

Revised nomenclature of högbomite, nigerite, and taaffeite minerals

THOMAS ARMBRUSTER

Laboratorium für chemische und mineralogische Kristallographie, Universität Bern, Freiestrasse 3,
CH-3012 Bern, Switzerland, e-mail: thomas.armbruster@krist.unibe.ch

Abstract: Minerals of the högbomite, nigerite, and taaffeite groups form polysomatic series composed of spinel (*S*) and nolanite (*N*) modules. The idealised formula of a spinel module is $T_2M_4O_8$ where T and M represent tetrahedrally and octahedrally coordinated cations. The nolanite module in nigerite and högbomite minerals has the formula $TM_4O_7(OH)$ whereas the nolanite module in the Be-bearing taaffeite minerals is modified (*N'*) and has the formula $BeTM_4O_8$. The modules are normalised to two closest-packed oxygen layers situated parallel to (001) in hexagonal setting. The composition of these minerals thus depends: (1) on the composition of the nolanite module, (2) on the composition of spinel module, (3) on the number of spinel and nolanite modules forming the structure. Högbomite- and nigerite-group minerals are distinguished by the dominant tetravalent cation in the nolanite module. If the molar concentration of Ti > Sn, the group name is högbomite. If the molar concentration of Sn > Ti, the group name is nigerite. Taaffeite-group minerals have a nolanite module without OH groups but with additional tetrahedral Be.

In the new nomenclature, approved by the *IMA CNMMN*, the subgroup name is chosen according to the composition of the aluminium-spinel module. If the spinel module is dominated by the gahnite component, $ZnAl_2O_4$, the prefix 'zinco' is used. If the spinel module is dominated by the hercynite component, $FeAl_2O_4$, the prefix 'ferro' is used. If the spinel module is dominated by the spinel component, $MgAl_2O_4$, the prefix 'magnesio' is used.

To characterise the various polysomes found for each subgroup a hyphenated suffix composed of the total number of nolanite (*N*) and spinel (*S*) modules is attached. The module symbols (*N*, *S*) are italicised and given in the sequence first *N* and then *S*. According to this new nomenclature pengzhizhongite-6*T* and pengzhizhongite-24*R* are replaced by magnesionigerite-2*N*1*S* and magnesionigerite-6*N*6*S*, respectively. Furthermore, magnesiotaaffeite-6*N'*3*S* and ferrotaafeite-6*N'*3*S* replace musgravite and pehrmanite, respectively.

Key-words: högbomite, nigerite, taaffeite, polysomatism, crystal structure, chemistry, nomenclature.

Högbomite- and nigerite-group minerals

Historical background

Högbomite was originally described by Gavelin (1916) as a rhombohedral rock-forming mineral from the Routevaara area, Lapland, Sweden. A simple chemical formula was not given but the chemical analyses (after correction for intergrown ilmenite and pleonast) yielded the composition (wt.%): $TiO_2 = 5.53$, $Al_2O_3 = 61.19$, $Fe_2O_3 = 17.41$, $Cr_2O_3 = 0.29$, $MnO = 0.14$, $MgO = 15.44$. A sum of 100.00 % was assumed and all iron was analysed as Fe_2O_3 . The name högbomite was chosen in honour of Professor Arvid Gustaf Högbom (University of Uppsala, Sweden).

Nigerite was originally described by Jacobson & Webb (1947) as a new tin mineral from the tin-bearing pegmatites of Kabba, central Nigeria. The name is after the type locality. Chemical analyses yielded (wt.%): $SnO_2 = 25.33$, $Al_2O_3 = 50.91$, $Fe_2O_3 = 11.90$, $ZnO = 4.51$, sum = 92.65. Independent of the true oxidation state all iron was analysed as Fe_2O_3 . Additional data on the same nigerite sample were

provided by Bannister *et al.* (1947) reporting the mineral as trigonal with $a = 5.72$ and $c = 13.86$ Å.

