

SULFOSALTS

CLASS C SULFOSALTS (Me^+ , Me^{2+} , etc.) $_x$ [(Bi, Sb, As) $^{3+}$, Te $^{4+}$] $_y$ X[(S, Se, Te) $^{2-}$] $_x$

GROUP A SULFOSALTS WITH ATOM RATIO OF CATION/CHALCOGEN = 1

TYPE A BINARY SULFOSALTS (MPnCh_2), where M = univalent cation (Cu, Ag, Tl); Pn = pnictogen (As, Sb, Bi); Ch = chalcogen.

SERIES A **MATILDITE ISOTYPIC SERIES. Trigonal Derivatives of PbS, according to (PbS) $_{111}$ slice.** American Mineralogist: 55: 2135.
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CAAAA	MATILDITE	AgBiS ₂	trig/P3m1
CAAAB	BOHDANOWICZITE	AgBiSe ₂	hex/P3m1
CAAAC	VOLYNSKITE	AgBiTe ₂	trig, P3m1

SERIES B **ARAMAYOITE ISOTYPES. Miargyrite a sheared Derivative of SnS Archetype. Structure consists of pairs of edge-sharing SbAs₃ tetrahedra linked by Ag to form chains // [010]; the chains are connected by additional Ag atoms.**

[Cuboargyrite](#), [Miargyrite](#) Isostructural with: [Aramayoite](#)
 The triclinic polymorph of [Miargyrite](#) and [Cuboargyrite](#).
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Palache, Charles, Harry Berman & Clifford Frondel (1944), The System of Mineralogy of James Dwight Dana and Edward Salisbury Dana Yale University 1837-1892, Volume I: Elements, Sulfides, Sulfosalts, Oxides. John Wiley and Sons, Inc., New York. 7th edition, revised and enlarged: 427-429.

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Effenberger, H., Paar, W.H., Topa, D., Criddle, A.J., and Fleck, M. (2002) The new mineal baumstarkite and a structural reinvestigation of aramayoite and miargyrite. American Mineralogist: 87: 753-764.

CAABA	ARAMAYOITE	Ag ₃ Sb ₂ (Sb,Bi)S ₆	tric/P1
CAABB	BAUMSTARKITE	Ag ₃ (Sb,As) ₂ SbS ₆	tric/P1
CAABC	CUBOARGYRITE (BGBAH)	AgSbS ₂	cub/
CAABD	MIARGYRITE	AgSbS ₂	mon/A2/a

SERIES C **TSYGANKOITE. mon/C2/c. The structure consists of an alternation of two thick layer-like arrays, one based on PbS-archetype and the second on SnS-archetype. Tsygankoite, ideally Mn₈Tl₈Hg₂(Sb₂₁Pb₂Tl) Σ 24S₄₈, is a new sulfosalt discovered at the Vorontsovskoe gold deposit, Northern Urals, Russia. It occurs as lath-like elongated crystals up to 0.2 mm embedded in calcite-dolomite-clinocllore matrix. The associated minerals also include aktashite, alabandite, arsenopyrite, barite, cinnabar, fluorapatite, orpiment, pyrite, realgar, routhierite, sphalerite, tilasite, and titanite. The new mineral is non-fluorescent, black, and opaque with a metallic lustre and black streak. It is brittle with an uneven fracture and no obvious parting and cleavage. Its Vickers hardness (VHN10) is 144 kg/mm² (range 131-167 kg/mm²) and its calculated density is 5.450 g cm. In reflected light, tsygankoite is white;**

between crossed polars it is dark grey to black. It is strongly anisotropic: rotation tints vary from light grey to dark grey to black. Pleochroism and internal reflections are not observed. The chemical composition of tsygankoite (wt %, electron-microprobe data) is: Mn 6.29, Hg 5.42, Tl 26.05, Pb 5.84, As 3.39, Sb 30.89, S 21.87, total 99.75. The empirical formula, calculated on the basis of 90 atoms pfu, is: $Mn_8.06Ti_8.00Hg_{1.90}(Sb_{17.87}As_{3.19}Pb_{1.99}Tl_{0.97})\Sigma_{24.02}S_{48.03}$. Tsygankoite is monoclinic, space group C2/m, $a = 21.362(4) \text{ \AA}$, $b = 3.8579(10) \text{ \AA}$, $c = 27.135(4) \text{ \AA}$, $\beta = 106.944(14)^\circ$, $V = 2139.19(17) \text{ \AA}^3$ and $Z = 1$. The five strongest diffraction peaks from X-ray powder pattern (listed as $(d, \text{\AA})(hkl)$) are: 3.587(100)(112), 3.353(70)(-114), 3.204(88)(405), 2.841(72)(-513), and 2.786(99)(-514). The crystal structure of tsygankoite was refined from single-crystal X-ray diffraction data to $R = 0.0607$ and consists of an alternation of two thick layer-like arrays, one based on PbS-archetype and the second on SnS-archetype. Tsygankoite has been approved by the IMA-CNMNC under the number 2017-088. It is named for Mikhail V. Tsyganko, a mineral collector from Severouralsk, Northern Urals, Russia, who collected the samples where the new mineral was discovered.

CAACA	TSYGANKOITE	$Mn_8Ti_8Hg_2(Sb_{21}Pb_2Tl)S_{48}$	
SERIES D	Open		
SERIES E	SMITHITE SINGLE SERIES. Structure consists of triplets of AsS_3 pyramids which are linked to form six-membered chair-like rings; these rings are connected by Ag atoms		
CAAEA	SMITHITE	$AgAsS_2$	mon/C2/c
SERIES F	TRECHMANNITE SINGLE SERIES. Cyclic Trigonal. The structure consists of three corner-sharing As pyramids forming rings that are linked into a 3-dimensional framework by Ag atoms.		
CAAFA	TRECHMANNITE	$AgAsS_2$	trig/R $\bar{3}$
SERIES G	EMPLECTITE ISOTYPIC SERIES. Structure consists of sheets of corner-sharing CuS_4 tetrahedra // (001), as in herzenbergite, alternate with sheets of corner-sharing $(Sb,Bi)_2S_4$ square pyramids. Structure of hansblockite represents the monoclinic polymorph of grundmannite with Hg and Pb being essential in stabilizing the monoclinic structure via the coupled substitution $Cu + Bi_3 \leftrightarrow Hg + Pb$.		
CAAGA	CHALCOSTIBITE	$CuSbS_2$	orth/Pnam
CAAGB	EMPLECTITE	$CuBiS_2$	orth/Pnam
CAAGC	GRUNDMANNITE	$CuBiSe_2$	orth/Pnma
CAAGD	HANSBLOCKITE	$(Cu,Hg)(Bi,Pb)Se_2$	mon/P2 $_1$ /c
CAAGE	PRIBRAMITE	$CuSbSe_2$	orth/ Pnma
SERIES H	WEISSBERGITE HOMEOTYPIC PAIR. In weissbergite, chains of corner-sharing $SbS^{[4+1]}$ trigonal dipyramids // [101] are linked by Tl and by weak S-Sb bonds to form sheets // (010). In lorandite, spiral chains of AsS_3 pyramids // [001] are linked by Tl atoms.		
CAAHA	WEISSBERGITE	$TlSbS_2$	tri/P $\bar{1}$ or P1
CAAHB	LORANDITE	$TlAsS_2$	tri/P $\bar{1}$ or P1
SERIES I	FERDOWSIITE ABX$_2$-type SERIES Ferdowskiite belongs to ABX $_2$ -type silver sulfosalts, combining Sb and As, although its crystal structure is different from other members of this group. The structure has four independent cations and four anion sites, where two are occupied by Ag, one by Sb, and the remaining site shows mixed occupancy. The structure contains zigzag chains of Sb connected via short Sb-S bonds and flanked by $(Sb,As)S_3$ groups and Ag polyhedra.		
CAAIA	FERDOWSIITE	$Ag_8(Sb_5As_3)S_{16}$	mon/P2 $_1$ /n
TYPE B	TERNARY SULFOSALTS (M1$^+$ M2$^{2+}$ PnS$_3$)		
SERIES A	FREIESLEBENITE (ISOTYPIC) SERIES (3-Dimensional PbS-Like Arrays). Structure consist of Pb octahedra, as pyramids, and Ag tetrahedra sharing edges to form a 3-dimensional framework; it has a strongly distorted PbS structure. Structure of quadratite consists of four double layers // (001) of $AgAsS_2$ chains in alternating [100] and [010] directions are interposed by layers of CdS chains in alternating [$\bar{1}$ 10] directions; all cations are in distorted octahedral coordinations.		

CABAA	FREIESLEBENITE	PbAgSbS ₃	mon/P2 ₁ /a, P2 ₁ /c
CABAB	MARRITE	PbAgAsS ₃	mon/P2 ₁ a
CABAC	DIAPHORITE	Pb ₁₀ Ag ₂ Sb ₂ S ₈	orth/Cmma
CABAD	QUADRAITITE	Ag(Cd,Pb)(As,Sb)S ₃	tetr/I4/amd
CABAE	SCHAPBACHITE	AgBiS ₂	cub/Fm3m
CABAF	<i>SCHIRMERITE (TYPE 1) (?)</i>	Ag ₄ PbBi ₄ S ₉	
CABAG	MANGANOQUADRATITE	AgMnAsS ₃	
CABAH	FERDOWSIITE	Ag ₈ (Sb ₅ As ₃) ₈ S ₁₆	mon/P2 ₁ /n

SERIES B **BOURNONITE ISOTYPIC SERIES.** The structure is a recombination structure based on a heterogeneous close packing formed by interpenetrated slabs of closest packings (c/h) of deformed galena-type structure and consists of Pb polyhedra, As pyramids and Cu tetrahedra sharing corners and edges to form a 3-dimensional framework; Cu tetrahedra share corners to form chains // [001].

CABBA	BOURNONITE	PbCuBiS ₃	orth/Pn2 ₁ m
CABBB	SELIGMANNITE	PbCuAsS ₃	orth/Pn2 ₁ m
CABBC	SOÜCEKITE	PbCuBi(S,Se) ₃	orth/Pn2 ₁ m
CABBD	CERROMOJONITE	CuPbBiSe ₃	orth/Pn2 ₁ m

SERIES C **MÜCKEITE ISOTYPIC SERIES.** Structure consists of CuS₄ tetrahedra and NiS₄ square planes sharing corners to form a framework. BiS₃ trigonal pyramids share edges with NiS₄ and corners with CuS₄. Lisiguangite is isomorphous with the other members of this series. Pt and Bi have a distorted octahedral coordination environments composed of two metal and four S and Cu has a distorted tetrahedral coordination environment with four S atoms. Each S atom is surrounded by four metal to give a tetrahedral environment. The crystal structure is a complex 3-dimensional network

CABCA	LAPIEITE	CuNiSbS ₃	orth/P2 ₁ 2 ₁ 2 ₁
CABCB	MÜCKEITE	CuNiBiS ₃	orth/P2 ₁ 2 ₁ 2 ₁
CABCC	MALYSHEVITE	PdCuBiS ₃	orth/P2 ₁ 2 ₁ 2 ₁
CABCD	LISIGUANGITE	CuPtBiS ₃	orth/P2 ₁ 2 ₁ 2 ₁

SERIES D **CHRISTITE SINGLE SERIES.** Structure consists of As pyramids to form infinite chains // [101]; Hg deformed octahedra form an [HgS₄] double chain // [100]. Tl polyhedra share edges and corners to form corrugated TlS₆ sheets // (001). AsS₃ pyramids are linked by Hg to form sheets // (010); Tl atoms are accommodated between the sheets. The structure of richardsollyite can be described as formed by (100) [Pb (AsS₃)] layers sandwiching Tl cations, and is isostructural with synthetic ABCX₃ compounds.

CABDA	CHRISTITE	TlHgAsS ₃	mon/P2 ₁ /n
CABDB	RICHARDSOLLYITE	TlPbAsS ₃	mon/P2 ₁ /c

TYPE C **QUATERNARY SULFOSALTS (M1⁺ M2⁺ M3²⁺ Pn₂S₅)**

SERIES A **HATCHITE ISOTYPES.** Structure consists of edge-sharing pairs of (Cu,Ag)S₄ tetrahedra and corner-sharing pairs of AsS₃ pyramids which are joined by As and S atoms to form double chains. The chains are linked by (Pb,Tl) and (Tl,Pb) atoms.

CACAA	HATCHITE	(Pb,Tl) ₂ AgAs ₂ S ₅	tric/P1
CACAB	WALLISITE	PbTl(Cu,Ag)As ₂ S ₅	tric/P1

SERIES B **RABERITE SERIES, tric/P1.** Structure consists of columns of nine-coordinated Tl irregular polyhedra extending along [001] and forming sheets // to (010). The Tl atoms in the columns are interrupted by Ag and As positions. The columns are decorated by corner sharing MS₃ pyramids and linked by AgS₃ triangles. Of the seven M positions, one is dominated by Sb and the others by As.

CACBA	RABERITE	Tl ₅ Ag ₄ As ₆ SbS ₁₅	
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GROUP B **LEAD SULFOSALTS WITH A PRONOUNCED 2D ARCHITECTURE, THEIR DERIVATIVES WITH A COMPOSITE STRUCTURE, AND RELATED COMPOUNDS.**

TYPE A **LAYERED SULFOSALTS RELATED TO THE TETRADYMITTE ARCHETYPE.**

SERIES A **ALEKSITE HOMOLOGOUS SERIES, Pb_(n-1)Bi₂Ch_(n+2)**

CBAAA	KOCHKARITE	PbBi ₄ Te ₇	trig
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CBAAB	POUBAITE	$\text{PbBi}_2(\text{Se}, \text{Te}, \text{S})_4$	hex/R $\bar{3}$ m
CBAAC	RUCKLIDGEITE	PbBi_2Te_4	hex/R $\bar{3}$ m
CBAAD	ALEKSITE	$\text{PbBi}_2\text{S}_2\text{Te}_2$	hex/
CBAAE	SADDLEBACKITE	$\text{Pb}_2\text{Bi}_2\text{Te}_2\text{S}_3$	hex
CBAAF	BABKINITE	$\text{Pb}_2\text{Bi}_2(\text{S}, \text{Se})_3$	hex/

TYPE B COMPOSITE STRUCTURES FROM ALTERNATING PSEUDOHEXAGONAL AND PbS/SnS-LIKE TETRAGONAL LAYERS.

