This is the peer-reviewed, final accepted version for American Mineralogist, published by the Mineralogical Society of America.
The published version is subject to change. Cite as Authors (Year) Title. American Mineralogist, in press.
DOI: https://doi.org/10.2138/am-2023-8971. http://www.minsocam.org/

Revision 1

Yuchuanite-(Y), $Y_2(CO_3)_3 \cdot H_2O$, a new hydrous yttrium carbonate mineral from the Yushui Cu deposit, South China

Wei Yao[1,2], Peng Liu[1*], Guowu Li[3], Ningyue Sun[3], Wenqiang Yang[1], Chengyao Jiang[4], Wei Du[4], Chao Zhang[1], Wenlei Song[1], Nigel J. Cook[5], Jingwen Mao[6]

[1] *State Key Laboratory of Continental Dynamics, Department of Geology, Northwest University, Xi'an 710069, China*

[2] *Xi'an Center of Mineral Resources Survey, China Geological Survey, Xi'an 710100, China*

[3] *Crystal Structure Laboratory, Science Research Institute, China University of Geosciences, 100083 Beijing, China*

[4] *School of Earth Sciences and Resources, Chang'an University, Xi'an 710054, China*

[5] *School of Chemical Engineering, The University of Adelaide, Adelaide, South Australia 5005, Australia*

[6] *Ministry of Natural Resources (MNR) Key Laboratory of Metallogeny and Mineral Assessment, Institute of Mineral Resources, Chinese Academy of Geological Sciences (CAGS), Beijing 100037, China*

Corresponding author: Peng Liu, pengliu@nwu.edu.cn

Always consult and cite the final, published document. See http:/www.minsocam.org or GeoscienceWorld

This is the peer-reviewed, final accepted version for American Mineralogist, published by the Mineralogical Society of America.
The published version is subject to change. Cite as Authors (Year) Title. American Mineralogist, in press.
DOI: https://doi.org/10.2138/am-2023-8971. http://www.minsocam.org/

ABSTRACT

A new mineral species, yuchuanite-(Y), ideally $Y_2(CO_3)_3 \cdot H_2O$, has been discovered and characterized in the Yushui Cu deposit, in South China. The mineral occurs in bedded/massive ore and is associated with bornite, chalcopyrite, galena, sphalerite, bastnäsite-(Y), xenotime-(Y), anhydrite, and quartz. Individual crystals range in size from 30 to 300 μm. No twinning is observed. The mineral is colorless and transparent with vitreous lustre. The calculated density is 3.62 g/cm^3. An electron microprobe analysis yields the empirical formula (based on 10 O apfu), $(Y_{1.61}Yb_{0.11}Er_{0.11}Dy_{0.08}Ho_{0.03}Gd_{0.02}Tm_{0.02})_{\Sigma 1.99}(CO_3)_3 \cdot H_2O$.

Yuchuanite-(Y) is triclinic, with space group *P*-1(#2), *Z* = 6, and unit–cell parameters *a* = 6.2134(3) Å, *b* = 8.9697(3) Å, *c* = 19.9045(7) Å, α = 91.062(3)°, β = 90.398(3)°, γ = 91.832(3)° and *V* = 1108.54(8) Å^3. The structure is constructed from (1 -1 0) sheets of eight-coordinated Y polyhedra and C trigonal planar groups. All Y polyhedra are linked by shared edges. The Y atoms occupy six independent crystallographic sites of two different coordination types: $[YO_7(H_2O)]$ and $[YO_8]$.

The chemical composition of yuchuanite-(Y) is similar to tengerite-(Y), $Y_2(CO_3)_3 \cdot 2–3H_2O$, but is distinct in the crystal structure, such as crystal system, space group, and unit cell, from that of tengerite-(Y). The Y polyhedra of tengerite-(Y) is nine-coordinated while those of yuchuanite-(Y) are eight-coordinated. Moreover, their structures could be both described as sheet structures built up from Y polyhedra and CO_3 trigonal planar groups but link together in significantly different ways. Thus, yuchuanite-(Y) is not polytype of tengerite-(Y) but is an independent mineral species.

***Keywords*:** New mineral; Yuchuanite-(Y); Hydrous yttrium carbonate; Yushui Cu deposit;

Always consult and cite the final, published document. See http:/www.minsocam.org or GeoscienceWorld

This is the peer-reviewed, final accepted version for American Mineralogist, published by the Mineralogical Society of America.
The published version is subject to change. Cite as Authors (Year) Title. American Mineralogist, in press.
DOI: https://doi.org/10.2138/am-2023-8971. http://www.minsocam.org/

INTRODUCTION

The hydrous yttrium carbonate mineral, tengerite-(Y), was described a long time ago (Svanberg and Tenger, 1838; Dana, 1868). However, due to limitations of analytical techniques, its chemical composition remains equivocal (e.g., Iimori, 1938). A hydrous yttrium carbonate with the chemical formula $Y_2(CO_3)_3 \cdot nH_2O$ (n = 2–3) was synthesized by Nagashima and Wakita (1968). Similarly, hydrothermal synthesis of single crystals of $Y_2(CO_3)_3 \cdot nH_2O$ (n = 2–3) was reported by Tareen et al. (1980). Miyawaki et al. (1993) determined the crystal structure of the synthetic $Y_2(CO_3)_3 \cdot nH_2O$ (n = 2–3), showed the phase identicalness to tengerite-(Y), and redefined tengerite-(Y) as $Y_2(CO_3)_3 \cdot nH_2O$ (n = 2–3). Moreover, Peng et al. (2019) synthesized $Y_2(CO_3)_3 \cdot H_2O$ crystal.

A new mineral species, yuchuanite-(Y), ideally $Y_2(CO_3)_3 \cdot H_2O$, has been found in the sediment-hosted Yushui copper deposit, South China, which has similar chemical compositions to tengerite-(Y). Yuchuanite-(Y) has been approved by the International Mineralogical Association Commission on New Minerals, Nomenclature and Classification (IMA2022-120). It is named in honor of Professor Yuchuan Chen (born in 1934), an economic geologist at the Institute of Mineral Resources, Chinese Academy of Geological Sciences (CAGS). Prof. Chen is a leading Chinese economic geologist with a global impact from his publication output and his significant contribution to international professional associations. Type material is deposited in the mineralogical collections of the Geological Museum of China, catalog number M16122.

