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SUDBURYITE, A NEW PALLADIUM-ANTIMONY MINERAL FROM SUDBURY, ONTARIO *

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ABSTRACT

Sudburyite is a newly discovered and characterized mineral with the ideal composition PdSb. Compositions, obtained by microprobe analysis, range from near the end-member PdSb to nickeloan varieties. The mineral is hexagonal with the unit cell *a* 4.06(2), *c* 5.59(2)Å. A pattern free of impurity lines could not be obtained for the mineral. The strongest lines on the *x*-ray powder pattern of synthetic PdSb are 2.98(7), 2.18(10), 2.03(7), 1.202(8), 0.9006(7), 0.8237(9), and 0.7790(10).

Sudburyite occurs as small, often elongated, inclusions (18 x 100 microns or less), most frequently in cobaltite or maucherite. Under reflected light, in air, for compositions nearest PdSb, it is white with a yellow tint, shows no bireflectance, and is weakly to moderately anisotropic; in oil, it is pale yellow, shows no bireflectance, and is moderately anisotropic, with colours light greyish yellow and dark greyish brown. For compositions richer in nickel, it is distinctly pale to light yellow and the anisotropism is moderate to distinct. Reflectances were measured for four grains with different compositions. Single micro-indentation hardness measurements on two grains gave $VHN_{25} = 281$ and $VHN_{25} = 311$.

An analysis is recorded of nickel-bearing antimonian michenerite that contains the highest antimony content so far reported for this mineral.

INTRODUCTION

The new mineral sudburyite was discovered during a detailed study of the mineralogy and distribution of the platinum-group elements (PG-elements) in the Sudbury area deposits. Earlier studies have shown that palladium is present in at least four minerals — palladian melonite, $(Ni,Pd,Pt)(Te,Bi)_2$; (Rucklidge 1969); michenerite, PdBiTe; froodite, $PdBi_2$; and unnamed mineral Pd(Te,Sb,Bi) (Cabri *et al.* 1973). Sudburyite is but one of several other palladium-bearing minerals present in these ores (Cabri 1974) and more extensive data will be reported on completion of detailed studies. The name sudburyite and the mineral data were approved by the Commission on New Minerals and Mineral Names, IMA. A polished section containing sudburyite is preserved in the Royal Ontario Museum (M32841).

MATERIAL AND METHOD OF INVESTIGATION

Sudburyite was first observed in a sample from the Frood mine, but the grain was too small for complete characterization. A sample from the Copper Cliff South mine contained numerous and larger grains of this mineral, and has permitted characterization of the new species. The Copper Cliff South mine is a newly developed mine of The International Nickel Company Ltd. along the Copper Cliff offset, south of the Creighton fault. The grains were concentrated by making gravity separations of sized fractions with separatory funnels (2.96 liquid) and with an elutriating tube (3.33 liquid). The samples were mounted in cold-setting plastic, polished on lead laps, and lightly buffed on a cloth lap using minus 0.05-μ alumina. The reflectance values were obtained with reference to a silicon standard N 2538.42 calibrated by the National Physical Laboratory, United Kingdom, using a 16.5:1 objective of 0.40 numerical aperture on areas varying between six and ten microns square. The micro-indentation hardness was measured with a Leitz Durimet tester. X-ray diffraction powder data were obtained by the film method using 57.3 and 114.6-mm Gandolfi and Debye-Scherrer cameras. Film shrinkage corrections were applied and the unit-cell parameters were refined by a least-squares computer program PARAM (Stewart *et al.* 1972) (using 26 and 14 reflections for synthetic PdSb and sudburyite, respectively).

The compositions were determined using a Materials Analysis Company Model 400 electron probe microanalyser, operated at 25 kv and with a specimen current of about 0.03 micro-amperes. The following *x*-ray lines and standards were used: Pd$L\alpha$, Sb$L\alpha$ (synthetic PdSb); Pd$L\alpha$, Bi$L\alpha$, Te$L\alpha$ (synthetic PdBiTe); As$K\alpha$ (synthetic Pd_5As_2); Ni$K\alpha$ (pure metal.) Corrections

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to these *x*-ray data were applied with the EMPADR VII computer program of Rucklidge & Gasparrini (1969). PdSb was synthesized by direct combination of the elements; by heating this polycrystalline material above the melting point, followed by slow cooling using the Bridgman method, a single-crystal boule was also produced.

