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## Girdite, oboyerite, fairbankite, and winstanleyite, four new tellurium minerals from Tombstone, Arizona

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**SUMMARY.** Girdite,  $H_2Pb_3(TeO_3)TeO_6$  is white,  $H = 2$ ,  $D = 5.5$ . Crystals are complexly twinned and appear monoclinic domatic. The X-ray cell is  $a = 6.241\text{\AA}$ ,  $b = 5.686$ ,  $c = 8.719$ ,  $\beta = 91^\circ 41'$ ;  $Z = 1$ .

Oboyerite is  $H_6Pb_6(TeO_3)_3(TeO_6)_2 \cdot 2H_2O$ .  $H = 1.5$ ,  $D = 6.4$ . Crystals appear to be triclinic but are too small for X-ray work.

Fairbankite  $PbTeO_3$  is triclinic  $a = 7.81\text{\AA}$ ,  $b = 7.11$ ,  $c = 6.96$ ,  $\alpha = 117^\circ 12'$ ,  $\beta = 93^\circ 47'$ ,  $\gamma = 93^\circ 24'$ ,  $Z = 4$ . Indices are  $\alpha = 2.29$ ,  $\beta = 2.31$ ,  $\gamma = 2.33$ .

Winstanleyite,  $TiTe_3O_8$ , is cubic  $Ia\bar{3}$ ,  $a = 10.963\text{\AA}$ . Crystals are cubes, sometimes modified by the octahedron; colour Chinese yellow,  $H = 4$ ,  $n_D = 2.34$ .

All of the above species were found in small amounts on the waste dumps of the Grand Central mine, Tombstone, Arizona, associated with a wealth of other tellurites and tellurates.

SINCE the discovery of rodalquilarite at Tombstone, Arizona, more than thirty new tellurium oxysalts have been found there. The use of a backhoe to excavate in the remains of waste dump material facilitated the discovery of eighteen new species at the Grand Central mine alone, and it was during this project that these four new species were found.

Tellurium minerals were noted by Rasor (1937) in the Joe Shaft, a companion to the Grand Central, but were not investigated. Evidently they were once abundant, for emmonsite and rodalquilarite are fairly common in the waste dumps. All other tellurium minerals are rare however, and they seem to have occurred only in the richest ores.

Little is known of the primary ores whose oxidation produced such a wealth of tellurites and tellurates. At the Grand Central mine the following

species have been identified: hessite, empressite, krennerite, rickardite, and tellurium. Altaite has not been found although relict galena is not uncommon.

*Girdite.* About a dozen samples displaying this mineral were found. Girdite usually occurs as spherules up to 3 mm in diameter. These are dense, chalky, and brittle with little hint of a crystalline druse on the surface. The spherules resemble those of oboyerite closely, they also resemble warty crusts of kaolin and hydronium alunite to be found at the locality. The first specimen found, however, was exceptional. This has spherules and bow-tie aggregates of slender tapered prisms; these spherules are up to 6 mm across. The tapered prisms are seen in thin section to be polycrystalline and at their terminations there may be clear, complexly twinned crystals that seem to be monoclinic with class  $m$  symmetry.

Girdite spherules usually occur on fracture surfaces within sheared vein quartz gangue or cutting a massive wallrock composed mostly of adularia. Species occurring within these ores (and presumably paragenetically older) include rodalquilarite, chlorargyrite, gold, anglesite, and unknown tellurites or tellurates. Still other unknown species occur on fractures with girdite.

Although spherules are tough and brittle the Mohs hardness is only 2. The specific gravity, determined by Berman Balance in toluene on a sample of 3.8 mg is  $5.5 \pm 0.2$  (avg. of three trials). Girdite is non-fluorescent.

Spectrographic analysis of girdite showed only Pb, Te, and Ag (the latter due to microscopic inclusions of chlorargyrite) and microchemical methods failed to detect any other anions. Wet chemical

TABLE I. Chemical analyses of girdite

	1	2	3	4	5
PbO	61.4%	60.7%	63.2%	0.283	65.4%
TeO <sub>2</sub>	16.6	15.3	16.5	0.103	15.6
TeO <sub>3</sub>	18.3	16.9	18.2	0.104	17.2
H <sub>2</sub> O	(2.0)	(2.0)	2.1	0.115	1.8
Insol.	0.7	2.5	—	—	—
	99.0	97.4	100.00		100.0

1. On 1620  $\mu\text{g}$
2. On 2242  $\mu\text{g}$
3. Avg. of 1 and 2 reset to 100%
4. Ratios
5. Theory for H<sub>2</sub>Pb<sub>3</sub>(TeO<sub>3</sub>)TeO<sub>6</sub>

analyses of two samples are presented in Table I. In each analysis, some quartz and chlorargyrite were recovered and weighed as 'insol.' but in dealing with such tiny amounts losses of even traces of material could easily explain the low analytical summations.

