

**NOMENCLATURE OF AMPHIBOLES: ADDITIONS AND REVISIONS TO THE
INTERNATIONAL MINERALOGICAL ASSOCIATION'S 1997 RECOMMENDATIONS**

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ABSTRACT

The introduction of a fifth group of amphiboles, the Na–Ca–Mg–Fe–Mn–Li group, defined by $0.50 < {}^B(\text{Mg,Fe}^{2+},\text{Mn}^{2+},\text{Li}) < 1.50$ and $0.50 \leq {}^B(\text{Ca,Na}) \leq 1.50$ atoms per formula unit, with members whittakerite and ottoliniite, has been required by recent discoveries of ${}^B(\text{Li,Na})$ amphiboles. These, and other new discoveries, such as sodicpedrizite (which is herein slightly, but significantly, changed from the original idealized formula), necessitate amendments to the IMA 1997 definitions of the Mg–Fe–Mn–Li, calcic, sodic-calcic and sodic groups. The discovery of obertiite and the finding of an incompatibility in the IMA 1997 subdivision of the sodic group require further amendments within the sodic group. All these changes, which have IMA approval, are summarized.

Keywords: amphibole nomenclature, whittakerite, ottoliniite, sodicpedrizite.

SOMMAIRE

L'introduction d'un cinquième groupe d'amphiboles, appelé le groupe Na–Ca–Mg–Fe–Mn–Li, défini selon les critères $0.50 < {}^B(\text{Mg,Fe}^{2+},\text{Mn}^{2+},\text{Li}) < 1.50$ et $0.50 \leq {}^B(\text{Ca,Na}) \leq 1.50$ atomes par unité formulaire, que satisfont les membres whittakerite et ottoliniite, a été provoquée par la découverte récente d'amphiboles à ${}^B(\text{Li,Na})$. Cette découverte, ainsi que d'autres faites récemment, par exemple la sodicpedrizite (dont la formule idéale est ici modifiée de façon importante), nécessitent des changements aux définitions des groupes Mg–Fe–Mn–Li, calcique, sodique-calcique et calcique entérinées dans le rapport IMA 1997. La découverte de l'obertiite et la présence d'une incompatibilité dans la subdivision du groupe des amphiboles sodiques dans le rapport de 1997 ont mené à des changements additionnels au sein de ce groupe. Tous ces changements ont l'approbation de l'IMA et sont résumés ici.

(Traduit par la Rédaction)

Mots-clés: nomenclature des amphiboles, whittakerite, ottoliniite, sodicpedrizite.

INTRODUCTION

After 13 years of conferring, the Subcommittee on Amphiboles of the International Mineralogical Association's Commission on New Minerals and Mineral Names (IMA CNMNMN) first published a standard, internationally agreed upon nomenclature of amphiboles in 1978 (IMA78; Leake 1978). After nine years of further work, the current scheme was agreed upon and published in 1997 (IMA97; Leake *et al.* 1997). This scheme retained the same four major groups of amphibole and classification parameters as in the 1978 scheme. Since 1997, several new amphibole root-names have been approved by IMA, including various Li-rich amphiboles, some of which (*e.g.*, ferriwhittakerite) have made it necessary to institute a new (fifth) group of amphiboles and to slightly revise the definitions of the previous four groups as formulated in IMA97. In addition, application of IMA97 to several thousand analyzed natural amphiboles has shown the need to slightly revise the parameters used to subdivide the sodic amphiboles (Mogessie *et al.* 2001). In this account, we summarize the IMA-approved additions and revisions to IMA97, but we do not repeat the main unchanged parts of IMA97, so this paper needs to be read in conjunction with IMA97.

