

Seleniferous lead-bismuth sulphosalts from Falun, Sweden: weibullite, wittite, and nordströmite

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Abstract

Studies of specimens from Falun, Sweden, reported to contain the two minerals weibullite and wittite have established at least *three* selenium-rich bismuth-lead sulphosalts of similar chemistry. A nomenclature is proposed in which two of the minerals retain the old names weibullite and wittite, while the third is given the new name nordströmite. Weibullite, $\text{Ag}_{0.32}\text{Pb}_{5.09}\text{Bi}_{8.55}\text{Se}_{6.08}\text{S}_{11.92}$, is orthorhombic $Pnma$ with $a = 53.68$, $b = 4.11$, $c = 15.40\text{\AA}$; nordströmite, $\text{CuPb}_3\text{Bi}_7(\text{Se}_4\text{S}_{10})$, is monoclinic $P2_1/m$ with $a = 17.97$, $b = 4.11$, $c = 17.62\text{\AA}$ and $\beta = 94.30^\circ$. Wittite, $\text{Pb}_{0.354}\text{Bi}_{0.4366}(\text{Se}_{0.2026}\text{S}_{0.7974})$, is monoclinic with two lattices. The sub-cells of these two lattices are: lattice A, $P2_1/m$, $a = 4.19$, $b = 4.08$, $c = 15.56\text{\AA}$, $\beta = 101.35^\circ$; lattice B, $C2/m$, $a = 7.21$, $b = 4.08$, $c = 15.50\text{\AA}$, $\beta = 98.75^\circ$. They are virtually identical to those found in cannizzarite.

Introduction

The early investigations of the mineral later known as weibullite were carried out by Nordström (1879), Atteberg (1874), and Weibull (1885), all of whom thought it to be a seleniferous galenobismutite. Flink (1910) proposed that it was really an independent species and named it weibullite. Johansson's studies in the 1920's were summarized by Wickman (1948). The chemical analyses and X-ray data in Johansson's notes indicated that he believed that this material was a selenium-bearing galenobismutite. This result was again challenged when Peacock and Berry (1940) examined "galeno-bismutite" from Falun, Sweden (ROM M12992) and found that it contained bismuthinite and two other minerals. They reported that the main one had a monoclinic cell with $a = 18.03$, $b = 4.04$, $c = 17.53\text{\AA}$, and $\beta = 94^\circ 29'$; the other was hexagonal with $a = 4.20$ and $c = 13.22\text{\AA}$. These two minerals were designated weibullite and selenjoseite respectively by Berry and Thompson (1962), who also concluded that specimens from Falun labelled "galenobismutite" (NMNH 84460; ROM M12992); weibullite (NMNH R6532); and "seleniferous chiviatite" (NRS, 24083, type, Falun, Sweden) were mixtures of weibullite, selenjoseite, and bismuthinite, and that published analyses of such

specimens therefore gave the composition of the mixtures.

Walker and Thompson (1921) concluded from microscopic examination and a chemical analysis (by Todd) that a specimen from Falun was a mixture of cosalite, bismuthinite, and guanajuatite. Texts such as Sindeeva (1964), Vlasov (1964) and Dana's System of Mineralogy (Palache *et al.*, 1944, p. 473) quote old chemical analyses for weibullite (Table 1) but acknowledge that the mineral may be a selenium-bearing galenobismutite rather than an independent species. Povarennykh (1972, p. 250) equates it with Se-galenobismutite.

Wittite was first described by Johansson (1924). Its composition was apparently well established (Bi 43.33, Pb 33.85, S 12.14, Se 8.46, plus minor amounts of Cu, Ag, Zn and Fe), as were its physical properties. However a crystal system was not definitely ascertained for this mineral.

