

SULPHATE MINERALS OF THE COMSTOCK LODGE, NEVADA.¹

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ABSTRACT.

Seventeen representative samples of supergene sulphates from old workings on the Comstock Lode are described. They range from simple minerals such as gypsum and epsomite to complex aggregates of four or more distinct species. All are well known species except a mineral of the copper (chalcantinite) or magnesium sulphate pentahydrate group, with about half the magnesium replaced by copper, zinc, ferrous iron, and manganese. Four new analyses of Comstock Lode mine waters are given.

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INTRODUCTION.

IN THE course of a recent investigation of the accessible mine workings of the Comstock Lode, all of the members of the party were impressed by the variety of form and color of the supergene

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sulphates that formed stalactites, crusts, and efflorescences on the walls and timbers of the old workings. To determine the composition of these deposits, Dr. V. P. Gianella, of the Nevada State Bureau of Mines, and Mr. Johnston collected seventeen representative samples of the sulphates, sealed them underground in tin cans by means of friction tape and shipped them for examination to the Chemical Laboratory of the Geological Survey. At the same time four half-gallon samples of mine waters were collected and sent to the laboratory. The waters were analyzed very soon after opening. The sulphates were exposed to the air of the laboratory for variable periods of one to eight months; there appeared, however, to be only minor changes in composition, if any, resulting from the exposure.

The samples were obtained in the following workings:

1. The Central Tunnel and connected shallow workings in Consolidated Virginia, California, and Ophir ground.
2. The tunnel of the Arizona Comstock and connected shallow workings in Hale and Norcross ground.
3. The Silver Hill mine, shallow workings.
4. The Sutro Tunnel and its north and south laterals.
5. The Alta shaft; old workings approximately 50 ft. above the 1,100 or Sutro Tunnel level.

Fig. 1 is a section through the Sutro Tunnel showing the approximate position of some of the samples.

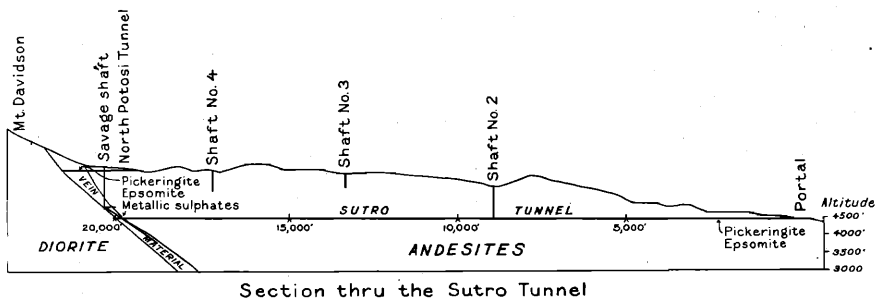


FIG. 1. A section through the Sutro Tunnel showing the approximate position of some of the samples described.

Thanks are due to Dr. Gianella who aided in collecting the specimens; to Miss Margaret Foster, of the Water Resources laboratory of the Survey, for assistance in the determination of fluorine in the waters; to Miss J. J. Glass for precise refractive index determinations; and to Dr. W. T. Schaller, of the Chemical Laboratory of the Survey, for unfailing advice whenever mineralogical difficulties appeared.

SULPHATE MINERALS.

The seventeen representative samples of the incrustations, stalactitic formations, and similar deposits in the mine are all sulphates, varying from simple minerals, such as gypsum, to complex mixtures of four or more distinct species. The individual crystals are, for the most part, of microscopic size and the specimens are not suitable for any precise goniometrical determinations. With one exception, all of the samples consist of well-known mineral species, the exception being a mineral of the copper or magnesium sulphate pentahydrate group, with about half the magnesium replaced by copper, zinc, ferrous iron, and manganese, in the order named.

The identification of the different mineral species was based on the usual petrographic and analytical procedures, supplemented by microchemical tests where indicated. The object of the investigation being the identification of the minerals present, exact and refined analytical methods were not called for. The heterogeneous and varying nature of the material available for analysis would have made precise analyses of no greater value than less exact, though sufficiently accurate, procedures. For most of the samples, therefore, the different metallic oxides and the acid (sulphuric in each case) were determined by the usual methods, and, after determination of the insoluble fraction, water was reckoned by difference. A fair degree of correspondence was obtained between the composition of the sample, as computed from the analysis, and the observed minerals, shown by the microscope.

A test for silver was made on a composite sample of the seventeen sulphate specimens with negative results.

The following species were identified: Gypsum $\text{CaO} \cdot \text{SO}_3 \cdot 2\text{H}_2\text{O}$; Epsomite $\text{MgO} \cdot \text{SO}_3 \cdot 7\text{H}_2\text{O}$; Melanterite $\text{FeO} \cdot \text{SO}_3 \cdot 7\text{H}_2\text{O}$; Goslarite $\text{ZnO} \cdot \text{SO}_3 \cdot 7\text{H}_2\text{O}$ including magnesian and cuprian varieties; Magnesium-copper-zinc sulphate pentahydrate; Pickeringite $\text{MgO} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SO}_3 \cdot 22\text{H}_2\text{O}$ including zinc, iron, and manganese varieties; Alunogen $\text{Al}_2\text{O}_3 \cdot 3\text{SO}_3 \cdot 16\text{H}_2\text{O}$; Copiapite $2\text{Fe}_2\text{O}_3 \cdot 5\text{SO}_3 \cdot 19\text{H}_2\text{O}$ (?); Coquimbite $\text{Fe}_2\text{O}_3 \cdot 3\text{SO}_3 \cdot 9\text{H}_2\text{O}$; Voltaite $3(\text{K}_2\text{Fe})\text{O} \cdot 2(\text{Al, Fe})_2\text{O}_3 \cdot 6\text{SO}_3 \cdot 9\text{H}_2\text{O}$ (?). Of uncertain determination were: Rhomboclase $\text{Fe}_2\text{O}_3 \cdot 4\text{SO}_3 \cdot 9\text{H}_2\text{O}$; and some poorly crystallized basic sulphates.

