



Article

New data on nordite-(Ce) and the establishment of the nordite supergroup

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Abstract

A nomenclature scheme has been set up for the nordite supergroup of minerals, which have the general formula $A_2BXYZT_6O_{17}$ and where $A = \text{Na}$; $B = \text{Na, Ca}$; $X = \text{Sr, Ca, Ba}$; $Y = \text{REE, Sr}$; $Z = \text{Zn, Fe, Mn, Mg}$ and $T = \text{Si}$. The nordite supergroup includes nordite-(La), nordite-(Ce), ferronordite-(La), ferronordite-(Ce) and manganonordite-(Ce), as well as meieranite which is considered as an unassigned member of the nordite supergroup. In the known nordite-group minerals the Y site is occupied by rare earth elements (REE), while in meieranite the Y site is occupied by Sr. The dominant element on the tetrahedral Z site determines the prefix used in the mineral name. New rootnames must be given to species with a different dominant element on the A, B or X sites. Nordite supergroup minerals are orthorhombic, although nordite-group minerals and meieranite crystallise in the *Pcca* and *P2₁nb* space groups, respectively. The proposed nomenclature scheme for the nordite supergroup has been approved by the Commission on New Minerals, Nomenclature and Classification (CNMNC) of the International Mineralogical Association (IMA). In addition, new chemical and structural investigations were performed on nordite-(Ce) from Illutalik (Igdlutalik), South Greenland, leading to the first crystal structure refinement for nordite-(Ce).

Keywords: nordite, nordite-(Ce), meieranite, nomenclature, crystal structure, REE

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Introduction

The first nordite species was discovered in Pegmatite No. 65 located in the Chinglusuai river valley, Lovozero alkaline complex, Kola Peninsula, Russia (Gerasimovsky, 1941). The original description showed the sample to be rich in Mn without Zn and with La being the dominating lanthanide. Semenov (1961) described a nordite from Pegmatite No. 66 in the Motchisuai river valley, Sengischorr Mt., Lovozero, containing 3.90 wt.% ZnO. In the same publication, the original nordite-(La) material from Gerasimovsky (1941) was reanalysed and revealed to contain 4.22 wt.% ZnO (Semenov, 1961). This means that the original analysis by Gerasimovsky (1941) was a Zn-dominated nordite rather than Mn-dominated as originally described. Pekov *et al.* (1998) described ferronordite-(Ce) as a new species from Pegmatite No 65 located in the Chinglusuai river valley and from Mt. Karnasurt, and manganonordite-(Ce) as a new species from Pegmatite No. 60, Mt Karnasurt and from Mt. Kedykverpakhk – all localities are within Lovozero. Ferronordite-(La) was described from the Bolshoi Punkaruaiiv Mountain, Lovozero by Pekov *et al.* (2001). In the Khibiny alkaline complex, Kola peninsula nordite-(La) was described from Kirovskii apatite mine, Mt. Kukisvumchorr (Khomyakov, 1990) and Mt. Eveslogchorr (Pekov, 1997). Outside the Lovozero and Khibiny complexes, nordite-supergroup minerals are rare and

only nordite-(Ce) has been described from Igdlutalik [now spelled Illutalik], Gardar Province, South Greenland (Upton *et al.*, 1976); Mont Saint-Hilaire, Québec, Canada (Wight and Chao, 1995); and Dara-i-Pioz, Tajikistan (Pekov *et al.*, 1998).

The first crystal structure refinement on a nordite-group mineral was performed by Bakakin *et al.* (1970) on a nordite-(La) from Lovozero, showing that nordite-(La) is orthorhombic (*Pcca*) with $a = 14.27(3)$, $b = 5.16(1)$, $c = 19.45(15)$ and $Z = 4$. Subsequently, the crystal structures of ferronordite-(Ce) and manganonordite-(Ce) were reported by Pushcharovsky *et al.* (1999), confirming the previous structural model established by Bakakin *et al.* (1970). A new mineral isostructural to nordite, and free from rare earth elements (REE) was published Yang *et al.* (2019), namely meieranite, ideally $\text{Na}_2\text{Sr}_3\text{MgSi}_6\text{O}_{17}$, from the Wessels Mine in the Kalahari manganese field, South Africa.

During a study of nordite-group minerals from the Ilimaussaq alkaline complex, South Greenland (Gulbransen, 2020) it became apparent that the nordite-(Ce) from Illutalik (South Greenland) published by Upton *et al.* (1976) should be re-investigated as the chemical data results in an empirical formula with significant deviation from the ideal composition. Furthermore, it was realised that there is no published structure solution for nordite-(Ce). Consequently, new chemical and crystallographic investigations are presented on nordite-(Ce) from Illutalik, South Greenland.

In addition, we present the newly approved nomenclature for the nordite-supergroup minerals, including nordite-(La), nordite-(Ce), ferronordite-(La), ferronordite-(Ce), manganonordite-(Ce) and meieranite. This nomenclature scheme has been approved by the Commission on New Minerals, Nomenclature and Classification

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Table 1. List of the valid nordite-supergroup minerals and their unit-cell parameters.