Recent studies of weibullite and wittite

Karup-Møller (1970) examined specimen BSF 1753 labelled "Weibullite from Falun Gruva" from the mineralogical collections at Bergsskolan in Filipstad, Sweden. His examination of this material, which Berry and Thompson's earlier work suggested would be a mixture of weibullite, selenjoseite, and

Table 1. Chemical analyses of "weibullite," taken from the literature

	1*	2	3	4
Fe	-	0.61	-	0.88
Cu	-	0.77	-	1.38
Pb	25.37	24.62	27.88	14.08
Ag	-	-	0.33	-
Bi	51.24	49.73	49.88	59.70
S	9.36	9.82	9.75	10.84
Se	14.03	13.61	12.43	12.54
	100.00	99.16	100.27	99.42

1,2 Weibull (1885)

3 Genth (1886)

4 Walker and Thompson (1921): analysis by Todd.

*Calculated eliminating CuFeS₂ impurity.

bismuthinite, included detailed chemical analysis of three minerals using microprobe technique. While the presence of the three minerals weibullite, selenjoseite, and bismuthinite was apparently confirmed (but see below), he did suggest that the mineral called selenjoseite by Berry and Thompson (1962) was actually identical with laitakarite, described by Vormann (1960). [Note however that Berry (1963) had already indicated the probable identity of laitakarite and selenjoseite.] Karup-Møller's identification of the three minerals in BSF 1753 was based upon their X-ray powder patterns, using the data given in Berry and Thompson (1962). He described the physical properties of each; thus weibullite had a variable habit ranging from irregular grains to shaped laths and prisms with some deformational twinning observable in rare cases. Microprobe analyses (Table 2)

Table 2a. Recent microprobe analyses of weibullite (as defined in this proposal)

	1	2	3	4	5	6
Fe	-	-	-	-	-	-
Cu	0.0	0.0	0.3	-	-	-
Pb	33.1	27.8	31.5	29.7	28.2	28.3
Ag	1.0	0.5	0.9	-	-	1.0
Bi	47.6	48.5	46.5	46.6	46.8	48.0
Se	11.5	11.6	11.8	15.3	15.3	12.8
S	10.5	10.2	10.2	9.6	9.8	10.3
As	-	-	-	0.8	-	-
	103.70	98.60	101.2	102.0	100.1	100.4

1,2,3 Karup-Møller (1970). Specimen BSF1753.

4,5 Johan and Picot (1976).

6 These laboratories using PbSe, Bi₂S₃ and Ag₂S as standards. PbL_α, BiL_α, SeK_α, SK_α and AgL_α. Jeol JXA-50A microprobe. The correction program, Magic IV, was developed by J. Colby of Bell Telephone Inc. Allantown, Pennsylvania. Specimen BSF1753.

suggested to Dr. Karup-Møller that, based on the monoclinic cell of Peacock and Berry (1940), the formula of weibullite was probably Pb₃Bi₆S₉Se₄.

Mumme (1976) tried to discriminate between the three chemically closely related minerals weibullite, wittite, and proudite. Specimens of weibullite and wittite provided respectively by Dr. Karup-Møller (Copenhagen University) and Dr. Åberg (Naturhistoriska Riksmuseet, Stockholm) were examined in our laboratories and an individual identity for each was established. However in contrast to the result in Berry and Thompson (1962), what we identified as weibullite in BSF 1753 [from Karup-Møller's (1970) description and comparison of the microprobe analyses (Table 2a)], was found to have orthorhombic symmetry, space group *Pnma*, with *a* = 53.68(9), *b* = 4.11(1), *c* = 15.40(2) Å. For the specimen of wittite (which in all probability was the material studied by Johansson—Dr. Åberg, private communication), X-ray single-crystal and powder data of poorer quality were obtained which made the study of its crystal structure impracticable. In fact the powder data for wittite were indexed using only a "sub-cell" determined from poor Weissenberg photographs obtained from small fragments. Nevertheless this specimen of wittite was determined to represent a unique species and was not a mixture of Se-rich hammarite as has been proposed by Strunz (1957), Povarennykh (1972) and Sineeva (1964).