The seventeen samples may be grouped into three divisions as follows:

A. Simple one-mineral deposits. There are eight of these.

Gypsum (S.S. 6200) and (36J45)
 Epsomite (36J17), (36J21) and (36J36)
 Melanterite (36J91)
 Magnesian goslarite (36J16)
 Magnesian cuprian ferroan goslarite (36J15)

B. Two-mineral deposits. There are five of these.

Pickeringite-epsomite (36J11), (36J18), (36J31), and (ST. 2260)
 Pickeringite—RO pentahydrate (36J12)

C. Complex deposits with ferric sulphates. Four of these.

Copiapite-pickeringite with a little epsomite and basic ferric sulphate (36J19)
 Copiapite-pickeringite-epsomite-voltaite (36J20)
 Copiapite-pickeringite-alunogen-coquimbite (SN. 1900)
 Copiapite-alunogen-epsomite-rhomboclase (36J10)

The first group includes fairly water-soluble sulphates which, except possibly melanterite, neither hydrolyze to basic salts nor oxidize to insoluble compounds. They are thus easily carried in solution and effectively removed from the place of their origin and association of contemporaneously-formed minerals.

The second group is a mixture of pickeringite with the hepta- or penta-hydrate of magnesium sulphate; these are also quite soluble, and their solution should be fairly stable under a variety of

conditions. In general, conditions favoring precipitation of pickeringite should favor precipitation of the accompanying minerals.

The third group is more complex, some of the constituent minerals being of low solubility. It is characterized by the presence of the ferric sulphate minerals. It is unlikely that these have traveled far from their points of origin; they indicate complex equilibria between oxidizing acid solutions and solid rock, which supplied the aluminum, potassium, magnesium, etc., present in these minerals. The oxidation of pyrite would furnish the acid ferric-iron sulphates characteristic of this group.

A. One-mineral Samples.

Gypsum.—Specimen no. S.S. 6200, from the south lateral of the Sutro Tunnel, 6,200 feet from its junction with the main tunnel and specimen no. 36J45 from a stope above the 1,100-foot level of the Alta shaft. Radiating blades, several millimeters long, and in more finely crystallized aggregates.

Epsomite.—Specimen no. 36J36, from the Arizona-Comstock 365 foot level. Abundant beard-like masses pendant from the roof of the drift. In places large masses have fallen from their support and collected on the floor or on old timbers (Figs. 2 and 3). White and finely fibrous almost like asbestos, with a little water-insoluble brownish clay. Fairly pure magnesium sulphate, with a little zinc and manganese, probably less than one per cent. Under the microscope the fibers are seen to be not homogeneous; under crossed nicols they are seen to be made up of a fine-grained mosaic of variously oriented particles. This indicates partial dehydration of the original heptahydrate to a lower hydrate.

Specimens nos. 36J17 and 36J21 from the 231 foot level of the California Mine, accessible in 1936 through the Central Tunnel. Beardlike masses pendant from the roof of the drift, and composed of a felt of delicate white fibers with the properties of epsomite. Sample no. 36J21 contained about 12 per cent of water insoluble earthy material and analysis of the water soluble portion gave

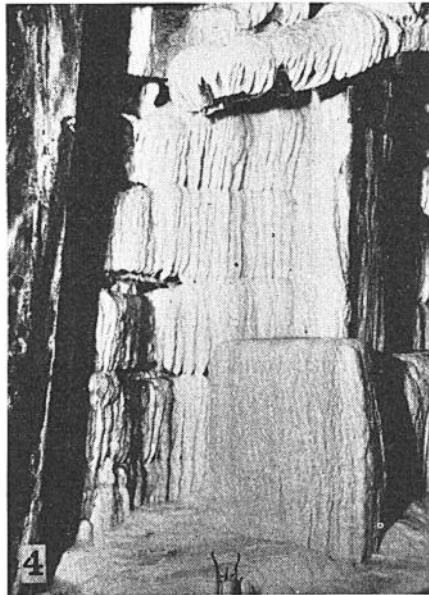


FIG. 2. "Feathers" of epsomite on quartz vein. Arizona Comstock 365 level.

FIG. 3. Epsomite growing behind and falling on lagging. Arizona Comstock 365 level.

FIG. 4. Calcite deposited on lagging and coating a barrel. Sutro Tunnel. 14,200 feet from portal. Analysis of depositing water is given on page 770.

