be mummeite (idealized formula $Ag_2PbCuBi_6S_{13}$) (bright phase) and cupro-plumbian mummeite (dark phase) or, alternatively, benjaminite (idealized formula $(Ag,Cu)_3(Bi,Pb)_7S_{12}$) – cupro-plumbian benjaminite. Crystal structure analyses, however, have to be done in order to resolve this issue. In any case, mummeite/benjaminite are new minerals to Norway.

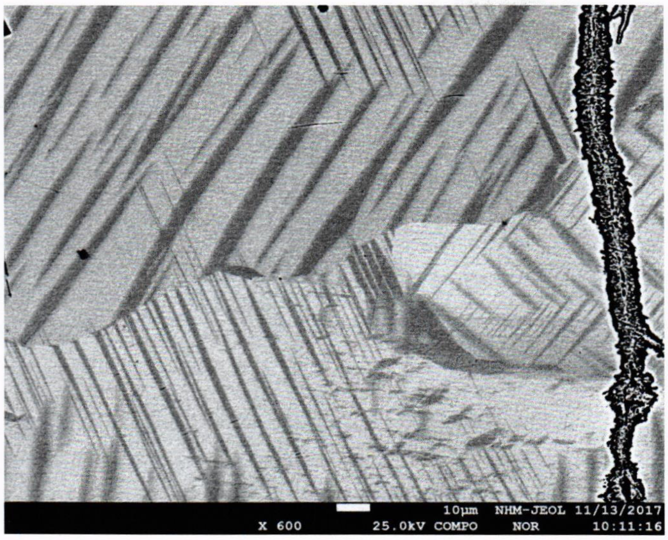

Fig. 8. *Electron microprobe backscatter image of sulfosalts in sample B showing a complex pattern of exsolved phases.*

Table 3. *The chemical composition (in wt.%) of sulfosalts from sample B.*

No.	S	Fe	Cu	Ag	Sb	Pb	Bi	Total
4	18.84	0.04	1.79	10.38	0.00	1.71	67.42	100.14
5	18.73	0.03	1.81	10.68	0.00	1.94	67.69	100.88
6	18.87	0.04	1.83	10.68	0.00	1.91	67.40	100.92
7	18.92	0.04	1.76	10.75	0.00	2.01	67.44	100.92
8	18.77	0.02	1.71	10.35	0.00	2.01	67.49	100.37
9	18.53	0.00	6.05	7.25	0.00	8.22	59.98	100.03
10	18.49	0.01	6.21	6.99	0.02	8.09	60.12	99.93
11	18.53	0.02	6.35	7.26	0.00	8.73	59.36	100.28
12	18.64	0.01	6.27	7.13	0.00	8.09	59.44	99.58
13	18.66	0.07	1.82	11.16	0.00	1.84	66.09	99.65
14	18.55	0.06	1.85	11.10	0.00	1.76	66.05	99.37
15	18.57	0.05	1.76	10.78	0.00	1.86	66.25	99.30
16	18.66	0.04	1.81	10.46	0.00	1.96	67.14	100.07
17	18.66	0.03	1.92	10.14	0.00	1.87	67.29	99.91
18	18.79	0.04	6.13	7.29	0.00	7.48	61.21	100.93
19	18.62	0.01	5.88	7.37	0.00	7.23	60.59	99.71
20	18.58	0.00	6.52	7.51	0.00	8.39	59.56	100.56
21	18.60	0.01	6.60	7.28	0.00	8.13	59.79	100.41
22	18.50	0.00	6.56	7.35	0.00	8.35	59.56	100.31

Conclusion

The present, initial study shows that the Riplusdalen deposits host a variety of Bi-sulfosalts, of which several are new minerals to Norway. Through further investigation it may be assumed that more species will be discovered.

Acknowledgements

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