

GOLDQUARRYITE



A New Cd-Bearing Phosphate Mineral from the Gold Quarry Mine, Eureka County, Nevada

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ABSTRACT

Goldquarryite, idealized formula $\text{CuCd}_2\text{Al}_3(\text{PO}_4)_4\text{F}_3(\text{H}_2\text{O})_{10}$, structure-derived formula $(\text{Cu}_{0.70}\square_{0.30})_{\Sigma 1.00}(\text{Cd}_{1.68}\text{Ca}_{0.32})_{\Sigma 2.00}\text{Al}_3(\text{PO}_4)_4\text{F}_3(\text{H}_2\text{O})_{10}[(\text{H}_2\text{O})_{1.00}\text{F}_{0.40}]_{\Sigma 1.40}$, is triclinic, space group $P1$, with unit-cell parameters derived from crystal structure: $a = 6.787(1)$, $b = 9.082(2)$, $c = 10.113(2)$ Å, $\alpha = 101.40(1)^\circ$, $\beta = 104.27(1)^\circ$, $\gamma = 102.51(1)^\circ$, $V = 568.7(3)$ Å³, $a:b:c = 0.7473:1:1.1135$, $Z = 1$. The strongest seven reflections in the X-ray powder-diffraction pattern are $[d(\text{Å})/(hkl)]$: $9.433(100)(001)$; $4.726(30)(002)$; $3.700(30)(022)$; $3.173(30b)(122, \bar{1}13, 120, 003)$; $3.010(30)(122, \bar{2}12)$; $2.896(30)(\bar{2}11)$; $2.820(50)(022)$. The mineral occurs on a single specimen collected from the 5,425-foot bench, Gold Quarry mine, Eureka County, Nevada, as isolated clusters of radiating sprays of crystals and as compact parallel crystal aggregates, which are both found on and between breccia fragments. Sprays and aggregates never exceed 3 mm in longest dimension and typically average about 0.5 mm in size. Goldquarryite is a late-stage supergene mineral associated with opal, carbonate-fluorapatite and hewettite, on a host rock composed principally of brecciated and hydrothermally rounded jasperoid fragments which have been lightly cemented by late-stage silicification. Individual euhedral crystals are acicular to bladed, elongate $[100]$, with a length-to-width ratio of approximately 20:1; the maximum size is 1.5 mm but most crystals do not exceed 0.4 mm in length. Forms are $\{010\}$,

$\{001\}$ major and $\{100\}$ very minor. The mineral is pleochroic; translucent (masses) to transparent (crystals); very pale blue to blue-gray (crystals) or blue (masses); with a white streak and a vitreous to glassy luster. Goldquarryite is brittle, lacks cleavage, has an irregular fracture, and is nonfluorescent; hardness (Mohs') is estimated at 3–4; measured density is $2.78(1)$ g/cm³ (sink-float techniques using methylene iodide-acetone mixtures), calculated density is 2.81 g/cm³ (for formula and unit-cell parameters derived from crystal structure). Optically, it is biaxial positive, $\alpha = 1.570$, $\beta = 1.573$, $\gamma = 1.578$; $2V(\text{meas.}) \sim 30^\circ$, $2V(\text{calc.}) = 76^\circ$; dispersion $r < v$, strong. Average electron-microprobe analysis: $\text{K}_2\text{O} = 0.17$, $\text{CuO} = 5.33$, $\text{CaO} = 1.25$, $\text{NiO} = 0.23$, $\text{ZnO} = 0.05$, $\text{CdO} = 26.24$, $\text{Al}_2\text{O}_3 = 15.22$, $\text{V}_2\text{O}_5 = 0.05$, $\text{P}_2\text{O}_5 = 28.04$, $\text{F} = 3.63$, H_2O (calculated assuming stoichiometry) = $[22.19]$, $-O = F = -1.53$, total ≈ 100.87 weight %, corresponding to $[(\text{Cu}_{0.66}\text{Ni}_{0.03}\text{Zn}_{0.01})_{\Sigma 0.70}\square_{0.30}]_{\Sigma 1.00}(\text{Cd}_{1.68}\text{Ca}_{0.32}\text{K}_{0.04})_{\Sigma 2.00}(\text{Al}_{2.92}\text{V}_{0.01})_{\Sigma 3.00}(\text{PO}_4)_{3.98}\text{F}_{1.87}\cdot\text{H}_2\text{O}_{12.06}$, based on 29.45 (O + F) anions. H_2O was confirmed by both infrared spectroscopy and crystal-structure analysis. The mineral name is for the locality.

