

1

## Revision 1

2

# Nomenclature of the Garnet Supergroup

3

Edward S. Grew (Chair)<sup>1\*</sup>, Andrew J. Locock<sup>2</sup>, Stuart J. Mills (Vice-Chair)<sup>3</sup>,

4

Irina O. Galuskina<sup>4</sup>, Evgeny V. Galuskin<sup>4</sup> and Ulf Hålenius<sup>5</sup>

5

<sup>1</sup>Department of Earth Sciences, University of Maine, Orono, Maine 04469, U.S.A.

6

<sup>2</sup>Department of Earth and Atmospheric Sciences, University of Alberta,

7

Edmonton, Alberta T6G 2E3, Canada

8

<sup>3</sup>Geosciences, Museum Victoria, GPO Box 666, Melbourne 3001, Victoria, Australia

9

<sup>4</sup>Faculty of Earth Sciences, Department of Geochemistry, Mineralogy and Petrography, University  
of Silesia, Będzińska 60, 41-200 Sosnowiec, Poland

10

11

<sup>5</sup>Swedish Museum of Natural History, Department of Mineralogy,

12

13

P.O. Box 50 007, 104 05 Stockholm, Sweden

14

\*[esgrew@maine.edu](mailto:esgrew@maine.edu)

15

16

### ABSTRACT

17

The garnet supergroup includes all minerals isostructural with garnet regardless of what elements occupy the four atomic sites, i.e., the supergroup includes several chemical classes. There are presently 32 approved species, with an additional 5 possible species needing further study in order to be approved. The general formula for the garnet supergroup minerals is  $\{X_3\}[Y_2](Z_3)\phi_{12}$ , where  $X$ ,  $Y$  and  $Z$  refer to dodecahedral, octahedral and tetrahedral sites, respectively, and  $\phi$  is O, OH or F. Most garnets are cubic, space group  $Ia-3d$  (no. 230), but two OH-bearing species (henritermierite and holtstamite) have tetragonal symmetry, space group,  $I4_1/acd$  (no. 142), and their  $X$ ,  $Z$  and  $\phi$  sites are split into more symmetrically-unique atomic positions. Total charge at the  $Z$  site and symmetry are criteria for distinguishing groups, whereas the dominant-constituent and dominant-valency rules are critical in identifying species. Twenty-nine species belong to one of five groups: the tetragonal henritermierite group and the isometric bitikleite, schorlomite, garnet and berzeliite groups with a total charge at  $Z$  of 8 (silicate), 9 (oxide), 10 (silicate), 12 (silicate) and 15 (vanadate, arsenate), respectively. Three species are single representatives of potential groups in which  $Z$  is vacant or occupied by monovalent (halide, hydroxide) or divalent cations (oxide). We recommend that suffixes (other than Levinson modifiers) not be used in naming minerals in the garnet supergroup. Existing names with suffixes have been replaced with new root names where necessary: bitikleite-(SnAl) to bitikleite, bitikleite-(SnFe) to dzhuluite, bitikleite-(ZrFe) to usturite and elbrusite-(Zr) to elbrusite. The name hibschite has been discredited in favor of grossular as Si is

34

35 the dominant cation at the Z site. Twenty-one end-members have been reported as subordinate  
36 components in minerals of the garnet supergroup of which six have been reported in amounts up to  
37 20 mol% or more, and, thus, there is potential for more species to be discovered in the garnet  
38 supergroup. The nomenclature outlined in this report has been approved by the Commission on  
39 New Minerals, Nomenclature and Classification of the International Mineralogical Association.

40 **Keywords:** garnet group, schorlomite group, bitikleite group, berzeliite group, henritermierite  
41 group, katoite, nomenclature, crystal chemistry

42

43

## INTRODUCTION

44 The garnets pose somewhat different nomenclature problems than other mineral supergroups  
45 recently considered for nomenclature review, i.e., sapphirine (Grew et al. 2008), apatite (Pasero et  
46 al. 2010), pyrochlore (Atencio et al. 2010), tourmaline (Henry et al. 2011) and amphibole  
47 (Hawthorne et al. in press), where a supergroup is defined as “consisting of two or more groups that  
48 have essentially the same structure and composed of chemically similar elements” (Mills et al.  
49 2009). Compared to the structures of the minerals in these groups, the archetypal garnet structure,  
50 cubic space group *Ia-3d* (no. 230) has few sites: only three cationic and one anionic (e.g., Menzer  
51 1928; Novak and Gibbs 1971; Merli et al. 1995; Geiger 2008), and the most common garnets have  
52 relatively simple chemical compositions. However, the garnet structure is remarkably flexible in a  
53 chemical sense: 53 elements were reported in the Inorganic Crystal Structure Database (Allmann  
54 and Hinek 2007) and five more are reported in synthetic garnets (Geller 1967; Ronniger and Mill’  
55 1973; Yudintsev 2003; Yudintsev et al. 2002; Utsunomiya et al. 2005). In the period 2009-2010, 10  
56 new species of garnet, with constituents such as Sc, Y, Sn, Sb and U, which have not been  
57 previously reported in significant quantities in natural garnet, were approved by the Commission on  
58 New Minerals, Nomenclature and Classification (CNMNC) of the International Mineralogical  
59 Association (IMA), resulting in a nearly 50% increase in the number of accepted species with the  
60 garnet structure. There are four more possible species, bringing to 26 the number of elements  
61 essential to defining existing and possible mineral species with the garnet structure.

62 In view of this situation, it seemed an opportune time to convene a subcommittee to review  
63 the nomenclature of garnets. The garnet group traditionally included only silicate minerals (e.g.,  
64 Yakovlevskaya 1972; Strunz and Nickel 2001; Back and Mandarino 2008). However, there are  
65 minerals from other classes, such as arsenates, vanadates, oxides and even fluorides that are  
66 isostructural with the silicate garnets, and whose major constituents show chemical similarities with  
67 constituents in silicate garnets, i.e., these minerals meet the criteria for inclusion in a broader entity,

68 the garnet supergroup (Mills et al. 2009). McConnell (1942) introduced the term “garnetoid” to  
69 “designate those substances which are not primarily silicates but have structures similar to that of  
70 true garnets,” such as “hydrogarnet,” berzeliite and the phosphate griphite (Headden 1891). It does  
71 not appear that garnetoid was discredited as a group name (Clark 1993), but our preference is to use  
72 the term garnet for the supergroup. Rinaldi (1978) showed that griphite is not isostructural with  
73 garnet, although he found that there are some structural features in common, which were also  
74 discussed by Sokolova and Hawthorne (2002), and thus griphite is not considered to be a garnet. In  
75 addition, the silicate mineral wadalite had been thought to be related to garnet because of  
76 similarities in cell dimensions and diffraction intensities (Feng et al. 1988; Tsukimura et al. 1993;  
77 Glasser 1995). Although wadalite lacks a center of symmetry, so that the single tetrahedral site  
78 found in grossular is split in wadalite into two sites, one of which is vacant, it still can be considered  
79 a derivative of grossular, but Glasser (1995) emphasized the much closer relationship of wadalite to  
80 mayenite. Recent crystal structure refinements make no mention of a relationship of wadalite or  
81 mayenite to garnet (Boysen et al. 2007; Iwata et al. 2008; Ma et al. 2011), and the structural  
82 relationship between garnet and wadalite (or mayenite) is sufficiently distant that these minerals are  
83 not included in the garnet supergroup. The so-called “tetragonal almandine-pyrope phase” (TAPP)  
84 has the stoichiometry, but not the structure of garnet (Harris et al. 1997; Finger and Conrad 2000),  
85 i.e., TAPP has edges shared between tetrahedra and octahedra, a feature not found in garnet (see  
86 below) and thus is not considered further in this report. Similarly, although some natural and  
87 synthetic arsenates of the alluaudite group, e.g., caryinite, are approximately polymorphous with the  
88 garnet supergroup mineral manganberzeliite (Ercit 1993; Khohari et al. 1995, 1997), the structures  
89 of alluaudite-group compounds are too different from garnet to warrant further consideration of the  
90 alluaudite group in this report.

91 Twenty-nine of the 32 approved species of the garnet supergroup are divided here into five  
92 groups on the basis of the total charge of cations at the tetrahedral site, leaving three ungrouped  
93 species (Table 1); four potential new species can be accommodated in two of these groups (see  
94 below). One group is also distinguished on the basis of symmetry: the tetragonal henritermierite  
95 group (Fig. 1a). The classification in Table 1 keeps the number of groups at a practical level that  
96 still reflects crystal-chemical relationships. Table 1 also gives the class for the five groups and  
97 ungrouped species in order to emphasize that the garnet supergroup comprises not only silicates  
98 (Fig. 1a, c-e), but also a halide (Fig. 1b), hydroxides, oxides, vanadates and arsenates (Fig. 1g). The  
99 groups are listed in order of increasing charge of cations that occupy the Z site of the end-members.  
100 Species within each group are listed as end-members with increasing atomic number of the Z site,  
101 followed by increasing atomic number of the Y site and lastly, by increasing atomic number of the X  
102 site, whereas species with joint occupancies at the Y site are placed last. Table 2 lists the 32 species

103 as end-members in the same order and compares formulae given in the 2009 list (updated in 2012)  
104 of minerals approved by the CNMNC with the end-member formulae approved with the  
105 classification presented here.

106 Subdivision of the groups into mineral subgroups or mineral series is not recommended, as  
107 these terms should be reserved for homologous or polysomatic series (Mills et al. 2009). This  
108 restriction constitutes another rationale for discouraging the traditional division of the garnet group  
109 into the “pyralspite” and “ugrandite” species (Winchell 1933) or series (Strunz and Nickel 2001),  
110 although there could be some fundamental structural differences that limit solid solution between  
111 the two groupings (e.g., Ungaretti et al. 1995; Boiocchi et al. 2012; cf. Geiger 2008).

112 Our procedure for distinguishing species relies heavily on the dominant-valency rule, which is  
113 an extension of the dominant-constituent rule (Hatert and Burke 2008). The latter rule states that  
114 species designation is based on the dominant constituent at a given crystallographic site, which  
115 works well when all constituents have the same valence. However, when ions at a given  
116 crystallographic site have different valences, it is essential that the dominant valence be determined  
117 first, and then species and group designation is determined by the dominant ion having this valence.  
118 Traditionally, identifying a garnet species has relied heavily on the proportion of end-member  
119 components, and therefore depended on a specific sequence of calculating end-member proportions:  
120 garnet end-member proportions constitute an underdetermined system from the point of view of  
121 linear algebra: there are more end-members than oxides (e.g., Rickwood 1968; Locock 2008).

122 The purpose of this report is to present the essential elements of garnet nomenclature, to  
123 define concepts that are central to garnet classification, and to provide practical guidelines for  
124 application of the nomenclature in distinguishing species. The nomenclature outlined in this report  
125 has been approved by the CNMNC (Voting proposal 11-D, April 3, 2012).

126

## 127 **CRYSTALLOGRAPHIC AND CRYSTAL-CHEMICAL ASPECTS** 128 **OF GARNET-SUPERGROUP MINERALS**

129 In the structure of cubic garnets (e.g., Menzer 1928; Novak and Gibbs 1971; Hawthorne 1981;  
130 Merli et al. 1995; Geiger 2008), space group *Ia-3d* (no. 230), there are only four symmetrically  
131 unique atomic sites (not including hydrogen): dodecahedral {*X*}, octahedral [*Y*] and tetrahedral (*Z*)  
132 cation sites, as well as an anionic site designated  $\phi$  to indicate O, OH, and F, giving a generalized  
133 chemical formula for the garnet supergroup,  $\{X_3\}[Y_2](Z_3)\phi_{12}$  (modified after Geller 1967). The three  
134 cation sites are at special positions fixed by symmetry, with the Wyckoff positions 24*c*, 16*a* and 24*d*  
135 respectively, whereas the anion site is located at a general position, 96*h*. The structure consists of

136 alternating  $Z\phi_4$  tetrahedra and  $Y\phi_6$  octahedra, which share corners to form a three-dimensional  
137 framework (Fig. 2). Cavities enclosed in this framework have the form of triangular dodecahedra  
138 surrounding the  $X$  site (Novak and Gibbs 1971). Each anion is coordinated by one  $Z$ , one  $Y$  and two  
139  $X$  cations, resulting in a high percentage of shared edges between the dodecahedra on the one hand  
140 and the octahedra and tetrahedra on the other. However, the octahedra and tetrahedra do not share  
141 edges with each other (cf. TAPP: Harris et al. 1997; Finger and Conrad 2000).

142 In hydrous garnets, the major mechanism of hydroxyl incorporation is by the coupled  
143 substitution  $4H + {}^Z\Box \rightarrow \Box + {}^ZSi$ , i.e., the hydrogen ions occupy a separate site of general symmetry  
144 (Wyckoff position  $96h$ ) coordinated to O defining the tetrahedral site, which is vacant (e.g., Ferro et  
145 al. 2003; Lager et al. 1987, 1989). The hydrogen ions lie approximately on the faces of the  
146 tetrahedron of O around a vacant center, as do the deuterium ions shown in Figure 3. The O $\Box$ H and  
147 O $\Box$ D distances reported for minerals or their synthetic analogues range from 0.65 Å in synthetic  
148 deuterium katoite (X-ray diffraction, Lager et al. 1987) and 0.68 Å in natural katoite (X-ray  
149 diffraction, Sacerdoti and Passaglia 1985) to 0.75 Å in henritermierite (X-ray diffraction,  
150 Armbruster et al. 2001) to 0.904–0.95 Å in synthetic katoite (neutron diffraction, Lager et al. 1987;  
151 Cohen-Addad et al. 1967). Allowing that O $\Box$ H and O $\Box$ D distances obtained by X-ray diffraction  
152 are shorter than those obtained by neutron diffraction, Lager et al. (1987) concluded that the  
153 reported distances are consistent with isolated OH groups (lacking H-bonding) and assumed that the  
154 residual density located near oxygen can be attributed to the displaced (bonding) electron between  
155 O and H and not to the hydrogen itself.

156 However, compositional data, nuclear magnetic resonance (NMR) spectra and infrared (IR)  
157 spectra have been cited as evidence for multiple H occupancy in grossular and garnets in the  
158 hydrogrossular series. Cation vacancies at the  $X$  and  $Y$  sites calculated from electron microprobe  
159 analyses without direct determination of  $H_2O$  have been cited as evidence for the presence of H in  
160 these polyhedra, either without crystallographic data (Birkett and Trzcieski 1984), or in  
161 conjunction with single-crystal refinements of Ca, Al, Fe and Si, whereas H could be located only  
162 in a few of the crystals studied and not quantified (Basso et al. 1984a,b; Basso and Cabella 1990).  
163 Kalinichenko et al. (1987) interpreted NMR spectra obtained on a grossular to indicate 2H in the  
164 octahedra and 1H in the tetrahedra. In a comprehensive IR study of the hydrogrossular series,  
165 Rossman and Aines (1991) reported that samples containing substantial H (>11.7 wt.%  $H_2O$   
166 equivalent to >5.43 OH per formula unit) gave spectra consistent with the substitution  $4H + {}^Z\Box \rightarrow$   
167  $\Box + {}^ZSi$ , whereas samples with much less H (<3.6 wt.%  $H_2O$ , mostly <0.5 wt.% ) gave 7 different  
168 types of IR spectra, suggesting OH groups were present in multiple site environments, an inference  
169 supported by NMR spectra on three grossular samples (Cho and Rossman 1993). On the basis of  
170 Fourier-transform IR spectra, Eeckhout et al. (2002) concluded that there is no evidence for a

171 multisite OH substitution in spessartine-almandine garnets from Brazilian pegmatites, leaving the  
172 hydrogarnet substitution as the only proposed mechanism for the incorporation of H. In summary,  
173 garnet samples in which concentrations of H are too low to be studied by conventional X-ray and  
174 neutron diffraction techniques give conflicting and equivocal results, whereas H-rich samples in  
175 which H can be determined by these techniques give data consistent with  $4\text{H} + {}^Z\text{□} \rightarrow \text{□} + {}^Z\text{Si}$ .  
176 Consequently, for nomenclature purposes, we have assumed that H is incorporated exclusively by  
177  $4\text{H} + {}^Z\text{□} \rightarrow \text{□} + {}^Z\text{Si}$ .

178 The symmetry of garnet is predominantly isometric, space group *Ia-3d* (no. 230) but the two  
179 species in the henritermierite group have tetragonal symmetry *I4<sub>1</sub>/acd* (no. 142), and the X, Z and φ  
180 sites are split into more symmetrically-unique sites, without altering the topology such that the  
181 idealized formula becomes  $\{\text{Ca}_{12}\}\{\text{Ca}_2\}[\text{R}^{3+}_2](\text{Si}_{12})(\text{□}_2)\text{O}_{14}\text{O}_{24}(\text{OH})_4$ , where  $\text{R}^{3+} = \text{Mn}$  or  $\text{Al}$ .  
182 Armbruster et al. (2001) concluded that Jahn-Teller distortion resulting from  $\text{Mn}^{3+}$  occupancy of Y  
183 and the arrangement of the hydroxyl tetrahedra are coupled, and together are responsible for the  
184 lowering to tetragonal symmetry in henritermierite. Moreover, stabilization of the Al-dominant  
185 analogue holtstamite has been thought to require a minimum  $\text{Mn}^{3+}$  content, which is estimated to be  
186 at least 0.2  $\text{Mn}^{3+}$  per formula unit (pfu), the amount reported in an isometric andradite (Armbruster  
187 1995) and no more than 0.64  $\text{Mn}^{3+}$  pfu, the lowest amount found in holtstamite, i.e., between 10%  
188 and 32% of the henritermierite end-member must be present to stabilize the tetragonal form  
189 (Hålenius 2004; Hålenius et al. 2005). However, these arguments are not supported by a Si-  
190 deficient spessartine containing no  $\text{Mn}^{3+}$ , but showing *I4<sub>1</sub>/acd* symmetry attributed to  $(\text{OH},\text{F})_4$   
191 groups (Boiocchi et al. 2012), implying symmetry lowering could have more than one cause.

192 In addition, there are numerous reports of natural garnets having orthorhombic, monoclinic, or  
193 triclinic symmetry, which have been attributed to crystal growth phenomena, multiple diffraction,  
194 strain, and/or cation ordering (e.g., Griffen et al. 1992; McAloon and Hofmeister 1993; Armbruster  
195 and Geiger 1993; Rossmann and Armbruster 1995; Hofmeister et al. 1998; Wildner and Andrut  
196 2001, Shtukenberg et al. 2005; Frank-Kamenetskaya et al. 2007). As these structures have  
197 essentially the same topology, they are not regarded as separate species (Nickel and Grice 1998).

198 Table 3 gives the relative abundance of the generalized cations ( $\text{R}^{n+}$  with  $n = 1 \text{--} 6$ ) and anions  
199 ( $\varphi^{1-}$ ,  $\varphi^{2-}$ ) at each of the sites reported in the *Ia-3d* structure, and presents the major reported cation  
200 and anion substituents in natural garnets for each of the valence states of the ions. Table 4  
201 summarizes significant heterovalent substitutions in natural garnet, as well as some chemical  
202 relations among species.

203

204 **SPECIFIC NOMENCLATURE ISSUES IN THE GARNET SUPERGROUP**

205 Historical information on the 32 approved species of the garnet supergroup is summarized in  
206 Appendix 1. A more complete list of 715 synonyms, varietal, obsolete, and discredited names  
207 applied to minerals in the garnet supergroup since antiquity has been compiled in Appendix 2<sup>1</sup>. This  
208 list includes the synonyms of current names that have been used in the mineralogical and  
209 gemological literature. In the following section, we discuss only those species in which there were  
210 problems or difficulties in their original characterization or where the name or formula has had to be  
211 significantly modified since the original description.

212

### 213 **Suffixes**

214 With the exception of manganberzeliite (see below), up until 2009, garnets have been given  
215 new root names, without prefixes or suffixes. However, since 2009 five new names with suffixes  
216 have been approved by the CNMNC. For one of these, menzerite-(Y), the suffix is a Levinson  
217 modifier for the rare earth elements (Levinson 1966), whereas the suffixes for the other four garnets  
218 identified the dominant tetravalent cation at the Y site, i.e., Sn vs. Zr in two bitikleite species  
219 [formerly bitikleite-(SnFe) and bitikleite-(ZrFe)] and elbrusite [formerly elbrusite-(Zr)], and the  
220 dominant trivalent cation at the Z site, i.e., Al vs. Fe [formerly bitikleite-(SnAl) and bitikleite-  
221 (ZrFe), Table 5). In the present report we restrict the term “rare earth elements” to the elements  
222 from La to Lu (atomic numbers 57–71) and Y (atomic number 39) as defined by Levinson (1966),  
223 rather than calling La–Lu “lanthanoids” and including Sc as well as Y in the rare earth elements as  
224 recommended by the International Union of Pure and Applied Chemistry. With the exception of the  
225 Levinson modifiers for the rare earth elements, e.g., menzerite-(Y), the application of suffixes  
226 results in unnecessary complexity in the nomenclature and could lead to confusion as further new  
227 species are discovered. Consequently, we recommend that suffixes (except Levinson modifiers for  
228 the REE) not be used for names of minerals in the garnet supergroup. Moreover, as the four garnets  
229 with suffixes, which are not Levinson modifiers, have only recently been described and are not  
230 entrenched in the literature, we have given these garnets new names without suffixes. This  
231 renaming has been approved by the CNMNC as part of the overall nomenclature (Table 5). The  
232 etymology of the new names can also be found in Appendix 1.

233

### 234 **“Hydrogarnets”**

---

<sup>1</sup>For copies of Appendices 2 and 4, Document item AM-YR-XXX, contact the Business Office of the Mineralogical Society of America (see inside front cover of recent issue) for price information. Deposit items may also be available on the American Mineralogist web site at <http://www.minsocam.org>.

235 The nomenclature of naturally-occurring garnet containing substantial amounts of the  
236 hydroxyl ion has had a complex history (e.g., Pertlik 2003). Many of these garnets have  
237 compositions intermediate between grossular ( $x = 0$ ) and katoite ( $x = 3$ ), i.e.,  $\{Ca_3\}[Al_2](Si_{3-x}\square_x)O_{12-4x}(OH)_{4x}$  where  $0 < x < 3$  and  $\square$  is vacancy. For the majority of these garnets,  $x < 1.5$  (e.g.,  
238 Passaglia and Rinaldi 1984). “Hibschite” was approved by the then Commission on New Minerals  
239 and Mineral Names (CNMMN, the predecessor of the CNMNC) as a name for OH-bearing  
240 grossular with  $x < 1.5$  (Dunn et al. 1985) because “hibschite” had priority (Cornu 1905, 1906) over  
241 “plazolite” (Foshag 1920) and “hydrogrossular” (Hutton 1943). However, “hibschite” is not distinct  
242 from grossular according to the dominant-constituent rule, i.e.,  $Si > \square$  at the Z site, therefore  
243 “hibschite” is discredited in favor of grossular (Table 5). Dunn et al. (1985) allowed that “the name  
244 hydrogrossular may still be applied to members of the series with appreciable OH content but  
245 undetermined  $SiO_4/(OH)_4$  ratio.”

247 Several names have also been used describe the OH-bearing garnets considered together,  
248 including the “grossularoid group” (Belyankin and Petrov 1941) and the “hydrogarnet series” (Flint  
249 et al. 1941). Dunn et al. (1985) implied that the term “hydrogrossular group” and “hydrogrossular  
250 series” would be acceptable for compositions along the grossular  $\square$  katoite join, but in our  
251 classification the binary would no longer qualify as a group, whereas the term “series” has a more  
252 restrictive meaning than a simple binary solid solution (Mills et al. 2009; see above).

253 The tetragonal hydroxyl-bearing garnets henritermierite and holtstamite (Fig. 1a) are  
254 considered to constitute a distinct group because of their lower symmetry and because one  
255 tetrahedral site is largely vacant, i.e.,  $\square > Si$  at one of the two sites corresponding to Z in the  
256 archetypal garnet structure (Aubry et al. 1969; Armbruster et al. 2001; Hålenius et al. 2005). Optical  
257 determinations are sufficient to distinguish this group from members of the garnet group, and  
258 crystal structure determinations are not necessary. Holtstamite is uniaxial and shows a high (0.030)  
259 birefringence. In contrast birefringent grossular garnets are normally biaxial (as a consequence of  
260 symmetry lowering to orthorhombic, monoclinic or triclinic symmetries) and show low to moderate  
261 (0.001- 0.010) birefringence (Shtukenberg et al. 2001, 2005), although birefringence as high as  
262 0.015 has been observed for compositions with considerable andradite component. In addition, the  
263 powder XRD pattern for holtstamite and grossular are distinct because they show different  $d$ -  
264 spacings for their respective 5 strongest reflections. Henritermierite and holtstamite are  
265 distinguished from each other on the basis of the dominant cation at the Y site, respectively  $Mn^{3+}$   
266 and Al.

267

268 **Elbrusite**



269 Elbrusite was originally described as “elbrusite-(Zr)” with the formula  
270  $\{\text{Ca}_3\}[\text{U}^{6+}\text{Zr}](\text{Fe}^{3+}_2\text{Fe}^{2+})\text{O}_{12}$  (Table 2 from Galuskina et al. 2010a). Determination of the site  
271 occupancies and valence states were hampered by its metamict state, which was nearly complete in  
272 elbrusite containing 24 wt.%  $\text{UO}_3$  (0.62 U per formula unit) and well advanced in U-rich kerimasite  
273 (Fe-dominant analogue of kimzeyite in the original description) (15–17 wt.%  $\text{UO}_3$ , 0.37–0.42 U  
274 pfu); single-crystal X-ray diffraction was only practical for kerimasite containing 9 wt.%  $\text{UO}_3$  (0.21  
275 U pfu) (Galuskina et al. 2010a). The authors noted that a Raman band below  $700\text{ cm}^{-1}$  could  
276 indicate the presence of some  $\text{Fe}^{2+}$  in elbrusite, but the only evidence for U being hexavalent is the  
277 association with vorlanite,  $\text{CaU}^{6+}\text{O}_4$ , for which the hexavalent state of U could be determined  
278 (Galuskin et al. 2011a).

279 The composition  $\{\text{Ca}_3\}[\text{U}^{6+}\text{Zr}](\text{Fe}^{3+}_2\text{Fe}^{2+})\text{O}_{12}$  is not a valid end-member because more than  
280 one site has two occupants (Hawthorne 2002). Instead, it can be considered as the sum of two valid  
281 end-members,  $\frac{2}{3}\{\text{Ca}_3\}[\text{U}^{6+}_{0.5}\text{Zr}_{1.5}](\text{Fe}^{3+}_3)\text{O}_{12} + \frac{1}{3}\{\text{Ca}_3\}[\text{U}^{6+}_2](\text{Fe}^{2+}_3)\text{O}_{12}$  (Fig. 4). Compositions of  
282 elbrusite and U-rich kerimasite plot in a linear trend in terms of U and the sum of tetravalent cations  
283 between the composition representing kerimasite,  $\{\text{Ca}_3\}[\text{R}^{4+}_2](\text{R}^{4+}\text{R}^{3+}_2)\text{O}_{12}$ , and  
284  $\{\text{Ca}_3\}[\text{U}^{6+}\text{R}^{4+}](\text{R}^{3+}_2\text{R}^{2+})\text{O}_{12}$  (Fig. 4). The trend is very close to the substitution mechanism  $\text{U}^{6+} + \text{R}^{2+}$   
285  $= 2\text{R}^{4+}$ , and thus is consistent with the interpretation by Galuskina et al. (2010a) that U is hexavalent  
286 and  $\text{Fe}^{2+}$  is present. Moreover, the compositions that Galuskina et al. (2010a) identified as elbrusite  
287 and kerimasite plot in the fields for  $\{\text{Ca}_3\}[\text{U}^{6+}\text{R}^{4+}](\text{R}^{3+}_2\text{R}^{2+})\text{O}_{12}$  and  $\{\text{Ca}_3\}[\text{R}^{4+}_2](\text{R}^{4+}\text{R}^{3+}_2)\text{O}_{12}$ ,  
288 respectively, requiring no revision of their species identifications if  $\{\text{Ca}_3\}[\text{U}^{6+}_{0.5}\text{Zr}_{1.5}](\text{Fe}^{3+}_3)\text{O}_{12}$  is  
289 considered to be the end-member of elbrusite. Therefore  $\{\text{Ca}_3\}[\text{U}^{6+}_{0.5}\text{Zr}_{1.5}](\text{Fe}^{3+}_3)\text{O}_{12}$  should now be  
290 used as the elbrusite end-member formula.

291 Yudintsev (2001) and Yudintsev et al. (2002) reported a U-rich garnet, one of three  
292 compounds synthesized in corundum crucibles from a  $(\text{Ca}_{2.5}\text{U}_{0.5})\text{Zr}_2\text{Fe}_3\text{O}_{12}$  bulk composition at  
293  $1400\text{ }^\circ\text{C}$  in air:  $\{\text{Ca}_{2.64}\text{U}_{0.36}\}[\text{Zr}_{1.66}\text{Fe}_{0.30}\text{U}_{0.04}](\text{Fe}_{1.85}\text{Al}_{1.15})\text{O}_{12}$ , whereas Utsunomiya et al. (2002)  
294 reported synthesis of a U-rich garnet with a slightly different composition,  
295  $\{\text{Ca}_{2.93}\text{U}_{0.07}\}[\text{Zr}_{1.52}\text{U}_{0.47}\text{Fe}_{0.01}](\text{Fe}_{1.83}\text{Al}_{1.17})\text{O}_{12}$ , under unspecified conditions, but presumably  
296 similar. Uranium is largely tetravalent in the starting material, and despite having been heated in a  
297 relatively oxidizing environment, was assumed by Yudintsev (2001) to have remained mostly  
298 tetravalent in the garnet because of its association with cubic oxide with the fluorite structure  
299 typical of  $\text{U}^{4+}$ . However, charge balance requires that 72–81 % of the U be hexavalent in the two  
300 synthetic garnets. If U is assumed to be tetravalent at the X site and hexavalent at the Y site, a  
301 distribution consistent with the relative sizes of the two U ions, the two formulae give 11.754 and  
302 12.030 positive charges respectively. The formula of the garnet synthesized by Utsunomiya et al.

303 2002) is very close to the proposed elbrusite end-member (Fig. 4), and thus provides support for use  
304 of this end-member for elbrusite.

305

### 306 **Ti-rich garnets: schorlomite and morimotoite**

307 The site occupancies of Ti-rich garnets have been the subject of considerable controversy  
308 despite being extensively studied using a diverse arsenal of spectroscopic techniques as well as X-  
309 ray diffraction (e.g., Chakhmouradian and McCammon 2005). The two species currently accepted  
310 by the CNMNC are schorlomite,  $\text{Ca}_3(\text{Ti}, \text{Fe}^{3+})_2(\text{Si}, \text{Fe})_3\text{O}_{12}$ , and morimotoite,  $\text{Ca}_3(\text{Ti}, \text{Fe}^{2+},$   
311  $\text{Fe}^{3+})_2(\text{Si}, \text{Fe}^{3+})_3\text{O}_{12}$  (Table 2). These formulae, which are listed as approved by the CNMNC, are too  
312 generalized to indicate what the distinction is between the two species, and clearly new formulae  
313 based on end-members are needed.

314 Schorlomite (Fig. 1f) was first described and named by Shepard (1846), who reported it to be  
315 a hydrous silicate containing Y, Fe and possibly Th from Magnet Cove, Arkansas, U.S.A. However,  
316 Whitney (1849) and Rammelsberg (1850a, b) showed schorlomite to be a silicate of Ca, Fe and Ti,  
317 reporting compositions approaching those obtained by modern techniques. Chemical data obtained  
318 subsequently of Ti-bearing andradite, often called by the varietal name “melanite”, showed that  
319  $\text{TiO}_2$  content ranged continuously from 0 to 19 wt.%, whereas Labotka (1995) reported  
320 immiscibility at one locality. Grapes et al. (1979) and Laverne et al. (2006) reported up to 30 wt.%  
321  $\text{TiO}_2$  in garnets having anomalous compositions, which will be discussed separately below.  
322 Chakhmouradian and McCammon (2005) summarized the criteria proposed by various authors for  
323 distinguishing schorlomite from Ti-bearing andradite; among the most frequently used have been  
324  ${}^Y\text{Ti} > {}^Y\text{Fe}^{3+}$  (Ito and Frondel 1967a; Deer et al. 1982), approximately the same as  $\text{TiO}_2 > 15$  wt.%  
325 (Zedlitz 1933) and about twice the minimum Ti content suggested by Howie and Woolley (1968).  
326 Chakhmouradian and McCammon (2005) recommended that the proportion of schorlomite be  
327 determined as the amount of  ${}^Y\text{Ti}$ , balanced by substitutions at the Z site, relative to the total  
328 occupancy in the Y site,  $({}^Y\text{Ti} - {}^Y\text{Fe}^{2+} - {}^Y\text{Mg} - {}^X\text{Na})/2$ , i.e., deducting a morimotoite component (see  
329 below) together with a contribution from a hypothetical  $\{\text{Na}_2\text{Ca}\}[\text{Ti}_2](\text{Si}_3)\text{O}_{12}$  component. Several  
330 end-member formulae have been proposed for schorlomite, e.g.,  $\{\text{Ca}_3\}[\text{Ti}_2](\text{Fe}^{3+}_2\text{Si})\text{O}_{12}$  (Ito and  
331 Frondel 1967a) and  $\{\text{Ca}_3\}[\text{Ti}_2](\text{Fe}^{3+}_2\text{Ti})\text{O}_{12}$  (Rickwood 1968), whereas Chakhmouradian and  
332 McCammon (2005) argued that the crystal chemistry was too complex to be represented by a single  
333 end-member, and proposed a generalized formula instead,  $\{\text{Ca}_3\}[\text{Ti}_2](\text{Si}_{3-x})(\text{Fe}^{3+}, \text{Al}, \text{Fe}^{2+})_x\text{O}_{12}$ .

334 Morimotoite was introduced by Henmi et al. (1995) with an end-member formula  
335  $\text{Ca}_3\text{TiFe}^{2+}\text{Si}_3\text{O}_{12}$ , based entirely on electron-microprobe data of garnet containing nearly 20 wt.%  
336  $\text{TiO}_2$  from Fuka, Okayama Prefecture, Japan. Formulae that we recalculated assuming 8 cations and

337 12 oxygen anions from three analyses in Henmi et al. (1995), including the one designated as type,  
338 gave 1 □ 8% andradite,  $\{\text{Ca}_3\}[\text{Fe}^{3+}_2](\text{Si}_3)\text{O}_{12}$ , 27 □ 34%  $\{\text{Ca}_3\}[\text{Ti}_2](\text{Fe}^{3+}_2\text{Si})\text{O}_{12}$  and 58 □ 71%  
339  $\{\text{Ca}_3\}[\text{TiFe}^{2+}](\text{Si}_3)\text{O}_{12}$  with minor Zr, Mg, Mn and Al included with Ti,  $\text{Fe}^{2+}$ , Ca and  $\text{Fe}^{3+}$  according  
340 to valence. Garnets synthesized by Henmi et al. (1995) under reducing conditions (iron-wüstite  
341 buffer) have compositions very similar to the natural material; end-member morimotoite could not  
342 be synthesized. However, no structural or spectroscopic data were obtained to confirm the assumed  
343 site occupancies and calculated Fe valence, and thus the report raised objections. Fehr and  
344 Amthauer (1996) and Rass (1997) questioned the assumption that Ti was all  $\text{Ti}^{4+}$ . The latter authors  
345 also dismissed the infra-red evidence that Henmi et al. (1995) used to justify their conclusion that  
346 OH was absent, and cited experiments by Kühberger et al. (1989) that OH is likely to be present in  
347 morimotoite. Their conclusion is supported by the report by Armbruster et al. (1998) that the  
348 morimotoite substitution,  $\text{Fe}^{2+} + \text{Ti}^{4+} \rightarrow 2\text{Fe}^{3+}$  at the Y site is coupled with  $4\text{OH}^- \rightarrow \text{SiO}_4^{4-}$  at the  
349 tetrahedral site in Ti-bearing andradite.

350 Despite the variety of methods deployed to locate cations in the structure of Ti-rich garnets,  
351 authors have yet to reach a consensus, which reflects not only differing interpretations of the  
352 spectroscopic and structural data, but probably also variation between samples. Nonetheless, the  
353 question confronting us is whether we can still propose a meaningful classification based on  
354 formulae calculated from a full electron microprobe analysis assuming 8 cations and 12 oxygen  
355 anions. There is little disagreement on the occupancy of the X site, which with rare exception  
356 contains at least 2.7 (Ca + Na) atoms per formula unit (apfu), to which are added sufficient Mn and  
357 Mg to bring total X site occupancy to 3, but fewer authors (e.g., Chakhmouradian and McCammon  
358 2005) would also place  $\text{Fe}^{2+}$  at the X site. Problematic issues include the valence and location of Ti  
359 and Fe, as well as the location of Al. Locock (2008) reviewed the literature on  $\text{Ti}^{3+}$  in garnet and  
360 concluded that the oxygen fugacities required for this valence were far too low to be found in most  
361 geologic environments. This conclusion is consistent with most spectroscopic studies, for example,  
362 X-ray absorption near-edge structure spectroscopy (XANES) has revealed little or no  $\text{Ti}^{3+}$  in natural  
363 garnet (Waychunas 1987; Locock et al. 1995), whereas electron spin resonance spectroscopy  
364 revealed that  $\text{Ti}^{3+}$  is much subordinate to  $\text{Ti}^{4+}$  in pyrope synthesized under relatively reducing  
365 conditions (Rager et al. 2003; Geiger 2004). In contrast, Malitesta et al. (1995) and Schingaro et al.  
366 (2004) reported significant  $\text{Ti}^{3+}$  in Ti-bearing garnet by X-ray photoelectron spectroscopy (XPS).  
367 Since XPS examines the near-surface of a solid (top 10 □ 50 Å, Hochella 1988), the discrepancy  
368 between the XPS and XANES results could be due to differences at the mineral surface not detected  
369 by XANES, and consequently we are inclined to accept the conclusion that  $\text{Ti}^{3+}$  plays a negligible  
370 role in natural terrestrial garnet, although it could be significant constituent in some meteoritic  
371 garnet (e.g., Ma 2012).

372 As regards the location of Ti, Armbruster et al. (1998) located Ti at Z as well as Y, but most  
373 authors place Ti only at Y, which seems reasonable in the relatively Si-rich and Ti-rich garnets (Si >  
374 2 apfu) because of the rarity of Si = Ti substitution at tetrahedral sites (Hartman 1969). Nonetheless,  
375 combined low pressure and high temperature could favor Ti substitution for Si at a tetrahedral site  
376 as it does in lamproitic richterite (Oberti et al. 1992). The most robust element-specific technique,  
377 XANES, yields results consistent with the bulk of Ti occupying the octahedral site in most natural  
378 garnets (Waychunas 1987; Locock et al. 1995). Significant Ti may occupy the Z site in Si-poor  
379 garnets such as elbrusite and bitikleite (e.g., Galuskina et al. 2010a, b), and its presence has been  
380 demonstrated in Si-free synthetic garnets (Povarennykh and Shabilin 1983; Cartie et al. 1992;  
381 Yamane and Kawano 2011). Another question is the possible presence of tetrahedrally coordinated  
382 Fe<sup>2+</sup>. Some studies reported Mössbauer spectroscopic evidence for significant Fe<sup>2+</sup> at the Z site  
383 (e.g., Locock et al. 1995; Koritnig et al. 1978), but the spectroscopic data do not always give  
384 unequivocal site assignments (Chakhmouradian and McCammon 2005). Lastly, there is the role of  
385 the hydroxyl ion; ignoring hydroxyl results in an underestimate of Fe<sup>2+</sup> in the formulae calculated  
386 by the method of Droop (1987). However, the effect would be serious only if >0.4 wt.% H<sub>2</sub>O were  
387 present, in which case nearly 0.1 Fe<sup>2+</sup> per formula unit (5 □ 10% of the total Fe) would not show up  
388 in the calculated formula unless OH were included in the formula calculation, i.e., (OH) + O = 12  
389 and  $\Sigma\{X\} + \Sigma[Y] + \Sigma(Z) + \sum_{(OH)/4}^Z = 8$ , or if F present, O + (OH) + F = 12 and  $\Sigma\{X\} + \Sigma[Y] + \Sigma(Z)$   
390  $+ \sum_{(OH)/4}^Z + \sum_{F/4}^Z = 8$ . The few analyses available in the recent comprehensive studies give  
391 0.02 □ 0.21 wt.% H<sub>2</sub>O for natural Ti-rich garnets with >12 wt.% TiO<sub>2</sub> (Kühberger et al. 1989;  
392 Locock et al. 1995; Amthauer and Rossman 1998; Chakhmouradian and McCammon 2005). An  
393 exception is “hydroschorlomite” with 5 wt.% H<sub>2</sub>O (Galuskin 2005); such H<sub>2</sub>O-rich garnets cannot  
394 be treated in the approach discussed below.

