

PLATINUM-GROUP ELEMENTS AND GOLD IN Cu Ni MINERALIZED PERIDOTITE AT GABBRO AKAREM, EASTERN DESERT, EGYPT

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ABSTRACT

The Akarem mafic ultramafic complex is located at 24°01'N, 34°08'E, 130 km east of Aswan, in the southern part of the Eastern Desert of Egypt. The late Proterozoic complex includes an earlier, mostly layered, gabbroic phase and a later peridotite phase. The latter was emplaced in two successive stages, with barren followed by mineralized (Cu Ni sulfide-bearing) peridotites. The gabbroic rocks are largely gabbro, olivine gabbro, troctolite and hornblende gabbro. Unmineralized peridotite is lherzolite, whereas the mineralized peridotite is dunite and harzburgite. The rocks are highly serpentinized. The estimated mode of the mineralized peridotite includes ≤35% olivine, 15% serpentine, ≤3% plagioclase, 16% clinopyroxene, 4% orthopyroxene, 6% amphibole, ≤15% pyrrhotite, ≤3% pentlandite and 3% chalcopyrite. The reserves in mineralized peridotite above 130 m depth has been inferred to be ~700,000 tonnes. The primary sulfides are pyrrhotite, pentlandite, chalcopyrite and cubanite. These minerals exhibit disseminated, massive and net textures in the olivine-rich ultramafic cumulate host. Secondary minerals include violarite, pyrite, monoclinic pyrrhotite, magnetite, mackinawite and millerite. Analyses of bulk rocks and selected coarse sulfide grains were made by a combination of techniques, including instrumental neutron activation (INAA) and inductively coupled plasma mass spectrometry (ICP MS), electron-probe micro-analysis (EPMA) and accelerator mass spectrometry (AMS). S/Se ratios and  $\delta^{34}\text{S}$  values of the sulfide-rich rocks, although not a definitive proof, are consistent with a magmatic S source with minimal crustal contamination. *In situ* Au levels measured by AMS are low: pyrrhotite contains 2–25 ppb, pentlandite 3–8 ppb and chalcopyrite 2–8 ppb. These values are much below bulk-rock levels (60–1080 ppb). Trace Pt (<2 ppb) is detected in the sulfides, also far below bulk levels (20–330 ppb). Coarse pyrrhotite

carries more Rh (20–120 ppb, mean 60 ppb) than bulk rock (mean 20 ppb) and other major sulfides. Ir is similar; other sulfides and bulk samples carry much less (a few ppb) than coarse pyrrhotite (30–100 ppb, mean 60 ppb). Coarse granular pentlandite has the highest Pd contents, up to 1030 ppb. Mass-balance calculations suggest that most Au and Pt probably form discrete grains of native Au and PGM. In contrast, most Pd, Rh and Ir are present within Fe–Ni–Cu sulfides, probably incorporated in the lattice of their host(s). PGE distributions can be explained by fractional crystallization of *mss* from parental sulfide liquid.

*Keywords:* mafic ultramafic rocks, magmatic sulfide, nickel, copper, mineralization, ore textures, platinum-group elements (PGE), gold, electron microprobe, accelerator mass spectrometry, sulfur isotopes, S/Se ratios, ore genesis, Eastern Desert, Egypt.

PLATINUM-GROUP MINERALS AS INDICATORS OF SULFUR FUGACITY IN OPHIOLITIC UPPER MANTLE: AN EXAMPLE FROM CHROMITITES OF THE RAY–IZ ULTRAMAFIC COMPLEX, POLAR URALS, RUSSIA

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ABSTRACT

The Ray–Iz ophiolite complex (Polar Urals, Russia) contains large chromite deposits associated with concordant to discordant bodies of dunite emplaced within harzburgitic mantle tectonite. Primary inclusions (1–25  $\mu\text{m}$ ) of platinum-group-minerals (PGM) occur in the chromite, consisting of laurite, erlichmanite, and Os–Ir alloys, accompanied by cuproiridsite ( $\text{Ir}_2\text{CuS}_4$ ), kashinite ( $\text{Ir}_2\text{S}_3$ ), rhodian pentlandite, unknown sulfides with stoichiometries varying from  $(\text{Ni}>\text{Fe}\geq\text{Cu})_2(\text{Ir}>\text{Rh})\text{S}_3$  to  $(\text{Ni}>\text{Fe}\geq\text{Cu})_2(\text{Ir}>\text{Rh})\text{S}_4$ , irarsite, cherepanovite ( $\text{RhAs}$ ), and unknown  $(\text{Rh},\text{Ni})_2\text{As}$ . The PGM paragenesis indicates deposition through an unusually wide range of  $f(\text{S}_2)$  and T compared with mantle-hosted chromitites from other ophiolite complexes. This wide range is ascribed to the crystallization of PGM and chromite down to a relatively low temperature (T), enabling the relative increase of  $f(\text{S}_2)$ . Such  $f(\text{S}_2)$ –T conditions, previously observed in chromitites of Tiebaghi (New Caledonia) and Kempirsai (southern Urals, Kazakhstan), seem to be peculiar to a chromite-forming system in fluid-metasomatized upper mantle of ophiolite complexes.

*Keywords:* platinum-group minerals, laurite, chromitite, sulfur fugacity, Ray–Iz complex, ophiolite,

Polar Urals, Russia.