GENERAL CLASSIFICATION OF THE AMPHIBOLES

The standard amphibole formula $A_{0-1} B_2 C_5 T_8 O_{22} (\text{OH})_2$ remains unchanged, but the order of allocation

of the cations has become even more critical than previously. In addition, some of the cations not considered in IMA97 have since been found to occur occasionally in amphiboles, and so a new list follows; the full explanation of the allocation procedure is given in IMA97:

(1) Sum *T* to 8.00 atoms per formula unit (*apfu*) using Si, then Al, then Ti.

(2) Sum *C* to 5.00 *apfu* using any excess Al and Ti from (1) and then successively Fe^{3+} , V, Cr, Mn^{3+} , Zr, Mg, Zn, Ni, Co, Fe^{2+} , Mn^{2+} , and Li.

(3) Sum *B* to 2.00 *apfu* using first any excess above 5.00 *apfu* from *C*, in the reverse order of (2), starting with Li and then Mn^{2+} , *etc.*, and then follow with Ca, Sr, Ba and Na.

(4) Any excess above 2.00 *apfu* in *B* is assigned to *A* in the reverse order of (3), starting with Na and then finally all the K is allocated to *A*.

Until recently, the amount of Li was only rarely determined in amphiboles, and all Li-rich varieties known belonged either to the orthorhombic holmquistite or the monoclinic clinoholmquistite series [\square Li₂ (Mg₃Al₂) Si₈ O₂₂ (OH)₂], being part of the Mg–Fe–Mn–Li group, or they were in the sodic amphibole group, being attributed to leakeite [$\text{Na Na}_2 (\text{LiMg}_2\text{Fe}^{3+}_2) \text{Si}_8 \text{O}_{22} (\text{OH})_2$] or kornite [(NaK) Na₂ (LiMg₂Mn³⁺₂) Si₈ O₂₂ (OH)₂] species. Other, less Li-rich Li-bearing amphiboles (Li > 0.25 *apfu* in the standard formula) were denoted by the optional modifier *lithian*, preceding a species name, which was determined by the rules formulating and subdividing the four amphibole groups. With the introduction of ion probes, the determination of Li concentration,

which electron microprobes cannot do, is now possible. Consequently, Li-rich amphiboles of a new type have been discovered which cannot be accommodated satisfactorily in the IMA97 classification, as they fall between the existing groups.

The 1997 scheme divided the amphiboles into the following four groups depending on the occupancy of the *B* sites as calculated arithmetically, *i.e.*, there is no consideration of where ions really are because for most amphibole samples, this is unknown, as structural studies are rare; however, the arithmetic approach places ions at their most likely sites.

1. The Mg–Fe–Mn–Li group, defined as $B(\text{Ca} + \text{Na}) < 1.00$ and $B(\text{Mg}, \text{Fe}^{2+}, \text{Mn}^{2+}, \text{Li}) \geq 1.00$ *apfu*.
2. The calcic group, with $B(\text{Ca} + \text{Na}) \geq 1.00$ and $B\text{Na} < 0.50$ *apfu*.
3. The sodic-calcic group, with $B(\text{Ca} + \text{Na}) \geq 1.00$, and $0.50 \leq B\text{Na} < 1.50$ *apfu*.
4. The sodic group, with $B\text{Na} \geq 1.50$ *apfu*.

At that time, nearly all known members of Group 1 had $B(\text{Mg}, \text{Fe}^{2+}, \text{Mn}^{2+}, \text{Li}) > 1.50$ *apfu*, and the calcic and sodic-calcic members had $(\text{Ca} + \text{Na}) > 1.50$ *apfu*. This subdivision led to the implicit assumption that the *B* sites of Group 1 contain only a small minority of Ca + Na ions, and that there is only a small minority of (Mg + Fe + Mn + Li) ions at the *B* sites of the remaining groups.

