

Table A1. Chemical data (wt. %) analyzed by EPMA for the zhonghongite (Zhh), watanabeite (Wa) and tennantite-tetrahedrite (Tn-Td).

No	Mineral	Cu	As	Sb	S	Hg	Mn	Te	Fe	Ag	Pb	Zn	Total
1	Zhh	42.22	10.62	15.06	25.38	3.91	0.63	0.40	0.11	bdl	1.07	bdl	99.44
2	Zhh	42.16	11.19	15.12	25.28	3.91	0.63	0.63	0.07	bdl	0.74	bdl	99.75
3	Zhh	41.97	11.62	14.73	25.17	3.87	0.65	0.52	0.08	bdl	0.64	0.05	99.31
4	Zhh	42.75	11.89	15.39	25.55	3.56	0.61	0.27	0.05	bdl	bdl	bdl	100.13
5	Zhh	42.25	11.18	16.48	25.27	3.89	0.73	0.24	0.06	0.05	bdl	bdl	100.19
6	Zhh	42.19	11.59	14.86	25.02	3.75	0.62	0.52	0.10	0.14	0.89	bdl	99.75
7	Zhh	42.13	10.90	15.15	25.50	4.16	0.68	0.54	0.11	bdl	0.39	bdl	99.63
8	Zhh	42.34	10.97	16.13	25.70	3.44	0.61	0.27	0.21	0.05	bdl	0.05	99.81
9	Zhh	42.41	10.91	16.19	25.72	4.02	0.71	0.17	0.33	bdl	bdl	bdl	100.56
10	Zhh	41.53	11.09	16.67	25.16	4.32	0.62	bdl	bdl	bdl	bdl	bdl	99.50
11	Zhh	42.31	11.70	15.38	25.45	3.52	0.68	0.19	0.05	bdl	bdl	bdl	99.38
12	Zhh	42.44	11.48	15.42	25.34	3.46	0.74	0.14	bdl	bdl	bdl	bdl	99.06
13	Zhh	42.34	11.49	15.91	25.56	3.47	0.76	0.15	0.04	bdl	bdl	bdl	99.81
14	Zhh	42.28	11.39	16.17	25.66	4.04	0.64	0.16	0.10	bdl	bdl	bdl	100.50
15	Zhh	42.34	11.48	16.61	25.73	3.09	0.51	0.34	0.24	0.05	bdl	0.08	100.50
16	Zhh	42.31	10.95	16.64	25.39	3.31	0.54	0.36	0.26	bdl	bdl	bdl	99.81
17	Zhh	41.59	10.48	16.69	25.45	4.22	0.79	0.23	0.09	0.05	bdl	bdl	99.56
18	Zhh	42.41	10.78	15.73	25.50	3.27	0.83	0.24	0.21	bdl	bdl	bdl	99.06
19	Zhh	42.69	12.12	15.70	25.73	3.21	0.58	0.35	0.05	0.06	bdl	bdl	100.63
20	Zhh	41.97	10.73	16.14	25.44	4.07	0.79	0.22	0.08	0.07	bdl	bdl	99.56
21	Zhh	42.03	11.27	16.13	25.67	3.85	0.72	0.19	0.12	0.08	bdl	bdl	100.13
22	Zhh	42.16	11.41	16.11	25.63	3.94	0.66	0.31	0.14	0.06	bdl	bdl	100.44
23	Zhh	42.13	11.49	15.70	25.58	4.24	0.65	0.23	0.09	bdl	bdl	bdl	100.19
24	Zhh	42.31	11.22	15.04	25.61	3.93	0.72	0.36	bdl	bdl	bdl	bdl	99.38
25	Zhh	42.22	10.91	15.63	25.63	4.10	0.60	0.19	0.12	0.07	bdl	bdl	99.50
26	Zhh	42.28	11.30	15.58	25.39	4.36	0.51	0.25	0.11	bdl	bdl	bdl	99.75
27	Zhh	42.63	11.55	15.23	25.33	3.60	0.58	0.29	0.07	bdl	bdl	bdl	99.31
28	Zhh	42.53	12.04	15.41	25.33	3.14	0.51	0.34	0.04	0.05	bdl	bdl	99.44
29	Zhh	42.31	10.75	16.36	25.19	3.38	0.65	0.24	0.18	bdl	bdl	0.05	99.13
30	Zhh	42.53	11.94	15.62	25.56	3.16	0.58	0.16	0.30	bdl	bdl	bdl	99.94
31	Zhh	42.44	10.72	16.69	25.44	3.31	0.51	0.26	0.15	0.10	bdl	bdl	99.69
32	Zhh	43.13	13.80	13.13	25.84	2.54	0.49	0.12	bdl	0.05	bdl	bdl	99.13
33	Zhh	41.75	9.78	17.69	25.39	4.08	0.86	0.18	0.08	bdl	bdl	bdl	99.88
34	Zhh	41.69	9.96	17.86	25.39	3.74	0.87	0.33	bdl	0.06	bdl	bdl	99.94
35	Zhh	41.59	10.13	18.09	25.38	4.00	0.79	0.13	bdl	0.05	bdl	bdl	100.19
36	Zhh	41.44	9.30	17.70	25.08	4.63	0.98	0.26	bdl	0.06	bdl	bdl	99.56
37	Zhh	41.47	10.41	17.83	25.22	4.05	0.74	0.21	0.04	0.05	bdl	bdl	100.00
38	Zhh	41.47	10.59	17.36	25.30	3.82	0.75	0.27	bdl	bdl	bdl	0.05	99.69
39	Zhh	42.03	9.66	17.42	25.42	4.67	0.92	0.34	bdl	bdl	bdl	bdl	100.56
40	Zhh	42.50	10.31	17.27	25.59	3.09	0.67	0.20	bdl	0.05	bdl	bdl	99.81
41	Zhh	42.41	12.45	15.67	25.61	2.61	0.49	0.43	0.04	bdl	bdl	bdl	99.75