THE PLATINUM-GROUP MINERALS OF THE BAIMKA PLACER DEPOSITS, ALUCHIN  
HORST, RUSSIAN FAR EAST

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ABSTRACT

An Alpine-type mafic–ultramafic complex and several Alaskan–Ural type (AUT) plutons are exposed in the Aluchin horst, Chukotka, Russian Far East. Platinum-group element (PGE) mineralization is observed in placer deposits associated with the occurrence of a local stratigraphic unit (Volga) of Late Jurassic sediments. The platinum-group minerals (PGM) in these placer deposits consist mainly of native platinum and grains of Pt–Fe alloy, with Fe contents ranging from 0.3 to 36.15 at.% and, rarely, iridium, cooperite and sperrylite. Minerals present as inclusions in the grains of Pt–Fe alloy are: bowieite, cooperite, kashinite, erlichmanite, hollingworthite, irarsite, cuprorhodsite, laurite, Ir oxide (or hydroxide), osmium, prassoite, guanglinitite, rhodarsenide, magnetite, plagioclase, silicate glass inclusions and unnamed PGE phases. Some PGM inclusions occur in assemblages of two or three phases indicative of a high-

temperature origin for these nuggets. The data on PGM and other mineral inclusions in the grains of Pt–Fe alloy as well as their distribution and occurrence suggest that the primary source for the majority of PGM placer grains studied are AUT mafic–ultramafic complexes.

*Keywords:* platinum-group minerals, electron-microprobe analysis, Alaskan–Ural type complex, nuggets, placers, Chukotka, Russia.

## PLATINUM-GROUP MINERALS FROM THE AIKORA RIVER AREA, PAPUA NEW GUINEA

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### ABSTRACT

Platinum-group minerals (PGM) were discovered in the Aikora River area of Papua New Guinea. This area is situated in the Papuan Ultramafic Belt, in the eastern part of the island. The PGM concentrates consist almost exclusively of PGE alloys, predominantly of Os–Ir–Ru alloys (88%) and subordinately of Pt–Fe alloy (12%). Osmium (70%) is the main mineral of the Os–Ir–Ru alloys, followed by ruthenium (13%), rutheniridosmine (13%) and iridium (4%). A few grains of Os–Ir–Ru alloy are characterized by an unusually high Pt content (up to 18 wt.%), and their compositions plot in the miscibility gap of the system Os–Ir–Ru. We infer that these grains crystallized at higher temperatures. Composite grains of the various types of alloys and oriented intergrowth are very common. Laurite is the only sulfide found, as inclusions in alloys, but more commonly as a product of alteration. Sulfarsenides, undefined arsenides and probable PGE oxides are of secondary origin. The compositions of the alloys and their textures suggest a high-temperature crystallization from a sulfur-depleted Os–Ir–Ru–Rh–Pt–Fe solid solution. The PGM in the placers of the Aikora River area seem to have been derived from ophiolites of the Papuan Ultramafic Belt.

*Keywords:* platinum-group minerals, placer deposits, Os–Ir–Ru alloys, Pt–Fe alloy, sulfides, sulfarsenides, PGE oxides, Papuan Ultramafic Belt, Aikora River area, Papua New Guinea.

PGE DISTRIBUTION IN BASE-METAL ALLOYS AND SULFIDES OF THE NEW  
CALEDONIA OPHIOLITE

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ABSTRACT

An Upper Eocene ophiolite nappe covering some 40% of New Caledonia consists of depleted mantle harzburgites, locally covered by mafic and ultramafic cumulates. These mantle harzburgites in places show an enrichment in sulfide and alloy (heazlewoodite, pentlandite, awaruite, millerite and native copper), accompanied by anomalous concentrations of the PGE, as revealed by the whole-rock analyses of three sulfide-enriched samples and by the heavy-mineral concentrates obtained from these samples (up to 1835 ppb Ir, 1527 ppb Rh, 9718 ppb Pt, 11,494 ppb Pd and 988 ppb Au). Although studies to determine the PGE-carrier minerals by SEM were unsuccessful, SIMS depth profiles show that Pt is strongly enriched in awaruite, albeit varying widely between



grains, *e.g.*, from 4 to 1210 ppm for 21 grains in one sample. In contrast, 11 grains of pentlandite from the same sample do not exceed 10 ppm Pt, whereas 10 out of 12 grains of heazlewoodite show no detectable Pt, and the Pt content of the other two grains is estimated to be very low (<1 ppm). SIMS ion images thus confirm that awaruite is a preferential host for Pt and that the Pt concentration could be related to the mineral's Fe, Cu, Ni and Co content. These images also show that the awaruite, whether or not Pt-bearing, contains some Au, whereas the heazlewoodite is Au-free. Textural features and trace-element distributions of the ore minerals suggest that the mineralization occurred in a two-step process. In the initial mineralizing event, primary PGE-bearing base-metal sulfides (BMS) crystallized in intergranular positions among the silicates. The second step was related to serpentinization and involved transformation of the primary BMS assemblage to the present secondary assemblage of heazlewoodite, awaruite, and pentlandite, but with a different pattern of PGE distribution.

*Keywords:* PGE, Au, awaruite, pentlandite, heazlewoodite, secondary-ion mass spectrometry, ophiolite, New Caledonia.

COMPOSITIONAL ZONING IN ORE MINERALS AT THE CRAIG MINE, SUDBURY,  
ONTARIO, CANADA

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ABSTRACT

The Craig mine, located on the North Range of the Sudbury Igneous Complex, in Ontario, is a typical Sudbury-district nickel sulfide deposit with announced reserves of 14.7 million tonnes of ore, grading 2.01% Ni and 0.74% Cu. The ores consist of massive to disseminated pyrrhotite with randomly dispersed veinlets and flames of pentlandite and scattered grains of chalcopyrite and magnetite. Very small quantities of pyrite occur as scattered subhedral to anhedral grains. The physical textures are typical of those of magmatic nickel sulfide deposits and appear to have formed through diffusion of nickel from a pre-existing monosulfide solid-solution during cooling. Chemical textures have been examined using the electron microprobe; element mapping used analysis times up to 12 hours and beam currents up to 1000 nA. The pyrrhotite has been found to contain nickel-depletion zones around pentlandite veinlets and flames; depletion zones also exist around non-nickel-bearing phases. The depletion zones appear to have formed as a result of nickel diffusion, which was arrested at low temperatures. Individual grains of pentlandite within veinlets contain significant inhomogeneities. Representative examples of the scattered grains of pyrite, although showing no physical variation, contain well-defined compositional zoning in terms of cobalt contents; nickel zoning is much less well defined. This zoning presumably resulted from selective loss of cobalt (and, to a lesser extent, nickel) from the monosulfide solid-solution as its compositional range was reduced at low temperatures.

