AM-78-077

American Mineralogist, Volume 63, pages 832–839, 1978

On cooperite, braggite, and vysotskite[1]

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Abstract

Detailed mineralogical analyses of cooperite, braggite, and vysotskite, together with phase equilibrium studies, reveal that, though there is no uncertainty regarding the identity of cooperite (PtS; $P4_2/mmc$), one may consider braggite (Pt,Pd)S and vysotskite PdS to be nickeloan members of an isomorphous solid-solution series (Pd,Pt)S ($P4_2/m$). The results also suggest that this solid-solution series (braggite series) may be subdivided by restricting the name vysotskite to those members with less than about 10 mole percent PtS. Cooperite and braggite can both form at magmatic temperatures of 1000°C or above, but vysotskite is only formed at submagmatic temperatures, possibly by crystallization from a residual immiscible sulfide-rich melt or by solid-state reaction.

Introduction

Cooperite, braggite, and vysotskite are the only Pt–Pd sulfide minerals with ideal compositions in the system Pt–Pd–S. Cooperite is ideally PtS, braggite (Pd,Pt)S, and vysotskite PdS. All analyses, however, report the presence of significant amounts of Ni, so mineralogically they must be considered as being in the system Pt–Pd–Ni–S. We aim to clarify the nomenclature and to present new data on the compositions of the minerals. It is a pleasure to be able to do so in the Frondel-Hurlbut issue of *The American Mineralogist*, because these two distinguished mineralogists have clarified so many similarly confusing issues in the nomenclature of minerals.

Braggite and cooperite are both important platinum-group minerals (PG-minerals) and are known from many areas of the world; in the great Merensky Reef deposits of the Bushveld Igneous Complex in the Transvaal they are major ore minerals. Vysotskite has not so far been found in sufficient quantities to be considered an important ore mineral. First discovered in the Noril'sk deposits of the USSR and reported by Genkin and Zvyagintsev (1962), vysotskite has since been reported, but not documented in detail, from the Stillwater Complex of Montana (Cabri and Laflamme, 1974) and the Lac des Isles deposit, Ontario (Cabri and Laflamme, 1976).

In this note we report new data on all three minerals from the Precambrian Stillwater Complex of Montana. Page *et al.* (1976) discussed the variations of PG-elements in the different mafic and ultramafic layers of the complex. In the layers identified by Page *et al.* as the Banded and Upper Zones we have identified, for the first time, the three minerals in the same deposit. The three minerals have not been found in contact so it is probable that the assemblage does not represent equilibrium, and its true significance can only be guessed at.

Previous mineralogical studies

Cooperite

Cooperite was discovered in samples from the Bushveld by Cooper (1928) and named by Wagner (1929) following a suggestion by a Mr. Wartenweiller in a published discussion following presentation of Cooper's paper. Bannister and Hey (1932) determined the mineral to be tetragonal with $a_0 = 4.91$ and

[1] Minerals Research Program, Processing Contribution No. 88.

Table 2. Electron microprobe analyses of cooperite-braggite-vysotskite from different localities