No	Mineral	Cu	As	Sb	S	Hg	Mn	Te	Fe	Ag	Pb	Zn	Total
42	Wa	43.34	15.94	13.27	26.02	bdl	bdl	0.17	bdl	0.05	bdl	0.05	99.00
43	Wa	43.66	16.81	12.64	26.20	bdl	bdl	bdl	bdl	bdl	bdl	bdl	99.44
44	Wa	43.63	17.75	11.43	26.19	bdl	bdl	0.11	bdl	bdl	bdl	bdl	99.19
45	Wa	43.78	14.64	13.98	26.25	0.39	0.05	0.22	bdl	0.08	bdl	bdl	99.44
46	Wa	43.03	15.65	14.59	25.81	0.25	bdl	0.19	bdl	0.05	bdl	bdl	99.75
47	Wa	42.50	13.47	17.53	25.94	0.18	0.06	bdl	bdl	0.06	bdl	bdl	99.94
48	Wa	43.53	17.27	11.89	26.34	0.17	bdl	0.13	bdl	bdl	bdl	bdl	99.50
49	Wa	43.56	16.75	13.14	26.36	bdl	bdl	bdl	bdl	bdl	bdl	bdl	99.94
50	Tn-Td	43.56	7.13	15.99	25.20	5.41	1.01	0.61	0.89	bdl	bdl	bdl	99.88
51	Tn-Td	42.69	7.68	14.84	25.03	7.80	1.11	0.90	0.24	0.07	bdl	bdl	100.38
52	Tn-Td	43.94	7.83	15.39	24.89	6.31	1.03	0.56	0.22	bdl	bdl	0.05	100.25
53	Tn-Td	41.81	7.34	15.39	25.17	7.66	1.45	1.03	0.28	0.06	bdl	bdl	100.25
54	Tn-Td	44.38	7.24	17.13	25.13	3.14	0.85	0.47	1.52	bdl	bdl	0.07	100.00
55	Tn-Td	43.56	6.82	17.63	24.97	4.23	1.03	0.62	0.88	0.05	bdl	0.08	99.94
56	Tn-Td	42.78	5.36	19.47	24.53	4.20	0.90	1.10	1.13	0.23	bdl	bdl	99.75
57	Tn-Td	43.63	6.56	18.06	24.70	3.48	0.85	1.29	1.13	0.15	bdl	bdl	99.94
58	Tn-Td	44.19	6.58	17.69	24.78	3.41	0.82	0.84	1.17	bdl	bdl	bdl	99.50

Au, Se, and Bi of minerals were also detected, but all below the detection limit.

Table A2. Information on structural refinement for zhonghongite.