395 In order to identify end-member formulae for the two Ti-rich garnet species schorlomite and  
396 morimotoite, we should compare the results from as many studies as possible, which necessitate our  
397 relying on chemical data. Few authors have supplemented chemical data with structure refinements  
398 using X-ray diffraction and with spectroscopic methods to determine site occupancy, and thus we  
399 think that relying on chemical data is the most consistent approach for treating compositional data  
400 from different studies. In addition, we have made the following assumptions in treating the  
401 chemical data:

- 402 1. Ti is Ti<sup>4+</sup> and preferentially occupies the Y site, which rules out the end-member  
403 {Ca<sub>3</sub>}[Ti<sub>2</sub>](TiFe<sup>3+</sup><sub>2</sub>)O<sub>12</sub> proposed by Rickwood (1968)
- 404 2. H<sub>2</sub>O content is ≤0.2 wt. %
- 405 3. Site occupancies are estimated using formulae calculated for 8 cations and 12 oxygen  
406 anions and the procedure outlined in the next section (see below)

407 Figure 5 is a plot of *Y*-site compositions for garnets containing >12 wt.% TiO<sub>2</sub> and Ti > Zr  
408 apfu in terms of the following generalized end-members {Ca<sub>3</sub>}[R<sup>3+</sup><sub>2</sub>](Si<sub>3</sub>)O<sub>12</sub>,  
409 {Ca<sub>3</sub>}[R<sup>4+</sup><sub>2</sub>](SiR<sup>3+</sup><sub>2</sub>)O<sub>12</sub>, and {Ca<sub>3</sub>}[R<sup>4+</sup>R<sup>2+</sup>](Si<sub>3</sub>)O<sub>12</sub>. For R<sup>4+</sup> = Ti, R<sup>3+</sup> = Fe<sup>3+</sup>, and R<sup>2+</sup> = Fe<sup>2+</sup>, these  
410 generalized end-members correspond, respectively, to andradite, the schorlomite end-member of Ito  
411 and Frondel (1967a), and the morimotoite end-member of Henmi et al. (1995), i.e., the same  
412 components plotted by Henmi et al. (1995, their Fig. 1). It turns out that 15 wt.% TiO<sub>2</sub>, which  
413 Zedlitz (1933) suggested as a cutoff for schorlomite, is a good estimate of the minimum TiO<sub>2</sub>  
414 content of compositions plotting in the morimotoite and schorlomite fields unless significant Zr is  
415 present.

416 Three reports of garnets reported to contain over 20 wt.% TiO<sub>2</sub> have not been plotted in  
417 Figure 5 either because of their high H<sub>2</sub>O content or because of their questionable identity as garnet.  
418 Galuskina and Galuskin (unpublished data) were able to confirm the identity of an OH-bearing  
419 schorlomite in a xenolith from the upper Chegem caldera, northern Caucasus by Raman  
420 spectroscopy. Analyses of the cores of two honey-colored crystals about 30 μm across enclosed in  
421 grossular+katoite give 12.61–13.75 wt.% SiO<sub>2</sub>, 25.42–25.86 wt.% TiO<sub>2</sub>, 0.41–0.49 wt.% SnO<sub>2</sub>,  
422 2.20–2.28 wt.% Al<sub>2</sub>O<sub>3</sub>, 24.86–26.09 wt.% Fe as Fe<sub>2</sub>O<sub>3</sub>, 31.03–31.71 wt.% CaO, ≤ 0.03 wt.%  
423 MgO and 0.27 to 1.2 wt.% H<sub>2</sub>O (calculated); Mn, Cr, Zr, Nb, V, Ce, La, Na, F and Cl were below  
424 the detection limit. These data correspond approximately to 73–76% {Ca<sub>3</sub>}[Ti<sup>4+</sup><sub>2</sub>](SiFe<sup>3+</sup><sub>2</sub>)O<sub>12</sub>, the  
425 highest proportion of the schorlomite end-member reported in a natural garnet, 12–13%  
426 {Ca<sub>3</sub>}[Ti<sup>4+</sup><sub>2</sub>](SiAl<sub>2</sub>)O<sub>12</sub> and 12–14% andradite plus its OH analogue. Grapes et al. (1979) reported  
427 an electron microprobe analysis of a garnet from Morotu, Sakhalin Island, Russia, containing 27.38  
428 wt.% TiO<sub>2</sub> and 33.50 wt.% Fe as FeO, but deficient in Si and Ca with the formula:  
429 {Ca<sub>1.53</sub>Fe<sup>2+</sup><sub>1.46</sub>Mn<sub>0.01</sub>}[Ti<sub>1.28</sub>Fe<sup>2+</sup><sub>0.71</sub>Mg<sub>0.01</sub>](Si<sub>1.84</sub>Ti<sub>0.60</sub>Fe<sup>3+</sup><sub>0.38</sub>Al<sub>0.18</sub>)O<sub>12</sub>, i.e., a morimotoite from site  
430 occupancies, but anomalous because so much Ti (or Fe<sup>2+</sup>) is forced by the formula calculation onto  
431 the Z site. A possible explanation for the high Fe and Ti contents is X-ray fluorescence from  
432 contiguous phases (Chakhmouradian and McCammon 2005). In a study of altered basalt from the  
433 equatorial east Pacific, Laverne et al. (2006) described a “hydroschorlomite” with 22.0–28.6 wt.%  
434 TiO<sub>2</sub>, 6.2–12.9 wt.% Fe as FeO and 22.5–26.5 % wt.% CaO. Laverne et al. (2006) tried to correct  
435 for celadonite impurities, which were manifested by the presence of ~1 wt.% K<sub>2</sub>O in the analyses.  
436 The study included SEM and TEM, as well as micro-Raman spectra, but none provided  
437 corroborative evidence that the mineral was indeed a garnet; the reported compositions suggest the  
438 mineral could be titanite.

439 Three analyses, including the holotype, from the type locality of morimotoite in Fuka, Japan,  
440 plot in the morimotoite field and show that Ti and Fe<sup>2+</sup> are the dominant R<sup>4+</sup> and R<sup>2+</sup> cations at *Y* if  
441 we assume that Ti and Fe<sup>2+</sup> do not occupy the Z site, whereas four of the five analyses of garnet

442 from the type locality of schorlomite at Magnet Cove, U.S.A., plot in the schorlomite field and  
443 show that Ti is the dominant  $R^{4+}$  cation, and  $Fe^{3+}$  is the dominant  $ZR^{3+}$  cation. The latter situation  
444 holds even if Al is assumed to preferentially occupy the Z site (e.g. Chakhmouradian and  
445 McCammon 2005), which is not supported by all studies (e.g. Locock et al. 1995; Armbruster et al.  
446 1998). Thus, we recommend that  $\{Ca_3\}[Ti^{4+}Fe^{2+}](Si_3)O_{12}$  and  $\{Ca_3\}[Ti^{4+}_2](SiFe^{3+}_2)O_{12}$  be the end-  
447 member formulae for morimotoite and schorlomite, respectively. Despite the assumptions and  
448 simplifications discussed above, we believe that Figure 5 can be used to distinguish schorlomite and  
449 morimotoite in the absence of structural and spectroscopic studies if allowance is made for the  
450 uncertainties in attempting to identify borderline cases.

451 Figure 5 shows that many garnets reported as schorlomite plot in the morimotoite and  
452 andradite fields; garnets plotting in the schorlomite field other than those from Magnet Cove are  
453 from Ardnamurchan, Scotland (Huggins et al. 1977), the Tamazeght complex, Morocco (Marks et  
454 al. 2008), the Polino carbonatite, Italy (Lupini et al. 1992) and Alnö Island, Sweden (Eckermann  
455 1974). The dominant  $ZR^{3+}$  cation in these garnets is  $Fe^{3+}$ , even if Al is assumed to preferentially  
456 occupy the Z site. Using the above assumptions, garnets plotting in the morimotoite field (with  $Fe^{2+}$   
457  $> Mg$  at the Y site) are from Iivaara, Finland (Zedlitz 1935), Afrikanda, Russia (Chakhmouradian  
458 and McCammon 2005), Ice River, Canada (Locock et al. 1995; Peterson et al. 1995), Sung Valley,  
459 India (Melluso et al. 2010) and Rusing Island, Kenya (Howie and Woolley 1968). However,  
460 Mössbauer spectroscopy of the Ice River garnet indicates that a significant proportion of the  $Fe^{2+}$  is  
461 located at the Z site and dominance of  $[(Ti,Zr)_2]$  over  $[(Ti,Zr)R^{2+}]$  at Y, so Locock et al. (1995) and  
462 Peterson et al. (1995) had reason to call this garnet schorlomite. Two relatively Zr-rich garnets from  
463 the Marathon Dikes, Ontario, Canada (Platt and Mitchell 1979) also plot in the morimotoite field,  
464 but are unique in that total  $Mg > Fe^{2+}_{total}$  (circled in Figure 5) suggesting the possibility of a Mg-  
465 dominant analogue of morimotoite (see the section on POSSIBLE NEW SPECIES AND COMPOSITIONAL  
466 VARIATIONS IN NATURAL GARNET).

467 All the analyses plotted in Figure 5 have  $Si > 2$  and total charge at Z  $> 11$ , i.e., all the garnets  
468 would be classed as garnet group, including compositions of schorlomite from the type locality  
469 (e.g., Appendix 3). This contradiction arises because the compositions include more garnet-group  
470 components, largely andradite,  $\{Ca_3\}[R^{3+}_2](Si_3)O_{12}$ , and morimotoite,  $\{Ca_3\}[R^{4+}R^{2+}](Si_3)O_{12}$ , than  
471 schorlomite-group components, largely,  $\{Ca_3\}[R^{4+}_2](SiR^{3+}_2)O_{12}$ .

#### 472 **Menzerite-(Y)**

473 The validity of menzerite-(Y) has been questioned because the end-member formula proposed  
474 for menzerite-(Y),  $\{Y_2Ca\}[Mg_2](Si_3)O_{12}$ , is quite far from the measured compositions of the type  
475 and only known material, which averages much closer to

476  $\{Y(Ca,Fe^{2+})_2\}[(Mg,Fe^{2+})(Fe^{3+},Al)](Si_3)O_{12}$ , an empirical formula that can be simplified to  
477  $\{YCa_2\}[MgFe^{3+}](Si_3)O_{12}$ . This simplified formula is not a valid end-member because it has two  
478 sites with two occupants (Hawthorne 2002). Instead, it can be resolved into an equal mixture of  
479  $\{Y_2Ca\}[Mg_2](Si_3)O_{12}$  (menzerite-(Y)) and  $\{Ca_3\}[Fe^{3+}_2](Si_3)O_{12}$  (andradite). Type menzerite-(Y)  
480 compositions are close to the midpoint between these two end-members, but in two grains divalent  
481 cations are dominant at the *Y* site and Mg is the dominant divalent cation at this site (e.g.,  
482 Appendices 3 and 4), confirming that menzerite-(Y) is a valid species (Grew et al. 2010). Of course,  
483 this approach depends on the accuracy of the electron microprobe analyses and calculation of  
484  $Fe^{3+}/Fe^{2+}$  ratio from stoichiometry (Droop 1987). The calculated  $Fe^{3+}/Fe^{2+}$  ratios are consistent with  
485 single-crystal X-ray diffraction data although not with preliminary micro-X-ray absorption near-  
486 edge spectroscopy (Grew et al. 2010).

487 A second argument forwarded to challenge the validity of menzerite-(Y) is that trivalent  
488 cations, i.e., Y+REE, are not dominant at the *X* site in any of the analyzed menzerite-(Y) grains, the  
489 maximum being 1.1 Y + REE per formula unit. Simple application of the dominant-valency rule  
490 gives  $\{Ca_3\}[Mg_2](Si_3)O_{12}$ , which is not balanced in charge. Charge balance allows only 2 (Y+REE)  
491 per formula unit, i.e., the menzerite end-member should be  $\{Y_2Ca\}[Mg_2](Si_3)O_{12}$ . The presence of  
492  $> 1$  (Y+REE) means that  $\{(Y,REE)_2Ca\}$  exceeds 50% of the maximum possible consistent with  
493 valency-imposed double site-occupancy.

494 Rates of diffusion of Y and REE in garnet provide evidence for the importance of the  
495 menzerite component in garnet, i.e. mobility of Y and REE at the *X* site is closely linked to mobility  
496 of Al at the *Y* site (Carlson 2012).

497

## 498 **Majorite**

499 The current list of CNMNC approved minerals (<http://pubsites.uws.edu.au/ima-cnmnc/>) gives  
500 the formula for majorite as  $Mg_3(Fe^{2+},Si)(SiO_4)_3$  (Table 2), equivalent to  $\{Mg_3\}[SiFe^{2+}](Si_3)O_{12}$ ,  
501 which indeed is a good approximation of the empirical formula of the type material reported by  
502 Smith and Mason (1970),  $(Mg,Na)_3(Fe,Si,Al,Cr)_2Si_3O_{12}$ . It was assumed that Fe occupied the *Y* site,  
503 but the valence and distribution of the Fe were not determined. Recalculating a formula for 8  
504 cations and 12 oxygen anions from the published analysis and listing cations at a given site in order  
505 of decreasing abundance gives:  $\{Mg_{2.91}Na_{0.09}\}[(Si_{0.71}Fe^{2+}_{0.60}Fe^{3+}_{0.41}Al_{0.22}Cr_{0.04}Mg_{0.02}](Si_3)O_{12}$ .

506 However, the assumption regarding  $Fe^{2+}$  occupancy is not supported by Mössbauer  
507 spectroscopic data on synthetic majorite (Geiger et al. 1991a, b; O'Neill et al. 1993a, b;  
508 McCammon and Ross 2003). In a study that included samples that Geiger et al. (1991a, b) and  
509 O'Neill et al. (1993a, b) had investigated, McCammon and Ross (2003) reported that  $X_{Fe^{2+}}/\Sigma Fe^{2+} =$

510 0.89–0.95, and  $\text{Fe}^{2+}/(\text{Fe}^{2+} + \text{Mg})$  at  $X$  (0.05–0.22) is three to seven times  $\text{Fe}^{2+}/(\text{Fe}^{2+} + \text{Mg})$  at  $Y$   
 511 (0.01–0.08) in 15 synthetic tetragonal majorite samples, and  ${}^X\text{Fe}^{2+}/\Sigma\text{Fe}^{2+} = 1.0$  in one isometric  
 512 synthetic sample, demonstrating that  $\text{Fe}^{2+}$  is strongly fractionated onto the  $X$  site. Because the  
 513 compositions of the type specimen and these synthetic samples are similar, we think it is reasonable  
 514 to assume that Fe distribution is the same in synthetic and natural majorite, and the partial ordering  
 515 at the  $X$  and  $Y$  sites in tetragonal samples does not significantly affect the Fe distribution. Assuming  
 516 that  $\text{Fe}^{2+}$  occupies only the  $X$  site, the formula of the type material becomes  
 517  $\{\text{Mg}_{2.31}\text{Fe}^{2+}_{0.60}\text{Na}_{0.09}\}[(\text{Si}_{0.71}\text{Mg}_{0.62}\text{Fe}^{3+}_{0.41}\text{Al}_{0.22}\text{Cr}_{0.04})](\text{Si}_3)\text{O}_{12}$ , i.e., the dominant component is  
 518  $\{\text{Mg}_3\}[\text{SiMg}](\text{Si}_3)\text{O}_{12}$ . Consequently, we recommend that  $\{\text{Mg}_3\}[\text{SiMg}](\text{Si}_3)\text{O}_{12}$  be used as the end-  
 519 member formula for majorite. A natural  ${}^X\text{Fe}^{2+}$  analogue has not been reported, and as far as we are  
 520 aware, it has not been synthesized (e.g., Kato 1986).

521 Although synthetic majorite has tetragonal symmetry (space group  $I4_1/a$ , no. 88) resulting  
 522 from a high degree of ordering of Mg and Si at the two symmetrically-unique octahedral sites (e.g.,  
 523 Angel et al. 1989), no naturally occurring tetragonal majorite has been reported. Apparently,  
 524 majorite in shocked meteorites was quenched with sufficient rapidity to preserve cubic symmetry  
 525 (Tomiooka et al. 2002). The problem of preserving cubic symmetry on cooling would probably not  
 526 arise in terrestrial majorite, which contains substantial Al, because incorporation of Al at the  $Y$  site  
 527 is thought to stabilize the cubic structure (Hatch and Ghose 1989). Moore and Gurney (1985)  
 528 confirmed isometric symmetry for garnet from the Monastery Mine kimberlite pipe, South Africa,  
 529 one of which we calculated to contain 36% of a generalized majorite component,  
 530  $\{\text{R}^{2+}_3\}[\text{MgSi}](\text{Si}_3)\text{O}_{12}$ .

531 The term “majoritic” has found wide use in the literature on garnets included in diamond  
 532 (e.g., Harte 2010; Collerson et al. 2010), i.e., garnet is described as “majoritic” if Si is incorporated  
 533 at the  $Y$  site through the “majorite” substitution  ${}^Y\text{R}^{2+} + {}^Y\text{Si} \rightarrow 2{}^Y\text{Al}$  (Table 4). Collerson et al. (2010)  
 534 also include the contribution from the generalized component  $\{\text{R}^{2+}\text{Na}_2\}[\text{R}^{4+}_2](\text{Si}_3)\text{O}_{12}$  in their  
 535 majorite substitution parameter,  $X^{\text{cat}}\text{Mj}$ . In contrast to majorite reported from shocked meteorites, in  
 536 which the majorite component is clearly dominant (Collerson et al. 2010), none of the “majoritic”  
 537 garnets occurring in diamonds are properly majorite, i.e., the majorite component  
 538  $\{\text{Mg}_3\}[\text{SiMg}](\text{Si}_3)\text{O}_{12}$  or  $(\text{R}^{2+} + \text{R}^{4+}) > 2\text{R}^{3+}$  at the  $Y$  site, is not dominant, even in sample JF-22  
 539 from the Jagersfontein kimberlite, South Africa (Tappert et al. 2005; Harte 2010), which has the  
 540 highest content of Si at the  $Y$  site among terrestrial garnet as far as we are aware: a maximum 47.2%  
 541  $\{\text{R}^{2+}_3\}[\text{R}^{4+}\text{Mg}](\text{Si}_3)\text{O}_{12}$  or 44.9%  $\{\text{R}^{2+}_3\}[\text{SiMg}](\text{Si}_3)\text{O}_{12}$  (Appendix 3, example 5). The “Ca-rich  
 542 majorite” in shock veins of crustal rocks from the Ries impact crater, Germany (Stähle et al. 2011)  
 543 is not majorite because  $({}^Y\text{Si} + {}^Y\text{Ti}) < ({}^Y\text{Al} + {}^Y\text{Fe}^{3+} + {}^Y\text{Cr})$ ; instead, the three average compositions



544 comprise about 58–71% pyrope–grossular–almandine, 17–33 %  $\{R^{2+}_3\}[R^{4+}Mg](Si_3)O_{12}$   
545 (generalized majorite), and 10–13%  $\{R^{2+}(Na,K)_2\}[R^{4+}_2](Si_3)O_{12}$ , where  $^YR^{4+} = 90\text{--}93\%$  Si.

546

### 547 **Manganberzeliite**

548 Manganberzeliite,  $\{Ca_2Na\}[Mn^{2+}_2](As^{5+}_3)O_{12}$  (Fig. 1g) has a complicated history revolving  
549 around the use of its name, which is briefly described below. Over 40 years after the original  
550 description of berzeliite from Långban, Filipstad district, Sweden (Kühn 1840), Igelström (1886)  
551 described a Sb-bearing, Mn-rich berzeliite-like mineral from the nearby Sjögruvan mine, and named  
552 it “pyrrhoarsenite”. On the basis of a new chemical analysis giving 28.38 wt.% MnO Igelström  
553 (1894) concluded that “pyrrhoarsenite” is a manganese dominant variety of berzeliite and could also  
554 be referred to as “Mangan-Berzeliit.”

555 In summarizing his discussion of the mineral, Hintze (1922) wrote that Igelström (1894) had  
556 found no antimony and had concluded from his studies that “pyrrhoarsenite” is just a Mn-rich  
557 variety of berzeliite. Hintze (1922) cited Igelström’s (1894) conclusion that the mineral containing  
558 28 % MnO can be referred to as “**Manganberzeliit**,” but Hintze (1922) wrote the name in bold type  
559 and unhyphenated.

560 Landergren (1930) used the terms “Mg-berzeliit” and “Mn-berzeliit” for the end-members of  
561 the series. These names were later used by other mineralogists studying this series e.g., Blix and  
562 Wickman (1959).

563 Moore (1972) reported powder XRD data for the type specimen of “pyrrhoarsenite” studied  
564 by Igelström (specimen NRM18870324 at the Swedish Museum of Natural History) from  
565 Sjögruvan. He concluded that “pyrrhoarsenite” = berzeliite. However, recent energy-dispersive  
566 spectroscopic analyses (Hålenius, unpublished data) of fragments of the mineral from this  
567 specimen, as well as cell parameter refinement (Locock, unpublished data) of Moore’s powder X-  
568 ray diffraction data, show that it is in fact Mn-dominant berzeliite, i.e. manganberzeliite (or  
569 “pyrrhoarsenite”). Prior to publication, Moore in 1971 submitted to the CNMMN a proposal to  
570 discredit several of the minerals outlined in his 1972 paper. After Moore published his paper, it was  
571 subsequently abstracted by Fleischer (1973), who noted that these minerals were discredited by the  
572 CNMMN and that “pyrrhoarsenite” was equivalent to berzeliite. However, the discreditation of  
573 pyrrhoarsenite was actually not included in Moore’s proposal to the CNMMN. Therefore, the report  
574 by Fleischer (1973), which was then carried forward by Nickel and Mandarino (1987), was in error.

575 This raises the question whether “pyrrhoarsenite” has priority over manganberzeliite and  
576 should be reinstated, although manganberzeliite has been the preferred name since 1894 (e.g.,  
577 Hintze 1922; Palache et al. 1951). Given that Igelström’s original description of the mineral was

578 poor even by the standards of the late 19<sup>th</sup> century, e.g., he did not detect the appreciable sodium  
579 content, in contrast to his contemporary Sjögren (1894), we conclude that priority does not justify  
580 reviving “pyrroarsenite” at the present time and manganberzeliite should remain the name for the  
581 Mn analogue of berzeliite.

582

## 583 **APPLYING THE NOMENCLATURE OF THE GARNET SUPERGROUP**

### 584 **Assumed cation occupancies**

585 A major objective of the classification is to provide a basis for identifying the species of an  
586 analyzed garnet from its chemical composition. As is the case for the tourmaline supergroup (Henry  
587 et al. 2011), chemical analyses of garnet establish which elements are present, but provide no  
588 information on which site(s) they occupy in the structure. Proper site allocation requires single-  
589 crystal or Rietveld structure refinement using X-ray or neutron diffraction methods, and  
590 spectroscopic data are often also needed for unambiguous site assignment, particularly when  
591 constituents could be present in more than one valence state, which is not rare in garnet. However,  
592 most investigators have only electron microprobe analyses, which provide no direct evidence of  
593 valence state. An added difficulty is that as a result of charge balance requirements, several garnet  
594 end-members have one site with mixed occupancy, the so-called valency-imposed double site-  
595 occupancy of Hatert and Burke (2008).

596 For all garnet-supergroup minerals we recommend that cations be allocated from a chemical  
597 analysis with the procedure given in the next section. This procedure is analogous to that proposed  
598 in connection with the nomenclature recommended for the tourmaline supergroup of Henry et al.  
599 (2011). It includes only constituents found in known end-members (Table 1) or some potential end-  
600 members (Tables 6, 7). Examples illustrating our recommended procedure are given in Appendix 3,  
601 and a spreadsheet is given in Appendix 4.

602 As in the case of many mineral groups, some reasonable assumptions can be made concerning  
603 site assignments of specific cations on the basis of relative abundance (Table 3). Lithium and H are  
604 the only light elements (atomic number less than 8) that have been reported in major amounts in  
605 garnet supergroup minerals, e.g., cryolithionite and katoite, respectively. When common silicate  
606 garnet species are checked for light elements, generally very little is found, i.e., Li contents are  
607 reported to not exceed 121 ppm, and Be and B contents, not to exceed 20 ppm (e.g., Grew et al.  
608 1990; Grew 2002a, b; Steppan 2003; Marschall 2005). An exception are the 259-1113 ppm Li in  
609 almandine from leucocratic granulite at Horní Bory, Czech Republic, corresponding to 0.019-0.079  
610 Li pfu, determined by laser ablation inductively coupled plasma mass spectroscopy (Cempírek et al.

611 2010 and unpublished data). According to Cempírek et al. (2010), Li could occupy either the *X* site  
612 as it does in synthetic  $\{\text{Li}_2\text{Mg}\}[\text{Si}_2](\text{Si}_3)\text{O}_{12}$  (Yang et al. 2009) or sites occupied by Li in synthetic  
613 garnets. The majority of synthetic Li garnets are compounds of REE, Ta, Nb, Te, Zr, Ba that are  
614 valued for their high ionic conductivity (e.g., Cussen 2006, 2010; O'Callaghan and Cussen 2007;  
615 Wang and Lai 2012). Lithium occupies not only the *Z* site, but also octahedral sites that are vacant  
616 in natural garnet, resulting in Li contents up to 6.8 apfu and cation totals up 11.8 apfu. Other  
617 exceptions involving light elements are the reports of 4.40 wt.%  $\text{B}_2\text{O}_3$  determined by electron  
618 microprobe analysis (EMPA) in andradite (Galuskin et al. 1995) and 0.45–2.09 wt.%  $\text{B}_2\text{O}_3$  by  
619 EMPA in OH-bearing grossular (Galuskina et al. 1998, 2001) from the Wiluy River, Yakutia,  
620 Russia. Pending studies of Li and B in silicate and hydroxyl garnet, it would be best to assume Li  
621 and B, as well as  $\text{S}^{6+}$  (up to 2.27 wt.%  $\text{SO}_3$ , equivalent to 0.11 S pfu, Passaglia and Rinaldi 1984;  
622 Galuskina et al. 2001), are located at the *Z* site.

623 Calcium has been assumed to occupy only the *X* site in natural garnet; even in synthetic  
624 garnets there are very few reports of Ca at the *Y* site and none can be considered unequivocal  
625 (Geller 1967; Lobanov et al. 1989). Nonetheless, it should be noted that Huggins et al. (1977) and  
626 Pieper et al. (1983) concluded that a small excess of cations at *X* and a correspondingly small deficit  
627 at *Y* could be explained in some cases by small amounts of Ca at *Y*, 0.024–0.055 apfu in andradite  
628 and 0.04 apfu in grossular, respectively. Gadas et al. (in press) suggested incorporation of Ca at the  
629 *Y* site by the substitution of  ${}^Y\text{Ca} + (\text{OH},\text{F})$  for  ${}^Y\text{Al} + \text{O}$  to explain Ca contents up to 3.08 apfu and  
630 deficiency at *Y* in grossular from pegmatite at Ruda nad Moravou, Czech Republic.

631 Scandium is assumed to occupy only the *Y* site as in eringaite, although its role could depend  
632 on the occupancy of *X* if synthetic garnets are any guide, where Sc preferentially occupies *Y* only in  
633 andradite, whereas in pyrope, *X* is favored and in grossular, a more even distribution (Oberti et al.  
634 2006; Quartieri et al. 2006). Titanium is assumed to be tetravalent, and V, either pentavalent or  
635 trivalent. The last assumption received validation from Bordage et al. (2010), who reported that V  
636 was entirely  $\text{V}^{3+}$  in a grossular (variety “tsavorite” containing 0.14 V pfu) based on the *K*-edge  
637 X-ray absorption near-edge structure (XANES) spectra obtained with high-energy resolution  
638 fluorescence-detected X-ray absorption spectroscopy. In contrast, Righter et al. (2011) reported  
639 mixed valences also based on the *K*-edge X-ray absorption near-edge structure in other garnets,  
640 viz.,  $2.46\text{--}2.55 \pm 0.15$  in pyrope of mantle origin and  $2.56\text{--}2.67 (\pm 0.15)$  for V valence in a  
641 goldmanite from the Czech Republic, i.e., 40% of the V in the goldmanite is  $\text{V}^{2+}$ , the remainder  $\text{V}^{3+}$ .  
642 However, this conclusion is in contrast to the structural and chemical data reported by these authors.

#### 643 **Site allocation of cations**

644 The assumed occupancies, most importantly,  ${}^Z\text{Li}$ ,  ${}^X\text{Ca}$ ,  ${}^Y\text{Sc}$ ,  $\text{Ti}^{4+}$ ,  ${}^Y\text{V}^{3+}$ , and  ${}^Z\text{V}^{5+}$  in  
645 conjunction with Table 3, lead to the following procedure for recasting chemical data into idealized  
646 site occupancies for purposes of classification:

- 647 1. Calculate formulae from the chemical analysis assuming 8 cations and 12 anions and  
648 apportion  $\text{Fe}^{2+}$  and  $\text{Fe}^{3+}$  or  $\text{Mn}^{2+}$  and  $\text{Mn}^{3+}$  if calculations give negative values for  $\text{Fe}^{2+}$   
649 (method of Droop 1987). If quantitative F or H data are available, assume  ${}^Z\Box = \frac{1}{4}\text{F} + \frac{1}{4}\text{H}$ .  
650 In this case, the basis for formula calculation becomes  $\text{O} + (\text{OH}) + \text{F} = 12$  and  $\Sigma\{\text{X}\} + \Sigma[\text{Y}]$   
651  $+ \Sigma(\text{Z}) + {}^Z\Box_{(\text{OH})4} + {}^Z\Box_{\text{F}4} = 8$
- 652 2. Li, Zn, P,  $\text{As}^{5+}$  and  $\text{V}^{5+}$  to Z. If  $\text{Li} < \frac{1}{4}\text{F}$ , assume sufficient vacancies to make up the deficit  
653 (see step 1).
- 654 3. Si and Ge: First to Z to a maximum of 3 apfu, including  $\Box$ , overflow to Y
- 655 4. Al: First to Z to bring total to 3 apfu, then Y
- 656 5.  $\text{Fe}^{3+}$ : First to Z to bring total to 3 apfu, then Y
- 657 6. Ca, Na, K, Y, REE, Th, Pb to X.
- 658 7. Al (remainder after deducting Al at Z),  $\text{Sc}^{3+}$ ,  $\text{Ti}^{4+}$ ,  $\text{V}^{3+}$ ,  $\text{Cr}^{3+}$ ,  $\text{Mn}^{3+}$ ,  $\text{Fe}^{3+}$  (remainder after  
659 deducting  $\text{Fe}^{3+}$  at Z), Ga,  $\text{Zr}^{4+}$ ,  $\text{Nb}^{5+}$ ,  $\text{Sn}^{4+}$ ,  $\text{Sb}^{5+}$ ,  $\text{Te}^{6+}$  and  $\text{U}^{6+}$  to Y. If Z is still less than 3  
660 apfu, then add  $\text{Fe}^{2+}$  to bring Z total to 3 apfu. If the content of Y exceeds 2 apfu, and Z is  
661 less than 3 apfu, then move Ti to Z to bring Z total to 3 apfu.
- 662 8. Mg: First to Y to bring total to 2 apfu, then to X
- 663 9.  $\text{Fe}^{2+}$  (remainder after deducting  $\text{Fe}^{2+}$  at Z): First to Y to bring total to 2 apfu, then to X
- 664 10.  $\text{Mn}^{2+}$ : First to Y to bring total to 2 apfu, then to X. This should bring total X to 3 apfu, if  
665 calculations were done correctly.

666 If H is suspected, but no quantitative data are available, as is the case with electron  
667 microprobe analyses, then either its content must be assumed so that  $\text{Fe}^{2+}/\text{Fe}^{3+}$  ratio can be  
668 calculated, or the  $\text{Fe}^{2+}/\text{Fe}^{3+}$  ratio must be assumed so that H content can be calculated. In garnets  
669 containing significant Si, it is reasonable to assume that H is incorporated at the expense of Si, that  
670 is,  $\text{H} = 4 * ({}^Z\Box)$ .

671 The site allocation procedure above, based solely on chemical data, fails to differentiate  
672 holtstamite from grossular, which would require additional information such as optical properties or  
673 crystallographic data, although henritermierite is uniquely determined because there is no report as  
674 yet of an isometric garnet having the composition  $\{\text{Ca}_3\}[\text{Mn}^{3+}_2](\text{Si}^{4+}_2\Box)\text{O}_8(\text{OH})_4$ .

675 We have also prepared an Excel spreadsheet (Appendix 4) to perform the above cation  
676 allocation, species and group determination, but have omitted several elements that rarely exceed 1  
677 wt.% in natural garnets: B, S, K, Ni, Sr; or which occur in significant amounts but whose  
678 occurrence is rare: Ga, Ge, Pb and Th (Tables 6, 8).

679

## 680 **Identifying a garnet species**

681       Once the cations have been allocated, then the dominant valence is determined for each site  
682 by summing the ions for each valence, e.g., Ca + Mg + Mn at the *X* site, and then the dominant  
683 cation identified. As species are defined in terms charge-balanced end-members (Hawthorne 2002),  
684 the possibility of valency-imposed double site-occupancy (Hatert and Burke 2008) must be  
685 considered. The dominant ion for each valence determines the species (e.g., bitikleite group, Fig. 6).  
686 Five examples are given in Appendix 3, and a calculation procedure for species and group  
687 determination in Appendix 4. Our discussion below is limited to the schorlomite and garnet groups  
688 because these are most likely to cause difficulties in identifying species.

689

## 690 **Applying the nomenclature to the schorlomite group**

691       Characteristic of the end-member formulae in this group is Si = 1 apfu; there are no divalent  
692 and trivalent cations at the *Y* site and no divalent or pentavalent cations at the *Z* site. However, in  
693 most analyses of Ti-, Zr- or Sn-rich garnets containing minor Sb<sup>5+</sup>, Nb<sup>5+</sup>, or U<sup>6+</sup>, Si commonly  
694 exceeds 1 apfu, e.g., all the analyses plotting in the schorlomite field in Figure 5 have Si > 2 apfu  
695 and total charge at the *Z* site > 11, because all contain substantial proportions of garnet group  
696 components (see above).

697       The primary criterion for a composition to belong to the schorlomite group is that the  
698 generalized schorlomite component  $\{R^{2+}_3\}[R^{4+}_2](R^{4+}R^{3+})O_{12}$  be the most abundant (Fig. 7); i.e., the  
699 spreadsheet gives this as the most abundant component possible. In the worked example of  
700 schorlomite from the type locality, Magnet Cove, Arkansas (Example 2), the schorlomite  
701 component is dominant, with  $R^{4+} > R^{3+} > R^{2+}$  at the *Y* site in the empirical formula (Example 2),  
702 whereas in the garnet-group mineral morimotoite, the generalized morimotoite component,  
703  $\{R^{2+}_3\}[R^{4+}R^{2+}](R^{4+}_3)O_{12}$ , is dominant with  $R^{4+} > R^{2+} > R^{3+}$  at the *Y* site in the empirical formula  
704 (Example 5). Homovalent substitutions at the *Y* and *Z* sites distinguish species within the  
705 schorlomite group (Figs. 7, 8), whereas the *X* site remains occupied exclusively by Ca in all end-  
706 members (Table 1).

707

## 708 **Applying the nomenclature to the garnet group**

709       In contrast to the schorlomite group, heterovalent substitutions relating species within the  
710 garnet group involve only the *Y* site, or the *X* and *Y* sites. Figure 9 illustrates the division of the  
711 garnet group in terms of valence of the *Y* site cations:  $R^{2+}$  – menzerite-(*Y*),  $R^{3+}$  – the familiar

712 silicate garnets and  $R^{2+}R^{4+}$  – majorite, morimotoite, which results from valency-imposed double  
713 site-occupancy.

714 Figure 10 illustrates one approach to identification of species in complex garnet-group  
715 minerals. It is the same as Figure 9, but adapted specifically for compositions of menzerite-(Y)  
716 reported by Grew et al. (2010), i.e.,  $R^{4+} = \text{Ti}$ ,  $R^{3+} = \text{Fe}^{3+}$ , Al and  $R^{2+} = \text{Mg}, \text{Fe}^{2+}$ , and differs from  
717 Figure 7a of Grew et al. (2010) in that the Ti corner is now  $\text{Ti}R^{2+}$ , representing a component in  
718 garnet, morimotoite. However, menzerite-(Y) is a four component system because of the  
719 substitution of  $R^{3+}$  for Si at the Z site, and compositions must be projected from four-component  
720 space onto the three-component plane shown in Figure 10. Appendix 3 (Example 3) gives the five  
721 possible generalized components in menzerite-(Y), of which only four are independent. We have  
722 selected the  $\{\text{Y}_3\}[\text{Al}_2](\text{Al}_3)\text{O}_{12}$ -type component to project menzerite-(Y) compositions. The  
723  $\{\text{Y}_3\}[\text{Al}_2](\text{Al}_3)\text{O}_{12}$ -type component comprises 4–8% of the analyzed menzerite-(Y) grains. Despite  
724 the differences between Figure 10 and Figure 7a of Grew et al. (2010), the disposition of the points  
725 is very similar.

726 The most widespread garnet-group minerals are related by homovalent substitutions at the X  
727 and Y sites, i.e.,  $\{R^{2+}_3\}[R^{3+}_2](\text{Si}^{4+}_3)\text{O}_{12}$ . Since only four constituents occupy the X site, the  
728 compositions can be plotted in a tetrahedron with Ca, Mg,  $\text{Mn}^{2+}$  and  $\text{Fe}^{2+}$  as vertices (Fig. 11a).  
729 Garnets with one of these cations dominant at the X site fill a volume whose edges inside the  
730  $\text{Ca-Mg-Mn}^{2+}\text{-Fe}^{2+}$  tetrahedron are shown as lines inside this tetrahedron. Figures 11b and 11c  
731 show compositions projected from the Mn and Ca vertices of the tetrahedron, respectively. These  
732 two faces of the tetrahedron suffice to illustrate the dispositions of the species. Final  
733 characterization will depend on the dominant occupancy of the Y site.

734

### 735 POSSIBLE NEW SPECIES AND COMPOSITIONAL VARIATIONS IN NATURAL GARNET

736 The compositional variations found in the 32 approved species by no means exhaust the  
737 compositional variations observed in natural garnet, which is greatly exceeded by the very extensive  
738 variations in synthetic garnet. In the present section we will consider these variations, note  
739 compositions containing components that could be new species if they were present in larger  
740 amounts (Table 6, 7), and briefly describe possible new species (Table 8). Synthetic garnets will be  
741 considered only in so far that they relate to natural garnets. The components are discussed under the  
742 group to which they would belong.

743

### 744 Vacancy dominant garnets – a “kenogarnet” group?

745 Vacancy-dominant garnets are distinguished by  $\varphi$  being a monovalent anion such as OH or F,  
746 as well as low content of cations at the Z site. Katoite is the only known garnet that is vacancy-  
747 dominant. However, there is considerable potential to discover more species, and thus a group could  
748 be recognized following the procedures outlined in Mills et al. (2009). In anticipation, we suggest  
749 the name “kenogarnet” from the Greek *kenos*, meaning “empty”, a term introduced as a prefix in  
750 pyrochlore supergroup nomenclature (Atencio et al. 2010).

751 The most abundant vacancy-dominant garnets are the so-called “hydrogarnets,” an informal  
752 term (Appendix 2) introduced by Flint et al. (1941) and generally used for any garnet containing  
753 OH incorporated by the substitution of (O<sub>4</sub>H<sub>4</sub>) tetrahedra for (SiO<sub>4</sub>) tetrahedra (Fig. 3). Significant  
754 incorporation of OH by this substitution is largely limited to garnet in which the X site is occupied  
755 by Ca, e.g., katoite, henritermierite and holtstamite. Up to 10 wt.% H<sub>2</sub>O has also been reported in  
756 andradite (Peters 1965; Lager et al., 1989; Armbruster 1995; Amthauer and Rossman 1998), leading  
757 to compositions with up to 35% of the Fe<sup>3+</sup> analogue of katoite (Table 6) and 4.5% of its Mn<sup>3+</sup>  
758 analogue (H content calculated by difference from Si occupancy determined by single crystal  
759 refinement, Armbruster 1995). Galuskina and Galuskin (2003) and Galuskin (2005) calculated OH  
760 contents of 2.6–2.9 apfu (equivalent to 4.8–5.1 wt.% H<sub>2</sub>O) from charge balance in  
761 “hydroschorlomite” containing 13.5–14.5 wt.% TiO<sub>2</sub> from the Wiluy River, Yakutia, Russia, the  
762 highest reported in Ti-rich garnets (cf. Chegem caldera schorlomite discussed above). In contrast,  
763 H<sub>2</sub>O contents in pyrope, almandine, and uvarovite are reported not to exceed 0.3 wt.%, and, in  
764 spessartine, not above 0.64 wt.% (e.g., Aines and Rossman 1984; Rossman et al. 1988; Smyth et al.  
765 1990; Andrut and Wildner 2001; Maldener et al. 2003; Beran and Libowitzky 2006; Johnson 2006).  
766 Wilkins and Sabine (1973) reported 2.5 wt.% H<sub>2</sub>O in spessartine, but this high content is anomalous  
767 and needs confirmation.

