

## Carlfriesite, $H_4Ca(TeO_3)_3$ , a new mineral from Moctezuma, Sonora, Mexico

SIDNEY A. WILLIAMS, Phelps Dodge Corporation, Douglas, Arizona

AND

RICHARD V. GAINES, Pottstown, Pennsylvania

**SUMMARY.** Carlfriesite is a new species found in relative abundance at the Bambollita (now La Oriental) mine in the Sierra La Huerta near Moctezuma, Sonora. Colour primrose yellow (R.H.S. 4B) with pale yellow streak.  $H = 3\frac{1}{2}$ ,  $D_{\text{meas}} = 6.3$ ,  $D_{\text{calc}} = 5.93$ . Fair cleavage on  $\{010\}$ . Monoclinic with  $a$  12.585 Å,  $b$  5.658,  $c$  9.985,  $\beta$  115° 35'. Space group  $Cc$  or  $C2/c$ . Strongest lines are 3.167 (10), 3.082 (9B), 5.063 (6), 2.832 (6), 3.369 (4), 4.825 (3), 2.698 (3), and 4.089 (2). Feeble pleochroism in pale yellow with  $\gamma > \alpha = \beta$ ;  $\alpha = 1.982$ ,  $\beta = 2.095$ ,  $\gamma = 2.19$ ;  $2V_\alpha = 79^\circ$  calc. Occurs with cerussite and chlorargyrite in an oxidized assemblage derived from hessite, galena, and bornite.

**Occurrence.** Mine workings have exposed several parallel veins of ore, which seldom exceed two inches in width. The wallrock is a brecciated rhyolite vitrophyre that has been intensely silicified; original textures are virtually obliterated. The altered rock consists of granular quartz, some interstitial sericite, and scattered, punky white dickite pseudomorphs after sanidine. The ore veins (and subparallel veinlets) carry calcite and baryte as gangue with scattered grains of bornite, hessite, and galena.

Where the carlfriesite was found the oxidation is slightly more advanced than elsewhere, although remnants of the hypogene ore minerals have survived. Oxidation has produced fairly abundant bright yellow carlfriesite and colourful green crusts, which are a mixture of an amorphous Cu-Te compound and dickite. Less common are electrum, cerussite, chlorargyrite, and an orthorhombic copper tellurite soon to be described.

Carlfriesite occurs as botryoidal crusts lining cavities and less frequently as tiny sprays of sharply euhedral crystals. It also commonly fills cleavage-plane fractures in the baryte or occurs in tiny veinlets cutting the rock in the vicinity of sulphide grains. Rarely it is implanted directly on hessite or bornite. The mineral can be found on mine dumps, where it was first noted by R. V. Gaines, and is common underground, where it was found in abundance by Peter Embrey and Pierre Bariand.

**Physical properties.** Carlfriesite is a bright primrose yellow colour (R.H.S. 4B) with a very pale yellow streak. The Mohs hardness is  $3\frac{1}{2}$  and the mineral is brittle. No fluorescence was noted in long- or short-wave U.V. The specific gravity was determined on about 1.9 mg of material as  $6.3 \pm 0.25$  using the Berman balance (in tetrabromethane at 24 °C).

**Chemistry.** Early probe analysis of carlfriesite indicated major tellurium and calcium with minor lead. A spectrographic analysis showed, in addition to tellurium and

calcium, traces of strontium and iron but no lead. Three polished grains were analysed (20 point counts each) by electron probe (Table I). Analysed wollastonite and tellurium were used as standards. Water was determined (both qualitatively and gravimetrically) by the Penfield method. The results of the chemical analysis approximate

TABLE I. *Chemical analysis of carlfriesite*

	1	2	3	4	5	6	7	8	
Ca	7.3	7.2	7.3	CaO	—	10.2	9.8	Ca	4.40
Te	69.3	69.3	70.0	TeO <sub>2</sub>	—	87.0	83.9	Te	13.28
				H <sub>2</sub> O	6.5	6.5	6.3	H	17.56
					103.7	100.0	99.99	O	39.74

- 1, 2, 3. Electron probe analyses by R. F. Symes (British Museum, Natural History).
4. By Penfield method on 1.879 mg.
5. Average analysis.
6. Average analysis recalculated to 100 %.
7. H<sub>4</sub>Ca(TeO<sub>3</sub>)<sub>3</sub>.
8. Empirical unit cell contents.

closely to H<sub>4</sub>Ca(TeO<sub>3</sub>)<sub>3</sub>. Crystals are decomposed in warmed 1:1 HCl but are unaffected by cold 1:1 HCl, 1:1 HNO<sub>3</sub> (hot or cold), or 40 % KOH (hot or cold).

*Morphology.* Clusters of tiny crystals were found on one of the dump samples. The largest of these crystals measured only 0.20 mm in longest dimension. On the

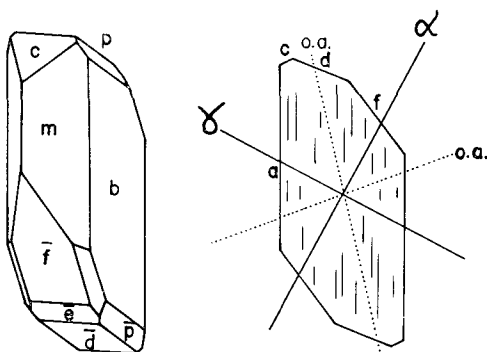


FIG. 1. Idealized crystal of carlfriesite (left) and optic orientation on *b* (010).

goniometer this crystal gave sharp reflections for most faces in the [010] zone and for *p* {111}; other *hkl* faces tend to be curved giving the crystal an 'axe head' habit somewhat reminiscent of sphene. No twinning could be proved either by goniometry or optical study.

