

Oberti et al. Eckermannite revised

Revision 1

**Eckermannite revised. The new holotype from the Jade Mine Tract,
Myanmar: crystal structure, mineral data and hints on the reasons for
the rarity of eckermannite**

**ROBERTA OBERTI^{1*}, MASSIMO BOIOCCHI², FRANK C. HAWTHORNE³, NEIL A. BALL³ AND GEORGE
E. HARLOW⁴**

¹CNR-Istituto di Geoscienze e Georisorse, UOS Pavia, via Ferrata 1, I-27100 Pavia, Italy

²Centro Grandi Strumenti, Università di Pavia, via Bassi 21, I-27100 Pavia, Italy

³Department of Geological Sciences, University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada

⁴Department of Earth and Planetary Sciences, American Museum of Natural History, Central Park
West at 79th Street New York, NY 10024-5192, USA

*E-mail: oberti@crystal.unipv.it

ABSTRACT

Following the characterization of the new amphibole species fluoro-leakeite, ideally $^A\text{Na}^B\text{Na}_2$
 $^C(\text{Mg}_2\text{Al}_2\text{Li})^T\text{Si}_8\text{O}_{22}^W\text{F}_2$, at Norra Kärr (Sweden), so far considered the type locality of eckermannite,
re-examination of the holotype material of eckermannite deposited at the Museum of Natural History in
London (BM 1949.151) and of the original sample analyzed by Törnebohm (1906) confirmed that they
both are actually fluoro-leakeite. A survey of literature data showed that the only analysis reported for
eckermannite is that of sample AMNH 108401 from the Jade Mine Tract, Myanmar. Complete

Oberti et al. Eckermannite revised

24 characterization of that sample has led to the approval of a new holotype for eckermannite (IMA-
25 CNMMC 2013-136), ideally ${}^A\text{Na} {}^B\text{Na}_2 {}^C(\text{Mg}_4\text{Al}) {}^T\text{Si}_8 \text{O}_{22} {}^W(\text{OH})_2$, which is described in this work.
26 Holotype eckermannite from Myanmar has the empirical unit formula ${}^A(\text{Na}_{0.87}\text{K}_{0.06})_{\Sigma=0.93}$
27 ${}^B(\text{Na}_{1.89}\text{Ca}_{0.11})_{\Sigma=2.00} {}^C(\text{Mg}_{3.87}\text{Fe}^{2+}_{0.09}\text{Mn}_{0.01}\text{Fe}^{3+}_{0.38}\text{Al}_{0.62})_{\Sigma=4.97} {}^T\text{Si}_{8.00} \text{O}_{22} {}^W(\text{F}_{0.03}\text{OH}_{1.97})_{\Sigma=2.00}$. It is
28 monoclinic, $C2/m$, with $a = 9.8087(7)$, $b = 17.8448(13)$, $c = 5.2905(4)$ Å, $\beta = 103.660(1)$, $V = 899.8(1)$
29 Å³; $Z = 2$, $D_{\text{calc}} = 3.02$ g/cm³. Optics: biaxial (-); α 1.605, β 1.630, γ 1.634 all ± 0.002 ($\lambda = 590$ nm).
30 The ten strongest reflections in the X-ray powder pattern [d values (in Å), I , (hkl)] are: 2.702, 100, [(-
31 331) (151)]; 3.395, 59, (131); 3.128, 56, (310); 2.525, 56, (-202); 8.407, 42, (110); 2.574, 36, [(061)
32 (002)]; 3.257, 34, (240); 2.161, 33, (261); 2.966, 33, (060); 4.460, 30, (040).
33 The reason for the rarity of eckermannite compositions are examined and discussed based on
34 considerations on the short-range order of A cations and W anions.

35

36 **Keywords:** eckermannite, new holotype, amphibole, chemical analysis, crystal structure, Myanmar

37

38

INTRODUCTION

39 Eckermannite is a "grandfathered" amphibole end-member with ideal formula ${}^A\text{Na} {}^B\text{Na}_2$
40 ${}^C(\text{Mg}_4\text{Al}) {}^T\text{Si}_8 \text{O}_{22} {}^W(\text{OH})_2$, which was named after the Swedish petrologist Claes.V.H. (Harry) von
41 Eckermann (1886-1969). The name was proposed by Adamson (1942) based on the study of rock
42 samples from Norra Kärr, Gränna, Jönköping, Småland, Sweden. According to Holtstam (1998), the
43 Norra Kärr locality (58°06'N, 14°40'E) is a small oval Proterozoic alkaline intrusion, composed mainly
44 of fine-grained schistose agpaitic nepheline-syenite (grennaite). Petrological and genetic aspects of
45 Norra Kärr have been described extensively by Adamson (1944), von Eckermann (1968), Blaxland
46 (1977) and Kramm and Koark (1988). Adamson (1942) re-calculated the analyses of R. Mauzelius
47 reported (together with optical properties) in Törnebohm (1906), and recognized that this was a new

Oberti et al. Eckermannite revised

48 amphibole species. It should be noted that a significant amount of Li (1.15 wt.% Li₂O, corresponding to
49 0.65 atoms per formula unit, apfu) was later reported in amphiboles from Norra Kärr by Sundius
50 (1945), who raised doubts on the composition of eckermannite. However, this did not result in re-
51 examination of the sample.

52 A few years ago, the study of a specimen from Norra Kärr in the collection of Renato and
53 Adriana Pagano showed the occurrence of a Li- and F-rich amphibole that was subsequently described
54 as fluoro-alumino-leakeite (IMA-CNMMNC 2009-012; Oberti et al., 2009), and became fluoro-
55 leakeite after Hawthorne et al. (2012). Based on the similarity of the published optical properties of
56 holotype eckermannite, that paper suggested that eckermannite did not occur at Norra Kärr. Re-
57 examination of the holotype specimen deposited at the Natural History Museum in London (BM
58 1949.151) and of the original material analyzed by Törnebohm (1906) (NRM 570725; courtesy of prof.
59 Ulf Hålenius, Stockholm) later confirmed this hypothesis, and showed that those samples are also
60 fluoro-leakeite.

61 Eckermannite is quite rare, and most of the available analyses of natural or synthetic samples
62 actually refer either to ferro-eckermannite or to fluoro-eckermannite (note that presently both these
63 species have the status of named amphiboles, so that their complete mineral descriptions have never
64 been reported). However, the rootname eckermannite was used by Hawthorne et al. (2012) to redefine
65 kozulite (IMA 1968-028; Nambu et al., 1969; formerly assigned by Leake et al., 1997) to mangano-
66 ferri-eckermannite based on the newly approved rules for amphibole classification and nomenclature.
67 Hence, it was not possible to discredit the root-name eckermannite. Instead of simply discrediting the
68 holotype material, we started a systematic characterization of the "eckermannite" samples published in
69 the literature. We found a specimen related to the ideal eckermannite composition only in the sample
70 from the collection of the American Museum of Natural History described in this work. After the

Oberti et al. Eckermannite revised

71 approval of IMA-CNMNC (vote 2013-136), the rock sample AMNH H108401 must be considered as
72 the holotype sample of eckermannite.