Girdite is readily soluble in cold 1:1 HNO<sub>3</sub> and HCl. Water was determined quantitatively in the closed tube (and easily seen) using a 3.777 mg sample. Loss of water occurred during decrepitation, followed by fusion to a blebby-yellow slag.

Although no single crystals were found, a few fragments were obtained from the tips of the bow-tie 'crystals' described earlier. Even the best fragments obtained showed only a few crystal faces and were too small to orient for optical goniometry. One such fragment was employed for rotation and Weissenberg level photographs giving the following cell:  $a = 6.241 \text{ \AA}$ ,  $b = 5.686$ ,  $c = 8.719$ ,  $\beta = 91^\circ 41'$ . With  $Z = 1$ , the calculated density is 5.49 g/cm<sup>3</sup> (using the ideal formula for the calculation). Powder data were used to refine the cell and are presented in Table II.

The crystal fragments gave the following optic orientation:  $\gamma = b$ ,  $\beta: [001] 34^\circ$  (in acute  $\beta$ ). The indices were measured in S-Se melts as  $\alpha = 2.44$ ,  $\beta = 2.47$ ,  $\gamma = 2.48$ . The  $2V_d$  measured is  $70^\circ$  and strong dispersion  $\rho > \nu$  can be seen in larger crystals. The petrographer probably could not identify the typically fine-grained material in thin section for it resembles any number of lead minerals; coarser crystals could easily be mistaken for fairbankite.

The mineral is named to honour Richard Gird, mining engineer and assayer, who assayed the first rich silver ores found at Tombstone and, with the Schicffelin brothers, worked to open up the district.

*Oboyerite*. This new species was found during

excavations in the waste dumps of the Grand Central mine at Tombstone. Only two fist-sized pieces were found. The first of these is also the only known specimen containing fairbankite and the study of both oboyerite and fairbankite was based entirely on this specimen.

TABLE II. X-ray powder data for girdite. Cr-K $\alpha$  radiation, 114 mm camera

<i>I</i> est	<i>d</i> meas	<i>d</i> calc	<i>hkl</i>	<i>I</i> est	<i>d</i> meas
1	5.027	5.004	101	7	1.682
7	3.118	3.119	200	7	1.670
10	3.054	3.055	11 $\bar{2}$	2	1.562
7	2.994	2.995	112	6	1.529
8	2.842	2.843	020	4	1.499
1/2	2.711	2.703	021	3	1.424
1/2	2.516	2.502	202	6	1.383
1/2	2.390	2.381	022	7	1.368
5	2.179	2.179	004	5	1.343
7	2.102	2.101	220	5	1.328
1	1.967	1.966	213	6	1.295
5	1.813	{ 1.814 1.811	{ 130 204	{ 3 3	{ 1.288 1.253
5	1.802	1.801	312	5	1.193
8	1.765	{ 1.762 1.764	{ 204 312	{ 7 4	{ 1.184 1.174
5	1.731	{ 1.729 1.726	{ 024 214	{ 4 4	{ 1.167 1.153

The rock consists mainly of fine-grained adularia (altered shale) hosting fine-grained jarosite pseudomorphs after pyrite and squarish, partly filled or lined voids derived from galena. These voids are typically lined with jarosite and fairbankite crystals, then coated with clear, botryoidal opal. Perched on the opal are tiny milk-white spherules of fibrous oboyerite. Later veins cut the rock carrying rodalquilarite, cerussite, and an unknown tellurium mineral.

The spherules have an estimated Mohs hardness of 1.5, readily breaking down into individual fibres no more than 60  $\mu\text{m}$  in length. No fluorescence was observed. The specific gravity was estimated as 6.4 using 213  $\mu\text{g}$  for Thoulet's method, but the precision on this tiny sample was  $\pm 0.6$ .

Spectrographic analysis showed major Pb, Te, Ca, and Ag (the latter as traces of included AgCl). Wet chemical analysis on a sample of 970  $\mu\text{g}$  provided the results in Table III. 16  $\mu\text{g}$  of quartz and chlorargyrite were recovered and weighed as insol. Water was determined on another sample of 1.010 mg by the Penfield method.

