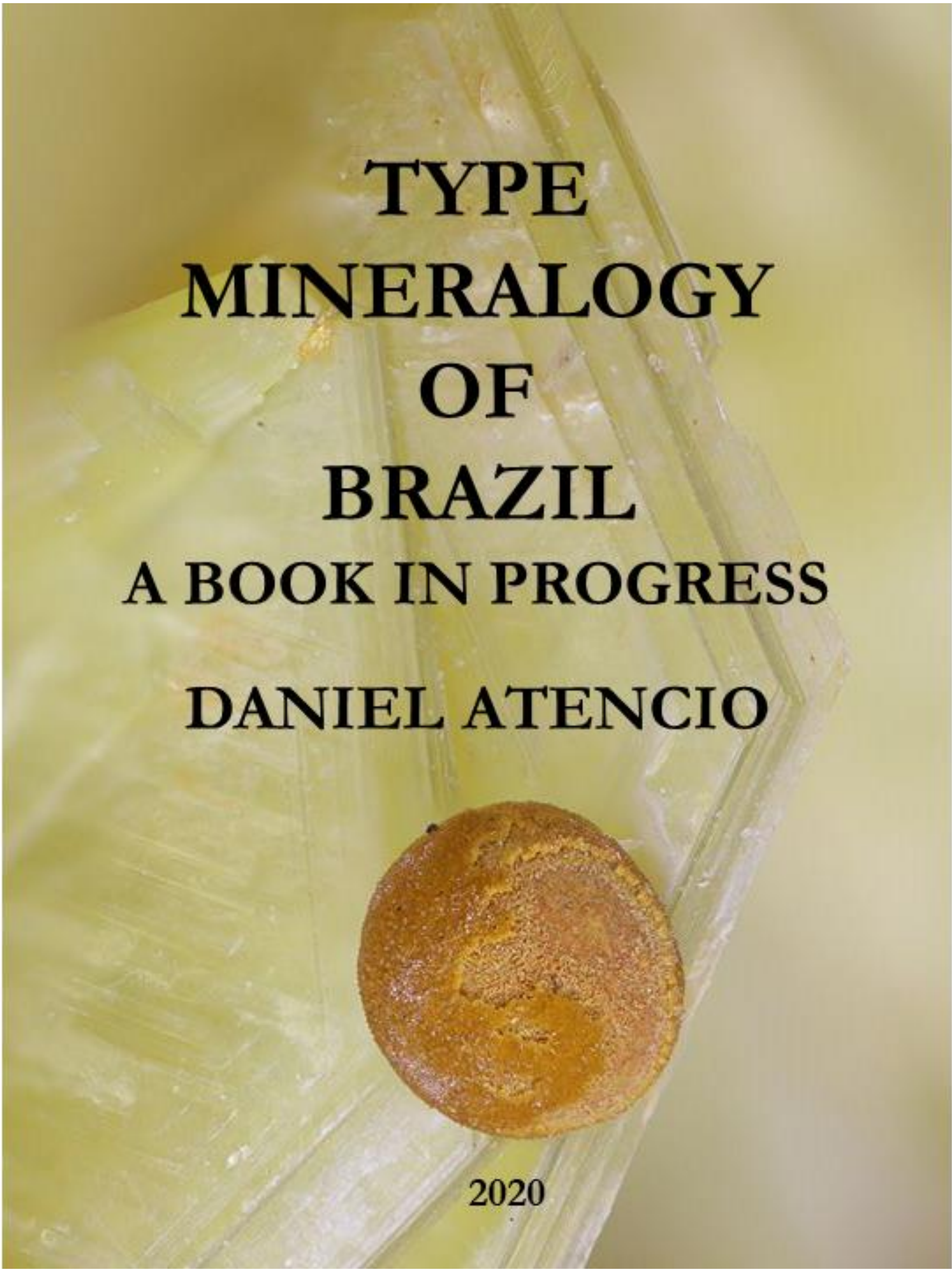

TYPE MINERALOGY OF BRAZIL

A BOOK IN PROGRESS

DANIEL ATENCIO

2020

Universidade de São Paulo
Instituto de Geociências

Type Mineralogy of Brazil: a book in progress

Daniel Atencio

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Cover: Brown spherical aggregate (1.65 mm) of ruifrancoite crystals over muscovite crystals, from the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. Specimen and photo: Martin Slama

Synopsis

This is a compilation of bibliographic (historical and descriptive) information for the minerals first described from Brazil; it includes both valid and invalid, discredited species, unnamed, unidentified, problematic minerals, and so on. This work brings together as much data as possible concerning type mineral species. It will save future researchers a lot of work because it contains data from many publications that are difficult to obtain.

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Foreword

CONGRATULATIONS!

This is an excellent book with outstanding illustrations. I know it will be very successful and will become an essential reference for Brazil's type minerals.

Moreover, I learned a tremendous amount about the Mineralogy of Brazil. Thanks for the opportunity.

Best wishes and good luck with the book!

Skip

William B. Simmons,
Research Director of the Maine Mineral and Gem Museum, Bethel, Maine, USA,
and Emeritus Professor of Mineralogy of the University of New Orleans, Louisiana, USA.

Preface

This is a compilation of bibliographic (historical and descriptive) information for the minerals first described from Brazil; it includes both valid and invalid, discredited species, unnamed, unidentified, problematic minerals, and so on. This work brings together as much data as possible concerning type mineral species. It will save future researchers a lot of work because it contains data from many publications that are difficult to obtain.

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Daniel Atencio
October 20, 2020

Introduction

The concept of a mineral species

The current official definition of a mineral is from Nickel and Grice (1998): *A mineral species is a naturally occurring solid that was formed by geological processes, either on earth or in extraterrestrial bodies, with well-defined chemical composition and crystallographic properties, and which merits a unique name. It is defined mainly on chemical composition and crystallographic properties, and these must therefore be the key factors in determining whether the creation of a new mineral species is justified.* Nevertheless, especially over the last 20 years, the reported definitions of a mineral, as stated in introductory geoscience- and mineralogy-related textbooks and online, generally have become progressively broader and more detailed (Caraballo *et al.* 2015). To some extent, this is likely due to the advancement of the mineralogical sciences that is, in part, driven by new characterization tools and methods, and, also, by an increase in the number of scientists who are interested in minerals. Recently, French *et al.* (2012) compiled up-to-date authoritative descriptions of the term mineral, producing the following definition: *Currently, minerals are most commonly defined as naturally occurring substances, produced by (bio)geochemical processes, with a highly ordered, repeating atomic arrangement (a crystalline substance) whose composition can be described by a chemical formula that is either fixed or variable (or, also as often stated, a definite, but not necessarily fixed, composition). Samples of the same mineral vary in terms of minor and/or trace element composition, and in the case of solid solution, major element composition, as long as these substitutions do not change the average crystal structure. Finally, it follows that minerals of the same major and minor element composition will express a set of measurable and consistent physical and chemical properties.* 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.

The Commission on New Minerals, Nomenclature and Classification (CNMNC) of the International Mineralogical Association (IMA) was formed in July 2006 by a merger between the Commission on New Minerals and Mineral Names (CNMMN) and the Commission on Classification of Minerals (CCM).

The CNMMN was established in 1959 to control the introduction of new minerals and mineral names, and of rationalizing mineral nomenclature. Since that time, the work of the CNMMN has gained overwhelming support from the international mineralogical community. The CCM´s objective was to review existing systems of mineral classification and provide advice on the classification of minerals to the mineralogical community. The CNMNC consists of representatives appointed by national mineralogical bodies and an executive committee composed of a chair, two vice-chairs and a secretary. An official IMA-CNMNC list of Mineral Names can be accessed on the IMA web-site.

The founding of the CNMMN marked a turning point in the history of mineral nomenclature (de Fourestier 2002). Up until that time, the naming of minerals had been a haphazard and inexact aspect of our science at best. This new Commission had the mandate to put order into many centuries of conflicting and divergent methods of giving names to naturally occurring chemical substances. There clearly had been less-than-adequate agreement on what constituted a mineral. In fact, many mixtures of minerals and most biogenic substances, such as amber or coal, were included in early treatises on minerals.

The mineral species in the latest official IMA-CNMNC list (September 2020) are 5,636, including 98 questionable minerals. The development of mineralogy in the latter half of the 20th. Century has been marked by an accelerating pace of new mineral discoveries. The number of minerals discovered worldwide since 1970 is roughly equal to that recorded throughout the preceding historical time (Khomyakov 2001). Skinner and Skinner (1980) concluded that there are no predictable limits to the number of minerals. According to the predictions of Khomyakov (1998a, b) based on correlation diagrams (the number of species versus time), the total number of known minerals will approach 11,000 by the year 2050. In contrast, the number of artificial compounds with a specific chemistry and specific properties amounts to many millions.

The long-held thesis that there is a limit to the number of mineral species is valid only for ordinary types of rocks and mineral deposits. The principal sources of new mineral discoveries are deposits formed in anomalous geotectonic and geochemical environments under conditions that virtually encompass the entire range of physicochemical parameters accessible to modern experimental mineralogy and, moreover, include geological time and other factors unattainable experimentally in the laboratory. All this serves to remove any barriers that limit the number of mineral species (Khomyakov 2001). A remarkably interesting paper on the trends in the discovery of new minerals is that by Barton (2019).

The description of a new mineral

The description of a new mineral species requires data from a wide variety of experimental — classical and modern — methods. The following information is from the IMA-CNMNC site: *Researchers finding a phase of which they think that it might be a new mineral are encouraged to use the following procedure in order to get it approved by the IMA-CNMNC. Please read carefully the procedures and guidelines of the IMA-CNMNC on the criteria for a new mineral species and the treatment of a new-mineral proposal. Please also consult these procedures and guidelines if proposing changes to existing nomenclature. If the possibility of a new mineral still stands after reading the procedures and guidelines, please download the checklist for new-mineral proposals. Provide the data asked for, as far as possible. Send the completed checklist (preferably in electronic format) to the CNMNC chairman. Send proposals to change existing nomenclature to the CNMNC vice-chairman.*

It is necessary that a new-mineral proposal be submitted for approval by the CNMNC before publication. Such a submission should contain as much information as possible so that the Commission can adequately judge the validity of the proposal (Nickel and Grice 1998). Ideally, a new-mineral proposal should contain information quoted in Table I.1.

Table I.1. Data for a new mineral nomenclature proposal.

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.
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 should also be calculated.
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.
Other data: Thermal behavior, infrared spectrum, response to chemical tests, etc.
Type material: The type material should be designated and deposited as permanent reference material in at least one major museum or a nationally recognized mineral collection.
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 these data; in such cases, the author should give reasons for the omissions. Of particular importance is the calculation of H_2O content in which it has not been determined analytically. If H_2O is reported by difference, the method of calculation should be clearly stated and, if possible, evidence for the presence of H_2O should be provided. Also, ample justification should be given for the allocation of hydrogen to H_2O, OH or H_3O. 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 (Nickel and Grice 1998).

The importance of the minerals

In general, we tend to think about minerals in mineralogical terms, instead of considering them in the broader context of inorganic materials. Some new minerals are also new compounds. Because of their chemical composition and crystal structure, some new minerals have interesting properties, whether physical, electronic, optical or magnetic, which have applications in technology. According to Khomyakov (2001), although the great majority of these will be mineralogical rarities, the identification and study of the yet undescribed natural phases are not only of interest from a purely scientific point of view but also have practical implications. Among the future minerals, there will undoubtedly be various types of commercial ores and compounds with unique structures and technologically useful properties. Having a broader view of our study material, we can explore our findings more fully and, at the same time, raise the scientific profile of descriptive mineralogy.

In the past, minerals were seen, in general, merely as sources of chemicals: iron ore, copper ore, etc. However, minerals are not just chemicals associations, since they display crystal structures. These two features together provide properties that can be technologically useful. Even though a mineral may occur in an exceedingly small amount, which precludes its extraction, it can serve as a model for obtaining a synthetic analog on an industrial scale. Several type minerals from Brazil are particularly technologically important, and some of them such as menezesite, coutinhoite, lindbergite, pauloabibite, waimirite-(Y), quintinite, palladseite, jacutingaite, melcherite, gorceixite, and tavorite, have their importance discussed in this book:

Mineral species first described from Brazil

Of the nearly 5,600 known mineral species, only 74 were first described from Brazil. These are the type minerals from Brazil. Nineteen were published between 1789 and 1959 (0.11 per year). From 1959, when the CNMMN (today CNMNC) – IMA was established, to 2000, 18 approved Brazilian mineral species remain valid (0.44 per year). However, the number of type minerals from Brazil approved in the last 20 years (2001 to 2020) substantially increased to 38 (1.90 per year). Nevertheless, this number is exceedingly small considering the wide range of Brazilian geological environments.

Compared with other parts of the world, we can mention that in several specific individual locations in various countries, many more new species were described than in Brazil, for example:

- The alkaline Khibiny massif in the Kola Peninsula, Russia: 122 new species.
- Iron and manganese mine Långban in Sweden: 73 new minerals.
- Franklin Mining District, Sussex Co., New Jersey, USA: 71 new species.
- Tsumeb, Otjikoto Region (Oshikoto), Namibia: 72 new species.
- Nepheline syenite of Mont Saint-Hilaire, Quebec, Canada: 69 new species.

Finally, within the Italian territory, much smaller than Brazil, 379 new species were discovered. These figures suggest that there has been a neglect of the Brazilian Geological and Mining sectors at all levels (mining companies, DNPM, universities, geologists and mining engineers) with respect to the knowledge of mineralogy of the deposits. Mineral species of high scientific and commercial value and new mineral species are probably being destroyed without having the opportunity to be known.

The IMA-CNMNC list includes two questionable minerals with Brazil as the type locality: Joséite-A and palladinite. In addition, arrojadite-(KFe), lipscombite, and tantalaeschynite-(Y) are erroneously described as Brazilian type minerals, and lanthanite-(La) is, also incorrectly, not recognized as a type specimen of Brazil.

Table I.2 gives the mineral names in chronological order; Table I.3 shows the chemical classification of valid Brazilian type specimens; and Table I.4 lists the species arranged by locality.

Table I.2: Valid type minerals from Brazil.

	IMA number	Mineral	Reference
1		Chrysoberyl	Werner (*in* Hoffmann 1789, and Karsten 1789)
2		Euclase	Delamétherie (1792); Hauy *in* Delamétherie (1797)
3		Palladium	Wollaston (1809)
4		Goyazite	Damour (1884)
5		Zirkelite	Hussak and Prior (1895)
6		Derbylite	Hussak and Prior (1897a)
7		Tripuhyite	Hussak and Prior (1897b)
8		Senaite	Hussak and Prior (1898)
9		Florencite-(Ce)	Hussak and Prior (1900)
10		Gorceixite	Hussak (1906d)
11		Brazilianite	Pough and Henderson (1945a, b, c, 1946)
12		Souzalite	Pecora and Fahey (1949a)
13		Scorzalite	Pecora and Fahey (1949a)
14		Frondelite	Lindberg (1949)
15		Faheyite	Lindberg and Murata (1953)
16		Moraesite	Lindberg *et al.* (1953)
17		Barbosalite	Lindberg and Pecora (1954b and 1955)
18		Tavorite	Lindberg and Pecora (1955)
19	1973-002a	Arsenopalladinite	Hey (1955)
20	1973-050	Atheneite	Clark *et al.* (1974)
21	1973-057	Isomertieite	Clark *et al.*(1974)
22	1974-027	Bahianite	Moore *et al.* (1976a)
23	1975-001	Whiteite-(CaFeMg)	Moore and Ito (1978)
24	1975-001	Whiteite-(MnFeMg)	Moore and Ito (1978)
25	1975-026	Palladseite	Davis *et al.* (1977)
26	1979-074	Lanthanite-(Nd)	Roberts *et al.* (1980)
27	1983-090	Minasgeraisite-(Y)	Foord *et al.* (1986)
28		Lanthanite-(La)	Nickel and Mandarino (1987)
29	1986-054	Zanazziite	Leavens *et al.* (1990)
30	1988-008	Arupite	Buchwald (1990)
31	1990-052	Yanomamite	Botelho *et al.* (1994)
32	1992-028	Quintinite	Chao and Gault (1997)
33	1998-006	Serrabrancaite	Witzke *et al.* (2000)
34	1998-018	Fluornatromicrolite	Witzke *et al.* (2011)
35	1998-053a	Bendadaite	Kolitsch *et al.* (2010)
36	1999-021	Dukeite	Burns *et al.* (2000)

37	2003-025	Coutinhoite	Atencio *et al.* (2004a)
38	2003-029	Lindbergite	Atencio *et al.* (2004c)
39	2004-013	Oxykinoshitalite	Kogarko *et al.* (2005)
40	2004-041	Atencioite	Chukanov *et al.* (2006b)
41	2004-047	Kalungaite	Botelho *et al.* (2006)
42	2005-011	Matioliite	Atencio *et al.* (2006a)
43	2005-023	Menezesite	Atencio *et al.* (2008a)
44	2005-056	Arrojadite-(PbFe)	Chopin *et al.* (2006)
45	2005-061	Ruifrancoite	Atencio *et al.* (2007)
46	2006-028	Guimarãesite	Chukanov *et al.* (2007)
47	2008-028	Brumadoite	Atencio *et al.* (2008b)
48	2009-039	Manganoeudialyte	Nomura *et al.* (2010)
49	2009-076	Ferroqingheiite	Hatert *et al.* (2010)
50		Hydroxycalcioroméite	Atencio *et al.* (2010a)
51	2010-047	Carlosbarbosaite	Atencio *et al.* (2012)
52	2010-078	Jacutingaite	Vymazalová *et al.* (2012)
53	2011-071	Fluor-elbaite	Bosi *et al.* (2013)
54	2011-103	Hydrokenomicrolite	Andrade *et al.* (2013a)
55	2012-036	Fluorcalciomicrolite	Andrade *et al.* (2013b)
56	2012-090	Pauloabibite	Menezes Filho *et al.* (2015a)
57	2012-099	Césarferreiraite	Scholz *et al.* (2014)
58	2013-007	Correianevesite	Chukanov *et al.* (2014a)
59	2013-020	Almeidaite	Menezes Filho *et al.* (2015b)
60	2013-073	Hydroxycalciomicrolite	Andrade *et al.* (2017)
61	2013-102	Fluorlamprophyllite	Andrade *et al.* (2018b)
62	2013-108	Waimirite-(Y)	Atencio *et al.* (2015)
63	2014-075	Lefontite	Yang *et al.* (2015)
64	2014-097	Jeffbenite	Nestola *et al.* (2016)
65	2015-018	Melcherite	Andrade *et al.* (2018a)
66	2015-034	Wilancookite	Hatert *et al.* (2017)
67	2016-031	Parisite-(La)	Menezes Filho *et al.* (2018)
68	2016-071a	Brandãoite	Menezes Filho *et al.* (2019)
69	2017-030	Hydroxykenopyrochlore	Miyawaki *et al.* (2017)
70	2017-118	Jahnsite-(MnMnMg)	Vignola *et al.* (2018)
71	2018-017	Jahnsite-(NaMnMg)	Kampf *et al.* (2018b)
72	2018-062	Breyite	Brenker *et al.* (2020)
73	2019-091	Ellinaite	Sharygin *et al.* (2020)
74	2019-110	Oxycalciomicrolite	Menezes da Silva *et al.* (2020)

Table I.3. Chemical classification of the valid Brazilian type minerals.

Native elements	Formula, crystal system
Palladium	Pd, cubic
Sulfides, selenides, arsenides, and antimonides	
Atheneite	$Pd_2(As_{0.75}Hg_{0.25})$, hexagonal
Arsenopalladinite	$Pd_8As_{2.5}Sb_{0.5}$, triclinic
Isomertieite	$Pd_{11}Sb_2As_2$, cubic
Palladseite	$Pd_{17}Se_{15}$, cubic
Jacutingaite	Pt_2HgSe_3, trigonal
Kalungaite	PdAsSe, cubic
Halides	
Waimirite-(Y)	YF_3, orthorhombic
Oxides and hydroxides	
Chrysoberyl	$BeAl_2O_4$, orthorhombic
Ellinaite	$CaCr^{3+}_2O_4$, orthorhombic
Pauloabibite	$NaNbO_3$, trigonal
Almeidaite	$PbZn_2(Mn^{2+},Y)(Ti,Fe^{3+})_{18}O_{37}(OH,O)$, trigonal
Senaite	$(Pb,Sr)Mn^{2+}(Fe^{2+},Zn)_2(Ti,Fe^{3+})_{18}(O,OH)_{38}$, trigonal
Tripuhyite	$Fe^{3+}Sb^{5+}O_4$, tetragonal
Derbylite	$Fe^{3+}_4Ti^{4+}_3Sb^{3+}O_{13}(OH)$, monoclinic
Bahianite	$Al_5Sb^{5+}_3O_{14}(OH)_2$, monoclinic
Hydroxykenopyrochlore	$(\square,\#)_2Nb_2O_6(OH)$, cubic
Fluornatromicrolite	$(Na,\#)_2Ta_2O_6F$, cubic
Fluorcalciomicrolite	$(Ca,\#)_2Ta_2O_6F$, cubic
Hydroxycalciomicrolite	$(Ca,\#)_2Ta_2O_6(OH)$, cubic
Oxycalciomicrolite	$Ca_2Ta_2O_6O$, cubic
Hydrokenomicrolite	$(\square,\#)_2Ta_2O_6(H_2O)$, cubic and trigonal
Hydroxycalcioromeite	$(Ca,\#)_2Sb^{5+}_2O_6(OH)$, cubic
Zirkelite	$(Ti,Ca,Zr)O_{2-x}$, cubic

Melcherite	$(Ba,K)_2(Na,Ca)_2Mg(Nb_6O_{19})\ 6H_2O$, trigonal
Menezesite	$(\square,Ba,K)_{12}(\square,Mg)_3Zr_4(BaNb_{12}O_{42})\ 12H_2O$, cubic
Carlosbarbosaite	$(UO_2)_2Nb_2O_6(OH)_2\cdot 2H_2O$, orthorhombic
Dukeite	$Bi^{3+}_{24}Cr^{6+}_8O_{57}(OH)_6\cdot 3H_2O$, trigonal
Quintinite	$Mg_4Al_2(OH)_{12}(CO_3)\ 3H_2O$, hexagonal
Carbonates	
Lanthanite-(Nd)	$(Nd,La)_2(CO_3)_3\cdot 8H_2O$, orthorhombic
Lanthanite-(La)	$(La,Nd)_2(CO_3)_3\cdot 8H_2O$, orthorhombic
Parisite-(La)	$CaLa_2(CO_3)_2F_2$, monoclinic
Tellurates	
Brumadoite	$Cu_3(Te^{6+}O_4)(OH)_4\cdot 5H_2O$, monoclinic
Phosphates	
Ferroqingheiite	$NaNaFe^{2+}(MgAl)(PO_4)_3$, monoclinic
Serrabrancaite	$Mn^{3+}(PO_4)\cdot H_2O$, monoclinic
Arupite	$Ni_3(PO_4)_2\cdot 8H_2O$, monoclinic
Correianevesite	$Fe^{2+}Mn^{2+}_2(PO_4)_2\cdot 3H_2O$, orthorhombic
Faheyite	$Be_2Mn^{2+}Fe^{3+}_2(PO_4)_4\cdot 6H_2O$, hexagonal
Wilancookite	$(Ba,K,Na)_8(Ba,Li,\square)_6Be_{24}(PO_4)_{24}\cdot 32H_2O$, cubic
Tavorite	$LiFe^{3+}(PO_4)(OH)$, triclinic
Lefontite	$Fe^{2+}_2Al_2Be(PO_4)_2(OH)_6$, orthorhombic
Goyazite	$SrAl_3(PO_4)(PO_3OH)(OH)_6$, trigonal
Florencite-(Ce)	$CeAl_3(PO_4)_2(OH)_6$, trigonal
Gorceixite	$BaAl_3(PO_4)(PO_3OH)(OH)_6$, trigonal or monoclinic
Brazilianite	$NaAl_3(PO_4)_2(OH)_4$, monoclinic
Scorzalite	$(Fe^{2+},Mg)Al_2(PO_4)_2(OH)_2$, monoclinic
Barbosalite	$Fe^{2+}Fe^{3+}_2(PO_4)_2(OH)_2$, monoclinic
Frondelite	$(Mn^{2+}_{0.5}Fe^{3+}_{0.5})_2Fe^{3+}_3(PO_4)_3(OH)_5$, orthorhombic
Arrojadite-(PbFe)	$PbFe^{2+}Na_2CaFe^{2+}_{13}Al(PO_4)_{11}(PO_3OH)(OH)_2$, monoclinic
Souzalite	$Mg_3Al_4(PO_4)_4(OH)_6\cdot 2H_2O$, triclinic
Moraesite	$Be_2(PO_4)(OH)\cdot 4H_2O$, monoclinic
Brandãoite	$BeAl_2(PO_4)_2(OH)_2\cdot 4H_2O$, triclinic
Jahnsite-(MnMnMg)	$Mn^{2+}Mn^{2+}Mg_2Fe^{3+}_2(PO_4)_4(OH)_2\cdot 8H_2O$, monoclinic
Jahnsite-(NaMnMg)	$(Na,Ca)Mn^{2+}(Mg,Fe^{3+})_2Fe^{3+}_2(PO_4)_4(OH)_2\cdot 8H_2O$, monoclinic
Whiteite-(CaFeMg)	$CaFe^{2+}Mg_2Al_2(PO_4)_4(OH)_2\cdot 8H_2O$, monoclinic
Whiteite-(MnFeMg)	$Mn^{2+}Fe^{2+}Mg_2Al_2(PO_4)_4(OH)_2\cdot 8H_2O$, monoclinic
Matioliite	$NaMgAl_5(PO_4)_4(OH)_6\cdot 2H_2O$, monoclinic

Zanazziite	$Ca_2(\square Mg)Mg_4Be_4(PO_4)_6[(OH)_4(H_2O)_2]\cdot 4H_2O$, monoclinic
Guimarãesite	$Ca_2(\square Zn)Zn_4Be_4(PO_4)_6[(OH)_4(H_2O)_2]\cdot 4H_2O$, monoclinic
Ruifrancoite	$Ca_2\square_2Fe^{3+}_4Be_4(PO_4)_6(OH)_6\cdot 4H_2O$, monoclinic
Atencioite	$Ca_2Fe^{2+}Mg_2Fe^{2+}_2Be_4(PO_4)_6(OH)_4\cdot 6H_2O$, triclinic
Arsenates	
Yanomamite	$In(AsO_4)\cdot 2H_2O$, orthorhombic
Bendadaite	$Fe^{2+}Fe^{3+}_2(AsO_4)_2(OH)_2\cdot 4H_2O$, monoclinic
Césarferreiraite	$Fe^{2+}Fe^{3+}_2(AsO_4)_2(OH)_2\cdot 8H_2O$, triclinic
Silicates	
Euclase	$BeAlSiO_4OH$, monoclinic
Jeffbenite	$Mg_3Al_2Si_3O_{12}$, tetragonal
Minasgeraisite-(Y)	$BiCa(Y,Ln)_2(\square,Mn^{2+})_2(Be,B,Si)_4Si_4O_{16}[(OH),O]_4$, triclinic
Coutinhoite	$(\square,\#)_2(UO_2)_2Si_5O_{13}\cdot 4H_2O$, monoclinic
Fluorlamprophyllite	$Na_3(SrNa)Ti_3(Si_2O_7)_2O_2F_2$, monoclinic
Breyite	$CaCa_2Si_3O_9$, triclinic
Fluor-elbaite	$Na(Li_{1.5}Al_{1.5})Al_6(Si_6O_{18})(BO_3)_3(OH)_3F$, trigonal
Manganoeudialyte	$Na_{14}Ca_6Mn^{2+}_3Zr_3[Si_{26}O_{72}(OH)_2]Cl_2\cdot 4H_2O$, trigonal
Oxykinoshitalite	$BaMg_3(Si_3Al)O_{10}O_2$, monoclinic
Oxalates	
Lindbergite	$Mn^{2+}(C_2O_4)\cdot 2H_2O$, monoclinic

Table I.4. Geographical distribution of the valid Brazilian type minerals.

Amazonas
Presidente Figueiredo
Pitinga mine
Waimirite-(Y)

Mato Grosso
Juína
São Luiz river alluvials
Jeffbenite
Breyite
Ellinaite

Goiás
Monte Alegre de Goiás
Mangabeira tin deposit
Yanomamite
Cavalcante
Buraco do Ouro gold mine
Kalungaite
Veríssimo river
Gorceixite

Rio Grande do Norte
Equador
Alto do Giz pegmatite
Hydrokenomicrolite

Paraíba
Frei Martinho
Alto Quixabá pegmatite
Fluornatromicrolite
Pedra Lavrada
Alto Serra Branca pegmatite
Serrabrancaite

Pernambuco
Fernando de Noronha Island
Oxykinoshitalite

Bahia
Brumado
Pedra Preta mine
Brumadoite
Érico Cardoso
Paramirim das Crioulas
Bahianite
Novo Horizonte
Mula mine
Almeidaite
Parisite-(La)

Minas Gerais

- *Araçuaí (probably)*
    - Chrysoberyl
- *São José da Safira*
    - Cruzeiro mine
        - Fluor-elbaite
- *Itinga*
    - Lavra da Ilha
        - Whiteite-(CaFeMg)
        - Whiteite-(MnFeMg)
        - Zanazziite
    - Lavra Ponte do Piauí
        - Guimarãesite
        - Wilancookite
    - Urubu mine
        - Fluor-elbaite
- *Conselheiro Pena*
    - Eduardo pegmatite
        - Césarferreiraite
    - Cigana (Jocão) mine
        - Correianevesite
- *Divino das Laranjeiras*
    - Córrego Frio granitic pegmatite, Linópolis
        - Brazilianite
        - Souzalite
        - Scorzalite
    - Lavra do Almerindo, Linópolis
        - Bendadaite
    - João Firmino claim, Linópolis
        - Atencioite
        - Brandãoite
    - Sebastião Cristino pegmatite, Linópolis
        - Ferroqingheiite
    - João Teodoro mine, Linópolis
        - Lefontite
- *Galileia*
    - Sapucaia pegmatite (Proberil mine), Sapucaia do Norte
        - Frondelite
        - Faheyite
        - Moraesite
        - Barbosalite
        - Tavorite
        - Ruifrancoite
        - Arrojadite-(PbFe)
        - Jahnsite-(MnMnMg)
        - Jahnsite-(NaMnMg)
    - Lavra da Boca Rica, Sapucaia do Norte
        - Lindbergite
    - Lavra Urucum
        - Coutinhoite
- *Mendes Pimentel*
    - Gentil mine
        - Matioliite

Conceição do Mato Dentro
- São José mine, Posse farm, Brejaúba
  - Dukeite

Morro do Pilar and Bom Sucesso, Serro
  - Palladium

Itabira
- Cauê mine
  - Arsenopalladinite
  - Atheneite
  - Isomertieite
  - Palladseite
  - Jacutingaite

Jaguaraçu
- José Pinto quarry
  - Minasgeraisite-(Y)
  - Carlosbarbosaite

Nazareno
- Volta Grande pegmatite
  - Hydrokenomicrolite
  - Fluorcalciomicrolite
  - Hydroxycalciomicrolite
- Fumal pegmatite
  - Oxycalciomicrolite

Diamantina
- Ribeirão do Inferno, Congonhas range of mountains
  - Goyazite
- neighbourhood of Diamantina (Datas, Cipó river etc.)
  - Senaite

Santo Antonio do Itambé
- Mata dos Crioulos
  - Florencite-(Ce)

Ouro Preto
  - Euclase
- Três Cruzes farm cinnabar mine, Tripuí
  - Derbylite
  - Tripuhyite
  - Hydroxycalcioromeite
  - Florencite-(Ce)
- Morro do Caxambu, near Tripuí
  - Florencite-(Ce)

Poços de Caldas
- Pedra Balão
  - Manganoeudialyte
- Morro do Serrote
  - Fluorlamprophyllite

Araxá
- CBMM mine
  - Hydroxykenopyrochlore

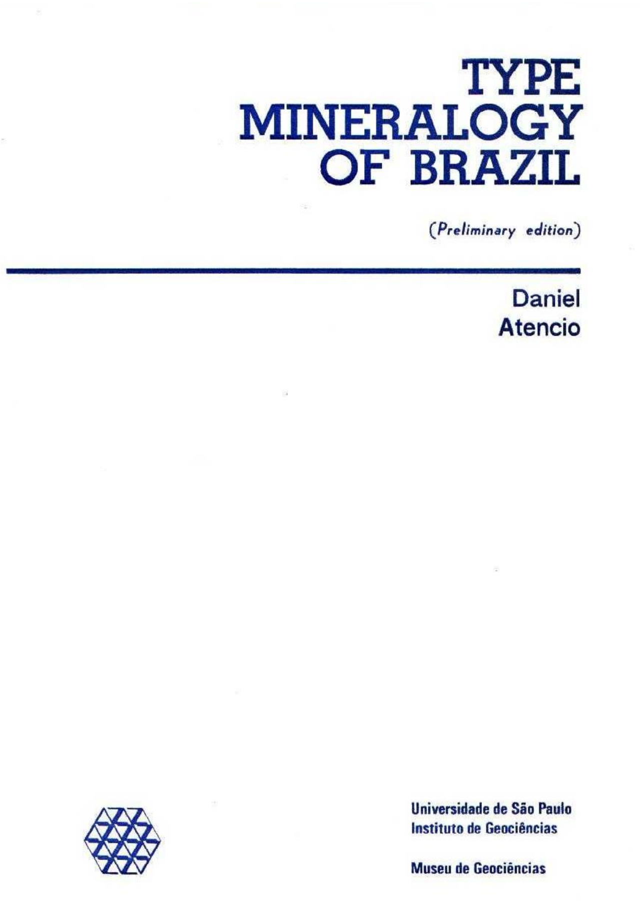
São Paulo
Cajati
Jacupiranga mine
Zirkelite
Quintinite
Menezesite
Pauloabibite
Melcherite

Paraná
Curitiba
Curitiba – Paranaguá highway
Lanthanite-(Nd)
Lanthanite-(La)

Santa Catarina
São Francisco do Sul
Morro do Rocio
Arupite

Previous work

There are some publications that deal specifically with Brazilian type minerals: Atencio (1996a, 1996b, 1998a, 1998b, 1999a, 2000a, 2000b, 2006a, 2006b, 2007a, 2007b, 2008a, 2008b, 2012a, 2012b, 2015, and 2016b), and Chaves *et al.* (2017). This book is an update of the one by Atencio (2000b).



TYPE
MINERALOGY
OF BRAZIL

(*Preliminary edition*)

Daniel
Atencio

Universidade de São Paulo
Instituto de Geociências

Museu de Geociências

Figure I.1. The preliminary version of this book (Atencio 2000b).

There are also some compilations that deal with all the minerals that occur in Brazil: Ferreira (1885), Ferraz (1928), Oliveira (1930), Abreu (1937 and 1960), Leonardos (1955), and Franco *et al.* (1972). The book by Ferraz (1928) was updated by Borges (1992). The text by Leonardos (1955) was updated by Franco (1981). The publications by Schobbenhaus and Coelho (1985, 1986, 1988) and Schobbenhaus *et al.* (1991, 1997a, 1997b) represent updates of the Abreu (1937 and 1960) books. There is also a compilation that deals with all the minerals that occur in the São Paulo State: Knecht (1950).

The Enciclopédia dos Minerais do Brasil is currently being published. It should have 10 volumes, 7 of which have already been released (Neves and Atencio 2013, 2014, 2015, 2016, 2017, 2018, and 2019a). There is already a second edition of the first volume (Neves and Atencio 2019b).

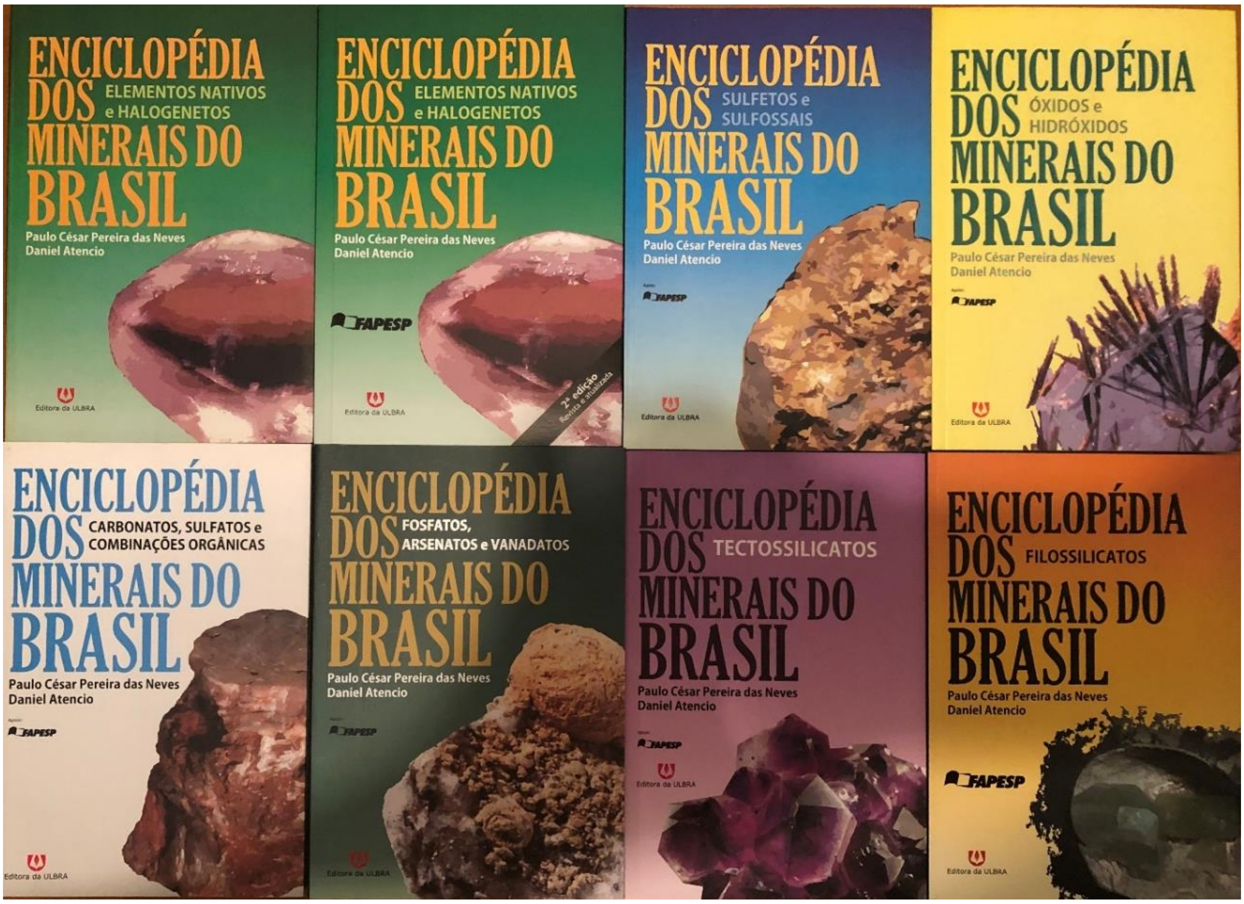


Figure I.2. The released volumes of Enciclopédia dos Minerais do Brasil (Neves and Atencio 2013, 2019b, 2014, 2015, 2016, 2017, 2018, and 2019a).

This book

Next, the description of the valid type minerals from Brazil are presented, as well as the discredited, invalid, unnamed, unidentified, problematic minerals, and so on. There are also some names of varieties of minerals and two names given to meteorites (catarinite and bendegite) are confused with mineral names.

Mineral science advances continuously with the publication of new data. Therefore, this book will be out of date quickly, requiring frequent updates. That is, it will always be an unfinished book. Hence the subtitle "a book in progress." It is my intention to publish new editions frequently.

In the formulas, “□” is a vacancy and “#” is understood to mean a subordinate amount of an unspecified charge-balancing component. Type-specimen data are in general from the original papers or from Lapaire (2020). The designations "UM..." come from the publication by Smith and Nickel (2007) and updated IMA-CNMNC lists (http://cnmnc.main.jp/). The designations "Unnamed (...)” are from the Mindat database.

Chapter 1

Native elements and intermetallic alloys, silicides, carbides, nitrides.

Porpezite

Fröbel (1843)

(=palladium-bearing gold)

Other names: porpezita, Porpezit, porpecita, ouro palladiado, ouro paladiado, ouro-paládio, palladium gold, palladiumgold, palladian gold, palladiated gold, palladiferous gold, ouro com paládio, ouro branco, oro branco, ouro podre, rotten gold, ouro cinzento, silver, rotten gold

Figure 1.1. Palladium-bearing gold ("porpezite") from Itabira, Minas Gerais (sample 1111/40-1, Museu de Geociências, Universidade de São Paulo). Photo: Thales Trigo.

The name porpezite (Porpezit) was introduced by Fröbel (1843) to designate a variety of palladium-bearing gold analyzed by Berzelius (1835). *"Labelled* ouro podre *(=*

rotten gold), E. Pohl sent me a type of native gold that is found in the Capitania de Porpez, in South America. This gold forms polyhedral grains of an impure gold color… this gold is composed, according to an analysis I did on a unique grain among the largest ones weighing 0.623g: Au 85.98%, Pd 9.85%, Ag 4.17%.” (Berzelius 1835).

Controversy exists about the origin of this material. According to Hussak (1906a, b), porpezite came from the state of Goiás (formerly the states were designated capitanias). The geologist Pohl traveled through Goiás and Berzelius might have misread his handwriting as “Porpez” instead of “Goyaz” (the old spelling of the state of Goiás). According to Eschwege (1833), the rotten gold was found abundantly in 1740 in alluvial deposits of the area known as “Arrayas, Goyaz” (today the municipal district of Arraias is in the state of Tocantins). On the other hand, O.A. Derby (personal communication, in Dana 1892) believed that Porpez was an error in the spelling of Pompéu mine (Pompeo or Pompeio), near Sabará, Minas Gerais. Today there is a town in Sabará called Pompéu and a nearby municipal district with the same name [the Fazenda do Pompéu, described by Eschwege (1833, p. 173, v. 2 and N. of T. 434, p. 294 and 295, v. 2) became this city].

A letter from Pedro Taques de Almeida to D. João de Lencastro, in 1700, in São Paulo, and published by Derby (1900) gives news of the first discoveries of gold by Borba Gato in the district of Sabará, Minas Gerais, and makes references to a metal found together with gold in the alluvium called “silver” due to its appearance. These data, according to Hussak (1906a, b), refer, very probably, to the palladium-bearing gold, then unknown, that is found in the area rich in itabirites.

Hussak (1906a, b) also believed that the alloy mentioned by Lampadius and Plattner (1833) with the composition Au 52.95, Pt 30.60, Ag 9.52 and Ir 1.42 wt.% was, in fact, porpezite, with some confusion arising between Pt and Pd.

The name “porpecita” was used by Gagarin and Cuomo (1949).

“Ouro branco” (= white gold) was used in the literature for palladium-bearing gold and also for native platinum. The first citation seems to be by Antonil (1711) who described material from a mine in the Itatiaia mountain, near Ouro Preto. Palladium-bearing gold can also be yellow, copper-red, and brown (Hussak 1906a, b).

Olivo *et al.* (1994 and 1995) identified palladium-bearing gold in “jacutinga” (a hydrothermally-altered Lake Superior-type carbonate-bearing oxide facies iron-formation) from the Cauê mine, Itabira, Minas Gerais, and obtained several point analyses by electron microprobe. This mineral occurs as inclusions in tourmaline and quartz; its chemical composition is: Au 78.5 to 99, Pd 1 to 19, Cu up to 4.6, Ag up to 0.6, Fe up to 3.2, Zn up to

3 wt.% (Olivo and Gammons 1996). Additional data were obtained by Kwitko *et al.* (2002) and Cabral *et al.* (2002a).

Palladium-bearing gold from Gongo Soco mine, Barão de Cocais, Minas Gerais, was studied by Cabral *et al.* (2002b) and Cabral and Lehmann (2003).

As it is just a variety of gold, the use of the name porpezite (and its several variants) is unacceptable and one should refer to the mineral as “palladium-bearing gold”.

See also. Unnamed oxygen-bearing compounds of Pt-Pd-Au-Cu-Fe-Mn, Au_7Pd, Au_2Pd and Au_3Pd

Unnamed Au_7Pd

Cabral *et al.* (2002c, 2002d), Cabral (2006)

Other names: palladian gold

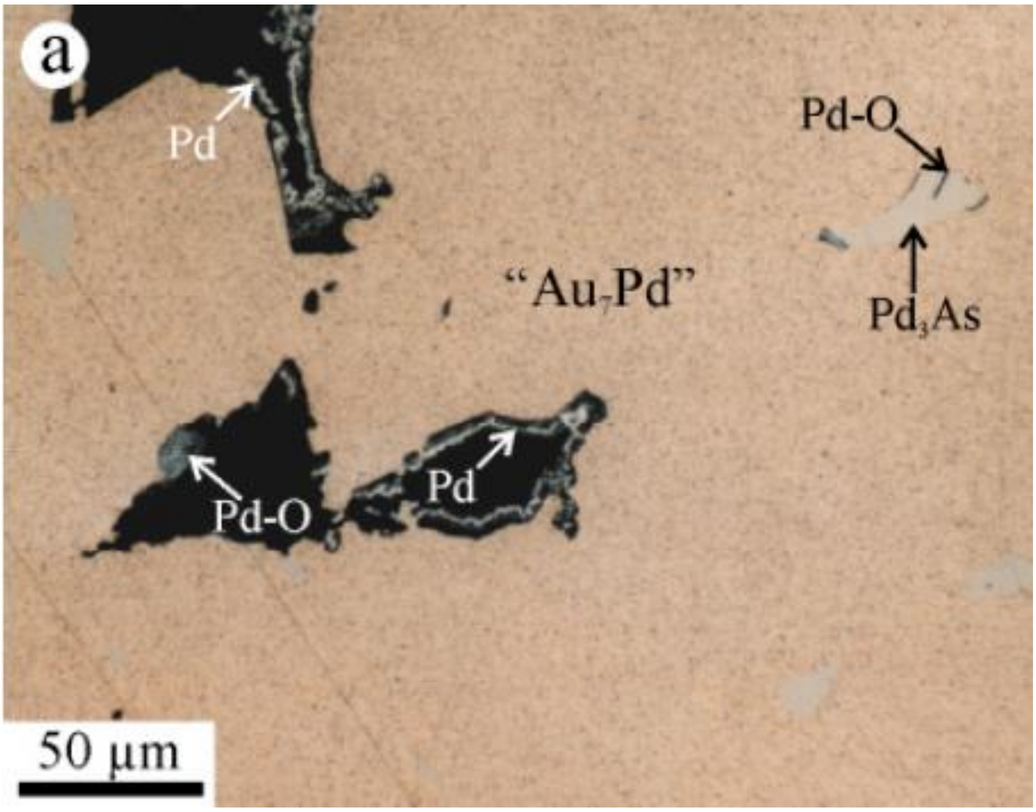


Figure 1.2. Reflected-light photomicrograph illustrating the relationships of native palladium (Pd) and a Pd–O phase in unnamed Au_7Pd from Serra Pelada, Carajás, Pará. Stripes of native palladium (white), associated with a Pd–O phase (dark grey), line vugs filled by goethite (black). Note incipient stage of Pd–O formation in a crystal of vincentite (the authors quoted "guanglinite (Pd_3As)", but this is the formula of vincentite). Cabral *et al.* (2002d).

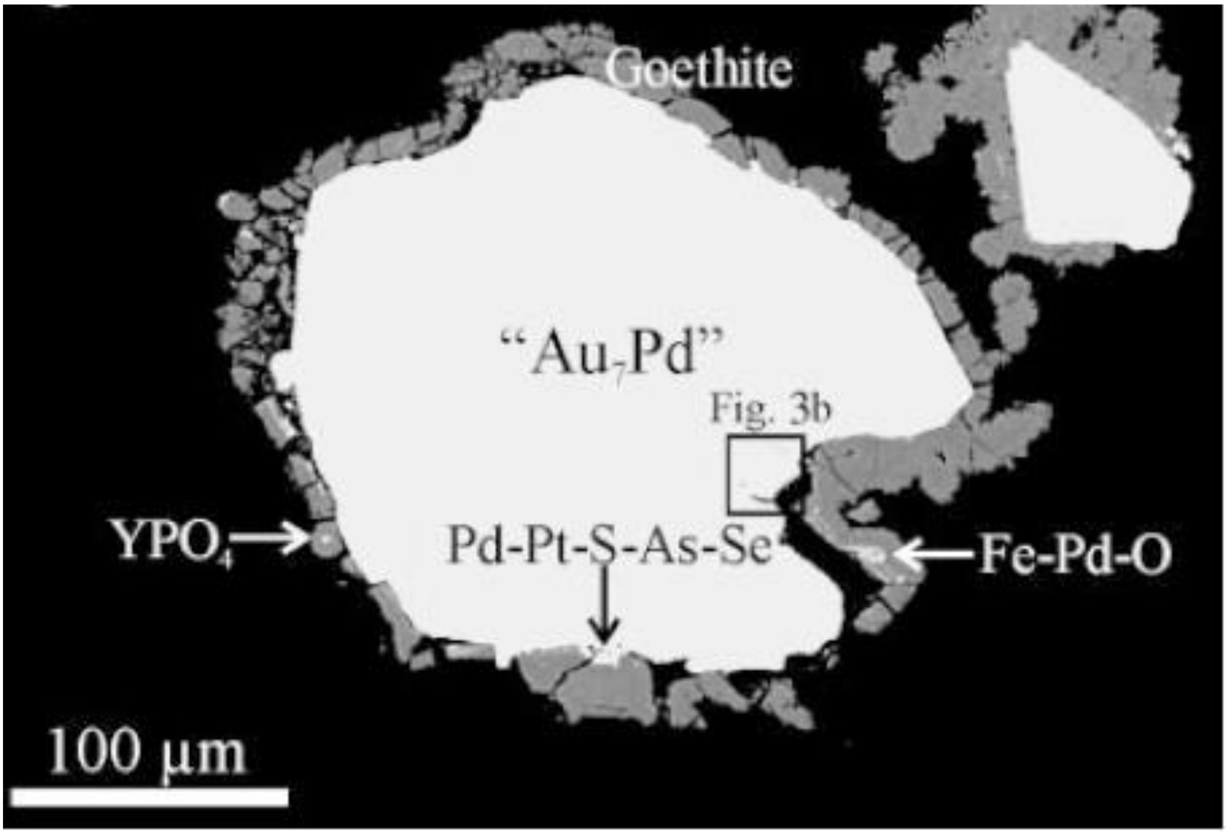


Figure 1.3. Back-scattered electron (BSE) images of unnamed Au_7Pd from Serra Pelada, Carajás, Pará, coated by goethite. Note inclusions of YPO_4 and Fe–Pd–O phase in the goethite coating. Black: resin. (Cabral *et al*. 2002d)

Cabral *et al.* (2002c, 2002d) and Cabral (2006) described dendritic and coarse-grained palladium-bearing gold from Serra Pelada, Carajás, Pará. Electron microprobe analyses of about forty individual crystals indicate a constant stoichiometry of Au_7Pd. The phase stability of the Au_7Pd structure is discussed by Sluiter *et al.* (2006). It displays a Ca_7Ge structure, with Au in a 4b site (1/2, 0, 0) and in a 24d site (0, ¼, ¼), and Pd in 4a site (0, 0, 0).

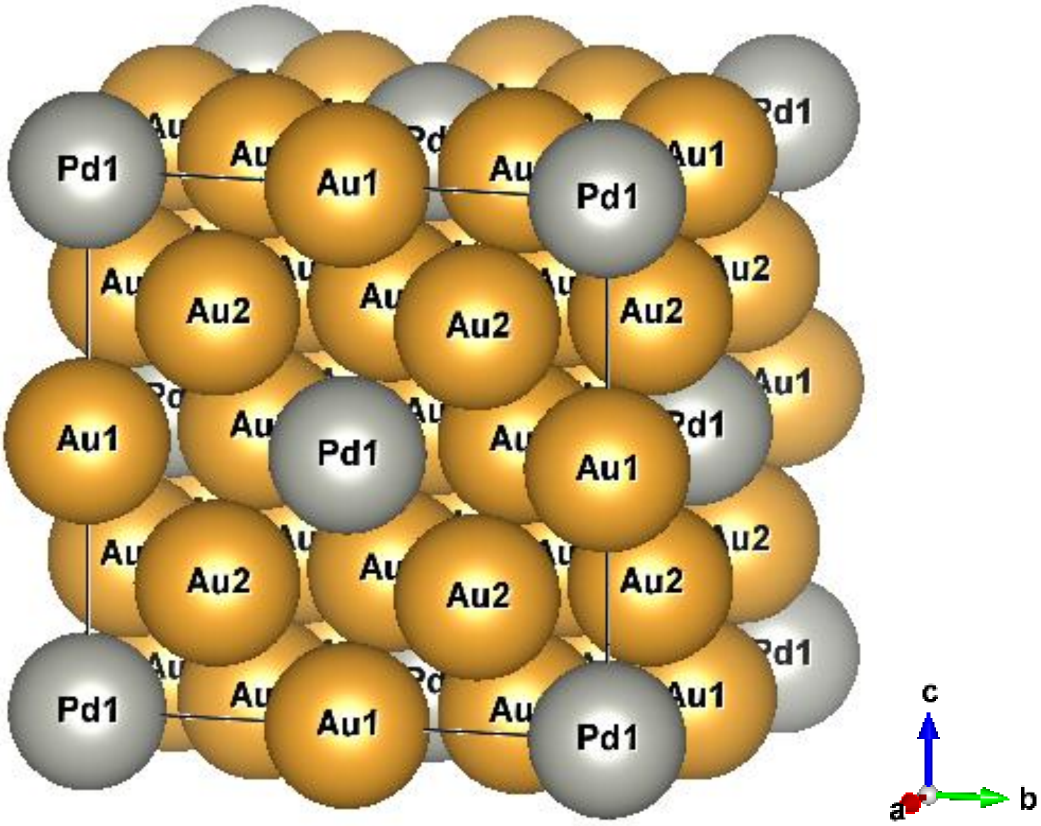


Figure 1.4. View of the hypothetical crystal structure of unnamed Au_7Pd, drawn using VESTA 3 (Momma and Izumi 2011). Data from Sluiter *et al*. (2006).

See also. Porpezite, unnamed Au_2Pd and Au_3Pd.

Unnamed Au_2Pd and Au_3Pd

Cabral *et al.* (2008)

Other names: Unnamed (Au-Pd Alloy I), UM2008-11-E:AuPd

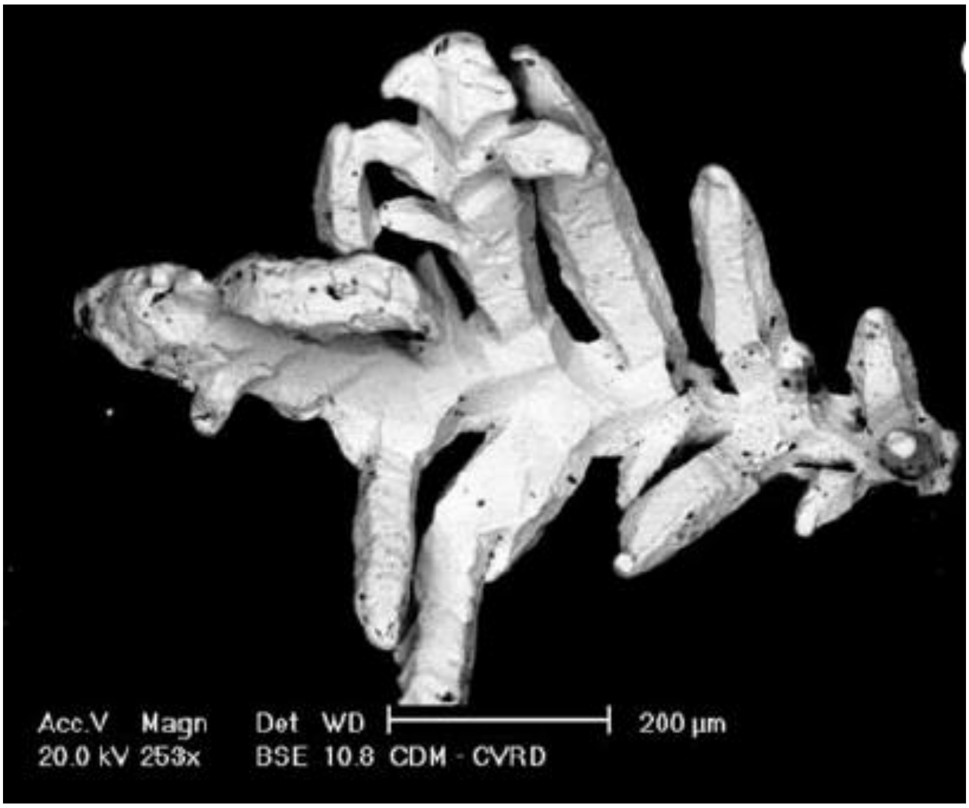


Figure 1.5. Arborescent grains of palladiferous gold from Córrego Bom Sucesso, Serro, Minas Gerais (Cabral *et al.* 2008).

Arborescent crystals of palladiferous gold were identified by Cabral *et al.* (2008) in platiniferous alluvium from Córrego Bom Sucesso, Serro region, Minas Gerais. The Córrego Bom Sucesso alluvium is regarded as the type locality of palladium, being also famous for dendritic Pt–Pd–Hg nuggets. Two near-stoichiometric alloys, Au_2Pd and Au_3Pd, determined by electron-microprobe analysis, may correspond to unnamed mineral phases.

In the Au–Pd synthetic system, a Au_3Pd phase with a cubic Cu_3Au-type crystal structure is known to be stable below 850°C (Nagasawa *et al.* 1965, Okamoto and Massalski 1985). The synthetic Au_3Pd compound, isostructural with bogdanovite, Au_3Cu, seems to be an analog to the natural phase documented by Cabral *et al.* (2008), though crystallographic confirmation is required. Theoretical calculation predicts long-period superstructures close to the natural alloy of Au_2Pd stoichiometry (Sluiter *et al.* 2006).

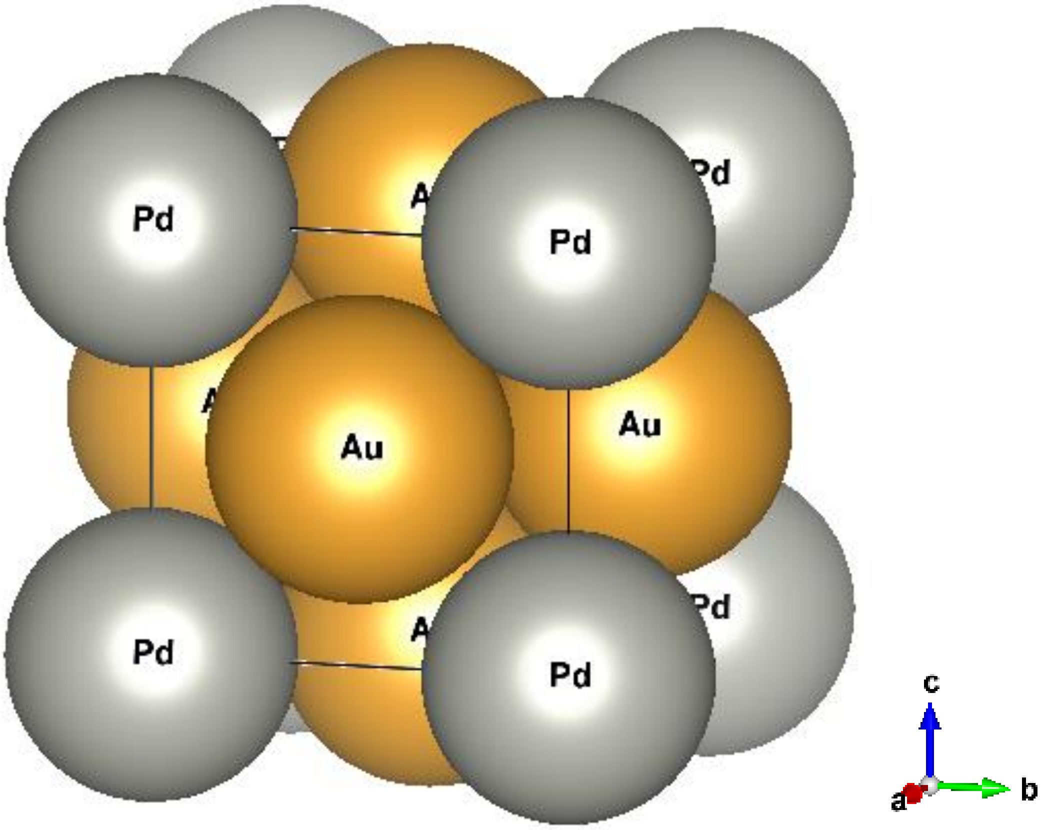


Figure 1.6. View of the hypothetical crystal structure of unnamed Au_3Pd, drawn using VESTA 3 (Momma and Izumi 2011). Data from Nagasawa *et al.* (1965) and Okamoto and Massalski (1985).

See also. Palladium, porpezite, and unnamed Au_7Pd.

Unnamed Au_3Hg

Baptista and Baptista (1986)

(probably weishanite)

Other names: gold amalgam, amálgama de ouro

Baptista and Baptista (1986) studied the sample labelled 6210M in the mineralogical collection of the National Museum of Rio de Janeiro, from Sumidouro (now Padre Viegas), district of Mariana, Minas Gerais. This sample consists of grains, among which are some microcrystalline aggregates and rosettes of pale yellow, metallic, hexagonal prismatic crystals, identified by X-ray diffractometry as Au_3Hg. Three X-ray powder diffraction patterns were compared to that of synthetic material. The study of a single-crystal by X-ray diffraction using a precession camera indicated hexagonal symmetry, with a 2.951 and c 4.810 Å.

Spectrochemical analyses showed Au, Hg, and Fe as principal elements, Mn, Pb, and Ag as secondary elements, and W, Zn, and Cu as trace elements. No quantitative chemical data were presented. Associated minerals are stolzite, raspite, galena, mimetite or vanadinite, a pyrochlore-group mineral, mercury and pyromorphite. Regarding the origin of the amalgam, some evidence points to its natural formation, whereas other data suggests that it could be the consequence of previous work of miners in the area (Baptista and Baptista 1986).

Jambor (1989) pointed out that the same mineral had already been described in China (Poshan Mining District, Tongban Co., Henan Province) and has been named weishanite. Weishanite is $(Au,Ag)_3Hg_2$, hexagonal, and its X-ray powder diffraction pattern is similar to that obtained for the Brazilian material.

Unnamed AgPd

Zang *et al.* (1992)

Other names: silver-palladium alloy, UM1992-06-E:AgPd

A silver-palladium alloy with a chemical formula close to AgPd was found in laterite from the Igarapé Bahia gold deposit, Serra de Carajás, Parauapebas, Pará, in a void in an iron oxide nodule, associated with goethite and hematite. The angular shape and protuberances of the alloy grains suggested to Zang *et al.* (1992) crystal growth in a lateritic environment, indicating that the alloy is a secondary mineral. Microprobe data (2): Pd 49.49, Ag 49.31, Cu 0.11, Pt, Au and Hg not detected, total 98.91 wt.%. Empirical formula: $Ag_{0.990}Pd_{1.007}Cu_{0.004}$. An abstract about this mineral as published by Jambor (1994). For the synthetic compound with the formula AgPd, space group *Fm*3*m*, ordered structure was not observed (Ziya *et al.* 2011). Consequently, it would be not a new mineral, but an intermediate member of the series silver-palladium.

Catarinite

Meunier (1884)

(= taenite + tetrataenite + troilite + schreibersite)

Other names: catarinita, Catarinit, catharinita

Figure 1.7. Santa Catarina meteorite (catarinite) from the Morro do Rocio, São Francisco do Sul, Santa Catarina. Specimen from the Museu de Ciência e Técnica da Escola de Minas de Ouro Preto, Minas Gerais. Photo: Ricardo Scholz.

The name was given to the Santa Catarina (Santa Catharina)'s “fer meteorique”, found in 1875. Based on chemical analyses by Damour (1877) [Fe 63.69, Ni 33.97, Co 1.48, P 0.05, S 0.16, C 0.20, Si 0.01, total 99.56 wt.%], Meunier (1884) assumed the formula Fe_2Ni and gave it the name “catarinite”. The density is between 7.75 and 7.84 g/cm^3 (Damour 1877). The name “catharinita” was used by Ferraz (1928). The material analyzed probably corresponds to a mixture of the minerals taenite [(Ni,Fe) cubic], tetrataenite (FeNi tetragonal), troilite FeS hexagonal), and schreibersite [$(Fe,Ni)_3P$ tetragonal], identified in the Santa Catarina meteorite.

See also. Tetrataenite, arupite and bendegite.

Bendegite

Meunier (1898)

Other names: bendigite, bendegita

Figure 1.8. Bendegó meteorite (bendegite) from near the Bendegó stream, Uauá, Bahia. Museu Nacional, Rio de Janeiro. Photo: André L.R. Moutinho.

This name was given to the Bendegó's "fer meteorique", found in 1784 (or 1774) near the Bendegó stream, Monte Santo (currently Uauá), Bahia. The minerals identified in this meteorite are iron, taenite, schreibersite, cohenite and chromite (Carvalho *et al.* 2011)

See also. Catarinite.

Tetrataenite

Clark and Scott (1980)

(type specimen is not from Brazil)

Other names: tetrataenita, clear taenite

Tetrataenite, FeNi tetragonal, was described simultaneously in several meteorites, including the Brazilian Santa Catarina (São Francisco do Sul, Santa Catarina), Avanhandava (Avanhandava, São Paulo), São José do Rio Preto (São José do Rio Preto, São Paulo), and Ipiranga (Foz do Iguaçu, Paraná), but Clark and Scott (1980) defined tetrataenite from the Estherville meteorite, Emmet Co., Iowa, USA, as the type specimen. It corresponds to the "clear taenite" of Taylor and Heymann (1971).

See also. Catarinite and arupite.

Osmiridium

Steffens (1824)

(= osmium-bearing iridium)

and

Iridosmine

Breithaupt (1827)

(= iridium-bearing osmium)

Other names: osmirídio, iridosmina, Osm-Iridium, Ore of Iridium, Irid-Osmin

The use of the names osmiridium and iridosmine and its countless variants (mentioned in Hey 1963) is quite intricate. All these names were officially abandoned (Harris and Cabri 1991); osmiridium is now osmium-bearing iridium (a cubic alloy with Ir predominant) and iridosmine is iridium-bearing osmium (a hexagonal alloy with Os predominant). The name rutheniridosmine was retained for hexagonal alloys in which Ir is the dominant element.

Natural alloys of Os and Ir have been known since the article by Wollaston (1805), who called the mineral "Ore of Iridium", although he knew osmium was an important constituent, and a number of later authors called it iridium (Hey 1963). The name Osm-

Iridium was attributed originally by Steffens (1824) to a hexagonal alloy from Brazil, of then unknown quantitative composition, the same alloy that Haüy (1822) had termed "Iridium osmié". This alloy, supplied by Wollaston [but the sample that Wollaston (1805) named "Ore of Iridium" was from Colombia], was later analyzed by Thomson (1826), who found Ir 72.9, Os 24.5, Fe 2.6 wt.%, but his method greatly underestimated the osmium content (Hey 1963). The name Irid-Osmin was applied by Breithaupt (1827) for a material without chemical analyses from Nizhnii Tagil, Sverdlovsk Oblast, Russia.

"Osmiridium" and "iridosmine" occur associated with platinum and palladium, in Minas Gerais (Ferraz 1928). Hussak (1906a, b) quoted osmiridium from Bom Successo and Condado mines, North of Serro city, near the Itambé peak, Minas Gerais. Lévy and Picot (1961) published the occurrence of native osmium [90.8% Os, 3.7% Ir] in platinum concentrates from an unknown location in Brazil. Native osmium occurs at the ultramafic complex of Campo Formoso, Bahia (Garuti *et al.* 2008) and in Niquelândia, Goiás (Milliotti and Stumpfl 1993, Garuti *et al.* 2012).

Additional studies on native osmium and iridium from Brazil are necessary. The original material being hexagonal, would be iridium-bearing osmium if Os is dominant, or rutheniridosmine if Ir is dominant. The type localities, after the redefinitions by Hey (1963), were: iridosmine, "Brazil"; osmiridium, the Ural Mountains, Russia; osmium, Borneo; and rutheniridosmine, Hokkaido, Japan. No type locality was defined for iridium. Today, the official IMA mineral list gives as type localities: osmium, Indonesia; iridium, Russia?; and rutheniridosmine, Japan.

See also. Unnamed Ru and Ir oxides and hydroxides

Palladium

Wollaston (1809)

Pd, cubic

Other names: paládio, palladio

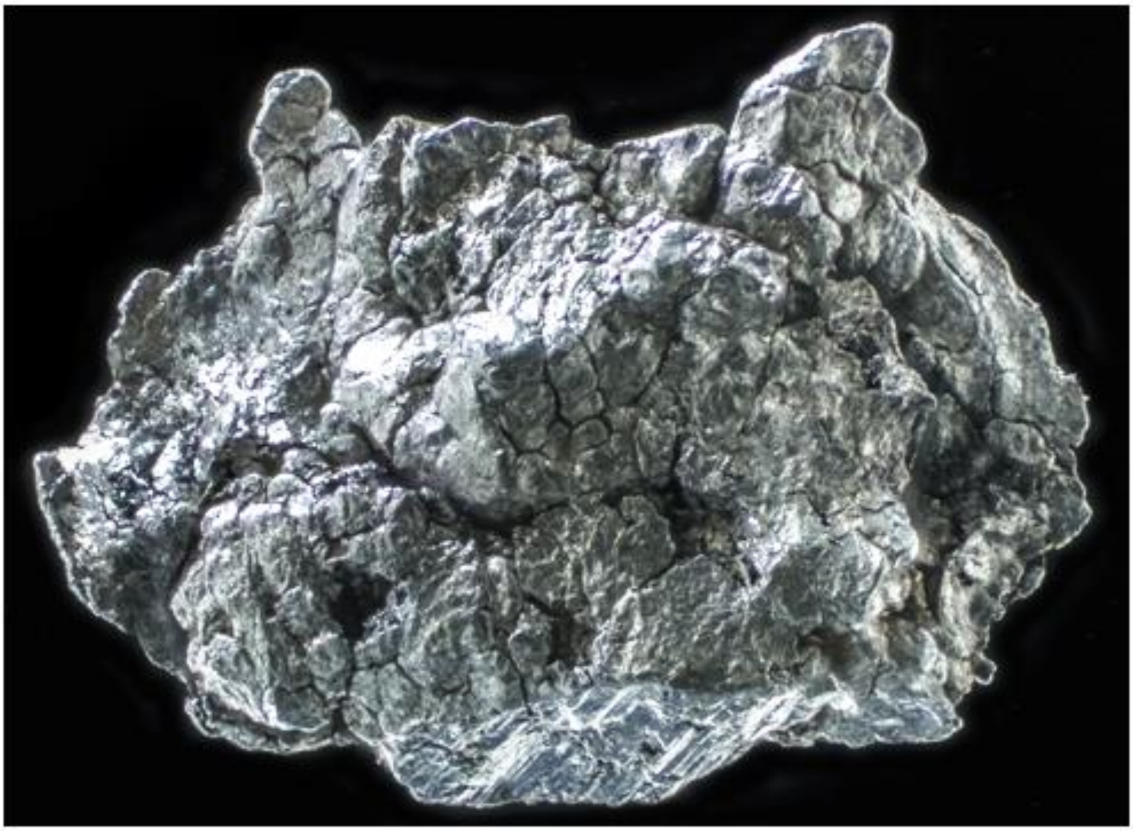


Figure 1.9. Palladium from Córrego Bom Sucesso, Serro, Minas Gerais. About 1 mm. Specimen: Paulo C.P. Neves, collected by Alexandre R. Cabral. Photo: Luciano Valério.

The citations regarding the discovery of the chemical element palladium and of the mineral native palladium are confusing. The original papers by Wollaston and some other review articles, however, suggest the following sequence of facts. The chemical element palladium was named by Wollaston in an anonymous footnote in an article by Chenevix (1803). According to Frondel (1972), Wollaston had already attributed this name to the element in 1802 in his laboratory notes. Also, according to Frondel (1972), a circular, privately printed in 1803 by Jacob Forster, announced the discovery of a new metal named palladium. The platinum samples used by Wollaston to isolate palladium and rhodium were acquired from J. Forster, collector and merchant of minerals in London, England. Later, Wollaston (1804 and 1805) published new data on the elements palladium and rhodium and how they were extracted from platinum (i.e. chemically separated, not the minerals palladium and rhodium). The provenance of the platinum samples was not mentioned, but, according to Frondel (1972), they were from South America.

Wollaston (1809) described new samples, from gold mines in Brazil, received from the ambassador of the court of Portugal, Souza Coutinho. In this article, he compares the new samples with the ones from the localities of Chocó and Santa Fé, "Peru", suggesting that the previously studied samples came from "Peru". At that time, the "Vice-kingdom of Peru" occupied almost the whole of Spanish America; today Chocó is in Colombia. Wollaston (1809) described the occurrence of the mineral native palladium for the first time, and identified some of the grains as palladium, found together with native platinum. Among the platinum grains, Wollaston found two grains with the same color, luster, and habit (divergent fibrous structure) as platinum, that were, however, more easily attacked by aqua regia; besides Pd, some Pt and Ir were also identified. Based on Wollaston's descriptions, Hussak (1906a, b), among others, thought that the samples most probably came from Lages creek, near Conceição do Serro (= Conceição do Mato Dentro), Minas Gerais, because it is the only place where native platinum occurs with this habit. According to Leonardos (1969 and 1970), the samples are from Fazenda Limeira (= Limeira farm), Lajes creek [Largos (Lajes) or Ouro Branco river], a tributary of the Santo Antônio river, 6.5 km from Conceição (= Conceição do Mato Dentro), in the district of Morro do Pilar, Minas Gerais, where platinum is found together with gold and black iron oxide, and also from Goiás. In Morro do Pilar, Barbosa (1962) also identified the mineral potarite. The habit, according to Cassedanne and Alves (1992) and Cassedanne *et al.* (1996) is typical of samples from Bom Sucesso creek and other creeks in the Serro area, Minas Gerais. According to Fleet *et al.* (2002), the two nuggets presumed to be of native palladium examined by Wollaston were likely to be composite. The study by Fleet *et al.* (2002) demonstrated unequivocally that the mineral palladium occurs as Pd-Pt solid solution with up to 65 at.% Pd, in the interior of the Bom Sucesso nuggets, and may have formed by alteration of earlier dendritic gold-rich potarite. These nuggets also contain several unnamed minerals: Au_2Pd, Au_3Pd, PdPt, and $(Pd,Au)_3Hg_2$.

According to Hussak (1906a, b), the massive native palladium occurs in the residual concentrates from the gold washings of auriferous "jacutinga" (a hydrothermally-altered Lake Superior-type carbonate-bearing iron-formation) from Itabira, Minas Gerais.

Olivo and Gauthier (1995) and Olivo *et al.* (1995) identified native palladium in “jacutinga” from the Cauê mine, Itabira, Minas Gerais, and presented the results of electron microprobe point analyses of palladium. The grains occur in quartz- and kaolinite-rich bands and are coated with pure gold. They generally have corroded interiors, partially replaced by gold (Olivo and Gammons 1996).

At Gongo Soco, Barão de Cocais, Minas Gerais, rosette-shaped, oxygen-deficient Pd-O associated with native Pd was quoted by Cabral and Kwitko-Ribeiro (2004), and native Pd formed by dehydroxylation of Pd-O-H was reported by Cabral *et al.* (2004).

Native Pd from the Serra Pelada Au-Pd-Pt deposit, Carajás mineral province, Curionópolis, Pará, characteristically situated in the goethite coating, is intimately associated with a Pd-O phase (Cabral *et al.* 2002d).

Palladium is considered a valid mineral species by CNMNC – IMA, but it still lacks a complete description in the literature. As quoted by Fleet *et al.* (2002), information on the occurrence and paragenetic position of the mineral palladium is sparse. Native palladium is a rare and poorly documented mineral (Cabral and Lehmann 2003). Most of the data presented in the following description of palladium are for synthetic material.

Occurrence. In alluvium, with platinum, potarite, anatase, cassiterite, crichtonite (or senaite?), hematite, ilmenite, kyanite, magnetite, muscovite, rutile, xenotime-(Y), zircon, gold, and diamond at Morro do Pilar County, and Bom Sucesso, Serro County, Minas Gerais (type locality). Palladium also occurs in several Brazilian and world localities.

Appearance and physical properties. Habit: commonly in grains, sometimes with a radial fibrous texture. Forms: rarely as octahedra {111}. Twinning: none mentioned. Color: megascopic color unknown. Streak: unknown. Luster: metallic. Opaque. Hardness (Mohs): 4½ to 5. Tenacity: malleable and ductile. Cleavage: none observed. Fracture: not given. Density :11.9 g/cm^3 (meas.), 11.87 g/cm^3 (calc.). Kwitko *et al.* (2002) described aggregates of native palladium over a mass of iron oxyhydroxide, associated with palladium-bearing gold from Cauê iron mine, Itabira, Minas Gerais. The aggregates consist of tiny rosette-like crystals whose pattern is formed roughly by the intersection of discs in three orthogonal directions. According to Cabral and Kwitko-Ribeiro (2004) it is a Pd-O compound, not native palladium.

Optical properties. In reflected light: white to pale steel-gray, isotropic, no bireflectance. Pleochroism: absent. R: (67.8) 540 nm.

Chemical data. Microprobe analysis (4): Pd 45.02, Pt 53.01, Hg 0.98, Au 0.09, total 99.10 wt.%. Empirical formula: $(Pd_{0.60}Pt_{0.39}Hg_{0.01})_{\Sigma 1.00}$ (Pt-rich palladium from Bom Sucesso stream alluvium, Serro, Minas Gerais, Fleet *et al.* 2002). Microprobe analysis: Pd

91.99, Au 1.98, Cu 1.31, Fe 1.31, Hg and Se not detected, total 96.65 wt.%. Empirical formula: $(Pd_{0.94}Fe_{0.03}Cu_{0.02}Au_{0.01})_{\Sigma 1.00}$ (Cauê iron mine, Itabira, Minas Gerais, Olivo and Gauthier 1995).

Crystallography. Cubic, *Fm*3*m*, *a* 3.8898 Å, *V* 58.85 Å^3, *Z* 4. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 2.246 (100) (111), 1.945 (42) (200), 1.376 (25) (220), 1.173 (24) (311), 1.1232 (8) (222), 0.9723 (3) (400), 0.8924 (13) (331), 0.8697 (11) (420).

Name. For the asteroid Pallas, discovered in 1802 by Dr. Olbers (Wollaston 1805). Nevertheless, according to Ferraz (1928), this name derives from *palladion*, diminutive of Pallas, referring to an image of the goddess Pallas Athena, given to the city of Troy. According to Greek mythology, the city could not be captured while the image remained there.

Type material. No data on the type specimen.

Relationship to other species. A member of the platinum group.

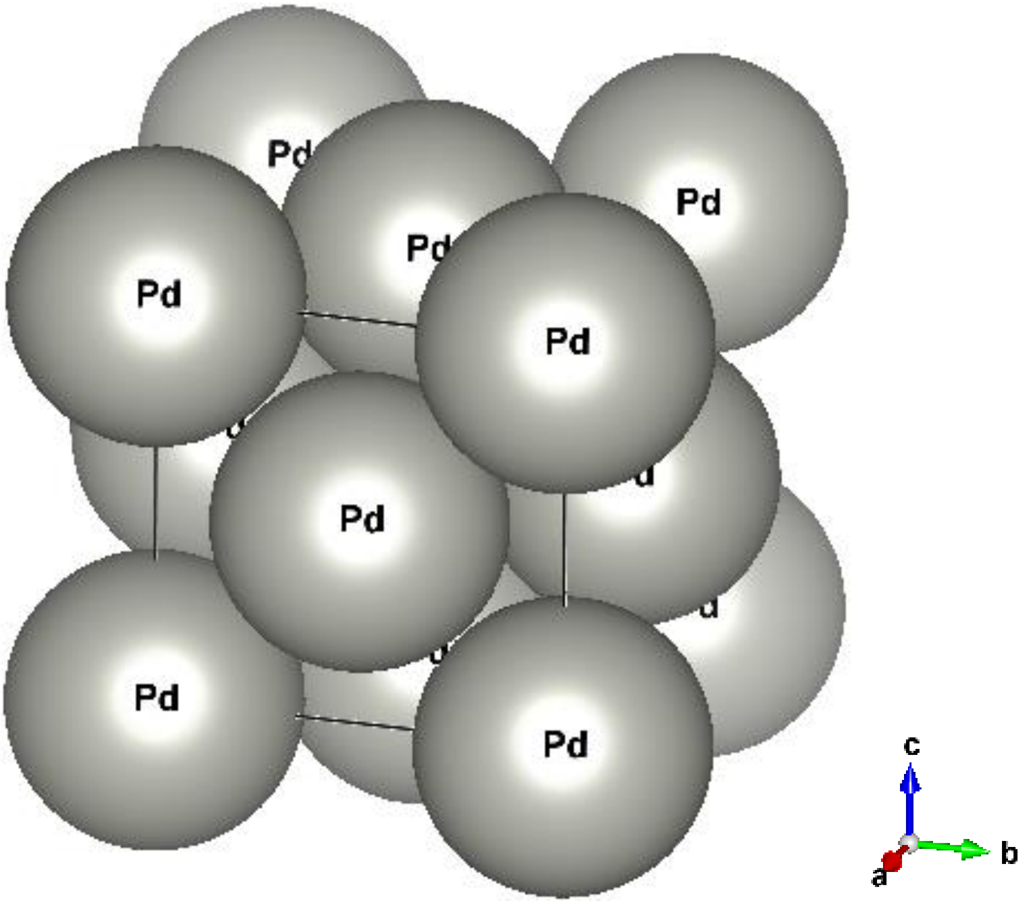


Figure 1.10. View of the crystal structure of palladium (synthetic), drawn using VESTA 3 (Momma and Izumi 2011). Data from Ellner (1981).

Crystal structure. Cubic closest packed (CCP), face-centered cubic (FCC) crystal structure.

Synthetic. Originally obtained by Wollaston (in Chenevix 1803). Metal nanoparticles, including Pd, can be obtained via two main approaches: subdivision of bulk metal (a physical method) or particle growth by reduction of the metal ionic precursor (a chemical method) (Saldan *et al.* 2015).

See also. Unnamed Au_2Pd, Au_3Pd, PdPt, $(Pd,Au)_3Hg_2$, oxygen-deficient Pd-O, Pd-O-H, Pd-O phase, senaite, palladseite, and Palladiumplatin.

Unnamed PdPt and $(Pt,Hg)_2Pd$

Cabral *et al.* (2006)

Other names: UM2006-02-E:HgPdPt

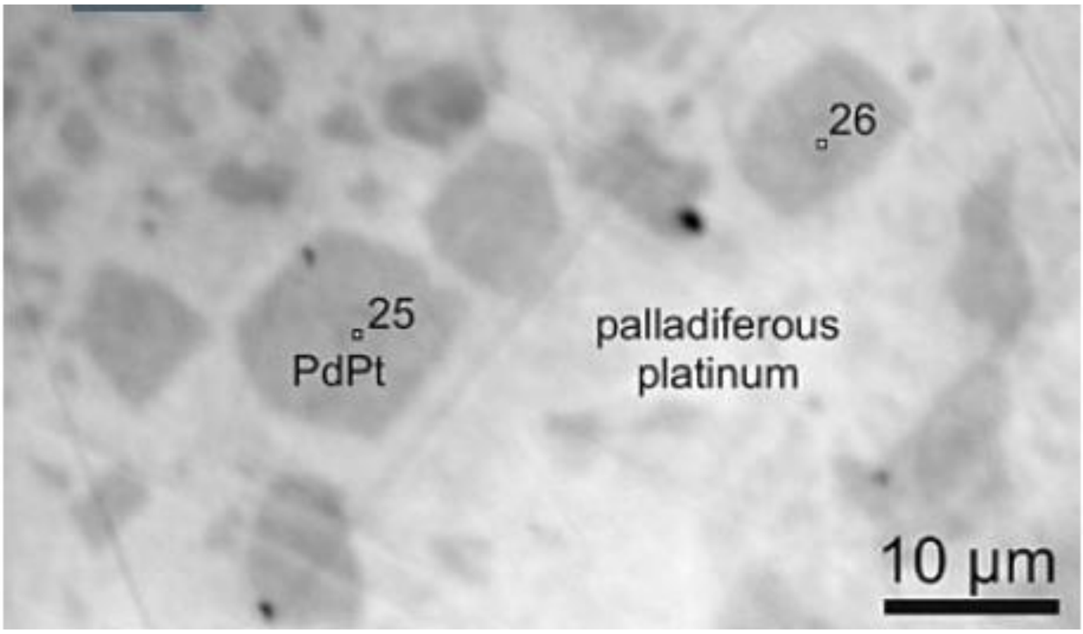


Figure 1.11. Hexagon-shaped crystals of unnamed PdPt in palladiferous platinum from a marginal zone of an arborescent grain, from Córrego Bom Sucesso, Serro, Minas Gerais (Cabral *et al.* 2006).

According to Fleet *et al.* (2002), the more common product of alteration of potarite from Córrego Bom Sucesso, Serro, Minas Gerais, is an alloy of composition near $Pt_{50}Pd_{50}$, whose status as a phase distinct from either platinum or palladium is dubious. Cabral *et al.*

(2006) also studied arborescent, botryoidal and reniform grains of platinum and palladium from Córrego Bom Sucesso. According to them, the nuggets reach a maximum length of 2.5 mm and exhibit core-to-rim compositional zoning in platinum, palladium and mercury contents. One grain is note-worthy for a marginal halo of mercury-rich palladiferous platinum and internal vermiform lamellae enriched in mercury and gold. The mercury-rich palladiferous platinum has 10–20 wt.% Hg and an empirical stoichiometry close to $(Pt,Hg)_2Pd$. Hexagonal crystals occur in palladiferous platinum, forming a peripheral zone of an arborescent grain. These crystals are compositionally analogous to stoichiometric PdPt and seem to represent to Cabral *et al.* (2006) an ordered phase distinct from either platinum or palladium in opposition to Fleet *et al.* (2002). Synthetic PdPt is a disordered cubic, *Fm*3*m* phase, intermediate between palladium and platinum (Raub 1959).

See also. Unnamed Au_2Pd, Au_3Pd, $(Pd,Au)_3Hg_2$, palladium, and Palladiumplatin

Palladiumplatin

Hussak (1906a, b)

(= palladium-rich platinum + platinum-rich palladium + pure platinum + gold-rich potarite)

Other names: palladian platinum, palladic platinum, platina palladiada

Figure 1.12. Botryoidal Pt–Pd nuggets from Bom Sucesso creek, Serro, Minas Gerais The largest is 4.2 × 2.6 × 1.3 mm. Specimen and photo: Edson Ferreira dos Santos.

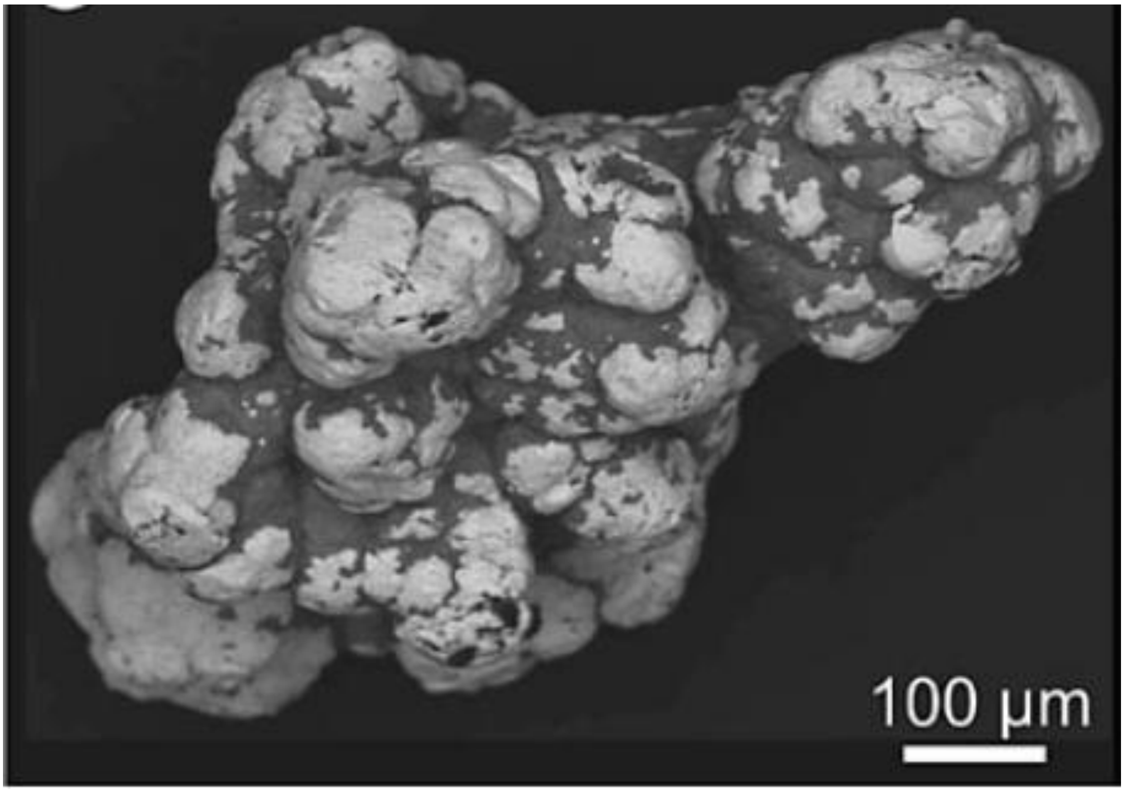


Figure 1.13. Botryoidal Pt–Pd nugget (white), partially coated with aggregates of titanium oxide, from Bom Sucesso creek, Serro, Minas Gerais (Cabral *et al.* 2006).

A name given by Hussak (1906a, b) to a variety of palladium-bearing platinum from Fazenda do Condado (= Condado farm), Serro, Minas Gerais, regarded as the type locality of palladium. The João Caboclo creek [near Bom Sucesso creek] corresponds to the Ignez creek of the early authors, who mentioned the area as Fazenda do Condado (Moraes *et al.* 1937). Cassedanne and Cassedanne (1974) and Cassedanne and Alves (1992) presented the results of wet chemical analyses for samples from Bom Sucesso creek. They are compared to the analyses of "platina palladiada" or "Palladiumplatin", from Fazenda do Condado, Serro, Minas Gerais, by Hussak (1906a, b), in Table 1.1. Analyses 3, 4, and 5 were done on polymineralic samples. It is also quite probable that analyses 1 and 2 refer to a mixture of phases. Nuggets from the Bom Sucesso stream alluvium have been investigated by electron-probe microanalysis by Fleet *et al.* (2002), who identified palladium-rich platinum, platinum-rich palladium, pure platinum and gold-rich potarite.

Table 1.1. Wet chemical analyses (wt.%) for “palladium-bearing platinum” from Serro, Minas Gerais

	1	2	3	4	5
Pt	73.99	72.96	85.2	78.1	68.0
Pd	21.77	21.82	11.7	18.6	29.3
Ir	0.08	0.88	1.2	2.1	1.4
Os	3.14	3.92	tr.	n.d.	tr.
Fe	0.10	tr.	1.9	tr.	n.d.
Cu	n.d.	n.d.	n.d.	n.d.	n.d.
Insol.	0.92	0.42	n.d.	n.d.	n.d.
Total	100.00	100.00	99.1	98.8	98.7

1 and 2: Hussak (1906a, b)

3 to 5: Cassedanne and Cassedanne (1974)

See also. Palladium. unnamed Au_2Pd, Au_3Pd, PdPt, and $(Pd,Au)_3Hg_2$.

Unnamed $(Pd,Au)_3Hg_2$

Fleet *et al.* (2002), Cabral *et al.* (2009)

Other names: Unnamed (Pd-Au-Hg Alloy)

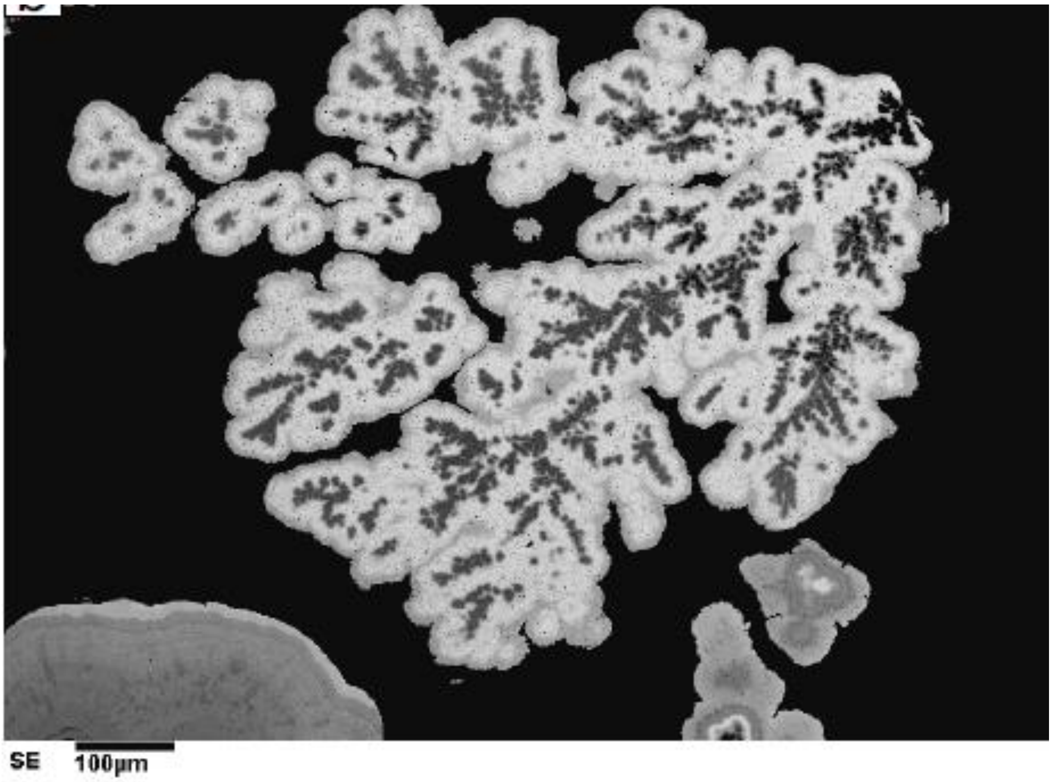


Figure 1.14. Arborescent nugget with a core of dendritic auriferous potarite, a broad interior zone of nearly pure platinum, and a narrow (20 µm) rim of palladian platinum, from Córrego Bom Sucesso, Serro, Minas Gerais (Fleet *et al.* 2002).

Potarite, ideally PdHg, is reported in the literature to have compositions varying from PdHg or Pd(Hg,Au) to Pd_3Hg_2. Such a Pd_3Hg_2 phase is unknown in the synthetic Pd–Hg binary system. For the first time, Pd–Hg grains recovered from the historical Córrego do Bom Sucesso alluvium, Serro, Minas Gerais, regarded as the type locality of palladium, were shown by Cabral *et al.* (2009) to consist of arborescent and lamellar intergrowths of two intermetallic compounds, compositionally close to empirical Pd(Hg,Au), i.e., auriferous potarite, and $(Pd,Au)_3Hg_2$. The Pd–Hg–Au grains have a rim of palladiferous Pt. The otherwise sharp Pd–Hg–Au intergrowths become diffuse at the contact with the palladiferous Pt rim. Both the Pd–Hg–Au compounds and the palladiferous Pt rim did not diffract using the electron-backscattered diffraction (EBSD) or powder X-ray microdiffraction techniques, indicating that they are poorly crystalline. Their poor crystallinity and the diffuse zone between the Pd–Hg–Au core and the Pt-rich overgrowth are suggestive of electrochemical metal precipitation from dilute solutions within the alluvium (Cabral *et al.* 2009). Fleet *et al.* (2002) yet characterized auriferous potarite from Bom Sucesso as an alloy varying in composition from Pd_3Hg_2 to near Pd(Hg,Au).

See also. Palladium, unnamed Au_2Pd, Au_3Pd, PdPt, and Palladiumplatin.

Unnamed Pd-Hg-Au alloy

Clark *et al.* (1974)

Clark *et al.* (1974) quoted that the concentrates of Cauê mine, Itabira, Minas Gerais, also contain a few grains of native gold, often intergrown with a palladium-mercury-gold alloy. No additional data.

See also. Unnamed $(Pd,Au)_3Hg_2$.

Carbonado

Tennant (1852)

(variety of diamond)

Other names: diamante negro, diamante amorpho, carbão, carbonita, carbono, carbonato, lavrita, lavrite, carbito, carbon bort

Figure 1.15. Carbonado (diamond) from Lençois, Bahia. 28.2 ×17.7 × 16.4 mm. Specimen and photo: Edson Ferreira dos Santos.

Black or grayish diamond, massive, and fine grained, it was first found in the Lavras - Diamantina region, Chapada Diamantina, Bahia, in 1843, and later recorded in the diamond area of Minas Gerais, between Diamantina and Grão Mongol, Serra do Espinhaço; in Goiás, Mato Grosso and Paraná (Oliveira 1930). According to Ferraz (1928), it is called “lavrita”, from Lavras locality, in Bahia. *“The designation we proposed in 1904* [Souza Carneiro 1904], *and at once admitted by us in the Escola Politécnica da Bahia, was lavrita”* (Souza Carneiro 1908).

Unnamed Fe_3N

Kaminsky and Wirth (2017)

Other names: Unnamed (Iron Nitride I)

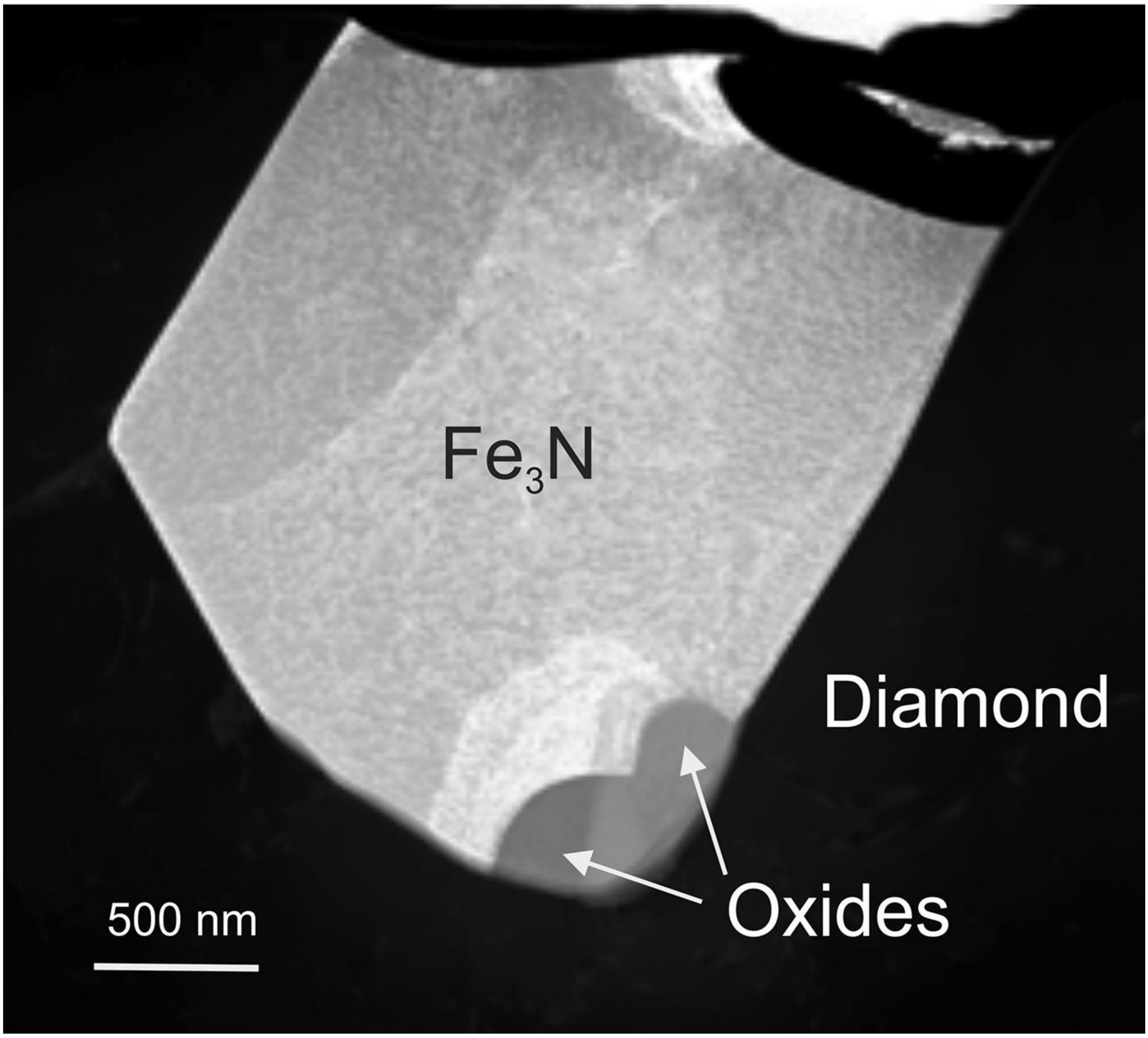


Figure 1.16. Unnamed Fe_3N as an inclusion in a diamond crystal from alluvial deposits of Sorriso river, Chicória farm, Juína, Mato Grosso (Kaminsky and Wirth 2017).

Unnamed Fe_3N was reported by Kaminsky and Wirth (2017) as inclusions in diamond crystals from alluvial deposits of Sorriso river, Chicória farm, Juína, Mato Grosso. It occurs as tabular or equidimensional single-phase grains, 1–2.5 µm in size. Some of such inclusions are intergrown with smaller (300–400 nm) grains of oxides. The synthetic equivalent (ε-Fe_3N) was obtained by a high pressure solid-state metathesis reaction between alkaline or alkaline-earth metal ferrite ($NaFeO_2$, $MgFe_2O_4$, and $Ca_2Fe_2O_5$) and boron nitride by Yin *et al.* (2014). It is trigonal, *P*312, *a* 4.7410(2), *c* 4.3862(2) Å, *V* 85.38 Å^3.

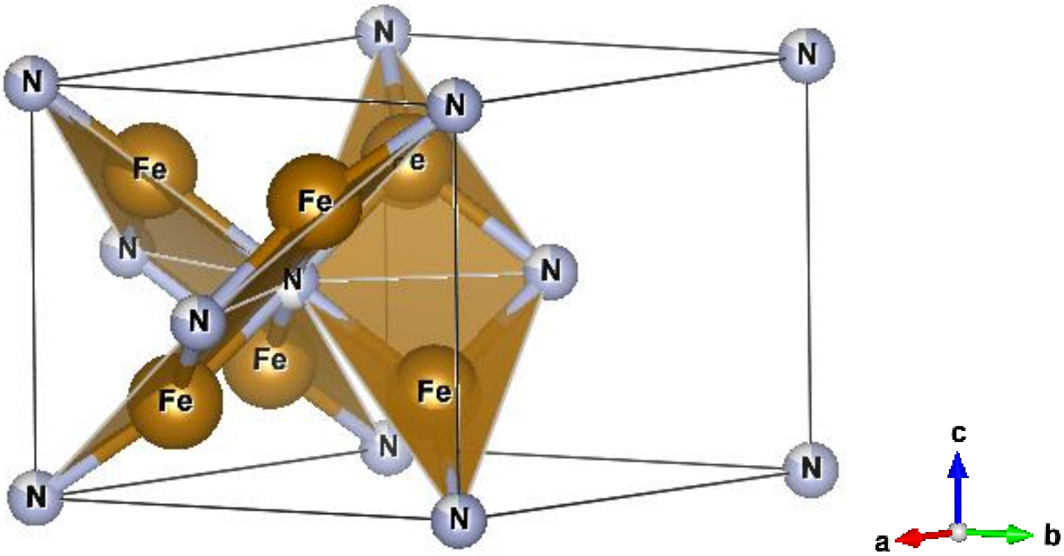


Figure 1.17. View of the crystal structure of unnamed Fe_3N (synthetic), drawn using VESTA 3 (Momma and Izumi 2011). Data from Yin *et al.* (2014).

Several other minerals as inclusions in the diamonds of Juína, Mato Grosso, were described.

See also. Jeffbenite, ellinaite, breyite, nitroyarlongite, nitrocohenite, nitrochalypite, unnamed Fe_2N, Fe_5SiC, $(Ba,Sr)AlF_5$, orthorhombic MgO, $MgCr_2O_4$, $Na_4Mg_3(PO_4)_2(P_2O_7)$, $Fe_2^{3+}Fe_5^{2+}(P_2O_7)_4$, and Na-Mg pyroxene.

Unnamed Fe_2N

Kaminsky and Wirth (2017)

Other names: Unnamed (Iron Nitride II)

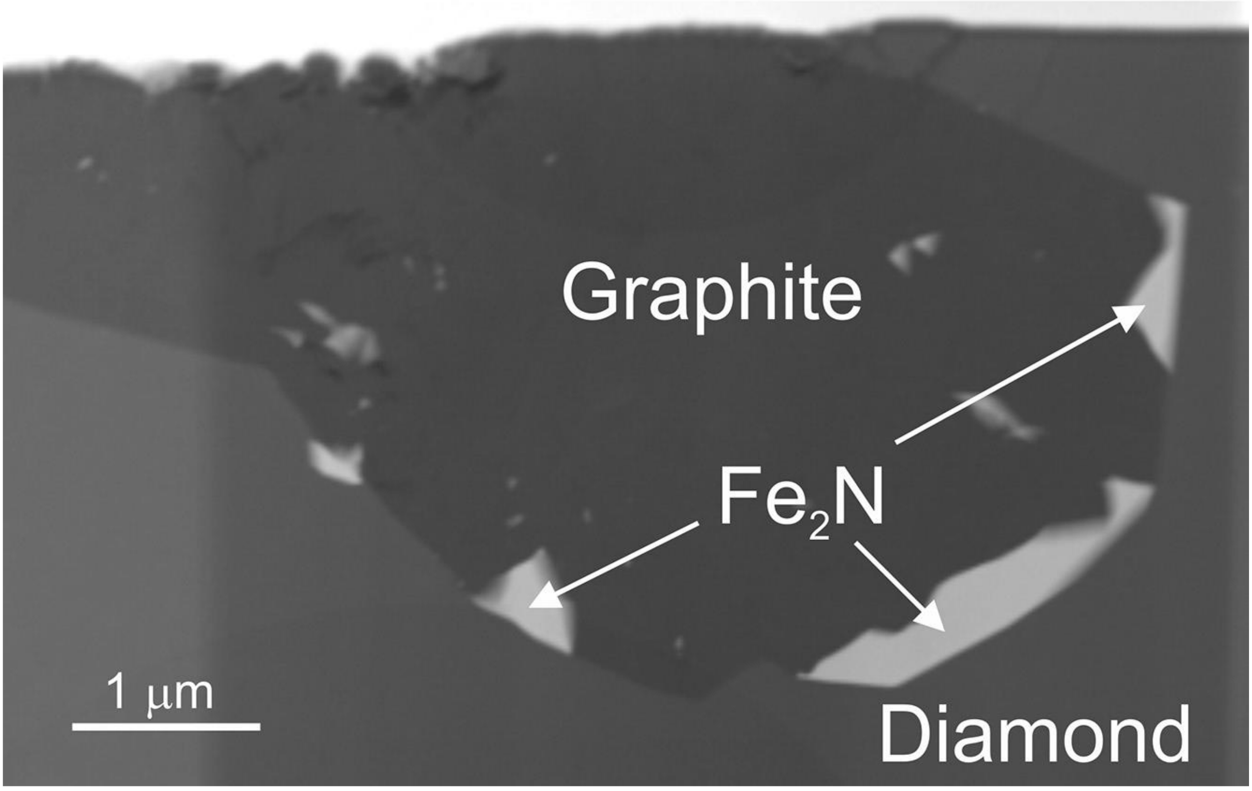


Figure 1.18. Unnamed Fe_2N as an inclusion in a diamond crystal from alluvial deposits of Sorriso river, Chicória farm, Juína, Mato Grosso (Kaminsky and Wirth 2017).

Unnamed Fe_2N was reported by Kaminsky and Wirth (2017) as inclusions in diamond crystals from alluvial deposits of Sorriso river, Chicória farm, Juína, Mato Grosso. It occurs as elongated inclusions, consisting of an aggregate of nitride and/or replacing polycrystalline graphite. Unnamed Fe_2N forms irregular, 0.5–1.5 µm grains along the periphery of the aggregate and smaller (0.1–0.3 µm), irregularly shaped, relics within the graphite matrix, demonstrating a typical structure of resorption of the initial nitride grain by graphite. In dark- and bright-field images the relic iron nitride grains show the same crystallographic orientation, confirming that they belong to a former, single large crystal. The synthetic equivalent was obtained in a short time by a simple direct nitriding reaction between metal and a supercritical nitrogen fluid at high pressures (about 10 GPa) and high temperatures (about 1800 K), using diamond anvil cell and YAG laser heating system, by Hasegawa and Yogi (2005). It is orthorhombic, *Pbcn*, *a* 4.423(4), *b* 5.531(3), *c* 4.821(3) Å, *V* 117.9(1) $Å^3$. The structure is PbO_2-type, where iron occupies 8*d* site and nitrogen does 4*c* site.

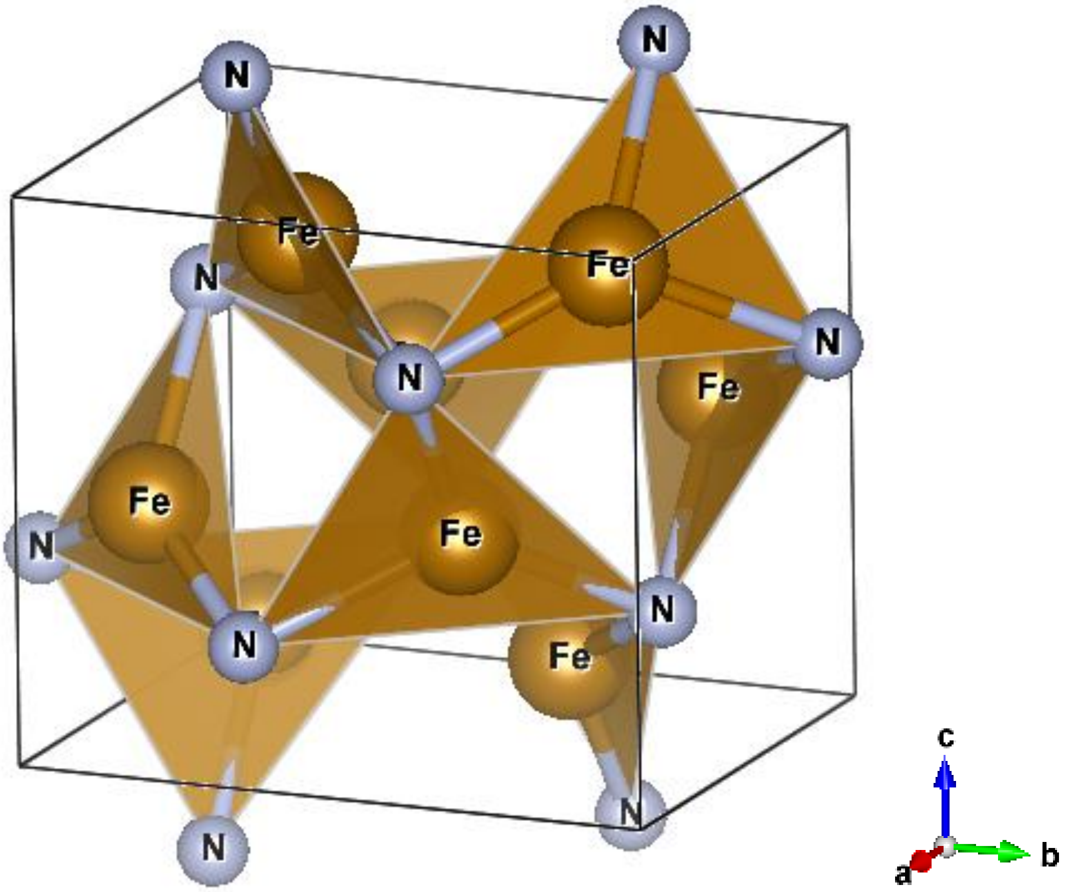


Figure 1.19. View of the crystal structure of unnamed Fe_2N (synthetic), drawn using VESTA 3 (Momma and Izumi 2011). Data from Hasegawa and Yogi (2005).

Several other minerals as inclusions in the diamonds of Juína, Mato Grosso, were described.

See also. Jeffbenite, ellinaite, breyite, nitroyarlongite, nitrocohenite, nitrochalypite, unnamed Fe_3N, Fe_5SiC, $(Ba,Sr)AlF_5$, orthorhombic MgO, $MgCr_2O_4$, $Na_4Mg_3(PO_4)_2(P_2O_7)$, $Fe_2^{3+}Fe_5^{2+}(P_2O_7)_4$, and Na-Mg pyroxene.

Unnamed Fe_5SiC

Kaminsky *et al.* (2015)

Unnamed Fe_5SiC was reported by Kaminsky *et al.* (2015) as inclusions in diamond crystals from alluvial deposits of Sorriso river, Chicória farm, Juína, Mato Grosso. This compound is well known among nanocomposite materials, but has never previously been identified in the natural environment. The structure and magnetic properties of the synthetic material, which was produced by the mechanical alloying of a mixture Fe:C:Si = 70:17:13 at.% and subsequent annealing of the resultant amorphous phase at 500°C for 1 h, have been studied by Lomaeva *et al.* (2005). Fe_5SiC is orthorhombic, *Cmc*2_1, with unit cell parameters *a* 10.043, *b* 7.944, and *c* 7.469 Å, *V* 595.89 Å^3, *Z* 16 (synthetic), and *a* 11.094, *b* 7.656, and *c* 7.423 Å (natural).

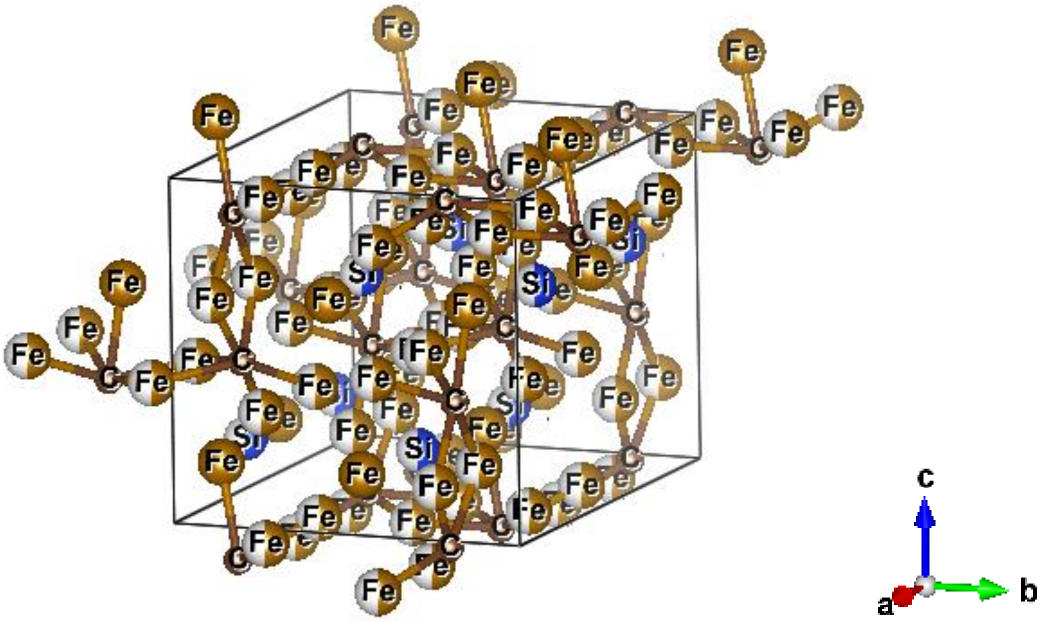


Figure 1.20. View of the crystal structure of unnamed Fe_5SiC (synthetic), drawn using VESTA 3 (Momma and Izumi 2011). Data from Lomaeva *et al.* (2005).

Several other minerals as inclusions in the diamonds of Juína, Mato Grosso, were described.

See also. Jeffbenite, ellinaite, breyite, nitroyarlongite, nitrocohenite, nitrochalypite, unnamed Fe_3N, Fe_2N, $(Ba,Sr)AlF_5$, orthorhombic MgO, $MgCr_2O_4$, $Na_4Mg_3(PO_4)_2(P_2O_7)$, $Fe_2^{3+}Fe_5^{2+}(P_2O_7)_4$, and Na-Mg pyroxene.

Nitroyarlongite

Kaminsky *et al.* (2015)

$Fe_9(N,C)_4$, trigonal

Other names: Unnamed (Iron Carbonitride)

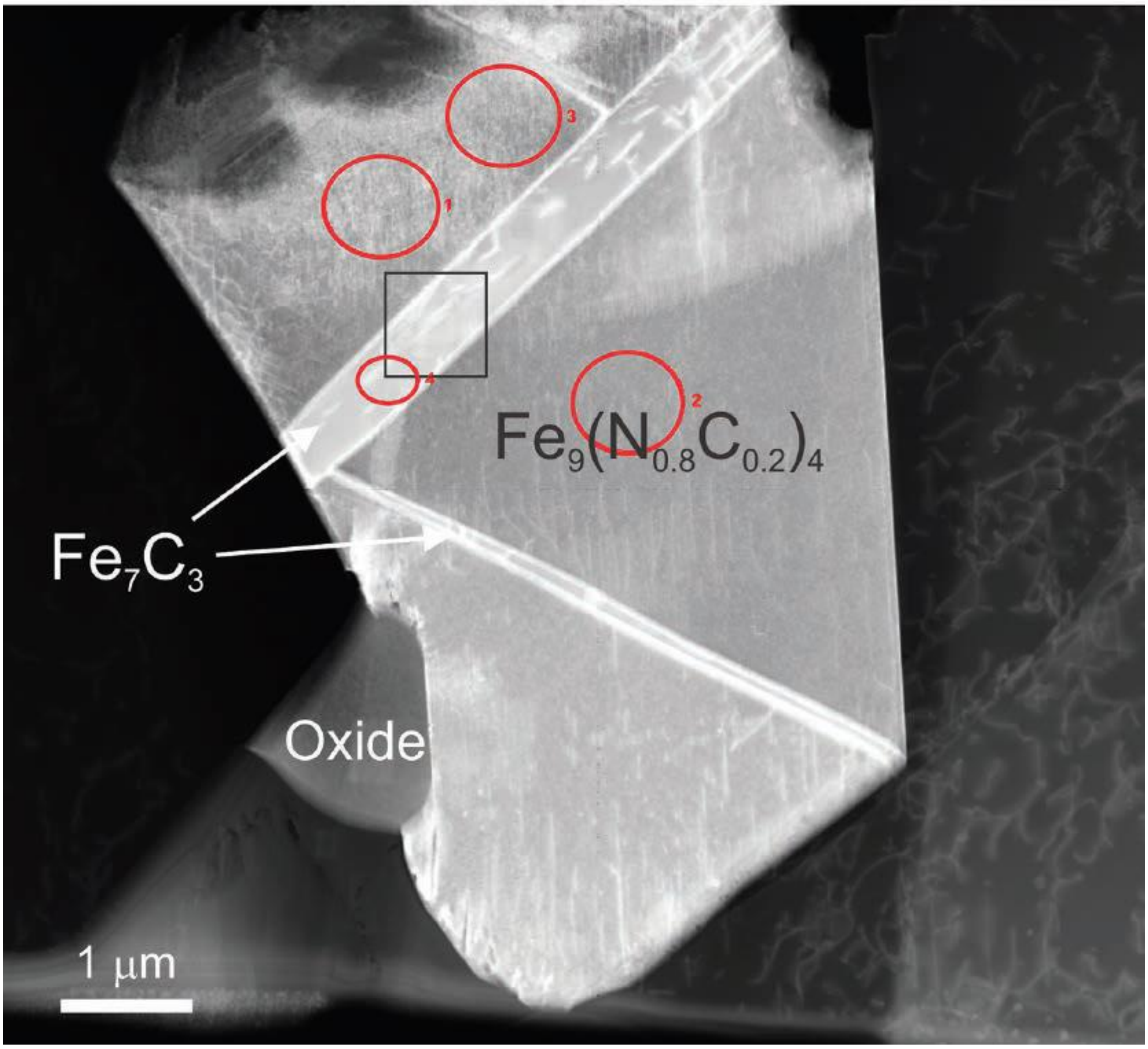


Figure 1.21. Nitroyarlongite, $Fe_9(N_{0.8}C_{0.2})_4$ and nitrochalypite, $Fe_7(C,N)_3$ or $Fe_2(C,N)$ from alluvial deposits of Sorriso river, Chicória farm, Juína, Mato Grosso (Kaminsky and Wirth 2017).

A trigonal iron carbonitride mineral was inferred by X-ray diffraction data as an inclusion in a diamond crystal from alluvial deposits of Sorriso river, Chicória farm, Juína, Mato Grosso (Kaminsky and Wirth 2011). The diffraction pattern is [*d* in Å (*hkl*)]: 4.47 (001), 4.02 (100), 2.99 (101). As such, the peaks could be indexed on the basis of a diffraction pattern of a synthetic alloy, ε-$Fe_3(N_{0.80}C_{0.20})_{1.38}$, which has Fe/(C+N) equal to 2.17, similar to the Fe_2C composition but with a C/(C+N) value of 0.20 (*i.e*., an extreme predominance of nitrogen over carbon) [*d* in Å (*hkl*)]: 4.406 (001), 4.135 (100), 3.015 (101) (Leineweber *et al.* 2001). The C:N ratio in this synthetic alloy can vary because both carbon and nitrogen are located in the interstitial positions of the lattice. The synthetic material was prepared by treating iron powder with NH_3, NH_3 - H_2 mixtures and a special carbonitriding atmosphere, in technical nitridation furnaces. The synthetic compound is a carbonitride of great importance in metallurgy. It is trigonal, $P\bar{3}1m$, *a* 4.7743, *c* 4.4063 Å, *V* 86.98 $Å^3$, *Z* 2 (Leineweber *et al.* 2001).

Kaminsky *et al.* (2015) applied the name nitroyarlongite to this mineral, without submission to IMA. Anyway, this name does not make sense, because yarlongite is $Cr_4Fe_4NiC_4$. The formula attributed by the authors was $Fe_9(C,N)_4$, but N>C in *apfu*. Consequently, the correct would be $Fe_9(N,C)_4$.

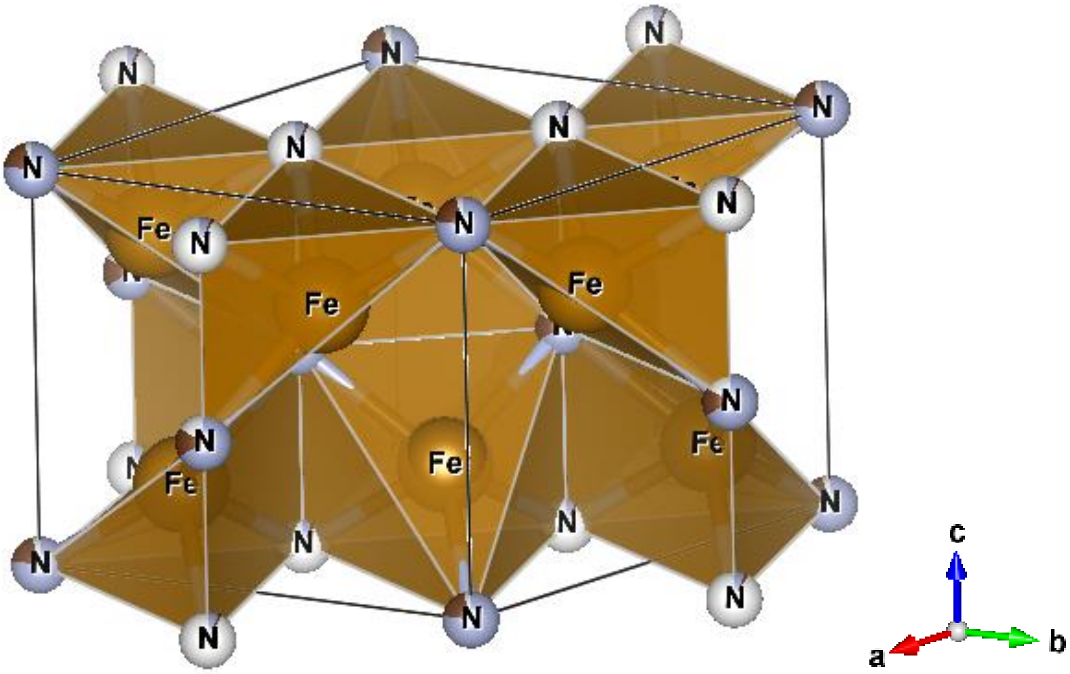


Figure 1.22. View of the crystal structure of nitroyarlongite (synthetic), drawn using VESTA 3 (Momma and Izumi 2011). Data from Leineweber *et al.* (2001).

Several other minerals as inclusions in the diamonds of Juína, Mato Grosso, were described.

See also. Jeffbenite, ellinaite, breyite, nitrocohenite, nitrochalypite, unnamed

Fe_3N, Fe_2N, Fe_5SiC, $(Ba,Sr)AlF_5$, orthorhombic MgO, $MgCr_2O_4$, $Na_4Mg_3(PO_4)_2(P_2O_7)$, $Fe_2^{3+}Fe_5^{2+}(P_2O_7)_4$, and Na-Mg pyroxene.

Nitrocohenite

Kaminsky *et al.* (2015)

$Fe_3(C,N)$, orthorhombic

(N-rich cohenite)

The name nitrocohenite was introduced, without submission to IMA, by Kaminsky *et al.* (2015) for an N-rich variety of cohenite, Fe_3C, which occurs as as inclusions in a diamond crystal from alluvial deposits of Sorriso river, Chicória farm, Juína, Mato Grosso.

Several other minerals as inclusions in the diamonds of Juína, Mato Grosso, were described.

See also. Jeffbenite, ellinaite, breyite, nitroyarlongite, nitrochalypite, unnamed Fe_3N, Fe_2N, Fe_5SiC, $(Ba,Sr)AlF_5$, orthorhombic MgO, $MgCr_2O_4$, $Na_4Mg_3(PO_4)_2(P_2O_7)$, $Fe_2^{3+}Fe_5^{2+}(P_2O_7)_4$, and Na-Mg pyroxene.

Nitrochalypite
Kaminsky *et al.* (2015)
$Fe_7(C,N)_3$ or $Fe_2(C,N)$
(N-rich chalypite)
Other names: Unnamed (Iron Carbide), Unnamed (Iron Carbide II)

See Figure 1.21.

The name nitrochalypite was introduced, without submission to IMA, by Kaminsky *et al.* (2015) for an N-rich variety of chalypite, a not valid mineral, which occurs as as inclusions in a diamond crystal from alluvial deposits of Sorriso river, Chicória farm, Juína, Mato Grosso.

Several other minerals as inclusions in the diamonds of Juína, Mato Grosso, were described.

See also. Jeffbenite, ellinaite, breyite, nitroyarlongite, nitrocohenite, unnamed Fe_3N, Fe_2N, Fe_5SiC, $(Ba,Sr)AlF_5$, orthorhombic MgO, $MgCr_2O_4$, $Na_4Mg_3(PO_4)_2(P_2O_7)$, $Fe_2^{3+}Fe_5^{2+}(P_2O_7)_4$, and Na-Mg pyroxene.

Unnamed (Ce,La)Si and (Al,Fe)Si
Kachalovskaja *et al.* (1999)
Other names: UM1999-31-Si:REE, UM1999-30-Si:AlFe

The occurrence of these phases, associated with “ferdisilicite” (now renamed linzhiite, $FeSi_2$, tetragonal) and native silicon, was described in the Fazenda Brasileiro gold mine, Barrocas, Bahia. Quartz, feldspar, carbonates, chlorite, muscovite, fluorite, apatite, zircon, titanite, pyrite, arsenopyrite, pyrrhotite, ilmenite, anatase, rutile, gold, scheelite, wolframite, sphalerite, and galena were identified in the ore. Silicides and native silicon were observed in crushed samples and in heavy mineral concentrates. In the opinion of the authors, the natural origin of these phases remains questionable.

The mean chemical composition of the unnamed (Ce,La)Si is: La 24.26, Ce 36.92, Pr 4.73, Nd 8,92, Gd 3.25, Si 16.75, Ca 3.61, Al 1.12, Fe 0.44, total 100.00 wt.% corresponding to $[(Ce_{0.40}La_{0.28}Nd_{0.09}Pr_{0.05}Gd_{0.03})_{\Sigma 0.85}Ca_{0.14}]_{\Sigma 0.99}(Si_{0.92}Al_{0.06}Fe_{0.02})_{\Sigma 1.00}$. It occurs as drops, lenticular, dendritic and irregular grains up to 50μm, intimately associated with linzhiite, unnamed (Al,Fe)Si and native silicon. Opaque, without cleavage, brittle, no internal reflection, VHN_{50}: 515 to 645 (mean 618) kg/mm^2. It is light cream-white in reflected light, visible anisotropism in faded colors, weakly bireflectant. Reflectance percentages (Si standard, in air) are given in 20 nm steps from 400 to 700 nm; representative *R* values are (Rg' and Rp'): 52.1, 46.7 (480 nm), 54.1, 49.4 (560 nm), 54.5, 50.0 (580 nm), and 56.8, 52.3 (660 nm). It is orthorhombic, space group *Imm*a, *a* 4.272, *b* 4.118, *c* 14.02 Å, *Z* 4. Strongest lines of the powder pattern (57 mm camera, Fe radiation) are [*d* in Å (*I*) (*hkl*)]: 3.49 (30) (004), 3.13 (20) (103), 2.76 (100) (112), 2.32 (50) (105,006), 2.13 (30) (200), 2.10 (50) (020), 1.908 (30) (211), 1.867 (30) (121), 1.841 (50) (116), 1.813 (40) (204,107), and 1.296 (20) (132).

The mean chemical composition of the unnamed (Al,Fe)Si is: Si 32.63, Fe 32.34, Al 17.29, La 3.68, Ce 7.90, Pr 1.03, Nd 2.65, Gd 0.50, Ca 1.85, total 100.00 wt.% corresponding to $(Al_{0.55}Fe_{0.50}Ce_{0.05}Ca_{0.04}La_{0.03}Nd_{0.02}Pr_{0.01})_{\Sigma 1.20}Si_{1.00}$. It occurs as irregular grains, up to 0.02 mm, intimately associated with the other silicides and native silicon. Opaque, VHN_{50} 753 to 893 (mean 824) kg/mm^2. Its color is white in reflected light, isotropic and, like (Ce,La)Si, it does not show internal reflections. Reflectance percentages (Si standard, in air) are given in 20 nm steps from 400 to 700 nm; representative *R* values are 46.7 (480), 48.9 (560), 49.0 (580), and 49.3 (660).

Chapter 2

Sulfides, selenides, arsenides, tellurides, and antimonides

Atheneite

Clark *et al.* (1974)

$Pd_2(As_{0.75}Hg_{0.25})$, hexagonal

Approved CNMMN - IMA 1973-050

Other names: atheneïte, atheneíta, ateneíta, atenasita

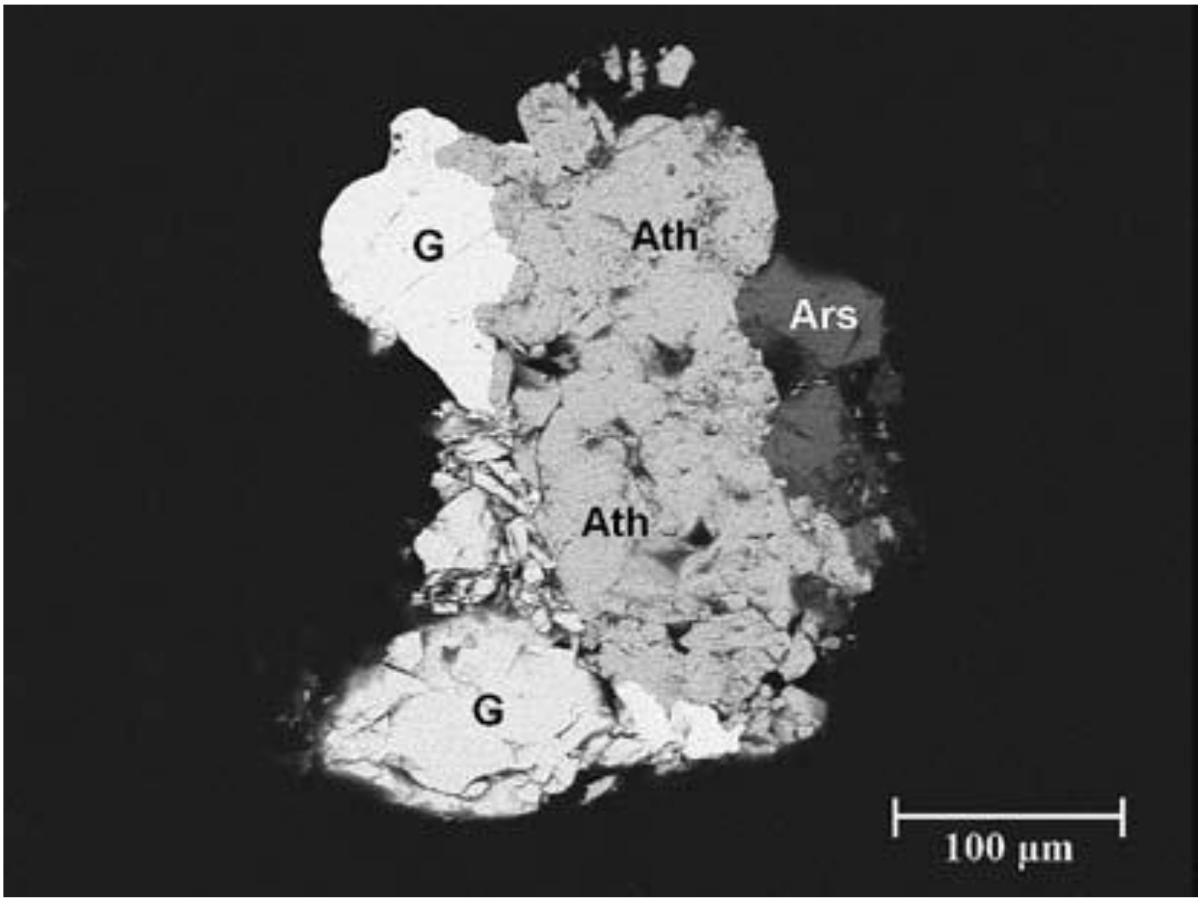


Figure 2.1. Back-scattered electron SEM photograph of atheneite (Ath), associated with arsenopalladinite (Ars) and gold (G) from the Cauê iron mine, Itabira, Minas Gerais (Bindi 2010).

See also Figures 2.10, 2.13, and 2.14.

A sample of residual concentrates from the gold washings of the Cauê iron mine, Itabira, Minas Gerais, was collected by Sanders and incorporated to the Natural History Museum, London, England (number BM 1934,72). From this sample, Hey (1955) defined the new mineral arsenopalladinite. Later studies by Clark *et al.* (1974) redefined arsenopalladinite and described atheneite and isomertieite. In addition, they noted the presence of a palladium selenide, later described and named palladseite (Davis *et al.* 1977). They also identified native gold, a Pd and Hg oxide (palladinite), a Pd-Hg-Au alloy, hematite, quartz, and superficial oxidation products. Davis *et al.* (1977) identified two isotropic Cu-bearing Pd oxides as inclusions in palladseite. Cabri (1981) added "porpezite", mertieite-II, temagamite, stibiopalladinite, and palladoarsenide to the list of minerals found on this sample. Based on studies of the same sample Cabri *et al.* (1977) and Clark and Criddle (1982) attributed new formulae to arsenopalladinite and isomertieite. Jedwab (1995) and Jedwab and Cassedanne (1998) identified a group of O-bearing Pt-Pd-Au-Cu-Fe-Mn compounds, coexisting with Fe and/or Mn oxides and hydroxides, corresponding to "ouro preto". Cauê mine is the type locality of arsenopalladinite, atheneite, isomertieite, palladseite and jacutingaite.

The historical data of atheneite were revised by Bindi (2010). Clark *et al.* (1974) supplied a detailed chemical and physical characterization of the mineral and described it as the first naturally occurring Pd–Hg arsenide with the formula $(Pd,Hg)_3As$ (with Pd 2.67 and Hg 0.33 *apfu*) and Z 2. They were able to index the diffraction pattern, obtained with a Gandolfi camera, using the parameters of a hexagonal unit-cell (*i.e.*, a 6.80, c 3.48 Å, space group $P6/mmm$) given by Claringbull and Hey (1957a) for the mineral arsenopalladinite. Clark *et al.* (1974) then stated: "The density of atheneite (given by Claringbull and Hey 1957a) is 10.2, comparing very favorably with the calculated value of 10.16 based on two formula units per unit cell". It is important to note that Clark *et al.* (1974) erroneously interpreted the measured density for the mineral atheneite [given by Claringbull and Hey (1957a)], which they used to estimate the Z of the atheneite formula. Actually, Claringbull and Hey (1957a) measured a value of 10.2 g/cm^3 for arsenopalladinite (with only Pd and As, without Hg), and not for atheneite. Therefore, the density of atheneite is definitely higher than that measured for arsenopalladinite, and the Z of the formula given by Clark *et al.* (1974) is likely wrong. The mistake of Clark *et al.* (1974) persisted in the mineralogical literature (e.g., Anthony *et al.* 1990), in several mineralogical databases (e.g., www.webmineral.com; www.mindat.org), as well as in successive studies on Pd-bearing arsenides (Cabral *et al.* 2008, and references therein). To help resolve the concerns relating to the mineral atheneite, crystal-structure data for the mineral from its type locality, the Itabira deposit, were investigated by Bindi (2010), together with physical and chemical data.

Occurrence. In gold-rich jacutinga (a hydrothermally-altered Lake Superior-type carbonate-bearing oxide facies iron-formation), originally recovered from residual concentrates from the gold washings, from Cauê iron mine, Itabira, Minas Gerais, associated with arsenopalladinite, isomertieite, palladseite, and other minerals. Intergrowths with arsenopalladinite are present. Rounded grains of hematite occur as inclusions. Atheneite in the Cauê mine was also documented by Kwitko *et al.* (2002). Also, known from other Brazilian and several world occurrences.

Appearance and physical properties. Anhedral to subhedral grains up to 200 µm across. It does not show any inclusions of other minerals or intergrowths. Morphology: could not be determined. Twinning: none mentioned. Color: gray-black (under a binocular microscope). Streak: unknown. Luster: metallic. Opaque. Hardness (Mohs): 5; VHN_{100} (2 grains): 419 to 442 (mean 431) kg/mm^2 (Clark *et al.* 1974); VHN_{100}: 415 to 435 (mean 427) kg/mm^2 (Bindi 2010). Tenacity: not given. Cleavage: none observed. Fracture: not given. Density: 11.36 g/cm^3 (calc.).

Optical properties. In reflected light: white with a yellowish-cream hue, faintly bluish, strong anisotropism, no bireflectance. Pleochroism: absent in air, very weak in oil, with tints from pale yellow-white to bluish-gray white. In plane-polarized light, the separate grains of atheneite appear to be the same color as arsenopalladinite. No evidence of growth zonation or twinning is observed. Under crossed polars, the mineral does not extinguish. It displays a range of bright anisotropic tints, from purple-brown through light grey to a metallic dark grey. R_1, R_2; ${}^{im}R_1$, ${}^{im}R_2$: (50.3, 53.0; 37.0, 39.9) 470 nm, (54.3, 56.9; 41.2, 43.8) 546 nm, (56.0, 58.0; 43.1, 45.0) 589 nm, (57.5, 58.7; 44.7, 45.7) 650 nm. According to Bindi (2010), reflectance percentages for Rmin and Rmax are 47.2, 54.3 (471.1 nm), 50.1, 57.8 (548.3 nm), 53.0, 60.7 (586.6 nm), and 55.2, 62.9 (652.3 nm), respectively, in excellent agreement with those measured by Clark *et al.* (1974).

Chemical data. Microprobe (WDS mode) analyses (6): Pd 65.33, Pt 0.83, Hg 15.69, Au 0.23, Fe 0.03, Cu 0.02, As 17.64, Sb 0.10, Sn 0.03, Se 0.04, Bi 0.03, total 99.97 wt.% (Bindi 2010). Empirical formula: $Pd_{1.98}Pt_{0.01}As_{0.76}Hg_{0.25}$. The ideal formula requires Pd 66.68, As 17.61, Hg 15.71, total 100.00 wt.%.

Crystallography. Hexagonal, $P\bar{6}2m$, *a* 6.813(1), *c* 3.4892(5) Å, *V* 140.26(4) Å^3, Z

3, *c*:*a* = 0.5121. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 2.423 (100) (111), 2.246 (90) (201), 2.221 (60) (210), 1.871 (70) (211), 1.371 (80) (212), 1.302 (80) (302), 1.286 (60) (410), 1.259 (80) (321), 1.205 (60) (411), 1.034 (70) (412). The grain used for the original determination of cell parameters of arsenopalladinite (Claringbull and Hey 1957a) was in fact of atheneite.

Name. In reference to its palladium content, from the Greek goddess Pallas Athena. Branco (1979) translated this name as “atenasita”.

Type material. The Natural History Museum, London, England, BM 1934,72, BM 1977,259 (holotype); National Museum of Natural History, Washington, D.C., USA, 142504A0 [donator Natural History Museum, London; on same specimen with and filed under arsenopalladinite, part of BM 1934,72] (type).

Relationship to other species. As noted by Bindi (2010), the crystal structure of atheneite strongly resembles that of synthetic MM’As compounds, with M = Ru, Rh, Pd, and M` = 3d transition element (Roy-Montreuil *et al.* 1968, Deyris *et al.* 1979).

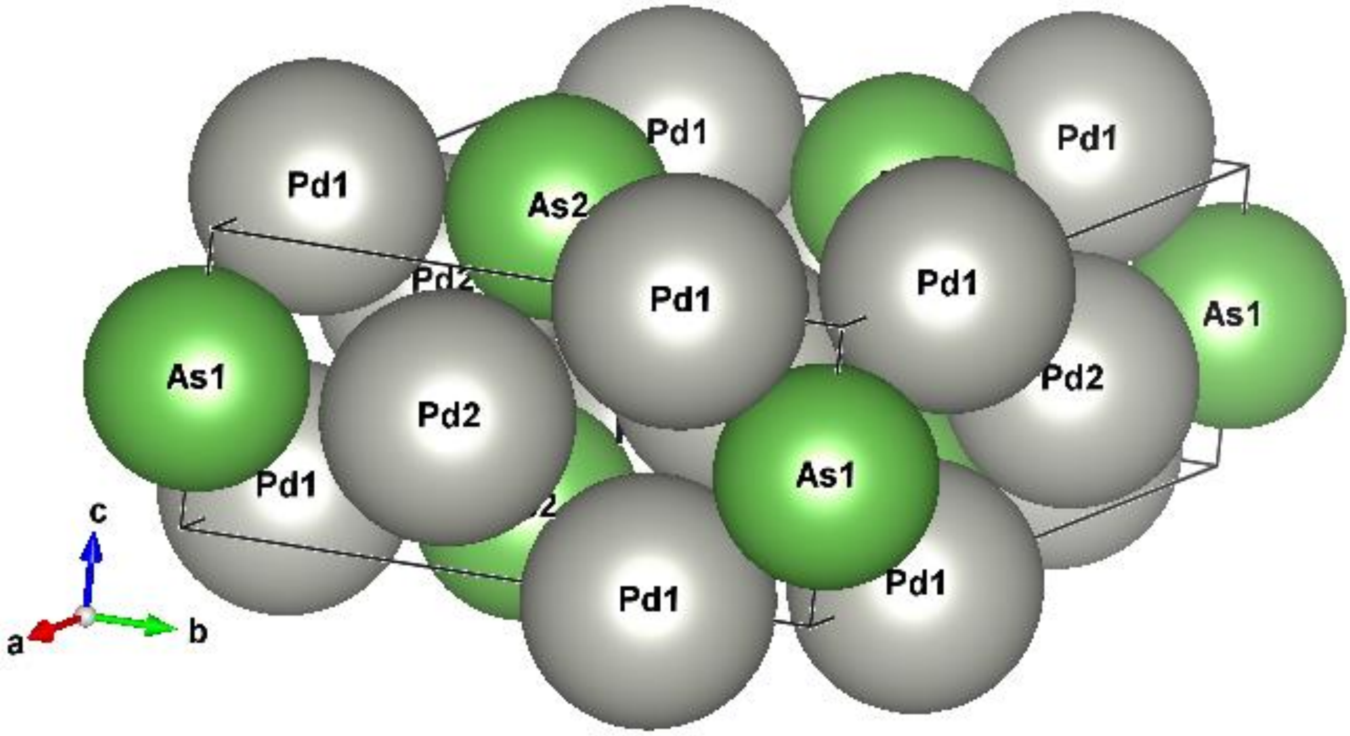


Figure 2.2. View of the crystal structure of atheneite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Bindi (2010).

Crystal structure. There are two fully occupied Pd sites: site Pd1 has ten-fold coordination, and Pd2, eleven-fold coordination. The two As atoms in the structure have a tricapped trigonal prismatic coordination; As1 is filled by arsenic only, whereas As2 has an occupancy of 0.60 As and 0.40 Hg. The presence of Hg at the As2 site accounts for the longer distances observed (Bindi 2010).

See also. Arsenopalladinite, isomertieite, palladseite, palladinite, porpezite, jacutingaite, unnamed Pd-Hg-Au alloy, and unnamed oxygen-bearing compounds of Pt-Pd-Au-Cu-Fe-Mn.

Arsenopalladinite

Hey (1955)

$Pd_8As_{2.5}Sb_{0.5}$, triclinic

Approved CNMMN - IMA 1973-002a

Other names: arsenopaladinita

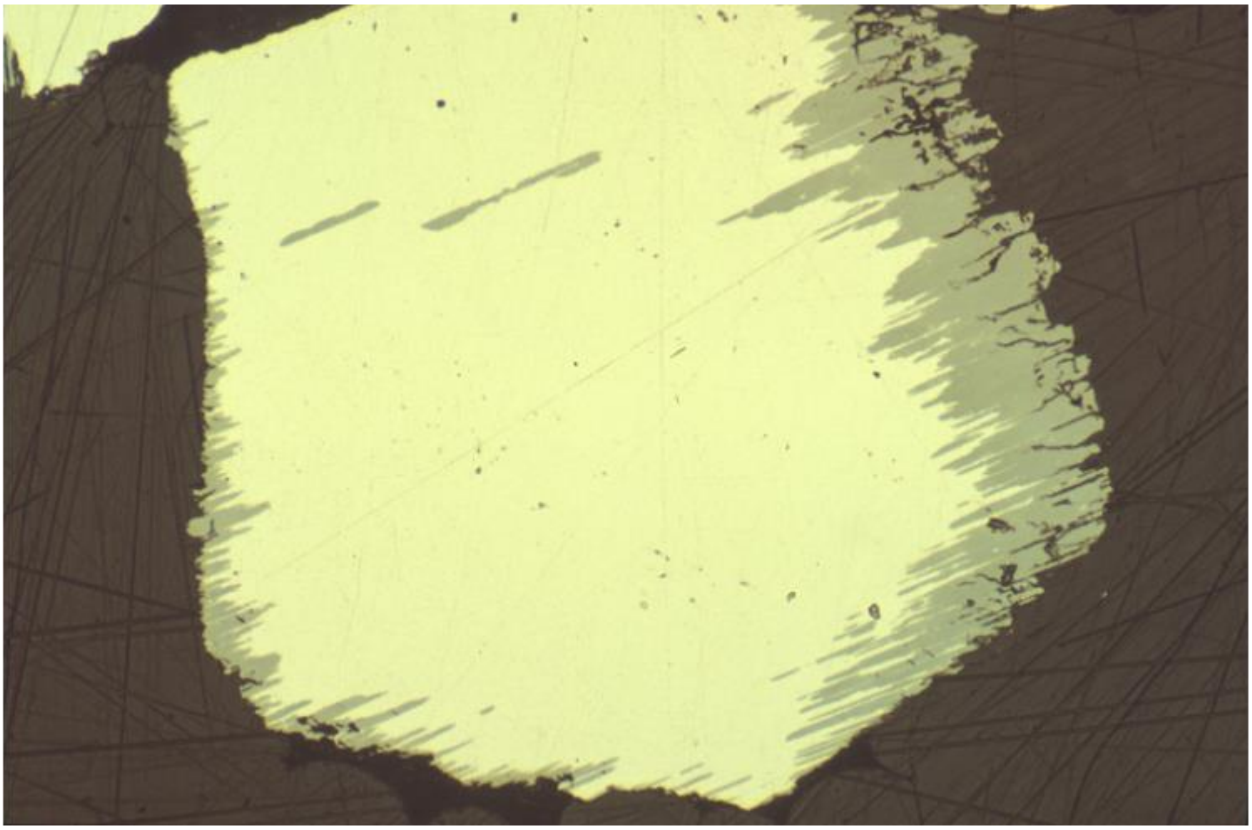


Figure 2.3. Arsenopalladinite (white), replaced by a mercurian variety of palladinite (grey) from Cauê mine, Itabira, Minas Gerais. This replacement, from grain margins, is crystallographically controlled, forming linear features in section. Reflected plane-polarized light digital image from transparency. Field of view: 1.2 mm. The type specimen, BM 1934,72, Natural History Museum, London, England. Photo: Chris J. Stanley.

See also Figure 2.1.

The name arsenopalladinite appeared in Hey (1955) as a personal communication from Bannister and mentioned in an unpublished work by Bannister, Claringbull and Hey

(1955). According to Hey (1955), an unpublished analysis, obtained by him, suggested a mineral with the composition Pd_3As. On June 7, 1956, a study of arsenopalladinite was presented by Claringbull and Hey (1957b) to a meeting of the Mineralogical Society, and a summary was published in Mineralogical Abstracts (Claringbull and Hey 1957a). According to them, small selected crystals of residual concentrates from the gold washings of the Cauê mine, Itabira, Minas Gerais, have Pd 79.8 and As 19.2 wt.%. A single-crystal X-ray diffraction study indicated a hexagonal unit cell with *a* 6.80, *c* 3.48 Å, Z 2, space group *P*6/*mmm*, assuming holohedral symmetry, overlain by an unusual type of superstructure. Clark *et al.* (1974) concluded that the specimen studied by Claringbull and Hey (1957a, b) consisted of several minerals. They redefined arsenopalladinite, the predominant mineral of the sample, as triclinic $Pd_5(As,Sb)_2$ with CNMMN - IMA approval (1973-002a) and gave name atheneite [$(Pd,Hg)_3As$] to the hexagonal mineral. Cabri *et al.* (1977) revised the formula of arsenopalladinite as $Pd_8(As,Sb)_3$. The correct formula is $Pd_8As_{2.5}Sb_{0.5}$ because As and Sb occupy separate sites in the structure (Karimova *et al.* 2020).

Occurrence. In gold-rich jacutinga (a hydrothermally-altered Lake Superior-type carbonate-bearing oxide facies iron-formation), originally recovered from residual concentrates from the gold washings, from Cauê iron mine, Itabira, Minas Gerais, associated with atheneite, isomertieite, palladseite, and other minerals. Cauê mine is the type locality of atheneite, arsenopalladinite, isomertieite, palladseite and jacutingaite. A superficial coating on the arsenopalladinite grains, which it replaced and penetrated in the form of oriented, parallel, wedge-like plates was described by Clark *et al.* (1974) as a palladium-mercury oxide (approx. 90% PdO and 10% HgO). This mineral is probably a mercurian variety of palladinite. Arsenopalladinite was also recorded in several world occurrences.

Appearance and physical properties. Grains from 0.3 to 1.8 mm, rarely intergrown with atheneite or isomertieite. Morphology: could not be determined. Twinning: complex polysynthetic. Color (megascopic): unknown. Streak: unknown. Luster: metallic. Opaque. Cleavage: none observed. Fracture: not given. Density: 10.4 g/cm^3 (meas.), 11.02 g/cm^3 (calc.). Hardness (Mohs): 4; VHN$_{100}$ (10 grains): 379 to 449 (mean 407) kg/mm^2. Tenacity not given.

Optical properties. In reflected light: white with a yellowish-cream hue, strong anisotropism, weak bireflectance. Pleochroism: absent. Under polarized light, the mineral does not extinguish-in any position, with colors from red and golden brown to blue-gray in air, khaki-brown to blue-gray and bright steel-gray in oil. R_1, R_2; $^{im}R_1$, $^{im}R_2$: (47.4, 48.5;

34.4, 35.5) 470 nm; (52.5, 54.3; 39.7, 41.5) 546 nm; (54.9, 56.8; 42.4, 44.2) 589 nm; (57.4, 59.0; 44.9, 46.5) 650 nm.

Chemical data. Microprobe (WDS mode) analyses (from 13 grains): Pd 77.56, As 17.08, Sb 5.15, total 99.79 wt.%. Empirical formula: $Pd_{8.02}(As_{2.51}Sb_{0.47})_{\Sigma 2.98}$. The ideal formula requires Pd 77.43, As 17.03, Sb 5.54, total 100.00 wt.%.

Crystallography. Triclinic, $P\bar{1}$, *a* 7.3344(7), *b* 7.3870(8), *c* 7.5255(7) Å, α 98.869(8), β 102.566(8), γ 119.096(11)°, *V* 331.19(7) Å^3, Z 2, *a:b:c* = 0.9929:1:1.0187 (from the crystal structure study by Karimova *et al.* (2020). X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 2.34 (60) ($\bar{2}31$), 2.28 (20) (122), 2.19 (20) ($\bar{2}15$), 2.13 (100) (030), 1.41 (40) ($\bar{2}19$), 1.39 (20) ($\bar{1}5\bar{1}$), 1.24 (30) ($\bar{1}.0.11$), 1.21 (30) ($\bar{6}32$). ICDD: 29-959 (*k* and *l* interchanged).

Name. For the chemical composition.

Type material. The Natural History Museum, London, England, BM 1934,72 (holotype); National Museum of Natural History; Smithsonian Institution, Washington, D.C., USA, 142504 [donator Natural History Museum, London; types of isomertieite, atheneite and palladseite on same specimen, part of BM 1934,72] (cotype); Royal Ontario Museum, Toronto, Ontario, Canada, M34726 (<1mg) (type).

Relationship to other species. Arsenopalladinite is not isotypical with the close related mineral mertieite-II, $Pd_8Sb_{2.5}As_{0.5}$. The structures of the both minerals are built up by nets of the same topology, but different stacking sequence is realized (Karimova *et al.* 2020).

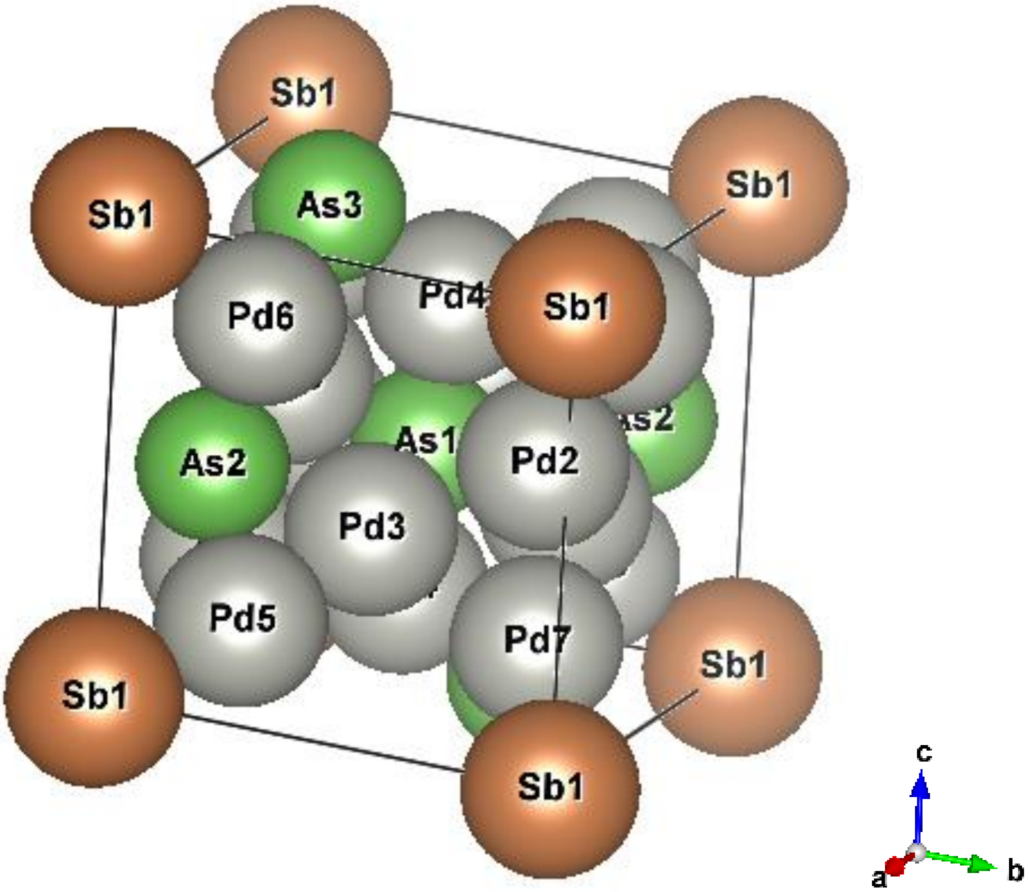


Figure 2.4. View of the crystal structure of arsenopalladinite (from the Kaarreoja River, Inari commune, Finnish Lapland, Finland), drawn using VESTA 3 (Momma and Izumi 2011). Data from Karimova *et al.* (2020).

Crystal structure. The crystal structure of mineral arsenopalladinite from the Kaarreoja River, Inari commune, Finnish Lapland, Finland, is formed by pnictogen (As, Sb) and palladium atoms layers. The layers are parallel to *xy* plane and stack along *z* axis of the unit cell. As- and (As, Sb)-nets have triangular topology (*A* and *D* nets). Palladium layers are triangular or pentagon-triangular nets (*B* and *C* nets). The unit cell contains 6 layers, stacking sequence is: *ABCDCBA* (Karimova *et al.* 2020).

See also. Atheneite, isomertieite, palladseite, palladinite, porpezite, jacutingaite, and unnamed Pd-Hg-Au alloy.

Isomertieite

Clark *et al.* (1974)

$Pd_{11}Sb_2As_2$, cubic

Approved CNMMN - IMA 1973-057

Other names: isomertieíta

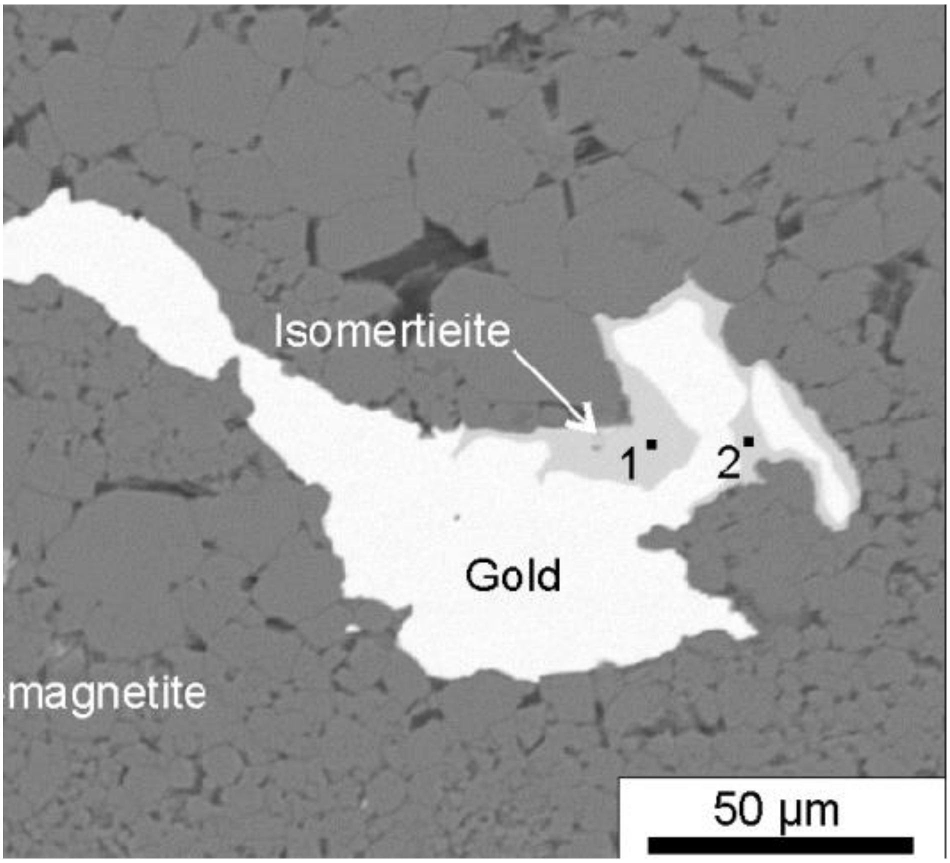


Figure 2.5. Isomertieite, Pd-rich gold, and Cr-rich magnetite, from the Cauê iron mine, Itabira, Minas Gerais (Cabral *et al*. 2002a).

The historical data of isomertieite were revised by Karimova *et al.* (2016). It was discovered in the concentrates from gold washing at Itabira, Minas Gerais (Clark *et al.* 1974). The concentrates were collected by B.H. Sanders, who left them for examination at British Museum (National History) in 1934. The first data for isomertieite, formula $(Pd,Cu)_5(Sb,As)_2$, space group $Fd\overline{3}m$, cell parameter *a* 12.382 Å, were published by Clark *et al.* (1974). The crystal structure of isomertieite was solved by X-ray powder diffraction (photographic methods) using a synthetic analog, Pd_5SbAs, by Shi *et al.* (1978). The reliability factor of the proposed model was relatively high (15%). Further studies of isomertieite samples from different localities led to a revision of the chemical formula. Cabri and Laflamme (1979) reported data for isomertieite from Lac des Isles, Ontario, Canada. Crystal structure investigations showed that the unit cell contains a total amount of 120 atoms: 88 Pd, 16 As, 16 Sb. A compound with composition $Pd_{11}Sb_2As_2$ was synthesized, and a re-analysis of isomertieite gave better agreement with the newly proposed stoichiometry (Cabri 1980). Therefore the chemical formula was revised to $Pd_{11}Sb_2As_2$ (Cabri 1981).

Occurrence. In gold-rich jacutinga (a hydrothermally-altered Lake Superior-type carbonate-bearing oxide facies iron-formation), originally recovered from residual concentrates from the gold washings, from the Cauê iron mine, Itabira, Minas Gerais, associated with arsenopalladinite, atheneite, palladseite, and other minerals. Cauê mine is the type locality of arsenopalladinite, atheneite, isomertieite, palladseite and jacutingaite. In one grain, intergrown with arsenopalladinite, isomertieite contains hematite Also, known from several Brazilian and world occurrences.

Appearance and physical properties. Grains from 0.4 to 0.8 mm. Morphology: could not be determined. Twinning: none mentioned. Color: pale yellow-white. Streak: not determined. Luster: metallic. Opaque. Hardness (Mohs): 5½; VHN_{100}: 585 to 598 (mean 592) kg/mm^2. Tenacity: not given. Cleavage: none observed; fracture not given. Density could not be measured, 11.09 g/cm^3 (calc.).

Optical properties. In reflected light: pale yellow-white, isotropic or slightly anisotropic, no bireflectance. Pleochroism: absent. R; ^{im}R: (46.4; 33.3) 470 nm; (54.0; 40.9) 546 nm; (56.8; 43.95) 589 nm; (59.45; 46.65) 650 nm.

Chemical data. Electron microprobe data (from 14 grains): Pd 72.53, Au 0.37, Cu 1.08, As 10.42, Sb 14.61, total 99.01 wt.%. Empirical formula: $(Pd_{10.65}Cu_{0.27}Au_{0.03})_{\Sigma 10.95}(As_{2.17}Sb_{1.88})_{\Sigma 4.05}$. These data are from Clark and Criddle (1982), where the formula $Pd_{11}Sb_2As_2$ is given, slightly different from that of the original work, $(Pd,Cu)_5(Sb,As)_2$. The ideal formula $Pd_{11}Sb_2As_2$ requires Pd 74.85, As 9.58, Sb 15.57, total 100.00 wt.%.

Crystallography. Cubic, $Fd\bar{3}m$, *a* 12.297(5) Å, *V* 1859.3(2)Å^3, Z 8 (single-crystal), *a* 12.283 Å, *V* 1853.16 Å^3, Z 8 (powder data). X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 2.356 (90) (511), 2.167 (100) (440), 1.533 (70) (800), 1.446 (60) (660), 1.287 (60) (931), 1.253 (70) (844), 1.234 (60) (933), 1.188 (70) (951), 1.182 (60) (10.2.2), 1.086 (60) (880). ICDD: 26-833 (17-221 and 29-958 ICDD cards probably refer to different minerals).

Name. For its crystallographic difference from mertieite-I, which has the same composition. The minerals guanglinite and fengluanite have been considered identical to isomertieite, but additional studies are needed.

Type material. The Natural History Museum, London, England, BM 1934,72, BM 1977,260 (holotype); National Museum of Natural History; Smithsonian Institution, Washington, D.C., USA, 142504 B0 [donator Natural History Museum, London, on the same specimen with and filed under arsenopalladinite, part of BM 1934,72], (cotype).

Relationship to other species. The cubic dimorph of mertieite-I. Isostructural with törnroosite.

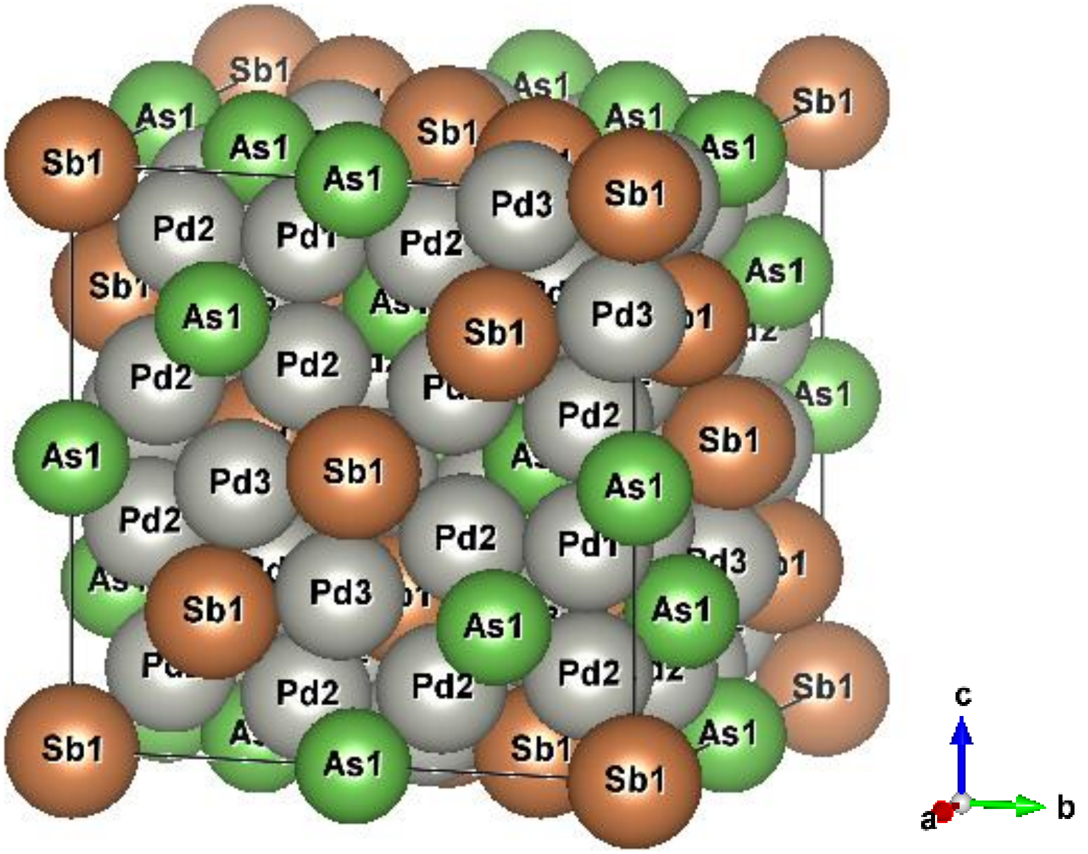


Figure 2.6. View of the crystal structure of isomertieite (specimen from the Monche-Tundra intrusion, Monchegorsk Igneous Complex, Kola Peninsula, Russia), drawn using VESTA 3 (Momma and Izumi 2011). Data from Karimova *et al.* (2016).

Crystal structure. There are three symmetrically independent Pd positions: *M*1, *M*2, and *M*3. *M*1 forms *M*1As$_4$ tetrahedra, *M*2 forms *M*2As$_2$Sb$_2$ tetrahedra, and *M*3 forms *M*3Sb$_3$ triangles connected via common edges and forming a framework in the structure (Karimova *et al.* 2016, specimen from the Monche-Tundra intrusion, Monchegorsk Igneous Complex, Kola Peninsula, Russia).

See also. Arsenopalladinite, atheneite, palladseite, palladinite, porpezite, jacutingaite, and unnamed Pd-Hg-Au alloy.

Palladseite

Davis *et al.* (1977)

$Pd_{17}Se_{15}$, cubic

Approved CNMMN - IMA 1975-026

Other names: palladseïte, paladseíta

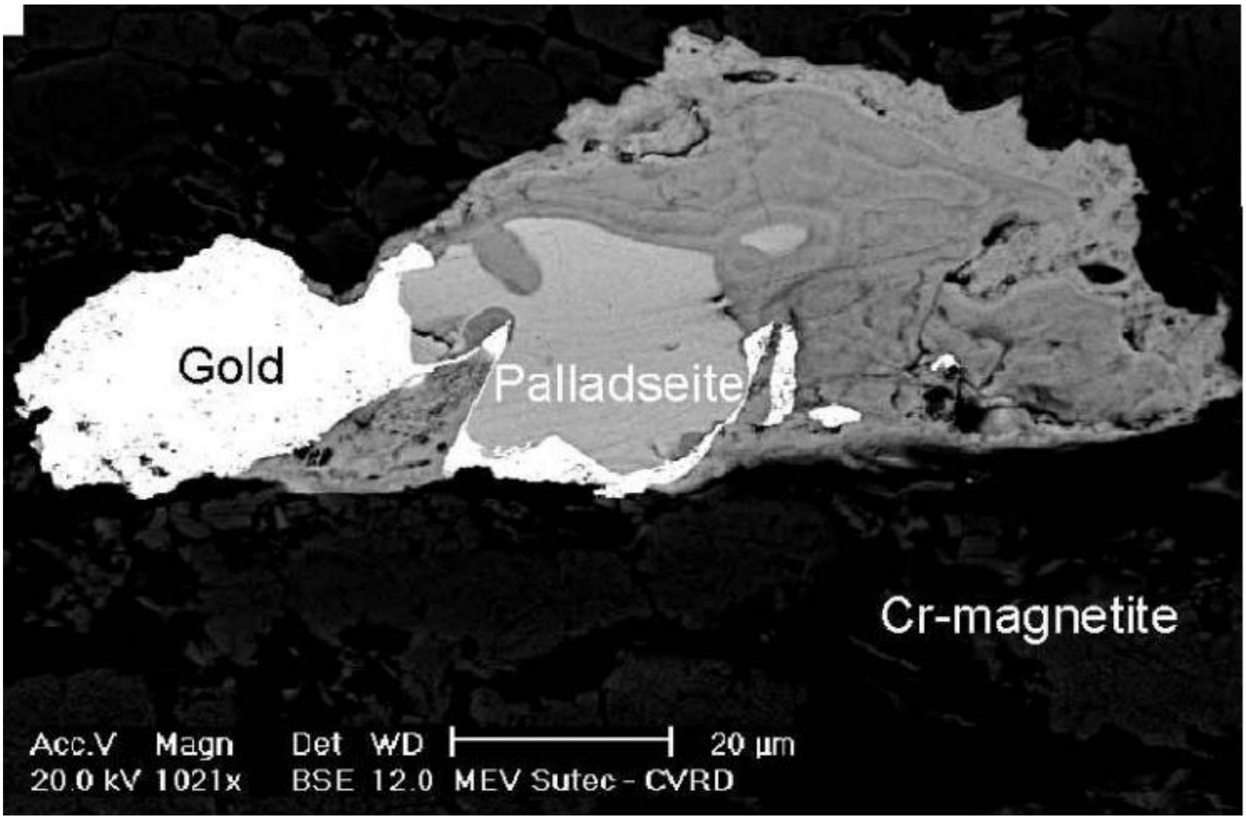


Figure 2.7. Palladseite, Pd-rich gold, and Cr-rich magnetite, from the Cauê iron mine, Itabira, Minas Gerais (Cabral *et al*. 2002a).

See also Figure 4.1.

Originally described as an unnamed mineral by Clark *et al.* (1974), this mineral was later named as palladseite by Davis *et al.* (1977). Platinum group metal chalcogenides have applications in catalysis, as low resistance ohmic contacts in semiconducting electronic devices, recording films in optical discs and lithographic films, and light image receiving materials with silver halides (Akhtar *et al.* 2011). $Pd_{17}Se_{15}$ can be characterized as an intermediate type-II superconductor as opposed to the strongly correlated superconductivity in $Rh_{17}S_{15}$, equivalent to miassite (Naren *et al.* 2011).

Occurrence. In gold-rich jacutinga (a hydrothermally-altered Lake Superior-type carbonate-bearing oxide facies iron-formation), originally recovered from residual concentrates from the gold washings, from the Cauê iron mine, Itabira, Minas Gerais, associated with arsenopalladinite, atheneite, isomertieite, and other minerals. It contains inclusions of isotropic copper-bearing oxides of palladium, not identified (probably it is not palladinite, which is tetragonal). Cauê mine is the type locality of arsenopalladinite, atheneite, isomertieite, palladseite and jacutingaite. Also, known from some other Brazilian and world occurrences.

Appearance and physical properties. Grains up to 0.5 mm. Morphology: could not be determined. Twinning: none mentioned. Color (megascopic): unknown. Streak: unknown. Luster: metallic. Opaque. Hardness (Mohs): 4½ to 5; VHN_{100}: 390 to 437 (mean 414) kg/mm^2. Tenacity: not given. Cleavage: none observed. Fracture: not given. Density could not be measured, 8.14 g/cm^3 (calc.).

Optical properties. In reflected light: white, isotropic, no bireflectance. Pleochroism: absent. R; ^{im}R: (44.0; 30.0) 470 nm; (45.75; 31.4) 546 nm; (45.7; 31.3) 589nm; (45.65; 31.3) 650 nm.

Chemical data. Electron microprobe data (from 3 grains): Pd 55.46, Pt 0.14, Cu 4.07, Hg 1.53, Se 38.98, total 100.18 wt.%. Empirical formula: $(Pd_{15.34}Cu_{1.89}Hg_{0.22}Pt_{0.02})_{\Sigma 17.47}Se_{14.53}$. The ideal formula requires Pd 60.43, Se 39.57, total 100.00 wt.%.

Crystallography. Cubic, $Pm\bar{3}m$. a 10.635 Å, V 1202.85 Å^3, Z 2. X-ray powder diffraction data [d in Å (I) (hkl)]: 2.827 (95) (321), 2.563 (85) (410), 2.426 (85) (331), 2.037 (85) (333), 1.870 (100) (440), 1.715 (85) (611), 1.295 (75) (733), 1.284 (75) (820), 1.248 (75) (660), 1.232 (75) (750).

Name. For the chemical composition: PALLADium SElenide.

Type material type. The Natural History Museum, London, England, BM 1934,72, BM 1977,500 (holotype); National Museum of Natural History; Smithsonian Institution, Washington, D.C., USA, 142504 [donator Natural History Museum, London, on the same specimen with and filed under arsenopalladinite, part of BM 1934,72], (cotype).

Relationship to other species. Isostructural with miassite, $Rh_{17}S_{15}$.