SERIES A COMMENSURATE STRUCTURES, NAGYAGITE HOMOLOGOUS SERIES.

CBBAA	BUCKHORNITE	$(\text{Pb}_2\text{BiS}_3)(\text{AuTe}_2)$	orth/Pmmn
CBBAB	NAGYAGITE	$[\text{Pb}_3(\text{Pb}, \text{Sb})_3\text{S}_6](\text{Te}, \text{Au})_3$	tetr/mon
CBBAC	MUSEUMITE	$[\text{Pb}_2(\text{Pb}, \text{Sb})_2\text{S}_8][\text{Te}, \text{Au}]_2$	mon/
CBBAD	BERRYITE	$\text{Cu}_3\text{Ag}_2\text{Pb}_3\text{Bi}_7\text{S}_{16}$	mon/P2 $_1$ /m or P2 $_1$
CBBAE	WATKINSONITE	$\text{Cu}_2\text{PbBi}_4(\text{Se}, \text{S})_8$	mon/P2/m, P2 or Pm
CBBAF	LITOCHEBITE	$\text{Ag}_2\text{PbBi}_4\text{Se}_8$	
CBBAG	JASZCZAKITE	$[\text{Bi}_3\text{S}_3][\text{AuS}_2]$	orth/Pmmn
CBBAH	LUXEMBOURGITE	$\text{AgCuPbBi}_4\text{Se}_8$	mon/P2 $_1$ /n

SERIES B NON-COMMENSURATE STRUCTURES. CYLINDERITE HOMOLOGOUS SERIES. The members of this group all possess a modulated structure based on layers of SnS₂-like structure and a double layer of distorted PbS-like structure. These layers are composed of two C-centered incommensurable sheets alternating regularly; one sheet is pseudo-tetragonal (tC), of SnS₍₁₁₁₎-type, and the other is pseudo-hexagonal (hC), of PbS₍₁₁₁₎-type. The merelaniite structure consists of alternating centered pseudo-tetragonal (Q) and pseudo-hexagonal (H) layers of the PbS and MoS₂ type.

CBBBA	FRANCKEITE	$\text{Pb}_{21.7}\text{Sn}_{9.3}\text{Fe}_{4.0}\text{Sb}_{8.1}\text{S}_{56.9}$	tric/A $\bar{1}$
CBBBB	CYLINDRITE	$\text{Pb}_4\text{Fe}_2\text{Sn}_4\text{Sb}_2\text{S}_{16}$	tric/P $\bar{1}$
CBBBC	POTOSIITE (D)	$\text{Pb}_6\text{Sn}_2\text{FeSb}_2\text{S}_{16}$	tric/P $\bar{1}$
CBBBD	INCAITE (D)	$(\text{Pb}, \text{Ag})_4\text{Sn}_4\text{FeSb}_2\text{S}_{15}$	mon/A2, Am or A2/m
CBBBE	LEVYCLAUDITE	$\text{Pb}_8\text{Sn}_7\text{Cu}_3(\text{Bi}, \text{Sb})_3\text{S}_{28}$	mon/A2, Am, A2/m
CBBBF	COIRAITE	$(\text{Pb}, \text{Sn})_{12.5}\text{As}_3\text{Sn}_5\text{FeS}_{28}$	mon/
CBBBG	ABRAMOVITE	$\text{Pb}_2\text{SnInBiS}_7$	tri/P $\bar{1}$
CBBBH	MERELANIITE	$\text{Mo}_4\text{Pb}_4\text{VSbS}_{15}$	tri/C $\bar{1}$ or C $\bar{1}$

SERIES C LENGENBACHITE. The structure consists of a semicomensurate intergrowth of a pseudotetragonal layer (T), a sheared four-atom-thick {100} PbS-like slice, and a slightly distorted five-atom-thick pseudo-orthohexagonal {111} M₂S₃ slice (O). Both layer types contain Pb and As atoms in cation sites, giving layer stoichiometries of T = (Pb,As)₄S₄ and O = (As,Pb)₂S₃. Related to the cylinderite structure.

CBBCA	LENGENBACHITE	$\text{Pb}_6(\text{Ag}, \text{Cu})_2\text{As}_4\text{S}_{13}$	tric/P $\bar{1}$
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SERIES D CANNIZZARITE ISOTYPIC PAIR. Structure consists of regularly alternating layers of SnS and PbS type layers // (001), with pseudo-tetragonal and pseudo-hexagonal sub-cells.

CBBDA	WITTITE	$\text{Pb}_3\text{Bi}_4(\text{S}, \text{Se})_9$	mon/P2/m
CBBDB	CANNIZZARITE	$\text{Pb}_4\text{Bi}_5\text{S}_{11}$	mon/P2 $_1$ /m

TYPE C COMMENSURATE COMPOSITE DERIVATIVES OF CANNIZZARITE

SERIES A CANNIZZARITE PLESIOTYPIC DERIVATIVES (STEPPED LAYERS) HOMOLOGOUS PAIRS. The structure of junote is based on zigzag ribbons of edge-shared octahedra, cross-linked by further pairs of edge-shared octahedra, provide a framework which is filled by the Bi and Pb atoms in 7- and 8-fold coordination, and by the pairs of tetrahedrally-coordinated Cu atoms. Family of sheared double-layer structures.

CBCAA	JUNOTE	$\text{Pb}_3\text{Cu}_2\text{Bi}_8(\text{S}, \text{Se})_{16}$	mon/C2/m
CBCAB	FELBERTALITE	$\text{Cu}_2\text{Ag}_x\text{Pb}_{6-2x}\text{Bi}_{8+x}(\text{S}, \text{Se})_{19}$	mon/B2/m
CBCAC	NORDSTRÖMITE	$\text{Pb}_3\text{CuBi}_7\text{S}_{10}\text{Se}_4$	mon/P2 $_1$ /m
CBCAD	PROUDITE	$\text{Pb}_{14}\text{Cu}_2\text{Bi}_{18}(\text{S}, \text{Se})_{44}$	mon/C2/m

SERIES B GALENOBISMUTITE HOMOLOGOUS SERIES WITH SHEARED LAYERS. The general structure is a recombination structure based on a heterogeneous packing formed by interpenetrated slabs of

closest packings (c/h) of deformed galena-type slabs, some parallel to (110) and other to (111). In galenobismuthite, edge- and corner-sharing BiS_3 trigonal pyramids form double chains // [001] which lie in sheets // (010); the sheets are linked by chains of Pb atoms // [001]. The weibullite structure consists of two types of blocks-one has a 7x2 array of metal atoms in galena-like octahedral coordination, and the other has a 6x2 array of metal atoms in irregular deformed-galena-like 7- and 8-fold co-ordinations; a homologue of galenobismutite. The nuffieldite structure consists of sheets // (100), combined with strips // [001]; alternating nuffieldite SnS- and PbS-type modules. Angelaite is a homeotype of galenobismutite with the Pb and Bi1 sites of Galenobismutite preserved, and the Bi2 site replaced by the combination of Ag and Cu sites describe above. See CM10-145.

CBCBA	WEIBULLITE	$\text{Pb}_5\text{Bi}_8(\text{S},\text{Se})_7$	orth/Pnma
CBCBB	GALENOBISMUTITE	PbBi_2S_4	orth/pnam
CBCBC	NUFFIELDITE	$\text{Pb}_2\text{Cu}(\text{Pb},\text{Bi})\text{Bi}_2\text{S}_7$	orth/Pbnm or Pna2 ₁
CBCBD	ANGELAITE	$\text{Cu}_2\text{AgPbBiS}_4$	mon/P2 ₁ /n

SERIES C **ROUXELITE-NEYITE SERIES, BOXWORK DERIVATIVES OF CANNIZZARITE.** The structure is built up of two types of ribbons // to b and alternating along a, rimmed by a ribbon-layer // to (010); the result is a three-component structure of the boxwork type, like neyite.

CBCCA	ROUXELITE	$\text{Cu}_2\text{HgPb}_{22}\text{Sb}_{28}\text{S}_{64}(\text{O},\text{S})_2$	mon/
CBCCB	NEYITE	$\text{AgCu}_3\text{Pb}_{12.5}\text{Bi}_{13}\text{S}_{34}$	mon/C2, Cm, or C2/m
CBCCC	CUPRONEYITE	$\text{Cu}_7\text{Pb}_{27}\text{Bi}_{25}\text{S}_{68}$	mon/C2/m
CBCCD	IMA20XX	$\text{Pb}_{15-2x}\text{Sb}_{14+2x}\text{S}_{36}\text{O}_x$	mon/C2/m

GROUP C **LEAD SULFOSALTS BASED ON LARGE 2D FRAGMENTS OF PbS/SnS ARCHETYPE.**

TYPE A **LILLIANITE HOMOLOGOUS SERIES (PbS Archetype).** The lillianite homologues consist of two alternating sets of galena-like layers with different thicknesses. For ramdohrite, two bicapped trigonal prismatic sites of Pb bridge and unite adjacent PbS slabs. These slabs contain five distinct coordination pyramids of Sb with trapezoidal cross sections, a mixed and disordered Sb-Ag-Cd-(Pb) site, refined as 0.39 Ab + 0.61 Ag, a pure Ag site with a very open, irregular tetrahedral coordination, and an octahedral site occupied by Pb.

Reference:

• Makovicky, E., Stöger, B., Topa, D. (2018): The incommensurately modulated crystal structure of roshchinite, $\text{Cu}_{0.09}\text{Ag}_{1.04}\text{Pb}_{0.65}\text{Sb}_{2.82}\text{As}_{0.37}\text{S}_{6.08}$. Zeitschrift für Kristallographie - Crystalline Materials, 233, 255-267.

The Pb–Ag–Sb sulfide roshchinite, $\text{Cu}_{0.09}\text{Ag}_{1.04}\text{Pb}_{0.65}\text{Sb}_{2.82}\text{As}_{0.37}\text{S}_{6.08}$, is a lillianite homologue $N=4$ with a complex incommensurate superstructure in the 8.46 Å direction of the orthorhombic crystal lattice with a 19.0804(1) Å, b 8.4591(2) Å and c 12.9451(3) Å, superspace group $\text{Pbcn}(0\sigma 20)00s$, $q=0.41458(3)b^*$. A structure solution and refinement in (3+1) superspace, based on 10,019 observed reflections and 437 refined parameters was terminated at Robs (wR) equal to 7.27 (8.07)% using satellites up to second order; Robs is 4.82 for main reflections only. The Pb atoms in trigonal coordination prisms on planes of unit-cell twinning are semiperiodically replaced by antimony. The marginal columns of (311)PbS slabs of the Sb–Ag based structure which is based on PbS-like topology contain Sb, Ag(Cu) and mixed Ag/Sb sites in a complicated sequence. Central portions of the slabs are occupied by Sb–S crankshaft chains, best exposed on the (100)PbS planes, which run diagonally across the slabs. In these planes, in their majority the chains display Sb_3S_4 form and two opposing orientations, zig-zagging along the [010] direction. Every six chains, a parallel configuration of two chains occurs, but occasionally this interval is reduced to five chains. This, together with related compositional changes in the Pb– and Ag–Sb column, explains the one-dimensionally incommensurate character of roshchinite. Modestly elevated contents of As replacing Sb are the probable reason of modulation and non-commensurability in roshchinite.

