

NAUMANNITE FROM KONGSBERG SILVER DEPOSIT, SOUTH NORWAY

OLE FRIDTJOF FRIGSTAD

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Naumannite (Ag_2Se) is described from a mine – Johannes Gruve – in the Kongsberg silver district of south Norway. Physical data and chemical analysis are given. Single crystal work decides an orthorhombic symmetry, and the cell parameters and a list of indexed d -values are presented. The mineral shows inversion twins. The naumannite-chalcopyrite-quartz-calcite paragenesis is formed by fracture filling.

O. F. Frigstad, Mineralogisk-geologisk museum, Sars gate 1, Oslo 5, Norway. Present address: Norges Geologiske Undersøkelse, Postbox 3006, 7001 Trondheim.

Selenium minerals have only been sparingly reported from Norway. Vogt (1886) mentioned clausenthalite (PbSe) from an unknown locality in the Telemark-Setesdal region, south Norway, and Heier (1953) reported clausenthalite from a mine – Herzog Ulrich Gruve – in the Kongsberg district and two not exactly well known localities in Numedal, north of Kongsberg. Naumannite (Ag_2Se) is now identified in a mineral sample from the dumps of Johannes Gruve in Kongsberg silver district.

History

Naumannite is a rather rare mineral which has been reported from eleven localities in scarce amounts. It was first described by Rose (1828) from Eskeborner Stoll, Tilkerode, West Germany, where it occurs in dolomitic dikes. The presented analysis was probably taken on a mixture of naumannite and clausenthalite. Later Domeyko (1866) described the mineral from Cacheuta in Argentina. An analysis was taken on a mixture of selenium minerals where naumannite might have occurred. In 1904 Hintze mentioned two very uncertain localities for naumannite in Mexico.

An analysis was also presented by Shannon (1920) on material from DeLamar Mine, Silver City district, Idaho. Geilmann & Rose (1928) reported naumannite from the calcite veins in St. Andreasberg, Harz, West Germany and Block & Ahlfeld (1937) found it in siderite veins in Pacajake, Bolivia. From the chalcocite-bornite deposits in Glava, Sweden, it was reported by Scherbina (1941) and in 1954 it was found by Thompson in a sulphide-quartz sample from Republic, Washington. In Kushikino Mine, Kagoshima



Fig. 1. Map of southern Norway showing the situation of Kongsberg and the Oslo Province.

Prefecture, Japan, naumannite was found in quartz veins (Mukaiyama & Izawa 1964) and in the magnetite skarn deposit at Snieznik Klodzki, Sudety, Poland it occurs in quartz zones (Banas 1965).

Occurrence

The sample is a quartz-biotite-dioritic gneiss with some garnets, traces of muscovite, apatite and epidote and without ore minerals. This fits in very well with the description of the rock around Johannes Gruve (Bugge 1917).

A one cm wide mineralized band occurs discordant in the gneiss. As seen in Fig. 2 this is well zoned, and in the following description each zone is denoted with letters A to E.

Zone A is a 4–5 mm wide chalcopyrite-impregnated gneiss where chalcopyrite replaces biotite, plagioclase and quartz. The garnets are partly transformed to biotite.

Zone B, 1 mm thick, is a chalcopyrite- and naumannite-impregnated gneiss where the naumannite occurs mainly as platy grains between biotite flakes (Fig. 3).

The 1 mm wide zone C has fine-grained to calcedony quartz with some chalcopyrite and many irregular naumannite grains. These have a large amount of 0.01 mm long tabular biotite inclusions, often grown together in six sided rings (Fig. 4).

