NEW LEAD SULFANTIMONIDES FROM MADOC, ONTARIO. PART 2—MINERAL DESCRIPTIONS

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ABSTRACT

Launayite, playfairite, sterryite, twinnite, guettardite, and sorbyite are new lead sulfantimonides from Madoc, Ontario. An additional sulfosalt, designated mineral QM, may be identical to Coleman's (1953) mineral Q from Yellowknife, N.W.T. The new minerals are associated with boulangerite, jamesonite, antimonian baumhauerite (Sb:As = ~1:1), zinckenite, semseyite, geocronite, robinsonite, and a few other sulfides and sulfosalts.

INTRODUCTION

In Part 1 (*Can. Mineral.* **9**, pt. 1, pp. 7–24) the geological occurrence of the Madoc sulfosalts and the methods used to determine their compositions were outlined, and two of the new minerals were described. Descriptions of the remainder of the new sulfosalts[1] and their associated minerals are given in the present article. The concluding paper (Part 3) will consist of remarks on the paragenesis, possible mode of origin of the Madoc minerals, and brief notes on the synthesis of some Pb-Sb-As sulfosalts.

Optical Properties

Data on polarization colours of the new Madoc sulfosalts are lacking in the descriptions given below. The correct determination of this property is discussed by Bowie & Taylor (1958), but the writer has unfortunately been unable to duplicate their data on known sulfosalts. The colours given in Part 1 for madocite and veenite will thus probably require revision. All the new sulfosalts described below have strong anisotropism, but the citing of polarization data must be deferred.

LAUNAYITE

Launayite is named in honour of L. de Launay in recognition of his contributions in the nineteenth century concerning the origin of mineral deposits.

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[1] The names have been approved by the I.M.A. Commission on New Minerals and Mineral Names.

Crystallography

Launayite is monoclinic, with the following cell dimensions:

d_{100} = 41.7 Å $\qquad a$ = 42.6 ± 0.8 Å
d_{010} = 4.02 × 2 $\qquad b = 2b'$ = 8.04 ± 0.05
d_{001} = 31.5 $\qquad c$ = 32.3 ± 0.6
β^* = 77°55′ $\qquad \beta$ = 102°05′ ± 45′

The *b*-dimension has been indicated above as being twice that of the pseudocell. Diffraction rows equivalent to $2b'$ are extremely weak and barely discernible. For the pseudocell, *hkl* diffraction spots appear only when the sum of *h* and *k* is even. The space group is therefore *C*2, *Cm*, or *C*2/*m* (Nos. 5, 8, or 12 respectively).

X-ray powder data for launayite are given in Table 1. The powder pattern is similar at first glance to that of cosalite, $2PbS \cdot Bi_2S_3$, but the analogous formula $2PbS \cdot Sb_2S_3$ is not compatible with any of the results obtained for launayite.

Because of the limited amount of material available and the possible presence of two perfect cleavages in launayite, the *x*-ray powder patterns

TABLE 1. LAUNAYITE: *X*-RAY POWDER DATA (Cu*K*α radiation).
Indexing based on pseudocell dimensions of a = 42.6, b' = 4.02, c = 32.2Å, β = 102°05′.

I (est)	*d* (meas)	*d* (calc),	*hkl*
<½	8.50 Å	8.67 Å	203
<½	7.84	7.87	004
<½	6.88	6.91,6.90	$\bar{6}02$,204
½	4.25	4.25,4.24	$\overline{10}$.0.2,605
8	4.17	4.18,4.17	$\overline{10}$.0.3,10.0.0
2	4.04	4.05,4.02	$\overline{10}$.0.4,$\bar{2}08$
3	3.97	3.98,3.97	804,$\bar{4}08$
2	3.87	3.87,3.86,3.86	$\overline{10}$.0.5,$\bar{3}11$,112
3	3.76	3.78,3.76	$\bar{6}08$,$\bar{1}13$
2	3.63	3.63,3.62,3.62	$\bar{5}11$,10.0.3,510
½	3.56	several possibilities	
<½	3.50	3.51,3.50	$\bar{8}08$,009
10	3.45	3.46,3.45	$\bar{5}12$,$\overline{12}$.0.4
6	3.40	3.41,3.41,3.40	$\bar{5}14$,$\bar{1}15$,10.0.4

I(est)	*d*(meas)	*I*(est)	*d*(meas)	*I*(est)	*d*(meas)	*I*(est)	*d*(meas)
2	3.34	5	2.752	½	2.187	<½	1.894
1	3.31	2	2.652	1	2.148	½B	1.872
<½	3.23	2	2.640	2	2.126	½	1.844
½	3.17	<½	2.610	1	2.095	1	1.809
1	3.10	<½	2.538		2.081	<½	1.796
2	3.01	1	2.495	1	2.048	<½	1.773
½	2.96	½	2.438	7	2.010	3B	1.729
8	2.92	2	2.319	<½	1.972	2	1.699
<½	2.874	2	2.280	<½	1.954	2B	1.657
5	2.836	½	2.228	½	1.936	1	1.635
2	2.787		2.222	1	1.913		

which have been obtained are not of very good quality. The data listed are therefore a composite of measurements obtained from both 57 mm and 114 mm films.

Properties

Launayite has been observed only in polished sections, where it occurs sparingly in association with veenite and boulangerite. Launayite dug out from polished sections tends to be somewhat fibrous, the elongation being [010]. The fibrous habit results from intersecting perfect {100} and {001} cleavages. The colour of the mineral is metallic lead-grey and the streak black.

In reflected light, launayite is fairly strongly pleochroic from white to grey. The maximum and minimum reflectivity percentages at λ470, 546, 589, and 650μ are, respectively, 46.2–38.6, 43.8–36.9, 42.7–36.2, 40.9–35.5. The Talmage hardness was estimated to be C; the mean Vickers hardness with a 50 gram load is 179 (171–197). Indentations are square and are accompanied by star radial and cleavage fractures. KOH gives a light brown tarnish which is characteristic and serves to distinguish launayite from all other Madoc sulfosalts. The remainder of the standard etch tests are negative except for 1:1 HNO_3, which rapidly tarnishes launayite iridescent, then black.

Chemistry and density

Microprobe analyses of two grains of launayite are given in Table 2. The results agree well with $9PbS \cdot 5Sb_2S_3$, but this formula requires $Z = 5$ for $D = 5.80$. A more satisfactory formula is $22PbS \cdot 13Sb_2S_3$, which with $Z = 2$ (pseudocell) yields a calculated density of 5.83 as compared to the determinative curve value of 5.75 for this composition.

