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MINERALS FROM LEONA HEIGHTS, ALAMEDA CO., CALIFORNIA

BY

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INTRODUCTION.

A small body of pyrite occurs near Leona Heights, Alameda Co., Cal., containing some chalcopyrite, and the ore has been mined for a number of years for the manufacture of sulphuric acid. In consequence of the oxidation of the sulphides, several secondary sulphates of iron and copper have been formed in and about the mine, and specimens of these secondary minerals have been collected and studied by the writer. These natural vitriols occur in such good crystals that an interesting crystallographic study can be made of them. Our present crystallographic knowledge of these sulphates has been largely dependent on the study of artificial crystals.

All of the minerals found at this locality, with one exception, were identified with known species. These are Pyrite, Chalcopyrite, Copper, Melanterite, Pisanite, Chalcanthite, Copiapite, Epsomite, Hematite, Limonite and Alunogen (?). Besides these, a copper sulphate with seven parts of water, Boothite, to be described later, was also observed. Of these pyrite, melanterite, pisanite, chalcanthite and boothite occur in good measurable crystals. Copiapite occurs, to some extent, in crystals, but they are all microscopic.

The crystals were measured with the two-circle goniometer, except a very few fragments, which were broken in such a manner as to render their setting up in true polar position impossible. The forms on these fragments were, consequently, determined from measurement of the interfacial angles. While many of the faces gave excellent reflections, the ratios obtained from the two-circle readings were, with one exception, not considered as more accurate than those previously obtained. The one exception is pisanite, for which elements were calculated from the readings. These, it is thought, approximate more closely to the true elements than those which heretofore have been accepted for pisanite.

In the chemical analyses the iron was determined by titration with potassium permanganate, with occasional checks by weighing the iron as ferric oxide. The copper was determined by iodometric titration. The water was weighed directly in a

calcium chloride tube, fractional water determinations being usually made. It was found, by experiment, that all of the water of these sulphates was given off below 300° C.

PYRITE.

General Description.—The ore of the Alma Mine consists chiefly of massive pyrite intermixed with some chalcopyrite and usually carrying small values of gold and silver. Crystals of pyrite occur scattered through the rock, which is rhyolite, often largely decomposed to clay. The crystals described here, were collected some years ago at the opening of the mine by Mr. Fritz Böhmer, of Alameda, who kindly placed them at the disposal of the writer.

Crystallographic Characters.—On examination with the lens, the crystals, ranging up to 3 mm. in diameter, and even occasionally somewhat larger, were found to consist principally of the pyritohedron {120}, with occasionally the cube and the octohedron. The cube faces are invariably narrow and the octahedral faces triangular in shape, the latter varying in size up to about one-third the size of the pyritohedron {120}.

All of the larger crystals are more or less rounded and the faces uneven and often dented, always giving a large number of reflections. The ten forms below were definitely established and a few more possibly are present, but on account of the lack of sharpness of the signals, their identification is somewhat uncertain.

Letter.	Symbol.		Letter.	Symbol.	
	Gdt.	Miller.		Gdt.	Miller.
a	0∞	100	*o*	1	111
d	∞	110	ω	$1\frac{1}{2}$	252
δ	$\infty\frac{4}{3}$	340	*n*	12	121
e	$\infty 2$	120	*t*	24	241
h	$\infty 4$	140	*s*	23	231

The forms {100}, {110}, {340} and {140} occur as narrow and rounded faces. Of the other forms only {120} and {111} were well developed. The remainder were all small and the complete number of faces belonging to each form was not always present.

The following table shows the measurements together with the calculated angles for these forms.

No.	Letter.	Symbol. Gdt.	Symbol. Miller.	Measured. ϕ	Measured. ρ	Calculated. ϕ	Calculated. ρ
1	*a*	0∞	100	0°00′	90°00′	0°00′	90°00′
2	*d*	∞	110	44 54	"	45 00	"
3	δ	$\infty\frac{4}{3}$	340	37 01	"	36 52	"
4	*e*	$\infty 2$	120	26 30	"	26 34	"
5	*h*	$\infty 4$	140	14 12	"	14 02	"
6	*o*	1	111	45 12	54 45	45 00	54 44
7	ω	$1\frac{1}{2}$	252	46 36	29 31	"	29 30
				20 46	71 24	21 48	69 37
8	*n*	12	121	44 45	33 46	45 00	35 16
				26 28	66 10	26 34	65 54
9	*t*	24	241	14 20	64 52	14 02	64 07
				26 15	77 06	26 34	77 23
10	*s*	23	231	23 45	37 18	26 34	36 42
				18 38	57 44	18 26	57 41
				33 46	75 29	33 41	74 30

The combinations of forms on the measured crystals are shown in the following table:

Cryst. No.	*a*	*d*	δ	*e*	*h*	*o*	ω	*n*	*t*	*s*
1	*a*	—	—	*e*	—	*o*	—	*n*	—	—
2	*a*	—	—	*e*	*h*	*o*	—	*n*	—	*s*
3	*a*	*d*	δ	*e*	*h*	*o*	ω	*n*	*t*	*s*
4	*a*	—	—	*e*	—	*o*	ω	*n*	*t*	*s*
5	*a*	*d*	δ	*e*	—	*o*	ω	*n*	—	*s*

Chemical Properties.—Chemical tests showed that the crystals of pyrite contained no copper. The massive ore, however, gave a reaction for copper, which probably comes from the admixed chalcopyrite. Other elements, such as arsenic or thallium were not tested for.

CHALCOPYRITE.

Some portions of the massive ore show a sulphide having the color of chalcopyrite and affording a qualitative test for copper. No crystals of chalcopyrite were met with; neither were any large masses of pure chalcopyrite found.

COPPER.

Native copper occurs very sparingly in a shaft sunk some distance above the Alma Mine, as small arborescent groups consisting of irregularly grouped, distorted crystals, possibly octahedrons.

MELANTERITE.

General Description. — The ferrous sulphate, melanterite, occurs rather widely distributed as an efflorescence, but only in small quantities. In the mine it occurs as small prismatic crystals, up to 2 mm. in size. A pale green mineral, probably melanterite, occurs with a deposit of copiapite near the mine.

Crystallographic Characters.—One specimen of loose crystals of various minerals, collected in the mine, shows a few minute well-formed crystals of melanterite, elongated in the direction of the vertical axis and giving an extinction angle, with the direction of elongation, of about 20°. The crystals measured average in size about 2 mm. in length and $\frac{1}{3}$ mm. in thickness. Some of the crystals are well developed, the faces, especially the prism {110} and the base {001}, giving perfect reflections.

Fifteen forms, besides a few vicinal ones, were observed on the nine crystals measured. Of these seven are new. These forms are quoted below in two columns, those in the second column being the new forms:

Letter.	Symbol. Gdt.	Miller.	Letter.	Symbol. Gdt.	Miller.
c	0	001	*l*	$\infty 2$	120
b	0∞	010	*d*	$+\frac{1}{2}0$	102
m	∞	110	*k*	$+\frac{2}{3}0$	203
w	$+\frac{1}{3}0$	103	*x*	$+\frac{3}{2}0$	302
v	$+10$	101	*q*	$+20$	201
o	01	011	*j*	$+\frac{9}{1}0$	904
r	$+1$	111	*B*	$+\frac{3}{2}$	332
σ	-12	$\bar{1}21$			

The measured and calculated angles are given in the table below for the forms observed on these crystals.