GEOLOGICAL BACKGROUND

The Yushui Cu-polymetallic deposit, containing enrichment in yttrium, heavy rare earths, and vanadium, is located about 16 km northeast of Meizhou City, Guangdong Province, China (24°25'18"N, 116°11'48"E). The deposit is concealed beneath Late Jurassic volcanic cover and is

Always consult and cite the final, published document. See http:/www.minsocam.org or GeoscienceWorld

mainly hosted within sedimentary rocks at the unconformity between Lower Carboniferous red sandstone (>300 m in thickness) and Upper Carboniferous dark-grey dolostone (Fig. 1). There are three types of Cu mineralization: (I) bedded/massive; (II) disseminated; and (III) vein-type. Types II and III are minor and hosted by the dolostone/limestone or red sandstone, respectively (Fig. 2). Yuchuanite-(Y) occurs in the lower part of the bedded/massive ore. Associated minerals are bornite, chalcopyrite, galena, sphalerite, bastnäsite-(Y), xenotime-(Y), anhydrite, and quartz (Fig. 3). The mineral assemblage was likely formed as a result of a fluid event with the temperature of mineralization estimated to be in the range 110–287 °C (Jiang et al., 2016).

The genesis of the Yushui deposit is controversial, and both syngenetic (Huang et al., 2015) and epigenetic (Liu, 1997) models have been proposed. Liu (1997) presented a sulfide Sm-Nd isochron age of 189.7 ± 1.8 Ma, and argued for a magmatic–hydrothermal origin. Based on a sulfide Re-Os isochron age of 308 ± 15 Ma, a SEDEX (sedimentary exhalative deposit) model was proposed by Huang et al. (2015). Recently, based on Sm-Nd dating, and Nd isotope data of jingwenite-(Y), Yushui was suggested to be a Triassic (223 Ma) deposit of sediment-hosted copper type with HREE-U enrichment (Liu et al., 2023).

ANALYTICAL METHODS

Polished sections were prepared from the yuchuanite-(Y) type specimen for analysis of chemical composition and Raman spectroscopy.

Chemical composition analysis

A quantitative major-element analysis of minerals was undertaken using a JEOL JXA-8230 electron microprobe analyzer at the State Key Laboratory for Continental Dynamics, Northwest University, China. All measurements were performed using an accelerating voltage of 15 kV, a beam current of

This is the peer-reviewed, final accepted version for American Mineralogist, published by the Mineralogical Society of America.
The published version is subject to change. Cite as Authors (Year) Title. American Mineralogist, in press.
DOI: https://doi.org/10.2138/am-2023-8971. http://www.minsocam.org/

50 nA, and a beam size of 10 μm. The analyzing crystals were LIF (Dy and Er), TAP(Y), LIFH (Yb, Tm, Ho, and Gd). The *L*α line was chosen for measurement of Y, Dy, Er, Yb, Tm, Ho, and Gd. The count times on peaks were 20 s for Y; 30 s for Dy, Er, Yb, Tm, Ho, and Gd. Background intensities were measured on both sides of the peak for half of the peak time. The standards were REE1 for Tm and Gd, REE2 for Yb, and REE4 for Dy and Er (Drake and Weill, 1972); synthetic HoP_5O_{14} for Ho; Yttrium-aluminum garnet for Y.

Crystal structure analysis

A transparent single crystal (0.02 × 0.015 × 0.01 mm) was cut by a double-focused ion beam (FIB) from the polished section, to be used for the subsequent X-ray diffraction studies. X-ray powder and single-crystal diffraction studies were carried out at the Science Research Institute, China University of Geosciences, China, with a Rigaku Oxford diffraction XtaLAB PRO-007HF single crystal diffractometer equipped with a rotating anode microfocus X-ray source (50 kV, 24 mA; Mo*K*α λ = 0.71073 Å) and a hybrid pixel array detector.

Raman spectroscopy analysis

Raman spectra of yuchuanite-(Y) were collected from a randomly oriented grain using a Renishaw Invia confocal Raman spectrometer equipped with 50× objective at the State Key Laboratory of Continental Dynamics, Northwest University, Xi'an. The excitation wavelength is 514.5 nm (semiconductor laser), and the output power of the laser was set at 100 mW. The spatial resolution was estimated to be 2 μm. The grating is 1800 grooves/mm, and the spectral resolution is 1.8 cm^{-1}. The spectra were collected for 30 s with 6 accumulations.

OPTICAL AND PHYSICAL PROPERTIES

Yuchuanite-(Y) occurs as vein aggregates or platy and columnar crystals. Individual crystals range in

Always consult and cite the final, published document. See http:/www.minsocam.org or GeoscienceWorld

size from 30 to 300 μm and are closely associated with bornite and minor euhedral bastnäsite-(Y) and anhydrite (Fig. 3). Optically, yuchuanite-(Y) is biaxial (+), the refractive index n is 1.65, which is calculated by N=Kd+1, K values are from Mandarino (1981). The dispersion is weak with r<v, and the pleochroism is with X = colorless, Y = colorless, Z = colorless. The *a: b: c* ratio from single-crystal X-ray diffraction data is 0.312: 0.451: 1. Yuchuanite-(Y) is colorless and transparent with light grey streak and vitreous lustre. The hardness (Mohs) is estimated to be not greater than 4. The cleavage is good on {1-10}. The calculated density is 3.62 g/cm^3 based on the empirical formula and unit cell volume determined from single crystal XRD data.

CHEMISTRY

Raman spectrum

The Raman spectrum of yuchuanite-(Y) (Fig. 4) shows bands of O-H stretching vibrations at 3584 cm^{-1}, bands of C-O stretching vibrations at 755, 794, 1105, 1138, 1382, 1482, and 1540 cm^{-1}, and bands of Y-O vibrations at 175, 271 and 332 cm^{-1}.

Chemical composition Yuchuanite-(Y) is a hydrous carbonate mineral of yttrium and heavy rare earths such as Y, Yb, Er, Dy, Gd, Ho, Tm. Chemical data are given in Table S1. The presence of CO_2 was confirmed by Raman spectroscopic measurements (Fig. 4) and qualitative analysis by Electron microprobe. The presence of H_2O was confirmed by Raman spectroscopic measurements (Fig. 4) and bond-valence calculations (Table S2). The amounts of CO_2 and H_2O were calculated on the basis of stochiometry derived from the crystal-structure refinement.

The empirical formula, based on 10 oxygen atoms per formula unit (apfu) and consistent with twelve Y and eighteen C structural sites, is: $(Y_{1.61}Yb_{0.11}Er_{0.11}Dy_{0.08}Ho_{0.03}Gd_{0.02}Tm_{0.02})_{\Sigma1.99}(CO_3)_3 \cdot H_2O$, which can be simplified into $(Y, Yb, Er, Dy)_2(CO_3)_3 \cdot H_2O$. The ideal formula is

$Y_2(CO_3)_3 \cdot H_2O$.