TABLE 2. LAUNAYITE: MICROPROBE ANALYSES AND THEORETICAL COMPOSITION
Analyst: G. R. Lachance

	Analyses wt. %			Atomic ratio (average)		Proportions	Ideal wt. %
	1	2	Av.				
Pb	48.5	48.5	48.5	0.2341		22	47.09
Sb	30	29	29.5	0.2423	0.2623	24.7	32.70
As	1.5	1.5	1.5	0.0200			
S	21.5	21	21.25	0.6627		62.3	20.21
	101.5	100.0	100.75				100.00

Analytical formula: $22PbS \cdot 13(Sb,As)_{1.90}S_{3.10}$
Idealized formula: $22PbS \cdot 13Sb_2S_3$

PLAYFAIRITE

Playfairite is named in honour of John Playfair (1748–1819), author of "Illustrations of the Huttonian Theory of the Earth".

Crystallography

Two fragements taken from a polished section yielded the following cell dimensions: a = 45.4 ± 0.5 Å, $b = 2b'$ = 8.29 ± 0.06, c = 21.3 ± 0.5, β = 92°30′ ± 30′. The only systematic extinction is $0k0$ with $k = 2n$, and even this is tentative because only two orders of $(0k0)$ can be recorded on precession films with copper radiation. The space group of the playfairite pseudocell is $P2$, Pm, or $P2/m$ if $k \neq 2n$, and $P2_1$ or $P2_1/m$ if $k = 2n$. The indexed x-ray powder pattern is given in Table 3.

Properties

Playfairite has been observed in a number of polished sections, always in very small amounts. The mineral characteristically occurs at the peri-

TABLE 3. PLAYFAIRITE: X-RAY POWDER DATA, 114.6 mm camera, Cu$K\alpha$ radiation. Indexed with a = 45.4, b' = 4.14, c = 21.3 Å, β = 92°30′.

I(est)	d(meas)	d(calc),	hkl
$<\frac{1}{2}$	12.0Å	12.08Å	301
$<\frac{1}{2}$	11.3	11.34	400
$<\frac{1}{2}$	9.9	10.19,9.83	$\bar{4}01,401$
$<\frac{1}{2}$	8.6	8.53	302
$<\frac{1}{2}$	8.0	7.93	$\bar{4}02$
$\frac{1}{2}$	7.5	7.60,7.56	402,600
1	7.02	7.06,7.06,7.03	$\bar{5}02,\bar{1}03,601$
$<\frac{1}{2}$	6.32	6.32	303
$<\frac{1}{2}$	6.14	6.14	$\bar{4}03$
$<\frac{1}{2}$	5.63	5.64	$\bar{7}02$
$<\frac{1}{2}$	5.35	5.32	004
$<\frac{1}{2}$	4.98	4.95,4.95	$\bar{9}01,304$
$<\frac{1}{2}$	4.71	4.74,4.68,4.68	$404,703,\bar{5}04$
$<\frac{1}{2}$	4.50	4.53,4.50,4.48	$\bar{8}03,504,902$
2	4.22	4.24,4.22,4.22	$\overline{10}.0.2,105,\bar{2}05$
2	4.10	4.11,4.08	$10.0.2,\overline{11}.0.1$
4	3.98	3.99,3.99,3.97	211,310,804

I(est)	d(meas)	I(est)	d(meas)	I(est)	d(meas)	I(est)	d(meas)
1	3.88	3	2.92	$<\frac{1}{2}$	2.277	$<\frac{1}{2}$	1.886
3	3.77	3	2.865	$<\frac{1}{2}$	2.247	1	1.868
3	3.66	7	2.785	$\frac{1}{2}$	2.228	1	1.822
$\frac{1}{2}$	3.59	$<\frac{1}{2}$	2.710	$<\frac{1}{2}$	2.202	2	1.785
4	3.49	1	2.646	2	2.172	4	1.768
10	3.39	1	2.578	2	2.133	$<\frac{1}{2}$	1.747
10	3.32	1	2.522	6	2.086	1	1.727
$\frac{1}{2}$	3.26	$\frac{1}{2}$	2.422	$<\frac{1}{2}$	2.049	1	1.705
$<\frac{1}{2}$	3.19	$<\frac{1}{2}$	2.417	$\frac{1}{2}$	2.028	1	1.687
3	3.14	$<\frac{1}{2}$	2.365	3	1.973	2	1.666
$\frac{1}{2}$	3.03	$\frac{1}{2}$	2.340	$\frac{1}{2}$	1.942		
4	2.97	$\frac{1}{2}$	2.309	$\frac{1}{2}$	1.926		

pheries of other sulfosalt grains, particularly boulangerite, and commonly extends into these minerals in the form of irregular microscopic veinlets.

In addition to its occurrence in polished sections, one loose grain of playfairite was found in the material collected in 1924. The fragment, a tabular crystal heavily striated parallel to its elongation, proved to be a multiple which also contained an additional sulfosalt contaminant. The elongation direction was nevertheless shown by Weissenberg photographs to be along the 8.3 Å axis.

Small fragments of playfairite are metallic lead-grey to black in colour and have a black streak. A perfect {100} cleavage is present. The Talmage hardness was estimated as $B+$ to $C-$ and the measured Vickers hardness was a 50 gram load is 154 (150–171). In polished sections, playfairite shows strong reflection pleochroism from white to brownish grey.

Twin lamellae on a very fine scale were observed in several grains. The maximum and minimum reflectivities obtained at the four standard wavelengths are 42.3–38.3 ($\lambda = 470$), 40.3–63.4, 39.2–35.4, 37.7–34.0 ($\lambda = 650$). Playfairite is negative to standard etch reagents except for KOH and 1:1 HNO_3, both of which rapidly tarnish the mineral iridescent. The iridescent tarnish obtained with KOH, the characteristic brownish grey pleochroism, and the frequent occurrence of playfairite at the margins of other Pb-Sb sulfosalts were found to be useful features for detecting the mineral in Madoc specimens.

Chemistry and density

Microprobe analyses of three grains of playfairite from different polished sections are given in Table 4. The $PbS:Sb_2S_3$ analytical ratio is close to 2:1 and the Sb:As ratio close to 8:1. The pseudocell dimensions yield a cell volume of 4,004 Å^3. For $11PbS \cdot 6Sb_2S_3$, the calculated and predicted densities are 5.81 and 5.83 respectively, but the formula requires $Z = 3$. A more satisfactory unit cell content of 4 formula weights in the true cell

TABLE 4. PLAYFAIRITE: MICROPROBE ANALYSES AND THEORETICAL COMPOSITION
Analyst: G. R. Lachance

	Analyses wt. %						
	1	2	3	Average	Atomic ratios	Proportions	Ideal wt. %
Pb	53	49	51	51.0	0.2461	16	48.15
Sb	28	28	28	28.0	0.2300	17.04	31.83
As	2	1	4	2.4	0.0320		
S	16.5	20	20	18.8	0.5863	38.11	20.02
	99.5	98	103	100.2			100.00

Analytical formula: $16PbS \cdot 9(Sb,As)_{1.89}S_{2.46}$
Idealized formula: $16PbS \cdot 9(Sb,As)_2S_3$

is obtained with the composition $16PbS \cdot 9Sb_2S_3$. The calculated and predicted densities are 5.72 and 5.80 respectively.