Mineral species	Formula	<i>a</i> (Å)	<i>b</i> (Å)	<i>c</i> (Å)	S.G.	Z	References
Nordite group							
Nordite-(La)	Na ₃ SrLaZnSi ₆ O ₁₇	14.468(8)	5.203(6)	19.88(2)	<i>Pcca</i>	4	Gerasmovsky (1941); Bakakin et al. (1970); *Sokolova et al. (1992)
Nordite-(Ce)	Na ₃ SrCeZnSi ₆ O ₁₇	14.389(1)	5.180(1)	19.755(1)	<i>Pcca</i>	4	Semenov (1961); *this work
Ferronordite-(La)	Na ₃ SrLaFeSi ₆ O ₁₇	14.440(5)	5.191(2)	19.86(1)	<i>Pcca</i>	4	*Pekov et al. (2001)
Ferronordite-(Ce)	Na ₃ SrCeFeSi ₆ O ₁₇	14.46(1)	5.194(3)	19.874(9)	<i>Pcca</i>	4	Pekov et al. (1998); *Pushcharovskii et al. (1999)
Manganonordite-(Ce)	Na ₃ SrCeMnSi ₆ O ₁₇	14.44(2)	5.187(5)	19.82(1)	<i>Pcca</i>	4	Pekov et al. (1998); *Pushcharovskii et al. (1999)
Unassigned member							
Meieranite	Na ₂ Sr ₃ MgSi ₆ O ₁₇	7.938(1)	10.492(1)	18.256(1)	<i>P2₁nb</i>	4	*Yang et al. (2019)

S.G. = Space Group. *Unit-cell parameters are taken from this reference.

Table 2. Cationic distribution in the crystal structure of the approved and hypothetical new end-members of the nordite supergroup.

	A	B	X	Y	Z	T	O	
Nordite group								
Nordite-(La)	Na ₂	Na	Sr	La	Zn	Si ₆	O ₁₇	
Nordite-(Ce)	Na ₂	Na	Sr	Ce	Zn	Si ₆	O ₁₇	
Ferronordite-(La)	Na ₂	Na	Sr	La	Fe	Si ₆	O ₁₇	
Ferronordite-(Ce)	Na ₂	Na	Sr	Ce	Fe	Si ₆	O ₁₇	
Manganonordite-(Ce)	Na ₂	Na	Sr	Ce	Mn	Si ₆	O ₁₇	
Magnesionordite*	Na ₂	Na	Sr	REE	Mg	Si ₆	O ₁₇	
<i>Rootname1</i>								
<i>Ferro-rootname1</i>	Na ₂	Na	Ba	REE	Zn	Si ₆	O ₁₇	
<i>Mangano-rootname1</i>	Na ₂	Na	Ba	REE	Fe	Si ₆	O ₁₇	
<i>Mangano-rootname1</i>	Na ₂	Na	Ba	REE	Mn	Si ₆	O ₁₇	
<i>Rootname2</i>								
	Na ₂	Na	Ca	REE	Zn	Si ₆	O ₁₇	
Meieranite group								
Meieranite	Na	Sr	Na	Sr	Sr	Mg	Si ₆	O ₁₇
Ferromeieranite	Na	Sr	Na	Sr	Sr	Fe	Si ₆	O ₁₇
Zincomeieranite	Na	Sr	Na	Sr	Sr	Zn	Si ₆	O ₁₇
<i>Rootname3</i>								
	Na	Sr	Na	Ba	Sr	Mg	Si ₆	O ₁₇

*In italic: hypothetical new end-member compositions.

(CNMNC) of the International Mineralogical Association (IMA) (Miyawaki et al., 2021).

Crystal chemistry of nordite-supergroup minerals

Six species are currently approved in the nordite supergroup. They can be described as silicates with the general formula $A_2BXYZT_6O_{17}$, where $^{[6-8]}A = \text{Na}$; $^{[6]}B = \text{Na, Ca}$; $^{[8]}X = \text{Ca, Sr, Ba}$; $^{[8]}Y = \text{Sr, REE}^{3+}$; $^{[4]}Z = \text{Mg, Mn}^{2+}, \text{Fe}^{2+}, \text{Zn}$ and $^{[4]}T = \text{Si}$ (Tables 1 and 2). In all described species, the *A* and *B* sites are dominated by Na and the *X* site by Sr. The *Y* site is either dominated by La or Ce in the nordite-group minerals, or by Sr in meieranite. In the nordite-group minerals the *Z* site is either dominated by Mn²⁺, Fe²⁺ or Zn, whereas in meieranite Mg is the dominant cation on the *Z* site.

Nordite-group minerals are all isostructural, orthorhombic, space group *Pcca* (#54); *Z* = 4; *a* ≈ 14.4, *b* ≈ 5.2 and *c* ≈ 19.8 Å. Meieranite, Na₂Sr₃MgSi₆O₁₇, is orthorhombic, space group *P2₁nb* (#33); *Z* = 4; *a* = 17.938(1), *b* = 10.492(1) and *c* = 18.256(1) Å. In the structure of meieranite the *A* site is split into two distinct sites, *A* and *A'* (Table 2). Starting from a nordite composition, meieranite may be obtained through the coupled heterovalent substitution $^A\text{Na}^+ + ^Y\text{REE}^{3+} \leftrightarrow ^A\text{Sr}^{2+} + ^Y\text{Sr}^{2+}$ (Yang et al., 2019).

Nordite-supergroup minerals are classified as inosilicates with ring-branched 12-periodic single chains. The silicate chains (*T* sites) are interconnected through the tetrahedrally coordinated

Z site forming layers consisting of 4-, 5- and 8-membered rings perpendicular to [010] (Fig. 1a). The *T1* and *T2* sites share one corner with the *Z* sites and two corners with other *T* sites. The *T3* site is tri-coordinated with the other *T* sites. The remaining apical oxygen atoms are shared with the *A*, *A'*, *B*, *X* and *Y* sites, that form heteropolyhedral layers (Fig. 1b). These sites are connected through edge and face sharing. In the species belonging to the nordite group the *A* site has a 7+1 square antiprism coordination and is typically occupied by Na. In the case of meieranite, the complete ordering of Na and Sr on the *A* site leads to the splitting of the *A* site into the *A* and *A'* positions; the *A* position is 7-coordinated and is occupied by Na, while the *A'* position is 8-fold coordinated and occupied by Sr. The *B* site has an octahedral coordination and is occupied by Na. The *X* and *Y* sites have an 8-fold square antiprism coordination; the *X* site is populated by large divalent cations such as Sr and Ba, while the *Y* site is occupied by REE (nordite group) or by large divalent cations such as Sr in the case of meieranite (Table 2).

