

MEASURING MINERAL ABUNDANCE IN SKARN. I. THE RIETVELD METHOD USING X-RAY POWDER-DIFFRACTION DATA

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ABSTRACT

We evaluate the Rietveld method for determining mineral abundance in natural and synthetic wollastonite skarn using X-ray powder-diffraction data. The results have promise for petrological applications that require modal analysis of large, heterogeneous samples and for mineral-exploration programs. Our main objective was to develop a practical procedure for rapid quantitative modal analysis with the Rietveld method using a conventional Bragg–Brentano X-ray diffractometer. Simulated samples of wollastonite ore were prepared from single-mineral powders, and the experimentally determined modes were compared to the nominal modes. For samples containing 30–99 wt.% wollastonite, the relative error ranges from 0.04 to 1.3%. For phases other than wollastonite, the relative error is generally dependent on the amount present. Above concentrations of 6 wt.%, the relative error is 6%, decreasing at high concentrations to about 1%. Below concentrations of 6 wt.%, the relative error increases rapidly. In addition, twenty drill-core samples from the Isk deposit, in northwestern British Columbia, containing up to thirteen phases, were analyzed with the Rietveld method. The results were compared to mineral abundances determined with a whole-rock chemical analysis and projection method. Determinations of wollastonite abundance by the two methods are in excellent agreement, except for certain samples with mineral assemblages atypical of the Isk wollastonite skarns. The discrepancy between the two methods therefore most likely results from invalid assumptions in the projection method.

Keywords: Rietveld refinement, modal analysis, X-ray powder-diffraction, wollastonite, skarn, Isk deposit, British Columbia.

MEASURING MINERAL ABUNDANCE IN SKARN. II. A NEW LINEAR PROGRAMMING FORMULATION AND COMPARISON WITH PROJECTION AND RIETVELD METHODS

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ABSTRACT

The problem of estimating mineral abundances from whole-rock compositions can be attacked with a formulation that allows the incorporation of theoretical and empirical data on the range of composition of the minerals. A change of variables allows this intrinsically nonlinear problem to be solved with standard linear programming techniques. Calculations based on bulk compositions of samples previously studied by the Rietveld method show very good agreement for major minerals. The results are superior to those obtained by a projection method that also uses bulk-composition data. Estimates of mineral abundances based on bulk-composition data can be obtained rapidly and inexpensively and provide a useful method for reconnaissance studies.

Keywords: modal analysis, linear programming, wollastonite, skarn.

UNUSUAL FORMS OF AMORPHOUS SILICA FROM SUBMARINE WARM SPRINGS,
JUAN DE FUCA RIDGE, NORTHEASTERN PACIFIC OCEAN*

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ABSTRACT

Some unusual forms of amorphous silica were formed in ephemeral warm spring vents along the rift axis of north Cleft Segment, Juan de Fuca Ridge, located off the Oregon coast. They are associated with low mounds constructed by the settling of fine sulfide smoke (pyrite and sphalerite) and precipitation of silica within clumps of juvenile tube-worms that choked vent orifices. The brief period of hydrothermal activity recorded by these mounds is interpreted to be synchronous with incremental spreading events that generated megaplumes in the area in 1989–1990. The earliest forms of silica that cement smoke or soot particles, and comprise 60% of the mound material, consist of microspheroids and amorphous masses. Later forms are more exotic; nested radial sprays of transparent cylindrical needles of silica nucleated on thin layers of spheroids that coat euhedral grains of sulfide minerals. These forms occur only inside worm-tube molds fossilized within sulfide soot matrix materials. They appear to represent the last gasp of waning hydrothermal activity.

Keywords: silica, amorphous, cylindrical needles, hydrothermal vents, smoke, Juan de Fuca Ridge.

As, Sb, AND Ce ENRICHMENT IN MINERALS FROM A METAMORPHOSED Fe–Mn DEPOSIT, VAL FERRERA, EASTERN SWISS ALPS

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ABSTRACT

Several small syngenetic-exhalative Fe–Mn deposits metamorphosed under blueschist- to greenschist-facies conditions occur in Triassic marbles of the Middle Penninic nappes in Val Ferrera (eastern Swiss Alps). Pink muscovite – aegirine – hematite – albite schists associated with the ores in one of these deposits (Starlera mine) contain an unusual assemblage of As-, Sb-, Be-, and REE-rich minerals that developed after the main deformation (D_1). In these pink schists, As is present in significant amounts in both titanite (to 3.46 wt% As_2O_5) and fluorapatite (to 13.8 wt% As_2O_5), and is a major component of bergslagite, $CaBeAsO_4(OH)$. Antimony is an essential constituent of rutile (to 30.63 wt% Sb_2O_5), titanite (to 9.55 wt% Sb_2O_5), and pyrophanite (to 1.91 wt% Sb_2O_5), in which it is accommodated *via* the exchange vector $Sb^{5+}Fe^{3+}Ti^{4+}_{-2}$. Roméite, $(Ca,Na,G)_{2}(Sb,Ti)_2O_6(F,OH,O)$, is also an important host for Sb, but in addition it incorporates major amounts of REE (to 23.4 wt% Ce_2O_3). The pink schists at Starlera are the second reported occurrence of natural Sb-rich rutile and Sb-rich titanite (after Praborna, western Italian Alps), and the third of As-bearing titanite (Praborna and Wannigletscher, Binntal, central Swiss Alps). The Starlera deposit is further characterized by the presence of thick veins of roméite–tilasite ($CaMgAsO_4F$). Most of these late (post- D_1) veins are closely associated with intensely foliated pink schists, indicating that they formed from fluids that passed through the schists. These fluids must have carried As, Sb, and Ti, and probably were similar to those responsible for growth of the post- D_1 As, Sb, Be, Ti, and REE minerals in the pink schists. The metal content of the fluids was most likely derived from the surrounding ores. The unusual assemblages in both veins and pink schists at Starlera document mobility of As, Sb, Be, Ti, and REE under lower greenschist-facies conditions and in a relatively oxidizing environment.