INTRODUCTION

During a thorough investigation of the mineralogy of the Gold Quarry mine, Eureka County, Nevada, Jensen *et al.* (1995) reported two undefined phosphate phases which they designated as "Unknown #1" and "Unknown #2". The latter phase, "Unknown #2", has now been formally characterized and the description of this new mineral is the subject of this paper.

The mineral is named goldquarryite after the type (and only known) locality, the Gold Quarry mine, Eureka County, Nevada. The mineral and mineral name have been approved by the Commission on New Minerals and Mineral Names, I.M.A. (2001-58). The holotype specimen (6 x 3.5 x 3 cm), one single-crystal mount and a few micron-sized fragments in a gelatin capsule are housed

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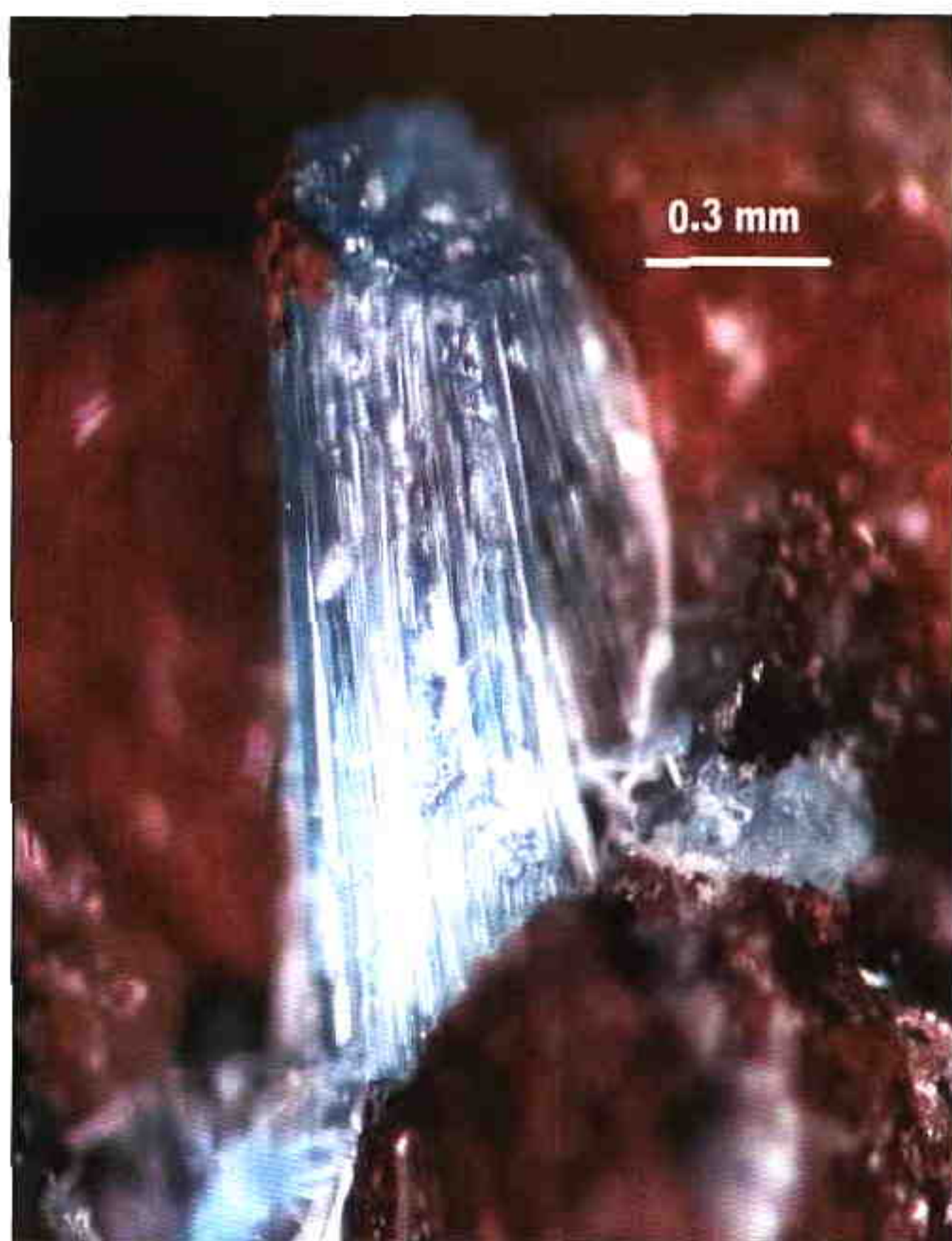


