

THE ACCUMULATION OF RARE-EARTH AND HIGH-FIELD-STRENGTH ELEMENTS
IN PERALKALINE GRANITIC ROCKS: THE GALIÑEIRO ORTHOGNEISSIC COMPLEX,
NORTHWESTERN SPAIN

PILAR MONTERO¹

*Centro de Instrumentación Científica, Universidad de Granada, Campus Fuentenueva, E-18002
Granada, Spain*

PETER FLOOR¹

Leiden University Office, PO Box 9500, 2300 RA Leiden, Netherlands

GUILLERMO CORRETGE¹

Departamento de Geología, Universidad de Oviedo, E-33005 Oviedo, Spain

¹ *E-mail addresses:* pmontero@goliat.ugr.es, pfloor@bvdu.leidenuniv.nl,
corretge@asturias.geol.uniovi.es

ABSTRACT

The Galiñeiro complex, in the Iberian Hercynian belt, is composed of pre-Hercynian gneissic peralkaline granitic rocks that host hydrothermal mineralization of rare-earth and high-field-strength elements. The *REE* and *HFSE* are hosted by a large variety of accessory minerals such as bastnäsite, *REE* silicates (*e.g.*, allanite, thalenite – yttrialite), *REE* niobotantalates (aeschnite, fergusonite – formanite, samarskite, pyrochlore – betafite), *REE* phosphates (monazite, xenotime), Th-rich minerals (thorite, P-rich thorite), and zircon. The original magma was derived from a mantle source and most likely had a volatile-rich alkaline basalt composition that evolved by crystal fractionation to give peralkaline silicic differentiates that crystallized at high levels in the crust 460–480 Ma ago. Magmatic fractionation produced residual fluids extremely enriched in fluorine and other ligands, which complexed the rare earths and high-field-strength elements. The decrease in fluorine activity related to falling temperature and the crystallization of F-bearing major minerals produced the breakdown of complexes, releasing the rare earths and the rest of the high-field-strength elements, which then precipitated *HFSE*- and *REE*-rich minerals. The elevated fluorine, CO₂ and sulfide contents of the Galiñeiro system, together with the energy inputs related to different phases of the Hercynian metamorphism, caused episodic remobilization, reflected by the zircon U–Pb concordant ages at 370 and 310 Ma, and the exotic geochemical features (*Zr/Hf* > 100, elevated levels of Be, Th, and *HREE*) of some samples.

Keywords: Galiñeiro peralkaline complex, accessory minerals, *REE–HFSE* mineralization, metasomatism, fluorine, Spain.

SOMMAIRE

Le complexe de Galiñeiro, faisant partie de la chaîne hercynienne dans la péninsule ibérique, contient des roches gneissiques anté-hercyniennes dont la composition rappelle les granites hyperalcalins; ces roches ont été enrichies en terres rares et en éléments à potentiel ionique élevé par voie hydrothermale. Ces éléments traces ont comme hôtes une grande variété de minéraux accessoires, par exemple la bastnäsite, des silicates de terres rares, (*e.g.*, allanite, thalénite – yttrialite), des niobotantalates de terres rares (aeschynite, fergusonite – formanite, samarskite, pyrochlore – bétafite), des phosphates de terres rares (monazite, xenotime), des minéraux de Th (thorite, thorite riche en P), et zircon. Le magma originel est issu d'une source dans le manteau, et aurait eu une composition de basalte alcalin enrichi en phase volatile; sa composition a évolué par cristallisation fractionnée pour mener à des magmas siliceux hyperalcalins qui ont cristallisé à faible profondeur dans la croûte il y a environ 460–480 Ma. Le fractionnement magmatique a produit des fluides résiduels extrêmement enrichis en fluor et autres ligands, qui ont complexé les terres rares et les éléments à potentiel ionique élevé. Une diminution de l'activité du fluor liée à une diminution de la température et à la cristallisation de minéraux majeurs contenant du fluor a causé une déstabilisation des complexes hydrothermaux, et une libération des cations complexés, qui ont par la suite précipité sous forme de minéraux accessoires. Les teneurs élevées en fluor, CO₂ et sulfures des roches du cortège de Galiñeiro, ainsi que l'ajout d'énergie liée aux diverses phases de métamorphisme hercynien, ont causé une remobilisation épisodique, comme en témoignent les interceptes dans le système U–Pb du zircon, dont les âges concordants seraient de 370 et 310 Ma, et les caractéristiques géochimiques exotiques (Zr/Hf > 100, teneurs élevées de Be, Th, et terres rares lourdes) dans certains échantillons.

(Traduit par la Rédaction)

Mots-clés: complexe hyperalcalin de Galiñeiro, minéraux accessoires, terres rares, éléments à potentiel ionique élevé, enrichissement hydrothermal, métasomatose, fluor, Espagne.

Mn–Fe SPINELS AND SILICATES IN MANGANESE-RICH ROCKS FROM THE OSSA–MORENA ZONE, SOUTHERN IBERIAN MASSIF, SOUTHWESTERN SPAIN

JUAN JIMÉNEZ-MILLÁN¹

*Departamento de Geología, Facultad de Ciencias Experimentales, Universidad de Jaén,
Campus Universitario, E-23071 Jaén, Spain*

NICOLÁS VELILLA

Departamento de Mineralogía y Petrología, Facultad de Ciencias, Universidad de Granada, E-18002 Granada, Spain

¹ *E-mail address:* jmillan@ujaen.es

ABSTRACT

Manganese-rich rocks occur in a greenschist-facies volcano-sedimentary complex of the Ossa–Morena Zone, in the Iberian Massif, southwestern Spain. Four unusually Fe-rich manganese associations containing Mn–Fe spinels and silicates have been identified: I) magnetite + pyroxmangite + spessartine + quartz, II) manganian jacobsonite + pyroxmangite + aegirine + quartz, III) jacobsonite + pyroxmangite + tephroite + spessartine + rhodochrosite, and IV) manganoan magnetite + rhodonite + ferroan tephroite + spessartine + rhodochrosite. Major compositional variations of these minerals are complex functions of several factors. Oxygen fugacity determines the Fe content of pyroxenoids in such a way that it is very low in the pyroxmangite of associations bearing Mn³⁺ spinels (<0.4 % FeSiO₃) and reaches 30% FeSiO₃ in associations with Fe²⁺-dominant spinels. The presence of tephroite indicates $X(\text{CO}_2)$ values lower than 0.2, a condition that evolved toward higher values, as indicated poikiloblasts of rhodonite. The most important effect of the whole-rock composition is the crystallization of tephroite in rocks with a Mn:Si ratio higher than 1.7. Local Ca availability determines the crystallization of rhodonite or pyroxmangite. In rocks with a low Mn:Fe ratio, the formation of tephroite is favored only when the accompanying pyroxenoid is rhodonite. In addition, in the absence of tephroite, the pyroxmangite is Fe-enriched (30% FeSiO₃), but in the absence of pyroxmangite, the tephroite may contain approximately 20% Fe₂SiO₄. The iron content of the garnet is controlled by coexisting minerals that preferentially partition Fe.

Keywords: Mn–Fe spinels, Mn–Fe silicates, Mn-rich rocks, chemical composition, $f(\text{O}_2)$, $X(\text{CO}_2)$, Iberian Massif, Spain.

SOMMAIRE

Des roches riches en manganèse ont été recristallisées dans le faciès schistes verts dans le complexe volcano-sédimentaire de Ossa–Morena Zone, dans le massif Iberique, dans le sud-ouest de l'Espagne. Nous décrivons quatre assemblages manganifères anormalement enrichis en fer contenant un spinelle et des silicates à Mn–Fe: I) magnétite + pyroxmangite + spessartine +

quartz, II) jacobsite riche en Mn^{3+} + pyroxmangite + aegyrine + quartz, III) jacobsite + pyroxmangite + tephroïte + spessartine + rhodochrosite, et IV) magnétite manganifère + rhodonite + tephroïte ferreuse + spessartine + rhodochrosite. Les variations importantes dans la composition de ces minéraux semblent être des fonctions complexes de plusieurs variables. La fugacité de l'oxygène détermine la teneur en Fe des pyroxénoïdes de telle sorte qu'elle est très faible dans la pyroxmangite des associations contenant le spinelle riche en Mn^{3+} (<0.4 % $FeSiO_3$) et atteint 30% de $FeSiO_3$ dans les associations où le Fe^{2+} est dominant dans le spinelle. La présence de tephroïte indique des valeurs de $X(CO_2)$ inférieures à 0.2, condition qui a évolué vers des valeurs plus élevées, comme le témoigne le développement de poikiloblastes de rhodonite. L'influence la plus marquée de la composition globale des roches serait la cristallisation de la tephroïte dans les roches dont le rapport Mn:Si dépasse 1.7. La disponibilité locale du Ca détermine la cristallisation de la rhodonite ou de la pyroxmangite. Dans les roches à faible rapport Mn:Fe, la formation de la tephroïte est favorisée là où le pyroxénoïde qui l'accompagne est la rhodonite. De plus, en l'absence de tephroïte, la pyroxmangite est enrichie en fer (30% $FeSiO_3$), mais sans pyroxmangite, la tephroïte peut contenir environ 20% Fe_2SiO_4 . La teneur en fer du grenat dépend de l'assemblage des minéraux coexistants qui pourraient capter le fer.

(Traduit par la Rédaction)

Mots-clés: spinelle à Mn-Fe, silicates à Mn-Fe, roches manganifères, composition chimique, $f(O_2)$, $X(CO_2)$, massif Ibérique, Espagne.

NEW DATA ON METAMORPHIC CHLORITE AS A PETROGENETIC INDICATOR MINERAL, WITH SPECIAL REGARD TO GREENSCHIST-FACIES ROCKS

ANTONELLA ZANE¹ AND RAFFAELE SASSI

Dipartimento di Mineralogia e Petrologia dell'Università di Padova, C.so Garibaldi 37, I-35137 Padova, Italy

CHARLES V. GUIDOTTI

Department of Geological Sciences, University of Maine, Orono, Maine 04469, U.S.A.

¹ *E-mail address: anto@dmp.unipd.it*

ABSTRACT

For rock-forming minerals, the extent and the behavior of solid solution are understandable only if considered in the context of a rigorous petrological framework, as has been shown repeatedly in the metamorphic petrology literature. Herein, we present a study of the composition of trioctahedral chlorites, with special focus on non-limiting mineral assemblages in rocks of low metamorphic grade. The goal has been to discern and understand any systematic changes of chlorite composition due to changing T, P, and bulk-rock composition. The three main compositional variations shown by the metamorphic chlorite in this study include the ratio Fe/Mg, the extent of Tschermak substitution, and deviation from trioctahedral toward dioctahedral chlorite. Our database includes 2619 chlorite compositions, of which 450 are selected from literature covering the temperature range subgreenschist – amphibolite facies, and 2169 are newly determined compositions from greenschist-facies rocks. All samples used are classified according to metamorphic grade, pressure, and bulk-rock composition, thereby establishing groups and subgroups of analytical data. These data are plotted on diagrams aimed at enabling one to discern more specifically how bulk-rock composition, temperature and pressure affect the three main compositional variations of chlorite from typical metamorphic rocks. Each of these parameters controls chlorite composition to some extent, but the control by the bulk-rock chemistry is clearly dominant. Commonly, it largely obscures the systematic compositional changes caused by temperature and pressure. Thus, despite numerous attempts, it is evident that chlorite composition by itself is non-viable for geothermobarometric purposes in the case of the non-limiting assemblages typical of the greenschist facies. Attempts to use chlorite from such assemblages for geothermobarometry should be restricted solely to approaches involving cation exchange with some coexisting phase(s).

Keywords: chlorite, electron-microprobe data, low-grade metamorphism, compositional variation, geothermobarometry.

SOMMAIRE

On peut parvenir à comprendre l'étendue et le comportement des séries de solution solide

parmi les minéraux des roches seulement dans un contexte rigoureusement défini du point de vue pétrologique, comme cela a maintes fois été prouvé dans la littérature sur la pétrologie métamorphique. Nous présentons ici les résultats d'une étude sur la composition des chlorites trioctaédriques, portant en particulier sur les assemblages non limitatifs équilibrés à faible degré de métamorphisme. Le but de notre étude était de discerner et de comprendre les changements systématiques de la composition de la chlorite dus aux variables T, P, et la composition globale des roches. Les trois variables compositionnelles de la chlorite métamorphique sont le rapport Fe/Mg, l'étendue de la substitution dite de Tschermak, et l'écart de la stoechiométrie trioctaédrique vers les pôles dioctaédriques. Notre banque de données compte 2619 compositions de chlorite, dont 450 sont tirées de la littérature sur l'intervalle de température représentatif du faciès inférieur aux schistes verts jusqu'au faciès amphibolite, et 2169 ont été déterminées récemment dans le contexte de notre travail sur les roches du faciès schistes-verts. Tous les assemblages ont été classés selon intensité du métamorphisme, pression et composition globale des roches, ce qui a mené à des groupes et des sous-groupes de données analytiques. Ces données ont été reportées sur des diagrammes conçus pour faire ressortir clairement l'influence de la composition globale des roches, la température et la pression sur les trois variables compositionnelles de la chlorite typique des roches métamorphiques. Chacun de ces paramètres exerce un contrôle jusqu'à un certain point, mais l'influence de la composition globale d'une roche est prédominant. Dans plusieurs cas, c'est ce paramètre qui domine, et obscurcit, par ce fait même, l'influence systématique de la température et de la pression. Malgré plusieurs tentatives, il semble évident que la composition de la chlorite, par elle-même, est insuffisante pour applications géothermobarométriques dans le cas des assemblages non limitatifs typiques du faciès schistes-verts. On devrait limiter toute tentative d'extraire de la chlorite des notions géothermobarométriques aux seules considérations d'échanges de cations avec certaines des phases coexistantes.

(Traduit par la Rédaction)

Mots-clés: chlorite, données de microsonde électronique, métamorphisme de faible intensité, variation en composition, géothermobarométrie.

THE COMPOSITION OF CHRYSOTILE AND ITS RELATIONSHIP WITH LIZARDITE

DAVID S. O'HANLEY¹

Trinity School at River Ridge, 2300 E. 88th Street, Bloomington, Minnesota 55425, U.S.A.

M. DARBY DYAR*

Department of Geology and Astronomy, West Chester University, West Chester, Pennsylvania 19383, U.S.A.

¹ *E-mail address:* ohanleys@aol.com

* In residence at the Department of Geology, Amherst College, Amherst, Massachusetts 01002, U.S.A. through September, 1998. *E-mail address:* mddyar@amherst.edu

ABSTRACT

Mössbauer data were obtained from 14 specimens of chrysotile taken from three geologically well-characterized serpentinites. These data were used in conjunction with results of electron- microprobe (major elements) and uranium-extraction analyses (H₂O) to generate a comprehensive set of compositions for chrysotile. Chrysotile contains both Al and Fe³⁺ as secondary tetrahedrally coordinated cations, with Al dominating over Fe³⁺. The proportion of ⁴⁴Fe³⁺ and ⁵⁶Fe³⁺ shows an inverse correlation that preserves a relatively constant total Fe³⁺ content. Most specimens have low Fe³⁺/Fe²⁺. The incorporation of trivalent cations is greater in the sheet of octahedra than in the sheet of tetrahedra, suggesting the presence of H⁺ vacancies; this result is consistent with measured H₂O contents. The Mössbauer parameters for chrysotile are similar but more scattered than those for lizardite, suggesting minimal differences in coordination polyhedra between the two minerals. However, chrysotile and lizardite are not polymorphs in natural systems. Compared to the associated lizardite, chrysotile contains more Fe²⁺ and ⁴⁴Al and fewer ⁴⁴Fe³⁺ ions and H⁺ vacancies. These data support the hypothesis that high Fe²⁺ content and H⁺ vacancies contribute to the replacement of lizardite by chrysotile, and *vice versa*, during serpentine replacement.

Keywords: chrysotile, Mössbauer spectroscopy, electron-microprobe data, uranium-extraction analysis, lizardite, phase relations, serpentine replacement, serpentinization.

SOMMAIRE

Nous avons caractérisé par spectroscopie de Mössbauer quatorze échantillons de chrysotile prélevés de trois exemples de serpentinite dont le contexte géologique est bien établi. Ces données ont servi, avec les résultats d'analyses à la microsonde (éléments majeurs) et par extraction à l'uranium (H₂O), à établir une collection de compositions complètes pour le chrysotile. Cette espèce contient à la fois Al et Fe³⁺ comme ions secondaires dans le site à coordinence tétraédrique, avec Al en prédominance. Les proportions de ⁴⁴Fe³⁺ et de ⁵⁶Fe³⁺ montrent une corrélation inverse qui mène à une teneur relativement constante de la teneur

globale en Fe^{3+} . La plupart des échantillons ont un faible rapport $\text{Fe}^{3+}/\text{Fe}^{2+}$. L'incorporation des ions trivalents est plus importante dans le feuillet d'octaèdres que dans le feuillet de tétraèdres, ce qui indiquerait la présence de lacunes dans le site H^+ ; ce phénomène expliquerait bien les teneurs en H_2O mesurées. Les spectres de Mössbauer du chrysotile ressemblent à ceux de la lizardite, mais ils sont plus irréguliers, ce qui fait penser que les différences impliquant les polyèdres de coordinence entre ces deux minéraux sont assez subtiles. Il est toutefois évident que chrysotile et lizardite ne sont pas des polymorphes dans les systèmes naturels. Par rapport à la lizardite coexistante, le chrysotile contient davantage de Fe^{2+} et de ^{41}Al , et moins de $^{56}\text{Fe}^{3+}$ et de lacunes dans les sites H^+ . Ces données étayent l'hypothèse d'un remplacement de la lizardite par le chrysotile là où la teneur en Fe^{2+} et le taux de lacunes dans la position H^+ sont favorisés, et *vice versa*, dans les cas de remplacement de serpentines.

(Traduit par la Rédaction)

Mot-clés: chrysotile, spectroscopie de Mössbauer, données de microsonde électronique, analyses par extraction à l'uranium, lizardite, relations de phase, remplacement de serpentines, serpentinitisation.

FIBROUS CHLORITE AND MUSCOVITE FROM THE KAISERSBERG GRAPHITE MINE, STYRIA, AUSTRIA

JOHANN G. RAITH¹

Institute of Geological Sciences, University of Leoben, A-8700 Leoben, Austria

HOJATOLLAH VALI¹

Electron Microscopy Center, McGill University, 3640 University Street, Montreal, Quebec H3A 2B2

¹ *E-mail address:* raith@grz08u.unileoben.ac.at, vali_h@geosci.lan.mcgill.ca

ABSTRACT

Phyllosilicates with unusual elongate platy to fibrous morphology occur at the Kaisersberg graphite mine, Styria, Austria, in Upper Carboniferous graphite schists of the Eastern Greywacke Zone. A detailed mineralogical investigation revealed that these aggregates of fibrous minerals consist of Mg–Fe-bearing chlorite (polytype IIb) and alkali-deficient muscovite (predominantly of $2M_1$ polytype). They occur as intergrowths with graphite (graphite- d_{1A} type; "semi-graphite") and in thin synmetamorphic veins in graphitic schists. The chlorite ($0.52 < X_{Mg} < 0.68$) is associated with quartz, muscovite, graphite and accessory rutile, pyrite, chalcopyrite, and ullmannite. In chlorite-poor assemblages, chloritoid ($0.08 < X_{Mg} < 0.26$) and kyanite are important minerals. Formation of this low-grade metamorphic assemblage is related to Alpine regional metamorphism, which reached lower greenschist-facies conditions (*ca.* 360–410°C, minimum pressure *ca.* 2 kbar) at Kaisersberg. The semi-graphitic nature of carbonaceous material is confirmed by reflectance and XRD measurements.

Keywords: asbestos, chlorite, alkali-deficient muscovite, graphite, Kaisersberg, Styria, Austria.

SOMMAIRE

Nous décrivons des phyllosilicates ayant une morphologie allongée en plaquettes, voire même asbestiforme, dans la mine de graphite de Kaisersberg, en Styrie, Autriche, dans des schistes graphitiques d'âge carbonifère de la zone orientale des grauwackes. D'après une étude minéralogique détaillée, ces agrégats fibreux contiennent une chlorite Mg–Fe (polytype IIb) et une muscovite déficitaire en alcalins (le polytype $2M_1$ surtout). Ceux-ci sont en intercroissance avec le graphite, de type d_{1A} ou "semi-graphite", en veinules étroites dans les schistes graphitiques. La chlorite ($0.52 < X_{Mg} < 0.68$) est associée au quartz, à la muscovite, au graphite et aux accessoires rutile, pyrite, chalcopyrite, et ullmannite. Dans les assemblages à faible teneur en chlorite, chloritoïde ($0.08 < X_{Mg} < 0.26$) et kyanite sont plus importants. La formation de cet assemblage typique d'un métamorphisme de faible intensité serait liée à l'événement alpin, qui a atteint le faciès schistes-verts inférieur (environ 360–410°C, pression minimum environ 2 kbar) à Kaisersberg. Des mesures de réflectance et de diffraction X confirment la nature semi-graphitique

de la fraction carbonée.

(Traduit par la Rédaction)

Mots-clés: asbestos, chlorite, muscovite déficitaire en alcalins, graphite, Kaisersberg, Styrie, Autriche.

HYDROTHERMAL SYNTHESIS OF A Cs FERRUGINOUS TRIOCTAHEDRAL MICA

MILAN DRÁBEK¹

Czech Geological Survey, Geologická 6, 152 00 Praha 5, Czech Republic

MILAN RIEDER¹

Department of Geochemistry, Mineralogy and Mineral Resources, Charles University, Albertov 6, 128 43 Praha, Czech Republic

CECILIA VITI¹

Dipartimento di Scienze della Terra, Università di Siena, Via delle Cerchia, 3, I-53100 Siena, Italy

ZDENĚK WEISS¹

Central Analytical Laboratory, Technical University Ostrava, Tř. 17. listopadu, 708 33 Ostrava-Poruba, Czech Republic

JIŘÍ FRÝDA

Czech Geological Survey, Geologická 6, 152 00 Praha 5, Czech Republic

¹ *E-mail addresses:* drabek@cgu.cz, rieder@prfdec.natur.cuni.cz or rieder@mbox.cesnet.cz, viti@dst.unisi.it, zdenek.weiss@vsb.cz

ABSTRACT

Hydrothermal experiments aimed at the synthesis of trioctahedral ferruginous Cs micas were carried out at 100 MPa and a constant temperature in the range 500–710 °C or in a temperature gradient. Starting mixes consisted of SiO₂, Fe₂O₃, Al₂O₃, Cs₂CO₃; there was excess water in all runs, and in some runs also an excess of CsOH or Cs₂CO₃ in solution. Two micas were grown with good yields, the Cs analog of annite and the Cs analog of tetra-ferri-annite. The former is usually accompanied by variable quantities of pollucite (± magnetite) or fayalite. An almost Al-free “Cs-tetra-ferri-annite” was synthesized from an aluminous mix in thermal gradient runs, and a pure “Cs-tetra-ferri-annite” was synthesized from an Al-free oxide mix. Rietveld refinement of the structure of “Cs-annite” shows it to be similar to the structures of annite, tetra-ferri-annite, and “Cs-tetra-ferri-annite”, which has the largest unit-cell of any mica synthesized to date.

Keywords: Cs mica, synthesis, trioctahedral mica, Cs ferruginous mica.