McKie (1963) restudied nine specimens of högbomite from seven of the fifteen recorded occurrences at that time. He used Weissenberg and rotation photographs to identify cell dimensions and lattice type (*H* and/or *R*). Among his studied samples were also specimens originally studied by Gavelin (1916). McKie (1963) found that the dimensions of the hexagonal unit cell for all specimens are $a = 5.72$ Å and c a multiple of 4.6. He introduced a series of **polytypes**, to each of which a symbol of the form nH or nR was attached in form of a hyphenated suffix (n is given by $c = n \times 4.6$ Å). The sample of Gavelin (1916) became högbomite-4*H*. In addition, McKie (1963) found in other samples the **polytypes** 5*H*, 6*H*, 15*H*, 15*R*, and 18*R*. At this time the crystal structure of högbomite was not known and the suggestion of **polytypism** was based on the varying c dimensions ($n \times 4.6$ Å) and the 'similar' chemical compositions. Furthermore, McKie (1963) has pointed out the relation between nigerite, taaffeite, and the högbomite polytypes, all of which have similar values of a , and c which are multiples of 4.6 Å.

There is considerable confusion about the correct usage of polytype suffixes indicating the crystal system. The *IMA CNMMN* (Nickel, 1993) recommended polytype symbols are: *C* (cubic), *H* (hexagonal), *R* (rhombohedral), *T* (trigonal), *Q* (tetragonal), *O* (orthorhombic), *M* (monoclinic), and *A* (triclinic). Structures having 6, 6₁, 6₂, 6₃, 6₄, 6₅, or $\bar{6}$ as principal axis are hexagonal (*H*). The trigonal structures with 3, 3₁, 3₂ or $\bar{3}$ as principal axis are subdivided into those with a primitive lattice (*T*) and into those with a rhombohedral Bravais lattice (*R*). For hexagonal axes the *R* lattice is centred at 2/3, 1/3, 1/3 and 1/3, 2/3, 2/3. In this paper, hexagonal axes are used for *H*, *T*, and *R* lattices. McKie (1963) and several other authors did not distinguish between *T* and *H* crystal systems but used the *-H* suffix for both of them. The *R* lattice can simply be identified on the basis of systematic extinctions in the diffraction pattern and was therefore recognised and distinguished by most authors.

Peacor (1967) identified nigerite and högbomite as structures with a closest-packed oxygen array and for this reason introduced a nomenclature (in analogy to other polytypic systems) where *n* referred to the thickness of one oxygen layer (2.3 Å; half of the value used by McKie (1963)). From then on the confusion started because according to Peacor (1967) the original högbomite-4*H* became högbomite-8*H*. In the same study Peacor (1967) described nigerite-24*R* from the Kabba pegmatite (Nigeria) in addition to the 6*T* polytype from the same locality (Bannister *et al.*, 1947).

The structural principles of högbomite and nigerite were unravelled by Grey & Gatehouse (1979) who described the structure of nigerite-24*R* (Peacor nomenclature) as composed of different modules, the nolanite module and the spinel module, where the nolanite module is associated with one oxygen sheet with a stacking environment corresponding to hexagonal closest-packing. The term **polysomatism** was not used by Grey & Gatehouse (1979) but their description conforms with the modular structure of **polysomes**. The modular concept was confirmed (Gatehouse & Grey, 1982) for the structure of högbomite-8*H* (Peacor nomenclature) and all other subsequent structural studies on members with different *c* translations.

Short description of polysomatism

Minerals of the högbomite and nigerite group form polysomatic series composed of spinel (*S*) and nolanite (*N*) modules. The idealised formula of a spinel module is T₂M₄O₈ where T and M represent tetrahedrally and octahedrally coordinated cations. The nolanite module has the formula TM₄O₇(OH). Note that the spinel module has twice the T sites of the nolanite module. Both modules are normalised to two oxygen layers. The closest-packed oxygen sheets in högbomite and nigerite minerals are parallel to (001) in hexagonal setting. The composition of högbomite- and nigerite-group minerals thus depends: (1) on the composition of the nolanite module, (2) on the composition of spinel module, and (3) on the number of spinel and nolanite modules forming the structure.

It seems that the presence of tetravalent cations (mainly Sn and Ti) in octahedral coordination is responsible for the

formation of nolanite modules. Members of the högbomite group have octahedral Ti⁴⁺ and members of the nigerite group have octahedral Sn⁴⁺ in the nolanite module. Published analyses of various nigerite and högbomite specimens indicate *ca.* 0.5–1 Ti⁴⁺ per nolanite module in högbomite minerals and *ca.* 1 Sn⁴⁺ in nigerite minerals. A review of the literature on this subject is given by Petersen *et al.* (1989), Armbruster (1998), and Hejny & Armbruster (2002). Up to now, all known högbomite- and nigerite-group minerals are composed of spinel modules belonging to the aluminium-spinel subgroup.