A subsequent crystal structure determination of proudite established its ideal composition to be close to CuPb_{7.5}Bi_{9.33}(S,Se)₂₂ (Mumme, 1976). Then, as part of a continuing investigation of selenium-bearing bismuth-lead sulphosalts, the crystal structure determi-

Table 2b. Microprobe analyses of proudite, wittite, and nordströmite

	1	2	3	4a	4b
Fe	-	-	-	-	-
Cu	1.0	-	-	2.0	2.0
Pb	33.0	35.3	33.2	21.7	22.1
Ag	-	-	-	-	-
Bi	42.7	43.9	45.5	51.9	52.5
Se	12.8	7.7	9.7	11.2	11.8
S	10.7	12.3	11.8	10.9	10.4
	100.2	99.5	100.2	97.7	97.8

1 Proudite, analysis 2, Table 2, Mumme (1976).

2 Wittite, analysis 6, Table 2, Mumme (1976).

3 Wittite, average of two analyses, Johan and Picot (1976).

4a,b Nordströmite from ROM M12992, conditions of analysis and standards are same as analysis 6 above, except metallic copper for CuK_α.

nation of weibullite in BSF 1753 was also undertaken, in terms of the new orthorhombic unit cell and the chemical analysis which Karup-Møller (1970) had established.

During this work, however, I learned that more or less concurrently Johan and Picot (1976) had examined species from Falun in the collection of the School of Mines, Paris. They reported having found an orthorhombic phase coexisting with a monoclinic phase in their specimens and called them *weibullite* and *wittite* respectively. The orthorhombic cell was obtained using single-crystal methods, but the unit-cell dimensions for the monoclinic phase, while reputedly similar to those which Peacock and Berry (1940) reported for weibullite in ROM M12992, were deduced from their unpublished powder data (which are now kindly provided for Table 3 by Dr. Johan). Their results suggested to Johan and Picot that both Peacock and Berry (1940) and Karup-Møller (1970) had previously studied wittite (the monoclinic phase) and that weibullite (the orthorhombic phase) had not been recognized by those workers. The orthorhombic unit cell ($a = 15.39$, $b = 4.068$, $c = 53.8\text{\AA}$, space group $Pcmm$ or $Pc2_1n$) and the powder data (Table 3a) which Johan and Picot obtained for the mineral they called weibullite were almost identical with data determined here for the mineral identified as weibullite in the specimen of BSF 1753 sent by Dr. Karup-Møller (Mumme, 1976). In my work to obtain single crystals for structure analyses, none with the monoclinic unit cell reported by Peacock and Berry (1940) and Johan and Picot (1976) have been isolated from our specimen of BSF 1753. However, examination of the Weissenberg films obtained by Peacock and Berry in their 1940 studies (kindly lent to me at this stage by Professor Berry and Professor Nuffield) definitely confirmed their verdict that a mineral with the monoclinic cell which they reported did exist; and eventually single crystals of this mineral were obtained here from the specimen they had studied (ROM M12992). This specimen has also provided crystals displaying single-crystal data identical to that of the *wittite* specimen obtained from the Riksmusset, Stockholm. ROM M12992 was generously provided by the Royal Ontario Museum.

The results of my microprobe analysis of the monoclinic phase in ROM M12992 are given in Table 2b. Compared with the orthorhombic weibullite from BSF 1753 (Table 2a, analyses 1, 2, 3, and 6), it contains copper rather than silver and has a higher Bi/Pb content.

Thus there are at least three Pb-Bi-S-Se minerals

Table 3a. X-ray powder data for weibullite (CuK α)