*Keywords:* pentlandite, pyrrhotite, pyrite, cobalt, nickel, zoning, diffusion, Craig mine, Sudbury, Ontario, Canada.

NIOBIAN ILMENITE, HYDROXYLAPATITE AND SULFATIAN MONAZITE:  
ALTERNATIVE HOSTS FOR INCOMPATIBLE ELEMENTS IN CALCITE KIMBERLITE  
FROM INTERNATSIONAL'NAYA, YAKUTIA

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ABSTRACT

Hypabyssal calcite kimberlite from the Internatsional'naya intrusion in Yakutia, Russia, consists of serpentinized olivine and laths of primary Sr-enriched calcite immersed in a mesostasis of serpentine and secondary Sr-poor calcite. Accessory groundmass minerals include spinel, pyrite, pyrrhotite, nickeliferous sulfides, baddeleyite, ilmenite, hydroxylapatite and monazite-(Ce). An unusual feature of this mineral assemblage is the absence of perovskite, which normally serves as a major depository for the rare-earth elements and Nb in kimberlites. At Internatsional'naya, these incompatible elements are concentrated in alternative mineral hosts, primarily ilmenite-group minerals and phosphates. Ilmenite-group minerals are represented by macrocrystal chromian ferroan geikielite, mantles of manganoan ilmenite on titaniferous spinels, and manganoan niobian ilmenite; the latter mineral occurs as platy crystals and radiating clusters ( $\leq 100 \mu\text{m}$ ) in the groundmass. The most evolved compositions of ilmenite are depleted in Mg, Cr and  $\text{Fe}^{3+}$ , and contain up to 9.5 wt.% MnO, 12.5 wt.%  $\text{Nb}_2\text{O}_5$  and 0.8 wt.%  $\text{Ta}_2\text{O}_5$ . Accommodation of Nb and Ta in ilmenite is accompanied by the creation of vacancies in the site normally occupied by divalent cations:  $(\text{Fe,Mn})^{2+} + 2\text{Ti}^{4+} \leftrightarrow \square + 2(\text{Nb,Ta})^{5+}$ . Hydroxylapatite is confined to the interstices between calcite laths, and serves as a host for light rare-earth elements ( $\leq 2.1$  wt.%  $\text{LREE}_2\text{O}_3$ ) and Sr ( $\leq 0.8$  wt.% SrO). Monazite is unusually enriched in S (6.8–8.4 wt.%  $\text{SO}_3$ ), Sr and Ca ( $\leq 4.9$  and 7.1 wt.% oxides, respectively), and depleted in Th. Incorporation of these elements in the mineral structure involves the complex substitution  $\text{Ce}^{3+} + \text{P}^{5+} \leftrightarrow \text{Ca}^{2+}(\text{Sr}^{2+}) + \text{S}^{6+}$ . The occurrence of these minerals in the kimberlite from Internatsional'naya reflects enrichment of a parental magma in incompatible elements, and probably assimilation of sulfate-bearing brine from the sedimentary country-rocks.

*Keywords:* niobian ilmenite, sulfatian monazite-(Ce), hydroxylapatite, kimberlite, Yakutia.

MAGNETITE–SILICATE INCLUSIONS IN OLIVINE OF METAGABBROS FROM THE MULHACÉN COMPLEX, BETIC CORDILLERA, SOUTHEASTERN SPAIN

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ABSTRACT

Submicroscopic magnetite–silicate inclusions in igneous olivine in metagabbroic rocks from the Betic Ophiolitic Association (BOA) of the Mulhacén Complex, Betic Cordillera, southeastern Spain, have been studied by TEM–AEM. The metamorphic history of these rocks includes a stage of ocean-floor metamorphism followed by polyphase Alpine metamorphism, its metamorphic climax being developed under conditions of subduction. The grains of olivine have a brown color, interpreted as due to blebs of magnetite that formed during the metasomatic and metamorphic processes superimposed on the igneous crystals. The magnetite precipitates display a fixed orientation relative to the olivine host, and form intergrowths with silicate phases. These include monoclinic amphibole, orthorhombic amphibole and monoclinic pyroxene, the association magnetite – monoclinic amphibole being the most common. Chemically, the exsolved amphiboles are calcic and may be subdivided into two types: actinolite, without Na, and edenite and pargasite, containing Na. The presence in the exsolution-induced blebs of a hydrated silicate phase, together with the existence of saline inclusions in the olivine, point to the ocean-floor stage for the influx of seawater, which contributed to the exsolution process. Petrographic observations and comparison of the chemical composition of the exsolved amphiboles with that of the amphiboles developed during the several metamorphic stages registered in the host gabbros allow us to infer the P–T

conditions during the exsolution process. Exsolution began during ocean-floor metamorphism, then continued during the prograde stage of the eo-Alpine event, at which point the kelyphitic amphibole-bearing coronas formed in the olivine.

*Keywords:* exsolution, magnetite – amphibole – pyroxene, TEM–AEM analysis, olivine metagabbro, ocean-floor metamorphism, Alpine orogeny, Mulhacén Complex, Betic Cordillera, Spain.