Oboyerite is readily soluble in cold, dilute HNO<sub>3</sub> and slowly soluble in 16% HCl. Fusion to a

TABLE III. *Chemical analysis of oboyerite*

	1	2	3
PbO	58.0%	0.260	58.6%
CaO	0.3	0.053	0.3
TeO <sub>2</sub>	22.1	0.138	21.4
TeO <sub>3</sub>	16.2	0.092	15.7
H <sub>2</sub> O	4.2	0.238	4.0
	100.8		100.0

1. By wet analysis on 954  $\mu\text{g}$  (after correcting for 16  $\mu\text{g}$  of insol.)

2. Ratios

3. Theory for  $\text{H}_6\text{Pb}_6(\text{TeO}_3)_3(\text{TeO}_6)_2 \cdot 2\text{H}_2\text{O}$  with Pb:Ca = 5:1

yellow-grey slag is easy and mineral evolves a white sublimate of TeO<sub>2</sub>.

Portions of four spherules were sacrificed for powder diffraction data (see Table IV) to ensure purity. All four patterns were identical and complex. The purity of the spherulites was also demonstrated by thin section study.

TABLE IV. *Powder data for oboyerite. Cr-K $\alpha$  radiation, 114 mm camera*

<i>I</i> est	<i>d</i> meas	<i>I</i> est	<i>d</i> meas
3	9.038	1	2.415
1/2	6.752	3B	2.264
3	6.077	2	2.206
1	4.819	3	2.140
2	4.534	1	2.088
2	3.710	1	2.062
3	3.600	3	2.026
2	3.388	1/2	1.911
3	3.273	1/2	1.871
7	3.180	1/2	1.842
10	3.040	4B	1.804
5	2.976	2	1.753
5	2.927	2	1.728
5	2.862	2	1.692
1/2	2.788	2	1.663
1	2.646	2	1.625
3B	2.540		

Despite determined efforts, the powder pattern could not be indexed by the Ito method and, due to the minute crystal size, single crystal work was impossible. Failure to index the pattern seems reasonable because the optics strongly suggest triclinic symmetry.

Optical examination of fibres discloses that individual crystals are thin blades with one perfect

cleavage. Viewed normal to the cleavage, one set of striae can be faintly seen at an angle of 63° to the length of the crystal, or the crystal may be truncated at this angle. The partial birefringence in this orientation is 0.002 with no observable dispersion. If a fibre is rotated on its length and viewed normal to the rotation axis, the maximum extinction angle of 37° occurs somewhere between the positions where the cleavage is normal and parallel to the direction of view. This fact demonstrates that the crystals are triclinic.

The minimum and maximum indices were determined in S-Se melts:  $\alpha = 2.24$ ,  $\gamma = 2.26$ .

The name for the mineral is taken from the first initial and last name of Oliver Boyer, one of two men who first staked the Grand Central lode claim, the type locality.

*Fairbankite*. One fist-sized specimen of fairbankite was found on the waste dump of the Grand Central mine. Since this piece is also the type specimen of oboyerite it is described under that species.

Crystals are colourless and clear, have a bright resinous to adamantine lustre, and could be easily confounded with cerussite or anglesite. The Mohs hardness is 2 and crystals are brittle, showing no good cleavage. The specific gravity was not determined due to paucity of material.

Spectrographic analysis of a tiny sample showed only Pb and Te with minor Si (opal) and microchemical testing failed to disclose any other anions. No water was found in the closed tube and fusion to a grey slag is easy. The mineral is very slowly soluble in cold dilute HNO<sub>3</sub> and HCl but solubility is easy when warmed.

Wet chemical analysis was performed on a sample of 272  $\mu\text{g}$  from which 11  $\mu\text{g}$  were recovered as 'insol.' (opal). The results of this analysis are presented in Table V.

No free-standing crystals were found, although exceptional crystals may attain 0.5 mm in diameter.

TABLE V. *Chemical analysis of fairbankite*

	1	2	3	4
PbO	50.9%	0.228	58.3%	58.31%
TeO <sub>2</sub>	36.4	0.228	41.7	41.69
PbCO <sub>3</sub>	13.0		—	—
	100.3		100.0	100.00

1. On 272  $\mu\text{g}$  (corrected to 261  $\mu\text{g}$  for insol.); some cerussite contamination

2. Ratios

3. Reset to 100%

4. Theory for PbTeO<sub>3</sub>

All crystals in the specimen are present as a thin crust plastered on the walls of voids left by leached galena. Single crystals broken free show only a few faces at best and the morphology appears to be complex. Although crystals are nearly equant, study of a number of them suggests a strong morphological zone parallel to the  $[b]$  axis.