768 Only “hydrogarnets” with the large cations Ca and Sr (Ito and Frondel 1967b; Ivanov-Emin et  
769 al. 1982a,b) at the X site have been synthesized, including katoite (Flint et al. 1941; Cohen-Addad et  
770 al. 1967). Syntheses of the hydroxyl-dominant analogues of uvarovite (Morán-Miguélez et al. 1986)  
771 and eringaite (Ivanov-Emin et al. 1982a); as well as of {Ca<sub>3</sub>}[Mn<sup>3+</sup><sub>2</sub>](□<sub>3</sub>)(OH)<sub>12</sub> (Ivanov-Emin et  
772 al. 1982b), {Ca<sub>3</sub>}[TiFe<sup>3+</sup>](Fe<sup>3+</sup>□<sub>2</sub>)(OH)<sub>8</sub>O<sub>4</sub> (Ito and Frondel 1967b) and  
773 {Ca<sub>3</sub>}[ZrFe<sup>3+</sup>](Fe<sup>3+</sup>□<sub>2</sub>)(OH)<sub>8</sub>O<sub>4</sub> (Ito and Frondel 1967b) have been reported. However, attempts to  
774 synthesize the end-member {Ca<sub>3</sub>}[Fe<sup>3+</sup><sub>2</sub>](□<sub>3</sub>)(OH)<sub>12</sub> failed, although a garnet with about 90%  
775 {Ca<sub>3</sub>}[Fe<sup>3+</sup><sub>2</sub>](□<sub>3</sub>)(OH)<sub>12</sub> and 10% andradite could be synthesized (Flint et al. 1941; Ito and Frondel  
776 1967b). The reported compositions are based on starting materials; only the compositions of katoite  
777 and a hydroxyl-dominant analogue of andradite, {Ca<sub>3</sub>}[Fe<sup>3+</sup><sub>2</sub>](Si<sub>1.15</sub>□<sub>1.85</sub>)(OH)<sub>7.4</sub>O<sub>4.6</sub>, have been  
778 confirmed independently (e.g., by structure refinement, Cohen-Addad 1970; Cohen-Addad et al.  
779 1967). In summary, the H<sub>2</sub>O contents of natural and synthetic garnets are consistent with the

780 conclusion reached by Lager et al. (1989) that the extent of OH substitution in garnets appears to be  
781 structurally controlled, i.e., it is greater when the effective ionic radius (Shannon 1976) of the cation  
782 at X exceeds 1.0 Å and the shared octahedral edge is longer than the unshared edge, which is the  
783 case for natural and synthetic garnets with Ca dominant at the X site (Novak and Gibbs 1971;  
784 Quartieri et al. 2006).

785 Fluorine contents up to 6 wt.% F, equivalent to about 11 mol.% of a  $\{R^{2+}_3\}[R^{3+}_2](\square_3)F_{12}$ ,  
786 have been reported in grossular, spessartine and andradite (Valley et al. 1983; Flohr and Ross 1989;  
787 Manning and Bird 1990; Smyth et al. 1990; Barbanson and Bastos Neto 1992; Visser 1993;  
788 Włodyka and Karwowski 2006; Chakhmouradian et al. 2008). Only Smyth et al. (1990) measured  
789 H<sub>2</sub>O content, reporting 0.64 wt.% in the F-bearing spessartine (Table 6), equivalent to 3%  
790  $\{R^{2+}_3\}[R^{3+}_2](\square_3)(OH)_{12}$ , but Flohr and Ross (1989) and Chakhmouradian et al. (2008) reported  
791 evidence for H<sub>2</sub>O in the infrared and Raman spectra. Attempts to synthesize an F-dominant  
792 analogue of katoite have not been successful (Takamori et al. 1987).

793 Chlorine was sought in four of the studies of F-bearing garnet cited above, but no more than  
794 0.01 wt.% Cl was reported. Up to 0.2 wt.% Cl was reported in OH-bearing grossular from the  
795 Wiluy River, Yakutia, Russia (Galuskina et al. 2001). Chesnokov (1996), Chesnokov and  
796 Bushmakin 1994, and Chesnokov et al. (1994, 2008) described “igumnovite”, ideally  
797  $\{Ca_3\}[Al_2](Si_2\square)O_8Cl_4$ , and “chlorhibschite”, ideally,  $\{Ca_3\}[Al_2](Si_{3-x}\square_x)O_8Cl_{4-x}$ , from burned  
798 material in the Chelyabinsk coal basin, Urals, Russia, but these compounds are not considered to be  
799 naturally formed, and thus do not qualify as minerals (e.g., “igumnovite”, Jambor et al. 1997). The  
800 reported cell parameter of 12.008 Å for “igumnovite” is smaller than expected for a Cl-rich garnet  
801 from the relationship of Langley and Sturgeon (1979). Although the measured composition for  
802 “igumnovite,”  $Ca_{3.04}Al_{1.72}Fe_{0.13}Mg_{0.01}Si_{2.07}F_{0.03}O_{7.90}Cl_{4.07}$  approaches ideal garnet stoichiometry, it  
803 is doubtful that either “igumnovite” or “chlorhibschite” are garnets. More likely, “igumnovite” is  
804 related to mayenite, wadalite and the new mineral eltyubyuite (Galuskin et al. 2011b), whereas  
805 “chlorhibschite” could be a mixture of grossular, wadalite and, perhaps, chlorides.

## 806 **Yafsoanite**

807 The 9% proportion of the component  $\{Pb^{2+}_3\}[Te^{6+}_2](Zn_3)O_{12}$  listed in Tables 6 and 7 is based  
808 on the single-crystal structure refinement of material from the type locality (Mills et al. 2010; cf.  
809 Jarosch and Zemmann 1989). Electron microprobe analyses reported in the original description gave  
810 11–16% of the Pb analogue (Kim et al. 1982), but the formulae deviate from ideal stoichiometry,  
811 possibly as a result of using sulfides, a silicate and a native element for standards. Ronniger and  
812 Mill’ (1973) reported synthesis of several  $Pb^{2+}$ -bearing vanadate garnets (berzeliite group) with Pb



813 at the *X* site, and Mill<sup>9</sup> (1970) reported synthesis of yafsoanite and other Te-bearing garnets, but  
814 neither reported attempts to synthesize the Pb<sup>2+</sup> analogue of yafsoanite.

815 The unnamed end-member {Ca<sup>2+</sup><sub>3</sub>}[U<sup>6+</sup><sub>2</sub>](Fe<sup>2+</sup><sub>3</sub>)O<sub>12</sub> is calculated to be major constituent of  
816 elbrusite (Fig. 4; Table 6) and dzhuluite (Appendix 3), but has not yet been synthesized.

### 817 **Henritermierite group**

818 Boiocchi et al. (2012) reported nearly end-member spessartine containing 0.09 Fe and 0.04 Ca  
819 pfu, but only 2.52 Si pfu, the deficiency being made up by OH and F in nearly equal proportions  
820 (Table 6). The *I4<sub>1</sub>/acd* symmetry indicates that the mineral is more closely analogous to holtstamite  
821 rather than katoite. The spessartine is the first example of a garnet showing *I4<sub>1</sub>/acd* symmetry but  
822 containing no Mn<sup>3+</sup>, and thus Boiocchi et al. (2012) attribute the lower symmetry to (OH, F)<sub>4</sub>  
823 groups. Si is partially ordered, preferentially occupying the Z1 site (93.0%) vs. the Z2 site (73.8%).  
824

### 825 **Bitikleite group**

826 Given the large number of elements found in analyses of garnets of the bitikleite group, the  
827 potential for new species is great. For example, analysis #10 of elbrusite in Table 2 of Galuskina et  
828 al. (2010a) corresponds to the Sn dominant analogue of elbrusite (Fig. 4), and is possibly a new  
829 species (Table 8). Zaitsev et al. (2010) reported a zone with up to 10.1 wt.% Nb<sub>2</sub>O<sub>5</sub> in a kerimasite  
830 crystal, this amount corresponds to 0.48 Nb per formula unit, or nearly 50% of a  
831 {Ca<sub>3</sub>}[NbZr](R<sup>3+</sup><sub>3</sub>)O<sub>12</sub> component, which implies the possibility of new species for R<sup>3+</sup> = Fe and Al,  
832 the Nb analogue of usturite (Table 8).

833 Up to 4 wt.% ThO<sub>2</sub> (0.1 Th pfu) has been reported in bitikleite and schorlomite-group  
834 minerals (Lupini et al. 1992; Galuskina et al. 2010a; Galuskina et al. 2010e), which would  
835 correspond to 20 mol.% of a {Th<sub>0.5</sub>Ca<sub>2.5</sub>}[R<sup>4+</sup><sub>2</sub>](R<sup>3+</sup><sub>3</sub>)O<sub>12</sub> component. The end-member with Zr and  
836 Fe, i.e., {Th<sub>0.5</sub>Ca<sub>2.5</sub>}[Zr<sup>4+</sup><sub>2</sub>](Fe<sup>3+</sup><sub>3</sub>)O<sub>12</sub>, has been synthesized (Ito and Frondel 1967a; Yudinsev  
837 2003; Utsunomiya et al. 2005).

838

### 839 **Yttrium-aluminum (YAG) and yttrium-iron (YIG) garnets**

840 The rare earth elements can form a large number of synthetic compounds having general  
841 formulae of the type {R<sup>3+</sup><sub>3</sub>}[R<sup>3+</sup><sub>2</sub>](R<sup>3+</sup><sub>3</sub>)O<sub>12</sub> and isostructural with garnet (e.g., Yoder and Keith  
842 1951; Geller 1967), of which {Y<sub>3</sub>}[Al<sub>2</sub>](Al<sub>3</sub>)O<sub>12</sub> (yttrium aluminum garnet or YAG) and  
843 {Y<sub>3</sub>}[Fe<sup>3+</sup><sub>2</sub>](Fe<sup>3+</sup><sub>3</sub>)O<sub>12</sub> (yttrium iron garnet or YIG) are the most relevant to minerals (Tables 6, 7).  
844 Although the total charge at Z is 9, the garnet end-members YAG and YIG have not been placed in  
845 the bitikleite group because of the very different occupancies at *Y* and *X*. Up to 5 mol.% of the YAG

846 component has been reported in spessartine and almandine (e.g., Jaffe 1951; Røhr et al. 2007), and  
847 5 mol.% of the YIG component has been reported in andradite (Kasowski and Hogarth 1968), but  
848 the maximum proportion of a generalized  $\{(Y,REE)_3\}[(Fe^{3+},Al)_2](Al_3)O_{12}$  component in a natural  
849 garnet is 8% in menzerite-(Y)-andradite solid solution (Grew et al. 2010).

850

### 851 **Schorlomite group**

852 Koritnig et al. (1978) reported Zr-rich schorlomite from calc-silicate inclusions in gabbro of  
853 Radautal, Harz Mountains, Germany. Analyses of three samples gave 6.2-6.8 wt.%  $Al_2O_3$  and 23.1-  
854 25.6 wt.%  $SiO_2$  contents; the sample giving the highest  $ZrO_2$  content ( $Zr = 0.55$  apfu) is plotted in  
855 Figure 5. Our calculations for this sample give 48.9-49.0 %  $\{Ca_3\}[R^{4+}_2](SiR^{3+}_2)O_{12}$  with  $Ti > Zr$  at  
856  $Y$  and  $Al > Fe^{3+}$  at  $Z$ , i.e., a possible Al analogue of schorlomite or Ti analogue of kimzeyite. Using  
857 Mössbauer spectroscopic data, Koritnig et al. (1978) gave the Z site composition as  
858  $(Si_{2.00}Al_{0.56}Fe^{2+}_{0.24}Ti_{0.16}Fe^{3+}_{0.03})$ . Ito and Frondel (1967a) synthesized end-member schorlomite and  
859 kimzeyite, but we are not aware of a successful synthesis of the end-member  $\{Ca_3\}[Ti_2](SiAl_2)O_{12}$ .

### 860 **Garnet group**

861 Formulae calculated from the two analyses richest in Ti from garnets of the Marathon dikes,  
862 Ontario (Platt and Mitchell 1979) plot in the morimotoite field (Fig. 5) and have total  $Mg/(Mg +$   
863  $Fe^{2+}) = 0.63 \square 0.64$ , i.e., the end-member  $\{Ca_3\}[TiMg](Si_3)O_{12}$ , the Mg analogue of morimotoite, is  
864 dominant (Table 8). However, the Marathon dike compositions plot close to the boundary with  
865 schorlomite and calculation of  $Fe^{2+}/Fe^{3+}$  ratio from stoichiometry has a large uncertainty (Giaramita  
866 and Day 1990); thus a clear dominance of  $\{Ca_3\}[TiMg](Si_3)O_{12}$  in a natural garnet remains to be  
867 demonstrated.

868 Gallium and Ge can form a large number of synthetic compounds isostructural with garnet  
869 (Geller 1967), but only  $\{Ca_3\}[Ga_2](Ge_3)O_{12}$  might have a natural analogue. Johan and Oudin (1986)  
870 reported from the Pyrenees of France equant, six-sided crystals up to 10  $\mu m$  across of a  $Ca \square Ga \square Ge$   
871 mineral having compositions consistent with garnet stoichiometry (abstract in Jambor et al. 1988b).  
872 Cores of the highly zoned grains are close to  $\{Ca_3\}[Ga_2](Ge_3)O_{12}$  in composition, whereas the rims  
873 have compositions approximately intermediate between this composition and grossular. The list of  
874 valid unnamed minerals (Smith and Nickel 2007) also gave  $\{Ca_3\}[Al_2](Ge_3)O_{12}$  as a possible new  
875 species (Table 8), but our recalculation of formulae from the two compositions closest to this end-  
876 member (Johan and Oudin 1986) gave  $Si > Ge$  at the  $Z$  site and minor Ge at the  $Y$  site assuming Si  
877 is preferentially incorporated at the  $Z$  site. The crystals were too small to confirm the identification  
878 as a garnet by the technologies available at the time.

879 Fermor (1926; 1938) introduced three hypothetical garnet end-members (Tables 6, 7;  
880 Appendix 2): “blythite,”  $\{\text{Mn}^{2+}_3\}[\text{Mn}^{3+}_2](\text{Si}_3)\text{O}_{12}$ , as a subordinate component in a garnet from  
881 Cargoan, Nagpur, India; “khoharite,”  $\{\text{Mg}^{2+}_3\}[\text{Fe}^{3+}_2](\text{Si}_3)\text{O}_{12}$ , as the precursor to enstatitic  
882 chondrules in the Khohar meteorite and as a subordinate component in a pyrope from a  
883 “garnet□diopside” xenolith (eclogite?) in kimberlite from South Africa; and “skiaigite,”  
884  $\{\text{Fe}^{2+}_3\}[\text{Fe}^{3+}_2](\text{Si}_3)\text{O}_{12}$ , as a component in almandine from Glen Skiag, Scotland. Although later  
885 studies have reported up to nearly 9 mol.% “blythite” based on measurement or stoichiometric  
886 calculation of  $\text{Mn}^{3+}$  in andradite from manganese formations, Otjosondu, Namibia (Amthauer et al.  
887 1989; Böhn et al. 1995), “khoharite” and “skiaigite” have been elusive, e.g., Virgo and Yoder (1974)  
888 failed to find “skiaigite” in spessartine□almandine from the type locality at Glen Skiag, Scotland.  
889 The main problem in identifying these components in complex natural garnets is that the calculation  
890 depends on the sequence of calculation (Rickwood 1968; Locock 2008), i.e.,  $\text{Fe}^{3+}$  is first assumed to  
891 be present as the andradite component; only leftover  $\text{Fe}^{3+}$  would be combined with  $\text{Fe}^{2+}$  or Mg in  
892 the “skiaigite” or “khoharite” components, respectively, and  $\text{Mn}^{3+}$  could be present as  
893  $\{\text{Ca}_3\}[\text{Mn}^{3+}_2](\text{Si}_3)\text{O}_{12}$  as well as  $\{\text{Mn}^{2+}_3\}[\text{Mn}^{3+}_2](\text{Si}_3)\text{O}_{12}$  in the Otjosondu garnet (Table 6). Garnets  
894 containing a significant proportion of the  $\{\text{Ca}_3\}[\text{Mn}^{3+}_2](\text{Si}_3)\text{O}_{12}$ , “blythite”, “khoharite” and  
895 “skiaigite” end-members have been synthesized at relatively high pressures, i.e., above 30 kbar  
896 (Coes 1955; Nishizawa and Koizumi 1975; Karpinskaya et al. 1982; Fursenko 1983; Woodland and  
897 O’Neill 1993, 1995; Arlt et al. 1998), and could become more abundant under mantle pressures.

898 Rudashevskii and Mochalov (1984) reported a Mn□Cr□Si mineral thought be a garnet in  
899 heavy concentrates from eluvium of Pt-bearing serpentinite in the Far East of Russia (summary in  
900 Jambor et al. 1988a). The mineral forms highly zoned grains 1-30  $\mu\text{m}$  across enclosed in Cr-Ni-  
901 bearing  $\gamma$ -Fe. The formula (with cations grouped by valence) for the analysis with the highest Cr  
902 content is  $\{\text{Mn}^{2+}_{2.99}\}[(\text{Cr}^{3+}_{1.14}\text{Mn}^{3+}_{0.51})\text{Ti}_{0.35}][(\text{Si}_{2.22}\text{Ti}_{0.35})(\text{Al}_{0.28}\text{Fe}^{3+}_{0.08})]\text{O}_{12}$ , i.e., a  
903  $\{\text{Mn}^{2+}_3\}[\text{Cr}^{3+}_2](\text{Si}_3)\text{O}_{12}$  component can be considered dominant, whereas that for the lowest Cr  
904 content is  $\{\text{Mn}^{2+}_3\}[(\text{Mn}^{3+}_{0.79}\text{Cr}^{3+}_{0.60}\text{Al}_{0.09}\text{Fe}^{3+}_{0.08})\text{Ti}_{0.22}\text{Mn}^{2+}_{0.22}](\text{Si}_{3.01})\text{O}_{12}$ , i.e., with “blythite”  
905 dominant. The presence of significant  $\text{Mn}^{3+}$  in association with  $\text{Fe}^0$  is unexpected, as is the  
906 preservation of metallic Fe in eluvium. In the absence of X-ray or electron diffraction patterns and  
907 clearer evidence for the natural origin of the concentrates, the natural occurrence of a  
908  $\{\text{Mn}^{2+}_3\}[\text{Cr}^{3+}_2](\text{Si}_3)\text{O}_{12}$ -dominant or  $\{\text{Mn}^{2+}_3\}[\text{Mn}^{3+}_2](\text{Si}_3)\text{O}_{12}$ -dominant garnet remains to be  
909 demonstrated.

910 Three components have been proposed for incorporation of Na in garnet-group minerals  
911 (Tables 4 and 6), all of which have been inferred to be favored by increasing pressure,  $^X\text{Na} + ^X(\text{Y},$   
912  $\text{Yb}) = 2^X\text{R}^{2+}$  (Enami et al., 1995; Røhr et al. 2007) and  $^X\text{Na} + ^Y\text{Si} = ^X\text{R}^{2+} + ^Y\text{Al}$  or  $^X\text{Na} + ^Y\text{Ti} = ^X\text{R}^{2+} +$

913 <sup>Y</sup>Al (Ringwood and Major 1971; Sobolev and Lavrent'ev 1971; Bobrov et al. 2008; Harte 2010;  
914 Collerson et al. 2010).

915

### 916 **Berzeliite group**

917 Phosphorus contents generally do not exceed 1 wt.% P<sub>2</sub>O<sub>5</sub> in pyrope, almandine and  
918 spessartine, both in wet chemical (e.g., Koritnig 1965; Deer et al. 1982) and in electron microprobe  
919 analyses (e.g., Bishop et al. 1978; Hiroi et al. 1997; Breiter et al. 2005; Kawakami and Hokada  
920 2010). Mason and Berggren (1942) reported 4.1 wt.% P<sub>2</sub>O<sub>5</sub> in spessartine from Wodgina, Australia  
921 (sample no. NRM 884695, Swedish Museum of Natural History), but Breiter et al. (2005) found  
922 only 0.24–0.27 wt.% with the electron microprobe. An energy-dispersive spectroscopic analysis of  
923 the spessartine in this specimen (normalized to 100%) with an SEM gave P contents closer to the  
924 amounts reported by Breiter et al. (2005): SiO<sub>2</sub> 35.78, Al<sub>2</sub>O<sub>3</sub> 20.52 FeO 3.91, MnO 39.15, CaO  
925 0.20, P<sub>2</sub>O<sub>5</sub> 0.42 (±0.12) (Hålenius, unpublished data). The spessartine grains are cut by  
926 microfissures ranging from < 1 μm to ca. 10 μm thick filled with Ca–Mn-phosphates. In some  
927 grains, the microfissures are sufficiently abundant to form networks, whereas in other grains they  
928 occurred singly up to 100 μm apart. It would have been nearly impossible to obtain a pure  
929 spessartine concentrate suitable for wet chemical analyses from this specimen.

930 Thompson (1975) reported experimental evidence for increased incorporation of P and Na  
931 with increasing pressure, a relationship consistent with the presence of up to 0.25 wt.% P<sub>2</sub>O<sub>5</sub> in  
932 pyrope associated with coesite at Dora Maira, Italy (Brunet and Lecocq 1999), exsolved apatite in  
933 garnet from mantle eclogite (Haggerty et al. 1994) and with the synthesis of {Na<sub>3</sub>}[Al<sub>2</sub>](P<sub>3</sub>)O<sub>12</sub> at  
934 150–170 kbar by Brunet et al. (2006). Thilo (1941) reported synthesis of {Na<sub>3</sub>}[Al<sub>2</sub>](P<sub>3</sub>)O<sub>12</sub> at  
935 atmospheric pressure, but subsequent attempts to reproduce such syntheses failed (Schwarz and  
936 Schmidt 1971). On the basis of a large number of analyses yielding up to 1.21 wt.% P<sub>2</sub>O<sub>5</sub>  
937 (equivalent to 0.086 P pfu) in almandine and spessartine from granitic rocks, Breiter et al. (2005)  
938 showed that: (1) P content varies inversely with Si, (2) Na/P ratio to be approximately 1/5 and (3)  
939 Al is relatively constant, consistent with the substitutions <sup>X</sup>□ + 2<sup>Z</sup>P = <sup>X</sup>R<sup>2+</sup> + 2<sup>Z</sup>Si and much  
940 subordinate <sup>X</sup>Na + <sup>Z</sup>P = <sup>X</sup>R<sup>2+</sup> + <sup>Z</sup>Si. There was no evidence in their data for the substitution  
941 <sup>Z</sup>(Al,Fe<sup>3+</sup>) + <sup>Z</sup>P = 2<sup>Z</sup>Si reported in an almandine-spessartine containing up to 2.1 wt.% P<sub>2</sub>O<sub>5</sub> from  
942 rhyolite, Tanzawa Mountainland, Japan (Arima and Yamashita 1994). Breiter et al. (2005) also  
943 concluded that the main control on incorporation of P seems to be the P contents in melt or post-  
944 magmatic fluid instead of pressure.

945 The maximum FeO content reported in a berzeliite-group mineral is 1.52 wt% in berzeliite  
946 from Montaldo mine, Italy, equivalent to 6% of the {Ca<sub>2</sub>Na}[Fe<sup>2+</sup><sub>2</sub>](As<sup>5+</sup><sub>3</sub>)O<sub>12</sub> end-member

947 (Nagashima and Armbruster 2012). Attempts to synthesize the Fe<sup>2+</sup> analogue of berzeliite have not  
948 been successful (Ito 1968; Schwarz and Schmidt 1971).

949

950

#### SUMMARY OF CONCLUSIONS, ACTIONS AND RECOMMENDATIONS

951

- The garnet supergroup comprises 32 approved species, with an additional 5 possible species needing further study in order to be approved.

952

953

- The supergroup includes all minerals isostructural with garnet regardless of what elements occupy specific cation or anion sites.

954

955

- We have subdivided the supergroup into groups based on symmetry and total charge at the tetrahedral Z site. Twenty-nine species belong to one of five groups, one tetragonal – henritermierite, and four isometric – bitikleite, schorlomite, garnet and berzeliite, in which the total Z charge is 8, 9, 10, 12 and 15, respectively. Three species are single representatives of potential groups in which total charge at Z is 0 (katoite), 3 (cryolithionite) and 6 (yafsoanite).

956

957

958

959

960

961

- Species are identified on the basis of the dominant-constituent and dominant-valency rules, and in some cases, by valency-imposed double site-occupancy.

962

963

- We recommend that suffixes (other than Levinson modifiers) not be used in naming minerals in the garnet supergroup. We have discredited existing names that have suffixes and replaced them with new root names where necessary, specifically, bitikleite-(SnAl) with bitikleite, bitikleite-(SnFe) with dzhuluite, bitikleite-(ZrFe) with usturite and elbrusite-(Zr) with elbrusite.

964

965

966

967

968

- We have discredited the name hibschite in favor of grossular, as Si is the dominant cation at the Z site.

969

970

- 21 end-members have been reported as subordinate components in minerals of the garnet supergroup of which six have been reported in amounts up to 20 mol% or more, whereas several others have been synthesized, which implies the potential for more species in the garnet supergroup.

971

972

973

974

975

#### ACKNOWLEDGMENTS

976

We thank Thomas Armbruster, Anton Chakhmouradian, Anastasia Chopelas and Anatoly Zaitsev for their assistance during preparation of these recommendations. Members of the CNMNC and Roberta Oberti commented on the version voted on by the CNMNC; Fernando Colombo, Darrell Henry and Milan Novák commented on the version submitted to *American Mineralogist* – we are grateful to all for their constructive reviews, which resulted in substantial improvement of

977

978

979

980

981 the manuscript. Makoto Arima is thanked for a translation of Arima and Yamashita (1994) and  
982 Pavel Kartashov for permission to publish his photograph of cryolithionite (Fig. 1b). We thank  
983 Carol Stockton for her assistance with Appendix 2. Jan Cempírek is thanked for sharing  
984 unpublished EMPA and LA-ICP-MS data on Li-bearing garnet from Horní Bory, Czech Republic.  
985 ESG is supported by U.S. National Science Foundation grant EAR 0837980 to the University of  
986 Maine.  
987

988

## REFERENCES

- 989 Agricola, G. (1546) *De natura fossilium*. Translated by M.C. Bandy and J. A. Bandy (1955)  
990 Textbook of Mineralogy, Geological Society of America Special Paper 63.
- 991 Aines, R.D. and Rossman, G.R. (1984) The hydrous component in garnets: pyralspites. American  
992 Mineralogist, 69, 1116-1126.
- 993 Allmann, R. and Hinek, R. (2007) The introduction of structure types into the inorganic crystal  
994 structure database ICSD. Acta Crystallographica, A63, 412-417.
- 995 Amthauer, G., Annersten, H., and Hafner, S.S. (1977) The Mössbauer spectrum of  $^{57}\text{Fe}$  in titanium-  
996 bearing andradites. Physics and Chemistry of Minerals, 1, 399-413.
- 997 Amthauer, G. and Rossman, G.R. (1998) The hydrous component in andradite garnet. American  
998 Mineralogist, 83, 835-840.
- 999 Amthauer, G., Katz-Lehnert, K., Lattard, D., Okrusch, M., and Woermann, E. (1989) Crystal  
1000 chemistry of natural  $\text{Mn}^{3+}$ -bearing calderite-andradite garnets from Otjosondu, SWA/Namibia.  
1001 Zeitschrift für Kristallographie, 189, 43-56.
- 1002 Andrut, M. and Wildner, M. (2001) The crystal chemistry of birefringent natural uvarovites: Part I.  
1003 Optical investigations and UV-VIS-IR absorption spectroscopy. American Mineralogist, 86,  
1004 1219-1230.
- 1005 Angel, R.J., Finger, L.W., Hazen, R.M., Kanzaki, M., Weidner, D.J., Liebermann, R.C., and  
1006 Veblen, D.R. (1989) Structure and twinning of single-crystal  $\text{MgSiO}_3$  garnet synthesized at 17  
1007 GPa and 1800 °C. American Mineralogist, 74, 509-512.
- 1008 Arima, M. and Yamashita, H. (1994)  $\text{P}_2\text{O}_5$ -rich garnet from Hosokawa-dani, Tanzawa  
1009 Mountainland. Journal of Mineralogy, Petrology and Economic Geology, 89, 166 (Abstract, in  
1010 Japanese).
- 1011 Arlt, T., Armbruster, T., Miletich, R., Ulmer, P., and Peters, T. (1998) High pressure single-crystal  
1012 synthesis, structure and compressibility of the garnet  $\text{Mn}^{2+}_3\text{Mn}^{3+}_2[\text{SiO}_4]_3$ . Physics and  
1013 Chemistry of Minerals, 26, 100-106.
- 1014 Armbruster, T. (1995) Structure refinement of hydrous andradite,  
1015  $\text{Ca}_3\text{Fe}_{1.54}\text{Mn}_{0.20}\text{Al}_{0.26}(\text{SiO}_4)_{1.65}(\text{O}_4\text{H}_4)_{1.35}$ , from the Wessels mine, Kalahari manganese field,  
1016 South Africa. European Journal of Mineralogy, 7, 1221-1225.
- 1017 Armbruster, T. and Geiger, C.A. (1993) Andradite crystal chemistry, dynamic X-site disorder and  
1018 structural strain in silicate garnets. European Journal of Mineralogy, 5, 59-71.
- 1019 Armbruster, T., Geiger, C.A., and Lager, G.A. (1992) Single-crystal X-ray structure study of  
1020 synthetic pyrope almandine garnets at 100 and 293 K. American Mineralogist, 77, 512-521.
- 1021 Armbruster, T., Birrer, J., Libowitzky, E., and Beran, A. (1998) Crystal chemistry of Ti-bearing  
1022 andradites. European Journal of Mineralogy, 10, 907-921.
- 1023 Armbruster, T., Kohler, T., Libowitzky, E., Friedrich, A., Miletich, R., Kunz, M., Medenbach, O.,  
1024 and Gutzmer, J. (2001) Structure, compressibility, hydrogen bonding, and dehydration of the  
1025 tetragonal  $\text{Mn}^{3+}$  hydrogarnet, henritermierite. American Mineralogist, 86, 147-158.
- 1026 Atencio, D., Andrade, M.B., Christy, A.G., Gieré, R., and Kartashov, P.M. (2010) The pyrochlore  
1027 supergroup of minerals: Nomenclature. Canadian Mineralogist, 48, 673-698.
- 1028 Aubry, A., Dusausoy, Y., Laffaille, A., and Protas, J. (1969) Détermination et étude de la structure  
1029 cristalline de l'henritermierite, hydrogrenat de symétrie quadratique. Bulletin de la Société  
1030 Française de Minéralogie et de Cristallographie, 92, 126-133.

- 1031 Back, M.E. and Mandarino, J.A. (2008) Fleischer's Glossary of Mineral Species 2008. The  
1032 Mineralogical Record Inc., Tucson, Arizona.
- 1033 Barbanson, L. and Bastos Neto, A.C. (1992) Hydroandradite titanifère fluorée et grenat  
1034 ( $\text{Spe}_{39}\text{Gro}_{31}\text{Alm}_{23}\text{And}_6$ ) fluoré des granitoïdes du district à fluorine de Santa Catarina (Brésil):  
1035 description minéralogique, mécanisme d'incorporation du fluor, signification pétrologique et  
1036 métallogénique. *Comptes Rendus de l'Académie des Sciences, Série 2*, 314, 63-69.
- 1037 Basso, R. (1987) The crystal structure of palenzonaite, a new vanadate garnet from Val Graveglia  
1038 (Northern Apennines, Italy). *Neues Jahrbuch für Mineralogie Monatshefte*, 1987, 136-144.
- 1039 Basso, R. and Cabella, R. (1990) Crystal chemical study of garnets from metarodingites in the  
1040 Voltri Group metaophiolites (Ligurian Alps, Italy). *Neues Jahrbuch für Mineralogie*  
1041 *Monatshefte*, 1990, 127-136.
- 1042 Basso, R., Cimmino, F., and Messiga, B. (1984a) Crystal chemistry of hydrogarnets from three  
1043 different microstructural sites of a basaltic metarodingite from the Voltri Massif (Western  
1044 Liguria, Italy). *Neues Jahrbuch für Mineralogie Abhandlungen*, 148, 246-258.
- 1045 Basso, R., Cimmino, F., and Messiga, B. (1984b) Crystal chemical and petrological study of  
1046 hydrogarnets from a Fe-gabbro metarodingite (Gruppo di Voltri, Western Liguria, Italy). *Neues*  
1047 *Jahrbuch für Mineralogie Abhandlungen*, 150, 247-258.
- 1048 Belyankin, D.S. and Petrov, V.P. (1941). The grossularoid group (hibschite, plazolite). *American*  
1049 *Mineralogist*, 26, 450-453.
- 1050 Beran, A. and Libowitzky, E. (2006) Water in natural mantle minerals II: Olivine, garnet and  
1051 accessory minerals. *Reviews in Mineralogy & Geochemistry*, 62, 169-191.
- 1052 Beudant, F.S. (1832) Spessartine. *Traité Élémentaire de Minéralogie*, Second edition, volume 2,  
1053 Paris, 52-55.
- 1054 Birkett, T.C. and Trzcinski, W.E., Jr. (1984) Hydrogarnet: multi-site hydrogen occupancy in the  
1055 garnet structure. *Canadian Mineralogist*, 22, 675-680.
- 1056 Bishop, F.C., Smith, J.V., and Dawson, J.B. (1978) Na, K, P and Ti in garnet, pyroxene and olivine  
1057 from peridotite and eclogite xenoliths from African kimberlites. *Lithos*, 11, 155-173.
- 1058 Blix, R. and Wickman, F.E. (1959) A contribution to the knowledge of the mineral berzeliite. *Arkiv*  
1059 *för Mineralogi och Geologi*, 2, 417-424.
- 1060 Bobrov, A.V., Litvin, Yu.A., Bindi, L., and Dymshits, A.M. (2008) Phase relations and formation  
1061 of sodium-rich majoritic garnet in the system  $\text{Mg}_3\text{Al}_2\text{Si}_3\text{O}_{12}$ - $\text{Na}_2\text{MgSi}_5\text{O}_{12}$  at 7.0 and 8.5 GPa.  
1062 *Contributions to Mineralogy and Petrology*, 156, 243-257.
- 1063 Boiocchi, M., Bellatreccia, F., Della Ventura, G., and Oberti, R. (2012) On the symmetry and  
1064 atomic ordering in (OH,F)-rich spessartine: towards a new hydrogarnet end-member.  
1065 *Zeitschrift für Kristallographie*, 227, 385-395. doi: 10.1524/zkri.2012.1487
- 1066 Bordage, A., Brouder, C., Balan, E., Cabaret, D., Juhin, A., Arrio, M.-A., Saintavit, P., Calas, G.,  
1067 and Glatzel, P. (2010). Electronic structure and local environment of substitutional  $\text{V}^{3+}$  in  
1068 grossular garnet  $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$ : K-edge X-ray absorption spectroscopy and first-principles  
1069 modeling. *American Mineralogist*, 95, 1161-1171.
- 1070 Boysen, H., Lerch, M., Stys, A., and Senyshyn, A. (2007) Structure and oxygen mobility in  
1071 mayenite ( $\text{Ca}_{12}\text{Al}_{14}\text{O}_{33}$ ): a high-temperature neutron powder diffraction study. *Acta*  
1072 *Crystallographica*, B63, 675-682.
- 1073 Breiter, K., Novák, M., Koller, F., and Cempírek, J. (2005) Phosphorus – an omnipresent minor  
1074 element in garnet of diverse textural types from leucocratic granitic rocks. *Mineralogy and*  
1075 *Petrology*, 85, 205-221.



- 1076 Brunet, F. and Lecocq, D. (1999) Phosphorus incorporation in garnet: natural and experimental  
1077 data. *European Journal of Mineralogy*, 11, 43 (abstract).
- 1078 Brunet, F., Bonneau, V., and Irifune, T. (2006) Complete solid-solution between  $\text{Na}_3\text{Al}_2(\text{PO}_4)_3$  and  
1079  $\text{Mg}_3\text{Al}_2(\text{SiO}_4)_3$  garnets at high pressure. *American Mineralogist*, 91, 211-215.
- 1080 Bubeck, W. and Machatschki, F. (1935) Die Kristallstruktur des Berzeliit  
1081  $(\text{Ca},\text{Na})_3(\text{Mg},\text{Mn})_2[\text{AsO}_4]_3$ . *Zeitschrift für Kristallographie*, 90, 44-50.
- 1082 Bühn, B., Okrusch, M., Woermann, E., Lehnert, K., and Hoernes, S. (1995) Metamorphic evolution  
1083 of Neoproterozoic manganese formations and their country rocks at Otjosondu, Namibia.  
1084 *Journal of Petrology*, 36, 463-496.
- 1085 Carlson, W.D. (2012) Rates and mechanism of Y, REE, and Cr diffusion in garnet. *American*  
1086 *Mineralogist*, 97, 1598-1618.
- 1087 Cartie, B., Archambault, F., Choynet, J., Rulmont, A., Tarte, P., and Abs-Wurmbach, I. (1992)  
1088 About the occurrence of tetrahedrally co-ordinated  $\text{Sn}^{4+}$  and  $\text{Ti}^{4+}$  in the new synthetic garnet-  
1089 type solid solution  $\text{Ca}_3\text{Sn}_{3-x}\text{Ti}_x\text{Fe}_2\text{O}_{12}$  ( $0.25 \leq x \leq 1.50$ ). *Journal of Materials Science Letters*,  
1090 11, 1163-1166.
- 1091 Cempírek, J., Novák, M., Dolníček, Z., Kotková, J., and Škoda, R. (2010) Crystal chemistry and  
1092 origin of grandierite, ominelite, boralsilite, and werdingite from the Bory Granulite Massif,  
1093 Czech Republic. *American Mineralogist*, 95, 1533-1547.
- 1094 Chakhmouradian, A.R. and McCammon, C.A. (2005) Schorlomite: a discussion of the crystal  
1095 chemistry, formula, and inter-species boundaries. *Physics and Chemistry of Minerals*, 32, 277-  
1096 289.
- 1097 Chakhmouradian, A.R., Cooper, M.A., Medici, L., Hawthorne, F.C., and Adar, F. (2008) Fluorine-  
1098 rich hibschite from silicocarbonatite, Afrikanda complex, Russia: Crystal chemistry and  
1099 conditions of crystallization. *Canadian Mineralogist*, 46, 1033-1042.
- 1100 Chesnokov, B.V. (1996) High-temperature chlorosilicate in burned-out mine spoil heaps in the  
1101 Chelyabinsk coal basin. *Transactions of the Russian Academy of Science, Earth Sciences*  
1102 *Section*, 345, 104-106.
- 1103 Chesnokov, B.V. and Bushmakin, A.F. (1995) New minerals from the burnt dumps of the  
1104 Chelyabinsk coal basin, (eighth communication). *Ural'skii Mineralogicheskii Sbornik*, 5, 3-22  
1105 (in Russian).
- 1106 Chesnokov, B.V., Vilisov, V.A., Bushmakin, A.F., Kotlyarov, V.A., and Belogub, Ye.V. (1994)  
1107 New minerals from the burnt dumps of the Chelyabinsk coal basin, (sixth communication),  
1108 *Ural'skii Mineralogicheskii Sbornik*, 3, 3-34 (in Russian).
- 1109 Chesnokov, B.V., Shcherbakova, Ye.P., and Nishanbayev, T.P. (2008) Minerals from the Burnt  
1110 Dumps of the Chelyabinsk Coal Basin. Miass, Russian Academy of Sciences, Urals Division,  
1111 Institute of Mineralogy.
- 1112 Cho, H. and Rossman, G.R. (1993) Single-crystal NMR studies of low-concentration hydrous  
1113 species in minerals: Grossular garnet. *American Mineralogist*, 78, 1149-1164.
- 1114 Clark, A.M. (1993) *Hey's Mineral Index. Mineral Species, Varieties and Synonyms*, Third edition.  
1115 Chapman and Hall, London.
- 1116 Coes, L., Jr. (1955) High pressure minerals. *Journal of the American Ceramic Society*, 38, 298.
- 1117 Cohen-Addad, C. (1970) Etude du composé  $\text{Ca}_3\text{Fe}_2(\text{SiO}_4)_{1.15}(\text{OH})_{7.4}$  par absorption infrarouge et  
1118 diffraction des rayons X et des neutrons. *Acta Crystallographica*, A26, 68-70.