More recent findings on polysomatism

Armbruster (1998) discussed the common nomenclature for högbomite and stated that the members of the högbomite and nigerite groups are not necessarily polytypes, depending on the ratio of nolanite (*N*) and spinel (*S*) modules. Similar arguments may be derived from the work of Neiva & Champness (1997) who found for nigerite from the Cabanas pegmatite (Portugal) that the rim of nigerite crystals is Sn-rich nigerite-6*H* (correct name: nigerite-6*T*) whereas the core is depleted in Sn and consists of nigerite-24*R*. Two types of nigerite, one Sn-rich (with low Zn) and the other Sn-depleted (with high Zn) were also reported by Tindle & Breaks (1998) from a granitic pegmatite in northwestern Ontario. The latter authors tentatively assigned the two chemically distinct nigerite varieties to nigerite-6*H* (correct name: nigerite-6*T*) and nigerite-24*R*.

The structural principles discussed by Armbruster (1998) imply that nigerite-24*R* has a *N/S* ratio of 1/1 whereas nigerite-6*T* has a *N/S* ratio of 2/1. As stated above, all structural analyses have shown that Sn is confined to the nolanite module which agrees with the different Sn concentration found in both 'varieties'.

Modular structures as found for högbomite and nigerite minerals should be treated as **polysomes**. Notice that here a **polysomatic series** (Thompson, 1978) is equivalent to Mackovicky's (1997) **homologous accretional series**. Because each of these polysomes has a different chemistry or/and different topology they should formally have species status provided they occur as well defined minerals and not as small domains (few unit cells wide) only detectable by transmission electron microscopy.

There are hexagonal (*H*) and/or (primitive) trigonal (*T*) nigerite and högbomite minerals with the same *N/S* ratio as the corresponding members of this group with a rhombohedral (*R*) Bravais lattice (identical *N/S* ratios have: 6*T* = 18*R*, 8*H* = 24*R*, 10*T* = 30*R*, 12*H* = 36*R*). Structural study of högbomite and nigerite minerals with 6, 10, and 14 oxygen sheets yielded trigonal (Hejny & Armbruster, 2002) but not hexagonal symmetry (thus the suffix *H* must be changed to *T*). Members with the same *N/S* ratio within each group (högbomite or nigerite) but different stacking sequence of the *N* and *S* modules may be considered **polytypes** according to Guinier *et al.* (1984). There are only scarce chemical data available to decide whether 'stacking variants' with the same *N/S* ratio have also 'identical' chemical composition (as required for polytypes). It could well be that clustering

Table 1. Oxygen stacking sequence and modular composition of högbomite- and nigerite-group polysomes and related structures. Notice: altered names suggested in this proposal are given in bold in the right column. All other högbomite and nigerite names given in this table require an independent new mineral proposal. The additional data are only presented to give a perspective of the nomenclature system.

nomenclature (Peacor, 1967)	space group / periodicity along c_h (Å)	sequence of cubic 'c' and hexagonal 'h' closed-packed oxygen layers	sequence of spinel (S)* and nolanite (N)* modules	sum of spinel (S) and nolanite (N) modules	theoretical composition	new names (in bold) for högbomite and nigerite group minerals
6C	$Fd\bar{3}m$ / 13.8	cccccc	SSS	3S	$3 \times T_2M_4O_8$	spinel
4H	$P6_3mc$ / 9.2	chch	NN	2N	$2 \times TM_4O_7(OH)$	nolanite ¹
6T	$P\bar{3}m1$ / 13.8	$2 \times (c + ch)$	NNS	2N1S	$2 \times T_2M_6O_{11}(OH)$	ferronigerite-2N1S ² zinconigerite-2N1S ³ magnesionigerite-2N1S ⁴
8H	$P6_3mc$ / 18.4	$2 \times (cc + ch)$	NSNS	2N2S	$2 \times T_3M_8O_{15}(OH)$	magnesiohögbomite-2N2S ⁵ ferrohögbomite-2N2S ⁶ zincohögbomite-2N2S ⁷
10T	$P\bar{3}m1$ / 23.0	$2 \times (ccc + ch)$	NSSNS	2N3S	$2 \times T_4M_{10}O_{19}(OH)$	magnesiohögbomite-2N3S ⁸
12H	$P6_3mc$ / 27.6	$2 \times (cccc + ch)$	NSSNSS	2N4S	$2 \times T_5M_{12}O_{23}(OH)$	structure modeled ⁸ observed for högbomite group but no chemical analysis given
14T	$P\bar{3}m1$ / 32.2	$2 \times (ccccc + ch)$	NSSSNSS	2N5S	$2 \times T_6M_{14}O_{27}(OH)$	structure modeled ⁹
16H	$P6_3mc$ / 36.8	$2 \times (cccccc + ch)$	NSSSNSSS	2N6S	$2 \times T_7M_{16}O_{31}(OH)$	zincohögbomite-2N6S ¹⁰
18R	$R\bar{3}m$ / 41.4	$3 \times (cc + chhc)$	$3 \times (NNS)$	6N3S	$6 \times T_2M_6O_{11}(OH)$	known for taaffeite group ¹¹ given for consistency
24R	$R\bar{3}m$ / 55.2	$3 \times (cccc + hcch)$	$3 \times (NNSS)$	6N6S	$6 \times T_3M_8O_{15}(OH)$	ferronigerite-6N6S ¹² zinconigerite-6N6S ³ magnesionigerite-6N6S ⁴ magnesiohögbomite-6N6S ¹³
30R	$R\bar{3}m$ / 69.0	$3 \times (cccccc + hcch)$	$3 \times (NNSSS)$	6N9S	$6 \times T_4M_{10}O_{19}(OH)$	structure predicted ⁸ observed for högbomite group but no chemical analysis given
36R	$R\bar{3}m$ / 82.8	$3 \times (ccccccc + hcch)$	$3 \times (NNSSSS)$	6N12S	$6 \times T_5M_{12}O_{23}(OH)$	ferrohögbomite-6N12S ¹⁴ structure predicted