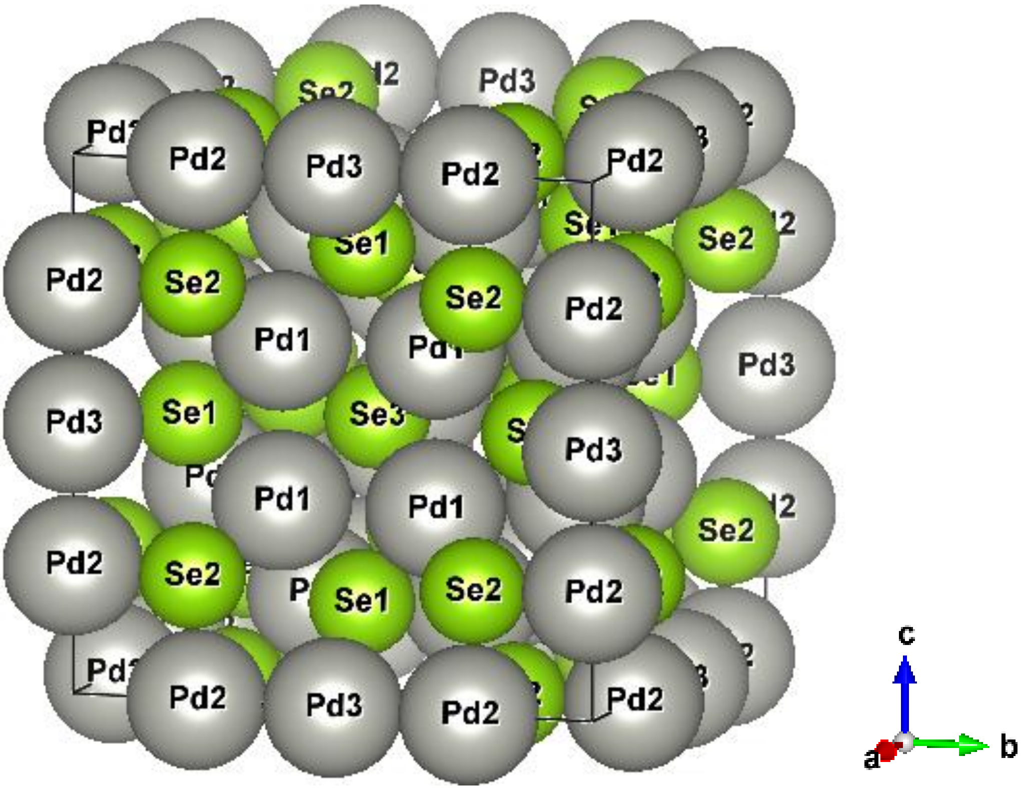


Figure 2.8. View of the crystal structure of palladseite (synthetic), drawn using VESTA 3 (Momma and Izumi 2011). Data from Geller (1962).

Crystal structure. There are four kinds of palladium atoms: 1) $PdSe_6$ regular octahedral; 2) Pd atom in a square of Se atoms and with 2 Pd atoms in a line perpendicular to the plane of the Se square; 3) Pd atom in a square of Se atoms and with 1 Pd atom in a line perpendicular to the plane of the Se square; 4) Pd atom in a “buckled” square (or flattened tetrahedron) of Se atoms about it (Geller 1962, crystal structure of synthetic $Pd_{17}Se_{15}$).

Synthetic. Several methods of palladseite synthesis exist. $Pd_{17}Se_{15}$ nanotubes have been synthesized in large quantities by Xiong *et al.* (2005) from the reaction between trigonal Se nanowires and Pd. Films of $Pd_{17}Se_{15}$ were obtained from the compound [bis(N,N-diethyl-N′-naphthoylselenoureato)palladium(II)] at 400, 450 and 500 °C by Akhtar *et al.* (2011). $Pd_{17}Se_{15}$ nanoparticles, synthesized by Joshi *et al.* (2013) from a single source precursor $[Pd(L)Cl_2]$ {L = 1,3-bis(phenylselenyl)propan-2-ol} and grafted onto graphene oxide, show high catalytic activity in C-O coupling between aryl/heteroaryl chlorides/bromides and phenol at room temperature (Pd loading 1 mol%; yield up to 94%).

Vymazalová *et al.* (2014) studied the phase equilibria in the system Ag–Pd–Se by the evacuated-silica glass tube method at 350, 430, and 530°C. They obtained $Pd_{17}Se_{15}$ equivalent to palladseite at these three temperatures. Several phases formed associated with $Pd_{17}Se_{15}$: Ag_2Se (equivalent to murmannite), $Ag_2Pd_3Se_4$ (equivalent to chrisstanleyite), $PdSe_2$ (orthorhombic, not equivalent to verbeekite, monoclinic), $(Ag,Pd)_{22}Se_6$, $AgPd_3Se$, $Pd_{34}Se_{11}$, Pd_7Se_4 and PdSe. The phases today only known as synthetic compounds can be expected to be discovered as new minerals associated with palladseite in the future (Vymazalová *et al.* 2014).

See also. Arsenopalladinite, isomertieite, atheneite, palladinite, porpezite, jacutingaite, isotropic copper-bearing oxides of palladium, unnamed Pd-Hg-Au alloy, and unnamed Pd_5Se_4.

Unnamed Pd_5Se_4

Cabral and Lehmann (2007)

(= palladseite?)

Sub- to euhedral crystals, not exceeding 100 µm in length, as inclusions in a nugget of Ag-bearing, Pd-poor gold (Pd < 0.4wt.%) from Gongo Soco, Barão de Cocais, Minas Gerais, were described by Cabral and Lehmann (2007). Based on microprobe data, they quoted:

a) two-point analyses resulting in the formula $(Pd,Sb,Ag,Hg)_5Se_4$. No mineral name was associated with this formula.

b) one point analysis resulting in the formula $(Pd,Ag,Cu,Hg)_5Se_4$, attributed to an "argentiferous palladseite-like phase".

In addition, Cabral and Lehmann (2007) obtained 5 point analyses of palladseite from Itabira, Minas Gerais, calculated for 9 *apfu*. Other analyses of palladseite from this occurrence, obtained by Davis *et al.* (1977) and Olivo and Gauthier (1995), have been recalculated in this way. All approach Pd_5Se_4.

According to Cabral and Lehmann (2007), palladseite is ideally stoichiometric $Pd_{17}Se_{15}$, but its empirical stoichiometry points to a compound of type Pd_5Se_4. However, a synthetic compound with formula Pd_5Se_4 was not obtained, unlike $Pd_{17}Se_{15}$. Since the correspondence between palladseite and the synthetic compound $Pd_{17}Se_{15}$ seems proven and when calculated for 32 *apfu* all formulae are not substantially different from $Pd_{17}Se_{15}$, it is more likely that all analyzed points refer to the well-established palladseite.

Other inclusions identified in the Gongo Soco nugget are chrisstanleyite, a phase similar to tischendorfite, unnamed $Pd_5(Sb,Ag,Hg)_2Se_6$ and $Pd_5(Hg,Sb,Ag,)_2Se_6$.

See also. Palladseite, unnamed $Pd_5(Sb,Ag,Hg)_2Se_6$ and $Pd_5(Hg,Sb,Ag,)_2Se_6$

Unnamed $(Pd,Pt)_{10}(Se,As)$

Cabral and Lehmann (2003)

Other names: UM2003-21-Se:AsPdPt

Cabral and Lehmann (2003) reported thin threads of a bright white Se-As-Pd-Pt phase along microfractures at the contact between the greyish Pd-O phase and isomertieite and/or hematite from Gongo Soco, Barão de Cocais, Minas Gerais. Microprobe data (mean of 4 analyses): Pd 43.87, Sb 0.05, Se 4.67, As 0.85, Pt 46.80, Cu 0.65, Fe 1.63, Hg 1.22, total 99.74. Empirical formula: $(Pd_{5.77}Pt_{3.36}Fe_{0.41}Cu_{0.14}Hg_{0.09})_{\Sigma 9.77}(Se_{0.83}As_{0.16}Sb_{0.01})_{\Sigma 1.00}$. Simplified formula: $(Pd,Pt)_{10}(Se,As)$.

Unnamed $Pd_5(Sb,Ag,Hg)_2Se_6$ and $Pd_5(Hg,Sb,Ag)_2Se_6$

Cabral and Lehmann (2007)

Based on microprobe data, Cabral and Lehmann (2007) quoted $Pd_5(Sb,Ag,Hg)_2Se_6$ and $Pd_5(Hg,Sb,Ag,)_2Se_6$ sub- to euhedral crystals, not exceeding 100 µm in length, as inclusions in a nugget of Ag-bearing, Pd-poor gold (Pd < 0.4wt.%) from Gongo Soco, Barão de Cocais, Minas Gerais.

See also. Unnamed Pd_5Se_4.

Unnamed Pd_9PtSe_2, Pd_9Se_2, $Pd_3(Se,Bi)$, and $(Pd,Hg,Pb)_3Se$

Cabral *et al.* (2002d), Cabral and Lehmann (2007)

Other names: UM2002-30-Se:BiPd, UM2002-37-Se:HgPd, UM2002-38-Se:Pd, UM2002-51-Se:PdPt

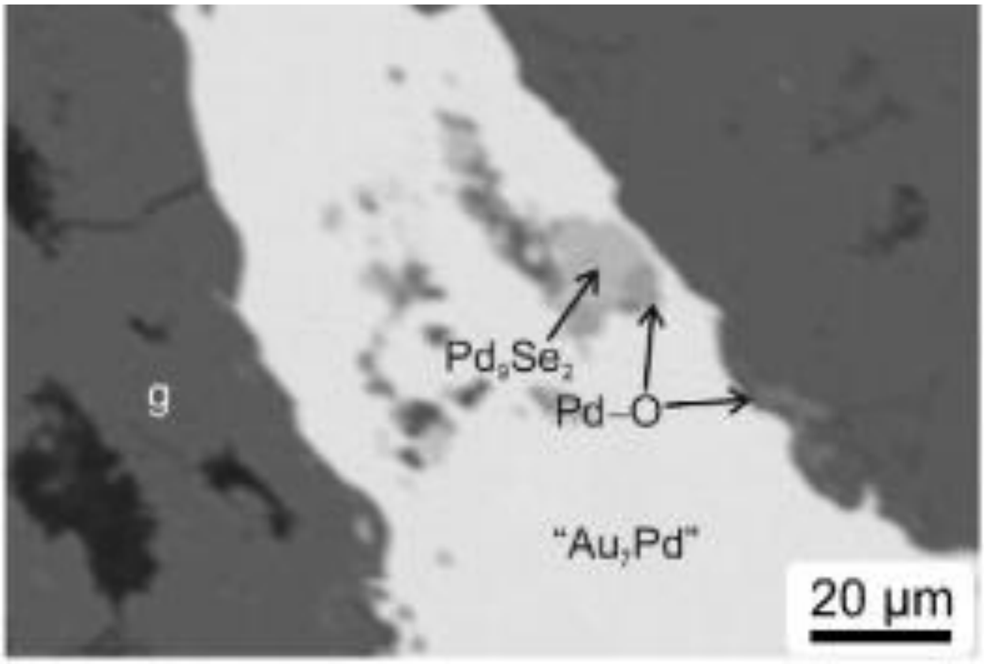


Figure 2.9. Ideal Pd_9Se_2 enclosed in Au–Pd alloy (empirically equivalent to "Au_7Pd"). The gold is enveloped by a dark-colored, Pd–O-bearing coating of goethite (g), characteristic of *ouro preto*, from Serra Pelada, Curionópolis, Pará (Cabral and Lehmann 2007).

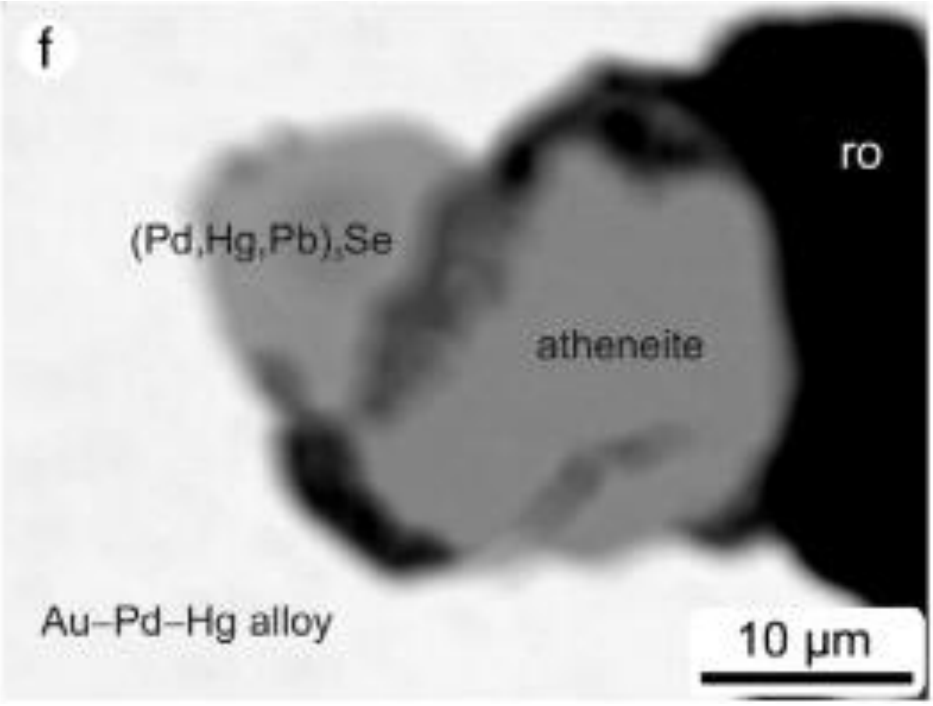


Figure 2.10. Ideal $(Pd,Hg,Pb)_3Se$ adjacent to atheneite, $Pd_2(As_{0.75}Hg_{0.25})$, on the margins of Au–Pd–Hg alloy in a groundmass of Mn–Ba oxide (possibly romanèchite, ro), from Serra Pelada, Curionópolis, Pará (Cabral and Lehmann 2007).

A number of Pd–Pt–Se phases occur as inclusions in, or attached to the margins of, the dendritic palladiferous gold of the Au-(Pd-Pt) deposit of Serra Pelada, Curionópolis, Pará. The minerals, up to 30 µm across, can be divided into two groups: (i) empirical Pd_9PtSe_2 and Pd_9Se_2, which are hosted in compositionally homogeneous Au_7Pd; and (ii) empirical $Pd_3(Se,Bi)$ and $(Pd,Hg,Pb)_3Se$, which are associated with Pd–Hg-bearing gold (Cabral and Lehmann 2007). Synthetic compounds with formulae Pd_9Se_2 and Pd_3Se are known (Olsen *et al.* 1979; Akhtar *et al.* 2011).

The trigonal Pd_9Se_2 phase is stable in the temperature range of 390 to 635°C (Olsen *et al.* 1979). The thermal stability of this phase is not in agreement with the temperature of formation of the Serra Pelada mineralization (below 150°C) (Cabral and Lehmann 2007). According to Vymazalová *et al.* (2014), the phase Pd_9Se_2 is probably stabilized by another element (Pt or Au) at a lower temperature in nature, or it corresponds to other palladium selenides (likely the phase Pd_4Se), but an X-ray diffraction study of the natural phase is desirable.

See also. Unnamed Au_7Pd.

Chalmersite

Hussak (1902)

(= cubanite)

Other names: chalmersita

Figure 2.11. A prismatic crystal of cubanite (“chalmersite”), between two flattened, clear brown siderite crystals and, in epitaxy, a smallest, almost black pyrrhotite crystal, from Morro Velho Mine, Nova Lima, Minas Gerais. Largest crystal size: 1.2 mm. Specimen and photo: Gianfranco Ciccolini.

Chalmersite, initially confused with millerite, NiS trigonal (Saxe-Cobourg-Gotha 1890), was named by Hussak (1902, 1903, 1906c), in honor of the engineer George Chalmers (1857-1928), superintendent of the Morro Velho mine. It occurs as needles, generally coated by chalcopyrite crystals, also associated with quartz, dolomite, pyrrhotite, and siderite, at the Morro Velho mine, Nova Lima, Minas Gerais. Palache (1907) studied the crystallography of chalmersite. The identity between chalmersite and cubanite, $CuFe_2S_3$ orthorhombic, was proved by Kalb and Bendig (1923), Merwin *et al.* (1923) and Zenzén (1925).

Joséite-A

Kenngott (1853)

Bi_4TeS_2, trigonal

An incompletely studied mineral

Other names: Josëit, joséite, joseíta, joseite, josëite, tellure de bismuth, bornine, Bornit, tellure bismuthifère du Brésil, tellurure de bismuth du Brésil, Schwefelselen-tellurwismuth, Bismuthotellurites Brasiliensis, Tellurbismuth, Tellurwismuth, josëite-A, joseite-A, joseíta-A, joseite-α, telureto de bismuto do Brasil

Joséite-A and joséite-B were described from many occurrences by different authors in dozens of papers. Nevertheless, these minerals have been incompletely studied and their crystal structures have not been determined. From X-ray diffraction patterns Bayliss (1991) observed the absence of ordering of Te and S in joséite-A and joséite-B, and also in the series Bi_4S_3 - Bi_4Te_3 (ikunolite - pilsenite). Following this interpretation the formulae would be $Bi_4(S,Te)_3$ for joséite-A and $Bi_4(Te,S)_3$ for joséite-B. According to him, this disorder is difficult to explain. Most of the relatively few studied specimens have approximately integer ratios of S:Te, which would favor an ordered structure. Joséite-A would have a formula similar to that of tellurian ikunolite, and joséite-B, similar to sulfurian pilsenite. A compilation by Cook *et al.* (2007), however, suggests that minerals in the Bi_4S_3–Bi_4Se_3–Bi_4Te_3 isoseries tend to have ordered structures.

The first mention of joséite, according to Leonardos (1973), seems to be that of Eschwege (1832), who noted the occurrence of six-faced tabular plates, in the auriferous veins of Furquim hill, between Mariana and São José, Minas Gerais. However, although Eschwege knew that the mineral was a telluride he did not say so, or state who analyzed it. The material would seem to be the bismuth telluride of Brazil found in a granular limestone in São José, near Mariana and first taken to France by the naturalist Claussen, who traveled through Minas Gerais in the first half of the 19th century. According to Leonardos (1973), Damour (1844) described the mineral and redescribed it in the following year using the name joséite (Damour 1845a, b). However, this is not correct, because the name joséite (Josëit) was introduced by Kenggott in 1853. Initially, this mineral was mistaken for "bornine" (= tetradymite) and tellurobismuthite. Later on, several researchers studied or simply mentioned the mineral: Glocker (1847) [Bismuthotellurites Brasiliensis], Hausmann (1852) [Bornit], Kenggott (1853) [Josëit], Dufrénoy (1856) [tellure bismuthifère du Brésil], Rammelsberg (1875) [Schwefelselen-tellurwismuth] and Genth (1886), among others. According to Ferraz (1928), it occurs in the sands of the mines of São José and São João do Morro, at the edge of the small village of Furquim, with mica, garnet, rutile and gold (8g/t). Its name derives from the São José mine, near Mariana, Minas Gerais.

Peacock (1941) restudied the type specimen, collected by Damour, stored in the U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA, number R 400, and the sample analyzed by Genth (1886) stored in the Harvard Mineralogical Museum, Harvard University, Cambridge, Massachusetts, USA, number 94935. He concluded that they were two different species, with unit cell parameters slightly different, Damour's specimen with formula $Bi_{4+x}Te_{1-x}S_2$ and Genth's specimen with formula $Bi_{4+x}(Te,Se)_{2-x}S$. In the first case, Bi + Te =5, and in the second case Bi +Te + Se = 6 *apfu*. Cell parameters for Damour's specimen are *a* 4.24, *c* 39.69 Å and for Genth's specimen: *a* 4.24, *c* 39.69 Å. The specimen studied by Genth (1886), however, is composed of two similar but distinct phases (Peacock 1941). Chemical data for Damour's specimen are Bi 79.15, Te 15.93, Se 1.48, S 3.15, total 99.71 wt.% and for Genth's specimen: Bi 81.23, Te 14.67, Se 1.46, S 2.84, total 100.20 wt.%. Empirical formulae are $Bi_{4.00}(Te_{1.41}Bi_{0.27}Se_{0.21}S_{0.11})_{\Sigma 2.00}S_{1.00}$ for Damour's specimen, and $Bi_{4.00}(Te_{1.32}Bi_{0.45}Se_{0.21}S_{0.02})_{\Sigma 2.00}S_{1.00}$ for Genth's specimen. In the first case, Bi +Te + Se =5.89, and in the second case Bi +Te + Se = 5.98 *apfu*. Consequently, the formula $Bi_{4+x}(Te,Se)_{2-x}S$ satisfies both Damour's and Genth's data. Nevertheless, the two types of formulae noted by Peacock (1941) have been recognized in further (not Brazilian) specimens. Thompson (1949) named $Bi_{4+x}Te_{1-x}S_2$ as joséite-A and $Bi_{4+x}Te_{2-x}S$ as joséite-B. Both Damour's and Genth's specimens are joséite-B.

A third type of Brazilian joséite, stored in the Muséum national d'Histoire naturelle de Paris, with a distinctly different X-ray powder diffraction pattern, was described by Garrido and Feo (1938), and Peacock (1941) obtained a similar pattern from a sample from Vernon, British Columbia, Canada. Cell parameters for the specimen from Vernon are *a* 4.41, *c* 42.09 Å. The chemical data presented by Garrido and Feo (1938) for the Brazilian specimen are the same as for the Damour's specimen.

Based on a systematic study of 24 joséite samples from 13 world deposits, Zav'lyalov and Begizov (1983) concluded that the formula of joséite-A is $Bi_{4+x}Te_{1-x-y}S_{2+y}$, with x = 0.08 to 0.33, and y = -0.11 to 0.09. Substitutions of Pb for Bi and Se for S, are small. According to them, the formula of joséite-B is $Bi_{4+x}Te_{2-x}S$, with x = -0.04 to 0.11.

Other names (joséite-C, joséite-D and protojoséite) were introduced for samples from other countries but are not recognized by the IMA. Because a complete description does not exist for the Brazilian samples, the following descriptions of joséite-A and joséite-B rely on data obtained from several localities.

Occurrence. (1) Said to occur in veins in limestone, associated with gold and "joséite-B", at São José mine (Tesoureiro mine), Fazenda Sagarana, Camargos district, Mariana, Minas Gerais, but the two analyses of joséite from São José mine refer to the composition of joséite-B (see above). (2) Bonfim, Sulista, Queiroz, Catolé II, Gupiara, Pedra Preta, Mulungu, and Matinha mines, Lajes Co., Rio Grande do Norte (Souza Neto *et al.* 2008) [The authors quoted this mineral as joséite; the chemical data correspond to joséite-A but a wrong calculated formula corresponding to joséite-B was presented]. Also from several world occurrences.

Appearance and physical properties. Habit: sheets and plates with occasional straight edges. Forms: none observed. Twinning: none observed. Color: galena-white, inclining to silver-white; old surfaces are lead-gray or tarnished iridescent, steel-blue to iron-black. Streak: not determined. Luster: metallic. Opaque. Hardness (Mohs): 2; VHN_{25} (5 indentations): 29 to 43 kg/mm^2. Tenacity: flexible, inelastic, sectile. Cleavage: {001} perfect. Fracture: not given. Density: 8.26 g/cm^3 (meas.), 8.218 g/cm^3 (calc.).

Optical properties. In reflected light, slightly whiter than galena, moderate anisotropism from light to dark greenish-gray. ($^{air}R_1$-$^{air}R_2$; $^{im}R_1$-$^{im}R_2$) = (54.5-51.6; 41.2-37.2) 470nm. (55.4-51.4; 41.45-36.5) 546nm. (55.5-51.0; 41.3-35.9) 589nm. (54.9-50.1; 40.6-34.8) 650nm [sample from Serranía de Ronda, Malaga, Spain]:

Chemical data. Microprobe data: Bi 81.79, Te 10.86, S 6.27, total 98.92 wt.%. Empirical formula: $Bi_{4.08}Te_{0.89}S_{2.04}$ [sample from Lajes, Rio Grande do Norte; Souza Neto *et al.* (2008) presented an incorrect empirical formula, $Bi_{4.000}Te_{1.902}S_{1.098}$, which corresponds to joséite-B]. Additional chemical data for joséite-A (quoted as joséite) from Bonfim II mine, Lajes, Rio Grande do Norte, by Pereira *et al.* (2019): Bi 83.04, Fe 0.09, Cu 0.07, Pb 0.33, Co 0.05, Ag 0.01, Se 0.32, Te 10.26, S 6.44, corresponding to $(Bi_{3.99}Pb_{0.01})_{\Sigma 4.00}(Te_{0.80}Se_{0.16})_{\Sigma 0.96}S_{2.01}$. The ideal formula requires Bi 81.34, Te 12.42, S 6.24, total 100.00 wt.%.

Crystallography. Trigonal, $R\bar{3}m$, *a* 4.25 *c* 39.81 Å, *V* 622.94 Å^3, Z 3, *c:a* = 9.3655. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 4.41 (30) (009), 3.10 (100) (107), 2.25 (80) (0.0.14), 2.13 (30) (110), 2.06 (30) (1.0.16), 1.973 (30) (0.1.17), 1.894 (30) (0.0.21), 1.752

(30) (027), 1.658 (30) (1.1.15), 1.415 (40) (1.1.21). [sample from Glacier Gulch, Hudson Bay Mountain, near Smithers, British Columbia, Canada].

Name. For the São José mine, related to joséite-B.

Type material. Quoted as U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA, number R 400 (Damour's sample), but the available chemical data are for joséite-B.

Relationship to other species. See the previous text and joséite-B.

Crystal structure. Not solved.

See also. Joséite-B and unnamed Bi_6Te_2S, Bi_3Te, Bi_5Te_2, Bi_8Te_3, and Bi_2Te.

Joséite-B

Thompson (1949)

Bi_4Te_2S, trigonal

An incompletely studied mineral

Other names: joseite-B, josëite-B, joseíta-B, joseite-ß

Figure 2.12. Joséite-B from São José mine (Tesoureiro mine), Fazenda Sagarana, Camargos district, Mariana, Minas Gerais. Harvard Mineralogical Museum, Harvard University, Cambridge, Massachusetts, USA, number 94935 (Genth's specimen).

According to Thompson (1949), joséite-B is identical with joséite-A in most physical properties and distinguished only by accurate specific gravity measurements. The type locality for joséite-B is also quoted as Glacier Gulch, Hudson Bay Mountain, near Smithers, British Columbia, Canada. See the text under joséite-A.

Occurrence. (1) In veins in limestone, associated with gold and joséite-A (?), at São José mine (Tesoureiro mine), Fazenda Sagarana, Camargos district, Mariana, Minas Gerais

[The only two analyses of joséite from São José mine refer to the composition of joséite-B (see the text under joséite-A)] (type locality). (2) Maria Lázara gold deposit, Guarinos Co., Goiás (Pulz *et al.* 1992) [The authors quoted the presence of joséite-B, but no mineralogical data were presented]. (3) São Sebastião gold deposit, Passagem de Mariana, Mariana, Minas Gerais (Cabral and Corrêa Neto 2015). Also, known from several world occurrences.

Appearance and physical properties. Habit: sheets and plates with occasional straight edges. Forms: none observed. Twinning: none observed. Color: galena-white, inclining to silver-white; old surfaces are lead-gray or tarnished iridescent, steel-blue to iron-black. Streak: not determined. Luster: metallic. Opaque. Hardness (Mohs): 2; VHN$_{25}$ (5 indentations): 46.1 (35.8 to 55.8) kg/mm^2. Tenacity: flexible, inelastic, sectile. Cleavage: {001} perfect. Fracture: not given. Density: 8.30 g/cm^3 (meas.). 8.439 g/cm^3 (calc.).

Optical properties. In reflected light, grayish, distinctly darker than the more yellowish native bismuth, with distinct to strong bireflectance and anisotropism. ($^{air}R_1$-$^{air}R_2$; $^{im}R_1$-$^{im}R_2$) = (56.8-54.9; 43.8-40.8) 470nm. (59.4-56.25; 46.3-41.95) 546nm. (60.4-56.7; 47.2-42.4) 589nm. (60.5-56.4; 47.2-42.1) 650nm [sample from Nagybörzsöny, Deutsch-Pilsen, Hungary].

Chemical data. (1) Bi 79.15, Te 15.93, Se 1.48, S 3.15, total 99.71 wt.%. Empirical formulae: $Bi_{4.00}(Te_{1.41}Bi_{0.27}Se_{0.21}S_{0.11})_{\Sigma 2.00}S_{1.00}$ (Damour’s specimen); (2) Bi 81.23, Te 14.67, Se 1.46, S 2.84, total 100.20 wt.%. Empirical formula: $Bi_{4.00}(Te_{1.32}Bi_{0.45}Se_{0.21}S_{0.02})_{\Sigma 2.00}S_{1.00}$ (Genth’s specimen). (3) Bi 74.91, Pb0.87, Te 20.66, S 2.38, Se 0.88, total 99.70 wt.%. Empirical formula: $(Bi_{3.95}Pb_{0.05})_{\Sigma 4.00}(Te_{1.84}Bi_{0.16})_{\Sigma 2.00}(S_{0.85}Se_{0.13}Te_{0.02})_{\Sigma 1.00}$ (São Sebastião gold deposit, mean of 4 analyses). The ideal formula requires Bi 74.43, Te 22.72, S 2.85, total 100.00 wt.%.

Crystallography. Trigonal, space group $R\bar{3}m$. Unit cell data: *a* 4.34 *c* 40.83 Å, *V* 666.02 Å^3, Z 3, *c:a* = 9.4078. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 4.53 (20) (009), 3.16 (100) (107), 2.30 (40) (0.1.14), 2.17 (50) (110), 1.949 (20) (0.0.21), 1.784 (30) (027), 1.570 (20) (1.1.18), 1.379 (20) (217). [sample from São José mine, Mariana, Minas Gerais].

Name. Related to joséite-A.

Type material. Harvard Mineralogical Museum, Harvard University, Cambridge, Massachusetts, USA, number 94935 (Genth's specimen). The type material quoted for joséite-A is at the U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA, number R 400 (Damour's sample), but the available chemical data are for joséite-B.

Relationship to other species. See joséite-A.

Crystal structure. Not solved.

See also. Joséite-A and unnamed Bi_8Te_3 and Bi_2Te.

Unnamed Bi_6Te_2S, Bi_3Te, and Bi_5Te_2

Oberthür and Weiser (2008)

Other names: UM2008-43-S:BiTe

Unnamed Bi_6Te_2S, Bi_3Te, and Bi_5Te_2 were described in the auriferous quartz–tourmaline lodes of a lode-gold deposit, the historically and economically important Passagem de Mariana mine, Passagem de Mariana district, Mariana, Minas Gerais, associated with arsenopyrite, löllingite, pyrite, marcasite, pyrrhotite, chalcopyrite, galena, native gold, native bismuth, maldonite, stibnite, berthierite, benjaminite, tetradymite, tellurobismuthite, cosalite, molybdenite, "wolframite", bismuthinite, aurostibite, and hedleyite.

The unnamed mineral Bi_6Te_2S occurs in aggregates together with native Bi and hedleyite, and also in association with maldonite and gold in one case. It is grey in color, has a reflectivity of ~60% in air, is distinctly anisotropic, and slightly softer than hedleyite. The samples carry up to Fe 1.49, Sb 0.88, As 0.21, Pb 0.11 wt.%, but no Se. The composition varies between $(Bi_{5.60}Sb_{0.07}As_{0.04}Fe_{0.40})_{\Sigma 6.11}Te_{1.87}S_{1.02}$ and $(Bi_{5.81}Sb_{0.11}As_{0.04}Pb_{0.01}Fe_{0.12})_{\Sigma 6.09}Te_{1.91}S_{1.00}$. This mineral was also described at the Viceroy mine, in Zimbabwe (Oberthür and Weiser 2008).

Analysis of "hedleyite" from Passagem de Mariana mine corresponds to the formula Bi_7Te_3 and also to Bi_3Te, Bi_5Te_2 and Bi_8Te_3 (Oberthür and Weiser 2008).

See also. Joséite-A, joséite-B, and unnamed Bi_8Te_3 and Bi_2Te.

Unnamed Bi_8Te_3 and Bi_2Te

Cabral and Corrêa Neto (2015)

Unnamed Bi_8Te_3 and Bi_2Te were described in the São Sebastião gold deposit, Passagem de Mariana district, Mariana, Minas Gerais, associated with dravite, chalcopyrite, pyrrhotite, gold, bismuth, hedleyite, and joséite-B. Heterogeneous material, consisting of intergrowths of Bi_8Te_3 and Bi_2Te and hedleyite (Bi_7Te_3), would give a ‘‘bulk’’ composition close to that of hedleyite. This line of reasoning finds support in the broad range of compositions reported for hedleyite (Cabral and Corrêa Neto 2015).

Bi_8Te_3 chemical data (mean of 9 analyses): Bi 81.34, Pb < 0.40, Te 18.13. S 0.05, Se 0.17, total 99.69 wt.%. Empirical formula: $Bi_{8.00}(Te_{2.92}Se_{0.04}S_{0.03})_{\Sigma 3.00}$. Bi_8Te_3, from a sample regarded as hedleyite, was also found in the Passagem de Mariana mine (Oberthür and Weiser 2008).

Bi_2Te chemical data (mean of 4 analyses): Bi 77.68, Pb < 0.40, Te 20.99. S 0.04, Se 0.75, total 99.46 wt.%. Empirical formula: $Bi_{2.04}(Te_{0.90}Se_{0.05}S_{0.01})_{\Sigma 0.96}$.

See also. Joséite-A, joséite-B, unnamed Bi_6Te_2S, Bi_3Te, and Bi_5Te_2.

Unnamed $Pd_3(Te,Bi)$, $Pd(O,Te,Bi)_2$, $(Pd,Fe,Cu)(O,Te)_2$, and Fe,Pd,Pt-O

(Mota-e-Silva *et al.* 2016)

Unnamed Pd-Te±Bi phases, including $Pd_3(Te,Bi)$, $Pd(O,Te,Bi)_2$, $(Pd,Fe,Cu)(O,Te)_2$, and Fe,Pd,Pt-O (Mota-e-Silva *et al.* 2016) occur in gossans developed on a Ni-Cu(-PGE) deposit in Limoeiro, Pernambuco, associated with goethite, sperrylite, irarsite, hollingworthite, unnamed Pd-Cu-O compounds, unnamed Pd-I-O compounds, and an unnamed Fe-Pt-Rh-O phase. They were only identified at shallow depths (<19m) coincident with the absence of merenskyite. They are interpreted to occur as pseudomorphs after merenskyite, assuming the same euhedral prismatic shape and size as merenskyite in the unaltered sulfide mineralization. The Pd-Te±Bi forms a patchy phase as it is partly oxidized and partly replaced by goethite. The extent of oxidation of the original merenskyite is variable. The whole area of individual merenskyite pseudomorphs (non-oxidized relict cores + oxidized parts + goethite) varies from $4\mu m^2$

to 4400μm^2, with an average of 475μm^2. This size range and average are very similar to the dimensions of the merenskyite grains described in the fresh massive sulfide ore. The Pd-Te±Bi grains are usually hosted by Cu- and S-bearing goethite. The non-oxidized portion of this mineral phase is generally too small (< 5μm) to be analyzed quantitatively. However, one of the identified grains provided a good quantitative analysis, which indicates that Pd-Te±Bi is relatively enriched in Pd up to 69 wt.% and has much less Te (22 wt.%) and Bi (8.4 wt.%) compared to the precursor merenskyite. Precursor merenskyite typically has 20 wt.% Pd, 48 wt.% Te and 23 wt.% Bi. The oxidized part of the Pd-Te±Bi contains elevated Pd (50–67 wt.%) and O (15–33 wt.%) in its composition with variable amounts of Fe, Pt, Cu and Ni. Finally, highly oxidized Pd-Te±Bi grains with rare relict PGM cores develop Pd-Cu-bearing Fe-oxides containing lower Pd (<44 wt.%), but higher Pt and base metals, especially Cu (≤ 4 wt.%) (Mota-e-Silva 2014).

See also. Unnamed Pd-Cu-O and Pd-I-O compounds, and unnamed Fe-Pt-Rh-O phase.

Jacutingaite

Vymazalová *et al.* (2012)

Pt_2HgSe_3, trigonal

Approved CNMNC - IMA 2010-078

Other names: jacutingaíta

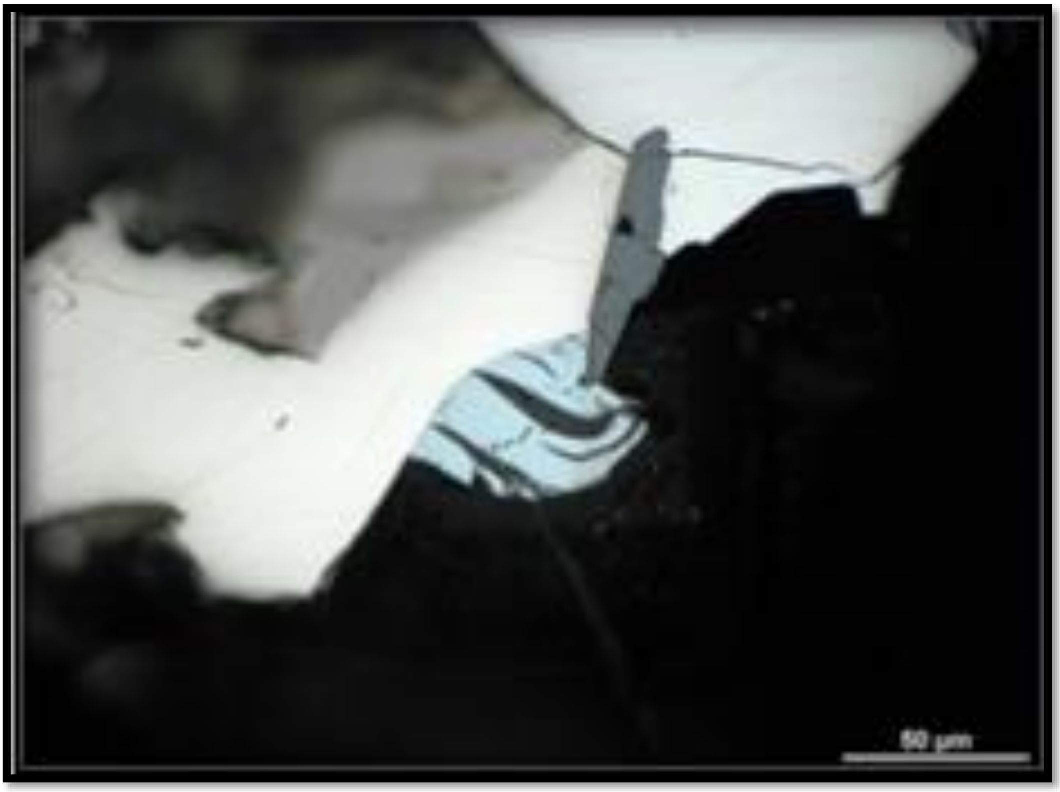


Figure 2.13. Jacutingaite (bluish-gray, in reflected light), with unnamed Pt–O on the surface of an aggregate of hematite, potarite and atheneite. From Cauê mine, Itabira, Minas Gerais. Holotype specimen (polished section), GeoMuseum “Geosammlung” at the Technical University of Clausthal, Germany, catalog number 26580. Photo: Alexandre Raphael Cabral.

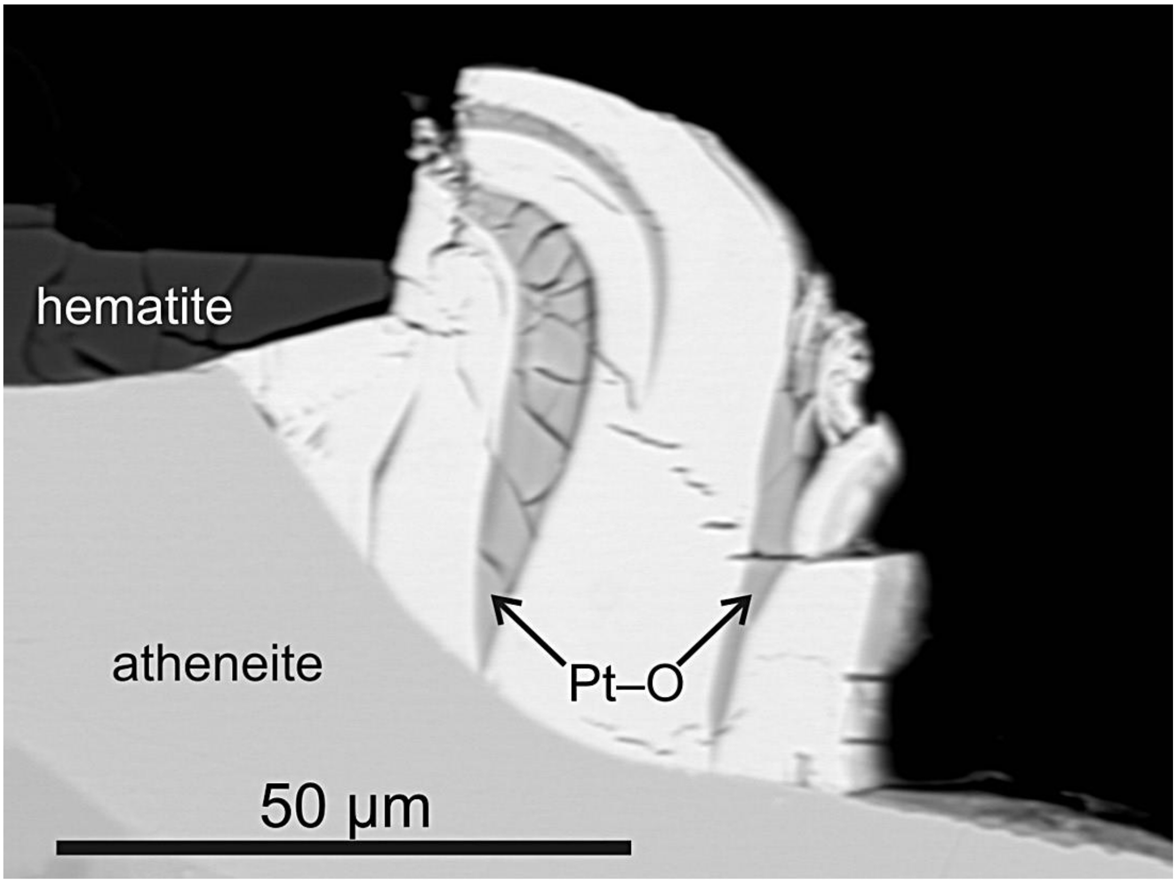


Figure 2.14. Back-scattered electron image of jacutingaite (white) with unnamed Pt–O on the surface of an aggregate of hematite, potarite and atheneite. Holotype specimen (polished section), GeoMuseum “Geosammlung” at the Technical University of Clausthal, Germany, catalog number 26580. Vymazalová *et al.* (2012).

Cabral *et al.* (2008) preliminarily quoted this mineral as an unnamed phase. With the support of documentation on the synthetic analog, Vymazalová *et al.* (2012) described jacutingaite as a new mineral species. The single grain of natural material and its small size prevented its extraction and investigation by X-ray diffraction. Therefore, the relevant crystallographic and structural investigations were performed on synthetic Pt_2HgSe_3 and natural and synthetic materials were shown to have the same structure by EBSD methods. This description and the recognition of a seleniferous signature in the Pd–Pt-bearing auriferous mineralization in Brazil (Cabral and Lehmann 2007) made the phase relations within the system Hg–Pt–Se relevant from a mineralogical point of view. Hence Drábek *et al.* (2012) undertook to experimentally study the phase relations within this system. Recent experimental studies have shown that jacutingaite displays the properties of a quantum spin Hall insulator, and theoretical studies indicate that its twodimensional monolayer is a insulator with a robust topological gap of ~0.5 eV. Jacutingaite is thus promising for potential applications to nanoelectronics and spintronics (Longuinhos *et al.* 2020).

Occurrence. The mineral was discovered in an aggregate about 2 mm in size, in a polished section, obtained from a heavy-mineral concentrate from friable Jacutinga vein-type mineralization from the Cauê iron-ore deposit, Itabira, Minas Gerais. Associated minerals are atheneite, potarite, an unknown Pt–O-like phase, and hematite. It was found in a hematite-rich vein. The mineral formed in an oxidizing hydrothermal system at relatively low temperature, probably below 300°C (Cabral *et al.* 2008). Cauê mine is also the type locality of arsenopalladinite, atheneite, isomertieite and palladseite. A second occurrence was described by Ma *et al.* (2020) at Tilkerode, Harz Mountains, Germany.

Appearance and physical properties. Jacutingaite occurs as a rounded fibrous grain about 50 μm in diameter, intergrown with atheneite, potarite, and hematite. It is partially altered to a Pt–O phase. Habit: laminated particles. Forms: none determined. Twinning: not known. Color: grey. Streak: grey. Luster: metallic. Opaque. Non-fluorescent. Hardness: VHN_{10} (15 indentations on five grains of synthetic Pt_2HgSe_3): 119 to 245 (mean 169) kg/mm^2, corresponding to a Mohs hardness of approximately 3½. Tenacity: brittle. Cleavage: {001} very good. Fracture: not observed. Density (meas.) 10.9 g/cm^{-3} for synthetic material by weighing in toluene. Density (calc.) 10.35 g/cm^{-3} (empirical formula)

Optical properties. Under plane-polarized light, jacutingaite is light grey, has a moderate to distinct bireflectance. Pleochroism: bluish-grey to rusty brown. Anisotropy: weak to distinct. Internal reflections: absent. Reflectance values of synthetic jacutingaite in air (Rmax, Rmin, in %): 51.1, 47.4 at 470 nm, 50.5, 48.2 at 546 nm, 49.6, 48.0 at 589 nm, and 47.8, 47.1 at 650 nm.

Chemical data. Microprobe (WDS mode) analyses (3): Pt 37.30, Pd 5.91, Hg 25.72, Ag 0.16, Cu 0.82, Se 31.48, total 101.39 wt.%. Empirical formula: $(Pt_{1.46}Pd_{0.42}Cu_{0.10}Ag_{0.01})_{\Sigma 1.99}Hg_{0.98}Se_{3.04}$. The ideal formula requires Pt 47.14, Hg 24.24, Se 28.62, total 100.00 wt.%.

Crystallography. Trigonal, *P*3*m*1, *a* 7.3477(2), *c* 5.2955(1) Å, *V* 247.59(1) $Å^3$, *Z* 2, *c:a* 0.721. X-ray powder diffraction data of synthetic analog [*d* in Å (*I*) (*hkl*)]: 5.2917 (100) (001), 2.7273 (16) (201), 2.4443 (10) (012), 2.0349 (18) (022), 1.7653 (37) (003), 1.3240 (11) (004), 1.0449 (11) (025).

Name. The mineral is named after the specular-hematite-rich vein-type gold mineralization locally known as "jacutinga". Jacutinga is characterized by palladiferous gold, together with Pd and Pt minerals in hematite–quartz–(talc–kaolinite) veins, which typically occur in some iron-ore deposits in the Quadrilátero Ferrífero of Minas Gerais (e.g., Henwood 1871, Hussak 1904, Cabral *et al.* 2009).

Type material. The holotype specimen (polished section) is deposited in the collections of GeoMuseum "Geosammlung" at the Technical University of Clausthal, Clausthal-Zellerfeld, Germany, catalog number 26580.

Relationship to other species. Isostructural with tilkerodeite, Pd_2HgSe_3 (Ma *et al.* (2020), and with the synthetic phases $Pt_4Tl_2S_6$, $Pt_4Tl_2Se_6$, and $Pt_4Tl_2Te_6$, all described by Bronger and Bonsmann (1995). The layered structure of jacutingaite shows structural features similar to minerals of the melonite group.

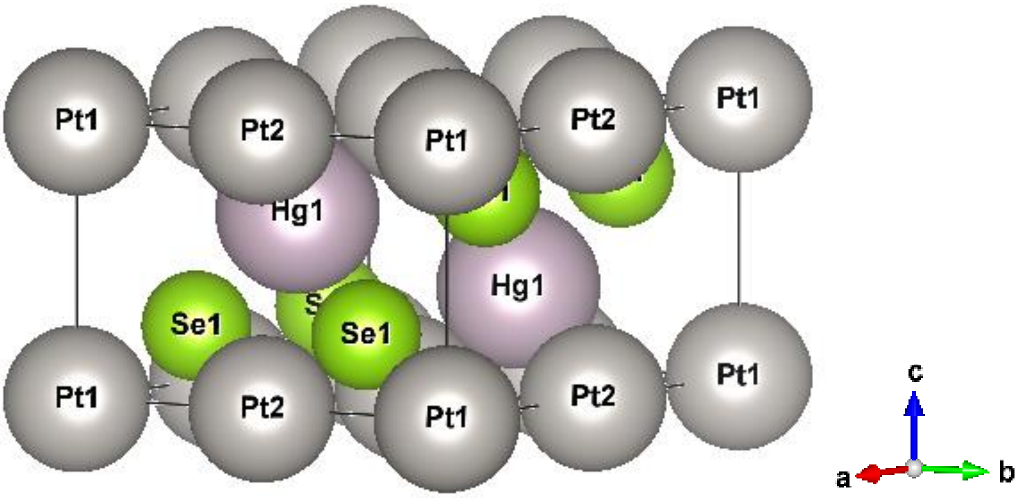


Figure 2.15. View of the crystal structure of jacutingaite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Vymazalová *et al.* (2012).

Crystal structure. The crystal structure of jacutingaite can be viewed as a layered structure composed of $PtSe_6$ octahedra and $PtSe_4$ squares. The layers are oriented parallel to (001); Hg atoms are between these layers. The layered character of the jacutingaite crystal structure is in accordance with its cleavage along {001} (Laufek *et al.* 2011, 2012).

Synthetic. Prepared using Kullerud's evacuated silica-glass-tube method (Kullerud 1971). Platinum, mercury, and selenium were used as starting materials. A carefully weighed sample was loaded into a high-purity silica tube, and a tightly fitting silica glass rod was placed on the top of the reagents to keep the charge in place and reduce the vapor volume on heating. The evacuated tube was sealed and annealed at 1200°C for 3 days. After cooling, the charge was ground in acetone and thoroughly mixed. The resulting material was sealed in an evacuated silica-glass tube and reheated at 800°C for 840 hours and 400°C for 1704 hours. The product was rapidly quenched in a cold-water bath (Vymazalová *et al.* 2012).

See also. Atheneite, unnamed Pt-O, arsenopalladinite, isomertieite and palladseite.

Brazil

Egleston (1892)

(= pyrite)

Other names: brassel, brasses, brassy, brazzil, brazzle, brassil

"Brazil" is listed as a synonym for pyrite (Egleston 1892), but with no references. Egleston (1892) gives a list of 15 books and journals consulted, as well as "all the collections of the School of Mines" [of Columbia College], but since the entry for "Brazil" has no reference, it is possible it was found in the collections. The name of the country *Brazil* (Brasil, in Portuguese) is derived from the Portuguese and Spanish word *brasil* (from *brasa*, ember*),* the name of an East Indian tree (also called *pau-brasil*) with reddish-brown wood from which a red dye was extracted. The name pyrite is from the Greek *pyr*, fire, in allusion to the sparking produced when iron is struck by a lump of pyrite. The names brazil (ember) and pyrite (fire) have a similar meaning, but it is also possible that Egleston misread a locality as the mineral name back when he was compiling his list.

According to Bates and Jackson (1987), brazil is an English dialectal term for pyrite, especially associated with coal. Also, by extension, a term applied to a coal containing much pyrite. Also spelled brassel, brasses, brassy, brazzil, brazzle, and brassil (Thrush 1968, Bates and Jackson 1987).

Unnamed Pd-Bi selenide

Marchetto and Figueiredo (1991)

(= padmaite?)

An unnamed palladium-bismuth selenide, containing minor Pt and Sb, was identified by electron microprobe in samples from the Buraco do Ouro gold mine, Cavalcante, Goiás. This mineral is probably padmaite, PdBiSe, which occurs associated with kalungaite.

See also. Kalungaite, unnamed Pb-Bi-Se-S mineral, and unnamed Ag-Pb-Bi-Se minerals.

Kalungaite

Botelho *et al.* (2006)

PdAsSe, cubic

Approved CNMMN - IMA 2004-047

Other names: kalungaíta

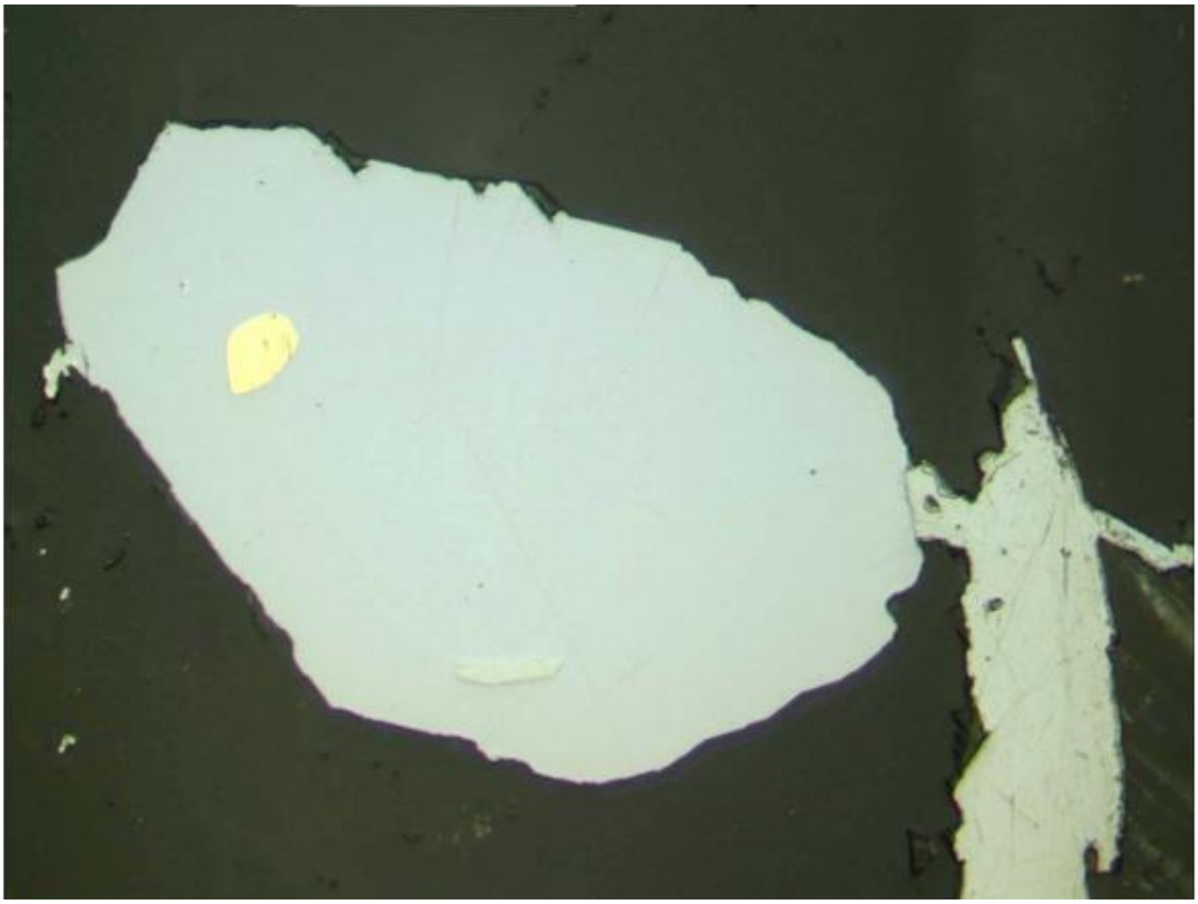


Figure 2.16. Kalungaite from Buraco do Ouro gold mine, Cavalcante, Goiás. Reflected light digital image of kalungaite (main phase) with inclusions of bright yellow gold and slightly greenish- white guanajuatite. Kalungaite grain is about 300 × 150 µm. Photo: Chris J. Stanley. Type specimen, BM 2004, 35, Natural History Museum, London, England.

Occurrence. The mineral occurs in the Buraco do Ouro gold mine, Cavalcante, Goiás. Associated minerals are quartz, muscovite, gold, bohdanowiczite, an unnamed Pb-Bi-Se-S mineral, clausthalite, stibiopalladinite, sperrylite, padmaite, and chalcopyrite. Kalungaite is hosted in a quartz-muscovite mylonite, related to an E-W shear zone in a

Palaeoproterozoic peraluminous granite, forming a small Au + PGE (platimum-group element) deposit, in which the ore minerals are concentrated in sigmoid structures. Although the association of gold and PGE minerals is unusual in this kind of rock, recent studies have demonstrated that other nearby gold occurrences, in the same peraluminous granitic suite, also contain PGE anomalies. This relationship suggests that kalungaite formed during deformation and hydrothermal alteration of the peraluminous granite. However, the source of these metals remains unknown.

Appearance and physical properties. Habit: irregular grains, reaching a maximum size of 0.2 mm, forming aggregates with gold, and the associated minerals listed above. Isolated pure grains are rare. Color: lead-grey. Streak: black. Luster: metallic. Opaque. Non-fluorescent. Hardness (Mohs): 4-5; VHN_{25}: 429 to 455 (mean 438) kg/mm^2. Tenacity: brittle. Cleavage: none observed. Fracture: uneven. Density could not be measured because of the small grain size. Density (calc.) 7.59 g/cm^3 (based on the empirical formula and *a* 6.089 Å).

Optical properties. In reflected light: creamy color (adjacent to gold grains), no internal reflections, isotropic. Reflectance values in air (and in oil): 47.5 (33.3) at 470 nm, 46.9 (32.6) at 546 nm, 46.8 (32.6) at 589 nm and 48.0 (34.0) at 650 nm.

Chemical data. Microprobe (WDS mode) analyses (8): Pd 41.32, As 27.49, Bi 0.35, Sb 1.59, Se 27.67, S 1.22, total 99.64 wt.%. Empirical formula: $Pd_{1.006}(As_{0.950}Sb_{0.034}Bi_{0.004})_{\Sigma 0.988}(Se_{0.908}S_{0.099})_{\Sigma 1.007}$. The ideal formula requires Pd 40.88, As 28.78, Se 30.33, total 100.00 wt.%.

Crystallography. Cubic, *Pa*3, *a* 6.089(4) Å, *V* 225.8(1) $Å^3$, Z 4. X-ray powder-diffraction data [*d* in Å (*I*) (*hkl*)]: 3.027 (75) (002), 2.725 65 (021), 2.478 (65) (112), 1.838 (100) (113), 1.625 (55) (123), 1.131 (60) (025), 1.077 (80) (044), 0.988 (70) (116), 0.929 (90) (335), 0.918 (70) (226).

Name. The name is for the Kalunga people, living outside Cavalcante and other nearby towns. This community is composed of descendants of African slaves, brought to Brazil by the Portuguese from the 16th to the 19th century; they were able to escape and to form their own society.

Type material. Type material is deposited in the Natural History Museum, London, England, BM 2004, 35. Cotype is a polished section CAV1B.

Relationship to other species. The mineral is a member of the cobaltite group, the Pd-dominant analog of jolliffeite (NiAsSe).

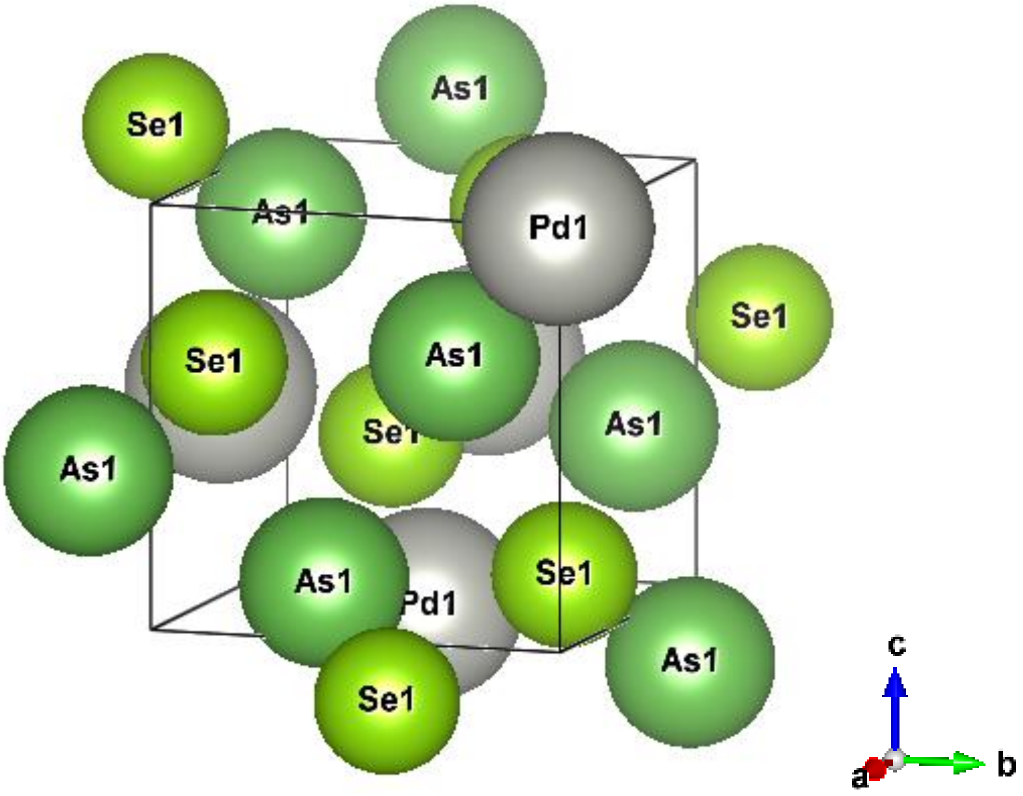


Figure 2.17. View of the crystal structure of kalungaite (synthetic), drawn using VESTA 3 (Momma and Izumi 2011). Data from Foecker and Jeitschko (2001).

Crystal structure. Kalungaite has a pyrite-type structure in which Pd atoms are located at the corners and face centers of the cube, and (As,Se) atoms are arranged in "dumb-bell" pairs centered at the midpoints of cube edges and the cube's body center. Each Pd atom is surrounded by six (As,Se) atoms at the corners of an octahedron, while the (As,Se) ions are tetrahedrally coordinated by three Pd ions and one (As,Se) ion. As the grain studied by Botelho *et al.* (2006) is not a single-crystal of kalungaite and also contains small inclusions of gold, the collection of diffraction data suitable for crystal structure refinement was not possible. A calculated X-ray diffraction pattern assumed (a) As and Se disordered at site 8*c*, (b) space group $Pa\bar{3}$, (c) *a* 6.087(2), and (d) the *x* coordinate of As and Se ($x = 0.38322$) based on the structure of $PdAs_2$ described by Brese and von Schnering (1994), showed a good match between the intensities calculated by the Rietveld method and the observed intensities from the Gandolfi film.

Synthetic. The synthetic equivalent to kalungaite was prepared by reaction of powder of PdSe with As in evacuated sealed silica tube. A silica tube with Pd and Se (Pd:Se = 1:1) was heated to ca. 1000°C under vacuum to evaporate any water. It was then flushed with argon, evacuated, sealed, placed in a cold furnace, heated to 450°C at a rate of 50°C/h, annealed at that temperature for 1 day, followed by heating to 800°C at 10°C/h, and kept at that temperature for 3 days. Finally, the sample was quenched in cold water. The product was crushed to a powder, thoroughly mixed with As (Pd:Se:As = 1:1:1), and sealed again in an evacuated silica tube. The sample was placed in a cold furnace and heated to 220°C at a rate of 50°C/h, kept at that temperature for 2 h, followed by heating to 400°C at 50°C/h, annealed at that temperature for 24 h, heated further to 690°C at 10°C/h, and annealed at that temperature for 20 days. It was then slowly cooled to room temperature at a rate of 2°C/h (Foecker and Jeitschko 2001).

See also. Unnamed Pb-Bi-Se-S mineral, unnamed Ag-Pb-Bi-Se minerals, and unnamed Pd-Bi selenide.

Unnamed Pb-Bi-Se-S mineral

Botelho *et al.* (2006)

This mineral occurs associated with kalungaite in the Buraco do Ouro gold mine, Cavalcante, Goiás. No additional data were furnished.

See also. Kalungaite, unnamed Ag-Pb-Bi-Se minerals and unnamed Pd-Bi selenide.

Unnamed Ag-Pb-Bi-Se minerals

Menez (2013)

According to Menez (2013), unidentified Ag-Pb-Bi-Se phases appear mainly as irregular overgrowths on guanajuatite from the Buraco do Ouro gold mine, Cavalcante, Goiás. The observed textures between guanajuatite and both the Ag-rich and Se-rich phase suggest a replacement of the guanajuatite grains by these minerals.

The phase richest in silver has 42.2 wt.% Ag, twice as much as the bohdanowiczite silver content, and the calculated ideal formula is Ag_3BiSe_2.

The phase richest in selenium is characterized by the same textural relationship observed in the Ag-rich selenide-guanajuatite association. This selenide has more than 50 wt.% Se (average value: 72.5 wt.%); no similar phase is described in the literature. By analogy with other alloys, this phase could be considered native selenium with bismuth, silver, lead, and copper impurities.

See also. Unnamed Pb-Bi-Se-S mineral (probably the same phase), unnamed Pb-Bi-Se mineral, kalungaite and unnamed Pd-Bi-selenide.

Unnamed Pb-Bi-Se mineral

Menez (2013)

Other names: Unnamed (Pb-Bi Selenide)

An unidentified selenide is the Pb-Bi-Se phase which has lead content ranging between 10.1 and 58.1 wt.% with an average value of 19.2 wt.% from the Buraco do Ouro gold mine, Cavalcante, Goiás. Although BSE images show a complex intergrowth between guanajuatite and clausthalite, which is dependent on the lead content, chemical data from homogeneous areas suggest a solid solution between these minerals, where the Pb-Bi-Se phase would represent an intermediate composition. Where the Pb-Bi-Se phase shows a lead content less than ~ 20 wt.%, the BSE image is similar to that of guanajuatite and where the lead content is greater than ~ 20 wt.% the image is similar to that of clausthalite. Otherwise, this Pb-Bi-Se phase could represent a specific non-described mineral. A similar species described in the literature is platynite [$PbBi_2(Se,S)_2$], which was however, discredited as a valid mineral, being a mixture of laitakarite [$Bi_4(Se,S)_3$] and selenian galena [$Pb(S,Se)$] (Holtstam and Söderhielm 1999). Such a mixture does not appear to be the case here because a unique phase has been identified in the BSE analysis.

See also. Unnamed Ag-Pb-Bi-Se minerals, Pb-Bi-Se-S mineral, kalungaite and Pd-Bi-selenide.

Unnamed $PbSb_2$, Pb_6Sb, and $PbSb_4$

Zaccarini *et al.* (2006)

Other names: Unnamed (Pb-Sb Alloy)

Investigation of minute grains of accessory minerals developed in layers of chromitite from Campo Formoso, Bahia, revealed the presence of rather exotic minerals, such as monazite-(La), monazite-(Ce), apatite, galena, bismuthinite, antimony, and unknown Pb-Sb minerals, corresponding to the formulae $PbSb_2$, Pb_6Sb, and $PbSb_4$. All these minerals are restricted to the secondary silicates of the matrix and to fractures crossing altered chromite grains. They are typically associated with chromian clinochlore. The minerals in the system Pb-Sb have been found as single-phase grains, attaining only a few µm across. The compositional data do not match any known species. They, thus, potentially represent new mineral species, but it was not possible to extend the investigation because of the small size of the grains. From the point of view of phase equilibria, lead is known to melt at 327ºC, and the addition of Sb lowers the freezing point to 247ºC. Thus, it is theoretically possible that the lead-antimony alloys and the antimony in this assemblage crystallized from globules of melt during the hydrothermal stage concomitantly with the growth of the chromian clinochlore. However, the phase diagram illustrated in the metallurgical literature is that of a simple binary system without solid solution and without binary compounds (Zaccarini *et al.* 2006).

Chemical data from microprobe (wt.%), normalized results:

Unnamed $PbSb_2$: Pb 33.65, Sb 65.51, Bi 0.84. Empirical formula: $Pb_{1.01}Sb_{1.97}Bi_{0.03}$.

Unnamed Pb_6Sb: Pb 84.78, Sb 14.31, Bi 0.91. Empirical formula: $Pb_{5.93}Sb_{1.00}Bi_{0.06}$.

Unnamed $PbSb_4$: (1) Pb 21.88, Sb 77.82, Bi 0.30. Empirical formula: $Pb_{1.09}Sb_{3.89}Bi_{0.02}$. (2) Pb 21.45, Sb 77.88, Bi 0.67 Empirical formula: $Pb_{1.07}Sb_{3.89}Bi_{0.03}$.

Unnamed OsRhAsS, RuTeAs, $OsAs_5$, OsRuAs and a complex Os-Re-As-Te-Fe-Y-Rh mineral

Marchetto (1986, 1990)

The occurrence of these phases was described at the O'Toole deposit, Fortaleza de Minas Co., Minas Gerais. The deposit is a Cu-Ni-Co sulfide lens, hosted by ultrabasic rocks. The main sulfides are pyrrhotite, pentlandite, and chalcopyrite. Cobaltite-gersdorffite series minerals and sphalerite are the most common accessory minerals. Kotulskite-melonite, irarsite, sperrylite, omeiite, osarsite, OsRhAsS, RuTeAs, $OsAs_5$, OsRuAs, and a complex Os-Re-As-Te-Fe-Y-Rh occur as inclusions in cobaltite-gersdorffite. The second world occurrence of unnamed ReS_2 (after named rheniite) was found in this deposit. No additional data were given for the unnamed minerals from Fortaleza de Minas.

Unnamed Ir-Ni sulfide and undetermined Os-Ir sulfide

Garuti *et al*. (2012)

An unnamed Ir-Ni sulfide and an undetermined Os-Ir sulfide were identified by Garuti *et al.* (2012) in the chromitites of Niquelândia, Goiás. Associated minerals are an unnamed Ru-Fe oxide, laurite, erlichmanite, kashinite, “iridosmine”, irarsite, malanite, isoferroplatinum, tetraferroplatinum, geversite, sudburyite, sobolevskite, kotulskite, moncheite and stumpflite.

See also. Iridosmine, unnamed Pd_2FeI, RuO_4, and Ru and Ir oxides and hydroxides

Chapter 3

Halides

Unnamed polymorph of fluocerite

Pires *et al.* (2006)

[= fluocerite-(Ce)]

Other names: polimorfo de fluocerita

An exsolved phase in gagarinite-(Y) from Pitinga mine, Presidente Figueiredo, Amazonas, was initially interpreted by Pires *et al.* (2006) as a polymorph of fluocerite, but further work (Bastos Neto *et al.* 2009, Pires 2010) proved it to be fluocerite-(Ce), hexagonal CeF_3. Microprobe data (mean of 10 analyses): F 35.01, Si 0.02, Ca 0.07, La 10.95, Ce 42.91, Nd 10.29, Sm 1.16, Eu 0.56, Gd 0.37, Dy 0.22, Er 0.01, Yb 0.02, Y 0.27, total 101.86 wt.%. Empirical formula: $(Ce_{0.50}La_{0.13}Nd_{0.12}Sm_{0.01}Eu_{0.01})_{\Sigma 0.77}F_{3.00}$. An excess of 0.69 negative charges is noted in this formula, implying an analytical error.

See also. Waimirite-(Y) and atroarite.

Waimirite-(Y)

Atencio *et al.* (2015)

YF_3, orthorhombic

Approved CNMNC – IMA 2013-108

Other names: waimirita, waimirite, waimirita-(Y)

Figure 3.1. Waimirite-(Y) bearing sample from Pitinga mine, Presidente Figueiredo, Amazonas. Cotype material (number DR919) deposited in the collections of the Museu de Geociências, Universidade de São Paulo (Atencio *et al.* 2015).

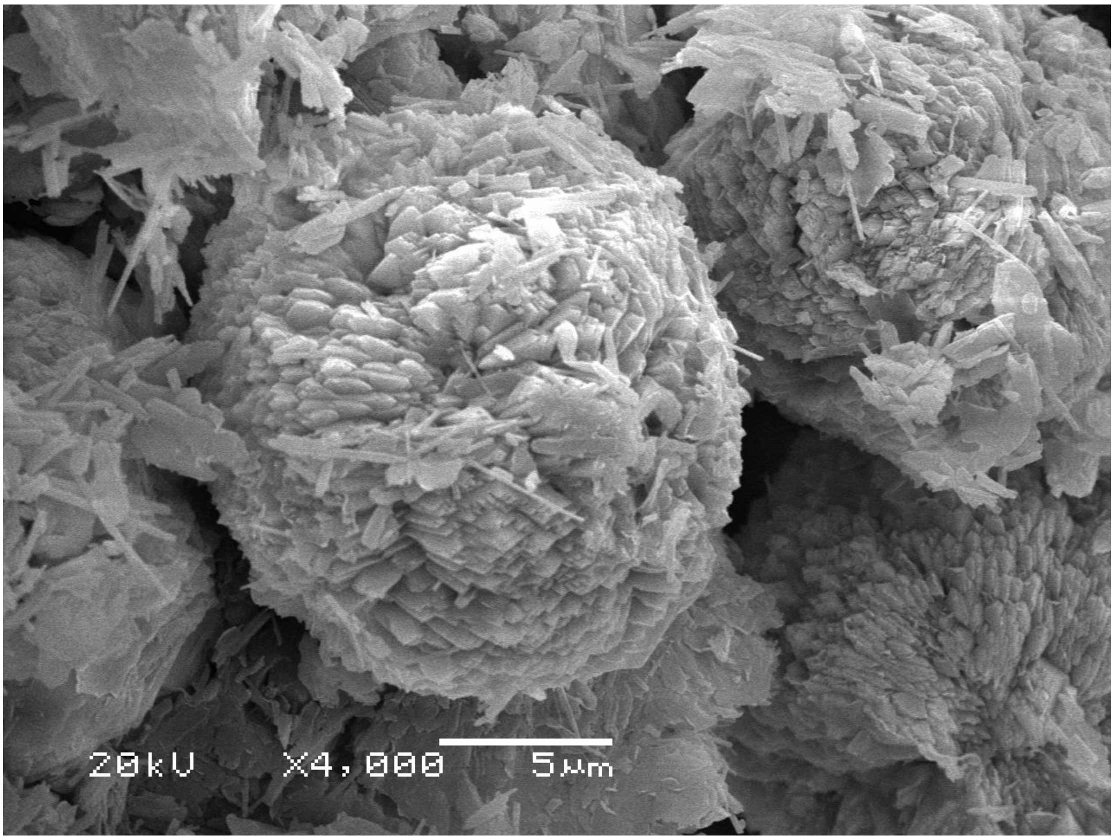


Figure 3.2. Backscattered electron image of waimirite-(Y) from Pitinga mine, Presidente Figueiredo, Amazonas (spherical aggregates of plates) and halloysite (tubes) (Atencio *et al.* 2015)

Fluoride crystalline materials are commonly studied owing to their applications in solid state lasers and scintillators. Indeed, their good optical properties beside their low non-radioactive emissions (mainly because of the low cut-off phonon frequencies) make these materials good host matrices for visible or infrared light emission and other optical applications. It is well known that fluoride materials can be used as active media for tunable solid-state lasers (Lage *et al.* 2004). The orthorhombic YF_3 crystals are non-hygroscopic and colourless under normal conditions essential for use as active laser materials. Kollia *et al.* (1995) showed that YF_3 could be a laser material.

A preliminary note on this mineral was published by Atencio *et al.* (2014). The luminescence properties of waimirite-(Y) were studied by Atencio *et al.* (2017b).

Occurrence. Waimirite-(Y) occurs in thin hydrothermal veins crosscutting the albite-enriched granite facies of an A-type Madeira granite (~1,820 Ma), Pitinga mine, Presidente Figueiredo, Amazonas. The albite-enriched granite facies corresponds to the Madeira world-class Sn-Nb-Ta (Y, REE, F, Zr, Li, and Th) deposit, with 130 million tons of disseminated ore. In the central portion of the albite-enriched zone, there is a massive cryolite deposit of 10 million tons with a grade of 31.9% Na_3AlF_6. Directly associated minerals are dickite and quartz. Other minerals in the albite-enriched granite are “alkali feldspar”, albite, riebeckite, biotite, muscovite, cryolite, zircon, polylithionite, cassiterite, pyrochlore-group minerals, hydrokenoralstonite (“atroarite”), “columbite”, thorite, lead, galena, fluorite, xenotime-(Y), gagarinite-(Y), fluocerite-(Ce), genthelvite-helvite, topaz, “illite”, kaolinite and “chlorite” (Bastos Neto *et al.* 2009). The occurrence of chiolite and thomsenolite were reported by Atencio *et al.* (2018). Waimirite-(Y) also occurs at Jabal Tawlah, Saudi Arabia (Atencio *et al.* 2015) and in the Tanintharyi Region of southern Myanmar (Sanematsu *et al.* 2016).

Appearance and physical properties. The mineral occurs as thin veins (up to 3 cm thick) of platy crystals up to about 1 μm in size. Forms: not determined, but synthetic YF_3 displays pinacoids, prisms and bipyramids (Qian *et al.* 2010). Twinning: none observed. Color: pale pink. Streak: white. Luster: nonmetallic. Transparent or translucent. Non-fluorescent. Hardness: not measured due to the crystal dimensions. Tenacity: not determined. Cleavage: none observed. Fracture: not determined. Density could not be measured because of small grain size. Density (calc.) 5.911 g/cm^3 using the empirical formula.

Optical properties. Biaxial. Due to the crystal dimensions, only a mean n 1.54 – 1.56 was measured.

Chemical data. Microprobe (EDS) analyses (9): F 33.28, Ca 0.90, Y 39.11, Nd 0.69, Sm 0.44, Eu 0.05, Gd 1.97, Tb 0.99, Dy 9.10, Ho 2.00, Er 7.01, Tm 1.13, Yb 6.27, total 102.94 wt.%. The empirical formula (based on 4 *apfu*) is $(Y_{0.74}Dy_{0.09}Er_{0.07}Yb_{0.06}Ca_{0.04}Gd_{0.02}Ho_{0.02}Nd_{0.01}Sm_{0.01}Tb_{0.01}Tm_{0.01})_{\Sigma 1.08}F_{2.93}$. The simplified formula requires: Y 60.93, F 39.07, total 100.00 wt.%.

Crystallography. Orthorhombic, *Pnma*, *a* 6.386(1), *b* 6.877(1), *c* 4.401(1) Å, *V* 193.28(7) Å^3, Z 4 (powder data), *a:b:c* = 0.929:1:0.640. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 3.707 (26) (011), 3.623 (78) (101), 3.438 (99) (020), 3.205 (100) (111), 2.894 (59) (210), 1.937 (33) (131), 1.916 (24) (301), 1.862 (27) (230).

Name. The name is for the Waimiri-Atroari Indian people of Roraima and Amazonas. The name “waimirite” was informally used for this mineral by Minuzzi *et al.* (2003). The suffix "(Y)" was introduced because it is a rare-earth mineral.

Type material. Type material is deposited in the collections of the Museu de

Geociências, Universidade de São Paulo, specimen number DR919, and the Museu de Mineralogia Luiz Englert, Instituto de Geociências, Universidade Federal do Rio Grande do Sul, Porto Alegre, specimen number 3620.

Relationship to other species. It is a perovskite supergroup, non-stoichiometric perovskite group, oskarssonite subgroup mineral (Mitchell *et al.* 2017). Fluocerite-(Ce) and fluocerite-(La) are hexagonal CeF_3 and LaF_3, respectively.

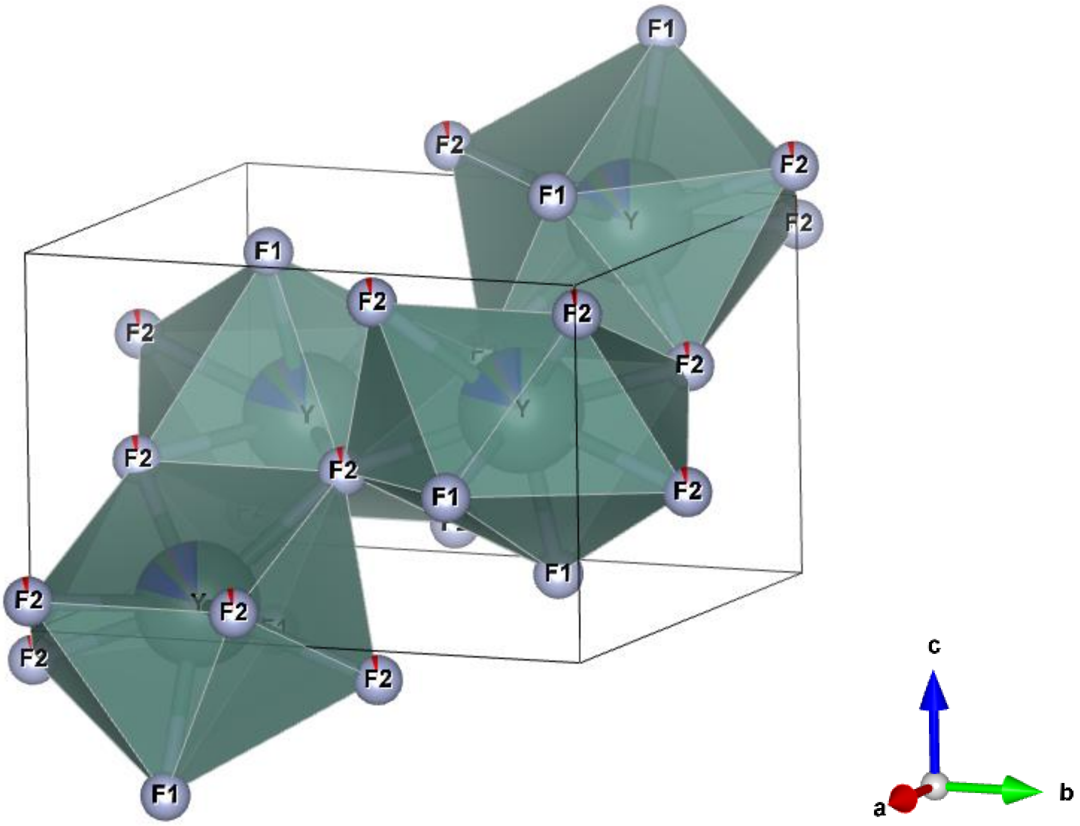


Figure 3.3. View of the crystal structure of waimirite-(Y) (from Jabal Tawlah, Saudi Arabia), drawn using VESTA 3 (Momma and Izumi 2011). Data from Atencio *et al.* (2015).

Crystal structure. It is a *B*-site vacant perovskite (Mitchell *et al.* 2017). The crystal structure of synthetic orthorhombic YF_3 was studied by Zalkin and Templeton (1953) and Cheetham and Norman (1974). The Y ion is coordinated by 9 F ions to give a slightly deformed trigonal prism with atoms opposite each of the lateral faces. Eight of the nearest neighbors lie at distances between 2.281 and 2.310 Å. The ninth distance is 2.538 Å.

Synthetic. The material has previously been synthesized and is well-studied (Zalkin and Templeton 1953, and Cheetham and Norman 1974). Several orthorhombic and hexagonal synthetic *REE*F_3 compounds were also obtained (Zalkin and Templeton, 1953).

See also. Atroarite and unnamed polymorph of fluocerite.

Atroarite

Minuzzi *et al.* (2003)

(= hydrokenoralstonite)

Other names: atroarita

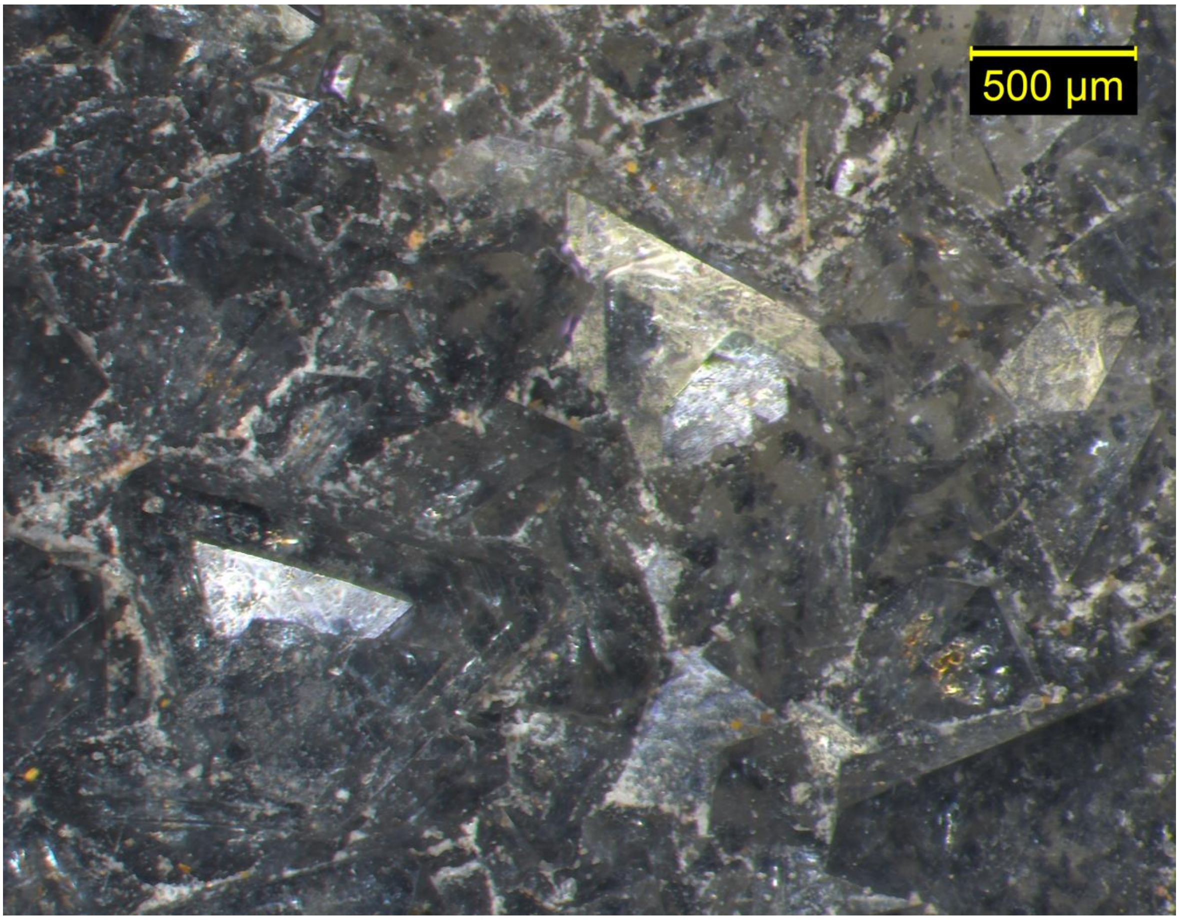


Figure 3.4. Hydrokenoralstonite (“atroarite”) from Pitinga mine, Presidente Figueiredo, Amazonas (Atencio *et al.* 2017a).

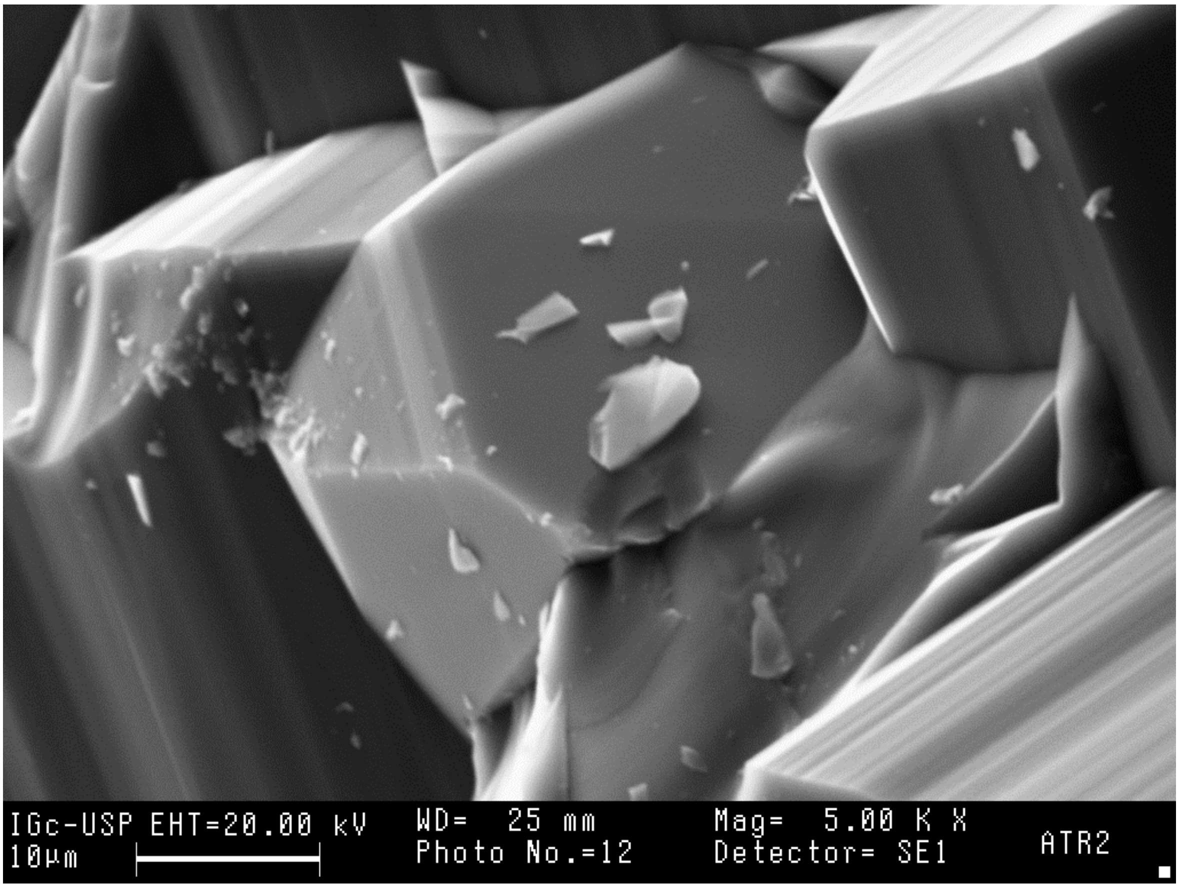


Figure 3.5. SEM image of hydrokenoralstonite (“atroarite”) from Pitinga mine, Presidente Figueiredo, Amazonas (Atencio *et al.* 2017a).

“Atroarite” occurs in thin veins in the core of the albite granite forming the nucleus of the Madeira granite in the Pitinga mine (Sn, Nb, Ta, Zr, Li, Y, *REE* and cryolite), Presidente Figueiredo, Amazonas. It forms dark grey octahedral crystals and is shown by EDS (Al-F-Mg-Na-Si-O) to be an alumino-fluoride (Minuzzi *et al.* 2003). The original publication does not provide a formula for the phase. Strongest XRD lines are 5.67(100), 2.97(28), 2.84(45), 1.89(66), 1.74(11). The name informally proposed is an etymological reference to the Waimiri Atroari tribe and can be confused with the approved artroeite, another alumino-fluoride.

A new study of "atroarite" (Atencio *et al.* 2017a) from the Pitinga mine led to the conclusion that it is identical to ralstonite [originally described by Brush (1871) in the Ivigtut cryolite deposit, Ivittuut (Ivigtut), Arsuk Fjord, Sermersooq, Greenland]. Following the established naming rules for pyrochlore supergroup minerals (Atencio *et al.* 2010a), ralstonite was renamed hydrokenoralstonite (Atencio *et al.* 2017a). The name ralstonite was transferred to the group (ralstonite group), where M^{3+} cations are dominant in the *B*-site, and Al is dominant among them, and F^{1-} is the dominant anion in the *X*-site.

Hydrokenoralstonite is intimately associated with galena and sphalerite. It forms chemically homogeneous octahedra crystals, from 0.1 to 1 mm in size. No twinning is observed. The mineral is colorless with white streak, vitreous luster, transparent, density (calc.): 2.554 g/cm^3.

Microprobe analyses (11): Na_2O 2.14, K_2O 0.02, Rb_2O 0.55, MgO 3.20, CaO 0.01, Al_2O_3 52.63, F 36.46, H_2O 22.70, O=F -15.35, total 102.36 wt.%. H_2O was calculated from crystal structure. Empirical formula [based on 6 (F+OH) anions a*pfu*)] is $(\square_{1.87}Na_{0.12}Rb_{0.01})_{\Sigma2.00}(Al_{1.86}Mg_{0.14})_{\Sigma2.00}[F_{3.46}(OH)_{2.54}]_{\Sigma6.00}(H_2O)$. Simplified formula is $\square_2Al_2F_6(H_2O)$.

The mineral is cubic, $Fd\bar{3}m$, *a* 9.8455(7) Å, *V* 954.36 (12) Å^3, Z 8 (single-crystal X-ray studies). X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 5.687 (100) (111), 2.973 (18) (311), 2.841 (28) (222), 1.893 (36) (511). Unit-cell parameters refined from powder data are *a* 9.849(9) Å, *V* 955(3) Å^3. Hydrokenoralstonite exhibits (Al,Mg) cations with octahedral coordination and Na cations are located within distorted cubes.

See also. Waimirite-(Y) and unnamed polymorph of fluocerite.

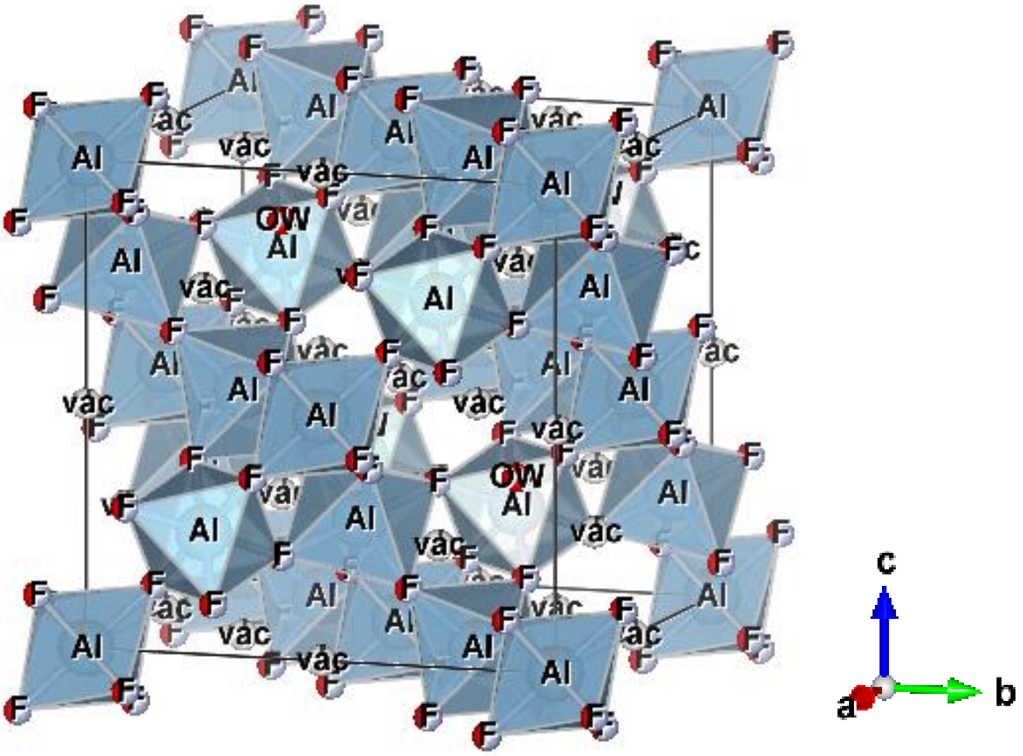


Figure 3.6. View of the crystal structure of hydrokenoralstonite (“atroarite”) from Pitinga mine, Presidente Figueiredo, Amazonas), drawn using VESTA 3 (Momma and Izumi 2011). Data from Atencio *et al.* (2017a).

Oxyfluoride-(La) and oxyfluoride-(Ce)

Teixeira and Botelho (2004, 2006)

Other names: oxifluoreto-(La), oxifluoreto-(Ce), oxifluoreto de ETR, REE-oxyfluoride

These minerals occur as dark brown, nearly opaque anhedral grains of variable size, associated with fluocerite in Sn-rich granites from Tocantins and Paranã subprovinces, north of Goiás. The grains core is zoned between oxyfluoride-(La) and oxyfluoride-(Ce). The borders are homogeneous, REE-poorer than the core (Teixeira and Botelho 2004). No chemical data are presented.

Few natural occurrences of REE oxyfluorides were known previous to this discovery. Subhedral opaque crystals consisting of submicroscopic intergrowths of REE-oxyfluorides occur in the zinnwaldite granite of the Cinovec (Zinnwald) granite cupola, Czech Republic. Fluocerite-(La) and two unnamed (Ce, La) oxyfluorides were observed: 1. $Ce_4O_5F_2$ with fluorite-type structure, a =5.470(8) Å and a possible hexagonal or tetragonal superstructure; 2. (Ce,La,Nd)OF, with a hexagonal, bastnäsite-type, unit-cell, *a* 7.007(10), *c* 9.840(15) Å (Johan and Johan 1994).

Håleniusite-(La), (La,Ce)OF cubic, with fluorite-type structure, is the first naturally occurring rare-earth oxyfluoride approved by the IMA CNMMN (Holtstam *et al.* 2004). It was discovered as a secondary phase at the Bastnäs deposit, Skinnskatteberg District, Västmanland Co., Sweden.

Teixeira and Botelho (2006) published two analyses for REE-oxyfluorides:

Serra Dourada Massif (Tocantins tin sub-province): F 9.89, P_2O_5 0.01, CaO 0.80, SiO_2 0.06, UO_2 0.03, ThO_2 1.74, La_2O_3 28.54, Ce_2O_3 38.52, Pr_2O_3 2.33, Nd_2O_3 6.60, Sm_2O_3 0.45, Eu_2O_3 0.34, Gd_2O_3 0.21, Dy_2O_3 0.09, Yb_2O_3 0.03, Fe_2O_3 0.01, Y_2O_3 0.22, O=F -4.16, total 85.71 wt.%. Empirical formula: $(Ce_{0.47}La_{0.35}Nd_{0.08}Pr_{0.03}Ca_{0.03}Sm_{0.01}Th_{0.01})_{\Sigma 0.98}O_{0.96}F_{1.04}$.

Pedra Branca Massif (Paranã tin sub-province): F 10.27, P_2O_5 0.03, CaO 0.71, SiO_2 0.48, UO_2 0.03, ThO_2 0.51, La_2O_3 32.54, Ce_2O_3 38.87, Pr_2O_3 3.82, Nd_2O_3 8.07, Sm_2O_3 0.76, Eu_2O_3 0.51, Gd_2O_3 0.42, Dy_2O_3 0.14, Yb_2O_3 0.02, Fe_2O_3 0.00, Y_2O_3 0.22, O=F -4.32, total 93.08 wt.%. Empirical formula: $(Ce_{0.44}La_{0.37}Nd_{0.09}Pr_{0.04}Ca_{0.02}Sm_{0.01}Eu_{0.01})_{\Sigma 0.98}Si_{0.01}O_{1.00}F_{1.00}$.

The simplified formula for both analyses is CeOF, but the totals are very low. This mineral could be “håleniusite-(Ce)” if cubic or the same unnamed hexagonal mineral from Cinomev. In both cases it would be a new mineral species.

Unnamed Pd_2FeI

Milliotti and Stumpfl (1996)

This phase occurs as an inclusion in chromite at the rim of a subhedral Pt-Fe alloy grain in goethite from Niquelândia, Goiás. It displays an irregular shape and is approximately 10 μm long and 2 to 3 μm across. The mineral appears anisotropic, with lower reflectance than goethite. Semi-quantitative microprobe analyses showed a large variation in Pd (50 to 67 wt.%) and Fe (7 to 13 wt.%), (iodine not quoted), and the best composition obtained was $(Pd_{1.96}Pt_{0.04})_{\Sigma 2.00}(Fe_{0.88}Cu_{0.12}Ni_{0.04})_{\Sigma 1.04}I_{0.92}$, which approximates to Pd_2FeI. The wide range in composition observed in a single grain may be attributed to the mineralizing processes linked to laterization. The coexistence of the Pt-Fe alloy and this phase suggests, according to Milliotti and Stumpfl (1996), not only the mobility of platinum group elements as an iodine complex in the alteration fluids, but also supports the supergene origin of the Pt-Fe alloys.

See also. Unnamed RuO_4, unnamed Ru and Ir oxides and hydroxides, unnamed Ir-Ni sulfide and undetermined Os-Ir sulfide, and unnamed Pd-I-O compounds.

Unnamed $(Ba,Sr)AlF_5$

Kaminsky *et al.* (2013)

Other names: Unnamed (Barium-Strontium Aluminium Fluoride)

See Figure 7.6.

The compound $(Ba,Sr)AlF_5$ was identified in deep mantle primary carbonatitic association, included in diamond from alluvial deposits of São Luiz river, Juína, Mato Grosso, where it forms 30 – 100 nm grains. Other inclusion minerals are dolomite, halite, sylvite, phlogopite, spinel, magnesite, eitelite, unnamed $Na_4Mg_3(PO_4)_2(P_2O_7)$, oskarssonite, unnamed $Fe_2^{3+}Fe_5^{2+}(P_2O_7)_4$, pentlandite, violarite, millerite, hematite, and native iron.

The phase is extremely sensitive to electron irradiation damage; therefore, it was possible to obtain only one *d*-spacing of approximately 13.1 Å before it decomposed. The chemical composition plus the one *d*-spacing only matches the unit cell parameter *a* for α-$BaAlF_5$. This compound is orthorhombic, $P2_12_12_1$, *a* 13.7168(3), *b* 5.6054(2), *c* 4.9329(1) Å, *V* 379.28 Å^3, *Z* 4 (Le Bail *et al.* 1990). This phase was obtained from the stoichiometric BaF_2:AlF_3 mixture (15 hours, 600°C) by solid state reaction in sealed tube, under inert atmosphere (argon).

See also. Jeffbenite, ellinaite, breyite, nitroyarlongite, nitrocohenite, nitrochalypite, unnamed Fe_2N, Fe_3N, Fe_5SiC, orthorhombic MgO, $MgCr_2O_4$, $Na_4Mg_3(PO_4)_2(P_2O_7)$, $Fe_2^{3+}Fe_5^{2+}(P_2O_7)_4$, and Na-Mg pyroxene.

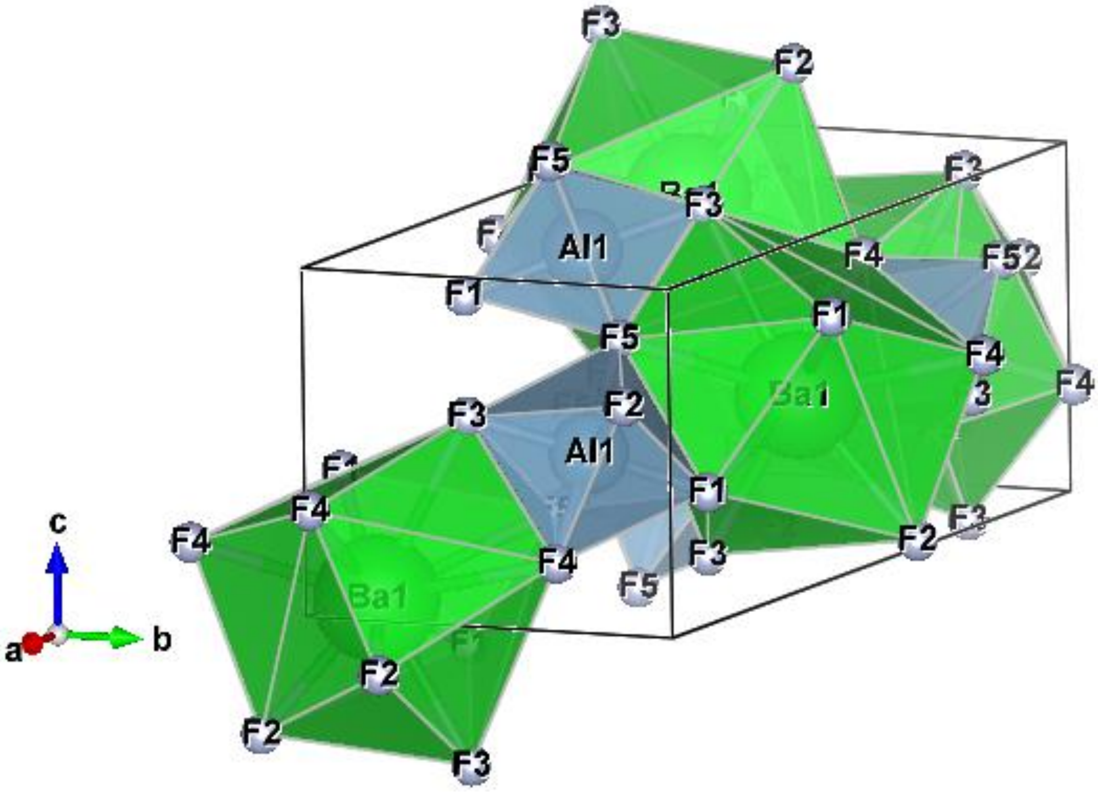


Figure 3.7. View of the crystal structure of α-$BaAlF_5$ (synthetic), drawn using VESTA 3 (Momma and Izumi 2011). Data from Le Bail *et al.* (1990).

Sergipite

Sonnenfeld and Kühn (1993)

(= ghiaraite)

Other names: sergipita

Sonnenfeld and Kühn (1993) quoted the possible occurrence of $CaCl_2 \cdot 4H_2O$ in a tachyhydrite deposit (evaporite) in Sergipe (potassium deposit of Muribeca Formation, Sergipe-Alagoas Basin), and named it sergipite, without submission to the CNMMN - IMA. No mineralogical data were published. Rossi *et al.* (2014) described ghiaraite, a triclinic mineral with this formula, as a sublimates in volcanic fumaroles on Mount Vesuvius, Italy.

Chapter 4

Oxides and hydroxides

Palladinite

Shepard (1857)

(probably a valid species)

Other names: Palladoxydat, iron-rich palladium oxidate, Palladiumoxydul, Palladiumocker, palladium-ochre, palladite, paladinita, palladinita, palladium-copper oxide

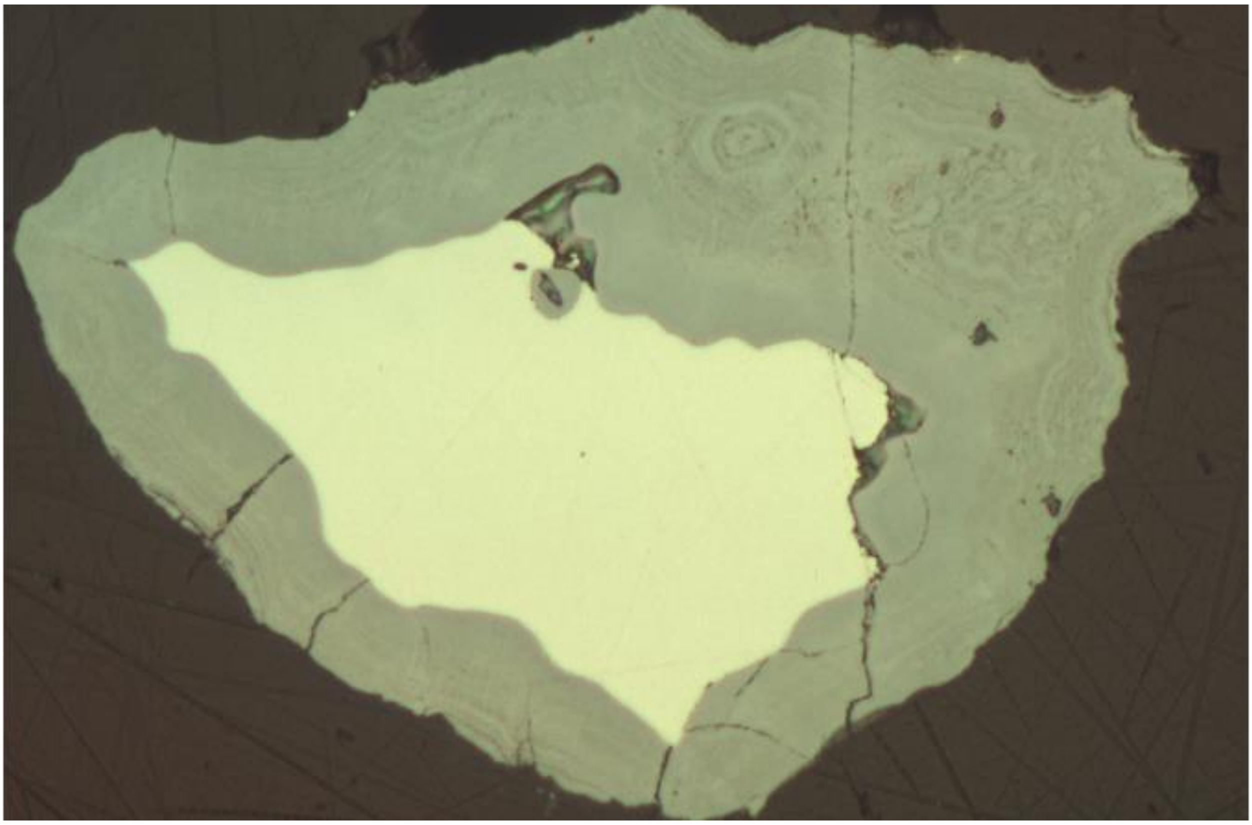


Figure 4.1. Palladseite (white) replaced around the margins by palladinite (grey, finely and rhythmically banded). From Cauê mine, Itabira, Minas Gerais. Reflected plane polarized light digital image from transparency. Field of view: 1.2 mm. Type specimen, BM 1934,72, Natural History Museum, London, England. Photo: Chris J. Stanley

See Figure 2.3.

The name palladinite was introduced for a PdO compound, from Gongo Soco, Barão de Cocais, Minas Gerais. However, the original material analyzed by Johnson and Lampadius (1837) was said to be "*an iron-rich palladium oxidate [palladoxydat] (probably an oxide)*". This paper was referred to by Rammelsberg (1847) under *Palladiumoxydul*. According to Johnson and Lampadius, "*this compound seems to accompany palladian gold, and, being mixed with iron oxide, forms a brown ochreous crust that is soluble in hydrochloric acid*". Jedwab and Cassedanne (1998) note that neither of these two statements are supported by the original literature:

a) the existence of a distinct palladium oxide ("oxydul" was then used for protoxide) is presented as a matter of fact.

b) the palladium oxide is claimed to be a mixture with a mineralogically distinct iron oxide.

Shepard's (1852) description of "palladium-ochre" reads: "*Occurs in very small spherical masses, with a radiated, fibrous structure. Color yellowish, or greyish-white. Blowpipe: acts like telluric acid. Found very rarely at Fauberg and Zalathna, in Siebenburg* [Fata Baii (Facebáj or Facebánya), near Zlatna, Transylvania, Romania]", without reference to Johnson and Lampadius (1837). Jedwab and Cassedanne (1998) consider all this information to be incorrect and is actually a description of tellurite. Shepard (1857) gave the name palladinite to the "palladium-ochre". Adam (1869) supplied the correct reference, but added a chemical formula PdO, disregarding the major iron.

Dana (1857) must be commended, according to Jedwab and Cassedanne (1998), for his remarkable care in his first entry: "*Palladium Ochre - The palladium ochre, which has still a doubtful existence, is called Palladinite by Shepard*", but his stand becomes less critical in 1858: "*A brown ochreous substance associated with the Palladium Gold of Brazil has been considered a Palladium Ochre or oxyd. It is soluble in muriatic acid. Detected by Johnson and Lampadius*" (Dana 1858). Vernadsky (1914) used the name "palladite" for this mineral.

The compound of Johnson and Lampadius (1837) seems to have been verified again in Gongo Soco by Cabral *et al.* (1998): "*An intriguing dark palladium- and iron-rich coating around gold grains suggests some late-stage palladium enrichment*".

According to Jedwab and Cassedanne (1998), PdO is known to exist in the Itabira iron mines, Minas Gerais (Clark *et al.* 1974, Jedwab *et al.* 1993, Olivo and Gauthier 1995), and has a tetragonal X-ray diffraction pattern and a stoichiometric composition, but this compound is not the mineral studied by Johnson and Lampadius (1837).

Palladinite (PdO tetragonal) was identified in a sample of residual concentrates from the gold washings of the Cauê mine, Itabira, Minas Gerais [The Natural History Museum, London, England, sample BM 1934,72, collected by Sanders]. From this sample, the new minerals arsenopalladinite, atheneite, isomertieite, and palladseite were described. Clark *et al.* (1974) observed PdO peaks in the X-ray diffraction pattern of atheneite. In addition, they described a coating of a grey, low-reflecting mineral (similar to hematite), which in crossed polars is strongly anisotropic and frequently associated with hematite. This phase also occurs as a superficial coating on arsenopalladinite grains, which it replaced and penetrated in the form of oriented, parallel, wedge-like plates. Clark *et al.* (1974) reported approximately 90 wt.% PdO and 10 wt.% HgO, and concluded that this mineral is probably a mercurian variety of palladinite.

Jedwab *et al.* (1993) informally proposed that, in the absence of the original Gongo Soco palladinite, the Itabira material should be defined as the new type locality for palladinite. According to them, unpolished grains display a deep black color, whereas polished ones are dark grey, without internal reflections. The formation of palladinite results from the oxidation of arsenides and antimonides (arsenopalladinite and isomertieite) and selenides (palladseite), which are still observed as relics in the palladinite. Palladium selenides alter more readily than arsenides and antimonides, and palladian gold is less prone to alteration. An occurrence of palladinite from Ruwe, Shaba, Zaire was mentioned by the same authors.

Additional data were obtained for palladinite (“palladium-copper oxide”) from “jacutinga” rock samples from the Cauê mine by Olivo *et al.* (1994 and 1995), Olivo and Gauthier (1995), and Olivo and Gammons (1996). According to Olivo and Gauthier (1995) the grains are medium to dark grey, darker than hematite, slightly anisotropic and without internal reflections in plane-polarized light in air or oil immersion. The grains are euhedral, finely-zoned, coated with films of gold, and commonly do not exceed 100 μm. Zoning is characterized by the alternation of dark-colored zones (high Pd/Cu ratios) with light areas (low Pd/Cu ratios). The Hg content is high in the cores (up to 1.42 wt.%) and diminishes toward the edges of the grains (Hg < 0.1 wt.%). Se and Sb contents are low (< 0.1 wt.%) and vary independently of the zone color and position in the grain (core or rim). Several wavelenght-dispersive analyses by electron microprobe were obtained by Olivo and Gauthier (1995), and Olivo *et al.* (1995) presented averages of two analyses for both dark and light bands. Dark zone: PdO 93.06, CuO 4.99, HgO 0.26, AuO 0.44, Fe_2O_3 1.19, SeO_2

0.08, Sb_2O_5 0.04, Total 100.06 wt.%. Light zone: PdO 89.13, CuO 6.90, HgO 1.13, AuO 0.31, Fe_2O_3 0.82, SeO_2 0.03, Sb_2O_5 0.04, Total 98.36 wt.%. Dark zone: $(Pd_{0.89}Cu_{0.07}Fe_{0.02})_{\Sigma 0.98}O$. Light zone: $(Pd_{0.87}Cu_{0.10}Fe_{0.01}Hg_{0.01})_{\Sigma 0.99}O$.

A complete mineralogical description of palladinite is still lacking in the literature, but Jedwab and Cassedanne (1998) note that this mineral "is in process of revalidation". The following description of palladinite is from unpublished data by Alan Criddle, Chris J. Stanley, Jacques Jedwab, and Paul Piret (with permission by Chris J. Stanley):

Occurrence. In gold-rich jacutinga (a hydrothermally-altered Lake Superior-type carbonate-bearing oxide facies iron-formation), originally recovered from residual concentrates from the gold washings, from Cauê iron mine, Itabira, Minas Gerais [The Natural History Museum, London, England; sample BM 1934, 72, collected by Sanders], associated with hematite, gold, palladian gold ("porpezite"), palladseite, arsenopalladinite, isomertiete, atheneite, and other minerals.

Appearance and physical properties. As individual grains and alteration crusts on gold, palladseite and arsenopalladinite. Color: Black, bluish-gray. Streak: black. Luster: metallic. Opaque. Cleavage: not observed. Fracture: not observed. Density: 8.209 g/cm^3 (calc.). In one part of the unpublished text, the authors cited: "VHN values varied from 220 to 680 units with a mean of 494" and in another: "VHN: 448/626 units". Tenacity: very brittle.

Optical properties. In reflected light: bluish-steel gray and zoned. Bireflectance: week to moderate. Pleochroism: week. Rmax & Rmin (air): (28.7, 25.9) 470 nm; (27.6, 25.5) 546 nm; (26.4, 24.6) 589 nm; (25.2, 23.7) 650 nm. In polished mount, the appearence in reflected plane-polarized light is to some extent determined by the mineral association. In general, the mineral is pale, somewhat bluish-gray, and of lower reflectance, bireflectance and anisotropy than hematite. Many of the arsenopalladinite and palladseite grains in the Sanders' concentrate are replaced in part by palladinite. However, one large (250 μm) inhomogeneous grain of palladinite was found in the concentrate. It is microgranular, with crystallites up to 4-5 μm in size, and is moderately bireflectant and pleochroic from pale blue gray to gray. Reflectance measurements in air and in immersion oil gave spectra that are consistent with a very weakly pleochroic mineral of modest bireflectance. The dispersion of the reflectance differs from that of hematite which is about 4% higher reflecting at the blue end of the spectrum.

Chemical data. Microprobe (WDS mode) analyses (mean of 5 sets): PdO 89.93, CuO 4.54, HgO 2.19, FeO 0.07, total 96.73 wt.%. Empirical formula: $(Pd_{0.82}Cu_{0.07}Hg_{0.01})_{\Sigma 1.00}O$. Quantitative analyses show the presence of Pd, Cu and Hg, and variable presence of Fe and Se. The resulting totals are generally too low, possibly due to the high porosity of the mineral or to the presence of water in the structure. Indeed, compounds with the formula $PdO \cdot xH_2O$ has been synthesized (Glemser and Peuschel 1955).

Crystallography. Tetragonal, $P4_2/mmc$, *a* 2.997(1), *c* 5.3245(2) Å, *V* 47.825 Å^3, Z 2, *c:a* = 1.777. X-ray powder diffraction data [*d* in Å *(I)* (*hkl*)]: 2.993 (5) (100), 2.679 (20) (002), 2.611 (100) (101), 2.120 (20) (110), 1.660 (30) (112), 1.527 (20) (103), 1.498 (15) (200), 1.329 (5) (004), 1.301 (25) (202), 1.129 (5) (114), 1.071 (10) (213). These data were obtained on a powder from black crusts separated by gentle crushing of the grains. A comparison of the experimental X-ray diffraction data of palladinite from Itabira with those of the standard synthetic PdO shows close similarity between the two sets and their relative intensities. However, a general shift of the Itabira palladinite peaks toward smaller *d* spacings is observed and shows that this is more similar to that of the synthetic compound $PdO \cdot xH_2O$, suggesting that the mineral may be hydrated. Glemser and Peuschel (1955) synthesized the compound $PdO \cdot xH_2O$ with varying H_2O concentrations. Cell parameters for Itabira palladinite suggest between 2 and 6 wt.% H_2O.

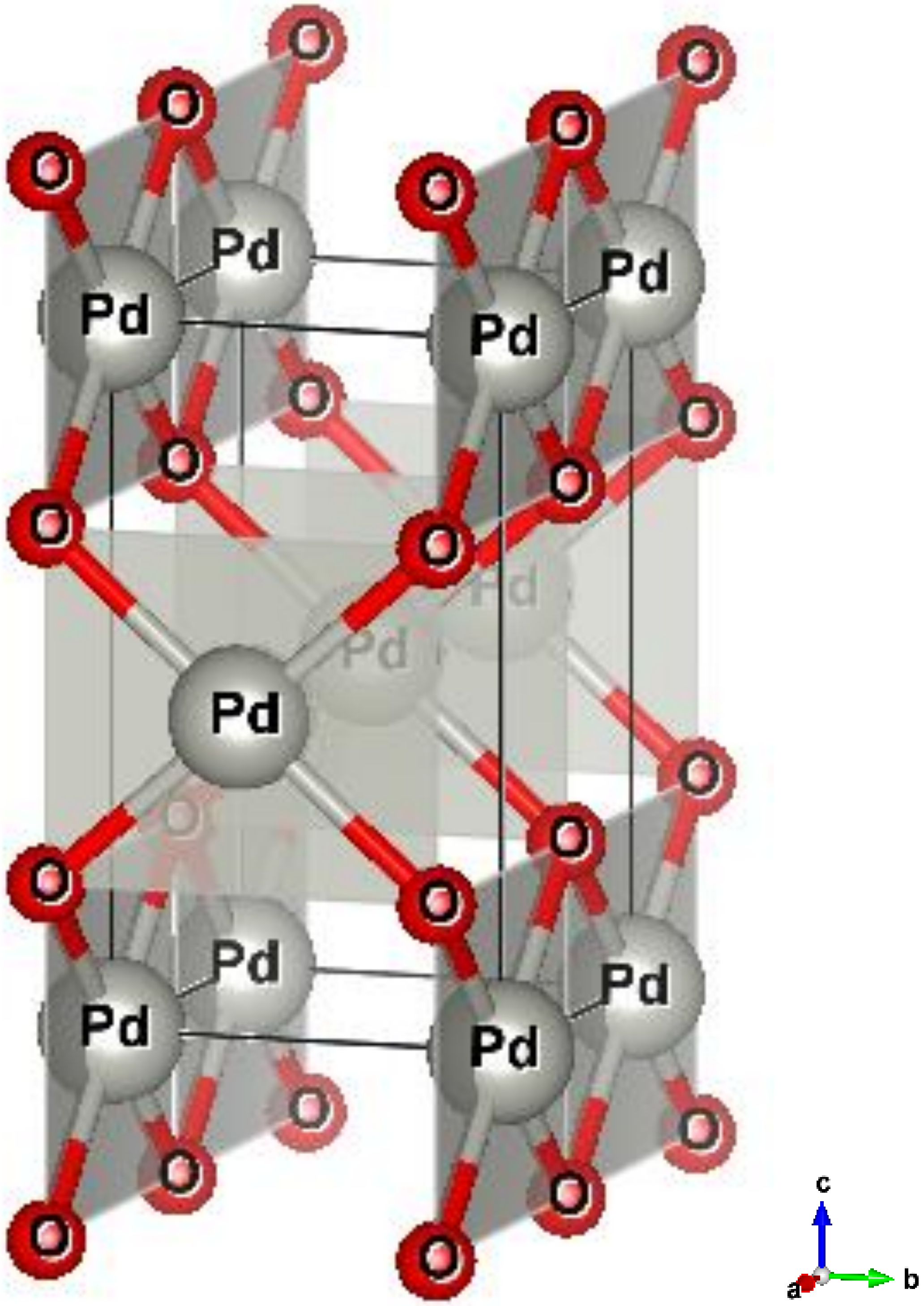


Figure 4.2. View of the crystal structure of palladinite (synthetic), drawn using VESTA 3 (Momma and Izumi 2011). Data from Waser *et al.* (1953).

Crystal structure. Based on neutron and X-ray diffraction data, the unit cell of PdO is confirmed to be formed by 2Pd at 0, 0, 0; ½, ½, ½ and 2O at ½, 0, 1/4; ½, 0, 3/4 (Waser *et al.* 1953). Each oxygen atom is bound to four palladium atoms at the corners of a nearly regular tetrahedron, and each palladium atom forms four coplanar bonds to oxygen atoms at the corners of the rectangle (Niu *et al.* 1990)

See also. Unnamed copper-bearing palladium oxides, isotropic, $Pd_5(Cu,As)O_3$, $Pd(OH)_2$, $PdO \cdot H_2O$, (Pd,Cu,Mn,Hg)O, and Pd-O-H, oxygen-deficient Pd-O, Pd-oxides, Pd_9O_5, Pd_8O_3, $Cu_5Pd_4O_9$ to $Cu_{5.5}Pd_{4.5}O_9$, $Pd_{2.5}O_2$ to Pd_3O_2, oxygen-bearing compounds of Pt-Pd-Au-Cu-Fe-Mn, arsenopalladinite, atheneite, isomertierite, palladseite, and porpezite.

Unnamed Pd_9O_5

Cabral *et al.* (2002d)

Other names: UM2002-03-O:AuHgPd

This palladium oxide occurs as an alteration halo on Pd-arsenide from the Serra Pelada Au-Pd-Pt deposit, Curionópolis, Carajás mineral province, Pará (Cabral *et al.* 2002d). Microprobe data: Pd 78.09, Se <0.20, Au 7.17, Pt <0.20, Cu 0.19, Hg 4.45, Fe <0.03, Mn 1.10, Cl 0.08. O 7.31, total 98.39. Empirical formula: $(Pd_{8.03}Au_{0.39}Hg_{0.24}Mn_{0.22}Cu_{0.03})_{\Sigma 8.91}O_{5.00}Cl_{0.02}$. Simplified formula: Pd_9O_5.

See also. Palladinite, unnamed copper-bearing palladium oxides, isotropic, $Pd_5(Cu,As)O_3$, $Pd(OH)_2$, $PdO \cdot H_2O$, (Pd,Cu,Mn,Hg)O, Pd-O-H, Pd-oxides, Pd_8O_3, $Cu_5Pd_4O_9$ to $Cu_{5.5}Pd_{4.5}O_9$, $Pd_{2.5}O_2$ to Pd_3O_2, and oxygen-deficient Pd-O.

Unnamed Pd_8O_3

Cabral *et al.* (2002d)

Other names: UM2002-11-O:PdPtSe

This palladium oxide occurs as an alteration halo on Pd-Pt-Se phase from the Serra Pelada Au-Pd-Pt deposit, Curionópolis, Carajás mineral province, Pará (Cabral *et al.* 2002d). Microprobe data (mean of 3): Pd 67.01, Se 4.01, Au <0.20, Pt 19.70, Cu 0.10, Hg 0.98, Fe 0.23, Mn 0.94, Cl 0.02. O 4.98, total 97.97. Empirical formula: $(Pd_{6.10}Pt_{0.98}Se_{0.49}Mn_{0.16}Hg_{0.05}Fe_{0.04}Cu_{0.02})_{\Sigma 7.84}O_{3.00}$. Simplified formula: Pd_8O_3.

See also. Palladinite, unnamed copper-bearing palladium oxides, isotropic, $Pd_5(Cu,As)O_3$, $Pd(OH)_2$, $PdO{\cdot}H_2O$, (Pd,Cu,Mn,Hg)O, Pd-O-H, Pd-oxides, Pd_9O_5, $Cu_5Pd_4O_9$ to $Cu_{5.5}Pd_{4.5}O_9$, $Pd_{2.5}O_2$ to Pd_3O_2, and oxygen-deficient Pd-O.

Unnamed $Cu_5Pd_4O_9$ to $Cu_{5.5}Pd_{4.5}O_9$

Cabral *et al.* (2002d)

Other names: UM2002-08-O:CuPd

This Pd-Cu-O phase occurs in association with mertieite-II at the Elefante Prospect, Curionópolis, Carajás mineral province, Pará (Cabral *et al.* 2002d). Microprobe data: (1) Pd 47.11, Se n.a, Au n.a., Pt n.a., Cu 34.74, Hg <0.20, Fe 0.30, Mn 0.02, Cl 0.06. O 16.29, total 98.52. Empirical formula: $Cu_{4.84}Pd_{3.92}Fe_{0.04}O_{9.00}Cl_{0.02}$. Simplified formula: $Cu_5Pd_4O_9$. (2) Pd 48.52, Se n.a, Au n.a., Pt n.a., Cu 34.76, Hg <0.20, Fe 0.38, Mn 0.03, Cl 0.10. O 14.58, total 98.37. Empirical formula: $Cu_{5.40}Pd_{4.50}Fe_{0.07}O_{9.00}Cl_{0.03}$. Simplified formula: $Cu_{5.5}Pd_{4.5}O_9$.

See also. Palladinite, unnamed copper-bearing palladium oxides, isotropic, $Pd_5(Cu,As)O_3$, $Pd(OH)_2$, $PdO{\cdot}H_2O$, (Pd,Cu,Mn,Hg)O, Pd-O-H, Pd-oxides, Pd_8O_3, Pd_9O_5, $Pd_{2.5}O_2$ to Pd_3O_2, and oxygen-deficient Pd-O.

Unnamed $Pd_{2.5}O_2$ to Pd_3O_2

Cabral *et al.* (2002d)

Native palladium from the Serra Pelada Au-Pd-Pt deposit, Curionópolis, Carajás mineral province, Pará, characteristically occurring in the goethite coating, is intimately associated with a Pd-O phase (Cabral *et al.* 2002d). Microprobe data: (1) Pd 80.15, Se <0.20, Au 3.50, Pt <0.20, Cu 1.75, Hg 1.74, Fe 0.08, Mn 2.59, Cl 0.16. O 9.11, total 99.08. Empirical formula: $(Pd_{2.64}Mn_{0.16}Cu_{0.10}Au_{0.06}Hg_{0.03})_{\Sigma 2.99}O_{2.00}Cl_{0.02}$. Simplified formula: Pd_3O_2. (2) Pd 80.00, Se <0.20, Au 2.21, Pt <0.20, Cu 1.36, Hg 0.60, Fe 0.17, Mn 3.66, Cl 0.46. O 11.29, total 99.75. Empirical formula: $(Pd_{2.13}Mn_{0.19}Cu_{0.06}Au_{0.03}Hg_{0.01}Fe_{0.01})_{\Sigma 2.47}O_{2.00}Cl_{0.04}$. Simplified formula: $Pd_{2.5}O_2$.

See also. Palladinite, unnamed copper-bearing palladium oxides, isotropic, $Pd_5(Cu,As)O_3$, $Pd(OH)_2$, $PdO·H_2O$, (Pd,Cu,Mn,Hg)O, Pd-O-H, Pd-oxides, Pd_8O_3, Pd_9O_5, $Cu_5Pd_4O_9$ to $Cu_{5.5}Pd_{4.5}O_9$, and oxygen-deficient Pd-O.

Unnamed oxygen-deficient Pd-O

Cabral and Lehmann (2003), Cabral and Kwitko-Ribeiro (2004)

Other names: UM2003-12-O:Pd

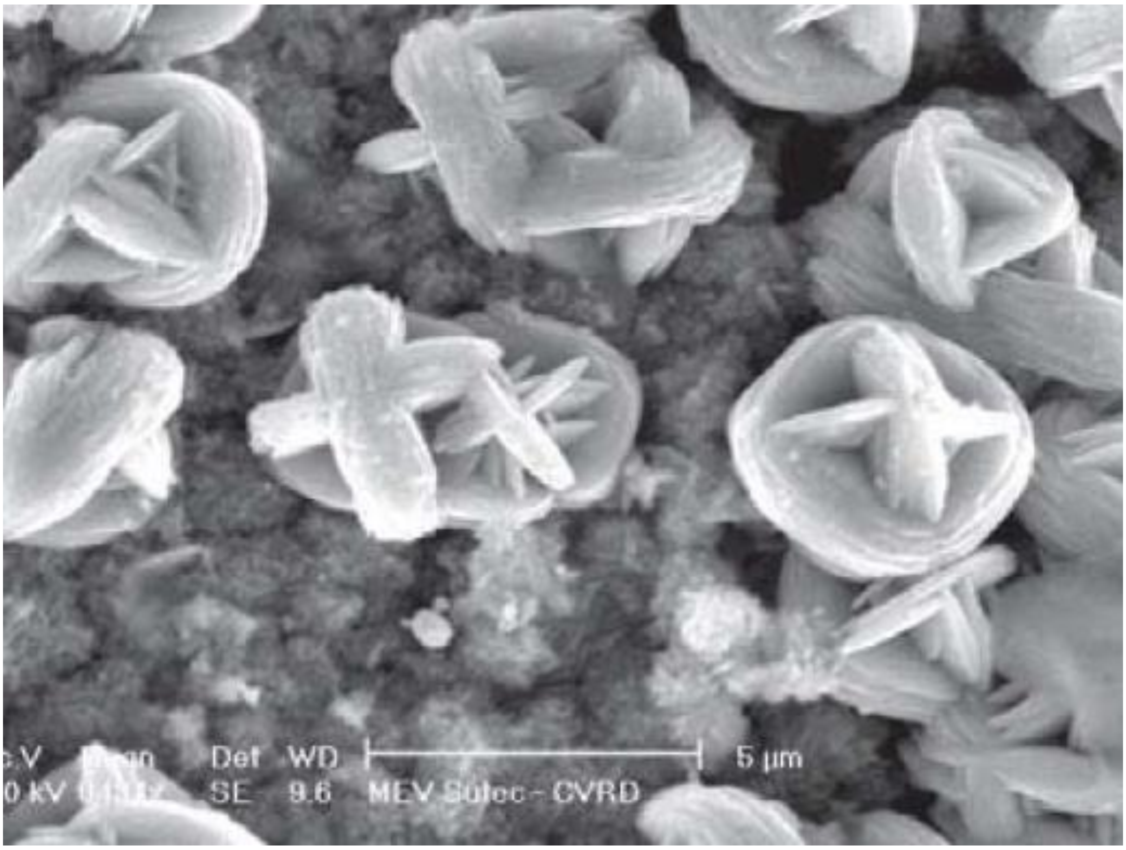


Figure 4.3. SEM images of the Pd-O compound rosettes from Cauê mine, Itabira, Minas Gerais (Kwitko *et al.* 2002).

Rosettes of a Pd-O compound occur at Cauê mine, Itabira, Minas Gerais, and at Gongo Soco, Barão de Cocais, Minas Gerais (Cabral and Kwitko-Ribeiro 2004). The rosettes from Itabira were erroneously described as “native palladium” by Kwitko *et al.* (2002), because oxygen was recognized, but attributed to the subjacent iron oxyhydroxide. At Gongo Soco, Dear friends, This is the link to download my new book, Type Mineralogy of Brazil: a book in progress for free. All the best, Daniel found native palladium derived from Pd–O masses that formed at the expense of a pre-existing arsenide–antimonide of palladium. The Pd-rich rosettes described at Gongo Soco differ from that from Itabira because no relics of a primary Pd–Sb–As mineral were detected. Instead of a primary PGM (platinum-group mineral), the rosettes seem to have crystallized as a Pd–O phase that precipitated directly from aqueous solution. Deoxygenation and dewatering at low temperatures could be responsible for the crystallization of native palladium from Pd–O precipitates. Quantitative electron-microprobe analyses of the Gongo Soco rosettes were hampered by the small grain-size (<2 μm). However, electron-microprobe analyses of Pd–O alteration halos on arsenide–antimonide of palladium indicate the existence of an oxygen-deficient Pd–Cu phase (Cabral *et al.* 2003) and a significant negative linear correlation between oxygen and palladium (Cabral and Lehmann 2003), suggesting a transitional range from an empirically derived PdO-like stoichiometry to native palladium, where native palladium would likely be the stable phase of palladium under supergene conditions (Cabral *et al.* 2004). It was not possible to define whether the Pd-rich rosettes are true PdO (or a palladium hydroxide or hydrated compound) or an oxygen-deficient phase close to native palladium. Whatever the case, this study gives evidence for the neoformation of PGM at low temperatures. Possibly, the Pd-rich rosettes are supergene in origin, formed under oxidizing conditions (stability field of hematite) (Cabral and Kwitko-Ribeiro 2004).

See also. Palladinite, unnamed copper-bearing palladium oxides, isotropic, $Pd_5(Cu,As)O_3$, $Pd(OH)_2$, $PdO \cdot H_2O$, (Pd,Cu,Mn,Hg)O, Pd-O-H, Pd-oxides, Pd_8O_3, Pd_9O_5, $Cu_5Pd_4O_9$ to $Cu_{5.5}Pd_{4.5}O_9$, and $Pd_{2.5}O_2$ to Pd_3O_2.

Unnamed $Pd(OH)_2$, $PdO \cdot H_2O$, (Pd,Cu,Mn,Hg)O, and Pd-O-H

Cabral *et al.* (2001 and 2004)

Several PdO species are documented from Gongo Soco, Barão de Cocais, Minas Gerais, always in association with Cu, Fe, Mn and Hg, and includes $Pd(OH)_2$ or $PdO \cdot H_2O$, and phases with metal excess in relation to oxygen, interpreted as metastable (Cabral *et al.* 2001).

Hydrogen determined in an unnamed Pd-O-H phase from Gongo Soco, Barão de

Cocais, Minas Gerais, is lost during extended analysis, and unstable compared to goethite. This fact would explain why such compound is deficient in oxygen, eventually giving rise, via a deoxygenation-dehydration process, to native Pd (Cabral *et al.* 2004).

See also. Palladinite, unnamed copper-bearing palladium oxides, isotropic, $Pd_5(Cu,As)O_3$, oxygen-deficient Pd-O, Pd-oxides, Pd_8O_3, Pd_9O_5, $Cu_5Pd_4O_9$ to $Cu_{5.5}Pd_{4.5}O_9$, and $Pd_{2.5}O_2$ to Pd_3O_2,.

Unnamed copper-bearing palladium oxides, isotropic

Davis *et al.* (1977)

Davis *et al.* (1977) observed inclusions in palladseite of two low reflecting minerals, both isotropic, with square outlines in residual concentrates from the gold workings at the Cauê mine, Itabira, Minas Gerais [The Natural History Museum, London, England; sample BM 1934, 72, collected by Sanders]. The lower reflecting grey phase encloses rectangular cores of a higher reflecting phase; both are copper-bearing palladium oxides. As they are isotropic they are unlikely to be palladinite (tetragonal). Kumar and Saxena (1989) studied cubic PdO and Pd_2O synthetic compounds. Cu-Pd oxides (Cu_2PdO_3 and $Cu_5Pd_2O_7$) were described from Broken Hill, Australia (Dennis *et al.* 1994), but their optical properties were not given. The occurrence of $Pd_5(Cu,As)O_3$ was noted from the Maquiné gold mine, Passagem de Mariana, Mariana Co., Minas Gerais.

See also. Palladinite, unnamed $Pd_5(Cu,As)O_3$, $Pd(OH)_2$, $PdO{\cdot}H_2O$, (Pd,Cu,Mn,Hg)O, Pd-O-H, Pd-oxides, oxygen-deficient Pd-O, Pd_8O_3, Pd_9O_5, $Cu_5Pd_4O_9$ to $Cu_{5.5}Pd_{4.5}O_9$, and $Pd_{2.5}O_2$ to Pd_3O_2.

Unnamed $Pd_5(Cu,As)O_3$

Varajão (1994)

Other names: undefined Pd-Cu phase

This oxide (Varajão 1994, Varajão *et al.* 1998, 1999, 2000) was described in itabirite from the Maquiné gold mine, Passagem de Mariana, Mariana Co., Minas Gerais, associated with palladian gold, stibiopalladinite, isomertieite, and sperrylite. It occurs as anhedral grains up to 70 μm, at the surface of Ag-Pd-bearing gold particles hosted in a hematite-quartz rich matrix (parental itabirite). These phases can be also accompanied by kaolinite crystallites and by an Al-Bi-bearing phosphate phase. Chemical analyses were obtained by electron microprobe (wt.%): Pd 77.00, Cu 10.17, As 1.13, O 7.60, total 95.90 corresponding to the empirical formula $Pd_{4.74}Cu_{1.05}As_{0.10}O_{3.11}$, with the ideal formula $Pd_5(Cu,As)O_3$.

See also. Palladinite, isomertieite, unnamed copper-bearing palladium oxides, isotropic, $Pd(OH)_2$, $PdO{\cdot}H_2O$, (Pd,Cu,Mn,Hg)O, Pd-O-H, oxygen-deficient Pd-O, Pd-oxides, Pd_8O_3, Pd_9O_5, $Cu_5Pd_4O_9$ to $Cu_{5.5}Pd_{4.5}O_9$, and $Pd_{2.5}O_2$ to Pd_3O_2,.

Unnamed Pd-Cu-O compounds
(Mota-e-Silva *et al*. 2016)

Unnamed Pd-Cu-O compounds with formulae $(Pd,Cu,Fe)O_2$ and (Pd,Cu,Fe)O (Mota-e-Silva *et al*. 2016) occur in gossans developed on a Ni-Cu(-PGE) deposit in Limoeiro, Pernambuco, associated with goethite, sperrylite, irarsite, hollingworthite, unnamed Pd-Te±Bi phases [$Pd_3(Te,Bi)$, $Pd(O,Te,Bi)_2$, $(Pd,Fe,Cu)(O,Te)_2$, and Fe,Pd,Pt-O], unnamed Pd-I-O phases [$Pd(O,I)_2$, $(Pd,Fe)(O,I)_2$, and Fe,Pd,I-O], and an unnamed Fe-Pt-Rh-O phase. Both saprolite and gossan host partly oxidized Pd-Cu-O compounds in the shallow environment (< 7m). These Pd-Cu phases replace the partially oxidized Pd-Te±Bi phases suggesting a continuum of alteration from the pristine merenskyite to Pd-Cu-O compounds in the Limoeiro supergene zone. Analogous to the Pd-Te±Bi phases, the Pd-Cu-O compounds occur mixed with goethite that is replacing merenskyite. The whole merenskyite alteration area including the Pd-Cu-O compounds, voids and goethite, ranges from $2µm^2$ to $2330µm^2$ with an average of $435µm^2$. These dimensions are very similar to those reported for merenskyite grains in the fresh massive sulfide ore and for the pseudomorphs filled with Pd-Te±Bi in the gossans. The degree of Pd-Te±Bi replacement by Pd-Cu-O compounds is variable. Relict tellurides partially replaced by Pd-Cu-O compounds and Fe-oxides appear strongly leached in open spaces or very porous areas of the samples. A less advanced replacement is proposed for smaller grains better protected by the enclosing goethite. These have patchy Pd-Cu-alloys occupying larger areas of the grains along with more consolidated masses of goethite. In most cases, however, goethite largely pseudomorphs precursor merenskyite and Pd-Cu aggregates are sparse. In detail, these goethite crusts are coated by tiny Pd-Cu crystals able to coalesce and eventually form an almost continuous crystal surface. Under high magnification, these Pd-Cu crystals show diverse habits suggesting a sequential crystal growth. They occur (i) in a globular habit, as Pd-Cu microspheres displaying a central axis, (ii) in a radial habit, with crystals diverging from the center, and (iii) in a rosette-like habit, with tabular crystals often in an "X" shape or as a combination of several forms. Pd-Cu rosettes mainly coat goethite in merenskyite pseudomorphs but they are also located around them, along contacts between crystals or fissures. Less often, they occur growing from goethite in voids lacking Pd-Te±Bi. Each rosette has a diameter of about 2 µm and crystal surfaces formed by accreted rosettes are less than 5 µm in length. None of them were large or uniform enough to obtain quantitative analysis clear of interference from their goethite substrate. The patchy Pd-Cu aggregates are also irregular but sometimes reach sizes up to 10 × 10 µm. The analyses achieved on these grains show a rather uniform composition close to "(Pd,Cu,Fe)O", with elevated Pd and Cu (Pd 61–70, Cu 8–14 wt.%), moderate oxygen (18–22 wt.%) and low Fe (0–4 wt.%) and Bi (0–1 wt.%). Compared to precursor Pd-Te, Pd-Cu grains contain similar or even higher Pd values but reflect a sharp increase in Cu up to 16 wt.% and almost a complete loss of Te and Bi (Mota-e-Silva 2014).

See also. Palladinite, unnamed copper-bearing palladium oxides, isotropic, $Pd_5(Cu,As)O_3$, $Pd(OH)_2$, $PdO{\cdot}H_2O$, (Pd,Cu,Mn,Hg)O, Pd-O-H, Pd_8O_3, Pd_9O_5, $Cu_5Pd_4O_9$ to $Cu_{5.5}Pd_{4.5}O_9$, $Pd_{2.5}O_2$ to Pd_3O_2, oxygen-deficient Pd-O, $Pd_3(Te,Bi)$, $Pd(O,Te,Bi)_2$, $(Pd,Fe,Cu)(O,Te)_2$, Fe,Pd,Pt-O, $Pd(O,I)_2$, $(Pd,Fe)(O,I)_2$, Fe,Pd,I-O phases, and Fe-Pt-Rh-O phase.

Unnamed $Pd(O,I)_2$, $(Pd,Fe)(O,I)_2$, and Fe,Pd,I-O phases

(Mota-e-Silva *et al.* 2016)

Other names: Unnamed (Pd-I-O Compound)

Unnamed Pd-I-O compounds, including $Pd(O,I)_2$, $(Pd,Fe)(O,I)_2$, and Fe,Pd,I-O phases occur in gossans developed on a Ni-Cu(-PGE) deposit in Limoeiro, Pernambuco, associated with goethite, sperrylite, irarsite, hollingworthite, unnamed Pd-Cu-O compounds, $Pd_3(Te,Bi)$, $Pd(O,Te,Bi)_2$, $(Pd,Fe,Cu)(O,Te)_2$, and Fe,Pd,Pt-O, and an unnamed Fe-Pt-Rh-O phase. The Pd-I-O compound occurs as single, small, and euhedral crystals ranging in area from 0.4 to 8.8 µm^2, and in one case appears to be replacing a relatively large euhedral mineral producing a pseudomorph 40 µm in diameter. Analyses of the largest and freshest grain (~5 µm in the longest dimension) reveal a composition of Pd 37, Fe 2, I 52, and O 9 wt.% that resembles a ‘‘Pd(O,I)$_2$’’ phase. Other grains yielded a similar composition with different proportions of these four elements including some Cu and S content. The Pd-I-O grains have an inhomogeneous surface, with parts that are more O-rich than others. Additionally, some of the tiny euhedral Pd-I-O grains exhibit corroded crystal faces. EDS analyses of these phases give an average composition of (Pd,Fe,Cu)$_{0.94}$(O,I)$_{2.06}$. The formation of I-rich PGM is a consequence of the dominance of saline groundwaters in the Limoeiro area (Mota-e-Silva *et al*. 2016).

See also. Unnamed Pd$_2$FeI, unnamed Pd-Cu-O compounds, unnamed Pd$_3$(Te,Bi), Pd(O,Te,Bi)$_2$, (Pd,Fe,Cu)(O,Te)$_2$, and Fe,Pd,Pt-O, and an unnamed Fe-Pt-Rh-O phase.

Unnamed Pt–O

Cabral *et al.* (2008), Vymazalová *et al.* (2012)

See Figures 2.13. and 2.14.

This mineral occurs associated with jacutingaite. No additional data were furnished.

See also. Jacutingaite.

Unnamed oxygen-bearing compounds of Pt-Pd-Au-Cu-Fe-Mn

Jedwab (1995)

Other names: ouro preto, black gold, oiro preto, ouro negro, unnamed hematite-looking Pt compound, iron-rich palladium oxidate, Palladoxydat, Unconventional Platinum Group Minerals and Mineraloids, UPGMandM, ouropretoite, Antonil compounds

The first reliable appearance of the name *ouro preto* (= black gold) is found in a report by Antonil (1711): *"As for the various sorts of gold, it is known that the one called ouro preto, because of its surface is colored like unburnt steel, appears with a vivid yolk yellow color when tried under the teeth. It is the finest gold, since it is almost 23 carats."*. The expression *ouro preto* was applied to gold with a dark surface or to the compounds that form this surface. Dark brown to black compounds associated with native gold were discovered in Minas Gerais, three hundred years ago, and have been known since then as *ouro preto* (Jedwab and Cassedanne 1998). During the first decades of the period called “gold cycle”, this gold was found in such abundance that the town of Villa Rica was later renamed Ouro Preto.

Studies of samples from Itabira, Minas Gerais (Jedwab 1995, Jedwab and Cassedanne 1998) demonstrated that the dark surface of *ouro preto* corresponds to a group of oxygen-bearing compounds of Pt-Pd-Au-Cu-Fe-Mn, visually indistinguishable from the coexisting Fe and/or Mn oxides and oxyhydroxides.

Ouro Preto from Timbopeba mine, Ouro Preto, Minas Gerais, was studied by Galbiatti *et al.* (2009). The gold comes from hematite-bearing veins which truncate the host iron formation, i.e. itabirite. Its black color originates from a dark coating consisting of hematite, goethite, and Pd-O phase(s). The Pd-O component of the dark coating occurs on palladium minerals located on the surface of palladiferous gold. The Pd-O coating has desiccation cracks, which represent the early stage of a deoxygenation-dehydration process from a Pd-O-H phase towards native palladium.

Dark brown to black compounds associated with native gold were discovered three hundred years ago in Minas Gerais, and have been known since then as “ouro preto”. Studies by Jedwab (1995) and Jedwab and Cassedanne (1998) of concentrates from the Cauê mine, Itabira, Minas Gerais, proved that ouro preto is composed of a group of oxygen-bearing compounds of Pt-Pd-Au-Cu-Fe-Mn, coexisting with minor Fe-Mn oxides and hydroxides and visually indistinguishable from them. These compounds were correctly determined as oxygen-bearing compounds of Pt-Pd-Fe by Lampadius and Plattner (1833), and Johnson and Lampadius (1837).

Lampadius and Plattner (1833) studied material from the area of “Sabará or Villa Rica”, Minas Gerais and they concluded that platinum could form, in combination with other elements; they state: “*a brittle pulverizable material of a color that resembles that of hematite, and can thus only with difficult be discerned by eye from the latter*”. According to Lampadius and Plattner (1833) the analysis of separate fractions of this unnamed hematite-looking Pt compound corroborates the former assumption and the visual impression that the platinum and its normal associates are not chemically bound to the gold in the studied ore, but instead, that the native argentian gold and the platinum ore occur mingled one close to the other in the iron ore. Considering that the mechanical separation of the gold from the hematite yielded no visible native platinum at all, that on the other hand hematite contained platinum according to the analyses, but that separate crystals of the same were entirely devoid of platinum, according to blow-pipe assay, the following must consequently be assumed: either the platinum occurs in the native state and is very finely dispersed in the iron ore, or it forms in combination with other materials a brittle, pulverizable material, which color resembles that of hematite, and can thus difficultly be discerned by eye from the same (Lampadius and Plattner 1833).

Johnson and Lampadius (1837) described material from Gongo Soco mine, Barão de Cocais, Minas Gerais, as "*an iron-rich palladium oxidate [Palladoxydat] (probably an oxide). We have here, as a matter of interest, the first occurrence of a metal connected with platinum in the oxidized state*". Unfortunately, these papers were misquoted in the literature and led to the erroneous definition of palladinite.

Carvalho da Silva *et al.* (1985), Roeser *et al.* (1989, 1991 and 1992) and Roeser and Schürmann (1990) detected only Fe oxides associated with traces of Cr-Al oxides. According to Roeser *et al.* (1992), "in fact, ouro preto is palladian gold, but the palladium is enclosed by the gold and not in the coating".

According to Jedwab (1995), the oxygen-bearing compounds of Pt-Pd-Au-Cu-Fe-Mn are encrustations deposited on, or included in, the gold grains observed in the heavy mineral concentrates. The gold grains may be associated with palladoarsenide, palladseite, isomertieite, palladinite etc.

The chemical compositions of these compounds are extremely varied, even within the same grain (Table 4.1). Although the presence of oxygen was shown qualitatively in the analytical spectra, only the values for the metals are given in the analyses. The non-metallic character of the described compounds was established either through observation of their color and weak RPM reflectivity, or through their lower apparent atomic number under the SEM compared to the native PGE generally present in the samples. The possible oxygen species, indicated by the presence of O^{2-}, OH^- and/or H_2O, could of course not to be established with the methods used.

Table 4.1. Electron microprobe analyses of oxygen-bearing compounds of Pt-Pd-Au-Cu-Fe-Mn from Cauê mine, Itabira, Minas Gerais (oxygen excluded). (Jedwab 1995).

	1	2	3	4	5
wt.%					
Pt	40.93	80.66	4.29	33.72	0.26
Pd	3.98	2.84	81.02	14.38	9.97
Au	0.35	1.60	n.d.	n.d.	6.03
Cu	0.76	1.30	11.52	4.29	n.d.
Mn	6.26	3.42	1.03	6.85	0.13
Fe	47.66	10.17	2.12	40.74	83.61
atoms %					
Pt	17.05	58.04	2.15	14.04	0.08
Pd	3.04	6.23	74.30	10.96	5.90
Au	0.15	1.29	n.d.	n.d.	1.95
Cu	0.98	5.11	17.74	5.49	n.d.
Mn	9.28	8.35	1.84	10.14	0.15
Fe	69.39	25.15	3.72	59.30	91.87
Number of analyses	3	3	1	1	3

The compounds show very diversified textures and are amorphous to X-rays. Their reflectance is generally weak, but variable (13 to 15 % at 588 nm). The color, the weak reflectance, absence of crystalline structure, and high Fe and/or Mn content would probably lead the uninitiated to classify these compounds as iron or manganese oxi-hydroxides (Jedwab 1995).

A very interesting text about these compounds is from Jedwab (2008):

“ANTONIL COMPOUNDS

About 10 years ago, I took part in a workshop devoted to “Unconventional Platinum Group Minerals” at the MNH-London [22nd. to 25th. August 1999]*, and I chatted briefly with Louis Cabri and the late Alan Criddle about how to designate them with a more precise, less negative- sounding name. Since then, and in recognition of their often and evidently complex and/or mixed composition, I set up a comprehensive web site devoted to*

“Unconventional PG Minerals and Mineraloids-UPGMandM” (//www.ulb.ac.be/sciences/upgm/mguide.

See also: //canmin.geoscienceworld.org/cgi/content/abstract/36/3/887)

Although it became obvious from gathering the literature that these compounds are extremely widespread (in fact, all PGE/PGM deposits are endowed with some UPGMandM, if one looks carefully), it is my contention that these compounds have received very little scientific attention, probably because of a lack of a useable, or at least, a heuristic name.

Naming such diverse members, which we feel are out of the realm of definable mineralogical species and classifications, is a challenging and risky task. Indeed, when a brown PGE-compound is examined under the reflecting light microscope, analyzed under the EMP, or under diffraction, one either gets no X-ray diagram, or only that of native Pt and/or Pd, which it is obviously not. Only 2-3 cases of crystallized palladinite (PdOtetr.) have been recorded. They often contain a lot of minor and trace elements, and we are often left in the dark about O, OH and H_2O*. It is thus absolutely out of question to give a name sounding like a species name: “ouropretoite,” for instance.*

My proposition is to collectively designate this group as “Antonil compounds”, in recognition of Padre Antonil, who was the first to describe in print the black auriferous mineral grains found around 1695-1700 in Minas Gerais, Brazil, and known since then as “ouro preto” (Pt was to be discovered 50 years later, and Pd 100 years).

It is not a mineralogical species name. It has no precise chemical meaning (except for the presence of major PGE-contents), and it has never been used for something else. It does not sound like a mineral name, but like other collective chemical objects (e.g.: Lewis compounds, Laves phases, Tutton's salts) which are of course much better defined.

I should very much appreciate receiving your opinions (pro et contra) about this rather unusual proposition, which I find timely, and which could be the subject of a formal publication in print.

Thanks to all,

Jacques Jedwab
Université Libre de Bruxelles”

See also. Palladinite, palladseite, isomertieite, and porpezite.

Unnamed Pt-Fe-containing black crusts on gold

Eschwege (1833)

According to Eschwege (1833): *"Ouro podre [rotten gold]: Mr. Döbereiner, Court Counsellor at Jena, to whom I sent a small portion of that gold, analyzed it; unfortunately, I lost his result, but I still remember clearly that it contained iron and a little platina."*

Unnamed brown crusts on gold yielding a Pd-reaction

Hussak (1906a, b)

"This palladian gold [from Itabira do Matto Dentro = Itabira, Minas Gerais*] is not rarely covered with a brown earthy, limonitic crust, which proved to be palladium oxide (PdO= palladinite), according to Lampadius. It is easily soluble in hydrochloric acid and yields the characteristical microchemical reactions of P*d." (Hussak 1906a, b).

Unnamed black crusts on Pt "probably due to a Mn-Fe oxide"

Guimarães (1958)

"The black color [of some of the mamillary platinum fragments from Fazenda Limeira (= Limeira farm), Lajes creek [Largos (Lajes) or Ouro Branco river], a tributary of the Santo Antônio river, 6.5 km from Conceição (= Conceição do Mato Dentro), in the district of Morro do Pilar, Minas Gerais*] is surficial, and probably due to an oxide of manganese and iro*n." Guimarães (1958 p. 18) [No analysis].

See also. Palladium and Palladiumplatin.

Unnamed Fe-Pt-Rh-O phase

Mota-e-Silva *et al*. (2016)

Unnamed Fe-Pt-Rh-O phase occur in gossans developed on a Ni-Cu(-PGE) deposit in Limoeiro, Pernambuco, associated with goethite, sperrylite, irarsite, hollingworthite, unnamed Pd-Te±Bi phases, $Pd(O,I)_2$, $(Pd,Fe)(O,I)_2$, and Fe,Pd,I-O phases, and unnamed Pd-Cu-O compounds.

See also. Unnamed $Pd_3(Te,Bi)$, $Pd(O,Te,Bi)_2$, $(Pd,Fe,Cu)(O,Te)_2$, and Fe,Pd,Pt-O, unnamed $Pd(O,I)_2$, $(Pd,Fe)(O,I)_2$, and Fe,Pd,I-O phases, and unnamed Pd-Cu-O compounds.

Unnamed Ru and Ir oxides and hydroxides

Milliotti and Stumpfl (1993)

A complex association of Ru- and Ir-bearing phases was identified by Milliotti and Stumpfl (1993) in the chromitites of Niquelândia, Goiás. They show very low reflectance (~ 15 %, similar to spinel) when compared to the associated platinum-group minerals. The phases are

a) Irregular brownish-gray masses, sometimes with scattered small inclusions of Ir-rich laurite with the composition Ru-Ir-Fe-Cr-Al-Ni and similar grains in native osmium with the composition Ru-Fe-Cr-Ti-Al.

b) Small pseudomorphic, euhedral light-brown crystals (up to 15 μm) in direct contact with chromite: Ru-Ir-Fe-Cr-Al-Ni, Ru-Ir-Fe-Cr-Al, and Ir-Fe-Cr-Al.

c) Light-brown alteration rims on laurite grains, preserving their original euhedral shape: Ru-Ir-Fe-Cr, Ru-Fe-Cr-Al, and Ru-Fe-Cr.

These phases were interpreted as oxides or hydroxides of platinum-group elements, formed at a late stage, probably during laterization. Later on, Milliotti and Stumpfl (1996) also described RuO_4 and Pd_2FeI in these chromitites.

See also. Unnamed Ir-Ni sulfide and undetermined Os-Ir sulfide, unnamed RuO_4 and Pd_2FeI.

Unnamed RuO_4

Milliotti and Stumpfl (1996)

Supergene ruthenium oxide occurs in the chromitites of Niquelândia, Goiás, as alteration rims in Os-rich laurite crystals enclosed by either chromite or goethite. The thickness of these rims varies from 1 to 5 μm depending on the degree of laurite alteration. Completion of the alteration process is indicated by euhedral RuO_4 pseudomorphs after Os-rich laurite in chromite. In reflected light, it is brownish-gray and can be distinguished by its low reflectance, similar to spinel, and isotropic character. The chemical composition approaches RuO_4, with variable content of Ru, Fe and Ir (Table 4.2).

Table 4.2. Electron microprobe for ruthenium oxide (Milliotti and Stumpfl 1996) (wt.%).

Grain #	1	2	3	4	5
Os	n.d.	0.03	1.07	n.d.	1.83
Ru	41.75	41.65	47.43	39.92	44.26
Fe	6.94	7.24	5.83	8.39	6.17
Pt	n.d.	0.66	0.10	0.01	0.04
Rh	0.74	0.56	1.39	0.65	0.98
Cu	0.53	0.54	0.27	0.57	0.16
Ir	9.60	8.94	1.98	8.88	7.48
Pd	n.d.	n.d.	n.d.	n.d.	n.d.
O	39.31	38.26	39.97	43.16	37.54
Total	98.87	97.88	98.04	101.58	98.46

1. $(Ru_{0.68}Fe_{0.20}Ir_{0.08}Rh_{0.01}Cu_{0.01})_{\Sigma 0.98}O_{4.02}$
2. $(Ru_{0.69}Fe_{0.22}Ir_{0.08}Rh_{0.01}Cu_{0.01}Pt_{<0.01})_{\Sigma 1.01}O_{3.99}$
3. $(Ru_{0.76}Fe_{0.17}Ir_{0.02}Rh_{0.02}Pt_{<0.01}Os_{<0.01}Cu_{<0.01})_{\Sigma 0.97}O_{4.02}$
4. $(Ru_{0.60}Fe_{0.23}Ir_{0.07}Rh_{0.01}Cu_{0.01})_{\Sigma 0.92}O_{4.08}$
5. $(Ru_{0.74}Fe_{0.19}Ir_{0.07}Rh_{0.01}Os_{0.01}Pt_{<0.01}Cu_{<0.01})_{\Sigma 1.02}O_{3.97}$

Garuti *et al.* (2002, 2012) also observed (Ru,Fe)-oxide in a heavy mineral concentrate obtained from chromitites of the Niquelândia layered intrusion by the use of hydroseparation technology.

The Niquelândia Complex is a large layered mafic-ultramafic cumulate sequence. A large variety of PGM (platinum-group mineral) inclusions within the chromitites, displaying distinct textures has been documented. Three PGM generations have been suggested by Milliotti and Stumpfl (1996): 1) early magmatic crystallization of Os-rich laurite, erlichmanite, and “iridosmine”, trapped as discrete, crystalline euhedral phases during chromite nucleation; 2) late magmatic crystallization of irarsite and Ir-Pt sulfides, formed in the silicate matrix after chromite crystallization had almost terminated; and 3) supergene formation of RuO_4 and Pd_2FeI, as well as precipitation of Pt-Fe and Os-Fe-Ir alloys from the alteration fluids, during chromite laterization. PGE (platinum-group elements)-bearing goethite, hosting PGM phases, was also documented by Milliotti and Stumpfl (1993).

See also. Iridosmine, unnamed Ru and Ir oxides and hydroxides, unnamed RuO_4 and Pd_2FeI, and unnamed Ir-Ni sulfide and undetermined Os-Ir sulfide.

Chrysoberyl

Werner (in Hoffmann 1789, and Karsten 1789)

$BeAl_2O_4$, orthorhombic

Other names: Krisoberil, Krysoberill, chriso-béril, chrysoberyll, cymophane, Alaunerde + Kieselerde, alumina + silica, cimofana, chrysoberyllo, cymophana, chrysolite, crisólita, crisólita do Brasil, crisólita-do-brasil, crisoberilo

Figure 4.4. Chrysoberyl from Água Branca community, Girau, Araçuaí, Minas Gerais. The largest dimension is 4.5 cm. Specimen: Edson Ferreira dos Santos. Photo: Daniel Atencio.

According to Leonardos (1970), it is probable that the chrysoberyl analyzed by Klaproth (1795) [alumina 71, silica 18, lime 6, oxide of iron 1.5, loss 3, total 99.5 wt.%] was from Brazil. In fact, chrysoberyl is $BeAl_2O_4$, but at that time beryllium had not been isolated. The gem, known in Brazil as chrysolite and classified by Werner (in Hoffmann 1789, and Karsten 1789) as chrysoberyl (Krisoberil), had been known since the middle of the 18th century from alluvium in northern Minas Gerais [especially in the area of Araçuaí, old Calhau, Minas Gerais (Leonardos 1945)], associated with colorless and blue topaz, aquamarine, tourmaline, and garnet. According to Hoffmann (1789), "*Chrysoberyl is characterized by its green asparagus color and is most commonly found in round grains. At the moment, it is only available in Brazil*". The name chrysolite was used by Romé de l'Isle (1772) for the gem variety of olivine, but, apparently, both de l'Isle and Werner confused the gem names of antiquity. Chrysolite or "gold stone" of Pliny probably was topaz, and chrysoberyl of antiquity, as the name indicates, was golden beryl. Klaproth (1795) simply designated chrysoberyl as Alaunerde + Kieselerde (alumina + silica). Haüy (1795) gave it the name cymophane. Nevertheless, the name chrysoberyl prevailed and Seybert (1824) obtained a correct analysis showing it to be a beryllium mineral.

According to Ferraz (1928), "chrysoberyllo or cymophana" occurs in quarries in Minas Gerais (Lufa stream and Gravatá river, in the NE part of the state; in the vicinity of Araçuaí; in the Urubu creek; Piauí river, Minas Novas; Calhau, Neves and Serro), in São Paulo (Canoas river), and in Espírito Santo (Colatina, Doce river).

Gem varieties include gem chrysoberyl in shades of light yellow, green and brown; alexandrite which shows color change from daylight to artificial light; cat's eye, a chatoyant yellow or green variety with oriented acicular inclusions; and cat's eye alexandrite.

Occurrence. It is widespread and found in granitic pegmatites and aplites, mica schists, rarely in dolomitic marble and fluorine-rich veins. Associated minerals include garnet, spinel, beryl, phenakite, corundum, tourmaline, columbite, gahnite, and apatite. Often found as a detrital mineral with diamond, corundum, garnet, and cassiterite. The type locality is unknown, but probably is Araçuaí, Minas Gerais (Leonardos 1970). Also, known from countless Brazilian and world occurrences.

Appearance and physical properties. Habit: usually occurs as tabular crystals on {100} or short prismatic along [001]. Forms: {100}, {010}, {011}, {110}, {120}, {130}, {101}, {111}, {121}; less common {001}, {021}, {230}, {211}, {122}; tabular on {100}, also short prismatic [001] or [100]; striated on {100} parallel to [001]. Twinning: common, with twin plane {031} and flattened perpendicular to the composition plane; contact and penetration twins, sometimes forming pseudohexagonal crystals. Color: various shades of green, yellow, greenish-brown, greenish-black, sometimes green or blue in daylight and red or brownish-pink in incandescent light (variety, alexandrite). Streak: white. Nonfluorescent, except for the alexandrite variety which fluoresces red. Luster: vitreous. Transparent or translucent, may be opaque and chatoyant with oriented inclusions. Hardness (Mohs): 8½. Tenacity: brittle. Cleavage: {011} distinct, {010} imperfect, {100} poor. Fracture: uneven to conchoidal. Density: 3.75 g/cm^3 (meas.), 3.78 g/cm^3 (calc.).

Optical properties. Biaxial (+), α 1.746, β 1.748, γ 1.756, 2*V* 70° (meas.), 53° (calc.). Dispersion: $r > v$. Pleochroism: generally absent or weak, but strong in alexandrite, with *X* reddish-purple, *Y* orange, *Z* green. Orientation: $X = a$, $Y = b$, $Z = c$.

Chemical data. BeO 19.15, FeO 3.60, Al_2O_3 76.34, TiO_2 0.55, total 99.64 wt.%. Empirical formula: $Be_{1.00}(Al_{1.95}Fe_{0.07}Ti_{0.01})_{\Sigma 2.03}O_{4.00}$. The ideal formula requires BeO 19.70, Al_2O_3 80.30, total 100.00 wt.%.

Crystallography. Orthorhombic, *Pbnm*, *a* 4.429, *b* 9.413, *c* 5.480 Å, *V* 228.46 Å^3, Z 4, *a*:*b*:*c* = 0.4705:1:0.5822. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 3.2345 (37) (111), 2.5609 (65) (130), 2.3199 (37) (131), 2.2622 (41) (112), 2.0884 (83) (122), 2,0779 (34) (140), 1.6175 (100) (222), 1.6129 (95) (240), 1.4645 (41) (152), 1.3614 (58) (062). [sample from Minas Gerais].

Name. From Greek *chrysos* (gold) and *beryllos* (beryl).

Type material. No precise information on the type occurrence of chrysoberyl or the whereabouts and description of the type material is available.

Relationship to other species. Structurally related to olivine.

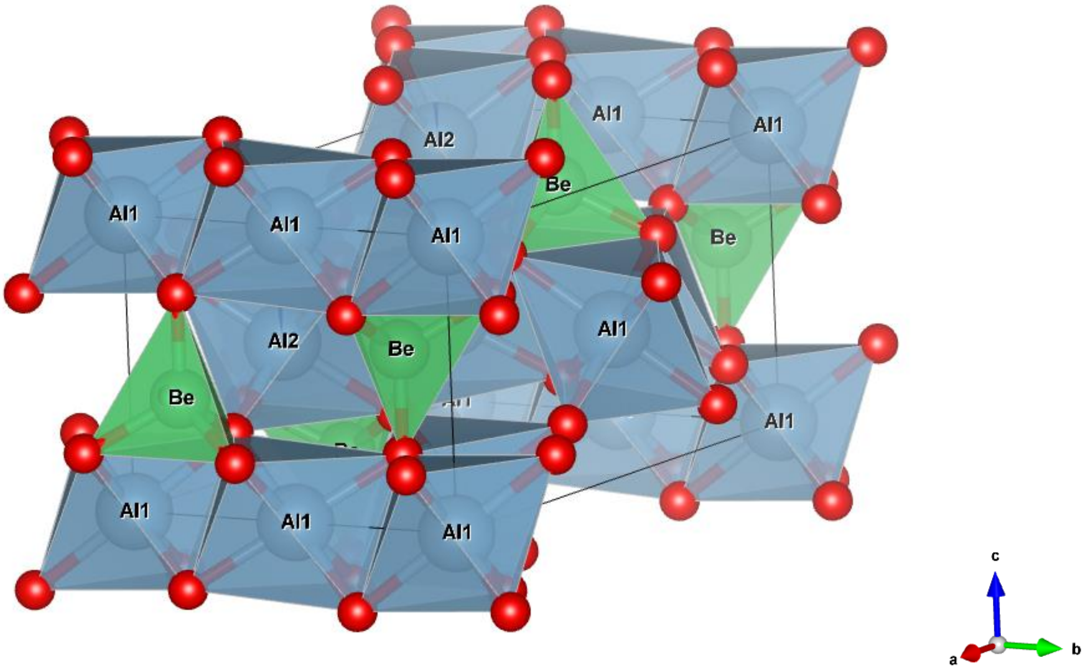


Figure 4.5. View of the crystal structure of chrysoberyl (from Malyshevo near Terem Tschanka, Sverdlovsk, Ural, Russia), drawn using VESTA 3 (Momma and Izumi 2011). Data from Weber *et al.* (2007).

Crystal structure. Edge- and corner-sharing AlO_6 octahedra are connected into a framework by isolated BeO_4 tetrahedra; olivine structure type (Farrell *et al.* 1963).

Unnamed orthorhombic MgO

Kaminsky *et al.* (2015)

MgO, orthorhombic

Other names: Unnamed (Orthorhombic Polymorph of Magnesium Oxide)

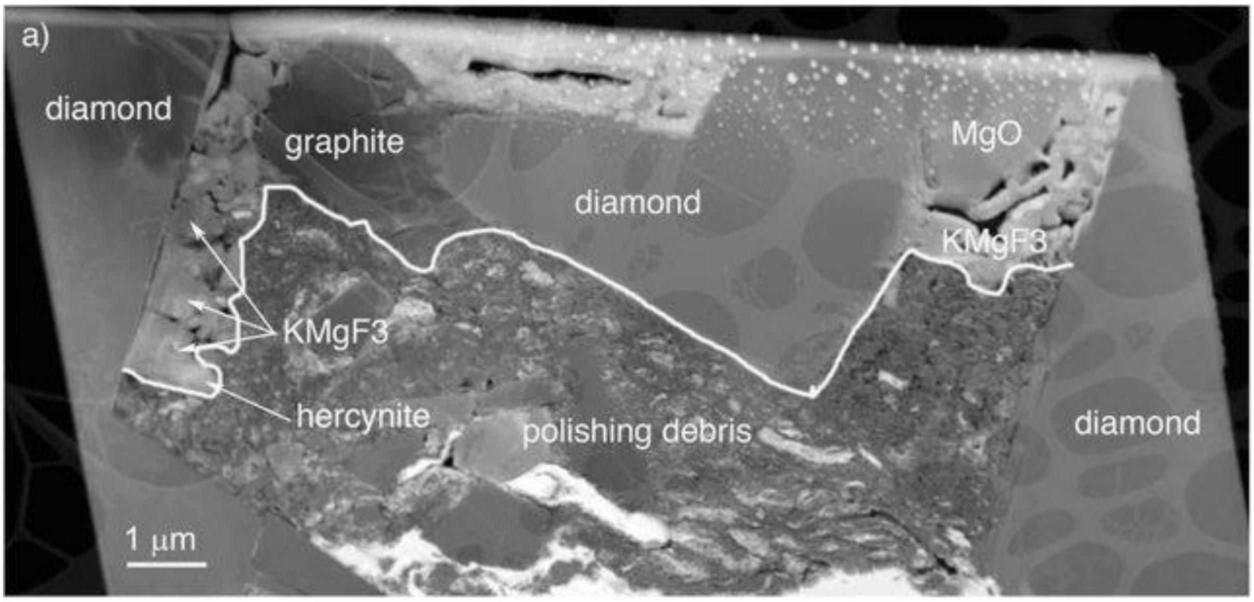


Figure 4.6. Cubic crystals of parascandolaite $KMgF_3$, intergrown with hercynite(?) and graphite (left), and with orthorhombic MgO (right) (Kaminsky *et al.* 2015).

MgO with an orthorhombic structure is a new phase, found in a microcrystalline polymineral aggregate, identified in inclusions within lower-mantle diamond from the Chicória farm, Sorriso river, Juína, Mato Grosso. It is intergrown with parascandolaite. Chemical composition results in the following empirical formula: $(Mg_{0.953}Fe_{0.033}Ca_{0.013})_{\Sigma 0.999}O$. It has unit cell parameters *a* 21.4078, *b* 6.1099, *c* 4.2597 Å, which could only be indexed using the orthorhombic crystal structure. Coexists with parascandolaite, ellinaite, unnamed $MgCr_2O_4$, Fe–rich periclase, calcite, “apatite”, “spinel”, periclase, wüstite, and probably nitrogen-bearing yarlongite (Kaminsky *et al.* 2015). Probably dimorphous with periclase. Today no synthetic orthorhombic MgO compound is known.

See also. Jeffbenite, ellinaite, breyite, nitroyarlongite, nitrocohenite, nitrochalypite, unnamed Fe_2N, Fe_3N, Fe_5SiC, $(Ba,Sr)AlF_5$, $MgCr_2O_4$, $Na_4Mg_3(PO_4)_2(P_2O_7)$, $Fe_2^{3+}Fe_5^{2+}(P_2O_7)_4$, and Na-Mg pyroxene.

Ellinaite

Sharygin *et al.* (2020)

$CaCr^{3+}_2O_4$, orthorhombic

Approved CNMNC – IMA 2019-091

Other names: ellinaíta, unnamed $CaCr_2O_4$, Unnamed (Calcium Chromium Oxide Postspinel)

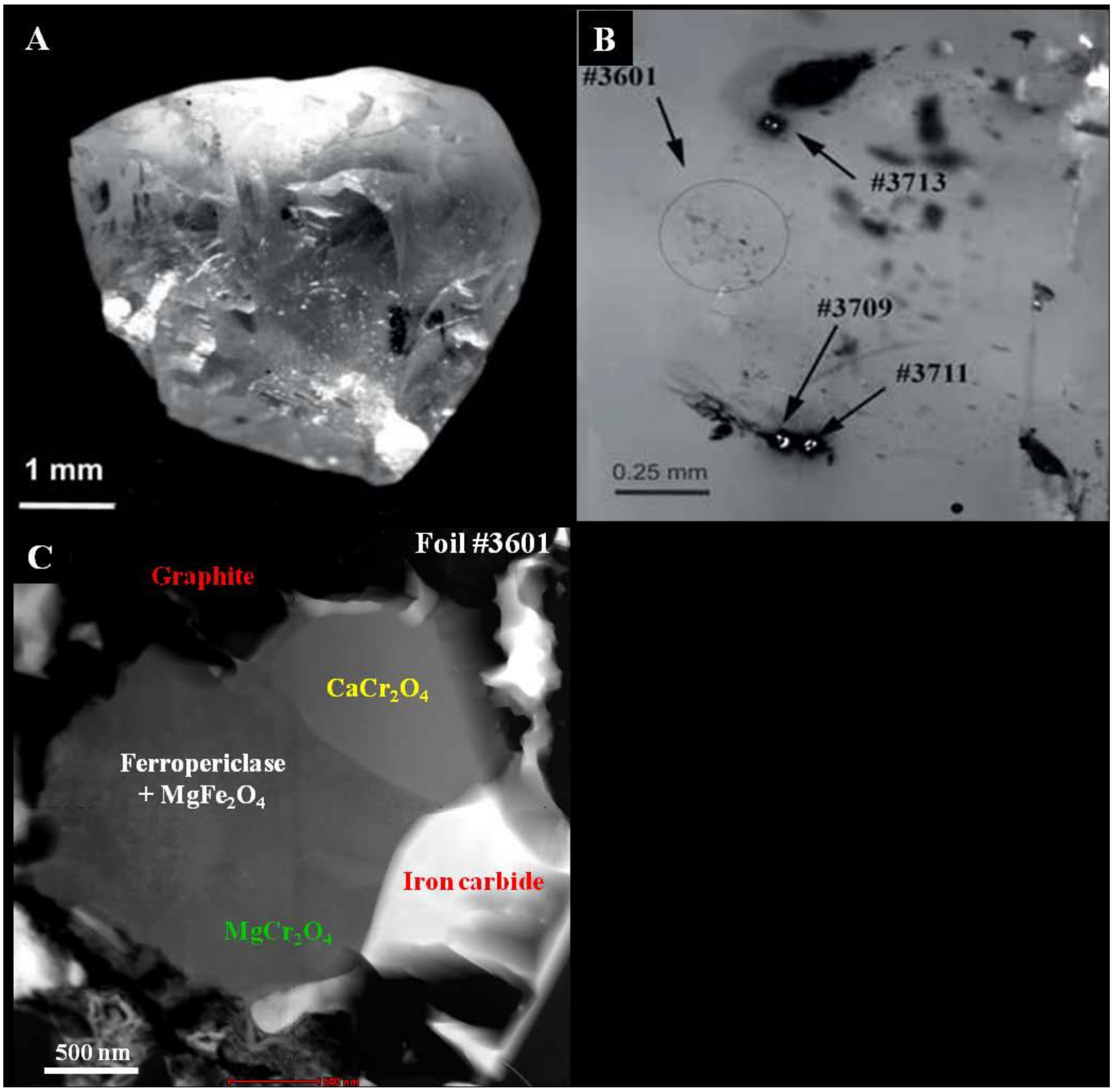


Figure 4.7. (A) General view of diamond #8-108, from the Chicória farm, Sorriso river, Juína, Mato Grosso. (B) Positions of foils in the diamond. (C) Polyphase mineral inclusion with ellinaite, TEM photo (Kaminsky *et al.* 2015). $CaCr_2O_4$: ellinaite; $MgCr_2O_4$: unnamed $MgCr_2O_4$; $MgFe_2O_4$: magnesioferrite.

