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Article

Cerite: a new supergroup of minerals and cerite-(La) renamed ferricerite-(La)

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Abstract
The cerite supergroup is established and includes the cerite group (silicates) and merrillite group (phosphates). Cerite-group minerals are cerite-(Ce), ferricerite-(La), aluminocerite-(Ce) and taipingite-(Ce). The merrillite group is subdivided into two subgroups: merrillite (merrillite, ferromerrillite, keplerite and matyhite) and whitlockite (whitlockite, strontiowhitlockite, wopmayite and hedegaardite). Cerite-(La) has been renamed ferricerite-(La). The new nomenclature has been approved by the International Mineralogical Association Commission on New Minerals, Nomenclature and Classification.

Keywords: cerite supergroup, cerite group, merrillite group, ferricerite-(La)

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Introduction

The cerite supergroup is constituted by two groups of isostructural trigonal *R*3*c* (#161) minerals, cerite (silicates) and merrillite (phosphates). The merrillite group is subdivided into two subgroups: merrillite (without OH in the Ø site) and whitlockite (with OH in the Ø site).

A general formula for the cerite supergroup is $A_9XM[TO_3(Ø)]_7W_3$, where: A = Ce, La, Ca, Sr, (Na), (other *REE*); X = □ [vacancy], Ca and Na; M = Mg, Fe^{2+}, Fe^{3+}, Al and Mn; T = Si and P; Ø = O and OH; W = □, OH and F.

The new nomenclature has been approved by the International Mineralogical Association (IMA) Commission on New Minerals, Nomenclature and Classification (CNMNC) (Miyawaki *et al.*, 2020). It is based on the dominant species of the dominant valence at each site. Table 1 gives the dominant site occupation for the cerite-supergroup minerals.

Table 1. Dominant site occupation for the cerite-supergroup minerals.

	A_9	X	M	T_7	$Ø_{28}$	W_3
CERITE GROUP						
Cerite-(Ce)	Ce	□	Mg	Si	O,OH	OH
Ferricerite-(La)	La	□	Fe^{3+}	Si	O,OH	OH
Aluminocerite-(Ce)	Ce	□	Al	Si	O,OH	OH
Taipingite-(Ce)	Ce	□	Mg	Si	O,OH	F
MERRILLITE GROUP						
Merrillite subgroup						
Merrillite	Ca	Na	Mg	P	O	□
Ferromerrillite	Ca	Na	Fe^{2+}	P	O	□
Keplerite	Ca	Ca	Mg	P	O	□
Matyhite	Ca	Ca	Fe^{2+}	P	O	□
Whitlockite subgroup						
Whitlockite	Ca	□	Mg	P	O,OH	□
Strontiowhitlockite	Sr	□	Mg	P	O,OH	□
Wopmayite	Ca	□	Mn	P	O,OH	□
Hedegaardite	Ca	Ca	Mg	P	O,OH	□

Nomenclature considerations

Cerite [later renamed cerite-(Ce)] was the first mineral in the group to be described. Therefore, it gives its name to the supergroup and also to the group composed of silicates. This follows the IMA-CNMNC procedures of Mills *et al.* (2009). Cerite was first described by Cronstedt (1751) as 'tungsten'. It was renamed by Hisinger and Berzelius (1804) as cerite, after the dwarf planet Ceres discovered by the Italian astronomer Guiseppe Piazzi in 1801. They discovered and named the chemical element cerium in this mineral.

The cerite supergroup is composed of 12 valid mineral species, three of them are pre-IMA [cerite-(Ce), merrillite and whitlockite], one was described in the 20th Century (strontiowhitlockite), and all the other eight were described in the 21st century. 'Bobdownsite' (IMA2008-037), a purported fluorophosphate analogue of whitlockite with Ø = F, was described by Tait *et al.* (2011) and discredited in McCubbin *et al.* (2018). Hedegaardite and keplerite have been approved (IMA2014-069, Witzke *et al.*, 2015; and IMA2019-108, Britvin *et al.*, 2020, respectively) but their complete descriptions have not yet been published. Additionally, a possible Mn-analogue to cerite-(Ce) was reported by Holtstam *et al.* (2020). There are a large number of synthetic compounds with the cerite structure, including arsenates and vanadates [see for instance Lipp and Schleid (2008), Deyneko *et al.* (2017) and Lazoryak *et al.* (2018)]. This indicates that the cerite supergroup may still grow substantially. These compounds are synthesised due to their important