- 1119 Cohen-Addad, C., Ducros, P., and Bertaut, E.F. (1967) Étude de la substitution du groupement  $\text{SiO}_4$   
1120 par  $(\text{OH})_4$  dans les composés  $\text{Al}_2\text{Ca}_3(\text{OH})_{12}$  et  $\text{Al}_2\text{Ca}_3(\text{SiO}_4)_{2.16}(\text{OH})_{3.36}$  de type grenat. *Acta*  
1121 *Crystallographica*, 23, 220-230.
- 1122 Collerson, K.D., Williams, Q., Kamber, B.S., Omori, S., Arai, H., and Ohtani, E. (2010) Majoritic  
1123 garnet: A new approach to pressure estimation of shock events in meteorites and the  
1124 encapsulation of sub-lithospheric inclusions in diamond. *Geochimica et Cosmochimica Acta*,  
1125 74, 5939-5957.
- 1126 Cornu, F. (1905) Neues Kontaktmineral "Hibschit". *Tschermaks Mineralogische und*  
1127 *Petrographische Mitteilungen*, 24, 327-328.
- 1128 Cornu, F. (1906) Beiträge zur Petrographie des Böhmisches Mittelgebirges. I. Hibschit, ein neues  
1129 Kontaktmineral. *Tschermaks Mineralogische und Petrographische Mitteilungen*, 25, 249-268.
- 1130 Cussen, E.J. (2006) The structure of lithium garnets: cation disorder and clustering in a new family  
1131 of fast  $\text{Li}^+$  conductors. *Chemical Communications*, 2006, 412–413. DOI: 10.1039/b514640b
- 1132 Cussen, E.J. (2010) Structure and ionic conductivity in lithium garnets. *Journal of Materials*  
1133 *Chemistry*, 20, 5167–5173. DOI: 10.1039/b925553b
- 1134 Dana, E.S. (1892) *System of Mineralogy*, Sixth edition, John Wiley and Sons, New York.
- 1135 Dana, J.D. (1837) *A System of Mineralogy*. Durrie and Peck and Herrick and Noyes, New Haven.
- 1136 Deer, W.A., Howie R.A., and Zussman J. (1982) *Rock-forming minerals*, Vol. 1A, Orthosilicates,  
1137 Second edition. Longman, London.
- 1138 Dowty, E. (1971) Crystal chemistry of titanian and zirconian garnet: I. Review and spectral studies.  
1139 *American Mineralogist*, 56, 1983-2009.
- 1140 Droop, G.T.R. (1987) A general equation for estimating  $\text{Fe}^{3+}$  concentrations in ferromagnesian  
1141 silicates and oxides from microprobe analyses, using stoichiometric criteria. *Mineralogical*  
1142 *Magazine*, 51, 431–435.
- 1143 Dunn, P.J., Fleischer, M., Langley, R.H., Shigley, J.E., and Zilczer, J.A. (1985) New mineral  
1144 names. *American Mineralogist*, 70, 871-881.
- 1145 Eckermann, H. von (1974) The chemistry and optical properties of some minerals of the Alnö  
1146 alkaline rocks. *Arkiv för Mineralogi och Geologi*, 5, 93-210.
- 1147 Eeckhout, S.G., Castañeda, C., Ferreira, A.C.M., Sabioni, A.C.S., de Grave, E., and Vasconcelos,  
1148 D.C.L. (2002) Spectroscopic studies of spessartine from Brazilian pegmatites. *American*  
1149 *Mineralogist*, 87, 1297-1306.
- 1150 Enami, M., Cong, B., Yoshida, T., and Kawabe, I. (1995) A mechanism for Na incorporation in  
1151 garnet: An example from garnet in orthogneiss from the Su-Lu terrane, eastern China.  
1152 *American Mineralogist*, 80, 475-482.
- 1153 Ercit, T.S. (1993) Caryinite revisited. *Mineralogical Magazine*, 57, 721-727.
- 1154 Fehr, K.T. and Amthauer, G. (1996) Comment on 'Morimotoite,  $\text{Ca}_3\text{TiFe}^{2+}\text{Si}_3\text{O}_{12}$ , a new titanian  
1155 garnet from Fuka, Okayama Prefecture, Japan' by Henmi *et al.* (1995). *Mineralogical*  
1156 *Magazine*, 60, 842-845.
- 1157 Feng, Q.L., Glasser, F.P., Howie, R.A., and Lachowski, E.E. (1988) Chlorosilicate with the  
1158  $12\text{CaO} \cdot 7\text{Al}_2\text{O}_3$  structure and its relationship to garnet. *Acta Crystallographica*, C44, 589-592.
- 1159 Fermor, L.L. (1909) The manganese-ore deposits of India. *Calderite*, in Chapter 6, *Memoirs of the*  
1160 *Geological Society of India*, 37, 182-186.
- 1161 Fermor, L.L. (1926) On the composition of some Indian garnets. *Records of the Geological Society*  
1162 *of India*, 59(2), 191-207.

- 1163 Fermor, L.L. (1938) On khoharite, a new garnet and on the nomenclature of garnets. Records of the  
1164 Geological Survey of India, 73(1), 145-156.
- 1165 Ferro, O., Galli, E., Papp, G., Quartieri, S., Szakáll, S., and Vezzalini, G. (2003) A new occurrence  
1166 of katoite and re-examination of the hydrogrossular group. European Journal of Mineralogy,  
1167 15, 419-426.
- 1168 Finger, L.W. and Conrad, P.G. (2000) The crystal structure of “Tetragonal Almandine-Pyrope  
1169 Phase” (TAPP): A reexamination. American Mineralogist, 85, 1804-1807.
- 1170 Fleischer, M. (1965) New mineral names. American Mineralogist, 50, 805-813.
- 1171 Fleischer, M. (1973) New mineral names. American Mineralogist, 58, 560-562.
- 1172 Flint, E.P., McMurdie, H.F., and Wells, L.S. (1941) Hydrothermal and X-ray studies of the garnet-  
1173 hydrogarnet series and the relationship of the series to hydration products of portland cement.  
1174 Journal of Research of the National Bureau of Standards, 26, 13-33.
- 1175 Flohr, M.J.K. and Ross, M. (1989) Alkaline igneous rocks of Magnet Cove, Arkansas:  
1176 Metasomatized ijolite xenoliths from Diamond Jo quarry. American Mineralogist, 74, 113-131.
- 1177 Foshag, W.F. (1920) Plazolite, a new mineral. American Mineralogist, 5, 183-185.
- 1178 Frank-Kamenetskaya, O.V., Rozhdestvenskaya, L.V., Shtukenberg, A.G., Bannova, I.I., and  
1179 Skalkina, Yu.A. (2007) Dissymmetrization of crystal structures of grossular-andradite garnets  
1180  $\text{Ca}_3(\text{Al, Fe})_2(\text{SiO}_4)_3$ . Structural Chemistry, 18, 493-503.
- 1181 Fursenko, B.A. (1983) Synthesis of new high-pressure silicate garnets  $\text{Mn}_3\text{M}_2\text{Si}_3\text{O}_{12}$  (M = V, Mn,  
1182 Ga). Doklady Akademii Nauk SSSR, 268, 421-424 (in Russian).
- 1183 Gadas, P., Novák, M., Talla, D., and Vašinová Galiová, M. (in press) Compositional evolution of  
1184 grossular garnet from leucotonalitic pegmatite at Ruda nad Moravou, Czech Republic; a  
1185 complex EMPA, LA-ICP-MS, IR and CL study. Mineralogy and Petrology.
- 1186 Galuskin, E.V. (2005) Minerals of the vesuvianite group from the achtarandite rocks (Wiluy River,  
1187 Yakutia). University of Silesia Publishing House, Katowice, Poland, 191 p. (in Polish).
- 1188 Galuskin, E.V., Galuskina, I.O., and Winiarska, A. (1995) Epitaxy of achtarandite on grossular –  
1189 the key to the problem of achtarandite. Neues Jahrbuch für Mineralogie Monatshefte, 1995(7),  
1190 306-320.
- 1191 Galuskin, E.V., Armbruster, T., Galuskina, I.O., Lazic, B., Winiarski, A., Gazeev, V.M.,  
1192 Dzierzanowski, P., Zadov, A.E., Pertsev, N.N., Wrzalik, R., Gurbanov, A.G., and Janeczek, J.  
1193 (2011a) Vorlanite  $(\text{CaU}^{6+})\text{O}_4$  – A new mineral from the Upper Chegem caldera, Kabardino-  
1194 Balkaria, Northern Caucasus, Russia. American Mineralogist, 96, 188-196.
- 1195 Galuskin, E.V., Bailau, R., Galuskina, I.O., Prusik, A.K., Gazeev, V.M., Zadov, A.E., Pertsev,  
1196 N.N., Ježak, L., Gurbanov, A.G., and Dubrovinsky, L. (2011b) Eltyubyuite, IMA 2011-  
1197 022. CNMNC Newsletter No. 10, October 2011, page 2553; Mineralogical Magazine, 75,  
1198 2549-2561.
- 1199 Galuskina, I.O. and Galuskin, E.V. (2003) Garnets of the hydrogrossular – “hydroandradite” –  
1200 “hydroschorlomite” series. Special Papers of the Mineralogical Society of Poland, 22, 54-57.
- 1201 Galuskina, I.O., Galuskin, E.V., and Sitarz, M. (1998) Atoll hydrogarnets and mechanism of the  
1202 formation of achtarandite pseudomorphs. Neues Jahrbuch für Mineralogie Monatshefte,  
1203 1998(2), 49-62.
- 1204 Galuskina, I.O., Galuskin, E.V., and Sitarz, M. (2001) Evolution of morphology and composition of  
1205 hibsichte, Wiluy River, Yakutia. Neues Jahrbuch für Mineralogie Monatshefte, 2001(2), 49-66.

- 1206 Galuskina, I.O., Galuskin, E.V., Dzierzanowski, P., Armbruster, T., and Kozanecki, M. (2005) A  
1207 natural scandian garnet. *American Mineralogist*, 90, 1688–1692.
- 1208 Galuskina, I.O., Galuskin, E.V., Armbruster, T., Lazic, B., Kusz, J., Dzierzanowski, P., Gazeev,  
1209 V.M., Pertsev, N.N., Prusik, K., Zadov, A.E., Winiarski, A., Wrzalik, R., and Gurbanov, A.G.  
1210 (2010a) Elbrusite-(Zr) — a new uranian garnet from the Upper Chegem caldera, Kabardino-  
1211 Balkaria, Northern Caucasus, Russia. *American Mineralogist*, 95, 1172-1181.
- 1212 Galuskina, I.O., Galuskin, E.V., Armbruster, T., Lazic, B., Dzierzanowski, P., Gazeev, V.M.,  
1213 Prusik, K., Pertsev, N.N., Winiarski, A., Zadov, A.E., Wrzalik, R., and Gurbanov, A.G.  
1214 (2010b) Bitikleite-(SnAl) and bitikleite-(ZrFe): New garnets from xenoliths of the Upper  
1215 Chegem volcanic structure, Kabardino-Balkaria, Northern Caucasus, Russia. *American*  
1216 *Mineralogist*, 95, 959-967.
- 1217 Galuskina, I.O., Galuskin, E.V., Dzierzanowski, P., Gazeev, V.M., Prusik, K., Pertsev, N.N.,  
1218 Winiarski, A., Zadov, A.E., and Wrzalik, R. (2010c) Toturite  $\text{Ca}_3\text{Sn}_2\text{Fe}_2\text{SiO}_{12}$  — A new  
1219 mineral species of the garnet group. *American Mineralogist*, 95, 1305-1311.
- 1220 Galuskina, I.O., Galuskin, E.V., Lazic, B., Armbruster, T., Dzierzanowski, P., Prusik, K., and  
1221 Wrzalik, R. (2010d) Eringaite,  $\text{Ca}_3\text{Sc}_2(\text{SiO}_4)_3$ , a new mineral of the garnet group. *Mineralogical*  
1222 *Magazine*, 74, 365-373.
- 1223 Galuskina, I.O., Galuskin, E.V., Gazeev, V.M., and Pertsev, N.N. (2010e) Natural uranian and  
1224 thorian garnets. In *Modern mineralogy: from theory to practice*, Proceedings of the XI Russian  
1225 Mineralogical Society General Meeting and the Fedorov Session 2010, no. 2010-1-169-0, p.  
1226 77-79 (in Russian, abstract). <http://www.minsoc.ru/2010-1-169-0>.
- 1227 Galuskina, I.O., Galuskin, E.V., Kusz, J., Dzierzanowski, P., Prusik, K., Gazeev, V.M., Pertsev,  
1228 N.N., and Dubrovinsky, L. (2011a) Bitikleite-(SnFe), IMA 2010-064. *CNMNC Newsletter No.*  
1229 *8*, April 2011, p. 290; *Mineralogical Magazine*, 75, 289-294.
- 1230 Galuskina, I.O., Galuskin, E.V., Prusik, K., Gazeev, V.M., Pertsev, N.N., and Dzierzanowski, P.  
1231 (2011b) Irinarassite, IMA 2010-073. *CNMNC Newsletter No. 8*, April 2011, p. 292;  
1232 *Mineralogical Magazine*, 75, 289-294.
- 1233 Gaudet, C., Orliac, M., Permingeat, F., and Parfenoff, E. (1969) L'henritermiérite, une nouvelle  
1234 espèce minérale. *Bulletin de la Société Française de Minéralogie et de Cristallographie*, 92,  
1235 185-190.
- 1236 Geiger, C.A. (2004) An introduction to spectroscopic methods in the mineral sciences and  
1237 geochemistry. In A. Beran and E. Libowitzky, Eds., *European Mineralogical Union Notes in*  
1238 *Mineralogy*, 6, Spectroscopic Methods in Mineralogy, p. 1-42. Eötvös Press, Budapest.
- 1239 Geiger, C.A. (2008) Silicate garnet: A micro to macroscopic (re)view. *American Mineralogist*, 93,  
1240 360-372.
- 1241 Geiger, C.A. and Armbruster, T. (1997)  $\text{Mn}_3\text{Al}_2\text{Si}_3\text{O}_{12}$  spessartine and  $\text{Ca}_3\text{Al}_2\text{Si}_3\text{O}_{12}$  grossular  
1242 garnet: Structural dynamic and thermodynamic properties. *American Mineralogist*, 82, 740–  
1243 747.
- 1244 Geiger, C.A., Rubie, D.C., Ross, C.R. II, and Seifert, F. (1991a) Synthesis and  $^{57}\text{Fe}$  Mössbauer  
1245 study of  $(\text{Mg,Fe})\text{SiO}_3$  garnet. *Terra Abstracts*, 3, 63 (abstract).
- 1246 Geiger, C.A., Rubie, D.C., Ross, C.R. II, and Seifert, F. (1991b) A cation partitioning study of  
1247  $(\text{Mg,Fe})\text{SiO}_3$  garnet using  $^{57}\text{Fe}$  Mössbauer spectroscopy. *American Geophysical Union Eos*  
1248 *Transactions* 72, 564-565 (abstract).
- 1249 Geller, S. (1967) Crystal chemistry of the garnets. *Zeitschrift für Kristallographie*, 125, 1-47.

- 1250 Geller, S. (1971) Refinement of the crystal structure of cryolithionite,  $\{Na_3\}[Al_2](Li_3)F_{12}$ . American  
1251 Mineralogist, 56, 18-23.
- 1252 Giaramita, M.J. and Day, H.W. (1990) Error propagation in calculations of structural formulas.  
1253 American Mineralogist, 75, 170-182.
- 1254 Glasser, F.P. (1995) Comments on wadalite,  $Ca_6Al_5SiO_{16}Cl_3$ , and the structures of garnet, mayenite  
1255 and calcium chlorosilicate. Addendum. Acta Crystallographica, C51, 340.
- 1256 Gnevushev, M.A. and Fedorova, L.G. (1964) Effect of isomorphous replacement on the infrared  
1257 spectra of garnets. Doklady of the Academy of Sciences of the U.S.S.R. Earth Sciences  
1258 Sections, 146, 115-117.
- 1259 Grapes, R., Yagi, K., and Okumura, K. (1979) Aenigmatite, sodic pyroxene, arfvedsonite and  
1260 associated minerals in syenites from Morotu, Sakhalin. Contributions to Mineralogy and  
1261 Petrology, 69, 97-103.
- 1262 Grew, E. S. (2002a) Borosilicates (exclusive of tourmaline) and boron in rock-forming minerals in  
1263 metamorphic environments. Reviews in Mineralogy, 33, 387-502.
- 1264 Grew, E. S. (2002b) Beryllium in metamorphic environments (emphasis on aluminous  
1265 compositions). Reviews in Mineralogy & Geochemistry, 50, 487-549.
- 1266 Grew, E.S., Chernosky, J.V., Werding, G., Abraham, K., Marquez, N., and Hinthorne, J.R. (1990)  
1267 Chemistry of kornorupine and associated minerals, a wet chemical, ion microprobe, and x-ray  
1268 study emphasizing Li, Be, B and F contents. Journal of Petrology, 31, 1025-1070.
- 1269 Grew, E.S., Hålenius, U., Pasero, M., and Barbier, J. (2008) Recommended nomenclature for the  
1270 sapphirine and surinamite groups (sapphirine supergroup). Mineralogical Magazine 72, 839-  
1271 876.
- 1272 Grew, E. S., Marsh, J.H., Yates, M.G., Lazic, B., Armbruster, T., Locock, A., Bell, S.W., Dyar,  
1273 M.D., Bernhardt, H.-J., and Medenbach, O. (2010) Menzerite-(Y), a new garnet species,  $\{(Y,$   
1274  $REE)(Ca, Fe^{2+})_2\}[(Mg, Fe^{2+})(Fe^{3+}, Al)](Si_3)O_{12}$ , from a felsic granulite, Parry Sound, Ontario,  
1275 and a new garnet end-member,  $\{Y_2Ca\}[Mg_2](Si_3)O_{12}$ . Canadian Mineralogist, 48, 1171-1193.
- 1276 Griffen, D.T., Hatch, D.M., Phillips, W.R., and Kulaksiz, S. (1992) Crystal chemistry and  
1277 symmetry of a birefringent tetragonal pyralispite<sub>75</sub>-grandite<sub>25</sub> garnet. American Mineralogist,  
1278 77, 399-406.
- 1279 Haggerty, S.E., Fung, A.T., and Burt D.M. (1994) Apatite, phosphorus and titanium in eclogitic  
1280 garnet from the upper mantle. Geophysical Research Letters, 21, 1699-1702.
- 1281 Hålenius, U. (2004) Stabilization of trivalent Mn in natural tetragonal hydrogarnets on the join  
1282 'hydrogrossular'-henritermierite,  $Ca_3Mn^{3+}_2[SiO_4]_2(H_4O_4)$ . Mineralogical Magazine, 68, 335-  
1283 341.
- 1284 Hålenius, U., Häussermann, U., and Harryson, H. (2005) Holtstamite,  $Ca_3(Al, Mn^{3+})_2(SiO_4)_3-$   
1285  $_x(H_4O_4)_x$ , a new tetragonal hydrogarnet from Wessels Mine, South Africa. European Journal of  
1286 Mineralogy, 17, 375-382.
- 1287 Harris, J., Hutchison, M.T., Hursthouse, M., Light, M., and Harte, B. (1997) A new tetragonal  
1288 silicate mineral occurring as inclusions in lower-mantle diamonds. Nature, 387, 486-488.
- 1289 Harte, B. (2010) Diamond formation in the deep mantle: the record of mineral inclusions and their  
1290 distribution in relation to mantle dehydration zones. Mineralogical Magazine, 74, 189-215.
- 1291 Hartman, P. (1969) Can  $Ti^{+4}$  replace  $Si^{+4}$  in silicates? Mineralogical Magazine, 37, 366-369.
- 1292 Hatch, D.M. and Ghose, S. (1989) Symmetry analysis of the phase transition and twinning in  
1293  $MgSiO_3$  garnet: Implications to mantle mineralogy. American Mineralogist, 74, 1221-1224.

- 1294 Hatert, F. and Burke, E.A.J. (2008) The IMA–CNMNC dominant-constituent rule revisited and  
1295 extended. *Canadian Mineralogist*, 46, 717-728.
- 1296 Hawthorne, F.C. (1976) Refinement of the crystal structure of berzeliite. *Acta Crystallographica*,  
1297 B32, 1581-1583.
- 1298 Hawthorne, F.C. (1981) Some systematics of the garnet structure. *Journal of Solid State Chemistry*,  
1299 37, 157-164.
- 1300 Hawthorne, F.C. (2002) The use of end-member charge-arrangements in defining new mineral  
1301 species and heterovalent substitutions in complex minerals. *Canadian Mineralogist*, 40, 699-  
1302 710.
- 1303 Hawthorne, F.C., Oberti, R., Harlow, G.E., Maresch, W.V., Martin, R.F., Schumacher, J.C., and  
1304 Welch, M.D. (in press) Nomenclature of the amphibole-supergroup. *American Mineralogist*
- 1305 Hazen, R.M., Downs, R.T., Finger, L.W., Conrad, P.G., and Gasparik, T. (1994) Crystal chemistry  
1306 of calcium-bearing majorite. *American Mineralogist*, 79, 581-584.
- 1307 Headden, W.P. (1891) A new phosphate from the Black Hills of South Dakota. *American Journal of*  
1308 *Science*, 141, 415-417.
- 1309 Henmi, C., Kusachi, I., and Henmi, K. (1995) Morimotoite,  $\text{Ca}_3\text{TiFe}^{2+}\text{Si}_3\text{O}_{12}$ , a new titanian garnet  
1310 from Fuka, Okayama Prefecture, Japan. *Mineralogical Magazine*, 59, 115-120.
- 1311 Henry, D.J., Novák, M., Hawthorne, F.C., Ertl, A., Dutrow, B.L., Uher, P., and Pezzotta, F. (2011)  
1312 Nomenclature of the tourmaline-supergroup minerals. *American Mineralogist*, 96, 895-913.
- 1313 Hess, H. (1832) Ueber den Uwarowit, eine neue Mineralspecies. *Annalen der Physik und Chemie*,  
1314 24, 388-389.
- 1315 Hintze, C.A.F. (1922) *Handbuch der Mineralogie*, volume 1, part 4:1, p. 213. Veit and Company,  
1316 Leipzig.
- 1317 Hiroi, Y., Motoyoshi, Y., Ellis, D. J., Shiraishi, K., and Kondo, Y. (1997) The significance of  
1318 phosphorus zonation in garnet from high grade pelitic rocks: a new indicator of partial melting.  
1319 In C.A. Ricci, Ed., *The Antarctic Region: Geological Evolution and Processes*, p. 73-77. Terra  
1320 Antarctica Publication, Siena, Italy.
- 1321 Hochella, M.F., Jr. (1988) Auger electron and X-ray photoelectron spectroscopies. *Reviews in*  
1322 *Mineralogy*, 18, 573-637.
- 1323 Hofmeister, A.M., Schaal, R.B., Campbell, K.R., Berry, S.L., and Fagan, T.J. (1998) Prevalence  
1324 and origin of birefringence in 48 garnets from the pyrope-almandine-grossularite-spessartine  
1325 quaternary. *American Mineralogist*, 83, 1293-1301.
- 1326 Howie, R.A. and Woolley, A.R. (1968) The role of titanium and the effect of  $\text{TiO}_2$  on the cell-size,  
1327 refractive index, and specific gravity in the andradite□melanite□schorlomite series.  
1328 *Mineralogical Magazine*, 36, 775-790.
- 1329 Huggins, F.E., Virgo D., and Huckenholz, H.G. (1977) Titanium-containing silicate garnets. II. The  
1330 crystal chemistry of melanites and schorlomites. *American Mineralogist*, 62, 646-665.
- 1331 Hutton, C.O. (1943) Hydrogrossular, a new mineral of the garnet-hydrogarnet series. *Royal Society*  
1332 *of New Zealand Transactions and Proceedings*, 73, 174-180.
- 1333 Igelström, L.J. (1886) Pyrrhoarsénit, nouveau minéral de Sjøgrufvan, paroisse de Grythytan,  
1334 gouvernement d'Ërebro, Suède. *Bulletin de la Société Française de Minéralogie*, 9, 218-220.
- 1335 Igelström, L.J. (1894) Mineralogische Notizen. 1. Lindesit. 2. Pyrrhoarsenit. *Zeitschrift für*  
1336 *Kristallographie, Mineralogie und Petrographie*, 23, 590-593.

- 1337 Ito, J. (1968) Synthesis of the berzeliite ( $\text{Ca}_2\text{NaMg}_2\text{As}_3\text{O}_{22}$ )—manganese berzeliite  
1338 ( $\text{Ca}_2\text{NaMn}_2\text{As}_3\text{O}_{12}$ ) series (arsenate garnet). *American Mineralogist*, 53, 316-319.
- 1339 Ito, J. and Frondel, C. (1967a) Synthetic zirconium and titanium garnets. *American Mineralogist*,  
1340 52, 773-781.
- 1341 Ito, J. and Frondel, C. (1967b) New synthetic hydrogarnets. *American Mineralogist*, 52, 1105-1109.
- 1342 Ivanov-Emin, B.N., Nevskaya, N.A., Zaitsev, B.E., and Tsirel'nikov, V.I. (1982a)  
1343 Hydroxoscandiates of calcium and strontium. *Zhurnal Neorganicheskoi Khimii*, 27, 2228-2230  
1344 (in Russian).
- 1345 Ivanov-Emin, B.N., Nevskaya, N.A., Zaitsev, B.E., and Ivanova, T.M. (1982b) Synthesis and  
1346 properties of calcium and strontium hydroxomanganates (III). *Zhurnal Neorganicheskoi*  
1347 *Khimii*, 27, 3101-3104 (in Russian).
- 1348 Iwata, T., Haniuda, M., and Fukuda, K. (2008) Crystal structure of  $\text{Ca}_{12}\text{Al}_{14}\text{O}_{32}\text{Cl}_2$  and  
1349 luminescence properties of  $\text{Ca}_{12}\text{Al}_{14}\text{O}_{32}\text{Cl}_2:\text{Eu}^{2+}$ . *Journal of Solid State Chemistry*, 181, 51-55.
- 1350 Jaffe, H.W. (1951) The role of yttrium and other minor elements in the garnet group. *American*  
1351 *Mineralogist*, 36, 133-155.
- 1352 Jambor, J.L., Grew, E.S., Puziewicz, J., and Vanko, D.A. (1988a) New mineral names. *American*  
1353 *Mineralogist*, 73, 439-445.
- 1354 Jambor, J.L., Bladh, K.W., Ercit, T.S., Grice, J.D., and Grew, E.S. (1988b) New mineral names.  
1355 *American Mineralogist*, 73, 927-935.
- 1356 Jambor, J.L., Pertsev, N.N., and Roberts, A.C. (1997) New mineral names. *American Mineralogist*,  
1357 82, 1038-1041.
- 1358 Jarosch, D. and Zemann, J. (1989) Yafsoanite: a garnet type calcium-tellurium(VI)-zinc oxide.  
1359 *Mineralogy and Petrology*, 40, 111-116.
- 1360 Johan, Z. and Oudin, E. (1986) Présence de grenats,  $\text{Ca}_3\text{Ga}_2(\text{GeO}_4)_3$ ,  $\text{Ca}_3\text{Al}_2[(\text{Ge}, \text{Si})\text{O}_4]_3$  et d'un  
1361 équivalent ferrifère, germanifère et gallifère de la sapphirine,  $\text{Fe}_4(\text{Ga}, \text{Sn}, \text{Fe})_4(\text{Ga}, \text{Ge})_6\text{O}_{20}$ ,  
1362 dans la blende des gisements de la zone axiale pyrénéenne. Conditions de formation des  
1363 germanifères et gallifère. *Compte Rendus de l'Académie des Sciences*, 303, Series II, 811-816.
- 1364 Johnson, E. A. (2006) Water in nominally anhydrous crustal minerals: Speciation, concentration,  
1365 and geologic significance. *Reviews in Mineralogy & Geochemistry*, 62, 117-154.
- 1366 Juhin, A., Morin, G., Elkaïm, E., Frost, D.J., Fialin, M., Juillot, F., and Calas, G. (2010) Structure  
1367 refinement of a synthetic knorringite,  $\text{Mg}_3(\text{Cr}_{0.8}\text{Mg}_{0.1}\text{Si}_{0.1})_2(\text{SiO}_4)_3$ . *American Mineralogist*, 95,  
1368 59-63.
- 1369 Kalinichenko, A.M., Proshko, V.Ya., Matyash, I.V., Pavlishin, V.I., and Gamarnik, M.Ya. (1987)  
1370 NMR Data on crystallochemical features of hydrogrossular. *Geochemistry International*, 24(4),  
1371 132-135.
- 1372 Karpinskaya, T.B., Ostrovskiy, I.A., and Yevstigneyeva, T.L. (1982) Synthetic pure iron garnet  
1373 skiagite. *Izvestiya Akademii Nauk SSSR. Seriya Geologicheskaya*, 1982, Issue 9, 128-129 (in  
1374 Russian).
- 1375 Kasowski, M.A. and Hogarth, D.D. (1968) Yttrian andradite from the Gatineau Park, Quebec.  
1376 *Canadian Mineralogist*, 9, 552-558.
- 1377 Kato, T. (1986) Stability relation of  $(\text{Mg}, \text{Fe})\text{SiO}_3$  garnets, major constituents in the Earth's interior.  
1378 *Earth and Planetary Science Letters*, 77, 399-408.
- 1379 Kawakami, T. and Hokada, T. (2010) Linking *P-T* path with development of discontinuous  
1380 phosphorus zoning in garnet during high-temperature metamorphism – an example from

- 1381 Lützow-Holm Complex, East Antarctica. *Journal of Mineralogical and Petrological Sciences*,  
1382 105, 175-186.
- 1383 Khorari, S., Rulmont, A., Cahay, R., and Tarte, P. (1995) Structures of the complex arsenates  
1384  $\text{NaCa}_2M^{2+}_2(\text{AsO}_4)_3$  ( $M^{2+} = \text{Mg, Ni, Co}$ ): First experimental evidence of a garnet–alluaudite  
1385 reversible polymorphism. *Journal of Solid State Chemistry*, 118, 267-273.
- 1386 Khorari, S., Rulmont, A., and Tarte, P. (1997) The arsenates  $\text{NaCa}_2M^{2+}_2(\text{AsO}_4)_3$  ( $M^{2+} = \text{Mg, Ni,}$   
1387  $\text{Co}$ ): Influence of cationic substitutions on the garnet–alluaudite polymorphism. *Journal of*  
1388 *Solid State Chemistry*, 131, 290-297.
- 1389 Kim, A. A., Zayakina, N. V., and Lavrent'yev, Yu. G. (1982) Yafsoanite ( $\text{Zn}_{1.38}\text{Ca}_{1.36}\text{Pb}_{0.26}$ ) $\text{Te}_1\text{O}_6$   
1390 – a new mineral of tellurium. *Zapiski Vsesoyuznogo Mineralogicheskogo Obshchestva*, 111,  
1391 118-121 (in Russian; English translation: *International Geology Review*, 24, 1295-1298).
- 1392 Klaproth, M.H. (1797) *Beiträge zur chemischen Kenntniss der Mineralkörper*, Volume 2, Posen and  
1393 Berlin.
- 1394 Koritnig, S. (1965) Geochemistry of phosphorus—I. The replacement of  $\text{Si}^{4+}$  by  $\text{P}^{5+}$  in rock-  
1395 forming silicate minerals. *Geochimica et Cosmochimica Acta*, 29, 361-371.
- 1396 Koritnig, S., Rösch, H., Schneider, A., and Seifert, F. (1978) Der Titan-Zirkon-Granat aus den  
1397 Kalksilikatfels-Einschlüssen des Gabbro im Radautal, Harz, Bundesrepublik Deutschland.  
1398 *Tschermaks Mineralogische und Petrographische Mitteilungen*, 25, 305-313.
- 1399 Krause, W., Blaß, G., and Effenberger, H. (1999) Schäferite, a new vanadium garnet from the  
1400 Bellberg volcano, Eifel, Germany. *Neues Jahrbuch für Mineralogie Monatshefte*, 1999(3), 123-  
1401 134.
- 1402 Kühberger, A., Fehr, T., Huckenholz, H.G., and Amthauer, G. (1989) Crystal chemistry of a natural  
1403 schorlomite and Ti-andradites synthesized at different oxygen fugacities. *Physics and*  
1404 *Chemistry of Minerals*, 16, 734-740.
- 1405 Kühn, O.B. (1840) Neues Mineral von Langbanshytta bei Fahlun. *Annalen der Chemie und*  
1406 *Pharmacie*, 34, 211-218.
- 1407 Labotka, T.C. (1995) Evidence for immiscibility in Ti-rich garnet in a calc-silicate hornfels from  
1408 northeastern Minnesota. *American Mineralogist*, 80, 1026-1030.
- 1409 Lager, G.A., Armbruster, T., and Faber, J. (1987) Neutron and X-ray diffraction study of  
1410 hydrogarnet  $\text{Ca}_3\text{Al}_2(\text{O}_4\text{H}_4)_3$ . *American Mineralogist*, 72, 756-765.
- 1411 Lager, G.A., Armbruster, T., Rotella, F.J., and Rossman, G.R. (1989) OH substitution in garnets: X-  
1412 ray and neutron diffraction, infrared, and geometric-modeling studies. *American Mineralogist*,  
1413 74, 840–851.
- 1414 Landergrén, S. (1930) Studier över berzeliitgruppens mineral. *Geologiska Föreningens i Stockholm*  
1415 *Förhandlingar*, 52, 123-133 (in Swedish).
- 1416 Langley, R.H. and Sturgeon, G.D. (1979) Lattice parameters and ionic radii of the oxide and  
1417 fluoride garnets. *Journal of Solid State Chemistry*, 30, 79-82.
- 1418 Laverne, C., Grauby, O., Alt, J.C., and Bohn, M. (2006) Hydroschorlomite in altered basalts from  
1419 Hole 1256D, ODP Leg 206: The transition from low-temperature to hydrothermal alteration.  
1420 *Geochemistry Geophysics Geosystems*, 7(10), Q10O03, doi:10.1029/2005GC001180.
- 1421 Lehijärvi, M. (1960) The alkaline district of Iivaara, Kuusamo, Finland. *Bulletin de la Commission*  
1422 *Géologique de Finlande*, 185, 1-62.
- 1423 Levinson, A.A. (1966) A system of nomenclature for rare-earth minerals. *American Mineralogist*,  
1424 51, 152-158.



- 1425 Lobanov, N.N., Butman, L.A., and Tsirel'son, V.G. (1989) Precision X-ray diffraction study of the  
1426 garnets.  $\text{Na}_3\text{Sc}_2\text{V}_3\text{O}_{12}$  and  $\text{Na}_{0.90}\text{Ca}_{2.38}\text{Mn}_{1.72}\text{V}_3\text{O}_{12}$ . *Journal of Structural Chemistry*, 30(1), 96-  
1427 104
- 1428 Locock, A.J. (2008) An Excel spreadsheet to recast analyses of garnet into end-member  
1429 components, and a synopsis of the crystal chemistry of natural silicate garnets. *Computers &*  
1430 *Geosciences*, 34, 1769-1780.
- 1431 Locock, A.J., Luth, R.W., Cavell, R.G., Smith, D.G.W., and Duke, M.J.M. (1995) Spectroscopy of  
1432 the cation distribution in the schorlomite species of garnet. *American Mineralogist*, 80, 27-38.
- 1433 Lupini, L., Williams, C.T., and Woolley, A.R. (1992) Zr-rich garnet and Zr- and Th-rich perovskite  
1434 from the Polino carbonatite, Italy. *Mineralogical Magazine*, 56, 581-586.
- 1435 Ma, C. (2012) Discovery of meteoritic eringaite,  $\text{Ca}_3(\text{Sc},\text{Y},\text{Ti})_2\text{Si}_3\text{O}_{12}$ , the first solar garnet.  
1436 *Meteoritics & Planetary Science*, 47, Supplement S1, Abstract 5015.
- 1437 Ma, C., Connolly, H.C., Jr., Beckett, J.R., Tschauer, O., Rossman, G.R., Kampf, A.R., Zega, T.J.,  
1438 Sweeney Smith, S.A., and Schrader, D.L. (2011) Brearleyite,  $\text{Ca}_{12}\text{Al}_{14}\text{O}_{32}\text{Cl}_2$ , a new alteration  
1439 mineral from the NWA 1934 meteorite. *American Mineralogist*, 96, 1199-1206.
- 1440 Maldener, J., Hösche, A., Langer, K., and Rauch, F. (2003) Hydrogen in some natural garnets  
1441 studied by nuclear reaction analysis and vibrational spectroscopy. *Physics and Chemistry of*  
1442 *Minerals*, 30, 337-344.
- 1443 Malitesta, C., Losito, I., Scordari, F., and Schingaro, E. (1995) XPS investigation of titanium in  
1444 melanites from Monte Vulture (Italy). *European Journal of Mineralogy*, 7, 847-858.
- 1445 Manning, C.E. and Bird, D.K. (1990) Fluorian garnets from the host rocks of the Skaergaard  
1446 intrusion: Implications for metamorphic fluid composition. *American Mineralogist*, 75, 859-  
1447 873.
- 1448 Marks, M.A.W., Schilling, J., Coulson, I.M., Wenzel, T., and Markl, G. (2008) The  
1449 alkaline-peralkaline Tamazeght Complex, High Atlas Mountains, Morocco: Mineral  
1450 chemistry and petrological constraints for derivation from a compositionally heterogeneous  
1451 mantle source. *Journal of Petrology*, 49, 1097-1131.
- 1452 Marschall, H.R. (2005) Lithium, beryllium and boron in high-pressure metamorphic rocks from  
1453 Syros (Greece). Unpublished Inaugural-Dissertation, Ruprecht-Karls-Universität Heidelberg,  
1454 Germany.
- 1455 Mason, B. and Berggren, T. (1942) A phosphate-bearing spessartite garnet from Wodgina, Western  
1456 Australia. *Geologiska Föreningens i Stockholm Förhandlingar*, 63, 413-418.
- 1457 McAloon, B.P. and Hofmeister, A.M. (1993) Single-crystal absorption and reflection infrared  
1458 spectroscopy of birefringent grossular-andradite garnets. *American Mineralogist*, 78, 957-967.
- 1459 McCammon, C.A. and Ross, N.L. (2003) Crystal chemistry of ferric iron in  $(\text{Mg},\text{Fe})(\text{Si},\text{Al})\text{O}_3$   
1460 majorite with implications for the transition zone. *Physics and Chemistry of Minerals*, 30, 206-  
1461 216.
- 1462 McConnell, D. (1942) Griphite, a hydrophosphate garnetoid. *American Mineralogist*, 27, 452-461.
- 1463 Melluso, L., Srivastava, R.K., Guarino, V., Zanetti, A., and Sinha, A.K. (2010) Mineral  
1464 compositions and petrogenetic evolution of the ultramafic-alkaline – carbonatitic complex of  
1465 Sung Valley, northeastern India. *Canadian Mineralogist*, 48, 205-229.
- 1466 Menzer, G. (1928) Die Kristallstruktur der Granate. *Zeitschrift für Kristallographie*, 69, 300-396.

- 1467 Merli, M., Callegari, A., Cannillo, E., Caucia, F., Leona, M., Oberti, R., and Ungaretti, L. (1995)  
1468 Crystal-chemical complexity in natural garnets: structural constraints on chemical variability.  
1469 European Journal of Mineralogy, 7, 1239-1249.
- 1470 Mill', B.V. (1970) New series of  $\text{Te}^{6+}$ -containing garnets. Doklady Akademii Nauk SSSR, 191, 86-  
1471 88 (in Russian).
- 1472 Mill', B.V., Belokoneva, E.L., Simonov, M.A., and Belov, N.V. (1977) Refined crystal structures of  
1473 the scandium garnets  $\text{Ca}_3\text{Sc}_2\text{Si}_3\text{O}_{12}$ ,  $\text{Ca}_3\text{Sc}_2\text{Ge}_3\text{O}_{12}$ , and  $\text{Cd}_3\text{Sc}_2\text{Ge}_3\text{O}_{12}$ . Journal of Structural  
1474 Chemistry, 18, 321-323.
- 1475 Mills, S.J., Hatert, F., Nickel, E.H., and Ferraris, G. (2009) The standardisation of mineral group  
1476 hierarchies: application to recent nomenclature proposals. European Journal of Mineralogy, 21,  
1477 1073-1080.
- 1478 Mills, S.J., Kampf, A.R., Kolitsch, U., Housley, R.H., and Raudsepp, M. (2010) The crystal  
1479 chemistry and crystal structure of kuznetsovite,  $\text{Pb}_3\text{Zn}_3\text{Te}^{6+}\text{P}_2\text{O}_{14}$ , and a note on the crystal structure  
1480 of yafsoanite,  $(\text{Ca,Pb})_3\text{Zn}(\text{TeO}_6)_2$ . American Mineralogist, 95, 933-938.
- 1481 Milton, C. and Blade, L.V. (1958) Preliminary note on kimzeyite, a new zirconium garnet. Science,  
1482 127, 1343.
- 1483 Milton, C., Ingram, B.L., and Blade, L.V. (1961) Kimzeyite, a zirconium garnet from Magnet Cove,  
1484 Arkansas. American Mineralogist, 46, 533-548.
- 1485 Moench, R.H., and Meyrowitz, R. (1964) Goldmanite, a vanadium garnet from Laguna, New  
1486 Mexico. American Mineralogist 49, 644-655.
- 1487 Momoi, H. (1964) A new vanadium garnet,  $(\text{Mn, Ca})_3\text{V}_2\text{Si}_3\text{O}_{12}$ , from Yamato mine, Amami  
1488 Islands, Japan. Memoirs of the Faculty of Science, Kyushu University, Series D, Geology,  
1489 15(1), 73-78.
- 1490 Moore, P.B. (1972) Contributions to the mineralogy of Sweden. III. On Igelström's manganese  
1491 arsenates and antimonates from the Sjö Mine, Grythyttan, Örebro County, Sweden. Geologiska  
1492 Föreningens i Stockholm Förhandlingar, 94, 423-434.
- 1493 Moore, R.O. and Gurney, J.J. (1985) Pyroxene solid solution in garnets included in diamond.  
1494 Nature, 318, 553-555.
- 1495 Morán-Miguélez, E., Alario-Franco, M.A., and Joubert, J.C. (1986) Hydrothermal synthesis and  
1496 field of existence of silicon-free garnets. Materials Research Bulletin, 21, 107-113.
- 1497 Munno, R., Rossi, G., and Tadini, C. (1980) Crystal chemistry of kimzeyite from Stromboli,  
1498 Aeolian Islands, Italy. American Mineralogist, 65, 188-191.
- 1499 Nagashima, M. and Armbruster, T. (2012). Palenzonaite, berzeliite, and manganberzeliite:  
1500  $(\text{As}^{5+}, \text{V}^{5+}, \text{Si}^{4+})\text{O}_4$  tetrahedra in garnet structures. Mineralogical Magazine, 76, 1081-1097.
- 1501 Nickel, E.H. and Grice, J.D. (1998) The IMA Commission on New Minerals and Mineral Names:  
1502 procedures and guidelines on mineral nomenclature, 1998. Canadian Mineralogist, 36, 913-  
1503 926.
- 1504 Nickel, E.H. and Mandarino, J.A. (1987) Procedures involving the IMA Commission on New  
1505 Minerals and Mineral Names and guidelines on mineral nomenclature. American Mineralogist,  
1506 72, 1031-1042.
- 1507 Nishizawa, H. and Koizumi, M. (1975) Synthesis and infrared spectra of  $\text{Ca}_3\text{Mn}_2\text{Si}_3\text{O}_{12}$  and  
1508  $\text{Cd}_3\text{B}_2\text{Si}_3\text{O}_{12}$  (B: Al, Ga, Cr, V, Fe, Mn) garnets. American Mineralogist, 60, 84-87.
- 1509 Nixon, P.H. and Hornung, G. (1968) A new chromium garnet end member, knorringite, from  
1510 kimberlite. American Mineralogist, 53, 1833-1840.