SERIES A **LILLIANITE HOMEOTYPIC SERIES (⁴L).**

CCAAA	GUSTAVITE	$\text{PbAgBi}_3\text{S}_6$	orth/Bbmm or Bb2 ₁ m
CCAAB	LILLIANITE	$\text{Pb}_3\text{Bi}_2\text{S}_6$	orth/Bbmm
CCAAC	TREASURITE	$\text{Pb}_6\text{Ag}_7\text{Bi}_{15}\text{S}_{32}$	mon/C2/m
CCAAD	VIKINGITE	$\text{Pb}_{10}\text{Ag}_4\text{Bi}_{12}\text{S}_{30}$	mon/C2/m
CCAAE	XILINGOLITE	$\text{Pb}_3\text{Bi}_2\text{S}_6$	mon/C2/m
CCAAF	ANDORITE-IV (Quatrandorite)	$\text{Ag}_{15}\text{Pb}_{18}\text{Sb}_{47}\text{S}_{96}$	mon/
CCAAG	ANDORITE-VI (Senandorite)	$\text{PbAgSb}_3\text{S}_6$	orth/Pmma
CCAAH	RAMDOHRITE	$\text{Pb}_{12}\text{CdAg}_{5.5}\text{Sb}_{21.5}\text{S}_{48}$	mon/P2 ₁ /n
CCAAI	FIZELYITE	$\text{Pb}_{13.74}\text{Ag}_{5.94}\text{Sb}_{20.84}\text{S}_{48}$	mon/P2 ₁ /n
CCAAJ	UCHUCCHACUAITE	$\text{Pb}_3\text{AgMnSb}_5\text{S}_{12}$	mon/P2 ₁ /n

CCAOK	ROSHCHINITE	Pb ₁₀ Ag ₁₉ Sb ₅ S ₉₆	orth/Pnma or P2 ₁ ma
CCAAL	MENCHETTIITE	Pb ₅ Mn ₃ Ag ₂ Ab ₆ As ₄ S ₂₄	mon/P2 ₁ /n
CCAAM	TERRYWALLACEITE	AgPb(Sb,Bi) ₃ S ₆	mon/P2 ₁ /c
CCAAN	OSCARKEMPFITE	Ag ₁₀ Pb ₄ (Sb ₁₇ Bi ₉) ₂₆ S ₄₈	orth/Pnca
CCAAO	JASROUXITE	Ag ₁₆ Pb ₄ (Sb ₂₄ As ₁₆)S ₄₀ S ₇₂	tri/P1
CCAAP	CLINO-OSCARKEMPFITE	Ag ₁₅ Pb ₆ Sb ₂₁ Bi ₁₈ S ₇₂	mon/P2 ₁ /c
CCAAQ	ARSENQUATRADORITE	Ag _{17.6} Pb _{12.8} Sb _{38.1} As _{11.5} S ₉₆	mon/P2 ₁ /c
CCAAR	ANDREADINIITE	CuHgAg ₇ Pb ₇ Sb ₂₄ S ₄₈	mon/P2 ₁ /c
CCAAS	ERZWIESITE	Ag ₈ Pb ₁₂ Bi ₁₆ S ₄₀	orth/Pbcn
CCAAT	STAROCESKEITE	Ag _{0.7} Pb _{1.6} (Bi _{1.35} Sb _{1.35}) _{2.70} S ₆	orth/Cmcm
CCAAU	OYONITE	Ag ₃ Mn ₂ Pb ₄ Sb ₇ As ₄ S ₂₄	mon/P2 ₁ /n

SERIES B HEYROVSKYITE HOMEOTYPIC SERIES (⁷L)

CCABA	HEYROVSKYITE	(Pb,Ag) ₆ Bi ₂ S ₉	orth/Cmcm
CCABB	ASCHAMALMITE	Pb ₆ Bi ₂ S ₉	mon/C2/m
CCABC	ESKIMOITE	Pb ₁₀ Ag ₇ Bi ₁₅ S ₃₆	mon/C2/m
CCABD	SCHIRMERITE	Pb ₆ Ag ₃ Bi ₇ S ₁₈	orth/Bbmm

SERIES C OURAYITE HOMEOTYPIC SERIES (^{11,11}L). Makovicky, E. and Karup-Møller, S. (1977b) Chemistry and crystallography of the lillianite homologous series. II. Definition of new minerals eskimoite, vikingite, ourayite and treasureite. Redefinition of schirmerite and new data on the lillianite-gustavite solid-solution series. Neues Jahrbuch für Mineralogie, Abhandlungen: 131: 56-82.
American Mineralogist (1979): 64: 243-244.
Canadian Mineralogist (1984): 22: 565-575.

CCACA	OURAYITE	Pb ₄ Ag ₃ Bi ₅ S ₁₃	orth/Bbmm
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SERIES D RELATED PHASES (?). Sakharova, M. S. (1955): Bismuth sulfosalts of Ustarasaisk deposit. Trudy Mineralogicheskogo Muzeya, Akademiya Nauk SSSR (1955), 7, 112-126 (in Russian).
American Mineralogist (1956): 41: 814.
Trudy Mineralogicheskogo Muzeya Akademii Nauk SSSR: 7: 112-126.

CCADA	USTARASITE Q/D	Pb(Bi,Sb) ₆ S ₁₀	?
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TYPE B PAVONITE HOMOLOGOUS SERIES

SERIES A PAVONITE SERIES. Structure consists of sheets of AgS₆ octahedra with pairs of BiS₃ square pyramids ([a] sheets) are linked by common S atoms to sheets of (Bi,Ag)S₆ octahedra ([b] sheets). Fundamental geometric units of the b sheets as n diagonal chains of (Bi,Ag)S₆ linked into bands // [010] by sharing S-S edges, similar to the (100) sheets in galena. Kudriavite structure description given in CM07-437 and is a member of the pavonite series with N = 3. Structure of berthierite, garavellite, clerite and gratianite consist of chains of edge-sharing FeS₆ octahedra, chains of edge-sharing SbS₃ pyramids, and double chains of Sb₂S₈ groups, all running // [001]. These are also members of the pavonite series with the ³P position.

CCBAA	PAVONITE	(Ag,Cu)(Bi,Pb) ₃ S ₅	mon/Cm
CCBAB	CUPROPAVONITE	(Cu ₂ Ag)(Bi ₅ Pb)S ₁₀	mon/C2/m
CCBAC	BENJAMINITE	Ag ₂₃ Cu ₅ Pb ₄ Bi ₆₈ S ₁₂₀	mon/Cm/2
CCBAD	MUMMEITE	Ag ₂₆ Cu ₈ Pb ₁₄ Bi ₆₅ S ₁₃₀	mon/C2/m, Cm
CCBAE	BORODAEVITE	(Ag ₅ (Fe,Pb)Bi ₇) ₁₃ (Sb,Bi) ₂ S ₁₇	mon/
CCBAF	MAKOVICKYITE	Ag ₂ Bi ₄ AgBi ₇ S ₁₈	mon/C2/m
CCBAG	GRUMIPLUCITE	HgBi ₂ S ₄	mon/C2/m
CCBAH	CUPROMAKOVICKYITE	Cu ₄ AgPb ₂ Bi ₉ S ₁₈	mon/C2/m
CCBAI	KUDRIAVITE	(Cd,Pb)Bi ₂ S ₄	mon/C2/m
CCBAJ	CUPROMAKOPAVONITE	Cu ₈ Pb ₄ Ag ₃ Bi ₁₉ S ₃₈	mon/C2/m
CCBAK	DANTOPAITE	Ag ₅ Bi ₁₃ S ₂₂	monC2/m
CCBAL	BERTHIERITE	FeSb ₂ S ₂	orth/Pnam
CCBAM	GARAVELLITE	FeSbBiS ₂	orth/nd
CCBAN	CLERITE	MnSb ₂ S ₄	orth/
CCBAO	GRATIANITE	MnBi ₂ S ₄	mon/C2/m

SERIES B PAVONITE DERIVATIVE STRUCTURES. Livingstonite belongs to rod-layers structures. In one type of layer, two double Sb₂S₄ chains are bound by disulfide groups [S]; in the other type, these chains are bound vis Hg²⁺ cations.

CCBBA	MOZGOVAITE	PbBi ₄ (S,Se) ₇	orth/
CCBBB	LIVINGSTONITE	HgSb ₄ S ₈	mon/A2/a

TYPE C CUPROBISMUTITE HOMOLOGOUS SERIES.

SERIES A CUPROBISMUTITE SERIES. The structure of this series is composed of two types of layers. One of these is the C-layer that incorporates on either side the attached lozenges of [CuBiS₁₀]. The other side is a wider layer of rather mixed nature that contains Bi atoms in octahedral and trigonal prismatic coordinations. Pb atoms are in trigonal prismatic coordination, and Cu in trigonal to tetrahedral coordination.

CCCAA	CUPROBISMUTITE	Cu ₁₀ Bi ₂₂ S ₂₃	mon/C2/m
CCCAB	HODRUSITE	Cu ₈ Bi ₁₂ S ₂₂	mon/A2,Am,A2/m
CCCAC	PADERAITE	Cu ₇ (Cu/Ag _{0.33} Pb _{1.33} Bi _{11.33}) ₁₃ S ₂₂	mon/P2 ₁ /m CM06-481
CCCAD	PIZGRISCHITE	Cu ₁₇ Bi ₁₇ S ₃₅	mon/C2/m
CCCAC	KUPČÍKITE	Cu _{3.4} Fe _{0.6} Bi ₅ S ₁₀	mon/C2/m

TYPE D MENEGHINITE HOMOLOGOUS SERIES (SnS ARCHETYPE)

SERIES A MENEGHINITE SERIES. The structures of this accretional homologous series can be described as being made up of (501) or (5̄01) slices of SnS-like structure. The surfaces of these slices form wavy composition planes on which the two adjacent slices face each other and are mutually related by an n-glide plane // to (010) of meneghinite. The structures in this series can also be regarded as being derived from that of bismuthinite by ordered substitution of Bi by Pb and insertion of Cu.

CCDAA	MENEGHINITE	Pb ₁₃ CuSb ₇ S ₂₄	orth/Pbnm
CCDAB	JASKOLSKIITE	Pb ₂₂ Cu ₂ (Sb,Bi) ₁₈ S ₅₀	orth/Pbnm

TYPE E JORDANITE HOMOLOGOUS SERIES

SERIES A JORDANITE ISOTYPIC PAIR. Structure consists of pseudo-hexagonal close packing of S atoms in a distorted PbS framework; metal layers alternate with S layers along [010]; Pb has 6-, 7-, and 8-coordination; (As,Sb,Bi)S₃ pyramids. The asymmetric unit of jordanite contains three metal layers of four atoms each. Each of the three layers contains three Pb and one semimetal (As or Sb) site. One of the Pb sites in the first layer is half occupied by semimetals. The structure is based on close packing of sulfur atoms. The structure of kirkiite is similar to that of jordanite and is described in CM2006-177. The new mineral species marcobaldiite, ~Pb₁₂(Sb₃As₂Bi)Σ₆S₂₁, has been discovered in a single specimen collected in a quartz vein embedded in tourmaline-bearing schist from the Pollone mine, Valdicastello Carducci, Pietrasanta, Apuan Alps, Tuscany, Italy. It occurs as a black blocky prismatic crystal, up to 1 cm in size, with a metallic luster, associated with Sb-rich tennantite. Under the ore microscope, marcobaldiite is white, with a distinct anisotropism, with grey to bluish-grey rotation tints. Polysynthetic lamellar twinning is common and characteristic. Reflectance percentages for the four COM wavelengths are [R_{min}, R_{max} (%), (λ)]: 31.6, 40.1 (470nm), 30.9, 39.6 (546 nm), 30.4, 38.5 (589nm), and 30.0, 37.6 (650nm). Electron microprobe analyses gave (average of 10 spot analyses in wt%): Pb 64.05(34), As 4.51(8), Sb 9.10(14), Bi 4.24(6), S 17.24(19), total 99.14(53). On the basis of ΣMe = 18 apfu, the empirical formula is $\text{Pb}_{11.98(4)}\text{Sb}_{2.90(3)}\text{As}_{2.33(3)}\text{Bi}_{0.79(1)}\text{S}_{20.80(20)}$. The main diffraction lines, corresponding to multiple hkl indices, are [d in Å (relative visual intensity)]: 3.568 (ms), 3.202 (ms), 3.016 (ms), 2.885 (ms), 2.233 (vs), 2.125 (s), 1.848 (s), and 1.775 (s). The crystal structure study gives a triclinic unit cell, space group P1, with a = 8.9248(9), b = 29.414(3), c = 8.5301(8)Å, α = 98.336(5), β = 118.175 23 (5), γ = 90.856(5)°, V = 1944.1(3)Å³, Z = 2. The crystal structure has been solved and refined to R₁ = 0.067 on the basis of 6193 reflections with Fo > 4σ(Fo) and 363 refined parameters. Marcobaldiite is a new N = 3.5 homologue of the jordanite homologous series, characterized by the 1:1 alternation of two kinds of layers of distorted octahedra, three- and four-octahedra thick, i.e. of the kirkiite and jordanite types, respectively. Layers are connected by one atomic layer of three bicapped trigonal prismatic Pb atoms and one triangular pyramidal As atom in split position. The name of this new mineral species honours the mineral amateur Marco Baldi (b. 1944) for his contribution to the knowledge of the mineralogy of the pyrite ± baryte ± iron oxide ore deposits from southern Apuan Alps.

CCEAA	GEOCRONITE	Pb ₂₈ (Sb,As) ₁₂ S ₄₆	mon/P2 ₁ /m
CCEAB	JORDANITE	Pb ₂₈ As ₁₂ S ₄₆	mon/P2 ₁ /m
CCEAC	ARSENMARCOBALDIITE	Pb ₁₂ (As _{3.2} Sb _{2.8}) ₆ S ₂₁	tric/P1
CCEAD	MARCOBALDIITE	Pb ₁₂ (Sb ₃ As ₂ Bi) ₆ S ₆	tric/P1

SERIES B KIRKIITE HOMOLOGUE. Sulfosalts of PbS archetype B : Galena derivatives, with Pb. The structure of kirkiite can be described as (010) slabs of octahedral, three octahedral thick and related mutually by a reflection plane situated in the intervening prismatic layer. In another interpretation, it is composed of slabs based on a transitional PbS-SnS archetype, with tightly bonded layers // to (083) of

kirkiite; the slabs are unit-cell twinned on (010) reflection planes. The structure contains one split As position, and two additional sites that could accommodate both As and Bi. Tsugaruite has similar properties with jordanite.

Walia, D. S. & Chang, L. L. Y. (1973): Investigations in the systems PbS-Sb₂S₃-As₂S₃ and PbS-Bi₂S₃-As₂S₃. Can. Mineral., 12, 113-119.

American Mineralogist (1986): 71: 1278-1279.

Anthony, Bideaux, Bladh & Nichols (1990), Handbook of Mineralogy, Vol. I.

Borodaev, Y.S., Garavelli, A., Kuzmina, O.V., Mozgova, N.N., Organova, N.I., Trubkin, N.V., and Vurro, F. (1998) Rare sulfosalts from Vulcano, Aeolian Islands, Italy. I. Se-bearing kirkiite, Pb₁₀(Bi,As)₆(S,Se)₁₉. Canadian Mineralogist: 36: 1105-1114.

Pinto, D. (2005): Mineralogy, crystal-chemistry and structures of sulfosalts from Vulcano (Aeolian Islands, Italy): Ag-free lillianite, Cl-bearing galenobismutite, kirkiite and the new mineral vurroite. Plinius, 31, 197-202.

Makovický, Emil, Tonèi Balić-Žunić, Ljiljana Karanovića and Dejan Poleti (2006), The crystal structure of kirkiite, Pb₁₀Bi₃As₃S₁₉: Canadian Mineralogist: 44(1): 177-188.

