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 $A = Na; B = Na, Ca; X = Sr, Ca, Ba; Y = REE, Sr; Z = Zn, Fe, Mn, Mg and$ $T = Si$. 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 $P_{ca}$ and $P_{2_1}nb$ 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 (Igdltulak), South Greenland, leading to the first crystal structure refinement for nordite-(Ce).

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

(Received 24 March 2021; accepted 7 May 2021; Accepted Manuscript published online: 12 May 2021; Associate Editor: Irina O Galuskina)

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. Kedykverpakkh – all localities are within Lovozero. Ferronordite-(La) was described from the Bolshoi Punkarauiv Mountain, Lovozero by Pekov et al. (2001). In the Khibiny alkaline complex, Kola peninsula nordite-(La) was described from Kirovskii apatite mine, Mt. Kukisvumchorn (Khomyakov, 1990) and Mt. Eveslogchorn (Pekov, 1997). Outside the Lovozero and Khibiny complexes, nordite-supergroup minerals are rare and only nordite-(Ce) has been described from Igdltulak [now spelled Ilulitulak], 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 ($P_{ca}$) 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 $Na_2Sr_3MgSi_6O_{17}$, from the Wessels Mine in the Kalahari manganese field, South Africa.

During a study of nordite-group minerals from the Ilímaussaq alkaline complex, South Greenland (Gulbransen, 2020) it became apparent that the nordite-(Ce) from Ilulitulak (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 Ilulitulak, 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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Cite this article: Dal Bo F., Gulbransen E.H. and Friis H. (2021) New data on nordite-(Ce) and the establishment of the nordite supergroup. Mineralogical Magazine 85, 431–437. https://doi.org/10.1180/mgm.2021.42
Meieranite, Na$_2$Sr$_3$MgSi$_6$O$_{17}$, is orthorhombic, space group Pcca. Ferronordite-(La) Na$_2$SrLaFeSi$_6$O$_{17}$, Nordite-(Ce) Na$_2$SrCeZnSi$_6$O$_{17}$, unassigned member Meieranite Na$_2$SrMgSi$_6$O$_{17}$. Crystal chemistry of nordite-supergroup minerals shows that they can be described as silicates with the general formula [8] Na Sr Na Ba Sr Mg Si$_6$O$_{17}$, where Na site is either dominated by Mn$^{2+}$/Fe$^{2+}$ or Zn, whereas in meieranite Mg is the dominant cation on the A site. The structure of meieranite the A site is either dominated by Mn$^{2+}$/Fe$^{2+}$ or Zn, whereas in meieranite Mg is the dominant cation on the A site.

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

| Mineral species            | Formula                   | a (Å)     | b (Å)     | c (Å)     | S.G. | Z | References                      |
|----------------------------|---------------------------|-----------|-----------|-----------|------|---|---------------------------------|
| Nordite group              |                           |           |           |           |      |   |                                 |
| Nordite-(La)               | Na$_2$SrLaZnSi$_6$O$_{17}$| 14.468(8) | 5.203(6)  | 19.88(2)  | Pcca | 4 | Gerassimovskiy (1941); Bakakin et al. (1970); Sokolova et al. (1992) |
| Nordite-(Ce)               | Na$_2$SrCeZnSi$_6$O$_{17}$| 14.39(1)  | 5.180(1)  | 19.755(1) | Pcca | 4 | Semenov (1961); *this work      |
| Ferronordite-(La)          | Na$_2$SrLaFeSi$_6$O$_{17}$| 14.40(5)  | 5.191(2)  | 19.86(1)  | Pcca | 4 | *Pekov et al. (2001)            |
| Ferronordite-(Ce)          | Na$_2$SrCeFeSi$_6$O$_{17}$| 14.46(1)  | 5.194(3)  | 19.687(9) | Pcca | 4 | Pekov et al. (1998); Pushcharovskii et al. (1999) |
| Manganonordite-(Ce)        | Na$_2$SrMnSi$_6$O$_{17}$  | 14.44(2)  | 5.187(5)  | 19.82(1)  | Pcca | 4 | Pekov et al. (1998); Pushcharovskii et al. (1999) |
| Unassigned member          |                           |           |           |           |      |   |                                 |
| Meieranite                 | Na$_2$SrZnSi$_6$O$_{17}$  | 7.938(1)  | 10.492(1) | 18.256(1) | P2$_1$nb | 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.