This mineral was originally described by Kaminsky *et al.* (2015) as unnamed Ca-Cr oxide with an orthorhombic structure, a new phase found in a microcrystalline polymineral aggregate identified in inclusions within lower-mantle diamond from the Chicória farm, Sorriso river, Juína, Mato Grosso.

Sharygin *et al.* (2020) described this mineral as ellinaite, from the gehlenite-rankinite paralavas in the Halamish and Zohar wadi, the southern part of the Hatrurim Basin, one of largest combustion metamorphism complexes of the Hatrurim Formation (also known as the "Mottled Zone") on the territory of Israel (holotype specimen), and from Sorriso river, Juína, Mato Grosso (cotype specimen).

Occurrence. In Brazil ellinaite has been found as a microcrystalline polymineral aggregate identified in inclusions within lower-mantle diamond from the Chicória farm, Sorriso river, Juína, Mato Grosso. Coexists with parascandolaite, unnamed $MgCr_2O_4$, Fe–rich periclase, unnamed orthorhombic MgO, calcite, "apatite", "spinel", periclase, wüstite, and probably nitrogen-bearing yarlongite. These diamond-hosted phases, including ellinaite, seem to be crystallized in lower mantle conditions and ellinaite might be potential host for both Ca and Cr in the deep mantle (Kaminsky *et al.* 2015).

Appearance and physical properties. Subhedral grain with size 2 × 1 μm. Color: black. Streak: black. Luster: sub-metallic. Fluorescence: non-fluorescent. Hardness (Mohs) ≈ 4½-5. Hardness (Micro-indentation): could not be measured because of the small grain size. Cleavage: none observed. Parting: none observed. Tenacity: brittle. Fracture: could not be observed. Density (meas.) could not be measured because of the small grain size. Density (calc.) = 5.217(1) g/cm^3 (for the Hatrurim sample) based on empirical formula and unit cell volume refined from single-crystal XRD data.

Optical properties. Opaque. In reflected light (Hatrurin specimen): Color: gray with blue tint. Bireflectance: none observed. Pleochroism: none observed. Anisotropy: weak. Internal reflections: weak, red-brown. Reflectance values (reference material: Si; measured in air): R_{max}, R_{min} (15.63, 15.35) 470 nm, (14.73, 14.59) 546 nm, (14.55, 14.42) 589 nm, (14.54, 14.48) 650 nm.

Chemical data. Brazilian specimen: Type of analysis: EDX TEM. Chemical analysis (in at.%, without oxygen): Ca = 35.72; Cr = 57.02; Fe = 1.93; Mg = 0.79; Mn = 0.69; Al = 0.80; Ti = 1.09; V = 1.96. The empirical formula calculated on the basis of 3 cations and 4 oxygen ions is: $Ca_{1.07}(Cr^{3+}_{1.71}Fe^{3+}_{0.06}V_{0.06}Ti_{0.03}Al_{0.03}Mg_{0.02}Mn_{0.02})_{\Sigma 1.93}O_4$. The ideal formula requires CaO 26.95; Cr_2O_3 73.05, total 100.00 wt.%. Insoluble in water.

Crystallography. Orthorhombic, *Pnma*, *a* 9.017, *b* 2.874, *c* 10.170 Å, *V* 263.55

Å^3, Z 4, a:b:c 3.1374:1:3.5386. X-ray powder diffraction data [d in Å (I) (hkl)] (calculated): 4.4341 (23) (200), 2.5887 (54) (004), 2.5671 (100) (302), 2.4241 (69) (112), 2.4181 (32) (210), 2.1476 (34) (113), 1.7671 (35) (214), 1.7579 (22) (410).

Name. Ellinaite is named in honor of Dr. Ellina Vladimirovna Sokol (b. 1961) from Novosibirsk, Russia, a well-known Russian mineralogist and petrologist, specialized in studies of pyrometamorphic and combustion metamorphic rocks around the world, including the Hatrurim Formation (Mottled Zone) rocks, Israel and Jordan.

Type material. The cotype sample, from Córrego Sorriso, Mato Grosso (foil from diamond) is located in the scientific collection of F.V. Kaminsky (Vernadsky Institute of Geochemistry and Analytical Chemistry, Moscow, Russia).

Relationship to other species. The Cr-analog of harmunite, $CaFe_2O_4$, and marokite, $CaMn_2O_4$. The Ca-analog of chenmingite, $FeCr_2O_4$, and xieite, $FeCr_2O_4$. Chemically similar to chromatite, $CaCr^{6+}O_4$.

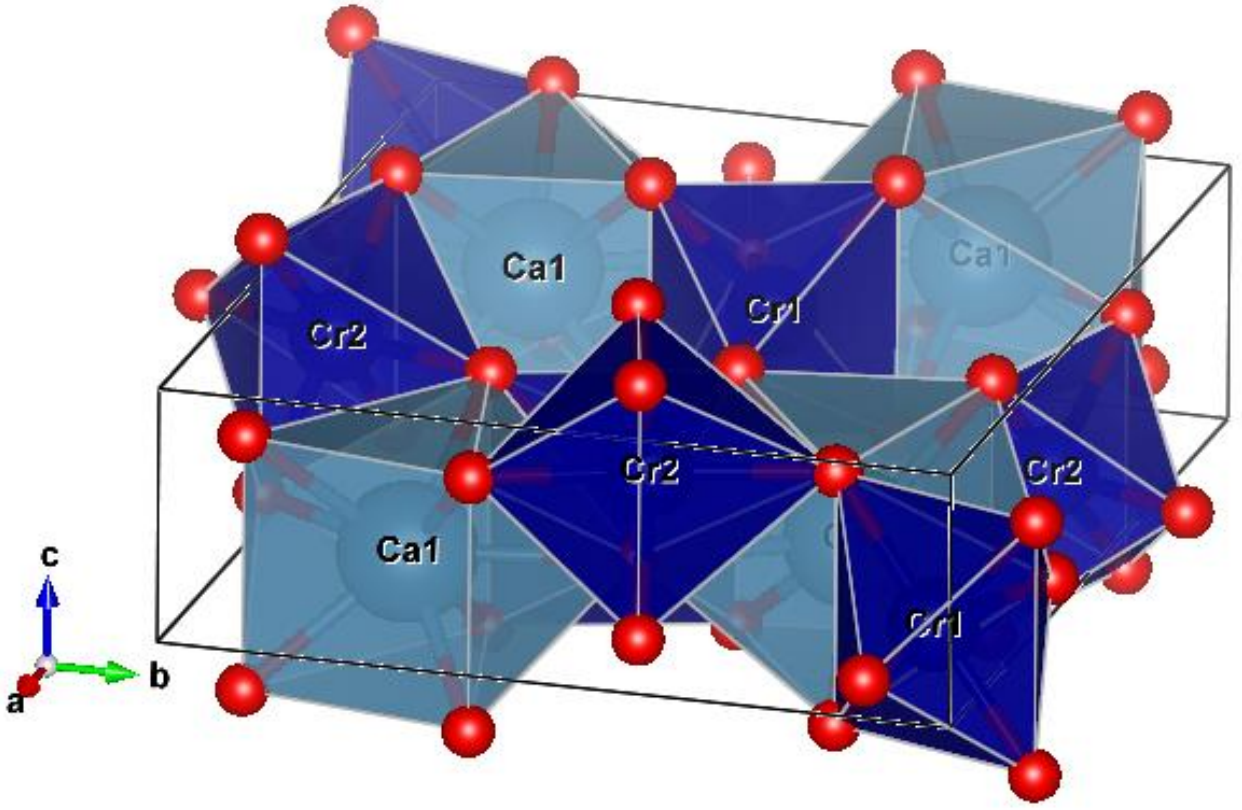


Figure 4.8. View of the crystal structure of synthetic β-$CaCr_2O_4$ (probably equivalent to ellinaite), drawn using VESTA 3 (Momma and Izumi 2011). Data from Hörkner and Müller Buschbaum (1976).

Crystal structure. The crystal structure of ellinaite is related to the orthorhombic tunnel structures of $CaFe_2O_4$, $CaTi_2O_4$, and $CaMn_2O_4$, which are considered to be post-spinel phases (Irifune *et al.* 1991, Kirby *et al.* 1996). A framework composed of edge- and corner-sharing [CrO_6] octahedra bears a system of channels propagated along the *b*-axis. The channels are occupied by calcium ions. Hörkner and Müller Buschbaum (1976) studied synthetic β-$CaCr_2O_4$ [orthorhombic, *Pbnm* (alternative orientation of *Pnma* space group), *a* 10.639, *b* 9.094, *c* 2.960 Å. *V* 286.38 $Å^3$, *Z* 4], probably equivalent to ellinaite.

Synthetic. Hörkner and Müller Buschbaum (1976) obtained single-crystals of β-$CaCr_2O_4$ by solid-state reaction (1300 °C, 7d) of CaO-Cr_2O_3 mixture.

See also. Jeffbenite, breyite, nitroyarlongite, nitrocohenite, nitrochalypite, unnamed Fe_2N, Fe_3N, Fe_5SiC, (Ba,Sr)AlF_5, orthorhombic MgO, $MgCr_2O_4$, $Na_4Mg_3(PO_4)_2(P_2O_7)$, $Fe_2^{3+}Fe_5^{2+}(P_2O_7)_4$, and Na-Mg pyroxene.

Unnamed $MgCr_2O_4$

Kaminsky *et al.* (2015)

$MgCr_2O_4$, orthorhombic

Other names: Unnamed (Mg analog of xieite)

See Figure 4.7.

Mg-Cr oxide with an orthorhombic structure is a new phase, found in a microcrystalline polymineral aggregate identified in inclusions within lower-mantle diamond from the Chicória farm, Sorriso river, Juína, Mato Grosso. Its chemical composition results in the following empirical formula: $(Mg_{0.90}Mn_{0.18})_{\Sigma 1.08}(Cr_{1.37}Fe^{3+}_{0.39}V_{0.11}Al_{0.05})_{\Sigma 1.92}O_4$. The best fit is with a synthetic pure $Fe^{2+}Cr_2O_4$, obtained by Chen *et al*. (2003) in experiments under pressure conditions above 20 GPa. Coexists with parascandolaite, ellinaite, Fe–rich periclase, unnamed orthorhombic MgO, calcite, “apatite”, “spinel”, periclase, wüstite, and probably nitrogen-bearing yarlongite (Kaminsky *et al*. 2015). Possibly the Mg analog of xieite, $Fe^{2+}Cr_2O_4$. The term

See also. Jeffbenite, ellinaite, breyite, nitroyarlongite, nitrocohenite, nitrochalypite, unnamed Fe_2N, Fe_3N, Fe_5SiC, (Ba,Sr)AlF_5, orthorhombic MgO, $Na_4Mg_3(PO_4)_2(P_2O_7)$, $Fe_2^{3+}Fe_5^{2+}(P_2O_7)_4$, and Na-Mg pyroxene.

Martite

Breithaupt (1828)

(hematite pseudomorphous after magnetite)

Other names: Martit, martita, Eisenoxyd

Name applied by Breithaupt (1828) (Martit) to octahedral crystals from Ipanema farm, Araçoiaba hill, Iperó, São Paulo, and Itapicuru, Bahia, recognized before by Haidinger (1827) and others as Eisenoxyd, dimorphous with hematite, Fe_2O_3. They were demonstrated to be hematite after X-ray diffraction studies by Aminoff (1919) and pseudomorphous after magnetite, Fe_3O_4, and perhaps, in part, after pyrite, FeS_2 (Gorceix 1880).

According to Leonardos (1973), Breithaupt examined the iron minerals collected by von Martius in Araçoiaba hill [Iperó, São Paulo], Gaspar Soares hill [Morro do Pilar, near the Lajes creek, Conceição do Mato Dentro, Minas Gerais] and Villa de Pedra Branca [today Santa Terezinha, Bahia], stored in the Brazilian Museum of Munich (Museum Brasilianum, composed of the collections formed by Spix and Martius; this museum was built in 1821 and closed in 1835), Germany. The name martite was given to an iron oxide characterized by the octahedral form and the "*semi-metallic luster of iron*". An ancient unpublished compilation of types organized by the Commission on Museums of the IMA gave erroneously "*Araosaiava Itapicuru, Minas Gerais*" as the type occurrence of martite, and the type specimen as being stored in the Technische Universität's museum, Bergakademie Freiberg, Germany. According to Gorceix (1880), Inficcionado (now Santa Rita Durão, Mariana, Minas Gerais) is the place that supplied the first martite samples, described by Spix and von Martius. Gorceix (1880) found a large amount of martite in the vicinity of Ouro Preto in the state of Minas Gerais. Martite derives from "mars, martis", the name given by the alchemists to iron (Breithaupt 1828). The name martite is not a tribute to von Martius, as might be imagined.

For a long time, martitization was interpreted as a retro-metamorphic transformation but is now understood to be a supergene process. Varajão *et al.* (1996) showed that, when magnetite is submitted to intense weathering conditions, it can be completely "martitized"; or partially transformed into maghemite or "keno-magnetite", which are more soluble than martite leaving skeletal martite crystals, usually found in the top of the weathering profiles.

Pseudorutile

Teufer and Temple (1966)

$(Fe^{3+},Ti^{4+})_4Ti^{4+}{}_4[O,(OH)]_{16}$, hexagonal

(type specimen is not from Brazil)

Other names: pseudo-rutilo

The name pseudorutile was introduced without CNMMN - IMA approval for a hexagonal mineral with the formula $Fe^{3+}{}_2Ti^{4+}{}_3O_9$. Several occurrences were noted, including one in Brazil (without specifying the exact locality). None of the investigated specimens was designated as the specimen-type. The name was rejected (CNMMN 1968), but subsequently it was officially validated (Grey *et al.* 1994) and a neotype from South Neptune Island, South Australia was proposed. The new formula is $(Fe^{3+},Ti^{4+})_4Ti^{4+}{}_4[O,(OH)]_{16}$ (Grey *et al.* 2013). Pseudorutile occurs in the “monazite” and ilmenite sands of Espírito Santo, and other localities.

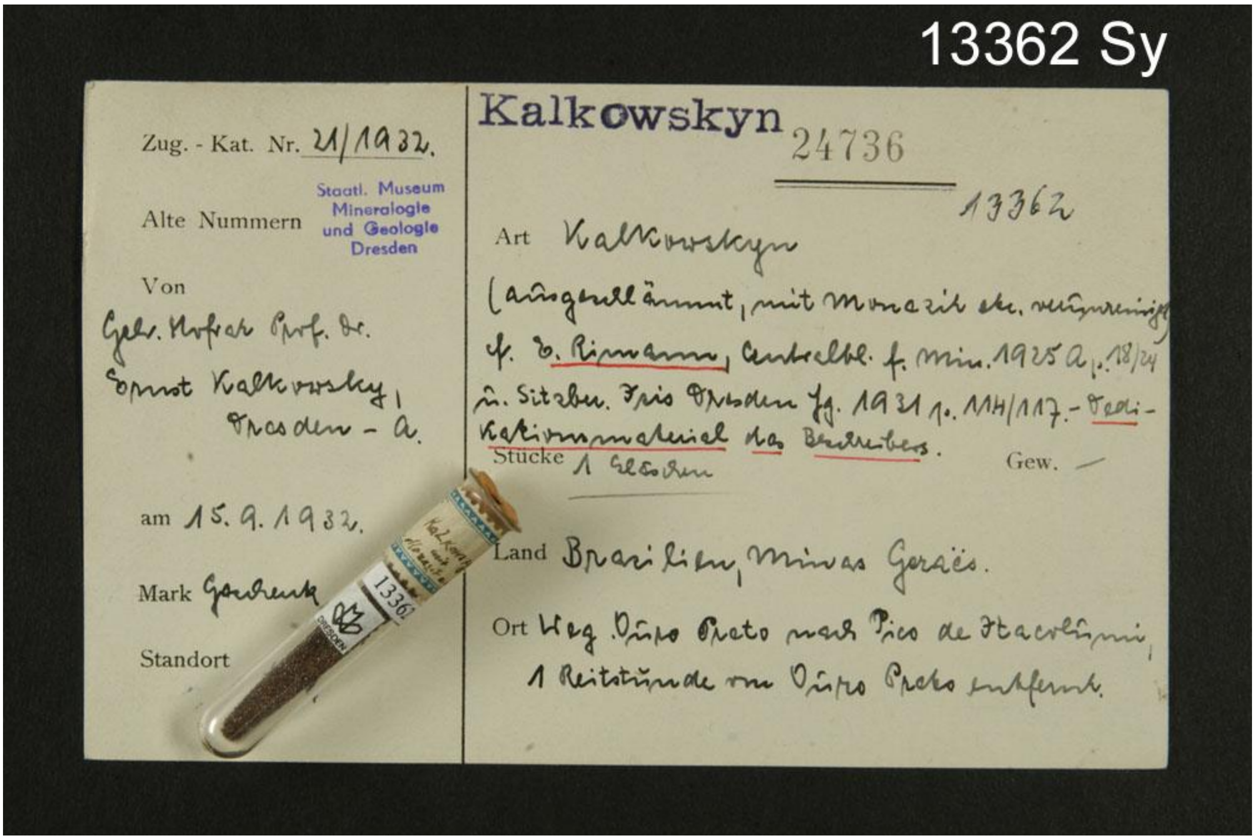
See also. Kalkowskyn and manganoan pseudorutile.

Kalkowskyn

Rimann (1925)

(a mixture of pseudorutile, rutile, and hematite)

Other names: kolkowskyn, kalkowskite, kalkowskita, kolkowoskynita, calcovskita, calcovsquita



13362 Sy

Zug. - Kat. Nr. 21/1932.

Alte Nummern

Staatl. Museum
Mineralogie
und Geologie
Dresden

Von
Geh. Hofrat Prof. Dr.
Ernst Kalkowsky,
Dresden - A.

am 15. 9. 1932.

Mark Geschenk

Standort

Kalkowskyn 24736

13362

Art Kalkowskyn
(ausgeschlämmt, mit Monazit etc. verunreinigt)
cf. E. Rimann, Centralbl. f. Min. 1925 A, p. 18/24
u. Sitzber. Isis Dresden Jg. 1931 p. 114/117. - Dedikationsmaterial des Beschreibers.

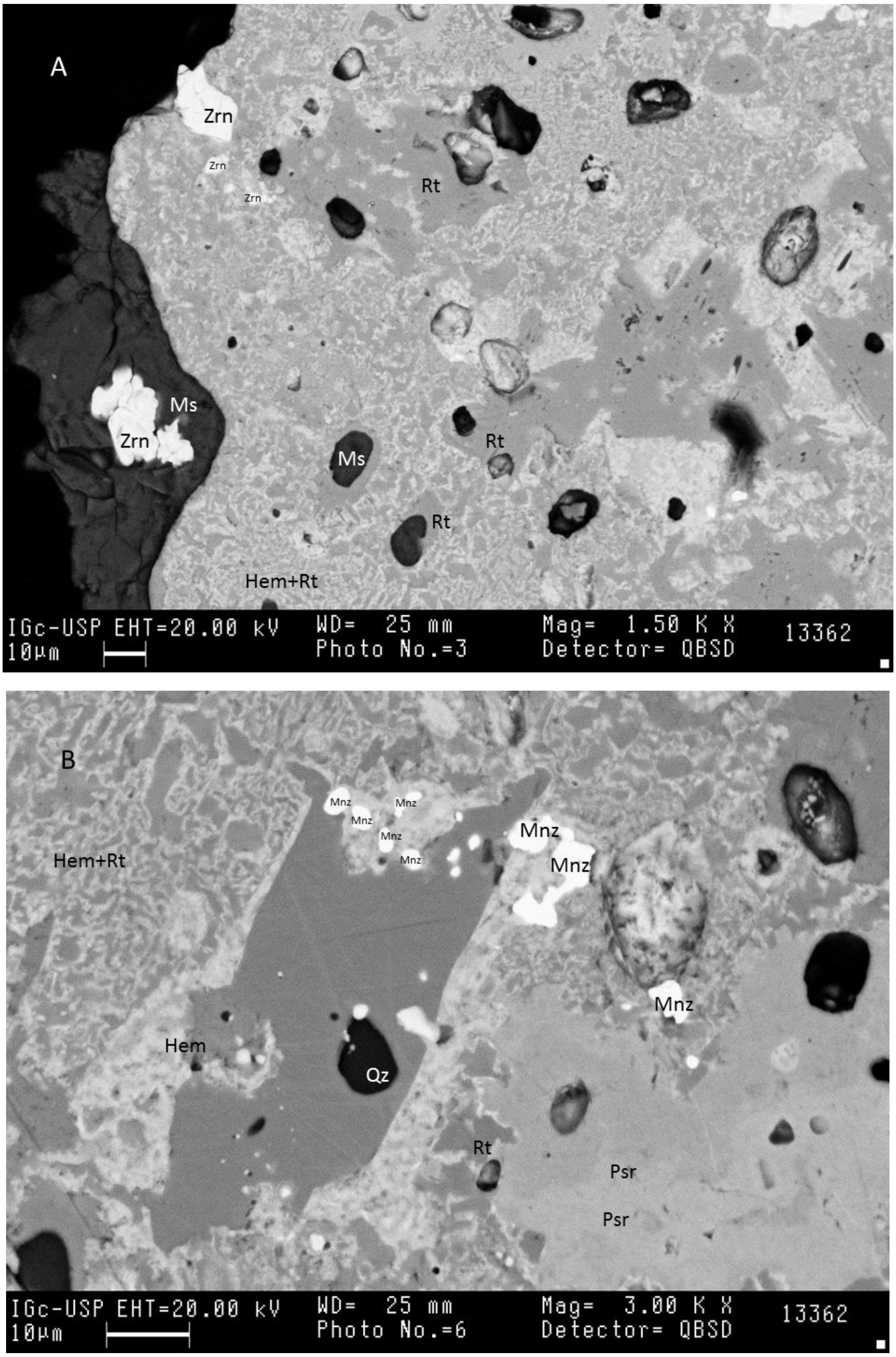
Stücke 1 Gläschen

Gew. –

Land Brasilien, Minas Geraës.

Ort Weg Ouro Preto nach Pico de Itacolumi,
1 Reitstunde von Ouro Preto entfernt.

Figure 4.9. Type specimen of “kalkowskyn” from Ouro Preto, Minas Gerais (Atencio and Thalheim 2013).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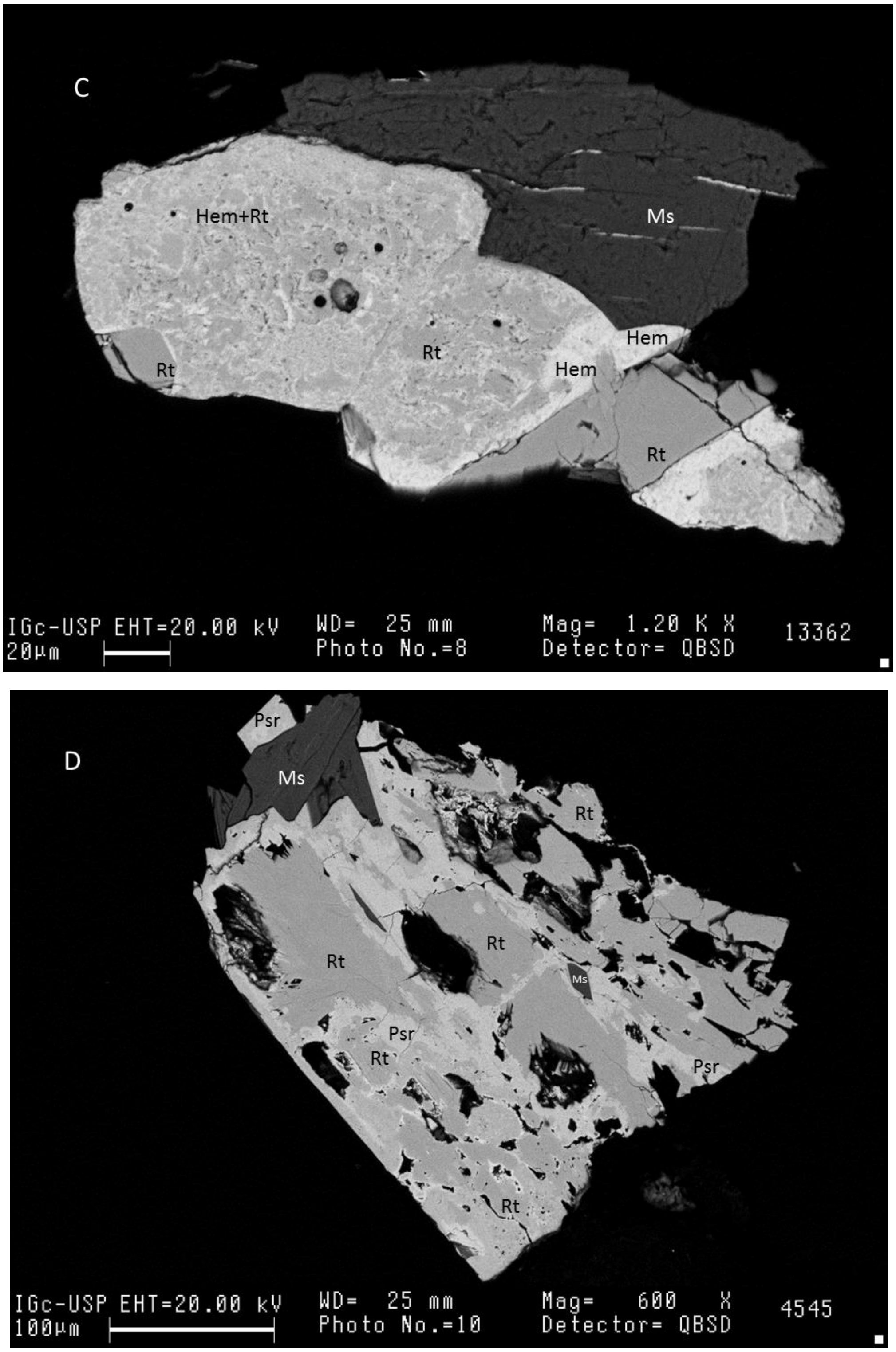

Figure 4.10. Minerals present in the holotype sample of “kalkowskyn” (A, B, and C) and in the additional sample number 4545 (D), from Ouro Preto, Minas Gerais: pseudorutile (Psr), rutile (Rt), hematite (Hem), zircon (Zrn), monazite-(Ce) (Mnz), muscovite (Ms), and quartz (Qz). Hematite and rutile are commonly intergrowth (Hem + Rt) (Atencio and Thalheim 2013).

Kalkowskyn was identified by Rimann (1925 and 1932) in a heavy mineral concentrate from a muscovite pegmatite vein in conglomeratic quartzite, which occurs between Ouro Preto and the Pico do Itacolomi, in a deep valley carved by the Funil river (“Ribeirão do Funil”), near a waterfall, “one hour by horse from Ouro Preto”, Minas Gerais, associated with zircon, monazite, and almandine. For geological background see Leite *et al.* (2010) and references therein. The name honors Professor Ernst Kalkowsky (1851-1938), of Dresden, Germany, who was Rimann's predecessor as a director of the Museum für Mineralogie und Geologie and as a Professor at the Technical College in Dresden (Tröger 1950; Mathé 1993). Several variants of this name appeared in the literature as, for example, “kalkowskite” (Foshag 1925; Palache *et al.* 1944, p. 773-774) and “kolkowskyn” (Ferraz 1928, p. 202-203).

Kalkowskyn occurs, according to Rimann (1925), as platy grains measuring 0.02 to 0.1 mm, formed by irregularly linked sheets, with fibrous structure (verified in transmitted light). The fibrous structure is a common feature of rutile, hematite, and ilmenite. The color is pale brown, dark brown, black, with a reddish-brown streak. Luster is bright, submetallic to greasy or resinous. It is transparent in thin splinters, cleavage is absent and fracture is conchoidal. Measured density is 4.01(3) g/cm^3 and Mohs hardness is 3½. Kalkowskyn is partially decomposed by HCl. In transmitted light, it is reddish-brown. The elongation of fibers is positive, birefringence is weak and it is non-pleochroic, with $n > 1.769$. Wet chemical analyses yield K_2O 0.67, CaO 1.64, MgO 0.48, $(Ce,La)_2O_3$ 2.66, SiO_2 5.63, Al_2O_3 2.21, Fe_2O_3 28.66, TiO_2 54.62, $(Ta,Nb)_2O_5$ 1.67, P_2O_5 0.28, H_2O 3.27, total 101.79 wt.%. Rimann (1925) presented the formula $(Fe,Ce)_2O_3.4(Ti,Si)O_2$, after deduction of contents of monazite-(Ce) and muscovite. He yet verified that the grains were not monomineralic. His description of kalkowskyn is for the submetallic material. The only extant X-ray diffraction data are the patterns obtained with a Cr-tube for fresh and altered kalkowskyn, and “arizonite” (Rimann 1932).

Foshag (1925) observed that if SiO_2 is excluded, the formula is similar to that of “arizonite”. “Arizonite” is a mixture of hematite, ilmenite, rutile and anatase according to Overholt *et al.* (1950). Later work by Karkhanavala (1959) suggests that “arizonite” may be a specific and unique mineral. Rimann (1932) did not agree with Foshag (1925). Later, Fleischer (1966) quoted “Kalkowskite, kalkowskyn (= ilmenite (?))”. Kalkowskyn is not recognized as a valid species by the CNMNC - IMA.

The type material, stored at the Museum für Mineralogie und Geologie Dresden (where Prof. Ernst Kalkowsky and also Prof. Eberhard Rimann were directors) under the inventory number Min 13362 Sy (MMG Dresden) and an additional kalkowskyn sample, from the Richard Baldauf collection, stored under the inventory number Min 4545 BaS (MMG Dresden) were investigated by Atencio and Thalheim (2013). Baldauf (1848-1931) was a friend from Kalkowsky and Rimann and probably he got the specimen from one of the two.

The minerals identified by EDS and X-ray diffractometry (Atencio and Thalheim 2013) correspond to a mixture of

rutile $(Ti_{0.89}Fe^{3+}_{0.08}Si_{0.03}Zr_{0.01})_{\Sigma 1.01}O_2$,
hematite $(Fe^{3+}_{1.71}Si_{0.10}Al_{0.06}Ti_{0.05}P_{0.02})_{\Sigma 1.94}O_3$,
pseudorutile $(Fe^{3+}_{3.12}Ti_{0.88})_{\Sigma 4.00}Ti_{4.00}[O_{12.86}(OH)_{3.14}]_{\Sigma 16.00}$,
monazite-(Ce) $(Ce_{0.40}La_{0.21}Nd_{0.10}Fe^{3+}_{0.18}Th_{0.04}Ca_{0.03}Ba_{0.02})_{\Sigma 0.98}P_{1.01}O_4$,
muscovite $K_{0.97}Al_{2.63}Fe^{3+}_{0.15}Si_{3.15}Ti_{0.02}O_{10}(OH)_2$, zircon, and quartz.

The minerals observed in the other grains, quartz, almandine, muscovite, monazite and zircon, have already been quoted by Rimann (1925).

To compare the new powder X-ray diffraction results with the original patterns we tried to calibrate the data from Rimann (1932), using rutile and quartz lines, but this was unsuccessful, because they have no scale or numeric value and therefore impossible to interpret.

The association of rutile, pseudorutile and hematite is usually interpreted as generated by alteration of ilmenite (e.g. Grey *et al.* 2013). The intergrowths of rutile and hematite are interpreted as formed from pseudorutile. The texture is characteristic of exsolution (Newhouse 1936).

See also. Pseudorutile and manganoan pseudorutile.

Manganoan pseudorutile
Cabral and Sattler (2004)
$(Mn^{3+},Ti^{4+})_4Ti^{4+}_4[O,(OH)]_{16}$, hexagonal
(the Mn-analog of pseudorutile, a new species?)
Other names: Mn-rich pseudorutile-like mineral, UM2004-26-O:FeMnTi

Alteration of Fe-bearing pyrophanite from the manganese oxide deposit Conta História, Antônio Pereira district, Ouro Preto, Minas Gerais, was investigated by electron-microprobe analysis. Mean of 8 point analyses (recalculated for oxides), wt.%: 55.90 TiO_2, 33.46 Mn_2O_3, 8.60 Fe_2O_3, total 97.96. By analogy with pseudorutile, the formula is $(Mn^{3+}_{2.76}Fe^{3+}_{0.69}Ti_{0.55})_{\Sigma 4.00}Ti_{4.00}[O_{12.55}(OH)_{3.45}]_{\Sigma 16.00}$

The microanalyses suggest that the alteration products range in composition from Mn-deficient pyrophanite to a hypothetical Mn-rich pseudorutile-like mineral. Crystals of Fe-bearing pyrophanite cut by gibbsite-filled veinlets and vugs are altered, whereas Mn-rich ilmenite from gibbsite pseudomorphs after garnet remains unaltered. As observed by Cabral and Sattler (2004), pseudorutile, $(Fe^{3+},Ti^{4+})_4Ti^{4+}_4[O,(OH)]_{16}$, is an intermediate alteration product of ilmenite, $Fe^{2+}Ti^{4+}O_3$. The alteration of ilmenite, which involves leaching of Fe^{2+} and oxidation of the remaining iron to Fe^{3+}, results in continuous phase transitions from “leached ilmenite” to pseudorutile. Because ilmenite is a widespread accessory mineral in igneous and metamorphic rocks, reaching ore grades in sand-type placer deposits, where it is almost invariably altered, the alteration of ilmenite has been investigated in detail. In contrast, pyrophanite, $Mn^{2+}Ti^{4+}O_3$, the manganese analog of ilmenite, is a rare mineral and, consequently, its alteration has not been characterized properly (Cabral and Sattler 2001).

See also. Pseudorutile and kalkowskyn.

Pauloabibite

Menezes Filho *et al.* (2015a)

$NaNbO_3$, trigonal

Approved CNMNC - IMA 2012-090

Other names: pauloabibita

Figure 4.11. Pinkish-brown pauloabibite intergrown with fersmite and hochelagaite, dolomite (white), and tochilinite (black), from the Jacupiranga mine, Cajati, São Paulo. Field of view: 4 mm. Menezes Filho *et al.* (2015a)

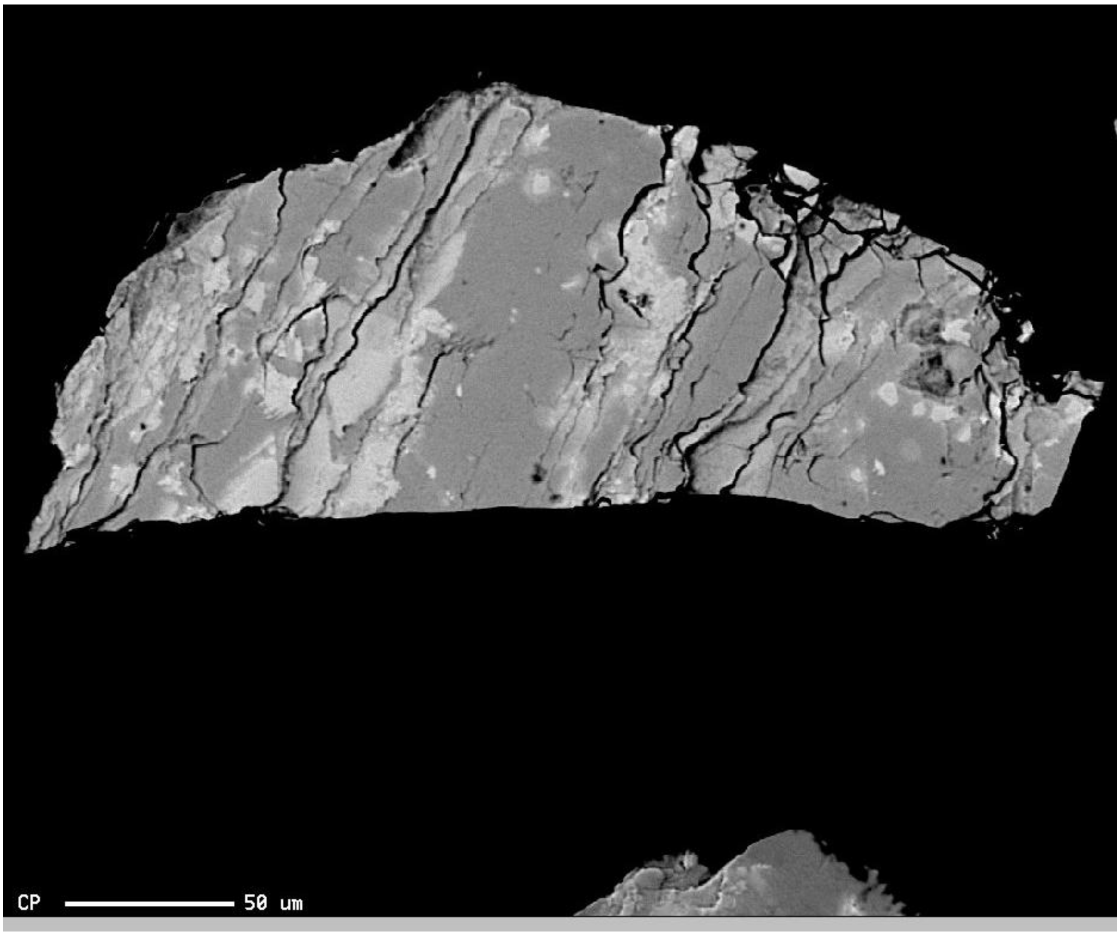

Figure 4.12. Backscattered electron image of pauloabibite (dark) intergrown with fersmite and hochelagaite (light), from the Jacupiranga mine, Cajati, São Paulo. Menezes Filho *et al.* (2015a)

$NaNbO_3$ is well-known to exhibit a rich polymorphism based on the perovskite structure, with a number of displacive transition occurring over a range of temperatures, which may also be sensitive to both pressure and crystallite size. Doped forms of the material are currently the focus of much attention because of their piezoelectric properties (Modeshia *et al.* 2009). Much work has been carried out on the synthesis of alkaline niobates because of their excellent nonlinear optical, ferroelectric, piezoelectric, electro-optic, ionic conductive, pyroelectric, photorefractive, selective ion exchange, and photocatalytic properties. For example, lead-free potassium and sodium niobates are potential substitutes for lead zirconium titanate as high-performance piezoelectric ceramics. The high lead content in piezoelectric PZT introduces serious concerns about environmental pollution during the fabrication, use and disposal of the materials, and therefore increasing attention has been paid to environmental issues nowadays, so research on potential substitutes is urgent (Wu *et al.* 2010).

Occurrence. The mineral occurs in the so-called “intermediate zone” (characterized by high dolomite and slightly anomalous pyrochlore content) in the Jacupiranga carbonatite, Cajati, São Paulo (Menezes Filho and Martins 1984). This is also the type locality of quintinite, menezesite, melcherite and zirkelite. Associated minerals are fersmite, hochelagaite, dolomite, calcite, magnetite, phlogopite, pyrite, pyrrhotite, ancylite-(Ce), tochilinite, fluorapatite, “pyrochlore”, vigezzite, and strontianite. Pauloabibite occurs embedded into the dolomite crystals, which in this zone of the mine can reach centimetric sizes.

Appearance and physical properties. Encrustations of platy crystals up to 2 mm in size in dolomite. Crystals are partially intergrown with fersmite and hochelagaite [in the paper by Menezes Filho *et al.* (2015a) these two minerals were quoted as “a still unidentified Ca-Nb oxide”]. Color: pinkish-brown. Streak: white. Luster: vitreous. Transparent. Non-fluorescent. Mohs hardness: not measured due to the small crystal size. Cleavage: perfect on {0001}. Parting: not observed. Fracture: not determined. Density was not measured due to the paucity of material. Density (calc.): 4.246 g/cm^3 (based on an empirical formula).

Optical properties. Uniaxial; n(mean)$_{\text{calc.}}$ 2.078 using the Gladstone-Dale relationship.

Chemical data. Electron microprobe data (from 17 points): Na_2O 16.36, MgO 0.04, CaO 1.36, MnO 0.82, FeO 0.11, SrO 0.02, BaO 0.16, SiO_2 0.03, TiO_2 0.86, Nb_2O_5 78.66, Ta_2O_5 0.34, total 98.76 wt.%. Empirical formula [based on 3 O *apfu*]: $(Na_{0.88}Ca_{0.04}Mn^{2+}_{0.02})_{\Sigma 0.94}(Nb_{0.98}Ti_{0.02})_{\Sigma 1.00}O_3$. The ideal formula requires Na_2O 18.91, Nb_2O_5 81.09, total 100.00 wt.%.

Crystallography. Trigonal, $R\bar{3}$, a 5.3287(5), c 15.6197(17) Å, V 384.10(7) Å^3, Z 6, c:a 2.9312. X-ray powder diffraction data [d in Å (I) (hkl)]: 5.204 (100) (003), 4.435 (2) (101), 3.977 (3) (012), 2.975 (4) (104), 2.666 (2) (110), 2.604 (5) (006), 2.372 (2) (113), 1.988 (2) (024).

Name. The name is in honor of Professor Paulo Abib Andery (1922-1976), Department of Mining Engineering at the Polytechnic School, Universidade de São Paulo, who developed a flotation process for Serrana SA Mining, producing an apatite concentrate that is used as a raw material for the production of phosphoric acid and a calcite tailing that is used for the manufacture of cement. He founded the mining research facility known as Paulo Abib Engenharia in the early 1970s, a pioneering institution in developing ore dressing technology in Brazil.

Type material. Deposited under the number DR740 in the Museu de Geociências, Instituto de Geociências, Universidade de São Paulo.

Relationship to other species. Pauloabibite belongs to the ilmenite group, which comprises trigonal ($R\bar{3}$) oxides (akimotoite, brizziite, ecandrewsite, geikielite, ilmenite, melanostibite, pauloabibite, and pyrophanite). Pauloabibite, trigonal, is polymorphous with isolueshite (cubic) and lueshite (orthorhombic). Natroniobite is a poorly described mineral that may be a monoclinic polymorph of $NaNbO_3$, or a mineral with formula $NaNb_2O_5(OH)$, related to fersmite (Chakhmouradian *et al.* 1997, Chakhmouradian and Mitchell 1998). Chakhmouradian and Mitchell (1998) investigated a museum specimen labeled “natroniobite” (not the type specimen) and concluded that it is a “complex aggregate of lueshite and its replacement products, set in a matrix of dolomite and fluorapatite”.

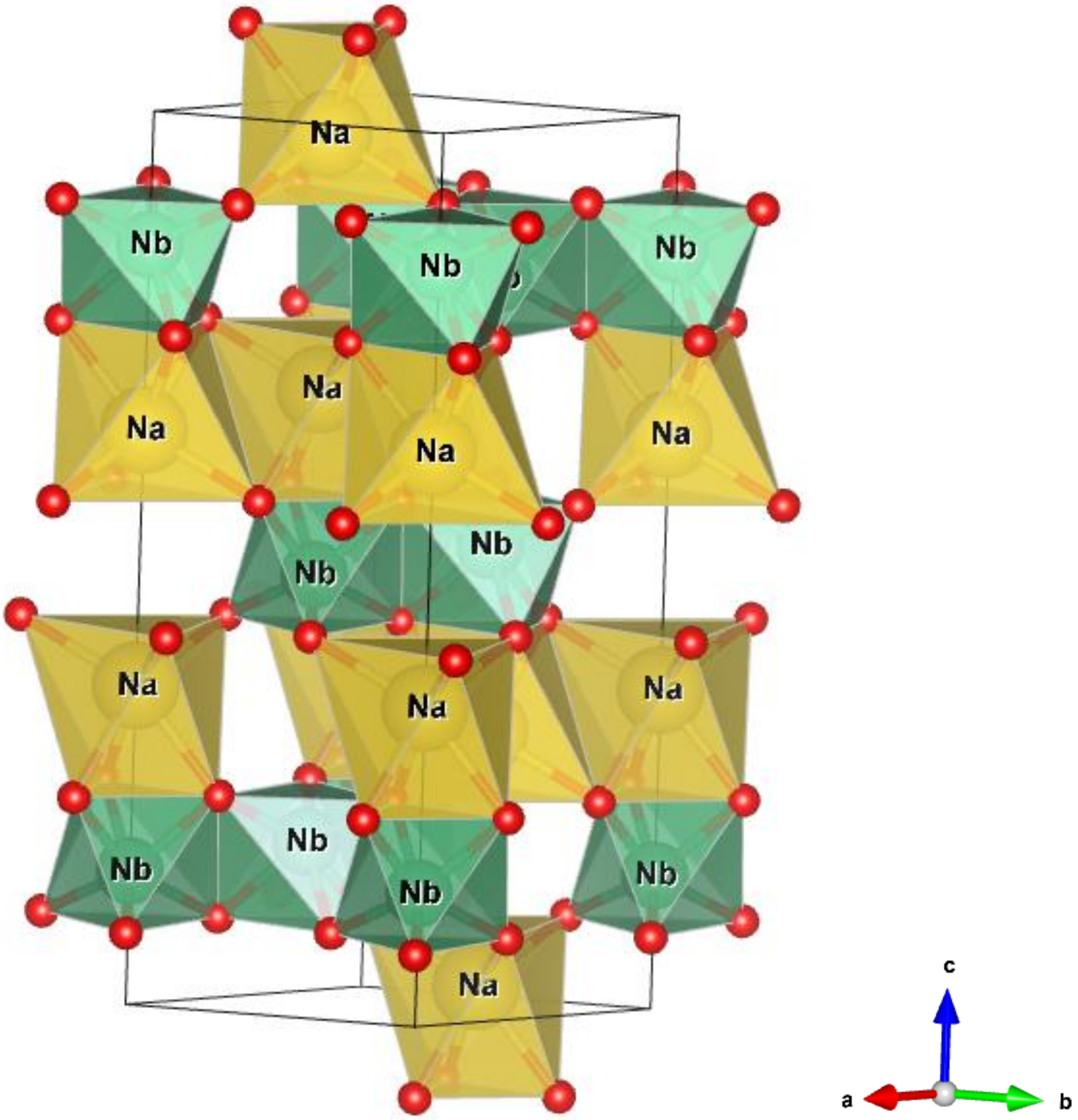

Figure 4.13. View of the crystal structure of pauloabibite (synthetic), drawn using VESTA 3 (Momma and Izumi 2011). Data from Kumata *et al.* (1990).

Crystal structure. Hexagonal close packing of oxygen atoms, with two-thirds of the octahedral interstices occupied by two unique sites of Na and Nb cations. A layered ilmenite ($FeTiO_3$) structure in which NaO_6 and NbO_6 distorted octahedra share edges to form fully ordered stacked Na and Nb layers along the *c* axis.

Synthetic. The synthetic analog of pauloabibite has been studied by several authors. $NaNbO_3$ isostructural with ilmenite was reported by Kinomura *et al*. (1984) and Kumata *et al*. (1990) in a two-step synthesis method, involving the preparation of $Na_8Nb_6O_{19}\cdot 13H_2O$ followed by hydrothermal reaction with NaOH in a silver-lined vessel at 250°C. It was also prepared directly in one step under mild hydrothermal conditions by lowering pH and using close to stoichiometric amounts of metal precursors at 240°C (Modeshia *et al.* 2009; Johnston *et al.* 2011).

See also. Quintinite, menezesite, melcherite, zirkelite, brazilite, barium phlogopite, and unidentified Ca-Nb oxide.

Unidentified Ca-Nb oxide

Menezes Filho *et al.* (2015a)

= fersmite + hochelagaite

Figure 4.14. Fersmite (pinkish beige) with pyrite, carbocernaite, and amesite (?) (colorless, radiated fibers) on calcite and dolomite from the Jacupiranga mine, Cajati, São Paulo. Photo: Liz Zanchetta.

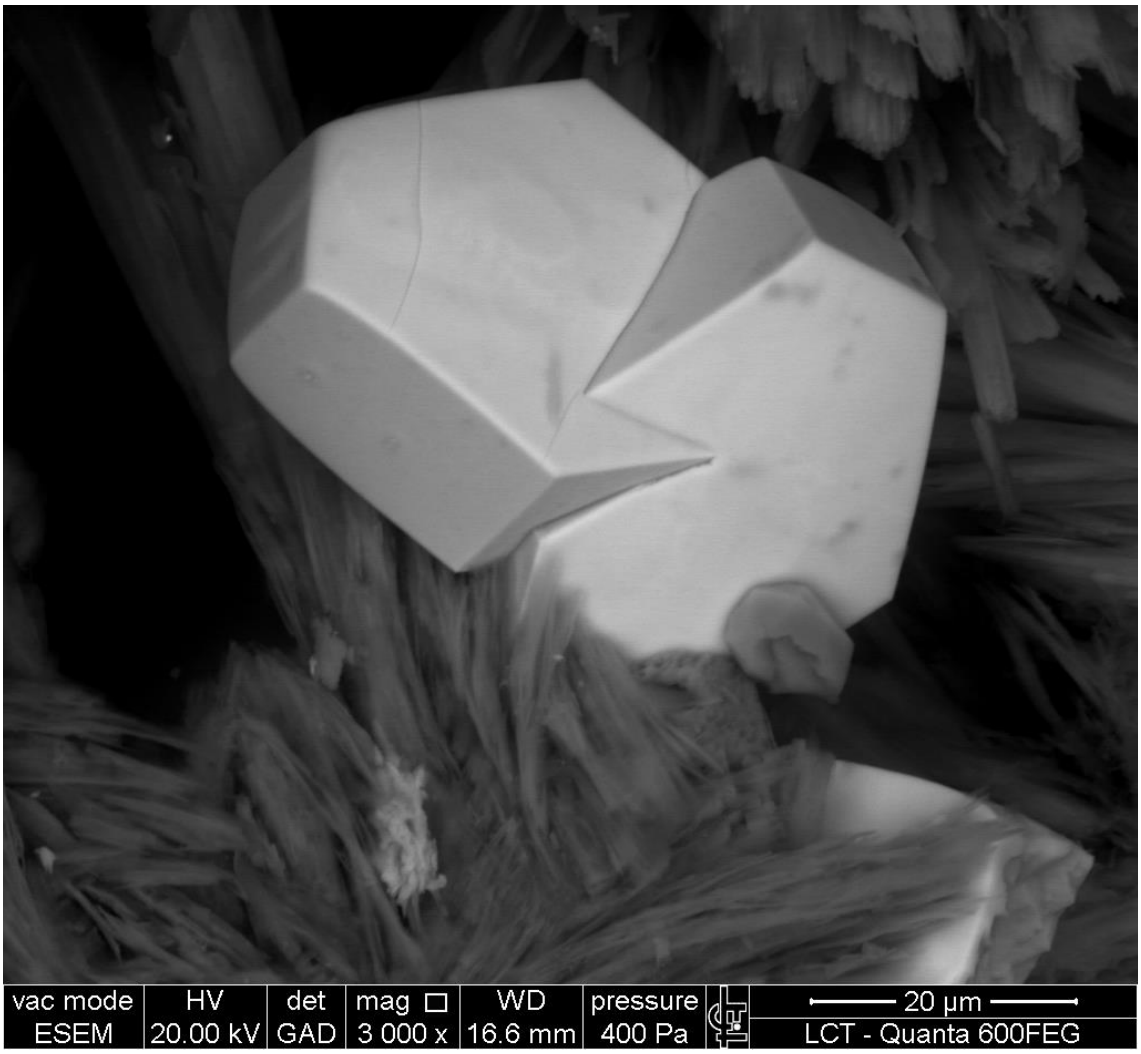

Figure 4.15. Fersmite (twinned by penetration) on amesite (?) from the Jacupiranga mine, Cajati, São Paulo.

“A still unidentified Ca-Nb oxide” was quoted by Menezes Filho *et al.* (2015a) associated with pauloabibite from the Jacupiranga mine, Cajati, São Paulo. Later, it was possible to identify by X-ray powder diffraction data and microprobe data that it is an association of fersmite, $(Ca,Ce,Na)(Nb,Ta,Ti)_2(O,OH,F)_6$, and hochelagaite, $CaNb_4O_{11}\cdot 8H_2O$. Fermite was also identified in other samples from the Jacupiranga mine (Atencio, unpublished data).

See also. Quintinite, menezesite, pauloabibite, melcherite, zirkelite, brazilite, and barium phlogopite.

Almeidaite

Menezes Filho *et al.* (2015b)

$PbZn_2(Mn^{2+},Y)(Ti,Fe^{3+})_{18}O_{37}(OH,O)$, trigonal

Approved CNMNC – IMA 2013-020

Other names: almeidaíta

Figure 4.16. Almeidaite, an isolated platy crystal flattened on [0001] exhibiting the typical cracked surface patterns and metallic shine (28.6 × 20.4 × 7.3 mm), from Garimpo da Mula, Vilarejo de Tapera, Novo Horizonte, Bahia. Specimen and photo: Edson Ferreira dos Santos.

Occurrence. This mineral was originally found in December 2011 on the dump of an abandoned (and back-filled) shaft (Garimpo da Mula, Vilarejo de Tapera) at Novo Horizonte, Bahia. In April 2013 another shaft was opened 10 m away from the original one from which it was possible to collect almeidaite in situ. The crystals are found in altered dacite, 2 m away from a hydrothermal quartz vein that intercepts the dacite. In association with almeidaite, several minerals were found that did not belong to the original dacite but are typical of the hydrothermal quartz veins abundantly present in the area: yellow rutile crystals, tabular hematite crystals, quartz crystals with rutile inclusions, and xenotime-(Y) crystals. Other associated minerals are anatase, kaolinite, muscovite, gramaccioliite-(Y), xenotime-(Y), parisite-(La), monazite-(La), rhabdophane-(La), bastnäsite-(La), fluocerite-(La) and brockite. Thus almeidaite is a product of the reaction of the hydrothermal fluids that generated the adjacent quartz vein with the dacite host rock. The dacites, together with rhyolites and andesites, constitute the so-called "Grupo Rio dos Remédios", a package of felsic metavolcanic rocks resulting from a peraluminous and alkaline magmatism. It was later found "in situ", in altered dacite close to a hydrothermal quartz vein. Garimpo da Mula is also the type locality of parisite-(La). Microprobe data obtained for "Zn- and Na-rich senaite" from Datas, Minas Gerais (Foord *et al.* 1984), and for crichtonite-group minerals from Bjørndalen Quarry, Tvedalen, Larvik, Vestfold, Norway (Larsen 1989), and from Khaldzan Buragtag massif, Altai Mts, Hovd Aimag (Khovd Aimag), Mongolia (Kartashov *et al.* 1993) correspond to almeidaite composition. Chaves and Menezes Filho (2017) published three chemical analyses for almeidaite (and other five for crichtonite, five for senaite, and four for gramaccioliite) from Guariba farm, Presidente Kubitschek, Minas Gerais. Consequently, these are additional occurrences of almeidaite.

Appearance and physical properties. Isolated crystals measuring up to 30 × 30 × 6 mm in size. Habit: platy crystals flattened on [0001]. Forms: dominated by the basal pinacoid {0001}, which is bounded by various, mostly steep rhombohedra, and the hexagonal prism $\{11\bar{2}0\}$. Twinning: most of the crystals are multiply twinned, with non-planar contact surfaces that are approximately parallel to the *c*-axis. Color: black. Streak: brown. Luster: submetallic. Opaque. Non-fluorescent. Hardness (Mohs): 6. Tenacity: brittle. Cleavage: none observed. Fracture: conchoidal. Density (meas.) 4.68(5) g/cm^3 by hydrostatic weighing. Density (calc.) 4.616 g/cm^3 using the empirical formula.

Optical properties. Uniaxial (+) (in reflected light). Birefringence: high. Reflectance values (silver standard in air) [(Ro, Re) λ (nm)]: (12.78, 15.39) 470; (12.86, 15.43) 546; (12.91, 15.55) 589; (13.04, 15.75) 650.

Chemical data. Microprobe (EDS) analyses (5), F, Na, Mg, Al, P, Cl, K, Sb and REE heavier than La are below detection limits. The Mössbauer spectrum displays only a doublet corresponding to trivalent iron. H_2O was determined by gas chromatography of products of ignition at 1200°C. CO_2 was not determined because of the absence of absorption bands corresponding to vibrations of C-O bonds in the IR spectrum. CaO 0.12, SrO 0.69, PbO 7.13, MnO 2.64, ZnO 6.26, Fe_2O_3 22.83, Y_2O_3 2.81, La_2O_3 0.25, TiO_2 56.10, H_2O 0.4(1), total 99.23. wt.%. The empirical formula (based on 38 O *apfu*) is $(Pb_{0.59}Sr_{0.12}Ca_{0.04}La_{0.03})_{\Sigma 0.78}(Mn^{2+}_{0.54}Y_{0.46})_{\Sigma 1.00}Zn_{1.43}(Ti_{13.02}Fe^{3+}_{4.98})_{\Sigma 18.00}(Fe^{3+}_{0.32}Mn_{0.15})_{\Sigma 0.47}[O_{37.18}(OH)_{0.82}]_{\Sigma 38.00}$. The simplified formula is $PbZn_2(Mn^{2+},Y)(Ti,Fe^{3+})_{18}O_{37}(OH,O)$. The end-member formula $PbZn_2Mn^{2+}Ti_{13}Fe^{3+}_5O_{37}(OH)$ requires PbO 11.72, ZnO 8.55, MnO 3.73, Fe_2O_3 20.97, TiO_2 54.56, H_2O 0.47, total 100.00 wt.%.

Crystallography. Trigonal, $R\bar{3}$, *a* 10.4359(2), *c* 21.0471(4) Å, *V* 1.985.10(7) Å^3, Z 3 (single-crystal), *a* 10.462(5), *c* 21.09(2) Å, *V* 2000(3) Å^3, Z 3 (powder data), *c:a* = 2.017. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)] 3.436 (48) (024), 3.074 (50) (205), 3.023 (50) (300), 2.907 (100) (116, 11$\bar{6}$, 12$\bar{4}$, 214, 107), 2.781 (44) (033, 303), 2.492 (55) (131, 31$\bar{1}$), 2.157 (55) (315, 13$\bar{5}$, 119, 11$\bar{9}$), 1.818 (43) (318, 407), 1.615 (50) (3.1. $\bar{1}$0), 1.449 (42) (250, 520).

Name. The mineral is named after Professor Fernando Flávio Marques de Almeida (1916-2013), a Brazilian geologist. Almeida did the central works to understand the South American geology.

Type material. Type material is deposited in the collections of the Museu de Geociências, Instituto de Geociências, Universidade de São Paulo, registration number DR744.

Relationship to other species. Almeidaite is a member of the crichtonite group with Pb dominant in the *A* site (with 12-fold coordination) and Zn dominant in the *T* site (with 4-fold coordination). Almeidaite is a Zn-analog of senaite and a Pb-analog of landauite. “Senaite” from St. Peters Dome, El Paso Co., Colorado, USA (Foord *et al.* 1984) is a new undescribed crichtonite-group mineral, the Y-equivalent of almeidaite.

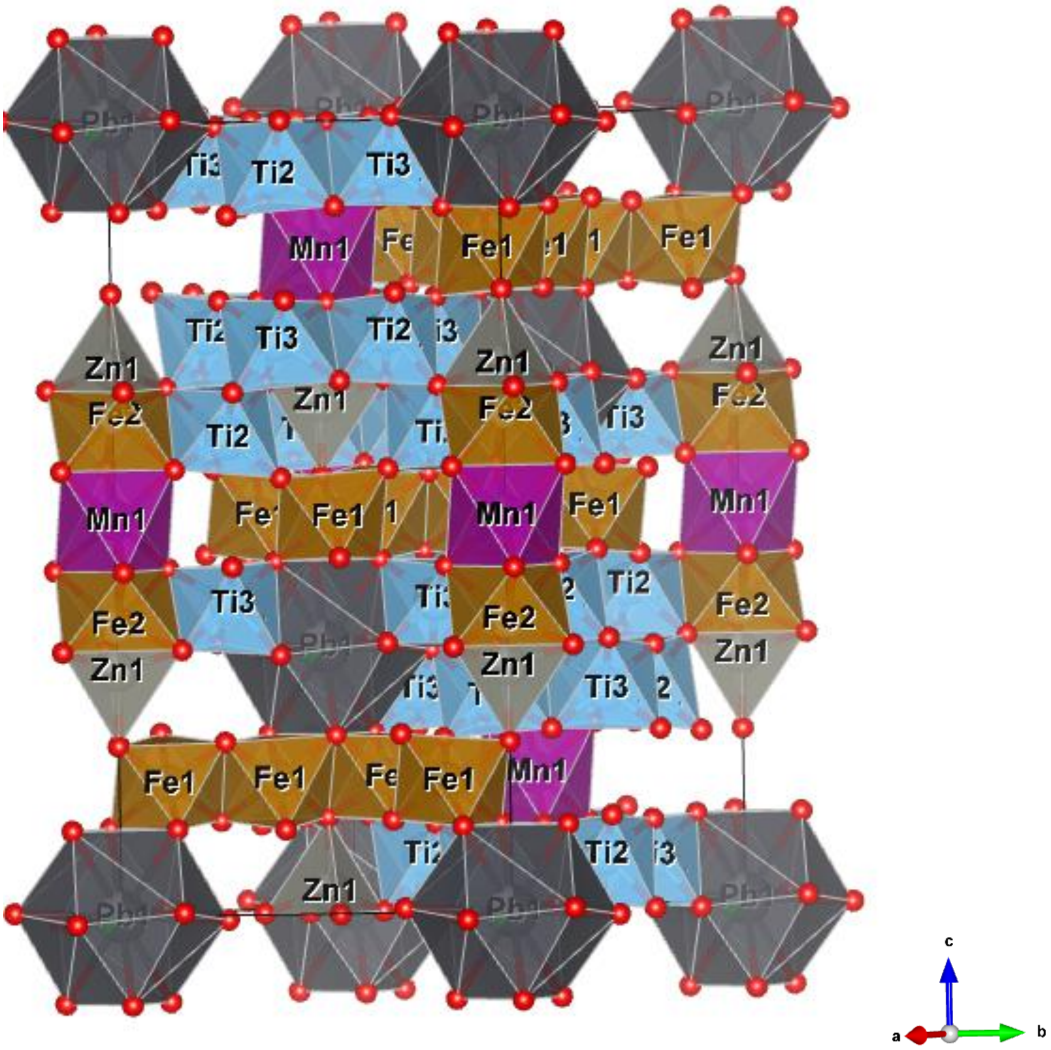

Figure 4.17. View of the crystal structure of almeidaite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Rastsvetaeva *et al.* (2014).

Crystal structure. The structure of almeidaite is consistent with that reported for senaite and all other members of the crichtonite group. It is based on a close-packed anion framework with a nine-layer stacking sequence *chhchh*… in which ^{XII}A occupies one of the anion sites within the cubic layers. Large cations, Pb, Na and Sr, occupy the 12-coordinate *M*0 site. The octahedron *M*1 is occupied by the largest octahedral cations Mn and Y. Zinc occupies the *M*2 tetrahedron. The three sites *M*3-*M*5 are grouped together under the *C* layer and are occupied by the cations Fe^{3+} and Ti^{4+} having rather close radii (0.55 and 0.605 Å, respectively). Additional octahedra coordinating *M*6-9 sites share the faces with the *M*0-5 polyhedra and can be occupied by cations only in case of vacant neighboring sites from the group *M*6-9 (Rastsvetaeva *et al.* 2014, Menezes Filho *et al.* 2015b).

See also. Senaite and parisite-(La).

Senaite

Hussak and Prior (1898)

$(Pb,Sr)Mn^{2+}(Fe^{2+},Zn)_2(Ti,Fe^{3+})_{18}(O,OH)_{38}$, trigonal

Other names: senaíta, Senaït, sénaïte, fer titané tantalifère, ferro titanado tantalífero

Figure 4.18. Senaite on quartz, from the Guariba farm, Presidente Kubitschek, Minas Gerais. RRUFF Project. The identification of this mineral has been confirmed only by single-crystal X-ray diffraction.

Figure 4.19. Type specimen of senaite from Diamantina, Minas Gerais. Muséum national d'Histoire naturelle, Paris, France. The label is 5 cm long. Donator: E. Hussak. Photo: Cristiano Ferraris.

Senaite was originally described by Hussak and Prior (1898) in the neighborhood of Diamantina, Minas Gerais (Datas, Cipó river etc.). The type specimen was collected in alluvium deposits near the city of Datas, Minas Gerais (Cassedanne and Chaves 1990). Additional information was obtained by Hussak and Reitinger (1903), who reported occurrences in Curralinho [now Extração], Varas stream, and near Diamantina. A translation, into Portuguese, of the part of this paper regarding senaite (Hussak 1920) has countless typographic errors that harm its content. Hussak (1917) reported that senaite was "found by me for the first time in the diamond sands of Datas, it was later found in the streams of Varas and Cipó, and in greater abundance in the so-called 'lavra dos Miúdos' of Mr. Pimenta, near Curralinho, Diamantina".

Senaite was recognized in Precambrian diamondiferous conglomerates near Diamantina, Minas Gerais, which were considered the source rocks of the diamondiferous gravel of Serra do Espinhaço (Freise 1930). Metelo (1968) studied samples stored in the Divisão de Geologia e Mineralogia museum, Departamento Nacional da Produção Mineral, Rio de Janeiro, from Datas (DGM/DNPM 1651) (= almeidaite); Várgeas, Diamantina (DGM/DNPM 1653); Cipó river, Diamantina (DGM/DNPM 1654) and Imbiruçu, Santa Quitéria (DGM/DNPM 1655), all in Minas Gerais State.

"Senaite" from St. Peters Dome, El Paso Co., Colorado, USA (= a new undescribed crichtonite-group mineral, the Y-equivalent of almeidaite), and "Zn- and Na-rich senaite" (= almeidaite) from Datas, Minas Gerais (sample DGM/DNPM 1651) were studied by Foord *et al.* (1984). It may be noticed that this last sample had been studied by Metelo (1968).

The discovery of senaite in alluvial gravel containing gold and platinum, near Serro, Minas Gerais (Cassedanne and Cassedanne 1974) initiated research hoping to determine the location of the source rock of this mineral. Based only on a semiquantitative emission spectrographic analysis, Cassedanne (1986), Hochleitner (1987), and Cassedanne and Chaves (1990) described the first *in situ* senaite occurrence in Brazil, at Guariba farm, on the right bank of the creek with the same name, south-southeast of Presidente Kubitschek, 40 km south of Diamantina, Minas Gerais. Quantitative results (Foord *et al.* 1994) showed, however, that the mineral is Pb-rich crichtonite rather than senaite. New single-crystal X-ray diffraction analyses suggested the presence of both crichtonite (RRUFF R060314 and R090006) and senaite (RRUFF 060644). Chaves and Menezes Filho (2017) published five chemical analyses for senaite (and other five for crichtonite, three for almeidaite, and four for gramaccioliite) from Guariba farm.

Senaite was probably known by Damour (1856) and described as "fer titané tantalifère". Due to dissolution by sulfuric acid and potassium sulfate, the lead precipitated as sulfate and was possibly analyzed as tantalum acid (Hussak and Reitinger 1903).

Occurrence. In diamondiferous alluvium of Diamantina, Datas, and its surroundings, Minas Gerais (Hussak and Prior 1898); in Precambrian diamondiferous conglomerates from Diamantina, Minas Gerais (Freise 1930); in alluvial gravel containing gold and platinum, near Serro, Minas Gerais (Cassedanne and Cassedanne 1974); and at Guariba farm, on the right bank of the creek with the same name, south-southeast of Presidente Kubitschek, 40 km south of Diamantina, Minas Gerais (Chaves and Menezes Filho 2017). Also, known from several world occurrences.

Appearance and physical properties. Habit: isolated tabular crystals. Forms: basal pinacoid, rhombohedra, hexagonal prism. The mineral is very rich in faces. The rhombohedral planes are very bright, while the basal plane, owing to twinning, is generally uneven and, like the prism faces, dull. Twinning: none observed. Color: greenish-brown. Streak: white. Luster: vitreous. Transparent. Non-fluorescent. Hardness (Mohs): 4½. Tenacity: brittle. Cleavage: none observed. Fracture: uneven. Density (meas.) 2.84(1) g/cm^3 (volumetric method), 2.86(1) g/cm^3 (equilibration in heavy liquids). Density (calc.) 2.832 g/cm^3 (from the empirical formula).

Optical properties. Uniaxial (-); n ~ 2.50 (Li). Lower to moderate reflectance. Pleochroism: absent. (R_1, R_2; ${}^{im}R_1$, ${}^{im}R_2$) nm: (20.1, 21.1; 7.10, 7.79) 470, (18.7, 19.7; 6.23, 6.90) 546, (18.2, 19.2; 5.92, 6.59) 589, (17.8, 18.8; 5.73, 6.40) 650

Chemical data. Microprobe data : MgO 0.02, CaO 0.10, MnO 4.08, FeO 8.53, NiO 0.08, SrO 0.20, PbO 9.21, Al_2O_3 0.05, Cr_2O_3 0.16, Fe_2O_3 16.20, Y_2O_3 0.86, La_2O_3 0.06, Ce_2O_3 0.07, Nd_2O_3 0.01, TiO_2 58.68, ZrO_2 0.09, HfO_2 0.13, ThO_2 0.12, V_2O_5 0.70, total 99.35 wt.%. [Grey *et al.* (1976), U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA, Mineralogy Division, #R7241 specimen)]. Empirical formula:

$(Pb_{0.77}Sr_{0.04}Ca_{0.03}La_{0.01}Ce_{0.01}Th_{0.01})_{\Sigma 0.87}(Mn^{2+}_{0.84}Y_{0.14}Zr_{0.01}Hf_{0.01})_{\Sigma 1.00}(Fe^{2+}_{1.97}Ni_{0.02}$
$Mg_{0.01})_{\Sigma 2.00}(Ti_{13.71}Fe^{3+}_{3.79}Mn_{0.24}V_{0.14}Cr_{0.04}Al_{0.02})_{\Sigma 17.94}Fe^{2+}_{0.25}O_{38}$.

Microprobe data (mean of five analyses): SrO 1.61, TiO_2 60.80, FeO 23.78 (all Fe calculated as Fe^{2+}), MnO 2.55, ZnO 0.59, Y_2O_3 1.66, PbO 7.30, total 98.29 wt.%. (Chaves and Menezes Filho 2017). Empirical formula:

$(Pb_{0.59}Sr_{0.29})_{\Sigma 0.88}(Mn^{2+}_{0.65}Y_{0.27})_{\Sigma 0.92}(Fe^{2+}_{1.87}Zn_{0.13})_{\Sigma 2.00}(Ti_{13.95}Fe^{3+}_{4.05})_{\Sigma 18.00}Fe^{2+}_{0.15}O_{38}$.

The ideal formula $PbMn^{2+}Fe^{2+}_2(Ti_{14}Fe^{3+}_4)O_{38}$ requires PbO 11.90, MnO 3.78, FeO 7.66, TiO_2 59.63, Fe_2O_3 17.03, total 100.00 wt.%.

Crystallography. Trigonal, $R\bar{3}$. Rhombohedral unit cell: a 9.172(1) Å, α 69.020(5)°, V 648.89 Å^3, Z 1. Hexagonal unit cell: a 10.393(2), c 20.811(5) Å, $c:a$ = 2.0024, V 1946.73 Å^3, Z 3 (data derived from the crystal structure study by Grey and Lloyd 1976). X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 3.43 (90) (024), 2.894 (100) (116), 2.468 (50) (131), 2.265 (50) (208), 2.146 (50) (315), 1.981 (75) (045), 1.603 (70) (1 3 10) and 1.447 (70) (2 2 12).

Name. Honors Professor Joaquim Cândido da Costa Sena (1852-1919), director of the Escola de Minas of Ouro Preto.

Type material. Muséum national d’Histoire naturelle, Paris, France (101.319, donator E. Hussak) (type); Musée Géologique Cantonal, Lausanne, Switzerland (MGL 53207 (part of type 101.319 from Muséum national d’Histoire naturelle, Paris, France, given in 1999, chemically analized in Lausanne); National Museum of Natural History; Smithsonian Institution, Washington, D.C., USA (R07241, donator E. Hussak, thru the Roebling collection, 1933) (type). Natural History Museum, London, England (83656, 86037).

Relationship to other species. A crichtonite group mineral, isostrutural with almeidaite

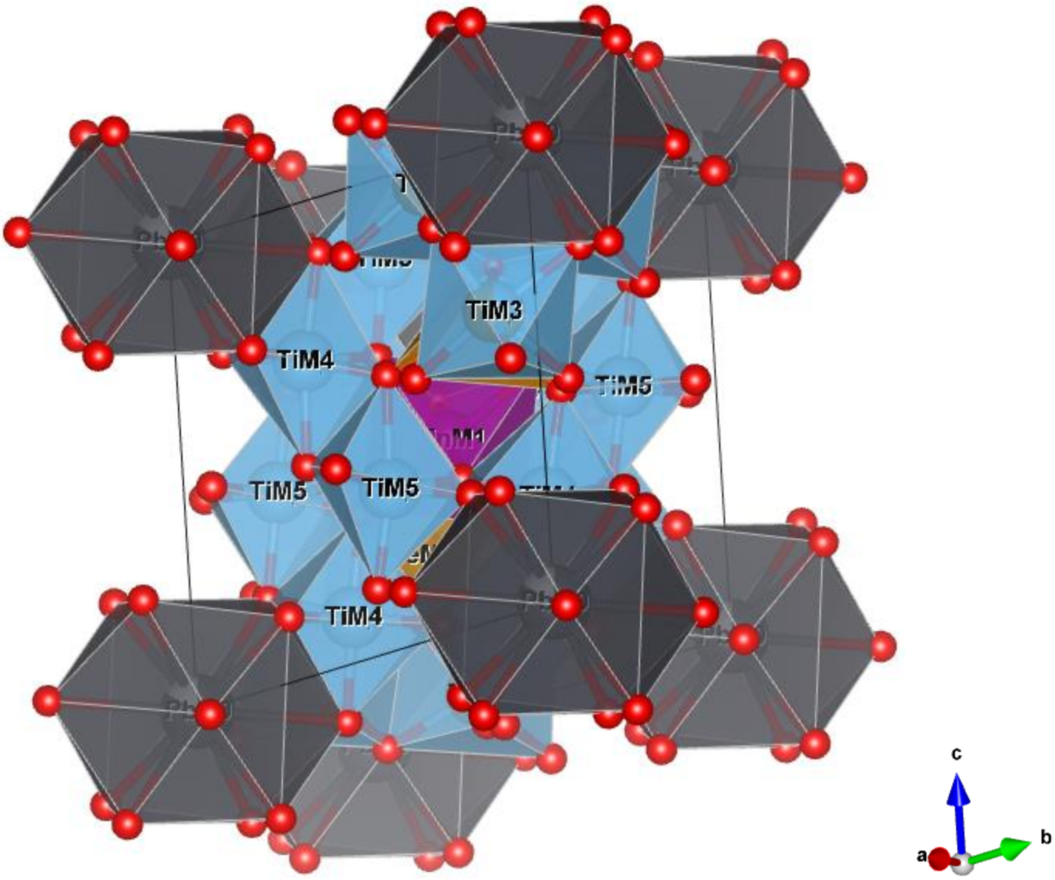

Figure 4.20. View of the crystal structure of senaite (from Datas, Minas Gerais), drawn using VESTA 3 (Momma and Izumi 2011). Data from Grey and Lloyd (1976).

Crystal structure. Determined by Grey and Lloyd (1976) using a sample from Datas, Minas Gerais U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA, Mineralogy Division, sample #R07241, type specimen): The structure is based on a nine-layer (*hhc*...) close-packed array of anions with lead atoms partially occupying one of the thirteen anion sites in the cubic layers. Metal atoms occupy nineteen of the available octahedral sites and two of the tetrahedral sites in the unit cell. The octahedral articulate to give two basic structural building units, a trigonal grouping of three edge-shared octahedral and a 6-member hexagonal ring of edge-shared octahedra. The trigonal triads link further by edge sharing into 12-member hexagonal rings. The tetrahedra and an octahedron link the 6-member and 12- member rings via corner sharing. The metal atoms are ordered in the structure.

See also. Almeidaite.

Staringite
Burke *et al.* (1969)
(= cassiterite + tapiolite)
Approved CNMMN - IMA 69-010
Other names: staringita

Staringite was described in the Seridozinho pegmatite, at Pedra Lavrada, Paraíba, by Burke *et al.* (1969) as inclusions in tapiolite. The name was given in honor of Dr. W. C. H. Staring (1808-1877), founder of geology and mineralogy in The Netherlands. The original formula was given as $(Fe,Mn)_{0.5}(Sn,Ti)_{4.5}(Ta,Nb)_{1.0}O_{12}$. Groat *et al.* (1992 and 1994) discredited the mineral, with CNMMN–IMA approval, showing that staringite is a submicroscopic mixture of cassiterite, SnO_2, and tapiolite, $(Fe,Mn)(Ta,Nb)_2O_6$, both tetragonal.

According to Cassedanne and Philippo (2015), good samples of staringite were produced at the José Pinto quarry, Jaguaraçu, Minas Gerais, before 1965, the largest specimens measuring 10 cm. They were made of partially and/or erratically oriented clusters of crystals. The groups correspond to very coarsely hexagonal stacks of flat individuals. Some faces present a spiral growth, whereas others are formed by the combination of individuals terminated by a pyramid. Grained to sub-conchoidal fracture, very dark brown to blackish. All the specimens were covered with a thin light-yellow coating.

Staringite was also quoted in Lutsiro, Sebeya River area, Rwanda (Daltry and von Knorring 1998).

See also. Minasgeraisite-(Y), carlosbarbosaite, and “yttrian milarite”.

Paredrite

Farrington (1916)

(variety of rutile)

Other names: paredrita

A black compact titanium dioxide, differing from rutile because it contains 0.6 wt.% H_2O, insufficient to form a hydrate, and no doubt present as an impurity. Its name derives of the Greek, meaning “an associate”, on account of its association with “favas” (bean-shaped pebbles) found with diamond in Brazil. It is probably a variety of rutile. The exact provenance was not given, and there is no mention of the whereabouts of the type specimen.

See also. Titan-favas.

Titan-favas

English-(1939)

(rutile or anatase)

Other names: favas de titânio

Term applied for “favas” (bean-shaped pebbles) made up of rutile or anatase. From the diamond sands of Brazil.

See also. Paredrite.

Tripuhyite

Hussak and Prior (1897b)

$Fe^{3+}Sb^{5+}O_4$, tetragonal

Other names: tripuhyíta, tripuhyte, tripuíta

Figure 4.21. Tripuhyite (colorless to pale honey yellow) and hydroxycalcioroméite (very dark brown through orange-brown to pale yellow) from Tripuí, Ouro Preto, Minas Gerais. Field of view: 2.3 mm. Type specimen of tripuhyite, BM 86044, Natural History Museum, London, England. Image by Alan Criddle, uploaded to the Mindat database by Chris J. Stanley. Berlepsch *et al*. (2003).

Tripuhyite from Tripuí, Ouro Preto, Minas Gerais, was originally described by Hussak and Prior (1897b) [translation into Portuguese: Hussak and Prior (1917)]. Hussak and Prior (1897b) suggested the formula $Fe^{2+}{}_2Sb^{5+}{}_2O_7$, but the valence of Fe and Sb was not tested. Palache *et al.* (1951) compiled known data of tripuhyite and proposed the formulae

$Fe^{3+}SbO_4$ or $Fe^{2+}{}_2Sb_2O_7$. A new tripuhyite occurrence was described in the Palo Verde and Argentina mines, El Antimonio, Sonora, Mexico (Mason and Vitaliano 1953) but all the Fe is trivalent in this mineral hence the formula $Fe^{3+}Sb^{5+}O_4$ was suggested. Additional data for tripuhyite from Tripuí were obtained by Tavora Filho (1955) and Baptista (1981). The chemical analyses (in Tavora Filho 1955) are Sb_2O_5 71.176, FeO 23.685, Fe_2O_3, 4.820, Al_2O_3 0.188, SiO_2 0.160 (plus CaO 0.01, SnO_2 0.01, MgO 0.002, MnO, CuO, TiO_2, S, K_2O, Na_2O traces), sum 100.055 wt.%. These analyses indicate most of the iron to be bivalent. However, no analytical details were given by Tavora Filho (1955). Furthermore, Tavora Filho (1955) noticed oxygen deficiency in his analyzed tripuhyite when comparing his results with the theoretical composition. He stated that this deficiency is practically corrected if it is assumed that all the iron is in the ferric state. Since Tavora Filho (1955) followed Mason and Vitaliano (1953) in writing the formula of tripuhyite as $FeSbO_4$ it may be concluded that the author indeed assumed all of the iron to be ferric (and thus got a charge balanced formula). Baptista (1981) erroneously gave the formula $Fe_2Sb_2O_6$ for tripuhyite when referring to Mason and Vitaliano (1953). Gakiel and Malamud (1969) used a sample of tripuhyite from Djebel Nador for a ^{57}Fe Mössbauer study and showed that iron in this sample is in the ferric state. They followed Mason and Vitaliano (1953) in writing $FeSbO_4$ as the formula of tripuhyite. By ^{121}Sb Mössbauer spectroscopy, Baker and Stevens (1977) determined the oxidation state of Sb in tripuhyite from Djebel Nador to be pentavalent. Teller *et al.* (1985) reported the Fe/Sb ratio in synthetic $FeSbO_4$ to be 1. A new find of tripuhyite at Falotta (Oberhalbstein, Switzerland) led to the article of Geiger and Cabalzar (1988) in which the authors share the opinions of Mason and Vitaliano (1953) as well as Gakiel and Malamud (1969) in writing the tripuhyite formula $FeSbO_4$. To address uncertainties related to the exact nature of tripuhyite Berlepsch *et al.* (2003) studied tripuhyite from Tripuí (type material, sample BM 86044, E 1565, P 8716, The Natural History Museum, London, England) and Falotta (Grisons, Switzerland) using single-crystal and powder X-ray diffraction, electron microprobe analysis, and ore microscopy. The comparison of their results with the data of squawcreekite by Foord *et al.* (1991) showed the identity between tripuhyite and squawcreekite (Berlepsch *et al.* 2003).

Occurrence. In the gravel of the Três Cruzes farm cinnabar mine, Tripuí (formerly Tripuhy), Ouro Preto, Minas Gerais. Associated minerals are xenotime, monazite, zircon, kyanite, tourmaline, rutile, hematite, pyrite, magnetite, gold, cinnabar, derbylite, hydroxycalcioroméite, florencite-(Ce), muscovite, quartz, and other minerals. Also from several world occurrences. The following data are from the tripuyite from the type occurrence.

Appearance and physical properties. In microcrystalline aggregates. Dull greenish-yellow with a canary yellow streak. Translucent. Density 5.82 g/cm^3(meas.).

Optical properties. Anomalously biaxial (+), α 2.19(1), β 2.20(1), γ 2.33(1), 2*V* small. Absorption: $r < v$, very strong. Pleochroism: absent.

Chemical data. Electron microprobe analyses: Fe_2O_3 30.0, Sb_2O_5 69.3, TiO_2 < 0.05 As_2O_5 < 0.2, total 99.3 wt.% (Berlepsch *et al.* 2003). Empirical formula $Fe^{3+}_{0.92}Sb^{5+}_{1.05}O_4$. The ideal formula $Fe^{3+}Sb^{5+}O_4$ requires Fe_2O_3 33.05, Sb_2O_5 66.95, total 100.00 wt.%.

Crystallography. Tetragonal, $P4_2/mnm$, *a* 4.625(4), *c* 3.059(5) Å, *V* 65.43 Å^3, Z 1, *c:a* = 0.6614. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 3.23 (90) (110), 2.53 (70) (103), 2.29 (70) (113), 1.702 (100) (213), 1.629 (70) (220), 1.522 (50) (006), 1.459 (70) (310), 1.381 (50) (116, 303), 1.373 (70) (215), 1.271 (50) (206). ICDD: 7-65.

Name. For Tripuí (formerly Tripuhy).

Type material. Muséum national d'Histoire naturelle, Paris, France (number 101.569, donated by E. Hussak). Peter Tandy, curator of mineralogy at the Natural History Museum, in London, England, gave the following personal communication: According to the register of accessions, BM 86044 is a tripuhyite from Tripuhy, Minas Gerais, which was at one time no. 498 in the Hussak collection. The specimen came to the Natural History Museum, London, from Krantz, of Bonn, in 1902, and, according to a note, is holotype material. This information was also published in the catalog of type specimens in the collection of the Natural History Museum, London, England.

Relationship to other species. Rutile group.

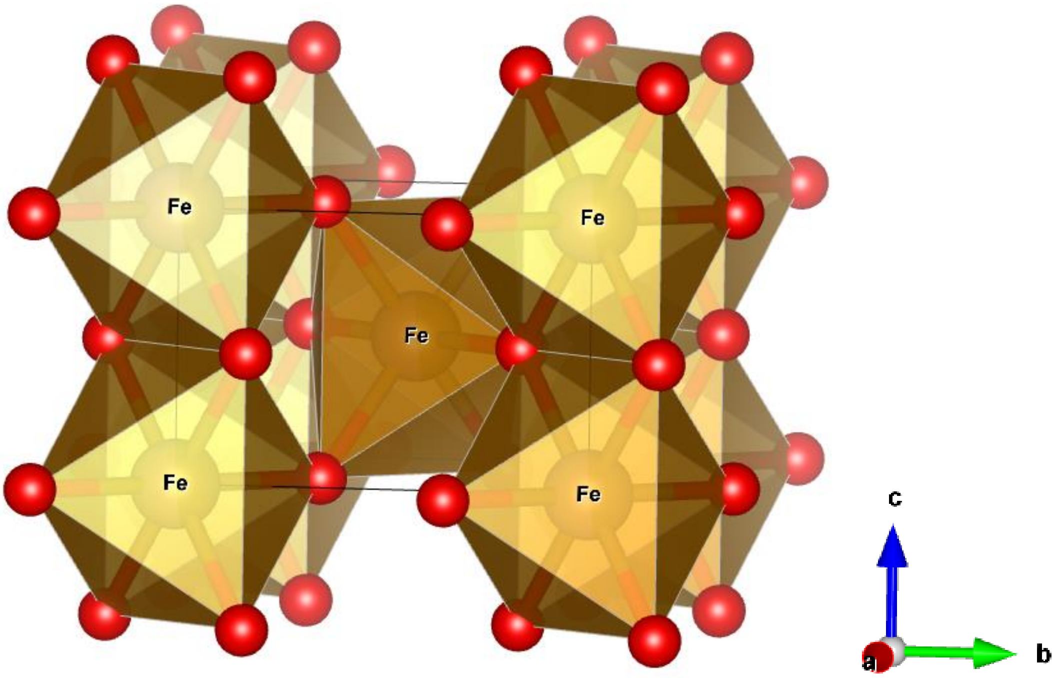

Figure 4.22. View of the crystal structure of tripuhyite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). “Fe” represents Fe and Sb. Data from Berlepsch *et al.* (2003).

Crystal structure. Tripuhyite has a rutile structure, has the ideal chemical formula $FeSbO_4$, and has no long-range Fe-Sb order. (Berlepsch *et al.* 2003, Basso *et al.* 2003). Each cation (Fe^{3+} and Sb^{5+}) is surrounded by six O^{2-} ions in slightly deformed octahedral coordination and each O^{2-} is bounded to three cations in triangular coordination.

Synthetic. Tripuhyite (“squawcreekite”) was synthesised by ball-milling stoichiometric amounts (molar ratio 1: 1) of Fe_2O_3 (Pfizer; 99.9%) and Sb_2O_3 (Aldrich; 99 + %) for 24 h in a minimum quantity of pure water, that were subsequently dried at 353K and sieved. The obtained powder mixture was poured in alumina crucibles and heated in a O_2 flux at 873K for 24 h, leading to the oxidation of Sb_2O_3 to Sb_2O_4; further heating at 1173K for 48 h triggers the reaction between Fe_2O_3 and Sb_2O_4, involving O_2, and the consequent formation of $FeSbO_4$ (Basso *et al.* 2003).

See also. Derbylite, hydroxycalcioroméite, and florencite-(Ce).

Derbylite

Hussak and Prior (1897a)

$Fe^{3+}_4Ti^{4+}_3Sb^{3+}O_{13}(OH)$, monoclinic

Other names: derbylita, derbilite

Figure 4.23. Cotype specimen of derbylite from the Três Cruzes farm cinnabar mine, Tripuí (formerly Tripuhy), Ouro Preto, Minas Gerais. Muséum national d'Histoire naturelle, Paris, France. The label is 5 cm long. Donator: E. Hussak. Photo: Cristiano Ferraris.

Derbylite was first found by Hussak and Prior (1895) and described as a new mineral by Hussak and Prior (1897a).

Occurrence. In the gravel of the Três Cruzes farm cinnabar mine, Tripuí (formerly Tripuhy), Ouro Preto, Minas Gerais. Associated minerals are xenotime, monazite, zircon, kyanite, tourmaline, rutile, hematite, pyrite, magnetite, gold, cinnabar, tripuhyite, hydroxycalcioroméite, florencite-(Ce), muscovite, quartz, and other minerals. Derbylite was first found in loose crystals, from 2 to 3 mm. long, and in fragments of crystals, in the sand. The crystals had often intergrowths of muscovite on the ends of the prisms, similar in this respect to hydroxycalcioroméite ("lewisite"), which often shows inclusions of quartz grains and flakes of muscovite. Later observations proved that both minerals come from the thin-bedded muscovite schist, which accompanies itabirite in the vicinity of Tripuí, and both these minerals have been found intergrown with hematite in fragments of this schist found in the gravel (Hussak and Prior 1897a). Also, found at the Buca della Vena Mine, Ponte Stazzemese (Mellini *et al.* 1983) and Monte Arsiccio Mine, Sant'Anna di Stazzema, (Biagioni *et al.* 2013) both in the Apuan Alps, Tuscany, Italy.

Appearance and physical properties. Prismatic crystals of up to 2 mm length. Forms: {100}, {110}, {120}, {$\bar{1}01$}, {010}, {$\bar{1}02$}, {$\bar{2}01$}, {$\bar{2}11$}, {$\bar{2}31$}. The {hk0} forms are the most highly developed. Twinning: cruciform, consisting of two and three individuals with the composition plane ($\bar{1}53$). Color: dark brown to black. Streak: brown. Luster: resinous to metallic. Transparent to opaque. Hardness (Mohs): 5; VHN_{100}: 1033 to 1121 kg/mm^2. Tenacity: very brittle. Cleavage: none observed. Fracture: conchoidal. Density: 4.62 g/cm^3 (meas.), 4.67 g/cm^3 (calc.).

Optical properties. Biaxial (+), α 2.45, β 2.45, γ 2.51, 2*V* nearly 0°. In reflected light: gray with bluish-green reflections, anisotropism not stated, bireflectance not stated. Pleochroism: absent. R_1, R_2; ${}^{im}R_1$, ${}^{im}R_2$: (19.5, 20.8; 6.66, 7.52) 470 nm; (18.0, 19.2; 5.85, 6.53) 546 nm; (17.5, 18.6; 5.52, 6.18) 589 nm; (17.0, 18.1; 5.26, 5.87) 650 nm.

Chemical data. Electron microprobe data, H_2O calculated to give one OH: TiO_2 36.6, Fe_2O_3 36.0, Sb_2O_3 21.5, Al_2O_3 3.8, Cr_2O_3 0.3, H_2O 1.3, total 99.5 wt.%. Empirical formula: $(Fe_{3.15}Al_{0.52}Cr_{0.03})_{\Sigma 3.70}Ti_{3.20}Sb_{1.03}O_{13.00}(OH)_{1.00}$. The ideal formula requires Fe_2O_3 44.74, TiO_2 33.58, Sb_2O_3 20.42, H_2O 1.26, total 100.00 wt.%.

Crystallography. Monoclinic, $P2_1/m$, *a* 7.160(1), *b* 14.347(3), *c* 4.970(1) Å, β 104.61(2)°, *V* 494.07 Å^3, Z 2, *a*:*b*:*c* = 0.4991:1:0.3464. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 3.997 (18) (021), 3.830 (16) ($\bar{1}21$), 3.186 (45) (140, 121), 3.118 (35) (220), 2.853 (100) (131), 2.647 (75) ($\bar{2}31$), 2.479 (25) ($\bar{1}02$), 2.393 (25) (060), 2.145 (17) ($\bar{2}51$, 061), 1.721 (14) $(\bar{1}62)$. ICDD: 30-90 [sample from Tripuí, U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA, C4430; the ICDD card erroneously gives the provenance as Diamantina, Minas Gerais, and this information was reproduced in the paper on the crystal structure (Moore and Araki 1976b). Derbylite does not occur in Diamantina.].

Name. For Orville Adelbert Derby (1851-1915), director of the Geographical and Geological Survey of the State of São Paulo, director of the Geological Survey of Brazil, and first director of the Brazilian Society of Geology.

Type material. The Natural History Museum, London, England (80143, 1 specimen) (holotype); Muséum national d'Histoire naturelle, Paris, France (97.31, donator E. Hussak, crystals on matrix) (cotype).

Relationship to other species. Isostructural with tomichite, $V^{3+}{}_{4}Ti^{4+}{}_{3}As^{3+}O_{13}(OH)$.

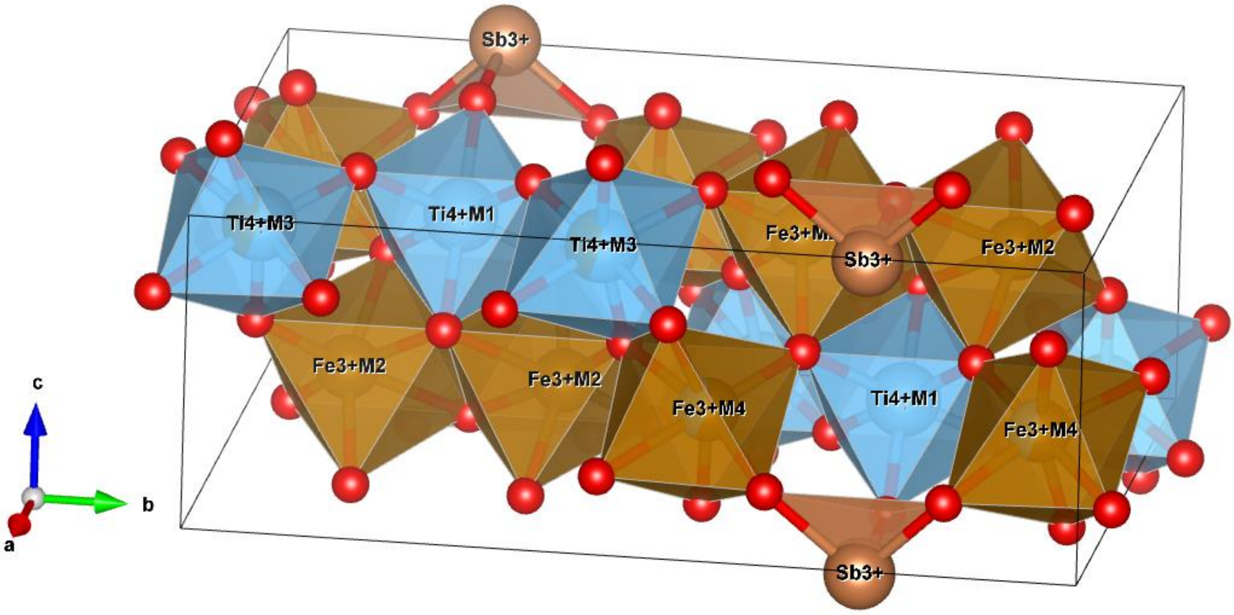

Figure 4.24. View of the crystal structure of derbylite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Moore and Araki (1976b).

Crystal structure. A close-packed oxide structure with sequence ...chh..., the close-packed layers are parallel to {100} and located at x ~ 0,1/3,2/3; determined on a crystal from the type locality (Moore and Araki 1976b).

See also. Tripuhyite, hydroxycalcioroméite, florencite-(Ce), and orvillite.

Guimarãesite (old name)

Gagarin and Cuomo (1949)

Other names: guimarãesita, unnamed mineral of Guimarães (1926b), UM1926-01-O:HNbTaTiU

This mineral was originally described as an unnamed mineral by Guimarães (1926b) in a pegmatite at Divinésia (formerly Divino de Ubá), Minas Gerais. The name guimarãesite was later given to it in honor of Djalma Guimarães (1895-1973), by Gagarin and Cuomo (1949) but it was a doubtful species and therefore cannot be considered a valid species today.

Guimarãesite occurs in parallel and divergent groups, associated with samarskite-(Y), columbite, and monazite in masses of 2 or more kilograms. Dark brown with a pale brown streak. Luster resinous. Fracture subconchoidal. Density 4.49 g/cm^3(meas.). Mohs hardness ~ 5½. Orthorhombic. Similar in habit to samarskite-(Y), but the crystals are flattened following (010) and not (100). In one sample, consisting of half a crystal, Guimarães (1926b) identified the faces (100), (010), and (101). The angle between (101) and $(\bar{1}01)$ in samarskite-(Y) is 87° and in guimarãesite it is approximately 75°. It is incompletely dissolved by warm H_2SO_4 and quickly dissolved by HF. Chemical data: Ta_2O_5 12.61, Nb_2O_5 31.53, TiO_2 19.14, ZrO_2 not detected, ThO_2 2.09, $(Ce,La)_2O_3$ 1.45, $(Y,Er)_2O_3$ 2.18, Fe_2O_3 6.43, UO_3 6.72, UO_2 not detected, SnO_2 0.56, PbO 1.54, CaO 0.36, MgO 0.27, H_2O 5.91, total 90.79 wt.%. Guimarães gives 100.80 as total. Palache *et al.* (1944) gives 6.72 for UO_2, instead of UO_3, and 15.91 for H_2O, total 100.79 wt.%. The first page number of Guimarães' paper is incorrectly given as 56 by Palache *et al.* (1944) and Clark (1993) but it should be page 46. This suggests that the original paper was not consulted, and the data were taken from Mineralogical Abstracts [3, 113], where the pages 56-57 are cited, instead of 46-48, and where it is said that the correct value for H_2O is 15.91 and not 5.91 as stated in the original paper. The empirical formula (based on 15.91 wt.% H_2O) is: $U^{6+}_{0.04}Y_{0.03}Ce^{3+}_{0.01}Mg_{0.01}Ca_{0.01}Pb^{2+}_{0.01})_{\Sigma 0.11}(Ti_{0.40}Nb_{0.40}Fe^{3+}_{0.14}Ta_{0.10}Sn_{0.01}Th_{0.01})_{\Sigma 1.06}[(OH)_{2.97}O_{1.03}]_{\Sigma 4.00}$.

Guimarães (1926b) obtained, in addition, a sample of this mineral associated with samarskite-(Y) and columbite, from São Miguel de Piracicaba, Minas Gerais.

The name guimarãesite was also applied to a phosphate by Chukanov *et al.* (2007).

See also. Guimarãesite, djalmaite, euxamite and oliveiraite.

Alvarolite

Florencio (1952a)

[= tantalite-(Mn)]

Other names: alvarolita

Figure 4.25. Tantalite-(Mn) (“alvarolite”) from the Bananal pegmatite, Salinas, Minas Gerais. About 4 ×3 cm. Specimen # 6428, C.D. Woodhouse collection. Photo: Rock Currier.

The mineral occurs in a pegmatite vein at Salinas, north of Minas Gerais, as twinned transparent crystals. The sample is 2 × 1.7 cm. Chemical analyses (average of 3): Ta_2O_5 85.15, Nb_2O_5 0.23, MnO 14.85, FeO 0.01, Al_2O_3 traces, TiO_2 not detected, total 100.24 wt.%, corresponding to Mn:Ta = 1.07:1 *apfu*. Reddish-brown with a pale yellow (cream) streak. Luster vitreous to adamantine. Density 7.27 g/cm^3 (meas.). Mohs hardness 6.5. Prismatic cleavage, conchoidal fracture. Biaxial (+), α 2.250, β 2.255, γ 2.3, 2*V* 38 to 40° (meas.). Pleochroism: *X* and *Y* very pale yellow, *Z* strong brown, extinction 45°. Non-fluorescent. The name is for Admiral Álvaro Alberto da Motta e Silva (1889-1976), first president of the Conselho Nacional de Pesquisas (CNPq).

Fleischer (1954) evaluated the status of the mineral. He pointed out that there is no discussion by Florencio (1952a) about the differences between alvarolite and tantalite-(Mn) ($MnTa_2O_6$, orthorhombic). Possibly the distinction was based on the extinction angle which indicates that alvarolite is monoclinic. Fleischer (1954) states that alvarolite cannot be accepted as a species until it is proven to be different from tantalite-(Mn).

Alvarolite was discredited and shown to be identical to tantalite-(Mn) by Tavora Filho (1955), who studied a fragment supplied by Florencio. The X-ray diffraction pattern was recorded in the ICDD card for tantalite-(Mn) (7-58). Francesconi (1972) used the name alvarolite for "colorless, transparent, vitreous tantalite" which occurs alongside “black, opaque, metallic tantalite” in the pegmatitic district of Nazareno and São João del Rei, Minas Gerais. He obtained an X-ray diffraction pattern for alvarolite, which is identical to that for tantalite. Moreover, Francesconi *et al.* (1976) used the name alvarolite for a mineral from the same occurrence, variable in color from deep red to white, translucent. Reduced to microscopic dimensions, alvarolite becomes transparent, retaining the color in the case of red specimens. According to them, alvarolite crystallizes in the monoclinic system. However, the same X-ray diffraction pattern presented by Francesconi (1972) matches that of tantalite-(Mn) and no basis is given to justify the monoclinic system.

Bahianite

Moore and Araki (1976a)

$Al_5Sb^{5+}_3O_{14}(OH)_2$, monoclinic

Approved CNMMN - IMA 1974-027

Other names: bahianita, bahiaíta, bahiaite

Figure 4.26. Bahianite from Érico Cardoso, Bahia. Specimen DR237, Museu de Geociências, Universidade de São Paulo. Photo: Thales Trigo.

Figure 4.27. Bahianite from Érico Cardoso, Bahia. Largest piece: 20 × 20 mm. Donator: Jacques Pierre Cassedanne. Museu de Ciências da Terra, Rio de Janeiro. Photo: Marcelo Lerner. Cornejo and Bartorelli (2020).

The crystal structure of bahianite (Moore and Araki 1976a) was published two years before its complete description (Moore *et al.* 1978); additional data were obtained by Cassedanne and Cassedanne (1980) and Cassedanne (1985).

Occurrence. In stream gravel concentrates in the Serra da Mangabeira, Paramirim region, near the village of Paramirim das Crioulas, Érico Cardoso (former Água Quente), Bahia, in a region, roughly within a 25-km radius of the Pico das Almas in the Serra das Almas, usually in cassiterite concentrates. The main occurrence, Morro do Chapéu prospect, is near the 1280 m elevation in the Pico das Almas river valley. Other localities are Serra do Porco Gordo (or Furnas), Brejo de Santa Teresa (or Brejinho), Lageado Preto, Aguada, Mata do Fumo, Riacho do Bosque, Riacho de Canabravinha, all in the Paramirim region, in the counties of Rio de Contas, Livramento do Nossa Senhora (former Livramento de Brumado), and Paramirim. It is associated with cassiterite, quartz, andalusite, kyanite, diaspore, zincian staurolite, gold, and eskolaite.

Appearance and physical properties. Water-worn pebbles ("favas") up to 5 cm, often with vugs, which contain curved and striated bahianite crystals. Commonly contains quartz inclusions. Morphology: not determined. Luster; adamantine; transparent; colorless, tan, pale violet, orange-brown to brown. Mohs hardness 9. Cleavage {100} perfect. Highly resistant to attack by acids or bases. Density 4.89 to 5.46 g/cm^3 (meas.), 5.07 g/cm^3 (calc.). Streak, luminescence, fracture, and tenacity not given.

Optical properties. Biaxial (-), α 1.81(1), β 1.87(1), γ 1.92(1), 2*V* large (meas.), 82° (calc.). Dispersion: $r > v$.

Chemical data. Mean of four sets of wet and electron microprobe analyses, H_2O by Penfield method: Sb_2O_5 57.28, Al_2O_3 35.37, Fe_2O_3 1.04, WO_3 1.20, BeO 0.75, SiO_2 1.03, H_2O 2.77, total 99.44 wt.%. Empirical formula: $(Al_{4.96}W_{0.04})_{\Sigma 5.00}(Sb^{5+}_{2.60}Fe^{3+}_{0.10})_{\Sigma 2.70}(Be_{0.22}Si_{0.13}Al_{0.13})_{\Sigma 0.48}O_{13.74}(OH)_{2.26}$. The ideal formula $Al_5Sb^{5+}_3O_{14}(OH)_2$ requires Sb_2O_5 64.00, Al_2O_3 33.62, H_2O 2.38, total 100.00 wt.%. Moore *et al.* (1978) give a compositional range of $Al_5Sb^{5+}_3O_{14}(OH)_2$ to $Al_5Sb^{5+}_3(Al,Be,Si)_{<2}O_{16}$.

Crystallography. Monoclinic, *C*2/*m*, *a* 9.406, *b* 11.541, *c* 4.410 Å, β 90.94°, *V* 478.66 Å^3, Z 2, *a*:*b*:*c* = 0.8150:1:0.3821. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 4.712 (70) (200), 3.241 (100) ($\bar{2}$01), 3.194 (100) (201), 2.457 (70) (240), 2.411 (70) (041), 2.156 (80) ($\bar{2}$41), 1.648 (70) ($\bar{2}$42), 1.635 (70) (242), 1.624 (70) (170), 1.373 (70) (081). ICDD: 29-3, 29-2 (calculated), 30-76.

Name. For the State of Bahia. Cassedanne and Cassedanne (1980) note that the name "bahiaite" would be more correct than bahianite but the name “bahiaite” had already been used by Washington (1914) for a pyroxenite found near Maracas, Bahia.

Type material. U.S. National Museum of Natural History, Smithsonian Institution, Washington, DC, USA (133875, donated by R.V. Gaines, 1975, and 135922, donated by University of Chicago, thru Moore, 1976); Muséum national d'Histoire naturelle, Paris, France (175.109, donated by J. Cassedanne, 1974; grains in a vial).

Relationship to other species. Structurally similar to simpsonite.

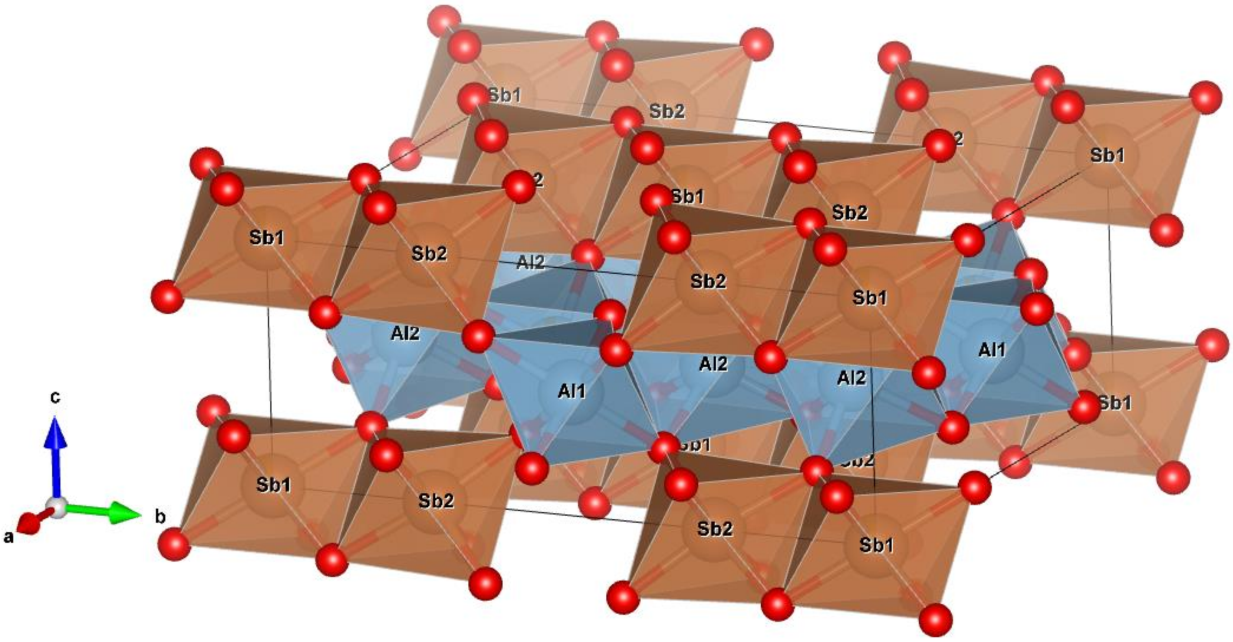

Figure 4.28. View of the crystal structure of bahianite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Moore and Araki (1976a).

Crystal structure. Based on hexagonal close-packed oxygen atoms with anion layers parallel to {001} and a new kind of octahedral ordering: $[Sb_3O_{14}]^{13-}$ edge-sharing trimers at $z = 0$ which corner link to $[Al_5O_{15}(OH)]^{16-}$ edge-sharing sheets at $z = ½$ (Moore and Araki (1976a).

See also. Calogerasite

Calogerasite

Guimarães (1944a and b)

(= simpsonite)

Other names: calogerasita

Figure 4.29. Simpsonite (”calogerasite”) from Alto do Giz, Equador, Rio Grande do Norte. Specimen 8110/1, Museu de Geociências, USP. Photo: Thales Trigo.

After two preliminary descriptions (Guimarães 1942a and 1943), this mineral received the name calogerasite (Guimarães 1944a and b, 1948a), in honor to João Pandiá

Calógeras (1870-1934), Brazilian engineer, geologist and politician. According to the preliminary descriptions, this mineral, from a pegmatite explored for tantalite, between Picuí and Currais Novos, near the boundary between the states of Rio Grande do Norte and Paraíba, occurs as honey-yellow tetragonal crystals, with distinct basal cleavage and conchoidal fracture; density 7.10 to 7.30 g/cm^3 (meas.). Under the microscope, it is colorless and transparent, uniaxial (-), with $n > 2$ and birefringence similar to quartz. An approximate chemical analysis resulted in Ta_2O_5 92, Nb_2O_5 1 to 2, Al_2O_3 3, MgO 2 to 3, CaO 3 wt.%, suggesting the formula $Al_2(Ta_2O_6)_3.(Ca,Mg)Ta_2O_6$.

Analyses on new samples and reported in the complete paper Guimarães (1944a and b, 1948a), gave Ta_2O_5 73.56 and Al_2O_3 26.16 wt.% (average of two analyses), corresponding to the formula $Al_6Ta_4O_{19}$. The occurrence is given as Alto do Giz, municipal district of Equador, Rio Grande do Norte (but Equador is not between Picuí and Currais Novos). Some additional properties were recorded: Faces generally striated, distorted by strain, “colorless” streak, Mohs hardness 6½ to 7, fracture irregular, prismatic habit, observed forms: {0001}, {1010}, and {1120}. It displays straight extinction, birefringence 0.042. The mineral fluoresces under short-wave ultraviolet radiation with a gold-yellow luster especially on the faces and less so on recent fracture surfaces. Another paper on the mineral was published by Rolff (1944). Kerr and Holmes (1945) and Pough (1945) established that calogerasite is identical with simpsonite, $Al_4Ta_3O_{13}(OH)$ hexagonal, originally described by Bowley (1939) from Tabba Tabba, Australia. Both the original specimen of simpsonite and the calogerasite first described by Guimarães (1942a and 1943) were impure, thus obscuring their true properties so that the two minerals appeared to be different. The definitive formula of simpsonite was established from crystal structure studies by Ercit *et al.* (1992a). Alto do Giz is also the type locality of hydrokenomicrolite-3*R*. The alumotantite occurrence in this pegmatite and its structural relationship with simpsonite were described by Ercit *et al.* (1992b). Simpsonite is related to bahianite. New data on simpsonite from Equador was published by the RRUFF project (R050629).

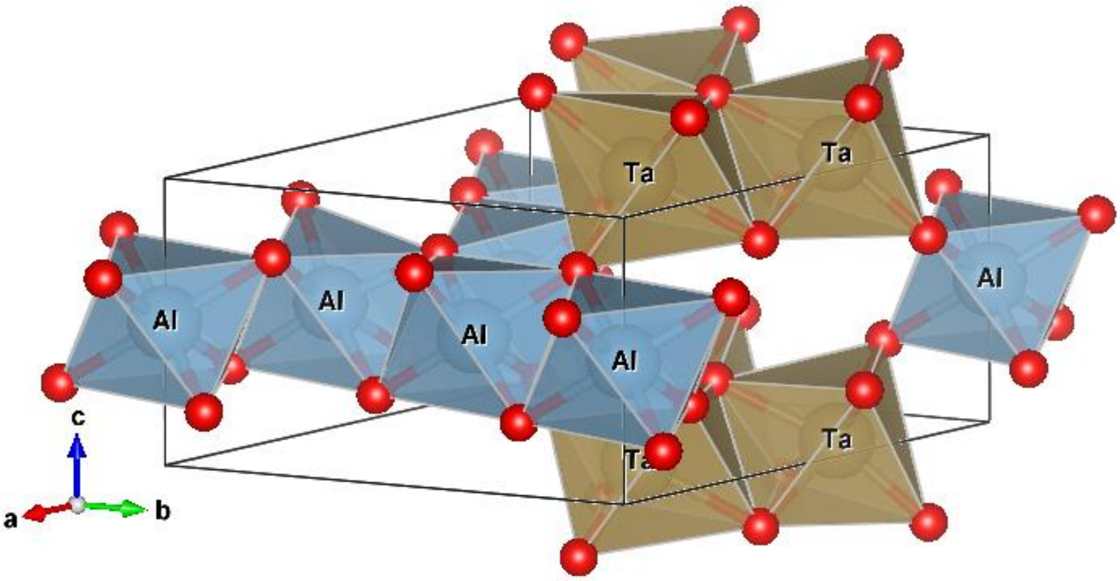

Figure 4.30. View of the crystal structure of simpsonite (“calogerasite” from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Ercit *et al.* (1992a).

See also. Bahianite and hydrokenomicrolite.

Reitingerite

Gagarin and Cuomo (1949)

(= baddeleyite)

Other names: Zirconoxyd, zirconium oxide, reitingerita, brazilite, zirkite, zircite, caldasite, brasilita, brazilita, zirkita, zircita, caldasita

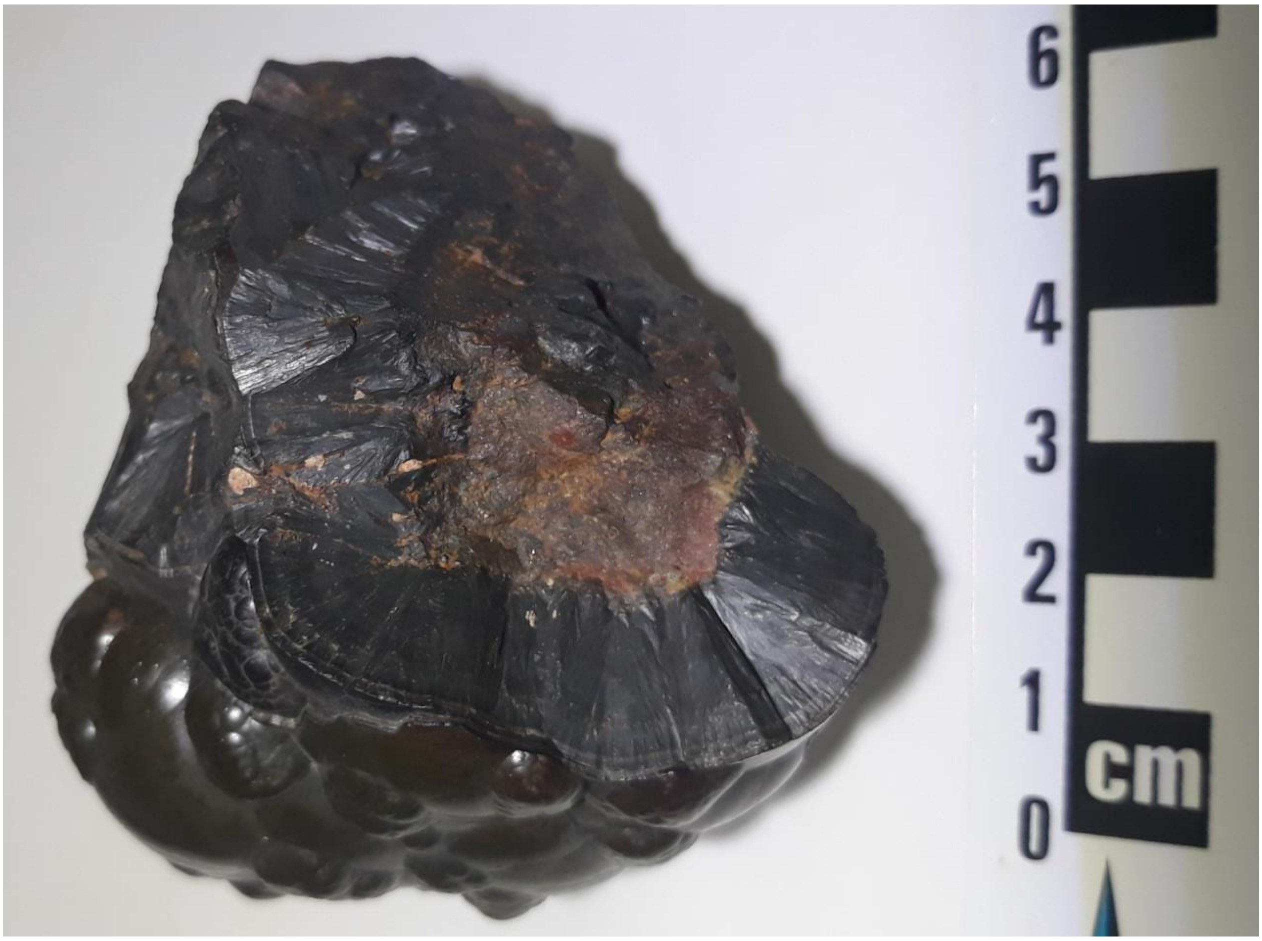

Figure 4.31. Radially fibrous, botryoidal baddeleyite (“reitingerite”) from Poços de Caldas, Minas Gerais. Specimen 511/4, Luiz Paixão collection, Museu de Geociências, Universidade de São Paulo. Photo: Ideval Souza Costa.

Hussak and Reitinger (1903) described zirconium oxide from Serra de Caldas, Minas Gerais, with radially fibrous botryoidal habit, presuming it to be a new zirconia modification, distinct from baddeleyite. They obtained density 5.538 g/cm^3 (meas.) and ZrO_2 97.19 wt.%. Yardley (1926) obtained an X-ray powder diffraction pattern for a similar fragment stored in the Natural History Museum (London, England) and showed it to be identical with baddeleyite, monoclinic ZrO_2. Gagarin and Cuomo (1949) attributed the name reitingerite to the material, in honor of J. Reitinger, of Munich. The names brazilite and zirkite were also used for this material. The name zircite was used by Ferraz (1928). According to Lee (1917 and 1919), the name caldasite had been introduced by Derby for a rock from the area of Caldas consisting almost entirely of baddeleyite. This name, however, was sometimes spelled “caldasita” (e.g. Oliveira 1930, Frayha 1948), as if it represented a mineral name.

See also. Brazilite and zirkite.

Brazilite

Hussak (1892)

(= baddeleyite)

Other names: brazilita, brasilita

Figure 4.32. Slender black baddeleyite ("brazilite") microcrystals to <1mm embedded in sugary quartz matrix with gray to green-gray crystals of forsterite to 3 mm, from the Jacupiranga mine, Cajati, São Paulo. Specimen and photo: Dakota Matrix Minerals, Tom Loomis.

Brazilite was described by Hussak (1892), from samples from Cajati (formerly Cajati was part of Jacupiranga), São Paulo, as a Ta and Nb mineral. Hussak (1893) published the first correct chemical analysis for the mineral (zirconium oxide). Fletcher (1893) verified the identity between brazilite and baddeleyite, ZrO_2 monoclinic, described from Sri Lanka (formerly Ceylon) by Fletcher (1892). Hussak (1895a and b) agreed and used the name baddeleyite for the mineral from Cajati.

According to Fletcher (1893), the name "brazilite" had been used since about 1884 for an oil-bearing rock from Bahia (marauite). Another use of the name "brazilite" refers to a fibrous botryoidal form of zirconium oxide which is perhaps distinct from baddeleyite (Meyer 1917, Schaller 1918, Rodd 1918), and has been named reitingerite.

See also. Reitingerite, quintinite, menezesite, melcherite, zirkelite, pauloabibite, barium phlogopite, and unidentified Ca-Nb oxide.

Zirkite

Anonymous (1916), Meyer (1917)

(= baddeleyite + zircon + “orvillite")

Other names: zirkita, brazilita, brasilita, brazilite

A trade name for a zirconia ore from Brazil containing 73 to 97 wt.% ZrO_2. It is stated to be a mechanical mixture of baddeleyite, zircon and “orvillite”.

See also. Reitingerite, brazilite, and orvillite.

Tantalaeschynite-(Y)

Adusumilli *et al.* (1974)

Type occurrence should not be considered as Brazil

Approved CNMMN - IMA 69-043

Other names: tântalo-aeschynita (Ce), tantal-aeschynite, tantal-aeschynite-(Y), tantal-aeschynita-(Ce), tantalaeschynita-(Y), tantalaeschynita-(Ce), tântalo-esquinita-(Y)

Figure 4.33. Tantalaeschynite-(Y) (rynersonite?) from the Raposa pegmatite, São José do Sabugi, Paraíba. Dimensions: 70 × 50 × 40 mm. Specimen and photo: Luc Vandenberghe.

From semi-quantitative chemical data for a mineral from the Raposa pegmatite, São José do Sabugi, Paraíba, Adusumilli (1968) introduced the name tantal-aeschynite-(Ce) [tântalo-aeschynita (Ce) in Portuguese] but from quantitative chemical data for the same specimen, Adusumilli *et al.* (1974) noted the predominance of Y. The mineral was originally named tantal-aeschynite, later modified to tantalaeschynite-(Y), supposing it to be the Ta-analog of aeschynite-(Y).

Tantal-aeschynite was described as a metamict mineral. When heated it gave an X-ray diffraction pattern similar to that of aeschynite. The formula $[Ca_{0.47}(Y,Ln)_{0.425}(Th,U)_{0.11}](Ta_{0.75}Ti_{0.62}Nb_{0.595}Fe_{0.05})O_6$ was derived from electron microprobe analyses. In Adusumilli *et al.* (1974)'s abstract, the value for Ca was erroneously printed as $Ca_{0.28}$ and the same error was repeated in the American Mineralogist [Amer. Mineral. 59 (1974), 1331-1332] and on the ICDD card 26-1. The correct value, $Ca_{0.47}$, appears in the body of the paper. The formula, recalculated from the original data, resulted in: $(Ca_{0.505}Y_{0.186}Th_{0.112}Ce_{0.103}Nd_{0.051}La_{0.036}Yb_{0.016}Pr_{0.016}Sm_{0.015}Gd_{0.015}Dy_{0.010}Er_{0.009}U_{0.007})_{\Sigma 1.081}$ $(Ta_{0.812}Nb_{0.731}Ti_{0.669}Fe_{0.051})_{\Sigma 2.263}O_6$ with the simplified formula $(Ca,Y)(Ta,Nb,Ti)_2O_6$. The sum Y + REE = 0.457, and Ca = 0.505, so, following the CNMMN - IMA rules of nomenclature (Nickel and Grice 1998), it should not be considered as a REE-mineral. A REE-mineral has REE + Y + Sc > Ca (in atomic numbers), thus, the suffix -(Y) is incorrect. Also, the mineral is not the Ta-analog of aeschynite-(Y) and consequently, the name tantalaeschynite-(Y), as applied for the mineral described by Adusumilli *et al.* (1974) should be reconsidered.

Rynersonite was described by Foord and Mrose (1978) as $Ca(Ta,Nb)_2O_6$ and the mineral from the Raposa pegmatite could be a metamict variety of Y-bearing rynersonite.

The first occurrence of tantalaeschynite-(Y), with the correctly assigned formula, is that of Paszowice quarry, Jawor Co., Lower Silesian Voivodeship, Poland (Szełęg and Ciurla 2004) and should be considered the true type occurrence, not that of the Raposa pegmatite.

Occurrence. Raposa pegmatite, São José do Sabugi, Borborema region, Paraíba. Associated minerals: quartz, red microcline, biotite, small crystals of titanian (?) magnetite, columbite, and beryl. Polished sections show veinlets of an unidentified mineral.

Appearance and physical properties. Euhedral crystals. Forms: {010}, {001}, {110}, and {130} (a crystal of 56 × 31 × 20 mm was used for these studies). Color: brownish-black to black. Streak: pale yellowish-brown. Luster: sub-metallic to resinous. Fracture: conchoidal. Density: 5.75 to 6.13 g/cm^3 (meas.), 6.39 g/cm^3 (calc.). Hardness (Mohs) 5½ to 6; VHN_{100}: 657 to 673 kg/mm^2.

Optical properties. In thin section; transparent, isotropic, yellowish-orange. In polished section; dark gray in oil immersion, with abundant white, yellowish-orange, and dark red internal reflections. Reflectance 470 nm, 14.5; 546 nm, 14.2; 589 and 650 nm, 14.0.

Chemical data. “Tantalaeschynite-(Ce)” (Adusumilli 1968), X-ray fluorescence: CaO 6.80, PbO 0.20, Fe_2O_3 1.00, La_2O_3 0.6, CeO_2 3.60, Nd_2O_3 2.40, Sm_2O_3 0.60, Gd_2O_3 0.70, Dy_2O_3 0.50, Er_2O_3 0.40, Yb_2O_3 0.50, Y_2O_3 3.50, TiO_2 10.00, ThO_2 6.30, UO_2 0.40, Nb_2O_5 17.00, Ta_2O_5 32.00, SnO_2 0.10, total 86.00 wt.%. “Tantalaeschynite-(Y)” (Adusumilli *et al.* 1974), electron microprobe: CaO 6.2, Fe_2O_3 0.9, La_2O_3 1.3, Ce_2O_3 3.7, Pr_2O_3 0.6, Nd_2O_3 1.9, Sm_2O_3 0.6, Gd_2O_3 0.6, Dy_2O_3 0.4, Er_2O_3 0.4, Yb_2O_3 0.7, Y_2O_3 4.6, TiO_2 11.7, ThO_2 6.5, UO_2 0.4, Nb_2O_5 18.7, Ta_2O_5 39.3, total 98.5 wt.%.

Crystallography. Amorphous to X-rays. Material heated in air or nitrogen at 700, 1000, or 1300ºC gave the same X-ray diffraction pattern, similar to aeschynite. Orthorhombic, *Pmnb*, *a* 7.38(2), *b* 10.97(2), *c* 5.34(2)Å, (*a* and *c* interchanged) *V* 432.32 Å^3, Z 4. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 3.71 (30) (200), 3.00 (100) (031), 2.94 (100) (211), 2.65 (50) (002), 2.21 (30) (240), 1.91 (30) (042), 1.86 (40) (400), 1.70 (50) (242), 1.58 (70) (431), 1,52 (30) (402). (Adusumilli *et al.*, 1974, ICDD 26-1)

Name. The name tantalaeschynite was originally used by Kornetova *et al.* (1963) for a mineral from a Siberian pegmatite, metamict, but showing after heating an X-ray diffraction pattern similar to aeschynite-(Y), with Ti:Ta:Nb = 0.89:0.57:0.52, that is, tantalian aeschynite-(Y).

Type material. Instituto de Geociências, Universidade de Brasília, Brasília, and Institute of Earth Sciences, Free University, Amsterdam, Holland. The type specimens in both institutes are labelled NT-52.

Relationship to other species. Aeschynite group.

Euxamite

Anonymous (1922)

[perhaps euxenite-(Y)]

Other names: euxamita

The only extant text for this mineral is the following:

Mrs. Alexander Grosse, F.R.G.S., has just returned from Brazil, from an expedition into the interior, where she discovered a radium mine (euxamite radio-active rare earth).

She is the first English (or American) woman to penetrate into these regions. At the base of the mountains is a medicinal lake used by the natives. This lake is radio-active.

Mrs Grosse is at present in Paris in consultation with Madame Curie.

Times.

From the newspaper Escanaba Morning Press, edition of March 8, 1922, Escanaba, Michigan:

Woman explorer

Mrs. Alexander Grosse, a Fellow of the Royal Geographical Society, has just returned to England from an expedition into the interior of Brazil, where she discovered what she believes to be a radium mine. She has now gone to Paris to consult with Mme. Curie, the famous discoverer of radium.

It is probable that this mineral is euxenite-(Y) from a pegmatite district around the cities of Rio Pomba, Tocantins, Ubá, and Divinésia, Minas Gerais; it was an important producer of euxenite-(Y), polycrase-(Y), samarskite-(Y) etc, until the late 1970's, when the Comissão Nacional de Energia Nuclear (the Brazilian atomic energy department) was buying this material to produce small amounts of U, Th and rare earths; this project was abandoned on the beginning of the 1980's and all those pegmatites were soon abandoned, except the ones that could also produce kaolinite of good grade (Luiz A.D. Menezes Filho 2010, http://www.mindat.org/loc-217598.html).

See also. Guimarãesite (old name) and oliveiraite.

Hydroxykenopyrochlore

Miyawaki *et al.* (2017)

$(\square,\#)_2Nb_2O_6(OH)$, cubic

Approved CNMNC – IMA 2017-030

Other names: hidroxikenopirocloro

Figure 4.34. Floatation concentrate: pyrochlore-group minerals retained on 200# Tyler sieve. CBMM mine, Araxá, Minas Gerais. (Issa Filho *et al.* 2001).

The complete paper on hydroxykenopyrochlore has not yet been published.

Pyrochlore group minerals from Araxá were already known as pyrochlore, bariopyrochlore, ceriopyrochlore, strontiopyrochlore and plumbopyrochlore (Guimarães 1957, van der Veen, 1963, Issa Filho *et al.* 2001, Nasraoui and Waerenborgh 2001, Traversa *et al.* 2001) but they had never been fully described. Hydroxykenopyrochlore corresponds to the old ceriopyrochlore. The Araxá carbonatite is the world's largest Nb deposit.

Occurrence. In the Companhia Brasileira de Metalurgia e Mineração (CBMM) carbonatite mine, Araxá, Minas Gerais. Horiuchi *et al.* (2017) quoted hydroxykenopyrochlore from the type occurrence and also from the Catalão Alkaline Complex, Goiás. Hydroxykenopyrochlore was described in the Kovdor Phoscorite-Carbonatite Complex, NW Russia (Ivanyuk *et al.* 2018 and 2019), and in the Bonga Complex, Angola (Amores-Casals *et al.* 2019).

Chemical data. The simplified formula is $(\square,Ce,Ba)_2(Nb,Ti)_2O_6(OH,F)$. An ideal formula $\square CeNb_2O_6(OH)$ requires Ce_2O_3 37.39, Nb_2O_5 60.56, H_2O 2.05, total 100.00 wt.%.

Crystallography. Cubic, $Fd\bar{3}m$, a 10.590(5) Å. V 1187.65 Å^3, Z 8. X-ray powder diffraction data [d in Å (I) (hkl)]: 6.02 (22) (111), 3.15 (14) (311), 3.02 (100) (222), 2.61 (29) (400), 1.847 (45) (440), 1.576 (32) (622), 1.199 (9) (662), 1.168 (8) (840).

Name. Hydroxykenopyrochlore is named according to the system of nomenclature for the pyrochlore supergroup minerals approved by IMA-CNMNC (Atencio *et al.* 2010a). It is characterized by OH dominance at the *Y* site, □ dominance at the *A* site, and Nb dominance at the *B* site.

Type material. National Museum of Nature and Science, Tsukuba, Japan, registration number NSM-MF16011 (type).

Relationship to other species. A member of the pyrochlore group, pyrochlore supergroup.

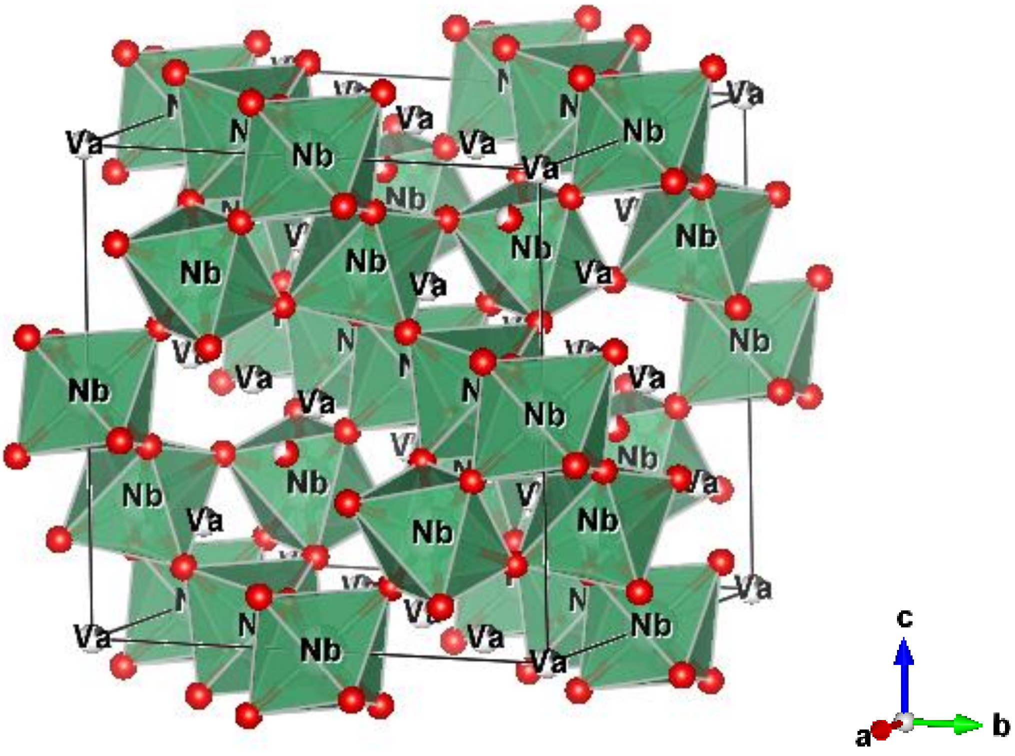

Figure 4.35. View of the crystal structure of hydroxykenopyrochlore (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Based on data from Miyawaki *et al.* (2017) for hydroxykenopyrochlore and from Chukanov *et al.* (2013) for hydroxymanganopyrochlore.

Crystal structure. The octahedra *B* site is occupied by Nb, Ti and others, whereas the *A* site is partially occupied by Ce, Ba and others.

See also. Fluornatromicrolite, fluorcalciomicrolite, hydroxycalciomicrolite, oxycalciomicrolite, hydrokenomicrolite, djalmaite, rijkeboerite, and hydroxycalcioromeite.

Fluornatromicrolite

Witzke *et al.* (2011)

$(Na,\#)_2Ta_2O_6F$, cubic

Approved CNMMN - IMA 1998-018

Other names: fluornatromicrolita

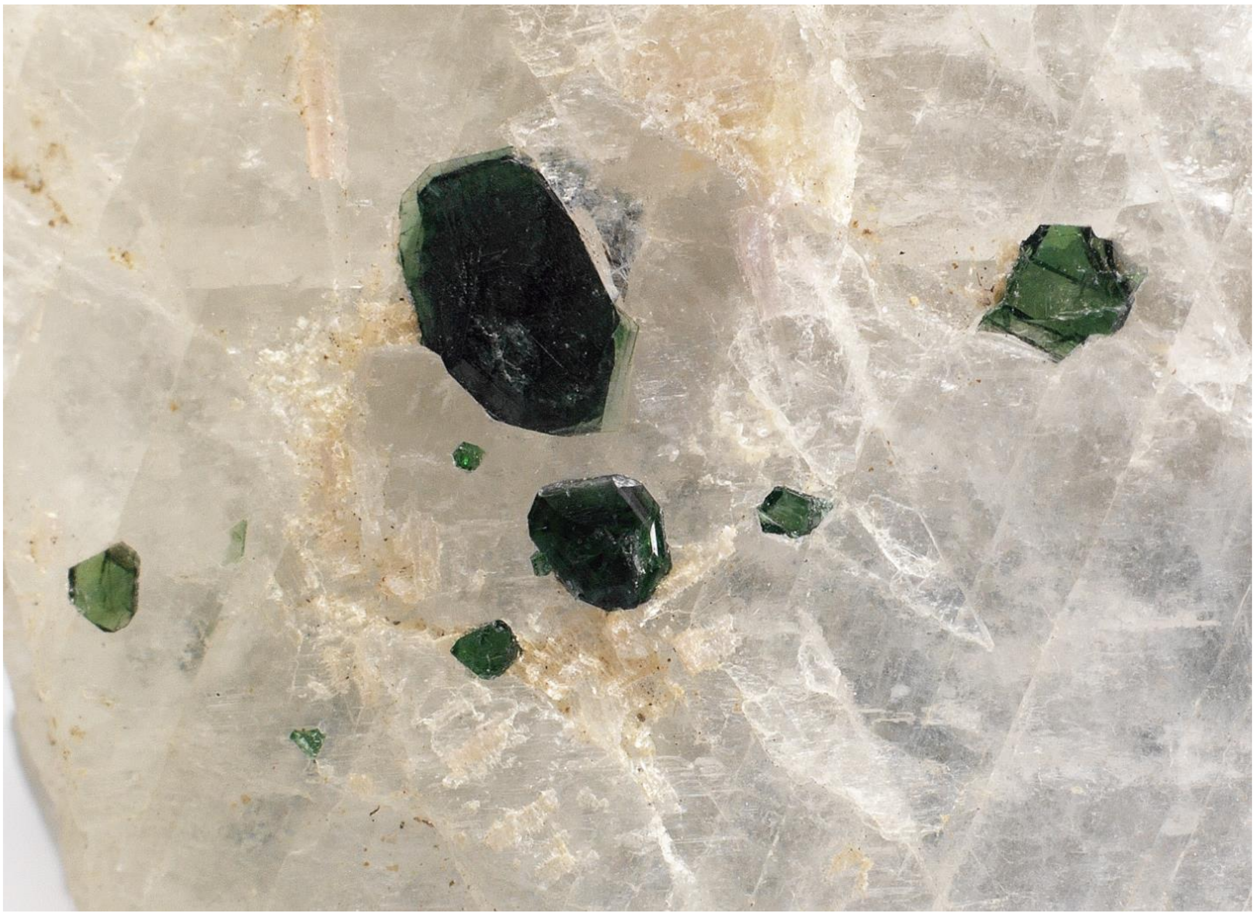

Figure 4.36. Fluornatromicrolite from Frei Martinho, Paraíba. The largest crystal is about 3mm long. Specimen DR290, Museu de Geociências, Universidade de São Paulo. Photo: Thales Trigo.

The IMA proposal 98–018 for fluornatromicrolite was approved in 1998, but the complete paper was only published in 2011. When the paper on fluornatromicrolite was submitted for the first time, in 1998, there were problems because, although approved by the CNMMN–IMA, the name fluornatromicrolite did not match the nomenclature of Hogarth (1977), then still *de rigueur*. Today, however, the name fluornatromicrolite is perfectly in line with the approved system of nomenclature (Atencio *et al.* 2010a).

Occurrence. Alto Quixabá pegmatite, 3 km North-west of Quixabá, Frei Martinho Co., Paraíba. The associated minerals are albite, quartz, elbaite, muscovite, amblygonite, and tantalite-(Mn). Chemical compositions that correspond to fluornatromicrolite from other occurrences are available in the papers by Ohnenstetter and Piantone (1992), Belkasmi *et al.* (2000), Huang *et al.* (2002) and Baldwin *et al.* (2005). An intermediate member between fluorcalciomicrolite and fluornatromicrolite, close to $NaCaTa_2O_6F$, from the Morro Redondo Mine, Coronel Murta, Minas Gerais, was studied by Andrade *et al.* (2011). The RRUFF Database contains data for the type material. In addition, a brown octahedron crystal constituted by a mixture of fluorcalciomicrolite dominated by fluornatromicrolite, associated with albite, from the Ponte da Raiz mine, Minas Gerais, is registered (R070365).

Appearance and physical properties. Crystals up to 6 mm. Habit: equant and flattened Forms: {111} octahedra. Twinning: none observed. Color: green. Streak: white. Luster: adamantine. Transparent. Hardness (Mohs): 5. Tenacity: brittle. Cleavage: none observed. Fracture: conchoidal. Density (meas.) 6.49(6) g/cm. Density (calc.) 6.632 g/cm^3 using the empirical formula.

Optical properties. Isotropic. The index of refraction measured by the immersion method is above 2.0 (wavelength 589 nm). An ellipsometric determination at 633 nm using a He–Ne laser yielded an index of refraction of 2.110(25).

Chemical data. Witzke *et al.* (2011): Microprobe (WDS mode) analyses (17): Na_2O 6.39, CaO 6.96, Bi_2O_3 6.71, Ta_2O_5 76.81, F 3.63, less O = F -1.53, total 98.97 wt.%. Empirical formula: $(Na_{1.19}Ca_{0.71}Bi_{0.17})_{\Sigma 2.07}Ta_{2.00}O_{6.00}F_{1.10}$ [The calculated formula in Witzke *et al.* (2011) is in error]. RRUFF Database (R060589): Microprobe (WDS mode) analyses (10): Na_2O 5.45, CaO 6.73, Bi_2O_3 7.19, Ta_2O_5 76.13, F 3.03, less O = F -1.28, total 97.25 wt.%. Empirical formula: $(Na_{1.02}Ca_{0.70}Bi_{0.18})_{\Sigma 1.90}Ta_{2.00}O_{6.00}(F_{0.93}O_{0.02})_{\Sigma 0.95}$. Use of only dominant species on each site suggests the ideal fluornatromicrolite ‘‘end-member’’ formula $Na_2Ta_2O_6F$, which is not electrically neutral and hence is physically impossible. Consequently, the formula $(Na,\#)_2Ta_2O_6F$ is appropriate.

Crystallography. Witzke *et al.* (2011): Cubic, $Fd\bar{3}m$, *a* 10.4451(2) Å, *V* 1139.56(8) Å^3, Z 8. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 6.023 (31) (111), 3.148 (33) (311), 3.015 (100) (222), 2.610 (27) (400), 2.010 (17) (333, 511), 1.846 (59) (440), 1.574 (47) (622), 1.198 (23) (662), 1.168 (18) (840), 0.8828 (21) (10 6 2). RRUFF Database (R060589): Cubic, $Fd\bar{3}m$, *a* 10.434(1) Å, *V* 1136.1(1) Å^3, *Z* 8 (single-crystal).

Name. Fluornatromicrolite is named according to the system of nomenclature for the pyrochlore supergroup minerals approved by IMA-CNMNC (Atencio *et al.* 2010a). It is characterized by F dominance at the *Y* site, Na dominance at the *A* site, Ta dominance at the *B* site.

Type material. The Mineralogical Collection of the Technische Universität, Bergakademie, Freiberg, Germany (micromount, No. 77975, donated by T. Witzke) (holotype); the Mineralogical Collection of the Martin-Luther Universität Halle, Institut für Geologische Wissenschaften, Halle, Germany (No. 010356) (type).

Relationship to other species. A member of the microlite group, pyrochlore supergroup.

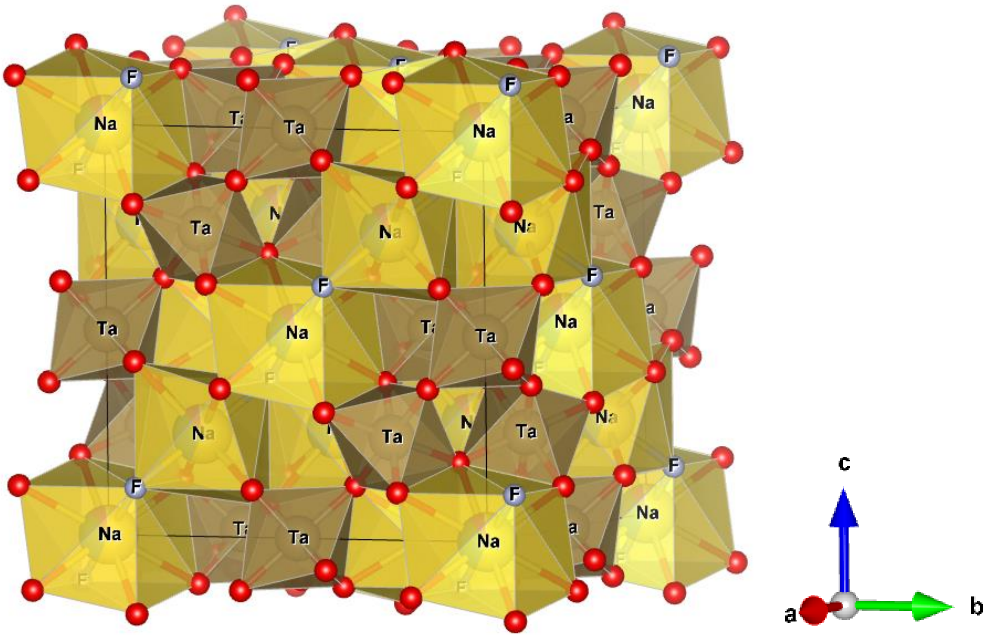

Figure 4.37. View of the crystal structure of fluornatromicrolite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Witzke *et al.* (2011).

Crystal structure. Fluornatromicrolite belongs to the pyrochlore structure type with the 8*a* position fully occupied by F. The 16*c* position (coordination number 8) is occupied by Na, Ca, and Bi. Two corners of this polyhedron are F-atoms. Ta occupies the 16*d* position and is coordinated by 6 equivalent O-atoms. The structure is built up of TaO_6 octahedra and $(Na,Ca,Bi)O_6F_2$ polyhedra. The (Na,Ca,Bi)–F distances are significantly shorter than the (Na,Ca,Bi)–O distances (Witzke *et al.* 2011).

See also. Hydroxykenopyrochlore, fluorcalciomicrolite, hydroxycalciomicrolite, oxycalciomicrolite, hydrokenomicrolite, djalmaite, rijkeboerite, and hydroxycalcioromeite.

Fluorcalciomicrolite

Andrade *et al.* (2013b)

$(Ca,\#)_2Ta_2O_6F$, cubic

Approved CNMNC – IMA 2012-036

Other names: fluorcalciomicrolita

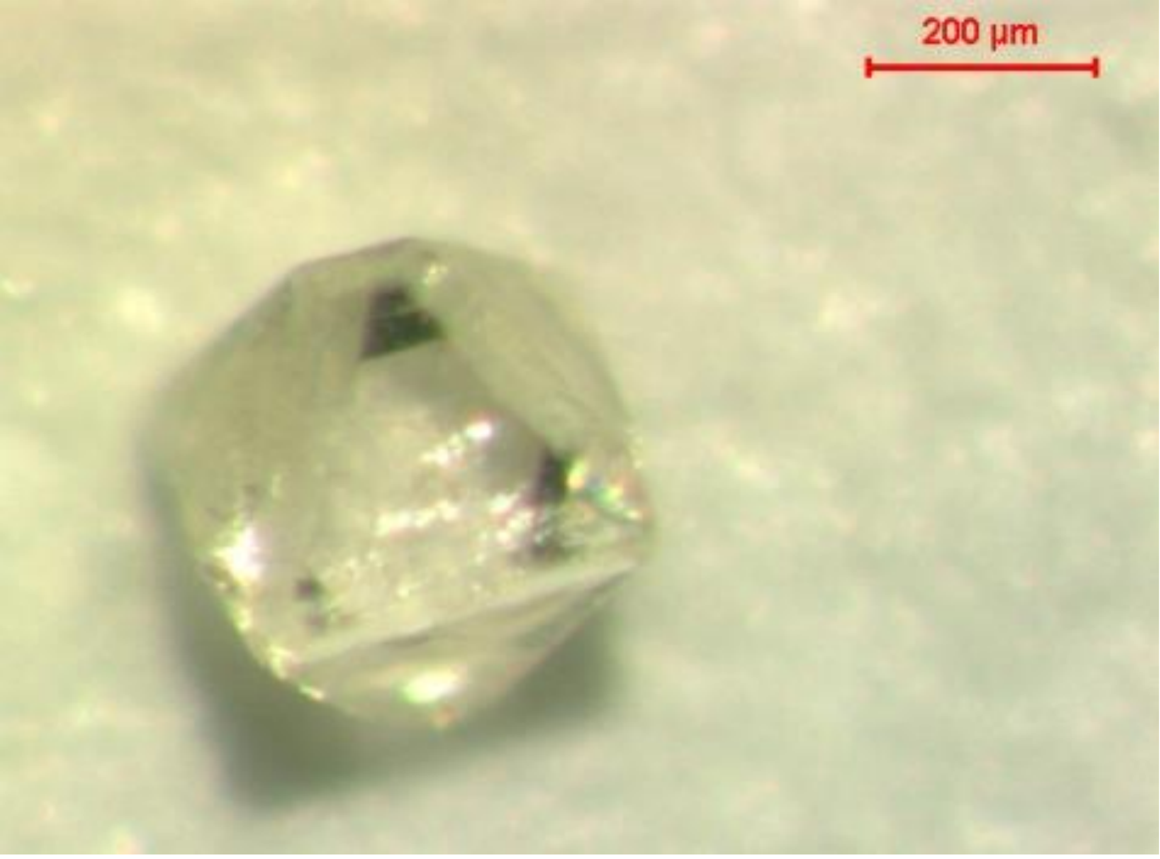

Figure 4.38. Fluorcalciomicrolite from Nazareno, Minas Gerais (type specimen). Photo: Daniel Atencio.

Figure 4.39. Fluorcalciomicrolite from Nazareno, Minas Gerais (RRUFF R120127). Andrade *et al.* (2013b)

Occurrence. The type fluorcalciomicrolite occurs as an accessory mineral in the Volta Grande pegmatite, Nazareno, Minas Gerais, and is associated with albite, apatite, beryl, cassiterite, epidote, fluorite, gahnite, “garnet”, gahnite, hydrokenomicrolite, hydroxycalciomicrolite, “lepidolite”, magnetite, microcline, monazite-(Ce), muscovite, quartz, rutile, spodumene, tantalite-(Mn), tourmaline, and zircon. This pegmatite belongs to the Sn-Ta-rich São João del Rei Pegmatite Province (Heinrich 1964, Lagache and Quéméneur 1997, Atencio *et al.* 2002, Faulstich *et al*. 2016). Nazareno is also the type locality of hydrokenomicrolite, hydroxycalciomicrolite, and oxycalciomicrolite. The fluorcalciomicrolite crystals were collected in a heavy minerals concentrate, so the paragenetic position has not been established. Other crystals of different colors, also corresponding to microlite group minerals, occur in the same concentrate. Some of these crystals are constituted by the association between hydrokenomicrolite and fluorcalciomicrolite, which may suggest that hydrokenomicrolite is an alteration product of fluorcalciomicrolite. The crystals used for the characterization of fluorcalciomicrolite, however, are homogeneous. Electron microprobe analyses showing fluorcalciomicrolite composition have been reported earlier, *e.g.,* Lumpkin *et al.* (1986), Baldwin (1989), Ohnenstetter and Piantone (1992), Tindle and Breaks (1998), Huang *et al.* (2002), Geisler *et al.* (2004), Tindle *et al.* (2005), but a complete description is missing. An intermediate member between fluorcalciomicrolite and fluornatromicrolite, close to $NaCaTa_2O_6F$, from the Morro Redondo mine, Coronel Murta, Minas Gerais, was studied by Andrade *et al.* (2011). The RRUFF Database has data for the type material and for four other Minas Gerais occurrences of fluorcalciomicrolite: Urubu mine, Itinga; Urucum mine, Galileia; Ipê mine, Marilac; and Virgem da Lapa. A brown octahedron crystal constituted by a mixture of fluorcalciomicrolite dominated by fluornatromicrolite, associated with albite, from Ponte da Raiz mine, Minas Gerais, is registered (R070365). Data for fluorcalciomicrolite from Emdal mines, Muiane, Mozambique, are also available in that database.

Appearance and physical properties. Crystals from 0.1 to 1.5 mm in size. Habit: euhedral. Forms: octahedral {111}, occasionally modified by rhombododecahedra {110}. Twinning: none observed. Color: colorless. Streak: white. Luster: vitreous to resinous. Translucent. Non-fluorescent. Hardness (Mohs): not measured, but probably 4½ – 5. Tenacity: brittle. Cleavage: none observed. Fracture: conchoidal. Density could not be measured because of a lack of sufficient pure material. Density (calc.) 6.160 g/cm^3 using the empirical formula.

Optical properties. Isotropic, $n_{calc.}$ 1.992 for the empirical formula (from the Gladstone-Dale relationship).

Chemical data. Microprobe (WDS mode) analyses (6), the contents of Bi, Ti, Mg and As are below detection limits. The amount of OH was assigned to obtain charge balance of the empirical formula and water was calculated accordingly. Na_2O 4.68, CaO 11.24, MnO 0.01, SrO 0.04, BaO 0.02, SnO_2 0.63, UO_2 0.02, Nb_2O_5 3.47, Ta_2O_5 76.02, F 2.80, H_2O 0.48, O=F –1.18, total 98.23. Empirical formula (based on 2 cations at the B-site) is $(Ca_{1.07}Na_{0.81}\square_{0.12})_{\Sigma 2.00}(Ta_{1.84}Nb_{0.14}Sn_{0.02})_{\Sigma 2.00}[O_{5.93}(OH)_{0.07}][F_{0.79}(OH)_{0.21}]$. The simplified formula requires CaO 15.66, Ta_2O_5 82.29, F 3.54, O = F -1.49, total 100.00 wt.%.

Crystallography. Cubic, $Fd\bar{3}m$, *a* 10.4191(6) Å. *V* 1131.07(11) Å^3, *Z* 8 (single-crystal), *a* 10.417(1) Å. *V* 1130.41(19) Å^3, *Z* 8 (powder data). X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 5.997 (59) (111), 3.138 (83) (311), 3.005 (100) (222), 2.602 (29)

(400), 2.004 (23) (511), 1.841 (23) (440), 1.589 (25) (533), 1.504 (24) (444).

Name. Fluorcalciomicrolite is named according to the system of nomenclature for the pyrochlore supergroup minerals approved by IMA-CNMNC (Atencio *et al.* 2010a). It is characterized by F dominance at the *Y* site, Ca dominance at the *A* site, Ta dominance at the *B* site.

Type material. Museu de Geociências, Instituto de Geociências, Universidade de São Paulo, sample number DR731 (type). Part of the cotype sample has been deposited at the RRUFF Project, University of Arizona, Mineralogical Collection, Geological Museum, Tucson, deposition number R120127.

Relationship to other species. A member of the microlite group, pyrochlore supergroup.

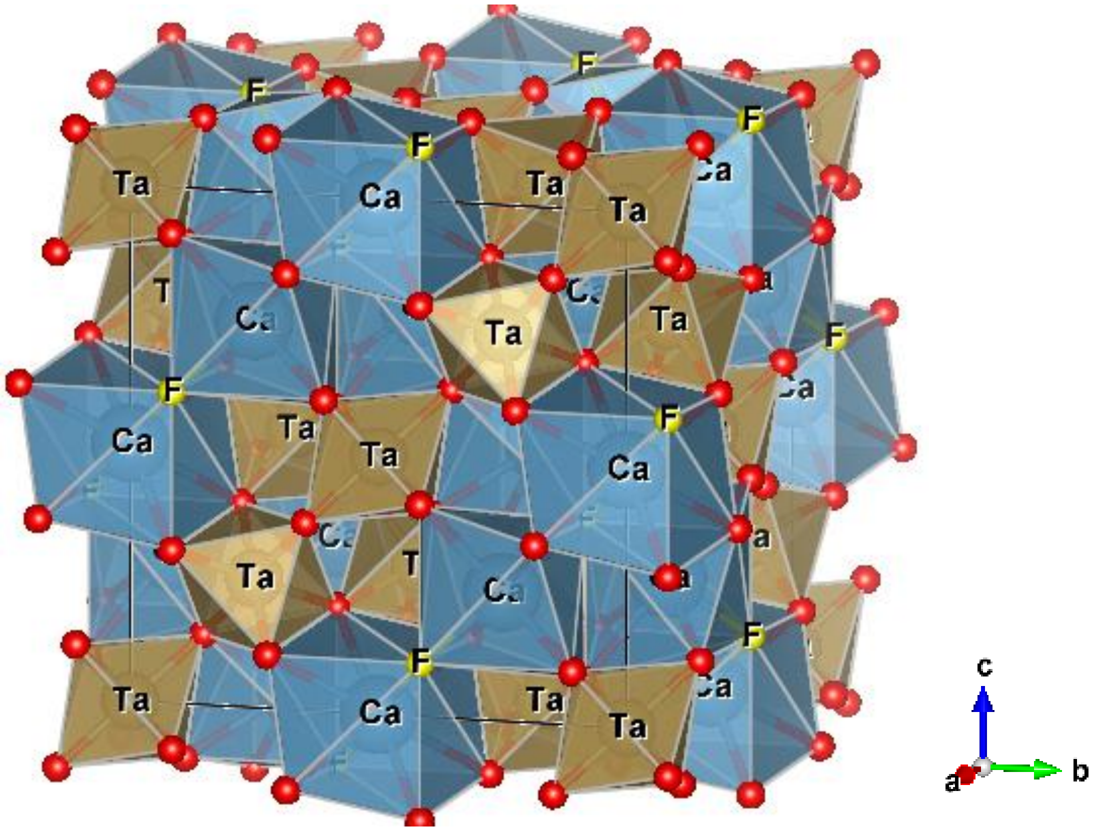

Figure 4.40. View of the crystal structure of fluorcalciomicrolite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Andrade *et al.* (2013b).

Crystal structure. The classic pyrochlore structures have all atoms occupying special positions ($A = 1d$, $B = 16c$, $X = 48f$ and $Y = 8b$) in $Fd\bar{3}m$ (Subramanian *et al.* 1983). The *A* position was initially assumed to be $A(16d)$ and the occupation was constrained by the microprobe chemical analysis as $(Ca_{1.04}Na_{0.91})_{\Sigma 1.95}$. The *X* and *B* sites were set at full occupancy and *B* was constrained to the value obtained from the chemical analysis, $(Ta_{1.76}Nb_{0.13}Si_{0.09}Sn_{0.02})_{\Sigma 2.00}$. The *Y* position was refined anisotropically and located at Wyckoff position 8*b*. The *Y* occupancy did not present any positional disorder during refinement. Charge balance was maintained by replacing O by OH at the *X* (48*f*) position, $[(O_{5.89}(OH)_{0.11}]_{\Sigma 6.00}$ (Andrade *et al.* 2013b).

See also. Hydroxykenopyrochlore, fluornatromicrolite, hydroxycalciomicrolite, oxycalciomicrolite, hydrokenomicrolite, djalmaite, rijkeboerite, and hydroxycalcioromeite.

Hydroxycalciomicrolite

Andrade *et al.* (2017)

$(Ca,\#)_2Ta_2O_6(OH)$, cubic

Approved CNMNC – IMA 2013-073

Other names: hidroxicalciomicrolita

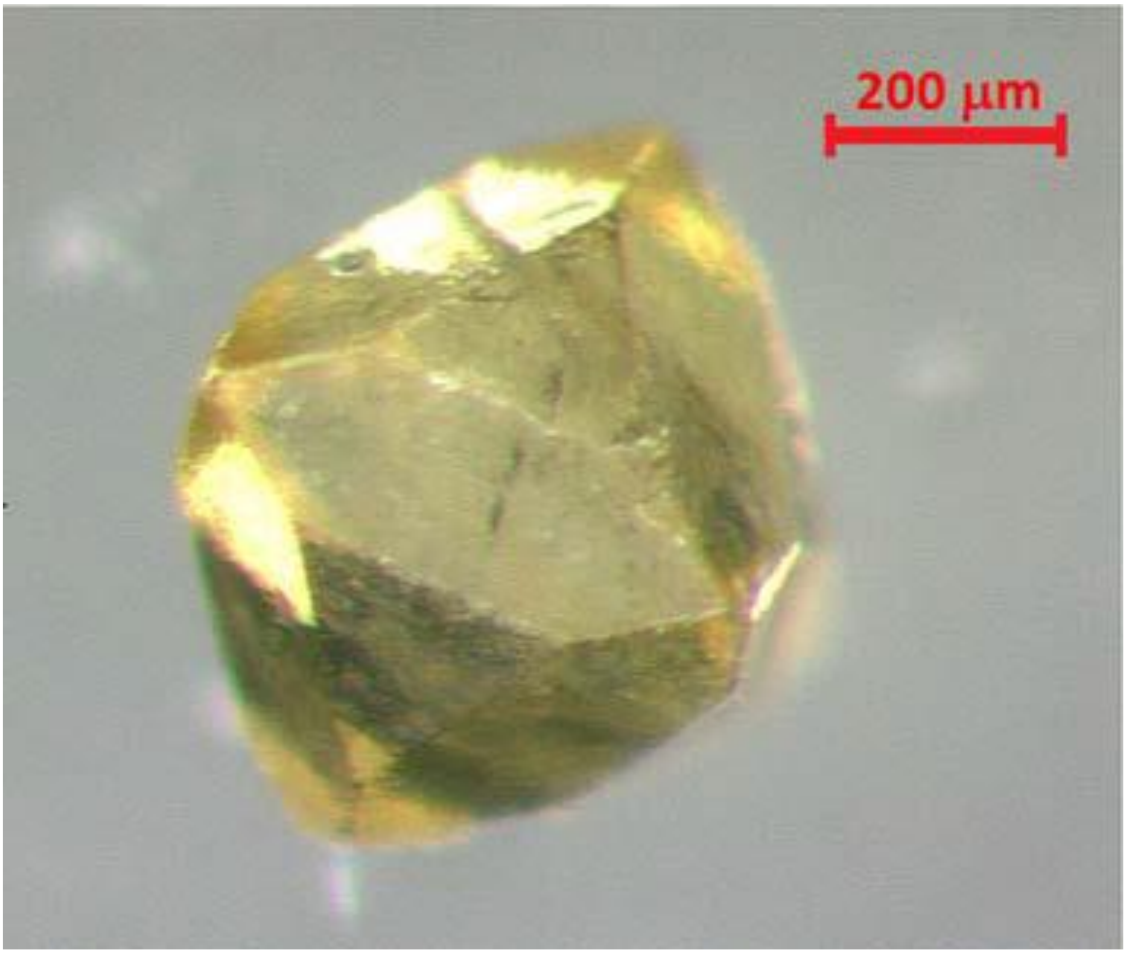

Figure 4.41. Hydroxycalciomicrolite crystal from Nazareno, Minas Gerais (Andrade *et al.* 2017)

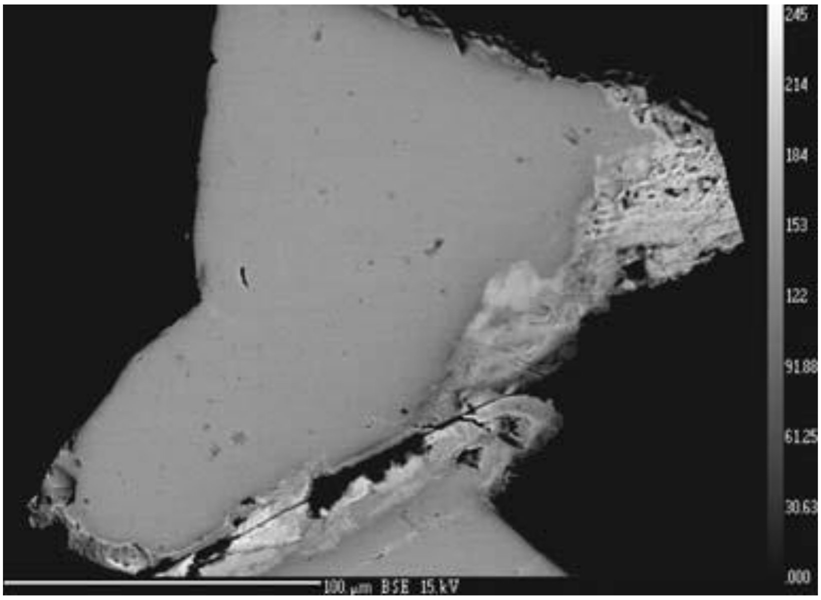

Figure 4.42. Backscattered electron image of the hydroxycalciomicrolite grain analyzed by Andrade *et al*. (2017).

Occurrence. Hydroxycalciomicrolite occurs as an accessory mineral in the Volta Grande pegmatite, Nazareno, Minas Gerais, and is associated with albite, apatite, beryl, cassiterite, epidote, fluorcalciomicrolite, fluorite, gahnite, "garnet", gahnite, hydrokenomicrolite, "lepidolite", magnetite, microcline, monazite-(Ce), muscovite, quartz, rutile, spodumene, tantalite-(Mn), tourmaline, and zircon. The hydroxycalciomicrolite crystals were collected in a heavy-minerals concentrate, so the paragenetic position has not been established. This pegmatite belongs to the Sn-Ta-rich São João del Rei Pegmatite Province (Heinrich 1964, Lagache and Quéméneur 1997, Atencio *et al.* 2002, Faulstich *et al*. 2016). Nazareno is also the type locality of hydrokenomicrolite, fluorcalciomicrolite and oxycalciomicrolite.

Appearance and physical properties. Crystals from 0.2 to 1.5 mm in size. Habit: equant, euhedral to anhedral. Forms: {111} octahedra, {110} rhombododecahedra. Twinning: none observed. Color: yellow. Streak: white. Luster: vitreous to resinous. Translucent. Non-fluorescent. Hardness: not measured. Tenacity: brittle. Cleavage: none observed. Fracture: conchoidal. Density could not be measured due to the absence of heavy liquids with $D > 5$ g/cm^3 and insufficient amounts of material to measure density by hydrostatic weighing or volumetric methods. Density (calc.) 6.176 g/cm^3 (using the empirical formula and unit-cell parameters from crystal structure).

Optical properties. Isotropic, $n_{\text{calc.}}$ 2.010 (from the Gladstone-Dale relationship).

Chemical data. Microprobe (WDS mode) analyses (16), Ti and U contents are below detection limits. H_2O was calculated by stoichiometry from the results of the crystal structure analysis. The presence of OH was confirmed by IR and Raman spectroscopy. Na_2O 0.43, CaO 15.03, SnO_2 0.65, Nb_2O_5 2.94, Ta_2O_5 76.41, MnO 0.11, F 1.09, H_2O 1.09, O = F -0.46, total 97.29. Empirical formula (based on 2 cations at the B-site) is $(Ca_{1.44}Na_{0.07}Mn_{0.01})_{\Sigma 1.52}(Ta_{1.86}Nb_{0.12}Sn_{0.02})_{\Sigma 2.00}O_6[(OH)_{0.65}F_{0.31}]$. The simplified formula requires CaO 15.72, Ta_2O_5 82.59, H_2O 1.68, total 100.00 wt.%.

Crystallography. Cubic, $P4_332$, *a* 10.4211(8) Å. *V* 1131.72(15) Å^3, *Z* 8 (single-crystal), *a* 10.4280(8) Å. *V* 1134.0(2) Å^3, *Z* 8 (powder data). X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 6.025 (100) (111), 3.145 (15) (311), 3.010 (73) (222), 2.606 (7) (400), 2.006 (7) (511, 333), 1.843 (8) (440), 1.762 (4) (531), 1.572 (5) (622), 1.505 (4) (444).

Name. Hydroxycalciomicrolite is named according to the system of nomenclature for the pyrochlore supergroup minerals approved by IMA-CNMNC (Atencio *et al.* 2010a). It is characterized by OH dominance at the *Y* site, Ca dominance at the *A* site, Ta dominance at the *B* site, and a *P* cubic lattice. Also, minor amounts of *F* cubic lattice crystals are present in the heavy minerals concentrate.

Type material. Museu de Geociências, Instituto de Geociências, Universidade de São Paulo, sample number DR917 (type). Part of the cotype sample has been deposited at the RRUFF Project, University of Arizona, Mineralogical Collection, Geological Museum, Tucson, deposition number R130269.

Relationship to other species. A member of the microlite group, pyrochlore supergroup.

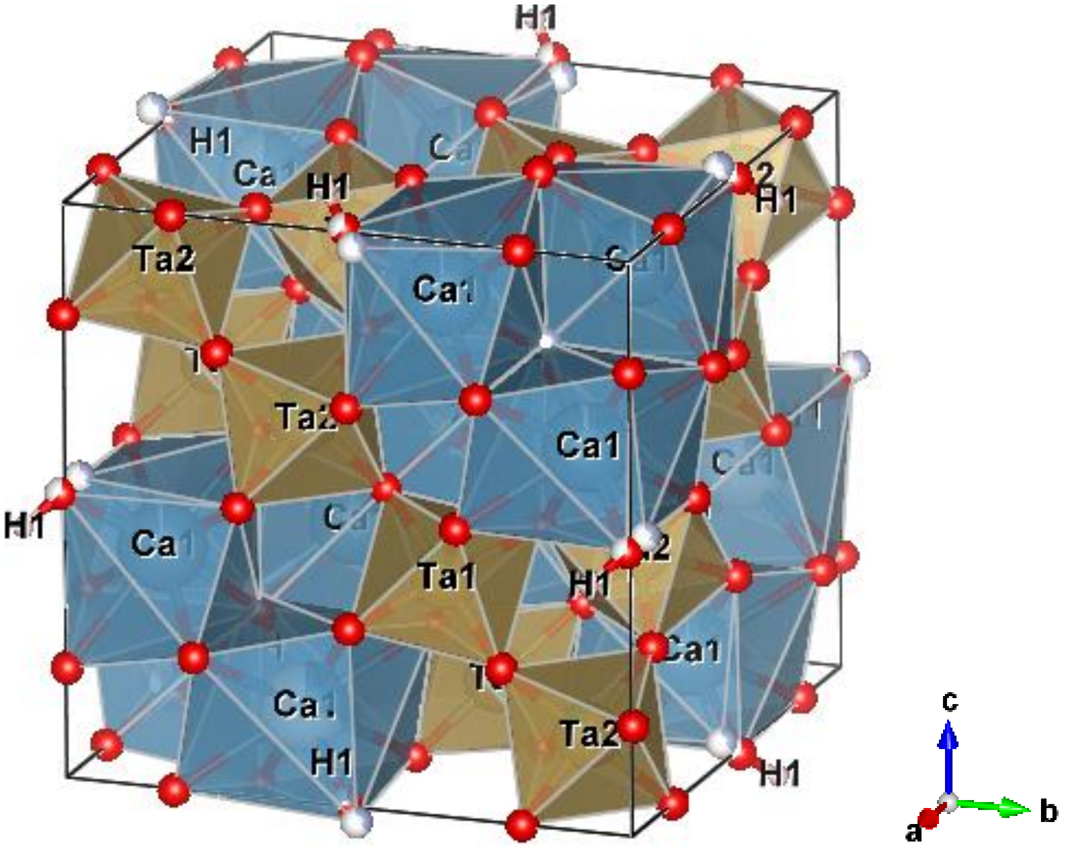

Figure 4.43. View of the crystal structure of hydroxycalciomicrolite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Andrade *et al.* (2017).

Crystal structure. This is the first pyrochlore-supergroup mineral exhibiting $P4_332$ symmetry, rather than $Fd\bar{3}m$. The presence of the P-lattice is demonstrated by the weak reflections (~ 70% of the total) violating the conditions for the F-centered lattice. Also, the splitting in the OH stretching region, 3580 and 3599 cm^{-1} for IR and 3586 and 3614 cm^{-1} for Raman, confirms this $F – P$ lowering of symmetry. This symmetry change has been observed in the synthetic compounds $Ca_{1.5}Ta_2O_6F$ and $Ca_{1.5}Nb_2O_6F$ while exploring thermal properties related to their synthesis processes (Le Berre *et al.* 2007). Initially, the refinement model assumed $Fd\bar{3}m$ space group, and the site occupancies were constrained to the microprobe chemical analysis. The final results exhibited excessive anisotropic ADPs associated with the $Y(8b)$ position suggesting the presence of positional disorder and a large number of reflections violating $Fd\bar{3}m$ symmetry.

See also. Hydroxykenopyrochlore, fluornatromicrolite, fluorcalciomicrolite, oxycalciomicrolite, hydrokenomicrolite, djalmaite, rijkeboerite, and hydroxycalcioromeite.

Oxycalciomicrolite

Menezes da Silva *et al.* (2020)

$Ca_2Ta_2O_6O$, cubic

Approved CNMNC – IMA 2019-110

Other names: oxicalciomicrolita

Figure 4.44. Oxycalciomicrolite from the Fumal pegmatite, Nazareno, Minas Gerais (Menezes da Silva *et al*. 2020)

Preliminary data on this mineral were published by Menezes da Silva *et al*. (2017 and 2018) and Menezes da Silva (2018)

Occurrence. An accessory mineral in the Fumal pegmatite, Nazareno, Minas Gerais. Crystals were collected in a heavy mineral concentrate from its saprolite and are associated with quartz, albite, microcline, muscovite, tantalite-(Fe), cassiterite, hematite, ilmenite, monazite-(Ce), xenotime-(Y), zircon, beryl, spinel, epidote, garnet group minerals, and other microlite group minerals (fluorcalciomicrolite, hydrokenomicrolite, "kenomicrolite" and "hydromicrolite"). The pegmatite belongs to the Sn-Ta-Li-rich São João del Rei Pegmatite Province (Heinrich 1964, Lagache and Quéméneur 1997, Atencio *et al.* 2002, Faulstich *et al.* 2016). Nazareno is also the type locality of hydrokenomicrolite, fluorcalciomicrolite and hydroxycalciomicrolite. Oxycalciomicrolite occurs also at Ipê mine, Governador Valadares, Minas Gerais (Andrade 2007). Two compositions of "stibiomicrolite" from Varuträsk, Skellefteå, Västerbotten County, Sweden, by Černý *et al.* (2004) are oxycalciomicrolite, and one is "calciomicrolite" (Atencio *et al.* 2010a). A sample quoted as microlite from Alpe Rosso, Orcesco, Verbano-Cusio-Ossola Province, Piedmont, Italy (Guastoni *et al.* 2008) is oxycalciomicrolite (Atencio *et al.* 2010a). Oxycalciomicrolite occurs at Malpensata pegmatitic dike (Olgiasca-Malpensata; Croce Quarry; Secondi dike), Piona Peninsula, Colico, Lecco Province, Lombardy, Italy (Vignola *et al.* 2011).

Appearance and physical properties. Octahedra, occasionally modified by rhombododecahedra crystals, from 0.2 to 0.5 mm in size. Color: brownish-yellow to brownish-red. Streak: white. Luster: vitreous to resinous. Non-fluorescent. Hardness (Mohs) was not measured, but probably 5 - 5½. Cleavage: not observed. Parting: not observed. Tenacity: brittle. Fracture: conchoidal. Density (meas.) could not be measured due to lack of pure material. Density (calc.) = 6.333 g/cm^{-} using the empirical formula and unit cell volume refined from single-crystal X-ray diffraction data. Magnetic properties: diamagnetic

Optical properties. Translucent. Isotropic, $n_{\text{calc.}}$ 2.037 (from the Gladstone-Dale relationship).

Chemical data. Microprobe (WDS mode) analyses (8), (OH) was calculated by charge balance. Thermo-gravimetric analysis indicated the absence of mass loss after heating to 1000ºC. Na_2O 0.36, CaO 15.71, SrO 0.61, PbO 0.07, FeO 0.14, MnO 0.27, SnO 1.03, La_2O_3 0.06, Ce_2O_3 0.18, Yb_2O_3 0.12, Ta_2O_5 75.78, Nb_2O_5 3.43, TiO_2 0.35, UO_2 1.10, F 0.70, O = F -0.27, total 99.64 wt.%. Empirical formula (based on 2 cations at the *B*-site) is $(Ca_{1.50}Na_{0.06}Sn_{0.04}Sr_{0.03}Mn_{0.02}U_{0.02}Fe_{0.01}Ce_{0.01})_{\Sigma 1.69}(Ta_{1.84}Nb_{0.14}Ti_{0.02})_{\Sigma 2.00}O_6[O_{0.61}F_{0.20}(OH)_{0.01}]_{\Sigma 0.82}$. The simplified formula requires CaO 20.24, Ta_2O_5 79.76, total 100.00 wt.%.

Crystallography. Cubic, $Fd\bar{3}m$, *a* 10.4325(4) Å. *V* 1135.46(14) $Å^3$, *Z* 8 (powder data). X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 6.023 (89) (111), 3.145 (44) (311), 3.011 (100) (222), 2.608 (25) (400), 2.393 (6) (331), 2.008 (14) (333), 1.8442 (48) (440), 1.7634 (11) (531), 1.7634 (11) (531), 1.5909 (10) (533), 1.5728 (33) (622) 1.5058 (8) (444), 1.4608 (6) (711).

Name. Oxycalciomicrolite is named according to the system of nomenclature for the pyrochlore supergroup minerals approved by IMA-CNMNC (Atencio *et al.* 2010a). It is characterized by O dominance at the *Y* site, Ca dominance at the *A* site, Ta dominance at the *B* site.

Type material. Museu Nacional, Universidade Federal do Rio de Janeiro, Quinta da Boa Vista, s/nº, 20940-040, Rio de Janeiro, registration number MN-7601-M.

Relationship to other species. A member of the microlite group, pyrochlore supergroup.

