

PHOSPHATES, ARSENATES, VANADATES

CLASS M Phosphates, Arsenates and Vanadates

GROUP A Phosphates Without Additional Anions, Without Water.

TYPE A Small Cations.

SERIES A **BERLINITE SERIES.** Quartz structure type, trig/P3₁21 or P3₂21. Structure consists of Si tetrahedra connected in such a way as to form spirals along [0001]; the spirals can be only left-handed or only right-handed; narrow channels along [0001] can accommodate Li atoms by the substitution of LiAl for Si. Quartz is isostructural.

MAAAA	BERLINITE	AlPO ₄
MAAAB	ALARSITE	AlAsO ₄
MAAAC	RODOLICOITE	FePO ₄

SERIES B **BERYLLONITE, mon/P2₁/n.** Trimerite Structure type. Structure consists of three P and 3 Be tetrahedra alternating in 6-membered rings connected into a honeycomb pattern, forming sheets // (010) ; the sheets are polymerized into a framework ; Na is accommodated in channels // [010].

MAABA	BERYLLONITE	Na(BePO ₄)
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SERIES C **HURLBUTITE SERIES, mon/P2₁/a.** Danburite Structure type. The hurlbutite structure consists of alternating BeO₄ and PO₄ tetrahedra forming a framework of 4-, 6-, and 8-membered rings analogous to danburite.

MAACA	HURLBUTITE	Ca(Be ₂ P ₂ O ₈)
MAACB	FILATOVITE	K[(Al,Zn) ₂ (As,Si) ₂ O ₈]
MAACC	STRONTIOHURLBUTITE	SrBe ₂ (PO) ₂

SERIES D **LITHIOPHOSPHATE, orth/Pbnm.** Structure consists of an oxygen topology as in triphylite; LiO₄ and PO₄ tetrahedra sharing corners to form a framework. Comparable to the Olivine structure type based on zigzag chains of edge-sharing octahedra cross-linked by Si tetrahedra sharing three edges with the octahedra.

MAADA	LITHIOPHOSPHATE	Li ₃ PO ₄
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SERIES E **NALIPOITE, orth/Pbnm.** The structure consists of LiO₄ tetrahedra forming open, corrugated sheets perpendicular to y; these sheets are cross-linked and reinforced by PO₄ tetrahedra and, to a lesser extent, by NaO₆ octahedra, which, by alternation with the PO₄ tetrahedra, form chains along x. Li and P tetrahedra share three corners to form a framework based on a stacking of interlinked, four-connected two-dimensional nets // (001), with Na octahedra in the cavities; the lattice is related to that of triphylite.

MAAEA	NALIPOITE	Li ₂ NaPO ₄
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SERIES F **OLYMPITE, Orth/P2₁2₁2₁.** PO₄ tetrahedra and pairs of Li tetrahedra share corners to form ribbons // [100]; the ribbons are linked by adjacent P tetrahedra to form an open framework that is interlaced with a network of Na polyhedra joined by corners, edges and faces.

MAAFA	OLYMPITE	Na ₃ PO ₄
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TYPE B Structures with Medium-sized Cations

SERIES A **FARRINGTONITE, Mon/P2₁/n.** Structure consists of Mg octahedra, Mg polyhedra and P tetrahedra linked by corners and edges to form a 3-dimensional framework.

MABAA FARRINGTONITE Mg₃(PO₄)₂

SERIES B **TRIPHYLITE SERIES. Orth/Pbnm. Olivine structure type.** Structure consists of edge-sharing M octahedra forming zigzag chains // [001], which are connected via corners and P groups to form a 3-dimensional framework. The P tetrahedra share edges with the octahedra.

MABBA TRIPHYLITE Li(Fe,Mn)PO₄
MABBB LITHIOPHILITE Li(Mn,Fe)PO₄
MABBC FERRISICKLERITE (Li,□)(Fe,Mn)[PO₄]
MABBD SICKLERITE (Li,□)(Mn,Fe)[PO₄]
MABBE HETEROSITE FePO₄
MABBF PURPURITE MnPO₄
MABBG NATROPHILITE NaMnPO₄
MABBH SIMFERITE Li(Mg,Fe,Mn)₂(PO₄)₂
MABBI BUCHWALDITE NaCa(PO₄)
MABBJ LITHIOPHOSPHATE Li₃PO₄
MABBK MARICITE NaFePO₄
MABBL KARENWEBBERITE Na(Fe²⁺,Mn²⁺)PO₄
MABBM CZOCHRALSKIITE Na₄Ca₃Mg(PO₄)₄
MABBN BRIANITE Na₂CaMg(PO₄)₂

SERIES C **SARCOPSIDE, mon/P2₁/a.** Triphylite derivative. Structure consists of zigzag triphylite chains, every fourth octahedral site is vacant, which splits up the chains into trimers of edge-sharing octahedra // [101]; these are connected via corners and P groups to form a 3-dimensional framework.

MABCA SARCOPSIDE (Fe,Mn,Ca)₃(PO₄)₂
MABCB CHOPINITE (Mg,Fe)₃(PO₄)₂
MABCC ZAVALIAITE (Mn²⁺,Fe²⁺,Mg)₃(PO₄)₂

SERIES D **GRAFTONITE SERIES mon/P2₁/c.** Structure consists of dimmers of edge-sharing M pentagonal dipyrramids sharing corners with similar dimmers to form sheets // (100); edge-sharing M trigonal dipyrramids form chains // [001]; these are linked into a framework by M square pyramids and P tetrahedra. Two new minerals of the grafftonite group, grafftonite-(Mn), ideally M1MnM2,M3Fe2(PO4)2, and grafftonite-(Ca), ideally M1CaM2,M3Fe2(PO4)2, were discovered in phosphate nodules of two beryl-columbite-phosphate pegmatites, respectively at Lutomia and Michałkowa in the Góry Sowie Block, Lower Silesia, SW Poland. Grafftonite-(Mn) is pinkish brown, whereas grafftonite-(Ca) shows more brownish coloration. Both minerals have a vitreous luster, a good cleavage. Grafftonite-(Ca) was collected at Michałkowa, 50°45'N, 16°27'E, in the middle part of the Góry Sowie Block, ~70 km SW of Wrocław, on a small pegmatite dump, a relic of excavation in the 19th century as a source of quartz and feldspar. During this work, Websky (1868) found and described sarcopside (type locality, TL), associated with hureaulite, vivianite and an apatite-group mineral. The dump is located on the left site of the Dział Michałowski Range, on the right side of the Młynówka stream, about 100 m from the Zagórze Śląskie – Lubachów – Michałkowa – Pieszycze road. The original pegmatite vein, ~10–12 m in length and 2–4 m in thickness, with visible zoning (wall zone – graphic zone – blocky feldspar zone), was composed of albite, microcline, quartz, muscovite, biotite, schorl evolving to foitite, almandine, sillimanite, andalusite and phosphate minerals in nodules reaching a few centimeters in diameter (Łodziński and Sitarz, 2009). Grafftonite-(Ca) was found in an outer zone of a small phosphate nodule (~2 cm in diameter) collected on the dump. The nodule was composed mainly of lamellar intergrowths of the primary magmatic phosphates: sarcopside and grafftonite-(Mn), with minor triphylite oxidized topotactically to ferrisicklerite and heterosite. In this zone, the magmatic phosphates underwent intensive Na and Ca metasomatism and were replaced by wolfeite, alluaudite, maneckiite, fluor- and hydroxylapatite, in places forming fine-grained mosaics (Pieczka et al., 2017a).

To date, ~50 phosphate minerals has been identified in the pegmatite (Grochowina, 2016), with such rare species as manekite (TL), wicksite, willieite, ferrowillieite, qingheite-(Fe), maghagendorfite, hagendorfite, ferrohagendorfite, johnsomervilleite, lazulite, gormanite, childrenite, souzalite and arrojadite-(KNa). Łodziński and Sitarz (2009) mentioned also the presence of qingheite, rosemeryite and simferite in nodules of the pegmatite, but these phosphates have not yet been confirmed by chemical analysis or X-ray diffraction. Beusite-(Ca), ideally $\text{CaMn}_2(\text{PO}_4)_2$, is a new graffonite-group mineral from the Yellowknife pegmatite field, Northwest Territories, Canada. It occurs in a beryl–columbite–phosphate rare-element pegmatite where it is commonly intergrown with triphylite–lithiophilite or sarcopside, and may form by exsolution from a high-temperature (Li,Ca)-rich graffonite-like parent phase. It occurs as pale-brown lamellae 0.1–1.5 mm wide in triphylite, and is pale brown with a vitreous lustre and a very pale-brown streak. It is brittle, has a Mohs hardness of 5, and the calculated density is 3.610 g/cm³. Beusite-(Ca) is colourless in plane-polarized light, and is biaxial (+) with $\alpha = 1.685(2)$, $\beta = 1.688(2)$, $\gamma = 1.700(5)$, and the optic axial angle is 46.0(5)°. It is non-pleochroic with $X \parallel b$; $Y \wedge a = 40.3^\circ$ in β obtuse; $Z \wedge a = 49.7^\circ$ in β acute. Beusite-(Ca) is monoclinic, has space group P21/c, $a = 8.799(2)$, $b = 11.724(2)$, $c = 6.170(1)$ Å, $\beta = 99.23(3)^\circ$, $V = 628.3(1)$ Å³ and $Z = 4$. Chemical analysis by electron microprobe gave P2O₅ 41.63, FeO 19.43, MnO 23.63, CaO 15.45, sum 100.14 wt.%. The empirical formula was normalized on the basis of 8 anions pfu: $(\text{Ca}_{0.94}\text{Fe}_{0.92}\text{Mn}_{1.13})\Sigma 2.99(\text{PO}_4)_2.00$. The crystal structure was refined to an R1 index of 1.55%. Beusite-(Ca) is a member of the graffonite group with Ca completely ordered at the [8]-coordinated M(1) site.

A classification and nomenclature scheme has been approved by the International Mineralogical Association Commission on New Minerals, Nomenclature and Classification for the minerals of the graffonite group. The crystal structures of these minerals have three distinct sites that are occupied by Fe²⁺, Mn²⁺ and Ca²⁺. These sites have coordination numbers [8], [5] and [6], and these differences lead to very strong order of Fe²⁺, Mn²⁺ and Ca²⁺ over these sites. As a result of this strong order, the following compositions have been identified as distinct species: graffonite: $\text{FeFe}_2(\text{PO}_4)_2$; graffonite-(Ca): $\text{CaFe}_2(\text{PO}_4)_2$; graffonite-(Mn): $\text{MnFe}_2(\text{PO}_4)_2$; beusite: $\text{MnMn}_2(\text{PO}_4)_2$; and beusite-(Ca): $\text{CaMn}_2(\text{PO}_4)_2$.

Two new minerals of the graffonite group, graffonite-(Mn), ideally $\text{M}(1)\text{MnM}(2),\text{M}(3)\text{Fe}_2(\text{PO}_4)_2$, and graffonite-(Ca), ideally $\text{M}(1)\text{CaM}(2),\text{M}(3)\text{Fe}_2(\text{PO}_4)_2$, were discovered in phosphate nodules of two beryl–columbite–phosphate pegmatites at Lutomia and Michałkowa, respectively, in the Góry Sowie Block, Lower Silesia, southwest Poland. Graffonite-(Mn) is pinkish brown, whereas graffonite-(Ca) shows more brownish colouration. Both minerals have a vitreous lustre, a good cleavage observed along (010) and irregular fracture; both are transparent and neither of them is fluorescent. They are brittle and have a Mohs hardness of ~5. The minerals are non-pleochroic, colourless in all orientations, biaxial (+), with mean refractive indices $\alpha = 1.710(2)$ and $1.690(2)$, $\beta = 1.713(2)$ and $1.692(2)$, and $\gamma = 1.725(2)$ and $1.710(5)$, respectively. With complete order of Ca at the M(1) site, the formulae of the holotype crystals are $\text{M}(1)(\text{Mn}_{0.70}\text{Ca}_{0.30})\text{M}(2),\text{M}(3)(\text{Fe}_{1.34}\text{Mn}_{0.60}\text{Mg}_{0.06}\text{Zn}_{0.01})\Sigma 3(\text{PO}_4)_2$ for graffonite-(Mn) and $\text{M}(1)(\text{Ca}_{0.98}\text{Mn}_{0.02})\text{M}(2),\text{M}(3)(\text{Fe}_{1.38}\text{Mn}_{0.56}\text{Mg}_{0.05})\Sigma 3(\text{PO}_4)_2$ for graffonite-(Ca). Both crystal chemistry and crystal-structure refinement ($R_1 = 2.34$ and 1.63% , respectively) indicate that the M(1) site is occupied dominantly by Mn in graffonite-(Mn) and by Ca in graffonite-(Ca), and the M(2) and M(3) sites are occupied by Fe²⁺ and Mn²⁺, with Fe²⁺ dominant over Mn²⁺ at the aggregate M(2) + M(3) sites. Graffonite-(Mn) and graffonite-(Ca) are isostructural with graffonite, $\text{M}(1)\text{FeM}(2),\text{M}(3)\text{Fe}_2(\text{PO}_4)_2$ (monoclinic system; space-group symmetry P21/c), with the unit-cell parameters $a = 8.811(2)$ Å, $b = 11.494(2)$ Å, $c = 6.138(1)$ Å, $\beta = 99.23(3)^\circ$ and $V = 613.5(4)$ Å³, and $a = 8.792(2)$ Å, $b = 11.743(2)$ Å, $c = 6.169(1)$ Å, $\beta = 99.35(3)^\circ$ and $V = 628.5(1)$ Å³, respectively. The densities calculated on the basis of molar weights and unit-cell volumes are 3.793 g/cm³ for graffonite-(Mn) and 3.592 g/cm³ for graffonite-(Ca). The eight strongest lines in powder X-ray diffraction patterns on the basis of single-crystal data are, respectively [d, Å, I (hkl)]: 2.874, 100, (230 + 040); 2.858, 79, (221); 3.506, 73, (130); 2.717, 79, (-311); 2.952, 55, (131); 2.916, 53, (-112); 2.899, 44, (300); 3.016, 35, (-102); and 3.654, 100, (130); 2.979, 85, (221); 3.014, 77, (230); 3.042, 76, (040 + -112); 2.834, 68, (-311); 3.097, 57, (131); 3.133, 56, (-102); 2.542, 30, (311). Both minerals are common primary phosphates in phosphate nodules, occurring as lamellar intergrowths with sarcopside ± triphylite/lithiophilite, products of exsolution from a (Li,Ca)-rich graffonite-like parent phase crystallized at high temperature from P-bearing hydrosaline melts.

MABDA	GRAFFONITE	$\text{Fe}^{2+}\text{Fe}^{2+}_2(\text{PO}_4)_2$
MABDB	BEUSITE	$\text{Mn}^{2+}\text{Mn}^{2+}_2(\text{PO}_4)_2$
MABDC	GRAFFONITE-(Ca)	$\text{CaFe}^{2+}(\text{PO}_4)_2$
MABDD	GRAFFONITE-(Mn)	$\text{MnFe}^{2+}(\text{PO}_4)_2$
MABDE	BEUSITE-(Ca)	$\text{CaMn}^{2+}(\text{PO}_4)_2$

SERIES E	XANTHIOSITE, $mon/P2_1/a$. Structure consists of chains of edge-sharing Ni octahedra sharing corners and edges with As tetrahedra to form slabs of cation-deficient olivine structure.		
MABEA	XANTHIOSITE	$Ni_3(AsO_4)_2$	
SERIES F	LAMMERITE, $mon/P2_1/a$. Structure consists of zigzag chains // [100] of edge-sharing Cu octahedra which are connected by Cu dipramids and As tetrahedra to form a framework with densely packed layers // (100). In the structure of lammerite-beta, three differently coordinated Cu-polyhedra form 6-membered rings by sharing vertexes or edges. Those rings form layers // to (010), which are double by joining through polyhedral Cu3 and As-tetrahedra. Those corrugated double layers are connected by As-tetrahedra into three-dimensional construction.		
MABFA	LAMMERITE	$Cu_3((As,P)O_4)_2$	
MABFB	LAMMERITE- β	$Cu_3(AsO_4)_2$	
MABFC	BORISENKOITE	$Cu_3[(V,As)_4]_2$	
SERIES G	STRANSKIITE, $tric/P1$. Structure consists of staggered chains // [010] of Cu tetragonal dipramids and dimers of two edge-sharing Zn trigonal dipramids are linked into a framework by As tetrahedra.		
MABGA	STRANSKIITE	$Zn_2Cu(AsO_4)_2$	
MABGB	MCBIRNEYITE	$Cu_3(VO_4)_2$	
SERIES H	LYONSITE, $orth/Pm\bar{c}n$. Structure consists of Cu octahedra sharing all six corners with V tetrahedra to form (3+3) pinwheels // (001); the pinwheels are connected into a framework by chains of edge-sharing Fe octahedra and chains of edge-sharing Cu trigonal prisms. The structure of pseudolyonsite consists of chains of edge-sharing distorted octahedra involving Cu2 running along the c axis and connected to each other by distorted octahedral involving Cu1. The octahedral of both types contain Cu and subordinate Zn. The corrugated octahedral layers are connected to each other by VO_4 tetrahedra. Both types of Cu octahedral are typically Jahn-Teller-distorted with four shorter and two longer Cu-O bonds.		
MABHA	LYONSITE	$Cu_3Fe_4(VO_4)_6$	
MABHB	PSEUDOLYSONITE	$Cu^{2+}Cu^{2+}_2(VO_4)_2$	$mon/p2_1/c$
SERIES I	ERICLAXMANITE, $tric/P1$. The structure is based on an interrupted framework built by edge- and corner-sharing Cu-centered, distorted tetragonal pyramids, trigonal bipyramids and octahedra.		
MABIA	ERICLAXMANITE	$Cu_4O(AsO_4)_2$	
SERIES J	KOZYREVS KITE, $orth/Pnma$. The structure is based on complicated ribbons of Cu-centered polyhedra running along the b axis. Each ribbon consists of two zigzag chains formed by edge-sharing Cu(1)-centered, distorted trigonal bipyramids and Cu(2)-centered square pyramids. Cu(3) trigonal bipyramids link adjacent chains sharing edges with two Cu(2)-centered polyhedra forming heteropolyhedral layers coplanar to (001) while As(2) tetrahedra link neighboring layers to form a three-dimensional quasi-framework..		
MABJA	KOZYREVS KITE	$Cu_4O(AsO_4)_2$	
SERIES K	POPOVITE, $tric/P1$. The structure is based on (010) layers forming an interrupted framework. The layer consists of Cu(I)O₆ octahedra with very strong Jahn-Teller distortion and Cu(2)O₅ and Cu(3)O₅ polyhedra. The linkage between the layers is reinforced by isolated AsO₄ tetrahedra. Pekov, I.V., Zubkova, N.V., Yapaskurt, V.O., Belakovskiy, D.I., Viggasina, M.F., Sidorov, E.G. and Pushcharovsky, D.Y. (2013) Popovite, IMA 2013-060. CNMNC Newsletter No. 17, October 2013, page 3003; Mineralogical Magazine, 77, 2997- 3005.		
MABKA	POPOVITE	$Cu_5O_2(AsO_4)_2$	

SERIES L **MOLINELLOITE, tric/P1. Structure consists of.**
MABLA MOLINELLOITE $\text{Cu}(\text{H}_2\text{O})(\text{OH})\text{V}^{4+}\text{O}(\text{VO}_4)$

SERIES M **ZUBKOVAITE, mon/C2.**
MABMA ZUBKOVAITE $\text{Cu}_3\text{Ca}_3(\text{AsO}_4)_4$

SERIES N. **RIOSECOITE, tric/P1.**
MABNA RIOSECOITE $\text{Ca}_2\text{Mg}(\text{AsO}_3\text{OH})_3(\text{H}_2\text{O})_2$

TYPE C Structures With Medium-sized and Large Cations.

SERIES A **HOWARDEVANSITE, tric/P1. Structure consists of edge-sharing Fe octahedra and Cu trigonal dipyramids sharing corners with V tetrahedra to form wide ribbons // [001]; the ribbons are terminated laterally by chains, also // [001], of face- and edge-sharing Na polyhedra. The crystal structure of grigorievite and koksharovite are based on the pseudo-frameworks built by V tetrahedra, MnO_6 octahedra and MnO_5 polyhedra. The Ca and Cu sites are located in tunnels. The crystal structure of ziminaite, solved from single-crystal data ($R_1 = 0.085$), is based upon heteropolyhedral framework built by VO_4 tetrahedra and Fe^{3+} -centred octahedra and five-fold polyhedra.**

MACAA HOWARDEVANSITE $\text{NaCuFe}_2(\text{VO}_4)_3$
MACAB GRIGORIEVITE $\text{Cu}_3\text{Fe}^{3+}_2\text{Al}_2(\text{VO}_4)_6$
MACAC KOKSHAROVITE $\text{CaMgFe}^{3+}(\text{VO}_4)_6$
MACAD ZIMINAITE $\text{Fe}^{3+}_6(\text{VO}_4)_6$

SERIES B **HAGENDORFITE SERIES, mon/I2/a. Structure consists of stepped chains of edge-sharing octahedra // [101] sharing corners with P or As tetrahedra to give pleated sheets // (010); chains of M polyhedra // [001] interlink the sheets.**

MACBA HAGENDORFITE $\text{NaCaMn}(\text{Fe},\text{Fe},\text{Mg})_2[\text{PO}_4]_3$
MACBB ALLUAUDITE $\text{NaCaFe}(\text{Mn},\text{Fe},\text{Fe},\text{Mg})_2[\text{PO}_4]_3$
MACBC ARSENIOPLEITE $\text{NaCaMn}(\text{Mn},\text{Mg})_2[\text{AsO}_4]_3$
MACBD CARYINITE $\text{Na}(\text{Ca},\text{Pb})(\text{Ca},\text{Mn})(\text{Mn},\text{Mg})_2[\text{AsO}_4]_3$
MACBE FERROALLUAUDITE $\text{NaCaFe}(\text{Fe},\text{Mn},\text{Fe})_2[\text{PO}_4]_3$
MACBF HAGENDORFITE $\text{NaCaMn}(\text{Fe},\text{Fe},\text{Mg})_2[\text{PO}_4]_3$
MACBG MAGHAGENDORFITE $\text{NaMnMg}(\text{Fe},\text{Fe})_2[\text{PO}_4]_3$
MACBH VARULITE $(\text{Na},\text{Ca})\text{Mn}(\text{Mn},\text{Fe},\text{Fe})_2[\text{PO}_4]_3$
MACBI BRADACZEKITE $\text{NaCu}_4(\text{AsO}_4)_3$
MACBJ JOHILLERITE $\text{Na}(\text{Mg},\text{Zn})_3\text{Cu}(\text{AsO}_4)_3$
MACBK O'DANIELITE $\text{Na}(\text{Zn},\text{Mg})_3\text{H}_2(\text{AsO}_4)_3$
MACBL NICKENICHITE $\text{Na}_{0.8}\text{Ca}_{0.4}\text{Cu}_{0.4}(\text{Mg},\text{Fe})_2(\text{AsO}_4)_3$
MACBM YAZGANITE $\text{NaFe}^{3+}_2(\text{Mg},\text{Mn})(\text{AsO}_4)_3 \cdot \text{H}_2\text{O}$
MACBN GROATITE $\text{NaCaMn}_2(\text{PO}_4)[\text{PO}_3\text{OH}]_2$
MACBO MANITOBAITE $\text{Na}_{16}\text{Mn}^{2+}_{25}\text{Al}_8(\text{PO}_4)_{30}$
MACBP HATERTITE $\text{Na}_2(\text{Ca},\text{Na})(\text{Fe}^{3+},\text{Cu})_2(\text{AsO}_4)_3$
MACBQ CANUTITE $\text{NaMn}_3[\text{AsO}_4]_2[\text{AsO}_2(\text{OH})_2]$
MACBR ZINCOBRADACZEKITE $\text{NaZn}_2\text{Cu}_2(\text{AsO}_4)_3$
MACBS BADALOVITE $\text{Na}_2\text{Mg}_2\text{Fe}(\text{AsO}_4)_3$
MACBT MAGNESIOCANUTITE $\text{NaMnMg}_2(\text{AsO}_4)_2(\text{AsO}_2(\text{OH})_2)$

MACBU	CALCIOJOHILLERITE	$\text{NaCaMg}_3(\text{AsO}_4)_3$
MACBV	MAGNESIOHATERTITE	$(\text{Na,Ca})_2\text{Ca}(\text{Mg,Fe})_2(\text{AsO}_4)_3$
MACBW	KHRENOVITE	$\text{Na}_3\text{Fe}^{3+}_2(\text{AsO}_4)_3$
MACBX	PARABERZELIITE	$\text{NaCa}_2\text{Mg}_2(\text{AsO}_4)_3$
MACBY	CAMANCHACITE	$\text{NaCaMg}_2[\text{AsO}_4][\text{AsO}_3(\text{OH})]_2$

SERIES C **WYLLIEITE SERIES, $\text{mon}/P2_1/n$. Structure consists of stepped chains of edge-sharing octahedra with a topology identical to those of the hagendorfite group.**

MACCA	FERROWYLLIEITE	$(\text{Na,Ca,Mn})(\text{Fe,Mn})(\text{Fe,Fe,Mg})\text{Al}(\text{PO}_4)_3$
MACCB	WYLLIEITE	$\text{Na}_7\text{Fe}_2\text{Al}(\text{PO}_4)_3$ $P2_1/n$
MACCC	ROSEMARYITE	$(\text{Na,Ca,Mn})(\text{Mn,Fe})(\text{Fe,Fe,Mg})\text{Al}(\text{PO}_4)_3$
MACCD	BOBFERGUSONITE	$\text{Na}_2\text{Mn}_5\text{FeAl}(\text{PO}_4)_6$ $P2_1/n$
MACCE	QINGHEIITE	$\text{Na}_2\text{NaMn}_2\text{Mg}_2(\text{Al,Fe})_2(\text{PO}_4)_6$
MACCF	FERROROSEMARYITE	$(\text{Na,Ca,Mn})(\text{Fe,Mn})(\text{Fe,Fe,Mg})\text{Al}(\text{PO}_4)_3$
MACCG	QINGHEIITE-(Fe^{2+})	$\text{Na}_2\text{Fe}^{2+}\text{MgAl}(\text{PO}_4)_3$
MACCH	ZHANGHUIFENITE	$\text{Na}_3\text{Mn}^{2+}_4\text{Mg}_2\text{Al}(\text{PO}_4)_6$
MACCI	FUPINGQUITE (D)=varulite	$(\text{Na,Mn}^{2+})_2\text{Fe}^{3+}(\text{PO}_4)_3$
MACCJ	FERROBOBFERGUSONITE	$\text{Na}_2\text{Fe}^{2+}_5\text{Fe}^{3+}\text{Al}(\text{PO}_4)_6$

SERIES D **BERZELIITE SERIES $\text{iso}/Ia\bar{3}d$. Structure is of the garnet type. The structure consists of corner-sharing alternating YO_6 octahedra and Si tetrahedral forming chains // to the three cube edges of the unit cell, resulting in a framework with pseudo-cubic cavities that accommodate the X atoms. Each pseudo-cube shares edges with two tetrahedral, four octahedra and another four pseudo-cubes**

MACDA	BERZELIITE	$(\text{Ca,Na}_2)_3(\text{Mg,Mn})_2(\text{AsO}_4)_3$
MACDB	MANGANBERZELIITE	$(\text{Ca,Na}_2)_3(\text{Mn,Mg})_2(\text{AsO}_4)_3$
MACDC	PALENZONAITE	$(\text{Ca}_2\text{Na})\text{Mn}_2(\text{VO}_4)_3$
MACDD	SCHAFFERITE	$(\text{Ca}_2\text{Na})\text{Mg}_2(\text{VO}_4)_3$

SERIES E **ACHYROPHANITE, $\text{orth}/P222_1$.**

MACEA	ACHYROPHANITE	$(\text{K,Na})_3(\text{Fe,Ti,Al,Mg})_5\text{O}_2(\text{AsO}_4)_5$
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SERIES F **VITUSITE, $\text{orth}/Pc2_1/b$. Structure consists of a column of face-sharing K-Na polyhedra // $[0001]$, which are connected by sulfate tetrahedra and by K ions to form a framework. In vitusite M octahedra and (3+3) phosphate tetrahedra form pinwheels arranged in rods // $[001]$. Glaserite-like structure.**

MACFA	VITUSITE-(Ce)	$\text{Na}_3(\text{Ce,La,Nd})(\text{PO}_4)_2$
MACFB	DYRNAESITE-(La)	$\text{Na}_8\text{Ce}^{4+}(\text{La,REE})_2(\text{PO}_4)_6$

SERIES G **OLGITE SERIES, $\text{hex}/P3$. Structure consists of sheets of edge-sharing M polyhedra and P tetrahedra alternating with layers of M polyhedra // (0001) . Three kinds of rods // (0001) connect the layers; face-sharing M polyhedra and Na octahedra; edge- and corner-sharing M polyhedra and P tetrahedra; M octahedra and P tetrahedra. Glaserite-related structure.**

MACGA	OLGITE-(Sr)	$\text{Na}(\text{Sr,Ba})\text{PO}_4$
MACGB	OLGITE-(Ba)	$\text{Na}(\text{Ba,Sr})\text{PO}_4$

SERIES H **WHITLOCKITE SERIES, trig/R₃c.** The structure consists of edge- and face-sharing Ca polyhedra, Mg octahedra and P tetrahedra forming chains // [0001]; the chains are linked by corner- and edge-sharing P tetrahedra. This structure is equal to the classic Ba₃P₂O₈ structure. Cerite belongs here. The recent structure refinement of merrillite shows it has a structural unit consisting of a [(Mg,Fe)(PO₄)₆]¹⁶⁻ complex anion that forms a “bracelet-and-pinwheel” arrangement. This arrangement differs from that found terrestrial whitlockite, bobdownsite or lunar REE-rich merrillite. Hwang, S.-L., Shen, P., Chu, H.-T., Yui, T.-F., Varela, M.-E., Iizuka, Y. (2019): New minerals tsangpoite Ca₅(PO₄)₂(SiO₄) and matyhite Ca₉(Ca_{0.5}□_{0.5})Fe(PO₄)₇ from angrite D'Orbigny. Mineralogical Magazine, 83, 293-313.

Abstract:

Tsangpoite, ideally Ca₅(PO₄)₂(SiO₄), the hexagonal polymorph of silicocarnotite, and matyhite, ideally Ca₉(Ca_{0.5}□_{0.5})Fe(PO₄)₇, the Fe-analogue of Ca-merrillite, were identified from the D'Orbigny angrite meteorite by electron probe microanalysis, electron microscopy and micro-Raman spectroscopy. On the basis of electron diffraction, the symmetry of tsangpoite was shown to be hexagonal, P6₃/m or P6₃, with a = 9.489(4) Å, c = 6.991(6) Å, V = 545.1(6) Å³ and Z = 2 for 12 oxygen atoms per formula unit, and that of matyhite was shown to be trigonal, R3c, with a = 10.456(7) Å, c = 37.408(34) Å, V = 3541.6(4.8) Å³ and Z = 6 for 28 oxygen atoms per formula unit. On the basis of their constant association with the grain-boundary assemblage: Fe sulfide + ulvöspinel + Al–Ti-bearing hedenbergite + fayalite–kirschsteinite intergrowth, the formation of tsangpoite and matyhite, along with kuratite (the Fe-analogue of rhönite), can be readily rationalised as crystallisation from residue magmas at the final stage of the D'Orbigny meteorite formation. Alternatively, the close petrographic relations between tsangpoite/matyhite and the resorbed Fe sulfide rimmed by fayalite + kirschsteinite symplectite, such as the nucleation of tsangpoite in association with magnetite ± other phases within Fe sulfide and the common outward growth of needle-like tsangpoite or plate-like matyhite from the fayalite–kirschsteinite symplectitic rim of Fe sulfide into hedenbergite, infer that these new minerals and the grain-boundary assemblage might represent metasomatic products resulting from reactions between an intruding metasomatic agent and the porous olivine–plagioclase plate + fayalite–kirschsteinite overgrowth + augite + Fe sulfide aggregates. Still further thermochemical and kinetics evidence is required to clarify the exact formation mechanisms/conditions of the euhedral tsangpoite, matyhite and kuratite at the grain boundary of the D'Orbigny angrite.

MACHA	WHITLOCKITE	Ca ₉ Mg(PO ₃ OH)(PO ₄) ₆
MACHB	STRONTIOWHITLOCKITE	Sr ₉ Mg(PO ₃ OH)(PO ₄) ₆
MACHC	TUITE	Ca ₃ (PO ₄) ₂ trig/R ₃ m
MACHD	FERROMERRILLITE	Ca ₉ NaFe(PO ₄) ₇
MACHE	MERRILLITE	(Ca,Y,REE) ₉ NaMg[PO ₄] ₇
MACHF	open	
MACHG	WOPMAYITE	Ca ₆ Na ₃ Mn(PO ₄) ₃ (PO ₃ OH) ₄
MACHH	HEDEGAARDITE	(Ca,Na) ₉ (Ca,Na)Mg(PO ₄) ₆ (PO ₃ OH)
MACHI	MATYHITE	Ca ₁₈ (Ca,□) ₂ Fe ²⁺ ₂ (PO ₄) ₁₄

SERIES I **FILLOWITE SERIES, trig/R₃.** Structure consists of slabs // (0001) composed of (3+3) pinwheels of M^[6] octahedra surrounded by Ca polyhedra and connected by P tetrahedra alternating with complex slabs of M^[5], M^[6] and M^[7] polyhedra linked by P tetrahedra. Related to the glaserite structure.

MACIA	FILLOWITE	Na ₂ Ca(Mn,Fe) ₇ (PO ₄) ₆
MACIB	JOHNSOMERVILLEITE	Na ₂ Ca(Mg,Fe,Mn) ₇ (PO ₄) ₆
MACIC	CHLADNIITE	Na ₂ CaMg ₇ (PO ₄) ₆
MACID	GALILEIITE	(Na,K) ₂ (Fe,Mn,Cr) ₈ (PO ₄) ₆
MACIE	STORNESITE-(Y)	(Y,Ca)Na ₆ (Ca,Na) ₈ (Mg,Fe) ₄₃ (PO ₄) ₃₆
MACIF	XENOPHYLLITE	Na ₄ Fe ₇ (PO ₄) ₆

SERIES J **KOSNARITE, trig/R₃c.** Structure consists of (3+3) pinwheels of Zr octahedra surrounded by 6 phosphate tetrahedra. The pinwheels are joined by the phosphate tetrahedra to form a 3-dimensional Zr₂(PO₄)₃ network with K atoms in the cavities.

MACJA	KOSNARITE	$\text{KZr}_2(\text{PO}_4)_3$
SERIES K	PANETHITE, mon/P2/n. Structure not known. Fuchs, L. H., Olsen, E. and Henderson, E. P. (1967): Occurrence of brianite and panethite, two new phosphate minerals from the Dayton meteorite. <i>Geochim. Cosmochim. Acta</i> : 31: 1711-1719. <i>American Mineralogist</i> (1968): 53: 509.	
MACKA	PANETHITE	$(\text{Na,Ca,K})_2(\text{Mg,Fe,Mn})_2(\text{PO}_4)_2$
SERIES L	STANFIELDITE, mon/P2/c. No structure known. Fuchs, L.H. (1967), Stanfieldite, a new phosphate mineral from stony iron meteorites. <i>Science</i> . <i>American Mineralogist</i> (1968): 53: 508.	
MACLA	STANFIELDITE	$\text{Ca}_4(\text{Mg,Fe,Mn})_5(\text{PO}_4)_6$
SERIES M	STAROVAITE, tri/P1. No structure description given. Pekov, I.V., Zelenski, M.E., Yapaskurt, V.O., Polekhovskiy, Y.S. and Murashko, M.N. (2013): Starovaite, $\text{KCu}_5\text{O}(\text{VO}_4)_3$, a new mineral from fumarole sublimates of the Tolbachik volcano, Kamchatka, Russia. <i>European Journal of Mineralogy</i> , 25 , 91-96.	
MACMA	STAROVAITE	$\text{KCu}_5\text{O}(\text{VO}_4)_3$
SERIES N	WRIGHTITE, orth/Pnma. Wrightite $\text{K}_2\text{Al}_2\text{O}(\text{AsO}_4)_2$ is a new mineral species. The specimen was found in 1983 at a fumarole on the Second cinder cone of the Great fissure Tolbachik eruption. Wrightite light yellow aggregates consist of transparent tabular crystals with the average size of $0.05 \times 0.03 \times 0.005$ mm ³ . Space group Pnma, $a = 8.230(5)$, $b = 5.555(4)$, $c = 17.584(1)$ Å, $V = 803.9(6)$ Å ³ , $Z = 4$, powder data. The empirical formula is $(\text{K}1.69\text{Na}0.38)\Sigma 2.07(\text{Al}1.80\text{Fe}0.24)\Sigma 2.04\text{As}1.96\text{O}9$. Crystal structure ($R = 0.043$) consists of $\text{Al}_2\text{O}(\text{AsO}_4)_2$ layers in the ab plane with clusters of edge-sharing AlO_6 octahedra. Each layer contains two independent isolated AsO_4 tetrahedra and two AlO_6 octahedra. AlO_6 octahedra are linked by edges, forming zigzag chains along the b-axis inside the Al-As layer. Eight- and six-coordinated K atoms are located in the interlayer space between $\text{Al}_2\text{O}(\text{AsO}_4)_2$ layers. The mineral is biaxial (-), $\alpha = 1.679(2)$, $\beta = 1.685(2)$, γ (calc.) = 1.687; $2V$ (meas.) = $62(10)^\circ$ ($\delta = 589$ nm). The strongest lines in the X-ray powder diffraction pattern (I-dobs. Å-hkl) are: 36-8.77-002; 17-4.458-111; 19-4.010-201,013; 19-3.875-104; 100-2.972-015. The mineral was named in honour of Adrian Carl Wright, Emeritus Professor at the University of Reading, UK.	
MACNA	WRIGHTITE	$\text{K}_2\text{Al}_2\text{O}(\text{AsO}_4)_2$
SERIES O	YURMARINITE, trig/R3. The structure is based on a 3D heteropolyhedral framework formed by M_4O_{18} clusters linked with AsO_4 tetrahedra. Na atoms occupy two octahedrally coordinated sites in the voids of the framework.	
MACOA	YURMARINITE	$\text{Na}_7(\text{Fe,Mg,Cu})_4(\text{AsO}_4)_6$
MACOB	ANATOLYITE	$\text{Na}_6(\text{Ca,Na})(\text{Mg,Fe}^{3+})_3\text{Al}(\text{AsO}_4)_6$
SERIES P	IWATEITE, trig/P3. Structure consists of tetrahedral and octahedral sheets linked through the corner oxygen and forming a layered structure. There is one layer-embedded site occupied by Na and one 2	
MACPA	IWATEITE	$\text{Na}_2\text{BaMn}(\text{PO}_4)_2$
SERIES Q	MORASKOITE, orth/Pbcn. The moraskoite structure is similar to that of its synthetic analogue. The structure consists of $(\text{FNa}_4\text{Mg}_2)^{7+}$ octahedra that share faces to produce $[\text{FNa}_2\text{Mg}]^{3+}$ chains // to the a axis with phosphate ions located between them. Karwowski, Ł., Kusz, J., Muszyński, A., Kryza, R., Sitarz, M., Galuskin, E.V. (2015): Moraskoite, $\text{Na}_2\text{Mg}(\text{PO}_4)\text{F}$, a new mineral from the Morasko IAB-MG iron meteorite (Poland). <i>Mineralogical Magazine</i> , 79 , 387-398.	
MACQA	MORASKOITE	$\text{Na}_2\text{Mg}(\text{PO}_4)\text{F}$
SERIES R	SHCHUROVSKYITE, mon/C2. Structure consists on a quasi-framework consisting of AsO_4 tetrahedra and polyhedra centred by Cu in shchurovskyite or by Cu and Al in dmisokolovite. K and Ca are	

located in channels of the quasi-framework. Pekov, I.V., Zubkova, N.V., Belakovskiy, D.I., Yapaskurt, V.O., Vigasina, M.F., Sidorov, E.G. and Pushcharovsky, D.Y. (2013) Shchurovskyite, IMA 2013-078. CNMNC Newsletter No. 18, December 2013, page 3253; *Mineralogical Magazine*, **77**, 3249-3258.

MACRA	SHCHUROVSKYITE	$K_2CaCu_6O_2(AsO_4)_4$
SERIES S	DMISOKOLOVITE, mon/C2/c. The structure of dmisokolovite is closely related to that of shchurovskyite. Pekov, I.V., Zubkova, N.V., Belakovskiy, D.I., Yapaskurt, V.O., Vigasina, M.F., Sidorov, E.G. and Pushcharovsky, D.Y. (2013) Dmisokolovite, IMA 2013-079. CNMNC Newsletter No. 18, December 2013, page 3253; <i>Mineralogical Magazine</i> , 77 , 3249-3258.	
MACSA	DMISOKOLOVITE	$K_3Cu_5AlO_2(AsO_4)_4$
SERIES T	PHARMAZINCITE, hex, P6₃. The structure has a structure based upon a tetrahedral tridymite-type {ZnAsO₄}⁻ framework. It is isostructural with megakalsilite. Pekov, I.V., Yapaskurt, V.O., Belakovskiy, D.I., Vigasina, M.F., Zubkova, N.V. and Sidorov, E.G. (2014) Pharmazincite, IMA 2014-015. CNMNC Newsletter No. 21, August 2014, page 798; <i>Mineralogical Magazine</i> , 78 , 797-804.	
MACTA	PHARMAZINCITE	$KZn(AsO_4)$
SERIES U	KATIARSITE, orth/Pna2₁. The structure is based on undulating chains of corner-connected Ti-centered octahedra. These chains are cross-linked via isolated As tetrahedra, forming a three-dimensional framework. K ions are located in channels of the framework Pekov, I.V., Yapaskurt, V.O., Britvin, S.N., Zubkova, N.V., Vigasina, M.F. and Sidorov, E.G. (2014) Katiarsite, IMA 2014- 025. CNMNC Newsletter No. 21, August 2014, page 800; <i>Mineralogical Magazine</i> , 78 , 797-804.	
MACUA	KATIARSITE	$KTiO(AsO_4)$
SERIES V	MELANARSITE, mon/C2/c. The structure is based upon a heteropolyheral pseudo-framework built by distorted Cu(1-3)O₆ and (Fe,Cu)O₆ octahedra and As(1-3)O₄ tetrahedra two crystallographically independent K cations are located in the tunnels and voids of the framework centering eight- and seven-fold polyhedra. Pekov, I.V., Zubkova, N.V., Yapaskurt, V.O., Polekhovskiy, Y.S., Vigasina, M.F., Belakovskiy, D.I., Britvin, S.N., Sidorov, E.G. and Pushcharovsky, D.Y. (2014) Melanarsite, IMA 2014-048. CNMNC Newsletter No. 22, October 2014, page 1244; <i>Mineralogical Magazine</i> , 78 , 1241-1248.	
MACVA	MELANARSITE	$K_3Cu_7FeO_4(AsO_4)_4$
SERIES W	EDTOLLITE, tric/P1₁.	
MACWA	EDTOLLITE	$K_2NaCu_5Fe^{3+}O_2(AsO_4)_4$
MACWB	ALUMOEDTOLLITE	$K_2NaCu_5AlO_2(AsO_4)_4$
SERIES X	OZEROVAITE, orth/Cmca. The new mineral species ozerovaitite was found in the fumarole of the second cinder cone of the Great Tolbachik Fissure Eruption. The colour of ozerovaitite varies from colourless to pale yellow. It is insoluble in water. The mineral occurs as tabular crystals, 0.04 × 0.02 × 0.004 mm³ average size; with aggregates of 0.02–0.3 mm. The empirical formula calculated on the basis of 16 O apfu is (Na_{1.82}K_{1.08})Σ_{2.90}(Al_{2.62}Fe_{0.32}Cu_{0.12}Zn_{0.02})Σ_{3.08}(As_{3.95}P_{0.07})Σ_{4.02}O₁₆, and the idealised formula is Na₂KAl₃(AsO₄)₄. Ozerovaitite is orthorhombic: Cmca, a = 10.615(2), b = 20.937(3), c = 6.393(1) Å, V = 1420.9(3) Å³, Z = 4. The crystal structure (R₁ = 0.031) is constructed of AlO₆ octahedra and AsO₄ tetrahedra, linked by the corners and edges. Adjacent layers are held together by six- and four-coordinated Na and six-coordinated K polyhedra. The eight strongest diagnostic lines of the X-ray powder diffraction pattern are (l, d in Å, hkl): 44, 10.37, 020; 47, 5.47, 200; 47, 4.84, 220; 17, 3.76, 240; 26, 3.07, 061; 83, 2.922, 260; 100, 2.824, 202; and 71, 2.735, 400. Ozerovaitite is biaxial, optically negative, α (calc.) = 1.645, β = 1.667(2), γ = 1.674(2) (589 nm), 2 V (meas.) = 58(10)°. Associated minerals are ponomarevite, piypite, dolerophanite, euchlorine, sylvite, lammerite, johillerite, urusovite, bradaczekite, filatovite, hatertite, hematite, tenorite and wrightite. The mineral is named in honour of the Russian scholar Dr. Nina Aleksandrovna Ozerova (1930–2012), for her contributions to geochemistry, geology, metallogeny, ecology and the eco-geochemistry of mercury.	
MACXA	OXEROVAITE	$Na_2KAl_3(AsO_4)_4$

MACXB	PANSNERITE	$K_3Na_3(Fe^{3+},Al)_6(AsO_4)_8$
SERIES Y	ALEUTITE, mon/C2/m.	
MACYA	ALEUTITE	$[Cu_5O_2](AsO_4)(VO_4).(Cu,K,Pb,Rb,Cs)Cl$
SERIES Z	PICAITE, mon/P2₁/c.	
MACZA	PICAITE	$NaCa[AsO_3OH][AsO_2(OH)_2]$
SERIES 27	UDINAITE, tetr/I4₂d. Structure	
MAC27A	UDINAITE	$NaMg_4(VO_4)_3$
MAC27B	ARSENUDINAITE	$NaMg_4(AsO_4)_3$

TYPE D Structures With Only Large Cations

SERIES A	NAHPOITE, mon/P2₁/m or P2₁. Structure not known. Coleman, L. C. & Robertson, B. T. (1981): Nahpoite Na_2HPO_4 , a new mineral from the Big Fish River area, Yukon territory. Canadian Mineralogist: 19: 373-376. Abstracted: American Mineralogist (1982): 67: 856-857. ROBINSON, G.W., VAN VELTHUIZEN, J., ANSELL, H.G. & STURMAN, B.D. (1992): Mineralogy of the Rapid Creek and Big Fish River area, Yukon Territory. Mineralogical Record 23, 1-47. Journal of the American Chemical Society (1995): 117: 5141-5147.	
MADAA	NAHPOITE	$Na_2[PO_3OH]$
SERIES B	MONETITE, tric/P1. Structure consists of chains of edge-sharing Ca polyhedra parallel to [010] and are linked by edge-and corner-sharing P(O,OH)₄ tetrahedra to form sheets parallel to (001); the sheets are linked by the Ca polyhedra and H bonds. In weilite, chains of edge-sharing Ca pentagonal dipyramids // [100] are linked by AsO₃OH tetrahedra.	
MADBA	MONETITE	$Ca[PO_3OH]$
MADBB	WEILITE	$Ca[AsO_3OH]$
SERIES C	ARCHERITE SERIES, tetr/I4₂d Structure consists of a framework of corner-sharing phosphate tetrahedra that is topologically equivalent to the cristobalite framework; the ammonium cations are linked to the phosphate tetrahedra, but are not part of the cristobalite-type framework.	
MADCA	ARCHERITE	$(K,NH_4)H_2PO_4$
MADCB	BIPHOSPHAMMITE	$(NH_4,K)H_2PO_4$
MADCC	PHOSPHAMMITE	$(NH_4)_2HPO_4$
SERIES D	SCHULTENITE, mon/P2/a. The structure consists of zigzag chains of H-bonded AsO₃OH tetrahedra and zigzag chains of edge-sharing Pb polyhedra, both // [100], are interlocked, forming sheets// (010); the sheets are linked by H-bonding.	
MADDA	SCHULTENITE	$PbHAsO_4$
SERIES E	XENOTIME SERIES, tetr/I4/amd. Structure based on a close packing arrangement where the O atoms form a special three-dimensional close packing and Zr atoms have dodecahedral coordination The Si atoms tetrahedral coordination. Structure is of the zircon type.	
MADEA	XENOTIME-(Y)	YPO_4
MADEB	CHERNOVITE-(Y)	$YAsO_4$
MADEC	WAKEFIELDITE-(Y)	YVO_4

MADED	WAKEFIELDITE-(Ce)	(Ce,Pb.Pb)VO ₄
MADEE	DREYERITE	BiVO ₄
MADEF	PRETULITE	ScPO ₄
MADEG	XENOTIME-(Yb)	YbPO ₄
MADEH	CLINOBISSVANITE	Bi(VO ₄)
MADEI	WAKEFIELDITE-(La)	LaVO ₄
MADEJ	WAKEFIELDITE-(Nd)	NdVO ₄

SERIES F **XIMENGITE-PUCHERITE SERIES, orth/Pnca.** The structure consists of BiO₈ polyhedra and P tetrahedra sharing edges to form chains // [0001]; the chains are cross-linked to 4 neighboring chains by sharing corners, creating large channels // [0001]; the chains are similar to those in monazite. In pucherite edge-sharing BiO₈ polyhedra form zigzag chains // [100], and these, by corner-sharing, form sheets // (001); the V tetrahedra share one edge and two corners with the Bi polyhedra.