Optical, Physical and Chemical Properties

Sudburyite

Under reflected light, in air, for compositions nearest PdSb, sudburyite is white with a yellow tint, shows no bireflectance and is weakly to moderately anisotropic. Under oil immersion the mineral is pale yellow in colour, shows no bireflectance, and is moderately anisotropic, with colours light greyish yellow and dark greyish brown. For the more Ni-rich compositions, sudburyite is distinctly pale to light yellow and the anisotropism varies, under oil, from moderate to distinct. The grain having the most Ni-rich composition (Analysis 6) had a distinct brownish cast and it is not certain if this grain has the sudburyite structure.

Reflectance measurements were made on four grains at the standard wavelengths 470, 546, 589, and 650 nm, but the values obtained at 650 nm will not be reported because they are not considered reliable. The very small area on which the reflectance was measured unduly influences the relatively low signal to the photosensing tube for that wavelength. The mean and range of four separate reflectance measurements are reported in Table 1. *Rg'* is larger for the more Ni-poor compositions but the effect of the other minor elements, if any, is unknown. Only two successful micro-indentation hardness measurements were made. One was for the grain whose composition is given as Analysis No. 5 (Table 2) where $VHN_{25} = 281$, and the other (Analysis No. 8, Table 2) had $VHN_{25} = 311$. This suggests that the Ni-content may affect the VHN

TABLE 1. REFLECTANCE MEASUREMENTS ON SUDBURYITE, IN AIR

Anal. No.	Pd:Ni	470 nm Rp'	470 nm Rg'	546 nm Rp'	546 nm Rg'	589 nm Rp'	589 nm Rg'
4	0.91:0.09	55.1 (54.4-55.8)	59.8 (58.9-60.5)	58.0 (57.0-59.5)	62.8 (62.3-63.7)	60.1 (59.1-61.5)	65.4 (64.5-66.7)
8	0.72:0.28	54.4 (53.3-55.7)	57.7 (56.1-59.8)	56.2 (55.2-57.1)	59.7 (58.0-61.4)	57.9 (57.1-58.8)	61.7 (60.5-63.7)
3	0.71:0.29	55.9 (54.8-57.1)	57.5 (56.8-58.7)	59.2 (58.1-59.9)	60.7 (59.9-61.1)	61.5 (60.5-62.3)	62.7 (61.7-63.3)
6	0.63:0.37	53.5 (53.1-54.1)	58.8 (58.4-59.4)	55.4 (54.6-56.7)	59.9 (58.4-61.0)	57.6 (56.2-59.6)	62.3 (60.8-63.8)