SOMMAIRE

Nous avons effectué des expériences hydrothermales afin de synthétiser des compositions de mica trioctaédrique ferrugineux césiques à 100 MPa et une température fixe entre 500 et

710°C ou bien dans un gradient de température. Les mélanges de matériaux de départ contenaient SiO_2 , Fe_2O_3 , Al_2O_3 , et Cs_2CO_3 ; il y avait un excédent d'eau dans chaque cas, et dans certains cas, un excédent de CsOH ou Cs_2CO_3 en solution. Nous avons pu synthétiser en quantités satisfaisantes deux micas, soit l'analogue césique de l'annite et de la tétra-ferri-annite. Dans le premier cas, le mica est généralement accompagné de quantités variables de pollucite (\pm magnétite) ou fayalite. Nous avons synthétisé la "Cs-tétra-ferri-annite" presque sans aluminium à partir d'un mélange alumineux dans un gradient de température, et la "Cs-tétra-ferri-annite" pure à partir d'un mélange d'oxydes sans Al. Un affinement de la structure de "Cs-annite" par méthode de Rietveld montre qu'il s'agit d'une structure très semblable à celles de l'annite, la tétra-ferri-annite, et de la "Cs-tétra-ferri-annite", qui possède la maille élémentaire la plus grande pour un mica synthétique connu jusqu'à maintenant.

(Traduit par la Rédaction)

Mots-clés: mica césique, synthèse, mica trioctaédrique, mica césique ferrugineux.

THE STABILITY AND CRYSTAL CHEMISTRY OF SYNTHETIC LOVERINGITE IN THE SYSTEM Ca–Mn–Ti–O UNDER STRONGLY REDUCING CONDITIONS

RONALD C. PETERSON¹

Department of Geological Sciences, Queen's University, Kingston, Ontario K7L 3N6

IAN E. GREY, LACHLAN M.D. CRANSWICK AND CHRISTINA LI

CSIRO Division of Minerals, Clayton 3169, Australia

¹E-mail address: peterston@geol.queensu.ca

ABSTRACT

The stability of loveringite, $\text{Ca}(\text{Ca}, \text{Mn}, \text{Ti}^{3+}, \text{Ti}^{4+})_{21}\text{O}_{38}$, in the system $\text{CaO–MnO–Ti}_2\text{O}_3\text{–TiO}_2$ was studied as a function of oxygen fugacity at 1100°C. Loveringite was prepared as a pure or dominant phase at oxygen fugacities in the range 10^{-15} to 10^{-18} atm. At higher fugacities, the stable assemblage is rutile + pyrophanite + perovskite, whereas at lower fugacities, loveringite becomes unstable relative to mixtures of perovskite + pyrophanite + $\text{Mn}_x\text{Ti}_{3-x}\text{O}_5$. Results of electron-microprobe analyses and of wet-chemical analyses for Ti^{3+} show that the compositional variations in loveringite (in atoms per formula unit, *apfu*) are $1.1 < \text{Ca} < 1.7$, $1.8 < \text{Mn} < 3.2$, $2.4 < \text{Ti}^{3+} < 5.6$ and $13.2 < \text{Ti}^{4+} < 14.4$. The dominant mode of compositional variation occurs by the charge-coupled mechanism of substitution $\text{Mn}^{2+} + \text{Ti}^{4+} \rightleftharpoons 2\text{Ti}^{3+}$. Crystal-chemical variations in synthetic loveringite were studied using Rietveld refinement of powder X-ray data. The unit-cell parameters are strongly correlated with the Ca and Mn contents. Calcium in excess of 1 *apfu* is ordered at the largest octahedral site, *M1*. Samples with higher Mn contents have Mn ordered at the *M1* site and the tetrahedral site *T*. Strongly reduced samples, with low manganese contents, have Mn preferentially at the *T* site, and Ti^{3+} at *M1*.

Keywords: loveringite, crichtonite, powder diffraction, Rietveld refinement, ilmenite.

SOMMAIRE

Nous avons étudié la stabilité de la loveringite, $\text{Ca}(\text{Ca}, \text{Mn}, \text{Ti}^{3+}, \text{Ti}^{4+})_{21}\text{O}_{38}$, dans le système $\text{CaO–MnO–Ti}_2\text{O}_3\text{–TiO}_2$ en fonction de la fugacité de l'oxygène à 1100°C. On prépare la loveringite comme composé pur ou dominant à une fugacité de l'oxygène dans l'intervalle 10^{-15} à 10^{-18} atm. Aux fugacités supérieures, l'assemblage stable est rutile + pyrophanite + pérovskite, tandis qu'aux fugacités plus faibles, la loveringite est déstabilisée au profit de mélanges de pérovskite + pyrophanite + $\text{Mn}_x\text{Ti}_{3-x}\text{O}_5$. Les résultats d'analyses à la microsonde électronique et d'analyses chimiques par voie humide pour établir la teneur en Ti^{3+} montrent que les variations en composition de la loveringite (exprimées en atomes par unité formulaire) sont $1.1 < \text{Ca} < 1.7$, $1.8 < \text{Mn} < 3.2$, $2.4 < \text{Ti}^{3+} < 5.6$ et $13.2 < \text{Ti}^{4+} < 14.4$. Le mode dominant de variation en composition implique le mécanisme couplé $\text{Mn}^{2+} + \text{Ti}^{4+} \rightleftharpoons 2\text{Ti}^{3+}$. Nous nous sommes servis d'affinements de données de diffraction X par méthode de Rietveld pour étudier les variations cristallographiques

dans la loveringite synthétique. Les paramètres réticulaires montrent une forte corrélation avec la teneur en Ca et Mn. Le Ca dépassant un atome par unité formulaire se trouve dans le site octaédrique le plus spacieux, *M1*. Les échantillons contenant des teneurs plus élevées en Mn ont cet élément dans le site *M1* et dans le site tétraédrique *T*. Dans les échantillons fortement réduits, ayant de faibles teneurs en manganèse, le Mn se trouve de préférence dans le site *T*, et le Ti^{3+} , dans le site *M1*.

Mots-clés: loveringite, crichtonite, diffraction X sur poudre, affinement par méthode de Rietveld, ilménite.

THE OCCURRENCE OF TWO RARE POLYTYPES OF WURTZITE, 4H AND 8H, AT MONT SAINT-HILAIRE, QUEBEC

GEORGE Y. CHAO¹

*Ottawa–Carleton Geoscience Centre, Department of Earth Sciences, Carleton University,
Ottawa, Ontario K1S 5B6*

ROBERT A. GAULT²

Research Division, Canadian Museum of Nature, Ottawa, Ontario K1P 6P4

¹ Present address: 2031 Delmar Drive, Ottawa, Ontario K1H 5P6.

² E-mail address: rgault@mus-nature.ca

ABSTRACT

The rare 4H and 8H polytypes of wurtzite have been identified on the basis of single-crystal X-ray diffraction from sodalite xenoliths in the nepheline syenite in the Poudrette Quarry, Mont Saint-Hilaire, Quebec. They are hexagonal, space group $P6_3mc$, a 3.8277(3), c 12.521(8) Å for wurtzite-4H and a 3.8286(3), c 25.041(8) Å for wurtzite-8H. Wurtzite-4H may be distinguished from the other polytypes by the presence of the 2.596, 1.997, 1.382 and 1.2283 Å lines and by the strong intensity of the 3.203 Å line in the powder-diffraction pattern. Wurtzite-8H is distinguished by the presence of the moderately strong 3.082 Å line and the weak 2.766, 1.876, 1.666 and 1.341 Å lines and by the increased intensity of the 3.129 and 1.633 Å lines. The mineral occurs as pale green or reddish brown, irregular grains with an adamantine to slightly waxy luster and as well-formed, hexagonal, short prismatic to tabular crystals with pedial terminations. Electron-microprobe analyses show the 4H polytype to be almost pure ZnS, with a metal:sulfur ratio of 1, whereas the 8H polytype shows minor substitution of Fe and Mn for Zn, and is metal-deficient with respect to sulfur.

Keywords: wurtzite-4H, wurtzite-8H, polytypes, X-ray diffraction, Mont Saint-Hilaire, Quebec.

SOMMAIRE

Les polytypes 4H et 8H de la wurtzite, très rares, ont été identifiés par diffraction X sur cristal unique dans des xénolithes à sodalite provenant de syénite néphélinique dans la carrière Poudrette, au mont Saint-Hilaire, Québec. Ils sont hexagonaux, groupe spatial $P6_3mc$, a 3.8277(3), c 12.521(8) Å pour la wurtzite-4H, et a 3.8286(3), c 25.041(8) Å pour la wurtzite-8H. On distingue la wurtzite-4H des autres polytypes par la présence des raies à 2.596, 1.997, 1.382 et 1.2283 Å et par la forte intensité de la raie à 3.203 Å dans le spectre de diffraction sur poudre. On distingue la wurtzite-8H par la présence de la raie à 3.082 Å, d'intensité relativement intense, et les faibles raies à 2.766, 1.876, 1.666 et 1.341 Å, ainsi que par l'intensité accrue des raies à 3.129 et 1.633 Å. La wurtzite se présente en cristaux vert pâle à brun rougeâtre de forme irrégulière, ayant un éclat adamantin ou légèrement cireux, et en cristaux hexagonaux bien formés

en prismes trappus ou tabulaires, avec terminaisons pédiales. D'après les analyses à la microsonde électronique, la composition du polytype $4H$ est le pôle ZnS presque pur, avec un rapport métal à S égal à 1, tandis que le polytype $8H$ contient de faibles teneurs en Fe et Mn à la place du Zn, et montre un léger déficit en métaux par rapport au soufre.

(Traduit par la Rédaction)

Mots-clés: wurtzite- $4H$, wurtzite- $8H$, polytypes, diffraction X, mont Saint-Hilaire, Québec.

THE CRYSTAL CHEMISTRY OF AEGIRINE FROM MONT SAINT-HILAIRE, QUEBEC

PAULA C. PIILONEN¹ AND ANDREW M. McDONALD²*Department of Earth Sciences, Laurentian University, Ramsey Lake Road, Sudbury, Ontario P3E 2C6*ANDRÉ E. LALONDE²*Ottawa – Carleton Geoscience Centre, Department of Geology, University of Ottawa, 140 Louis Pasteur Street, Ottawa, Ontario K1N 6N5*

¹ Present address: Ottawa – Carleton Geoscience Centre, Department of Geology, University of Ottawa, 140 Louis Pasteur Street, Ottawa, Ontario K1N 6N5. *E-mail address:* lattice@sympatico.ca

² *E-mail addresses:* amcdonal@nickel.laurentian.ca, aelsc@uottawa.ca

ABSTRACT

Aegirine from five different microenvironments within the peralkaline East Hill Suite (EHS) at Mont Saint-Hilaire, Quebec, were studied by SEM–EDS, Mössbauer spectroscopy, wet-chemical and ICP–MS methods. Pyroxene compositions range from aegirine-augite (Ae₃₈Di₃₉Hd₂₃) to end-member aegirine (Ae₉₇Di_{1.5}Hd_{1.5}); all the crystals exhibit strong zoning, with a core enriched in Ca + Zr and a rim enriched in Na + Ti. More than 85% of the Fe is present as octahedrally coordinated Fe³⁺, suggesting conditions of extreme oxidation prior to aegirine crystallization. All samples of aegirine are enriched in the *REE* relative to chondrite and display a strong negative Eu anomaly. A concave pattern, with enrichments in both heavy and light *REE*, is found in all microenvironments except the one that led to fibrous aegirine. Such fibrous sprays show a steep, negative slope and are strongly enriched in the light *REE*. The aegirine is the product of fractionated batches of late-stage melt enriched in incompatible elements (*e.g.* Zr, Ti and *REE*) and Na. The extremely low Fe²⁺/Fe³⁺ values restrict pyroxene fractionation trends to the Di–Ae tie-line, unlike those noted elsewhere. The Ae and trace-element contents of the pyroxenes were used to develop an evolutionary scheme for the EHS. Fractional crystallization of a parental mafic magma, possibly accompanied by liquid immiscibility, resulted in the formation of nepheline and sodalite syenites. Further fractionation of the melt that gave sodalite syenite, enriched in volatiles and incompatible elements, led to crystallization of the aplites and pegmatite dikes, units which display identical aegirine, and to later igneous breccias. A secondary fluid-rich phase is considered responsible for very late-stage metasomatic overgrowths of fibrous aegirine in the pegmatite dikes.

Keywords: aegirine, peralkaline complex, clinopyroxene, chemical composition, Mössbauer spectroscopy, rare-earth elements, fractionation, Mont Saint-Hilaire, Quebec.

SOMMAIRE

Nous avons étudié l'aegyrine provenant de cinq microenvironnements dans la suite hyperalcaline de East Hill au mont Saint-Hilaire, Québec, par microscopie électronique à balayage avec dispersion d'énergie, spectroscopie de Mössbauer, analyse chimique par voie humide et par plasma à couplage inductif avec spectrométrie de masse. Les compositions de pyroxène vont d'augite aegyrinique ($\text{Ae}_{38}\text{Di}_{39}\text{Hd}_{23}$) au pôle aegyrine ($\text{Ae}_{97}\text{Di}_{1.5}\text{Hd}_{1.5}$); tous les cristaux font preuve de zonation marquée, à partir d'un noyau enrichi en Ca + Zr vers une bordure enrichie en Na + Ti. Plus de 85% du fer est à l'état ferrique et en coordinence octaédrique, ce qui témoignerait d'une forte oxydation du magma avant sa cristallisation. Tous les échantillons d'aegyrine sont enrichis en terres rares par rapport aux chondrites, et montrent une forte anomalie négative en Eu. Un spectre concave des terres rares, c'est-à-dire avec des teneurs relativement élevées en terres rares légères et lourdes, caractérise l'aegyrine dans tous les milieux sauf celui qui a produit l'aegyrine fibreuse. De tels amas fibroradiés font preuve d'un spectre à forte pente négative, et donc avec un fort enrichissement en terres rares légères. L'aegyrine a cristallisé à partir de venues tardives de magma évolué, enrichi en éléments incompatibles (*e.g.*, Zr, Ti et les terres rares) et Na. A cause des valeurs extrêmement faibles du rapport $\text{Fe}^{2+}/\text{Fe}^{3+}$, les tracés d'évolution du clinopyroxène sont parallèles au vecteur Di–Ae, ce qui diffère des tracés d'autres complexes alcalins. La composition du clinopyroxène permet le développement d'un schéma évolutif pour la suite de East Hill. Une cristallisation fractionnée d'un magma parental mafique, possiblement accompagnée d'une immiscibilité du magma, a mené à la formation de syénites à néphéline et à sodalite. Un fractionnement plus poussé du magma qui a produit la syénite à sodalite, enrichi en composants volatils et en éléments incompatibles, a mené à la cristallisation d'aprites et de pegmatites en filons et à des brèches ignées tardives. L'aegyrine et l'assemblage de minéraux primaires sont identiques dans les aprites et pegmatites. Nous attribuons à une phase fluide secondaire la formation tardive métasomatique des amas fibroradiés en surcroissance dans les filons de pegmatite.

(Traduit par la Rédaction)

Mots-clés: aegyrine, complexe hyperalcalin, clinopyroxène, composition chimique, spectroscopie de Mössbauer, terres rares, fractionnement, mont Saint-Hilaire, Québec.

GERENITE-(Y), $(\text{Ca,Na})_2(\text{Y,REE})_3\text{Si}_6\text{O}_{18}\cdot 2\text{H}_2\text{O}$, A NEW MINERAL SPECIES, AND AN ASSOCIATED Y-BEARING GADOLINITE-GROUP MINERAL, FROM THE STRANGE LAKE PERALKALINE COMPLEX, QUEBEC-LABRADOR

JOHN L. JAMBOR¹

Department of Earth Sciences, University of Waterloo, Waterloo, Ontario N2L 3G1

ANDREW C. ROBERTS

Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8

JOEL D. GRICE

Research Division, Canadian Museum of Nature, P.O. Box 3443, Station D, Ottawa, Ontario K1P 6P4

TYSON C. BIRKETT

SOQUEM, 2600, boulevard Laurier, Sainte-Foy, Quebec G1V 4M6

LEE A. GROAT

Department of Earth and Ocean Sciences, University of British Columbia, 6339 Stores Road, Vancouver, British Columbia V6T 1Z4

STEVE ZAJAC

206-1300 Islington Avenue, Toronto, Ontario M9A 5C4

¹ *E-mail address: jlj@wimsey.com*

ABSTRACT

Gerenite-(Y), ideally $(\text{Ca,Na})_2(\text{Y,REE})_3\text{Si}_6\text{O}_{18}\cdot 2\text{H}_2\text{O}$, is a new mineral from the Strange Lake peralkaline complex, Quebec-Labrador boundary. The mineral is white to creamy in color, translucent, brittle, and has a vitreous luster, white streak, hardness of 5, uneven fracture, and is nonfluorescent in ultraviolet light; $D_{\text{calc.}}$ is 3.46 g/cm^3 for the ideal formula and $Z = 1$. The mineral is biaxial negative, α 1.602(1), β 1.607(2), γ 1.611(1), $2V_{\text{meas.}}$ $73(3)^\circ$, $2V_{\text{calc.}}$ 83° , $X \wedge b = 7^\circ$. A single-crystal X-ray study indicates triclinic symmetry, space group $P1$ or $P1$, a 9.245(5), b 9.684(6), c 5.510(3) Å, α 97.44(6), β 100.40(6), γ 116.70(6) $^\circ$. The strongest six lines of the X-ray powder-diffraction pattern [d in Å(I)(hkl)] are: 8.44(80)(010), 8.01(50)(110,100), 4.51(50)(210,111), 3.76(70)(121,021), 2.973(100)(320,310,021) and 2.930(60)(131). Most Gerenite-(Y) occurs in magmatic aplite-pegmatite as anhedral masses, 1–2 cm across, that consist of eutectoid-like intergrowths of sheaves of Gerenite-(Y) and interstitial quartz. Also present within the aplite-pegmatite are kainosite-(Y) and a gadolinite-group mineral, the latter considered to be the principal source of Be in the deposit. Electron-microprobe compositions of the gadolinite-group mineral indicate that its formula is of the type $(X)_2\text{Si}_2\text{Be}_2(\text{O,OH})_{10}$, where X is

either predominantly Ca or Y. The results suggest that the mineral is a new member of the gadolinite group.

Keywords: gerenite-(Y), kainosite-(Y), gadolinite-group mineral, new mineral species, Ca–Y silicates, Strange Lake deposit, Quebec–Labrador boundary.

SOMMAIRE

Nous décrivons ici la gérénite-(Y), de formule idéale $(\text{Ca,Na})_2(\text{Y,REE})_3\text{Si}_6\text{O}_{18}\cdot 2\text{H}_2\text{O}$, nouvelle espèce minérale provenant du complexe peralcalin de Strange Lake, sur la frontière Québec–Labrador. Il s’agit d’un minéral blanc à crèmeux, translucide, cassant, à l’éclat vitreux, la rayure blanche, dureté de 5, et cassure inégale. La gérénite est non fluorescente en lumière ultraviolette. Sa densité calculée selon la formule idéale est 3.46 ($Z = 1$). Le minéral est biaxe négatif, α 1.602(1), β 1.607(2), γ 1.611(1), $2V_{\text{mes.}}$ 73(3)°, $2V_{\text{calc.}}$ 83°, $X \wedge b = 7^\circ$. Une étude par diffraction X sur cristal unique indique une symétrie triclinique, groupe spatial $P1$ ou $P\bar{1}$, a 9.245(5), b 9.684(6), c 5.510(3) Å, α 97.44(6), β 100.40(6), γ 116.70(6)°. Les six raies les plus intenses du spectre de diffraction X (méthode des poudres) [d en Å(I)(hkl)] sont: 8.44(80)(010), 8.01(50)(110,100), 4.51(50)(210,111), 3.76(70)(121,021), 2.973(100)(320,310,021) et 2.930(60)(131). Dans la plupart des cas, la gérénite-(Y) se présente dans l’aplite et la pegmatite litées en amas xénomorphes de 1 à 2 cm de diamètre. Ceux-ci constituent en fait une intercroissance eutectoïde d’essaims de gérénite-(Y) et de quartz interstitiel. Sont aussi présents dans l’aplite et la pegmatite litées kainosite-(Y) et un minéral du groupe de la gadolinite. Nous considérons ce dernier comme la source principale de Be dans ce gisement. Les données obtenues sur sa composition par microsonde électronique démontrent une formule de type $(X)_2\text{Si}_2\text{Be}_2(\text{O,OH})_{10}$, avec soit Ca, soit Y prédominant dans la position X . Cette phase serait un nouveau membre du groupe de la gadolinite.

(Traduit par la Rédaction)

Mots-clés: gérénite-(Y), kainosite-(Y), gadolinite-group, minéral du groupe de la gadolinite, nouvelle espèce minérale, silicates de Ca–Y, gisement de Strange Lake, frontière Québec–Labrador.

THE CRYSTAL STRUCTURE OF GERENITE-(Y), $(\text{Ca,Na})_2(\text{Y,REE})_3\text{Si}_6\text{O}_{18}\cdot 2\text{H}_2\text{O}$, A CYCLOSILICATE MINERAL

LEE A. GROAT¹

Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, British Columbia V6T 1Z4

¹ *E-mail address:* lgroat@eos.ubc.ca

ABSTRACT

The crystal structure of gerenite-(Y), ideally $(\text{Ca,Na})_2(\text{Y,REE})_3\text{Si}_6\text{O}_{18}\cdot 2\text{H}_2\text{O}$, a 9.257(4), b 9.684(4), c 5.520(1) Å, α 97.36(3), β , 100.52(3), γ 116.57(3)°, V 422.6(3) Å³, space group $P1$, $Z = 1$, has been solved by direct methods, and refined to an R index of 5.2% based on 2175 unique reflections measured with $\text{MoK}\alpha$ radiation. The structure consists of the following elements: (1) Si_6O_{18} rings, oriented approximately parallel to (101), (2) chains of edge-sharing $\text{Y}(1)\text{O}_6$ and $\text{Y}(2)\text{O}_6$ octahedra oriented approximately parallel to [101], and (3) $\text{Ca}\phi_8$ polyhedra. The Si_6O_{18} rings share corners with the chains of YO_6 octahedra to form a three-dimensional framework. The Ca positions are located outside of and between pairs of Si_6O_{18} rings. Bond-valence analysis shows that one of the apical anions coordinating the cation at the Ca position is a molecule of H_2O . The $\text{Ca}\phi_8$ polyhedra share corners and edges with adjacent Si_6O_{18} rings and YO_6 chains. The crystal structure of gerenite-(Y) has elements similar to those of kainosite-(Y) and leifite, both of which occur with gerenite-(Y) at the Strange Lake locality.

Keywords: gerenite-(Y), crystal structure, cyclosilicate, Strange Lake, Quebec – Labrador.