No.	Letter.	Symbol.		Measured.		Calculated.	
		Gdt.	Miller.	ϕ	ρ	ϕ	ρ
1	c	0	001	89° 59′	14° 14′	90° 00′	14° 16′
2	b	0∞	010	0 00	90 00	0 00	90 00
3	m	∞	110	41 06	"	41 06	"
4	l	$\infty 2$	120	24 11	"	23 34	"
5	w	$+\frac{1}{3}0$	103	89 59	35 01	90 00	35 06
6	d	$+\frac{1}{2}0$	102	90 15	42 27	"	42 50
7	k	$+\frac{2}{3}0$	203	"	48 44	"	49 02
8	r	$+10$	101	89 49	58 22	"	58 00
9	x	$+\frac{3}{2}0$	302	90 15	66 18	"	66 15
10	q	$+20$	201	"	71 28	"	71 22
11	j	$+\frac{9}{4}0$	904	"	73 00	"	73 03
12	o	01	011	9 22	57 18	9 21	57 24
13	σ	-12	$\bar{1}21$	19 43	73 26	19 29	73 00

For the two forms $r = \{111\}$ and $B = \{332\}$, in the zone $c\ m$, the following interfacial angles were measured and calculated:

	Measured.	Calculated.
$c:r = (001) : (111) =$	55° 55′	55° 59′
$c:B = (001) : (332) =$	63° 13′	63° 13′

Of the seven new forms, five were positive orthodomes, occurring on one crystal. Each form gave a distinct signal so that the faces did not insensibly grade into one another.

$l = \infty 2 = \{120\}$. This new prism was present on two crystals as a fairly large form. The reflections, in both cases, were but fair.

$d = +\frac{1}{2}0 = \{102\}$. This dome was relatively a large face, about equal in size to $w = \{103\}$. The reflection was fair.

$k = +\frac{2}{3}0 = \{203\}$. This form was not quite as broad as the preceding dome.

$x = +\frac{3}{2}0 = \{302\}$. Two occurrences of this dome were noted, on crystal No. 5, as a very narrow face, and on crystal No. 8, as a broader face.

$q = +20 = \{201\}$. This form was a very narrow dome.

$j = +\frac{9}{4}0 = \{904\}$. This dome was also very narrow. The crystal on which these domes occurred was somewhat

bruised below this form, so that it is possible that another dome, large and triangular in shape, possibly {301}, was originally present.

$B = +\frac{3}{2} = \{332\}$. This pyramid was observed on two fragments. It gave good reflections.

Figs. 1–3, Plate 19, show some of the combinations observed on these crystals.

Besides these forms, given above, a few vicinal ones were observed on crystal No. 6, of which the symbols calculated from the measurements and the probable true symbols, are given below.

Calculated symbols.	Probable symbols.
{5.1.12}	{102}
{7.14.2}	{120}
{$\bar{6}$.12.5}	{$\bar{1}$21}

The habit of the crystals is prismatic with the unit prism and the base the predominating forms.

The following table shows the combinations of the forms on the crystals:

Cryst. No.	*c*	*b*	*m*	*l*	*w*	*d*	*k*	*r*	*x*	*q*	*j*	*o*	*r*	*B*	*σ*
1	*c*	—	*m*	—	—	—	—	—	—	—	—	—	—	—	—
2	*c*	—	*m*	—	—	—	—	—	—	—	—	—	*r*	*B*	—
3	*c*	*b*	*m*	—	—	—	—	—	—	—	—	*o*	—	—	—
4	*c*	—	*m*	—	—	—	—	—	—	—	—	—	—	—	—
5	*c*	—	*m*	—	*w*	*d*	*k*	*r*	*x*	*q*	*j*	—	—	—	—
6	*c*	*b*	*m*	*l*	*w*	—	—	—	—	—	—	—	—	—	*σ*
7	—	—	*m*	—	*w*	—	—	*r*	—	—	—	—	—	—	—
8	*c*	*b*	*m*	*l*	—	—	—	—	*x*	—	—	—	—	—	—
9	*c*	—	*m*	—	—	—	—	—	—	—	—	—	*r*	*B*	—

The axial ratio, $a:b:c = 1.1823 : 1 : 1.5421$; $\beta = 104° 14'$, was calculated from the three following measurements of interfacial angles, in preference to a calculation from the averages of p'_0, q'_0 and e', since the polar adjustment was not perfect.

$$c : m = (001) : (110) = 80° 42'$$
$$c : o = (001) : (011) = 56° 13'$$
$$m : m' = (110) : (1\bar{1}0) = 97° 47'$$

This ratio agrees very closely with the one obtained by Zepharovich,* which is

$$a : b : c = 1.1828 : 1 : 1.5427; \quad \beta = 104° 15\tfrac{1}{2}'.$$

* Zeitschr. Krys. 1880, 4, 107.

A calculation of the seven new forms to correspond to Goldschmidt's Winkeltabellen is given in the following table, based on the elements derived by Zepharovich:

Number.	Letter.	Gdt.	Miller.	ϕ	ρ	ξ_0	η_0	ξ	η	x' (Prism) ($x : y$)	y'	$d' = \text{tg}\,\rho$
1	*l*	$\infty 2$	120	23° 34′	90° 00′	90°00′	90°00′	23° 34′	66° 26′	0.4363	∞	∞
2	*d*	$+\frac{1}{0}$	102	90 00	42 50	42 50	0 00	42 50	0 00	0.9271	0	0.9271
3	*k*	$+\frac{3}{0}$	203	"	49 02	49 02	"	49 02	"	1.1515	"	1.1515
4	*x*	$+\frac{3}{2}0$	302	"	66 15	66 15	"	66 15	"	2.2732	"	2.2732
5	*q*	$+2\,0$	201	"	71 22	71 22	"	71 22	"	2.9666	"	2.9666
6	*j*	$+\frac{9}{1}0$	904	"	73 03·	73 03·	"	73 03·	"	3.2828	"	3.2828
7	*B*	$+\frac{3}{2}$	332	44 29·	72 52	66 15	66 38	42 02·	42 58·	2.2732	2.3141	3.2438

Physical Properties. — The determination of the optical properties gave results agreeing with those already determined. A cleavage piece (parallel to the base) showed, with convergent light, a biaxial interference figure, with a large angle. The trace of the axial plane was parallel to the trace of the clinopinacoid. Tests with the quartz wedge showed that this section was normal to an axis of maximum elasticity, that is, it gave a negative sign. As, however, the obtuse bisectrix emerges on the base, the mineral is positive with $Bx_a = c$, nearly parallel to the clino-axis.

The cleavage is basal, perfect. The mineral is colorless to very pale green. In its pyrognostic characters, it agrees well with those already ascribed to melanterite.