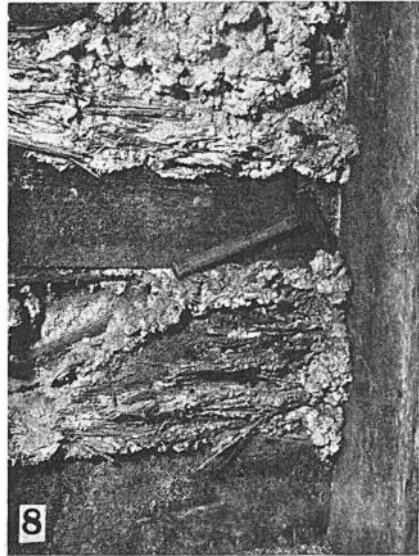
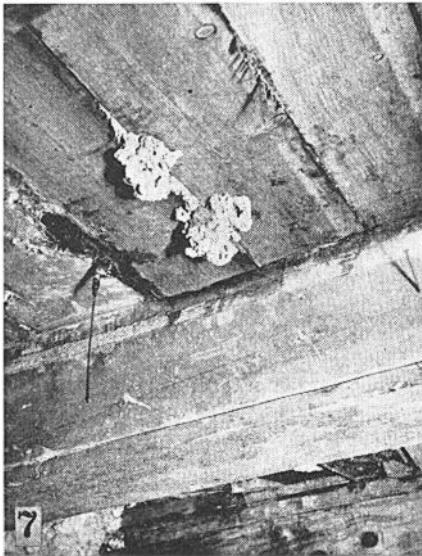
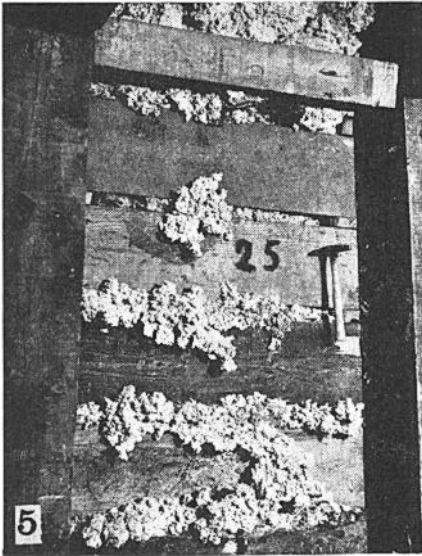


FIG. 5. Pickeringite and epsomite growing between lagging. Sutro Tunnel, north lateral.

FIG. 6. Pickeringite and epsomite aggregate breaking lagging in roof. Sutro Tunnel, north lateral.

FIG. 7. Light colored cauliflower-like masses of pickeringite and epsomite and dark stalactite of complex ferric sulphates. Sutro Tunnel, north lateral.

FIG. 8. Pickeringite and epsomite shredding lagging in zone of pyritized andesite remote from the Lode. Sutro Tunnel, 2,100 ft. from portal.

	Ratios		
Al ₂ O ₃ , Fe ₂ O ₃ , Mn ₂ O ₃.....	.49		
CaO.....	.21		
MnO, ZnO.....	.30		
MgO.....	14.35	356	1.00
SO ₃	28.77	359	1.01
H ₂ O (by diff.).....	55.88	3104	8.72
	100.00		

The RO:SO₃ is almost exactly 1:1; the ratio of H₂O exceeds the 7:1 of epsomite, but this may be due to moisture of the sample, and to the water content of the insoluble portion (which was weighed after ignition).

Melanterite.—Specimen no. 36J91 from the footwall gouge of the 60 foot level of the Silver Hill mine. Leek-green or bluish-green crystals, a centimeter or so across, partly oxidized to a yellowish-brown pasty mass. The sample was moist, yielding a small excess of water. The analysis gave

	Ratios		
Insoluble.....	1.50		
Al ₂ O ₃	1.09	11	
Fe ₂ O ₃.....	.66	4	
FeO.....	23.41	326	1.00
MgO.....	.14	3	
SO ₃	27.15	339	1.03
H ₂ O (by diff.).....	46.05	2555	7.77
	100.00		

The analysis indicates that the sample is about 92 per cent melanterite, FeSO₄·7H₂O.

Goslarite.—Two samples of goslarite were analyzed. Both samples contained several per cent of MgO and one sample contained, in addition, appreciable quantities of both CuO and FeO. In both samples, however, ZnO is the dominant base.

Specimen no. 36J16, from the 145 foot or Central tunnel level of the California mine. Vitreous and clear, very pale bluish-white crystals, in a massive crust. The exterior is altered to a

dull white powdery substance; however, optical examination shows little difference between the fresh and altered portions of the crystals, except that the dull exterior coating consists of a mass of randomly oriented brightly polarizing particles. The clear grains yield good negative interference figures of small optic angle; the refractive indices are close to $X = 1.447$, $Z = 1.470$.

Neglecting the minor constituents, the analysis indicates a composition of about 54 per cent $ZnSO_4 \cdot 7H_2O$ and 46 per cent of $MgSO_4 \cdot 7H_2O$. The calculated indices of refraction are: $\alpha = 1.446$, $\gamma = 1.473$, agreeing closely with the determined values. A very small quantity of a fibrous mineral resembling pickeringite is also present.

An analysis of the white crust gave

	Ratios			
Insoluble (mostly Fe_2O_3)	.16			
CuO	.19	2	349	1.00
MnO	.20	3		
ZnO	14.05	173		
MgO	6.90	171		
Al_2O_3, Fe_2O_3	.31		3	
SO_3	30.00		375	1.07
H_2O (by diff.)	48.19		2674	7.66
	100.00			

This analysis computes reasonably close to $(Zn, Mg)O \cdot SO_3 \cdot 7H_2O$ 98 per cent and pickeringite 2 per cent.

Although the percentage of ZnO is more than twice that of MgO, the molecular ratio of the two oxides is nearly 1:1, with, however, the ZnO in slight excess. Hence the material is referred to goslarite, and may be called a magnesian goslarite.

Specimen no. 36J15 from the Central tunnel level of the California mine. Pale bluish-green stalagmitic masses and incrustations, slightly coated with a dull white material. The distribution of the color is irregular, the greenish crystals grading into colorless or white.

The measured indices of refraction of the bluish-green material are $\alpha = 1.463$, $\beta = 1.475$, $\gamma = 1.480$, all $\pm .003$. Optically negative, $2V$ moderate.