The stacking of the tetrahedral and heteropolyhedral layers shows that the $^{[8]}X$ and $^{[8]}Y$ sites are located above and below the 8-membered rings, while the $^{[8]}A$ and $^{[6]}B$ sites occur above and below the 5- and 4-membered rings, respectively (Fig. 1c). In meieranite, the situation is more complex due to change from the centrosymmetric space group *Pcca* to the non-centrosymmetric space group *P2₁nb*. In that regard, in meieranite the successive tetrahedral layers are oriented in a different way, and therefore the $^{[7]}A$ and $^{[6]}B$ sites sit above and below the 4- and 5-membered rings, the $^{[8]}A'$ and $^{[8]}X$ sites sit above and below the 5- and 8-membered rings, and the $^{[8]}Y$ sites are located solely above and below the 8-membered rings.

The nodal net describing the tetrahedral layer of nordite-group minerals is unique among silicate minerals and is given by [(4.5.8)₈(5².8)₄(5.8.5.8)₂]₂ (Hawthorne et al., 2019). However, as shown in Fig. 2, the tetrahedral layer in the nordite-group minerals and meieranite has a different symmetry, and consequently a different topology. In both nordite-group species and meieranite, the tetrahedral layer can be reconstructed from the same tetrahedral chains (Fig. 2a), in which the basic unit is one 5-membered ring pointing upwards (green), one 5-membered ring pointing downwards (red), and one 4-membered ring (blue). Simplified, in the nordite-group minerals the adjacent chains are symmetrically related through a mirror plane perpendicular to the *a* axis and passing through the *Z* site positions (Fig. 2b). In meieranite the chains are related through a 2-fold axis parallel to the *b* axis and going through the *Z* site positions (Fig. 2c).

Methodology

A sample from the collection of NHM in Oslo (KNR 44277) was used for the study of nordite-(Ce). The sample is from the same locality studied by Upton et al. (1976), which is a trachyte dyke on the island

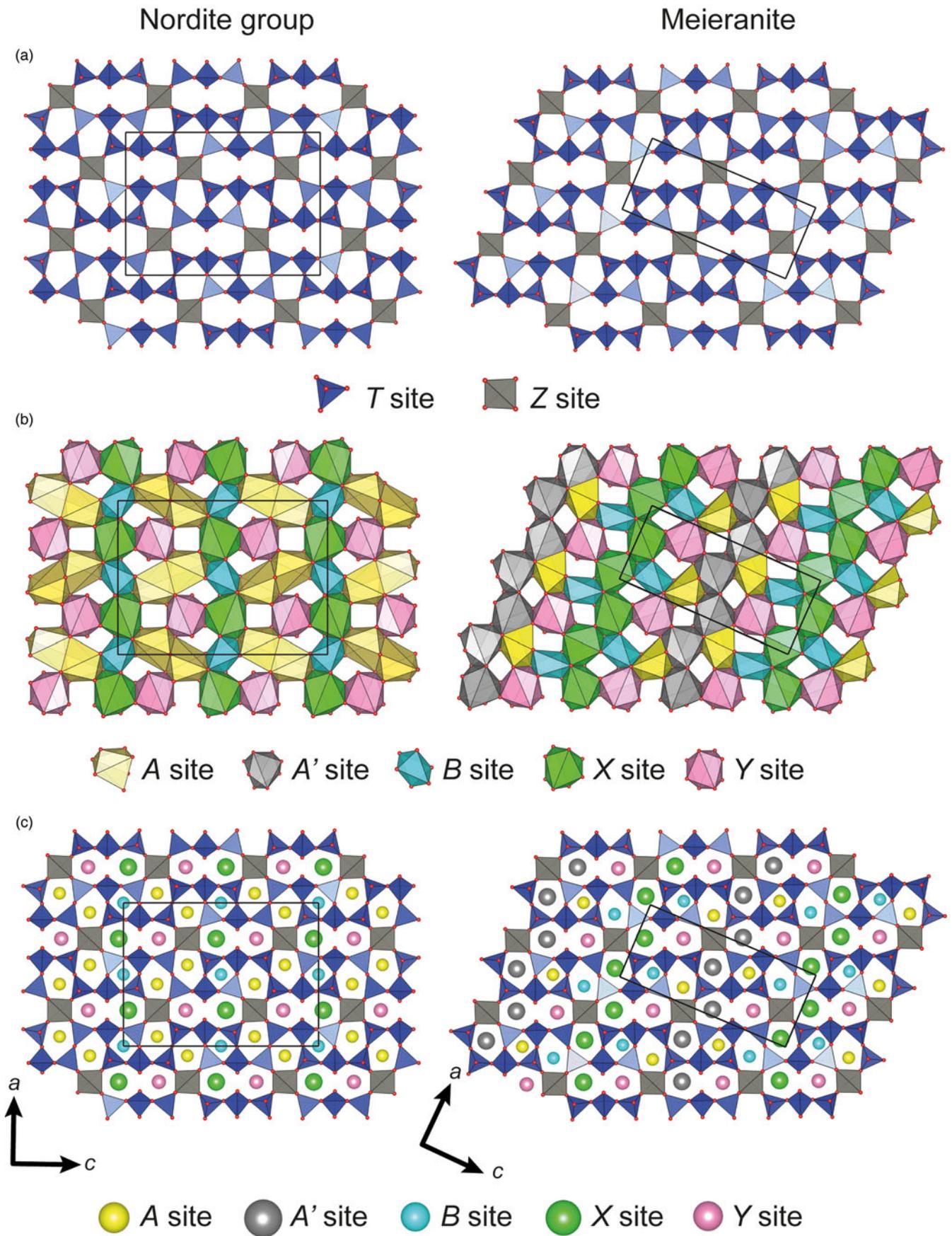


Fig. 1. View along the *b* axis of (a) tetrahedral layers, (b) heteropolyhedral layers and (c) stacking of both layers. The solid lines show one unit-cell.