Keywords: Fe–Mn deposit, rutile, titanite, roméite, fluorapatite, bergslagite, Val Ferrera, Swiss Alps.

LOCAL Pb^{2+} -G DISORDER IN THE CRYSTAL STRUCTURE OF JAMESITE,
 $\text{Pb}_2\text{ZnFe}^{3+}_2(\text{Fe}^{3+}_{2.8}\text{Zn}_{1.2})(\text{AsO}_4)_4(\text{OH})_8[(\text{OH})_{1.2}\text{O}_{0.8}]$, AND REVISION OF THE CHEMICAL
FORMULA

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ABSTRACT

The crystal structure of jamesite, $\text{Pb}^{2+}_2\text{ZnFe}^{3+}_2(\text{Fe}^{3+}_{2.8}\text{Zn}_{1.2})(\text{AsO}_4)_4(\text{OH})_8[(\text{OH})_{1.2}\text{O}_{0.8}]$, triclinic, a 5.583(1), b 9.542(2), c 10.219(2) Å, α 109.81(2), β 90.57(2), γ 97.71(2)°, V 506.6(2) Å³, space group $P1$, $Z = 1$, $D_{\text{calc.}} = 5.084$ g/cm³, has been solved by direct methods and refined to an R index of 4.9% based on 1609 observed (56) reflections measured with MoK α X-radiation. There is one unique Pb site that is split into two subsites $Pb(1a)$ and $Pb(1b)$ with a separation of 0.59(2) Å and both occupied by lone-pair-stereoactive Pb^{2+} . There are two unique As sites both occupied by As^{5+} in tetrahedral coordination. There are five unique M sites occupied by Fe^{3+} and Zn ; $M(1) = \text{Zn}$, $M(2) \approx M(3) = \text{Fe}^{3+}$, $M(4) \approx M(5) = (\text{Fe}^{3+}, \text{Zn})$. Bond-valence analysis shows four anions to be (OH) and one anion to be (OH,O), leading to the revised formula given above. The polyhedra link together to form two types of heteropolyhedral chain: the A chain = $[M_3(\text{TO}_4)_4\text{ö}_6]$, as found in kotoite, lindgrenite and frankhawthorneite, and the B chain = $[M(\text{TO}_4)_2\text{ö}_2]$, as found in the minerals of the krohnkite, talmessite and fairfieldite groups. These chains link through an additional octahedron to form a sheet, and these sheets stack along [010] to form a heteropolyhedral framework. The Pb^{2+} cations occur in interstices of this framework. The splitting of the Pb site is driven by local bond-valence requirements around the O(7) anion: where $\text{OH}(5) = (\text{OH})$, the O(7) anion receives a H-bond; where $\text{OH}(5) = \text{O}^{2-}$, the O(7) anion does not receive a H-bond, and the Pb^{2+} cation is displaced toward O(7), forming a $Pb\text{-O}(7)$ bond and compensating for the absence of a H-bond.

Keywords: jamesite, crystal structure, arsenate, lead mineral, Tsumeb, Namibia.

THE CRYSTAL STRUCTURE OF BETPAKDALITE, AND A NEW CHEMICAL
FORMULA: $\{\text{Mg}(\text{H}_2\text{O})_6\} \text{Ca}_2(\text{H}_2\text{O})_{13} [\text{Mo}^{6+}_8 \text{As}^{5+}_2 \text{Fe}^{3+}_3 \text{O}_{36}(\text{OH})] (\text{H}_2\text{O})_4$

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ABSTRACT

The crystal structure of betpakdalite, monoclinic, $C2/m$, a 19.531(2), b 11.061(1), c 15.257(2) Å, β 131.57(1)°, V 2466.6(5) Å³, $Z = 2$, has been refined to an R index of 2.5% for 3077 observed (56) reflections measured on a single crystal with MoK α X-radiation. A crystal fragment was analyzed with an electron microprobe. Compared with previous work, the chemical analysis showed the absence of K and the presence of Mg. Moreover, the site assigned to K in previous work is far more stereochemically compatible with occupancy by Mg. The chemical formula of betpakdalite is redefined as $\{\text{Mg}(\text{H}_2\text{O})_6\} \text{Ca}_2(\text{H}_2\text{O})_{13} [\text{Mo}^{6+}_8 \text{As}^{5+}_2 \text{Fe}^{3+}_3 \text{O}_{36}(\text{OH})] (\text{H}_2\text{O})_4$.