TABLE 2. ELECTRON MICROPROBE ANALYSES OF SUDBURYITE AND MICHENERITE

Mineral*, dimensions & association**	Elements Weight Per cent: Pd	Ni	Sb	Bi	Te	As	Total	Atomic Proportions: Pd	Ni	Σ	Sb	Bi	Te	As	Σ
1. 33x38μm co,cp,ga	45.2 (44.8-45.5)	1.06 (1.02-1.12)	52.8 (52.4-53.2)	0.53	0.07	2.04	101.70	0.96	0.04	*1.00*	0.98	0.01	0.002	0.06	*1.05*
2. 33x38μm mau,cp,ga	36.1 (35.6-36.7)	7.6 (7.1-7.9)	55.5 (55.4-55.7)	0.77	0.79	0.71	101.47	0.72	0.28	*1.00*	0.97	0.01	0.01	0.02	*1.01*
3. 18x100μm mau	36.1 (35.5-36.8)	8.0 (7.7-8.1)	55.2 (54.5-55.7)	0.60	0.82	1.06	101.78	0.71	0.29	*1.00*	0.95	0.01	0.01	0.03	*1.00*
4. 27x70μm co,br,cp	41.9 (41.2-42.9)	2.18 (1.96-2.43)	49.6 (48.5-51.2)	5.4	0.14	0.03	99.25	0.91	0.09	*1.00*	0.95	0.06	0.002	----	*1.012*
5. 27x27μm mau,ga	34.8 (33.7-35.0)	8.7 (8.2-9.2)	56.2 (56.0-56.5)	0.84	0.68	0.96	102.18	0.69	0.31	*1.00*	0.97	0.01	0.01	0.03	*1.02*
6. 25x88μm co,br	31.1 (29.2-33.2)	10.3 (8.7-11.6)	57.7 (56.5-59.3)	0.75	1.13	0.62	101.60	0.63	0.37	*1.00*	1.01	0.01	0.02	0.02	*1.06*
7. 25x88μm co,br	40.8 (40.6-40.9)	3.2 (3.1-3.5)	51.3 (51.0-52.1)	4.5	0.12	0.52	100.44	0.88	0.12	*1.00*	0.96	0.05	0.002	0.02	*1.032*
8. 38x38μm mau	35.5 (34.4-36.4)	7.8 (6.9-8.4)	55.5 (55.2-55.9)	0.76	0.84	0.80	101.20	0.72	0.28	*1.00*	0.98	0.01	0.01	0.02	*1.02*
9. 12x24μm ni,co	44.4***	0.53	45.3	3.3	3.9	1.88	99.31	0.98	0.02	*1.00*	0.87	0.04	0.07	0.06	*1.04*
10. 21x32μm co	44.4***	0.48	49.6	3.2	0.17	0.88	98.73	0.98	0.02	*1.00*	0.96	0.03	0.002	0.03	*1.02*
11. 28x32μm cp	23.8***	0.6	5.4	39.1	29.9	----	98.80	0.95	0.05	*1.00*	0.19	0.80	1.00	----	*1.99*

* Nos. 1-10 are sudburyite, except possibly for No. 6 (see text), No. 11 is michenerite.
** Abreviations employed: co=cobaltite, cp=chalcopyrite, ga=galena, mau=maucherite, br=breithauptite, ni=nickeline.
*** No significant variation observed for any element.

values but the paucity of data does not permit any firm conclusion.

Sudburyite occurs as small, often elongated, inclusions which are found most frequently in cobaltite or maucherite. (Fig. 1). It is also associated with breithauptite, galena, nickeline, and chalcopyrite (Fig. 2). Other minerals present in the sample were pentlandite, pyrrhotite and michenerite. The longest grain was 18 × 100 microns and the smallest were one micron or less in diameter.

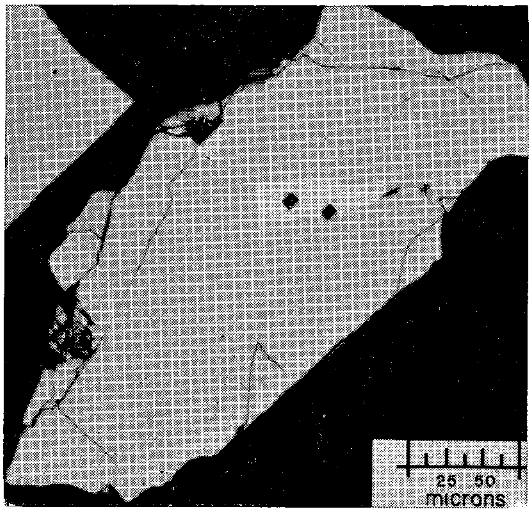

FIG. 1. Typical elongated inclusion of sudburyite (white), with two micro-indentations, in maucherite. The smaller sudburyite inclusion, near the edge of the maucherite, fractured on making a micro-indentation test.