STERRYITE

Sterryite is named in honour of T. Sterry Hunt (1826–1892), first mineralogist with the Geological Survey of Canada.

Crystallography

Sterryite is orthorhombic, with $a = 28.4 \pm 0.5$ Å, $b = 42.6 \pm 0.6$, $c = 2c' = 8.20 \pm 0.05$. As is indicated above, the 4 Å pseudoperiod present in the other Madoc sulfosalts is also present in sterryite. On Weissenberg and precession photographs, all orders of $hk0$ and hkl are present. The following systematic extinctions are present in the pseudocell: $h0l$, $h = 2n$, and $0kl$, $k = 2n$. The space group of the pseudocell is therefore $Pba2$ (No. 32) or $Pbam$ (No. 55). Indexed x-ray powder data are given in Table 5.

Properties

Sterryite is rare, but has been found both in polished sections and as loose fragments. In the sections, sterryite has been observed as needle-like laths which cut veenite parallel to its direction of polysynthetic twinning, and as single anhedral grains also associated with veenite. Sterryite has not been observed in contact with any other minerals. Loose fragments are plumose and characteristically occur as bundles of fibres. No other mineral at Madoc has this habit.

The small fragments of sterryite available are black in colour and streak. X-ray examination of plumose material shows that c is the direction of elongation, and at least one perfect cleavage is parallel to it. The Talmage hardness is B. In polished section sterryite is white, with strong reflection pleochroism from white to grey. Very fine lamellar twinning was observed in one grain. The maximum and minimum reflectivity percentages obtained from two grains are similar to those of other Madoc sulfosalts; at the four standard wavelengths the values are 40.4–37.6 ($\lambda = 470$), 38.7–36.0, 37.7–35.1, 36.3–33.9 ($\lambda = 650$). Sterryite does not react with standard etch reagents up to, and including, 1:1 HNO_3. The lack of reaction with nitric acid is suspect because the test could not be made without interference from the associated violently reactive carbonate matrix.

Chemistry

Microprobe analyses of sterryite from two polished sections are given in Table 6. The summation of the analyses is low in both cases, the results

TABLE 5. STERRYITE: *X*-RAY POWDER DATA, Cu$K\alpha$ radiation, 114.6 mm camera. Indexed with $a = 28.4$, $b = 42.6$, $c' = 4.10$ Å

I(est)	*d*(meas)	*d*(calc)	*hkl*
2	11.77 Å	11.82 Å	220
<½	10.69	10.65	040
<½	8.64	8.65	320
<½	8.20	8.16	150
<½	7.94	7.88	330
3	7.11	7.10,7.10,7.08	060,400,340
<½	6.38	6.35,6.35	264,430
½	5.96	5.95	170
<½	5.29	5.27	530
<½	4.98	4.99	280
1	4.72	4.73,4.73,4.70	600,550,610
1	4.50	4.49,4.49	290,630
½	4.34	4.33	640
2	4.26	4.26,4.26	0.10.0,480
5	4.14	4.14	650
½	4.08	4.08	2.10.0
5	3.94	3.94,3.94	201,490
9	3.68	3.69,3.66,3.66	241,151,750
4	3.63	3.64	331
6	3.54	several possibilities	
2	3.45	3.44,3.44,3.44	261,830,351
2	3.37	3.38,3.37	171,840
10	3.26	3.26,3.25	1.13.0,081

I(est)	*d*(meas)	*I*(est)	*d*(meas)	*I*(est)	*d*(meas)	*I*(est)	*d*(meas)
½	3.19	2	2.778	½	2.435	2	2.183
2	3.09	3	2.732	½	2.415	3	2.142
5	3.03	2B	2.684	½	2.370	½	2.126
6	2.965	2B	2.622	6	2.353	6	2.049
3	2.913	<½	2.516	½	2.260	2	2.020
7	2.836	<½	2.487	1	2.232		

from plumose loose fragments mounted in polished sections being both low and erratic because of physical destruction by the electron beam. However, optical spectrographic analyses of sterryite gave no indications that any additional major or minor elements are present in the mineral.

In the microprobe determinations, antimony, arsenic, and sulfur generally gave consistent results whereas lead values were somewhat erratic. The uncorrected analytical values (Table 6) give a formula close to $7PbS\cdot4(Sb,As)_2S_3$. With Sb:As = 12:5 and $Z = 6$, the formula gives a calculated density of 5.85 as compared to the predicted value of approximately 5.67. The agreement is not unreasonable in view of the extensive Sb-As solid solution present; less satisfactory is the requirement of six formula weights in the cell. The writer thus prefers to tentatively assign to sterryite the formula $12PbS\cdot5(Sb,As)_2S_3$ which with $Z = 4$ (pseudocell) yields a calculated density of 5.91 as compared to the predicted value of about 6.00.

TABLE 6. STERRYITE: MICROPROBE ANALYSES
Analyst: G. R. Lachance

	Analyses	Atomic ratios	Proportions	
Pb	44.5%	0.2148	1	
Ag	<0.5			
Cu	tr			
Sb	21	0.1725	0.0831	1.145
As	5.5	0.0734	0.3417	
S	21.5	0.6705	3.1215	
	92.5			
Pb	47%	0.2268	1	
Sb	23	0.1889	0.8329	1.186
As	6	0.0801	0.3532	
S	20.5	0.6393	2.8188	
	96.5			

Formula from average of above: $7PbS \cdot 4(Sb,As)_{2.04}S_{3.45}$

Analytical and tentative idealized composition of sterryite:

	Average Analysis	$12PbS \cdot 5(Sb,As)_2S_3$ with Sb:As = 12:5
Pb	45.74%	56.10%
Sb	22	19.39
As	5.75	4.97
S	21	19.54
	94.50	100.00

TWINNITE

Twinnite is named in honour of the late R. M. Thompson, professor of mineralogy in the University of British Columbia. The appellation Thompson is "son of Thomas", the latter being Aramaic, "a twin". The name twinnite is not inappropriate in that it also alludes to the polysynthetic twinning present in both the Madoc mineral and sartorite, its arsenic analogue. Although of simple composition, sartorite ($PbAs_2S_4$) is a crystallographically complex mineral that has been plagued with nomenclature problems. Both these aspects have been reviewed in detail by Nowacki *et al.* (1961) and need not be repeated here.