Pinto, D., Balić-Žunić, T., Garavelli, A., Garbarino, C., Makovický, E., and Vurro, F. (2006) First occurrence of close-to-ideal kirkiite at Vulcano (Aeolian Islands, Italy): chemical data and single crystal X-ray study. European Journal of Mineralogy: 18: 393-401.

Shimizu, M., Miyawaki, R., Kato, A., Matsubara, S., Matsuyama, F. and Kiyota, K. (1998): Tsugaruite, Pb₄As₂S₇, a new mineral species from the Yunosawa mine, Aomori Prefecture, Japan. Mineralogical Magazine: 62(6): 793-799.

CCEBA	KIRKIITE	Pb ₁₀ Bi ₃ As ₃ S ₁₉	hex/P6 ₃ 22
CCEBB	TSUGARUITE	Pb ₂₈ As ₁₅ S ₅₀ Cl	orth/Pnn2 or Pnnm

TYPE F SINGLE TYPE (PbS HEXAGONAL DERIVATIVE).

SERIES A GRATONITE. Structure consists of AsS₃ pyramids pointing in the same direction. Pb has [4+3] coordination.

CCFAA	GRATONITE	Pb ₉ As ₄ S ₁₅	trig/R3m
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TYPE G PLAGIONITE HOMOLOGOUS SERIES.

SERIES A PLAGIONITE SERIES. Structure consists of slabs // (102) which are linked by Pb^[8,7], whereby a and b remain approximately equal, and c increases from 17 to 24.5 Å.

CCGAA	FÜLÖPPITE	Pb ₃ Sb ₈ S ₁₅	mon/C2/c	Reference: ▪ Matsushita, Y. (2018): Reexamination of the crystal structure of semseyite, Pb ₉ Sb ₈ S ₂₁ . Zeitschrift für Kristallographie - Crystalline Materials, 233, 279-284.
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The crystal structure of semseyite, Pb₉Sb₈S₂₁ was successfully refined using a single-crystal specimen from Wolfsberg, Harz, Germany, having chemical composition (EPMA) Pb_{9.01}(1)Sb_{8.00}(3)S_{21.05}(5). The structure belongs to the monoclinic C2/c space group (a=13.6267(10) Å, b=11.9742(9) Å, c=24.5891(18) Å, β=105.997(3)°, V=3856.8(5) Å³, Z=4, D_c=6.048 g/cm³). Crystal structure refinement with all atoms refined anisotropically converged to R₁=4.64% (I>2σ(I)). The crystal structure is built of two subunits (A and B) showing TISbS₂-like topology. Each of them stacks parallel to (001), and c/2 in thickness. Two cation sites (Pb1 and Sb5) located at central part of the subunit, show mixed occupancy behavior as 95% Pb and 5% Sb at the Pb5 site, and 95% Sb and 5% Pb at the Sb1 site, respectively. Each of subunits are related by unit cell-level twinning mechanism "tropochemical cell twinning" with the TISbS₂-like subunits alternatively parallel to (1 1 -4) and (-1 1 4) planes.

CCGAB	PLAGIONITE	Pb ₅ Sb ₈ S ₁₇	mon/C2/c
CCGAC	HETEROMORPHITE	Pb ₇ Sb ₈ S ₁₉	mon/C2/c
CCGAD	SEMSEYITE	Pb ₉ Sb ₈ S ₂₁	mon/C2/c
CCGAE	RAYITE	Pb ₈ (Ag,Tl) ₂ Sb ₈ S ₂₁	mon/nd

TYPE H SARTORITE HOMOLOGOUS SERIES (SnS archetype).

SERIES A SARTORITE HOMEOTYPES

THE MINERALS OF THIS FOUR SERIES HAVE STRUCTURES WHICH ARE COMPOSED OF DUFRENOYSITE (D) LAYERS AND SARTORITE (S) LAYERS. Structure consists of linear As₄S₈ chains along [001] which are linked by Pb^[6+3] into sheets // (100). Structure consists of infinite [001] chains with Pb^[9,6] forming two SnS-related sheets // (010). The structure of guettardite contains six coordination polyhedra of cations. Pb1 and Pb2 form slightly skewed tricapped trigonal coordination prisms arranged in a zig-zag layer. Two distinct As and two Sb sites in a chess-board

arrangement form MeS_5 pyramids with trapezoidal bases. Guettardite is a homologue of sartorite, ideally PbAs_2S_4 , and is the $N=3$ member of the sartorite homologous series of sulfosalts. In Barikaite, a member of the sartorite homologous series, the unit cell contains eight cation sites and ten anion sites. Four of the cation sites have mixed occupancies– the split sites $\text{As}_2\text{-Sb}_2$, $\text{As}_3\text{-Sb}_3$, $\text{Ag}_5\text{-As}_5$ and the site Me_6 with three cations involved. Two of the lead sites, Pb_1 and Pb_2 , display tricapped trigonal prismatic coordinations and alternate along the a direction. They form zig-zag walls // to (001). There are three distinct [100] columns of alternating cations, $\text{As}_1\text{-(As,Sb)}_2$, $\text{Sb}_4\text{-(As,Sb)}_3$ and $\text{(As,Ag)}_5\text{-(Pb,Sb)}_6$ which together form trapezoidally configured single (013) layers. These layers aggregate into tightly-bonded double layers, separated by lone electron pair micelles. In barikaite, the predominantly As-occupied and Sb-occupied sites are distributed in a chess-board-like scheme. Philrothite is the $N=4$ homolog of the sartorite homologous series. Thallium assumes tricapped prismatic sites alternating to form columns perpendicular to the b axis, organized into zigzag layers // to (010). Between the zigzag walls are coordination pyramids of As(Sb) forming diagonally oriented double layers separated by broader interspaces that house the lone-pair electrons. New data on veenite shows it to be $N=4$ of the sartorite group. The structure has zig-zag walls of trigonal coordination prisms of Pb which separate slabs of diagonally oriented double-layers populated by Sb and As with partial Pb substitution orientation of three-membered crankshaft chains formed by strong (As,Sb) - S bonds on the two surfaces of double-layers differs substantially from that in dufrenoyite. The bernarlottiite structure can be described as being formed by 1:1 alternation of sartorite-type ($N=3$) and dufrenoyite-type ($N=4$) layers along c , connected by Pb atoms with tricapped trigonal prismatic coordination. Each layer results from the stacking of two types of ribbons along a , a centrosymmetric one alternating with two acentric ones. The three main building operators of the structure are (1) the interlayers As versus Pb crossed substitution, stabilizing the combined $N=(3,4)$ baumhauerite homologue, (2) the inter-ribbon Sb partitioning in the sartorite-type layer, with “symmetrization” of the Sb -rich ribbon, that induces the $3a$ superstructure, and (3) the common (As,Sb) polymerization through short (As-Sb)-S bonds. Polloneite is a new $N = 4$ member of the sartorite homologous series with substantial Sb and small, but important, Ag contents. It is a three-fold superstructure with a tripled unit-cell parameter 7.9 \AA of the sartorite homologues. In the As-Sb rich slabs, several types of crankshaft chains and isolated (As,Sb)-S polyhedra occur. A sequence of three different, tightly-bonded double layer fragments (broad ribbons) contains two asymmetric fragments with long crankshaft chains whereas the third fragment type, with Ag , contains small mirror-symmetrical metalloid groups and no crankshaft chains. This configuration can potentially cause order-disorder phenomena in the structure. The threefold superstructure and the mixed As-Sb character distinguish polloneite from veenite and from dufrenoyite, respectively. Hyršlite, $\text{Pb}_8\text{As}_{10}\text{Sb}_6\text{S}_{32}$, is a new member of the sartorite homologous series of Pb-(As,Sb) sulfosalts. It occurs in the Uchucchacua polymetallic deposit, Oyon district, Catajumbo, Lima Department, Peru. Compositionally it lies between guettardite and twinnite on the one hand, and hendekasartorite on the other hand. Hyršlite is grey, opaque with metallic lustre. It is brittle, without observable cleavage or parting. Mohs hardness is derived as 4, based on VHN_{25} range of microhardness (202–221, mean 215 kg mm^{-2}). Density (calc.) = 5.26 g cm^{-3} using a simplified chemical formula. Reflectance percentages (R_{\min} and R_{\max}) for the four standard COM wavelengths are 32.6, 39.0 (470 nm), 32.1, 38.5 (546 nm), 31.5, 37.9 (589 nm), and 30.7, 36.7 (650 nm), respectively. The formula based on 32 S atoms per formula unit (*apfu*) is $\text{Pb}_{7.90}\text{Sb}_{5.98}\text{As}_{10.00}\text{S}_{32}$. The unit cell of Hyršlite was refined from single-crystal data, with monoclinic symmetry, space group $P2_1$ $a = 8.475(3) \text{ \AA}$, $b = 7.917(3) \text{ \AA}$, $c = 20.039(8) \text{ \AA}$, $\beta = 102.070(6)^\circ$, $V = 1314.8(9) \text{ \AA}^3$. The crystal structure of Hyršlite contains 12 independent cation and 16 distinct sulfur sites. There are four fully occupied Pb sites, two fully occupied As sites, one Sb site and five mixed (As,Sb) sites. In projection parallel to the 8.5 \AA axis, the crystal structure is a typical member of the sartorite homologous series, a sartorite homologue $N = 3;3$, and homeotype of twinnite and guettardite. Opposing surfaces of the tightly bonded double-layer in the (As,Sb) -rich slabs of the structure have different cation configurations – one resembles coordinations observed in guettardite but the opposite one, with (As,Sb) cation pairs and single polyhedra, appears unique among sartorite homologues.

CCHAA	SARTORITE	$\text{Pb}_4\text{As}_8\text{S}_{16}$ (SS)	orthPbca
CCHAB	TWINNITE	$\text{Pb(Sb,As)}_2\text{S}_4$	orth/Pnmm
CCHAC	GUETTARDITE	PbSbAsS_4	mon/ $P2_1/c$
CCHAD	BARIKAITE	$\text{Ag}_3\text{Pb}_{10}(\text{Sb}_8\text{As}_{11})\text{S}_{19}\text{S}_{40}$	mon/ $P2_1/n$
CCHAE	PHILROTHITE	TlAs_3S_5	mon/ $P2_1/c$
CCHAF	POLLONEITE	$\text{AgPb}_{46}\text{As}_{26}\text{Sb}_{23}\text{S}_{120}$	mon/ $P2_1$
CCHAG	HEPTASARTORITE	$\text{Tl}_7\text{Pb}_{22}\text{As}_{55}\text{S}_{108}$	mon/ $P2_1/c$
CCHAH	ENNEASARTORITE	$\text{Tl}_6\text{Pb}_{32}\text{As}_{70}\text{S}_{140}$	mon/ $P2_1/c$
CCHAI	HENDERKASARTORITE	$\text{Tl}_2\text{Pb}_{48}\text{As}_{82}\text{S}_{172}$	mon/ $P2_1/c$
CCHAJ	ECRINSITE	$\text{AgTl}_3\text{Pb}_4\text{As}_{11}\text{Sb}_9\text{S}_{36}$	tric/ $P1$
CCHAK	NEW MEMBER	$\text{Pb}_{33.31}\text{Ag}_{3.17}\text{Tl}_{0.40}(\text{As}_{50.1}\text{As}_{1.0})\text{S}_{112}$	tric/ $P1$
CCHAL	INCOMSARTORITE	$\text{Tl}_6\text{Pb}_{144}\text{As}_{246}\text{S}_{516}$	mon/ $P2_1/n$
CCHAM	VEENITE	$\text{Ag}_{0.15}\text{Pb}_{16}\text{Sb}_{8.8}\text{As}_{7.0}\text{S}_{40}$	mon/ $P2_1$
CCHAN	HYRSLITE	$\text{Pb}_8\text{As}_{10}\text{Sb}_6\text{S}_{32}$	mon/ $P2_1$
CCHAO	DEKATRIASARTORITE	$\text{TlPb}_{58}\text{As}_{97}\text{S}_{204}$	mon/ $P2_1/c$

SERIES B BAUMHAUERITE HOMEOTYPES

CCHBA	BAUMHAUERITE	Pb ₁₂ As ₁₆ S ₃₂ (DS)	tric/P1
CCHBB	ARGENTOBAUMHAUERITE	Pb ₁₁ Ag _{0.7} (As,Sb) ₁₈ S ₃₆	mon/P2 ₁ /m
CCHBC	BOSCARDINITE	Ag _{0.3} Tl _{1.2} Pb ₃ (Sb _{7.8} As _{1.7})S ₁₈	tric/P1
CCHBD	BERNARLOTTIITE	Pb ₆ (As ₅ Sb ₃)S ₁₈	tric/P1

SERIES C LIVEINGITE HOMEOTYPE

CCHCA	LIVEINGITE	Pb _{18.5} As ₂₅ S ₅₆ (DSDDSD)	mon/P2 ₁
CCHCB	ARTENTOLIVEINGITE	Ag _x Pb _{40-2x} As _{48+x} S ₁₁₂	tric/P1

SERIES D DUFRENOYSITE HOMEOTYPES Crystal-structure refinements in space group P21/c were performed on five grains of rathite with different types and degrees of thallium, silver, and antimony substitutions, as well as quantitative electron-microprobe analyses of more than 800 different rathite samples. The results of these studies both enlarged and clarified the complex spectrum of cation substitutions and the crystal chemistry of rathite. The [Tl+ + As3+] ↔ 2Pb2+ scheme of substitution acts at the structural sites Pb1, Pb2, and Me6, the [Ag+ + As3+] ↔ 2Pb2+ substitution at Me5, and the Sb-for-As substitution at the Me3 site only. The homogeneity range of rathite was determined to be unusually large, ranging from very Tl-poor compositions (0.16 wt%; refined single-crystal unit-cell parameters: a = 8.471(2), b = 7.926(2), c = 25.186(5) Å, β = 100.58(3)°, V = 1662.4(6) Å³) to very Tl-rich compositions (11.78 wt%; a = 8.521(2), b = 8.005(2), c = 25.031(5) Å, β = 100.56(3)°, V = 1678.4(6) Å³). The Ag content is only slightly variable (3.1 wt%–4.1 wt%) with a mean value of 3.6 wt%. The Sb content is strongly variable (0.20 wt%–7.71 wt%) and not correlated with the Tl content. With increasing Tl content (0.16 wt%–11.78 wt%), a clear increase of the unit-cell parameters a, b, and V, and a slight decrease of c is observed, although this is somewhat masked by the randomly variable Sb content. The revised general formula of rathite may be written as Ag_xTl_yPb_{16-2(x+y)}As_{16+x+y-z}Sb_zS₄₀ (with 1.6 < x < 2, 0 < y < 3, 0 < z < 3.5). Based on Pb–S bond lengths, polyhedral characteristics and Pb-site bond-valence sums, we conclude that the Pb1 site is more affected by Tl substitution than the Pb2 site. When Tl substitution reaches values above 13 wt% (or 3 apfu), a new phase (“SR”), belonging to the rahite group, appears as lamellar exsolution intergrowths with Tl-rich rathite (11.78 wt%). Rathite is found only in the Lengenbach and Reckibach deposits, Binntal, Canton Wallis, Switzerland.