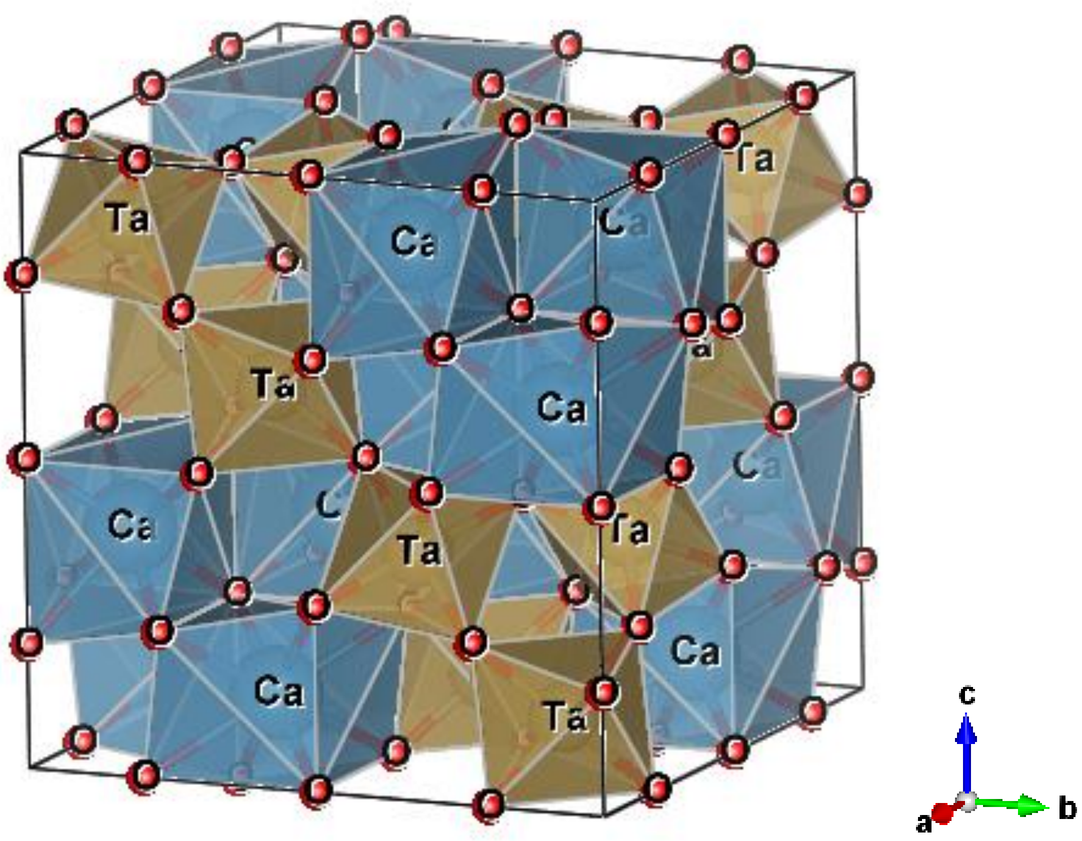

Figure 4.45. View of the crystal structure of oxycalciomicrolite (synthetic), drawn using VESTA 3 (Momma and Izumi 2011). Data from Gasperin (1955).

Crystal structure. The *A* position is fully occupied by Ca, *B* by Ta, *X* and *Y* by O (Gasperin 1955).

Synthetic. Methods not specified (Gasperin 1955).

See also. Hydroxykenopyrochlore, fluornatromicrolite, fluorcalciomicrolite, hydroxycalciomicrolite, hydrokenomicrolite, djalmaite, rijkeboerite, hydroxycalcioromeite, kenomicrolite and hydromicrolite.

Hydrokenomicrolite

Andrade *et al.* (2013a)

$(\square,\#)_2Ta_2O_6(H_2O)$, cubic and trigonal

Approved CNMNC – IMA 2011-103

Other names: hidrokenomicrolita, parabariomicrolite, parabariomicrolita, “altered microlite”

Figure 4.46. Hydrokenomicrolite-3*C* from Nazareno, Minas Gerais (Andrade *et al.* 2013a).

Hydrokenomicrolite-3*C* was described by Andrade *et al.* (2013a). A preliminary note on this mineral was published by Andrade *et al.* (2012). Parabariomicrolite (Ercit *et al*. 1986) was discredited by Atencio (2016a) as the polytype hydrokenomicrolite-3*R*.

The following data for hydrokenomicrolite-3*C* are from Andrade *et al*. (2013a) and those for hydrokenomicrolite-3*R* are from Ercit *et al*. (1986).

Occurrence.

Hydrokenomicrolite-3*C* polytype: An accessory mineral in the Volta Grande pegmatite, Nazareno, Minas Gerais, associated with albite, apatite, beryl, cassiterite, epidote, fluorcalciomicrolite, fluorite, gahnite, “garnet”, gahnite, hydrocalciomicrolite, "lepidolite", magnetite, microcline, monazite-(Ce), muscovite, quartz, rutile, spodumene, tantalite-(Mn), tourmaline, and zircon. This pegmatite belongs to the Sn-Ta-rich São João del Rei Pegmatite Province (Heinrich 1964, Lagache and Quéméneur 1997, Atencio *et al.* 2002, Faulstich *et al*. 2016). The hydrokenomicrolite-3*C* crystals were collected in a heavy minerals concentrate, so the paragenetic position has not been established. Other crystals of different colors, also corresponding to microlite group minerals, occur in the same concentrate. Some of these crystals are formed by the association between hydrokenomicrolite-3*C* and fluorcalciomicrolite, which may suggest that hydrokenomicrolite-3*C* is an alteration product of fluorcalciomicrolite. The crystals used for characterization of hydrokenomicrolite-3*C*, however, are homogeneous. The discredited minerals bariomicrolite and uranmicrolite apparently are vacancy dominant at the *A* position and (OH) or H_2O as a predominant component at the *Y* position, and as such are probably hydroxykenomicrolite or hydrokenomicrolite-3*C*. Nazareno is also the type locality for fluorcalciomicrolite, hydoxycalciomicrolite and oxycalciomicrolite.

Hydrokenomicrolite-3*R* polytype: Alto do Giz pegmatite, located 2 km S of the main road connecting Equador and Parelhas, Equador, Rio Grande do Norte. During a general study of the paragenesis of simpsonite, a detailed examination of the Alto do Giz occurrence revealed a translucent white mineral associated with abundant microlite, described as parabariomicrolite (Ercit *et al.* 1986, approved by CNMMN - IMA 84-3, but later discredited by Atencio 2016a). Pough (1945) was the first to comment on this mineral referring to it as "altered microlite"; however, he did not carry out X-ray, chemical or optical investigations. Associated minerals are simpsonite (originally described as calogerasite), tantalite-(Fe), tantalite-(Mn), "tapiolite", natrotantite, alumotantite, stibiotantalite, beryl, spodumene, and petalite. A second probable occurrence of hydrokenomicrolite-3*R* was recorded at near Lake Kivu, Zaire (Ercit *et al.* 1986).

Appearance and physical properties.

Hydrokenomicrolite-3*C* polytype: Crystals from 0.2 to 1.5 mm in size. Habit: euhedral. Forms: octahedra {111}, occasionally modified by rhombododecahedra {110}. Twinning: none observed. Color: salmon pink. Streak: white. Luster: vitreous to resinous. Translucent. Non-fluorescent. Hardness (Mohs): not measured, but probably 4½ - 5. Tenacity: brittle. Cleavage: none observed. Fracture: conchoidal. Density could not be measured because of a lack of pure material. Density (calc.) 6.666 g/cm^3 using the empirical formula.

Hydrokenomicrolite-3*R* polytype: As topotactic replacements (up to 60 % by volume) of green “microlite” octahedra (up to 1 cm in diameter) and more rarely as open-space fillings in oxide mineral assemblage. Individual crystals range from 0.01 to 0.1 mm in open-space fillings. Aggregates of crystals are up to 2 mm across. Twinning: possibly due to the topotactic replacement. Color: white to pale pink. Streak: white. Luster: vitreous to pearly. Translucent. Non fluorescent. Hardness (Mohs): 4. Tenacity: very brittle. Cleavage: well developed {001} and {101}. Density (calc.) 5.97 g/cm^3.

Optical properties.

Hydrokenomicrolite-3*C* polytype: Isotropic, $n_{\text{calc.}}$ 2.055 for the empirical formula (from the Gladstone-Dale relationship).

Hydrokenomicrolite-3*R* polytype: Uniaxial. Both refractive indices above 2.0 (white light). Gladstone-Dale calculations indicate mean *n* 1.96.

Chemical data.

Hydrokenomicrolite-3*C* polytype: Microprobe (WDS mode) analyses (3), the contents of F, Na, P, S, Cl, K, Fe, and Th are below detection limits. H_2O calculated from crystal-structure analysis. CaO 0.12, MnO 0.27, SrO 4.88, BaO 8.63, PbO 0.52, La_2O_3 0.52, Ce_2O_3 0.49, Nd_2O_3 0.55, Bi_2O_3 0.57, UO_2 4.54, TiO_2 0.18, SnO_2 2.60, Nb_2O_5 2.18, Ta_2O_5 66.33, SiO_2 0.46, Cs_2O 0.67, H_2O 4.84, total 98.35 wt.%. Empirical formula (based on 2 cations at the *B* site) is $[\square_{0.71}(H_2O)_{0.48}Ba_{0.33}Sr_{0.27}U_{0.10}Mn_{0.02}Nd_{0.02}Ce_{0.02}La_{0.02}Ca_{0.01}Bi_{0.01}Pb_{0.01}]_{\Sigma 2.00}(Ta_{1.75}Nb_{0.10}Sn_{0.10}Si_{0.04}Ti_{0.01})_{\Sigma 2.00}[O_{5.77}(OH)_{0.23}]_{\Sigma 6.00}[(H_2O)_{0.97}Cs_{0.03}]_{\Sigma 1.00}$. The simplified formula is $(\square,H_2O,Ba)_2Ta_2(O,OH)_6(H_2O)$.

Hydrokenomicrolite-3*R* polytype: Microprobe (WDS) analysis (number of points analyzed not quoted). H_2O by crystal structure determination. Na_2O 0.4, K_2O 0.3, SrO 0.8, BaO 10.5, PbO 0.4, Nb_2O_5 1.5, Ta_2O_5 80.6, H_2O 5.2, total 99.7 wt.%. Empirical formula: $(\square_{1.49}Ba_{0.36}Na_{0.04}Sr_{0.04}K_{0.03}Pb_{0.01})_{\Sigma 2.00}(Ta_{1.94}Nb_{0.06})_{\Sigma 2.00}[O_{4.92}(OH)_{1.08}]_{\Sigma 6.00}(H_2O)_{1.00}$. The simplified formula is $(\square,Ba)_2Ta_2(O,OH)_6(H_2O)$.

The only charge-balanced end-member variant of this formula is $\square_2Ta_2[O_4(OH)_2](H_2O)$ which requires Ta_2O_5 92.46, H_2O 7.54, total 100.00 wt.%.

Crystallography.

Hydrokenomicrolite-3*C* polytype: Cubic, $Fd\bar{3}m$, *a* 10.454(1) Å. *V* 1142.5(2) Å^3, *Z* 8 (single-crystal), *a* 10. 5733(9) Å. *V* 1182.0(3) Å^3, *Z* 8 (powder data). X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 6.112 (86) (111), 3.191 (52) (311), 3.052 (100) (222), 2.642 (28) (400), 2.035 (11) (511, 333), 1.869 (29) (440), 1.788 (10) (531), 1.594(24)

(622).

Hydrokenomicrolite-3*R* polytype: Trigonal, $R\bar{3}m$, *a* 7.4290(6), *c* 18.505(2) Å, *V* 884.5(1), *c*:*a* = 2.4909, *Z* 3. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 6.18 (50) (00.3), 6.08 (35) (10.1), 3.172 (65) (02.1), 3.085 (41) (00.6), 3,040 (100) (20.2), 2.641 (50) (02.4), 1.878 (38) (20.8), 1.857 (39) (22.0), 1.603 (24) (02.10), 1.591 (42) (22.6).

Name. Hydrokenomicrolite is named according to the system of nomenclature for the pyrochlore supergroup minerals approved by IMA-CNMNC (Atencio *et al.* 2010a). It is characterized by H_2O dominance at the *Y* site, □ dominance at the *A* site, Ta dominance at the *B* site. “Parabariomicrolite” was named for its chemical and structural similarity with bariomicrolite (a discredited mineral).

Type material.

Hydrokenomicrolite-3*C* polytype: Museu de Geociências, Instituto de Geociências, Universidade de São Paulo, sample number DR725 (type).

Hydrokenomicrolite-3*R* polytype: Royal Ontario Museum, Toronto, Ontario, Canada (M22607) (cotype); U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA (104739, donator M. Slavin, 1943) (type).

Relationship to other species. A member of the microlite group, pyrochlore supergroup. Hydrokenomicrolite-3*R* is isostructural with fluornatrocoulsellite.

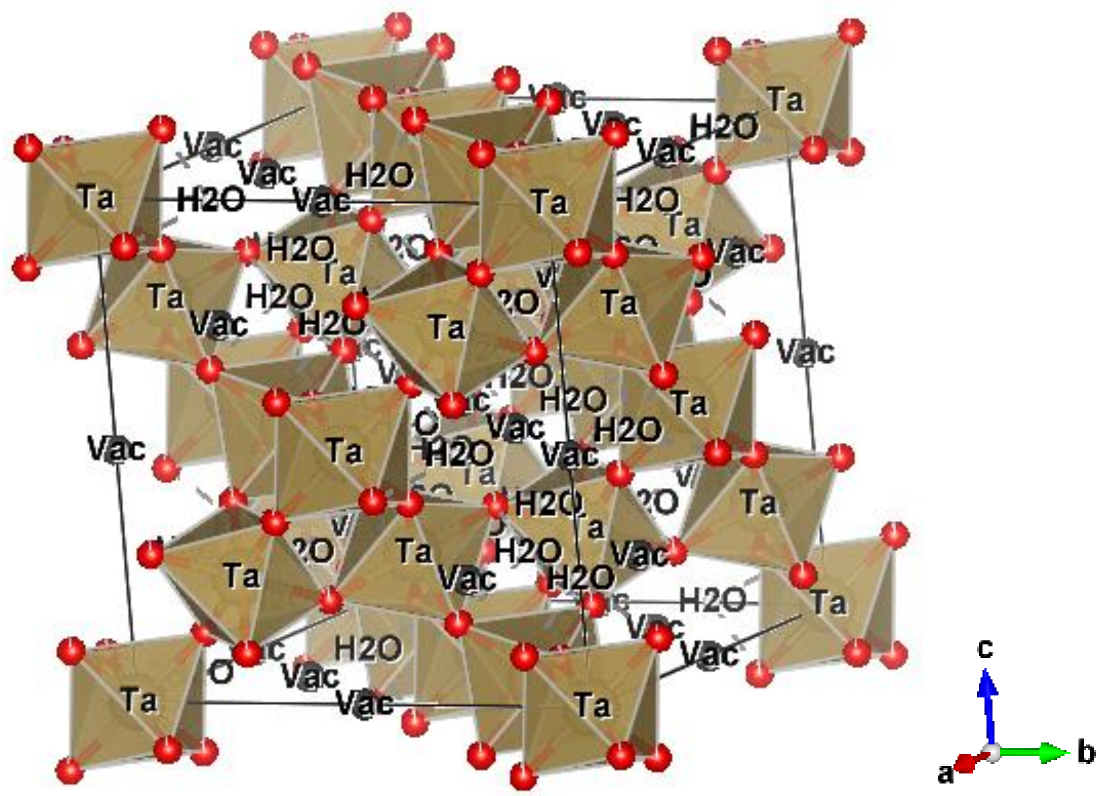

Figure 4.47. View of the crystal structure of hydrokenomicrolite-3*C* (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Andrade *et al.* (2013a).

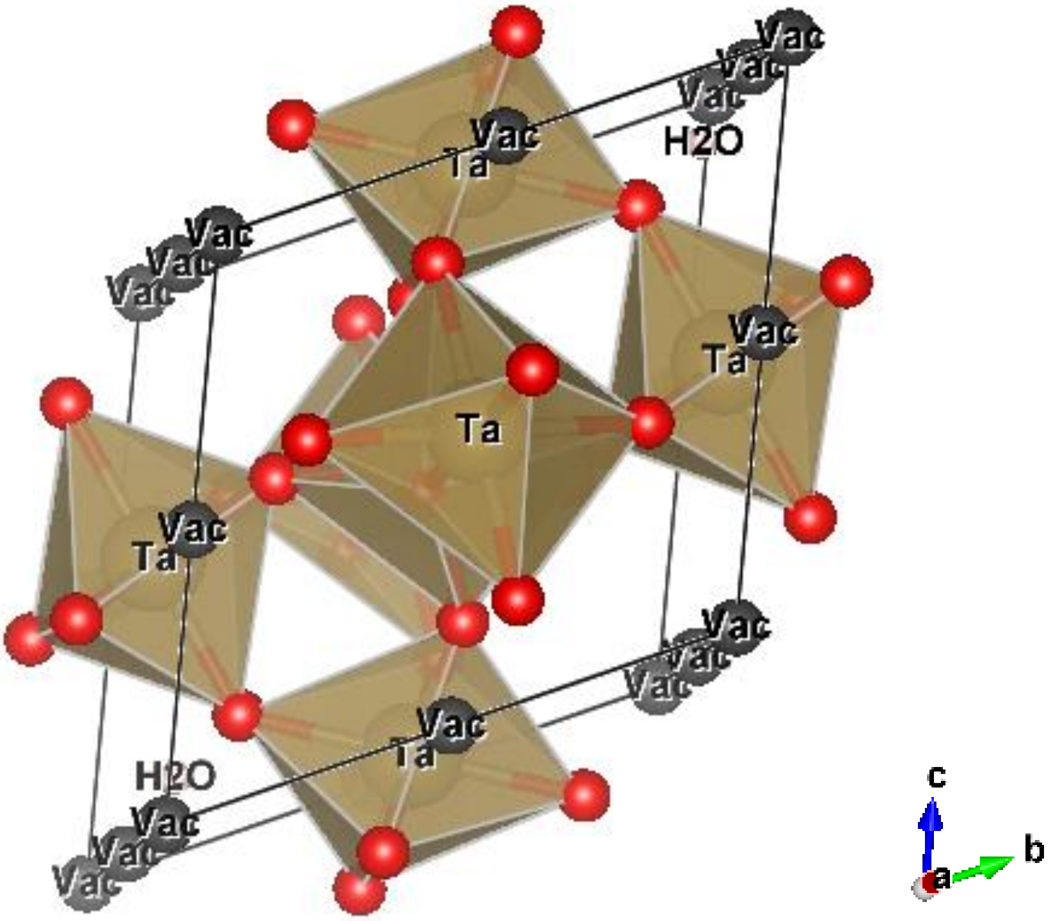

Figure 4.48. View of the crystal structure of hydrokenomicrolite-3*R* (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Based on data from Ercit *et al.* (1986) for parabariomicrolite (=hydrokenomicrolite-3*R*) and from Mumme *et al.* (2010) for coulsellite (= flurnatrocoulsellite).

Crystal structure. Hydrokenomicrolite-3*C* polytype: The $Ta(O,OH)_6$ octahedra are linked through all vertices. The refinement results and the approximate empirical bond-valences sums for the positions *A* (1.0 v.u.) and *Y′* (0.5 v.u.), compared to valence calculations from electron microprobe analysis (EMPA) and ranges expected for H_2O molecules, confirm the presence of H_2O at the *A*(16*d*) site and displaced from the *Y*(8*b*) to the *Y′*(32*e*) position. Hydrokenomicrolite-3*R* polytype: A layered structure derived from that of pyrochlore (Ercit *et al.* 1986).

See also. Hydroxykenopyrochlore, fluornatromicrolite, fluorcalciomicrolite, hydroxycalciomicrolite, oxycalciomicrolite, djalmaite, rijkeboerite, hydroxycalcioromeite, and calogerasite.

Kenomicrolite

Menezes da Silva (2018)

$(\square,\#)_2Ta_2O_6\square$, cubic

Other names: kenomicrolita

Figure 4.49. Grains of varying composition between hydrokenomicrolite, kenomicrolite and hydromicrolite observed in stereomicroscopy (Menezes da Silva 2018).

Kenomicrolite was described by Menezes da Silva (2018) as an accessory mineral in the Fumal pegmatite and surroundings (near Volta Grande mine), Nazareno, Minas Gerais. Two abstracts on the matter were also published (Menezes da Silva *et al.* 2017 and 2018). For additional information on this occurrence see oxycalciomicrolite. Crystals were collected in a heavy mineral concentrate from its saprolite. Kenomicrolite occurs in grains of varying composition between hydrokenomicrolite, kenomicrolite and hydromicrolite. Fluorcalciomicrolite and oxycalciomicrolite were also observed in the saprolite. The average of 4 microprobe analyses is: Na_2O 0.02, MnO 0.23, SrO 2.71, BaO

3.66, FeO 0.21, PbO 4.64, SnO_2 2.43, Bi_2O_3 0.02, Ce_2O_3 1.78, La_2O_3 0.20, Nd_2O_3 0.01, Sm_2O_3 0.02, Er_2O_3 0.01, Yb_2O_3 0.09, UO_2 3.47, Ta_2O_5 73.89, Nb_2O_5 3.04, TiO_2 0.33, ZrO_2 0.02, HfO_2 0.02, Al_2O_3 0.05, F 0.09, F=O -0.04, total 96.86 wt.%. In the absence of a crystal structure study or H_2O chemical analysis, however, it cannot be guaranteed that it is kenomicrolite. For instance, if we calculate H_2O by difference, the chemical formula would be: $(\square_{1.44}Sr_{0.14}Ba_{0.13}Pb_{0.11}U_{0.07}Ce_{0.06}Mn_{0.02}Fe^{2+}_{0.02}La_{0.01})_{2.00}(Ta_{1.76}Nb_{0.12}Sn_{0.09}Ti_{0.02}Al_{0.01})_{\Sigma=2.00}[O_{5.18}(OH)_{0.82}]_{\Sigma6.00}[(H_2O)_{0.50}\square_{0.48}F_{0.02}]_{\Sigma1.00}$, that is, hydrokenomicrolite.

See also. Hydroxykenopyrochlore, fluornatromicrolite, fluorcalciomicrolite, hydroxycalciomicrolite, hydrokenomicrolite, djalmaite, rijkeboerite, hydroxycalcioromeite, oxycalciomicrolite and hydromicrolite.

Hydromicrolite

Menezes da Silva (2018)
$(H_2O,\#)_2Ta_2O_6(H_2O)$, cubic
Other names: hidromicrolita

See Figure 4.49.

Hydromicrolite was described by Menezes da Silva (2018) as an accessory mineral in the Fumal pegmatite and surroundings (near Volta Grande mine), Nazareno, Minas Gerais. Two abstracts on the matter were also published (Menezes da Silva *et al.* 2017 and 2018). For additional information on this occurrence see oxycalciomicrolite. Crystals were collected in a heavy mineral concentrate from its saprolite. Hydromicrolite occurs in grains of varying composition between hydrokenomicrolite, kenomicrolite and hydromicrolite. Fluorcalciomicrolite and oxycalciomicrolite were also observed in the saprolite. The average of 2 microprobe analyses is: MnO 0.04, SrO 0.40, BaO 0.07, FeO 0.03, PbO 21.42, SnO_2 1.27, Bi_2O_3 3.85, Ce_2O_3 0.22, La_2O_3 1.67, Pr_2O_3 0.24, Nd_2O_3 0.25, Er_2O_3 0.01, Yb_2O_3 0.05, Sc_2O_3 0.05, UO_2 0.09, Ta_2O_5 46.17, Nb_2O_5 15.52, TiO_2 2.14, ZrO_2 1.37, HfO_2 0.20, Al_2O_3 0.04, K_2O 0.01, total 95.11 wt.%. In the absence of a crystal structure study or H_2O chemical analysis, however, it cannot be guaranteed that it is hydromicrolite. For instance, if we calculate H_2O by difference, the chemical formula would be:

$[\square_{1.28}Pb_{0.51}Bi_{0.09}La_{0.05}Sr_{0.02}(H_2O)_{0.02}Ce_{0.01}Nd_{0.01}Pr_{0.01}]_{\Sigma=2.00}(Ta_{1.12}Nb_{0.62}Ti_{0.14}Zr_{0.06}Sn_{0.05}Hf_{0.01})_{\Sigma=2.00}[O_{5.14}(OH)_{0.86}]_{\Sigma6.00}(H_2O)_{1.00}$, that is, hydrokenomicrolite.

See also. Hydroxykenopyrochlore, fluornatromicrolite, fluorcalciomicrolite, hydroxycalciomicrolite, hydrokenomicrolite, djalmaite, rijkeboerite, hydroxycalcioromeite, oxycalciomicrolite, and kenomicrolite.

Djalmaite

(Guimarães 1939a, 1939b, 1941, 1948b)

(type material is probably hydroxykenomicrolite or hydrokenomicrolite)

Other names: uran-microlite, Uran-Mikrolit, uranmicrolite, uranmicrolita, uranomicrolita, djalmaíta

The original description of djalmaite, collected by Octavio Barbosa, appears in four publications (Guimarães 1939a, 1939b, 1941, 1948b). Based on preliminary X-ray diffraction data from the type specimen of djalmaite, Tavora Filho (1948) concluded that it is cubic but he did not include the cell parameter, space group, or observed pattern in his note. Tavora Filho (1949) presented X-ray diffraction data for samples described as djalmaite from other occurrences. One of these patterns appears on the ICDD card for the mineral (43-693). The name djalmaite was officially discarded in favor of uranmicrolite, a name introduced by Strunz (1957), to conform to the nomenclature system for pyrochlore group minerals, approved by CNMMN – IMA (Hogarth 1977). The Hogarth system requires that uranmicrolite must contain U exceeding 20% of the total *A*-atoms, which is not the case of the samples studied by Tavora Filho (1949). Only the original djalmaite specimen studied by Guimarães (1939a, 1939b, 1941, 1948b) conforms to the uranmicrolite definition but unfortunately, no X-ray diffraction data are available for this specimen except that Tavora Filho (1948) notes that it is cubic. Pires (1995) published a review paper on the mineral.

According to the new system of nomenclature for the pyrochlore supergroup, uranmicrolite was discredited. No samples described as uranmicrolite (e.g., Baldwin 1989, Rub *et al.* 1998, Tindle and Breaks 1998, Novák and Černý 1998, Zhang *et al.* 2004, Breiter *et al.* 2007, van Lichtervelde *et al.* 2007, Uher *et al.* 2007) are rich enough in U to warrant status as a separate species (Atencio *et al.* 2010a).

Occurrence. In alluvium near the altered granitic pegmatite at Posse farm (São José mine), 1 km distant of Brejaúba town, Conceição do Mato Dentro, Minas Gerais. The minerals of the pegmatite are kaolinized microcline, quartz, "bismuth ore", muscovite, beryl (green, bluish, and brown), "garnet", "columbite", magnetite, "monazite", samarskite-(Y), and "tourmaline". This is also the type locality of dukeite, which occurs associated with pucherite, schumacherite, bismutite and hechtsbergite. Chrombismite is also quoted (http://www.mindat.org/min-6871.html). In addition to the pegmatitic minerals, the alluvium contains a mineral similar to eschwegeite, which is the djalmaite of Guimarães (1939a and 1948b). According to Guimarães (1939b and 1941) [English version], the alluvium contains a mineral similar to eschwegeite, emerald (rare), and djalmaite. Djalmaite (actually with less than 20% U in the *A* site) was later found in the Volta Grande and Germinal pegmatites, Nazareno, Minas Gerais (Guimarães 1950). This djalmaite probably corresponds to hydrokenomicrolite described in the Volta Grande mine (Andrade *et al.* 2013a)

Appearance and physical properties. Forms: octahedra {111} modified by the trapezohedron {113}. Color: brownish-yellow, greenish-brown, or brownish-brilliant black. Streak: pale yellow. Hardness (Mohs): 5½. Cleavage: absent. Fracture: irregular. Density (meas.) 5.75 to 5.88 g/cm^3.

Optical properties. In thin section, translucent, yellowish-brown, with a greasy luster. *n* 1.97.

Chemical data. Chemical analyses (methods not specified): Ta_2O_5 72.27, Nb_2O_5 1.41, TiO_2 2.54, SnO_2 traces, ZrO_2 0.80, UO_2 2.17, UO_3 9.38, WO_3 0.18, Bi_2O_3 0.98, PbO 1.10, FeO 0.56, CaO 3.40, MgO 0.24, H_2O 4.62, total 99.65 wt.%. Empirical formula: $[\square_{1.05}Ca_{0.32}(H_2O)_{0.30}U^{6+}_{0.17}U^{4+}_{0.04}Fe^{2+}_{0.04}Mg_{0.03}Pb_{0.03}Bi^{3+}_{0.02}]_{\Sigma 2.00}(Ta_{1.74}Ti_{0.17}Nb_{0.06}Zr_{0.03})_{\Sigma 2.00}[O_{4.88}(OH)_{1.12}](OH)$ [hydroxykenomicrolite] or $[\square_{1.05}Ca_{0.32}(H_2O)_{0.30}U^{6+}_{0.17}U^{4+}_{0.04}Fe^{2+}_{0.04}Mg_{0.03}Pb_{0.03}Bi^{3+}_{0.02}]_{\Sigma 2.00}(Ta_{1.74}Ti_{0.17}Nb_{0.06}Zr_{0.03})_{\Sigma 2.00}[O_{5.88}(OH)_{0.12}](H_2O)$ [hydrokenomicrolite]. However, the original data were probably obtained from wet analyses and represent a mean of several compositions within an individual octahedra as observed by Atencio *et al.* (2002) in crystals collected in the type locality. Internal constitution of crystals is commonly heterogeneous. Complex zoning, or veining with diffuse boundaries, are rather common features.

Crystallography. Cubic. The data on the ICDD 43-693 card (uranmicrolite) is actually for a mineral with less than 20% U in the *A* site and the locality is also incorrect because the sample is not from Posse farm, but from Germinal (Volta Grande, Mortes river), Nazareno, Minas Gerais, studied by Tavora Filho (1949) and Guimarães (1950).

Name. Originally djalmaite, in honor of Djalma Guimarães (1895-1973), Brazilian mineralogist and petrologist. Renamed uranmicrolite, according to the CNMMN - IMA rules for pyrochlore group of minerals (Hogarth 1977). Djalma Guimarães was also honored with the name guimarãesite (two definitions).

Type material. Divisão de Geologia e Mineralogia museum, Departamento Nacional da Produção Mineral, Rio de Janeiro (Tavora Filho 1949).

Relationship to other species. Microlite group, pyrochlore supergroup.

Crystal structure. Not solved.

See also. Hydroxykenopyrochlore, fluornatromicrolite, fluorcalciomicrolite, hydroxycalciomicrolite, oxycalciomicrolite, hydrokenomicrolite, rijkeboerite, hydroxycalcioromeite, dukeite, eschwegeite, and guimarãesite (two definitions).

Rijkeboerite

van der Veen (1963)

(type material is probably hydroxykenomicrolite or hydrokenomicrolite)

Other names: bariomicrolita, bariomicrolite, rijkeboerita

Rijkeboerite was described by van der Veen (1963). It occurs as an alteration product in a pegmatite near Chi-chico, Nazareno (in the past, Nazareno was part of São João del Rei), Minas Gerais. The mineral was renamed as bariomicrolite by Hogarth (1977) to conform to the nomenclature of the pyrochlore group approved by IMA.

The status of bariomicrolite was discussed by Ercit *et al.* (1986). Type bariomicrolite has a parabariomicrolite-like formula (based on 4 B cations): $A_{0.78}B_4O_{9.56}(OH)_{2.44}\cdot2.92H_2O$, where A = 0.35 Ba + 0.14 Sn^{2+} + 0.13 Fe^{2+} + 0.06 U + 0.04 Pb + 0.03 Ce + 0.01 Mn + 0.01 Sr, and B = 3.38 Ta + 0.46 Nb + 0.16 Ti. However, it deviates from parabariomicrolite in its low A-site sum and high H_2O-content, much of which may be due to cation exchange during heavy-liquid (Clerici solution) separation done prior to the chemical analysis. Parabariomicrolite was discredited as hydrokenomicrolite-3*R* by Atencio (2016a).

The X-ray diffraction pattern for the type bariomicrolite (van der Veen 1963) indicates that it is isostructural with pyrochlore, not parabariomicrolite; however, van der Veen (1963) reported three additional diffraction maxima and ascribed them to contaminant phases. In light of the parabariomicrolite-like formula and the presence of additional diffraction maxima, Ercit *et al.* (1986) hoped to re-examine the type bariomicrolite to determine whether it is truly isostructural with pyrochlore, but the whereabouts of the type specimen of bariomicrolite is unknown.

According to the new system of nomenclature for the pyrochlore supergroup, bariomicrolite was discredited. The bariomicrolite species of Hogarth (1977), equivalent to the “rijkeboerite” of van der Veen (1963), and also that studied by Beurlen *et al.* (2005) are too poor in Ba to warrant this name (Atencio *et al.* 2010a).

Occurrence. In cassiterite concentrates from a pegmatite near Chi-Chico, Nazareno, Minas Gerais. Chi-chico (or Chichico) apparently is not the name of the locality. Perhaps the correct would be “Chichico mine”. Chichico (nickname of Francisco Ribeiro de Carvalho) was a miner (mainly of cassiterite) and mayor of Nazareno (https://www.jornaldaslajes.com.br/integra/ldquocozinha-de-tancredordquo-nazareno-tambem-teve-prefeito-pernambucano-/946/).

Appearance and physical properties. Color: pink, reddish, yellowish-brown, colorless, or white. Hardness (Mohs): 4½ to 5, VHN_{100}: 491 (485 to 498) kg/mm^2. Density: 5.68 to 5.80 (average 5.71) g/cm^3 (meas.), 5.60 g/cm^3 (calc.).

Optical properties. Van der Veen (1963) observed reflectivity of 12.8 to 13.6, mean 13.2, which is equivalent to *nD* 2.141 (three measurements in air relative to a glass standard with a reflectivity of 8.3%, refractive index 1.809).

Chemical data. X-ray fluorescence and wet analyses, corrected for impurities: CaO 0.01, BaO 5.15, SrO 0.10, FeO 0.91, MnO 0.10, PbO 0.92, Ce_2O_3 0.48, Sb_2O_3 0.01, Bi_2O_3 0.03, ThO_2 0.20, U_3O_8 ?? 1.72, Tl_2O 1.66, TiO_2 1.24, SnO_2 2.05, Nb_2O_5 6.02, Ta_2O_5 72.81, H_2O 7.27 (ignition loss), total 100.68 wt.%. Tl was considered to have been adsorbed from the Clerici solution during the separation process. Empirical formula: $[\square_{1.44}(H_2O)_{0.26}Ba_{0.17}Fe^{2+}_{0.06}U^{4+}_{0.03}Pb^{2+}_{0.02}Mn^{2+}_{0.01}Ce^{3+}_{0.01}]_{\Sigma 2.00}(Ta_{1.63}Nb_{0.22}Ti_{0.08}Sn^{4+}_{0.07})_{\Sigma 2.00}$ $[O_{3.52}(OH)_{2.48}](OH)$ [hydroxykenomicrolite] or $[\square_{1.44}(H_2O)_{0.26}Ba_{0.17}Fe^{2+}_{0.06}U^{4+}_{0.03}Pb^{2+}_{0.02}Mn^{2+}_{0.01}Ce^{3+}_{0.01}]_{\Sigma 2.00}(Ta_{1.63}Nb_{0.22}Ti_{0.08}Sn^{4+}_{0.07})_{\Sigma 2.00}$ $[O_{4.52}(OH)_{1.48}](H_2O)$ [hydrokenomicrolite].

Crystallography. Cubic, $Fd\bar{3}m$, *a* 10.570 Å, *V* 1180.93 Å^3, *Z* 8. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 6.04 (80) (111), 3.18 (65) (311), 3.034 (100) (222), 2.631 (60) (400), 1.865 (60) (440), 1.784 (35) (531), 1.591 (45) (622), 1.211 (35) (662), 1.079 (40) (844), 1.017 (35) (10 2 2). ICDD: 16-616.

Name. Originally rijkeboerite, in honor to Dutch chemist A. Rijkeboer (? - ?), chief of the analytical department, N.V. Hollandse Metallurgische Industrie Billiton, Arnhem, Netherlands, where the analysis was done. Renamed bariomicrolite by Hogarth (1977).

Type material. Not preserved.

Relationship to other species. Microlite group, pyrochlore supergroup.

Crystal structure. Not solved.

See also. Hydroxykenopyrochlore, fluornatromicrolite, fluorcalciomicrolite, hydroxycalciomicrolite, oxycalciomicrolite, hydrokenomicrolite, djalmaite, and hydroxycalcioromeite.

Hydroxycalcioroméite

Atencio *et al.* (2010a)

$(Ca,\#)_2Sb^{5+}{}_2O_6(OH)$, cubic

Approved CNMNC - IMA 2010

Other names: Lewisit, lewisite, lewisita, hidroxicalcioromeíta

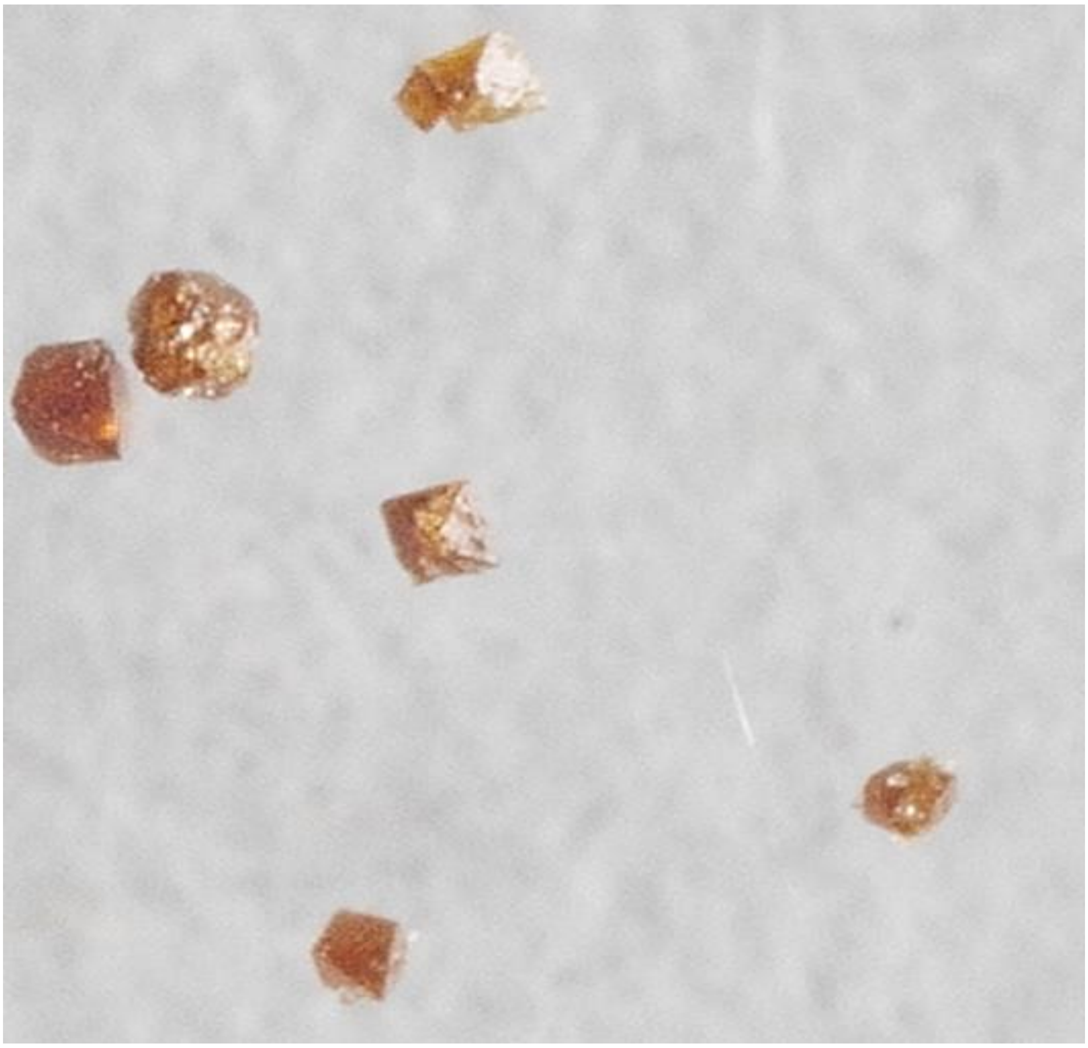

Figure 4.50. Hydroxycalcioroméite from Tripuí, Minas Gerais. Crystals are less than 1 mm in size. Specimen: Daniel Atencio. Photo: Thales Trigo.

See also Figure 4.21.

Roméite, originally described by Damour (1841) in the Praborna mine, Piemont, Italy, is today a group of the pyrochlore supergroup of minerals, and lewisite corresponds to the hydroxycalcioroméite species (Atencio *et al.* 2010a). Roméite and lewisite were listed as separate species in most reference manuals (e.g. Fleischer and Mandarino 1995), but lewisite was considered by some authors as a titanian variety of roméite (e.g. Palache *et al.* 1951, Tavora Filho 1955).

Lewisite was originally described by Hussak and Prior (1895) [translated into Portuguese: Hussak (1905)] from the Tripuí (formerly Tripuhy) cinnabar mine, Ouro Preto, Minas Gerais. The ideal formula $5CaO.3Sb_2O_5.2TiO_2$ (= $Ca_5Sb_6Ti_2O_{24}$) was determined from two wet chemical analyses. Hussak and Prior (1895) noted that the mineral was related to roméite and the pyrochlore group and this was confirmed by X-ray diffraction data reported by Machatschki and Zedlitz (1932), Tavora Filho (1955), and Baptista (1981). Machatschki and Zedlitz (1932) observed, however, that the chemical composition obtained by Hussak and Prior (1895) did not agree with the formula of minerals with the pyrochlore structure, because there was an excess of Sb in the *B* site.

Brugger *et al.* (1997), on the basis of the chemical composition, X-ray diffraction data and optical properties of lewisite from Tripuí, suggested that it should be considered a mixture of roméite and a hexagonal (trigonal?) phase structurally related to pyrochlore. This second phase grows at the expense of roméite, but is characterized by the ordering of the vacancies in the *A*-sites, similar to what occurs in hydrokenomicrolite-3*R*. These data, however, were not obtained from the type specimen. The cationic distribution suggested by Brugger *et al.* (1997), with the total Sb as Sb^{5+} and concentrated in the *B*-site generated formulae with a high vacancy in the *A*-site. Densities calculated for these formulae are lower than those observed. Thus, it would seem more logical to distribute Sb as Sb^{5+} and Sb^{3+} in the *B*- and *A*-sites respectively. Rouse *et al.* (1998) studied the type specimen stored in the U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA (USNM R5741), and, based on their crystal structure determination, found that the *A*-site is split to accommodate the different coordination requirements of Sb^{3+} and Ca^{2+}. The *A*-site is split into 8-coordinated Ca^{2+} on *A*(16d) and Sb^{3+} on an asymmetrically 5-coordinated site *A'*(96g). However, the crystal structure determination by Zubkova *et al.* (2000) on the type specimen of lewisite stored in The Natural History Museum, London, England (BM 80141) did not confirm the splitting of the *A*-site.

Occurrence. In gravel of the Três Cruzes farm cinnabar mine, Tripuí (formerly Tripuhy), Ouro Preto, Minas Gerais. Associated minerals are “xenotime”, “monazite”, zircon, kyanite, “tourmaline”, rutile, hematite, pyrite, magnetite, gold, cinnabar, tripuhyite, derbylite, florencite-(Ce), muscovite, quartz, and other minerals. The crystals had often intergrowths of quartz grains and flakes of muscovite on the ends of the prisms, similar to intergrowths of derbylite, which often shows inclusions of muscovite. Later observations proved that both minerals come from the thin-bedded muscovite schist, which accompanies itabirite in the neighborhood of Tripuí, and both these minerals have been found intergrown with hematite in fragments of this schist found in the gravel (Hussak and Prior 1897a). Tripuí is also the type locality for tripuhyite, derbylite, and florencite-(Ce). Hydroxycalcioroméite may contain inclusions of quartz, hematite, and rutile.

Appearance and physical properties. Crystals rarely greater than 1 mm in size. According to Berlepsch *et al.* (2003), type material of tripuhyite (BM 86044, Natural History Museum, London, England) forms massive aggregates of grains up to ~0.1 mm in size. Embedded in this fine-grained matrix are substantially larger grains of lewisite up to ~0.35 mm (see Figure 4.21). Habit: euhedral. Forms: {111} octahedra. Twinning: on {111} rare. Color: honey yellow to brown. Streak: yellowish-brown. Luster: vitreous to resinous. Translucent. Non-fluorescent. Hardness (Mohs): 5½. Tenacity: not brittle. Cleavage: {111} perfect. Fracture: conchoidal. Density (meas.) 4.950 g/cm^3. Density (calc.) 4.966 g/cm^3. Insoluble in acids.

Optical properties. Isotropic, *n* 2.20. Between crossed polars, lewisite varies in color and translucency from an almost opaque very dark brown through orange-brown to pale yellow. It is supposed that the variation in color and opacity is related to variation in the composition of the mineral. Internal reflections are abundant and mask any anisotropy though, as the mineral is cubic, this would be anomalous. R; ^{im}R: (12.55; 2.46) 470 nm; (11.85; 2.27) 546 nm; (11.75; 2.21) 589 nm; (11.55; 2.19) 650 nm (Berlepsch *et al.* 2003).

Chemical data.

[Rouse *et al.* (1998), type specimen, U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA (USNM R5741)]: Microprobe (WDS mode) analyses: Na_2O 0.1, CaO 14.4, MnO 1.2, Al_2O_3 0.7, Fe_2O_3 3.8, Sb_2O_5 39.7, Sb_2O_3 23.5, TiO_2 15.0, H_2O 2.0, total 100.4 wt.%. Empirical formula: $(Ca_{1.04}Sb^{3+}_{0.65}Mn^{2+}_{0.07}Na_{0.01})_{\Sigma 1.77}(Sb^{5+}_{0.99}Ti^{4+}_{0.76}Fe^{3+}_{0.19}Al_{0.06})_{\Sigma 2.00}O_6(OH)_{0.91}$.

[Zubkova *et al.* (2000), type specimen, Natural History Museum, London, England (BM 80141)]: Microprobe (EDS mode) analyses (6): Na_2O 0.90, CaO 12.80, MnO 1.64, Al_2O_3 1.70, Fe_2O_3 4.43, Sb_2O_5 64.66, TiO_2 14.47, SO_3 0.65, total 101.25 wt.%. Empirical formula [for ideal O and (OH) contents]: $(Ca_{0.91}Sb^{3+}_{0.66}Na_{0.12}Mn^{2+}_{0.09})_{\Sigma 1.78}(Sb^{5+}_{0.93}Ti^{4+}_{0.72}Fe^{3+}_{0.22}Al_{0.13})_{\Sigma 2.00}O_6(OH)$. The ideal formula requires CaO 20.19, Sb_2O_5 77.65, H_2O 2.16, total 100.00 wt.%.

Crystallography. Cubic, $Fd\bar{3}m$ or $F\bar{4}3m$ (pseudo $Fd\bar{3}m$), *a* 10.277(1) Å, *V* 1085.4(2)

Å^3, Z 8 (single-crystal, Rouse *et al.* 1998), a 10.311(7) Å, V 1096.23 Å^3, Z 8 (single-crystal, Zubkova *et al.* 2000). X-ray powder diffraction data [d in Å (I) (hkl)]: 2.9394 (97) (222), 2.5415 (22) (400), 1.8097 (32) (440), 1.7328 (13) (531), 1.5434 (100) (622), 1.4389 (10) (551), 1.3364 (12) (731), 1.2832 (19) (800).

Name. The ancient name lewisite honors William James Lewis (1847-1926), professor of geology, University of Cambridge, England. The name hydroxycalcioroméite is in agreement with the new nomenclature for the pyrochlore supergroup (Atencio *et al.* 2010a) and refers to a roméite-group mineral with Ca as the dominant species of the dominant-valence group at the A site, and (OH) as the dominant species of the dominant-valence group at the Y site.

Type material. The Natural History Museum, London, England (BM 80141) (cotype); U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA (USNM R5741) (type).

Relationship to other species. A roméite-group, pyrochlore-supergroup mineral.

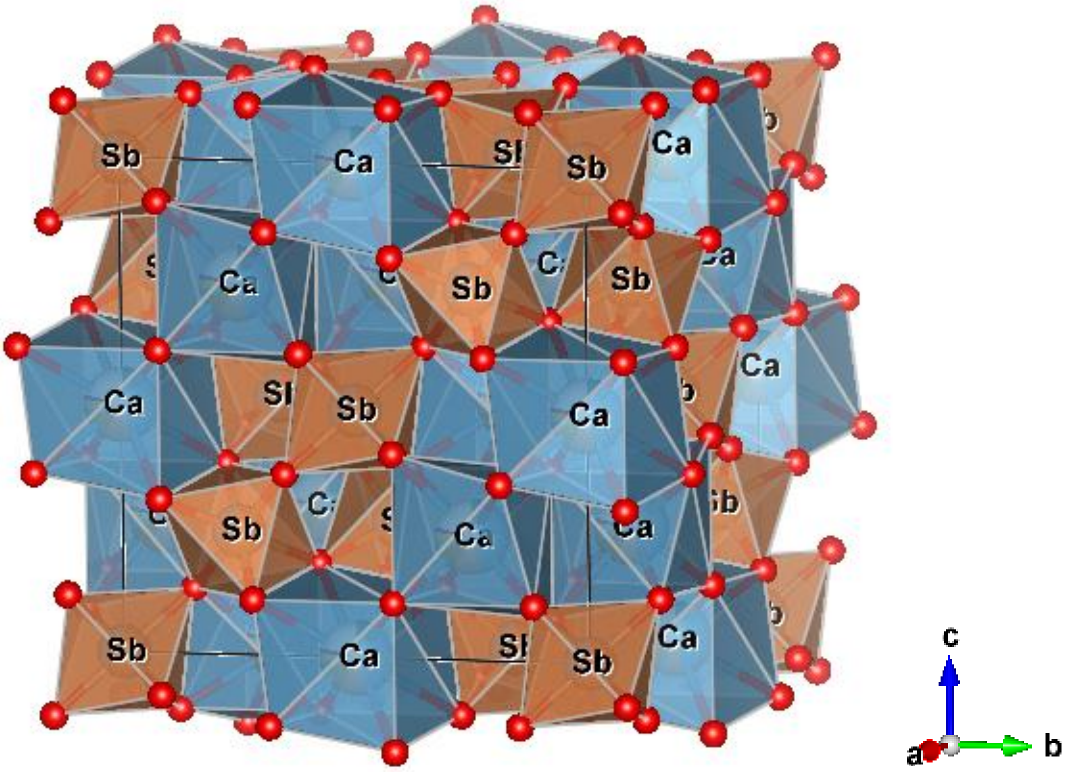

Figure 4.51. View of the crystal structure of hydroxycalcioroméite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Zubkova *et al.* (2000).

Crystal structure. Similarly to other pyrochlore-supergroup minerals, the structure of hydroxycalcioroméite is based on a defective simple cubic packing of the OH and O atoms, with (Ca, Sb^{3+}) and (Sb^{5+}, Ti) occupying half of the cubic voids. The large cations (Ca, Sb^{3+}) have cubic coordination and (Sb^{5+}, Ti) have six-fold coordination due to the vacancies of anions (Zubkova *et al.* 2000).

See also. Hydroxykenopyrochlore, fluornatromicrolite, fluorcalciomicrolite, hydroxycalciomicrolite, oxycalciomicrolite, hydrokenomicrolite, djalmaite, rijkeboerite tripuhyite, derbylite, and florencite-(Ce).

Zirkelite

Hussak and Prior (1895)

$(Ti,Ca,Zr)O_{2-x}$, cubic

Other names: zirkelita

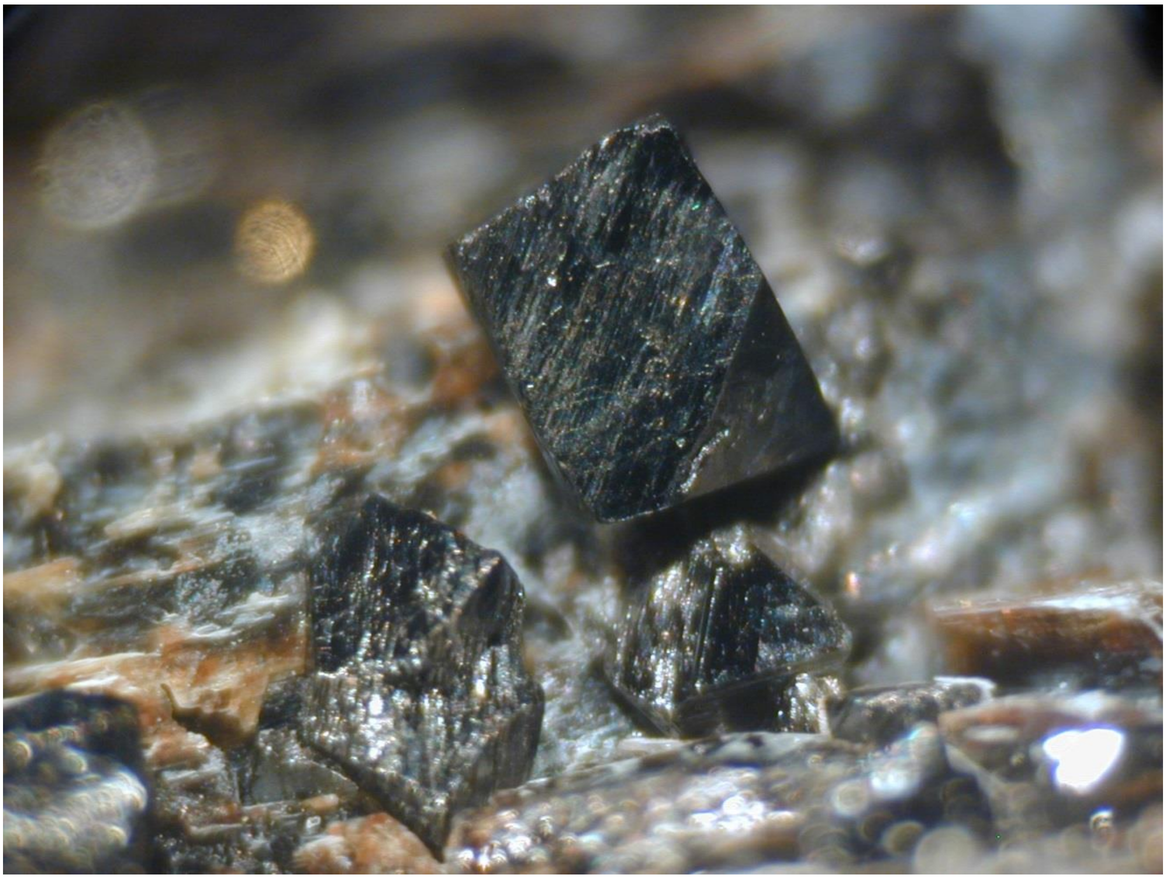

Figure 4.52. Zirkelite on phlogopite from the Jacupiranga mine, Cajati, São Paulo. The crystals have 1 to 5 mm. Specimen: Luiz A.D. Menezes Filho. Photo: Tatiana Dias Menezes.

Zirkelite was originally described by Hussak and Prior (1895), with additional chemical data published by Prior (1896) [both translated into Portuguese: Hussak (1905)], from Cajati (formerly Cajati was part of Jacupiranga), São Paulo. A brief preliminary notice of this mineral (without name) was published by Hussak (1895a, pp. 408-10). It received little attention until Pudovkina *et al.* (1974) obtained new chemical and X-ray diffraction data for the type specimen. They observed that, in the natural state, the crystals were metamict, although one specimen showed a faint, diffuse reflection on a Laue photograph. When heated to 800°C, the samples produced cubic defect fluorite-type patterns, with *a* 5.08 Å. At 1200°C the X-ray diffraction pattern of the heated crystals was identified as the monoclinic zirconolite. Differing results were obtained by Sinclair and Ringood (1981): the natural (unheated) samples gave a cubic defect fluorite-type diffraction pattern and continued to display this diffraction pattern up to 1100°C. At 1200°C, the mineral was completely transformed into monoclinic zirconolite.

Bayliss *et al.* (1989) published a nomenclature revision paper for zirkelite and zirconolite, with approval of CNMMN - IMA. According to them, zirconolite is the non-crystalline (metamict) mineral or mineral with undetermined polytype; zirconolite-3*O* is the orthorhombic polytype; zirconolite-3*T* is the trigonal polytype; zirconolite-2*M* is the monoclinic polytype; and zirkelite is the cubic mineral. The formula $CaZrTi_2O_7$ refers to all the zirconolite polytypes and $(Ti,Ca,Zr)O_{2-x}$ refers to zirkelite. Bellatreccia *et al.* (1999) studied zirkelite crystals collected and described by Menezes Filho and Martins (1984) from Cajati, São Paulo, and found that they were completely metamict.

The following data are for zirkelite from Cajati, São Paulo.

Occurrence. In disaggregated jacupirangite (magnetite pyroxenite) from Cajati, São Paulo, associated with baddeleyite, perovskite, and other minerals. Menezes Filho and Martins (1984) found zirkelite crystals in a small pocket in the jacupirangite from Cajati, attached to phlogopite. Cajati is also the type locality for quintinite, menezesite, pauloabibite, and melcherite.

Appearance and physical properties. Octahedra, always flattened parallel to an octahedral face and deeply striated parallel to the same face due to polysynthetic twinning. Luster: resinous. Black, with a dark brownish-black streak. Opaque, except in very thin splinters, which are translucent with a dark brown color. Twinning according to {111} very common, the forms being simple spinel-like types or complicated fourlings. Zirkelite described by Menezes Filho and Martins (1984) occurs as sharp prismatic crystals measuring 1 to 5 mm, with typical striations due to polysynthetic twinning. Cleavage absent, fracture distinctly conchoidal. Brittle. Non-magnetic. Density 4.741 g/cm^3 (meas.). Mohs hardness 5½.

Optical properties. Isotropic, *n* 2.19(1).

Chemical data. Table 4.3 shows the chemical analyses results for zirkelite from Cajati, São Paulo. The empirical formulae approach $CaZrTi_2O_7$, which corresponds to CaO

16.54, ZrO_2 36.34, TiO_2 47.12, total 100.00 wt.%.

Table 4.3. Chemical analyses for zirkelite from Cajati, São Paulo (wt.%).

	1	2	3	4	5	6
CaO	11.61	10.79	14.4	11.5	9.80	11.10
ThO_2	-	7.31	8.0	6.6	14.00	8.65
Y_2O_3	-	0.21	-	-	-	-
La_2O_3	-	-	-	-	0.06	0.04
Ce_2O_3	-	2.52	1.5	2.6*	0.74	1.17
Pr_2O_3	-	-	-	-	0.20	0.25
Nd_2O_3	-	-	0.5	-	1.03	1.19
Sm_2O_3	-	-	-	-	0.30	0.36
Eu_2O_3	-	-	-	-	0.08	0.12
Gd_2O_3	-	-	-	-	0.32	0.43
Dy_2O_3	-	-	-	-	0.17	0.06
UO_2	-	1.40	-	0.4	0.86	0.36
PbO	-	-	-	-	0.16	0.09
ZrO_2	48.90	52.89	32.8	35.2	31.40	33.20
Hf_2O_3	-	-	-	-	0.70	0.66
TiO_2	30.89	14.95	25.3	24.3	21.00	22.30
FeO	6.64	7.72	-	7.2	7.16	7.37
Fe_2O_3	-	-	7.9	-		-
Nb_2O_5	-	-	10.5	11.3	9.98	11.20
MgO	0.49	0.22	-	0.4	0.71	0.37
MnO	-	-	-	0.2	0.28	0.26
Ta_2O_5	-	-	-	0.2	2.75	1.76
Al_2O_3	-	-	-	-	0.12	0.22
Ignition loss	1.02	1.02	-	-	-	-
Total	99.55	99.03	100.9	99.9	102.01	101.40

1. Hussak and Prior (1895).

2. Prior (1896).

3. Pudovkina *et al.* (1974): $(Ca_{0.98}Th_{0.12}Ce_{0.04}Nd_{0.01})_{\Sigma 1.15}Zr_{1.01}(Ti_{1.20}Fe^{3+}_{0.38}Nb_{0.30})_{\Sigma 1.88}O_7$

4. Sinclair and Ringood (1981):

$(Ca_{0.80}Th_{0.10}REE_{0.06}U_{0.01})_{\Sigma 0.97}Zr_{1.12}(Ti_{1.19}Fe^{2+}_{0.39}Nb_{0.33}Mg_{0.04}Mn_{0.01}Ta_{0.01})_{\Sigma 1.97}O_7$

5. e 6. Williams and Gieré (1996):

5.:$(Ca_{0.72}Th_{0.22}REE_{0.08}U_{0.01})_{\Sigma 1.03}(Zr_{1.05}Hf_{0.01})_{\Sigma 1.06}(Ti_{1.08}Fe^{2+}_{0.41}Nb_{0.31}Mg_{0.07}Ta_{0.05}Mn_{0.02}Al_{0.01})_{\Sigma 1.95}O_7$

6.:$(Ca_{0.79}Th_{0.13}REE_{0.09}U_{0.01})_{\Sigma 1.02}(Zr_{1.07}Hf_{0.01})_{\Sigma 1.08}(Ti_{1.11}Fe^{2+}_{0.41}Nb_{0.34}Mg_{0.04}Ta_{0.03}Mn_{0.02}Al_{0.02})_{\Sigma 1.97}O_7$

* ΣREE_2O_3

Crystallography. The crystals are metamict, although one specimen showed a faint, diffuse reflection on a Laue photograph. When heated to 800°C, the samples produced cubic defect fluorite-type patterns, with *a* 5.08 Å (Pudovkina *et al.* 1974).

Name. In honor of Ferdinand Zirkel (1838-1912), a pioneer in the microscopic investigation of rocks, Professor of Mineralogy, University of Lemberg, later at University of Leipzig, Germany.

Type material. The Natural History Museum, London, England (holotype, BM 80142) and Muséum national d'Histoire naturelle, Paris, France (type, 97.29, donator E. Hussak).

Relationship to other species. Zirkelite is dimorphous with zirconolite. Tazheranite, $(Zr,Ti,Ca)O_{2-x}$ is isomorphous with zirkelite.

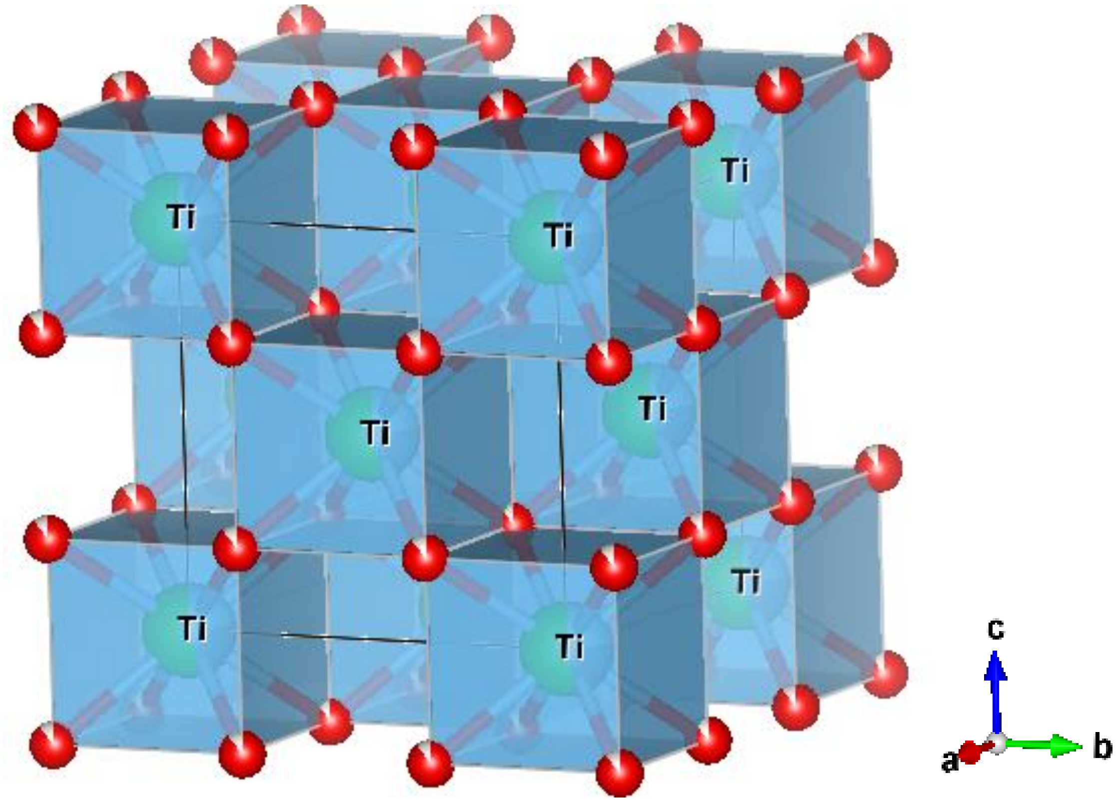

Figure 4.53. View of the crystal structure of zirkelite (heated), drawn using VESTA 3 (Momma and Izumi 2011). Based on data for tazheranite by Rastsvetaeva *et al.* (1998).

Crystal structure. When heated to 800°C, the samples produced cubic defect fluorite-type patterns, with *a* 5.08 Å (Pudovkina *et al.* 1974).

See also. Quintinite, menezesite, melcherite, pauloabibite, brazilite, barium phlogopite, and unidentified Ca-Nb oxide.

Melcherite

Andrade *et al*. (2018a)

$(Ba,K)_2(Na,Ca)_2Mg(Nb_6O_{19})\cdot 6H_2O$, trigonal

Approved CNMNC 2015-018

Other names: melcherita

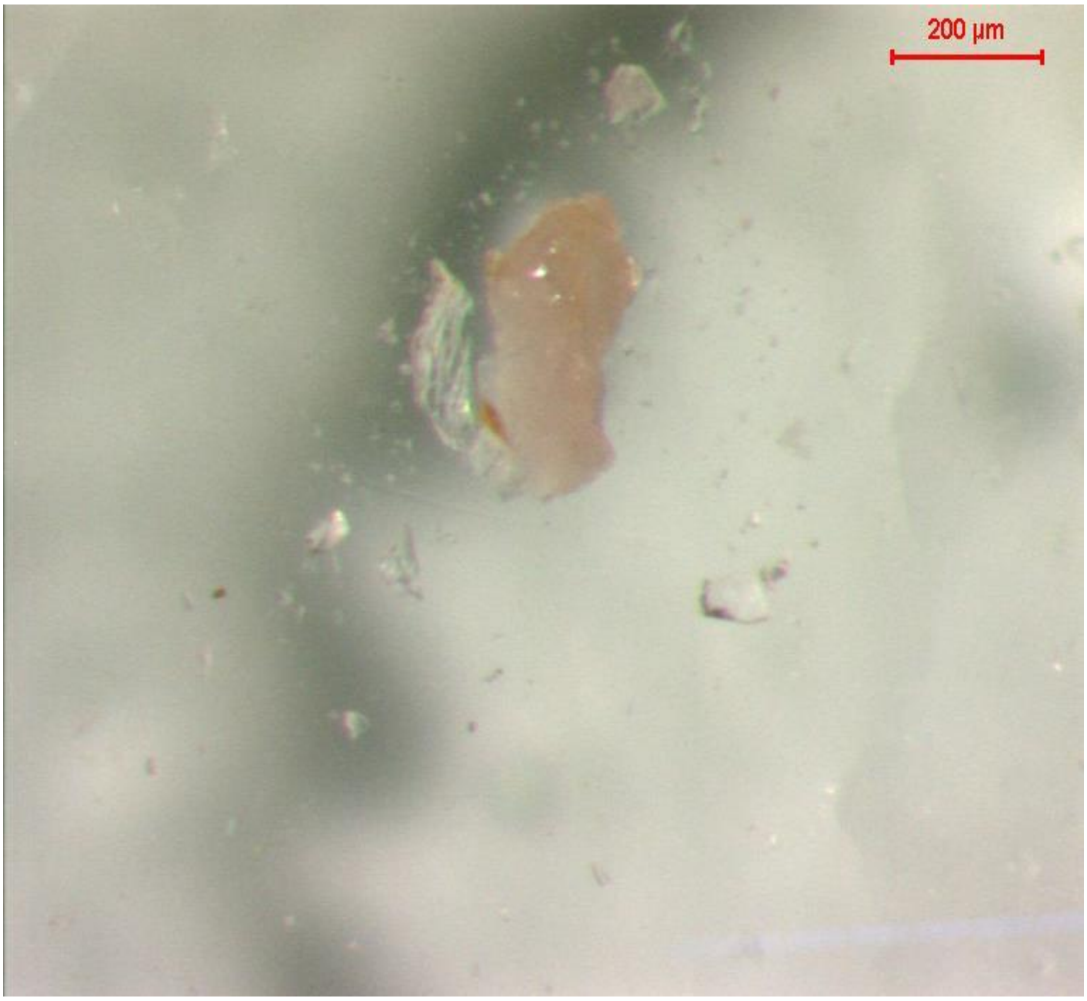

Figure 4.54. Melcherite from the Jacupiranga mine, Cajati, São Paulo (Andrade *et al.* 2018a).

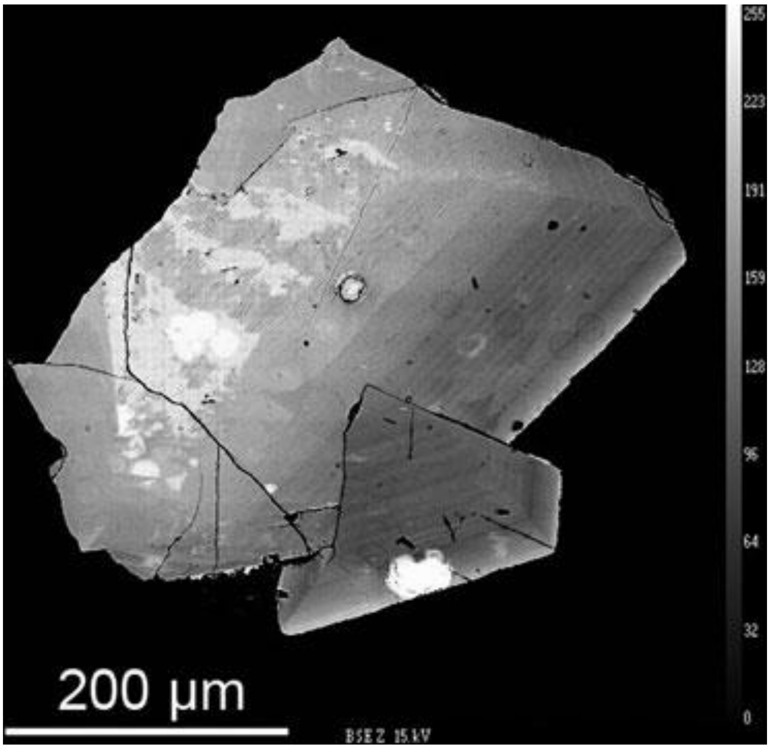

Figure 4.55. Back-scattered electron image of melcherite from the Jacupiranga mine, Cajati, São Paulo (Andrade *et al.* 2018a).

Melcherite is the second natural hexaniobate. The first is peterandresenite (Friis *et al*. 2014) and the third is hansesmarkite (Friis *et al*. 2017). Polyoxometalates of niobium are dominated by the Linqdvist hexaniobate ion, $(Nb_6O_{19})^{8-}$, and its synthesis and stability require alkaline conditions. The crystal structure of these compounds was first described by Lindqvist (1953). Hexaniobates are negatively charged clusters of six mutually edge-sharing NbO6 octahedra forming a super-octahedron (Nyman 2011). Possible polyoxoniobate applications include their use as reagents in the break-down of nerve agents and in the development of filter media protection against chemical warfare agents (Kinnan *et al*. 2014). Polyoxometalates have also been investigated in coordination chemistry, leading to the development of hybrid organometallic hexametalate complexes (Abramov *et al*. 2016), and the synthesis of new polyoxoniobates coordinated to copper complexes (Wang *et al*. 2008).

Occurrence. The mineral occurs in the carbonatite of the Jacupiranga mine, Cajati County, São Paulo (Menezes Filho and Martins 1984). For general information about this carbonatite see Menezes Filho *et al.* (2015a). This is also the type locality for zirkelite, quintinite, menezesite, and pauloabibite. Although the joint occurrence of menezesite, pauloabibite and melcherite has not been observed, these minerals may be related genetically. Pauloabibite is trigonal $NaNbO_3$, isostructural with ilmenite (Menezes Filho *et al.* 2015a). The synthetic analog of pauloabibite was reported by Kinomura *et al.* (1984) and Kumata *et al.* (1990) from a two-step synthesis method, involving the preparation of $Na_8Nb_6O_{19}\cdot 13H_2O$ (a hexaniobate) followed by hydrothermal reaction with NaOH in a silver-lined vessel at 250°C. Menezesite is a heteropolyoxoniobate, cubic $(\square,Ba,K)_{12}(\square,Mg)_3Zr_4(BaNb_{12}O_{42})\cdot 12H_2O$ (Atencio *et al.* 2008a). According to Nyman *et al.* (2002), the heteropolyanions of W, Mo and V are formed simply by acidification of solutions of their oxoanions. Under similar conditions, these oxoanion precursors are not available for Nb, and Nb-oxo chemistry is dominated by the formation of the Lindquist ion $[Nb_6O_{19}]^{8-}$ (present in melcherite). However, heteropolyniobate (present in menezesite) formation is favored in hydrothermal reactions of aqueous, alkaline precursor mixtures. A competing phase to the formation of polyoxoniobates in hydrothermal aqueous reactions involving Nb and an alkali hydroxide is $NaNbO_3$, avoided by using short reaction times (*i.e.* 24 hours or less) (Nyman *et al.* 2002). So melcherite could have originally formed under acid conditions, and afterward, under basic conditions, menezesite and pauloabibite could have formed. Quintinite, menezesite, pauloabibite and melcherite occur in the so-called ‘intermediate zone’, characterized by a high dolomite and slightly anomalous ‘pyrochlore’ content. Associated minerals are dolomite, calcite, magnetite, pyrrhotite, tochilinite, ‘pyrochlore’, pyrite and fluorapatite. Melcherite formed as a carbonatite vug mineral.

Appearance and physical properties. Irregular, tabular crystals up to 200 μm in maximum dimension. Transparent. Vitreous luster. Beige. Streak: white. Non-fluorescent. Perfect cleavage on {001}. Fracture was not determined. Twinning and parting were not observed. The Mohs hardness and density were not measured due to the paucity of material but the calculated density is 3.733 g/cm^3 [based on the empirical formula $(Ba_{0.99}K_{1.00})_{\Sigma 1.99}(Na_{1.02}Ca_{0.96})_{\Sigma 1.98}(Mg_{0.95}Mn_{0.05})_{\Sigma 1.00}Nb_{6.02}O_{19.00}\cdot 6H_2O$].

Optical properties. Refractive indices were not measured due to the paucity of material. The mean refractive index is estimated to be 1.924 using the Gladstone-Dale relationship.

Chemical data. Microprobe (WDS) analysis (25), H_2O was initially assumed by difference prior to the matrix correction (PAP) and then calculated by stoichiometry post matrix correction due to software limitations. The brighter areas of the melcherite crystal (back-scattered electron image) have the following composition: K_2O 0.70, Na_2O 4.30, BaO 20.66, CaO 0.83, MgO 3.00, MnO 0.09, Al_2O_3 0.08, Nb_2O_5 61.74, SiO_2 0.02, H_2O

8.35, total 99.77 wt.%, corresponding to $(Ba_{1.75}K_{0.19})_{\Sigma1.94}(Na_{1.80}Ca_{0.19})_{\Sigma1.99}(Mg_{0.96}Mn_{0.02}Al_{0.02})_{\Sigma1.00}Nb_{6.02}O_{19.00}\cdot6H_2O$ (mean of four analytical points). The end-member formula $Ba_2Na_2Mg[Nb_6O_{19}]\cdot6H_2O$ requires Na_2O 4.72, BaO 23.33, MgO 3.07, Nb_2O_5 60.66, H_2O 8.23, total 100.00 wt.%. The darker areas have the following composition K_2O 3.88, Na_2O 2.60, BaO 12.44, CaO 4.41, MgO 3.15, MnO 0.28, Al_2O_3 0.02, Nb_2O_5 65.79, SiO_2 0.00, H_2O 8.90, total 101.47 wt.%, and correspond to $(Ba_{0.99}K_{1.00})_{\Sigma1.99}(Na_{1.02}Ca_{0.96})_{\Sigma1.98}(Mg_{0.95}Mn_{0.05})_{\Sigma1.00}Nb_{6.02}O_{19.00}\cdot6H_2O$ (mean of eight analytical points). The enrichment in Ba is coupled to the enrichment in Na and depletion of K and Ca. The analyses were obtained in points of several shades of grey observed in back-scattered electron images distributed in different crystals. Chemical composition varies from $Ba_2Na_2Mg[Nb_6O_{19}]\cdot6H_2O$ to $(BaK)(NaCa)Mg[Nb_6O_{19}]\cdot6H_2O$. Coupled heterovalent substitutions at two sites are verified. As discussed by Hatert and Burke (2008), where a heterovalent substitution occurs at a given crystallographic site, the charge balance can also be maintained by coupling this substitution to another heterovalent substitution at a different site. At the *Ba* site, the atom Ba^{2+} is replaced progressively by K^+, and to maintain charge balance, the atom Na^+ is replaced progressively by Ca^{2+} at the *Na* site. The substitution mechanism is $Ba^{2+} + K^+ \leftrightarrow Na^+ + Ca^{2+}$. The boundary site occupancy between the two members of the series is $(BaK)(NaCa)Mg[Nb_6O_{19}]\cdot6H_2O$. We could imagine a solid-solution series from $Ba_2Na_2Mg[Nb_6O_{19}]\cdot6H_2O$ to $K_2Ca_2Mg[Nb_6O_{19}]\cdot6H_2O$, with two mineral species, but the composition varies only from the first end-member to the intermediate member. As no analyses correspond to predominant K and Ca, only one mineral species was defined.

Crystallography. Trigonal, $R\overline{3}$, *a* 9.022(2), *c* 23.410(6) Å, *V* 1650.2(8) Å^3 *Z* 3 (powder data). Trigonal, $R\overline{3}$, *a* 9.0117(6), *c* 23.3986(16) Å, *V* 1645.64(19) Å^3, *Z* 3 [data for a single-crystal with the composition $(Ba_{1.06}K_{0.94})(Na_{1.09}Ca_{0.91})Nb_6Mg[O_{18.98}(OH)_{0.02}]_{\Sigma19.00}\cdot6H_2O$]. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 7.805 (100) (010, 003), 7.410 (14) (011), 4.508 (10) (110), 3.904 (22) (020, 113), 3.852 (21) (021), 3.250(33) (024, 115), 3.074 (9) (017), 2.952 (13) (120, 116). 2.165 (30) (036, 029). 2.160 (12) (131).

Name. The mineral is named in honor of Geraldo Conrado Melcher (1924-2011). He was a professor at the Department of Mining Engineering at the Polytechnic School, University of São Paulo. He was also a pioneer in Jacupiranga Carbonatite studies (Melcher 1966).

Type material. Deposited under the number DR982 in the Museu de Geociências, Universidade de São Paulo.

Relationship to other species. The mineral is similar structurally to the synthetic compounds $Cs_6Na_2(Nb_6O_{19})\cdot 18H_2O$ and $Rb_6(H_2Nb_6O_{19})\cdot 19H_2O$, studied by Nyman *et al.* (2006). They have the same space group as melcherite. The unit-cell dimensions and arrangement of the Lindqvist ion $[Nb_6O_{19}]^{8-}$ are very similar.

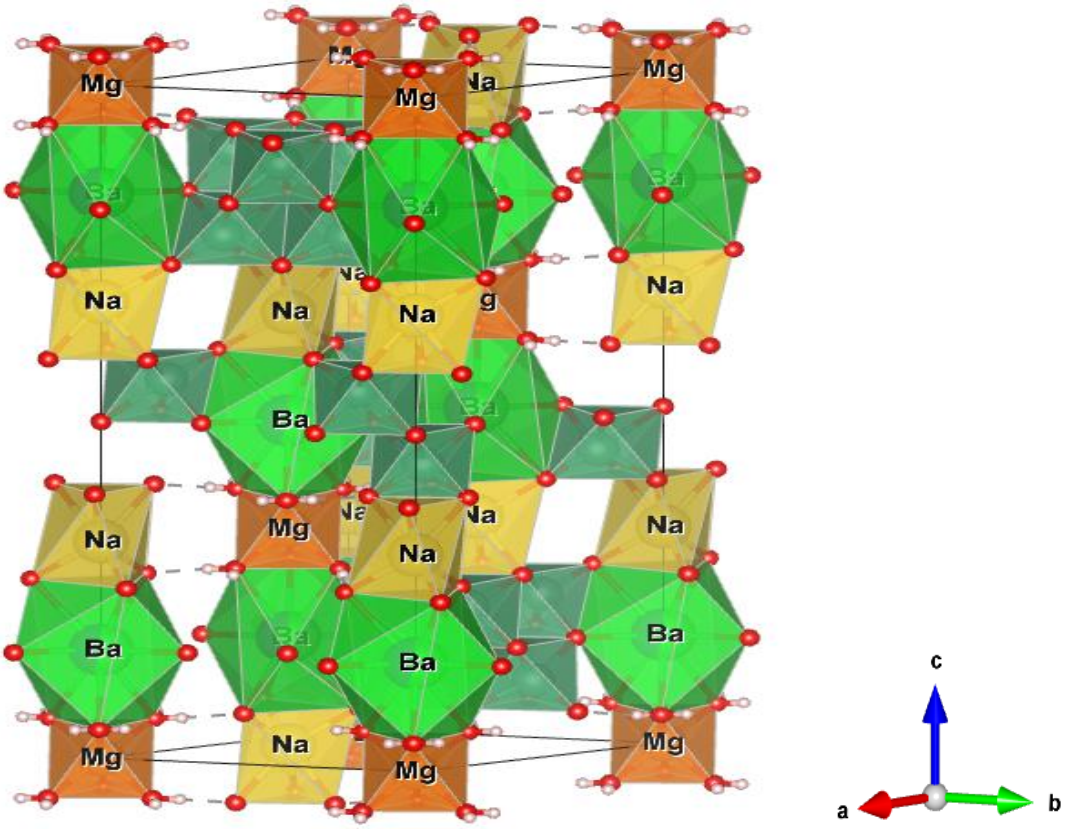

Figure 4.56. View of the crystal structure of melcherite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Andrade *et al.* (2018a).

Crystal structure. The melcherite structure is built by layers of $[(Ba,K)(O,H_2O)_9]$ polyhedra and the $[Nb_6O_{19}]^{8-}$ super-octahedron (Lindqvist anion) interconnected by $[(Na,Ca)O_6]$ polyhedra. Cations of Mg^{2+} are bonded to six water molecules each and are not associated with Lindqvist oxygen ions.

See also. Quintinite, menezesite, pauloabibite., zirkelite, brazilite, barium phlogopite, and unidentified Ca-Nb oxide.

Menezesite

Atencio *et al.* (2008a)

$(\square,Ba,K)_{12}(\square,Mg)_3Zr_4(BaNb_{12}O_{42})\cdot 12H_2O$, cubic

Approved CNMMN - IMA 2005-023

Other names: menezesita

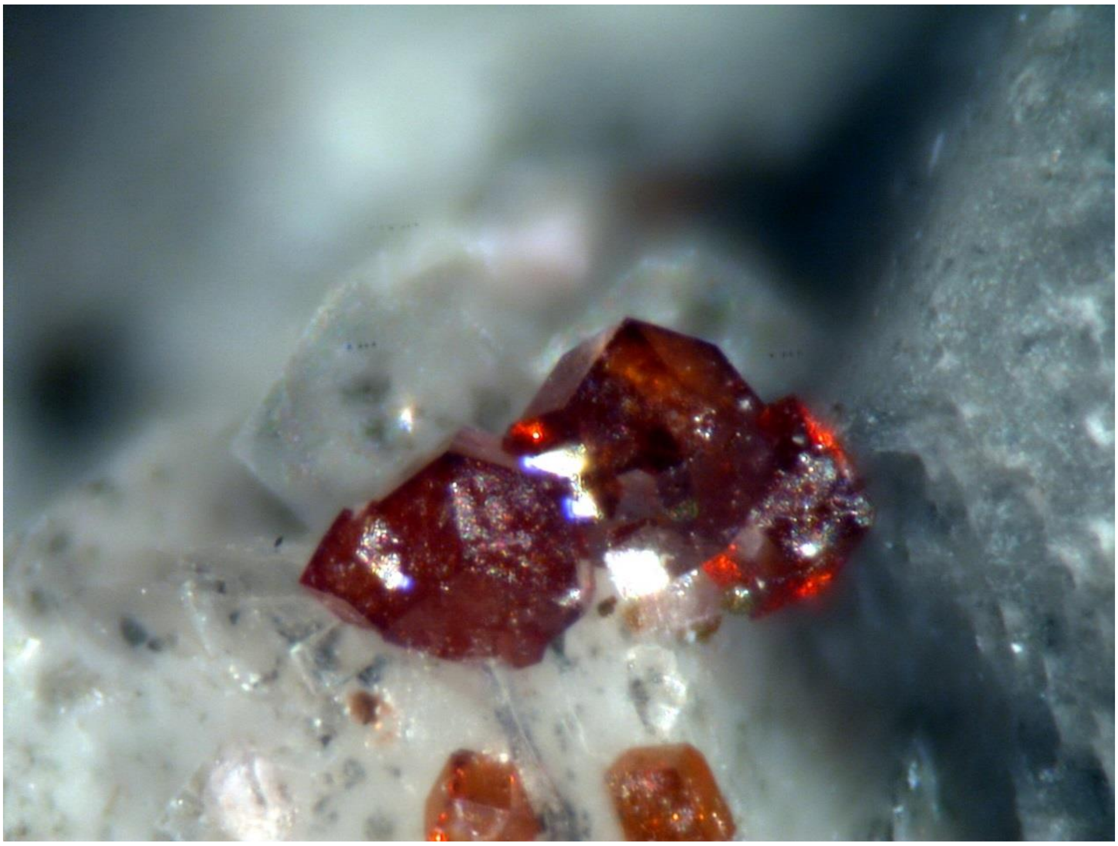

Figure 4.57. Menezesite, ~0.5 mm reddish-brown rhombododecahedra crystals, on dolomite, from the Jacupiranga mine, Cajati, São Paulo. Specimen: Luiz A.D. Menezes Filho. Photo: Tatiana Dias Menezes. Atencio *et al.* (2008a).

Figure 4.58. Menezesite from the Jacupiranga mine, Cajati, São Paulo. Specimen DR458 (the type specimen), Museu de Geociências, Universidade de São Paulo. Photo: Thales Trigo.

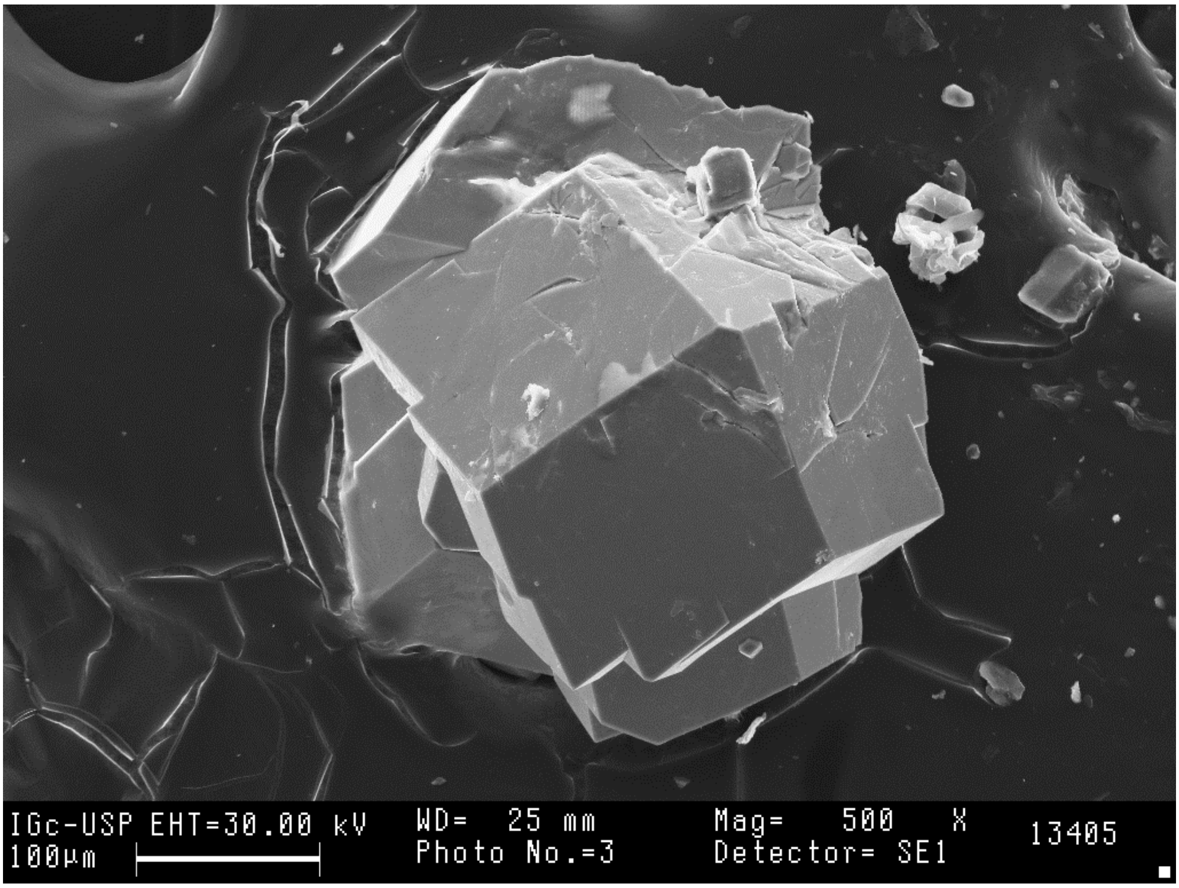

Figure 4.59. Menezesite rhombododecahedra. Secondary electron image. Atencio *et al.* (2008a).

Menezesite is the first natural heteropolyniobate. The second natural heteropolyniobate, aspedamite, isostructural with menezesite, was described in Southern Norway, by Cooper *et al.* (2012). The first synthetic heteropolyniobates were obtained by Nyman *et al.* (2002, 2004). The “heteropolyniobates” obtained by Dale and Pope (1967), Dale *et al.* (1969), and Flynn and Stucky (1969a, b) are not heteropolyniobates *sensu stricto*, because the ligands do not form a cage about the heteroatom. Heteropolyanions are negatively charged clusters of corner- and edge-sharing early transition-metal MO_6 octahedra and a heteroatom usually located in the interior of the cluster. The geometry, composition, and charge of these clusters are varied through synthesis parameters, and cluster properties are highly tunable as a function of these characteristics. Heteropolyanions have been employed in a range of applications that include virus-binding inorganic drugs (including AIDs virus), homogeneous and heterogeneous catalysts, electro-optic and electrochromic materials, metal and protein binding, and as building blocks for nanostructuring of materials. The heteropolyanions of W, Mo, and V, which have found numerous applications, are formed simply by acidification of solutions of their oxoanions. Under similar conditions, these oxoanion precursors are not available for Nb, and Nb-oxo chemistry is dominated by the formation of the Lindquist ion $[Nb_6O_{19}]^{8-}$ only (as in melcherite). However, heteropolyniobate formation is favored in hydrothermal reactions of aqueous, alkaline precursor mixtures. Unlike other heteropolyanions, heteropolyniobates are basic rather than acidic, which means they can survive longer and possibly even thrive in the generally basic or neutral environments of radioactive wastes and blood, respectively. Once such compounds bind with a virus, it is no longer capable of entering a cell to damage it. Heteropolyanions may also bind with radionuclides (actinides), which remove them from the mixture by phase separation for easier and safer storage. Menezesite has been found in the last years of the decade of 1970 by Luiz Alberto Dias Menezes Filho, but its study has begun only in May 2003. A preliminary note on this mineral was published by Atencio *et al.* (2006b). Additional data can be found in the RRUFF Database (R060979).

Occurrence. The mineral occurs in the contact zone between dolomite carbonatite and “jacupirangite” (=a pyroxenite) at the Jacupiranga mine, in Cajati Co., São Paulo state (Menezes Filho and Martins 1984). This is the type locality of zirkelite, quintinite, pauloabibite, and melcherite. Associated minerals: dolomite, calcite, magnetite, clinohumite, phlogopite, ancylite-(Ce), strontianite, pyrite, and tochilinite. Menezesite was formed as a vug mineral.

Appearance and physical properties. Habit: crystals up to 1 mm isolated or in aggregates. Forms: rhombododecahedra {110}. Twinning: none observed. Color: reddish-brown. Streak: white. Luster: vitreous. Transparent. Non-fluorescent. Hardness (Mohs) about 4. Cleavage: none observed. Fracture: not determined. Density was not measured due to the paucity of material. Density (calc.): 4.181 g/cm^3 (based on the empirical formula).

Optical properties. Isotropic, *n* meas. > 1.93(1) (white light). *n* calc. 2.034 using the Gladstone-Dale relationship. Weak anomalous birefringence.

Chemical data. Microprobe (WDS) analysis (10), H_2O from the crystal structure determination: Na_2O 0.06, K_2O 0.86, CaO 0.60, BaO 11.50, La_2O_3 0.09, Ce_2O_3 0.94, Nd_2O_3 0.57, MgO 1.29, FeO 0.57, MnO 0.55, Al_2O_3 0.05, ZrO_2 11.58, ThO_2 4.94, UO_2 0.23, TiO_2 8.90, Nb_2O_5 41.97, Ta_2O_5 2.71, SiO_2 0.25, H_2O 7.40, total 95.06 wt.%. Empirical formula: $(\square_{9.34}Ba_{1.47}K_{0.53}Ca_{0.31}Ce_{0.17}Nd_{0.10}Na_{0.06}La_{0.02})_{\Sigma 12.00}(\square_{1.57}Mg_{0.94}Mn_{0.23}Fe_{0.23}Al_{0.03})_{\Sigma 3.00}(Zr_{2.75}Ti_{0.96}Th_{0.29})_{\Sigma 4.00}[(Ba_{0.72}Th_{0.26}U_{0.02})_{\Sigma 1.00}(Nb_{9.23}Ti_{2.29}Ta_{0.36}Si_{0.12})_{\Sigma 12.00}O_{42.03}]\cdot 12H_2O$. The simplified formula is $(\square,Ba,K)_{12}(\square,Mg)_3Zr_4(BaNb_{12}O_{42})\cdot 12H_2O$. The end-member formula was originally expressed as $Ba_2MgZr_4(BaNb_{12}O_{42})\cdot12H_2O$, but it should be more correctly expressed as $\square_{12}Mg_3Zr_4(BaNb_{12}O_{42})\cdot12H_2O$ (Cooper *et al.* 2012), which requires MgO 4.69, ZrO_2 19.12, BaO 5.95, Nb_2O_5 61.86, H_2O 8.39, total 100.00 wt.%.

*Crystallography***.** Cubic, *Im*3, *a* 13.017(1) Å, *V* 2206(1) Å^3, *Z* 2. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 9.183 (100) (011), 4.592 (12) (022), 4.136 (11) (013), 3.256 (16) (004), 3.070 (13) (033, 114), 2.923(11) (024), 2.655 (13) (224), 1.741 (21) (246).

Name. The mineral was named in honor of Luiz Alberto Dias Menezes Filho (1950-2014), mining engineer, mineral collector, and merchant. He studied the minerals from the Jacupiranga mine (Menezes Filho and Martins 1984) and collected the samples that were used for the first official description of several new Brazilian minerals [for instance: lanthanite-(Nd), quintinite, fluornatromicrolite, lindbergite, ruifrancoite, guimarãesite, bendadaite, carlosbarbosaite, pauloabibite, almeidaite, melcherite, and menezesite].

Type material. Type material is deposited under the number DR458 in the Museu de Geociências, Universidade de São Paulo.

Relationship to other species. Isostructural with aspedamite, $\square_{12}(Fe^{3+},Fe^{2+})_3Nb_4[Th(Nb,Fe^{3+})_{12}O_{42}]\{(H_2O),(OH)\}_{12}$ (Cooper *et al.* 2012), and with the synthetic compound $Mg_7[MgW_{12}O_{42}](OH)_4\cdot8H_2O$ studied by Günter *et al.* (1990).

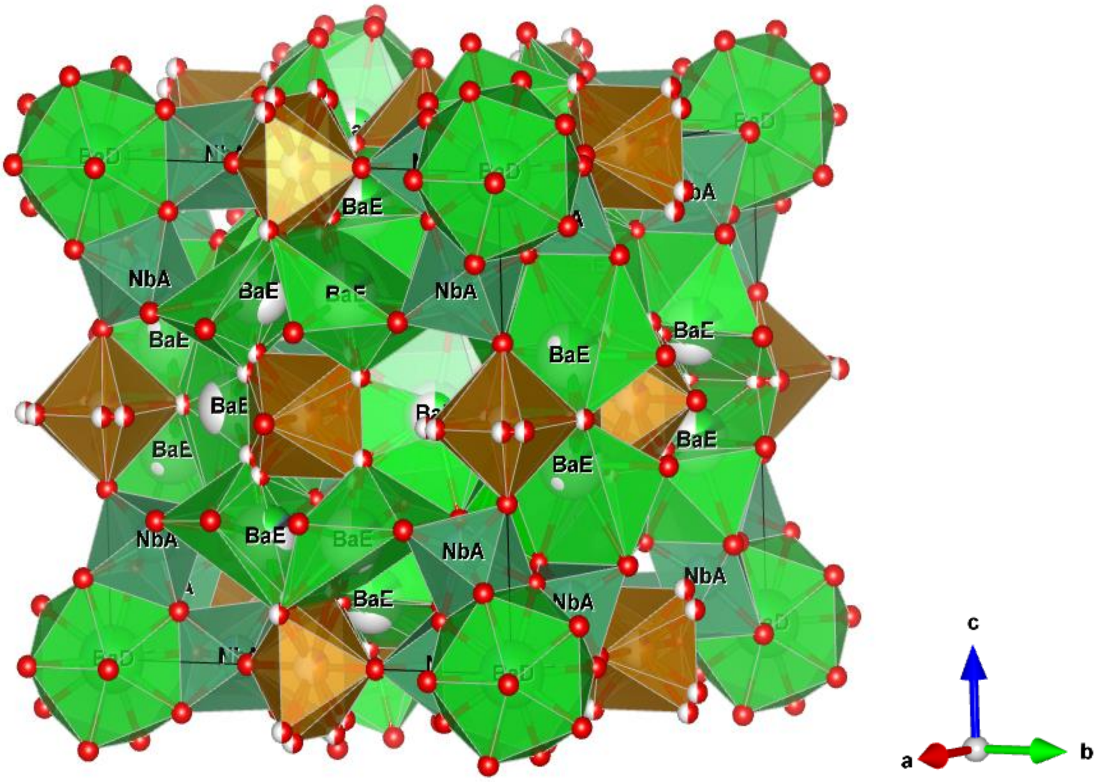

Figure 4.60. View of the crystal structure of menezesite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Atencio *et al.* (2008a).

Crystal structure. The structure is based on the heteropolyanion $[BaNb_{12}O_{42}]^{22-}$, which consists of twelve face- and corner-sharing NbO_6 octahedra that surround the [12]-coordinated Ba cation. This type of heteropolyanion was originally described by Dexter and Silverton (1968). There are eight heteropolyanions at the corners of the unit cell, with an additional heteropolyanion at the center, forming an *I*-centered arrangement. Each heteropolyhedral cluster is decorated by eight ZrO_6 octahedra, each of which bridges two adjacent clusters along the body diagonals of the cell. Further intercluster linkage is provided by the six $[MgO_2(H_2O)_4]$ octahedra, which link pairs of adjacent clusters in the *a* direction. There are three extra sites for Ba, K, Ca and *REE*. They are very close and therefore cannot be simultaneously occupied. Each of these sites can have up to 12 cations per formula unit, but they are practically empty.

See also. Quintinite, melcherite, pauloabibite, zirkelite, brazilite, barium phlogopite, and unidentified Ca-Nb oxide.

Carlosbarbosaite

Atencio *et al.* (2012)

$(UO_2)_2Nb_2O_6(OH)_2\cdot 2H_2O$, orthorhombic

Approved CNMNC 2010-047

Other names: carlosbarbosaíta

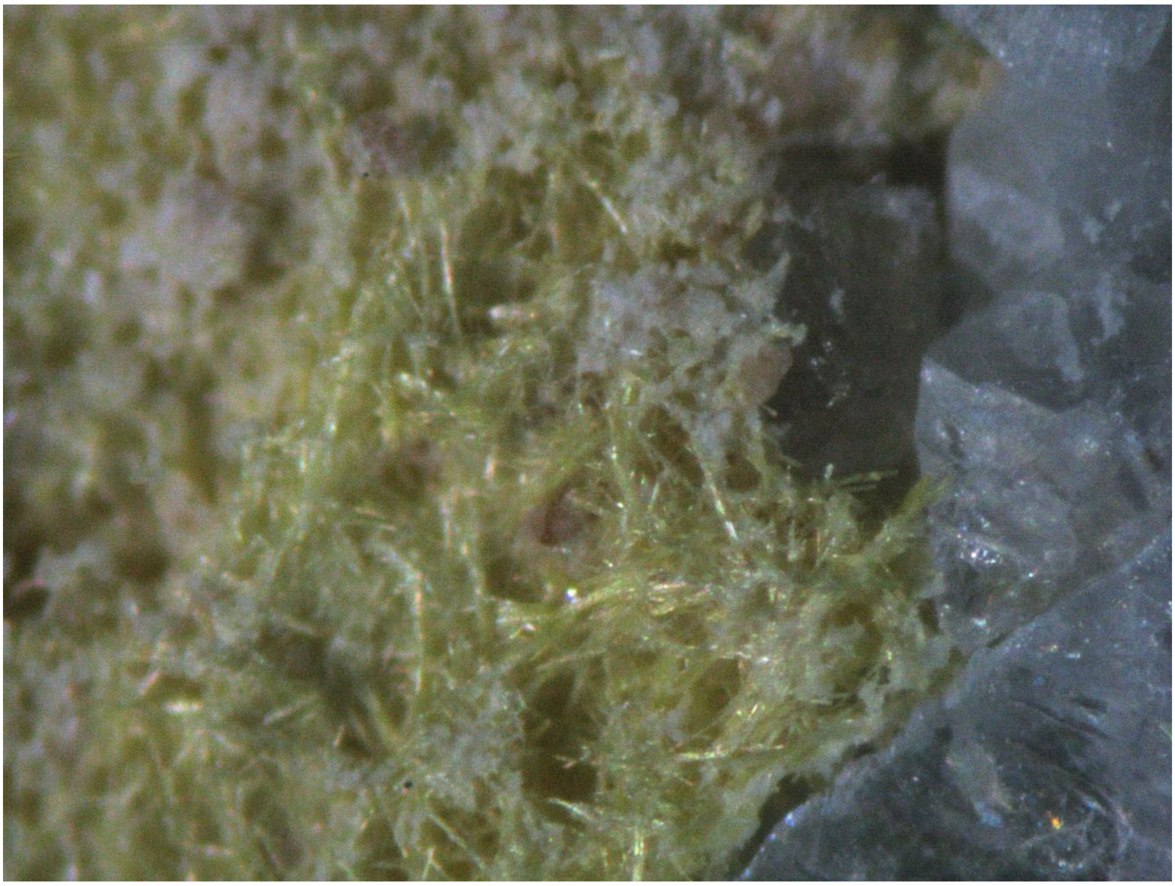

Figure 4.61. Carlosbarbosaite from Jaguaraçu, Minas Gerais. The field of view is ~3 mm across. (Atencio *et al.* 2012)

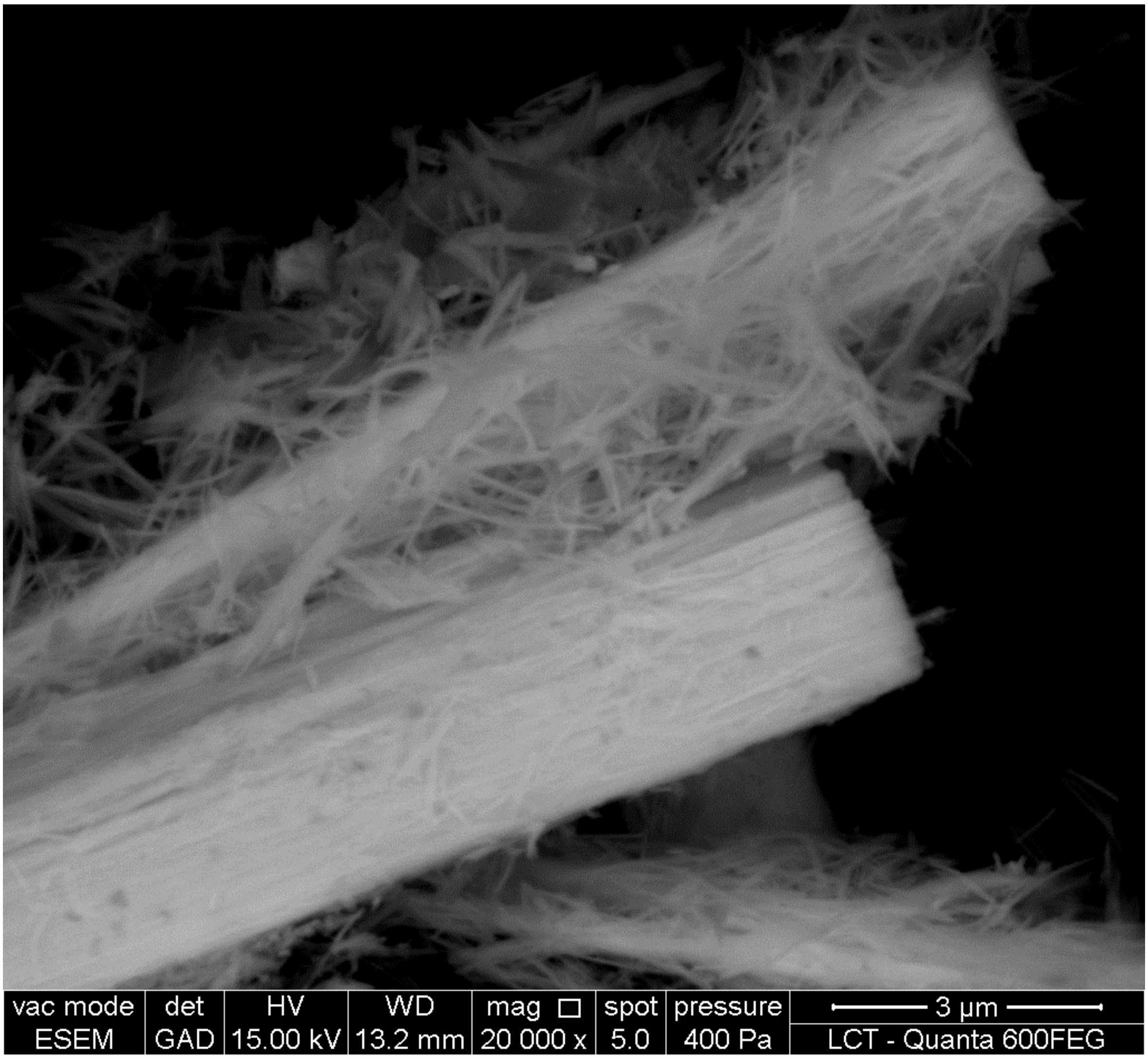

Figure 4.62. Back-scattered electron image of carlosbarbosaite from Jaguaraçu, Minas Gerais (Atencio *et al.* 2012)

Occurrence. The mineral occurs in the Jaguaraçu pegmatite, Jaguaraçu municipality, Minas Gerais. The pegmatite body, also known as the Lavra do Senhor José Pinto, José Miranda, and Carneirinho, is located adjacent to a soccer field. The pegmatite, as exposed, is lenticular, with a strike length of at least 100 m and a maximum width of 20 m. It crops out on a steep hillside, and, at the uppermost end, pinches out to less than 1 m in width. Other minerals identified in the pegmatite are quartz, orthoclase (also var. adularia), microcline (var. amazonite), albite, muscovite, beryl, elbaite, schorl, spodumene, fluorapatite, fluorite, almandine-spessartine, lepidolite and biotite series minerals, anatase, cassiterite, uraninite, pyrite, zircon, columbite-(Fe), tapiolite-(Fe), cerussite, pyromorphite, monazite-(Ce), euxenite-(Y), chernovite-(Y), milarite, agakhanovite (“yttrian milarite”), minasgeraisite-(Y), churchite-(Y), hematite, ilmenite, magnetite, manganese oxides, kaolinite, montmorillonite, and nontronite (Foord *et al.* 1986, Cassedanne and Alves 1994). This is also the type locality for minasgeraisite-(Y) (Foord *et al.* 1986). Carlosbarbosaite occurs as a late cavity filling in albite. Closely associated minerals are zircon, muscovite, kaolinite and columbite-(Fe). Carlosbarbosaite is probably the same as the "U-Nb-oxide" [unnamed mineral UN 1398 (Smith and Nickel 2007), ICDD 00-29-1373] described from Cerro Blanco de Tanti, Córdoba, Argentina, by Arcidiácono and Bedlivy (1976). The XRD pattern and optical data are similar for the two specimens. Carlosbarbosaite may also be known from the El Erediya granite, Eastern Desert of Egypt (Abd El-Naby 2008). Bardelli *et al.* (2018) described carlosbarbosaite from the La Chinchilla granite, sierra de Velasco, La Rioja, Argentina.

Appearance and physical properties. The crystals are up to 120 μm long and have a thickness of about 2-5 μm. Larger crystals have a length to width ratio that exceeds 10:1. Some material is fibrous and powdery. The crystals are elongated along [001] and flattened on (100). The fibers have a rectangular cross-section apparently bound by (100) and (010); these are also presumably cleavage planes. The vast majority of the elongated fibers are bent. Habit: long, flattened, lath-shaped crystals with very simple orthorhombic morphology. Forms: {001}, {010}, and {100} pinacoids. Twinning: none observed. Color: cream to pale yellow. Streak: yellowish-white. Luster: vitreous. Transparent (individual crystals) to translucent (masses). Non-fluorescent. Hardness: unknown (too little pure material), but the mineral is easily crushed between two glass slides. Tenacity: flexible. Cleavage: presumably {100} and {010}. Fracture: uneven. Density could not be measured because too little pure material was available. Density (calc.) 4.713 g/cm^3 (sample 1) and 4.172 (sample 2).

Optical properties. Biaxial (+), α 1.760(5), β 1.775(5), γ 1.795(5), $2V$ 70(1)° (meas.), 82.6° (calc.) (white light). Orientation: $X // a$, $Y // b$, $Z // c$. Pleochroism: weak, in yellowish-green shades, which are most intense in the Z direction.

Chemical data. Two samples were analyzed. Infrared spectra show that both (OH) and H_2O are present. H_2O content calculated by stoichiometry from the results of the crystal-structure analysis. Sample 1 (7 point analysis from 7 crystals, EDS and WDS): UO_3 54.52, CaO 2.07, Ce_2O_3 0.33, Nd_2O_3 0.49, Nb_2O_5 14.11, Ta_2O_5 2.20, TiO_2 0.41, SiO_2 2.14, FeO 0.97, Al_2O_3 0.73, H_2O 5.97, total 98.78 wt.%. Empirical formula: $(\square_{0.68}Ca_{0.28}Nd_{0.02}Ce_{0.02})_{\Sigma 1.00}[U_{1.44}\square_{0.56}O_{2.88}(H_2O)_{1.12}](Nb_{0.80}Ta_{0.52}Si_{0.27}Ti_{0.21}Al_{0.11}Fe_{0.10})_{\Sigma = 2.01}O_{4.72}(OH)_{3.20}(H_2O)_{2.08}$. Sample 2 (7 point analysis, WDS): UO_3 41.83, CaO 2.10, Ce_2O_3 0.31, Nd_2O_3 1.12, Nb_2O_5 14.64, Ta_2O_5 16.34, TiO_2 0.95, SiO_2 3.55, Fe_2O_3 0.89,

Al_2O_3 0.71, H_2O (calc.) 14.99, total 97.43 wt.%. Empirical formula: $(\square_{0.67}Ca_{0.27}Nd_{0.05}Ce_{0.01})_{\Sigma 1.00}[U_{1.04}\square_{0.96}O_{2.08}(H_2O)_{1.92}](Nb_{0.79}Ta_{0.53}Si_{0.42}Ti_{0.08}Al_{0.10}Fe_{0.08})_{\Sigma=2.00}O_{4.00}(OH)_{3.96}(H_2O)_{2.04}$. The ideal formula requires UO_3 64.14, Nb_2O_5 29.80, H_2O 6.06, total 100.00 wt.%.

Crystallography. Orthorhombic, *Cmcm*, *a* 14.150(6), *b* 10.395(4), *c* 7.529(3) Å, *a*:*b*:*c* = 1.361:1:0.724, *V* 1107(1) Å^3, *Z* 4 (single-crystal); *a* 14.177(3), *b* 10.405(3), *c* 7.552(2) Å, *a*:*b*:*c* = 1.363:1:0.726, *V* 1114.0(5) Å^3, *Z* 4 (powder data). X-ray powder-diffraction data [*d* in Å (*I*) (*hkl*)]: 8.405 (80) (110), 7.081 (100) (200), 4.201 (90) (220), 3.333 (60) (202), 3.053 (80) (022), 2.931 (70) (420), 2.803 (60) (222), 2.589 (50) (040, 402).

Name. The name honors Carlos do Prado Barbosa (1917-2003). Graduated as a chemical engineer in 1943, he developed a long career as a dealer in mineral specimens, with special attention to the discovery and study of rare mineral species, especially from the Brumado magnesite mine in Bahia state, and from the pegmatites in Minas Gerais state, including this Jaguaraçu pegmatite. He was one of the co-authors in 1986 of the descriptions of minasgeraisite-(Y) and bahianite.

Type material. Museu de Geociências, Universidade de São Paulo, registration number DR707. Microgram portions are housed in the Systematic Reference Series of the National Mineral Collection at the Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, K1A 0E8 Canada.

Relationship to other species. Carlosbarbosaite is closely related to a family of synthetic [U – Nb – O] framework tunnel structures (Surblé *et al.* 2006) and displays a new framework variation {*ie*. (OH)-bearing} and tunnel occupant {*ie*. $Ca(H_2O)_4$}. The structure of carlosbarbosaite also resembles that of holfertite (Sokolova *et al.* 2005, Belakovskiy *et al.* 2006), but the carlosbarbosaite structure is reasonably well-ordered whereas that of holfertite is very much disordered.

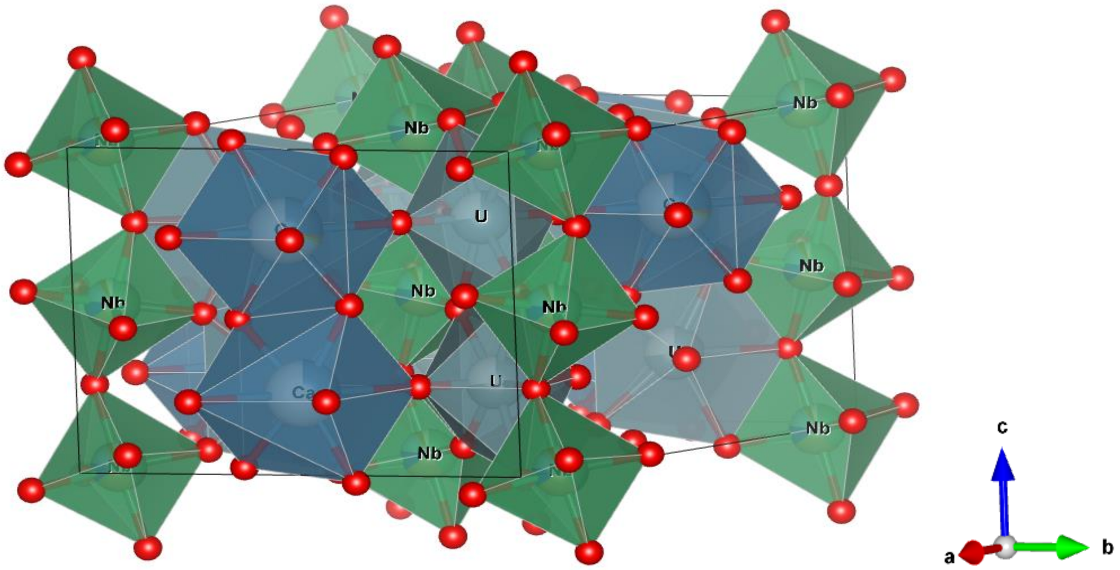

Figure 4.63. View of the crystal structure of carlosbarbosaite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Atencio *et al.* (2012).

Crystal structure. The crystal structure contains a single *U* site with an appreciable deficiency in electron scattering, which is populated by U atoms and vacancies. The *U* site is surrounded by seven O atoms in a pentagonal bipyramidal arrangement. The *Nb* site is coordinated by four O atoms and two OH groups in an octahedral arrangement. The half-occupied tunnel *Ca* site is coordinated by four O atoms and four H_2O groups. Octahedrally coordinated Nb polyhedra share edges and corners to form $[Nb_2O_6(OH)_2]$ double chains, and edge-sharing pentagonal bipyramidal U polyhedra form $[UO_5]$ chains. The $[Nb_2O_6(OH)_2]$ and $[UO_5]$ chains share edges to form an open [U – Nb – ø] framework with tunnels along [001] that contain $Ca(H_2O)_4$ clusters.

See also. Yttrian milarite, minasgeraisite-(Y), brumadoite, bahianite, and staringite.

Dukeite

Burns *et al.* (2000)

$Bi^{3+}_{24}Cr^{6+}_{8}O_{57}(OH)_6 \cdot 3H_2O$, trigonal

Approved CNMMN - IMA 1999-021

Other names: dukeíta

Figure 4.64. Dukeite from the São José mine, Posse farm, Brejaúba, Conceição do Mato Dentro, Minas Gerais. Type specimen. Photo: John A. Stirling.

Occurrence. Found on a museum specimen (an altered granitic pegmatite?) from São José mine, Posse farm, Brejaúba, Conceição do Mato Dentro, Minas Gerais [the type locality of djalmaite (uranmicrolite)]. The associated minerals are pucherite, schumacherite, bismutite, and hechtsbergite. The minerals of the pegmatite are kaolinized microcline, quartz, “bismuth ore”, muscovite, beryl (green, bluish, and brown), “garnet”, “columbite”, magnetite, “monazite”, samarskite-(Y), and “tourmaline”. Chrombismite is also quoted (http://www.mindat.org/min-6871.html). Also, known from Val-d'Ajol, Vosges, Lorraine, France, as a coating of tiny platy, bright yellow, with pearly luster crystals of dukeite (0.01 mm each), associated with atelestite and weathered emplectite (http://www.mindat.org/gallery.php?loc=13008andmin=7089). Harada *et al.* (2012) described an additional occurrence at Kinkei mine, Chino City, Nagano Prefecture, Japan.

Appearance and physical properties. As tight groups of 1 × 0.3 mm-sized sheaves. Individual acicular crystals, elongated along [001], do not exceed 100 × 1-2 μm. Yellow to dirty yellow-brown, with a bright yellow streak. Luster: resinous. Transparent. Brittle. Non-fluorescent. Mohs hardness 3 to 4. Brittle with an uneven to splintery fracture. Density 7.171 g/cm^3 (calc.). Slowly soluble in concentrated HCl.

Optical properties. In reflected plane-polarized light in air, gray to purplish-gray with strong yellow internal reflections. Very weak bireflectance.

Chemical data. Electron microprobe data (from 8 points): Bi_2O_3 85.06, CrO_3 11.65, V_2O_5 0.59, H_2O (from the ideal formula) 1.66, total 98.96 wt.%. Empirical formula: $Bi^{3+}_{23.95}(Cr^{6+}_{7.64}V^{5+}_{0.43})_{\Sigma 8.07}O_{56.84}(OH)_{6.16}\cdot 3.01H_2O$. The ideal formula $Bi^{3+}_{24}Cr^{6+}_{8}O_{57}(OH)_{6}\cdot 3H_2O$ requires Bi_2O_3 86.03, CrO_3 12.31, H_2O 1.66, total 100.00 wt.%.

Crystallography. Trigonal, $P31c$, a 15.067(3), c 15.293(4) Å, V 3006(2) Å^3, Z 2, c:a 1.0150. X-ray powder diffraction data [d in Å (I) (hkl)]: 7.650 (50) (002), 3.812 (40) (004), 3.382 (100) (222), 2.681 (70) (224), 2.175 (40) (600), 2.106 (40) (226), 1.701 (50) (228).

Name. The name honors Duke University, Durham, North Carolina, USA, in whose collection the mineral was found and also recognizes the contribution of the Duke family to the advancement of science.

Type material. The Natural History Museum, London, England (type, BM 199,26, polished section used for microprobe and reflectance studies); National Mineral Collection of Canada, Geological Survey of Canada, Ottawa, Ontario, Canada (NMC 68082); U.S. National Museu of Natural History (Smithsonian Institution), Washington DC, USA (holotype, 172012).

Relationship to other species. None obvious.

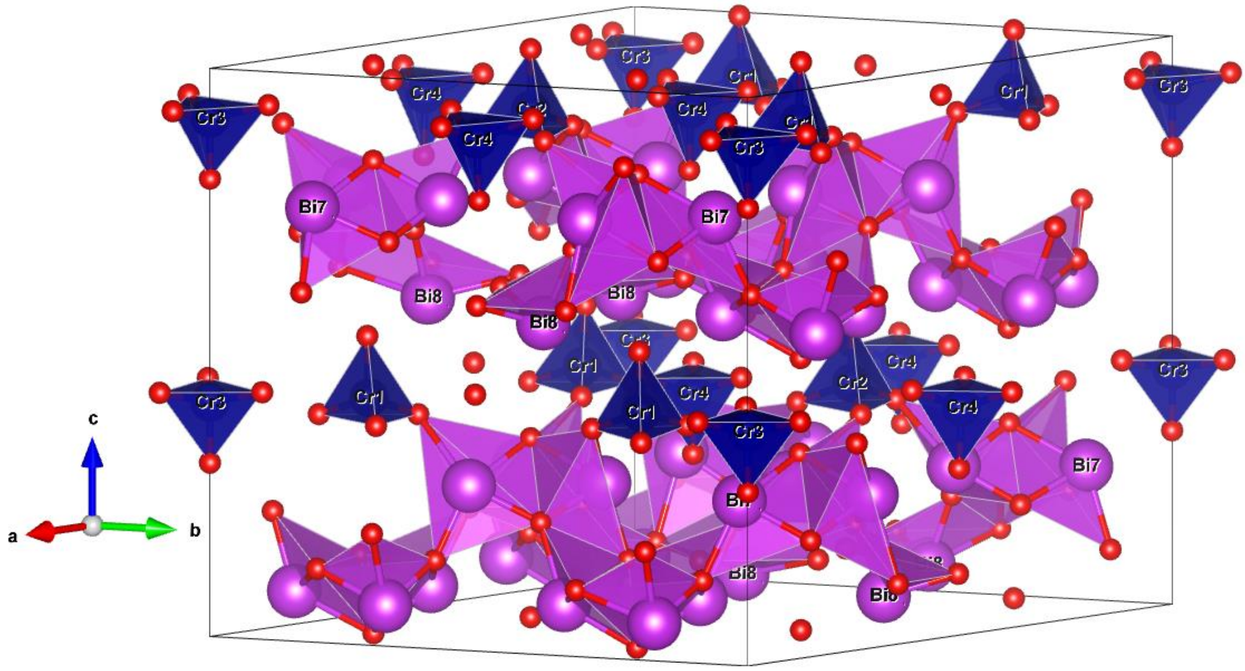

Figure 4.65. View of the crystal structure of dukeite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Burns *et al.* (2000).

Crystal structure. Irregular layers of Bi(O,OH,H_2O)$_n$ polyhedra parallel to (001), separated and connected by a layer of CrO_4 tetrahedra (Burns *et al.* 2000).

See also. Djalmaite.

Quintinite

Chao and Gault (1997)

$Mg_4Al_2(OH)_{12}(CO_3)\cdot3H_2O$, hexagonal

Approved CNMMN - IMA 1992-028

Other names: quintinita, UM1996-25-OH:AlCMg

Figure 4.66. Quintinite-2*H* crystal with predominant hexagonal trapezohedron, pinacoid and prism forms, from Jacupiranga mine, Cajati, São Paulo. Largest crystal size: 2.5 mm. Specimen and photo: Gianfranco Ciccolini.

Figure 4.67. Quintinite-2*H* from Jacupiranga mine, Cajati, São Paulo. Specimen: Luiz A.D. Menezes Filho. Photo: Tatiana Dias Menezes.

Quintinite is a member of the important group of layered double hydroxides, with many applications ranging from catalysis and absorption to carriers for drug delivery, DNA intercalation and carbon dioxide sequestration. Another area of interest is the theory of the origin of life on Earth, as they may serve as matrices for the origin of life in prebiotic systems. For details, see Krivovichev *et al.* (2011).

The 2*H* and 3*T* polytypes of quintinite were initially described as distinct mineral species and were assigned separate IMA proposal numbers (IMA 1992-028 and IMA 1992-029, respectively) (Chao and Gault 1997); they are now regarded as polytypes of a single species (Mills *et al.* 2012). The 2*H* polytype was originally identified by Menezes Filho and Martins (1984), in the carbonatite of Cajati (Cajati was formerly part of Jacupiranga), São Paulo, as “manasseite” [manasseite was discredited as the 2*H* polytype of hydrotalcite (Mills *et al.* 2012)], $Mg_6Al_2(OH)_{16}(CO_3)\cdot4H_2O$ hexagonal. The predominant hexagonal trapezohedral form observed (possible only in the 622 class), however, is incompatible with the space group of “manasseite”, $P6_3/mmc$. Chao and Gault (1997) verified that it was a new mineral, with formula $Mg_4Al_2(OH)_{12}(CO_3)\cdot3H_2O$ and space group $P6_322$, to which they gave the name quintinite-2*H*. The 3*T* polytype was initially described from Mont Saint-Hilaire, Québec, Canada. Chao and Gault (1997) reported several other instances in which phases with a quintinite-like composition had been wrongly described as either hydrotalcite or manasseite.

Arakcheeva *et al.* (1996) had previously examined the 2*H* polytype from Cajati without describing it as a new mineral; however, they reported a different space group ($P\bar{6}2m$) and unit-cell parameters *a* 5.283 and *c* 15.150 Å, with *Z* 1. Zhitova *et al.* (2010) studied quintinite-2*H* from Kovdor alkaline massif, Kola peninsula, Russia, and determined space group $P6_3/mcm$. Zhitova *et al.* (2018) quoted the space group as $P6_3/mmc$. The hexagonal trapezohedral form observed is incompatible with these three space groups.

Quintinite from the Kovdor alkaline massif, Kola peninsula, Russia, was examined by Krivovichev *et al.* (2010a,b,c) and Zhitova *et al.* (2010, 2018). Their single-crystal X-ray study confirmed that quintinite occurs in several structural polytypes, with different stacking sequences and different degrees of long-range order. They published structure solutions for several new polytypes of quintinite, but they found none with a space group belonging to class 622.

One hypothesis is that quintinite from Cajati occurs in different polytypes, as in Kovdor, and the specimen studied by Arakcheeva *et al.* (1996) was different from that studied by Chao and Gault (1997), not a crystal with the hexagonal trapezohedral form.

The following description is for quintinite-2*H* from Cajati.

Occurrence. In vugs in dolomitic carbonatite of Cajati, São Paulo. Other minerals are ancylite-(Ce), aragonite (secondary), baddeleyite, barite, brucite, calcite (primary and secondary), chalcopyrite, clinohumite, dolomite, fluorapatite, forsterite, galena, geikielite, magnesian ilmenite, magnetite, phlogopite, pyrite, pyrrhotite, quartz (secondary), serpentine, strontianite, oxycalciopyrochlore, valleriite (Menezes Filho and Martins 1984), and menezesite. This is the type locality of zirkelite, menezesite, pauloabibite, and melcherite. Chao and Gault (1997) observed that a hexagonal mineral with a composition identical to that of quintinite-2*H* was found in the evaporite deposits of the pre-Caspian depression and in those of central Asia (Drits *et al.* 1986 and 1987), and the name "manasseite" was given to it. Quintinite occurs in several world localities.

Appearance and physical properties. Commonly as equant crystals up to 5 mm across and prismatic crystals up to 3 mm long. Forms {0001} pinacoid and an {hkil} trapezohedron with or without $\{10\bar{1}0\}$ hexagonal prism. Twinning not observed.

Transparent, deep orange-red to orange to pale brown, with a white streak. Vitreous luster. Non-fluorescent. Mohs hardness about 2; brittle. Cleavage {0001} perfect; uneven fracture. Attacked slightly by 1:1 HCl, more strongly by 1:1 HNO_3, and very strongly by 1:1 H_2SO_4, all with effervescence. Density 2.14(1) g/cm^3 (meas.), 2.15 g/cm^3 (calc.).

Optical properties. Uniaxial (+), ω 1.533(1), ε 1.533(1). Pleochroism: ω yellow, ε lighter yellow.

Chemical data. Microprobe analyses, H_2O and CO_2 calculated (average of 4 analyses): MgO 33.19, FeO 0.74, Fe_2O_3 1.15, Al_2O_3 20.52, CO_2 9.17, H_2O 33.80, total 98.57 wt.%. Empirical formula $(Mg_{3.95}Fe_{0.05})(Al_{1.93}Fe_{0.07})(OH)_{12}(CO_3)_3 \cdot 3H_2O$. The ideal formula requires MgO 34.35, Al_2O_3 21.72, CO_2 9.38, H_2O 34.55, total 100.00 wt.%.

Crystallography. Chao and Gault (1997): Hexagonal, $P6_322$, *a* 10.571(1), *c* 15.139(7) Å, *V* 1465(1) Å^3, Z 4, *c:a* = 1.4321. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 7.63 (100) (002), 3.785 (100) (004), 2.603 (15) (221), 2.496 (15) (222), 2.341 (15) (223), 2.166 (15) (224), 1.991 (15) (225), 1.825 (20) (226), 1.495 (15) (602). Arakcheeva *et al.* (1996): Hexagonal, $P\bar{6}2m$, *a* 5.283(3), *c* 15.150(9) Å, *V* 366.19 Å^3, Z 1, *c:a* = 2.8677.

Name. In honor of Quintin Wight (1935 -), of Ottawa, Ontario, Canada, author of *The Complete Book of Micromounting*, 1993.

Type material. Cotype stored in the collection of the Canadian Museum of Nature, Ottawa, Ontario, Canada, under catalog numbers CMNMI 81546, CMNMI 47266 and CMNMI 81548, and in the collection of the Royal Ontario Museum, Toronto, Ontario, Canada, under catalog numbers M46768, M46769 and M46770.

Relationship to other species. Quintinite belongs to the quintinite-group of minerals (quintinite, charmarite, caresite, zaccagnaite, chlormagaluminite, comblainite), hydrotalcite supergroup (Mills *et al.* 2012).

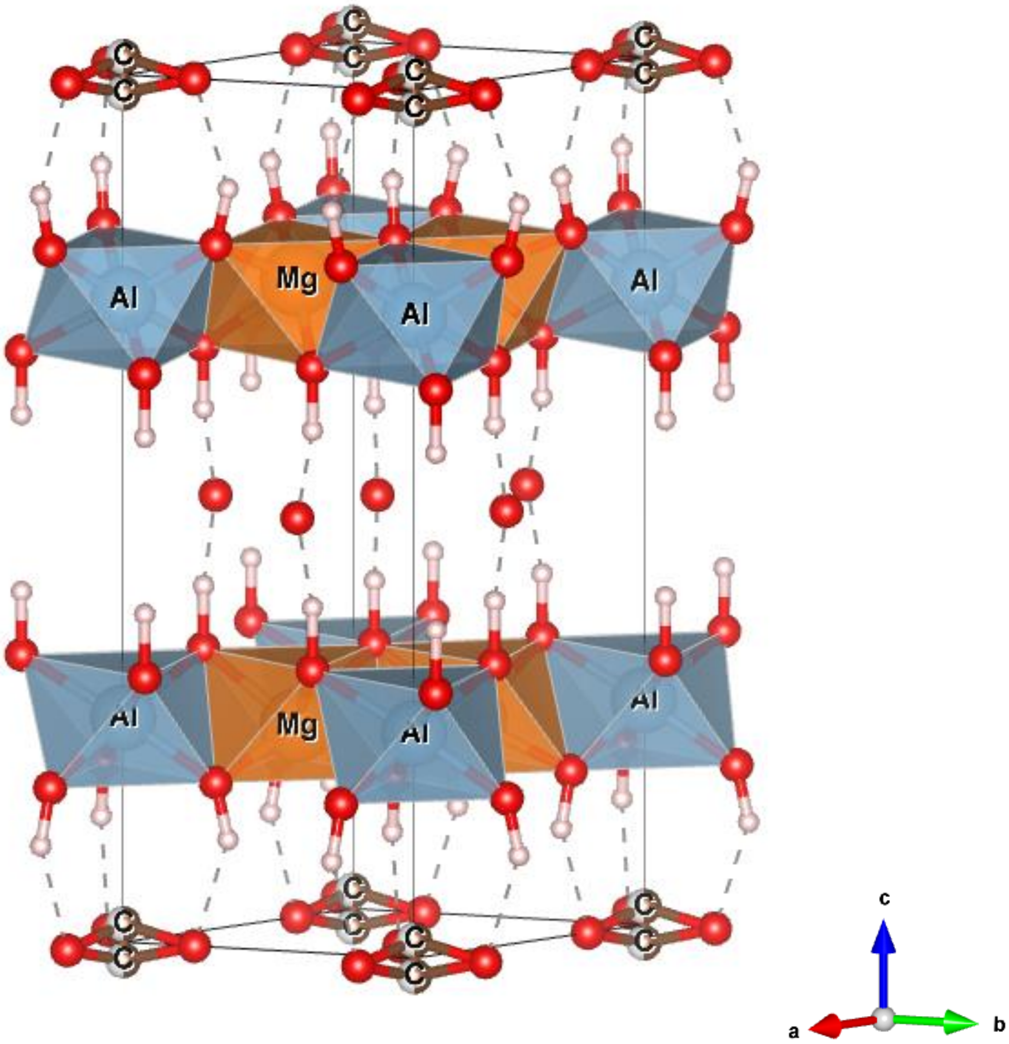

Figure 4.68. View of the crystal structure of quintinite-2*H* (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Arakcheeva *et al.* (1996).

Crystal structure. Layered double hydroxide compound, in which layers with a brucite-like structure [$Mg(OH)_2$] carry a positive charge, due to the partial substitution of trivalent octahedrally coordinated cations (Al) for divalent cations (Mg), giving a layer formula $[(Mg_{2/3}Al_{1/3})(OH)_2]^{1/3+}$ or $[(Mg_4Al_2)(OH)_{12}]^{2+}$. This positive charge is balanced by anions $(CO_3)^{2-}$ which are intercalated between the layers. Intercalated molecular water ($3H_2O$) provides hydrogen bonding between the brucite layers.

See also. Melcherite, menezesite, pauloabibite, zirkelite, brazilite, barium phlogopite, and unidentified Ca-Nb oxide.

Tantalum samarskite-(Y)

Warner and Ewing (1993)

Warner and Ewing (1993) quoted a “samarskite-(Y) with Ta > Nb” from Ceará (Ceará is a state of Brazil). The calculated formula is $(Y_{0.37}Fe^{3+}_{0.23}Mn_{0.12}Sn_{0.09}\mathit{REE}_{0.08}Ti_{0.07}Zr_{0.02}U_{0.02}Al_{0.01}Fe^{2+}_{0.01}Pb_{0.01})_{\Sigma 1.03}(Ta_{0.77}Nb_{0.21})_{\Sigma 0.98}$. As Ta > Nb in *apfu*, the mineral is not samarskite. Three minerals present the formula $YTaO_4$: yttrotantalite-(Y), formanite-(Y), and iwashiroite-(Y). No occurrence of these minerals is known in the Ceará state.

Unnamed Y- and REE- vanadoniobate

Rimann (1931)

Other names: Vanadinniobat, Y-vanadiumniobat

Anatase, zircon, and a Y- and REE- vanadoniobate occur as inclusions in opal from Piracuruca, Piauí, in the Parnaíba river basin. Opal mineralization along fractures, near or in the diabase-sandstone contact, are known in the area of the Parnaíba river basin (Pedro II, Piripiri, Campo Maior and Capitão de Campos municipalities). The vanadoniobate occurs as reddish-brown, partially irregular grains 0.009 to 0.015 mm, with elongated prism faces and pyramidal terminations. Tabular cleavages (?). It has very high birefringence, straight extinction, absorption dark brown, parallel to *c*, and light to dark yellow, perpendicular to *c*. It is biaxial, probably orthorhombic. It contains major Nb, V, Y, La, Ce, Ta, minor U and Pb, and also Fe and Zr as impurities due to admixture with zircon. Ti was not detected. According to Rimann (1931), if it is not a new mineral, it should be regarded as a variety of samarskite-(Y), $YFe^{3+}Nb_2O_8$, with V but no Ti, and poor in U and Fe. Fergusonite is different because is tetragonal and uniaxial (-). Another similar mineral is “robellazite”, vanadate, tungstate, niobate and tantalate of Fe, Al, and Mn, described in Colorado, USA.

Eschwegeite

Guimarães (1926a)

[= euxenite-(Y) or polycrase-(Y)]

Other names: eschwegeíta, eschwegite, echwegeite

During a trip to the Piracicaba river (a tributary of the Doce river) region, near Antônio Dias, Minas Gerais, Eusébio de Oliveira collected samples of a mineral similar to rutile in a gravel (Oliveira 1930). These samples were studied by Guimarães (1926a).

According to Guimarães (1926a), the two samples were very rounded. Eschwegeite is brownish-red, and is dark red in thin splinters. Conchoidal fracture. Density 5.87 g/cm^3 (meas.). Mohs hardness ~ 5½. Isotropic, *n* 2.15 to 2.20. Chemical data: Ta_2O_5 21.58, Nb_2O_5 25.17, TiO_2 18.75, Y_2O_3 + Er_2O_3 27.28, Ce_2O_3 not detected, ThO_2 0.57, UO_2 1.96, Fe_2O_3 2.05, CaO and MgO not detected, H_2O 3.09, total 100.45 wt.%. Empirical formula: $(Y_{0.82}U^{4+}_{0.02}Th_{0.01})_{\Sigma 0.85}(Ti^{4+}_{0.79}Nb_{0.64}Ta_{0.33}Fe^{3+}_{0.09})_{\Sigma 1.85}[O_{4.84}(OH)_{1.16}]_{\Sigma 6.00}$.

The formula given by Guimarães (1926a) is $2Ta_2O_5 \cdot 4Nb_2O_5 \cdot 10TiO_2 \cdot 5Y_2O_3 \cdot 7H_2O$. Strunz (1941) classified eschwegeite in the pyrochlore group and gave the formula $Y(Nb,Ta,Ti)_2O_6(OH,H_2O)$; Palache *et al.* (1944) placed eschwegeite as a probable member of the euxenite-(Y) series, in the section on Nb, Ta and Ti multiple oxides with the formula AB_2O_6, where A = Y, Er, U, Th, and B = Nb, Ta, Ti, Fe^{3+}.

Tavora Filho (1951a) studied the eschwegeite sample number 3512 of the Divisão de Geologia e Mineralogia museum, Departamento Nacional da Produção Mineral, Rio de Janeiro, from Nova Era (formerly Presidente Vargas), Minas Gerais, which he believed to be the type specimen, collected by Oliveira (Antônio Dias and Nova Era are neighboring counties).

As eschwegeite is metamict, Tavora Filho (1951a) obtained X-ray powder diffraction data for a sample heated to 1000ºC for 2 hours. The results indicated that eschwegeite is a member of the series euxenite-(Y) - polycrase-(Y), more specifically, according to him, euxenite-(Y). If we consider the dominant cation of the dominant valence, the mineral is euxenite-(Y), YNb_2O_6 because Nb + Ta > Ti and Nb > Ta. However, if we consider only the dominant cation, the mineral is polycrase-(Y), $Y(Ti,Nb)_2(O,OH)_6$, because Ti > Nb and Ti > Ta.

The name eschwegeite honors Baron W.L. von Eschwege (1777-1855). The name eschwegite, used for eschwegeite by Palache *et al.* (1944), was applied to several other minerals. See Chapters 6 and 9.

A mineral of the “eschwegeite-djalmaite” group was described by Rolff (1948) from São João del Rei, Minas Gerais. According to Tavora Filho (1949) this mineral is djalmaite (uranmicrolite).

See also. Djalmaite, eschwegite (several definitions).

Oliveiraite

Lee (1917)

(= tazheranite?)

Other names: oliveiraíta, oliveirita

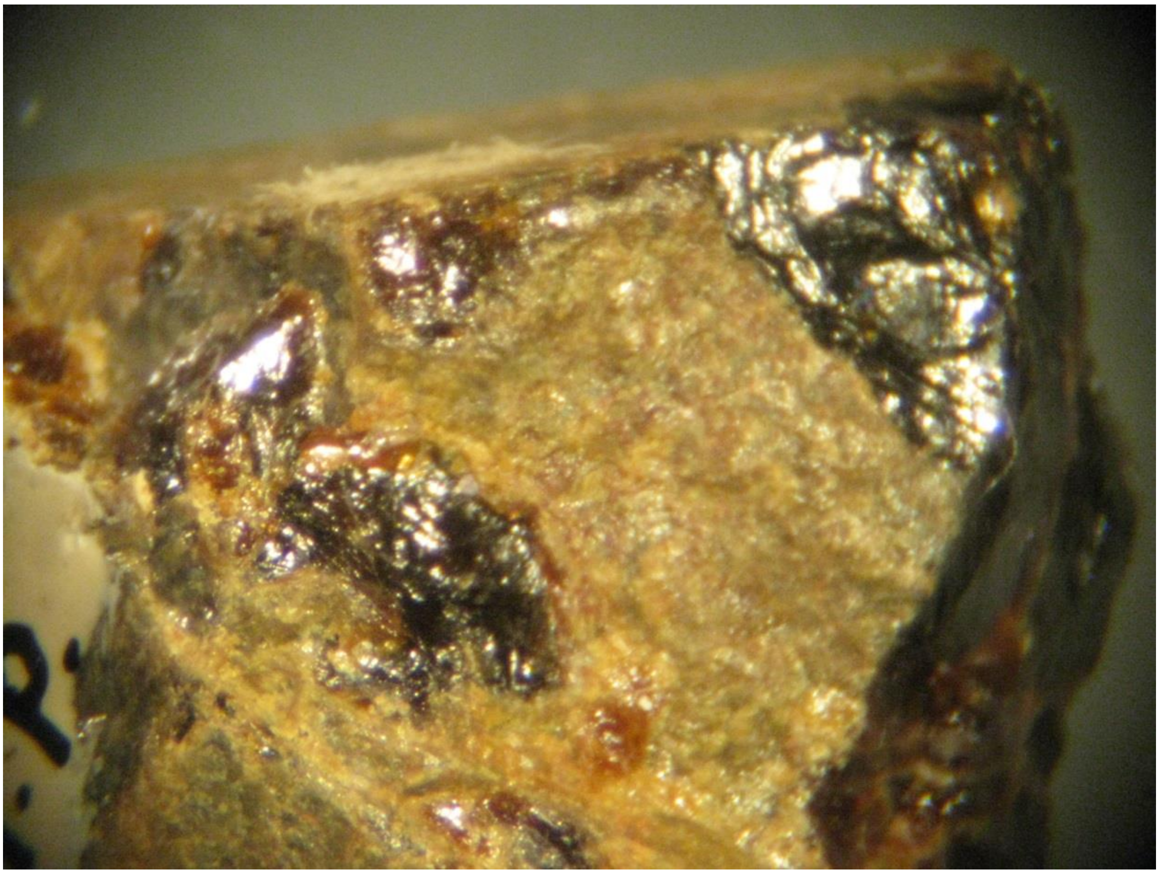

Figure 4.69. "Oliveiraite" with euxenite-(Y) or polycrase-(Y) ? from Santa Clara farm, Tocantins, Minas Gerais. Approximately 1 cm wide. Specimen 561-1 (41651), Museu de Geociências, Universidade de São Paulo, donated by Jorge de Araujo Ferraz. Photo: Thales Trigo.

This name was introduced by Lee (1917 and 1919) for greenish-yellow, radially fibrous masses associated with euxenite-(Y) or polycrase-(Y) ? from Santa Clara farm, Tocantins station, on the old Leopoldina railway, Tocantins municipality, (in the past, Rio Pomba, formerly Pomba), Minas Gerais. The sample was given by Jorge de Araujo Ferraz to T.H. Lee. Wet chemical analyses resulted in ZrO_2 63.36, TiO_2 29.92, H_2O 6.48, total 99.76 wt.%, corresponding to the formula $Zr_{2.89}Ti_{2.10}O_{9.98}\cdot2.02H_2O$ or $Zr_3Ti_2O_{10}\cdot2H_2O$, and which can be expressed as $(Zr,Ti)_5O_{10}\cdot2H_2O$ or $(Zr,Ti)O_2\cdot0.4H_2O$. Perhaps this material is tazheranite, $(Zr,Ti,Ca)O_2$ cubic. The name honors the Brazilian geologist Dr. Francisco de Paula Oliveira (1857-1925). Ferraz (1928) spelled the name as “oliveirita”.

See also. Guimarãesite (old name) and euxamite.

Ferri-ferri-wodginite or ferri-ixiolite

Beurlen *et al.* (2007, 2008)

$Fe^{3+}TaO_4$

Other names: Ferri-ferriwodginite

Beurlen *et al.* (2007, 2008) applied the names ferri-ferri-wodginite and ferri-ixiolite for a mineral from the Roncadeira pegmatite, Nova Palmeira, Paraíba, with formula near $Fe^{3+}TaO_4$. No additional data were published.

See also. Zinconigerite-6*N*6*S*.

Zinconigerite-6*N*6*S*

Beurlen *et al.* (2013)

$(Zn,Al,Fe)_3(Al,Sn,Fe)_8O_{15}(OH)$, trigonal

(probably a valid species)

Other names: zinconigerita-6*N*6*S*

A few up to 0.3 mm sized grains of a Zn–Sn–Al-bearing mineral were tentatively identified by Beurlen *et al.* (2013) as “zinconigerite-6*N*6*S*”, a Zn-dominant polysome still not approved by IMA (Armbruster 2002), unlike the well-known ferronigerite-6*N*6*S* (with Fe > Zn) of the nigerite group. The mineral occurs in the Roncadeira pegmatite lenses, Borborema Pegmatite Province, 4 km WNW from the Nova Palmeira township, Paraiba. No additional data were published.

See also. Ferri-ferri-wodginite or ferri-ixiolite.

Brazilianite (old name)

Mawe (1818)

(= gibbsite)

Other names: brazilianita, claussenita, claussenite

Mawe collected a radially fibrous mamillary mineral in the Carmo stream, between Ouro Preto and Mariana, near Mariana, Minas Gerais. In 1813 Wollaston analyzed it and concluded that it was not barite, as Mawe thought, but “hydrargillite” [= gibbsite, $Al(OH)_3$]. Mawe (1818) named it brazilianite (for Brazil), while Dufrénoy (1845) named it claussenite, probably in honor of the Danish collector and naturalist Peter Claussen (or Clausen) (his birth and death dates are unclear, sometimes recorded as 1804-1855 or as 1801–1872). A new analysis was done by Eustis (1883) and the occurrence was described by Costa Sena (1884). Unfortunately, according to Leonardos (1970), dozens of tons of spectacular stalactitic masses were used as ore in the Saramenha plant, a property of Alumínio de Minas Gerais company, and the small ore deposit was worked out. Chester (1896), Embrey and Fuller (1980), and Clark (1993) gave brazilianite (of Mawe) as a synonym for wavellite, but actually, it is the wavellite of Dewey (1820), that corresponds to the “hydrargillite” of Cleaveland (1822) = gibbsite (of Torrey 1822). The name now accepted for this material is gibbsite; and “hydrargillite” has been discarded. The name brazilianite was used again by Pough and Henderson (1945a, b, c and 1946) for $NaAl_3(PO_4)_2(OH)_4$.

See also. Brazilianite (the other meaning).

Minasite

Farrington (1912)

(a mixture, bauxite?)

Other names: minasita

Chemical analysis of a pebble (“fava”) from the diamond washings of Minas Gerais suggested a new aluminum hydroxide, of composition $2Al_2O_3{\cdot}3H_2O$, but Farrington (1916) found it to be a mixture and discarded the name. Ford (1916) incorrectly described it as a hydrous aluminum phosphate. The name honors Minas Gerais, as also geraesite and minasgeraisite.

See also. Geraesite and minasgeraisite.

Chapter 5

Carbonates

Lanthanite-(Nd)

Roberts *et al.* (1980)

$(Nd,La)_2(CO_3)_3 \cdot 8H_2O$, orthorhombic

Approved CNMMN - IMA 1979-074

Other names: lantanita-(Nd), coutinite, neodymite, coutinita, neodimita, lanthanite, lantanita

and

Lanthanite-(La)

Nickel and Mandarino (1987)

$(La,Nd)_2(CO_3)_3 \cdot 8H_2O$, orthorhombic

Other names: lantanita-(La), coutinhite, neodymite, coutinhita, neodimita, lanthanite, lantanita

Figure 5.1. Lanthanite-(La) and lanthanite-(Nd) (both specimens have the two species) from Curitiba, Paraná. The left crystal is approximately 8 mm in the largest dimension. Specimen: Daniel Atencio. Photo: Thales Trigo.

Figure 5.2. Lanthanite-(La) and lanthanite-(Nd) on calcrete, from Curitiba, Paraná. Photo width approximately 8 mm. Specimen 15210/4, Museu de Geociências, Universidade de São Paulo. Photo: Thales Trigo.

Today, three lanthanite species are known: lanthanite-(La), lanthanite-(Nd), and lanthanite-(Ce). The first lanthanite to be described was from Bastnäs, Sweden (Berzelius 1825). It was always considered to be lanthanite-(La). The formula $(La,Ce)_2(CO_3)_3\cdot 8H_2O$ was attributed following a more complete chemical analysis of the mineral from Bastnäs by Lindström (1910): $(La,Di)_2O_3$ 28.34, Ce_2O_3 25.52, Y_2O_3 0.79, CO_2 21.95, Ce_2O_3 25.52, H_2O 23.40, total 100.13 wt.%. Di represents 'didymium', a name applied to several rare earth elements (*REE*), including Nd, Pr, etc., which could not be chemically differentiated at that time; accordingly, the value of 28.34 wt.% represents not only La_2O_3, but also Di_2O_3. The true percentage of La_2O_3 could, therefore, be lower than that of Ce_2O_3 in the analysis, and, if so, the predominant *REE* would be Ce (or Nd) and not La. To establish the mineral species name of lanthanite from the original locality, Bastnäs, Atencio *et al.* (1989) analyzed a sample from the National Museum of Natural History of the Smithsonian Institution (catalog number B10531) and confirmed the species to be lanthanite-(Ce). As until today, there is no chemical analysis with La dominant for Bastnäs, it is not correct to consider this as the type locality for lanthanite- (La), as it is quoted in the official IMA list.

The type locality of lanthanite-(Nd) is the city of Curitiba (Paraná State) and the neighboring region where several outcrops have been found in the sediments of the Guabirotuba Formation of the Curitiba Basin (Coutinho 1955, Ansell *et al.* 1976, Cesbron *et al.* 1979, Roberts *et al.* 1980, Svisero and Mascarenhas 1981, Fujimori 1981, Trescases *et al.* 1986, Trescases and Fortin 1988, Fortin 1989, Formoso *et al.* 1989). The name lanthanite-(Nd) was applied for the first time by Roberts *et al.* (1980) with CNMMN - IMA approval. Actually, in each lanthanite crystal from Curitiba some points correspond to lanthanite-(La) and the others to lanthanite-(Nd).

Two publications contain results of chemical analysis for lanthanite from Curitiba where La is greater than Nd in *apfu*. The first is the ICDD card 30-678. H.G. Ansell (personal communication to D.Atencio, 1996), noted that the analyses yielding the La-rich material (La:Nd = 1.04) were made on the three samples studied by Ansell *et al*. (1976), NMC 12213, NMC 12214 and NMC 12215, stored in the Geological Survey of Canada, Ottawa, Ontario, Canada, which are also the type specimens for lanthanite-(Nd). Since these are the first published analyses of lanthanite-(La), the type specimens of lanthanite-(Nd) could also be considered as the type specimens of lanthanite- (La). Therefore, Curitiba would be the type locality for both species. The second publication is the article by Svisero and Mascarenhas (1981), where La: Nd = 1.09.

Svisero and Mascarenhas (1981) and Fujimori (1981), having never heard about the paper by Roberts *et al.* (1980), also described the mineral from Curitiba. Without IMA approval, Svisero and Mascarenhas (1981) applied the names "coutinhite" (in honor of Prof. Dr. José Moacyr Vianna Coutinho, born 1924) and "neodymite" (in analogy to lanthanite) for a mineral which corresponds to lanthanite-(La), while Fujimori (1981) applied the names "coutinite" (also in honor of Prof. Dr. José Moacyr Vianna Coutinho) and "neodymite" for a mineral which corresponds to lanthanite-(Nd). The names "coutinite", "coutinhite", and "neodymite" do not follow the rules of nomenclature for rare earth minerals and were formally discarded (Nomenclature Proposal 98-B), with CNMMN - IMA approval (Atencio 1999b). The name coutinhoite was further applied to a silicate,

The second occurrence, in a single outcrop, was found in the sediments of the Caçapava Formation (Taubaté Basin) at Santa Isabel, São Paulo State (Coimbra *et al.* 1989). The published analysis correspond to La:Nd = 1.01 in *apfu*. A third occurrence (Waber

1990) was discovered in the Morro do Ferro (Poços de Caldas, Minas Gerais).

All the chemical analysis for the Curitiba mineral and the one for the Santa Isabel sample have an Nd:La ratio of approximately 1:1. No quantitative chemical data are available for the Poços de Caldas lanthanite; however, energy dispersive spectra obtained by Waber (1990) suggest a Nd:La ratio similar to that for Curitiba and Santa Isabel minerals.

The following description, valid for both lanthanite-(La) and lanthanite-(Nd), is based mainly in Roberts *et al.* (1980) for the Curitiba material. Additional data can be found in the RRUFF Database: R060467 (Curitiba) and R060470 (Santa Isabel).

Occurrence. On white calcrete that fills irregular cm-wide fractures in green arenaceous mudstone, associated with calcite and dendritic crusts of Mn and Fe oxides, both at Curitiba (and nearby cities), Paraná (type locality), and Santa Isabel, São Paulo. Morro do Ferro mine, Poços de Caldas, Minas Gerais. The first samples, studied by Coutinho (1955), were collected in an outcrop close to the approach to the Clube de Campo Santa Mônica [Rodovia Régis Bittencourt, BR 116, km 6.5, Bairro Mauá, Colombo municipality], in the Curitiba - São Paulo direction. According to Cornejo and Bartorelli (2010), the samples studied by Roberts *et al.* (1980) were collected by Luiz A.D. Menezes Filho at the end of the first kilometer of the Curitiba – Paranaguá highway, in a cut on the left side of the road, Curitiba municipality, but Roberts *et al.* (1980) acknowledge Carlos do Prado Barbosa, "who provided nearly all the lanthanite-(Nd) which was examined". Also, known from the Brazilian occurrences quoted above and some world occurrences (Graham *et al.* 2007).

Appearance and physical properties. Well-formed crystals are rare and do not exceed 2 mm in length. Morphology: {001}, {010}, {100}, {101}, {122}, and {121}; flattened on {010}. Twinning on [101]. Vitreous to pearly; transparent; bright pink with a white streak. Non-fluorescent. Mohs hardness 2½ to 3; tenacity not given. Cleavage {010} perfect, {101} very good; fracture not given. Effervesces vigorously in dilute HCl. Density 2.81 g/cm^3 (meas.), 2.716 g/cm^3 (calc.).

Optical properties. Biaxial (-), α 1.532(1), β 1.590(1), γ 1.614(1), 2*V* 61° (meas.), 63.5° (calc.). $X = b$, $Y = c$, $Z = a$.

Chemical data. Wet chemical analysis, with H_2O by Penfield method gave: Nd_2O_3 21.84, La_2O_3 19.44, Pr_2O_3 5.18, Sm_2O_3 4.10, Gd_2O_3 1.69, Eu_2O_3 0.60, Dy_2O_3 0.44, Y_2O_3 0.22, Ce_2O_3 0.03, ThO_2 0.03, CO_2 22.15, H_2O 22.75, total 98.47 wt.%. Empirical formula: $(Nd_{0.77}La_{0.71}Pr_{0.19}Sm_{0.14}Gd_{0.06}Eu_{0.02}Dy_{0.01}Y_{0.01})_{\Sigma 1.91}C_{3.00}O_{8.86}\cdot 7.53H_2O$. The formula with Nd:La 1:1 requires Nd_2O_3 27.70, La_2O_3 26.82, CO_2 21.74, H_2O 23.74, total 100.00 wt.%.

The pure Nd-member requires: Nd_2O_3 54.92, CO_2 21.55, H_2O 23.53, total 100.00 wt.%. The pure La-member requires: La_2O_3 54.12, CO_2 21.93, H_2O 23.95, total 100.00 wt.%.

Crystallography. Orthorhombic, *Pbnb, a* 9.476(4), *b* 16.940(8), *c* 8.942(4) Å, *V* 1435.40 Å^3, Z 4, *a:b:c* = 0.5594:1:0.5279. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 8.50 (100) (020), 4.741 (52) (200), 4.473 (56) (002), 4.233 (28) (040), 4.139 (34) (220), 3.953 (32) (022), 3.252 (63) (202), 3.038 (58) (222), 2.579 (30) (242), 2.032 (29) (422).

Name. For the chemical composition.

Type material. NMC 12213, NMC 12214 and NMC 12215, cotype, stored in the Geological Survey of Canada, Ottawa, Ontario, Canada. National Museum of Natural History, Washington, D.C., USA, cotype, 147003 (donator Geological Survey of Canada, Ottawa, Ontario, Canada, thru H.G. Ansell, 1980).

Relationship to other species. Lanthanite-(La) and lanthanite-(Nd) are respectively the La- and the Nd-dominant analogs of lanthanite-(Ce).

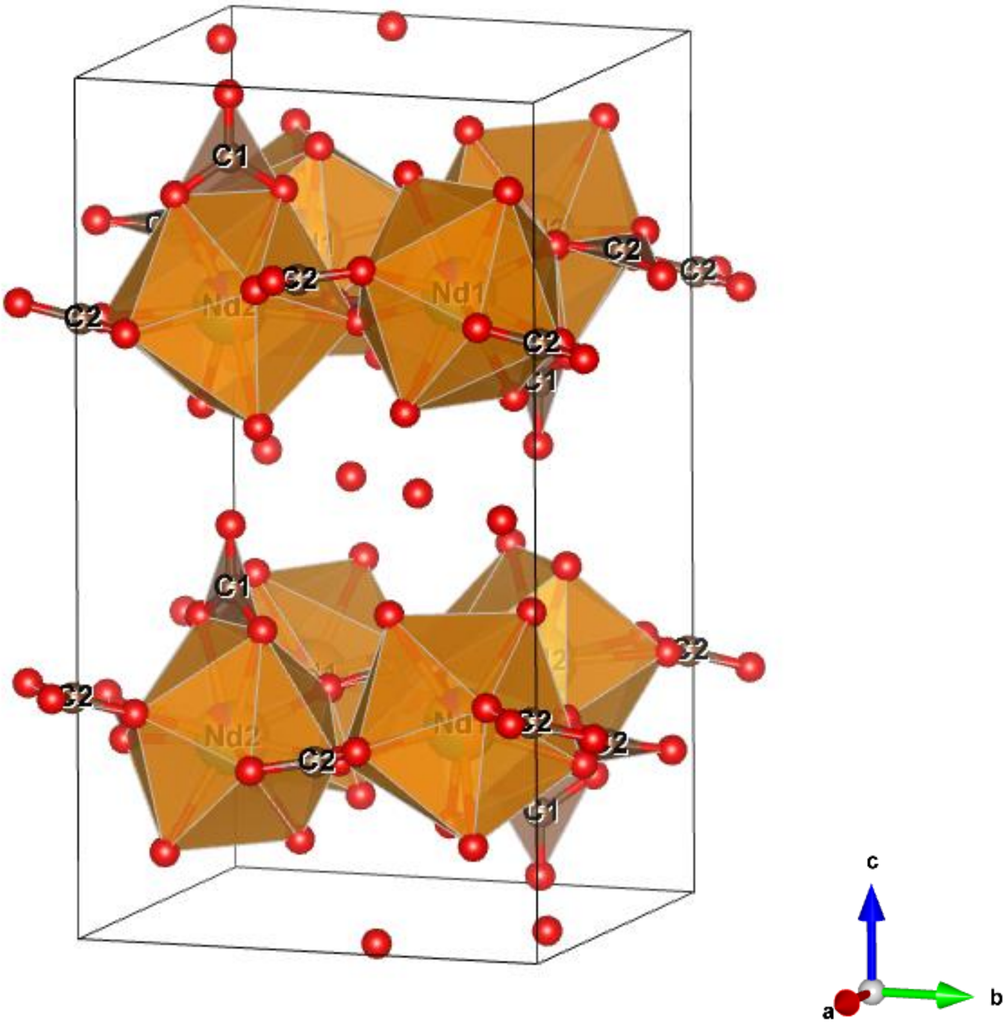

Figure 5.3. View of the crystal structure of lanthanite-(Nd) (from Mitsukoshi, Hizen-cho, Karatsu City, Saga Prefecture, Japan), drawn using VESTA 3 (Momma and Izumi 2011). Data from Morrison *et al.* (2013).

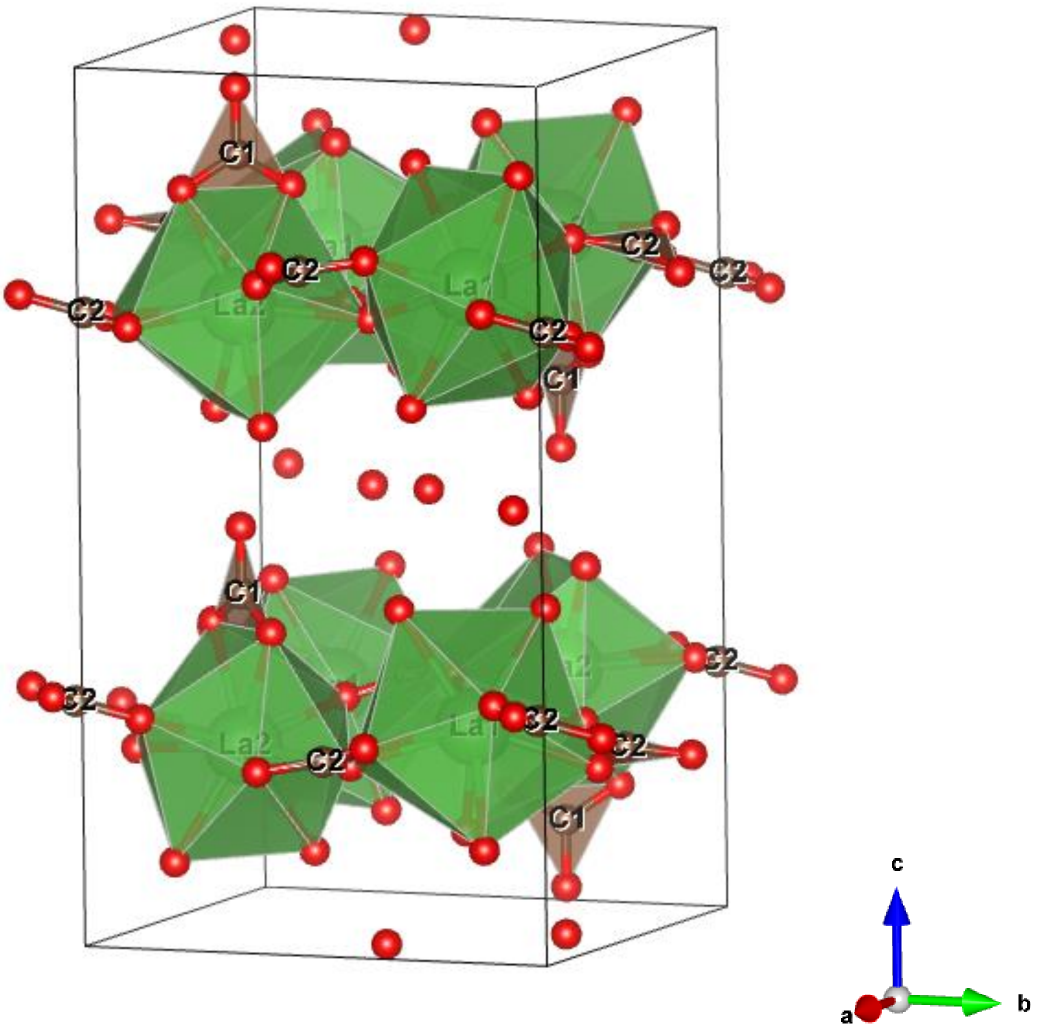

Figure 5.4. View of the crystal structure of lanthanite-(La) (synthetic), drawn using VESTA 3 (Momma and Izumi 2011). Data from Shinn and Eick (1968).

Crystal structure. The lanthanite group minerals are characterized by the general formula $REE_2(CO_3)_3 \cdot 8H_2O$, where *REE* is a 10-coordinated rare earth element. Based on single-crystal X-ray diffraction of a natural sample from Mitsukoshi, Hizen-cho, Karatsu City, Saga Prefecture, Japan, Morrison *et al.* (2013) presented the first structure determination of lanthanite-(Nd). Its structure is very similar to that of other members of the lanthanite group. It is composed of infinite sheets made up of corner- and edge-sharing of two NdO_{10}-polyhedra (both with site symmetry ..2) and two carbonate triangles (site symmetries ..2 and 1) parallel to the ab plane, and stacked perpendicular to c. These layers are linked to one another only through hydrogen bonding involving the water molecules.

Synthetic. A popular method for the synthesis of lanthanite is homogeneous precipitation by hydrolysis of trichloroacetate. By use of this and related processes, carbonates have been prepared for all the lanthanides (Shinn and Eick 1968).

Parisite-(La)

Menezes Filho *et al.* (2018)

$CaLa_2(CO_3)_3F_2$, monoclinic

Approved CNMNC - IMA 2016-031

Other names: parisita-(La)

Figure 5.5. Partial pseudomorphs of monazite-(La), bastnäsite-(La) and rhabdophane-(La) after parisite-(La), from the Mula mine, Tapera village, Novo Horizonte, Bahia (Menezes Filho *et al.* 2018).

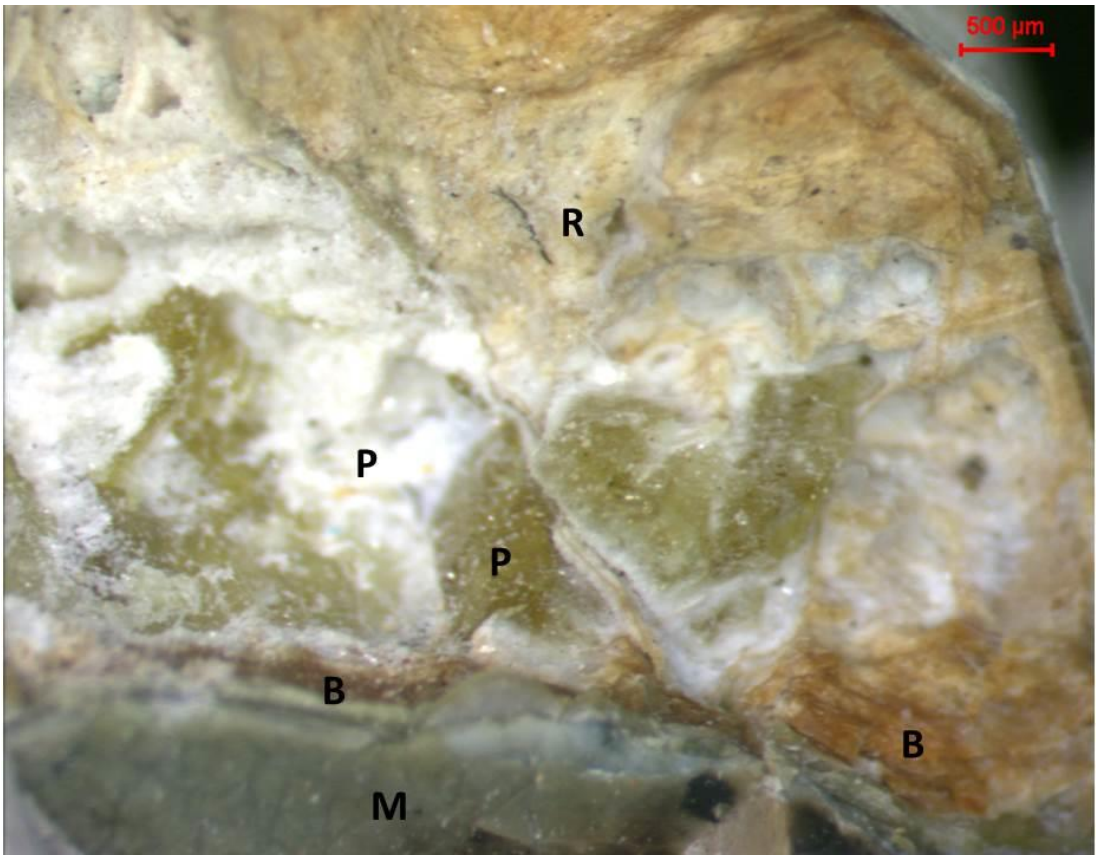

Figure 5.6. Partial pseudomorphs of monazite-(La)[M], bastnäsite-(La) [B] and rhabdophane-(La) [R] after parisite-(La) [P], from the Mula mine, Tapera village, Novo Horizonte, Bahia. Menezes Filho *et al.* (2018).

Occurrence. In a late-stage hydrothermal vein crosscutting a metarhyolite of the Rio dos Remédios Group, at the Mula mine, Tapera village, Novo Horizonte, Bahia, associated with hematite, rutile, almeidaite, fluocerite-(Ce), brockite, monazite-(La), rhabdophane-(La) and bastnäsite-(La). The pit of the Mula mine is composed of brecciated quartz veins cemented by chalcedony. The veins show a stockwork pattern, which is typical of hydraulic fracturing processes, and are partially kaolinized. This pit is also the type locality of almeidaite. Minerals with a chemical composition consistent with that of parisite-(La) were reported in several studies from different localities (Menezes *et al.* 2018).

Appearance and physical properties. Residual nuclei (up to 5 mm) in steep doubly-terminated pseudo-hexagonal pyramidal crystals (up to 8.2 cm) with corrugated faces. The crystals are similar to what is usually described for parisite-(Ce): acute dipyramids with horizontally striated faces, terminated by a pinacoid. The pinacoid faces are cleavage planes. The crystals are prismatic in appearance due to the oscillatory combination of steep pyramids, but true prism faces are lacking or very small. The forms of parisite-(La) could be pedion, pinacoid and sphenoid if the space group is *C*2, pedion, pinacoid and dome if *Cm*, or pinacoid and prism if *C*2/*m*. These crystals were partially replaced by bastnäsite-(La), monazite-(La) and rhabdophane-(La). Crusts consisting of microcrystals of parisite-(La) also occur. Vitreous (when yellow-green) to dull (when white) luster; transparent, yellow-green to white, with a white streak. Non-fluorescent. Mohs hardness 4 to 5; brittle. Cleavage is distinct on pseudo-{001}; fracture laminated, conchoidal, or uneven. Density 4.273 g/cm^3 (calc.).

Optical properties. Pseudo-uniaxial (+), ω 1.670(2), ε 1.782(5) (589 nm). In transmitted light, parisite-(La) is colorless. Pleochroism was not observed.

Chemical data. Microprobe (WDS mode) analyses (25): CaO 10.10, Y_2O_3 0.52, La_2O_3 24.77, Ce_2O_3 11.16, Pr_2O_3 4.73, Nd_2O_3 15.82, Sm_2O_3 1.25, Eu_2O_3 0.07, F 7.30, CO_2(calc.) 24.50, O=F -3.07, total 97.15 wt.%. Empirical formula: $Ca_{0.98}(La_{0.83}Nd_{0.51}Ce_{0.37}Pr_{0.16}Sm_{0.04}Y_{0.03})_{\Sigma 1.94}C_{3.03}O_{8.91}F_{2.09}$. The idealized formula requires: La_2O_3 60.80, CaO 10.46, CO_2 24.63, F 7.09, O = F –2.98, total 100.00 wt.%.

Crystallography. Monoclinic (pseudo-trigonal), *C*2, *Cm*, or *C*2/*m*, *a* 12.356(1), *b* 7.1368(7), *c* 28.299(3) Å, β = 98.342(4)°, *V* 2469.1(4) Å^3, Z 12, *a*:*b*:*c* = 1.7313:1:3.9652 (single-crystal X-ray studies). X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 13.95 (55) (002), 6.98 (20) (004), 4.655 (37) (006), 3.555 (88) (020, $\bar{3}11$), 2.827 (100) (026, 315, $\bar{3}17$), 2.055 (58) ($\bar{3}31$, $\bar{6}02$), 1.950 (38) (0.2.12, 3.1.11, $\bar{3}$.1.13), 1.880 (36) (335, $\bar{3}37$, 604, $\bar{6}08$), 1.663 (23) (046, 624, $\bar{6}28$).

Name. For its relationship with parisite-(Ce).

Type material. Museu de Geociências, Instituto de Geociências, Universidade de São Paulo, registration number DR1032 (part of the holotype), and University of Arizona Mineral Museum (RRUFF Project deposition # R130687).

Relationship to other species. Parisite-(La) is the La-dominant analog of parisite-(Ce).

Crystal structure. Unfortunately, despite determining monoclinic unit-cell parameters from the single-crystal pattern, the authors could not obtain single-crystal data suitable for the structure refinement.

See also. Almeidaite.

Chapter 6

Sulfates and tellurates

Eschwegite

Zincken (1819)

(= celestine or strontian barite)

Other names: Eschwegit, eschwegita

The name eschwegite (Eschwegit) was given by Zincken (1819) to the strontian variety of barite, $BaSO_4$ orthorhombic, from Mariana, Minas Gerais, collected by Eschwege. The name honors Baron W.L. von Eschwege (1777-1855). This name was also attributed by Lévy (1837) to celestine, $SrSO_4$ orthorhombic, from Antônio Pereira, Ouro Preto, Minas Gerais. Antônio Pereira is a town in Ouro Preto, near the boundary with Mariana. According to Branco (1979), it is a granular variety of barite with strontium and iron, from Ouro Preto, Minas Gerais. Perhaps the minerals of Zincken and Lévy are the same. This name was given by Döbereiner (1823) to the material that later would be named anthosiderite (pseudomorph of quartz and goethite after cummingtonite) from Antônio Pereira, Ouro Preto, Minas Gerais. For a detailed study of sulfate in the Mariana and Ouro Preto rocks, see Cabral *et al.* (2013). The Mn ore hosted in the Itabira (Itabirito Cauê) iron formation is enriched in Sr up to approximately 1900 ppm (Cabral *et al.* 2002e).

See also. Eschwegite (several meanings) in Chapters 4 and 9.

Harttite

Hussak (1906d)

(= svanbergite)

Other names: harttita, Harttit

Harttite was described by Hussak (1906d and 1917) as flesh-red pebbles (“favas”) in the diamond-sands of the São José river, near Lençóis, Bahia. The name honors the geologist Prof. Charles Frederick Hartt (1840-1878), the first director of the Geological Survey of Brazil. According to Hussak (1906d and 1917), Damour had studied phosphatic flesh-red pebbles in the diamond-sands of Bahia. Hussak (1906d and 1917) noted the likeness between the chemical composition of harttite and svanbergite, $SrAl_3(SO_4)(PO_4)(OH)_6$ trigonal. The identity between these minerals was shown by Tavora Filho (1951b) from X-ray powder diffraction and chemical data for a specimen from the type locality, stored in the museum of the Divisão de Geologia e Mineralogia, Departamento Nacional da Produção Mineral, Rio de Janeiro. Despite this, the name harttite was still used by Gomes *et al.* (1996).

Ferrohalotrichite
Vieira de Mello (1969)
(= halotrichite)
Other names: ferrohalotriquita

The name ferrohalotrichite was applied by Vieira of Mello (1969) to halotrichite, $FeAl_2(SO_4)_4{\cdot}22H_2O$ monoclinic, from Frecheiras and Capa-Rosa, in the municipal district of Piripiri, and Mocambo, in the municipal district of Pedro II, state of Piauí. The mineral occurs as white efflorescences in schist with pyrite, associated with epsomite and native sulfur. Chemical analysis: FeO 10.30, Fe_2O_3 0.70 MgO 0.55, CaO 0.10, Al_2O_3 9.40, SO_3 35.70, H_2O 42.20, total 98.95 wt.%. Density 1.75 g/cm^3 (meas.). Biaxial, α 1.480, γ 1.486, $2V$ 30 to 40°, $Z \wedge c$ 33°. Unit cell parameters refined from powder data: a 21.836, b 23.763, c 12.754 Å, β 97°22'. In accordance with Povarennykh (1972), the formula of the mineral halotrichite would be $(Mg,Fe)Al_2(SO_4)_4{\cdot}22H_2O$, with two “subspecies”, magnesiohalotrichite (= pickeringite) and ferrohalotrichite (= halotrichite). The name ferrohalotrichite was rejected by IMA (1980).