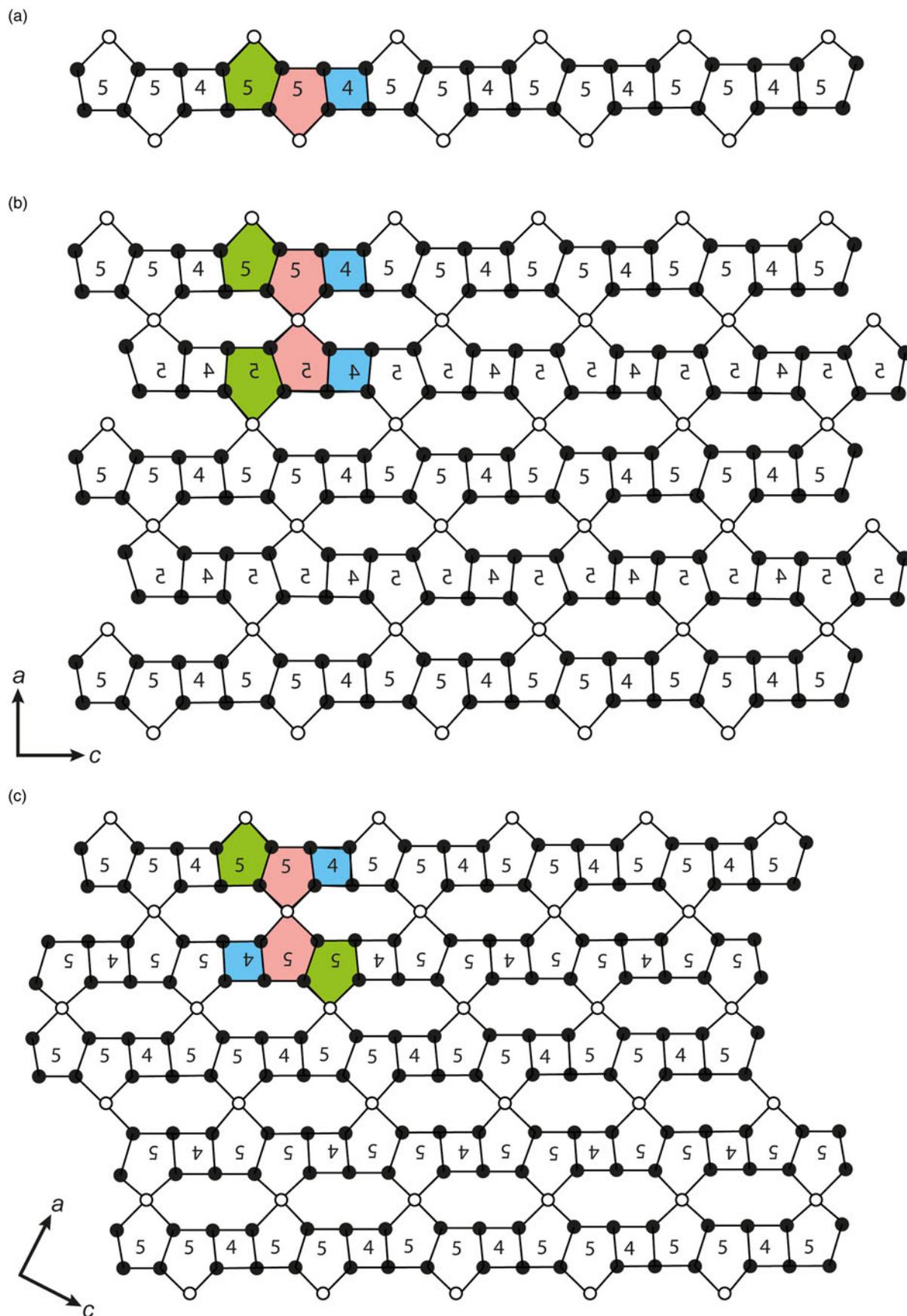


Fig. 2. Idealised topological representation of (a) tetrahedral chains occurring in the layers of (b) a nordite-group mineral and (c) meieranite. The solid and open circles represent the *T* and *Z* sites, respectively. For clarity, the numbers show the type of rings.

Table 3. Chemical composition of nordite-(Ce) from Illutalik.

Sample	KNR 44277		Upton <i>et al.</i> (1976)	
	8		8	
	wt.%	apfu	wt.%	apfu
SiO ₂	45.2(5)	5.97	46.48	6.06
Na ₂ O	11.9(2)	3.06	11.15	2.82
MgO	0.10(3)	0.02	0.13	0.02
CaO	1.4(1)	0.20	1.48	0.20
SrO	9.7(5)	0.75	9.73	0.74
BaO	1.0(6)	0.05	0.99 [#]	0.05
MnO	0.09(3)	0.01	–	–
FeO	0.2(1)	0.02	0.22	0.02
ZnO	9.6*	0.94	9.74	0.94
La ₂ O ₃	8.3*	0.41	8.84	0.41
Ce ₂ O ₃	10.4*	0.50	10.84 ^{##}	0.52
Pr ₂ O ₃	0.7*	0.03	–	–
Nd ₂ O ₃	1.3*	0.06	1.35	0.06
Total	99.89		100.59	

* From LA-ICPMS. [#] is given as 8.99 in Upton *et al.* (1976), but the 8 is a typo for zero. – Not determined. ^{##} has been converted from CeO₂.