Crystal data	
Apfu derived from refinement	$\text{Cu}_{27.02}\text{Hg}_{0.92}\text{Mn}_{0.62}\text{As}_{6.46}\text{Sb}_{5.54}\text{Te}_{0.05}\text{S}_{33}$
Formula weight	4157.67
Crystal size (mm)	0.03*0.02*0.004
Crystal system	Orthorhombic
Space group	$F2mm$ (#42)
Unit cell dimensions (Å)	$a = 10.37741(5)$, $b = 14.69821(9)$, $c = 36.7645(2)$
Volume (Å ³)	5607.66(5)
<i>Z</i>	4
Density (g/cm ³)	4.925
Data collection and refinement	
Instrument	Rigaku Synergy at 50 kV, 1mA
Radiation, wavelength (Å), temperature (K)	Cu $K\alpha$, 1.54184, 293(2)
$F(000)$	7595.0
2 θ range (°)	4.808 to 156.212
Total reflections	27028
Unique ref (all)	2467
Unique ref [$I > 2\sigma(I)$]	2446
R_{int}	0.0264
R_{σ}	0.0136
Range of h, k, l	$-13 \leq h \leq 9$, $-18 \leq k \leq 18$, $-46 \leq l \leq 46$
R_1, wR_2 [$I > 2\sigma(I)$]	$R_1 = 0.0234$, $wR_2 = 0.0648$
R_1, wR_2 [all data]	$R_1 = 0.0235$, $wR_2 = 0.0649$
Goodness-of-fit	1.026
No. of parameters, restraints	217, 1
Max./min. residual peak (e Å ⁻³)	1.02/-1.06
Flack parameter	-0.026(7)

Table A3. Atomic coordinates, site occupancy factors (s.o.f), equivalent isotropic displacement parameters (in Å²) and bond valence sums (in valence units) for zhonghongite.

Site	<i>Wyck.</i>	<i>s.o.f</i>	<i>x/a</i>	<i>y/b</i>	<i>z/c</i>	<i>U</i> _{eq}	BVS*
As1	8 <i>c</i>	As _{0.955(9)} Sb _{0.045(9)}	0.40415(14)	0.5	0.04999(2)	0.0134(3)	3.288
As2	8 <i>d</i>	As _{0.933(9)} Sb _{0.067(9)}	0.12522(15)	0.10983(8)	0	0.0172(4)	2.924
As3	16 <i>e</i>	As _{0.452(8)} Sb _{0.548(8)}	0.37893(7)	0.26176(4)	0.14986(2)	0.0169(2)	3.274
As4	8 <i>c</i>	As _{0.366(9)} Sb _{0.634(9)}	0.40394(11)	0	0.24413(2)	0.0180(2)	3.311
As5	8 <i>c</i>	As _{0.074(11)} Sb _{0.926(11)}	0.40869(9)	0	0.05965(2)	0.0176(2)	2.814
Te1	4 <i>a</i>	Te _{0.053(5)}	0.0163(17)	0	0	0.0133(50)	
Cu1	8 <i>c</i>	Cu _{0.938(11)}	0.35666(29)	0.5	0.15077(6)	0.0528(13)	0.865
Mn1	16 <i>e</i>	Mn _{0.088(8)}	0.3564(22)	0.4179(14)	0.15252(40)	0.0416(68)	
Cu2	16 <i>e</i>	Cu _{0.947(7)}	0.14163(25)	0.39405(12)	0.19318(5)	0.0503(9)	0.869
Mn2A	16 <i>e</i>	Mn _{0.067(6)}	0.0656(20)	0.4327(13)	0.20799(49)	0.0258(60)	
Cu2B	16 <i>e</i>	Cu _{0.065(6)}	0.2266(20)	0.3548(12)	0.17640(48)	0.0291(61)	
Cu3	16 <i>e</i>	Cu _{1.00}	0.15376(21)	0.38545(11)	0.10845(5)	0.0497(6)	0.909
Cu4	8 <i>c</i>	Cu _{0.983(9)}	0.42386(28)	0	0.15288(8)	0.0508(10)	0.904
Hg4	8 <i>c</i>	Hg _{0.0249(19)}	0.4147(15)	0	0.11736(29)	0.0085(42)	
Cu5	8 <i>d</i>	Cu _{1.00}	0.16901(22)	0.37389(12)	0	0.0243(5)	0.994
Cu6	16 <i>e</i>	Cu _{1.00}	0.13548(16)	0.12503(8)	0.10279(3)	0.0227(3)	0.981
Cu7	16 <i>e</i>	Cu _{0.989(3)} Hg _{0.011(3)}	0.40259(14)	0.25957(8)	0.05040(2)	0.0232(4)	1.038
Cu8	16 <i>e</i>	Cu _{0.879(3)} Hg _{0.121(3)}	0.13883(13)	0.12598(5)	0.20025(3)	0.0244(4)	1.196
Cu9	8 <i>b</i>	Cu _{0.831(3)} Hg _{0.169(3)}	0.39095(16)	0.25	0.25	0.0245(4)	1.287
S1	4 <i>a</i>	S _{1.00}	0.02024(36)	0.5	0	0.0172(7)	2.302
S2	8 <i>d</i>	S _{1.00}	0.03518(24)	0.24701(15)	0	0.0139(5)	1.984
S3	16 <i>e</i>	S _{1.00}	0.26419(19)	0.13274(10)	0.04944(4)	0.0148(4)	2.247
S4	16 <i>e</i>	S _{1.00}	0.26652(18)	0.38251(11)	0.05578(4)	0.0131(3)	1.935
S5	8 <i>c</i>	S _{1.00}	0.00022(24)	0	0.10479(6)	0.0139(5)	1.963
S6	16 <i>e</i>	S _{1.00}	0.02660(18)	0.26335(11)	0.10219(4)	0.0147(3)	1.932
S7	16 <i>e</i>	S _{1.00}	0.28273(19)	0.11575(12)	0.14985(4)	0.0155(4)	1.942
S8	8 <i>c</i>	S _{1.00}	-0.00177(26)	0	0.19691(6)	0.0185(5)	2.076
S9	16 <i>e</i>	S _{1.00}	0.02577(19)	0.26487(11)	0.19796(4)	0.0182(4)	2.030
S10	16 <i>e</i>	S _{1.00}	0.25648(21)	0.12032(11)	0.25533(5)	0.0195(4)	2.063
S11	8 <i>c</i>	S _{1.00}	0.14034(27)	0.5	0.14912(5)	0.0178(5)	1.938