The discovery of more or less continuous ranges of compositions, involving Li-rich amphiboles, between the Mg–Fe–Mn–Li group on the one hand and the calcic, sodic-calcic and sodic groups on the other, makes nonsense of the above limits. Thus an amphibole with $B(\text{Na}_{1.01}\text{Li}_{0.99})$ falls in the sodic-calcic group, although it contains no Ca, and one with $B(\text{Ca}_{0.52}\text{Na}_{0.49}\text{Li}_{0.99})$ is classified into the calcic group, although Ca is not its dominant *B* cation. If the unchanged IMA97 rules were to be applied to the recently discovered ferriwhittakerite, ideally Na (NaLi) (LiMg₂Fe³⁺)₂ Si₈O₂₂ (OH)₂ (Oberti *et al.* 2004), it would sit exactly on the boundary between the Mg–Fe–Mn–Li group and the sodic-calcic group; such an amphibole with Li > 1.00 *apfu* would fall into the first group, but if Li is less than 1.00 *apfu*, it would belong to the second. This sort of naming was explicitly avoided in IMA97. Consequently, the IMA97 definitions need to be modified to take into account the complete solid-solution between Li and Na at *B* sites (Oberti *et al.* 2003a). New definitions of the amphibole groups follow.

Group 1. Where the sum of the L-type ions $B(\text{Mg}, \text{Fe}, \text{Mn}, \text{Li}) \geq 1.50$ *apfu*, then the amphibole is a member of the magnesium – iron – manganese – lithium group. (The L-type ions are divalent Mg, Fe, Mn, Zn, Ni, Co, *etc.*, and Li, as described in IMA97.)

Group 2. Where $B(\text{Mg}, \text{Fe}^{2+}, \text{Mn}^{2+}, \text{Li}) \leq 0.50$, $B(\text{Ca}, \text{Na}) \geq 1.00$ and $B\text{Na} < 0.50$ *apfu*, then the amphibole is a member of the calcic group.

Group 3. Where $B(\text{Mg}, \text{Fe}^{2+}, \text{Mn}^{2+}, \text{Li}) \leq 0.50$, $B(\text{Ca}, \text{Na}) \geq 1.00$, and $0.50 \leq B\text{Na} < 1.50$ *apfu*, then the amphibole is a member of the sodic-calcic group.

Group 4. Where $B(\text{Mg}, \text{Fe}^{2+}, \text{Mn}^{2+}, \text{Li}) \leq 0.50$, and $B\text{Na} \geq 1.50$ *apfu*, then the amphibole is a member of the sodic group.

Group 5. A new amphibole group is here defined. Where $0.50 < B(\text{Mg}, \text{Fe}^{2+}, \text{Mn}^{2+}, \text{Li}) < 1.50$ and $0.50 \leq B(\text{Ca}, \text{Na}) \leq 1.50$ *apfu*, then the amphibole is a member of the sodium – calcium – magnesium – iron – manganese – lithium group. This cumbersome title is clearer than any alternative and may be referred to as “Group 5”. The definitions of the prefixes and modifiers given in IMA97 that are stated to apply to all groups apply to the new group, with the addition that the prefix *alumno*, where ${}^{\text{C}}\text{Al} > 1.00$ *apfu* (but not = 1.00 *apfu*), also applies.

APPLICATIONS OF THE REVISED NOMENCLATURE

In general, no change is made to the nomenclature of any composition defined as a species in IMA97, but there are regrettable changes to some more recently described species, mainly because a special adjustment was initially approved to the IMA97 use of the prefix “sodic” in Group 1 in an attempt to avoid instituting a fifth group of amphiboles. Later, however, as still more Li-rich amphiboles were discovered, the recognition of a Group 5 became unavoidable, and the use of sodic in Group 1 reverted to its IMA97 meaning of total Na > 0.50 *apfu*. The IMA rule forbidding validity of root names until they have been found in Nature, when combined with the short time to respond to proposals for new species, renders difficult any coherent systematic approach to a series of closely related species, proposed over several years. Ideally, one should wait a few years until the range of variation becomes apparent.