| Mineral species             | A     | B     | X     | Y     | Z     | T     | O     | References |
|----------------------------|-------|-------|-------|-------|-------|-------|-------|------------|
| 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$_{17}$|            |
| Rootname1                  | Na$_2$| Na    | Ba    | REE   | Zn    | Si$_6$| O$_{17}$|            |
| Ferro-rootname1            | Na$_2$| Na    | Ba    | REE   | Fe    | Si$_6$| O$_{17}$|            |
| Mangano-rootname1          | Na$_2$| Na    | Ba    | REE   | Mn    | Si$_6$| O$_{17}$|            |
| Rootname2                  | Na$_2$| Na    | Ca    | REE   | Zn    | Si$_6$| O$_{17}$|            |

*In italics: 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 $A_2$BXY$ZT_2$O$_{17}$, where $[6-8]$ $A$ = Na, $B$ = Na, Ca; $[8]$ $X$ = Ca, Sr, Ba; $Y$ = Sr, REE$^{3+}$; $[4]$ $Z$ = Mg, Mn$^{2+}$, Fe$^{2+}$, Zn and $[4]$ $T$ = 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 Mn$^{2+}$/Fe$^{2+}$ or Zn, whereas in meieranite Mg is the dominant cation on the Z site.

Nordite-group minerals are all isostructural, orthorhombic, space group Pcca ($\#54$); $Z = 4; a \approx 14.4, b \approx 5.2$ and $c \approx 19.8$ Å. Meieranite, Na$_2$Sr$_3$MgSi$_6$O$_{17}$, is orthorhombic, space group P$\overline{2}$$_1$nb ($\#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 $4Na^+ + 4REE^{3+} \leftrightarrow A'^{3+} + 4Sr^{2+} + 4Sr^{2+}$ (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 4-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 antiprisrn 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 $[6]$A and $[6]$B sites occur above and below the 5- and 4-membered rings, respectively (Fig. 1c). Meieranite, the situation is more complex due to change from the centrosymmetric space group Pcca to the non-centrosymmetric space group P$\overline{2}$$_1$nb. In that regard, 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 $[(4.5.8)_{0}(5.8.5.8)_{0}]_{2}$ (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.
of Illutalik (formerly spelled as Igdllutalik), 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), Sm, Nb, Cs, Os, and Os 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.

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 NHM in Oslo. The instrument was drift monitored using NIST610 and BCR2G while Si from EPMA was used as internal standard. Data collection and structure refinement details for nordite-(Ce) from Illutalik.

**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 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 [Na0.95Sr0.05Ce0.50La0.41Nd0.06Pr0.03]Σ0.99Si8.97O17, 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 higher and Si slightly lower (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 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 [Na0.95Sr0.05Ce0.50La0.41Nd0.06Pr0.03]Σ0.99Si8.97O17, 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 higher and Si slightly lower (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 Ce site has a low scattering factor (35.8 e⁻) compared to Sr, which is explained by the incorporation of 0.2 Ca atoms per formula unit (apfu) into the SrO site. The incorporation of 0.2 Ca atoms per formula unit (apfu) into the SrO site is also reported by Upton et al. (1976) and 0.2 Ca atoms per formula unit (apfu) into the SrO site by Upton et al. (1976). However, the new data does provide a better stoichiometry than that previously reported despite Na being slightly higher and Si slightly lower (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 Sr, respectively. The refinement of the site scattering factors shows that the Ce site has a low scattering factor (35.8 e⁻) compared to Sr, which is explained by the incorporation of 0.2 Ca atoms per formula unit (apfu) into the SrO site. The incorporation of 0.2 Ca atoms per formula unit (apfu) into the SrO site is also reported by Upton et al. (1976) and 0.2 Ca atoms per formula unit (apfu) into the SrO site by Upton et al. (1976). However, the new data does provide a better stoichiometry than that previously reported despite Na being slightly higher and Si slightly lower (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.