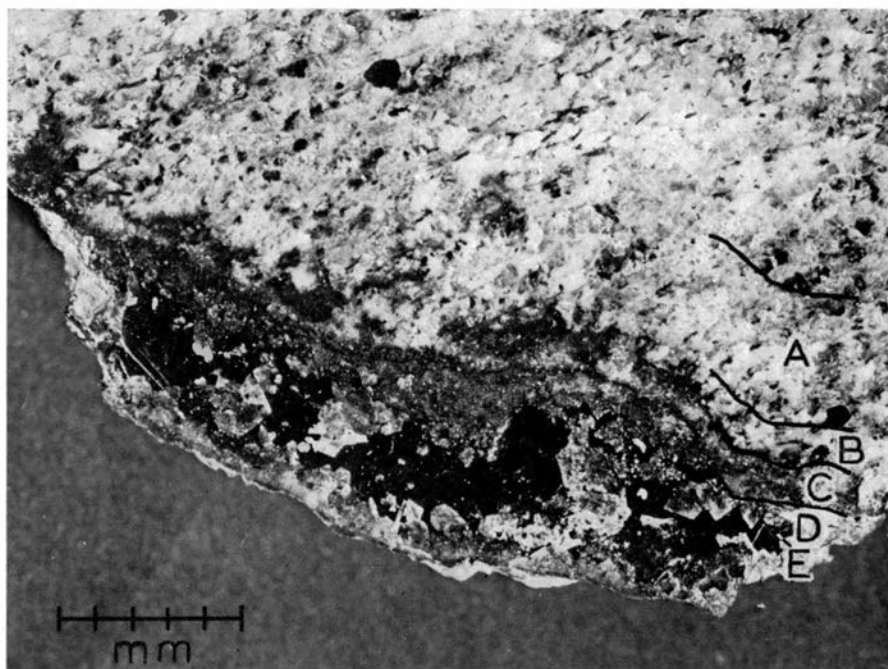


Fig. 2. The mineralized band with its zones (A-E).

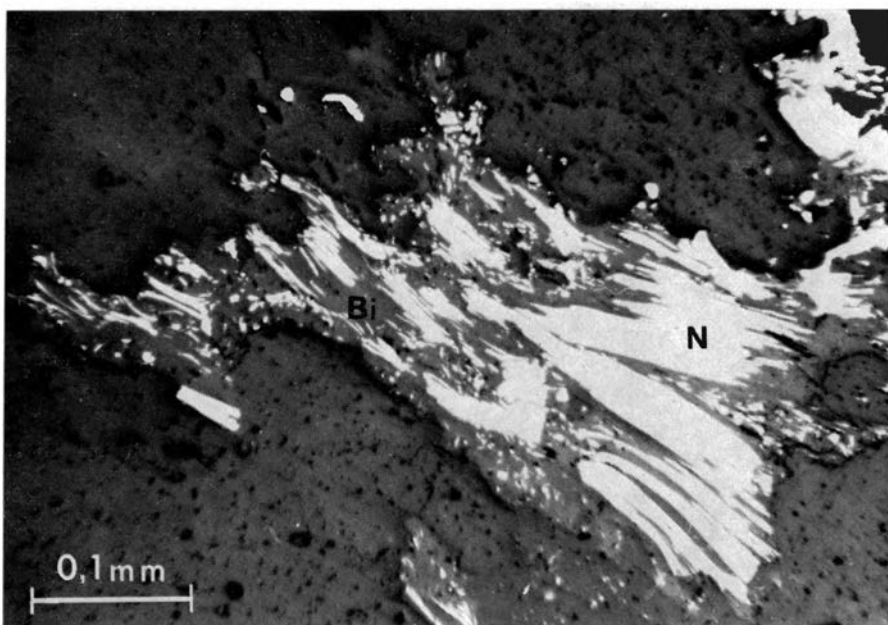


Fig. 3. Flakes of naumannite (N) and biotite (Bi) in quartz.