Brumadoite

Atencio *et al.* (2008b)

$Cu_3(Te^{6+}O_4)(OH)_4\cdot5H_2O$, monoclinic

Approved CNMNC – IMA 2008-028

Other names: brumadoíta

Figure 6.1. Brumadoite (blue) on magnesite, from Pedra Preta mine, Serra das Éguas, Brumado, Bahia. The longest dimension of the specimen is 6.5 cm. Specimen: Paulo A. Matioli. Photo: Thales Trigo. Atencio *et al.* (2008b)

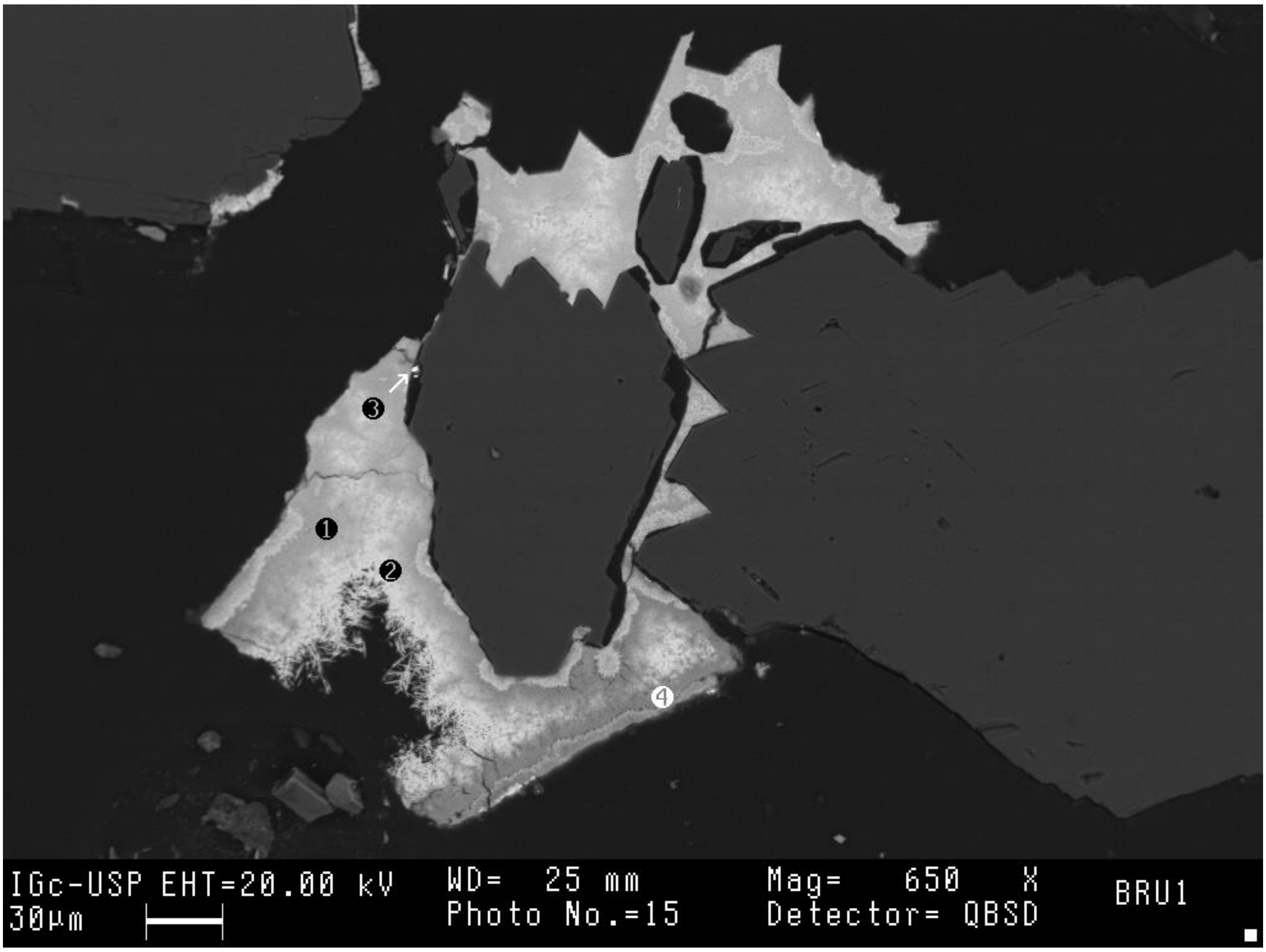

Figure 6.2. Backscattered image of brumadoite (1, 2 and 4) and mottramite (3) from Pedra Preta mine, Serra das Éguas, Brumado, Bahia.

Occurrence. Brumadoite occurs in association with magnesite at the Pedra Preta mine, Serra das Éguas, Brumado, Bahia. This mineral was found by Paulo A. Matioli and the late Carlos P. Barbosa in 1993 and only one specimen, to date, has been found. Brumado was also the type locality of uvite. The prominent basement rocks in the Brumado area are Precambrian in age and consist predominantly of gneisses, schists, and amphibolites. A metamorphosed sequence, comprising a lower unit of dolomite and an upper unit of quartzite, overlies the basement rocks. The dolomite (with minor thin quartzite layers) is generally saccharoidal and ranges from grey to tan in color. The upper unit consists of several hundred meters of white to grey quartzite that forms prominent outcrops in the area. The deposits of magnesite are probably the result of the replacement of dolomite and, to a lesser extent, of fracture filling. The wealth of minerals found at Brumado is inferred to be related to the intrusion of igneous dikes and associated hydrothermal mineralization. Brumadoite occurs as a late fracture filling in the coarse-grained magnesite. It is associated with mottramite and quartz. The primary origin of the tellurium is unknown.

Bodenlos (1954) lists the following magnesite deposits in the Serra das Éguas: Pedra Preta, Bate-Pé, Boa Vista, Gravatá, Pirajá, Noroeste, Fábrica, Jatobá, Catiboaba, Cabeceiras, Coité, and Cordeiro. More recently, deposits such as the Pomba area and other smaller prospects and quarries have been exploited (Barbosa *et al.* 2000).

Several minerals were reported for the Pedra Preta mine: actinolite, albite, “apatite”, azurite, beryl, calcite, chamosite, kyanite, clinochlore, “chlorite”, corundum, dolomite, dravite, enstatite, hematite, “lepidolite”, malachite, magnesite, magnetite, metazeunerite, “monazite”, mottramite, nováčekite-I, opal, parisite-(Ce), phlogopite, pyrite, quartz, rutile, sklodovskite, spodumene, talc, titanite, topaz, tremolite, uraninite, “xenotime” and zircon (Cassedanne and Cassedanne 1978, Cassedanne and Resende 1983, Cornejo and Bartorelli 2010).

Appearance and physical properties. Brumadoite occurs as microcrystalline aggregates both on and, rarely, pseudomorphous after magnesite. Habit: platy, subhedral crystals (SEM study shows them to be 1 to 2 μm in size). Forms: pinacoid {100} from SAED study. Twinning: SAED shows twinning on a submicrometric scale. Color: blue. Streak: pale blue. Luster: vitreous. Transparent (individual crystals) to translucent (masses). Non-fluorescent. Tenacity: brittle. Hardness: unknown (too little pure material, but the mineral is easily crushed between two glass slides). Cleavage: none observed. Fracture: uneven. Density (meas.): too little pure material for a Berman balance density determination. Density (calc.): 4.768 g/cm^3 (with empirical formula and unit-cell parameters refined from powder data).

Optical properties. In transmitted light: mean *n* ~ 1.79 (white light), pleochroic. In reflected light: color: blue; anisotropy: unknown, masked by internal reflections (ubiquitous blue). Reflectance [only very small area (10 × 10 μm) available for air data because of ubiquitous internal reflections; air, SiC standard, R’ because there was no detectable change on rotation of the stage; oil data were impossible due to internal reflections]. Reflectance data for brumadoite [reflectance in % (wavelength in nm)]: 10.2 (470), 8.9 (546), 8.3 (589), 8.3 (650).

Chemical data. Microprobe (WDS) analyses (16), H_2O by difference: CuO 43.05, PbO 1.70, CaO 0.07, TeO_3 30.58, SiO_2 0.55, H_2O 24.05, total 100.00 wt.%. Empirical formula (based on 13 oxygen atoms): $(Cu_{2.90}Pb_{0.04}Ca_{0.01})_{\Sigma 2.95}[(Te^{6+}_{0.93}Si_{0.05})_{\Sigma 0.98}O_{3.92}](OH)_{3.84}\cdot 5.24H_2O$. The ideal formula requires CuO 44.16, TeO_3 32.50, H_2O 23.34, total 100.00 wt.%.

Crystallography. Monoclinic, $P2_1/m$ or $P2_1$, *a* 8.629(2), *b* 5.805(2), *c* 7.654(2) Å, ß 103.17(2)°, *V* 373.3(2) Å^3 *Z* 2, *a:b:c* = 1.4865:1:1.3185. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 8.432 (100) (100), 3.162 (66) ($\bar{2}$02), 2.385 (27) (220), 2.291 (12) ($\bar{1}$22), 1.916 (11) (312), 1.666 (14) ($\bar{4}$22, 114), 1.452 (10) (323, 040), 1.450 (10) (422, 403).

Name. The name is for the type locality.

Type material. Part of the holotype material is deposited under the code DR679 in the Museu de Geociências, Universidade de São Paulo, and part in the Museu de Ciências Naturais e Centro Cultural Joias da Natureza, São Vicente, São Paulo State (code M5528) [this museum no longer exists]. Microgram portions (with magnesite) are housed within the Systematic Reference Series of the National Mineral Collection at the Geological Survey of Canada, Ottawa (code 068161). The polished section used for both the electron-microprobe analyses and the reflectance study is preserved at the National History Museum, London, England, as BM 2008, 32

Relationship to other species. Chemistry and powder-diffraction data indicate that the mineral is unique and bears no close resemblance to any other phases listed in the Powder Diffraction File (release 2007). In the absence of a crystal-structure determination, the mineral can be classified as a hydroxide or as a tellurate.

Crystal structure. Single-crystal X-ray studies could not be carried out because of the small crystal size.

See also. Uvite.

Chapter 7

Phosphates

Ferroqingheiite

Hatert *et al.* (2010)

$NaNaFe^{2+}MgAl(PO_4)_3$, monoclinic

Approved CNMNC - IMA 2009-076

Other names: ferroqingheiíta, qingheiite-(Fe^{2+}), qingheiíta-(Fe^{2+})

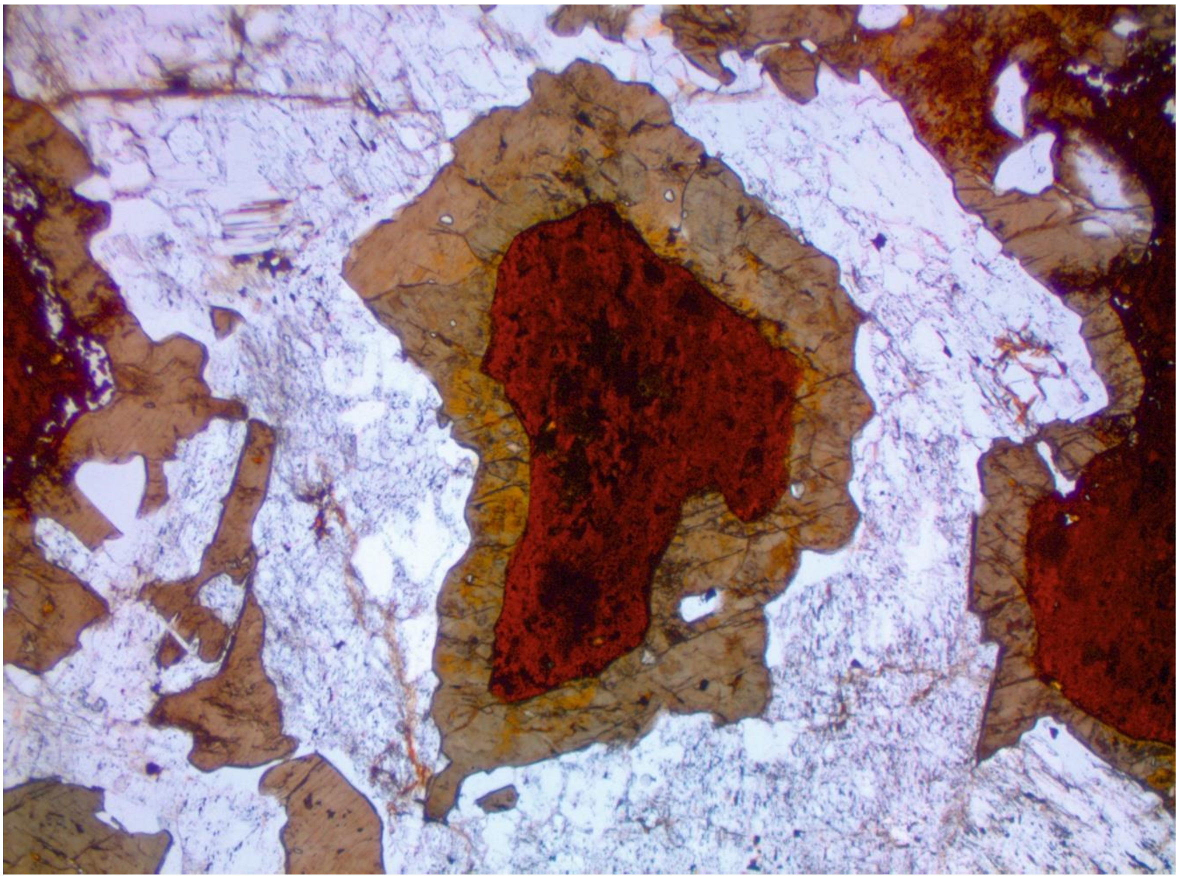

Figure 7.1. Ferroqingheiite from the Sebastião Cristino pegmatite, Linópolis, Divino das Laranjeiras, Minas Gerais, forming a reaction rim between frondelite (red) and albite (white). Plane-polarized light, length of the photomicrograph = 5 mm. Hatert *et al.* (2010), Hatert (2019), reproduction authorized by Simon Philippo.

Occurrence. Sebastião Cristino pegmatite, about 4 km SE of the well-known mine of Córrego Frio, Linópolis, Divio das Laranjeiras, Minas Gerais. The pegmatite occurs within the garnet-, biotite-, and sillimanite-bearing schists of the São Tomé Formation (Rio Doce group, Late Proterozoïc), and is probably related to the Galileia granitoid (595 Ma; Nalini *et al.* 2000). The Sebastião Cristino mine is now deserted but the dumps still contain quartz, graphic microcline, albite, muscovite, schorl, almandine, fluorapatite and beryl (Cassedanne 1983). Phosphate minerals also occur in these dumps, particularly brazilianite. These phosphates form a dendritic assemblage with albite and quartz. Muscovite also occurs in the matrix, and frondelite is locally replaced by cyrilovite and Fe-Mn oxides. Rims of ferroqingheiite probably result from a reaction between a primary Mg-bearing triphylite (source of Fe, Mn, Mg, P) and albite from the matrix (source of Na, Al). This reaction certainly took place at high temperatures, since wyllieite group minerals are generally considered as being primary (Moore and Ito 1973, Moore and Molin-Case 1974). The oxidation processes affecting the pegmatite in the hydrothermal stage subsequently oxidized triphylite in ferrisicklerite and then in frondelite. Cyrilovite and Fe-Mn-oxides crystallized under meteoric conditions.

Appearance and physical properties. Rims (200 μm to 1 mm thick) around frondelite grains (up to 1 cm in length) included in a quartz + albite matrix. Forms: none observed. Twinning: none observed. Color: dark green. Streak: pale to bottle green. Luster: resinous, Transparent. Non-fluorescent. Hardness (Mohs): 4. Tenacity: brittle. Cleavage: perfect {010}. Fracture: not observed. Density: 3.6(2) g/cm^3 (meas. by Berman balance); 3.54 g/cm^3 (calc.).

Optical properties. Biaxial (–), α 1.692(5), β 1.718(3), γ 1.720(5) (590 nm), 2V 31° (calc.). Dispersion: $r > v$, strong. Orientation: β along the b crystallographic axis; α and γ in the (010) plane. Pleochroism: X pale pinkish-brown, Y pale green, Z pale bluish-grey. The mineral shows pleochroism from olive green to pinkish-brown in thin sections.

Chemical data. Microprobe (WDS) analyses (6), H_2O and CO_2 not determined in line with the structural analysis: P_2O_5 46.51, Al_2O_3 6.94, Fe_2O_3 10.58, FeO 11.46, MgO 6.32, MnO 11.23, CaO 0.24, Na_2O 6.27, K_2O 0.01, total 99.56 wt.%. Empirical formula: $(\square_{0.65}Na_{0.35})_{\Sigma1.00}(Na_{0.58}Mn_{0.40}Ca_{0.02})_{\Sigma1.00}(Fe^{2+}_{0.68}Mn_{0.32})_{\Sigma1.00}(Mg_{0.72}Fe^{3+}_{0.23}Fe^{2+}_{0.05})_{\Sigma1.00}$ $(Al_{0.62}Fe^{3+}_{0.38})_{\Sigma1.00}(PO_4)_3$. The ideal formula $NaNaFe^{2+}MgAl(PO_4)_3$ requires Na_2O 14.15, FeO 16.40, MgO 9.20, Al_2O_3 11.64, P_2O_5 48.61, total 100.00 wt.%. A formula $(\square_{0.5}Na_{0.5})(Na_{0.5}Mn_{0.5})Fe^{2+}MgAl(PO_4)_3$ better agrees with the chemical data.

Ferroqingheiite would be an intermediate member between □MnFe^{2+}MgAl(PO$_4$)$_3$ and NaNaFe^{2+}MgAl(PO$_4$)$_3$

Crystallography. Monoclinic, $P2_1/n$, a 11.910(2), b 12.383(3), c 6.372(1) Å, β 114.43(3)°, V 855.6(3) Å^3, Z 4 (single-crystal), a 11.878(3), b 12.379(4), c 6.368(2) Å, β 114.42(2)°, V 852.6(3) Å^3, Z 4 (powder data), a:b:c = 0.962:1:0.515. X-ray powder diffraction data [d in Å (I) (hkl)]: 3.468 (35) (310), 3.047 (100) ($11\bar{2}$), 2.849 (80) ($31\bar{2}$), 2.810 (35) ($22\bar{2}$), 2.711 (40) (330), 2.688 (90) (240), 2.500 (40) ($13\bar{2}$, 112), 2.074 (30) ($31\bar{3}$).

Name. The other wyllieite-group minerals are wyllieite, ferrowyllieite, rosemaryite, ferrorosemaryite, and qingheiite. This mineral should consequently be named ferroqingheiite, but the name qingheiite-(Fe^{2+}) was originally chosen (Hatert *et al.* 2010) according to the CNMNC suffix-type nomenclature (Burke 2008). Several modifications introduced by Burke were reverted (Pasero *et al.* 2010) and the name qingheiite-(Fe^{2+}) was modified to ferroqingheiite for consistency with the other names of the wyllieite-group minerals (Hatert 2019).

Type material. Collections of the Laboratory of Mineralogy, University of Liège, Belgium, catalog number 20381.

Relationship with other species. Ferroqingheiite belongs to the wyllieite group of minerals, alluaudite supergroup. A mineral named “ferrowyllieite-Mn^{2+}NaNa” from the Smith mine pegmatite, Chandler's Mills, near Newport, New Hampshire, USA (Moore and Ito 1979) seems to be an intermediate member between ferroqingheiite and ferrowyllieite [Mg = Fe^{2+} in the $M(2a)$ site].

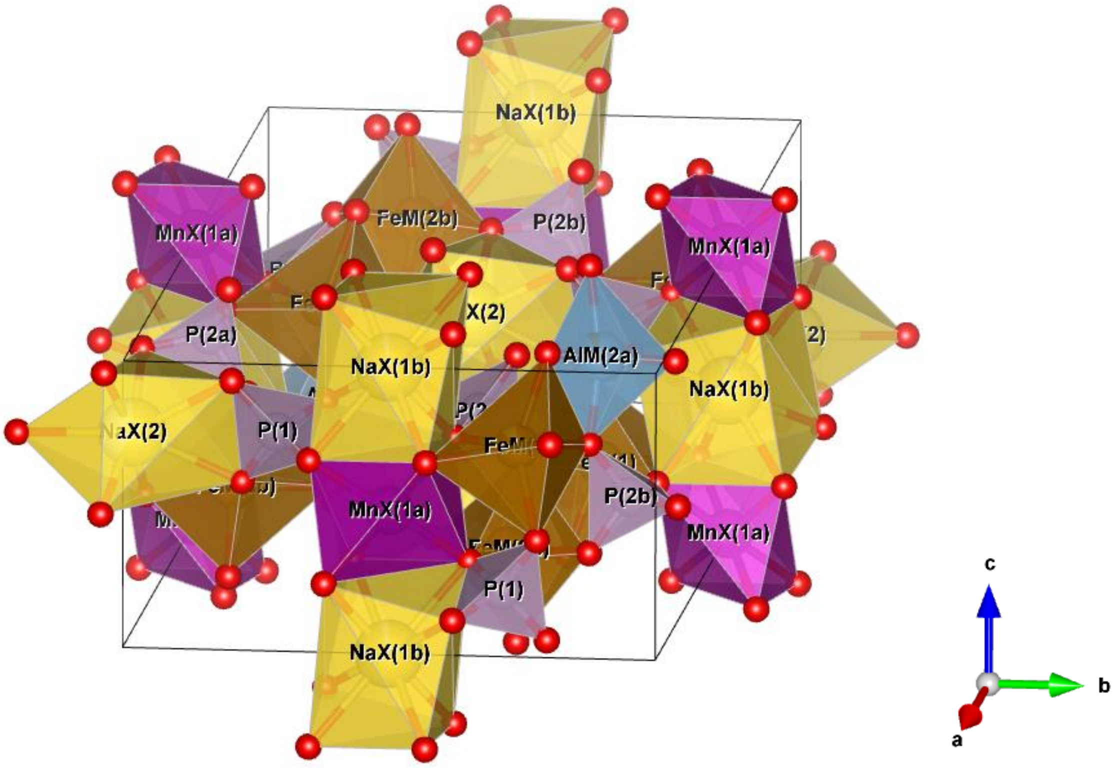

Figure 7.2. View of the crystal structure of ferroqingheiite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Hatert *et al.* (2010).

Crystal structure. Kinked chains of edge-sharing octahedra stacked parallel to {101}. These chains are formed by a succession of *M*(2*a*)-*M*(2*b*) octahedral pairs, linked by highly distorted *M*(1) octahedra. Equivalent chains are connected in the *b* direction by the *P*(1), *P*(2*a*) and *P*(2*b*) phosphate tetrahedra to form sheets oriented perpendicular to [010]. These interconnected sheets produce channels parallel to *c*, which contain the large *X* sites. The *X*(1*a*) site of ferroqingheiite is a distorted octahedron, whereas the *X*(1*b*) site can be described as a very distorted cube. The morphology of the *X*(2) site corresponds to very distorted gable disphenoid with a [7 + 1] coordination (Hatert *et al.* 2010).

This mineral needs additional studies. The chemical and structural data are quite confusing, especially the occupation of the different atomic positions. The “empirical formula deduced from the electron-microprobe analyses” do not correspond to the “results of the chemical analysis” (Table 6 of Hatert *et al.* 2010). The authors suggest that the *X*(2) site hosts a significant amount of Mn^{2+}, substituting for Na; on the other hand, a significant amount of Na was placed in the octahedral site *M*(1) instead of Mn^{2+}. “Ferro” is part of the mineral name but Mössbauer spectroscopy was not used to verify the ratio Fe^{2+}:Fe^{3+}.

The classification and nomenclature of wyllieite-group minerals also seem inadequate. Na is only 0.93 *apfu* in the empirical formula of ferroqingheiite, but the ideal formula is expressed with 2 Na atoms; Mn is 0.72 *apfu* (11.23 wt.%) in the empirical formula but it does not appear in the ideal formula. This occurs because in the wyllieite group, the $X(1a)$ and $X(1b)$ sites are grouped together for nomenclature purposes, but these two sites do not show similar crystal-chemical behavior. The $X(1a)$ site of ferroqingheiite is a distorted octahedron, whereas the $X(1b)$ site can be described as a very distorted cube.

See also. Brazilianite, frondelite, and avelinoite.

Bobdownsite-Mg and bermanite-Mg

Baijot (2015)

Baijot (2015) quoted these two potential new species in pegmatites of the Conselheiro Pena district, Minas Gerais. As I did not have access to the full text, I cannot say more details. The mineral bobdownsite was discredited as identical to whitlockite, $Ca_9Mg(PO_4)_6(HPO_4)$, trigonal (McCubbin *et al.* 2018). Bermanite is $Mn^{2+}Mn^{3+}_2(PO_4)_2(OH)_2\cdot 4H_2O$, monoclinic.

Unnamed $Ca_9(Ca_{0.5}\square_{0.5})Mg(PO_4)_7$

Keil *et al.* (1976), Dowty (1977)

(= keplerite)

This phase was described in the Angra dos Reis meteorite, a pyroxenite, which fell on January 20, 1869, into the bay near Angra dos Reis city, Rio de Janeiro. It occurs as sparsely distributed, milimeter-sized grains in widely separated areas (Prinz *et al.* 1977). Associated minerals are augite, forsterite, hercynite, iron, troilite, kirschsteinite, celsian, anorthite, baddeleyite, and magnetite. Microprobe data: CaO 49.4, Na_2O 0.68, Ce_2O_3 0.25, Y_2O_3 0.01, MgO 2.82, FeO 1.29, P_2O_5 45.1, SiO_2 0.67, total 100.22 wt.% (Keil *et al.* 1976), which corresponds to

$Ca_{9.00}(Ca_{0.51}Na_{0.24}Ce_{0.02}\square_{0.23})_{\Sigma 1.00}(Mg_{0.76}Fe^{2+}_{0.19})_{\Sigma 0.95}(P_{0.86}Si_{0.12})_{\Sigma 0.98}O_{24}$. The simplified formula is $Ca_9(Ca,Na,\square)Mg(PO_4)_7$. The crystal structure was studied by Dowty (1977). It involves three 8- and 9-fold-coordinated Ca sites, one octahedral *M* site, one six-coordinated *X*, and three almost perfect [PO_4] tetrahedra. Trigonal, *R*3*c*, *a* 10.362(1), *c* 37.106(5) Å, *V* 3450 Å^3, *Z* 6, *c*:*a* 3.58 (single-crystal). Density: 3.13 g/cm^3 (calc.). It is a whitlockite group mineral and corresponds to keplerite (Britvin *et al*. 2020). The holotype specimen of keplerite is from the Marjalahti meteorite (stony-iron, main group pallasite, fell June 01, 1902 at the northern coast of the Ladoga sea, Karelia, Russia. The cotype material was found in pyrometamorphic rocks of the Hatrurim Formation in the Negev Desert near Arad, Israel.

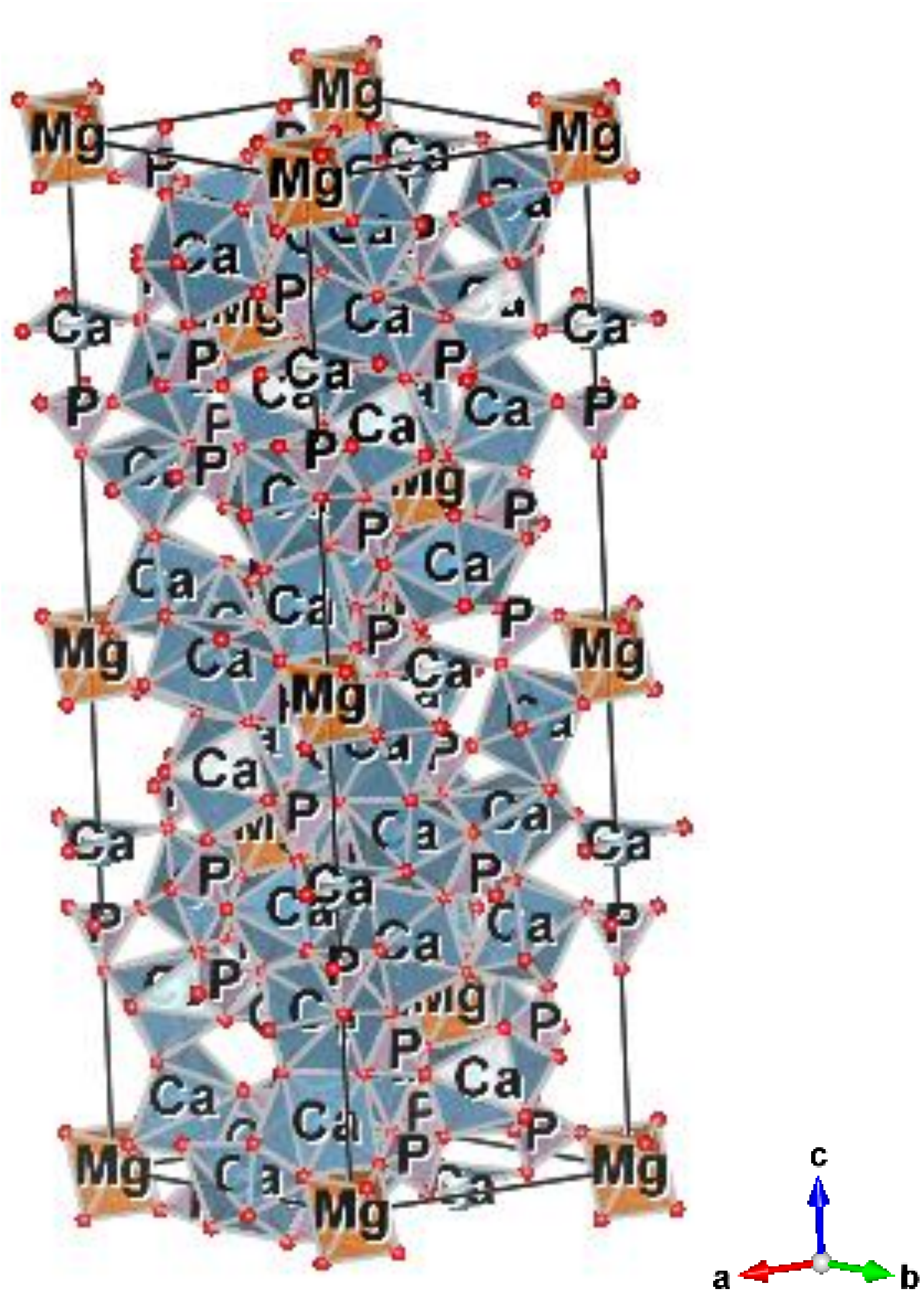

Figure 7.3. View of the crystal structure of unnamed $Ca_9(Ca_{0.5}\square_{0.5})Mg(PO_4)_7$ (keplerite) (from the Angra dos Reis meteorite), drawn using VESTA 3 (Momma and Izumi 2011). Data from Dowty (1977).

Unnamed $Na_4Mg_3(PO_4)_2(P_2O_7)$

Kaminsky *et al.* (2013)

Other names: Unnamed (Sodium-Magnesium Phosphate)

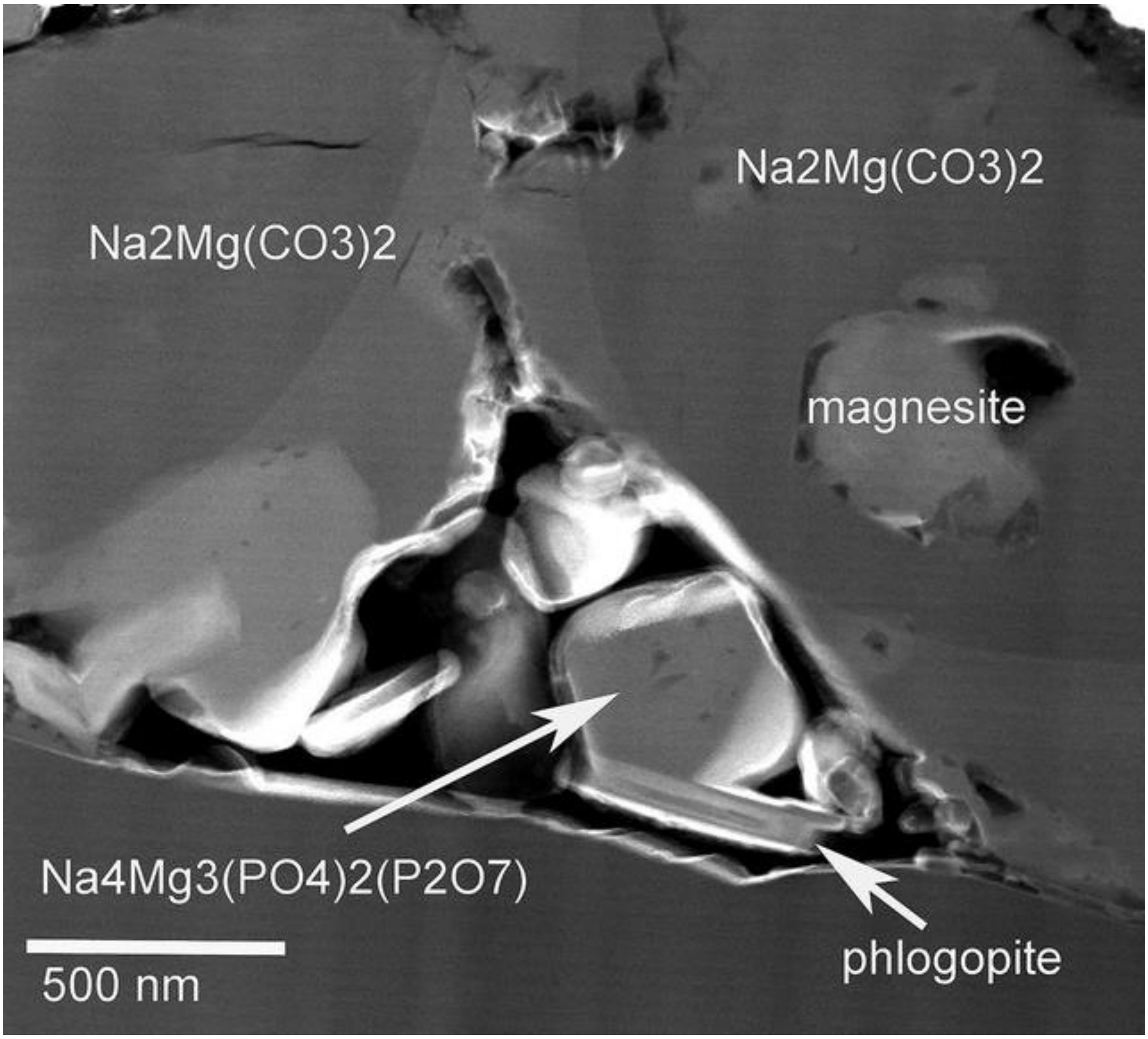

Figure 7.4. High-angle annular dark-field image of eitelite + magnesite + unnamed $Na_4Mg_3(PO_4)_2(P_2O_7)$ + phlogopite, from alluvial deposits of São Luiz river, Juína, Mato Grosso. Note perfect octahedral shape of the phosphate crystal, intergrown with a lath of phlogopite (Kaminsky *et al.* 2013).

This mineral occurs as several bipyramidal (erroneously quoted as octahedral) crystals *ca*. 500 nm in size, in deep mantle primary carbonatitic association, included in diamond from alluvial deposits of São Luiz river, Juína, Mato Grosso. Other inclusion minerals are dolomite, halite, sylvite, phlogopite, spinel, magnesite, eitelite, unnamed $Fe^{3+}_2Fe^{2+}_5(P_2O_7)_4$, oskarssonite, unnamed $(Ba,Sr)AlF_5$, pentlandite, violarite, millerite, hematite, and iron.

The X-ray diffraction data are [*d* in Å (*hkl*)]: 6.58 (010), 5.11 (002), 3.28 (203), 3.06 (220), 2.94 (213), 2.59 (222). It has the same structure as established for mixed-anion phosphate $Na_4Mg_3(PO_4)_2(P_2O_7)$, which was synthesized by Essehli *et al.* (2010).

Single-crystals of $Na_4Mg_3(PO_4)_2P_2O_7$ were grown by melting a mixture of Na_2CO_3, MgO and $NH_4H_2PO_4$ in the molar ratio Na/Mg/P = 4/3/4. After grinding, the mixture was heated at 200◦C, 500◦C and finally at (900±20)◦C in a zircon crucible. The sample was held at (900±20)◦C for 1 h, cooled to 400 ◦C at rate of 10 ◦C/h. Finally, it was cooled to room temperature by turning off the furnace power. Colorless crystals were obtained (Essehli *et al.* 2010).

The synthetic compound belongs to the orthorhombic space group $Pn2_1a$ with *a* 17.985(2), *b* 6.525(9), *c* 10.511(1) Å, *V* 1233.58 and *Z* 4. The framework is composed of $[PO_4]$ tetrahedra, $[P_2O_7]$ groups, and $[MgO_6]$ octahedra. The three-dimensional structure consists of $[Mg_3P_2O_{13}]_\infty$ infinite layers parallel to the *bc* plane. The layers are composed of $[MgO_6]$ octahedra and $[PO_4]$ tetrahedra, connected along the *a* axis by O–P–O–P–O bridges of the diphosphate groups. Large tunnels extending along the three main crystallographic directions host four crystallographically distinct Na cations (Essehli *et al.* 2010).

Two chemical compositions, obtained from the EDX spectra, are close to stoichiometric. Kaminsky *et al.* (2013) presented data in at% for two analyses: (1) Na 34.0, Mg 30.0, Fe 4.6, P 31.4; (2) Na 43.0, Mg 26.6, Fe 1.8, P 28.6. The correspondent unbalanced formulae are (1) $Na_{3.25}(Mg_{2.87}Fe_{0.44})_{\Sigma3.31}(PO_4)_2(P_2O_7)$; (2) $Na_{4.51}(Mg_{2.79}Fe_{0.19})_{\Sigma2.98}(PO_4)_2(P_2O_7)$. The natural compound differs from the known synthetic one by only a 1.8–4.6 at.% admixture of Fe, which isomorphically replaces Mg in octahedral coordination.

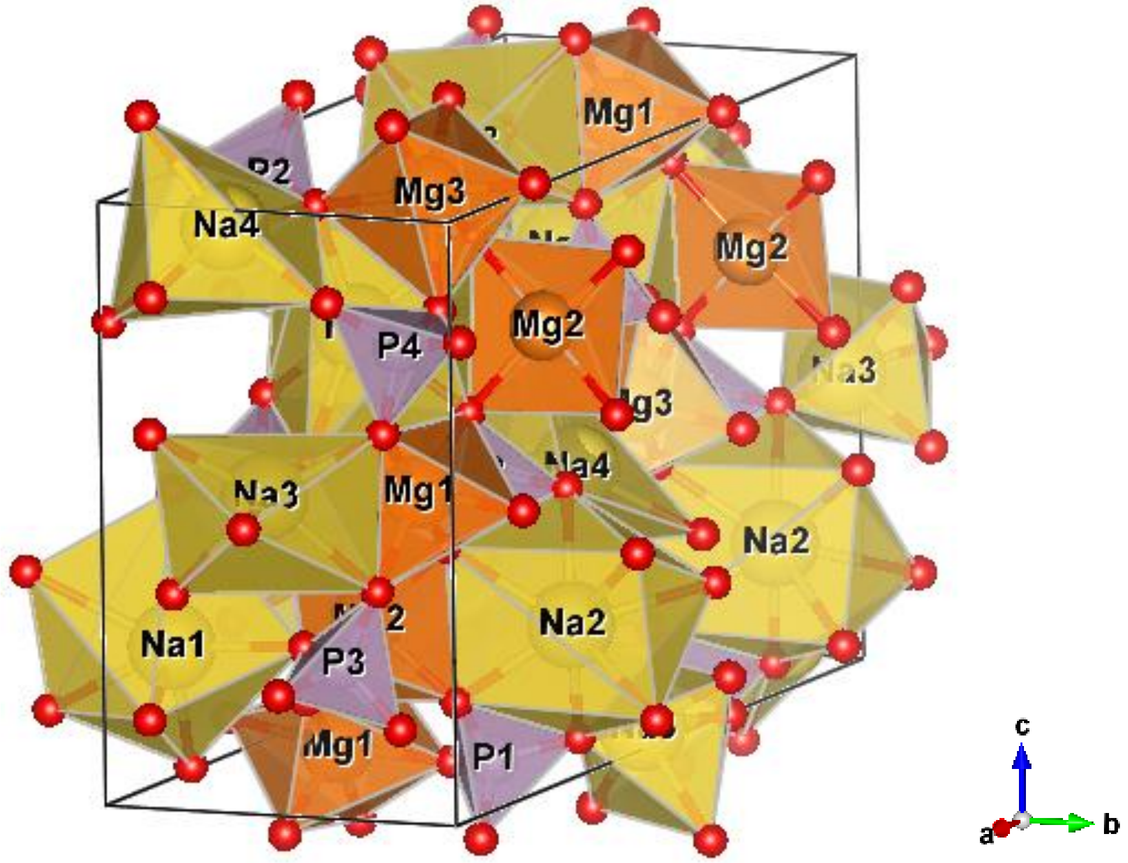

Figure 7.5. View of the crystal structure of unnamed $Na_4Mg_3(PO_4)_2(P_2O_7)$ (synthetic), drawn using VESTA 3 (Momma and Izumi 2011). Data from Essehli *et al.* (2010).

See also. Jeffbenite, ellinaite, breyite, nitroyarlongite, nitrocohenite, nitrochalypite, unnamed Fe_2N, Fe_3N, Fe_5SiC, $(Ba,Sr)AlF_5$, orthorhombic MgO, $MgCr_2O_4$, $Fe_2^{3+}Fe_5^{2+}(P_2O_7)_4$, and Na-Mg pyroxene.

Unnamed $Fe^{3+}_2Fe^{2+}_5(P_2O_7)_4$

Kaminsky *et al.* (2013)

Other names: Unnamed (Iron Diphosphate)

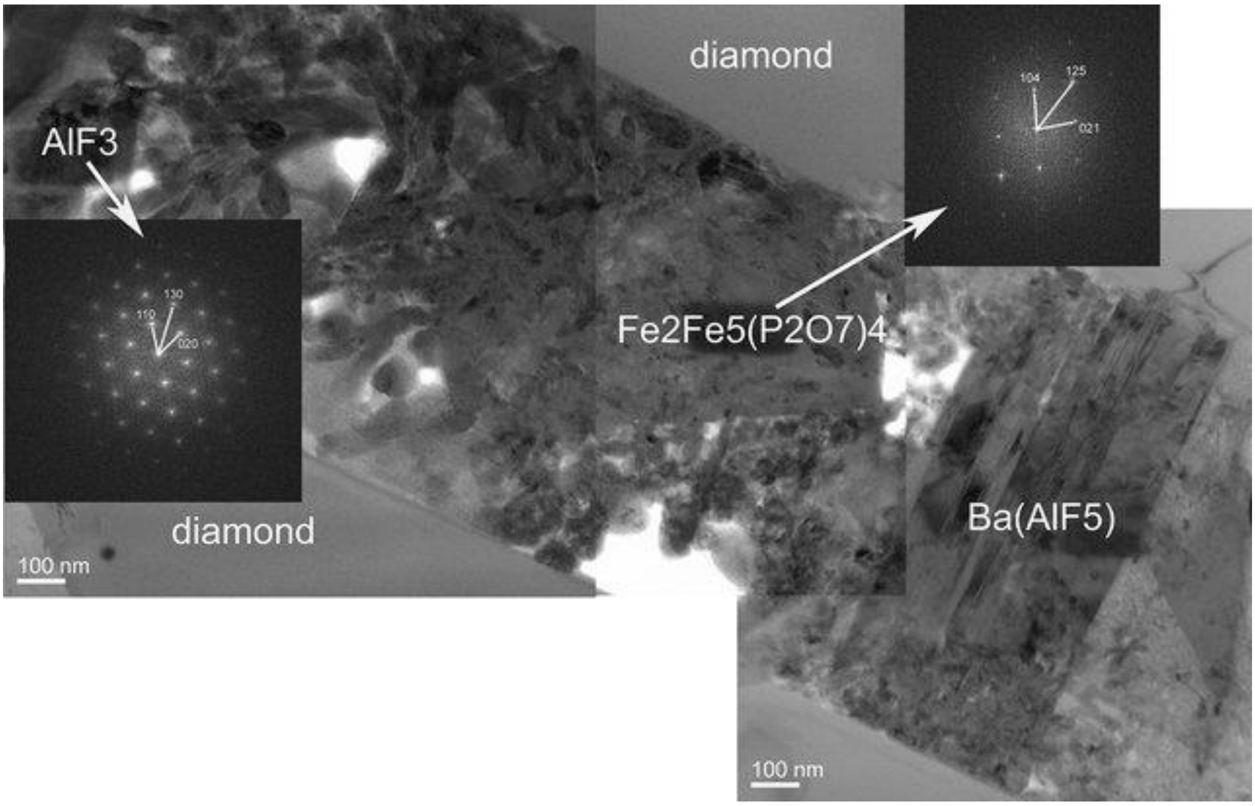

Figure 7.6. Plate-like inclusion with oskarssonite AlF_3 + $Fe^{3+}_2Fe^{2+}_5(P_2O_7)_4$ + $(Ba,Sr)AlF_5$ + pores, from alluvial deposits of São Luiz river, Juína, Mato Grosso. TEM bright field images with the corresponding diffraction patterns (fast Fourier transforms) inserted (Kaminsky *et al.* 2013).

This mineral has been identified by Kaminsky *et al.* (2013) in deep mantle primary carbonatitic association, included in diamond from alluvial deposits of São Luiz river, Juína, Mato Grosso, where it forms 50 – 200 nm grains. Other inclusion minerals are dolomite, halite, sylvite, phlogopite, spinel, magnesite, eitelite, unnamed $Na_4Mg_3(PO_4)_2(P_2O_7)$, oskarssonite, unnamed $(Ba,Sr)AlF_5$, pentlandite, violarite, millerite, hematite, and native iron.

The X-ray diffraction data are [*d* in Å (*hkl*)]: 4.87 (104), 4.77 (021), 3.17 (125). There is no reliable chemical composition data available for this mineral because, due to the nanometer size of its grains, there is always an overlap with other mineral grains. Although diphosphates have many uses in industrial chemistry and are very important in biochemistry, this mineral has not previously been observed in nature, possibly because diphosphates have the highest solubility among the phosphates (Hogan 2011) and have to be preserved in diamond to be observed. This mineral was synthesized from a mixture of Fe_2O_3 and $(NH_4)H_2(PO_4)$ under hydrothermal conditions at a temperature of 450 °C (Genkina *et al.* 1992). The synthetic compound belongs to the orthorhombic space group $C222_1$ with *a* 8.451, *b* 9.691), *c* 23.626 Å, *V* 1934.94 $Å^3$, and *Z* 4.

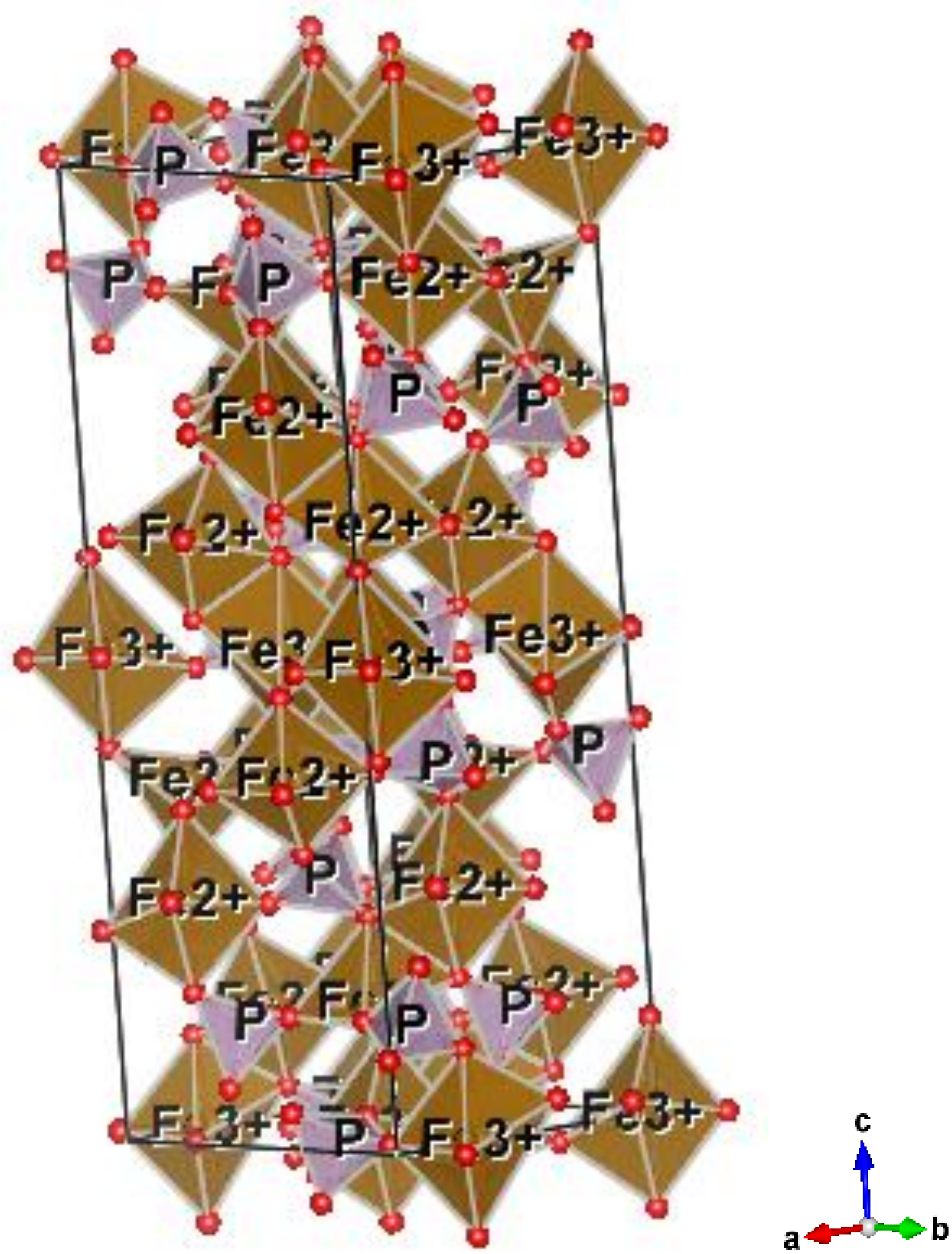

Figure 7.7. View of the crystal structure of unnamed $Fe^{3+}_2Fe^{2+}_5(P_2O_7)_4$ (synthetic), drawn using VESTA 3 (Momma and Izumi 2011). Data from Genkina *et al.* 1992).

See also. Jeffbenite, ellinaite, breyite, nitroyarlongite, nitrocohenite, nitrochalypite, unnamed Fe_2N, Fe_3N, Fe_5SiC, (Ba,Sr)AlF_5, orthorhombic MgO, $MgCr_2O_4$, $Na_4Mg_3(PO_4)_2(P_2O_7)$, and Na-Mg pyroxene.

Mineral (b)

Hirson (1965)

Other names: um novo fosfato, fosfato (b), a new phosphate, phosphate (b)

Hirson (1965) described a zinc phosphate, not specifically determined, in triphylite veins, in the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais, quoted as “a new phosphate", "phosphate (b)", and "mineral (b)". Spectrographic analysis revealed the presence of Zn, Fe and Mn. In view of the lack of X-ray diffraction data and quantitative chemical analysis, nothing can be said about this mineral.

See also. Arrojadite-(PbFe), faheyite, barbosalite, frondelite, moraesite, ruifrancoite, tavorite, jahnsite-(MnMnMg), jahnsite-(NaMnMg), whiteite-(MnMnMg), whiteite-(FeMgNa), unknown silky white mineral, lipscombite, and avelinoite.

Unknown silky white mineral

Moore and Ito (1978)

(meurigite-K?)

See Figure 7.86

Moore and Ito (1978b) described an unknown silky white mineral replacing rockbridgeite from the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. Birch *et al.* (1996) suggested this mineral could be meurigite-K, $KFe^{3+}_8(PO_4)_6(OH)_7 \cdot 6.5H_2O$, monoclinic. Meurigite-K was described at the Sapucaia pegmatite by Atencio *et al.* (2007).

See also. Arrojadite-(PbFe), faheyite, barbosalite, frondelite, moraesite, ruifrancoite, tavorite, jahnsite-(MnMnMg), jahnsite-(NaMnMg), whiteite-(MnMnMg), whiteite-(FeMgNa), whiteite-(FeMgNa), mineral (b), lipscombite, and avelinoite.

Chavesite

Murdoch (1958)

(= monetite)

Other names: chavesita

This mineral was described by Murdoch (1958) on fracture surfaces of lithiophilite in the Boqueirão pegmatite, Parelhas, Rio Grande do Norte, associated with hureaulite and tavorite. It occurs as an intermittent thin colorless crystalline coating, which sometimes shows poorly-formed individual crystals. The name was given in honor of Dr. Onofre Chaves, an engineer of the Departamento Nacional da Produção Mineral. According to Murdoch (1958), it is a hydrated calcium manganese phosphate, but not enough is available for chemical analyses. Hardness is near 3. The mineral displays two good cleavages, in the prism zone and nearly perpendicular to each other. Optically, it is biaxial positive, with $2V$ large, and refractive indices α 1.60, β 1.62, γ 1.65. Multiple twinning was observed, with a twin plane parallel to the elongation of the crystals. Extinction is about 30º to the twin plane. Rotation, and Weissenberg equator, first and second layer lines about c show it to be triclinic with a 5.49, b 13.07, c 5.79 Å, α 9l°18½', β 108º3', γ 99º44', $a : b : c = 1.4200 : 1 : 0.4438$. The powder pattern closely resembles that of monetite, and it has been suggested (Mrose, priv. commun. to Murdoch) that chavesite and monetite may be isostructural (Murdoch 1958).

Kampf and Dunn (1994), studying the original material, stored in the Department of Earth and Space Sciences, University of California, Los Angeles (UCLA), USA, concluded that it is monetite, $CaH(PO_4)$ triclinic. Their studied material from UCLA was then cataloged at the Natural History Museum, Los Angeles, USA, under numbers 38919-38925. Kampf and Dunn (1994) noted that a Gandolfi 114.6-mm X-ray film of chavesite and one obtained from monetite from Mona Island, Puerto Rico, coincide in every detail. The cell parameters for chavesite refined from powder data with monetite indexing are a 6.921(5), b 6.643(6), c 6.938(7) Å, α 96.25(5), β 103.87(6), γ 88.32(6)º. The cell parameters reported by Murdoch could not be duplicated in the precession study nor could they be derived from the monetite cell. Kampf and Dunn (1994) assumed that Murdoch was in error in his interpretation of the Weissenberg films. A chavesite crystal from one of the type specimens was subjected to electron microprobe analysis, yielding CaO 39.6, MnO 0.6, FeO 0.2, P_2O_5 50.3 wt.%. This compares reasonably well with the theoretical composition of monetite, CaO 41.22, P_2O_5 52.16, H_2O 6.62 wt.%. The Mn noted by Murdoch was apparently determined by a qualitative test. The small amount of MnO in the material could have provided a positive microchemical test, or his sample may have been contaminated by lithiophilite or hureaulite. The Commission on New Minerals and New Mineral Names, IMA, has approved the discreditation of chavesite as a distinct mineral species. Murdoch (1958) also described two unidentified minerals [mineral A and mineral B] in the Boqueirão pegmatite.

Despite research on the spot by many mineralogists and amateurs, for decades, no other monetite sample could be found. The dumps of the works operated during the second world war are buried deep or have been partly used for the ballasting of nearby tracks (Cassedanne and Philippo 2015).

See also. Tavorite, mineral A, and mineral B.

Mineral A

Murdoch (1958)

Other names: UM1958-02-PO:Fe

Murdoch (1958) described this “mineral A” in the Boqueirão pegmatite, Parelhas, Rio Grande do Norte, associated with chavesite and “mineral B”:

*“MINERAL A. One of the variscite specimens shows an unidentified mineral, chestnut brown in color, occurring in radiating blades, and with one good cleavage. Qualitative tests show it to be an anhydrous (?) iron phosphate, with index well over 1.74: extinction parallel to elongation; biaxial negative, with 2*V *large; pleochroic pale to amber brown. The powder pattern gives the following spacings and intensities for the stronger lines: 3.145 – 10, 2.405 – 6, 3.57 – 5, 3.36 – 5, 4.74 – 4.*

See also. Chavesite and mineral B.

Mineral B

Murdoch (1958)

Other names: UM1958-01-PO:CaMn

Murdoch (1958) described this “mineral B” in the Boqueirão pegmatite, Parelhas, Rio Grande do Norte, associated with chavesite and “mineral A”

“MINERAL B. Associated with tavorite are small, spherulitic aggregate, greenish-white in color, of a calcium manganese phosphate with very high index of refraction. It is too fine grained to make further optical determinations. The powder pattern does not appear to match that of any published mineral. Spacing and intensities of the stronger lines are as follows: 4.67 – 10, 3.42 – 5, 3.01 – 5, 2.52 – 2.”

See also: Chavesite and mineral A.

Castelnaudite

Damour (1853)

[= xenotime-(Y) + diaspore]

Other names: castelnaudita, castelnauite, hydro-phosphate d'yttria, yttrium hydrophosphate

Damour (1853) described a “yttrium hydrophosphate”, as grayish-white or pale yellow crystals, associated with quartz, feldspar, rutile, anatase, brookite, zircon, diaspore, gold, magnetite, etc., in diamondiferous sands at Chapada, Bahia. It was named castelnaudite, in honor of the French consul M. de Castelnau [François Louis Nompar de Caumont Laporte (1810-1880), naturalist and diplomat] who also studied diamondiferous sands of Bahia at the same time as Damour. According to Ferraz (1928), castelnaudite is a variety of xenotime that occurs in the sands of Diamantina, Minas Gerais, and Bahia. Damour (1856) noted the presence of two yttrium phosphates in the sands of Chapada, Bahia: the first is a white yttrium phosphate (this corresponds to castelnaudite, but here appears without a name) and the second is a titanian yttrium phosphate [= xenotime-(Y) but also without a name and previously said to be a yttrium silicate; see thellite]. Regarding the first phosphate, Damour (1856) observed: *“In a previous note, I designated this species an* *yttrium hydrophosphate, since I recognized that it contained water. I made sure later that the presence of water in the first analyzed samples was due to lamellae of diaspore, a species associated with this mineral in the sand, and with external characteristics that are easily confused with those of the white yttrium phosphate".*

In conclusion, Damour decided that castelnaudite was a mixture of xenotime-(Y), $Y(PO_4)$ tetragonal, and diaspore, AlO(OH) orthorhombic.

See also. Hussakite and thellite.

Thellite

Phipson (1870)

[= xenotime-(Y)]

Other names: thellita, thelline, yttria silicate (of Damour), yttrium silicate (of Damour)

Damour (1853) described a probable yttrium silicate, but with an undetermined composition, from the diamond sands of Chapada, Bahia. It was brown, Mohs hardness 5 to 6, and density 4.391 g/cm^3 (meas.). However, Damour (1856) published the following information:

"Titanian yttrium phosphate - I also made a mistake when describing this species with the name of yttrium silicate. It generates a mixture of titanium and zirconium acids, which I confused, in the first moment, with silica. This substance occurs as round grains, with small cavities in the surface; sometimes also as octahedra with a square basis, and with smoothed faces as those of zircon. It is opaque and has cinnamon-brown color; its density is 4.39. It scratches weakly the glass. Phosphorus salt dissolves it with difficulty. Boiling sulfuric acid decomposes it, leaving a white, insoluble residue, formed by titanium and zirconium acids. The analysis resulted in:

Phosphoric acid	*0.3164*
Yttria	*0.6040*
Titanium and zirconium acids	*0.0740*
Uranium and iron oxides	*0.0120*
	1.0064

The crystals of this material observed in the sands of Bahia present all the external characteristics of the yttrium phosphate that is found in the Hitteroë pegmatites, Norway…"

Certainly ignoring the work of Damour (1856), Phipson (1870) published the following note (total content):

"ON A MINERAL FROM SAN PAOLO.
By Dr. T.L.PHIPSON, F.C.S.,
Member of the Chemical Society of Paris.

A mineral from San Paolo [= São Paulo]*, Brazil, was placed in my hands a short time ago in Paris; it was supposed to be a silicate of yttria, and was called Thelline or Thellite. It corresponded in appearance and properties with the silicate of yttria, described by M. Damour, in 1858, as having been found in the diamond sands of Bahia, Brazil; a brown mineral, said to be "probably a silicate of yttria", which whitens before the blowpipe, but does not fuse, and was found to be insoluble in phosphorus salt.*

A small sample of the specimen from San Paolo was confided to me for analysis, with a request that I would make known the result at an early opportunity.

The following is a description of the mineral and its analysis: It is light brown, translucent on the thin edges, and in the veins which traverse its substance; when pulverized it gives a light yellow powder of great brilliancy, which becomes bright red when heated; it is partially attacked by strong acids. Before the blowpipe it is infusible, but darkens and turns black in the inner flame, and, by continuing the heat for some time, the surface becomes quite white. It scratches glass like a diamond and cuts it very nearly as easily as the latter, but it will not attack quartz; it gives flashes and sparks of fire when struck smartly in an agate mortar; it is quite devoid of crystallization, and its fracture is imperfectly conchoidal. No trace of yttria could be obtained from this mineral, but it was found to contain about 1 per cent of glucina as an accidental constituent. It yielded

Silicic acid	*90.09*
Water	*4.54*
Peroxide of iron and alumina with about 1 per cent of glucina	*4.56*
	100.00

The presence of glucina in this mineral, which is evidently a kind of hydrated sílica, menilite [= grayish-brown opal], *or resinite* [= yellowish-brown opal], *is rather interesting, and leads me to believe that this earth will be found in other natural kinds of silica. Silicate of glucina (Phenakite) is so closely allied to quartz in appearance and crystalline form that it is easily mistaken for it, and substances possessing, when crystallized, the same crystalline form are often found together in nature. I do not conclude from the above that the mineral I have examined is identical with M. Damour's silicate of yttria, for I am not aware that I have ever seen the later. Doubtless, he will someday publish an analysis of it.*

Analytical Laboratory, Putney, S.W."

Based on the above, the "yttrium silicate" of Damour would be an yttrium phosphate [xenotime-(Y), originally described in Norway]. The hardness and the density presented by Damour coincide reasonably with that of xenotime-(Y). The presence of titanium may be ascribed to inclusions of thin rutile needles (Hussak 1917). As a curiosity, it may be noted that the yttrium silicate thalenite-(Y), described in 1898, in Sweden, 28 years after the note by Phipson, has a name similar to thellite.

The mineral of "São Paulo", studied by Phipson, was probably opal or phenakite.

See also. Castelnaudite and hussakite.

Hussakite

Kraus and Reitinger (1901, 1902)

[= xenotime-(Y), zircon]

Other names: hussakita, Hussakit

Xenotime-(Y), $Y(PO_4)$ tetragonal, was identified by Gorceix (1885) in diamondiferous sands of Datas, Minas Gerais. Kraus and Reitinger (1901, 1902) found about 6 % SO_3 and gave the name hussakite to the mineral, a sulfo-phosphate of Y, Er, and small percentage of Gd. The name honors Dr. Franz Eugen Hussak (1856-1911), of the Geological Survey of São Paulo.

Subsequent analyses of identical material by Hussak (1907) did not confirm the presence of SO_3 in sufficient amounts (0.25 % at the most) for a new species to be designated.

Hussak (1907) determined that the rock-forming mineral identified as hussakite by Rösler (1902) is zircon.

See also. Castelnaudite and thellite.

Serrabrancaite

Witzke *et al.* (2000)

$Mn^{3+}(PO_4)\cdot H_2O$, monoclinic

Approved CNMMN - IMA 1998-006

Other names: serrabrancaíta

Figure 7.8. Serrabrancaite from Alto Serra Branca, Pedra Lavrada, Paraíba. Specimen: Reynaldo R. Contreira Filho. Photo: Daniel Atencio.

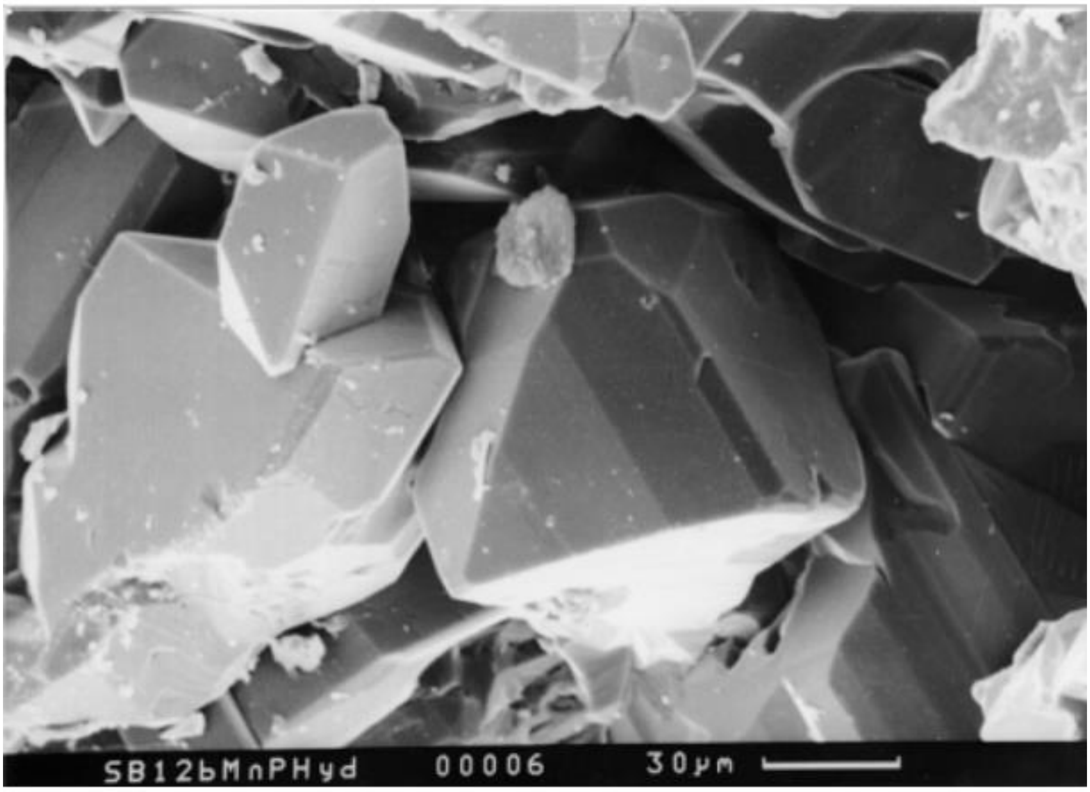

Figure 7.9. SEM micrography of serrabrancaite from Alto Serra Branca, Pedra Lavrada, Paraíba (Witzke *et al.* 2000).

Occurrence. As an alteration product in a phosphate granitic pegmatite intruded into biotite schist at Alto Serra Branca, 11 km south-west of Pedra Lavrada, Paraíba. Minerals in the pegmatite are quartz, microcline, muscovite, albite, amblygonite, “apatite”, beryl, uraninite, elbaite, tantalite-group minerals, secondary uranium minerals, triphylite, triplite, purpurite, rockbridgeite, tavorite, barbosalite, huréaulite, eosphorite, phosphosiderite, carlhintzeite, colquirite, pachnolite, hydrokenoralstonite and fluellite. Serrabrancaite is a product of alteration of triplite and is closely associated with phosphosiderite and vernadite. This is also the type locality of the original arrojadite. Serrabrancaite also occurs in some other Brazilian and world localities.

Appearance and physical properties. Habit: equant or short-prismatic crystals up to 0.3 mm. Forms: no forms were mentioned, but some are visible in the SEM images. Twinning: none mentioned. Color: dark brown to dark greenish-black. Streak: olive green. Luster: adamantine. Translucent in thin fragments. Hardness (Mohs): 3½. Tenacity: brittle. Cleavage: none discernible. Fracture: uneven. Density: 3.17(1) g/cm^3 (meas.), 3.10 g/cm^3 (calc.).

Optical properties. Biaxial (sign not given), α 1.75(1), β 1.79(1), γ > 1.79. 2V could not be measured because the larger crystals were too dark and the smaller crystals were unsuitable. Pleochroism: dark brown to olive greenish-brown.

Chemical data. Microprobe (WDS mode) analyses (4): Mn_2O_3 46.85, P_2O_5 42.72, H_2O 9.8 (from thermal analysis), total 99.37 wt.%. Empirical formula: $Mn_{0.98}(PO_4)_{1.00}\cdot 0.90H_2O$. The ideal formula requires Mn_2O_3 47.01, P_2O_5 42.26, H_2O 10.73, total 100.00 wt.%.

Crystallography. Monoclinic, *C*2/*c*, *a* 6.914(2), *b* 7.468(2), *c* 7.364(2) Å, *β* 112.29(3)°, *V* 351.8(1) Å^3, *Z* 4, *a*:*b*:*c* = 0.926:1:0.986. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 4.856 (12) (110), 4.633 (15) ($\bar{1}11$), 3.503 (100) (111), 3.271 (10) (021), 2.957 (10) ($\bar{2}02$), 2.530 (9) ($\bar{2}21$), 2.516 (19) (022), 2.104 (12) (221), 1.633 (7) ($\bar{2}24$), 1.521 (7) (133).

Name. For the type locality.

Type material. The Mineralogical Collection of the Technische Universität, Bergakademie, Freiberg, Germany (No. 78025) and the Mineralogical Collection of the Martin-Luther Universität Halle, Institut für Geologische Wissenschaften, Halle, Germany (No. 010355).

Relationship to other species. Natural analog of synthetic $Mn(PO_4)\cdot H_2O$ and phosphate analog of synthetic $MnAsO_4\cdot H_2O$. Structurally related to the kieserite group.

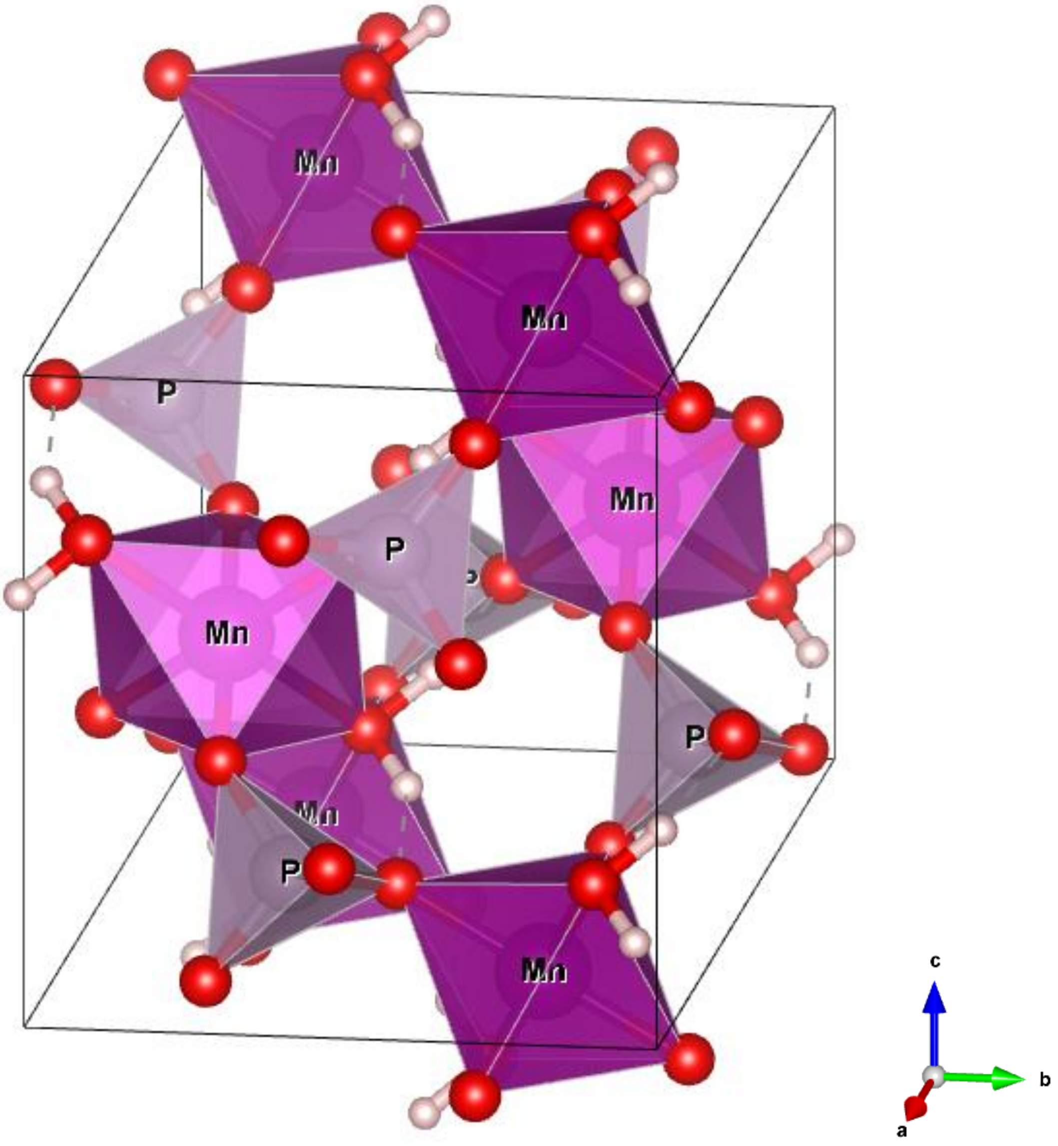

Figure 7.10. View of the crystal structure of serrabrancaite (synthetic), drawn using VESTA 3 (Momma and Izumi 2011). Data from Lightfoot *et al.* (1987).

Crystal structure. The structure of the synthetic analog was described by Lightfoot *et al.* (1987). It consists of axially distorted MnO octahedra linked together, through the oxygen atom of the water molecule at a common vertex, to form zigzag –Mn-O-Mn- chains running parallel to [101]. These chains are interconnected by (PO_4) tetrahedra to form a continuous three-dimensional network.

Synthetic. A sample of $Mn(PO_4)\cdot H_2O$ was obtained as a pale green powder by the following method: Mn_3O_4 (prepared by the decomposition of manganese(II) oxalate, at 600°C) was added to a mixture of $H_3(PO_4)$ (85% in water) and H_2O to produce an approximate 1:10:50 molar ratio of Mn_3O_4:$H_3(PO_4)$:H_2O. This mixture was sealed in a

Teflon-lined stainless-steel autoclave and held at 200°C for 3 days. The product was filtered, washed with cold water, and dried at room temperature (Lightfoot *et al.* 1987).

See also. Tavorite, barbosalite, atroarite, and arrojadite.

Calcio-rhabdophane

Soubiès *et al.* (1992)

[= Ca-rich rhabdophane-(Ce)]

Other names: calcio-rabdofânio.

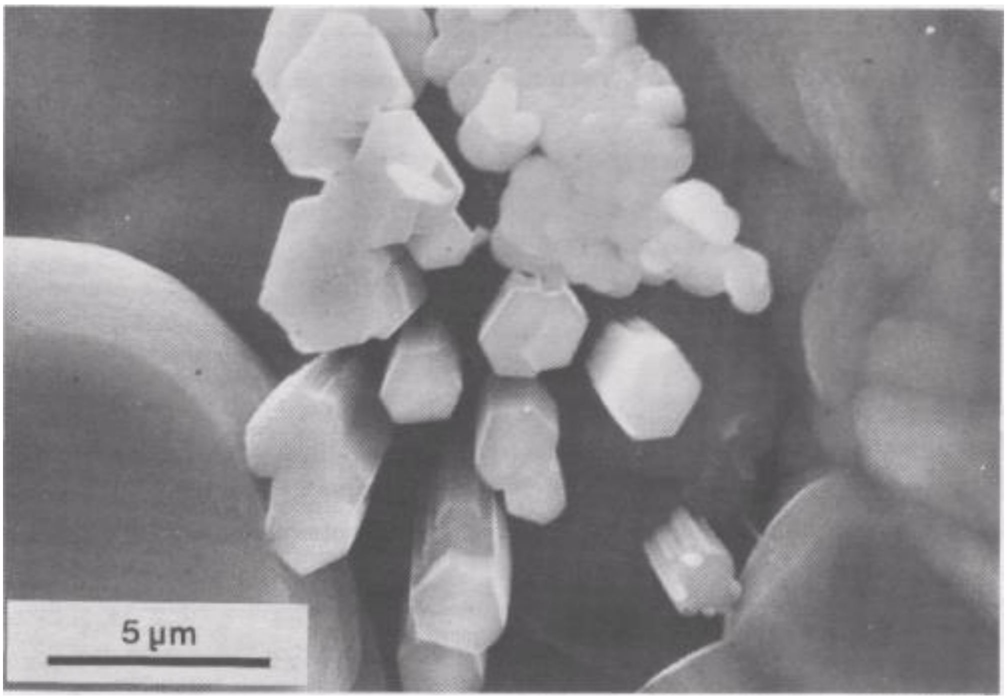

Figure 7.11. Ca-rich rhabdophane-(Ce) from Tapira, Minas Gerais (Soubiès *et al.* 1991a).

Soubiès *et al.* (1992) gave the name calcio-rhabdophane to a mineral from Tapira, Minas Gerais, described by Soubiès *et al.* (1991a). The formula is $(Ca_{0.38}Ce_{0.26}La_{0.21}Nd_{0.10}\ldots)[PO_{3.62}(OH)_{0.38}]\cdot xH_2O(x\sim1)$. The sum *REE* + Y + Sc > Ca (in atomic numbers) so following the CNMMN – IMA rules of nomenclature (Nickel and Grice 1998) it should be considered as a *REE*-mineral. It should be referred to as Ca-rich rhabdophane-(Ce), $Ce(PO_4)\cdot H_2O$, hexagonal.

See also. Unidentified Ca-La-Nd-phosphate.

Unidentified Ca-La-Nd-phosphate

Sant'Anna *et al.* (1999)

(probably a rhabdophane-group mineral)

The occurrence of a phosphate with Ca and *REE* (La, Nd) in a mudstone deposit of the Resende Formation, located on the northern border of the Resende Basin, Resende municipality, Rio de Janeiro, was described by Sant'Anna *et al.* (1999). The prismatic hexagonal habit and chemical composition suggested it is a rhabdophane-group mineral. This phosphate is authigenic and its origin is related to the dissolution of detritic apatite grains, probably by alkaline hydrothermal solutions.

See also. calcio-rhabdophane.

Arupite

Buchwald (1990)

$Ni_3(PO_4)_2 \cdot 8H_2O$, monoclinic

Approved CNMMN - IMA 1988-008

Other names: arupita

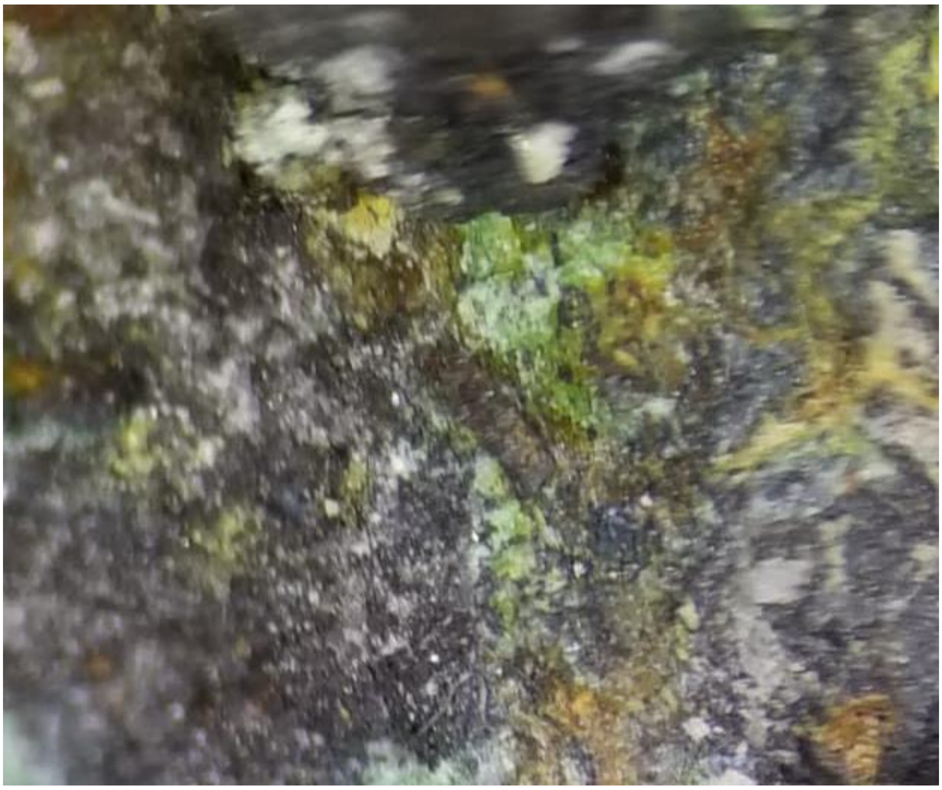

Figure 7.12. Arupite, honessite, reevesite and other secondary minerals in the corroded parts of the Santa Catarina meteorite, found in the Morro do Rocio, São Francisco do Sul, Santa Catarina. Field of view: 1mm. Specimen from the Museu Nacional, Rio de Janeiro. Photo: Maria Elizabeth Zucolotto.

Figure 7.13. Arupite, honessite, reevesite and other secondary minerals in the corroded parts of the Santa Catarina meteorite, found in the Morro do Rocio, São Francisco do Sul, Santa Catarina. Field of view: 1.5 cm. Specimen from the Museu de Ciência e Técnica da Escola de Minas de Ouro Preto, Minas Gerais. Photo: Ricardo Scholz.

This mineral was described in the Santa Catarina meteorite, from which the name catarinite originated. The meteorite is severely weathered due to very long exposure to the subtropical climate. The unaffected parts of the meteorite consist of taenite, tetrataenite, troilite, and schreibersite.

Occurrence. In the corroded parts of the Ni-rich iron meteorite Santa Catarina, found in 1875, in the Morro do Rocio, São Francisco do Sul, Santa Catarina. Associated secondary minerals are honessite, reevesite, heazlewoodite, pentlandite, akaganeite, goethite, hematite, and magnetite. Also, known from Sugashima island, Toba, Mie, Japan (Matsubara 2002).

Appearance and physical properties. Habit: earthy aggregates up to 2 mm in diameter. Forms: Individual grains are short prisms, 2 to 5 μm long. Color: sky-blue to turquoise-blue. Luster: earthy. Translucent. Non-fluorescent. Hardness (Mohs): 1.5 to 2. Density 2.90 g/cm^3 (calc.).

Optical properties. Biaxial, α' 1.632(5), γ' 1.680(5) (white light). Pleochroism: X blue and Z colorless.

Chemical data. Microprobe (WDS mode) analyses (23): NiO 40.18, CoO 0.39, FeO 4.53, P_2O_5 27.60, H_2O 27.30 (by difference), total 100.00 wt.%. Empirical formula: $(Ni_{2.78}Fe_{0.33}Co_{0.03})_{\Sigma 3.14}(PO_4)_{2.01}O_{0.12}\cdot 7.84H_2O$. The ideal formula requires NiO 43.93, P_2O_5 27.82, H_2O 28.25, total 100.00 wt.%.

Crystallography. Monoclinic, *I*2/*m*. *a* 9.889(15), *b* 13.225(11), *c* 4.645(4) Å, *β* 102.41(11)° *V* 981.8(7) Å^3, *Z* 2. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 7.878 (36) (110), 6.624 (100) (020), 4.818 (61) (200), 3.805 (50) (101), 2.922 (72) ($\bar{3}01$), 2.672 (46) (321).

Name. In honor of Hans Henning Arup (1928–2012), director of the Danish Corrosion Center, Copenhagen, Denmark.

Type material. U.S. National Museum of Natural History (Smithsonian Institution), Division of Meteorites, Washington DC, USA, under the registration numbers 659, 804, 877, and others.

Relationship with other species. Vivianite group; the Ni-analog of vivianite.

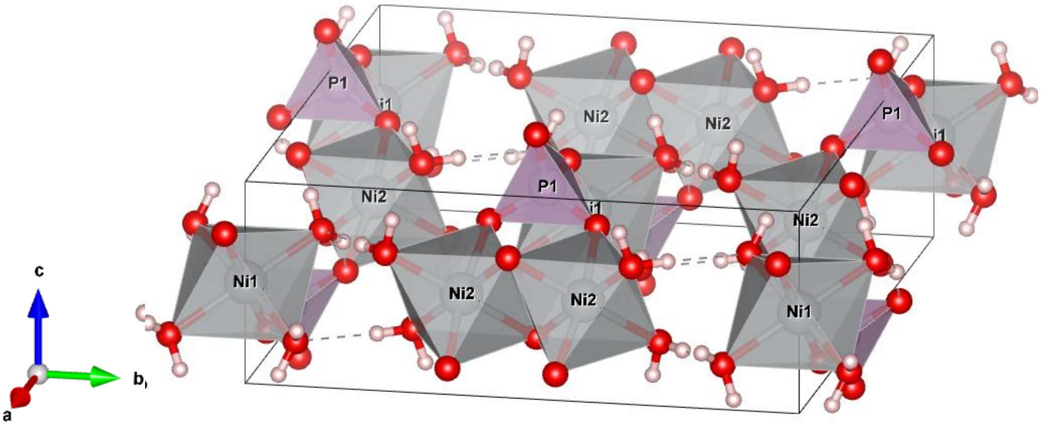

Figure 7.14. View of the crystal structure of arupite (synthetic), drawn using VESTA 3 (Momma and Izumi 2011). Data from Shouwen *et al.* (2008).

Crystal structure. All the Ni atoms are located in slightly distorted octahedral coordination environments. Two phosphate groups and two Ni atoms share a centrosymmetric four-membered ring and an eight-membered ring such that the four-membered ring is inside the eight-membered ring. The eight-membered rings are connected with the other Ni atoms (lying on centers of symmetry) through phosphate anions, generating a one-dimensional chain structure. Adjacent chains are connected through hydrogen bonds, forming a three-dimensional network (Shouwen *et al.* 2008).

Synthetic. The synthetic equivalent of arupite was synthesized hydrothermally in a 23 ml Teflon-lined autoclave by heating a mixture of 1-(4-(1H-imidazol -1-yl)butyl)-1H-imidazole (0.143 g, 0.75 mmol), nickel acetate dihydrate (0.25 g, 1 mmol), phosphoric acid (0.11 g, 1 mmol), and deionized water (6 ml) at 130˚C for 10 days. Then it was slowly cooled to room temperature, giving blue block crystals (Shouwen *et al*. 2008).

See also. Catarinite and tetrataenite.

Correianevesite

Chukanov *et al.* (2014a)

$Fe^{2+}Mn^{2+}_2(PO_4)_2\cdot 3H_2O$, orthorhombic

Approved CNMNC – IMA 2013-007

Other names: correianevesita

Figure 7.15. Brown crystals of correianevesite with hureaulite (23 × 19 × 12 mm), from Cigana (Jocão) mine, Conselheiro Pena, Minas Gerais. Specimen and photo: Edson Ferreira dos Santos.

Figure 7.16. Brown crystals of correianevesite from Cigana (Jocão) mine, Conselheiro Pena, Minas Gerais. Field of view: 3 mm. Specimen and photo: Jhonatan Gomes.

Correianevesite was considered as reddingite, $Mn^{2+}_3(PO_4)_2 \cdot 3H_2O$ before Mössbauer data have been obtained (Frost *et al.* 2012).

Occurrence. Cigana (Jocão) mine, Conselheiro Pena, Minas Gerais. Associated minerals are triphylite, hureaulite, microcline, albite, quartz, schorl, columbite-tantalite, elbaite, fluorapatite, muscovite, beryl, spodumene, triphylite, lithiophilite, frondelite, rockbridgeite, eosphorite, hureaulite, vivianite, spessartine, fairfieldite, leucophosphite, cyrilovite, phosphosiderite, pyrite and arsenopyrite. The mineral formed in a phosphate-rich granite pegmatite. The genesis is related to an early hydrothermal process involving the alteration of triphylite. Also, known from some world occurrences.

Appearance and physical properties. Equant crystals up to 4 mm in size in cavities in triphylite**.** Habit: bipyramidal, pseudo-octahedral. Forms: {111} bipyramid. Twinning: none observed Color: light brown to reddish-brown. Streak: white, Luster: vitreous. Transparent. Non-fluorescent. Hardness (Mohs): 3½. Tenacity: brittle. Cleavage: poor on

{010}. Fracture: laminated; uneven across cleavage. Density: 3.25(2) g/cm^3 (meas. by flotation in heavy liquids; 3.275 g/cm^3 (calc. using the empirical formula).

Optical properties. Biaxial (+), α 1.661(5), β 1.673(5), γ 1.703(5) (589 nm). 2*V* 70(10) (meas.), 67º (calc.). Dispersion: $r > v$, strong. Orientation: $Y = b$. Pleochroism: absent.

Chemical data. Microprobe (EDS) analyses (7), the contents of F, Na, Mg, Al, Si, S, K, Ca, Ti, Zn and As are below their detection limits. Total iron content analyzed by microprobe and initially calculated as FeO was 23.13 wt.%; it was apportioned between FeO and Fe_2O_3 (as well as between two sites) based on Mössbauer data. H_2O was analyzed by gas chromatography of products of ignition at 1200°C. CO_2 was not analyzed because of the absence of absorption bands corresponding to vibrations of C-O bonds in the IR spectrum. MnO 29.21, FeO 21.74, Fe_2O_3 1.54, P_2O_5 34.59, H_2O 12.6(1), total 99.68 wt.%. The empirical formula is $Fe^{2+}(Mn^{2+}_{1.69}Fe^{2+}_{0.24}Fe^{3+}_{0.08})_{\Sigma 2.01}(PO_4)_2\cdot 2.86H_2O$. The simplified formula requires MnO 34.63, FeO 17.54, P_2O_5 34.64, H_2O 13.19, total 100.00 wt.%.

Crystallography. Orthorhombic, *Pbna*, *a* 9.4887(2), *b* 10.1149(2), *c* 8.7062(2) Å, *V* 835.60(3) Å^3, *Z* 4 (single-crystal), *a* 9.491(7), *b* 10.121(7), *c* 8.721(9) Å, *V* 838(2)Å^3, *Z* 4 (powder data), *a*:*b*:*c* = 0.9381:1:0.8607. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 5.08 (43) (020), 4.314 (28) (002, 210), 3.220 (100) (221, 202), 3.125 (25) (122), 2.756 (35) (103, 230), 2.686 (25) (222, 113), 2.436 (22) (123), 2.236 (23) (411, 331).

Name. In memory of Professor José Marques Correia Neves (1929-2011), who was the most active geoscientist in the study of Brazilian pegmatites, especially in the region of Conselheiro Pena and Araçuaí, as well as in Alto Ligonha in Mozambique, where he discovered hafnon, the Hf analog of zircon.

Type material. The type specimen of correianevesite (a part of the holotype) is deposited in the mineralogical collections of the Museu de Ciência e Técnica, Escola de Minas, Universidade Federal de Ouro Preto, Praça Tiradentes, Ouro Preto, Minas Gerais, registration number SAA-081B.

Relationship to other species. Correianevesite is a member of the reddingite group with Fe^{2+} dominant in the *M*1 site and Mn^{2+} dominant in the *M*2 site.

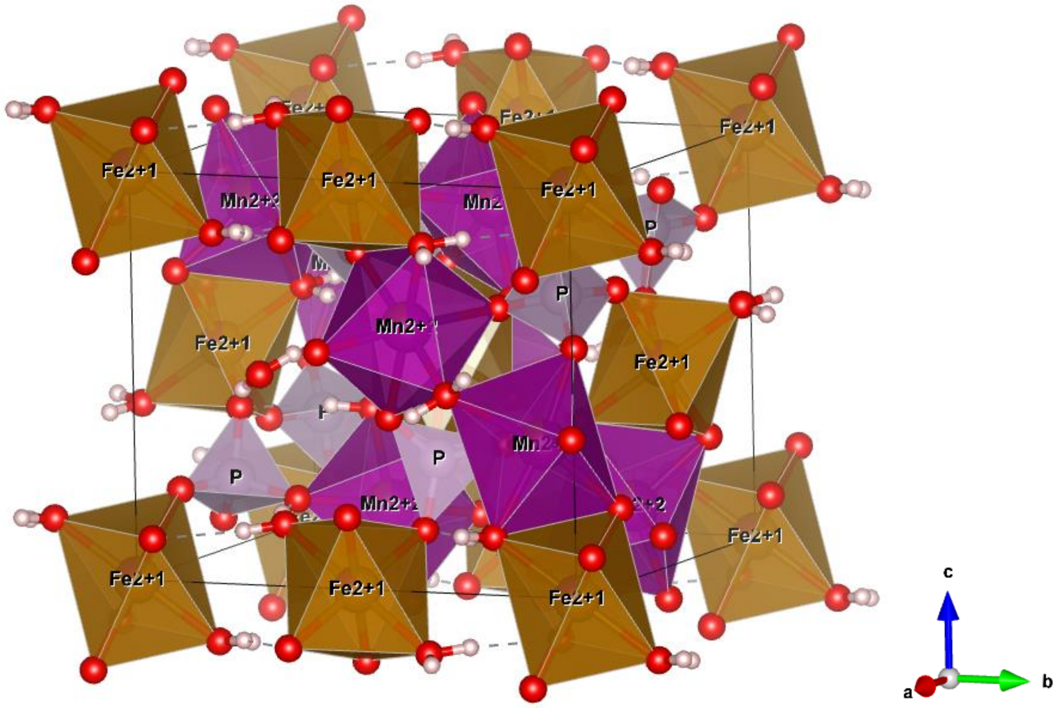

Figure 7.17. View of the crystal structure of correianevesite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Chukanov *et al.* (2014a).

Crystal structure. Reddingite-group minerals are orthorhombic phosphates with the general formula $M1M2_2(PO_4)_2(OH,H_2O)_3$ where octahedral sites *M*1 and *M*2 can contain Mn^{2+}, Fe^{2+}, Mg and Fe^{3+} with a minor admixture of Ca and Al and some other (trace) components. Mn^{2+} preferably occupies the larger octahedron *M*2, but in reddingite both *M*1 and *M*2 sites are dominantly occupied by Mn^{2+}. Based on interatomic distances and observed trends in site populations, Moore *et al.* (1980) assumed the existence of a hypothetical reddingite-group mineral with the end-member formula $Fe^{2+}Mn^{2+}{}_2(PO_4)_2{\cdot}3H_2O$, in which Fe^{2+} occupies the *M*1 site and Mn^{2+} occupies the *M*2 site. Taking into account Mössbauer spectroscopy data, the results of the crystal structure refinement, compositional data and general trends in the cation distribution between the sites *M*1 and *M*2 (Moore *et al.* 1980), the crystal-chemical formula of correianevesite can be written as $(Fe^{2+}{}_{0.72}Mn^{2+}{}_{0.20}Fe^{3+}{}_{0.08})(Mn^{2+}{}_{1.48}Fe^{2+}{}_{0.52})(PO_4)_2(H_2O,OH)_3$ (Chukanov *et al.* 2014a).

See also. Jahnsite-(MnMnFe).

Faheyite

Lindberg and Murata (1953)

$Be_2Mn^{2+}Fe^{3+}_2(PO_4)_4\cdot6H_2O$, trigonal

Other names: faheyíta, faheylite

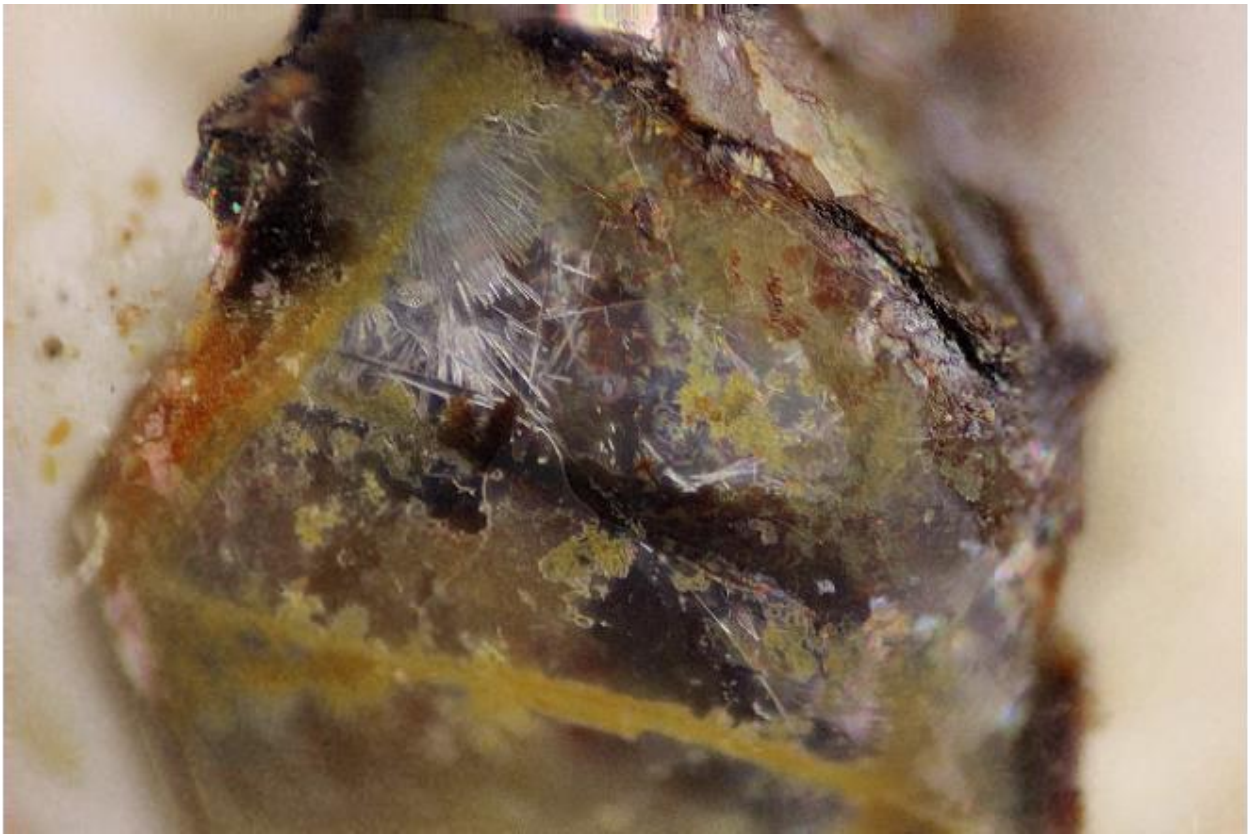

Figure 7.18. Faheyite on muscovite from the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. Field of view: 2.1 mm. Specimen and photo: Martin Slama.

This mineral, from the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais, was described in two preliminary notes (Lindberg and Murata 1952a, b) and one complete paper (Lindberg and Murata 1953) as hexagonal (*a* 9.43, *c* 16.00 Å, Z 3) $Be_2(Mn,Mg,Na)Fe^{3+}_2(PO_4)_4\cdot6H_2O$. Single-crystal X-ray diffraction study showed that faheyite has Laue symmetry 6/*mmm* and systematically absent reflections that are consistent with the enantiomorphic space groups $P6_222$ and $P6_422$, in crystal class 622, with *a* 9.42(2), *c* 15.98(3) Å (Lindberg 1964). The crystal structure of faheyite from the Roosevelt mine, South Dakota, USA, trigonal, *a* 9.404(7), *c* 15.920(11) Å, *V* 1219(2) Å^3, *Z* 3, space group $P3_121$, has been solved and refined by Cooper and Hawthorne (2015).

Occurrence. The mineral occurs in the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais, which is the type locality of other eight phosphates [arrojadite-(PbFe), barbosalite, frondelite, moraesite, ruifrancoite, tavorite, jahnsite-(MnMnMg) and jahnsite-(NaMnMg); see notes about this occurrence under ruifrancoite], as a secondary alteration product, associated with several other phosphates. This is still the only deposit in Brazil. According to Cassedanne and Philippo (2015): "*In spite of about thirty visits to the Sapucaia deposit, since the end of the 1960s, none of the many white hairy samples collected as likely to be faheyite was identified as such. They were always moraesite; the diffractogram of which is extremely different from that of the wanted mineral.*" Most likely, recent photos of "faheyite" from Sapucaia that have been posted on the internet are actually of moraesite.

Also, known from Noumas II pegmatite, Steinkopf, Namakwa, Northern Cape, South Africa (von Knorring 1985), and the Roosevelt mine, South Dakota, USA (Robinson *et al.* 1992).

Appearance and physical properties. Habit: in vugs, as fibers coating other minerals, botryoidal masses of fibers completely enclosing euhedral quartz crystals, or attached to muscovite sheets, flat rosettes of fibers between sheets of muscovite, and tufts of fibers on variscite crystals, on botryoidal frondelite, and between frondelite layers. Individual fibers average 0.08 mm in length and 0.01 mm in thickness. The fibers usually grow normal to the surfaces of the other minerals and may be terminated by pyramid faces. Color: white, bluish-white, brownish-white. Transparent. Hardness (Mohs): 3. Cleavage: perfect parallel to *c*. Density 2.660 g/cm^3 (meas.), 2.719 g/cm^3 (calc.). Slowly dissolved by hot dilute HCl, HNO_3 and H_2SO_4.

Optical properties. Uniaxial (+), ω 1.631, ε 1.652. Elongation parallel to *c*.

Chemical data. Unspecified methods: BeO 7.26, MnO 5.99, MgO 1.14, Na_2O 0.84, K_2O traces, FeO n.d., Fe_2O_3 21.42, Al_2O_3 0.10, Mn_2O_3 n.d., P_2O_5 38.11, F traces, H_2O 14.90, Insol. (quartz and muscovite) 9.44, total 99.20 wt.%. Empirical formula: $Be_{2.13}(Mn_{0.62}Mg_{0.21}Na_{0.20})_{\Sigma 1.03}(Fe^{3+}_{1.97}Al_{0.01})_{\Sigma 1.98}(PO_4)_{3.95}\cdot 6.08H_2O$. The ideal formula requires BeO 7.44, MnO 10.55, Fe_2O_3 23.74, P_2O_5 42.20, H_2O 16.07, total 100.00 wt.%.

Crystallography. Trigonal, $P3_121$, *a* 9.404(7), *c* 15.920(11) Å, *V* 1219(2) Å^3, *Z* 3, *c:a* = 1,6929 (Cooper and Hawthorne 2015). X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 7.28 (90) (101), 5.72 (100) (102), 3.962 (50) (201), 3.244 (60) (203), 3.085 (60) (210), 3.029 (60) (211), 2.724 (30) (300), 2.673 (30) (213), 1.268 (30) (2 0 12) (Lindberg and Murata 1953).

Name. In honor of Dr. Joseph John Fahey (1901-1980), geochemist, U.S. Geological

Survey, coauthor of two Brazilian type minerals, scorzalite and souzalite. A preliminary notice of the title of the paper [American Mineralogist 37 (Nov./Dec. 1952), p. x], gives the form “faheylite”.

Type material. U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA, holotype, 112653 (donator U.S. Geological Survey, 1956).

Relationship to other species. The crystal structures of fransoletite and parafransoletite also contain beryllophosphate chains topologically identical to those found in faheyite (Cooper and Hawthorne 2015).

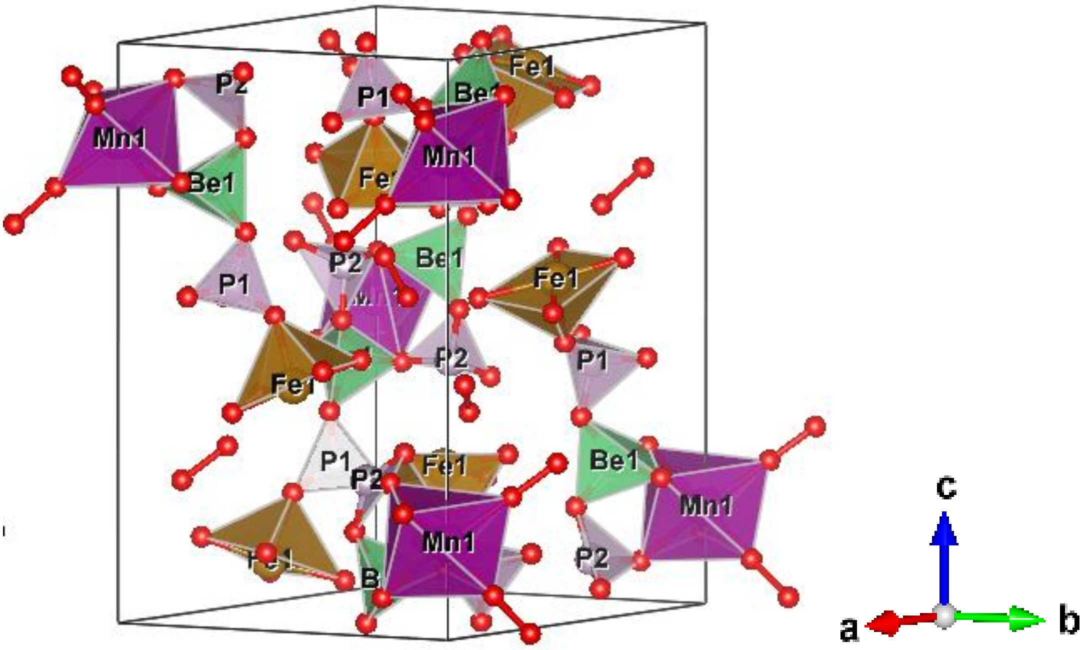

Figure 7.19. View of the crystal structure of faheyite (from the Roosevelt mine, South Dakota, USA), drawn using VESTA 3 (Momma and Izumi 2011). Data from Cooper and Hawthorne (2015).

Crystal structure. Each vertex of the *Be* tetrahedron is shared with a vertex of a neighboring *P* tetrahedron, and two vertices of each *P* tetrahedron are shared with neighboring *Be* tetrahedra to form a corner-sharing [$Be(PO_4)_2$] chain, with *P* tetrahedra flanking the *Be* tetrahedra of the central spine in the sequence -*P*(1)/*P*(1)-*Be*-*P*(2)/*P*(2)-*Be*-. Faheyite has a chiral structure, with the [$Be(PO_4)_2$] chain twisting about the **c**-axis in a clockwise direction for the refined $P3_121$ enantiomer. The *Mn* octahedron lies along the 3_1 screw axis within the core region of the [$Be(PO_4)_2$] chain, forming [$MnBe_2(PO_4)_4$] spires that are wrapped by *Fe* octahedra that share vertices with *P* tetrahedra (Cooper and

Hawthorne 2015).

See also. Arrojadite-(PbFe), barbosalite, frondelite, moraesite, ruifrancoite, tavorite, jahnsite-(MnMnMg), jahnsite-(NaMnMg), whiteite-(MnMnMg), whiteite-(FeMgNa), unknown silky white mineral, mineral (b), lipscombite, and avelinoite.

Unnamed hydrous phosphate of alumina and lime

Damour (1853)

Other names: hydro-phosphate d'alumine et de chaux, cabocle, caboclo

A compact mineral, of a pale or dark brick-red color, found in rolled pebbles with the diamond sands of Bahia was supposed by Damour (1853) to be a hydrated phosphate of aluminium and calcium.

Wilancookite

Hatert *et al.* (2017)

$(Ba,K,Na)_8(Ba,Li,\square)_6Be_{24}P_{24}O_{96}\cdot 32H_2O$, cubic

Approved CNMNC – IMA 2015-034

Other names: wilancookita

Figure 7.20. Wilancookite with moraesite and eosphorite from Ponte do Piauí claim, Taquaral, Itinga, Minas Gerais. Field of view: 1.5 mm. Specimen and photo: Jhonatan Gomes.

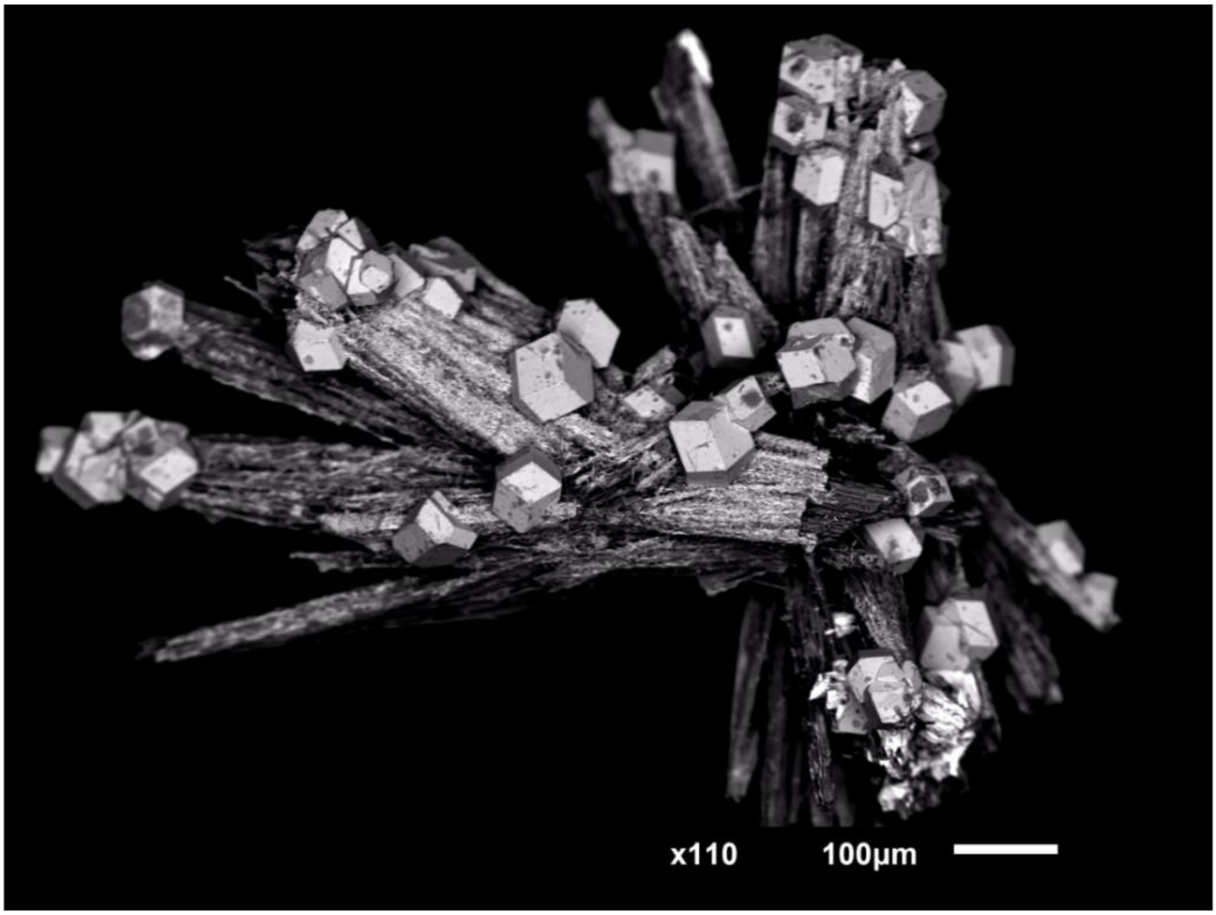

Figure 7.21. Group of moraesite crystals in association with wilancookite, from Ponte do Piauí claim, Taquaral, Itinga, Minas Gerais. Specimen in the arquives of the Geology Department, Federal University of Ouro Preto.

Occurrence. A secondary mineral occurring in phosphate nodules adjacent to the quartz core of a granitic pegmatite in the Lavra Ponte do Piauí complex, Itinga, Minas Gerais. The pegmatite has been mined for gemstones and samples for the collectors market. It is heterogeneous with well-developed mineralogical and textural zonation (Cassedanne and Philippo 2015). The pegmatite is hosted by biotite schist of the Neoproterozoic Salinas Group. The contact is not well exposed and did not allow determining the orientation of the pegmatite body. A discontinuous quartz core is surrounded by small miarolitic cavities. Associated primary minerals are albite, montebrasite, Li-bearing micas, cassiterite, elbaite, and quartz. The secondary phosphate association contains fluorapatite, childrenite, eosphorite, zanazziite, greifenstenite, guimarãesite, ushkovite, saléeite, and moraesite. Beryllium-rich secondary phosphates formed during late stages, by a reaction between montebrasite and beryl. This process produced several species, like beryllonite, greifenstenite, guimarãesite, moraesite, and zanazziite. Wilancookite crystallized in the very late conditions since the crystals are deposited on moraesite fibers. Wilancookite was discovered by Luiz A.D. Menezes Filho in 2009. This is also the type locality for guimarãesite.

Appearance and physical properties. Tiny dodecahedral {110} crystals, deposited on moraesite fibers. The crystals reach a diameter of 100 μm. Color: colorless. Transparent. Luster: vitreous. Streak: white. Non-fluorescent under either long or short-wavelength ultraviolet light. Hardness (Mohs): 4–5, by analogy with pahasapaite. No cleavage has been observed. Tenacity: brittle. Fracture: irregular. Density could not be measured due to small grain size; the calculated density if 3.05 g/cm^3.

Optical properties. isotropic, colorless, non-pleochroic, with $n = 1.560(2)$ (measured under $\lambda = 590$ nm).

Chemical data. Electron- and ion-microprobe analyses: P_2O_5 36.19, SiO_2 0.04, Al_2O_3 0.41, BaO 34.65, Na_2O 0.09, K_2O 0.32, BeO 12.86, Li_2O 0.50, H_2O_{calc} 12.31, total 97.37 wt.%. Empirical formula (on the basis of 96 anhydrous oxygen atoms): $(Ba_{7.54}K_{0.32}Na_{0.14})_{\Sigma 8.00}(Ba_{3.04}Li_{1.57}\square_{1.39})_{\Sigma 6.00}Be_{24.08}(P_{23.88}Al_{0.38}Si_{0.03})_{\Sigma 24.29}O_{96}\cdot 32H_2O$. The simplified formula $Ba_8(Ba_3Li_2\square)Be_{24}P_{24}O_{96}\cdot 32H_2O$ requires P_2O_5 37.06, BeO 13.06, BaO 36.69, Li_2O 0.65, H_2O 12.54, total 100.00 wt.%.

Crystallography. Cubic, *I*23, *a* 13.5398(2) Å, *V* 2482.21(7) Å^3, *Z* 1 (single-crystal). X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 6.90(60)(200), 5.54(80)(211), 3.630(60)(321, 312), 3.212(70)(330, 411), 3.043(100)(420, 402), 2.885(70)(332), 2.774(80)(422), and 2.398(60)(440).

Name. In honor of William (Bill) R. Cook Jr. (1927–2006) and his wife Anne, who endowed the mineralogy chair at the Cleveland Museum of Natural History; they were founding members of the Mineralogical Society of Cleveland and also of the Micromineral Society of the Cleveland Museum of Natural History. Bill was a mineralogist and crystallographer.

Type material. The cotypes are deposited in the collections of the Laboratory of Mineralogy, University of Liège (cotype used for optics, crystal structure and Gandolfi measurements: catalog number 20394), and in the collections of the Natural History Museum of Luxembourg (cotype used for chemical analyses: catalog number 2011-33).

Relationship to other species. Wilancookite belongs to the pahasapaite group.

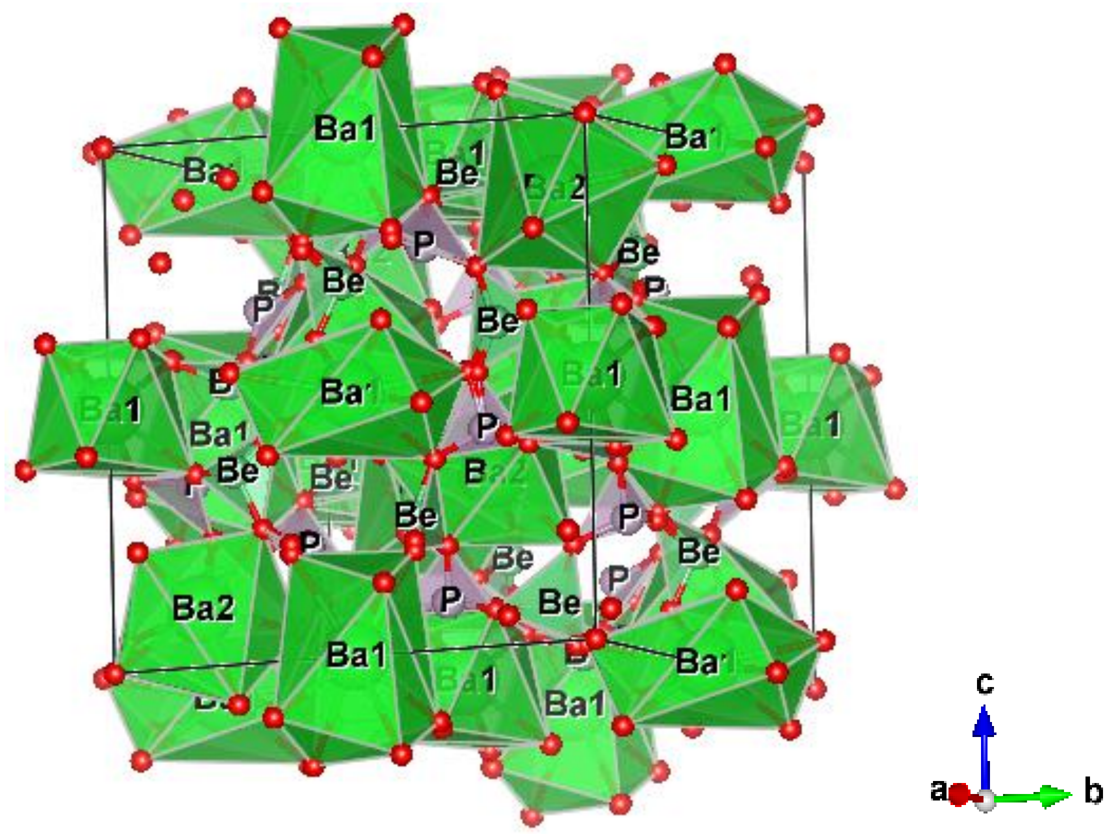

Figure 7.22. View of the crystal structure of wilancookite (from the type locality), drawn using VESTA 3 (Momma and Izumi 2011). Data from Hatert *et al.* (2017).

Crystal structure. The crystal structure of wilancookite is characterized by a beryllophosphate framework similar to that of pahasapaite, $(Ca,Li,K,\square)_{24}Li_8Be_{24}P_{24}O_{96}\cdot38H_2O$ and is based on corner-sharing BeO_4 and PO_4 tetrahedra forming a large cavity in which occur Ba atoms and water molecules. The positions of Ba atoms and water molecules are significantly different from those of Ca and Li in pahasapaite; however, the general topology of the framework is preserved. Wilancookite and pahasapaite are the only known phosphate minerals with a zeolite-type topology.

See also. Guimarãesite, moraesite, and zanazziite.

Tavorite

Lindberg and Pecora (1955)

$LiFe^{3+}(PO_4)(OH)$, triclinic

Other names: tavorita

Figure 7.23. The type specimen containing tavorite from the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. Harvard Mineralogical Museum, Harvard University, Cambridge, Massachusetts, USA, 107298 (donator U.S. Geological Survey, thru M.L. Lindberg).

One important class of fluorophosphates materials comprises compounds based on the tavorite structure. Lithium transition metal phosphates and fluorophosphates are important positive electrode materials for safe, low-cost lithium-ion cells. (Ellis *et al.* 2011). Three-dimensional frameworks based on phosphates have recently been identified as possible electrode materials for lithium batteries applications, especially since the discovery of the good electrochemical performance, with high thermal and chemical stability, delivered by optimized nanosized $LiFePO_4$ materials. The high structural stability of the phosphate materials during the lithium insertion/deinsertion process is due to the presence of highly covalent PO_4^{3-} groups. Furthermore, the inductive effect induced by these PO_4^{3-} groups increases the ionicity of the *M*–O bond *versus* oxides and thus raises the potential of the transition metal ion redox couple. In the continuous search for new polyanion-based insertion hosts, $LiFePO_4(OH)$ appeared to be an interesting candidate with a theoretical specific capacity of 153 mAh/g and a three-dimensional framework with tunnels being expected to promote good lithium mobility (Marx *et al.* 2010).

A preliminary note about this mineral was published by Lindberg and Pecora (1954b). The complete paper was released by Lindberg and Pecora (1955).

Occurrence. The mineral occurs in the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais, which is the type locality of eight other phosphates [arrojadite-(PbFe), barbosalite, frondelite, moraesite, ruifrancoite, faheyite, jahnsite-(MnMnMg) and jahnsite-(NaMnMg); see notes about this occurrence under ruifrancoite], as a secondary alteration product, associated with several other phosphates. Also, known from several Brazilian and world occurrences.

Appearance and physical properties. Mainly disseminated along discontinuous veinlets, less than 5 mm in width, at or near the contact of heterosite and barbosalite. It also occurs as a microscopic network veining heterosite, ferrisicklerite, and barbosalite. Scattered flakes of tavorite are sparsely distributed along cleavage cracks in altered triphylite. Tavorite intimately replaces both barbosalite and crystals of hureaulite. Color: greenish-yellow. Twinning: thin polysynthetic. Density: 3.288 g/cm^3 (meas.), 3.346 g/cm^3 (calc.).

Optical properties. Biaxial (+), α 1.795, β 1.810, γ 1.835, 2*V* large (meas.), 76.4° (calc.). Pleochroism: *X* and *Y* yellow-green, *Z* colorless. Absorption *Z* > *Y* > *X*. Dispersion: *r* > *v*, strong *v*.

Chemical data. Wet analyses: Li_2O 7.64, FeO 2.39, MnO 1.47, Fe_2O_3 42.57, P_2O_5 39.78, H_2O 5.76, total 99.61 wt.% (Lindberg and Pecora 1955). Empirical formula $Li_{0.91}Fe^{2+}_{0.06}Mn^{2+}_{0.04}Fe^{3+}_{0.95}(PO_4)_{1.00}[(OH)_{0.96}(H_2O)_{0.09}]_{\Sigma 1.05}$. Microprobe analyses (Baijot *et* *al.* 2012): (1) Li_2O 7.93, MnO 0.56, MgO 0.21, CaO 0.15, ZnO 0.10, K_2O 0.06, Fe_2O_3 45.25, P_2O_5 40.20, SiO_2 0.01, H_2O (calc.) 5.10, total 99.57 wt.%. Empirical formula $Li_{0.94}Mn^{2+}_{0.01}Mg_{0.01}Fe^{3+}_{1.00}(PO_4)_{1.00}(OH)_{1.00}$. (2) Li_2O 9.00, MnO 2.27, MgO 0.53, CaO 0.06, ZnO 0.10, Na_2O 0.09, K_2O 0.01, Fe_2O_3 44.87, P_2O_5 42.32, H_2O (calc.) 5.37, total 104.60 wt.%. Empirical formula $Li_{1.01}Mn^{2+}_{0.05}Mg_{0.02}Fe^{3+}_{0.95}(PO_4)_{1.00}(OH)_{1.00}$. The ideal formula requires Li_2O 8.54, Fe_2O_3 45.70, P_2O_5 40.61, H_2O 5.15, total 100.00 wt.%.

Crystallography. Lindberg and Pecora (1955): Triclinic, $P\bar{1}$, *a* 5.138, *b* 5.307, *c* 7.442 Å, α 67.48, β 67.72, γ 61.98°, *V* 173.45 Å^3, *Z* 2, *a:b:c* = 0.9682:1:1.402. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 4.99 (50) (010), 4.68 (30) (101), 3.95 (20) (111), 3.323 (20) (112), 3.285 (90) (012), 3.045 (100) ($1\bar{1}1$), 2.474 (40) (113), 2.360 (20) (202), 1.6662 (30) ($\bar{2}12$). Marx *et al.* (2010), synthetic: Triclinic, $P\bar{1}$, *a* 5.3528(6), *b* 7.2896(7), *c* 5.1187(5) Å, α 109.359(4), β 97.733(5), γ 106.359(5)°, *V* 174.98(3) Å^3, *Z* 2, *a:b:c* = 0.7343:1:0.7022.

Name. In honor of Prof. Elysiario Tavora Filho (1911-2001), University of Brazil and DNPM, Rio de Janeiro.

Type material. According to Lindberg and Pecora (1955): U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA (USNM 106, 842), and "Museu Nacional of the Departamento Nacional da Produção Mineral", Rio de Janeiro [Museu Nacional and Departamento Nacional da Produção Mineral are two different museums]. According to Lapaire (2020): Harvard Mineralogical Museum, Harvard University, Cambridge, Massachusetts, USA, (type) 107298/9 (donator U.S. Geological Survey, thru M.L. Lindberg); Natural History Museum, London, England, (type) BM 1965,209; U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA, Mineralogy Division, (type) 106842 (on the same specimen with type barbosalite).

Relationship to other species. Amblygonite group.

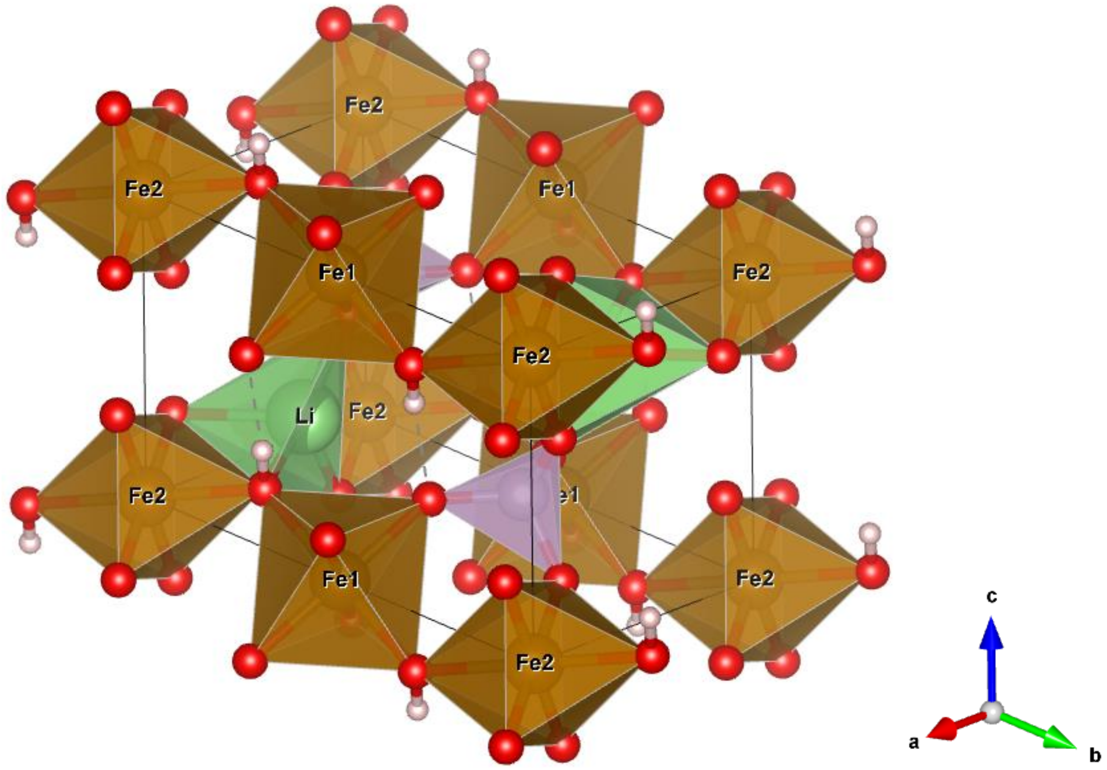

Figure 7.24. View of the crystal structure of tavorite (synthetic), drawn using VESTA 3 (Momma and Izumi 2011). Data from Marx *et al.* (2010).

Crystal structure. The structure, determined in the synthetic equivalent by Marx *et al.* (2010), consists of a three-dimensional network with iron(III) octahedra (FeO_6) sharing corners, forming chains that run along the b direction. These chains are interconnected by PO_4 tetrahedra, the resulting framework encloses tunnels of two different sizes running along the *a* and *c* axis. The lithium and hydrogen atoms are localized in these tunnels.

Synthetic. Synthetic tavorite was prepared by hydrothermal synthesis: $FePO_4{\cdot}4H_2O$ and $CH_3COOLi{\cdot}2H_2O$ were mixed in the molar ratio 1:4 together with water in a 600 mL Parr reactor at 170°C for 24 h (Marx *et al.* 2010).

See also. Arrojadite-(PbFe), faheyite, barbosalite, frondelite, moraesite, ruifrancoite, jahnsite-(MnMnMg), jahnsite-(NaMnMg), whiteite-(MnMnMg), whiteite-(FeMgNa), unknown silky white mineral, mineral (b), lipscombite, and avelinoite.

Lefontite

Yang *et al.* (2015)

$Fe^{2+}_2Al_2Be(PO_4)_2(OH)_6$, orthorhombic

Approved CNMNC – IMA 2014-075

Other names: lefontita

Figure 7.25. Lefontite from the João Teodoro mine, Linópolis, Divino das Laranjeiras, Minas Gerais. Brown prismatic crystals, associated with light-brown greifensteinite, dark green acicular gormanite, and white fine-grained leucophosphite. Type specimen, RRUFF Project R140428.

Figure 7.26. Lefontite from the João Teodoro mine, Linópolis, Divino das Laranjeiras, Minas Gerais. SEM image. Type specimen. RRUFF Project R140428.

Until today the complete paper for this mineral was not published. Nevertheless, almost all the data are available in the RRUFF project site. The previously unpublished data are presented here with authorization from Hexiong Yang.

Occurrence. Lefontite was originally found in a rock specimen from the João Teodoro mine, Linópolis District, Divino das Laranjeiras, Minas Gerais. Subsequently, it was also found in samples from “Galileia”, Minas Gerais [the correct locality for this occurrence seems to be the João Firmino mine, Linópolis District, Divino das Laranjeiras, Minas Gerais; see discussion under atencioite], and the Palermo No. 1 mine, Groton, New Hampshire, USA. The João Teodoro mine was designated as the type locality. Lefontite from the João Teodoro mine is associated with greifensteinite, gormanite, and leucophosphite. The minerals associated with lefontite from (probably) João Firmino mine are microcline, muscovite, albite, ushkovite, atencioite, and rockbridgeite. Lefontite from the Palermo No. 1 mine is associated with palermoite, natropalermoite, childrenite, eosphorite, goethite, and quartz. The mineral assemblages are thought to have formed as a result of hydrothermal events in phosphate-rich zones of granite pegmatites.

Appearance and physical properties. Lefontite crystals are up to 0.4 × 0.5 × 2.0 mm in size. Habit: prismatic along [100], with wedge-shaped terminations, in radial or spherical radiating groups. Forms: {100} and {001} dominant. Twinning: none observed. Color: reddish-brown to dark brown. Streak: light brown. Luster: vitreous. Transparent. Non-fluorescent. Hardness (Mohs): ~5. Tenacity: brittle. Cleavage: {100} poor. Parting: none observed. Fracture: subconchoidal to uneven. Density: 3.20(3) g/cm^3 (meas.) by floatation in heavy liquids, 3.186 g/cm^3 (calc.) using the empirical formula.

Optical properties. Biaxial (–), *α* 1.685(2), *ß* 1.690(2), *γ* 1.6903(20) (white light). 2*V* 26(1)° (meas.), 27° (calc.). Dispersion: *r* > *v*, strong. Orientation: *X* = *b*, *Y* = *a*, *Z* = *c*. Pleochroism: weak, yellow to orange.

Chemical data. Microprobe (WDS mode) analyses (11), BeO and Li_2O measured with an X-Series 2 quadrupole ICP-MS, H_2O calculated by stoichiometry from the results of the crystal-structure analysis and confirmed by Raman spectroscopy: FeO 23.62, MnO 5.98, MgO 0.56, CaO 0.41, Al_2O_3 22.11, P_2O_5 30.64, BeO 5.55, Li_2O 0.26, H_2O 11.75, total 100.88 wt.%. Empirical formula: $(Fe^{2+}_{1.51}Mn^{2+}_{0.39}Mg_{0.06}Ca_{0.03})_{\Sigma 1.99}Al_{1.99}(Be_{1.02}Li_{0.08})_{\Sigma 1.10}(P_{0.99}O_4)_2(OH)_6$ (RRUFF Project R140428).The simplified formula requires BeO 5.36, FeO 30.79, Al_2O_3 21.85, P_2O_5 30.42, H_2O 11.58, total 100.00 wt.%.

Crystallography. Orthorhombic, *Cmca*, *a* 7.0087(3), *b* 10.5082(4), *c* 13.1179(5) Å, *V* 966.12(7) Å^3, *Z* 4 (single-crystal); *a* 6.9759(5), *b* 10.4878(2), *c* 13.1956(5) Å, *V* 965.42(6) Å^3, *Z* 4 (powder data), *a:b:c* = 0.667:1:1.258. X-ray powder diffraction data [*d* in Å (*I*) (*hkl)*]: 6.5998 (97) (002), 5.2448 (100) (020), 4.8717 (42) (021), 4.3596 (73) (112), 4.1049 (61) (022), 3.3694 (54) (023), 2.6219 (38) (040), 2.3574 (36) (025).

Name. The mineral is named in honor of Mr. Mark Roger LeFont (b. 1955), in recognition of his contributions to mineralogical sciences and public outreach. The donation of his mineral collection to the University of Arizona Mineral Museum and an endowment for a Professorship in Mineralogy to the Department of Geosciences at the University of Arizona has saved the Museum, and ensured the relevance of academic mineralogical studies in Arizona.

Type material. Cotype samples have been deposited in the collections of the Mineral Museum of the University of Arizona, Tucson, Arizona, USA, catalog number 19802, and the RRUFF Project, deposition number R140428.

Relationship to other species. Lefontite is isomorphous with the childrenite-eosphorite series.

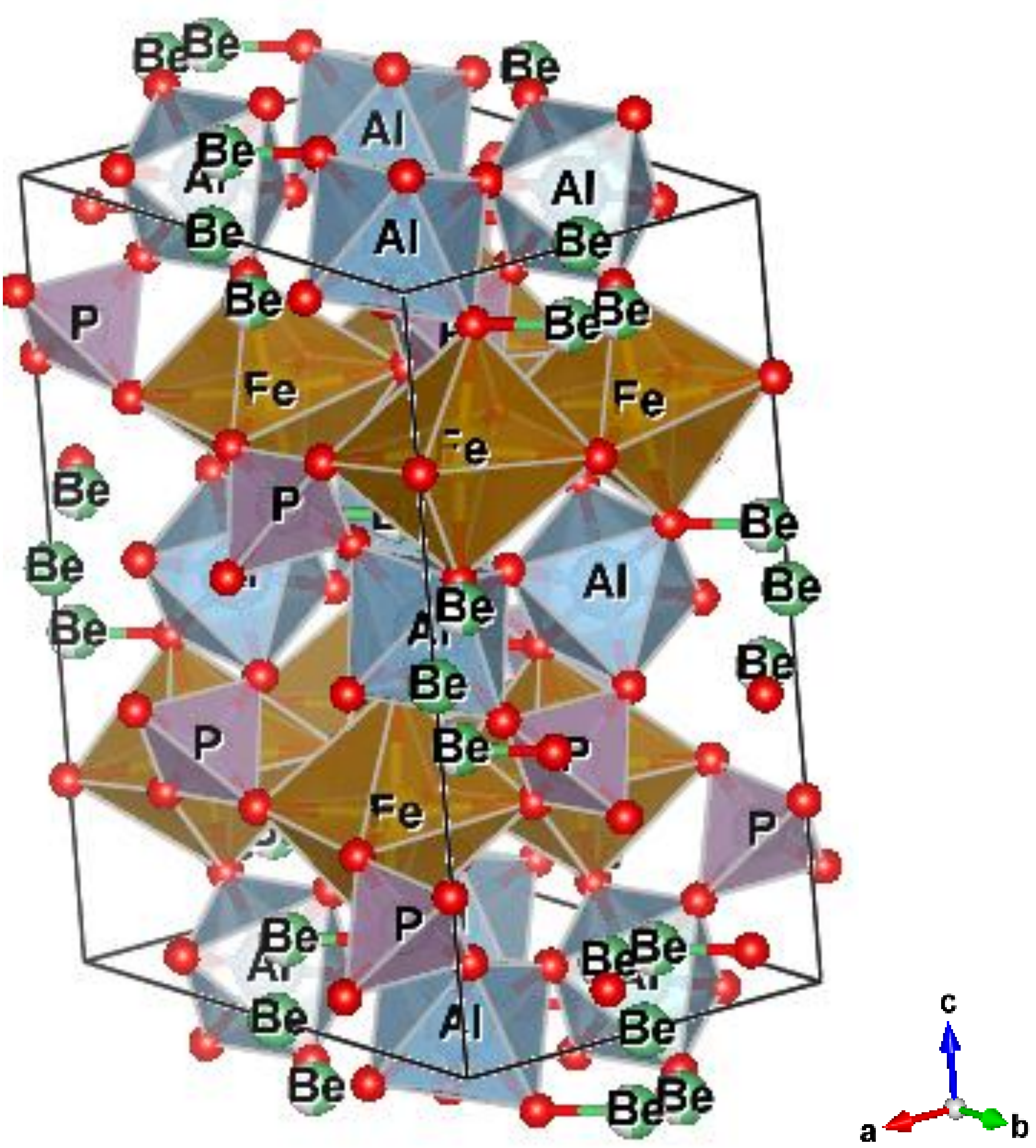

Figure 7.27. View of the crystal structure of lefontite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Yang *et al.* (2015).

Crystal structure. The crystal structure of lefontite is characterized by two types of octahedral chains running parallel to the *a* axis. One is composed of $MO_4(OH)_2$ (M = Fe + Mn) octahedra sharing opposite O-O edges and the other of $AlO_2(OH)_4$ octahedra sharing opposite vertices. The two chains alternate along the *c* axis, sharing OH vertices to form an undulating sheet parallel to (010). Adjacent sheets are held together by (PO_4) tetrahedra, Be atoms and hydrogen bonds, giving rise to a three-dimensional network. The key difference between lefontite and childrenite lies in the chemical substitution of

(Be^{2+} + $2OH^-$) in the former for ($2H_2O$) in the latter. The Be atoms in lefontite are situated in channels parallel to the *a* axis and disordered over two sites. These channels in childrenite and eosphorite are empty. The substitution of (Be^{2+} + $2OH^-$) in lefonite for ($2H_2O$) in childrenite results in marked differences in the unit cell parameters. Specifically, the *a* and *b* dimensions in lefontite are significantly longer than those in childrenite, whereas the *c* dimension is noticeably shorter. The disordering of the Be atoms in lefontite is believed to be responsible for the broadening of its Raman peaks.

See also. Atencioite.

Goyazite

Damour (1884)

$SrAl_3(PO_4)(PO_3OH)(OH)_6$, trigonal

Other names: goyazita, goyasita, goiasita, goiazita, goiaíta, geraesite, geraesita

Goyazite was originally described by Damour (1884) from sands furnished by Prof. A. de Bovet, who worked in a diamond mine at Ribeirão do Inferno, near Diamantina, Minas Gerais (Hussak 1917). Damour (1884), however, stated that the material was from diamond soils of Minas Gerais. In the first chemical analysis, the mineral was described as a basic phosphate of calcium and aluminum. The mineral hamlinite was described at Lord Hill Quarry, Stoneham, Oxford County, Maine, USA, by Hidden and Penfield (1890) and Penfield (1897) as a basic phosphate of strontium and aluminum. The original samples of goyazite studied by Damour, stored in the Muséum national d'Histoire naturelle, Paris, France, were re-studied by Hussak (1906d, 1917), who discovered that strontium was an important constituent, but he didn`t publish complete chemical data. In the first chemical analysis, Damour (1884) confused Sr with Ca. Hussak (1906d, 1917) also studied “hamlinite” from diamond sands from Congonhas range of mountains, Grão Mogol region, north of Diamantina, donated by Gonzaga de Campos, and published complete chemical data for the mineral, which correspond to the goyazite composition. Schaller (1911 and 1917) discredited hamlinite as identical to goyazite.

The following is a combined description of several occurrences since there is no complete data on goyazite from the type occurrence.

Occurrence. In a diamond mine at Ribeirão do Inferno, Congonhas range of mountains, near Diamantina, Minas Gerais (type locality), in diamond sands from Congonhas range of mountains, Grão Mogol region, north of Diamantina, Minas Gerais, and several other Brazilian and world occurrences.

Appearance and physical properties. Forms: small rhombohedral (pseudo-cubic) $\{10\bar{1}2\}$ or tabular {0001} crystals. Rhombohedral faces often striated horizontally. Also, as pebbles and rounded grains. Color: colorless, pink, honey-yellow. Transparent. Luster: greasy to resinous; pearly on {0001}. Cleavage: {0001} perfect. Hardness (Mohs): 4½ to 5. Density: 3.220 g/cm^3 (meas.), 3.244 g/cm^3 (calc.). Slowly soluble in acids.

Optical properties. Uniaxial (+), ω 1.629, ε 1.639. Sometimes anomalously biaxial.

Chemical data. Wet analyses: SrO 21.63, Al_2O_3 33.01, P_2O_5 29.72, H_2O 14.01, total 98.37 wt.%. Empirical formula: $Sr_{0.97}Al_{3.02}(PO_4)(P_{0.95}O_3OH_{1.25})(OH)_6$. (“hamlinite“ from Congonhas range of mountains, Grão Mogol region, North of Diamantina, Minas Gerais, Hussak 1917). The ideal formula requires SrO 22.45, Al_2O_3 33.13, P_2O_5 30.75, H_2O 13.66, total 100,00 wt.%.

Crystallography. Trigonal, $R\bar{3}m$, a 7.0218, c 16.597 Å, V 708.69 Å^3, Z 3, c:a = 2.3636. X-ray powder diffraction data [d in Å (I) (hkl)]: 5.704 (65) (101), 3.511 (40) (110), 2.991 (13) (021), 2.965 (100) (113), 2.765 (20) (006), 2.209 (45) (107), 1.903 (20) (033), 1.756 (12) (220).

Name. In honor of the state of Goiás (at that time, Goyaz). According to Hussak (1917), as the mineral is from the state of Minas Gerais and unknown in the state of Goiás, a better name would be “geraesite”. But later the mineral was described in occurrences in the state of Goiás. See the other meaning attributed to geraesite.

Type material. The original samples studied by Damour were stored in the Muséum national d'Histoire naturelle, Paris, France, but they are no longer there (Cristiano Ferraris, personal communication, 2020). Were they fully handed over to Hussak? According to Lapaire (2020), there is no data on the type specimen.

Relationship to other species. Plumbogummite group, alunite supergroup (Bayliss *et al.* 2010).

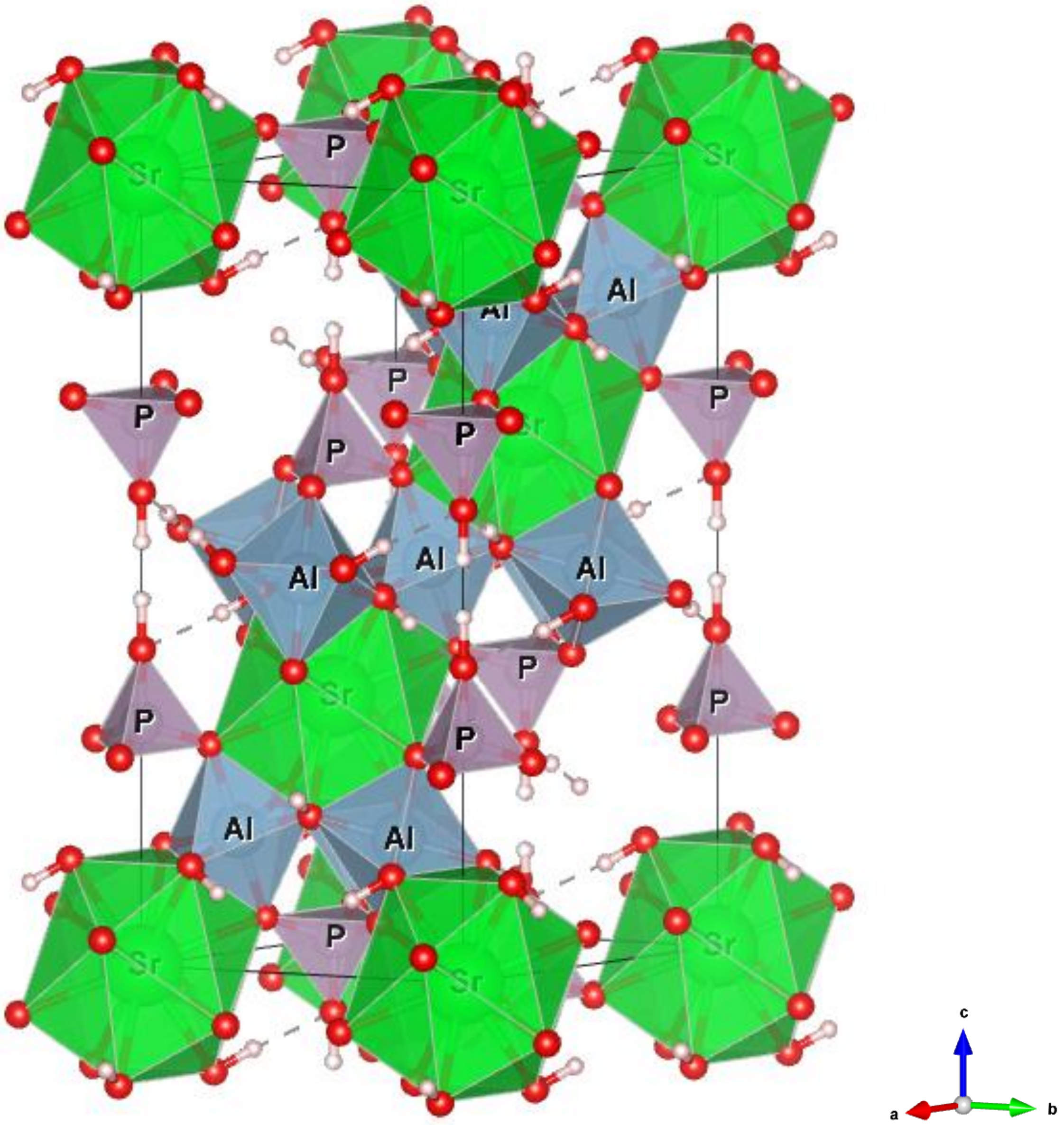

Figure 7.28. View of the crystal structure of goyazite (from Palermo mine, North Groton, New Hampshire, USA), drawn using VESTA 3 (Momma and Izumi 2011). Data from Kato (1987).

Crystal structure. Refined by Kato (1987), using a crystal from the Palermo mine, North Groton, New Hampshire, USA. Sheets made up of corner-sharing Al octahedra linked into trigonal and hexagonal rings. Sr cations occupy the distorted cavities inside the 12-coordinated rings, close to four O^{2-} and four OH^{-} within the ring.

Synthetic. Schwab *et al*. (1990a) obtained synthetic goyazite (pure end member) from freshly precipitated $Al(OH)_3$ (by NH_3), $Sr(OH)_2$, and H_3PO_4, which were transferred into a teflon vessel and kept for at least three month in an autoclave at 200°C and 15 bar.

See also. Geraesite, gorceixite, and florencite-(Ce)

Florencite-(Ce)

Hussak and Prior (1900)

$CeAl_3(PO_4)_2(OH)_6$, trigonal

Other names: florencita-(Ce), florencite, florencita

Figure 7.29. Type specimen of florencite-(Ce) from Mata dos Crioulos, Santo Antonio do Itambé, Minas Gerais. Muséum national d'Histoire naturelle, Paris, France. The label is 5 cm long. Donator: E. Hussak. Photo: Cristiano Ferraris.

This mineral was originally described by Hussak and Prior (1900) from three Brazilian occurrences. A few lines communicating the discovery of the mineral had already been published in the previous year (Hussak and Prior 1899). Lefebvre and Gasparrini (1980) published chemical data, and for the first time distinguishing the different rare-earth elements. They also provided new X-ray powder diffraction data for florencite-(Ce) from Mata dos Crioulos, Santo Antonio do Itambé (quoted as Diamantina) (specimen M11571, Royal Ontario Museum, Canada).

Occurrence. (1) Fazenda Três Cruzes, Tripuí, Ouro Preto; (2) Mata dos Crioulos, Santo Antonio do Itambé; and (3) Morro do Caxambu, a locality known for its yellow topaz, near Tripuí, Ouro Preto; all in Minas Gerais. At the first occurrence, the mineral occurs as well-developed crystals up to 0.5 cm in length associated with monazite, xenotime-(Y), hydroxycalcioromeite, and derbylite. In the second occurrence, larger crystals and rounded grains were found. This was the material used for the original chemical analyses, where the rare-earth elements were not differentiated. In the third occurrence, florencite-(Ce) occurs in relatively large amount as a microscopic accessory of red mica schists, and in quartz lenses with topaz, kaolinite, and hematite. Also, known from several other Brazilian and world occurrences.

Appearance and physical properties. Forms: small rhombohedral crystals, either $\{02\bar{2}1\}$ predominant, or $\{10\bar{1}1\}$ and pseudo-cubic in appearance. Color: clear pale yellow. Transparent. Luster: greasy to resinous. Cleavage: {0001} good, $\{11\bar{2}0\}$ in traces. Fracture: splintery to subconchoidal. Hardness (Mohs): 5 to 6. Density: 3.586 g/cm^3 (meas.), 3.731 g/cm^3 (calc.). Partly soluble in HCl.

Optical properties. In transmitted light, colorless. Uniaxial (+), ω 1.680, ε 1.685.

Chemical data. Microprobe analyses: La_2O_3 9.0, Ce_2O_3 13.4, Nd_2O_3 3.7, Sm_2O_3 1.3, Gd_2O_3 1.0, CaO 0.4, MgO 2.3, Al_2O_3 32.0, P_2O_5 28.6, SiO_2 0.5, H_2O 11.65 (calc.), total 103.85 wt.%. Empirical formula: $(Ce_{0.40}Mg_{0.28}La_{0.27}Nd_{0.11}Sm_{0.04}Gd_{0.03}Ca_{0.03})_{\Sigma 1.16}Al_{3.06}(P_{1.96}Si_{0.04})_{\Sigma 2.00}O_8(OH)_{6.31}$. The sample from Santo Antonio do Itambé is zoned between extremes of composition in which Ce and La are concentrated in similar amounts (~ 14 wt.%) and in which Ce predominates over La (analysis above) (Lefebvre and Gasparrini 1980). The ideal formula requires Ce_2O_3 31.99, Al_2O_3 29.81, P_2O_5 27.67, H_2O 10.54, total 100.00 wt.%.

Crystallography. Trigonal, $R\bar{3}m$, *a* 6.96, *c* 16.33 Å, *V* 685.07 Å^3, *Z* 3, *c:a* = 2.3463.

X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 5.63 (90) (101), 3.48 (70) (110), 2.93 (100) (113), 2.21 (70) (205), 2.16 (80) (107), 1.885 (80) (303), 1.741 (70) (220), 1.428 (60) (0 2 10) (Mata dos Crioulos, Santo Antonio do Itambé).

Name. The name honors the mineralogist Dr. Guilherme (William) Florence (1864-1942), of the Comissão Geográfica e Geológica de São Paulo.

Type material. U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA (type, R052090, donator E. Hussak, thru Roeblin collection, 1927), Muséum national d'Histoire naturelle, Paris, France (type, 101.320, donator E. Hussak) and The Natural History Museu, London, England (type).

Relationship to other species. Plumbogummite group, alunite supergroup (Bayliss *et al.* 2010), isostructural with goyazite and gorceixite.

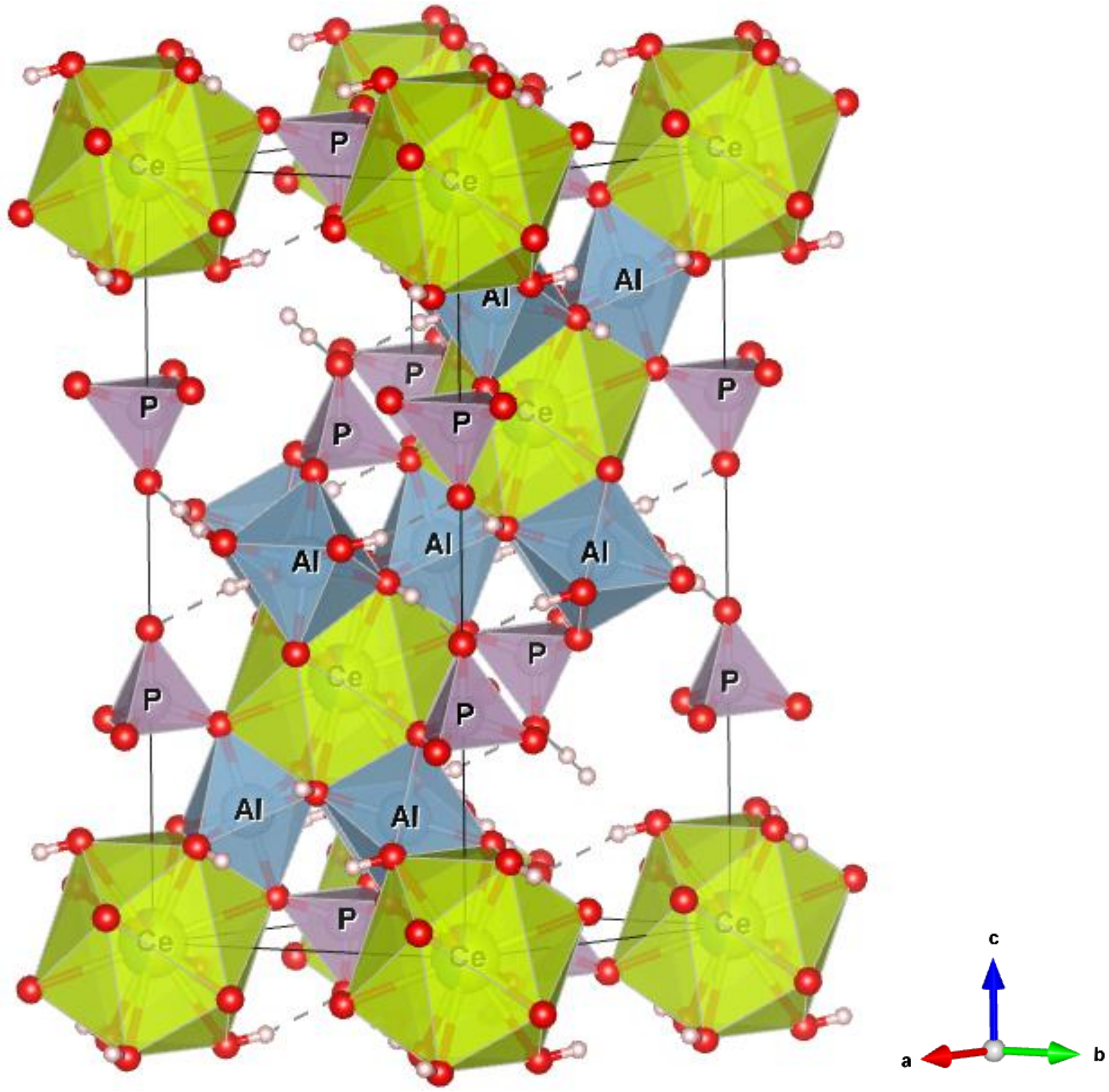

Figure 7.30. View of the crystal structure of florencite-(Ce) (from Backbone Ranges of Mackenzie Mountains, Northwest Territories, Canada), drawn using VESTA 3 (Momma and Izumi 2011). Data from Kato (1990).

Crystal structure. Kato (1990), using a crystal from Backbone Ranges, Mackenzie Mountains, Northwest Territories, Canada. Sheets made up of corner-sharing Al octahedra linked into trigonal and hexagonal rings. Ce cations occupy the distorted cavities inside the 12-coordinated rings, close to four O^{2-} and four OH^{-} within the ring.

Synthetic. Schwab *et al.* (1990b) obtained synthetic florencite-(Ce) (pure end member) from freshly precipitated $Al(OH)_3$ (by NH_3), $Ce(OH)_3$, and H_3PO_4, which were transferred into a teflon vessel and kept for at least three month in an autoclave at 200°C and 15 bar.

See also. Florencite-(Y), goyazite, gorceixite. hydroxycalcioromeite, tripuhyite, and derbylite.

Florencite-(Y)

Chaves (2014)
$YAl_3(PO_4)_2(OH)_6$, trigonal
(probably a valid species)
Other names: florencita-(Y)

Based on electron microprobe analyses, there is an indication of the occurrence of florencite-(Y) at Bom Sucesso, Minas Gerais (Chaves 2014). This possible mineral species was found as a 20 × 50 µm subhedral crystal with churchite-(Y) in the borders, included in microcline, in a potassic peraluminous foliated granitoid. Microprobe data (2): Y_2O_3 10.35, La_2O_3 5.60, Ce_2O_3 0.96, Nd_2O_3 7.20, Pr_2O_3 0.59, Sm_2O_3 1.02, Dy_2O_3 1.65, Gd_2O_3 1.18, PbO 0.38, ThO_2 0.04, UO_2 0.04, CaO 0.97, FeO 0.24, Al_2O_3 30.81, P_2O_5 27.41, SiO_2 0.87, H_2O (calc.) 11.0, Total 100.32 wt.%. Empirical formula: $(Y_{0.402}Nd_{0.213}La_{0.171}Ca_{0.086}Dy_{0.044}Gd_{0.032}Ce_{0.029}Sm_{0.029}Pr_{0.018}Fe_{0.017}Pb_{0.008}Th_{0.001}U_{0.001})_{\Sigma 1.051}Al_{3.002}(P_{0.959}Si_{0.039}O_4)_2(OH)_{6.073}$.

See also. Florencite-(Ce).

Gorceixite

Hussak (1906d)

$BaAl_3(PO_4)(PO_3OH)(OH)_6$, trigonal or monoclinic

Other names: gorceixita, gorceixcita

Figure 7.31. Type specimen of gorceixite from the Veríssimo river, Goiás. Muséum national d'Histoire naturelle, Paris, France. The label is 5 cm long. Donator: E. Hussak. Photo: Cristiano Ferraris.

Figure 7.32. Gorceixite from the Douradinho river, Coromandel, Minas Gerais. Dimensions: 2.7 × 1.3 × 1.2 cm. Specimen and photo: Rodrigo Guerra.

GORCEIXITA

Grupo Mineral: wavellita-lazulita

Fórm. Química: **BaAl3(PO4)(PO3OH)(OH)6**

Doador: Djalma Guimarães

Procedência: Datas

Diamantina MG

Figure 7.33. Gorceixite from Datas, Minas Gerais. Largest piece: 1.5 × 1.7 cm. Museu de Ciências da Terra, Rio de Janeiro. Cornejo and Bartorelli (2020).

See also Figure 7.37.

Gorceixite is a plumbogummite-group mineral whose economical interest is growing while the high-quality phosphate deposits become scarce. The crystal structure investigation of plumbogummite-group minerals can be useful as a subsidy for the development of processing techniques for low-grade phosphate ores. These minerals are tested as a substitute for apatite in fertilizers production. Furthermore, gorceixite presents an open structure that allows for metallic ions substitution, similar to the zeolite structure, and could be promising for use in environmental applications, as for the elimination of mercury from contaminated environments (Ferrari *et al.* 2007).

Occurrence. The occurrence of gorceixite was quoted by Hussak (1906d) in several localities, without the definition of a type occurrence:

1. in the area of Diamantina, at Curralinho (now Extração), Datas etc.;
2. in Abaeté river, Minas Gerais, very common here;
3. Patrocínio de Sapucaí and Canoas river, São Paulo state;

4, Bagagem and Douradinho rivers, Minas Gerais, very common;

5. in the south of Goiás, Paranaíba and Veríssimo rivers.

Hussak (1917) added the Jequitinhonha river.

This information about the localities is very vague. For instance, Hussak (1906d) mentions the occurrence of gorceixite in the Abaeté river. This river runs through the municipalities of São Gotardo, Rio Paranaíba, Matutina, Arapuá, Tiros, Carmo do Paranaíba, Patos de Minas, Varjão de Minas, and São Gonçalo do Abaeté. In the Mindat database, it is said that the municipality is São Gonçalo do Abaeté. Hussak (1906d) mentions the occurrence of gorceixite in the Veríssimo river. This river runs through the municipalities of Anhanguera, Campo Alegre de Goiás, Catalão, Corumbaíba, Cumari, Goiandira, Ipameri, and Nova Aurora. In the Mindat database, it is said that the municipality is Ipameri. I don't know where the definitions of these municipalities originated. The Mindat database quotes Palache *et al.* (1951), but municipalities are not mentioned in that publication.

Gorceixite is from one of the diamond producing area. The diamond extraction areas on the Veríssimo River are concentrated in the municipalities of Ipameri and Catalão. Possibly the source of the gorceixite for the Veríssimo river is the carbonatite of Catalão, from which gorceixite was chemically and structurally studied (see below). Lapaire (2020) quotes the type locality as Ouro Preto, but this is incorrect. The type specimen stored at the Muséum national d'Histoire naturelle, Paris, France, is from the

Veríssimo river, in Goiás. Gorceixite also occurs in several other Brazilian and world occurrences.

The following description is based on several occurrences, as there are no complete data for the localities cited by Hussak (1906d).

Appearance and physical properties. Habit: grains and pebbles, which are in part microcrystalline (“favas”). Color: brown to salmon pink, sometimes mottled. Transparent. Luster: vitreous to dull. Fracture: porcelaineous. Hardness (Mohs): 6. Density: 3.04 to 3.19 g/cm^3 (meas.), 3.41 g/cm^3 (calc.).

Optical properties. In transmitted light, colorless. Uniaxial (+), ω 1.618(2) to 1.623(2), ε 1.615(2) to 1.620(2).

Chemical data. Hussak (1906d) published two wet analyses for gorceixite from Abaeté river, Minas Gerais: (I) BaO 15.42, CaO 3.55, Al_2O_3 35.00, Fe_2O_3 4.10, CeO 1.55, P_2O_5 22.74, SiO_2 1.55,TiO_2 0.67, H_2O 14.62, total 99.20 wt.%. (II) BaO 15.30, CaO 2.24, Al_2O_3 35.20, Fe_2O_3 1.67, CeO 2.35, P_2O_5 21.47, SiO_2 6.50,TiO_2 0.35, H_2O 14.73, total 100.21 wt.%. These chemical data do not allow the calculation of a reasonable formula for the mineral.

Microprobe (WDS) analyses, H_2O by difference: CaO 2.03, SrO 1.97, BaO 22.77, La_2O_3 0.03, Ce_2O_3 0.17, Al_2O_3 27.18, Fe_2O_3 3.90, SiO_2 0.37, P_2O_5 26.97, H_2O (12.61), total (100.00) wt.%. Empirical formula: $(Ba_{0.76}Ca_{0.19}Sr_{0.10}Ce_{0.01})_{\Sigma1.06}(Al_{2.74}Fe^{3+}_{0.25})_{\Sigma2.99}(P_{0.96}Si_{0.03})_{\Sigma0.99}O_4)(PO_3OH)(OH)_{6.02}$ (sample from Catalão I mine, Catalão, Goiás, Ferrari *et al.* 2007).

The ideal formula requires: BaO 30.00, Al_2O_3 29.91, P_2O_5 27.76, H_2O 12.33, total 100.00 wt.%.

Crystallography. The crystal structure of gorceixite was interpreted as trigonal $R3m$ by Radoslavich and Slade (1980) and Ferrari *et al.* (2007), as trigonal $R\bar{3}m$ by Dzikowski *et al.* (2006), and as monoclinic *Cm* by Radoslavich (1982), Ferrari *et al.* (2007), and RRUFF Project R060158).

Trigonal, $R3m$, a 7.0791(3), c 17.089(1) Å, V 741.68(7) Å^3, Z 3, $c:a$ = 2.4140 (Rietveld refinement, Catalão I mine, Catalão, Goiás, Ferrari *et al.* 2007).

Trigonal, $R\bar{3}m$, a 7.0538(3), c 17.2746(6) Å, V 744.4(2) Å^3, Z 3, $c:a$ = 2.4490 (single-crystal, Rapid Creek area, Yukon Territory, Canada, Dzikowski *et al.* 2006).

Monoclínic, *Cm*, a 12.195(8), b 7.040(5), c 7.055(5) Å, β 125.19(5)°, V 495 Å^3, Z = 2, $a:b:c$ = 1.7322:1:1.0021 (Rietveld refinement, Catalão I mine, Catalão, Goiás, Ferrari *et* *al.* 2007).

X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 5.678 (90) (101), 3.490 (56) (110, 104), 2.9666 (100) (113), 2.2684 (21) (205, 107), 2.2099 (26) (122, 116), 1.9013 (31) (303, 125), 1.7493 (29) (220, 208) (indexed as *Cm*, Santo Inácio, Paraná, Coutinho *et al.* 1999).

Name. The name honors the professor at Ecole des Mines in Paris, and founder and first director of the Escola de Minas de Ouro Preto, Minas Gerais, geologist Claude Henri "Henrique" Gorceix (1842-1919).

Type material. Muséum national d'Histoire naturelle, Paris, France, 108.104(2), 108.105(2) (type), from Veríssimo river, Goiás. Lapaire (2020) and the Mindat database erroneously quoted the type locality as Ouro Preto, Minas Gerais.

Relationship to other species. Plumbogummite group, alunite supergroup (Bayliss *et al.* 2010).

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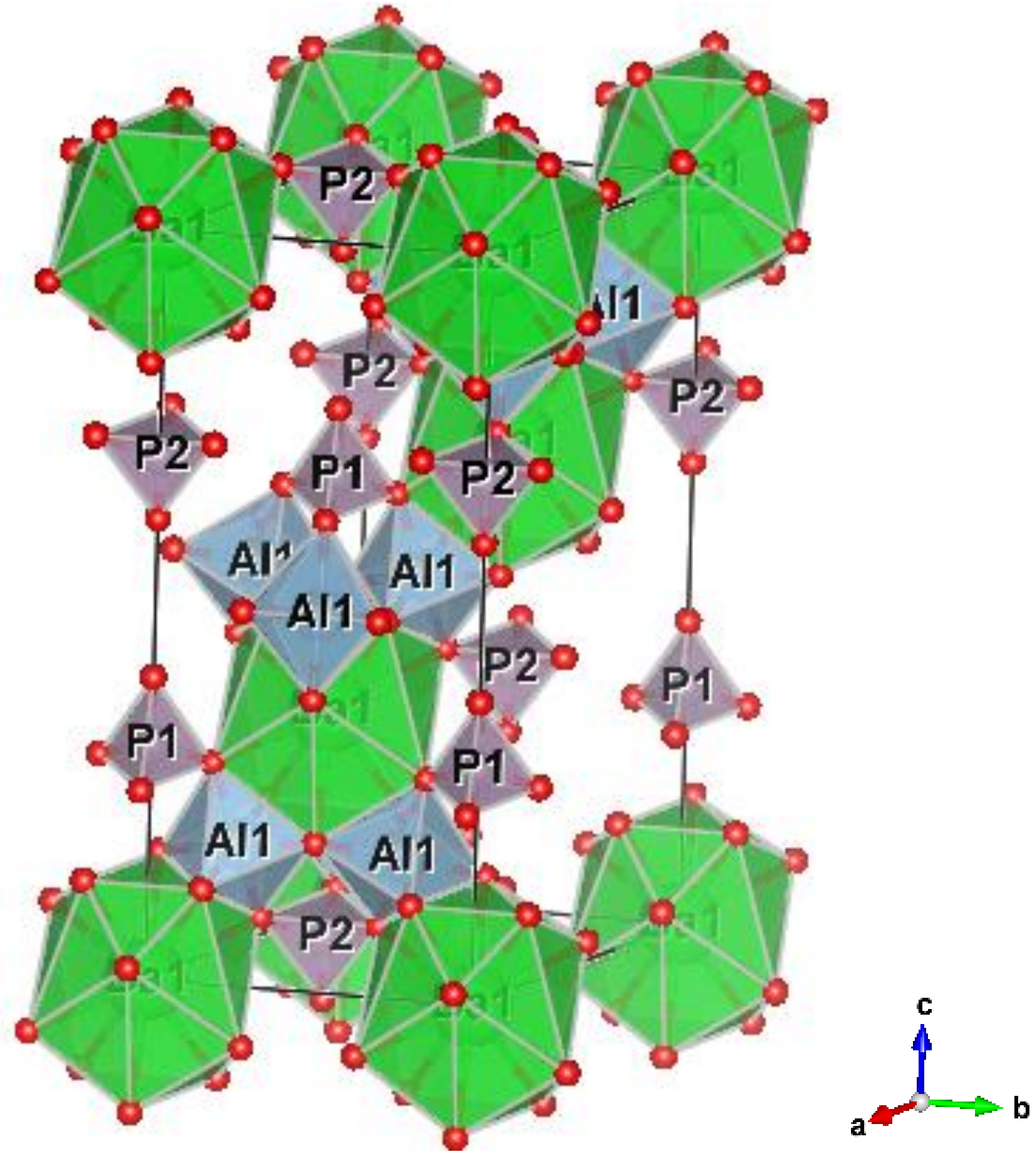

Figure 7.34. View of the crystal structure of gorceixite (*R*3*m*, from Catalão I mine, Catalão, Goiás), drawn using VESTA 3 (Momma and Izumi 2011). Data from Ferrari *et al.* (2007).

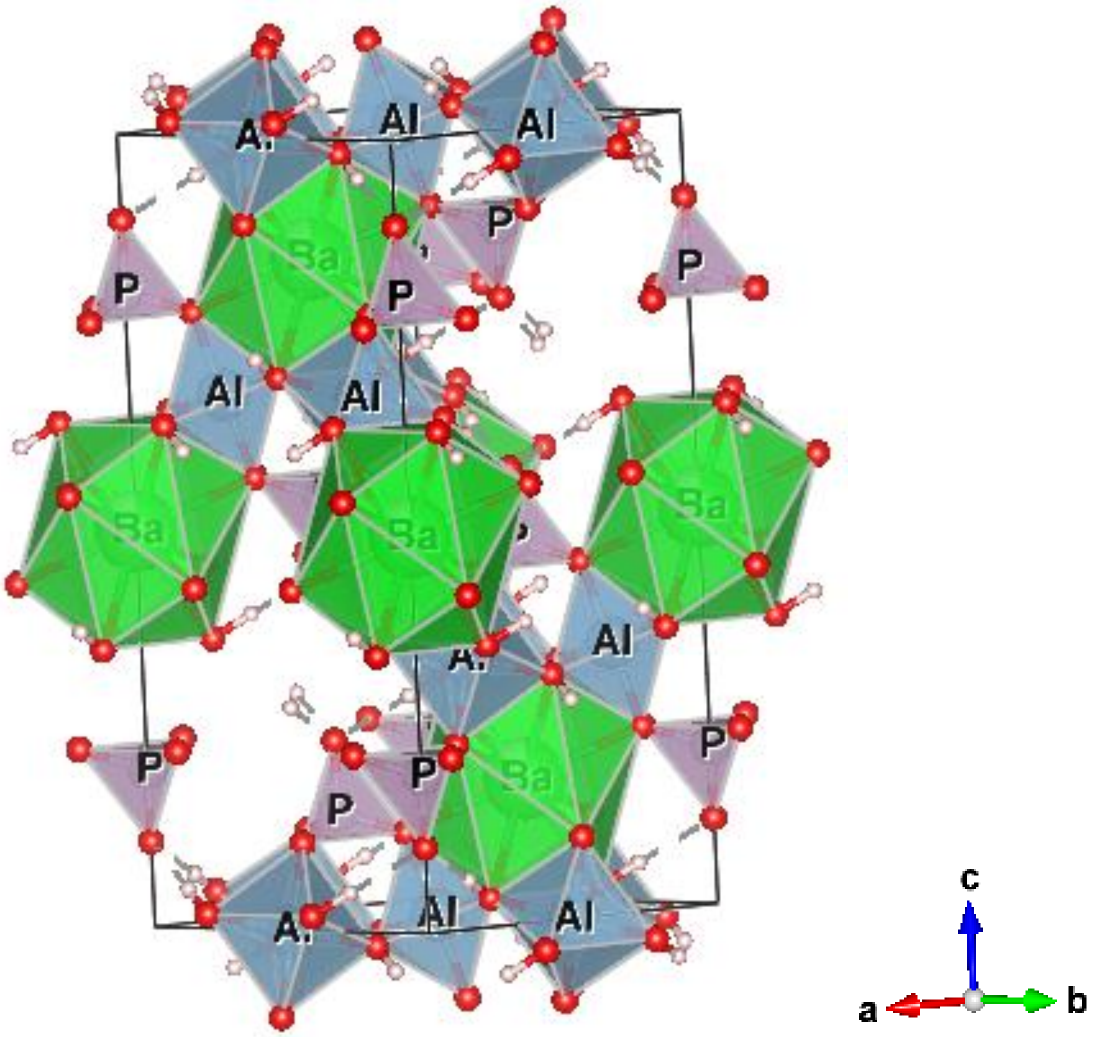

Figure 7.35. View of the crystal structure of gorceixite ($R\bar{3}m$, from Rapid Creek area, Yukon Territory, Canada), drawn using VESTA 3 (Momma and Izumi 2011). Data from Dzikowski *et al.* (2006).

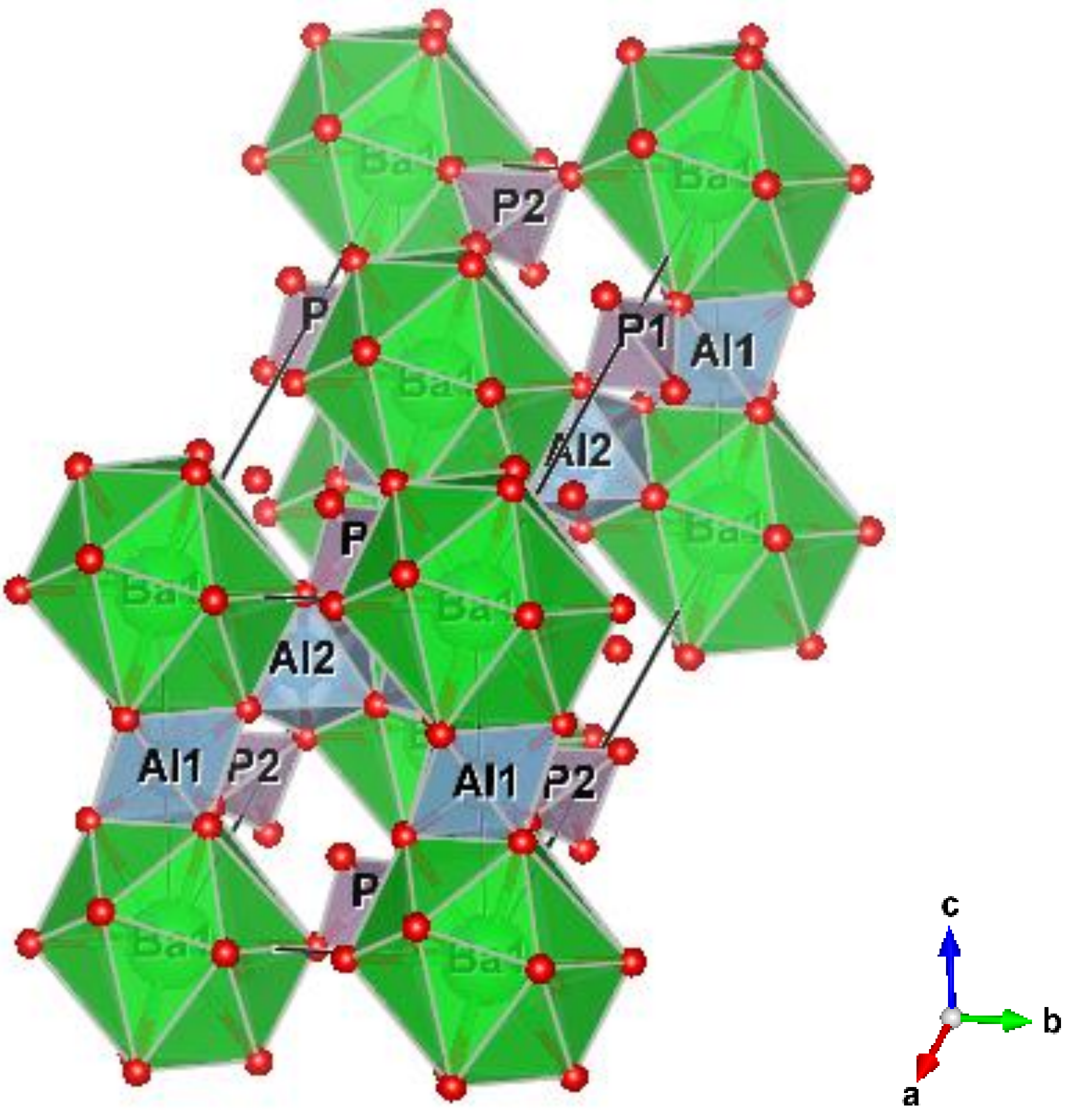

Figure 7.36. View of the crystal structure of gorceixite (*Cm*, from Catalão I mine, Catalão, Goiás), drawn using VESTA 3 (Momma and Izumi 2011). Data from Ferrari *et al.* (2007).

Crystal structure. Sheets made up of corner-sharing Al octahedra linked into trigonal and hexagonal rings. Ba cations occupy the distorted cavities inside the 12-coordinated rings, close to four O^{2-} and four OH^{-} within the ring.

Synthetic. Schwab *et al.* (1990a) obtained synthetic gorceixite (pure end member) from freshly precipitated $Al(OH)_3$ (by NH_3), $Ba(OH)_2$, and H_3PO_4, which were transferred into a teflon vessel and kept for at least three month in an autoclave at 200°C and 15 bar.

See also. Ferrazite, goyazite, florencite-(Ce), geraesite, and barium-hamlinite.