Crystallography

Single crystal studies of natural sartorite from Binnental, Switzerland, have been carried out by Bannister *et al.* (1939), Berry (1940), Nowacki *et al.* (1961, 1964), and Iitaka & Nowacki (1961). Synthetic material has been examined by Rösch & Hellner (1959). Comparison of the results obtained by the various authors (Table 7) shows that, while there is general agreement regarding the pseudocell dimensions, the true cell is

Table 7. Sartorite: Unit Cell as Reported by Various Authors

	Bannister *et al.* (1939)	Berry (1940)	Nowacki *et al.* (1961)	Rösch & Hellner (1959)		Twinnite, Madoc
a'	19.46 Å	19.52 Å	19.62 Å	19.46 Å	19.4 Å	19.6 Å
b'	7.79	4.16	7.89	4.17	4.15	7.99
c'	4.17	7.88	4.19	7.79	7.82	4.30
$a =$	$3a'$	$4a'$	$3a'$	a'	a'	a'
$b =$	b'	$20b'$	b'	b'	$2b'$	b'
$c =$	$20c'$	c'	$11c'$	c'	c'	$2c'$
pseudocell space group	$P2_12_12_1$	$P2_12_12_1$	$Pbmm$	$P2_12_12_1$	$P2_12_12_1$	

considerably more complex and probably varies from specimen to specimen. This is also borne out in the statement by Nowacki *et al.* (1964) that the "normal 3 × 11 superstructure" is not always present.

For twinnite from Madoc, Weissenberg and precession photographs about the three axes of several fragments yielded $a = 19.6 \pm 0.2$, $b = 7.99 \pm 0.05$, $c = 2c' = 8.60 \pm 0.05$ Å, $\alpha = \beta = \gamma = 90°$. Indexed *x*-ray powder data are given in Table 8.

Unlike most of the Madoc sulfosalts, the supercell diffraction rows in twinnite are of moderate rather than weak intensity on rotation photographs, and hence the diffraction aspects of the true cell were examined. Twinnite proved to be no less complex than sartorite; the symmetry of the true cell appears to be triclinic, but there are strong systematic pseudo-extinctions of $h00$, $0k0$, $00l$, and $0kl$, where h, k and $l \neq 2n$ and $k + l \neq 2n$. The pseudo-space group is thus $Pnmn$. The last three extinction conditions are destroyed by the appearance of only a few, extremely weak, and easily overlooked diffraction spots; the condition $h00 = 2n$ is found to hold for all of the films available.

Properties

Twinnite is rare at Madoc, only two megascopic grains, the larger about 1.5 mm in diameter, and four microscopic grains having been found. Fragments appear metallic black and have a black streak with a slight brownish tint observable on powder smeared on a white background. The mineral grains observed are polysynthetically twinned, the trace of the composition plane being parallel to {100} as in sartorite. A perfect {100} cleavage is also present. Twinnite is brittle, less so than sartorite, but much more so than most other lead sulfantimonides. In polished section, twinnite is white. The reflection pleochroism is strong and twin lamellae are readily seen upon rotation of the microscope stage. The maximum and minimum reflectivity percentages obtained at the four standard

Table 8. Twinnite: *X*-ray Powder Data, 114.6 mm camera, Cu$K\alpha$ radiation. Indexing based on true cell, $a = 19.56$, $b = 7.98$, $c = 8.57$ Å

I(est)	*d*(meas)	*d*(calc)	*hkl*
4	9.8 Å	9.78 Å	200
<½	7.3	7.39	110
<½	6.5	6.45	201
1	6.18	6.18	210
½	5.89	5.84	011
1	5.56	5.60	111
½	5.20	5.19	301
1	4.90	4.89	400
<½	4.37	4.35	311
5	4.18	4.19,4.17	102,410
2	3.99	3.99	020
5	3.91	3.91	120
½	3.74	3.75	411
3	3.70	3.71,3.70	112,220
2	3.59	3.58	302
1	3.56	3.56,3.56	501,121
10	3.51	3.52,3.51	212,510
2	3.41	3.40,3.39	320,221
½	3.29	3.27	312
3	3.26	3.26,3.25	600,511
3	3.09	3.09	420
4	3.01	3.02	610
1	2.98	2.99	412
1	2.90	2.91,2.89,2.89	421,502,122
<½	2.86	2.85	611
4	2.83	2.83	103
7	2.78	2.79	520
5	2.689	2.690	013
5	2.645	2.637,2.636	710,130
½	2.567	2.576	230
1	2.529	2.524	620

I(est)	*d*(meas)	*I*(est)	*d*(meas)	*I*(est)	*d*(meas)	*I*(est)	*d*(meas)
<½	2.478	4	2.087	2	1.851	1	1.575
½	2.468	1	2.037	2	1.828	2	1.551
8	2.344	<½	2.014	1B	1.794	1	1.501
<½	2.309	1	1.987	2	1.755	½	1.475
<½	2.292	1	1.975	2	1.738	1	1.448
½	2.264	½	1.956	½	1.707	1	1.421
2	2.244	1	1.949	1B	1.681	½	1.402
½	2.225	½	1.931	½	1.651	<½	1.370
½	2.189	2	1.910	1B	1.633	½	1.354
5	2.154	1	1.886		1.622	2	1.330
1	2.127	2	1.873	½	1.599		

wavelengths are 45.6–38.7 (λ = 470), 43.0–36.9, 41.6–35.9, 39.6–34.6 (λ = 650). The Talmage hardness was estimated as *B*, and the mean Vickers hardness with a 50 gram load is 147 (131–152). Indentations are straight or concave. Cleavage dislocation planes are commonly present and are occasionally accompanied by cleavage fractures.

KOH rapidly tarnishes twinnite iridescent and leaves a characteristic flat brownish grey colour when the reagent is rubbed off. Other standard etch tests are negative except for 1:1 HNO_3, which rapidly tarnishes the mineral black.

Chemistry and density

A microprobe analysis of twinnite is given in Table 9. The results are in fair agreement with the idealized formula, $PbS \cdot (Sb,As)_2S_3$. Taking $Sb{:}As$ as 3:2, *M* is 541.5, *V* is 1,351 Å^3, and thus D/Z is 0.6654. With $Z=8$ the calculated density is 5.323, in good agreement with the predicted value of about 5.26.

TABLE 9. TWINNITE: MICROPROBE ANALYSIS
Analyst: G. R. Lachance

	Analysis	Atomic ratios	Proportions	
Pb	41%	0.1979	1	
Sb	28	0.2300	1.162	1.90
As	11	0.1468	0.742	
S	23	0.7173	3.625	
	103			

Analytical formula: $PbS \cdot (Sb,As)_{1.9}S_{2.62}$ with $Sb{:}As = 3{:}2$
Idealized formula: $PbS \cdot (Sb,As)_2S_3$

GUETTARDITE

Guettardite is named in honour of Jean Etienne Guettard (1715–1786), French geologist. An approximate English pronunciation of the name is gay-taar-ite.