SOMMAIRE

La structure cristalline de la gerenite-(Y) (prononciation: *guèrenite*), de formule idéale $(\text{Ca,Na})_2(\text{Y,TR})_3\text{Si}_6\text{O}_{18}\cdot 2\text{H}_2\text{O}$ (TR : terres rares), a 9.257(4), b 9.684(4), c 5.520(1) Å, α 97.36(3), β , 100.52(3), γ 116.57(3)°, V 422.6(3) Å³, groupe spatial $P1$, $Z = 1$, a été établie par méthodes directes jusqu'à un index R de 5.2% en utilisant 2175 réflexions uniques mesurées avec rayonnement $\text{MoK}\alpha$. La structure contient les éléments structuraux suivants: (1) des anneaux Si_6O_{18} orientés plus ou moins parallèles à (101), (2) des chaînes d'octaèdres $\text{Y}(1)\text{O}_6$ et $\text{Y}(2)\text{O}_6$ à arêtes partagées, à peu près parallèles à [101], et (3) des polyèdres $\text{Ca}\phi_8$. Les anneaux Si_6O_{18} partagent leur coins avec les chaînes d'octaèdres YO_6 pour ainsi former une trame tri-dimensionnelle. Les positions occupées par le Ca sont externes par rapport aux anneaux de Si_6O_{18} ou entre ceux-ci. Une analyse des valences de liaison montre qu'un des anions apicaux en coordination avec le Ca est une molécule de H_2O . Les polyèdres $\text{Ca}\phi_8$ partagent des coins et des arêtes avec les anneaux Si_6O_{18} et les chaînes YO_6 adjacents. La structure de la gerenite-(Y) ressemble en certains points à celle de la kainosite-(Y) et de la leifite, que l'on retrouve avec la gerenite-(Y) au gisement de Strange Lake.

(Traduit par la Rédaction)

Mots-clés: gerenite-(Y), structure cristalline, cyclosilicate, Strange Lake, Québec – Labrador.

THE CRYSTAL STRUCTURE OF KUKHARENKOITE-(Ce), Ba₂REE(CO₃)₃F, AND AN INTERPRETATION BASED ON CATION-COORDINATED F TETRAHEDRA

SERGEY V. KRIVOVICHEV* AND STANISLAV K. FILATOV

Department of Crystallography, St. Petersburg University, University Emb. 7/9, St. Petersburg 199034, Russia

ANATOLY N. ZAITSEV

Department of Mineralogy, St. Petersburg University, University Emb. 7/9, St. Petersburg 199034, Russia

* To whom correspondence should be addressed. *E-mail address:* flt@cryst.geol.pu.ru

ABSTRACT

The crystal structure of kukharenkoite-(Ce), Ba₂REE(CO₃)₃F, from the Khibina carbonatite, Kola Peninsula, Russia, has been refined to $R = 0.044$ ($wR = 0.112$) from 2296 reflections. The mineral is monoclinic, space group $P2_1/m$, with a 13.374(3), b 5.1011(8), c 6.653(1) Å, β 106.56(1)°, V 435.1(1) Å³, $Z = 2$. The structure is similar to that determined by Mercier & Leblanc (1993) for synthetic Ba₂Ce(CO₃)₃F. The F⁻ anion is tetrahedrally coordinated by three Ba and one Ce cations. F-centered [FCeBa₃] tetrahedra are linked through shared edges to form double chains {**uB**, 2_∞¹} [FCeBa] along the b axis. C(3)O₃ carbonate groups are positioned on the faces of the [FCeBa₃] tetrahedra, resulting in complex [FCeBa](CO₃) chains. These chains are positioned in sheets parallel to (001) (layer **A**) and alternating along [001] with sheets formed by C(1)O₃ and C(2)O₃ groups and Ba atoms that do not bond with fluorine (layer **B**). The structures of other fluorocarbonates with fluorine-centered tetrahedra contain the following tetrahedral complexes: double chains {**uB**, 2_∞¹} [F₂M₅] in cebaite-(Ce), Ba₃Ce₂(CO₃)₅F₂, and Ba₃La₂(CO₃)₅F₂, layers {**uB**, 1_∞²} [F₂M₃] in huanghoite-(Ce), BaCe(CO₃)₂F, and BaSm(CO₃)₂F, layers {**uB**, 1_∞²} [FM] in kettnerite, CaBiOF(CO₃), frameworks {_∞³} [FM] in brenkite, Ca₂F₂(CO₃), and Pb₂F₂(CO₃), frameworks {_∞³} [FM] in BaCu(CO₃)F₂, and frameworks {_∞³} [FM₄] in horváthite-(Y), NaY(CO₃)F₂. Topologically similar structural units composed of [OM₄] tetrahedra have been described in oxysalts with “additional” oxygen atoms.

Keywords: kukharenkoite-(Ce), fluorocarbonate, Khibina, crystal structure, fluorine-centered tetrahedra.

SOMMAIRE

Nous avons affiné la structure cristalline de la kukharenkoite-(Ce), Ba₂TR(CO₃)₃F (TR: terres rares) provenant d'une carbonatite du complexe de Khibina, dans la péninsule de Kola, en Russie, jusqu'à un résidu R de 0.044 ($wR = 0.112$) en utilisant 2296 réflexions. Il s'agit d'un minéral monoclinique, groupe spatial $P2_1/m$, a 13.374(3), b 5.1011(8), c 6.653(1) Å, β 106.56(1)°, V 435.1(1) Å³, $Z = 2$. La structure ressemble à celle qu'ont déterminé Mercier et

Leblanc (1993) pour le composé synthétique $\text{Ba}_2\text{Ce}(\text{CO}_3)_3\text{F}$. L'anion F^- est en coordinence tétraédrique avec trois atomes de Ba et un de Ce. Des tétraèdres $[\text{FCeBa}_3]$ sont liés par arêtes partagées pour former des chaînes doubles $\{\mathbf{uB}, 2_{\infty}^1\}[\text{FCeBa}]$ le long de l'axe b . Des groupes $\text{C}(3)\text{O}_3$ sont disposés sur les faces de ces tétraèdres $[\text{FCeBa}_3]$ pour donner des chaînes complexes de stoechiométrie $[\text{FCeBa}](\text{CO}_3)$. Ces chaînes sont disposées en feuillets parallèles à (001) (couche **A**) et alternent le long de [001] avec des feuillets formés de groupes $\text{C}(1)\text{O}_3$ et $\text{C}(2)\text{O}_3$ et d'atomes de Ba non liés au fluor (couche **B**). Les structures d'autres fluorocarbonates contenant des tétraèdres centrés sur le fluor contiennent les complexes tétraédriques suivants: des chaînes doubles $\{\mathbf{uB}, 2_{\infty}^1\}[\text{F}_2\text{M}_5]$ dans la cébaïte-(Ce), $\text{Ba}_3\text{Ce}_2(\text{CO}_3)_5\text{F}_2$, et $\text{Ba}_3\text{La}_2(\text{CO}_3)_5\text{F}_2$, des couches $\{\mathbf{uB}, 1_{\infty}^2\}[\text{F}_2\text{M}_3]$ dans la huanghoïte-(Ce), $\text{BaCe}(\text{CO}_3)_2\text{F}$, and $\text{BaSm}(\text{CO}_3)_2\text{F}$, des couches $\{\mathbf{uB}, 1_{\infty}^2\}[\text{FM}]$ dans la kettnerite, $\text{CaBiOF}(\text{CO}_3)$, des trames $\{\infty^3\}[\text{FM}]$ dans la brenkite, $\text{Ca}_2\text{F}_2(\text{CO}_3)$, and $\text{Pb}_2\text{F}_2(\text{CO}_3)$, des trames $\{\infty^3\}[\text{FM}]$ dans le composé $\text{BaCu}(\text{CO}_3)\text{F}_2$, et des trames $\{\infty^3\}[\text{FM}_4]$ dans la horváthite-(Y), $\text{NaY}(\text{CO}_3)\text{F}_2$. Des modules structuraux topologiquement semblables composés de tétraèdres $[\text{OM}_4]$ ont été décrits dans les oxysels contenant des atomes d'oxygène "additionnels".

Mots-clés: kukharenkoïte-(Ce), fluorocarbonate, Khibina, structure cristalline, tétraèdres centrés sur le fluor.

REFINEMENT OF THE CRYSTAL STRUCTURE OF TADZHIKITE

FRANK C. HAWTHORNE¹ AND MARK A. COOPER*Department of Geological Sciences, University of Manitoba, Winnipeg, Manitoba R3T 2N2*

MATTHEW C. TAYLOR

*Department of Earth Sciences, University of California, Riverside, California 92521, U.S.A.*¹ *E-mail address: frank_hawthorne@umanitoba.ca*

ABSTRACT

The crystal structure of tadhikite, monoclinic, a 19.058(4), b 4.729(1), c 10.321(2) Å, β 111.39(1)°, V 866.1(3) Å³, $Z = 2$, space group $P2/a$, has been refined to an R index of 4.9% for 1702 observed reflections measured with MoK α X-radiation. The crystal used to collect the X-ray-diffraction data was subsequently analyzed with an electron microprobe. Tadhikite is isostructural with hellandite, but shows strong positional disorder of the *REE* cations that is presumably related to partial metamictization. Bond-valence analysis shows that the structure contains essential H as OH, and site populations were assigned on the basis of the refined site-scattering values and the results of electron-microprobe analysis. The general formula of tadhikite can be written as $\text{Ca}_2(\text{Ca}, \text{Y})_2(\text{Ti}^{4+}, \text{Fe}^{3+})(\text{R}^{3+}, \text{Q})_2[\text{B}_4\text{Si}_4\text{O}_{16}(\text{O}, \text{OH})_6](\text{OH})_2$.

Keywords: tadhikite, crystal-structure refinement, electron-microprobe analysis, hellandite, metamictization.

SOMMAIRE

Nous avons affiné la structure cristalline de la tadhikite [monoclinique, a 19.058(4), b 4.729(1), c 10.321(2) Å, β 111.39(1)°, V 866.1(3) Å³, $Z = 2$, groupe spatial $P2/a$] jusqu'à un résidu R de 4.9% en utilisant 1702 réflexions observées mesurées avec rayonnement MoK α . Le cristal qui a servi a ensuite été analysé avec une microsonde électronique. La tadhikite est isostructurale avec la hellandite, mais elle fait preuve d'un désordre de position important impliquant les atomes de terres rares, que nous attribuons à une métamictisation partielle. Une analyse des valences de liaison montre que le minéral possède des atomes de H sous forme de groupes OH. Les atomes ont été répartis selon la dispersion affinée des rayons X associée aux divers sites et les résultats des analyses chimiques. On peut exprimer ainsi la formule générale de la tadhikite: $\text{Ca}_2(\text{Ca}, \text{Y})_2(\text{Ti}^{4+}, \text{Fe}^{3+})(\text{R}^{3+}, \text{Q})_2[\text{B}_4\text{Si}_4\text{O}_{16}(\text{O}, \text{OH})_6](\text{OH})_2$.

(Traduit par la Rédaction)

Mots-clés: tadhikite, affinement de la structure cristalline, données de microsonde électronique, hellandite, métamictisation.

THE CRYSTAL STRUCTURE OF DUGGANITE, $\text{Pb}_3\text{Zn}_3\text{Te}^{6+}\text{As}_2\text{O}_{14}$

ANITA E. LAM AND LEE A. GROAT¹

Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, British Columbia V6T 1Z4

T. SCOTT ERCIT

Research Division, Canadian Museum of Nature, Ottawa, Ontario K1P 6P4

¹ *E-mail address: lgroat@eos.ubc.ca*

ABSTRACT

The crystal structure of dugganite, ideally $\text{Pb}_3\text{Zn}_3\text{Te}^{6+}\text{As}_2\text{O}_{14}$, a 8.460(2), c 5.206(2) Å, V 322.6(2) Å³, space group $P321$, $Z = 1$, has been solved by direct methods and Patterson techniques, and refined to an R index of 2.7% based on 636 unique reflections measured using $\text{MoK}\alpha$ radiation on an automated four-circle diffractometer. The structure consists of heteropolyhedral sheets of edge-sharing TeO_6 octahedra and PbO_8 snub disphenoids, oriented parallel to (001). The sheets are cross-linked by AsO_4 and ZnO_4 tetrahedra, which share corners to form an interlinked, two- and three-connected two-dimensional net parallel to (001). Cheremnykhite and kuskite are considered to be isostructural with dugganite, but with V and P respectively dominant at the As site.

Keywords: dugganite, crystal structure, tellurate, arsenate, lead.

SOMMAIRE

Nous avons affiné la structure cristalline de la dugganite, de formule idéale $\text{Pb}_3\text{Zn}_3\text{Te}^{6+}\text{As}_2\text{O}_{14}$, a 8.460(2), c 5.206(2) Å, V 322.6(2) Å³, groupe spatial $P321$, $Z = 1$, par méthodes directes et par techniques de Patterson, jusqu'à un résidu R de 2.7%; cet affinement a utilisé 636 réflexions uniques mesurées avec rayonnement $\text{MoK}\alpha$ et un diffractomètre automatisé à quatre cercles. La structure contient des feuillettes de hétéropolyèdres, plus précisément des octaèdres TeO_6 à arêtes partagées et des disphénoïdes aplatis PbO_8 , orientés parallèles à (001). Ces feuillettes sont interliés par des tétraèdres AsO_4 et ZnO_4 partageant des coins, pour former un réseau à deux et trois noeuds en deux dimensions parallèle à (001). Nous considérons la cheremnykhite et la kuskite des minéraux isostructuraux, avec V et P, respectivement, comme occupants du site As.

(Traduit par la Rédaction)

Keywords: dugganite, structure cristalline, tellurate, arsenate, plomb.

STRUCTURAL RELATIONS AMONG SCHOEPITE, METASCHOEPITE AND “DEHYDRATED SCHOEPITE”

ROBERT J. FINCH¹ AND FRANK C. HAWTHORNE

Department of Geological Sciences, University of Manitoba, Winnipeg, Manitoba R3T 2N2

RODNEY C. EWING

Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, Michigan 48109, U.S.A.

¹ *E-mail address: finch@cmt.anl.gov*

ABSTRACT

Schoepite, $[(\text{UO}_2)_8\text{O}_2(\text{OH})_{12}](\text{H}_2\text{O})_{12}$, transforms slowly in air at ambient temperature to metaschoepite, $\text{UO}_3 \cdot n\text{H}_2\text{O}$ ($n \approx 2$), and crystals commonly contain an intergrowth of both minerals. The transformation may be due to the loss of one-sixth of the interlayer H_2O groups in schoepite, and a possible structural formula for metaschoepite is $[(\text{UO}_2)_8\text{O}_2(\text{OH})_{12}](\text{H}_2\text{O})_{10}$. The transformation of schoepite (a 14.337, b 16.813, c 14.731 Å, $P2_1ca$) to metaschoepite (a 13.99, b 16.72, c 14.73 Å, $Pbna$) is characterized by a 2% decrease in the a cell dimension, a slight decrease in the b dimension, and little or no change in the c dimension. Unit-cell changes probably reflect the reorganization of H-bonds. Differences in unit-cell volumes induce strain in crystals in which the transformation to metaschoepite is incomplete, and stored strain energy may be sufficient to rapidly drive the transformation of the remaining schoepite to “dehydrated schoepite” [a 6.86, b 4.26, c 10.20 Å, $Abcm$ (?)] when partly altered crystals are exposed to an external stress (*e.g.*, heat, sunlight or mechanical pressure). Metaschoepite is apparently stable and does not alter further; canary yellow altered crystals commonly consist of a polycrystalline mixture of “dehydrated schoepite” and metaschoepite. The alteration of schoepite to “dehydrated schoepite” occurs in three steps: (1) loss of all interlayer H_2O from schoepite, causing collapse of the layers, (2) atomic rearrangement within the structural sheets to a configuration that may be similar to that of metaschoepite, and (3) further re-arrangement to a defect $\alpha\text{-UO}_2(\text{OH})_2$ -type sheet. The complete reaction is $[(\text{UO}_2)_8\text{O}_2(\text{OH})_{12}](\text{H}_2\text{O})_{12} \Rightarrow 8 [(\text{UO}_2)\text{O}_{0.25}(\text{OH})_{1.5}] + 12\text{H}_2\text{O}$. We propose that “dehydrated schoepite” forms an omission solid-solution over the compositional range $\text{UO}_3 \cdot 0.75\text{H}_2\text{O}$ to $\text{UO}_3 \cdot \text{H}_2\text{O}$, represented by the general formula $(\text{UO}_2)\text{O}_{0.25-x}(\text{OH})_{1.5+2x}$ ($0 \leq x \leq 0.25$).

Keywords: schoepite, metaschoepite, uranyl oxide hydrate, uranium minerals, dehydration, phase transformation.

SOMMAIRE

La schoepite, $[(\text{UO}_2)_8\text{O}_2(\text{OH})_{12}](\text{H}_2\text{O})_{12}$, se transforme lentement en métaschoepite, $\text{UO}_3 \cdot n\text{H}_2\text{O}$ ($n \approx 2$), dans l'air à température ambiante; les cristaux contiennent en général un

mélange des deux minéraux. La transformation pourrait bien être due à la perte d'un sixième des molécules de H₂O présents dans la schoepite. Il est donc possible que la formule structurale de la métaschoepite soit [(UO₂)₈O₂(OH)₁₂](H₂O)₁₀. La transformation de la schoepite (*a* 14.337, *b* 16.813, *c* 14.731 Å, *P2₁ca*) en métaschoepite (*a* 13.99, *b* 16.72, *c* 14.73 Å, *Pbna*) est accompagnée d'une diminution de 2% du paramètre réticulaire *a*, une légère diminution de la dimension *b*, et très peu (ou pas) de changement dans le paramètre *c*. Ces changements témoignent probablement de la réorganisation des liaisons H. Les différences des volumes de la maille qui en résultent mènent à la formation de contraintes dans les cristaux dans lesquels la transformation en métaschoepite est amorcée mais incomplète. L'énergie accumulée pourrait suffire pour causer une transformation rapide de la schoepite résiduelle en "schoepite déshydratée" [*a* 6.86, *b* 4.26, *c* 10.20 Å, *Abcm* (?)] quand les cristaux partiellement altérés reçoivent une contrainte externe, due par exemple à la chaleur, les rayons du soleil, ou bien une pression mécanique. Dans cette situation, la métaschoepite semble stable, et demeure inchangée. Les cristaux altérés jaune serin contiennent en général un mélange polycristallin de "schoepite déshydratée" et de métaschoepite. L'altération de la schoepite en "schoepite déshydratée" s'effectuerait donc en trois étapes: (1) perte des molécules de H₂O de la position interfeuille de la schoepite, causant un affaissement de ces feuillets, (2) une réorganisation des atomes à l'intérieur des feuillets pour atteindre un agencement semblable à celui de la métaschoepite, et (3) réorganisation plus avancée, menant à un feuillet de type α-UO₂(OH)₂ avec lacunes. La réaction complète serait donc [(UO₂)₈O₂(OH)₁₂](H₂O)₁₂ ⇒ 8 [(UO₂)O_{0.25}(OH)_{1.5}] + 12H₂O. Nous considérons la "schoepite déshydratée" exemple de solution solide par omission dans l'intervalle de composition UO₃•0.75H₂O à UO₃•H₂O, que représente la formule générale (UO₂)O_{0.25-x}(OH)_{1.5+2x} (0 ≤ *x* ≤ 0.25).

(Traduit par la Rédaction)

Mots-clés: schoepite, métaschoepite, oxyde à uranyle hydraté, minéraux d'uranium, déshydratation, transformation de phases.

CCD AREA DETECTORS OF X-RAYS APPLIED TO THE ANALYSIS OF MINERAL STRUCTURES

PETER C. BURNS¹

Department of Civil Engineering and Geological Sciences, University of Notre Dame, Notre Dame, Indiana 46556-0767, U.S.A.

¹ *E-mail address:* Peter.Burns.50@nd.edu

ABSTRACT

The recently available CCD (charge-coupled device) area detector for X-rays provides many advantages over a scintillation detector mounted on a serial diffractometer, including 1) improved sensitivity to weak reflections, which permits the study of very small crystals with a sealed-tube laboratory X-ray source, 2) improved resolution, permitting the study of long-axis problems, and 3) reduced data-collection times. The applicability of the CCD detector to the analysis of mineral structures is demonstrated with several examples. The CCD detector provides structure refinements that are comparable to those obtained using a serial diffractometer in a fraction of the time. More significantly, the sensitivity and resolution of the CCD detector permit the successful elucidation of mineral structures that were previously unattainable. As such, the CCD detector will likely revolutionize the acquisition of diffraction data for the analysis of mineral structures.

Keywords: CCD detector, X-ray diffraction, structure analysis, minerals.

SOMMAIRE

Le développement récent d'une nouvelle génération de détecteur de rayons X muni d'une aire couplée à charge (détecteur dit CCD) possède plusieurs avantages par rapport à un détecteur de scintillation installé sur un diffractomètre en série. Parmi ces avantages, on note 1) une sensibilité accrue aux réflexions de faible intensité, ce qui permet l'étude de très petits cristaux avec une source de rayons X à anode scellé courante, 2) une résolution améliorée, ce qui permet l'étude de cristaux dont la période est longue, et 3) un temps de prélèvement des données beaucoup plus court. L'application d'un détecteur CCD à l'analyse de structures minérales est ici illustré par quelques exemples. Le détecteur CCD permet des affinements de structures cristallines tout-à-fait comparables à ceux que l'on peut obtenir avec un diffractomètre en série, ceci dans une fraction du temps de prélèvement des données. Plus important encore, la sensibilité et la résolution du détecteur CCD permettent la solution de structures qui devaient rester sans solution auparavant. Il est clair que l'avènement de détecteurs CCD révolutionnera l'acquisition de données de diffraction nécessaires à la solution de structures de minéraux.

(Traduit par la Rédaction)

Mots-clés: détecteur CCD, diffraction X, analyse de structure, minéraux.

OENITE, CoSbAs, A NEW MINERAL SPECIES FROM THE TUNABERG Cu–Co-SULFIDE SKARNS, BERGSLAGEN, SWEDEN

RENÉ T.M. DOBBE¹

De Beers GeoScience Centre, P.O. Box 82232, Southdale, Johannesburg 2135, Republic of South Africa

MAREK A. ZAKRZEWSKI

Faculty of Earth Sciences, Vrije Universiteit, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands

¹ *E-mail address:* rdobbe@debeers.co.za

ABSTRACT

Oenite, ideally CoSbAs, is a new mineral species from the Tunaberg Cu–Co-sulfide skarns, southeastern Bergslagen, Sweden. It occurs as up to 300 µm silver-white anhedral aggregates in chalcopyrite as replacements of cobaltite and löllingite. Oenite is further associated with allargentum, bismuth, bornite, breithauptite, gudmundite, nisbite and tetrahedrite. Oenite is opaque with a metallic luster, grey streak and uneven fracture. The calculated density D_{calc} for oenite is 7.91 g cm⁻³ ($Z = 4$); $\text{VHN}_{100} = 599$. In reflected plane-polarized light, the mineral is silver-white; a weak bireflectance and pleochroism from white to slightly darker creamish white are only visible in oil on grain boundaries. Anisotropism, in reddish brown and purplish colors, is distinct in air and in oil. Reflectance values (nm, $R_2\%/R_1\%$): 470, 58.2/55.5; 546, 56.8/55.6; 589, 55.8/55.5; 650, 55.0/55.5. On the basis of results of eighty electron-microprobe analyses on six samples, oenite shows continuous solid-solution in the system CoSbAs–FeSbAs–NiSbAs between CoSbAs and (Fe,Ni)SbAs, an unnamed (Fe,Ni)-rich member with Fe > Co. The relatively constant chemical composition of oenite in a chalcopyrite-rich specimen was chosen as representative; the mean values for 21 analyses are (in wt.%): Co 15.4(1.3), Fe 5.6(1.5), Ni 2.7(0.9), Cu 0.1(0.1), Sb 47.4(1.0), As 26.9(2.1), S 2.0(1.2), sum 100.1(0.7). The average chemical formula is $(\text{Co}_{0.65}\text{Fe}_{0.24}\text{Ni}_{0.11})_{\Sigma 1.00}(\text{Sb}_{0.96}\text{As}_{0.04})_{\Sigma 1.00}(\text{As}_{0.85}\text{S}_{0.15})_{\Sigma 1.00}$ or, ideally, CoSbAs. The most Co-rich composition of oenite corresponds to $(\text{Co}_{0.86}\text{Fe}_{0.04}\text{Ni}_{0.10})_{\Sigma 1.00}\text{Sb}_{1.00}(\text{As}_{0.89}\text{S}_{0.07})_{\Sigma 1.00}$. The unit cell is orthorhombic, space group unknown, a 3.304(6), b 6.092(8), c 10.258(13) Å, $V = 206.5(8)$ Å³. The strongest seven X-ray powder reflections [d in Å(I)(hkl)] are 2.63(10)(022), 2.53(8)(112), 1.942(10)(015), 1.730(4)(130), 1.640(4)(016 or 132), 1.396(4)(222), and 1.118(8)(240 or 137 or 152). This XRD pattern is almost identical with that of synthetic CoSbAs (in prep.). The name honors Professor Ing Soen Oen, Amsterdam, for his important contributions to ore geology and ore mineralogy.