	Weight percent					Formula					Mineral*	Sample
	Pt	Pd	Ni	S	Total	Pt	Pd	Ni	ΣM	S		
1.	81.6(73.0-84.8)	2.6(0.08-10.2)	0.74	14.6(13.9-15.8)	99.54	0.92	0.05	0.03	1.00	1.00	C	5
2.	71.8	4.0	7.3	17.3	100.4	0.69	0.07	0.23	0.99	1.01	C	5
3.	84.4	0.82	0.94	14.9	101.06	0.94	0.02	0.03	0.99	1.01	C	5
4.	69.5(66.0-71.4)	7.0(6.1-11.5)	6.0(5.5-6.5)	17.0(16.6-18.0)	99.5	0.68	0.12	0.19	0.99	1.01	B	5
5.	70.1(68.6-72.7)	6.9(6.2-8.8)	5.6(4.7-6.0)	16.5(16.2-16.6)	99.1	0.69	0.13	0.18	1.00	1.00	B	5
6.	67.0(66.0-68.6)	9.5(8.6-9.7)	5.6(4.3-6.3)	16.9(15.5-17.0)	99.0	0.65	0.17	0.18	1.00	1.00	B	5
7.	68.9(67.9-70.1)	8.1(7.5-8.1)	5.7(5.5-6.1)	16.5(16.0-16.6)	99.2	0.68	0.14	0.19	1.01	0.99	B	5
8.	3.7(0.19-8.4)	61.8(57.7-65.9)	10.2(9.0-10.8)	24.8(24.2-24.9)	100.5	0.02	0.75	0.23	1.00	1.00	V	5
9.	60.3	15.7	6.3	17.8	100.1	0.55	0.27	0.19	1.01	0.99	B	5
10.	48.0(46.6-49.2)	26.9(26.0-28.1)	5.0(4.5-6.0)	19.[illegible](18.8-19.1)	99.0	0.42	0.43	0.14	0.99	1.01	B	5
11.	63.6	13.8	5.4	16.8	99.6	0.61	0.24	0.17	1.02	0.98	B	5
12.	58.3	19.5	5.1	17.6	100.5	0.53	0.33	0.16	1.02	0.98	B	5
13.	51.6(43.9-57.3)	22.6(19.2-26.5)	7.3(6.2-10.0)	18.9(17.7-20.3)	100.4	0.44	0.36	0.21	1.01	0.99	B	5
14.	47.5(42.1-51.5)	24.4(23.6-27.4)	9.0(8.8-9.5)	19.3(18.9-20.6)	100.2	0.40	0.37	0.25	1.02	0.98	B	5
15.	37.0(16.7-45.5)	37.6(31.9-52.6)	6.0(3.[illegible]-9.3)	20.3(18.5-22.4)	100.9	0.30	0.55	0.16	1.01	0.99	B	5
16.	37.0(24.4-50.4)	31.6(24.2-40.2)	10.4(5.9-14.0)	20.5(18.6-21.8)	99.5	0.29	0.46	0.27	1.02	0.98	B	5
17.	40.9	33.9	5.1	19.6	99.5	0.34	0.52	0.14	1.00	1.00	B	5
18.	40.3(36.1-42.6)	32.4(29.9-36.7)	7.1(6.3-9.0)	19.7(18.9-20.4)	99.5	0.33	0.49	0.19	1.01	0.99	B	5
19.	48.9(41.0-54.6)	24.9(22.0-28.5)	7.7(5.0-9.7)	19.0(18.1-20.1)	100.5	0.41	0.39	0.22	1.02	0.98	B	5
20.	67.4(66.0-69.8)	9.4(8.6-12.5)	5.7	16.9(16.9-17.6)	99.4	0.65	0.17	0.18	1.00	1.00	B	4
21.	67.9	8.8	5.7	16.8	99.2	0.66	0.16	0.18	1.00	1.00	B	4
22.	55.8	19.7	5.7	18.5	99.7	0.50	0.32	0.17	0.99	1.01	B	4
23.	68.1	8.5	5.6	16.7	98.9	0.67	0.15	0.18	1.00	1.00	B	4
24.	55.3(52.9-56.6)	21.4(19 9-22.3)	5.2(5.0-5.2)	18.5(18.2-18.8)	100.4	0.49	0.35	0.16	1.00	1.00	B	4
25.	49.9	26.3	5.2	19.2	100.6	0.43	0.41	0.15	0.99	1.01	B	4
26.	53.0	23.4	5.3	18.0	99.7	0.48	0.38	0.16	1.02	0.98	B	2
27.	59.8(57.4-60.8)	17.6(16.7-19.9)	5.2(4.9-5.5)	17.6(17.3-17.8)	100.2	0.55	0.30	0.16	1.01	0.99	B	2
28.	53.1	23.9	5.5	18.4	100.9	0.47	0.39	0.16	1.02	0.98	B	2
29.	51.7	24.5	5.6	18.4	100.2	0.46	0.39	0.16	1.01	0.99	B	2
30.	52.7	23.9	5.5	18.3	100.4	0.47	0.39	0.16	1.02	0.98	B	2