73

74 **MINERAL DATA**

75 **Occurrence and paragenesis**

76

77 The sample was extracted from a jadeitite-amphibole fels rock catalogued as AMNH H108401
78 in the mineral collection of the American Museum of Natural History, acquired in Myanmar by one of
79 us (GEH) in 2000. The rock consists of a boundary layer between mixed white and emerald green
80 jadeitite and a black amphibole fels, a sharp boundary separating the two parts. The rock was mined in
81 the Jade Mine Tract, Kachin Province, Myanmar. It is not known whether the rock comes from a
82 tectonic block in serpentinite or as part of a boulder extracted from the Uru River conglomerates
83 (Hughes et al., 2000). Associated minerals are jadeite and albite. All of the amphibole in this sample
84 falls within eckermannite-dominant compositions with $(\text{Mg}/(\text{Mg}+\text{Fe}^{2+}))$ between 0.84 and 1.

85 Amphibole fels adjacent to jadeitite from the Jade Mine Tract in Myanmar have been ascribed
86 to reactions between hydrous fluids that crystallized jadeitite and hosting serpentinitized ultramafic
87 mantle wedge during subduction, but timing (whether jadeitite or fels formed first) is uncertain (Shi et
88 al., 2003, 2012). Conditions of formation in this high-pressure – low-temperature regime are not well
89 constrained, but are somewhere in the blueschist facies of metabasites, probably $300^{\circ}\text{C} < T < 400^{\circ}$ and
90 $5 \text{ kbar} < P < 15 \text{ kbar}$.

91

92 **Appearance, physical and optical properties**

93

Oberti et al. Eckermannite revised

94 The amphibole fels is grey with white veins (Figure 1) and grains of eckermannite are
95 intergrown prisms generally less than 1 mm in maximum dimension. They are colorless to grey in
96 color, transparent, vitreous, and non-fluorescent. The tenacity is brittle and single crystals show a
97 perfect cleavage according {110}. The density calculated from the unit formula and cell dimensions is
98 3.02 g/cm³.

99 A spindle stage was used to orient a crystal for measurement of refractive indices and $2V$ by
100 extinction curves (Bartelmehs et al., 1992). The optical orientation was determined by transferring the
101 crystal from the spindle stage to a single-crystal diffractometer and measuring the relative axial
102 relations by X-ray diffraction. In transmitted light, eckermannite is biaxial negative with indices of
103 refraction $\alpha = 1.605$, $\beta = 1.630$, $\gamma = 1.634$ (all ± 0.002), measured with gel-filtered Na light ($\lambda = 589.9$
104 nm); $2V_{obs} = 43.0(5)$, $2V_{calc} = 43^\circ$. Orientation is $X \wedge a = 23.8^\circ$ (in β obtuse), $Y \parallel b$, $Z \wedge c = 10.1^\circ$ (in β
105 acute), and pleochroism is as follows: X = medium grey (strongest), Y = pale grey to colourless
106 (weakest), Z = light grey (medium).

107

108 **Crystallography**

109

110 For samples AMNH H108401 (single crystal 120 x 60 x 40 μm in size) and NMR 570725
111 (single crystal 200 x 160 x 60 μm in size), diffraction data were collected in the 2θ range 2-60° with a
112 Bruker-AXS CCD diffractometer with graphite-monochromatized $\text{MoK}\alpha$ X-radiation ($\lambda = 0.7107 \text{ \AA}$).
113 For both crystals, omega-rotation frames (scan width 0.3°, scan time 20 s, sample-to-detector distance
114 50 mm) were processed with the SAINT software (Bruker, 2003) and intensities were corrected for
115 Lorentz and polarization effects; absorption effects were empirically evaluated by the SADABS
116 software (Sheldrick, 1996) and an absorption correction was applied to the data.

Oberti et al. Eckermannite revised

117 A total of 6891 reflections collected for sample AMNH H108401 was reduced to 1377 unique
118 reflections (mean redundancy = 5, $R_{\text{int}} = 2.3\%$), and accurate unit-cell dimensions were calculated by
119 least-squares refinement of the positions of 1998 independent reflections with $I_o > 10 \sigma I$ in the θ range
120 2-30°. For sample NMR 570725, 6580 collected reflections were reduced to 1321 unique reflections
121 (mean redundancy = 5, $R_{\text{int}} = 1.3\%$), and accurate unit-cell dimensions were calculated by least-squares
122 refinement of the positions of 4074 independent reflections with $I_o > 10 \sigma I$ in the θ range 2-30°.
123 For samples BM 1949.151, XRD analysis was done with a Philips PW1100 4-circle diffractometer ($\lambda =$
124 $\text{MoK}\alpha$). Two monoclinic equivalents were collected in the 2θ range 4-70°; corrections for absorption
125 and L_p were applied and 3960 collected data were merged to 2017 unique reflections ($R_{\text{sym}} = 2.2 \%$).
126 Unit-cell parameters were calculated from least-squares refinement of the d^* values obtained for 60 rows
127 of the reciprocal lattice by measuring the centre of gravity of each reflection and of its antireflection in the
128 2θ range -70° to 70°.
129 For all samples, only the reflections with $I_o > 3 \sigma I$ were considered as observed during unweighted full-
130 matrix least-squares refinement on F done with a program locally written to handle complex solid-
131 solutions. Scattering curves for fully ionized chemical species were used at sites where chemical
132 substitutions occur; neutral vs. ionised scattering curves were used at the T and anion sites [except
133 O(3)]. More details on the refinement procedure and on the terminology used are given in Oberti et al.
134 (1992) and in Hawthorne et al. (1995). The $A(m)$ and $A(2)$ sites were inserted into the model to better
135 account for the irregular shape of the electron density within the A cavity, and testify to the presence of
136 significant ordering of the A cations. The absence of residual electron-density along the b direction at
137 around 0.40 Å from the $M(4)$ site (i.e., at the $M(4')$ site) indicates the absence of significant amounts of
138 smaller B cations (e.g., Li^+ , Fe^{2+} , Mg^{2+}).
139 The final values of R_{obs} and R_{all} are 2.9 and 4.0% for AMNH H188401, 1.6 and 2.6% for BM 1949.151,
140 and 2.1 and 2.3% for NMR 570725. Refined coordinates, atomic-displacement parameters, site

Oberti et al. Eckermannite revised

141 occupancies and selected bond lengths and angles are given in Tables 1 and 2. Measured structure
142 factors have been deposited with the cif file.
143 X-ray powder-diffraction data ($\text{CuK}\alpha$, $\lambda = 1.54178 \text{ \AA}$) for eckermannite AMNH H108401 were
144 calculated from the single-crystal data using the XPREP utility of SAINT (Bruker, 2003). No Lorentz
145 and polarization correction was applied. Data are given in Table 3.

