

Christite, a new thallium mineral from the Carlin gold deposit, Nevada

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Abstract

Christite, TlHgAsS_3 , occurs with realgar, orpiment, and lorandite in barite veins and with realgar, lorandite, and getchellite in mineralized carbonaceous silty dolomite in the Carlin gold deposit, north-central Nevada. The mineral is named for Dr. Charles L. Christ of the U.S. Geological Survey. The color is crimson or deep red, but varies to bright orange in thinner plates and crystals; the streak is bright orange, and the luster is adamantine. The mineral is monoclinic, space group $P2_1/n$, $a = 6.113(1)$, $b = 16.188(4)$, $c = 6.111(1)$ Å, with $\beta = 96.71(2)^\circ$, $Z = 4$, and cell volume = 600.6 \AA^3 . Strongest X-ray powder diffraction lines, in Å, and their relative intensities are 2.98 (10), 3.62 (8), 3.49 (6), 2.692 (6), 2.216 (5), 4.03 (6), and 3.36 (5). Electron microprobe analyses gave Tl 35.2, Hg 35.1, As 13.1, S 16.6, sum 100.0 weight percent. The mineral occurs in small subhedral to anhedral grains which usually lack well-developed forms but may show a bladed or flattened habit. Synthetic crystals are tabular, show {010} and {101} pinacoids, and {110} and {011} prisms, and have perfect {010}, excellent {110} and {001}, and good {101} cleavages. Vickers hardness varied from 28.3–34.6 and averaged 31.5 kg mm^{-2} (10 determinations). Density of synthetic TlHgAsS_3 is 6.2(2) (meas) and 6.37 g cm^{-3} (calc). In reflected light christite is grayish-white with a faint blue tint, lacks visible bireflectance, is anisotropic, and has a brilliant red-orange internal reflection. Reflectances in air are: $R_{650\text{nm}} = 23.7\text{--}23.9$; $R_{589\text{nm}} = 24.9\text{--}25.2$; $R_{546\text{nm}} = 26.5\text{--}26.9$; and $R_{470\text{nm}} = 29.6\text{--}30.0$.

Introduction

The Carlin gold deposit, located about 50 km northwest of the town of Elko in north-central Nevada, is the largest of the disseminated replacement-type gold deposits in North America. Large amounts of mercury, arsenic, antimony, and thallium are closely associated with gold in mineralized silty argillaceous dolomite beds in the Robert Mountains For-

mation. These elements occur with gold on the surfaces of pyrite grains and form a wide variety of sulfide and sulfosalt minerals. Christite has been found in specimens containing large amounts of arsenic-rich minerals.

Christite is named for Dr. Charles L. Christ of the U.S. Geological Survey in recognition of his outstanding contributions in the fields of crystallography, mineralogy, and geochemistry. Christite is

pronounced *krist'-ite* (as in crystal). The name has been approved by the Commission of New Minerals and Mineral Names of the International Mineralogical Association.

The type material is deposited in the Smithsonian Institution, Washington, D. C., and in the Collection of Epithermal Ores and Minerals, Department of Geology, Stanford University, Stanford, California.

Occurrence

Christite has been found in two areas in the Carlin deposit, with somewhat different mineral associations and host materials. Small isolated euhedral to subhedral crystals of christite occur intergrown with lorandite, realgar, and orpiment between platy crystals of barite in small cavities and open spaces along the margins of barite veinlets. This area is near the bottom of the oxidized section in the East ore zone between the 6400 and 6420 benches near mine coordinates 22,800 N, 19,750 E (Radtke, 1973). Christite also occurs with abundant realgar and small amounts of lorandite, getchellite, and an undescribed new thallium-arsenic-sulfide mineral, in small veinlets filling microfractures and in small seams and patches along bedding planes in mineralized silty carbonaceous dolomite beds of the Roberts Mountains Formation in the East ore zone. Samples which contained christite in this latter occurrence were found on the 6340 and 6360 benches between mine coordinates 23,100 N, 20,300 E and 23,500 N, 20,700 E (Radtke, 1973).

Christite is one member of a group of primary Tl-bearing minerals of hydrothermal origin found at the Carlin deposit. These include Tl-bearing orpiment (Radtke *et al.*, 1974), lorandite, TlAsS_2 (Radtke *et al.*, 1973a), carlinitite, Tl_2S (Radtke and Dickson, 1975), weissbergite, TlSbS_2 (Dickson and Radtke, unpublished manuscript), and a yet undescribed mineral of composition Tl_3AsS_3 . In oxidized zones the secondary mineral avicennite, Tl_2O_3 , has been found (Radtke, Dickson and Slack, unpublished manuscript); it is probable that other decomposition products of primary Tl-bearing minerals also occur at Carlin.