* Bond valence sums are calculated using the program ECoN21 by Ilinca (2022)

Table A4. Anisotropic displacement parameters (in Å²) for zhonghongite.

Site	U_{11}	U_{22}	U_{33}	U_{23}	U_{13}	U_{12}
As1	0.0122(6)	0.0133(5)	0.0145(5)	0	0.0017(5)	0
As2	0.0172(7)	0.0180(5)	0.0163(5)	0	0	0.0025(5)
As3	0.0180(4)	0.0166(3)	0.0162(3)	-0.0004(2)	0.0009(2)	-0.0006(2)
As4	0.0161(5)	0.0185(3)	0.0195(4)	0	0.0014(4)	0
Sb5	0.0160(4)	0.0153(3)	0.0217(3)	0	-0.0035(3)	0
Cu1	0.0234(15)	0.1112(32)	0.0239(11)	0	-0.0037(8)	0
Cu2	0.0651(18)	0.0421(10)	0.0439(11)	0.0230(7)	-0.0334(11)	-0.0291(11)
Cu3	0.0650(15)	0.0390(7)	0.0451(8)	-0.0238(6)	0.0329(9)	-0.0302(9)
Cu4	0.0199(14)	0.0185(10)	0.1139(24)	0	0.0013(12)	0
Cu5	0.0262(11)	0.0293(8)	0.0174(8)	0	0	-0.0076(7)
Cu6	0.0209(8)	0.0195(6)	0.0277(6)	-0.0023(4)	-0.0047(5)	-0.0007(5)
Cu7	0.0248(9)	0.0236(6)	0.0211(6)	-0.0001(4)	0.0005(5)	0.0066(6)
Cu8	0.0216(7)	0.0242(5)	0.0274(5)	0.0031(3)	0.0003(4)	0.0006(4)
Cu9	0.0310(9)	0.0218(5)	0.0206(5)	-0.0005(4)	0	0
S1	0.0134(17)	0.0177(14)	0.0206(15)	0	0	0
S2	0.0131(12)	0.0153(9)	0.0133(9)	0	0	0.0012(8)
S3	0.0161(8)	0.0144(8)	0.0139(6)	-0.0003(5)	-0.0003(6)	0.0020(6)
S4	0.0149(8)	0.0106(6)	0.0139(6)	-0.0009(5)	-0.0019(6)	-0.0004(5)
S5	0.0111(11)	0.0143(9)	0.0161(9)	0	-0.0042(8)	0
S6	0.0141(9)	0.0146(7)	0.0153(7)	-0.0010(5)	-0.0010(6)	-0.0011(6)
S7	0.0137(9)	0.0146(7)	0.0180(8)	0.0002(5)	-0.0008(6)	0.0009(7)
S8	0.0154(13)	0.0251(11)	0.0149(10)	0	-0.0013(9)	0
S9	0.0194(10)	0.0168(7)	0.0183(7)	0.0029(5)	-0.0027(6)	-0.0037(7)
S10	0.0209(10)	0.0189(7)	0.0187(7)	0.0027(6)	0.0035(7)	0.0030(6)
S11	0.0175(13)	0.0161(9)	0.0197(10)	0	0.0002(8)	0