THE ORIGIN OF THE ATSHAN TALC DEPOSIT IN THE HAMATA AREA, EASTERN  
DESERT, EGYPT: A GEOCHEMICAL AND MINERALOGICAL STUDY

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ABSTRACT

The Atshan talc mine is one of several talc deposits in the Hamata area of southeastern Egypt. Our detailed geochemical and mineralogical investigation suggests that precursors to the talc orebodies were impure dolomitic limestones locally intercalated with clastic sediments. The extremely low concentrations of trace elements, including the *REE*, and the low and variable Al concentrations in these rocks are inconsistent with igneous protoliths. The magnesium needed to form the talc orebodies was derived from the breakdown of pre-existing carbonates. This mode of origin is comparable to that in other carbonate-hosted talc deposits on the global scale, such as the Rabenwald and Lassing deposits in Austria. Rocks at the Atshan mine have been subjected to at least two episodes of metamorphism, contact and regional. Mineral assemblages (a) enstatite + cordierite + hercynite (granulite facies) and (b) enstatite + clinopyroxene (pyroxene hornfels facies) probably crystallized during emplacement of the Reidi grey granite (contact metamorphism), and represent relict high-temperature assemblages in the clastic fragments. Temperatures above 600°C are suggested for the enstatite–cordierite pair, and a minimum range of temperatures between 500° and 600°C was estimated for the pyroxene hornfels. The serpentine

+ talc + tremolite + chlorite assemblage replaced the carbonates during regional metamorphism and associated faulting and shearing. The maximum temperature for this mineral assemblage is limited to  $<500^{\circ}\text{C}$ , and the  $X(\text{CO}_2)$  of the fluid is limited to  $<0.2$  by the ubiquitous presence of serpentine. Stable reactions in the system of  $\text{CaO} - \text{MgO} - \text{SiO}_2 - \text{H}_2\text{O} - \text{CO}_2$  demonstrate that serpentine and tremolite at the Atshan deposit could have formed during prograde reactions, and talc, during retrograde reactions. Small lenses of massive and disseminated sulfide (pyrite, pyrrhotite, sphalerite, chalcopyrite) within the talc orebodies may represent sulfide segregation in the original sediments prior to metamorphism. Some of the pyrite and pyrrhotite grains are fragmented and rimmed by talc, suggesting that they were present prior to talc mineralization. Chalcopyrite was probably remobilized, and it occurs along tremolite cleavages and fractures.

*Keywords:* Atshan deposit, talc, carbonate, sediments, serpentine, contact metamorphism, regional metamorphism, geochemistry, rare-earth elements, Eastern Desert, Egypt.

## THE COMPOSITIONAL SPACE OF MUSCOVITE IN GRANITIC ROCKS

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## ABSTRACT

The compositional range of igneous muscovite (Ms) and the nature and extent of the solid solutions are defined. For this purpose, a database of 189 muscovite compositions taken from the literature has been used. Most (159) are from peraluminous granites (*sensu lato*), and a few (30) are from pegmatites and aplites. The compositions were recalculated on the basis of 22 O, and all iron was considered as Fe<sup>2+</sup>. A quality screen was applied to the whole dataset; about 10% of the compositions were rejected owing to the anomalous chemical contents of the octahedral or interlayer sites. All chemical data were then processed by statistical analysis of the chemical variability, and plotted on specific binary diagrams useful to assess the extent of the main substitutions. Muscovite in granitic rocks turns out to have moderate celadonic and paragonitic contents. In 98.8% of the cases, the indicators of celadonic substitution fall in the following ranges:  $s = \text{Si} - 6$  between 0.031 and 0.036 *apfu*,  $Fm = \text{Fe}^{2+} + \text{Mg}$  between 0.135 and 1.349 *apfu*, and  $a = 6 - \text{Al}$  between 0.019 and 2.087 *apfu*. Concerning the extent to the solid solution toward paragonite, the value of 100 Na/(Na + K) varies between 5 and 23.2% in 87.5% of the cases. On the basis of limited data, muscovite from pegmatites and aplites have limited extents of the celadonite and paragonite substitutions.

*Keywords:* muscovite, chemical composition, granitic rocks.



CRYSTALLIZATION AND ALTERATION HISTORY OF BRITHOLITE IN RARE-EARTH-ELEMENT-ENRICHED PEGMATITIC SEGREGATIONS ASSOCIATED WITH THE EDEN LAKE COMPLEX, MANITOBA, CANADA

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ABSTRACT

Pegmatitic segregations and quartzofeldspathic veins associated with the Eden Lake Complex, Manitoba, Canada, contain significant abundances of rare-earth elements (*REE*), U and Th, concentrated in minerals such as titanite, apatite, allanite and britholite. Titanite and apatite are typically found as discrete, zoned, and locally euhedral crystals. Allanite occurs both as discrete crystals as well as irregular segregations, whereas britholite occurs only as irregular masses. The allanite and britholite typically share sharp but irregular contacts with the host silicate minerals (aegirine-augite, K-feldspar and quartz). Allanite normally occurs between britholite and the silicate minerals, suggesting that it formed as the result of reaction between a *REE*-bearing fluid rich in P and F and the silicate minerals. Within the irregular masses of britholite, one sees an unusual polygonal mosaic-like texture with polygons ranging from 20 to 200  $\mu\text{m}$ . Polygon boundaries are straight to slightly curved, intersect at triple junctions, and converge at angles from 60 to 180°. This texture is likely the product of reheating and annealing of the britholite. However, as a result of metamictization, the britholite retains little long-range order. Many of the polygons are altered preferentially along polygon boundaries. Chemical analyses indicate that U, Th, La, Ce, F and Cl were mobile during the alteration, whereas Y seems to have been immobile. Altered britholite has lower La and Ce contents than unaltered britholite, but the La/Ce value remains essentially unchanged. Altered britholite has lower F/Cl values than unaltered britholite, and U and Th contents show significant scatter that in turn is related to elevated Cl contents.