During the main period of hydrothermal activity, arsenic, antimony, and thallium were deposited on surfaces of pyrite grains; gold and mercury were also deposited on pyrite and combined with carbonaceous materials to form various gold and gold-mercury organic compounds. The occurrences of antimony-arsenic-mercury-thallium sulfide and sulfosalt minerals in veinlets that cut zones of gold mineralization suggest that the veinlets formed during late-stage hydrothermal activity (Radtke and Dickson, 1974).

Physical and optical properties

Christite in barite veinlets occurs in subhedral grains varying from about 0.5 mm to 1 mm in length. The crystals are usually bounded by grains of realgar and lorandite and also occur surrounded by or locked within orpiment crystals. Two grains of christite separated from barite are shown in Figure 1. In the other occurrence small anhedral christite grains up to 0.25 mm in diameter occur intergrown with lorandite, getchellite, and realgar.

The mineral usually lacks well-developed forms, although the habit of some grains is somewhat bladed or flattened. Synthetic crystals are tabular parallel to $\{010\}$ and are slightly elongated parallel to the *c* axis. Dominant forms are the $\{010\}$ and $\{T01\}$ pinacoids and the $\{110\}$ and $\{011\}$ prisms. Synthetic TlHgAsS_3 has perfect $\{010\}$ cleavage, excellent $\{110\}$ and $\{001\}$ cleavage, and good $\{T01\}$ cleavage. Fragments tend to be dominated by the micaceous $\{010\}$ cleavage, but closely-spaced slippage along other cleavages causes fragments to deform ductily to smooth curved surfaces.

The hardness of christite as determined with a Leitz hardness indenter with a 10 g load ranged from 28.3 to 34.6 and averaged 31.5 kg mm^{-2} (10 determinations). Values for synthetic TlHgAsS_3 ranged from 27.1 to 33.0 and averaged 29.8 kg mm^{-2} (8 determinations). These average hardnesses correspond to a value between 1 to 2 on the Mohs scale. The density of the mineral could not be determined because it could not be separated cleanly from other minerals. The density of synthetic christite, measured using a

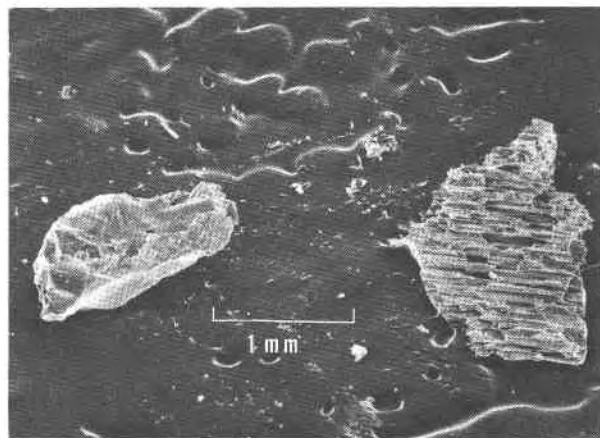


Fig. 1. Scanning electron microscope photograph of christite grains taken from a barite matrix. Fragment on left is probably lying on most prominent $\{010\}$ cleavage. Fragment on right is broken across most prominent cleavage and shows characteristically developed intersecting cleavages.

Berman balance, is $6.2(2) \text{ g cm}^{-3}$ and the calculated density is 6.37 g cm^{-3} .

Christite is deep red or crimson in color and is darker than realgar. Thin plates and small crystals are red-orange to bright orange in color, and the streak is bright orange. The luster is adamantine. The color in transmitted light ranges from deep red to orange in thick grains to deep orange, yellow-orange, and yellow in successively thinner plates. In reflected light in air the mineral is grayish-white with a faint blue tint, lacks bireflectance, and is anisotropic. The very strong brilliant red-orange internal reflection precludes determination of the degree of anisotropism. Optical properties for synthetic TlHgAsS_3 and christite are similar. Data on the reflectivities of christite and synthetic TlHgAsS_3 are given in Table 1.

Crystallography

Christite is monoclinic, space group $P2_1/n$, with $Z = 4[\text{TlHgAsS}_3]$. Unit-cell constants determined for a synthetic crystal are $a = 6.113(1)$, $b = 16.188(4)$, $c = 6.111(1) \text{ \AA}$, with $\beta = 96.71(2)^\circ$ and $V = 600.6 \text{ \AA}^3$ (Brown and Dickson, 1977). Synthetic euhedral crystals of christite display typical monoclinic $2/m$ forms.