Chemical Properties.—Only a very small quantity of material could be collected for an analysis, which, in consequence, is only approximate and serves but to identify the mineral. It is worth noting that no magnesia could be detected. The analysis gave:

	Analysis.	Calc. for Melanterite.
FeO	28.1	25.9
SO_3	31.2	28.8
H_2O	42.0	45.3
CuO, MgO	none	
	101.3	100.0

This gives the formula, $FeSO_4+7\ H_2O$.

According to fractional water determinations, $\frac{6}{7}$ of the water is given off at a temperature of about 110°, while a temperature above 200° is necessary to drive off the remaining molecule. It would thus seem as if the last molecule might be considered as constitutional, only six molecules being water of crystallization. Following the suggestion of Prof. Remsen,* the structural formula for melanterite may be written,

$$OS\begin{matrix} O \\ O \end{matrix}\!>\!Fe\begin{matrix} O \\ O \end{matrix}\!>\!H_2 + 6\ H_2O.$$

PISANITE.

General Description.—The most abundant secondary mineral occurring in the mine is pisanite. Long prisms of this mineral are seen almost everywhere and large magnificent specimens are rather abundant, especially near the mouth of the northern tunnel. Unfortunately, on the slightest jarring most of the crystals readily detach themselves from the rock. Many of the crystals seem to have formed directly on the rock and were lying loose, unattached. Others again were feebly united to the rock, especially at one end of the prisms and these hung downward in large groups. No radial or other regular grouping of the crystals was observed. The specimens are quite free from other minerals, the conditions, at the time of formation of the crystals, seeming to have been just right for pisanite and not right for any other mineral.

The mineral probably crystallized out from a solution of iron and copper sulphates. Zonal structure, though common in the artificial crystals, was not observed in the natural ones. Inclusions of pyrite are not uncommon and drusy pyrite frequently covers the crystals to a large extent.

Crystallographic Characters.—The crystals average about 5 mm. in length and about 1 mm. in thickness. Many are much longer and the thickest one measured 3 mm. by 4 mm. on the base. Certain crystals of pisanite had been partially dissolved, the re-solution going on with a remarkable difference in

* Inorganic Chemistry, by Ira Remsen, 5th edition, 1898, pp, 218, 709.

rapidity in different directions. Many of the crystals are hollow, the inside being entirely dissolved away. Occasionally portions of the prism faces are also dissolved, leaving merely shells.

Hitherto, our knowledge of the crystallography of pisanite has been limited to the results obtained by Des Cloizeaux, who derived his elements from three interfacial angles. The method of measurement, with the two-circle goniometer is peculiarly well adapted for the determination of the axial elements since all of the readings can be used. From the average values of p'_0, q'_0 and e', and the readings on the prism faces, the following axial ratio was obtained by the writer:

$$a:b:c = 1.1670 : 1 : 1.5195;\ \beta = 105^\circ\ 11'.$$

The ratio does not vary much from that obtained by Des Cloizeaux, namely: $a:b:c = 1.1609:1:1.5110$; $\beta = 105^\circ\ 22'$, but is believed to be nearer the true one. The crystals were readily adjusted in true polar position, as usually all four of the prism faces were present and all gave excellent reflections.

In all, seventeen forms were observed, of which ten are new. These forms are given below in two columns, those in the second column being the new ones.

Letter.	Symbol. Gdt.	Miller.	Letter.	Symbol. Gdt.	Miller.
c	0	001	*a*	$\infty 0$	100
b	0∞	010	*h*	2∞	210
m	∞	110	*f*	$\frac{3}{2}\infty$	320
w	$+\frac{1}{2}0$	103	*l*	$\infty 2$	120
t	-10	$\bar{1}01$	*v*	$+10$	101
o	01	011	*g*	$-\frac{2}{5}0$	$\bar{2}05$
π	$-\frac{1}{2}$	$\bar{1}12$	*r*	$+1$	111
			E	$-\frac{3}{5}$	$\bar{3}35$
			D	-2	$\bar{2}21$
			σ	-12	$\bar{1}21$

The angles measured, together with those calculated from the elements obtained by the writer, for the forms, are given in the table below.

Number.	Letter.	Symbol.		Measured.				Calculated.			
		Gdt.	Miller.	ϕ		ρ		ϕ		ρ	
1	*c*	0	001	90°	00′	15°	11′	90°	00′	15°	11′
2	*b*	0∞	010	0	02	90	00	0	00	90	00
3	*a*	$\infty 0$	100	89	32	"		90	00	"	
4	*h*	2∞	210	60	25	"		60	37	"	
5	*f*	$\frac{3}{2}\infty$	320	53	26	"		53	06	"	
6	*m*	∞	110	41	36	"		41	36	"	
7	*l*	$\infty 2$	120	23	45	"		23	56	"	
8	*w*	$+\frac{1}{3}0$	103	90	00	36	00	90	00	35	48
9	*v*	$+10$	101	90	02	58	12	"		58	19
10	*g*	$-\frac{2}{5}0$	$\bar{2}05$	90	03	15	00	"		15	01
11	*t*	-10	$\bar{1}01$	90	02	47	13	"		47	09
12	*o*	01	011	10	28	57	03	10	07	57	04
13	*r*	$+1$	111	46	43	65	35	46	50	65	46
14	π	$-\frac{1}{2}$	$\bar{1}12$	27	22	40	21	27	57	40	42
15	*E*	$-\frac{3}{5}$	$\bar{3}35$	30	28	46	28	30	33	46	38
16	*D*	-2	$\bar{2}21$	39	04	75	25	38	37	75	35
17	σ	-12	$\bar{1}21$	19	40	72	25	19	32	72	46

The following are the new forms, briefly described:

$a = \infty 0 = \{100\}$. The orthopinacoid was noted twice, once as a broad face and once as a narrow face.

$h = 2\infty = \{210\}$. This prism was noted on three crystals, as rather large faces.

$f = \frac{3}{2}\infty = \{320\}$. On crystal No. 1 was noted a small face in the prism zone, the measurement of which agrees well with the calculated value, though the reflection was very poor.

$l = \infty 2 = \{120\}$. This prism always occurred with *h*, and was about equal to it in size. Crystal No. 15 showed the three new forms, *a*, *h* and *l*, in the prism zone.

$v = +10 = \{101\}$. Only once was this form noticed, as a small face with a poor reflection.

$g = -\frac{2}{5}0 = \{\bar{2}05\}$. This dome also occurred but once as a rather large face. It gave a good reflection.

$r = +1 = \{111\}$. The unit pyramid was represented by a long narrow face, giving a good reflection.

$E = -\frac{3}{5} = \{\bar{3}35\}$. This form was noted but once as a long narrow face. The face is in the zone $c\ m$.

$D = -2 = \{\bar{2}21\}$. This form occurs on two crystals. The reflections in both cases were fair.

$\sigma = -12 = \{\bar{1}21\}$. A small face represents this form.

The base and the unit prism are the predominating forms, the other forms being subordinate in size. The common habit is long prismatic. Most of the crystals show only the two forms *c* and *m*. The crystals measured and shown in Figures 4–7, Plate 19, are not so long, and consequently deviate slightly from the common long prismatic habit.