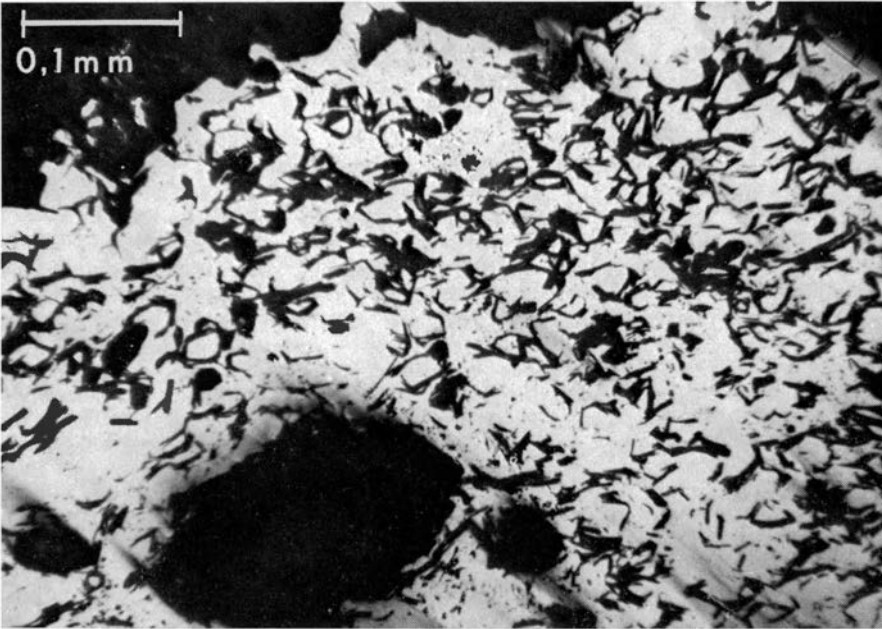


Fig. 4. Naumannite (white) with flakes of biotite (black).

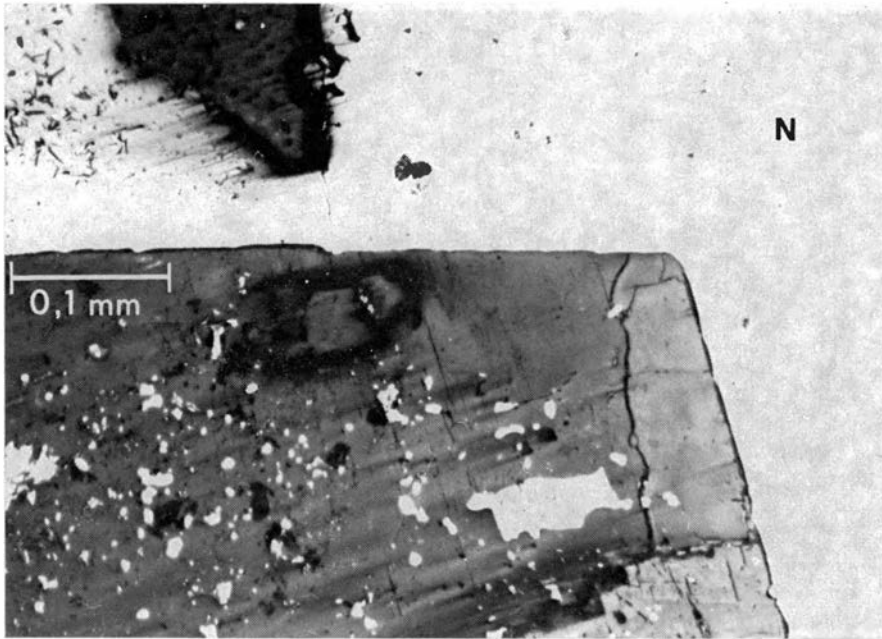


Fig. 5. Naumannite (N) inclusions in a calcite crystal.