Group 1, the Mg–Fe–Mn–Li amphiboles

Holmquistite and clinoholmquistite, $\square \text{Li}_2 (\text{Mg}_3\text{Al}_2) \text{Si}_8 \text{O}_{22} (\text{OH})_2$, have $B\text{Li} \geq 1.00$ *apfu*, but no significant ${}^{\text{C}}\text{Li}$. The discovery of sodic-ferripedrizite, ${}^{\text{A}}\text{Na} {}^{\text{B}}\text{Li}_2 {}^{\text{C}}(\text{LiMg}_2\text{Fe}^{3+}) \text{Si}_8 \text{O}_{22} (\text{OH})_2$ (Oberti *et al.* 2000, Caballero *et al.* 2002), and the equivalent sodic-ferri-ferropedrizite (Oberti *et al.* 2003b) species, in which it is critical to have ${}^{\text{C}}\text{Li} \geq 0.50$ *apfu* to distinguish them from holmquistite and clinoholmquistite, justify the following names:

Sodicpedrizite $\text{Na Li}_2 (\text{LiMg}_2\text{Fe}^{3+}\text{Al}) \text{Si}_8 \text{O}_{22} (\text{OH})_2$

“Sodic-ferropedrizite” $\text{Na Li}_2 (\text{LiFe}^{2+}_2\text{Fe}^{3+}\text{Al}) \text{Si}_8 \text{O}_{22} (\text{OH})_2$.

The prefix *sodic* is derived from the IMA97 rules for the use of prefixes, in which *sodic* applies in Group 1 only, and then only to samples with total Na > 0.50 *apfu*. Those with total Na ≤ 0.50 *apfu* are pedrizite unless K > 0.50 *apfu*, which would be “potassicpedrizite”. Likewise, the prefix *ferri* for $\text{Fe}^{3+} > 1.00$ *apfu* (not =

1.00), applies to all groups except the sodic amphiboles. All the prefix rules listed in IMA97 remain unchanged. It is recognized that a few samples that only marginally fell into the IMA97 Group 1 may now belong to Group 5. The revised classification is shown in Figure 1. The only substantive change is to Li-rich amphiboles.

Group 2, the calcic amphiboles

There are no changes, or additions, of names in this group. Application of the prefix *parvo*, as described below, necessitates overriding the new ${}^B(\text{Mg,Fe}^{2+}, \text{Mn}^{2+}, \text{Li}) \leq 0.50$ *apfu* rule.

Group 3, the sodic-calcic amphiboles

Again, there are no changes or additions in this group, and the same provision applies to the use of *parvo* as in the calcic amphiboles.

Group 4, the sodic amphiboles

There are no changes deriving from the introduction of Group 5 except for the use of *parvo* as in the previous groups. However, since IMA97 was published (Leake *et al.* 1997), extensive tests have been carried out on published compositions of amphibole to see how robust is the nomenclature, especially with respect to compositions marginal in the four groups. Mogessie *et al.* (2001) calculated the names of over 500 analyzed amphiboles of all types as listed in Deer *et al.* (1997). They found about four compositions of sodic amphibole that could not be classified; although these were clearly sodic amphiboles, they did not fall into any of the nomenclature diagrams for such amphiboles. Consequently, two amendments were made to avoid this situation. First, the oxidation state of Mn, which is rarely known, is made much less crucial than in IMA97 by grouping $\text{Mn}^{2+} + \text{Mn}^{3+}$ together for the initial classification, although Mn^{3+} contents are still required to distinguish kornite from leakeite. Secondly, the classification parameter $(\text{Mg} + \text{Fe}^{2+} + \text{Mn}^{2+}) < \text{or} > 2.5$ *apfu* is completely discarded, as it conflicts with other conditions. The result of these changes gives a new nomenclature diagram for sodic amphiboles (Fig. 2).