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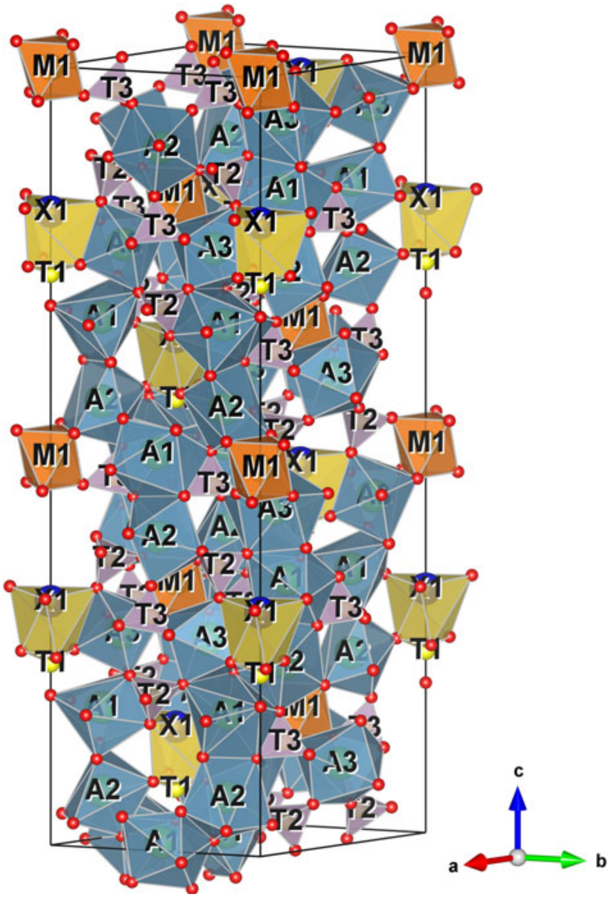

Fig. 1. Schematic view of the crystal structure of cerite-supergroup minerals, drawn using *VESTA 3* (Momma and Izumi, 2011).

technological properties. The vanadates are currently considered promising for white light emission diodes, phosphors and light converters (Lazoryak *et al.*, 2018).

When simplified, the crystal structure of these minerals involves three 8- and 9-fold-coordinated *A* sites, one six-coordinated *X*, one octahedral *M* site and three almost perfect [TO_3(Ø)] tetrahedral sites. The cerite-supergroup minerals structure consists of [$M(TO_4)_6$] clusters linked by {$A_9X(TO_3$Ø)} groups (Figs 1 and 2).

The end-member formulas for merrillite, ferromerrillite, whitlockite and strontiowhitlockite are charge balanced. For the other eight species they are not charge balanced. Charge balance is attained by substitutions at the *A*, *X* and *M* sites. In these cases, it is not advisable to force the existence of a specific member formula. For example, although the taipingite-(Ce) formula could be idealised as $(Ce_7Ca_2)_{\Sigma 9}Mg(SiO_4)_3[SiO_3(OH)]_4F_3$, this is not the only mechanism by which charge balance can be obtained, and Ca is not an essential element in the species. If the minority element at site *X* were Sr or Ba, the species remains the same. Otherwise, there would be an unwanted proliferation of species, controlled by non-dominant elements. Possible, but unspecified, charge-balancing substituents are best indicated by '#', as done in the list of species in the Appendix. This approach is also used to great effect in the pyrochlore supergroup (Atencio *et al.*, 2010).