An analysis of the blue-green material gave

	Ratios			
Insoluble in water (mainly Fe_2O_3) . . .	.13			
$\text{Fe}_2\text{O}_3, \text{Al}_2\text{O}_3$ . . . . .	.30			
CuO	4.27	54	364	1.00
PbO	None			
FeO	2.85	40		
MnO} . . . . .	.30	4		
ZnO	11.77	145		
MgO	4.86	121		
SO_3	29.41				367	1.01
H_2O (by diff.)	46.11		2562	7.04
	100.00			

The ratios agree very closely with the general formula $\text{RO} : \text{SO}_3 \cdot 7\text{H}_2\text{O}$. According to the component composition calculated from the analysis, as shown below, the calculated indices of refraction are: $\alpha = 1.454$, $\beta = 1.472$, $\gamma = 1.478$. α as determined is 1.463, the difference of .009 being greater than the error of determination, β and γ as determined are slightly higher also, but not more than the possible error of determination. The quantity of water present is almost exactly that required for the heptahydrate; it may be however that a slight degree of dehydration exists, which would tend to raise the indices; the $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ on dehydration to $\text{MgSO}_4 \cdot 5\text{H}_2\text{O}$ changes in indices, α from 1.433 to 1.482, β from 1.455 to 1.492, γ from 1.461 to 1.493. The greatest change is in the α index.

Zinc oxide is the dominant base, both in percentage values and ratio, hence the material is goslarite, with MgO , CuO , FeO , and MnO isomorphously replacing a portion of the ZnO . The composition of the sample may be explained as an isomorphous mixture of the following components, in weight percentage, as calculated from the analysis:

ZnO·SO ₃ ·7H ₂ O.....	42
MgO·SO ₃ ·7H ₂ O.....	30
CuO·SO ₃ ·7H ₂ O.....	16
FeO·SO ₃ ·7H ₂ O.....	11
MnO·SO ₃ ·7H ₂ O.....	1
	100

Of the analyses of goslarite listed by Hintze² several have about the same quantities of either MgO, CuO, FeO, or MnO, as the material here described; but none of the ten analyses contains such quantities of all these bases.

B. Two-mineral Samples.

Pickeringite and Epsomite.—Four of the five specimens in this group are mixtures of pickeringite and epsomite with pickeringite dominant, forming from 70 to 92 per cent of the specimen. The four analyses are grouped together in Table I in the order of increasing percentage of pickeringite.

Specimen no. 36J18 from the 231 foot level of the Central tunnel. Tough matter felt of fibers, generally white but in places pale blue, encrusting old timbers. Small irregular gray particles (up to 2 mm.) of quartz are disseminated through the crust. Some of the epsomite is in relatively large clear masses and some of it in the mosaic-like "pseudomorphous" aggregate.

Specimen no. 36J11, from the 242 foot level of the Central Tunnel. A heavy crust deposited behind the lagging, generally of a white color, but locally very pale blue. Microscopically, it is seen to consist of pickeringite and epsomite, with much of the latter apparently transformed to a mosaic of brightly polarizing particles, possibly a lower hydrate. The pickeringite gave a strong test for zinc with mercuric thiocyanate. However, only 0.99 per cent of zinc oxide was present in the composite sample analyzed, and the indications are, therefore, that the epsomite is substantially free from zinc.

Specimen no. 36J31, from the Central Tunnel level. Stalactitic, very pale blue crusts on timbers. A mass of radiating fibers, mainly pickeringite in finely twinned fascicles. A very

² Hintze, Carl: Handb. d. Mineralogie. 1: pt. 3, 4353, 1930.

little quartz is present. Another undetermined mineral, resembling very thin flakes of muscovite, is sparsely present. The two observed indices are close to 1.46; the mineral is optically negative with a moderate axial angle. A lower hydrate of magnesium sulphate is a possibility.

Specimen no. ST 2260 from the Sutro Tunnel is a white fibrous crust slightly coated with a yellowish or light brown film.

The analyses of these four samples are given in Table I.

TABLE I.
ANALYSES OF FOUR SAMPLES OF MIXTURES OF PICKERINGITE AND EPSOMITE.

Sample no.....	36J18	36J11	36J31	ST 2260
Composition:				
Pickeringite.....	70	80	84	92
Epsomite.....	30	20	16	8
Insoluble.....	2.22	0.28	0.26	0.17
MgO.....	6.28	6.75	6.15	5.54
MnO.....	.72	.66	.63	.13
FeO.....	None	None	.34	.11
CuO.....	.52	.17	.87	....
ZrO.....	1.57	.99	.11	....
Al ₂ O ₃	7.42	8.33	9.82	9.90
Fe ₂ O ₃.....	.75	.18	None	1.11
SO ₃	35.78	36.02	36.07	36.83
H ₂ O (by diff.).....	44.74	46.62	45.75	46.21
	100.00	100.00	100.00	100.00

Pickeringite and epsomite appear to mark zones in a highly pyritized andesite. They are abundant in both north and south laterals of the Sutro Tunnel and occur in many places along the main tunnel. Approximately one-half mile from the portal of the tunnel (specimen ST 2260) and remote from the lode itself is a zone of pyritized andesite conspicuously marked by the abundant sulphates in and behind the lagging (Fig. 8). Here pyritization and subsequent oxidation are later than the precious metal mineralization, and probably later than the pyritization of the wall rocks of the Comstock Lode.

The deposition of pickeringite and epsomite causes much damage to timbers underground (Figs. 5 to 8). Lagging is dis-

placed, broken, and even shredded by the growing sulphate masses.