Keywords: oenite, new mineral species, unnamed (Fe,Ni)SbAs, microprobe analyses, system CoSbAs–NiSbAs–FeSbAs, Tunaberg Cu–Co-sulfide skarns, Bergslagen, Sweden.

SOMMAIRE

L'oenite, nouvelle espèce minérale dont la composition idéale est CoSbAs, a été découverte dans les skarns minéralisés en sulfures de Cu et de Co de Tunaberg, dans le sud-est du Bergslagen, en Suède. On la trouve en agrégats de couleur blanc argenté 300 µm de diamètre dans la chalcopirite, en remplacement de la cobaltite et de la löllingite. L'oenite est aussi associée aux phases allargentum, bismuth, bornite, breithauptite, gudmundite, nisbite et tétraédrite. C'est un minéral opaque ayant un éclat métallique, une rayure grise et une cassure inégale. La densité calculée D_{calc} est 7.91 ($Z = 4$); $\text{VHN}_{100} = 599$. En lumière réfléchie, nicols non croisés, l'oenite est blanc argenté, avec une faible biréflexion et un pléochroïsme allant du blanc au blanc légèrement crémeux, visible seulement dans l'huile en bordure des grains. L'anisotropie, en couleurs brun rougeâtre à violacée, est distincte dans l'air comme dans l'huile. Les valeurs de réflectance (nm, $R_2\%/R_1\%$) sont 470, 58.2/55.5; 546, 56.8/55.6; 589, 55.8/55.5; 650, 55.0/55.5. D'après les résultats de quatre-vingt analyses à la microsonde électronique, prélevées sur six échantillons, l'oenite fait preuve d'une solution solide continue dans le système CoSbAs–FeSbAs–NiSbAs, entre CoSbAs et (Fe,Ni)SbAs, membre sans nom dans lequel la proportion du Fe dépasse celle du Co. La composition relativement constante de l'oenite dans un échantillon riche en chalcopirite a été choisie représentative de l'espèce. Les résultats moyens de 21 analyses (en %, poids) sont: Co 15.4(1.3), Fe 5.6(1.5), Ni 2.7(0.9), Cu 0.1(0.1), Sb 47.4(1.0), As 26.9(2.1), S 2.0(1.2), total 100.1(0.7). La formule chimique représentative est

$(\text{Co}_{0.65}\text{Fe}_{0.24}\text{Ni}_{0.11})_{\Sigma 1.00}(\text{Sb}_{0.96}\text{As}_{0.04})_{\Sigma 1.00}(\text{As}_{0.85}\text{S}_{0.15})_{\Sigma 1.00}$ ou, idéalement, CoSbAs. La composition la plus riche en Co correspond à $(\text{Co}_{0.86}\text{Fe}_{0.04}\text{Ni}_{0.10})_{\Sigma 1.00}\text{Sb}_{1.00}(\text{As}_{0.89}\text{S}_{0.07})_{\Sigma 1.00}$. La maille élémentaire est orthorhombique, mais le groupe spatial est méconnu; a 3.304(6), b 6.092(8), c 10.258(13) Å, $V = 206.5(8)$ Å³. Les sept raies les plus intenses du spectre de diffraction [d en Å(I)(hkl)] sont 2.63(10)(022), 2.53(8)(112), 1.942(10)(015), 1.730(4)(130), 1.640(4)(016 ou 132), 1.396(4)(222), et 1.118(8)(240 ou 137 ou 152). Ce spectre est presque identique à celui de l'équivalent synthétique CoSbAs. Le nom honore Ing Soen Oen, professeur à Amsterdam, pour ses contributions importantes à la géologie des gîtes minéraux et à la minéralogie des minerais.

(Traduit par la Rédaction)

Mots-clés: oenite, new mineral species, unnamed (Fe,Ni)SbAs, microprobe analyses, system CoSbAs–NiSbAs–FeSbAs, Tunaberg Cu–Co-sulfide skarns, Bergslagen, Sweden.

FRIEDRICHITE FROM BĂIȚA BIHOR, ROMANIA

MASAAKI SHIMIZU¹*Department of Earth Sciences, Faculty of Science, Toyama University, Gofuku 3190, Toyama 930-0887, Japan*

AKIRA KATO

Department of Geology, National Science Museum, 3-23-1 Hyakunin-cho, Shinjuku, Tokyo 169-0073, Japan

GRATIAN CIOFLICA AND MARIAN LUPULESCU

Department of Mineralogy, Faculty of Geology & Geophysics, University of Bucharest, N. Balcescu Bd. 1, Bucharest 70111, Romania

MARINA SHIMIZU

*Department of Earth Sciences, Faculty of Science, Toyama University, Gofuku 3190, Toyama 930-0887, Japan*¹ *E-mail address:*

ABSTRACT

Friedrichite is reported from three western Romanian localities: the Antoniu magnesian skarn deposit, the “Blidar Contact” and “Secundar Contact” calcic skarn deposits, in Băița Bihor, in the northern Apuseni Mountains, Romania. Friedrichite occurs as isolated, short-prismatic grains up to $500 \times 100 \mu\text{m}$ in size, usually included in cuprobismutite or cupropavonite, and as aggregates with Ag- and Bi-bearing galena. In plane-polarized light in air, fiedrichite is creamy yellowish white with a brownish tint. Bireflectance and pleochroism are weak, and anisotropism is strong. No internal reflections were noted. The average chemical compositions of fiedrichite from the three skarn deposits (basis of calculation: S + Se = 18) are, respectively:

$(\text{Cu}_{5.40}\text{Ag}_{0.01})_{\Sigma 5.41}(\text{Pb}_{5.03}\text{Fe}_{0.01})_{\Sigma 5.04}(\text{Bi}_{6.82}\text{Sb}_{0.02})_{\Sigma 6.84}\text{S}_{18}$ (Antoniu),
 $(\text{Cu}_{4.99}\text{Ag}_{0.01})_{\Sigma 5.00}(\text{Pb}_{4.62}\text{Fe}_{0.01})_{\Sigma 4.63}(\text{Bi}_{7.22}\text{Sb}_{0.03})_{\Sigma 7.25}(\text{S}_{17.96}\text{Se}_{0.04})_{\Sigma 18}$ (“Blidar Contact”) and
 $(\text{Cu}_{5.26}\text{Ag}_{0.01})_{\Sigma 5.27}(\text{Pb}_{4.91}\text{Fe}_{0.02})_{\Sigma 4.93}(\text{Bi}_{6.95}\text{Sb}_{0.01})_{\Sigma 6.96}\text{S}_{18}$ (“Secundar Contact”). All of them deviate slightly from the ideal formula, $\text{Cu}_5\text{Pb}_5\text{Bi}_7\text{S}_{18}$. X-ray powder pattern and reflectance spectra for the Antoniu fiedrichite are given. The calculated unit-cell parameters are: a $3 \times 11.299(5)$, b $11.640(5)$, c $4.034(2)$ Å. Electron-microprobe-derived compositions of sulfosalts in the system $\text{Cu}_2\text{S} - \text{PbS} - \text{Bi}_2\text{S}_3$ system from the above deposits are concentrated on the join Bi_2S_3 (bismuthinite) – CuPbBiS_3 (aikinite), with a deviation to the Cu-excess side, as pointed out by Cook (1997) on northern Romanian materials.

Keywords: fiedrichite, X-ray diffraction, chemical data, optical data, Antoniu deposit, magnesian

skarn, “Blidar Contact” deposit, “Secundar Contact” deposit, calcic skarn, Băița Bihor, Romania.

SOMMAIRE

Nous décrivons ici la friedrichite de trois endroits en Roumanie occidentale: les cornéennes magnésiennes d’Antoniou, et les cornéennes calciques de “Blidar Contact” et “Secundar Contact”, dans le Băița Bihor, dans le nord des montagnes Apuseni. La friedrichite se présente en amas isolés de grains prismatiques trappus jusqu’à $500 \times 100 \mu\text{m}$ de taille, généralement inclus dans la cuprobismutite ou la cupropavonite, et en agrégats avec la galène enrichie en Ag et Bi. En lumière polarisée en plan et dans l’air, la friedrichite est blanc jaunâtre crémeux avec une teinte brunâtre. La biréflexance et le pléochroïsme sont faibles, mais l’anisotropie est marquée. Nous n’avons pas décelé de réflexions internes. La composition chimique moyenne de la friedrichite provenant de ces trois gisements est recalculée sur une base de $S + Se = 18$: $(\text{Cu}_{5.40}\text{Ag}_{0.01})_{\Sigma 5.41}(\text{Pb}_{5.03}\text{Fe}_{0.01})_{\Sigma 5.04}(\text{Bi}_{6.82}\text{Sb}_{0.02})_{\Sigma 6.84}\text{S}_{18}$ (Antoniou), $(\text{Cu}_{4.99}\text{Ag}_{0.01})_{\Sigma 5.00}(\text{Pb}_{4.62}\text{Fe}_{0.01})_{\Sigma 4.63}(\text{Bi}_{7.22}\text{Sb}_{0.03})_{\Sigma 7.25}(\text{S}_{17.96}\text{Se}_{0.04})_{\Sigma 18}$ (“Blidar Contact”) et $(\text{Cu}_{5.26}\text{Ag}_{0.01})_{\Sigma 5.27}(\text{Pb}_{4.91}\text{Fe}_{0.02})_{\Sigma 4.93}(\text{Bi}_{6.95}\text{Sb}_{0.01})_{\Sigma 6.96}\text{S}_{18}$ (“Secundar Contact”). Dans chaque cas, il y a de légers écarts à la formule idéale, $\text{Cu}_5\text{Pb}_5\text{Bi}_7\text{S}_{18}$. Nous présentons des données de diffraction X et les spectres de réflectance pour la friedrichite d’Antoniou. Les paramètres réticulaires calculés sont: $a 3 \times 11.299(5)$, $b 11.640(5)$, $c 4.034(2)$ Å. En termes du système $\text{Cu}_2\text{S} - \text{PbS} - \text{Bi}_2\text{S}_3$, les compositions de sulfosels de ces trois gisements, telle que dérivée des données de microsonde électronique, montrent une concentration le long de la série Bi_2S_3 (bismuthinite) – CuPbBiS_3 (aikinite), avec une déviation vers un excédent de Cu, comme l’avaient indiqués les résultats de Cook (1997) sur des échantillons du nord de la Roumanie.

(Traduit par la Rédaction)

Mots-clés: friedrichite, diffraction X, données chimiques, données optiques, gisement d’Antoniou, cornéennes magnésiennes, gisement de “Blidar Contact”, gisement de “Secundar Contact”, cornéennes calciques, Băița Bihor, Roumanie.

COMPOSITIONAL VARIATIONS IN Cu–Ni–PGE SULFIDES OF THE DUNKA ROAD DEPOSIT, DULUTH COMPLEX, MINNESOTA: THE IMPORTANCE OF COMBINED ASSIMILATION AND MAGMATIC PROCESSES

ROBERT D. THÉRIAULT¹ AND SARAH-JANE BARNES

Département des Sciences Appliquées, Université du Québec à Chicoutimi, Chicoutimi, Québec G7H 2B1

¹ Current address: Ministère des Ressources naturelles du Québec, Québec, QC G1H 6R1.

E-mail address: sgq@mrn.gouv.qc.ca

ABSTRACT

The Dunka Road deposit is one of ten occurrences of Cu–Ni sulfides bearing platinum-group elements (PGE) on the northwestern margin of the Duluth Complex, in Minnesota. Mineralization has been linked to contamination of the host troctolitic magma through assimilation of argillaceous rocks from the Virginia Formation. On the basis of texture and composition, the sulfide mineralization is divided into five types: 1) norite-hosted disseminated sulfides, 2) troctolite-hosted disseminated sulfides, 3) PGE-rich disseminated sulfide horizons, 4) pyrrhotite-rich massive sulfides, and 5) chalcopyrite-rich disseminated sulfides. The norite-hosted sulfides exhibit features suggestive of the magma's substantial contamination, such as high proportions of pyrrhotite and arsenide minerals, and high mean values of S/Se (9,700) and $\delta^{34}\text{S}$ (11.2‰). They are also generally metal-poor, implying that the sulfides interacted with a relatively low volume of silicate melt (*i.e.*, low *R* factor). The troctolite-hosted sulfides formed at moderate degrees of contamination, as indicated by their intermediate mean values of S/Se (4,600) and $\delta^{34}\text{S}$ (7.8‰). The PGE-rich sulfide horizons show little sign of contamination, and have mantle-like mean values of S/Se (2,600) and $\delta^{34}\text{S}$ (2.1‰). Their very high PGE contents suggest that they formed at elevated *R* factors. The pyrrhotite-rich massive sulfides and associated chalcopyrite-rich disseminated sulfides have relatively high mean values of S/Se (8,000) and $\delta^{34}\text{S}$ (10.2‰), indicative of significant contamination. The former are interpreted to represent a cumulate of monosulfide solid-solution (*mss*), whereas the chalcopyrite-rich sulfides represent the fractionated sulfide liquid. A general increase in the degree of contamination is observed toward the base of the intrusion, associated with a decrease in *R* factor and metal concentration of the sulfides. This likely results from the introduction of partial melt from the metasedimentary country-rocks, which was cooler than the mafic magma and led to the early crystallization of the sulfide liquid.

Keywords: sulfide deposits, assimilation, sulfur isotopes, S/Se ratios, *R* factor, *mss* fractionation, troctolite, platinum-group elements, nickel, copper, arsenides, Dunka Road deposit, Duluth Complex, Minnesota.

SOMMAIRE

Le gisement de Dunka Road fait partie d'un groupe de dix gisements de sulfures de Cu–Ni

enrichis en éléments du groupe du platine (EGP) regroupés le long de la bordure nord-ouest du complexe de Duluth, au Minnesota. La minéralisation serait liée à une contamination du magma-hôte troctolitique due à une assimilation de roches argileuses de la formation de Virginia. D'après leur texture et leur composition, les sulfures sont divisés en cinq types: 1) sulfures disséminés dans la norite comme hôte, 2) sulfures disséminés dans la troctolite comme hôte, 3) horizons de sulfures disséminés enrichis en EGP, 4) sulfures massifs enrichis en pyrrhotite, et 5) sulfures disséminés enrichis en chalcopirite. Les caractéristiques des sulfures dans la norite, par exemple les proportions élevées de pyrrhotite et de minéraux arsénifères, et des valeurs moyennes élevées de S/Se (9 700) et $\delta^{34}\text{S}$ (11.2‰), font penser que le magma a subi une importante contamination. De plus, ces sulfures sont généralement appauvris en métaux, ce qui implique qu'ils ont réagi avec un faible volume de magma silicaté (*i.e.*, faible facteur R). Les sulfures dans la troctolite se sont formés à des niveaux moyens de contamination, tel qu'indiqué par leurs valeurs moyennes intermédiaires de S/Se (4 600) et $\delta^{34}\text{S}$ (7.8‰). Les horizons de sulfures enrichis en EGP montrent très peu de signes de contamination, et ont des valeurs moyennes de S/Se (2 600) et $\delta^{34}\text{S}$ (2.1‰) qui rappellent celles du manteau. Leur très forte teneur en EGP témoigne de facteurs R élevés. Les sulfures massifs enrichis en pyrrhotite, et les sulfures disséminés enrichis en chalcopirite avec lesquels ils sont associés, ont des valeurs moyennes relativement élevées de S/Se (8 000) et $\delta^{34}\text{S}$ (10.2‰), indications d'une importante contamination. Les sulfures massifs résulteraient d'une accumulation d'une solution solide de monosulfure (*mss*), alors que les sulfures enrichis en chalcopirite représentent un liquide sulfuré fractionné. Une augmentation générale du degré de contamination est observée vers la base de l'intrusion, associée à une diminution du facteur R et de la concentration en métaux des sulfures. Ceci résulte possiblement de l'introduction d'un produit de fusion partielle dérivé des roches métasédimentaires encaissantes, plus froid que le magma mafique, qui aurait ainsi mené à la cristallisation hâtive du liquide sulfuré.

Mots-clés: gisement de sulfures, assimilation, isotopes de soufre, rapports S/Se, facteur R , fractionnement de *mss*, troctolite, complexe de Duluth, éléments du groupe du platine, nickel, cuivre, arséniures, gisement de Dunka Road, complexe de Duluth, Minnesota.

HISTORICAL OBSERVATIONS ON OXYGEN-BEARING COMPOUNDS OF PLATINUM AND PALLADIUM IN MINAS GERAIS, BRAZIL

JACQUES JEDWAB¹

Laboratoire de Géochimie et de Minéralogie, CP 160/02, Université Libre de Bruxelles, 50, Avenue F. Roosevelt, B-1050 Bruxelles, Belgique

JACQUES CASSEDANNE

Rua do Russel, 680/41, 22.210 Rio de Janeiro, Brazil

¹ *E-mail address:* jjedwab@resul.ulb.ac.be

ABSTRACT

Dark brown to black compounds associated with native gold were discovered three hundred years ago in Minas Gerais, Brazil, and have been known since then as *ouro preto* (black gold). These compounds were correctly determined as oxygen-bearing compounds of platinum – palladium – iron as early as 1833 and 1837, but the oversight of the presence of major iron in their composition led to an erroneous definition of *palladinite* and to the much-delayed recognition of a group of platinum- group-element oxides.

Keywords: platinum, palladium, oxide, *ouro preto*, Minas Gerais, Brazil.

SOMMAIRE

Des composés brun-sombre à noirs associés à de l'or natif ont été découverts il y a trois cents ans dans le Minas Gerais, Brésil, et ont été connus depuis sous le nom d' *ouro preto* (or noir). Ces composés ont été correctement déterminés comme composés oxygénés de platine – palladium – fer dès 1833 et 1837. La négligence de la présence du fer majeur a conduit à une définition erronée de la *palladinite* ainsi qu' à la reconnaissance tardive d'un groupe d'oxydes des éléments du groupe du platine.

Mots-clés: platine, palladium, oxyde, *ouro preto*, Minas Gerais, Brazil.

MELILITOLITES: A NEW SCHEME OF CLASSIFICATION

ELIZABETH ANN DUNWORTH¹ AND KEITH BELL

*Ottawa – Carleton Geoscience Centre, Department of Earth Sciences, Carleton University,
Ottawa, Ontario K1S 5B6*

¹ Present address: Mineralogisk-Geologisk Museum, Sars' gate 1, Oslo N-0562, Norway. *E-mail address:* e.a.dunworth@toyen.uio.no

ABSTRACT

A new scheme of classification is proposed for melilite-bearing plutonic rocks with more than 10% melilite and less than 50% primary carbonate phases, based on the absolute modal abundances of the dominant minerals. Melilitolite is retained as a “general” root-name for all such rocks. Previous definitions of terms used in the classification of these rocks, including afrikandite, kugdite, okaite, turjaite and uncompahgrite, are modified in order to provide “specific” root-names for melilitolites. A new rock-name, “ultramelilitolite”, is proposed as a specific root-name for samples with more than 65% melilite. The use of multiple root-names and the problems associated with the use of mineral modifiers in rock nomenclature are discussed.

Keywords: melilitolite, afrikandite, kugdite, okaite, turjaite, uncompahgrite, “ultramelilitolite”, modifier, root-name.

SOMMAIRE

Nous présentons ici un nouveau schéma de classification visant les roches plutoniques contenant plus de 10% de mélilite et moins de 50% de phases carbonatées primaires, et fondé sur la teneur des minéraux dominants en termes absolus. Nous retenons le terme “mélilitolite” comme racine du nom de telles roches. Les définitions utilisées antérieurement dans le classification de ces roches, par exemple, afrikandite, kugdite, okaïte, turjaïte et uncompahgrite, sont ici modifiées afin d'en arriver à des noms de base spécifiques dans ce schéma. Un nouveau nom, “ultramélilitolite”, est proposé pour les échantillons contenant plus de 65% de mélilite. Nous discutons l'utilisation de noms de base multiples et les problèmes associés à l'utilisation de noms de minéraux comme qualificatifs dans la nomenclature de ces roches.

(Traduit par la Rédaction)

Mots-clés: mélilitolite, afrikandite, kugdite, okaïte, turjaïte, uncompahgrite, “ultramélilitolite”, qualificatifs, noms de base.

NOMENCLATURE OF THE MICAS

MILAN RIEDER¹

Department of Geochemistry, Mineralogy, and Mineral Resources, Charles University, Albertov 6, 12843 Praha 2, Czech Republic

GIANCARLO CAVAZZINI

Dipartimento di Mineralogia e Petrologia, Università di Padova, Corso Garibaldi, 37, I-35122 Padova, Italy

YURII S. D'YAKONOV

VSEGEI, Srednii pr., 74, Saint-Peterburg, 199026, Russia

VIKTOR A. FRANK-KAMENETSKII*

GLAUCO GOTTARDI[†]

STEPHEN GUGGENHEIM

Department of Geological Sciences, University of Illinois at Chicago, 845 West Taylor Street, Chicago, Illinois 60607-7059, U.S.A.

PAVEL V. KOVAL'

Institut geokhimii SO AN Rossii, ul. Favorskogo 1a, Irkutsk, 664033, Russia

GEORG MÜLLER

Institut für Mineralogie und Mineralische Rohstoffe, Technische Universität Clausthal, Postfach 1253, D-38670 Clausthal-Zellerfeld, Germany

ANA M.R. NEIVA

Departamento de Ciências da Terra, Universidade de Coimbra, Apartado 3014, 3049 Coimbra CODEX, Portugal

EDWARD W. RADOSLOVICH[‡]

JEAN-LOUIS ROBERT

Centre de Recherche sur la Synthèse et la Chimie des Minéraux, C.N.R.S., 1A, rue de la Férollerie, F-45071 Orléans Cedex 2, France

FRANCESCO P. SASSI

Dipartimento di Mineralogia e Petrologia, Università di Padova, Corso Garibaldi, 37, I-35122 Padova, Italy

HIROSHI TAKEDA

Chiba Institute of Technology, 2-17-1 Tsudanuma, Narashino City, Chiba 275, Japan

ZDENĚK WEISS

Central Analytical Laboratory, Technical University of Mining and Metallurgy, Tr. 17.listopadu, 708 33 Ostrava-Poruba, Czech Republic

DAVID R. WONES[§]

¹ *E-mail address: rieder@mbox.cesnet.cz*

* Russia; died 1994; † Italy; died 1988; ‡ Australia; resigned 1986; § U.S.A.; died 1984.