The crystal structure (Brown and Dickson, 1977) can be described as consisting of trigonal pyramids of AsS_3 joined together by HgS_4 tetrahedra to form a polymeric two-dimensional sheet structure parallel to $\{010\}$. Thallium atoms are situated between the sheets and are weakly bonded to them. The structure of christite places it as a member of the IIa ($\phi = 3$) group of sulfosalts in the classification of Nowacki (1970).

Routhierite (Johan *et al.*, 1974) with formula $(\text{Tl,Cu,Ag})(\text{Hg,Zn})(\text{As,Sb})\text{S}_3$, is compositionally related to christite. However, in routhierite the mole ratio $\text{Tl}/(\text{Ag} + \text{Cu})$ is approximately unity, whereas christite contains no Cu or Ag (nor Zn or Sb). Routhierite differs in crystallographic properties, being tetragonal with an I -centered cell, $a = 9.997$, $c = 11.290 \text{ \AA}$, and $Z = 8$.

X-ray powder diffraction data for christite and synthetic TlHgAsS_3 and calculated d spacings and intensity values obtained from crystallographic data are given in Table 2. Data for synthetic TlHgAsS_3 were obtained from a diffractometer powder mount, and that for christite was taken from a powder film pattern generated in a Gandolfi camera. The calculated d spacings and the observed values for both christite and synthetic TlHgAsS_3 all agree reasonably well. Intensity data for christite agree well with those calculated from the structure; the variations in the intensity ratios observed in the diffractometer pattern

Table 1. Reflectivities of christite and synthetic TlHgAsS_3

Phase	Wavelength (nm)			
	470	546	589	650
Christite	29.6–30.0	26.5–26.9	24.9–25.2	23.7–23.9
Synthetic TlHgAsS_3	29.4–29.7	26.4–26.8	24.8–25.0	23.8–24.1

for the synthetic material are due in part to preferred orientations induced by the cleavages.

Chemical composition

Results of chemical analyses of christite done with the electron microprobe and the analytical conditions used are given in Table 3. The composition is TlHgAsS_3 and no other elements were present at levels detectable by microprobe analysis. Emission spectrographic analysis done on a composite sample containing several hand-picked grains confirmed the low level of other elements. Other elements detected (weight percent) include $\text{Sb} = 0.005$; $\text{Cu} = 0.002$; $\text{Fe} = 0.001$; $\text{Pb} = 0.001$; $\text{Mn} = 0.001$; $\text{Ag} = 0.0005$.

Synthesis

Christite can be synthesized by reacting fine-grained mixtures of TlAsS_2 and HgS in stoichiometric proportions in evacuated sealed glass tubes at 290°C and below. This process produces a powder with d spacings that correspond very closely with those of the mineral (Table 2). Heating above 300°C causes thermal decomposition; TlHgAsS_3 splits off HgS and an Hg-deficient TlHgAsS_3 phase is formed. At about 360°C , the Hg-deficient TlHgAsS_3 melts to produce a liquid which coexists with metacinnabar.

Single crystals were prepared for a structure determination (Brown and Dickson, 1977) by recrystallizing previously prepared TlHgAsS_3 powder in contact with a 1 percent $\text{Na}_2\text{B}_4\text{O}_7$ solution in a sealed gold tube for 4 days at 285°C and 250 bars. The recrystallized material included a small amount of some individual platy crystals on the inner walls of the gold tube as well as a porous holocrystalline cake that made up the bulk of the sample.

Conclusions

Christite is one of a group of minerals in the Carlin deposit that are remarkably pure in composition, but which occur at similar depths both as dispersed grains and in veinlets that cut unoxidized gold ores. These minerals include carlinitite Tl_2S , lorandite TlAsS_2 , realgar AsS , orpiment As_2S_3 , getchellite AsSbS_3 , weissbergite TlSbS_2 , stibnite Sb_2S_3 , and