146

147 **EMP analysis**

148

149 Chemical analysis of the refined crystal of eckermannite (10 point analyses) was done with a
150 CAMECA SX-100 electron microprobe (WDS mode, 15 kV, 10 nA, 5 μm beam diameter). The
151 following standards were used for $\text{K}\alpha$ X-ray lines: Si: diopside, TAP; Ca: diopside, LPET; Ti: titanite,
152 LLiF; Fe: fayalite, LLiF; Mn: spessartine, LLiF; Cr: chromite, LLiF; Mg: forsterite, LTAP; Al:
153 andalusite, TAP; K: orthoclase, LPET; Na: albite, TAP; F: fluoro-riebeckite, LTAP. Zn, Cr and Cl
154 contents are below detection limits. H_2O was calculated from the unit formula to obtain 2 (OH + F) in
155 the absence of dehydrogenation, as indicated by the single-crystal structure refinement. The total Fe
156 content was first estimated as FeO; the ferrous and ferric populations were estimated later, imposing
157 electroneutrality and crystal-chemical constraints obtained from structure refinement. The results are
158 reported in Table 4. The empirical formula (based on 24 anions pfu) is $^{\text{A}}(\text{Na}_{0.87}\text{K}_{0.06})_{\Sigma=0.93}$
159 $^{\text{B}}(\text{Na}_{1.89}\text{Ca}_{0.11})_{\Sigma=2.00}$ $^{\text{C}}(\text{Mg}_{3.87}\text{Fe}^{2+}_{0.09}\text{Mn}_{0.01}\text{Fe}^{3+}_{0.38}\text{Al}_{0.62})_{\Sigma=4.97}$ $^{\text{T}}\text{Si}_{8.00}$ O_{22} $^{\text{W}}(\text{F}_{0.03}\text{OH}_{1.97})_{\Sigma=2.00}$. The end-
160 member formula is $^{\text{A}}\text{Na}$ $^{\text{B}}\text{Na}_2$ $^{\text{C}}(\text{Mg}_4\text{Al})$ $^{\text{T}}\text{Si}_8$ O_{22} $^{\text{W}}(\text{OH})_2$, which requires SiO_2 59.80, Al_2O_3 6.34, MgO
161 20.05, Na_2O 11.57, H_2O 2.24, total 100.00 wt%.

162

Oberti et al. Eckermannite revised

163 **Compatibility**

164

165 The final $1 - (K_p/K_C)$ index for eckermannite AMNH H108401 is 0.010 (superior).

166

167 **Type material**

168

169 Type material for eckermannite is deposited in the collections of the Department of Earth and
170 Planetary Sciences, American Museum of Natural History, New York, New York, USA, specimen
171 number AMNH H108401. The refined and analyzed crystal of this work has the code 1213 in the
172 amphibole database of the CNR-IGG Pavia, where the refined fluoro-leakeite crystal from sample BM
173 1949.151 has the code 1161, and that from sample NMR 570725 has the code 1245.

174

175 **DISCUSSION**

176 A comparison of the new holotype eckermannite from the Jade Mine tract, Myanmar, holotype
177 fluoro-leakeite from Norra Kärr, Sweden (Oberti et al., 2009), the former "holotype eckermannite" BM
178 1949.151, and the original material analyzed by Törnebohm (1906) (NMR 570725), is shown in Table
179 5. The three latter samples are nearly identical, both with regard to the geometrical (unit-cell
180 parameters and refined site geometry) and crystal-chemical (refined site-scattering values) parameters,
181 except for the higher site-scattering value refined at the $M(3)$ site in NMR 570725, which indicates a
182 slightly lower ${}^6\text{Li}$ content coupled with a slightly lower ${}^{M(2)}\text{Fe}^{3+}$ content (as shown by the longer
183 $\langle M(2)\text{-O} \rangle$ distance). This confirms that samples BM 1949.151 and NMR 570725 are fluoro-leakeite,
184 and hence that eckermannite has never been found at Norra Kärr.

185 In contrast, eckermannite can be easily distinguished from fluoro-leakeite by comparing either
186 unit-cell parameters or optical properties or the details of the structure refinement.

Oberti et al. Eckermannite revised

187 Inspection of refined bond-lengths and site-scattering values allowed us to derive accurate site
188 populations starting from the unit formula obtained by EMP analysis. They are reported in Table 6. As
189 expected, trivalent cations are ordered at the $M(2)$ site. For comparison, the site populations derived for
190 the C cations in holotype fluoro-leakeite by Oberti et al. (2009) are: $M(1)$: 1.76 Mg + 0.20 Fe²⁺ + 0.04
191 Zn, $d_{\text{obs}} = d_{\text{cal}} = 2.064 \text{ \AA}$; $M(2)$: 1.13 Al + 0.75 Fe³⁺ + 0.09 Fe²⁺ + 0.03 Ti⁴⁺, $d_{\text{obs}} = 1.968 \text{ \AA}$, $d_{\text{cal}} = 1.972$
192 \AA ; $M(3)$: 0.09 Mn²⁺ + 0.91 Li⁺, $d_{\text{obs}} = 2.133 \text{ \AA}$, $d_{\text{cal}} = 2.105 \text{ \AA}$ (which by the way implies that the effect
193 of ^{O(3)}F on the $M(3)$ site geometry in ^CLi amphiboles is lower than observed in "standard" amphiboles).
194 From the crystal-chemical point of view, the two amphibole compositions have the same charge
195 arrangement for the A, B, C, T groups of cations and W anions, but differ by: (i) the coupled
196 heterovalent exchange allowing the entrance of ^CLi into the amphibole structure, i.e. $M(2)(\text{Mg,Fe})^{2+} +$
197 $M(3)(\text{Mg,Fe})^{2+} \rightarrow M(2)\text{Fe}^{3+} + M(3)\text{Li}^+$; (ii) the homovalent exchange $^{\text{O}(3)}(\text{OH})^- \rightarrow ^{\text{O}(3)}\text{F}^-$. Exchange (1)
198 makes the refined site-scattering value at $M(3)$ much lower and shortens the $\langle M(2)\text{-O} \rangle$ distances
199 significantly, notwithstanding the fact that the Fe content in fluoro-leakeite is much higher (29.70 vs.
200 37.00 electrons per formula unit, epfu). Exchange (ii) shortens the $M(1,3)\text{-O}(3)$ distances significantly,
201 and hence the $\langle M(1,3)\text{-O} \rangle$ distances; both these effects are evident from the structure refinements (note
202 that the $\langle M(3)\text{-O} \rangle$ distance is much larger in fluoro-leakeite due to the presence of Li ($\langle \text{Li-O} \rangle = 2.119$
203 \AA and $\langle \text{Mg-O} \rangle = 2.078 \text{ \AA}$ for amphiboles). Exchange (ii) also affects the ordering of A cations; as
204 expected (according to the conclusions of Hawthorne et al., 1996), Na occurs at the $A(m)$ and $A(2)$ sites
205 in eckermannite, but is ordered at $A(m)$ in fluoro-leakeite.
206 There are other issues which require comment: why are eckermannite compositions so rare in Nature,
207 and why are eckermannitic amphiboles often enriched in Fe (thus falling in the compositional field of
208 magnesio-arfvedsonite and arfvedsonite) or in fluorine? Hawthorne (1997) examined the effect of OH-
209 F substitution in arfvedsonite. In both arfvedsonite and fluoro-arfvedsonite, ^ANa is ordered at $A(m)$.
210 Where $M(2) = \text{Mg}$, the locally associated $A(m)$ site is occupied by Na. Where $M(2) = \text{Al}$, the locally