Crystallography

Guettardite typically occurs as isolated anhedral grains; no euhedral or subhedral crystals have been found. The following cell dimensions were obtained from Weissenberg and precession photographs:

$d_{100} = 19.7$ Å $\qquad a = 20.0 \pm 0.4$ Å
$d_{010} = 7.94 \qquad b = 7.94 \pm 0.03$
$d_{001} = 8.54 \qquad c = 8.72 \pm 0.06$
$\beta^* = 78°25' \pm 30' \qquad \beta = 101°35' \pm 30'$

Diffraction spots appear for $h00$ and $h0l$ only when h is even, and for $0k0$ only when k is even. The space group of guettardite is thus $P2_1/a$ (No. 14). Measurements obtained from the *x*-ray powder pattern of guettardite are given in Table 10. The patterns superficially resemble that of twinnite and sartorite, particularly in the stronger lines at low diffraction angles. This similarity also extends to the single crystal photographs, the dimensions of the a^*b^* nets of twinnite and guettardite being virtually identical.

TABLE 10. GUETTARDITE: *X*-RAY POWDER DATA, 114.6 mm camera, Cu$K\alpha$ radiation. Indexed with a = 20.17, b = 7.94, c = 8.72 Å, β = 101°35′

I(est)	d(meas)	d(calc)	hkl
3	9.89 Å	9.88 Å	200
<½	7.41	7.37	110
1	6.20	6.19	210
1	5.82	5.80	$\bar{1}11$
1	5.33	5.34	$\bar{2}11$
1	4.93	4.94	400
½	4.68	4.68	$\bar{3}11$
5	4.19	4.19	410
1	3.97	3.97,3.95	020,401
5	3.90	3.89	120
3	3.69	3.68	220
2	3.60	3.61,3.60	$\bar{4}02,\bar{1}21$
10	3.52	3.54,3.53	510,411
1	3.40	3.40	320
1	3.27	3.29,3.29,3.29	221,600,$\bar{4}12$
2	3.25	3.28	$\bar{3}21$
3	3.10	3.09,3.08	420,$\bar{5}11$
½	3.04	several possibilities	
1	3.00	3.00	$\bar{5}12$
3	2.97	2.95	402
1	2.912	2.908,2.905	022,$\bar{6}02$
9	2.795	2.806,2.801,2.799	$\bar{3}22$,520,421
5	2.670	2.671	422
5	2.653	2.660	710

I(est)	d(meas)	I(est)	d(meas)	I(est)	d(meas)	I(est)	d(meas)
½	2.561	½	2.195	1	1.911	1	1.751
1	2.531	4	2.136	1	1.866	1	1.737
1	2.475	2	2.063	1	1.871	1	1.688
½	2.456	<½	2.050	1	1.844	1	1.669
<½	2.405	½	2.013	1	1.832	1	1.654
3	2.357	½	1.979	1	1.816	1	1.637
4	2.334	1	1.961	1	1.798	<½	1.603
1	2.318	2	1.950	½	1.776	½	1.571
2	2.238	1	1.928	1	1.761	1	1.544

The close relationship of the two minerals is also evident on the a^*c^* plane. In twinnite, a rectangular lattice array 19 × 8.5 Å is formed whereas in guettardite the same array requires a (2 × 19) × 8.5 Å period.

Properties

In its appearance and properties guettardite is very similar to twinnite. Guettardite is very brittle and tends to spray fragments when scratched with a needle under the microscope. The megascopic colour is metallic greyish black; under the binocular microscope, small fragments are black. The streak is also black, with a brown tint appearing on material smeared on a white background. For practical purposes guettardite is opaque, but a slight reddish internal reflection is observable in minute fragments under a very strong light. Nearly all guettardite observed is polysynthetically twinned, the twin units having sharply-defined contacts as in veenite, twinnite, and baumhauerite. The composition plane is parallel to {100}. The mineral has perfect cleavage and a conchoidal fracture.

In polished section, guettardite is white. The reflection pleochroism in air is relatively strong so that adjacent twin units are readily seen upon rotation of the microscope stage. The maximum and minimum reflectivity percentages obtained at the four standard wavelengths are as follows: 44.2–36.3 ($\lambda = 470$), 42.0–34.8, 40.8–34.0, 39.0–32.2 ($\lambda = 650$). The Talmage hardness was estimated as *B* whereas the mean Vickers hardness with a 50 gram load is 187 (180–197). Indentations are square and are accompanied by star radial and side radial fractures.

HNO_3 tarnishes guettardite black. KOH tarnishes it iridescent, leaving the flat brownish grey colour as was also mentioned for twinnite. Reactions with other standard reagents are negative.

Chemistry and density

Microprobe analyses of two grains of guettardite are given in Table 11. The analyses correspond to $6PbS \cdot 5(Sb,As)_2S_3$, with Sb:As ~ 10:9. Antimonian baumhauerite, which is discussed in a later section, gave

TABLE 11. GUETTARDITE: MICROPROBE ANALYSES AND THEORETICAL COMPOSITION
Analyst: G. R. Lachance

		Analysis	Atomic ratios	Proportions
1.	Pb	44.5%	0.2148	9
	Sb	22	0.1807	14.56
	As	12	0.1669	
	S	21.5	0.6705	28.10
		100.5		Sb:As = 100:92
2.	Pb	43.5%	0.2099	9
	Sb	22	0.1807	14.62
	As	12	0.1602	
	S	20.5	0.6393	27.41
		98		Sb:As = 100:89

Formula from 1: $9PbS \cdot 8(Sb,As)_{1.82}S_{2.39}$
Formula from 2: $9PbS \cdot 8(Sb,As)_{1.83}S_{2.30}$

Analytical and idealized composition of guettardite:

	Average Analysis	$9PbS \cdot 8(Sb,As)_2S_3$ with Sb:As = 10:9
Pb	44.0%	41.30%
Sb	22.0	22.70
As	12.25	12.57
S	21.0	23.43
	99.25	100.00

Sb:As $\sim$ 1:1 and hence was not named. In guettardite, however, additional partial analyses consistently indicate that Sb > As, and hence the name is proposed for the antimony-rich rather than the arsenic members of a presumed solid solution series. Although guettardite is similar to some of the Pb-As sulfosalts from Binnental, its arsenic analogue has apparently not been found among the Swiss minerals.

As indicated above, the analytical formula gives a ratio of $PbS/(Sb,As)_2S_3$ of about 1.2. The proportion of antimony and arsenic relative to lead is thus very high, and small Sb:As variations will therefore have a large effect on the density. From the sulfantimonide and sulfarsenide determinative curves, however, the lead content of guettardite indicates that its density should be in the neighbourhood of 5.3 to 5.4. The cell volume of guettardite is 1364 Å^3, and for $6PbS \cdot 5(Sb,As)_2S_3$ reasonable densities are not obtained. However, for $9PbS \cdot 8(Sb,As)_2S_3$ with $Z = 1$ and Sb:As = 10:9, the calculated density is 5.49. The predicted value for the pure antimony end-member is 5.44, but the presence of substantial arsenic in the natural mineral lowers the predicted value to 5.31. While not altogether satisfactory, the agreement is considered to be acceptable. The deviation may reflect a departure from the stoichiometry of the proposed ideal formula.