Ferrazite

Lee and Moraes (1919)

(= gorceixite)

Other names: ferrazita, camposite, camposita

Figure 7.37. Gorceixite ("ferrazite") from Diamantina, Minas Gerais. Specimen 41581/3, Museu de Geociências, Universidade de São Paulo. Photo: Thales Trigo.

The petrographer Dr. Jorge Belmiro de Araujo Ferraz (1883-1926) submitted some pebbles ("favas") for chemical analysis from the late Eugen Hussak's collection, bearing Hussak's own label "Pb-Al hydrophost. D. 3.095. Neu!". The pebbles, found in diamond washings, were discoid in shape, dark yellowish-white, resembling old ivory, and showed a granular structure in thin section. The results of the analysis were published by Lee and

Moraes (1919) and Lee and Moraes-Rego (1920). The provenance of the samples was not given by these authors but Ferraz (1928) and Palache *et al.* (1951) gave the locality as Diamantina, Minas Gerais.

Hussak died when he was studying a mineral to be named camposite, in honor of Dr. Luiz Fellipe Gonzaga de Campos (1856-1925) [the same of the mineral gonzagaite]. It is likely that ferrazite is the mineral for which Hussak, as revealed to his family and friends, booked the never-used name camposite (Leonardos 1955, Franco 1981).

From the results of the preliminary analysis it appeared to Lee and Moraes (1919) that, in addition to Pb, Ba was also present, prompting them to carry out a complete analysis, which gave the following results: BaO 8.87, CaO traces, PbO 45.63, Al_2O_3 3.48, SiO_2 2.44, P_2O_5 26.24, H_2O 14.20, total 100.86 wt.%. After deducting silica and alumina, possibly derived from kaolin and wavellite, the formula was given as $3(Ba,Pb)O \cdot 2P_2O_5 \cdot 8H_2O$. The density of the pebbles varied between 3.0 and 3.3 g/cm^3. The mineral was named ferrazite after Dr. Jorge Belmiro de Araújo Ferraz (1883-1926), petrographer on the Geological and Mineralogical Survey of Brazil, of which for a time he acted as director. Dr. Araujo Ferraz had an extensive private collection, and he was responsible for the display of Brazilian minerals at the Torino exhibition in 1911 and at the Brazilian centenary exhibition in 1922 (Spencer 1930). He translated and edited E. Hussak's work, “Os satellites do diamante” (Hussak 1917).

Atencio and Clark (1996) obtained a sample, with the same characteristics as above, from Dr. J.B.A. Ferraz's collection (now in the Museu de Geociências, Universidade de São Paulo) labeled "Ferrazita. Diamantina, Minas Gerais" (Sample 41.5.8.1/3 - 625A/1). The sample was identified by X-ray powder diffraction and electron microprobe chemical data as gorceixite, $BaAl_3(PO_4)(PO_3OH)(OH)_6$.

X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 5.775 (99) (101), 3.527 (68) (110, 104), 3.003 (100) (113), 2.875 (22) (006, 202), 2.286 (38) (205, 107), 2.227 (19) (122, 116), 1.915 (24) (303, 125).

Microprobe (WDS) analyses (10), H_2O by difference: Na_2O 0.06, K_2O 0.10, CaO 0.76, SrO 1.81, BaO 23.52, PbO 0.53, Al_2O_3 31.25, Fe_2O_3 3.76, SiO_2 0.95, P_2O_5 26.19, H_2O (11.07), total (100.00) wt.%. Empirical formula:

$(Ba_{0.78}Sr_{0.09}Ca_{0.07}Pb_{0.01}K_{0.01}Na_{0.01})_{\Sigma 0.97}(Al_{3.12}Fe^{3+}_{0.24})_{\Sigma 3.36}(P_{0.88}Si_{0.08})_{\Sigma 0.96}O_4)(PO_3OH)$ $(OH)_{5.26}$

The density measured by Hussak and by Lee and Moraes agrees with that for gorceixite [Density 3.04 to 3.19 g/cm^3 (meas.), 3.41 g/cm^3 (calc.)]. A mean index of refraction (Atencio and Clark 1996) is between 1.620 and 1.625, as in gorceixite.

Atencio and Clark (1996) also carried out an electron microprobe and X-ray diffraction investigation of the type specimen of ferrazite stored in The Natural History Museum, London, England (B.M. 1920,131). The probe study was carried out on an energy-dispersive Hitachi instrument. The pebble was examined in an unpolished state, so the results should be regarded as semi-quantitative. They are PbO 1.36, BaO 17.17, P_2O_5 19.09, FeO 0.52, ZnO 0.76, Al_2O_3 19.18 wt.%. The Debye-Scherrer X-ray powder diffraction pattern was taken at the same spot on the sample (film no. X10211) and is a good match for gorceixite.

Lee and Moraes (1919) did not state their chemical analytical methods but they probably analyzed Pb and Ba by gravimetry with precipitation of $PbSO_4$ and $BaSO_4$, thus confusing Ba with Pb.

In conclusion, ferrazite is identical to gorceixite. The name gorceixite (Hussak 1906d) was published before ferrazite and therefore has historical priority. The nomenclature proposal (number 95-F) was approved by CNMMN - IMA.

See also. Gorceixite, gonzagaite, geraesite, and barium-hamlinite.

Geraesite

Farrington (1912)

(= impure gorceixite)

Other names: geraesita

As a result of a chemical analysis of a pebble (“fava”) from the diamond washings from Minas Gerais, Farrington (1912), in a preliminary abstract proposed the name geraesite for a “hydrous barium aluminum phosphate more acidic that gorceixite”. The name honors Minas Gerais (at that time, “Minas Geraes”). Minasite and minasgeraisite-(Y) also honor Minas Gerais. In the complete paper (Farrington 1916), the name geraesite does not appear, the material being probably impure gorceixite, $BaAl_3(PO_4)(PO_3OH)(OH)_6$ trigonal. The name geraesite was also suggested for goyazite.

See also. Minasite, minasgeraisite-(Y), gorceixite, goyazite, barium-hamlinite and ferrazite

Barium-hamlinite

Farrington (1916)

(= impure gorceixite)

Other names: bario-hamlinita, Barium-Hamlinit

In the same paper where he introduced the name paredrite, Farrington (1916) analyzed three phosphate “favas”, the first gorceixite, the second a mixture, and the third, with the composition $2BaO{\cdot}4Al_2O_3{\cdot}3P_2O_5{\cdot}11H_2O$. For the latter, he suggested “hamlinite with barium replacing strontium” (hamlinite = goyazite). In the German abstracts of this paper (Chem. Zentralblatt, 1918, pt. I, p. 858; Fortsch. Min. Krist. Petr., 1920, v. 6, p. 68), the name “Barium-Hamlinit” was used. Like geraesite, it is probably impure gorceixite, $BaAl_3(PO_4)(PO_3OH)(OH)_6$.

See also. Ferrazite, geraesite, paredrite, goyazite, and gorceixite.

Unnamed calcium phosphate of Guimarães (1934)

(apatite and crandallite ?)

Guimarães (1934) described a new mineral associated with quartz, chlorite, muscovite, and hematite, in gray nodules in the phyllite of Damásio, Diamantina, Minas Gerais. The Damásio diamond mine is located near the village of Sopa, west of the road that connects to the village of São João da Chapada. The mine preserves a large volume of lithified metaconglomerate, forming large walls. The hematite phyllite emerges to the west in the form of vertical lenses (Bezerra Neto 2016). Chemical composition is: MgO 5.92, CaO 41.70, Al_2O_3 15.15, P_2O_5 30.33, Cl 0.22, H_2O 6.67, oxygen equivalent –0.05, total 99.94 wt.%. Empirical formula: $(Ca_{3.48}Mg_{0.69})_{\Sigma 4.17}Al_{1.39}(PO_4)_2O_{1.51}(OH)_{3.46}Cl_{0.03}$. The mineral forms prisms with about 0.5 mm. It is hexagonal, uniaxial negative with ε 1.628 and ω 1.633 (for *D* Fraunhofer wavelength, 5893Å). According to Guimarães (1934), *"dennisonite is an alteration product by hydration of the described mineral"*. Davisonite was originally named dennisonite by Larsen and Shannon (1930) as $2CaO{\cdot}Na_2O{\cdot}6Al_2O_3{\cdot}4P_2O_5{\cdot}17H_2O$, but the naming was in error and was later corrected to davisonite (Palache *et al.* 1951). Davisonite was discredited by Dunn and Francis (1986) as a mixture of apatite and crandallite. These authors erroneously understood that Guimarães had identified his mineral as dennisonite (dennisonite is an alteration product of his mineral) and quoted: *"A purported davisonite from Brazil was reported by Guimarães (1934), but its chemical composition is only* slightly *similar to that of davisonite (after deduction of 28.56% insoluble residues). Because the indices of refraction for this material are not similar to those reported for davisonite* (ω 1.601 and ε 1.591) *and because the description of davisonite does not permit its facile differentiation from carbonate-fluorapatite* (= fluorapatite)*, this Brazilian 'occurrence' can reasonably be dismissed as a false report."*

Brazilianite

Pough and Henderson (1945a, b, c, 1946)

$NaAl_3(PO_4)_2(OH)_4$, monoclinic

Other names: brazilianita, brasilianite, brasilianita

Figure 7.38. Brazilianite from Córrego Frio granitic pegmatite, Linópolis, Divino das Laranjeiras, Minas Gerais. Largest dimension of the crystal: 6 cm. Specimen: Museu de Geociências, Universidade de São Paulo. Photo: Thales Trigo.

Brazilianite was described by Pough and Henderson (1945a, b, c, and 1946), and the correct location of the outcrop was supplied by Godoy (1945). Some additional contributions were made by Tavora Filho (1945 and 1946), Hurlbut and Weichel (1946) and Franco and Loewenstein (1946). The second world occurrence of brazilianite was described by Frondel and Lindberg (1948), in the Palermo pegmatite, North Groton, Grafton Co., New

Hampshire, USA. In that work, the authors presented new data for the Brazilian brazilianite.

A detailed description regarding the type occurrence, several other brazilianite occurrences in the vicinity of the Córrego Frio mine, and the history of the discovery of this mineral was given by Cassedanne (1983).

Occurrence. Córrego Frio granitic pegmatite, Linópolis district, Divino das Laranjeiras township, Minas Gerais, which is also the type locality for scorzalite and souzalite. The minerals associated with brazilianite in the type occurrence are albite, arsenopyrite, beraunite, childrenite, dufrenite, fluorapatite, frondelite, garnet, jahnsite, microcline, muscovite, quartz, a roscherite-group mineral, sabugalite, scorzalite, souzalite, strunzite, tapiolite, tourmaline, uraninite, wyllieite, and zircon (Cassedanne 1983). Several other Brazilian and world occurrences.

Appearance and physical properties. Habit: nearly equant to short prismatic [001] crystals, with the prism zone striated parallel to [001]; also elongated on [100]. Up to 20 cm. Also, globular with a radial, fibrous structure. Color: chartreuse yellow, colorless, pale yellowish to yellowish-green. Translucent to transparent. Luster: vitreous. Streak: white. Hardness (Mohs): 5½. Tenacity: brittle. Cleavage: {010} good. Fracture: conchoidal. Density: 2.970 g/cm^3 (meas.), 2.993 g/cm^3 (calc.). Insoluble in HCl.

Optical properties. Biaxial (+), α 1.602(1), β 1.609(1), γ 1.621(1), 2V 75.0° (calc.). $Y = b$. $X \wedge c = -20°$. Absorption $Z > Y > X$. Dispersion: $r < v$, weak.

Chemical data. Wet analysis: Na_2O 8.42, K_2O 0.37, Al_2O_3 43.82, P_2O_5 37.97, H_2O 9.65, total 100.23 wt.%. Empirical formula: $(Na_{0.99}K_{0.03})_{\Sigma1.02}Al_{3.12}(PO_4)_{1.94}[(OH)_{3.89}O_{0.35}]_{\Sigma4.24}$. The ideal formula requires Na_2O 8.56, Al_2O_3 42.25, P_2O_5 39.23, H_2O 9.96, total 100.00 wt.%.

Crystallography. Monoclinic, $P2_1/n$, a 11.233(6), b 10.142(5), c 7.097(4) Å, β 97.37(2)°, V 801.85 Å^3, Z 4, $a:b:c$ = 1.1076:1:0.6998 (single-crystal). X-ray powder diffraction data [d in Å (I) (hkl)]: 5.7812 (20) (011), 5.0645 (100) (020), 3.7518 (11) ($\bar{2}20$), 3.2888 (10) ($\bar{3}11$), 2.9869 (33) (311), 2.8735 (23) ($\bar{1}22$), 2.738 (18) ($\bar{2}31$), 2.7303 (18) (122), 2.6852 (30) ($\bar{2}22$), 1.9798 (11) ($\bar{2}42$) (sample from the Córrego Frio pegmatite).

Name. In honor of Brazil. According to Pough and Henderson (1945c), "*the authors decided that such an important mineral should bear the name of its country of origin. Brazilite would have been our preference, but unfortunately this name had already been applied to baddeleyite, and therefore not available. Our next choice was brazilianite*". Pough and Henderson (1945b) spelled it "brasilianite", and Pough and Henderson (1945c) spelled it "brazilianite". The second is the accepted spelling. Not to be confused with the brazilianite of Mawe (1818). Brazilite and brazil are also names related to Brazil.

Type material. U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA. "Rio Doce and Rio São Mathews (S slope of hill dividing), Divino River (near the head of a small tributary of), Córrego Frio". Sample 105048 (donator American Museum of Natural History, New York, 1945).

Relationship to other species. None apparent.

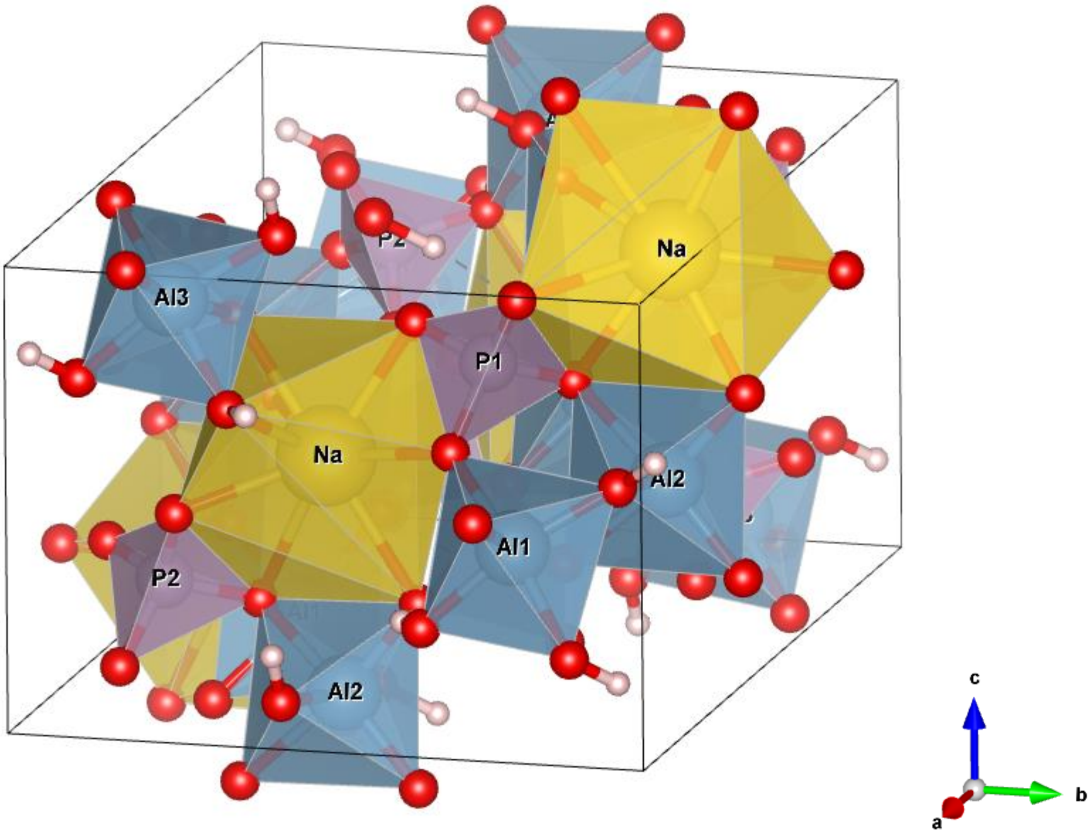

Figure 7.39. View of the crystal structure of brazilianite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Gatehouse and Miskin (1974).

Crystal structure. Determined by Gatehouse and Miskin (1974), using a sample from the type locality, and by Gatta *et al.* (2013), using a sample from the Telírio pegmatite, near Linópolis, Minas Gerais. The building-block units of the brazilianite structure consist of chains of edge-sharing $AlO_4(OH)_2$ and $AlO_3(OH)_3$ octahedra. Chains are connected, via corner-sharing, by P-tetrahedra to form a three-dimensional framework, with Na atoms located in distorted cavities running along [100].

See also. Frondelite, scorzalite, souzalite, brazilite, brazil, and brazilianite (old name)

.

Scorzalite

Pecora and Fahey (1949a)

$(Fe^{2+},Mg)Al_2(PO_4)_2(OH)_2$, monoclinic

Other names: scorzalita

Figure 7.40. Scorzalite from Córrego Frio granitic pegmatite, Linópolis, Divino das Laranjeiras, Minas Gerais. Greatest dimension: 3 cm. Specimen: Luiz A.D. Menezes Filho. Photo: Thales Trigo.

Figure 7.41. Scorzalite from Córrego Frio granitic pegmatite, Linópolis, Divino das Laranjeiras, Minas Gerais. Dimensions: 40 × 50 mm. Donator: William T. Pecora. Museu de Ciências da Terra, Rio de Janeiro. Photo: Marcelo Lerner. Cornejo and Bartorelli (2020).

After the publication of four abstracts (Pecora and Fahey 1947, 1948a, b, c), the complete description of this mineral was published by Pecora and Fahey (1949a). A detailed description of the occurrence and the history of the discovery of this mineral was given by Cassedanne (1983). A second scorzalite occurrence was described in the Victory pegmatite, near Custer, South Dakota, USA, by Pecora and Fahey (1949b). In this work, the authors presented new data for the Brazilian scorzalite.

Occurrence. Córrego Frio granitic pegmatite, Linópolis district, Divino das Laranjeiras township, Minas Gerais with albite, arsenopyrite, beraunite, brazilianite, childrenite, dufrenite, fluorapatite, frondelite, garnet, jahnsite, microcline, muscovite, quartz, a roscherite-group mineral, sabugalite, souzalite, strunzite, tapiolite, tourmaline, uraninite, wyllieite, and zircon (Cassedanne 1983). Córrego Frio is also the type locality for brazilianite and souzalite. Also, known from several Brazilian and world occurrences.

Appearance and physical properties. Habit: massive. Twinning: on {100}. Color: dark blue. Cleavage: {110} good. Fracture: not given. Hardness (Mohs): 6. Tenacity: not given. Density: 3.268 g/cm^3 (meas.), 3.304 g/cm^3 (calc.).

Optical properties. Biaxial (-), α 1.633, β 1.663, γ 1.673, 2*V* 62° (calc.). Orientation: *X* near *c*, *Y* = *b*. Pleochroism: *X* colorless, *Y* blue, *Z* darker blue. Absorption *Z* > *Y* > *X*. Dispersion: *r* > *v*, perceptible.

Chemical data. Analytical methods not specified: MgO 4.23, CaO 0.02, MnO 0.11, FeO 14.74, ZnO 0.17, Al_2O_3 30.87, Fe_2O_3 0.54, P_2O_5 42.90, H_2O 5.86, SnO n.d., TiO_2 0.10, total 99.54 wt.%. Empirical formula: $(Fe^{2+}_{0.67}Mg_{0.34}Mn_{0.01}Zn_{0.01})_{\Sigma 1.03}(Al_{1.97}Fe^{3+}_{0.02})_{\Sigma 1.99}(PO_4)_{1.97}(OH)_{2.12}$. The ideal formula requires FeO 21.53, Al_2O_3 30.54, P_2O_5 42.53, H_2O 5.40, total 100.00 wt.%.

Crystallography. Monoclinic, $P2_1/c$, *a* 7.1568, *b* 7.3018, *c* 7.2481 Å, *β* 120.59°, *V* 326.06 Å^3, *Z* 2, *a:b:c* = 0.9801:1:0.9926. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 6.17 (20) (100), 4.748 (19) (011), 3.246 (75) ($\bar{1}12$), 3.206 (100) ($\bar{2}11$, 111), 3.152 (50) (021), 3.081 (35) (200), 2.554 (19) ($\bar{2}21$), 2.222 (16) (211), 1.5764 (18) ($\bar{2}42$, 042), 1.5696 (15) (330). (All data for samples from Pennington Co., South Dakota, USA).

Name. In honor of Dr. Evaristo Pena Scorza (1899-1969), mineralogist, Departamento Nacional da Produção Mineral.

Type material. U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA (type, C05862, donator E. R. Swoboda, thru Canfield collection, 1948); the Natural History Museum, London, England, (type, BM 1965,20883); and Harvard Mineralogical Museum, Harvard University, Cambridge, USA (type, donator U.S. Geological Survey).

Relationship to other species. A member of the lazulite group; isomorphous with barbosalite.

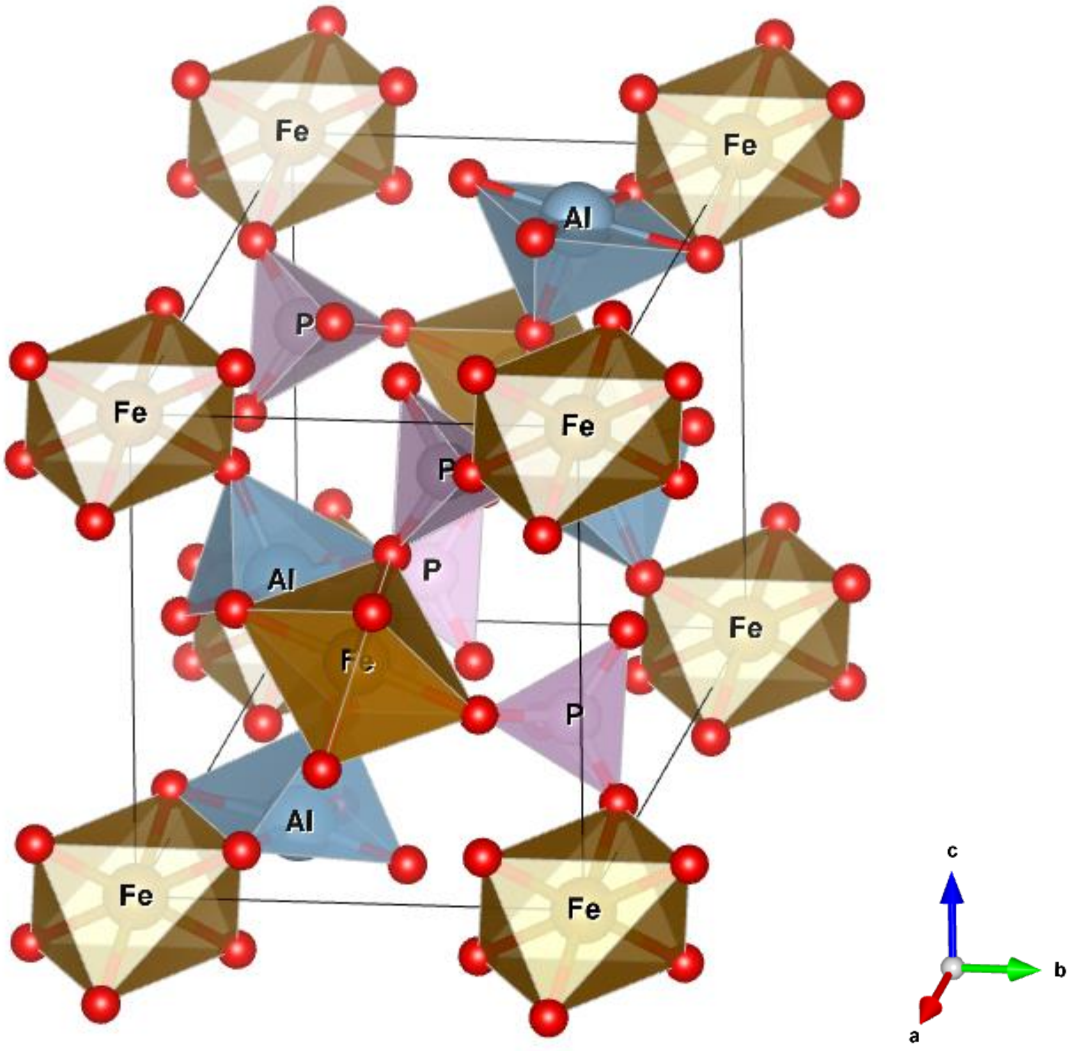

Figure 7.42. View of the crystal structure of scorzalite (from Pennington Co., South Dakota, USA), drawn using VESTA 3 (Momma and Izumi 2011). Data from Lindberg and Christ (1959).

Crystal structure. Determined by Lindberg and Christ (1959), using a sample from Pennington Co., South Dakota, USA. This mineral has face-sharing $Al_2Fe^{2+}O_8(OH)_4$ octahedral trimers forming chains along the *c*-axis with every fourth octahedron vacant (Redhammer *et al.* 2000). The resultant triplets were designated as *h*-clusters by Moore (1970) and are also found in many other phosphate minerals. Lipscombite is a related structure in which the vacancy is disordered among the face-sharing octahedra. Between those chains are corner-sharing $AlO_4(OH)_2$ octahedra that share two corners with bridging phosphate tetrahedra; these run parallel to the [101] direction (Dyar *et al.* 2014).

See also. Brazilianite, frondelite, souzalite, barbosalite, and lipscombite.

Barbosalite

Lindberg and Pecora (1955)

$Fe^{2+}Fe^{3+}_2(PO_4)_2(OH)_2$, monoclinic

Other names: barbosalita

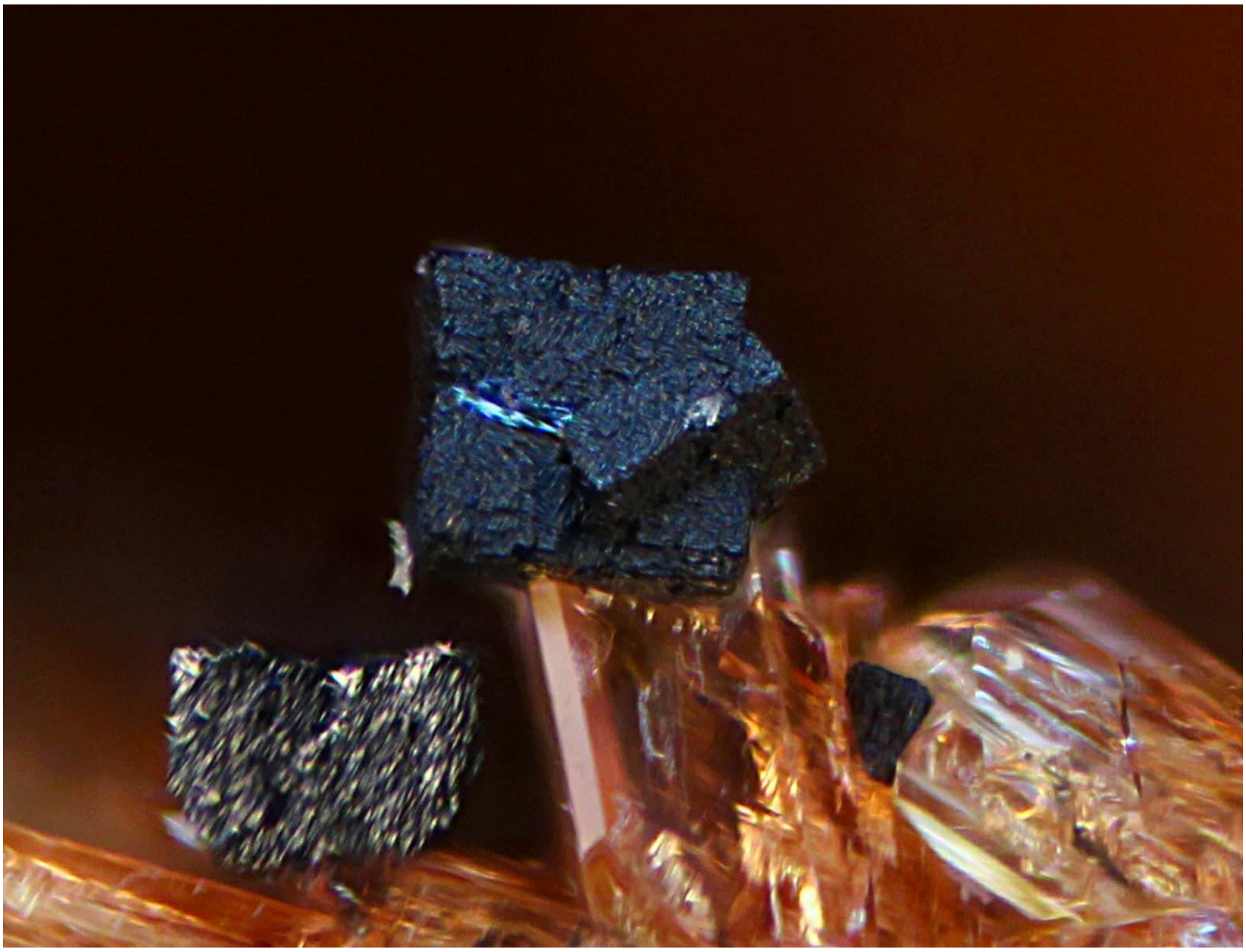

Figure 7.43. Barbosalite on hureaulite from the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. Field of view: 1 mm. Specimen and photo: Jhonatan Gomes.

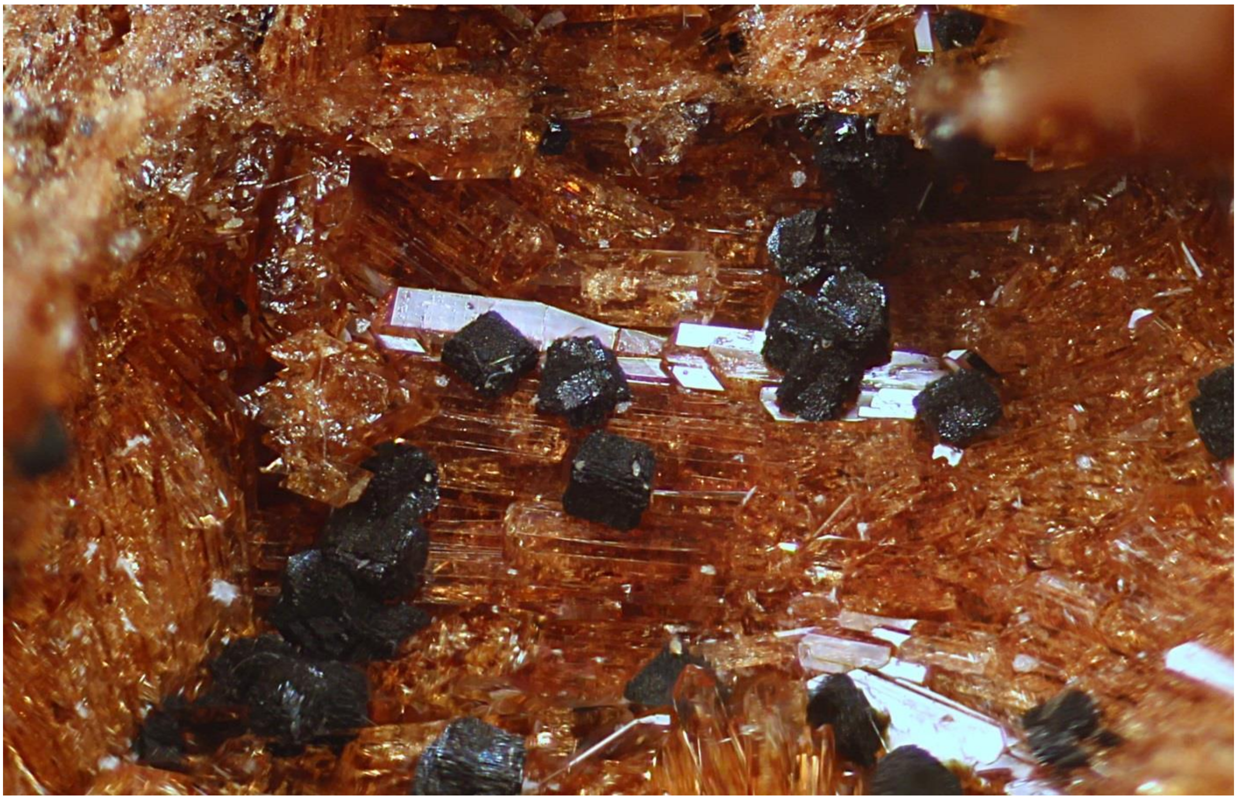

Figure 7.44. Barbosalite on hureaulite from the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. Field of view: 3 mm. Specimen and photo: Jhonatan Gomes.

A preliminary note about this mineral was published by Lindberg and Pecora (1954b). The complete paper was released by Lindberg and Pecora (1955).

Occurrence The mineral occurs in the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais, which is the type locality of other eight phosphates [arrojadite-(PbFe), frondelite, moraesite, ruifrancoite, tavorite, faheyite, jahnsite-(MnMnMg) and jahnsite-(NaMnMg); see notes about this occurrence under ruifrancoite], as a secondary alteration product. Also, known from several Brazilian and world occurrences, and from the Paso Robles soils on Mars (Lane *et al.* 2008).

Appearance and physical properties. Habit: it occurs principally as a very fine-grained layer between heterosite and porous triphylite. The contact with heterosite is well defined, but with the porous triphylite it is gradational, locally extending irregularly or along cleavage cracks into unaltered triphylite. The width of the layer ranges from a few mm to about 1 cm. In the cavities, barbosalite occurs as a massive material deposited among hureaulite crystals or as a thin coating of very fine crystalline aggregates on hureaulite crystals. Color: dark blue-green. Translucent. Hardness (Mohs): 6. Cleavage: {100}. Density: 3.60 g/cm^3 (meas.), 3.652 g/cm^3 (calc.). Slowly soluble in hot dilute HCl, and insoluble in dilute HNO_3 and H_2SO_4.

Optical properties. Biaxial (+), α 1.77, β 1.785, γ 1.815, 2V 64 (meas.), 71.5° (calc.). Pleochroism: *X* and *Y* very dark green-blue, *Z* dark olive-green. Dispersion: $r > v$, strong.

Chemical data. Wet analyses (recalculated to 100 % after deduction of mixed tavorite): FeO 13.10, MnO 2.82, Fe_2O_3 41.65, P_2O_5 37.50, H_2O 4.93, total 100.00 wt.% (Lindberg and Pecora 1954b, 1955). Empirical formula: $(Fe^{2+}_{0.69}Mn^{2+}_{0.15})_{\Sigma 0,84}Fe^{3+}_{1.98}(PO_4)_{2.00}[(OH)_{1.62}(H_2O)_{0.23}]_{\Sigma 1.85}$. Microprobe data: FeO 16.61, MnO 0.53, MgO 0.38, ZnO 0.14, CaO 0.03, Fe_2O_3 42.40, P_2O_5 37.22, H_2O (calc.) 4.72, total 102.03 wt.% (Baijot *et al.* 2012). Empirical formula: $(Fe^{2+}_{0.89}Mg_{0.04}Mn^{2+}_{0.03}Fe^{3+}_{0.02}Zn_{0.01})_{\Sigma 0,99}Fe^{3+}_{2.00}(PO_4)_{2.00}(OH)_{2.00}$. The ideal formula requires FeO 18.35, Fe_2O_3 40.79, P_2O_5 36.26, H_2O 4.60, total 100.00 wt.%.

Crystallography. Monoclinic, $P2_1/c$, *a* 7.313, *b* 7.489, *c* 7.520 Å, β 120.19°, *V* 355.99 Å^3, Z 2, *a*:*b*:*c* = 0.9765:1:1.0041. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 4.84 (60) (110), 3.361 (100) ($\bar{1}12$), 3.313 (80) (111), 3.239 (60) ($\bar{1}21$), 3.160 (60) (200), 2.614 (30) ($\bar{2}21$), 2.327 (40) ($\bar{1}31$), 2.292 (30) (211), 2.027 (30) (310), 1.681 (30) ($\bar{2}24$) (Specimen from Galileia).

Name. In honor of Prof. Aluizio Licinio de Miranda Barbosa (1916-2013), Escola de Minas de Ouro Preto, Minas Gerais.

Type material. According to Lindberg and Pecora (1955), U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA (USNM 106, 842, donator W.T. Pecora, 1954, with and filed under tavorite), and “Museu Nacional of the Departamento Nacional da Produção Mineral”, Rio de Janeiro [Museu Nacional and Departamento Nacional da Produção Mineral are two different museums]. According to the unpublished list of type-specimens produced by the Commission of Museums of the International Mineralogical Association, U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA, and The Natural History Museu, London, England, cotype, BM 1965,209.

Relationship with other species. A member of the lazulite group; isomorphous with scorzalite and dimorphous with lipscombite.

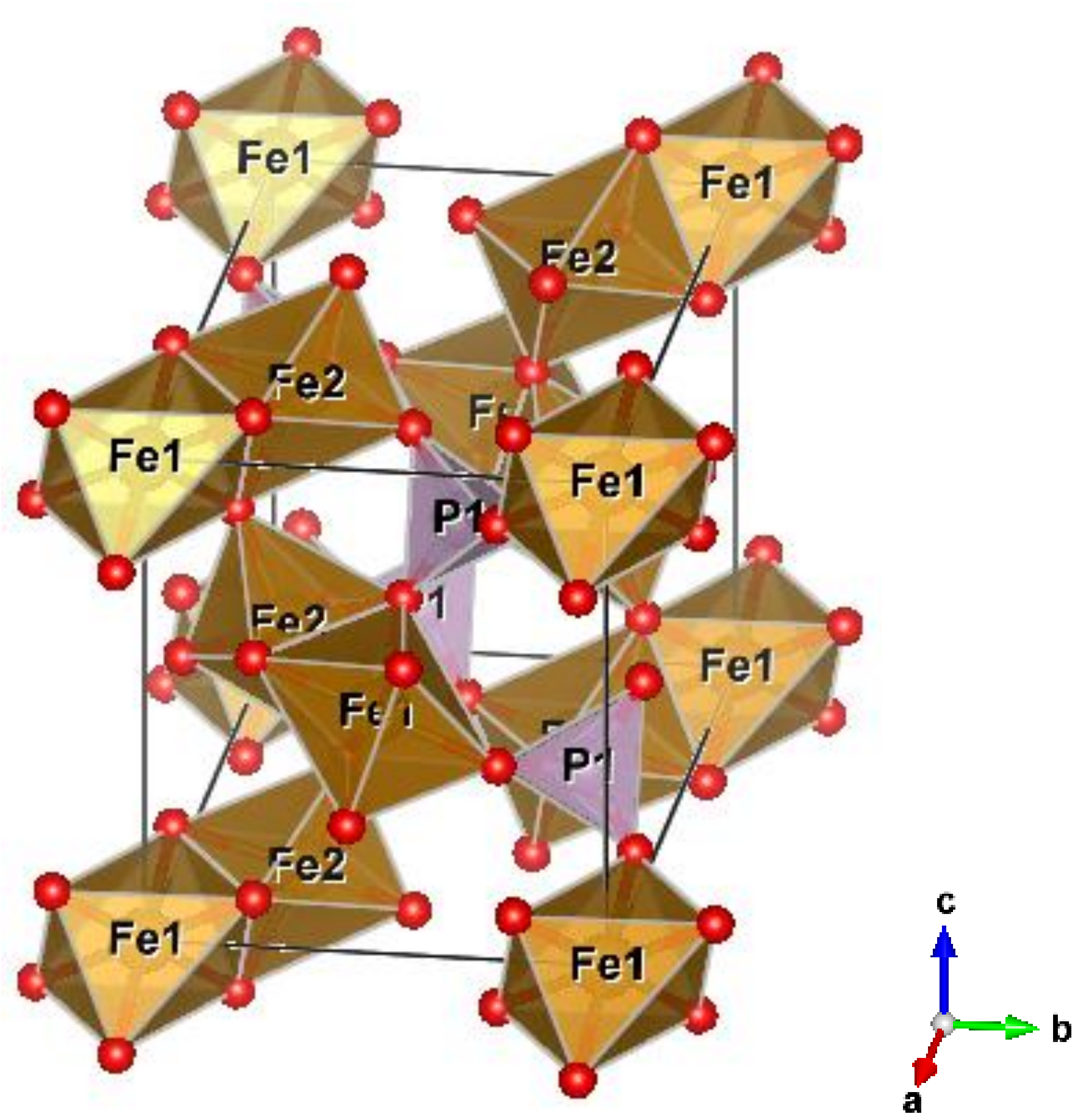

Figure 7.45. View of the crystal structure of barbosalite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Lindberg and Christ (1959).

Crystal structure. Determined by Lindberg and Christ (1959), using a sample from the type occurrence. This mineral has face-sharing $Fe^{3+}{}_2Fe^{2+}O_8(OH)_4$ octahedral trimers forming chains along the *c*-axis with every fourth octahedron vacant (Redhammer *et al.* 2000). The resultant triplets were designated as *h*-clusters by Moore (1970) and are also found in many other phosphate minerals. Lipscombite is a related structure in which the vacancy is disordered among the face-sharing octahedra. Between those chains are corner-sharing $Fe^{3+}O_4(OH)_2$ octahedra that share two corners with bridging phosphate tetrahedra; these run parallel to the [101] direction (Dyar *et al.* 2014).

Synthetic. Gheith (1953) obtained barbosalite (“ferrous ferric lazulite”) in five different experiments, with varied reagents and pressure conditions, and temperatures varying between 180 and 185°C, in periods of 4 to 13 days.

See also. Arrojadite-(PbFe), faheyite, frondelite, moraesite, ruifrancoite, tavorite, jahnsite-(MnMnMg), jahnsite-(NaMnMg), whiteite-(MnMnMg), whiteite-(FeMgNa), unknown silky white mineral, mineral (b), lipscombite, and avelinoite.

Berkeyite

Kerr (1926)

(= lazulite)

Other names: berkeyíta

A blue gem from Brazil, identified as lazulite by Kunz (1926). The name honors Prof. Charles Peter Berkey (1867-1955), of the University of Columbia, New York, USA.

Lipscombite

Lindberg (1962)

Type occurrence should not be considered as Brazil

Other names: manganoan lipscombite, lipscombita.

The name lipscombite was first used by Gheith (1951 and 1953) for synthetic compounds with compositions ranging from $Fe^{2+}_8(PO_4)_4(OH)_4$ to $Fe^{3+}_{5.3}(PO_4)_4(OH)_4$. Lindberg and Pecora (1958) published an abstract on a mineral from the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais, occurring as a secondary alteration product in a pegmatite, associated with several other phosphates. They referred to this mineral as “manganoan lipscombite” with the formula $(Mn^{2+},Fe^{2+})Fe^{3+}_2(PO_4)_2(OH)_2$.

Čech *et al.* (1961) described the “first natural occurrence of lipscombite”, with the formula $Fe^{2+}Fe^{3+}_2(PO_4)_2(OH)_2$, from Otov, near Domazlice, Bohemia, Czech Republic. Lindberg (1962) published the complete description of “manganoan lipscombite”, this time with the formula $(Fe^{2+},Mn^{2+})Fe^{3+}_2(PO_4)_2(OH)_2$, and suggested that the type locality for lipscombite should be Galileia, Minas Gerais. The “manganoan lipscombite”, described by Lindberg (1962) seems to be a different species when compared with that of Čech *et al.* (1961), with Mn or Fe^{3+} predominant over Fe^{2+} in the A-site. The X-ray powder diffraction data is virtually identical, but the chemical results for the Brazilian sample are very poor and insufficient to derive a good empirical formula. Based on these considerations, the Czech Republic should be the type locality for lipscombite, as it was considered by Mandarino and Back (2004), Chukanov *et al.* (2006a) and Neves and Atencio (2017), but Sapucaia is the type occurrence of lipscombite for the IMA official list and for the other editions of the Fleischer’s Glossary of Mineral Species (*e.g.* Back 2018). The Brazilian mineral needs to be restudied, because it seems to be a new species. The description of the mineral from Galileia is presented below.

Lipscombite with Mn^{2+}:Fe^{2+} > 1 (in atomic proportions) was described also from Cyrilovský pegmatite in Western Moravia, Czech Republic (Staněk, 1971).

Occurrence. The mineral occurs in the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais, which is the type locality of nine phosphates [arrojadite-(PbFe), barbosalite, frondelite, moraesite, ruifrancoite, tavorite, faheyite, jahnsite-(MnMnMg) and jahnsite-(NaMnMg); see notes about this occurrence under ruifrancoite], as a secondary alteration product in a pegmatite, associated with several other phosphates.

Appearance and physical properties. Habit: as crystal aggregates, intimately intergrown with cyrilovite (see avelinoite) and phosphosiderite in vugs of frondelite. Color: olive green to black. Luster: splendent. Opaque. Hardness (Mohs): not determined. Density: 3.66(1) g/cm^3 (meas.).

Optical properties. Not studied.

Chemical data. Wet analyses: MnO 7.91, FeO 3.75, Fe_2O_3 50.45, P_2O_5 33.37, H_2O 4.45, total 100.00 wt.%. Empirical formula: $(Fe^{3+}_{2.69}Mn^{2+}_{0.47}Fe^{2+}_{0.22})_{\Sigma 3.38}(PO_4)_2(OH)_{2.10}$. As quoted by Lindberg (1962), “*the analyzed sample… shows an excess of iron and manganese ions and a deficiency of phosphate and hydroxyl*”. Also according to Lindberg (1962), “*the ratio of Mn^{2+} to Fe^{2+} is greater than 2:1 but a new name is not here proposed for the manganoan equivalent of lipscombite*”. In reality, this chemical analysis does not distinguish between the formulae $(Mn^{2+},Fe^{3+},Fe^{2+})Fe^{3+}_2(PO_4)_2(OH)_2$ and $(Fe^{3+},Mn^{2+},Fe^{2+})Fe^{3+}_2(PO_4)_2(OH)_2$ for the mineral. However, it is possible to conclude that the formula differs from $Fe^{2+}Fe^{3+}_2(PO_4)_2(OH)_2$.

Crystallography. Tetragonal, $P4_12_12$, *a* 7.40, *c* 12.81, *V* 701.48 Å^3, *Z* 4, *c:a* = 1.7311. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 4.84 (30) (102), 3.314 (100) (210), 3.206

(60) (211), 2.617 (20) (220), 2.302 (30) (311), 2.054 (30) (320), 2.028 (20) (321), 1.656 (40) (420), 1.601 (40) (008), 1.309 (30) (440) (specimen from Sapucaia). Katz and Lipscomb (1951) synthesized $Fe_7(PO_4)_4(OH)_4$ with symmetry $I4_122$ and *a* 5.37, *c* 12.81 Å. Vochten and de Grave (1981) and Vochten *et al.* (1983) gave the cell parameters of synthetic lipscombite as *a* 5.3020(5), *c* 12.8800(5) Å. Vencato *et al.* (1989) presented the structure of synthetic lipscombite with symmetry $P4_32_12$ and *a* 7.310(3), *c* 13.212(7) Å. According to Huminicki and Hawthorne (2002), lipscombite is an enigma.

Name. In honor of Prof. William Nunn Lipscomb (1919-2011) of the University of Minnesota, USA.

Type material. Whereabouts unknown.

Relationship to other species. Lipscombite is dimorphous with barbosalite.

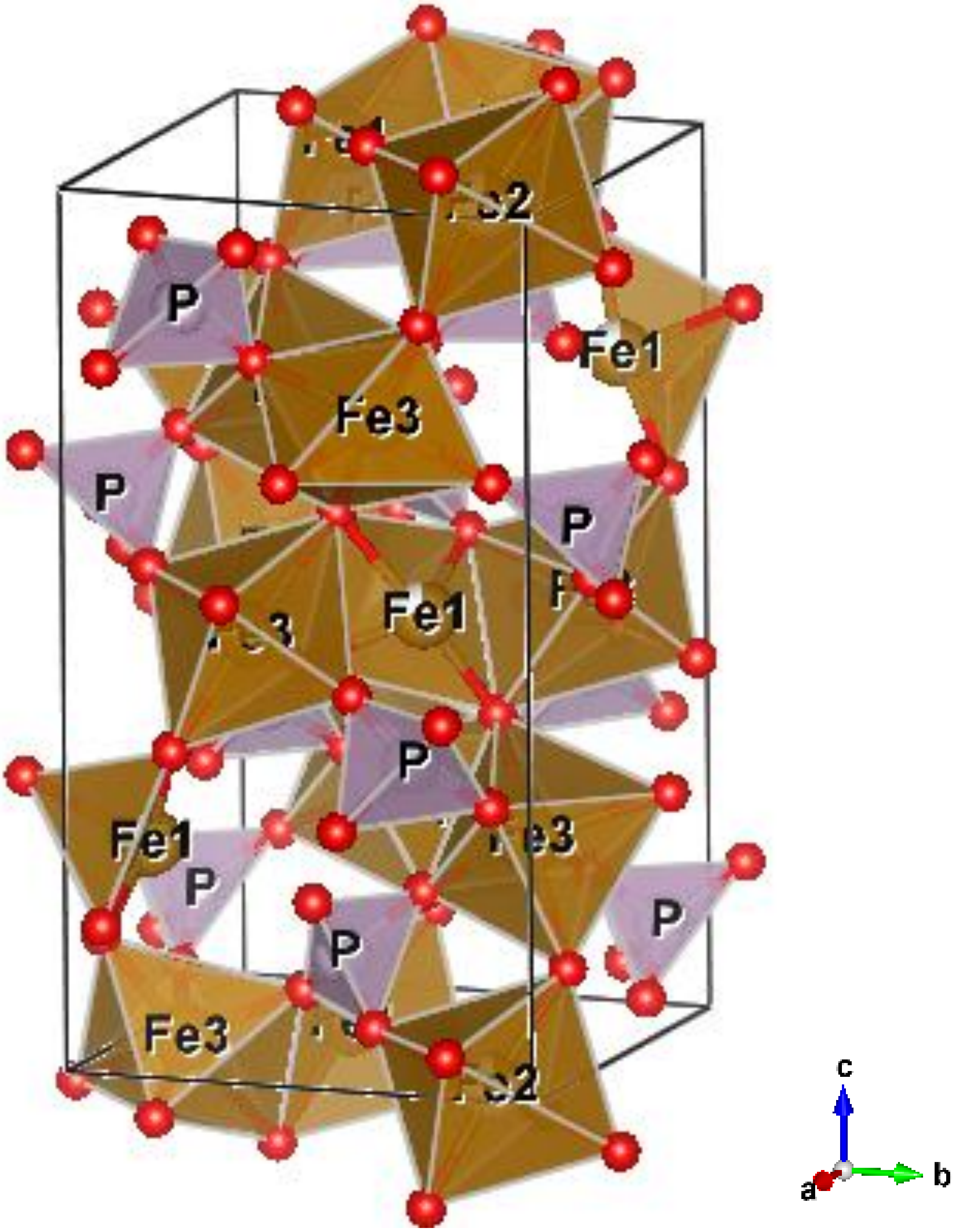

Figure 7.46. View of the crystal structure of lipscombite (synthetic), drawn using VESTA 3 (Momma and Izumi 2011). Data from Vencato *et al.* (1989).

Crystal structure. The crystal structure of $Fe^{2+}Fe^{3+}_2(PO_4)_2(OH)_2$ was studied by Vencato *et al.* (1989). The structure of lipscombite is closely related to mineral species in the lazulite group described above. All these minerals have chains of corner-sharing $Fe^{2+}O_4(OH)_2$ octahedra that share two corners with phosphate tetrahedra and run parallel to the [101] direction. What distinguishes lazulite from lipscombite is the occupancy of the other chains, which are face-sharing Fe^{3+} and Fe^{2+} octahedral running along the *x* direction. Every fourth octahedron is vacant in barbosalite (Redhammer *et al.* 2000), but in lipscombite the location of the vacancy is disordered, with the Fe3 site fully occupied by Fe^{3+} and the Fe1 and Fe2 sites partially occupied by Fe^{2+} (Rouzies and Millet 1993, Rouzies *et al.* 1995, Dyar *et al.* 2014).

Synthetic. According to Chukanov *et al.* (2006a), both Mn-free lipscombite with variable Fe^{2+}:Fe^{3+} ratios [and the formulas varying from $Fe^{2+}_{0.97}Fe^{3+}_{2.03}(PO_4)_{1.98}(OH)_{1.99}$ to $Fe^{2+}_{0.63}Fe^{3+}_{2.31}(PO_4)_{1.96}(OH)_{2.13}$] and related Mn-bearing phases $(Fe^{2+}_{x}Mn^{2+}_{y})Fe^{3+}_{3-x-y}(PO_4)_2(OH)_{3-x-y}$ (with y up to 0.26) have been synthesized and investigated using X-ray diffraction, Mössbauer spectroscopy and electrokinetic methods (Vochten and de Grave 1981; Vochten *et al.* 1983). Gheith (1953) obtained lipscombite in 11 different experiments, with varied reagents and pressure conditions, and temperatures varying between 100 and 188°C, in periods of 1 to 10 days.

See also. Arrojadite-(PbFe), faheyite, barbosalite, frondelite, moraesite, ruifrancoite, tavorite, jahnsite-(MnMnMg), jahnsite-(NaMnMg), whiteite-(MnMnMg), whiteite-(FeMgNa), unknown silky white mineral, mineral (b), and avelinoite.

Frondelite

Lindberg (1949)

$(Mn^{2+}_{0.5}Fe^{3+}_{0.5})_2Fe^{3+}_3(PO_4)_3(OH)_5$, orthorhombic

Other names: frondelita

Figure 7.47. Type specimen of frondelite from the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. Harvard Mineralogical Museum, Harvard University, Cambridge, Massachusetts, USA, 100808 (donator U.S. Geological Survey, thru M.L. Lindberg, 1949).

Figure 7.48. Botryoidal radially fibrous masses of frondelite (105 × 90 mm). Specimen: Antonio Carlos Chagas Ramos. Photo: Marcelo Lerner. Cornejo and Bartorelli (2010).

This mineral was originally described as $Mn^{2+}Fe^{3+}_4(PO_4)_3(OH)_5$ (Lindberg 1949) but the correct ideal formula is $(Mn^{2+}_{0.5}Fe^{3+}_{0.5})_2Fe^{3+}_3(PO_4)_3(OH)_5$ (Grey *et al.* 2019a, b). Grey *et al.* (2019b) re-studied the type specimen 105946, stored in the U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA.

Occurrence. The mineral occurs in the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais, which is the type locality of other eight phosphates [arrojadite-(PbFe), barbosalite, moraesite, ruifrancoite, tavorite, faheyite, jahnsite-(MnMnMg) and jahnsite-(NaMnMg); see notes about this occurrence under ruifrancoite], as a secondary alteration product, associated with triphylite, vivianite and a member of the heterosite–purpurite series. Also, known from several Brazilian and world occurrences.

Appearance and physical properties. Habit: in large radially fibrous masses, occurring as crusts, botryoidal and drusy masses, which form the host rock for many other phosphate minerals. The fibers are parallel to *c*. Minute doubly-terminated crystals with high luster have also been noted, together with crystals of cyrilovite, phosphosiderite, and leucophosphite, in a vuggy zone in the larger fibrous botryoidal masses. Forms: {100}, {010}, {110}, and {101}. Color: dark brown. Luster: dull to vitreous. Transparent. Hardness (Mohs): 4½. Tenacity: brittle. Cleavage: {100} excellent, {010} good, {001} fair. Fracture: irregular. Density: 3.476 g/cm^3 (meas.), 3.546 g/cm^3 (calc.).

Optical properties. Biaxial (-), α 1.860, β 1.880, γ 1.893, 2V moderate (meas.), 77.0° (calc.). $X = c$. Pleochroism: X pale yellow-brown, Y and Z orange-brown. Absorption $Z > Y > X$. Dispersion: $r > v$.

Chemical data. Unspecified methods (Lindberg 1949):

FeO n.d., MnO 7.74, MgO 0.02, CaO 0.02, Na_2O 0.98, K_2O 0.12, Fe_2O_3 48.85, Mn_2O_3 1.75, Al_2O_3 1.31, P_2O_5 31.28, H_2O 7.52, Insol. 0.32, total 100.09 wt.%. Empirical formula: $(Fe^{3+}_{1.06}Mn^{2+}_{0.74}Mg_{0.03}Mn^{3+}_{0.17})_{\Sigma 2.00}(Fe^{3+}_{3.10}Al_{0.17})_{\Sigma 3.27}(PO_4)_{3.00}O_{1.04}(OH)_{3.96}$.

The structural formula obtained by Rietveld refinement (Grey *et al.* 2019b) for the type specimen is

$(Fe^{3+}_{0.74}Mn^{2+}_{0.66}Zn_{0.07}Mg_{0.04}Fe^{2+}_{0.080.41})_{\Sigma 2.00}Fe^{3+}(Fe^{3+}_{2.341.66})_{\Sigma 4.00}(PO_4)_{3.00}(OH)_{4.94}(H_2O)_{0.06}$.

Microprobe analyses (Baijot *et al.* 2012):

(1) MnO 7.39, FeO 3.67, MgO 0.26, CaO 0.13, ZnO 0.23, K_2O 0.04, Na_2O 0.03, Fe_2O_3 47.04, Al_2O_3 0.63, P_2O_5 32.49, SiO_2 0.05, H_2O (calc.) 6.88, total 98.84 wt.%. Empirical formula:

$(Fe^{3+}_{1.00}Mn^{2+}_{0.68}Fe^{2+}_{0.24}Mg_{0.04}Zn_{0.02}Ca_{0.01}Na_{0.01})_{\Sigma 2.00}(Fe^{3+}_{2.85}Fe^{2+}_{0.10}Al_{0.08})_{\Sigma 3.03}(PO_4)_{3.00}(OH)_{4.98}$.

(2) MnO 5.17, MgO 0.25, CaO 0.14, ZnO 0.24, K_2O 0.02, Na_2O 0.08, Fe_2O_3 47.96, Al_2O_3 0.84, Mn_2O_3 4.24, P_2O_5 33.37, SiO_2 0.05, H_2O (calc.) 7.07, total 99.43 wt.%. Empirical formula: $(Fe^{3+}_{1.00}Mn^{2+}_{0.47}Mn^{3+}_{0.27}Mg_{0.04}Zn_{0.02}Ca_{0.02}Na_{0.02})_{\Sigma 1,84}(Fe^{3+}_{2.83}Al_{0.10}Mn^{3+}_{0.07})_{\Sigma 3.00}(PO_4)_{3.00}(OH)_{4.97}$.

The ideal formula requires MnO 10.94, Fe_2O_3 49.27, P_2O_5 32.84, H_2O 6.95, total 100.00 wt.%.

Crystallography. Orthorhombic, *Bbmm*, *a* 13.8069(6), *b* 16.9640(6), *c* 5.1827(2) Å, *V* 1213.89 Å^3, *Z* 4, *a:b:c* = 0.8139:1:0.3055 [by Rietveld refinement (Grey *et al*. 2019b) for the type specimen]. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 6.910 (17) (200), 3.615 (40) (240), 3.445 (25) (301), 3.381 (85) (410), 3.191 (100) (141, 321), 3.046 (20) (250), 2.779 (12) (151), 2.415 (17) (351, 511), 1.7188 (11) (571), 1.5953 (19) (642).

Name. In honor of Prof. Clifford Frondel (1907-2002) of Harvard University.

Type material. U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA, type, 105946 (donator: U.S. Geological Survey, thru M.L. Lindberg, 1949); Harvard Mineralogical Museum, Harvard University, Cambridge, Massachusetts, USA, (type) 100808 (donator U.S. Geological Survey, thru M.L. Lindberg, 1949).

Relationship to other species. Rockbridgeite group (Grey *et al.* 2019a).

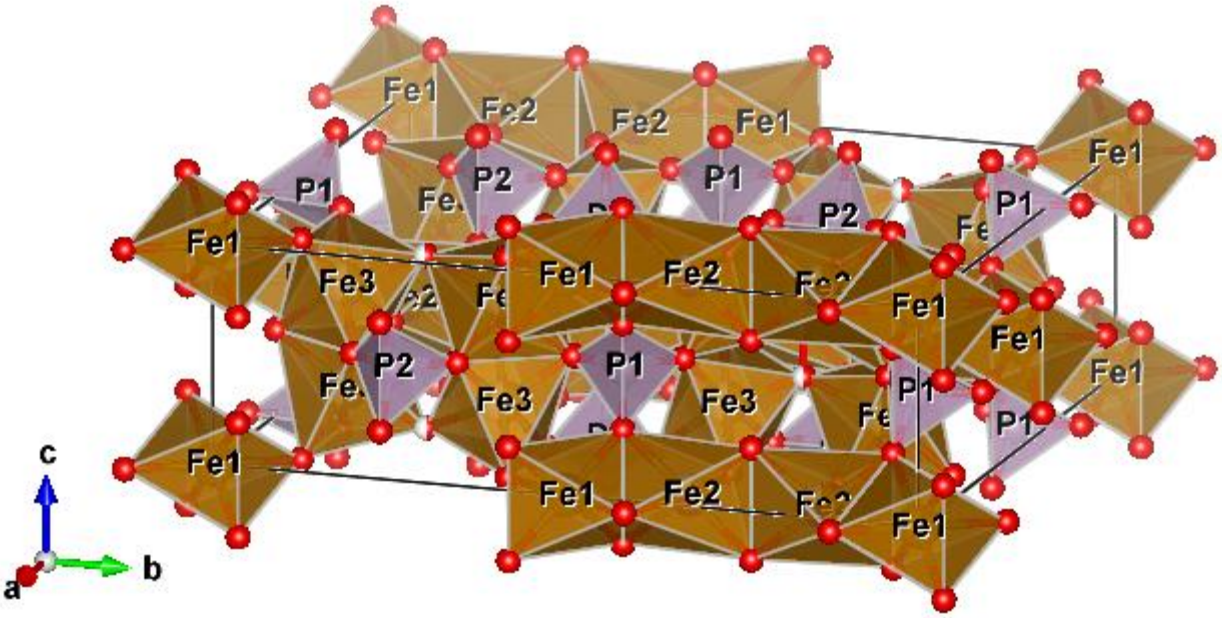

Figure 7.49. View of the crystal structure of frondelite (from the 93 m level of the Hagendorf Süd pegmatite mine, Bavaria, Germany), drawn using VESTA 3 (Momma and Izumi 2011). Data from Grey *et al.* (2019b).

Crystal structure. The structure of rockbridgeite-group minerals is built of two types of (100) layers. The first type of layer contains double columns along [001] of face- and corner-connected *M*3-centred octahedra that are interconnected along [010] via corner-connection with PO_4 tetrahedra. The second type of layer contains the *M*1- and *M*2-centred octahedra, which form face-sharing trimers. The trimers connect into chains along [010] by edge-sharing between the *M*2-centred octahedra. The chains are interconnected along [001] by corner-sharing with PO_4 tetrahedra (Grey *et al.* 2019b).

See also. Arrojadite-(PbFe), faheyite, barbosalite, moraesite, ruifrancoite, tavorite, jahnsite-(MnMnMg), jahnsite-(NaMnMg), whiteite-(MnMnMg), whiteite-(FeMgNa), unknown silky white mineral, mineral (b), lipscombite, and avelinoite.

Arrojadite

Guimarães (1924)

[? perhaps arrojadite-(K) or arrojadite-(KFe)]

Other names: arrojadita, arrojadite-(KFe), arrojadita-(KFe), arrojadite-(K), arrojadita-(K)

Figure 7.50. Arrojadite from Alto Serra Branca pegmatite, Pedra Lavrada, Paraíba, classified as arrojadite-(KFe), but there are no chemical analyzes. The label is 6.5 cm long. Museu de Ciência e Técnica, Escola de Minas, Universidade Federal de Ouro Preto, Minas Gerais. Photo: Anderson Vital Sales.

Originally, arrojadite was a mineral species, but today it is a group of minerals (Cámara *et al.* 2006, Chopin *et al.* 2006). Arrojadite was described as a new mineral species by Guimarães (1924) on a sample from the Alto Serra Branca pegmatite, Pedra Lavrada Co., Paraíba. Additional data were published by Guimarães (1926c and 1942b). Mason (1941) suggested that Serra Branca arrojadite might be identical with an unnamed phosphate mineral long known from the Nickel Plate pegmatite, Keystone, Pennington Co., South Dakota, United States of America (Headden 1891). Ziegler (1914) used the name “soda-triphylite” and Quensel (1937) introduced the name “headdenite” for this mineral. Material from the arrojadite type-locality, Serra Branca, was restudied (optics, X-ray powder diffraction) on U.S. National Museum sample no. 96111 by Lindberg (1950), who confirmed its similarity to the Nickel Plate Mine material thereby establishing the precedence of arrojadite over “headdenite” [but several Serra Branca samples in museum collections turned out to be triplite or an alteration mixture (Lindberg 1950; study of ENSMP sample no. 38427 by Chopin *et al.* 2006)]. Moore and Ito (1979) published data on the arrojadite occurrence in the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais, later defined as arrojadite-(PbFe). According to them, the “supposed arrojadite” from Serra Branca appears to be so highly altered as to constitute a probable mixture or possibly some other species. Given these uncertainties, the Nickel Plate Mine material described but not named by Headden (1891) and reinvestigated by Krutik *et al.* (1979), Moore and Ito (1979), Merlino *et al.* (1981), and Moore *et al.* (1981) was considered as a co-type of arrojadite. The investigation of ENSMP sample no. 38431 from the same locality by Chopin *et al.* (2006) leads to the same conclusion.

According to the new nomenclature system for the arrojadite-mineral group (Cámara *et al.* 2006, Chopin *et al.* 2006), the mineral from the Nickel Plate mine was renamed arrojadite-(KFe) and becomes type-material for it. According to Chopin *et al.* (2006), in the absence of a more reliable analysis than the original one, the material from Paraíba cannot be specified further than arrojadite-(K), even if the pegmatitic occurrence makes an arrojadite-(KFe) – $(KNa)Fe^{2+}(CaNa_2)Fe^{2+}{}_{13}Al(PO_4)_{11}(PO_3OH)(OH)_2$ - composition likely. Nevertheless, the empirical formula (see below) is very different from the formula of arrojadite-(KFe) and the other arrojadite-group minerals.

Arrojadite from Paraíba is described below.

Occurrence. In the Alto Serra Branca pegmatite, Pedra Lavrada, Paraíba, associated with several other phosphates: triphylite, lithiophilite, amblygonite, tavorite, zwieselite, rockbridgeite, hureaulite, phosphosiderite, variscite, roscherite, cyrilovite, and mitridatite (Farias and Silva 1986). Guimarães (1924, 1926c and 1942b) cited that arrojadite is intimately associated with an unidentified dark red mineral with higher refractive indices and birefringence, and it was not possible to separate the two minerals for chemical analyses. This is also the type locality of serrabrancaite.

Appearance and physical properties. Habit: massive, with hematite, cassiterite, and quartz inclusions. Color: dark green. Translucent. Cleavage: parallel to {110}. Hardness (Mohs): slightly above 5.

Optical properties. Biaxial (-), α 1.662, β 1.668, γ 1.672, 2*V* 80 (meas.), 78.2°

(calc.). Pleochroism: weak, *X* and *Y* colorless, *Z* light green.

Chemical data. Wet analyses: Na_2O 4.67, K_2O 1.45, Li_2O traces, CaO 5.69, Fe_2O_3 12.39, FeO 19.84, MnO 12.33, MgO 1.85, SnO_2 1.52, P_2O_5 34.32, H_2O 4.96, insol. 0.66, total 99.68 wt.%. This corresponds to $(Na_{1.74}K_{0.76})Fe^{2+}(Ca_{2.54}Na_{2.00})(Fe^{2+}{}_{5.85}Mn_{4.31}Fe^{3+}{}_{2.85}Mg_{1.14}Sn_{0.25})_{\Sigma 14.4}Fe^{3+}(PO_4)_{11}(PO_3OH)(OH)_{12.66}$.

Crystallography. Monoclinic. The only X-ray powder diffraction pattern for arrojadite from Pedra Lavrada obtained by Lindberg (1950) is unindexed and, because several lines cannot be indexed by analogy with the patterns obtained for material from South Dakota, it represents a mixture.

Name. In honor of Dr. Miguel Arrojado Ribeiro Lisbôa (1872-1932), Brazilian geologist.

Type material. U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA, neotype, 096111 (deposited by M.L. Lindberg); Natural History Museum, London, England, cotype BM 1927,1145.

See also. Unidentified dark red mineral associated with arrojadite, arrojadite-(PbFe), tavorite, and serrabrancaite.

Unidentified dark red mineral associated with arrojadite

Guimarães (1924, 1926c and 1942b)

Guimarães (1924, 1926c and 1942b) cited that arrojadite from Serra Branca mine, Pedra Lavrada, Paraíba, is intimately associated with an unidentified dark red mineral with higher refractive indices and birefringence, and it was not possible to separate the two minerals for chemical analyses. It seems to be an alteration product of arrojadite, biaxial (+), α 1.703(1), β 1.703(1), γ 1.724, 2*V* 16°. Pleochroism: *X* vivid yellow, *Y* orange yellow, *Z* dark red.

See also. Arrojadite.

Arrojadite-(PbFe)

Chopin *et al.* (2006)

$PbFe^{2+}Na_2CaFe^{2+}_{13}Al(PO_4)_{11}(PO_3OH)(OH)_2$, monoclinic

Approved CNMMN - IMA 2005-056

Other names: arrojadita-(PbFe)

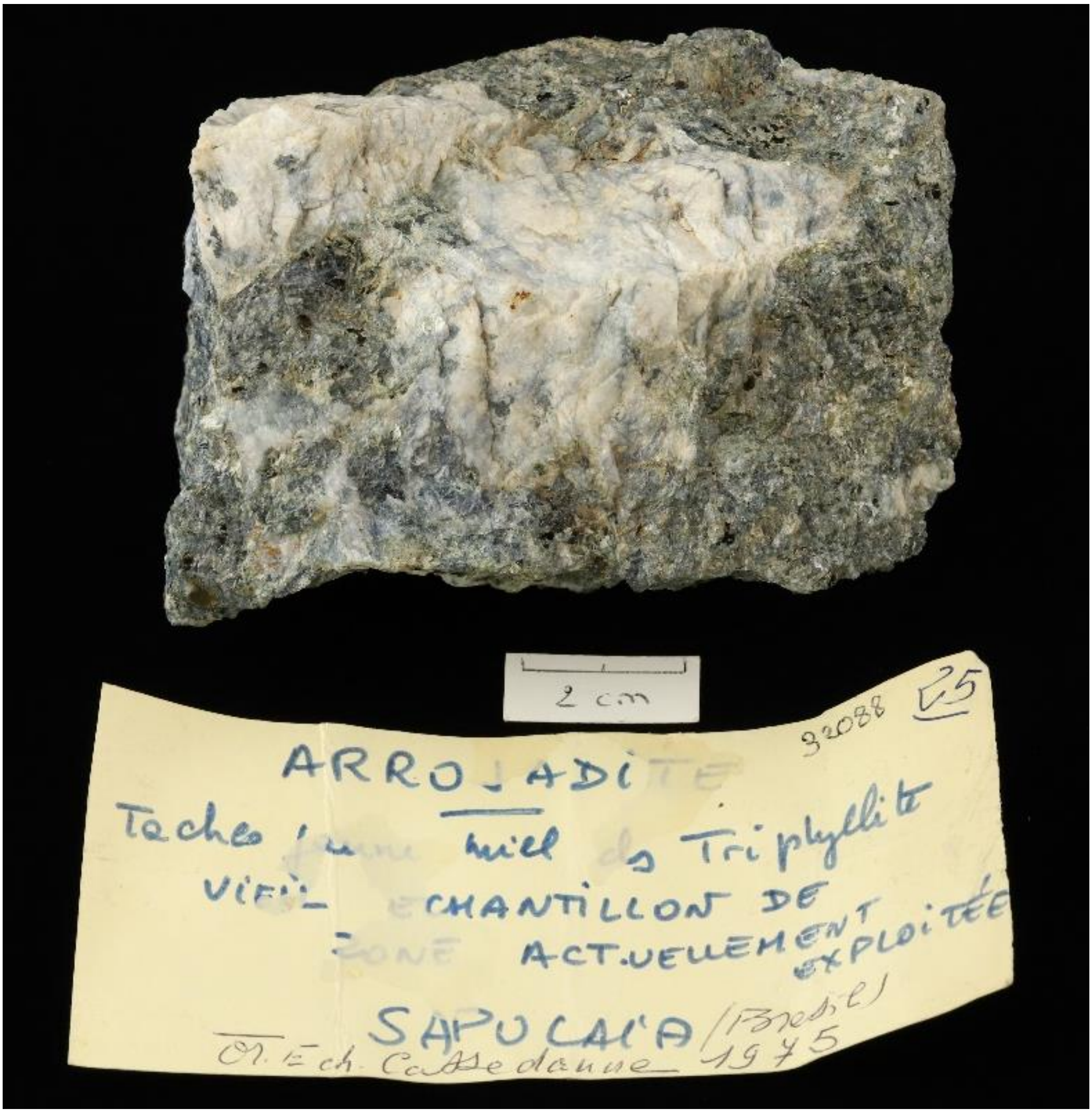

Figure 7.51. The holotype specimen of arrojadite-(PbFe) from the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. Copyright: Musée de Minéralogie MINES ParisTech / Photo: Eloïse Gaillou. Catalog number of the specimen: ENSMP 32088.

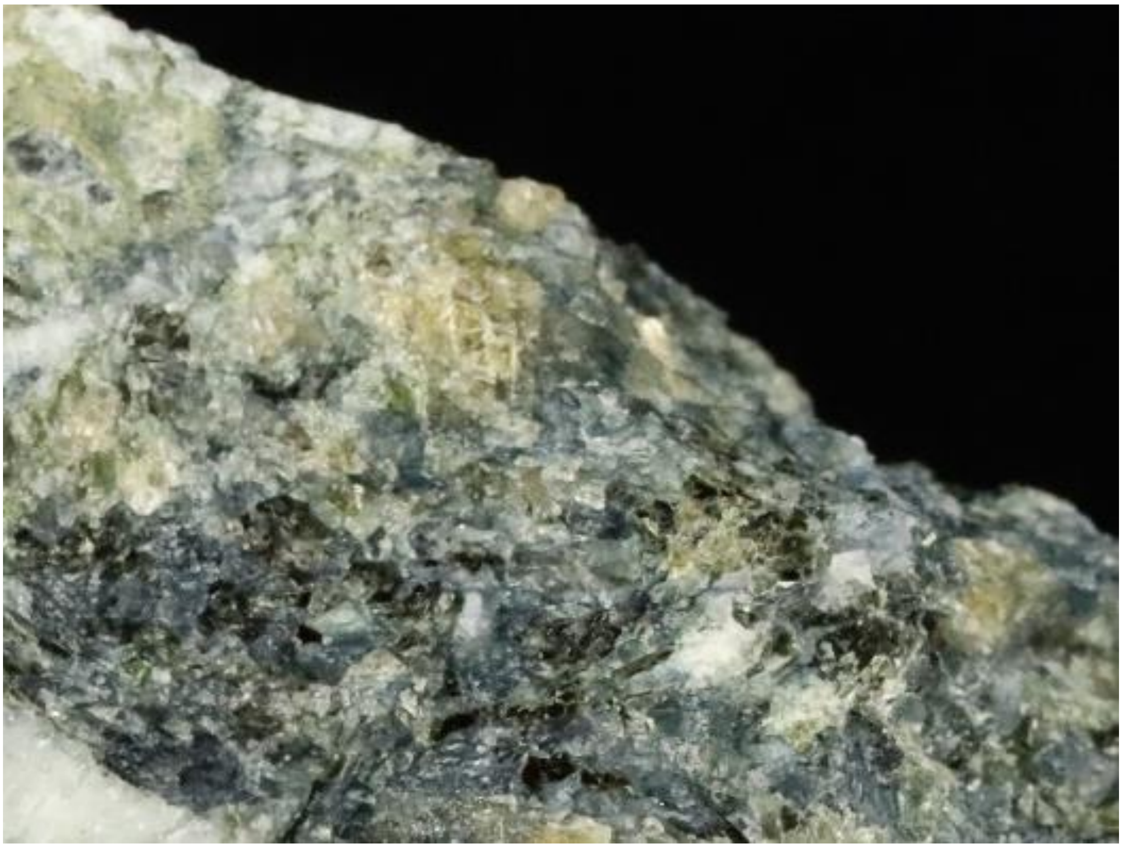

Figure 7.52. Pale honey-yellow arrojadite-(PbFe) crystals in a groundmass of triphylite with some chloritized biotite and albite. The holotype specimen from the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. Detail of the previous figure. Copyright: Musée de Minéralogie MINES ParisTech / Photo: Eloïse Gaillou. Catalog number of the specimen: ENSMP 32088.

Occurrence. The mineral occurs in the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais, which is the type locality of other eight phosphates [barbosalite, frondelite, moraesite, ruifrancoite, tavorite, faheyite, jahnsite-(MnMnMg) and jahnsite-(NaMnMg); see notes about this occurrence under ruifrancoite]. In the late 1970s, arrojadite was abundant there and occurred with walnut-sized black grains of metamict fillowite (or johnsomervilleite?); it was studied by Moore and Ito (1979), whose wet-chemical and electron microprobe analyses both suggested dominant Pb at the *A*1 site. This material may have been discarded after P.B. Moore left the University of Chicago. Material from that locality supplied by Jacques Cassedanne in 1975 to the Musée de Minéralogie, Ecole des Mines de Paris (ENSMP no. 32088) was re-investigated by Chopin *et al.* (2006), and the analyses confirmed those given by Moore and Ito (1979). This sample is holotype material for arrojadite-(PbFe).

Appearance and physical properties. The mineral forms clear, up to millimeter-sized, anhedral (corroded), isolated crystals in a groundmass of triphylite with some chloritized biotite and albite. Forms: none observed. Twinning: none observed. Color: pale honey-yellow. Streak: white. Luster: vitreous. Transparent. Non-fluorescent. Hardness: not determined, probably near 5 by analogy with other arrojadite-group minerals. Tenacity: brittle. Cleavage: not prominent, probably {001}. Density was not measured. Density: 3.596 g/cm^3 (calc.).

Optical properties. Biaxial (+), α 1.6585(5), β 1.6600(5), γ 1.6680(5) (589 nm), 2*V* 58.2(1)° (direct measure); 57.5(10)° (meas. from spindle-stage extinction curves), 2*V* 47° (calc., possible range 38-60°). Dispersion: $r > v$. Orientation: $a = b$. Pleochroism: none discernible.

Chemical data. Microprobe analyses (4), H_2O calculated by stoichiometry, confirmed by the results of the crystal-structure analysis, Li analyzed by LAM-ICP MS: P_2O_5 40.00, SiO_2 0.11, TiO_2 0.03, Al_2O_3 2.30, Fe_2O_3 0.15, FeO 18.78, MgO 6.64, MnO 13.70, ZnO 0.19, CaO 2.15, SrO 0.45, BaO 2.01, PbO 5.29, Na_2O 4.60, K_2O 0.66, Li_2O 0.606, F 0.53, – O = F -0.22, H_2O 1.02, total 99.00 wt.%. Empirical formula: $(Na_{3.15}Ca_{0.81}Pb_{0.50}K_{0.30}Ba_{0.28}Sr_{0.09})_{\Sigma 5.13}(Fe^{2+}_{5.54}Mn^{2+}_{4.10}Mg_{3.49}Al_{0.96}Li_{0.86}Zn_{0.05}Fe^{3+}_{0.04}Ti_{0.01})_{14.04}[(P_{11.96}Si_{0.04})_{\Sigma 12.00}O_{47}(OH)_{1.00}][(OH)_{1.41}F_{0.59}]_{\Sigma 2.00}$. The empirical formula does not match the ideal formula, but single-crystal X-ray studies showed the *A*1 site is occupied dominantly by divalent cations, and Pb is predominant among them; and at the *B*1 site, $Fe^{2+} > 0.5$ *apfu* (Chopin *et al.* 2006). The ideal formula requires P_2O_5 37.41, Al_2O_3 2.23, FeO 44.18, CaO 2.46, Na_2O 2.72, PbO 9.81, H_2O 1.19, total 100.00 wt.%.

Crystallography. Monoclinic, *Cc*, *a* 16.4304 (9), *b* 9.9745 (5), *c* 24.5869 (13) Å, β 105.485(2) °, *V* 3883.2(5) Å^3, *Z* 4, $a:b:c$ = 1.6472 : 1 : 2.4650. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 4.5534 (25.1) (114), 3.2082 (43.1) (206), 3.0186 (100) ($\bar{4}24$), 2.8291 (35.0) ($\bar{3}32$), 2.8196 (32.9) ($\bar{3}18$), 2.8132 (28.7) (330), 2.7496 (29.1) ($\bar{4}08$), 2.6982 (54.8) (226), 2.6941 (32.3) ($\bar{3}34$), 2.5376 (30.4) (424).

Name. The name defines an arrojadite [Fe > (Mg, Mn)], in which Pb is dominant at the *A*1 site and Fe at the *B*1 site.

Type material. The holotype sample no. 32088 supplied by Jacques Cassedanne in 1975 is part of the collection of the Musée de Minéralogie, Ecole des Mines de Paris, France. The fragment of the holotype used for crystal structure refinement and chemical analysis is also preserved in the same collection.

Relationship to other species. An arrojadite-group mineral (Chopin *et al.* 2006, Cámara *et al.* 2006).

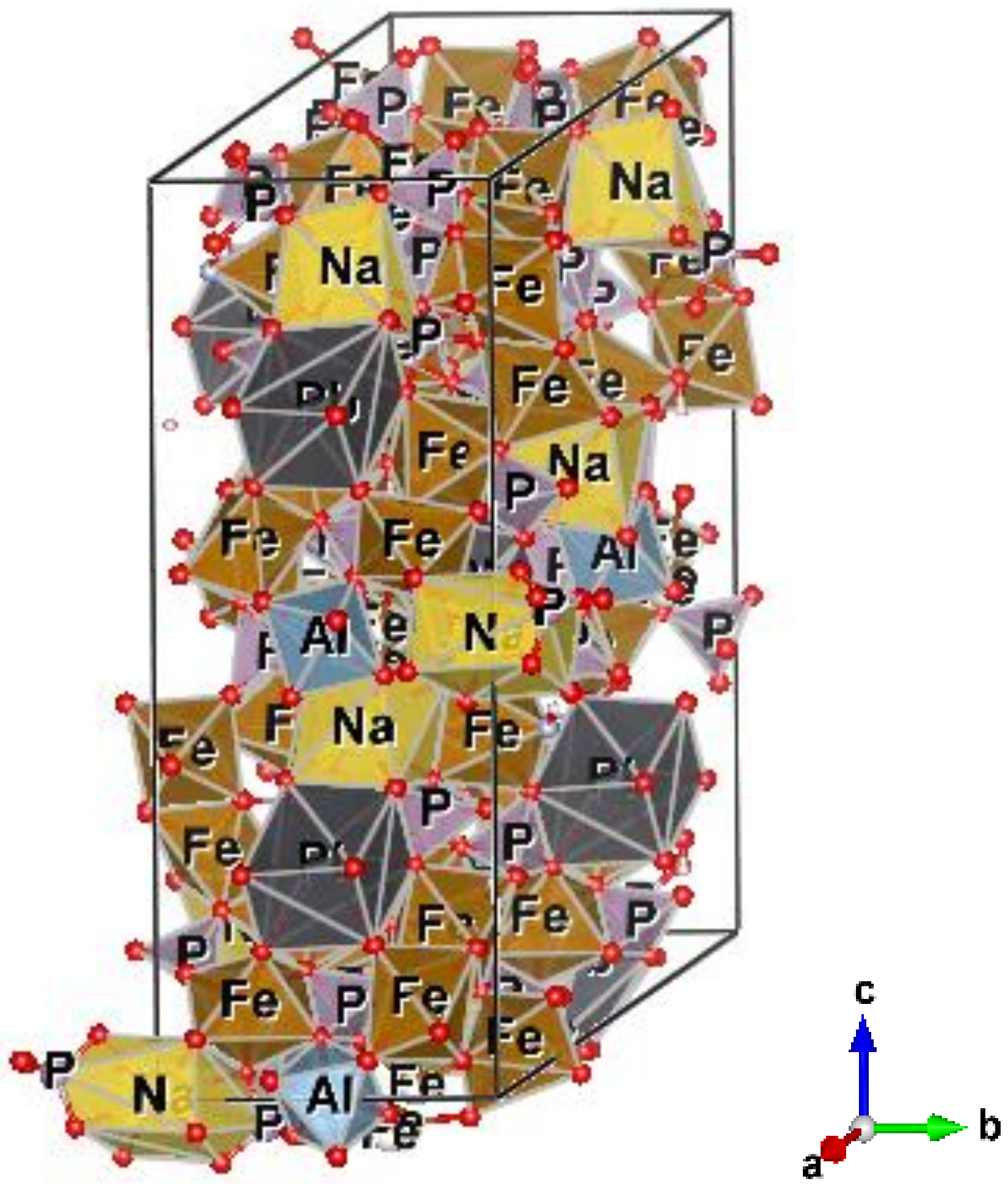

Figure 7.53. View of the crystal structure of arrojadite-(PbFe) (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Based on data for arrojadite-(PbFe) from Chopin *et al.* (2006) and for arrojadite-(SrFe) from Cámara *et al.* (2006).

Crystal structure. In arrojadite-(PbFe), the main structural and crystal-chemical features (Chopin *et al.* 2006) are

- 12 independent tetrahedral phosphate groups: 11 (PO_4) and 1 (PO_3OH);
- 13 independent octahedral *M* sites, which are occupied by Fe^{2+};
- 8 independent alkali sites, three of which are vacant (*A*2, *B*2 and *Na*3); the *A*1 site is

occupied dominantly by Pb. At the *B*1 site, Fe^{2+} is predominant. The other alkali sites are *Ca*, *Na*1 and *Na*2;

- one *Al* site;
- The number of (OH) groups is 3 *pfu*, and one hydroxyl is coordinated to one (PO_4) group.

According to Chopin *et al.* (2006), “details on the structure and crystal-chemistry will be given in the future” but it never happened.

See also. Faheyite, barbosalite, frondelite, moraesite, ruifrancoite, tavorite, jahnsite-(MnMnMg), jahnsite-(NaMnMg), whiteite-(MnMnMg), whiteite-(FeMgNa), unknown silky white mineral, mineral (b), lipscombite, and avelinoite.

Souzalite

Pecora and Fahey (1949a)

$Mg_3Al_4(PO_4)_4(OH)_6 \cdot 2H_2O$, triclinic

Other names: souzalita, sousalita

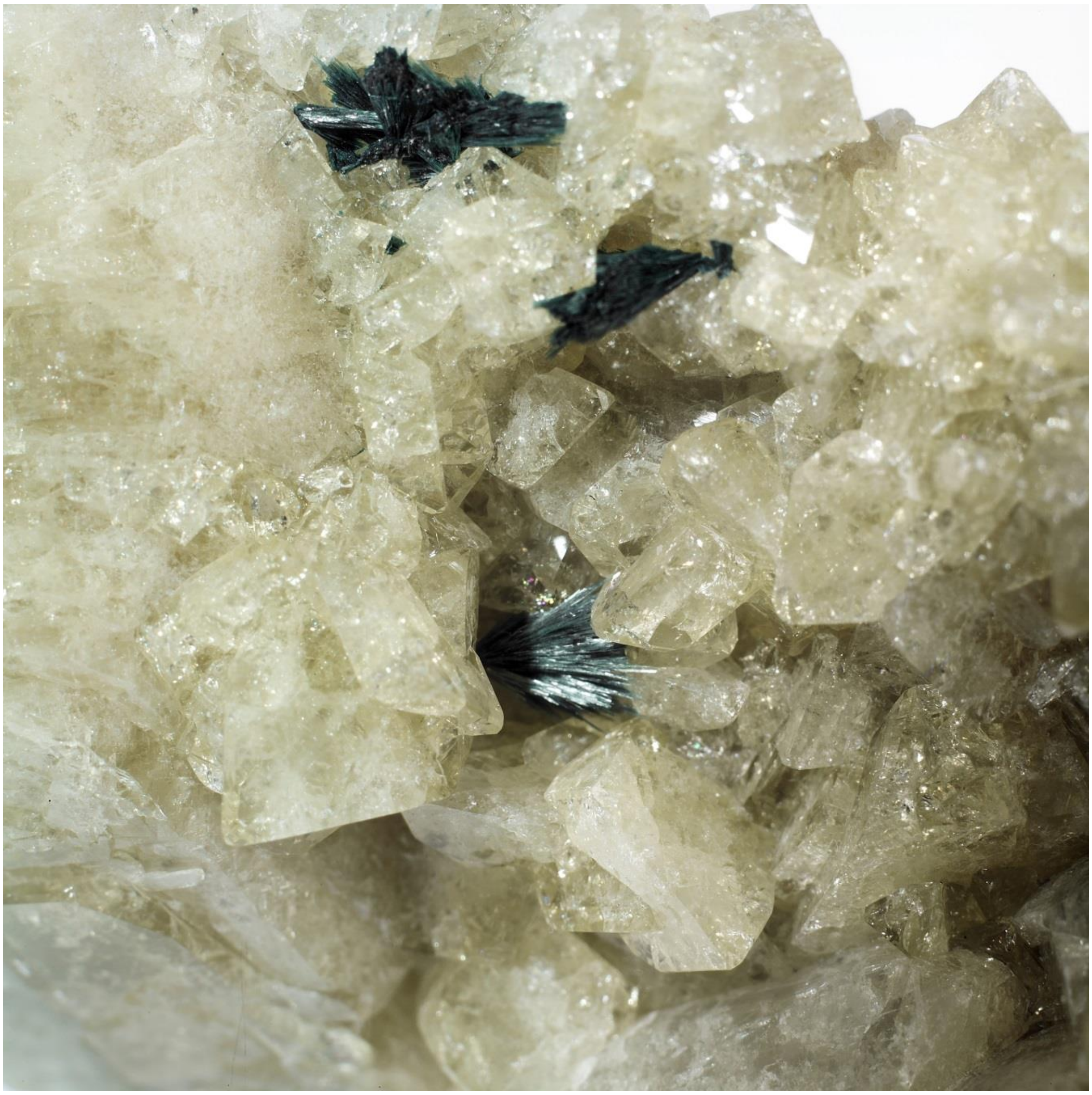

Figure 7.54. Souzalite on brazilianite from Córrego Frio granitic pegmatite, Linópolis, Divino das Laranjeiras, Minas Gerais. The upper cluster of souzalite crystals is 7 mm in the largest dimension. Specimen: Luiz A.D. Menezes Filho. Photo: Thales Trigo.

Figure 7.55. Souzalite from Córrego Frio granitic pegmatite, Linópolis, Divino das Laranjeiras, Minas Gerais. Dimensions: 30 × 35 mm. Donator: William T. Pecora. Museu de Ciências da Terra, Rio de Janeiro. Photo: Marcelo Lerner. Cornejo and Bartorelli (2020).

After the publication of four abstracts (Pecora and Fahey 1947, 1948a, b, c), the complete description of this mineral was published by Pecora and Fahey (1949a). A detailed description of the occurrence and the history of the discovery of this mineral was given by Cassedanne (1983). Sturman *et al.* (1981) also studied the souzalite type specimen and discovered that the X-ray powder-diffraction data given in the original description is incorrect. The powder pattern was prepared with Fe radiation, but the *d* values were calculated using Cu radiation wavelengths.

Occurrence. Córrego Frio granitic pegmatite, Linópolis district, Divino das Laranjeiras township, Minas Gerais. As a hydrothermal alteration product of scorzalite, with albite, arsenopyrite, beraunite, brazilianite, childrenite, dufrenite, fluorapatite, frondelite, garnet, jahnsite, microcline, muscovite, quartz, a roscherite-group mineral, sabugalite, strunzite, tapiolite, tourmaline, uraninite, wyllieite, and zircon (Cassedanne 1983). Also, known in other occurrences in Brazil and in the world.

Appearance and physical properties. Habit: coarse fibrous aggregates. Morphology: could not be determined. Twinning: polysynthetic, composition plane {001}; twin axis [010]. Color: dark green to blue-green. Streak: pale green. Luster: vitreous. Transparent.

Nonfluorescent under short- and long-wave ultraviolet light. Hardness (Mohs): 5½ to 6. Tenacity: not given. Cleavage: poor parallel to {001}. Fracture: not given. Density: 3.09 g/cm^3 (meas.), 3.08 g/cm^3 (calc.).

Optical properties. Biaxial (-), α 1.618, β 1.642, γ 1.652, 2*V* 68° (meas.), 65°(calc.). Dispersion $r > v$, strong, symmetrical. Pleochroism: *X* colorless, *Y* blue, *Z* colorless to pale yellow. Absorption: $X = Z < Y$. Orientation: *X* nearly normal to composition plane, *Z* nearly parallel to elongation (*b*-axis), $Z \wedge b = 10°$.

Chemical data. Analytical methods not specified: MgO 9.62, CaO 0.02, MnO 0.31, FeO 11.49, Al_2O_3 26.07, Fe_2O_3 2.65, P_2O_5 37.70, H_2O 12.04, SnO 0.04, TiO_2 0.07, total 100.01 wt.%. Empirical formula: $(Mg_{1.78}Fe^{2+}_{1.19}Mn_{0.03})_{\Sigma 3.00}(Al_{3.81}Fe^{3+}_{0.25})_{\Sigma 4.06}(PO_4)_{3.96}(OH)_{6.30}\cdot 1.83H_2O$. The ideal formula requires MgO 17.30, Al_2O_3 29.18, P_2O_5 40.63, H_2O 12.89, total 100.00 wt.%.

Crystallography. Triclinic, *P*1 or $P\bar{1}$, *a* 11.74(1), *b* 5.11(1), *c* 13.58(1) Å, α 90.92(8)°, β 99.08(8)°, γ 90.33(8)°, *V* 804.53 Å^3, *Z* 2, *a*:*b*:*c* = 2.2975:1:2.6575. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 6.72 (30) (002), 4.760 (60) (011), 3.386 (100) ($0\bar{1}3$), 3.341 (30) (013), 3.152 (60) ($1\bar{1}3$, 302), 3.086 (20) ($\bar{2}\bar{1}3$), 3.060 (40) ($\bar{2}13$), 2.921 (80) ($\bar{4}01$, 311), 2.553 (90) (020, $\bar{4}11$), 1.658 (20) ($\bar{2}26$, $0\bar{3}2$) (specimen from the Córrego Frio pegmatite). Le Bail *et al.* (2003) studied the crystal structure of a sample exactly in the middle of the souzalite/gormanite series, and found a different unit cell: $P\bar{1}$, *a* 7.2217(2), *b* 11.7812(3), *c* 5.1172(1) Å, α 90.160(2)°, β 109.942(1)°, γ 81.324(2)°, *V* 404.03 Å^3, *Z* 1.

Name. For Dr. Antonio José Alves de Souza (1896-1961), former Director of the Departamento Nacional da Produção Mineral, Rio de Janeiro. According to Leonardos (1955), the correct spelling is Sousa, and the name of the mineral should be sousalite.

Type material. Harvard Mineralogical Museum, Harvard University, Cambridge, Massachusetts, USA, type, 100680 (donator United States Geological Survey); and U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA, type C05863 (donator E.R. Swoboda, thru Canfield collection, 1948) and 160114 (donator U.S. Geological Survey, thru M.E. Mrose, 1983).

Relationship to other species. The Mg-dominant analog of gormanite.

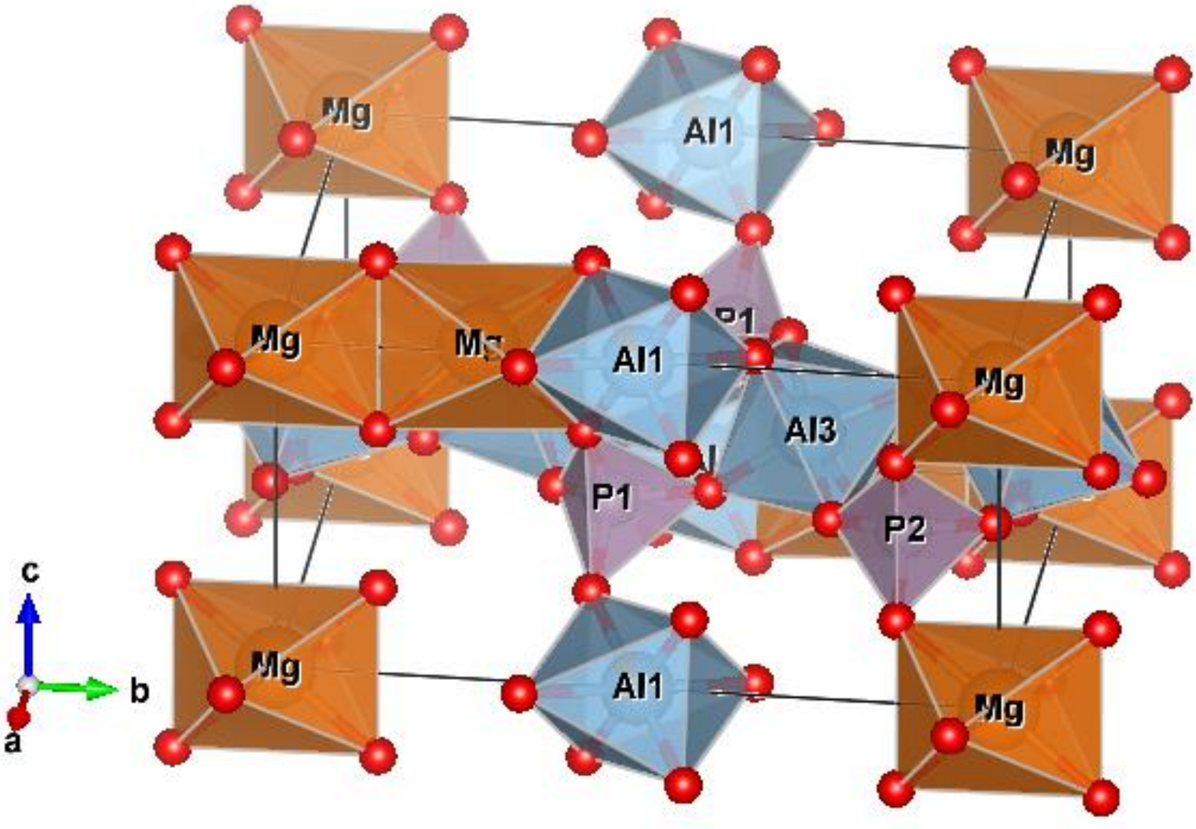

Figure 7.56. View of the crystal structure of souzalite (from Rapid Creek, Yukon, Canada), drawn using VESTA 3 (Momma and Izumi 2011). The sample is exactly in middle of the souzalite-gormanite series. Data from Le Bail *et al.* (2003).

Crystal structure. Infinite chains of alternating [MgO_6] and [AlO_6] octahedra sharing faces and/or edges, interconnected by corners with trimers of corner-sharing [AlO_6] octahedra, forming octahedral layers linked by [PO_4] groups (Le Bail *et al.* 2003).

See also. Scorzalite, brazilianite, and frondelite.

Moraesite

Lindberg *et al.* (1953)

$Be_2(PO_4)(OH)\cdot 4H_2O$, monoclinic

Other names: moraesita

Figure 7.57. Moraesite on ruifrancoite from the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. Field of view: 15 mm. Specimen and photo: Martin Slama.

Figure 7.58. The cotype specimen of moraesite from the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. Copyright: Musée de Minéralogie MINES ParisTech / Photo: Eloïse Gaillou. Catalog number of the specimen: ENSMP 50740.

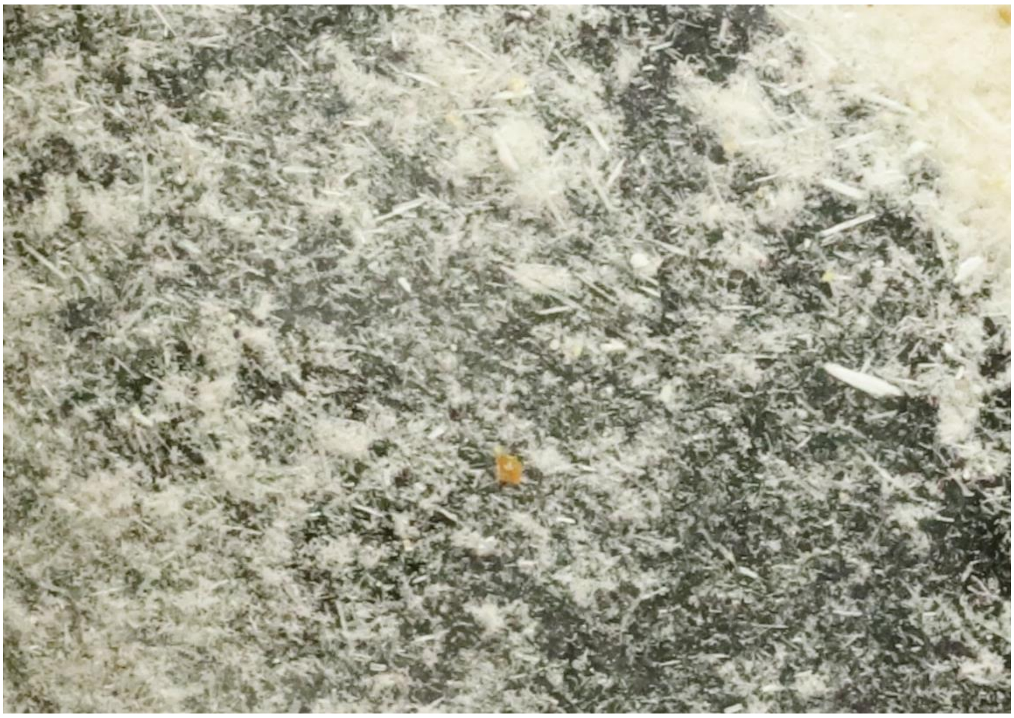

Figure 7.59. The cotype specimen of moraesite from the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. Detail of the inside of the bottle in the previous figure. Copyright: Musée de Minéralogie MINES ParisTech / Photo: Eloïse Gaillou. Catalog number of the specimen: ENSMP 50740.

Occurrence. The mineral occurs in the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais, which is the type locality of other eight phosphates [arrojadite-(PbFe), barbosalite, frondelite, faheyite, ruifrancoite, tavorite, jahnsite-(MnMnMg), and jahnsite-(NaMnMg); see notes about this occurrence under ruifrancoite], as a secondary alteration product. Also, found in other localities in Brazil and the world.

Appearance and physical properties. Habit: in tufted or radial aggregates, as fibrous coatings, or spherulitic masses on the walls of vugs that have developed in or adjacent to beryl, and on surfaces of albite, quartz, and muscovite. Moraesite frequently occurs on the botryoidal surfaces of frondelite and contains unaltered fragments of beryl. On exposed surfaces, crystals form a fragile and delicate assortment of individual needles that grade into crusts with a coarse fibrous structure. Crystals are minute laths with needle-like terminations, acicular parallel to *c*, and tabular on {001}. Forms: {100}, {111}, {130}, {131}. Color: white. Streak: white. Translucent. Hardness (Mohs): not given. Cleavage: {100} and {001}. Density: 1.805 g/cm^3 (meas.), 1.806 g/cm^3 (calc.).

Optical properties. Biaxial (-), α 1.462, β 1.482, γ 1.490, 2V 65° (meas.), 63.9°

(calc.). $Z = b$, $Y \wedge c = 11°$.

Chemical data. Unspecified methods: BeO 25.28, Fe_2O_3 0.11, Al_2O_3 n.d., P_2O_5 34.76, H_2O 39.80, Insol. 0.30, total 100.25 wt.%. Empirical formula: $Be_{2.05}(PO_4)_{0.99}(OH)_{1.13}\cdot3.90H_2O$. The ideal formula requires BeO 24.75, P_2O_5 35.12, H_2O 40.13, total 100.00 wt.%.

Crystallography. Monoclinic, *Cc*, *a* 8.55, *b* 36.9, *c* 7.13 Å, β 97.68°, *V* 2229.30 Å^3, *Z* 12, *a:b:c* = 0.2317:1:0.1932. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 7.00 (100) (130), 6.15 (40) (060), 5.28 (30) ($\bar{1}31$), 4.24 (60) (200), 3.278 (90) ($\bar{2}61$), 3.198 (30) (191), 3.071 (30) (0 12 0), 3.023 (60) (132), 2.819 (60) (0 12 1), 2.753 (30) (330) (specimen from Sapucaia).

Name. In honor of Dr. Luciano Jacques de Moraes (1896-1968), Brazilian geologist.

Type material. According to Lindberg *et al.* (1953), U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA (USNM 106, 577), and Museu Nacional, Rio de Janeiro. According to Lapaire (2020), the Smithsonian sample (type, donator W.T. Pecora, 1954) and École nationale supérieure des Mines de Paris, France, cotype, 50740 (donator A.L. de M. Barbosa, thru J. Cassedanne, 1969).

Relationship to other species. Isomorphous with bearsite, $Be_2AsO_4(OH)\cdot4H_2O$.

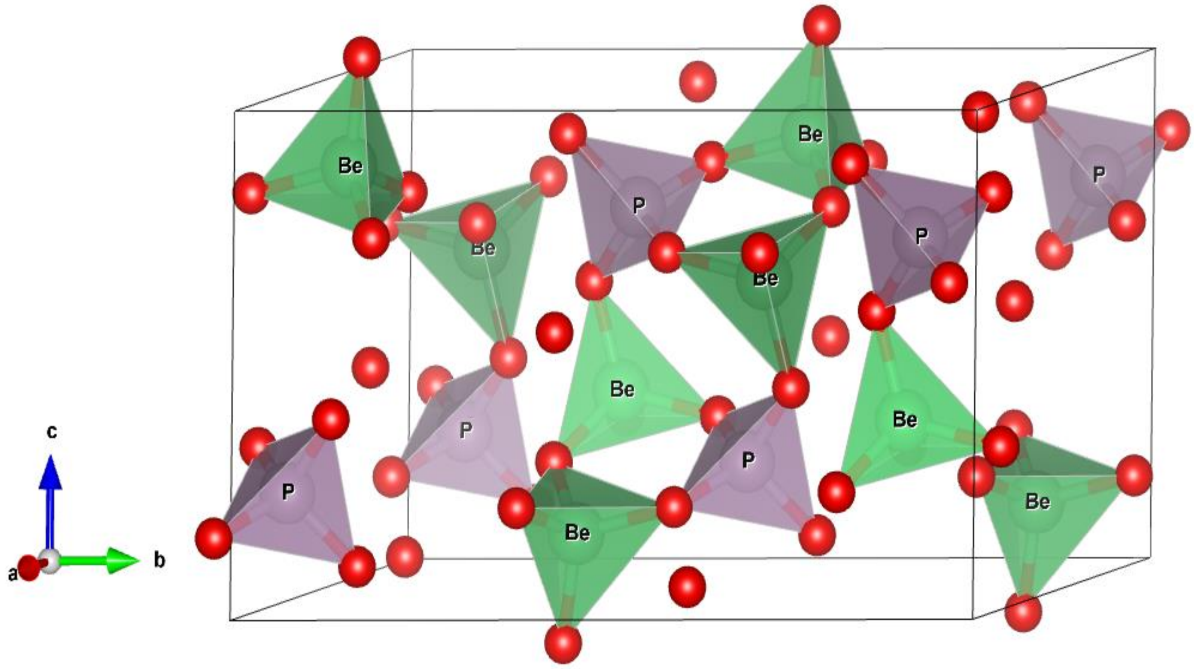

Figure 7.60. View of the crystal structure of moraesite [from Lavra do Eurico (Orico), Fazenda Humaitá, Medeiros, Minas Gerais], drawn using VESTA 3 (Momma and Izumi 2011). Data from Merlino and Pasero (1992).

Crystal structure. Determined by Merlino and Pasero (1992): The structure is characterized by infinite double chains, running along *c*, formed by [PO_4] and [$BeO_2(OH)H_2O$] tetrahedra. Within such chains three- and four-membered rings of tetrahedra occur. Additional water molecules, not linked to any cation, fill the large channels of the structure. Within each channel, the hydrogen bonds assume either of two schemes.

See also. Arrojadite-(PbFe), faheyite, barbosalite, frondelite, ruifrancoite, tavorite, jahnsite-(MnMnMg), jahnsite-(NaMnMg), whiteite-(MnMnMg), whiteite-(FeMgNa), unknown silky white mineral, mineral (b), lipscombite, and avelinoite.

Brandãoite

Menezes Filho *et al.* (2019)

$BeAl_2(PO_4)_2(OH)_2 \cdot 5H_2O$, triclinic

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Other names: brandãoíta

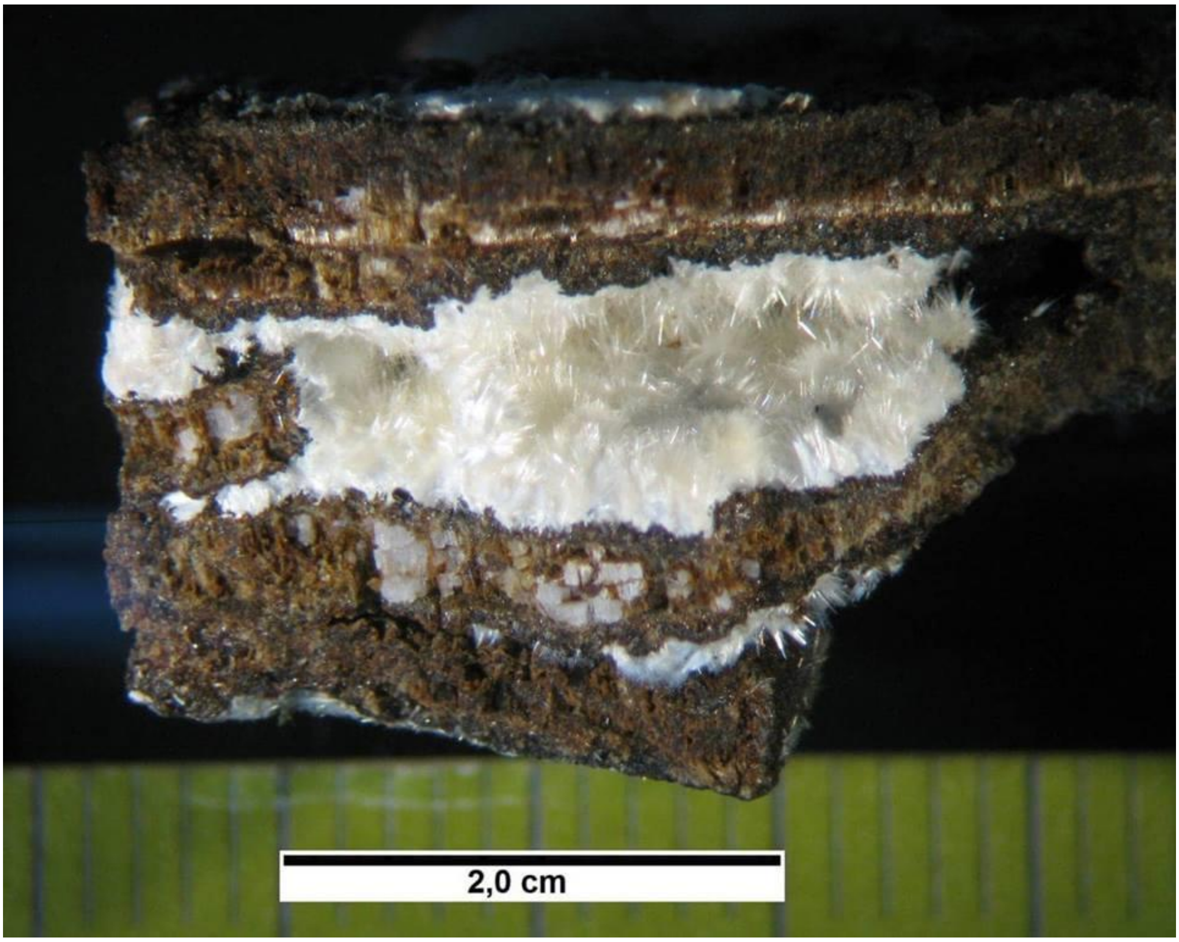

Figure 7.61. Brandãoite, atencioite, albite, and other minerals from the João Firmino mine, Pomarolli farm region, Linópolis, Divino das Laranjeiras, Minas Gerais. Specimen and photo: Paulo Roberto Gomes Brandão.

Occurrence. João Firmino mine, Pomarolli farm region, Linópolis, Divino das Laranjeiras, Minas Gerais, in an albite pocket of a granitic pegmatite, with other secondary phosphates, including beryllonite, atencioite and zanazziite. Besides quartz, microcline, albite, beryl, green tourmaline, spodumene and muscovite, the following phosphate-assemblage minerals have been described from the João Firmino pegmatite: montebrasite, autunite, brazilianite, childrenite–eosphorite, fluorapatite, phosphosiderite, frondelite, gormanite, heterosite– purpurite, hydroxylherderite, moraesite and roscherite–zanazziite (Chaves *et al.* 2005, Chaves and Scholz 2008). This mine is also the type locality of atencioite. The chemically similar mineral lefontite probably also occurs in the João Firmino mine (see discussion under atencioite).

Appearance and physical properties. Habit: acicular crystals <10 μm wide and <100 μm long that form compact, radiating spherical aggregates up to 1.0–1.5 mm across. Individual fibers within the aggregates generally consist of complex interpenetrating crystals in parallel growth about the fiber axis. Rare single-crystals are elongated along [100] and are terminated by (0kl) faces that are too small to index but are possibly {001}, {011} and {01$\bar{1}$} pinacoids, forming pseudo-hexagonal prisms. The flat orientation is perpendicular to {001}. Color: colorless in single-crystals and white in aggregates. Streak: white. Transparent. Luster: vitreous. Tenacity: brittle. Fracture: conchoidal. Hardness (Mohs): 6. It does not fluoresce in ultraviolet light. Cleavage and parting were not observed. Density: 2.353 g/cm^3 (calc.).

Optical properties. Biaxial (+), α 1.544(2), β 1.552(2), γ 1.568(2), 2*V* 69.7(10)° (meas.), 71.2° (calc.). No pleochroism was observed.

Chemical data. Chemical analysis of a 4 μm wide needle-shaped crystal by electron microprobe and secondary ion mass spectrometry gave P_2O_5 28.42, Al_2O_3 20.15, BeO 4.85, H_2O 21.47, total 74.89 wt.%. Empirical formula, normalized on the basis of 15 anions pfu with (OH) = 2 and (H_2O) = 5 *apfu* (from the crystal structure): $Be_{0.98}Al_{1.99}(PO_4)_{2.02}(OH)_2 \cdot 5H_2O$. The ideal formula requires BeO 6.63, Al_2O_3 27.04, P_2O_5 37.65, H_2O 28.67, total 100.00 wt.%.

Crystallography. Triclinic, $P\bar{1}$, *a* 6.100(4), *b* 8.616(4), *c* 10.261(5) Å, α 93.191(11), β 95.120(11), γ 96.863(11)°, *V* 532.1(8) Å^3, *Z* 2, *a*:*b*:*c* = 0.7080:1:1.1909. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 6.772 (82) (0$\bar{1}$1), 5.243 (85) ($\bar{1}$10), 4.982 (73) (101), 4.268 (100) (020), 3.846 (48) (021), 3.091 (53) ($\bar{1}$03), 2.789 (68) (0$\bar{3}$1), 2.712 (76) ($\bar{2}$02) (calculated pattern).

Name. After Professor Paulo Roberto Gomes Brandão (1944-), Department of Mining Engineering, Universidade Federal de Minas Gerais. Dr. Brandão specializes in the mineralogical characterization of ores and the development of improved ore-concentration techniques.

Type material. Holotype material is deposited in the collections of the Department of Natural History (Mineralogy), Royal Ontario Museum, Toronto, Ontario, Canada under catalog number M57443.

Relationship to other species. Brandãoite and lefontite are the only phosphate minerals known to contain essential Be and Al.

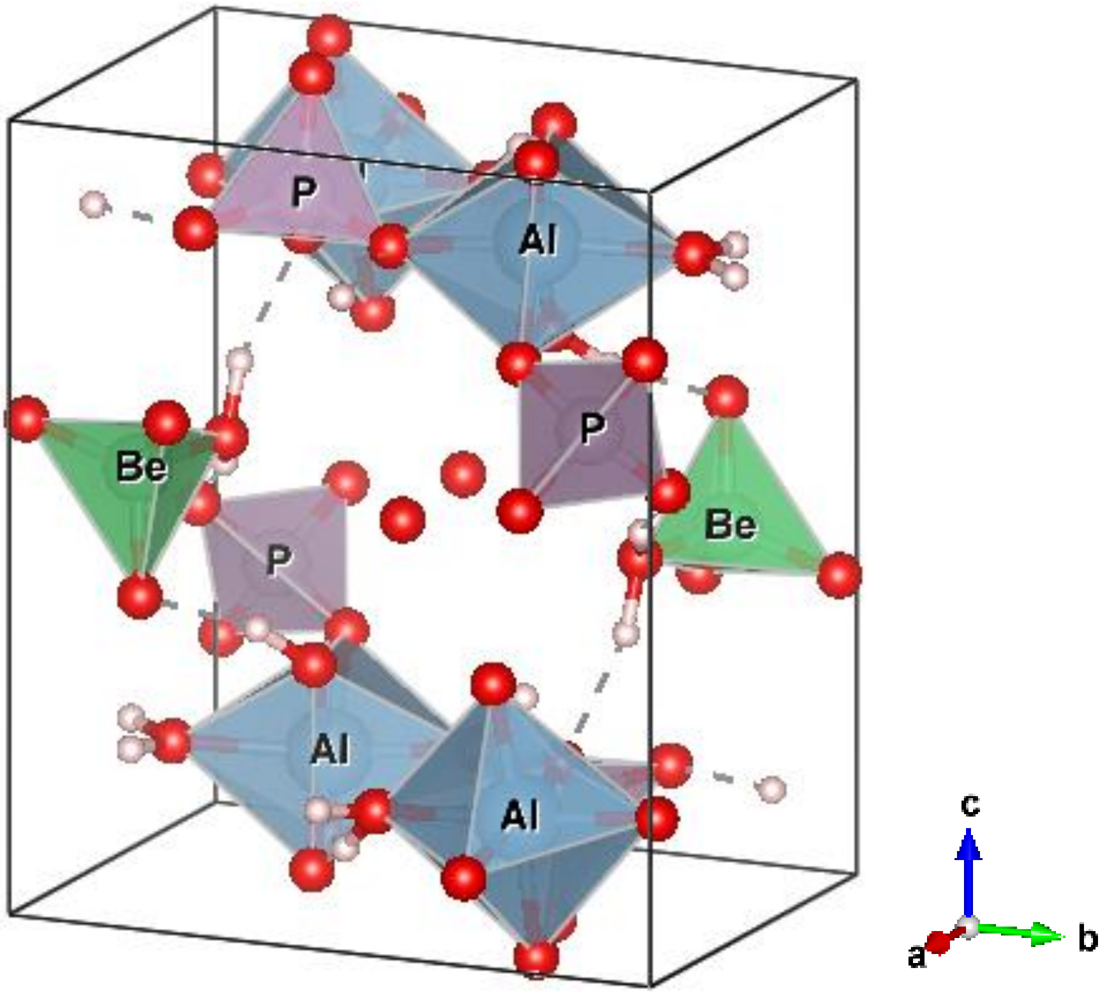

Figure 7.62. View of the crystal structure of brandãoite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Menezes Filho *et al.* (2019).

Crystal structure. There are two P sites, two Al sites, and one Be site. There are 15 anions, two of which are (OH) groups and five of which are (H_2O) groups. Be and P tetrahedra share corners to form a four-membered ring. Al octahedra share a common vertex to form a [$Al_2\varphi_{11}$] dimer, and these dimers are cross-linked by P tetrahedra to form a complex slab of polyhedra parallel to (001). These slabs are cross-linked by $BeO_2(OH)(H_2O)$ tetrahedra, with interstitial (H_2O) groups in channels that extend along [100].

See also. Atencioite, lefontite, frondelite, moraesite, brazilianite, and zanazziite.

Jahnsite-(MnMnMg)

Vignola *et al.* (2019a)

$Mn^{2+}Mn^{2+}Mg_2Fe^{3+}{}_2(PO_4)_4(OH)_2{\cdot}8H_2O$, monoclinic

Approved CNMNC - IMA 2017-118

Other names: jahnsita-(MnMnMg)

Figure 7.63. Jahnsite-(MnMnMg) from the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. Field of view: 1.5 mm. Specimen and Photo: Jhonatan Gomes.

Figure 7.64. Jahnsite-(MnMnMg) from the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. Field of view: 3.0 mm. Specimen and Photo: Jhonatan Gomes.

The occurrence of jahnsite-(MnMnMg) at the Sapucaia (Proberil) mine, Galileia, Minas Gerais, was quoted by Baijot *et al.* (2012). The name was applied without previous submission to IMA. Only microprobe data were published. New data were obtained from a specimen collected by Sergio Varvello [who also collected the type specimen of jahnsite-(MnMnMg)]. The complete paper was published by Vignola *et al.* (2019a) after approval by IMA.

Occurrence. The mineral occurs in the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais, which is the type locality of other eight phosphates [arrojadite-(PbFe), barbosalite, frondelite, faheyite, moraesite, ruifrancoite, tavorite, and jahnsite-(NaMnMg); see notes about this occurrence under ruifrancoite], as single-crystals or groups of crystals perched on albite crystals in hydrothermal cavities, hosted by a metasomatic unit of the pegmatite, composed of large lamellar aggregates of albite, in close association with frondelite, leucophosphite, and mangangordonite. Baijot *et al.* (2012) and Baijot (2015) described jahnsite-(MnMnMg) as an end member of the series, with jahnsite-(MnMnMg) to jahnsite-(CaMnMg) occurring as rim or intergrowths with ferrisicklerite, or as acicular yellow crystals.

Appearance and physical properties. Habit: prisms weakly elongated on [100], flattened on [010], and up to 200 or 250 µm in length. The crystals show a particular indented texture of (001) terminations. Forms: {011} prism, {001} prism, {100} pinacoid. Color: yellow to honey-colored or greenish-yellow. Streak: very pale yellow. Non-fluorescence at 254 nm (short wave) and 366 nm (long wave). Partially transparent. Luster: vitreous. Tenacity: brittle. Fracture: irregular. Twinning: by reflection on {001}. Hardness (Mohs): 4 (inferred). Cleavage: good or perfect on {001} Density: 2.625 g/cm^3 (calc.).

Optical properties. Biaxial (-), α 1.616(1), β 1.619(3), γ 1.656(2), 2*V* 74° (calc.) (sodium light, λ 589 nm). Optical orientation: α roughly perpendicular to the (001) cleavage. Dispersion: *r*>*v* strong. Pleochroism: *X* greenish-grey, *Y* yellow, Z greenish-yellow. *X*<*Z*<*Y*.

Chemical data.

Baijot *et al.* (2012): Microprobe data (39): Na_2O 0.64, K_2O 0.03, CaO 2.07, MgO 5.90, ZnO 0.04, MnO 12.98, FeO 6.50, Fe_2O_3 17.07, Al_2O_3 1.43, P_2O_5 33.37, SiO_2 0.21, H_2O (calc.) 19.20, total 99.44 wt.%. Empirical formula: $(Mn^{2+}_{0.55}Ca_{0.31}Na_{0.17})_{\Sigma 1.03}Mn^{2+}(Mg_{1.23}Fe^{2+}_{0.77})_{\Sigma 2.00}(Fe^{3+}_{1.81}Al_{0.23})_{\Sigma 2.04}(P_{3.97}Si_{0.03})O_{16}(OH)_2\cdot 8\,H_2O$.

Vignola *et al.* (2019a): Microprobe data (5): Na_2O 0.77, CaO 1.72, MgO 6.16, ZnO 0.12, MnO 17.41, FeO 1.79, Fe_2O_3 15.75, Al_2O_3 2.31, P_2O_5 34.45, H_2O 19.35 (calc.), total 99.83 wt.%. Empirical formula: $(Mn^{2+}_{0.50}Ca_{0.25}Na_{0.20})_{\Sigma 0.95}Mn^{2+}(Mg_{1.26}Mn^{2+}_{0.52}Fe^{2+}_{0.21}Zn_{0.01})_{\Sigma 2.00}(Fe^{3+}_{1.63}Al_{0.37})_{2.00}(PO_4)_4(OH)_{1.70}\cdot 8H_2O$.

The ideal formula requires MgO 9.73, MnO 17.13, Fe_2O_3 19.28, P_2O_5 34.28, H_2O 19.58, total 100.00 wt.%.

Crystallography. Monoclinic, *P*2/*a*, *a* 15.177(2), *b* 7.176(1), *c* 10.006(3) Å, β 110.01(2)°, *V* 1017.3(2) Å^3, *Z* 2, *a*:*b*:*c* = 2.115:1:1.394. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 9.282 (100) (001), 4.945 (39) (111), 4.627 (20) (002), 3.984 (18) (211), 3.521 (43) (112), 2.988 (52) ($21\bar{3}$), 2.842 (81) (022), 1.958 (27) (024).

Name. The MnMnMg member of the jahnsite subgroup, jahnsite group. The root name is in honor of Richard Henry Jahns (1915-1983), mineralogist and pegmatite expert, Stanford University, Palo Alto, California, USA.

Type material. Holotype material is deposited in the Mineralogical Collection of the Laboratoire de Minéralogie, University of Liège, Belgium (number 21140).

Relationship to other species. Jahnsite subgroup, jahnsite group (Kampf *et al.*

2018a).

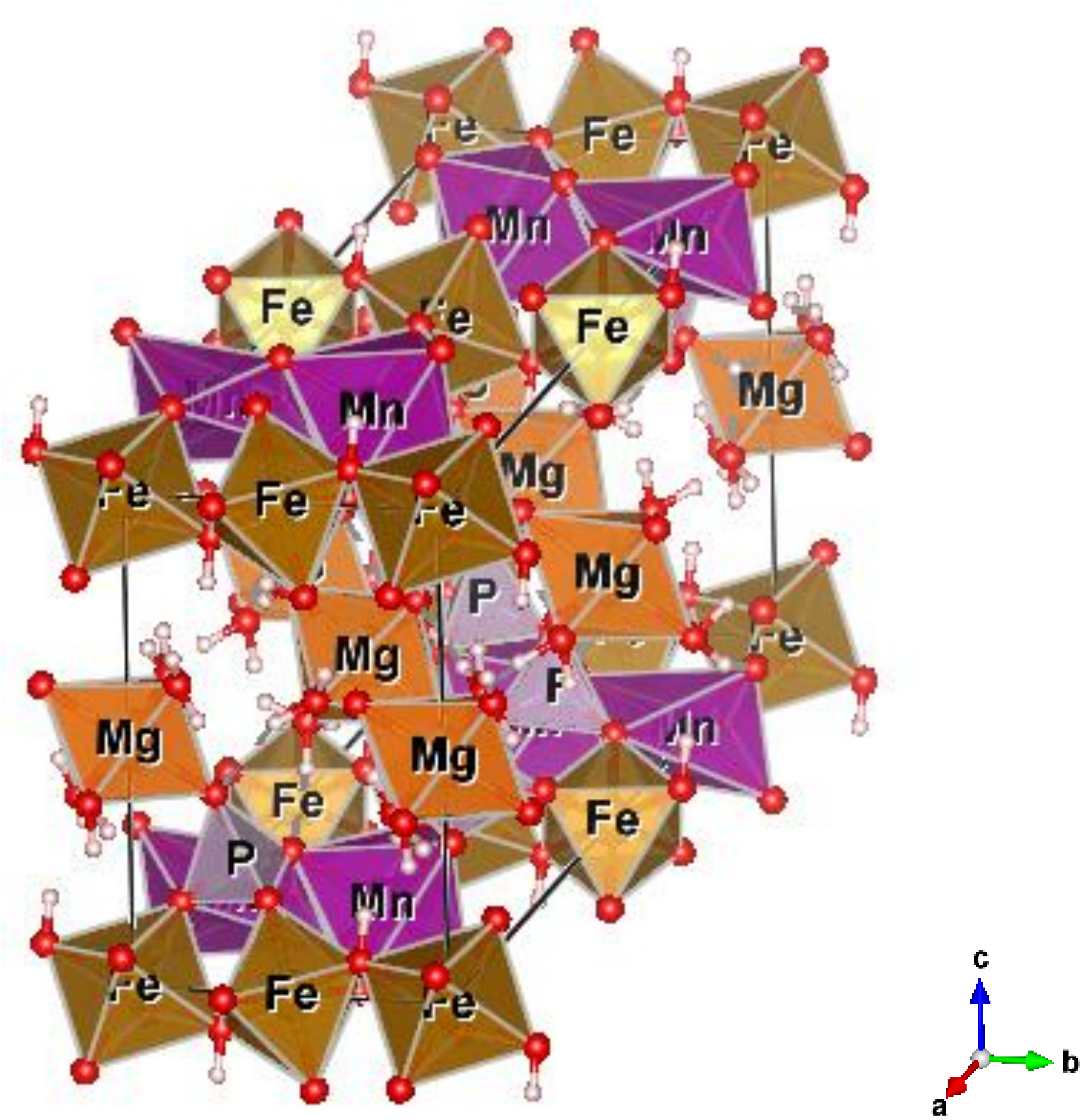

Figure 7.65. View of the crystal structure of jahnsite-(MnMnMg) (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Vignola *et al.* (2019a).

Crystal structure. The jahnsite-(MnMnMg) structure is characterized by a chain of $M3^{3+}$ octahedral sites linked on the opposite corner via OH anions. The chains are linked together through perpendicular dense slabs with composition $[XM1M3_2(OH)_2(PO_4)_4]^{4-}$ parallel to {001}, which are bridged in the *c* direction by PO_4 corner-sharing to $M2$-$(O,H_2O)_6$ octahedra, with X = Mn^{2+}, $M1$ = Mn^{2+}, $M2$ = Mg, and $M3$ = Fe^{3+}.

See also. Arrojadite-(PbFe), barbosalite, frondelite, faheyite, moraesite, ruifrancoite, tavorite, jahnsite-(NaMnMg), jahnsite-(MnMnFe), whiteite-(CaFeMg), whiteite-(MnFeMg), whiteite-(MnMnMg), whiteite-(FeMgNa), unknown silky white mineral, mineral (b), lipscombite, and avelinoite.

Jahnsite-(NaMnMg)

Kampf *et al.* (2018b)

(Na,Ca)$Mn^{2+}(Mg,Fe^{3+})_2Fe^{3+}{}_2(PO_4)_4(OH)_2\cdot 8H_2O$, monoclinic

Approved CNMNC - IMA 2018-017

Other names: jahnsita-(NaMnMg)

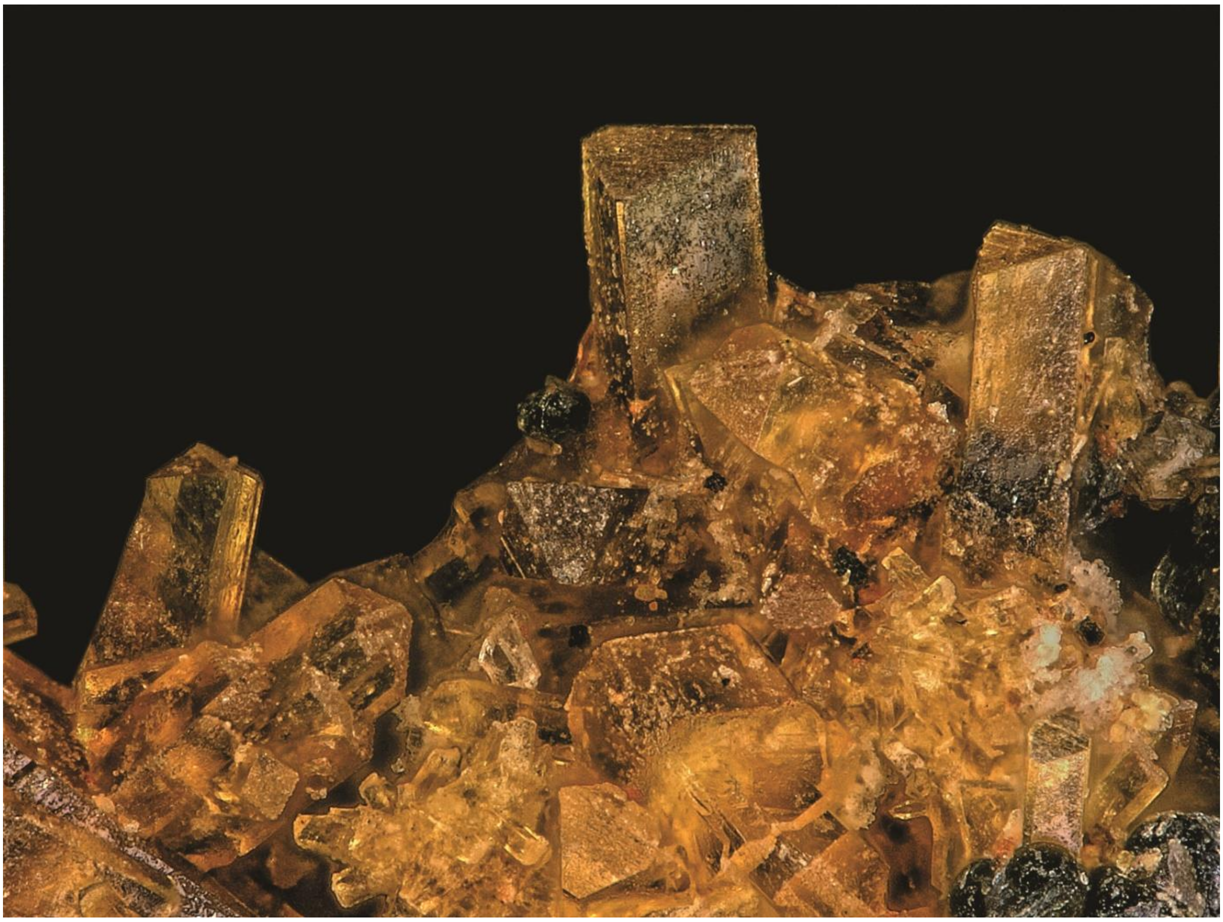

Figure 7.66. Twinned jahnsite-(NaMnMg) prisms with black rockbridgeite from the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. Field of view: 0.84 mm across. Kampf *et al.* (2018b).

Jahnsite-(NaMnMg) has been found at two localities. The holotype specimen was collected in 2010 by one of the authors [Sergio Varvello, who also collected the type specimen of jahnsite-(MnMnMg)] on the dumps of the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais.The cotype specimen was collected in 1993 from the White Rock No. 2 quarry, in the Bimbowrie Conservation Park, Olary, South Australia. Jahnsite-(NaMnMg) was previously reported from the Tip Top pegmatite, South Dakota, USA, by Kampf *et al.* (2008), forming small zones in crystals that were mostly jahnsite-(NaFeMg); however, the limited extent of these zones did not permit the full characterization of the species. The data of the Brazilian specimen are presented below.

Occurrence. The mineral occurs in the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais, which is the type locality of other eight phosphates [arrojadite-(PbFe), barbosalite, frondelite, faheyite, moraesite, ruifrancoite, tavorite, and jahnsite-(MnMnMg); see notes about this occurrence under ruifrancoite], in a matrix consisting mostly of frondelite and albite, in association with meurigite-K (K slightly dominant over Na), phosphosiderite, and strengite. Jahnsite-(NaMnMg) crystals are found growing directly on the surfaces of altered albite blades, which presumably are the source of the Na.

Appearance and physical properties. Habit: prisms elongate on [100] up to 0.5 mm long. Color: light orange to orange-yellow. Streak: very pale yellow. Non-fluorescence at 254 nm (short wave) and 366 nm (long wave). Transparent. Luster: vitreous. Tenacity: brittle. Fracture: irregular and stepped (splintery). Twinning: ubiquitously twinned by reflection on {001}. Hardness (Mohs): about 4. Cleavage: perfect on {001} Density: 2.68 g/cm^3 (meas.), 2.684 g/cm^3 (calc.). At room temperature, slowly soluble in dilute HCl.

Optical properties. Biaxial (-), α 1.642(1), β 1.675(1), γ 1.677(1), 2V 27(2) (meas.), 27.2° (calc.). Optical orientation: $Z = b$; X^$c = 51°$ in obtuse β. Dispersion: $r > v$ very strong. Pleochroism: X colorless, Y and Z orange-yellow. $X < Y \approx Z$.

Chemical data. Microprobe data (14): Na_2O 2.16, CaO 1.73, MgO 7.64, MnO 8.27, Fe_2O_3 23.83, Al_2O_3 1.31, P_2O_5 35.23, H_2O (calc.) 20.31, total 100.48 wt.%. Empirical formula: $(Na_{0.56}Ca_{0.25}Mn^{2+}_{0.09})_{\Sigma 0.90}(Mn^{2+}_{0.85}Fe^{3+}_{0.15})_{\Sigma 1.00}(Mg_{1.53}Fe^{3+}_{0.47})_{\Sigma 2.00}(Fe^{3+}_{1.79}Al_{0.21})_{\Sigma 2.00}(PO_4)_4(OH)_{1.83}(H_2O)_{8.17}$ The end-member formula for jahnsite-(NaMnMg), $NaMn^{2+}Mg_2Fe_2(PO_4)_4(OH)_2(H_2O)_8$, is not charge balanced. Charge balance is attained by Ca and Mn^{2+} substituting at the X site and Fe^{3+} and/or Mn^{3+} substituting at the M1 and M2 sites.

Crystallography. Monoclinic, $P2/a$, a 15.1045(15), b 7.1629(2), c 9.8949(7) Å, β

110.640(7)°, *V* 1001.83(13) Å^3, *Z* 2, *a:b:c* = 2.1087:1:1.3810. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 9.29 (100) (001), 5.02 (27) (210), 4.91 (30) (111), 3.546 (32) (31$\bar{2}$, 400), 2.975 (26) (401), 2.834 (91) (022), 2.601 (33) (42$\bar{1}$), 1.9436 (33) (232, 40$\bar{5}$, 024).

Name. The NaMnMg member of the jahnsite subgroup, jahnsite group. The root name is in honor of Richard Henry Jahns (1915-1983), mineralogist and pegmatite expert, Stanford University, Palo Alto, California, USA.

Type material. The holotype specimen from the Sapucaia mine is housed in the collections of the Mineral Sciences Department, Natural History Museum of Los Angeles County, Los Angeles, California, USA, catalog number 66701.

Relationship to other species. Jahnsite subgroup, jahnsite group (Kampf *et al*. 2018a).

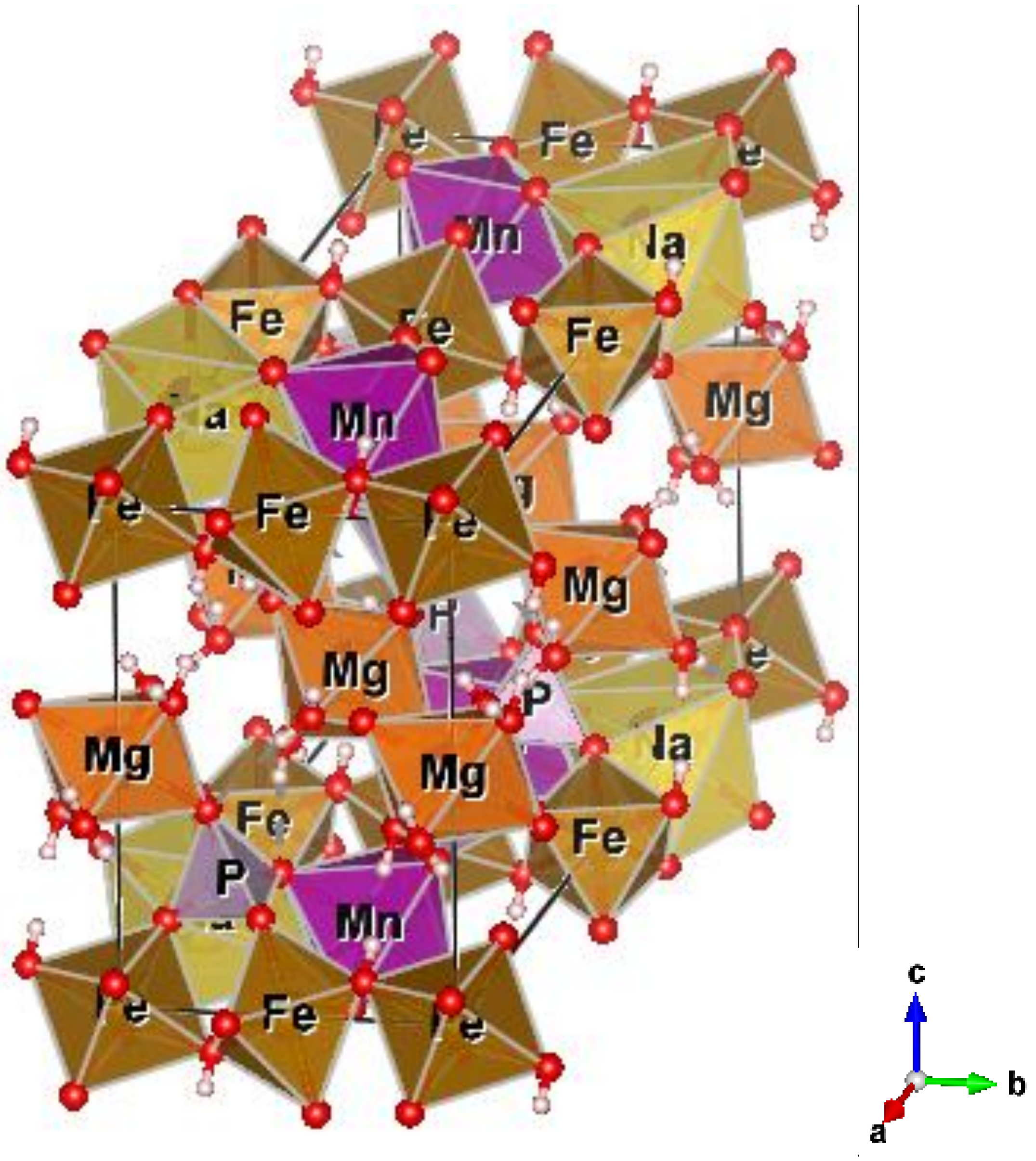

Figure 7.67. View of the crystal structure of jahnsite-(NaMnMg) (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Kampf *et al.* (2018b).

Crystal structure. The jahnsite-(NaMnMg) structure is characterized by a chain of $M3^{3+}$ octahedral sites linked on opposite corner via OH anions. The chains are linked together through perpendicular dense slabs with composition $[XM1M3_2(OH)_2(PO_4)_4]^{4-}$ parallel to {001}, which are bridged in the *c* direction by PO_4 corner-sharing to $M2$-$(O,H_2O)_6$ octahedra, with X = Na, $M1$ = Mn^{2+}, $M2$ = Mg, and $M3$ = Fe^{3+}.

See also. Arrojadite-(PbFe), barbosalite, frondelite, faheyite, moraesite, ruifrancoite, tavorite, jahnsite-(MnMnMg), jahnsite-(MnMnFe), whiteite-(CaFeMg), whiteite-

(MnFeMg), whiteite-(MnMnMg), whiteite-(FeMgNa), unknown silky white mineral, mineral (b), lipscombite, and avelinoite.

Jahnsite-(MnMnFe)

Baijot *et al.* (2014)

$Mn^{2+}Mn^{2+}Fe^{2+}_2Fe^{3+}_2(PO_4)_4(OH)_2·8H_2O$, monoclinic

Type occurrence is not Brazil

Other names: jahnsita-(MnMnFe)

The occurrence of this mineral in the LCT-type granitic pegmatite at the Jocão (Cigana) mine, Conselheiro Pena, Minas Gerais, was quoted by Baijot *et al.* (2014). The name was published without submission to IMA. It is deep yellow and non-pleochroic. Only microprobe data (mean of 8) were published: MnO 12.34, FeO 18.41, MgO 4.19, CaO 1.95, ZnO 0.03, Na_2O 0.78, K_2O 0.01, Fe_2O_3 12.04, Al_2O_3 0,63, P_2O_5 33.53, SiO_2 0.00, H_2O (calc.) 19.15, total 103.06 wt.%. Empirical formula $(Fe^{2+}_{2.17}Mn^{2+}_{1.47}Fe^{3+}_{1.28}Mg_{0.88}Ca_{0.29}Na_{0.21}Al_{0.10})_{\Sigma 6.40}(PO_4)_4(OH)_2·8H_2O$. The published composition seems to have an error due to too high cation totals with 6.40 *apfu*, exceeding the maximum possible 6 *apfu* as structurally available cation positions in the jahnsite structure. The ideal formula requires MnO 15.92, FeO 16.12, Fe_2O_3 17.92, P_2O_5 31.85, H_2O 18.20, total 100.00 wt.%. This is the type locality of correianevesite.

Later, the complete description of this mineral was made, but another type locality was defined, the Malpensata Pegmatite, Olgiasca, Colico Municipality, Lecco Province, Italy (Vignola *et al.* 2019b).

See also. Correianevesite, jahnsite-(MnMnMg), jahnsite-(NaMnMg), whiteite-(CaFeMg), whiteite-(MnFeMg), whiteite-(FeMgNa), and whiteite-(MnMnMg).

Whiteite-(CaFeMg)

Moore and Ito (1978a)

$CaFe^{2+}Mg_2Al_2(PO_4)_4(OH)_2\cdot 8H_2O$, monoclinic

Approved CNMMN - IMA 1975-001

Other names: whiteite-(CaFe^{2+}Mg), whiteite-(CaFeMg), whiteite-(Ca), whiteíta, whiteite, “the type witheite”

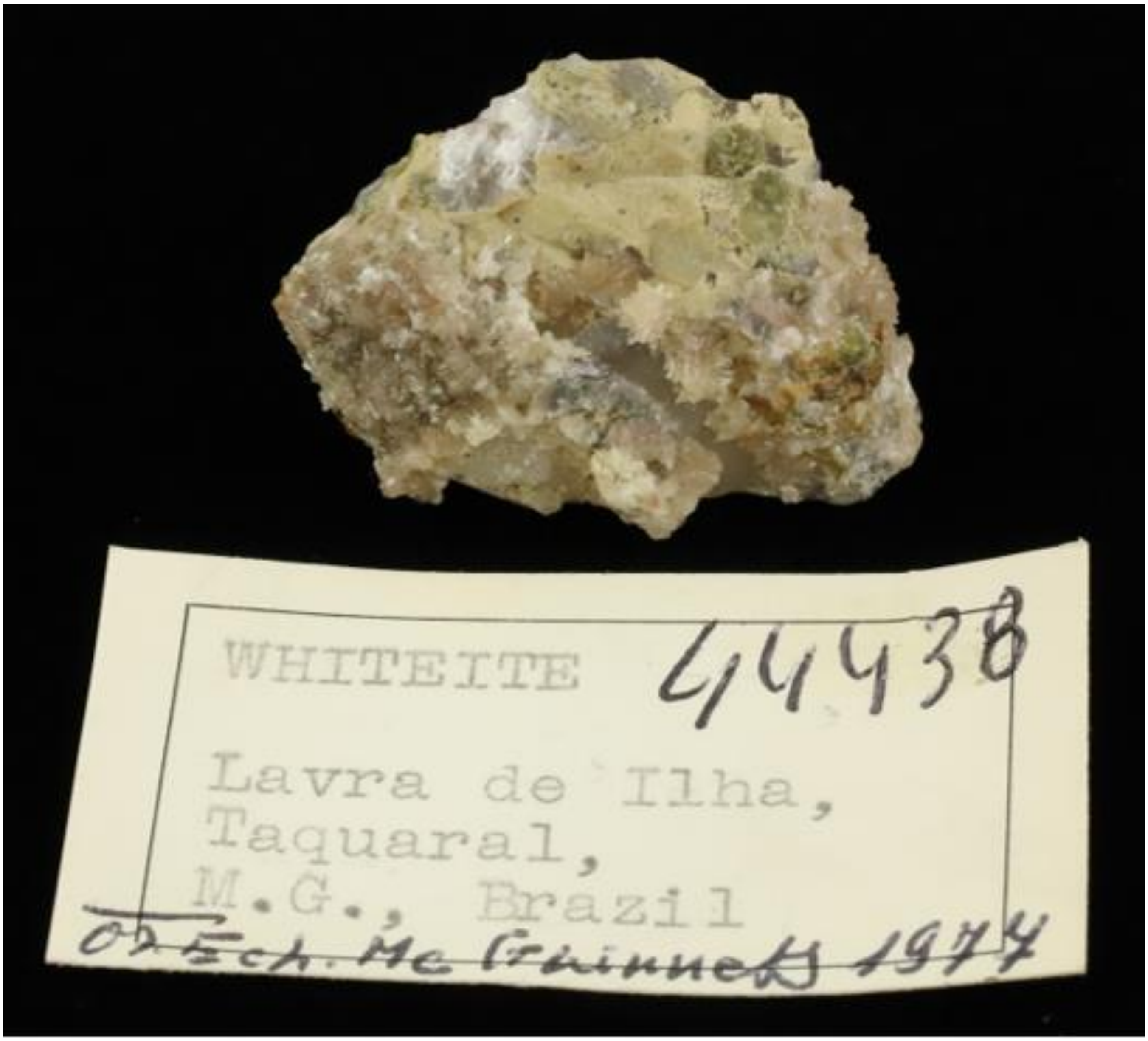

Figure 7.68. Whiteite from Lavra da Ilha, Taquaral, Minas Gerais. Dimensions: 3.6 × 2.8 × 2.4 cm. Copyright: Musée de Minéralogie MINES ParisTech / Photo : Eloïse Gaillou. Catalog number of the specimen: ENSMP 44438.

Figure 7.69. Whiteite from Lavra da Ilha, Taquaral, Minas Gerais. Detail of the previous figure. Copyright: Musée de Minéralogie MINES ParisTech / Photo: Eloïse Gaillou. Catalog number of the specimen: ENSMP 44438.

Originally, Moore and Ito (1978a) considered whiteite-(CaFeMg) and whiteite-(MnFeMg) as one species (only one CNMMN proposal was voted), but they suggested a series with established members whiteite-(CaFe^{2+}Mg) and whiteite-(Mn^{2+}Fe^{2+}Mg). They quoted whiteite-(CaFeMg) as “the type whiteite” and whiteite-(MnFeMg) as “Ca-poor variant”. The names whiteite-(Ca) and whiteite-(Mn) were applied by White (1990).

Occurrence. Lavra da Ilha pegmatite, on an island in the Jequitinhonha River, approximately 3 km north of Taquaral, Itinga, in north-eastern Minas Gerais. The associated minerals are colorless and pink quartz (euhedral crystals), eosphorite, muscovite as greenish crystals, brown sphalerite, columbite-tantalite, cassiterite, beryl, amblygonite, albite, microcline, elbaite, rockbridgeite, montgomeryite, wardite, apatite, triphylite, vivianite, whiteite-(MnFeMg), atencioite, and zanazziite (Cassedanne 1987 and White 1990). This is also the type locality of whiteite-(MnFeMg) and zanazziite. Also, known from other Brazilian and world occurrences.

Appearance and physical properties. Habit: bunched aggregates of small (1 to 5 mm) tabular, curved crystals. Forms: {001} and $\{\bar{1}11\}$; the form {001} is very large and consequently, the crystals are tabular with a rhomb-shaped outline. Twinning: crystals invariably twinned by reflection on {001}, imparting a pseudo-orthorhombic appearance. Color: tan. Translucent. Hardness (Mohs): 3 to 4. Cleavage: {001} good to perfect. Density: 2.58 g/cm^3 (meas.), 2.51 g/cm^3 (calc.).

Optical properties. Biaxial (+), α 1.580(3), β 1.585(3), γ 1.590(3). Mean calculated *n* (Gladstone-Dale) 1.58, 2*V* 40 to 50° (meas.). $\alpha // b$, $\beta // a$.

Chemical data. Microprobe analysis: CaO 6.0, MgO 10.5, MnO 3.1, FeO 6.1, Al_2O_3 12.0, P_2O_5 36.0, H_2O not analyzed, total 73.7 wt.%. Empirical formula: $(Ca_{0.84}Mn^{2+}_{0.16})_{\Sigma 1.00}(Fe^{2+}_{0.67}Mn^{2+}_{0.18}Mg_{0.05})_{\Sigma 0.90}Mg_{2.00}Al_{1.86}(PO_4)_{4.00}(OH)_{1.38}\cdot 8H_2O$. The ideal formula requires CaO 7.41, FeO 9.50, MgO 10.65, Al_2O_3 13.48, P_2O_5 37.52, H_2O 21.44, total 100.00 wt.%.

Crystallography. Monoclinic, *P*2/*a*. *a* 14.90(4), *b* 6.98(2), *c* 10.13(2) Å, β 113°07(10)’, V 968.95 Å^3, *Z* 2, *a*:*b*:*c* = 2.135:1:1.451. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 9.304 (100) (001), 5.593 (15) (011), 4.849 (20) ($\bar{2}02$), 4.660 (30) (002), 3.487 (15) (020), 2.946 (20) ($\bar{4}03$), 2.863 (15) (401), 2.789 (65) (022), 2.542 (20) ($\bar{4}21$) and 1.936 (20) ($\bar{4}32$).

Name. The nomenclature of the jahnsite group is based on a root name followed by parentheses containing three chemical suffixes. The root name whiteite is in honor of John S. White, Jr. (b. 1933), retired curator-in-charge of minerals at the Smithsonian Institution; founder, editor, and publisher of the *Mineralogical Record*. The chemical suffixes are based upon the dominant cations in the four non-tetrahedral cation sites in the structure, designated *X*, *M*1, *M*2, and *M*3. (Actually, *M*2 and *M*3 each consist of two very similar cation sites.) The generalized formula is $XM1M2_2M3_2(PO_4)_4(OH)_2\cdot 8H_2O$. The *M*3 site determines the root name, whiteite if *M*3 is Al^{3+} and jahnsite if *M*3 is Fe^{3+}. The chemical elements in the remaining three sites, *X*, *M*1, and *M*2 are combined into the extension (Kampf *et al.* 2008).

Type material. U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA, type, 123013 (donator R.A. Kosner, 1971). In addition, Lapaire (2020) quoted: Ecole nationale supérieure des Mines de Paris, France, type (donator P.B. Moore, 1978). However, there are two whiteite specimens in this museum: (1) one from Blow River, Yukon Territory, Canada, catalog number 51065, donated by Moore in 1977 [studied by Moore and Ito (1978a)]; and (2) one from Lavra da Ilha, not a type (see Figures 7.68 and 7.69), acquired through McGuinness, also in 1977 (Eloïse Gaillou, personal communication, 2020).

Relationship to other species. Whiteite subgroup, jahnsite group (Kampf *et al.* 2018a).

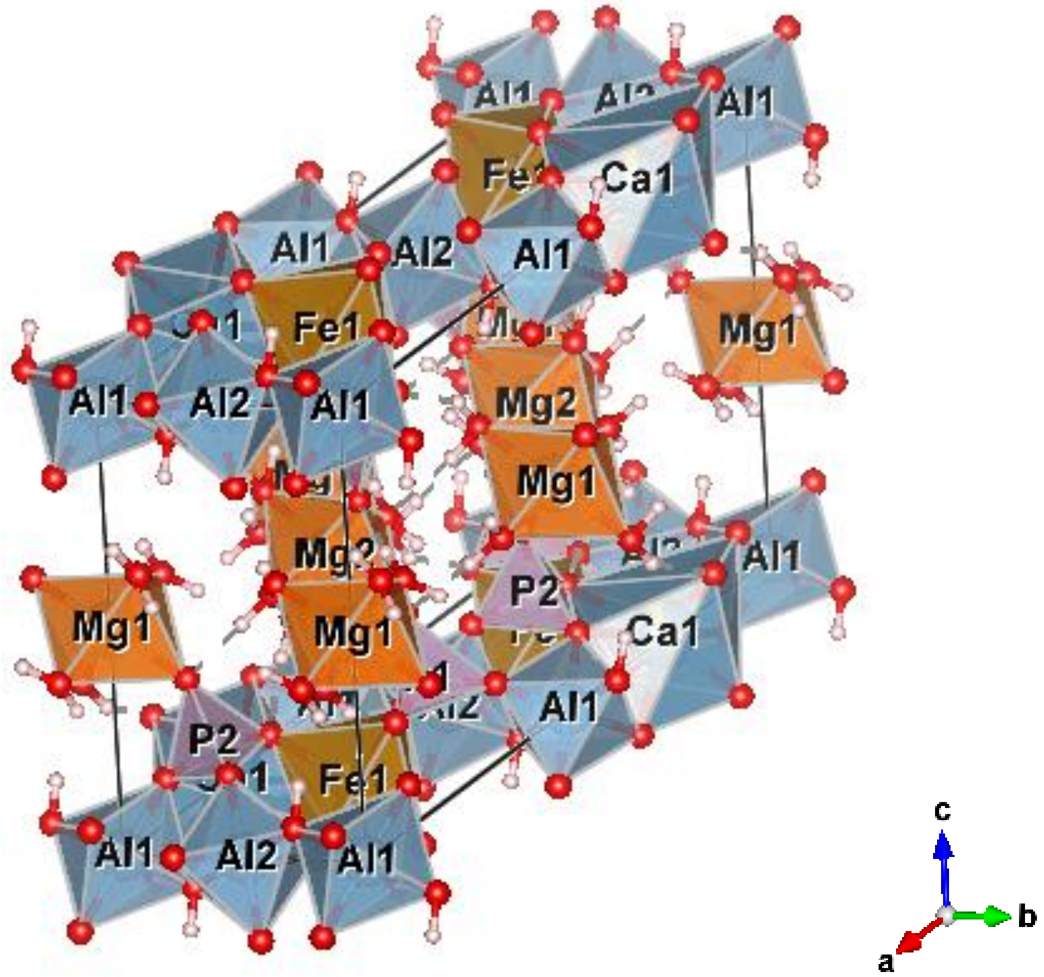

Figure 7.70. View of the crystal structure of whiteite-(CaFeMg) (from Crosscut Creek, Yukon, Canada), drawn using VESTA 3 (Momma and Izumi 2011). Data from Capitelli *et al.* (2011).

Crystal structure. The whiteite-(CaFeMg) structure is characterized by a chain of $M3^{3+}$ octahedral sites linked on opposite corner via OH anions. The chains are linked together through perpendicular dense slabs with composition $[XM1M3_2(OH)_2(PO_4)_4]^{4-}$ parallel to {001}, which are bridged in the *c* direction by PO_4 corner-sharing to $M2$-$(O,H_2O)_6$ octahedra, with X = Ca, $M1 = Fe^{2+}$, $M2$ = Mg, and $M3$ = Al, determined for whiteite-(CaFeMg) from Crosscut Creek, Yukon, Canada. Phosphorus atoms display tetrahedral (PO_4) coordination, while magnesium, iron(II) and aluminum are in regular octahedral coordination; calcium displays a complex CaO_8 coordination. $MgO_2(H_2O)_4$, FeO_6, $AlO_4(OH)_2$, CaO_8 polyhedra and (PO_4) groups are arranged to form a three-dimensional framework via edge- and vertex-sharing arrangements. Strong O—H … O hydrogen bonds contribute to stabilizing the array (Capitelli *et al.* 2011).

See also. Jahnsite-(MnMnMg), jahnsite-(NaMnFe), jahnsite-(MnMnFe), whiteite-(MnFeMg), whiteite-(MnMnMg), whiteite-(FeMgNa), atencioite, and zanazziite.

Whiteite-(MnFeMg)

Moore and Ito (1978a)

$Mn^{2+}Fe^{2+}Mg_2Al_2(PO_4)_4(OH)_2 \cdot 8H_2O$, monoclinic

Approved CNMMN - IMA 1975-001

Other names: whiteite-($Mn^{2+}Fe^{2+}Mg$), whiteite-(Mn), whiteíta-(MnFeMg), whiteíta, whiteite, “Ca-poor variant of whiteite”

For historical data on whiteite-(MnFeMg) see the text under whiteite-(CaFeMg).

Occurrence. Lavra da Ilha pegmatite, Itinga, Minas Gerais [see notes about this occurrence under whiteite-(CaFeMg)]. A second occurrence of whiteite-(MnFeMg) was described at the Boa Vista mine, Galileia, Minas Gerais (Cassedanne and Cassedanne 1978). Also, in other Brazilian and worldwide occurrences.

Appearance and physical properties. Habit: large (up to 1.5 or 2 cm) thick tabular individuals, curved crystals. Forms: {001} and {$\bar{1}$11} nearly equally developed, forming a canoe-shaped outline to the crystals; this appearance is made more pronounced by the curved aspect of the {$\bar{1}$11} faces resulting in almond-shaped cross-sections. Twinning:

crystals invariably twinned by reflection on {001}, imparting a pseudo-orthorhombic appearance. Color: chocolate brown. Translucent. Hardness (Mohs): 3 to 4. Cleavage: {001} good to perfect. Density 2.67 g/cm^3 (meas.), 2.62 g/cm^3 (calc.).

Optical properties. Biaxial (+), α 1.575(5), β 1.585(5), γ 1.595(5), *n* mean calculated (Gladstone-Dale) 1.59, 2*V* 80 to 90º (meas.), $\alpha \perp$ {001}.

Chemical data. Microprobe analysis: CaO 1.4, MgO 10.1, MnO 7.6, FeO 7.9, Al_2O_3 12.7, P_2O_5 36.4, H_2O not analyzed, total 76.1 wt.%. Empirical formula: $(Mn^{2+}_{0,81}Ca_{0,19})_{\Sigma1.00}(Fe^{2+}_{0,86}Mn^{2+}_{0,03})_{\Sigma0.89}Mg_{1.95}Al_{1.94}(PO_4)_4(OH)_{1.50}\cdot8H_2O$. The ideal formula requires MnO 9.20, FeO 9.31, MgO 10.45, Al_2O_3 13.22, P_2O_5 36.80, H_2O 21.02, total 100.00 wt.%.

Crystallography. Monoclinic, *P*2/*a*. *a* 14.99(2), *b* 6.96(1), *c* 10.14(1) Å, β 113°19(6)’, *V* 971.51 Å^3, *Z* 2, *a*:*b*:*c* = 2.154:1:1.457. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 9.318 (100) (001), 5.598 (30) (011), 4.824 (50) ($\bar{2}02$), 4.644 (40) (002), 3.518 (35) ($\bar{4}02$), 3.454 (30) (112), 3.245 (35) (021), 2.948 (45) ($\bar{4}03$), 2.776 (90) ($\bar{3}20$), 1.927 (30) ($\bar{4}15$).

Name. See whiteite-(CaFeMg).

Type material. U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA, holotype, 161211 (found in the collection, polished section).

Relationship to other species. Whiteite subgroup, jahnsite-group (Kampf *et al.* 2018a).

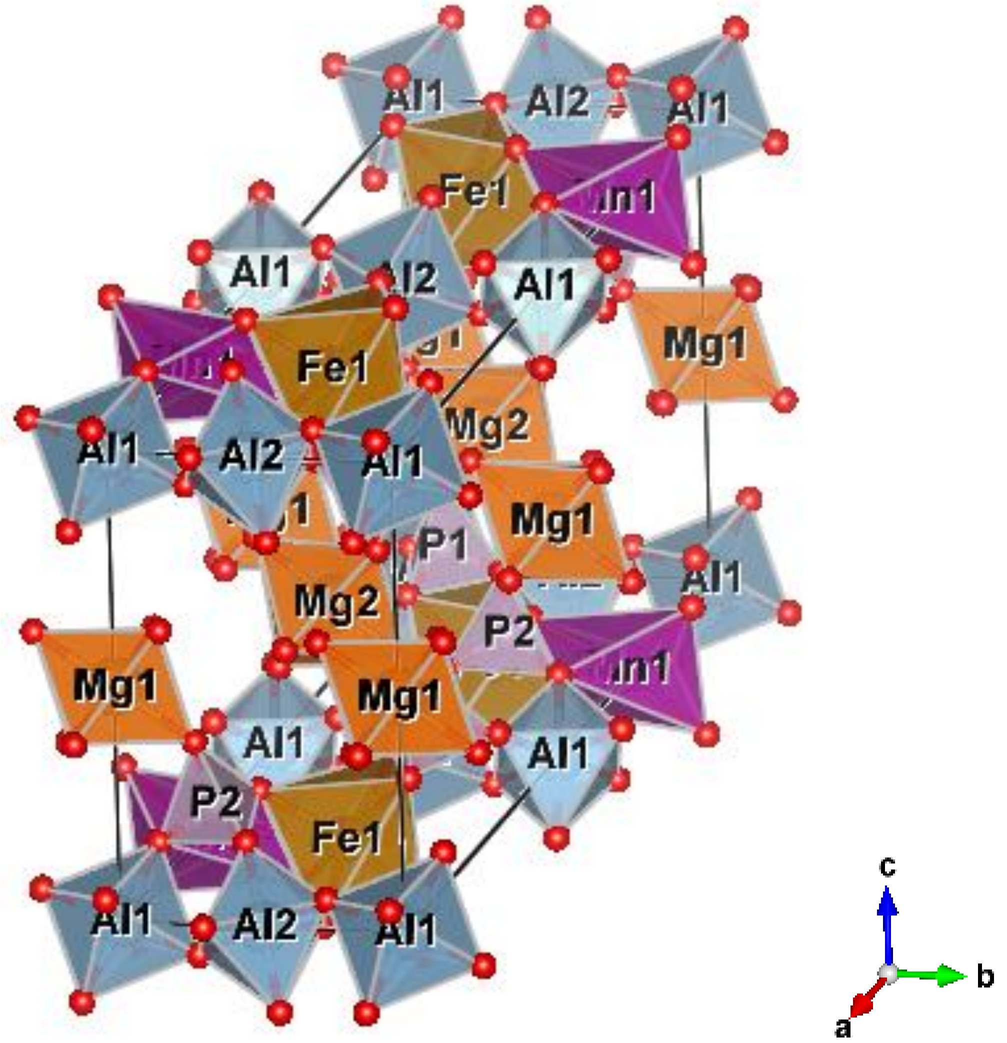

Figure 7.71. View of the crystal structure of whiteite-(MnFeMg) (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from ICSD 5130, FIZ Karlsruhe - Leibniz Institute for Information Infrastructure, 2016.

Crystal structure. The whiteite-(MnFeMg) structure is characterized by a chain of $M3^{3+}$ octahedral sites linked on opposite corners via OH anions. The chains are linked together through perpendicular dense slabs with composition $[XM1M3_2(OH)_2(PO_4)_4]^{4-}$ parallel to {001}, which are bridged in the *c* direction by PO_4 corner-sharing to $M2$-$(O,H_2O)_6$ octahedra, with X = Mn, $M1$ = Fe^{2+}, $M2$ = Mg, and $M3$ = Al.

See also. Jahnsite-(MnMnMg), jahnsite-(NaMnFe), jahnsite-(MnMnFe), whiteite-(CaFeMg), whiteite-(MnMnMg), whiteite-(FeMgNa), atencioite, and zanazziite.

Whiteite-(MnMnMg)

Baijot *et al.* (2012, 2014)

$Mn^{2+}Mn^{2+}Mg_2Al_2(PO_4)_4(OH)_2\cdot 8H_2O$, monoclinic

Type occurrence is not Brazil

Other names: whiteíta-(MnMnMg)

The first occurrence of this mineral was quoted by Baijot *et al.* (2012) in the LCT-type granitic pegmatite at the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. No chemical or crystallographic data were published. Sapucaia mine is the type locality for arrojadite-(PbFe), barbosalite, frondelite, faheyite, moraesite, ruifrancoite, tavorite, jahnsite-(NaMnMg), and jahnsite-(MnMnMg); see notes about this occurrence under ruifrancoite The name was published without submission to IMA.

A second occurrence was quoted by Baijot *et al.* (2014) in the LCT-type granitic pegmatite at the Jocão (Cigana) mine, Conselheiro Pena, Minas Gerais. This is the type locality of correianevesite. Whiteite-(MnMnMg) is yellow and non-pleochroic. Only microprobe data (mean of 8) were published: MnO 16.81, FeO 8.99, MgO 6.34, CaO 2.35, ZnO 0.09, Na_2O 0.05, K_2O 0.00, Al_2O_3 14.40, P_2O_5 36.83, SiO_2 0.00, H_2O (calc.) 19.65, total 105.51 wt.%. Empirical formula: $(Al_{2.18}Mn^{2+}_{1.83}Mg_{1.21}Fe^{2+}_{0.96}Ca_{0.32}Na_{0.01}Zn_{0.01})_{\Sigma 6.52}(PO_4)_4[O_{1.20}(OH)_{0.80}]\cdot 8H_2O$. The published composition seems to have an error due to too high cation totals with 6.52 *apfu*, exceeding the maximum possible 6 *apfu* as structurally available cation positions in the whiteite structure. The ideal formula requires MnO 18.41, MgO 10.46, Al_2O_3 13.23, P_2O_5 36.84, H_2O 21.05, total 100.00 wt.%.

Later, the complete description of this mineral was made, but another type locality was defined, Iron Monarch open cut, Iron Knob, Middleback Range, Eyre Peninsula, South Australia (Elliott and Willis 2019).

See also. Correianevesite, jahnsite-(MnMnMg), jahnsite-(NaMnMg), jahnsite-(MnMnFe), whiteite-(CaFeMg), whiteite-(MnFeMg), whiteite-(FeMgNa), arrojadite-(PbFe), barbosalite, frondelite, tavorite, ruifrancoite, faheyite, moraesite, unknown silky white mineral, mineral (b), lipscombite, and avelinoite.

Whiteite-(FeMgNa)

Cassedanne and Philippo (2015)

Other names: whiteíta-(FeMgNa)

Whiteite-(FeMgNa) supposedly exists lining boxworks in albite, close to hureaulite from the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais, according to Luiz A.D. Menezes Filho (personal communication to Cassedanne, September 2003).

See also. Arrojadite-(PbFe), faheyite, barbosalite, frondelite, moraesite, ruifrancoite, tavorite, jahnsite-(MnMnMg), jahnsite-(NaMnMg), whiteite-(MnMnMg), whiteite-(FeMgNa), unknown silky white mineral, mineral (b), lipscombite, and avelinoite.

Harbortite

Brandt (1932)

(= wardite)

Other names: harbortita, Harbortit, harborite, harborita, trauirita, trauirite

The mineral harbortite was originally described by Brandt (1932). The locality was only given as "the coast of northern Brazil in Maranhão". Subsequently, the actual occurrence was published as the Trauíra island, Cândido Mendes municipality, and at the Pirocaua Plateau, Godofredo Viana municipality, both in the state of Maranhão (Abreu 1937 and 1939, Leonardos 1973). The formula $6Al_2O_3\cdot4P_2O_5\cdot17H_2O$ [= $Al_3(PO_4)_2(OH)_3\cdot2.75H_2O$, which differs from that of wavellite by containing less water] was determined at from 12 chemical analyses. These showed, however, appreciable amounts of Na and Fe, that could be essential to the mineral. The name is in honor of Prof. Dr. Erich Harbort (1879-1929), German geologist, a professor in the field of deposit science, of the Technical University of Berlin-Charlottenburg. Harbort studied the phosphate deposits of the Trauíra island, but, shortly after his return to Germany, he died of psittacosis contracted from parrots taken from Brazil (Leonardos 1973). Branco (2008) mistakenly stated that the name harbortite "probably derives from the English harbor (archipelago) because the mineral was discovered on an island" (harbor does not mean archipelago).

Argentière (1971) observed that Brandt (1932) should have given the name “trauirite” to the mineral. According to Strunz (1957), “Harbortit” is a mixture of millisite and crandallite (L. Capdecomme, private communication to Strunz, 1954). Costa *et al.* (1980), Oliveira (1980), and Costa (1982) restudied the mineralogy of Trauíra island, specifically the spherulites, and verified the identity between harbortite and wardite, $NaAl_3(PO_4)_2(OH)_4 \cdot 2H_2O$ tetragonal. Unaware of the work by these authors, Strunz and Nickel (2001) stated that “harborite” is a hydrated Al-phosphate.

The mineral was found in phosphatized laterite overlying diabase, with light green biotite, Fe oxy-hydroxide, and sericite; epidote and quartz in lesser quantity, and apatite as an accessory (Brandt, 1932). The deposit probably owes its origin to the action of phosphatic solutions from guano on laterite (Brandt, 1932). For the geology of aluminium phosphates see Dill (2001). According to Costa *et al.* (1980), wardite is abundant in the Trauíra island and in the Jandiá hill, associated with crandallite-goyazite and goethite. In Itacupim, it occurs disseminated in a clay horizon, as an alteration product of apatite and wavellite.

Wardite (“harbortite”) occurs as small white to brown spherulites (oolites) and pseudo-octahedra [at first thought to be “pyrite pseudomorphs”, but Costa *et al.* (1980) showed that the crystals are tetragonal bipyramids and not pseudomorphs]. Density: 2.781 to 2.798 g/cm^3 (meas.). Hardness (Mohs): 5 to 5½. Biaxial (wardite is sometimes anomalously biaxial), *n* 1.602 to 1.618. Birefringence is weak. Parallel extinction. Fibers show negative elongation. Under the microscope, it is spherulitic and acicular-radial, yellowish, sometimes surrounded by a goethite film, and displays undulating extinction (Costa *et al.* 1980). Chemical data for the mineral are in Table 7.1. Certainly, other minerals were associated, such as, for example, goethite, which is responsible for high Fe values.

Table 7.1. Chemical analyses for “harbortite” and wardite (wt. %).

	1	2	3	4	5	6	7	8
Na_2O	4.2	3.9	4.1	4.6	3.4	2.0	5.2	7.71
CaO	1.2	1.3	1.2	1.0	0.8	0.7	1.0	
Al_2O_3	32.8	32.1	29.6	32.7	28.3	24.5	35.1	38.43
Fe_2O_3	4.9	6.8	13.3	5.0	12.4	26.5	4.7	
P_2O_5	34.6	34.3	31.8	34.8	33.3	25.7	33.5	35.67
SiO_2	1.6	1.0	0.4	1.0	1.0	1.5	2.5	
TiO_2	1.1	1.1	0.9	1.5	1.8	2.0	0.19	
H_2O	18.3	18.6	18.0	18.3	18.2	16.9	17.3	18.11
Total	98.7	99.1	99.3	98.9	99.2	99.8	99.85	100.00

1 to 6. “Harbortite” from Trauíra island, Cândido Mendes, Maranhão: 1. white spherulites (mean of 3 analyses), 2. yellowish spherulites (mean of 2 analyses), 3. brownish spherulites (mean of 2 analyses), 4. white bipyramid (mean of 2 analyses), 5. yellowish bipyramid (mean of 2 analyses), 6. brown bipyramid (1 analysis) (Brandt 1932).

7. Wardite from Trauíra island, Cândido Mendes, Maranhão. Microprobe analyses. Total includes MgO 0.06, K_2O 0.3 wt. %, and traces of SrO (Costa *et al.* 1980). Empirical formula: $(Na_{0.68}Ca_{0.07}K_{0.03}Mg_{0.01})_{\Sigma 0.79}(Al_{2.79}Fe^{3+}_{0.24})_{\Sigma 3.03}(P_{1.91}Si_{0.17}Ti_{0.01})_{\Sigma 2.09}O_{7.05}(OH)_{4.22}\cdot 2.73H_2O$.

8. Ideal values for wardite.

X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 4.97 (20) (110), 4.77 (80) (111), 4.72 (100) (004), 3.10 (30) (211), 3.08 (40) (203), 3.02 (23) (115), 2.993 (45) (212), 2.819 (20) (213), 2.584 (25) (205) (Costa *et al.* 1980).

Avelinoite

Lindberg and Pecora (1954a)

(= cyrilovite)

Other names: avelinoíta

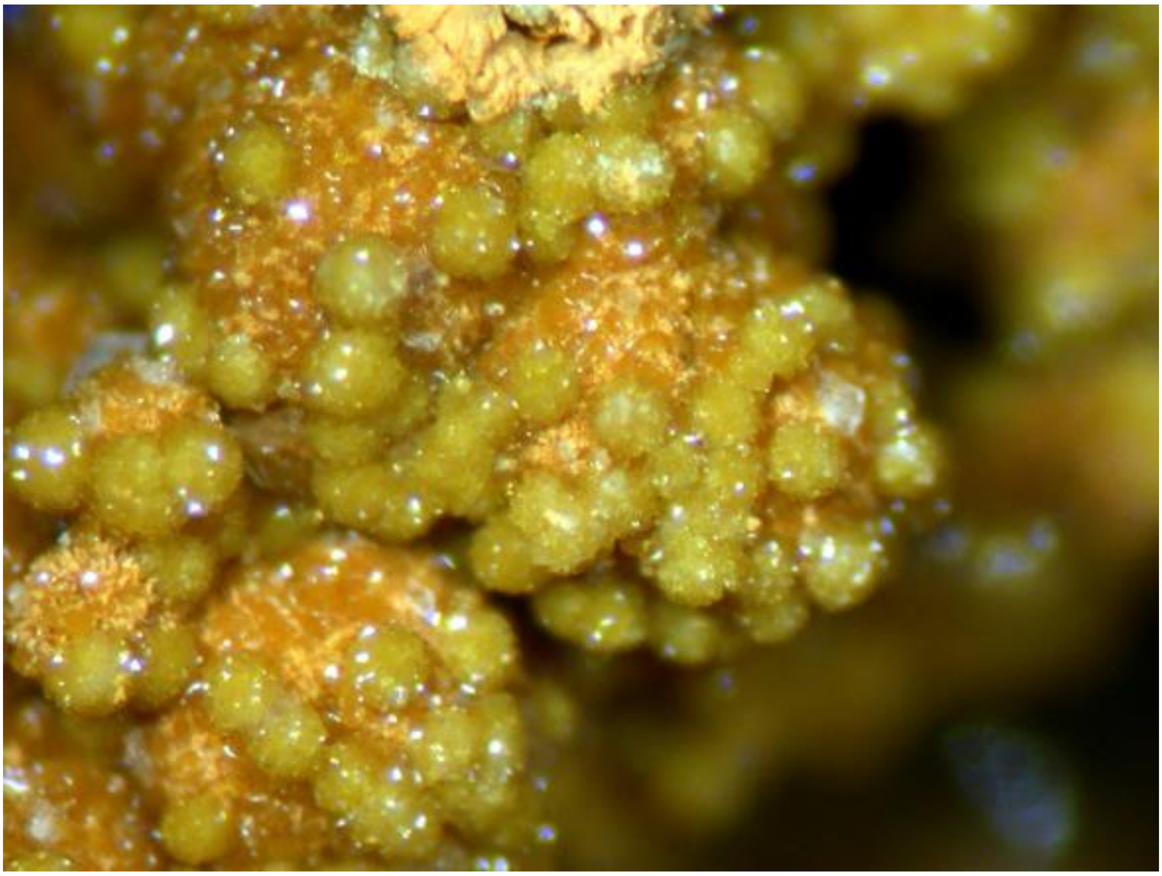

Figure 7.72. Yellow cyrilovite (“avelinoite”) on light brown roscherite from Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. Field of view: 2 mm. Specimen and photo: Sergio Varvello.