Keywords: betpakdalite, crystal-structure refinement, electron-microprobe analysis, chemical formula.

ESPERANZAITE, $\text{NaCa}_2\text{Al}_2(\text{As}^{5+}\text{O}_4)_2\text{F}_4(\text{OH})\cdot 2\text{H}_2\text{O}$, A NEW MINERAL SPECIES FROM THE LA ESPERANZA MINE, MEXICO: DESCRIPTIVE MINERALOGY AND ATOMIC ARRANGEMENT

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ABSTRACT

Esperanzaite, ideally $\text{NaCa}_2\text{Al}_2(\text{As}^{5+}\text{O}_4)_2\text{F}_4(\text{OH})\cdot 2(\text{H}_2\text{O})$, $Z = 2$, is a new mineral species from the La Esperanza mine, Durango State, Mexico. The mineral occurs as blue-green botryoidal crystalline masses on rhyolite, with separate spheres up to 1.5 mm in diameter. The Mohs hardness is 4.5, and the specific gravity, 3.24 (obs.) and 3.36(3) (calc.). Optical properties were measured in 589 nm light. Esperanzaite is biaxial (-), $X = Y = Z = \text{colorless}$, $n_x = 1.580(1)$, $n_y = 1.588(1)$, and $n_z = 1.593(1)$; $2V_{\text{obs}}$ is $74(1)^\circ$ and $2V_{\text{calc}}$ is 76.3° . The dispersion is medium, $r < v$, and the optic axes are oriented according to $a \wedge Z = +50.5^\circ$, $b = Y$, $c \wedge X = +35^\circ$. The strongest five X-ray-diffraction maxima in the powder pattern [d in $\text{\AA}(\text{I})(hkl)$] are: 2.966(100)(131, 311, 031), 3.527(90)(220), 2.700(90)(221, 002, 040), 5.364(80)(001, 020) and 4.796(80)(011). Esperanzaite is monoclinic, $a = 9.687(5)$, $b = 10.7379(6)$, $c = 5.5523(7)$ \AA , $\beta = 105.32(1)^\circ$, space group $P2_1/m$. The atomic arrangement of esperanzaite was solved by direct methods and Fourier analysis ($R = 0.032$). The Fundamental Building Block (FBB) is formed of [001] stacks of heteropolyhedral tetramers; the tetramers are formed of two arsenate tetrahedra and two Al octahedra, corner-linked in four-member rings. The FBBs are linked by irregular NaO_5 and CaO_8 polyhedra.

Keywords: esperanzaite, new mineral species, crystal structure, La Esperanza mine, Durango, Mexico.

THE CRYSTAL STRUCTURE OF WOOLDRIDGEITE, $\text{Na}_2\text{CaCu}^{2+}_2(\text{P}_2\text{O}_7)_2(\text{H}_2\text{O})_{10}$, A NOVEL COPPER PYROPHOSPHATE MINERAL

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ABSTRACT

The crystal structure of wooldridgeite, $\text{Na}_2\text{CaCu}^{2+}_2(\text{P}_2\text{O}_7)_2(\text{H}_2\text{O})_{10}$, orthorhombic, a 11.938(1), b 32.854(2), c 11.017(1) Å, V 4321.2(8) Å³, $Z = 8$, was solved by direct methods in the space group $Fdd2$ and refined by a full-matrix least-squares method to an R index of 3.4% for 1649 observed ($|F_o| > 5\sigma|F_o|$) reflections. There are two distinct P sites, each tetrahedrally coordinated by four O atoms; the resulting phosphate tetrahedra link through a common anion to form a $[\text{P}_2\text{O}_7]$ group. There is one unique Cu site octahedrally coordinated by four O atoms and two (H_2O) groups, with typical Jahn–Teller distortion ($1.94 \leq \text{Cu}-(\text{O}, \text{H}_2\text{O}) \leq 3.39$ Å). There is one unique Ca site octahedrally coordinated by four O atoms and two (H_2O) groups, and one unique Na site octahedrally coordinated by two O atoms and four (H_2O) groups. The $(\text{Cu}\ddot{\text{o}}_6)$ ($\ddot{\text{o}}$: unspecified anion) octahedra each share two *trans* vertices to form a $[\text{Cu}\ddot{\text{o}}_5]$ chain of corner-sharing octahedra that is decorated with flanking (P_2O_7) groups to form a $[\text{Cu}(\text{P}_2\text{O}_7)(\text{H}_2\text{O})]$ chain. These chains are arranged parallel in layers orthogonal to $[010]$, and the chains in adjacent layers are mutually orthogonal. This array of chains is held together by interstitial Ca and Na, and a network of H bonds.

Keywords: wooldridgeite, crystal structure, phosphate, hydrogen bonds.