The fifth specimen of group B, specimen no 36J12, from the 242 foot level of the Central tunnel, is a massive crust, deposited on the lagging. It is composed of two distinct substances, the principal one being a light greenish-blue, massive mineral; the other, coating this, a pale brown finely fibrous and radially crystallized druse. The bluish mineral can be obtained in sufficient quantity for analysis, but the brown fibers cannot be separated from the blue sufficiently well, and themselves are not homogeneous. From optical and chemical study, however, they are essentially pickeringite mixed with a brown ferric sulphate.

The blue mineral belongs to the triclinic chalcantite group, with the general formula $RO \cdot SO_3 \cdot 5H_2O$. The analysis shows that it is dominantly magnesium sulphate but copper, zinc, and in minor quantity, iron and manganese, are also present. Expressed as sulphate molecules with $5H_2O$, these last four components together constitute 50 per cent of the mineral.

The optical properties, determined by Miss J. J. Glass of the Geological Survey, are as follows: $\alpha = 1.495$, $\beta = 1.512$, $\gamma = 1.518$, negative with $2V = 55^\circ$, dispersion $r < v$. Habit fine granular or slightly platy, color in transmitted light pale sky blue with no observable pleochroism.

The bluish mineral has the following composition :

	Analysis	Ratios		
Insoluble.....	0.20	.....	
MgO.....	9.40	0.233	} .438	} 1.00
MnO.....	.30	.004		
FeO.....	1.36	.019		
CuO.....	9.00	.113		
ZnO.....	5.60	.069		
Al ₂ O ₃	Trace			
SO ₃	35.07	.438		1.00
H ₂ O (by diff.).....	39.07	2.168		4.95
	100.00			

The mineral has the following component composition, by weight percentage :

MgO·SO ₃ ·5H ₂ O.....	50
CuO·SO ₃ ·5H ₂ O.....	27
ZnO·SO ₃ ·5H ₂ O.....	17
FeO·SO ₃ ·5H ₂ O.....	5
MnO·SO ₃ ·5H ₂ O.....	1
	100

Based on the component composition given above, the measured and calculated indices of refraction show good agreement.

Measured	Calculated
α 1.495.....	1.498
β 1.512.....	1.513
γ 1.518.....	1.517
$\gamma - \alpha$.023.....	.019

The ratios obtained from the analysis are very close to 1 : 1 : 5, indicating that the mineral is a pentahydrate, with MgO the principal base. Although not recognized as an established species and hence not named, magnesium sulphate pentahydrate has been described several times in the literature. An analysis of apparently the pentahydrate of magnesium sulphate from the Cripple Creek district, Colorado, was published³ by Hobbs in 1905. The analysis, by W. O. Hotchkiss, is given in column 1 of Table II. The material was called "epsomite." Three years later, Keller published⁴ an analysis of a copper bearing magnesium sulphate pentahydrate. His material occurred as earthy, friable, bluish-white masses, associated with chalcantite, from Copaque, Province of Tarapaca, Chile. From his analysis (no. 2, Table II), the ratios of RO:SO₃:H₂O are calculated as 1.05:1.03:4.92, or essentially 1 : 1 : 5. Expressed in component composition the Chilean mineral consists of:

MgO·SO ₃ ·5H ₂ O.....	58
CuO·SO ₃ ·5H ₂ O.....	38
FeO·SO ₃ ·5H ₂ O.....	3
MnO·SO ₃ ·5H ₂ O.....	1
	100

³ Hobbs, W. H.: Contributions from the mineralogical laboratory of the University of Wisconsin. *Am. Geol.* 36: 184, 1905.

⁴ Keller, H. F.: Notes on some Chilean copper minerals. *Am. Philos. Soc. Proc.*, 47: 81-82, 1908.

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The mineral from Nevada (no. 4, Table II) is similar in composition to the Chilean mineral except that considerable zinc is present.

The cupromagnesite from Vesuvius, a sulphate of copper and magnesium, is of unknown hydration. From its water solution, crystals of the heptahydrate crystallized out.

Practically pure magnesium sulphate pentahydrate, a natural dehydration product of epsomite and showing a pseudomorphous structure microscopically, being an aggregate of minute variously oriented grains, was described^b by Allen and Day from The Geysers, near Cloverdale, Sonoma County, California. The analysis (no. 3, Table II), shows that the material was almost of ideal purity.

The available analyses of magnesium sulphate pentahydrate from four localities are brought together in Table II.

TABLE II.
ANALYSES OF NATURAL MAGNESIUM SULPHATE PENTAHYDRATE.

	1 Colorado	2 Chile	3 California	4 Nevada	5 Calculated
MgO.....	19.35	11.39	17.91	9.40	19.15
CuO.....	.....	12.43	.....	9.00	.....
ZnO.....	.....	.....	.....	5.60	.....
FeO.....	.....	1.01	.23	1.36	.....
MnO.....	.....	.32	.14	.30	.....
NiO.....	.....	.06	.11	.....	.....
CaO.....	.....	.....	.13	.....	.....
SO ₃	38.51	35.70	38.13	35.07	38.07
H ₂ O.....	42.03	38.38	42.97	39.07	42.78
Insol.....	.....	.....	.....	.20	.....
	99.89	99.29	99.62	100.00	100.00

Although copper is present in two of the analyses to a considerable extent and zinc and iron in smaller but appreciable quantities, magnesium is the principal base of all. Nevertheless, the writers are hesitant about proposing a mineralogical name for the pentahydrate at present chiefly because the mineral from Nevada is only half magnesium sulphate and also because other

^b Allen, E. T., and Day, A. L.: Steam wells and other thermal activity at "The Geysers," California. Carnegie Inst. Wash., Pub. 378: 42, 1927.

properties, such as the optical ones, are not clearly defined for the pure magnesium salt.