CCHDA	DUFRENOYSITE	Pb ₁₆ As ₁₆ S ₄₀ (DD)	mon/P2 ₁ /m
CCHDB	open		
CCHDC	RATHITE	(Pb,Tl) ₁₂ (As,Sb) ₂₀ S ₄₀ (DD)	mon/P2 ₁ /c
CCHDD	CARDUCCIITE	(Ag ₂ Sb ₂)Pb ₁₂ (As,Sb) ₁₆ S ₄₀	mon/P2 ₁ /c
CCHDE	ARSENODUFRENOYSITE	Ag ₃ Pb ₂₆ As ₃₅ S ₈₀	tric/P1

SERIES E HOMOLOGUES WITH LONG-RANGE PERIODICITY.

CCHEA	MARUMOITE	Pb ₃₂ As ₄₀ S ₉₂	mon/P2 ₁
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SERIES F DUFRENOYSITE DERIVATIVE. In chabourneite, SnS-type sheets // (010) alternate with PbS-type sheets along [010]. Spiral chains of AsS₃ pyramids // [001] are linked by Tl atoms. A new structure of Pb-rich chabourneite is formed by the alternation of two pairs of slabs along the b axis, deriving from the SnS and PbS archetypes, respectively. Slab interfaces show the alternation, along c, of Tl sites, ninefold coordination, with Pb, Sb or mixed/split (Pb,Sb) and (Pb,Tl) sites. Within the slabs, 72 independent M3+ sites (M3+ = As,Sb) occur. Ms3 triangular pyramidal groups are condensed according to various MmSn chain fragments.

CCHFA	CHABOURNEITE	(Tl,Pb) ₂₃ (Sb,As) ₉₁ S ₁₄₇	tri/P1
CCHFB	DALNEGROITE	Tl _{5-x} Pb _{2x} (As,Sb) _{21-x} S ₃₄	tri/P1
CCHFC	PROTOCHABOURNEITE	Tl ₂ Pb(Sb ₉₋₈ As ₁₋₂) ₁₀ S ₁₇	tri/P1

SERIES G PIERROTITE HOMEOTYPIC PAIR. In pierrotite, as and Sb pyramids and SbS₄ and SbS₅ polyhedra form a 3-dimensional framework; some TlS₉ polyhedra share faces to form columns // [001], and others share corners to form layers // (100). In parapierrrotite, Sb polyhedra form a double layer // (101); tl has 8- and 9-fold coordination. The parapierrrotite structure can also be regarded as slabs of the PbS archetype cut // (211), and connected by Sb and Tl cations.

CCHGA	PIERROTITE	Tl(Sb,As) ₅ S ₈	orth/Pna2 ₁
CCHGB	PARAPIERROTITE	Tl(Sb,As) ₅ S ₈	mon/P2 ₁ /n

SERIES H **SICHERITE LONE PAIR. PbS archetype.** American Mineralogist (2001): 86: 1087-1093.

CCHHA	SICHERITE	Ag ₂ Tl(As,Sb) ₃ S ₆	orth/Pmnb
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TYPE I **UNCLASSIFIED**

SERIES A **MUTNOVSKITE.** Structure consists of three independent cation positions: Pb1 and Pb2 have tricapped trigonal prismatic coordinations with S and I atoms (completed with one As atom in the case of Pb2), while As has threefold coordination with S atoms, which form the base of a trigonal pyramid with As at the apex. Pairs of Pb1-Pb2 prisms are connected in columns that extend along c. AsS₃ coordinations are isolated from each other. S atoms and half of the Pb atoms form wavy close packed layers. Two kinds of channels // to b occur between the layers. The smaller channels host As atoms close to the channel walls, with their lone-electron pairs occupying the median part, while the bigger ones accommodate rows of alternating halogen and Pb atoms.

CCIAA	MUTNOVSKITE	Pb ₂ AsS ₃ (I,Cl,Br)	orth/Pnma
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GROUP D **SULFOSALTS BASED ON 1D DERIVATIVES OF THE PbS/SnS ARCHETYPE (ROD-TYPE BUILDING BLOCKS).**

TYPE A **ROD-LAYER SUB-TYPE (BOULANGERITE PLESIOTYPIC FAMILY).**

SERIES A **BOULANGERITE SERIES.** The structure is a recombination structure based on an heterogeneous packing formed by interpenetrated slabs of closest packings (c/h) of deformed galena-type structure, most of them parallel to (110). In dadsonite, the structure consists of rods of an SnS-like arrangement, infinite along [001] of the SnS archetype. These rods, 3 coordination pyramids of Pb or Sb wide, and four combined sulfur-and metal sheets thick, are organized into two alternating, distinct types of layers (CM06-1499). Robinsonite is a member of a large family of rod-based sulphosalts, composed of rods of SnS archetype. In robinsonite, two types of rods, respectively 2 and 3 Sb coordination pyramids broad, combine. Their arrangement results in two types of rod-layers, denoted according to their inter-rod connections as Type 1 and Type 4, respectively. In the former case, a tightly bonded double-layer continues from one rod into the other. In the latter, the rods are interconnected by the smallest possible fragment of SnS-like configuration that is rotated 90° in respect to the SnS-like arrangement in the rod interiors.

In the literature, many seemingly contradictory structure models of boulangerite, ideally Pb₅Sb₄S₁₁, and the related mineral falkmanite have been reported. These can be explained by a phase transition between a low-temperature (LT) modification (P21/c, a ≈ 8.07 Å, b ≈ 23.5 Å, c ≈ 21.6 Å, β ≈ 100.7°) and a disordered high-temperature (HT) modification [Pnma, a = 23.530(2) Å; b = 4.0385(8) Å and c = 21.273(2) Å, R1(obs) = 0.039] that occurs above ca. 350–400 °C. The almost completely ordered distribution of lead and antimony cations in the LT modification involves a superstructure; the corresponding reflections are obvious in electron and X-ray diffraction patterns. Partial ordering may render them more or less diffuse. They vanish upon heating above the transition temperature, also for originally ordered natural boulangerite (from Trepča, Kosovo), and appear again after annealing below the phase transition temperature (e.g. at 330 °C). The HT phase is characterized by pronounced cation disorder. Cation ordering can be described by group-subgroup relationships which may also serve for a unified description of various structure models from literature. Starting from the orthorhombic HT phase, a translationengleiche followed by an isomorphous symmetry reduction yields the degrees of freedom required for cation ordering. The non-standard setting A21/d11 is optimal for a unified comparison of all known structure models. Varying degrees of ordering reported in literature and observed for various new samples suggest that the transition is kinetically controlled. These relationships also contribute to the long-lasting discussion about the nomenclature of minerals with the sum formula Pb₅Sb₄S₁₁ or very similar ones. A precise structure determination of a single crystal (grown by chemical vapor transport) using synchrotron radiation along with detailed electron diffraction investigations and high-resolution electron microscopy confirms the statistically disordered structure model of the quenched high-temperature phase. Bond-valence sums (BVS) and interatomic distances confirm the interpretation of cation split positions as the superposition of the corresponding independent cation positions in the LT phase. Measurements of transport properties indicate very low n-type electrical and thermal conductivities for both modifications. The order-disorder transition significantly affects the Seebeck coefficient.

CDAAB	FALKMANITE	Pb _{5.4} Sb _{3.6} S ₁₁	mon/P2 ₁ /a
CDAAC	BOULANGERITE	Pb ₅ Sb ₄ S ₁₁	mon/P2 ₁ /a
CDAAD	ROBINSONITE	Pb ₄ Sb ₆ S ₁₃	mon/I2/m
CDAAE	DADSONITE	Pb ₂₃ Sb ₂₅ S ₆₀ Cl	tri/P1
CDAAF	MOËLOITE	Pb ₆ Sb ₆ S ₁₄ (S ₃)	orth/P2 ₁ 22 ₁
CDAAG	DISULFODADSONITE	Pb ₁₁ Sb ₁₃ S ₃₀ (S ₂) _{0.5}	tric/P1
CDAAH	LOPATKAITE	Pb ₅ Sb ₃ AsS ₁₁	

SERIES B JAMESONITE ISOTYPIC SERIES. The structure consists of chains of edge-sharing PbS₇ polyhedra and chains of edge-sharing Fe octahedra, both // [001], and are linked by Sb pyramids.

CDABA	JAMESONITE	Pb ₄ FeSb ₆ S ₁₄	mon/P2 ₁ /a
CDABB	BENAVIDESITE	Pb ₄ (Mn,Fe)Sb ₆ S ₁₄	mon/P2 ₁ /a

TYPE B CYCLIC SUB-TYPE AND CHESSBOARD DERIVATIVES (ZINKENITE FAMILY).

SERIES A ZINKENITE PLESIOTYPIC SERIES (CYCLIC ROD-TYPE). The structure of Marrucciite is complex. Hg is in two specific distorted octahedral coordinations. There are 40 other independent positions: 7 Pb, 2 (Pb,Sb), 8 Sb and 23 S. The general architecture of the structure is strongly related to that of hexagonal Ba₁₂Bi₂₄S₄₈, with three types of Me₁₀S₁₄ rods around a HgSb₂Pb₄S₄ central column. In zinckenite, hexagonal columns // [0001] of SnS-like bonded Pb and Sb create tunnels // [0001] that are filled by columns of face-sharing PbS₆ octahedra. In scainiite, pseudo-hexagonal columns // [010] of SnS-like bonded Pb,Sb, bands create tunnels // [010] that are filled by kermesite-type ribbons (Sb₂S₂O). The structure of vurroite contains lozenge-shaped composite rods made of coordination polyhedra of Pb and Sn, interconnected into layers // to (010) of the standard monoclinic setting. These layers are separated by ribbons of As and Bi, each in distorted octahedral coordination. The riggings form wavy, discontinuous double layers of PbS archetype. Lone electron pairs of As and Bi are accommodated in the central portions of the PbS-like layers. The structure can be considered a box-work structure containing the smallest possible pseudo-hexagonal block in the form of a sole octahedron. The fundamental building block of sterryite and parasterryite is a complex column centered on a Pb₆S₁₂ triangular prismatic coReference:

▪ Biagioni, C., Bindi, L., Moëlo, Y. (2018): Another step toward the solution of the real structure of zinckenite. *Zeitschrift für Kristallographie - Crystalline Materials*, 233, 269-277.

The crystal structure of Cu-bearing zinckenite from Saint-Pons (Alpes Maritimes department, France), having idealized chemical composition Cu_{0.7}Pb_{9.7}Sb_{21.3}S₄₂, has been studied. It has a pronounced hexagonal sub-cell, with unit-cell parameters a=22.1219(11), c=4.3207(3) Å, V=1831.2(2) Å³, space group P6₃, Z=1. The sub-cell crystal structure was refined to R1=0.072 on the basis of 3905 reflections with Fo>4σ(Fo) and 133 refined parameters. It can be described as formed by one kind of rod, with walls of columns of (Pb/Sb)-centered polyhedra flanking both the rods and the sites located along the 63 screw axis. Minor Cu is hosted in the tetrahedral voids between the rods and the walls of polyhedra. Alternatively, the crystal structure of zinckenite can be described as formed by trigonal rods, delimited by lone electron-pair micelles, and tunnels hosting (Pb/Sb) atoms. The occurrence of weak superstructure reflections points to a triclinic unit cell with parameters a=38.271(2), b=22.1219(13), c=8.6475(5) Å, α=89.931(3), β=90.030(3), γ=89.957(3)°, V=7323.6(7) Å³, space group P1, Z=4. The twin laws making the twin lattice hexagonal have been taken into account and the crystal structure has been solved and refined. Notwithstanding the very low R1 value (R1=0.038 on the basis of 22563 reflections with Fo>4σ(Fo) and 1194 refined parameters), several shortcomings, mainly due to the low diffraction quality of the available crystals, allow only the description of the main structural features of the superstructure of zinckenite, indicating the correctness of the triclinic model hypothesized by previous authors. re, with two additional long and short arms. The main chemical and topological differences relate to the short arm, which induces a relative a/4 shift of the constitutive rod layers. Selection of the shortest (Sb,As)-S bonds permitted to enhance the polymeric organization of (Sb,As) atoms with triangular pyramidal coordination. These two quasi-homeotypic structures are expanded derivatives of owyheeite. The structure of tubulite is probably an expanded derivative of owyheeite. The structure of chovanite has 11 independent Pb sites, 13 Sb sites, some of which are split into two partially occupied non-overlapping positions, and 5 mixed (Pb,Sb) sites. Chovanite has a typical rod-based structure of a Pb-Sb boxwork type, and is similar to those of pillaitite and pellouxite.