Figure 1. Compact parallel aggregates of goldquarryite. Scale bar: 0.3 mm.

in the Systematic Reference Series of the National Mineral Collection of Canada at the Geological Survey of Canada, Ottawa, under catalog number 68084.

OCCURRENCE AND ASSOCIATED MINERALS

The new species was found at the Gold Quarry mine, 11 km northwest of Carlin, Eureka County, Nevada. The mine is a large open-pit Carlin-type gold deposit presently operated by the Newmont Gold Company. Jensen *et al.* (1995) discuss the mineralogy, history and geology of this interesting deposit. Only one specimen containing goldquarryite, about 8 x 8 cm in size (since split for mineralogical study), was preserved from a freshly blasted muck pile exposed on the 5,425-foot bench at mine coordinates 16500N, 19500E. The piece, collected in February 1992, consists of brecciated and hydrothermally-rounded jasperoid fragments lightly cemented by late-stage silicification. Supergene minerals on the surface of the jasperoid breccia include a uniformly thin, colorless, botryoidal opal crust and a later coating (and local microcrystals) of pale yellow, impure carbonate-fluorapatite. Hewettite, in radiating sprays (to 10 mm) of lustrous maroon-red fibrous crystals, and goldquarryite were the last minerals to form, and occur as isolated clusters on and between breccia fragments; the two species do not occur in immediate association and their paragenetic relationship is not known. The largest crystal cluster of goldquarryite is a radiating spray 3 mm across consisting of stoutly acicular aqua-blue crystals up to 1.5 mm in length. Perhaps a total mass of 100 mg of this new species is present on the entire specimen. Goldquarryite is a late-stage supergene mineral, but the source of the cadmium is unknown at this time. However, greenockite, CdS, also occurs in this deposit.