Oberti et al. Eckermannite revised

211 associated $A(m)$ site is vacant; however, the A cavity still contains Na, but the Na occupies the $A(m)$ site
212 on the other side of the cavity, away from the $M(2)$ site containing Al. In arfvedsonite, the separation of
213 the two locally associated (split) $A(m)$ sites is quite small as the Na at $A(m)$ has to minimize its
214 interaction with the H atom of the OH group. In fluoro-arfvedsonite, the separation of the two locally
215 associated (split) $A(m)$ sites is considerably larger (Hawthorne et al. 1996, Fig. 8) as there is no H (i.e.
216 OH at the O(3) site) to repel Na. These interactions will be increased in eckermannite as the octahedral
217 strip contains Mg_4Al instead of $Fe^{2+}_4Fe^{3+}$ (as in arfvedsonite) and hence will be smaller, constraining
218 the A cavity to be smaller than in arfvedsonite and making the Na-H interaction in eckermannite even
219 more constraining than in arfvedsonite. These arguments suggest that arfvedsonite will be much more
220 common than eckermannite, and that the fluoro- species should be more common than the OH species.

221

222

IMPLICATIONS

223 The results of this work emphasize that minerals with complex composition and crystal-
224 chemistry should be carefully characterized using a combination of independent techniques. In
225 particular, the occurrence of Li in amphiboles (either as a B or C cation, or both) should be carefully
226 checked where the geochemistry of the system is compatible with Li. The analyses reported by
227 Adamson (1942), but done by Törnebohm (1906), did not consider either F or Li; rather ironically,
228 the presence of Li would have been easier to detect at a time where wet-chemical analysis was the only
229 method to derive mineral composition. Indeed, Sundius (1945) reported the presence of Li in
230 amphiboles from Norra Kärr, but did not consider re-examination and possibly re-definition of
231 eckermannite. Admittedly, at this time, little was known about amphibole crystal-chemistry; however,
232 it is strange that neither Adamson nor the other scientists studying the Norra Kärr locality (e.g.,
233 Adamson, 1944; von Eckermann, 1968; Blaxland, 1977; Kramm and Koark, 1988) re-considered the
234 composition of "eckermannite". It is worth noting in this regard that any attempt to do structure

Oberti et al. Eckermannite revised

235 refinement data of "eckermannite" would have quickly shown deficiencies in the chemical
236 characterization, confirming that SREF is a very powerful analytical technique.

237 Another conclusion to be drawn from the present work is that one must be cautious with regard
238 to the use of older names in amphiboles (and in other groups or supergroups of rock-forming minerals)
239 as names have been grandfathered without requiring proper characterization. Eckermannite and its
240 ferro- (i.e., magnesio-arfvedsonite) and fluoro-counterparts, katophorite and kaersutite, have all had
241 significant issues with regard to composition, and trivial names have been proposed after recognition
242 solely of homovalent substitutions. We hope that the latest report on amphibole nomenclature
243 (Hawthorne et al., 2012) has put some order in this matter and built a clear set of rules to be followed in
244 the future. In this regard, we are presently checking and characterizing some grandfathered
245 compositions

246

247 **ACKNOWLEDGMENTS**

248

249 Thanks are due to David Smith, loans manager of the Natural History Museum in London for
250 providing a few crystals of sample BM 1949.151, and to Ulf Hålenius of the Swedish Museum of
251 National History for providing crystals from the original material (NMR 570725) described by
252 Törnebohm (1906). This work was funded by the MIUR grant 2009NHLC57_006 to the project
253 "Structure, microstructures and cation ordering: a window on to geological processes and geomaterial
254 properties" by R. Oberti, and by a Canada Research Chair in Crystallography and Mineralogy and a
255 Discovery Grant to FCH from the Natural Sciences and Engineering Research Council of Canada, and
256 by Canada Foundation for Innovation grants to FCH

257

258

Oberti et al. Eckermannite revised

- 259 **REFERENCES CITED**
- 260 Adamson, O.J. (1942) Eckermannite, a new alkali amphibole. Geologiska Föreningens i Stockholm
261 Förhandlingar, 64, 329-334.
- 262 Adamson, O.J. (1944) The petrology of the Nora Kärr district. Geologiska Föreningens i Stockholm
263 Förhandlingar, 66, 113-255.
- 264 Anthony, J.W., Bideaux, R.A., Bladh, K.V., and Nichols, M.C., Eds., Handbook of Mineralogy,
265 Mineralogical Society of America, Chantilly, VA 20151-1110, USA.
266 <http://www.handbookofmineralogy.org/>.
- 267 Bartelmehs, K.L., Bloss, F.D., Downs, R.T., and Birch, J.B. (1992) EXCALIBUR II. Zeitschrift für
268 Kristallographie, 199, 185-196.
- 269 Blaxland, A.B. (1977) Agpaitic magmatism at Norra Kärr? Rb-Sr isotopic evidence. Lithos, 10, 1-8.
- 270 Bruker (2003) SAINT Software Reference Manual. Version 6. Bruker AXS Inc., Madison, Wisconsin,
271 USA.
- 272 Hawthorne, F.C. (1997) Short-range order in amphiboles: a bond-valence approach. Canadian
273 Mineralogist, 35, 201-216.
- 274 Hawthorne, F.C., Ungaretti, L., and Oberti, R. (1995) Site populations in minerals: terminology and
275 presentation of results. Canadian Mineralogist, 33, 907-911.
- 276 Hawthorne, F.C., Oberti, R., and Sardone, N. (1996) Sodium at the *A* site in clinoamphiboles: the effects
277 of composition on patterns of order. Canadian Mineralogist, 34, 577-593.
- 278 Hawthorne, F.C., Oberti, R., Harlow, G.E., Maresch, W.V., Martin, R.F., Schumacher, J.C., and
279 Welch, M.D. (2012) Nomenclature of the amphibole supergroup. American Mineralogist, 97,
280 2031-2048.
- 281 Holtstam, D. (1998) Jinshajiangite from the Norra Kärr alkaline intrusion, Jönköping, Sweden.
282 Geologiska Föreningens I Stockholm Förhandlingar, 120, 373-374.