MADFA	PUCHERITE	BiVO ₄
MADFB	XIMENGITE	Bi[PO ₄] trig/P3 ₁ 21

SERIES G **MONAZITE SERIES, mon/P2₁/n.** Structure consists of linear chains // [001] of alternating edge-sharing REE polyhedra and P tetrahedra which are cross-linked by zigzag chains of edge-sharing REE polyhedra // [100].

MADGA	MONAZITE-(Ce)	(Ce,La)PO ₄
MADGB	MONAZITE-(La)	(La,Ce)PO ₄
MADGC	MONAZITE-(Nd)	(Nd,Ce)PO ₄
MADGD	MONAZITE-(Sm)	SmPO ₄
MADGE	ROOSEVELTITE	BiAsO ₄
MADGF	CHERALITE	(Ca,REE)(Th,REE)(PO ₄ ,SiO ₄) ₂
MADGG	GASPARITE-(Ce)	(Ce,La,Nd)AsO ₄
MADGH	GASPARITE-(La)	La(AsO ₄)

SERIES H **SCHEELITE SERIES, tetr/I4₁/a.** The structure is a non-layered structure, and is formed by isolated W tetrahedra separated by Ca atoms, each of which is bonded to 8 oxygen atoms forming a dodecahedron. It is a distortion derivative of the zircon structure. The structure of tillmannsite contains isolated tetrahedra (V,As)O₄ and tetrahedral clusters (Ag₃Hg) formed by metallic atoms. Each (Ag,Hg) metallic atom is coordinated by 3 metallic neighbors and by 3 oxygens.

MADHA	TETRAROSEVELTITE	BiAsO ₄
MADHB	TILLMANNSITE	(Ag ₃ Hg)(V,As)O ₄ tetr/I4 (related to scheelite ?)

SERIES I **CHURSINITE, mon/P2₁/c.** Structure consists of linear O-Hg-Hg-O groups sharing O atoms with arsenate tetrahedra to form chains // [101] ; three O atoms of the tetrahedra are bonded along the chains, and one O atom links the chains along [010]. Forming puckered layers // (101); there is weak bonding between the layers.

MADIA	CHURSINITE	(Hg ¹⁺) ₃ (AsO ₄)
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SERIES J **GURIMITE, trig/R3.** Galuskina, I.O., Vapnik, Y., Prusik, K., Dzierz'anowski, P., Murashko, M. and Galuskin, E.V. (2013) Gurimite, IMA 2013-032. CNMNC Newsletter No. 16, August 2013, page 2708; Mineralogical Magazine, 77, 2695- 2709.

MADJA	GURIMITE	Ba ₃ (VO ₄) ₂
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GROUP B Phosphates with Additional Anions, But Without Water.

TYPE A Structures With Small and Medium-sized Cations.

SERIES A VAYRYNENITE, *mon/P2₁/a*. Euclase structure type. Structure based on zigzag chains of 3-membered rings of BeO₂(OH)₂ and P tetrahedra, and zigzag chains of edge-sharing MnO₅(OH) octahedra, both // [01], are cross-linked by a common O₅(OH) to form a 3-dimensional framework with weak bonds // (010).

MBAAA VÄYRYNENITE (Mn,Fe)Be(PO₄)(OH,F)

SERIES B HERDERITE SERIES, *mon/P2₁/c*. Gadolinite structure type. Sheets of 4- and 8- membered rings of corner-sharing Be and R tetrahedra // (0010 alternate with sheets of edge-sharing Ca polyhedra; the sheets are linked by sharing corners of octahedra and tetrahedra.

MBABA HERDERITE Ca₂Be₂P₂O₈(F,OH)

MBABB HYDROXYL-HERDERITE Ca₂Be₂P₂O₈(OH,F)

MBABC BERGSLAGITE CaBe(AsO₄)(OH)

MBABD DRUGMANITE Pb₂(Fe,Al)H(PO₄)₂(OH)₂

SERIES C BABEFPHITE, *tetr/Fdd2*. Structure consists of a 3-dimensional framework composed of interwoven chains of corner-sharing PO₄ and Be(O,F)₄ tetrahedra, enclosing edge-sharing Ba polyhedra.

MBACA BABEFPHITE BaBe[F/PO₄]

TYPE B Structures With only Medium-sized Cations (OH, etc):RO₄ \leq 1:1.

SERIES A AMBLYGONITE SERIES, *tric/P1*. Structure consists of chains of corner-sharing AlO₄(F,OH)₂ octahedra // [010] which are combined by corner-sharing with P tetrahedra to form a 3-dimensional framework with (Li,Na) in pseudo-hexagonal cavities.

MBBAA AMBLYGONITE (Li,Na)Al(PO₄)(F,OH)

MBBAB MONTEBRASITE LiAl(PO₄)(F,OH)

MBBAC Open

MBBAD TAVORITE LiFe(PO₄)(F,OH)

SERIES B TRIPLITE SERIES, *mon/I2/a*. Structure consists of edge-sharing MO₄F₂ octahedra // [100] and [010] and are connected via common corners and by sharing corners of phosphate tetrahedra to form a 3-dimensional framework; similar to the tripodite structure.

MBBBA TRIPLITE (Mn,Fe,Mg)₂(PO₄)F

MBBBB Open

MBBBC Open

MBBBD ZWIESELITE (Fe,Mn)₂(PO₄)F

SERIES C WAGNERITE SERIES, *mon/P2₁/a*. Structure composed of chains of alternating edge- and corner-sharing MO₄(OH)₂ octahedra and MO₃O(OH) trigonal dipyramids // [100] and [010] are connected via common corners and by sharing corners of P tetrahedra to form a 3-dimensional framework; structure similar to that of triplite. The crystal structures of the two polytypes of stanekite consists of a rather regular P tetrahedron and two symmetrically different strongly distorted MO₆ octahedra. Independent of their valency, the cations M are distributed over the octahedral sites. The MO₆ octahedra share common edges to form zigzag chains running // to [010] for [(M1)O₆] and to [100] for [(M2)O₆], respectively. Both chain types are further interconnected by additional edges along the c axis to build an open framework that hosts the P tetrahedra.

MBBCA WAGNERITE-Ma2bc Mg₂PO₄F

MBBCB TRIPLOIDITE (Mn,Fe)₂(PO₄)(OH)

MBBCC WOLFEITE (Fe,Mn)₂(PO₄)(OH)

MBBCD	SARKINITE	$Mn_2(AsO_4)(OH)$	
MBBCE	STANEKITE-Mabc	$Fe(Mn,Fe,Mg)(PO_4)O$	
MBBCF	WAGNERITE-Ma5bc	$(Mg,Fe,Ti)(PO_4)(F,OH)$	mon/1a
MBBCG	STANEKITE-Ma2bc	$Fe(Mn,Fe,Mg)(PO_4)O$	
MBBCH	JOOSTEITE	$Mn^{2+}(Mn^{3+},Fe)(PO_4)O$	
MBBCI	HYDROXYLWAGNERITE	$Mg_2PO_4(OH,F)$	
MBBCJ	SARKINITE-(Ce)		
MBBJK	SARKINITE-(La)		
MBBJL	ARSENOWAGNERITE	$Mg_2(AsO_4)F$	

SERIES D **SATTERLYITE SERIES, hex/P31m ,P31m.** Structure consists of pairs of face-sharing (Mg,Fe) octahedra sharing edges to form double chains // [0001]; the double chains share corners and corners of the phosphate tetrahedra to produce a 3-dimensional framework. A structural relationship exists with phosphoellenbergite.

MBBDA	SATTERLYITE	$(Fe,Mg,Fe)_2(PO_4)(OH)$	
MBBDB	HOLTEDAHLITE	$Mg_{12}(PO_3OH,CO_3)(PO_4)_5(OH,O)_6$	

SERIES E **ALTHAUSITE-STOIBERITE-FINGERITE SERIES, orth/Pnma.** Structure contains chains of edge-sharing $MgO_4(OH)F$ octahedra // [010] and pairs of edge-sharing $MgO_3(OH)F$ trigonal dipyramids; both of these units are bonded via common edges and by sharing corners with P tetrahedra to form a 3-dimensional framework. Magnesium atoms occur in both five- and six-fold coordination and the coordination polyhedra are highly distorted. The Mg octahedra form chains along b by edge-sharing. Hydroxyl and fluorine occur in a largely ordered distribution among two different structural sites and occupy alternating positions along channels parallel to b. Partial vacancy in the (OH,F) sites is confirmed, the population factor for the F site being 81 percent.

Crystal structure of averievite $Cu_5O_2(VO_4) \cdot nMClx$ (M = Cu, Cs, Rb, K) has been refined using the holotype specimen from the Tolbachik volcano in the space group P-3m1 [a = 6.3778(2), c = 8.3966(3) Å] to R = 0.041 for 489 independent reflections with $F > 4\sigma(F)$. The structure contains two Cu sites, of which Cu1 has a square-planar coordination, whereas the Cu2 site has a trigonal bipyramidal coordination. One symmetrically independent V5+ cation forms vanadate tetrahedra with the average $V-O$ length (V—O) = 1.714 Å. Among three symmetrically independent O sites, the Oq atom is not bonded with V5+ cations, and is coordinated by four Cu atoms, forming the oxocentered (OCu4)6+ tetrahedron. These tetrahedra, sharing their vertices, form [02Cu5]6+ sheets of six-member rings, in which two joint tetrahedra are oriented into opposite directions relatively to the sheet plane parallel to (100). Triangular faces of oxocentered tetrahedra are linked to the (VO4)3- tetrahedra according to the 'face-to-face' principle, which results in formation of electroneutral porous framework $\{[O_2Cu_5](VO_4)_2\}_0$ with wide channels elongated parallel to the c axis and having crystallographic free diameter about 3.7 Å. The channels accommodate two cations (M1, M2) and one anion (Cl) sites with the 1 : 1 cation : anion ratio.

MBBEA	ALTHAUSITE	$Mg_2(PO_4)(OH,F,O)$	
MBBEB	STOIBERITE	$Cu_5[O/VO_4]_2$	
MBBEC	FINGERITE	$Cu_{11}O_2(VO_4)_6$	
MBBED	AVERIEVITE	$Cu_5O_2(VO_4) \cdot nMClx$	

SERIES F **OLIVENITE SERIES, orth/Pnmm.** The structure (adamite) is based on $ZnO_4(OH)_2$ octahedra sharing edges to produce chains parallel to the c axis, and share corners with edge-sharing $ZnO_4(OH)$ trigonal bipyramids in the a- and b-axis directions. AsO_4 groups connect the two Zn polyhedron types to produce a dense framework structure in which all O atoms and OH groups are trigonally coordinated. All species of the group are isostructural. All minerals have the andalusite structure type.

MBBFA	OLIVENITE	$Cu_2(OH)(AsO_4)$	
MBBFB	LIBETHENITE	$Cu_2(OH)(PO_4)$	
MBBFC	ADAMITE	$Zn_2(OH)(AsO_4)$	

MBBFD	EVEITE	$Mn_2(OH)(AsO_4)$
MBBFE	ZINCOLIBETHENITE	$(Zn,Cu)_2(OH)(PO_4)$
MBBFF	ZINCOLIVENITE	$CuZn(OH)(AsO_4)$
MBBFG	AURIACUSITE	$Fe^{3+}Cu^{2+}(As,Sb)O_4O$
SERIES G	TARBUTTITE SERIES, tric/P1. Structure contains chains of edge-sharing $ZnO_3(OH)_2$ trigonal dipyramids // [010] and dimmers of two edge-sharing $ZnO_3O(OH)$ trigonal dipyramids; both of these units and R tetrahedra are corner-linked to form a 3-dimensional framework.	
MBBGA	PARADAMITE	$Zn_2(OH)(AsO_4)$
MBBGB	TARBUTTITE	$Zn_2(OH)(PO_4)$
SERIES H	LAZULITE SERIES, mon/P2₁/c. The structure consists of the packing of $(Mg,Fe)O_6$ octahedra and PO_4 tetrahedra. It contains chains of AlO_6 corner-sharing octahedra, along the <u>c</u> axis, linked by face-sharing $(Mg,Fe)O_6$ octahedra. The resulting layers are linked by PO_4 tetrahedra. The jagowerrite structure consists of a network of PO_4 tetrahedra sharing corners with $Al(O,OH)$ octahedra which in turn share edges in pairs. The Ba is 12-coordinated in a cavity formed by four pairs of edge-shared octahedra.	
MBBHA	LAZULITE	$(Mg,Fe)Al_2(OH)_2(PO_4)_2$
MBBHB	SCORZALITE	$(Fe,Mg)Al_2(OH)_2(PO_4)_2$
MBBHC	BARBOSALITE	$FeFe_2(OH)_2(PO_4)_2$
MBBHD	HENTSCHELITE	$CuFe_2(OH)_2(PO_4)_2$
SERIES I	LIPSCOMBITE-TROLLEITE SERIES, tetr./P4. The structure consists of face-sharing $FeO_4(OH)_2$ octahedra forming chains // [110] and [1 $\bar{1}$ 0], alternating in planes // (001); both are corner-linked by common (OH) groups and P tetrahedra to form a 3-dimensional framework. In trolleite, two face-sharing Al octahedra form $Al_2O_6(OH)_3$ dimers that are corner-linked to form double chains // [001] which are further linked into a 3-dimensional framework by P tetrahedra.	
MBBIA	RICHELLITE	$Ca_3Fe_{10}(PO_4)_8(OH,F)_{12}6H_2O$
MBBIB	LIPSCOMBITE	$FeFe_2(OH)_2(PO_4)_2$
MBBIC	TROLLEITE	$Al_4(PO_4)_3(OH)_3$
MBBID	ZINCLIPSCOMBITE	$ZnFe^{3+}_2(PO_4)_2(OH)$
SERIES J	NAMIBITE, Tric/P1. The structure consists of a three-dimensional network formed by linkages of Bi-O polyhedra to one slightly distorted $V^{5+}O_4$ tetrahedron that decorates chains of corner-sharing CuO_6 polyhedra. Layers of Bi atoms parallel to (100) alternate with layers of parallel heteropolyhedral $[Cu(VO_4)O_2(OH)]$ chains. The structure of Namibite represents a slightly distorted ordered variant of the monoclinic structure of brendelite.	
MBBJA	NAMIBITE	$Cu(BiO)_2(VO_4)(OH)$
SERIES K	ELLENBERGERITE SERIES, hex/P63mc. Structure consist of dimmers of face-sharing MgO_5OH and Al octahedra sharing edges to form 2-periodic zigzag chains // [0001]; these dimmers are linked by shared OH to form 3-membered channels that contain insular Si(P) tetrahedra, and 6-membered channels that contain linear chains of face-sharing $(Mg,Ti,Zr)O_4(OH)_2$ octahedra and six interconnected P tetrahedra; the linear chains are surrounded by two H ions. There is a close structural relationship with the satterlyite structure.	
MBBKA	PHOSPHOELLENBERGERITE	$Mg_{14}(PO_4)_6[(PO_3OH)_{1.24}(CO_3)_{0.76}]_2(OH)_6$
SERIES L	OPEN	

SERIES M **BATAGAYITE**, mon/P2₁. Structure based upon complex heteropolyhedral layers // the (001) plane. The layer can be considered as consisting of three sublayers, one A and two B. The central A layer has the composition [M₄(PO₄)₄(H₂O)₄]⁴⁺ and consists of the zigzag chains of edge-sharing (MO₆) octahedra running // to the a axis and linked into layers by sharing peripheral O atoms. The phosphate tetrahedra are attached above and below the holes created by the linkage of zigzag octahedral chains. The B sublayer consists of chains of (ZnO₄) and (PO₃OH) tetrahedra. The interlayer space is occupied by the Ca cations and water molecules

MBBMA BATAGAYITE CaZn₂(Zn,Cu)₂(PO₄)₄[PO₃(OH)₃]₃·12H₂O

TYPE C Structures With Only Medium-sized cations, (OH, etc.) : RO₄ > 1:1 and < 2:1

SERIES A **ANGELELLITE-AERUGITE SERIES**, tric/trigonal. Structure consists of edge-sharing Fe octahedra build staircase-like chains // [001] which are corner-linked along [100] to form sheets // (010); the sheets are linked by As tetrahedra. In aerugite, sheets // (0001) of edge-sharing Ni octahedra and As tetrahedra alternate with halite-like sheets of As and Ni octahedra.

MBCAA AERUGITE Ni_{8.5}As[O₈/(AsO₄)₂]

MBCAB ANGELELLITE Fe₄(AsO₄)₂O₃

SERIES B **ROCKBRIDGEITE SERIES**, mon/Bbmm. Structure consists of trimers of 3 face-sharing (Fe,Mn) octahedra which are linked into zigzag chains // [010] by edge-sharing (Fe,Mn) octahedra. These chains are cross-linked into (010) slabs by P tetrahedra and dimmers of corner-sharing octahedra. The rockbridgeite group has been officially established by the IMA Commission on New Minerals, Nomenclature and Classification. The general formula is based on the structure and is A₂B₃(PO₄)₃(OH, H₂O)₅, where A = the octahedrally coordinated M2 site, in which divalent cations are ordered, and B = the octahedrally coordinated M1 + M3 sites, which contain predominantly Fe³⁺, with trace Al. The different rockbridgeite-group minerals are distinguished by the occupancy of the A site. The ideal formula for rockbridgeite is Fe₂p 0:5 Fe₃p 0:5 Å Å 2 Fe₃p 3 PO₄ δ p 3 OH δ p 5, that for frondelite is Mn₂p 0:5 Fe₃p 0:5 Å Å 2 Fe₃p 3 PO₄ δ p 3 OH δ p 5 and that for plimerite is Zn₂ Fe₃p 3 PO₄ δ p 3 OH δ p 4 δH 2 Op. In order to preserve the identity of frondelite and rockbridgeite within the structure-based formalism, these species correspond to mid-series compositions. We describe here the new end-member, ferrorockbridgeite, with dominant Fe²⁺ in the A site, from the Hagendorf Süd pegmatite mine, Oberpfalz, Bavaria. Electron microprobe analyses, coupled with Mössbauer spectroscopy, gives the empirical formula Fe₂p 1:33 Mn₂p 0:52 Zn_{0:03} Ca_{0:05} Fe₃p 3:03 Al_{0:01} P_{2:97} H_{6:17} O₁₇. The simplified formula is Fe₂p ; Mn₂p δ p 2 Fe₃p 3 PO₄ δ p 3 OH δ p 4 δH 2 Op. Ferrorockbridgeite is orthorhombic, space group Bbmm, with a = 13.9880(4), b = 16.9026(5), c = 5.1816(1) ° Å, V = 1225.1 ° Å³ and Z = 4. The six strongest lines in the X-ray powder diffraction pattern are [d meas / ° Å (hkl) Optically, ferrorockbridgeite is biaxial (-) with a = 1.763(3), b = 1.781(calc), c = 1.797(3) (white light) and 2V (meas.) = 87(1)° from extinction data. The optical orientation is X = c, Y = a, Z = b. The pleochroism is X = blue green, Y = olive green, Z = yellow brown; X % Y > Z.

MBCBA ROCKBRIDGEITE FeFe₄(OH)₅(PO₄)₃

MBCBB FRONDELITE MnFe₄(OH)₅(PO₄)₃

MBCBC PLIMERITE ZnFe³⁺₄(PO₄)₃(OH)₅

MBCBD FERROROCKBRIDGEITE (Fe,Mn)₂Fe₃(PO₄)₃(OH)₄(H₂O)

MBCBE FERRIROCKBRIDGEITE (Fe³⁺_{0.67}□_{0.33})₂(Fe³⁺)₃(PO₄)₃(OH)₄(H₂O)

SERIES C **IANBRUCEITE**, mon/P2₁/c. Structure consists of [[5]Zn[6]Znφ7] chains extending in the c direction and are linked in the b direction by sharing corners with As tetrahedral to form slabs with a composition [Zn₂(OH)(H₂O)(AsO₄)]. The space between these slabs is filled with disordered wagger groups and minor lone-pair As³⁺. The structure consists of [5]-coordinated Zn triangular bipyramids which share common (OH) vertices to form chains that extend in the c direction. These chains are decorated by Zn octahedra, each of which shares edges with adjacent Zn triangular bipyramids and form zigzag chains extending in the c direction. These chains are, in turn, linked in the b direction by sharing corners with arsenate groups to form sheets. Two of these sheets link by sharing edges between Zn octahedra and vertices between both Zn polyhedra and As tetrahedra to form a slab with a composition of [Zn₂(OH)(H₂O)(AsO₄)]. There are two possible disordered water groups in the interstitial space between adjacent slabs.

MBCCA IANBRUCEITE $[Zn_2(OH)(H_2O)(AsO_4)(H_2O)_2]$

SERIES D **YAROSHEVSKITE, tric/P1.** The structure is unique. It is based on corrugated layers made up of chains of edge-sharing flat squares with central Cu cations; neighbouring chains are connected via groups consisting of three Cu-centered squares. Neighbouring layers are connected via pairs of $Cu(2)O_4Cl$ five-coordinated polyhedra and isolated VO_4 tetrahedra. The structure can also be considered in terms of oxygen-centered tetrahedra: $O(7)Cu_4$ tetrahedra are connected via common $Cu(4)$ and $Cu(5)$ vertices to form pyroxene-like chains. In context, the structural formula can be written $Cu_3[O_2Cu_6][VO_4]_4Cl_2$. Pekov, I.V., Zelenski, M.E., Zubkova, N.V., Yapaskurt, V.O., Polekhovsky, Y.S., Pushcharovsky, D.Y. (2012) Yaroshevskite, IMA 2012-003. CNMNC Newsletter No. 13, June 2012, page 813; Mineralogical Magazine, 76, 807-817.

MBCDA YAROSHEVSKITE $Cu_9O_2(VO_4)_4Cl_2$

MBCDB DOKUCHAEVITE $Cu_8O_2(VO_4)_3Cl_3$

SERIES E **ABUITE, orth/P2₁2₁2₁.** Structure consists of infinite chains of Al octahedra along [001] *cis*-linked by sharing two F atoms. two different chains are linked by P tetrahedra, giving rise to channels along [001] delimited by a helical distribution of O anions in which the Sr cations are found. Enju, S. and Uehara, S. (2015) Abuite, IMA 2014-084. CNMNC Newsletter No. 23, February 2015, page 58; Mineralogical Magazine, 79, 51 -58.

MBCEA ABUITE $CaAl_2(PO_4)_2F_2$

TYPE D Structures with only Medium-sized cations, (OH, etc.) : $RO_4 = 2:1$

SERIES A **PSEUDOMALACHITE SERIES, mon/P2₁/c.** Structure consists of Cu polyhedra sharing three edges to form sheets // (100) of 5-membered rings; vacant octahedral sites are capped on both sides of the sheet by two opposing XO_4 tetrahedra that link the sheets by sharing corners with the octahedra. The structure of turanite consists of layers of the Cu octahedra which are // to (001) and make a basis of crystal structure. There are three Cu sites, first of which is coordinated by four (OH) groups and two O atoms; the $Cu(2)$ and $Cu(3)$ sites are coordinated by two (OH) groups and four O atoms respectively. Also there is a single four-coordinated V site surrounded by the O atoms. Each of the VO_4 tetrahedra leans by three of four its vertices on the vertices of the vacant octahedra. Being located between the Cu octahedra layers, the tetrahedra form a structure of sandwich.

MBDAA PSEUDOMALACHITE $Cu_5(PO_4)_2(OH)_4$

MBDAB CORNWALLITE $Cu_5(AsO_4)_2(OH)_4 \cdot H_2O$

MBDAC LUDJIBAITTE $Cu_5(PO_4)_2(OH)_4$

MBDAD CORNUBITE $Cu_5(AsO_4)_2(OH)_4$

MBDAE REICHENBACHITE $Cu_5(PO_4)_2(OH)_4$

MBDAF TURANITE $Cu_5(VO_4)_2(OH)_4$

SERIES B **ARSENOCASITE-PARWELITE SERIES, orth/ P2₁2₁2₁.** Members of this group have extremely complicated structures. The arsenoclasite structure can be visualized as ribbons of edge-sharing Mn octahedra, 3-membered rings formed by chains of corner-sharing Mn trigonal bipyramids linked to corner-sharing RO_4 tetrahedra, and chains of corner-linked RO_4 and MnO_4 tetrahedra. The structure is constructed of a double hexagonal close-packed array of oxygen atoms whose layers are stacked perpendicular to the c-axis. This arrangement is based on walls and chains of three distinct coordination polyhedra: $Mn^{6+}-O$ octahedra, $Mn^{5+}-O$ trigonal bipyramids and $Mn^{4+}-O$ tetrahedra (trigonal pyramids). The cationic occupancies are very complicated. Three non-equivalent octahedra, $Mn(2)-O$, $Mn(3)-O$ and $Mn(4)-O$, link by edge-sharing to form walls alternately one- and two-octahedra wide which run parallel to the b-axis. Also running parallel to this axis are chains of corner-sharing $Mn(1)-O$ trigonal bipyramids which further link by corner-sharing to $As(2)-O$ tetrahedra forming three-membered rings; and chains of corner-linked $As(1)-O$ and $Mn(5)-O$ tetrahedra.

MBDBA ARSENOCASITE $Mn_5(AsO_4)_2(OH)_4$

MBDBB REPPIAITE $Mn_5(VO_4)_2(OH)_4$

MBDBC GATEHOUSEITE $Mn_5(PO_4)_2(OH)_4$

MBDBD PARWELITE $(Mn,Ca,Mg)_5Sb^{5+}[O_4/AsO_4/SiO_4]$

TYPE E. Structures With only Medium-sized cations, (OH, etc.):RO₄ > 2:1

SERIES A **AUGELITE SERIES, mon/C2/m.** In augelite, (001) layers of edge-sharing Al octahedra and Al polyhedra are linked by P tetrahedra. In grattarolaite, three edge-sharing FeO₅ trigonal dipramids form Fe₃O₁₀ clusters that are connected by P tetrahedra. In cornetite, chains of edge-sharing Cu octahedra // [001] are cross-linked by dimmers of edge-sharing octahedra, forming layers // (100); the layers are linked by P tetrahedra that share edges with the dimmers. Clinoclase has a polyhedral framework of As tetrahedra, CuO₃(OH)₃ octahedra and CuO₂(OH)₃ square pyramids. In gilmarite, Cu octahedra and Cu square pyramids form chains // [010]; the chains are combined into sheets // (001) by Cu square pyramids, and the sheets are linked by As tetrahedra.

MBEAA	AUGELITE	Al ₂ (OH) ₃ (PO ₄)	
MBEAB	GRATTAROLAITE	Fe ₃ O ₃ PO ₄	
MBEAC	CORNETITE	Cu ₃ (OH) ₃ (PO ₄)	orth/Pbca
MBEAD	CLINOCLASE	Cu ₃ (AsO ₄)(OH) ₃	
MBEAE	GILMARITE	Cu ₃ (AsO ₄)(OH) ₃	
MBEAF	ARHBARITE	Cu ₂ (Mg(AsO ₄)(OH) ₃)	mon/tric

SERIES B **ALLACTITE-FLINKITE SERIES, mon/P2₁/a.** Structure consists of chains of edge-sharing Mn octahedra // [010] which are linked by Mn square pyramids to form open sheets //(001); the sheets are linked by As tetrahedra. Both structures can be visualized as comprising strips of the brucite structure.

MBEBA	ALLACTITE	Mn ₇ (AsO ₄) ₂ (OH) ₈
MBEBB	FLINKITE	Mn ₂ Mn(OH) ₄ (AsO ₄)
MBEBC	RAADEITE	Mg ₇ (PO ₄) ₂ (OH) ₈
MBEBD	ARGANDITE	Mn ₇ (VO ₄) ₂ ((OH) ₈)

SERIES C **CHLOROPHOENICITE-GERDTREMMELITE SERIES, mon/C2/m & tric/P1.** The structure is based on infinite insular slabs of the formula units parallel to a. Slabs are H bonded to each other only and perfect a cleavage is observed. The slabs are in turn made up of Mn-(O,OH) octahedral pyrochroite fragments or bands three octahedra wide running parallel to b, connected along c by As and Zn tetrahedral chains which also run parallel to b. The structure contains fragments of the pyrochroite structure.

MBECA	GERDTREMMELITE	(Zn,Fe)(Al,Fe) ₂ (AsO ₄)(OH) ₅
MBECB	CHLOROPHOENICITE	(Mn,Mg) ₃ Zn ₂ (AsO ₄)(OH,O) ₆
MBECC	MAGNESIUM-CHLOROPHOENICITE	(Mg,Mn) ₃ Zn ₂ (AsO ₄)(OH,O) ₆
MBECD	JAROSEWICHITE	Mn ₃ Mn(AsO ₄)(OH,O) ₆

SERIES D **HEMATOLITE SERIES, trig/R3, R3c, P6₃22.** The structure is based on the dense-packed stacking sequence .hhhch. Which includes 34 oxygens and one lone electron pair with seven anions per layer. The five non-equivalent layers are 1) isolated octahedra; 2) octahedral and tetrahedral sheet identical to that found in welinite, 3) octahedral and trigonal pyramidal sheet much like 2); 4) insular octahedra and tetrahedra, and 5) octahedral sheets of the type [M₃φ₇] found in chalcophanite. These layers are coupled to each other by corner- and edge-sharing. In dixenite, a metallic [As³⁺₄Cu¹⁺] cluster is identified in the oxide matrix. Structure of hematolite is based on three different sheets // (0001): a) edge-sharing Mn octahedra and corner-sharing As tetrahedra; b) groups of edge-sharing octahedra linked by AsO₃ trigonal pyramids; and c) edge-sharing Mn octahedra. The sheets are linked by Mn octahedra and As tetrahedra. The structures of mcgovernite, dixenite, arakiite and kraisslite are similar except for the occurrence of CuAs₄ tetrahedra in one of the sheets in dixenite. The kraisslite structure consists of five crystallographically distinct layers of polyhedral, labeled m = 0 – 4. Layer m = 0 consists of corner-sharing Zn and (Si, As⁵⁺) tetrahedral, and layers m = 1-4 each consist of trimers of Mn²⁺ octahedral linked by (Si,As) tetrahedral and intrasheet H bonds (M = 1,3) or (Si,As) tetrahedra and (Fe,Al) octahedral (m = 2) or (As) tetrahedral and (As³⁺+O³⁻) triangular pyramids and intrasheet H

bonds ($m = 4$). The layers stack along [001] with reversal of the sequence. The crystal structures of carlfrancisite, ideally $Mn_3Zn_3(Mn_2, Mg, Fe_3, Al)_4(As_3O_3)_2(As_5O_4)_4[(Si, As_5)O_4]_8(OH)_4$, hexagonal (rhombohedral), $R\bar{3}m$ with $Z = 6$, and unit-cell parameters: $a = 8.2238(2)$, $c = 205.113(6)$ Å and $V = 12013.5(4)$ Å³, from the Kombat mine, Otavi Valley, Namibia, and mcgovernite, ideally $Zn_3(Mn_2, Mg, Fe_3, Al)_4(As_3O_3)_2(As_5O_4)_4[(Si, As_5)O_4]_8(OH)_4$, hexagonal (rhombohedral), $R\bar{3}m$ with $Z = 6$, and unit-cell parameters: $a = 8.2061(3)$, $c = 204.118(8)$ Å and $V = 11903.8(6)$ Å³, from Sterling Hill, New Jersey, have been solved by direct methods and refined to R_1 values of 3.37 and 5.02% for 3837 and 3772 unique observed reflections, respectively; they are isostructural. Chemical analysis by electron microprobe and crystal-structure refinement gave the following compositions: carlfrancisite: As₂O₅ 12.89, As₂O₃ 3.33, P₂O₅ 0.50, V₂O₅ 0.74, SiO₂ 8.96, Al₂O₃ 0.78, FeO 0.22, MnO 53.25, MgO 9.37, H₂O(calc) 8.42, sum 98.50 wt.%; mcgovernite: As₂O₅ 13.06, As₂O₃ 3.71, SiO₂ 9.34, Al₂O₃ 0.20, FeO 1.38, MnO 44.58, ZnO 8.81, MgO 8.89, H₂O(calc) 8.24, sum 98.21 wt.%. The H₂O contents and the valence states of As were determined by crystal-structure analysis.

There are 18 crystallographically distinct cation sites in both carlfrancisite and mcgovernite. There are two [4]-coordinated As sites fully occupied by As⁵⁺, and four T sites occupied by Si and As⁵⁺ in solid solution. The As(3) site has triangular pyramidal coordination with distances of 1.808 and 1.817 Å, typical of As³⁺. The Z(1) site, occupied by Mn²⁺ in carlfrancisite and Zn in mcgovernite, has tetrahedral coordination, and the Z(2) site is only partly occupied by Mg and Mn²⁺ in both structures. There are nine M sites, all of which are octahedrally coordinated and contain dominantly Mn²⁺ and Mg, with minor Al and Fe. There are three cation sites with significant vacancies: As(3), Z(2), M(3), and there are complicated patterns of short-range order involving the cations and vacancies at these sites.

The carlfrancisite–mcgovernite structure contains 84 layers of approximately close-packed polyhedra along one translation on c . The anions in the structure are arranged in approximately close-packed layers orthogonal to the c axis. Fourteen layers stack along the c axis in the sequence [**hhchhch] (* denotes a layer of anions displaced from close packed). There are eight distinct layers of cation-centred polyhedra that repeat via a centre of symmetry at the origin, and via the R -centering to give 84 layers per unit-cell.

MBEDA	SYNADELPHITE	orth/Pnma	$(Mn, Mg, Ca, Pb)_9(AsO_3)(AsO_4)_2(OH)_9 \cdot 2H_2O$
MBEDB	HEMATOLITE		$(Mn, Mg, Al)_{15}(AsO_3)(AsO_4)_2(OH)_{23}$
MBEDC	KRAISSLITE		$(Mn, Mg)_{25}Zn_3Fe(AsO_3)_2(AsO_4)_4(SiO_4)_6(OH)_{16}$
MBEDD	DIXENITE		$Cu^{+1}Mn_{14}Fe(AsO_3)_5(SiO_4)_2(AsO_4)(OH)_6$
MBEDE	MCGOVERNITE		$(Mn, Mg, Zn)_{22}(AsO_3)(AsO_4)_3(SiO_4)_3(OH)_{20}$
MBEDF	ARAKIITE		$(Zn, Mn^{2+})(Mn^{2+}, Mg)_{12}(Fe^{3+}, Al)_2(As^{3+}O_3)(As^{5+}O_4)_2(OH)_{23}$
MBEDG	TURTMANNITE		$(Mn, Mg)_{25.5}[(V, As)O_4]_3(SiO_4)_3O_5(OH)_{20}$
MBEDH	CARLFRANCISITE		$Mn^{2+}_3(Mn^{2+}, Fe^{3+}, Al)_{42}[As^{3+}O_3]_2(As^{5+}O_4)_4[(Si, As^{5+})O_4]_6[(As^{5+}, Si)O_4]_2(OH)_{42}$

SERIES E **HOLDENITE-KOLICITE SERIES, orth/Abma.** The structure is based on an open tetrahedral sheet of composition $^2_{-}[Zn_2SiO_6(OH)_2]$, oriented parallel to {010}, further links to AsO₄ tetrahedra to form thick slabs of composition $^2_{-}[Zn_2As_2SiO_{12}(OH)_2]$. Insular Zn(OH)₄ tetrahedra also occur in the structure. These link to complex aggregates of Mn(O,OH)₆ condensed octahedra to form a framework structure. Structure of hematolite is based on three different sheets // (0001): a) edge-sharing Mn octahedra and corner-sharing As tetrahedra; b) groups of edge-sharing octahedra linked by AsO₃ trigonal pyramids; and c) edge-sharing Mn octahedra. The sheets are linked by Mn octahedra and As tetrahedra. The structures of mcgovernite, dixenite, arakiite and kraisslite are similar except for the occurrence of CuAs₄ tetrahedra in one of the sheets in dixenite.

MBEEA	HOLDENITE		$(Mn, Mg)_6Zn_3(OH)_8(AsO_4)_2(SiO_4)$
MBEEB	KOLICITE		$Mn_7Zn_4(OH)_8(AsO_4)_2(SiO_4)_2$ Cmca

SERIES F **SABELLIITE, trig/P3.** Structure consists of edge-sharing Cu- and Zn octahedra forming brucite-like layers // (0001); clusters of six edge-sharing Zn octahedra linked by As tetrahedra are accommodated between the layers.

MBEFA	SABELLIITE		$(Cu, Zn)_2Zn[(As, Sb)O_4](OH)_3$
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SERIES G **THEISITE, orth. Structure not known.** Williams, S. A. (1982): Theisite, a new mineral from Colorado. Mineralogical Magazine: 46: 49-50.
American Mineralogist (1983): 68: 282.
European Journal of Mineralogy (1995): 7: 1325. The crystal structure is unknown. Unlike in the formula

suggested in the original publication, the Sb is probably present in octahedral coordination as $\text{Sb}(\text{OH})_6$ or $\text{Sb}(\text{H}_2\text{O})_6$ groups.

MBEGA THEISITE $\text{Cu}_5\text{Zn}_5[(\text{As},\text{Sb})\text{O}_4]_2(\text{OH})_{14}$

SERIES H **COPARSITE, orth/Pbcm. Structure consists of triplets of one CuO_4Cl_2 tetragonal dipyramid sharing edges with two CuO_4 square planes which are connected into a framework by sharing corners with CuO_4Cl tetragonal pyramids and As tetrahedra.**

MBEHA COPARSITE $\text{Cu}_4\text{O}_2[(\text{As},\text{V})\text{O}_4]\text{Cl}$

SERIES I **DOMEROCKITE, tri/P1. The structure comprises $[\text{Cu}(\text{O},\text{OH})_4]$ chains of edge-sharing, distorted octahedral that extend along [1011] and are decorated by AsO_4 tetrahedra to form sheets in the (010) plane. Dimers of edge-sharing $[\text{CuO}_4(\text{OH})(\text{H}_2\text{O})]$ octahedral share corners with dimers of edge-sharing $[\text{CuO}_4(\text{OH})]$ square pyramids to form zigzag chains which extend along [101]. The chains lie between and link to the sheets by sharing corners of octahedral, square pyramids and tetrahedral to form a heteropolyhedral framework.**

MBEIA DOMEROCKITE $\text{Cu}_4\text{H}(\text{AsO}_4)_2(\text{AsO}_3\text{OH})(\text{OH})_3 \cdot \text{H}_2\text{O}$

TYPE F Structures With Medium-sized and Large Cations, (OH), etc.): $\text{RO}_4 < 0.5:1$.

SERIES A **ARROJADITE SERIES, mon/C2/c. The complex structure of arrojadite is based on 49 nonequivalent atoms in the asymmetric unit, fifteen are larger cations, whose coordination polyhedra include six symmetry-independent octahedra, one tetrahedron, one square pyramid, one seven-coordinated polyhedron, two distorted cubes, one non-cubic polyhedron of order eight, two of ten, and one of twelve-coordination.**

MBFAA ARROJADITE-(KFe) $\text{KNa}_4\text{CaMn}_4\text{Fe}_{10}\text{Al}(\text{PO}_4)_{12}(\text{OH},\text{F})_2$
 MBFAB DICKINSONITE-(KMnNa) $(\text{K},\text{Ba})(\text{Na},\text{Ca})_5(\text{Mn},\text{Fe},\text{Mg})_{14}\text{Al}(\text{PO}_4)_{12}(\text{OH},\text{F})_2$
 MBFAC ARROJADITE-(BaFe) $(\text{Ba},\text{K},\text{Pb})\text{Na}_3(\text{Ca},\text{Sr})(\text{Fe},\text{Mg},\text{Mn})_{14}\text{Al}(\text{OH})_2(\text{PO}_4)_{12}$
 MBFAD ARROJADITE-(SrFe) $\text{SrFe}^{2+}\text{Na}_2\text{Ca}(\text{Fe},\text{Mn},\text{Mg})_{13}\text{Al}(\text{PO}_4)_{11}(\text{PO}_3\text{OH})(\text{OH},\text{F})_2$
 MBFAE ARROJADITE-(KNa) $\text{KNa}_4\text{NaMn}_4\text{Fe}_{10}\text{Al}(\text{PO}_4)_{12}(\text{OH},\text{F})_2$
 MBFAF FLUORARROJADITE-(BaFe) $(\text{Ba},\text{K},\text{Pb})\text{Na}_3(\text{Ca},\text{Sr})(\text{Fe},\text{Mg},\text{Mn})_{14}\text{Al}(\text{F},\text{OH})_2(\text{PO}_4)_{12}$
 MBFAG ARROJADITE-(PbFe) $(\text{Pb},\text{Ba},\text{K})\text{Na}_3(\text{Ca},\text{Sr})(\text{Fe},\text{Mg},\text{Mn})_{14}\text{Al}(\text{OH})_2(\text{PO}_4)_{12}$
 MBFAH ARROJADITE-(BaNa) $\text{NaNa}_3(\text{NaCa})\text{Fe}^{2+}_{13}\text{Al}(\text{PO}_4)_{11}(\text{PO}_3\text{OH})(\text{OH})$
 MBFAI FLUORCAMOITE-(BaNa) $(\text{Ba}\square)\text{Na}_2\square\text{CaMg}_{13}\text{Al}(\text{PO}_4)_{11}(\text{PO}_3\text{OH})\text{F}_2$
 MBFAJ FLUORARROJADITE-(BaNa) $\text{BaNa}_4\text{CaFe}_{13}\text{Al}(\text{PO}_4)_{11}(\text{PO}_3\text{OH})\text{F}_2$

SERIES B **SAMUELSONITE, mon/C2/m. The structure is based on the fundamental column of composition $[\text{Ca}_4(\text{PO}_4)_{12}]$. This unit is fused by a screw axis to form double columns of composition $[\text{Ca}_4(\text{PO}_4)_{10}]$; the structure shows close similarities to apatite with respect to the columns. A complex structure based on double apatite-like columns // [010] of pinwheels consisting of Ca polyhedra sharing six faces with P tetrahedra. The columns, which are similar to those found in apatite, are bounded laterally by separate chains // [010] of edge-sharing M octahedra and corner-sharing Al octahedra.**

MBFBA SAMUELSONITE $(\text{Ca},\text{Ba})\text{Fe}_2\text{Mn}_2\text{Ca}_8\text{Al}_2(\text{PO}_4)_{10}(\text{OH})_2$

SERIES C **GRIPHITE-NABIASITE SERIES, cub/P2₁/a3. In graphite, CaO_6F_2 cubes, mostly corner-sharing MO_6 octahedra and P tetrahedra create a 3-dimensional cubic framework. In nabiasite, BaO_{12} dodecahedra share edges with six V tetrahedra, combined by edge-sharing MnO_6 and $\text{MnO}_5(\text{OH})$ octahedra to form a densely-packed cubic framework.**

MBFCA GRIPHITE $\text{Na}_4\text{Ca}_6(\text{Mn},\text{Fe},\text{Mg})_{19}\text{Li}_2\text{Al}_8(\text{PO}_4)_{24}(\text{F},\text{OH})_8$

MBFCB NABIASITE $\text{BaMn}_9[(\text{V},\text{As})\text{O}_4]_6(\text{OH})_2$

TYPE G Structures With Medium-sized and Larger Cations, (OH), etc.): $\text{RO}_4 = 0.5:1$.

SERIES A	BRACKENBUSCHITE SERIES, mon/P2₁/m. . In gamagarite, linear chains of edge-sharing Fe and Mn octahedra // [010] are linked by V tetrahedra; face-sharing Ba polyhedra form double chains // [010]. In brackebuschite, linear chains of edge-sharing Mn octahedra // [010] are decorated by V tetrahedra; the chains are linked by Pb polyhedra. In tsumebite, linear chains of edge-sharing Cu octahedra // [010] are linked into a framework by sharing corners with P and S tetrahedra and P b polyhedra The structure is based on the chain unit [Cu(CrO ₄)(PO ₄)OH]. Parallel chains are linked by interstitial Pb ²⁺ cations. The structure of tornebohmitite is the same and is based on linear octahedral chains that run parallel to [010]. Insular [SiO ₄] that corner-link to the octahedral chains are arranged in trans configuration to these chains. These admit the large REE cations that form a serrated wall of linked REE _{φ10} polyhedra that is oriented parallel to the {001} plane. The minerals pyrobeldonite and descloizite show a close structural relationship.	
MBGAA	ARSENBRACKEBUSCHITE	Pb ₂ (Fe,Zn)(AsO ₄) ₂ (OH)
MBGAB	ARSENTSUMEBITE	Pb ₂ Cu(AsO ₄)(SO ₄)·H ₂ O
MBGAC	BEARTHITE	Ca ₂ Al(PO ₄) ₂ (OH)
MBGAD	BRACKEBUSCHITE	Pb ₂ (Mn,Fe)(VO ₄) ₂ (OH)
MBGAE	GAMAGARITE	Ba ₂ (Fe,Mn)(VO ₄) ₂ ·H ₂ O
MBGAF	GOEDKENITE	(Sr,Ca) ₂ Al(PO ₄) ₂ (OH)
MBGAG	TSUMEBITE	Pb ₂ Cu(PO ₄)(SO ₄)·H ₂ O
MBGAH	FEINGLOSITE	Pb ₂ (Zn,Fe)(AsO ₄) ₂ ·H ₂ O
MBGAI	CALDERONITE	Pb ₂ Fe(VO ₄) ₂ (OH)
MBGAJ	BUSHMAKINITE	Pb ₂ Al(VO ₄)(PO ₄)(OH)
MBGAK	TOKYOITE	Ba ₂ Mn(VO ₄) ₂ (OH)
MBGAL	GRANDAITE	Sr ₂ Al(AsO ₄) ₂ (OH)
MBGAM	FERRIBUSHMAKINITE	Pb ₂ Fe(PO ₄)(VO ₄)(OH)
MBGAN	CANOSIOITE	Ba ₂ Fe ³⁺ (AsO ₄) ₂ (OH)
MBGAO	LOMBARDOITE	Ba ₂ Mn ³⁺ (AsO ₄) ₂ (OH)
SERIES B	MELONJOSEPHITE, orth/Pbam. The structure is based on chains of edge-sharing Fe-O octahedra oriented parallel to the c axis. Dimers of edge-sharing Fe-O octahedra share vertices with octahedra of the chains to form sheets parallel to {010} with the formula [Fe ₂ (OH)(Op) ₇] ²⁻ . The phosphate tetrahedra link within and between sheets to form a framework structure. The CaO ₇ polyhedron occurs in pockets between the sheets. Regions of the melonjosephite structure can be directly related to the octahedral tetramer in leluophosphite, and regions of the structure of olmsteadite and related compounds. Structure consists of chains of edge-sharing Fe octahedra // [001] which are linked by dimmers of edge-sharing Fe octahedra, forming sheets // (010). P tetrahedra link within and between sheets to form a framework. Ca polyhedra are in pockets between the sheets.	
MBGBA	MELONJOSEPHITE	CaFeFe(PO ₄) ₂ (OH)
MBGBB	KAPUNDAITE	
SERIES C	PROSPERITE, mon/C2/c or Cc. Structure consists of a complex framework of Ca polyhedra, Zn trigonal dipyramids and arsenate tetrahedra that are connected by sharing faces, edges and corners.	
MBGCA	PROSPERITE	HCaZn ₂ (AsO ₄) ₂ (OH)
SERIES D	TANCOITE, orth/Pbcb. Structure consists of chains of corner-sharing AlO ₆ octahedra and PO ₄ tetrahedra // [001] which are cross-linked by Na and Li atoms.	
MBGDA	TANCOITE	HN ₂ Li(Al(PO ₄) ₂ (OH))
SERIES E	KAMPELITE, orth/Pnma. Structure is based upon complex [MgBa ₂ Sc ₄ (PO ₄) ₆] layers consisting of the Ba-PO ₄ zig-zag sheet inserted between two Mg-Sc-PO ₄ sheets.	
MBGEA	KAMPELITE	Ba ₃ Mg _{1.5} Sc ₄ (PO ₄) ₁₆ (OH) ₃ ·4H ₂ O

TYPE H **Structures With Medium-sized and mostly Large Cations (OH, etc.):RO₄ =**
1:1

SERIES A **THADEUITE-JAGOWERITE SERIES, orth/C222₁.** The structure is based on three basic features: helical chains of M(3) octahedra parallel to c; slightly distorted chains composed of alternating M(1) and M(2) octahedra parallel to a; and insular phosphate tetrahedra, which cross link the M(3) chains to form a network of channels parallel to a into which the M(1)-M(2) chains fit. The basic polyhedra is [MO₄(OH)₂]⁸⁻, with the cation compositions: M(1) = Mg; M(2) = CaMn; M(3) = MgFeMn. Structure consists of edge-sharing pairs of Al octahedra that are corner-linked to eight P tetrahedra, forming a framework that accommodates Ba polyhedra. In thadeuite, helical chains of edge-sharing M octahedra // [001] are cross-linked by P tetrahedra to form a framework with a network of channels // [100] which contain distorted chains of edge-sharing Mg and Ca octahedra.