- 1511 Novak, G.A. and Gibbs, G.V. (1971) The crystal chemistry of the silicate garnets. American  
1512 Mineralogist, 56, 791-825.
- 1513 Oberti, R., Ungaretti, L., Cannillo, E., and Hawthorne, F.C. (1992) The behaviour of Ti in  
1514 amphiboles: I. Four- and six-coordinate Ti in richterite. European Journal of Mineralogy, 4,  
1515 425-439.
- 1516 Oberti, R., Quartieri, S., Dalconi, C.M., Boscherini, F., Iezzi, G., Boiocchi, M., and Eeckout, S.G.  
1517 (2006) Site preference and local geometry of Sc in garnets: Part I. Multifarious mechanisms in  
1518 the pyrope-grossular join. American Mineralogist, 91, 1230-1239.
- 1519 O'Callaghan, M.P. and Cussen, E.J. (2007) Lithium dimer formation in the Li-conducting garnets  
1520  $\text{Li}_{5+x}\text{Ba}_x\text{La}_{3-x}\text{Ta}_2\text{O}_{12}$  ( $0 < x \leq 1.6$ ). Chemical Communications, 2007, 2048-2050. DOI:  
1521 10.1039/b700369b
- 1522 O'Neill, H.St.C., McCammon, C.A., Canil, D., Rubie, D.C., Ross, C.R., II, and Seifert, F. (1993a)  
1523 Mössbauer spectroscopy of mantle transition zone phases and determination of minimum  $\text{Fe}^{3+}$   
1524 content. American Mineralogist, 78, 456-460.
- 1525 O'Neill, H.St.C., Rubie, D.C., Canil, D., Geiger, C.A., Ross, C.R., II, Seifert, F., and Woodland,  
1526 A.B. (1993b) Ferric iron in the upper mantle and in transition zone assemblages: implications  
1527 for relative oxygen fugacities in the mantle. In E. Takahashi, R. Jeanloz, and D.C. Rubie, Eds.,  
1528 Evolution of the Earth and Planets, Geophysical Monograph 74, p. 73-88. American  
1529 Geophysical Union, Washington DC.
- 1530 Ottonello, G., Bokreta, M., and Sciuto, P.F. (1996) Parameterization of energy and interactions in  
1531 garnets: End-member properties. American Mineralogist, 81, 429-447.
- 1532 Palache, C., Berman, H., and Frondel, C. (1951) The system of mineralogy of James Dwight Dana  
1533 and Edward Salisbury Dana, Yale University, 1837-1892. Seventh edition. John Wiley and  
1534 Sons, New York.
- 1535 Pasero, M., Kampf, A.R., Ferraris, C., Pekov, I.V., Rakovan, J., and White, T.J. (2010).  
1536 Nomenclature of the apatite supergroup minerals. European Journal of Mineralogy, 22, 163-  
1537 179.
- 1538 Passaglia, E. and Rinaldi, R. (1984) Katoite, a new member of the  $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3\text{-Ca}_3\text{Al}_2(\text{OH})_{12}$   
1539 series and a new nomenclature for the hydrogrossular group of minerals. Bulletin de la Société  
1540 Française de Minéralogie et de Cristallographie, 107, 605-618.
- 1541 Pekov, I.V. (1998) Minerals first discovered on the territory of the former Soviet Union. Ocean  
1542 Pictures, Moscow.
- 1543 Pertlik, F. (2003) Bibliography of hibschite, a hydrogarnet of grossular type. GeoLines, 15, 113-  
1544 119.
- 1545 Peters, Tj. (1965) A water-bearing andradite from the Totalp serpentine (Davos, Switzerland).  
1546 American Mineralogist, 50, 1482-1486.
- 1547 Peterson, R.C., Locock, A.J., and Luth, R.W. (1995) Positional disorder of oxygen in garnet: The  
1548 crystal-structure refinement of schorlomite. Canadian Mineralogist, 33, 627-631.
- 1549 Piddington, H. (1850) On calderite, an undescribed siliceo-iron-and-manganese rock, from the  
1550 district of Burdwan. Journal of the Asiatic Society of Bengal, 19, 145-148.
- 1551 Pieper, G., Fuess, H., Töpel-Schadt, J., and Anthauer, G. (1983) Die Bestimmung der  
1552 Kationenverteilung in den natürlichen Granatan Pyrop und Hessonit durch Neutronenbeugung.  
1553 Neues Jahrbuch für Mineralogie Abhandlungen, 147, 147-159.
- 1554 Platt, R.G. and Mitchell, R.G. (1979) The Marathon Dikes. I: Zirconium-rich titanian garnets and  
1555 manganoan magnesian ulvöspinel-magnetite spinels. American Mineralogist, 64, 546-550.

- 1556 Povarennykh, A.S. and Shabilin, B.G. (1983) Structural role of titanium and iron in synthetic  
1557 zirconium- and titanium-containing garnets. *Geologicheskii Zhurnal*, 43, 45-50 (in Russian).
- 1558 Quartieri, S., Oberti, R., Boiocchi, M., Dalconi, M.C., Boscherini, F., Safonova, O., and Woodland,  
1559 A.B. (2006) Site preference and local geometry of Sc in garnets: Part II. The crystal-chemistry  
1560 of octahedral Sc in the andradite  $\square$ Ca<sub>3</sub>Sc<sub>2</sub>Si<sub>3</sub>O<sub>12</sub> join. *American Mineralogist*, 91, 1240-1248.
- 1561 Rager, H., Geiger, C.A., and Stahl, A. (2003) Ti(III) in synthetic pyrope: A single-crystal electron  
1562 paramagnetic resonance study. *European Journal of Mineralogy*, 15, 697-699.
- 1563 Rammelsberg, K.F.A. (1850a) V. Mineralogical Notices. Schorlamite  $2(3\text{RO} + 2\text{SiO}^3) + 3(2\text{RO} +$   
1564  $\text{TiO}^2)$ . *Philosophical Magazine and Journal of Science*, 36, 21.
- 1565 Rammelsberg, K.F. (1850b) Analysis of the schorlomite of Shepard. *American Journal of Science*  
1566 *and Arts*, 9, 429.
- 1567 Rass, I.T. (1997) Morimotoite, a new titanian garnet? — discussion. *Mineralogical Magazine*, 61,  
1568 728-730.
- 1569 Rickwood, P.C. (1968) On recasting analyses of garnet into end-member molecules. *Contributions*  
1570 *to Mineralogy and Petrology*, 18, 175-198.
- 1571 Righter, K., Sutton, S., Danielson, L., Pando, K., Schmidt, G., Yang, H., Berthet, S., Newville, M.,  
1572 Choi, Y., Downs, R.T., and Malavergne, V. (2011) The effect of  $f_{\text{O}_2}$  on the partitioning and  
1573 valence of V and Cr in garnet/melt pairs and the relation to terrestrial mantle V and Cr content.  
1574 *American Mineralogist*, 96, 1278-1290.
- 1575 Rinaldi, R. (1978) The crystal structure of griphite, a complex phosphate, not a garnetoid. *Bulletin*  
1576 *de Minéralogie*, 101, 543-547.
- 1577 Ringwood, A.E. and Major, A. (1971) Synthesis of majorite and other high pressure garnets and  
1578 perovskites. *Earth and Planetary Science Letters*, 12, 411-418.
- 1579 Røhr, T.S., Austrheim, H., and Erambert, S. (2007) Stress-induced redistribution of yttrium and  
1580 heavy rare-earth elements (HREE) in garnet during high-grade polymetamorphism. *American*  
1581 *Mineralogist*, 92, 1276-1287.
- 1582 Ronniger, G. and Mill', B.V. (1973) New ions in the garnet structure. *Kristallografiya*, 18, 539-543  
1583 (in Russian).
- 1584 Rossman, G.R. and Aines, R.D. (1991) The hydrous components in garnets: Grossular-  
1585 hydrogrossular. *American Mineralogist*, 76, 1153-1164
- 1586 Rossman, G.R., Rauch, F., Livi, R., Tombrello, T.A., Shi, C.R., and Zhou, Z.Y. (1988) Nuclear  
1587 reaction analysis of hydrogen in almandine, pyrope and spessartite garnets. *Neues Jahrbuch für*  
1588 *Mineralogie Monatshefte*, 1988(4), 172-178.
- 1589 Rossmanith, E. and Armbruster, T. (1995) The intensity of forbidden reflections of pyrope:  
1590 Umweganregung or symmetry reduction? *Zeitschrift für Kristallographie*, 210, 645-649.
- 1591 Rudashevskii, N.S. and Mochalov, A.G. (1984) New associations of native elements in ultrabasites.  
1592 *Geologiya i Geofizika*, 25(4), 38-44 (English translation: *Soviet Geology and Geophysics*,  
1593 25(4), 35-41).
- 1594 Sacerdoti, M. and Passaglia, E. (1985) The crystal structure of katoite and implications within the  
1595 hydrogrossular group of minerals. *Bulletin de Minéralogie*, 108, 1-8.
- 1596 Saha, A., Ganguly, S., Ray, J., and Chatterjee, N. (2010) Evaluation of phase chemistry and  
1597 petrochemical aspects of Samchampi–Samteran differentiated alkaline complex of Mikir Hills,  
1598 northeastern India. *Journal of Earth System Science*, 119, 675–699.

- 1599 Schingaro, E., Scordari, F., Capitanio, F., Parodi, G., Smith, D.C., and Mottana, A. (2001) Crystal  
1600 chemistry of kimzeyite from Anguillara, Mts. Sabatini, Italy. *European Journal of Mineralogy*,  
1601 13, 749-759.
- 1602 Schingaro, E., Scordari, F., Pedrazzi, G., and Malitesta, C. (2004) Ti and Fe speciation by X-ray  
1603 photoelectron spectroscopy (XPS) and Mössbauer spectroscopy for a full chemical  
1604 characterization of Ti-garnets from Colli Albani (Italy). *Annali di Chimica*, 94, 185–196.
- 1605 Schwarz, H. and Schmidt, L. (1971) Arsenate des Typs  $\{NaCa_2\}[M^{II}_2](As_3)O_{12}$ . *Zeitschrift für*  
1606 *anorganische und allgemeine Chemie*, 382, 257-269.
- 1607 Shannon, R.D. (1976) Revised effective ionic radii and systematic studies of interatomic distances  
1608 in halides and chalcogenides. *Acta Crystallographica*, A32, 751-767.
- 1609 Shepard, C.U. (1846) On three new mineral species from Arkansas, and the discovery of the  
1610 diamond in North Carolina. *American Journal of Science*, 2, 249–254.
- 1611 Shtukenberg, A.G., Punin, Yu.O., Frank-Kamenetskaya, O.V., Kovalev, O.G., and Sokolov, P.B.  
1612 (2001) On the origin of anomalous birefringence in grandite garnets. *Mineralogical Magazine*,  
1613 65, 445-459.
- 1614 Shtukenberg, A.G., Popov, D.Yu., and Punin, Yu.O. (2005) Growth ordering and anomalous  
1615 birefringence in ugrandite garnets. *Mineralogical Magazine*, 69, 537-550.
- 1616 Sjögren, S.A.H. (1894) Contributions to Swedish mineralogy - 17. On soda berzeliite from  
1617 Långban. *Bulletin of the Geological Institution of the University of Uppsala*, 2, 92-95.
- 1618 Smith, J.V. and Mason, B. (1970) Pyroxene-garnet transformation in Coorara meteorite. *Science*,  
1619 168, 832-833.
- 1620 Smith, D.G.W. and Nickel, E.H. (2007) A system of codification for unnamed minerals: Report of  
1621 the SubCommittee for Unnamed Minerals of the IMA Commission on New Minerals,  
1622 Nomenclature and Classification. *Canadian Mineralogist*, 45, 983-1055.
- 1623 Smyth, J.R., Madel, R.E., McCormick, T.C., Munoz, J.L., and Rossman, G.R. (1990) Crystal-  
1624 structure refinement of a F-bearing spessartine garnet. *American Mineralogist*, 75, 314-318.
- 1625 Sobolev, N.V., Jr. and Lavrent'ev, Ju.G. (1971) Isomorphic sodium admixture in garnets formed at  
1626 high pressures. *Contributions to Mineralogy and Petrology*, 31, 1-12.
- 1627 Sokolova, E. and Hawthorne, F.C. (2002) Reconsideration of the crystal structure of paranatisite  
1628 and the crystal chemistry of  $[^{[6]}M_2\ ^{[4]}T_2\phi_{12}]$  sheets. *Canadian Mineralogist*, 40, 947-960.
- 1629 Stähle, V., Altherr, R., Nasdala, L., and Ludwig, T. (2011) Ca-rich majorite derived from high-  
1630 temperature melt and thermally stressed hornblende in shock veins of crustal rocks from the  
1631 Ries impact crater (Germany). *Contributions to Mineralogy and Petrology*, 161, 275-291.
- 1632 Steppan, N. (2003) Li, Be und B in Mineralen metapelitischer Gesteine: Fallstudien auf der Insel  
1633 Ikaria, im Künischen Gebirge und den Schweizer Alpen. Unpublished Inaugural-Dissertation,  
1634 Ruprecht-Karls-Universität, Heidelberg, Germany.
- 1635 Strunz, H. and Nickel, E.H. (2001) *Strunz Mineralogical Tables. Chemical-Structural Mineral*  
1636 *Classification System*, Ninth edition, 870 p. E. Schweizerbart'sche Verlagsbuchhandlung,  
1637 Stuttgart.
- 1638 Takamori, T., Shafer, M.W., Cooper, E.I., and Figat, R.A. (1987) Partial fluoridation of  
1639 hydrogarnet. *Journal of Materials Science Letters*, 6, 60-62.
- 1640 Tanaka, H., Endo, S., Minakawa, T., Enami, M., Nishio-Hamane, D., Miura, H., and Hagiwara, A.  
1641 (2010) Momoiite,  $(Mn^{2+}, Ca)_3(V^{3+}, Al)_2Si_3O_{12}$ , a new manganese vanadium garnet from Japan.  
1642 *Journal of Mineralogical and Petrological Sciences*, 105, 92-96.

- 1643 Tappert, R., Stachel, T., Harris, J.W., Muehlenbachs, K., Ludwig, T., and Brey, G.P. (2005)  
1644 Subducting oceanic crust: The source of deep diamonds. *Geology*, 33, 565-568.
- 1645 Thilo, E. (1941) Über die Isotypie zwischen Phosphaten der allgemeinen Zusammensetzung  
1646  $(Me_1)_3(Me_2)_2[PO_4]_3$  und den Silikaten der Granatgruppe. *Naturwissenschaften*, 29, 239.
- 1647 Thompson, R.N. (1975) Is upper-mantle phosphorus contained in sodic garnet? *Earth and Planetary*  
1648 *Science Letters*, 26, 417-424.
- 1649 Tomioka, N., Fujino, K., Ito, E., Katsura, T., Sharp, T., and Kato, K. (2002) Microstructures and  
1650 structural phase transition in  $(Mg,Fe)SiO_3$  majorite. *European Journal of Mineralogy*, 14, 7-14.
- 1651 Tsukimura, K., Kanazawa, Y., Aoki, M., and Bunno, M. (1993) Structure of wadalite  
1652  $Ca_6Al_5Si_2O_{16}Cl_3$ . *Acta Crystallographica*, C49, 205-207.
- 1653 Ungaretti, L., Leona, M., Merli, M., and Oberti, R. (1995) Non-ideal solid-solution in garnet:  
1654 crystal-structure evidence and modelling. *European Journal of Mineralogy*, 7, 1299-1312.
- 1655 Ussing, N.V. (1904) Sur la cryolithionite, espèce minérale nouvelle. *Oversigt over det Kongelige*  
1656 *Danske Videnskabernes Selskabs Forhandling*, 1, 3-12.
- 1657 Utsunomiya, S., Wang, L.M., Yudintsev, S., and Ewing, R.C. (2002) Ion irradiation-induced  
1658 amorphization and nano-crystal formation in garnets. *Journal of Nuclear Materials*, 303, 177-  
1659 187.
- 1660 Utsunomiya, S., Yudintsev, S., and Ewing, R.C. (2005) Radiation effects in ferrate garnet. *Journal*  
1661 *of Nuclear Materials*, 336, 251-260.
- 1662 Valley, J.W., Essene, E.J., and Peacor, D.R. (1983) Fluorine-bearing garnets in Adirondack calc-  
1663 silicates. *American Mineralogist*, 68, 444-448.
- 1664 Virgo, D. and Yoder, H.S., Jr. (1974) The alleged skiaigite molecule in garnet from two type  
1665 localities in Scotland. *Year Book - Carnegie Institution of Washington*, 73, 433-436.
- 1666 Visser, D. (1993) Fluorine-bearing hydrogarnets from Blengsvatn, Bamble Sector, South Norway.  
1667 *Mineralogy and Petrology*, 47, 209-218.
- 1668 Wang, Y. and Lai, W. (2012) High ionic conductivity lithium garnet oxides of  $Li_{7-x}La_3Zr_{2-x}Ta_xO_{12}$   
1669 compositions. *Electrochemical and Solid-State Letters*, 15 (5), A68-A71.
- 1670 Waychunas, G.A. (1987) Synchrotron radiation XANES spectroscopy of Ti in minerals: Effects of Ti  
1671 bonding distances, Ti valence, and site geometry on absorption edge structure. *American*  
1672 *Mineralogist*, 72, 89-101.
- 1673 Whitney, J.D. (1849) Examination of three new mineralogical species proposed by Prof. C. U.  
1674 Shepard. *Journal of Natural History, Boston*, 6, 42-48.
- 1675 Whittle, K.R., Lumpkin, G.R., Berry, F.J., Oates, G., Smith, K.L., Yudintsev, S., and Zaluzec, N.J.  
1676 (2007) The structure and ordering of zirconium and hafnium containing garnets studied by  
1677 electron channeling, neutron diffraction, and Mössbauer spectroscopy. *Journal of Solid State*  
1678 *Chemistry*, 180, 785-791.
- 1679 Wildner, M. and Andrut, M. (2001) The crystal chemistry of birefringent natural uvarovites: Part II.  
1680 Single-crystal X-ray structures. *American Mineralogist*, 86, 1231-1251.
- 1681 Wilkins, R.W.T. and Sabine, W. (1973) Water content of some nominally anhydrous silicates.  
1682 *American Mineralogist*, 58, 508-516.
- 1683 Winchell, A.N. (1933) *Elements of Optical Mineralogy. An Introduction to Microscopic*  
1684 *Petrography. Part II Descriptions of Minerals*, Third edition, 459 p. John Wiley and Sons, New  
1685 York.

- 1686 Włodyka, R. and Karwowski, L. (2006) Fluorine-bearing garnets from the teschenite sill in the  
1687 Polish Western Carpathians. *Acta Mineralogica-Petrographica Abstract Series*, 5, 131.
- 1688 Woodland, A.B. and O'Neill, H.St.C. (1993) Synthesis and stability of  $\text{Fe}^{2+}_3\text{Fe}^{3+}_2\text{Si}_3\text{O}_{12}$  garnet and  
1689 phase relations with  $\text{Fe}_3\text{Al}_2\text{Si}_3\text{O}_{12}$  -  $\text{Fe}^{2+}_3\text{Fe}^{3+}_2\text{Si}_3\text{O}_{12}$  solutions. *American Mineralogist*, 78,  
1690 1002-1015.
- 1691 Woodland, A.B. and O'Neill, H.St.C. (1995) Phase relations between  $\text{Ca}_3\text{Fe}^{3+}_2\text{Si}_3\text{O}_{12}$ -  
1692  $\text{Fe}^{2+}_3\text{Fe}^{3+}_3\text{Si}_3\text{O}_{12}$  garnet and  $\text{CaFeSi}_2\text{O}_6$ - $\text{Fe}_2\text{Si}_2\text{O}_6$  pyroxene solid solutions. *Contributions to*  
1693 *Mineralogy and Petrology*, 121, 87-98.
- 1694 Yakovlevskaya, T.A. (1972) Garnet group. In F.V. Chukhrov, Ed., *Minerals Handbook*, p. 17-95.  
1695 Volume III. Part I. Moscow, Nauka (in Russian).
- 1696 Yamane, H. and Kawano, T. (2011) Preparation, crystal structure and photoluminescence of garnet-  
1697 type calcium tin titanium aluminates. *Journal of Solid State Chemistry*, 184, 965–970.
- 1698 Yang, H., Konzett, J., Downs, R.T., and Frost, D.J. (2009) Crystal structure and Raman spectrum of  
1699 a high-pressure Li-rich majoritic garnet,  $(\text{Li}_2\text{Mg})\text{Si}_2(\text{SiO}_4)_3$ . *American Mineralogist*, 94, 630-  
1700 633.
- 1701 Ye, K., Cong, B., and Ye, D. (2000) The possible subduction of continental material to depths  
1702 greater than 200 km. *Nature*, 407, 734-736.
- 1703 Yoder, H.S. and Keith, M.L. (1951) Complete substitution of aluminum for silicon: The system  
1704  $3\text{MnO}\cdot\text{Al}_2\text{O}_3\cdot 3\text{SiO}_2 - 3\text{Y}_2\text{O}_3\cdot 5\text{Al}_2\text{O}_3$ . *American Mineralogist*, 36, 519-533.
- 1705 Yudintsev, S.V. (2001) Incorporation of U, Th, Zr and Gd into the garnet-structured host.  
1706 Proceedings of ICEM'01, 8th International Conference Environment Management, Bruges,  
1707 Belgium, September 30–October 4, 2001, 20-23.
- 1708 Yudintsev, S.V. (2003) A structural–chemical approach to selecting crystalline matrices for actinide  
1709 immobilization. *Geology of Ore Deposits*, 45, 151–165.
- 1710 Yudintsev, S.V., Lapina, M.I., Ptashkin, A.G., Ioudintseva, T.S., Utsunomiya, S., Wang, L.M., and  
1711 Ewing, R.C. (2002) Accommodation of uranium into the garnet structure. In B.P. McGrail and  
1712 G.A. Cragnolino, Eds., *Scientific Basis for Nuclear Waste Management XXV*, Materials  
1713 Research Society Symposium Proceedings, 713, p. 477-480.
- 1714 Zaitsev, A.N., Williams, C.T., Britvin, S.N., Kuznetsova, I.V., Spratt, J., Petrov, S.V., and Keller, J.  
1715 (2010) Kerimasite,  $\text{Ca}_3\text{Zr}_2(\text{Fe}^{3+}_2\text{Si})\text{O}_{12}$ , a new garnet from carbonatites of Kerimasi volcano  
1716 and surrounding explosion craters, northern Tanzania. *Mineralogical Magazine*, 74, 803–820.
- 1717 Zedlitz, O. (1933) Über titanhaltige Kalkeisengranate. *Zentralblatt für Mineralogie, Geologie und*  
1718 *Paläontologie, Abteilung A: Mineralogie und Petrographie*, 225-239
- 1719 Zedlitz, O. (1935) Über titanhaltige Kalkeisengranate. II. *Zentralblatt für Mineralogie, Geologie*  
1720 *und Paläontologie, Abteilung A: Mineralogie und Petrographie*, 68-78.

1721 Table 1. A classification of the 32 approved species in the garnet supergroup

1722	Z charge	GROUP or species name	Class	X	Y	Z	$\phi$
1723	<b>0</b>	<b>Katoite</b>	Hydroxide	Ca <sub>3</sub>	Al <sub>2</sub>	$\square$	(OH) <sub>12</sub>
1724	<b>3</b>	<b>Cryolithionite</b>	Halide	Na <sub>3</sub>	Al <sub>2</sub>	Li <sub>3</sub>	F <sub>12</sub>
1725	<b>6</b>	<b>Yafsoanite</b>	Oxide	Ca <sub>3</sub>	Te <sup>6+</sup> <sub>2</sub>	Zn <sub>3</sub>	O <sub>12</sub>
1726	<b>8</b>	<b>HENRITERMIERITE</b>	Silicate				
1727		<b>Holtstamite</b>		Ca <sub>3</sub>	Al <sub>2</sub>	Si <sub>2</sub>   $\square$	O <sub>8</sub> (OH) <sub>4</sub>
1728		<b>Henritermierite</b>		Ca <sub>3</sub>	Mn <sup>3+</sup> <sub>2</sub>	Si <sub>2</sub>   $\square$	O <sub>8</sub> (OH) <sub>4</sub>
1729	<b>9</b>	<b>BITIKLEITE</b>	Oxide				
1730		<b>Bitikleite</b>		Ca <sub>3</sub>	Sb <sup>5+</sup> Sn <sup>4+</sup>	Al <sub>3</sub>	O <sub>12</sub>
1731		<b>Usturite</b>		Ca <sub>3</sub>	Sb <sup>5+</sup> Zr	Fe <sup>3+</sup> <sub>3</sub>	O <sub>12</sub>
1732		<b>Dzhuluite</b>		Ca <sub>3</sub>	Sb <sup>5+</sup> Sn <sup>4+</sup>	Fe <sup>3+</sup> <sub>3</sub>	O <sub>12</sub>
1733		<b>Elbrusite</b>		Ca <sub>3</sub>	U <sup>6+</sup> <sub>0.5</sub> Zr <sub>1.5</sub>	Fe <sup>3+</sup> <sub>3</sub>	O <sub>12</sub>
1734	<b>10</b>	<b>SCHORLOMITE</b>	Silicate				
1735		<b>Kimzeyite</b>		Ca <sub>3</sub>	Zr <sub>2</sub>	SiAl <sub>2</sub>	O <sub>12</sub>
1736		<b>Irinarassite</b>		Ca <sub>3</sub>	Sn <sup>4+</sup> <sub>2</sub>	SiAl <sub>2</sub>	O <sub>12</sub>
1737		<b>Schorlomite</b>		Ca <sub>3</sub>	Ti <sub>2</sub>	SiFe <sup>3+</sup> <sub>2</sub>	O <sub>12</sub>
1738		<b>Kerimasite</b>		Ca <sub>3</sub>	Zr <sub>2</sub>	SiFe <sup>3+</sup> <sub>2</sub>	O <sub>12</sub>
1739		<b>Toturite</b>		Ca <sub>3</sub>	Sn <sup>4+</sup> <sub>2</sub>	SiFe <sup>3+</sup> <sub>2</sub>	O <sub>12</sub>
1740	<b>12</b>	<b>GARNET</b>	Silicate				
1741		<b>Menzerite-(Y)</b>		Y <sub>2</sub> Ca	Mg <sub>2</sub>	Si <sub>3</sub>	O <sub>12</sub>
1742		<b>Pyrope</b>		Mg <sub>3</sub>	Al <sub>2</sub>	Si <sub>3</sub>	O <sub>12</sub>
1743		<b>Grossular</b>		Ca <sub>3</sub>	Al <sub>2</sub>	Si <sub>3</sub>	O <sub>12</sub>
1744		<b>Spessartine</b>		Mn <sup>2+</sup> <sub>3</sub>	Al <sub>2</sub>	Si <sub>3</sub>	O <sub>12</sub>
1745		<b>Almandine</b>		Fe <sup>2+</sup> <sub>3</sub>	Al <sub>2</sub>	Si <sub>3</sub>	O <sub>12</sub>
1746		<b>Eringaite</b>		Ca <sub>3</sub>	Sc <sub>2</sub>	Si <sub>3</sub>	O <sub>12</sub>
1747		<b>Goldmanite</b>		Ca <sub>3</sub>	V <sup>3+</sup> <sub>2</sub>	Si <sub>3</sub>	O <sub>12</sub>
1748		<b>Momoiite</b>		Mn <sup>2+</sup> <sub>3</sub>	V <sup>3+</sup> <sub>2</sub>	Si <sub>3</sub>	O <sub>12</sub>
1749		<b>Knorringite</b>		Mg <sub>3</sub>	Cr <sup>3+</sup> <sub>2</sub>	Si <sub>3</sub>	O <sub>12</sub>
1750		<b>Uvarovite</b>		Ca <sub>3</sub>	Cr <sup>3+</sup> <sub>2</sub>	Si <sub>3</sub>	O <sub>12</sub>
1751		<b>Andradite</b>		Ca <sub>3</sub>	Fe <sup>3+</sup> <sub>2</sub>	Si <sub>3</sub>	O <sub>12</sub>
1752		<b>Calderite</b>		Mn <sup>2+</sup> <sub>3</sub>	Fe <sup>3+</sup> <sub>2</sub>	Si <sub>3</sub>	O <sub>12</sub>
1753		<b>Majorite</b>		Mg <sub>3</sub>	SiMg	Si <sub>3</sub>	O <sub>12</sub>
1754		<b>Morimotoite</b>		Ca <sub>3</sub>	TiFe <sup>2+</sup>	Si <sub>3</sub>	O <sub>12</sub>
1755	<b>15</b>	<b>BERZELIITE</b>	Vanadate, arsenate				
1756		<b>Schäferite</b>		Ca <sub>2</sub> Na	Mg <sub>2</sub>	V <sup>5+</sup> <sub>3</sub>	O <sub>12</sub>
1757		<b>Palenzonaite</b>		Ca <sub>2</sub> Na	Mn <sup>2+</sup> <sub>2</sub>	V <sup>5+</sup> <sub>3</sub>	O <sub>12</sub>
1758		<b>Berzeliite</b>		Ca <sub>2</sub> Na	Mg <sub>2</sub>	As <sup>5+</sup> <sub>3</sub>	O <sub>12</sub>
1759		<b>Manganberzeliite</b>		Ca <sub>2</sub> Na	Mn <sup>2+</sup> <sub>2</sub>	As <sup>5+</sup> <sub>3</sub>	O <sub>12</sub>

1760 Notes: Formulae are given in the form {X<sub>3</sub>}[Y<sub>2</sub>](Z<sub>3</sub>) $\phi$ <sub>12</sub>. Group names are given in small capitals.



1761 Table 2. Former formulae and end-member formulae approved in the present report

1762	Name	Former formula	Approved end-member formula
1763	<b>Katoite</b>	$\text{Ca}_3\text{Al}_2(\text{SiO}_4)_{3-x}(\text{OH})_{4x}$ ( $x=1.5-3.0$ )	$\{\text{Ca}_3\}[\text{Al}_2](\square_3)(\text{OH})_{12}$
1764	<b>Cryolithionite</b>	$\text{Na}_3\text{Al}_2(\text{LiF}_4)_3$	$\{\text{Na}_3\}[\text{Al}_2](\text{Li}_3)\text{F}_{12}$
1765	<b>Yafsoanite</b>	$\text{Ca}_3\text{Te}^{6+}_2\text{Zn}_3\text{O}_{12}$	$\{\text{Ca}_3\}[\text{Te}^{6+}_2](\text{Zn}_3)\text{O}_{12}$
1766	<b>Holtstamite</b>	$\text{Ca}_3\text{Al}_2(\text{SiO}_4)_2(\text{OH})_4$	$\{\text{Ca}_3\}[\text{Al}_2](\text{Si}_2)(\square)\text{O}_8(\text{OH})_4$
1767	<b>Henritermierite</b>	$\text{Ca}_3(\text{Mn}^{3+})_2(\text{SiO}_4)_2(\text{OH})_4$	$\{\text{Ca}_3\}[\text{Mn}^{3+}_2](\text{Si}_2)(\square)\text{O}_8(\text{OH})_4$
1768	<b>Bitikleite*</b>	$\text{Ca}_3\text{SbSnAl}_3\text{O}_{12}$	$\{\text{Ca}_3\}[\text{Sb}^{5+}\text{Sn}^{4+}](\text{Al}_3)\text{O}_{12}$
1769	<b>Usturite*</b>	$\text{Ca}_3\text{SbZrFe}_3\text{O}_{12}$	$\{\text{Ca}_3\}[\text{Sb}^{5+}\text{Zr}](\text{Fe}^{3+}_3)\text{O}_{12}$
1770	<b>Dzhuluite*</b>	$\text{Ca}_3(\text{SnSb}^{5+})\text{Fe}^{3+}_3\text{O}_{12}$	$\{\text{Ca}_3\}[\text{Sb}^{5+}\text{Sn}^{4+}](\text{Fe}^{3+}_3)\text{O}_{12}$
1771	<b>Elbrusite*</b>	$\text{Ca}_3(\text{U}^{6+}\text{Zr})(\text{Fe}^{3+}_2\text{Fe}^{2+})\text{O}_{12}$	$\{\text{Ca}_3\}[\text{U}^{6+}_{0.5}\text{Zr}_{1.5}](\text{Fe}^{3+}_3)\text{O}_{12}$
1772	<b>Kimzeyite</b>	$\text{Ca}_3(\text{Zr}, \text{Ti})_2(\text{Si}, \text{Al}, \text{Fe}^{3+})_3\text{O}_{12}$	$\{\text{Ca}_3\}[\text{Zr}_2](\text{SiAl}_2)\text{O}_{12}$
1773	<b>Irinarassite</b>	$\text{Ca}_3\text{Sn}_2\text{Al}_2\text{SiO}_{12}$	$\{\text{Ca}_3\}[\text{Sn}^{4+}_2](\text{SiAl}_2)\text{O}_{12}$
1774	<b>Schorlomite</b>	$\text{Ca}_3(\text{Ti}, \text{Fe}^{3+})_2[(\text{Si}, \text{Fe})\text{O}_4]_3\text{O}_{12}$	$\{\text{Ca}_3\}[\text{Ti}_2](\text{SiFe}^{3+}_2)\text{O}_{12}$
1775	<b>Kerimasite</b>	$\text{Ca}_3\text{Zr}_2(\text{Fe}^{3+}_2\text{Si})\text{O}_{12}$	$\{\text{Ca}_3\}[\text{Zr}_2](\text{SiFe}^{3+}_2)\text{O}_{12}$
1776	<b>Toturite</b>	$\text{Ca}_3\text{Sn}_2\text{Fe}_2\text{SiO}_{12}$	$\{\text{Ca}_3\}[\text{Sn}^{4+}_2](\text{SiFe}^{3+}_2)\text{O}_{12}$
1777	<b>Menzerite-(Y)</b>	$\{\text{CaY}_2\}[\text{Mg}_2](\text{Si}_3)\text{O}_{12}$	$\{\text{Y}_2\text{Ca}\}[\text{Mg}_2](\text{Si}_3)\text{O}_{12}$
1778	<b>Pyrope</b>	$\text{Mg}_3\text{Al}_2(\text{SiO}_4)_3$	$\{\text{Mg}_3\}[\text{Al}_2](\text{Si}_3)\text{O}_{12}$
1779	<b>Grossular</b>	$\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$	$\{\text{Ca}_3\}[\text{Al}_2](\text{Si}_3)\text{O}_{12}$
1780	<b>Spessartine</b>	$(\text{Mn}^{2+})_3\text{Al}_2(\text{SiO}_4)_3$	$\{\text{Mn}^{2+}_3\}[\text{Al}_2](\text{Si}_3)\text{O}_{12}$
1781	<b>Almandine</b>	$(\text{Fe}^{2+})_3\text{Al}_2(\text{SiO}_4)_3$	$\{\text{Fe}^{2+}_3\}[\text{Al}_2](\text{Si}_3)\text{O}_{12}$
1782	<b>Eringait</b>	$\text{Ca}_3\text{Sc}_2(\text{SiO}_4)_3$	$\{\text{Ca}_3\}[\text{Sc}_2](\text{Si}_3)\text{O}_{12}$
1783	<b>Goldmanite</b>	$\text{Ca}_3(\text{V}^{3+})_2(\text{SiO}_4)_3$	$\{\text{Ca}_3\}[\text{V}^{3+}_2](\text{Si}_3)\text{O}_{12}$
1784	<b>Momoiite</b>	$(\text{Mn}^{2+}, \text{Ca})_3(\text{V}^{3+}, \text{Al})_2\text{Si}_3\text{O}_{12}$	$\{\text{Mn}^{2+}_3\}[\text{V}^{3+}_2](\text{Si}_3)\text{O}_{12}$
1785	<b>Knorringite</b>	$\text{Mg}_3\text{Cr}_2(\text{SiO}_4)_3$	$\{\text{Mg}_3\}[\text{Cr}^{3+}_2](\text{Si}_3)\text{O}_{12}$
1786	<b>Uvarovite</b>	$\text{Ca}_3\text{Cr}_2(\text{SiO}_4)_3$	$\{\text{Ca}_3\}[\text{Cr}^{3+}_2](\text{Si}_3)\text{O}_{12}$
1787	<b>Andradite</b>	$\text{Ca}_3(\text{Fe}^{3+})_2(\text{SiO}_4)_3$	$\{\text{Ca}_3\}[\text{Fe}^{3+}_2](\text{Si}_3)\text{O}_{12}$
1788	<b>Calderite</b>	$(\text{Mn}^{2+})_3(\text{Fe}^{3+})_2(\text{SiO}_4)_3$	$\{\text{Mn}^{2+}_3\}[\text{Fe}^{3+}_2](\text{Si}_3)\text{O}_{12}$
1789	<b>Majorite</b>	$\text{Mg}_3(\text{Fe}^{2+}, \text{Si})_2(\text{SiO}_4)_3$	$\{\text{Mg}_3\}[\text{SiMg}](\text{Si}_3)\text{O}_{12}$
1790	<b>Morimotoite</b>	$\text{Ca}_3(\text{Ti}, \text{Fe}^{2+}, \text{Fe}^{3+})_2(\text{Si}, \text{Fe}^{3+})_3\text{O}_{12}$	$\{\text{Ca}_3\}[\text{TiFe}^{2+}](\text{Si}_3)\text{O}_{12}$
1791	<b>Schäferite</b>	$\text{NaCa}_2\text{Mg}_2(\text{VO}_4)_3$	$\{\text{Ca}_2\text{Na}\}[\text{Mg}_2](\text{V}^{5+}_3)\text{O}_{12}$
1792	<b>Palenzonaite</b>	$\text{NaCa}_2(\text{Mn}^{2+})_2(\text{VO}_4)_3$	$\{\text{Ca}_2\text{Na}\}[\text{Mn}^{2+}_2](\text{V}^{5+}_3)\text{O}_{12}$
1793	<b>Berzeliite</b>	$\text{NaCa}_2\text{Mg}_2(\text{AsO}_4)_3$	$\{\text{Ca}_2\text{Na}\}[\text{Mg}_2](\text{As}^{5+}_3)\text{O}_{12}$
1794	<b>Manganberzeliite</b>	$\text{NaCa}_2(\text{Mn}^{2+})_2(\text{AsO}_4)_3$	$\{\text{Ca}_2\text{Na}\}[\text{Mn}^{2+}_2](\text{As}^{5+}_3)\text{O}_{12}$

1795 Note: Former names from IMA-CNMNC List of Mineral Names compiled in March, 2009 by E.H.  
 1796 Nickel and M.C. Nichols and from the Official IMA list of mineral names (updated from March  
 1797 2009 list) at <http://pubsites.uws.edu.au/ima-cnmnc/>. Names of minerals approved after the list was  
 1798 published are taken from the original description. \*Table 5 lists the names under which these four  
 1799 minerals were originally described.

1800

1801 Table 3. Relative site abundances of cations and anions in garnet-supergroup minerals.

1802	Site	Relative abundance of ions	Cations and anions at each site in order of relative abundance
1803	X	$R^{2+} \gg R^{3+} \gg R^{1+} \gg R^{4+}$	
1804			$R^{2+}$ : <b>Fe ~ Mn ~ Ca</b> > <b>Mg</b> >> Pb
1805			$R^{3+}$ : Y > HREE > LREE
1806			$R^{1+}$ : Na
1807			$R^{4+}$ : Th
1808	Y	$R^{3+} > R^{4+} > R^{2+} > R^{5+} > R^{6+}$	
1809			$R^{3+}$ : <b>Al ~ Fe</b> > V, Cr, Mn > Sc >> Ga
1810			$R^{4+}$ : <b>Ti</b> > <b>Zr</b> > Si, Sn
1811			$R^{2+}$ : Mg > Fe, Mn
1812			$R^{5+}$ : Sb, Nb
1813			$R^{6+}$ : Te, U
1814	Z	$R^{4+} > R^{3+} > R^{5+} \sim \square$ (vacancy) > $R^{2+}, R^{1+}$	
1815			$R^{4+}$ : <b>Si</b> >> Ti > Ge
1816			$R^{3+}$ : <b>Fe ~ Al</b>
1817			$R^{5+}$ : As > V > P
1818			$R^{2+}$ : Zn, Fe
1819			$R^{1+}$ : Li
1820	$\phi$	$\phi^{2-} \gg \phi^{1-}$	
1821			$\phi^{2-}$ : <b>O</b>
1822			$\phi^{1-}$ : <b>OH</b> > F

1823 Note: The cations and anions shown in bold type represent the most common ions at these sites.  
 1824 HREE and LREE are heavy and light rare-earth elements, respectively, excluding Y.