According to Merwin⁶ there may be three modifications of $\text{MgO} \cdot \text{SO}_3 \cdot 5\text{H}_2\text{O}$. The relations of hexahydrate, described as the hexahydrate of magnesium sulphate, to the penta- and heptahydrates, are not yet clearly established.

C. Complex Samples with Ferric Sulphates.

All four samples of this complex group contain copiapite mixed with other ferric sulphates and other iron-free sulphates.

Pickeringite, Copiapite, and Epsomite.—Specimen no. 36J19 from the 231 foot level of the Central Tunnel. Massive crust, part of it like wet snow (pickeringite), the other part like finely divided sulphur (copiapite), with a small sprinkling of a saffron-colored material. A little epsomite was also noted.

The pickeringite is crystallized in the usual hair-like needles which gave decided microchemical tests for aluminum and magnesium, with minor reactions for zinc and manganese. The copiapite shows the usual aggregate of microscopic plates, with good crystallographic development, and refractive indices considerably above and below 1.55. The saffron mineral is indistinguishable from the yellow copiapite, except by a somewhat deeper color under the microscope, and is a somewhat more basic (?) ferric sulphate derived by a slight hydrolysis of the yellow copiapite.

Pickeringite, Copiapite, Alunogen, and Coquimbite.—Specimen no. SN 1900 from the north lateral of the Sutro Tunnel 1,900 feet from its junction with the main tunnel. Lumps of white crystalline material, heavily coated with scales of copiapite. Masses of this mineral alone are also present. Also noted were dark brown or greenish black particles, associated with fragments of quartzitic rock.

The white material consists of relatively coarsely-crystallized alunogen, fibrous crystals of pickeringite, and a finely crystallized

⁶ Personal communications to W. T. Schaller, May 16, 1938, and June 6, 1938.

coquimbite, resembling wet snow in appearance. All of these are fine-grained, no crystals being larger than half a millimeter.

The alunogen consists of glistening white crystalline masses, colorless under the microscope. The mean index of refraction is close to 1.47, the birefringence around 0.01. It is readily soluble in water, gives no test for iron, and a strong test for aluminum (using caesium chloride). The alunogen crystals resemble in outline those of the copiapite, having a similar platy habit, but are coarser and less perfectly formed.

The fibers of pickeringite are similar to those described elsewhere in this paper.

The coquimbite is colorless under the microscope, short prismatic, with positive elongation. The mean index of refraction is close to 1.55, the birefringence low, the interference color an abnormal blue. It is not readily soluble in cold water; the acid solution gives good tests for ferric iron and sulphate, a slight test for magnesium, and none for ferrous iron.

Larsen and Berman⁷ list coquimbite as having a composition $\text{Fe}_2\text{O}_3 \cdot 3\text{SO}_3 \cdot 9\text{H}_2\text{O}$, uniaxial positive, with indices 1.550 and 1.556, and being soluble in water. Another listing (page 69) of a questionable coquimbite has a slightly different composition, and the mineral is described as soluble in boiling water, and has much greater birefringence. Dana⁸ says coquimbite is wholly soluble in cold water, and is decomposed on boiling.

The copiapite is well crystallized, showing under the microscope a general tabular habit, with excellent development of the faces m, o, s, and b as figures in Dana's System.⁹ No interference figures were obtained on the plates. Pleochroism is distinct from practically colorless to yellow. The two measured refractive indices on the plates were 1.535 and 1.59.

Larsen and Berman¹⁰ give $\alpha = 1.530$, $\beta = 1.550$, $\gamma = 1.592$.

⁷ Larsen, E. S., and Berman, Harry: The microscopic determination of the non opaque minerals. U. S. Geol. Surv., Bull. 848: 69-70, 1934.

⁸ Dana, J. D., System of mineralogy, 1915, p. 956.

⁹ *Op. cit.*, p. 965.

¹⁰ *Op. cit.*, p. 104.

The very small deep green or brown or black particles and patches seem to be opaque under the microscope. It is impossible to separate them from the other constituents clearly enough for chemical determination. They may be altered voltaite.

Pickeringite, Epsomite, Copiapite, and Voltaite.—Specimen no. 36J20 from the Central Tunnel, 231 foot level. Crust on drift wall, composed of variously colored minerals, all sulphates, except for some fragments of quartz. Hydrolysis has occurred, resulting in the formation of free sulphuric acid, which has attacked the paper bag in which the samples were wrapped.

The minerals recognized are white pickeringite and epsomite, yellow copiapite, and greenish-black voltaite; in fairly equal proportions, with perhaps least of the epsomite.

The pickeringite and epsomite probably deviate in composition from the simple formulas $MgO \cdot Al_2O_3 \cdot 4SO_3 \cdot 22 H_2O$ and $MgSO_4 \cdot 7H_2O$, respectively, for tests on the bulk sample showed both zinc and manganese to be present in minor quantity. The copiapite occurs in the usual excellent microscopic platy crystals. In part, it seems to have been altered to a darker reddish-brown substance, of variable but higher indices of refraction, suggesting a mixture of poorly defined substances.