*Keywords:* britholite, titanite, allanite, annealed texture, rare-earth element, anorogenic, Eden Lake complex, Manitoba, Canada.

DURANUSITE, PRODUCT OF REALGAR ALTERATION, MINA CAPILLITAS,  
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ABSTRACT

Realgar, AsS, occurs as disseminated grains within layers of banded rhodochrosite of the Mina Capillitas, an epithermal deposit in the Province of Catamarca, Argentina. The realgar has been altered by deuteric solutions to form the rare mineral duranusite, As<sub>4</sub>S. Duranusite is associated with crusts and small hemispherical bodies of nearly pure sphalerite. Duranusite occurs as thin lamellae and filaments intimately intergrown with sphalerite.

*Keywords:* duranusite, realgar, epithermal deposit, Mina Capillitas, Argentina.

WALFORDITE, A NEW TELLURITE SPECIES, FROM THE WENDY OPEN PIT, EL  
INDIO – TAMBO MINING PROPERTY, CHILE

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ABSTRACT

Walfordite, a tellurite, is a new mineral species from the Wendy open pit, Tambo mine, El Indio – Tambo mining property, Coquimbo Province, Chile. It is orange, with an orange-yellow streak, and forms simple cubes 0.2 mm across, or cubes modified by octahedral faces. It has an adamantine luster and is opaque. Crystals are too small to provide measurements of the hardness, but they are brittle, with no observed cleavage or parting. Walfordite is isotropic, with  $n \gg 2.0$ ; the calculated value, 2.23, was obtained from the Gladstone–Dale relationship. An attempt to measure the index of refraction using the reflectance method resulted in an erroneously high value

of  $n_{\text{air}}$ , 2.28. In a polished section in plane-polarized light, walfordite is pale gray, and is neither bireflectant nor pleochroic. An electron-microprobe analysis gave MgO 0.38, Fe<sub>2</sub>O<sub>3</sub> 8.30, TiO<sub>2</sub> 1.11, TeO<sub>2</sub> 81.74 and TeO<sub>3</sub> 8.67, total 100.20 wt.%. Enough Te was calculated as Te<sup>4+</sup>O<sub>2</sub> to give Te<sup>4+</sup> = 3 *apfu* in the formula, the remainder was calculated as Te<sup>6+</sup>O<sub>3</sub>, and the Fe was calculated as Fe<sub>2</sub>O<sub>3</sub> to maintain charge balance, on the basis of a crystal-structure analysis. This calculation yields the empirical formula (Fe<sup>3+</sup><sub>0.61</sub>Te<sup>6+</sup><sub>0.29</sub>Ti<sub>0.08</sub>Mg<sub>0.06</sub>)<sub>sss1.04</sub>Te<sup>4+</sup><sub>3</sub>O<sub>8</sub> or, ideally, (Fe<sup>3+</sup>,Te<sup>6+</sup>)Te<sup>4+</sup><sub>3</sub>O<sub>8</sub>,  $Z = 8$  and  $D_{\text{calc}} = 5.841 \text{ g/cm}^3$ . A crystal-structure analysis shows the mineral to be cubic, space group  $I2_1/a\bar{3}$  (space group #206), with  $a = 11.011(5) \text{ \AA}$ . The strongest lines in the X-ray powder pattern [ $d$  in  $\text{\AA}(I)(hkl)$ ] are: 4.486(29)(211), 3.175(100)(222), 2.943(23)(321), 2.749(37)(400), 2.592(22)(411), 1.944(44)(440) and 1.658(45)(622). The crystal structure of walfordite is similar to that of synthetic phases of the type  $M^{4+}\text{Te}^{4+}_3\text{O}_8$ , and to that of winstanleyite. It is the Fe<sup>3+</sup> analogue of winstanleyite.

*Keywords:* walfordite, new mineral species, tellurite, crystal structure, El Indio – Tambo mining property, Chile.

SIDPIETERSITE,  $\text{Pb}^{2+}_4(\text{S}^{6+}\text{O}_3\text{S}^{2-})\text{O}_2(\text{OH})_2$ , A NEW THIOSULFATE-BEARING MINERAL SPECIES FROM TSUMEB, NAMIBIA

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ABSTRACT

Sidpietersite, ideally  $\text{Pb}^{2+}_4(\text{S}^{6+}\text{O}_3\text{S}^{2-})\text{O}_2(\text{OH})_2$ , is triclinic,  $P\bar{1}$ , with unit-cell parameters refined from powder data:  $a$  7.447(4),  $b$  6.502(4),  $c$  11.206(4) Å,  $\alpha$  114.30(3),  $\beta$  89.51(4),  $\gamma$  89.04(6)°,  $V$  494.4(5) Å<sup>3</sup>,  $a:b:c$  1.1453:1:1.7235,  $Z = 2$ . The strongest eight lines of the X-ray powder-diffraction pattern [ $d$  in Å( $I$ )( $hkl$ )] are: 10.13(100)(001), 5.93(50)(010), 4.401(35)(011), 3.414(100)(003), 3.198(80)(02 $\bar{2}$ ), 2.889(35)(02 $\bar{3}$ ,211), 2.805(35)( $\bar{2}$ 11,01 $\bar{4}$ ) and 2.622(40)( $\bar{2}$ 1 $\bar{3}$ ). The mineral occurs on a single specimen collected from the 40th to 44th levels of the Tsumeb mine, Tsumeb, Namibia,