MODULAR APPROACH IN SOLVING THE CRYSTAL STRUCTURE OF A SYNTHETIC DIMORPH OF NACAPHITE, $\text{Na}_2\text{Ca}[\text{PO}_4]\text{F}$, FROM POWDER-DIFFRACTION DATA

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ABSTRACT

By comparison with the known structures of nacaphite and arctite, the crystal structure of a synthetic dimorph of nacaphite, $(\text{Na}_{0.67}\text{Ca}_{0.33})_3\text{PO}_4\text{F}$, has been solved using a modular approach. The structure model, refined by Rietveld method on the basis of X-ray powder-diffraction data including minor quantities of villiaumite, fluorite and fluorapatite, consists of a stacking of 15 nacaphite-type $7.1 \times 7.1 \times 2.7 \text{ \AA}$ modules (slabs) along the [001] direction of a rhombohedral $R3m$ cell with $a = 7.0179(7)$, $c = 40.56(4) \text{ \AA}$. Nacaphite, on the other hand, is triclinic and is based on the stacking of only four such slabs. The slabs and their links in nacaphite and its synthetic dimorph are quite different in detail; thus the two compounds are polymorphs and not polytypes. The role of nacaphite modules in building minerals of hyperagpaitic rocks is discussed in terms of merotype and plesiotype series. Modular relationships with sulphohalite-type minerals

also are discussed.

Keywords: nacaphite dimorph, crystal structure, powder diffraction, polysomatic series.

HAINITE FROM POÇOS DE CALDAS, MINAS GERAIS, BRAZIL

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ABSTRACT

Hainite occurs in evolved alkaline rocks (nepheline syenites and tinguaite) of the Poços de Caldas massif, Minas Gerais, Brazil. It forms pale brownish yellow anhedral, elongate or tabular crystals. The crystals display a perfect {100} cleavage, indistinct and irregular {010} and {001} cleavages, and twinning on {100} that may be either simple or lamellar. Its streak is pale yellow. Hainite is generally poikilitic (except inside the vugs), enclosing alkali feldspar, nepheline and other minerals. Optically, the mineral is biaxial (+), with α 1.662(1), β 1.663(1), γ 1.675(1), $2V_z$ (obs.) 30 to 45°, $2V_z$ (calc.) 32.4°. Dispersion $r < v$ crossed, very strong. Its pleochroic scheme is: X colorless, Y colorless to pale yellow, and Z golden yellow. The mineral is triclinic, space group $P1$, a 9.584(2), b 7.267(2), c 5.708(1) Å, α 89.85(2), β 101.22(2), γ 101.03(1)°, V 382.50 Å³, Z = 1. The calculated density is 3.170 g/cm³. The strongest seven lines of the observed X-ray powder-diffraction pattern [d in Å(I)(hkl)] are 3.081(100)(300), 2.970(43)(021), 2.635(11)(202), 1.904(10)(421), 2.312(9)(302), 2.496(8)(301) and 3.966(7)(201). The empirical formulae, derived from results of electron-microprobe analyses, are in good agreement with the structural formula $\{Na_2Ca[Ti(OH)_2(Si_2O_7)_2]\}\{Ca_3(Ca_{0.7}Mn_{0.1}Fe_{0.1}Ce_{0.1})F_2\}$. The simplified formula is $Na_2Ca_5Ti(Si_2O_7)_2(OH)_2F_2$.

Keywords: hainite, silicate, crystal structure, optical properties, chemical composition, Poços de Caldas, Minas Gerais, Brazil.

Sr-BEARING PEROVSKITE AND LOPARITE FROM LAMPROITE AND AGPAITIC NEPHELINE SYENITE PEGMATITES

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ABSTRACT

The paragenesis and compositional variation of strontium-bearing perovskite and loparite occurring in lamproites and agpaitic nepheline syenite pegmatites is described. Olivine lamproites from West Kimberley (Australia), Kapamba (Zambia) and Prairie Creek – American Mine (Arkansas) typically contain perovskite with complex oscillatory zoning and a low Sr content (< 3 wt.% SrO). Perovskite in olivine-free madupitic lamproite from the Leucite Hills (Wyoming) is enriched in Sr (3–7 wt.% SrO) and rare-earth elements relative to perovskite occurring in olivine lamproite. The perovskite in the lamproite from Hills Pond (Kansas) is unusual in containing Si (0.2–2.0 wt.% SiO₂), being relatively-enriched in Sr (3–6 wt.% SrO), and exhibiting complex sector-zoning. Perovskite crystals from lamproites show no regularities in zonation trends, which may be either of increasing or decreasing Sr content from core to rim. Agpaitic nepheline syenite pegmatites from Pegmatite Peak and Gordon Butte (Montana) contain strontian calcian loparite (10–19 wt.% SrO), and are significantly enriched in Sr relative to loparite found in agpaitic nepheline syenites from the Khibina and Lovozero (Russia) complexes. Naturally occurring perovskite-group minerals exhibit a continuous solid-solution between tausonite and loparite-(Ce), but not between tausonite and perovskite. The Sr-rich perovskite, strontian loparite, and ceroan tausonite are found only in alkaline silicate rocks that lack primary carbonates; Na–Sr-poor, Nb-rich perovskite belonging to the perovskite – latrappite – lueshite series form in SiO₂-poor environments characterized by the presence of primary carbonate. In the magmas that form the latter rocks, Sr is preferentially partitioned into carbonates rather than titanates.