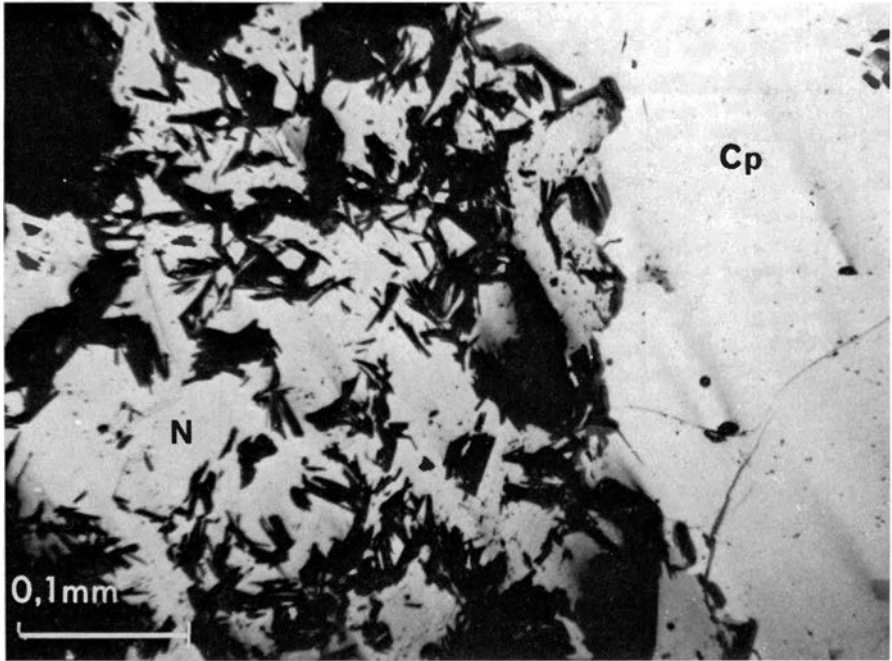


Fig. 6. Chalcopyrite (Cp) and naumannite (N) with inclusions.

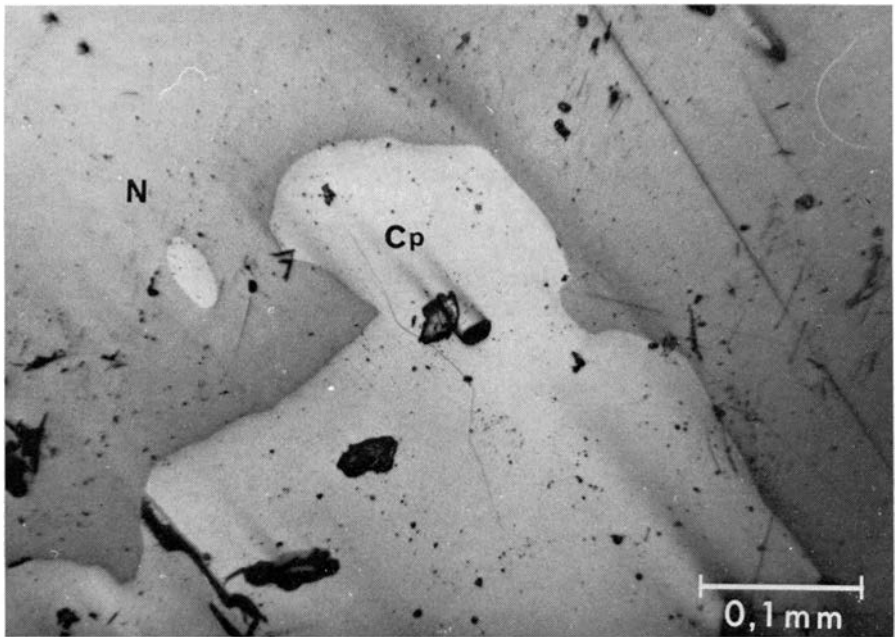


Fig. 7. Naumannite (N) and chalcopyrite (Cp) in zone E.