Oberti et al. Eckermannite revised

- 283 Hughes, R.W., Galibert, O., Bosshart, G., Ward, F., Thet, O., Smith, M., Sun, T.T., and Harlow, G.E.
284 (2000) Burmese jade: the inscrutable gem. *Gems and Gemology*, 36, 2-26.
- 285 Kramm, U., and Koark, H.J. (1988) Isotopic composition of galena lead from the Norra Kärr
286 peralkaline complex, Sweden. *Geologiska Föreningens i Stockholm Förhandlingar*, 110, 311-316.
- 287 Leake, B.E., Woolley, A.R., Arps, C.E.S., Birch, W.D., Gilbert, M.C., Grice, J.D., Hawthorne, F.C.,
288 Kato, A., Kisch, H.J., Krivovichev, V.G., Linthout, K., Laird, J., Mandarino, J.A., Maresch, W.V.,
289 Nickel, E.H., Rock, N.M.S., Schumacher, J.C., Smith, D.C., Stephenson, N.C.N., Ungaretti, L.,
290 Whittaker, E.J.W., and Guo, Y. (1997) Nomenclature of amphiboles: Report of the subcommittee
291 on amphiboles of the International Mineralogical Association, Commission on New Minerals and
292 Mineral Names. *Canadian Mineralogist*, 35, 219-246.
- 293 Nambu, M., Tanida, K., and Kitamura, T. (1969) Kôzulite, a new alkali amphibole, from Tanohata
294 mine, Iwate Prefecture, Japan. *Journal of the Japanese Association of Mineralogists, Petrologists
295 and Economic Geologists*, 62, 311-328.
- 296 Oberti, R., Ungaretti, L., Cannillo, E., and Hawthorne, F.C. (1992) The behaviour of Ti in amphiboles: I.
297 Four- and six-coordinated Ti in richterites. *European Journal of Mineralogy*, 4, 425-439.
- 298 Oberti, R., Cámara, F., Hawthorne, F.C., and Ball, N.A. (2009) Fluoro-aluminoleakeite,
299 $\text{NaNa}_2(\text{Mg}_2\text{Al}_2\text{Li})\text{Si}_8\text{O}_{22}\text{F}_2$, a new mineral of the amphibole group from Norra Kärr, Sweden:
300 description and crystal structure. *Mineralogical Magazine*, 73, 817-824.
- 301 Sheldrick, G.M. (1996). SADABS Siemens Area Detector Absorption Correction Program. University
302 of Göttingen, Göttingen.
- 303 Shi, G.H., Cui, W.Y., Tropper, P., Wang, C.Q., Shu, G.M., and Yu, H.X. (2003) The petrology of a
304 complex sodic and sodic-calcic amphibole association and its implications for the metasomatic
305 processes in the jadeitite area in northwestern Myanmar, formerly Burma. *Contributions to
306 Mineralogy and Petrology*, 145, 355-376.

Oberti et al. Eckermannite revised

- 307 Shi, G.H., Harlow, G.E., Wang, Ji., Wang, Ju., Enoch, N.G., Wang, X., Cao, S., and Cui, W. (2012)
308 Mineralogy of jadeitite and related rocks from Myanmar: a review with new data. European
309 Journal of Mineralogy, 24, 345-370.
- 310 Sundius, N. (1945) The composition of eckermannite and its position in the amphibole group. Årsbok
311 Sveriges Geologiska Undersökning, 39 (8), 3-7.
- 312 Törnebohm, A. (1906): Katapleit-syenit, en nyupptäkt variant af nefelinsyenit i Sverige. Sveriges
313 Geologiska Undersökning, C 199, 1-54 (in Swedish).
- 314 von Eckermann, C.V.H. (1968) New contributions to the interpretation of the genesis of the Norra Kärr
315 alkaline body in Southern Sweden. Lithos, 1, 76-88.
- 316
- 317

Oberti et al. Eckermannite revised

318 **TABLE 1.** Refined site-scattering values (ss), atom coordinates and displacement parameters ($\beta_{ii} \times 10^4$)
 319 for eckermannite AMNH H108401, fluoro-leakeite BM 1949.151(former eckermannite holotype) and
 320 fluoro-leakeite NMR 570725.