Keywords: perovskite, loparite, tausonite, lamproite, agpaitic nepheline syenite, carbonatite.

THE STRUCTURE OF EDOYLERITE DETERMINED FROM A MICROCRYSTAL

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ABSTRACT

The structure of edoylerite, $\text{Hg}^{2+}_3\text{Cr}^{6+}\text{O}_4\text{S}_2$, $Z = 4$, monoclinic, a 7.5283(4), b 14.8325(8), c 7.4629(4) Å, β 118.746(1)°, V 730.6(1) Å³, space group $P2_1/c$, has been solved by direct methods and refined by full-matrix least-squares techniques to an agreement factor (R) of 7.9% and a goodness-of-fit (S) of 1.31 using 1193 unique observed reflections ($|F_o| > 4\sigma_F$) collected for a microcrystal with a volume of 400 μm^3 using MoK α X-radiation and a CCD (charge-coupled device) area detector. The structure contains three symmetrically distinct Hg^{2+} sites, each of which is strongly bonded to two S anions to form approximately linear S–Hg–S clusters. The S–Hg–S clusters link to form crankshaft-type chains composed of eight-membered rings of alternating Hg^{2+} and S that are parallel to [101]. The Hg^{2+} cations are weakly bonded to additional anions, resulting in distorted-octahedral coordinations in two cases and a pentagonal bipyramidal coordination in the other case. The Hg^{2+} polyhedra link to each other and to CrO_4 tetrahedra by the sharing of polyhedron edges and corners, resulting in a heteropolyhedral framework structure.

Keywords: edoylerite, mercury mineral, microcrystal, structure determination.

NEW DATA ON THE MERCURY OXIDE–CHLORIDE MINERAL POYARKOVITE: THE SECOND FIND, AND CRYSTAL-STRUCTURE DETERMINATION

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ABSTRACT

Poyarkovite was first found in the Khaydarkan (Kyrgyzstan) antimony–mercury deposit in 1981. A second find is recorded in the oxidized cinnabar ores of the Arzak mercury deposit, situated about 12 km northeast of the well-known Terlig–Khaya mercury mine, Pii–Khem district, Tuva Republic, Russia. Here, poyarkovite is closely associated with supergene eglestonite, calomel, terlinguaite, montroydite, and native mercury. All these minerals occur in cavities with partly leached primary cinnabar. Poyarkovite is a rare constituent in ores. It forms small, mostly irregular, grains as inclusions in eglestonite and calomel aggregates, and sporadically as minute crystals growing on surfaces of altered cinnabar. The Arzak poyarkovite has the same physical properties as the Khaydarkan specimen, *i.e.*, vitreous to adamantine luster, purple or red-purple color, red or red-crimson streak, translucent (thin fragments and edges of grains), brittle, uneven or subconchoidal fracture, no cleavage, and hardness 2–2½. The measured density (9.56 g/cm³) is in good agreement with the calculated value (9.64 g/cm³), refined according to an X-ray structural study. The strongest seven lines in the X-ray powder-diffraction pattern [d in Å(I)(hkl)] are: 3.09(4–5)(514), 2.96(4)(600), 2.83(10)(132), 2.74(8)(512), 2.61(6)(712), 1.884(4)(1002), and 1.799(6)(640). The electron-microprobe analyses gave, on average, Hg = 91.70, Cl = 5.38, O = 2.45 (inferred value), total = 99.53 wt.%, corresponding to Hg_{3.000}O_{1.005}Cl_{0.995}, based on a total of five atoms. In the X-ray structural study, we have used poyarkovite from Khaydarkan. The structure of poyarkovite (Hg₃ClO, a 19.009(3), b 9.018(4), c 16.848(9) Å, β 110.82(3)°, V 2700(2) Å³, space group $C2/c$, $Z = 24$) was solved by direct methods, and refined to $R = 6.0\%$ on the basis of 1614 unique reflections measured with MoK α radiation on a CAD–4 automated diffractometer. The unit cell contains nine independent mercury atoms forming the six (Hg–Hg)²⁺ dimers, with the Hg–Hg distances equal to 2.502(2)–2.565(3) Å. Of six Hg₂ pairs, three are formed by the 1 or 2 symmetry-bonded atoms. The mercury dimers are located in three mutually

orthogonal directions. Each O atom forms four Hg–O bonds in a tetrahedral arrangement [1.95(2)–2.60(2) Å, Hg–O–Hg 88.1(6)–121.4(9)°]. The shortest Hg–Cl distances are 2.816(10) Å. In terms of only the Hg–Hg and Hg–O bonds, the poyarkovite structure can be represented as two frameworks enclosed one inside the other. The frameworks are bound by the translation of the *C* unit cell (0.5, 0.5, 0). These interpenetrating frameworks of Hg and O atoms bind the Cl atoms together; the latter complement the Hg coordination.