1				2			
d _{obs}	d _{calc}	h k l	I	d _{obs}	d _{calc}	h k l	I
				7.78	7.76	6.0.1	3
					7.71	0.0.2	
				5.11	5.11	1.0.3	3
					5.08	10.0.1	
4.100	4.121	11.0.2	½				
3.969	3.973	0.1.1	4	3.960	3.934	0.1.1	1
3.868	3.852	0.0.4	7	3.847	3.849	0.0.4	10
	3.842	1.0.4			3.847	14.0.0	
	3.867	12.0.2					
3.750	3.719	14.0.1	1	3.733	3.733	14.0.1	3
3.626	3.619	1.1.2	2	3.637	3.647	13.0.2	5
3.605	3.638	13.0.2	1				
	3.595	2.1.2					
3.538	3.555	3.1.2	1				
	3.538	6.0.4					
	3.537	11.0.3					
3.506	3.527	7.1.1	1	3.505	3.497	15.0.1	3
	3.506	8.1.0					
3.409	3.431	14.0.2	1	3.435	3.442	7.0.4	3
					3.440	14.0.2	
3.363	3.362	6.1.2	1	3.363	3.365	16.0.0	2
	3.372	12.0.3					
3.303	3.306	9.1.1	1				
3.279	3.277	16.0.1	1	3.268	3.259	7.1.2	8
	3.279	7.1.2					
3.233	3.244	15.0.2	½				
3.210	3.210	0.1.3	1	3.191	3.188	0.1.3	1
	3.217	13.0.3					
3.188	3.187	2.1.3	3				
3.145	3.159	3.1.3	½				
3.125	3.122	4.1.3	½				
	3.129	10.0.4					
3.080	3.072	14.0.3	10	3.080	3.083	9.1.2	9
	3.075	16.0.2			3.077	14.0.3	
					3.075	1.0.5	
3.025	3.027	12.1.0	1	3.019	3.026	11.0.4	7
					3.014	12.1.0	
3.011	3.021	6.1.3	3				
2.967	2.961	7.1.3	4	2.951	2.960	5.0.5	5
					2.958	12.1.1	
					2.945	7.1.3	
2.898	2.895	8.1.3	4				
	2.921	17.0.2					
2.868	2.859	7.0.5	4	2.864	2.858	7.0.5	5
	2.862	13.1.1					
2.811	2.804	14.1.0	1	2.811	2.819	13.0.4	7
	2.808	16.0.3			2.814	16.0.3	
					2.814	9.1.3	
					2.806	12.1.2	
2.703	2.689	17.0.3	1	2.697	2.695	17.0.3	3
					2.692	20.0.0	
2.689	2.682	6.1.4	2				
2.648	2.635	14.1.2	½	2.639	2.652	20.0.1	2
	2.643	20.0.1					
2.563	2.565	1.0.6	½	2.557	2.563	1.0.6	2
					2.557	16.1.1	
					2.554	2.0.6	
2.543	2.556	2.0.6					
	2.542	3.0.6					
	2.543	9.1.4					
2.412	2.401	14.0.5	½	2.407	2.410	18.1.0	2
					2.404	14.0.5	
2.317	2.314	8.1.5	½	2.318	2.318	13.1.4	1
	2.316	10.0.6			2.316	10.0.6	
					2.315	16.1.3	
					2.315	23.0.1	
					2.282	19.0.4	6
					2.273	11.0.6	
2.248	2.241	10.1.5	3	2.241	2.243	24.0.0	5
					2.240	23.0.2	
					2.197	1.0.7	1
					2.195	11.1.5	
2.109	2.116	6.1.6	4	2.138	2.136	6.0.7	6
	2.117	18.1.5		2.101	2.097	22.1.1	1
	2.098	22.1.0					
2.068	2.074	14.1.5	½	2.073	2.074		1
					2.071	26.2.0	
2.053	2.056	0.2.0	6	2.046	2.043	18.1.4	5
	2.046	9.1.6					
	2.064	26.0.0					