MBHAA	THADEUITE	Mg(Ca,Mn)(Mg,Fe,Mn) ₂ (PO ₄) ₂ (OH,F) ₂
MBHAB	JAGOWERITE	BaAl ₂ (PO ₄) ₂ (OH) ₂

SERIES B **TILASITE SERIES, mon/C2/c.** The structure is a framework and consists of infinite chains of TiO₆ octahedra linked by their corners; between these chains and parallel to the c axis run columns of distorted calcium prisms. Si tetrahedra link the Ti chains in the (010) plane. The lacroixite structure is isostructural and consists of chains of corner-sharing AlO₄F₂ octahedra cross-linked by PO₄ tetrahedra. The resulting large cavities in the framework are filled with Na atoms in 7-fold coordination. The octahedral chains are kinked. Isotypes of titanite structure.

MBHBA	DURANGITE	NaAl(AsO) ₄ F
MBHBB	TILASITE	CaMg(AsO) ₄ F
MBHBC	ISOKITE	CaMg(PO ₄)(F,OH)
MBHBD	LACROIXITE	NaAl(PO ₄)F
MBHBE	MAXWELLITE	NaFe(AsO ₄)F
MBHBF	PANASQUEIRAITE	CaMg(PO ₄)(OH,F)
MBHBG	KONONOVITE	NaMg(SO ₄)F
MBHBH	ARSENATROTITANITE	NaTi(AsO ₄)O

SERIES C **BJAREBYITE SERIES, mon/P2₁/m.** The structure is based on an octahedral chain of composition [Al₂O₆(OH)₃] which runs parallel to the b axis and consists of pairs of edge-sharing octahedra, each such edge-sharing pair in turn sharing a corner with another such pair. Similar chains occur in carminite and palermoite. Perloffite is isostructural with other members of the bjarebyite group. Edge-linked [M₂₂O₆(OH)₄] dimmers link via corners to form chains along [010]. Chains are decorated with PO₄ tetrahedra and link in the a direction via [M1O₅(OH)] octahedra and (Ba,Sr) atoms to form a complex framework

MBHCA	BJAREBYITE	(Ba,Sr)(Mn,Fe,Mg) ₂ Al ₂ (PO ₄) ₃ (OH) ₃
MBHCB	KULANITE	Ba(Fe,Mn,Mg) ₂ Al ₂ (PO ₄) ₃ (OH) ₃
MBHCC	PENIKISITE	Ba(Mg,Fe) ₂ Al ₂ (PO ₄) ₃ (OH) ₃
MBHCD	PERLOFFITE	Ba(Mn,Fe) ₂ Al ₂ (PO ₄) ₃ (OH) ₃
MBHCE	JOHNTOMAITE	BaFe ²⁺ ₂ Al ³⁺ ₂ (PO ₄) ₃ (OH) ₃
MBHCF	STRONTIOPERLOFFITE	SrMn ²⁺ ₂ Fe ³⁺ ₂ (PO ₄) ₃ (OH) ₃

SERIES D **PALERMOITE-BERTOSSAITE SERIES, orth/Imcb.** The structure is based on an M-O octahedral chain consisting of edge-linked dimer which is corner-linked. The carminite structure consists of Fe octahedra connected to each other by an edge at the mirror plane and by a corner at a two fold axis. The octahedra extend unbroken parallel to the z-direction in projection on (010) and are connected together in the x-direction by arsenate tetrahedra. Coordination about the lead atoms is eight fold. The structure is very similar to that of brackenbuschite. Structure consists of chains of edge- and corner-sharing AlO₄(OH)₂ octahedra // [100] which are linked by P tetrahedra to form slabs // (010). The large cations are accommodated in distorted cubic cavities in the framework.

MBHDA	PALERMOITE	(Sr,Ca)(Li,Na) ₂ [Al ₄ (PO ₄) ₄ (OH) ₄]
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MBHDB	BERTOSSAITE	$\text{Ca}(\text{Li},\text{Na})_2\text{Al}_4(\text{PO}_4)_4(\text{OH},\text{F})_4$
MBHDC	NATROPALERMOITE	$\text{Na}_2\text{SrAl}_4(\text{PO}_4)_4(\text{OH})_4$
MBHDD	PICCOLIITE	$\text{NaCaMn}^{3+}_2(\text{AsO}_4)_2\text{O}(\text{OH})$

SERIES E **CARMINITE SERIES, orth/Cccm.** Structure consists of chains of edge- and corner-sharing $\text{FeO}_4(\text{OH})_2$ octahedra // [001] are linked by corner-sharing As tetrahedra to form layers // (010; cavities in and between the layers are occupied by Pb. Attakolite belongs here.

MBHEA	CARMINITE	$\text{Pb}_2[\text{Fe}_4(\text{OH})_4(\text{AsO}_4)_4]$
MBHEB	SEWARDITE	$\text{CaFe}_2[\text{Fe}_4(\text{OH})_4(\text{AsO}_4)_4]$
MBHEC	CRIMSONITE	$\text{PbFe}^{3+}_2(\text{PO}_4)_2(\text{OH})_2$

SERIES F **ADELITE SERIES, orth/P2₁2₁2₁.** The structure consists of edge-sharing M octahedra forming linear chains // [001] that are linked by corner-sharing As tetrahedra, producing a framework with cavities that accommodate the large cations. In cobaltaustinite, the CoO_6 octahedra share edges to form chains extending // (001), which are cross linked by Ca^{2+} ions and by sharing vertices with isolated AsO_4 tetrahedra. The Ca^{2+} ions are situated in square antiprisms formed by eight O atoms.

MBHFA	ADELITE	$\text{CaMg}(\text{AsO}_4)(\text{OH},\text{F})$
MBHFB	CONICALCITE	$\text{CaCu}(\text{AsO}_4)(\text{OH},\text{F})$
MBHFC	AUSTINITE	$\text{CaZn}(\text{AsO}_4)(\text{OH},\text{F})$
MBHFD	COBALTAUSTINITE	$\text{Ca}(\text{Co},\text{Cu})(\text{AsO}_4)(\text{OH},\text{F})$
MBHFE	DUFTITE	$\text{PbCu}(\text{AsO}_4)(\text{OH},\text{F})$
MBHFF	GOTTLOBITE	$\text{CaMg}(\text{VO}_4,\text{AsO}_4)(\text{OH})$
MBHFG	ARSENDESCLOIZITE	$\text{PbZn}[\text{OH}/\text{AsO}_4]$
MBHFH	NICKELAUSTINITE	$\text{Ca}(\text{Ni},\text{Cu})(\text{AsO}_4)(\text{OH},\text{F})$
MBHFI	open	
MBHFJ	TANGEITE	$\text{CaCu}(\text{VO}_4)(\text{OH},\text{F})$
MBHFK	HERMANNROSEITE	$\text{CaCu}(\text{PO}_4)(\text{OH})$

SERIES G **DESCLOIZITE SERIES, orth/Pnam or Pna2₁.** Structure consists of chains of edge-sharing M octahedra // [010] are cross-linked by V tetrahedra, forming an open framework that accommodates the large Pb atoms.

MBHGA	CECHITE	$\text{Pb}(\text{Fe},\text{Mn})(\text{VO}_4)(\text{OH})$
MBHGB	DESCLOIZITE	$\text{PbZn}(\text{VO}_4)(\text{OH})$
MBHGC	MOTTRAMITE	$\text{PbCu}(\text{VO}_4)(\text{OH})$
MBHGD	PYROBELONITE	$\text{PbMn}(\text{VO}_4)(\text{OH})$
MBHGE	KHORIXASITE	$(\text{BiO}_{0.67}\square_{0.33})\text{Cu}(\text{VO}_4)(\text{OH})$

SERIES H **BAYLDONITE-LENINGRADITE SERIES, mon/C2/c.** Structure consists of chains of edge-sharing Cu octahedra // [010] which are connected into gibbsite-like sheets // (001) of 6-membered rings decorated by arsenate tetrahedra on both sides of the sheets; these tetrahedra share three of their corners with octahedra in the sheets; the sheets are linked by Pb ions and H-bonding. In leningradite, the structure contains one symmetrically unique Pb position coordinated by four O and four Cl atoms. The V^{5+} cation is tetrahedrally coordinated by four O atoms. There are two symmetrically independent Cu sites in distorted octahedral [4O =2Cl] coordination. The structure can be described in terms of fundamental chains consisting of corner-sharing CuO_4 squares and V tetrahedra. The chains are // to the c axis and are linked into a three-dimensional framework with elliptical channels occupied by the Pb cations and Cl anions. Structural description of leningradite is given in CM07-445.

MBHHA	BAYLDONITE	$\text{Cu}_3\text{PbO}(\text{HOAsO}_3)_2(\text{OH})_2$
MBHHB	VESIGNIEITE	$\text{BaCu}_3(\text{VO}_4)_2(\text{OH})_2$ C2/m

MBHHC	LENINGRADITE	$\text{PbCu}_3(\text{VO}_4)_2\text{Cl}_2$	orth/lbam
SERIES I	RUDABANYAITE, iso/		
MBHIA	RUDABANYAITE	$(\text{Ag}_2\text{Hg}_2)(\text{AsO}_4)\text{Cl}$	
TYPE J	Structures With Medium-sized and Large Cations, (OH, etc.): $\text{RO}_4 = 1.5:1$ No examples known.		
TYPE K	Structures With Medium-sized and Large Cations, (OH, etc.): $\text{RO}_4 = 2:1, 2.5:1$.		
SERIES A	BRAZILIANITE, $\text{mon}/\text{P}2_1/\text{n}$. Structure consists of chains // [010] of edge-sharing $\text{Al}(\text{O},\text{OH})_6$ octahedra linked by PO_4 tetrahedra to form a framework with Na in the cavities.		
MBKAA	BRAZILIANITE	$\text{NaAl}_3(\text{PO}_4)_2(\text{OH})_4$	
SERIES B	MEDENBACHITE SERIES, $\text{tric}/\text{P}1$. Structure consists of chains of edge-sharing octahedra of $[\text{Fe}^{3+}\text{O}_4(\text{OH})_2]$ and $[(\text{Cu}^{2+},\text{Fe}^{2+})\text{O}_4(\text{OH})_4]$ running along [010]. These chains of octahedra are corner linked by AsO_4 tetrahedra to form $[\text{Fe}^{3+}(\text{Cu},\text{Fe})(\text{OH})_2(\text{AsO}_4)]$ layers parallel to (001). The irregular Bi^{3+}O_7 coordination polyhedra are joined by O5 atoms to form zigzag bands arranged in (001) and running parallel to [100]. These connect the octahedra layers across (001).		
MBKBA	MEDENBACHITE	$\text{Bi}_2\text{Fe}(\text{Cu},\text{Fe})(\text{O},\text{OH})_2(\text{OH})_2(\text{AsO}_4)_2$	
MBKBB	NEUSTÄDELITE	$\text{Bi}_2\text{Fe}^{3+}_2(\text{O},\text{OH})_2(\text{OH})_2(\text{AsO}_4)_2$	
MBKBC	COBALTNEUSTÄDELITE	$\text{Bi}_2\text{Fe}(\text{Co},\text{Fe})(\text{O},\text{OH})_2(\text{OH})_2(\text{AsO}_4)_2$	
SERIES C	CURETONITE, $\text{mon}/\text{P}2_1/\text{n}$. The structure consists one tetrahedrally coordinated P position by four oxygens and two unique Al positions octahedrally coordinated by four oxygens and two hydroxyls and four oxygens and two fluorines, respectively. These octahedra and tetrahedra link by sharing corners to form a sheet of general stoichiometry $\text{M}(\text{TO}_4)_2$ that constitutes the structural unit of the mineral. The sheets are linked by tenfold-coordinated interstitial Ba atoms. Structure consists of chains of corner-sharing (Al,Ti) octahedra // [100] which are linked by P tetrahedra to form sheets // (010); the sheets are connected by Ba polyhedra.		
MBKCA	CURETONITE	$\text{Ba}(\text{Al},\text{Ti})(\text{PO}_4)(\text{OH}),\text{O}\text{F}$	
SERIES D	HEYITE, $\text{mon}/\text{P}2_1/\text{m}$. Structure not known. Williams, S.A. (1973): Heyite, $\text{Pb}_5\text{Fe}_2(\text{VO}_4)_2\text{O}_4$, a new mineral from Nevada. Mineralogical Magazine: 39, 65-68. American Mineralogist: 59: 382. Identical with calderonite (U. Kolitsch, unpublished data; discreditation proposal to be submitted to IMA).		
MBKDA	HEYITE = CALDERONITE	$\text{Pb}_5\text{Fe}_2(\text{VO}_4)_2\text{O}_4$	
SERIES E	JAMESITE SERIES, $\text{Tric}/\text{P}1$. Structure consists of compact trimers of edge-sharing Zn and Fe octahedra share edges with adjoining trimers to form $[\text{M}_3(\text{OH},\text{O})_{10}]$ chains // [100] like those in kotoite, lindgrenite and frankhawthorneite, and are decorated by as tetrahedra. Parallel to these chains are ladder-like structure consisting of linear trimers of edge-sharing octahedra connected by As tetrahedra. The chains and ladders are linked into a sheet // (010) by octahedra that share corners with octahedra in the chains and ladders, and with the As tetrahedra. The sheets are linked along [010] to form a heteropolar framework with large cavities that accommodate the Pb ions.		
MBKEA	JAMESITE	$\text{Pb}_2\text{ZnFe}^{3+}_2(\text{Fe}^{3+}_{2.8}\text{Zn}_{1.2})(\text{AsO}_4)_4(\text{OH})_8[(\text{OH})_{1.2}\text{O}_{0.8}]$	
MBKEB	LULZACITE	$\text{Sr}_2\text{Fe}^{2+}(\text{Fe},\text{Mg})_2\text{Al}_4(\text{PO}_4)_4(\text{OH})_{10}$	$\text{tric}/\text{P}1$
SERIES F	IANGREYITE, $\text{trig}/\text{P}321$. The structure consists of blocks of the crandallite-type structure that are interconnected along c via corner-sharing of crandallite-block PO_4 tetrahedra with $\text{AlO}_2(\text{H})_3$ bipyramids. This linkage generates large channels along [110] bounded by 10-membered rings of		

octahedra, tetrahedra and trigonal bipyramids, that are occupied by Ca and water molecules. The mineral is structurally related to perhamite group.

MBKFA IANGREYITE $\text{Ca}_2\text{Al}_7(\text{PO}_4)_2(\text{PO}_3\text{OH})_2(\text{OH},\text{F})_{15}\cdot 8\text{H}_2\text{O}$

SERIES G LANGBANSHYTTANITE, *Tric/P1*. Structure consists of edge-sharing $\text{MnO}_2(\text{OH})_4$ octahedra forming zig-zag columns that are linked by isolated AsO_4 tetrahedra. Pb cations have six-fold coordination and are located between the AsO_4 tetrahedra. Isolated $\text{Mg}(\text{H}_2\text{O})_6$ octahedra are located in the inter-block space.

MBKGA LANGBANSHYTTANITE $\text{Pb}_2\text{Mn}_2\text{Mg}(\text{AsO}_4)_2(\text{OH})_4\cdot 6\text{H}_2\text{O}$

TYPE L Structures With Medium-sized and Large cations, $(\text{OH}, \text{etc.}):\text{RO}_4 = 3:1$.

SERIES A CRANDALLITE SERIES, *trig/R3m*. The hexagonal structure consists of corner-sharing Al octahedra which are linked into trigonal and hexagonal rings to form sheets perpendicular to the c axis. Ca ions, surrounded by 12 oxygen and hydroxyl ions, lie in large cavities between the sheets. Each phosphate tetrahedron shares three corners with three Al octahedra forming a trigonal ring in the sheet. The unshared corner points away from the trigonal hole towards the adjacent sheet to which it is H bonded. In pattenonite, the unique crystal structure consists of an interrupted three-dimensional framework based on intersecting zig-zag chains of corner-sharing FeO_6 octahedra, linked by P tetrahedra. The [8]-coordinated Pb atom is located within elliptical [100] channels. Members of this group have the alunite structure type. The structure of pattenonite consists of an interrupted three-dimensional framework based on intersecting zig-zag chains of corner-sharing FeO_6 octahedra, linked by phosphate tetrahedra. The 8-coordinated Pb atom is located within elliptical [100] channels the asymmetric unit contains one unique Pb, three Fe, one P, seven O and one mixed $[(\text{H}_2\text{O})_{0.5}(\text{OH})_{0.5}]$ ligand with a calculated bond-valence of 0.75 and 3.5 H atoms.

MBLAA	ARSENOCRANDALLITE	$(\text{Ca},\text{Sr})\text{Al}_3((\text{As},\text{P})\text{O}_4)_2(\text{OH})_5\cdot \text{H}_2\text{O}$
MBLAB	ARSENOFLORENCITE-(Ce)	$(\text{Ce},\text{La})\text{Al}_3((\text{As},\text{P})\text{O}_4)_2(\text{OH})_5\cdot \text{H}_2\text{O}$
MBLAC	ARSENOFLORENCITE-(La)	$(\text{La},\text{Ce})\text{Al}_3((\text{As},\text{P})\text{O}_4)_2(\text{OH})_5\cdot \text{H}_2\text{O}$
MBLAD	open	
MBLAE	ARSENOGORCEIXITE	$\text{BaAl}_3(\text{AsO}_4)(\text{AsO}_3\text{OH})(\text{OH})_6$
MBLAF	ARSENOGOYAZITE	$(\text{Sr},\text{Ca},\text{Ba})\text{Al}_3((\text{As},\text{P})\text{O}_4)_2(\text{OH})_5\cdot \text{H}_2\text{O}$
MBLAG	CRANDALLITE	$\text{CaAl}_3(\text{PO}_4)_2(\text{OH})_5\cdot \text{H}_2\text{O}$
MBLAH	DUSSERTITE	$\text{BaFe}_3(\text{AsO}_4)_2(\text{OH})_5$
MBLAI	EYLETTERSITE	$(\text{Th},\text{Pb})_{1-x}\text{Al}_3(\text{PO}_4,\text{SiO}_4)_2(\text{OH})_6$
MBLAJ	FLORENCITE-(Ce)	$\text{CeAl}_3(\text{PO}_4)_2(\text{OH})_6$
MBLAK	FLORENCITE-(La)	$(\text{La},\text{Ce})\text{Al}_3(\text{PO}_4)_2(\text{OH})_6$
MBLAL	FLORENCITE-(Nd)	$(\text{Nd},\text{Ce})\text{Al}_3(\text{PO}_4)_2(\text{OH})_6$
MBLAM	GORECEIXITE	$\text{BaAl}_3(\text{PO}_4)(\text{PO}_3\text{OH})(\text{OH})_6$
MBLAN	GOYAZITE	$(\text{Sr},\text{Ca},\text{Ba})\text{Al}_3(\text{PO}_4)_2(\text{OH})_5\cdot \text{H}_2\text{O}$
MBLAO	BENAUITE	$\text{HSrFe}_3(\text{PO}_4)_2(\text{OH})_6$
MBLAP	PHILIPSBORNITE	$\text{PbAl}_3(\text{AsO}_4)_2(\text{OH})_5\cdot \text{H}_2\text{O}$
MBLAQ	PLUMBOGUMMITE	$\text{PbAl}_3(\text{PO}_4)_2(\text{OH})_5\cdot \text{H}_2\text{O}$
MBLAR	WAYLANDITE	$(\text{Bi},\text{Ca})\text{Al}_3(\text{PO}_4,\text{SiO}_4)_2(\text{OH})_6$
MBLAS	ZAIRITE	$\text{Bi}(\text{Fe},\text{Al})_3(\text{PO}_4)_2(\text{OH})_6$
MBLAT	SEGNITITE	$\text{PbFe}_3(\text{AsO}_4)_2(\text{OH})_6$
MBLAU	SPRINGCREEKITE	$\text{BaV}_3(\text{PO}_4)_2(\text{OH},\text{H}_2\text{O})_6$
MBLAV	GRAULICHITE-(Ce)	$(\text{Ce},\text{La},\text{Nd},\text{Ba})(\text{Fe},\text{Al})_3[(\text{As},\text{Al})\text{O}_4]_2(\text{OH})_6$
MBLAW	PATTERSONITE	$\text{PbFe}_3(\text{PO}_4)_2(\text{OH})_4[(\text{H}_2\text{O})_{0.5}(\text{OH})_{0.5}]_2$

MBLAX	KINTOREITE	$\text{PbFe}_3(\text{PO}_4)_2(\text{OH},\text{H}_2\text{O})_6$
MBLAY	KOLITSCHITE	$\text{Pb}[\text{Zn}_{0.25-0.5}\square_{0.75-0.5}]\text{Fe}_3\text{H}(\text{AsO}_4)_2(\text{OH})_6$
MBLAZ	FLORENCITE-(Sm)	$(\text{Sm},\text{Nd})\text{Al}_3(\text{PO}_4)_2(\text{OH})_6$
MBLA27	ARSENOFLORENCITE-(La)	$\text{LaAl}_3(\text{AsO}_4)_2(\text{OH})_6$
MBLA28	GALLOPLUMBOGUMMITE	$\text{Pb}(\text{Ga},\text{Al},\text{Ge})_3(\text{PO}_4)_2(\text{OH})_6$

SERIES B **VIITANIEMIITE, mon/P2₁/m. Structure consists of alternating chains of corner-sharing Al octahedra and edge-sharing (Ca,Mn) octahedra // [010] which are connected by F atoms to form sheets // (010). The sheets are linked by P tetrahedra and Na polyhedra.**

MBLBA	VIITANIEMIITE	$\text{Na}(\text{Ca},\text{Mn})\text{Al}[\text{PO}_4](\text{F},\text{OH})_3$
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SERIES C **DUGGANITE SERIES. Trig/P321. Structure consists of TeO₆ octahedra and PbO₈ disphenoids sharing edges to form open sheets // (0001); these sheets alternate with open sheets of corner-sharing As and Zn tetrahedra; the sheets are linked by sharing corners of the various polyhedra. The structure of joelbruggerite, the Sb analog of dugganite, is composed of heteropolyhedral sheets of edge-sharing (Sb,Te)O₆ octahedra and PbO₈ disphenoids, oriented // to (001). The sheets are cross-linked by AsO₄ and ZnO₄ tetrahedra, which share corners to form an interlinked, two- and three-connected two-dimensional net // to (001)**

MBLCA	DUGGANITE	$\text{Pb}_3\text{TeZn}_3[\text{O}_6/(\text{AsO}_4)_2]$
MBLCB	KUKSITE	$\text{Pb}_3\text{TeZn}_3[\text{O}_6/(\text{PO}_4)_2]$
MBLCC	CHEREMNYKHITE	$\text{Pb}_3\text{TeZn}_3[\text{O}_6/(\text{VO}_4)_2]$
MBLCD	JOËLBRUGGERITE	$\text{Pb}_3\text{SbZn}_3[\text{O}_6(\text{AsO}_3\text{OH})_2]$

SERIES D **ARTSMITHITE, mon/C2/c. Structure consists of-pending** Canadian Mineralogist (2003): 41:721-725.

MBLDA	ARTSMITHITE	$\text{Hg}^{1+}_4\text{Al}(\text{PO}_4)_{2-x}(\text{OH})_{1-3x}$
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TYPE M Structures With Medium-sized and Large Cations, (OH, etc.):RO₄ = 4:1

SERIES A **RETZIAN SERIES, orth/Pban. The structure consists of zigzag chains of edge-sharing Mn octahedra // [100] sharing edges with REE square antiprisms to form sheets // (001); the sheets are linked by As tetrahedra which are located over vacant octahedral sites in the sheets.**

MBMAA	RETZIAN-(Ce)	$\text{Mn}_2\text{Ce}(\text{AsO}_4)(\text{OH})_4$
MBMAB	RETZIAN-(La)	$(\text{Mn},\text{Mg})_2(\text{La},\text{Ce},\text{Nd})(\text{AsO}_4)(\text{OH})_4$
MBMAC	RETZIAN-(Nd)	$\text{Mn}_2(\text{Nd},\text{Ce},\text{La})(\text{AsO}_4)(\text{OH})_4$

SERIES B **PAULKELLERITE-BRENDELITE SERIES, mon/C2/c. Structure consists of zigzag chains of alternating corner-sharing Fe octahedra and P tetrahedra // [001] which are arranged in sheets // (100); these sheets are interspersed with sheets of Bi polyhedra.**

MBMBA	BRENDELITE	$(\text{Bi},\text{Pb})_2\text{Fe}(\text{O},\text{OH})_3\text{PO}_4$
MBMBB	PAULKELLERITE	$\text{Bi}_2\text{Fe}(\text{PO}_4)\text{O}_2(\text{OH})_2$

SERIES C **WATERHOUSEITE, mon/P2₁/c. Structure is characterized by a dense, complex framework of Mn(O,OH)₆ octahedra and phosphate tetrahedra, which are linked by both edges and corners. Two different subunits can be recognized in the structure: arsenoclasite-type strips of edge-sharing octahedra (fragments of brucite-pyrochroite-type strips of octahedra) and finite chains of edge-sharing octahedra (fragments of infinite rutile-type chains). The phosphate tetrahedra provide a connection between the strips and the chains.**

MBMCA	WATERHOUSEITE	$\text{Mn}_7(\text{PO}_4)_2(\text{OH})_8$ CM05-1401 (str.)
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SERIES D **GALLISKIITE, tri/P1.** Crystal structure consists of double chains of alternating corner-sharing AlF_3O_3 octahedra and PO tetrahedra along the a axis. The chains are joined into a framework via bonds to four distinct Ca atoms. Ca atoms are also linked by sharing isolated F atoms and water molecules. The double-chain motif in the structure is distinct from that in any other known phosphate.

MBMDA GALLISKIITE $\text{Ca}_4\text{Al}_2(\text{PO}_4)_2\text{F}_8 \cdot 5\text{H}_2\text{O}$

SERIES E **EUREKADUMPITE, mon/P2,Pm, or P2/m.** Pekov I.V., Chukanov N.V., Zadov A.E., Roberts A.C., Jensen M.C., Zubkova N.V., Nikischer A.J. (2010) Eurekaumpite, $(\text{Cu,Zn})_{16}(\text{TeO}_3)_2(\text{AsO}_4)_3\text{Cl}(\text{OH})_{18} \cdot 7\text{H}_2\text{O}$, a new hypergene mineral. Zapiski Rossiyskogo Mineralogicheskogo Obshchestva, 139(4, 26-35 (in Russian). English translation: (2011) Geology of Ore Deposits, 53, 575-582.

Pekov I.V., Jensen M.C., Roberts A.C. and Nikischer A.J. (2010) A New Mineral from an Old Locality: Eurekaumpite Takes Seventeen Years to Characterize. Mineral News, Vol. 26, No. 2, pages 1ff.

MBMEA EUREKADUMPITE $(\text{Cu,Zn})_{16}(\text{TeO}_3)_2(\text{AsO}_4)_3\text{Cl}(\text{OH})_{18} \cdot 7\text{H}_2\text{O}$

TYPE N Structures with only Large Cations, (OH), etc.): $\text{RO}_4 = 0.33:1$

SERIES A **FLUOR SERIES, trig/P6₃/m.** Structure consists of Ca polyhedra sharing faces to form chains // [0001]; the chains are linked into a hexagonal array by sharing edges and corners with P tetrahedra. F and OH ions are located in wide hexagonal channels // [0001].

MBNAA	BELOVITE-(Ce)	$(\text{Sr,Ce,Na,Ca})_5(\text{PO}_4)_3(\text{OH})$
MBNAB	FLUORBRITHOLITE-(Y)	$(\text{Y,Ca,Ln})_5[(\text{Si,P})\text{O}_4]_3\text{F}$
MBNAC	APATITE-(SrF)	$(\text{Sr,Ca})_5(\text{PO}_4)_3\text{F}$
MBNAD	CARLIESECKEITE-(Nd)	$\text{NaNdCa}_3(\text{PO}_4)_3\text{F}$
MBNAE	FLUORAPATITE	$\text{Ca}_5(\text{PO}_4)_3\text{F}$
MBNAF	HYDROXYLAPATITE	$\text{Ca}_5(\text{PO}_4)_3(\text{OH})$
MBNAG	JOHNBAUMITE	$\text{Ca}_5(\text{AsO}_4)_3(\text{OH})$
MBNAH	FLUORSTROPHITE	$(\text{Sr,Ca})_5(\text{PO}_4)_3(\text{OH},\text{F})$
MBNAI	SVABITE	$\text{Ca}_5(\text{AsO}_4)_3\text{F}$
MBNAJ	BELOVITE-(La)	$\text{Sr}_3\text{Na}(\text{La,Ce})[\text{PO}_4]_3(\text{F},\text{OH})$
MBNAK	DELONEITE	$\text{NaCa}_2\text{SrCe}(\text{PO}_4)_3\text{F}$
MBNAL	FLUORCAPHITE	$(\text{Ca,Sr,Na,REE})_5(\text{PO}_4)_3\text{F}$
MBNAM	MIYAHISAITE	$(\text{Sr,Ca})_2\text{Ba}_3(\text{PO}_4)_3\text{F}$
MBNAN	PIECZKAITE	$\text{Mn}_5(\text{PO}_4)_3\text{Cl}$
MBNAO	PLINIUSITE	$\text{Ca}_5(\text{VO}_4)_3\text{F}$

SERIES B **CHLORAPATITE-PYROMORPHITE SERIES, hex/P6₃/m.** Structure same as fluorapatite series. Parafiniukite, ideally $\text{Ca}_2\text{Mn}_3(\text{PO}_4)_3\text{Cl}$, is a new apatite-supergroup mineral from the Szklary pegmatite, Lower Silesia, Poland. It occurs as anhedral grains, up to 250 μm in size, dark olive green in colour, embedded in a mixture of Mn-oxides and smectites around beusite. It has a vitreous luster, and it is brittle with irregular, uneven fracture. The calculated density is 3.614 $\text{g}\cdot\text{cm}^{-3}$. Parafiniukite is hexagonal, space group P6₃/m, with unit-cell parameters $a = 9.4900(6)$, $c = 6.4777(5)$ Å, $V = 505.22(5)$ Å³, $Z = 2$. The eight strongest reflections in the calculated X-ray powder diffraction pattern of parafiniukite are [d in Å (I) hkl]: 3.239 (39) 002; 2.801 (55) 211; 2.801 (76) 121; 2.740 (100) 300; 2.675 (50) 112; 2.544 (69) 202; 1.914 (31) 222; and 1.864 (22) 132. Chemical analysis by an electron microprobe gave (in wt%) P₂O₅ 39.20, MgO 0.19, CaO 24.14, MnO 31.19, FeO 2.95, Na₂O 0.05, F 0.39, Cl 3.13, H₂O(calc) 0.68, O=(Cl,F) -0.87, sum 101.05. The resulting empirical formula on the basis of 13 anions per formula unit is $(\text{Mn}_{2.39}\text{Ca}_{2.34}\text{Fe}_{0.22}\text{Mg}_{0.03}\text{Na}_{0.01})\Sigma 4.99\text{P}_3.00\text{O}_{12}[\text{Cl}_{0.48}(\text{OH})_{0.41}\text{F}_{0.11}]$. The crystal structure of parafiniukite was refined to an $R_1 = 0.0463$ for 320 independent reflections with $F_o > 4\sigma(F_o)$ and 41 refined parameters. Parafiniukite is isotypic with apatites. Manganese is the dominant cation at the M(2) site, and Ca is the dominant cation at the M(1) site.

MBNBA ALFORSITE $\text{Ba}_5(\text{PO}_4)_3\text{Cl}$

MBNBB	CHLORAPATITE	$\text{Ca}_5(\text{PO}_4)_3\text{Cl}$
MBNBC	GORYAINOVITE	$\text{Ca}_2\text{PO}_4\text{Cl}$
MBNBD	HEDYPHANE	$\text{Pb}_3\text{Ca}_2(\text{AsO}_4)_3\text{Cl}$
MBNBE	MIMETITE	$\text{Pb}_5(\text{AsO}_4)_3\text{Cl}$
MBNBF	MORELANDITE	$(\text{Ba,Ca,Pb})_5(\text{AsO}_4,\text{PO}_4)_3\text{Cl}$
MBNBG	PYROMORPHITE	$\text{Pb}_5(\text{PO}_4)_3\text{Cl}$
MBNBH	TURNEAUREITE	$\text{Ca}_5(\text{As,PO}_4)_3\text{Cl}$
MBNBI	VANADINITE	$\text{Pb}_5(\text{VO}_4)_3\text{Cl}$
MBNBK	KUANNERSUITE-(Ce)	$\text{Ba}_3\text{NaCe}(\text{PO}_4)_3(\text{F,Cl})$
MBNBL	FLUORPHOSPHOHEDYPHANE	$\text{Ca}_2\text{Pb}_3(\text{PO}_4)_3\text{F}$
MBNBM	VANACKERITE	$\text{Pb}_4\text{Cd}(\text{AsO}_4)_3(\text{Cl,OH})$
MBNBN	HYDROXYLPYROMORPHITE	$\text{Pb}_5(\text{PO}_4)_3(\text{OH})$
MBNBO	PARAFINIUKITE	$\text{Ca}_2\text{Mn}_3(\text{PO}_4)_3\text{Cl}$
MBNBP	HYDROXYLHEDYPHANE	$\text{Ca}_2\text{Pb}_3(\text{AsO}_4)_3(\text{OH})$

SERIES C **ARCTITE, trig/R $\bar{3}$ m. Structure consists of three different layers // (0001). (a) Ba icosohedra linked by P tetrahedra. (b) triplets of edge-sharing Ca polyhedra with P tetrahedra and F atoms; and (c) face-sharing triplets of Na polyhedra. The layers are linked by P tetrahedra.**

MBNCA	ARCTITE	$\text{Na}_5\text{BaCa}_7[\text{F}_3/(\text{PO}_4)_6]$
MBNCB	ARAVAITE	$\text{Ba}_2\text{Ca}_{18}(\text{SiO}_4)_6(\text{PO}_4)^3(\text{CO}^3)\text{F}^3\text{O}$

TYPE O Structures With only Large Cations, (OH< etc.):RO4 >= 1:1

SERIES A **NACAPHITE, orth/Cmma or C2ma. Structure consists of columns of edge-sharing Na octahedra and Ca polyhedra // {100} which are linked by phosphate tetrahedra that share edges with the Ca polyhedra.**

MBOAA	NACAPHITE	$\text{Na}_2\text{CaPO}_4\text{F}$
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SERIES B **SCHUMACHERITE SERIES, tric/P1. The structure consists of clusters of six Bi atoms that are connected by two oxygens and two OH groups. These Bi₆O₂(OH)₂ groups are linked by the AsO₄ tetrahedra to form a framework. Structure consists of clusters of six edge- and corner-sharing Bi(O,OH)₄ square pyramids which are linked into a framework by P, As, or V tetrahedra.**

MBOBA	SCHUMACHERITE	$\text{Bi}_3((\text{V,As,P})\text{O}_4)_2\text{O}(\text{OH})$
MBOBB	PETITJEANITE	$\text{Bi}_3((\text{P,V,As})\text{O}_4)_2\text{O}(\text{OH})$
MBOBC	PREISINGERITE	$\text{Bi}_3(\text{AsO}_4)_2\text{O}(\text{OH})$

SERIES C **ATELESTITE SERIES, mon/P2₁/a. Structure consists of clusters of six edge- and corner-sharing Bi(O,OH)₄ square pyramids which are linked into a framework by P, As or V tetrahedra. Structures similar to preisingerite.**

MBOCA	ATELESTITE	$\text{Bi}_8(\text{AsO}_4)_3\text{O}_5(\text{OH})_5$
MBOCB	SMRKOVECITE	$\text{Bi}_2\text{O}(\text{OH})(\text{PO}_4)$
MBOCC	HECHTSBERGITE	$\text{Bi}_2\text{O}(\text{OH})(\text{VO}_4)$

SERIES D **SAHLINITE SERIES, mon/C2/c. Structure consist of double sheets // (010) consisting of two sheets of Pb(O,Cl)₅₋₈ polyhedra connected by V tetrahedra which are linked to adjacent double sheets by a layer of Cl atoms. The structure is related to litharge. The main structure unit is composed of the [Pb₁₄(VO₄)₂O₉]⁴⁺ double sheet, and adjacent sheets are linked by Cl anions. The structure unit consists of two sheets of the tetragonal PbO structure in which 1/8 of the Pb positions are replaced by V, with the addition of two apical O anions and the omission of one O anion within the Pb-O sheet.**

MBODA	KOMBATITE	$Pb_{14}(VO_4)_2O_9Cl_4$	
MBODB	SAHLINITE	$Pb_{14}(AsO_4)_2O_9Cl_4$	
SERIES E	HENEUITE, tric/P$\bar{1}$. Structure consists of a 3-dimensional framework of edge- and corner-sharing Mg octahedra, Mg trigonal dipyramids, Ca polyhedra, P tetrahedra and carbonate trigonal plates.		
MBOEA	HENEUITE	$CaMg_5(PO_4)_3(CO_3)(OH)$	
SERIES F	NEFEDOVITE, tet/I$\bar{4}$. Structure consists of four-fold columns of edge-sharing Na polyhedra // [001] and chains of corner-sharing Na polyhedra // [001]; edge- and corner-sharing Ca polyhedra form walls // (110) and (1$\bar{1}$0); phosphate tetrahedra share corners and edges with the Na and Ca polyhedra.		
MBOFA	NEFEDOVITE	$Na_5Ca_4(PO_4)_4F$	
SERIES G	KUZNETSOVITE, cub/P$2_1$3 Structure consists of cluster of 3 Hg atoms within a polyhedron of 12 O atoms and four Cl atoms; the polyhedra are linked by arsenate tetrahedra.		
MBOGA	KUZNETSOVITE	$Hg_3Cl(AsO_4)$	
SERIES H	Open		
GROUP C	Phosphates without Additional Anions, with water.		
TYPE A	Structures with Small and Large/Medium Cations.		
SERIES A	FRANSOLETITE SERIES, mon/P$2_1/a$. Structure consists of corner-sharing Be and P tetrahedra alternating to form 4-membered rings that are linked to form chains // [100] ; the chains are linked by Ca atoms and H bonding. Ehrleite (tric/P$\bar{1}$) is similar and consists corner-sharing Zn, Be, P tetrahedra forming 4-membered rings that are combined into thick sheets // (010); the sheets are linked by Ca atoms and H bonds.		
MCAAA	FRANSOLETITE	$Ca_3Be_2(PO_4)_2(PO_3OH)_2 \cdot 4H_2O$	mon/P $2_1/a$
MCAAB	PARAFRANSOLETITE	$Ca_3Be_2(PO_4)_2(PO_3OH)_2 \cdot 4H_2O$	tric/P $\bar{1}$
SERIES B	EHRLEITE, tric/P$\bar{1}$. Structure consists of corner-sharing Zn, Be, and P tetrahedra forming 4-membered rings that are combined into thick sheets // (010); the sheets are linked by Ca atoms and H bonds.		
MCABA	EHRLEITE	$Ca_2ZnBe(PO_4)_2(PO_3OH) \cdot 4H_2O$	
SERIES C	FAHEYITE, trig/P$3_1$21. Structure consists of both Be and P tetrahedra. Each vertex of the Be tetrahedron is shared with a vertex of a neighboring P tetrahedron, and two vertices of each P tetrahedron are shared with neighboring Be tetrahedra to form a corner-sharing [Be(PO$_4$)$_2$] chain, with P tetrahedra flanking the Be tetrahedra of the central spine in the sequence –P(1)/P(1)-Be-P(2)/P(2)-Be. Faheyite has a chiral structure, with the chain twisting about the c-axis in a clockwise direction for the refined P$3_1$21 enantiomer. The Mn octahedron lies along the 3$_1$ screw axis within the core region of the chain, forming [MnBe$_2$(PO$_4$)$_2$] spires that are wrapped by Fe octahedra that share vertices with P tetrahedra. Lindberg & Murata (1953): Faheyite, a new phosphate mineral from the Sapucaia pegmatite mine, Minas Gerais, Brazil. <i>American Mineralogist</i>. 38, 263-270, 349. <i>American Mineralogist</i> (1964): 49: 395.		
MCACA	FAHEYITE	$(Mn,Mg)Be_2Fe_2(PO_4)_4 \cdot 6H_2O$	
SERIES D	GAINESITE SERIES, tetr/I$\bar{4}$/amd. The structure is based on a [Zr$_2$Be(PO$_4$)$_4$] framework. The ZrO$_6$ octahedron is fully occupied, the P- and Be-tetrahedral centers exactly half-occupied, leading to local domains of [P$_4$BeO$_{16}$] pentameric clusters alternating with large open pockets, if P-P shared tetrahedral faces are to be avoided. The entire structure can be visualized as a ∞^3[Zr$_2$Be$_9$TrO$_4$]$_4$ framework where Tr symbolized a trigonal bipyramid which arise by the fusion of two tetrahedral faces of two (PO$_4$)$^{3-}$ anionic radicals.		

MCADA	GAINESITE	$\text{Na}_2\text{Zr}_2[\text{Be}(\text{PO}_4)_4]$
MCADB	MCCRILLISITE	$\text{NaCsZr}_2[(\text{Be},\text{Li})(\text{PO}_4)_4] \cdot 1-2\text{H}_2\text{O}$
MCADC	SELWYNITE	$\text{NaKSr}_2[(\text{Be},\text{Al})(\text{PO}_4)_4] \cdot 2\text{H}_2\text{O}$

SERIES E **PAHASAPAITE, cub/I23.** The structure is based upon a three-dimensional berylllophosphate tetrahedral framework, which may be visualized as an array of truncated cubo-octahedra (α cages) linked together through flat octagonal prisms (double 8-rings). There are two indential, interpenetrating systems of cages and prisms related to one another by the body-centering translation of the lattice. Access from the cages of one system to those of the other is through shared 6-rings. Both polyhedra (cages and prisms) are strongly distorted, and the entire tetrahedral framework is a distorted form of the ideal zeolite rho framework. Structurally related to faujasite. The structure of wilancookite is based on zeolite-RHO cages. The tetrahedral framework is distorted and built by an array of truncated cube-octahedralc ages, linked together through octagonal prisms strongly distorted.

MCAEA	PAHASAPAITE	$\text{Li}_8(\text{Ca},\text{Li},\text{K})_{10.5}\text{Be}_{24}(\text{PO}_4)_{24} \cdot 38\text{H}_2\text{O}$
MCAEB	WILANCOOKITE	$(\text{Ba},\text{K},\text{Na})_8(\text{Ba},\text{Li},\square)_6\text{Be}_{24}\text{P}_{24}\text{O}_{96} \cdot 32\text{H}_2\text{O}$

SERIES F **HOPEITE SERIES, orth/Pnma.** Structure consists of Zn tetrahedra and P tetrahedra sharing corners to form sheets of 3- and 4-membered rings // (010). In parahopeite, the two types of tetrahedra form sheets of 4-membered rings // (010) alternating with sheets of $\text{ZnO}_2(\text{H}_2\text{O})_4$ octahedra. The structure of davidlloydite consists of sheets of corner-sharing AsO_4 and ZnO_4 tetrahedra which are linked by $\text{ZnO}_2(\text{H}_2\text{O})_4$ octahedra. The structure is related to parahopeite.

MCAFA	HOPEITE	$\text{Zn}_3(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$	orth/Pnma
MCAFB	PARAHOPEITE	$\text{Zn}_3(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$	tric/P $\bar{1}$
MCAFC	ARSENHOPEITE	$\text{Zn}_3(\text{AsO}_4)_2 \cdot 4\text{H}_2\text{O}$	
MCAFD	DAVIDLLOYDITE	$\text{Zn}_3(\text{AsO}_4)_2 \cdot 4\text{H}_2\text{O}$	tric/P $\bar{1}$
MCAFE	NIZAMOFFITE	$\text{Mn}^{2+}\text{Zn}_2(\text{PO}_4)_2(\text{H}_2\text{O})_4$	orth/Pnma
MCAFF	REAPHOOKHILLITE	$\text{MgZn}_2(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$	tric/P $\bar{1}$

SERIES G **WARIKAHNITE, tric/P $\bar{1}$.** Structure consists of chains of edge-sharing Zn octahedra and ZnO_4 tetrahedra // [101] which are linked to adjoining chains by edge-sharing and by As tetrahedra.

MCAGA	WARIKAHNITE	$\text{Zn}_3(\text{AsO}_4)_2 \cdot 2\text{H}_2\text{O}$
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SERIES H **PHOSPHOPHYLLITE, mon/P21/c.** Structure consists of puckered sheets // (100) of 3- and 4-membered rings of corner-sharing Zn and P tetrahedra are interleaved with sheets of face-sharing Fe octahedra.

MCAHA	PHOSPHOPHYLLITE	$\text{Zn}_2\text{Fe}(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$	
MCAHB	STEINMETZITE	$\text{Zn}_2\text{Fe}(\text{PO}_4)_2(\text{OH}) \cdot 3\text{H}_2\text{O}$	
MCAHC	IMA2018-051A	$\text{CaZn}_2(\text{AsO}_4)_2 \cdot 4\text{H}_2\text{O}$	mon/Pc

SERIES I **SCHOLZITE SERIES, orth/Pbc2 $_1$.** The structure consists of chains of ZnO_4 tetrahedra parallel to [001]. These chains connected to other similar chains by isolated PO_4 tetrahedra. The Ca atoms are surrounded by distorted oxygen octahedra which are formed by one oxygen from each of four different PO_4 tetrahedra and two oxygens from two water molecules. The water molecules, in groups of four, occupy cages surrounded by two CaO_6 octahedra and four PO_4 tetrahedra. Structure consists of chains of corner-sharing Zn tetrahedra // [001] which are connected into slabs // (100) by insular P tetrahedra. The slabs are linked by Ca polyhedra.