X-ray rotation and Weissenberg level photographs demonstrate that fairbankite is triclinic, probably  $P\bar{1}$ . The cell is  $a = 7.81\text{\AA}$ ,  $b = 7.11$ ,  $c = 6.96$ ,  $\alpha = 117^\circ 12'$ ,  $\beta = 93^\circ 47'$ ,  $\gamma = 93^\circ 24'$ ; if  $Z = 4$ ,  $\rho_{\text{calc}} = 7.45\text{ g/cm}^3$ .

The indexed powder data given in Table VI were used to refine the cell. The pattern looks complex and fades rapidly into a blur of faint lines below  $d = 1.6$ .

TABLE VI. X-ray powder data for fairbankite. Cr-K $\alpha$  radiation

<i>I</i> est	<i>d</i> meas	<i>d</i> calc	<i>hkl</i>	<i>I</i> est	<i>d</i> meas
2	5.150	5.145	1 $\bar{1}$ 0	3	1.944
2	4.652	4.661	110	2	1.920
1	3.561	3.544	02 $\bar{1}$	2	1.825
10	3.265	3.265	21 $\bar{1}$	2	1.789
6	3.148	3.152	111	2	1.777
		3.146	020	2	1.753
6	3.098	3.098	1 $\bar{1}$ 2	2	1.731
5	3.020	3.023	120	1	1.671
6	2.828	2.818	120	1	1.656
		2.828	2 $\bar{1}$ 1	2	1.632
5	2.516	2.509	2 $\bar{1}$ 2	1	1.585
		2.507	211	2	1.574
3	2.076	2.078	1 $\bar{3}$ 0	1	1.552
2	2.052	2.038	10 $\bar{3}$	1	1.537

In thin section fairbankite resembles girdite or anglesite, although it exhibits higher birefringence. The indices were measured in S-Se melts and are:  $\alpha = 2.29$ ,  $\beta = 2.31$ ,  $\gamma = 2.33$ . The  $2V_\gamma$  is  $86^\circ$  (measured),  $91^\circ$  (calculated). Dispersion is negligible.

Fairbankite is named for Nathaniel Kellogg Fairbank, an important figure in the early development of Tombstone. It was he who organized the company that developed the Grand Central lode, the type locality.

*Winstanleyite*. This species was first found in a large (c. cubic foot) piece of waste rock during excavations on the dump of the Grand Central mine. Several other pieces, some quite rich, were subsequently found.

At the Grand Central mine, most ores occurred in fractured shales converted to an opal-adularia

rock, or in quartz veins traversing it. Within the workings, however, is a near-vertical granodiorite dike. This rock has also locally been converted to quartz-adularia-opal. Although mineralization seldom occurred in the dike, all of the winstanleyite found occurs in fragments of granodiorite and none was found in altered shales.

In pieces containing winstanleyite, the dike rock is not only severely altered but also hosts 20 to 50% coarse pyrite by volume. The pyrite is leached and entirely replaced by crystalline jarosite, chlorargyrite, and beautiful euhedra of rodalquilarite. In some voids, winstanleyite occurs with the jarosite, not in others. It only occurs where the pyrite nucleated in biotite, hornblende, or sphene. Evidently the titanium was not mobile during oxidation.

Most winstanleyite crystals are simple cubes up to 0.5 mm on edge; a few show partial modification by the octahedron. Crystals commonly occur in delicate, castellated groups and frequently show concave, dished faces. The Mohs hardness is 4 and crystals are tough and brittle with no observable cleavage. The colour is usually Chinese yellow (RHS 20B) but may incline to tan or cream. The paler colours seem to indicate partial leaching of tellurium and the appearance of leucoxene. The streak is very pale yellow. The specific gravity (Berman Balance) on a 4.932 mg sample is  $5.57 \pm 0.04$  (three trials).

Spectrographic analysis showed Ti and Te, less Fe and Si (as included opal). The chemical analyses (Table VII) indicate that the sum of Ti+Fe is very close to  $\frac{1}{3}$  that of Te. Although jarosite and rodalquilarite occur with winstanleyite, they would have been easily spotted in the material picked for analysis; clearly the  $\text{Fe}_2\text{O}_3$  is not a mechanically included contaminant. Small beads of opal locked in the crystals were a more serious problem.