Table 2. X-ray powder diffraction data for christite and synthetic TlHgAs₃

hkl	Synthetic TlHgAs ₃			Christite		
	Diffractometer Pattern		I	Powder Pattern		I
	calculated* d Å hkl	observed** d Å hkl		calculated d Å hkl	observed*** d Å hkl	
020	8.094	8.08	6	9	8.10	<1
110	5.685	5.70	<1	2	5.69	<1
011	5.683					
120,021	4.856					
101	4.567	4.87	3	14	4.83	3
		4.57	1	19	4.58	2
111	4.396	4.40	1	7	4.41	1
101	4.062	4.06	8	3	---	---
040	4.047	4.04	44	47	4.03	6
130,031	4.033					
121	3.977					
121	3.630	3.63	18	83	3.62	8
131	3.486	3.49	20	55	3.49	6
140	3.368	3.37	26	31	3.36	5
041	3.367					
131	3.245					
200	3.036	---	---	<1	---	---
002	3.035	---	---	<1	---	---
141	3.029	3.03	15	24	---	---
210	2.984	2.983	21	100	2.98	10
012	2.983					
141	2.867	---	---	6	---	---
150	2.857	2.853	10	5	---	---
051	2.856					
220	2.842					
022	2.841	2.841	8	23	2.84	3
211	2.808	2.804	5	31	2.81	3.5
112	2.808					
060	2.698	2.695	100	49	2.692	6
221	2.689	---	---	2	---	---
122	2.689	---	---	1	---	---
230	2.646	---	---	1	---	---
032	2.645	---	---	1	---	---
151	2.641	2.642	2	<1	---	---
211	2.564	---	---	2	---	---
112	2.563	---	---	1	---	---
231	2.521	2.518	2	7	2.511	1
132	2.521					
221,122	2.472					
160,061	2.465	2.469	22	16	2.461	3
240,042	2.428	2.428	1	2	---	---
231	2.340	---	---	2	---	---
132	2.339	---	---	2	---	---
241	2.331	---	---	<1	---	---
142	2.331	---	---	<1	---	---
161	2.323	2.322	1	2	2.326	<1
202	2.284	2.283	1	15	2.272	<1
212	2.261	2.259	<1	3	---	---
161	2.247	2.246	1	2	---	---
250,052	2.214	2.210	19	41	2.216	5
241,142	2.185	2.186	2	7	---	---
170,071	2.161	2.158	2	1	---	---
251	2.140	---	---	<1	---	---
152	2.140	---	---	<1	---	---
232	2.103	2.101	2	12	2.102	2
171	2.063	2.062	12	10	2.059	2
202	2.031	---	---	4	---	---
251,152	2.025	---	---	<1	---	---
080	2.023	2.022	10	4	2.020	2.5
260	2.017	---	---	1	---	---
062	2.016	---	---	1	---	---

*All calculated hkl's listed for $d_{hkl} \geq 2.016\text{\AA}$. The complete pattern is available from the Joint Committee on Powder Diffraction Standards, 1601 Park Lane, Swarthmore, Pennsylvania 19081. d values and I calculated were determined from crystallographic data on synthetic TlHgAs₃.

**X-ray diffractometer conditions are: Ni-filtered Cu radiation; CuK α = 1.54178Å; silicon internal standard; scanned at $\frac{1}{2}^\circ$ 2 θ per minute.

***Film 789, 1975, A.S. Radtke, U.S. Geological Survey; Ni-filtered Cu radiation, CuK α = 1.54178Å; Gandolfi camera, exposure 17 hours.

Table 3. Microprobe chemical analyses of christite

Grain	Weight Percent				
	Tl	Hg	As	S	Total
1	34.9	35.1	13.2	16.6	99.8
2	35.1	35.3	13.1	16.4	99.9
3	35.9	34.6	12.9	16.8	100.2
4	34.8	35.2	13.2	16.7	99.9
Avg.	35.2	35.1	13.1	16.6	100.0
TlHgAs ₃	34.82	35.48	13.00	16.70	100.00

Analytical conditions: (1) Thallium, Mo characteristic line, ADP crystal, 15 KV; (2) Mercury, Mo characteristic line, ADP crystal, 15 KV; (3) Arsenic, L α characteristic line, ADP crystal, 15 KV; (4) Sulfur, Ka characteristic line, ADP crystal, 15 KV. Synthetic TlHgAs₃ used as standard. Beam defocused slightly to 15 μ diameter.

Tl₃As₃. Exceptionally, some orpiments contain Sb and Tl in solid solution (Radtke *et al.*, 1973b, 1974), and some stibnites contain As (Dickson *et al.*, 1975). The system Tl-Hg-As-Sb-S has natural phases of complex compositions (Johan *et al.*, 1974) and synthetic phases of fixed intermediate compositions or with extensive solid solutions (Moore and Dickson, 1973; Peterson, 1976). Where crystals have formed from polycomponent solutions or melts, it seems clear that they develop complex compositions. The implication for Carlin is that at the time of deposition these minerals grew from solutions of simple compositions in open spaces that were not effectively connected, or that they formed at different times. Probably they formed as a result of inhomogeneities of solution composition caused by fluids boiling at differential rates during the late stage of hydrothermal activity, when the boiling water-gas interface retreated into previously mineralized rocks at deeper levels (Radtke and Dickson, 1974).

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