MCAIA	SCHOLZITE	$\text{CaZn}_2(\text{PO}_4)_2(\text{OH})_2$	
MCAIB	PARASCHOLZITE	$\text{CaZn}_2(\text{PO}_4)_2(\text{OH})_2$	mon/Cc or C2/c

SERIES J **KEYITE SERIES, mon/I2/a.** The structure consists of a complex arrangement of the atoms. There are two Cu^{2+} sites; Cu(1) is octahedrally coordinated by four oxygen atoms and two H_2O groups, and

is exactly half-occupied by Cu^{2+} ; Cu(2) is coordinated by four oxygen atoms in a square-planar arrangement. There is one Zn site, occupied by Zn and minor Cu, and octahedrally coordinated by six oxygen atoms. There is one Cd site occupied dominantly by Cd and coordinated by six oxygen atoms in a trigonal prismatic arrangement. There are two As sites, both occupied by As^{5+} and tetrahedrally coordinated by oxygen atoms. The $\text{Cu}(1)_{\phi_6}$ octahedra share corners to form a $[\text{Cu}\phi_5]$ chain in which only alternate octahedra are occupied. This chain is flanked by arsenate tetrahedra and CdO_6 polyhedra to form a heteropolyhedral ribbon that extends along the c axis. These ribbons are cross-linked by CuO_4 groups into a sheet parallel to (100). These sheets alternate with parallel sheets of $[\text{Zn}_2\text{O}_{10}]$ octahedral dimers and arsenate tetrahedra to form a very complex heteropolyhedral framework. Structure consists of Cd_2 trigonal prisms, Zn_4 octahedral dimers, $\text{CuO}_4(\text{H}_2\text{O})_2$ octahedra and Cu square planes share corners with six As tetrahedra to form two kinds of sheets // (100): $\text{Zn}_{2+2} \text{As}_4$, and $\text{Cd}_2\text{CuCu}_2\text{As}_2$; the sheets are cross-linked along [100], but form strong polyhedral chains // [001], and layers // (010) and (001).

MCAJA	KEYITE	$\text{Cu}_3^{2+}(\text{Zn,Cu})_4\text{Cd}_2(\text{AsO}_4)_6(\text{H}_2\text{O})_2$
MCAJB	ERIKAPOHLITE	$\text{Cu}_3^{2+}(\text{Zn,Cu})_4\text{Ca}_2(\text{AsO}_4)_6(\text{H}_2\text{O})_2$

SERIES K PUSHCHAROVSKITE, tric/P1. Structure consists of edge- and corner-sharing Cu square dipyramids, Cu square pyramids and As tetrahedra forming thick sheets // (110); the sheets are linked by additional Cu square pyramids; water molecules are accommodated between the sheets.

MCAKA	PUSHCHAROVSKITE	$\text{Cu}_2[\text{AsO}_3\text{OH}](\text{H}_2\text{O})$
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TYPE B Structures with only Medium-sized cations, $\text{RO}_4:\text{H}_2\text{O} = 1:1$.

SERIES A SERRABRANCAITE, mon/C2/c. Isostructural with Kieserite.

MCBAA	SERRABRANCAITE	$\text{MnPO}_4 \cdot \text{H}_2\text{O}$
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SERIES B HUREAULITE SERIES, mon/C2/c. Structure consists of five edge-sharing M octahedra forming pentameters that are connected to other pentameters and to P tetrahedra by corner sharing. ■ Meisser, N., Plášil, J., Brunspurger, T., Lheur, C., Škoda, R. (2019): Giftgrubeite, $\text{CaMn}_2\text{Ca}_2(\text{AsO}_4)_2(\text{AsO}_3\text{OH})_2 \cdot 4\text{H}_2\text{O}$, a new member of the hureaulite group from Sainte-Marie-aux-Mines, Haut-Rhin Department, Vosges, France. Journal of Geosciences, 64, 73-80.

Abstract:

Giftgrubeite, ideally $\text{CaMn}_2\text{Ca}_2(\text{AsO}_4)_2(\text{AsO}_3\text{OH})_2 \cdot 4\text{H}_2\text{O}$, is a new mineral occurring at the Giftgrube Mine, St Jacques vein, Rauenthal, Sainte-Marie-aux-Mines, Haut-Rhin Department, Grand Est, France and named after the type-locality. Giftgrubeite is mostly associated with Mn-bearing calcite, native arsenic, löllingite, and picroparmacolite. It is a recent secondary mineral, formed by alteration of the arsenical vein minerals after mining. Giftgrubeite occurs in colorless, rarely pearl white to pale yellow rosettes of brittle tabular crystals flattened on {1 0 0} and up to 0.2 mm in size. Hardness (Mohs) is $3 \frac{1}{2}$, D_{meas} is 3.23(2) g·cm⁻³, D_{calc} is 3.24 g·cm⁻³. The new mineral is biaxial negative without pleochroism. Measured 2V angle is $\sim 72^\circ$ and calculated 2V angle is 75.1° ; the refractive indices measured in white light are: $\alpha = 1.630(2)$, $\beta = 1.640(2)$ and $\gamma = 1.646(2)$. The most prominent Raman bands are at 902, 885, 864, 851, 824, 797 and 759 cm⁻¹. The empirical chemical formula is $(\text{Ca}_{3.04}\text{Mn}_{1.30}\text{Mg}_{0.38}\text{Fe}_{0.28})\Sigma 5.00(\text{AsO}_4)_{1.99}(\text{AsO}_3\text{OH})_2 \cdot 4\text{H}_2\text{O}$. Giftgrubeite is monoclinic, C2/c, Z = 4, with $a = 18.495(7)$ Å, $b = 9.475(4)$ Å, $c = 9.986(4)$ Å, $\beta = 96.79(3)^\circ$ and $V = 1737.7(12)$ Å³. The six strongest lines in the X-ray powder diffraction pattern are [d in Å (l)(hkl)]: 3.33 (100)(-2 2 2), 3.18 (80)(2 2 2), 2.414 (60)(7 1 1), 4.80 (50)(-3 1 1), 4.65 (50)(-2 0 2) and 3.05 (50)(1 1 3). The structure of giftgrubeite was solved from the crystal retrieved from the type specimen by the charge-flipping algorithm. Giftgrubeite contains a well-known structure type parent to the hureaulite group of minerals, which is based upon an octahedral edge-sharing pentamers of M_2+ -polyhedra, pentamers linked into a loose framework by sharing corners with octahedra in adjacent pentamers and further by AsO_4 and AsO_3OH tetrahedra. There are three distinct octahedral sites: M1, M2, and M3. In the case of giftgrubeite, two of the M sites were found to be fully occupied by Ca; namely M1 and M3. The M2 site was then found to contain Mg besides dominant Mn. Considering the refined site occupancies, the structural formula for giftgrubeite is $\text{Ca}_3\text{Mn}_{1.30}\text{Mg}_{0.70}(\text{AsO}_4)_2(\text{AsO}_3\text{OH})_2(\text{H}_2\text{O})_4$. Giftgrubeite is an ordered intermediate member between villyaellenite, $\text{MnMn}_2\text{Ca}_2(\text{AsO}_3\text{OH})_2(\text{AsO}_4)_2 \cdot 4\text{H}_2\text{O}$ and sainfeldite, $\text{CaCa}_2\text{Ca}_2(\text{AsO}_4)_2(\text{AsO}_3\text{OH})_2 \cdot 4\text{H}_2\text{O}$.

MCBBA	VILLYAELLENITE	$\text{Mn}_5(\text{H}_2\text{O})_4(\text{AsO}_3\text{OH})_2(\text{AsO}_4)$
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MCBBB	HUREAULITE	$Mn_5(H_2O)_4[PO_3OH]_2[PO_4]$
MCBBC	SAINFELDTITE	$Ca_5[(AsO_3OH)_2/(AsO_4)_2] \cdot 4H_2O$
MCBBD	IRHTEMITE	$Ca_4Mg[(AsO_3OH)_2/(AsO_4)_2] \cdot 4H_2O$
MCBBE	NYHOLMITE	$Cd_3Zn_2(AsO_3OH)_2(AsO_4)_2 \cdot 4H_2O$
MCBBF	MIGUELROMEROITE	$Mn_5(H_2O)_4(AsO_3OH)_2(AsO_4)$
MCBBG	CHONGITE	$Ca_3Mg_2(AsO_4)_2(AsO_3OH)_2 \cdot 4H_2O$
MCBBH	GIFTGRUBEITE	$CaMn_2Ca_2(AsO_4)_2(AsO_3OH)_2 \cdot 4H_2O$

SERIES C **KRAUTITE-KORITNIGITE SERIES, tric/P1 or P1.** Structure consists of edge-sharing chains of M octahedra // [101] which are linked into sheets // (010) by As tetrahedra. The structure of geminite consists of four unique Cu^{2+} sites, each coordinated by six anions in a [4 + 2] distorted octahedral arrangement. There are four unique As^{5+} sites, each coordinated by three oxygen atoms and an OH group in a distorted tetrahedral arrangement; the three As-O distances are shorter than the As-OH distances in each tetrahedron. The Cu_{ϕ_6} polyhedra share edges to form $[Cu_{\phi_4}]$ chains parallel to [010]; As_{ϕ_4} tetrahedra cross-link these chains into sheets parallel to (001), and there are two symmetrical distinct but topologically identical sheets in the structure. These sheets are linked into a three-dimensional structure by a network of H bonds.

MCBCA	FLUCKITE	$CaMnH_2(AsO_4)_2 \cdot 2H_2O$
MCBCB	YVONITE	$Cu(AsO_3OH)_2H_2O$ Am Min. 98-383
MCBCC	KRAUTITE	$Mn(H_2O)(AsO_3OH)$ mon/P2 ₁
MCBCD	KORITNIGITE	$(Zn,Co)[AsO_3(OH)] \cdot H_2O$
MCBCE	COBALTKORITNIGITE	$(Co,Zn)[AsO_3(OH)] \cdot H_2O$
MCBCF	GEMINITE	$Cu_2[AsO_3OH](H_2O)$
MCBCG	MAGNESIOKORITNIGITE	$Mg(AsO_3OH) \cdot H_2O$
MCBCH	MAGNESIOFLUCKITE	$CaMg(AsO_3OH)_2(H_2O)_2$

SERIES D **CARDITE, orth/Cmcm.**

MCBDA	CARDITE	$Zn_{5.5}(AsO_4)_2(AsO_3(OH))_3 \cdot 3H_2O$
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TYPE C **Structures with only Medium-sized Cations, $RO_4:H_2O = 1:1.5$.**

SERIES A **PHOSPHOFERRITE SERIES, orth/Pbna.** Structure consists of trimers of edge-sharing (Fe,Mn) octahedra forming chains // [001] that are linked by phosphate tetrahedra to form a framework with water molecules in the cavities.

MCCAA	REDDINGITE	$(Mn,Fe)_3(PO_4)_2 \cdot 3H_2O$
MCCAB	PHOSPHOFERRITE	$(Fe,Mn)_3(PO_4)_2 \cdot 3H_2O$
MCCAC	GARYANSELLITE	$(Mg,Fe)_6(PO_4)_4(OH)_3 \cdot 3H_2O$
MCCAD	KRYZHANOVSKITE	$MnFe_2(PO_4)_2(OH)_2 \cdot H_2O$
MCCAE	LANDESITE	$(Mn,Mg)_9Fe_3(PO_4)_8(OH)_3 \cdot 9H_2O$
MCCAF	CORREIANEVESITE	$Fe^{2+}Mn^{2+}_2(PO_4)_2 \cdot 3H_2O$

SERIES B **KAATIALAITE SERIES, mon/P2₁ or P2₁/m.** Structure consists of Fe octahedra sharing corners with arsenate tetrahedra to form columns // [001] with interstitial zeolitic water molecules.

MCCBA	KAATIALAITE	$Fe(HAsO_4)_3 \cdot 3H_2O$
MCCBB	KANKITE	$Fe(AsO_4) \cdot 3H_2O$
MCCBC	HILARIONITE	$Fe_3^{3+}(SO_4)(AsO_4)(OH) \cdot 6H_2O$
MCCBD	CURRIERITE	$Na_4Ca_3MgAl_4(AsO_3OH)_{12} \cdot 9H_2O$

TYPE D Structures with only Medium-sized Cations, RO₄:H₂O = 1:2.

SERIES A METAVARISCITE SERIES, mon/P2₁/n. The structure is a framework consisting of interlinked AlO₄(H₂O)₂ octahedra and PO₄ tetrahedra. In detail, the tetrahedral sheet consists of zig-zag chains of corner sharing AlO₄ tetrahedra running parallel to the c axis connected by shared corners with PO₄ groups to produce a complex sheet of three and four-membered rings.

MCDAA	METAVARISCITE	AlPO ₄ ·2H ₂ O	
MCDAB	KOLBECKITE	(Sc,V,Fe,Al)((P)O ₄)·2H ₂ O	
MCDAC	PHOSPHOSIDERITE	FePO ₄ ·2H ₂ O	
MCDAD	PARASCORODITE	FeAsO ₄ ·2H ₂ O	hex/trig
MCDAE	BONACINAITE	Sc(AsO ₄) ₂ ·2H ₂ O	

SERIES B VARISCITE SERIES, orth/Pcab. The structure is a framework consisting of interlinked AlO₄(H₂O)₂ octahedra and PO₄ tetrahedra.

MCDBA	MANSFIELDITE	AlAsO ₄ ·2H ₂ O	
MCDBB	SCORODITE	FeAsO ₄ ·2H ₂ O	
MCDBC	STRENGITE	FePO ₄ ·2H ₂ O	
MCDBD	VARISCITE	AlPO ₄ ·2H ₂ O	
MCDBE	YANOMAMITE	InAsO ₄ ·2H ₂ O	

SERIES C LUDLAMITE-STERLINGHILLITE SERIES, mon/P2₁a. Structure consists of trimers of three edge-sharing M octahedra that are linked by RO₄ tetrahedra to form slabs // (001).

MCDCA	STERLINGHILLITE	Mn ₃ (AsO ₄) ₂ ·4H ₂ O	
MDCDB	LUDLAMITE	Fe ₃ (PO ₄) ₂ (H ₂ O) ₄	

SERIES D ROLLANDITE, orth/Pnma. Structure consists of edge-sharing CuO₆ octahedra forming open sheets // (010) to which are attached arsenate tetrahedra. The sheets are linked into a framework by chains // [100] of CuO₅ square pyramids and by H bonding from water molecules in the channels // [100].

MCDDA	ROLLANDITE	Cu ₃ (AsO ₄) ₂ ·4H ₂ O	
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SERIES E BETTERTONITE, mon/C2/c. Grey, I.E., Kampf, A.R., Price, J.R. and MacRae, C.M. (2015) Bettertonite, IMA 2014-074. CNMNC Newsletter No. 23, February 2015, page 55; *Mineralogical Magazine*, 79, 51-58. Chemically similar to liskeardite. **The structure was solved using SHELXT and refined using SHELXL (Sheldrick, 2008). Partially occupied water molecule sites were located in difference Fourier maps. The final refinement incorporated anisotropic displacement parameters for all heteropolyhedral layer atoms and an overall isotropic displacement parameter for the partially occupied intralayer water sites. The agreement factors are $R_1 = 0.083$ for 2164 observed reflections with $F > 4\sigma(F)$ and 0.119 for all 3005 reflections to a resolution of 1.0 Å. Refined coordinates, equivalent isotropic displacement parameters and site occupancies are given in Table 3. Polyhedral bond lengths, reported in Table 4, are within the expected normal ranges for the metal atoms.**

Bettertonite has a layer structure, with the layers parallel to (010) as shown in Figure 2. The layers comprise hexagonal rings of edge-shared Al-centred octahedra that are interconnected by corner-sharing with AsO₄ tetrahedra. The layers are strongly undulating and their packing produces large channels along [010], centred on the cell axes at $x = 0$, $z = \frac{1}{2}$ and $x = \frac{1}{2}$, $z = 0$. The channels are filled with water molecules, which become progressively disordered as their distance from the channel walls increases.

MCDEA	BETTERTONITE	Al ₆ (AsO ₄) ₃ (OH) ₉ ·16H ₂ O	
MCDEB	PENBERTHYCROFTITE	[Al ₆ (AsO ₄) ₃ (OH) ₉ (H ₂ O) ₅] ₂ ·8H ₂ O	

SERIES F VANINIITE, *mon/P2₁/c*.
MCDFA VANINIITE $\text{Ca}_2\text{Mn}^{2+}_3\text{Mn}^{3+}_2\text{O}_2(\text{AsO}_4)_4 \cdot 2\text{H}_2\text{O}$

SERIES G SMAMITE, *tric/P1*.
MCDGA SMAMITE $\text{Ca}_2\text{Sb}(\text{OH})_4[\text{H}(\text{AsO}_4)_2] \cdot 6\text{H}_2\text{O}$

TYPE E Structures with only Medium-sized Cations, RO₄:H₂O ≤ 1:2.5.

SERIES A LINDACKERITE SERIES, tric/P1. The structure contains M octahedra sharing corners with AsO₄ and AsO₃OH tetrahedra to form a 3-dimensional framework. The bond valence calculation reveals that one O position represents OH group and 7 others water molecules. The substituting Co and Ni atoms enter presumably the special position at ½, 0, 0 denoted as M. of other two position Cu(1) is five-coordinated in configuration of square pyramid, whereas Cu(2) is octahedrally coordinated. Edge-sharing Cu(1) pyramids and Cu(2) octahedral form infinite bands // to [110]. The adjacent bands are linked together by two kinds of As tetrahedra. As a result a layer // to (001) is formed. The adjacent layers are connected via M atoms. In addition, the M position is surrounded by eight half-occupied water molecules in four independent positions. This arrangement can be interpreted as two interpenetrating octahedral (with common corners shared with As(2) tetrahedra) turned by ~ 45°.

MCEAA	CHUDOBAITE	$(\text{Mg}, \text{Zn})_5(\text{AsO}_4)_2(\text{AsO}_3\text{OH})_2(\text{H}_2\text{O})_8 \cdot 2\text{H}_2\text{O}$
MCEAB	GEIGERITE	$\text{Mn}_5(\text{AsO}_4)_2(\text{AsO}_3\text{OH})_2(\text{H}_2\text{O})_8 \cdot 2\text{H}_2\text{O}$
MCEAC	LINDACKERITE	$(\text{Cu}, \text{Co}, \text{Ni})\text{Cu}_4(\text{AsO}_4)_2(\text{AsO}_3\text{OH})_2 \cdot 9\text{H}_2\text{O}$
MCEAD	PRADETITE	$(\text{Co}, \text{Cu}, \text{Ni})(\text{Cu}_4(\text{AsO}_4)_2(\text{AsO}_3\text{OH})_2) \cdot 9\text{H}_2\text{O}$
MCEAE	VESELOVSKYITE	$(\text{Zn}, \text{Cu}, \text{Co})\text{Cu}_4(\text{AsO}_4)_2(\text{AsO}_3\text{H})_2 \cdot 9\text{H}_2\text{O}$
MCEAF	ONDRUSITE	$\text{CaCu}_4(\text{AsO}_4)_2(\text{AsO}_3\text{OH})_2 \cdot 10\text{H}_2\text{O}$
MCEAG	KLAJITE	$\text{MnCu}_4(\text{AsO}_4)_2(\text{AsO}_3\text{OH})_2 \cdot 9\text{-}10\text{H}_2\text{O}$
MCEAH	HLOUSEKITE	$(\text{Ni}, \text{Co})\text{Cu}_4(\text{AsO}_4)_2(\text{AsO}_3\text{OH})_2 \cdot 9\text{H}_2\text{O}$

SERIES B NEWBERYITE-BRASSITE SERIES, orth/Pbca. Structure consists of insular Mg octahedra which are connected by corners to P tetrahedra to form layers // (010); the layers are linked by H bonds. In brassite, Mg octahedra share corners with As tetrahedra to form chains // [010]; the chains are linked into (001) layers by H bonds.

MCEBA	BRASSITE	$\text{MgH}(\text{AsO}_4) \cdot 4\text{H}_2\text{O}$ Pbca
MCEBB	NEWBERYITE	$\text{MgHPO}_4 \cdot 3\text{H}_2\text{O}$
MCEBC	DORFMANITE	$\text{Na}_2\text{HPO}_4 \cdot 2\text{H}_2\text{O}$ (structure not known)

SERIES C RÖSSLERITE SERIES, mon/C2/c. Structure consists of insular Mg(H₂O)₆ and P tetrahedra which are linked by H bonds to form a 3-dimensional framework.

MCECA	RÖSSLERITE	$\text{MgHAsO}_4 \cdot 7\text{H}_2\text{O}$
MCECB	PHOSPHORRÖSSLERITE	$\text{MgHPO}_4 \cdot 7\text{H}_2\text{O}$

SERIES D KONINCKITE, tetr/P4₁2₁2. The structure is a heteropolyhedral framework with zeolite-like tunnels along [001]. The DFT computations were used to locate water molecules in the channels and to complete the structural description. Cesàro (1883-1884) Soc. géol. Belgique, Ann. Mem.: 11: 247.

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MCEDA KONINCKITE $\text{Fe}^{3+}[\text{PO}_4] \cdot 3\text{H}_2\text{O}$

SERIES E SWITZERITE SERIES, $\text{mon}/P2_1/a$. The structure consists of a sheet of composition $[\text{Mn}_4\text{O}_{10}(\text{H}_2\text{O})_4]$ which lies parallel to (001), and which is similar to the atomic sheet by vertex-sharing, forming a complex slab of composition $[\text{Mn}_6\text{O}_{14}(\text{H}_2\text{O})_{10}]_2$. Phosphate groups knit together the slabs internally to form a neutral layer. Between these neutral layers are free water molecules, eight per cell, bonded to the layers by H bonds. Switzerite transforms to metaswitzerite by expulsion of 3/4 of the free water molecules and condensation of the neutral layers along c into a framework structure. Structure consists of Mn octahedra sharing edges and corners to form layers of 6-membered rings // (001). These layers are linked by P tetrahedra and H bonds. The structure of castellaroite consists of four different arsenate tetrahedra, five different MnO_6 octahedra and one MnO_5 square pyramid. The octahedra centered by Mn1, Mn2, Mn3 and Mn4 share edges forming kinked chains // to [100]. The chains are linked to each other by coner-sharing, forming sheets // to [100]. All four arsenate tetrahedra corner-link with octahedra in the sheet, forming a heteropolyhedral layer. Mn_5O_6 - Mn_6O_5 edge-sharing dimers are located between the heteropolyhedral layers and share corners with octahedra and tetrahedra in adjacent layers, thereby linking the layers in the [001] direction.

MCEEA SWITZERITE $(\text{Mn},\text{Fe})_3(\text{PO}_4)_2 \cdot 7\text{H}_2\text{O}$

MCEEB METASWITZERITE $(\text{Mn},\text{Fe})_3(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$

MCEEC CASTELLAROITE $\text{Mn}^{2+}_3(\text{AsO}_4)_2 \cdot 4\text{H}_2\text{O}$

SERIES F STEIGERITE SERIES, $\text{mon}/P2_1$ or $P2_1/m$. Structures not known.

Palache, C., Berman, H., & Frondel, C. (1951), *The System of Mineralogy of James Dwight Dana and Edward Salisbury Dana, Yale University 1837-1892, Volume II*. John Wiley and Sons, Inc., New York, 7th edition, revised and enlarged, 1124 pp.: 1049-1050.

Ankinovich, E.A., F.A. Kurmakaeva, and I.S. Zazubina (1987) Steigerite and vanalite from carbonaceous-siliceous vanadium-bearing formations of northwestern Kara-Tau (southern Kazakhstan). *Zapiski Vserossiyskogo Mineralogicheskogo Obshchestva*: 116: 100–113 (in Russian with English abstract).

MCEFA .open

MCEFB STEIGERITE $\text{Al}(\text{VO}_4) \cdot 3\text{H}_2\text{O}$

SERIES G VIVIANITE SERIES, $\text{mon}/C2/m$. The structure is based on a distorted closest packing of oxygen and water molecules, with Fe atoms in octahedral voids, and P atoms in tetrahedral voids. The transition metals are randomly distributed over insular single and double (edge-sharing) octahedral groups of O atoms and water molecules connected by AsO_4 tetrahedra to form complex slabs parallel to (010). These sheets are held together by H bonding alone. *American Mineralogist* (1962): 47: 637-648. *American Mineralogist* (1979): 64: 713.

MCEGA ANNABERGITE $\text{Ni}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$

MCEGB ARUPITE $\text{Ni}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$

MCEGC BARICITE $(\text{Mg},\text{Fe})_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$ CM01-1317

MCEGD ERYTHRITE $\text{Co}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$

MCEGE HÖRNESITE $\text{Mg}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$

MCEGF KÖTTIGITE $\text{Zn}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$

MCEGG PARASYMPLESITE $\text{Fe}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$

MCEGH VIVIANITE $\text{Fe}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$

MCEGI BOBIERRITE $\text{Mg}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$

MCEGJ MANGANESE-HÖRNESITE $(\text{Mn},\text{Mg})_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$

MCEGK SANTABARBARAITE $\text{Fe}^{3+}_3(\text{PO}_4)_2(\text{OH})_2 \cdot 5\text{H}_2\text{O}$

MCEGL	SCHODERITE	$\text{Al}_2(\text{PO}_4)(\text{VO}_4) \cdot 8\text{H}_2\text{O}$
MCEGM	FERRISYMPLESITE	$\text{Fe}_3(\text{AsO}_4)_2(\text{OH})_3 \cdot 5\text{H}_2\text{O}$
MCEGN	METAKÖTTIGITE	$(\text{Zn}, \text{Fe}, \text{Fe})_3(\text{AsO}_4)_3 \cdot 8\text{H}_2\text{O}$
MCEGO	Open	
MCEGP	METASCHODERITE	$\text{Al}_2(\text{PO}_4)(\text{VO}_4) \cdot 6\text{H}_2\text{O}$
MCEGQ	PAKHOMOVSKYITE	$\text{Co}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$
MCEGR	BABANEKITE	$\text{Cu}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$

SERIES H MALHMOODITE SERIES, $\text{mon}/P2_1/c$. Structure of zigrasite consists of ZrO_6 octahedron which shares corners with six PO_4 tetrahedra, forming a $[\text{Zr}(\text{PO}_4)_2]$ sheet // to (001). These sheets are stacked in the c direction and dlinked by $(\text{MgO}_2(\text{H}_2\text{O})_4)$ octahedra that share O atoms with the PO_4 groups. The structure is formally a heteropolyhedral framework structure, but the linkage is weaker in the c direction, accounting for the markedd (001) cleavage.

MCEHA	MALHMOODITE	$\text{Fe}[\text{Zr}(\text{PO}_4)_2] \cdot 4\text{H}_2\text{O}$	
MCEHB	ZIGRASITE	$\text{MgZr}(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$	tric/P1
MCEHC	IMA	$\text{CaZr}(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$	

SERIES I SLAVKOVITE, $\text{tri}/P1$. The crystal structure is based upon sheets consisting of copper polyhedra linked by arsenate and hydrogen arsenate tetrahedra. The sheets ae linked by $\text{Cu}_6\text{-}\Phi$ polyhedra. In the asymmetric unit of the unit-cell, seven symmetrically independent Cu^{2+} atoms, five As^{5+} atoms and 34 O atoms were found.

MCEIA	SLAVKOVITE	$\text{Cu}_{13}(\text{AsO}_4)_6(\text{AsO}_3\text{OH})_4 \cdot 23\text{H}_2\text{O}$
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SERIES J LAPEYREITE, $\text{mon}, C2/m$. The structure consists of a three-dimentional network of CuO_5 square pyramids and AsO_4 tetrahedra with a water molecule in the structural cavities. There is some similarities to that of theoparacelsite.

MCEJA	LAPEYREITE	$\text{Cu}_3\text{O}[\text{AsO}_3(\text{OH})]_2 \cdot 0.75\text{H}_2\text{O}$
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SERIES K BURGESSITE, $\text{mon}/P2_1/n$. The structure consists of one unique As site that is 4-coordinated. Pairs of adjacent $\text{Co}\Phi_6$ octahedra share an edge to form a $[\text{Co}_2\Phi_{10}]$ dimer and AsO_4 tetrahedra link pairs of vertices in the adjacent octahedral to form a compact $[\text{Co}_2(\text{AsO}_4)_2\Phi_6]$ cluster. This cluster is one of four predicted to be the most stable of the graphical and geometrical isomers of the form. In burgessite, these clusters polymerize in the a direction t rough linkage of tetrahedron vertices to the shared edge of two octahedral of each adjacentg cluster to form a chain of the form $[\text{Co}_2(\text{H}_2\text{O})_4[\text{As}^{5+}\text{O}_3(\text{OH})]_{12}]$. These chains extend in the [100] direction andjoccur at the vertices of an ortho hom ic net. They are linked into a three-dimensional structure by H bonds that involve (OH) bonded to As.

MCEKA	BURGESSITE	$\text{Co}_2(\text{H}_2\text{O})_4[\text{AsO}_3(\text{OH})]_2 \cdot \text{H}_2\text{O}$
MCEKB	HONZAITE	$\text{Ni}_2(\text{AsO}_3\text{OH})_2 \cdot 5\text{H}_2\text{O}$

TYPE F Structures with Large and Medium-sized Cations, $\text{RO}_4:\text{H}_2\text{O} > 1:1$.

SERIES A WICKSITE SERIES, $\text{orth}/Pcab$. Structure consists of M octahedra, Na octahedra, and Ca polyhedra sharing corners with R tetrahedra to form a 3-dimensional framework.

MCFAA	GRISCHUNITE	$\text{NaCa}_2\text{Mn}(\text{Mn}, \text{Fe})_2(\text{H}_2\text{O})_2(\text{AsO}_4)_6$
MCFAB	WICKSITE	$\text{NaCa}_2(\text{Fe}, \text{Mn})_4\text{MgFe}(\text{PO}_4)_6 \cdot 2\text{H}_2\text{O}$
MCFAC	BEDERITE	$(\square, \text{Na})\text{Ca}_2(\text{Mn}, \text{Mg}, \text{Fe})_2(\text{Fe}, \text{Mg}, \text{Al})_2\text{Mn}_2(\text{PO}_4)_6(\text{H}_2\text{O})_2$
MCFAD	TASSIEITE	$(\text{Na}, \square)\text{Ca}_2(\text{Mg}, \text{Fe}, \text{Fe})_2(\text{Fe}, \text{Mg})_2(\text{Fe}, \text{Mg})_2(\text{PO}_4)_6(\text{H}_2\text{O})_2$
MCFAE	MANECKIITE	$(\text{Na}, \square)\text{Ca}_2\text{Fe}^{2+}_2(\text{Fe}^{3+}\text{Mg})\text{Mn}_2(\text{PO}_4)_6 \cdot 2\text{H}_2\text{O}$

SERIES B FAIRFIELDITE SERIES, tric/P1. Structures consist of chains // [001] of corner-sharing M octahedra and R tetrahedra, as in roselite, are connected by Ca atoms. The Ca polyhedra share edges to form sheets of 6-membered rings // (010).

MCFBA	CASSIDYITE	$\text{Ca}_2(\text{Ni,Mg})(\text{PO}_4)_2 \cdot 2\text{H}_2\text{O}$
MCFBB	COLLINSITE	$\text{Ca}_2(\text{Mg,Fe})(\text{PO}_4)_2 \cdot 2\text{H}_2\text{O}$
MCFBC	FAIRFIELDITE	$\text{Ca}_2(\text{Mn,Fe})(\text{PO}_4)_2 \cdot 2\text{H}_2\text{O}$
MCFBD	GAITITE	$\text{Ca}_2\text{Zn}(\text{PO}_4)_2 \cdot 2\text{H}_2\text{O}$
MCFBE	MESSELITE	$\text{Ca}_2(\text{Fe,Mn})(\text{PO}_4)_2 \cdot 2\text{H}_2\text{O}$
MCFBF	PARABRANDTITE	$\text{Ca}_2\text{Mn}(\text{AsO}_4)_2 \cdot 2\text{H}_2\text{O}$
MCFBG	ROSELITE-BETA	$\text{Ca}_2\text{Co}(\text{AsO}_4)_2 \cdot 2\text{H}_2\text{O}$
MCFBH	TALMESSITE	$\text{Ca}_2\text{Mg}(\text{AsO}_4)_2 \cdot 2\text{H}_2\text{O}$
MCFBI	HILLITE	$\text{Ca}_2(\text{Zn,Mg})[\text{PO}_4]_2 \cdot 2\text{H}_2\text{O}$
MCFBJ	NICKELTALMESSITE	$\text{Ca}_2\text{Ni}(\text{AsO}_4)_2 \cdot 2\text{H}_2\text{O}$
MCFBK	RRUFFITE	$\text{Ca}_2\text{Cu}(\text{AsO}_4)_2 \cdot 2\text{H}_2\text{O}$

SERIES C ROSELITE SERIES, mon/P2₁/c. Structure consists of M octahedra sharing corners with four R tetrahedra to form linear chains // [001] that are connected by Ca atoms. The Ca polyhedra share edges to forms sheets of 6-membered rings // (010). Kroehnkite belongs here.

MCFCA	BRANDTITE	$\text{Ca}_2(\text{Mn,Mg})(\text{AsO}_4)_2 \cdot 2\text{H}_2\text{O}$
MCFCB	ROSELITE	$\text{Ca}_2(\text{Co,Mg})(\text{AsO}_4)_2 \cdot 2\text{H}_2\text{O}$
MCFCC	WENDWILSONITE	$\text{Ca}_2(\text{Mg,Co})(\text{AsO}_4)_2 \cdot 2\text{H}_2\text{O}$
MCFCD	ZINCROSELITE	$\text{Ca}_2\text{Zn}(\text{AsO}_4)_2 \cdot 2\text{H}_2\text{O}$

SERIES D TSUMCORITE SERIES, mon/C2/m, C2, Cm. Structure consists of chains of edge-sharing M(O,OH)₆ octahedra // [010] which are connected by corner-sharing AsO₄ tetrahedra to form sheets // to (001). The sheets are linked by Pb atoms and H bonds. This is the natrochalcite structure type. The structure of pottsite can be described as the packing of isolated VO₄ tetrahedra, linked with heavy cations via common O atoms to form 2D blocks or double-layered (DL) structural units that are // to (001). The DL units are formed by pairs of vanadate tetrahedra arranged opposite one to each other and oriented in opposite directions. Water molecules are located in between vanadate tetrahedral groups to form [(VO₄)₄(H₂O)]³⁻ chains which are separated from adjacent chains in the (001) plane by rows of Pb and Bi cations extending in the [120] direction. The structure of pottsite is compared to that of related vanadate minerals based on isolated vanadate tetrahedra with formation of DL units. Kaliochalcite is a sulfate member of this group.

MCFDA	LOTHARMEYERITE	$\text{Ca}(\text{Mn,Zn})_2(\text{AsO}_4)_2(\text{OH,H}_2\text{O})_2$	
MCFDB	FERRILOTHARMEYERITE	$\text{Ca}(\text{Fe,Zn})_2(\text{AsO}_4)_2(\text{OH,H}_2\text{O})_2$	
MCFDC	COBALTOLOTHARMEYERITE	$\text{Ca}(\text{Co,Fe,Ni})_2(\text{AsO}_4)_2(\text{OH,H}_2\text{O})_2$	
MCFDD	GARTRELLITE	$\text{Pb}(\text{Cu,Fe})(\text{Fe,Zn,Cu})(\text{AsO}_4)_2(\text{OH,H}_2\text{O})_2$	
MCFDE	PHOSPHOGARTRELLITE	$\text{PbCuFe}(\text{PO}_4)_2(\text{OH,H}_2\text{O})_2$	
MCFDF	TSUMCORITE	$\text{Pb}(\text{Zn}_{2-x}\text{Fe}_x)(\text{AsO}_4)_2(\text{OH})_x(\text{H}_2\text{O})_{2-x}$	
MCFDG	THOMETZEKITE	$\text{Pb}(\text{Cu,Zn,Al,Fe})_2[(\text{AsO}_4)_{1.32}(\text{SO}_4)_{0.92}]_2[(\text{OH})_{0.74}(\text{H}_2\text{O})_{1.32}]_2$	
MCFDH	MOUNANAITE	$\text{PbFe}_2(\text{VO}_4)_2(\text{OH})_2$	
MCFDI	ZINGGARTRELLITE	$\text{Pb}(\text{Zn,Fe,Cu})_2(\text{AsO}_4)_2(\text{OH,H}_2\text{O})_2$	tri/P ₁
MCFDJ	KRETTNICHITE	$\text{PbMn}_2(\text{VO}_4)_2(\text{OH})_2$	
MCFDK	NICKELLOTHARMEYERITE	$\text{Ca}(\text{Ni,Fe,Co})_2(\text{AsO}_4)_2(\text{OH,H}_2\text{O})_2$	mon. C2/m
MCFDL	SCHNEEBERGITE	$\text{Bi}(\text{Co,Ni})_2(\text{AsO}_4)_2(\text{OH,H}_2\text{O})_2$	
MCFDM	NICKELSCHNEEBERGITE	$\text{Bi}(\text{Ni,Co})_2(\text{AsO}_4)_2(\text{OH,H}_2\text{O})_2$	
MCFDN	COBALTTSUMCORITE	$\text{Pb}(\text{Co,Fe})_2(\text{AsO}_4)_2(\text{OH,H}_2\text{O})_2$	

MCFDO	LUKRAHNITE	$\text{Ca}(\text{Cu},\text{Zn})(\text{Fe},\text{Zn})(\text{AsO}_4)_2(\text{OH},\text{H}_2\text{O})_2$
MCFDP	CABALZARITE	$\text{Ca}(\text{Mg},\text{Al},\text{Fe})_2(\text{AsO}_4)_2(\text{OH},\text{H}_2\text{O})_2$
MCFDQ	MANGANLOTHARMEYERITE	$\text{Ca}(\text{Mn}^{3+},\text{Mg},\square)_2(\text{AsO}_4)_2(\text{OH},\text{H}_2\text{O})_2$
MCFDR	HELMUTWINKLERITE	$\text{PbZn}_2(\text{AsO}_4)_2 \cdot 2\text{H}_2\text{O}$
MCFDS	MAWBYITE	$\text{Pb}(\text{Fe},\text{Zn})_2(\text{AsO}_4)_2(\text{OH})_{1.5}(\text{H}_2\text{O})_{0.5}$ mon/C2/m
MCFDT	POTTSITE	$(\text{Pb}_3\text{Bi})\text{Bi}(\text{VO}_4)_4 \cdot \text{H}_2\text{O}$
MCFDU	RAPPOLDITE	$\text{Pb}(\text{Co},\text{Ni},\text{Zn})_2(\text{AsO}_4)_2 \cdot 2\text{H}_2\text{O}$
MCFDV	YANCOWINNAITE	$\text{PbCuAl}(\text{AsO}_4)_2(\text{OH}) \cdot \text{H}_2\text{O}$
MCFDW	NICKELTSUMCORITE	$\text{Pb}(\text{Ni},\text{Fe})_2(\text{AsO}_4)_2(\text{H}_2\text{O},\text{OH})_2$
MCFDX	WILHELMKLEINITE	$\text{ZnFe}_2(\text{AsO}_4)_2(\text{OH})_2$
MCFDY	ARMELLINOITE-(Ce)	$\text{Ca}_4\text{Ce}^{4+}(\text{AsO}_4)_4 \cdot \text{H}_2\text{O}$

TYPE G Structures with Large and Medium-sized Cations, $\text{RO}_4:\text{H}_2\text{O} < 1:1$.

SERIES A

WALENTAITE-ANAPAITE SERIES, orth/, tric/P1. The structure consists of As, Ca, and Mg coordination polyhedra sharing edges and vertices forming corrugated (100) layers, which are linked by H bonding only. Four independent water molecules are sandwiched between adjacent layers, and build up [001] H-bonded chains. The Mg coordination octahedron and the Ca polyhedra show typical bond distances, so that no significant Ca/Mg substitution should occur in any cation site. The structures of guerinite and ferrarisite show close structural relationships to picropharmacolite. In anapaite, clusters consisting of a Fe octahedron sharing opposite corners with two P tetrahedra are linked into a framework by Ca polyhedra. The crystal structure of walentaite, originally reported as a calcium iron arsenate phosphate, has been determined and the As has been found to be predominantly in the trivalent state, as AsO_3 trigonal pyramids and as As_3O_6 trimeric clusters. The mineral has body-centred orthorhombic symmetry with $a = 26.188(5)$, $b = 7.360(2)$, $c = 10.367(2)$ Å. The structure was solved in space group Imma using synchrotron single-crystal diffraction data and refined to $R_1 = 0.054$ for 1454 observed reflections. The walentaite structure is based on the stacking of heteropolyhedral layers along [100] with the layers held together by hydrogen bonds to interlayer hydrated cations $\text{M}(\text{H}_2\text{O})_6$, $\text{M}=\text{Mn}^{2+}$, Fe^{2+} , Ca^{2+} , Na^+ . The layers, of composition $\text{Fe}_3+3(\text{P}0.84\text{As}0.16\text{O}_4)_2(\text{O},\text{OH})_6$, have the same topology of corner-connected octahedra and tetrahedra as in the alunite-super group mineral kintoreite-1c. Unit-cell-scale twinning of the kintoreite-like layers gives a saw-tooth aspect to the layers. The AsO_3 , As_3O_6 and $(\text{Ca},\text{Na})\text{O}_6$ groups are attached to the surface of the layers. Although the kintoreite-like heteropolyhedral layers are fully ordered in Imma , the surface-attached groups and the interlayer hydrated cations are highly disordered, so the Imma model represents the average structure. Models for the local ordering have been developed from interpretation of the partial site occupancies and splitting of the disordered atoms. The crystal structure results have been combined with electron microprobe analyses to obtain a new formula for walentaite, $\text{Fe}_3+3(\text{P}0.84\text{As}0.16\text{O}_4)_2(\text{O},\text{OH})_6\text{As}_3+2.56\text{Ca}0:42\text{Na}0:28\text{Mn}^{2+}0.35\text{Fe}+0.30\text{O}6.1(\text{OH})0.9(\text{H}_2\text{O})0.9$, in which 89% of the As is present as As^{3+} .

MCGAA	WALENTAITE	$\text{H}(\text{Ca},\text{Mn},\text{Fe})\text{Fe}_3(\text{AsO}_4, \text{PO}_4)_7\text{H}_2\text{O}$
MCGAB	ANAPAITE	$\text{Ca}_2\text{Fe}(\text{H}_2\text{O})_4[\text{PO}_4]_2$
MCGAC	PICROPHARMACOLITE	$\text{Ca}_4\text{Mg}(\text{H}_2\text{O})_7(\text{AsO}_3\text{OH})_2(\text{AsO}_4)_2 \cdot 4\text{H}_2\text{O}$
MCGAD	NATROWALENTAITE	$[\text{Fe}^{3+}_{0.5}\text{Na}_{0.5}(\text{H}_2\text{O})_6][\text{NaAs}^{3+}_2(\text{Fe}^{3+}_{2.33}\text{W}^{6+}_{0.67})(\text{PO}_4)_2\text{O}_7]$ orth/ Imma

SERIES B

FAHLEITE, orth/. Structures not known. Barahonaite is mon/P2/a or Pa. American Mineralogist: 74: 501-502. Yakhontova L.K. (1956), Dokl. Akad. Nauk. SSSR, 109(4): 849. American Mineralogist (1957): 42: 307. American Mineralogist (1974): 59: 1141. Smith, L. K., Han, K. N. & Lawson, F. (1977): On the occurrence of smolyaninovite in the Mount Cobalt deposit, in north-western Queensland, Australia. Mineralogical Magazine 41, 385-388. Neues Jahrbuch für Mineralogie, Monatshefte (1996): 97-102. Konstitutsia I svoistva mineratov: 7: 120-123. American Mineralogist (1989): 74: 502. Viñals, J., Jambor, J.L., Raudsepp, M., Roberts, A.C., Grice, J.D., Kokinos, M., Wise, W.S. (2008): Barahonaite-(Al) and barahonaite-(Fe), new Ca-Cu arsenate mineral

species, from Murcia Province, southeastern Spain, and Gold Hill, Utah. Canadian Mineralogist, 46, 205-217. Viñals, J., Jambor, J.L., Raudsepp, M., Roberts, A.C., Grice, J.D., Kokinos, M., Wise, W.S. (2008): Barahonaite-(Al) and barahonaite-(Fe), new Ca-Cu arsenate mineral species, from Murcia Province, southeastern Spain, and Gold Hill, Utah. Canadian Mineralogist, 46, 205-217.

MCGBA	FAHLEITE	$Zn_5CaFe_2(AsO_4)_6 \cdot 14H_2O$
MCGBB	SMOIYANINOVITE	$Co_5CaFe_2(AsO_4)_6 \cdot 14H_2O$
MCGBC	BARAHONAITE-Fe	$(Ca,Cu,Na,Fe,Al)_{12}Fe_2(AsO_4)_8(OH,Cl)_x \cdot nH_2O$ n ~ 16-18
MCGBD	BARAHONAITE-Al	$(Ca,Cu,Na,Fe,Al)_{12}Al_2(AsO_4)_8(OH,Cl)_x \cdot nH_2O$ n ~ 16-18

SERIES C **FRANCOANELLITE SERIES, trig/R3c or R3c.** Structure consists of corner-sharing biphosphate tetrahedra and Al octahedra forming sheets // (0001); phosphate groups are accommodated in the cavities; the sheets are linked by H-bonding to form water molecules. The structure for gengenbachite consist of FeO_6 octahedra and phosphate tetrahedral forming a three-dimensional framework with 8-membered ring channels running along the [100], [010] and [110] directions. CM2013-223. In the structure of camaronesite (R1 = 2.28% for 1138 Fo > 4sF), three types of Fe octahedra are linked by corner sharing with (PO3OH) tetrahedra to form polyhedral layers perpendicular to c with composition $[Fe^{3+}(H_2O)_2(PO_3OH)]$. Two such layers are joined through SO_4 tetrahedra (in two half-occupied orientations) to form thick slabs of composition $[Fe^{3+}(H_2O)_2(PO_3OH)]_2(SO_4)$. Between the slabs are partially occupied H_2O groups. The only linkages between the slabs are hydrogen bonds. The most distinctive component in the structure consists of two Fe octahedra linked to one another by three PO_4 tetrahedra yielding an $[Fe_2(PO_4)_3]$ unit. This unit is also the key component in the sodium super-ionic conductor (NASICON) structure and has been referred to as the lantern unit. The polyhedral layers in the structure of camaronesite are similar to those in the structure of taranakite. The Raman spectrum exhibits peaks consistent with sulfate, phosphate, water and OH groups.

MCGCA	FRANCOANELLITE	$H_6(K,Na)_3(Al,Fe)_2(PO_4)_8 \cdot 13H_2O$
MCGCB	TARANAKITE	$(K,NH_4)Al_3(PO_4)_3(OH) \cdot 9H_2O$
MCGCC	GENGENBACHITE	$KFe_3H_8(PO_4)_6 \cdot 6H_2O$
MCGCD	CAMARONESITE	$Fe^{3+}_2(PO_3OH)_2(SO_4)(H_2O)_4 \cdot 1-2H_2O$ R32

SERIES D **DITTMARITE SERIES, orth/Pmn2₁.** Structure consists of corner-sharing MnO_6 octahedra to form sheets // (010) to which phosphate tetrahedra are attached at top and bottom; the sheets are linked by a layer of ammonium groups and water molecules.