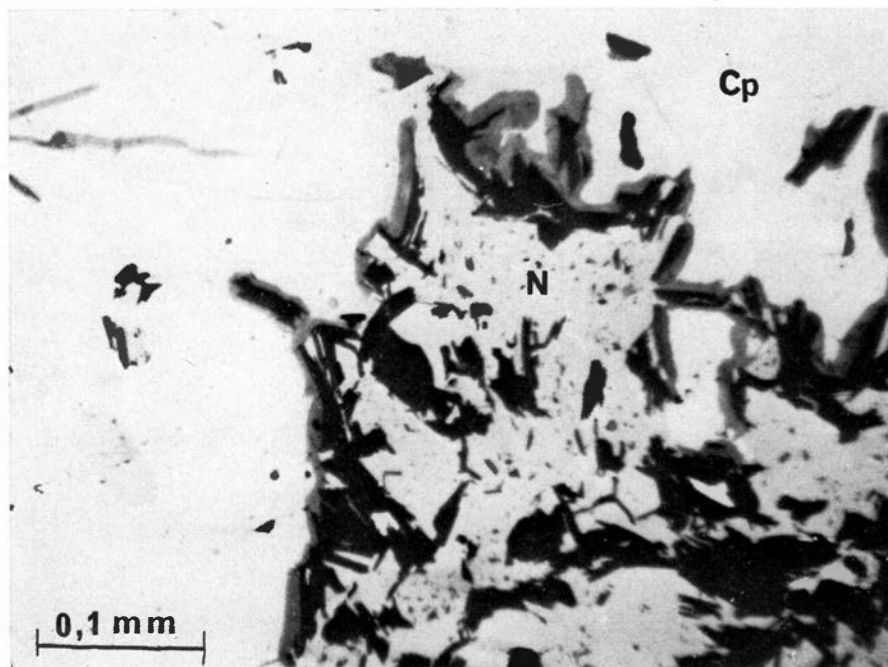


Fig. 8. Chalcopyrite (Cp) transformed to malachite (grey) at the contact to naumannite (N)-biotite masses.

Zone D has idiomorphic calcite and hypidiomorphic quartz with naumannite and chalcopyrite in between. The calcite has drop-like inclusions of naumannite (Fig. 5). As seen in Fig. 6, chalcopyrite is free from biotite inclusions, but naumannite still has them strongly concentrated near some 1 mm large hematite grains. The hematite is partly replaced by biotite and naumannite.

The central zone E is composed of naumannite (free from biotite) and some chalcopyrite. The boundaries between them are smooth (Fig. 7). Chalcopyrite alteration to malachite occurs along cracks and contacts to naumannite-biotite masses (Fig. 8).

Physical properties

The mineral has a metallic lustre and is steel grey in colour with a weak bluish tint. It is malleable and has a sectile tenacity. Only cleavage along (110) was observed.

In polished section the naumannite is light grey with weak bireflection in red-brownish grey to green yellowish grey. The anisotropism is distinct, red-brownish to cream yellow. At some places twins of microcline type were observed (Fig. 9). In high magnification they look lamellar. Obviously the twin pattern was formed during high-low inversion of the mineral. Broken pieces often show irregular areas lying parallel or at right angles to the

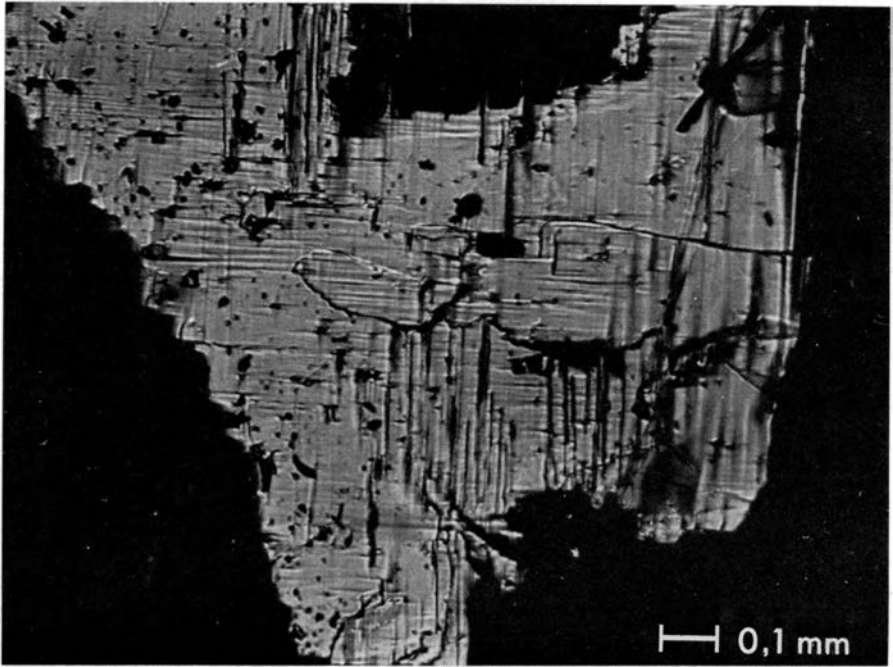


Fig. 9. Naumannite showing inversion twin pattern.