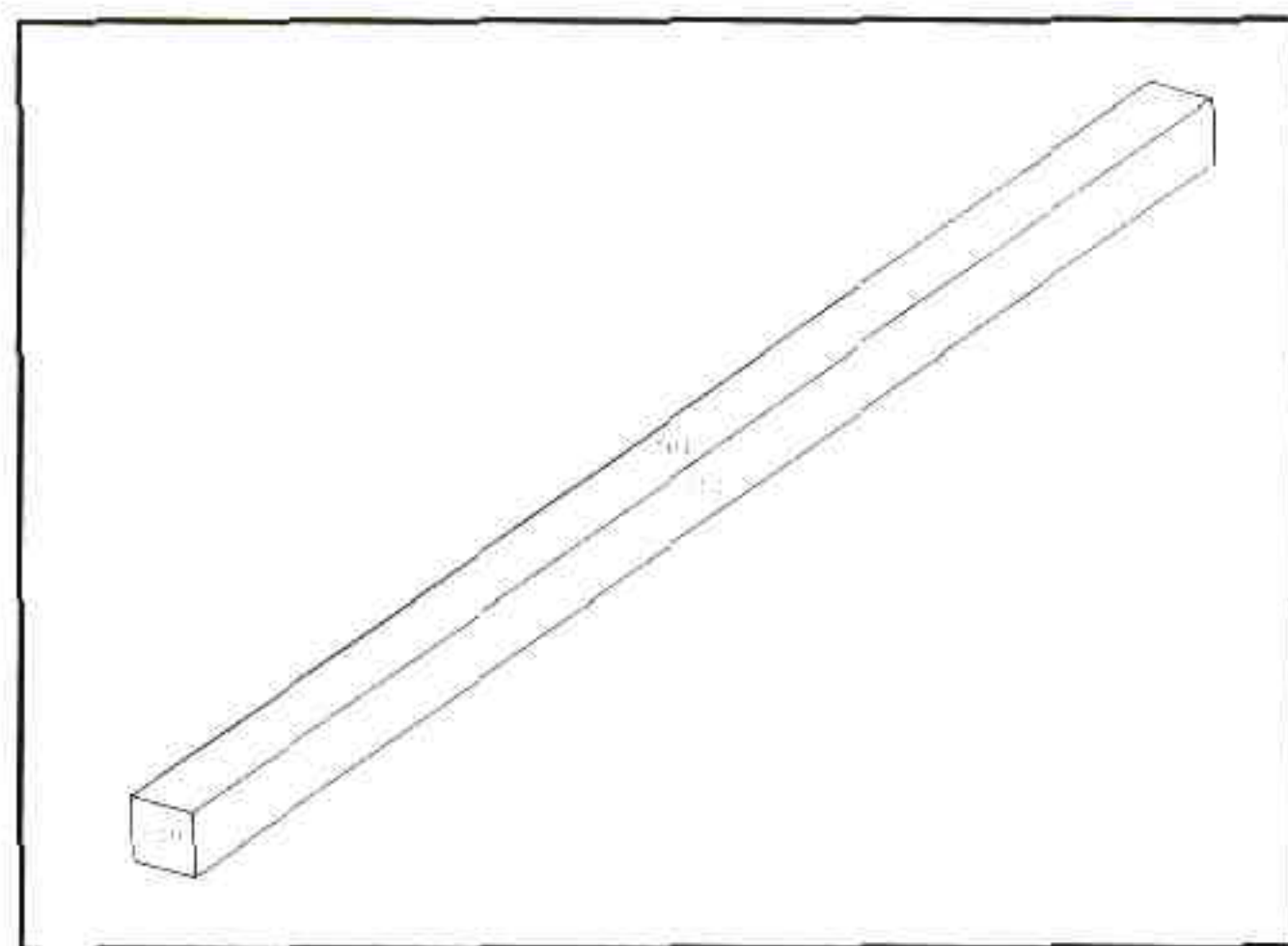


Figure 2. Goldquarryite, idealized crystal drawing.

PHYSICAL AND OPTICAL PROPERTIES

Goldquarryite occurs as isolated clusters of radiating crystals and as compact parallel aggregates of crystals, on and between breccia fragments. The largest known cluster on the type specimen (Fig. 1) is approximately 3 mm in longest dimension, but most clusters average about 0.5 mm in size. The maximum crystal size is about 1.5 mm in length with a diameter of 0.1 mm. Most crystals, however, do not exceed 0.4 mm in length, are euhedral, elongate along [100], and have a length-to-width ratio of about 20:1. Crystals may be acicular or prismatic elongated flattened blades with dominant {010} and {001} and very minor {100} forms. The mineral is multiply twinned with {001} as the twin plane; single-crystal precession studies show twinning by 180° rotation about c^* . Crystals are very pale blue to blue-gray, masses are blue, and the streak is white. The luster is vitreous to glassy, and crystals are transparent, whereas aggregates are translucent. Goldquarryite is brittle, with an irregular fracture, no observable cleavage, and no fluorescence under either longwave or shortwave ultraviolet light. The hardness (Mohs') is estimated to be 3–4. The measured density, by sink-float techniques using methylene iodide-acetone mixtures, is 2.78(1) g/cm³. The calculated density, on the basis of both the chemical formula and unit-cell parameters derived from the crystal structure, is 2.81 g/cm³.