of Illutalik (formerly spelled as Igdlutalik), South Greenland. Electron probe microanalyses (EPMA) were undertaken with a CAMECA SX100 housed in the Department of Geosciences, University of Oslo. The instrument is equipped with five spectrometers and was operated in wavelength dispersive mode. The instrument conditions were an acceleration voltage of 15 kV, beam current of 15 nA and a beam size of 5 µm. The following natural and synthetic standards were used: wollastonite (Si and Ca), albite (Na), pyrophanite (Mn), MgO (Mg), BaSO₄ (Ba), Sr-glass (Sr) and pure metal (Fe). The intensity data were corrected for inter-element overlaps and for matrix effects using the PAP procedure (Pouchou and Pichoir, 1984). Because of elemental overlaps that could not be successfully resolved, an Aurora Elite M90 ICPMS equipped with a Cetax LSX-213 G2+ laser (LA-ICPMS) housed at Department of Geosciences, University of Oslo was used for the following elements: Si, Ca, Zn, Rb, Y, Zr, Nb, Cs, REE³⁺, Hf, Ta, Th and U. Instrument drift was monitored using NIST610 and BCR2G while Si from EPMA was used as internal standard. Raw data were reduced using the *Glitter* program (Griffin *et al.*, 2008), using a linear fit to standards within a session. The formula calculated based on 17 anions is presented in Table 3.

For the single-crystal investigation, intensity data were collected at room temperature with monochromated MoK α radiation (50 kV and 1 mA) on a Rigaku Synergy-S diffractometer equipped with a HyPix-6000He detector housed at NHM in Oslo. The instrument has Kappa geometry and both data collection and subsequent data reduction, and face based absorption corrections were carried out using the Rigaku *CrysAlis Pro* software. The structure was solved by direct methods and refined by *SHELXL* (Sheldrick, 2008) using neutral atom scattering factors and the *WinGX* interface (Farrugia, 2012). Table 4 contains details about data collection and refinement of nordite-(Ce). The atomic coordinates, anisotropic atomic displacement parameters and the bond distances are given in Tables 5–6. The crystallographic information file has been deposited with the Principal Editor of *Mineralogical Magazine* and is available as Supplementary material (see below).

Results

Nordite-(Ce) from Illutalik occurs as single euhedral, colourless-to-white crystals up to 150 µm in size or as aggregates up to a

Table 4. Data collection and structure refinement details for nordite-(Ce) from Illutalik.

Crystal data	
Ideal structural formula	Na ₂ NaSrCeZnSi ₆ O ₁₇
Temperature (K)	293(2)
Cell setting	Orthorhombic
Space group	<i>Pcca</i> (No. 54)
Lattice parameters	
<i>a</i> (Å)	14.3891(2)
<i>b</i> (Å)	5.17986(6)
<i>c</i> (Å)	19.7554(2)
<i>V</i> (Å ³)	1472.44(3)
<i>Z</i>	4
Calculated density (g cm ⁻³)	3.643
Crystal size (mm)	0.120 × 0.066 × 0.026
Crystal form	Blocky
Crystal colour	Colourless
Data collection	
Diffractometer	Rigaku XtaLAB Synergy, HyPix Detector
Radiation; λ (Å)	MoK α ; 0.71073
Absorption coefficient, μ (mm ⁻¹)	8.393
<i>F</i> (000)	1526
σ range (°)	2.062–34.385
Index range	–22 < <i>h</i> < 22, –7 < <i>k</i> < 8, –31 < <i>l</i> < 31
No. of measured reflections	67858
Total reflections (<i>N</i> _{tot})/unique(<i>N</i> _{ref})	2998/2641
Criterion for observed reflections	<i>I</i> > 2 σ (<i>I</i>)
Refinement	
Refinement on	Full-matrix least squares on <i>F</i> ²
<i>R</i> , <i>wR</i> (<i>I</i> > 2 σ (<i>I</i>))	1.29, 1.71
<i>R</i> ₂ , <i>wR</i> ₂ (all reflection)	3.44, 3.54
<i>R</i> _{int} (%)	2.67
No. of refinement parameters (<i>N</i> _{par})	138
Weighting scheme	1/($\sigma^2(F_o)^2 + 0.0184(P)^2 + 0.6112(P)$)
$\Delta\rho_{max}$, $\Delta\rho_{min}$ (e ⁻ Å ⁻³)	–0.49/0.46
GoF (obs/all)	1.07/1.07

$$P = ((F_o)^2 + 2(F_c)^2)/3$$

300 µm in size. The mineral has been found in the part of the locality that also contains narsarsukite, but not in direct contact with emeleusite. The matrix is a fine-grained aegirine and albite dyke of trachytic composition (Upton *et al.*, 1976, 1978) and accessory minerals include pectolite, a britholite-group mineral, calcite and zircon. The empirical formula for nordite-(Ce) is Na_{3.06}(Sr_{0.75}Ca_{0.20}Ba_{0.05}) Σ 1.00(Ce_{0.50}La_{0.41}Nd_{0.06}Pr_{0.03}) Σ 1.00(Zn_{0.94}Fe_{0.02}Mg_{0.02}Mn_{0.01}) Σ 0.99Si_{5.97}O₁₇, which is similar to that reported by Upton *et al.* (1976). However, the new data does provide a better stoichiometry than that previously reported despite Na being slightly high and Si slightly low (Table 3). The new chemical data confirms that the 8.99 wt.% BaO reported by Upton *et al.* (1976) was a typo and that the correct value was 0.99 wt.% BaO. The values for Zn, La, Ce, Nd and Pr are taken from LA-ICPMS analyses. The other elements analysed by LA-ICPMS are only present in trace amounts.