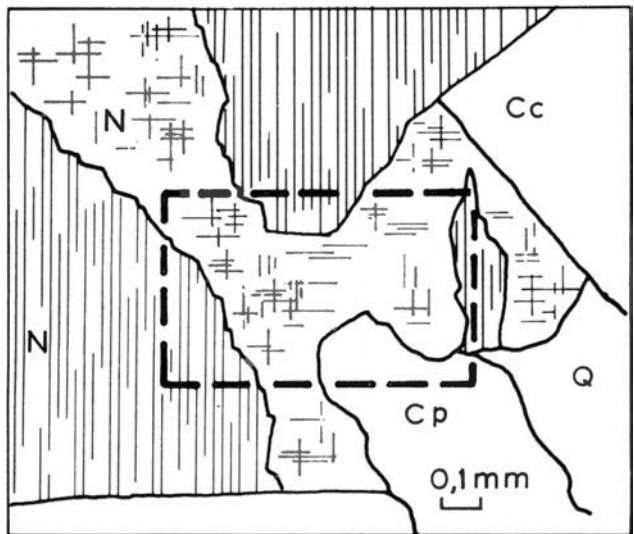


Fig. 10. Sketch of a broken surface showing the relation between cleavage and inversion twin orientation. At the right side calcite (Cc), quartz (Q) and chalcopyrite (Cp). N-naumannite. The outline of Fig. 9 is dashed.

cleavage (Fig. 10). On the areas along the cleavage, the inversion twins can be seen in simple relation to the cleavage of neighbouring areas. These observations lead to the idea that the mineral is composed of individuals in a second twin system.

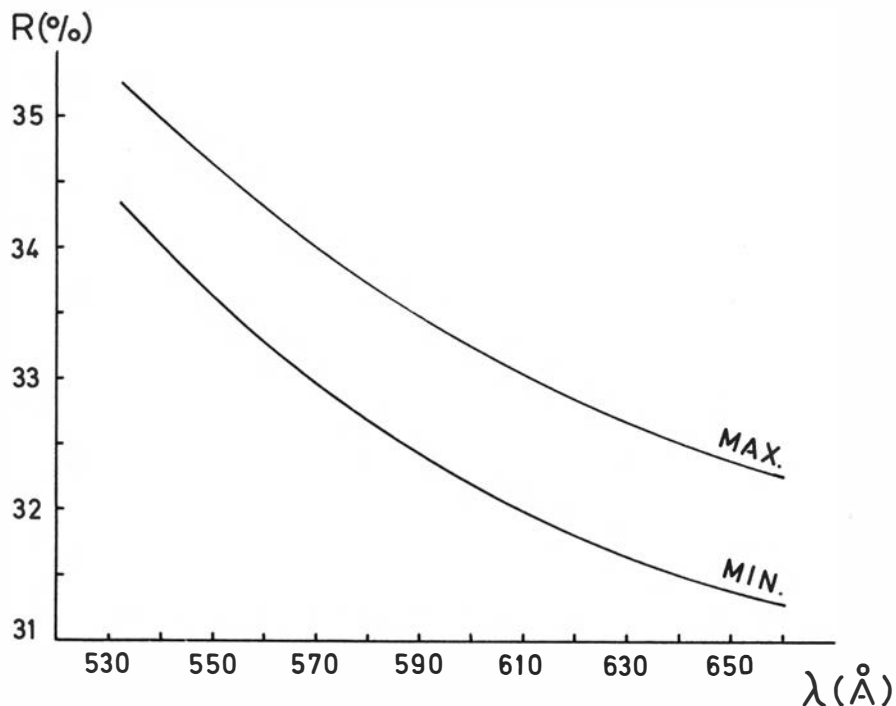


Fig. 11. Maximum and minimum reflectivity of naumannite against wavelength.

Table 1. Physical data on naumannite.