CRYSTALLOGRAPHY

Unit-cell parameters obtained from the single-crystal and powder X-ray diffraction data (Fig. 5; Table S3) are: a = 6.2134(3) Å, b = 8.9697(3) Å, c = 19.9045(7) Å, α = 91.062(3)°, β = 90.398(3)°, γ = 91.832(3)°, and V = 1108.54(8) Å^3, and a = 6.2105(1) Å, b = 8.9726(1) Å, c = 19.9078(3) Å, α = 91.120(1)°, β = 90.410(2)°, γ = 91.920(2)°, and V = 1108.49(16) Å^3, respectively. The crystal structure determination and refinement process of yuchuanite-(Y) were performed using OLEX2-1.3 (Dolomanov et al., 2010). The structural model was solved with the SHELXT using intrinsic phasing method and refined with a full matrix least square program, SHELXL (Sheldrick, 2015a, b). Crystallographic data and refinement statistics are given in Table S4. The structure was solved in space group P-1 (#2) and refined with anisotropic displacement parameters for all sites (except hydrogen atoms). Atom occupancies are refined toward minimum R1 and show good agreement with the chemical compositions in Table S1. For simplicity, only Y, Er, Yb, and Dy are considered in the rare earth elements (REE) refinement, since they are the major elements according to our electron microprobe data. The positions of the H atoms were found by the difference Fourier.

The refinement of converged into R_1=0.0390, wR_2=0.0537 for a total of 5045 unique reflections, and R_1=0.0282, wR_2=0.0515 for 4268 reflections of $I \geq 2\sigma(I)$. The final atomic coordinates and displacement parameters are listed in Table S5, and selected bond lengths are provided in Table 1. The bond-valence sums of atoms are presented in Table S2. The structure is illustrated in Fig. 6a, b.

DISCUSSION

The structure of yuchuanite-(Y) can be described as a sheet structure built up from Y polyhedra and C trigonal planar groups. (Fig. 6a). There are six independent Y positions, all eight-coordinated and dominated by Y amoung the rare earth elements (REEs). They can be further divided into two coordination environments. The first is [$YO_7(H_2O)$] (Y1, Y3, and Y5), whereas the second is [YO_8] (Y2, Y4, and Y6). All Y polyhedra are linked by shared edges and form a (1-10) sheet (Fig. 6b). As the empirical chemical formula shows, the mineral also contains other heavy REE (Yb, Er, and Dy, in order of abundance). The bond-valence sums (BVS) at Y1, Y2, Y3, and Y4 are slightly higher than 3, probably because we only considered all REE as trivalent cations (e.g., Y^{3+}) in the structural refinement (for simplicity) but tetravalent REE cations may occur at Y1, Y2, Y3, or Y4. There are nine independent C positions, and all are in the form of [CO_3] triangles. Three independent molecular water positions are located in a single unit cell, (O28, O29 and O30). Terminal oxygen atoms are only attached to a single, nearest central Y ion. All the H positions are successfully found on the difference Fourier electron density map, and the calculation of hydrogen-bond valences is based on O-O bond lengths (Brown and Altermatt, 1985). All the hydrogen geometries are reasonable (Table 2) (Table S1). The crystal structure of yuchuanite-(Y) may represent a new structural type of hydrated normal carbonates [$AmGn(QO_3)p{\cdot}xH_2O$, with $(m+n):p < 1:1$] and may therefore be classified as a new member of Dana classification 15.4, in addition to tengerite-(Y), lanthanite-(Nd) and so on.

The chemical composition of tengerite-(Y) is similar to yuchuanite-(Y), and both minerals are hydrous REE carbonate minerals with carbonate to REE ratios of 3:2. Nevertheless, their crystal structures are quite different. In contrast to the sheets parallel to (1-10) in yuchuanite-(Y), the crystal structure of tengerite-(Y) is constructed from corrugated (001) sheets (Miyawaki et al., 1993) (Fig. 6c, d). These corrugated sheets are connected to one another with carbonate ions wedged between them, holding the sheets together. The sheets in yuchuanite-(Y) link together in ways that are significantly different from those in tengerite-(Y). As a result, the crystal system (orthorhombic), space group (*Bb*2$_1$*m*), and unit cell of tengerite-(Y) are distinct from those of yuchuanite-(Y) (Table 3), respectively. More importantly, another essential difference between the two Y-minerals is the coordination of the Y atoms. The Y polyhedra in tengerite-(Y) are nine-coordinated and the Y atom is coordinated by eight O atoms of carbonate groups and a H_2O molecule. In contrast, Y atoms in yuchuanite-(Y) are eight-coordinated with two types. Consequently, yuchuanite-(Y) is a new mineral species independent from tengerite-(Y), but not a polytype of tengerite-(Y). By comparison, the synthesized $Y_2(CO_3)_3 \cdot H_2O$ crystal and yunchuanite-(Y) have different crystal structures. The honeycomb-like framework structure of synthesized $Y_2(CO_3)_3 \cdot H_2O$ crystal consists of $[YO_9]$ and $(CO_3)^{2-}$ groups, while water resides in the center of the hexagonal channels (Peng et al., 2019). The crystal system (hexagonal), space group (*P6$_3$/mcm*), and unit cell of synthesized $Y_2(CO_3)_3 \cdot H_2O$ crystal are also different from those of yuchuanite-(Y).

IMPLICATIONS

The Yushui deposit features HREE and vanadium enrichments (HREE grade in Cu ore: up to 6.1 wt.%). It contains abundant HREE-/HREE-V minerals, including hingganite-(Y), xenotime-(Y), thortveitite, jingwenite-(Y) ($Y_2Al_2V^{4+}{}_2[SiO_4]_2O_4[OH]_4$) (Liu et al., 2023), synchysite-(Y), chernovite-(Y), and imoriite-(Y), occurring in the lower part of the bedded ore. Based on petrology, trace element analyses and Nd isotope data of multiple HREE-bearing minerals, the HREEs were thought to be leached from the footwall sandstone by oxidized basinal brines, mobilized into the sediment-hosted Cu system, and then precipitated in organic-rich beds in the overlying dolostone/limestone, which acted as a reductant and which also provided P for efficient REE fixation (Liu et al., in review). This model could be equally applied to the formation of yuchuanite-(Y).

HREEs were similarly leached from the footwall red sandstone via basinal brines and carbon was sourced from overlying dolostone/limestone via fluid-rock reactions.

ACKNOWLEDGMENTS

We thank Xiaolin Wang for technical assistance with Raman spectroscopy.

FUNDING

This research was jointly funded by the National Natural Science Foundation of China (grants 42272070, 42102080, 42130102, and 41820104010) and the Natural Science Basic Research Program in Shaanxi Province of China (2022JC-DW5-01).

REFERENCES CITED

Iimori, T (1938) Tengerite found in Iisaka, and its chemical composition. Scientific Papers of the Institute of Physical and Chemical Research (Tokyo), 34, 832-841.

Brown, I.D., and Altermatt, D. (1985) Bond-valence parameters obtained from a systematic analysis of the Inorganic Crystal Structure Database. Acta Crystallographica, B41, 244–247.

Chen, M.H., Ke, C.H., Tian, Y.F., Chen, G., Ma, K.Z., Ma, S.X., Peng, Y.X., and Zhang, W. (2021) Sedimentary-exhalative massive sulfide deposits in shallow marine environment: a case study from Yushui copper deposit, Guangdong Province. Acta Geologica Sinica, 95, 1774–1791 (in Chinese with English abstract).