The refinement of the site scattering factors shows that the A and B sites are fully occupied by Na, and the Y site by REE. The X site has a low scattering factor (35.8 e⁻) in comparison to a full occupancy by Sr, which is explained by the incorporation of 0.2 Ca atoms per formula unit (apfu). The incorporation of significant amount of Ca on the X site is also reported in nordite-(La) (Bakakin *et al.*, 1970). The Z site shows only a minor deviation (28.9 e⁻) from the ideal value of 30, which is attributed to the incorporation of small amounts of Fe, Mg and Mn. The detailed cationic distribution on the different crystallographic sites is provided in Table 7 and is in good agreement with the chemical data and the different structural parameters.

Table 5. Site population, atomic coordinates atomic equivalent isotropic and anisotropic displacement parameters (\AA^2) for nordite-(Ce).

Site	Site population	<i>x</i>	<i>y</i>	<i>z</i>	$U_{\text{eq}}/U_{\text{iso}}$	U^{11}	U^{22}	U^{33}	U^{12}	U^{13}	U^{23}
A	Na _{1.00}	0.07003(5)	-0.4924(1)	0.17153(2)	0.0197(1)	0.0321(3)	0.0137(3)	0.0132(2)	0.0013(2)	-0.0019(2)	-0.0035(2)
B	Na _{1.00}	0	-1/2	1/2	0.0183(1)	0.0216(4)	0.0108(3)	0.0226(3)	0.0029(3)	-0.0101(3)	-0.0017(3)
X	Sr _{0.75} Ca _{0.20} Ba _{0.05}	1/4	1/2	0.52346(2)	0.00796(5)	0.00780(8)	0.00764(7)	0.00844(7)	0.000	0.000	0.00003(5)
Y	REE _{1.00}	1/4	1/2	0.31959(2)	0.00645(3)	0.00650(4)	0.00621(4)	0.00666(4)	0.000	0.000	0.00040(3)
Z	Zn _{0.95} Fe _{0.02} Mg _{0.02} Mn _{0.01}	1/4	0	0.66959(2)	0.00795(6)	0.0078(1)	0.0100(1)	0.00611(9)	0.000	0.000	-0.00002(6)
T1	Si	0.09852(2)	0.03662(6)	0.56508(2)	0.00686(6)	0.0076(1)	0.0066(1)	0.0064(1)	-0.00026(9)	-0.00046(9)	0.0003(1)
T2	Si	0.10235(2)	0.03951(6)	0.27420(2)	0.00657(6)	0.0065(1)	0.0067(1)	0.0066(1)	-0.00021(9)	-0.00060(9)	0.00035(9)
T3	Si	0.11201(2)	0.95459(6)	0.41883(2)	0.00676(6)	0.0073(1)	0.0071(1)	0.0058(1)	-0.00002(9)	0.00067(9)	0.0005(1)
O1	O	-0.00525(5)	0.1607(2)	0.58231(4)	0.0102(1)	0.0076(3)	0.0107(4)	0.0122(3)	-0.0006(3)	0.0014(3)	-0.0001(3)
O2	O	0.17083(5)	0.1991(1)	0.60980(4)	0.0103(1)	0.0106(3)	0.0101(3)	0.0101(3)	-0.0009(3)	-0.0038(3)	0.0000(3)
O3	O	0.11844(5)	0.1432(1)	0.48585(4)	0.0094(1)	0.0128(4)	0.0090(3)	0.0065(3)	-0.0005(2)	0.0011(3)	-0.0002(3)
O4	O	0.10247(6)	-0.2674(2)	0.56762(4)	0.0117(1)	0.0152(4)	0.0074(3)	0.0124(3)	0.0004(3)	-0.0012(3)	0.0002(3)
O5	O	0.000000	0.1427(2)	0.250000	0.0121(2)	0.0085(5)	0.0102(5)	0.0176(5)	0.000	-0.0040(4)	0.000
O6	O	0.17692(5)	0.2106(1)	0.23279(4)	0.0096(1)	0.0103(3)	0.0096(3)	0.0088(3)	-0.0006(3)	0.0024(3)	-0.0008(3)
O7	O	0.11891(5)	1.1498(1)	0.35307(4)	0.0095(1)	0.0136(4)	0.0086(3)	0.0063(3)	0.0004(2)	-0.0006(3)	-0.0022(3)
O8	O	0.11453(6)	-0.2636(1)	0.27265(4)	0.0118(1)	0.0143(4)	0.0081(3)	0.0130(3)	-0.0012(3)	-0.0031(3)	0.0013(3)
O9	O	0.31429(6)	1.27215(16)	0.41826(4)	0.0109(1)	0.0109(4)	0.0117(4)	0.0101(3)	0.0008(3)	-0.0002(3)	0.0037(3)

Table 6. Selected bond distances (*d* in \AA) for nordite-(Ce).

A-O1	2.689(1)	X-O2 ×2	2.509(1)	T1-O1	1.661(1)
A-O2	2.429(1)	X-O3 ×2	2.699(1)	T1-O2	1.604(1)
A-O4	2.445(1)	X-O4 ×2	2.419(1)	T1-O3	1.684(1)
A-O5	2.644(1)	X-O9 ×2	2.459(1)	T1-O4	1.577(1)
A-O6	2.489(1)	<X-O>	2.521	<T1-O>	1.631
A-O8	2.409(1)				
A-O8	3.110(1)	Y-O6 ×2	2.509(1)	T2-O5	1.638(1)
<A-O>	2.602	Y-O7 ×2	2.699(1)	T2-O6	1.614(1)
		Y-O8 ×2	2.419(1)	T2-O7	1.677(1)
B-O1 ×2	2.396(1)	Y-O9 ×2	2.459(1)	T2-O8	1.580(1)
B-O3 ×2	2.530(1)	<Y-O>	2.521	<T2-O>	1.627
B-O4 ×2	2.326(1)				
<B-O>	2.417	Z-O2 ×2	1.938(1)	T3-O1	1.648(1)
		Z-O6 ×2	1.964(1)	T3-O3	1.648(1)
		<Z-O>	1.951	T3-O7	1.649(1)
				T3-O9	1.583(1)
				<T3-O>	1.632

The bond-valence sums (BVS) calculated according to the cationic distribution are presented in Table 8.