1 Guinier data, Mumme (1976), indexed from weissenberg films

2 Johan & Picot (1976).

Table 3b. X-ray powder data for wittite

1				2				3			
d _{obs}	d _{calc}	h k l	I	d _{obs}	d _{calc}	h k l	I	d _{calc}	h k l		
				7.73	7.72	0.0.2	A	2	7.74	2.0.1	
					7.68	0.0.2	B				
				5.13	5.14	0.0.3	A	2	5.14	3.0.2	
					5.12	0.0.3	B				
				4.42				1	4.436	4.0.1	
4.085	4.103	1.0.0	A	1/2							
3.955	3.955	1.0.2	A	1							
3.848	3.811	0.0.4	A	3	3.847	3.858	0.0.4	A	10	3.858	1.1.1
	3.827	0.0.4	B		3.839	0.0.4	B		3.830	1.1.1	
3.788	3.779	1.0.1	A	1							
3.607	3.590	2.0.1	B	3	3.616	3.576	2.0.1	B	2	3.627	2.1.1
										3.616	1.1.2
3.529	3.553	1.0.3	A	4	3.525	3.508	1.0.3	A	3	3.497	0.0.5
	3.537	1.1.0	B								
3.434	3.434	2.0.2	B	7							
3.390	3.391	1.1.1	B	3	3.387	3.393	1.1.1	B	4	3.383	1.0.5
3.362	3.348	1.0.2	A	2							
3.297	3.307	1.1.2	B	1	3.290	3.301	1.1.2	B	3	3.290	1.1.3
3.138	3.121	1.1.2	B	3							
	3.153	2.0.3	B								
	3.114	1.0.4	A								
					3.186	3.196	0.1.3	B	1	3.175	2.0.5
										3.175	3.1.2
3.058	3.056	2.0.2	B	4	3.058	3.064	2.0.2	B	8	3.058	2.1.3
3.038	3.048	0.0.5	A	3							
3.004	3.015	1.1.3	B	5	2.997	3.010	1.1.3	B	8	3.004	4.1.0
										2.996	6.0.0
										2.992	6.0.1
2.887	2.891	1.1.0	A	10	2.884	2.890	1.1.0	A	9	2.888	4.1.2
2.849	2.831	2.0.4	B	3							
	2.838	1.1.2	A								
2.800	2.808	1.1.3	B	3	2.798	2.817	1.1.3	B	2	2.796	4.1.2
2.700	2.701	1.1.4	B	2	2.691	2.697	1.1.4	B	4	2.686	5.1.0
					2.567	2.572	0.0.6	A	1	2.570	7.0.1
						2.559	0.0.6	B		2.566	6.0.4
					2.243	2.249	1.1.5	A	5	2.247	8.0.0
						2.242	1.1.5	B		2.247	3.1.6
										2.244	3.0.7
2.103	2.103	1.0.7	A	1	2.101	2.096	1.0.7	A	2	2.099	2.1.7
2.041	2.039	0.2.0	A	5	2.042	2.039	0.2.0	A	8	2.045	3.1.7
	2.037	0.2.0	B			2.038	0.2.0	B		2.044	8.0.3

1. Guinier data, CuK α , Mumme (1976). Indexed using A, $a = 4.19$, $b = 4.08$, $c = 15.56$, $\beta = 101.35^\circ$; B, $a = 7.21$, $b = 4.08$, $c = 15.50$, $\beta = 98.75^\circ$. Weissenberg films used.
2. Data from Johan & Picot (private communication). Although they successfully indexed this data using the monoclinic unit cell of nordströmite (3), their chemical analysis showed no Cu and is much closer to wittite than nordströmite. Indexed using A, $a = 4.16$, $b = 4.08$, $c = 15.66$, $\beta = 99.80^\circ$, B, $a = 7.18$, $b = 4.08$, $c = 15.51$, $\beta = 98.15^\circ$.
3. Data in (2) from Johan & Picot indexed (by them) using $a = 18.034$, $b = 4.040$, $c = 17.53$, $\beta = 94.31^\circ$.

in specimens from Falun, for which at present only two names exist, and obviously this has caused the confusion of their identities. In particular, the name *wittite* has recently been used for the mineral I obtained from Dr. Åberg with the composition, powder pattern, and "subcell" reported in Mumme (1976), as well as the mineral described by Johan and Picot (1976), for which they obtain a similar composition

(Table 2b) but inferred a different unit cell, the same in fact as the monoclinic mineral in ROM M12992. On the other hand, a fortuitous agreement was established between the recent nomenclature used independently by Mumme (1976) and Johan and Picot (1976) to the extent that the orthorhombic phase ($a \sim 53.7$, $b \sim 4.1$, $c \sim 15.4\text{Å}$) found in Falun specimens has been called *weibullite* in both studies. Uncer-

Table 3c. X-ray powder data for nordströmite

I	d _{obs}	d _{calc}	h k l
1	7.671	8.236	2.0.1
1	5.139	5.081	2.0.3
		5.122	3.0.2
1	4.393	4.480	4.0.0
3	3.882(B)	3.892	1.1.1
		3.876	4.0.2
5	3.583	3.622	1.1.2
		3.678	2.1.1
		3.695	4.0.3
3	3.484	3.500	0.0.5
3	3.427	3.499	1.0.5
		3.401	1.0.5
		3.419	3.0.4
		3.437	4.0.3
		3.461	5.0.1
½	3.190	3.206	5.1.2
		3.261	4.0.4
10	3.066	3.106	2.1.3
3	3.012	3.029	4.1.0
3	2.899	2.929	0.0.6
		2.926	1.0.6
		2.963	1.1.4
		2.879	3.1.3
1	2.764	2.803	2.1.4
		2.765	6.0.2
1	2.692	2.701	5.1.0
		2.670	4.0.5
3	2.577	2.609	5.0.5
		2.561	6.0.4
½	2.406	2.402	5.1.3
		2.388	6.0.4
½	2.331	2.341	2.1.6
		2.354	4.1.5
7	2.242	2.260	3.1.6
		2.240	8.0.0
1	2.211	2.189	5.0.6
		2.201	8.0.1
3	2.105	2.114	3.0.8
		2.086	5.1.5
3	2.052	2.055	0.2.0
		2.054	4.1.6
		2.044	5.1.6
1	1.931	1.937	0.1.8
		1.926	1.0.9
		1.947	8.1.2
		1.930	9.0.3