1825 Table 4. Significant garnet coupled heterovalent substitutions.

1826	Generalized coupled substitution	Relationship
1827	$Z\Box + 4\phi^{1-} \rightarrow ZSi^{4+} + 4O^{2-}$	relates katoite, henritermierite and holtstamite to OH-free minerals in the garnet group
1828	$YR^{2+} + YR^{4+} \rightarrow 2YR^{3+}$	relates morimotoite ( $^{[6]}Ti$ ) and majorite ( $^{[6]}Si$ ) to other garnet-group minerals
1829	$ZR^{4+} + YR^{3+} \rightarrow ZR^{3+} + YR^{4+}$	relates the schorlomite group to the garnet group
1830	$X(Y, REE)^{3+} + ZR^{3+} \rightarrow XR^{2+} + ZR^{4+}$	introduces Y + REE as a YAG, $\{Y_3\}[Al_2](Al_3)O_{12}$ -type component
1831	$X(Y, REE)^{3+} + XNa^{1+} \rightarrow 2XR^{2+}$	introduces Y + REE into garnet-group minerals
1832	$X(Y, REE)^{3+} + YR^{2+} \rightarrow XR^{2+} + YR^{3+}$	relates menzerite-(Y) to other garnet-group minerals
1833	$YR^{5+} + ZR^{3+} \rightarrow YR^{4+} + ZR^{4+}$	relates bitikleite, dzhuluite and usturite with schorlomite-group minerals
1834	$Y0.5R^{6+} + ZR^{3+} \rightarrow Y0.5R^{4+} + ZR^{4+}$	relates elbrusite with schorlomite-group minerals
1835	$YU^{6+} + ZR^{2+} \rightarrow YR^{4+} + ZR^{4+}$	observed relationship between elbrusite and schorlomite group minerals (Fig. 4)
1836	$0.5^XTh^{4+} + ZR^3 \rightarrow 0.5^XR^{2+} + ZR^{4+}$	introduces Th into minerals of the bitikleite and schorlomite groups
1837	$YR^{4+} + 0.5^ZV^{5+} \rightarrow 0.5^ZR^{3+} + YSb^{5+}$	introduces V into bitikleite
1838	$YR^{4+} + ZV^{5+} \rightarrow YU^{6+} + ZR^{3+}$	introduces V into elbrusite
1839	$XNa^{1+} + YR^{4+} \rightarrow XR^{2+} + YR^{3+}$	introduces Na and $^{[6]}Si$ or $^{[6]}Ti$ into the garnet group
1840	$XNa^{1+} + ZR^{5+} \rightarrow XR^{2+} + ZR^{4+}$	relates the berzeliite group to the garnet group
1841	Note: <i>R</i> represents generalized cations (see Table 3)	

1842 Table 5. Former names, new names and approved end-member formulae for renamed/discredited minerals listed in this report.

1843	Former name	New name	Formula (approved by CNMNC)
1844		(approved by CNMNC)	
1845	Bitikleite-(SnAl)	<b>Bitikleite</b>	$\{\text{Ca}_3\}[\text{Sb}^{5+}\text{Sn}^{4+}](\text{Al}_3)\text{O}_{12}$
1846	Bitikleite-(SnFe)	<b>Dzhuluite</b>	$\{\text{Ca}_3\}[\text{Sb}^{5+}\text{Sn}^{4+}](\text{Fe}^{3+}_3)\text{O}_{12}$
1847	Bitikleite-(ZrFe)	<b>Usturite</b>	$\{\text{Ca}_3\}[\text{Sb}^{5+}\text{Zr}](\text{Fe}^{3+}_3)\text{O}_{12}$
1848	Elbrusite-(Zr)	<b>Elbrusite</b>	$\{\text{Ca}_3\}[\text{U}^{6+}_{0.5}\text{Zr}_{1.5}](\text{Fe}^{3+}_3)\text{O}_{12}$
1849	Hibschite*	<b>Grossular</b>	$\{\text{Ca}_3\}[\text{Al}_2](\text{Si}_{3-x}\square_x)\text{O}_{12-4x}(\text{OH})_{4x}$ where $x < 1.5^\#$

1850 Note: \* Former formula:  $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_{3-x}(\text{OH})_{4x}$ , where  $x = 0.2-1.5$ . #Includes OH-bearing grossular.

1851 Ideal anhydrous grossular has the formula:  $\{\text{Ca}_3\}[\text{Al}_2](\text{Si}_3)\text{O}_{12}$ .

1852

1853

1854 Table 6. Components and end-members reported in the literature, but not yet found to be dominant in natural garnet.

1855	Name	X	Y	Z	$\phi$	Syn?	Occurrence in natural garnet	(sources)
1856	<b>“Kenogarnet” group</b>							
1857	Fe <sup>3+</sup> analogue of katoite	Ca <sub>3</sub>	Fe <sup>3+</sup> <sub>2</sub>	□ <sub>3</sub>	(OH) <sub>12</sub>	Yes	≤ 35 mol.% in andradite	(1)
1858	F analogue of katoite	Ca <sub>3</sub>	Al <sub>2</sub>	□ <sub>3</sub>	F <sub>12</sub>	No	≤ 11 mol.% in OH-bearing grossular	(2)
1859	Mn <sup>2+</sup> , F analogue of katoite	Mn <sup>2+</sup> <sub>3</sub>	Al <sub>2</sub>	□ <sub>3</sub>	F <sub>12</sub>	--	≤ 8 mol.% in spessartine	(3)
1860	<b>Unnamed group</b>							
1861	Pb <sup>2+</sup> analogue of yafsoanite	Pb <sub>3</sub>	Te <sup>6+</sup> <sub>2</sub>	Zn <sub>3</sub>	O <sub>12</sub>	--	9 mol.% in yafsoanite	(4)
1862	unnamed	Ca <sub>3</sub>	U <sup>6+</sup> <sub>2</sub>	Fe <sup>2+</sup> <sub>3</sub>	O <sub>12</sub>	--	≤ 24 mol.% in elbrusite	(5)
1863	<b>Henritermierite group</b>							
1864	Mn <sup>2+</sup> analogue of holtstamite	Mn <sup>2+</sup> <sub>3</sub>	Al <sub>2</sub>	Si <sub>2</sub>   □	O <sub>8</sub> (OH) <sub>4</sub>	--	28 mol.% in spessartine	(6)
1865	Mn <sup>2+</sup> , F analogue of holtstamite	Mn <sup>2+</sup> <sub>3</sub>	Al <sub>2</sub>	Si <sub>2</sub>   □	O <sub>8</sub> F <sub>4</sub>	--	20 mol.% in spessartine	(6)
1866	<b>Bitikleite group</b>							
1867	unnamed	Th <sub>0.5</sub> Ca <sub>2.5</sub>	R <sup>4+</sup> <sub>2</sub>	R <sup>3+</sup> <sub>3</sub>	O <sub>12</sub>	Yes	≤ 20 mol.% in kerimasite	(7)
1868	<b>Unnamed group</b>							
1869	Y <sub>3</sub> Al <sub>5</sub> O <sub>12</sub> , Y <sub>3</sub> Fe <sub>5</sub> O <sub>12</sub>	(Y,REE) <sup>3+</sup> <sub>3</sub>	R <sup>3+</sup> <sub>2</sub>	R <sup>3+</sup> <sub>3</sub>	O <sub>12</sub>	Yes	≤ 8 mol.% in menzerite-(Y), spessartine, andradite	(8)
1870	<b>Garnet group</b>							
1871	“Blythite” in part	R <sup>2+</sup> <sub>3</sub>	Mn <sup>3+</sup> <sub>2</sub>	Si <sub>3</sub>	O <sub>12</sub>	Yes	≤ 9 mol.% in calderite-andradite±spessartine	(9)
1872	Fe analogue of menzerite-(Y)	Y <sub>2</sub> Ca	Fe <sup>2+</sup> <sub>2</sub>	Si <sub>3</sub>	O <sub>12</sub>	--	≤ 20 mol.% in menzerite (Y)	(10)
1873	unnamed	(Y,Yb) <sub>1.5</sub> Na <sub>1.5</sub>	R <sup>3+</sup> <sub>2</sub>	Si <sub>3</sub>	O <sub>12</sub>	--	≤ 7 mol.% in almandine, spessartine, grossular	(11)
1874	unnamed	R <sup>2+</sup> Na <sub>2</sub>	Si <sub>2</sub>	Si <sub>3</sub>	O <sub>12</sub>	Yes	≤ 12 mol.% in pyrope-grossular	(12)
1875	<b>Berzeliite group</b>							
1876	unnamed	Na <sub>3</sub>	Al <sub>2</sub>	P <sub>3</sub>	O <sub>12</sub>	Yes	< 1 mol.% in almandine and pyrope	(13)
1877	unnamed	Ca <sub>2</sub> Na	Fe <sup>2+</sup> <sub>2</sub>	As <sup>5+</sup> <sub>3</sub>	O <sub>12</sub>	No	< 6 mol.% in berzeliite	(14)

1878 Note: Syn? – has compound been synthesized? Yes: synthesis in which component is dominant as well as syntheses in which component constitutes  
 1879 100%. No: synthesis attempted but failed. Sources for contents in natural garnets and syntheses of end-members:

- 1880 (1) Armbruster (1995); Cohen-Addad (1970)  
 1881 (2) Chakhmouradian et al. (2008); Takamori et al. (1987)  
 1882 (3) Smyth et al. (1990).  
 1883 (4) Mills et al. (2010).  
 1884 (5) Galuskina et al. (2010a).

- 1885 (6) Si and □ are not fully ordered at Z1 and Z2. Boiocchi et al. (2012).  
1886 (7) Ito and Frondel (1967a); Yudintsev (2003); Galuskina et al. (2010e and unpublished).  
1887 (8) Yoder and Keith (1951); Geller (1967); Jaffe (1951); Kasowski and Hogarth (1968) ; Grew et al. (2010).  
1888 (9) Fursenko (1982); Nishizawa and Koizuma (1975); Böhn et al. (1995); Amthauer et al. (1989); Arlt et al. (1998).  
1889 (10) Grew et al. (2010).  
1890 (11) Enami et al. (1995); Røhr et al. (2007).  
1891 (12) Ringwood and Major (1971); Stähle et al. (2011).  
1892 (13) Bishop et al. (1978); Ye et al. (2000); Breiter et al. (2005); Brunet et al. (2006).  
1893 (14) Nagashima and Armbruster (2012); Ito (1968)

1894 Table 7. Summary of specific components potentially significant in  
 1895 natural garnets

1896	Name	Synthesis	Formula
1897	–	62 to 90%	$\{\text{Fe}^{2+}_3\}[\text{Al}_2](\square_3)(\text{OH})_{12}$
1898	–	No	$\{\text{Ca}_3\}[\text{Al}_2](\square_3)\text{F}_{12}$
1899	–	–	$\{\text{Mn}^{2+}_3\}[\text{Al}_2](\square_3)\text{F}_{12}$
1900	–	–	$\{\text{Fe}^{2+}_3\}[\text{Al}_2](\square_3)\text{F}_{12}$
1901	–	–	$\{\text{Pb}^{2+}_3\}[\text{Te}^{6+}_2](\text{Zn}_3)\text{O}_{12}$
1902	–	–	$\{\text{Ca}_3\}[\text{U}^{6+}_2](\text{Fe}^{2+}_3)\text{O}_{12}$
1903	–	–	$\{\text{Mn}^{2+}_3\}[\text{Al}_2](\text{Si}_2)(\square)\text{O}_8(\text{OH})_4$
1904	–	–	$\{\text{Mn}^{2+}_3\}[\text{Al}_2](\text{Si}_2)(\square)\text{O}_8\text{F}_4$
1905	–	100%	$\{\text{Th}_{0.5}\text{Ca}_{2.5}\}[\text{Zr}_2](\text{Fe}^{3+}_2)\text{O}_{12}$
1906	YIG	100%	$\{\text{Y}_3\}[\text{Al}_2](\text{Al}_3)\text{O}_{12}$
1907	YAG	100%	$\{\text{Y}_3\}[\text{Fe}^{3+}_2](\text{Fe}^{3+}_3)\text{O}_{12}$
1908	“Blythite”	100%	$\{\text{Mn}^{2+}_3\}[\text{Mn}^{3+}_2](\text{Si}_3)\text{O}_{12}$
1909	–	100%	$\{\text{Ca}_3\}[\text{Mn}^{3+}_2](\text{Si}_3)\text{O}_{12}$
1910	“Khoharite”	100%	$\{\text{Mg}_3\}[\text{Fe}^{3+}_2](\text{Si}_3)\text{O}_{12}$
1911	“Skiagite”	100%	$\{\text{Fe}^{2+}_3\}[\text{Fe}^{3+}_2](\text{Si}_3)\text{O}_{12}$
1912	–	–	$\{\text{Y}_2\text{Ca}\}[\text{Fe}^{2+}_2](\text{Si}_3)\text{O}_{12}$
1913	–	–	$\{\text{Y}_{1.5}\text{Na}_{1.5}\}[\text{Al}_2](\text{Si}_3)\text{O}_{12}$
1914	–	100%	$\{\text{CaNa}_2\}[\text{Si}_2](\text{Si}_3)\text{O}_{12}$
1915	–	100%	$\{\text{CaNa}_2\}[\text{Ti}_2](\text{Si}_3)\text{O}_{12}$
1916	–	100%	$\{\text{Na}_3\}[\text{Al}_2](\text{P}_3)\text{O}_{12}$
1917	–	No	$\{\text{Ca}_2\text{Na}\}[\text{Fe}^{2+}_2](\text{As}^{5+}_3)\text{O}_{12}$

1918 Note: Syntheses: percentage gives the amount of the component  
 1919 reported in the synthesis; no – synthesis attempted but without  
 1920 success, dash – synthesis has not been not attempted. Sources are  
 1921 given in the text and Table 6.

1922

1923 Table 8. Possible new species in the garnet supergroup.

1924	Relationship to known species	UM #	End-member formula	Criteria	(source)
1925	<b>BITIKLEITE GROUP</b>				
1926	Sn analogue of elbrusite		$\{\text{Ca}_3\}[\text{U}^{6+}_{0.5}\text{Sn}^{4+}_{1.5}](\text{Fe}^{3+}_3)\text{O}_{12}$	$\text{Sn}/(\text{Sn} + \text{Zr}) = 0.93$	(1)
1927	Nb analogue of usturite		$\{\text{Ca}_3\}[\text{NbZr}](\text{Fe}^{3+}_3)\text{O}_{12}$	1.33 Zr, 0.05 Ti, 0.48 Nb pfu at Y site	(2)
1928	<b>SCHORLOMITE GROUP</b>				
1929	Al analogue of schorlomite		$\{\text{Ca}_3\}[\text{Ti}_2](\text{SiAl}_2)\text{O}_{12}$	$\text{Al}/(\text{Al} + \text{Fe}^{3+}) = 0.65$	(3)
1930	(Ti analogue of kimzeyite)				
1931	<b>GARNET GROUP</b>				
1932	Mg analogue of morimotoite		$\{\text{Ca}_3\}[\text{TiMg}](\text{Si}_3)\text{O}_{12}$	$\text{Mg}/(\text{Mg} + \text{Fe}^{2+}) = 0.63\text{--}0.64$	(4)
1933	Ga□Ge analogue of grossular	UM1986-19	$\{\text{Ca}_3\}[\text{Ga}_2](\text{Ge}_3)\text{O}_{12}$	${}^Z\text{Ge} > {}^Z\text{Si}; {}^Y\text{Ga} > {}^Y\text{Fe}^{3+}, {}^Y\text{Al}$	(5)
1934	Ge analogue of grossular	UM1986-20	$\{\text{Ca}_3\}[\text{Al}_2](\text{Ge}_3)\text{O}_{12}$	Criterion of ${}^Z\text{Ge} > {}^Z\text{Si}$ not met.	(5)

1935 Note: UM # refers to the list of valid unnamed minerals, update 2011-01 (Smith and Nickel 2007).

1936 Sources: (1) Galuskina et al. (2010a); (2) Zaitsev et al. (2010); (3) Koritnig et al. (1978); (4) Platt and

1937 Mitchell (1979); (5) Johan and Oudin (1986); Jambor et al. (1988b).



1938

### Figure Captions

1939 Figure 1. Photographs of representative garnet supergroup minerals illustrating the diversity in  
1940 appearance exhibited by the supergroup. A. Holtstamite, formula  
1941  $\{Ca_3\}[Al,Mn^{3+}_2](Si_2)(\square)O_8(OH)_4$ , as a yellow brown crystal between grains of Mn- and Cu-rich  
1942 vesuvianite (purplish black) and calcite (white) in the holotype specimen from Wessels Mine, South  
1943 Africa. Swedish Museum of Natural History specimen #19960380. Photo by U. Hålenius. B.  
1944 Cryolithionite, end-member formula  $\{Na_3\}[Al_2](Li_3)F_{12}$ : a transparent, colorless single grain in  
1945 yellowish-white fine-grained cryolite. Specimen size is 4.5 x 2 x 1.7 cm. From the type locality,  
1946 Ivigtut Cryolite deposit, Ivittuut (Ivigtut), Kitaa, Greenland. Pavel M. Kartashov collection and  
1947 photograph. C. Grossular, end-member formula  $\{Ca_3\}[Al_2](Si_3)O_{12}$ : a trapezohedron  $\{211\}$ , 3.5 cm  
1948 across on the left and crystals in a cyclic intergrowth on the right, from the type locality, Wiluy  
1949 River, Sakha-Yakutia Republic, Russia. The distinctive brown color is due a 30-50  $\mu m$  zone of  
1950 brown andradite a short distance under the crystal faces. Evgeny and Irina Galuskin collection and  
1951 Evgeny Galuskin photograph. D. Uvarovite, end-member formula  $\{Ca_3\}[Cr^{3+}_2](Si_3)O_{12}$ : green  
1952 dodecahedral crystals on chromite, from the type locality, Saranovskii Mine, Permskaya Oblast,  
1953 Middle Urals, Russia. Largest crystal is 4 mm across. Museum of the Faculty of Earth Sciences,  
1954 University of Silesia, no. WNoZ/M/9/19. Evgeny Galuskin photograph. E. Almandine, end-member  
1955 formula  $\{Fe_3\}[Al_2](Si_3)O_{12}$ : a crystal group 2.5 cm across on granite, Mount Lady Franklin,  
1956 Barnawartha, Victoria, Australia. Museum Victoria registration no. M34200. Frank Coffa  
1957 photograph. F. Schorlomite, end-member formula  $\{Ca_3\}[Ti_2](SiFe^{3+}_2)O_{12}$ : an incomplete crystal  
1958 from the type locality, Magnet Cove, Hot Spring County, Arkansas. E.S. Grew collection and  
1959 photograph. G. Manganberzeliite, end-member formula  $\{Ca_2Na\}[Mn^{2+}_2](As^{5+}_3)O_{12}$ , from the type  
1960 locality, Långban, Sweden. The largest crystals are 3 mm across. Swedish Museum of Natural  
1961 History specimen #19170722. M. Cooper photograph.  
1962  
1963 Figure 2. Portion of the garnet structure projected along [001].

57

1964

1965 Figure 3. Local coordination environment of the tetrahedral position from the low-T (200 K)  
1966 refinement of synthetic deuterated katoite (Lager et al. 1987) showing that the deuterium ions are  
1967 approximately on the faces of the O tetrahedron and  $\sim 1.3 \text{ \AA}$  from the ideal tetrahedral cation  
1968 position, which is vacant. O-O distances shown as thin rods, O-D bonds as thick rods.

1969

1970 Figure 4. Compositions of U-rich garnets (Galuskina et al. 2010a; Utsunomiya et al. 2002). The red  
1971 lines mark the boundaries between elbrusite, kerimasite and an unnamed species based on the  
1972 relative proportions of the kerimasite end-member, new elbrusite end-member and the unnamed  
1973  $\{\text{Ca}_3\}[\text{U}^{6+}_2](\text{R}^{2+}_3)\text{O}_{12}$  end-member. Yellow circle indicates the Sn-dominant analogue of elbrusite,  
1974 which was included in the least-squares fit.

1975

1976 Figure 5. Plot of the Y-site contents of 40 natural garnets with  $\text{TiO}_2 > 12 \text{ wt.}\%$  based on formulae  
1977 normalized to 8 cations and 12 oxygen anions (excluding H); BaO and ZnO not included. Y-site  
1978 contents were calculated from the relative proportions of (1) Ti + Zr ( $=\text{R}^{3+}$  at Z), (2) remaining Ti +  
1979 Zr as  $\text{R}^{4+}\text{R}^{2+}$ , and (3)  $\text{R}^{3+}$ , which correspond to schorlomite, morimotoite and andradite,  
1980 respectively. Sources of data: Zedlitz (1935); Lehijärvi (1960); Gnevushev and Fedorova (1964);  
1981 Howie and Woolley (1968); Dowty (1971); Eckermann (1974); Amthauer et al. (1977); Huggins et  
1982 al. (1977); Koritnig et al. (1978) Platt and Mitchell (1979); Flohr and Ross (1989); Lupini et al.  
1983 (1992); Henmi et al. (1995); Labotka (1995); Locock et al. (1995); Chakhmouradian and  
1984 McCammon (2005); Marks et al. (2008); Melluso et al. (2010); Saha et al. (2010). Circles for Mg >  
1985  $\text{Fe}^{2+}$  (total for analysis) have been added only for compositions plotting in the morimotoite field.  
1986 The square enclosing a triangle indicates the schorlomite in which  ${}^Z\text{Al} > {}^Z\text{Fe}^{3+}$  and 0.55 Zr pfu  
1987 reported by Koritnig et al. (1978); it is a possible new species, the Al-dominant analogue of  
1988 schorlomite. Compositions are plotted under the assumption that Al preferentially is incorporated at  
1989 the Z site (except from Fuka, see text).

1990

1991 Figure 6. *Y*-site occupancy in species of the bitikleite group, including the possible unnamed Sn-  
1992 dominant analogue of elbrusite. Placement of the divisions is indicated.

1993

1994 Figure 7. Diagram for discriminating the five species of the schorlomite group from Ca species in  
1995 the garnet group.

1996

1997 Figure 8. *Y*-site occupancy in species of the schorlomite group.

1998

1999 Figure 9. Diagram distinguishing menzerite-(Y) from species within the garnet group.

2000

2001 Figure 10. Plot of menzerite-(Y) compositions at the *Y* site projected from  $\{Y_3\}[R^{3+}_2](R^{3+}_3)O_{12}$  onto  
2002 the plane defined by the components  $\{Ca_3\}[Ti^{4+}R^{2+}](Si^{4+}_3)O_{12}$ ,  $\{Ca_3\}[R^{3+}_2](Si^{4+}_3)O_{12}$ , and  
2003  $\{(REE)_2Ca\}[R^{2+}_2](Si^{4+}_3)O_{12}$  (cf. Figure 7a, Grew et al. 2010).  $R^{2+}$  = Fe in morimotoite, Mg in  
2004 menzerite-(Y);  $R^{3+}$  = Fe in andradite. Numbers refer to grains used for the crystal-structure  
2005 refinement (SREF), optical measurements, and menzerite-(Y) sensu stricto (Mzr), including grain  
2006 #5 used as the holotype to characterize the mineral. The points for SREF and Optic are  
2007 superimposed. Open diamonds indicate the other nine grains analyzed (data from Grew et al. 2010).

2008

2009 Figure 11. A. Tetrahedron illustrating divisions in the garnet group based on occupancy of the *X*  
2010 site. One compositional volume is shown with shading. B. Projection from the Mn vertex onto front  
2011 face of the tetrahedron to distinguish species. C. Projection from the Ca vertex onto left face of the  
2012 tetrahedron to distinguish species.

2013

2014 **Appendix 1. List of garnet species, end-member formulae, modifications, etymology, type**  
2015 **localities; crystal structure refinements**

2016

2017 The following garnet species either have been previously accepted by the IMA-CNMNC or  
2018 have been modified by the current garnet subcommittee. Modifications to the original garnet species  
2019 descriptions are noted except for grandfathered species. One or two references are given for the  
2020 crystal structure, either of natural material (when available) or of synthetic material, or both.

2021

*Almandine*

2022 End-member formula:  $\{\text{Fe}^{2+}_3\}[\text{Al}_2](\text{Si}_3)\text{O}_{12}$

2023 Group: Garnet

2024 IMA number: Grandfathered.

2025 Modifications: None.

2026 Etymology: The “Alabandic carbuncles” of Pliny were so named as they were cut and polished in

2027 Alabanda (Dana 1837, 1892), an ancient city in what is presently Aydin Province, Turkey.

2028 Type locality: Not known.

2029 Crystal system, space group and structure refinement: Isometric, *Ia-3d*. Novak and Gibbs (1971);

2030 synthetic material: Armbruster et al. (1992).

2031 Original or oldest description: Known in ancient times. Name first used by D.L.G. Karsten in 1800

2032 (Dana 1892).

2033

*Andradite*

2034 End-member formula:  $\{\text{Ca}_3\}[\text{Fe}^{3+}_2](\text{Si}_3)\text{O}_{12}$

2035 Group: Garnet

2036 IMA number: Grandfathered.

2037 Modifications: None.

2038 Etymology: For José Bonifácio de Andrada e Silva (1763–1838), the Brazilian mineralogist who

2039 described a variety under the name “allochroite” in 1800 (Dana 1892; Clark 1993).

2040 Type locality: Not known.

2041 Crystal system, space group and structure refinement: Isometric, *Ia-3d*. Armbruster and Geiger

2042 (1993).

2043 Original or oldest description: “allochroite” of de Andrada in 1800 and “melanite” of Werner in

2044 1800 (Dana 1892).

2045

*Berzeliite*

2046 End-member formula:  $\{\text{Ca}_2\text{Na}\}[\text{Mg}_2](\text{As}^{5+}_3)\text{O}_{12}$

2047 Group: Berzeliite

2048 IMA number: Grandfathered.

- 2049 Modifications: None.
- 2050 Etymology: For Jacob Berzelius (1799–1848), a Swedish chemist.
- 2051 Type locality: Långban, Filipstad district, Värmland, Sweden.
- 2052 Crystal system and structure refinement: Isometric, *Ia-3d*. Hawthorne (1976); Nagashima and  
2053 Armbruster (2012).
- 2054 Original or oldest description: Kühn (1840).
- 2055 *Bitikleite*
- 2056 End-member formula:  $\{\text{Ca}_3\}[\text{Sb}^{5+}\text{Sn}^{4+}](\text{Al}_3)\text{O}_{12}$
- 2057 Group: Bitikleite
- 2058 IMA number: 2009-052.
- 2059 Modifications: Originally described as bitikleite-(SnAl) with the same formula.
- 2060 Etymology: From Bitikle, the name of an old fortification near the type locality.
- 2061 Type locality: Upper Chegem caldera, Kabardino-Balkaria, North Caucasus, Russia.
- 2062 Crystal system, space group and structure refinement: Isometric, *Ia-3d*. Galuskina et al. (2010b).
- 2063 Original or oldest description: Galuskina et al. (2010b).
- 2064 *Calderite*
- 2065 End-member formula:  $\{\text{Mn}^{2+}_3\}[\text{Fe}^{3+}_2](\text{Si}_3)\text{O}_{12}$
- 2066 Group: Garnet
- 2067 IMA number: Grandfathered.
- 2068 Modifications: None.
- 2069 Etymology: For James Calder, a member of the Asiatic Society of Bengal, originally applied to the  
2070 rock containing the mineral (Piddington 1850).
- 2071 Type locality: Either in Burdwan (Bardhaman) district, West Bengal State, or near Hazaribagh,  
2072 Jharkhand State, India.
- 2073 Crystal system, space group and structure report: Isometric, *Ia-3d*. No structure refinement;  
2074 structure optimization by distance least-squares refinement (Ottonello et al. 1996).
- 2075 Original or oldest description: Fermor (1909, 1926).
- 2076 *Cryolithionite*
- 2077 End-member formula:  $\{\text{Na}_3\}[\text{Al}_2](\text{Li}_3)\text{F}_{12}$
- 2078 Group: ungrouped
- 2079 IMA number: Grandfathered.
- 2080 Modifications: None.
- 2081 Etymology: From the presence of Li and its relation to cryolite.
- 2082 Type locality: The Ivigtut cryolite deposit, Ivittuut (Ivigtut), Arsuk, Kitaa Province, Greenland.
- 2083 Crystal system, space group and structure refinement: Isometric, *Ia-3d*. Geller (1971).

- 2084 Original or oldest description: Ussing (1904).
- 2085 *Dzhuluite*
- 2086 End-member formula:  $\{\text{Ca}_3\}[\text{Sb}^{5+}\text{Sn}^{4+}](\text{Fe}^{3+}_3)\text{O}_{12}$
- 2087 Group: Bitikleite
- 2088 IMA number: 2010-64.
- 2089 Modifications: Originally described as bitikleite-(SnFe) with the same formula.
- 2090 Etymology: After Dzhulu Mountain near the type locality.
- 2091 Type locality: Upper Chegem caldera, Kabardino-Balkaria, North Caucasus, Russia.
- 2092 Crystal system and space group: Isometric, *Ia-3d*. Structure not yet refined.
- 2093 Original or oldest description: Galuskina et al. (2011a).
- 2094 *Elbrusite*
- 2095 End-member formula:  $\{\text{Ca}_3\}[\text{U}^{6+}_{0.5}\text{Zr}_{1.5}](\text{Fe}^{3+}_3)\text{O}_{12}$
- 2096 Group: Bitikleite
- 2097 IMA number: 2009-051.
- 2098 Modifications: Originally described as elbrusite-(Zr) with a formula  $\{\text{Ca}_3\}[\text{U}^{6+}\text{Zr}](\text{Fe}^{3+}_2\text{Fe}^{2+})\text{O}_{12}$ .
- 2099 Etymology: From the highest peak in Europe – Mount Elbrus (5642 m)
- 2100 Type locality: Upper Chegem caldera, Kabardino-Balkaria, North Caucasus, Russia.
- 2101 Crystal system, space group and structure refinement: Isometric, *Ia-3d*. The structure of elbrusite
- 2102 has not yet been refined, but that of U-rich kerimasite has been refined (under the name “Fe-
- 2103 dominant analogue of kimzeyite”, Galuskina et al. 2010a).
- 2104 Original or oldest description: Galuskina et al. (2010a).
- 2105 *Eringaite*
- 2106 End-member formula:  $\{\text{Ca}_3\}[\text{Sc}_2](\text{Si}_3)\text{O}_{12}$
- 2107 Group: Garnet
- 2108 IMA number: 2009-054.
- 2109 Modifications: None.
- 2110 Etymology: From the Eringa River, a tributary of the Wiluy River.
- 2111 Type locality: Wiluy River, Sakha-Yakutia Republic, Russia. (63.0°N, 112.3°E).
- 2112 Crystal system, space group and structure refinement: Isometric, *Ia-3d*. Synthetic material: Mill’ et
- 2113 al. (1977), Quartieri et al. (2006).
- 2114 Original or oldest description: Galuskina et al. (2010d).
- 2115 *Goldmanite*
- 2116 End-member formula:  $\{\text{Ca}_3\}[\text{V}^{3+}_2](\text{Si}_3)\text{O}_{12}$
- 2117 Group: Garnet
- 2118 IMA number: 1963-003.

- 2119 Modifications: None.
- 2120 Etymology: For Marcus I. Goldman (1881-1965), a sedimentary petrologist with the U.S.  
2121 Geological Survey.
- 2122 Type locality: Sandy (or South Laguna) mine area, Laguna, New Mexico, U.S.A.
- 2123 Crystal system, space group and structure refinement: Isometric, *Ia-3d*. Novak and Gibbs (1971);  
2124 Righter et al. (2011).
- 2125 Original or oldest description: Moench and Meyrowitz (1964).
- 2126 *Grossular*
- 2127 End-member formula:  $\{\text{Ca}_3\}[\text{Al}_2](\text{Si}_3)\text{O}_{12}$
- 2128 Group: Garnet
- 2129 IMA number: Grandfathered.
- 2130 Modifications: None.
- 2131 Etymology: From the color resembling gooseberry, *Ribes grossularia* (Dana 1892; Clark 1993).
- 2132 Type locality: Wiluy River, Sakha-Yakutia Republic, Russia.
- 2133 Crystal system, space group and structure refinement: Isometric, *Ia-3d*. Novak and Gibbs (1971).  
2134 Synthetic material: Geiger and Armbruster (1997).
- 2135 Original or oldest description: A.G. Werner in 1808-1809. However, grossular was described earlier  
2136 under other names, viz. as “Cinnamon Stone” (Kanelstein) from Sri Lanka by Werner in 1803-  
2137 1804 and as “Granat” by Pallas in 1793 (Dana (1892)).
- 2138 *Henritermierite*
- 2139 End-member formula:  $\{\text{Ca}_3\}[\text{Mn}^{3+}_2](\text{Si}_2)(\square)\text{O}_8(\text{OH})_4$
- 2140 Group: Henritermierite
- 2141 IMA number: 1968-029
- 2142 Modifications: None.
- 2143 Etymology: For Henri-François-Émile Termier (1897-1989), a French geologist.
- 2144 Type locality: Tachgagalt mine, Morocco.
- 2145 Crystal system, space group and structure refinement: Tetragonal, *I4<sub>1</sub>/acd*. Armbruster et al. (2001).  
2146 Original or oldest description: Gaudefroy et al. (1969).
- 2147 *Holtstamite*
- 2148 Formula:  $\{\text{Ca}_3\}[\text{Al},\text{Mn}^{3+}_2](\text{Si}_2)(\square)\text{O}_8(\text{OH})_4$
- 2149 Group: Henritermierite
- 2150 IMA number: 2003-047.
- 2151 Modifications: None.
- 2152 Etymology: For Dan Holtstam (b. 1963), a Swedish mineralogist.
- 2153 Type locality: Wessels Mine, Kalahari manganese field, South Africa.

2154 Crystal system, space group and structure refinement: Tetragonal,  $I4_1/acd$ . Hålenius et al. (2005)

2155 Original or oldest description: Hålenius (2004), Hålenius et al. (2005).

2156 *Irinarassite*

2157 End-member formula:  $\{Ca_3\}[Sn^{4+}_2](SiAl_2)O_{12}$

2158 Group: Schorlomite

2159 IMA number: 2010-73.

2160 Modifications: None.

2161 Etymology: For Irina Rass (b. 1940), a Russian mineralogist.

2162 Type locality: Upper Chegem caldera, Kabardino-Balkaria, North Caucasus, Russia.

2163 Crystal system and space group: Isometric,  $Ia-3d$ . Structure not yet refined.

2164 Original or oldest description: Galuskina et al. (2011b).

2165 *Katoite*

2166 End-member formula:  $\{Ca_3\}[Al_2](\square_3)(OH)_{12}$

2167 Group: ungrouped

2168 IMA number: 1982-080.

2169 Modifications: None.

2170 Etymology: For Akira Kato (b. 1931), a Japanese mineralogist.

2171 Type locality: Campomorto quarry, Pietra Massa, Viterbo, Lazio, Italy.

2172 Crystal system, space group and structure refinement: Isometric,  $Ia-3d$ . Sacerdoti and Passaglia  
2173 (1985); synthetic material (Lager et al. 1987).

2174 Original or oldest description: Passaglia and Rinaldi (1984).

2175 *Kerimasite*

2176 End-member formula:  $\{Ca_3\}[Zr_2](SiFe^{3+}_2)O_{12}$

2177 Group: Schorlomite

2178 IMA number: 2009-29.

2179 Modifications: None.

2180 Etymology: For the Kerimasi volcano.

2181 Type locality: Kerimasi volcano, Gregory Rift, northern Tanzania.

2182 Crystal system, space group and structure refinement: Isometric,  $Ia-3d$ . Zaitsev et al. (2010), and  
2183 under the name kimzeyite, Schingaro et al. (2001); synthetic material under the name kimzeyite  
2184 (Whittle et al. 2007).

2185 Original or oldest description: Zaitsev et al. (2010). Under the name kimzeyite: Schingaro et al.  
2186 (2001) and Galuskina et al. (2005); under the name “Fe-dominant analog of kimzeyite”  
2187 (Galuskina et al. 2010a, b, c).

2188 *Kimzeyite*



- 2189 End-member formula:  $\{\text{Ca}_3\}[\text{Zr}_2](\text{SiAl}_2)\text{O}_{12}$
- 2190 Group: Schorlomite
- 2191 IMA number: Not recorded.
- 2192 Modifications: None.
- 2193 Etymology: For members of the Kimzey family, who were instrumental in obtaining and preserving
- 2194 mineral specimens from Magnet Cove.
- 2195 Type locality: Kimzey quarry, Magnet Cove, Arkansas, U.S.A.
- 2196 Crystal system, space group and structure refinement: Isometric, *Ia-3d*. Munno et al. (1980)
- 2197 Original or oldest description: Milton and Blade (1958), Milton et al. (1961).
- 2198 *Knorringite*
- 2199 End-member formula:  $\{\text{Mg}_3\}[\text{Cr}^{3+}_2](\text{Si}_3)\text{O}_{12}$
- 2200 Group: Garnet
- 2201 IMA number: 1968-010.
- 2202 Modifications: None.
- 2203 Etymology: For Oleg von Knorring (1915-1994), a Russian mineralogist who worked in Finland
- 2204 and the United Kingdom.
- 2205 Type locality: Kao kimberlite pipe, Butha-Buthe, Lesotho
- 2206 Crystal system, space group and structure refinement: Isometric, *Ia-3d*. Synthetic material: Juhin et
- 2207 al. (2010).
- 2208 Original or oldest description: Nixon and Hornung (1968).
- 2209 *Majorite*
- 2210 End-member formula:  $\{\text{Mg}_3\}[\text{SiMg}](\text{Si}_3)\text{O}_{12}$
- 2211 Group: Garnet
- 2212 IMA number: 1969-018.
- 2213 Modifications: Formula originally given as  $\{(\text{Mg,Na})_3\}[(\text{Fe,Si,Al,Cr})_2](\text{Si}_3)\text{O}_{12}$ .
- 2214 Etymology: For Alan Major, who assisted A.E. Ringwood in experiments.
- 2215 Type locality: Coorara L6 chondrite (recovered in Western Australia).
- 2216 Crystal system, space group and structure refinement: Isometric, *Ia-3d*. Synthetic material: Hazen et
- 2217 al. (1994).
- 2218 Original or oldest description: Smith and Mason (1970).
- 2219 *Manganberzeliite*
- 2220 End-member formula:  $\{\text{Ca}_2\text{Na}\}[\text{Mn}^{2+}_2](\text{As}^{5+}_3)\text{O}_{12}$
- 2221 Group: Berzeliite
- 2222 IMA number: Grandfathered.
- 2223 Modifications: See text.

- 2224 Etymology: The manganese analogue of berzeliite.
- 2225 Type locality: Långban, Filipstad district, Värmland, Sweden.
- 2226 Crystal system, space group and structure refinement: Isometric, *Ia-3d*. Qualitative description of  
2227 the structure: Bubeck and Machatschki (1935); Nagashima and Armbruster (2012).
- 2228 Original or oldest description: Igelström (1886, 1894).
- 2229 *Menzerite-(Y)*
- 2230 End-member formula:  $\{Y_2Ca\}[Mg_2](Si_3)O_{12}$
- 2231 Group: Garnet
- 2232 IMA number: 2009-050.
- 2233 Modifications: None.
- 2234 Etymology: For Georg Menzer (1897-1989), the German crystallographer who was the first to solve  
2235 the structure of garnet (Menzer 1928); the suffix Y is a Levinson modifier that indicates that Y  
2236 is dominant among the sum of Y and the rare-earth elements.
- 2237 Type locality: Bonnet Island in Georgian Bay, near Parry Sound, Ontario, Canada
- 2238 Crystal system, space group and structure refinement: Isometric, *Ia-3d*. Grew et al. (2010).
- 2239 Original or oldest description: Grew et al. (2010).
- 2240 *Momoiite*
- 2241 End-member formula:  $\{Mn^{2+}_3\}[V^{3+}_2](Si_3)O_{12}$
- 2242 Group: Garnet
- 2243 IMA number: 2009-026.
- 2244 Modifications: None; see the “yamatoite” of Momoi (1964), which was not approved because this  
2245 component was not dominant in the material that they investigated (Fleischer 1965).
- 2246 Etymology: For Hitoshi Momoi (1930-2002), the Japanese mineralogist who was the first to  
2247 recognize  $\{Mn^{2+}_3\}[V^{3+}_2](Si_3)O_{12}$  as a component in garnet.
- 2248 Type locality: Kurase mine, Ehime Prefecture, Japan.
- 2249 Crystal system and space group: Isometric, *Ia-3d*. Structure not yet refined, but the atomic  
2250 coordinates were predicted by Novak and Gibbs (1971).
- 2251 Original or oldest description: Tanaka et al. (2010).
- 2252 *Morimotoite*
- 2253 End-member formula:  $\{Ca_3\}[TiFe^{2+}](Si_3)O_{12}$
- 2254 Group: Garnet
- 2255 IMA number: 1992-017.
- 2256 Modifications: None.
- 2257 Etymology: For Nobuo Morimoto (b. 1925), a Japanese mineralogist.
- 2258 Type locality: Fuku, Bitchu-Cho, Okayama Prefecture, Japan.