Nomenclature scheme

Following the recommendations of Mills *et al.* (2009) on the standardisation of mineral group hierarchies we propose the establishment of the nordite supergroup, subdivided into

Table 8. Bond-valence sums (valence units) for nordite-(Ce).

	A	B	X	Y	Z	T1	T2	T3	Σ
O1	0.091	0.202 ×2↓				0.910		0.939	2.14
O2	0.184		0.273 ×2↓		0.533 ×2↓	1.054			2.04
O3		0.140 ×2↓	0.172 ×2↓			0.856		0.940	2.11
O4	0.176	0.243 ×2↓	0.262 ×2↓			1.130			1.81
O5	0.103 ×2→						0.965 ×2→		2.14
O6	0.157			0.381 ×2↓	0.498 ×2↓		1.025		2.06
O7				0.227 ×2↓			0.874	0.937	2.04
O8	0.194, 0.029			0.485 ×2↓			1.119		1.83
O9			0.283 ×2↓	0.435 ×2↓				1.113	1.83
Σ	0.93	1.17	1.98	3.06	2.06	3.95	3.98	3.93	
VS	1.00	1.00	2.00	3.00	2.00	4.00	4.00	4.00	

Note: bond-valence parameters are recalculated according to the site occupancies (see Table 5) and taken from Brown and Altermatt (1985) for the all the cations apart Si, for which the parameters from Gagné and Hawthorne (2015) have been used. VS: valence sums calculated from the site population.

Table 7. Cationic distribution in the crystal structure of nordite-(Ce).

Site	RSS (e ⁻)	Site-population (apfu)	CSS (e ⁻)	ABL (\AA)	CBL (\AA)
[7]A	11.0	Na _{1.00}	11.0	2.602	2.530
[6]B	11.0	Na _{1.00}	11.0	2.417	2.420
[8]X	35.8	Sr _{0.75} Ca _{0.20} Ba _{0.05}	35.3	2.620	2.660
[8]Y	56.5	REE _{1.00}	58.0	2.521	2.563
[4]Z	28.9	Zn _{0.95} Fe _{0.02} Mg _{0.02} Mn _{0.01}	29.5	1.951	1.981

RSS: Refined site scattering factor; CSS: Calculated site scattering factor; ABL: average observed bond lengths; CBL: calculated bond lengths; Ideal bond distances are calculated using the ionic radii of Shannon (1976). Ce³⁺ is used as a proxy for all REE.

the nordite group containing the following five mineral species: nordite-(La), nordite-(Ce), ferrorndite-(La), ferrorndite-(Ce) and manganonordite-(Ce) (Table 1). Due to structural and compositional differences meieranite is considered as an unassigned member of the nordite supergroup and it will be the first mineral of the potential meieranite group if a related species is reported. The supergroup is named according to the first described species, nordite-(La) (Gerasimovsky, 1941).

Members of the nordite supergroup are classified according to the following rules. The rootname is dependent on the dominant cation located on the X site (Table 2). In the nordite group, the *nordite* rootname is applied to species with X = Sr, and new rootnames will be applied to species with X ≠ Sr. In the potential

meieranite group, the *meieranite* rootname is applied to species with $X = \text{Sr}$ and new rootnames are required for species with $X \neq \text{Sr}$. In the case of the species belonging to the nordite group the Levinson suffix (Bayliss and Levinson, 1988) is added to the names to indicate the dominant REE on the crystallographic Y site.

In both nordite and meieranite groups a prefix is added according to the dominant chemical composition of the tetrahedral Z site; *magnesio* (Mg), *mangano* (Mn^{2+}), *ferro* (Fe^{2+}) and *zinco* (Zn). The first described nordite-group mineral, nordite-(La), has $Z = \text{Zn}$, and consequently the prefix *zinco* is not used in approved or new species belonging to the nordite group. The prefix rule is the same in the potential meieranite group when $Z = \text{Mg}$. The first described species (meieranite) has $Z = \text{Mg}$, therefore the prefix *magnesio* is not added.

The published data on nordite-group minerals indicate that only limited cationic substitutions occur on the A and B sites. Although, in the case of end-members with $A \neq \text{Na}$ or $B \neq \text{Na}$ a new rootname must be used and the rules given above have to be applied. Meieranite has so far been reported from only one locality, and therefore it is challenging to predict all potential new members. The nomenclature scheme proposed herein provides to the mineralogical community a tool for the classification of nordite-supergroup minerals according to their crystal-chemical properties.