TABLE VII. Chemical analysis of winstanleyite

	1	2	3	4	5	6
TiO <sub>2</sub>	11.0	10.3	—	10.9	0.136	14.3
Fe <sub>2</sub> O <sub>3</sub>	3.15	3.15	—	3.2	0.020	—
TeO <sub>2</sub>	82.6	83.9	84.8	85.8	0.538	85.7
	96.75	97.35		99.9		100.0

1. On 644  $\mu\text{g}$ ; remainder is opal
2. On 2077  $\mu\text{g}$ ; remainder is opal
3. On 347  $\mu\text{g}$
4. Average analysis set to 100%
5. Ratios
6. Theory for  $\text{TiTe}_3\text{O}_8$

Because the mineral was fused prior to analysis, and because of the tiny amounts used, it was not practical to determine Si. However, the low sums surely reflect its presence.

Fusion prior to analysis was effected with  $K_2S_2O_7$ . Solubility in warm 1:1  $HNO_3$  is extremely slow and only slightly greater in 1:1 HCl. The mineral readily fuses in the closed tube and evolves no visible water.

Single crystal study by rotation and Weissenberg methods establish the symmetry as cubic  $Ia_3$  with  $a = 10.963\text{\AA}$ . As noted by R. Gaines (pers. comm.) the powder pattern is close to that of cliffordite. Indexed powder data are given in Table VIII.

TABLE VIII. Powder data for winstanleyite.  
Cr-K $\alpha$  radiation, 114 mm camera

<i>I</i>	<i>d</i>	<i>d</i>		<i>I</i>	<i>d</i>
est	meas	calc	<i>hkl</i>	est	meas
2	5.482	5.482	200	8	1.653
6	4.474	4.476	211	3	1.617
2	3.877	3.876	220	2	1.582
10	3.165	3.165	222	2	1.551
4	2.930	2.930	321	2	1.493
7	2.741	2.741	400	1	1.466
4	2.583	2.584	411	4	1.392
3	2.452	2.451	420	1	1.371
3	2.151	2.150	431	4	1.350
2	2.001	2.002	521	2	1.330
8	1.938	1.938	440	2	1.311
3	1.881	1.880	433	1/2	1.293
1/2	1.825	1.827	600	4	1.275
		1.827	442	3	1.258
3	1.778	1.778	611	3	1.226
		1.778	532	1	1.211
2	1.734	1.734	620	3	1.197
3	1.692	1.692	541	3	1.183
				2	1.157

In thin section winstanleyite retains its yellow colour but crystals are often cloudy. In addition to the easily visible crystals in vugs, more winstanleyite is commonly seen within and interstitial to crystalline, massive jarosite. Anomalous birefringence up to 0.011 was observed and winstanleyite could be easily mistaken for species such as microlite, bromargyrite, etc. The refractive index of isotropic crystals in S-Se melt is  $2.34 \pm 0.02$ .

Winstanleyite is named for B. J. Winstanley, amateur mineralogist of Douglas, Arizona, who found the type specimen and brought it to my attention.

*Discussion.* No compounds similar to girdite and oboyerite have been reported previously but there is a host of compounds similar to fairbankite. Several lead tellurites (hydrated or not) have been reported artificially but the powder data of none of these match fairbankite.

Domeyko (1875) described a 'tellurate de plomb' from Chile as a yellow compound returning, by analysis, 15 mg of  $TeO_3$  (?) for 33 mg of PbO but suspected contamination by anglesite. The analysis is clearly incomplete and a mixture of anglesite and rodalquilarite is a distinct possibility.

E. E. Fairbanks (1946) named the species 'dunhamite' but did no work at all on the material. He used data reported earlier by Dunham (1935). The species has been given more credence than it deserves, for not even qualitative chemical work was done, and the composition ('lead tellurite') is mere guesswork.<sup>1</sup>

No species even remotely like winstanleyite has been observed previously in nature, but the compound has been created artificially by Galy and Meunier (1969). Their data agree closely with information obtained for the natural material.

*Acknowledgements.* I am grateful to Marjarie Duggan for the chemical analyses of these species. My thanks also go to Carl Francis and Robert Weber for assistance in tracking down 'dunhamite'.

<sup>1</sup> I have observed a mineral matching the scanty data for 'dunhamite' in material from its type locality (Hilltop mine, Organ dist., New Mexico) and from two other localities including Tombstone. It is not a simple 'lead tellurite' and it is certainly not fairbankite. Type 'dunhamite', as described by Dunham, does not appear to have been preserved, unfortunately.

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