MCGDA	DITTMARITE	$(NH_4)MgPO_4 \cdot H_2O$
MCGDB	NIAHITE	$(NH_4)(Mn,Mg,Ca)PO_4 \cdot H_2O$

SERIES E **SCHERTELITE-STRUVITE SERIES, orth/Pmn2₁, orth/Pbca.** Structure consists of insular clusters composed of one $Mg(H_2O)_6$ octahedron and two PO_3OH groups, like those in anapaite, which are linked by H bonding from the OH groups, water molecules and ammonium ions. In hannayite, (110) layers of corner-sharing Mg octahedra and P tetrahedra are linked by H bonds from the water molecules and ammonium ions. In Struvite, insular Mg octahedra, P tetrahedra and ammonium groups are linked by H bonds. In the structure of apexite, there are four components. The first (1) is a $[Na_2Mg_4(H_2O)_{14}]^{10+}$ heteropolyhedral cation cluster; (2) a trans edge-sharing chain of $Na(H_2O)_6$ octahedra; (3) an isolated PO_4 group; and (4) an isolated water group. The structural components are linked to one another only via H bonds.

MCGEA	HANNAYITE	$(NH_4)_2Mg_3H_4(PO_4)_4 \cdot 8H_2O$
MCGEB	STRUVITE	$NH_4MgPO_4 \cdot 6H_2O$
MCGEC	SCHERTELITE	$(NH_4)_2MgH_2(PO_4)_2 \cdot 4H_2O$
MCGED	STRUVITE-K	$KMgPO_4 \cdot 6H_2O$
MCGEE	HAZENITE	$KNaMg_2(PO_4)_2 \cdot 14H_2O$
MCGEF	APEXITE	$NaMg(PO_4) \cdot 9H_2O$

SERIES F **RIMKOROLGITE-BRAKHCHISARAITSEVITE SERIES, mon/P2₁/c.** Structure consists of contorted chains ~ // [100] of edge-sharing $(Mg,Fe)O_6$ octahedra which are linked by corners of octahedra to

forms sheets // (001); the sheets are linked into an open framework by edge-sharing dimmers of (Mg,Fe)O₆ octahedra and phosphate tetrahedra; Na and water molecules are accommodated in channels. The main elements are zigzag chains of the MgO₆ edge-sharing octahedral. The chains are linked via common vertices to form an octahedral sheet in which Mg atoms are located at the vertices of the 63 hexagonal net. The P tetrahedra are above and below hexagonal rings of Mg octahedral and are linked to them by sharing common O vertices. The Ba atoms and water groups are located between the sheets providing their linkage into three-dimensional structure. The structure of rimkorolgitite is closely related to that of bakhchisaraitsevite. Both structures are based on the octahedral-tetrahedral sheets of the same type. In bakhchisaraitsevite, the sheets are linked into three-dimensional framework by edge-sharing between the MgO₆ octahedra from two adjacent sheets, whereas in rimkorolgitite, there is no linkage between adjacent sheets. The structure of rimkorolgitite can be considered as bakhchisaraitsevite-like framework interrupted by the presence of large Ba cations.

MCGFA	RIMKOROLGITE	(Mg,Mn) ₅ (Ba,Sr,Ca)(PO ₄) ₄ · 8H ₂ O
MCGFB	BAKHCHISARAITSEVITE	[Na ₂ (H ₂ O) ₂]{(Mg _{4.5} Fe _{0.5})(PO ₄) ₄ (H ₂ O) ₅ }

SERIES G **CATTIITE, tric/P1. Structure not known.** Britvin, S.N., G. Ferraris, G. Ivaldi, A.N. Bogdanova & N.V. Chukanov (2002) Cattiite, Mg₃(PO₄)₂·22H₂O, a new mineral from Zhelezny mine (Kovdor Massif, Kola Peninsula, Russia). Neues Jahrbuch für Mineralogie, Monatshefte 2002: 160-168. Zeitschrift für Kristallographie: 155: 53-64.

MCGGA	CATTIITE	Mg ₃ [PO ₄] ₂ ·22H ₂ O
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SERIES H **LIVERSIDGEITE, tric/P1. The structure is based on two distinct, infinite zigzag chains of edge-sharing Zn₆ octahedra that extend in the a direction. The chains link to each other via common corners and also via corner-sharing PO₄ tetrahedra, forming sheets // to the (011) plane. The sheets link via [Zn₂₈] dimeric building units, comprising edge-sharing Zn₅ trigonal bipyramids and Zn₄ tetrahedra, resulting in an open framework. Large ellipsoidal channels extend along the a direction and are occupied by interstitial water groups and the H atoms of the water groups that coordinate to the Zn cations. An extensive network of H bonds provides additional linkage between the sheets in the structure, via the interstitial water groups.**

MCGHA	LIVERSIDGEITE	Zn ₆ (PO ₄) ₄ ·7H ₂ O
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TYPE H Structures with only Large Cations.

SERIES A **STERCORITE-MUNDRABILLAITE SERIES, tric/P1. Structure consists of edge-sharing Na octahedra forming chains // [010] that are sandwiched between insular phosphate tetrahedra to form (100) layers; the layers are linked by ammonium groups and water molecules.**

MCHAA	STERCORITE	Na(NH ₄)H(PO ₄) ₃ H ₂ O
MCHAB	MUNDRABILLAITE	(NH ₄) ₂ Ca(HPO ₄) ₂ ·H ₂ O
MCHAC	SWANKNOITE	(NH ₄) ₂ Ca(HPO ₄) ₂ ·H ₂ O ortho/

SERIES B **NABAPHITE-NASTROPHITE SERIES, cub/P2₁3. Structure consists of an open framework of edge-sharing (Sr,Ba) polyhedra and Na octahedra, with interstitial phosphate tetrahedra and water molecules linked to the framework by H bonding.**

MCHBA	NABAPHITE	NaBaPO ₄ ·9H ₂ O
MCHBB	NASTROPHITE	Na(Sr,Ba)PO ₄ ·9H ₂ O

SERIES C **HAIDINGERITE-VLADIMIRITE SERIES, mon/P2₁/c. Structure consists of Ca polyhedra and As tetrahedra which share edges and corners to form sheets // (010) with large channels along [0120]. The sheets are linked by Ca octahedra and H bonds.**

MCHCA	VLADIMIRITE	Ca ₄ (AsO ₄) ₂ (AsO ₃ OH)·4H ₂ O
MCHCB	HAIDINGERITE	CaH(AsO ₄)(H ₂ O)

SERIES D	FERRARISITE SERIES, tric/P1. Structure consists of two Ca polyhedra sharing edges and corners with As tetrahedra to form sheets // (001); Ca is accommodated between the sheets, forming channels // [010] and [100] that contain water molecules.		
MCHDA	GUERINITE	$\text{Ca}_5(\text{HAsO}_4)(\text{AsO}_4)_2 \cdot 9\text{H}_2\text{O}$	mon/P2 ₁ /n
MCHDB	FERRARISITE	$\text{Ca}_5(\text{HAsO}_4)(\text{AsO}_4)_2 \cdot 9\text{H}_2\text{O}$	tric/P ₁
MCHDC	JEANKEMPITE	$\text{Ca}_5(\text{AsO}_4)_2(\text{AsO}_3\text{OH})_2(\text{H}_2\text{O})_7$	tric/P ₁
SERIES E	MACHATSCHKIITE-RAUENTHALITE SERIES, trig/R3c. Structure consists of Ca polyhedra sharing edges with As(O,OH)₄ tetrahedra to form chains // to the edges of the rhombohedral Bravais cell; the chains are linked by corner-sharing As(O,OH)₄ tetrahedra. In rauenthalite and phaunouxite, Ca polyhedra and arsenate tetrahedra share corners and edges to form sheets.		
MCHEA	MACHATSCHKIITE	$\text{Ca}_6(\text{AsO}_4)_2(\text{AsO}_3\text{OH})_2(\text{SO}_4) \cdot 15\text{H}_2\text{O}$	
MCHEB	RAUENTHALITE	$\text{Ca}_3(\text{AsO}_4)_2 \cdot 10\text{H}_2\text{O}$	
MCHEC	PHAUNOUXITE	$\text{Ca}_3(\text{AsO}_4)_2 \cdot 11\text{H}_2\text{O}$	
SERIES F	RHABDOPHANE SERIES, hex/P6₂22. The structure consists of columns of alternating edge-sharing XO₈ polyhedra and phosphate tetrahedra // [0001] that are linked to adjacent columns by corner-sharing, producing open [0001] channels that accommodate the water molecules.		
MCHFA	BROCKITE	$(\text{Ca,Th,Ce})\text{PO}_4 \cdot \text{H}_2\text{O}$	
MCHFB	GRAYITE	$(\text{Th,Pb,Ca})\text{PO}_4 \cdot \text{H}_2\text{O}$	
MCHFC	NINGYOITE	$(\text{Th,Ca,Ce})\text{PO}_4 \cdot \text{H}_2\text{O}$	
MCHFD	RHABDOPHANE-(Ce)	$(\text{Ce,L a})\text{PO}_4 \cdot \text{H}_2\text{O}$	
MCHFE	RHABDOPHANE-(La)	$(\text{La,Ce})\text{PO}_4 \cdot \text{H}_2\text{O}$	
MCHFF	RHABDOPHANE-(Nd)	$(\text{Nd,Ce,L a})\text{PO}_4 \cdot \text{H}_2\text{O}$	
MCHFG	TRISTRAMITE	$(\text{Ca,U,Fe})(\text{PO}_4,\text{SO}_4) \cdot 2\text{H}_2\text{O}$	
MCHFH	RHABDOPHANE-(Y)	$\text{YPO}_4 \cdot \text{H}_2\text{O}$	
SERIES G	CHURCHITE SERIES, mon/A2/a. Structure consists of sheets of edge- and corner-sharing P tetrahedra and (Ca,Y) polyhedra // (010) which are linked by the H bonds of water molecules. Gypsum structure type. The structure of krautite is built up by (010) layers of AsO₄ and MnO₆ polyhedra that share edges and vertices. Adjacent layers are related by the 2₁ operation and linked by H bonding only.		
MCHGA	BRUSHITE	$\text{CaH}(\text{PO}_4)(\text{OH}_2)_2$	
MCHGB	PHARMACOLITE	$\text{CaH}(\text{AsO}_4)(\text{OH}_2)_2$	
MCHGC	CHURCHITE-(Y)	$(\text{Y,Ca})(\text{PO}_4)(\text{OH}_2)_2$	
MCHGD	open		
MCHGE	ARDEALITE	$\text{CaH}((\text{P,S})\text{O}_4)(\text{OH}_2)_2$	
SERIES H	MCNEARITE, tric/P1. Structure not known but may be related to autunite. Sarp, H., Deferne, J., Liebich, B. W. (1981): La mcnearite, NaCa₅H₄(AsO₄)₅·4H₂O, un nouvel arséniate hydraté de calcium et de sodium. Schweizerische Mineralogische und Petrographische Mitteilungen 61, 1-6.		
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	Ondruš, P. & Hyršl, J. (1989): New finds and revision of secondary minerals from Příbram district. Acta Universitatis Carolinae, Geologica 1989, 521-533. [PXRD data]		
MCHHA	MCNEARITE	$\text{NaCa}_5\text{H}_4(\text{AsO}_4)_5 \cdot 4\text{H}_2\text{O}$	
SERIES I	SINCOSITE SERIES. Tetr/P4/n or P4/nmm. No structure known. A. Pring, U. Kolitsch, W. D. Birch, B. D. Beyer, P. Elliott, P. Ayyappan and A. Ramanan (1999): Bariosincosite, a new hydrated barium vanadium phosphate, from the Spring Creek Mine, South Australia. Mineral. Mag. 63, 735-741.		

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MCHIA SINCOSITE $\text{Ca}(\text{VO})_2(\text{PO}_4)_2 \cdot 5\text{H}_2\text{O}$

MCHIB BARIOSINCOSITE $\text{Ba}(\text{VOPO}_4)_2 \cdot 4\text{H}_2\text{O}$

SERIES J STEPITE, tetr/ $I4_1/acd$. The structure consists of sheets perpendicular to {001}, made up of eight-coordinated U atoms and hydroxyarsenate tetrahedra. The ligands surrounding the U atom consist of six O atoms which belong to the hydroxyarsenate groups and two oxygen atoms which belong to interlayer water molecules. Each UO₈ polyhedron is connected to five other U polyhedra via six AsO₃OH groups. Adjacent electroneutral sheets, of composition $[\text{U}^{4+}(\text{AsO}_3\text{OH})_2]$. Which are linked by H bonding involving water molecules in the interlayers and (OH) groups in the sheets.

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MCHJA STEPITE $\text{U}(\text{AsO}_3\text{OH})_2 \cdot 4\text{H}_2\text{O}$

SERIES K ROWLEYITE, iso/ $Fd\bar{3}m$. Structure consists of $[\text{V}_4\text{O}_{16}]^{12+}$ polyoxovanadate units that link to one another via shared vertices with $[(\text{P,As})\text{O}_4]^{3-}$ tetrahedra to form a 3D framework possessing large interconnected channels. The channels contain a 3D ordered $[\text{Na}(\text{NH}_4, \text{K})_9\text{Cl}_4]^{6+}$ salt net, which apparently served as a template for the formation of the framework. In that respect, rowleyite can be considered a salt-inclusion solid (SIS).

MCHKA ROWLEYITE $[\text{Na}(\text{NH}_4, \text{K})_9\text{Cl}_4][\text{V}_4^{5+, 4+}(\text{P, As})\text{O}_8] \cdot n[\text{H}_2\text{O}, \text{Na}, \text{NH}_4, \text{K}, \text{Cl}]$

SERIES L THORASPHITE, orth/ $Pbcn$. Structure determined.

MCHLA THORASPHITE $\text{Th}_2\text{H}(\text{PO}_4, \text{AsO}_4)_3 \cdot 6\text{H}_2\text{O}$

GROUP D Phosphates with Additional Anions, with Water.

TYPE A With Small Cations.

SERIES A MORAESITE SERIES, mon/ $C2/c$. Structure consists of double chains of corner-sharing Be and P tetrahedra // [001] which are linked by corner-sharing to form a framework with large channels // [001] that accommodate water molecules.

MDAAA MORAESITE $\text{Be}_2(\text{OH})(\text{PO}_4)(\text{OH}_2)_4$

MDAAB BEARSITE $\text{Be}_2(\text{OH})(\text{AsO}_4)(\text{OH}_2)_4$

MDAAC GLUCINE $\text{CaBe}_4[(\text{OH})_2/\text{PO}_4]_2 \cdot 0.5\text{H}_2\text{O}$

SERIES B ROSCHERITE SERIES, mon/ $tric-C2/c/C1$. Structure consists of chains of edge-sharing Mg, Fe octahedra // [110] and $[\bar{1}\bar{1}0]$ which are linked by corner-sharing P tetrahedra; other chains // [100]

consist of 4-membered rings of corner-sharing P and Be tetrahedra; the various chains are linked by water and H bonding to form a framework, with Ca and water in cavities.

MDABA	ROSCHERITE	$\text{Ca}_2(\text{Mn,Fe})_5\text{Be}_4(\text{PO}_4)_6(\text{OH})_4 \cdot 6\text{H}_2\text{O}$
MDABB	ZANAZZIITE	$\text{Ca}_2(\text{Mg,Fe})_5\text{Be}_4(\text{PO}_4)_6(\text{OH})_4 \cdot 6\text{H}_2\text{O}$
MDABC	GREIFENSTEINITE	$\text{Ca}_2(\text{Fe,Mn})_5\text{Be}_4(\text{PO}_4)_6(\text{OH})_4 \cdot 6\text{H}_2\text{O}$
MDABD	ATENCIOITE	$\text{Ca}_2\text{Fe}^{2+}\square\text{Mg}_2\text{Fe}^{2+}_2\text{Be}_4(\text{PO}_4)_6(\text{OH})_4 \cdot 6\text{H}_2\text{O}$
MDABE	RUIFRANCOITE	$\text{Ca}_2\square_2(\text{Fe,Mn,Mg})_4\text{Be}_4[(\text{OH})_4/(\text{PO}_4)_6] \cdot 6\text{H}_2\text{O}$
MDABF	GUIMARAESITE	$\text{Ca}_2(\text{Zn,Mg,Fe})_5\text{Be}_4(\text{PO}_4)_6(\text{OH})_4 \cdot 6\text{H}_2\text{O}$
MDABG	FOOTEMINEITE	$\text{Ca}_2\text{Mn}^{2+}\square\text{Mn}^{2+}_2\text{Mn}^{2+}\text{Be}_4(\text{PO}_4)_6(\text{OH})_4 \cdot 6\text{H}_2\text{O}$
MDABH	OKRUSCHITE	$\text{Ca}_2\text{Mn}^{2+}_5\text{Be}_4(\text{AsO}_4)_6(\text{OH})_4 \cdot 6\text{H}_2\text{O}$

SERIES C URALOLITE, *mon/P2₁/n*. Structure consist of 3-, 4- and 8-membered rings of corner-sharing Be and P tetrahedra forming layers // (010); the layers are connected by $\text{CaO}_5(\text{H}_2\text{O})_2$ polyhedra and free water molecules.

MDACA	URALOLITE	$\text{Ca}_2\text{Be}_4(\text{PO}_4)_3(\text{OH})_3 \cdot 5\text{H}_2\text{O}$
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SERIES D WEINEBENITE, *mon/Cc*. Structure consists of Be and P tetrahedra sharing corners to form layers // (100) consisting of 4- and 8-membered rings; these layers are connected by Be tetrahedra to form a framework. Ca polyhedra are accommodated in channels // [001].

MDADA	WEINEBENITE	$\text{CaBe}_3[\text{OH}/\text{PO}_4]_2 \cdot 4\text{H}_2\text{O}$
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SERIES E TIPTOPITE, *hex/P6₃*. Tiptopite is isotypic with the members of the cancrinite group, being the berylllophosphate analogue of basic cancrinite, and could therefore be considered a zeolite. The tetrahedral framework is geometrically identical to that of cancrinite but is composed of BeO_4 and PO_4 groups, with Be and P completely ordered. In the channels, the large cation and the two nonframework oxygens occupy the same sites in the two structures.

MDAEA	TIPTOPITE	$\text{K}_2(\text{Li,Na,Ca})_6\text{Be}_6(\text{PO}_4)_6(\text{OH})_2 \cdot \text{H}_2\text{O}$
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SERIES F VESZELYITE, *mon/P2₁/a*. The structure consists of two types of connecting sheets parallel to (001): an octahedral sheet formed of edge-sharing $[\text{Cu}(1)(\text{OH})_4\text{O}(\text{H}_2\text{O})]$ and $[\text{Cu}(2)\text{O}(\text{OH})_3(\text{H}_2\text{O})_2]$ octahedra, and a mixed tetrahedra sharing corners. The open octahedral sheet is a novel type that consists of 8-membered rings of alternating Cu(1) and Cu(2) octahedra. The 8-membered octahedral ring is stretched and is oriented the same way as the 8-membered tetrahedral ring. Open channels pass through these rings to accommodate the water molecules, which are thus somewhat zeolitic in character. The tetrahedral sheet is composed of tetrahedral chains with alternating phosphate and zinc tetrahedra running parallel the a axis. These chains share corners to form a sheet parallel to (001). The interconnection of the chains results in the formation of four- and eight-membered rings. Kipushite and philipsburgite are quite similar.

MDAFA	VESZELYITE	$(\text{Cu,Zn})_3(\text{PO}_4)(\text{OH})_3 \cdot 2\text{H}_2\text{O}$
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SERIES G KIPUSHITE SERIES, *mon/Pe1/a*. Structure consists of sheets // (001) of corner-sharing Zn and P tetrahedra, $[\text{ZnOHPO}_4]^{2-}$, as in veszelyite, alternate with mixed double sheets of edge-sharing octahedra and tetrahedra, $[(\text{Cu,Zn})_5(\text{OH})_5(\text{H}_2\text{O})\text{PO}_4]^{2+}$; both are connected via common corners into a framework with water molecules. Structure of philipsburgite, $\text{Cu}_5\text{Zn}((\text{As,P})\text{O}_4)_2(\text{OH})_6 \cdot \text{H}_2\text{O}$. *Physics and Chemistry of Minerals*, 45, 917–923. Philipsburgite, $\text{Cu}_5\text{Zn}((\text{As,P})\text{O}_4)_2(\text{OH})_6 \cdot \text{H}_2\text{O}$, from the Middle Pit, Gold Hill Mine, Tooele Co., Utah, USA, was studied by single-crystal X-ray diffraction and scanning electron microscopy. The empirical formula of the studied sample is $(\text{Cu}_{4.69}\text{Zn}_{1.23})(\text{As}_{0.86}\text{P}_{0.18}\text{O}_4)_2(\text{OH})_{5.61} \cdot \text{H}_2\text{O}$, which agrees well with the previous reports on the mineral. Philipsburgite is monoclinic, *P2₁/c*, $a = 12.385(6)$, $b = 9.261(4)$, $c = 10.770(5)$ Å, $\beta = 97.10(1)^\circ$, $V = 1225.7(9)$ Å³ (at 100 K), and $Z = 4$. The crystal structure was refined to $R_1 = 0.046$ for 2563 unique observed reflections with $|F_o| \geq 4\sigma F$. The crystal structure of philipsburgite is isotypic to that of kipushite and can be considered as a complex three-dimensional framework consisting of two types of layers stacked parallel to the a-axis. The A-type layer is formed by the edge-sharing Jahn–Teller-distorted $\text{Cu}\phi_6$ octahedra [$\phi = \text{O}^{2-}, (\text{OH})^-$,

H2O]. Two adjacent octahedral layers are linked via (As2O4) tetrahedra. The B-type layer is built by corner-sharing (ZnO4) and (As1O4) tetrahedra and is formed by the four- and eight-membered tetrahedral rings. The A:B ratio of the A and B layers is equal to 2:1. The hydrogen bonding network in philipsburgite is rather complex and consists of two- and three-center hydrogen bonds. The As1 site accommodates ca. 18% of P and is a preferable position for the P substitution in philipsburgite. The observed selectivity of the As1 site for P may indicate that, for the intermediate compositions with the P:As ratios close to 1:1, there is a fully ordered species with P prevalent at the As1 site and As prevalent at the As2 site. The intermediate composition would, therefore, be Cu5Zn(AsO4)(PO4)(OH)6·H2O and such a mineral can be considered as a separate species, according to the rules of the International Mineralogical Association (IMA). Philipsburgite should be considered as structurally complex with the Shannon information contents of 4.954 bits/atom and 614.320 bits/cell. The obvious reason for the structural complexity of the mineral is its modularity, i.e., the presence of two structurally distinct modules, the octahedral–tetrahedral (A) and tetrahedral (B) layers.

MDAGA	KIPUSHITE	$(\text{Zn,Cu})_3(\text{PO}_4)(\text{OH})_3 \cdot \text{H}_2\text{O}$
MDAGB	PHILIPSBURGITE	$(\text{Cu,Zn})_3(\text{AsO}_4)(\text{OH})_3 \cdot \text{H}_2\text{O}$

SERIES H **SPENCERITE, mon/P2/c.** Structure consists of chains of face-and edge-sharing $\text{ZnO}_4(\text{OH})_2$ octahedra // [001] which are connected into sheets // (100) by phosphate tetrahedra and $\text{ZnO}_2(\text{OH})\text{H}_2\text{O}$ tetrahedra with only H bonding between the sheets.

MDAHA	SPENCERITE	$\text{Zn}_4(\text{PO}_4)_2(\text{OH})_2 \cdot 3\text{H}_2\text{O}$
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SERIES I **MRAZEKITE, mon/P2₁/n.** Structure consists of chains of corner-sharing Cu square planes which are linked by P tetrahedra to form ribbons // [010]; these ribbons are connected into sheets // (103) by corner-sharing Cu square planes, and the sheets are linked by edge-sharing dimmers of Bi polyhedra and H bonds.

MDAIA	MRAZEKITE	$\text{Bi}_2\text{Cu}_3(\text{PO}_4)_2(\text{OH})_2\text{O}_2 \cdot 2\text{H}_2\text{O}$
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SERIES J **ATTIKAITE, orth/Pban, Pbam, or Pba2. No structure yet.** Chukanov, N.V., Pekov, I.V., Zadov, A.E. (2007): Attikaite, $\text{Ca}_3\text{Cu}_2\text{Al}_2(\text{AsO}_4)_4(\text{OH})_4 \cdot 2\text{H}_2\text{O}$, a new mineral. Proceedings of the Russian Mineralogical Society (Zapiski RMO), 136(2), 17-24. [American Mineralogist 94,1076 (2009)(abstract)]

Chukanov, N.V., Pekov, I.V., Zadov, A.E. (2007): Attikaite, $\text{Ca}_3\text{Cu}_2\text{Al}_2(\text{AsO}_4)_4(\text{OH})_4 \cdot 2\text{H}_2\text{O}$, a new mineral species. Geology of Ore Deposits, 49(8), 720-726. [ENGLISH TRANSLATION]

MDAJA	ATTIKAITE	$\text{Ca}_3\text{Cu}_2\text{Al}_2[\text{OH}/\text{AsO}_4]_4 \cdot 2\text{H}_2\text{O}$
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SERIES K **BRANDAOITE, tric/P1.** Menezes Filho, L.A.D., Chaves, M.L.S.C., Cooper, M.A., Ball, N.A., Abdu, Y.A., Sharpe, R., Day, M.C., Hawthorne, F.C. (2019): Brandãoite, $[\text{BeAl}_2(\text{PO}_4)_2(\text{OH})_2(\text{H}_2\text{O})_4](\text{H}_2\text{O})$, a new Be-Al-phosphate mineral from the João Firmino mine, Pomarolli farm region, Divino das Laranjeiras county, Minas Gerais State, Brazil: description and crystal structure. [i]Mineralogical Magazine[i], [b]83[b], 261-267.

Abstract:

Brandãoite, $[\text{BeAl}_2(\text{PO}_4)_2(\text{OH})_2(\text{H}_2\text{O})_4](\text{H}_2\text{O})$, is a new Be-Al-phosphate mineral from the João Firmino mine, Pomarolli farm region, Divino das Laranjeiras County, Minas Gerais State, Brazil, where it occurs in an albite pocket with other secondary phosphates, including beryllonite, atencioite and zanazziite, in a granitic pegmatite. It occurs as colourless acicular crystals less than 10 µm wide and less than 100 µm long that form compact radiating spherical aggregates up to 1.0-1.5 mm across. It is colourless and transparent in single crystals and white in aggregates, has a white streak and a vitreous lustre, is brittle and has conchoidal fracture. Mohs hardness is 6, and the calculated density is 2.353 g/cm³. Brandãoite is biaxial positive, $\alpha = 1.544$, $\beta = 1.552$, $\gamma = 1.568$, all 0.002; $2V_{\text{obs}} = 69.7(10)^\circ$, $2V_{\text{calc}} = 71.2^\circ$. No pleochroism was observed. Brandãoite is triclinic, space group P-1, $a = 6.100(4)$, $b = 8.616(4)$, $c = 10.261(5)$ Å, $\alpha = 93.191(11)$, $\beta = 95.120(11)$, $\gamma = 96.863(11)^\circ$, $V = 532.1(8)$ Å³, $Z = 2$. Chemical analysis of a needle 4 µm wide by electron microprobe and secondary-ion mass spectrometry gave P2O5 = 28.42, Al2O3 20.15, BeO 4.85, H2O 21.47, sum 74.89 wt%. The empirical formula, normalized on the basis of 15 anions pfu with (OH) = 2 and (H2O) = 5 apfu (from the crystal structure) is Be0.98Al1.99P2.02H12O15. The crystal structure was solved by direct methods and refined to an R1 index of 7.0%. There are two P sites occupied by P5+, two Al sites occupied by octahedrally coordinated Al3+, and one Be site occupied by tetrahedrally coordinated Be2+. There are fifteen anions, two of which are (OH) groups and five of which are (H2O) groups. The simplified ideal formula is thus $[\text{BeAl}_2(\text{PO}_4)_2(\text{OH})_2(\text{H}_2\text{O})_4](\text{H}_2\text{O})$ with $Z = 2$. Be and P tetrahedra

share corners to form a four-membered ring. Al octahedra share a common vertex to form an [Al₂φ₁₁] dimer, and these dimers are cross-linked by P tetrahedra to form a complex slab of polyhedra parallel to (001). These slabs are cross-linked by BeO₂(OH)(H₂O) tetrahedra, with interstitial (H₂O) groups in channels that extend along [100].

MDAKA BRANDAOITE BeAl₂(PO₄)₂(OH)₂(H₂O)₅

TYPE B Structures with Medium-sized Cations, (OH, etc.): RO₄ < 1:1.

SERIES A **DIADOCHITE-SARMIENTITE SERIES, mon/P2₁/c.** Structure consists of two Fe octahedra and one phosphate tetrahedron share corners to form a 3-membered polyhedral ring; the rings are linked into chains // to c by sharing corners of the phosphate tetrahedra. Sulphate tetrahedra are attached to the chains by sharing one of their corners with the octahedra. The chains are linked into slabs // (010) by H bonds; water molecules are accommodated between the slabs. The structure of rossiantonite shows similarities with minerals belonging to the sanjuanite-destinezite group. Specifically, the structure is built of PO₄ and AlO₆ polyhedral rings, creating complex chains // to b by sharing the OH-OH edge belonging to the Al(3) polyhedron. Three symmetrically independent Al sites can be identified, namely: Al(1), Al(2), and Al(3). Tetrahedral sites, occupied by P, share all their apexes with AlO₆ octahedra. Unshared octahedral apeses are occupied by water molecules. Four additional water molecules are placed between the previously identified chains. Two oxygen tetrahedra, occupied by S atoms, are connected along the chains by means of weak H bonding.

MDBAA	DIADOCHITE	Fe ₂ (PO ₄)(SO ₄)(OH)
MDBAB	SARMIENTITE	Fe ₂ (AsO ₄)(SO ₄)(OH)
MDBAC	SANJUANITE	Al ₂ (PO ₄)(SO ₄)(OH)·9H ₂ O
MDBAD	BUKOVSKYITE	Fe ₂ (AsO ₄)(SO ₄)(OH)·H ₂ O
MDBAE	ZYKAITE	Fe ₄ (AsO ₄) ₃ (SO ₄)(OH)·15H ₂ O
MDBAF	GINIITE	FeFe ₄ (PO ₄) ₄ (OH) ₂ ·2H ₂ O
MDBAG	PITTICITE	Fe ₂ (AsO ₄)(SO ₄)(OH)·nH ₂ O
MDBAH	ARANGASITE	Al ₂ (SO ₄)(PO ₄)F·9H ₂ O
MDBAI	DESTINEZITE	Fe ₂ (PO ₄)(SO ₄)(OH)·6H ₂ O
MDBAJ	ROSSIANTONITE	Al ₃ (PO ₄)(SO ₄) ₂ (OH) ₂ (H ₂ O) ₁₀ ·4H ₂ O

SERIES B **VASHEGYITE-SASAITE SERIES, orth/Pnam. Structures not known.** Martini, J. (1978): Sasaite, a new phosphate mineral from West Driefontein Cave, Transvaal, South Africa. Mineral. Mag., 42, 401–404. [Abs. in American Mineralogist (1979): 64: 464-465.]

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MDBBA	VASHEGYITE	$\text{Al}_6(\text{PO}_4)_5(\text{OH})_3 \cdot 23\text{H}_2\text{O}$
MDBBB	SASAITE	$(\text{Al,Fe})_{14}(\text{PO}_4)_{11}(\text{SO}_4)(\text{OH})_7 \cdot 83\text{H}_2\text{O}$

SERIES C **SCHOONERITE**, orth/Pmab. The structure is based on edge-sharing Fe^{2+} -O octahedral chains joined by sharing corners with Fe^{3+} -O octahedra and phosphate tetrahedra that form a sheet parallel to {010}. To this sheet are linked additional phosphate tetrahedra, $[\text{MnO}_6]$ octahedra and $[\text{ZnO}_5]$ polyhedra. The resultant slabs are joined in the b direction by a network of H bonds only. Interlayer water molecules contribute to this H bond network. Structure consists of chains of corner-sharing Fe octahedra // [100] which are linked to Mn octahedra and Zn polyhedra by P tetrahedra, forming complex sheets // (010); the sheets are connected by water molecules and H bonds. The structure of flurlite has a heteropolyhedral layer structure, with layers // to (001) and with water molecules packing between the layers. The slab-like layers contain two types of polyhedral chains running // to [001]: (a) chains of edge-sharing octahedra containing predominantly Zn and (b) chains in which Fe^{3+} -centered octahedra share their apices with dimers comprising Zn-centered trigonal bipyramids sharing an edge with phosphate tetrahedra. The two types of chains are interconnected by corner-sharing along [010]. A second type of P tetrahedron connects the chains to $\text{MnO}_2(\text{H}_2\text{O})_4$ octahedra along [010] to complete the structure of the (001) slabs. Flurlite has the same stoichiometry as schoonerite, but with dominant Zn rather than Fe^{2+} in the edge-shared chains. Schoonerite has a similar heteropolyhedral layer structure with the same layer dimensions. The different symmetry (orthorhombic, Pmab) for schoonerite reflects a different topology of the layers. The ideal formula for flurlite has been revised to $\text{Zn}_4\text{Fe}_3+(\text{PO}_4)_3(\text{OH})_2(\text{H}_2\text{O})_7 \cdot 2\text{H}_2\text{O}$ and its Mn analogue, manganflurlite (IMA2017-076), $\text{ZnMn}_2+3\text{Fe}_3+(\text{PO}_4)_3(\text{OH})_2(\text{H}_2\text{O})_7 \cdot 2\text{H}_2\text{O}$ has been found on two specimens of phosphophyllite from the Hagendorf-Süd pegmatite, Oberpfalz, Bavaria, Germany. Manganflurlite occurs as long, very thin, rectangular laths, up to 0.5 mm long and less than 10 μm thick. Laths are elongated on [100], flattened on {001} and exhibit the forms {1 0 0}, {0 1 0} and {0 0 1}. The mineral is orange brown in colour and transparent with a vitreous iridescent lustre and buff streak. Crystals are flexible and elastic with irregular fracture, and three cleavages: perfect on {0 0 1}, good on {1 0 0} and {0 1 0}. The Mohs' hardness is ca. 2½. The measured density is 2.73(2) g cm⁻³. At room temperature, the mineral dissolves rapidly in dilute HCl. Optically, manganflurlite is biaxial (-), with $\alpha = 1.623(\text{calc})$, $\beta = 1.649(2)$, $\gamma = 1.673(2)$ (white light); $2V = 86(1)^\circ$. The dispersion is $r > v$, slight; the optical orientation is $X = c$, $Y = b$, $Z = a$. The pleochroism is $X = \text{pale yellow brown}$, $Y = \text{orange brown}$, $Z = \text{light yellow brown}$, $Y > Z > X$. Electron microprobe analyses for crystals from the holotype specimen gave the empirical formula $\text{Zn}(\text{Mn}_2+1.51\text{Fe}_2+0.69\text{Zn}0.68\text{Mg}0.08)\Sigma 2.96(\text{Fe}_3+0.95\text{Al}0.05)\Sigma 1.00(\text{PO}_4)_3(\text{OH})1.92(\text{H}_2\text{O})9.08$. Manganflurlite is monoclinic, P21/m, $a = 6.4546(8)$, $b = 11.1502(9)$, $c = 13.1630(10)$ Å, $\beta = 99.829(5)^\circ$, $V = 933.44(16)$ Å³ and $Z = 2$. The crystal structure, refined including all protons to Robs = 0.034 for 2219 observed reflections [$I > 3\sigma$], shows the mineral to be isostructural with flurlite. These minerals have a heteropolyhedral layer structure that is a topological isomer of the schoonerite structure. Grey, I.E., Keck, E., Kampf, A.R., Cashion, J.D., Macrae, C.M., Glenn, A.M., Gozukara, Y. (2019): Schmidite and wildenauerite, two new schoonerite-group minerals from the Hagendorf Süd pegmatite, Oberpfalz, Bavaria. Mineralogical Magazine, 83, 181-190.

Abstract:

Schmidite, $\text{Zn}(\text{Fe}_3+0.5\text{Mn}_2+0.5)2\text{ZnFe}_3+(\text{PO}_4)_3(\text{OH})_3(\text{H}_2\text{O})_8$ and wildenauerite, $\text{Zn}(\text{Fe}_3+0.5\text{Mn}_2+0.5)2\text{Mn}_2+\text{Fe}_3+(\text{PO}_4)_3(\text{OH})_3(\text{H}_2\text{O})_8$ are two new oxidized schoonerite-group minerals from the Hagendorf-Süd pegmatite, Hagendorf, Oberpfalz, Bavaria, Germany. Schmidite occurs as radiating sprays of orange brown to copper red laths on and near to altered phosphophyllite in a corroded triphylite nodule, whereas wildenauerite forms dense compacts of red laths, terminating Zn-bearing rockbridgeite. The minerals are biaxial (+) with $\alpha = 1.642(2)$, $\beta = 1.680(1)$, $\gamma = 1.735(2)$, $2V(\text{meas}) = 81.4(8)^\circ$ for schmidite, and with $\alpha = 1.659(3)$, $\beta = 1.687(3)$, $\gamma = 1.742(3)$, $2V(\text{meas}) = 73(1)$ for wildenauerite. Electron microprobe analyses, with H₂O from thermal analysis and FeO/Fe₂O₃ from Mössbauer spectroscopy, gave FeO 0.4, MgO 0.3, Fe₂O₃ 23.5, MnO 9.0, ZnO 15.5, P₂O₅ 27.6, H₂O 23.3, total 99.6 wt% for schmidite, and FeO 0.7, MgO 0.3, Fe₂O₃ 25.2, MnO 10.7, ZnO 11.5, P₂O₅ 27.2, H₂O 24.5, total 100.1 wt% for wildenauerite. The empirical formulae, scaled to 3 P and with OH-adjusted for charge balance are $\text{Zn}1.47\text{Mn}_2+0.98\text{Mg}0.05\text{Fe}_2+0.04\text{Fe}_3+2.27(\text{PO}_4)_3(\text{OH})2.89(\text{H}_2\text{O})8.54$ for schmidite and $\text{Zn}1.11\text{Mn}_2+1.18\text{Mg}0.05\text{Fe}_2+0.08\text{Fe}_3+2.47(\text{PO}_4)_3(\text{OH})3.25(\text{H}_2\text{O})9.03$ for wildenauerite. The two minerals have orthorhombic symmetry, Pmab, $Z = 4$. The unit-cell parameters from refinement of powder XRD data are $a = 11.059(1)$, $b = 25.452(1)$ and $c = 6.427(1)$ Å for schmidite,

and $a = 11.082(1)$, $b = 25.498(2)$ and $c = 6.436(1)$ Å for wildenauerite. The crystal structures of schmidite and wildenauerite differ from that of schoonerite in having minor partitioning of Zn from the [5]Zn site to an adjacent vacant tetrahedral site [4]Zn, separated by ~1.0 Å from [5]Zn. The two minerals are distinguished by the cation occupancies in the octahedral M1 to M3 sites. Schmidite has $M1 = M2 = (Fe^{3+} + 0.5Mn^{2+} + 0.5)$, $M3 = Zn$ and wildenauerite has $M1 = M2 = (Fe^{3+} + 0.5Mn^{2+} + 0.5)$, $M3 = Mn^{2+}$.

MDBCA	SCHOONERITE	$ZnMnFe_2Fe(PO_4)_3(OH)_2 \cdot 9H_2O$
MDBCB	FLURLITE	$Zn_3Mn^{2+}Fe^{3+}(PO_4)_3(OH)_2 \cdot 9H_2O$ mon/P2 ₁ m
MDBCC	WILHELMGUMBELITE	$ZnFe^{2+}Fe^{3+}_3(PO_4)_3(OH)_4(H_2O)_5 \cdot 2H_2O$
MDBCD	SCHMIDITE	$[Zn_2(Fe^{3+}, Mn^{2+})_2Fe^{3+}(PO_4)_3(OH)_3(H_2O)_6] \cdot 2H_2O$
MDBCE	WILDENAUERITE	$Zn(Fe^{3+}, Mn^{2+})_2MnFe^{3+}(PO_4)_3(OH)_3(H_2O)_6 \cdot 2H_2O$
MDBCF	MANGANFLURLITE	$ZnMn^{2+}_3Fe^{3+}(PO_4)_3(OH)_2(H_2O)_7 \cdot 2H_2O$

SERIES D **SINKANKASITE-MCAUSLANITE SERIES, tric/P1.** The structure consists of corner-sharing chains of Al octahedra, decorated on both sides by phosphate tetrahedra. These heteropolyhedral chains are linked through the Mn octahedra to form continuous sheets of composition $MnAlP_2O_6(OH)_3 \cdot 4H_2O$. There are two interlayer anion positions, both of which are occupied by water groups. There are eight unique H bonds between the interlayer cations and the sheets on either side, and no other bonding occurs between the sheets. Structure consists of chains // [001] of corner-sharing Al octahedra flanked by two sheets of P tetrahedra which are linked by Mn octahedra to form sheets // (100); the sheets are linked by water molecules and H bonds.

MDBDA	SINKANKASITE	$Mn^{2+}(H_2O)_4[As(PO_3OH)_2(OH)](H_2O)_2$
MDBDB	MCAUSLANITE	$HFe_3Al_2(PO_4)_2F \cdot 18H_2O$

SERIES E **MITRYAEVAITE, tric/P1 or P1.** The structure consists of five-membered finite chains of corner-sharing Al octahedra. The chains are cross-linked via P tetrahedra to produce complex slabs that are // [100] and that are in turn linked through additional P tetrahedra to form layers // to the (011) plane. The heteropolyhedral layers are linked together through H bonds to water groups located in the interlayer region. CM01-179.

MDBEA	MITRYAEVAITE	$Al_5(PO_4)_2[(P,S)O_3(OH,O)]F_2(OH)_2(H_2O)_8 \cdot 6.48H_2O$
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SERIES F **WHITECAPSITE, hex/P6₃/m.** The structure consists of a heteropolyhedral cluster with the $Fe^{3+}O_6$ trigonal prism as a central polyhedron. These clusters are isolated from each other and linked only via H bonds to the water molecules located in the interstitial space. Whitecapsite is related to another arsenate mineral, bouazzerite.

MDBFA	WHITECAPSITE	$H_{16}Fe^{2+}_5Fe^{3+}_{14}Sb^{3+}_6(AsO_4)_{18}O_{16} \cdot 120H_2O$
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SERIES G **JOTEITE, tric/P1.** In the structure of joteite ($R_1 = 7.72\%$ for 6003 $F_o > 4sF$), AsO_4 and $AsO_3(OH)$ tetrahedra, AlO_6 octahedra and Cu_2O_5 square pyramids share corners to form sheets parallel to {001}. In addition, 7- and 8-coordinate Ca polyhedra link to the periphery of the sheets yielding thick slabs. Between the slabs are unconnected $AsO_3(OH)$ tetrahedra, which link the slabs only via hydrogen bonding. The Raman spectrum shows features consistent with OH and/or H_2O in multiple structural environments. The region between the slabs may host excess Al in place of some As. Kampf, A. R., Mills, S. J., Housley, R. M., Rossman, G. R., Nash, B. P., Dini, M., & Jenkins, R. A. (2013). Joteite, $Ca_2CuAl[AsO_4][AsO_3(OH)]_2(OH)_2 \cdot 5H_2O$, a new arsenate with a sheet structure and unconnected acid arsenate groups. Mineralogical Magazine, 77(6), 2811-2823.

MDBGA	JOTEITE	$Ca_2CuAl[AsO_4][AsO_3OH]_2(OH)_2(H_2O)_5$
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SERIES H **BOHUSLAVITE, tric/P1.**

MDBHA	BOHUSLAVITE	$Fe^{3+}_4(PO_3)(SO_4)(OH) \cdot nH_2O$ ($15 < n < 24$)
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TYPE C **Structures with only Medium-sized Cations, (OH, etc.): $RO_4 = 1:1$ and $< 2:1$**

SERIES A **STRASHIMIRITE-EUCHROITE SERIES, mon/C2/c.** The structure consists of thick heteropolyhedral slabs parallel to (100), linked solely by a network of H bonds. Each slab consists of a sheet of

corner-sharing $[\text{Cu}_{\phi_{10}}]$ dimers sandwiched between two $[\text{M}(\text{T}_{\phi_4})_{\phi_3}]$ sheets of corner-sharing (Mg_{ϕ_6}) and P_{ϕ_4} polyhedra; in each sheet, the polyhedra occupy the vertices of a 6^3 net. One of the H_2O groups in the formula unit is not bonded to Mg, Cu, or P but is held in the structure solely by a network of H bond. Structure consists of thick slabs // (100) which are composed of sheets of corner-sharing dimers of edge-sharing Cu octahedra sandwiched between sheets of corner-sharing Mg octahedra and P tetrahedra; the slabs are linked by water molecules.

MDCAA	EUCHROITE	$\text{Cu}_2(\text{OH})(\text{AsO}_4)(\text{H}_2\text{O})_3$
MDCAB	Open	
MDCAC	NISSONITE	$[\text{CuMg}(\text{PO}_4)(\text{OH})(\text{H}_2\text{O})_2]_2(\text{H}_2\text{O})$
MDCAD	STRASHIMIRITE	$\text{Cu}_8(\text{AsO}_4)_4(\text{OH})_4 \cdot 5\text{H}_2\text{O}$

SERIES B **LEGRANDITE SERIES, mon/P21/c.** Structure consists of edge-sharing Zn octahedra forming chains // [100] that are linked by corner-sharing As tetrahedra and Zn trigonal dipyramids. In kovdorskite, clusters of four edge-sharing octahedra are linked by P tetrahedra into a framework with channels // [010] that accommodate water molecules. The structure consists of infinite, undulating, edge-sharing chain of zinc polyhedra parallel to the a axis which is weakened once per repeat unit by the presence of a 2.99 Å Zn-O bond. The arsenate tetrahedra share apices with the zinc polyhedra and serve to link chains together.

MDCBA	LEGRANDITE	$\text{Zn}_4(\text{AsO}_4)_2(\text{OH})_2 \cdot 2\text{H}_2\text{O}$
MDCBB	KOVDORSKITE	$\text{Mg}_5(\text{PO}_4)_2(\text{CO}_3)(\text{OH})_2 \cdot 4\text{-}5\text{H}_2\text{O}$
MDCBC	KLEEMANITE	$\text{ZnAl}_2(\text{PO}_4)_2(\text{OH})_2 \cdot 3\text{H}_2\text{O}$

SERIES C **WHITMOREITE SERIES, mon/P2₁/c.** The structure consists of open sheets of composition $[\text{Fe}^{3+}_2(\text{OH})_2(\text{Op})_6]$. These are linked by PO_4 tetrahedra to form slabs parallel to {100} of composition $[\text{Fe}^{3+}_2(\text{OH})_2[\text{PO}_4]_2]^{2-}$; the remaining tetrahedral vertices are corner-linked to trans- $[\text{Fe}^{2+}(\text{Op})_2(\text{H}_2\text{O})_4]$ octahedra.