In addition, the new anhydrous sodic species obertiite $\text{Na Na}_2 (\text{Mg}_3\text{Fe}^{3+}\text{Ti}) \text{Si}_8 \text{O}_{22} \text{O}_2$, which is characterized by $\text{Ti} > 0.50$ and $(\text{OH} + \text{F} + \text{Cl}) < 1.00$ *apfu*, has recently been described by Hawthorne *et al.* (2000). As this can be derived from magnesio-arfvedsonite by substitution of Ti and O for Mg and (OH), it appears in the same box as magnesio-arfvedsonite in the Group-4 nomenclature diagram. As $\text{Ti} > 0.50$ *apfu* is an essential aspect of the root name, the prefix *titano* is not used, nor is the modifier *oxygenian*, because $(\text{OH} + \text{F} + \text{Cl})$ is less than 1.00 *apfu* by definition.

Group 5, the Na–Ca–Mg–Fe–Mn–Li amphiboles, where ${}^B\text{Li} > 0.50$ apfu

The members of this new group that have ${}^B\text{Li} > 0.50$ *apfu* derive from the discovery by Oberti *et al.* (2004) of ferriwhittakerite, ${}^A\text{Na}{}^B(\text{NaLi}){}^C(\text{LiMg}_2\text{Fe}^{3+}_2)\text{Si}_8\text{O}_{22}(\text{OH})_2$, with $A \geq 0.50$ *apfu*, and of ferri-ottoliniite, ${}^A\Box{}^B(\text{NaLi}){}^C(\text{Mg}_3\text{Fe}^{3+}_2)\text{Si}_8\text{O}_{22}(\text{OH})_2$, with $A < 0.50$ *apfu*. Both must have ${}^B\text{Li} > 0.50$ *apfu*. Usually, there is also significant ${}^C\text{Li}$. The classification is shown in Figure 3, and the end-member compositions are listed below.

Whittakerite $\text{Na}(\text{NaLi})(\text{LiMg}_2\text{Fe}^{3+}\text{Al})\text{Si}_8\text{O}_{22}(\text{OH})_2$ and

“Ferrowhittakerite” $\text{Na}(\text{NaLi})(\text{LiFe}^{2+}_2\text{Fe}^{3+}\text{Al})\text{Si}_8\text{O}_{22}(\text{OH})_2$

Ottoliniite $\Box(\text{NaLi})(\text{Mg}_3\text{Fe}^{3+}\text{Al})\text{Si}_8\text{O}_{22}(\text{OH})_2$ and

“Ferro-ottoliniite” $\Box(\text{NaLi})(\text{Fe}^{2+}_3\text{Fe}^{3+}\text{Al})\text{Si}_8\text{O}_{22}(\text{OH})_2$.

All the prefixes and modifiers listed and defined in IMA97 apply in the new group, and use of the prefix *alumno* for ${}^C\text{Al} > 1.00$ *apfu* is extended to this group. In accordance with IMA97, the modifier *lithian* is not used in species defined by the presence of Li.

Group 5, the Na–Ca–Mg–Fe–Mn–Li amphiboles, where ${}^B\text{Li} \leq 0.50$ apfu

It is well known that in the calcic and sodic-calcic groups, it is usual for the total of the cations initially allocated to *C* to exceed the limit of 5.00 *apfu*, and the excess of the larger ions to overflow into *B*. This situation is particularly common where “cummingtonite solid-solution” in calcic amphiboles occurs. Occasionally, the total $(\text{Mg} + \text{Fe}^{2+} + \text{Mn}^{2+} + \text{Li})$ at *B* slightly exceeds 0.50 *apfu*, although ${}^B\text{Li}$ is less than 0.50 *apfu*. This case is usually due to erroneously low $(\text{OH} + \text{F} + \text{Cl})$, giving too large a cation total, but there are a few reliably analyzed amphiboles with such excesses above ${}^B0.50$ and with ${}^B\text{Li} \leq 0.50$ *apfu*. Such samples only slightly exceed ${}^B0.50$ *apfu* because the presently known miscibility limit of such amphiboles is only slightly greater than ${}^B0.50$ *apfu*. In order to avoid a rash of new root names for such compositions with **small** cations in *B* (and small or zero Li), the prefix *parvo* from the Latin for “small” should be added to the root name derived for a species in the calcic, sodic-calcic or sodic groups, as if Group 5 did not exist, *i.e.*, overriding, in this instance only, the requirement in Groups 2, 3 and 4 for ${}^B(\text{Mg,Fe}^{2+}, \text{Mn}^{2+}, \text{Li}) \leq 0.50$ *apfu*. This measure preserves familiar IMA97 names, makes no distinction as to what the dominant L-type ion is at *B*, and avoids