The mineral is biaxial positive with $\alpha = 1.570$, $\beta = 1.573$, $\gamma = 1.578$; $2V$ (measured) = ~ 30°, $2V$ (calculated) = 76°. The dispersion is $r < v$, strong. Crystals are pleochroic, deep blue parallel to the elongation and very pale blue normal to the elongation.

X-RAY STUDIES

Two crystals of goldquarryite, one mounted with a^* and the other mounted with b^* parallel to the dial axis, were examined by single-crystal precession methods with Zr-filtered Mo X-radiation. The crystal mounted about b^* is twinned by 180° rotation about c^* . The following levels were photographed: $hk0 \rightarrow hk2$, $h0l \rightarrow h2l$, and $0kl \rightarrow 2kl$. The mineral is triclinic with space-group choices $P1(1)$ or $P\bar{1}(2)$ (diffraction aspect P^*). The crystal-structure determination (Cooper and Hawthorne, manuscript in preparation) indicates that $P\bar{1}$ is the correct space group. The refined unit-cell parameters from powder data: $a = 6.777(3)$, $b = 9.081(4)$, $c = 10.104(5)$ Å, $\alpha = 101.40(4)^\circ$, $\beta = 104.24(4)^\circ$, $\gamma = 102.56(4)^\circ$, $V = 567.1(4)$ Å³, $a:b:c = 0.7463:1:1.1127$, $Z = 1$, are based on 29 reflections with d values between 4.726 and 1.577 Å for which unambiguous indexing was possible, based on visual inspection of single-crystal precession films. A fully indexed powder pattern is

Table 1. X-ray powder-diffraction data for goldquarryite.

I_{obs}	$d\text{\AA}_{\text{meas}}$	$d\text{\AA}_{\text{calc}}$	hkl	I_{obs}	$d\text{\AA}_{\text{meas}}$	$d\text{\AA}_{\text{calc}}$	hkl
100	9.433	9.442	001	*	10	2.314	$\bar{1}24$
10	8.567	8.546	010	3	2.284	2.281	122
20	7.406	7.386	011	*	20	2.250	223
20	6.326	6.306	100	*	15	2.213	041
20	6.204	6.176	$\bar{1}01$	*	5	2.172	042
10	5.644	5.635	011			2.141	$\bar{2}14$
10	5.277	5.263	$\bar{1}11$	10	2.140	2.138	$\bar{3}20$
10	4.828	4.810	$\bar{1}\bar{1}1$			2.136	040
*	30	4.726	002	15	2.102	2.102	300
3	4.489	4.485	$\bar{1}02$			2.101	$\bar{1}24$
*	20	4.281	020	*	20	2.059	$\bar{3}03$
*	10	4.119	120	*	15	2.034	$\bar{2}41$
		3.887	$\bar{1}12$			2.016	$\bar{1}15$
25	3.875	3.854	$\bar{1}21$	5	2.017	2.012	$\bar{1}33$
*	30	3.700	022	*	5	1.996	$\bar{1}24$
		3.554	021			1.985	$\bar{2}41$
15b	3.544	3.526	$\bar{1}\bar{1}2$	10b	1.975	1.981	$\bar{1}05$
*	10	3.311	$\bar{2}01$			1.968	$\bar{1}34$
3	3.270	3.270	$\bar{2}10$	*	20	1.932	301
		3.179	$\bar{1}22$	*	5	1.890	$\bar{1}42$
		3.162	$\bar{1}13$			1.876	$\bar{3}04$
30b	3.173	3.151	120	10	1.871	1.869	230
		3.147	003			1.846	044
3	3.095	3.088	202	10	1.845	1.839	114
30	3.010	3.015	122	3	1.834	1.831	$\bar{3}22$
		3.002	$\bar{2}12$	3	1.811	1.809	$\bar{2}34$
*	25	2.940	023	3	1.788	1.794	$\bar{1}35$
*	30	2.896	211			1.786	$\bar{3}23$
*	50	2.820	022	*	10	1.769	$\bar{1}44$
		2.755	$\bar{1}23$			1.735	302
15	2.753	2.751	$\bar{2}21$	15	1.732	1.732	141
*	15	2.722	210	3	1.707	1.706	320
3	2.673	2.672	$\bar{1}13$	*	5	1.693	$\bar{1}51$
*	5	2.635	222	*	15	1.675	105
*	15	2.574	$\bar{1}23$			1.657	$\bar{4}22$
*	5	2.527	103	20b	1.653	1.653	$\bar{4}02$
*	5	2.491	$\bar{2}30$			1.648	$\bar{1}06$
		2.469	$\bar{1}04$	*	5	1.635	$\bar{4}20$
15	2.462	2.456	$\bar{2}12$	3	1.618	1.614	$\bar{1}45$
3	2.431	2.432	$\bar{1}23$	*	15	1.598	$\bar{4}31$
*	10	2.395	$\bar{2}21$	*	25	1.577	$\bar{1}45$
		2.349	$\bar{1}32$				
10	2.349	2.347	024				