| Atom | ss (epfu.) | <i>x/a</i> | <i>y/b</i> | <i>z/c</i> | <i>B</i> _{eq} (Å ²) | β_{11} | β_{22} | β_{33} | β_{12} | β_{13} | β_{23} |
|---------------------|------------|-------------|-------------|-------------|--|--------------|--------------|--------------|--------------|--------------|--------------|
| AMNH H108401 | | | | | | | | | | | |
| O(1) | | 0.11100(17) | 0.08805(9) | 0.21287(32) | 0.85(3) | 19 | 8 | 76 | -2 | 9 | -4 |
| O(2) | | 0.11802(17) | 0.16990(9) | 0.73412(31) | 0.94(4) | 24 | 7 | 82 | 0 | -4 | -1 |
| O(3) | 16.49(6) | 0.10828(24) | 0 | 0.70978(46) | 1.05(5) | 25 | 9 | 101 | - | 7 | - |
| O(4) | | 0.36274(19) | 0.25079(10) | 0.79757(34) | 1.16(4) | 43 | 7 | 103 | -5 | 21 | 0 |
| O(5) | | 0.34970(17) | 0.12893(10) | 0.08338(32) | 1.03(4) | 21 | 11 | 79 | -1 | 3 | 8 |
| O(6) | | 0.34156(17) | 0.11827(10) | 0.58486(32) | 1.09(4) | 27 | 11 | 73 | 0 | 4 | -7 |
| O(7) | | 0.33725(25) | 0 | 0.28952(49) | 1.15(6) | 30 | 7 | 142 | - | 13 | - |
| T(1) | | 0.27930(6) | 0.08630(3) | 0.29240(12) | 0.67(1) | 18 | 6 | 55 | 0 | 4 | -1 |
| T(2) | | 0.28706(6) | 0.17250(3) | 0.80083(12) | 0.73(1) | 21 | 6 | 59 | -1 | 6 | 0 |
| M(1) | 25.72(14) | 0 | 0.09002(6) | 1/2 | 0.80(3) | 23 | 7 | 66 | - | 8 | - |
| M(2) | 29.70(14) | 0 | 0.18130(5) | 0 | 0.81(2) | 21 | 7 | 72 | - | 7 | - |
| M(3) | 12.95(4) | 0 | 0 | 0 | 0.77(4) | 24 | 6 | 58 | - | 4 | - |
| M(4) | 23.81(18) | 0 | 0.27541(8) | 1/2 | 1.51(4) | 46 | 11 | 162 | - | 40 | - |
| A | 3.52(4) | 0 | 1/2 | 0 | 1.6(2) | 21 | 19 | 206 | - | 61 | - |
| A(m) | 3.03(11) | 0.0259(16) | 1/2 | 0.0717(25) | 3.0(4) | 80 | 26 | 245 | - | 10 | - |
| A(2) | 4.87(11) | 0 | 0.4733(40) | 0 | 3.1(2) | 86 | 9 | 574 | - | 153 | - |
| H | 1.75(16) | 0.204(5) | 0 | 0.740(9) | 1.0 | | | | | | |
| BM 1949.151 | | | | | | | | | | | |
| O(1) | | 0.10796(9) | 0.09295(5) | 0.21081(17) | 0.70(2) | 15 | 7 | 64 | -1 | 9 | -2 |
| O(2) | | 0.11774(9) | 0.17108(5) | 0.74128(18) | 0.68(2) | 16 | 6 | 70 | 0 | 8 | 1 |
| O(3) | 17.29(8) | 0.11398(13) | 0 | 0.69640(25) | 0.99(3) | 27 | 7 | 105 | - | 3 | - |
| O(4) | | 0.36646(10) | 0.25172(5) | 0.80655(18) | 0.80(2) | 29 | 5 | 79 | -4 | 20 | -2 |
| O(5) | | 0.35207(10) | 0.12899(5) | 0.08840(18) | 0.73(2) | 18 | 8 | 60 | 0 | 11 | 7 |
| O(6) | | 0.34187(10) | 0.12059(5) | 0.58567(18) | 0.76(2) | 22 | 8 | 52 | 1 | 9 | -7 |
| O(7) | | 0.33211(15) | 0 | 0.30121(28) | 0.92(3) | 30 | 4 | 115 | - | 14 | - |
| T(1) | | 0.27745(3) | 0.08705(2) | 0.29475(7) | 0.46(1) | 14 | 4 | 41 | -1 | 6 | -1 |
| T(2) | | 0.28951(3) | 0.17255(2) | 0.80684(6) | 0.48(1) | 15 | 4 | 40 | -1 | 8 | 0 |
| M(1) | 28.83(8) | 0 | 0.08757(3) | 1/2 | 0.59(1) | 20 | 5 | 48 | - | 13 | - |
| M(2) | 36.50(8) | 0 | 0.17914(2) | 0 | 0.51(1) | 15 | 4 | 48 | - | 8 | - |
| M(3) | 4.90(4) | 0 | 0.0000 | 0 | 0.83(6) | 27 | 5 | 76 | - | 2 | - |
| M(4) | 22.06(5) | 0 | 0.27668(5) | 1/2 | 1.08(2) | 37 | 7 | 121 | - | 40 | - |
| A | 1.79(19) | 0 | 1/2 | 0 | 1.5(1) | | | | | | |
| A(m) | 12.56(8) | 0.0425(2) | 1/2 | 0.0888(4) | 2.7(1) | 100 | 16 | 322 | - | 133 | - |
| H | 0.49(10) | 0.203(13) | 0 | 0.734(24) | 1.0 | | | | | | |
| NMR 570725 | | | | | | | | | | | |
| O(1) | | 0.10827(10) | 0.09276(6) | 0.21145(19) | 0.82(2) | 22 | 9 | 61 | -1 | 10 | -2 |
| O(2) | | 0.11782(11) | 0.17085(6) | 0.74050(19) | 0.81(2) | 23 | 7 | 68 | -1 | 7 | 0 |
| O(3) | 17.29(4) | 0.11319(15) | 0 | 0.69597(27) | 1.10(3) | 33 | 7 | 106 | - | 6 | - |
| O(4) | | 0.36628(11) | 0.25151(6) | 0.80595(20) | 0.98(2) | 39 | 6 | 80 | -4 | 21 | 0 |
| O(5) | | 0.35170(11) | 0.12899(6) | 0.08874(19) | 0.85(2) | 24 | 9 | 60 | 0 | 11 | 7 |
| O(6) | | 0.34210(11) | 0.12043(6) | 0.58625(19) | 0.88(2) | 27 | 9 | 57 | 0 | 10 | -6 |
| O(7) | | 0.33217(17) | 0 | 0.30097(31) | 1.10(3) | 38 | 5 | 120 | - | 12 | - |
| T(1) | | 0.27760(4) | 0.08704(2) | 0.29523(7) | 0.59(1) | 21 | 5 | 45 | -1 | 8 | -1 |
| T(2) | | 0.28923(4) | 0.17251(2) | 0.80668(7) | 0.62(1) | 22 | 5 | 44 | -1 | 10 | 0 |
| M(1) | 28.28(6) | 0 | 0.08783(3) | 1/2 | 0.72(1) | 25 | 6 | 52 | - | 14 | - |
| M(2) | 36.63(5) | 0 | 0.17940(2) | 0 | 0.68(1) | 22 | 6 | 53 | - | 11 | - |
| M(3) | 6.14(2) | 0 | 0.0000 | 0 | 0.89(5) | 31 | 6 | 72 | - | 9 | - |

Oberti et al. Eckermannite revised

| | | | | | | | | | | | |
|-----------------------|----------|-------------|------------|-------------|---------|-----|----|-----|---|-----|---|
| <i>M</i> (4) | 22.08(5) | 0 | 0.27654(5) | 1/2 | 1.25(2) | 43 | 9 | 129 | - | 43 | - |
| <i>A</i> | 1.72(4) | 0 | 1/2 | 0 | 1.4(2) | 32 | 21 | 87 | - | 50 | - |
| <i>A</i> (<i>m</i>) | 12.72(8) | 0.04191(35) | 1/2 | 0.08706(65) | 2.9(1) | 111 | 17 | 340 | - | 138 | - |
| H | 0.41(12) | 0.208(5) | 0 | 0.735(26) | 1.0 | | | | | | |

321

322

Oberti et al. Eckermannite revised

323 **TABLE 2.** Selected interatomic distances (Å) and angles (°) in eckermannite AMNH H108401 and
 324 fluoro-leakeite BM 1949.151 and NMR 570725.