Dana, J.D. (1868) A system of mineralogy, Wiley, New York. 710 p

Drake, M.J., and Weill, D.F. (1972) New rare earth elements standards for electron microprobe analysis. Chemical Geology, 10, 179–181.

Dolomanov, O.V., Bourhis, L.J., Gildea, R.J., Howard, J., and Puschmann, H. (2010) Olex2: a complete structure solution, refinement and analysis program. Journal of Applied Crystallography, 42, 339–341.

Huang, Y., Sun, X.M., Shi, G.Y., Sa, R.N., Guang, Y., Jiang, X.D., and Que, H.H. (2015) Re-Os dating of sulphides from the Yushui Cu-polymetallic deposit in eastern Guangdong Province, South China. Ore Geology Reviews, 70, 281–289.

Jiang, B.B., Zhu, X.Y., Cheng, X.Y., and Wang, H. (2016) Characteristics and geological significance of fluid inclusions in the Yushui copper polymetallic deposit, Guangdong Province. Geology in China, 43, 2163–2172 (in Chinese with English abstract).

Liu, P., Gu, X.P., Zhang, W.L., Hu, H., Chen, X.D., Wang, X.L., Song, W.L., Yu, M., and Cook, N.J. (2023) Jingwenite-(Y) from the Yushui Cu deposit, South China: The first occurrence of a V-HREE-bearing silicate mineral. American Mineralogist, 108, 192-196.

Liu, P., Gleeson, S.A., Cook, N.J., Lehmann, B., Zhao, C., Yao, W., Bao, Z.A., Wu, S.T., Tian, Y.F., Mao, J.W. Final assembly of Gondwana enhances (HREE and U) endowment of South China. Submitted to Geology, in review.

Liu, J.Q. (1997) Thermobaro geochemistry, ore-forming age and genesis study for the Yushui copper-rich multimetal deposit in Meixian county, Guangdong Province, Southern China: Geology and Mineral Resources of South China, 1, 37–50 (in Chinese with English abstract).

Mandarino, J.A. (1981) The Gladstone-Dale relationship: Part IV. The compatibility concept and its application. The Canadian Mineralogist, 19, 441–450.

Miyawaki, R., Kuriyama, J. and Nakai, I. (1993) The redefinition of tengerite-(Y), $Y_2(CO_3)_3 \cdot 2\text{-}3H_2O$, and its crystal structure. American Mineralogist, 78, 425–432.

Momma, K., and Izumi, F. (2011) VESTA 3 for three-dimensional visualization of crystal, volumetric and morphology dat*a.* Journal of Applied Crystallography, 44, 1272–1276.

This is the peer-reviewed, final accepted version for American Mineralogist, published by the Mineralogical Society of America.
The published version is subject to change. Cite as Authors (Year) Title. American Mineralogist, in press.
DOI: https://doi.org/10.2138/am-2023-8971. http://www.minsocam.org/

Nagashima, K., and Wakita, H. (1968) On the composition of tengerite. Nippon Kagaku Zasshi, 89, 856-859 (in Japanese).

Peng, G., Lin, C.S., Yang, Y.Y., Zhao, D., Lin, Z.S., Ye, N., and Huang, J.M. (2019) $Y_2(CO_3)_3 \cdot H_2O$ and $(NH_4)_2Ca_2Y_4(CO_3)_9 \cdot H_2O$: Partial Aliovalent Cation Substitution Enabling Evolution from Centrosymmetry to Noncentrosymmetry for Nonlinear Optical Response. Chemistry of Materials, 31, 52-56.

Sheldrick, G.M. (2015a) SHELXT-Integrated space-group and crystal structure determination. Acta Crystallographica, A71, 3–8.

Sheldrick, G.M. (2015b) Crystal structure refinement with SHELX. Acta Crystallographica, C71, 3–8.

Svanberg, A.F., and Tenger, C. (1838) Kolsyrad ytterjord. Årsberättelse om Framstegen i Fysik och Kemi, 16: 206-207 (in Swedish; not seen; extracted from Dana's System of Mineralogy (7th edition), 2, 275-276, 1951).

Tareen, J.A.K., Narayanan Kutty, T.R., and Krishnamurty, K.V. (1980) Hydrothermal growth of $Y_2(CO_3)_3 \cdot nH_2O$ (tengerite) single crystals. Journal of Crystal Growth, 49, 761-765.

Figure captions

Fig. 1. (a) Geological map of the Yushui deposit (after Huang et al., 2015). (b) Geological cross section of the exploration line a–b (from Chen et al., 2021).

Fig. 2. (a) Stratigraphic column of the Yushui deposit. (b) Photograph of drillcore of red sandstone; (c)-(e) Photographs of bedded orebody. (f) Photomicrograph of disseminated ore in red sandstone. (g) Photograph of vein-style orebody in red sandstone. Bn-bornite; Cc-chalcocite; Ccp-chalcopyrite.

Fig. 3. Photomicrographs showing occurrence and mineral association of yuchuanite-(Y). (a)

Always consult and cite the final, published document. See http:/www.minsocam.org or GeoscienceWorld

euhedral yuchuanite-(Y) (Ych-Y) crystal with bornite (Bn) and sphalerite (Sp) (reflected light, parallel nicols). (b) same view as (a) but in transmitted light, parallel nicols, showing the platy shape and colorless nature of yuchuanite-(Y) (Ych-Y). (c)euhedral yuchuanite-(Y) (Ych-Y) crystals and yuchuanite-(Y) veins with bornite (Bn), xenotime-(Y) and quartz (Qz) (reflected light, parallel nicols). (d) euhedral yuchuanite-(Y) (Ych-Y) crystal with bornite (Bn) and chalcopyrite (Ccp) and quartz (Qz) (reflected light, parallel nicols). (e) Back-scattered electron image of the same crystal of euhedral yuchuanite-(Y) (Ych-Y) crystal (e) with bornite (Bn). (f) Back-scattered electron image of aggregates of yuchuanite-(Y) (Ych-Y) crystals with anhydrite (Anh), bornite (Bn) and galena (Gn), containing a euhedral bastnäsite-(Y) (Bsn-Y) crystal.

Fig. 4. Raman spectrum (selected Raman shift area) for yuchuanite-(Y).

Fig. 5. Simulated and measured powder X-ray diffraction patterns for yuchuanite-(Y).

Fig. 6. Crystal structure of yuchuanite-(Y) (a, b) and tengerite-(Y) (c, d) depicted with VESTA (Momma and Izumi, 2011). (a) a view along the b-axis (unit-cell outlined in black lines); (b) a view along [110] (unit-cell outlined in black lines). (c) a view along the a-axis (unit-cell outlined in black lines); (d) a view along c-axis (unit-cell outlined in black lines). The data of tengerite-(Y) after Miyawaki et al. (1993).