114.6 mm Debye-Scherrer powder camera, Cu radiation, Ni-filter ($\lambda\text{CuK}\alpha$ 1.54178 Å; intensities estimated visually, b = broad line; not corrected for shrinkage and no internal standard; * = reflections used for unit-cell refinement; indexed with $a = 6.777$, $b = 9.081$, $c = 10.104$ Å, $\alpha = 101.40^\circ$, $\beta = 104.24^\circ$, $\gamma = 102.56^\circ$.

presented in Table 1. Cell parameters derived from the crystal-structure determination are: $a = 6.787(1)$, $b = 9.082(2)$, $c = 10.113(2)$ Å, $\alpha = 101.40(1)^\circ$, $\beta = 104.27(1)^\circ$, $\gamma = 102.51(1)^\circ$, $V = 568.7(3)$ Å³, and $a:b:c = 0.7473:1:1.1135$. Full details of the structure will be published elsewhere. The powder-diffraction data are unique and bear no resemblance to any other inorganic phase listed in the Powder Diffraction File. Goldquarryite is the first Cd-bearing phosphate phase to be found in Nature.

CHEMISTRY

Goldquarryite crystals were analyzed with a JEOL 733 electron microprobe using Tracor Northern 5500 and 5600 automation,

utilizing an operating voltage of 15 kV, a beam current of 20 nA, and a beam diameter of 40 µm. Data reduction was done with a PAP routine in XMAQNT (personal communication C. Davidson, CSIRO) and a potential Cd/K peak overlap was corrected. The following standards were used: sanidine (K $K\alpha$), cuprite (Cu $K\alpha$), diopside (Ca $K\alpha$), nichromite (Ni $K\alpha$), zincite (Zn $K\alpha$), synthetic Cd₃(PO₄)₂(OH) (Cd $L\alpha$), gehlenite (Al $K\alpha$), synthetic VP₂O₇ (V $K\alpha$), apatite (P $K\alpha$) and phlogopite (F $K\alpha$). A 100s energy-dispersion scan showed no elements other than those reported. Mg, Mn, Fe, Ga, Bi, Cl, Si, Sr, Sn and As were sought but not detected. The valency states for all elements and the number of O and F atoms were determined by crystal-structure analysis prior to the

Table 2. Compositional data for goldquarryite.