Most material is not well crystallized. Thin sections show a tendency for crystals to be curved on {010}, which is a plane of fair cleavage, or intergrown in complex fishbone textures with random orientations of individual crystallites. Some specimens

exhibit botryoidal crusts, which are seen in thin section to be radially disposed aggregates of flat, spear-shaped crystallites elongated approximately on [001].

The measured crystal is shown in fig. 1 but the crystal has been thickened somewhat on [010] to facilitate drawing. Table II is an angle table for this crystal calculated from the refined X-ray cell. Face poles could generally be located within a degree or less with the two-circle goniometer.

*Optics.* In thin section carlfriesite is very pale buttery yellow and, with its high birefringence, resembles sulphur. Pleochroism is weak (in yellows) with  $\gamma > \alpha = \beta$ . The indices of refraction for the sodium D line are  $\alpha$  1.982,  $\beta$  2.095,  $\gamma$  2.19. The  $\gamma$  value was determined in S-Se melts. The  $2V_\alpha$  calculated is  $79^\circ$  and  $80^\circ$  measured on the universal stage. The optic orientation is shown in fig. 1. The value for  $\alpha$ : [001] is  $28^\circ$  in the acute angle  $\beta$ , and  $\beta \parallel [010]$ . Crystal fragments lying on the {010} cleavage show maximum birefringence and give a flash figure.

TABLE II. *Calculated angle table for carlfriesite*

$$a:b:c = 2.22:1:1.76 \quad \beta = 115^\circ 42'$$

	<i>hkl</i>	$\phi$	$\rho$	$\phi_2$	$\rho_2$	C	A
<i>c</i>	001	90° 00'	25° 42'	64° 18'	90° 00'	—	64° 18'
<i>b</i>	010	0° 00'	90° 00'	—	0° 00'	90° 00'	90° 00'
<i>m</i>	110	26° 34'	90° 00'	0° 00'	26° 34'	78° 49'	63° 26'
<i>d</i>	101	-90° 00'	21° 59'	111° 59'	90° 00'	47° 40'	111° 59'
<i>e</i>	302	-90° 00'	40° 14'	130° 14'	90° 00'	65° 55'	130° 14'
<i>f</i>	201	-90° 00'	52° 11'	142° 11'	90° 00'	77° 53'	142° 11'
<i>t</i>	111	37° 41'	65° 54'	36° 13'	43° 45'	52° 25'	56° 06'
<i>p</i>	111	-12° 51'	61° 08'	111° 59'	31° 22'	69° 29'	101° 14'
<i>q</i>	211	-36° 04'	65° 26'	142° 11'	42° 41'	81° 49'	122° 23'

TABLE III. *X-ray powder data for carlfriesite, Cr-K $\alpha$  radiation*  
114 mm camera

<i>I</i> <sub>est</sub>	<i>d</i> <sub>meas</sub>	<i>d</i> <sub>calc</sub>	<i>hkl</i>	<i>I</i> <sub>est</sub>	<i>d</i> <sub>meas</sub>	<i>d</i> <sub>calc</sub>	<i>hkl</i>	<i>I</i> <sub>est</sub>	<i>d</i> <sub>meas</sub>	<i>d</i> <sub>calc</sub>	<i>hkl</i>
6	5.063	5.064	110	9B	3.082	{ 3.083	112	3	2.698	2.699	021
3	4.825	4.829	111			{ 3.073	402	1	2.571	2.570	221
2	4.089	4.090	111	1	2.960	2.960	202	2	2.498	2.495	204
4	3.369	3.370	311			{ 2.829	020				
10	3.167	3.167	312	6	2.832	{ 2.838	400				
						{ 2.833	113				

plus 20 additional lines to  $d = 1.583$ , none stronger than  $I_{est} = 2$

*X-ray.* Several powder patterns were taken representing crystals, botryoidal material, and slightly greenish botryoidal crusts. Results were remarkably consistent with no measurable variations in  $d$  spacings. An indexed pattern is given in Table III.

The measured single crystal was examined by rotation and Weissenberg methods and the diffraction symmetry obtained permits space groups  $Cc$  or  $C2/c$ . No other evidence was obtained to indicate symmetry less than  $2/m$ . Cell parameters found by single crystal work were refined from powder film measurements giving  $a$   $12.585 \text{ \AA} \pm 0.024$ ,  $b$   $5.658 \pm 0.008$ ,  $c$   $9.985 \pm 0.028$ ;  $\beta$   $115^\circ 35' \pm 7'$ . For the cell volume the calculated specific gravity is 5.93 if  $Z = 4$ .

Carlfriesite is named in honour of Carl Fries, Jr. (1910-65), of the U.S. Geological Survey and the Instituto de Geologia of the National University, Mexico. Nearly all

of Carl Fries's professional life was spent in Mexico, a country he loved and understood and which became his adopted home. He made important contributions to the geology and mineralogy of Mexico, and is especially remembered for his monumental studies of the geology of Morelos state, and of the Pachuca Mining District. Type specimens of carlfriesite are at the British Museum (Natural History) and the University of Paris. Doubtless several grammes of material have been found at the locality.

The species and name have been approved by the I.M.A. Commission on New Minerals and Mineral Names.

*Acknowledgements.* We are grateful to R. F. Symes of the British Museum (Natural History) for electron probe analyses (including sample preparation).

[*Manuscript received 26 August 1974*]