Table captions

Table 1. Selected bond lengths (Å) of yuchuanite-(Y).

Table 2. Proposed hydrogen-bond geometries in the yuchuanite-(Y) crystal structure.

Table 3. A comparison between yuchuanite-(Y) and tengerite-(Y).

This is the peer-reviewed, final accepted version for American Mineralogist, published by the Mineralogical Society of America.
The published version is subject to change. Cite as Authors (Year) Title. American Mineralogist, in press.
DOI: https://doi.org/10.2138/am-2023-8971. http://www.minsocam.org/

Table 1 (revision 1)

Bond	Length	Bond	Length	Bond	Length
Y1–O3	2.244(3)	Y2–O6	2.373(3)	Y3–O9	2.299(3)
Y1–O4	2.254(3)	Y2–O7	2.190(3)	Y3–O10	2.525(3)
Y1–O10	2.246(3)	Y2–O8	2.350(3)	Y3–O11	2.450(3)
Y1–O18	2.306(3)	Y2–O9	2.371(3)	Y3–O12(1)	2.257(3)
Y1–O19	2.481(3)	Y2–O11	2.377(3)	Y3–O12(2)	2.511(3)
Y1–O20	2.448(3)	Y2–O13(1)	2.445(3)	Y3–O15	2.239(3)
Y1–O21	2.506(3)	Y2–O13(2)	2.317(3)	Y3–O19	2.252(3)
Y1–O28	2.351(3)	Y2–O14	2.405(3)	Y3–O29	2.338(3)
<Y1–O>	**2.355**	**<Y2–O>**	**2.354**	**<Y3–O>**	**2.356**
Y4–O5	2.434(3)	Y5–O1(1)	2.319(3)	Y6–O2	2.421(3)
Y4–O6	2.463(3)	Y5–O1(2)	2.504(3)	Y6–O5	2.353(3)
Y4–O14	2.315(3)	Y5–O2	2.399(3)	Y6–O23(1)	2.315(3)
Y4–O16	2.193(3)	Y5–O3	2.462(3)	Y6–O23(2)	2.613(3)
Y4–O17	2.354(3)	Y5–O21	2.279(3)	Y6–O24	2.408(3)
Y4–O18	2.381(3)	Y5–O24	2.349(3)	Y6–O25	2.330(3)
Y4–O20	2.383(3)	Y5–O25	2.311(3)	Y6–O26	2.220(3)
Y4–O22	2.311(3)	Y5–O30	2.340(3)	Y6–O27	2.377(3)
<Y4–O>	**2.354**	**<Y5–O>**	**2.370**	**<Y6–O>**	**2.380**
C1–O1	1.273(5)	C2–O4	1.244(5)	C3–O7	1.246(5)
C1–O2	1.284(5)	C2–O5	1.300(5)	C3–O8	1.279(5)
C1–O3	1.277(4)	C2–O6	1.285(5)	C3–O9	1.306(5)
<C1–O>	**1.278**	**<C2–O>**	**1.276**	**<C3–O>**	**1.277**
C4–O10	1.279(4)	C5–O13	1.284(5)	C6–O16	1.252(5)
C4–O11	1.281(4)	C5–O14	1.298(5)	C6–O17	1.265(5)
C4–O12	1.273(5)	C5–O15	1.240(5)	C6–O18	1.305(5)
<C4–O>	**1.278**	**<C5–O>**	**1.274**	**<C6–O>**	**1.274**
C7–O19	1.290(5)	C8–O22	1.253(5)	C9–O25	1.311(5)
C7–O20	1.281(5)	C8–O23	1.284(5)	C9–O26	1.246(5)
C7–O21	1.278(5)	C8–O24	1.275(5)	C9–O27	1.284(5)
<C7–O>	**1.283**	**<C8–O>**	**1.271**	**<C9–O>**	**1.280**

Always consult and cite the final, published document. See http:/www.minsocam.org or GeoscienceWorld

This is the peer-reviewed, final accepted version for American Mineralogist, published by the Mineralogical Society of America.
The published version is subject to change. Cite as Authors (Year) Title. American Mineralogist, in press.
DOI: https://doi.org/10.2138/am-2023-8971. http://www.minsocam.org/

Table 2 (revision 1)

D–H···A	D–H(Å)	H···A(Å)	D···A(Å)	D–H···A angle(°)	H–D–H angle(°)
O28–H28A···O6	0.88(8)	2.33(7)	3.121(5)	149(7)	}99(6)
O28–H28B···O17	0.90(6)	1.78(6)	2.664(5)	163(5)	
O29–H29A···O8	0.86(5)	1.80(5)	2.659(5)	177(6)	}101(12)
O29–H29B···O14	0.88(10)	2.31(12)	3.164(5)	162(15)	
O30–H30A···O27	0.88(9)	1.77(9)	2.650(5)	173(8)	}102(8)
O28–H30B···O23	0.86(9)	2.20(9)	2.939(5)	143(8)	

Always consult and cite the final, published document. See http:/www.minsocam.org or GeoscienceWorld

This is the peer-reviewed, final accepted version for American Mineralogist, published by the Mineralogical Society of America.
The published version is subject to change. Cite as Authors (Year) Title. American Mineralogist, in press.
DOI: https://doi.org/10.2138/am-2023-8971. http://www.minsocam.org/

Table 3 (revision 1)

	Yuchuanite-(Y)	Tengerite-(Y)
Ideal Formula	$Y_2(CO_3)_3\cdot H_2O$	$Y_2(CO_3)_3\cdot 2\text{-}3H_2O$
Crystal System	Triclinic	Orthorhombic
Space Group	*P*-1	$Bb2_1m$
Unit-cell parameters	a = 6.2134(3) Å b = 8.9697(3) Å c = 19.9045(7) Å α = 91.062(3)° β = 90.398(3)° γ = 91.832(3)° V= 1108.54(8) $Å^3$	a = 6.078(4) Å b = 9.157(2) Å c = 15.114(6) Å V= 841.2(7) $Å^3$
Reference	This study	Miyawaki *et al.* (1993)

Always consult and cite the final, published document. See http:/www.minsocam.org or GeoscienceWorld

This is the peer-reviewed, final accepted version for American Mineralogist, published by the Mineralogical Society of America.
The published version is subject to change. Cite as Authors (Year) Title. American Mineralogist, in press.
DOI: https://doi.org/10.2138/am-2023-8971. http://www.minsocam.org/