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The refinement of the site scattering factors shows that the A and B sites are fully occupied by Na and Sr, respectively. The refinement of the site scattering factors shows that the Ce site has a low scattering factor (35.8 e⁻) compared to Sr, which is explained by the incorporation of 0.2 Ca atoms per formula unit (apfu) into the SrO site. The incorporation of 0.2 Ca atoms per formula unit (apfu) into the SrO site is also reported by Upton et al. (1976) and 0.2 Ca atoms per formula unit (apfu) into the SrO site by Upton et al. (1976). However, the new data does provide a better stoichiometry than that previously reported despite Na being slightly higher and Si slightly lower (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.

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

| Mineral          | wt.% apfu | wt.% apfu |
|------------------|-----------|-----------|
| SiO₂             | 45.2(5)   | 5.97      |
| Na₂O             | 11.9(2)   | 3.06      |
| MgO              | 0.10(3)   | 0.02      |
| CaO              | 1.4(1)    | 0.20      |
| SrO              | 9.7(5)    | 0.75      |
| BaO              | 1.0(6)    | 0.05      |
| MnO              | 0.09(3)   | 0.01      |
| FeO              | 0.2(1)    | 0.02      |
| ZnO              | 9.6(6)    | 0.94      |
| La₂O₃            | 8.3(4)    | 0.41      |
| Ce₂O₃            | 10.4(4)   | 0.50      |
| Pr₂O₃            | 0.7(1)    | 0.03      |
| Nd₂O₃            | 1.3(4)    | 0.06      |

Total: 99.89

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

| Parameter | Value |
|-----------|-------|
| Space group | Pcca |
| a (Å) | 14.3893(2) |
| b (Å) | 5.17896(6) |
| c (Å) | 19.7554(2) |
| V (Å³) | 1472.44(3) |
| R (all) | 4 |
| wR (all) | 3.464 |
| Δρ (e/Å³) | 0.120 × 0.066 × 0.026 |

Crystal data

Ideal structural formula: Na₂SrCeZnSi₆O₁₇

Cell setting: Orthorhombic

Lattice parameters:
- a (Å): 14.3893(2)
- b (Å): 5.17896(6)
- c (Å): 19.7554(2)
- V (Å³): 1472.44(3)
- Z: 4

Calculated density (g cm⁻³): 3.643

Crystal size (mm): 0.120 × 0.066 × 0.026

Crystal form: Blocky

Crystal colour: Colourless

Diffractometer:
- Rigaku XtaLAB Synergy
- HyPix Detector
- MoKα; 0.71073

Absorption coefficient, μ (mm⁻¹) for 0(000): 8.393

α range (°): 2.062–34.385

Index range: -22 < h < 22, -7 < k < 8, -31 < l < 31

No. of measured reflections: 67858

Total reflections (Nₚar)/unique(N_uar): 2998/2641

Criterion for observed reflections: I > 2σ(I)

Refinement:
- Full matrix least squares on F²
- R = 1.29, 1.71
- wR = 3.44, 3.54
- R = 2.67

No. of refinement parameters (Nₚar): 138

Weighting scheme: 1/σ(Fo)² + 0.0184(P²) + 0.6112(P)

GoF (obs/all): 0.99/0.96

GoF (obs/all): 1.07/1.07

P = (F₀² + 2F₁²)/3
Table 5. Site population, atomic coordinates and isotropic displacement parameters (Å²) for nordite-(Ce).

| Site          | Site population | x    | y    | z    | Ueq (Å²) | U₁₁ | U₂₂ | U₃₃ | U₁₂ | U₁₃ | U₂₃ |
|---------------|-----------------|------|------|------|----------|-----|-----|-----|-----|-----|-----|
| A Na₂[0.80]   | 0.07003(5)      | -0.492(1) | 1.175(2) | 0.019(1) | 0.0321(3) | 0.0137(3) | 0.0132(2) | 0.0013(2) | -0.0019(2) | -0.0035(2) |
| B Na₂[0.80]   | 0               | -V₁  | V₁  | 0.183(1) | 0.0216(4) | 0.0108(3) | 0.0226(3) | 0.0029(3) | -0.0101(3) | -0.0017(3) |
| X Sr₀.₇₅Ca₀.₂₅Ba₀.₀₅ | ¼   | V₁  | V₁  | 0.5234(2) | 0.0796(5) | 0.0078(8) | 0.0076(4) | 0.0084(7) | 0.0000(5) |
| Y REE₁₂₅      | ⅛              | V₁  | V₁  | 0.31995(2) | 0.0645(3) | 0.0065(0) | 0.0062(4) | 0.0066(4) | 0.0000(3) |
| Z Zn₁₀₁₂Fe₁₆₆O₃₅Mg₁₂₀Mn₈ₐ₀.₀₁ | ⅛   | 0   | 0   | 0.60695(2) | 0.0795(6) | 0.0078(5) | 0.0100(1) | 0.0061(9) | 0.0000(3) |