The most interesting mineral in this aggregate is the voltaite. It forms rather conspicuous dark green masses, without any definite boundaries, intimately mixed with the other minerals. It is practically impossible to isolate it pure enough in quantities sufficient for accurate analysis, but by washing with cold water most of the other minerals may be removed. An excellent test for potassium was obtained from the material thus cleaned, also tests for ferrous and ferric iron. The larger masses do not show clearly-defined optical characters, some parts being apparently isotropic. Other parts have a vague radial crystallization. Good crystals, however, of microscopic size, can be found enmeshed in the pickeringite and especially the copiapite aggregates. These are dark-green (lighter-green by transmitted light), of high index, near 1.59, and low birefringence. Under crossed nicols some appear to be isotropic; the variously-birefringent segments of

others suggest fourlings or fivelings, as have been previously described for voltaite.

In view of the complex and uncertain formula for voltaite, and the heterogeneity of the sample, an analysis was not undertaken, as its interpretation would rest on too many variable assumptions.

Alunogen, Epsomite, Gypsum, Copiapite, and Rhomboclase.—Specimen no. 36J10 from the Central Tunnel level. Stalactitic crusts, the individual stalactites averaging 1 to 2 centimeters in length and about a centimeter thick, showing concentric banding on a very fine scale, with the interior portion pale-yellow, the outer brick-red. With a hand lens the pale-yellow interior is seen to consist of two materials, one granular like tiny grains of sulphur, and the other glistening colorless micaceous appearing scales.

Optical examination, supplemented by qualitative tests, showed the outer brick-red zones to be of rather variable nature, both in the indices of refraction, ranging below and above 1.57, and in intensity of color. Some of it appears uncrystallized and some an exceedingly fine-grained aggregate of brightly polarized particles. From the bulk analysis given below it is inferred that the material is a basic ferric sulphate, related to rhomboclase, $\text{Fe}_2\text{O}_3 \cdot 4\text{SO}_3 \cdot 9\text{H}_2\text{O}$. Its precise nature cannot be determined, owing to its complexity. Scattered about the outermost brown shell are numerous bright red or scarlet masses of microscopic size. They have rounded contours, rather than angular, and appear to be hygroscopic, to some degree liquid. They may be a saturated solution of ferric sulphate in equilibrium with a crystalline phase of some basic ferric sulphate.¹¹

The sulphur-yellow particles are too fine-grained for any definite microscopic study. They appear to have rather high indices and birefringence, and may be copiapite.

¹¹ Concerning this, Hintze, (*op. cit.*, p. 4394) states that all the mineral ferric sulphates, including both the truly basic and the so-called "normal" salts, are ferric hydroxy-compounds. Even the "acid ferric sulphate" is considered to be a hydroxy-compound, derived from complex ferrisulphuric acids, of which botryogen and roemerite are salts. Hintze further classes the basic ferric sulphates according to the $\text{SO}_3 : \text{Fe}_2\text{O}_3$ ratio, varying from 3:1 in coquimbite to less than 1:1 in amorphous gels such as glockerite and pissophane.

The colorless micaceous-appearing material resolves itself under the microscope into two distinct minerals, one having the characters of epsomite, the other, present in about equal quantity, consisting of minute flakes of very low birefringence, with the lowest observed index near 1.46, and the highest near 1.465. From the mixture of the two minerals (it being impossible to separate them) a fair test for ferric iron and a strong test for aluminum were obtained; it is therefore inferred that the weakly-polarizing flakes are a basic aluminum sulphate, with some ferric iron isomorphously present. Much difficulty was found in determining the optical character; the plates were very small, and gave a vague figure of possibly negative character. These characters accord with those of alunogen, which has a platy development parallel to (010), to which the obtuse bisectrix is normal. The small optic angle can only be observed on the acute bisectrix, which is nearly parallel to the plates.

Besides the epsomite and alunogen, minute quantities of sharp prisms, extinguishing around 45° , and showing "swallow-tail" cleavage and terminal re-entrant angles, were seen; they have indices near 1.52, and are probably gypsum. It is also possible that a little pickeringite is also present. It thus appears that in addition to the identified epsomite and alunogen, there are less certainly determined basic ferric sulphates, as rhomboclase and copiapite, and, in very minor quantity, gypsum and pickeringite.

An analysis of one of the stalactites gave:

		Ratios
Insoluble.....	.13	
CuO.....	.19	2
FeO.....	.83	11
MgO.....	4.31	107
CaO.....	Trace	
MnO.....	.65	9
ZnO.....	Trace	
Al ₂ O ₃	6.74	66
Fe ₂ O ₃	8.49	54
SO ₃	35.63	445
H ₂ O (by diff.).....	43.03	2388
	<hr/>	
	100.00	

This analysis may be computed into 42 per cent alunogen, 30 per cent epsomite, and the remainder basic ferric sulphates such as rhomboclase and copiapite. The computation, however, is

merely an approximation to the actual composition of the complex stalactites.

Composition of the Samples.

Table III recapitulates the mineralogical composition of the seventeen samples. The figures represent approximate percentage of the entire sample. X indicates the mineral is abundant in the sample and x that it is present in small quantities.

TABLE III.

Mineral	Sample number																
	36J01	36J16	36J21	36J17	36J36	36J15	36J12	36J11	36J18	36J31	ST 2260	36J19	SN 1900	36J20	36J10	SS 6200	36J45
Gypsum.....																	
Epsomite.....			88	88	99			20	30	16	8	x		X	x	X	100
Goslarite.....		98				99											
Melanterite...	92																
Magnesium sulphate pentahydrate.....							X										
Pickeringite...		2					x	80	68	84	92	X	X	X	?		
Coquimbite...													X				
Alunogen.....													X		X		
Copiapite.....												X	X	X	?		
Voltaite.....													?	X			
Rhombochase..															?		
Basic ferric sulphates.....							x										
Clay, etc.....	8		12	12	1	1			2			x					

MINE WATERS.