TABLE 2 - Continued

	Weight percent					Formula					Mineral*	Sample**
	Pt	Pd	Ni	S	Total	Pt	Pd	Ni	ΣM	S		
31.	14.9(11.6-17.7)	54.4(53.0-58.0)	6.8(6.0-9.5)	23.1(22.8-23.2)	99.2	0.11	0.72	0.16	0.99	1.01	V?	1
32.	12.1(11.1-13.0)	57.4(56.7-53.6)	6.0	23.3(23.0-23.4)	98.8	0.09	0.75	0.14	0.98	1.02	V	1
33.	83.2	0.73	2.3	14.7	100.93	0.92	0.02	0.08	1.02	0.98	C	2
34.	80.7	3.4	1.1	15.6	106.8	0.87	0.07	0.04	0.98	1.02	C	2
35.	63.3(58.4-68.3)	14.6(9.8-19.5)	4.6	17.3(16.9-18.7)	100.3	0.59	0.25	0.14	0.98	1.02	B	6
36.	60.9	16.6	4.2	18.0	99.7	0.57	0.28	0.13	0.98	1.02	B	6
37.	63.0(59.2-66.8)	14.7(10.7-18.7)	4.6	18.2(17.7-18.7)	100.5	0.58	0.25	0.14	0.97	1.03	B	6
38.	12.6(9.1-14.4)	57.1(54.8-59.6)	6.6	23.0	99.3	0.09	0.75	0.16	1.00	1.00	V	7
39.	0.28	67.5	8.4	24.9	101.08	0.01	0.81	0.18	1.00	1.00	V	7
40.	8.2(7.5-9.1)	59.3(58.3-60.6)	8.9	23.9	100.3	0.06	0.74	0.20	1.00	1.00	V	7
41.	33.0(27.7-43.8)	39.6(31.5-41.9)	4.6(3.8-5.5)	20.8	98.0	0.27	0.59	0.12	0.98	1.02	B	7
42.	4.2(3.6-4.9)	58.6(57.5-59.7)	11.7(10.2-12.5)	24.9	99.4	0.03	0.71	0.26	1.00	1.00	V	7
43.	12.0(10.6-13.2)	58.9(58.0-61.0)	5.7	23.1	99.7	0.09	0.77	0.13	0.99	1.01	V	7
44.	3.4(2.5-4.6)	60.1(57.1-62.0)	12.1	25.3	100.9	0.02	0.72	0.26	1.00	1.00	V	7
45.	4.3	65.7	5.3	23.7	99.0	0.03	0.84	0.12	0.99	1.01	V	7
46.	5.0(1.6-9.6)	60.0(56.1-62.7)	9.3(7.5-10.4)	24.4	98.7	0.03	0.75	0.21	0.99	1.01	V	7
47.	54.9	26.2	2.8	18.6	102.5	0.49	0.43	0.08	1.00	1.00	B	7
48.	58 (56.2-59.9)	19.9(18.8-20.8)	3.2(2.9-3.6)	18.3	99.8	0.54	0.33	0.10	0.97	1.03	B	7
Anal.	49 to 53, taken from Brynard et al (1976)											
Anal.	54 to 64, taken from Schwellnus et al (1976)											
65.	54.3(51.8-56.6)	22.7(20.5-24.2)	6.3	18.9	102.2	0.47	0.36	0.18	1.01	0.99	B	8
66.	58.9(57.4-61.0)	18.5(17.7-19.3)	6.1	17.9	101.4	0.53	0.31	0.18	1.02	0.98	B	8
67.	60.4(57.0-61.4)	17.9(16.5-19.4)	5.5	18.0	101.8	0.55	0.30	0.16	1.01	0.99	B	8
68.	61.4(60.4-62.9)	16.3(15.4-17.5)	6.0	17.9	101.6	0.56	0.27	0.18	1.01	0.99	B	8
69.	57.2(54.3-61.2)	19.3(17.1-21.1)	6.6	18.0	101.1	0.51	0.32	0.19	1.02	0.98	B	8
70.	52.6(48.5-55.6)	23.8(22.0-25.8)	6.7	19.0	102.1	0.45	0.37	0.19	1.01	0.99	B	8
71.	65.6(59.8-69.8)	14.2(11.5-18.7)	4.7	16.7	101.2	0.63	0.25	0.15	1.03	0.97	B	8
72.	55.0(53.4-56.9)	21.7(20.1-23.2)	6.2	18.2	101.1	0.49	0.35	0.18	1.02	0.98	B	8
73.	83.5	1.4	0.64	14.2	99.74***	0.96	0.03	0.02	1.01	0.99	C	9
74.	44.1	31.1	4.8	19.9	99.9***	0.37	0.48	0.13	0.98	1.02	B	9
75.	64.6	13.5	3.9	17.1	99.1***	0.63	0.24	0.12	0.99	1.01	B	9
76.	2.0	69.5	3.9	23.7	99.1***	0.01	0.89	0.09	0.99	1.01	V	10
77.	45.4(39.0-49.1)	30.0(26.5-36.0)	4.7	19.6(19.1-20.5)	99.7	0.39	0.47	0.13	0.99	1.01	B	9