Some comments could be made on the naming of the supergroup members. As cerite-(Ce) has Mg, and cerite-(La) has Fe^{3+} in the *M* site, cerite-(La) is renamed here as ferricerite-(La). Note that inconsistent precedents for the use of chemical prefixes have been set in the whitlockite and merrillite subgroups. 'Ferro' in ferromerrillite refers to the composition of the *M* site, while 'strontio' of strontiowhitlockite refers to the *X* site. This means that 'ferrostrontiowhitlockite' is a hypothetical member of the

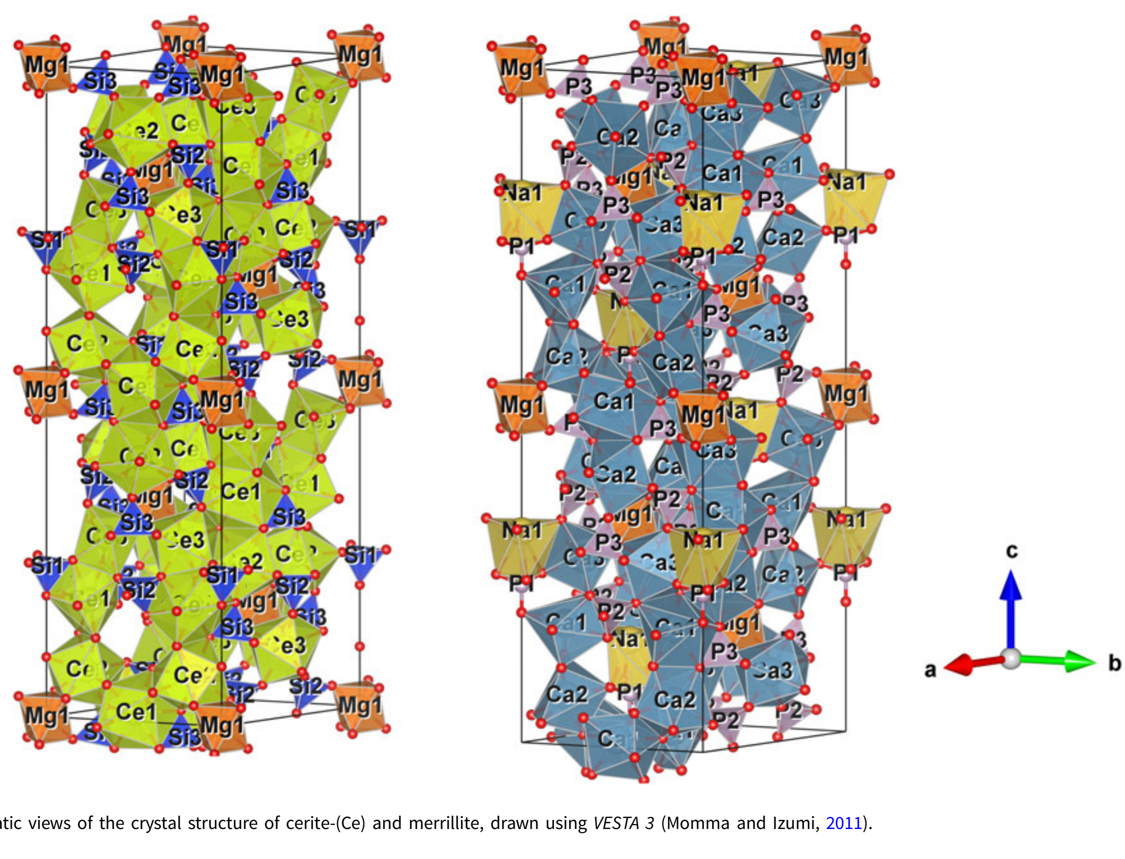

Fig. 2. Schematic views of the crystal structure of cerite-(Ce) and merrillite, drawn using *VESTA 3* (Momma and Izumi, 2011).

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group, a long and awkward name. If the prefix were restricted to refer to the *M* site only, then strontiowhitlockite would need to be renamed. Such prefix usage might also encourage renaming of matyhite as 'ferrokeplerite' and wopmayite as 'manganowhitlockite'. However, as the renaming of well-established minerals is traumatic and should be avoided, we did not propose changes at this moment beyond that of cerite-(La) to ferricerite-(La). Other minerals with such chemical inconsistencies have also been renamed in the past (c.f. aluminopharmacosiderite to pharmacoalumite; Rumsey *et al.*, 2010).