	Density, g/cm ³	Hardness, Vicker	Reflectivity, %, in air
Rose 1828	8.00		
Shannon 1920	6.527*		
Earley 1950	7.69–7.79		
Roy et al. 1959	8.14 ± 0.01		
Bowie & Taylor 1958		115–185	32.6
Banas 1965		45	30
Young & Millmann 1964		31–37	
Sindeeva 1964		36	
Schneiderhöhn & Ramdohr 1931			36 green 34.5 orange 30 red
This study	8.10 ± 0.05	25–30	33.8–34.8 green 32.4–33.5 orange 31.4–32.4 red

* Contaminated.

The specific gravity was determined by a Berman density balance. The mean of 5 measurements was 8.10 ± 0.05 g/cm³. The calculated specific gravity is 8.12 g/cm³.

The microhardness was measured using a Leitz Duriment hardness tester with 100 g load. Naumannite has an anisotropic hardness. The calculated range of Vickers hardness from 30 measurements is 25–30.

The reflectivity was measured by a photoelectric cell with SiC as standard. Naumannite has an anisotropic reflectivity. The minimum and maximum value of 10 measurements in air with different λ is presented in Fig. 11.

Table 1 summarizes the physical data.

X-ray studies

The only existing X-ray work on naturally occurring material was presented by Earley (1950) as a list of d-values. He was not able to index the pattern. Cell parameters are not known on naturally occurring naumannite. Many years before the synthetic results were presented, Schneiderhöhn & Ramdohr (1931) mentioned a possible orthorhombic symmetry for the mineral. They also reported that naumannite has a cubic modification above 133 °C (128 °C as measured by Roy et al. 1959). Synthetic material was first investigated by Boettcher et al. (1955). They did not find any orthorhombic modifications of Ag_2Se , only three tetragonal forms ($a = b = 7.06 \text{ \AA}$, $c = 4.67$), ($a = b = 4.98$, $c = 4.78$) and ($a = b = 7.06$, $c = 4.98$). Another electron diffraction study was done by Pinsker et al. (1965), who found an orthorhombic structure with $a = 7.05$, $b = 7.85$, $c = 4.33$, $Z = 4$. The calculated specific gravity is 8.16 g/cm^3 , which is in good agreement with the observed data. The Kongsberg material was subjected to 9 cm Guinier X-ray run with Fe radiation and $\text{Pb}(\text{NO}_3)_2$ as internal standard. The calculated d-values (Table 3) are quite consistent with Earley's data. Material for single crystal work was prepared by crushing in liquid nitrogen, because of the soft nature of the mineral. Precession films show an orthorhombic symmetry. The reflections were not clear enough to decide the space group caused by slight deformation of the grain. The rough cell parameters from the precession work offered a chance for indexing the powder pattern, and the more exact cell parameters were calculated by an EDB programme based on all the d-values. The cell parameters of the Kongsberg naumannite are presented in

Table 2. Chemical analysis of naumannite.

	Tilkerode, Rose (1828)	DeLamar, Shannon (1920)	Kongsberg, author
Ag	65.56	75.98	72.88
Pb	4.91	—	—
Se	29.53	22.92	26.40
S	—	1.10	0.12
Total	100.00	100.00	99.40
Ag+Pb:Se+S	1.69	2.17	2.00

Analyst: author.

Table 3. X-ray data from powder diagrams of naumannite.

Kongsberg				Tilkerode (Earley 1950)		
hkl	I	d.obs.	d.calc.	I	d.obs.	d.calc.
020	2	3.888	3.904			
011	1	3.786	3.787	½	3.76	3.773
101	1	3.700	3.699			
111	4	3.338	3.342	1	3.29	3.328
021	5	2.894	2.899	1	2.88	2.882
201	5	2.740	2.748	1	2.71	2.734
121	10	2.679	2.685	10	2.66	2.668
211	10	2.584	2.592	10	2.56	2.578
130	6	2.431	2.444	2	2.42	2.421
221	5	2.255	2.248	6	2.23	2.232
031	4	2.240	2.231			
002	2	2.169	2.165			
131	5	2.121	2.128	2	2.11	2.112
012	8	2.090	2.087			
102	3	2.072	2.071	2	2.07	2.066
311	4	2.014	2.010			
112	5	2.004	2.002	4	2.00	1.996
040	1	1.942	1.952	½	1.936	1.933
140	2	1.882	1.882	2	1.868	1.864
202	2	1.849	1.849			
122	3	1.829	1.829	1	1.816	1.822
212	1	1.800	1.800			
141	1	1.721	1.726	1	1.714	1.712
222	1	1.670	1.671	1	1.665	1.664
421	2	1.619	1.618			
411	2	1.609	1.609	1	1.606	1.598
302	2	1.596	1.598			
312	2	1.564	1.566			