* $N = TM_4O_7(OH)$, $S = T_2M_4O_8$

¹Gatehouse *et al.*, 1983; ²Jacobson & Webb (1947), Bannister *et al.* (1947), Arakcheeva *et al.* (1995); ³Neiva & Champness (1997); ⁴Chen *et al.* (1989); ⁵Gavelin (1916), McKie (1963); ⁶Gatehouse & Grey (1982); ⁷Ockenga *et al.* (1998), Armbruster (1998); ⁸McKie (1963), Hejny & Armbruster (2002); ⁹Hejny & Armbruster (2002); ¹⁰Armbruster *et al.* (1998); ¹¹Nuber & Schmetzer (1983); ¹²Burke *et al.* (1977), Grey & Gatehouse (1979); ¹³Schmetzer & Berger (1990), Hejny & Armbruster (2002), ¹⁴Nel (1949), McKie (1963).

of nolanite modules as found by crystal-structure analysis of rhombohedral stacking variants (Table 1) is actually favoured for specific chemical compositions. At least for högbomite-24R and högbomite-8H strong differences in the Ti concentration have been observed (*e.g.*, Gatehouse & Grey, 1982; Schmetzer & Berger, 1990; Hejny & Armbruster, 2002). This seems to be sufficient ground to assign **species status** to all members (also to those with the same N/S ratio). An additional argument is that **polysomes** with the same N/S ratio are distinct by their different structural topology.

Existing nomenclature

Högbomite group

The following högbomite 'polytypes' have been reported according to the Peacor (1967) nomenclature: -8H, -10T,

-12H, -30H, 24R, -30R, -36R (Table 1). Notice that Fe^{2+} - and Mg^{2+} -dominant högbomite 'species' were hitherto not distinguished by different (CNMMN-accepted) names, although various papers show that both 'species' exist.

For zincohögbomite -8H and -16H 'polytypes' were described according to the Peacor (1967) nomenclature.

Nigerite group

According to the Peacor (1967) nomenclature -6T, and -24R 'polytypes' have been reported. Notice that Fe^{2+} - and Zn^{2+} -dominant nigerite 'species' were hitherto not distinguished by different (CNMMN-accepted) names although various papers show that both 'species' exist.

The name pengzhizhongite describes the Mg-dominant form of nigerite (reported 'polytypes' according to the Peacor (1967) nomenclature: -6T, -24R).

General ideas of a new nomenclature

Accepting that each ordered stacking 'variety' of hōgbomite and nigerite has **species status**, an unwanted large number of independent new mineral names could arise which would rather confuse than clarify the subject. For this reason a unified nomenclature is favoured. Continuing the existing **polytype** nomenclature is also not desirable because most ordered '**polytypes**' of nigerite and hōgbomite reveal (1) different stoichiometry, (2) different ratios of octahedrally and tetrahedrally coordinated cations, and (3) different degrees of hydroxylation (OH groups are associated with the nolanite module) and therefore do not conform with the definition of **polytypism** (Guinier *et al.*, 1984). Furthermore, the presently used ambiguous polytype nomenclature (McKie, 1963; Peacor, 1967) gave rise to confusion about the 'true' stacking periodicity.