Group 1: Mg-Fe-Mn-Li amphiboles

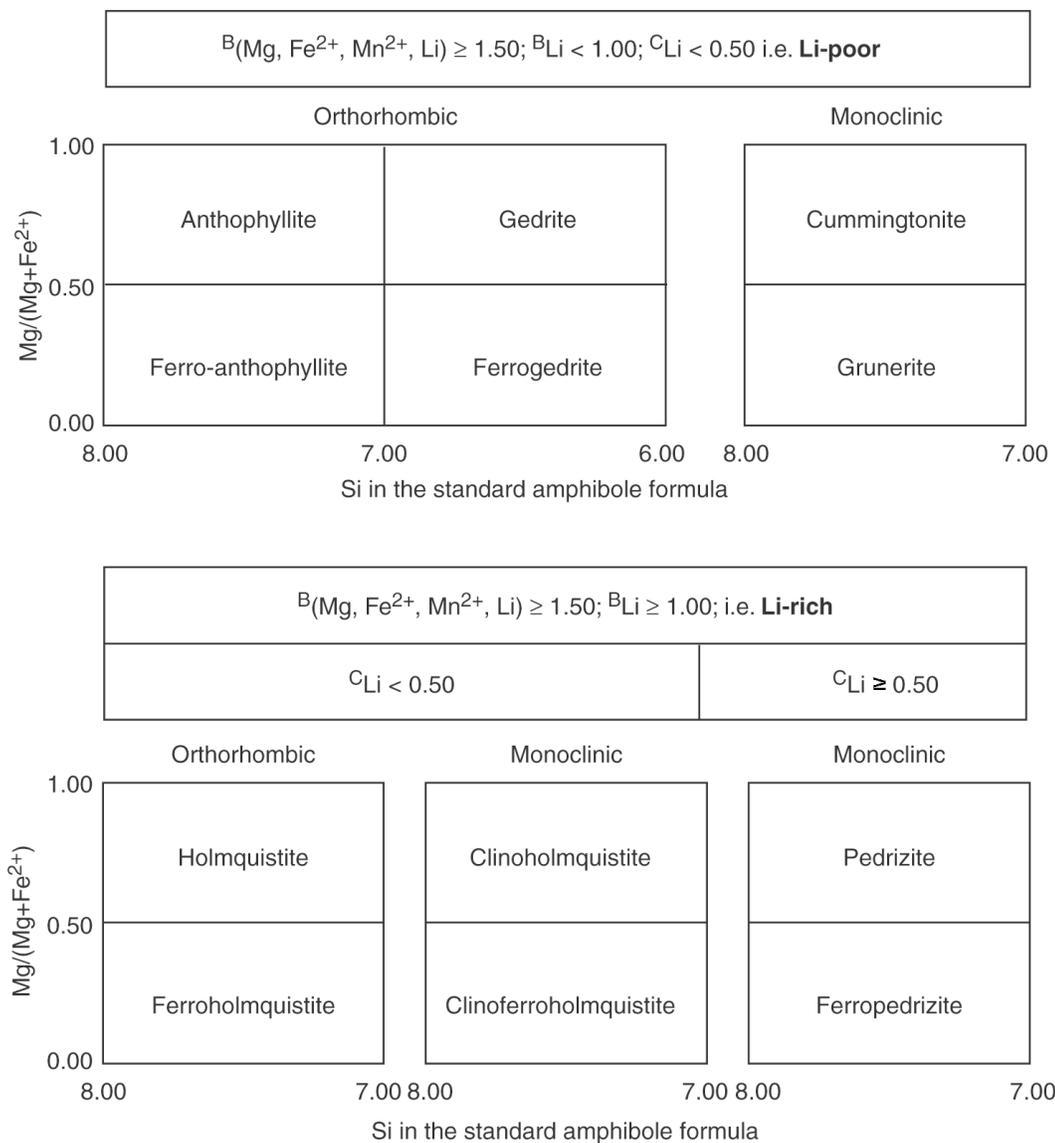
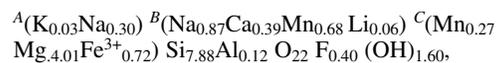