ABSTRACT

End-members and species, defined with permissible ranges of composition, are presented for the true micas, the brittle micas, and the interlayer-deficient micas. The determination of the crystallochemical formula for different available chemical data is outlined, and a system of modifiers and suffixes is given to allow the expression of unusual chemical substitutions or polytypic stacking arrangements. Tables of mica synonyms, varieties, ill-defined materials, and a list of names formerly or erroneously used for micas are presented. The Mica Subcommittee was appointed by the Commission on New Minerals and Mineral Names of the International Mineralogical Association. The definitions and recommendations presented were approved by the Commission.

Keywords: mica nomenclature, brittle micas, interlayer-deficient micas, species, end members.

SOMMAIRE

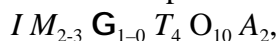
Les pôles des diverses espèces de mica sont ici définis, ainsi que les intervalles de composition permis, ceci pour les vrais micas, les micas cassants, et les micas déficitaires dans la position interfeuillet. On décrit la détermination de la formule cristallochimique à partir des diverses données chimiques disponibles; un système de qualificatifs et de suffixes permet d'exprimer des vecteurs de substitution peu courants et des agencements d'empilement polytypique. Sont inclus un tableau de synonymes, une liste de variétés et de matériaux méconnus, ainsi qu'une liste de noms désuets ou erronés utilisés pour décrire les micas. Le comité de nomenclature des micas a été mandaté par la Commission des nouveaux minéraux et des noms de minéraux de l'Association internationale de Minéralogie. Les définitions et recommandations de ce comité ont été approuvées par la Commission.

Keywords: nomenclature des micas, micas cassants, micass déficitaire dans la position interfeuillet, espèces, pôles.

DEFINITION

Micas are phyllosilicates in which the unit structure consists of one *octahedral sheet* (*Os*)

between two opposing *tetrahedral sheets* (*Ts*). These sheets form a *layer* that is separated from adjacent layers by planes of non-hydrated *interlayer cations* (*I*). The sequence is: ... *ITs Os Ts ITs Os Ts* ... The tetrahedral sheets have composition T_2O_5 , and tetrahedra are linked by sharing each of three corners (= basal atoms of oxygen) to a neighboring tetrahedron; the fourth corner (= apical atom of oxygen) points in one direction for a given tetrahedral sheet. The coordinating anions around octahedrally coordinated cations (*M*) consist of apical atoms of oxygen of adjacent tetrahedral sheets and anions *A*. The coordination of interlayer cations is nominally twelve-fold, and their charge should not be less than 0.6 per formula. The simplified formula can be written as:



where *I* is commonly Cs, **K**, **Na**, NH₄, Rb, Ba, **Ca**,

M is commonly **Li**, **Fe** (di- or trivalent), **Mg**, Mn (di- or trivalent), Zn, **Al**, Cr, V, **Ti**,

G represents a vacancy,

T is commonly Be, **Al**, B, **Fe** (trivalent), **Si**, and

A is commonly Cl, **F**, **OH**, O (oxy-micas), S.

(The most frequently encountered elements are set in bold face; note that other substitutions are possible). The number of formula units, *Z*, may vary depending on the structure, but is equal to 2 in a *1M* structure.

SUBDIVISIONS

Depending on the interlayer cation, the micas are subdivided into *true micas* (if $\geq 50\%$ *I* cations present are monovalent) or *brittle micas* (if $> 50\%$ *I* cations present are divalent); if the formula exhibits < 0.85 and ≥ 0.6 positive interlayer charges, it represents an interlayer-cation-deficient mica or, stated in an abbreviated form, an *interlayer-deficient mica*. In special cases (*e.g.*, wonesite), the interlayer charge may be lower than 0.6 provided the material does not have swelling or expanding capabilities. The 0.85 charge divide holds for dioctahedral micas. To date, there are insufficient data to define an analogous limit in trioctahedral micas.

Regardless of the mica subgroup, it is *dioctahedral* if it contains < 2.5 octahedral cations (*M*) per formula unit; micas with ≥ 2.5 octahedral cations are *trioctahedral*. Micas with intermediate octahedral occupancies occur frequently, but no provision is made for any other divisions or terms (*e.g.*, “ $2\frac{1}{2}$ octahedral”); the use of such terms is discouraged. Also discouraged is the division of micas into “disilicic”, “trisilicic”, and “tetrasilicic” according to the number of silicon atoms per formula.

Octahedrally coordinated *M* cations may be distributed over three crystallographic positions (octahedral ordering) or two positions in structures with the *C2/m* space group. Because of this ordering, some end-member formulas do not conform to the “chemical” 50% rule of Nickel (1992). To a lesser extent, the same applies to tetrahedrally coordinated *T* cations.

PRINCIPLES OF CLASSIFICATION

The present classification is based on the chemical composition of micas and embodies generalizations derived from crystal-structure determinations. The inclusion of physical determinative properties as classification criteria was avoided because these properties cannot unambiguously differentiate members of the micas. Moreover, the approach adopted here reflects the belief that mica classification should be based on easily accessible chemical data and a minimum of physical

measurements.

The crystallochemical formula should be based on chemical data, density, and cell data. If chemical data only are available, the recommended procedure to calculate a formula is as follows: (1) If there is a reliable determination of H₂O, the formula should be based on twelve O + F atoms. (2) If there is no determination of H₂O, as in electron-microprobe analyses, an idealized anion group must be assumed, and the formula should be based on 22 positive charges. (3) If there is no determination of H₂O and there are grounds to suspect that a *later* oxidation of iron in the mica caused deprotonation of the anion group, the formula should be based on 22 + *z* positive charges, where *z* is the quantity of trivalent iron (Stevens 1946, Foster 1960, Rimsaite 1970). It should be noted that lithium, concentrations of which cannot be determined with current electron-microprobe techniques, is commonly overlooked in wet-chemical analyses because of its low molecular weight. Also, failure to establish the concentration of lithium has caused a number of erroneous identifications.

END MEMBERS

End-member names given below are associated with formulas containing the most frequently encountered A anion only. End members in which other A anions dominate should be designated with the prefixes “fluoro” (*e.g.*, in muscovite), “hydroxy” (*e.g.*, in polyolithionite), or “oxy” (*e.g.*, in annite). When such phases are found in nature, their proposed new mineral status and name should nonetheless be submitted for approval to the Commission on New Minerals and Mineral Names, IMA.

This report contains end-member formulas that are stoichiometric on the scale of the asymmetric part of the unit cell. Those mica species that do not meet this requirement (such as those in which the main end-members are not yet clear) appear as “species that are not end members”. To express chemical variation in compositional plots, hypothetical end-members may be employed. However, because these end members have not been documented as mineral species, they may not receive mineral-like names, and only formulas or formula-like expressions should be used in such plots. Experimental determinations of miscibility limits in natural mica series will help in establishing species and in positioning boundaries between them.

Lists of valid names for true, brittle, and interlayer-deficient micas appear in Tables 1, 2, and 3, respectively. The compositional space for some dioctahedral interlayer-deficient and true micas is shown in Figure 1.

MODIFIERS AND SUFFIXES

Chemical deviations from end-member compositions may be expressed by adjectival modifiers. These must be based on actual determinations to support the claim. The usage of adjectival modifiers is not mandatory. Modifiers like “rubidian” should be used only if the element in question exceeds 10%, but not 50%, of the real occupancy of the respective position in the end-member formulas involved. Thus, a rubidian muscovite may contain between 0.1 and 0.5 Rb atoms per formula unit. If an element can enter more than one coordination, a further differentiation is possible, such as “tetra-ferrian” or “octa-ferrian”. If the concentration of an element is less than that necessary for the assignment of a modifier, and if the author wishes to acknowledge its presence, it may be done by using a modifier such as “rubidium-bearing”. The latter type of modifier should be used also if the analysis is incomplete, thus preventing the calculation of a complete crystallochemical formula.

For cases where a polytype determination has been made, the name may be suffixed with an appropriate polytype symbol (Nickel 1993), *e.g.*, muscovite-3*T*. There are two universal systems of polytype symbolism, both based on the modified Gard notation: one presented jointly by IMA and IUCr (Bailey *et al.* 1978), and another, more generalized, by IUCr (Guinier *et al.* 1984). Because of international acceptance and common usage, the Ramsdell symbolism is preferred for the micas unless exact stacking sequences or other special information need clarification; for the latter cases, see Ross *et al.* (1966), Takeda & Sadanaga (1969), Zvyagin (1964, 1967), Zvyagin *et al.* (1979), or Dornberger-Schiff & Đurovič (Đurovič 1981). When using the other systems or when using symbolism that is not commonly known, the author must reference its source or, preferably, specify the stacking sequence represented by the symbols used. A review of polytypes in micas found to date can be found in Baronnet (1980), Bailey (1984), or Takeda & Ross (1995).

SERIES NAMES AND LISTS OF INVALID NAMES

This report also includes series names intended to designate incompletely investigated micas that are to be used by field geologists or petrographers (Table 4). Such names (*e.g.*, “biotite”) are defined only in some series, thus in fact sanctioning a practice that is common already. Assigning a name to an incompletely investigated layer silicate may be risky, and it should be preceded by at least optical examination. Once such material has been studied in detail, end-member names should be preferred, with or without modifiers and suffixes. Series names are not to be associated with varietal modifiers.

Names whose usage is discouraged were divided into synonyms and varieties (Table 5), ill-defined materials and mixtures (Table 6), and names formerly or erroneously used for micas (Table 7).

JUSTIFICATION

This paragraph summarizes grounds for some of the Mica Subcommittee’s decisions.

- **Aluminocladonite.** The alternative term for this mica, *leucophyllite*, was considered unjustified because it invites confusion with an identical rock-name and because the type-locality leucophyllite (Starkl 1883) is too low in alkalis to represent a mica.
- **Aspidolite.** The Subcommittee voted to resurrect the name *aspidolite* (von Kobell 1869), which represented an old description of what was in more recent years referred to as *sodium phlogopite* (Schreyer *et al.* 1980). It must be pointed out that no one ever applied formally for the mineral name *sodium phlogopite*.
- **Brammallite.** A reasoning similar to that concerning *illite* has led the Subcommittee to list it as a series name. A more precise end-member nomenclature might develop at a later time.
- **Divisions within the interlayer-deficient micas.** In the subgroup of interlayer-deficient micas, some divisions comply with Nickel’s (1992) nomenclature for mineral solid-solutions, but some do not. The non-50% limits adopted by the Subcommittee as divides between volumes in interlayer-deficient micas are essentially those of Bailey *et al.* (1979).

- **Illite.** This name has been used relatively vaguely, and the Subcommittee found it suitable as a series name for a relatively large volume in compositional space, as a counterpart to *glauconite*.
- **Interlayer-deficient micas versus hydromicas.** The Subcommittee was unable to find any *hydromica* that has an excess of H₂O over the equivalent of (OH,F)₂ and could not be interpreted as a *mixed-layer structure* (such as biotite – vermiculite, illite – smectite). At the same time, all micas described as *hydromicas* exhibit a deficiency in the interlayer cation position. Accordingly, the Subcommittee voted to abandon the subgroup name *hydromicas* and replace it with *interlayer-cation-deficient micas* or, in an abbreviated form, *interlayer-deficient micas*.
- **Phengite.** Phengite was elevated to a series name for solid solutions between muscovite, aluminoceladonite, and celadonite.
- **Species that are not end members.** The Subcommittee voted to consider as end members only formulas that are stoichiometric on the scale of the asymmetric part of the unit cell. This principle ruled out a number of micas; the Subcommittee decided it would be best to refer to nonstoichiometric micas that have a fairly constant and recurring composition as “*species that are not end members*”. The micas so designated are *montdorite*, *trilithionite* and *wonesite*.
- **Synonyms (s) and varieties (v).** The list is based on tabulations of Heinrich *et al.* (1953) and Hey (1962, 1963), modified and supplemented. Labels “(s)” or “(v)” could only be attached where there was sufficient information. If a series name appears to the right of a variety rather than a species name, it is because no more precise information is available.
- **Tainiolite.** The Subcommittee prefers the original spelling *tainiolite* to *taeniolite*. The spelling of Flink (1899) was based on Greek words ταινία (a band or strip) and λίθος (a stone). It should be noted that the Russian spelling has always been тайниолит.
- **Tetra-ferri-annite.** Inasmuch as Wahl’s (1925) analytical results do not make the case for ^{IV}Fe³⁺ sufficiently strongly, his *monrepite* was rejected as an end member, with *tetra-ferri-annite* taking its place. Parallel with it is the name *tetra-ferriphlogopite*.

ACKNOWLEDGEMENTS

Since its establishment in 1976, the Mica Subcommittee benefitted from, and is indebted for, ideas offered by a large number of mineralogists; there were so many of them that they cannot be acknowledged individually. The votings on the nomenclature in the CNMMN, IMA and the handling of associated problems was facilitated thanks to the expertise of Joel D. Grice and William D. Birch. We thank Charlie V. Guidotti and Robert F. Martin for valuable final comments on the text and tables.

REFERENCES

BAILEY, S.W. (1984): Classification and structures of the micas. *In* Micas (S.W. Bailey, ed.). *Rev.*

Mineral. **13**, 1-12.

_____, BRINDLEY, G.W., KODAMA, H. & MARTIN, R.T. (1979): Report of the Clay Minerals Society Nomenclature Committee. *Clays Clay Minerals* **27**, 238-239.

_____, FRANK-KAMENETSKII, V.A., GOLDSZTAUB, S., KATO, A., PABST, A., SCHULZ, H., TAYLOR, H.F.W., FLEISCHER, M. & WILSON, A.J.C. (1978): Report of the International Mineralogical Association (IMA) – International Union of Crystallography (IUCr) Joint Committee on Nomenclature. *Can. Mineral.* **16**, 113-117.

BARONNET, A. (1980): Polytypism in micas: a survey with emphasis on the crystal growth aspect. *In* Current Topics in Materials Science **5** (E. Kaldis, ed.). North-Holland Publ. Co., Amsterdam, The Netherlands (447-548).

ĐUROVIČ, S. (1981): OD-Charakter, Polytypie und Identifikation von Schichtsilikaten. *Fortschr. Mineral.* **59**, 191-226.

FLINK, G. (1899): Tainiolite. *In* Mineraler fra Julianehaab indsamlede af G. Flink 1897 (G. Flink, O.B. Bøggild & C. Winther, eds.). *Meddelelser Grønland.* **24**, 115-120.

FOSTER, M.D. (1960): Interpretation of the composition of trioctahedral micas. *U.S. Geol. Surv., Prof. Pap.* **354-B**, 11-49.

GUINIER, A., BOKIJ, G.B., BOLL-DORNBERGER, K., COWLEY, J.M., ĐUROVIČ, S., JAGODZINSKI, H., KRISHNA, P., DE WOLFF, P.M., ZVYAGIN, B.B., COX, D.E., GOODMAN, P., HAHN, T., KUCHITSU, K. & ABRAHAMS, S.C. (1984): Nomenclature of polytype structures. Report of the International Union of Crystallography Ad-Hoc Committee on the Nomenclature of Disordered, Modulated and Polytype Structures. *Acta Crystallogr.* **A40**, 399-404.

HEINRICH, E.W., LEVINSON, A.A., LEVANDOWSKI, D.W. & HEWITT, C.H. (1953): Studies in the natural history of micas. *Engineering Research Institute, University of Michigan, Ann Arbor, Project M978*.

HEY, M.H. (1962): *An Index of Mineral Species & Varieties Arranged Chemically*. British Museum, London, U.K.

_____. (1963): *Appendix to the Second Edition of An Index of Mineral Species and Varieties Arranged Chemically*. British Museum, London, U.K.

VON KOBELL, F. (1869): Ueber den Aspidolith, ein Glied aus der Biotit- und Phlogopit-Gruppe. *Sitzungsber. königl. bayer. Akad. Wiss. München* **1869(I)**, 364-366.

NICKEL, E.H. (1992): Solid solutions in mineral nomenclature. *Can. Mineral.* **30**, 231-234.

_____ (1993): Standardization of polytype suffixes. *Can. Mineral.* **31**, 767-768.

RIMSAITE, J. (1970): Structural formulae of oxidized and hydroxyl-deficient micas and decomposition of the hydroxyl group. *Contrib. Mineral. Petrol.* **25**, 225-240.

ROSS M., TAKEDA, H. & WONES, D.R. (1966): Mica polytypes: systematic description and identification. *Science* **151**, 191-193.

SCHREYER, W., ABRAHAM, K. & KULKE, H. (1980): Natural sodium phlogopite coexisting with potassium phlogopite and sodian aluminian talc in a metamorphic evaporite sequence from Derrag, Tell Atlas, Algeria. *Contrib. Mineral. Petrol.* **74**, 223-233.

STARKL, G. (1883): Ueber neue Mineralvorkommnisse in Oesterreich. *Jahrb. kaiserl.-königl. geol. Reichsanst. Wien* **33**, 635-658.

STEVENS, R.E. (1946): A system for calculating analyses of micas and related minerals to end members. *U.S. Geol. Surv., Bull.* **950**, 101-119.

TAKEDA, H. & ROSS, M. (1995): Mica polytypism: identification and origin. *Am. Mineral.* **80**, 715-724.

_____ & SADANAGA, R. (1969): New unit layers for micas. *Mineral. J. (Japan)* **5**, 434-449.

WAHL, W. (1925): Die Gesteine des Wiborger Rapakiwgebietes. *Fennia* **45**, 83-88.

ZVYAGIN, B.V. (1964): Электроннография и Структурная Кристаллография Глинистых Минералов. Nauka, Moscow, Russia (in Russ.).

_____ (1967): *Electron-Diffraction Analysis of Clay Mineral Structures*. Plenum Press, New York, N.Y.

_____, VRUBLEVSKAYA, Z.V., ZHUKHLISTOV, A.P., SIDORENKO, O.V., SOBOLEVA, S.V. & FEDOTOV, A.F. (1979): Высоковольтная Электроннография в Исследовании Слоистых Минералов (*High-Voltage Electron Diffraction in the Study of Layered Minerals*). Nauka, Moscow, Russia (in Russ.).

Received May 27, 1998.

FIG. 1. A three-dimensional plot illustrating the relation of some true dioctahedral micas to interlayer-deficient dioctahedral micas. a. Two slabs cut from the chemographic volume (b) shown in terms of formulas (small solid circles). Dashed lines indicate approximate borders, dotted lines complete the solid. The ratio ${}^{\text{VI}}R^{2+}/({}^{\text{VI}}R^{2+} + {}^{\text{VI}}R^{3+})$ is equal to $x/2$ (Table 3) for micas with 2.0 octahedral cations. End-member formulas in (a) are shown by solid circles. Glauconite with $\text{Na} > \text{K}$ should be referred

to as “natroglaucouite”.

THE IMA COMMISSION ON NEW MINERALS AND MINERAL NAMES:
PROCEDURES AND GUIDELINES ON MINERAL NOMENCLATURE, 1998

ERNEST H. NICKEL*

Division of Exploration and Mining, CSIRO, Private Bag, P.O., Wembley, W.A., 6014, Australia

JOEL D. GRICE**

Mineral Sciences Division, Canadian Museum of Nature, P.O. Box 3443A, Station "D", Ottawa, Ontario KIP 6P4

*Vice-chairman, IMA Commission on New Minerals and Mineral Names. *E-mail address:* ernien@per.dem.csiro.au

**Chairman, IMA Commission on New Minerals and Mineral Names. *E-mail address:* jgrice@mus-nature.ca

INTRODUCTION

The Commission on New Minerals and Mineral Names (hereafter abbreviated as CNMMN) of the International Mineralogical Association was established in 1959 for the purpose of controlling the introduction of new minerals and mineral names, and of rationalizing mineral nomenclature. Since that time, the work of CNMMN has gained overwhelming support from the international mineralogical community. The CNMMN consists of representatives appointed by national mineralogical bodies, and an executive committee consisting of chairman, vice-chairman and secretary. A list of current members is given in Appendix I.

The activities of the CNMMN, and its various recommendations for mineral nomenclature, have been widely published in a substantial number of mineralogical journals over a number of years; there is a clear need to consolidate these reports to provide an up-to-date account of the procedures currently followed by the CNMMN and updated guidelines on mineral nomenclature. In this paper, which represents a consensus of CNMMN members, and which has benefitted from their suggestions, we attempt to do that. It incorporates material from previous reports on mineral nomenclature and procedures of the CNMMN, including general papers such as those by Hey *et al.* (1961), Fleischer (1970), Donnay & Fleischer (1970), Dunn & Mandarino (1988), Mandarino *et al.* (1984) and Nickel & Mandarino (1987), as well as papers on more specific topics, which will be referred to in the body of this paper. This paper is therefore a revised update of the procedures employed by the CNMMN and of general guidelines for mineral nomenclature.

It must be understood that the CNMMN does not wish to impose an arbitrary set of rigid rules on the mineralogical community, but rather to provide a set of coherent guidelines that provide a reasonably consistent approach to the introduction of new minerals and the application of mineral nomenclature. The guidelines presented herein probably apply

reasonably well to the great majority of cases, but inevitably situations arise that do not conform so readily. As is mentioned several times in the text, each case must be judged on its own merits.

CRITERIA FOR A NEW MINERAL SPECIES

General considerations

A mineral substance is a naturally occurring solid that has been formed by geological processes, either on earth or in extraterrestrial bodies (Nickel 1995a). A mineral species is a mineral substance with well-defined chemical composition and crystallographic properties, and which merits a unique name. General criteria for defining mineral species are given below. In practice, most mineral species conform to these criteria, but exceptions and borderline cases inevitably arise, and ultimately each proposal to introduce a new mineral species or to change mineral nomenclature must be considered on its own merits.

The concept of a mineral species

A mineral species is defined mainly on the basis of its chemical composition and crystallographic properties, and these must therefore be the key factors in determining whether the creation of a new mineral species and a new mineral name is justified. If a mineral is found whose composition or crystallographic properties (or both) are substantially different from those of any existing mineral species, there is a possibility that it may be a new species. A general guideline for compositional criteria is that at least one structural site in the potential new mineral should be predominantly occupied by a different chemical component than that which occurs in the equivalent site in an existing mineral species.

Example 1: Hydroxylapatite and fluorapatite both crystallize in the hexagonal system, with the same space group, and have similar unit-cell parameters. They are considered as separate species because the relevant structural site is predominantly occupied by OH in hydroxylapatite, and by F in fluorapatite.

Example 2: Sphalerite (ZnS) and "marmatite" ([Zn,Fe]S) are both cubic, with the same space group and similar unit-cell parameters, but they are not regarded as separate species because the cationic structural site is predominantly occupied by Zn in both cases. "Marmatite" is regarded as a ferroan variety of sphalerite.

Substances formed by human intervention

Anthropogenic substances, *i.e.* those made by Man, are not regarded as minerals. However, there are other cases in which human intervention in the creation of a substance is less direct, and the borderline between mineral and non-mineral can be unclear. One such case is the occurrence of new substances that owe their origin, at least in part, to human activities such as mining or quarrying. If such substances are formed purely as a result of the exposure of existing rock or minerals to the atmosphere or to the effects of groundwater, they can generally be accepted as minerals. However, if their occurrence is due, at least in part, to the interaction of existing minerals with substances of non-geological origin such as blasting powder, corroded human artifacts or industrially contaminated water, then such products are

not to be regarded as minerals.