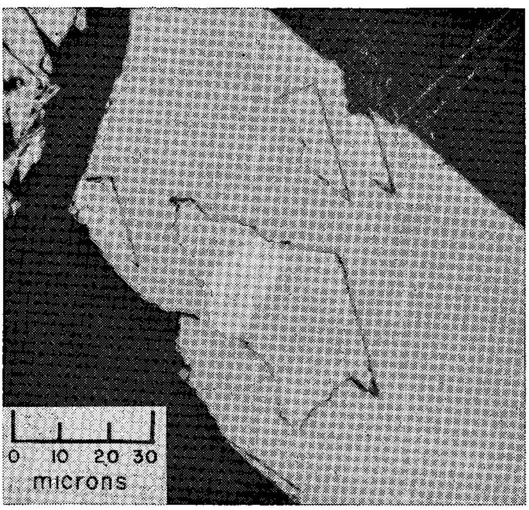

FIG. 2. Cobaltite with inclusions of nickeline containing an inclusion of sudburyite (white). The composition of this sudburyite grain is given as Analysis No. 9.

Ten microprobe analyses of sudburyite are reported in Table 2; each analysis was obtained from five to six spot analyses per element. Of the ten analyses listed, it is not certain that Analysis No. 6 is of a phase with the sudburyite structure. This grain has the highest nickel content and is distinctly brownish when compared to the closely associated sudburyite with less nickel (Analysis No. 7). The intergrowth of these two phases is shown in Figure 3. The range of compositions between the lowest nickel-bearing composition (Analysis No. 10) and that of nickeloan sudburyite may be expressed as $(Pd_{0.98}Ni_{0.02})$ $(Sb_{0.96}Bi_{0.03}As_{0.03})_{\Sigma=1.02}$ to $(Pd_{0.63}Ni_{0.37})$ $(Sb_{1.01}Bi_{0.01}As_{0.02}Te_{0.02})_{\Sigma=1.06}$. Because the analyzed grains invariably occurred as inclusions in arsenic-rich minerals and because the mole sum of Sb+Bi+Te+As is above 1.00 for nine of the ten analyses, it was considered possible that some of the arsenic content was due to the host mineral. A re-consideration of the operating conditions and procedures employed during analysis have led the authors to believe that the bulk of the arsenic detected is not due to the host mineral but must be present in the sudburyite grains themselves.

Three grains (Analyses 1, 3 and 4) were removed for *x*-ray powder diffraction but all gave powder patterns contaminated by the host mineral(s). A maucherite grain containing numerous sudburyite inclusions was then extracted from a polished section and treated with nitric acid to

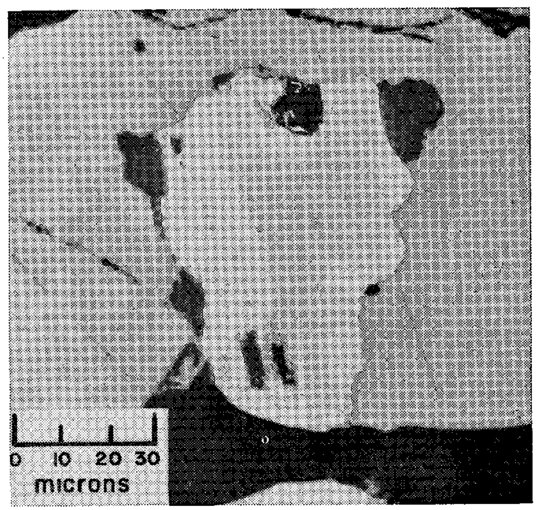

FIG. 3. Twinned cobaltite with a complex inclusion. The white area is sudburyite having a relatively low Ni content (Analysis No. 7), and the enclosed darker phase is sudburyite(?) with the high Ni content (Analysis No. 6). The darker areas near the sudburyite-cobaltite boundary are breithauptite. Partly crossed nicols.

dissolve the maucherite. After washing and drying, the residue of small particles was mounted on a glass fibre and *x*-rayed using a Gandolfi camera. The results in Table 3 show that the sample still contained impurities of both maucherite and cobaltite, as well as a third, but unknown, impurity which has a fairly strong reflection at 3.21Å. It is, therefore, difficult to make use of the strongest reflections in characterizing the *x*-ray pattern because of superposition of some reflections by those of the impurities.