as ill-formed, almost warty, nodular masses and crystal groups, as earthy masses and, rarely, as free-standing to radiating bladed-crystal aggregates. Masses, groups and aggregates never exceed 3 mm in longest dimension. It is the last mineral to form in an assemblage that includes smithsonite, zincite, galena, sphalerite, and very minor quartz and greenockite. Individual subhedral to almost euhedral crystals are bladed, elongate  $[01\bar{1}]$ , with a length-to-width ratio of approximately 4:1 and not exceeding 0.2 to 0.3 mm in maximum length. Forms are  $\{001\}$  major, and possible very thin  $\{100\}$  and  $\{01\bar{1}\}$  minor. Cleavage is perpendicular to  $[01\bar{1}]$ . The mineral is opaque (masses) to transparent (crystals), beige-cream to off-white to colorless (crystals), with a cream to off-white streak, and a vitreous (crystals) to earthy (masses) to pearly luster. Sidpietersite is sectile, with an uneven fracture, and is nonfluorescent; H(VHN load 25 g) 57–67, H(Mohs) 1–2;  $D$  (calc.)  $6.765 \text{ g/cm}^3$  for the idealized formula. In polished section, sidpietersite is light grey in plane-polarized reflected light in air, with ubiquitous brilliant white to yellow-brown internal reflections; the phase is birefractant and perhaps slightly pleochroic. Averaged results of electron-microprobe analyses yield PbO 89.55,  $\text{S}^{6+}\text{O}_3$  7.58,  $\text{S}^{2-}$  3.035,  $\text{H}_2\text{O}$  [1.79], sum 101.955, less  $\text{O} = \text{S}^{2-} - 1.51$ , total [100.45] wt.%. The empirical formula, derived from results of the crystal-structure analysis and electron-microprobe analyses, is  $\text{Pb}^{2+}_{4.09} (\text{S}^{6+}_{0.97}\text{O}_{2.90}\text{S}^{2-}_{0.97}) \text{O}_{2.09}(\text{OH})_{2.03}$ , on the basis of  $\text{O} + \text{S}^{2-} = 8$  and with  $(\text{OH}) = 2.00$ . The infrared-absorption spectrum shows bands for structural (OH) and thiosulfate. The mineral name honors Sidney Pieters, Windhoek, Namibia, for his outstanding contributions to Namibian mineralogy over the last fifty years.

*Keywords:* sidpietersite, new mineral species, lead hydroxide–oxide–thiosulfate, X-ray data, electron-microprobe data, infrared spectroscopy, Tsumeb mine, Tsumeb, Namibia.

# THE STRUCTURE TOPOLOGY OF SIDPIETERSITE, $\text{Pb}^{2+}_4 (\text{S}^{6+}\text{O}_3\text{S}^{2-}) \text{O}_2 (\text{OH})_2$ , A NOVEL THIOSULFATE STRUCTURE

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## ABSTRACT

The crystal structure of sidpietersite,  $\text{Pb}^{2+}_4 (\text{S}^{6+}\text{O}_3\text{S}^{2-}) \text{O}_2 (\text{OH})_2$ , triclinic,  $a$  7.455(2),  $b$  6.496(2),  $c$  11.207(4) Å,  $\alpha$  114.33(2),  $\beta$  89.65(2),  $\gamma$  88.69(2)°,  $V$  494.3(3) Å<sup>3</sup>,  $Z = 2$ , space group  $P\bar{1}$ , has been solved by direct methods and refined to an  $R$  index of 3.0% for 1292 observed ( $|F_o| > 5\sigma|F_o|$ ) reflections measured with MoK $\alpha$  X-radiation. There are four symmetrically distinct  $Pb$  sites occupied by  $\text{Pb}^{2+}$  in very asymmetric coordinations typical of stereoactive lone-pair behavior. Sidpietersite contains a thiosulfate group,  $(\text{S}^{6+}\text{O}_3\text{S}^{2-})$ , and is the first thiosulfate mineral to be characterized structurally. The  $\langle \text{S}^{6+}-\text{O} \rangle$  distance is 1.48 Å, the  $\text{S}^{6+}-\text{S}^{2-}$  distance is 1.98 Å, and the four anions form a distorted tetrahedral arrangement about the central cation. A ladder of  $\text{Pb}^{2+}$  and O atoms (a motif from the structure of PbO) extends along the  $a$  axis; this ladder is decorated by peripheral Pb atoms, and the resultant ribbons are cross-linked by thiosulfate groups to form a thick slab orthogonal to [001]. These slabs are linked along the  $c$  axis by weak Pb– $\text{S}^{2-}$  bonds. The structure of sidpietersite is unrelated to any synthetic thiosulfate structures. The latter have cation:thiosulfate ratios between 1:1 and 2:1, and the structures consist of thiosulfate groups linked by weak bonds. In sidpietersite, the cation:thiosulfate ratio is 4:1, and the cations form extended polymerized arrays that are cross-linked by thiosulfate groups. There seems no intrinsic reason why more complex structures such as sidpietersite should not occur, at least as synthetic materials.

*Keywords:* sidpietersite, thiosulfate, crystal structure, Pb mineral, Tsumeb, Namibia.

STRUCTURE OF A SYNTHETIC Cs URANYL OXIDE HYDRATE AND ITS RELATIONSHIP TO COMPREIGNACITE

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ABSTRACT

Cesium uranyl oxide hydrate (designated CsUOH),  $\text{Cs}_3[(\text{UO}_2)_{12}\text{O}_7(\text{OH})_{13}](\text{H}_2\text{O})_3$ ,  $Z = 3$ , is a new phase. Its structure is rhombohedral, space group  $R\bar{3}$ ,  $a$  14.1241(6),  $c$  22.4073(14) Å,  $V$  3871.16(8) Å<sup>3</sup> and refined to an agreement factor ( $R$ ) of 5.1% for 3883 unique observed reflections ( $|F_o| \geq 4\sigma_F$ ). It is related to the structure of compreignacite,  $\text{K}_2[(\text{UO}_2)_3\text{O}_2(\text{OH})_3]_2(\text{H}_2\text{O})_7$ , but the phases are not isostructural. The structure of CsUOH contains sheets of pentagonal bipyramidal uranyl polyhedra that share equatorial edges and corners to form sheets that are parallel to (100). Cesium occurs in the interlayer at the center of an eight-coordinated distorted polyhedron. H<sub>2</sub>O groups are also contained in the interlayer.