FIG. 1. Classification of the Group-1 amphiboles, the Mg-Fe-Mn-Li amphiboles. Concentration of atoms are expressed in atoms per formula unit (*apfu*).

making new names as a consequence of creating Group 5 to deal with certain Li-rich amphiboles. Thus such compositions are named exactly as they were before Group 5 existed, but with the added prefix *parvo*.

An unusually large $B(\text{Mg}, \text{Fe}, \text{Mn}, \text{Li})$ value of 0.74 *apfu* occurs in the following rare composition, which was in Group 3, but which now falls into Group 5:



which was reported by Oberti & Ghose (1993). According to IMA97, this is a sample of winchite, or with modifiers, fluorian manganian winchite. It now becomes parvowinchite or fluorian manganian parvo-

Group 5: Na-Ca-Mg-Fe-Mn-Li amphiboles

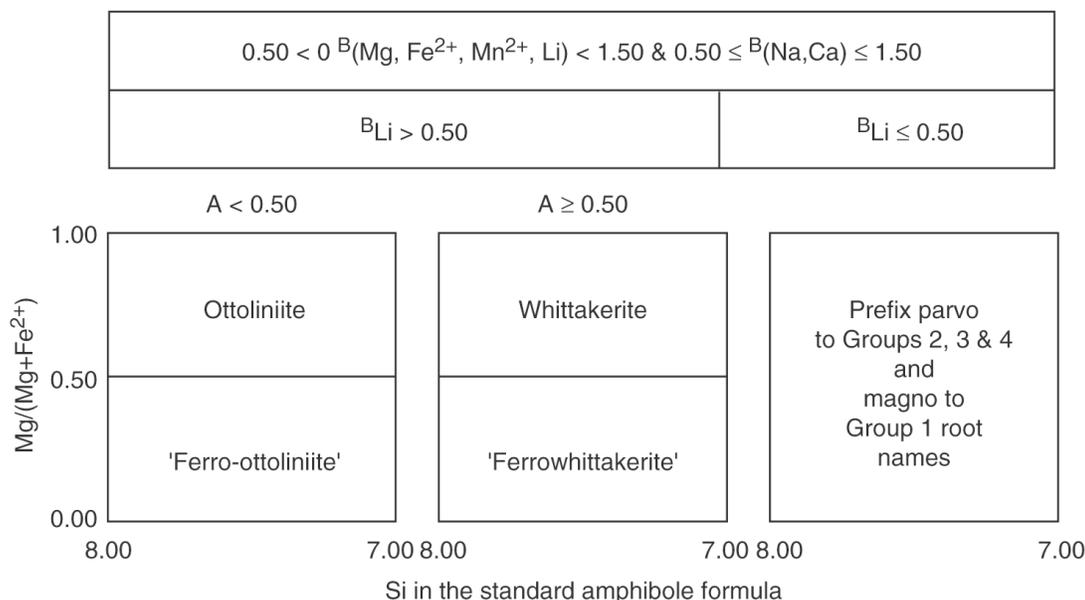
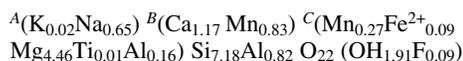