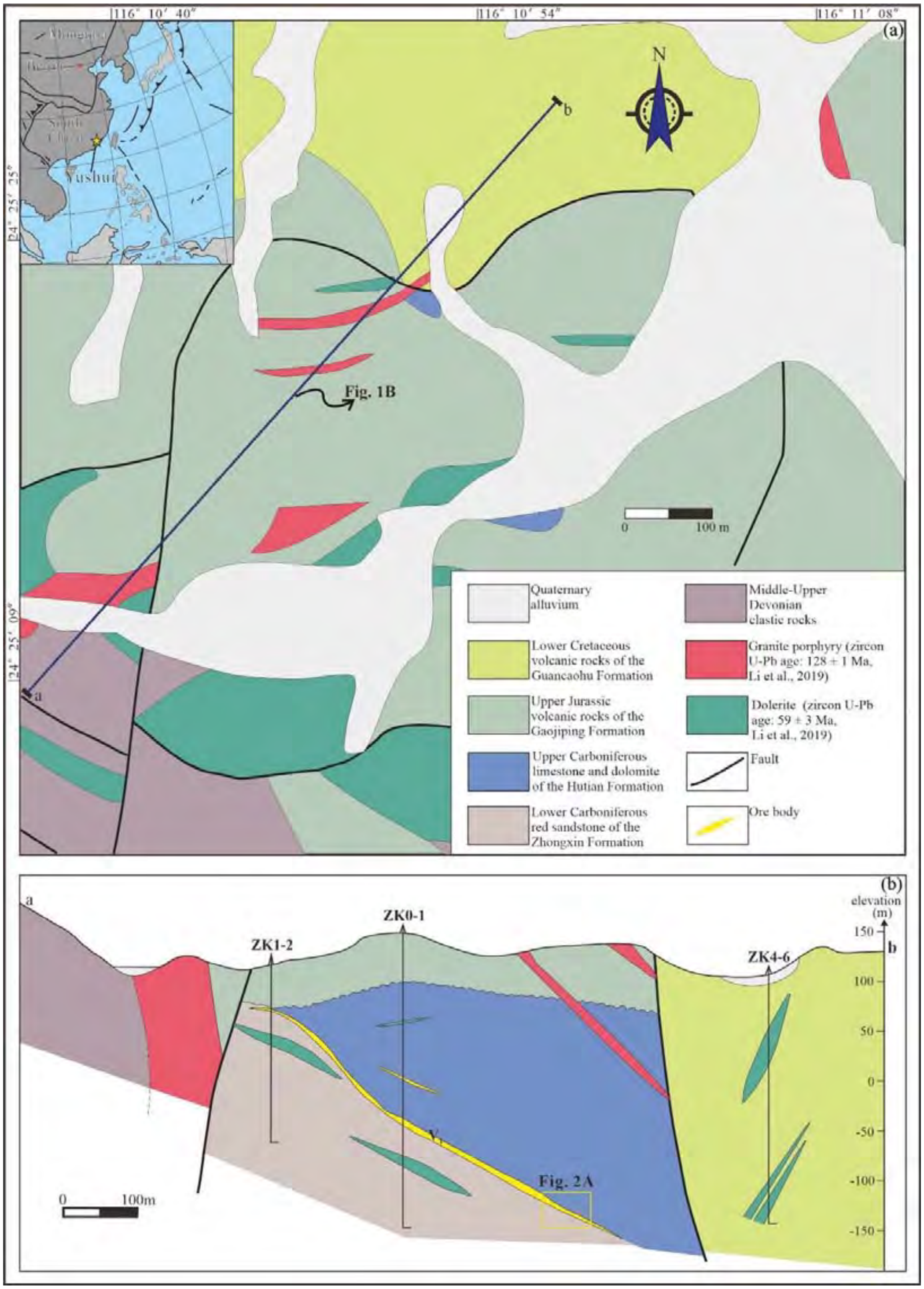

Figure 1 (revision 1)

Always consult and cite the final, published document. See http:/www.minsocam.org or GeoscienceWorld

This is the peer-reviewed, final accepted version for American Mineralogist, published by the Mineralogical Society of America.
The published version is subject to change. Cite as Authors (Year) Title. American Mineralogist, in press.
DOI: https://doi.org/10.2138/am-2023-8971. http://www.minsocam.org/

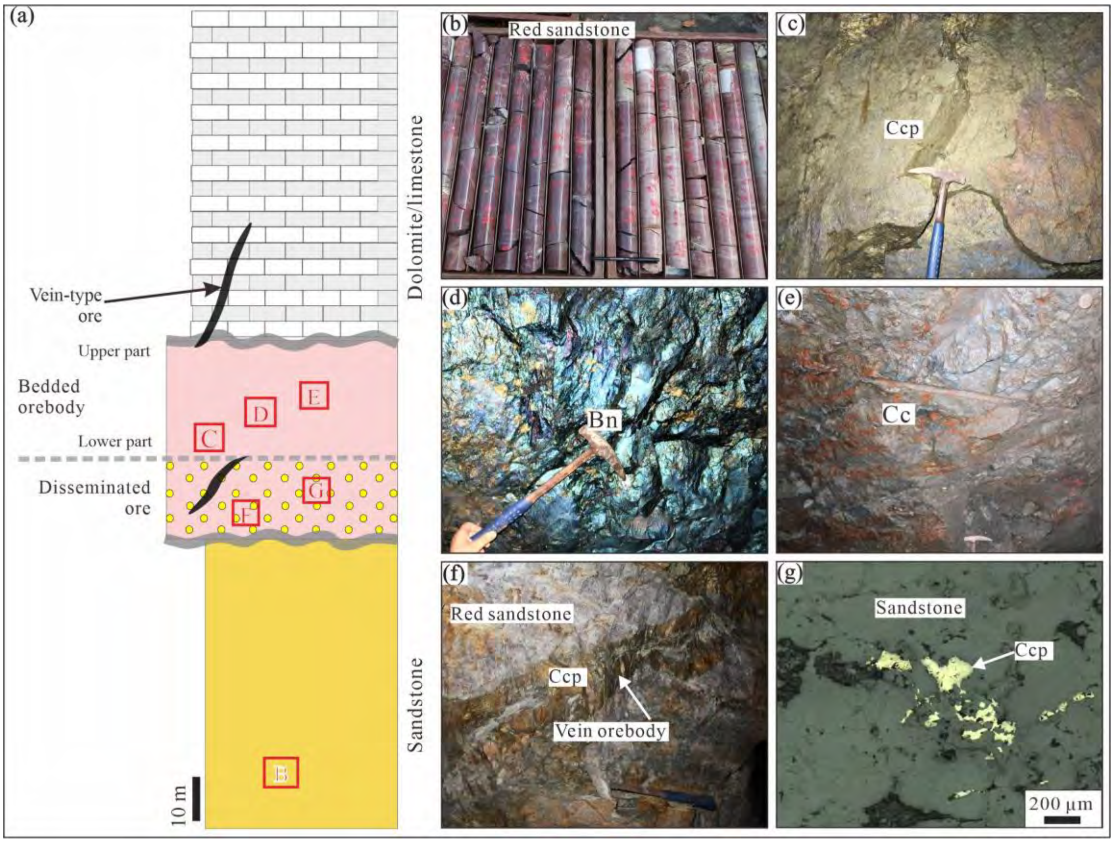

Figure 2 (revision 1)