The structure of gladkovskyite contains five independent atoms sites in asymmetric unit. There is one Tl, one As, and two S atoms. Thallium is coordinated by nine S atoms in the form of a distorted tricapped trigonal prism. The asymmetry of the coordination environment around Tl site suggests that lone-electron pair on Tl is active. Arsenic is coordinated by three S atoms forming a regular trigonal pyramid. These pyramids form [001] chains via charged S atoms. Manganese is

coordinated by six S atoms as a regular MnS_6 octahedron. These octahedra share triangular faces and form [001] chains via shared S atoms. These octahedra share triangular faces and form [001] columns. Periodicity // to [001] is as follows: two ;Mn octahedrons match two As pyramids with different orientation but only one Tl polyhedron, the alternating polyhedron along [001] is assumed by its lone electron pair. The structure of gladvkovskyite is one more representative of the small group of cyclic sulfosalts structures, with zinkenite as one of the largest representatives.

CDBAA	ZINKENITE	$Pb_9Sb_{22}S_{42}$	hex/ $P6_3$, $P6_3/m$
CDBAB	SCAINIITE	$Pb_{14}Sb_{30}S_{54}O_5$	mon/ $C2/m$
CDBAC	PILLAITE	$Pb_9Sb_{10}S_{23}ClO_{0.5}$	mon/ $C2/m$
CDBAD	PELLOUXITE	$(Cu,Ag)Pb_{10}Sb_{12}S_{27}(Cl,S)_{0.6}O$	mon/ $C2/m$
CDBAE	OWYHEEITE	$Pb_{4.43}Ag_{1.5}Sb_{6.07}S_{14}$	mon/ $P2_1/c$
CDBAF	VURROITE	$Pb_{20}Sn_2(Bi,As)_{22}S_{54}Cl_6$	mon/ $C2/c$
CDBAG	MARRUCCIITE	$Hg_3Pb_{16}Sb_{18}S_{46}$	
CDBAH	TAZIEFFITE	$Pb_{20}Cd_2(As,Bi)_{22}S_{50}Cl_{10}$	mon/ $C2/c$
CDBAI	PARASTERRYITE	$Ag_4Pb_{20}Sb_{14}As_{10}S_{58}$	mon/ $P2_1/c$
CDBAJ	TUBULITE	$Ag_2Pb_{22}Sb_{20}S_{53}$	mon/ Pc
CDBAK	STERRYITE	$Cu(Ag,Cu)_3Pb_{19}(Sb,As)_{22}(As-As)S_{56}$	mon/ $P2_1/c$
CDBAL	MEERSCHAUTITE	$(Ag,Cu)_6Pb_{43-2x}Sb_{44+2x}S_{112}O_x$	$x \sim 0.5$ mon/ $P2_1$
CDBAM	CHOVANITE	$Pb_{15-2x}Sb_{14+2x}S_{36}O_{0.2}$	mon/ $B2/m$
CDBAN	CIRIOTTIITE	$Cu(Cu,Ag)_3Pb_{19}(Sb,As,Bi)_{22}(As_2)S_{56}$	mon/ $P2/n$
CDBAO	GLADKOVSKYITE	$MnTlAs_3S_6$	trig/ $R31c$

SERIES B CHESSBOARD DERIVATIVES (KOBELLITE HOMOLOGOUS SERIES). The structures of members of the kobellite homologous series can be described in terms of two types of rods interested in a pseudo-trigonal pattern. The one type of rod is based on a PbS-like archetype, and the other is a SnS-like archetype. Two strings of (Cu,Fe) atoms for each pair of rods are added in the interfaces of the rods. High-angle annular dark-field scanning transmission electron microscopy is a powerful Z-contrast technique able to depict the structural motifs in Pb-(Bi-Sb)-sulfosalts. Using two homologs from the kobellite homologous series, a group of “chessboard derivative structures,” represented by Bi-, and Sb-rich pairs of natural phases (the kobellite-tintinaite isotypic series and giessenite-izoklakeite homeotypic series), we visualize the slabs underpinning crystal structural modularity for the N = 2 homolog kobellite and the N = 4 homolog, in this case a Bi-rich izoklakeite [$Sb/(Sb+Bi) = 0.35$]. The homolog number, N, can be readily calculated as $N = n1/6 - 1$ and $N = n2/4$, where n1 and n2 are the numbers of atoms in the PbS- and SnS-motifs, respectively. Atom-scale imaging of thinned foils extracted in situ from samples for which compositional data are available also reveals syntactic unit-cell scale intergrowths on [001] zone axis with akobellite || bizoklakeite. These are as small as half-unit cells of bizoklakeite and one-unit cell akobellite. Replacement relationships are also observed as irregular slabs of kobellite “intruding” into izoklakeite. Both banded and irregular intergrowths account for the compositional fields measured at the micrometer scale.

CDBBA	KOBELLITE	$Pb_{22}Cu_4(Bi,Sb)_{30}S_{69}$	orth/ $Pnmm$ or $Pnmm$
CDBBB	TINTINAITE	$Pb_{22}Cu_4(Sb,Bi)_{30}S_{69}$	orth/ $Pnmm$

SERIES C GIESSENITE HOMEOTYPIC PAIR

CDBCA	IZOKLAKEITE	$Pb_{27}(Cu,Fe)_2(Sb,Bi)_{19}S_{57}$	orth/ $Pnmm$
CDBCB	GIESSENITE	$Pb_{26}Cu_2(Bi,Sb)_{20}S_{57}$	mon/ $P2_1/n$
CDBCC	ECLARITE (related)	$Pb_9(Cu,Fe)Bi_{12}S_{28}$	orth/ $Pnma$
CDBCD	ZOUBEKITE (related)	$Pb_4AgSb_4S_{10}$	orth/

TYPE C BISMUTHINITE – AIKINITE HOMEOTYPIC SERIES
The minerals in this series are composed of bismuthinite ribbons (B), krupkaite ribbons (K), and aikinite ribbons (A).

SERIES A BISMUTHINITE-AIKINITE SERIES

CDCAA	BISMUTHINITE	Bi_2S_3 (B)	orth/ $Pbnm$
CDCAB	PEKOITE	$CuPbBi_{11}(S,Se)_{18}$ (4B+2K)	orth/ $P2_1/am$
CDCAC	GLADITE	$CuPbBi_5S_9$ (2B+4K)	orth/ $Pnma$
CDCAD	KRUPKAITE	$CuPbBi_3S_6$ (K)	orth/ $Pmc2$
CDCAE	LINDSTRÖMITE	$Cu_3Pb_3Bi_7S_{15}$ (8K+2A)	orth/ $P2_1/am$
CDCAF	HAMMARITE	$Cu_2Pb_2Bi_4S_9$ (4K+2A)	orth/ $Pbnm$
CDCAG	FRIEDRICHITE	$Cu_5Pb_5Bi_7S_{28}$ (2K+4A)	orth/ $Pbnm$
CDCAH	AIKINITE	$CuPbBiS_3$ (A)	orth/ $Pb2_1n$

CDCAI	PAARITE	$\text{Cu}_{1.6}\text{Pb}_{1.6}\text{Bi}_{6.4}\text{S}_{12}$ (8K + 2A)	orth/Pmcn
CDCAJ	SALZBURGITE	$\text{Cu}_{1.6}\text{Pb}_{1.6}\text{Bi}_{6.4}\text{S}_{12}$ (8K + 2A)	orth/
CDCAK	EMILITE	$\text{Cu}_{10.7}\text{Pb}_{10.7}\text{Bi}_{21.3}\text{S}_{48}$	orth/Pmc ₂ ₁

TYPE D RELATED SULFOSALTS (?).

SERIES A CRYSTAL STRUCTURES UNKNOWN. Jambor, J. L. (1967): New lead sulfantimonides from Madoc, Ontario. Part 1. Canadian Mineralogist 9, 7-24.

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CDDAA	MADOCITE	$\text{Pb}_{17}(\text{Sb,As})_{16}\text{S}_{41}$	orth/Pba2 or Pbam
CDDAB	PLAYFAIRITE	$\text{Pb}_{16}\text{Sb}_{18}\text{S}_{43}$	mon/P2 ₁ /m
CDDAC	ARDAITE	$(\text{Pb,Fe})_{19}\text{Sb}_{13}\text{S}_{35}\text{Cl}_7$	mon/
CDDAD	SORBYITE	$\text{Pb}_{19}(\text{Sb,As})_{20}\text{S}_{49}$	mon/C2/m
CDDAE	LAUNAYITE	$\text{Pb}_{22}\text{Sb}_{26}\text{S}_{61}$	mon/C2/m
CDDAF	ZNAMENSKYITE	$\text{Pb}_4\text{In}_2\text{Bi}_4\text{S}_{13}$	orth/Pbam
CDDAG	DALIRANITE	$\text{PbHgAs}_2\text{S}_6$	mon/P2, Pm or P2/m

GROUP E	SPECIFIC Tl (Pb) AND Hg SULFOSALTS: STRUCTURES WITH AsS LAYERS (WITH OR WITHOUT ADDITIONAL LAYERS).		
TYPE A	HUTCHINSONITE MEROTYPIC SERIES.		
SERIES A	HUTCHINSONITE – BERNARDITE HOMOLOGOUS PAIR. In hutchinsonite, As_4S_8 spiral chains // [001] are joined by AsS_3 pyramids to form complex layers // (010); these layers alternate with galena-like layers consisting of As_2S_3 groups and Pb atoms; the layers are linked by (Tl,Pb) and As atoms. The structure of ambrinoite can be described as an order-disorder (OD) structure, built up by two different kinds of layers. Taking into account only the short (As,Sb)-S bonds, (As,Sb) S_3 triangular pyramids form double chains similar to those described in other natural and synthetic compounds, like gillulyite and gerstleyite.		
CEAAA	HUTCHINSONITE	$(Pb,Tl)_2As_5S_9$	orth/Pbca
CEAAB	BERNARDITE	$Tl(As,Sb)_5S_8$	mon/
CEAAC	AMBRINOITE	$(K,NH_4)_2(As,Sb)_6(Sb,As)_2S_{13} \cdot H_2O$	
SERIES B	EDENHARTERITE-JENTSCHITE PAIR. In jentschite and edenharterite, Tl and S form TlS_5 double chains // [001]; Pb and S form planes // (010). In jentschite, four-edged Sb_2S_3 rings with two attached As_2S_5 groups form infinite $[As_4Sb_2S_{12}]$ groups; in edenharterite, As_2S_2 rings form infinite As_6S_{121} groups.		
CEABA	EDENHARTERITE	$TlPbAs_3S$	orth/
CEABB	JENTSCHITE	$TlPbAs_2SbS_6$	mon/
SERIES C	IMHOFITE-GILLULYITE PAIR. In imhofite, TlS_6 prisms share corners to form chains // [101] which are linked by AsS_3 pyramids; the as pyramids are combined into finite groups of four (As_3S_6) rings. Structure consists of chains of edge-sharing Tl polyhedra // [010] connected by isolated 3-membered rings of As pyramids forming sheets // (001). These sheets alternate with sheets formed by chains of edge-sharing As pyramids connected by 3-membered rings of As pyramids. The structure can also be regarded as consisting of PbS-like slabs of As polyhedra alternating with slabs consisting of TlS_5 polyhedra and As_2S_3 groups.		
CEACA	IMHOFITE	$Tl_6CuAs_{16}S_{40}$	mon/P2 ₁ /n
CEACB	GILLULYITE	$Tl_2[As_8S_{13}]$	mon/
CEACC	FANGITE (may be related)	Tl_3AsS_4	orth/
SERIES D	GERSTLEYITE. The structure consists of SbS_3 pyramids that share corners to form a complex chain parallel to [100]. Na-S bonds cross-link the chains into a slab structure parallel to (010). Structure consists of corner-sharing SbS_3 pyramids forming complex chains // [010] that are cross-linked by $Na[S_4(H_2O)_2]$.		
CEADA	GERSTLEYITE	$Na_2(Sb,As)_8S_{13} \cdot 2H_2O$	mon/Cm
TYPE B	REBULITE PLESIOTYPIC PAIR.		
SERIES A	JANKOVICITE. Structure consist of SnS-type layers // (001), one and two polyhedral thick, are linked by layers consisting of TlS_8 cubes and (Sb,As) S_3 pyramids.		
CEBAA	REBULITE (R)	$Tl_5Sb_5As_8S_{22}$	
CEBAB	JANKOVICITE	$Tl_5Sb_9(As,Sb)_4S_{22}$	orth/Pbnm
TYPE C	SINGLE TYPE: SICHERITE.		
SERIES A	SICHERITE No structure given. American Mineralogist (2001): 86: 1087-1093.		
CECAA	SICHERITE	$Ag_2Tl(As,Sb)_3S_6$	orth/Pmnb
TYPE D	UNCLASSIFIED		
SERIES A	UNCLASSIFIED SERIES. Structure of erniggliite consists of stable (0001) sheets of two Tl polyhedra and two AsS_3 pyramids which are linked to adjoining sheets by a Sn antiprism. The structure of gabrielite consists of two types of sulfur layers, one with 3 ⁴ .6 mesh, and the other composed of triangles, squares and pentagons with idealized plane-symmetries p3 and p31m, respectively. A full		

description is found in CM2006-141. In vrbaitite, infinite As_2SbS_5 chains // [001] are joined by TI atoms to form slabs // (010); these slabs alternate with $\text{Hg}_3\text{As}_4\text{S}_{10}$ sheets, and are linked by TI atoms.