New nomenclature accepted by IMA CNMMN

The group name (hōgbomite or nigerite) is determined by the dominant tetravalent cation in the nolanite module. If the molar concentration of Ti > Sn, the group name is hōgbomite. If the molar concentration of Sn > Ti, the group name is nigerite.

Hōgbomite group

The subgroup name is chosen according to the composition of the aluminium-spinel module. If the spinel module is dominated by the gahnite component, ZnAl₂O₄, the prefix 'zinco' is used. If the spinel module is dominated by the hercynite component, FeAl₂O₄, the prefix 'ferro' is used. If the spinel module is dominated by the spinel component, MgAl₂O₄, the prefix 'magnesio' is used. A corresponding choice of prefixes is required if hōgbomite minerals with other spinel modules are discovered.

If only chemical analyses are available, the dominant divalent cation determines the subgroup. A special problem occurs for iron without specified valence. In general, the valence of iron can not be estimated from the bulk Fe composition if the polysome is unknown. If the polysome is known (see Appendix), the minimum amount of Fe²⁺ can be calculated by assuming that all T sites of a spinel T₂M₄O₈ module are occupied by Zn + Mg + Mn²⁺ + Co²⁺ + Ni²⁺ + Fe²⁺. At first all well-defined divalent cations are assigned to the spinel T sites and then the T occupancy is completed with Fe²⁺.

To characterise the **various polysomes** found for each subgroup (zincohōgbomite, ferrohōgbomite, magnesiohōgbomite) a hyphenated suffix composed of the total number of nolanite (*N*) and spinel (*S*) modules is attached. The module symbols (*N*, *S*) are italicised and given in the sequence first *N* and then *S*. Table 1 shows how the Peacor (1967) polytype nomenclature is transformed to the new polysome nomenclature. Notice that each polysome has species status and thus requires approval by *CNMMN*.

Magnesiohōgbomite subgroup: The original hōgbomite described by Gavelin (1916) and restudied by McKie (1963) is

a magnesiohōgbomite-2*N*2*S*, other magnesiohōgbomites are: magnesiohōgbomite-2*N*3*S* (McKie, 1963; Hejny & Armbruster, 2002), magnesiohōgbomite-6*N*6*S* (Schmetzer & Berger, 1990; Hejny & Armbruster, 2002).

Ferrohōgbomite subgroup: Potential members of the ferrohōgbomite subgroup, -2*N*2*S* (Gatehouse & Grey, 1982) and -6*N*12*S* (Nel, 1949; McKie, 1963), are not subject of the new nomenclature but need acceptance as new minerals and require an independent proposal. These examples are only given to provide a more complete view of the subject. Members of this subgroup were hitherto named hōgbomite. Thus Mg- and Fe²⁺-dominant members were not distinguished.

Zincohōgbomite subgroup: Zincohōgbomite-2*N*6*S* (Armbruster *et al.*, 1998) and zincohōgbomite-2*N*2*S* (Ockenga *et al.*, 1998, Armbruster, 1998) have recently been described.

Nigerite group

The subgroup name is chosen according to the composition of the aluminium-spinel module. If the spinel module is dominated by the hercynite component, FeAl₂O₄, the prefix 'ferro' is used. If the spinel module is dominated by the gahnite component, ZnAl₂O₄, the prefix 'zinco' is used. A corresponding choice of prefixes is required if nigerite minerals with other spinel modules are discovered. If the spinel module is dominated by the spinel component, MgAl₂O₄, the new name is magnesionigerite replacing pengzhizhongite.

To characterise the **various polysomes** found for each subgroup (zinconigerite, ferronigerite, magnesionigerite) a hyphenated suffix composed of the total number of nolanite (*N*) and spinel (*S*) modules is attached. The module symbols (*N*, *S*) are italicised and given in the sequence first *N* and then *S*. Table 1 shows how the Peacor (1967) polytype nomenclature is transformed to the new polysome nomenclature. Notice that each polysome has species status and thus requires approval by *CNMMN*.

Ferronigerite subgroup: The original nigerite described by Jacobson & Webb (1947) and Bannister *et al.* (1947) is ferronigerite-2*N*1*S*, the other polysome is ferronigerite-6*N*6*S* (Burke *et al.*, 1977; Grey & Gatehouse, 1979).