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References

- Bakakin V.V., Belov N.V., Borisov S.V. and Solovyeva, L.P. (1970) The crystal structure of nordite and its relationship to melilite and datolite-gadolinite. *American Mineralogist*, **55**, 1167–1181.
- Bayliss P. and Levinson A. (1988) A system of nomenclature for rare-earth mineral species: revision and extension. *American Mineralogist*, **73**, 422–423.
- Brown I.D. and Altermatt D. (1985) Bond-valence parameters obtained from a systematic analysis of the Inorganic Crystal Structure Database. *Acta Crystallographica*, **B41**, 244–247, with updated parameters from https://www.iucr.org/_data/assets/file/0011/150779/bvparam2020.cif.
- Farrugia L.J. (2012) WinGX and ORTEP for Windows: and update. *Journal of Applied Crystallography*, **45**, 849–854.
- Gagné O.C. and Hawthorne F.C. (2015) Comprehensive derivation of bond-valence parameters for ion pairs involving oxygen. *Acta Crystallographica*, **B71**, 562–578.
- Gerasimovsky V.I. (1941) Nordite, a new mineral of the Lovozero tundra. *Doklady Akademii Nauk SSSR*, **32**, 496–498.
- Griffin W.L., Powell W.J., Pearson N.J. and O'Reilly S.Y. (2008) Glitter: Data reduction software for laser ablation ICP-MS. Pp. 307–311 in: *Laser Ablation ICPMS in the Earth Sciences: Current Practices and Outstanding Issues* (P. Sylvester, editor). Mineralogical Association of Canada Short Course Series, 40.
- Gulbransen E.H. (2020) *Characterization and Paragenesis of Nordite-Group Minerals from the Ilmaussaq Alkaline Complex, South Greenland*. Unpublished MSc Thesis, University of Oslo, pp. 126.
- Hawthorne F.C., Uvarova Y.A. and Sokolova E. (2019) A structure hierarchy for silicate minerals: sheet silicates. *Mineralogical Magazine*, **83**, 3–55.
- Khomyakov A.P. (1990) *Mineralogy of the Hyperagpaitic Alkaline Rocks*. Nauka Publishing, Moscow, 196 pp. [in Russian]
- Mills S.J., Hatert F., Nickel E. and Ferraris G. (2009) The standardisation of mineral group hierarchies: application to recent nomenclature proposals. *European Journal of Mineralogy*, **21**, 1073–1080.
- Miyawaki R., Hatert F., Pasero M. and Mills S.J. (2021) Newsletter 60. *Mineralogical Magazine*, **85**, <https://doi.org/10.1180/mgm.2021.30>.
- Pekov I.V. (1997) *Mineralogy of Rare-Earth Elements in Peralkaline Pegmatites and Hydrothermalites (Khibiny, Lovozero and Ilmaussaq Complexes)*. PhD thesis, Lomonosov Moscow State University, Moscow, 237 pp. [in Russian].
- Pekov I.V., Chukanov N.V., Kononkova N.N., Belakovskiy D.I., Pushcharovskiy D.Yu. and Vinogradova S.A. (1998) Ferronordite-(Ce) $\text{Na}_3\text{SrFeSi}_6\text{O}_{17}$ and manganonordite-(Ce) $\text{Na}_3\text{SrMnSi}_6\text{O}_{17}$ – two new minerals from Lovozero massif, Kola Peninsula. *Zapiski Vserossijskogo Mineralogicheskogo Obshchestva*, **127**, 32–41.
- Pekov I.V., Chukanov N.V., Turchkova A.G. and Grishin V.G. (2001) Ferronordite-(La), $\text{Na}_3\text{Sr}(\text{La,Ce})\text{FeSi}_6\text{O}_{17}$, a new mineral of the nordite group from Lovozero Massif, Kola Peninsula. *Zapiski Vserossijskogo Mineralogicheskogo Obshchestva*, **130**, 53–58.
- Pouchou J.L. and Pichoir F. (1984) A new model for quantitative X-ray micro-analysis. I. Application to the analysis of homogeneous samples. *La Recherche Aéropatiale*, **3**, 13–38.
- Pushcharovskii D.Y., Pekov I.V., Pluth J.J., Smith J., Ferraris G., Vinogradova S.A., Arakcheeva A.V., Soboleva S.V. and Semenov E.I. (1999) Raité, manganonordite-(Ce), and ferronordite-(Ce) from the Lovozero massif: Crystal structures and mineralogical geochemistry. *Crystallography Reports*, **44**, 565–574.
- Semenov E.I. (1961) New data on nordite. *Trudy, Mineralogicheskiiy Muzeya Akademii Nauk SSSR*, **11**, 199–201.
- Shannon R.D. (1976) Revised effective ionic radii and systematic studies of interatomic distances in halides and chalcogenides. *Acta Crystallographica*, **A32**, 751–767.
- Sheldrick G.M. (2008) A short history of SHELX. *Acta Crystallographica*, **A64**, 112–122.
- Sokolova E.V. Kabalov Y.K. and Khomyakov A.P. (1992) Isomorphism in the crystal structure of the Khibiny nordite, $\text{Na}_3\text{SrTR}\{\text{M}^{2+}[\text{Si}_6\text{O}_{17}]\}$, TR = La, Ce, Nd, Pr; $\text{M}^{2+} = \text{Zn}, \text{Mg}, \text{Fe}, \text{Mn}$. *Vestnik Moskovskogo Gosudarstvennogo Universiteta*, **4**, 97–102 [in Russian].
- Upton B., Macdonald R., Hill P., Jefferies B. and Ford, C. (1976) Narsarsukite: a new occurrence in peralkaline trachyte, south Greenland. *Mineralogical Magazine*, **40**, 737–746.
- Upton B., Hill P.G., Johnsen O. and Petersen O.V. (1978) Emeleusite: a new $\text{LiNaFe}^{\text{III}}$ silicate from south Greenland. *Mineralogical Magazine*, **42**, 31–34.
- Wight Q. and Chao G.Y. (1995). Mont Saint-Hilaire: Revisited Part 2. *Rocks & Minerals*, **70**, 90–138.
- Yang H., Gu X., Downs R.T., Evans S.H., Van Nieuwenhuizen J.J., Lavinsky R.M. and Xie X. (2019) Meieranite, $\text{Na}_2\text{Sr}_3\text{MgSi}_6\text{O}_{17}$, a new mineral from the Wessels mine, Kalahari manganese fields, South Africa. *The Canadian Mineralogist*, **57**, 457–466.