Substances formed by combustion are not generally regarded as minerals. A contentious issue is the occurrence of substances in the combustion products of coal mines, waste dumps or peat bogs. The origin of a particular fire is often difficult to determine, and therefore the possibility of human intervention cannot be entirely eliminated, nor can the possibility of human artifacts contributing to the combustion products. It has therefore been decided that, as a general rule, products of combustion are not to be considered as minerals in the future.

Another contentious issue is whether substances formed by the action of air or water on anthropogenic substances should be regarded as minerals. A well-known example is that of the Laurium "minerals" formed by the reaction of seawater with ancient metallurgical slags. A potential problem with accepting similar products as minerals in the modern age is that a multitude of unusual substances could be created purposely by exposing exotic Man-made materials to the influence of weathering agents, and it would not be appropriate to give such substances the same status as minerals formed entirely by geological processes. It was therefore decided that substances formed from Man-made materials by geological agents should not be accepted as minerals in the future (Nickel 1995a). However, the exclusion of such substances from the mineral lexicon does not preclude their description as artificial substances.

Substances that would not be accepted as minerals according to the above criteria, but which have been accepted in the past are not to be automatically discredited as a result of the new rulings, as it is not our intention to roll back the clock but rather to establish guidelines for the future.

Biogenic substances

It is not always possible to draw a sharp distinction between biogenic substances, *i.e.* those produced by biological processes, and minerals, which are normally produced by geological processes. For instance, it is becoming increasingly clear that many of the processes associated with diagenesis are influenced, to some extent, by bacterial action, and the biosphere is commonly regarded as an integral part of the geochemical cycle. Nevertheless, it is necessary to make a formal distinction so as to prevent a host of purely biological materials being incorporated into the world of minerals. Some biogenic substances, such as hydroxylapatite in teeth, whewellite in urinary calculi or aragonite in the shells of molluscs, also exist as minerals formed by geochemical processes, and therefore are regarded as valid minerals. However, purely biogenic substances that have no geological counterparts, or whose origin owes essentially nothing to geological processes, are not regarded as minerals.

However, substances formed by the action of geological processes on organic material, such as the chemical compounds crystallized from organic matter in shale or from bat guano, can be accepted as minerals.

Amorphous substances

Amorphous substances are non-crystalline, and therefore do not meet the normal requirements for mineral species. The term "crystalline", as generally used in mineralogy, means atomic order on a scale that can produce a regular array of diffraction spots when the substance is traversed by a wave of suitable wavelength (X-ray, electrons, neutrons, *etc.*).

However, some geologically derived substances such as gels, glasses and bitumens are non-crystalline. Such substances can be divided into two categories: amorphous, those substances that have never been crystalline and do not diffract, and metamict, those that were crystalline at one time, but whose crystallinity has been destroyed by ionizing radiation. Some mineralogists are reluctant to accept amorphous substances as mineral species because of the difficulty of determining whether the substance is a true chemical compound or a mixture, and the impossibility of characterizing it completely; the term "mineraloid" is sometimes applied to such substances. However, in the past some amorphous substances (*e.g.*, georgeite, calcio-uranoite) have been accepted as mineral species by the CNMMN.

With modern techniques, it is possible to study amorphous phases more effectively than was possible in the past. Spectroscopic methods associated with a complete chemical analysis can in many cases identify an amorphous phase unequivocally. In fact, appropriate spectroscopic techniques (*e.g.*, IR, NMR, Raman, EXAFS, Mössbauer) can reveal the three-dimensional short-range structural environment (chemical bonds) of each atom in the structure. Of course, without the possibility of obtaining a complete crystal-structure analysis, which can give the coordinates and the nature of the atoms, the need for a complete chemical analysis is more stringent with amorphous material than with a crystalline phase.

The basis for accepting a naturally occurring amorphous phase as a mineral species could be a series of complete quantitative chemical analyses that are sufficient to reveal the homogeneous chemical composition of a substantial number of grains in the specimen, and physicochemical data (normally spectroscopic) that prove the uniqueness of the phase.

Metamict substances, if formed by geological processes, are accepted as mineral species if it can be established with reasonable certainty that the original substance (before metamictization) was a crystalline mineral of the same bulk composition. Evidence for this includes the restoration of crystallinity by appropriate heat-treatment and the compatibility of the diffraction pattern of the heat-treated product with the external morphology (if any) of the original crystal, *e.g.*, fergusonite-(Y).

The matter of size

The main criteria for defining a mineral species are its composition and crystal structure; with the development of modern analytical techniques, it is now possible to perform complete chemical and crystal-structure analyses on nanometric volumes, *i.e.*, on the scale of a few Ångström units. Should such submicroscopic domains be accepted as valid mineral species? There is a wide range of opinions on this subject. On the one hand, it is argued that if a mineral substance can be characterized in terms of composition and crystallography, then it should be regarded as a valid mineral species. On the other hand, it is contended that the other properties traditionally reported for minerals, such as color, hardness, optical properties, *etc.*, cannot be determined on an area of that size, and that the description is therefore incomplete. Furthermore, the size of the described particle should be sufficiently large so that sufficient type material can be retained to enable a later independent examination to confirm the original characterization. Another argument against the acceptance of nanometric specimens as valid mineral species is that such substances cannot be adequately displayed in mineral museums. It has not been possible to reach agreement on a minimal acceptable size for a mineral substance to be regarded as a species, and therefore each case must be decided on its own merits.

Stability under ambient conditions

Many minerals were formed under conditions of high temperature or pressure (or both) and are metastable under ambient conditions; others may tend to hydrate or dehydrate when removed from their place of origin. Such minerals may require special procedures to prevent their decomposition before the investigation is complete. The use of special procedures in the investigation does not preclude the acceptance of a metastable substance as a mineral species if it can be adequately characterized and if it meets the other criteria for a mineral.

Polymorphs

Polymorphic minerals are those that have essentially the same chemical composition, but different crystal structures. The polymorphic forms of a mineral are regarded as different species if their structures are topologically different. However, if the crystal structures of the polymorphs have essentially the same topology, differing only in terms of a structural distortion or in the order – disorder relationship of some of the atoms comprising the structure, such polymorphs are not regarded as separate species. The names of such topologically similar polymorphs can be distinguished by the addition of crystallographic suffixes to the mineral name, as discussed in a later section.

Although the formal definition of polymorphism is restricted to substances with identical chemical compositions, this strict limitation is broadened somewhat to include relatively minor chemical variations when the topology of the structure is retained.

Example 1: Graphite and diamond are polymorphs of crystalline carbon; both have the same composition, but their structures are topologically different, and therefore minerals such as these are regarded as separate species.

Example 2: Analcime has a number of topologically similar polymorphs, *e.g.*, cubic, tetragonal, orthorhombic, monoclinic, triclinic and possibly even trigonal, caused by relatively minor variations in symmetry due to different degrees of order of Si and Al with related different occupancies of the nearest Na structural site. Such polymorphs are not to be regarded as separate species.

Example 3: Orthoclase and microcline have essentially the same composition and topologically similar structures. According to current practice, these minerals would not be regarded as separate species, but their names are retained in the mineral lexicon for historical reasons.

Polytypes and polytypoids

Polytypes are substances that occur in several different structural modifications, each of which may be regarded as being built up by the stacking of layers of (nearly) identical structure and composition, and with the modifications differing only in their stacking sequence (Guinier *et al.* 1984). Polytypoids are substances that do not fit the strict definition of a polytype, and include minerals with the same topology and with somewhat different compositions. Polytypes and polytypoids are not regarded as separate species and, like topologically similar polymorphs, they can be distinguished by the addition of a crystallographic suffix to the mineral name, as indicated in a later section.

Example 1: Högbomite exists in a number of different hexagonal and rhombohedral polytypes owing to variations in the stacking of the basic structural layers. These polytypes are not regarded as separate mineral species, and can be distinguished by appropriate suffixes (see later).

Example 2: Pyrrhotite, Fe_{1-x}S , where x varies between 0 and 0.12, exists in a number of different crystallographic forms owing to variations in the degree of order of the Fe vacancies in the S lattice; because of the variable chemical composition, the different types of pyrrhotite can be regarded as polytypoids and are not regarded as separate species.

Regular interstratifications

Regular interstratifications of two or more minerals are accepted as separate species if the kinds of layers, their relative proportions, chemical compositions, and regularity of interstratification in three dimensions on a micrometric or nanometric scale have been well documented. Such information can commonly be obtained by transmission electron microscopy (TEM) using lattice-imaging techniques. However, if the evidence for regularity of stratification is based on X-ray diffraction data, then the criteria of Bailey (1981) should be applied.

Example: A regular interstratification of talc and a trioctahedral smectite qualifies as a separate mineral species, *aliettite*.

Polysomatic series

Homologous structures are those that consist of structural units built on common structural principles; these structures contain the same chemical elements, although in different proportions, and differ with respect to the size of the units. A homologous series is a series of structures that can be derived from one type of basic structural unit using one type of recombination principle. Homologous series can be classified into two categories, accretional and variable-fit; combinations of the two types are known also to occur.

An accretional homologous series, also known as a polysomatic series, is one in which the types of building blocks (rods, layers, *etc.*) and the principles that define their mutual relationships remain preserved, but in which the sizes of these blocks vary incrementally (Veblen 1991). A member of an accretional homologous series can be regarded as a distinct species if it has the following properties: a) unique size of the fundamental building block, b) unique crystallographic unit-cell, and c) unique composition or a limited compositional range (Makovicky 1989).

Example 1: The structures of the sulfosalt minerals lillianite, eskimoite, vikingite, ourayite, gustavite and heyrovskyite can all be interpreted as consisting of alternating galena-like modules twinned on (131) of the galena motif (Makovicky & Karup-Møller 1977). The sizes of the modules, the unit-cell parameters, and the chemical compositions of these minerals are all different, which justifies their existence as separate species.

Example 2: Composite structures of members of the cylindrite group are formed of two kinds of layers, pseudo-hexagonal (H) and pseudo-tetragonal (Q). Cylindrite and franckeite have the same Q–H–Q–H sequence of stratification, but in franckeite the width of the Q layer is twice that of the Q layer of cylindrite. The two minerals are therefore regarded as separate species.

A variable-fit homologous series can also be regarded as coupled homeotypes forming a composite structure. Such a series is one in which the structure consists of two kinds of alternating, mutually non-commensurate building blocks. Each kind of building block has its own short-range periodicity, and it takes m periods of one block and n periods of the other block before they meet in the same configuration as was observed at the preselected origin. The non-commensurability of the building blocks may be one- or two-dimensional, and is usually connected with geometrical and compositional long-range modulation of both layer types (Makovicky & Hyde 1981). The period of the long-range match may vary within certain relatively broad limits because of incremental changes in the value of m or n . Because of this, the structures are infinitely adaptive, and a great number of possible variants can result. For this reason, individual members of variable-fit homologous series should not be regarded as separate species (see a later section for suggestions in the nomenclature of this group of minerals).

Example: The cylindrite structure has been interpreted as consisting of incommensurate alternating layers of pseudotetragonal and pseudo-hexagonal symmetry. Several different coincident lattices have been reported for this mineral (Makovicky & Hyde 1981), but these do not qualify for separate species status.

Modulated structures

Misfits between structural units can also be accommodated by structural perturbations. If these perturbations are of a periodic nature, the resultant structures are termed modulated structures, and are generally manifested in diffraction patterns by the appearance of superstructure reflections. Modulated variants of an existing mineral species do not warrant separate species status.

Example: In the antigorite structure, a misfit between the octahedral and tetrahedral layers is resolved by structural adjustments that result in the formation of structural waves with different periodicities. The various modulations are not regarded as separate species.

Solid-solution series

In a continuous binary solid-solution series, only the two end-members are regarded as species, and the compositional range of the species is taken to apply from that of the end member to 50 mol% of the series; this is generally known as the “50% rule”. If a binary solid-solution is incomplete, and the composition of one of the end members exceeds 50 mol% by a small amount, then, strictly speaking, that part of the series exceeding the 50% mark could be regarded as a separate species. However, for practical purposes, it may not be desirable to create a new species defining only a very short compositional range, and therefore

such cases should be considered on their individual merits.

In multiple solid-solution series, the 50% rule is interpreted to mean predominant occupancy of a particular structural site. Thus, if there are two types of atom in a structural site, the species is to be defined by the atom comprising at least 50% of that site. If there are more than two substituting atoms in the site, the species is defined by the predominant atom occupying the site. For the purpose of species definition, site vacancies, commonly shown as **G** in chemical formulae, are to be regarded as atoms.

In minerals with complex structures and a multiplicity of structural sites that can accommodate a variety of different elements, the 50% rule may be difficult to apply, and authors of new-mineral proposals that rely on this rule for a particular structural site should substantiate their designation by a crystal-structure analysis.

The problem of applying the 50% rule to members of a complex group is exemplified by the amphibole minerals. The example given below shows that the 50% rule should not be applied too rigorously, and that a certain degree of latitude must be permitted when dealing with complex minerals.

Example: With a generalized amphibole composition expressed by the formula $AB_2C_5T_8O_{22}(OH)_2$, the *C* “site” actually comprises 5 different sites, and the *T* “site” actually comprises 8 sites. With the *C* sites able to accommodate Mg, Fe^{2+} , Mn^{2+} , Li, and a number of less common elements, there is a great opportunity for the proliferation of mineral species if the 50% rule for each structural site were strictly adhered to. Added to this is the difficulty of accurately determining site-populations for elements with similar scattering powers. The Amphibole Subcommittee therefore decided to regard the different *C* sites as one composite site, and to apply the 50% rule to it. The *T* sites, normally occupied by Si and Al, presented a different problem, as petrologists had long regarded the partial replacement of Si by Al as being of petrological significance. The 8 *T* sites were therefore not considered as one composite site, and smaller increments in the Si:Al ratio were taken as the effective boundaries between species.

In some cases, solid-solution series do not extend to either end member, but instead, the compositions cluster around the 50% mark. For practical reasons, it may not be appropriate to denote the compositions on the two sides of the 50% mark as separate species. Such cases should be considered on their own merits.

Example: In pentlandite, $(Fe,Ni)_9S_8$, Fe and Ni substitute for each other to a limited extent, with compositions centered around $Fe_{4.5}Ni_{4.5}S_8$. It has not been found necessary to divide pentlandite into two species, an Fe-dominant one and a Ni-dominant one.

Some additional details applying to multiple and partial solid-solution series are given in Nickel (1992).

REQUIREMENTS FOR THE APPROVAL OF NEW MINERALS

Before a new mineral and its name can be accepted into the literature, they must be

approved by the CNMMN. To obtain this approval, the senior investigator should submit a proposal to the chairman of the CNMMN (see Appendix I), either directly, or through a national new-minerals committee, if appropriate; at present, national committees perform this function in Russia and China.

It is important that a new-mineral proposal be submitted for approval **before** publication. Such a submission should contain as much information as possible so that the CNMMN can adequately judge the validity of the proposal. Ideally, a new-mineral proposal should contain the following information:

Proposed name and reason for its selection.

Description of the occurrence (geographic and geological occurrences, paragenesis, and a list of associated minerals, particularly those in apparent equilibrium with the new mineral).

Chemical composition and method of analysis.

Chemical formula, empirical and simplified.

Crystallography: crystal system, crystal class, space group, point group, unit-cell parameters, unit-cell volume, number of formula units per unit cell, and X-ray powder-diffraction data.

Crystal structure: general description, site populations, structural formula, reliability factor.

General appearance and physical properties: grain or crystal size, morphology, type of aggregate, color, streak, luster, transparency, hardness, tenacity, cleavage, parting, fracture, density, both measured and calculated (Mandarino 1981a).

Optical properties

a) Non-opaque minerals: optical character (isotropic or anisotropic; uniaxial or biaxial), optical sign, indices of refraction, $2V$, dispersion, orientation, pleochroism and absorption. The compatibility index using the Gladstone – Dale relationship (Gladstone & Dale 1864) should also be calculated (Mandarino 1981b, Bloss *et al.* 1983).

b) Opaque minerals: color in reflected plane-polarized light, internal reflections, reflectance, bireflectance, pleochroism and anisotropy. The reflectance must be measured relative to a reflectance standard approved by the IMA Commission on ore microscopy (IMA-COM), ideally from 400 to 700 nm at intervals of 20 nm. The **minimum** requirement is for reflectance data at the wavelengths 470, 546, 589 and 650 nm. Where data are supplied for measurements in oil, the oil used should conform to the German standard DIN 58.884; this and other recommendations of the IMA-COM are contained in Criddle & Stanley (1993).

Other data: Thermal behavior, infrared spectrum, response to chemical tests, *etc.*

Type material: The type material should be designated according to the criteria published by Dunn & Mandarino (1987) and deposited as permanent reference material in at least one major museum or a nationally recognized mineral collection (Dunn 1988).

Relationship to other species.

Relevant references

Any other data that will clarify difficult parts of the description.

It is recognized that it may not always be possible to obtain all the above data; in such cases, the author should give reasons for the omissions. Of particular importance is the calculation of H₂O content where it has not been determined analytically. If H₂O is reported by difference, the method of calculation should be clearly stated and, if possible, evidence for the presence of H₂O should be provided. Also, ample justification should be given for the

allocation of hydrogen to H₂O, OH or H₃O.

Because of great differences in the amount and type of information that can be obtained from the study of a particular mineral specimen, it is not practical to specify the irreducible minimum of information required for a mineral to be approved; each proposal must be considered on its own merits.

A general outline of the procedures involved in establishing a new mineral species is given by Dunn (1977). To assist potential authors of new-mineral proposals, a check-list has been drawn up (Mandarino 1987) and should be submitted as part of the proposal. Copies of an official check-list can be obtained from the chairman of the CNMMN or from one of the national representatives (Appendix I). Guidelines on some aspects of new-mineral proposals are given below.

To assist scientists who do not have all the technical facilities to obtain some important data for the complete definition of a new mineral, the CNMMN (*via* its chairman or secretary) may ask some of its members, or specialists of some subcommittees, to collaborate with these scientists in order to improve their proposal.

It happens in some cases that non-mineralogical specialists such as crystallographers or chemists publish a crystal-structure description of a new mineral that has not been officially approved by the CNMMN. Such descriptions should not include a name for the mineral.

If the entire mineral specimen has been consumed during the course of the investigation, and consequently nothing of the specimen remains to be deposited in an appropriate collection, approval for the new mineral will not be given; this is because some material should always remain for possible later re-examination.

TREATMENT OF A NEW-MINERAL PROPOSAL

When the chairman of the CNMMN receives a new-mineral proposal from authors, either directly or *via* the national new minerals committee in the country of origin, he will acknowledge receipt of the proposal, and may write to the authors asking for more information if he considers this desirable, or he may point out possible objections either to the mineral or to the name. If the authors so desire, the chairman is required to submit a proposal to the CNMMN whether or not he approves of it. In such cases, the chairman will inform the authors that he will give his reasons as to the unsuitability of the proposal under "Chairman's Remarks". The chairman's abstract of a proposal is sent by air mail to each member of the CNMMN, and approximately 60 days are allowed for receipt of voting papers.

Members of the CNMMN are urged, not only to vote, but also to comment in detail. The chairman is authorized to suspend voting on a proposal to enable more information to be obtained, or he may call for a second vote on a proposal if, in his opinion, important comments made by members should be seen by all the members. Second votes have the same voting periods (about 60 days) and require the same majorities as those for original proposals (see below). Any member of the CNMMN who objects to a proposal may ask the chairman to suspend voting or to call for a new vote, but the final decision to do so rests with the chairman.

Abstracts of proposals dealing with opaque minerals may be sent to some members of the IMA-COM at the discretion of the Chairman. Similarly, the chairman may submit abstracts of any proposals to other specialists for advisory opinions. Such advisors do not vote, but their comments are considered by the chairman. Serious objections raised by any advisors

are to be treated by the chairman as specified above.

Proposals dealing with minerals belonging to mineral groups for which subcommittees have been organized by the CNMMN may be sent to the appropriate subcommittee chairman for circulation among the subcommittee members if the CNMMN chairman thinks such action is advisable. Subcommittee members are invited to submit opinions, and serious objections raised by them are to be treated as specified above.

If two or more proposals for the same new mineral are received by the chairman, the proposal that arrived first in the chairman's office will have priority. Exceptions can be made if the new-mineral proposal has been submitted *via* a national new-mineral committee and if the CNMMN chairman has been given prior notification of the receipt of the proposal by the national committee.

A proposed new mineral will be considered approved if more than half (1/2) of the members of the CNMMN vote on the proposal, and if more than two-thirds (2/3) of these members have voted "yes". A proposed name will be considered approved if more than one-half (1/2) of the members who vote on the proposal vote "yes". In assessing the voting results, an abstention is regarded as a negative vote, as it suggests that additional information is required. After the voting on a proposal is completed, the chairman sends the results to the CNMMN members and to the author of the proposal. He includes the comments of the voting members, but the votes of individual members are not disclosed. Reconsideration of adverse votes can be requested by an author at any time if **significant new data or new interpretations** are obtained. If a mineral is approved, but not the name, a new name should be requested by the chairman when he notifies the author of the voting results. In cases of repeat voting, approvals of the mineral and the name require the same majorities as in the original voting.

Authors who have described new minerals without names do not have any priority rights on the subsequent naming of such minerals. However, as a matter of courtesy, it is recommended that a person proposing a name for a previously unnamed mineral communicate with the original authors of the unnamed mineral. Any new names proposed subsequently have to be approved by the CNMMN, as do the minerals for which the names are proposed.

The publication of a non-approved name, or the publication of a name for a non-approved mineral is not acceptable, and journal editors should guard against the introduction of such names.

MINERAL GROUPS

The nomenclature of mineral groups is generally dealt with by subcommittees comprising specialists in the group under consideration, and including at least one member of the CNMMN. The following subcommittees have been established in the past: Pyrochlore, Amphiboles, Pyroxenes, Sulfosalts, Micas, Zeolites, Platinum-Group Minerals, Nomenclature, and Unnamed Minerals.

The creation of a subcommittee, and the composition of its membership, must be approved by the CNMMN. The subcommittee is expected to formulate recommendations for the nomenclature of minerals in the group under consideration, and these recommendations are submitted to the CNMMN for approval by a voting procedure. The recommendations of a group subcommittee are regarded as being of an advisory nature, with the final decision regarding the adoption of the recommendations resting with the CNMMN.

Proposals for the creation of new subcommittees should be submitted to the chairman of the CNMMN. If the establishment of a new subcommittee is approved, the CNMMN secretary (see Appendix I) is authorized to deal with procedural matters involving the subcommittee.

CHANGES TO EXISTING NOMENCLATURE

General

Changes to existing mineral nomenclature, including the redefinition or discreditation of existing mineral species, the renaming of minerals, or the revalidation of discredited or obsolete mineral names, must be approved by the CNMMN **before** publication. Toward this end, a suitable proposal should be submitted to the vice-chairman of the CNMMN (see Appendix I).

A list of changes in nomenclature approved by the CNMMN since 1987 is given in Appendix II.