Magnesionigerite subgroup: This subgroup comprises magnesionigerite-2*N*1*S* and magnesionigerite-6*N*6*S* (Chen *et al.*, 1989).

Zinconigerite subgroup: Potential members of the zinconigerite subgroup -2*N*1*S* and -6*N*6*S* (Burke *et al.*, 1977; Čech *et al.*, 1978; Neiva & Champness, 1997) are not subject of the new nomenclature but need acceptance as new minerals and require an independent proposal. These examples are only given to provide a more complete view of the subject. Members of this subgroup were hitherto named nigerite. Thus Zn- and Fe²⁺-dominant members were not distinguished.

Additional advantages of the new nomenclature

Considering that nolanite (*N*) and spinel (*S*) modules have the simplified compositions $\text{TM}_4\text{O}_7(\text{OH})$ and $\text{T}_2\text{M}_4\text{O}_8$, respectively, the simplified formula of each polysome can be determined by adding the modular formulas (examples are given in Table 1). Each module is normalised to two oxygen layers or in other words each module along the *c* axis (hexagonal setting) is 4.6 Å thick. Thus the total number of modules given in the suffix multiplied by 4.6 Å yields the length of the *c* axis (in hexagonal setting). Structural systematics of högbomite- and nigerite-group polysomes (Hejny & Armbruster, 2002) have indicated that polysomes with even numbers of modules are hexagonal, those with odd numbers of modules are trigonal. An exception are polysomes where both the number of *N* and of *S* modules can be divided by three, those polysomes are rhombohedral (Table 1).

Taaffeite-group minerals

As already noted by McKie (1963) taaffeite, $\text{Mg}_3\text{BeAl}_8\text{O}_{16}$, (Anderson *et al.*, 1951) is a Be mineral structurally related to högbomite and nigerite. The name taaffeite is for Count Edward Charles Richard Taaffe (1898-1967), a gemologist from Dublin, Ireland, who noted the first specimen. According to McKie's (1963) nomenclature musgravite, $\text{Mg}_2\text{BeAl}_6\text{O}_{12}$, was originally described as a 9*R* polytype of taaffeite (Hudson *et al.*, 1967) and only years later *IMA CNMMN* approved the name musgravite (Schmetzer, 1983). Pehrmanite, also a 9*R* polytype (McKie's (1963) nomenclature), is the Fe^{2+} analogue of musgravite (Burke & Lustenhouwer, 1981). Taprobanite (Moor *et al.*, 1981) was found to be identical with taaffeite (Schmetzer, 1983).

Structural study of taaffeite-4*H* and musgravite-9*R* (Peng & Wang, 1963; Moor *et al.*, 1981; Nuber & Schmetzer, 1983) showed that these minerals are also composed of spinel and nolanite modules with the difference that the nolanite module is modified. Be occupies a tetrahedral position close to the site occupied by hydrogen in the nolanite module of nigerite- and högbomite-group minerals, making taaffeite- group minerals anhydrous. If this modified nolanite module is labelled *N'* the suggested nomenclature for högbomite- and nigerite-group minerals can also be extended to the taaffeite-related Be minerals.

New nomenclature accepted by IMA CNMMN

The taaffeite group is newly defined for minerals composed of spinel and modified nolanite modules where Be occupies a tetrahedral site close to the hydrogen position in the nolanite module. The modified nolanite module has the composition BeTM_4O_8 .

The subgroup name is chosen according to the composition of the aluminium-spinel module. If the spinel module is dominated by the spinel component, MgAl_2O_4 , the prefix 'magnesian' is used. If the spinel module is dominated by the hercynite component, FeAl_2O_4 , the prefix 'ferro' is used.

Table 2a. New names for högbomite-group minerals defined in this paper.