MDCCA	ARTHURITE	$\text{CuFe}_2(\text{As,P,SO}_4)_2(\text{O,OH})_2 \cdot 4\text{H}_2\text{O}$
MDCCB	EARLSHANNONITE	$(\text{Mn,Fe})\text{Fe}_2(\text{PO}_4)_2(\text{OH})_2 \cdot 4\text{H}_2\text{O}$
MDCCC	OJUELAITE	$\text{ZnFe}_2(\text{AsO}_4)_2(\text{OH})_2 \cdot 4\text{H}_2\text{O}$
MDCCD	WHITMOREITE	$\text{Fe}^{2+}\text{Fe}^{3+}_2(\text{OH})_2(\text{H}_2\text{O})_4[\text{PO}_4]_2$
MDCCE	COBALTARTHURITE	$\text{Co}^{2+}\text{Fe}^{3+}_2(\text{AsO}_4)_2(\text{OH})_2 \cdot 4\text{H}_2\text{O}$
MDCCF	BENDADAITE	$\text{Fe}^{2+}\text{Fe}^{3+}_2(\text{AsO}_4)_2(\text{OH})_2 \cdot 4\text{H}_2\text{O}$
MDCCG	KUNATITE	$\text{CuFe}^{3+}_2\text{PO}_2(\text{OH})_2 \cdot 4\text{H}_2\text{O}$
MDCCH	CORALLOITE	$\text{Mn}^{2+}\text{Mn}^{3+}_2(\text{AsO}_4)_2(\text{OH})_2 \cdot 4\text{H}_2\text{O}$

SERIES D **BERAUNITE-BERMANITE SERIES, mon/C2/c.** Structure consists of chains of edge-sharing Mn octahedra // [101] which are corner-linked by P tetrahedra to form slabs // (010). The slabs are linked by Mn octahedra sharing corners with the P tetrahedra. In beraunite, trimers of face-sharing Fe octahedra are corner-linked to other Fe octahedra to form zigzag chains // [001] and [100]; the chains are linked by sharing corners with P tetrahedra, forming thick sheets // (010); water molecules are accommodated in the channels // [101]. The structure of bermanite is based on linear edge-sharing chains of Mn^{3+} -O octahedra that run parallel to the [101] direction. Each shared edge is linked by one phosphate oxygen (Op) and one hydroxyl group (OH) and the remaining vertices receive Op. The chain formula can be expressed as $^{1-}[\text{Mn}^{3+}(\text{OH})(\text{Op})_3]$. The phosphate tetrahedra link in such a way as to form a dense-packed slab parallel to {010} with formal composition $[\text{Mn}^{3+}_2(\text{OH})_2(\text{PO}_4)_2]^{2-}$.

MDCDA	BERAUNITE	$\text{FeFe}_5(\text{OH})_5(\text{H}_2\text{O})_4(\text{PO}_4)_4 \cdot 2\text{H}_2\text{O}$
MDCDB	BERMANITE	$\text{Mn}^{2+}(\text{H}_2\text{O})_4[\text{Mn}^{3+}_2(\text{OH})_2(\text{PO}_4)_2]$
MDCDC	ERCITITE	$\text{NaMn}^{3+}(\text{PO}_4)(\text{OH})(\text{H}_2\text{O})_2$
MDCDD	TVRDYITE	$\text{Fe}^{2+}\text{Fe}^{3+}(\text{PO}_4)_4(\text{OH})_5(\text{H}_2\text{O})_4 \cdot 2\text{H}_2\text{O}$
MDCDE	ELEONORITE	$\text{Fe}^{3+}_6(\text{PO}_4)_4\text{O}(\text{OH})_4 \cdot 6\text{H}_2\text{O}$
MDCDF	ZINCOBERAUNITE	$\text{ZnFe}^{3+}_6(\text{PO}_4)_4(\text{OH})_6 \cdot 6\text{H}_2\text{O}$

MDCDG	MENGEITE	$\text{Ba}(\text{Mg}, \text{Mn}^{2+})\text{Mn}^{3+}_4(\text{PO}_4)_4(\text{OH})_4 \cdot 4\text{H}_2\text{O}$
MDCDH	MAGNESIOBERMANITE	$\text{MgMn}^{3+}_2(\text{PO}_4)_2(\text{OH})_2 \cdot 4\text{H}_2\text{O}$

SERIES E **STRUNZITE SERIES, tric/P1.** Structure consists of corner-sharing Fe octahedra forming [001] chains that are linked by phosphate tetrahedra to form sheets // (100); the sheets are connected by Mn octahedra to form a framework. In metavauxite similar chains of Al octahedra // [001] are linked by phosphate tetrahedra to form sheets // (100); the sheets are connected into a framework by Fe octahedra.

MDCEA	STRUNZITE	$\text{MnFe}_2(\text{PO}_4)_2(\text{OH})_6 \cdot 2\text{H}_2\text{O}$
MDCEB	FERROSTRUNZITE	$\text{FeFe}_2(\text{PO}_4)_2(\text{OH})_6 \cdot 2\text{H}_2\text{O}$
MDCEC	FERRISTRUNZITE	$\text{FeFe}_2(\text{PO}_4)_2(\text{OH})_6 \cdot 2\text{H}_2\text{O}$
MDCED	METAVAUXTITE	$\text{FeAl}_2(\text{PO}_4)_2(\text{OH})_2(\text{H}_2\text{O})_6 \cdot 2\text{H}_2\text{O}$
MDCEE	METAVIVIANITE	$\text{Fe}_{3-x}\text{Fe}_x(\text{PO}_4)_2(\text{OH})_x \cdot 8\text{H}_2\text{O}$
MCCEF	SYMPLESITE	$\text{Fe}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$
MCCEG	ZINCOSTRUNZITE	$\text{ZnFe}_2(\text{PO}_4)_2(\text{OH})_2 \cdot 6.5\text{H}_2\text{O}$
MCCEH	FERRIVAUXTITE	$\text{Fe}^{3+}\text{Al}_2(\text{PO}_4)_2(\text{OH})_3 \cdot 5\text{H}_2\text{O}$

SERIES F **LAUEITE-STEWARTITE SERIES, tric/P1.** Structure consists of chains // [001] of OH-corner-sharing $[\text{FeO}_2(\text{OH})_2(\text{H}_2\text{O})_2]$ octahedra which are bridged by P tetrahedra to form open sheets // (010); the sheets are connected into a framework by expanded $[\text{MnO}_2(\text{H}_2\text{O})_4]$ octahedra, with two free water molecules in the cavities. The structure of this group contains corner-sharing chains of octahedra of composition $[\text{Fe}^{3+}(\text{OH})(\text{H}_2\text{O})(\text{O}_p)_3]$. Phosphate tetrahedra bridge these chains to form sheets oriented parallel to {010}. These sheets are bridged along [010] by trans-Mn $(\text{H}_2\text{O})_4(\text{O}_p)_2$ octahedra.

MDCFA	GORDONITE	$\text{MgAl}_2(\text{PO}_4)_2(\text{OH})_6 \cdot 2\text{H}_2\text{O}$
MDCFB	LAUEITE	$\text{MnFe}_2(\text{PO}_4)_2(\text{OH})_6 \cdot 2\text{H}_2\text{O}$
MDCFC	PARAVAUXTITE	$\text{FeAl}_2(\text{PO}_4)_2(\text{OH})_6 \cdot 2\text{H}_2\text{O}$
MDCFD	SIGLOITE	$\text{FeAl}_2(\text{PO}_4)_2(\text{OH})_6 \cdot 2\text{H}_2\text{O}$
MDCFE	USHKOVITE	$\text{MgFe}_2(\text{PO}_4)_2(\text{OH})_5 \cdot 2\text{H}_2\text{O}$
MDCFF	STEWARTITE	$\text{MnFe}_2(\text{PO}_4)_2(\text{OH})_6 \cdot 2\text{H}_2\text{O}$
MDCFG	MANGANGORDONITE	$(\text{Mn}, \text{Mg})\text{Al}_2(\text{PO}_4)_2(\text{OH})_6 \cdot 2\text{H}_2\text{O}$
MDCFH	PSEUDOLAUEITE	$\text{MnFe}_2(\text{PO}_4)_2(\text{OH})_6 \cdot 2\text{H}_2\text{O}$
MDCFI	KASTNINGITE	$(\text{Mn}, \text{Fe}, \text{Mg})\text{Al}_2(\text{PO}_4)_2(\text{OH})_2 \cdot 8\text{H}_2\text{O}$
MDCFJ	MAGHREBITE	$\text{MgAl}_2(\text{AsO}_4)_2(\text{OH})_2 \cdot 8\text{H}_2\text{O}$
MDCFK	NORDGAUITE	$\text{MnAl}_2(\text{PO}_4)_2(\text{F}, \text{OH})_2 \cdot 5.5\text{H}_2\text{O}$
MDCFL	FERROLAUEITE	$\text{Fe}^{2+}(\text{H}_2\text{O})_4\text{Fe}^{3+}_2(\text{H}_2\text{O})_2(\text{OH})_2(\text{PO}_4)_2 \cdot 2\text{H}_2\text{O}$
MDCFM	CESARFERREIRAITE	$\text{Fe}^{2+}\text{Fe}^{3+}_2(\text{AsO}_4)_2(\text{OH})_2 \cdot 8\text{H}_2\text{O}$
MDCFN	KAYROBERTSONITE	$[\text{MnAl}_2(\text{PO}_4)_2(\text{OH})_2(\text{H}_2\text{O})_4] \cdot \text{H}_2\text{O}$
MDCFO	KUMMERITE	$\text{Mn}^{2+}\text{Fe}^{3+}\text{Al}(\text{PO}_4)_2(\text{OH})_2 \cdot 8\text{H}_2\text{O}$

SERIES G **VANTASSELITE-VAUXITE SERIES, tri/P1.** Structure consists of chains // [001] of alternating, edge-sharing Fe and Al octahedra which are corner-linked on two sides to chains of corner-sharing P tetrahedra and Al octahedra, forming a triple chain. The triple chains are connected by corner-sharing Al and Fe octahedra to form a framework with water molecules in the cavities. The structure of tinticite and kamarizaitite consist of zig-zag chains along [110] of edge-sharing FeO_6 octahedron. The chains are corner-linked by the $(\text{As}/\text{P})\text{O}_4$ tetrahedra into a 3D framework additionally strengthened by medium-strong to weak H-bonding.

MDCGA	VAUXITE	$\text{Fe}(\text{H}_2\text{O})_4[\text{Al}_4(\text{OH})_4(\text{H}_2\text{O})_4(\text{PO}_4)_4] \cdot 4\text{H}_2\text{O}$
MDCGB	VANTASSELITE	$\text{Al}_4(\text{PO}_4)_3(\text{OH})_3 \cdot 9\text{H}_2\text{O}$

MDCGC	TINTICITE	$\text{Fe}^{3+}_3(\text{PO}_4)_2(\text{OH})_3 \cdot 3\text{H}_2\text{O}$
MDCGD	KAMARIZAIT	$\text{Fe}_3^{3+}(\text{AsO}_4)_2(\text{OH})_3 \cdot 3\text{H}_2\text{O}$
MDCGE	FERRIVAUXITE	$\text{Fe}^{3+}\text{Al}_2(\text{PO}_4)_2(\text{OH})_3 \cdot 5\text{H}_2\text{O}$

SERIES H **CACOXENITE, hex/P6₃/m or P6₃. Structure consists of two fundamental building blocks: a cluster [PFe₆O₂₈] of edge- and corner-sharing Fe octahedra with attached P tetrahedra; and tetramers composed of four edge- and corner-sharing octahedra linked into chains by P tetrahedra. These building blocks are linked by Fe octahedra and Al trigonal dipyramids to create a framework with very large open channels that contain water molecules.**

MDCHA	CACOXENITE	$(\text{Fe,Al})_{25}(\text{PO}_4)_{17}\text{O}_6(\text{OH})_{12} \cdot 75\text{H}_2\text{O}$
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SERIES I **SOUZALITE SERIES, tric, P1. Structure probably contains clusters of 3 face-sharing octahedra linked by P tetrahedra.**

MDCIA	SOUZALITE	$(\text{Mg,Fe})_3(\text{Al,Fe})_4(\text{PO}_4)_4(\text{OH})_6 \cdot 2\text{H}_2\text{O}$
MDCIB	GORMANITE	$\text{Fe}_3(\text{Al,Fe})_4(\text{PO}_4)_4(\text{OH})_6 \cdot 2\text{H}_2\text{O}$
MDCIC	KENNGOTTITE	$\text{Mn}^{2+}_3\text{Fe}^{3+}_4(\text{PO}_4)_4(\text{OH})_6(\text{H}_2\text{O})_2$ mon/P2/a

SERIES J **WAVELLITE-KINGITE SERIES, orth/Pcmm. The structure is formed by two kinds of AlO₆ octahedra along the c axis, linked together by PO₄ tetrahedra. This linkage creates a dense layer of octahedra and tetrahedra in the plane (010), which are in turn connected by alternating AlO₄ octahedra and water molecules. This arrangement is seen as a framework of AlO₆ octahedral chains linked by PO₄ tetrahedra.**

MDCJA	WAVELLITE	$\text{Al}_3(\text{PO}_4)_2(\text{OH,F})_3 \cdot 5\text{H}_2\text{O}$
MDCJB	KINGITE	$\text{Al}_3(\text{PO}_4)_2(\text{OH,F})_3 \cdot 9\text{H}_2\text{O}$
MDCJC	KRIBERGITE	$\text{Al}_5(\text{PO}_4)_3(\text{SO}_4)(\text{OH})_4 \cdot 2\text{H}_2\text{O}$
MDCJD	ALLANPRINGITE	$\text{Fe}_3(\text{PO}_4)_2(\text{OH})_3 \cdot 5\text{H}_2\text{O}$
MDCJE	FLUORWAVELLITE	$\text{Al}_3(\text{PO}_4)_2(\text{OH})_2\text{F} \cdot 5\text{H}_2\text{O}$

SERIES K **MAPIMITE, mon/Cm. Structure consists of clusters of five edge-sharing (Zn,Fe)(O,OH,H₂O)₆ octahedra which are linked by arsenate tetrahedra to form a framework with water molecules in the cavities.**

MDCKA	MAPIMITE	$\text{Zn}_2\text{Fe}_3(\text{AsO}_4)_3(\text{OH})_4 \cdot 10\text{H}_2\text{O}$
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SERIES L **FALSTERITE, mon/P2₁/c. The structure of falsterite contains edge-sharing chains of Fe²⁺/Fe³⁺O₆ octahedra and corner-sharing chains of ZnO₄ tetrahedra along a. These chains are linked to one another by PO₄ tetrahedra, forming a sheet // to {010}. Mn²⁺O₆ octahedra and cAO₇ polyhedra also link to this sheet, resulting in a thick slab. The slabs are bridged in the [010] direction by edge-sharing dimers of MgO₆ octahedra, which link to the slabs by sharing edges with ZnO₄ tetrahedra in adjacent slabs. An extensive network of hydrogen bonds further links the slabs.**

MDCLA	FALSTERITE	$\text{Ca}_2\text{MgMn}^{2+}_2(\text{Fe}^{2+}_{0.5}\text{Fe}^{3+}_{0.5})_4\text{Zn}_4(\text{PO}_4)_8(\text{OH})_4(\text{H}_2\text{O})_{14}$
MDCLB	FERRAILOITE	$\text{MgMn}^{2+}_4(\text{Fe}^{2+}_{0.5}\text{Al}_{0.5})_4\text{Zn}_4(\text{PO}_4)_8(\text{OH})_4(\text{H}_2\text{O})_{20}$

TYPE D **Structures with only Medium-sized Cations, (OH, etc.): RO₄ = 2:1**

SERIES A **CHENEVIXITE SERIES, mon/P2₁/m. Structure consists of edge-sharing Cu distorted octahedra forming chains // [100], decorated by Fe octahedra on two sides of the chain; the chains are connected into sheets // (001) by sharing corners of octahedra with those of arsenate tetrahedra; the sheets are linked by sharing O atoms between sheets.**

MDDAA	CHENEVIXITE	$\text{Cu}_2\text{Fe}_2(\text{AsO}_4)(\text{OH})_4\cdot\text{H}_2\text{O}$
MDDAB	LUETHEITE	$\text{Cu}_2\text{Al}_2(\text{AsO}_4)(\text{OH})_4\cdot\text{H}_2\text{O}$

SERIES B **AKROCHORDITE, mon/P2₁/c.** The structure is based on a sheet of composition $^{2\infty}[\text{M}_5(\text{OH})_4(\text{H}_2\text{O})_4(\text{AsO}_4)_2]$ parallel to the {010} plane. Of the six unique H bonds O-H...O, four penetrate the c-axial glide planes and bond symmetry-equivalent sheets together. The sheets are made of fundamental building blocks based on $^1\infty[\text{M}_5\phi_2\phi_{12}]$ octahedral walls of amphibole type. These walls are connected in stepwise fashion by O(2) and O(3) of $[\text{AsO}_4]$ to form the sheet-like modular units.

MDDBA	AKROCHORDITE	$\text{Mn}_4\text{Mg}(\text{OH})_4(\text{AsO}_4)_2\cdot 4\text{H}_2\text{O}$
MDDBB	OGDENSBURGITE	$\text{Ca}_2\text{Fe}_4(\text{Zn},\text{Mn})(\text{AsO}_4)_4(\text{OH})_6\cdot 6\text{H}_2\text{O}$
MDDBC	GUANACOITE	$\text{Cu}_2\text{Mg}_2(\text{Mg},\text{Cu})(\text{OH})_4(\text{H}_2\text{O})_4(\text{AsO}_4)_2$

SERIES C **TURQUOISE SERIES, tric/ P1.** The structure consists of dimmers of edge-sharing Al octahedra which are linked by four P tetrahedra to form chains // [010]; the chains are linked by insular Al octahedra to form zigzag chains // [001]; further linkages are provided by $\text{Cu}(\text{OH})_4(\text{H}_2\text{O})_2$ distended octahedra.

MDDCA	TURQUOISE	$\text{CuAl}_6(\text{PO}_4)_4(\text{OH})_8\cdot 4\text{H}_2\text{O}$
MDDCB	AHEYLITE	$(\text{Fe},\text{Zn})\text{Al}_6(\text{PO}_4)_4(\text{OH})_8\cdot 4\text{H}_2\text{O}$
MDDCC	CHALCOSIDERITE	$\text{CuFe}_6(\text{PO}_4)_4(\text{OH})_8\cdot 4\text{H}_2\text{O}$
MDDCD	KOBOKOBOITE	$\text{Al}_6(\text{PO}_4)_4(\text{OH})_6\cdot 11\text{H}_2\text{O}$ (closely related)
MDDCE	FAUSTITE	$(\text{Zn},\text{Cu})\text{Al}_6(\text{PO}_4)_4(\text{OH})_8\cdot 4\text{H}_2\text{O}$
MDDCF	PLANERITE	$\text{Al}_6(\text{PO}_4)_4(\text{PO}_3\text{OH})_2(\text{OH})_8\cdot 4\text{H}_2\text{O}$
MDDCG	AFMITE	$\text{Al}_3(\text{OH})_4(\text{H}_2\text{O})_3(\text{PO}_4)(\text{PO}_3\text{OH})\cdot\text{H}_2\text{O}$

SERIES D **CHILDRENITE SERIES, orth/Bbcm.** Structure consists of edge-sharing $(\text{Fe},\text{Mn})\text{O}_4(\text{OH})_2$ octahedra and corner-sharing $\text{AlO}_2(\text{OH})_2(\text{H}_2\text{O})_2$ octahedra forming chains, both // [001]; the chains are corner bonded by OH to form sheets // (100); two of the P tetrahedra strengthen the Al chains, and two O atoms interconnect the sheets.

MDDDA	CHILDRENITE	$\text{FeAl}(\text{PO}_4)(\text{OH})_2\cdot\text{H}_2\text{O}$
MDDDB	EOSPHORITE	$\text{MnAl}(\text{PO}_4)(\text{OH})_2\cdot\text{H}_2\text{O}$
MDDDC	ERNSTITE	$(\text{Mn}_{1-x}\text{Fe}_x)\text{AlPO}_4(\text{OH})_{2-x}\text{O}_x$
MDDDD	LEFONTITE	$\text{Fe}_2\text{Al}_2\text{Be}(\text{PO}_4)_2(\text{OH})_6$

SERIES E **AXELITE, tetr/P4bm.**

MDDEA	AXELITE	$\text{Na}_{14}\text{Cu}_7(\text{AsO}_4)_8\text{F}_2\text{Cl}_2$
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TYPE E **Structures with only Medium-sized Cations, (OH, etc.): RO₄ = 3:1.**

SERIES A **SENEGALITE-FLUELLITE SERIES, orth/P2₁nb.** The structure is based on chains of composition $^1\infty[\text{Al}^{[5]}\text{Al}^{[6]}\text{Al}(\text{OH})_3(\text{H}_2\text{O})(\text{Op})_4]$ where ϕ is a coordinating oxygen and Op is phosphate oxygen. Two symmetry-equivalent chains run parallel to [101] and $[\bar{1}01]$, each based on distorted $\text{Al}(\text{OH})_3(\text{H}_2\text{O})(\text{Op})_2$ octahedral and $\text{Al}(\text{OH})_3(\text{Op})_2$ trigonal bipyramidal edge-sharing dimers which further corner-link to complete the chain. Corner-linking (PO_4) tetrahedra knit neighboring chains to form an open sheet parallel to (010). Further tetrahedral corner-links to chains related by the b-axial glide form an open polyhedral framework structure.

MDEAA	SENEGALITE	$\text{Al}_2(\text{OH})_3(\text{H}_2\text{O})[\text{PO}_4]$
MDEAB	BOLIVARITE	$\text{Al}_2(\text{PO}_4)(\text{OH})_3\cdot 4\text{H}_2\text{O}$
MDEAC	BULACHITE	$\text{Al}_2(\text{AsO}_4)(\text{OH})_3\cdot 3\text{H}_2\text{O}$
MDEAD	FLUELLITE	$\text{Al}_2\text{F}_2(\text{PO}_4)(\text{H}_2\text{O})_3(\text{OH})\cdot 4\text{H}_2\text{O}$

SERIES B	ZAPATALITE-CERULEITE SERIES, tetr/ (structures not known). The structure of ceruleite has a unique arrangement that consists of $\text{Al}(\text{O},\text{OH})_6$ octahedra that are sharing edges to form rhombus-shaped tetramers. AsO_4 tetrahedra share two corners with one such rhombus and the other two corners with each of two other rhombi, linking them into a very open mesoporous framework. $\text{Cu}(\text{OH})_2(\text{H}_2\text{O})_2$ squares lie in the channels and link Al_4 rhombi along $\parallel b$. Water molecules are also located in the channels. The crystal structure of ceruleite, $\text{CuAl}_4[\text{AsO}_4]_2(\text{OH})_8(\text{H}_2\text{O})_4$, has been solved to an R_1 of 0.0307, using the world's largest crystals from the Cap Garonne mine, France. Ceruleite crystallises in space group $P2_1/n$, with the unit cell $a = 7.2000(14)$, $b = 11.345(2)$, $c = 9.856(2)$ Å, $\beta = 105.57(3)^\circ$, $V = 775.6(3)$ Å ³ and $Z = 1$. Ceruleite has a unique structure that consists of $\text{Al}(\text{O},\text{OH})_6$ octahedra that are sharing edges to form rhombus-shaped tetramers. AsO_4 tetrahedra share two corners with one such rhombus and the other two corners with each of two other rhombi, linking them into a very open mesoporous framework. $\text{Cu}(\text{OH})_2(\text{H}_2\text{O})_2$ squares lie in the channels and link Al_4 rhombi along $\parallel b$. H_2O molecules are also located in the channels.		
MDEBA	ZAPATALITE	$\text{Cu}_3\text{Al}_4(\text{PO}_4)_3(\text{OH})_9 \cdot 4\text{H}_2\text{O}$	
MDEBB	CERULEITE	$\text{Cu}_2\text{Al}_7(\text{AsO}_4)_4(\text{OH})_{13} \cdot 12\text{H}_2\text{O}$	
MDEBC	ALDERMANITE	$\text{Mg}_5\text{Al}_{12}(\text{PO}_4)_8(\text{OH})_{22} \cdot 32\text{H}_2\text{O}$	

SERIES C **TAPIAITE, mon/ $P2_1/n$.** The structure of tapiaite ($R_1 = 5.37\%$ for $1733 F_o > 4sF$) contains $\text{Al}(\text{AsO}_4)(\text{OH})_2$ chains of octahedra and tetrahedra that are topologically identical to the chain in the structure of linarite. CaO_8 polyhedra condense to the chains, forming columns, which are decorated with additional peripheral AsO_4 tetrahedra. The CaO_8 polyhedra in adjacent columns link to one another by corner-sharing to form thick layers parallel to $\{101\}$ and the peripheral AsO_4 tetrahedra link to CaO_6 octahedra in the interlayer region, resulting in a framework structure.

Kampf, A.R., Mills, S.J., Nash, B., Dini, M. and Molina Donoso, A.A. (2014) Tapiaite, IMA 2014-024. CNMNC Newsletter No. 21, August 2014, page 800; *Mineralogical Magazine*, 78, 797-804.

Kampf, Anthony R., Mills, Stuart J., Nash, Barbara P., Dini, Maurizio, and Molina Donoso, A. A., 2014. Tapiaite, $\text{Ca}_5\text{Al}_2(\text{AsO}_4)_4(\text{OH})_4 \cdot 12\text{H}_2\text{O}$, a new mineral from the Jote mine, Tierra Amarilla, Chile. *Mineralogical Magazine*, 78.

MDECA	TAPIAITE	$\text{Ca}_5\text{Al}_2(\text{AsO}_4)_4(\text{OH})_4 \cdot 12\text{H}_2\text{O}$	
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TYPE F Structures with only Medium-sized Cations, (OH, etc.): $\text{RO}_4 > 3:1$

SERIES A **HOTSONITE-RUSAKOVITE SERIES, tric/.** Structures not known. Burkes et al. (1984): Hotsonite, a new hydrated aluminum-phosphate-sulfate from Pofarder, South Africa. *American Mineralogist* 68, 979-983. *American Mineralogist*: 69: 979-983. *American Mineralogist*: 76: 1734.

MDFAA	HOTSONITE	$\text{Al}_5(\text{PO}_4)(\text{SO}_4)(\text{OH})_{10}$	tric/ $P1$ or $P\bar{1}$
MDFAB	Open		
MDFAC	EVANSITE	$\text{Al}_3\text{PO}_4(\text{OH})_6 \cdot 6\text{H}_2\text{O}$	
MDFAD	ROSIERESITE	Hydrous phosphate of Al, Pb and Cu	
MDFAE	RUSAKOVITE	$(\text{Fe},\text{Al})_5(\text{V},\text{PO}_4)_2(\text{OH})_9 \cdot 9\text{H}_2\text{O}$	

SERIES B **SIELECKIITE-LIROCONITE SERIES, tric/ $P1$.** Structure consists of dimmers of edge-sharing Cu octahedra which are corner-linked to $[100]$ chains of edge-sharing $\text{Al}(\text{O},\text{OH})_6$ octahedra and arsenate tetrahedra to form a framework; channels $\parallel [100]$ and $[001]$ accommodate water molecules. The structure of sieleckiite is composed of a framework of corner, edge- and face-sharing Cu and Al octahedra and PO_4 tetrahedra.

MDFBA	SIELECKIITE	$\text{Cu}_3\text{Al}_4(\text{PO}_4)_{12} \cdot 2\text{H}_2\text{O}$	mon/ $C2/m$
MDFBB	LIROCONITE	$\text{Cu}_2\text{Al}(\text{AsO}_4)(\text{OH})_4(\text{H}_2\text{O})_4$	

SERIES C **CHALCOPHYLLITE SERIES, orth/ $P2_122$.** The structure consists of nine edge-sharing $\text{Cu}(\text{OH})_6$ octahedra and on Al octahedron forming open sheets $\parallel (001)$, decorated on both sides by As

tetrahedra that share three corners with the Cu octahedra surrounding vacant sites in the sheets; the sheets are linked by S tetrahedra and H bonds.

MDFCA	CHALCOPHYLLITE	$\text{Cu}_9\text{Al}[(\text{OH})_{12}/(\text{SO}_4)_{1.5}/(\text{AsO}_4)_2] \cdot 18 \text{H}_2\text{O}$
MDFCB	TIBERIOBARDIITE	$\{\text{Cu}_9\text{Al}[\text{SiO}_3(\text{OH})]_2(\text{OH})_{12}(\text{H}_2\text{O})_6\}(\text{SO}_4)_{1.5} \text{ trig/R}\underline{3}$
MDFCC	KRENDELEVITE	$\text{Cu}_{18}\text{Al}_2(\text{SO}_4)_3(\text{PO}_4)_3(\text{OH})_{27} \cdot 33\text{H}_2\text{O}$

SERIES D **PARNAUITE, orth/Pmn2₁.** The structure is of a new type, and contains Cu in 6 distinct sites, forming two three-polyhedron wide ribbons of edge-sharing Cu-O polyhedral extending // to the a-axis. The two ribbons lie back-to-back and are bridged by two As tetrahedra. The collection of 6Cu + 2As cations plus ligands forms a rod-like moiety extending // to a. These rods link through polyhedral corners to form complex, corrugated (010) layers. The interlayer space is occupied by water molecules. Disorder arises because each As tetrahedron shares a face with a $\text{Cu}(\text{O},\text{OH},\text{H}_2\text{O})_{5-6}$ polyhedron in the substructure, necessitating partial occupancy of both As and Cu sites. The S atoms were not located in the refinement, but four electron-density maxima in the interlayer region were interpreted as water molecules. Hence, the simplified structural formula derived from the substructure is $(\text{Cu}_{10}\square_2)(\text{As}_2\square_2)\text{O}_8(\text{OH})_{14}\cdot 8\text{H}_2\text{O}$. The discrepancy presumably arises due to strong delocalization of the sulphur and the apical oxygen of the SO_4 tetrahedron in the substructure. Short-range order of the Cu-As and Cu-S // a can occur independently in the relevant structural rods, which accounts for the observed long-range disorder.

MDFDA	PARNAUITE	$(\text{Cu}_{10}\square_2)(\text{As}_2\square_2)\text{O}_8(\text{OH})_{14}\cdot 8\text{H}_2\text{O}$
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SERIES E **FORETITE, tri/P₁.** Structure not determined due to poor quality of crystals.

MDFEA	FORETITE	$\text{Cu}_2\text{Al}_2(\text{AsO}_4)(\text{OH},\text{O}, \text{H}_2\text{O})_6$
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SERIES F **SEGERSTROMITE, cub/I213.** Crystal structure is constructed from three different polyhedral units: distorted CaO_8 cubes, rigid As^{5+}O_4 arsenate tetrahedra, and neutral $\text{As}^{3+}(\text{OH})_3$ arsenite triangular pyramids. The Ca-groups form layers of corrugated crankshaft chains that lie // to the cubic axes. These chains are linked by the isolated As^{5+}O_4 and $\text{As}^{3+}(\text{OH})_3$ groups. Hexiong Yang, Benjamin N. Schumer, Robert A. Jenkins, J. Rueben Bautista, Robert T. Downs and Stanley H. Evans (2014) Segerstromite, IMA 2014-001. CNMNC Newsletter No. 20, June 2014, page 554; Mineralogical Magazine, 78, 549- 558.

MDFFA	SEGERSTROMITE	$\text{Ca}_3(\text{AsO}_4)_2[\text{As}(\text{OH})_3]_2$
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SERIES G **BARROTITE, trig/P31 or P32.** Sarp, H. and Cerny, R. (2013) Barrotite, IMA 2011-061a. CNMNC Newsletter No. 16, August 2013, page 2698; *Mineralogical Magazine*, **77**, 2695-2709.

Sarp H., Cerny R., Puscharovsky D.Yu., Schouwink P., Teyssier J., Williams P.A., Babalik H., Mari G. (2014): La barrotite, $\text{Cu}_9\text{Al}(\text{HSiO}_4)_2[(\text{SO}_4)(\text{HAsO}_4)_{0.5}](\text{OH})_{12}\cdot 8\text{H}_2\text{O}$, un nouveau minéral de la mine de Roua (Alpes-Maritimes, France). *Riviera Scientifique*, 98, 3-22.

MDFGA	BARROTITE	$\text{Cu}_9\text{Al}(\text{HSiO}_4)_2[(\text{SO}_4)(\text{HAsO}_4)_{0.5}](\text{OH})_{12}\cdot 8\text{H}_2\text{O}$
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SERIES H **CAMARONESITE, trig/R32.** Kampf, A. R., Mills, S. J., Nash, B. P., Housley, R. M., Rossman, G. R., Dini, M. and Gatta G.D. (2013): Camaronesite, $[\text{Fe}^{3+}(\text{H}_2\text{O})_2(\text{PO}_3\text{OH})]_2(\text{SO}_4)\cdot 1-2\text{H}_2\text{O}$, a new phosphate-sulfate from the Camarones Valley, Chile, structurally related to taranakite. *Mineral. Mag.* **77**, 453-465.

MDFHA	CAMARONESITE	$\text{Fe}^{3+}_2(\text{PO}_3\text{OH})_2(\text{SO}_4)(\text{H}_2\text{O})_4\cdot 1-2\text{H}_2\text{O}$
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TYPE G **Structures with only Medium-sized Cations, (OH, etc.): $\text{RO}_4 > 0.5:1$**

SERIES A **LAVENDULAN SERIES, Mon/P21/n.** The lavendulan structure is based on $\text{Cu}(\text{O},\text{H}_2\text{O},\text{Cl})_5$ pyramids forming $[\text{Cu}_4\text{O}_{12}\text{Cl}]$ clusters, which are connected by XO_4 groups into heteropolyhedral sheets. These sheets ideally have p4mm symmetry and are aligned // to (010), the cleavage plane, and are linked to adjacent // sheets via NaO_6 and CaO_7 polyhedra as well as by weak H bonding. The structure of mahnertite is dominated by mixed polyhedral sheets // (001) comprised of two symmetrically independent distorted CuO_5 square pyramids and As tetrahedra, identical to those found in zdenekite. The mixed polyhedral sheets in both minerals are related by different modes of stacking. Very similar sheets are found in andyrobbersite, calico-andyrobbersite (-1M), calico-andyrobbersite-2O,

richelsdorffite, and probably bleasdaleite, mahnerite, lemanskiite and the inadequately characterized, lavendulan-related species shubnikovite.

MDGAA	SHUBNIKOVITE	$\text{Ca}_2\text{Cu}_8(\text{AsO}_4)_6\text{Cl}(\text{OH})\cdot 7\text{H}_2\text{O}$
MDGAB	LAVENDULAN	$\text{NaCaCu}_5(\text{AsO}_4)_4\text{Cl}\cdot 5\text{H}_2\text{O}$
MDGAC	SAMPLEITE	$\text{NaCaCu}_5(\text{PO}_4)_4\text{Cl}\cdot 5\text{H}_2\text{O}$
MDGAD	MAHNERTITE	$(\text{Na,Ca})\text{Cu}_3(\text{AsO}_4)_2\text{Cl}\cdot 5\text{H}_2\text{O}$
MDGAE	ZDENEKITE	$\text{NaPbCu}_5[\text{AsO}_4]_4\text{Cl}\cdot 5\text{H}_2\text{O}$
MDGAF	LEMANSKIITE	$\text{NaCaCu}_5(\text{AsO}_4)_4\text{Cl}\cdot 5\text{H}_2\text{O}$

TYPE H Structures with Large and Medium-sized Cations, (OH, etc.): $\text{RO}_4 < 1:1$

SERIES A **MINYULITE**, orth/Pba2. The structure consists of a dimeric cluster of two Al^{3+} -O octahedra sharing one F⁻ vertex and two PO_4 tetrahedra, which further link the octahedra. The clusters link via shared octahedral-tetrahedral vertices to form sheets parallel to {001}. Cavities in the sheets are occupied by K^+ ions.

MDHAA MINYULITE $\text{KAl}_2(\text{PO}_4)_2(\text{OH,F})\cdot 4\text{H}_2\text{O}$

SERIES B **LEUCOPHOSPHITE SERIES**, mon/P2₁/n. The structure is based on an octahedral cluster which consists of an edge-sharing doublet whose two common corners each fuse by corner-sharing to two other octahedra forming a tetramer. The tetramer is an insular octahedral cluster and is joined to surrounding symmetry equivalent tetramers by the bridging phosphate ligands, resulting in a three-dimensional linkage of Fe-O-P-O bonds. The K ions are located in channels created by the tetramers. Structure consists of clusters of four edge- and corner-sharing Fe octahedra which are corner-linked by P tetrahedra into a framework with 8-membered channels // [010] that accommodate the large cations and water molecules.

MDHBA LEUCOPHOSPHITE $\text{K}_2[\text{Fe}_4^{3+}(\text{OH})_2(\text{H}_2\text{O})_2(\text{PO}_4)_4]\cdot 2\text{H}_2\text{O}$

MDHBB SPHENISCIDITE $(\text{NH}_4,\text{K})(\text{Fe,Al})_2(\text{PO}_4)_2(\text{OH})\cdot 2\text{H}_2\text{O}$

MDHBC TINSLEYITE $\text{KAl}_2(\text{PO}_4)_2(\text{OH})\cdot 2\text{H}_2\text{O}$

SERIES C **JAHNSITE SERIES**, mon/P2₁/a. The structure is based on a backbone of corner-linked Fe-OH-Fe octahedra with a novel arrangement of phosphate tetrahedra about these chains. The structure possesses dense slabs of $[\text{CaMnFe}_2(\text{OH})_2[\text{PO}_4]_4]^{4-}$ oriented parallel to {001} which are bridged by PO_4 corner-sharing to $\text{Mg}(\text{O,H}_2\text{O})_6$ octahedra. Structure consists of dense slabs of edge-sharing M octahedra and P tetrahedra // (001) which are linked by corner-sharing M octahedra. Jahnsite-(NaMnMg), $(\text{Na,Ca})(\text{Mn}^{2+},\text{Fe}^{3+})(\text{Mg,Fe}^{3+},\text{Mn}^{3+})_2\text{Fe}_3+2(\text{PO}_4)_4(\text{OH})_2(\text{H}_2\text{O})_8$, is a new mineral from the Sapucaia pegmatite, Conselheiro Pena pegmatite district, Minas Gerais, Brazil, and the White Rock No. 2 quarry, Bimbowrie Conservation Park, South Australia, Australia. At both localities, it is a low temperature, secondary mineral formed as the result of alteration of primary phosphates. The mineral occurs as light orange to orange-yellow prisms, elongate on [100], exhibiting the forms {100}, {001}, and {011} and twinned by reflection on {001}. The streak is white, the luster is vitreous, and crystals are transparent to translucent. The Mohs hardness is about 4. The tenacity is brittle, the fracture is irregular, stepped (splintery), and there is one very good cleavage on {001}. The measured density is 2.68(1) g/cm³ (Sapucaia). The mineral is slowly soluble in dilute HCl. Jahnsite-(NaMnMg) from Sapucaia is biaxial (-), with α 1.642(1), β 1.675(1), γ 1.677(1) (white light). The measured 2V is 29(1)°. Dispersion is very strong, $r < v$. The optical orientation is Z = b; X ^ c = 51° in obtuse β . Pleochroism is X = colorless, Y and Z = orange-yellow; Y \approx Z > X. Electron-microprobe analyses gave the empirical formulae $(\text{Na}0.56\text{Ca}0.25\text{Mn}2+0.09)\Sigma 0.90(\text{Mn}2+0.85\text{Fe}3+0.15)\Sigma 1.00(\text{Mg}1.53\text{Fe}3+0.47)\Sigma 2.00(\text{Fe}3+1.79\text{Al}0.21)\Sigma 2(\text{PO}4)_4(\text{OH})1.83(\text{H}_2\text{O})8.17$ for the Sapucaia material and $(\text{Na}0.63\text{Ca}0.23\text{Mn}2+0.14)\Sigma 1.00(\text{Mn}2+0.68\text{Mn}3+0.26\text{Fe}3+0.05\text{Mg}0.01)\Sigma 1.00(\text{Mg}1.26\text{Mn}2+0.43\text{Mn}3+0.16\text{Fe}3+0.15)\Sigma 2.00(\text{Fe}3+1.97\text{Al}0.02)\Sigma 1.99(\text{PO}4)_4(\text{OH})1.98(\text{H}_2\text{O})8.02$ for the White Rock material. The mineral is monoclinic, space group P2₁/a, with cell parameters (Sapucaia) a 15.1045(15), b 7.1629(2), c 9.8949(7) Å, β 110.640(7)°, V 1001.83(13) Å³, and Z = 2. The structure refinements of crystals from both localities were generally consistent and showed the mineral to be a member of the jahnsite group (Sapucaia: R1 = 3.19% for 1941 lo > 2 σ l reflections; White Rock: R1 = 6.94% for 13485 lo > 2 σ l reflections). □

Jahnsite-(MnMnZn) (IMA2017-113), $\text{Mn}_2+2\text{Zn}_2\text{Fe}_3+2(\text{PO}_4)_4(\text{OH})_2\cdot 8\text{H}_2\text{O}$, is a new member of the jahnsite group from the Herdade dos Pendões mine, Beja district, southwest Portugal. It formed in a

highly altered gossan in association with Zn-bearing libethenite, quartz, rhodochrosite and santabarbarite. It occurs in sub-parallel bundles of light golden brown prisms up to 0.3 mm long. Crystals are transparent with vitreous to silky lustre and white streak. The mineral is brittle with irregular, splintery fracture, good cleavage parallel to {001} and Mohs' hardness of about 4. The measured density is 2.89(2) g cm⁻³. Optically, it is biaxial (+), with $\alpha = 1.655(2)$, $\beta = 1.662(2)$, $\gamma = 1.673(2)$ (white light); $2V = 78(1)^\circ$; pleochroism: X nearly colourless, Y and Z beige; $X < Y \approx Z$. Electron microprobe analyses gave the empirical formula $(\text{Mn}^{2+}_{0.71}\text{Na}_{0.15}\text{Ca}_{0.10})\Sigma_{0.96}(2+1.00)(\text{Zn}_{1.00}\text{Mn}^{2+}_{0.66}\text{Fe}^{2+}_{0.21}\text{Mg}_{0.10}\text{Fe}^{3+}_{0.03})\Sigma_{2.00}(\text{Fe}^{3+}_{1.99}\text{Al}_{0.01})\Sigma_{2.00}(\text{P}_{1.01}\text{O}_4)_4(\text{OH})_2 \cdot 8\text{H}_2\text{O}$. Jahnsite-(MnMnZn) is monoclinic, P2/a, $a = 15.222(6)$, $b = 7.187(6)$, $c = 10.028(5)$ Å, $\beta = 111.746(16)$, $V = 1019.0(11)$ Å³ and $Z = 2$. The eight strongest lines in the X-ray powder diffraction pattern are [dobs/Å (I) (hkl)]: 9.25 (63) (001), 5.00 (40) (210,21-1,111), 4.648 (33) (002), 3.509 (41) (40-2), 2.842 (100) (022), 1.9984 (37) (422,42-4), 1.9506 (30) (024) and 1.5853 (33) (820,82-4). The jahnsite group has now been officially established by the Commission on New Minerals, Nomenclature and Classification. The general formula for jahnsite-group minerals is $\text{XM}_1\text{M}_2\text{M}_3(\text{H}_2\text{O})_8(\text{OH})_2(\text{PO}_4)_4$; the ionic radii for the cation sites generally increase as follows: $\text{M}_3 < \text{M}_2 < \text{M}_1 < \text{X}$, and the M_3 site determines whether the species belongs to the jahnsite subgroup ($\text{M}_3 = \text{Fe}^{3+}$) or the whiteite subgroup ($\text{M}_3 = \text{Al}$). The subgroup name is generally used as the species root name to be followed by a suffix of the form -(XM₁M₂). Using this as a guide for the jahnsite described herein results in the following site assignments: X = Mn, M₁ = Mn, M₂ = Zn, and M₃ = Fe; and the name jahnsite-(MnMnZn).

MDHCA	JAHNSITE-(CaMnFe)	CaMnFe ₂ Fe ₂ (PO ₄) ₄ (OH) ₂ ·8H ₂ O
MDHCB	JAHNSITE-(CaMnMg)	CaMn(Mg,Fe) ₂ Fe ₂ (PO ₄) ₄ (OH) ₂ ·8H ₂ O
MDHCC	JAHNSITE-(CaMnMn)	CaMnMn ₂ Fe ₂ (PO ₄) ₄ (OH) ₂ ·8H ₂ O
MDHCD	KECKITE	CaMn ²⁺ (Fe ³⁺ Mn ²⁺)Fe ³⁺ ₂ (PO ₄) ₄ (OH) ₃ ·7H ₂ O
MDHCE	RITTMANNITE	(Mn,Ca)Mn(Fe,Mn) ₂ (Al,Fe) ₂ (PO ₄) ₄ (OH) ₂ ·8H ₂ O
MDHCF	WHITEITE-(CaFeMg)	Ca(Fe,Mn)Mg ₂ Al ₂ (PO ₄) ₄ (OH) ₂ ·8H ₂ O
MDHCG	WHITEITE-(CaMnMg)	CaMnMg ₂ Al ₂ (PO ₄) ₄ (OH) ₂ ·8H ₂ O
MDHCH	WHITEITE-(MnFeMg)	(Mn,Ca)(Fe,Mn)Mg ₂ Al ₂ (PO ₄) ₄ (OH) ₂ ·8H ₂ O
MDHCI	JAHNSITE-(MnMnMn)	CaMnMn ₂ Mn ₂ (PO ₄) ₄ (OH) ₂ ·8H ₂ O
MDHCJ	XANTHOXENITE (Related)	Ca ₄ Fe ₂ ³⁺ [OH/(PO ₄) ₂] ₂ · 3H ₂ O
MDHCK	JAHNSITE-(NaFeMg)	NaFe ³⁺ Mg ₂ Fe ₃ ²⁺ (PO ₄) ₄ (OH) ₂ ·8H ₂ O
MDHCL	WHITEITE-(CaMnMn)	CaMnMn ₂ Fe ₂ (PO ₄) ₄ (OH) ₂ ·8H ₂ O
MDHCM	JAHNSITE-(CaFeMg)	CaFeMg ₂ Fe ₂ (PO ₄) ₄ (OH) ₂ ·8H ₂ O
MDHCN	WHITEITE-(MnMnMg)	Mn ²⁺ Mn ²⁺ Mg ₂ Al ₂ (PO ₄) ₄ (OH) ₂ ·8H ₂ O
MDHCO	WHITEITE-(CaMgMg)	CaMg ₃ Al ₂ (PO ₄) ₄ (OH) ₂ ·8H ₂ O
MDHCP	JAHNSITE-(MnMnZn)	MnMnZn ₂ Fe ₂ (PO ₄) ₄ (OH) ₂ ·8H ₂ O
MDHCQ	JAHNSITE-(MnMnMg)	Mn ²⁺ Mn ²⁺ Mg ₂ Fe ₂ (PO ₄) ₄ (OH) ₂ ·8H ₂ O
MDHCR	JAHNSITE-(NaMnMg)	(Na,Ca)(Mn,Fe)(Mg,Fe) ₂ Fe ₂ (PO ₄) ₄ (OH) ₂ (H ₂ O) ₈
MDHCS	HAHNSITE-(MnMnFe)	Mn ²⁺ Mn ²⁺ Fe ²⁺ Fe ³⁺ ₂ (PO ₄) ₄ (OH) ₂ ·8H ₂ O

SERIEC D OVERITE SERIES, orth/Pcca. These structures contain similar slabs to those of the Jahnsite group, but the M octahedra linking the slabs are oriented differently.