Redefinition

Advances in knowledge such as those resulting from structure refinements or new chemical knowledge extending known ranges of solid solution do not, in general, need to be referred to the CNMMN. However, approval of the CNMMN is required if it is proposed to redefine a mineral a) on structural grounds, b) by adding or deleting one or more chemical components regarded as essential to the definition, or c) by proposing compositional limits in a solid-solution series that are not compatible with the existing definition of the 50% rule (or its equivalent in multicomponent systems). In case of doubt, the authors are invited to consult with the vice-chairman of the CNMMN.

If a mineral is shown to be a mixture and one of the components is otherwise new, the name should usually be transferred to the new phase.

Redefinition of a mineral species requires a review of the literature on the mineral to be redefined, a re-examination of the type specimen (see below), a comparison of the new data with the original, and justification for the redefinition.

Discreditation

A mineral or mineral name may be discredited if it can be shown that the mineral is identical to another one that has priority, or if the name is misleading. Requirements for discrediting a mineral species or name are similar to those for redefinition (above), and have been outlined by Dunn (1990).

Revalidation

A mineral that has been discredited or fallen into disuse may be revalidated if a re-examination shows that the mineral meets the normal criteria for a distinct mineral species or that it is a mixture containing a new mineral species. Requirements for revalidating a mineral species are similar to those for redefinition, as given above.

Type specimens

Wherever possible, the redefinition, discreditation or revalidation of a mineral should be based on a study of type material. If a type specimen exists and if the original description,

though faulty, represents a reasonable approximation to material on the specimen, the mineral is to be defined by reference to the type material rather than to the original description. This means that errors in the original description cannot be held to discredit a mineral unless the original description was so grossly inaccurate that, in the words of J.D. Dana (1868) "a recognition of the mineral by means of it is impossible".

If type material cannot be obtained for study, the investigator may propose a neotype to the CNMMN, clearly stating the efforts made to seek the original type-specimen, and providing satisfactory evidence for the identity of the neotype with the original. Both the acceptance of the neotype and approval of the proposal are within the authority of the CNMMN.

Preparation of a nomenclature proposal

A proposal to change mineral nomenclature should include all relevant information, including a summary of the original description of the mineral, a review of subsequent reports, the submission of new data, and recommendations for change.

If one or more of the original authors of the mineral to be discredited or redefined are alive, the author of the discreditation or redefinition proposal should write to the original authors asking them to comment on the proposal, and these comments should accompany the submission to the CNMMN.

A proposal for a change of nomenclature should be sent to the vice-chairman of the CNMMN, who is authorized to write to the author pointing out possible deficiencies in the proposal and making suggestions for its improvement. The proposal, modified if necessary, is then submitted to members of the CNMMN as a draft proposal, inviting them to comment. Such comments, if any, are forwarded to the authors of the draft proposal, who are asked to respond to the comments, amend the proposal, or withdraw it, as appropriate. If the proposal is not withdrawn, the amended proposal is submitted to the CNMMN membership for a formal vote, together with the comments on the draft proposal and the authors' responses. The voting procedure is similar to that followed in the case of new-mineral proposals, and at least a two-thirds majority is required to approve such proposals.

GENERAL GUIDELINES FOR MINERAL NOMENCLATURE

Choice of a new mineral name

The responsibility for the choice of a name for a new mineral rests primarily with the author(s) of the original description, although the name must ultimately be approved by the CNMMN. A mineral is commonly named for the geographical locality of its occurrence, for the discoverer of the mineral (although not if he or she is the author), for a person prominent in the field of mineralogy, or for a particular property of the mineral.

The naming of minerals for organizations or interest groups, although done in the past (*e.g.*, *minrecordite*, *mgriite*) is to be discouraged, so as to avoid possible excesses, such as commercial advertising.

If the mineral is to be named after a geographical occurrence, care must be taken to ensure that the spelling conforms to that in use at the locality; the spelling should not be taken from translations.

If the mineral is to be named after a living person, that person's permission must be obtained by the author, and this should be done prior to the submission of the proposal to the

CNMMN. When deciding to name a mineral after a person, it is well to recall J. D. Dana's (1854) precept: "It should be remembered that the use of names of persons eminent in other sciences, or of such as are ignorant of all science, is wholly at variance with good usage and propriety; moreover, an attempted flattery of the politically distinguished is degrading to science, and cannot be too strongly discountenanced". If the mineral is named after a person with a space or a capital letter in the name, the name should be modified to eliminate them, *e.g.*, *mcnearite*, **not** *mcNearite*; *joesmithite*, **not** *joe smithite*. Otherwise, the original spelling of the person's name should be retained.

Although the CNMMN does not have a fixed policy on the use of compounded personal names, some members feel that they should be discouraged, particularly where they become cumbersome or cacophonous, or where they unnecessarily distort the true names of the individual who is supposedly being honored.

Mineral names proposed in languages that use other than the Latin alphabet should be transliterated into the Latin alphabet by the author of the name according to the prevalent system operative in the country of origin. Such transliterated names should be reported, in national journals, for example, when the name of the mineral is written according to other alphabets or phonetic rules. Diacritical marks should be retained wherever possible, but it is recognized that not all printing establishments have the necessary facilities for printing all types of diacritical marks; in such cases, diacritical marks may be omitted.

Re-use of a discredited or obsolete name for a new or redefined mineral is to be discouraged, except when the new mineral is a component of a mixture originally described as a single mineral; in such a case, the original name may be transferred to the new phase. Re-use of a discredited name may also be permitted if there is a good reason why the discredited name is particularly appropriate for the mineral in question, and the discredited or obsolete name has not appeared in the active literature (except for the report of its discreditation) for **fifty years**. A proposal to re-use an obsolete name must be accompanied or preceded by a proposal to discredit the obsolete name. If the CNMMN does not approve a proposal to re-use a discredited name, the author of the proposal has no priority for the use of the discredited name, although he is free to propose the name again at a future time.

The re-use of an obsolete or discredited name is not permitted if the name has been used to a significant extent outside the field of mineralogy (*e.g.*, in petrography, metallurgy, palaeontology, *etc.*), or to indicate two or more minerals.

If an artificial substance has been given a name, and a mineral corresponding to that substance is subsequently discovered, the name given to the artificial substance does not necessarily have to be applied to the mineral.

The name must be sufficiently different from existing ones to prevent confusion, both in the author's language and in others. Existing mineral nomenclature already displays a number of examples of unfortunate names that are easily confused; names such as *celadonite* and *caledonite*, or *mallardite* and *malladrite* can easily be misspelled; names such as *rhodesite*, *rhodizite* and *rhodusite* are euphonically very similar. Introduction of new names that can create similar problems must be avoided.

If the new mineral is clearly and simply related to an existing one, it is very desirable that this relationship be indicated in the new name, *e.g.*, *clinoenstatite* for the monoclinic dimorph of enstatite, or *magnesiocopiapite* for the Mg analogue of copiapite. Such a name should consist of one word only (*e.g.*, *magnesiocopiapite*, **not** *magnesium copiapite*).

Efforts should be made to choose a simple name rather than an excessively complicated one that may be difficult to read or pronounce. The use of excessively long names should be avoided, as these may cause difficulties in pronunciation, tabulations, and computer databases.

Rare-earth minerals

The name of a mineral with essential rare-earth elements (*REE*), or the chemically related elements Y or Sc, must have a suffix indicating the dominant rare-earth element, *e.g.*, *bastnäsité-(Ce)*, and if a new mineral with the same structure and analogous composition, but with a different dominant rare-earth element, is discovered, it should be given a name that is analogous to that of the existing mineral, *e.g.*, *bastnäsité-(Y)*. A suffix of this type is known as a **Levinson modifier** after the person who introduced this procedure (Levinson 1966). A subsequent clarification (Bayliss & Levinson 1988) specifies that more than one chemical symbol may be appended only if the elements occupy different crystal-structure sites. A compilation of rare-earth minerals, appropriately suffixed, was given as an Appendix to Nickel & Mandarino (1987).

An example of a situation that may arise is one in which a mineral with a particular structural site is occupied by both Ca and *REE*, and the sum of *REE* elements (in molar proportions) is greater than that of Ca, but individual *REE* elements are subordinate to that of Ca. In such a case, the mineral is regarded as a rare-earth mineral, with a Levinson modifier specifying the predominant *REE*.

Extended Levinson modifiers

As noted above, Levinson modifiers are used primarily in the nomenclature of rare-earth minerals. In a few cases, however, the procedure has been extended to other mineral groups that can contain different substituting elements in one or more structural sites, *e.g.*, *jahnsite* and *pumpellyite*. In zeolites, such modifiers are used to indicate exchangeable cations. In general, the use of extended Levinson modifiers is acceptable in cases where only one substituting element is suffixed, but suffixes consisting of multiple elements are conditionally acceptable in cases where the structure is complex, and use of such suffixes simplifies the nomenclature.

Adjectival modifiers

In mineralogical nomenclature, it is important to distinguish the name proper from adjectival modifiers that may precede the name and are not connected to it. An adjectival modifier is not considered to be part of the mineral name, and is normally used to indicate a compositional variant, *e.g.*, *ferroan manganotantalite*, where *ferroan* is the adjectival modifier that indicates the presence of some ferrous iron, and *manganotantalite* is the name proper. It is recommended that Latin-derived adjectives should be used whenever possible (Hey & Gottardi 1980), *e.g.*, *natrian versus sodian*, and *kalian versus potassian*. The adjectival modifiers recommended by Schaller (1930) have found general acceptance, and they have been augmented by additional ones in the more comprehensive list of adjectival modifiers published by Nickel & Mandarino (1987). In constructing an adjectival modifier that is not in the list, the ending *oan* is to be used for the ion with the lower valency, and *ian* for the higher. If the valency of an element in a particular mineral is not known, the adjectival modifier derived from the more likely, or more common, valence state of the element should be used.

As adjectival modifiers are not considered to be a part of the mineral name, they should be ignored in the preparation of alphabetical indexes. Occasionally an adjectival modifier is given in the form of a hyphenated chemical prefix, *e.g.*, *Li-tosudite*, rather than *lithian tosudite* or *lithium-bearing tosudite*. Such usage is incorrect and should be avoided.

Varietal names

The existing names of mineral varieties such as *amethyst*, *kunzite*, *etc.*, which are not regarded as species, do not come under the jurisdiction of the CNMMN, and are therefore unregulated. The introduction of new varietal names, however, is to be discouraged, as it tends to create confusion in the mineralogical literature.

Nomenclature of mineral groups

As noted above, subcommittees have been established for a number of complex mineral groups. Some of these subcommittees have produced reports that have been approved by the CNMMN, and these reports have been published in a number of different journals. The reports, which include guidelines for the nomenclature of minerals comprising these groups, are too complex to be summarized adequately here; readers are advised to consult the published reports of these subcommittees, as follows: pyrochlore: Hogarth (1977), pyroxenes: Morimoto *et al.* (1989), platinum-group minerals: Harris & Cabri (1991), amphiboles: Leake *et al.* (1997), zeolites: Coombs *et al.* (1997) and micas: Rieder *et al.* (1998).

In general, names of less complex mineral groups are well established in the mineralogical literature, and frequently one of the species names of the minerals comprising the group is used for this purpose. The use of such group names is not regulated by the CNMMN, but the creation of a new name must have the approval of the CNMMN.

Nomenclature of polytypes, polytypoids and polymorphs

The approved system for denoting polytypes is the modified Gard notation recommended by the International Mineralogical Association and the International Union of Crystallography (Bailey *et al.* 1978, Guinier *et al.* 1984, Nickel 1993). It consists of the mineral name followed by a hyphenated, italicized suffix comprising an alphabetic character to indicate crystal system, preceded by a numerical symbol to indicate multiplicity of the structural unit, as first proposed by Ramsdell (1947). This system can also be used for topologically similar polymorphs and for polytypoids. The alphabetical characters to be used in the suffixes are as follows: cubic: *C*, tetragonal: *Q* (for Quadratic), hexagonal: *H*, trigonal: *T*, rhombohedral: *R*, orthorhombic: *O*, and triclinic: *A* (for Anorthic).

Example 1: Muscovite-1*M* is the monoclinic polytype of muscovite with $c = 10 \text{ \AA}$; muscovite-2*M*₁ is the monoclinic polytype of muscovite with $c = 20 \text{ \AA}$, and muscovite-3*T* is the trigonal polytype of muscovite with $c = 30 \text{ \AA}$.

Example 2: Analcime has a number of topologically identical polymorphs caused by different degrees of order of Al and Si in the tetrahedral structural sites. The different polymorphs are distinguished by the suffixes -1*C*, -1*Q*, -1*M*, *etc.*

Nomenclature of nanometric domains

If a domain of nanometric dimensions in a larger mineral grain has a unique composition or crystal structure but is not sufficiently large to qualify as a mineral species, it should not be given a distinctive mineral name. If it is deemed necessary to refer to such a domain by name, it should retain the name of the host mineral, with the addition of an appropriate suffix to indicate the crystallographic or compositional nature of the domain. Such suffixes do not require approval by the CNMMN.

Nomenclature of variable-fit homologous series

Individual names should not be given to members of variable-fit homologous series (see a previous section). Instead, an optional descriptive modifier may be appended, describing the match between the building blocks. The contents of the appended symbol will vary according to the precision required or the method used, should contain the word “homologue”, and should be enclosed by < > brackets. An example is “*cylindrite* < *homologue* (19, 13)Q/(30, 12)H> ” for a homologue of the cylindrite series with a tetragonal (quadratic) building block of 19 by 13 units that is commensurable with a hexagonal block of 30 by 12 units.

Prefixes in mineral names

In applying compositional prefixes to mineral names, it is recommended that Latin-derived prefixes should be used instead of other linguistic derivatives (Hey & Gottardi 1980), e.g., *ferro-* instead of *eisen-*, *natri-* instead of *soda-*, or *stanno-* instead of *olovo-*.

Prefixes are an integral part of the mineral name, and should generally be treated as such in the preparation of alphabetical compilations or indexes. However, an exception can be made in the case of prefixed symbols such as Greek letters or their spelled-out Latin equivalents, which may be positioned after the main name in alphabetical listings; e.g., β -*roselite* may be written as *roselite*- β or *roselite-beta*.

The prefix *para* should be used only for names of dimorphs or polymorphs of known minerals. The prefix *meta* should be used only for names of lower hydrates of known minerals.

Hyphens in mineral names

Hyphens are used in mineral names to connect suffixed symbols, such as polytype suffixes and Levinson modifiers. The use of a hyphen to distinguish a prefix from the root name is to be discouraged, but where an unhyphenated name is awkward and a hyphen assists in deciphering the name, it may be used, e.g., *bario-orthojoaquinite*.

Mineral names for synthetic substances

Unmodified mineral names should not, in general, be used for synthetic substances corresponding to existing minerals, chemical analogues of existing minerals, or hypothetical minerals. However, synthetic substances that correspond to existing minerals may be given mineral names if such names are suitably modified to clearly indicate their synthetic origin (Nickel 1995b), or if the synthetic origin of such substances is clearly stated.

The published paper describing the new mineral should include sufficient information, comparable to that given in the proposal to the CNMMN. Publication in a brief abstract in which only some of the data are given should be avoided.

Authors of approved proposals should publish descriptions of the minerals covered by these proposals **within two years** of being notified of the approval by the chairman or vice-chairman. If new-mineral descriptions, discreditations, redefinitions or revalidations are not published within that time, the proposals are no longer considered as approved. Any extensions of this deadline must be approved by the chairman or vice-chairman, as appropriate.

ADVICE TO EDITORS

Journal editors will do a service to the earth science community if they cooperate fully with the CNMMN. All aspects of the nomenclature in submitted manuscripts should be evaluated according to the guidelines given here, and assurance should be sought from authors that they have submitted all matters dealing with mineral nomenclature to the CNMMN, and that their proposals have been approved. Unless they have definite proof of approval, editors should consult with their national representatives on the CNMMN, or with members of the CNMMN executive. Editors should be particularly cautious about the final acceptance of a paper bearing phrases like "has been submitted" or "will be submitted" to the CNMMN. Acceptance of such papers should be delayed until evidence is produced that the nomenclature **has been approved** by the CNMMN.

In the case of new minerals, editors should insist on evidence that a type specimen of the new mineral has been lodged in at least one major museum or a nationally recognized mineral collection. This information should be included in the published paper.

It would be appreciated if all journals that publish mineralogical papers include the following statement in their instructions to authors: **This journal follows the rules of the Commission on New Minerals and Mineral Names of the IMA in all matters concerning mineral names and nomenclature.**

REFERENCES

ALLEN, F.M. (1992): Mineral definition by HRTEM: problems and opportunities. *In* Minerals and Reactions at the Atomic Scale: Transmission Electron Microscopy (P.R. Buseck, ed.). *Rev. Mineral.* **27**, 289-333.

BAILEY, S.W. (1981): A system of nomenclature for regular interstratifications. *Can. Mineral.* **19**, 651-655.

_____, FRANK-KAMENETSKII, V. A., GOLDSZTAUB, S., KATO, A., PABST, A., SCHULZ, H., TAYLOR, H.F.W., FLEISCHER, M. & WILSON, A.J.C. (1978): Report of the International Mineralogical Association (IMA) – International Union of Crystallography (IUCr) joint meeting on nomenclature. *Can. Mineral.* **16**, 113-117.

BAYLISS, P. & LEVINSON, A.A. (1988): A system of nomenclature for rare-earth mineral species: revision and extension. *Am. Mineral.* **73**, 422-423.

- BLOSS, F.D., GUNTER, M., SU, SHU-CHUN & WOLFE, H.E. (1983): Gladstone–Dale constants: a new approach. *Can. Mineral.* **21**, 93-99.
- COOMBS, D.S. *et al.* (1997): Recommended nomenclature for zeolite minerals: report of the Subcommittee on Zeolites of the International Mineralogical Association, Commission on New Minerals and Mineral Names. *Can. Mineral.* **35**, 1571-1606.
- CRIDDLE, A.J. & STANLEY, C.J., eds. (1983): *Quantitative Data File for Ore Minerals* (3rd ed.). Chapman & Hall, London, U.K.
- DANA, J.D. (1854): *A System of Mineralogy* (4th ed.). John Wiley & Sons, New York, N.Y.
- _____ (1868): *A System of Mineralogy* (5th ed.). John Wiley & Sons, New York, N.Y.
- DONNAY, G. & FLEISCHER, M. (1970): Suggested outline for new mineral descriptions. *Am. Mineral.* **55**, 1017-1019.
- DUNN, P.J. (1977): From unknown to known: the characterization of new mineral species. *Mineral. Rec.* **8**, 341-349.
- _____ (1988): Protocols for scientists on the deposition of investigated mineral specimens. *Am. Mineral.* **73**, 1480.
- _____ (1990): The discreditation of mineral species. *Am. Mineral.* **75**, 928-929.
- _____ & MANDARINO, J.A. (1987): Formal definitions of type mineral specimens. *Am. Mineral.* **72**, 1269-1270.
- _____ & _____ (1988): The Commission on New Minerals and Mineral Names of the International Mineralogical Association; its history, purpose and general practice. *Mineral. Rec.* **19**, 319-323.
- FLEISCHER, M. (1970): Procedures of the International Mineralogical Association Commission on New Minerals and Mineral Names. *Am. Mineral.* **55**, 1016-1017.
- GLADSTONE, J.H. & DALE, T.P. (1864): Researches on the refraction, dispersion, and sensitiveness of the liquids. *Phil. Trans., R. Soc. London* **153**, 317-343.
- GUINIER, A. *et al.* (1984): Nomenclature of polytype structures. Report of the International Union of Crystallography *ad-hoc* Committee on the Nomenclature of Disordered, Modulated and Polytype Structures. *Acta Crystallogr.* **A40**, 399-404.
- HARRIS, D.C. & CABRI, L.J. (1991): Nomenclature of platinum-group-element alloys: review and revision. *Can. Mineral.* **29**, 231-237.

HEY, M.H. & GOTTARDI, G. (1980): On the use of names, prefixes and suffixes, and adjectival modifiers in the mineralogical nomenclature. *Can. Mineral.* **18**, 261-262.

_____, GUILLEMIN, C., PERMINGEAT, F. & DE ROEVER, J.P. (1961): Sur la nomenclature minéralogique. Décisions de la Commission des Nouveaux Minéraux et des Noms de Minéraux de L'Association Internationale de Minéralogie. *Bull. Soc. fr. Minéral. Cristallogr.* **84**, 96-105.

HOGARTH, D.D. (1977): Classification and nomenclature of the pyrochlore group. *Am. Mineral.* **62**, 403-410.

LEAKE, B.E. *et al.* (1997): Nomenclature of amphiboles: report of the Subcommittee on Amphiboles of the International Mineralogical Association Commission on New Minerals and Mineral Names. *Can. Mineral.* **35**, 219-246.

LEVINSON, A.A. (1966): A system of nomenclature for rare-earth minerals. *Am. Mineral.* **51**, 152-158.

MAKOVICKY, E. (1989): Modular classification of sulphosalts – current status. Definition and application of homologous series. *Neues Jahrb. Mineral., Abh.* **160**, 269-297.

_____ & HYDE, B.G. (1981): Non-commensurate (misfit) structures. *Structure and Bonding* **46**, 103-176.

_____ & KARUP-MØLLER, S. (1977): Chemistry and crystallography of the lillianite homologous series. *Neues Jahrb. Mineral., Abh.* **130**, 264-287.

MANDARINO, J.A. (1981a): Comments on the calculation of the density of minerals. *Can. Mineral.* **19**, 531-534.

_____ (1981b): The Gladstone–Dale relationship. IV. The compatibility concept and its application. *Can. Mineral.* **19**, 441-450.

_____ (1987): The check-list for submission of proposals for new minerals to the Commission on New Minerals and Mineral Names, International Mineralogical Association. *Can. Mineral.* **25**, 775-783.

_____, NICKEL, E.H. & CESBRON, F. (1984): Rules of procedure of the Commission on New Minerals and Mineral Names, International Mineralogical Association. *Can. Mineral.* **22**, 367-368.

MORIMOTO, N. *et al.* (1989): Nomenclature of pyroxenes. *Can. Mineral.* **27**, 143-156.

NICKEL, E.H. (1992): Solid solutions in mineral nomenclature. *Can. Mineral.* **30**, 231-234.

- _____ (1993): Standardization of polytype suffixes. *Can. Mineral.* **31**, 767-768.
- _____ (1995a): Definition of a mineral. *Can. Mineral.* **33**, 689-690.
- _____ (1995b): Mineral names applied to synthetic substances. *Can. Mineral.* **33**, 1335.
- _____ & MANDARINO, J.A. (1987): Procedures involving the IMA Commission on New Minerals and Mineral Names and guidelines on mineral nomenclature. *Can. Mineral.* **25**, 353-377.
- RAMSDELL, L.S. (1947): Studies on silicon carbide. *Am. Mineral.* **32**, 64-82.
- RIEDER, M. *et al.* (1998): Nomenclature of the micas. *Can. Mineral.* **36**,
- SCHALLER, W.T. (1930): Adjectival ending of chemical elements used as modifiers to mineral names. *Am. Mineral.* **15**, 567-574.
- VEBLEN, D.R. (1991): Polysomatism and polysomatic series: a review and applications. *Am. Mineral.* **76**, 801-826.

Received May 4, 1998.