| | AMNH | BM | NMR | | AMNH | BM | NMR |
|----------------------------|----------|----------|----------|---------------------------------|----------|----------|----------|
| | H108401 | 1949.151 | 570725 | | H108401 | 1949.151 | 570725 |
| <i>T</i> (1)–O(1) | 1.605(2) | 1.600(1) | 1.599(1) | <i>T</i> (2)–O(2) | 1.612(2) | 1.619(1) | 1.616(1) |
| <i>T</i> (1)–O(5) | 1.624(2) | 1.628(1) | 1.625(1) | <i>T</i> (2)–O(4) | 1.584(2) | 1.591(1) | 1.588(1) |
| <i>T</i> (1)–O(6) | 1.627(2) | 1.626(1) | 1.624(1) | <i>T</i> (2)–O(5) | 1.668(2) | 1.656(1) | 1.657(1) |
| <i>T</i> (1)–O(7) | 1.643(1) | 1.630(1) | 1.630(1) | <i>T</i> (2)–O(6) | 1.678(2) | 1.662(1) | 1.662(1) |
| < <i>T</i> (1)–O> | 1.625 | 1.621 | 1.619 | < <i>T</i> (2)–O> | 1.636 | 1.632 | 1.631 |
| <i>M</i> (1)–O(1) ×2 | 2.068(2) | 2.054(1) | 2.052(1) | <i>M</i> (2)–O(1) ×2 | 2.155(2) | 2.027(1) | 2.035(1) |
| <i>M</i> (1)–O(2) ×2 | 2.056(2) | 2.102(1) | 2.094(1) | <i>M</i> (2)–O(2) ×2 | 2.032(2) | 1.988(1) | 1.993(1) |
| <i>M</i> (1)–O(3) ×2 | 2.094(2) | 2.039(1) | 2.038(1) | <i>M</i> (2)–O(4) ×2 | 1.936(2) | 1.894(1) | 1.895(1) |
| < <i>M</i> (1)–O> | 2.073 | 2.065 | 2.061 | < <i>M</i> (2)–O> | 2.041 | 1.970 | 1.974 |
| <i>M</i> (3)–O(1) ×4 | 2.084(2) | 2.119(1) | 2.118(1) | <i>M</i> (4)–O(2) ×2 | 2.396(2) | 2.394(1) | 2.393(1) |
| <i>M</i> (3)–O(3) ×2 | 2.063(2) | 2.159(1) | 2.155(1) | <i>M</i> (4)–O(4) ×2 | 2.348(2) | 2.362(1) | 2.358(1) |
| < <i>M</i> (3)–O> | 2.077 | 2.132 | 2.131 | <i>M</i> (4)–O(5) ×2 | 2.900(2) | 2.842(1) | 2.842(1) |
| <i>A</i> –O(5) ×4 | 2.823(2) | 2.800(1) | 2.802(1) | <i>M</i> (4)–O(6) ×2 | 2.558(2) | 2.493(1) | 2.497(1) |
| <i>A</i> –O(6) ×4 | 3.175(2) | 3.177(1) | 3.172(2) | < <i>M</i> (4)–O> | 2.551 | 2.523 | 2.523 |
| <i>A</i> –O(7) ×2 | 2.460(3) | 2.539(1) | 2.537(2) | <i>A</i> (<i>m</i>)–O(5) ×2 | 2.887(2) | 2.941(2) | 2.941(2) |
| < <i>A</i> –O> | 2.891 | 2.899 | 2.897 | <i>A</i> (<i>m</i>)–O(5) ×2 | 2.816(2) | 2.761(2) | 2.761(2) |
| <i>A</i> (2)–O(5) ×2 | 2.450(2) | - | - | <i>A</i> (<i>m</i>)–O(6) ×2 | 2.886(2) | 2.803(2) | 2.804(3) |
| <i>A</i> (2)–O(6) ×2 | 2.880(2) | - | - | <i>A</i> (<i>m</i>)–O(7) | 2.400(3) | 2.558(2) | 2.557(3) |
| <i>A</i> (2)–O(7) ×2 | 2.505(3) | - | - | <i>A</i> (<i>m</i>)–O(7) | 3.329(3) | 3.158(2) | 3.166(4) |
| < <i>A</i> (2)–O> | 2.612 | | | <i>A</i> (<i>m</i>)–O(7) | 2.582(3) | 2.636(2) | 2.629(3) |
| | | | | < <i>A</i> (<i>m</i>)–O> | 2.832 | 2.818 | 2.818 |
| O(3)–H | 0.91(1) | 0.84(1) | 0.89(1) | <i>T</i> (1)–O(5)– <i>T</i> (2) | 134.6(1) | 133.6(1) | 133.8(1) |
| <i>M</i> (1)– <i>M</i> (2) | 3.107(1) | 3.102(1) | 3.100(1) | <i>T</i> (1)–O(6)– <i>T</i> (2) | 137.9(1) | 139.0(1) | 138.7(1) |
| | | | | <i>T</i> (1)–O(7)– <i>T</i> (1) | 139.2(1) | 142.5(1) | 142.5(1) |
| O(5)–O(6)–O(5) | 171.1(1) | 172.3(1) | 172.4(1) | O(6)–O(7)–O(6) | 107.3(1) | 110.5(1) | 110.3(1) |

325

326

Oberti et al. Eckermannite revised

327 **TABLE 3.** Powder X-ray data for eckermannite AMNH H108401. The ten strongest line are in bold.

| <i>I</i> _{rel} | <i>d</i> (calc) | <i>h k l</i> | <i>I</i> _{rel} | <i>d</i> (calc) | <i>h k l</i> | <i>I</i> _{rel} | <i>d</i> (calc) | <i>h k l</i> | <i>I</i> _{rel} | <i>d</i> (calc) | <i>h k l</i> |
|-------------------------|-----------------|---------------|-------------------------|-----------------|---------------|-------------------------|-----------------|--------------|-------------------------|-----------------|--------------|
| 4 | 8.920 | 0 2 0 | 36 | 2.574 | 0 6 1 | 4 | 1.921 | -3 5 2 | 8 | 1.628 | 4 8 0 |
| 42 | 8.407 | 1 1 0 | | | 0 0 2 | 9 | 1.895 | 5 1 0 | 9 | 1.599 | 1 11 0 |
| 13 | 4.859 | -1 1 1 | 56 | 2.525 | -2 0 2 | 4 | 1.876 | 2 4 2 | 6 | 1.588 | 6 0 0 |
| 6 | 4.766 | 2 0 0 | 5 | 2.384 | -2 6 1 | 4 | 1.862 | -4 6 1 | 21 | 1.579 | -1 5 3 |
| 30 | 4.460 | 0 4 0 | 7 | 2.373 | 3 5 0 | 8 | 1.846 | -1 9 1 | 11 | 1.521 | -6 0 2 |
| 9 | 4.028 | 1 1 1 | 27 | 2.315 | -3 5 1 | 4 | 1.824 | -4 4 2 | 23 | 1.508 | -2 6 3 |
| 16 | 3.850 | -1 3 1 | 18 | 2.275 | -1 7 1 | 4 | 1.816 | 5 3 0 | 14 | 1.487 | 0 12 0 |
| 59 | 3.395 | 1 3 1 | 20 | 2.261 | -3 1 2 | 7 | 1.786 | 1 9 1 | 6 | 1.445 | 3 11 0 |
| 34 | 3.257 | 2 4 0 | 9 | 2.197 | -2 4 2 | | | 0 10 0 | 6 | 1.440 | -6 4 2 |
| 56 | 3.128 | 3 1 0 | 33 | 2.161 | 2 6 1 | 4 | 1.732 | -5 1 2 | 28 | 1.430 | -6 6 1 |
| 7 | 2.997 | -3 1 1 | 10 | 2.128 | -3 3 2 | 9 | 1.687 | -1 3 3 | 3 | 1.415 | -5 3 3 |
| 33 | 2.966 | 0 6 0 | 17 | 2.067 | 2 0 2 | | | 0 2 3 | 11 | 1.379 | 5 1 2 |
| 12 | 2.915 | -1 5 1 | 9 | 2.023 | 3 5 1 | 9 | 1.684 | -1 3 3 | 7 | 1.348 | -5 5 3 |
| 18 | 2.802 | 3 3 0 | 8 | 1.999 | -4 0 2 | | | 0 2 3 | | | 5 3 2 |
| 100 | 2.702 | -3 3 1 | 6 | 1.942 | 4 2 1 | 8 | 1.672 | -2 8 2 | | | |
| | | 1 5 1 | | | 1 9 0 | 25 | 1.654 | 4 6 1 | | | |