See also Figure 7.88.

Lindberg and Pecora (1954a) described the mineral avelinoite in the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais, as a secondary alteration product in a pegmatite, associated with several other phosphates (see notes about this occurrence under ruifrancoite). Avelinoite occurs as small (1 mm) yellow crystals in cavities of altered phosphates. It is tetragonal-pyramidal, with $a:c$ = 1:2.650. The observed forms were {001}, {113}, and {012}. Density 3.60 g/cm^3 (meas.). Uniaxial (-), ε 1,769, ω 1,803. $P4_1$, a 7.32, *c* 19.4 Å, *Z* 4. Chemical analyses: P_2O_5 29.06, Al_2O_3 1.36, Fe_2O_3 47.87, MnO 0.99, CaO 0.10, Na_2O 4.70, K_2O 0.63, H_2O 14.45, insol. 1.04, total 100.20 wt.%. The name honors Avelino Ignacio de Oliveira (1891-1970), eminent Brazilian geologist and manager of the Departamento Nacional da Produção Mineral, Rio de Janeiro. Proved by Strunz (1956) and Lindberg (1957) to be cyrilovite, $NaFe^{3+}_3(PO_4)_2(OH)_4\cdot 2H_2O$ tetragonal, described a year earlier than avelinoite (Novotný and Stanek 1953). Lindberg (1957) observed that cyrilovite was inadequately described: the original chemical analyses, formula, and X-ray diffraction data are wrong, suggesting that the name avelinoite should take precedence.

See also. Arrojadite-(PbFe), faheyite, barbosalite, frondelite, moraesite, ruifrancoite, tavorite, jahnsite-(MnMnMg), jahnsite-(NaMnMg), whiteite-(MnMnMg), whiteite-(FeMgNa), unknown silky white mineral, mineral (b), and lipscombite.

Matioliite

Atencio *et al.* (2006a)

$NaMgAl_5(PO_4)_4(OH)_6 \cdot 2H_2O$, monoclinic

Approved CNMMN - IMA 2005-011

Other names: matioliíta

Figure 7.73. Matioliite (blue crystals, 2 mm long) with fluorapatite (light purple crystals) and woodhouseite (white, pseudo-cubic), from the Gentil mine granitic pegmatite, Mendes Pimentel, Minas Gerais. Specimen: Luiz A.D. Menezes Filho. Photo: Tatiana Dias Menezes.

Figure 7.74. Matioliite (blue, tabular, vertically striped crystals, largest crystal size: 0.8 mm) with fluorapatite (at the center, two small hexagonal prisms, very light green), crandallite (rhombohedral crystals of light brown color), and gormanite-souzalite (to the right of the photo, parallel aggregates of acicular crystals, elongated and thin tabular, of blue green color). From the Gentil mine granitic pegmatite, Mendes Pimentel, Minas Gerais. Specimen and photo: Gianfranco Ciccolini.

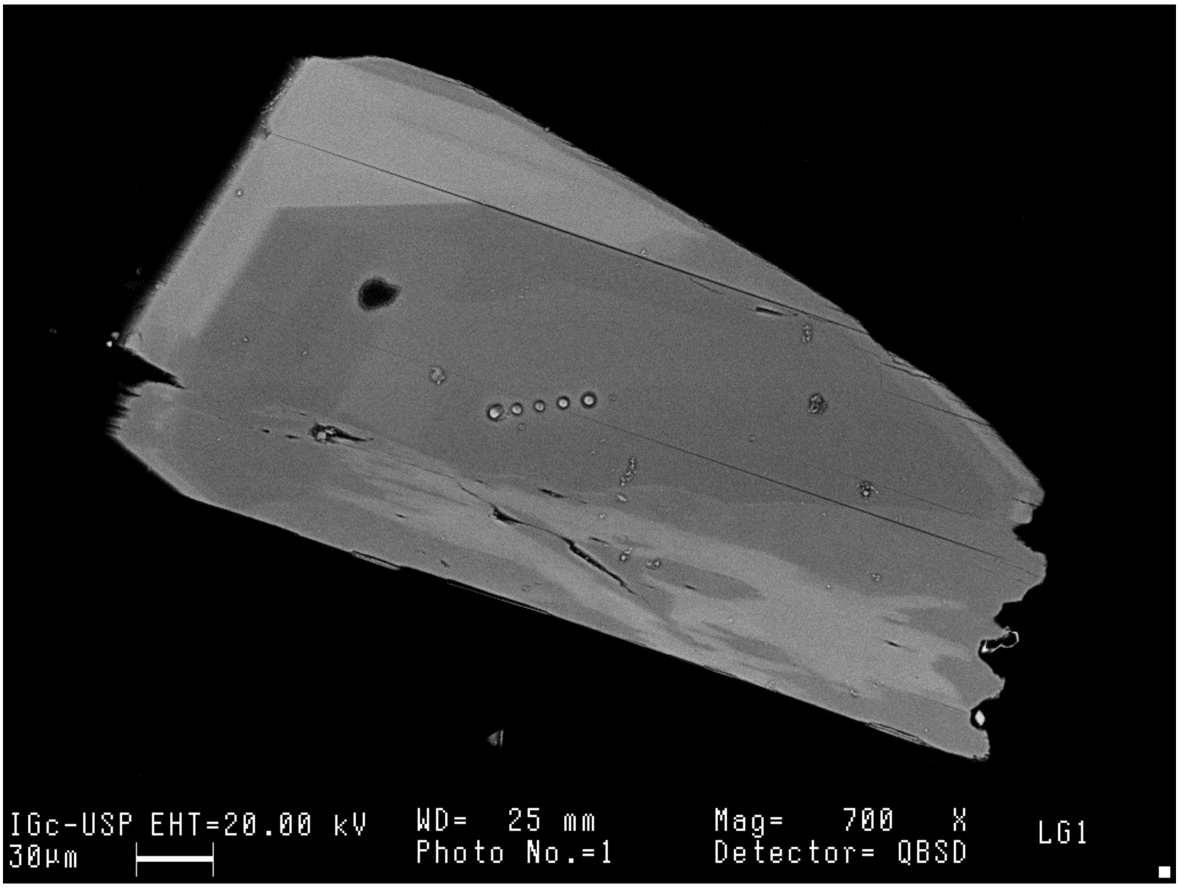

Figure 7.75. Back-scattered electron image of a zoned crystal where the darker parts correspond to matioliite and the lighter parts to a Fe-rich phase with a Fe^{2+}:Mg ratio of approximately 1:1, corresponding to an intermediate burangaite-matioliite composition. A line of spots from EDS is in the center of the figure. From the Gentil mine granitic pegmatite, Mendes Pimentel, Minas Gerais (Atencio *et al.* 2006a).

The first samples of matioliite were collected in 2004 by Paulo Anselmo Matioli and Sergio Varvello. The “magnesium analog of burangaite” quoted by Jensey *et al.* (1995) at the Gold Quarry mine, Carlin-trend, Eureka Co., Nevada, United States; and the “burangaite” from Hochgosch, Millstätter See-Rücken, Kärnten, Austria, described by Walter and Ettinger (2001) are probably matioliite. Burangaite is $NaFe^{2+}Al_5(PO_4)_4(OH)_6 \cdot 2H_2O$, isomorphous with matioliite.

The “burangaite” quoted by Bermanec *et al.* (2004a, b) at Córrego Pomarolli, Linópolis, Divino das Laranjeiras, Minas Gerais, is also matioliite, and the occurrence is not correct. The samples are from the type occurrence of matioliite, Gentil mine, Mendes Pimentel, Minas Gerais (https://www.mindat.org/mesg-7-178453.html).

Occurrence. Matioliite occurs as a secondary vug mineral in the Gentil mine granitic pegmatite, Mendes Pimentel Co., Minas Gerais. This occurrence was studied by Scholz (2002), Chaves *et al.* (2005), and Chaves and Scholz (2008), who quoted the following minerals: quartz, albite, microcline, muscovite, beryl, elbaite, schorl, almandine, cassiterite, columbite, tantalite, arsenopyrite, pharmacosiderite, autunite, barbosalite, eosphorite, fluorapatite, frondelite, gormanite, heterosite, hureaulite, lazulite, lithiophilite, montebrasite, phosphosiderite, purpurite, scorzalite, souzalite, triphylite, triplite, and vivianite. Matioliite is intimately associated with fluorapatite, woodhouseite, crandallite, and gormanite. Some crystals are zoned between matioliite and burangaite. Also, known from some other world occurences.

Appearance and physical properties. Habit: long prismatic to tabular crystals up to 2 mm. Forms: prisms and pinacoids. Twinning: none observed. Color: blue to colorless. Streak: white. Luster: vitreous. Transparent. Non-fluorescent. Hardness (Mohs): about 5. Cleavage: {100} perfect. Fracture: not determined. Density was not measured due to the paucity of material. Density: 2.948 g/cm^3 (calc.).

Optical properties. Biaxial (-), α 1.597(2), β 1.627(2), γ 1.632(1) (white light). 2*V* 43(2)° (meas.), 44° (calc.). Dispersion: $r > v$. Orientation: $X = b$, $Z \wedge c = 6°$. Pleochroism: $Y > X > Z$, *X* light blue to colorless, *Y* blue, *Z* colorless.

Chemical data. Microprobe analyses (17), H_2O and Fe^{2+}:Fe^{3+} ratio calculated: Na_2O 4.07, CaO 0.06, MgO 4.92, FeO 1.10, Fe_2O_3 1.45, MnO 0.14, Al_2O_3 34.36, P_2O_5 39.79, H_2O 12.19, total 98.08 wt.%. Empirical formula: $(Na_{0.94}Ca_{0.01})_{\Sigma 0.95}(Mg_{0.88}Fe^{2+}_{0.11}Mn_{0.01})_{\Sigma 1.00}(Al_{4.84}Fe^{3+}_{0.13})_{\Sigma 4.97}(PO_4)_{4.00}(OH)_{5.76}\cdot 2H_2O$. The ideal formula requires: Na_2O 4.43, MgO 5.76, Al_2O_3 36.41, P_2O_5 40.54, H_2O 12.87, total 100.00 wt.%.

Crystallography. Monoclinic, *C*2/*c*, *a* 25.075(1), *b* 5.0470(3), *c* 13.4370(7) Å, β 110.97(3)°, *V* 1587.9(4) Å^3, *Z* 4, *a*:*b*:*c* = 4.9683:1:2.6624. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 11.654 (100) (200), 6.581 (62) $(\bar{2}02)$, 5.833 (20) (400), 4.862 (62) (202), 3.291 (23) $(\bar{3}13)$, 3.103 (31) (511), 3.027 (40) $(\bar{6}04)$, 2.666 (45) $(\bar{8}04)$.

Name. The mineral is named in honor of Paulo Anselmo Matioli (b. 1975), mineral collector, co-author of the Brazilian type minerals brumadoite, lindbergite, and coutinhoite. He is the founder and curator of the Museu de Ciências Naturais e Centro Cultural Joias da Natureza, São Vicente, São Paulo State. This museum no longer exists.

Type material. The type material is deposited under the number DR453 in the Museu de Geociências, Universidade de São Paulo, and in the Museu de Ciências

Naturais e Centro Cultural Joias da Natureza, São Vicente, São Paulo State (this museum no longer exists).

Relationship to other species. Isostructural with burangaite, dufrénite, and natrodufrénite.

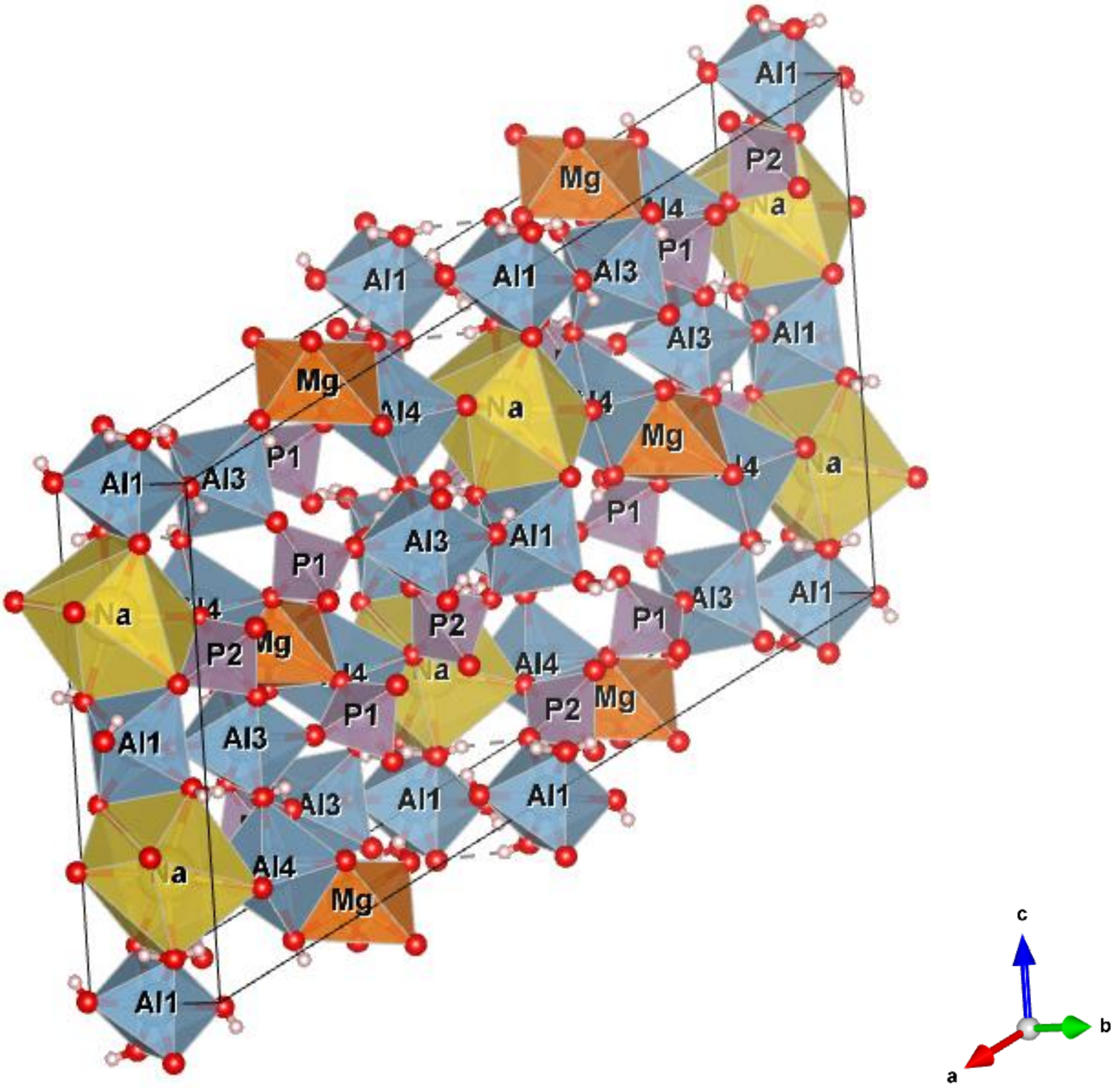

Figure 7.76. View of the crystal structure of matioliite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Atencio *et al.* (2006a).

Crystal structure. Like burangaite, NaFe^{2+}Al$_5$(PO$_4$)$_4$(OH)$_6$·2H$_2$O (Selway *et al.* 1997), the fundamental building block of the structure of matioliite is a face-sharing triplet of octahedra [Alϕ_6-Mgϕ_6-Alϕ_6] corner-linked to two Alϕ_6 octahedra and two PO$_4$ tetrahedra (ϕ: unspecified anionic species). This block is polymerized parallel to the c-axis to form dense slabs in the {100} plane. Alternating Alϕ_6 octahedra and Naϕ_8

polyhedra form a chain parallel to the *c*-axis, and the dense slab and chain alternate along the *a*-axis. The Na site is coordinated by six O anions and two (H_2O) groups to form a cubic antiprism. Magnesium is coordinated by four O anions and two (OH) groups in an octahedral arrangement. Aluminum occurs at three symmetrically distinct sites, each coordinated in an octahedral arrangement. The Al(1) site is coordinated by two O anions, two (OH) groups and two (H_2O) groups. The Al(3) site is coordinated by three O anions and three (OH) groups. The Al(4) site is coordinated by four O anions and two (OH) groups. Phosphorus occurs at two symmetrically distinct sites, each coordinated in a tetrahedral arrangement (Atencio *et al.* 2006a).

See also. Brumadoite, lindbergite, coutinhoite, barbosalite, frondelite, scorzalite, and souzalite.

Zanazziite

Leavens *et al*. (1990)

$Ca_2(\square Mg)Mg_4Be_4(PO_4)_6[(OH)_4(H_2O)_2]\cdot 4H_2O$, monoclinic

Approved CNMMN - IMA 1986-054

Other names: roscherite-*M*, zanazziíta

Figure 7.77. Green crystals of zanazziite, with rose-brown eosphorite on quartz, from Lavra da Ilha pegmatite, Itinga, Minas Gerais. Field of view: 3 mm. Specimen and photo: Jhonatan Gomes.

Figure 7.78. Green crystals of zanazziite, with rose-brown eosphorite on quartz, from Lavra da Ilha pegmatite, Itinga, Minas Gerais. Field of view: 3 mm. Specimen and photo: Jhonatan Gomes.

Zanazziite from the type occurrence was originally described as “roscherite” (Cassedanne *et al.* 1971, Cassedanne and Cassedanne 1973, Fanfani *et al.* 1975). The history of the roscherite group is somewhat complex (Atencio *et al.* 2007). Roscherite was first described by Slavík (1914) as a monoclinic hydrous phosphate of calcium, manganese, iron, and aluminum, with Mn > Fe. With the results of spectrographic and chemical analyses, Lindberg (1958) showed that beryllium occurs as a major constituent, and aluminum, only in traces. Lindberg (1958) also studied Fe^{2+} and Fe^{3+} analogs of this mineral, but used the name roscherite for the three species. Fanfani *et al.* (1975) described the Mg-dominant species isostructural with roscherite, but also applied the name roscherite. Fanfani *et al.* (1977) described a triclinic Mn-dominant roscherite-group mineral, but did not introduce a new name for it. The name zanazziite was created for the Mg-dominant species by Leavens *et al.* (1990). They also cited a triclinic Fe-Mg member of this group. The name greifensteinite was introduced for the Fe^{2+} species by Chukanov *et al.* (2002). Chukanov *et al.* (2006b) described atencioite, a triclinic Fe-Mg member of this group. Atencio *et al.* (2008c) named the triclinic Mn-dominant roscherite-group mineral footemineite. A monoclinic Zn-dominant roscherite-group mineral was named guimarãesite by Chukanov *et al.* (2007). Atencio *et al.* (2007) described a new species, ruifrancoite, the monoclinic Fe^{3+}-dominant member of the group, probably the same as the one first studied by Lindberg (1958). The first arsenate of this group, okruschite, was described by Chukanov *et al.* (2014b). For several roscherite-group minerals from Brazil see Atencio *et al.* (2005).

Occurrence. Lavra da Ilha pegmatite, Itinga, Minas Gerais (see notes about this occurrence under whiteite-(CaFeMg). This is also the type locality of whiteite-(CaFeMg) and whiteite-(MnFeMg). Also, known from other Brazilian and world occurrences.

Appearance and physical properties. Habit: barrel-shaped crystals up to 4 mm long and 1 to 2 mm in diameter. Multiple crystals vary from simple groups of subparallel individuals to divergent sprays resulting in hemispherical forms. Also, less commonly in bladed crystals of similar morphology. Forms: the crystals commonly have major {100} and {110} forms; faces of {001} are irregular and rounded. Bladed crystals have {100} dominant modified by minor {110}, and irregular, rounded {001} faces. Color: pale to dark olive green. Streak: white. Luster: vitreous to slightly pearly on the cleavage surfaces. Transparent. Cleavage: {100} good, {010} distinct. Non-fluorescent. Density: 2.76 g/cm^3 (meas.), 2.77 g/cm^3 (calc.). Hardness (Mohs): 5.

Optical properties. Biaxial (+), α 1.606(2), β 1.610(2), γ 1.620(2), 2*V* 72° (meas.), 65° (calc.). Orientation: $X = b$, Z : [100] = 3° in β obtuse.

Chemical data. Microprobe analyses, Be by AAS, H_2O by CHN, Fe^{2+}:Fe^{3+} ratio by titration: CaO 10.65, BeO 9.81, MgO 11.66, FeO 9.63, MnO 1.77, SiO_2 0.36, Al_2O_3 1.54, Fe_2O_3 0.76, P_2O_5 39.27, H_2O 13.32, total 98.77 wt.%. Empirical formula: $(Ca_{1.97}Mn_{0.03})_{\Sigma 2.00}(\square_{0.99}Mg_{0.61}Fe^{2+}_{0.40})_{\Sigma 2.00}(Mg_{2.38}Fe^{2+}_{1.08}Mn_{0.23}Al_{0.31}Fe^{3+}_{0.10})_{\Sigma 4.10}Be_4(P_{5.73}Be_{0.06}Si_{0.06})_{\Sigma 5.85}O_{24}[(OH)_{3.40}(H_2O)_{2.60}]_{\Sigma 6.00}\cdot 4H_2O$. The ideal formula requires CaO 11.40, BeO 10.17, MgO 20.48, Fe_2O_3 0.76, P_2O_5 43.29, H_2O 14.66, total 100.00 wt.%.

Crystallography. Monoclinic, *C*2/*c*. *a* 15,874(4), *b* 11,854(3), *c* 6,605(1) Å, β 95°21(2)’. *V* 1237 Å^3, *Z* 2. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 9.50 (90) (110), 5.91 (100) (020), 3.16 (70) (330), 3.05 (50) (510), 2.766 (50) (240), 2.682 (40b) (600), 2.208 (40) ($15\bar{1}$, 710), 1.642 (50b) [calculated pattern, originally attributed to roscherite-*M*].

Name. In honor of Pier F. Zanazzi (b. 1939), professor of mineralogy, Università di Perugia, Italy.

Type material. U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA, type, R17847 (Roebling collection, 1972).

Relationship to other species. A monoclinic roscherite-group mineral.

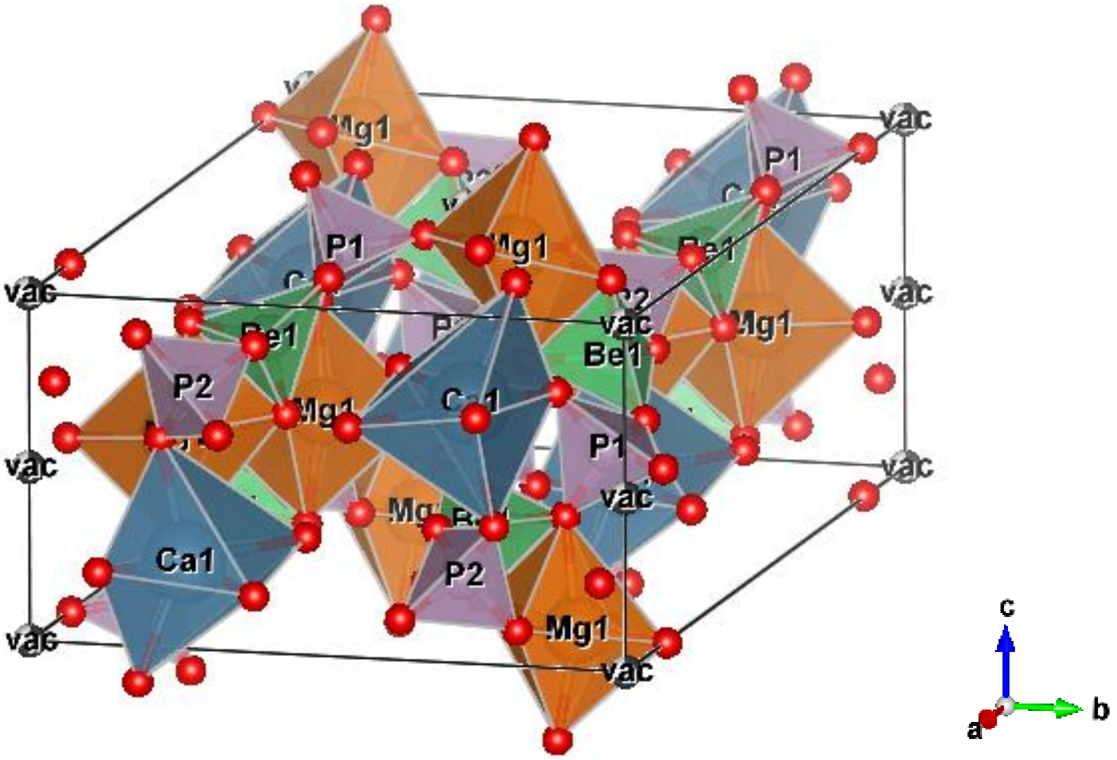

Figure 7.79. View of the crystal structure of zanazziite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data modified from Fanfani *et al.* (1975).

Crystal structure. Originally identified as roscherite-*M*, the crystal structure was studied by Fanfani *et al.* (1975). Based on partial chemical data, they derived an imperfect formula. Later on, Fanfani *et al.* (1977) revised the structural formula to one that conforms with the complete chemical data obtained by Leavens *et al.* (1990). For a crystal structure description see guimarãesite.

See also. Guimarãesite, ruifrancoite, atencioite, Zn-containing greifensteinite, whiteite-(CaFeMg), and whiteite-(MnFeMg).

Zn-containing greifensteinite

Barinova *et al.* (2004)

(variety of greifensteinite)

The crystal structure of Zn-containing greifensteinite from the Pirineus Mine, Itinga, Minas Gerais, was refined. The unit-cell parameters are *a* 15.941(3) Å, *b* 11.877(3) Å, *c* 6.625(2) Å, *β* 95.09(2)°, *V* 1249.37 Å^3, space group *C*2/*c*, and *Z* 2. The structural formula is $(Mn_{1.14}Fe_{2.35}Zn_{0.72}Al_{0.28}Mg_{0.19})Ca_2Be_4(PO_4)_6(OH)_4(H_2O)_6$. The idealized formula is $[Mn(Fe^{2+},Zn)_4]Ca_2Be_4(PO_4)_6(OH)_4{\cdot}6H_2O$. The mineral is isostructural with the previously studied monoclinic representatives of the roscherite group from different deposits and differs from these representatives in that it contains Zn in one of two octahedral positions (Barinova *et al.* 2004).

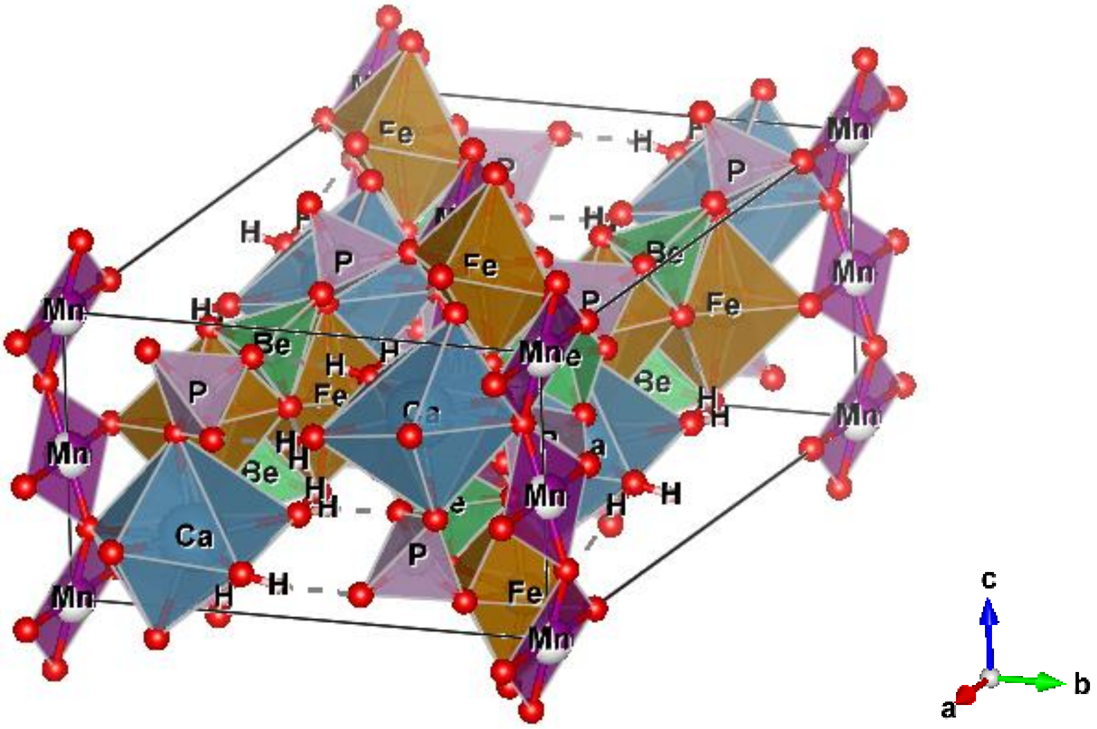

Figure 7.80. View of the crystal structure of Zn-containing greifensteinite (from the Pirineus Mine, Itinga, Minas Gerais), drawn using VESTA 3 (Momma and Izumi 2011). Data from Barinova *et al.* (2004).

See also. Guimarãesite, ruifrancoite, atencioite, and zanazziite.

Guimarãesite

Chukanov *et al.* (2007)

$Ca_2(\square Zn)Zn_4Be_4(PO_4)_6[(OH)_4(H_2O)_2]\cdot 4H_2O$, monoclinic

Approved CNMMN - IMA 2006-028

Other names: guimarãesita

Figure 7.81. Guimarãesite and other(s) roscherite-group mineral(s) from Lavra Ponte do Piauí, Itinga, Minas Gerais. Larger dimension: 1.5 cm. Specimen: Museu de Geociências, Universidade de São Paulo (type specimen). Photo: Thales Trigo.

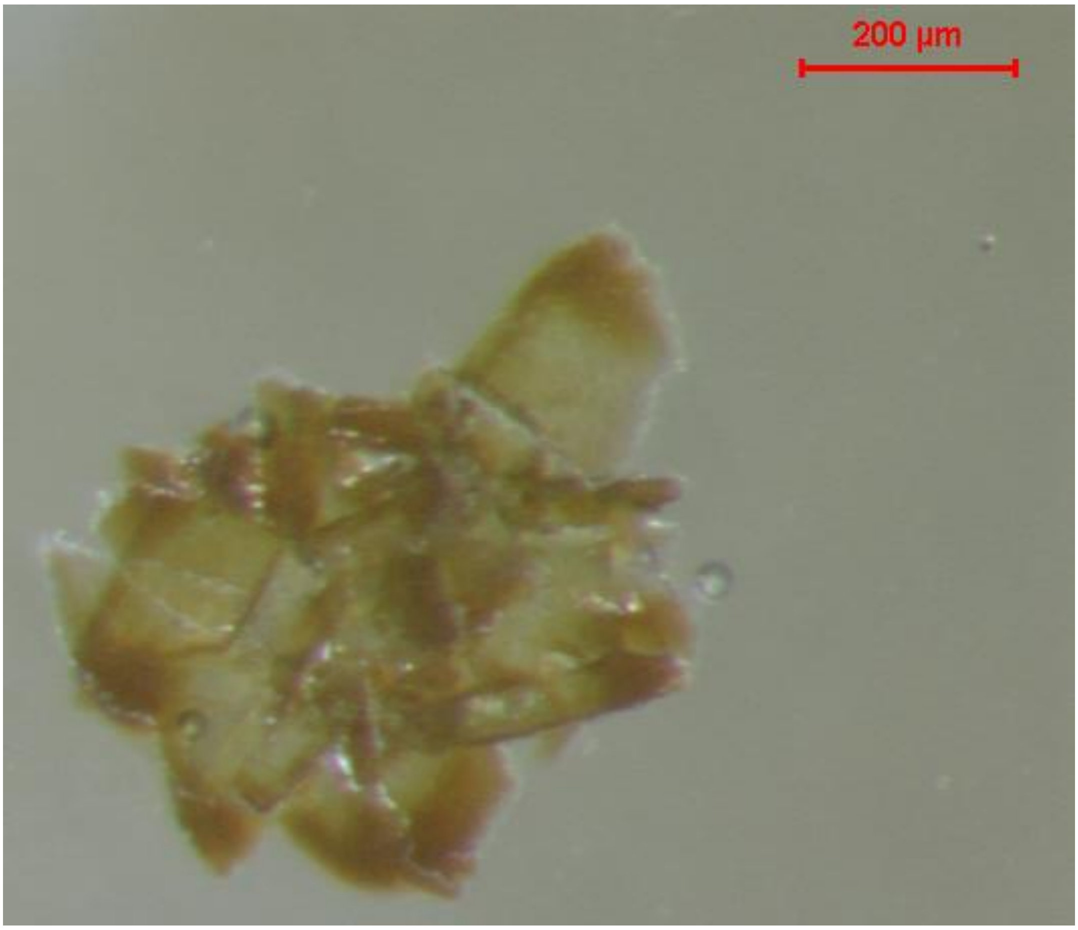

Figure 7.82. Crystals of roscherite-group mineral(s) with guimarãesite peripheral zones, from Lavra Ponte do Piauí, Itinga, Minas Gerais. Photo: Daniel Atencio. Chukanov *et al.* (2007).

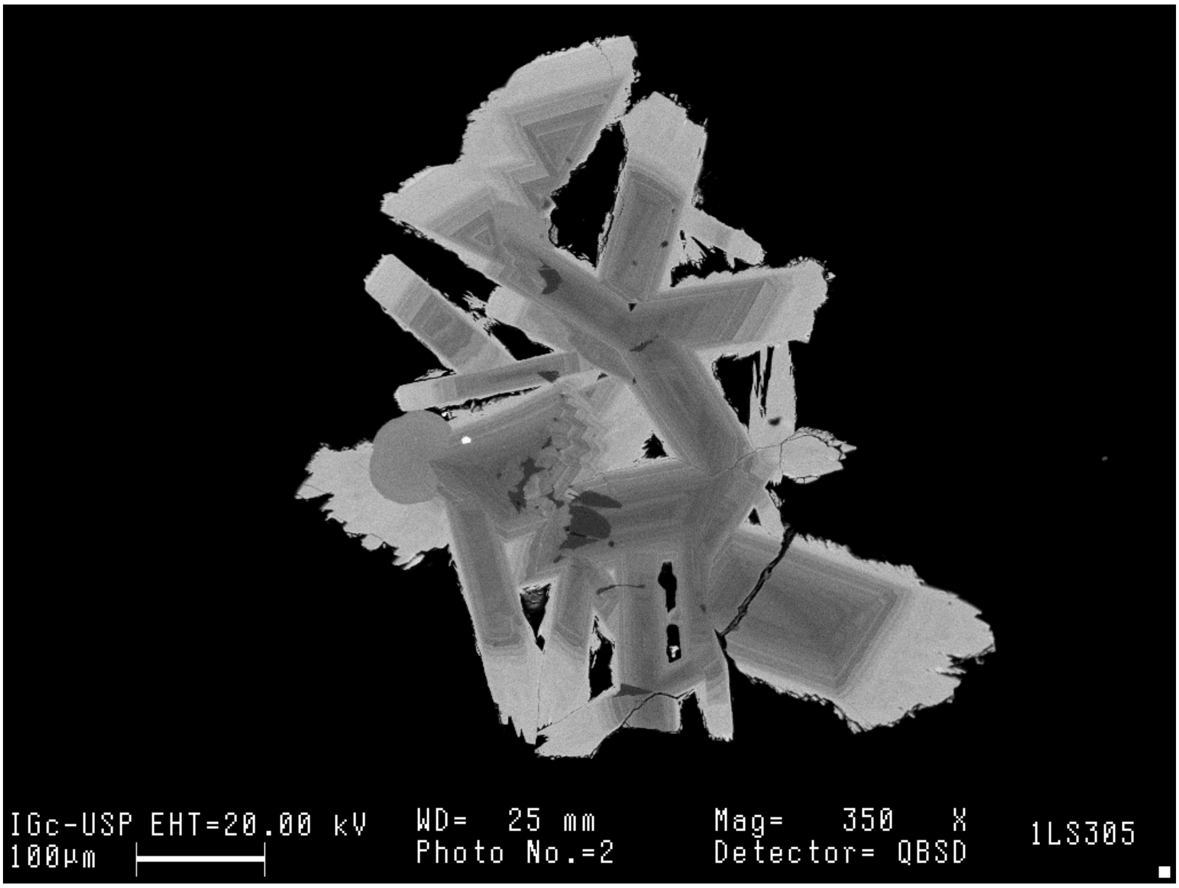

Figure 7.83. Polished section of aggregates of roscherite-group mineral(s) with guimarãesite peripheral zones (the same crystals of Figure 7.82), from Lavra Ponte do Piauí, Itinga, Minas Gerais. SEM photo. Chukanov *et al.* (2007).

Occurrence. The mineral occurs in the granite pegmatite of Lavra Ponte do Piauí, near the Piauí river, Itinga Co., Minas Gerais. Associated minerals are albite, microcline, quartz, elbaite, “lepidolite”, schorl, eosphorite, moraesite, saleéite, zanazziite, a Fe-dominant roscherite-group mineral, and opal. The mineral formed in a phosphate-rich granite pegmatite. This is also the type locality of wilancookite.

Appearance and physical properties. Guimarãesite forms peripheral zones (up to 0.1 mm thick) in crystals of roscherite-group minerals. The inner zones of the crystals are Mg-rich (and correspond to zanazziite) or Fe-rich (greifensteinite and/or ruifrancoite?). The crystals are not adequate for morphological observations. Habit: tabular parallel to (100). Forms: probably {100}, {001} and {010} (from prismatic habit). Twinning: none observed. Color: brown. Streak: white. Luster: vitreous. Transparent. Non-fluorescent. Hardness (Mohs): probably 4½ by analogy with other roscherite-group minerals. Tenacity: brittle. Cleavage: probably perfect on {100} and good on {010}by analogy with other roscherite-group minerals. Fracture: uneven. Density could not be measured because of zoned grains. Density 2.963 g/cm^3 (calc. with empirical formula).

Optical properties. Biaxial (–), *α* 1.596(2), *β* 1.600(2), *γ* 1.602(2) (589 nm). 2*V* 55-75° (meas.), 70°(calc.). Dispersion: none observed. Orientation: the optical *X* axis coincides with the elongation direction. Pleochroism: absent. Colorless under the microscope.

Chemical data. Microprobe (EDS) analysis (3), BeO calculated from the condition Be:P = 2:3 (the stable atomic proportion for roscherite-group minerals following from specific features of their crystal structures), H_2O by difference: CaO 9.72, MgO 4.00, MnO 2.18, FeO 2.65, ZnO 19.06, Al_2O_3 1.70, P_2O_5 38.20, BeO 8.975, H_2O 13.515, total 100.00 wt.%. Empirical formula: $Ca_{1.93}(\square_{1.16}Zn_{0.50}Mn_{0.34})_{\Sigma 2.00}(Zn_{2.11}Mg_{1.11}Fe^{2+}_{0.41}Al_{0.37})_{\Sigma 4.00}Be_{4.00}(PO_4)_{6.00}[(OH)_{3.90}(H_2O)_{2.10}]\cdot 4.31H_2O$. The ideal formula requires CaO 9.43, ZnO 34.22, BeO 8.41, P_2O_5 35.81, H_2O 12.12, total 99.99 wt.%.

Crystallography. Monoclinic, *C*2/*c*, *a* 15.98(1), *b* 11.84(2), *c* 6.63(1) Å, *β* 95.15(15)°, *V* 1249.4(34) Å^3, *Z* 2 (powder data); *a* 15.9(1), *b* 11.85(15), *c* 6.7(1) Å, *β* 95(1)°, *V* 1258(25) Å^3 *Z* 2 (single-crystal), *a*:*b*:*c* = 1.3497:1:0.5600. X-ray powder-diffraction data [*d* in Å (*I*) (*hkl*)]: 9.98 (90) (110), 5.98 (100) (020), 4.82 (80) (310), 3.152 (90) ($\bar{2}02$), 3.052(70) ($\bar{4}21$), 2.961 (70) (040, 202), 2.841 (70) ($\bar{3}12$), 2.708 (80) (041).

Name. In honor of the Brazilian mineralogist Djalma Guimarães (1895-1973). He published several papers and books on geology, petrology, mineralogy and geochemistry, and is the author of the mineral arrojadite and of problematic minerals as eschwegeite, giannettite, and pennaite. Djalma Guimarães was honored with the name djalmaite (later renamed as uranmicrolite and now discredited). The name guimarãesite was improperly applied (Gagarin and Cuomo 1949) to an unnamed mineral, incompletely described by Guimarães (1926b).

Type material. Holotype material is deposited under the number DR591 in the Museu de Geociências, Universidade de São Paulo.

Relationship to other species. A monoclinic roscherite-group mineral.

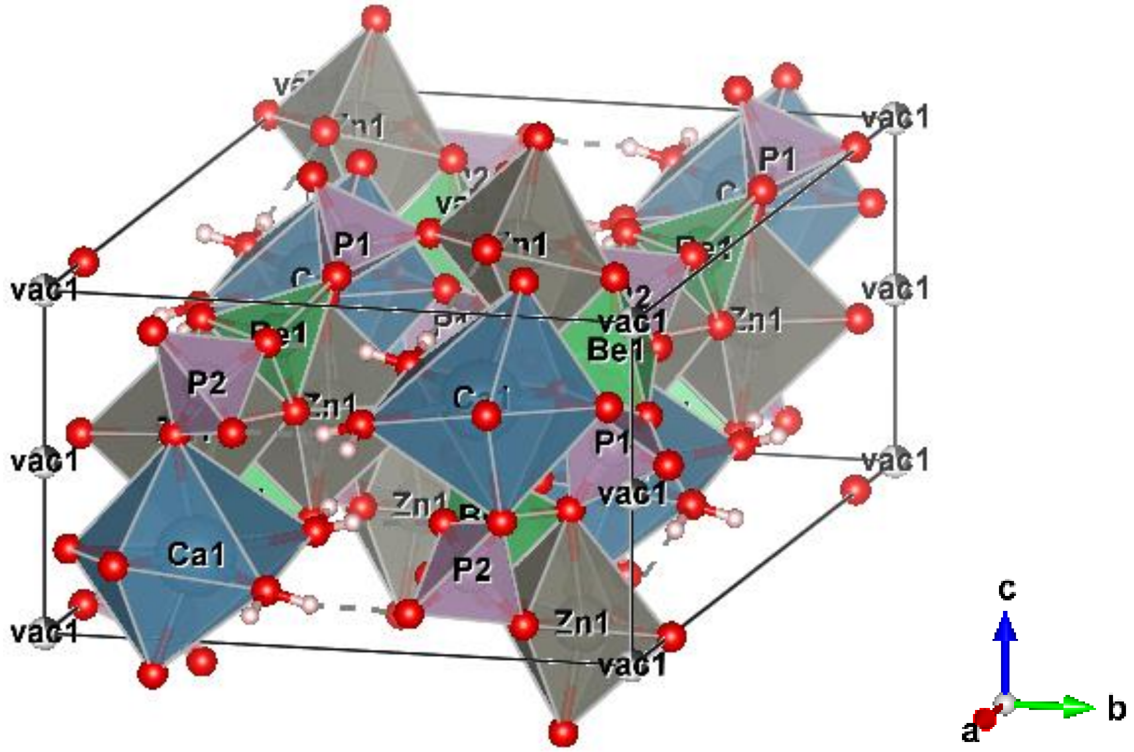

Figure 7.84. View of the crystal structure of guimarãesite, drawn using VESTA 3 (Momma and Izumi 2011). Based on data from Barinova *et al.* (2004) for Zn-rich greifensteinite from the Pirineus Mine, Itinga, Minas Gerais, and Chukanov *et al.* (2007) for guimarãesite from the type occurrence.

Crystal structure. The crystal structure of all monoclinic representatives of the roscherite group studied previously (Fanfani *et al.* 1975; Rastsvetaeva *et al.* 2002, 2004a, 2005; Barinova *et al.* 2004), is based on a three-dimensional framework composed of tetrahedra, octahedra, and calcium seven-vertex polyhedra. The Be and P tetrahedra form infinite chains combined into a mixed framework through M octahedra, which, in turn, form octahedral chains by sharing edges. Calcium occurs in the framework cavities. The octahedra in the cell points are partially populated and, hence, the total number of *M* cations is reduced from six to five. All these minerals are characterized by the space group *C*2/*c*. The simplified crystal-chemical formula of monoclinic roscherite-type minerals is $Ca_2D_2M_4Be_4(PO_4)_6(OH)_6\cdot 4H_2O$ where *D* and *M* are octahedral cations Mg, Mn^{2+}, Fe^{2+}, Fe^{3+}, Al, Zn. The site *M* is fully occupied; the site *D* contains ≥ 50% vacancies. Monoclinic mineral species from the roscherite group are distinguished by the prevailing octahedral cation (in guimarãesite it is Zn). Among monoclinic roscherite-group minerals, guimarãesite has the largest value of the *a* unit-cell dimension and the lowest value of refractive index γ. In the structurally investigated Zn-rich greifensteinite from the Pirineus Mine, Itinga, Minas Gerais (Barinova *et al.* 2004), all Zn is localized in the *M* site.

See also. Moraesite, zanazziite, ruifrancoite, atencioite, Zn-containing greifensteinite, arrojadite, eschwegeite, giannettite, pennaite, djalmaite, guimarãesite (old name), and wilancookite.

Ruifrancoite

Atencio *et al.* (2007)

$Ca_2\square_2Fe^{3+}_4Be_4(PO_4)_6(OH)_6\cdot4H_2O$, monoclinic

Approved CNMMN - IMA 2005-061

Other names: Fe^{3+}-dominant roscherite-group mineral, ruifrancoíta

Figure 7.85. Brown spherical aggregates of ruifrancoite crystals with tiny white spheres of meurigite-K over muscovite crystals, from Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. Specimen: Daniel Atencio, photo: Thales Trigo.

Figure 7.86. Brown spherical aggregates of ruifrancoite crystals with tiny white spheres of meurigite-K over muscovite crystals, from the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. Specimen: Luiz A.D. Menezes Filho. Photo: Tatiana Dias Menezes.

Figure 7.87. Brown spherical aggregate (1.65 mm) of ruifrancoite crystals over muscovite crystals, from the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. Specimen and photo: Martin Slama. The cover of this book.

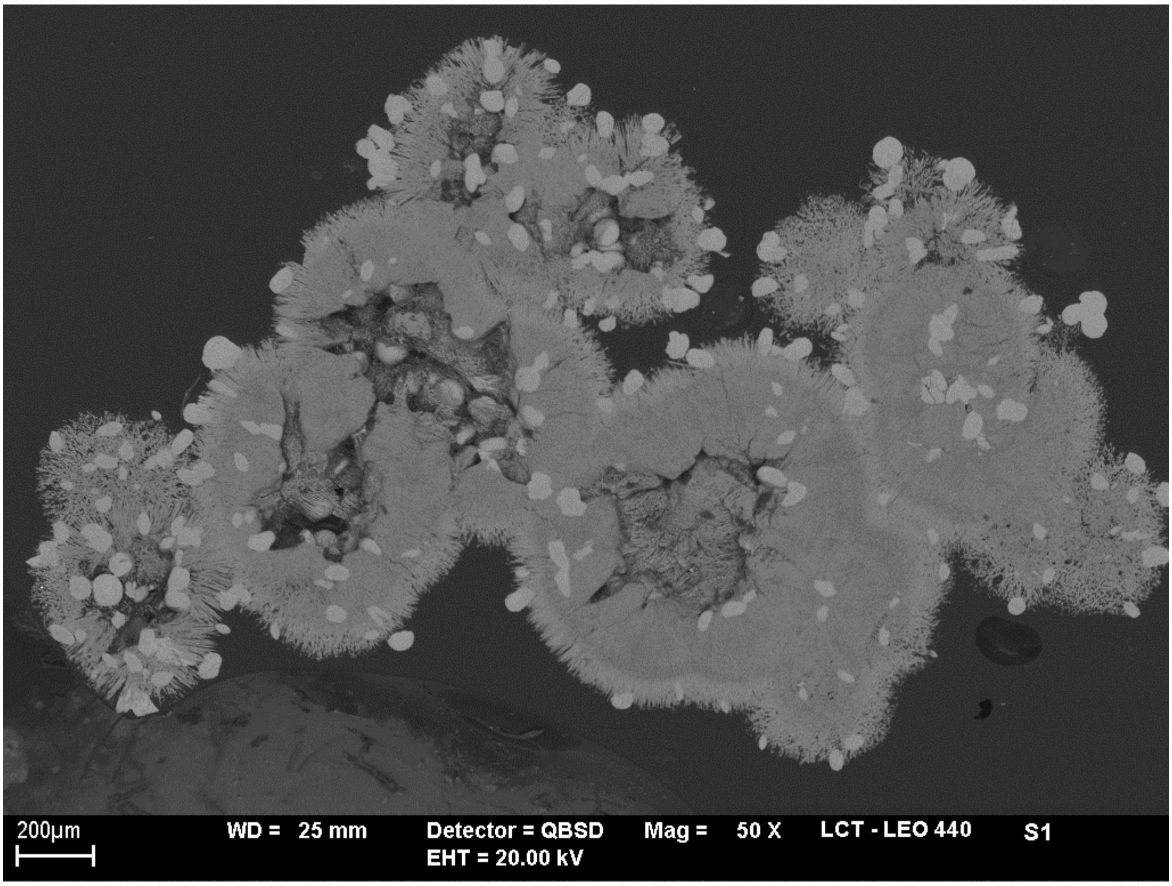

Figure 7.88. Back-scattered electron image. The darker radiating aggregates correspond to ruifrancoite, and the lighter colored grains, to cyrilovite. From the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais (Atencio *et al.* 2007).

A preliminary description of this mineral, as Fe^{3+}-dominant roscherite-group mineral, was published by Atencio *et al.* (2005).

Occurrence. Ruifrancoite occurs as a late vug-filling product in the zoned, LCT-type granitic pegmatite at the Sapucaia pegmatite (Proberil mine), Galileia, Minas Gerais. It crystallized on albite and muscovite and occurs in close association with cyrilovite (see avelinoite), and meurigite-K. The Sapucaia mine has been an important producer of muscovite and beryl, extracted from various zones of the oval-shaped pegmatite (Pecora *et al.* 1950). In the core zone, essentially composed of quartz, perthite, muscovite, and beryl, there is an irregular body of triphylite weighing several hundred tonnes, which was partially altered by hydrothermal fluids and later, because of weathering. An assemblage of rare phosphates resulted, nine of which have been described as new mineral species: frondelite, faheyite, moraesite, barbosalite, tavorite, arrojadite-(PbFe), ruifrancoite, jahnsite-(MnMnMg), and jahnsite-(NaMnMg). Detailed studies of the phosphate mineral associations (Lindberg and Pecora 1958, Cassedanne and Baptista 1999) have revealed three principal assemblages corresponding to separate geochemical environments: (1) the triphylite assemblage, as fracture fillings and replacements in massive triphylite, (2) the frondelite assemblage, consisting of residual phosphates enclosed by frondelite, results of a massive replacement of that mineral, and minerals on walls of vugs in frondelite, and (3) the silicate assemblage, formed by secondary crusts on altered albite, products of the alteration of beryl, and replacement and vug filings in muscovite. Ruifrancoite occurs in the third assemblage. Some of the other phosphates in the deposit are apatite, bermanite, childrenite, gordonite, heterosite, hureaulite, leucophosphite, phosphosiderite ("metastrengite"), montebrasite, "roscherite" (probably ruifrancoite), saleeite, strengite, variscite, vivianite, and some unidentified phosphates (Lindberg and Pecora, 1958); dufrenite, ferrisicklerite, and an unidentified zinc phosphate [mineral (b)] (Hirson 1965); lazulite, sabugalite, rockbridgeite, wardite, and scorzalite (Farias 1976); herderite, phosphuranylite, and autunite (Svisero 1976); jahnsite (Moore and Ito 1978a); an unknown silky white mineral replacing rockbridgeite (Moore and Ito 1978b); johnsomervilleite (Araki and Moore 1981); augelite, berlinite, strunzite, and a metamict phosphate (Cassedanne and Cassedanne 1985); robertsite, mitridatite, and cacoxenite (Horvath and Atencio 1998); beraunite (Bilal *et al.* 1998); laueite, xenotime-(Y), and monazite-(Ce) (Cassedanne and Baptista 1999). Additional data on material from the type occurrence can be find in the RRUFF Database (R070049). The monoclinic Fe^{3+}-dominant roscherite-group mineral described earlier from Sapucaia mine under the name "roscherite" by Lindberg (1958) and Lindberg and Pecora (1958) is probably ruifrancoite.

A second Brazilian occurrence of ruifrancoite is Lavra Pomarolli, Linópolis, Divino das Laranjeiras, Minas Gerais (Atencio *et al.* 2005, 2007). An occurrence of ruifrancoite at Poço d'Antas claim, Piauí Valley, Taquaral, Itinga, Minas Gerais, is quoted in the Mindat database.

Appearance and physical properties. The crystals are not adequate for morphological observations because of their habit and size. Habit: needles and laths with a thickness of 1 to 2 µm and a length to about 100 µm in fan-shaped botryoidal arrangements. Forms: apparently two pinacoids, {010} and {100}, and a prism. Twinning: none observed. Color: reddish-brown. Streak: orange-brown. Luster: vitreous. Transparent. Non-fluorescent. Hardness (Mohs): probably about 4½ by analogy with other roscherite-group minerals. Tenacity: brittle. Cleavage: probably perfect on {100} and good on {010} by analogy with other roscherite-group minerals. Fracture: not determined. Density: 2.88(1) g/cm^3 (meas. with the hydrostatic weighing method), 2.859 g/cm^3 (calc.).

The monoclinic Fe^{3+}-dominant roscherite-group mineral described earlier from Sapucaia mine under the name “roscherite” by Lindberg (1958) and Lindberg and Pecora (1958), probably ruifrancoite, occurs as brown, prismatic single-crystals, crystal aggregates, and granular masses, in vugs in muscovite, and as crusts on beryl. The mineral is characterized by well-developed faces of the forms {111}, {010}, and {100}. On a few crystals, small faces of the forms {102}, {201}, {101}, {201}, {301}, and {111} are present, but are of poor quality. The crystals are tabular parallel to (100).

Optical properties. Biaxial (+), α 1.665(3), β 1.665(3), γ 1.682(3) (white light). $2V$ 0-10° (meas.), 0° (calc.). Orientation: $b = X$, $Y \wedge c \sim 16°$. Dispersion: $r > v$, very strong. Pleochroism: γ (brownish-red) > $\alpha = \beta$ (light brownish-red).

Chemical data. Microprobe (EDS) analyses (2), Fe^{2+}:Fe^{3+} ratio by Mössbauer data, BeO by ICP-AES, H_2O by Penfield method: CaO 9.81, MgO 3.23, MnO 8.10, FeO 3.93, Fe_2O_3 12.51, Al_2O_3 0.86, BeO 8.41, P_2O_5 39.46, H_2O 12.56, total 98.87 wt.%. Empirical formula (with calculated BeO of 9.26 wt.%): $Ca_{1.89}(\square_{1.45}Mn^{2+}_{0.55})_{\Sigma 2.00}(Fe^{3+}_{1.69}Mg_{0.87}Mn^{2+}_{0.68}Fe^{2+}_{0.59}Al_{0.18})_{\Sigma 4.00}Be_{4.00}(PO_4)_6[(OH)_{4.75}(H_2O)_{1.25}]_{\Sigma 6.00}\cdot 3.90H_2O$. The ideal formula requires CaO 10.35, Fe_2O_3 29.48, BeO 9.23, P_2O_5 39.30, H_2O 11.64, total 100.00 wt.%.

Crystallography. Monoclinic, $C2/c$, a 15.911(7), b 11.894(7), c 6.625(7) Å, β 94.5(1)°, V 1250(1) Å^3, Z 2, a:b:c = 1.3432:1:0.5594. X-ray powder-diffraction data [d in Å (I) (hkl)]: 9.485 (44) (110), 5.943 (100) (020), 4.821 (65) (310), 3.176 (44) (330), 2.784 (41) (240), 2.643 (42) (600).

Name. The mineral is named after Professor Rui Ribeiro Franco (1916-2008), in recognition of his outstanding contributions to Brazilian mineralogy and geology. We cite in particular the three-volume treatise Minerais do Brasil (Franco *et al.* 1972), and several papers, chapters and books on mineralogy, geochemistry, gemology, petrography, petrology and geology (*e.g.*, Franco 1981).

Type material. The holotype sample is deposited under the number DR587 in the Museu de Geociências, Universidade de São Paulo. The cotype material (used for Mössbauer spectroscopy) is deposited in the Mineralogical Collection of the Technische Universität Bergakademie Freiberg with the inventory number 81420.

Relationship to other species. A monoclinic roscherite-group mineral.

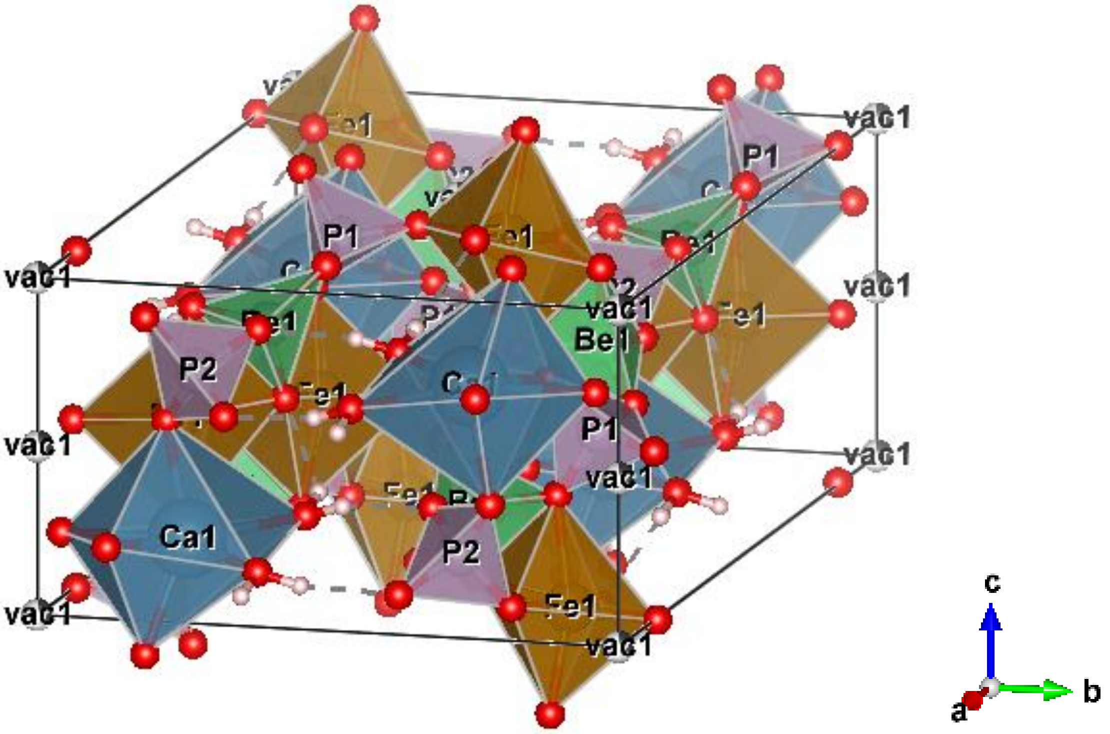

Figure 7.89. View of the crystal structure of ruifrancoite, drawn using VESTA 3 (Momma and Izumi 2011). Based on data from Barinova *et al.* (2004) for Zn-rich greifensteinite from the Pirineus Mine, Itinga, Minas Gerais, and Atencio *et al.* (2007) for ruifrancoite from the type occurrence.

Crystal structure. For a crystal structure description see guimarãesite.

See also. Frondelite, faheyite, moraesite, barbosalite, tavorite, arrojadite-(PbFe), jahnsite-(MnMnMg), jahnsite-(NaMnMg), whiteite-(MnMnMg), whiteite-(FeMgNa), avelinoite, lipscombite, unknown silky white mineral, mineral (b), scorzalite, zanazziite, guimarãesite, Zn-containing greifensteinite, and atencioite.

Atencioite

Chukanov *et al.* (2006b)

$Ca_2Fe^{2+}Mg_2Fe^{2+}{}_2Be_4(PO_4)_6(OH)_4\cdot 6H_2O$, triclinic

Approved CNMMN – IMA 2004-041

Other names: triclinic Fe-dominant roscherite, magnesium-rich triclinic analog of greifensteinite, atencioíta

Figure 7.90. Atencioite from João Firmino mine, Pomarolli farm region, Linópolis, Divino das Lranjeiras, Minas Gerais.. Brownish spherules on quartz and albite. The major spherule has approximately 8 mm in diameter. Specimen: Museu de Geociências, Universidade de São Paulo. Photo: Thales Trigo.

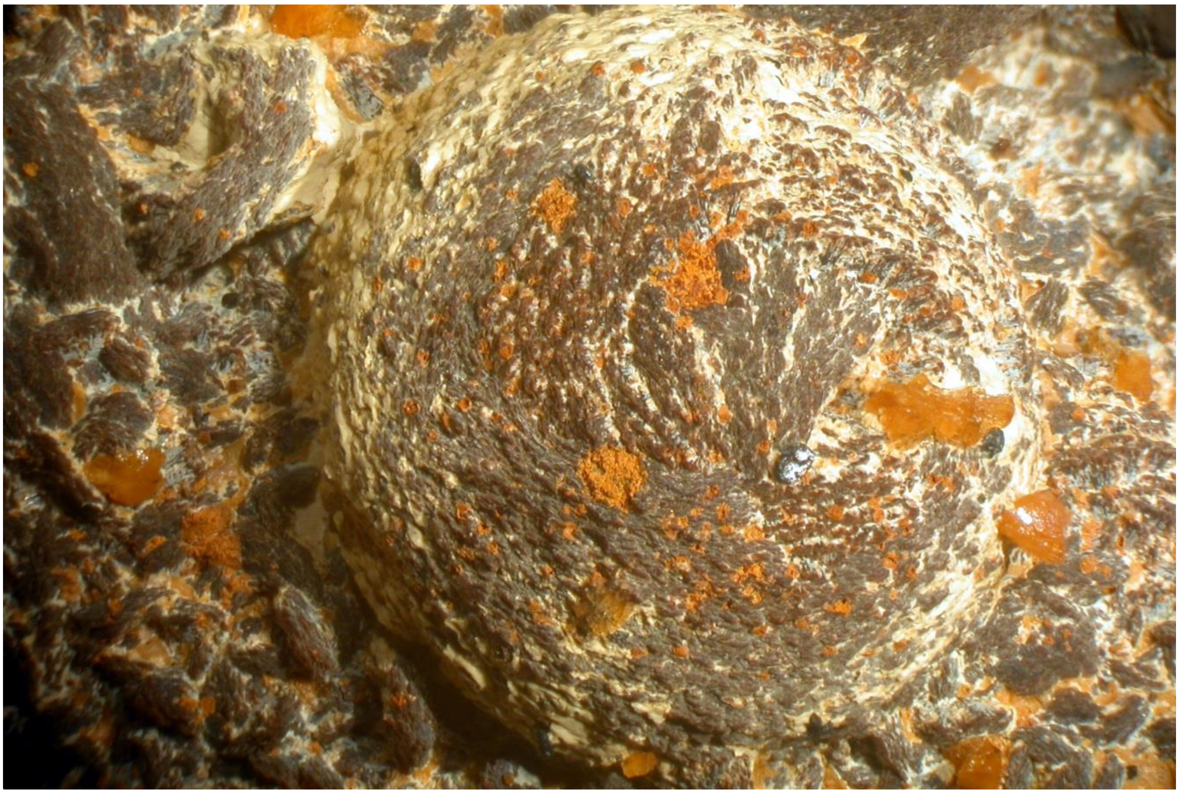

Figure 7.91. Atencioite spherical cluster (9 mm wide) of brown crystals with orange ushkovite crystals. João Firmino mine, Pomarolli farm region, Linópolis, Divino das Laranjeiras, Minas Gerais. Specimen: Luiz A.D. Menezes Filho. Photo: Tatiana Dias Menezes.

Two preliminary notes about this mineral were published by Chukanov and Möckel (2005) and Chukanov *et al.* (2005). The complete paper was released by Chukanov *et al.* (2006b). The crystal structure of atencioite was studied by Rastsvetaeva *et al.* (2004b).

The correct type locality of atencioite is the João Firmino mine, Pomarolli farm region, Linópolis town, Divino das Laranjeiras County, Minas Gerais State. However, in the first article on the crystal structure, where it is mentioned as “a magnesium-rich triclinic analog of greifensteinite”, Rastsvetaeva *et al.* (2004b) quoted the occurrence as “a mine in the vicinity of Galileia (Minas, Gerais, Brazil)” (Galileia and Divino das Laranjeiras are neighboring municipalities). Subsequently, in the complete paper on atencioite (Chukanov *et al.* 2006b), the occurrence was given as “in a granite pegmatite near the town of Linópolis, Minas Gerais”. In the RRUFF Project specimen that contains lefontite (R140074), ushkovite (R060954), and atencioite, the provenance was only given as Galileia (perhaps as a result of the same wrong information of the structure paper on atencioite). The sample referred to as from this occurrence (photos from RRUFF) is identical to the ones from the João Firmino mine, with atencioite and ushkovite. This sample is probably from João Firmino mine. The type locality of atencioite is given correctly in the article of the original description of brandãoite (Menezes Filho *et al.* 2019), another type mineral from the João Firmino mine.

Occurrence. The mineral occurs at João Firmino claim, Pomarolli farm region, Linópolis, Divino das Laranjeiras, Minas Gerais. Associated minerals are albite, quartz, “lepidolite”, beryllonite, moraesite, ushkovite, and probably lefontite. This is also the type locality of brandãoite. The mineral formed in a phosphate-rich granite pegmatite.

The “triclinic Fe-dominant roscherite” from Lavra da Ilha pegmatite, Itinga, Minas Gerais (Leavens *et al.* 1990) is probably atencioite: A remarkable spray of pale green crystals which approach 2 cm in length is in the Smithsonian collection (NMNH #C6719). The crystals are complexly and irregularly zoned. Some sectors contain as much as 8% MgO and approach the zanazziite composition field (triclinic Mg-dominant “roscherite”?). The minerals associated with this triclinic Fe-dominant “roscherite” are earlier-crystallized albite and muscovite, along with later eosphorite and another generation of albite in very small and sharply developed crystals scattered sparsely over triclinic Fe-dominant “roscherite” (Leavens *et al.* 1990).

An additional occurrence at Lavra Poço D’Antas, Piauí creek, Itinga, Minas Gerais, is quoted in the Mindat database.

Appearance and physical properties. Groups of sub-parallel individuals and spherules up to 8 mm. Habit: coarse, split, elongated crystals, spherules. Forms: none observed. Twinning: none observed. Color: greenish-brown. Streak: white. Luster: vitreous. Transparent. Non-fluorescent. Hardness (Mohs): 4½. Tenacity: brittle. Cleavage: none observed. Fracture: uneven. Density: 2.84(1) g/cm^3 (meas., volumetric method), 2.86(1) g/cm^3 (meas., equilibration in heavy liquids), 2.832 g/cm^3 (calc. from the empirical formula).

Optical properties. Biaxial (–), α 1.613(2), β 1.620(2), γ 1.626(2) (589 nm), $2V$ 60(10)° (meas.), 85° (calc.). Dispersion: none observed. Pleochroism: β (greenish-brown) > α (brown) > γ (brown).

Chemical data. Microprobe (EDS mode) analyses (3), Fe^{2+}:Fe^{3+} ratio by Mössbauer data, BeO by wet-chemical analysis, H_2O by Penfield method: CaO 9.91, MgO 8.54, MnO 1.30, FeO 13.44, Fe_2O_3 3.92, Al_2O_3 0.41, BeO 9.30 P_2O_5 40.28, H_2O 13.20, total 100.30. Empirical formula:

$Ca_{1.87}Mg_{2.24}Mn_{0.19}Fe^{2+}_{1.98}Fe^{3+}_{0.52}Al_{0.08}Be_{3.93}(PO_4)_6(OH)_{4.22}·5.63H_2O$. The simplified formula requires: BeO 9.28, MgO 7.47, CaO 10.40, FeO 19.99, P_2O_5 39.49, H_2O 13.37, total 100.00 wt.%.

Crystallography. Triclinic, *P*1, *a* 6.668(1), *b* 9.879(2), *c* 9.883(1) Å, α 73.53(1)°, β 85.60(1)°, γ 86.93(1)°, *V* 622.8(4) Å^3, *Z* 1, *a:b:c* = 0.6750:1:1.0004 (single-crystal); *a* 6.671(3) Å, *b* 9.886(8) Å, *c* 9.890(8) Å, α 73.5(2)°, β 86.1(4)°, γ 86.7(3)°, *V* 623(1) Å^3, *Z* 1, *a:b:c* = 0.6748:1:1.0004 (powder data). X-ray powder diffraction data [*d* in Å (*I)* (*hkl*)]: 9.47 (41) (010), 5.92 (100) ($0\bar{1}1$), 3.31 (34) ($\bar{1}\bar{2}1$, $1\bar{2}1$), 3.17 (53) (210), 2.784 (86) ($\bar{1}03$), 2.639 (30) ($\bar{2}02$), 2.202 (32) ($\bar{1}\bar{3}2$, $\bar{1}24$).

Name. The name is for Daniel Atencio (born 1959), author of this book.

Type material. Mineralogical Museum of the Technische Universität Bergakademie, Freiberg, Germany, inventory number 80905.

Relationship to other species. A triclinic roscherite-group mineral, isostructural with footemineite (Atencio *et al.* 2008c).

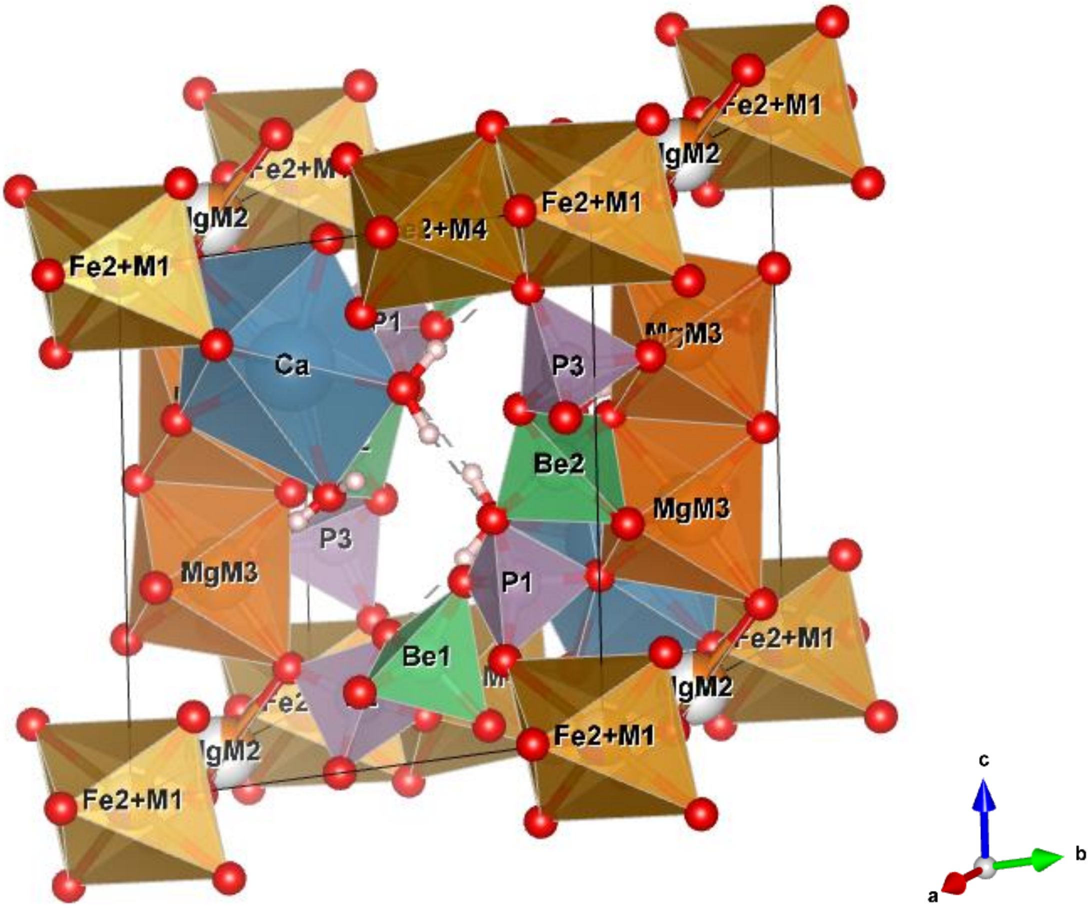

Figure 7.92. View of the crystal structure of atencioite (from the type occurrence, erroneously quoted as from Galileia), drawn using VESTA 3 (Momma and Izumi 2011). Data from Rastsvetaeva *et al.* (2004b).

Crystal structure. The structure of atencioite (Rastsvetaeva *et al.* 2004b), like those of other representatives of the roscherite group previously studied, is a three-dimensional edifice composed of tetrahedra, octahedra, and calcium seven-vertex polyhedra. The Be and P tetrahedra form infinite chains combined into a mixed framework through *M* octahedra, which, in turn, form octahedral chains by sharing edges. Calcium occurs in the framework cavities. The octahedra in the cell points are partially populated and, hence, the total number of *M* cations is reduced from six to five, and the chains are split statistically into pairs of octahedra. The environment of the *M*(1) octahedral site includes two water molecules at distances of 1.939 Å, while in the *M*(2) site, corresponding distances are 1.549 Å. The shorter distances are due to the very low population of the position by Mg atoms (0.2) and partial replacement of a water molecule by an OH group. The Ca polyhedron is coordinated by four oxygen atoms and three water molecules, one of these being a part of the environments of the *M*(1) and *M*(2) octahedra. The monoclinic minerals of the roscherite group have two octahedral sites, but only one position, the fourfold, is species-forming, because the other position (located at a center of inversion) tends to be vacant (in greifensteinite) or contains the same prevailing cation as the main one (in zanazziite). In triclinic members of the roscherite group, three positions (apart from the vacancy) are significant for systematization. In particular, the crystal-chemical formula of atencioite can be written as follows: $Ca_2(Fe^{2+},Mn)(\square,Mg)(Mg,Fe^{3+},Fe^{2+})_2(Fe^{2+},Mg)_2Be_4(PO_4)_6(OH)_4 \cdot 6H_2O$.

See also. Zanazziite, ruifrancoite, guimarãesite, and Zn-containing greifensteinite.

Mineral X

Camargo (1965)

(= phurcalite)

Other names: unnamed uranyl phosphate

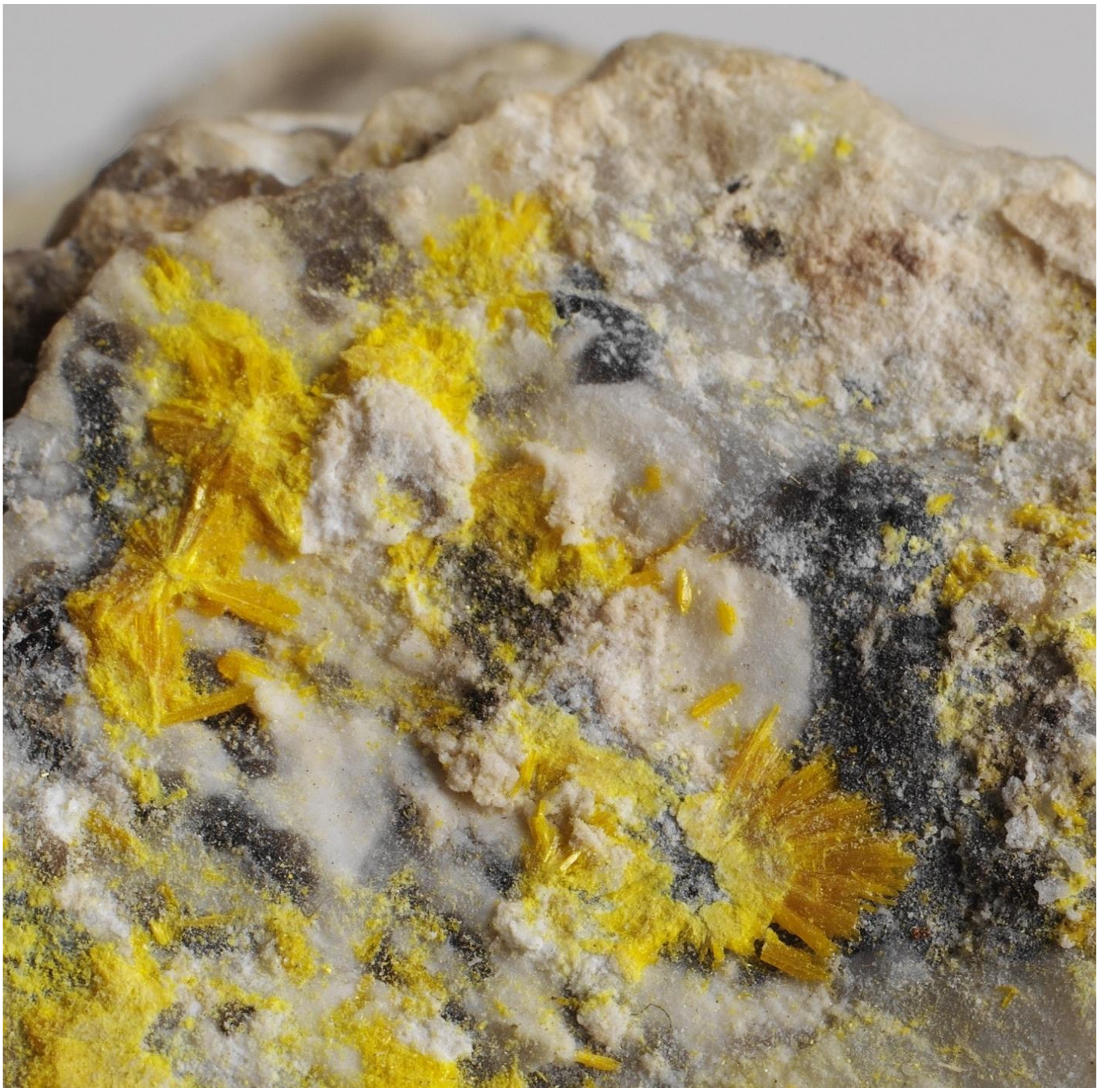

Figure 7.93. Phurcalite (“mineral X”) from Perus, São Paulo. The largest crystals are about 5 mm long. Specimen: Daniel Atencio. Photo: Thales Trigo.

Figure 7.94. Radiating crystals of phurcalite (“mineral X”) from Perus, São Paulo (Atencio *et al.* 1991).

Camargo (1965) recorded morphological, optical, and X-ray diffraction data for a mineral similar to phosphuranylite, as a fracture filling in a schist surrounding tourmaline granite, locally pegmatitic, at Perus, São Paulo. The small amount of material, however, prevented quantitative chemical analyses. Even so, that author concluded that it was a new species and named it “mineral X”. Fleischer (1974) and Fleischer *et al.* (1984) referred to “mineral X” from Perus as “unnamed uranyl phosphate”. Other uranium phosphates and silicates observed in the fracture filling are chernikovite, uranophane, beta-uranophane, phosphuranylite, torbernite, metatorbernite, meta-uranocircite, haiweeite, barium-rich weeksite, and uranian opal (see paulistanite) (Atencio 1988, Atencio 1991, Atencio and Hypolito 1994).

A comparison between the data published for “mineral X” from Perus and phurcalite, $Ca_2(UO_2)_3O_2(PO_4)_2 \cdot 7H_2O$ orthorhombic, suggests the identity between these two minerals. A new sample of “mineral X”, from a fracture surface in the granitic pegmatite (Atencio 1991, Atencio *et al.* 1991), made possible the additional studies needed to check this. Perus is, in fact, the first described occurrence of phurcalite and its crystals are the largest known.

Phurcalite from Perus forms aggregates of radiating, euhedral crystals, tabular on [010] and elongated parallel to [001]. Morphological studies by Camargo (1965) showed the presence of pinacoids {010} and {100}, rhombic prism {110} and rhombic dipyramid {111}. The crystals studied by Atencio *et al.* (1991) are up to 5 mm in length, whereas those first described by Camargo (1965) and all the others cited in the literature have a maximum length of 1 mm.

Phurcalite is bright yellow, transparent, and displays a vitreous luster, grading to adamantine in the largest crystals and to silky in fine aggregates. The streak is pale yellow. The crystals studied by Atencio *et al.* (1991) do not fluoresce in short- (254 nm) or long-wave (366 nm) ultraviolet radiation. Camargo (1965) noted weak, pale green fluorescence only under short-wave ultraviolet radiation. Phurcalite has good cleavages on {001} and {100}, and a perfect cleavage on {010}. It is brittle, with a conchoidal fracture. VHN_5 (two indentations): 86 and 95 (mean 90.5) kg/mm^2, corresponding to a Mohs hardness of 2.4. Density: 4.22(4) g/cm^3 (meas.), 4.220 g/cm^3 (calc.). Phurcalite is insoluble or very slowly soluble in water but soluble in cold 1:1 HCl (readily, with effervescence), HNO_3 (readily), and H_2SO_4 (slowly, producing a grey coating).

The mineral is biaxial (-), with α 1,677(2), β 1,732(2), γ 1,766(2), $2V_x$ 75° (meas.), 74° (calc.). Dispersion $r > v$, medium. orientation $X = b$, $Y = a$ and $Z = c$, absorption $X < Y < Z$, positive elongation. The mineral is orthorhombic, space group *Pbca*, *a* 17.415(2), *b* 16.035(3), *c* 13.598(3) Å, *V* 3797(2) Å^3, Z 8. The empirical formula for phurcalite from Perus (based on 23 atoms of oxygen) is $(Ca_{1.97}K_{0.05})_{\Sigma 2.02}(UO_2)_{2.87}O_{1.93}[(PO_4)_{1.90}(SiO_4)_{0.04}]_{\Sigma 1.94} \cdot 7.57H_2O$.

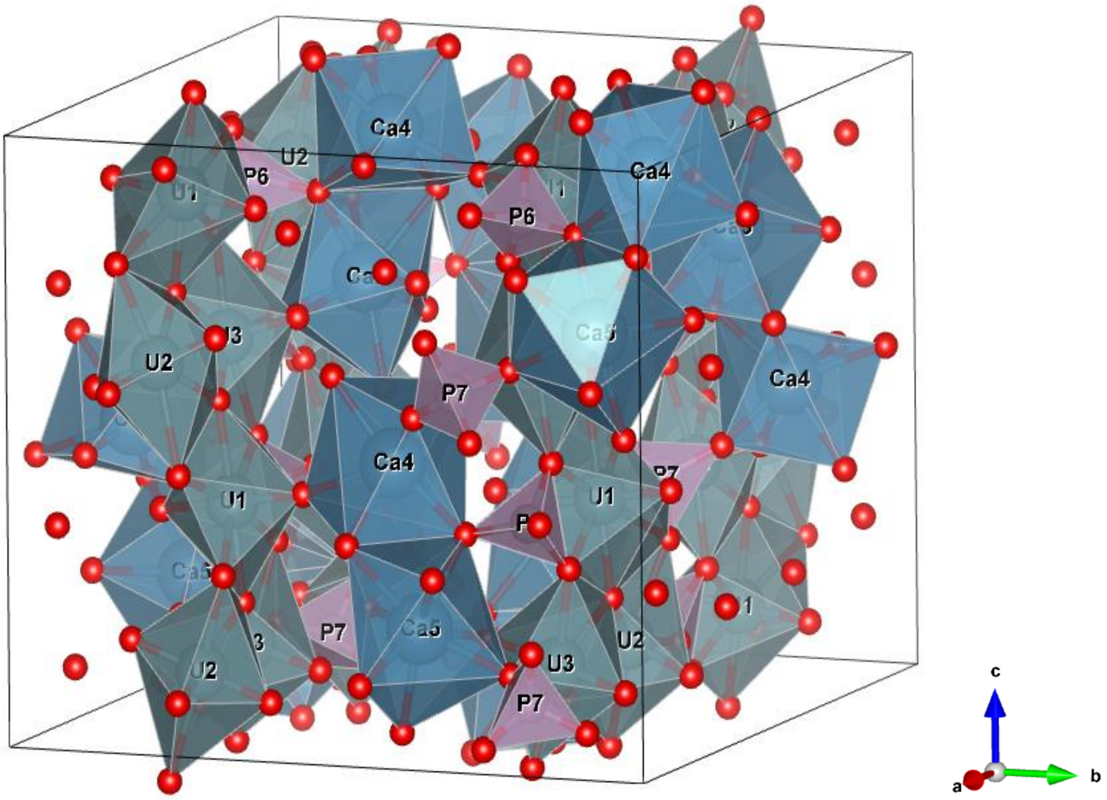

Figure 7.95. View of the crystal structure of phurcalite (“mineral X” from Perus, São Paulo), drawn using VESTA 3 (Momma and Izumi 2011). Data from Atencio *et al.* (1991).

The crystal structure of phurcalite was solved by Piret and Declercq (1978) who derived the formula $Ca_2(UO_2)_3(PO_4)_2(OH)_4\cdot4H_2O$. However, there are problems with their structure. Bond-valence considerations derived from the bond lengths determined by Piret and Declercq (1978) clearly suggest that (i) O(14) and O(17) are isolated O^{2-} anions and not $(OH)^-$ groups, (ii) O(24) to O(29) are all H_2O groups, and (iii) an additional oxygen atom linked to Ca(5) might exist. To resolve these points, a new structural study of phurcalite was undertaken using a crystal from the occurrence at Perus (Atencio *et al.* 1991). As a consequence of this work, the structural formula of phurcalite must be changed to $Ca_2(UO_2)_3O_2(PO_4)_2\cdot7H_2O$. The structure consists of $[(UO_2)_3O_2(PO_4)_2]_n^{4n-}$ layers, parallel to (010), which are connected by Ca^{2+} ions and H_2O. The coordination polyhedra are for U(I) a hexagonal bipyramid, for U(2) and U(3) pentagonal bipyramids, for Ca(4) and Ca(5) a capped trigonal prism and a dodecahedron with triangular faces, respectively, and for P(6) and P(7), tetrahedra.

See also. Paulistanite.

Chapter 8

Arsenates

Yanomamite

Botelho *et al.* (1994)

$InAsO_4 \cdot 2H_2O$, orthorhombic

Approved CNMMN - IMA 1990-052

Other names: yanomamita, mineral X

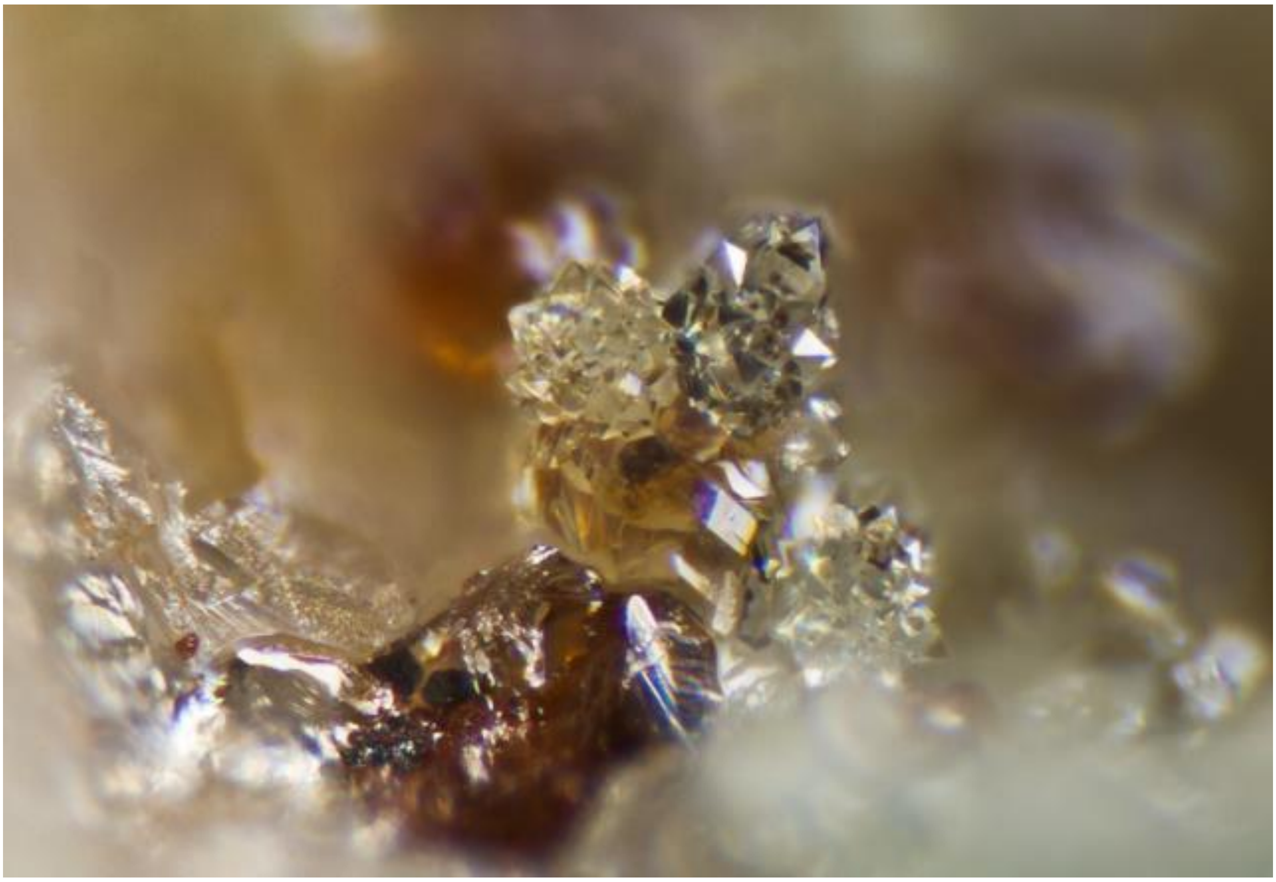

Figure 8.1. Colorless crystals of yanomamite from the Periquito mine, Monte Alegre de Goiás, Goiás. Field of view 0.4 mm. Specimen and photo: Vincent Bourgoin.

Occurrence. Periquito mine, Mangabeira tin deposit, at the edge of GO-118 road, 1 km north of Passa-e-fica, Monte Alegre de Goiás, Goiás, in quartz-topaz greisen veins in a Li-topaz-albite granite. Associated minerals are topaz, quartz, zinnwaldite, wolframite, cassiterite, arsenopyrite, indium-rich sphalerite, chalcopyrite, pyrite, enargite, stannite, cosalite, scorodite, beudantite, covellite, chalcocite, löllingite, roquesite, galena, digenite, agardite-(Y), dzhalindite, chenevixite, pharmacosiderite, and metazeunerite. Moura and Botelho (1994) and Moura *et al.* (2007) described unnamed Ba-Fe, Bi-, Pb-Fe, and Sn-Fe-arsenates. Yanomamite crystals are often coated by a thin film of epitactic In-rich scorodite. Yanomamite and In-bearing scorodite are cogenetic, formed by alteration of early arsenopyrite and In-rich sphalerite. A second occurrence is Aveleiras Mine, Mire de Tibães, Braga, Portugal (Alves *et al.* 2010).

Appearance and physical properties. Bipyramidal crystals (mean size 0.1 mm, maximum size 0.2 mm). Aggregates can reach 1 cm. Intimately intergrown with scorodite. Pale to yellowish-green, with a white streak. Luster vitreous. Transparent. Cleavage not observed. Fracture subconchoidal. Non-fluorescent. Density 3.876(3) g/cm^3 (calc.). Hardness (Mohs): 3.5 to 4; VHN$_{25}$: 571 to 743 (mean 631) kg/mm^2.

Optical properties. Biaxial (+), mean n 1.65, $2V_z$ 55 to 76º (meas.). Dispersion: $r > v$, strong, orientation $X = a$, $Y = c$, $Z = b$.

Chemical data. Means of 12 sets of electron microprobe analyses: In_2O_3 45.8(3), Fe_2O_3 1.1(2), Al_2O_3 0.21(2), As_2O_5 40.1(2), H_2O 12.78 (by difference), total 100.00 wt.%. Empirical formula: $(In_{0.94}Fe_{0.04}Al_{0.01})AsO_4{\cdot}2.02H_2O$. The ideal formula requires In_2O_3 47.90, As_2O_5 39.66, H_2O 12.44, total 100.00 wt.%.

Crystallography. Orthorhombic, *Pbca*. a 10,446(6), b 9,085(4), c 10,345(6) Å. V 981,8(7) Å^3, Z 8, a:b:c 1.1498:1:1.1387. X-ray powder diffraction data [d in Å (I) (hkl)]: 5.70 (70) (111), 4.53 (100) (020, 210), 4.163 (50) (021), 3.874 (60) (121), 3.250 (60) (122), 3.110 (50) (311), 2.656 (40) (123), 2.541 (40) (231). Synthetic: Orthorhombic, *Pbca*. a 10.478(1), b 9.0998(8), c 10.345(1) Å. V 986.4(2) Å^3, Z 8 (Tang *et al.* 2002); Orthorhombic, *Pbca*. a 9.090(4), b 10.344(4), c 10.468(4) Å. V 984.27 Å^3, Z 8 (Chen *et al.* 2002).

Name. For the Yanomami Indian people of the Amazon region. Referred to as “mineral X” by Botelho and Roger (1990). The name yanomamite was first used by Botelho (1992).

Type material. Holotype specimens preserved in the Mineralogical Collection of the Instituto de Geociências, Universidade de Brasília, Brasília, and in the Musée de Minéralogie, Ecole Nationale Supérieure des Mines, Paris, France, 54608 (donator Botelho, 1991).

Relationship to other species. Variscite group.

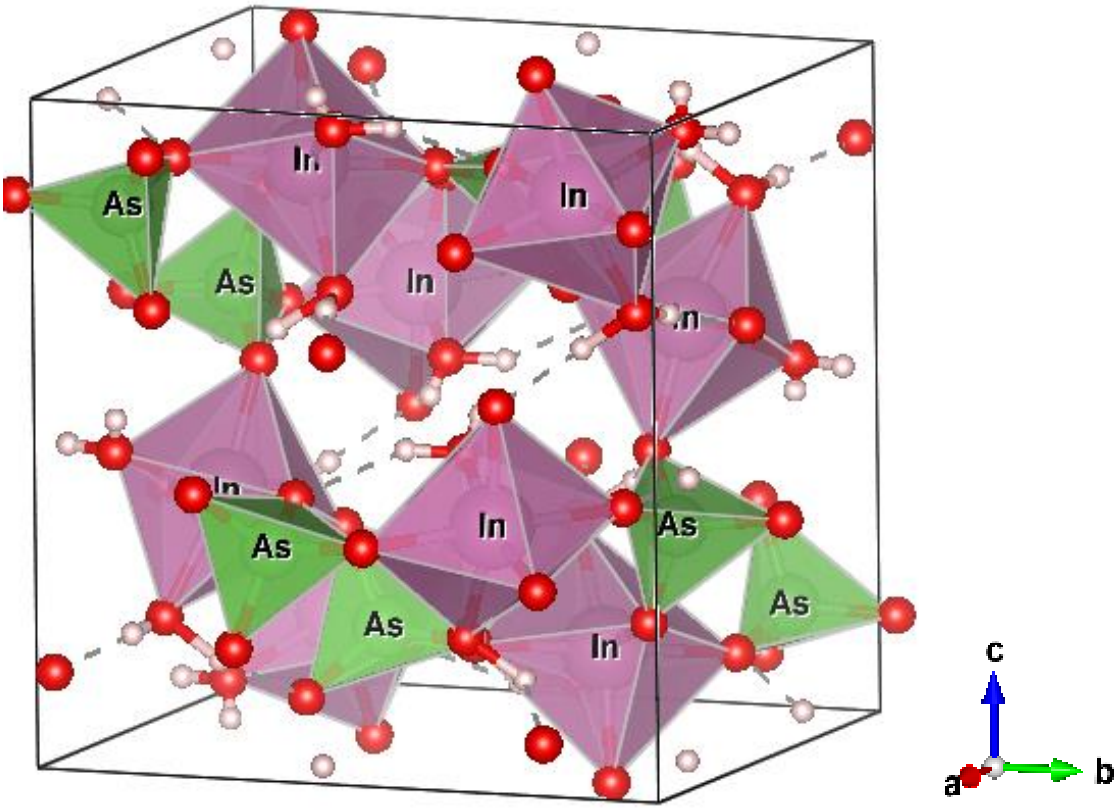

Figure 8.2. View of the crystal structure of yanomamite (synthetic), drawn using VESTA 3 (Momma and Izumi 2011). Data from Chen *et al.* (2002).

Crystal structure. Yanomamite is isomorphic with variscite. Its three-dimensional framework consists of corner-sharing $InO_4(H_2O)_2$ octahedra and AsO_4 tetrahedra. The indium octahedron is distorted, while the arsenate group forms a regular tetrahedron. The framework generates eight-member-ring channels {4 × $[InO_4(H_2O)_2]$ and 4 × (PO_4)} parallel to the *c*-axis, and six-member-ring channels {3 × $[InO_4(H_2O)_2]$ and 3 × (PO_4)} running along (*a* + *b*)-axis. Despite the significant difference between the two indium-water distances, both water molecules are true H_2O species (Tang *et al.* 2002).

Synthetic. A mixture of $InCl_3$, $As_2O_5 \cdot xH_2O$, $(CH_3)_4NOH \cdot 5H_2O$, $CsNO_3$, $Cd(C_2H_3O_2) \cdot 2H_2O$, and water in a molar ratio 4:1:2:4:8:776 was sealed under vacuum in a thick-wall pyrex tube (~20% filled). The reaction was carried out at 160°C for 12 days followed by slow cooling to room temperature. The products were filtered, washed with water and acetone, and dried at room temperature. Two phases were found to be present: synthetic yanomamite in about 80% yield, and $CsIn(HAsO_4)_2$ (Tang *et al.* 2002).

See also. Unnamed Ba-Fe-arsenate, unnamed Bi-arsenate, unnamed Pb-Fe-arsenate, and unnamed Sn-Fe-arsenate.

Unnamed Ba-Fe-arsenate

Moura and Botelho (1994), Moura *et al.* (2007)

Other names: UM2007-07-AsO:BaFeHK

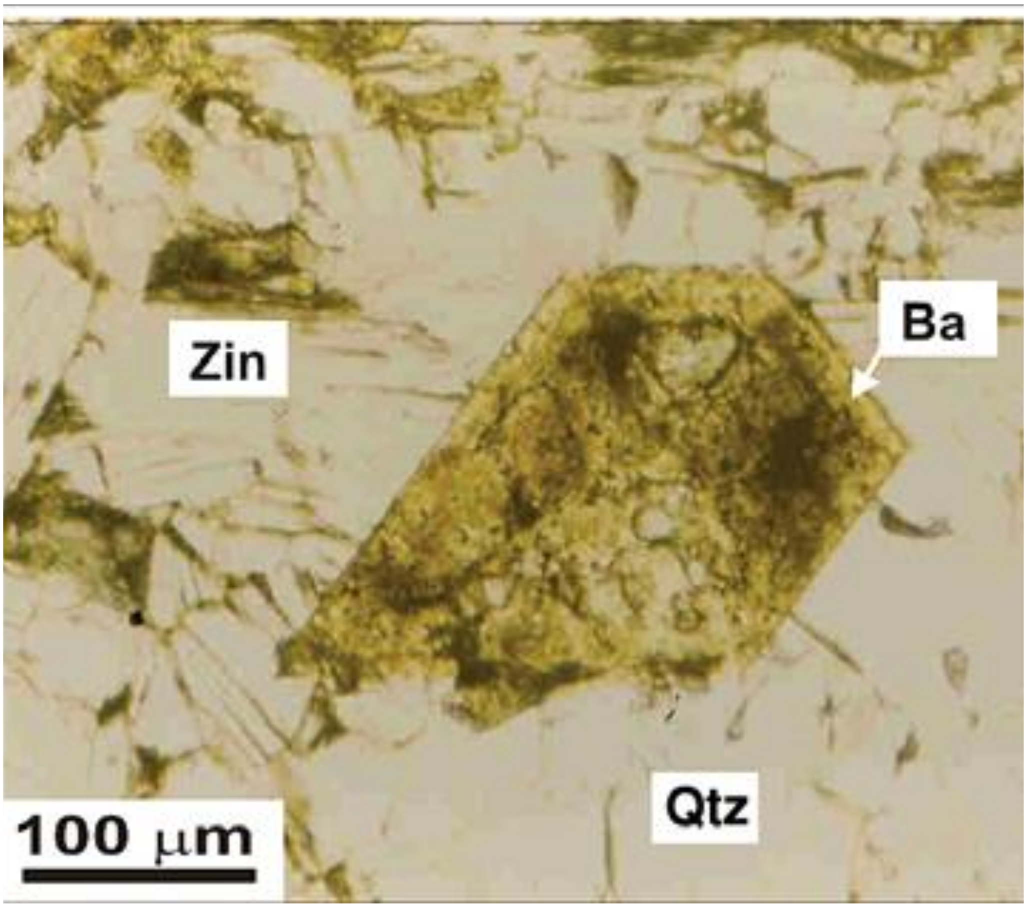

Figure 8.3. Euhedral unnamed Ba-Fe-arsenate (Ba) in quartz–topaz rock from Periquito mine, Mangabeira tin deposit, Monte Alegre de Goiás, Goiás (transmitted, plain-polarized light). Symbols: Qtz: quartz, Zin: zinnwaldite. Moura *et al.* (2007).

An unnamed Ba-Fe-arsenate was described in the quartz–topaz rock of the Periquito mine, Mangabeira tin deposit, Monte Alegre de Goiás, Goiás, where yanomamite was identified. The mineral occurs as grains up to 500 µm in size. Light yellow to yellowish-brown, medium to high relief, usually associated with scorodite masses. Generally massive and rarely with rhombic habit. The euhedral grains are isotropic, but some have an anomalous grayish-blue interference-color. The massive grains are, in some cases, associated with masses of scorodite, and also appear to be products of the alteration of arsenopyrite. Despite some scatter, attributed to the massive nature of the grains studied and their hydrated nature, the data point to an unknown barium mineral with a composition that can be considered in some way similar to that of bariopharmacosiderite. Electron microprobe data (6 analyses): SO_3 0.07, As_2O_5 45.55, SnO_2 0.02, Fe_2O_3(t) 38.26, Al_2O_3 0.33, In_2O_3 0.03, BaO 8.68, PbO 0.22, CuO 0.17, ZnO 0.19, K_2O 0.79, H_2O 5.72 (by difference), total 100.00 wt.%. Empirical formula: $(Ba_{0.44}K_{0.13})_{\Sigma 0.57}(Fe^{3+}_{3,74}Al_{0.05}Pb_{0.04}Cu_{0.02})_{\Sigma 3.85}(As_{3.10}S_{0.01}O_{12})(OH)_4\cdot 0.48H_2O$. Bariopharmacosiderite is $Ba_{0.5}Fe^{3+}_4(AsO_4)_3(OH)_4\cdot 5H_2O$.

See also. Yanomamite, unnamed Bi-arsenate, unnamed Pb-Fe-arsenate, and unnamed Sn-Fe-arsenate.

Unnamed Bi-arsenate

Moura and Botelho (1994), Moura *et al.* (2007)

An unnamed Bi-arsenate was described in the quartz–topaz rock of the Periquito mine, Mangabeira tin deposit, Monte Alegre de Goiás, Goiás, where yanomamite was identified. The bismuth arsenate is rare in the Mangabeira quartz–topaz rock, in which it occurs either as discrete grains 200μm across included in quartz or filling fractures in altered arsenopyrite. The mineral is dark brown under uncrossed nicols and has a high relief. Electron microprobe data (5 analyses): As_2O_5 18 to 25, Fe_2O_3(t) 0.24 to 6.1, Bi_2O_3 59 to 74, H_2O (estimated) 14 to 2 wt.%. Results of electron-microprobe analyses vary widely, possibly owing to the loose character of the grains studied. The composition is considered to be similar to preisingerite, $Bi_3(AsO_4)_2$ (OH), although at Mangabeira, the bismuth arsenate is optically different.

See also. Yanomamite, unnamed Ba-Fe-arsenate, unnamed Pb-Fe-arsenate, and unnamed Sn-Fe-arsenate.

Unnamed Pb-Fe-arsenate

Moura and Botelho (1994), Moura *et al.* (2007)

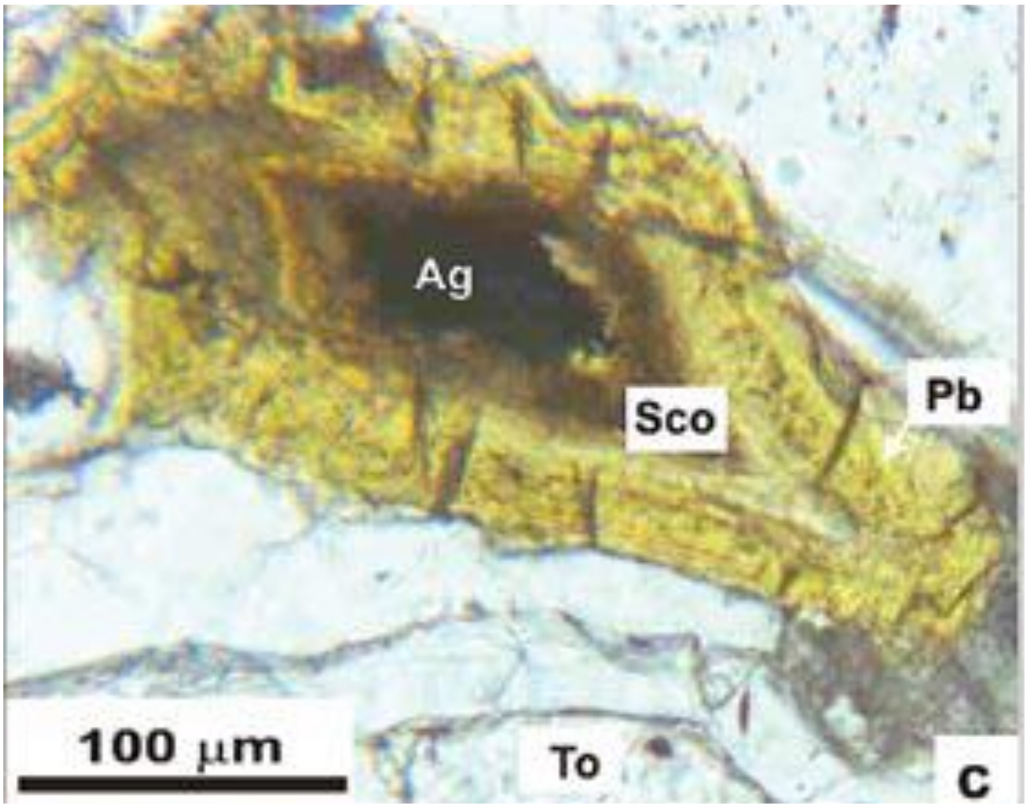

Figure 8.4. Grain in quartz–topaz rock from the Periquito mine, Mangabeira tin deposit, Monte Alegre de Goiás, Goiás, where argentite (nucleus) grades to scorodite and is finally overgrown by the unnamed Pb-Fe arsenate (transmitted, plane polarized light). Symbols: Ag: argentite, Sco: scorodite, Pb: unnamed Pb-Fe arsenate, To: topaz. Moura *et al.* (2007).

An unnamed Pb-Fe-arsenate was described in the quartz–topaz rock of the Periquito mine, Mangabeira tin deposit, Monte Alegre de Goiás, Goiás, where yanomamite was identified. The lead arsenate mineral is pale yellow, has a high index of refraction, and occurs as either filling of microfractures in quartz and zinnwaldite grains or as discrete grains in altered quartz–topaz rock. It has an anomalous blue interference-color where filling fractures. The mineral also forms zoned grains where it is associated with the tin arsenate, such that its nucleus is rich in lead and its border is rich in tin, or with argentite and scorodite. In the latter case, the nucleus of the grain is argentite and grades to an intermediate zone of scorodite and an outer zone of lead arsenate. Quantitative electron-microprobe analyses yielded a mean composition of 28 wt.% As_2O_5, 24% Fe_2O_3, 31% PbO, 5% Al_2O_3, 12% calculated H_2O, and no SO_3. Segnitite [$PbFe^{3+}_3AsO_4(AsO_3OH)(OH)_6$] have optical characteristics similar to those found in this arsenate and this arsenate was tentatively classified as segnitite.

See also. Yanomamite, unnamed Ba-Fe-arsenate, unnamed Bi-arsenate, and unnamed Sn-Fe-arsenate.

Unnamed Sn-Fe-arsenate

Moura and Botelho (1994), Moura *et al.* (2007)

Other names: UM2007-08-AsO:FeHSn, Unnamed (Sn-Fe Arsenate-Hydrate)

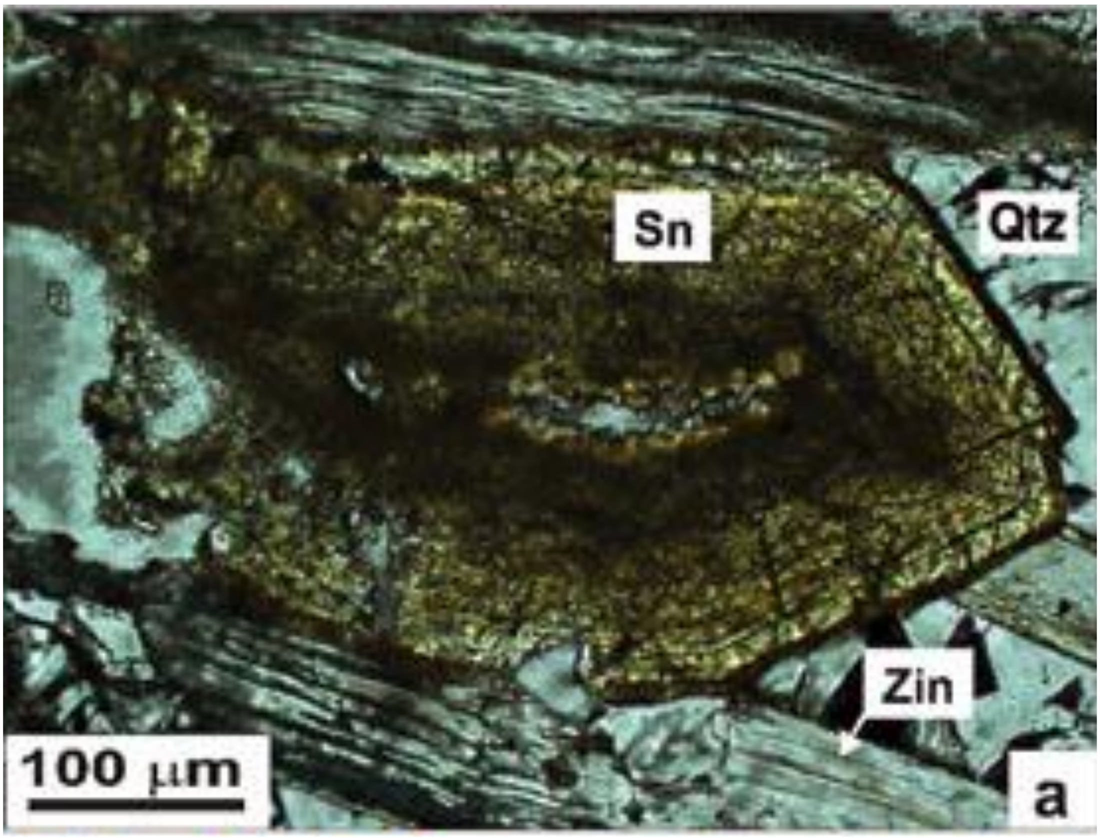

Figure 8.5. Zoned unnamed Sn-Fe-arsenate (transmitted, plane-polarized light) in quartz–topaz rock from the Periquito mine, Mangabeira tin deposit, Monte Alegre de Goiás, Goiás. Symbols: Qtz: quartz, Sn: unnamed Sn-Fe-arsenate, Zin: zinnwaldite. Moura *et al.* (2007).

An unnamed Sn-Fe-arsenate was described in the quartz–topaz rock of the Periquito mine, Mangabeira tin deposit, Monte Alegre de Goiás, Goiás, where yanomamite was identified. According to Moura and Botelho (1994), this mineral is intense yellow, presents prismatic habit, medium to high relief, is zoned, and isotropic. Electron microprobe data (15 analyses): As_2O_5 15 to 18, Fe_2O_3(t) 17 to 22, SnO_2 49 to 55, H_2O 4 to 9, Al_2O_3 1 to 1.5, SO_3 0.2 to 0.8, CuO 0.3 to 0.7 wt.%. According to Moura *et al.* (2007), the unnamed tin arsenate mineral occurs as either discrete grains or filling fractures of pre-existing minerals in strongly altered quartz–topaz rock. Locally, it is associated with probable native tin. The arsenate grains are yellow to brownish-yellow, anhedral, rarely euhedral, 0.1 to 1 mm across, zoned, isotropic and with a high index of refraction. The chemical composition of the yellow zones (mean of 11 analyses, H_2O by difference) is: As_2O_5 16.88, SO_3 0.53, SnO_2 52.42, Fe_2O_3 20.74, Al_2O_3 1.17, In_2O_3 1.47, CuO 0.49, ZnO 0.08, H_2O (6.22), total (100.00) wt.%. In its brownish zones, the mineral seems poorly crystalline, and its tin content decreases, whereas iron and sulfur increase. Moura *et al.* (2007) proposed the simplified empirical formula $Sn_3Fe_2(AsO_4)\cdot 3H_2O$, calculated on the basis of 13 cations, for this unknown mineral, but this formula did not agree with the presented chemical data and is not charge-balanced. The empirical formula is
$(Fe^{3+}_{6.79}Al_{0.60}In_{0.28}Cu^{2+}_{0.16}Zn_{0.03})_{\Sigma 7.86}Sn^{4+}_{9.09}(As^{5+}_{3.84}S_{0.17})_{\Sigma 4.01}O_{39.98}\cdot 9.02H_2O$.
The simplified formula is $Fe^{3+}_8Sn^{4+}_9(AsO_4)_4O_{24}\cdot 9H_2O$.

See also. Yanomamite, unnamed Ba-Fe-arsenate, unnamed Bi-arsenate, and unnamed Pb-Fe-arsenate.

Bendadaite

Kolitsch *et al.* (2010)

$Fe^{2+}Fe^{3+}_2(AsO_4)_2(OH)_2\cdot 4H_2O$, monoclinic.

Approved CNMMN - IMA in 2007, proposal 1998-053a

Other names: bendadaíta

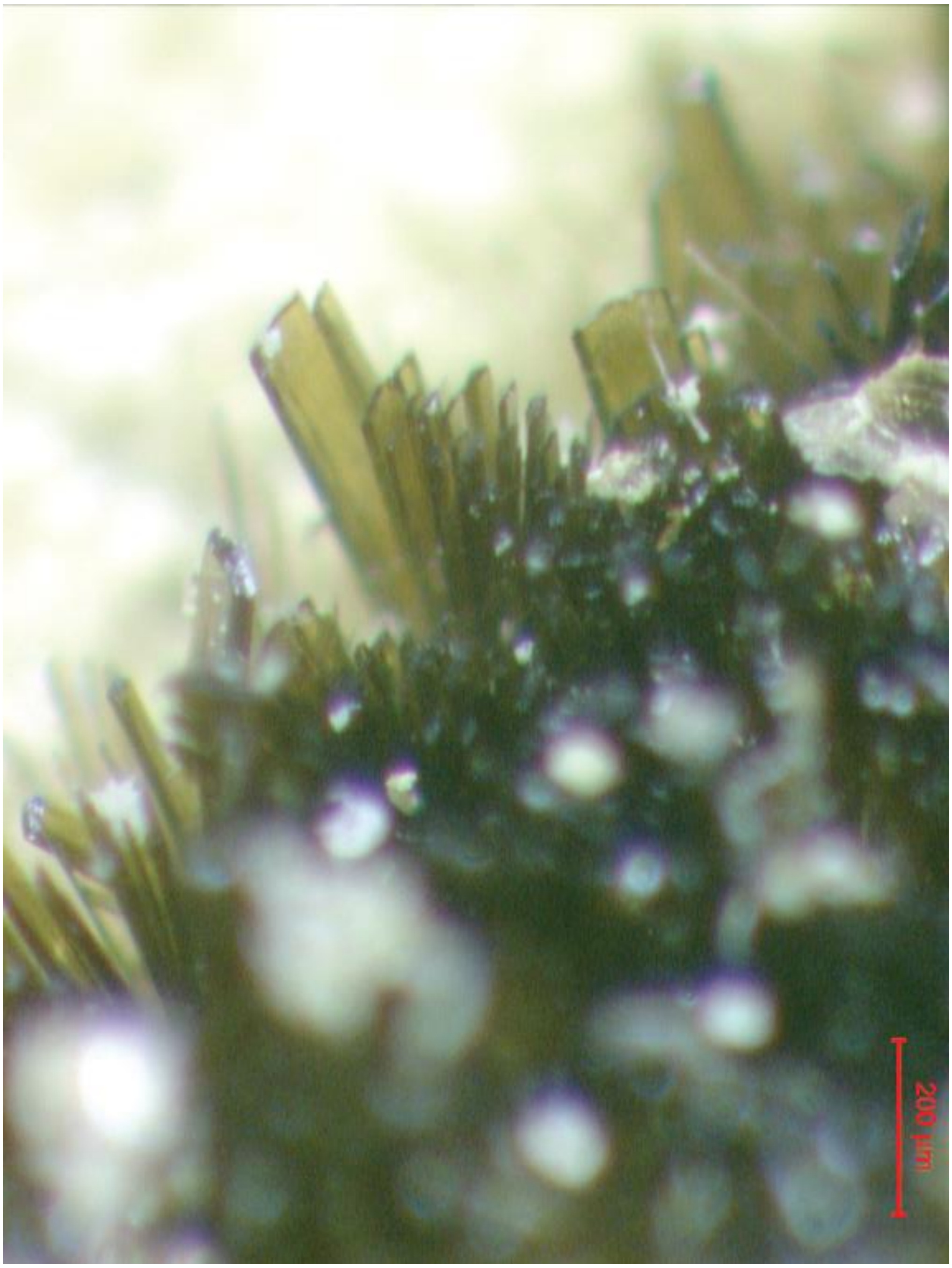

Figure 8.6. Tabular crystals of bendadaite from Lavra do Almerindo. Photo: Daniel Atencio. (Kolitsch *et al.* 2010).

During a Portugal field trip of members of the Institut für Mineralogie und Kristallchemie of the Universität Stuttgart, Germany, in 1987, the mineralogy student J. Argyrakis collected an arsenopyrite-bearing hand specimen on the dumps of the phosphate-bearing pegmatite Bendada, central Portugal. A later close inspection of the hand specimen by Uwe Kolitsch in about 1993 showed an unknown blackish-green to dark brownish mineral forming tiny tufts on and near corroded, massive arsenopyrite. Detailed investigations on the very scarce available material revealed the mineral to be a new hydrated iron arsenate mineral and a new end-member of the arthurite group. An original submission as a new mineral species in 1998 (IMA 98-053) was put on hold due to inadequate electron microprobe data. Additional data were subsequently obtained from new finds of the mineral in Brazil, Chile and Morocco. After resubmission of an improved proposal, including a crystal-structure analysis of a crystal from Brazil, and additional spectroscopic data, the description and name were approved by the Commission on New Minerals and Mineral Names, IMA, in 2007. Additional data for bendadaite from Almerindo quarry are available in the RRUFF Database (R080112). Following is the description of the Brazilian cotype occurrence.

Occurrence. The granite pegmatite of Lavra do Almerindo (Almerindo quarry), Linópolis, Divino das Laranjeiras, Minas Gerais, is the cotype locality of bendadaite. The species accompanying bendadaite are albite, muscovite, quartz, schorl, elbaite, löllingite, scorodite, pharmacosiderite, saléeite and phosphuranylite. Bendadaite from Brazil is very scarce: it was found inside small cavities in albite, some decimeters away from a large block of löllingite. Bendadaite formed as a secondary (or low-T late-hydrothermal?) mineral with Fe and As derived from weathered arsenopyrite. Also, known from several world occurrences.

Appearance and physical properties. Only five hand-size specimens were found, and only one had a 5 mm-thick layer of elongated tabular dark greenish-brown bendadaite crystals, partially coated with tufts of divergent pale yellowish-green acicular bendadaite crystals; the remaining four specimens contained globular to pellet-like aggregates of very pale yellowish-green acicular bendadaite crystals, measuring up to 0.3 mm, and were associated with spherical light gray clusters of scorodite crystals, over a matrix of corroded albite. Forms: no idiomorphic single-crystals; {010} cleavage flakes only. Twinning: none observed. Color: blackish-green to dark brown with a greenish tint. Streak: greenish-yellow. Luster: vitreous, vitreous to adamantine on cleavage planes, dull on hemisphere surfaces.

Aggregates are opaque, and thin elongated cleavage flakes are translucent. Non-fluorescent. Hardness (Mohs): ~3. Tenacity: brittle. Cleavage: {010}, good. Fracture: irregular. Density (meas.) 3.15(10) g/cm^3 by suspension in heavy liquid (sodium polytungstate solution), with glass cubes of know density as standards. Density (calc.) 3.178 g/cm^3 (with empirical formula of cotype material and single-crystal data).

Optical properties. Determined on two different materials. Dark brown cluster of fibers or divergent plates have α 1.720(4), β 1.760(4), γ 1.787(4), 2V ~90°, $Z \wedge c$ ~10-20°. Pleochroism: medium-strong, Z (dark brown) > X, Y (greenish-brown). Clusters of very fine divergent colorless to pale yellow needles (1 to 3 μm) are characterized by α 1.725(5), β 1.755(5), γ 1.785(5), 2V ~90°, $Z \wedge c$ ~10-12°. Pleochroism: recognizable, $Z > Y = X$.

Chemical data. Microprobe data (5, dark material), Fe^{2+}:Fe^{3+} ratio by Mössbauer data, H_2O by Alimarin method: MnO 0.57, FeO 10.07, Fe_2O_3 33.22, Al_2O_3 0.72, As_2O_5 37.72, P_2O_5 5.40, H_2O 18.60, total 106.30 wt.%. Empirical formula: $(Fe^{2+}_{0.69}Fe^{3+}_{0.13}Mn_{0.04}\square_{0.14})_{\Sigma1.00}(Fe^{3+}_{1.93}Al_{0.07})_{\Sigma2.00}(As_{1.62}P_{0.38})]_{\Sigma2.00}O_8(OH)_{1.82}\cdot4.18H_2O$. Analyses of pale crystals show slightly higher Al and Mn. The ideal formula requires: FeO 13.03, Fe_2O_3 28.96, As_2O_5 41.68, H_2O 16.33, total 100.00 wt.%.

Crystallography. Monoclinic, $P2_1/c$, a 10.200(1), b 9.718(1), c 5.5432(5) Å, β 94.05(1)°, V 548.1(1) Å^3, Z 2, a:b:c = 1.050:1:0.570. X-ray powder diffraction data [d in Å (I) (hkl)]: 10.18 (10.0) (100), 7.02 (9.1) (110), 4.245 (1.5) (111), 3.086 (1.5) (130), 2.896 (1.5) ($\bar{3}$11).

Name. The name is for the type locality, Bendada.

Type material. The cotype material has been deposited in the Museu de Geociências, Universidade de São Paulo (catalog number DR625).

Relationship to other species. A member of the arthurite group. The arsenate analog of whitmoreite. Chemically related to césarferreiraite.

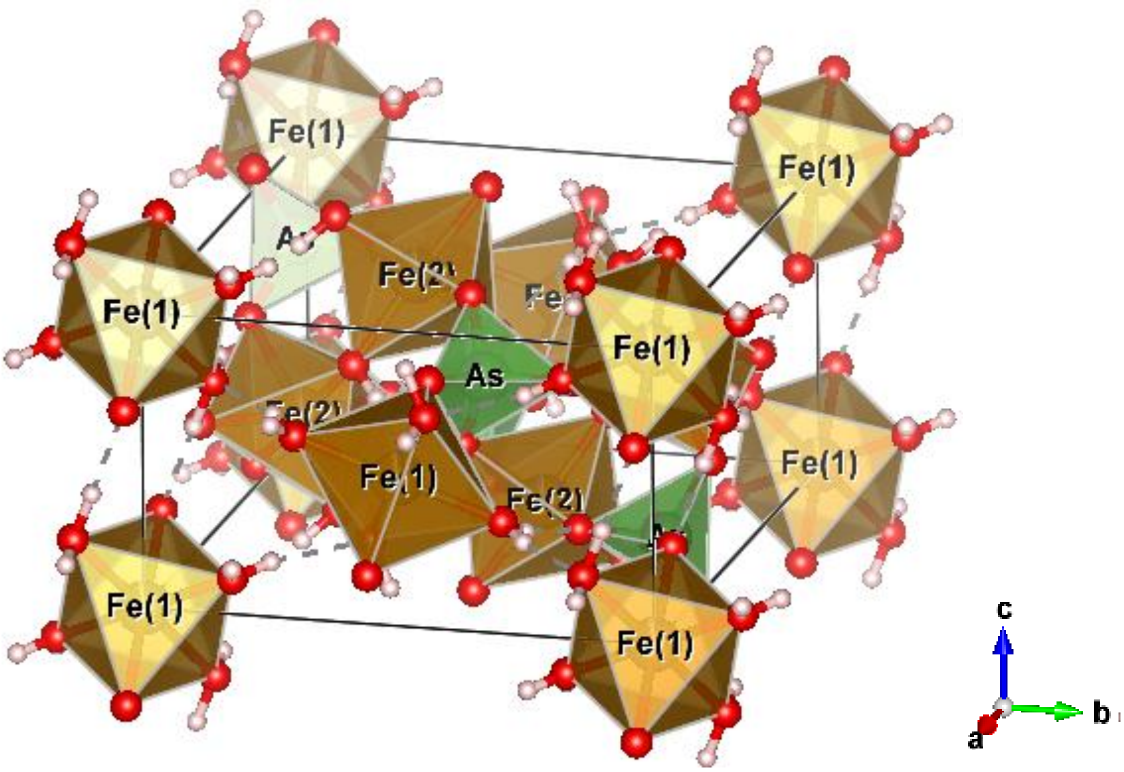

Figure 8.7. View of the crystal structure of bendadaite (from the Brazilian occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Kolitsch *et al.* (2010).

Crystal structure. A single-crystal structure determination was feasible using a crystal from the Brazilian occurrence. The structure model is in good agreement with those of the other arsenate members of the arthurite group. The arrangement of atoms in bendadaite is characterized by a unique corrugated open sheet of (Fe^{3+}–O)$_6$ octahedra, each of which shares four of its six vertices with adjacent octahedra. Vertices with (OH)– ligands are corner-linked to adjacent octahedra, forming a stepped corner-chain parallel to [001]. These chains are linked into a sheet parallel to (100) by sharing O(1)–O(1) edges with equivalent chains. Above and below the sheet of octahedra are AsO_4 tetrahedra, which share three of four vertices with the octahedra, to form a slab. The slabs are joined by isolated (Fe^{2+}– O)$_6$ octahedra, which share two opposite vertices with the remaining vertices of the AsO_4 tetrahedra not shared with the (Fe^{3+}–O)$_6$ octahedra, from above and below each slab.

See also. Césarferreiraite.

Césarferreiraite

Scholz *et al.* (2014)

$Fe^{2+}Fe^{3+}_2(AsO_4)_2(OH)_2\cdot8H_2O$, triclinic

Approved CNMNC - IMA 2012-099

Other names: cesarferreiraíta

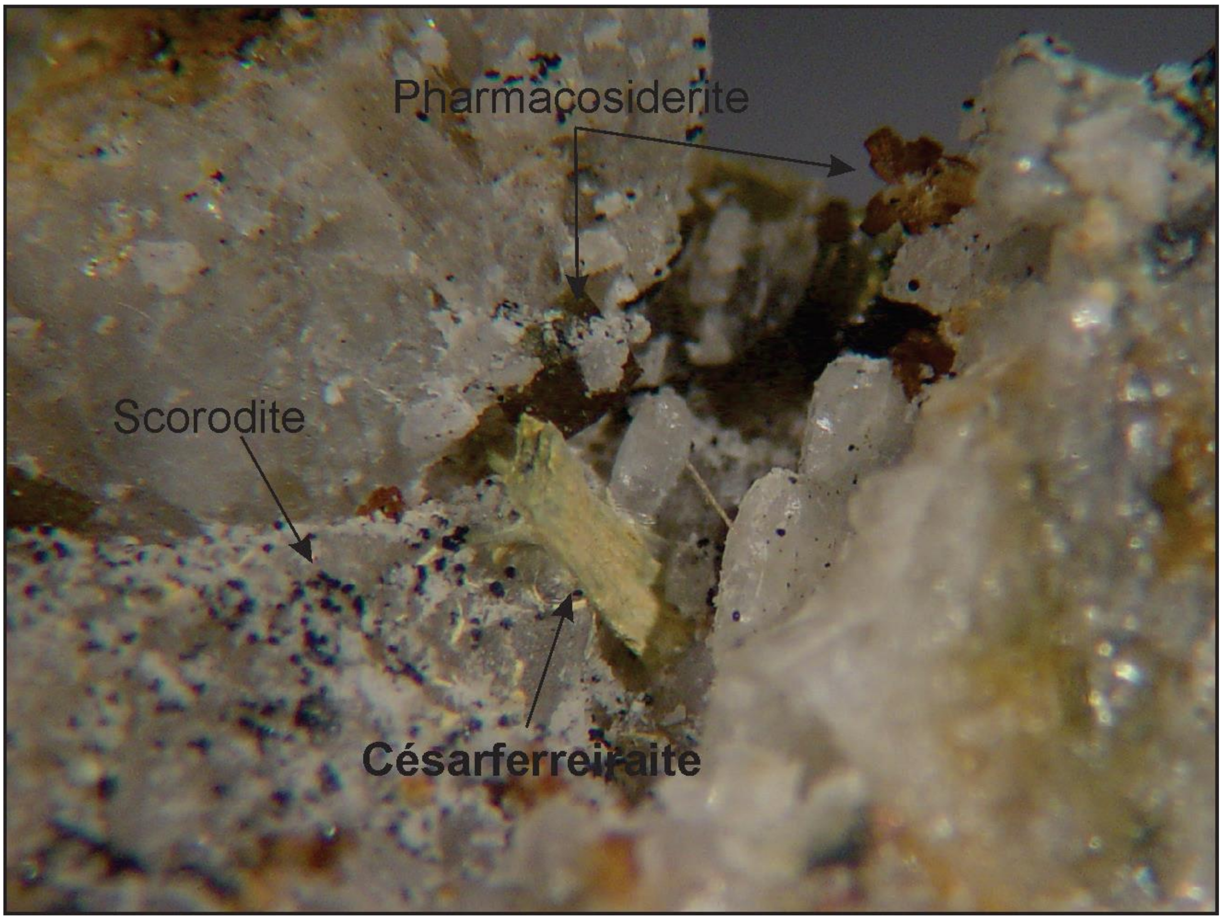

Figure 8.8. Césarferreiraite crystal aggregate (2 mm) from the Eduardo pegmatite, Conselheiro Pena, Minas Gerais. in association with pharmacosiderite and scorodite. Field of view: 1.0 cm (Scholz *et al.* 2014)

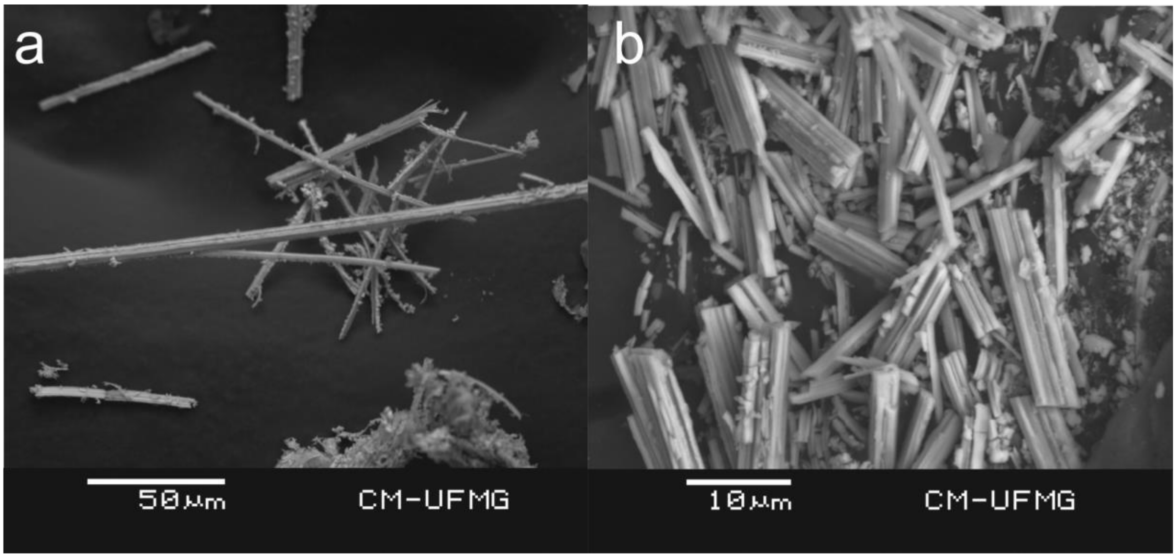

Figure 8.9. BSE-SEM images of césarferreiraite from the Eduardo pegmatite, Conselheiro Pena, Minas Gerais (Scholz *et al.* 2014).

The mineral was collected by Ricardo Scholz during a preparatory field trip in the Eastern Pegmatite Province for the 4th International Symposium on Granitic Pegmatites (PEG 2009). Due to the tiny size of single-crystals forming friable aggregates, single-crystal diffraction data were not obtained. However, the analogy with laueite group minerals in stoichiometry and X-ray powder diffraction data, as well as the excellent compatibility confirms the correctness of the data obtained.

Occurrence. The mineral occurs in the Eduardo pegmatite, near Boa Vista creek, Conselheiro Pena, Minas Gerais. Césarferreiraite is associated with pharmacosiderite and earlier arsenopyrite and probably replaces the latter. The pegmatite forms a lenticular body with a strike length of at least 20 m and a maximum width of 12 m. It crops out on a steep hillside, and, at the uppermost end, pinches out to less than 1 m in width. Other minerals found in the pegmatite, including secondary species, are albite, almandine-spessartine, beryl, bismuth, bütschliite, cryptomelane, cyrilovite, löllingite, fourmarierite, frondelite-rockbridgeite, heterosite, hureaulite, kaolinite, leucophosphite, löllingite, manganese oxides, metatorbenite, microcline, muscovite, phosphosiderite-strengite, quartz, saléeite, schorl, spodumene, triphylite-lithiophilite, ushkovite, and variscite (Bermanec *et al.* 2011).

Appearance and physical properties. Césarferreiraite occurs as fibrous to tabular aggregates. Crystals are up to 10 µm long with a thickness of about 1-2 µm. Habit: single-crystals are imperfect, flattened and lath-shaped. Crystals are elongated along [001] and flattened on (100). The fibers have a rectangular cross-section apparently bound by the

{100} and {010}. Forms: pinacoids. Twinning: none observed. Color: pale yellow to greenish-yellow. Streak: pale yellow to greenish-yellow. Luster: vitreous. Transparent (individual crystals) to translucent (masses). Non-fluorescent. Hardness: not known (too little pure material), but the mineral is easily crushed between two glass slides. Tenacity: brittle. Cleavage: distinct, presumably on {010} and {100}. Fracture: uneven. Density could not be measured because of small crystal size. Density (calc.) 2.934 g/cm^3 based on the empirical formula.

Optical properties. Needles consist of very thin fibers. Therefore only minimum and maximum refractive indices were measured. The mineral is biaxial (+), n (min) 1.747(3), n (max) 1.754(3) (589 nm). The mean value is about 1.751.

Chemical data. Microprobe data (4). H_2O calculated by stoichiometry; too little material was available for a direct determination of H_2O, but its presence was confirmed by IR. CO_2 was not analyzed because bands of CO_3^{2-} anions are absent in the IR spectrum. FeO and Fe_2O_3 partitioned from the condition Fe^{2+}:Fe^{3+} = 1:2, taking into account that for laueite group minerals M^{2+}:M^{3+} = 1:2. This assumption is confirmed by the excellent Gladstone-Dale compatibility. Contents of Mg, Al and Mn are below detection limits. FeO 11.50, Fe_2O_3 25.56, As_2O_5 33.51, H_2O 26.01, total 100.12 wt.%. Empirical formula: $Fe^{2+}_{0.98}Fe^{3+}_{1.96}[(AsO_4)_{1.79}(PO_4)_{0.31}](OH)_{1.52}\cdot 8.08H_2O$. The ideal formula requires FeO 11.52, Fe_2O_3 25.61, As_2O_5 36.86, H_2O 26.01, total 100.00 wt.%.

Crystallography. Triclinic, $P\bar{1}$, *a* 5.383(2), *b* 10.363(3), *c* 6.878(2), Å, α 96.42(4), β 109.19(3), γ 102.30(2)°, *V* 347.1(2) Å^3, *Z* 1, *a:b:c* = 0.783:1:1.507. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 9.85 (95) (010), 6.35 (100) (001), 3.671 (29) ($\bar{1}21$), 3.158 (32) ($1\bar{3}0$), 2.960 (39) ($02\bar{2}$), 2.884 (35) ($\bar{1}31$), 2.680 (29) ($\bar{2}11$), 2.540 (23) ($\bar{2}10$).

Name. The name is in honor of Professor César Mendonça Ferreira (1942-). Graduating as a Geology Engineer in the School of Mines of Ouro Preto in 1970, Professor Ferreira developed a long career as Professor in Mineralogy and Gemmology. Professor Ferreira engaged in many studies of the mineralogy of ores and in the field of geometallurgy. During the last 15 years he was responsible for establishing the Gemmological Laboratory of the Federal University of Ouro Preto.

Type material. A portion of the holotype has been deposited in the mineralogical collection of the Museu de Ciência e Técnica, Escola de Minas, Universidade Federal de Ouro Preto, Praça Tiradentes, Ouro Preto, Minas Gerais, registration number SAA-011.

Relationship to other species. Maghrebite group, laueite supergroup (Mills and Grey 2015). The arsenate-analog of ferrolaueite. Related to stewartite and bendadaite.

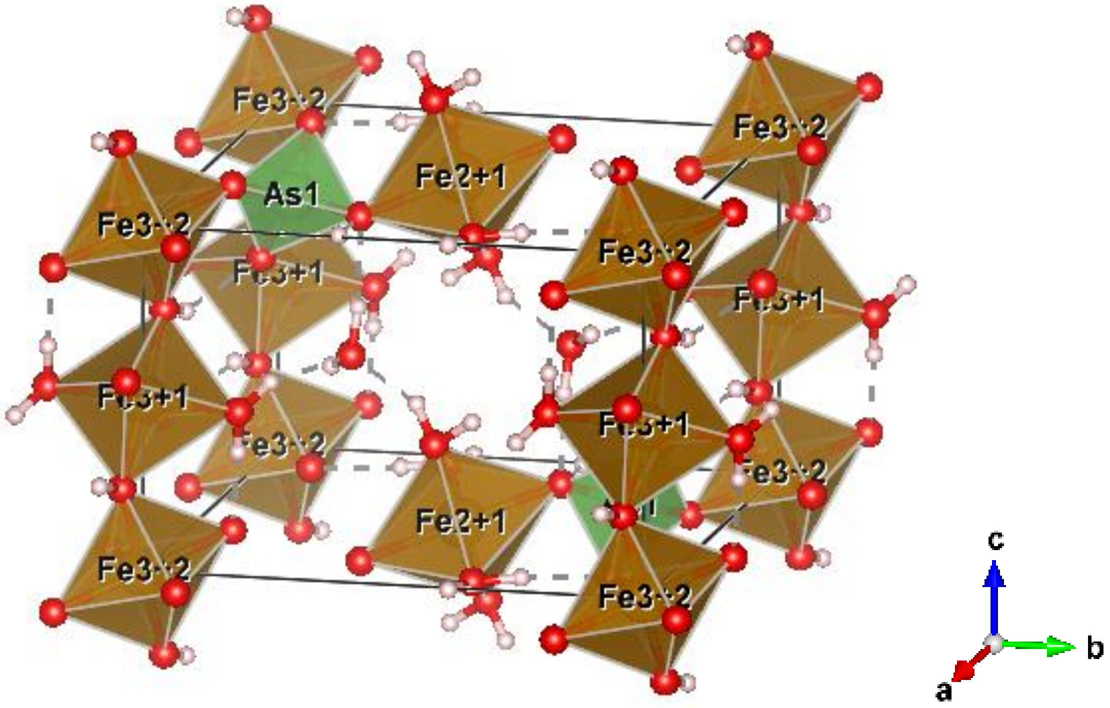

Figure 8.10. View of the crystal structure of césarferreiraite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Based on data by Scholz *et al.* (2014) for césarferreiraite and Meisser *et al.* (2012) for maghrebite, $MgAl_2(AsO_4)_2(OH)_2 \cdot 8H_2O$.

Crystal structure. Single-crystal X-ray studies were not carried out because of the absence of suitable crystals, but, by analogy with the crystal structure of maghrebite (Meisser *et al.* 2012), césarferreiraite structure is based upon $[Fe^{3+}(AsO_4)(OH)(H_2O)_3]^-$ layers parallel to (010) and interlinked by $[Fe^{2+}(H_2O)_6]^+$ octahedra. In addition, there is one H_2O molecule in the structure that is not bonded to any cation but is held in between the layers by hydrogen bonds only.

See also. Bendadaite.

Chapter 9

Silicates

Euclase

Delamétherie (1792b); Hauy *in* Delamétherie (1797)

$BeAlSiO_4OH$, monoclinic

Other names: euclásio, euclasita

Figure 9.1. Euclase from Ouro Preto, Minas Gerais. Muséum national d'Histoire naturelle, Paris, France, holotype. Field of view: 3 cm. Photo: Cristiano Ferraris.

Euclase

Localité inconnue,
Brésil
Ramenée par M. Dombey
(1785)

Figure 9.2. Euclase from Ouro Preto, Minas Gerais. Muséum national d'Histoire naturelle, Paris, France. Field of view: 2 cm. Photo: Cristiano Ferraris.

Figure 9.3. Euclase from Ouro Preto, Minas Gerais. Specimen: Museu de Geociências, Universidade de São Paulo. Photo: Thales Trigo.

An abstract of euclase appeared in Haüy (1796) and the complete data in Haüy (1801). According to Haüy (1801), the name euclase was previously published by Daubenton in an early edition of his *Tableaux méthodiques des Minéraux* (the first edition is dated 1784). According to Dana (1867), Delamétherie (1792b) published the name and description of euclase, without crediting Haüy (who would be the author of the name euclase). The name of Delamétherie does not appear as the author of the 1792b paper, but this is inferred because the article is a complement of the book by Delamétherie (1792a). Subsequently, Delamétherie (1797) gives Haüy full credit.

It is probable that the first specimens of euclase taken to Europe by the French botanist Joseph Dombey, in 1785 [on one of the labels of the Muséum national d'Histoire naturelle, Paris, France, it is registered 1779 and on another 1785], came from Ouro Preto, Minas Gerais, and not from Peru, where it is not known to occur (Leonardos 1970) [but one occurrence of euclase was quoted in Pasto Bueno, Pampas District, Pallasca Province, Áncash, Peru, by Hyrsl and Rosales (2003)]. According to Delamétherie (1792b), the euclase crystals first studied probably were from Brazil, but according to Haüy (1796 and 1801) and Joseph Dombey they were from Peru. Eschwege (1822) recognized the provenance of the mineral when he identified it in a topaz lot originating from Ouro Preto. A revision of the occurrence of this mineral in Brazil was made by Chaves and Karfunkel (1994).

Occurrence. A low-temperature hydrothermal mineral in pegmatites and alpine veins; also found in chlorite schist and phyllite. Associated minerals include quartz, albite, chlorite, topaz, beryl, mica, calcite, and ankerite. Some localities in Ouro Preto, Minas Gerais are Boa Vista, Trino, Ranchador, Capão do Lana, Fundão, Morro do Gabriel and Caxambu mines. Also, known from several Brazilian and world occurrences.

Appearance and physical properties. Commonly prismatic and striated parallel to [100], with {021}, {011}, {001}, and {010} dominant; terminations complex with dominant {111}, {$13\bar{1}$}, and {120}. Less commonly flattened on {010}. Vitreous, sometimes pearly on cleavage planes; transparent to translucent: colorless, white, pale green, yellowish-green, greenish-blue, pale blue, deep blue, with a white streak. Luminescence not reported. Twinning: Not reported. Mohs hardness 7½; brittle. Cleavage: {010} perfect; {110} and {001} imperfect; fracture conchoidal. Density: 3.065 g/cm^3 (meas.), 3.11 g/cm^3 (calc.).

Optical properties. Biaxial (+), α 1.651, β 1.657, γ 1.675; 2*V* 60° (meas.), 60.5° (calc.). Dispersion: $r > v$, distinct. Pleochroism: distinct in shades of deep blue. Orientation: $Z \wedge c = 41°$.

Chemical data. Electron microprobe analysis of a specimen from Fazenda Santana do Encoberto, São Sebastião do Maranhão, Minas Gerais, with Be determined by the pyrophosphate method and H_2O determined gravimetrically by wt. loss, gave: Na_2O 0.13, K_2O 0.04, BeO 16.95, FeO 0.28, Al_2O_3 34.76, SiO_2 41.60, H_2O 5.95, total 99.71 wt.% (Graziani and Guidi 1980). Empirical formula: $(Be_{0.99}Na_{0.01}Fe_{0.01})_{\Sigma 1.01}Al_{1.00}Si_{1.01}O_{4.04}(OH)_{0.96}$. The ideal formula requires: BeO 17.24, Al_2O_3 35.14, SiO_2 41.41, H_2O 6.21, total 100.00 wt.%.

Crystallography. Monoclinic, $P2_1/a$, *a* 4.771, *b* 14.308, *c* 4.631Å, β 100.33°, *V* 311.0Å^3, Z 4, *a:b:c* = 0.3334:1:0.3237. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 7.15 (100) (020), 3.836 (35) (021), 3.576 (14) (040), 3.219 (50) ($\bar{1}21$), 2.773 (35) (121), 2.543

(25) (131), 2.444 (35) (150), 2.252 (14) ($\bar{2}01$), 1.991 (18) ($\bar{1}61$), 1.880 (2) (221). ICDD 14-65 (specimen from Ouro Preto).

Name. From the Greek *eu* (good) and *klas* (break) with reference to its excellent cleavage.

Type material. Muséum national d'Histoire naturelle, Paris, France, holotype, 3300 (collection R.J. Haüy, 1792; 2 measured crystals)

Relationship to other species. Structurally similar to väyrynenite, (Mn,Fe)Be(PO_4)(OH).

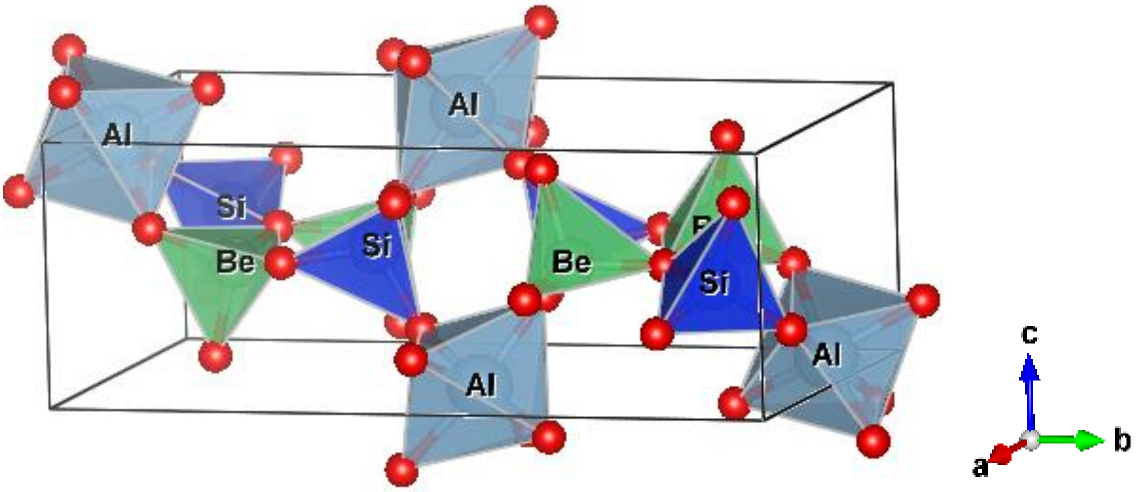

Figure 9.4. View of the crystal structure of euclase (from Ouro Preto, Minas Gerais), drawn using VESTA 3 (Momma and Izumi 2011). Data from Mrose and Appleman (1962).

Crystal structure. Be(O,OH)$_4$ and SiO_4 tetrahedra form chains of 3-membered rings parallel to [100]; these chains are linked by zigzag chains of edge-sharing AlO_6 octahedra (Mrose and Appleman 1962, Demartin *et al.* 1992).

See also. Imperial topaz.

Orvillite

Lee (1917 and 1919)

(= altered zircon?)

Other names: orvillita, orvilita

A “hydrated zirconium silicate”, occurring with zircon, in cavities of "caldasite" - a zirconium ore composed of baddeleyite, from Caldas, Minas Gerais. A relatively soluble zirconium silicate corresponding to $8ZrO_2·6SiO_2·5H_2O$. Some of the material was separated under the microscope by Orville Derby and analyzed: ZrO_2 68.04, SiO_2 25.45, volatile matter and combined H_2O 6.35, sum 99.72 percent. No description of the physical properties is given. It is probably an “altered zircon”, $ZrSiO_4$ tetragonal. Named in honor of the geologist Orville Adelbert Derby (1851-1915), director of the Geographical and Geological Survey of the State of São Paulo, director of the Geological Survey of Brazil, and first director of the Brazilian Society of Geology.

See also. Zirkite, ribeirite, and derbylite.

Ribeirite

Florencio (1952b)

(= altered zircon)

Other names: ribeirita

Ribeirite is the name used by Florencio (1952b) for an “altered zircon” (“a new variety of zircon”), $ZrSiO_4$ tetragonal, with 7.45 wt.% yttrium and 8.43 wt.% H_2O, from Maracani, Bahia. Tavora Filho (1955) obtained a weak X-ray powder pattern on type material, with 10 lines corresponding closely to the strongest lines of zircon. The heated sample gave a sharp pattern corresponding closely to that of zircon. The name honors the Brazilian physicist, Prof. Joaquim Costa Ribeiro (1906-1960).

See also. Orvillite.

Jeffbenite

Nestola *et al.* (2016)

$Mg_3Al_2Si_3O_{12}$, tetragonal

Approved CNMNC – IMA 2014-097.

Other names: TAPP, tetragonal-almandine-pyrope-phase, jeffbenita

Figure 9.5. The single-crystal of jeffbenite from Juína, Mato Grosso, on which the crystal structure was determined together with all physical and optical properties. The emerald green color is characteristic for this phase (Nestola *et al.* 2016).

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Jeffbenite was found as inclusions inside the so-called “super deep diamonds” from Juína, Mato Grosso. Harris *et al.* (1997) reported a new mineral showing a chemical formula very close to that of a pyrope-almandine garnet but with a tetragonal symmetry and called the new phase “TAPP”, “tetragonal-almandine-pyrope-phase”, but TAPP phase has not much in common with the structure of a garnet. The TAPP phase was never submitted to the IMA CNMNC for approval and was never described in detail, probably due to its extreme rarity. Only a few samples have been reported so far in the literature and very rarely as single-crystals suitable for a complete crystallographic, optical, and physical characterization.

Occurrence. The type specimen of jeffbenite occurred as an inclusion in an alluvial diamond from Juína, Mato Grosso, from which it was extracted by crushing the diamond. This very rare grain, with a crystal size of 0.07 × 0.05 × 0.03 mm was used for crystallographic, optical and physical characterization. Several other mineral species were quoted as inclusions in the diamonds from Juína: breyite, ellinaite, cohenite, haxonite, native iron, graphite, magnetite, dolomite, halite, sylvite, phlogopite, spinel, magnesite, eitelite, oskarsonite, pentlandite, violarite, millerite, hematite, periclase, perovskite, titanite, ilmenite, majorite, enstatite, forsterite, merwinite, native nickel, nitroyarlongite, nitrocohenite, nitrochalypite, unnamed Fe_2N, Fe_3N, Fe_5SiC, $(Ba,Sr)AlF_5$, $Na_4Mg_3(PO_4)_2(P_2O_7)$, $Fe^{3+}{}_2Fe^{2+}{}_5(P_2O_7)_4$, and Na-Mg pyroxene. Juína is also the type locality for breyite and ellinaite. Although the origin of jeffbenite is still controversial, some recent laboratory experiments have proposed its origins as either: (a) entrapment in diamonds in the upper mantle; or (b) retrograde formation from a high pressure garnet or “Mg-perovskite” precursor (Armstrong and Walter 2012). An ultradeep origin for jeffbenite is favored by the coexisting mineral assemblage, which is considered typical of the transition zone (410-660 km depth) or of the shallower part of the lower mantle (perhaps 660-750 km depth). In contrast, the absence of octahedral silicon in the crystal structure would imply an upper mantle origin. However, it is well known that other mantle transition zone silicates like ringwoodite and wadsleyite do not show Si in octahedral coordination (Kudoh 2001). Thus the coordination of silicon alone cannot be a strong indication of depth of origin of any mineralogical phase. Also, known from the Kankan diamond District, Kankan Region, Guinea (Brenker *et al.* 2002).

Appearance and physical properties. Habit: since jeffbenite was only found as an inclusion in diamond it is impossible to observe its real morphology and habit as it is not an isolated crystal growth out of the diamond. According to Harris *et al.* (1997), it forms apple green crystals, 30–100 µm in diameter, as inclusions in diamond. Forms: the crystals typically have a cubo-octahedral morphology imposed by the diamond morphology, but one is elongate, tabular. Twinning: not observed. Color: emerald (or apple?) green. Streak: white. Luster: vitreous. Transparent. Non-fluorescent. Hardness (Mohs): 7 (Vickers hardness = 1346). Tenacity: brittle. Cleavage: not observed. Parting: not observed. Fracture: irregular. Density could not be measured because of small grain size. Density: 3.576 g/cm^3 (calc.) using the empirical formula.

Optical properties. Uniaxial (–), ω 1.733(5), ε 1.721(5) (589 nm). Pleochroism: ε light blue, ω colorless.

Chemical data. Microprobe (WDS mode) analyses (5): SiO_2 41.74, TiO_2 0.06, Al_2O_3 23.84, Cr_2O_3 2.86, FeO 2.55, Fe_2O_3 2.27, MnO 0.79, MgO 25.16, CaO 0.09, Na_2O 0.10, total 99.46 wt.%. The Fe^{3+}/Fe_{tot} ratio assumed based on the Droop method. Empirical formula:
$(Mg_{1.80}Fe^{2+}_{0.15}Mn_{0.05}Ca_{0.01}Na_{0.01})_{\Sigma 2.02}(Al_{1.86}Cr_{0.16})_{\Sigma 2.02}(Mg_{0.82}Fe^{3+}_{0.12})_{\Sigma 0.94}(Si_{2.91}Al_{0.09})_{\Sigma 3.00}O_{12}$. The simplified formula requires MgO 29.99, Al_2O_3 25.29, SiO_2 44.71, total 100.00 wt.%.

Crystallography. Tetragonal, $I\bar{4}2d$, *a* 6.5231(1), *c* 18.1756(3) Å, *V* 773.38(2) Å^3, Z 4 (single-crystal); *a* 6.5355(2), *c* 18.1576(11) Å, *V* 775.56(5) Å^3, Z 4 (powder data), *c:a* = 2.786 (single-crystal data). X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 3.069 (11) (202), 2.881 (24) (211), 2.647 (100) (204), 2.220 (19) (206), 2.056 (11) (224), 1.625 (44) (325), 1.390 (13) (424), 1.372 (11) (2.0.12).

Name. The name is for Jeffrey W. Harris (b. 1940), School of Geographical and Earth Sciences, University of Glasgow, and Ben Harte (b. 1941), Centre for Science at Extreme Conditions, School of GeoSciences, University of Edinburgh, who not only discovered the new mineral but are among the most internationally recognized scientists in the science of diamonds and have published hundreds of peer-reviewed papers on the mineralogy, petrology and geochemistry of diamonds and their mineral inclusions.

Type material. The holotype is deposited in the collections of the Museum of Mineralogy of the University of Padova, Padova, Italy, catalog number MMP M12660.

Relationship to other species. Dimorph of pyrope, isostructural with niasite, $Ni^{2+}_{4.5}(AsO_4)_3$.

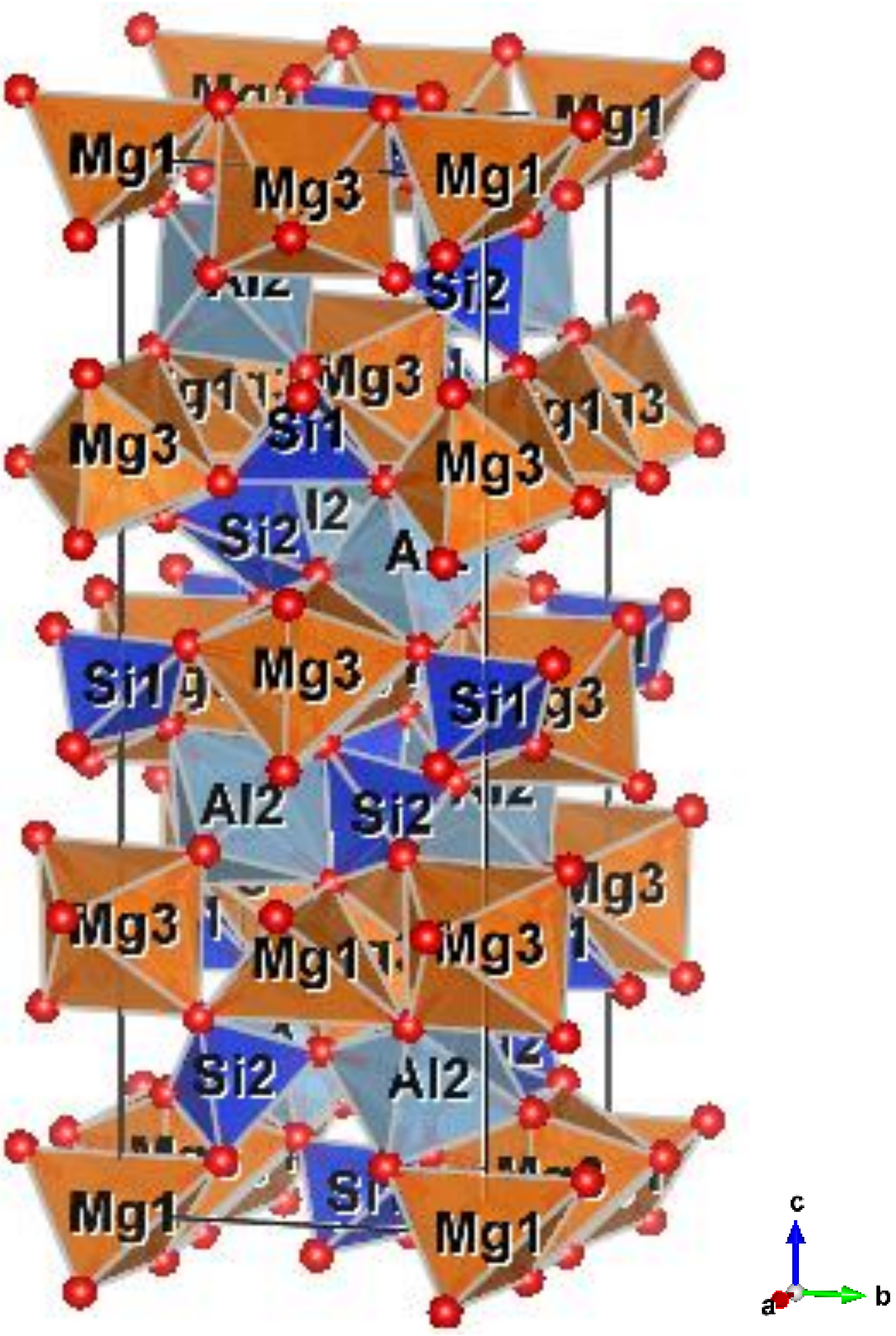

Figure 9.6. View of the crystal structure of jeffbenite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Finger and Conrad (2000).

Crystal structure. The crystal structure of jeffbenite is constituted by 5 different cation positions: the *M*1 site is represented by a capped tetrahedron, *M*2 and *M*3 are two significantly different octahedral sites, *T*1 and *T*2 are two symmetrically independent tetrahedral sites. The general formula could be written as $(M1)(M2)_2(M3)_2(T1)(T2)_2O_{12}$ with *M*1 dominated by Mg, *M*2 dominated by Al, *M*3 dominated again by Mg and both *T*1 and *T*2 almost fully occupied by Si. The two tetrahedra do not share any oxygen with each other. The *T*1 tetrahedron shares all its oxygen atoms with *M*2 and *M*3 octahedra, while *T*2 shares one edge with the *M*2 site and two vertexes. Therefore, jeffbenite can be classified as a nesosilicate.

See also. Ellinaite, breyite, nitroyarlongite, nitrocohenite, nitrochalypite, unnamed Fe_2N, Fe_3N, Fe_5SiC, $(Ba,Sr)AlF_5$, orthorhombic MgO, $MgCr_2O_4$, $Na_4Mg_3(PO_4)_2(P_2O_7)$, $Fe_2^{3+}Fe_5^{2+}(P_2O_7)_4$, and Na-Mg pyroxene.

Imperial topaz

Other names: topázio imperial

Figure 9.7. Imperial topaz from Ouro Preto, Minas Gerais. 29.8 × 10.4 × 9.2 mm. Specimen and photo: Edson Ferreira dos Santos.

Figure 9.8. Imperial topaz from Ouro Preto, Minas Gerais. The largest crystal is approximately 55 mm high. Specimens and photo: Edson Ferreira dos Santos.

Orange to brownish-orange (rarely of other colors) topaz, in rhombic prismatic crystals, with pyramidal terminations, rarely double-terminated, found for the first time in Ouro Preto, Minas Gerais. It is much more valuable than the other varieties because of its great rarity. If carefully heated, imperial topaz acquires a beautiful pink color; this being the process used to produce most of the pink topaz on the market. A detailed study of imperial topaz from Ouro Preto was made by Gandini (1994). According to him, the possible chromophors of this gem are Cr, V, and Fe, all in the trivalent state. The imperial topaz deposits, and probably also the euclase deposits, were described as long ago as 1760 (Chaves and Karfunkel 1994). The “imperial” designation was attributed to the gem in honor of the Brazilian imperor D. Pedro I who would was delighted with the exuberance of the nuances and shades of the topaz crystals offered to him during a stay in the old Villa Rica (today Ouro Preto), in Minas Gerais, where they were extracted.

See also. Euclase.

Minasgeraisite-(Y)

Foord *et al.* (1986)

$BiCa(Y,Ln)_2(\square,Mn^{2+})_2(Be,B,Si)_4Si_4O_{16}[(OH),O]_4$, triclinic

Approved CNMMN - IMA 1983-090

Other names: minasgeraisita-(Y), minasgeraisita, minasgeraisite

Figure 9.9. Minasgeraisite-(Y) purple crystals on muscovite from José Pinto quarry, Jaguaraçu, Minas Gerais (sample from Luiz A.D. Menezes Filho, RRUFF Project).

Figure 9.10. Minasgeraisite-(Y) purple crystals on muscovite, from José Pinto quarry, Jaguaraçu, Minas Gerais. Field of view: 4.2 mm. Specimen and photo: Martin Slama.

Foord *et al.* (1986) described minasgeraisite [changed to minasgeraisite-(Y) to conform to the IMA's new rules of nomenclature for rare-earth minerals] as $CaBe_2Y_2Si_2O_{10}$, monoclinic, isostructural with gadolinite-group minerals. Nevertheless, a gadolinite-group mineral with this formula is regarded as very doubtful (Demartin *et al.* 2001, Bačík *et al.* 2017). A crystal structure study revealed that minasgeraisite-(Y) is $BiCa(Y,Ln)_2(\square,Mn^{2+})_2(Be,B,Si)_4Si_4O_{16}[(OH),O]_4$, triclinic (Cooper and Hawthorne 2018).

Occurrence. As a sparse, accessory, late-stage mineral, in small druses in the zoned complex of the Jaguaraçu granitic pegmatite, in the Mr. José Pinto quarry, adjacent to a soccer field, Jaguaraçu, Minas Gerais. Associated minerals are milarite, agakhanovite ("yttrian milarite"), albite, quartz, muscovite, hematite, microcline var. amazonite, adularia, almandine-spessartine, magnetite, churchite-(Y), elbaite, pyrite, cerussite, pyromorphite, and anatase. This is also the type occurrence of carlosbarbosaite. Some world occurrences of minasgeraisite-(Y) were also quoted (Habel and Habel 2009, Kadlec 2010, Brosseau-Liard 2012), but the published data are incomplete,

Appearance and physical properties. As 0.2- to 1.0-mm-diameter rosettes coating and intergrown with milarite, agakhanovite, albite, quartz, and muscovite. In clusters. Individual crystals usually less than 3 to 5 μm. Lavender to lilac purple, with a pale purple streak. Luster earthy to subvitreous. Transparent. Cleavage {100} excellent and {001} good. Non magnetic. Non fluorescent. Density > 4.25 g/cm^3 (meas.), 4.90 g/cm^3 (calc.). Mohs hardness 6 to 7. Slowly soluble in common acids.

Optical properties. Biaxial (+), α 1.740(4), β 1.754(4), γ 1.786(4), 2V_Z 68º (meas.). *X* colorless, *Y* pale grayish-yellow, *Z* lavender purple, $Z > Y > X$. Dispersion: $r > v$, very weak.

Chemical data. ICP, AAS and electron microprobe analyses: CaO 11.47, Na_2O <0.1, MnO 2.83, MgO 0.61, FeO 0.69, ZnO 0.35, CuO 0.14, BeO 7.8, B_2O_3 1.45, SiO_2 26.37, Al_2O_3 0.32, TiO_2 0.02, ZrO <0.02, P_2O_5 1.21, Y_2O_3 16.38, La_2O_3 0.25, Ce_2O_3 0.20, Pr_2O_3 0.13, Nd_2O_3 0.50, Sm_2O_3 0.26, Eu_2O_3 0.00, Gd_2O_3 0.32, Tb_2O_3 0.23, Dy_2O_3 1.26, Ho_2O_3 0.37, Er_2O_3 1.94, Tm_2O_3 0.75, Yb_2O_3 7.86, Lu_2O_3 1.71, Bi_2O_3 14.7, total 99.8 wt.%. A Bi-richer area was also recorded. Empirical formula (Foord *et al*. 1986): $(Ca_{0.45}Mn^{2+}_{0.20}Mg_{0.08}Fe_{0.05}Zn_{0.02}Cu_{0.01}\square_{0.19})_{\Sigma 1.00}(Be_{1.55}B_{0.21}Si_{0.24})_{\Sigma 2.00}(Y_{0.72}REE_{0.41}Ca_{0.56}Bi_{0.31})_{\Sigma 2.00}(Si_{1.95}P_{0.08})_{\Sigma 2.03}O_{10}$. Structural formula (Cooper and Hawthorne 2018): $(Y_{1.42}Ca_{1.19}Bi_{0.81}Er_{0.58})_{\Sigma=4.00}(\square_{1.37}Mn^{2+}_{0.63})_{\Sigma=2.00}(Be_{3.32}B_{0.40}Si_{0.28})_{\Sigma=4.00}Si_4O_{16}[(OH)_{2.74}O_{1.26}]_{\Sigma=4.00}$.

Crystallography. Triclinic, *P*1. *a* 9.994(4), *b* 7.705(3), *c* 4.764(2) Å, α 90.042(9), *β* 90.218(14), γ 90.034(9)º, *V* 366.8(5) Å^3, Z 1, *a:b:c* = 1.2971:1:0.6103. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 5.99 (30) (110), 3.71 (30) ($\bar{1}11$), 3.41 (30) ($\bar{2}01$), 3.11 (100) ($\bar{2}11$), 2.830 (100) ($\bar{1}21$), 2.540 (90) ($\bar{3}11$), 2.250 (30) (012), 1.768 (35) ($\bar{5}11$).

Name. In honor of the State of Minas Gerais (see minasite and geraesite).

Type material. U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA (cotype, 164209, donator R.V. Gaines, 1986).

Relationship to other species. Gadolinite subgroup, gadolinite group, gadolinite supergroup (Bačík *et al.* 2017).

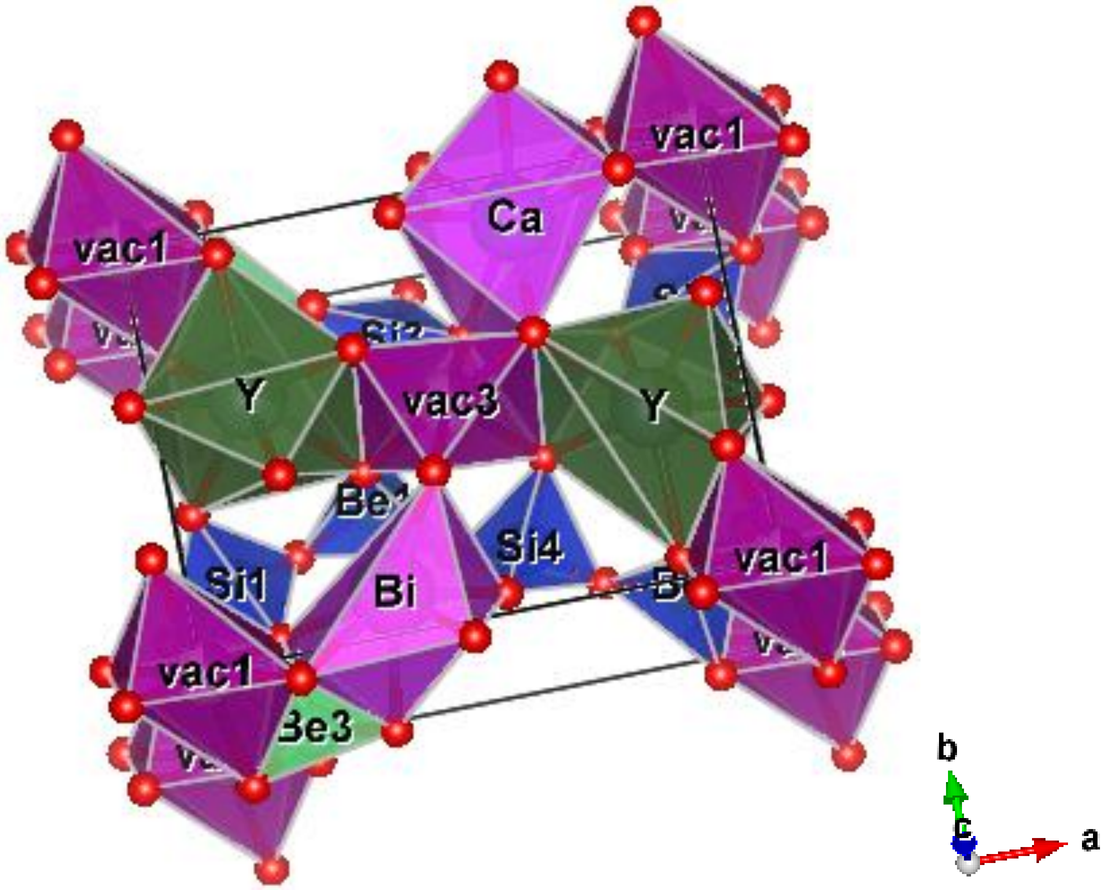

Figure 9.11. View of the crystal structure of minasgeraisite-(Y) (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Cooper and Hawthorne (2018).

Crystal structure. The $P1$ structure of minasgeraisite-(Y) maintains the same bond topology as the other gadolinite group minerals, and accordingly minasgeraisite-(Y) might be regarded as a triclinic polymorphic form of hingganite-(Y). The general formula for the gadolinite group is $A_2MQ_2T_2O_8\varphi_2$ ($Z = 2$) (Bačík *et al.* 2017) which were expanded to 20 anions ($Z = 1$) to show the A-site cation ordering present in ‘minasgeraisite-(Y)’. Bismuth, Ca and *REE* are ordered over four A sites, with Bi dominant at $A1$, Ca dominant at $A2$, and Y dominant at $A3$ and $A4$. The dominant constituent at the M sites is a vacancy, and Ca does not occur at the M sites. Significant B and Si are assigned to the Be-dominant Q sites, and the T sites are occupied by Si. (Cooper and Hawthorne 2018).

See also. Carlosbarbosaite, yttrian milarite, minasite, geraesite, and staringite.

Coutinhoite

Atencio *et al.* (2004a)

$(\square,\#)_2(UO_2)_2Si_5O_{13}\cdot 4H_2O$, monoclinic

Approved CNMMN 2003-025

Other names: coutinhoíta

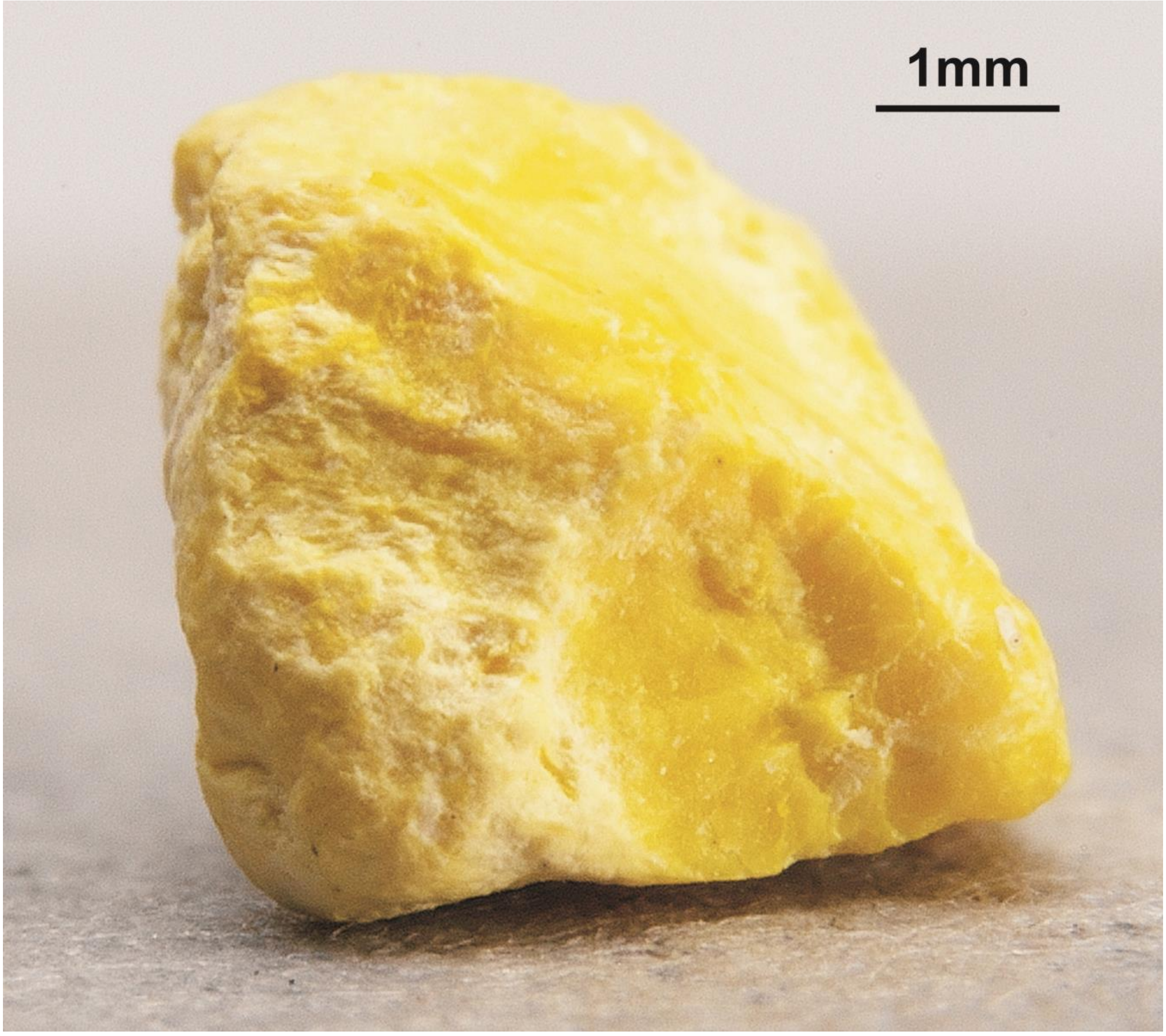

Figure 9.12. Coutinhoite, an irregular aggregate with very small flaky crystals, from Córrego do Urucum mine, Galileia, Minas Gerais. Type specimen. Photo: Thales Trigo. Atencio *et al.* (2004a).