	Weight %	Range
K ₂ O	0.17	0.12 – 0.22
CuO	5.33	5.10 – 5.63
CaO	1.25	1.14 – 1.34
NiO	0.23	0.19 – 0.24
ZnO	0.05	0.00 – 0.23
CdO	26.24	25.65 – 26.60
Al ₂ O ₃	15.22	15.01 – 15.58
V ₂ O ₅	0.05	0.00 – 0.11
P ₂ O ₅	28.04	27.70 – 28.18
F	3.63	3.46 – 3.77
H ₂ O ¹	[22.19] ¹	
–O = F	–1.53	
Total	[100.87]	

¹Determined by stoichiometry with H₂O calculated assuming 2F atoms.

final interpretation of the electron-microprobe results. The paucity of pure, uncontaminated material prevented the quantitative determination of H₂O by classical methods. However, its presence as molecular H₂O was confirmed both by crystal-structure analysis and powder infrared-absorption spectroscopy; the formula was normalized on 29.45 O+F anions. The average of five determinations and ranges are given in Table 2 and the empirical formula for goldquarryite is [(Cu_{0.06}Ni_{0.03}Zn_{0.01})_{20.70}□_{0.30}]_{21.00}(Cd_{2.00}Ca_{0.22}K_{0.01})_{22.20}(Al_{2.92}V_{0.01})_{22.93}(PO₄)_{3.85}F_{1.87}·(H₂O)_{12.06}. The crystal-structure-derived formula, (Cu_{0.70}□_{0.30})_{21.00}(Cd_{1.68}Ca_{0.32})_{22.00}Al₃(PO₄)₄F₂(H₂O)₁₀[(H₂O)_{1.60}F_{0.40}]_{22.00}, requires CuO = 5.79, CdO = 22.43, CaO = 1.87, Al₂O₃ = 15.91, P₂O₅ = 29.52, F = 4.74, H₂O = 21.73, sum = 101.99, less O = F = –1.99, total = 100.00 weight %. The idealized formula is CuCd₂Al₃(PO₄)₄F₂(H₂O)₁₀(H₂O)₂.

The *K_p* value is 0.204 and is derived from the average index of refraction (*n*) 1.574 and the calculated density of 2.81 g/cm³. The *K_c* value is 0.202 and is based on the crystal-structure-derived formula given above. The compatibility index (1–*K_p/K_c*) is –0.012, which, according to Mandarino (1981), is “superior.”

INFRARED-ABSORPTION SPECTROSCOPY

The equipment and procedures for acquiring the infrared-absorption spectrum for goldquarryite were reported by Roberts *et al.* (1994) and are not repeated here. The sample was analyzed using a Bomem Michelson MB-100 FTIR spectrometer equipped with a wide-band mercury-cadmium telluride detector. The transmittance spectrum (Fig. 3) clearly shows absorption bands for structural H₂O. A strong-intensity band, centered at 3293 cm^{–1} with a shoulder at 3123 cm^{–1}, is due to O–H stretching, and a medium-