MDHDA	LUN'OKITE	(Mn,Ca)(Mg,Fe,Mn)Al(PO ₄) ₂ (OH)·4H ₂ O
MDHDB	MANGANOSEGELERITE	(Mn,Ca)(Mn,Fe,Mg)Fe(PO ₄) ₂ (OH)·4H ₂ O
MDHDC	OVERITE	CaMgAl(PO ₄) ₂ (OH)·4H ₂ O
MDHDD	SEGELERITE	CaMgFe(PO ₄) ₂ (OH)·4H ₂ O
MDHDE	WILHELMVIERLINGITE	CaMnFe(PO ₄) ₂ (OH)·4H ₂ O
MDHDF	JUONNIITE	CaMgSc(PO ₄) ₂ (OH)·4H ₂ O

SERIE E MONTGOMERYITE SERIES, mon/C2. Structure consists of chains of corner-sharing Al octahedra // [001] which are edge-linked by P tetrahedra to form slabs // (010). The slabs are linked by Mg

octahedra and Ca polyhedra. Fanfaniite, Ca₄Mn₂₊Al₄(PO₄)₆(OH,F)₄·12H₂O, is a new secondary phosphate mineral from the Foote spodumene mine, 14 North Carolina, USA and the Hagendorf-Süd pegmatite, Bavaria, Germany. At the Foote mine, it forms radial aggregates up to 15 0.5 mm in diameter of colourless, transparent, thin blades, flattened on {010} and elongated on [001], associated with whiteite-16 (CaMnMn). At Hagendorf-Süd, the mineral occurs as isolated very thin laths on the surface of fibrous spheroids of kayrobertsonite 17 and is associated with altered triplite-zwieselite and whiteite-(CaMnMn). The measured density (Foote mine) is 2.58(2) g cm⁻³. 18 Optically, fanfaniite (Foote mine) is biaxial (-), with a = 1.573(2), b = 1.582(2), c = 1.585(2) and 2V(meas) = 57(1)°. Dispersion was 19 not observed. The optical orientation is: Z = b, X ^ c % 40° in b obtuse. Pleochroism was not evident. Electron microprobe analyses 20 gave the empirical formulas Ca 3.91 Mn 2p 0:77 Mg 0.10 Zn 0.02 Al 3.89 Fe 3p 0:21 (PO 4) 6 (OH) 3.90 (H 2 O) 12.10 (Foote mine) and Ca 3.73 Mn 2p 0:76 Mg 0.25 21 Zn 0.08 Al 3.89 Fe 3p 0:29 (PO 4) 6 F 1.10 (OH) 3.08 (H 2 O) 11.82 (Hagendorf-Süd). Fanfaniite has monoclinic symmetry, space group C2/c, with 22 a = 10.021(4) Å, b = 24.137(5) Å, c = 6.226(3) Å, β = 91.54(2)° and V = 1505(1) Å³. The crystal structure was refined to 23 R_{obs} = 0.043 for 1909 unique reflections to a resolution of 0.7 Å. Fanfaniite is the Mn²⁺-dominant analogue of montgomeryite. The 24 name honours Luca Fanfani who structurally characterised many phosphate minerals including montgomeryite. 25

MDHEA	CALCIOFERRITE	Ca ₄ Fe(Fe,Al) ₄ (PO ₄) ₆ (OH) ₄ ·13H ₂ O
MDHEB	KINGSMOUNTITE	(Ca,Mn) ₄ (Fe,Mn)Al ₄ (PO ₄) ₆ (OH) ₄ ·12H ₂ O
MDHEC	MONTGOMERYITE	Ca ₃ MnFeAl ₄ (PO ₄) ₆ (OH) ₄ ·12H ₂ O
MDHED	ZODACITE	Ca ₄ MnFe ₄ (PO ₄) ₆ (OH) ₄ ·12H ₂ O
MDHEE	ANGASTONITE	CaMgAl ₂ (PO ₄) ₂ (OH) ₄ ·7H ₂ O
MDHEF	FANFANIITE	Ca ₃ Mn ²⁺ Fe ²⁺ Al ₄ (PO ₄) ₆ (OH) ₄ ·12H ₂ O

SERIES F **MATRIDATITE SERIES, mon/A2/a.** Structure consists of edge-sharing MO₆ octahedra forming trigonal 9-membered rings that are linked into sheets // (001) by corner-sharing RO₄ tetrahedra; the sheets are linked by Ca polyhedra and water molecules. Kittatinnyite belongs here. The structure of sailaufite contains characteristic nonamer rings of edge-sharing MnO₆ octahedra forming compact pseudotrigonal [Mn₉O₆(AsO₄)₆(CO₃)₃]⁹⁻ sheets which are linked by layers composed of (Ca,Na)O₅(H₂O)₂ polyhedra and isolated water molecules, the octahedral nonamer rings correspond to those occurring in the Fe phosphate mitridatite.

MDHFA	ARSENOSIDERITE	Ca ₆ Fe ₉ O ₆ (H ₂ O) ₆ (AsO ₄) ₉ ·3H ₂ O
MDHFB	ROBERTSITE	Ca ₂ Mn ₃ O ₂ (PO ₄) ₃ ·3H ₂ O
MDHFC	MITRIDATITE	Ca ₆ Fe ₉ O ₆ (H ₂ O) ₆ (PO ₄) ₉ ·3H ₂ O
MDHFD	PARAROBERTSITE	Ca ₂ Mn ₃ O ₂ (H ₂ O) ₃ (PO ₄) ₃ ·3H ₂ O AM2000-1302
MDHFE	KOLFANITE	Ca ₂ Fe ₃ O ₂ (AsO ₄) ₃ ·2H ₂ O
MDHFF	ENGLISHITE	Na ₂ Ca ₁₀ Al ₁₅ (PO ₄) ₂₁ (OH) ₇ ·26H ₂ O
MDHFG	SAILAUFITE	Ca ₂ Mn ₃ O ₂ (AsO ₄) ₂ (CO ₃) ₃ ·3H ₂ O
MDHFH	YUKONITE	Ca ₂ Fe ₃₋₅ (AsO ₄) ₃ (OH) ₄₋₁₀ ·2-11H ₂ O
MDHFI	WALLKILLDELLITE-(Mn)	Ca ₄ Mn ₆ [AsO ₄] ₄ (OH) ₈ ·18H ₂ O hex/P6 ₃ /mmc, P6 ₃ mc, or P6 ₂ c
MDHFJ	WALLKILLDELLITE-(Fe)	(Ca,Cu) ₄ Fe ₆ [AsO ₄] ₄ (OH) ₈ ·18H ₂ O

SERIES G **MANTIENNEITE SERIES, orth/Pbca.** Structure consists of corner-sharing M and Ti octahedra which are linked into a framework by P tetrahedra; large cavities are occupied by K and water molecules.

MDHGA	MANTIENNEITE	KMg ₂ Al ₂ Ti(PO ₄) ₄ (OH) ₃ ·15H ₂ O
MDHGB	PAULKERRITE	K(Mg,Mn) ₂ (Fe,Al) ₂ Ti(PO ₄) ₄ (OH) ₃ ·15H ₂ O
MDHGC	BENYACARITE	(H ₂ O,K) ₂ Ti(Mn,Fe) ₂ (Fe) ₂ (PO ₄) ₄ (O,F) ₂ ·14H ₂ O

SERIES H **ANDYROBERTSITE SERIES, mon/P2₁/m.** Structurally related to the lavendulan series. In andyrobersite, there are three crystallographically distinct As sites, each occupied by As⁵⁺ in

tetrahedral coordination. One of the As sites is coordinated by two O atoms and two (OH) groups to form a doubly acid arsenate group, $[\text{As}(\text{OH})_2\text{O}_2]$. There are four crystallographically distinct Cu sites, each occupied by Cu^{2+} in square-pyramidal coordination. There is one crystallographically distinct M site occupied by Cd, Ca and Mn^{2+} coordinated by four O atoms and two water groups in a trigonal-prismatic arrangement. Variation in the occupancy of this site gives rise to the two related species andyrobbersite (Cd dominant) and calico-andyrobbersite (Ca dominant). There is one distinct K site occupied by K and coordinated by four O atoms, two (OH) groups and two water groups in a distorted-cube arrangement. Four (CuO_5) polyhedra link to a central anion to form a $[\text{Cu}_4\text{O}_{13}]$ group. The anions at the base of this group corner-share to four arsenate tetrahedra that link to a fifth $[\text{CuO}_5]$ square pyramid. A single (AsO_4) tetrahedron links to the central anion of the $[\text{Cu}_4\text{O}_{13}]$ group to form a $[\text{Cu}_5(\text{AsO}_4)_4(\text{AsO}_4)_4(\text{AsO}_4)\text{O}_5]$ cluster. These clusters are arranged at the vertices of non-coplanar 4^4 nets // to (100) and corner-link to form a heteropolyhedral framework with interstitial M and K sites between adjacent 4^4 nets. Structurally related to the [Lavendulan Group](#). The crystal structure of epifanovite contains four symmetrically independent Cu sites, each coordinated by five O atoms by forming short equatorial (1.905—1.964 Å) and one elongated (2.467—2.720 Å) Cu—O bonds. Four CuO_5 pyramids centered by the Cu2, Cu3 and Cu4 sites are linked at the O11 atom to form $[\text{Cu}_4\text{O}_{13}]$ tetramers. The $[\text{Cu}_4\text{O}_{13}]$ tetramers and Cu_1O_5 pyramids are linked via phosphate groups into the complex, which is incrustated by disordered $[\text{AsO}_2(\text{OH})_2]$ - group to form fundamental building blocks in the structure. The blocks are linked through phosphate groups to form layers parallel to the (001) plane. The layers are joined into a three-dimensional framework by sharing of the apical atoms of the Cu_1O_5 pyramids and O atoms of disordered arsenate groups. Epifanovite is related to the group of minerals and inorganic compounds based upon the $[\text{Cu}_4\text{O}(\text{TO}_4)_4]$ layers (T = As, P). The most closely related to epifanovite are monoclinic polytypes of the andyrobbersite-calcioandyrobbersite $\text{KMeCu}_5(\text{AsO}_4)_4[\text{As}(\text{OH})_2\text{O}_2] \cdot 2\text{H}_2\text{O}$ (Me = Cd, Ca).

Cooper, M.A., Hawthorne, F.C., Pinch, W.W., and Grice, J.D. (1999) Andyrobbersite and calicoandyrobbersite, two new minerals from the Tsumeb Mine, Tsumeb, Namibia. *Mineralogical Record*: 30: 181-186.

Cooper, M.A. and Hawthorne, F.C. (2000): Highly undersaturated anions in the crystal structure of andyrobbersite - calico-andyrobbersite, a doubly acid arsenate of the form $\text{K}(\text{Cd},\text{Ca})[\text{Cu}_2+5(\text{AsO}_4)_4\{\text{As}(\text{OH})_2\text{O}_2\}](\text{H}_2\text{O})_2$. *Canadian Mineralogist*: 38: 817-830.

Structurally related to the [Lavendulan Group](#).

MDHHA	ANDYROBERTSITE	$\text{KCd}[\text{Cu}_5^{2+}(\text{AsO}_4)_4\{\text{As}(\text{OH})_2\text{O}_2\}](\text{H}_2\text{O})_2$
MDHHB	CALCIO-ANDYROBERTSITE	$\text{KCa}[\text{Cu}_5^{2+}(\text{AsO}_4)_4\{\text{As}(\text{OH})_2\text{O}_2\}](\text{H}_2\text{O})_2$
MDHHC	EPIFANOVITE	$\text{NaCaCu}_5(\text{PO}_4)_4[\text{AsO}_2(\text{OH})_2] \cdot 7\text{H}_2\text{O}$

SERIES I **GOLDQUARRYITE, Tric/P1.** The structure contains two distinct PO_4 groups, three distinct $[\text{AlO}_4\text{F}_2]$ octahedra, one $[\text{CdO}_4(\text{H}_2\text{O})_2]$ octahedron and one $\text{CuO}_2(\text{H}_2\text{O})_4$ octahedron. The $[\text{Al}(1)\text{O}_4\text{F}_2]$ and $[\text{Al}(2)\text{O}_4\text{F}_2]$ octahedra share corners through common f vertices to form an Al octahedral chain. This chain is decorated by P tetrahedra that link to the four O atoms of each Al octahedron, linking the Al chain along its length to form an $[\text{Al}(\text{PO}_4)_2\text{F}]$ chain. $[\text{CdO}_4(\text{H}_2\text{O})_2]$ octahedra share edges to form a $[\text{AlCd}(\text{PO}_4)_3\text{F}(\text{H}_2\text{O})_2]$ chain that also extends along a. These two types of chains link through the P tetrahedra to form a sheet of composition $[\text{AlCd}(\text{PO}_4)_2\text{F}(\text{H}_2\text{O})_2]$, which is designated the A layer in the (001) plane. The A and B layers alternate along the c axis to form a heteropolyhedral framework. There are interstitial channels within this framework, also extending along a, and these are filled with the H atoms of the water groups that coordinate the cations of the B layer. **CM04-753.**

MDHIA	GOLDQUARRYITE	$\text{CuCd}_2\text{Al}_3(\text{PO}_4)_4\text{F}_2(\text{H}_2\text{O})_{10}[(\text{H}_2\text{O})_{1.6}\text{F}_{0.4}]_2$
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SERIES J **NEVADAITE, orth/P2₁mn.** The structure consists of ordered layers of vertex-sharing octahedra and tetrahedra alternating with layers of disordered vertex-sharing and face-sharing octahedra in the [010] direction. Chains of Al octahedra are decorated by P tetrahedra that share vertices with octahedra adjacent in the chain. These chains link in the [001] direction by sharing vertices between octahedra and tetrahedra to form an ordered layer of the form $[\text{Al}_8(\text{PO}_4)_8\text{F}_8(\text{H}_2\text{O})_8]$. In the disordered layer, octahedra containing positionally disordered Cu^{2+} , V^{3+} , Al and □ share trans faces to form columns that link by sharing octahedron vertices to form ribbons extending in the [001] direction.

MDHJA	NEVADAITE	$(\square, \text{Cu}^{2+}\text{V}^{3+})_8\text{Al}_8(\text{PO}_4)_8\text{F}_8(\text{H}_2\text{O})_{23}$
MDHJB	CLONCURRYITE	$(\text{Cu},\text{VO})\text{Al}_2(\text{PO}_4)_2(\text{F},\text{OH})_{2.4.5}\text{H}_2\text{O}$

SERIES K	ARSMIRANDITE, mon/C2/m. Pekov, I.V., Britvin, S.N., Yapaskurt, V.O., Polekhovsky, Y.S., Krivovichev, S.V., Vigasina, M.F. and Sidorov, E.G. (2015) Arsmirandite, IMA 2014-081. CNMNC Newsletter No. 23, February 2015, page 57; <i>Mineralogical Magazine</i> , 79 , 51-58.		
MDHKA	ARSMIRANDITE	$\text{Na}_{18}\text{Cu}_{12}\text{Fe}^{3+}\text{O}_8(\text{AsO}_4)_8\text{Cl}_5$	
MDHKB	LEMANNITE	$\text{Na}_{18}\text{Cu}_{12}\text{TiO}_8(\text{AsO}_4)_8\text{FCl}_5$	
SERIES L	ESPADAITE, orth/Ccce.		
MDHLA	ESPADAITE	$\text{Na}_4\text{Ca}_3\text{Mg}_2[\text{AsO}_3(\text{OH})]_2[\text{AsO}_2(\text{OH})_2]_{10}\cdot 7\text{H}_2\text{O}$	
TYPE I	Structures with Large and Medium-sized Cations, (OH, etc.): RO₄ = 1:1		
SERIES A	OLMSTADITE SERIES. Orth/Pb2₁. Structure consists of edge-sharing Feoctahedra forming linear chains // [001]; the chains are linked by corner-sharing Nb octahedra and P tetrahedra, and by K polyhedra.		
MDIAA	OLMSTEADITE	$\text{K}_2\text{Fe}_2[\text{Fe}_2(\text{Nb,Ta})_2\text{O}_4(\text{H}_2\text{O})_4(\text{PO}_4)_4]$	Pb2 ₁ m
MDIAB	JOHNWALKITE	$\text{K}_2\text{Fe}_2[\text{Mn}_2(\text{Nb,Ta})_2\text{O}_4(\text{H}_2\text{O})_4(\text{PO}_4)_4]$	
SERIES B	GATUMBAITE, mon/. Structure not known. von Knorring, O & A-M. Fransolet (1977): "Gatumbaite, a new species from Buranga pegmatite, Rwanda": <i>Neues Jahrb. Mineral., Monatsh.</i> 12: 561-568; <i>Am.Min.</i> : 63: 793-794.(abstract)		
	Duggan, M.B., et al. (1990): "Phosphate minerals in altered andesite from Mount Perry, Queensland, Australia": <i>Can. Min.</i> : 28: 125-131.		
MDIBA	GATUMBAITE	$\text{CaAl}_2(\text{PO}_4)_2(\text{OH})_2\cdot \text{H}_2\text{O}$	
SERIES C	CAMGASITE, mon/P2₁/m. Structure not known. <i>American Mineralogist</i> : 76: 2021. <i>Aufschluss</i> : 40: 369-372.		
MDICA	CAMGASITE	$\text{CaMg}(\text{AsO}_4)(\text{OH})\cdot \text{H}_2\text{O}$	
SERIES D	Walenta, K. & Dunn, P. J. (1984): Phosphofibrit, ein neues Eisenphosphat aus der Grube Clara im mittleren Schwarzwald (BRD). <i>Chem. Erde</i> , 43, 11-16. (in German).		
	<i>American Mineralogist</i> (1984): 69: 1192.		
	Kolitsch, U. (1999): Evidence for the identity of meurigite and phosphofibrite by transmission electron microscopy and X-ray powder diffraction. <i>European Journal of Mineralogy</i> : 11, Beih. no.1, 132.		
	Kampf, A. R., J.J. Pluth, & Y. Chen (2007): The crystal structure of meurigite. <i>American Mineralogist</i> 92, 1518-1524.		
	A. R. Kampf and U. Kolitsch (2008): The relationship between phosphofibrite and meurigite. M&M6, 6th Intern. Conf. on Mineralogy & Museums, Colorado School of Mines, Golden, Colorado, USA, September 7-9, 2008; Program and Abstract Volume, 26.		
]2A. R. Kampf, P. M. Adams, U. Kolitsch and I. M. Steele (2009): Meurigite-Na, a new species, and the relationship between phosphofibrite and meurigite. <i>Am. Mineral.</i> 94, 720-727.		
SERIES E	JUNGITE, orth/Pcmm. The structure of skorpionite consists of ZnO ₄ and PO ₄ tetrahedra forming corner linked to result in corrugated sheets. The structure forms a three-dimensional network of [Ca ₂ Zn ₂ (OH) ₂ (PO ₄) ₂] ⁰ and [Ca(CO ₃)(H ₂ O)] ⁰ layers that are linked by H bonds and by Ca-O bonds. <i>American Mineralogist</i> (1980): 65: 1067. Borg, G., Karner, K., Buxton, M., Armstrong, R., Schalk van der Merwe, W. (2003) Geology of the Skorpion supergene zinc deposit, southern Namibia. <i>Economic Geology</i> , 98, 749-771.		

Jahn, S. (2007) Tarbuttit von der Skorpion Zink Mine, Namibia. Mineralien-Welt 18 (4), 56-66. (in German)

Krause, W., et al. (2008) Skorpionite, a new mineral from Namibia: description and crystal structure. Eur. J. Mineralogy 20, 271-280.

MDIEA	JUNGITE	$\text{Ca}_2\text{Zn}_4\text{Fe}_8(\text{PO}_4)_9(\text{OH})_9 \cdot 16\text{H}_2\text{O}$
MDIEB	SKORPIONITE	$\text{Ca}_3\text{Zn}_2[(\text{OH})_2/\text{CO}_3/(\text{PO}_4)_2] \cdot \text{H}_2\text{O}$ mon/C2/c

SERIES F **WYCHEPROOFITE, tric/P1.** Structure characterized by two different alternating layers // to (001); the first layer is composed of corner-linked ZrO_6 octahedra and P tetrahedra. The second layer is built from zigzag chains of edge-sharing $\text{AlO}_2(\text{OH})_4$ octahedra along [100], and of $\text{Na}(1) - \text{O}_3(\text{OH})_2(\text{H}_2\text{O})_{2-y}$ polyhedra. Adjacent layers are connected by O ligands shared between P tetrahedra and $\text{AlO}_2(\text{OH})_4$ octahedra. Only very weak H bonding is necessary to reinforce the structural framework. A close relationship exists to the family of yavapaiite-related layered $\text{AM}(\text{XO}_4)_2$ compounds. Eur. Jour. Min., 15, 6, 1029-1034. Comparisons with the structures of the few other known natural Zr phosphates such as kosnarkite, selwynite, mahlmoodyite demonstrates that a heteropolyhedral layer composed of corner-linked $\text{P}(\text{O})_4$ tetrahedra and ZrO_6 octahedra is a common structural feature of several of these phosphates, and that it links them closely to the family of yavapaiite-related layered $\text{AM}(\text{XO}_4)_2$ compounds.

MDIFA	WYCHEPROOFITE	$\text{NaAlZr}[\text{PO}_4]_2(\text{OH})_2 \cdot \text{H}_2\text{O}$
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SERIES G **BRAITHWAITEITE, tri/P1.** The structure motif consists of a chain of corner-sharing (Sb,TiO_6) octahedra that is decorated with AsO_4 tetrahedra to form a $[(\text{SbTi})(\text{AsO}_4)_4\text{O}_2]$ chain that extends along the a-direction and defines the cell dimension in this direction at about 7Å. These chains are cross-linked in the b-direction by chains of edge-sharing (CuO_6) octahedra that are decorated by arsenate tetrahedra to form a $[\text{Cu}_2(\text{AsO}_4\text{OH})_2\text{O}_4]$ chain; these two chains link to form a sheet // to (001). These sheets stack along the c-direction and are linked by CuO_6 and NaO_6 octahedra, together with an extensive network of H bonds.

MDIGA	BRAITHWAITEITE	$\text{NaCu}_5(\text{SbTi})\text{O}_2(\text{AsO}_4)_4(\text{AsO}_3\text{OH})_2 \cdot 8\text{H}_2\text{O}$
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SERIES H **ANGARFITE, orth/C222₁.** The structure contains zig-zag chains of edge-sharing Fe^{3+}O_6 octahedra along c, which are linked into sheets // to {010} by sharing corners with octahedra in adjacent chains and by sharing corners with peripheral PO_4 tetrahedra. Insular octahedra between the sheets share two sets of cis corners with tetrahedra in adjacent sheets, thereby linking the sheets into a framework. Channels in the framework // to c contain a partially occupied Na site and a disordered water site. Identical sheets of octahedra and tetrahedra are found in the structures of bakhchisaraitsevite and mejilonesite.

MDIHA	ANGARFITE	$\text{NaFe}_5(\text{PO}_4)_4(\text{OH})_4 \cdot 4\text{H}_2\text{O}$
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SERIES I **GLADIUSITE, mon/P2₁/n.** Structure consists of one P site tetrahedrally coordinated by four O atoms. There are six distinct octahedrally coordinated M sites containing Fe^{3+} , Fe^{2+} , Mg, and Mn^{2+} , the octahedra are coordinated by O atoms, OH and water groups. The $\text{M}\phi_6$ octahedra each share two trans edges to form a rutile-like $\text{M}\phi_4$ chain along [001]. Pairs of chains shifted relative to each other by a half-octahedron, link together through common edges to form a ribbon extending along c; thus, each octahedron shares four edges with other octahedra. These ribbons are connected through common vertices of the M octahedra into a framework with channels along the c axis. The P tetrahedra share each of two vertices with three M octahedra and the remaining two vertices are connected to octahedra through H bonds. There is a system of H bonds in the structure, some of them bifurcated. Liferovich, R.P., Sokolova, E.V., Hawthorne, F.C., Laajoki, K.V.O., Gehör, S., Pakhomovsky, Ya.A., and Sorokhtina, N.V. (2000) Gladiusite, $\text{Fe}^{3+} 2(\text{Fe}^{2+}, \text{Mg})_4(\text{PO}_4)(\text{OH})_{11}(\text{H}_2\text{O})$, a new hydrothermal mineral species from the phoscorite-carbonatite unit, Kovdor complex, Kola Peninsula, Russia. Canadian Mineralogist: 38: 1477-1485.

MDIIA	GLADIUSITE	$\text{Fe}^{3+}_2(\text{Fe}^{2+}, \text{Mg})_4(\text{PO}_4)(\text{OH})_{11}(\text{H}_2\text{O})$
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SERIES J **HAIGERACHITE, mon/B2/b.** Walenta, K. and Theye, Th. (1999): Haigerachit, ein neues Phosphatmineral von der Grube Silberbrünnele bei Gengenbach im mittleren Schwarzwald. Aufschluss, 50, 1-7. (in German).

Waerstad, K. R. & Frazier, A. W. (1987): X-ray powder diffraction and single-crystal data for the isomorphous series (Fe,Al)₃(K,NH₄,H₃O)H₁₄(PO₄)₈.4H₂O. Powder Diffraction 2, 187-190.
 Anisimova, N., Chudinova, N. & Serafin, M. (1997): Preparation and crystal structure of potassium iron hydrogen phosphate KFe₃(HPO₄)₂(H₂PO₄)₆.4(H₂O). Zeitschrift für Anorganische und Allgemeine Chemie 623, 1708-1714.

MDIJA HAIGERACHITE $KFe^{2+}_3(H_2PO_4)_6(HPO_4)_2 \cdot 4H_2O$

SERIES K **PAGANOITE, tric/ P1.** The structure contains As tetrahedra and distorted Ni²⁺O₆ octahedra, as well as one-sided BiO₅ polyhedra due to the presence of an s² lone pair of electrons on the Bi cation. The structure is an open framework composed dimers of edge-sharing NiO⁶ that are linked by vertex sharing with As tetrahedra. Bi cations occur within voids in the framework, and bond only to framework elements. The structure of paganoite is very closely related to that of jaowerrite, which possesses an identical framework of octahedra and tetrahedra. A.C. Roberts, P.C. Burns, R.A. Gault, A.J. Criddle, M.N. Feinglos & J.A.R. Stirling (2001): Paganoite, NiBi₃+As₅+O₅, a new mineral from Johanngeorgenstadt, Saxony, Germany: Description and crystal structure.- European Journal of Mineralogy 13, 167-175.

MDIKA PAGANOITE Ni(BiO)(AsO₄)

SERIES L **KOLOVRATITE, no structure known, question of validity.** Vernadsky (1922) Comptes rendus de académie des sciences Russie: 37.

Palache, C., Berman, H., & Frondel, C. (1951), The System of Mineralogy of James Dwight Dana and Edward Salisbury Dana, Yale University 1837-1892, Volume II. John Wiley and Sons, Inc., New York, 7th edition, revised and enlarged, 1124 pp.: 1048-1049.

Jambor, J.L. and G.R. Lachance (1962) On kolovratite. Canadian Mineralogist, 7, 311–314.

American Mineralogist (1962): 47: 1222 (abstract).

Pekov, I.V. (1998) Minerals first discovered on the territory of the former Soviet Union, 116. Vernadsky (1922) Comptes rendus de académie des sciences Russie: 37.

Palache, C., Berman, H., & Frondel, C. (1951), The System of Mineralogy of James Dwight Dana and Edward Salisbury Dana, Yale University 1837-1892, Volume II. John Wiley and Sons, Inc., New York, 7th edition, revised and enlarged, 1124 pp.: 1048-1049.

Jambor, J.L. and G.R. Lachance (1962) On kolovratite. Canadian Mineralogist, 7, 311–314.

American Mineralogist (1962): 47: 1222 (abstract).

Pekov, I.V. (1998) Minerals first discovered on the territory of the former Soviet Union, 116.

MDILA KOLOVRATITE Q/D Ni-Zn hydrous vanadate

SERIES M **CATALANOITE, orth/lbca (no data).** Preliminary data, partly from IMA-CNMMN list of new minerals approved in 2002; partly from info provided to the press by Mz. Teresita del Valle Ruiz, Universidad de Salta.

MDIMA CATALANOITE Na₂H(PO₄).8H₂O

SERIES N **SVENEKITE, tri/P1.** The structure consists of corner-sharing CaO₈ polyhedra and AsO₂OH₂ groups, stacked // to (001). Adjacent sheets are linked by H bonds. The structure possesses very short H bonds. Journal of the Czech Geological Society, Prague (2003): 48(3-4): 151.
 P. Ondruš, R. Skála, J. Plášil, J. Sejkora, F. Veselovský, J. Čejka, A. Kallistová, J. Hloušek, K. Fejfarová, R. Škoda, M. Dušek, A. Gabašová, V. Machovič, L. Lapčák (2013): Švenekite, Ca[AsO₂(OH)₂]₂, a new mineral from Jáchymov, Czech Republic. Mineral. Mag. 77, 2711-2724.

MDINA SVENEKITE Ca(H₂AsO₄)₂

SERIES O **MEJILLONESITE, orth/Pbca.** The structure contains zigzag chains of edge-sharing Fe³⁺-O₆ octahedra along c, which are linked into sheets parallel to {010} by sharing corners with octahedra in adjacent

chains. As in mejillonesite, the sheets are decorated with phosphate tetrahedral. The structure is related to that of angarfitite and bakhchisaraitsevite.

MDIOA MEJILLONESITE $\text{HNaMg}_2(\text{HPO}_4)(\text{PO}_4)(\text{OH}) \cdot 2\text{H}_2\text{O}$

TYPE J Structures with Large and Medium-sized Cations, (OH, etc.): $\text{RO}_4 > 1:1$ and $< 2:1$.

SERIES A SANTAFEITE, orth/B22₁2. Structure not known.

Sun, M. S. and R.H. Weber (1958): Santafeite, a new hydrated vanadate from New Mexico. American Mineralogist 43, 677-687.

Dunn, P.J. and D.R. Peacor (1986): Santafeite, a re-examination and new empirical formula. Mineralogical Magazine 50, 299-300. [abstract: American Mineralogist (1987): 72: 1028].

MDJAA SANTAFEITE $(\text{Mn,Fe,Al,Mg})_8(\text{Mn,Mn})_8(\text{Ca,Sr,Na})_{12}[(\text{VO}_4)(\text{AsO}_4)]_{16}(\text{OH})_{20} \cdot 8\text{H}_2\text{O}$

SERIES B PHARMACOSIDERITE SERIES, cub/P4₃m. Structure consists of clusters of 4 edge-sharing Fe octahedra which are linked by six As tetrahedra to form a framework with large cavities that contain water molecules and the large cations. The structure of liskeardite is of an open framework type in which intersecting polyhedral slabs // to (101) and (101) form channels along [010], with water molecules occupying the channels. Small amounts of Na, K, and Cu are probably absorbed at the channel walls. The framework comprises columns of pharmacalumite-type, intergrown with chiral chains of six cis edge-sharing octahedral. It can be described in terms of cubic close packing, with vacancies at both the anion and cations sites. The compositional and structural relationships between liskeardite and pharmacalumite are discussed.

MDJBA	PHARMACOALUMITE	$\text{KAl}_4(\text{AsO}_4)_3(\text{OH})_4 \cdot 6-7\text{H}_2\text{O}$
MDJBB	PHARMACOSIDERITE	$\text{KFe}_4(\text{AsO}_4)_3(\text{OH})_4 \cdot 6-7\text{H}_2\text{O}$
MDJBC	NATROPHARMACOSIDERITE	$(\text{Na,K})\text{Fe}_4(\text{AsO}_4)_3(\text{OH})_4 \cdot 6-7\text{H}_2\text{O}$
MDJBD	BARIOPHARMACOSIDERITE	$\text{BaFe}_8[\text{AsO}_4]_6(\text{OH})_8 \cdot 14\text{H}_2\text{O} (?)$
MDJBE	HYDRONIUMPHARMACOSIDERITE	$(\text{H}_3\text{O})\text{Fe}_4(\text{AsO}_4)_3(\text{OH})_4 \cdot 4\text{H}_2\text{O}$
MDJBF	NATROPHARMACOALUMITE	$\text{NaAl}_4(\text{AsO}_4)_3(\text{OH})_4 \cdot 4\text{H}_2\text{O}$
MDJBG	BARIOPHARMACOALUMITE	$\text{Ba}_{0.5}\text{Al}_4(\text{AsO}_4)_3(\text{OH})_4 \cdot 4\text{H}_2\text{O}$
MDJBH	HYDRONIUMPHARMACOALUMITE	$(\text{H}_3\text{O})\text{Al}_4(\text{AsO}_4)_3(\text{OH})_4 \cdot 4.5\text{H}_2\text{O}$
MDJBI	LISKEARDITE	$[(\text{Al,Fe})_{32}(\text{AsO}_4)_{18}(\text{OH})_{42}(\text{H}_2\text{O})_{22} \cdot 52\text{H}_2\text{O}]$
MDJBJ	CAESIUMPHARMACOSIDERITE	$\text{CsFe}_4[(\text{AsO}_4)_3(\text{OH})_4] \cdot 4\text{H}_2\text{O}$
MDJBK	STRONTIOPHARMACOSIDERITE	$\text{Sr}_{0.5}\text{Fe}_4(\text{AsO}_4)_3(\text{OH})_4 \cdot 4\text{H}_2\text{O}$
MDJBL	THALLIUMPHARMACOSIDERITE	$\text{TlFe}_4[(\text{AsO}_4)_3(\text{OH})_4] \cdot 4\text{H}_2\text{O}$
MDJBM	PLUMBOPHARMACOSIDERITE	$\text{Pb}_{0.5}\text{Fe}_4(\text{AsO}_4)_3(\text{OH})_4 \cdot 5\text{H}_2\text{O}$

SERIES C DUFRENITE SERIES, mon/C2/c. Structure consists of clusters of 3 face-sharing M octahedra and corner-sharing octahedra triplets which are linked into slabs // (100) by P tetrahedra; water molecules and the large cations are accommodated in cavities in the structure. The structure of meurigite is a framework consisting of face-sharing octahedral Fe_{23}O_9 dimers, which are linked by sharing corners with corner-sharing dimers and isolated Fe_3O_6 octahedra to form thick slabs of octahedra parallel to the a-c plane. PO_4 tetrahedra further link octahedra within the slabs and also link slabs to one another perpendicular to the a-c plane. Relatively large channels through the framework along the b axis contain disordered K atoms and H_2O molecules, which take part in two overlapping arrays. Partial vacancies in the Fe and P sites may account for discrepancies between the empirical and ideal chemical formulas. Packing considerations suggest that the empirical formula should be based on the total number of large ions ($\text{K} + \text{Na} + \text{O} = 38.5$ per formula unit), which for the chemical analysis provided in the original description yields $[(\text{K}_{0.91}\text{Na}_{0.03})_{\Sigma 0.94}(\text{H}_2\text{O})_{2.56}]_{\Sigma 3.50}[(\text{Fe}_{3+7.52}\text{Al}_{0.17}\text{Cu}_{0.03})_{\Sigma 7.72}(\text{PO}_4)_{5.48}(\text{CO}_3)_{0.21}(\text{OH})_{7.20}(\text{H}_2\text{O})_{5.23}]$. The meurigite structure is related to those of other brous ferric phosphates with 5 Å b per axes and shows a particularly close relationship with the structure of dufrénite. Crystal chemical evidence suggests that, even if

meurigite and phosphobrite are isostructural, phosphobrite may qualify as a distinct species based upon its low K content (<0.5 apfu based on a recalculation of the original chemical analysis).

Walenta, K. & Dunn, P. J. (1984): Phosphofibrit, ein neues Eisenphosphat aus der Grube Clara im mittleren Schwarzwald (BRD). Chem. Erde, 43, 11-16. (in German).

American Mineralogist (1984): 69: 1192.

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Kampf, A. R., J.J. Pluth, & Y. Chen (2007): The crystal structure of meurigite. American Mineralogist 92, 1518-1524.

A. R. Kampf and U. Kolitsch (2008): The relationship between phosphofibrite and meurigite. M&M6, 6th Intern. Conf. on Mineralogy & Museums, Colorado School of Mines, Golden, Colorado, USA, September 7-9, 2008; Program and Abstract Volume, 26.

A. R. Kampf, P. M. Adams, U. Kolitsch and I. M. Steele (2009): Meurigite-Na, a new species, and the relationship between phosphofibrite and meurigite. Am. Mineral. 94, 720-727.

MDJCA	DUFRENITE	$\text{Ca}_{0.5}\text{Fe}_6(\text{OH})_6(\text{H}_2\text{O})_2(\text{PO}_4)_4$
MDJCB	BURANGAITE	$(\text{Na,Ca})_2(\text{Fe,Mg})_2\text{Al}_{10}(\text{PO}_4)_8(\text{OH},\text{O})_{12}\cdot 4\text{H}_2\text{O}$
MDJCC	NATRODUFRENITE	$\text{Na}(\text{Fe},\text{Fe})(\text{Al},\text{Fe})_5(\text{OH})_6(\text{H}_2\text{O})_2(\text{PO}_4)_4$
MDJCD	MEURIGITE-K	$[\text{K}(\text{H}_2\text{O})_{2.5}][\text{Fe}_8^{3+}(\text{PO}_4)_6(\text{OH})_7(\text{H}_2\text{O})_4]$
MDJCE	MATIOLIITE	$\text{NaMgAl}_5(\text{PO}_4)_4(\text{OH})_6\cdot 2\text{H}_2\text{O}$
MDJCF	MEURIGITE-Na	$[\text{Na}(\text{H}_2\text{O})_{2.5}][\text{Fe}_8^{3+}(\text{PO}_4)_6(\text{OH})_7(\text{H}_2\text{O})_4]$
MDJCG	GAYITE	$\text{NaMn}^{2+}\text{Fe}^{3+}_5(\text{PO}_4)_4(\text{OH})_6\cdot 2\text{H}_2\text{O}$
MDJCH	PHOSPHOFIBRITE	$\text{KCuFe}_{15}(\text{PO}_4)_{12}(\text{OH})_{12}\cdot 12\text{H}_2\text{O}$

SERIES D **KIDWELLITE-MATULAITE SERIES, mon/P2/c. The structure contains seven-member chain segments of AlO_6 octahedra decorated by PO_4 tetrahedra. The PO_4 tetrahedra also link to isolated FeO_6 octahedra, resulting in a pinwheel (FePO_4)₆ group. The linkage of octahedra and tetrahedra defines a thick layer // to {001}. The only linkage between layers is via H bonding to interlayer water molecules.**

Moore, P.B. and J. Ito (1980) Jungit und Matulait: Zwei neue taflige Phosphat-Mineralien. Aufschluss, 31, 55-61 (in German with English abs.).

American Mineralogist (1980): 65: 1067.

Kampf, A.R., Mills, S.J., Rossman, G.R., Steele I.M., Pluth, J.J. and Favreau, G. (2011) Afmite, $\text{Al}_3(\text{OH})_4(\text{H}_2\text{O})_3(\text{PO}_4)(\text{PO}_3\text{OH})\cdot\text{H}_2\text{O}$, a new mineral from Fumade, Tarn, France: description and crystal structure. European Journal of Mineralogy, 23, 269-277. [mentions new formula of matulaite]

Kampf, A.R., Mills, S.J., Rumsey, M.S., Spratt, J. and Favreau, G. (2012) The crystal structure determination and redefinition of matulaite, $\text{Fe}_3+\text{Al}_7(\text{PO}_4)_4(\text{PO}_3\text{OH})_2(\text{OH})_8(\text{H}_2\text{O})_8\cdot 8\text{H}_2\text{O}$. Mineralogical Magazine, 76(3), 517-534. Moore, P.B. & Ito, J. (1978): Kidwellite, $\text{NaFe}_3+9(\text{OH})_{10}(\text{PO}_4)_6\cdot 5\text{H}_2\text{O}$, a new species.

Mineralogical Magazine, 42, 137-140.

American Mineralogist (1979): 64: 242-243.

Braithwaite, R.S.W. and Corke, H. (1980) Kidwellite from Cornwall. Mineralogical Magazine, 43, 952-953.

Kolitsch, U. (2004): The crystal structures kidwellite and 'laubmannite', two complex fibrous iron phosphates. Mineralogical Magazine, 68, 147-165.

MDJDA	MATULAITE	$\text{Fe}^{3+}\text{Al}_7(\text{PO}_4)_4(\text{PO}_3\text{OH})_2(\text{OH})_8(\text{H}_2\text{O})_8\cdot 8\text{H}_2\text{O}$
MDJDB	KIDWELLITE	$\text{Na}(\text{Fe}^{3+},\text{Mn})_{9+x}(\text{OH})_{11}(\text{H}_2\text{O})_3(\text{PO}_4)_6$ mon/P2/b

SERIES E **RICHELSDORFITE, mon/C2/m. Structure consists of {001} layers formed by corner-sharing Cu and Ca polyhedra and As tetrahedra alternating with layers containing $\text{Sb}(\text{OH})_6$ octahedra and water molecules.**

MDJEA	RICHELSDORFITE	$\text{Ca}_2\text{Cu}_5\text{Sb}(\text{AsO}_4)_4(\text{OH})_6\text{Cl}\cdot 6\text{H}_2\text{O}$
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SERIES F **BLEASDALEITE, orth/ Structure not known.** B. Birch, A. Pring and U. Kolitsch (1999): Bleasdaleite, $(Ca, Fe^{3+})_2Cu_5(Bi, Cu)(PO_4)_4 \cdot (H_2O, OH, Cl)_{13}$, a new mineral from Lake Boga, Victoria, Australia. Australian Journal of Mineralogy 5, 69-75. Structure unsolved; probably related to richelsdorffite.

MDJFA BLEASDALEITE $(Ca, Fe)_2Cu_5(Bi, Ce)(PO_4)_4(H_2O, OH, Cl)_{13}$

SERIES G **KRASNOVITE, orth/Pnna or Pnnn. Structure not known.** Britvin, S. N., Pakhomovskii, Ya. A. and Bogdanova, A. N. (1996): Krasnovite, $Ba(Al, Mg)(PO_4, CO_3)(OH)_2 \cdot H_2O$ - a new mineral. Zapiski Vserossiyskogo Mineralogicheskogo Obshchestva: 125: 110-112. Mineralogical Record: 28: 221-222.

MDJGA KRASNOVITE $Ba(Al, Mg)(PO_4, CO_3)(OH)_2 \cdot H_2O$

TYPE K Structures with Large and Medium-sized Cations, (OH, etc.): $RO_4 > 1:1$ and

SERIES A **FOGGITE, orth/A2,22.** The structure is related to that of the pyroxenes and consists of $Al(OH)_2(Op)_2$ octahedral edge-sharing zig-zag chain which runs parallel to the c axis. Its tetrahedral envelope and closely associated $Ca(1)O_8$ polyhedron lead to a sheet oriented parallel to {010} which possesses the composition $[CaAl_2(OH)_4(PO_4)_2]^{2-}$. Equivalent sheets are weakly linked along [010] by Ca-O polyhedra, the water molecules possessing a disordered character.

MDKAA FOGGITE $(CaAl_2(PO_4)_2(OH)_4) \cdot Ca(H_2O)_2$

SERIES B **WARDITE SERIES, tetr/P4₁2₁2₁ or P4₃2₁2.** Structure consists of corner-sharing M octahedra forming a sheet of interconnected 8-membered rings // (001); the sheets are linked by P tetrahedra and Na atoms.

MDKBA WARDITE $NaAl_3(PO_4)_2(OH)_4 \cdot 2H_2O$

MDKBB CYRILOVITE $NaFe_3(PO_4)_2(OH)_4 \cdot 2H_2O$

MDKBC MILLISITE $(Na, K)CaAl_6(PO_4)_4(OH)_9 \cdot 3H_2O$

MDKBD FLUOROWARDITE $NaAl_3(PO_4)_2F_2(OH)_2(H_2O)_2$

SERIES C **MIXITE SERIES, hex/P6₃/m.** Structure consists of rutile-like chains // [0001] of edge-sharing Cu tetragonal pyramids which are linked into a framework by sharing edges and corners with Bi tricapped trigonal prisms and arsenate tetrahedra; the large cations and zeolitic water are accommodated in channels // [0001]. In argardite, edge-sharing Cu octahedra form rutile-like chains // [0001] that are linked by M polyhedra and arsenate tetrahedra to form a framework with [0001] channels that contain REE polyhedra and water molecules. The structure for agardite-(y) has been solved. It is characterized by infinite chains of edge-sharing CuO_5 square pyramids extending down the c axis, connected in the ab plane by edge-sharing YO_9 polyhedra and corner-sharing AsO_4 tetrahedra. HO groups occupy each corner of the CuO_5 square pyramids not shared by a neighboring As or Y atom. Each YO_9 polyhedron is surrounded by three tubular channels. The walls of the channels, // to the c axis, are six-membered hexagonal rings comprised of CuO_5 and AsO_4 polyhedra in a 2:1 ratio, and contain free molecules of lattice water.

Aksenov, S.M., Chukanov, N.V., Göttlicher, J., Möckel, S., Varlamov, D., Van, K.V., Rastsvetaeva, R.K. (2018): New insights into the crystal chemistry of agardite-(Ce): refinement of the crystal structure, hydrogen bonding, and epitaxial intergrowths with the Sb-analogue of auriacusite. Physics and Chemistry of Minerals 45, 39-50.

analysis, single-crystal X-ray analysis, XANES spectroscopy and IR spectroscopy. Hexagonal unit-cell parameters are: $a = 13.598(6)$, $c = 5.954(3)$ Å; $V = 953.5(2)$ Å³; space group P6₃/m. The structure has been solved and refined to final $R_1 = 3.87\%$, $wR_2 = 5.02$ for 786 I > 3σ(I). Hydrogen atoms have been localized. The crystal-chemical formula is (Z = 2): $A(1)(Ce_{0.82}Ca_{0.14}Sr_{0.04})\Sigma 1.00 A(2)(Ca_{0.03}Ce_{0.02})\Sigma 0.05 [Cu_{5.75}(Fe^{3+}, Mn)_{0.20}]\Sigma 5.95 [T(1)(AsO_4) 2.96 T(2)(SbO_4)_{0.04}]\Sigma 3.00 (OH)_{5.96}O_{0.04} \cdot 3H_2O$. Hydrogen bonding in agardite-series minerals has been characterized for the first time. IR spectra of agardite-(Ce) and agardite-(Nd) from Lavrion used for comparison, as well as structural data indicate the presence of isolated H⁺ cations that do not form strong covalent bonds with coordinating O atoms. Agardite-(Ce) from Clara Mine forms epitaxial growths with the Sb-analogue of auriacusite. The latter mineral was characterized by EDS analyses; its typical empirical formulae are $Ca_{0.06}Ce_{0.04}Fe_{3+1.06}Cu_{0.89}[(SbO_4)_{0.58}(AsO_4)_{0.38}(SiO_4)_{0.04}]\Sigma 1.00(O, OH)$ and $Ca_{0.075}Ce_{0.04}Fe_{3+0.93}Cu_{0.97}[(SbO_4)_{0.59}(AsO_4)_{0.35}(SiO_4)_{0.06}]\Sigma 1.00(O, OH)$. The formation of uniaxial growths of the Sb-analogue of auriacusite and agardite-(Ce) is caused by the close values of their c parameters (for auriacusite s.s. $c = 5.9501(5)$ Å). Three-valence state of iron and five-valence

of antimony in both minerals has been validated by means of Fe K-And Sb L 2,3-edge XANES spectroscopy.

MDKCA	AGARDITE-(La)	(La,Ce)Cu ₆ (AsO ₄) ₃ (OH) ₆ ·3H ₂ O
MDKCB	AGARDITE-(Y)	(Y,Ce)Cu ₆ (AsO ₄) ₃ (OH) ₆ ·3H ₂ O
MDKCC	AGARDITE-(Nd)	(Nd,Ce)Cu ₆ (AsO ₄) ₃ (OH) ₆ ·3H ₂ O
MDKCD	AGARDITE-(Ce)	(Ce,Nd)Cu ₆ (AsO ₄) ₃ (OH) ₆ ·3H ₂ O
MDKCE	GOUDEYITE	(Al,Y)Cu ₆ (AsO ₄) ₃ (OH) ₆ ·3H ₂ O
MDKCF	MIXITE	BiCu ₆ (AsO ₄) ₃ (OH) ₆ ·3H ₂ O
MDKCG	PETERSITE-(Y)	(Y,Ce,Nd,Ca)Cu ₆ (PO ₄) ₃ (OH) ₆ ·3H ₂ O
MDKCH	ZALESITE	CaCu ₆ [(AsO ₄)(AsO ₃ OH)(OH) ₆ ·3H ₂ O
MDKCI	JUANITAITE	(Cu,Ca,Fe) ₁₀ Bi(AsO ₄) ₄ (OH) ₁₁ ·2H ₂ O
MDKCJ	CALCIOPETERSITE	CaCu ₆ [(PO ₄)(PO ₃ OH)(OH) ₆ ·3H ₂ O
MDKCK	PLUMBOAGARDITE	(Pb,REE,Ca)Cu ₆ (AsO ₄) ₃ (OH) ₆ ·3H ₂ O
MDKCL	PETERSITE-(Ce)	CeCu ₆ (PO ₄) ₃ (OH) ₆ ·3H ₂ O
MDKCM	PETERSITE-(La)	LaCu ₆ (PO ₄) ₃ (OH) ₆ ·3H ₂ O

SERIES D WALLKILLDELLITE SERIES, hex/P6₃/mmc, P6₃mc, or P6₂c. Structure pending. Kittatinnyite belongs here. American Mineralogist (1983): 68: 1029-1032.