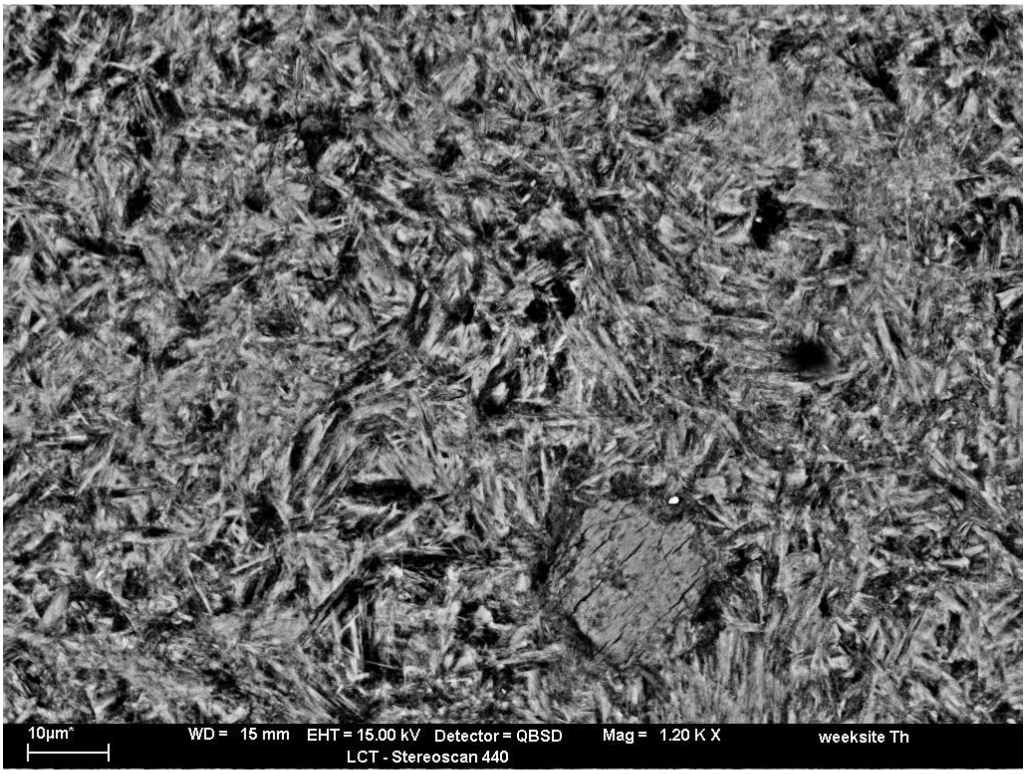

Figure 9.13. Back-scattered electron image of coutinhoite from Córrego do Urucum mine, Galileia, Minas Gerais. Atencio *et al.* (2004a).

Atencio *et al.* (2004a) described a new “thorium” uranyl silicate hydrate mineral, coutinhoite, with a simplified chemical formula $Th_{0.5}(UO_2)_2Si_5O_{13}\cdot1\text{-}3.5H_2O$, from the Córrego do Urucum pegmatite, Urucum mine, Galileia, Minas Gerais. Coutinhoite presents an X-ray diffraction pattern similar to that of weeksite. Since it was not possible to determine its crystal structure, due to the small dimensions of the crystals, the X-ray diffraction pattern was indexed by analogy with weeksite, which at that time was believed to be orthorhombic. Subsequently, Fejfarová *et al.* (2012) determined the crystal structure of weeksite as monoclinic and its formula is $K_2(UO_2)_2Si_5O_{13}\cdot4H_2O$. According to them, the crystal symmetry and unit-cell parameters of coutinhoite should be reevaluated based on the new structure data on weeksite.

The importance of uranium mineralogy to understanding the genesis of uranium deposits, as well as for environmental applications, was emphasized by Jackson and Burns (2001). Uranyl compounds that may form by the alteration of nuclear waste will incorporate radionuclides into their structures, thereby retarding their release. Uranyl silicates (e.g., uranophane, uranophane-beta, boltwoodite, haiweeite, weeksite) are likely to be abundant in a geological repository for nuclear waste, owing to the alteration of spent nuclear fuel and borosilicate waste glass in the presence of silicon derived from repository host-rocks. Thus, an understanding of the structures of uranyl silicates may be a key to understanding the long-term performance of a geological repository for nuclear waste. Coutinhoite is a uranyl silicate probably isostructural with weeksite. The weeksite structure would be an important depository of Th^{4+} (Atencio *et al.* 2004a).

Here the description of coutinhoite has been modified to adapt to the new data of weeksite.

Occurrence. The Córrego do Urucum pegmatite, Lavra (= mine) Urucum (also known as Lavra do Tim), Galileia Co. (19º0’S 41º32’W, DMS), Minas Gerais. Associated minerals: quartz, albite, microcline, muscovite, biotite, beryl, spodumene, elbaite, fluorapatite, spessartine, microlite, cassiterite, titanite, uraninite, montmorillonite, nontronite, dickite, cookeite, opal, hematite, hörnesite, karibibite, löllingite, pharmacosiderite, phosphuranylite, saleeite, schneiderhöhnite, scorodite, stokesite, bismuth, sulfur, vivianite, wölsendorfite (Cassedanne 1986). Coutinhoite is a secondary hydrothermal mineral. No additional occurrence was described.

Appearance and physical properties. Irregular aggregate with very small flaky crystals (Fig. 1), up to 10 µm long, and a thickness up to about 0.5 µm. Color: yellow. Streak: yellow. Luster: waxy to silky. Transparent to translucent. Non-fluorescent. H Mohs impossible to measure. Brittle. Cleavage and fracture: not determinable. Density was not measured due to the paucity of material. Density (calc.): 3.868 g/cm^3.

Optical properties. Biaxial (–), α 1.620(3), β 1.627(3), γ 1.629(3) (white light). $2V$ 40(5)° (meas.), 56.1° (calc.). Dispersion: $r < v$, strong. Orientation: Y ^ c = zero to small. Pleochroism: $Z > Y$, X yellow.

Chemical data. Chemical analyses (12) were carried out by means of an electron microprobe (WDS mode, 15 kV, 20 nA, 1 µm beam diameter). The presence of H_2O was identified by an IR spectrum. Atencio *et al.* (2004a) calculated H_2O by difference Now, H_2O was calculated for $4H_2O$ in the unit formula: ThO_2 8.12, BaO 2.76, K_2O 0.28, CaO 0.22, UO_3 54.78, SiO_2 28.19, P_2O_5 0.59, H_2O 6.88, total 101.82 wt.%. The empirical formula (based on Si + P = 5 *apfu*) is: $(\square_{1.39}Th_{0.32}Ba_{0.19}K_{0.06}Ca_{0.04})_{\Sigma 2.00}(UO_2)_{2.01}(Si_{4.91}P_{0.09})_{\Sigma 5.00}O_{12.95}\cdot 4H_2O$. The simplified formula was expressed by Atencio *et al.* (2004a) as $Th_{0.5}(UO_2)_2Si_5O_{13}\cdot 1\text{-}3.5H_2O$, but it is more accurately expressed as $(\square,\#)_2(UO_2)_2Si_5O_{13}\cdot 4H_2O$, since □ is dominant in the first site. Thorium is not essential, # may be any cation or cations but presence of # is necessary to maintain electrical neutrality of the formula. So, the title of the Atencio *et al*. (2004a) paper, “Coutinhoite, a new thorium uranyl silicate…” is not correct. An ideal formula $Th_{0.5}(UO_2)_2Si_5O_{13}\cdot4H_2O$ requires: ThO_2 12.26, UO_3 53.14, SiO_2 27.90, H_2O 6.70, total 100.00 wt.%.

Crystallography. Unit-cell parameters for coutinhoite were recalculated from the X-ray powder data presented by Atencio *et al.* (2004a), by analogy with the data for weeksite by Fejfarová *et al.* (2012). The new calculated unit-cell, based on all the observed *d* values, is monoclinic, *C*2/*m*, *a* 14.181(5), *b* 14.194(6), *c* 9.622(4) Å, *β* 111,54(4), *V* 1801(1) Å^3, Z 4, *a:b:c* = 0.9992:1:0.6780. These values are close to that of weeksite. Reindexed X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 8.919 (45) (001), 7.059 (100) (020), 5.563 (59) (021), 4.581 (47) (201), 3.826 (48) ($\bar{2}22$), 3.528 (86) ($\bar{4}01$), 3.287 (57) ($\bar{4}02$), 3.188 (73) ($\bar{2}03$), 2.981 (46) (003), 2.904 (78) ($\bar{2}23$).

Name. The mineral is named in honor of José Moacyr Vianna Coutinho (1924-), professor of mineralogy and petrology at the Instituto de Geociências of Universidade de São Paulo, who has made significant contributions to the Brazilian mineralogy and geology.

Type material. The holotype material is deposited under the number DR523 in the Museu de Geociências, Universidade de São Paulo, and in the Museu Jobas de Ciências Naturais “José Bonifácio de Andrade e Silva”, São Vicente, São Paulo State (this museum no longer exists).

Relationship to other species. Coutinhoite is probably isostructural with weeksite, ideally $K_2(UO_2)_2Si_5O_{13}\cdot4H_2O$.

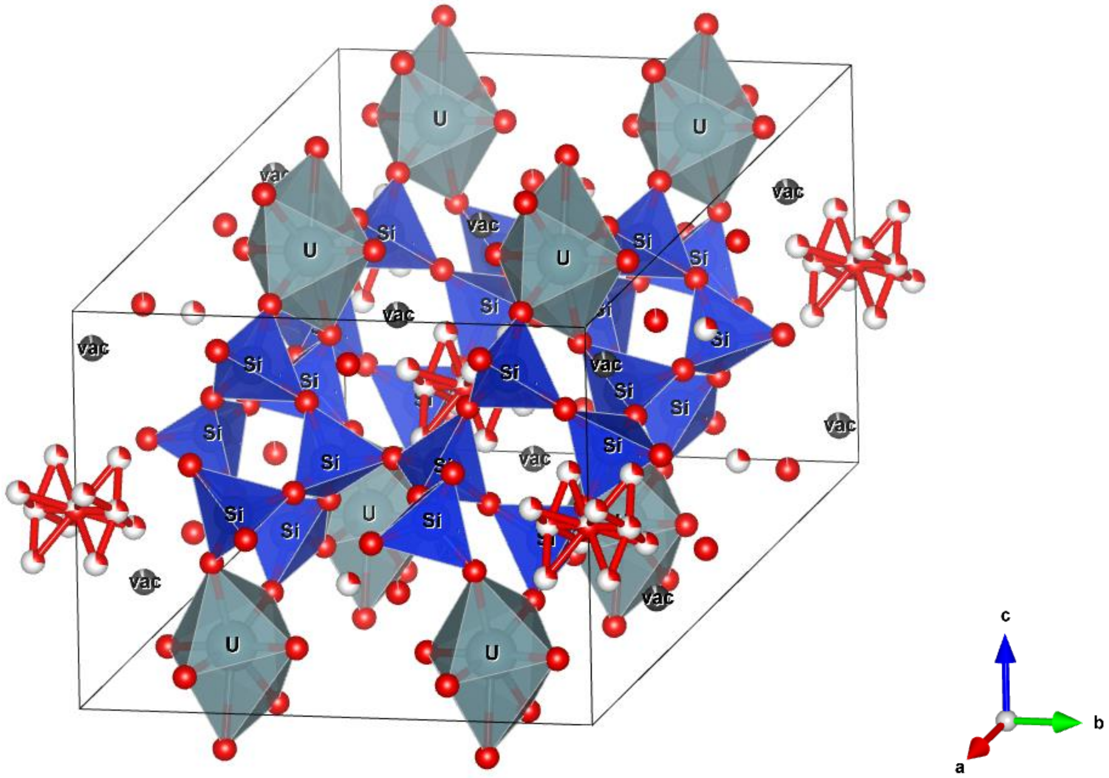

Figure 9.14. View of the crystal structure of coutinhoite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Based on data by Fejfarová *et al.* (2012) for weeksite.

Crystal structure. No single-crystal study was done, due to the crystal dimensions, but the mineral is probably isostructural with weeksite. The crystal structure of weeksite was determined by Fejfarová *et al.* (2012). The $(UO_2)O_5$ uranyl pentagonal bipyramids share equatorial edges to form chains parallel to [100], which in turn share edges with SiO_4 tetrahedra. The uranyl silicate chains are linked to crankshaft-like chains of vertex-sharing SiO_4 tetrahedra, resulting in layers that are connected through vertex-sharing between SiO_4 tetrahedra to form an open framework. The channels of the uranyl silicate framework are dominantly occupied by K in the weeksite structure, and are dominantly empty in the coutinhoite structure. Ba, Ca, Na, Th, as well as H_2O molecules, are also located in these channels.

Fluorlamprophyllite

Andrade *et al.* (2018b)

$Na_3(SrNa)Ti_3(Si_2O_7)_2O_2F_2$, monoclinic

Approved CNMNC – IMA 2013-102

Other names: fluorlamprofilita

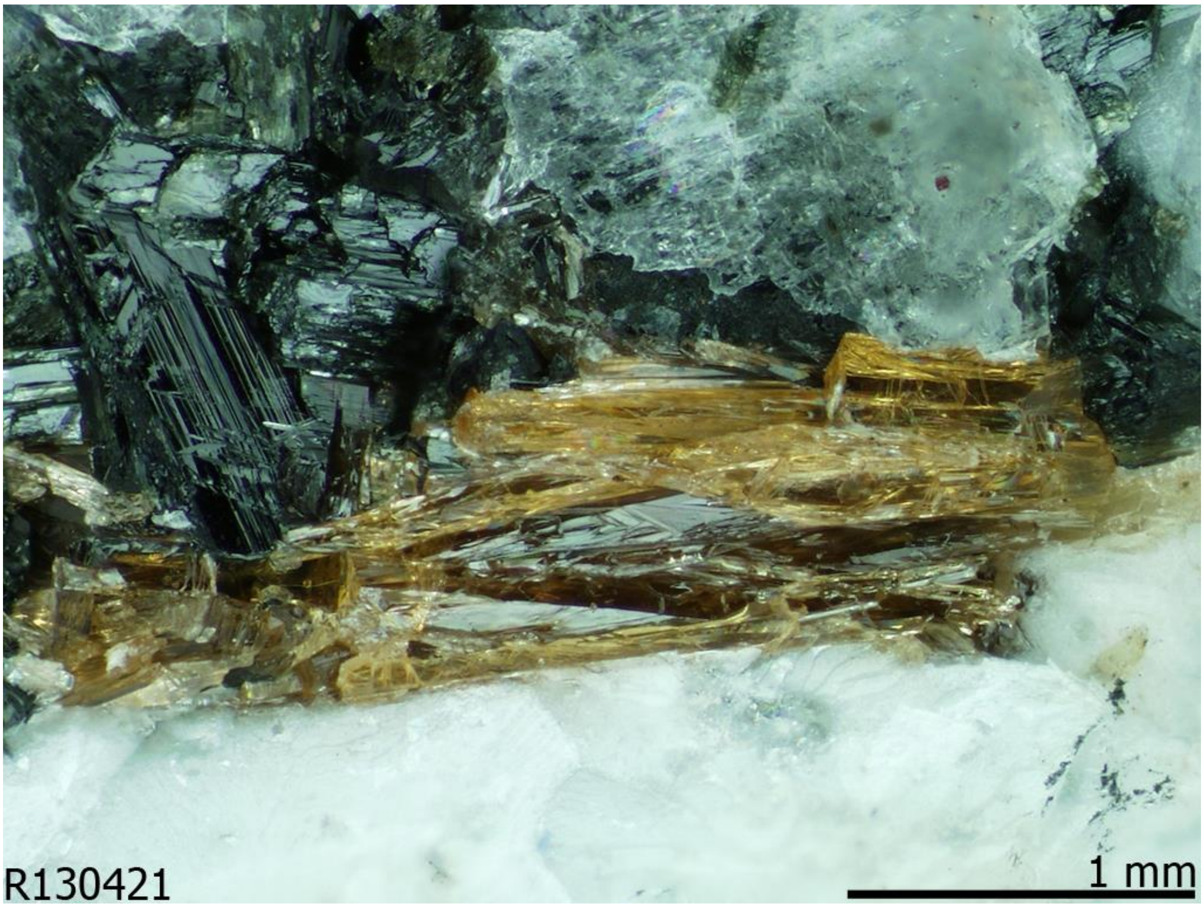

Figure 9.15. A microscopic view of brownish-orange, bladed fluorlamprophyllite crystals in the nepheline syenite from Morro do Serrote, Poços de Caldas, Minas Gerais (Andrade *et al.* 2018b).

Occurrence. Fluorlamprophyllite occurs as an accessory mineral in a nepheline syenite located in the Morro do Serrote, Poços de Caldas alkaline massif, Minas Gerais. Associated minerals are aegirine, analcime, natrolite, nepheline and microcline. The nepheline syenite at Morro do Serrote is an intrusive body (9 km^2, 60-65 Ma) in phonolites, located in the central-western portion of the subcircular Mid-Cretaceous Poços de Caldas alkaline massif (800 km^2). The massif's geology and petrology have been studied since the 19th century and a systematic study of its structure and petrology has been presented by Ulbrich (1984), including a comprehensive classification of the different nepheline syenite facies from Morro do Serrote. Fluorlamprophyllite is the fluorine analog of lamprophyllite and the second reported F-dominant member of the lamprophyllite group (Chukanov *et al.* 2012). Poços de Caldas is also the type locality for manganoeudialyte.

Appearance and physical properties. The mineral occurs as orange, bladed-crystal aggregates. Habit: thin bladed crystals, elongated along [001]. Forms: dominated by {100} and {110}. Twinning: none observed. Color: golden to orange in transmitted light. Streak: pale yellow. Luster: adamantine. Transparent. Non-fluorescent. Hardness: Mohs *ca* 3. Tenacity: brittle. Cleavage: perfect on {100}. Fracture: uneven. Density could not be measured because of the amount of material available. Density (calc.) 3.484 g/cm^3 (from the empirical formula).

Optical properties. Biaxial (+), α 1.735(7), β 1.749(7), γ 1.775(9) (white light). $2V$ 72(3)° (meas.), 74° (calc.). Dispersion: not measured. Orientation: X perpendicular to b, $Z \wedge c \cong 5°$. Pleochroism: X yellow-green, Y yellow-brown, Z brown.

Chemical data. Microprobe (WDS mode) analyses (9), H_2O was calculated by stoichiometry from the results of the crystal-structure analysis with OH+F = 2 pfu. The presence of OH was confirmed by Raman spectroscopy: Na_2O 10.63, K_2O 0.47, SiO_2 30.51, SrO 18.30, MgO 0.81, Al_2O_3 0.23, CaO 1.11, MnO 5.03, TiO_2 27.41, Fe_2O_3 2.45, F 2.86, H_2O 1.00, O = F -1.20, total 99.61 wt.%. Empirical formula (based on 18 anions pfu):
$(Na_{2.30}Mn_{0.54}Mg_{0.15})_{\Sigma 2.99}(Sr_{1.35}Na_{0.33}Ca_{0.15}K_{0.08})_{\Sigma 1.91}(Ti_{2.63}Fe_{0.24}Al_{0.04})_{\Sigma 2.91}Si_{3.89}O_{16}[F_{1.15}(OH)_{0.85}]_{\Sigma 2.00}$. The ideal formula requires Na_2O 16.99, SrO 14.20, SiO_2 22.94, TiO_2 32.85, F 5.21, O = F -2.19, total 100.00 wt.%.

Crystallography. Monoclinic, $C2/m$, a 19.255(2), b 7.0715(7), c 5.3807(6) Å, β 96.794(2)°, V 727.5(1) Å^3, Z 2 (single-crystal), $a{:}b{:}c$ = 2.723:1:0.761. X-ray powder diffraction data [d in Å (I) (hkl)]: 4.1468 (60) (111), 3.7255 (36) $(\bar{3}11)$, 3.3935 (20) (510), 3.2012 (21) (600), 2.7765 (100) (221), 2.1336 (32) $(\bar{2}22)$, 2.0182 (16) (530), 1.7686 (24) (040), 1.5992 (22) (023), 1.4781 (14) $(\bar{2}42)$.

Name. The name is because it is F-dominant with respect to lamprophyllite, which is OH-dominant.

Type material. Parts of the cotype sample have been deposited in the collections of the University of Arizona Mineral Museum, Tucson, Arizona, USA, catalog number

19589, and the RRUFF Project, deposition number R130421.

Relationship to other species. Lamprophyllite group, seidozerite supergroup (Sokolova and Cámara 2017).

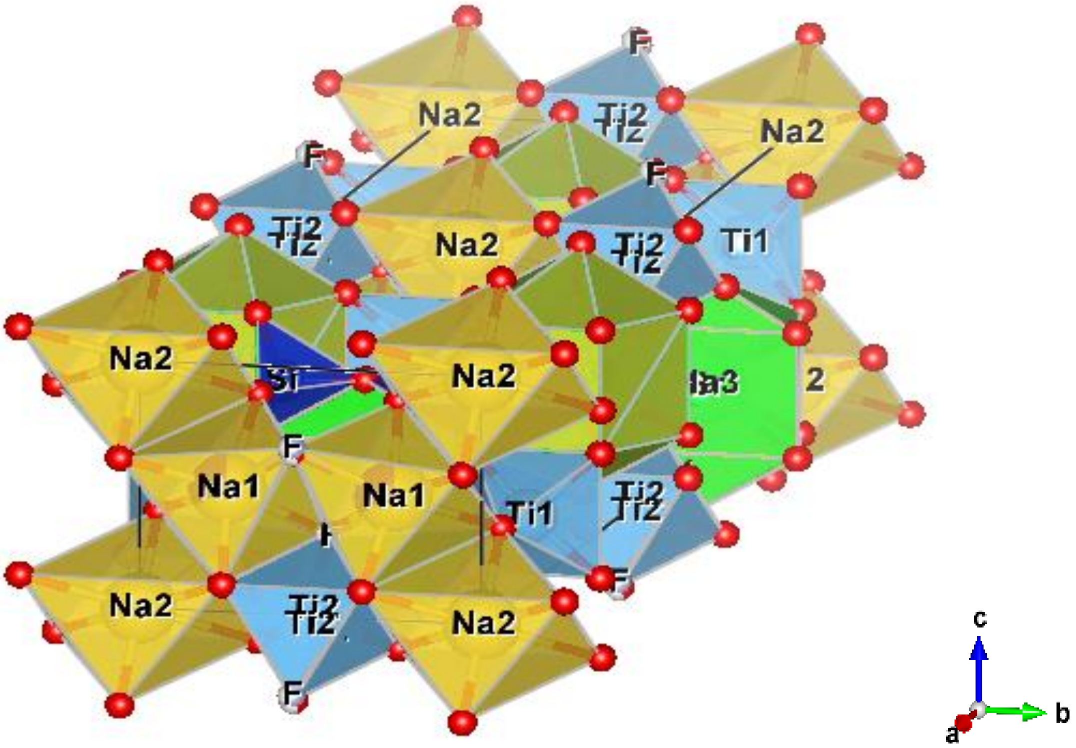

Figure 9.16. View of the crystal structure of fluorlamprophyllite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Andrade *et al.* (2018b).

Crystal structure. Fluorlamprophyllite is a layered oxide inasmuch as the O atoms are arranged in well-defined, though not necessarily close-packed layers. The polyhedral units also form three distinct layers parallel to (100), designated as A = (Si_2O_7) dimers connected by TiO_5 polyhedra, B = brucite layer of close-packed (Na1)O_6, (Na2)O_6 and (Ti2)O_6 edge-sharing octahedra, and C = (Sr + Na3). Sandwiches of strongly bonded ABA layers are separated by the weaker bonded C layers, responsible for the perfect cleavage on {100}. The cations in layer C (Sr + Na) are coordinated to 6 O atoms on one side of the layer and 4 on the other. OH/F is situated at the only anion position in the B layer that is not linked to A-cations. In contrast to the structures of other members in the lamprophyllite group, the Ti2 site in fluorlamprophyllite appears to be split, with a Ti2-Ti2 distance of 0.391 Å.

See also. Manganoeudialyte, Ta-rich eudialyte, giannettite, pennaite, unnamed $Ti_3(UO_2)_3SiO_8$, unidentified silicate inclusions in giannettite, and unidentified Mn-Fe-silicate and Zr-silicates.

Giannettite

Guimarães (1948c)

(= hainite)

Other names: giannettita, giannetite, giannetita, mineral Zr-D

Figure 9.17. Vug filling, pale brownish-yellow prismatic to fibrous hainite (“giannettite”) crystals from the Bortolan quarry, Poços de Caldas, Minas Gerais. Photo width about 4cm. Specimen: Daniel Atencio. Photo: Thales Trigo.

Figure 9.18. Vug filling, pale brownish-yellow prismatic hainite (“giannettite”) crystals from the Bortolan quarry, Poços de Caldas, Minas Gerais. Photo width about 6 mm. Photo: Andrezza de Almeida Azzi.

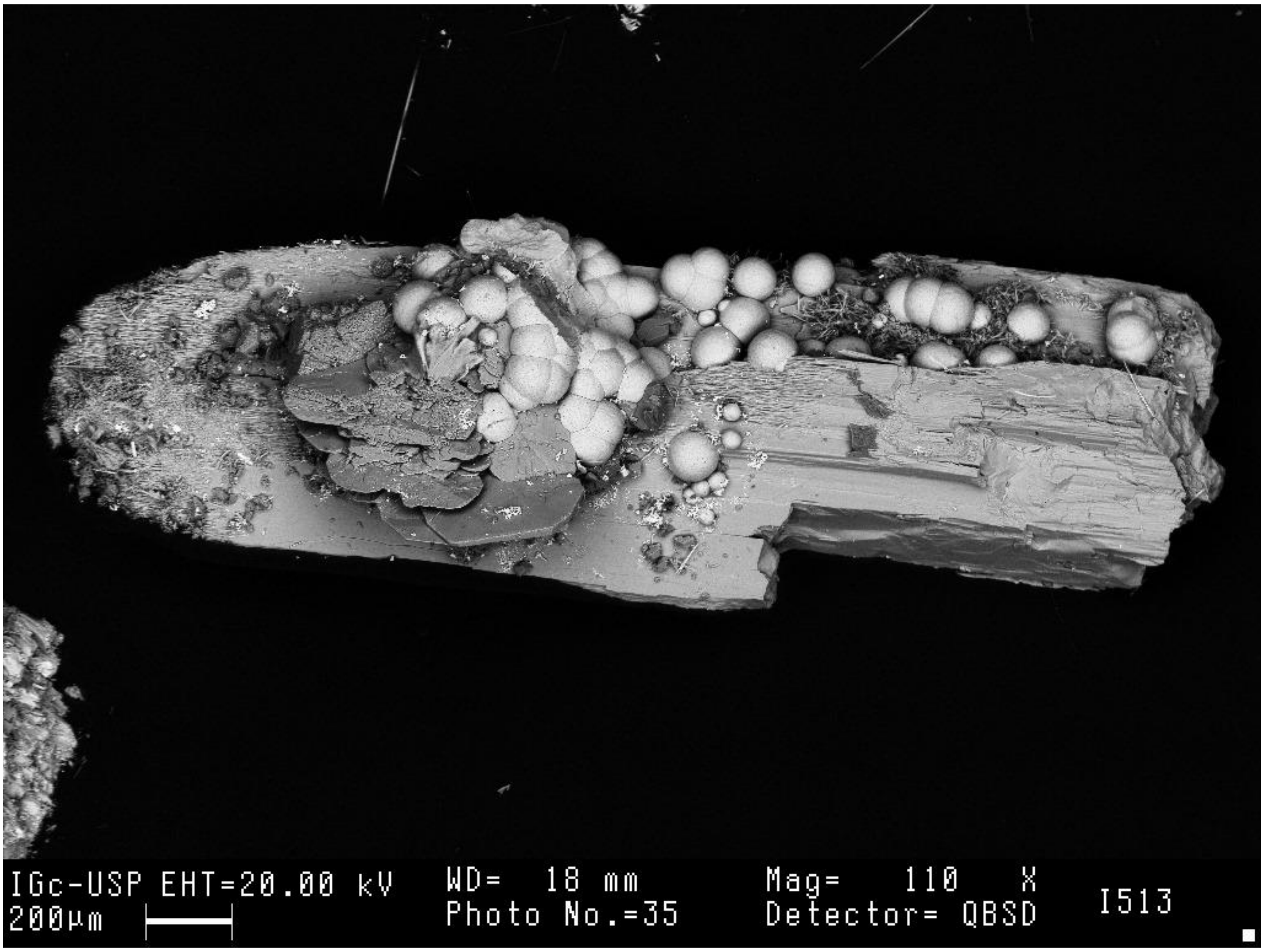

Figure 9.19. SEM backscattered image of a hainite ("giannettite") crystal from the Bortolan quarry, Poços de Caldas, Minas Gerais. White spherical gaidonnayite crystal aggregates and calcite plates over hainite. Azzi *et al.* (2018).

Giannettite was described by Guimarães (1948c) in alkaline rocks of the Poços de Caldas massif, Minas Gerais. The original description of giannettite is so poor, that the species and name are not considered valid. From the study of new giannettite specimens, Atencio *et al.* (1999) suggested its identity with hainite. The name hainite was changed to hainite-(Y) by Sokolova and Cámara (2017). Since the formula $Na(NaCa)Ca_2Ca_2TiSi_4O_{14}(OF)F_2$ is not electronically neutral, Sokolova and Cámara (2017) have modified it for $Na(NaCa)Ca_2(CaY)TiSi_4O_{14}(OF)F_2$. However this formula does not make sense. Hainite has very little or no Y (in *apfu*). The hainite-(Y) formula $Na(NaCa)Ca_2(CaY)TiSi_4O_{14}(OF)F_2$ can be resolved into two end-member compositions: $NaCa_2Ca_2Ca_2TiSi_4O_{14}(OF)F_2$ (götzenite) and $NaNa_2Ca_2Y_2TiSi_4O_{14}(OF)F_2$ [fogoite-(Y)]. Hainite-(Y) could be considered as the intermediate member of the series götzenite - fogoite-(Y) and the real hainite corresponds to götzenite. As hainite was described before götzenite, the name hainite should be preserved and götzenite discarded, of course after IMA approval. In conclusion, giannettite corresponds to hainite.

Occurrence. Giannettite occurs in alkaline rocks (foyaites, phonolites, tinguaites, lujavrites, nepheline syenites) of the Poços de Caldas massif, Minas Gerais. This alkaline massif is not entirely located in the municipality of Poços de Caldas, but it also occupies areas in other municipalities in the states of Minas Gerais and São Paulo. Guimarães (1948c) noted the associated minerals eudialyte, catapleiite, aegirine, fluorite, sanidine, nepheline, and sodic amphibole. Azzi *et al. (*2018) identified several minerals associated to hainite (“giannettite”) from the Bortolan quarry, Poços de Caldas, Minas Gerais: pectolite, rinkite-(Ce), fluorapatite, stronadelphite, members of the britholite group (some of them new minerals under study), villiaumite, fluorite, manganoeudialyte, natrolite, aegirine, lorenzenite, batisite, chlorbartonite, tuppersuatsiaite, astrophyllite, lamprophyllite, gaidonnayite, pyrophanite, vishnevite, sodalite, pyrite, polezhaevaite, ferrobustamite, vinogradovite, burbankite, ancylite-(Ce) and ancylite-(La). Giannettite appears to be a pneumatolitic to hydrothermal phase. Its crystallization precedes only that of a fibrous aegirine and zeolites (Schorscher *et al.* 1992). Atencio *et al.* (1999) recorded data from giannettite crystals collected in vugs of the subvolcanic phonolite (tinguaite), mined at Bortolan quarry, and also from the matrix of the nepheline syenite of Pedreira da Prefeitura ("City Hall Quarry"), Poços de Caldas, Minas Gerais. The vug filling crystals of giannettite studied by Atencio *et al.* (1999) are associated with some unidentified minerals (see unidentified silicate inclusions in giannettite). The occurrence of giannettite was also quoted in the Maciço Ilha Fecho dos Morros, Mato Grosso do Sul (Guimarães and Dutra 1962).

Appearance and physical properties. Giannettite occurs as pale brownish-yellow anhedral, prismatic or acicular crystals. Its streak is pale yellow. The forms {010}, {012}, {250}, {111}, {320} and {120} were identified by Guimarães (1948c) who also noted the following cleavages: perfect on {100}, indistinct and irregular on {010} and {001}, and twinning on {100} which may be either simple or lamellar. Giannettite from the rock matrix is generally poikilitic, including feldspar, nepheline, and other minerals. Giannettite from vugs may show an intimate association with unidentified minerals, and with manganoan pectolite, or else it may appear idiomorphic and isolated in the cavity. Microcline, aegirine and natrolite are also present in the vugs. The calculated density is 3.274 g/cm^3 (vug crystals).

Optical properties. Guimarães (1948c): α 1.663(2), β 1.664(2), γ 1.675(2), birefringence 0.012, $2V_{z\,\mathrm{obs.}}$(°) 30, $2V_{z\,\mathrm{calc.}}$(°) 33.7, c ^ Y (°) 23, dispersion not cited, pleochroism: colorless to pale yellow. *XY* plane is nearly perpendicular to (010) and *X* is at about 16° to the normal to the (010) face. Atencio *et al.* (1999) three vug crystals, average values for refractive indices, 2*V* and *c* ^ *Y*: *α* 1.662(1), *β* 1.663(1), *γ* 1.675(1), birefringence 0.013, 2*Vz* obs.(°) 30 to 45, 2*Vz* calc.(°) 30.5, *c* ^ *Y* (°) 20, dispersion: *r*<*v* very strong, crossed, pleochroism: *X* = colorless, *Y* = colorless to pale yellow, *Z* = golden yellow. Other average values: on (100): *c* ^ *Y'* = ca. 18°; on (010): *c* ^ *Y'* = ca. 2°; on section ⊥ *c*: trace of (100) ^ *X'* = 14°.

Chemical data. Chemical data obtained by Guimarães (1948c) are inaccurate. He made a spectrographic study on a few grains and showed the presence of Si, Ti, Zr, Mn, Fe, Ca, and Na, with traces of Ta and the absence of rare earth elements. Since the mineral could not be separated, chemical analyses were performed on material dissolved from two rock samples. Microprobe data are available for giannettite (alternatively quoted as hainite or götzenite) from three occurrences in Poços de Caldas, Minas Gerais: Morro do Cristo (Soubiès *et al.* 1991b, Duvallet 2000), Prefeitura quarry (Schorscher *et al.* 1992, Atencio *et al.* 1999), and Bortolan quarry (Schorscher *et al.* 1992, Atencio *et al.* 1999, RRUFF project R130010 and R141182).

Microprobe (WDS mode) analyses: CaO 35.17, SrO 1.02, Na_2O 6.81, MnO 0.97, FeO 0.65, Al_2O_3 0.03, La_2O_3 1.16, Ce_2O_3 1.16, Nd_2O_3 0.24, TiO_2 9.16, Nb_2O_5 0.81, ZrO_2 3.30, HfO_2 0.13, SiO_2 31.43, F 6.19, O=F -2.77, total 96.39 wt.%. Empirical formula (based on 4 Si *apfu*):
$Na_{1.00}Ca_{2.00}(Ca_{1.48}Zr_{0.13}Mn_{0.10}Sr_{0.08}Fe_{0.07}La_{0.05}Nd_{0.01})_{\Sigma 2.00}(Ca_{1.32}Na_{0.88})_{\Sigma 2.00}(Ti_{0.88}Zr_{0.07}Nb_{0.05})_{\Sigma 1.00}(Si_2O_7)_{2.00}[O_{0.80}F_{0.65}(OH)_{0.55}]_{\Sigma 2.00}F_{2.00}$ (Azzi *et al.*, unpublished data from a specimen from the Bortolan quarry). The ideal formula $NaCa_2Ca_2Ca_2TiSi_4O_{14}(OF)F_2$ requires CaO 46.69, Na_2O 4.30, TiO_2 11.09, SiO_2 33.35, F 7.91, O=F -3.33, total 100.00 wt.%.

Crystallography. Triclinic, $P\bar{1}$, *a* 9.6170(3), *b* 5.72477(16), *c* 7.3106(2) Å, *α* 89.894(1), *β* 101.115(1), γ 100.940(1)°, *V* 387.505(19) Å^3, *Z* 1, *a:b:c* = 1.6799:1:1.2770 (Azzi *et al.*, unpublished data from a specimen from the Bortolan quarry, derived from single-crystal studies). X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 3.966 (7) ($\bar{2}01$), 3.081 (100) (300), 2.970 (43) (021, $1\bar{2}1$), 2.635 (11) ($\bar{2}02$), 2.496 (8) (301), 2.312 (9) (400, $\bar{3}02$), 1.904 (10) ($4\bar{2}1$), 1.825 (6) ($\bar{1}40$), 1.683 (5) ($\bar{1}23$, $0\bar{2}3$) (specimen from Pedreira Bortolan, Poços de Caldas, Minas Gerais, sample 4, Atencio *et al.* 1999, some errors here corrected).

Name. In honor of Dr. Americo René Giannetti (1896-1954), mining engineer and former mayor of Belo Horizonte city.

Type material. A specimen of giannettite from Cascatinha (SP-342 highway, km 239, Águas da Prata, São Paulo State) was donated by Djalma Guimarães to the U.S. National Museum of Natural History (Smithsonian Institution), Washington DC, USA. (type minerals collection, catalog #105972.00).

Relationship to other species. Rinkite group, seidozerite supergroup (Sokolova and Cámara 2017).

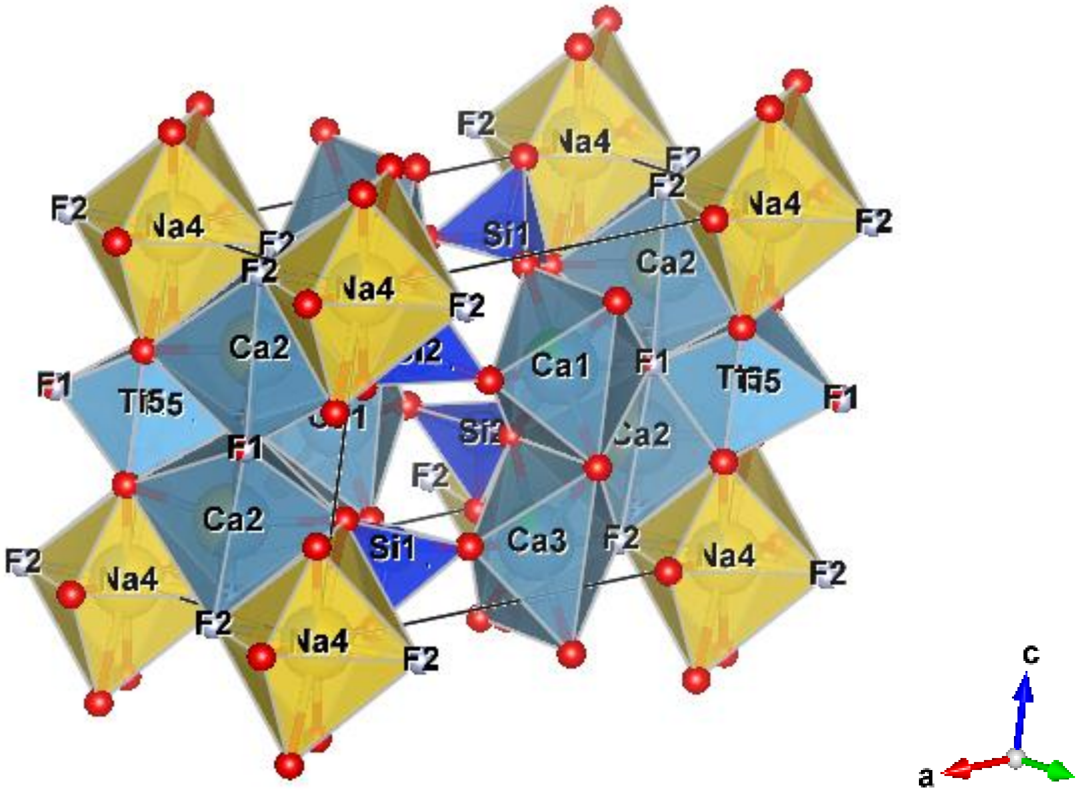

Figure 9.20. View of the crystal structure of "giannettite" (= hainite, from the Bortolan quarry, Poços de Caldas, Minas Gerais), drawn using VESTA 3 (Momma and Izumi 2011). Data from Azzi *et al.* (in preparation).

Crystal structure. The main feature of the crystal structure is the presence of "walls" of octahedral and eight-cornered polyhedra parallel to (100) which are connected by "ribbons" of octahedral parallel to [001] and by Si_2O_7 groups. The coordination polyhedra of Ti and Ca are octahedra; that of Na is an eight-cornered polyhedron which can be described as a hexagonal bipyramid (Cannillo *et al.* 1972). Crystal structure data for the Brazilian mineral were obtained by Rastsvetaeva *et al.* (1995) and by Azzi *et al.* (in preparation).

See also. Manganoeudialyte, Ta-rich eudialyte, fluorlamprophyllite, pennaite, unnamed $Ti_3(UO_2)_3SiO_8$, unidentified silicate inclusions in giannettite, and unidentified Mn-Fe-silicate and Zr-silicates.

Unidentified silicate inclusions in giannettite

Atencio *et al.* (1999)

Other names: UPC1, UPC2, UPC3

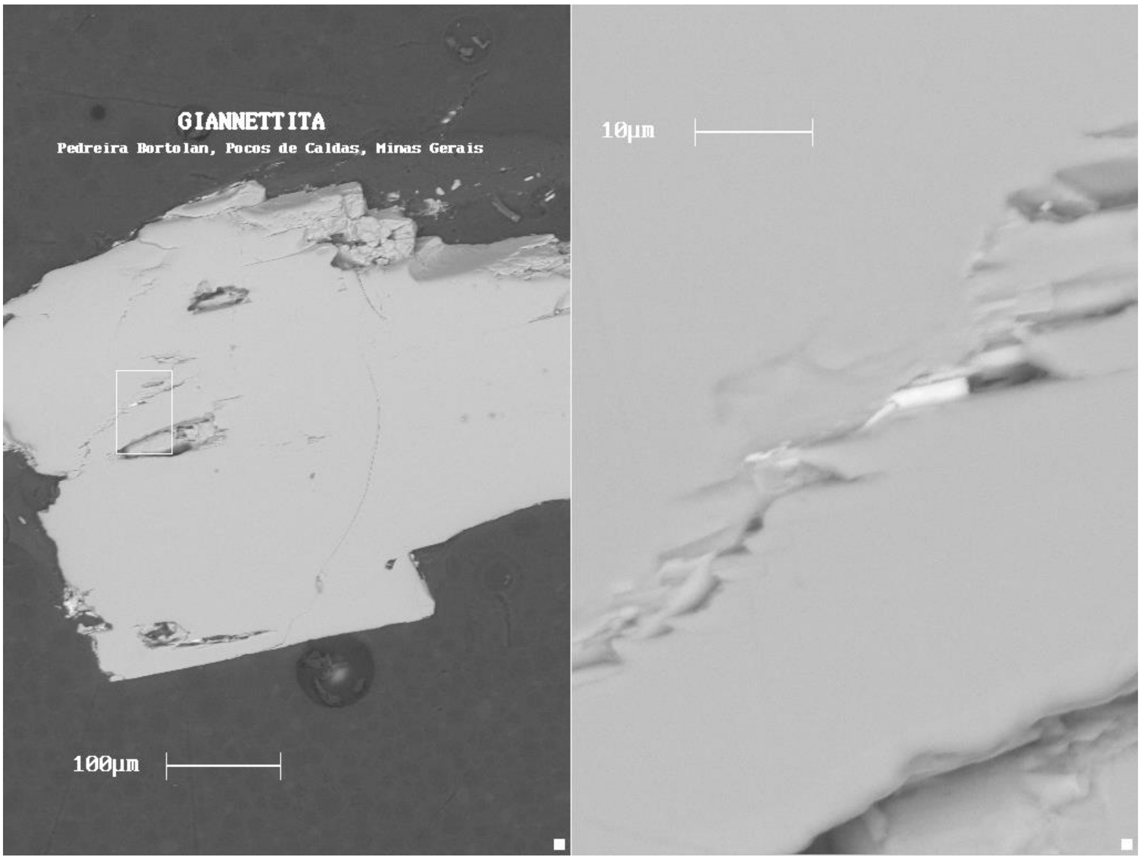

Figure 9.21. Backscattered electron images of unidentified silicate inclusion (UPC1) in giannettite (hainite) from the Bortolan quarry, Poços de Caldas, Minas Gerais.

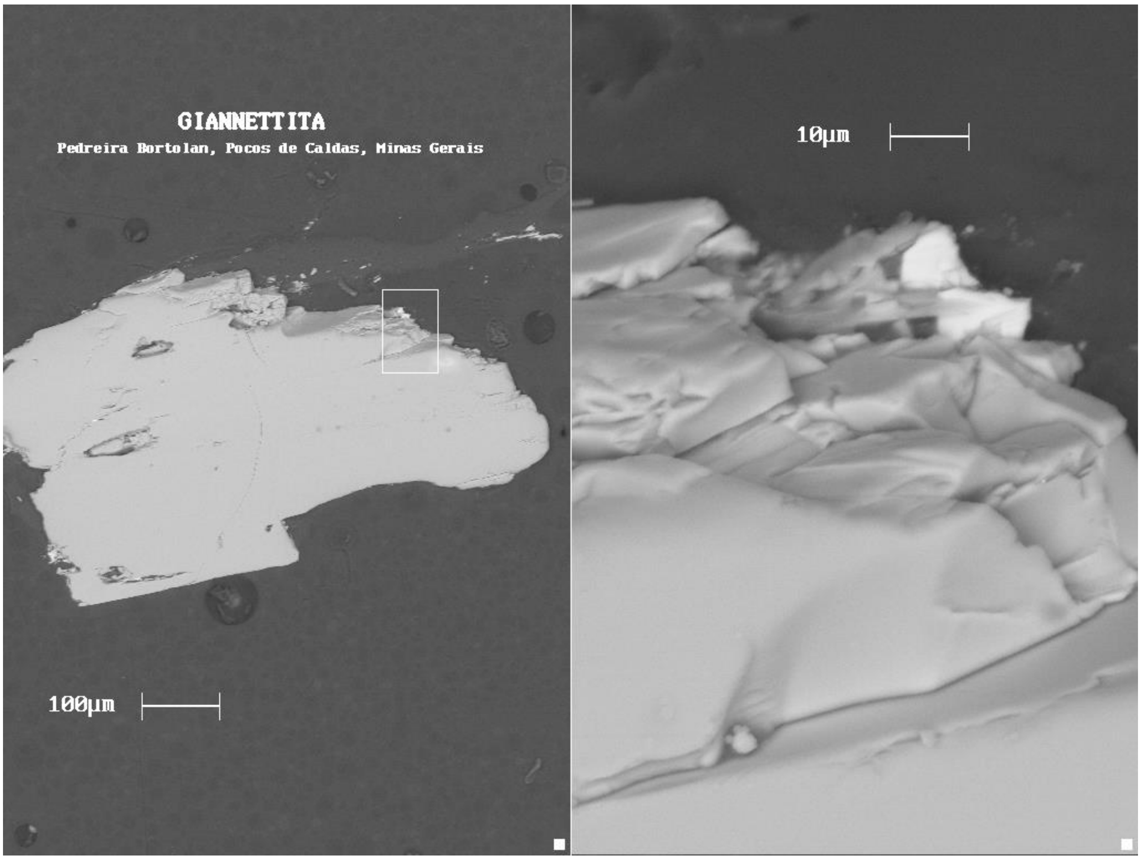

Figure 9.22. Backscattered electron images of unidentified silicate inclusion (UPC2) in giannettite (hainite) from the Bortolan quarry, Poços de Caldas, Minas Gerais.

The vug filling crystals of giannettite (hainite) from the Bortolan quarry, Poços de Caldas, Minas Gerais, are associated with some unidentified minerals. Mineral UPC1 (= unidentified from Poços de Caldas 1), displays a rectangular outline and maximum dimensions of 8 × 0,2 µm, it develops along fracture surfaces of giannettite crystals. EDS analyses indicated a Sr, Ce, Ca, La, and Na silicate-phosphate, with F and Cl. A second unidentified mineral (UPC2), grows around the same giannettite grain. It is anhedral, its area measures about 10 × 10 µm, and is a Ba, Na, Nb, Ti, and Ca silicate. In another sample, giannettite is associated with Mn-rich pectolite, tuperssuatsiaite and a third unidentified mineral (UPC3). The latter is a Ti, Na, Mn, Fe, Ca, K, and Al silicate with rectangular outlines and maximum dimensions of 120 × 15 µm. It is difficult to evaluate the influence of the matrix giannettite on the resulting chemical data.

See also. Manganoeudialyte, Ta-rich eudialyte, fluorlamprophyllite, pennaite, giannettite, unnamed $Ti_3(UO_2)_3SiO_8$, and unidentified Mn-Fe-silicate and Zr-silicates.

Pennaite

Guimarães (1948c)

Other names: pennaíta

Pennaite was described by Guimarães (1948c) in alkaline rocks of Poços de Caldas, Minas Gerais, as a yellow to light brown, prismatic to acicular mineral. It is biaxial (+), with β 1.70 and birefringence 0.044, $2V$ 25°, $c \wedge Y$ 13°. Guimarães (1960) published the values α 1.696, β 1.700, and γ 1.740. Pleochroism: X dark or dirty yellow, Y grayish-yellow, Z bright yellow or yellowish-brown. It shows polysynthetic twinning and may be triclinic. The presence of Zr, Ti, Ca, Fe, and Mn was ascertained. Pennaite could not be separated for testing except in minute amounts and chemical analysis produced only approximate values: SiO_2 40 to 45, TiO_2 8 to 10, ZrO_2 4 to 6, FeO 10 to 15, MnO 3 to 4, CaO 10 to 15, Na_2O 10 to 12, Cl 2 to 3 wt.%. Soluble in HCl. Spectrographic traces of Ta are present. Guimarães (1960) considered pennaite as a pseudo-monoclinic variety of giannettite. The name honors José Moreira dos Santos Penna, chief of the Instituto de Tecnologia Industrial, Minas Gerais.

See also. Manganoeudialyte, Ta-rich eudialyte, fluorlamprophyllite, giannettite, unnamed $Ti_3(UO_2)_3SiO_8$, unidentified silicate inclusions in giannettite, and unidentified Mn-Fe-silicate and Zr-silicates.

Breyite

Brenker *et al.* (2020)

$CaCa_2Si_3O_9$, triclinic

Approved CNMNC – IMA 2018-062

Other names: breyíta, wollastonite-II, $CaSiO_3$-walstromite, unnamed walstromite-structurated $CaSiO_3$, unnamed (Ca silicate)

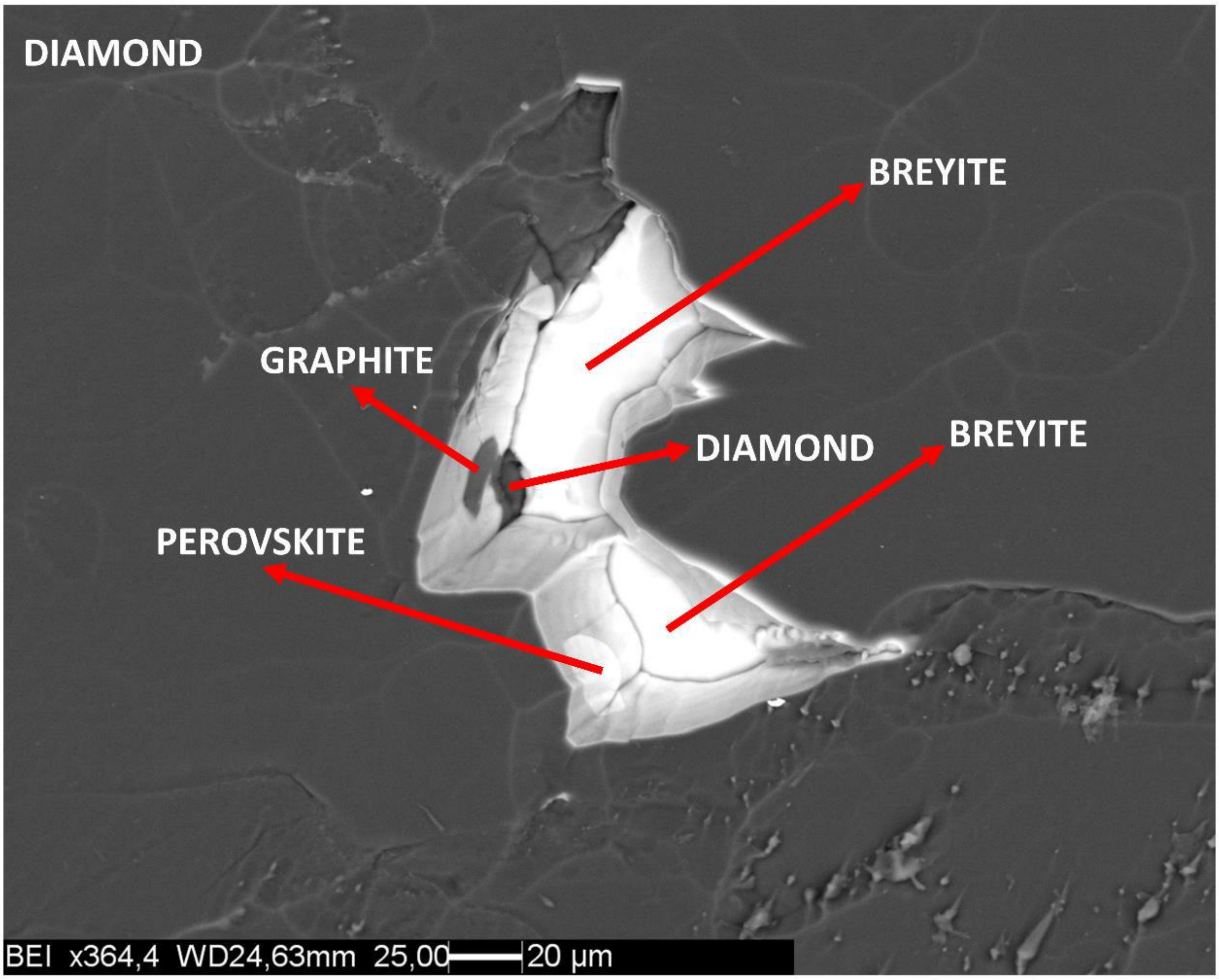

Figure 9.23. Backscattered electron images of breyite from Juína, Mato Grosso, within its diamond host (Brenker *et al.* 2020).

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Breyite, quoted as “walstromite-structured $CaSiO_3$” and “$CaSiO_3$-walstromite”, was identified by electron microprobe and infrared spectrometry as inclusions inside the so-called “super-deep diamonds” from the São Luiz river alluvial deposits, Juína, Mato Grosso, by Zedgenizov *et al.* (2014). Walstromite is triclinic $BaCa_2Si_3O_9$.

Occurrence. As inclusions inside the super-deep diamonds from the São Luiz river alluvial deposits, Juína, Mato Grosso. The diamond studied by Zedgenizov *et al.* (2014) contains also inclusions of merwinite and forsterite. In the type specimen of breyite, studied by Brenker *et al.* (2020), it is associated with perovskite and graphite. Several mineral species were quoted as inclusions in the diamonds from Juína: jeffbenite, ellinaite, cohenite, haxonite, native iron, graphite, magnetite, dolomite, halite, sylvite, phlogopite, spinel, magnesite, eitelite, oskarsonite, pentlandite, violarite, millerite, hematite, periclase, perovskite, titanite, ilmenite, majorite, enstatite, forsterite, merwinite, native nickel, nitroyarlongite, nitrocohenite, nitrochalypite, unnamed Fe_2N, Fe_3N, Fe_5SiC, $(Ba,Sr)AlF_5$, $Na_4Mg_3(PO_4)_2(P_2O_7)$, $Fe^{3+}{}_2Fe^{2+}{}_5 (P_2O_7)_4$, and Na-Mg pyroxene. Juína is also the type locality for jeffbenite and ellinaite. Breyite also occurs in the Kankan diamond District, Kankan Region, Guinea (Joswig *et al.* 1999).

Appearance and physical properties. Habit: since breyite was only found as an inclusion in diamond it is impossible to observe its real morphology and habit as it is not an isolated crystal growth out of the diamond. The size of the studied crystal is approximately 140 × 150 × 100 µm. Twinning: not observed. Color: colorless. Streak: not determined. Luster: vitreous. Transparent. Non-fluorescent. Hardness: not determined. Tenacity: not determind. Cleavage: not observed. Parting: not observed. Fracture: irregular. Density could not be measured because of small grain size. Density: 3.072 g/cm^3 (calc.) using the empirical formula.

Optical properties. Not determined. The calculated mean refractive index is 1.642.

Chemical data. Microprobe data: CaO 47.3, SiO_2 51.6, TiO_2 0.04, Al_2O_3 0.01, FeO 0.31, Na_2O 0.03, total 99.29 wt.%. Empirical formula: $(Ca_{0.99}Fe^{2+}{}_{0.01})_3Si_3O_9$ (Zedgenizov *et al.* 2014). Semiquantitative EDS analyses (4): CaO 48.04, SiO_2 51.96, total 100.00 wt.%. Empirical formula: $Ca_{3.01}Si_{2.98}O_9$ (Brenker *et al.* 2020). The ideal formula requires CaO 48.28, SiO2 51.72, total 100.00 wt.%.

Crystallography. Triclinic, $P\bar{1}$, *a* 6.6970(4), *b* 9.2986(7) *c* 6.6501(4) Å, *α* 83.458(6), *β* 76.226(6), γ 69.581(7)°, *V* 376.72(4) Å^3, Z 2, *a:b:c* = 0.720:1:0.715 (single-crystal data). X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 5.01 (32) (101), 3.87 (15) (121), 3.15 (40) (112), 3.03 (58) (220), 2.90 (100) (030), 2.63 (24) $(\bar{2}10)$, 2.38 (15) $(\bar{1}\bar{2}2)$, 1.83 (15) (042), 1.79 (18) $(2\bar{3}1)$ 1.71 (15) $(\bar{2}22)$ (calculated pattern).

Name. Named in honor of Gerhard Peter Brey (1947-), German mineralogist, petrologist, and professor at the Goethe-University of Frankfurt. He is an expert in the study of mineral inclusions in diamonds.

Type material. The holotype of breyite is deposited at the Museum of Mineralogy of University of Padova under the catalog number MMP 20371.

Relationship to other species. Breyite is a wollastonite and pseudowollastonite polymorph. It belongs to the margarosanite group (Krzątała *et al.* 2020).

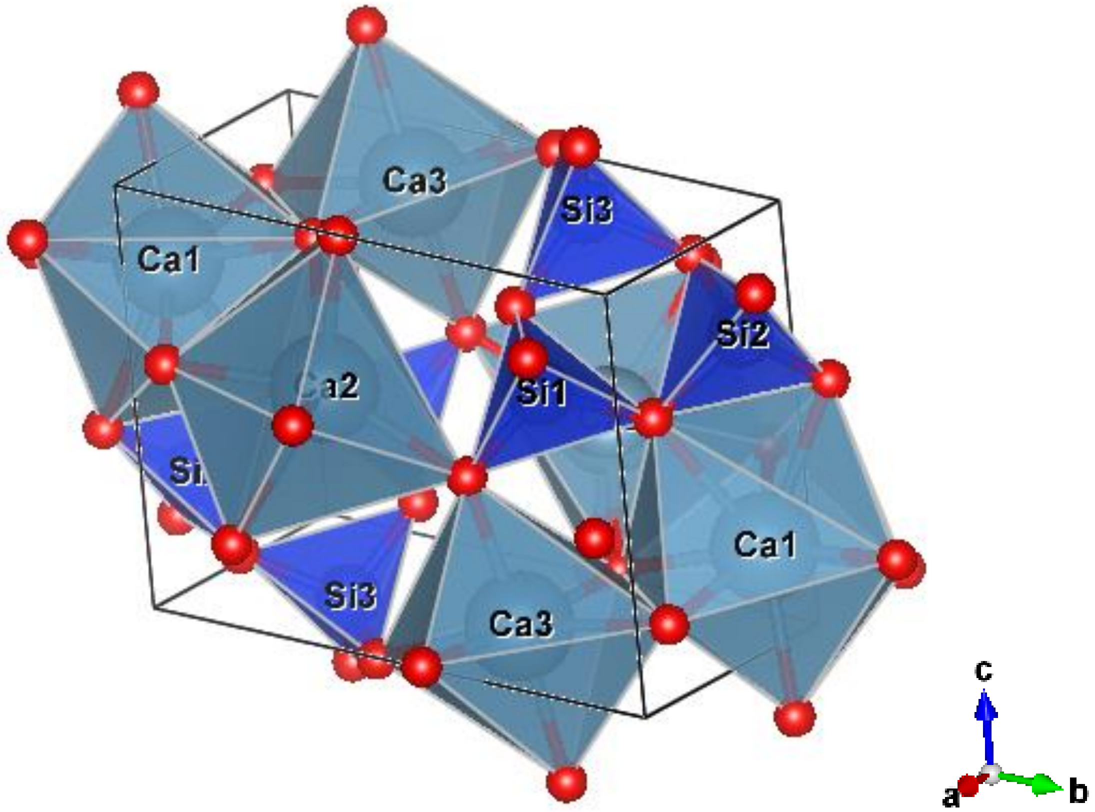

Figure 9.24. View of the crystal structure of breyite (synthetic), drawn using VESTA 3 (Momma and Izumi 2011). Data from Trojer (1969).

Crystal structure. The basic structural features of this high-pressure phase of $CaSiO_3$ are CaO layers and Si_3O_9 rings. The layers contain two types of Ca atoms, one coordinated by six oxygen atoms the other by eight oxygen atoms. The Si_3O_9 rings are located between these layers. The third type of Ca atom, also coordinated by six oxygen atoms, connects neighboring layers, thus sharing the space with the Si_3O_9 rings (Trojer 1969).

Synthetic. The synthetic crystals were made from $CaSiO_3$ glass at 65 kbar and approximately 1300°C (Trojer 1969).

See also. Jeffbenite, ellinaite, nitroyarlongite, nitrocohenite, nitrochalypite, unnamed Fe_2N, Fe_3N, Fe_5SiC, $(Ba,Sr)AlF_5$, orthorhombic MgO, $MgCr_2O_4$, $Na_4Mg_3(PO_4)_2(P_2O_7)$, $Fe_2^{3+}Fe_5^{2+}(P_2O_7)_4$, and Na-Mg pyroxene.

Fluor-elbaite

Bosi *et al.* (2013)

$Na(Li_{1.5}Al_{1.5})Al_6(Si_6O_{18})(BO_3)_3(OH)_3F$, trigonal.

Approved CNMNC – IMA 2011-071.

Other names: fluor-elbaíta

Figure 9.25. Fluor-elbaite from the Cruzeiro mine, São José da Safira, Minas Gerais. Dimensions: 1.7 × 0.4 × 0.3 cm. Specimen and photo: Luciana Barbosa.

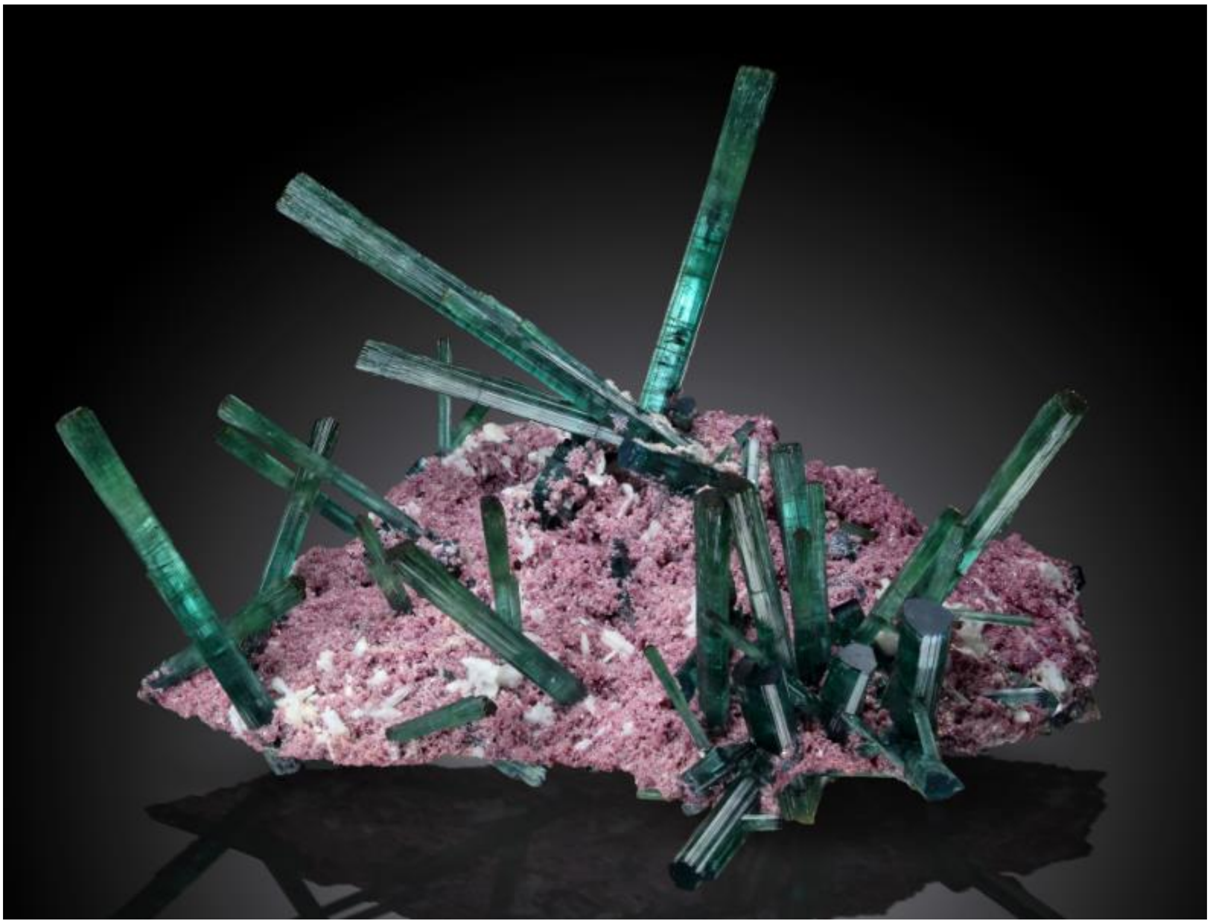

Figure 9.26. Fluor-elbaite from the Cruzeiro mine, São José da Safira, Minas Gerais. Dimensions: 30 × 40 cm. Specimen: Marco Tironi. Photo: Roberto Appiani. Cornejo and Bartorelli (2020).

Occurrence. Fluor-elbaite was described at two deposits. The first one is the Cruzeiro mine (São José da Safira, Minas Gerais), associated with quartz, pink muscovite, "lepidolite", spodumene, spessartine, and pink beryl (Federico *et al.* 1998). The mineral is also found in the Urubu mine (Itinga, Minas Gerais). Other minerals in the Urubu pegmatite are albite, amblygonite, arsenopyrite, beryl, cassiterite, columbite-group minerals, "lepidolite", microcline, microlite-group minerals, monazite-(Ce), montebrasite, muscovite, petalite, pollucite, quartz, rankamaite, simpsonite, schorl, sphalerite, spodumene, thoreaulite, topaz, xenotime-(Y), and "zinnwaldite" (Cassedanne and Cassedanne 1981; Quéméneur and Lagache 1999, Atencio *et al.* 2011). Both the Cruzeiro and Urubu fluor-elbaite crystals formed from late-stage hydrothermal solutions inside (or close to) miarolitic cavities of the granitic pegmatite. Also, known from several Brazilian and world occurrences.

Appearance and physical properties. Habit: elongated prisms with striated faces terminated by a prominent pedion. The Urubu crystal studied has approximately 1.3 × 1.2 × 2.3 cm in size. Forms: $\{10\bar{1}0\}$ prism, $\{11\bar{2}0\}$ prism, $\{0001\}$ pedion. Twinning: none observed. Color: blue-green. Streak: white. Luster: vitreous. Transparent. Non-fluorescent. Hardness (Mohs): 7½. Tenacity: brittle. Cleavage: none observed. Fracture: sub-conchoidal. Density (calc.) 3.091 g/cm^3 (Cruzeiro) and 3.123 g/cm^3 (Urubu).

Optical properties. Uniaxial (-). Cruzeiro: ω 1.640(5), ε 1.625(5) (white light). Pleochroism: in thin section, *O* green and *E* pale green. Urubu: ω 1.648(2), ε 1.629(2) (Na light, 589.9 nm). Pleochroism: in thin section, *O* bluish-green and *E* pale green.

Chemical data. Analysis by a combination of electron microprobe (WDS mode, 10 spots each sample), secondary ion mass spectrometry, and Mössbauer spectroscopy. Cruzeiro: SiO_2 37.48, B_2O_3 10.83, Al_2O_3 37.81, FeO 3.39, MnO 2.09, ZnO 0.27, CaO 0.34, Na_2O 2.51, K_2O 0.06, Li_2O 1.58, F 1.49, H_2O 3.03, –O=F –0.63, total 100.25 wt.%. Empirical formula: $^{X}(Na_{0.78}\square_{0.15}Ca_{0.06}K_{0.01})^{Y}(Al_{1.15}Li_{1.02}Fe^{2+}_{0.46}Mn^{2+}_{0.28}Zn_{0.03})^{Z}Al_6{}^{T}(Si_{6.02}O_{18})^{B}(BO_3)_3$ $^{V}(OH)_3$ $^{W}[F_{0.76}(OH)_{0.24}]$. Urubu: SiO_2 36.70, B_2O_3 10.73, Al_2O_3 37.73, FeO 6.69, MnO 0.64, ZnO 0.53, CaO 0.10, Na_2O 2.65, Li_2O 1.14, F 1.37, H_2O 2.95, –O=F –0.58, total 100.67. Empirical formula: $^{X}(Na_{0.83}\square_{0.15}Ca_{0.02})^{Y}(Al_{1.20}Li_{0.74}Fe^{2+}_{0.91}Mn^{2+}_{0.09}Zn_{0.06})^{Z}Al_6{}^{T}(Si_{5.94}O_{18})^{B}(BO_3)_3{}^{V}(OH)_3$ $^{W}[F_{0.70}(OH)_{0.19}]$. The ideal formula requires SiO_2 38.41, B_2O_3 11.12, Al_2O_3 40.73, Li_2O 2.39, Na_2O 3.30, F 2.02, H_2O 2.88, –O=F –0.85. total 100.00 wt.%.

Crystallography. Trigonal, $R3m$. Cruzeiro: *a* 15.8933(2), *c* 7.1222(1) Å, *V* 1558.02(4) Å^3, *Z* 3 (single-crystal), *a* 15.8970(6), *c* 7.1227(3) Å, *V* 1558.9(1) Å^3, *Z* 3 (powder data). X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 4.200 (49) (211), 3.974 (58) (220), 3.447 (67) (012), 2.939 (92) (122), 2.568 (100) (051), 2.031 (57) (152), 1.650 (31) (063), and 1.444 (32) (642). Urubu: *a* 15.9083(6), *c* 7.1229(3) Å, *V* 1561.12(19) Å^3, *Z* 3 (single-crystal), *a* 15.915(3), *c* 7.120(2) Å, *V* 1561.8(7) Å^3, *Z* 3 (powder data). X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 6.332 (32) ($\bar{1}11$), 4.957 (32) (021), 4.206 (66) ($\bar{2}31$), 3.977 (78) ($\bar{2}40$), 3.449 (60) (012), 2.939 (81) ($\bar{1}32$), 2.569 (100) (051), 2.034 (69) ($\bar{2}43$, $\bar{1}62$), 1.911 (43) ($\bar{3}72$).

Name. Assigned according to the chemical composition, as recommended by Henry *et al.* (2011).

Type material. The holotype specimen from the Cruzeiro mine is deposited in the collections of the Museum of Mineralogy, Earth Sciences Department, Sapienza

University of Rome, Italy, catalog number 33045. The holotype specimen from the Urubu mine is deposited in the collection of the Department of Natural History, Royal Ontario Museum, Canada, catalog number M56418.

Relationship to other species. A member of the tourmaline supergroup, alkali-tourmaline group (Henry *et al.* 2011).

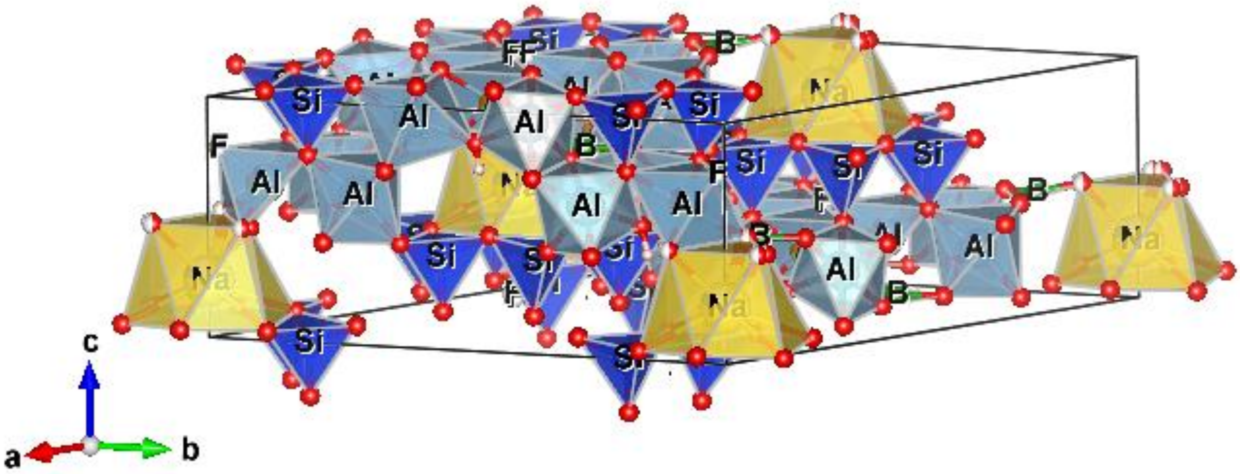

Figure 9.27. View of the crystal structure of fluor-elbaite (from the Cruzeiro mine, São José da Safira, Minas Gerais), drawn using VESTA 3 (Momma and Izumi 2011). Data from Bosi *et al.* (2013).

Crystal structure. The general formula of tourmaline may be written as: $^{[9]}X^{[6]}Y_3{}^{[6]}Z_6{}^{[4]}T_6\text{O}_{18}({}^{[3]}\text{BO}_3)_3{}^{[3]}V_3{}^{[3]}W$, where X = Na^+, K^+, Ca^{2+}, □; Y = Al^{3+}, Fe^{3+}, Cr^{3+}, V^{3+}, Mg^{2+}, Fe^{2+}, Mn^{2+}, Li^+; Z = Al^{3+}, Fe^{3+}, Cr^{3+}, V^{3+}, Mg^{2+}, Fe^{2+}; T = Si^{4+}, Al^{3+}, B^{3+}; B = B^{3+}; V = OH^{1-}, O^{2-}, W = OH^{1-}, F^{1-}, O^{2-}. The dominance of such ions at one or more sites of the structure gives rise to many distinct mineral species (Henry *et al.* 2011). It belongs to the subclass of cyclosilicate as consists of rings of six $T\text{O}_4$ tetrahedra, lying in a plane parallel to (0001). Because all tetrahedra point in the same direction, tourmaline lacks center symmetry (polar character) and is both pyroelectric and piezoelectric (electrical properties). Each tetrahedron shares one edge with the trigonal antiprism $X\text{O}_9$, which is located along the threefold axis passing through the center of each six-membered ring [$T_6\text{O}_{18}$]. The X-site occupancy usually reflects the paragenesis of the rock in which tourmaline crystallizes (petrologic information), and tourmaline supergroup is classified into primary groups based on the dominant occupancy of the X site: vacant, alkali, and calcic groups (Henry *et al.* 2011). The antiprism $X\text{O}_9$ and the ring [$T_6\text{O}_{18}$] combine with two sets of three octahedra $Y\text{O}_6$: an [$Y_3\text{O}_{15}$] triplet of octahedra caps the $X\text{O}_9$ polyhedron toward the +*c* axis and the other [Y_3O_{13}] caps the [T_6O_{18}] ring of tetrahedra toward the –*c* axis. The most extensive compositional variation occurs at the *Y* site, which is able to incorporate constituents of different sizes and charges (including vacancies) that makes tourmaline famous for its extensive range of colors (all rainbow colors) even within individual crystals (oscillatory and sector zoning). The BO_3 groups oriented sub-parallel to (0001) lie between the tetrahedral rings and are fully occupied by B, which makes tourmaline one of the most important B-bearing minerals (reservoir of B) in the Earth. The structural arrangement of [T_6O_{18}], XO_9, [Y_6O_{18}], and $(BO_3)_3$ form “islands” that are stacked in columns along the *c* axis. These islands are attached along the *a* and *b* crystallographic axes by spiral chains of ZO_6 octahedra, which also extend along to the *c* axis according to a 3_1 triad screw axis. The three-dimensional framework of the tourmaline structure is therefore given by the screw-like arrangement of ZO_6 (Bosi 2018).

See also. Uvite and paraibaite.

Uvite

Clark *et al.* (2010)

$CaMg_3(Al_5Mg)(Si_6O_{18})(BO_3)_3(OH)_3(OH)$, trigonal

Type specimen is no longer from Brazil.

Other names: hydroxyuvite, uvita

Figure 9.28. Short prismatic green crystals of uvite on magnesite from Brumado, Bahia. RRUFF material.

Uvite, originally defined by Kunitz (1929), was considered to have an ideal formula $CaMg_3(Al_5Mg)(Si_6O_{18})(BO_3)_3(OH)_4$. This formula was based on the examination of tourmalines from Uva (Sri Lanka), De Kalb (New York) and Gouverneur (New York) with OH contents of approximately 4 *apfu*. However, all other analyses from these localities contain F in the 0.5–1.0 *apfu* range. Dunn *et al.* (1977) designated a sample of uvite from Uva, Sri Lanka as a neotype, and this sample has an anion content of

($OH_{2.90}F_{0.76}O_{0.34}$). This anion content would mandate that the *W* site would be dominated by F and that the type uvite should most properly be termed fluor-uvite.

A tourmaline-group mineral, with OH dominant on the *W* site, from the "Brumado mine", Bahia, was submitted as "hydroxyuvite" (IMA 2000-030) and was suspended while the Tourmaline Subcommittee was set up to deal with tourmaline nomenclature. The proposal was erroneously quoted as approved by Grice and Ferraris (2001) and de Fourestier (2002). Due to the redefinition of "uvite" as the OH-dominant member (Novák *et al.* 2009, Henry *et al.* 2011), Clark *et al.* (2010) have modified the proposed name to uvite in the new submission (IMA 2000-030a). The proposal was approved but complete data were never published. The few published data can be found in Grice and Ferraris (2001), Clark *et al.* (2010), and Henry *et al.* (2011). X-ray powder diffraction data are correct in Grice and Ferraris (2001) and in error in Clark *et al.* (2010). Approval for this mineral has been withdrawn. Subsequent analytical work undertaken by the authors shows this material to be a potentially new oxy-tourmaline (Hålenius *et al.* 2018).

A new proposal for uvite, from a new type occurrence (Facciatoia Quarry, San Piero in Campo, Campo nell'Elba, Elba Island, Livorno Province, Tuscany, Italy) was approved (Bosi *et al.* 2020). Brumado is no more the type locality for uvite.

A mineral from Brumado was described as "fluor-uvite" in the RRUFF Database (R050301), but no fluorine was detected. Consequently, the mineral is uvite. The following description of the Brumado tourmaline countains data from Barbosa *et al.* (2000), Grice and Ferraris (2001), Clark *et al.* (2010), Henry *et al.* (2011), and from the RRUFF Database.

Occurrence. Brumado, Bahia. Mine not specified. Uvite is an abundant accessory mineral in Brumado (Barbosa *et al.* 2000). Brumado is also the type locality of brumadoite.

Appearance and physical properties. According to Barbosa *et al.* (2000), it occurs as superb specimens that range in color from dark green to bright red-brown to yellow. Trivalent iron is dominant in the dark red-brown varieties; divalent iron causes the dark green color; and bright green or very dark green-black may have vanadium as the chromophore. Morphology ranges from prismatic to equidimensional crystals that are up to 8 cm. Dravite occurs in crystals that resemble uvite in color and morphology. Chemical analysis is necessary to distinguish dravite from uvite. The material from the RRUFF Database (R050301) is described as short prismatic green crystals. The crystal studied by

Clark *et al.* (2000) is orange, vitreous, and transparent.

Optical properties. Uniaxial (–), ω 1.646, ε 1.624.

Chemical data. RRUFF Database (R050301): Microprobe (WDS) analysis (20), B_2O_3 and H_2O calculated here. SiO_2 37.92, B_2O_3 11.00, Al_2O_3 29.39, MgO 14.00, CaO 3.99, Na_2O 0.72, K_2O 0.02, TiO_2 0.70, FeO 0.06, MnO 0.01, H_2O 3.79, total 101.60 wt.%. Empirical formula: $(Ca_{0.68}Na_{0.22})_{\Sigma 0.90}(Mg_{2.30}Al_{0.48}Ti_{0.08}Fe^{2+}_{0.01})_{\Sigma 2.87}(Al_5Mg)(Si_6O_{18})(BO_3)_3(OH)_3(OH)$. The ideal formula requires SiO_2 37.04, B_2O_3 10.73, Al_2O_3 26.19, MgO 16.57, CaO 5.76, H_2O 3.70, total 100.00 wt.%.

Crystallography. Clark *et al.* (2010): Trigonal, *R*3*m*. *a* 15.954(1), *c* 7.214(1) Å, *V* 1590.2 Å^3, *Z* 3, *c*:*a* = 0.4522 (single-crystal). X-ray powder diffraction data [*d* in Å (*I*)]: 6.38 (50), 4.981 (50), 4.596 (50), 4.234 (90), 3.978 (100), 3.491 (70), 2.969 (80), 2.582 (90) (Grice and Ferraris 2001). RRUFF Database (R050301, powder data): *a* 15.9567(3), *c* 7.2126(3) Å, *V* 1590.40(6) Å^3, *Z* 3, *c*:*a* = 0.4520. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 4.9894 (25) (021), 4.6063 (25) (300), 4.2303 (60) (211), 3.9892 (64) (220), 3.4898 (41) (012), 2.9676 (87) (122), 2.5808 (100) (051), 2.0445 (42) (152), 1.9222 (37) (342).

Name. Named for the type locality area of the currently defined fluor-uvite, Uva Province, Sri Lanka. Uvite is redefined as the hydroxy equivalent to fluor-uvite. Assigned according to the chemical composition, as recommended by Henry *et al.* (2011).

Type material. The specimen studied by Clark *et al.* (2010) is deposited in the Royal Ontario Museum (Toronto, Canada), specimen number M55101.

Relationship to other species. A member of the tourmaline supergroup, calcic-tourmaline group (Henry *et al.* 2011).

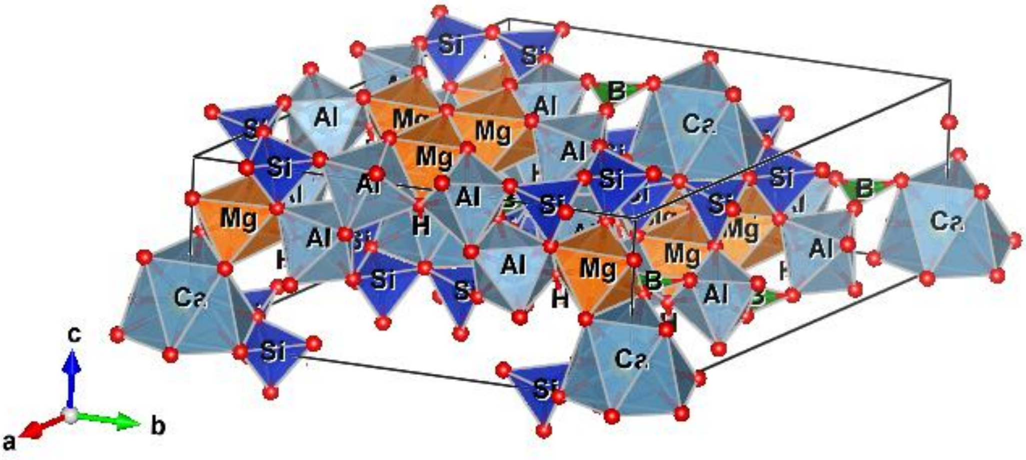

Figure 9.29. View of the crystal structure of uvite (from Brumado, Bahia), drawn using VESTA 3 (Momma and Izumi 2011). Data from Hawthorne *et al.* (unpublished data).

Crystal structure. See fluor-elbaite.

See also. Fluor-elbaite and paraibaite.

Paraibaite

Dietrich (1985)

(= copper-bearing elbaite)

Other names: paraibaíta, heitorite, heitorita, Paraíba tourmaline, cuprian-elbaite, cuprian elbaite, turmalina da Paraíba, turmalina Paraíba, cupro-elbaíta

Figure 9.30. Copper-bearing elbaite (“paraibaite”) from São José da Batalha, Paraíba. Photo width: about 16cm. Specimen DR132, Museu de Geociências, Universidade de São Paulo. Photo: Thales Trigo.

Figure 9.31. Copper-bearing elbaite (“paraibaite”) com quartzo from the Batalha mine, São José da Batalha, Paraíba. 29 × 9 × 9 mm. Specimen and photo: Edson Ferreira dos Santos.

Known since 1980, this elbaite variety forms deep blue, sapphire-blue, turquoise-blue, yellowish-green, light blue, neon blue, greenish, and sometimes bicolor crystals with purple hues. The deep blue crystals are locally referred to as heitorite, in honor of Heitor Dimas Barbosa, founder of COGASBRA, the mining cooperative that operates the deposit. The mineral occurs in pegmatites at the Batalha mine, located in the Serra do Frade, near the town of São José da Batalha, 4.5 km NE of the city of Salgadinho, Paraíba. Associated minerals are microcline, quartz, spodumene, albite, “lepidolite”, tantalite-(Mn), and “tourmaline” (Cornejo 1996). Few samples are gem-quality, but because of its extraordinary colors, they are eagerly sought after by collectors. Rossman *et al.* (1991) verified that the mineral contains up to 1.92 wt.% Cu (or 2.38 wt.% CuO).

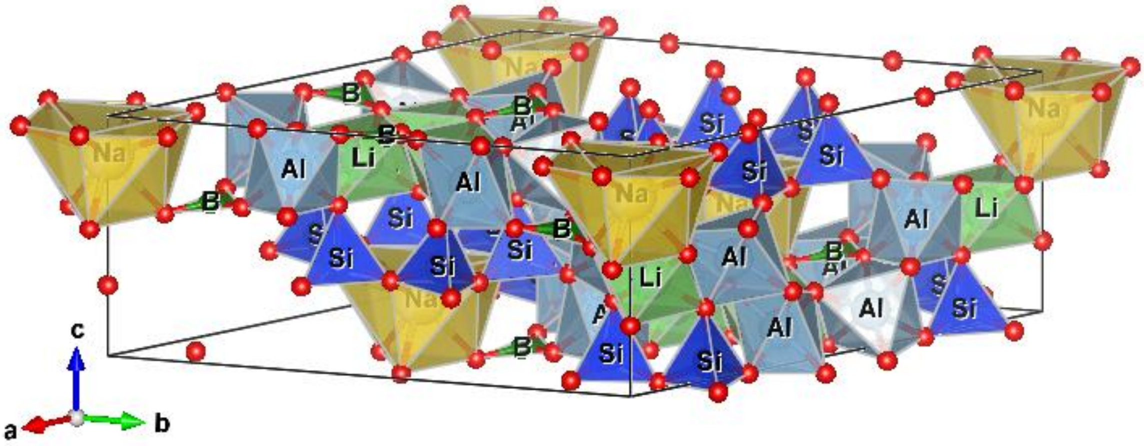

Figure 9.32. View of the crystal structure of Cu-bearing elbaite ("paraibaite" from the Batalha mine, Serra do Frade, São José da Batalha, Salgadinho, Paraíba), drawn using VESTA 3 (Momma and Izumi 2011). Data from MacDonald and Hawthorne (1995).

Crystal structure refinement of copper-bearing tourmaline from Paraiba, rim composition
$(Na_{0.54}Ca_{0.05})(Li_{1.21}Mn_{0.04}Cu_{0.10}Al_{1.66})Al_6(Si_{5.92}Al_{0.08})O_{18}(BO_3)_3[(OH)_{3.56}F_{0.44}]$,
core composition
$(Na_{0.55}Ca_{0.01})(Li_{1.16}Mn_{0.08}Cu_{0.05}Al_{1.71})Al_6(Si_{5.88}Al_{0.12})O_{18}(BO_3)_3[(OH)_{3.70}F_{0.30}]$,
shows the octahedrally coordinated *Z* site to be completely occupied by Al, and Li to occur only at the octahedrally coordinated *Y* site. The high displacement factors at the O1 and 02 positions indicate significant positional disorder that is induced by occupancy of the *X* and *Y* sites by cations of very different size and charge (MacDonald and Hawthorne 1995).

See also. Fluor-elbaite and uvite.

Yttrian milarite
(Černý *et al.* 1991, Hawthorne *et al.* 1991)
[= agakhanovite-(Y)]

Figure 9.33. Agakhanovite-(Y) (“yttrian milarite”) and/or milarite from José Pinto quarry, Jaguaraçu, Minas Gerais. Largest cristal size 12 mm. Specimen and photo: Martin Slama.

This mineral from the Jaguaraçu granitic pegmatite, in the Mr. José Pinto quarry, adjacent to a soccer field, Jaguaraçu, Minas Gerais, quoted by Černý *et al.* (1991), Hawthorne *et al.* (1991), Hawthorne (2002), and Hatert and Burke (2008), was named agakhanovite-(Y) by Hawthorne *et al.* (2014). Černý *et al.* (1991) present five-point analyzes of a Jaguaraçu crystal, two of which are from agakhanovite- (Y) and three from milarite. Type occurrence was defined as Heftetjern, Tørdal, southern Norway. The ideal formula is $(YCa)\square_2KBe_3Si_{12}O_{30}$ and it is hexagonal.

See also. Minasgeraisite-(Y), carlosbarbosaite, and staringite.

Manganoeudialyte

Nomura *et al.* (2010)

$Na_{14}Ca_6Mn^{2+}{}_3Zr_3[Si_{26}O_{72}(OH)_2]Cl_2\cdot 4H_2O$, trigonal

Approved CNMNC – IMA 2009-039

Other names: manganoeudialita

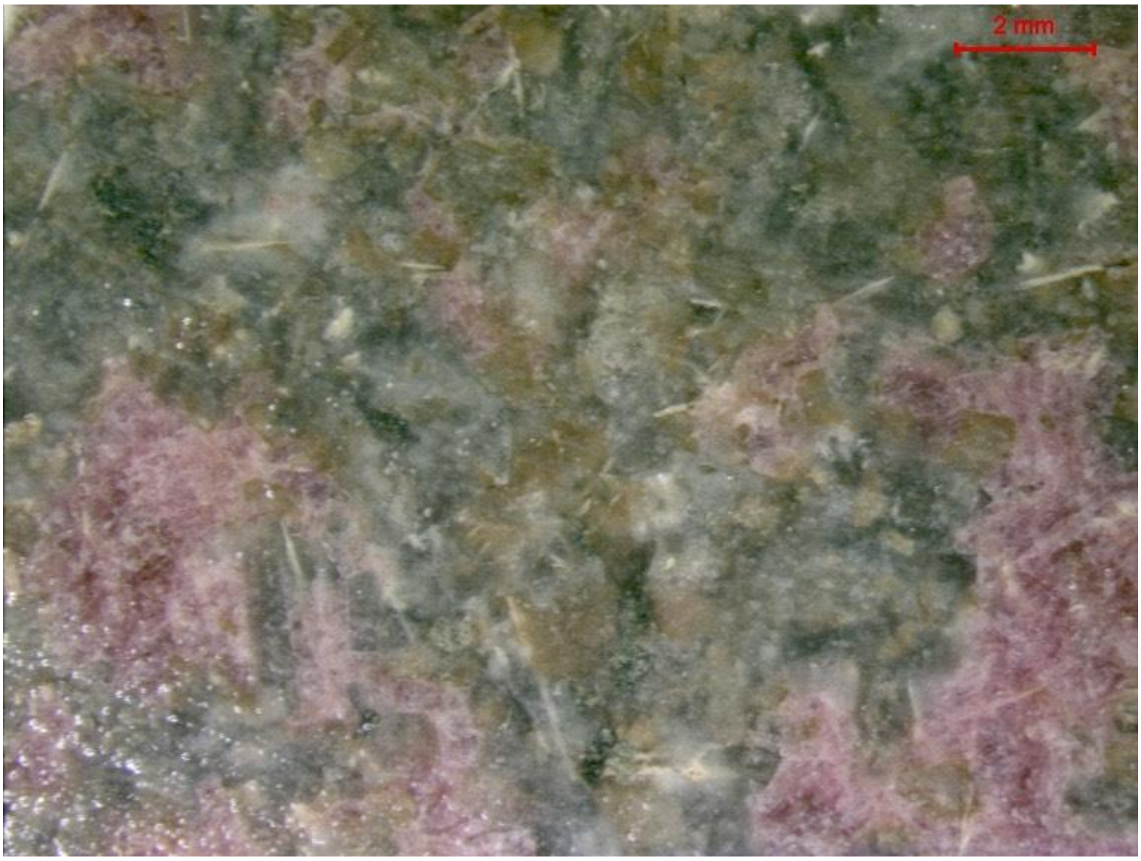

Figure 9.34. Manganoeudialyte in a khibinite, from Pedra Balão, Poços de Caldas, Minas Gerais. Specimen and photo: Daniel Atencio.

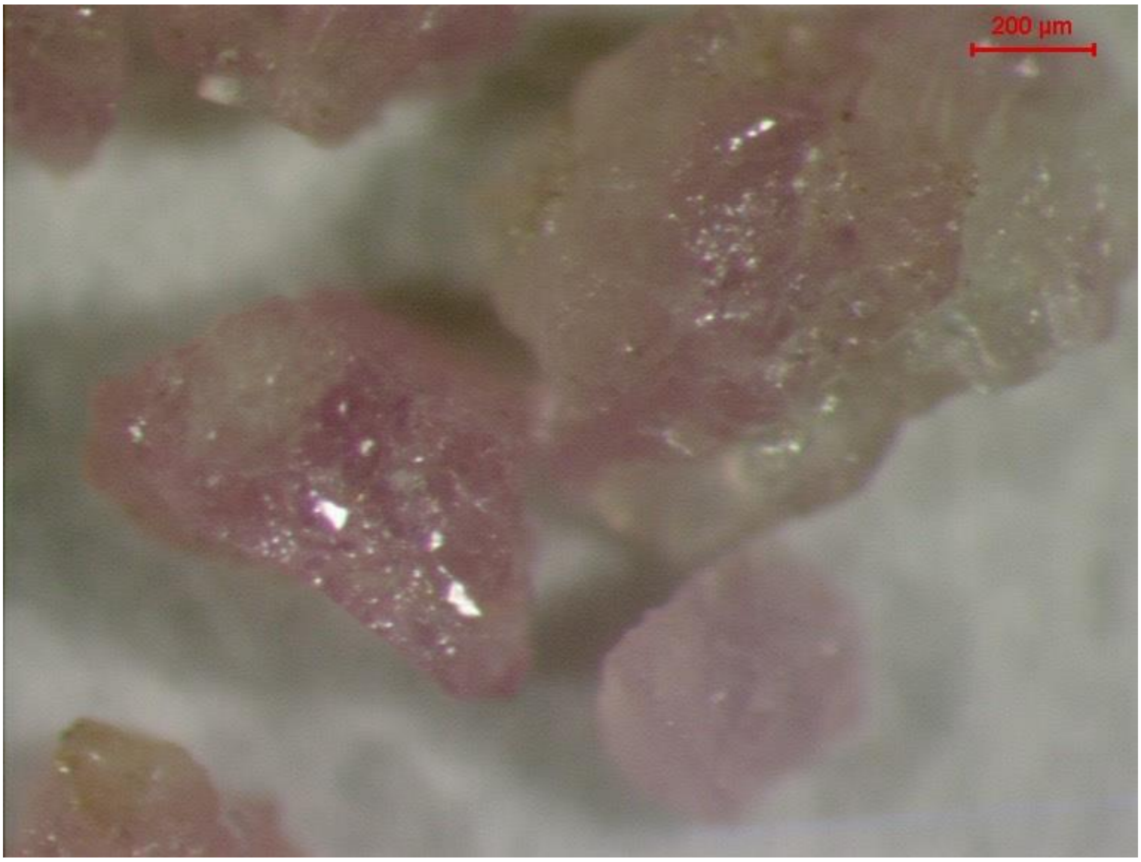

Figure 9.35. Manganoeudialyte from Pedra Balão, Poços de Caldas, Minas Gerais. Specimen and photo: Daniel Atencio.

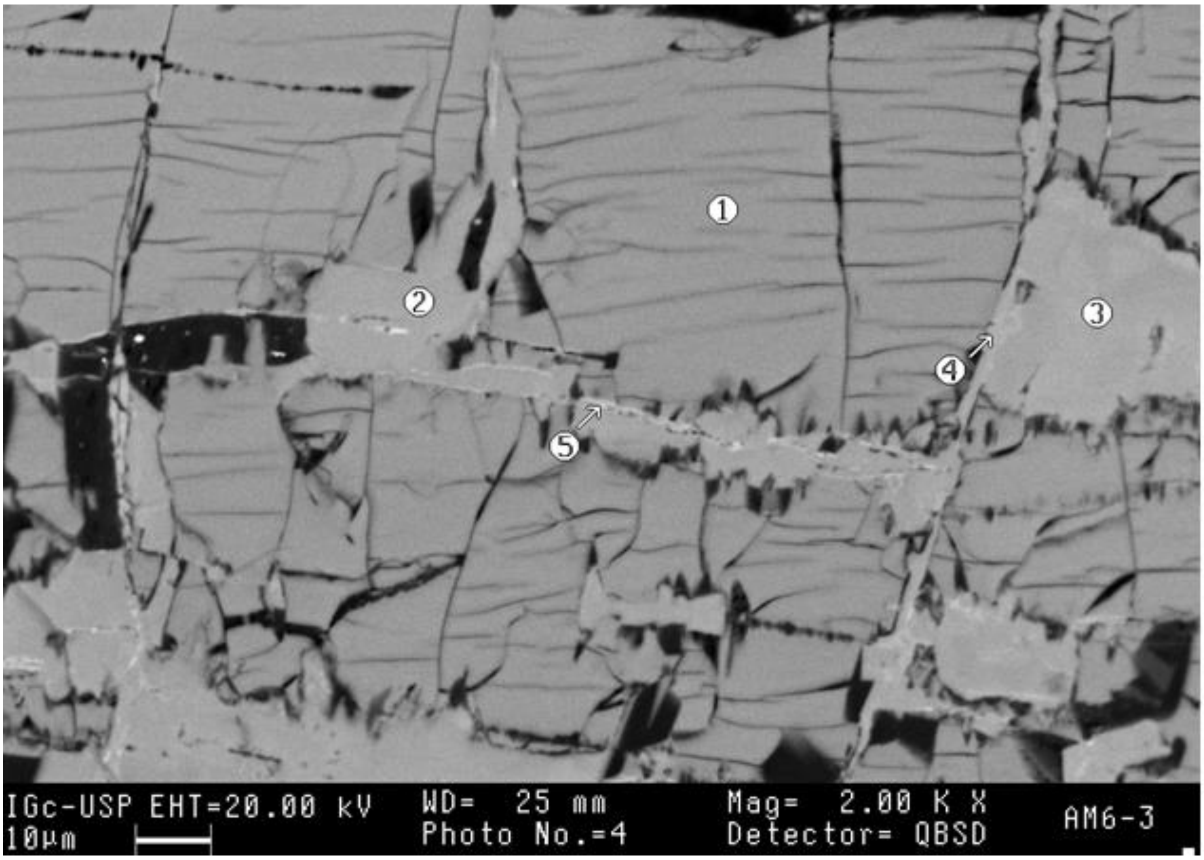

Figure 9.36. Backscattered electron image of manganoeudialyte (1) and gaidonnayite (2 to 5) from Pedra Balão, Poços de Caldas, Minas Gerais.

Eudialyte-group minerals are Na-rich zirconosilicates with varying amounts of the species-determining cations Ca^{2+}, Fe^{2+}, Fe^{3+}, Mn^{2+}, REE^{3+}, Sr^{2+}, K^{+}, Ti^{4+}, Nb^{5+}, W^{6+} and H_3O^{+}, water molecules, and additional anions Cl^{-}, F^{-}, OH^{-}, CO_3^{2-}, SO_4^{2-}. Their general formula (Johnsen *et al.* 2003) can be written as $N(1)_3N(2)_3N(3)_3N(4)_3N(5)_3M(1)_6M(2)_{3-6}M(3)M(4)Z_3[\mathrm{Si}_{24}\mathrm{O}_{72}]\mathrm{O}'_{4-6}X_2$. They are trigonal, $a \approx 14$ Å, $c \approx 30$ Å (rarely ≈ 60 Å), crystallizing in $R\bar{3}m$, $R3m$ or $R3$.

Eudialyte (*lato sensu*) was reported in the rocks of the Poços de Caldas alkaline massif, Minas Gerais, by Guimarães (1948c) and Ulbrich and Ulbrich (1992). Microprobe analyses were obtained by Gualda and Vlach (1996) and Johnsen and Gault (1997). Based on optical data, Gualda and Vlach (1996) classified one specimen as “eudialyte” (uniaxial positive), another one as “mesodialyte” (optically isotropic), and two specimens as “eucolite” (uniaxial negative). Johnsen *et al.* (1997) showed that the terms “mesodialyte” and “eucolite” are meaningless. According to Atencio *et al.* (2000), following the sequence of steps defined by Johnsen and Grice (1999), both the “eudialyte” and the “mesodialyte” of Gualda and Vlach (1996) are eudialyte (*stricto* *sensu*). One “eucolite” studied by Gualda and Vlach (1996) is kentbrooksite, and the other is ferrokentbrooksite. The specimen from Poços de Caldas studied by Johnsen and Gault (1997) is eudialyte (*stricto sensu*).

Manganoeudialyte (Nomura *et al.* 2010) is also a eudialyte-group mineral from Poços de Caldas. An abstract on manganoeudialyte was published by Atencio *et al.* (2010b). Additional data are available in the RRUFF Database (R110212). Duvallet (2000) presented chemical analyzes for eudialyte from Pedra Balão, which is actually manganoeudialyte.

Occurrence. In a khibinite, at the Pedra Balão, northern edge (“Anel Norte”) of the Upper Cretaceous alkaline Poços de Caldas massif, a circular intrusion of almost 800 km^2, Minas Gerais. Emplaced in Precambrian basement rocks and Jurassic sandstones, the intrusion consists of tinguaite, phonolite, nepheline syenite, phonolitic lavas, volcanoclastics, lujavrite and khibinite. Hydrothermal alteration and ore deposition have occurred in all rock types, with emphasis on the inner tinguaite and nepheline syenite. Two small lujavrite-khibinite bodies, an eastern and a western one are exposed at the northern edge of the alkaline Poços de Caldas massif (Ulbrich and Ulbrich, 2000). The mineral association of manganoeudialyte includes eudialyte, K-feldspar, nepheline, aegirine, analcime, sodalite, rinkite, lamprophyllite, astrophyllite, gaidonnayite, titanite, fluorite, and cancrinite. Poços de Caldas is also the type-locality for fluorlamprophyllite. Also, known from several world occurrences.

Appearance and physical properties. Concentrated in cm-sized patches interstitial to the main minerals at the locality. Habit: none observed. Forms: none observed. Twinning: none observed. Color: pink to purple. Streak: white. Luster: vitreous. Transparent (individual crystals) to translucent (masses). Non-fluorescent. Hardness (Mohs): 5-6. Tenacity: brittle. Cleavage: none observed. Fracture: uneven. Density (meas.) 2.890 g/cm^3 by sink/float in bromoform-methylene iodide mixtures. Density (calc.) 2.935 g/cm^3 from empirical formula and single-crystal unit cell parameters.

Optical properties. Uniaxial (+), ω 1.603(2), ε 1.608(2) (white light). Pleochroism: absent.

Chemical data. Microprobe (WDS mode) analyses (12), H_2O content determined by the Penfield method. Na_2O 12.01, K_2O 0.59, CaO 10.70, MnO 3.51, SrO 3.00, FeO 2.72, Al_2O_3 0.41, La_2O_3 0.15, Ce_2O_3 0.12, SiO_2 48.70, TiO_2 0.47, ZrO_2 12.08, Nb_2O_5 1.21, HfO_2 0.25, F 0.08, Cl 0.99, H_2O 3.5, -O=(Cl,F) -0.26, total 100.23 wt.%. Empirical formula (derived from and consistent with the results of the single-crystal X-ray structure analysis):

$[Na_{11.93}Sr_{0.81}(H_3O)_{0.70}K_{0.39}Ce_{0.07}]_{\Sigma 13.90}[Ca_6][^{VI}Mn^{2+}{}_{1.56}{}^{V}Fe^{2+}{}_{1.20}{}^{V}Na_{0.24}]_{\Sigma 3.00}[Zr_3][^{IV}(Si_{0.38}Al_{0.25})^{VI}(Nb_{0.29}Zr_{0.08})]_{\Sigma 1.00}[^{IV}Si_{0.81}{}^{VI}Ti_{0.19}]_{\Sigma 1.00}[Si_{24}O_{72}][(OH)_2][(H_2O)_{3.55}Cl_{0.88}(OH)_{0.84}O_{0.40}F_{0.13}]_{\Sigma 5.80}$. The ideal formula requires Na_2O 14.18, CaO 11.00, MnO 6.96, SiO_2 51.05, ZrO_2 12.08, Cl 2.32, H_2O 2.94, -O=Cl -0.52, total 100.00 wt.%.

Crystallography. Trigonal, *R*3*m*, *a* 14.2418(1), *c* 30.1143(3) Å. *V* 5289.7(1) Å^3, *Z* 3 (single-crystal), *a* 14.253(1), *c* 30.079(4) Å. *V* 5292(1) Å^3, *Z* 3 (powder data), *c:a* 2.115. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 6.421 (37) (104), 4.329 (30) (205), 3.526 (46) (027), 3.218 (100) (208), 3.023 (25) (042), 1.609 (77) (4.1.15), 1.605 (41) (4.0.16).

Name. The mineral is named for its relation with eudialyte, following the nomenclature of eudialyte-group minerals (Johnsen *et al.* 2003).

Type material. Type material is deposited in the collections of the Museu de Geociências, Universidade de São Paulo, sample number DR704.

Relationship to other species. A member of the eudialyte group (Johnsen *et al.* 2003, Rastsvetaeva and Chukanov 2012). The mineral is the Mn-analog of eudialyte.

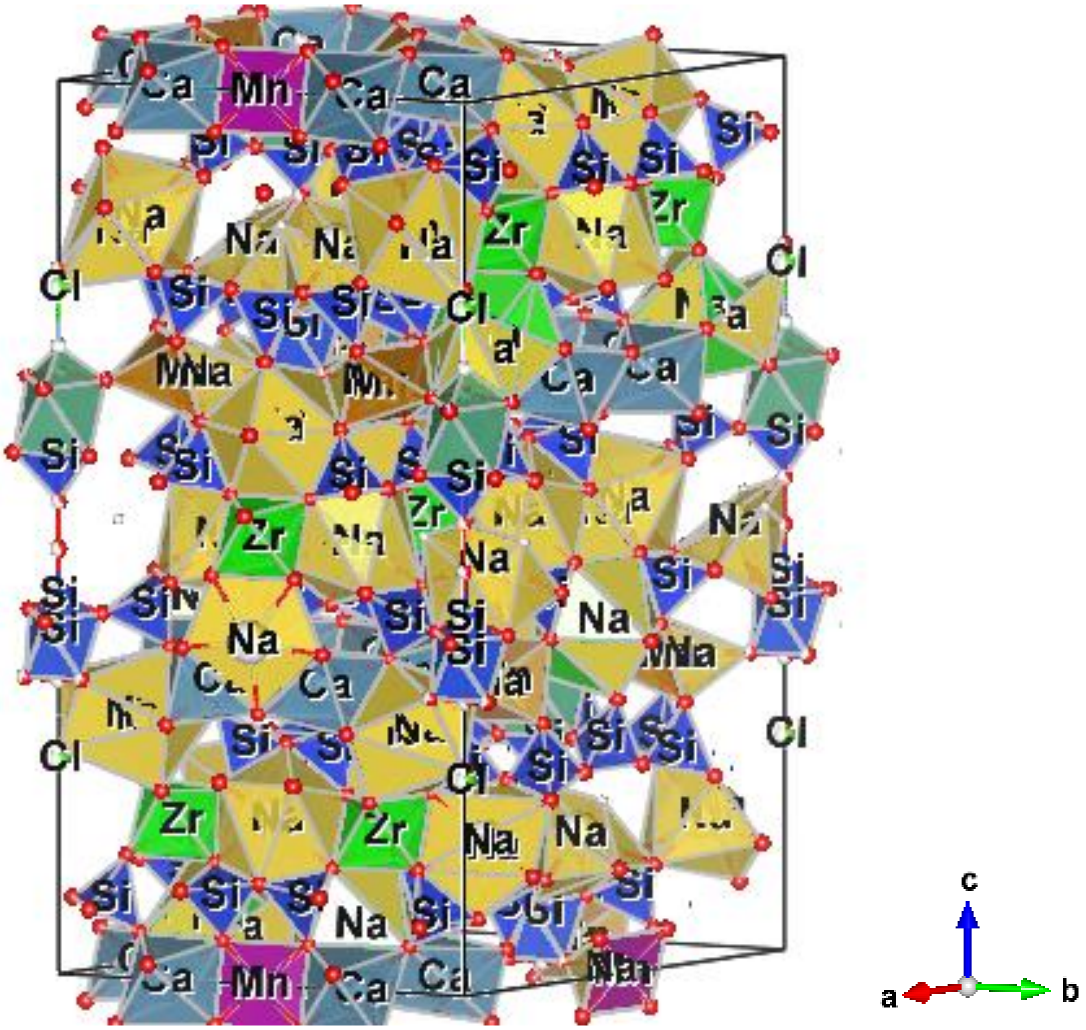

Figure 9.37. View of the crystal structure of manganoeudialyte (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Nomura *et al.* (2010).

Crystal structure. Eudialyte-group minerals belong to the large family of alkaline silicates with heteropolyhedral frameworks. A framework consisting of SiO_4 tetrahedra and MO_6 octahedra (where M is usually Ti, Nb, or Zr) is a specific structure feature of these minerals (Chukanov and Pekov 2005).

See also. Giannettite, Ta-rich eudialyte, fluorlamprophyllite, pennaite, unnamed $Ti_3(UO_2)_3SiO_8$, unidentified silicate inclusions in giannettite, and unidentified Mn-Fe-silicate and Zr-silicates.

Unidentified Mn-Fe-silicate and Zr-silicates

Duvallet (2000)

Other names: mineral Y

Duvallet (2000) studied the transformation of eudialyte (actually manganoeudialyte) from Pedra Balão, Poços de Caldas, Minas Gerais, into catapleiite, mineral X (georgechaoite?), mineral Y and unidentified Zr silicates. Mineral Y corresponds to an opaque reddish-brown product dispersed in small nuclei in mineral X. Chemical composition (microprobe, average of 4 analyzes): Na_2O 0.11, K_2O 0.67, CaO 3.88, SrO 0.36, MgO 3.16, MnO 33.94, FeO 14.34, Al_2O_3 5.25, SiO_2 21.69, TiO_2 0.05, ZrO_2 0.04 Cl 0.06, total 83.54 wt.%. Duvallet (2000) also presents a table with a large number of point analyzes of unidentified Zr silicates, associated with manganoeudialyte and its other transformation products.

See also. Manganoeudialyte, Ta-rich eudialyte, giannettite, unidentified silicate inclusions in giannettite, pennaite, unnamed $Ti_3(UO_2)_3SiO_8$, and fluorlamprophyllite.

Ta-rich eudialyte

Rastsvetaeva *et al.* (2003)

(variety of eudialyte)

Other names: UM2003-39-SiO:CaClFeHHfNaNbSrTaTiZr

The crystal structure of a new tantalum-rich variety of eudialyte from pegmatites of the Poços de Caldas alkaline massif, Minas Gerais, was established by X-ray diffraction analysis (sp. gr. $R3m$, *a* 14.245(4), *c* 30.163(7) Å, *V* 5300.66 Å^3). The main structural characteristic of this mineral is the presence of Ta atoms in the specific positions in the centers of planar “squares” with Ta–O distances ranging from 2.035(7) to 2.116(8) Å. Two additional oxygen atoms located at distances of 2.44 and 2.66 Å can complete these “squares” to strongly distorted octahedra. The crystallochemical formula of the mineral at *Z* = 3 can be written as follows: $[(Na_{1.9}K_{0.6}Mn_{0.3}Ba_{0.1}Ce_{0.1})(Na_{2.7}Sr_{0.3})]Na_8(Ca_{5.28}Mn_{0.72})(Zr_{2.85}Hf_{0.15})[^{V}Fe_{1.35}\square_{1.14}{}^{IV}Ta_{0.51}][Si_{0.78}{}^{VI}Nb_{0.13}{}^{VI}W_{0.09}][Si_{0.5}Al_{0.3}Ti_{0.2}][Si_{24}O_{72}](OH,O)_{3.54}Cl_{0.8}\cdot 1.2H_2O$, where the compositions of the key positions are indicated in the parentheses and brackets, and the coordination numbers of some cations are indicated by Roman numerals. The simplified formula is:

$Na_{12}(Na,K,Mn,Sr)_2Ca_5(Ca,Mn)(Zr,Hf)_3(Fe,\square,Ta)_3(Si,Nb,W)(Si,Al,Ti)Si_{24}O_{72}(OH,O)_{3.5}Cl\cdot 1.2H_2O$ (Rastsvetaeva *et al.* 2003).

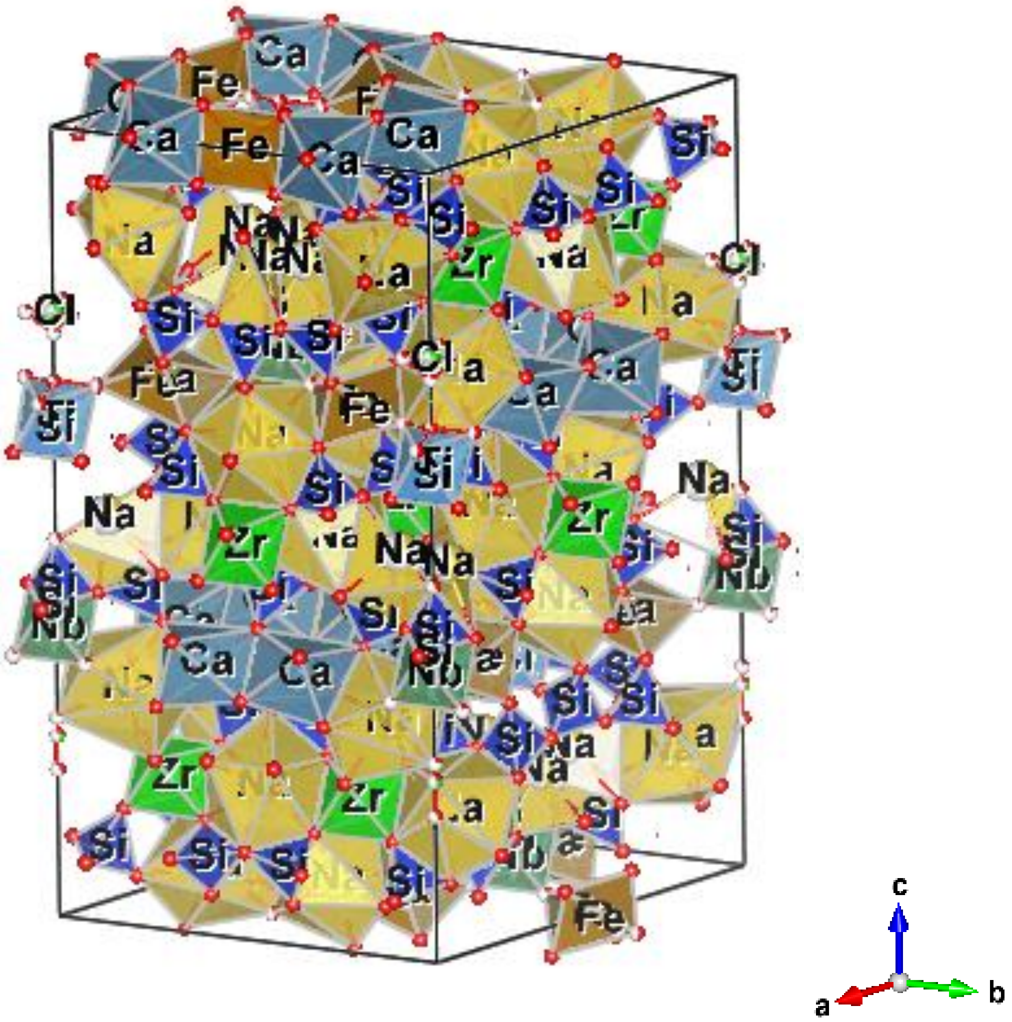

Figure 9.38. View of the crystal structure of Ta-rich eudialyte (from Poços de Caldas, Minas Gerais), drawn using VESTA 3 (Momma and Izumi 2011). Data from Rastsvetaeva *et al.* (2003).

See also. Manganoeudialyte, giannettite, fluorlamprophyllyte, pennaite, unnamed $Ti_3(UO_2)_3SiO_8$, unidentified silicate inclusions in giannettite, and unidentified Mn-Fe-silicate and Zr-silicates.

Maxixe-aquamarine

Wild (1933)

(variety of beryl)

Other names: água-marinha maxixe, Maxixeberyll, maxixe-beryl, berilo maxixe

The mineral occurs at the Maxixe claim, Piauí valley, Taquaral, Itinga, Minas Gerais, consisting of “a blue alkali-beryl of gem-quality”. According to Wild (1933), maxixe-aquamarine appears to be distinct from blue beryl. It is pleochroic, almost colorless in one direction, and the color fades on exposure to light. Spectroscopic analysis showed it to be a Be-silicate with Li and Na, but without Fe, Mn, and Co. It contains Cs_2O 2.8 and Li_2O 1 wt.%. Schlossmacher and Klang (1935) and Roedling and Trommau (1935) used the name maxixe beryl. According to Branco (1984), it is a dark blue barian beryl.

Halbanite

Other names: halbanita

Figure 9.39. Beryl (morganite, halbanite variety) from Barra do Salinas, Coronel Murta, Minas Gerais. 84 × 64 × 51mm. Specimen and photo: Martin Slama.

Commercial name of beryl (morganite variety) from Barra do Salinas, Coronel Murta, Minas Gerais. When properly heated, it acquires a beautiful violet-blue or indigo-blue color, and is sold as aquamarine. The color fades on exposure to light. The name honors Halley Baptiste, proprietor of the mine where the mineral occurs (Branco 2008). According to Read (1988), “halbanita aquamarine” is a CO_3-rich beryl.

Unnamed Na-Mg pyroxene
Hutchison *et al.* (2001)
(= Na-rich clinoenstatite)
Other names: UM2001-19-SiO:AlCaMgNa

The mineral occurs as inclusions in diamonds from the alluvial deposits of São Luiz river, Juína, Mato Grosso. Microprobe analyses (mean of 2): Na_2O 6.08, K_2O 0.02, CaO 5.20, MgO 16.30, MnO 0.80, FeO 3.40, NiO 0.02, Al_2O_3 9.23, Cr_2O_3 2.22, TiO_2 0.01, SiO_2 56.41, total 99.69 wt.%, corresponding to $(Na_{0.41}Mg_{0.37}Ca_{0.20}Mn_{0.02})_{\Sigma 1.00}(Mg_{0.48}Al_{0.36}Fe^{2+}_{0.10}Cr_{0.06})_{\Sigma 1.00}(Si_{1.98}Al_{0.02})_{\Sigma 2.00}O_6$, simplified as $(Na,Mg,Ca)(Mg,Al)Si_2O_6$. Single-crystal X-ray structure study indicated monoclinic symmetry, space group *C*2/*c*, *a* = 9.587(4), *b* = 8.699(6), *c* = 5.247(4) Å, β = 108.33(4)°, *D*calc = 3.344 g/cm^3 for *Z* = 4. The formula $NaMgSi_2O_6$ is not electronically neutral. The dominant valence in the first site is 2+ (Mg + Ca + Mn =0.59; Na = 0.41 apfu). So the correct formula should be expressed as $Mg_2Si_2O_6$ and the mineral is clinoenstatite.

See also. Jeffbenite, ellinaite, breyite, nitroyarlongite, nitrocohenite, nitrochalypite, unnamed Fe_2N, Fe_3N, Fe_5SiC, $(Ba,Sr)AlF_5$, orthorhombic MgO, $MgCr_2O_4$, $Na_4Mg_3(PO_4)_2(P_2O_7)$, and $Fe_2^{3+}Fe_5^{2+}(P_2O_7)_4$.

Sideroschisolite
Wernekinck (1824)
(= cronstedtite)
Other names: siderosquisolita, Sideroschisolith

Sideroschisolite was described in Congonhas (formerly Congonhas do Campo), Minas Gerais, by Wernekinck (1824) and chemically analyzed by Thomson (1831). Leonhard (1826) suspected it might be identical to cronstedtite, $Fe^{2+}_2Fe^{3+}(Si,Fe)_2O_5(OH)_4$. Zepharovich (1875) obtained crystallographic data and showed the identity between sideroschisolite and cronstedtite.

Eunicite

Paiva Netto (1955)

(= montmorillonite)

Other names: eunicita.

The name eunicite was introduced by Paiva Netto (1955) for a montmorillonite variety, $(Na,Ca)_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2 \cdot nH_2O$, monoclinic, green-yellow to green, formed by the decomposition of melaphyre from Serra de Botucatu, São Paulo. The origin of the name was not given.

Malacacheta

(mica or talc)

Other names: maracacheta, maracaxeta

Brazilian term used for mica. Antonil (1711) applies the terms maracacheta and maracaxeta. Silva (1823) registers mica and talc as synonyms of malacacheta. Dictionaries quote “etymology of obscure origin” but the term is possibly linked to the Malacacheta Indians, also known as Machacali, Maxakali, Machacaris, Macachacalizes, and Malacaxis (Paraíso 1994), who inhabited the region where today is the municipality of Malacacheta, in Minas Gerais.

Oxykinoshitalite

Kogarko *et al.* (2005)

$BaMg_3(Si_3Al)O_{10}O_2$, monoclinic

Aproved CNMMN - IMA 2004-013

Other names: oxikinoshitalita

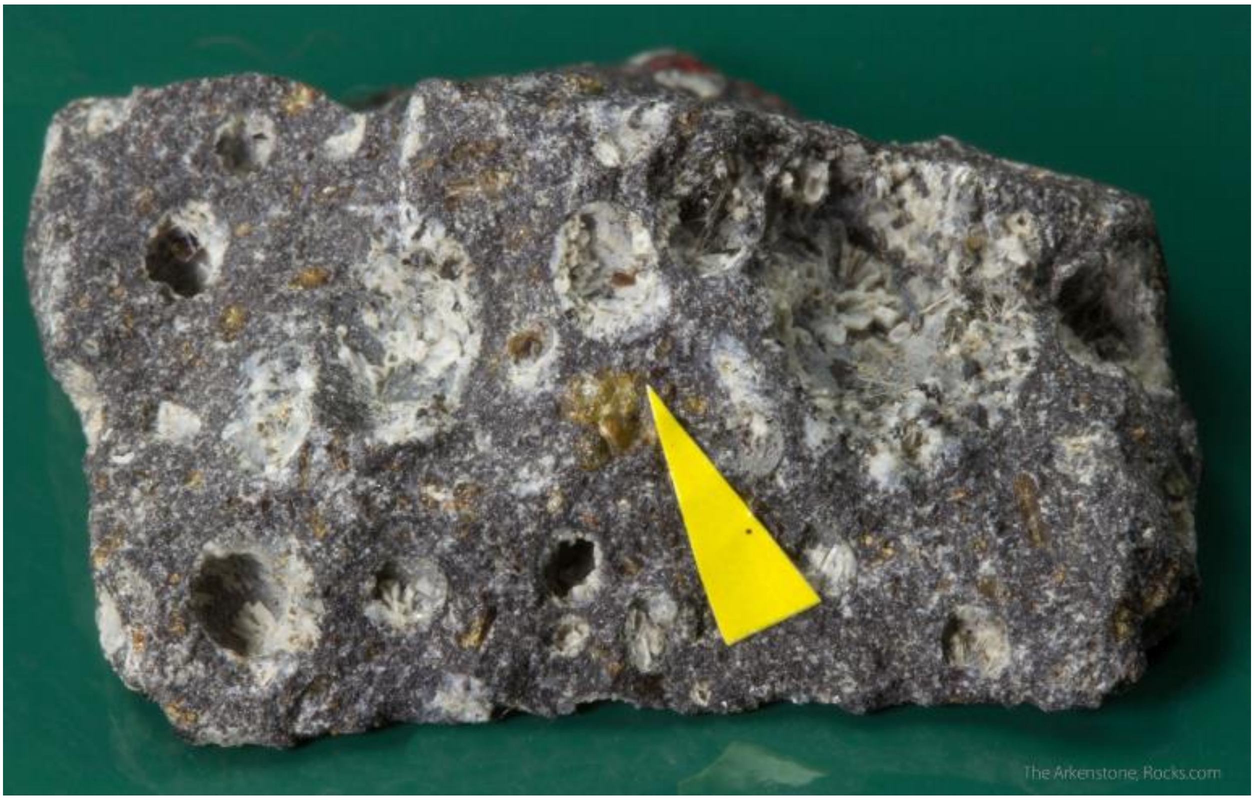

Figure 9.40. Oxykinoshitalite (or another mica-group mineral?) in olivine nephelinite from Fernando de Noronha Island, Pernambuco. Orange-brown, prismatic to plate crystals associated with nepheline, calcite and an apatite-group mineral. Dimensions: 3.0 × 2.0 × 1.0 cm. Specimen: Reynaldo R. Contreira Filho. Photo: Rob Lavinsky (the previous owner).

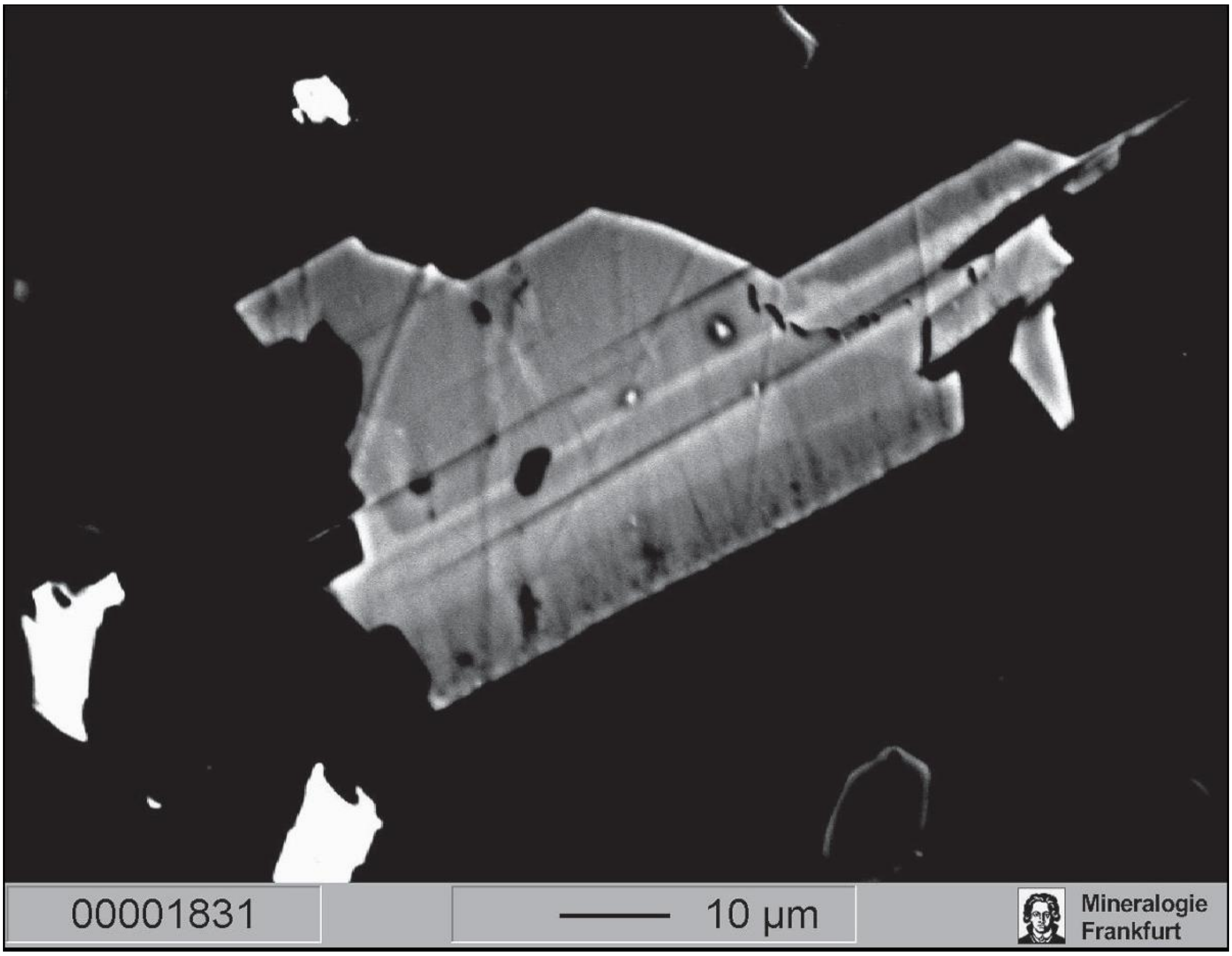

Figure 9.41. Back-scattered-electron image of oxykinoshitalite, showing the prominent {001} cleavage (Kogarko *et al.* 2005).

Lopes (2002) had already studied this mica, obtaining 14 microprobe analyzes, but she did not realize that it was a new mineral species and described it as "biotite strongly enriched in BaO (17 to 19 wt.%) and TiO_2 (13 to 14 wt.%) and low in F (<0.4 wt.%)". Lopes (2002) only verified this enrichment in Ba in one of the many samples of mica studied. The formula obtained by Kogarko *et al.* (2005) is equivalent to the midpoint of the oxykinoshitalite-oxyphlogopite series, since Ba = 0.50 and K + Na = 0.50 *apfu*. The mineral studied by Lopes (2002) is really oxykinoshitalite: Ba + Ca = 0.66, and K + Na = 0.38 *apfu* in the analysis presented below.

Occurrence. The mineral occurs as a very minor groundmass mineral in an olivine nephelinite (nepheline basalt) of the Quixaba Formation, in the Fernando de Noronha Island, Pernambuco. The principal minerals of the nephelinite are olivine, clinopyroxene, Fe–Ti oxide and nepheline; accessory minerals are calcite, apatite, and K-feldspar. It is of magmatic origin. Kogarko *et al.* (2005) did not reveal the location on the island where the mineral was found. The sample studied by Lopes (2002) comes from olivine melanephelinite lava, collected at the top of the Morro do Francês. Oxykinoshitalite was also identified in other world localities.

Appearance and physical properties. Corroded, irregularly shaped grains, 0.1 to 0.2 mm across. Habit: tabular. Forms: {001}. Twinning: none observed. Color: bright orange to brown. Streak: brown. Luster: vitreous. Transparent. Non-fluorescent. H Mohs 2½. Brittle. Cleavage: {001}, perfect. Fracture: splintery. Density (meas.) 3.3(1) g/cm^3 by the volumetric method in ethanol. Density (calc.) 3.453 g/cm^3.

Optical properties. Biaxial (+), α 1.708(1), β 1.710(1), γ 1.719(1) (589 nm). 2*V* 56(2)° (meas.), 51° (calc.). Dispersion: $r > v$, medium. Orientation: $X \wedge c = 2^{\circ}$ (in β obtuse), $Y = b$, $Z \wedge a = 8^{\circ}$ (in β obtuse). Pleochroism: *X* pale brown, $Y \sim Z$ deep red-brown.

Chemical data.

Lopes (2002): Microprobe analyses (one out of 14): Na_2O 0.20, K_2O 3.14, BaO 18.87, CaO 0.06, MgO 9.65, FeO 11.38, Al_2O_3 17.11, SiO_2 25.88, TiO_2 13.68, F 0.25, Cl 0.01, - O=F and O=Cl -0.11, total 100.12 wt.%. The empirical formula (based on 12 anions O + OH + F) is:

$(Ba_{0.65}K_{0.35}Na_{0.03}Ca_{0.01})_{\Sigma 1.04}(Mg_{1.26}Ti^{4+}_{0.90}Fe_{0.84})_{\Sigma 3.00}(Si_{2.27}Al_{1.77})_{\Sigma 4.04}O_{10}[O_{1.93}F_{0.07}]_{\Sigma 2.00}$.

Kogarko *et al.* (2005): Analysis by a combination of electron microprobe, SIMS and crystal-structure refinement (25 crystals): Na_2O 0.39, K_2O 4.05, BaO 15.49, CaO 0.03, MnO 0.14, MgO 10.74, FeO 3.84, Fe_2O_3 9.07, Al_2O_3 15.26, Cr_2O_3 0.03, SiO_2 28.92, TiO_2 11.94, F 0.91, H_2O 0.55, - O=F -0.38, total 100.97 wt.%. The empirical formula (based on 12 anions O + OH + F) is:

$(Ba_{0.50}K_{0.43}Na_{0.07})_{\Sigma 1.00}(Mg_{1.33}Ti^{4+}_{0.74}Fe^{3+}_{0.57}Fe^{2+}_{0.27}Mn^{2+}_{0.01})_{\Sigma 2.92}(Si_{2.40}Al_{1.49})_{\Sigma 3.89}O_{10}[O_{1.46}(OH)_{0.30}F_{0.24}]_{\Sigma 2.00}$.

The ideal formula requires MgO 23.92, BaO 30.34, Al_2O_3 10.09, SiO_2 35.66, total 100.00 wt.%.

Crystallography. Single-crystal studies: monoclinic, *C*2/*m*, *a* 5.3516(7), *b* 9.2817(11), *c* 10.0475(13) Å, β 100.337(3)°, *V* 490.98(18) Å^3, Z 2, *a*:*b*:*c*: 0.5766:1:1.0825. X-ray powder-data: monoclinic, *C*2/*m*, *a* 5.350(11), *b* 9.273(13), *c* 10.049(12) Å, β 100.084(14)°, *V* 490.8(9) Å^3, Z 2. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 2.637 (10) $(\bar{1}31)$, 2.172 (9) $(\bar{1}33)$, 3.646 (7) $(\bar{1}12)$, 3.130 (7) (112), 3.383 (6) (002), 2.902 (5) $(\bar{1}13)$, 2.435 (5) (201), 1.988 (5) (133), 1.661 (5) $(\bar{1}35)$, 1.547 (5) (312), and 1.526 (5) $(\bar{2}06)$.

Name. The name is in accordance with the dominance of O^{2-} at the *A* site. It is the O-analog of kinoshitalite.

Type material. Holotype material is deposited at the Canadian Museum of Nature, Ottawa, Ontario, Canada.

Relationship to other species. Mica group, a trioctahedral brittle mica (Rieder *et al.* (1998).

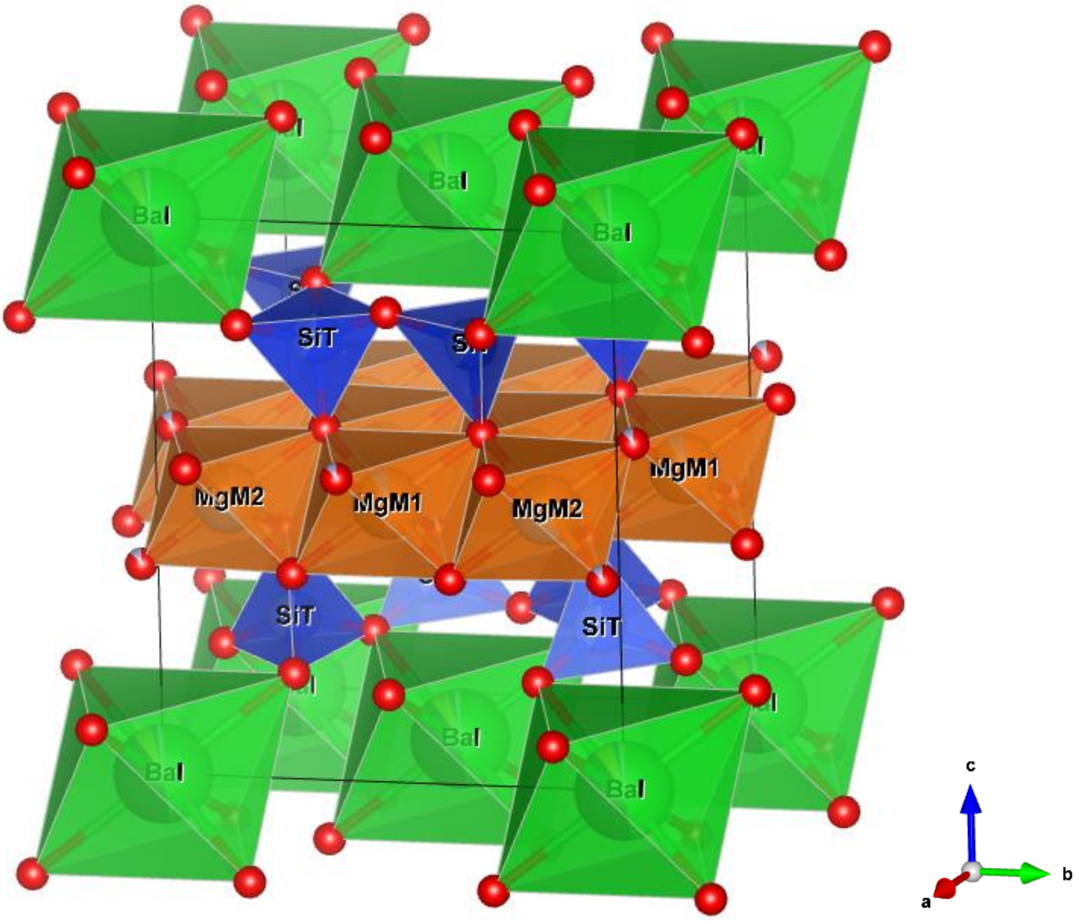

Figure 9.42. View of the crystal structure of oxykinoshitalite (from the type occurrence), drawn using VESTA 3 (Momma and Izumi 2011). Data from Kogarko *et al.* (2005).

Crystal structure. It is the *1M* polytype of oxykinoshitalite. There is one tetrahedrally coordinated *T* site, <T-O> = 1.671 Å, occupied by ($Si_{2.47}Al_{1.53}$). There are two octahedrally coordinated sites, M(1) occupied by ($Mg_{0.90}Fe^{2+}_{0.65}Ti_{0.43}Mn_{0.01}$) with <M(1)-O> = 2.065 Å, and M(2) occupied by ($Mg_{0.47}Ti_{0.33}Fe^{2+}_{0.20}$) with <M(2)-O> = 2.111 Å. The interstitial [12]-coordinated *I* site is occupied by ($Ba_{0.52}K_{0.44}Na_{0.06}$) with <I-O> = 3.107 Å. Oxykinoshitalite has dominant O^{2-} at the *A* site. There are two main coupled substitutions in this structure: (1) Ti^{4+} for Mg at the M(1,2) sites and O^{2-} for $(OH)^{-}$ + F^{-} at the *A* site, and (2) K for Ba at the *I* site and (OH) for O^{2-} at the *A* site

(Kogarko *et al.* 2005).

See also. Barium phlogopite.

Barium phlogopite

Gaspar and Wyllie (1982)

(= Ba-rich phlogopite)

Figure 9.43. (Ba-rich?) phlogopite from the Jacupiranga mine, Cajati, São Paulo. 11 × 10 × 3 cm. Specimen and photo: Rafael H. Corrêa-Silva.

The name barium phlogopite, which means the Ba-equivalent of phlogopite, $KMg_3(AlSi_3O_{10})(OH)_2$, where Ba>K in *apfu*, was applied to a mica-group mineral from the Jacupiranga carbonatite, Cajati, São Paulo by Gaspar and Wyllie (1982). Cajati is the type locality for zirkelite, quintinite, menezesite, pauloabibite, and melcherite. The Ba-equivalent of phlogopite is kinoshitalite, $BaMg_3(Al_2Si_2O_{10})(OH)_2$. The Ba-richest analysis recorded by the authors is: SiO_2 32.4, Al_2O_3 20.5, FeO 1.83, MgO 22.9, CaO 0.04, Na_2O 0.47, K_2O 6.83, BaO 10.03, total 95.00 wt.%. The empirical fórmula is: $(K_{0.65}Ba_{0.30}Na_{0.06})_{\Sigma 1.01}(Mg_{2.59}Al_{0.29}Fe^{2+}_{0.12})_{\Sigma 3.00}(Si_{2.46}Al_{1.54})_{\Sigma 4.00}O_{10}(OH)_{2.06}$. Consequently, the mineral described by Gaspar and Wyllie (1982) has K>Ba in *apfu* and is a Ba-rich phlogopite, not kinoshitalite.

See also. Oxykinoshitalite, zirkelite, brazilite, quintinite, menezesite, pauloabibite, melcherite, and unidentified Ca-Nb oxide.

Ibitiarite

(Zeemann 1975)

(= pyrophyllite)

Other names: ibitiarita

The name ibitiarite was applied to pyrophyllite, $Al_2Si_4O_{10}(OH)_2$, by Zeemann (1975), Instituto Nacional de Tecnologia (198#), Duailibi Filho (1982), and Sánchez Soto and Pérez Rodrigues (1998), from Serra do Fogo do Caetano, Ibitiara, Bahia. The name is for Ibitiara County.

An extant text for this mineral is the following:

"NEW MINERAL IS DISCOVERED

Brazilian scientists found in Bahia a mineral that can be used as insulating material with conditions of supporting temperatures that vary from 200 to 1200 °C. It was named ibitiarite." (Anonymous 1975).

Amazonite

Breithaupt (1847)

(= microcline or orthoclase)

Other names: amazonita, Amazonia jade, Brazilian jade

The name is derived from the Amazon river. The first samples of the green mineral received in Europe were thought to come from “the banks of the Amazon”. However, there is no known occurrence of amazonite in the vicinity of the Amazon river. It is a green to blue-green variety of K-feldspar, usually microcline, but sometimes applied to orthoclase.

Eschwegite

Döbereiner (1823)

(pseudomorph of quartz and goethite after cummingtonite)

Other names: Eschwegit, eschwegita, anthosiderite, antossiderita, Anthosiderit

This name was given to a “ferric hydrosilicate” from Antônio Pereira, Ouro Preto, Minas Gerais, by Döbereiner (1823). It is another example of the many uses of the name eschwegite. See the several meanings of this name in Chapters 4 and 6. The name honors Baron W.L. von Eschwege (1777-1855). Chester (1896) quoted eschwegite as “an impure hematite from Brazil, after Baron W.L. von Eschwege, who described it.” The same material was later named anthosiderite (from *anthos*, flower, and *sideros*, iron) by Hausmann and Wohlers (1841a and b). It was shown to be a pseudomorph of quartz and goethite after cummingtonite, $\square Mg_2Mg_5(Si_8O_{22})(OH)_2$ monoclinic, by Lacroix (1915).

Paulistanite

Argentière (1954)

(= uranian opal)

Other names: paulistanita

Figure 9.44. Opal (“paulistanite”) (green) with haiweeite (yellow) from Perus, São Paulo. Museu de Geociências, Universidade de São Paulo. Photo: Ideval Souza Costa.

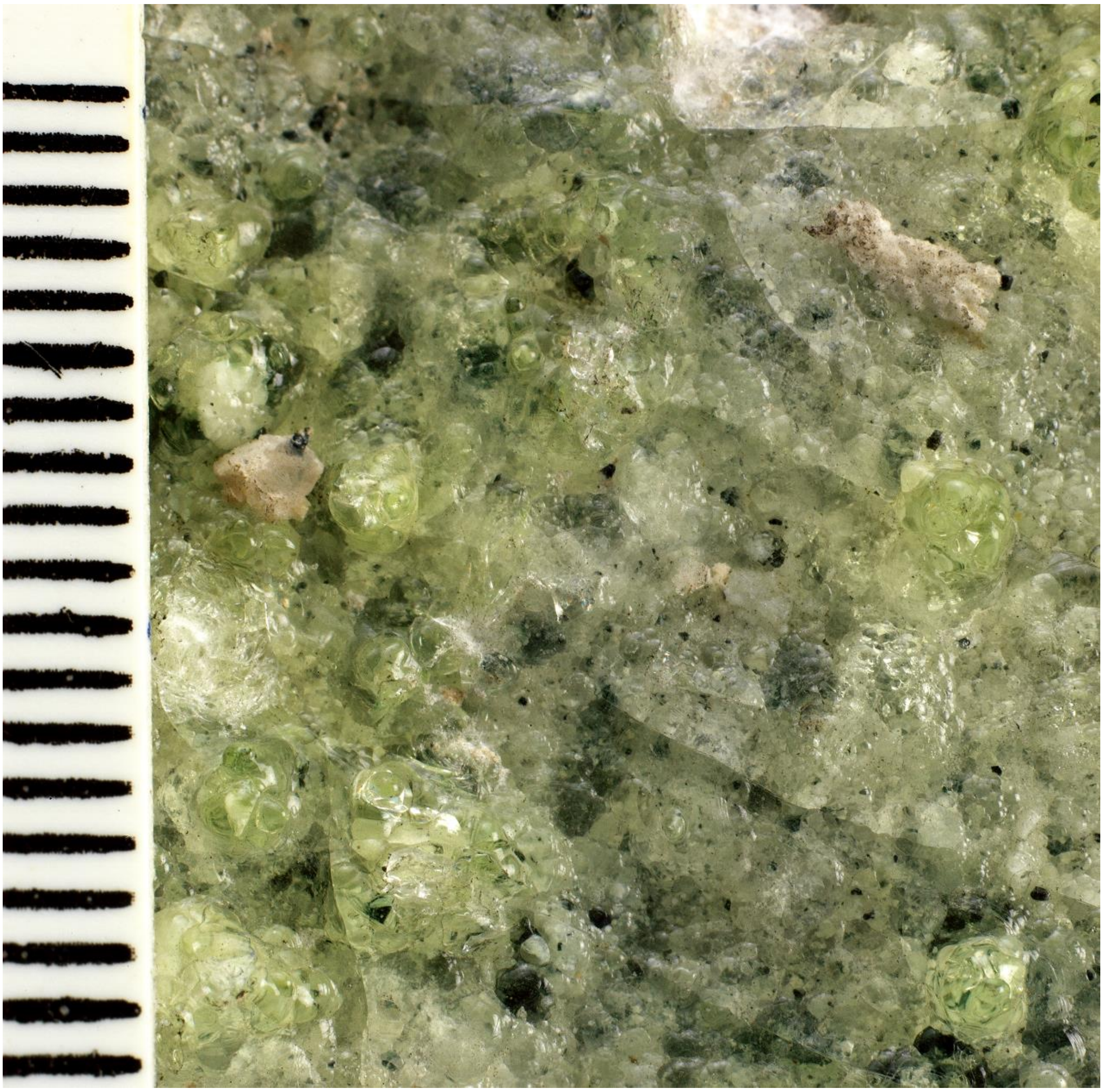

Figure 9.45. Opal (“paulistanite”) from Perus, São Paulo. Specimen 212/67, Museu de Geociências, Universidade de São Paulo. Photo: Thales Trigo.

This name was suggested by Argentière (1954) for milky opal with small amounts of uranium. It occurs as fracture fillings in a tourmaline granite, locally pegmatitic, from Perus, São Paulo city. The name honors the State of São Paulo (“paulista” means “from São Paulo state”) and was also used by Cornejo (1998).

See also. Mineral X (= phurcalite).

Unnamed $Ti_3(UO_2)_3SiO_8$

Simova *et al.* (1984)

Other names: unnamed uranium-titanium silicate, UM1984-38-SiO:TiU

The mineral occurs as fine-grained (less than 10 μm) aggregates, disseminated in tinguaite of the Campo do Cercado, Poços de Caldas, Minas Gerais. It is associated with coffinite, zircon, monazite, and Ce-, La-, and U-oxides. Electron microprobe data: UO_2 67. 00, ThO_2 0.43, SiO_2 4.97, TiO_2 18.90, CuO 0.27, PbO 0.27, MgO 0.06, CaO 1.11, BaO 0.34, Na_2O 0.21, K_2O 1.25, total 94.81 wt.%. Regarding Ba, Na, K, and possibly Ca as impurities, and normalizing to 100 % (justified by assuming the mineral to be metamict), this analysis results in $U_{2.94}Th_{0.01}Ti_{2.81}Si_{0.97}O_{14}$, or ideally $U_3Ti_3SiO_{14}$. Neither optical nor X-ray diffraction data were given. An abstract about this mineral was published by Hawthorne *et al.* (1986).

See also. Manganoeudialyte, Ta-rich eudialyte, fluorlamprophyllite, pennaite, giannettite, unidentified silicate inclusions in giannettite, and unidentified Mn-Fe-silicate and Zr-silicates.

Chapter 10

Oxalates and organic compounds

Lindbergite

Atencio *et al.* (2004c)

$Mn^{2+}(C_2O_4)\cdot 2H_2O$, monoclinic

Approved CNMMN - IMA 2003-029

Other names: lindbergita

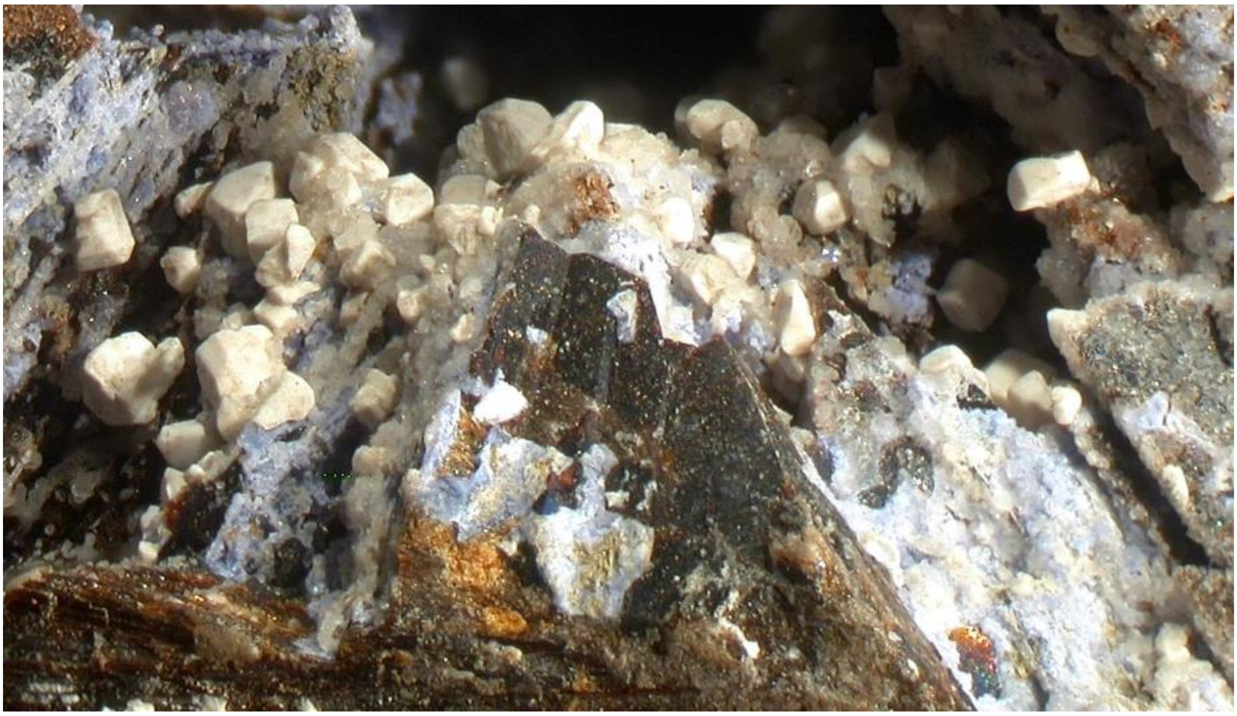

Figure 10.1. Lindbergite (white) pseudomorphous after falottaite, with several phosphates, from the Boca Rica mine, Sapucaia do Norte, Galileia, Minas Gerais. The largest crystals are about 200 µm. Specimen: Luiz A.D. Menezes Filho. Photo: Tatiana Dias Menezes.

Figure 10.2. Lindbergite (white) pseudomorphous after falottaite, with violet phosphosiderite, from the Boca Rica mine, Sapucaia do Norte, Galileia, Minas Gerais. Field of view: 2.4 mm. Specimen and photo: Gianfranco Ciccolini.

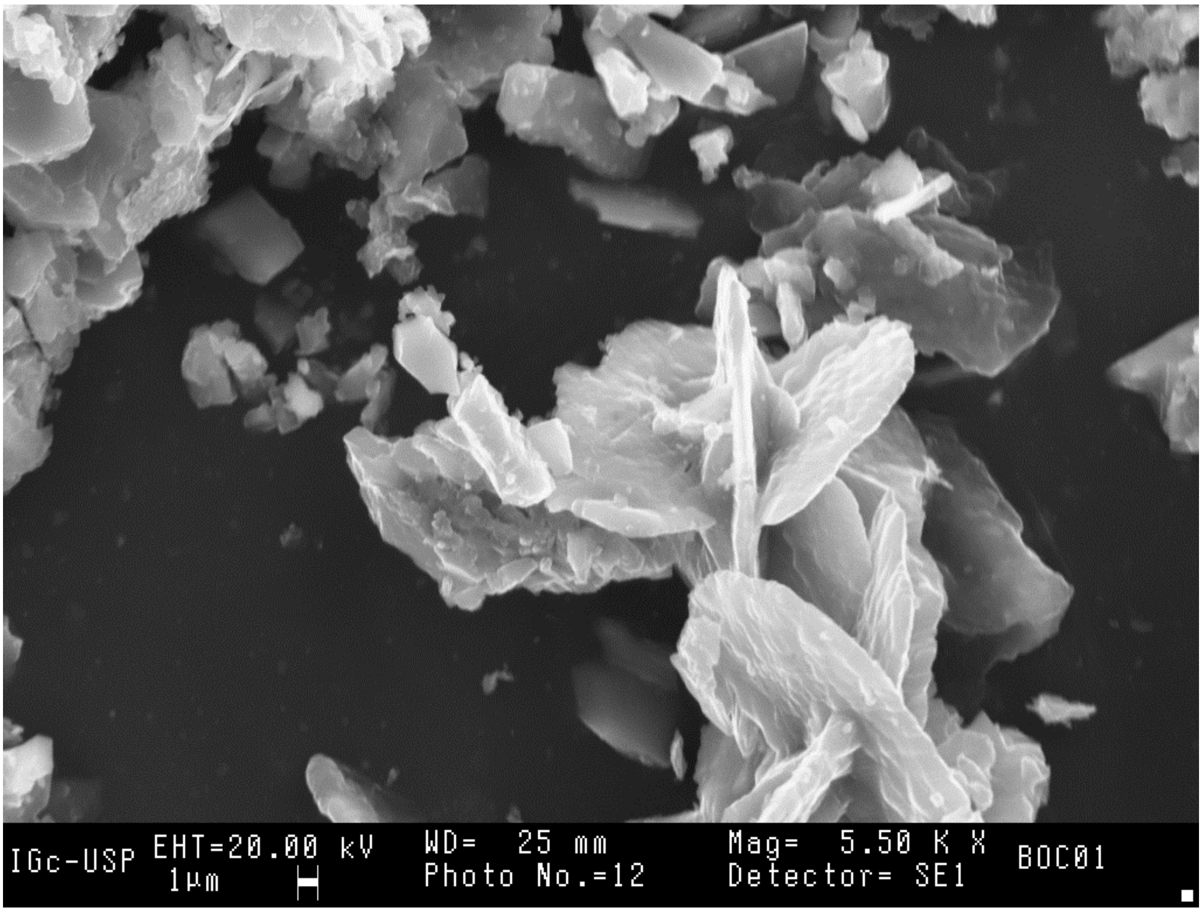

Figure 10.3. Secondary electron image of interlocked irregularly contoured platelets of lindbergite. Specimen from the Boca Rica mine, Sapucaia do Norte, Galileia, Minas Gerais (Atencio *et al.* 2004c).

See also Figures 10.5 and 10.6.

The study of soluble oxalates is related to their use as precursors in the synthesis of high temperature superconductive ceramic materials, in the preparation of nanomaterials and a number of other new materials because the precipitation processes provide the possibility of controlling the chemical and physical properties of the final products. Oxalate systems are traditionally used for the separation and concentration of elements, especially rare earth and transuranian elements (Donkova *et al.* 2004). In addition, the use of synthetic $Mn^{2+}C_2O_4 \cdot 2H_2O$ in the process of photographic revelation and as a standard for chemical analysis was studied, respectively, by Huizing *et al.* (1977) and Coltman (1924).

The first lindbergite samples were obtained from the Boca Rica mine, Sapucaia do Norte, Galileia, Minas Gerais, in 2002 by Luiz A.D. Menezes Filho. Additional samples were collected by Daniel Atencio and Paulo Anselmo Matioli and obtained through the mineral dealer Mr. Ramiro Sardinha in Governador Valadares, Minas Gerais. A preliminary note on this mineral was published by Atencio *et al.* (2004b). The following are the descriptive data for Brazilian lindbergite.

Occurrence. The mineral occurs in the Lavra (= mine) da Boca Rica (a granite pegmatite), Sapucaia do Norte, Galileia Co., Minas Gerais. Associated minerals: the phosphates triphylite, phosphosiderite, frondelite, strengite, cyrilovite (see avelinoite), bermanite, rockbridgeite, huréaulite, tavorite, reddingite, heterosite, laueite, and unidentified minerals. Lindbergite is a secondary mineral. It has also been recorded at several world occurrences.

Appearance and physical properties. Lindbergite from Boca Rica mine display two habits: (1) short prismatic crystals 0.1 to 0.3 mm with faces of {100}, {*hk*0}, {010}, and {0*kl*} forms, rounded edges, and twinning on (010). This habit was interpreted as a pseudomorphous after an unnamed trihydrate [$Mn^{2+}(C_2O_4)\cdot 3H_2O$], later named falottaite. The "crystals" are actually groups of smaller crystals, some of which present lozenge-shaped sections; (2) aggregates in 0.1 mm thick translucent crusts consisting of interlocked irregularly contoured platelets up to 0.03 mm in length. In this case the mineral should have formed originally as a dihydrate. Color: white (crystals), greyish-white (aggregates). Streak: white. Luster: vitreous. Transparent. Non-fluorescent. H Mohs: 2½. Cleavage: {010} perfect. Parting: not observed. Tenacity: crumbly. Density (obs.) 2.10(3) g/cm^3; density (calc.) 2.356 g/cm^3 (2.251 g/cm^3 for ideal formula).

Optical properties. Biaxial (-), α 1.424(3), β 1.550(3), γ 1.65(1) (white light), 2*V* 80(2)° (meas.), 77°(calc.). Dispersion: not detectable or $r > v$, very weak. Orientation: Y ^ c = 20°. Pleochroism: none.

Chemical data. Microprobe (EDS) analyses (10), C_2O_3 and H_2O by CHN analysis: MnO 39.99, Al_2O_3 0.24, Na_2O 0.21, C_2O_3 34.90, H_2O 19.62, total 94.96 wt.%. The low total is likely to be the effect of impure (phosphosiderite contaminant) handpicked material for the CHN analysis. Empirical formula: $(Mn^{2+}_{1.11}Na_{0.01}Al_{0.01})_{\Sigma 1.13}(C_{1.94}O_4)\cdot 2.15H_2O$. The ideal formula requires MnO 39.63, C_2O_3 40.24, H_2O 20.13, Total 100.00 wt.%.

Crystallography. Monoclinic, *C*2/*c*, *a* 11.955(5), *b* 5.632(2), *c* 9.967(7) Å, *β* 128.34(4)°, *V* 528.1(5) Å^3 *Z* 4, *a*:*b*:*c* = 2.1298:1:1.7697. X-ray powder diffraction data [*d* in Å (*I*) (*hkl*)]: 4.855 (26) ($\bar{1}11$), 4.803 (100) ($\bar{2}02$), 4.699 (84) (200), 3.907 (23) (002), 3.622 (22) (111), 2.996 (58) ($\bar{4}02$), 2.679 (14) ($\bar{1}13$), 2.652 (12) (112), 2.286 (10) (022).

Name. The mineral is named lindbergite in honor of Marie Louise Lindberg (-Smith)

(1918-2005), from the USGS, who described several new mineral species from the nearby Sapucaia quarry (frondelite, faheyite, moraesite, barbosalite, and tavorite).

Type material. Museu de Geociências, Universidade de São Paulo (number DR542) and Museu de Ciências Naturais e Centro Cultural Joias da Natureza, São Vicente, São Paulo State (this museum no longer exists).

Relationship to other species. Isotypic with humboldtine, $Fe^{2+}C_2O_4·2H_2O$.

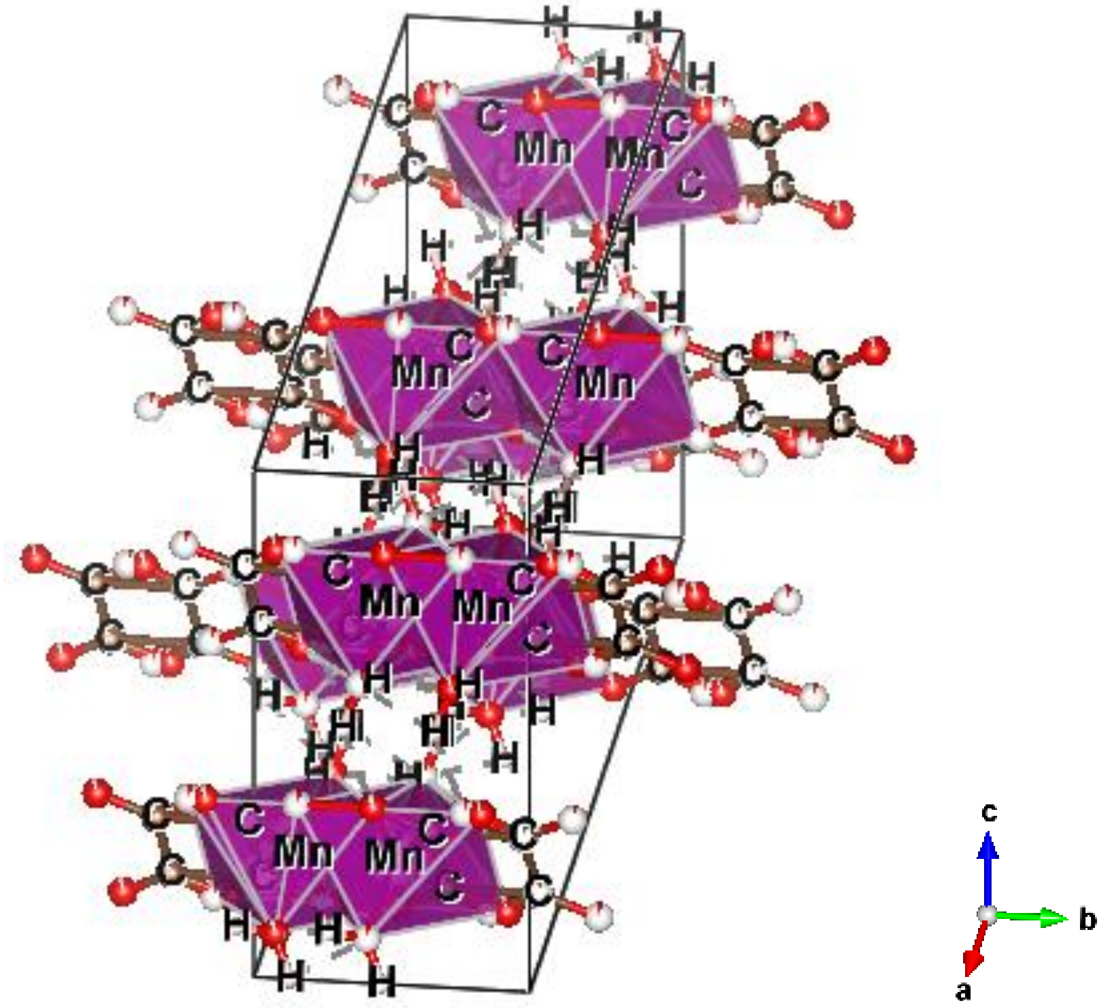

Figure 10.4. View of the crystal structure of lindbergite (synthetic, the α′- modification), drawn using VESTA 3 (Momma and Izumi 2011). Data from Puzan *et al*. (2018).

Crystal structure. There are three synthetic polymorphic modifications of $Mn^{2+}C_2O_4·2H_2O$: γ, orthorhombic (Huizing *et al.* 1977, Lethbridge *et al*. 2003), α′ and α″, both monoclinic, space group *C*2/*c* (Deyrieux *et al*. 1973, Puzan *et al*. 2018). Soleimannejad *et al.* (2007) described the crystal structure of the α″-polymorph, which is isomorphous with humboldtine. Lindbergite is the natural equivalent of the α′-modification. Both α′- and α″-modifications contain one-dimensional infinite Mn-oxalate chains in which every manganese atom is coordinated with the two chelate oxalates in equatorial plane and two water molecules in axial positions, with the difference that these chains are shifted along the two-fold axis.

Synthetic. Initially, a powder was obtained via precipitation from the heated concentrated water solutions of manganese acetate [$Mn(CH_3COO)_2 \cdot 4H_2O$] and oxalic acid ($H_2C_2O_4 \cdot 2H_2O$). Then needle-like single crystals of $Mn^{2+}C_2O_4 \cdot 3H_2O$ crystals were obtained by slow diffusion in the water solution at room temperature. It was observed that these crystals are unstable and turn into the formless turbid particles every of which represents the few single crystals of $Mn^{2+}C_2O_4 \cdot 2H_2O$, during a few-days standing in the mother liquid. Single crystal X-ray study showed that these crystals were characterized by very similar but not identical lattice constants. This fact allows assigning these crystals to the α′ and α″ modifications (Puzan *et al*. 2018).

See also. Unnamed $Mn^{2+}(C_2O_4) \cdot 3H_2O$, frondelite, tavorite, avelinoite, faheyite, moraesite, and barbosalite.

Unnamed $Mn^{2+}(C_2O_4)\cdot 3H_2O$

(= falottaite)

Atencio *et al.* (2004c)

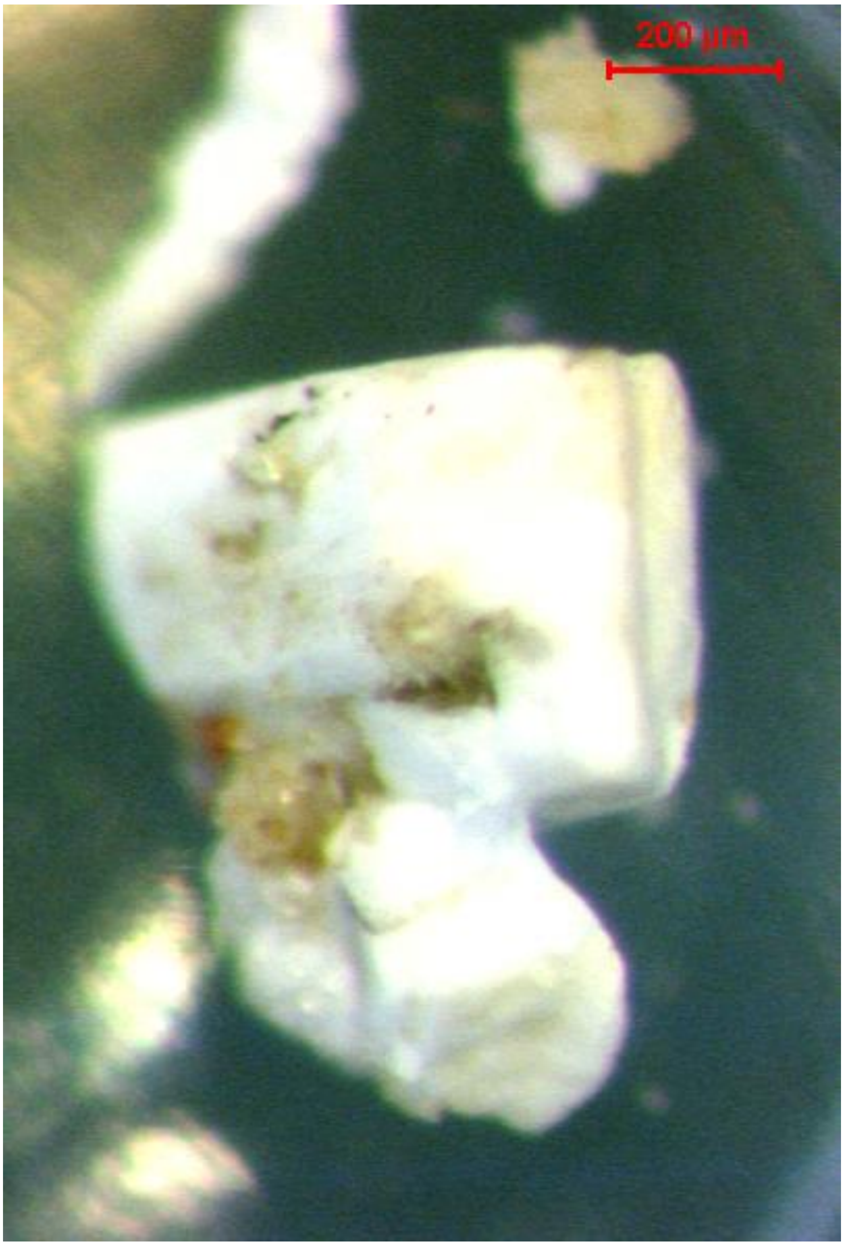

Figure 10.5. Lindbergite pseudomorphous after twinned falottaite from the Boca Rica mine, Sapucaia do Norte, Galileia, Minas Gerais. Specimen and photo: Daniel Atencio.

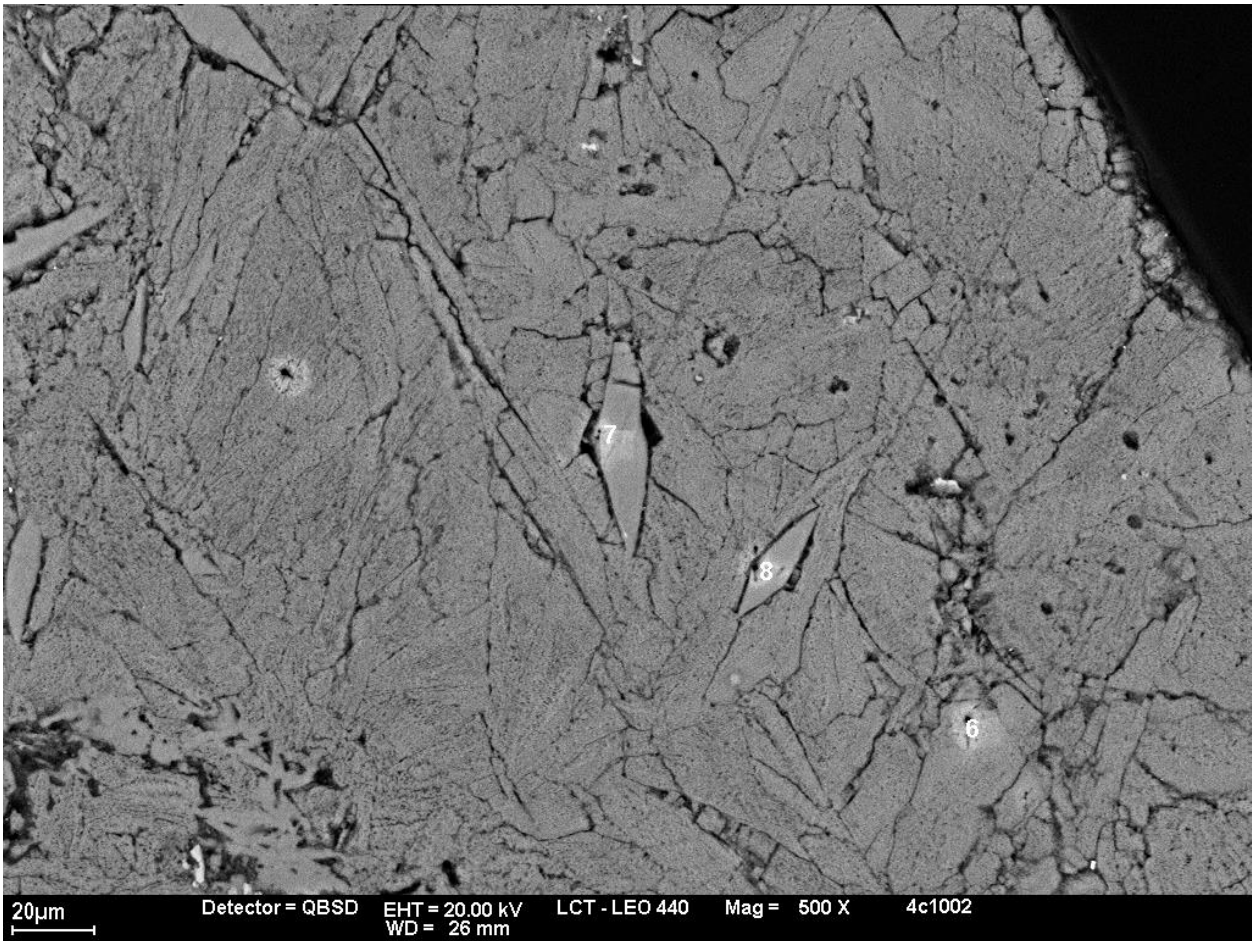

Figure 10.6. Backscattered electron image of lindbergite pseudomorphous after falottaite from the Boca Rica mine, Sapucaia do Norte, Galileia, Minas Gerais. The "crystals" (falottaite forms) are actually groups of smaller crystals (lindbergite), some of which present lozenge-shaped section. Specimen and photo: Daniel Atencio.

See also Figures 10.1 and 10.2.

In 1977, the presence of excellent, completely colorless transparent crystals of a conspicuous ship-like morphology was recorded by Stefan Graeser, at an abandoned manganese mine at Falotta, Oberhalbstein, Grisons, Switzerland. These crystals were identified by single-crystal analysis and Gandolfi films as orthorhombic $Mn^{2+}(C_2O_4)\cdot 3H_2O$, identical with the synthetic compound quoted in the ICDD card 32-648, later described as falottaite (Graeser and Gabriel 2016). From EDS, it was learned that it contained Mn and C. When performing the single-crystal study the crystal began to lose its transparency and turned milky white, retaining its morphology. Using Debye-Scherrer films this new material was identified as monoclinic $Mn^{2+}(C_2O_4)\cdot 2H_2O$, as recorded in the ICDD card 25-544, equivalent to lindbergite. All the remaining trihydrate also changed to the dihydrate, and no additional material could be found. Lindbergite from Boca Rica mine, Sapucaia do Norte, Galileia Co., Minas Gerais, is pseudomorphous after falottaite, but the type occurrence of falottaite was defined as Falotta, Oberhalbstein, Grisons, Switzerland.

See also. Lindbergite.

Gonzagaite

Oliveira (1930)

Other names: gonzagaíta, gelo

Gonzagaite is the term introduced by Oliveira (1930) to replace "gelo" (= ice), a name used by Branner (1912) for a "hydrocarbon" found in the diamond-bearing gravels from the Caetano Martins diamond washings, Xique-xique, Bahia. Chemical data: water 19.43, volatile combustible matter 35.47, fixed carbon 40.06, ash 5.07, total 100.03 wt.% (Branner 1912). The name gonzagaite honors Dr. Luiz Fellipe Gonzaga de Campos (1856-1925), who was also honored by the name camposite. According to Branco (1984), the term "gelo" is used in the Piauí state for rocky material, different from the mud, that overlies the diamond gravel.

See also. Camposite.

Unnamed iron humate crusts on Pt nuggets

Freise (1933)

"A larger shipment of the original conglomerate from the Diamantina area allowed for the separation by panning of two types of gold, as a conglomerate component and cement, and as a granular mineral (0.3-0.45 mm) with a dark brown to black, pebbled surface, with a noteworthy density. When treated with dilute hydrochloric acid, this brown surficial material disappears: the grains now appear with a steel-grey, dull surface. A chemical study showed that one was dealing with platinum intergrown with chromite... The brown crust described above, which thickness rarely exceeds 0.1 mm,

was found to be an iron humate, precipitated from the humic or black waters, which imported also the conglomerate-cementing gold." (Freise 1933).

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