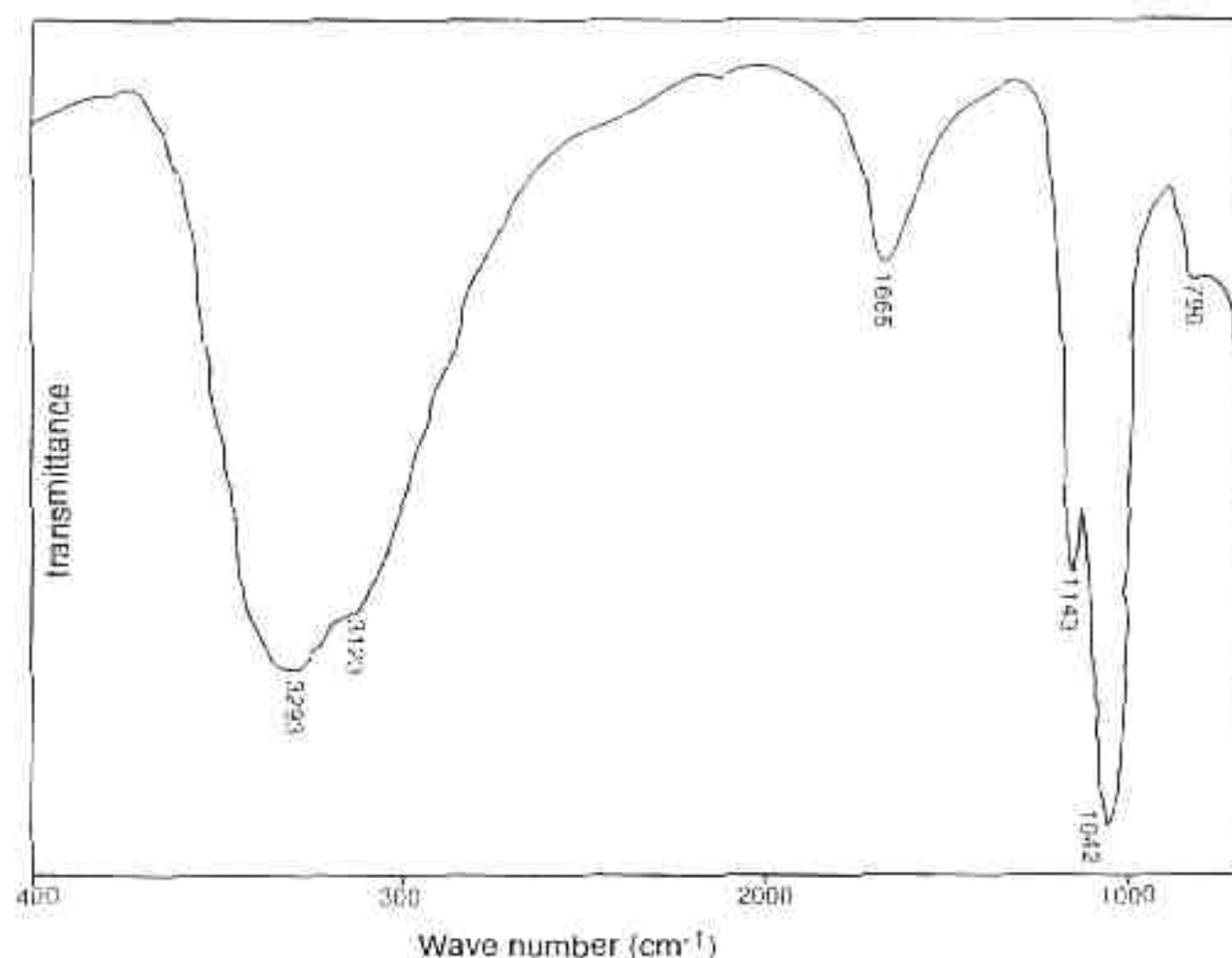


Figure 3. Infrared-absorption spectrum for goldquarryite.

intensity band, centered at 1665 cm^{–1}, is due to H–O–H bending in the H₂O group. In addition, the very strong band at 1042 cm^{–1} is the ν₃ fundamental stretching band for phosphate, as is the medium-strong band at 1143 cm^{–1}.

ACKNOWLEDGMENTS

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REFERENCES

- JENSEN, M. C., ROTA, J. C., and FOORD, E. E. (1995) The Gold Quarry mine, Carlin-Trend, Eureka County, Nevada. *The Mineralogical Record*, **26**, 449–469.
- MANDARINO, J. A. (1981) The Gladstone-Dale relationship: Part IV. The compatibility concept and its application. *Canadian Mineralogist*, **19**, 441–450.
- ROBERTS, A. C., ERCIT, T. S., CRIDDLE, A. J., JONES, G. C., WILLIAMS, R. S., CURETON, F. F. II, and JENSEN, M. C. (1994) McAlpineite, Cu₃TeO₆·H₂O, a new mineral from the McAlpine mine, Tuolumne County, California, and from the Centennial Eureka mine, Juab County, Utah. *Mineralogical Magazine*, **58**, 417–424. ☒

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