Analyses of eight samples of mine waters from the Comstock Lode are given in Table IV. Of these, nos. 1 to 4 are new and nos. 5 to 8 have been taken from published reports. With the exception of no. 8, the waters are all of the same general type being essentially solutions of calcium (magnesium, sodium, potassium) sulphate and bicarbonate or carbonate. Nos. 2, 3, 4, and 5 are cold water of undoubted meteoric origin that have descended these fissures and old mine workings and have dissolved mineral matter en route. They differ very little from the hot waters represented by analyses 1, 6, and 7 except that the two

samples from deep workings (nos. 6 and 7) contain less carbonate in solution.

TABLE IV.
MINE WATERS OF THE COMSTOCK LODE, NEVADA.
(Parts per million.)

	1	2	3	4	5	6	7	8
	Yellow Jacket Sutro Tunnel level	Central Tunnel	Sutro Tunnel	Hale and Norcross Sutro Tunnel level	Savage 600' level	C. & C. Shaft 2250' level	Union Consol. 2650' level	Central Tunnel
Temperature.....	130° F.	Cold	80° F.	Cold	...	Hot	130° F.	Cold
CO ₂	None	None	None	None	....	....	9.3	....
HCO ₃	387	184	301	307	236	41.7	None	....
SO ₄	972	725	320	1,302	380.7	474.8	752	193,450
Cl.....	8	34	10	14	1.3	19.0	12.0	128
HS'.....	0.3	None	None	0.8	....	....	....	....
F.....	0.8	0.4	None	0.8	....	....	....	....
Ca.....	334	217	141	218	148.3	100.4	204.0	1,244
Mg.....	82	86	31	113	20.9	5.8	4.0	6,519
Na.....	55	32	54	45	57.1	130.6	145.0	535
K.....	10	15	9	9	8.4	53.4	8.4	....
Al'''.....	....	....	....	....	....	....	....	9,638
Fe'''.....	....	....	....	....	....	....	....	5,025
Mn.....	....	....	....	....	....	....	None	900
Cu.....	....	....	....	....	....	....	....	148
SiO ₂	49	13	34	24	30.5	133.4	61.0	616
Al ₂ O ₃	1.9	3.2	0.8	1.9	....	2.5	....	....
Fe ₂ O ₃	0.7	0.6	0.4	0.6	....	9.1	None	....
OH.....	....	....	....	....	....	....	7.5	....
H.....	....	....	....	....	....	....	....	2,822
Total.....	1,900.7	1,310.2	901.2	2,041.6	883.2	970.7	1,203.2	221,025

1. Water flowing from cross-cut to Yellow Jacket mine on the Sutro Tunnel level. Rate of flow, 100± gal. per minute. Temperature, 130° F. (U. S. G. S. 8377). Charles Milton, analyst.

2. Central Tunnel. Descending mine water flowing one-half gal. per minute from chute on 231 ft. level (U. S. G. S. 8826). Charles Milton, analyst.

3. Drip in Sutro Tunnel about 14,200 feet from portal. Drip approximately 29 gals. per minute, 80° F. (U. S. G. S. 8829). Charles Milton, analyst.

4. Water flowing from cross-cut to the Hale and Norcross mine, Sutro Tunnel level. Rate of flow approximately 25 gal. per minute (U. S. G. S. 8876). Charles Milton, analyst.

5. Savage mine, 600 ft. level. S. W. Johnson, analyst. Ex-

plorations of the Fortieth Parallel, vol. III, p. 87. (Analysis recalculated.)

6. C. & C. Shaft, 2250 ft. level. N. E. Wilson, analyst. John A. Reid, Bull. California Univ. Dept. of Geol., vol. 4, pp. 177-199, 1905. (Analysis recalculated.)

7. Hot water (130° F.) from Union Consolidated mine, 2650 ft. level. Chase Palmer, analyst. Edson S. Bastin, Bull. U. S. G. S. 735-C, pp. 41-63.

8. Vadose water, Central Tunnel. N. E. Wilson, analyst. See paper by J. F. Reid above cited, p. 192 (analysis recalculated and adjusted). However, Wilson,¹² who analyzed no. 6, notes that his CO₂ determination is low because the sample was exposed to air for some days before analysis. Wilson also evaporated 10 liters of this water and by microscopic measurement of the assay button determined the precious metal content to be 0.298 milligrams of gold and 2.92 milligrams of silver per ton of water. This silver content—about 3 parts in a thousand million—lies very near the limit of analytical skill. Even though the results are accurate, it should be noted that sea water, from the Kristiana Fjord, Norway, was found to contain 5 to 6 milligrams of gold and 19 to 20 milligrams of silver per ton.¹³

In the analyses of Comstock waters listed, the writers see no internal evidence to support a magmatic origin for them.

Analyses 1 to 7 represent waters too dilute to deposit sulphates although some of them are depositing carbonates. Fig. 4 shows a deposit of calcium carbonate from water no. 3 that coats lagging on the wall of the tunnel and a barrel resting on the tunnel floor.

The only analysis of a highly concentrated sulphate water of the type from which the salts herein described might be deposited is no. 8. In addition to the metallic constituents determined it is probable that several hundred parts per million of zinc are also present.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.,
Aug. 9, 1938.

¹² Reid, J. A.: The structure and genesis of the Comstock Lode, Univ. of Calif. Pub., Bull. of the Dept. of Geology, 4: 190, 1905.

¹³ Clarke, F. W.: Data of geochemistry. U. S. Geol. Surv. Bull. 770: 124, 1924.