SORBYITE

Sorbyite is named in honour of Henry Clifton Sorby (1826–1908), the founder of metallography.

Crystallography

Several fragments have been examined by Weissenberg and precession methods. The following unit cell parameters were obtained:

$d_{100} = 41.2$ Å	$a = 44.9 \pm 0.5$ Å
$d_{010} = 8.28$	$b = 2b' = 8.28 \pm 0.1$ Å
$d_{001} = 24.2$	$c = 26.4 \pm 0.5$ Å
$\beta^* = 66°35'$	$\beta = 113°25' \pm 30'$

In the pseudocell, *hkl* reflections are present only when the sum of *h* and *k* is even. The space group is therefore *C*2, *Cm*, or *C*2/*m* (Nos. 5, 8, or 12 respectively).

Properties

Several loose crystal fragments of sorbyite were found among the material collected in 1924. The crystals are equant to thin tabular {100}, always elongate [010], and commonly heavily striated [010]. A perfect {001} cleavage is present. Measurable terminal faces are not present, but one crystal has a pyramidal face (*A*) which intersects a smaller pyramidal or domatic face (*B*). Measured on {100}, the interior angles of intersection are A $\wedge$ B = $\sim$ 117°, A $\wedge$ (001) = $\sim$ 127°, B $\wedge$ (001) = $\sim$ 115°. Only crude goniometric data could be obtained from the best formed of the crystals. The measurements obtained from an elongate prism are given in Table 12. All signals were blurred and most were multiple. The crystal consisted of three principal segments and reflected light as though it were curved. In cases where no signal was obtained, ordinary reflection was used to bring the face into approximate position. The angular values in Table 12 are thus very crude, but they serve to show the magnitude of form development in sorbyite.

TABLE 12. GONIOMETRIC DATA FOR THE ZONE [010] ON SORBYITE

Face	Description	Φ	Possible Miller Index
1	broad, flat	00°00′	100
2	broad, flat	66°49′	001
3	very narrow	86°30′–89°*	109(?)
4	moderate size	117°18′	$\bar{1}01$
5	narrow	144°35′	$\bar{7}01$(?)
6	broad, flat	181°33′	$\bar{1}00$
7	moderate size	217°*	$\bar{1}0\bar{1}$
8	broad, flat	247°35′	$00\bar{1}$
9	very narrow	272°*	$\bar{1}0\bar{9}$(?)
10	moderate size	297°43′	$10\bar{1}$
11	very narrow	327°*	$70\bar{1}$(?)

*No signal.

The available small fragments of sorbyite are metallic black under the binocular microscope, but massive material is undoubtedly lead-grey. The streak is black.

In polished section, sorbyite is white, with irregular twin lamellae which differ markedly from the sharp, parallel units present in veenite, twinnite, and guettardite. The reflection pleochroism of sorbyite is relatively strong; twin units can be seen only with difficulty, but grain boundaries are readily apparent. Reflectivity percentages decrease from λ 470 to λ 650 mm as follows: 45–39, 43–37, 41–36, 40–34. The mean Vickers hardness with a 50 gram load is 175 (172–186). The predominantly square indentations are accompanied by star, side radial, and cleavage fractures, with the first type the most common. KOH tarnishes sorbyite brown to iridescent; 1:7 HNO_3 tarnishes it brown; and 1:1 HNO_3 tarnishes it iridescent to black.

Chemistry and density

Microprobe analyses of two grains of sorbyite are given in Table 13. The analytical values are close to 12 $PbS \cdot 7(Sb,As)_2S_3$, and Sb:As is about 3:1. The cell dimensions used to index the x-ray powder pattern (Table 14) yield a pseudocell volume of 4540 Å^3, and for the above analytical values, $D/Z = 1.859$. With $Z = 3$, the calculated and predicted densities are 5.58 and 5.67 respectively. A more plausible formula is $17PbS \cdot 11(Sb,As)_2S_3$; with $Z = 2$ the calculated density is 5.52 and the

TABLE 13. SORBYITE: MICROPROBE ANALYSES AND THEORETICAL COMPOSITION
Analyst: G. R. Lachance

	Analyses (wt. %)			Atomic ratios	Proportions	$17PbS \cdot 11(Sb,As)_2S_3$	
	1	2	Average	(Average)	(Average)	(Sb:As = 3:1)	
Pb	46	47	46.5	0.2244	17	Pb	46.68%
Sb	25	25.5	25.25	0.2074 }		Sb	26.62
As	6	5	5.5	0.0734 }	21.27	As	5.46
S	21	21.5	21.25	0.6627	50.20	S	21.24
	98	99.0	98.50				100.00

TABLE 14. SORBYITE: X-RAY POWDER DATA, 114.6 mm camera, Cu$K\alpha$ radiation
Indexed with $a = 45.1$, $b' = 4.14$, $c = 26.5$ Å, $\beta = 113°25'$

I(est)	d(meas)	d(calc)	hkl
2	11.1 Å	11.27 Å	$\bar{4}01$
$<\frac{1}{2}$	10.3	10.33,10.12	$400,\bar{4}02$
1	9.3	9.01	202
1	7.43	7.46	$\bar{6}01$
1	6.78	6.74	$\bar{6}03$
$\frac{1}{2}$	6.10	6.07	004
$<\frac{1}{2}$	5.52	5.52	$\bar{8}01$
$<\frac{1}{2}$	5.19	5.17,5.17	$602,800$
$<\frac{1}{2}$	4.44	4.44	603
$<\frac{1}{2}$	4.29	4.31	$\bar{2}06$
6	4.13	4.12	110
4	4.02	4.04	111
$<\frac{1}{2}$	3.82	3.83	$10.0.1$
2	3.72	3.73	803
3	3.64	3.65,3.62	$312,\bar{5}13$
1	3.52	3.51	$\bar{3}14$
10	3.44	3.45,3.42	$\bar{5}14,\bar{7}13$
9	3.38	3.39,3.38	$710,512$

I(est)	d(meas)	I(est)	d(meas)	I(est)	d(meas)	I(est)	d(meas)
1	3.29	$<\frac{1}{2}$	2.627	5	2.099	4	1.775
$<\frac{1}{2}$	3.19	$\frac{1}{2}$	2.579	1	2.021	1	1.753
1	3.12	1	2.545	2	1.993	2	1.718
4	3.04	$\frac{1}{2}$	2.420	1	1.967	1	1.692
6	2.96	$<\frac{1}{2}$	2.382	$<\frac{1}{2}$	1.937	1	1.675
3	2.882	2	2.349	2	1.920	1	1.615
1	2.820	3	2.301	2	1.894	1	1.589
3	2.777	1	2.258	$\frac{1}{2}$	1.882	$\frac{1}{2}$	1.556
2	2.732	3	2.192	1	1.846	$\frac{1}{2}$	1.527
1	2.696	$<\frac{1}{2}$	2.173	1	1.811		
3	2.658	1	2.151				

predicted value about 5.59. The analytical values correspond to $17PbS \cdot 11(Sb,As)_{1.93}S_{3.02}$.