MDKDA	WALLKILLDELLITE-(Mn)	Ca ₄ Mn ₆ [AsO ₄] ₄ (OH) ₈ ·18H ₂ O
MDKDB	WALLKILLDELLITE-(Fe)	(Ca,Cu) ₄ Fe ₆ [AsO ₄] ₄ (OH) ₈ ·18H ₂ O

SERIES E BOUAZZERITE, mon/P2₁/n. Structure based upon [Bi₃Fe₇O₆(OH)₂(AsO₄)₉]¹¹⁻ anionic nanoclusters that are built around trigonal prismatic Fe³⁺ and octahedral Fe³⁺(OH)O₁₂)₂ groups, containing one Fe ion in trigonal prismatic coordination and six Fe ions in octahedral coordination. The nanoclusters have a diameter of about 1.3 nm and are linked together by chains of Mg(O,H₂O)₆ octahedra. The resulting arrangement desplays channels down [100] that contain structural water.

MDKEA	BOUAZZERITE	Bi ₆ (Mg,Co) ₁₁ Fe ₁₄ [AsO ₄] ₁₈ O ₁₂ (OH) ₄ (H ₂ O) ₈₆
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TYPE L Structures with Large and Medium-sized Cations, (OH, etc.): RO₄ > 2:1

SERIES A MORINITE SERIES, mon, P2₁/m. Structure consists of face- and edge-sharing Ca polyhedra forming zigzag chains // [010]; the chains are linked by NaF₂O₃ trigonal dipyramids and clusters consisting of two corner-sharing Al octahedra and two phosphate tetrahedra. In esperanzaite, two OH corner-sharing Al octahedra each share two of their other corners with two bridging arsenate tetrahedra to form stable heteropolyhedral tetramers; the tetramers are stacked into columns // [001] that are linked by Na and Ca polyhedra.

MDLAA	ESPERANZAITE	NaCa ₂ Al ₂ (AsO ₄) ₂ F ₄ (OH) ₂ ·2H ₂ O
MDLAB	MORINITE	NaCa ₂ Al ₂ (PO ₄) ₂ (F,OH) ₅ ·2H ₂ O

SERIES B TYROLITE, mon/P2₁/c. Structure based upon 2 nm-thick Cu arsenate layers with complex architecture; there are five Cu(II) sites. The layers are insulated by Ca²⁺ cations, (CO₃)₂ groups and water molecules. The layers are held together by H groups. The structure consists of a thick heteropolyhedral sheet // to (001) which is built of distorted Cu(O,OH, H₂O)⁵⁻⁶ polyhedra and arsenate tetrahedral sharing edges and corners. The single sulfate tetrahedron is located in the interlayer space. The interlayer space also hosts four H-bonded water molecules.

MDLBA	TYROLITE	Ca ₂ Cu ₉ (AsO ₄) ₄ (CO ₃)(OH) ₈ ·10H ₂ O
MDLBB	TANGDANITE	Ca ₂ Cu ₉ (AsO ₄) ₄ (SO ₄) _{0.5} (OH) ₉ ·9H ₂ O mon/C2/c
MDLBC	LEOGANGITE	Cu ₁₀ [(OH) ₆ /SO ₄ /(AsO ₄) ₄ ·8H ₂ O

MDLBD	Open	
MDLBE	UNNAMED	$\text{Cu}_{10}(\text{AsO}_4)_4(\text{SO}_4)(\text{OH})_6 \cdot 8\text{H}_2\text{O}$

SERIES C **DELVAUXITE-PHOSPHOVANADYLITE SERIES, iso, I43m.** Structure consists of clusters of four edge-sharing VO_6 octahedra which are linked into a framework by P tetrahedra; large cavities in the framework are occupied by zeolitic cations and water molecules. Specifically, the structure of phosphovanadylite-Ca contains $\text{V}^{4+}_4\text{O}_{16}$ polyvanadate clusters of four edge-sharing V^{4+}O_6 octahedra. The polyvanadate clusters are linked into a three-dimensional zeolite-type framework by sharing corners with PO_4 tetrahedra. The open space in the framework is dominated by water with the equivalent of one large cation pfu sharing the OW1 site.

MDLCA	DELVAUXITE	$\text{CaFe}_4(\text{PO}_4, \text{SO}_4)_2(\text{OH})_8 \cdot 5\text{H}_2\text{O}$ (amor)
MDLCB	PHOSPHOVANADYLITE-Ba	$\text{Ba}[\text{V}^{4+}_4\text{P}_2\text{O}_{12}(\text{OH})_4] \cdot 12\text{H}_2\text{O}$
MDLCC	PHOSPHOVANADYLITE-Ca	$\text{Ca}[\text{V}^{4+}_4\text{P}_2\text{O}_{12}(\text{OH})_4] \cdot 12\text{H}_2\text{O}$

TYPE M Structures with Large Cations, (OH, etc.): $\text{RO}_4 > 2:1$ and

SERIES A **NATROPHOSPHATE, cub/Fd $\bar{3}c$.** Structure consists of six $\text{Na}(\text{H}_2\text{O})_5\text{F}$ octahedra sharing edges and converging at a common F vertex to form the cationic complex $[\text{Na}_6\text{F}(\text{H}_2\text{O})^{18}]^{5+}$. These complexes are linked into a framework by phosphate tetrahedra and a tetrahedron at a site statistically occupied by a Na atom or water molecule.

MDMAA	NATROPHOSPHATE	$\text{Na}_7(\text{PO}_4)_2\text{F} \cdot 19\text{H}_2\text{O}$
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SERIES B **LERMONTOVITE-VYACHESLAVITE SERIES, orth/Ccca. Structures not known.** Melkov, V. G.; Belova, L. N.; Gorshkov, A. I.; Ivanova, O. A.; Sivtsov, A. V.; Boronikhin, V. A. (1983): New data on lermontovite. Mineralogicheskii Zhurnal: 5(1), 82-87. (in Russian.).

American Mineralogist (1958): 43: 379.

American Mineralogist (1984): 69: 214-215. Belova, L.N., Gorshkov, A.I., Ivanova, O.A., Sivtsov, A.V. & Boronikhin, V.A. (1983): New natural uranium(IV) phosphate. Doklady Akademii Nauk SSSR: 3, 1460-1462. (in Russian).

Belova, L.N., Gorshkov, A.I., Ivanova, O.A., Sivtsov, A.V., Lizorkina, L.I. & Voronikhan, V.A. (1984): Vyacheslavite $\text{U}^{4+}(\text{PO}_4)(\text{OH}) \cdot n\text{H}_2\text{O}$ - a new uranium phosphate. Zapiski Vserossiyskogo Mineralogicheskogo Obshchestva: 113(3): 360-365. (in Russian).

American Mineralogist (1985): 70: 878.

MDMBA	LERMONTOVITE	$\text{U}(\text{PO}_4)(\text{OH}) \cdot \text{H}_2\text{O}$
MDMBB	VYACHESLAVITE	$\text{U}(\text{PO}_4)(\text{OH}) \cdot 2.5\text{H}_2\text{O}$

SERIES C **VYSOKYITE, tric/P $\bar{1}$.** The structure consists of UO_8 square antiprisms sharing all of their vertices with 8 As-tetrahedra to form infinite chains // to [010]. These chains are linked by H bonds involving terminal (OH) groups of the double-protonated As-tetrahedra and molecules of water located between the chains.

MDMCA	VYSOKYITE	$\text{U}^{4+}[\text{AsO}_2(\text{OH})_2]_4 \cdot 4\text{H}_2\text{O}$
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TYPE N Structures with Additional Anions + Phosphate, Arsenate or Vanadate.

SERIES A **GIRVASITE, mon/P2 $\bar{1}$ /c.** Structure consists of three Mg, two Ca, and one Na sites. The Mg atoms are octahedrally coordinated by O atoms and water molecules. The Ca sites are coordinated by eight anions each, whereas the Na site has a coordination number equal to seven. The structure is based upon heteropolyhedral sheets formed by polymerization of Mg octahedra, phosphate tetrahedra, and carbonate groups. The sheets consist of fundamental building units formed by two Mg octahedral that share edges to form dimers decorated by three PO_4 tetrahedra and linked to a unit consisting of a MgO_6 octahedron sharing an edge with a carbonate triangle. The FBUs

polymerize to form chains running // to the a axis. The chains are further polymerized to compose heteropolyhedral sheets of H bonds. Girvasite is the most structurally complex mineral among natural phosphate carbonates known to date.

MDNAA	GIRVASITE	$\text{NaCa}_2\text{Mg}_3(\text{PO}_4)_3(\text{CO}_3)(\text{H}_2\text{O})_6$
SERIES B	VOGGITE, mon/I2/m. The structure consists of layers of edge-sharing Zr-O pentagonal bipyramids, separated by layers of Na-(O,H ₂ O) octahedra. The carbonate ion acts as a bidentate ligand in the Zr-O polyhedron. (with phosphates).	
MDNBA	VOGGITE	$\text{Na}_2\text{Zr}(\text{CO}_3)(\text{PO}_4)(\text{OH})_2\text{H}_2\text{O}$
SERIES C	PEISLEYITE, mon/. No structure known. Mineralogical Magazine (1982): 46: 449-452. American Mineralogist (1983): 68: 849-850. Frost, R.L., S.J. Mills, and K.L. Erickson, (2004): Thermal decomposition of peisleyite: a thermogravimetry and hot stage Raman spectroscopic study. Thermochimica Acta, 419(1-2), 109-114. Mills, S.J., Ma, C. and Birch, W.D. (2011) A contribution to understanding the complex nature of peisleyite. Mineralogical Magazine, 75, 2733-2737.	
MDNCA	PEISLEYITE	$\text{Na}_3\text{Al}_{16}(\text{SO}_4)_2(\text{PO}_4)_{10}(\text{OH})_{17}20\text{H}_2\text{O}$
SERIES D	SCHLEGELITE, orth/Pnca. Structure consists of ribbons of Bi atoms shortly linked by oxo-oxygen atoms // to [100]. The ribbons are connected to AsO ₄ and MoO ₄ tetrahedra forming layers // to (001). Compare Petitjeanite.	
MDNDA	SCHLEGELITE	$\text{Bi}_7\text{O}_4(\text{MoO}_4)_2(\text{AsO}_4)_3$
SERIES E	PARWANITE, mon/P2,Pm,P2/m,P21, Pc or P21/c. IMA website - Proposals approved in January 2007 Birch, W. & D. Henry: "Phosphate Minerals of Victoria", p.147 (1997) [contains a preliminary description] William D. Birch, Stuart J. Mills, Karolina Schwendtner, Allan Pring, John A. Webb, Ralph Segnit and John A. Watts (2007): "Parwanite: a new hydrated Na-Mg-Al-phosphate from a lava cave at Parwan, Victoria, Australia". Australian Journal of Mineralogy, 13, 23-30.	
MDNEA	PARWANITE	$(\text{Na},\text{K})(\text{Mg},\text{Ca})_4\text{Al}_8(\text{PO}_4)_8(\text{CO}_3)(\text{OH})_7 \cdot 30\text{H}_2\text{O}$
SERIES F	BIRCHITE, orth/Pnma. The structure consists of alternating [CdO ₄ (H ₂ O) ₂] octahedra and [CuO ₃ (H ₂ O) ₂] square-pyramids that share edges to form chains that extend along the a axis, which are linked by PO ₄ tetrahedra to form [CdCu(PO ₄)(H ₂ O) ₂ O] sheets in the (010) plane. Two layers, which are related by mirror symmetry, are linked via (SO ₄) tetrahedra vertices to form a heteropolyhedral framework structure. Interstitial channels within the framework extend along both the a and c axes and are occupied by a single water molecule.	
MDNFA	BIRCHITE	$\text{Cd}_2\text{Cu}_2(\text{PO}_4)_2(\text{SO}_4).5\text{H}_2\text{O}$
SERIES G	JORGKELLERITE, trig/P3. The structure is built up of the layers composed of disordered edge-sharing MnO ₆ octahedra. Each fourth Mn site in each octahedral layer is vacant that results in appearance of ordered system of hexagonal "holes" occupied by carbonate groups. The overall composition of the layer can be expressed as [Mn ₃ O ₈ (CO ₃)]. These manganese-carbonate layers are linked in the third dimension by phosphate tetrahedra and Na-polyhedra.	
MDNGA	JORGKELLERITE	$(\text{Na},\square)_3\text{Mn}^{3+}_3(\text{PO}_4)_2(\text{CO}_3)(\text{O},\text{OH})_2.5\text{H}_2\text{O}$
SERIES H	PEATITE SERIES, hex/P6m2 and orth//P222. The structures of peatite and ramkite have similar but not isostructural. They are dominated by Mφ ₈ polyhedra. These are linked into six-membered, edge- or corner-sharing cluster, which in turn are joined together by PO ₄ tetrahedra. Both LiO ₆ octahedra and CO ₃ groups are positioned within the corner-sharing clusters. Linkages among all these polyhedral produce an open, equidimensional framework structure, with Na occupying the resulting	

cavities. Both structures may be considered as complex derivatives of cation-deficient perovskite-related structures.

MDNHA PEATITE-(Y) $\text{Li}_4\text{Na}_{12}(\text{Y}, \text{Ca}, \text{REE})_{12}(\text{PO}_4)_{12}(\text{CO}_3)_4(\text{F}, \text{OH})_8$
 MDNHB RAMIKITE-(Y) $\text{Li}_4(\text{Na}, \text{Ca})_{12}(\text{Y}, \text{Ca}, \text{REE})_6\text{Zr}_6(\text{PO}_4)_{12}(\text{CO}_3)_4\text{O}_4[(\text{OH}), \text{F}]_4$

SERIES I **VANDERHEYDENITE, *mon/P2₁/n***. Elliott, P. and Kolitsch, U. (2015) Vanderheydenite, IMA 2014-076. CNMNC Newsletter No. 23, February 2015, page 56; *Mineralogical Magazine*, **79**, 51-58. **The crystal structure of vanderheydenite (R1 = 0.0497 for 939 reflections with Fo > 4σF) contains chains of edge-sharing ZnO6 octahedra parallel to a that are linked by edge- and corner-sharing ZnO5 trigonal bipyramids and TO4 (T = P, As) tetrahedra forming zig-zag sheets parallel to {0 1 0}. Sheets are linked by half-occupied, distorted TO4 (T = P, S) tetrahedra in the [0 1 1] direction. Interstitial channels extend parallel to the a-direction and are occupied by strongly to weakly hydrogen-bonded H2O groups.**

MDNIA VANDERHEYDENITE $\text{Zn}_6(\text{PO}_4)_2(\text{SO}_4)(\text{OH})_4 \cdot 7\text{H}_2\text{O}$

SERIES J **JUANSILVAITE, *mon/C2/c***. In the structure of juansilvaite, Al1O_6 and $\text{Al2O}_5(\text{H}_2\text{O})$ octahedra and As1O_3 , $\text{As2O}_3(\text{OH})$ and $\text{As3O}_2(\text{OH})_2$ tetrahedra share O vertices, yielding a layer // to {001} in which octahedra link only to tetrahedra, and not to other octahedra. Na1 and Na2 cations peripheral to the layers and Na3 cations within cavities in the layer form bonds to the vertices of the octahedra and tetrahedra in the layers. Na1 and Na2 also form bonds to an SO_4 tetrahedron in between the layers and both Na1 and Na3 bond to an otherwise isolated water group. The topology of the layer of alternating octahedra and tetrahedra also appears to be unique. Adjacent Al1 and Al2 octahedra are triple-linked to one another across adjacent faces by the three different As tetrahedra.

MDNJA JUANSILVAITE $\text{Na}_5\text{Al}_3[\text{AsO}_3(\text{OH})]_4[\text{AsO}_2(\text{OH})_2]_2(\text{SO}_4)_2 \cdot 4\text{H}_2\text{O}$

SERIES K **VASILSEVERGINITE, *mon/P2₁/n***.

MDNKA VASILSEVERGINITE $\text{Cu}_9\text{O}_4(\text{AsO}_4)_2(\text{SO}_4)_2$

GROUP E STRUCTURES OF URANYL PHOSPHATES AND ARSENATES

TYPE A $\text{UO}_2:\text{RO}_4 = 1:2$

SERIES A **WALPURGITE SERIES, *tric/P1***. Structure consists of edge-sharing BiO_5 pentagonal pyramids and BiO_4 tetragonal pyramids, with Bi at the apex, forming chains // [101] in walpurgite and // [010] in orthowalpurkite. The chains are linked into chains // (010) in walpurgite and (001) in orthowalpurkite by sharing corners of polyhedra. The sheets are linked by AsO_4 tetrahedra, UO_{2+4} tetragonal dipyramids and water molecules. Structure consists of edge-sharing BiO_5 pentagonal pyramids and BiO_4 tetragonal pyramids, with Bi at the apex forming chains // [010] in walpurgite and // [010] in orthowalpurkite. The sheets are linked by AsO_4 tetrahedra, UO_{2+4} tetragonal dipyramids and water molecules.

MEAAA WALPURGITE $\text{Bi}_4(\text{UO}_2)(\text{AsO}_4)_2\text{O}_4 \cdot 3\text{H}_2\text{O}$ tric/P1

MEAAB ORTHOWALPURGITE $\text{Bi}_4(\text{UO}_2)(\text{AsO}_4)_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ orth/Pbcm

MEAAC PHOSPHOWALPURGITE $\text{Bi}_4(\text{UO}_2)(\text{PO}_4)_2\text{O}_4 \cdot 3\text{H}_2\text{O}$ tric/P1

SERIES B **PARSONSITE SERIES, *tric/P1***. Structure consists of dimmers of edge-sharing UO_7 pentagonal dipyramids which are connected into chains // [010] by edge- and corner-sharing phosphate tetrahedra; the chains are lined by Pb atoms.

MEABA PARSONSITE $\text{Pb}_2(\text{UO}_2)(\text{PO}_4)_2 \cdot 2\text{H}_2\text{O}$

MEABB HALLIMONDITE $\text{Pb}_2(\text{UO}_2)(\text{AsO}_4)_2$

SERIES C **ULRICHITE, *mon/P2/m***. Structure consists of edge-sharing Ca and UO_{2+5} polyhedra linked into sheets // (100) by P tetrahedra; the sheets are connected by CuO_4 square planes and water molecules. The structure contains groups in which strongly elongated CuO_6 octahedra (CuO_4 squares) are corner-linked to two P tetrahedra via two opposite, equatorial O atoms. Edge- and

corner-sharing UO_7 , CaO_8 and PO_4 polyhedra form heteropolyhedral sheets // to (001) that are linked to adjacent sheets via the CuO_6 octahedra and H bonds.

MEACA ULRICHITE $\text{CaCu}(\text{UO}_2)(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$

SERIES D LAKEBOGAITE, *mon/Cc*. Structure consists of pairs of edge-sharing UO_7 pentagonal bipyramids that are inter-linked via corner-sharing with PO_4 tetrahedra, to form chains // to the c-axis. Each UO_7 polyhedron also shares one of its edges with another P tetrahedron. The $(\text{UO}_2)_2(\text{PO}_4)_4$ chains are cross-linked via corner-sharing between the P tetrahedra and $\text{Fe}^{3+}\text{O}_4(\text{OH})_2$ octahedra. The octahedra join together by corner-sharing via OH anions to form chains // to b. The Na and Ca cations, and 4 water molecules occupy eight-sided channels along [010]. The remaining water molecules occupy large ten-sided channels directed along [001] and intersecting the [010] channels.

MEADA LAKEBOGAITE $\text{CaNaFe}_2(\text{UO}_2)_2(\text{PO}_4)_4(\text{OH})_2(\text{H}_2\text{O})_8$

TYPE B $\text{UO}_2:\text{RO}_4 = 1:1$

SERIES A URANOSPATHITE-SABUGALITE SERIES, *orth/Pnn2*. Structure consists of autunite-type sheet $[(\text{UO}_2)((\text{As},\text{P})\text{O}_4)]$ -constituted by corner-sharing UO_6 octahedron located in the interlayer of the structure. Eight independent and isolated water molecules are also located in the interlayer. A very complex network of H-bonds links the water molecules together, to the Al octahedral and to the uranyl-arsenate sheets. Fluorine was not accurately located by the current structure model and is supposed to replace some of the water molecules in the octahedron.

MEBAA ARSENURANOSPATHITE $\text{Al}[(\text{UO}_2)(\text{AsO}_4)]_2\text{F}(\text{H}_2\text{O})_{20}$

MEBAB URANOSPATHITE $\text{Al}[(\text{UO}_2)(\text{PO}_4)]_2\text{F}(\text{H}_2\text{O})_{20}$

MEBAC SABUGALITE $\text{H}_{0.5}\text{Al}_{0.5}(\text{UO}_2)_2(\text{PO}_4)_2(\text{H}_2\text{O})_8 \cdot n\text{H}_2\text{O}$

SERIES B AUTUNITE SERIES, *tetr/I4/mmm*. The structure consists of UO_{2+4} tetragonal dipyramids sharing corners with four R tetrahedra, forming continuous sheets in which UO_2 is surrounded by four RO_4 and each RO_4 is surrounded by 4 UO_2 groups; these sheets alternate with sheets of divalent cations and water molecules.

MEBBA AUTUNITE $\text{Ca}(\text{UO}_2)_2(\text{PO}_4)_2(\text{H}_2\text{O})_8 \cdot n\text{H}_2\text{O}$

MEBBB FRITZSCHEITE $\text{Mn}(\text{UO}_2)_2((\text{P},\text{V})\text{O}_4)_2(\text{H}_2\text{O})_8 \cdot n\text{H}_2\text{O}$

MEBBC HEINRICHITE $\text{Ba}(\text{UO}_2)_2(\text{AsO}_4)_2(\text{H}_2\text{O})_8 \cdot n\text{H}_2\text{O}$

MEBBD KAHLERITE $\text{Fe}(\text{UO}_2)_2(\text{AsO}_4)_2(\text{H}_2\text{O})_8 \cdot n\text{H}_2\text{O}$

MEBBE NOVACEKITE-I $\text{Mg}(\text{UO}_2)_2(\text{AsO}_4)_2(\text{H}_2\text{O})_8 \cdot 12\text{H}_2\text{O}$

MEBBF SALEEITE $\text{Mg}(\text{UO}_2)_2(\text{PO}_4)_2(\text{H}_2\text{O})_8 \cdot n\text{H}_2\text{O}$

MEBBG METASALEEITE $\text{Mg}(\text{UO}_2)_2(\text{PO}_4)_2(\text{H}_2\text{O})_8 \cdot 8\text{H}_2\text{O}$

MEBBH TORBERNITE $\text{Cu}(\text{UO}_2)_2(\text{PO}_4)_2(\text{H}_2\text{O})_8 \cdot n\text{H}_2\text{O}$

MEBBI TRÖGERITE $(\text{UO}_2)_3(\text{AsO}_4)_2(\text{H}_2\text{O})_8 \cdot n\text{H}_2\text{O}$

MEBBJ URANOCIRCITE $\text{Ba}(\text{UO}_2)_2(\text{PO}_4)_2(\text{H}_2\text{O})_8 \cdot n\text{H}_2\text{O}$

MEBBK URANOSPINITE $\text{Ca}(\text{UO}_2)_2(\text{AsO}_4)_2(\text{H}_2\text{O})_8 \cdot n\text{H}_2\text{O}$

MEBBL ZEUNERITE $\text{Cu}(\text{UO}_2)_2(\text{AsO}_4)_2(\text{H}_2\text{O})_8 \cdot n\text{H}_2\text{O}$

MEBBM XIANGJIANGITE $(\text{Fe},\text{Al})(\text{UO}_2)_4(\text{PO}_4)_2(\text{SO}_4)_2(\text{OH}) \cdot 22\text{H}_2\text{O}$

MEBBN METARAUCHITE $\text{Ni}(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$

MEBBO RAUCHITE $\text{Ni}(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot 10\text{H}_2\text{O}$

MEBBP NOVACEKITE-II $\text{Mg}(\text{UO}_2)_2(\text{AsO}_4)_2(\text{H}_2\text{O})_8 \cdot 10\text{H}_2\text{O}$

SERIES C META-AUTUNITE SERIES, *tetr/orth/P4/nmm*. The structure of this group is based on a waffle-like $[\text{UO}_2\text{XO}_4]_n^{n+}$ sheet. The position of the interlayer water molecules are based on an ideal arrangement in which four water molecules are H-bonded together to form squares which lie between the uranyl ions of successive layers. Each water molecule of a square

group is also H-bonded to a water molecule in an adjacent square and to an arsenate O atom, thus attaining a distorted tetrahedral coordination.

MEBCA	ABERNATHYITE	$K_2(UO_2)_2(AsO_4)_2(H_2O)_4 \cdot nH_2O$	
MEBCB	BASSETITE	$Fe(UO_2)_2(PO_4)_2(H_2O)_4 \cdot nH_2O$	
MEBCC	CHERNIKOVITE	$(H_3O)_2(UO_2)_2(PO_4)_2(H_2O)_4 \cdot nH_2O$	
MEBCD	META-ANKOLEITE	$K_2(UO_2)_2(PO_4)_2(H_2O)_4 \cdot nH_2O$	
MEBCE	META-AUTUNITE	$Ca(UO_2)_2(PO_4)_2(H_2O)_4 \cdot nH_2O$	
MEBCF	METAHEINRICHITE	$Ba(UO_2)_2(AsO_4)_2(H_2O)_4 \cdot nH_2O$	
MEBCG	METAKAHLERITE	$Fe(UO_2)_2(AsO_4)_2(H_2O)_4 \cdot nH_2O$	
MEBCH	METAKIRCHHEIMERITE	$Co(UO_2)_2(AsO_4)_2(H_2O)_4 \cdot nH_2O$	
MEBCI	META-LODEVITE	$Zn(UO_2)_2(AsO_4)_2(H_2O)_4 \cdot nH_2O$	
MEBCJ	METANOVACEKITE	$Mg(UO_2)_2(AsO_4)_2(H_2O)_4 \cdot nH_2O$	
MEBCK	METATORBERNITE	$Cu(UO_2)_2(PO_4)_2(H_2O)_4 \cdot nH_2O$	
MEBCL	METAURANOCIRCITE	$Ba(UO_2)_2(PO_4)_2(H_2O)_4 \cdot 8H_2O$	mon/P2 ₁
MEBCM	META-URANOSPINITE	$Ca(UO_2)_2(AsO_4)_2(H_2O)_4 \cdot nH_2O$	
MEBCN	METAZEUNERITE	$Cu(UO_2)_2(AsO_4)_2(H_2O)_4 \cdot nH_2O$	
MEBCO	NATROURANOSPINITE	$(Na_2,Ca)(UO_2)_2(AsO_4)_2(H_2O)_4 \cdot nH_2O$	
MEBCP	URAMPHITE	$(NH_4)_2(UO_2)_2(PO_4)_2(H_2O)_4 \cdot nH_2O$	
MEBCQ	LEHNERITE	$(Mn,Fe)(UO_2/PO_4)_2 \cdot 8H_2O$	mon/P2 ₁ /n
MEBCR	open		
MEBCS	open		
MEBCT	METANATROAUTUNITE	$Na_2(UO_2)_2(PO_4)_2(H_2O)_6 \cdot 6-8H_2O$	
MEBCU	PRZHEVALSKITE	$Pb(UO_2)_2(PO_4)_2 \cdot 4H_2O$	
MEBCV	URAMARSITE	$(NH_4,H_3O)_2(UO_2)_2(AsO_4, PO_4)_2 \cdot 6H_2O$	

SERIES D **THREADGOLDITE SERIES, mon/C2/m. Structure consist of corner-sharing UO₆ tetragonal dipyramids and P tetrahedra forming sheets // (010) and (001); the sheets are lined by OH ions, water molecules and dimmers of edge-sharing Al octahedra.**

MEBDA	RANUNCULITE	$HAl(UO_2)PO_4(OH)_3 \cdot 4H_2O$	
MEBDB	TRIANGULITE	$Al_3(UO_2)_4(PO_4)_4(OH)_5 \cdot 5H_2O$	tric/P1 or P1
MEBDC	THREADGOLDITE	$Al(UO_2)_2(PO_4)_2(OH) \cdot 8H_2O$	Cc or C2/c
MEBDD	open		
MEBDE	CHISTYAKOVAITE	$Al(UO_2)_2(AsO_4)_2(F,OH) \cdot 6H_2O$	

SERIES E **VOCHTENITE-COCONINOITE, mon/ Structures not known.** DILL, H.G., MELCHER, F., GERDES, A. and WEBER, B. (2008): The origin and zoning of hypogene and supergene Fe-Mn-Mg-Sc-U-REE-Zn phosphate mineralization from the newly discovered Trutzhofmühle aplite (Hagendorf pegmatite province, Germany). *Canadian Mineralogist* 46, 1131-1157. Young, E. J., Weeks, A. D. & Meyrowitz, R. (1966): Coconinoite, a new mineral from Utah and Arizona. *American Mineralogist* 51, 651-663.

Belova, L. N.; Gorshkov, A. I.; Doinikova, O. A.; Mokhov, A. V.; Trubkin, N. V.; Sivtsov, A. V. (1993): New data on coconinoite. *Doklady Akademii Nauk* 329, 772-775. (In Russian.)

MEBEA	VOCHTENITE	$(Fe,Mg)Fe((UO_2)(PO_4))_4(OH) \cdot 12-13H_2O$	
MEBEB	COCONINOITE	$Fe_2Al_2(UO_2)_2(PO_4)_4(SO_4)(OH)_2 \cdot 20H_2O$	

SERIES F **HORAKITE, mon/C2/c. Horákite, ideally (Bi7O7OH)[(UO2)4(PO4)2(AsO4)2(OH)2]·3.5H2O, is a new uranyl mineral discovered on a specimen originating from Jáchymov, Czech Republic (most probably from the Geister vein, Rovnost mine). It occurs as a supergene alteration mineral in**

association with phosphuranylite (overgrowing older metatorbernite-metazeunerite) in a quartz gangue with abundant tennantite. Horákitite forms greenish-yellow to pale yellow prismatic crystals clustering to acicular aggregates, up to 1 mm across. Crystals are transparent to translucent with a vitreous luster. The mineral has a light yellow streak. Estimated Mohs' hardness is ~2. The cleavage is perfect on {100}. The calculated density is 6.358 g/cm³. Horákitite is optically biaxial (+), $\alpha \approx 1.81$, $\beta \approx 1.84$, $\gamma \approx 1.88$ (measured in white light); 2Vobs. is 78(1)°, 2Vcalc. is 83°; non-pleochroic. The optical orientation is X = b, Z = c. Electron-microprobe analysis yielded the empirical formula (Bi_{7.01}Pb_{0.14})O₇OH[(U_{1.01}O₂)₄(P_{1.03}O₄)₂(As_{0.74}Si_{0.23}O₄)₂(OH)₂].3.5H₂O based on 37.5 O apfu. Horákitite is monoclinic, C2/c, a = 21.374(2), b = 15.451(3), c = 12.168(2) Å, $\beta = 122.26(1)^\circ$ and V = 3398.1(10) Å³, Z = 4. The eight strongest X-ray powder-diffraction lines are [dobs Å(l)(hkl)]: 11.77(100)(110), 6.21(23)(-202), 5.55(23)(310, -112), 4.19(27)(-331), 3.54(61)(510, -423), 3.29(20)(331), 3.14(58)(241, 023) and 3.02(98)(150, 113, -533, mult.). The crystal structure refinement of horákitite, refined to R = 5.95 % for 1774 unique observed reflections, revealed a novel sheet structure. It consists of topologically unique [(UO₂)₄(PO₄)₂(AsO₄)₂(OH)₂] sheets (i.e., horákitite topology), and an interstitial {(Bi₇O₇OH)(H₂O)_{3.5}} complex. Sheets result from the polymerization of UO₇ bipyramids by sharing edges to form tetrameric units; tetrahedrally coordinated sites are linked to the UO₇ both monodentately (T1 to U1) and bidentately (T2 to U2). The mineral is named after František Horák (1882-1919), the mining engineer in Jáchymov, and his grandson, Vladimír Horák (born 1964), an amateur mineralogist and expert on the mining history of the Jáchymov ore district.

MEBFA HORAKITE (Bi₇O₇OH)[(UO₂)₄(PO₄)₂(AsO₄)₂(OH)₂].3.5H₂O

TYPE C UO₂:RO₄ = 3:2

SERIES A UPALITE-PHURALUMITE SERIES, mon/P2₁/a. Structure consists of UO₇ and UO₈ polyhedra sharing edges with each other and faces with P tetrahedra to form (UO₂)O(OH)(PO₄)₂ layers. These layers are linked by water molecules and cation polyhedra – Al(H₂O, O)₆ octahedra.

MECAA UPALITE Al(UO₂)₃(PO₄)₂O(OH)·7H₂O
 MECAB FRANCOISITE-(Nd) (Nd, Y, Sm)(UO₂)₃(PO₄)₂O(OH)·6H₂O
 MECAC PHURALUMITE Al₂(UO₂)₃(PO₄)₂(OH)₆·10H₂O
 MECAD MUNDITE Al₂(UO₂)₆(PO₄)₄(OH)₆·11H₂O
 MECAE FRANCOISITE-(Ce) (Ce, Nd, Ca)(UO₂)₃(PO₄)₂O(OH)·6H₂O

SERIES B PHOSPHURANYLITE-PHURCALITE SERIES, orth/Bmmb. The structure of phurcalite (orth/Pbca) consists of [(UO₂)₃O₂(PO₄)₂]_n⁴ⁿ⁻ layers, parallel to (010), which are connected by Ca ions and H₂O. The coordination polyhedra are: for U(1) a hexagonal bipyramid, for U(2) and U(3) pentagonal bipyramids, for Ca(4) and Ca(5) a capped trigonal prism and a triangulated dodecahedron, respectively, and for P(6) and P(7), tetrahedra. In the structures of hugelite/dumontite, the sheets of uranyl pentagonal and hexagonal bipyramids and arsenate tetrahedra are oriented // to (100) and the interlayer contains four symmetrically independent Pb atoms, each of which is coordinated by two oxygen atoms from the uranyl ions, two O atoms from arsenate tetrahedra, and three symmetrically distinct water groups.

MECBA DEWINDTITE Pb(UO₂)₂(PO₄)₂·3H₂O
 MECBB PHOSPHURANYLITE KCa(H₃O)₃(UO₂)₇(PO₄)₄O₄·8H₂O
 MECBC ARSEURANYLITE Ca(UO₂)₄(AsO₄)₂(OH)₄·6H₂O
 MECBD BERGENITE (Ba, Ca)₂(UO₂)₄(PO₄)₂(OH)₄·5.5H₂O mon/P2₁/c
 MECBE YINGJIANGITE K₂Ca(UO₂)₇(PO₄)₄(OH)₆·6H₂O C222₁
 MECBF PHURCALITE Ca₂(UO₂)₃(PO₄)₂O₂·7H₂O
 MECBG CHISTYAKOVAITE Al(UO₂)[(OH)₄/Cl₈].H₂O
 MECBH NIELSBOHRITE K(UO₂)₃(AsO₄)(OH)₄·H₂O
 MECBI DUMONTITE Pb₂((UO₂)₃(PO₄)(OH)₄)₃·3H₂O
 MECBJ HÜGELITE Pb₂((UO₂)₃(AsO₄)(OH)₄)₃·3H₂O

SERIES C Open

SERIES D	VANMEERSSCHEITE SERIES, orth/Pmn2₁. Structure consists of a phosphuranylite type with U or Th atoms connecting the layers.	
MECDA	VANMEERSSCHEITE	U(UO ₂) ₃ (PO ₄) ₇ (OH) ₆ ·4H ₂ O
MECDB	METAVANMEERSSCHEITE	U(UO ₂) ₃ (PO ₄) ₇ (OH) ₆ ·2H ₂ O
MECDC	ALTHUPITE	AlTh(UO ₂)((UO ₂) ₃ O(OH)(PO ₄) ₂) ₂ (OH) ₃ ·15H ₂ O
MECDD	ARSENOVANMEERSSCHEITE	U(OH) ₄ [(UO ₂) ₃ (AsO ₄) ₂ (OH) ₂].4H ₂ O

SERIES E **MOREAUTE-KAMITUGAITE SERIES, tric/P1 or P1. Structure based upon infinite sheets of uranyl and phosphate polyhedra, stacked perpendicular to c; these sheets result from edge-sharing of UO₇ and UO₈ bipyramids, forming chains approximately // to b, which are linked by P tetrahedra. Such a sheet has not been observed in minerals or synthetic compounds and is related to the phosphuranylite topology. There are two distinct interlayer complexes in kamitugaite: one involving Pb²⁺ and water groups and another involving octahedrally coordinated Al and isolated water groups. Adjacent sheets are linked a) through the Pb-O and H-bonds, and b) via H-bonds only in case of the interlayer with Al, the bonding differences being largely attributable to the very different stereochemistry of Pb²⁺ compared to Al³⁺. American Mineralogist (1985): 70: 437.**

Bulletin de la Société française de Minéralogie et de Cristallographie (1984): 107: 15-19. American Mineralogist (1985): 70: 1330-1331.

Bulletin de la Société française de Minéralogie et de Cristallographie (1985): 108: 9-13.

MECEA	KAMITUGAITE	PbAl(UO ₂) ₅ ((P,As)O ₄) ₂ (OH) ₉ ·9.5H ₂ O
MECEB	MOREAUTE	Al(UO ₂)(PO ₄) ₃ (OH) ₂ ·13H ₂ O

SERIES F **ASSELBORNITE SERIES, cub/Im3m, I432, Im3, or I23. Structure not known. Sarp, H., J. Bertrand & J. Deferne (1983): Asselbornite, (Pb,Ba)(UO₂)₆(BiO)₄[(As,P)O₄]₂(OH)₁₂·3H₂O, a new uranium, bismuth, lead and barium hydrous arsenate: Neues Jahrbuch für Mineralogie, Monatshefte: 417-423.**

American Mineralogist (1984): 69: 565.

Sejkora, Jiří; Čejka, Jiří (2007), Šreinite from Horní Halže, the Krušné hory Mountains, Czech Republic, a new mineral species, its comparison with asselbornite from Schneeberg, and new data for asselbornite. Neues Jahrbuch für Mineralogie - Abhandlungen, Volume 184(2)197-206.

MECFA	ASSELBORNITE	Pb(UO ₂) ₄ (BiO) ₃ (AsO ₄) ₂ (OH) ₇ ·4H ₂ O
MECFB	SREINITE	Pb(UO ₂) ₄ (BiO) ₃ (PO ₄) ₂ (OH) ₇ ·4H ₂ O

TYPE D **UO₂:RO₄ = 2:3**

SERIES A **URANOPHANE SERIES, tric/P1. The structure of furongite contains infinite uranyl phosphate sheets of composition [(UO₂)₄(PO₄)₆]¹⁰⁻ which are // to (101). The sheets are constituted by UrO₅ pentagonal bipyramids and P tetrahedra which share edges and vertices, and adjacent sheets are linked by a dense network of H bonds. Running through the sheets and connected mainly to the free apical O atom of the P tetrahedra are Al octahedra connected together to form remarkable Al₂O₅(OH)(H₂O)₅ and Al₄O₈(OH)₈(H₂O)₁₀ clusters. These Al clusters are only bonded to one sheet, and do not connect two adjacent sheets together. The topology of the uranyl phosphate sheets is related to the uranophane anion topology, and can be described as a new geometrical isomer of the uranophane group.**

MEDAA	FURONGITE	Al ₄ [(UO ₂) ₄ (PO ₄) ₆](OH) ₂ (H ₂ O) _{19.5}
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GROUP F **POLYPHOSPHATES, POLYARSENATES, POLYVANADATES**

TYPE A **Diphosphates, Divanadates, and Diarsenates.**

SERIES A **BLOSSITE SERIES, orth/Fdd2. In blossite, corner-sharing V tetrahedra form V₂O₇ dimers lying in the (100) plane; these dimers are linked along [001] by sharing corners of CuO₃₊₂ trigonal dipyramids;**

the dipyramids share edges to form zigzag chains // [011] and [013]. In ziesite, the dimmers are joined by corner-sharing square-based CuO_{4+1} pyramids. Thortveitite group belongs here.

MFAAA	ZIESITE	$\text{Cu}_2[\text{V}_2\text{O}_7]$	mon/A2/a
MFAAB	BLOSSITE	$\text{Cu}_2[\text{V}_2\text{O}_7]$	orth/Fdd2
SERIES B	CHERVETITE, mon/P2₁/a. Structure consists of corner-sharing V tetrahedra forming V_2O_7 dimers that are linked into a framework by sharing edges and corners with PbO_{8-9} polyhedra.		
MFABA	CHERVETITE	$\text{Pb}_2[\text{V}_2\text{O}_7]$	
SERIES C	KAINOTROPITE, orth/Pnma.		
MFACA	KAINOTROPITE	$\text{Cu}_4\text{Fe}^{3+}\text{O}_2(\text{V}_2\text{O}_7)(\text{VO}_4)$	
SERIES D	FIANELITE, mon/P2₁/n. Structure consists of edge-sharing $\text{MnO}_5(\text{H}_2\text{O})$ octahedra forming zigzag chains // [101] which are cross-linked into a framework by sharing corners of V dimmers and by H-bonding.		
MFADA	FIANELITE	$\text{Mn}^{2+}_2\text{V}^{5+}(\text{V}^{5+}\text{As}^{5+})\text{O}_7\cdot 2\text{H}_2\text{O}$	
MFADB	MESAITE	$\text{CaMn}^{2+}_5(\text{V}_2\text{O}_7)_3\cdot 12\text{H}_2\text{O}$	
MFADC	RUDLINGERITE	$\text{Mn}^{2+}\text{V}^{5+}\text{As}^{5+}\text{O}_7\cdot 2\text{H}_2\text{O}$	
SERIES E	CANAPHITE, mon/Pa. . Structure consists of chains // [001] of alternating Ca octahedra and P dimers which are linked by Na atoms and water molecules.		
MFAEA	CANAPHITE	$\text{CaNa}_2\text{P}_2\text{O}_7\cdot 4\text{H}_2\text{O}$	
SERIES F	PINTADOITE. Structure not known.		
MFAFA	PINTADOITE (Q/D)	$\text{Ca}_2[\text{V}_2\text{O}_7]\cdot 9\text{H}_2\text{O}$	
SERIES G	PETEWILLIAMSITE, mon/C2. The structure contains 15 symmetrically distinct As cations, each of which is tetrahedrally coordinated by four O atoms, and pairs of these As tetrahedra share a vertex which results in an As dimer group which are in layers // to (010). The structure also has 16 distinct transition-metal M sites of which there are one tetrahedral, four square bipyramidal, and 11 octahedral arrangements. Adjacent pyroarsenate groups are linked through bonds to M cations.		
MFAGA	PEETWILLIAMSITE	$(\text{Ni},\text{Co})_{30}(\text{As}_2\text{O}_7)_{15}$	
SERIES H	WOOLDRIDGEITE, orth/Fdd2. Structure consists of distorted $\text{CuO}_4(\text{H}_2\text{O})_2$ octahedra sharing opposite corners to form linear chains decorated by P_2O_7 groups; the chains are in parallel arrangement in layers // (010), with the chains mutually orthogonal in alternating layers. The chains are linked by Ca and Na octahedra and by H bonding.		
MFAHA	WOOLDRIDGEITE	$\text{Na}_2\text{CaCu}_2(\text{P}_2\text{O}_7)_2(\text{H}_2\text{O})_{10}$	
SERIES I	VOLBORTHITE, mon/C2/m. Structure consists of chains of edge-sharing Cu octahedra along [010], [1110] and [110] forming (001) sheets. The sheets are linked by the divanadate groups and H-bonding. The structure of engelhauptite is based upon the $[\text{Cu}^{2+}_3(\text{V}_2\text{O}_7)(\text{OH})_2]^0$ framework formed by the linkage of deficient brucite-like layers of Jahn-Teller distorted $\text{Cu}(\text{O},\text{OH})_6$ octahedra via V_2O_7 groups. The framework contains large channels occupied by K cations and Cl anions. And can be considered as its analog resulting from the replacement of water molecules by the equal amounts of K and Cl ions.		
MFAIA	VOLBORTHITE	$\text{Cu}_3[\text{V}_2\text{O}_7](\text{OH})_2\cdot 2\text{H}_2\text{O}$	
MFAIB	MARTYITE	$\text{Zn}_3[\text{V}_2\text{O}_7](\text{OH})_2\cdot 2\text{H}_2\text{O}$	
MFAIC	KARPENKOITE	$\text{Co}_3[\text{V}_2\text{O}_7](\text{OH})_2\cdot 2\text{H}_2\text{O}$	
MFAID	ENGELHAUPTITE	$\text{KCu}_3(\text{V}_2\text{O}_7)(\text{OH})_2\text{Cl}$	$\text{P6}_3/\text{mmc}$

SERIES J THEOPARACELSITE SERIES. Sarp, H. and Cerny R., 2001, Theoparacelsite, $\text{Cu}_3(\text{OH})_2\text{As}_2\text{O}_7$, a new mineral: its description and crystal structure: Arkives de Science Genève: 54(1): 7-14.

American Mineralogist (2002): 87: 356-357.

MFAJA THEOPARACELSITE $\text{Cu}_3(\text{OH})_2(\text{As}_2\text{O}_7)$ orth/Pmma
MFAJB LAPEYROITE $\text{Cu}_3\text{O}[\text{AsO}_3(\text{OH})]_2 \cdot \text{H}_2\text{O}$

SERIES K URUSOVITE, mon/P2₁/c. Structure consists of chains // [100] of corner sharing Al tetrahedra which are connected into sheets by As tetrahedra; the sheets are linked by CuO_5 square pyramids.

MFAKA URUSOVITE $\text{Cu}[\text{AlAsO}_5]$

SERIES L CHINCHORROITE SERIES, tric/P1.

MFALA CHINCHORROITE $\text{Na}_2\text{Mg}_5(\text{As}_2\text{O}_7)_2(\text{AsO}_3\text{OH})_2(\text{H}_2\text{O})_{10}$

TYPE B TRIPHOSPHATE (ISOLATED GROUPS OF $(\text{P}_3\text{O}_{10})$ TETRAHEDRA

SERIES A KANONEROVITE SERIES, mon/P2₁/c. The structure of hylbrownite consists of $[\text{Mg}(\text{H}_2\text{O})_3\text{P}_3\text{O}_{10}]$ clusters which link in the b direction to NaO_6 octahedra, by face and corner sharing. Edge sharing NaO_6 octahedra and NaO_7 polyhedra form Na_2O_9 groups which link via corners to form chains along the b direction. Chains link to $[\text{Mg}(\text{H}_2\text{O})_3\text{P}_3\text{O}_{10}]$ clusters via corner-sharing in the c direction and form a thick sheet // to (100). Sheets are linked in the a direction via H bonds. Popova, V.I., V.A. Popov, E.V. Sokolova, G. Ferraris & N.V. Chukanov (2002): Kanonervite, $\text{MnNa}_3\text{P}_3\text{O}_{10} \cdot 12\text{H}_2\text{O}$, the first triphosphate mineral (Kazennitsa pegmatite, Middle Urals, Russia). Neues Jahrbuch für Mineralogie, Monatshefte 2002, 117-127.

Acta Crystallographica C43, 4-7. Elliott, P., Brugger, J. and Caradoc-Davies, T. (2010) Hylbrownite, IMA 2010-054. CNMNC Newsletter No. 7, February 2010, page 29; Mineralogical Magazine, 75, 27-31.

Elliott, P., Brugger, J. and Caradoc-Davies, T. (2013): Hylbrownite, $\text{Na}_3\text{MgP}_3\text{O}_{10} \cdot 12\text{H}_2\text{O}$, a new triphosphate mineral from the Dome Rock Mine, South Australia: description and crystal structure. Mineral. Mag. 77, 385-398.

MFBA A KANONEROVITE $\text{MnNa}_3[\text{P}_3\text{O}_{10}] \cdot 12\text{H}_2\text{O}$
MFBAB HYL BROWNITE $\text{MgNa}_3[\text{P}_3\text{O}_{10}] \cdot 12\text{H}_2\text{O}$

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