Keywords: poyarkovite, mercury oxychloride, physical properties, composition, X-ray data, crystal structure, second find, Arzak mercury deposit, Tuva, Russia.

ZONING AND SUBSTITUTIONS IN Co–Ni–(Fe)–PGE SULFARSENIDES FROM THE MOUNT GENERAL'SKAYA LAYERED INTRUSION, ARCTIC RUSSIA

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ABSTRACT

Zoning patterns and element correlations in platinum-group element (*PGE*)–Co–Ni–Fe sulfarsenides from the Mount General'skaya complex, in Arctic Russia, reveal the following. (1) Members of the cobaltite–gersdorffite series (*MCGS*) form an extensive solid-solution series between relatively S-rich CoAsS and (Ni_{0.667}Fe_{0.333})AsS, and a Ni–Fe order probably exists in their crystal structure. Co increases, whereas Ni–(Fe), *PGE*, X_{Rh} [100Rh/(Rh + Pd)] and the ratio As/S (atom.%) decrease toward the edge in the cryptically zoned *MCGS*. (2) The *PGE* are relatively enriched in the earlier sulfarsenide phases (typically in the core). (3) Ir–(Pt) is more effectively partitioned into the earliest phase than Rh; Rh is more strongly partitioned into the core than Pd, and transition metals are concentrated in the latest (marginal) phases. (4) The *PGE* substitute for Co, not for Ni and Fe in the *MCGS*. (5) Similar to Ni and Fe, the *PGE* correlate positively with As (and the As/S) and negatively with S, and they are selectively incorporated in relatively As-rich

(S-poor) *MCGS*. In contrast, Co displays a strong negative correlation with As, and a positive one with S. A link seems to exist between cation and (di)-anion substitutions in the *MCGS*, and the incorporation of the *PGE* and other metals probably is controlled by charge balance. The higher temperature of crystallization of Ir-(Pt)AsS *versus* RhAsS, of RhAsS *versus* (Rh,Pd)AsS, and of (*PGE*)AsS *versus* *MCGS* may be crucial to form the zoning patterns and compositional trends of these sulfarsenides.

Keywords: platinum-group elements, platinum-group minerals, cobaltite–gersdorffite, sulfarsenides, isomorphous substitutions, zoning, mafic–ultramafic rocks, layered intrusion, Mount General’skaya, Kola Peninsula, Russia, Fennoscandian Shield.

THE UM SAMIUKI VOLCANOGENIC Zn–Cu–Pb–Ag DEPOSIT, EASTERN DESERT,
EGYPT: A POSSIBLE NEW OCCURRENCE OF CERVELLEITE

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ABSTRACT

A cervelleite-like mineral has been recorded in the Precambrian Ag-rich volcanogenic Zn–Cu–Pb deposits of Um Samiuki, Eastern Desert, Egypt. The optical properties, mineral associations and chemical composition of the mineral are described. The associated hypogene minerals comprise sphalerite, pyrite, chalcopyrite, galena, bornite, tetrahedrite–tennantite, hessite and electrum, whereas the supergene minerals comprise covellite and mckinstryite. The cervelleite-like mineral has been observed in two textural positions, a) as small (15–40 μm) subhedral crystals close to margins of hessite and galena grains, and b) as inclusions in sphalerite, where it is associated with silver-rich bornite, chalcopyrite and hessite. Compositionally, two varieties of the cervelleite-like mineral are recognized, Cu-rich (up to 6.0 wt.%) and Cu-poor (<0.25 wt.%). Silver shows well-defined reciprocal variation with Cu. The chemical composition of the mineral (calculated formula approaching Ag_4TeS) depends on the mineral association and bulk composition. The mode of occurrence of the cervelleite-like mineral suggests a hypogene origin. The mineral forms in an environment of very high Ag activity, and the minimum $f(\text{Te}_2)$ values required to stabilize silver tellurides.

Keywords: cervelleite, silver minerals, chemical composition, tellurium activity, hypogene, volcanogenic deposit, Um Samiuki, Egypt.

ALKALI-DEFICIENT FIBROUS TOURMALINE (FOITITE) FROM THE
SEBINKARAHISAR, GIRE SUN Pb–Zn–Cu–(U) MINERALIZED AREA, NORTHERN
TURKEY

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ABSTRACT

Fibrous alkali-deficient tourmaline (foitite) occurs in cavities in quartz veins near Sebinkarahisar town, Giresun mineralized area [Pb–Zn–Cu–(U)], in northern Turkey. Veins of quartz + fibrous tourmaline generally cut monzonitic and syenitic rocks. Acicular and hairlike light gray crystals of foitite have a mean composition of $G_{0.43}Na_{0.52}Ca_{0.07}(Fe_{1.55}Mn_{0.08}Mg_{0.52}Al_{0.67}Ti_{0.01})Al_6(BO_3)_3Si_6O_{18}(OH,O)_3(OH)_1$. The crystals of this low-temperature tourmaline radiate from irregular patches of schorl in cavities of quartz veins. Each fiber is zoned along its length with respect to Fe, Mn, Mg, Ca, Na, K, and P. The fibrous foitite from the Sebinkarahisar area contains higher Mg, Ca and Na contents than that from southern California and Elba.