CEDAA	ERNIGGLIITE	$\text{Tl}_2\text{SnAs}_2\text{S}_6$	trig/
CEDAB	VRBRAITE	$\text{Tl}_4\text{Hg}_3\text{As}_8\text{Sb}_2\text{S}_{20}$	orth/C2ca
CEDAC	SIMONITE	$\text{TIHgAs}_3\text{S}_6$	mon/P2 ₁ /n
CEDAD	VAUGHANITE	$\text{TIHgSb}_4\text{S}_7$	tric/
CEDAE	GABRIELITE	$\text{Tl}_6\text{Ag}_3\text{Cu}_6\text{As}_9\text{S}_{21}$	tric/P1

GROUP F SULFOSALTS WITH AN EXCESS OF SMALL (UNIVALENT) CATIONS (Ag, Cu) RELATIVE TO (As, Sb, Bi).

TYPE A Cu (Ag)-RICH SULFOSALTS.

SERIES A WITTICHENITE HOMEOTYPIC PAIR. The sulfur framework can be described as a deformed (1122)_{hcp} twinned hcp array. Sb has trigonal pyramidal coordination in the bases of trigonal coordination prisms created by the unit-cell twinning of the S array. Most Cu sites have a triangular coordination. Cu(4) is split into two irregularly tetrahedral, [3 + 1] co-ordinations. Cu(3) and Cu(4) are in triangular faces common to two tetrahedral voids of the S array, and the remaining Cu atoms are in such faces common to tetrahedral and octahedral voids. Structure consists of insular (Sb,As) pyramids, CuS_3 triangles and CuS_4 tetrahedra which are connected to form a 3-dimensional framework based on hexagonal close-packing of sulfur atoms. Infinite (Sb,Bi) Cu_3S_3 chains // [001] are joined by Cu-s bonds to form sheets // (010); adjacent sheets are linked by Cu-S and Bi-S bonds. See CM95-655 (Wittichenite).

CFAAA	SKINNERITE	Cu_3SbS_3	mon/P2 ₁ /c
CFAAB	WITTICHENITE	Cu_3BiS_3	orth/P2 ₂ 2 ₁ 2 ₁

SERIES B TETRAHEDRITE ISOTYPIC SERIES. *cub/I4₃m*. Structure consists of a tetrahedral framework based on sphalerite, with two additional S in the elementary cell. S is octahedrally coordinated by six Cu atoms and tetrahedrally by Cu_3As ; As is linked to three S atoms in the form of a trigonal pyramid. The metal atoms have tetrahedral and triangular co-ordinations. We report the characterisation of two new tetrahedrite-group minerals, rozhdestvenskayaite, $\text{Ag}_{10}\text{Zn}_2\text{Sb}_4\text{S}_{13}$, and argentotetrahedrite, $\text{Ag}_6\text{Cu}_4(\text{Fe}^{2+},\text{Zn})_2\text{Sb}_4\text{S}_{13}$, and discuss the structural chemistry of the Ag-rich tetrahedrite group in order to identify correlations between structure and composition. Argentotetrahedrite is the Sb-analogue of argentotennantite. Rozhdestvenskayaite is named for Irina Rozhdestvenskaya in recognition of her important contributions to mineralogy, and to the crystal chemistry of the tetrahedrite group in particular. Rozhdestvenskayaite is cubic *I4⁻3m* with unit-cell parameter $a = 10.9845(7)$ Å and $V = 1325.37(15)$ Å³, and has a Mohs' hardness of 3.0. Argentotetrahedrite is cubic *I4⁻3m* with unit-cell parameter $a = 10.6116(1)$ Å and $V = 1194.92(2)$ Å³, and has a Mohs' hardness of 3.9. The five strongest peaks in the X-ray powder diffraction patterns (*hkl*, d_{obs} (Å), I_{max} (%)) are: rozhdestvenskayaite [(222), 3.161, 100], [(004), 2.738, 35], [(044), 1.936, 24], [(226), 1.651, 19], [(134,015), 2.147, 18]; argentotetrahedrite [(222), 3.063, 100], [(044), 1.876, 35], [(004), 2.652, 28], [(226), 1.599, 25], [(134,015), 2.081, 19]. The large unit-cell volume of rozhdestvenskayaite is due to the high Ag content (70%) of the BS_4 tetrahedron. A major issue for understanding the crystal chemistry of the tetrahedrite group relates to the occupancy of the Z site in which sulfur is coordinated octahedrally to monovalent metals (Cu or Ag). It is shown that this site can be completely empty, as in freibergite, and that this vacancy leads to a marked reduction in the volume of the $\text{Z}(\text{A}_6)$ octahedron from 16 Å³ in tetrahedrite with a fully occupied site to 11 Å³ in freibergite with a vacant Z site. In freibergite, the Ag–Ag distance of the Ag_6 octahedron is 2.84 Å and is almost the same as that of silver metal (2.85 Å), strongly suggesting the presence of metallic bonding in this octahedral group. In contrast, the corresponding Ag–Ag distances of argentotetrahedrite and rozhdestvenskayaite are 3.23 Å and 3.24 Å, respectively, indicative of no metallic bonding. An important consequence of the metallicly bonded Ag_6 group of freibergite is that it has an aggregate formal charge of +4 (not +6), leading to a charge-balanced ideal formula $(\text{Ag}_6)^{4+}(\text{Cu}^+)_4(\text{Zn},\text{Fe}^{2+})_2\text{Sb}_4\text{S}_{12}$.

Proposal 18-K on the tetrahedrite group is accepted. The general structural formula of minerals belonging to this group is $\text{M}(2)\text{A}_6\text{M}(1)(\text{B}_4\text{C}_2)\Sigma 6\text{X}(3)\text{D}_4\text{S}(1)\text{Y}_{12}\text{S}(2)\text{Z}$ (Z = 2), where A = Cu⁺, Ag⁺, □; B = Cu⁺, Ag⁺; C = Zn²⁺, Fe²⁺, Hg²⁺, Cd²⁺, Mn²⁺, Cu²⁺, Cu⁺, Fe³⁺; D = Sb³⁺, As³⁺, Bi³⁺, Te⁴⁺; Y = S²⁻, Se²⁻; and Z = S²⁻, Se²⁻, □. The tetrahedrite group is divided into five different series on the basis of the A, B, D, and Y constituents, i.e. the tetrahedrite, tennantite, freibergite, hakite, and giraudite series. The nature of the dominant C constituent is made explicit using a hyphenated suffix between parentheses. Eleven minerals belonging to the tetrahedrite group can be considered as valid species: argentotennantite-(Zn), argentotetrahedrite-(Fe), kenoargentotetrahedrite-(Fe), giraudite-(Zn), goldfieldite, hakite-(Hg), rozhdestvenskayaite-(Zn), tennantite-(Fe), tennantite-(Zn), tetrahedrite-(Fe), and tetrahedrite-(Zn). Furthermore, annivite is formally discredited.

CFABA	TETRAHEDRITE-(Fe)	$\text{Cu}_6\text{Cu}_4(\text{Fe}^{2+}, \text{Zn})_2\text{Sb}_4\text{S}_{12}\text{S}$
CFABB	TETRAHEDRITE-(Zn)	$\text{Cu}_6\text{Cu}_4(\text{Zn}, \text{Fe}^{2+})_2\text{Sb}_4\text{S}_{12}\text{S}$
CFABC	ARGENTOTETRAHEDRITE-(Fe)	$\text{Ag}_6\text{Cu}_4(\text{Fe}^{2+}, \text{Zn})_2\text{Sb}_4\text{S}_{12}\text{S}$
CFABD	KENOARGENTOTETRAHEDRITE-(Fe)	$(\text{Ag}, \text{Cu}, \square)_{10}\text{Fe}^{2+}_2\text{Sb}_4\text{S}_{12}\square$
CFABE	TENNANTITE-(Fe)	$\text{Cu}_6\text{Cu}_4(\text{Fe}^{2+}, \text{Zn})_2\text{As}_4\text{S}_{12}\text{S}$
CFABF	TENNANTITE-(Zn)	$\text{Cu}_6\text{Cu}_4(\text{Zn}, \text{Fe}^{2+})_2\text{As}_4\text{S}_{12}\text{S}$
CFABG	ARGENTOTENNANTITE-(Zn)	$\text{Ag}_6\text{Cu}_4(\text{Fe}^{2+}, \text{Zn})_2\text{As}_4\text{S}_{12}\text{S}$
CFABH	ROZHDESTVENSKEYAITE-(Fe)	$\text{Ag}_6\text{Ag}_4\text{Fe}^{2+}_2\text{Sb}_4\text{S}_{12}\text{S}$
CFABI	ROZHDESTVENSKEYAITE-(Zn)	$\text{Ag}_6\text{Ag}_4\text{Zn}_2\text{Sb}_4\text{S}_{12}\text{S}$
CFABJ	GIRAUDITE-(Zn)	$\text{Cu}_6\text{Cu}_4(\text{Fe}^{2+}, \text{Zn})_2\text{As}_4\text{Se}_{12}\text{Se}$
CFABK	GOLFIELDITE	$(\text{Cu}_{10}, \square_2)\text{Te}_4\text{S}_{12}\text{S}$
CFABL	HAKITE-(Hg)	$\text{Cu}_6\text{Cu}_4\text{Hg}_2\text{Sb}_4\text{Se}_2\text{Se}$

SERIES C

NOWACKIITE ISOTYPIC SERIES. Structure consists of a defect ZnS-type structure with one vacant S site, and all the metal atoms are in 4-fold coordination. In Aktashite, corner-sharing HgS_4 and CuS_4 tetrahedra form a framework with channels // $[0001]$ that contain the As atoms. The sinnerite structure is based on a sphalerite-like substructure and contains two kinds of twisted, chain-like groups of $[\text{AsS}_3]$ pyramids; one group contains 3 pyramids, the other 5 pyramids. Structure is a sphalerite substructure, with 2.5 of the tetrahedra replaced by AsS_3 pyramids; 4 pyramids share corners to form As_4S_{12} clusters that are linked into twisted chain-like structures; the chains are linked by CuS_4 tetrahedra.

CFACA	NOWACKIITE	$\text{Cu}_6\text{Zn}_3\text{As}_4\text{S}_{12}$	hex/R3
CFACB	AKTASHITE	$\text{Cu}_6\text{Hg}_3\text{As}_4\text{S}_{12}$	hex/R3
CFACC	GRUZDEVITE	$\text{Cu}_6\text{Hg}_3\text{Sb}_4\text{S}_{12}$	hex/nd
CFACD	SINNERITE	$\text{Cu}_6\text{As}_4\text{S}_9$	tric/P1
CFACE	WATANABEITE	$\text{Cu}_4(\text{As}, \text{Sb})_2\text{S}_5$	tetr/
CFACF	LAFFITTITE	HgAgAsS_3	mon/A2/a

SERIES D

ROUTHIERITE ISOTYPIC PAIR. Structure consists of CuS_4 and ZnS_4 tetrahedra sharing corners to form a framework with channels // $[001]$ containing the Tl and As polyhedra that share corners and edges with the tetrahedra. Arsiccioite is derived from isotype routhierite, with a framework of two independent $(\text{Hg}, \text{Ag})\text{S}_4$ corner-sharing tetrahedral hosting channels // to $[001]$. These channels contain TlS_3 and $(\text{As}, \text{Sb})\text{S}_3$ polyhedra that share corners and edges with the tetrahedron framework. Ralphcannonite has a three-dimensional framework of (Af, Zn)-centered tetrahedra (1 M1 + 2 M2), with channels // to $\{001\}$ hosting TlS_6 and $(\text{As}, \text{Sb})\text{S}_3$ disymmetric polyhedra. Ralphcannonite is derived from its isotype routhierite through the double heterovalent substitution.

CFADA	ROUTHIERITE	TlHgAsS_3	tetr/14/mmm, 14m2, 142m
CFADB	STALDERITE	$(\text{Tl}, \text{Cu})(\text{Zn}, \text{Fe}, \text{Hg})\text{AsS}_3$	tetr/14/mmm
CFADC	ARSICCIOITE	$\text{AgHg}_2\text{Tl}(\text{As}, \text{Sb})_2\text{S}_6$	tetr/142m
CFADD	RALPHCANNONITE	$\text{AgZn}_2\text{TlAs}_2\text{S}_6$	tetr/142m
CFADE	FERROSTALDERITE	$\text{CuFe}_2\text{TlAs}_2\text{S}_6$	tetr/142m

SERIES E

UNCLASSIFIED Cu (Ag) SULFOSALTS. American Mineralogist (1980): 65: 784-788. Bulletin de la Société française de Minéralogie et de Cristallographie (1976): 99: 310-313.

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The structure of quijarroite can be considered a galena derivative and could be derived from that of bournonite.