Seventeen crystals were measured, of which two showed only the unit prism faces, both ends being broken off. Many more were examined with a lens, but no other forms were seen. The combinations seen on these crystals are shown in the following table:

Cryst. No.	*c*	*b*	*a*	*h*	*f*	*m*	*l*	*w*	*v*	*g*	*t*	*o*	*r*	*π*	*E*	*D*	*σ*
1	*c*	—	—	—	*f*	*m*	—	—	—	—	—	*o*	—	*π*	—	*D*	—
2	*c*	—	—	—	—	*m*	—	—	—	*g*	—	—	—	—	—	—	—
3	*c*	—	—	*h*	—	*m*	*l*	—	—	—	*t*	—	*r*	—	—	—	—
4	*c*	—	—	—	—	*m*	—	—	—	—	*t*	—	—	—	*E*	—	—
5	*c*	*b*	—	—	—	*m*	—	*w*	—	—	—	*o*	—	*π*	—	—	—
6	*c*	—	—	—	—	*m*	—	—	—	—	*t*	*o*	—	—	—	—	—
7	*c*	—	—	—	—	*m*	—	*w*	—	—	—	—	—	—	—	—	—
8	*c*	—	—	—	—	*m*	—	—	—	—	*t*	—	—	—	—	—	—
9	*c*	*b*	—	—	—	*m*	—	—	—	—	—	*o*	—	*π*	—	*D*	—
10	—	—	—	—	—	*m*	—	—	—	—	—	—	—	—	—	—	—
11	*c*	*b*	—	—	—	*m*	—	—	—	—	—	—	—	—	—	—	—
12	—	—	—	—	—	*m*	—	—	—	—	—	—	—	—	—	—	—
13	*c*	*b*	—	—	—	*m*	—	—	—	—	—	—	—	—	—	—	—
14	—	*b*	—	*h*	—	*m*	*l*	—	—	—	—	—	—	—	—	—	—
15	*c*	—	*a*	*h*	—	*m*	*l*	—	—	—	—	—	—	—	—	—	*σ*
16	—	—	—	—	—	*m*	—	—	—	—	*t*	*o*	—	—	—	—	—
17	*c*	—	*a*	—	—	*m*	—	—	*v*	—	—	—	—	—	—	—	—

All of the forms observed by Des Cloizeaux were noted on these crystals, except $-\frac{8}{9} = \{\bar{8}89\}$ and $-\frac{5}{2\bar{2}} = \{\bar{5}.5.22\}$, which are probably vicinal.

In the following table the values are derived from the measurements by the writer, and show a slight difference from those given by Goldschmidt:

$a = 1.1670$	$\lg a = 0.06707$	$\lg a_0 = 9.88537$	$\lg p_0 = 0.11464$	$a_0 = 0.7680$	$p_0 = 1.3021$
$c = 1.5195$	$\lg c = 0.18170$	$\lg b_0 = 9.81830$	$\lg q_0 = 0.16628$	$b_0 = 0.6581$	$q_0 = 1.4665$

$\mu = 180 - \beta = 74° 49'$, $\lg h = \lg \sin \mu = 9.98457$, $\lg e = \lg \cos \mu = 9.41814$, $\lg \frac{p_0}{q_0} = 9.94836$, $h = 0.9651$, $e = 0.2619$

Number.	Letter.	Gdt.	Miller.	ϕ	ρ	ξ_0	η_0	ξ	η	x' (Prism) $(x:y)$	y'	$d' = \text{tg}\rho$
1	*c*	0	001	90° 00′	15° 11	15° 11′	0° 00′	15° 11′	0° 00′	0.2714	0	0.2714
2	*b*	0∞	010	0 00	90 00	0 00	90 00	0 00	90 00	0	∞	∞
3	*a*	∞0	100	90 00	"	90 00	0 00	90 00	0 00	∞	0	"
4	*h*	2∞	210	60 37	"	"	90 00	60 37	29 23	1.7758	∞	"
5	*f*	$\frac{3}{2}\infty$	320	53 06	"	"	"	53 06	36 54	1.3319	"	"
6	*m*	∞	110	41 36	"	"	"	41 36	48 24	0.8879	"	"
7	*l*	∞2	120	23 56	"	"	"	23 56	66 04	0.4440	"	"
8	*w*	$+\frac{1}{10}$	103	90 00	35 48	35 48	0 00	35 48	0 00	0.7211	0	0.7211
9	*v*	+10	101	"	58 19	58 19	"	58 19	"	1.6206	"	1.6206
10	*g*	$-\frac{1}{10}$	$\bar{2}05$	$\overline{90}$ 00	15 01	$\overline{15}$ 01	"	$\overline{15}$ 01	"	$\bar{0}$.2683	"	0.2683
11	*t*	−10	$\bar{1}01$	"	47 09	$\overline{47}$ 09	"	$\overline{47}$ 09	"	$\bar{1}$.0778	"	1.0778
12	*o*	01	011	10 07	57 04	15 11	56 39	8 29	55 42	0.2714	1.5196	1.5436
13	*r*	+1	111	46 50	65 46	58 19	"	41 42	38 35	1.6206	1.5196	2.2215
14	*π*	$-\frac{1}{2}$	$\bar{1}12$	$\overline{27}$ 57	40 42	$\overline{21}$ 58	37 13	$\overline{17}$ 48	35 10	$\bar{0}$.4032	0.7598	0.8602
15	*E*	$-\frac{3}{5}$	$\bar{3}35$	$\overline{30}$ 33	46 38	$\overline{28}$ 17	42 21	$\overline{21}$ 41	38 45	$\bar{0}$.5381	0.9117	1.0587
16	*D*	−2	$\bar{2}21$	$\overline{38}$ 37	75 35	$\overline{67}$ 36	71 47	$\overline{37}$ 11	49 11	$\bar{2}$.4270	3.0392	3.8890
17	*σ*	−12	$\bar{1}21$	$\overline{19}$ 32	72 46	$\overline{47}$ 09	"	$\overline{18}$ 37	64 11	1.0778	"	3.2245

Physical Properties.—The plane of symmetry is also the plane of the optic axes. A section of the mineral cut approximately parallel to the clinopinacoid showed that the axis of elasticity nearly parallel to the clino-axis was the axis of minimum elasticity. A section cut normal to this axis of elasticity, showed, in convergent light, a biaxial interference figure with a large angle. This figure also showed its positive character. A cleavage piece (parallel to the base) also showed a figure nearly equal in size to the first one seen but perhaps a trifle larger. This latter figure gave a negative sign, with the quartz wedge. The mineral is therefore positive with the obtuse bisectrix emerging nearly normal to the basal pinacoid. The mineral agrees, therefore, in its optical properties with pisanite.

The mineral does not occur massive but only in crystals. Concretionary and stalactitic forms were not met with. The mineral is blue in color, vitreous and transparent when free from

any coating of pyrite. It is very brittle and shows a good basal cleavage. The crystals, which have lain in trays, exposed to the air for almost a year, have not become ocherous externally. Exposed to the sunlight, however, they become white and opaque.