- 2259 Crystal system and space group: Isometric, *Ia-3d*. Structure not yet refined.
- 2260 Original or oldest description: Henmi et al. (1995).
- 2261 *Palenzonaite*
- 2262 End-member formula:  $\{\text{Ca}_2\text{Na}\}[\text{Mn}^{2+}_2](\text{V}^{5+}_3)\text{O}_{12}$
- 2263 Group: Berzeliite
- 2264 IMA number: 1986-011.
- 2265 Modifications: None.
- 2266 Etymology: For Andrea Palenzona (b. 1935), an Italian chemist.
- 2267 Type locality: Molinello mine, Ne, Val Graveglia, Liguria, Italy.
- 2268 Crystal system, space group and structure refinement: Isometric, *Ia-3d*. Basso (1987); Nagashima
- 2269 and Armbruster (2012).
- 2270 Original or oldest description: Basso (1987).
- 2271 *Pyrope*
- 2272 End-member formula:  $\{\text{Mg}_3\}[\text{Al}_2](\text{Si}_3)\text{O}_{12}$
- 2273 Group: Garnet
- 2274 IMA number: Grandfathered.
- 2275 Modifications: None.
- 2276 Etymology: From the Greek *πυρρός* (pyropos) – firelike for its deep-red color.
- 2277 Type locality: Bohemia (Czech Republic).
- 2278 Crystal system, space group and structure refinement: Isometric, *Ia-3d*. Novak and Gibbs (1971);
- 2279 synthetic material: Armbruster et al. (1992).
- 2280 Original or oldest description: Recognized by Georgius Agricola (1546), but the name pyrope was
- 2281 introduced by A.G. Werner in 1800 (Dana 1892; Clark 1993).
- 2282 *Schäferite*
- 2283 End-member formula:  $\{\text{Ca}_2\text{Na}\}[\text{Mg}_2](\text{V}^{5+}_3)\text{O}_{12}$
- 2284 Group: Berzeliite
- 2285 IMA number: 1997-048.
- 2286 Modifications: None.
- 2287 Etymology: For Helmut Schäfer (b. 1931), an amateur German mineralogist who discovered the
- 2288 mineral.
- 2289 Type locality: Bellberg volcano near Mayen, Eifel, Germany.
- 2290 Crystal system, space group and structure refinement: Isometric, *Ia-3d*. Krause et al. (1999).
- 2291 Original or oldest description: Krause et al. (1999).
- 2292 *Schorlomite*
- 2293 End-member formula:  $\{\text{Ca}_3\}[\text{Ti}_2](\text{SiFe}^{3+}_2)\text{O}_{12}$

- 2294 Group: Schorlomite
- 2295 IMA number: Grandfathered.
- 2296 Modifications: Extensive; see main text.
- 2297 Etymology: For its resemblance to schorl.
- 2298 Type locality: Magnet Cove, Hot Springs County, Arkansas, U.S.A.
- 2299 Crystal system, space group and structure refinement: Isometric, *Ia-3d*. Chakhmouradian and  
2300 McCammon (2005).
- 2301 Original or oldest description: Shepard (1846), Whitney (1849) and Rammelsberg (1850a,b).  
2302 *Spessartine*
- 2303 End-member formula:  $\{\text{Mn}^{2+}_3\}[\text{Al}_2](\text{Si}_3)\text{O}_{12}$
- 2304 Group: Garnet
- 2305 IMA number: Grandfathered.
- 2306 Modifications: None.
- 2307 Etymology: From the Spessart Mountains, Germany.
- 2308 Type locality: Sommer quarry, Wendelberg Mt., Spessart Mountains, Bavaria, Germany.
- 2309 Crystal system, space group and structure refinement: Isometric, *Ia-3d*. Novak and Gibbs (1971);  
2310 for F-bearing, Smyth et al. (1990). Synthetic material: Geiger and Armbruster (1997).
- 2311 Original or oldest description: Recognized by M.H. Klaproth (1797), but the name spessartine was  
2312 introduced by F.S. Beudant (1832) according to Dana (1892) and Clark (1993).
- 2313 *Toturite*
- 2314 End-member formula:  $\{\text{Ca}_3\}[\text{Sn}^{4+}_2](\text{SiFe}^{3+}_2)\text{O}_{12}$
- 2315 Group: Schorlomite
- 2316 IMA number: 2009-033.
- 2317 Modifications: None.
- 2318 Etymology: From both the Totur River situated in Eltybyu village near the type locality and the  
2319 name of a Balkarian deity and ancient warrior.
- 2320 Type locality: Upper Chegem caldera, Kabardino-Balkaria, North Caucasus, Russia.
- 2321 Crystal system and space group: Isometric, *Ia-3d*. Structure not yet refined.
- 2322 Original or oldest description: Galuskina et al. (2010c).
- 2323 *Usturite*
- 2324 End-member formula:  $\{\text{Ca}_3\}[\text{Sb}^{5+}\text{Zr}](\text{Fe}^{3+}_3)\text{O}_{12}$
- 2325 Group: Bitikleite
- 2326 IMA number: 2009-053.
- 2327 Modifications: Originally described as bitikleite-(ZrFe) with the same formula.
- 2328 Etymology: From the Ustur Mountain near the type locality.

- 2329 Type locality: Upper Chegem caldera, Kabardino-Balkaria, North Caucasus, Russia.
- 2330 Crystal system and space group: Isometric, *Ia-3d*. Structure not yet refined.
- 2331 Original or oldest description: Galuskina et al. (2010b).
- 2332 *Uvarovite*
- 2333 End-member formula:  $\{\text{Ca}_3\}[\text{Cr}^{3+}_2](\text{Si}_3)\text{O}_{12}$
- 2334 Group: Garnet
- 2335 IMA number: Grandfathered.
- 2336 Modifications: None.
- 2337 Etymology: For Count Sergei Semenovich Uvarov (1786-1855), a Russian historian.
- 2338 Type locality: Saranovskiy mine Biserskoye chromite deposit, Perm district, Urals, Russia (Pekov
- 2339 1998).
- 2340 Crystal system, space group and structure refinement: Isometric, *Ia-3d*. Novak and Gibbs (1971).
- 2341 For birefringent uvarovite: Wildner and Andrut (2001).
- 2342 Original or oldest description: Hess (1832).
- 2343 *Yafsoanite*
- 2344 End-member formula:  $\{\text{Ca}_3\}[\text{Te}^{6+}_2](\text{Zn}_3)\text{O}_{12}$
- 2345 Group: ungrouped
- 2346 IMA number: 1981-022.
- 2347 Modifications: Introduced with the idealized formula  $(\text{Zn}_{1.38}\text{Ca}_{1.36}\text{Pb}_{0.26})_{\Sigma=3.00}\text{TeO}_6$ ; current formula
- 2348 from Jarosch and Zemann (1989) and Mills et al. (2010).
- 2349 Etymology: From the acronym Yakyt'skii Filial Sibirskogo Otdeleniya Akademii Nauk (Yakyt Filial
- 2350 of the Siberian Branch of the Academy of Sciences).
- 2351 Type locality: Kuranakh gold deposit, near Aldan, Yakutia, Russia (Pekov 1998).
- 2352 Crystal system, space group and structure refinement: Isometric, *Ia-3d*. Mills et al. (2010)
- 2353 Original or oldest description: Kim et al. (1982).
- 2354
- 2355

2356 **Appendix 3. Six worked examples to illustrate the procedure to identify a garnet**

2357 OUTLINE OF RECOMMENDED PROCEDURE

2358

2359 Step 1. Calculate a formula on the basis of 12 anions and 8 cations (e.g., Appendix Table 1).

2360

2361 Step 2. Allocate cations (see section **Site allocation of cations**, e.g., Appendix Table 2).

2362

2363 Step 3. Identify dominant valences at each site, and dominant cation for each valence, being  
2364 mindful of valency-imposed double site-occupancy (e.g., Appendix Table 3). This will identify the  
2365 garnet by group and species.

2366

2367 Step 4. Write an empirical formula, ordering the cations first by valence and then by abundance.

2368

2369 Step 5. Calculate the maximum proportions of generalized components using the spreadsheet in  
2370 Appendix 4 (e.g., Appendix Table 4).

2371

2372 Step 6. It may be necessary to factor in the results from step 4 before finalizing species  
2373 identification (see notes).

2374

2375 Step 7. In some cases the maximum proportions of generalized components total 100% (examples  
2376 2, 6), in which case the components are all independent variables and can be used for plotting in  
2377 Figures 6-9, 11. In most cases, the maximum proportions will total above 100%, and a subset of  
2378 independent generalized components must be selected and recalculated to 100% for plotting, which  
2379 is done for the other four examples.

2380

2381 Note: Discrepancies in the last decimal place are the result of rounding of tabulated values.

2382

---

2383 EXAMPLE 1. URANIAN DZHULUITE FROM THE NORTHERN CAUCASUS (GALUSKINA AND GALUSKIN,  
2384 UNPUBLISHED DATA)

2385

2386 Appendix Table 1. Electron microprobe  
2387 analysis with calculated Fe<sup>2+</sup>/Fe<sup>3+</sup> ratio

	wt.%	apfu per 12 O	
2389 UO <sub>3</sub>	11.15	U <sup>6+</sup>	0.282
2390 Nb <sub>2</sub> O <sub>5</sub>	0.87	Nb <sup>5+</sup>	0.047
2391 Sb <sub>2</sub> O <sub>5</sub>	14.79	Sb <sup>5+</sup>	0.661
2392 SiO <sub>2</sub>	0.15	Si	0.018
2393 TiO <sub>2</sub>	1.32	Ti	0.120
2394 ZrO <sub>2</sub>	3.48	Zr	0.204
2395 SnO <sub>2</sub>	16.20	Sn	0.777
2396 Al <sub>2</sub> O <sub>3</sub>	4.26	Al	0.604
2397 Sc <sub>2</sub> O <sub>3</sub>	0.13	Sc	0.014
2398 Fe <sub>2</sub> O <sub>3</sub>	20.96	Fe <sup>3+</sup>	1.897
2399 MgO	0.03	Mg	0.005
2400 CaO	22.79	Ca	2.936
2401 FeO	4.35	Fe <sup>2+</sup>	0.437
2402 Sum	100.48		8.000

2403

2404 Appendix Table 2. Site Allocation

2405

Z

2406	Fe <sup>2+</sup>	0.437	0.379
2407	Al <sup>3+</sup>	0.604	0.604
2408	Fe <sup>3+</sup>	1.897	1.897
2409	Si <sup>4+</sup>	0.018	0.018
2410	Ti <sup>4+</sup>	0.044	0.103
2411	Sum	3.000	3.000
2412	charge	8.625	8.793

2413

2414		Y	
2415	Sc <sup>3+</sup>	0.014	0.014
2416	Ti <sup>4+</sup>	0.075	0.016
2417	Sn <sup>4+</sup>	0.777	0.777
2418	Zr <sup>4+</sup>	0.204	0.204
2419	Nb <sup>5+</sup>	0.047	0.047
2420	Sb <sup>5+</sup>	0.661	0.661
2421	U <sup>6+</sup>	0.282	0.282
2422	Sum	2.060	2.000

2423

2424		X	
2425	Ca	2.936	2.936
2426	Mg	0.005	0.005
2427	Fe <sup>2+</sup>	0.000	0.059
2428	Sum	2.941	3.000

2429

2430 1. Si, Al, Fe<sup>3+</sup>, Fe<sup>2+</sup> and sufficient Ti to fill Z

2431 2. Sc, remaining Ti, Sn, Nb, Sb and U to Y.

2432 3. Ca and Mg to X

2433 Column 1 gives allocation from Appendix 4. Because of the assignment of Fe<sup>2+</sup> to the Z site in  
 2434 advance of Ti, calculated Y site occupancy exceeds 2 apfu, and X site occupancy is less than 3 apfu.  
 2435 Column 2 allocation with distribution of Fe<sup>2+</sup> to achieve stoichiometry.

2436

2437 Appendix Table 3. Dominant valences, constituents and percent of  
 2438 homovalent cations (from column 1 of Table 1)

2439	Site	Valence	Constituent	%	Identification
2440	Z	+3	Fe	76	Bitikleite group
2441	Y	+5	Sb	93	Dzhuluite
2442	Y	+4	Sn	74	Dzhuluite
2443	X	+2	Ca	99.8	Dzhuluite

2444 Note: Y is constrained to have two occupants because of valency-  
 2445 imposed double site-occupancy.

2446

2447 Empirical formula from Table 2, column 1 (dominant cation for dominant valence in bold):

2448 {**Ca**<sub>2.936</sub>Mg<sub>0.005</sub>}[(**Sn**<sub>0.777</sub>Zr<sub>0.204</sub>Ti<sub>0.075</sub>)(**Sb**<sub>0.661</sub>Nb<sub>0.047</sub>)U<sub>0.282</sub>Sc<sub>0.014</sub>](**(Fe**<sup>3+</sup><sub>1.897</sub>Al<sub>0.604</sub>)Fe<sup>2+</sup><sub>0.437</sub>(Ti<sub>0.044</sub>Si<sub>0.</sub>  
 2449 018))O<sub>12</sub>

2450

2451 Empirical formula from Table 2, column 2 (dominant cation for dominant valence in bold):

2452 {**Ca**<sub>2.936</sub>Fe<sup>2+</sup><sub>0.059</sub>Mg<sub>0.005</sub>}[(**Sn**<sub>0.777</sub>Zr<sub>0.204</sub>Ti<sub>0.016</sub>)(**Sb**<sub>0.661</sub>Nb<sub>0.047</sub>)U<sub>0.282</sub>Sc<sub>0.014</sub>](**(Fe**<sup>3+</sup><sub>1.897</sub>Al<sub>0.604</sub>)Fe<sup>2+</sup><sub>0.379</sub>(  
 2453 Ti<sub>0.103</sub>Si<sub>0.018</sub>))O<sub>12</sub>

2454

2455

2456 Appendix Table 4. Proportions of generalized components

Component	Maximum Proportion*	Proportion as independent variable <sup>#</sup>	Group or formula type
$\{R^{2+}_3\}[R^{6+}_2](R^{2+}_3)O_{12}$	14.08%	12.62%	yafsoanite-type
$\{R^{2+}_3\}[R^{4+}_{1.5}R^{6+}_{0.5}](R^{3+}_3)O_{12}$	56.32%	5.85%	Bitikleite: elbrusite-type
$\{R^{2+}_3\}[R^{5+}R^{4+}](R^{3+}_3)O_{12}$	70.78%	70.78%	Bitikleite: dzhuluite-type
$\{R^{2+}_3\}[R^{4+}_2](R^{4+}R^{3+}_2)O_{12}$	6.24%	10.07%	Schorlomite
$\{R^{2+}_3\}[R^{3+}_2](R^{4+}_3)O_{12}$	0.68%	0.68%	Garnet: eringaite-type
Total	141.11%	100.00%	

Note: \*From column 1. <sup>#</sup>From column 2. The five generalized components are independent variables, but proportions as independent variables can only be calculated from a formula for ideal stoichiometry.

Comment: Uranium is split between two components (bitikleite and yafsoanite-type), both of which are subordinate, and thus Table 4 (either column 2 or column 3) and the empirical formulae give the same identification, dzhuluite, which has the generalized formula,  $\{R^{2+}_3\}[R^{5+}R^{4+}](R^{3+}_3)O_{12}$ .

#### EXAMPLE 2. GARNET MCO<sub>4</sub>, HIGH TI, SCHORLOMITE FROM MAGNET COVE, ARKANSAS (CHAKHMOURADIAN AND MCCAMMON 2005)

##### Appendix Table 5. Electron microprobe analysis with calculated Fe<sup>2+</sup>/Fe<sup>3+</sup> ratio

	Wt%	apfu per 12 O	
SiO <sub>2</sub>	26.16	Si	2.250
TiO <sub>2</sub>	16.52	Ti	1.069
ZrO <sub>2</sub>	1.31	Zr	0.055
Al <sub>2</sub> O <sub>3</sub>	1.60	Al	0.162
Fe <sub>2</sub> O <sub>3</sub>	17.07	Fe <sup>3+</sup>	1.105
FeO	3.44	Fe <sup>2+</sup>	0.247
MnO	0.48	Mn	0.035
MgO	1.21	Mg	0.155
CaO	31.54	Ca	2.907
Na <sub>2</sub> O	0.09	Na	0.015
Sum	99.42	Sum	8.000

##### Appendix Table 6. Site Allocation

Z	
Si	2.250
Al	0.162
Fe <sup>3+</sup>	0.588
Sum	3.000
Charge	11.250
Y	
Ti	1.069
Zr	0.055
Fe <sup>3+</sup>	0.517
Mg	0.155
Fe <sup>2+</sup>	0.204
Sum	2.000
X	
Fe <sup>2+</sup>	0.043



2508	Ca	2.907
2509	Mn	0.035
2510	Na	0.015
2511	Sum	3.000
2512		
2513	1.	Si to Z
2514	2.	Al to Z
2515	3.	Fe <sup>3+</sup> to Z to bring total to 3 apfu, then Y
2516	4.	Ca and Na to X
2517	5.	Ti <sup>4+</sup> , remaining Fe <sup>3+</sup> , and Zr to Y.
2518	6.	Mg: First to Y
2519	7.	Fe <sup>2+</sup> First to Y to bring total to 2 apfu, then to X
2520	8.	Mn <sup>2+</sup> to X, which brings total X to 3 apfu

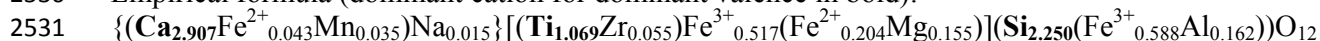
2522 Appendix Table 7. Dominant valences, constituents and percent of  
 2523 homovalent cations

Site	Valence	Constituent	%	Identification
2525 Z	+4	Si	100	Garnet group*
2526 Y	+4	Ti	95	Schorlomite
2527 X	+2	Ca	97	Schorlomite

2528 Note: \*Cf. Appendix Table 8, which gives schorlomite group

2529

2530 Empirical formula (dominant cation for dominant valence in bold):



2532

2533 Appendix Table 8. Maximum proportions of generalized components

Component	Proportion	Group and type
2535 $\{R^{2+}_3\}[R^{4+}_2](R^{4+}R^{3+}_2)\text{O}_{12}$	37.5%	Schorlomite
2536 $\{R^{2+}_3\}[R^{3+}_2](R^{4+}_3)\text{O}_{12}$	25.9%	Garnet: andradite-type
2537 $\{R^{2+}_3\}[R^{4+}R^{2+}](R^{4+}_3)\text{O}_{12}$	35.9%	Garnet: morimotoite-type
2538 $\{R^{2+}_2R^{2+}\}[R^{4+}_2](R^{4+}_3)\text{O}_{12}$	0.8%	Garnet: $\{\text{Na}_2\text{Ca}\}[\text{Ti}_2](\text{Si}_3)\text{O}_{12}$ -type
2539 Total	100.00%	

2540 Note: The four generalized components are independent variables.

2541

2542 Comment: The empirical formula gives  $R^{4+}$  the dominant valence at Z and Y, but the identification  
 2543 is clear only from Table 8, which gives,  $\{R^{2+}_3\}[R^{4+}_2](R^{4+}R^{3+}_2)\text{O}_{12}$ , schorlomite, as the dominant  
 2544 component. The contradiction results from garnet-group components together being dominant,  
 2545 whereas schorlomite is more abundant than any one of the garnet components.

2546

2547

2548 EXAMPLE 3. HOLOTYPE MENZERITE, PARRY SOUND, ONTARIO, CANADA-(Y) (GRAIN NO. 1-5, GREW  
 2549 ET AL. 2010)

2550

2551 Appendix Table 9. Electron microprobe  
 2552 analysis with calculated Fe<sup>2+</sup>/Fe<sup>3+</sup> ratio

	Wt%		apfu per 12 O
2554 SiO <sub>2</sub>	30.64	Si	2.820
2555 TiO <sub>2</sub>	1.10	Ti	0.076
2556 Al <sub>2</sub> O <sub>3</sub>	4.87	Al	0.528
2557 Sc <sub>2</sub> O <sub>3</sub>	0.17	Sc	0.014
2558 V <sub>2</sub> O <sub>3</sub>	0.17	V	0.013

2559	Cr <sub>2</sub> O <sub>3</sub>	0.04	Cr	0.003
2560	Fe <sub>2</sub> O <sub>3</sub>	8.36	Fe <sup>3+</sup>	0.579
2561	Y <sub>2</sub> O <sub>3</sub>	16.93	Y	0.829
2562	La <sub>2</sub> O <sub>3</sub>	0.00	La	0.000
2563	Ce <sub>2</sub> O <sub>3</sub>	0.01	Ce	0.000
2564	Pr <sub>2</sub> O <sub>3</sub>	0.00	Pr	0.000
2565	Nd <sub>2</sub> O <sub>3</sub>	0.12	Nd	0.004
2566	Sm <sub>2</sub> O <sub>3</sub>	0.15	Sm	0.005
2567	Eu <sub>2</sub> O <sub>3</sub>	0.01	Eu	0.000
2568	Gd <sub>2</sub> O <sub>3</sub>	0.36	Gd	0.011
2569	Tb <sub>2</sub> O <sub>3</sub>	0.11	Tb	0.003
2570	Dy <sub>2</sub> O <sub>3</sub>	1.52	Dy	0.045
2571	Ho <sub>2</sub> O <sub>3</sub>	0.63	Ho	0.018
2572	Er <sub>2</sub> O <sub>3</sub>	2.40	Er	0.069
2573	Tm <sub>2</sub> O <sub>3</sub>	0.38	Tm	0.011
2574	Yb <sub>2</sub> O <sub>3</sub>	2.03	Yb	0.057
2575	Lu <sub>2</sub> O <sub>3</sub>	0.68	Lu	0.019
2576	MgO	3.98	Mg	0.546
2577	CaO	13.92	Ca	1.372
2578	MnO	0.85	Mn	0.066
2579	FeO	11.84	Fe <sup>2+</sup>	0.911
2580	Sum	101.26	Sum	8.000

2581

2582 Appendix Table 10. Site Allocation

2583  $Z$

2584	Si	2.820
2585	Al	0.180
2586	Sum	3.000
2587	Charge	11.820

2588  $Y$

2589	Ti	0.076
2590	Al	0.348
2591	Sc	0.014
2592	V	0.013
2593	Cr	0.003
2594	Fe <sup>3+</sup>	0.580
2595	Mg	0.546
2596	Fe <sup>2+</sup>	0.422
2597	Sum	2.000

2598  $X$

2599	Y + REE	1.072
2600	Ca	1.372
2601	Mn	0.066
2602	Fe <sup>2+</sup>	0.489
2603	Sum	3.000

2604

- 2605 1. Si: First to  $Z$
- 2606 2. Al to  $Z$  to bring total to 3 apfu, then  $Y$
- 2607 3. Fe<sup>3+</sup> to  $Y$
- 2608 4. Ca, Y, REE to  $X$
- 2609 5. Al (after deducting Al at  $Z$ ), Sc<sup>3+</sup>, Ti<sup>4+</sup>, V<sup>3+</sup>, Cr<sup>3+</sup>, Fe<sup>3+</sup> to  $Y$ .
- 2610 6. Mg: First to  $Y$

- 2611 7. Fe<sup>2+</sup> First to Y to bring total to 2 apfu, then to X  
 2612 8. Mn<sup>2+</sup> to X, which brings total X to 3 apfu

2613

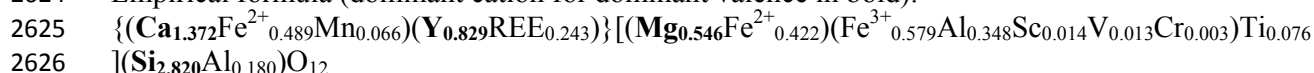
2614 Appendix Table 11. Dominant valences, constituents and percent  
 2615 of homovalent cations

Site	Valence	Constituent	%	Identification
2617 Z	+4	Si	100	Garnet group
2618 Y	+2	Mg	56	Menzerite-(Y)
2619 X	+3	Y	77	Menzerite-(Y)
2620 X	+2	Ca	71	Menzerite-(Y)

2621 Note: X is constrained to have two occupants because of valency-  
 2622 imposed double site-occupancy.

2623

2624 Empirical formula (dominant cation for dominant valence in bold):



2627

2628 Appendix Table 12. Proportions of generalized components

Component	Maximum Proportion*	Proportion as independent variable <sup>#</sup>	Group and type
2632 $\{\mathbf{R}^{3+}_3\}[\mathbf{R}^{3+}_2](\mathbf{R}^{3+}_3)\text{O}_{12}$	6.02%	6.02%	{Y <sub>3</sub> }[Al <sub>2</sub> ](Al <sub>3</sub> )O <sub>12</sub> -type
2633 $\{\mathbf{R}^{2+}_3\}[\mathbf{R}^{4+}_2](\mathbf{R}^{4+}_3\mathbf{R}^{3+}_2)\text{O}_{12}$	3.81%	—	Schorlomite
2634 $\{\mathbf{R}^{2+}_3\}[\mathbf{R}^{4+}_3\mathbf{R}^{2+}_2](\mathbf{R}^{4+}_3)\text{O}_{12}$	7.61%	7.61%	Garnet: morimotoite-type
2635 $\{\mathbf{R}^{3+}_2\mathbf{R}^{2+}_2\}[\mathbf{R}^{2+}_2](\mathbf{R}^{4+}_3)\text{O}_{12}$	48.42%	44.61%	Garnet: menzerite-(Y)-type
2636 $\{\mathbf{R}^{2+}_3\}[\mathbf{R}^{3+}_2](\mathbf{R}^{4+}_3)\text{O}_{12}$	47.77%	41.75%	Garnet: andradite-type
2637 Total	113.64	100.00%	

2638 Note: Y represents Y and REE. \*From Appendix 4. Only four of these generalized components are  
 2639 independent. <sup>#</sup>One of two sets of independent variables

2640

2641 EXAMPLE 4. FLUORINE-BEARING SPESSARTINE FROM CLEAR CREEK COUNTY, COLORADO (SMYTH ET  
 2642 AL. 1990)

2643

2644 Appendix Table 13. Electron microprobe  
 2645 analysis with calculated Fe<sup>2+</sup>/Fe<sup>3+</sup> ratio

	Wt%		apfu per 12 O
2647 SiO <sub>2</sub>	32.55	Si	2.681
2648 TiO <sub>2</sub>	0.06	Ti	0.004
2649 Al <sub>2</sub> O <sub>3</sub>	20.13	Al	1.954
2650 Fe <sub>2</sub> O <sub>3</sub>	0.33	Fe <sup>3+</sup>	0.020
2651 FeO	4.50	Fe <sup>2+</sup>	0.310
2652 MnO	37.98	Mn <sup>2+</sup>	2.650
2653 CaO	0.60	Ca	0.053
2654		Sum	7.672
2655 H <sub>2</sub> O+	0.64	OH	0.352
2656 F	3.68	F	0.959
2657 O=F	-1.55	O	10.690
2658 Total	98.92	Sum	12.000

2659 Note: H<sub>2</sub>O content by IR spectroscopy.

2660

2661 Appendix Table 14. Site Allocation

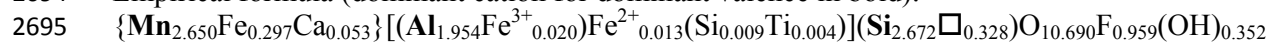
2662		Z
2663	Si	2.672
2664	vacancies	0.328
2665	Sum	3.000
2666	Charge	10.690
2667		Y
2668	Al	1.954
2669	Fe <sup>3+</sup>	0.020
2670	Fe <sup>2+</sup>	0.013
2671	Si	0.009
2672	Ti	0.004
2673	Sum	2.000
2674		X
2675	Mn <sup>2+</sup>	2.650
2676	Fe <sup>2+</sup>	0.297
2677	Ca	0.053
2678	Sum	3.000

- 2679
- 2680 1. Vacancies equal to ¼ F plus ¼ (OH) to Z
  - 2681 2. Si to Z to bring total of Si and vacancies to 3
  - 2682 3. Remaining Si to Y
  - 2683 4. Al, Ti to Y
  - 2684 5. Fe<sup>2+</sup> to Y to bring total to 2 apfu
  - 2685 6. Mn, Ca and remaining Fe<sup>2+</sup> to X

2686  
 2687 Appendix Table 15. Dominant valences, constituents and percent  
 2688 of homovalent cations

2689 Site	Valence	Constituent	%	Identification
2690 Z	+4	Si	100	Garnet group
2691 Y	+3	Al	99	Garnet group
2692 X	+2	Mn	88	Spessartine

2693  
 2694 Empirical formula (dominant cation for dominant valence in bold):



2696  
 2697 Appendix Table 16. Proportions of generalized components

2698 Generalized Component	Maximum proportion*	Proportion as independent variable <sup>#</sup>	Group or formula type
2701 $\{\mathbf{R}^{2+}_3\}[\mathbf{R}^{3+}_2](\square)_3(\text{OH})_{12}$	2.93%	2.93%	katoite-type
2702 $\{\mathbf{R}^{2+}_3\}[\mathbf{R}^{3+}_2](\square)_3\text{F}_{12}$	7.99%	7.99%	{Mn <sub>3</sub> }[Al <sub>2</sub> ](□) <sub>3</sub> F <sub>12</sub> -type
2703 $\{\mathbf{R}^{2+}_3\}[\mathbf{R}^{3+}_2](\mathbf{R}^{4+}_2\square)(\text{OH})_4$	8.79%	—	Henritermierite-type
2704 $\{\mathbf{R}^{2+}_3\}[\mathbf{R}^{4+}_2](\mathbf{R}^{4+}_2\mathbf{R}^{3+}_2)\text{O}_{12}$	0.02%	—	Schorlomite-type
2705 $\{\mathbf{R}^{2+}_3\}[\mathbf{R}^{4+}_2\mathbf{R}^{2+}](\mathbf{R}^{4+}_3)\text{O}_{12}$	1.27%	1.27%	Garnet: morimotoite-type
2706 $\{\mathbf{R}^{2+}_3\}[\mathbf{R}^{3+}_2](\mathbf{R}^{4+}_3)\text{O}_{12}$	89.08%	87.81%	Garnet: spessartine-type
2707 Total	110.06%	100.00%	

2708 Note: \* From Appendix 4.

2709  
 2710 EXAMPLE 5. GARNET JF22. „MAJORITIC“ GARNET INCLUDED IN DIAMOND, JAGERSFONTEIN  
 2711 KIMBERLITE, SOUTH AFRICA (TAPPERT ET AL. 2005)

2712

2713 Appendix Table 17. Electron microprobe  
 2714 analysis with calculated Fe<sup>2+</sup>/Fe<sup>3+</sup> ratio

2715	Wt%	apfu per 12 O	
2716	P <sub>2</sub> O <sub>5</sub>	0.09	P 0.006
2717	SiO <sub>2</sub>	48.70	Si 3.525
2718	TiO <sub>2</sub>	0.50	Ti 0.027
2719	Al <sub>2</sub> O <sub>3</sub>	9.65	Al 0.823
2720	Cr <sub>2</sub> O <sub>3</sub>	0.22	Cr 0.013
2721	Fe <sub>2</sub> O <sub>3</sub>	2.49	Fe <sup>3+</sup> 0.135
2722	MgO	21.70	Mg 2.341
2723	CaO	5.73	Ca 0.444
2724	MnO	0.36	Mn 0.022
2725	FeO	9.46	Fe <sup>2+</sup> 0.573
2726	Na <sub>2</sub> O	0.65	Na 0.091
2727	Sum	99.55	Sum 8.000

2728

2729 Appendix Table  
 2730 18. Site Allocation

2731	<i>Z</i>	
2732	P	0.006
2733	Si	2.994
2734	Sum	3.000
2735	Charge	12.006
2736		
2737	<i>Y</i>	
2738	Si	0.530
2739	Ti	0.027
2740	Al	0.823
2741	Cr	0.013
2742	Fe <sup>3+</sup>	0.135
2743	Mg	0.472
2744	Sum	2.000
2745		
2746	<i>X</i>	
2747	Na	0.091
2748	Ca	0.444
2749	Mn	0.022
2750	Fe	0.573
2751	Mg	1.870
2752	Sum	3.000

2753

- 2754 1. Si and P to *Z* to a maximum of 3 apfu, overflow of Si to *Y*
- 2755 2. Ca and Na to *X*
- 2756 3. Ti<sup>4+</sup>, Cr<sup>3+</sup>, Fe<sup>3+</sup> to *Y*
- 2757 4. Mg: First to *Y* to bring total to 2 apfu, then to *X*
- 2758 5. Fe<sup>2+</sup> to *X*
- 2759 6. Mn<sup>2+</sup> to *X*, which brings total to 3 apfu

2760

2761 Appendix Table 19. Dominant valences,  
 2762 constituents and percent of homovalent cations

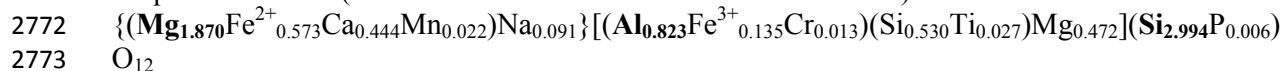
2763	Site	Valence	Constituent	%	Identification
------	------	---------	-------------	---	----------------

2764	Z	+4	Si	100	Garnet group
2765	Y	+3	Al	85	Pyrope
2766	X	+2	Mg	64	Pyrope

2767 Note: Because of valency-imposed double site-occupancy at Y,  
 2768  $R^{4+}Mg$  is considered as a unit, which is still subordinate to  $2R^{3+}$   
 2769 (Table 8).

2770

2771 Empirical formula (dominant cation for dominant valence in bold):



2774

2775 Appendix Table 20. Proportions of generalized components

2776 Component	Maximum	Proportion as	Group and type
2777	Proportion *	independent	
2778		variable <sup>#</sup>	
2779 $\{R^{1+}_3\}[R^{3+}_2](R^{5+}_3)O_{12}$	0.18%	0.18%	Berzeliite: $\{Na_3\}[Al_2](P_3)O_{12}$ -type
2780 $\{R^{2+}_2R^{1+}\}[R^{2+}_2](R^{5+}_3)O_{12}$	0.18%	—	Berzeliite-type
2781 $\{R^{2+}_2R^{2+}\}[R^{4+}_2](R^{4+}_3)O_{12}$	4.56%	4.28%	Garnet: $\{Na_2Ca\}[Ti_2](Si_3)O_{12}$ -type
2782 $\{R^{2+}_3\}[R^{3+}_2](R^{4+}_3)O_{12}$	48.55%	48.37%	Garnet: pyrope-type
2783 $\{R^{2+}_3\}[R^{4+}R^{2+}](R^{4+}_3)O_{12}$	47.16%	47.16%	Garnet: majorite-type
2784 Total	100.64%	100.00%	

2785 Note: \*From Appendix 4. Only four of these generalized components are independent.

2786 \*One of two sets of independent variables.

2787

2788 Comment: No matter which set of independent components is chosen, the generalized component,  
 2789  $\{R^{2+}_3\}[R^{3+}_2](Si_3)O_{12}$ , pyrope, is dominant.

2790 EXAMPLE 6. HOLOTYPE MORIMOTOITE, FUKA, OKAYAMA PREFECTURE, JAPAN (HENMI ET AL. 1995)

2791

2792 Appendix Table 21. Electron microprobe  
 2793 analysis with calculated  $Fe^{2+}/Fe^{3+}$  ratio

2794	Wt%		12 O
2795 $SiO_2$	26.93	Si	2.319
2796 $TiO_2$	18.51	Ti	1.199
2797 $ZrO_2$	1.48	Zr	0.062
2798 $Al_2O_3$	0.97	Al	0.098
2799 $Fe_2O_3$	11.44	$Fe^{3+}$	0.741
2800 $FeO$	7.77	$Fe^{2+}$	0.559
2801 $MnO$	0.23	Mn	0.017
2802 $MgO$	0.87	Mg	0.112
2803 $CaO$	31.35	Ca	2.893
2804 Sum	99.54	Sum	8.000

2805

2806 Appendix Table 22. Site Allocation

2807	Z	
2808 Si	2.319	
2809 Al	0.098	
2810 $Fe^{3+}$	0.583	
2811 Sum	3.000	
2812 Charge	11.319	
2813	Y	
2814 Ti	1.199	

2815	Zr	0.062
2816	Fe <sup>3+</sup>	0.158
2817	Mg	0.112
2818	Fe <sup>2+</sup>	0.469
2819	Sum	2.000
2820		X
2821	Fe <sup>2+</sup>	0.091
2822	Ca	2.893
2823	Mn	0.017
2824	Sum	3.000

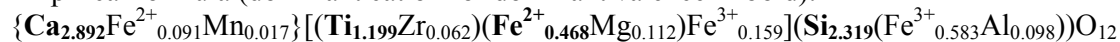
- 2825
- 2826 1. Si to Z
- 2827 2. Al to Z
- 2828 3. Fe<sup>3+</sup> to Z to bring total to 3 apfu, then Y
- 2829 4. Ca to X
- 2830 5. Ti<sup>4+</sup>, remaining Fe<sup>3+</sup>, and Zr to Y.
- 2831 6. Mg; to Y
- 2832 7. Fe<sup>2+</sup> First to Y to bring total to 2 apfu, then to X
- 2833 8. Mn<sup>2+</sup> to X, which brings total X to 3 apfu
- 2834

Appendix Table 23. Dominant valences, constituents and percent of homovalent cations

Site	Valence	Constituent	%	Identification	
2837					
2838	Z	+4	Si	100	Garnet group
2839	Y	+4	Ti	95	Morimotoite
2840	Y	+2	Fe	81	Morimotoite
2841	X	+2	Ca	96	Morimotoite

Note: Y is constrained to have two occupants because of valency-imposed double site-occupancy.

Empirical formula (dominant cation for dominant valence in bold):



Appendix Table 24. Maximum proportions of generalized components

Component	Proportion	Group	
2849			
2850	$\{R^{2+}_3\}[R^{4+}_2](R^{4+}R^{3+}_2)O_{12}$	34.05%	Schorlomite
2851	$\{R^{2+}_3\}[R^{3+}_2](R^{4+}_3)O_{12}$	7.93%	Garnet: andradite-type
2852	$\{R^{2+}_3\}[R^{4+}R^{2+}](R^{4+}_3)O_{12}$	58.01%	Garnet: morimotoite type
2853	Total	100.00%	

Note: The three generalized components are independent variables.

Comment: The empirical formula gives R<sup>4+</sup> the dominant valence at Z and Y, with R<sup>2+</sup> second at Y, but the identification is clear from Table 20, which gives {R<sup>2+</sup><sub>3</sub>}[R<sup>4+</sup>R<sup>2+</sup>](R<sup>4+</sup><sub>3</sub>)O<sub>12</sub>, morimotoite, as the dominant component.

#### Appendix 4. Description of the Excel spreadsheet

##### Purpose

2864 Appendix 4 is intended to determine the dominant species present from a chemical analysis of a  
2865 natural garnet. This appendix consists of an Excel spreadsheet that can accept up to 50 analyses at a  
2866 time, and yields for each analysis its group and species, as well as an empirical formula.

2867

#### 2868 **Input**

2869 The data from a chemical analysis are entered into the Data\_Report worksheet as oxides in  
2870 percent by weight, with the exception of fluorine, which is entered as the element in percent by  
2871 weight. Mathematical operations are undertaken on the linked Calculation worksheet; data should  
2872 not be input directly into this latter worksheet. The list of inputs for the Data\_Report worksheet in  
2873 percent by weight includes: SiO<sub>2</sub>, TiO<sub>2</sub>, ZrO<sub>2</sub>, SnO<sub>2</sub>, UO<sub>3</sub>, TeO<sub>3</sub>, Sb<sub>2</sub>O<sub>5</sub>, As<sub>2</sub>O<sub>5</sub>, V<sub>2</sub>O<sub>5</sub>, Nb<sub>2</sub>O<sub>5</sub>, P<sub>2</sub>O<sub>5</sub>,  
2874 Y<sub>2</sub>O<sub>3</sub> (include REE<sub>2</sub>O<sub>3</sub> as the equivalent proportion of Y<sub>2</sub>O<sub>3</sub> along with the measured Y<sub>2</sub>O<sub>3</sub> content),  
2875 Al<sub>2</sub>O<sub>3</sub>, Sc<sub>2</sub>O<sub>3</sub>, Cr<sub>2</sub>O<sub>3</sub>, V<sub>2</sub>O<sub>3</sub>, FeO, Fe<sub>2</sub>O<sub>3</sub> (but see below), ZnO, MnO, MgO, CaO, Na<sub>2</sub>O, Li<sub>2</sub>O, H<sub>2</sub>O<sup>+</sup>  
2876 (water of crystallization), and F. Any correction needed for the oxygen equivalence of fluorine is  
2877 calculated by the spreadsheet. The user must decide whether any vanadium content is expressed as  
2878 V<sub>2</sub>O<sub>3</sub> or V<sub>2</sub>O<sub>5</sub>.