MINERAL QM

The *x*-ray powder pattern of this mineral was first obtained by the writer in 1961 from a microscopic veinlet which cut jamesonite in the Madoc suite. No more of the mineral was found until 1966, when a new polished section was made of robinsonite from the Red Bird Mercury mine, Pershing County, Nevada, the specimen of type material having been kindly loaned to the writer by L. G. Berry. In the robinsonite section, mineral QM is present as a single grain less than half a millimeter in diameter which is intergrown with robinsonite and indistinguishable from it under the microscope. The *x*-ray powder pattern of a portion of the grain is identical to the pattern obtained from the Madoc mineral, (Table 15) and in addition, there is marked similarity to the data given in Berry & Thompson (1962) for the sulfosalt from Yellowknife which was

TABLE 15. *X*-RAY POWDER DATA FOR MINERALS Q AND QM; 57 mm camera, Cu*K*α radiation

Mineral Q (Berry & Thompson, 1962) *I*(est)	*d*(meas)	Mineral QM Madoc, Ontario *I*(est)	*d*(meas)
		5	4.11 Å
		2	3.94
		3	3.77
8	3.65 Å	5	3.64
10	3.35	10	3.38
		½	3.25
3	3.12	2	3.13
1	3.00	2	3.00
1	2.89	½	2.88
		4	2.84
6	2.79	6	2.80
		4	2.727
½	2.62	2	2.647
		½	2.510
		½	2.457
½	2.36	2	2.375
		1	2.258
1	2.23	2	2.223
		½	2.17
		½	2.13
3	2.05	3	2.063
		½	1.99
		½	1.93
2	1.881	3	1.888
½	1.797		
½	1.719	2	1.726
		1	1.695

designated only as mineral "Q" because of its incompletely known chemistry. The *x*-ray powder patterns of mineral Q are of poor quality and until its identity with the Madoc mineral can be proved, the latter has been temporarily named Mineral QM.

Microprobe analysis of mineral QM in the robinsonite specimen is given in Table 16. Because of the erroneous values which were obtained from the associated robinsonite, the reliability of the microprobe analysis for mineral QM is questionable. However, the density determinative curve could have been used had single crystal data been obtainable. In this connection, Coleman's (1953) cell dimensions for mineral Q yield a volume of 1,345 Å^3, and the Pb:Sb ratio from the microprobe analysis (Table 16) is about 11:12. With $Z = 1$, the formula $11PbS \cdot 6Sb_2S_3$ gives a calculated density of 5.76 as compared to the predicted value of 5.82 for this composition.

TABLE 16. MICROPROBE ANALYSES OF MINERAL QM AND ASSOCIATED ROBINSONITE FROM RED BIRD MERCURY MINE, NEVADA
Analyst: G. R. Lachance

	Mineral QM	Atomic ratios	Proportions
Pb	49.3%	0.2379	11
Sb	31.7	0.2603	12.03
S	20.7	0.6455	29.84
	101.3		

	Robinsonite by microbrobe	Theoretical robinsonite $7PbS \cdot 6Sb_2S_3$
Pb	45.5%	39.06%
Sb	35.4	39.35
S	20.5	21.59
	101.4	100.00

PREVIOUSLY KNOWN SULFOSALTS

Boulangerite

Boulangerite from Madoc is unusual in that in most cases the mineral is arsenian. As a result of the arsenic content, the lattice dimensions are sufficiently decreased that the effect is easily recognized on 57 mm films by direct comparison with normal boulangerites. In this connection, the diffraction line given by Berry & Thompson (1962) at θ(Cu) = 24.5°, intensity 8, is particularly useful as a reference line.

X-ray powder diffraction examination of several boulangerites from various localities showed that there are very slight varitions in cell dimensions from specimen to specimen. The variations also appear among ten synthetic boulangerites selected because of the good quality of their x-ray patterns. The cell size of the synthetic samples could not be correlated with the duration of the runs, or crystallization in the presence of water or arsenic. In the case of the Madoc boulangerites the correlation of cell size and arsenic content has been proved by microprobe analyses of four of the samples. Using long counting times in order to obtain more precise results, it was found that the two samples with normal cell dimensions contained zero per cent arsenic, whereas the remaining two samples with slightly smaller cell dimensions each contain two per cent arsenic.

Antimonian baumhauerite

Baumhauerite is an extremely rare mineral at Madoc, only a few microscopic grains having been found. X-ray powder patterns of the mineral are very similar to those of baumhauerite from Binnental, but in detail there are several differences as well as the Madoc patterns being contracted in the low 2θ region.

Microprobe analyses of Madoc baumhauerite are given in Table 17. The Sb:As ratio of one analysis is essentially 1:1, and probably correctly reflects the tenor of antimony in the mineral. However, the average antimony content of the microprobe analyses is less than that required for a Sb:As ratio of 1:1, and as there are no variations in the cell dimensions indicated in the x-ray powder patterns, a new name for this mineral is not necessary.

TABLE 17. MICROPROBE ANALYSES OF ANTIMONIAN BAUMHAUERITE FROM MADOC
Analyst: G. R. Lachance

	Wt. %	Atomic ratios	Proportions	
Pb	48	0.2317	1	
Sb	19	0.1560	0.6736	1.394
As	12.5	0.1669	0.7205	
S	21.5	0.6705	2.8945	
	101.00			
Pb	47.5	0.2292	1	
Sb	19.5	0.16015	0.6986	1.397
As	12	0.16019	0.6988	
S	21	0.6549	2.8568	
	100.00			

Formula from first analysis: $3PbS \cdot 2(As,Sb)_{2.09}S_{2.84}$ with As:Sb = 100:93
Formula from second analysis: $3PbS \cdot 2(As,Sb)_{2.10}S_{2.79}$ with As:Sb = 100:99.98

X-ray powder data for the Madoc variety of baumhauerite are given in Table 18. Single crystal examination of one fragment of the antimonian

TABLE 18. ANTIMONIAN BAUMHAUERITE FROM MADOC: X-RAY POWDER DATA
Obtained with filtered copper radiation, camera diameter 114.6 mm.
Indexing based on $a = 23.2$, $b = 8.33$, $c = 8.02$ Å, $\beta = 97°30'$