*Keywords:* uranyl, uranium, structure determination, compreignacite.



## Ta–Nb ORDER IN THE CRYSTAL STRUCTURE OF NIOBIUM-RICH CALCOTANTITE

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## ABSTRACT

The crystal structure of niobium-rich calciotantite,  $\text{Ca}(\text{Ta}_{2.82}\text{Nb}_{1.18})\text{O}_{11}$ , hexagonal,  $a$  6.2261(6),  $c$  12.280(1) Å,  $V$  412.18(8) Å<sup>3</sup>, space group  $P6_322$ ,  $Z = 1$ ,  $D_{\text{calc.}} = 6.735$  g/cm<sup>3</sup>, has been refined to an  $R$  index of 1.8% based on 414 observed (4sss) reflections measured with MoK $\alpha$  X-radiation. There is one unique  $Ca$  site occupied by Ca and coordinated by eight O-atoms with a  $\langle Ca-O \rangle$  distance of 2.512 Å. There are two unique  $Ta$  sites both occupied by Ta and Nb; the  $Ta(1)$  site is coordinated by seven O atoms in a distorted pentagonal dipyramidal arrangement, and the  $Ta(2)$  site is coordinated by six O atoms in a distorted octahedral arrangement. The  $Ta(2)\text{O}_6$  and  $Ca\text{O}_8$  polyhedra occupy alternate vertices of a  $6^3$  net to form an open network of edge-sharing polyhedra of the form  $[\text{CaTaO}_8]$ . The  $Ta(1)\text{O}_7$  polyhedra share four of their pentagonal edges to form a  $[\text{Ta}_3\text{O}_{11}]$  sheet with triangular holes at the vertices of a  $6^3$  net. These sheets alternate along  $[001]$  to form a dense framework structure. The structure of calciotantite is topologically similar to that of natrotantite,  $\text{Na}_2\text{Ta}_4\text{O}_{11}$ ; the  $[\text{Ta}_3\text{O}_{11}]$  sheets are topologically identical in both structures, and the  $[\text{CaTaO}_8]$  and  $[\text{Na}_2\text{TaO}_8]$  sheets are the same if they are written as  $[\mathbf{G}\text{CaTaO}_8]$  and  $[\text{Na}_2\text{TaO}_8]$ . The  $[\text{Ta}_3\text{O}_{11}]$  sheet is also topologically identical to the  $[(\text{UO}_2)_3\phi_5]$  ( $\phi = \text{O}, \text{OH}$ ) in billietite, protasite, becquerelite and  $\alpha\text{-U}_3\text{O}_8$ . Niobium is slightly preferentially ordered (relative to Ta) at the  $Ta(1)$  site, indicating a slight difference in the crystal-chemical behavior of Ta and Nb.

*Keywords:* calciotantite, crystal structure, Ta–Nb order, natrotantite.

ONEILLITE: A NEW Ca-DEFICIENT AND REE-RICH MEMBER OF THE EUDIALYTE GROUP FROM MONT SAINT-HILAIRE, QUEBEC, CANADA

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ABSTRACT

Oneillite, ideally  $\text{Na}_{15}\text{Ca}_3\text{Mn}_3\text{Fe}_3\text{Zr}_3\text{Nb}(\text{Si}_{25}\text{O}_{73})(\text{O},\text{OH},\text{H}_2\text{O})_3(\text{OH},\text{Cl})_2$ , is a new member of the eudialyte group from Mont Saint-Hilaire, Quebec. It occurs as yellowish brown anhedral grains up to 2 mm in diameter. Associated minerals include albite, sodalite, pyrite and aegirine. It is transparent to translucent, with a vitreous luster and white streak. It is brittle, with a hardness of 5–6 (Mohs scale). It has no cleavage, no parting, and an uneven fracture. It is uniaxial negative with  $\omega$  1.6450(3) and  $\epsilon$  1.6406(3). It is trigonal, space group  $R\bar{3}$ ,  $a$  14.192(1) and  $c$  29.983(3) Å,  $V$  5230(1) Å<sup>3</sup>,  $Z = 3$ . The strongest X-ray powder-diffraction lines [ $d$  in Å ( $I$ )( $hkl$ )] are: 11.348(44.2)(101), 7.100(33)(110), 6.021(36.1)(021), 5.683(30.8)(202), 4.291(36.5)(205), 3.199(30.8)(208), 3.150(34.9)( $\bar{2}$ 37), 2.964(100)( $\bar{3}$ 45) and 2.844(89.1)(404). The infrared spectrum is given. An electron-microprobe analysis of the grain of oneillite chosen for refinement of the structure gave  $\text{Na}_2\text{O}$  13.60,  $\text{K}_2\text{O}$  0.28,  $\text{CaO}$  2.90,  $\text{MnO}$  7.70,  $\text{FeO}$  3.00,  $\text{SrO}$  0.09,  $\text{Al}_2\text{O}_3$  0.18,  $\text{Y}_2\text{O}_3$  0.78,  $\text{La}_2\text{O}_3$  2.88,  $\text{Ce}_2\text{O}_3$  5.14,  $\text{Pr}_2\text{O}_3$  0.48,  $\text{Nd}_2\text{O}_3$  1.45,  $\text{Gd}_2\text{O}_3$  0.20,  $\text{SiO}_2$  43.46,  $\text{ZrO}_2$  11.44,  $\text{HfO}_2$  0.16,  $\text{Nb}_2\text{O}_5$  3.48,  $\text{Ta}_2\text{O}_5$  0.14,  $\text{Cl}$  0.76,  $\text{H}_2\text{O}$  0.63,  $\text{O} \equiv \text{Cl}$  0.17, total 98.58 wt.%. The proportion of  $\text{H}_2\text{O}$  was calculated from stoichiometry on the basis of the crystal-structure analysis. The empirical formula of oneillite, based on 78.09 anions as determined in the crystal-structure analysis is:  $(\text{Na}_{14.37}\text{REE}_{1.53}\text{K}_{0.20}\text{Sr}_{0.03})_{\Sigma 16.13}(\text{Ca}_{1.77}\text{REE}_{0.59}\text{Na}_{0.66})_{\Sigma 3.02}(\text{Mn}_{2.76}\text{Y}_{0.24})_{\Sigma 3.00}(\text{Fe}_{1.43}\text{Mn}_{0.96}\text{Zr}_{0.25})_{\Sigma 2.64}(\text{Zr}_{2.93}\text{Nb}_{0.05}\text{Hf}_{0.03})_{\Sigma 3.01}(\text{Nb}_{0.85}\text{Ta}_{0.02})_{\Sigma 0.87}(\text{Si}_{24.77}\text{Al}_{0.12})_{\Sigma 24.89}\text{O}_{73}(\text{O},\text{OH},\text{H}_2\text{O})_{3.09}(\text{OH}_{1.27}\text{Cl}_{0.73})_{\Sigma 2.00}$ .  $D_{\text{meas.}} = 3.20(3)$ ,  $D_{\text{calc.}} = 3.22(3)$  g/cm<sup>3</sup>. Compared to the eudialyte structure, the unique feature in oneillite is the ordering of Mn and Ca + REE at the M1 site, which lowers the symmetry from  $R\bar{3}m$  to  $R\bar{3}$ . Determination of the crystal structure was dependent on the recognition of a merohedral twin. The REE content is the highest hitherto reported, with REE occupying almost 50% of Na(4).