Further data omitted

Table 4 together with the calculated data on the Tilkerode material based on Earley's d-values. These cell dimensions are in close agreement with the data on synthetic material from Pinsker et al. With respect to Boettcher et al.'s tetragonal cells, some have cell edges similar to the orthorhombic and cubic cell. Therefore, a reindexing of their patterns might reveal an orthorhombic modification gradually changing to cubic. Further studies need to be done to state possible tetragonal modifications of Ag_2Se .

Table 4. Cell parameters of naumannite.

	Kongsberg		Tilkerode		Synthetic (Pinsker et al. 1965)
		s		s	
a	7.114	0.011 Å	7.061	0.041 Å	7.05 Å
b	7.808	0.010 Å	7.733	0.017 Å	7.85 Å
c	4.330	0.005 Å	4.323	0.012 Å	4.33 Å

s: standard deviation.

Chemistry

A sample was prepared for analysis using a Franz isodynamic separator, Clerici solution and handpicking under the microscope. The material (100 mg) was analysed by the wet chemical methods described by Hillebrand & Lundell (1955), Erdey (1965) and Kolthoff & Sandell (1963). The material was dissolved in diluted HNO_3 , and some small amounts of dissolved calcite impurities should be added to the analytical data. An optical spectrogram of naumannite shows the following elements with their estimated concentrations in %. Cu (0.1), Sb (0.05), Te (0.03), Sn (0.03), Pb (0.01), Au (0.01), Fe (below 0.01), Ni, Co, As not detected. The analysis corresponds to the formula Ag_3Se .

Genesis

In the Kongsberg silver district, gneisses which are commonly sulphide-impregnated (fahlband) are intersected by two sets of vein systems. They are thought to be connected to the Permian granite intrusion of the Oslo Province (Neumann 1944). The veins are sulphide-bearing quartz-breccia veins and calcite-Ni-Co-arsenide-native silver veins. At some places there also occurs a complex type which was formed as quartz veins and later subjected to hydrothermal transformation (rotten veins), or later mineralizations of the calcite-native silver paragenesis (main veins). Calcedony quartz is typical of these complex veins, and the naumannite sample which contains calcedony quartz probably belongs to one of them. The rotten veins have mica but no silver, whereas the main veins have silver but no mica. The occurrence of both mica and silver minerals in the sample suggests that both hydrothermal transformation and mineralization processes were involved in its formation. Bugge (1917) pointed out the difficulty in deciding between rotten and main veins for one of the veins in Johannes Gruve.

A similar vein occurs in the Herzog Ulrich Gruve where Heier (1953) reported clausenthalite. Perhaps this very poorly developed selenium mineralization in Kongsberg is restricted to these uncommon types of vein. Remnants of the fahlband minerals are present as partly replaced bornite in the centre of chalcopyrite, and rounded hematite grains, probably after magnetite. This, together with the impregnation of naumannite and chalcopyrite in the bedrock, demonstrates the lesser role of replacement processes in the formation of the naumannite vein, but the structure of the vein clearly indicates a fracture-filling as the main process. Sindeeva (1964) emphasized calcite veins as the normal type of naumannite occurrences (Tilkerode, St. Andreasberg, Casheuta and Pacajake). The Kongsberg locality, which shows striking similarity to St. Andreasberg (Neumann 1944), fits well with this type of occurrence. The main difference is the lack of clausenthalite as intergrowth in the naumannite, but the low content of Pb in the Kongsberg veins could be an explanation.

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