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Appendix. Cerite supergroup species

'$\square$' indicates a vacancy and '#' indicates possible, but unspecified, charge-balancing substituents.

Cerite-(Ce)
IMA Number: pre-IMA mineral
IMA List formula: $(Ce,La,Ca)_9(Mg,Fe^{3+})(SiO_4)_3(SiO_3OH)_4(OH)_3$
Generalised formula: $(Ce,\#)_9(\square,\#)(Mg,\#)(SiO_4)_3[SiO_3(OH)]_4(OH)_3$
Original description: Hisinger and Berzelius (1804)
Type locality: St Görans Mine, Bastnäs Mines, Riddarhyttan, Skinnskatteberg, Västmanland County, Sweden
Crystal structure: Moore and Shen (1983)
Unit-cell parameters: $a = 10.779(6)$ Å, $c = 38.0610(70)$ Å and $V = 3829.73$ Å^3

Ferricerite-(La)
[Originally named cerite-(La)]
IMA Number: 2001-042
IMA List formula: $(La,Ce,Ca)_9(Fe^{3+},Ca,Mg)(SiO_4)_3(SiO_3OH)_4(OH)_3$
Generalised formula: $(La,\#)_9(\square,\#)(Fe^{3+},\#)(SiO_4)_3[SiO_3(OH)]_4(OH)_3$

Original description: Pakhomovsky *et al.* (2002)
Type localities: Yukspor Mt, Khibiny Massif, Murmansk Oblast, Russia
Crystal structure: Pakhomovsky *et al.* (2002)
Unit-cell parameters: a = 10.7493(6) Å, c = 38.318(3) Å and V = 3834.37 Å^3

Aluminocerite-(Ce)
IMA Number: 2007-060
IMA List formula: $(Ce,REE,Ca)_9(Al,Fe^{3+})(SiO_4)_3[SiO_3(OH)]_4(OH)$
Generalised formula: $(Ce,\#)_9(\square,\#)(Al,\#)(SiO_4)_3[SiO_3(OH)]_4(OH)_3$
Original description: Nestola *et al.* (2009)
Type locality: Ratti quarry, near Baveno, Italy
Crystal structure: Nestola *et al.* (2009)
Unit-cell parameters: a = 10.6450(10) Å, c = 38.019(5) Å and V = 3730.98 Å^3

Taipingite-(Ce)
IMA Number: 2018-123a
IMA List formula: $(Ce_7Ca_2)_{\Sigma 9}Mg(SiO_4)_3[SiO_3(OH)]_4F_3$
Generalised formula: $(Ce,\#)_9(\square,\#)(Mg,\#)(SiO_4)_3[SiO_3(OH)]_4F_3$
Original description: Qu *et al.* (2020)
Type locality: Taipingzhen REE deposit, North Qinling Orogen, Central China
Crystal structure: Qu *et al.* (2020)
Unit-cell parameters: a = 10.7246(3) Å, c = 37.9528(14) Å and V = 3780.4(3) Å^3

Merrillite
IMA Number: pre-IMA mineral
IMA List formula: $Ca_9NaMg(PO_4)_7$
Generalised formula: $(Ca,\#)_9(Na,\#)(Mg,\#)(PO_4)_7$
Original description: Wherry (1917)
Type locality: Alfianello meteorite, Alfianello, Brescia Province, Lombardy, Italy
Crystal structure: Xie *et al.* (2015)
Unit-cell parameters: a = 10.3444(3) Å, c = 37.0182(11) Å and V = 3430.5(2) Å^3

Ferromerrillite
IMA Number: 2006-039
IMA List formula: $Ca_9NaFe^{2+}(PO_4)_7$
Generalised formula: $(Ca,\#)_9(Na,\#)(Fe^{2+},\#)(PO_4)_7$
Original description: Britvin *et al.* (2016)
Type locality: Shergotty Martian meteorite, Gaya District, Bihar, India
Crystal structure: Britvin *et al.* (2016)
Unit-cell parameters: a = 10.372(2) Å, c = 37.217(13) Å and V = 3467(3) Å^3