old name	reference	new name space group, cell dimensions
högbomite-8 <i>H</i>	Gavelin (1916), McKie (1963)	magnesianhögbomite-2 <i>N</i> 2 <i>S</i> $P6_3mc$, $a = 5.73$, $c = 18.39$ Å
högbomite-10 <i>T</i>	McKie (1963), Hejny & Armbruster (2002)	magnesianhögbomite-2 <i>N</i> 3 <i>S</i> $P3m1$, $a = 5.72$, $c = 23.0$ Å
högbomite-24 <i>R</i>	Schmetzer & Berger (1990), Hejny & Armbruster (2002)	magnesianhögbomite-6 <i>N</i> 6 <i>S</i> $R\bar{3}m$, $a = 5.70$, $c = 55.8$ Å
zincohögbomite-8 <i>H</i>	Ockenga <i>et al.</i> (1998), Armbruster (1998)	zincohögbomite-2 <i>N</i> 2 <i>S</i> $P6_3mc$, $a = 5.71$, $c = 18.33$ Å
zincohögbomite-16 <i>H</i>	Armbruster <i>et al.</i> (1998)	zincohögbomite-2 <i>N</i> 6 <i>S</i> $P6_3mc$, $a = 5.73$, $c = 37.10$ Å

Table 2b. New names for nigerite-group minerals defined in this paper.

old name	reference	new name space group, cell dimensions
nigerite-6 <i>T</i>	Jacobson & Webb (1947), Bannister <i>et al.</i> (1947), Arakcheeva <i>et al.</i> (1995)	ferro-nigerite-2 <i>N</i> 1 <i>S</i> $P\bar{3}m1$, $a = 5.72$, $c = 13.69$ Å
nigerite-24 <i>R</i>	Burke <i>et al.</i> (1977), Grey & Gatehouse (1979)	ferro-nigerite-6 <i>N</i> 6 <i>S</i> $R\bar{3}m$, $a = 5.73$, $c = 55.60$ Å
pengzhizhongite-6 <i>T</i>	Chen <i>et al.</i> (1989)	magnesian-nigerite-2 <i>N</i> 1 <i>S</i> $P3m1$, $a = 5.69$, $c = 13.78$ Å
pengzhizhongite-24 <i>R</i>	Chen <i>et al.</i> (1989)	magnesian-nigerite-6 <i>N</i> 6 <i>S</i> $R\bar{3}m$, $a = 5.69$, $c = 55.12$ Å

Notice that nigerite-6*T* and pengzhizhongite-6*T* were originally named nigerite-6*H* and pengzhizhongite-6*H*, however, the space-group symmetry is trigonal, thus in the existing Peacor (1967) nomenclature the correct suffix must be -6*T* (Nickel, 1993).

Table 2c. New names for taaffeite-group minerals defined in this paper.

old name	reference	new name space group, cell dimensions
taaffeite	Anderson <i>et al.</i> (1951), Nuber & Schmetzer (1983)	magnesian-taaffeite-2 <i>N'</i> 2 <i>S</i> $P6_3mc$, $a = 5.69$, $c = 18.34$ Å
musgravite	Hudson <i>et al.</i> (1967), Nuber & Schmetzer (1983)	magnesian-taaffeite-6 <i>N'</i> 3 <i>S</i> $R\bar{3}m$, $a = 5.68$, $c = 41.10$ Å
pehrmanite	Burke & Lustenhouwer (1981)	ferro-taaffeite-6 <i>N'</i> 3 <i>S</i> $R\bar{3}m$, $a = 5.70$, $c = 41.16$ Å

A corresponding choice of prefixes is required if taaffeite minerals with other spinel modules are discovered.

To characterise the **various polysomes** found for each subgroup (magnesiotaaffeite and ferrottaaffeite) a hyphenated suffix composed of the total number of modified nolanite (N') and spinel (S) modules is attached. The module symbols (N' , S) are italicised and given in the sequence first N' and then S .

Magnesiotaaffeite subgroup

Taaffeite-8*H* (nomenclature according to Peacor (1967)) becomes magnesiotaaffeite-2*N'*2*S*, as it is composed of two spinel $\text{Mg}_2\text{Al}_4\text{O}_8$ modules and two modified nolanite modules of $\text{BeMgAl}_4\text{O}_8$ composition. Correspondingly, musgravite-18*R* (nomenclature according to Peacor (1967)) becomes magnesiotaaffeite-6*N'*3*S*.

Ferrottaaffeite subgroup

Pehrmanite-18*R* (nomenclature according to Peacor (1967)) with spinel modules of $\text{Fe}_2\text{Al}_4\text{O}_8$ composition becomes ferrottaaffeite-6*N'*3*S*.