Fig. 3. Classification of the Group-5 amphiboles, the Na-Ca-Mg-Fe-Mn-Li amphiboles. Concentration of atoms are expressed in atoms per formula unit (*apfu*).

winchite. As the authors interpret it as being “on the verge of exsolution”, it may be near the extreme value of high ${}^B(\text{Mg}, \text{Fe}^{2+}, \text{Mn}^{2+})$ in Li-poor Group 5. Similarly, there are rare ${}^B\text{Li} \leq 0.50$ *apfu* amphiboles that were previously in Group 2, but now fall in Group 5. Thus a most extraordinary calcic amphibole, in its high level of ${}^B(\text{Mn})$, is:



(Skogby & Rossman 1991). If this is not a mixture of phases, then it was, according to IMA97, a sample of “mangano-edenite”, and it now becomes “parvo-mangano-edenite”. Usually, any excess of ${}^B(\text{Mg}, \text{Fe}^{2+}, \text{Mn}^{2+})$ above 0.50 *apfu* in Li-poor ($\text{Li} < 0.50$ *apfu*) calcic amphiboles is trivial.

Equally, to avoid new root names proliferating for rare amphiboles with compositions of ${}^B\text{Li} \leq 0.50$ *apfu* that were in Group 1 but now fall into Group 5 because of significant ${}^B(\text{Ca}, \text{Na})$, these should be named as previously with Group-1 root names and prefixes but prefixed *magno* to indicate the entry of **large** cations at the *B* position in Group 5.

It should be noted that in the first published use of sodic-ferripedrizite (Oberti *et al.* 2000), one of the ana-

lyzed crystals is sodic-ferripedrizite as above, whereas the second is now ferriwhittakerite, because the ideal formula of pedrizite was later changed to contain ${}^B\text{Li}_2$, whereas ${}^B(\text{NaLi})$ amphiboles became whittakerite or ottoliniite. The second published use of ferripedrizite (Caballero *et al.* 2000) had ${}^B\text{Li}_2$ and is only changed now by being prefixed with *sodic*, as above.

ERRATUM

In IMA97, Table 2, the modifier *ferrian*, which applies in all but the sodic group, should have been stated as $0.75 < \text{Fe}^{3+} \leq 1.00$ (and not 0.99) *apfu*.

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APPENDIX

Listed below is information concerning the etymology, the type locality and the unit-cell parameters of amphibole root-name end-members described since IMA97.

Obertiite

Named after Roberta Oberti of Pavia, Italy.
Type locality: Bellerberg, Laacher See district, Eifel, Germany.
X-ray data: *a* 9.776, *b* 17.919, *c* 5.292 Å, β 104.05°.
Reference: Hawthorne *et al.* (2000).

Ottoliniite

Named after Luisa Ottolini of Pavia, Italy.
Type locality: Fuente Grande, Eastern Pedriza Masif, Sierra de Guadarrama, Central System, Spain.
X-ray data: *a* 9.535, *b* 17.876, *c* 5.234 Å, β 102.54°.
Reference: Oberti *et al.* (2004).

Pedrizite

Named after the locality.
Type locality: Fuente Grande, Eastern Pedriza Masif, Sierra de Guadarrama, Central System, Spain.
X-ray data: *a* 9.501, *b* 17.866, *c* 5.292 Å, β 102.17°.
Reference: Caballero *et al.* (2002); name first used by Oberti *et al.* (2000). Ferropedrizite is described in Oberti *et al.* (2003b).

Whittakerite

Named after Eric J.W. Whittaker of Oxford, England.
Type locality: Fuente Grande, Eastern Pedriza Masif, Sierra de Guadarrama, Central System, Spain.
X-ray data: *a* 9.712, *b* 17.851, *c* 5.297 Å, β 103.63°.
Reference: Oberti *et al.* (2004), first used in Oberti *et al.* (2003a).