Cold water readily dissolves the crystals, from which solution ferric hydrate is copiously precipitated on heating. Its pyrognostic characters are similar to those of melanterite, except that it readily gives a reaction for copper. Heated in a closed tube, it readily melts in its water of crystallization and on stronger ignition is reduced to a black, magnetic mass. Its hardness is about 2.5 and its specific gravity is close to 1.8–1.9.

Chemical Properties.—It was not possible to pick out enough material for an analysis, without including a good deal of pyrite. The abundance of the mineral, however, allowed of several analyses of different specimens, the average of which analyses is seen in the table below.

	Average Analysis.	Same with Insol. deducted.	Molecular Ratio.	Calculated.
CuO	13.39	15.73	1.11	14.11
FeO	10.48	12.31	.97	12.75
SO_3	24.02	28.21	2.00	28.40
H_2O	38.44	45.14	14.23	44.74
Insol.	14.85	.....	.....	.....
	101.18	101.39		100.00

The last column is the calculated percentage for the formula $CuO.\ FeO.\ 2SO_3 + 14\ H_2O$.

Water was given off at the temperatures stated in the following proportions:

		Ratio.
H_2O (110°)	33.58	6.11
H_2O (above 200°)	4.86	.89

Practically no water is given off between 110° and 200°. It would thus seem as if $\frac{6}{7}$ of the water content of pisanite is given off at a low temperature and that nearly twice that temperature is necessary to expel the last molecule of water, a fact which suggests that, structurally, the six molecules play a different *rôle* from the seventh. The six molecules are water of crystallization while the seventh is constitutional water.

As with melanterite, the formula for pisanite may be written,

$$OS\begin{cases} O \\ O \end{cases}\!>R \qquad \begin{cases} O \\ O \end{cases}\!>H_2 \quad +6\ H_2O$$

where R represents (Fe,Cu) in the ratio of 1:1. Pisanite may then be regarded as a salt of tetrahydroxyl sulphuric acid, $OS(OH)_4$, in which half of the hydrogen is replaced by iron and copper in equal proportions.

Just what the temperature is, at which all of the six molecules of water of crystallization are driven off, is difficult to say. It is probably not far from 100°–110°. A temperature of about 250° will probably expel all of the water of the mineral.

A partial analysis of a specimen of pisanite, with a larger amount of insoluble matter, gave:

		Ratio.
CuO	8.60	.99
FeO	7.61	.97
SO_3	17.53	2.00

We thus have good evidence that the pure crystals of pisanite have the definite formula $FeO.CuO.2SO_3.2H_2O+12\ H_2O$.

The original analysis of pisanite, by Pisani,* gives a ratio agreeing quite well with this formula. His analysis, together with the ratios calculated therefrom, is:

		Ratio.
CuO	15.56	1.04
FeO	10.98	.82
SO_3	29.90	2.00
H_2O	43.56 (by diff.?)	12.95
	100.00	

Analyses of other specimens show that this ratio is not necessarily constant. The material is much poorer and is not in good crystals, like the pisanite already described. An analysis of the specimen collected by Mr. Booth is given in the table below. In the last column is given the composition calculated from the formula $2FeO.CuO.3SO_3+21\ H_2O$.

*Comptes Rendus, 1859, 48, 807

	Analysis.	Insol. deducted.	Ratio.	Calculated.
CuO	8.13	9.22	.95	9.45
FeO	14.53	16.47	1.88	17.08
SO_3	25.74	29.18	3.00	28.53
H_2O	40.34	45.74	20.88	44.94
Insol.	11.80	.....	.....	.....
	100.54	100.61		100.00

Water was given off at the temperatures stated in the following proportions:

		Ratio.
H_2O (102°)	34.68	17.96 or 5.99
H_2O (above 102°)	5.66	2.92 .97

Crystallographically and optically the properties of the two substances are identical. Some of the material was dissolved in water, the gangue filtered off and the filtrate slowly evaporated. A little sulphuric acid was added to prevent the precipitation of the iron as a basic salt. Crystals were obtained, isomorphous with pisanite, and having a definite ratio of FeO to CuO of 2:1. A mixture of artificial sulphate of copper and iron in the proper proportion was dissolved in water and allowed to evaporate. Crystals were obtained, having the definite composition expressed by the formula, $2FeO.CuO.3SO_3+21H_2O$. The crystals are isomorphous with pisanite, and showed the forms, {001}, {110}, {103}, {101}, {011} and {$\bar{1}$21}. The axial ratio calculated from a few poor readings is:

$$a:b:c = 1.1739:1:1.5218;\ \beta = 104°\ 30'.$$

The artificial salt corresponding to this formula has been described by von Hauer and the crystals measured by Brezina,* who made them triclinic. It is interesting to note that the crystals of pisanite, described by Hintze† and of which a partial analysis is given, also correspond fairly well with this formula. His analysis gives only determinations of CuO and SO_3. Assuming that no gangue was present in his material, his analysis becomes:

* Pogg: Annalen 1865, p. 635.
† Zeitsch. Krys. 1878, 2, 309.

		Calc. for formula.
FeO	(16.15)	17.08
CuO	10.07	9.45
SO_3	28.84	28.53
H_2O	(44.94)	44.94
	100.00	100.00

Still a third specimen of pisanite shows a variation from either of the two specimens described. The most noticeable difference is the presence of about three per cent. of magnesia. The material is somewhat impure and not in good crystals. In the last column, below, is the calculated percentage for the formula $3CuO.FeO.MgO.5SO_3.5H_2O + 30H_2O$. The analysis gave:

	Analysis.	Insol. deducted.	Ratio.	Calculated.
CuO	16.40	17.95	3.09	17.28
FeO	4.99	5.46	.99	5.21
MgO	2.58	2.82	.99	2.92
SO_3	26.72	29.25	5.00	28.97
H_2O (110°)	31.28	34.25	26.00	39.10
H_2O (above 110°)	10.01	10.96	8.32	6.52
Insol.	8.67	.....	.....	.....
	100.65	100.69		100.00

Though the fractional water determination is not very good, it would seem as if the formula of this mineral might be written $OS\begin{matrix}/\,O\\ \backslash\,O\end{matrix}\!\!>\!R\begin{matrix}O\\O\end{matrix}\!\!>\!H_2 + 6H_2O$, where R = (Cu,Fe,Mg) in the ratio of 3:1:1. If we consider the magnesia as replacing part of the iron, the formula becomes $3CuO.2FeO.5SO_3+35H_2O$, which is not far from pisanite, taken two and a half times, $2\frac{1}{2}CuO.2\frac{1}{2}\ FeO.5SO_3+35H_2O$.

The mineral, described and named *salvadorite* by W. Herz,* is of especial interest as differing somewhat from normal pisanite. It is probably a variety of pisanite, in which the copper predominates, approximating the formula $2CuO.FeO.3SO_3+21H_2O$.

BOOTHITE.

General Description.—One of the secondary minerals occurring in the Alma mine proves on investigation to be a new copper

* Zeitschr. Kryst. 1896, 26, 16.

sulphate crystallizing with seven parts of water instead of five, as is the case with chalcanthite.

The mineral occurs massive, with a crystalline structure, and also as fibrous fragments, differing somewhat in physical properties from the massive variety. Chalcanthite is intimately associated with the massive variety.