Keywords: foitite, tourmaline, fibers, alkali-deficient, cavity, quartz vein, Pb–Zn–Cu–(U) mineralization, Sebinkarahisar, northern Turkey.

MINERALOGY AND GEOCHEMISTRY OF PROTEROZOIC BASALTIC INTRUSIONS,
SPIONKOP RIDGE, SOUTHWESTERN ALBERTA

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ABSTRACT

Three suites of basaltic intrusions occur on Spionkop Ridge in southwestern Alberta. The oldest consists of glomeroporphyritic, alkaline sills and dikes offset by Proterozoic faults, along which a second generation of amygdaloidal alkaline to transitional dikes have been emplaced. The youngest is a tholeiitic diabasic sill containing abundant epidote. The basaltic suites can be distinguished by their TiO₂, Al₂O₃, P₂O₅ and Yb concentrations. The glomeroporphyritic intrusions have ~ 3.7% TiO₂, 15% Al₂O₃, 0.74% P₂O₅ and 4.1 ppm Yb, the amygdaloidal intrusions ~2.5% TiO₂, 16% Al₂O₃, 0.47% P₂O₅ and 3.3 ppm Yb, and the diabasic intrusions ~ 4% TiO₂, 12% Al₂O₃, 0.49% P₂O₅ and 2.4 ppm Yb. Petrographic and geochemical data for similar intrusions and lava flows from locations throughout the Lewis Thrust Sheet are consistent with this three-fold subdivision.

Keywords: Purcell Supergroup, Lewis Thrust Sheet, basalt, chemical composition, Alberta.

CALCITE – AMPHIBOLE – CLINOPYROXENE ROCK FROM THE AFRIKANDA COMPLEX, KOLA PENINSULA, RUSSIA: MINERALOGY AND A POSSIBLE LINK TO CARBONATITES. I. OXIDE MINERALS¹

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¹ This work is dedicated to the memory of our close friend, petrologist Max Poritskiy (1968–1995), who is sorely missed.

ABSTRACT

A calcite – amphibole – clinopyroxene rock (CAPR) occurs as branching veins and segregations in ultramafic alkaline lithologies of the Afrikanda complex, Kola Peninsula, in Russia. The rock is composed predominantly of diopside, magnesiohastingsite, calcite, titanite, chlorite and oxide phases. In the present study, a complete characterization of morphology, interrelations, and compositional variation of the oxide minerals is given, and eleven phases are described at Afrikanda for the first time. Three parageneses are distinguished among the oxide minerals, based on their geochemical features and relative position in the crystallization history. These are (in order of formation): primitive (early magnetite, lamellar ilmenite, primary perovskite, baddeleyite, calzirtite, zirconolite), evolved (secondary perovskite, loparite, lueshite, betafite, late magnetite, discrete ilmenite, thorutite, thorianite) and replacement (rutile, hematite, fersmite, pyrochlore, an unidentified *REE*–Ti oxide) associations. The primitive and evolved associations were formed in the temperature range 500–550 °C at $f(\text{O}_2)$ approximately 10^{-20} – 10^{-22} bar, and $a(\text{SiO}_2)$ generally below $10^{-1.2}$. The replacement assemblage crystallized immediately prior to the precipitation of calcite under increasing $a(\text{SiO}_2)$ and $f(\text{O}_2)$ (? decreasing temperature). This assemblage is closely associated with late silicate minerals, including titanite, chlorite and Zr-bearing silicates. The complex mineralogy of CAPR cannot be explained in terms of simple differentiation of a parental

silicocarbonatitic melt. The textural and mineralogical features indicate that the evolution of CAPR involved substantial interaction between a CO₂-rich liquid (? fluid) and the ultramafic wallrocks.

Keywords: magnetite, perovskite, ilmenite, Zr oxides, thorutite, pyrochlore, carbonatite, clinopyroxenite, Afrikanda, Kola Peninsula, Russia.

COORDINATION AND LOCAL STRUCTURE OF MAGNESIUM IN SILICATE MINERALS AND GLASSES: Mg *K*-edge XANES STUDY

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ABSTRACT

We present Mg *K*-edge XANES spectra of selected Mg-bearing oxide and silicate minerals with different coordination states of Mg. The Mg *K*-edge peak shifts to higher energy with increasing coordination, from ^[4]Mg in spinel, to ^[5]Mg in grandidierite, to ^[6]Mg in diopside and many other silicates, and to ^[8]Mg in pyrope. The correlation between the energy of the Mg *K*-edge and Mg–O bond distance of the model minerals is also established; it can be used to estimate the average Mg–O bond distance in disordered systems. The curve fitting of Mg *K*-edge XANES spectra may be used to distinguish the coordination of Mg, and to determine the relative proportion of different coordination sites, as demonstrated in yoderite, which contains both ^[5]Mg and ^[6]Mg. The structural role of Mg in CaMgSi₂O₆ (Di) – NaAlSi₃O₈ (Ab) glasses was studied using Mg *K*-edge XANES spectra. The Mg–O bond distance in these glasses is estimated to be 2.00 ± 0.04 Å. Thus, Mg in these glasses may be five-coordinated with oxygen, or Mg may have multiple structural sites, ^[4]Mg, ^[5]Mg and ^[6]Mg. Structurally, the Di–Ab glasses may possess a medium-range order, and have dramatically different multiple scattering (MS) paths from those of crystalline model minerals.