NEW MINERALS RECENTLY APPROVED
BY THE
COMMISSION ON NEW MINERALS AND MINERAL NAMES
INTERNATIONAL MINERALOGICAL ASSOCIATION

The information given here is provided by the Commission on New Minerals and Mineral Names, International Mineralogical Association (IMA), for comparative purposes and as a service to mineralogists working on new species. Each mineral is described in the following format:

IMA Number
Chemical formula (any relationship to other minerals)
Crystal system, space group
unit- cell parameters
Color, lustre, diaphaneity
Optical properties
Strongest lines in the X-ray powder-diffraction pattern [d in Å(I)]

The names of these approved species are considered confidential information until the authors have published their descriptions or released information themselves. No other information will be released by the Commission.

Joseph A. Mandarino, Chairman Emeritus and Joel D. Grice, Chairman
Commission on New Minerals and Mineral Names
International Mineralogical Association

1997 PROPOSALS

IMA No. **97-001**

(Bi,Pb)₂Fe(O,OH)₃PO₄

Chemically related to **paulkerrite**

Monoclinic: *C2/m*

a 12.278, b 3.815, c 6.899 Å, β 111.14°

Black to dark brown; vitreous to adamantine; opaque to translucent

Biaxial (-), α 2.06, β 2.15(calc.), γ 2.19, $2V$ (meas.) 70°

5.726(54), 3.372(77), 3.322(37), 3.217(46), 3.011(100), 2.863(34), 2.750(62)

IMA No. **97-002**

Ca₂B₂SiO₇

The boron-dominant analogue of **gehlenite** (melilite group)

Tetragonal: *P42₁m*

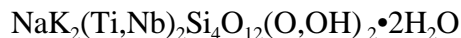
a 7.116, c 4.815 Å

Creamy-white; earthy; earthy

Probably uniaxial (-), n 1.67

3.479(40), 2.862(55), 2.654(100), 2.231(15), 2.129(20), 1.920(35), 1.644(20)

IMA No. **97-003**



The Ti-dominant analogue of **nenadkevichite**

Monoclinic: $C2/m$

a 14.39, b 13.900, c 7.825 Å, β 117.6°

Colorless; vitreous; transparent to translucent

Biaxial (+), α 1.667, β 1.677, γ 1.802, $2V(\text{meas.})$ 32°, $2V(\text{calc.})$ 33°

6.94(61), 6.39(43B), 3.186(100), 3.100(96), 2.600(28), 2.586(28), 2.489(24)

IMA No. **97-004**



A polymorph of **miargyrite**

Cubic: $Fm\bar{3}m$

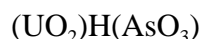
a 5.650 Å

Greyish black; metallic; opaque

In reflected light: grey. R : 34.5% (470 nm), 33.8% (546 nm), 32.8% (589 nm), 28.7% (650 nm).

3.26(9), 2.83(10), 1.998(8), 1.703(6), 1.630(5), 1.296(2), 1.263(3)

IMA No. **97-005**



Tetragonal: space group unknown

a 11.00, c 15.96 Å

Yellow; dull; translucent

Uniaxial (–), ω 1.84, ϵ 1.75

5.58(8), 4.95(10), 4.40(6), 3.33(8), 3.03(6), 2.91(5)

IMA No. **97-007**



The Mn^{2+} -dominant analogue of **nordite-(Ce)**

Orthorhombic: $Pcca$

a 14.449, b 5.187, c 19.849 Å

Colorless, pale brownish, brown; vitreous; transparent

Biaxial (–), α 1.623, β 1.636, γ 1.642, $2V(\text{meas.})$ 60°, $2V(\text{calc.})$ 68°

7.22(38), 4.215(100), 3.326(67), 2.965(83), 2.875(55), 2.597(54), 2.443(35)

IMA No. **97-008**



The Fe^{2+} -dominant analogue of **nordite-(Ce)**

Orthorhombic: $Pcca$

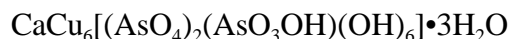
a 14.460, b 5.187, c 19.848 Å

Colorless or light coffee color; vitreous; transparent

Biaxial (–), α 1.623, β 1.636, γ 1.642, $2V(\text{meas.})$ 60°, $2V(\text{calc.})$ 68°

7.22(41), 4.216(100), 3.325(67), 2.964(73), 2.879(62), 2.595(46), 2.444(31)

IMA No. **97-009**



The calcium- and arsenate-dominant member of the **mixite** group

Hexagonal: $P6_3/m$

a 13.571, c 5.880 Å

Pale green; vitreous; transparent

Uniaxial (+), ω 1.688, ϵ 1.765
11.64(100), 4.431(41), 3.387(17), 3.254(22), 2.9347(42), 2.6932(29), 2.5624(30)

IMA No. **97-010**

$\text{Pb}_4\text{As}_2\text{S}_7$

Orthorhombic: $Pba2$ or $Pbam$

a 15.179, b 38.117, c 4.0428 Å

Silvery lead grey; metallic; opaque

In reflected light: white with a greenish tint, distinct anisotropism (dark grey to greenish grey, weak bireflectance, weak pleochroism. $R_{\min.}$ & $R_{\max.}$: 33.8, 34.0% (470 nm), 31.8, 31.9% (546 nm), 31.2, 31.3% (589 nm), 30.4, 30.4% (650 nm)

4.462(40), 3.699(37), 3.392(100), 2.817(45), 2.735(31), 2.156(25), 2.150(22)

IMA No. **97-012**

$\text{Ca}(\text{Al,Fe}^{2+},\text{Mg,Mn})_2(\text{AsO}_4)_2(\text{OH})_2$

Monoclinic: $C2$

a 8.9252, b 6.1427, c 7.352 Å, β 115.25°

Light brownish to brownish pink, orange-brown; vitreous; transparent

Biaxial (sign unknown), n 1.76 parallel to fiber, n 1.70 perpendicular to fiber

4.914(58), 3.376(65), 3.164(100), 3.084(61), 2.945(72), 2.687(53), 2.522(84)

IMA No. **97-013**

$\text{Ca}_8\text{Mg}(\text{SiO}_4)_4\text{Cl}_2$

Cubic: $Fd\bar{3}$

a 15.0850 Å

Orange brown to amber; vitreous; transparent

Isotropic, n 1.676

2.901(40), 2.666(100), 2.549(30), 1.9637(30), 1.8845(30), 1.7774(30), 1.5400(50), 1.4585(30)

IMA No. **97-014**

$\text{Mg}_2\text{Al}_3\text{B}_2\text{O}_9(\text{OH})$

Chemically and structurally related to **sinhalite**

Monoclinic: $P2_1/c$

a 7.49, b 4.33, c 9.85 Å, β 110.7°

Colorless; vitreous; transparent

Biaxial (-), α 1.691, β 1.713, γ 1.730, $2V(\text{meas.})$ 80.0°, $2V(\text{calc.})$ 82°

3.21(40), 2.61(40), 2.14(100), 2.102(60), 1.625(100), 1.607(40), 1.399(40)

IMA No. **97-015**

$(\text{Na,Ca})_5\text{Ca}(\text{Ti,Nb})_5\text{Si}_{12}\text{O}_{34}(\text{OH,F})_8 \cdot 5\text{H}_2\text{O}$

A Ca-dominant polymorph of **zorite**

Orthorhombic: $C222$

a 7.024, b 23.155, c 6.953 Å

Pale brown, brown, orange-yellow; vitreous; transparent to translucent

Biaxial (+), α 1.599, β 1.610, γ 1.696, $2V(\text{meas.})$ 38°, $2V(\text{calc.})$ 41°

11.564(100), 6.932(90), 5.258(40), 4.446(40), 3.052(75), 2.977(70), 2.582(40)

IMA No. **97-017**

Sb_2O_4 ($\text{Sb}^{3+}\text{Sb}^{5+}\text{O}_4$, β -phase)

A monoclinic polymorph of **cervantite**

Monoclinic: $C2/c$

a 12.061, b 4.836, c 5.383 Å, β 104.60°

Colorless; vitreous; transparent

Biaxial (sign unknown), α' 1.72, γ' 2.10

3.244(VS), 2.920(M), 2.877(S), 1.619(M)

IMA No. **97-018**

$\text{K}(\text{Ca},\text{Mn},\text{Na})_2(\text{K}_{2-x}\square_x)_2\text{Zn}_3\text{Si}_{12}\text{O}_{30}$

A member of the **milarite** group

Hexagonal: $P6/mcc$

a 10.505, c 14.185 Å

Colorless, white; vitreous; transparent to translucent

Uniaxial (+), ω 1.561, ϵ 1.562

7.11(35), 3.830(100), 3.345(60), 3.304(40), 2.940(50), 2.795(85), 2.627(35)

IMA No. **97-019**

$\text{Zn}_4\text{Al}_2(\text{OH})_{12}(\text{CO}_3)\cdot 3\text{H}_2\text{O}$

The zinc-dominant member of the **manasseite** group

Hexagonal: $P6_3/mmc$

a 3.0725, c 15.1135 Å

White; vitreous; transparent

Optical properties could not be measured

7.51(vs), 3.794(m), 2.511(mw), 2.175(mw), 1.830(mw), 1.542(ms), 1.539(ms)

IMA No. **97-021**

HgBi_2S_4

Monoclinic: $C2/m$

a 14.164, b 4.053, c 13.967 Å, β 118.28°

Grey-black; metallic; opaque

In reflected light: creamy-white, distinct anisotropism, low bireflectance, nonpleochroic. R_1 & R_2 :

35.7, 37.8% (470 nm), 35.4, 37.5% (546 nm), 34.9, 37.0% (589 nm), 33.9, 35.8% (650 nm)

3.86(m), 3.55(m), 3.05(S), 2.914(mS), 2.865(mS), 2.644(m), 1.913(m), 1.805(m)

IMA No. **97-022**

$(\text{Cd},\text{Ca},\text{Mn})\text{KCu}_5(\text{AsO}_4)_4[\text{As}(\text{OH})_2\text{O}_2](\text{H}_2\text{O})_2$

The cadmium-dominant analogue of 97-023

Monoclinic: $P2_1/m$

a 9.8102, b 10.0424, c 9.9788 Å, β 101.686°

Electric blue; vitreous; transparent

Biaxial (-), α 1.720, β 1.749, γ 1.757, $2V$ (meas.) 50°, $2V$ (calc.) 55°

9.64(100), 4.46(40), 3.145(50), 3.048(40), 2.698(40)

IMA No. **97-023**

$(\text{Ca},\text{Cd},\text{Mn})\text{KCu}_5(\text{AsO}_4)_4[\text{As}(\text{OH})_2\text{O}_2](\text{H}_2\text{O})_2$

The calcium-dominant analogue of 97-022

Monoclinic: $P2_1/m$

a 9.8102, b 10.0424, c 9.9788 Å, β 101.686°

Electric blue; vitreous; transparent

Biaxial (–), α 1.713, β 1.743, γ 1.749, $2V(\text{meas.})$ 50° , $2V(\text{calc.})$ 48°

9.64(100), 4.46(40), 3.145(50), 3.048(40), 2.698(40)

IMA No. **97-024**

$\text{Cu}_4\text{Cd}(\text{SO}_4)_2(\text{OH})_6 \cdot 4\text{H}_2\text{O}$

The cadmium-dominant analogue of **campigliaite**

Monoclinic: $P2_1/m$

a 5.543, b 21.995, c 6.079 Å, β 92.04°

Bluish green; vitreous; transparent

Biaxial (–), α 1.619, β 1.642, γ 1.661, $2V(\text{meas.})$ 66° , $2V(\text{calc.})$ 83°

11.02(90), 5.496(100), 5.322(25), 4.079(50), 3.437(30), 3.243(40), 2.470(30)

IMA No. **97-025**

$\text{UO}_2\text{CO}_3 \cdot \text{H}_2\text{O}$

Hexagonal: space group unknown

a 15.79, c 23.93 Å

Canary yellow; silky; translucent

Uniaxial (+), ω 1.588, ϵ 1.612

7.86(47), 6.91(55), 6.56(77), 4.76(40), 4.34(36), 3.39(33), 3.056(100)

IMA No. **97-026**

$\text{Ca}_{19}(\text{Al}, \text{Mg}, \text{Fe}, \text{Ti})_{13}(\text{B}, \text{Al}, \square)_5\text{Si}_{18}\text{O}_{68}(\text{O}, \text{OH}, \text{F})_{10}$

The boron-dominant analogue of **vesuvianite**

Tetragonal: $P4/nnc$

a 15.752, c 11.717 Å

Dark green; vitreous; translucent

Uniaxial (+), ω 1.721, ϵ 1.725

2.776(100), 2.617(61), 2.592(43), 2.491(61), 2.121(20), 1.660(26), 1.640(23)

IMA No. **97-027**

$\text{Ca}(\text{Co}, \text{Fe}, \text{Ni})_2(\text{AsO}_4)_2(\text{OH}, \text{H}_2\text{O})_2$

The cobalt-dominant analogue of **lotharmeyerite**

Monoclinic: $C2/m$

a 9.024, b 6.230, c 7.421 Å, β 115.15°

Brown; vitreous; translucent

Biaxial (+), α 1.78, β 1.79, γ 1.85(calc.), $2V(\text{meas.})$ 48°

4.955(38), 3.398(85), 3.188(28), 3.115(33), 2.972(100), 2.709(28), 2.545(34)

IMA No. **97-029**

$\text{Rh}_{17}\text{S}_{15}$

The rhodium- and sulfur-dominant analogue of **palladseite**

Cubic: $Pm\bar{3}m$, $P4\bar{3}m$ or $P4\bar{3}2$

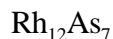
a 10.024 Å

Color unknown; metallic; opaque

In reflected light: grey with slight bluish tint, isotropic. R: 38.6% (480 nm), 39.0% (540 nm), 39.1% (580 nm), 38.8% (660 nm)

3.33(2), 3.17(7), 3.02(9), 2.68(5), 2.24(9), 1.931(8), 1.774(10)

IMA No. **97-030**



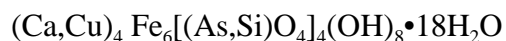
Hexagonal: $P6_3/m$

a 9.31, c 3.64 Å

Color unknown; metallic; opaque

In reflected light: brownish grey, weak anisotropism from grey to brownish grey, weak bireflectance, nonpleochroic. $R_{\min.}$ & $R_{\max.}$: 44.5, 47.8% (480 nm), 44.7, 48.3% (540 nm), 46.4, 49.2% (580 nm), 48.6, 51.3% (660 nm)
2.33(4), 2.03(2), 1.852(9), 1.767(6), 1.755(10), 1.549(8)

IMA No. **97-032**



The Fe^{2+} -dominant analogue of **walkkildellite**

Hexagonal: $P6_3/mmc$, $P6_3mc$ or $P62c$

a 6.548, c 23.21 Å

Brown-yellow; vitreous to resinous; translucent

Uniaxial (-), ω 1.750, ϵ could not be determined

11.6(100), 5.670(80), 3.275(70), 2.850(10), 2.760(15), 2.547(10), 1.641(25)

IMA No. **97-034**



Monoclinic: $P2_1/n$

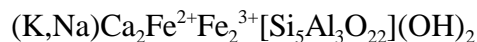
a 6.629, b 7.616, c 7.379 Å, β 91.79°

Dark green; adamantine; translucent

Biaxial (sign unknown), n 1.94, mineral reacts with liquids of $n > 1.9$

3.385(100), 3.315(78), 2.939(47), 2.839(28), 2.381(29), 2.331(29), 1.652(32), 1.621(34)

IMA No. **97-035**



A member of the amphibole group

Monoclinic: $C2/m$

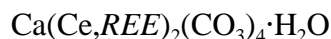
a 9.94, b 18.08, c 5.38 Å, β 105.5°

Black; vitreous; transparent

Biaxial (-), α 1.696, β not determined, γ 1.715, $2V(\text{meas.})$ 45°

8.44(90), 3.405(25), 3.285(30), 3.145(100), 2.823(26), 2.722(52), 2.606(27), 2.579(25)

IMA No. **97-036**



Triclinic: $P1$

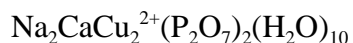
a 6.397, b 6.389, c 12.383 Å, α 96.58°, β 100.85°, γ 100.46°

Colorless to white; vitreous; translucent

Biaxial (-), α 1.635, β 1.725, γ 1.750, $2V(\text{calc.})$ 53°

5.901(59), 5.049(72), 4.695(37), 4.468(36), 4.006(110), 3.899(45), 3.125(39), 3.0051(448)

IMA No. **97-037**



Orthorhombic: $Fdd2$

a 11.938, b 32.854, c 11.017 Å

Blue-green; vitreous; transparent

Biaxial (+), α 1.508, β 1.511, γ 1.517, $2V$ (meas.) 76.2°, $2V$ (calc.) 71°

8.23(30), 6.52(100), 4.05(40), 3.255(40), 2.924(40), 2.807(25), 2.614(20)

IMA No. **97-041**

$\text{Na}_2\text{Zn}(\text{SO}_4)_2 \cdot 4\text{H}_2\text{O}$

The zinc-dominant analogue of **blödite**

Monoclinic: $P2_1/a$

a 11.077, b 8.249, c 5.532 Å, β 100.18°

Colorless; vitreous; transparent

Biaxial (-), α 1.507, β 1.512, γ 1.516 (all for synthetic material)

4.550(58), 4.245(32), 3.325(25), 3.289(100), 3.262(35), 3.245(25), 2.631(27)

IMA No. **97-042**

$\text{Pb}_9\text{Sb}_{10}\text{S}_{24}$

Triclinic: $P1$

a 24.789, b 8.26, c 21.787 Å, α 90.53°, β 99.58°, γ 94.78°

Black; metallic; opaque

In reflected light: black, low anisotropism, low bireflectance, nonpleochroic. R_1 & R_2 : 38.95, 37.64% (470 nm), 42.35, 38.26% (546 nm), 41.67, 37.63% (589 nm), 37.43, 36.53% (650 nm)
3.47(vs), 3.35(ms), 3.24(ms), 2.986(s), 2.947(s), 2.229(ms)

IMA No. **97-043**

PbSnS_3

Orthorhombic: $Pnma$

a 8.8213, b 3.7725, c 14.0053 Å

Greyish black; metallic; opaque

In reflected light: white, weak anisotropism, weak bireflectance, nonpleochroic. R_1 & R_2 : 33.9, 36.0% (470 nm), 31.3, 32.9% (546 nm), 30.0, 31.4% (589 nm), 28.8, 29.9% (650 nm)
4.128(100), 3.730(30), 3.1085(28), 2.8081(51), 2.7421(41), 2.6692(51), 1.9335(54)

IMA No. **97-044**

$(\text{Mg,Fe})\text{SiO}_3$

A member of the **ilmenite** group

Hexagonal (trigonal): $R3$

a 4.78, c 13.6 Å

Colorless; vitreous; transparent

Uniaxial, no other data could be determined

3.509(61), 2.616(100), 2.366(52), 2.097(45), 1.755(45), 1.636(65), 1.366(50)

IMA No. **97-045**

$\text{Na}_2\text{LiAlF}_6$

Monoclinic: $P2_1$ or $P2_1/m$

a 7.5006, b 7.474, c 7.503 Å, β 90.847°

Pale buff-cream; somewhat greasy; transparent to translucent

Almost isotropic (birefringence = 0.0009), biaxial, n 1.359, $2V$ (meas.) up to 27°

4.33(100), 2.65(60), 2.25(70), 2.18(50), 2.158(40), 1.877(90)

IMA No. **97-047**

(Na,Y)(Y,REE)(HCO₃)(OH)₂•5H₂O

Monoclinic: *P2* (pseudo-tetragonal)

a 4.566, *b* 13.018, *c* 4.566 Å, β 90.15°

White to yellow; vitreous; translucent to transparent

Uniaxial (–), ω 1.540, ε 1.40, 2*V*(meas.) 0–5°

12.97(10), 6.52(3), 4.57(3), 4.32(5), 3.223(3), 3.133(5), 2.016(4)

IMA No. **97-048**

NaCa₂Mg₂(VO₄)₃

The magnesium-dominant analogue of **palenzonaite**

Cubic: *Ia3d*

a 12.427 Å

Red; adamantine; transparent

Isotropic, *n* 1.94

3.108(44), 2.779(100), 2.652(20), 2.535(39), 1.723(26), 1.662(40)

IMA No. **97-049**

KFe³⁺₃(H₂PO₄)₆(HPO₄)₂•4H₂O

Monoclinic: *C2/c*

a 16.95, *b* 9.59, *c* 17.57 Å, β 90.85°

White; vitreous; translucent

Biaxial (–), α 1.557, β 1.598, γ 1.602, 2*V*(meas.) 32°, 2*V*(calc.) 34°

8.83(10), 7.60(4), 3.75(10), 3.30(4), 3.23(5), 3.11(4), 3.02(9)

IMA No. **97-050**

BaMn₉[(V,As)O₄]₆(OH)₂

Cubic: *Pa3*

a 12.845 Å

Dark red; adamantine; transparent

Isotropic, *n* > 2.0

3.01(87), 2.790(100), 2.608(100), 2.332(44), 2.134(53), 1.510(99), 1.0020(35)

IMA No. **97-051**

TlAg₂(As,Sb)₃S₆

Orthorhombic: *Pnmb* or *P2₁nb*

a 12.479, *b* 15.522, *c* 5.719 Å

Dark grey; metallic; opaque

In reflected light: pure white, extremely weak anisotropism, no bireflectance, nonpleochroic. *R*_{min.} & *R*_{max.}: 31.43, 33.43% (470 nm), 28.31, 30.52% (546 nm), 27.10, 29.11% (589 nm), 25.57, 27.44% (650 nm)

3.655(16), 3.363(50), 3.290(23), 3.210(26), 3.118(27), 2.822(100), 2.540(17), 2.070(15)

IMA No. **93-029**



Monoclinic: $P2/a$ (?)

a 23.88, b 14.40, c 7.238 Å, β 91.0°

Yellow, pink-yellow or cream; vitreous and silky; translucent

Biaxial (-), α 1.542, β 1.569, γ 1.571, $2V(\text{meas.})$ 28°, $2V(\text{calc.})$ 30°

12.36(100), 3.232(13), 3.190(29), 3.108(29), 3.087(21), 3.058(13), 2.708(12)

IMA No. **96-016**



Orthorhombic: $Pcmm$, $Pcm2_1$, or $Pc2m$

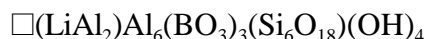
a 11.215, b 3.124, c 19.21 Å

Yellowish white; vitreous or pearly; translucent

Biaxial (-), α 1.532, $\beta \sim \gamma$ 1.562, $2V(\text{meas.}) \leq 5^\circ$

11.41(29), 9.78(46), 9.60(38), 4.25(20), 3.498(100)

IMA No. **96-018**



A member of the tourmaline group

Hexagonal (trigonal): $R3m$

a 15.770, c 7.085 Å

Pink; vitreous; translucent

Uniaxial (-), ω 1.645, ϵ 1.624

4.181(58), 3.950(100), 3.434(52), 2.924(56), 2.552(93), 1.898(72)

IMA No. **96-061**



Hexagonal or trigonal dimorph of **scorodite**

Hexagonal: $P-c$ - (extinction symbol)

a 8.9327, c 9.9391 Å

White to light yellow-brown; vitreous; translucent

Uniaxial (sign unknown), ω and $\epsilon > 1.72$

4.973(61), 4.184(44), 4.076(100), 3.053(67), 2.806(68), 2.661(59), 2.520(54), 2.2891(44)