Crystallographic Characters.—Two incomplete crystals of boothite were obtained which showed, with one or two exceptions, only one face of each of the forms present.

The crystals are monoclinic and have the following eight forms:

Letter.	Symbol. Gdt.	Miller.
c	0	001
a	∞0	100
m	∞	110
t	—10	$\bar{1}01$
z	—30	$\bar{3}01$
π	—½	$\bar{1}12$
e	—1	$\bar{1}11$
σ	—12	$\bar{1}21$

The angle β was measured directly and is probably fairly accurate. From the average of several calculations of p'_0 and q'_0, together with β, an axial ratio was calculated which is to be considered as approximate. The calculations gave:

$$a:b:c = 1.1622:1:1.5000,\ \beta = 105^\circ\ 36'.$$

The angles measured, together with those calculated for these forms, from the axial ratio just given, are quoted below:

Number.	Letter.	Symbol. Gdt.	Miller.	Measured. ϕ	ρ	Calculated. ϕ	ρ
1	*c*	0	001	90° 00′	15° 36′	90° 00′	15° 36′
2	*a*	∞0	100	"	90 00	"	90 00
3	*m*	∞	110	41 10	"	41 47	"
4	*t*	—10	$\bar{1}01$	90 01	46 20	90 00	45 37
5	*z*	—30	$\bar{3}01$	89 54	74 39	"	74 29
6	π	—½	$\bar{1}12$	27 29	41 17	27 31	40 13
7	*e*	—1	$\bar{1}11$	34 35	61 25	35 16	61 26
8	σ	—12	$\bar{1}21$	19 46	72 49	19 28	72 33

The combinations of the forms on the two crystals (Figs. 8 and 9, Pl. 19) are shown in the following table:

Cryst. No.	*c*	*a*	*m*	*t*	*z*	π	*e*	σ
1	*c*	*a*	*m*	—	—	π	*e*	—
2	—	*a*	*m*	*t*	*z*	π	—	σ

$c = 0 = \{001\}$. The base occurred only on one crystal. The reflections were excellent from both faces.

$a = \infty 0 = \{100\}$. The orthopinacoid was present on both crystals but gave only a good reflection on the one crystal.

$m = \infty = \{110\}$. The prism faces were small and very poorly developed. The reflections were poor.

$t = -10 = \{\bar{1}01\}$. This dome occurred as a large face. The reflection was fair.

$z = -30 = \{\bar{3}01\}$. This form occurred as a face not so large as *t*, the reflection being but fair.

$\pi = -\frac{1}{2} = \{\bar{1}12\}$. This pyramid was noted on both crystals.

$e = -1 = \{\bar{1}11\}$. This pyramid and the preceding one occurred on one crystal, the unit pyramid being rather large. The faces lay in the zone *cm*.

$\sigma = -12 = \{\bar{1}21\}$. This form occurred as two large faces, the reflections being, however, poor.

The following table gives the calculation of the forms observed:

$a = 1.1622$ $\quad \lg a = 0.06528$ $\quad \lg a_0 = 9.88919$ $\quad \lg p_0 = 0.11079$ $\quad a_0 = 0.7747$ $\quad p_0 = 1.2906$

$c = 1.5000$ $\quad \lg c = 0.17609$ $\quad \lg b_0 = 9.82391$ $\quad \lg q_0 = 0.15978$ $\quad b_0 = 0.6667$ $\quad q_0 = 1.4447$

$\mu = 180 - \beta = 74°\,24'$ $\quad \lg h = \lg \sin \mu = 9.98370$ $\quad \lg e = \lg \cos \mu = 9.42962$ $\quad \lg \frac{p_0}{q_0} = 9.95101$ $\quad h = 0.9632$ $\quad e = 0.2689$

Number.	Letter.	Gdt.	Miller.	ϕ	ρ	ξ_0	η_0	ξ	η	x' (Prism) $(x:y)$	y'	$d' = \text{tg}\,\rho$
1	*c*	0	001	90° 00′	15° 36′	15° 36′	0° 00′	15° 36′	0° 00′	0.2792	0	0.2792
2	*a*	$\infty 0$	100	"	90 00	90 00	"	90 00	"	∞	0	∞
3	*m*	∞	110	41 47	"	"	90 00	41 47	48 13	0.8933	∞	"
4	*t*	-10	$\bar{1}01$	90 00	45 37	45 37	0 00	45 37	0 00	$\bar{1}$.0217	0	1.0217
5	*z*	-30	$\bar{3}01$	"	74 29	74 29	"	74 29	"	$\bar{3}$.6030	"	3.6030
6	π	$-\frac{1}{2}$	$\bar{1}12$	27 31	40 13	21 21	36 52	17 22	34 56	$\bar{0}$.3908	0.7500	0.8457
7	*e*	-1	$\bar{1}11$	35 16	61 26	46 41	56 18	30 28	45 49	$\bar{1}$.0608	1.5000	1.8372
8	σ	-12	$\bar{1}21$	19 28	72 33	"	71 34	18 32	64 05	"	3.0000	3.1820

Physical Properties.—An examination of the crushed massive material on the stage of the microscope showed several roughly square cleavage plates (parallel to the base) which, with convergent light, showed a biaxial interference figure with a large angle. From a study of this figure the following facts were ascertained. The optic axial plane is parallel to the clinopinacoid. The bisectrix emerging nearly normal to the base is an axis of maximum elasticity. The mineral boothite agrees thus with melanterite and pisanite and like them is probably positive, the obtuse bisectrix emerging on the base.

The cleavage is basal, imperfect. Several of the long fibrous fragments show numerous cracks parallel to the base and transverse to the direction of elongation. The hardness of the mineral is 2 to 2.5, and the specific gravity about 2.1. The color is blue, like chalcanthite, except perhaps a little paler blue. Many of the specimens have whitened on exposure to the air, showing that the mineral is probably unstable in dry air. In the fibrous pieces the luster is decidedly silky or pearly, while in the more massive variety it is vitreous.

Chemical Properties.—The mineral is readily soluble in cold water, and in its pyrognostic characters behaves like chalcanthite. It does not fuse in a closed tube, but whitens, and finally, upon strong ignition, becomes black.