Debye-Scherrer film, radius = 114.6 mm, CuK α radiation.
Indexed using Weissenberg films.

tainty as to this mineral's composition remains only to the extent that Johan and Picot have reported significant As but no Ag in their specimens (Table 2a). Their As analyses, using native As and lorandite, were made on the K β line to avoid interference with Pb. Ag was also specifically checked and was not found in weibullite from the Paris collection (private communications from Dr. Johan).

Proposed nomenclature

The problem of identifying which of these minerals is which really relates to the availability of their holotypes. This is a particular difficulty in the present case where quite often at least two of them occur in the same hand specimen, and the old chemical analyses seem to have been made on mixtures.

Flink (1910) originally used the name weibullite for a group of specimens in the collections of the Stockholm Riksmuseum. His main concern was to distinguish this mineral from selenian galenobismutite. His sketchy definition is based on hardness, density, cleavage characteristics, and the chemical data already determined by Weibull (1885) (which is actually the galenobismutite composition with 3/8 of the sulphur content replaced by selenium). Thus Weibull's "selenhaltig Galenobismutit" to which Flink attached the name weibullite had already been characterized chemically (Table 1). However Weibull's Bi/Pb ratio, 2.02, is intermediate between that of the orthorhombic mineral (av. = 1.59) and the monoclinic mineral (av. = 2.48). Admixture of the basically lead-free minerals bismuthinite and laitakarite with the monoclinic mineral cannot account for his analyses; only their admixture with the orthorhombic mineral can. Thus Weibull's analyses are reasonably interpreted as deriving from such a mixture of the orthorhombic mineral with bismuthinite and/or laitakarite. As Flink's intention was to provide a name for Weibull's material, from the above reasoning, the name weibullite must have been meant for the orthorhombic mineral. Fortunately the recent usage of the name is in agreement with this.

It is therefore proposed that the name weibullite be applied to the orthorhombic mineral as it is considered this was the original intention of Flink, and that the monoclinic mineral whose cell was first reported by Peacock and Berry (1940) should be given the new name nordströmite. The name wittite should be reserved for the mineral studied by Johansson which is preserved in the Naturhistoriska Riksmuseet, Stockholm (Mumme, 1976) and this should now be regarded as the type specimen. Nordströmite is named for T. Nordström, who first studied many Se-bearing Bi-Pb sulphosalts from Falun. It was accepted as a new mineral by the IMA in December 1978.

Interpretation of the most recent Weissenberg data obtained here for wittite now indicates that this mineral is monoclinic with two lattice sets. One has a monoclinic subcell, $P2/m$, with $a = 4.19(1)$, $b = 4.08(1)$, $c = 15.56(4)\text{Å}$, $\beta = 101.35^\circ(16)$, while the other has a monoclinic subcell, $C2/m$, with $a = 7.21(2)$, $b = 4.08(1)$, $c = 15.50(5)\text{Å}$, $\beta = 98.75^\circ(15)$. These parameters were obtained by least-squares refinement of the previously reported powder data, now re-indexed using both lattice sets (Table 3b). They are almost the same as those reported by Graham *et al.* (1953) for the mineral cannizzarite, and a

close structural relationship, if not identity, must exist between wittite and cannizzarite.

Physical, chemical and X-ray data for weibullite, wittite, and nordströmite

To summarize, by using the above definitions, it is now possible to say which of these three minerals has been identified in the historical specimens recently examined here, and by the other workers referred to above.