I(est)	d(meas)	d(calc)	hkl
1	7.75 Å	7.83 Å	110
1	7.21	7.23	101
½	6.87		
1	6.17	6.17	201
1	5.87	5.91	$\bar{3}01$
<½	5.63	5.63	310
<½	5.46	5.46	111
½	5.19	5.19	301
<½	4.59	4.59	500
2	4.41	4.41,4.39	311,401
4	4.20	4.22	$\bar{5}01$
6	4.10	4.10	120
1	3.94	3.92,3.92	$\bar{2}02$,220
5	3.87	3.88	411
2	3.69	3.69,3.68	021,$\bar{1}21$
4	3.61	3.61,3.61,3.61	202,$\bar{1}12$,121
2	3.57	3.59,3.58	012,$\bar{2}21$
7	3.41	3.43,3.41	511,$\bar{3}12$
3	3.40	3.40	$\bar{3}21$
7	3.29	3.28,3.28	601,700
1	3.25	3.25	321
10	3.18	3.19,3.18	$\bar{4}21$,$\bar{7}01$
4	3.09	3.08,3.08	402,520
4	3.03	3.05,3.02	710,421
8	2.96	2.97,2.96,2.96	$\bar{7}11$,$\bar{5}21$,$\bar{6}02$
2	2.92	2.90	701
½	2.87	2.88,2.87	022,800
4	2.82	2.83,2.82,2.82,2.82	502,122,$\bar{8}01$,620
6	2.76	2.78,2.76	$\bar{6}12$,130
4	2.73	2.74,2.74,2.73	$\bar{6}21$,711,222

I(est)	d(meas)	I(est)	d(meas)	I(est)	d(meas)	I(est)	d(meas)
<½	2.67	1	2.297	1	2.009	3B	1.775
<½	2.66	1	2.269	<½	1.968		1.764
½	2.625	5B	2.226	3	1.937	1	1.740
<½	2.578		2.214	½	1.920		1.726
2	2.524	1	2.177	4	1.872	2	1.701
½	2.466	8	2.090	3B	1.839		1.682
9	2.371	2	2.062		1.830	½	1.645
½	2.332	1	2.015	1	1.810	½	1.627

material dug out from polished section gave $d_{100} = 23.1 \pm 0.2$ Å, $d_{010} = 8.28 \pm 0.2$, $d_{001} = 7.88 \pm 0.1$. The above cell dimensions are very close to those given in Berry & Thompson (1962) for baumhauerite: $a = 22.74$, $b = 8.33$, $c = 7.89$ Å, $\beta = 97°25'$. The β-angle of antimonian baumhauerite is uncertain because of complications arising from polysynthetic twinning. The twinning is parallel to $\{100\}$ as in normal baumhauerite, and by analogy to baumhauerite the perfect cleavage present is also $\{100\}$.

Under a strong light, small fragments of the Madoc mineral show a deep red internal reflection which is a manifestation of the high arsenic content present. Likewise, the streak is brownish black rather than black.

Etching the mineral with HNO_3 gives a black tarnish, but at 1:1 concentrations the reaction is sometimes slow in starting. The only other standard etch reagent that gives a reaction is KOH. With it, an iridescent tarnish is produced and a smooth pale pink surface remains when the reagent is washed off. This colour is characteristic and has been found to be a most useful criterion for identifying antimonian baumhauerite in polished sections.

Robinsonite

Robinsonite was previously known only from the type locality, the Red Bird Mercury mine, Pershing County, Nevada. A small microscopic grain a fraction of a millimeter in diameter associated with jamesonite at Madoc constitutes the second occurrence of robinsonite. Microprobe analysis of this grain gave results differing from the theoretical lead and antimony contents required for the formula $7PbS \cdot 6Sb_2S_3$ which was derived by Berry *et al.* (1952) for robinsonite. A polished section of robinsonite type material kindly loaned to the writer by Berry was also analyzed by the microprobe technique. The results (Table 15) differ considerably from the theoretical requirements for $7PbS \cdot 6Sb_2S_3$, but are almost exactly equivalent to $3PbS \cdot 2Sb_2S_3$. Using the cell dimensions given by Berry *et al.* (1952), the unit cell volume is 1,141 Å^3, and with this value no formula which approximates the analytical results and gives a reasonable density could be found. In order to eliminate a possible source of error in the microprobe determinations, some of Berry's material was mounted in the polished section containing the mineral standards. The probe results were consistently reproducible and gave the aforementioned high lead and low antimony results. The reason for this is not known.

Jamesonite, semseyite, and geocronite

Jamesonite is one of the most abundant of the Madoc sulfosalts, being particularly common as disseminated grains in marble surrounding the main pit. None of the properties of the Madoc jamesonite is unusual except that the mineral is slightly cuprian. Microprobe analyses have shown that the normal tenor of iron is present, and about 0.1 per cent of the element has been replaced by copper. Arsenic has not been detected in any of the Madoc jamesonites examined by microprobe, and this is in agreement with the fact that the mineral appears to have normal unit cell dimensions.

Semseyite was not present in the original (1924) Madoc material, but has proved to be rather common in fresh exposures in the enlarged pit. The mineral generally occurs in very coarse-grained calcite and imparts to it a characteristic dark grey colour.

Geocronite has also been found only in recently collected specimens. *X*-ray powder patterns of the mineral are not quite identical to natural jordanite or synthetic geocronite; in Part 1, therefore, the identification was considered to be tentative. However, an incomplete single crystal *x*-ray study of twinned material indicates that the identification is probably correct.

Zinckenite

Zinckenite is rare at Madoc, only a few microscopic grains having been observed in polished sections. Although zinckenite has long been known to be amenable to arsenic uptake, *x*-ray powder patterns of the Madoc material indicate that it contains little or no arsenic.

Supergene alteration products

Supergene minerals are not particularly prominent at Madoc. Most of the alteration consists of brownish limonitic residues after sphalerite, with lesser amounts of yellow Pb-Sb oxides on the sulfantimonides. Goethite, bindheimite, and traces of anglesite have been identified, but the yellow ochers have not been studied in detail. Green crusts on limonite and weathered marble specimens are predominantly malachite and zincian malachite, with some aurichalcite and rare brochantite and linarite.

Conclusions

At least nine new lead sulfantimonide minerals occur at Madoc, this number being greater than the sum of all previously known species in the system. It is felt, however, that the present study has by no means exhausted the mineralogical work and additional new minerals will undoubtedly be found.

The Madoc deposit is unique not only because of the great variety of sulfosalts present, but also because the minerals provide excellent examples of extensive As-Sb solid solution among lead sulfarsenides and sulfantimonides.

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Manuscript received June 20, 1967, emended August 10, 1967