Always consult and cite the final, published document. See http:/www.minsocam.org or GeoscienceWorld

This is the peer-reviewed, final accepted version for American Mineralogist, published by the Mineralogical Society of America.
The published version is subject to change. Cite as Authors (Year) Title. American Mineralogist, in press.
DOI: https://doi.org/10.2138/am-2023-8971. http://www.minsocam.org/

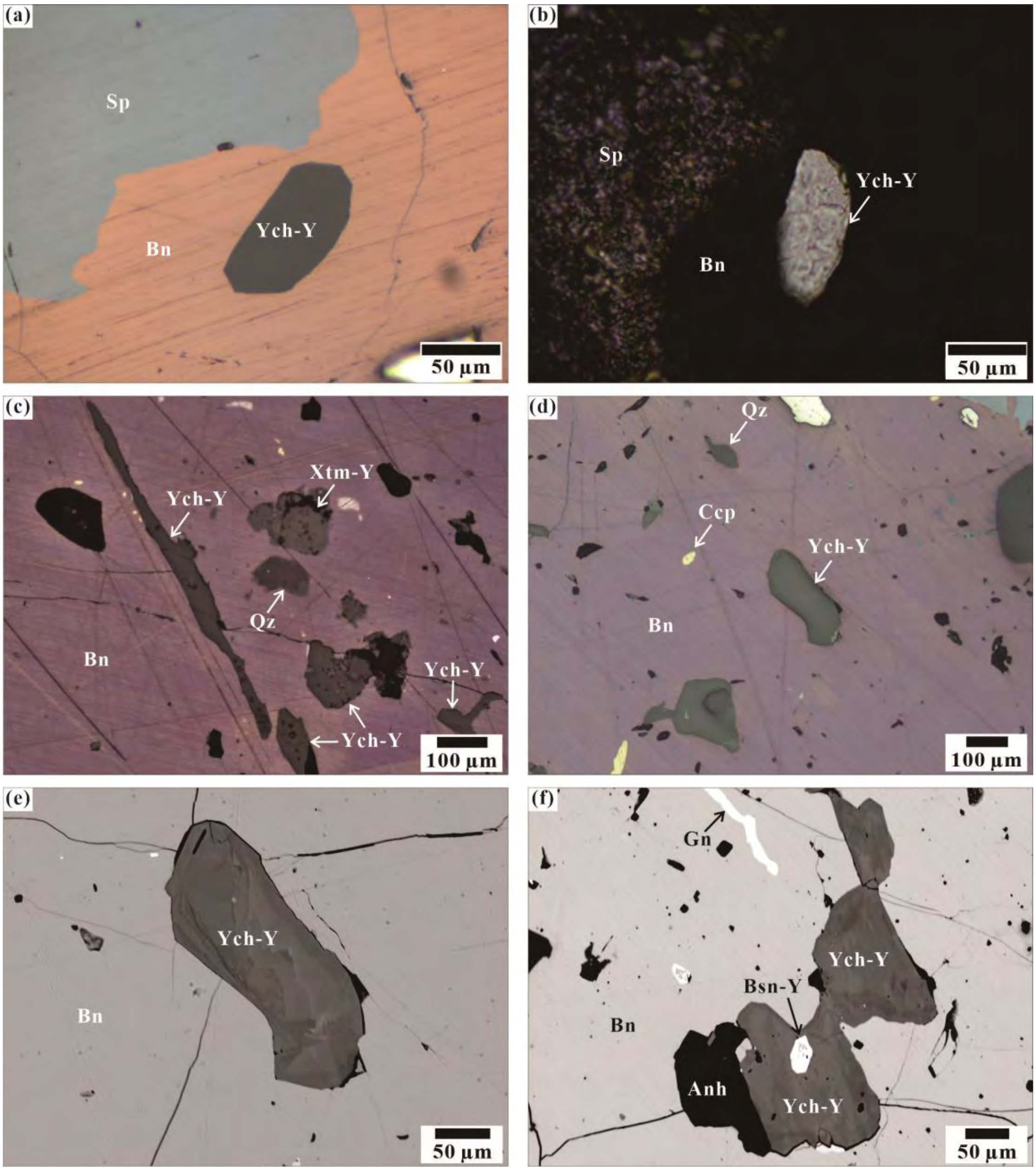

Figure 3 (revision 1)

Always consult and cite the final, published document. See http:/www.minsocam.org or GeoscienceWorld

This is the peer-reviewed, final accepted version for American Mineralogist, published by the Mineralogical Society of America.
The published version is subject to change. Cite as Authors (Year) Title. American Mineralogist, in press.
DOI: https://doi.org/10.2138/am-2023-8971. http://www.minsocam.org/