Keplerite
(Complete paper not yet published)
IMA Number: 2019-108
IMA List formula: $Ca_9(Ca_{0.5}\square_{0.5})Mg(PO_4)_7$
Generalised formula: $(Ca,\#)_9(Ca,\#)(Mg,\#)(PO_4)_7$
Original description: Britvin *et al.* (2020)
Type locality: Marjalahti meteorite, Viipuri, Pitkyaranta mining district (Pitkäranta mining district), Ladoga Region, Republic of Karelia, Russia
Crystal structure: Britvin *et al.* (2020)
Unit-cell parameters: a = 10.3330(4) Å, c = 37.0668(24) Å and V = 3427.4(3) Å^3

Matyhite
IMA Number: 2015-121
IMA List formula: $Ca_9(Ca_{0.5}\square_{0.5})Fe^{2+}(PO_4)_7$
Generalised formula: $(Ca,\#)_9(Ca,\#)(Fe^{2+},\#)(PO_4)_7$
Original description: Hwan *et al.* (2019)
Type locality: D'Orbigny meteorite, Coronel Suárez, Buenos Aires Province, Argentina
Crystal structure: not determined
Unit-cell parameters: a = 10.456(7) Å, c = 37.408(34) Å and V = 3541.6 (4.8) Å^3

Whitlockite
IMA Number: pre-IMA species
IMA List formula: $Ca_9Mg(PO_3OH)(PO_4)_6$
Generalised formula: $(Ca,\#)_9(\square,\#)(Mg,\#)[PO_3(OH)](PO_4)_6$
Original description: Frondel (1941)
Type locality: Palermo No. 1 Mine, Groton, Grafton Co., New Hampshire, USA
Crystal structure: Calvo and Gopal (1975)
Unit-cell parameters: a = 10.330(2) Å, c = 37.103(5) Å and V = 3428.785Å^3

Strontiowhitlockite
IMA Number: 1989-040
IMA List formula: $Sr_9Mg(PO_3OH)(PO_4)_6$
Generalised formula: $(Sr,\#)_9(\square,\#)(Mg,\#)[PO_3(OH)](PO_4)_6$
Original description: Britvin *et al.* (1991)
Type locality: Kovdor Zheleznyi Mine (Iron Mine), Kovdor Massif, Murmansk Oblast, Russia
Crystal structure: not determined
Unit-cell parameters: a = 10.644(9) Å, c = 39.54(6)Å and V = 3880 Å^3

Wopmayite
IMA Number: 2011-093
IMA List formula: $Ca_6Na_3\square Mn(PO_4)_3(PO_3OH)_4$
Generalised formula: $(Ca,\#)_9(\square,\#)(Mn,\#)[PO_3(OH)]_4(PO_4)_3$
Original description: Cooper *et al.* (2013)
Type locality: Tanco Mine, Bernic Lake, Lac-du-Bonnet area, Manitoba, Canada
Crystal structure: Cooper *et al.* (2013)
Unit-cell parameters: a = 10.3926(2) Å, c = 37.1694(9) Å and V = 37.1694(9) Å^3

Hedegaardite
(Complete paper not yet published)
IMA Number: 2014-069
IMA List formula: $(Ca,Na)_9(Ca,Na)Mg(PO_4)_6(PO_3OH)$
Generalised formula: $(Ca,\#)_9(Ca,\#)(Mg,\#)[PO_3(OH)](PO_4)_6$
Original description: Witzke *et al.* (2015)
Type localities: South slope of Punta de Lobos, Rio Seco, ~90 km south of Iquique, Tarapacá, I Region, Chile, and Cerro Mejillones, Mejillones Peninsula, Mejillones, Antofagasta, II Region, Chile
Crystal structure: Witzke *et al.* (2015)
Unit-cell parameters: a = 10.3519(9) Å, c = 37.064(5) Å and V = 3439.7(6) Å^3

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