BSF 1753 from Bergsskolan, Filipstad, Sweden, contains weibullite, together with previously reported

laitakarite and bismuthinite. ROM M12992 from the Royal Ontario Museum contains nordströmite with some wittite (and bismuthinite). The mineral fragment sent here from the Stockholm Riksmuseum, which was from the only specimen labelled wittite in the K. Johansson collection, is composed entirely of that mineral.

The Falun specimens in the Paris collection examined by Johan and Picot (1976) did contain weibullite and wittite. This is deduced because of the close agreement between the analyses of their monoclinic mineral and those of type-specimen wittite (Table

Table 4. Mineralogical, chemical, and crystallographic data for weibullite, nordströmite, and wittite

Minerals	Weibullite	Nordströmite	Wittite ("Se-cannizzarite")
Hand specimen			
Colour	lead-grey	lead-grey	lead-grey
hardness	2-2½	2-2½	2-2½
cleavage		Good cleavage parallel to elongation. Fibrous appearance	Good cleavage, giving platy appearance
Polished section			
Colour & bireflectance	light grey weak	white with grey tinge - in contrast to wittite in same specimen. bireflectance not noticeable.	cream-white bireflectance not noticeable
Reflectivity data	(1) 420nm: 42.9-51.0 540nm: 39.7-46.6 620nm: 37.8-44.4		(1) 420nm: 45.2-44.0 540nm: 42.4-44.0 660nm: 40.0-37.3
Anisotropy	Dark grey to red brown	Dark grey to brown	Dark grey to brown
Microhardness	(1) Parallel to 100, 116 Kg/mm ² (VHN ₂₅) 010,75 Kg/mm ² (VHN ₂₅) (2) 39-73 Kg/Sq.mm (VHN ₂₀)	(3) Five readings at VHN ₂₅ gave 136, 143, 130, 132, 134 Kg/mm ²	
Chemical formulae	Ag _{0.32} Pb _{5.09} Bi _{8.55} Se _{6.08} S _{11.90}	Cu _{0.94} Pb _{3.05} Bi _{7.24} Se _{4.12} S _{9.89}	Pb _{0.3541} Bi _{0.4366} Se _{0.2026} S _{0.7974} (1) Pb _{0.3263} Bi _{0.4435} Se _{0.2502} S _{0.7498}
Structural formulae	Ag _{0.33} Pb _{5.33} Bi _{8.33} (Se ₆ S ₁₂)	CuPb ₃ Bi ₇ (Se ₄ S ₁₀)	
X-ray data			
Symmetry	Orthorhombic	Monoclinic	Monoclinic
Unit cell	a = 53.68(9) b = 4.11(1) c = 15.40(3)	a = 17.97(8) b = 4.11(2) c = 17.62(8) β = 94.3 (2)	Lattice A a = 4.19(1) b = 4.08(1) c = 15.56(4) β = 101.4 (2) Lattice B a = 7.21(1) b = 4.08(1) c = 15.50(5) β = 98.8 (2)
Space group	Pnma	P2 ₁ /m	P2/m C2/m

(1) Johan & Picot (1976) (2) Karup-Møller (1970) (3) Dr. A. Kato & S. Matsubaru (National Science Museum, Tokyo)

2b). The absence of Cu eliminates nordströmite as the mineral on which the probe analysis was determined, and the powder data provided by Dr. Johan, which was originally indexed with the unit cell of nordströmite, can be satisfactorily re-indexed with the unit-cell data most recently determined here for wittite (Table 3). The possibility that the probe data reported by Johan and Picot were from wittite, while their X-ray powder data were from crystal fragments of unrecognized nordströmite present in their samples, should also probably be considered.

X-ray powder data for all three minerals, internally calibrated with KCl ($a = 6.2929\text{\AA}$), and obtained using $\text{CuK}\alpha$ and Guinier and Debye-Scherrer methods, are given in Table 3. All mineralogical, chemical, and crystallographic data which are presently available are summarized in Table 4. Figures 1 and 2 illustrate the typical habit of weibullite, wittite, and nordströmite in those hand specimens and polished sections studied here.