328

Oberti et al. Eckermannite revised

329 **TABLE 4.** EMP analysis (10 points) and unit formula calculated based on 24 (O,OH,F,Cl) and 2
 330 (OH,F,Cl) for the refined crystal of holotype eckermannite AMNH H108401 (1213 in the CNR-IGG-
 331 Pv database); ss = site scattering (electrons per formula unit, epfu); bdl = below detection limit

| | wt% esd | | | apfu |
|-----------------------------------|---------|------------|------------------|------|
| SiO ₂ | 59.30 | 0.24 | Si | 8.00 |
| TiO ₂ | 0.03 | 0.02 | Al | 0.00 |
| Al ₂ O ₃ | 3.89 | 0.61 | Σ T | 8.00 |
| Cr ₂ O ₃ | bdl | | Ti | 0.00 |
| Fe ₂ O ₃ | 3.78 | | Al | 0.62 |
| FeO* | 0.80 | | Fe ³⁺ | 0.38 |
| MnO | 0.07 | 0.02 | Fe ²⁺ | 0.09 |
| MgO | 19.25 | 0.14 | Mg | 3.87 |
| ZnO | bdl | | Mn ²⁺ | 0.01 |
| CaO | 0.77 | 0.12 | Σ C | 4.97 |
| Na ₂ O | 10.56 | 0.18 | Ca | 0.11 |
| K ₂ O | 0.32 | 0.03 | Na | 1.89 |
| F | 0.06 | 0.04 | Σ B | 2.00 |
| Cl | bdl | | Na | 0.87 |
| O=F,Cl | 0.03 | | K | 0.06 |
| (H ₂ O) _{cal} | 2.19 | | Σ A | 0.93 |
| Total | 101.00 | | F | 0.03 |
| | | | OH | 1.97 |
| | | | Σ W | 2.00 |
| calculated ss | | refined ss | | |
| ss C | 67.08 | ss C | 68.37 | |
| ss B | 23.00 | ss B | 23.81 | |
| ss A | 10.35 | ss A | 11.42 | |
| Total | 100.75 | Total | 103.60 | |

332 * esd for FeO(total) = 0.59

333

Oberti et al. Eckermannite revised

334 **TABLE 5.** Comparative data for holotype eckermannite AMNH H108401 (this work), holotype fluoro-
 335 leakeite (Oberti et al., 2009), the discredited holotype eckermannite kept at the Natural History
 336 Museum in London (with optical properties taken by the compilation in the Handbook of Mineralogy
 337 (Anthony et al., presently © MSA) and marked with *), and sample NMR 570725 originally described
 338 in Törnebohm (1906).

| | Eckermannite Jade Mine tract AMNH H108401 | Fluoro-leakeite Norra Kärr | "Eckermannite" Norra Kärr BM 1949.151 | "Eckermannite" Norra Kärr NMR 570725 |
|---------------------------------|---|-------------------------------|---|--|
| <i>a</i> (Å) | 9.8087(7) | 9.7043(5) | 9.7073(5) | 9.7094(6) |
| <i>b</i> | 17.8448(13) | 17.7341(8) | 17.7339(6) | 17.7305(12) |
| <i>c</i> | 5.2905(4) | 5.2833(3) | 5.2850(4) | 5.2815(3) |
| β (°) | 103.660(1) | 104.067(4) | 104.029(5) | 104.040(1) |
| <i>V</i> (Å ³) | 899.83(11) | 881.97(8) | 882.67(9) | 882.06(10) |
| <i>a:b:c</i> | 0.550:1:0.297 | 0.547:1:0.298 | 0.547:1:0.298 | 0.548:1:0.298 |
| Space group | <i>C2/m</i> | <i>C2/m</i> | <i>C2/m</i> | <i>C2/m</i> |
| Optic sign | Biaxial (-) | Biaxial (-) | Biaxial (-)* | Biaxial (-) |
| α | 1.605 | 1.632 | 1.610-1.640* | 1.636 |
| β | 1.630 | 1.638 | 1.625-1.650* | 1.644 |
| γ | 1.634 | 1.643 | 1.630-1.655* | 1.649 |
| $2V$ (°) | 43 | 98 | 15-80* | 74 |
| Colour | Pale grey | Pale greenish blue | Bluish green to dark green* | Bluish green to dark green* |
| Pleochroism | Pale grey to medium grey | Pale-green to dark-green | Pale green to dark green | Colourless to bluish green |
| < <i>T</i> (1)-O> (Å) | 1.625 | 1.620 | 1.621 | 1.619 |
| < <i>T</i> (2)-O> (Å) | 1.636 | 1.631 | 1.632 | 1.631 |
| < <i>M</i> (1)-O> (Å) | 2.073 | 2.064 | 2.065 | 2.061 |
| < <i>M</i> (2)-O> (Å) | 2.041 | 1.968 | 1.970 | 1.974 |
| < <i>M</i> (3)-O> (Å) | 2.077 | 2.133 | 2.132 | 2.131 |
| < <i>M</i> (4)-O> (Å) | 2.551 | 2.523 | 2.523 | 2.523 |
| ss <i>M</i> (1) (epfu) | 25.72 | 28.86 | 28.83 | 28.28 |
| ss <i>M</i> (2) (epfu) | 29.70 | 37.00 | 36.50 | 36.63 |
| ss <i>M</i> (3) (epfu) | 12.95 | 4.81 | 4.90 | 6.14 |
| ss <i>M</i> (4) (epfu) | 23.81 | 22.30 | 22.06 | 22.08 |
| ss <i>A</i> (epfu) | 3.52 | 3.75 | 1.79 | 1.72 |
| ss <i>A</i> (<i>m</i>) (epfu) | 3.03 | 10.69 | 12.56 | 12.72 |
| ss <i>A</i> (2) (epfu) | 4.87 | - | - | - |

Oberti et al. Eckermannite revised

339 **TABLE 6.** Site occupancies proposed for eckermannite AMNH H108401 based on the results of
340 the structure refinement.

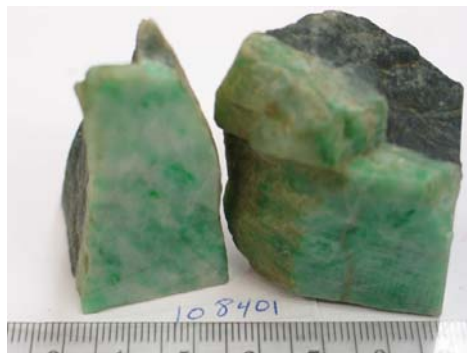
| Site | Site population (apfu) | site scattering (epfu) | |
|--------------|---|------------------------|------------|
| | | refined | calculated |
| <i>T</i> (1) | 4 Si | | |
| <i>T</i> (2) | 4 Si | | |
| <i>M</i> (1) | 1.90 Mg + 0.10 Fe ²⁺ | 25.72 | 25.40 |
| <i>M</i> (2) | 1.04 Mg + 0.62 Al + 0.34 Fe ³⁺ | 29.70 | 29.38 |
| <i>M</i> (3) | 0.96 Mg + 0.03 Fe ²⁺ + 0.01 Mn | 12.95 | 12.55 |
| Σ C sites | | 69.37 | 67.33 |
| B site | 1.89 Na + 0.11 Ca | 23.81 | 22.99 |
| A site | 0.87 Na + 0.06 K | 11.42 | 10.71 |

341

342

Oberti et al. Eckermannite revised

343



344

345

346 **FIGURE 1.** Jadeitite-amphibole fels rock catalogued as AMNH H108401 in the mineral collection of the
347 American Museum of Natural History

348