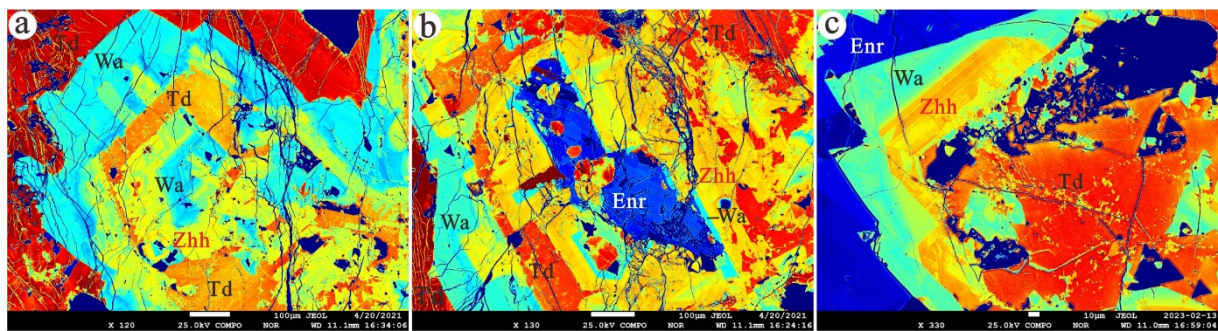


Figure A1. Pseudo-color images of Fig.2 b - d. Enr: enargite, Wa: watanabeite, Zhh: zhonghongite, Td: tetrahedrite

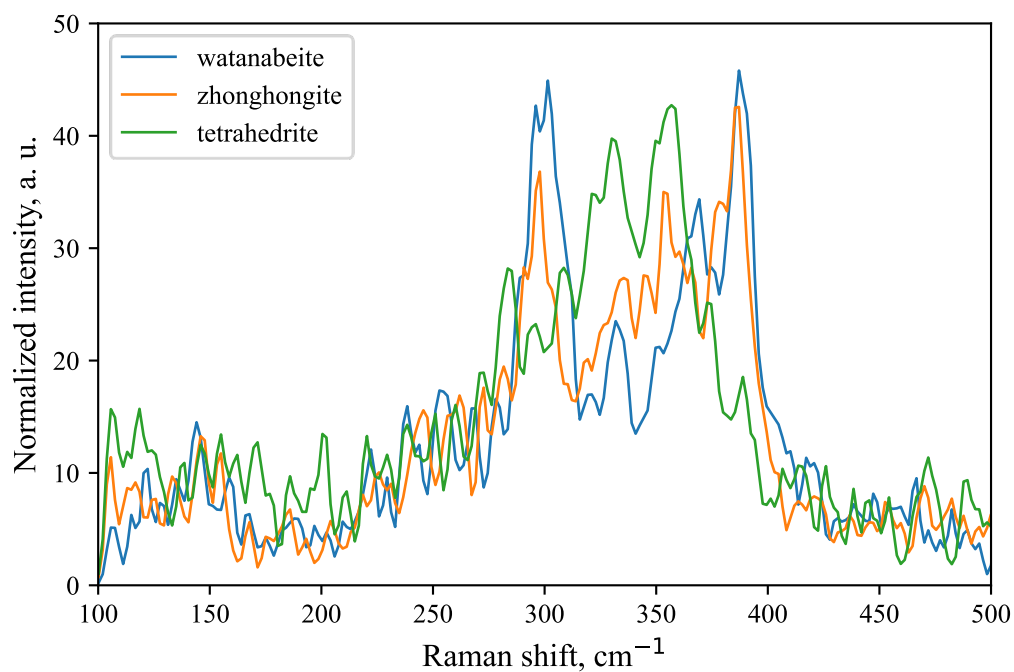


Figure A2. The Raman spectra for the intergrown watanabeite, zhonghongite and tetrahedrite.