Two analyses of fresh material were made, one of the fibrous fragments and one of the more massive material. Both lead to the same formula. The water was weighed direct in a calcium tube, and the copper determined in the usual volumetric way. The mean analysis of the fibrous fragments gave:

	Analysis.	Insol. deducted.	Ratio.	Calculated.
CuO	26.80	27.83	1.00	27.85
FeO, MgO	trace	trace	.....	.....
SO_3	27.32	28.37	1.00	28.02
H_2O (105°)	35.29	36.64	5.80	37.83
H_2O (above 105°)	7.14	7.42	1.19	6.30
Insol.	3.70	.....	.....	.....
	100.25	100.26		100.00

The analysis of the massive mineral gave the following results:

	Analysis.	Insol. deducted.	Ratio.	Calculated.
CuO	27.52	28.53	1.00	27.85
FeO	0.27	0.28	.....	.....
MgO	trace	trace	.....	.....
SO_3	27.63	28.65	1.00	28.02
H_2O	42.21	43.76	6.78	44.13
Insol.	3.54	.....	.....	.....
	101.17	101.22		100.00

The ratio of $CuO:SO_3:H_2O$ in both is 1:1:7; $\frac{6}{7}$ of the water or 6 molecules being given off at 105°. This mineral may then also be considered as a salt of tetrahydroxyl sulphuric acid. The formula for boothite then becomes $CuSO_4.H_2O+6H_2O$, or, writing it structurally,

$$OS\begin{matrix}\diagup O\\ \diagup O\end{matrix}>Cu \begin{matrix}\diagdown O\\ \diagdown O\end{matrix}>H_2 + 6\ H_2O.$$

As has been shown for manganese sulphates,* the amount of water of crystallization depends on the temperature at which crystallization takes place. The same law doubtless holds good for copper sulphate. It is probably due to this fact that we have a copper sulphate crystallizing with seven parts of water instead of five. The temperature at which this septahydrate of copper forms is probably near 0° C., a temperature which must often be reached in the Alma mine.

The name *boothite* is proposed for this new sulphate of copper, in honor of Mr. Edward Booth of the Department of Chemistry, University of California, who was the first to direct the writer's attention to this deposit of sulphates.

The three minerals, melanterite, pisanite and boothite, form an isomorphous series whose general formula may be written, $RSO_4.H_2O+6H_2O$. They are all monoclinic and their axial ratios vary but little.

	a	*c*	*β*
Melanterite	1.1828	1.5427	104° 16′
Pisanite	1.1670	1.5195	104 30
Boothite	1.1622	1.5000	105 36

* Dr. F. G. Cottrell, Journ. of Phys. Chem., Vol. IV, p. 637, 1900.

CHALCANTHITE.

General Description.—Chalcanthite is, next to pisanite, the most abundant secondary mineral in the mine. It occurs as drusy coatings on the massive ore and on the timbers of the mine, and as loose crystals. The loose crystals are of a dark blue color, while the drusy coatings vary in color from a light blue to a pale green.

Crystallographic Characters.—The crystals vary in size, the drusy crystals being very small, while the loose dark blue crystals average about $1\times3\times5$ mm. Many, however, are very much larger, the largest one found measuring $4\times10\times35$ mm. Most of the crystals are not rich in forms, but occasionally a crystal was found which showed quite a rich combination. The following fourteen forms were observed on the seven crystals measured, two of which, $l = \{120\}$ and $g = \{1\bar{4}1\}$, are new:

Letter.	Symbol. Gdt.	Miller.	Letter.	Symbol. Gdt.	Miller.
c	0	001	*v*	01	011
b	0∞	010	*q*	$0\bar{2}$	$0\bar{2}1$
a	∞0	100	*w*	$0\bar{3}$	$0\bar{3}1$
m	∞	110	*p*	$\bar{1}0$	$\bar{1}01$
l	∞2	120	*s*	$\bar{1}1$	$\bar{1}11$
M	$\infty\bar{\infty}$	$1\bar{1}0$	*z*	$\bar{1}3$	$\bar{1}31$
h	$\infty\bar{2}$	$1\bar{2}0$	*g*	$1\bar{4}$	$1\bar{4}1$

The measurements, with the calculated values, taken from Goldschmidt's Winkeltabellen, are given in the following table:

Number.	Letter.	Symbol. Gdt.	Miller.	Measured. ϕ		ρ		Calculated. ϕ		ρ	
1	*c*	0	001	31°	57′	29°	59′	31°	54′	29°	46′
2	*b*	0∞	010	0	00	90	00	0	00	90	00
3	*a*	∞0	100	79	16		”	79	19		”
4	*m*	∞	110	53	03·		”	53	03		”
5	*l*	∞2	120	37	10		”	37	14		”
6	*M*	$\infty\bar{\infty}$	$1\bar{1}0$	110	34		”	110	33		”
7	*h*	$\infty\bar{2}$	$1\bar{2}0$	133	11		”	133	11		”
8	*v*	01	011	16	45	47	55	15	56	47	45
9	*q*	$0\bar{2}$	$0\bar{2}1$	154	48	35	24	155	24	35	59
10	*w*	$0\bar{3}$	$0\bar{3}1$	165	52	51	25	166	13·	51	47
11	*p*	$\bar{1}0$	$\bar{1}01$	$\bar{6}7$	02	37	30	$\bar{6}7$	39	37	41·
12	*s*	$\bar{1}1$	$\bar{1}11$	$\bar{3}9$	08	48	46	$\bar{3}9$	30	48	19·
13	*z*	$\bar{1}3$	$\bar{1}31$	$\bar{1}53$	27	56	29	$\bar{1}53$	22·	57	54
14	*g*	$1\bar{4}$	$1\bar{4}1$	140	36	64	32	140	45	64	23

$l = \infty 2 = \{120\}$. This new prism was observed but once, as an extremely narrow face, giving, however, a fairly good reflection.

$g = 1\bar{4} = \{1\bar{4}1\}$. This new pyramid was observed on only one crystal, though both faces of the form are present, one face giving a good reflection and the other face a poor one. The form lies in the zone $M\ w$.

The crystals show two habits. In one the form $p = \{\bar{1}01\}$ is very large, and the crystals are tabular parallel to this form and sometimes extremely thin. In the second habit the prism zone is well developed, and the faces elongated somewhat in the direction of the vertical axis, giving a prismatic habit to the crystals. Other forms are abundant on crystals of this latter habit, notably the domes, $p = \{\bar{1}01\}$, $q = \{0\bar{2}1\}$ and $w = \{0\bar{3}1\}$. Figs. 10, 11, Plate 19, show the two habits.

The combinations occurring are given in the following table:

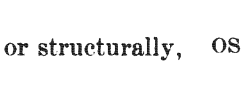
Cryst. No.	*c*	*b*	*a*	*m*	*l*	*M*	*h*	*v*	*q*	*w*	*p*	*s*	*z*	*g*
1	—	—	*a*	*m*	—	*M*	—	—	—	—	*p*	—	—	—
2	—	*b*	*a*	*m*	—	*M*	—	—	*q*	—	*p*	—	—	—
3	—	*b*	*a*	*m*	—	*M*	*h*	—	*q*	*w*	*p*	—	*z*	*g*
4	—	—	*a*	*m*	—	*M*	—	—	*q*	*w*	*p*	—	—	—
5	*c*	*b*	*a*	*m*	—	*M*	*h*	—	—	—	*p*	*s*	—	—
6	*c*	*b*	*a*	*m*	*l*	*M*	*h*	*v*	*q*	*w*	*p*	*s*	—	—
7	—	*b*	*a*	*m*	—	*M*	*h*	—	*q*	—	*p*	—	*z*	—

The following table gives a calculation of the two new forms, $l = \{120\}$ and $g = \{1\bar{4}1\}$:

Number.	Letter.	Gdt.	Miller.	ϕ	ρ	ξ_0	η_0	ξ	η	x' (Prism) $(x:y)$	y'	d' $= \mathrm{tg}\,\rho$
1	*l*	$\infty 2$	120	37° 14′	90° 00′	90 00′	90° 00′	37° 14′	52° 46′	0.7601	∞	∞
2	*g*	$1\bar{4}$	$1\bar{4}1$	140 45	64 23	52 50	$\bar{5}8$ 14	34 47	$\bar{4}4$ 17	1.3193	$\bar{1}$.6147	2.0851

Chemical Properties.—All of the analyses showed merely a trace of magnesia, and no iron. The crystals represent, therefore, a rather pure copper sulphate. The average of the analyses gave:

	Analysis.	Ratio.	
CuO	31.14	.97	
FeO	none		
MgO	trace		
SO_3	32.06	1.00	
H_2O (110°)	28.20	3.91	4.95
H_2O (above 110°)	7.50	1.04	
Insol.	.81		
	99.71		

Considering, as before, that the water given off at 110° is water of crystallization, while the remaining molecule is constitutional water, we may write the formula of chalcanthite, $CuSO_4.H_2O+4H_2O$, or structurally,  $+4H_2O$.