Thomassen (1928) proposed that PdSb has the hexagonal NiAs structure and this was confirmed by Pratt *et al.* (1968) who gave unit-cell dimensions *a* 4.076(1) *c* 5.591(1). The unit-cell of sudburyite was successfully indexed with dimensions *a* 4.06(2) *c* 5.59(2), which compare favourably with the unit-cell that we obtained for synthetic PdSb *a* 4.079(3) *c* 5.587(3) and with the values reported by Thomassen and Pratt *et al.* The symmetry for synthetic PdSb was also confirmed by the precession method. The *x*-ray powder pattern data for synthetic PdSb are given in Table 3 for comparison with sudburyite and also because the data are not listed in the 1972 Inorganic Powder Diffraction file of the J.C.P.D.S. The measured density of synthetic PdSb is 9.37 g/cm³. For Z=2, the calculated density of synthetic PdSb is 9.41 g/cm³.

TABLE 3. *X*-RAY DIFFRACTION DATA FOR SUDBURYITE AND SYNTHETIC PdSb

Sudburyite[1] *a*=4.06(2) *c*=5.59(2)				Synthetic PdSb[2] *a*=4.079(3) *c*=5.587(3)		
I	*d*(meas.)	*d*(calc.)	*hkl*	*I*	*d*(meas.)	*d*(calc.)
			100	2	3.5	3.53
5	3.21	?				
3	2.96	2.979	101	7	2.98	2.985
8*	2.72					
2**	2.51					
1*	2.37					
1/2**	2.26					
5	2.16	2.190	102	10	2.18	2.191
10*	2.03	2.032	110	7	2.03	2.039
1*	1.95					
2*	1.90					
4	1.75	1.759	200	1	1.76	1.766
2*	1.70					
1**	1.67	1.678	201	4	1.68	1.684
1/2	1.65	1.644	103,112	4	1.64	1.647
1*	1.63					
1/2**	1.54					
1/2	1.491	1.489	202	6	1.489	1.492
1*	1.446					
1/2	1.381	1.399	004	3	1.397	1.397
			120	2	1.331	1.335
			104,121	5	1.296	1.298
			203	3	1.280	1.281
4*	1.206	1.201	122	8	1.202	1.204
1	1.180	1.173	300	4	1.175	1.177
			114,301	6	1.152	1.152
1*	1.129					
1*	1.108					
			204	1/2	1.092	1.095
2	1.081	1.082	123,302	4	1.083	1.085
1	1.066	1.066	105	3	1.065	1.065
			220	3	1.017	1.019
			205	3	0.943	0.944
			312	5	0.9235	0.9245
			106,304	7	0.9006	0.9004
			401	3	0.8715	0.8723
			313	4	0.8669	0.8671
			215	4	0.8571	0.8569
			402	5	0.8413	0.8421
			206,224	9	0.8237	0.8237
			314,321	6	0.8014	0.8020
			403,007	4	0.7993	0.7981
			107,322	10	0.7790	0.7785

1. 57.3 mm Gandolfi camera, Co radiation, Fe filter.
2. 114.6 mm Debye-Scherrer camera, Cu radiation, Ni filter.
* maucherite
** cobaltite

Michenerite

Michenerite was recently redefined from the type area as PdBiTe (Cabri *et al.* 1973), and was shown to contain nil to 3.3 wt% Sb replacing Bi. The analysis listed in Table 2 is of the only grain of michenerite found in this sample and is notable for its higher Sb content, as well as being the first recorded instance of a nickel-bearing variety. The formula corresponds to $(Pd_{0.95}Ni_{0.05})(Bi_{0.80}Sb_{0.19})Te_{1.00}$; this grain may be described as nickel-bearing antimonian michenerite

Summary

Sudburyite is characterized as a new mineral species with ideal end member PdSb and has hexagonal symmetry with the NiAs structure. Nickel replaces the palladium in amounts up to about 8.7 wt%, possibly even 10.3 wt%, and appears to influence the reflectance. The compositional variations may also influence VHN values. Minor amounts of bismuth, arsenic, and tellurium replace the antimony. Sudburyite occurs as inclusions in either sulpharsenides or arsenides, and is also closely associated with breithauptite, galena, nickeline, and chalcopyrite.

Although we do not present quantitative data, this is the first report of the occurrence of breithauptite in the Sudbury ores. The first analysis of a nickel-bearing antimonian michenerite is also recorded.

Acknowledgments

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