CFAEA	MIHARAITE	$\text{Cu}_4\text{FePbBiS}_6$	orth/Pbmn, Pb2m or Pb2 ₁
CFAEB	PETROVICITE	$\text{Cu}_3\text{HgPbBiSe}_5$	mon/Pnam or Pna2 ₁
CFAEC	MAZZETTIITE	$\text{Ag}_3\text{HgPbSbTe}_5$	orth/
CFAED	CHAMEANITE = Mgriiite?	$(\text{Cu,Fe})_4\text{As}(\text{Se,S})_4$	cub/nd
CFAEE	MGRIIITE	$(\text{Cu,Fe})_3\text{AsSe}_3$	cub/Fd3m
CFAEF	LAROSITE	$(\text{Cu,Ag})_{21}\text{PbBiS}_{13}$	orth/nd
CFAEG	ARCUBISITE	$\text{CuAg}_6\text{BiS}_4$	nd/nd
CFAEH	PERMINGEAITE	Cu_3SbSe_4	Sphalerite superstructure type
CFAEI	QUIJARROITE	$\text{Cu}_6\text{HgPb}_2\text{Bi}_4\text{Se}_{12}$	orth/Pmn2 ₁

SERIES F **BYTIZITE SERIES. Orth/Pnma. Structure consists of trigonal groups (CuSe_3), Cu2 atom is coordinated tetrahedrally and Sb1 atom as trigonal pyramids. The structure contains two Cu, one Sb, and two Se sites. In the structure of both synthetic Cu_3SbSe_3 and bytizite, there are groups of three cis-edge-sharing tetrahedra [Cu_3Se_8], which are interlinked to a 3D framework by SbSe_3 groups.**

CFAFA BYTIZITE Cu_3AbSe_3

SERIES G **GALKHAITE SERIES, iso/I43m. The galkhaite structure has been revised. It is a three-dimensional framework of HgS_4 and AsS_3 polyhedra, with Cs hosted in large 12-fold coordinated cavities. The introduction of Cs^+ , as well as minor TI^+ , at these structural positions requires the replacement of Hg^{2+} by Cu^+ .**

CFAGA	GALKHAITE	$(\text{Cs,Tl})(\text{Hg,Cu,Zn})_6(\text{As,Sb})_4\text{S}_{12}$
CFAGB	VORONTSOVITE	$(\text{Hg}_5\text{Cu})_6\text{TlAs}_4\text{S}_{12}$
CFAGC	FERROVORONTSOVITE	$(\text{Fe}_5,\text{Cu})_6\text{TlAs}_4\text{S}_{12}$

TYPE B **Ag-RICH SULFOSALTS.**

SERIES A **SAMSONITE. Structure consists of MnS_6 octahedra, AgS_4 tetrahedra, AgS_3 triangles and AbS_3 trigonal pyramids sharing edges and corners to form a framework.**

CFBAA SAMSONITE $\text{Ag}_4\text{MnSb}_2\text{S}_6$ mon/P2/n

SERIES B **PROUSTITE. The structure is based on a complex packing of AsS_3 pyramidal groups and Ag atoms. The Ag atoms are linked to S atoms forming spiral chains along the c axis. In ellisite, TlS_5 polyhedra share edges and corners with AsS_3 pyramids, and corners with TlS_5 polyhedra, to form a 3-dimensional framework showing a strongly distorted PbS structure.**

CFBBA	PROUSTITE	Ag_3AsS_3	hex/R3c
CFBBB	PYRARGYRITE	Ag_3SbS_3	hex/R3c
CFBBC	ELLISITE	Tl_3AsS_3	hex/R3m

SERIES C **PYROSTILPNITE ISOTYPIC PAIR. Structure consists of infinite Ag-As trigonal spiral chains // [001] connected by AsS_3 pyramids; all AsS_3 pyramids point in the same direction, resulting in a polar c-axis. The structure of billingsleyite consists of $(\text{As,Sb})_4$ tetrahedra and Ag polyhedra forming a three-dimensional framework. Billingsleyite is placed here because of its close relationship to xanthoconite and the polybasite-pearceite series. The structure of eckerite consists of AsS_3 pyramids which are joined by AgS_3 triangles to form double sheets // to (001); the sheets are linked by Cu(Ag) atoms in a quasi-tetrahedral coordination. Among the three metals sites, Ag(2) is dominated by Cu. The mineral is topologically identical to that of xanthoconite and pyrostilpnite. Bindi, L., Nestola, F., Graeser, S., Tropper, P. and Raber, T. (2015) Eckerite, IMA 2014-063. CNMNC Newsletter No. 23, February 2015, page 52; *Mineralogical Magazine*, 79, 51-58. *American Mineralogist*: 73: 439.**

CFBCA	XANTHOCONITE	Ag ₃ AsS ₃	mon/C2/c
CFBCB	PYROSTILPNITE	Ag ₃ SbS ₃	mon/P2 ₁ /c
CFBCC	BILLINGSLEYITE	Ag ₇ (As,Sb)S ₆	cubic/P2 ₁ 3
CFBCD	ECKERITE	Ag ₂ CuAsS ₃	mon/C2/c

SERIES D POLYBASITE-PEARCEITE ISOTYPIC SERIES. Structure can be described as a regular alternation of two kinds of layers stacked along the c axis: the first layer, has general composition [(Ag₁₃Cu₃)(Ag_{1.2}Sb_{0.82})S₁₁], and the second layer has general composition [Ag₉CuS₄]²⁺. The (As,Sb) atoms form isolated (As,Sb)S₃ pyramids, as typically occur in sulfosalts, and copper atoms link two S atoms in linear coordination, whereas the Ag atoms are highly disordered and are distributed along well-defined diffusion-like paths joining low-coordination sites. The structure of fettelite consists of the stacking of two module layers along [001]. The first layer has a composition of [Ag₆As₂S₇]²⁻ and the second layer has a composition of [Ag₁₀HgAs₂S₈]²⁺. The As atoms form isolated AsS₃ pyramids typical of sulfosalts. Hg links two sulfur atoms in linear coordination, and Ag occupies sites with coordination ranging from quasi linear to almost tetrahedral.

CFBDA	POLYBASITE-T2ac/M2a2b2c	(Ag,Cu) ₁₆ Sb ₂ S ₁₁	mon/C2/m
CFBDB	PEARCEITE-T2ac/M2a2b2c	(Ag,Cu) ₁₆ (As,Sb) ₂ S ₁₁	mon/C2/m
CFBDC	PEARCEITE-Tac	(Ag,Cu) ₁₆ As ₂ S ₁₁	mon/C2/m
CFBDD	POLYBASITE-Tac	(Ag,Cu) ₁₆ (Sb,As) ₂ S ₁₁	mon/C2/m
CFBDE	SALENOPOLYBASITE-Tac	[(Ag,Cu) ₆ (Sb,As) ₂ (S,Se) ₇][Ag ₉ Cu(S,Se) ₂ Se ₂]	mon/C2/m
CFBDF	CUPROPEARCEITE	[Cu ₆ As ₂ S ₇][Ag ₉ CuS ₄]	mon/C2/m
CFBDG	CUPROPOLYBASITE	(Cu,Ag) ₁₆ (Sb,As) ₂ S ₁₁	mon/C2/m
CFBDH	FETTELITE	[Ag ₆ Sa ₂ S ₇][Ag ₁₀ HgAs ₂ S ₈]	mon/C2
CFBDI	BENLEONARDITE	Ag ₁₅ Cu(Sb,As) ₂ S ₇ Te ₄	mon/P3m1

SERIES E STEPHANITE ISOTYPIC PAIR. Structure consists of Ag triangles connected to SbS₃ pyramids, which all point in the same direction, resulting in a polar structure; Ag-Ag metallic bonding is in the (023) plane.

CFBEA	STEPHANITE	Ag ₅ SbS ₄	orth/Cmc2 ₁
CFBEB	SELENOSTEPHANITE	Ag ₅ Sb(Se,S) ₄	orth/Cmc2 ₁

SERIES F UNCLASSIFIED Ag SULFOSALTS

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CFBFA	open		
CFBFB	open		
CFBFC	TSNIGRIITE	Ag ₉ Sb(S, Se) ₃ Te ₃	mon/
CFBFD	SPALTIITE	Tl ₂ Cu ₂ As ₂ S ₅	mon/P2 ₁ /c

SERIES G DEBATTISTIITE STRUCTURE, tric/P1. The structure consists of corner-sharing As(S,Te)₃ pyramids which form three-membered distorted rings linked by Ag atoms in triangular or distorted tetrahedral coordination. Certain features of that linkage are similar to those in the structures of trechmannite and minerals of the pearceite-polybasite group the Hg atom is in a nearly perfect linear coordination with two Te/S atoms.

CFBGA	DEBATTISTIITE	Ag ₉ Hg _{0.5} As ₆ S ₁₂ Te ₂	
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TYPE C SULFOSALTS OF THE CaF₂ STRUCTURE TYPE.

SERIES A	ELDRAGONITE. No structure given. Cooper, M.A., Moëlo, Y., Paar, W.H., Raith, J.G., Rowe, R., Roberts, A.C., Stirling, J. and Stanley, C.J. (2011) Eldragónite, IMA 2010-077. CNMNC Newsletter No. 8, April 2011, page 293; Mineralogical Magazine, 75, 289-294.		
CFCAA	ELDRAGONITE	Cu ₆ BiSe ₄ (Se ₂)	orth/Pmcn
GROUP G	UNCLASSIFIED SULFOSALTS.		
TYPE A	OXYSULFOSALTS.		
SERIES A	SARABAUITE. The structure consists of SbO ₃ pyramids forming four-membered Sb ₄ O ₈ rings, which are connected by four-membered Sb ₄ S ₆ O ₂ rings and two-membered Sb ₂ O ₄ rings to form a two-dimensional network. The role of the Ca atoms is to connect these networks into a three-dimensional structure. Structure consists of corner-sharing SbO ₃ pyramids form 8-membered rings, and edge-sharing Sb pyramids form 4- membered Sb-O rings; these rings are linked to form zigzag chains // [001]; the chains are linked into slabs// (100) by CaO ₈ polyhedra; Sb(S,O) ₃ pyramids form 8-membered Sb-S rings that are connected to the slabs by shared O atoms. The main structural feature of cetineite is an infinite tunnel parallel to the 6 ₃ axis, formed by the linkage of SbO ₃ pyramids. Na(H ₂ O) ₆ octahedra are statistically located within the tunnel, with “zeolitic” character. K atoms are on the interior of the tunnel wall and connect the S atoms of external SbS ₃ pyramids to form a three-dimensional framework. Ottensite is the Na analogue.		
CGAAA	SARABAUITE	CaSb ₁₀ O ₁₀ S ₆	mon/C2/c
CGAAB	CETINEITE	(K,Na) ₃ (Sb ₂ O ₃) ₃ (SbS ₃)(OH) _{0.6} ·2.4H ₂ O	hex/P6 ₃
CGAAC	OTTENSITE	(Na,K) ₃ (Sb ₂ O ₃) ₃ (SbS ₃)(OH) _{0.6} ·2.4H ₂ O	hex/P6 ₃
TYPE B	SUBSULFOSALTS.		
SERIES A	TVALCHRELIDZEITE. Structure can be viewed as a sequence of sheets // to (101). These sheets are composed of [Hg ₆ Sb ₂ As ₂ S ₆] ribbon-like units extending along the b axis linked together by the short Hg1-As bonds. CM07-1529.		
CGBAA	TVALCHRELIDZEITE	Hg ₃ SbAsS ₃	mon/P2 ₁ /n
CGBAB	CRIDDLEITE	Au ₃ Ag ₂ TlSb ₁₀ S ₁₀	mon/A2/m, A2, or Am
CGBAC	JONASSONITE	Au(Bi,Pb) ₅ S ₄	mon/F2/m, F2 or Fm
TYPE C	PGE SULFOSALTS?		
SERIES A	UNCLASSIFIED. COOK, N.J., WOOD, S.A., GEBERT, W., BERNHARDT, H.J. & MEDENBACH, O. (1994): Crerarite, a new Pt-Bi-Pb-S mineral from the Cu-Bi-Ni-PGE deposit at Lac Sheen, Abitibi-Témiscamingue, Québec, Canada. Neues Jahrbuch für Mineralogie, Monatshefte, 567-575.		
	33rd International Geological Congress (2008) session MPM-04 Platinum-group mineralogy: Crerarite a Pt-Bi-S mineral: A new occurrence and re-investigation of its chemical formula and crystal structure.		
CGCAA	BOROVSKITE	Pd ₃ SbTe ₄	cub/
CGCAB	CRERARITE	(Pt,Pb)Bi ₃ (S,Se) _{4-x}	cub/
GROUP H	COMPLEX SULFIDE STRUCTURES RELATED TO SULFOSALTS.		
TYPE A	A₂X₃ RIBBON-TYPE STRUCTURES.		
SERIES A	STIBNITE. The structure is a recombination structure based on an heterogeneous packing formed by interpenetrated slabs of closest packings (c/h) of deformed galena type structure parallel to (110). The structure can also be imagined as Sb ₂ S ₃ chains linked together along the <u>a</u> axis forming bands, what is in agreement with the perfect (010) cleavage.		
CHAAA	STIBNITE	Sb ₂ S ₃	orth/Pbnm
CHAAB	GUANAJUATITE	Bi ₂ (Se,S) ₃	orth/Pnma
CHAAC	OTTEMANNITE	Sn ₂ S ₃	orth/Pnma
CHAAD	METASTIBNITE	Sb ₂ S ₃	amorphous
CHAAE	ANTIMONSELITE	Sb ₂ Se ₃	orth/
SERIES B	ORPIMENT. The orpiment structure is based on As ₂ S ₃ sheets where As is trigonal pyramidal coordinated by S atoms. The As ₂ S ₃ sheets are packed along the <u>b</u> axis, and repeat at the third sheet. The perfect cleavage parallel to (010) is in agreement with this structural description. The structure		

of anorpiment is similar to that of orpiment in that it is composed of layers of As_2S_3 macromolecules, but arranged in a different stacking sequence.

CHABA	ORPIMENT	As_2S_3	mon/ $P2_1/n$
CHABB	LAPHAMITE	$\text{As}_2(\text{Se},\text{S})_3$	mon/ $P2_1/n$
CHABC	GETCHELLITE	AsSbS_3	mon/ $P2_1/a$
CHABD	ANORPIMENT	As_2S_3	tric/ $P1$
CHABE	PAKKONENITE	Sb_2AsS_2	mon/ $B2/m$
SERIES C	KERMESITE. Structure consists of $[\text{Sb}_4\text{S}_4\text{O}_2]_n$ chains // [010] and sheets // (100).		
CHACA	KERMESITE	$\text{Sb}_2\text{S}_2\text{O}$	tri/ps.mon/ $C2/m$
SERIES D	KALGOORLIEITE, mon/$C2/m$. Structure consists of.		
CHADA	KALGOORLIEITE	As_2Te_3	

Updated 05/11/19