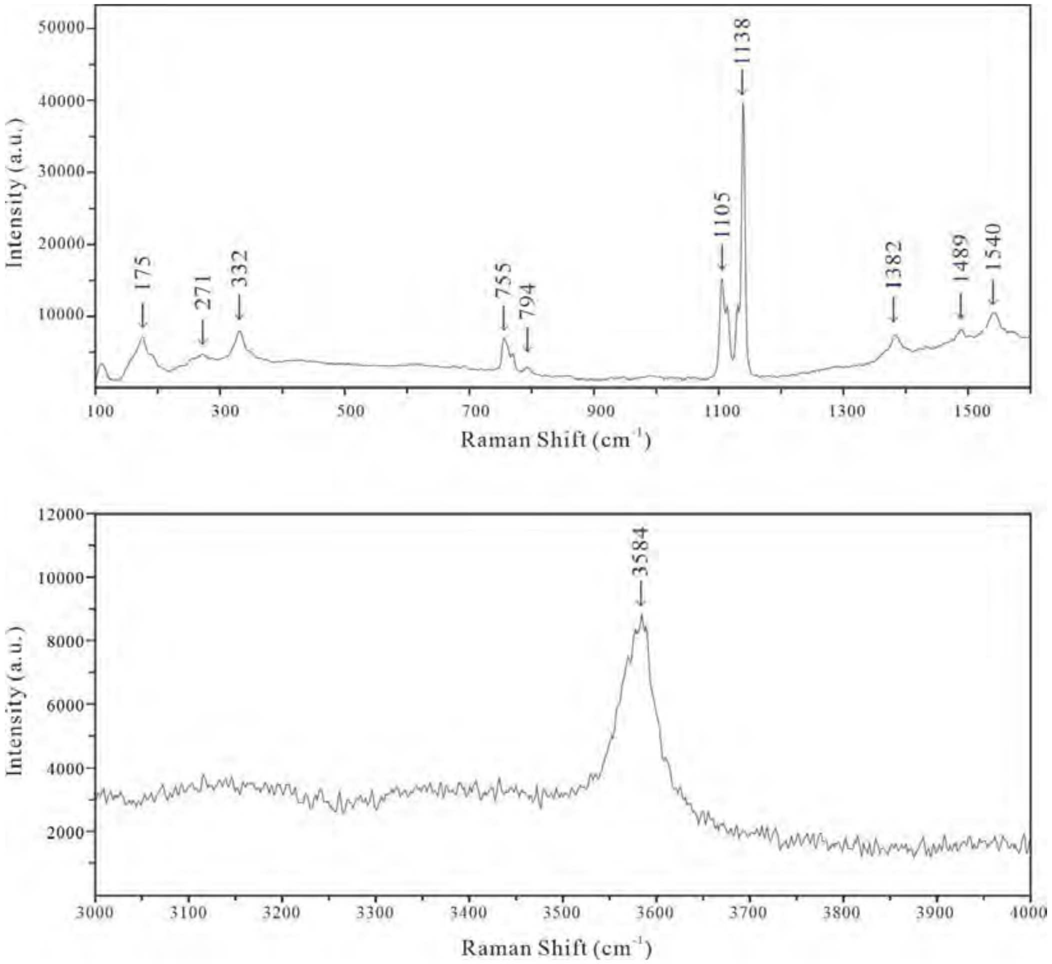

Figure 4 (revision 1)

Always consult and cite the final, published document. See http:/www.minsocam.org or GeoscienceWorld

This is the peer-reviewed, final accepted version for American Mineralogist, published by the Mineralogical Society of America.
The published version is subject to change. Cite as Authors (Year) Title. American Mineralogist, in press.
DOI: https://doi.org/10.2138/am-2023-8971. http://www.minsocam.org/

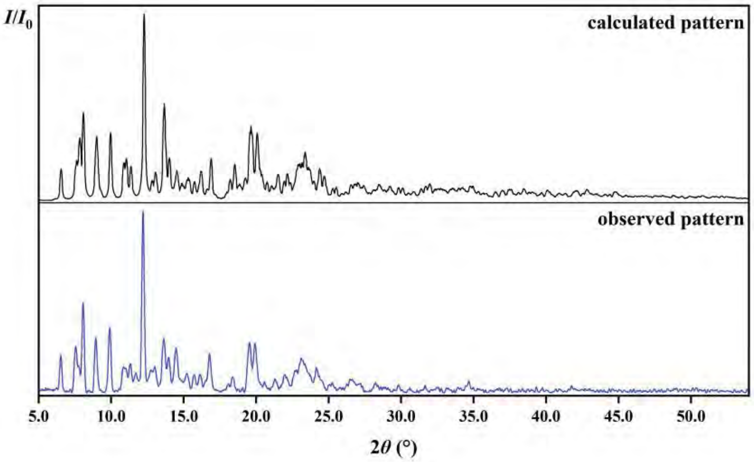

Figure 5 (revision 1)

Always consult and cite the final, published document. See http:/www.minsocam.org or GeoscienceWorld

This is the peer-reviewed, final accepted version for American Mineralogist, published by the Mineralogical Society of America.
The published version is subject to change. Cite as Authors (Year) Title. American Mineralogist, in press.
DOI: https://doi.org/10.2138/am-2023-8971. http://www.minsocam.org/

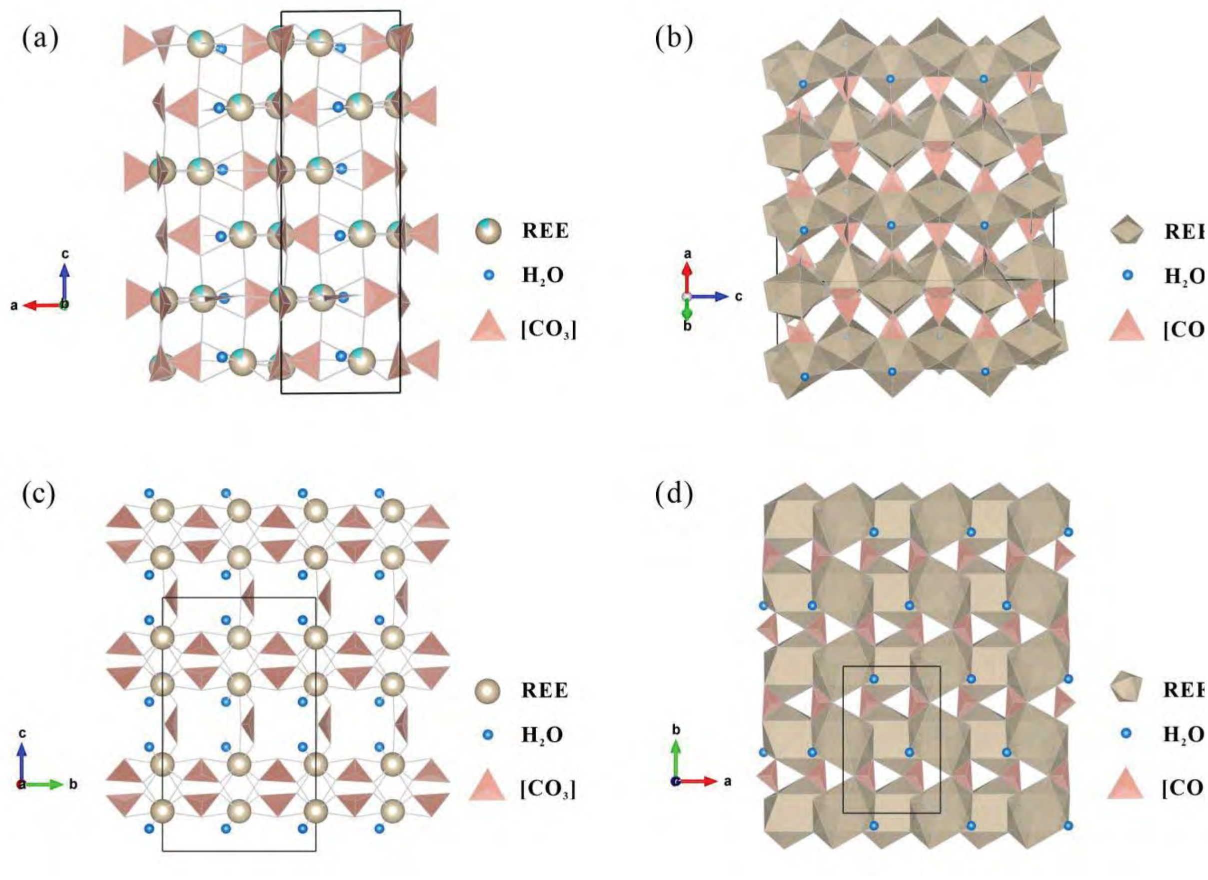

Figure 6 (revision 1)

Always consult and cite the final, published document. See http:/www.minsocam.org or GeoscienceWorld