Table 6. Selected bond distances (d in Å) 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-O₃         | 2.445(1)        | X-O₄ ×2 | 2.419(1) | T₁-O₃ | 1.684(1) |
| A-O₄         | 2.664(1)        | X-O₅ ×2 | 2.459(1) | T₁-O₄ | 1.577(1) |
| A-O₅         | 2.489(1)        | X-O₆ ×2 | 2.509(1) | T₁-O₅ | 1.638(1) |
| A-O₆         | 2.409(1)        | X-O₇ ×2 | 2.699(1) | T₁-O₆ | 1.614(1) |
| A-O₇         | 3.110(1)        | X-O₈ ×2 | 2.419(1) | T₁-O₇ | 1.677(1) |
| A-O₈         | 2.602           | X-O₉ ×2 | 2.509(1) | T₂-O₁ | 1.580(1) |
| A-O₉         | 2.530(1)        | X-O₁₀ ×2 | 2.521 | T₂-O₂ | 1.627 |
| A-O₁₀        | 2.326(1)        | X-O₁₁ ×2 | 1.938(1) | T₃-O₁ | 1.648(1) |
| A-O₁₁        | 2.417           | X-O₁₂ ×2 | 1.964(1) | T₃-O₂ | 1.648(1) |

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 the nordite group containing the following five mineral species: nordite-(La), nordite-(Ce), ferronordite-(La), ferronordite-(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

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

| Site          | RSS (e⁻) | Site-population (apfu) | CSS (e⁺) | ABL (Å) | CBL (Å) |
|---------------|----------|------------------------|----------|---------|---------|
| [1]I          | 11.0     | Na₂[0.80]              | 11.0     | 2.602   | 2.530   |
| [2]I          | 11.0     | Na₂[0.80]              | 11.0     | 2.417   | 2.420   |
| [3]X          | 35.8     | Sr₀.₇₅Ca₀.₂₅Ba₀.₀₅     | 35.3     | 2.620   | 2.660   |
| [4]Y          | 56.5     | REE₁₂₅                 | 58.0     | 2.521   | 2.563   |
| [5]Z          | 28.9     | Zn₁₀₁₂Fe₁₆₆O₃₅Mg₁₂₀Mn₈ₐ₀.₀₁ | 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). Ce⁺ is used as a proxy for all REE.

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

| A          | B          | X          | Y          | Z          | T₁         | T₂         | T₃         | Σ          |
|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| 0.091      | 0.202      | 0.273      | 0.533      | 0.910      | 0.939      | 2.14       |
| 0.184      | 0.273      | 0.172      | 0.856      | 1.054      | 2.04       |
| 0.140      | 0.243      | 0.262      | 1.130      | 0.865      | 2.11       |
| 0.176      | 0.032      | 0.498      | 0.485      | 1.119      | 2.04       |
| 0.194      | 0.485      | 0.498      | 0.965      | 1.131      | 2.14       |
| 0.083      | 0.318      | 0.874      | 0.937      | 1.131      | 2.06       |
| 0.001      | 0.119      | 0.798      | 0.397      | 1.131      | 2.06       |
| 0.001      | 3.98       | 3.98       | 3.98       | 3.98       | 3.98       |
| 1.00       | 1.00       | 2.00       | 2.00       | 2.00       | 2.00       |

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 Gagne and Hawthorne (2015) have been used. VS: valence sums calculated from the site population.
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), mangan (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.

Acknowledgements. We thank Principal Editor Stuart J. Mills and Irina Galuskina for handling the manuscript as well as Igor V. Pekov and two anonymous reviewers for their helpful suggestions and comments that improved the manuscript.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1180/mgm.2021.42

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