*Keywords:* oneillite, eudialyte, new mineral species, crystal structure, merohedral twin, Mont Saint-Hilaire, Quebec, Canada.

XENOTIME-(Yb),  $\text{YbPO}_4$ , A NEW MINERAL SPECIES FROM THE SHATFORD LAKE PEGMATITE GROUP, SOUTHEASTERN MANITOBA, CANADA

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ABSTRACT

Xenotime-(Yb), ideally  $\text{YbPO}_4$ , occurs as a primary phase in the saccharoidal albite unit of a granitic pegmatite located near the margin of the Lac du Bonnet batholith in the Shatford Lake pegmatite group, southeastern Manitoba, Canada. Xenotime-(Yb) occurs as granular aggregates  $\leq 50 \mu\text{m}$  across and as isolated small ( $\sim 20 \mu\text{m}$ ) grains encased in clots of ferrian muscovite, which are scattered throughout the saccharoidal albite unit. It is also associated with ferrocolumbite, albite, microcline and quartz. Xenotime-(Yb) is transparent, colorless to slightly yellowish or brownish with a white streak, vitreous luster and no observed fluorescence. Cleavage and parting were not observed, tenacity is brittle, and the fracture is uneven. Xenotime-(Yb) has no observable pleochroism and is uniaxial positive with  $\omega = 1.715(3)$ ,  $\varepsilon = 1.802(5)$ . It is tetragonal, space group  $I4_1/amd$ , with  $a$  6.866(2) Å,  $c$  6.004(3) Å,  $V$  283.0(2) Å<sup>3</sup> and  $Z = 4$ . The strongest lines of the (Gandolfi) X-ray-diffraction pattern [ $d$  in Å( $I$ )( $hkl$ )] are: 4.52(7)(011), 3.44(10)(020), 2.73(3)(121), 2.56(8)(112), 2.14(3)(031) and 1.76(5)(132). Electron-microprobe analysis of one of the grains characterized by X-ray diffraction gave an average composition of  $(\text{Yb}_{0.48}\text{Y}_{0.20}\text{Er}_{0.11}\text{Lu}_{0.09}\text{Dy}_{0.05}\text{Tm}_{0.04}\text{Ho}_{0.01}\text{Gd}_{0.004}\text{Tb}_{0.003})_{\Sigma 0.99} \text{P}_{1.00} \text{O}_4$ . The ratio Y/Yb (at.) varies between 0.39 and 0.68; this range is roughly comparable to the variation defined by xenotime-(Y) and xenotime-(Yb) in granitic pegmatites from

the Kola Peninsula, Russia.

*Keywords:* xenotime-(Yb), new mineral species, phosphate, granitic pegmatite, Shatford Lake, Manitoba, Canada.

## GROWTH TEXTURE AND SYMMETRY OF HEULANDITE-Ca FROM POONA, INDIA

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## ABSTRACT

Heulandite-Ca specimens from Poona, India consist mainly of  $\{\bar{1}11\}$ ,  $\{001\}$ ,  $\{100\}$  growth sectors. The growth sectors are optically triclinic, though the optical extinction angles relative to the b axis are larger in the  $\{\bar{1}11\}$  and  $\{001\}$  sectors than in the  $\{100\}$  sector. All cell dimensions, determined by single-crystal X-ray methods, indicate that the  $\{\bar{1}11\}$  and  $\{001\}$  sectors are triclinic and the  $\{100\}$  sector is monoclinic or nearly so. The triclinic structures are explained by the ordering of Al and Si on the crystal faces.

*Keywords:* heulandite-Ca, crystal growth, optical sectors, cell dimensions, chemical composition, Poona, India.

## THE DISCREDITATION OF PLATYNITE

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### ABSTRACT

Platynite, formerly considered as a valid mineral species from Falun, Dalecarlia, Sweden, is discredited as being a mixture of laitakarite and selenian galena. The discreditation has been approved by the IMA Commission on New Minerals and Mineral Names.

*Keywords:* platynite, discreditation, laitakarite, selenian galena, Falun, Sweden.