Keywords: Mg *K*-edge XANES, silicate minerals, CaMgSi₂O₆ – NaAlSi₃O₈ glasses, coordination of Mg.

EFFECTS OF DOSE RATE AND TEMPERATURE ON THE CRYSTALLINE-TO-METAMICT TRANSFORMATION IN THE ABO_4 ORTHOSILICATES

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ABSTRACT

Displacive radiation-induced effects that accumulate during geological time in the uranium- and thorium-bearing orthosilicate minerals zircon, hafnon, thorite, and huttonite were investigated by ion- bombardment techniques and compared with radiation-damaged natural specimens. The atomic-scale changes in microstructure that occur with increasing dose of radiation are similar in both cases, but a polycrystalline microstructure occurs in the natural minerals that has only been found in synthetic specimens irradiated at elevated temperature. For ion-beam-irradiated synthetic crystals and natural crystalline thorite from the Kipawa complex, western Quebec, the dose required for amorphization increases with increasing temperature. At temperatures above 600°C, the amorphization dose increases in the order: Kipawa thorite, synthetic thorite, hafnon, zircon and huttonite. The synthetic polymorphs of $ThSiO_4$ require a similar dose for amorphization at temperatures below 500°C; thus huttonite is not intrinsically more radiation-damage-resistant than thorite. Rather, huttonite recrystallizes more rapidly at elevated temperatures. The temperature above which amorphization cannot be induced by α -decay processes was calculated by further developing and applying a recently derived model that can also predict the transformation from crystalline to metamict state in zircon as a function of age and temperature. The model was refined and expanded to include thorite and huttonite.

Keywords: zircon, hafnon, thorite, huttonite, metamict state, amorphization, irradiation.

THE ORIGIN OF FLUIDS ASSOCIATED WITH SERPENTINIZATION PROCESSES: EVIDENCE FROM STABLE-ISOTOPE COMPOSITIONS

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ABSTRACT

Values of δD for serpentine minerals from the Mesozoic Cassiar serpentinite in north-central British Columbia (δD from -196 to -103‰), and from several serpentinites from the Archean Abitibi greenstone belt in Ontario (δD from -147 to -54‰) are variable, low, and many are consistent with those expected from modern meteoric water, regardless of the probable age of serpentinization. In contrast, $\delta^{18}O$ values are relatively constant, although different for each area. Such a pattern of variable hydrogen but constant oxygen isotopic compositions, would be expected from hydrogen-isotope exchange, rather than rock–fluid interaction with varying water:rock ratios. Exchange is greater near faults, where enhanced flow of fluid would be expected. Values of $\delta^{18}O$ correlate with mineralogy and texture (whereas δD does not), and the oxygen isotope thermometer gives temperatures consistent with those inferred from mineral assemblages (*e.g.*, 250 to 300°C). Antigorite has higher δD values than lizardite and chrysotile because antigorite forms impervious rocks, attains a greater grain-size, and has a greater degree of crystallinity relative to lizardite or chrysotile. Isotopic data from other studies of serpentinites show similar patterns and can be attributed to the same process of later hydrogen-isotope exchange. On the basis of data for antigorite from serpentinized komatiitic flows from the Abitibi belt, Archean seawater had δD values similar to those of modern seawater.

Keywords: stable isotopes, Archean seawater, antigorite, chrysotile, lizardite, isotope exchange,

Abitibi belt, Ontario, Cassiar District, British Columbia.

REPRODUCIBILITY OF ELECTRON-MICROPROBE BULK ANALYSES OF FINE-GRAINED MEDIA: A CASE STUDY USING MODERN BONE CHINA

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ABSTRACT

The reproducibility of data on the bulk composition of very fine-grained media, and specifically the concentration of the major elements as established by electron-microprobe analysis, has been statistically assessed in order to establish criteria for analysis. Two sets of spot analyses, one using a beam diameter of 20 μm , the other of 40 μm , were undertaken on each of three fragments cut from a sample of modern bone china. Student's t-tests were run to determine if there was a significant difference (at 95% precision) between the two datasets. The results show that as few as 35 spot analyses need be averaged to provide a reliable indication of bulk composition, provided that the beam diameter is at least as large as the coarsest grains, and much larger than the average grain-size of the medium being analyzed.

Keywords: electron microprobe, analysis, porcelain, student's t-test, raster, statistics.