Concluding remarks

Weibullite and nordströmite are now definitely proved to be two different mineral species. The unit

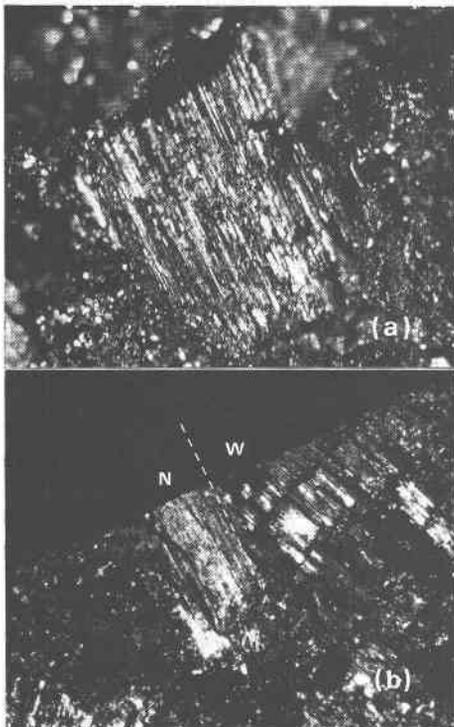


Fig. 1. Habit of nordströmite in ROM M12992. Photographs show (a) fibrous nature of nordströmite ($\times 10$), (b) juxtaposition of nordströmite and wittite ($\times 10$). N = nordströmite, W = wittite. Wittite has somewhat duller appearance and less perfect cleavage.

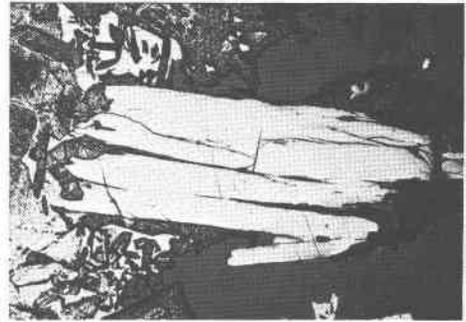


Fig. 2. Polished section of portion of BSF 1753 ($\times 40$). Large weibullite grain surrounded by minerals which include quartz, chalcocopyrite and bismuthinite. Etched 1 minute with HNO_3 .

cell of weibullite from BSF 1753 is orthorhombic with $a = 53.68$, $b = 4.11$, $c = 15.40\text{\AA}$, and its structural formula determined by single-crystal structure analysis is $\sim \text{Ag}_{0.33}\text{Pb}_{5.33}\text{Bi}_{8.33}(\text{Se}_6\text{S}_{12})$ (Mumme, 1980a). The "ideal" unsubstituted formula for weibullite is $\text{Pb}_6\text{Bi}_8(\text{Se}_6\text{S}_{12})$. The unit cell of nordströmite is monoclinic with $a = 17.97$, $b = 4.11$, $c = 17.62\text{\AA}$, $\beta = 94.30^\circ$; its ideal structural formula is $\text{CuPb}_3\text{Bi}_7(\text{Se}_4\text{S}_{10})$ (Mumme, 1980b).

The monoclinic 'subcells' for the two lattices in wittite indicate that this mineral has a crystal structure which is related closely to that of cannizzarite (Matzat, 1979). However, it may be differentiated from cannizzarite at this stage by virtue of its high selenium content (about 8 wt %). The composition of wittite determined by microprobe analysis in our laboratories is $\text{Pb}_{0.3541}\text{Bi}_{0.4366}(\text{S},\text{Se})_1$ (Table 2b). Matzat's formula for cannizzarite, which in the absence of exact chemical data is based on his structure determination and the assumption of stoichiometry, is $\text{Pb}_{46}\text{Bi}_{54}\text{S}_{127}$ i.e. $\text{Pb}_{0.3622}\text{Bi}_{0.4252}\text{S}_1$.

It is suggested that until the full details of the crystal structure relationships between wittite and cannizzarite are finally deduced, the name "wittite" should be preferred to "Se-cannizzarite" when discussing the Falun mineral.

Acknowledgments

Apart from the considerable assistance indicated in the text, I acknowledge with thanks the advice and help of Dr. M. H. Hey, Dr. A. Kato, Dr. E. Makovicky, and Dr. S. Sølver.

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*Manuscript received, September 20, 1978;
accepted for publication, March 4, 1980.*