This formula differs from that of boothite only in the fact that it has four molecules of water of crystallization, instead of six.

COPIAPITE.

General Description.—A yellow ferric sulphate is quite abundant, both at the mine and in the immediate neighborhood, which agrees well in its various properties with copiapite. Some distance from the mine, on what is probably an old prospecting dump, a thick layer of copiapite occurs which was selected for the analyses. Some distinct, though microscopic crystals, occur associated with pisanite, but the entire amount of this material is too small for a chemical analysis.

Under the microscope, with the highest power, the minute crystals are seen to be six-sided tabular crystals, nearly colorless and nonpleochroic if thin, but somewhat pleochroic if rather thick. The pleochroism is colorless to pale yellow. Cleavage is perfect parallel to the plates, which are probably copiapite crystals tabular to the clinopinacoid. They are too small to show the emergence of a bisectrix.

Chemical Properties.—Under the microscope the material analysed was seen to consist of a granular mass with no distinct crystals, with which a few colorless prisms were intermixed. Some of these prisms give parallel extinction and are probably epsomite while others give varying angles of extinction up to

about 20° and were possibly melanterite. The amounts of ferrous iron, magnesia and alumina varied somewhat in different samples. The average of several analyses of this material gave the following results:

	Analysis.	Ratio.	
Fe_2O_3	25.04	15.65	
Al_2O_3	0.31	0.30	= 2.0
FeO	0.44	0.61	
MgO	0.29	0.73	
SO_3	38.36	47.95	= 5.5
H_2O	29.71	165.06	= 19.1
Insol.	5.43		
	99.58		

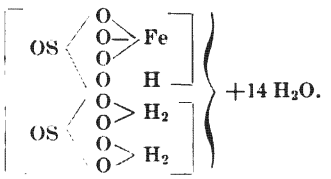
A fractional determination of the water gave:

H_2O (at 110°)	20.25
" (at 150°)	3.10
" (at 200°)	2.26
" (at 260°)	1.77
" (above 260°)	2.33
	29.71

These water determinations were not carried out very accurately but they show that about two-thirds of the water is given off at 110°. To assume that exactly two-thirds or 12 molecules of the water are given off at 110°, which is probably water of crystallization, would give us, for the formula of copiapite, $2Fe_2O_3.5SO_3.6H_2O+12H_2O$. If, now to obtain the acid of which copiapite is the ferric salt, we substitute for Fe''' its equivalence 3H, we obtain $2(3H)_2O_3.5SO_3.6H_2O+12H_2O$. Neglecting the twelve molecules of water of crystallization, and reducing the first part of the formula, we obtain $6H_2O.5SO_3$ $6H_2O=5H_2SO_4.7H_2O$ as the acid from which copiapite is derived —a very improbable acid.

If, however, we assume that fourteen molecules of the water, instead of twelve, are water of crystallization, we then have $2Fe_2O_3.5SO_3.4H_2O+14H_2O$. as a formula for copiapite. Again substituting 3H for Fe''', this becomes $6H_2O.5SO_3.4H_2O+14H_2O$., or, neglecting the fourteen molecules of water, $2H_2O.SO_3 = H_2SO_4.H_2O$, which latter is tetrahydroxyl sulphuric acid, as the acid of which copiapite is the ferric salt. This formula would require

that 24.2 per cent. of water be given off at the first temperature, about 110°. Structurally, the formula for copiapite would then become,

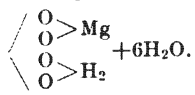


EPSOMITE.

General Description.—Epsomite occurs in the mine, and was also frequently observed in the immediate vicinity, as an efflorescence. It occurs as bent and curved fibrous prisms, showing, however, no crystal surfaces. Under the microscope the prisms give straight extinction.

Chemical Properties.—The analysis served merely to identify the mineral.

	Analysis.	Insol. deducted.	Calculated.
MgO	12.4	14.8	16.3
SO_3	26.5	31.7	32.5
H_2O (110°)	34.1	40.8	51.2
H_2O (above 110°)	10.2	12.2	
Insol.	16.3	.....	
Al_2O_3	trace	trace	
FeO, CuO	none		
	99.5	99.5	100.0

The formula for epsomite may be written, like that of melanterite, 

ALUNOGEN.

A coating of white powder, intimately associated with pieces of copper sulphate, covers the bunkers in front of the mine. The powder is readily soluble in cold water, which solution gave tests for copper from the admixed copper sulphate, aluminum, sulphuric acid and water, with traces of ferrous iron and magnesia. Under the microscope the mass consists of a granular aggregate of a white mineral, only partially transparent. The mineral agrees, so far as can be

determined, with alunogen, and is tentatively referred to that species.

Besides the efflorescences of epsomite in the neighborhood, an occasional specimen was met with which, besides giving a test for magnesia, showed also the presence of aluminum in fairly large quantities. It is probably a mixture of alunogen and epsomite. All of the specimens were, however, impure and dehydrated to some extent, so that no analysis was made of any of these aluminium sulphates.

HEMATITE AND LIMONITE.

The alteration of pyrite is usually accompanied by the formation of oxides of iron, and both hematite and limonite occur at the mine. The hematite is in the form of a compact red ochre. A specimen gave 10 per cent. of water, which may have been occluded, or the mineral may be classed as turgite. The limonite occurs mostly as yellow ochre, although occasionally it is in compact brown masses.

SUMMARY.

By the study of the sulphate crystals formed by the oxidation of the pyrite ore, ten new forms are established for pisanite, seven for melanterite and two for chalcanthite. A new sulphate of copper containing seven molecules of water, instead of five, occurs as one of the secondary minerals, to which the writer gives the name *boothite*. The three minerals,, pisanite, melanterite and boothite form an isomorphous series.

The theory is advanced that all of these hydrous sulphates may be regarded as salts of tetrahydroxyl sulphuric acid, since they apparently contain one molecule of constitutional water.

In conclusion, the writer wishes to express his thanks to Dr. Arthur S. Eakle, under whose guidance the investigations were carried out. Also to Dr. W. C. Blasdale and Mr. Booth of the Chemical Department, and to Mr. Storch, the superintendent of the pyrite mine, grateful acknowledgements are due, for much assistance.

University of California,
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