2879 If the total iron content of the analysis is entered as FeO (wt.%), then the method of Droop  
2880 (1987) is used to calculate the proportions of Fe<sup>2+</sup> and Fe<sup>3+</sup> and Mn<sup>2+</sup> and Mn<sup>3+</sup> (this latter  
2881 constituent only in the absence of Fe<sup>2+</sup>) on the basis of 12 anions, where the anions are the sum of  
2882 O<sup>2-</sup>, (OH)<sup>-</sup>, and F<sup>-</sup>. If the user inputs some or all of the iron content as Fe<sub>2</sub>O<sub>3</sub> (wt.%), then this  
2883 calculation of Fe<sup>2+</sup> and Fe<sup>3+</sup>, and Mn<sup>2+</sup> and Mn<sup>3+</sup>, is not performed. In any case, the user should not  
2884 input Mn<sub>2</sub>O<sub>3</sub>, but rather allow the spreadsheet to calculate this quantity as necessary.

2885 The cation proportions are calculated on the basis of 12 anions, with charge-balance used (as  
2886 described above) to attempt to obtain a total of 8 non-H cations. The elements or valences B, S, K,  
2887 V<sup>2+</sup>, Ni, Ga, Ge, Sr, Ba, Pb, Th and U<sup>4+</sup> are not included in the spreadsheet.

2888 For analyses suspected to be of the tetragonal-symmetry minerals henritermierite or  
2889 holtstamite, the entry FALSE should be given in the cells that query “cubic? (true / false)”, whereas  
2890 for other hydrous garnets, TRUE should be entered. For convenience, the lower symmetry and  
2891 distinct structures of the tetragonal garnets are otherwise ignored in this spreadsheet.

2892

#### 2893 **Site allocation of cations**

2894 Appendix 4 allocates the cations to the three distinct structural sites using an inflexible set of  
2895 assumptions. It need hardly be stated that structural and/or spectroscopic data are preferable to  
2896 using such an algorithm, but such information is not commonly available for large data sets, in  
2897 contrast to the abundant chemical data obtained from electron microprobe analyses.

2898 The site allocation assumptions follow those of Table 3 of the manuscript. The priority of  
2899 filling each cation site is summarized here as follows:



2900  $Z > Y > X$ ;

2901  $Z = (\text{As}, \text{V}^{5+}, \text{P}, \text{Li}, \text{Zn}) > \text{Si} > \text{Al} > \text{Fe}^{3+} > \text{Fe}^{2+}, \text{Ti}$ ;

2902  $Y = (\text{Zr}, \text{Sn}, \text{U}, \text{Te}, \text{Sb}, \text{Nb}, \text{Sc}, \text{Cr}, \text{V}^{3+}) > (\text{Si}, \text{Ti}, \text{Al}, \text{Mn}^{3+}, \text{Fe}^{3+}) > \text{Mg} > \text{Fe}^{2+} > \text{Mn}$ ;

2903  $X = (\text{Y}, \text{Ca}, \text{Na}, \text{Mn}, \text{Fe}^{2+}) > \text{Mg}$ .

2904 As per the manuscript, hydrogen is incorporated via the “hydrogarnet substitution”:  $4\text{H} + \text{Z}\square$   
2905  $\rightarrow \square + \text{ZSi}$ , and tetrahedral vacancies are also assumed if fluorine is present in the absence of  
2906 corresponding quantities of lithium.

2907

### 2908 **Extended dominant-constituent rule**

2909 Hatert and Burke (2008) defined “the *rule of the dominant constituent*: a mineral is a distinct  
2910 species if the set of dominant constituents at the sites in the crystal structure is distinct from that of  
2911 any other mineral with the same structural arrangement.” Because of “cases of coupled  
2912 heterovalent–homovalent substitutions”, it was necessary for the rule to be “extended with the  
2913 dominant-valency rule by considering a group of atoms with the same valency state as a single  
2914 constituent.” And therefore, “the extension [of the dominant-constituent rule] with the dominant-  
2915 valency rule is necessary to establish charge-balanced end-member formulae for solid-solution  
2916 series with complex mechanisms of substitution” (Hatert and Burke 2008).

2917 In the garnet supergroup, in which the approved species (manuscript Table 1) are formulated as  
2918 end-members, following Hawthorne (2002), the effect of the *extended dominant-constituent rule* is  
2919 to arrange the end-members into general charge-balanced formulae. This is reflected in the  
2920 classification of the approved species, in which the end-members are classified into groups by the  
2921 effective charge of the Z site.

2922 The spreadsheet determines group and species in accord with the extended dominant-  
2923 constituent rule. For each cation site, the spreadsheet sums the homovalent cations that occupy that  
2924 site. For example, for the X site,  $\text{Ca} + \text{Mg} + \text{Mn} + \text{Fe}$  yields the sum of the divalent ions, the sodium  
2925 content gives the value for monovalent ions, and yttrium yields the value for trivalent ions. From  
2926 the proportions of the dominant valences, the maximum content of each type of charge-balanced  
2927 end-member formula is then calculated. These maxima are calculated separately from each other.  
2928 However, in several cases, the proportions of different end-member formulae may be limited by the  
2929 same minimum quantity of a valence state, e.g.,  $\text{Na}^+$ , present in the analysis. In such cases, the  
2930 maximum contents of the end-member formulae are not independent, and their sum will therefore  
2931 exceed 100%.

2932 Having found the most abundant charge-balanced formula, the group to which it belongs is  
2933 assigned (manuscript Table 1). From the assignment of the group, and from the site allocations of  
2934 the cations, the principal cations that occupy the charge-balanced formula of that group are

2935 determined, and thus the dominant species is assigned. A set of hypothetical end-members is  
2936 included in the calculations of the spreadsheet to assist in the rare cases in which an approved  
2937 species is not found for an analysis.

2938

### 2939 **Results and empirical formula**

2940 From the allocation of the cations, and the anions determined from the chemical analysis, a  
2941 preliminary empirical formula is given, with the quantities rounded to a maximum of three decimal  
2942 places. The constituents of the empirical formula are ordered by atomic site, and organized in each  
2943 site by decreasing abundance. The results, including group, dominant species, and empirical  
2944 formula, are given below each corresponding original analysis on the Data\_Report worksheet.

2945 Because of the limitations of text formats for calculated cells in Excel, the cations  $\text{Fe}^{2+}$  and  $\text{Fe}^{3+}$   
2946 are given respectively as Feii and FeIII in the *Y* and/or *Z* sites of an empirical formula. Similarly,  
2947  $\text{Mn}^{2+}$  and  $\text{Mn}^{3+}$  are reported on the *Y* site of an empirical formula as Mnii and MnIII. In contrast,  
2948 cations whose occurrence is restricted to a given site, e.g.,  $\text{V}^{3+}$  on the *Y* site, are expressed without  
2949 any charge designation, as there should be no ambiguity as to their identities. Cation vacancies on  
2950 the *Z* site are not shown explicitly in the formulae yielded by the Excel spreadsheet, but are  
2951 established by difference from the ideal proportions, and from the presence of F and/or OH.



Figure 1

Garnet  
(001) slice

Atomic sites

Brown - X

Green - Y

Blue - Z

Red -  $\phi$

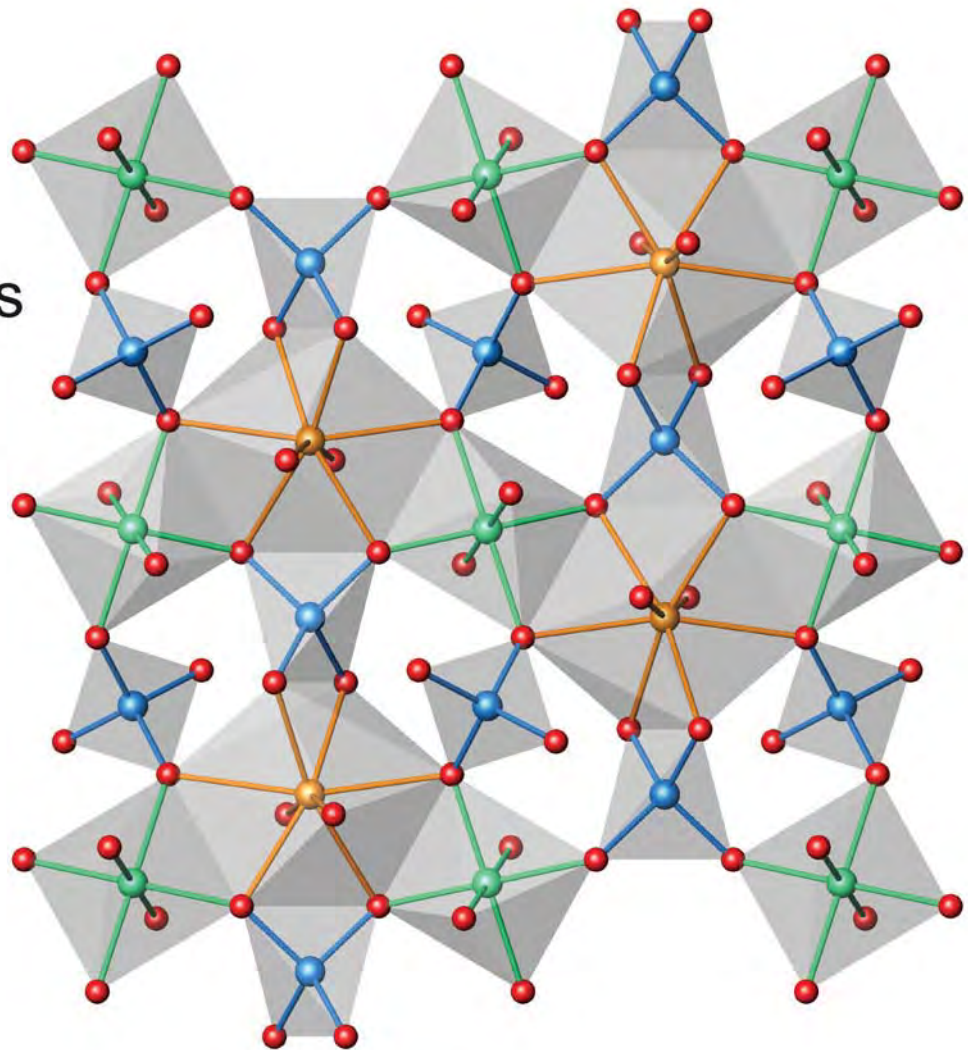
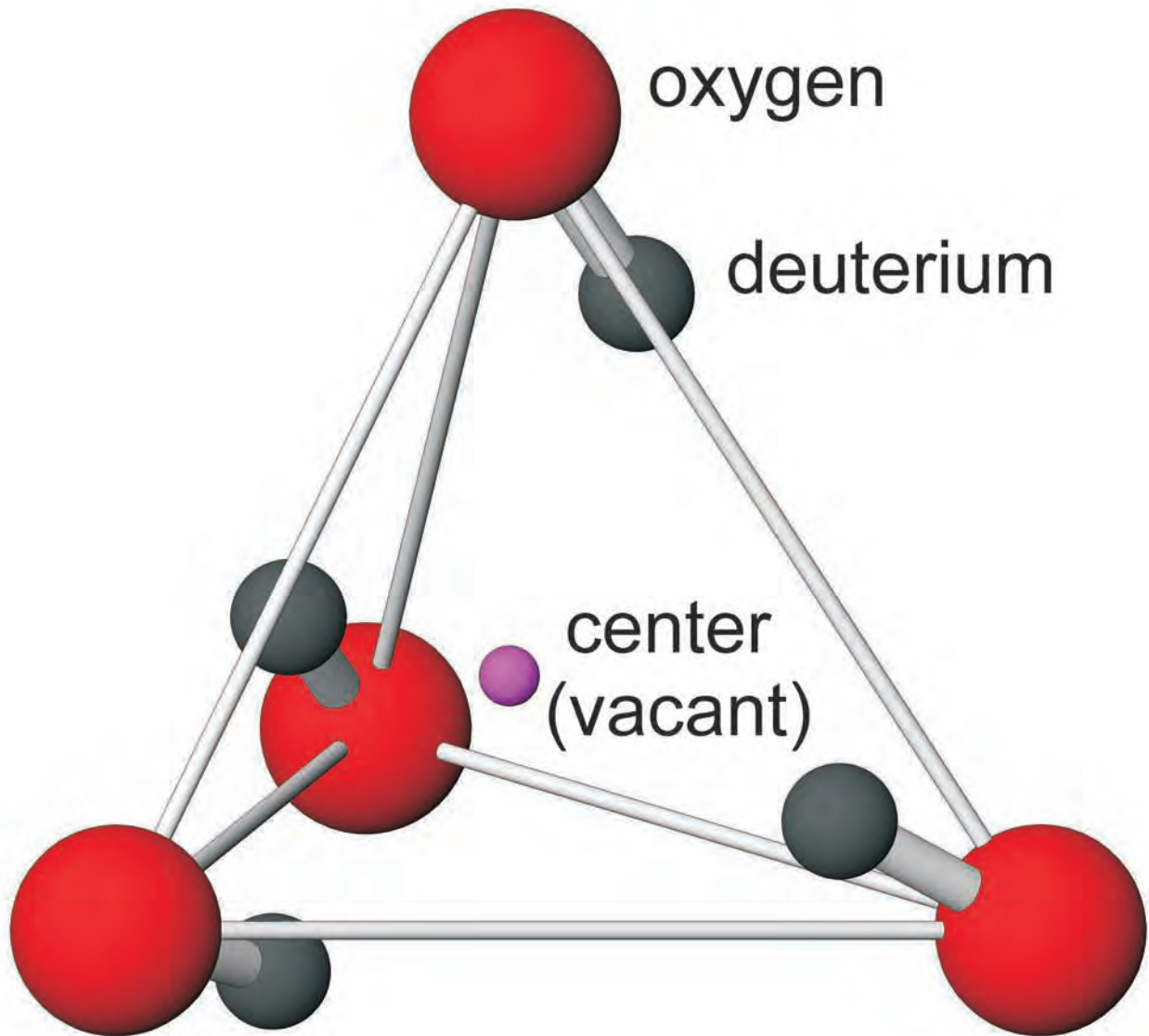


Figure 2



oxygen

deuterium

center  
(vacant)

**U-rich garnets, Upper Chegem caldera, Northern Caucasus, Russia**

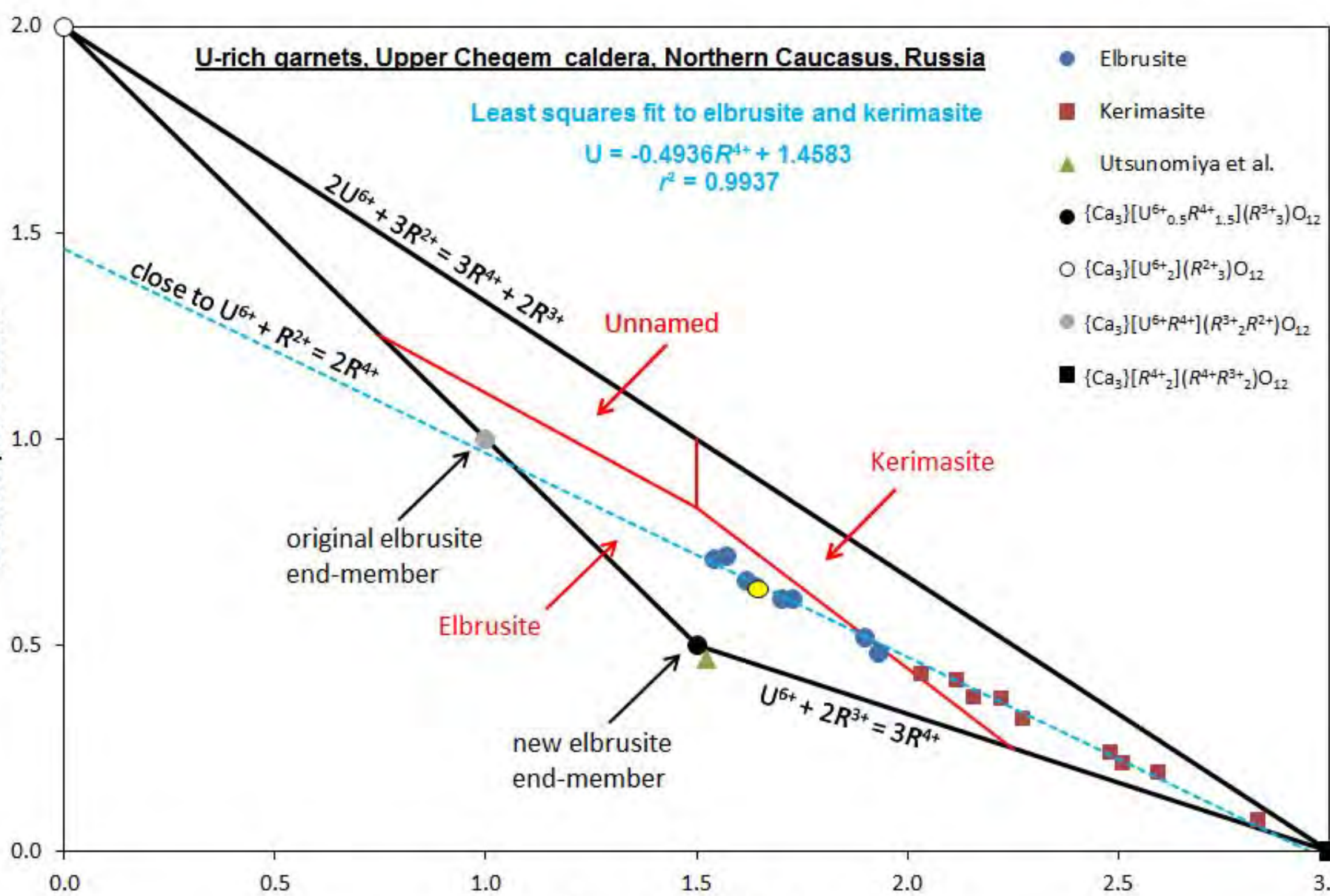
Least squares fit to elbrusite and kerimasite

$$U = -0.4936R^{4+} + 1.4583$$

$$r^2 = 0.9937$$

- Elbrusite
- Kerimasite
- ▲ Utsunomiya et al.
- $\{Ca_3\}[U^{5+}_{0.5}R^{4+}_{1.5}](R^{3+}_3)O_{12}$
- $\{Ca_3\}[U^{6+}_2](R^{2+}_3)O_{12}$
- $\{Ca_3\}[U^{5+}R^{4+}](R^{3+}_2R^{2+})O_{12}$
- $\{Ca_3\}[R^{4+}_2](R^{4+}R^{3+}_2)O_{12}$

Uranium per 8 cations



Sum  $R^{4+}$  per 8 cations

close to  $U^{6+} + R^{2+} = 2R^{4+}$

$2U^{6+} + 3R^{2+} = 3R^{4+} + 2R^{3+}$

$U^{6+} + 2R^{3+} = 3R^{4+}$

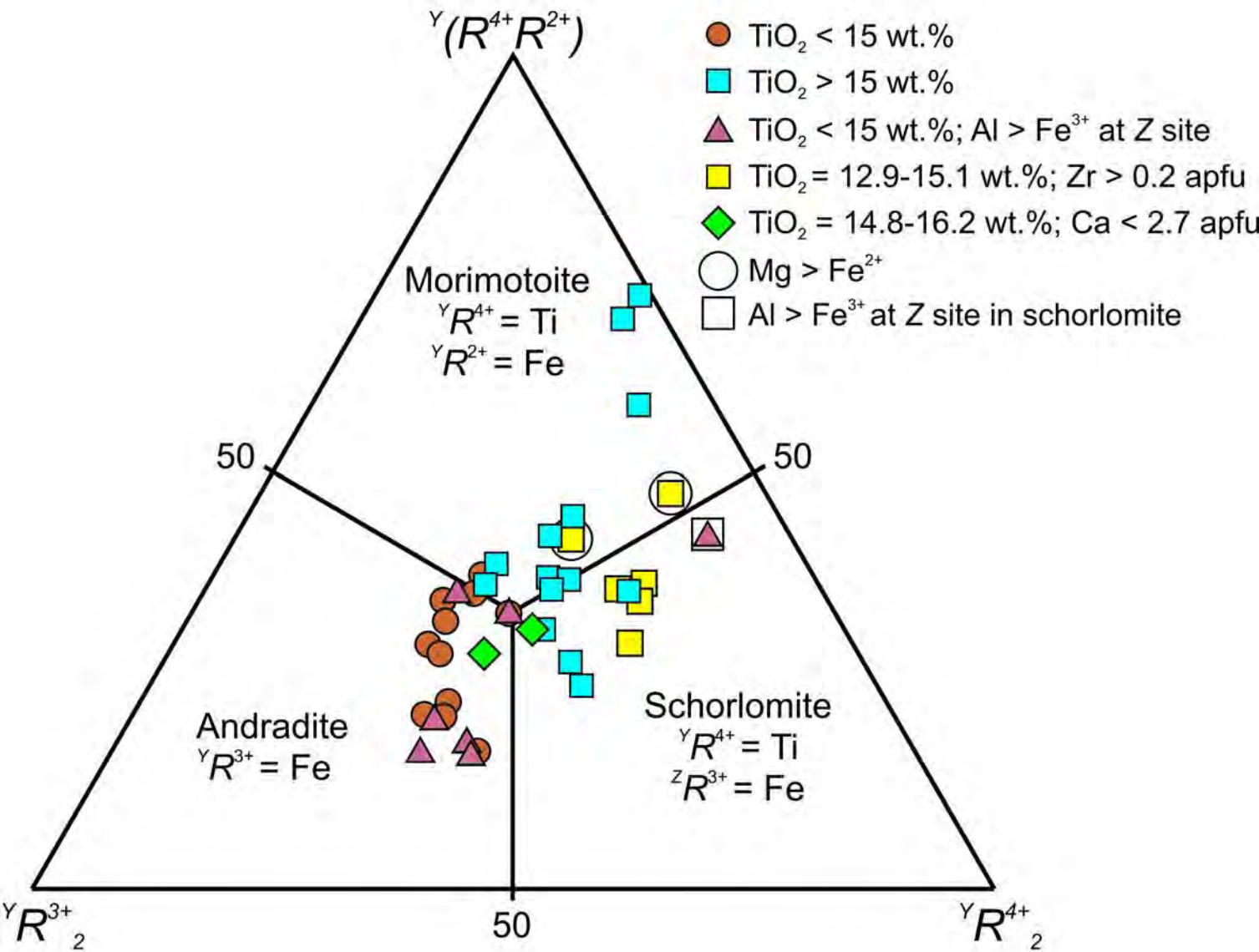
original elbrusite end-member

new elbrusite end-member

Unnamed

Kerimasite

Elbrusite







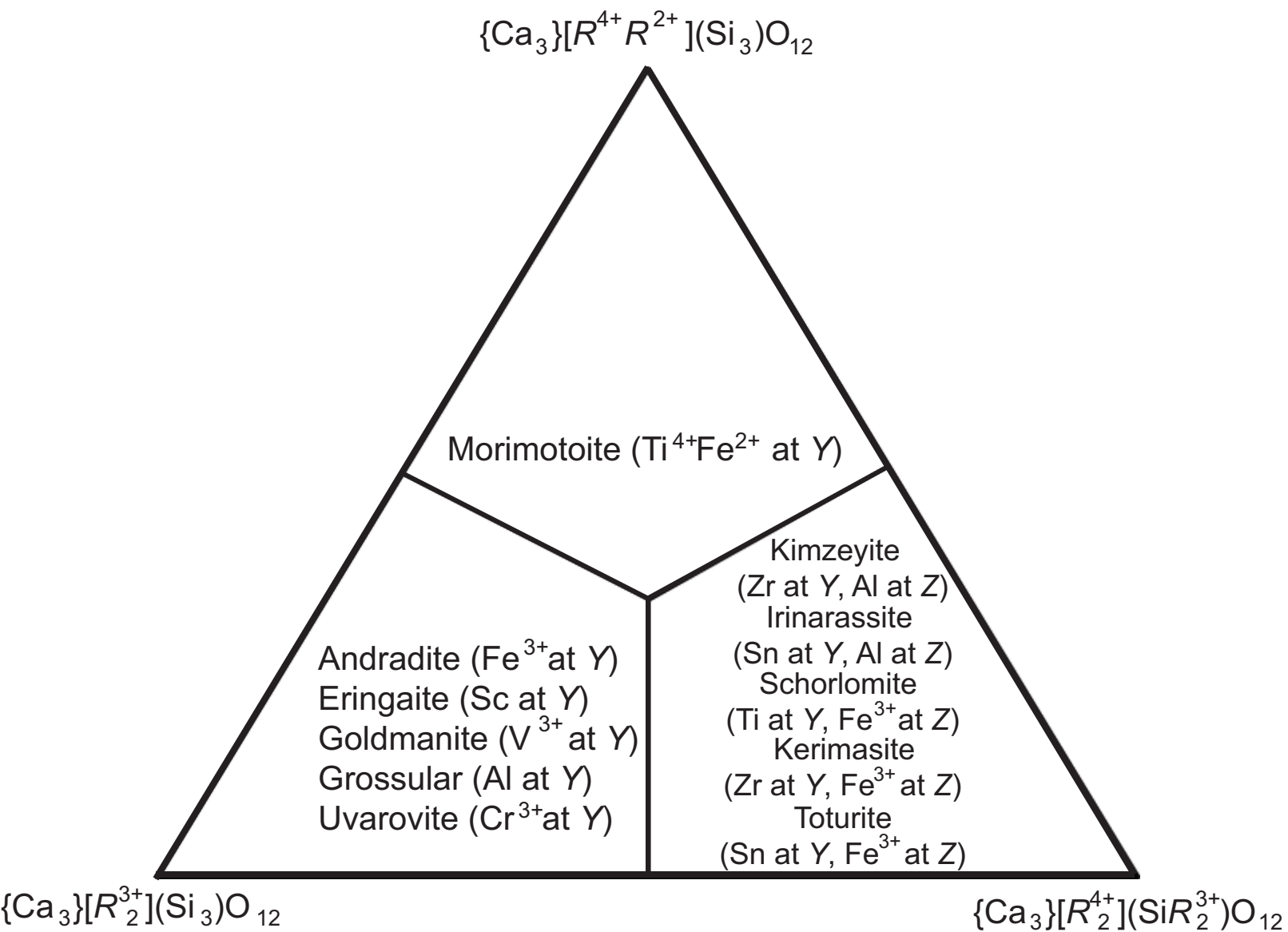


Figure 7

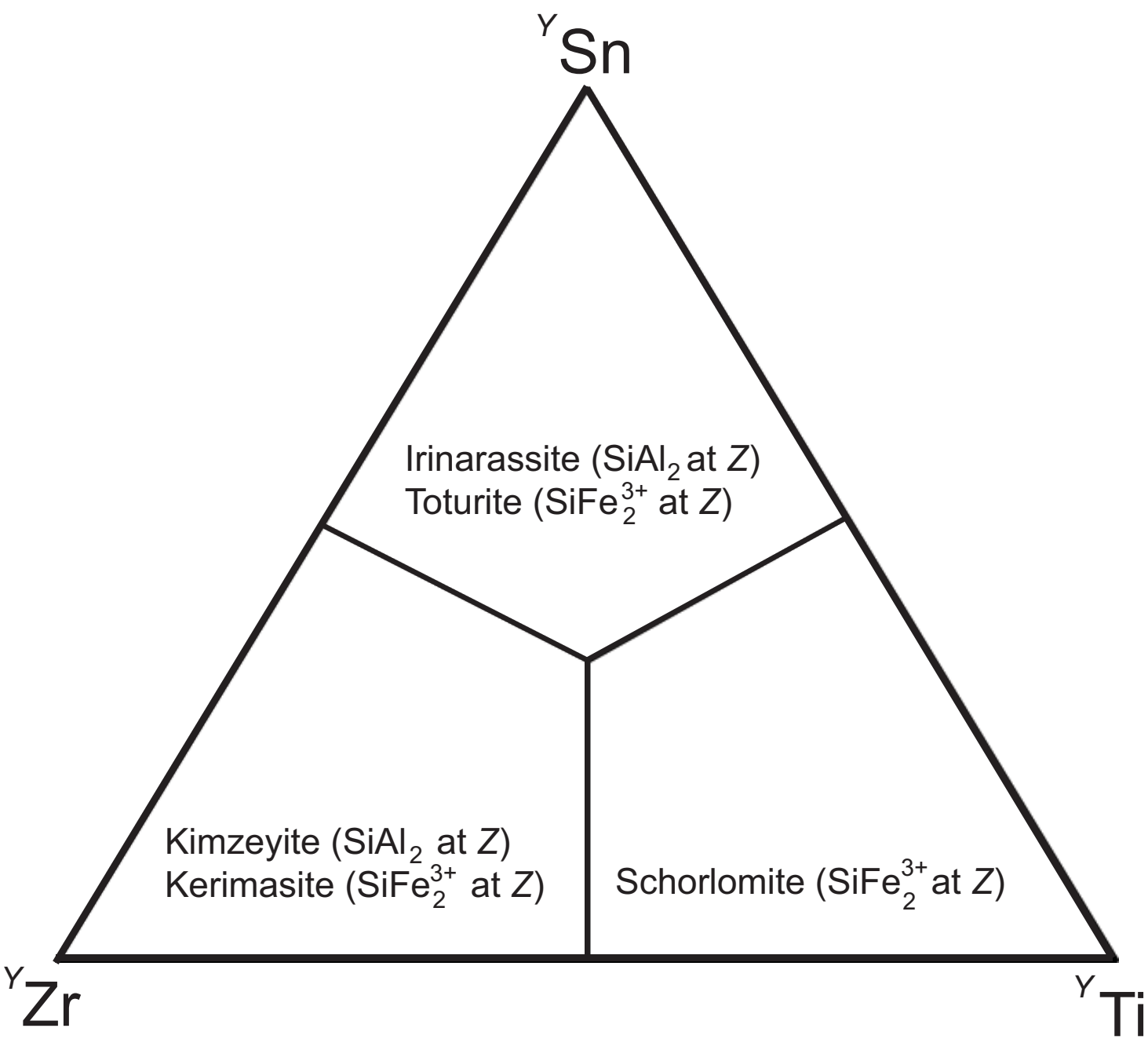


Figure 8

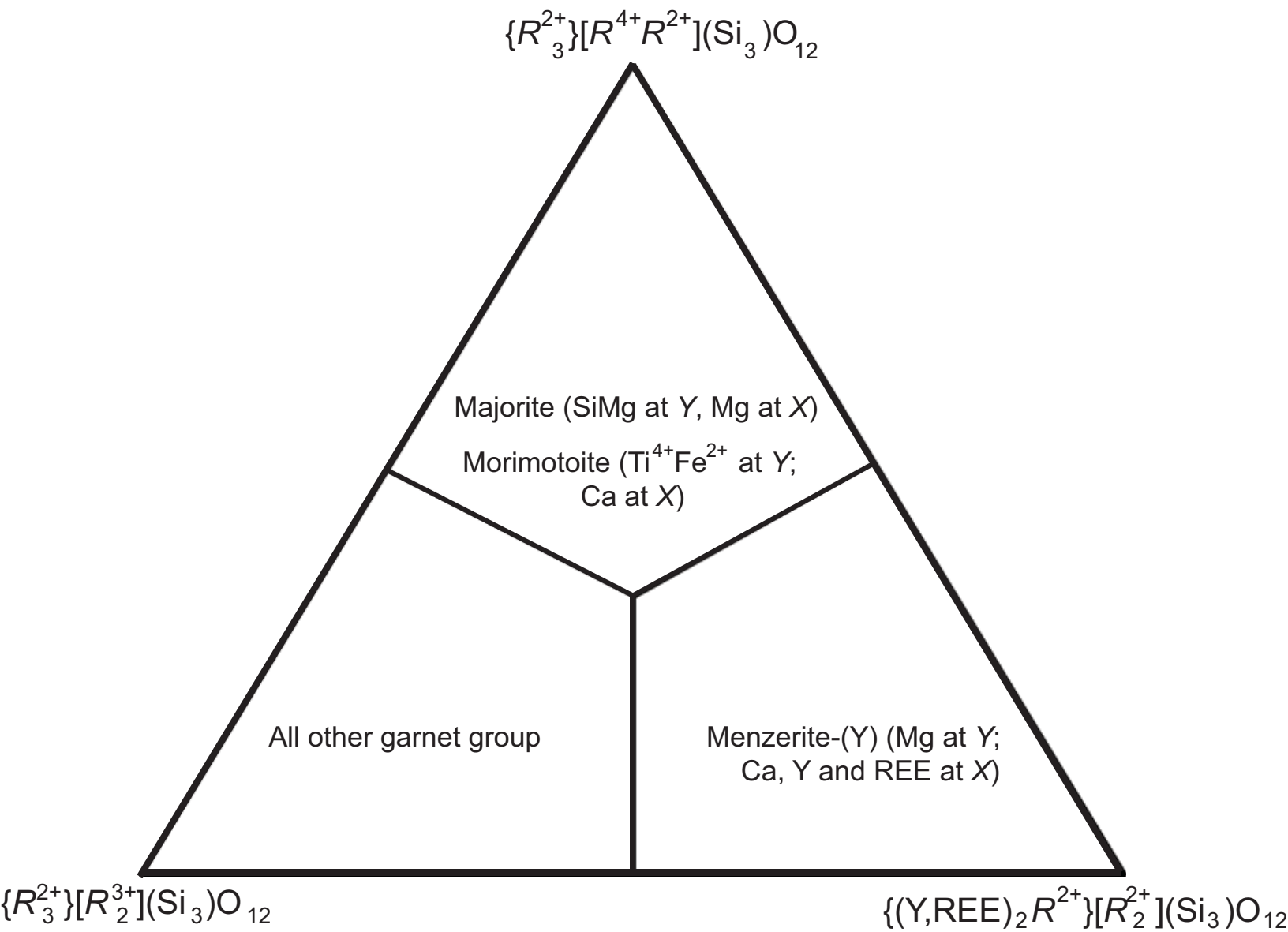


Figure 9

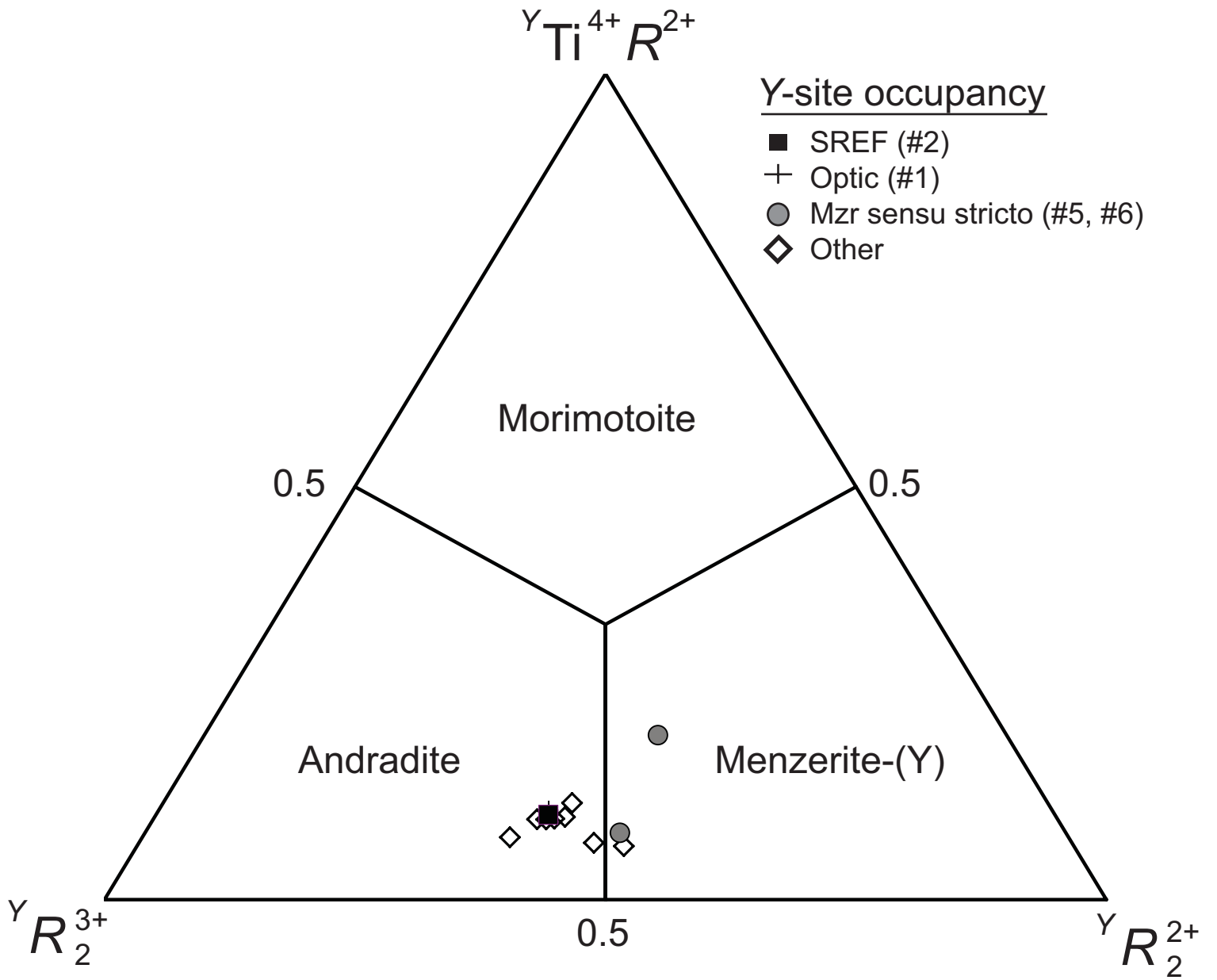


Figure 10

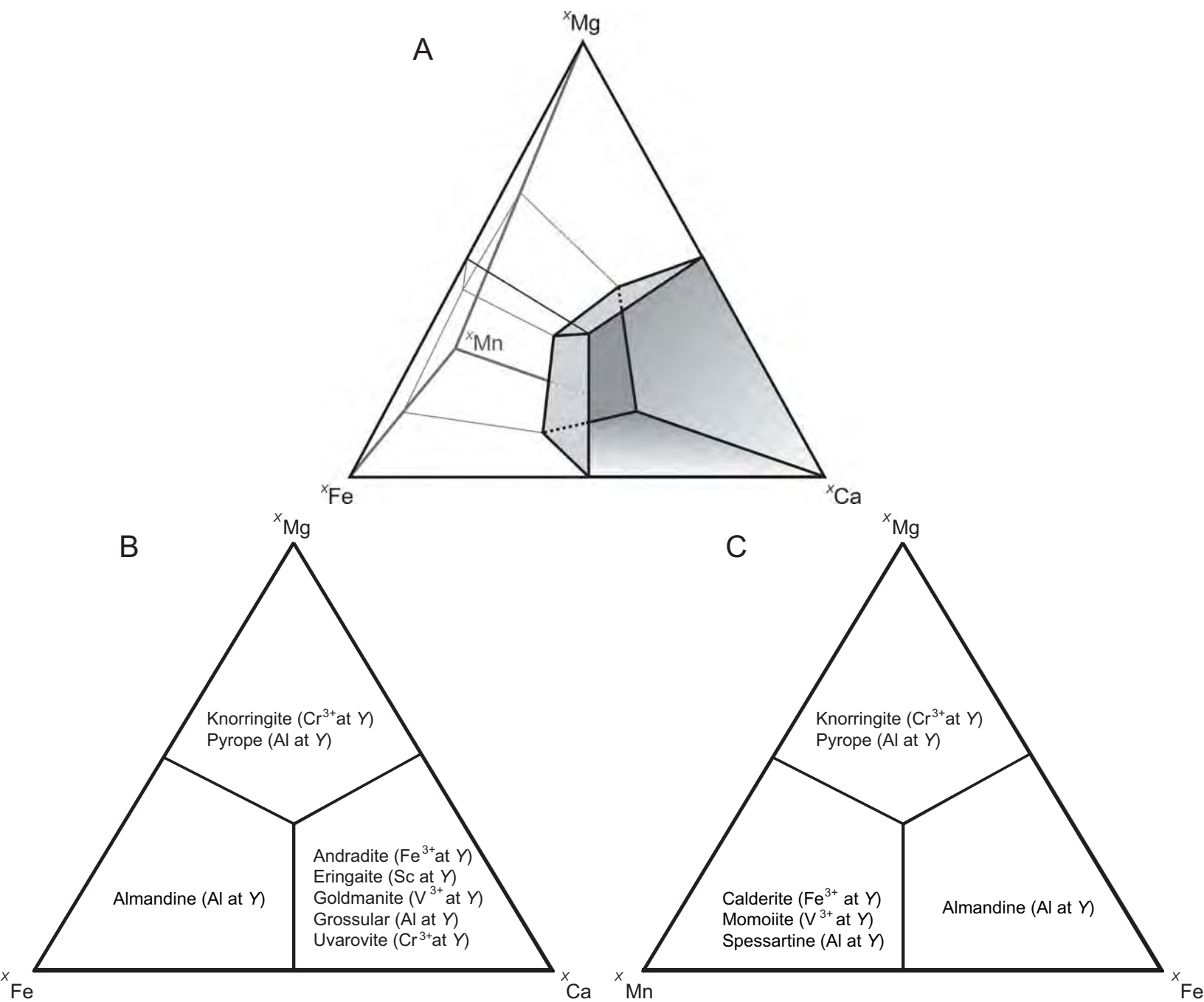


Figure 11