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

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Abstract

Christite, \( \text{TlHgAsS}_3 \), 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 \( P2_1/n \), \( a = 6.113(1) \), \( b = 16.188(4) \), \( c = 6.111(1) \) \( \text{Å} \), with \( \beta = 96.71(2)^\circ \), \( Z = 4 \), and cell volume = 600.6 \( \text{Å}^3 \). Strongest X-ray powder diffraction lines, in \( \text{Å} \), 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 \( \{011\} \) pinacoids, and \( \{110\} \) and \( \{011\} \) prisms, and have perfect \( \{010\} \), excellent \( \{110\} \) and \( \{001\} \), and good \( \{011\} \) 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: \( R_{600nm} = 23.7–23.9 \); \( R_{589nm} = 24.9–25.2 \); \( R_{546nm} = 26.5–26.9 \); and \( R_{470nm} = 29.6–30.0 \).

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 Formation. 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 sub-hedral 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), carlinite, Tl$_2$S (Radtke and Dickson, 1975), weissbergite, TlSbS$_2$ (Dickson and Radtke, unpublished manuscript), and a yet undescribed mineral of composition Tl$_2$AsS$_3$. In oxidized zones the secondary mineral avicennite, Tl$_2$O$_3$, 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 flattened or flattened. Synthetic crystals are tabular parallel to (010) and are slightly elongated parallel to the c axis. Dominant forms are the (010) and (101) pinacoids and the (110) and (011) prisms. Synthetic TlHgAsS$_3$ has perfect (010) cleavage, excellent (110) and (001) cleavage, and good (011) cleavage. Fragments tend to be dominated by the micaceous (010) cleavage, but closely-spaced slipage along other cleavages causes fragments to deform ductily to smooth curved surfaces.

The hardness of christite as determined with a Leitz hardness indentor 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.
Radtke et al.: Christite

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

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 anisotropy. Optical properties for synthetic \(\text{TlHgAsS}_3\) and christite are similar. Data on the reflectivities of christite and synthetic \(\text{TlHgAsS}_3\) 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 \(a = 6.113(1) \text{ Å}, b = 16.188(4) \text{ Å}, c = 6.1111(1) \text{ Å}, \beta = 96.71(2)°\) and \(V = 600.6 \text{ Å}^3\) (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 \(\text{AsS}_3\) joined together by \(\text{HgS}_4\) 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 \((\text{Tl},\text{Cu},\text{Ag}) (\text{Hg},\text{Zn}) (\text{As},\text{Sb})\text{S}_3\) is compositionally related to christite. However, in routhierite the mole ratio \(\text{Tl}/(\text{Ag} + \text{Cu})\) is approximately unity, whereas christite contains no \(\text{Cu}\) or \(\text{Ag}\) (nor \(\text{Zn}\) or \(\text{Sb}\)). Routhierite differs in crystallographic properties, being tetragonal with an \(I\)-centered cell, \(a = 9.997 \text{ Å}, c = 11.290 \text{ Å},\) and \(Z = 8\).

X-ray powder diffraction data for christite and synthetic \(\text{TlHgAsS}_3\) and calculated \(d\) spacings and intensity values obtained from crystallographic data are given in Table 2. Data for synthetic \(\text{TlHgAsS}_3\) 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 \(\text{TlHgAsS}_3\) 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 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 \(\text{TlHgAsS}_3\) 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 \(\text{TlAsS}_2\) and \(\text{HgS}\) 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; \(\text{TlHgAsS}_3\) splits off \(\text{HgS}\) and an Hg-deficient \(\text{TlHgAsS}_3\) phase is formed. At about 360°C C, the Hg-deficient \(\text{TlHgAsS}_3\) 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 \(\text{TlHgAsS}_3\) 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 carlinite \(\text{TlS}_2\), lorandite \(\text{TlAsS}_2\), realgar \(\text{AsS}\), orpiment \(\text{As}_2\text{S}_3\), getchellite \(\text{AsSbS}_3\), weissbergite \(\text{TISbS}_3\), stibnite \(\text{Sb}_2\text{S}_3\), and
Table 2. X-ray powder diffraction data for christite and synthetic TlHgAsS$_3$

<table>
<thead>
<tr>
<th></th>
<th>Synthetic TlHgAsS$_3$</th>
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<th>Christite</th>
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<tbody>
<tr>
<td></td>
<td>Powder Diffractometer</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Pattern calculated</td>
<td></td>
<td>observed</td>
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<td></td>
<td>d Å</td>
<td>hkl</td>
<td>t</td>
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<td>4.04</td>
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<td>47</td>
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</table>

*All calculated hkl's listed for d Å < 2.015. The complete pattern is available from the Joint Committee on Powder Diffractometer Standards, 1601 Park Lane, Swarthmore, Pennsylvania 19081. d values and I calculated were determined from crystallographic data on synthetic TlHgAsS$_3$. 

**X-ray diffractometer conditions are: Ni-filtered Cu radiation; CuKα = 1.54178Å; silicon internal standard; scanned at 5° 2θ per minute.

Table 3. Microprobe chemical analyses of christite

<table>
<thead>
<tr>
<th>Grain</th>
<th>Tl</th>
<th>Hg</th>
<th>As</th>
<th>S</th>
<th>Total</th>
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<tr>
<td>1</td>
<td>34.9</td>
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<td>13.2</td>
<td>16.6</td>
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<td>2</td>
<td>35.1</td>
<td>35.3</td>
<td>13.1</td>
<td>16.4</td>
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</tr>
<tr>
<td>3</td>
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<td>34.6</td>
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<tr>
<td>4</td>
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<td>35.2</td>
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<tr>
<td>Avg.</td>
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<td>35.1</td>
<td>13.1</td>
<td>16.6</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Tl$_x$AsS$_y$. Exceptionally, some orpiments contain Sb and Tl in solid solution (Radtke et al., 1973b, 1974), and some stibinites 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).

Acknowledgments

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