Summary and consequences

The names in the left column of Tables 2a-c are in use in literature (according to the Peacor (1967) nomenclature) and the names given in the right column are the new names accepted by *IMA CNMMN*. The relation between crystallisation of a specific polysomatic member of the hōgbomite, nigerite, and taaffeite group on one hand and the formation conditions on the other hand, are up to now not understood. This lack of knowledge should encourage petrologists not only to estimate formation conditions and to analyse chemical compositions but, most important, to determine the polysome by diffraction methods. Either structure determinations or structure models leading to atomic coordinates are referenced in Table 1. Cell dimensions and atomic coordinates allow the calculation of powder diffraction data for almost all polysomes using a computer program like LAZY-PULVERIX (Yvon *et al.*, 1977).

Appendix

Example for naming nigerite-group polysomes

Burke *et al.* (1977) described Fe-rich nigerite from the Rosendal pegmatite and aplites, Kemiö island, southwestern Finland (Table 3). At the time of their study the polysome was not known but according to the reported X-ray powder reflections the polysome is 'nigerite-6*N6S*', leading to a bulk composition of $6 \times \text{T}_2\text{M}_4\text{O}_8 + 6 \times \text{TM}_4\text{O}_7(\text{OH})$. In the next step, the formula is normalised on 66 cations (18*T* + 48*M*). Based on the resulting formula (Table 3) 12 tetrahedral sites (in the spinel modules) are occupied by divalent cations. Thus samples 1 and 2 in Table 3 have $(\text{Mn}_{0.09}\text{Mg}_{0.53}\text{Zn}_{3.28}\text{Fe}^{2+}_{8.10})_{\Sigma=12}$ and $(\text{Mn}_{0.09}\text{Mg}_{0.53}\text{Zn}_{2.60}$

Table 3. Electron microprobe analyses of 'nigerite-6*N6S*' from Rosendal (1-3) (Burke *et al.*, 1977), from Bohemia (4) (Čech *et al.*, 1978), (5) from northern Queensland (Grey & Gatehouse, 1979), (6) from northern Portugal (Neiva & Champness, 1997); all Fe assumed as Fe^{2+} .

	(1)	(2)	(3)	(4)	(5)	(6)
MnO	0.15	0.15	0.35	0.80	0.34	0.09
MgO	0.50	0.50	0.60	-	-	-
ZnO	6.30	5.00	12.00	11.55	7.75	20.79
FeO	16.28	18.10	10.09	9.81	13.51	2.40
Al ₂ O ₃	55.80	55.85	56.15	53.82	52.47	54.00
TiO ₂	0.15	0.35	0.15	1.07	-	0.25
SiO ₂	0.10	0.05	0.30	0.51	0.56	0.48
Nb ₂ O ₅	0.30	0.45	0.15	0.37	-	-
				(Ta ₂ O ₅)		
SnO ₂	21.00	18.85	21.30	18.16	22.37	20.77
Sum	100.58	99.3	101.9	96.09	97.00	98.78
normalised on 66 cations						
Mn	0.09	0.09	0.21	0.50	0.21	0.06
Mg	0.53	0.53	0.63	-	-	-
Zn	3.28	2.60	6.25	6.29	4.26	11.25
Fe	9.60	10.68	5.95	6.05	8.41	1.47
Al	46.36	46.44	46.54	46.78	46.05	46.72
Ti	0.08	0.19	0.08	0.59	-	0.13
Si	0.07	0.04	0.21	0.38	0.42	0.36
Nb	0.10	0.14	0.05	0.07	-	-
				(Ta)		
Sn	5.90	5.30	5.99	5.34	6.64	6.08

$\text{Fe}^{2+}_{8.78})_{\Sigma=12}$, respectively, that leads to ferronigerite-6*N6S*, whereas sample 3 has $(\text{Mn}_{0.21}\text{Mg}_{0.63}\text{Zn}_{6.25}\text{Fe}^{2+}_{4.91})_{\Sigma=12}$ and would be named 'zinconigerite-6*N6S*'. The same procedure can be applied to the Bohemian nigerite, sample 4 in Table 3 (Čech *et al.*, 1978), yielding $(\text{Mn}_{0.50}\text{Zn}_{6.29}\text{Fe}^{2+}_{5.21})_{\Sigma=12}$ which classifies the sample as 'zinconigerite-6*N6S*'. Furthermore, samples 5 and 6 in Table 3 become ferronigerite-6*N6S* and 'zinconigerite-6*N6S*', respectively. Notice that the suggested new name 'zinconigerite-6*N6S*' requires separate approval by *CNMMN*.

Acknowledgements: This work was supported by the 'Schweizerischer Nationalfonds zur Förderung der wissenschaftlichen Forschung'. The helpful assistance by Giovanni Ferraris (Vice-Chairman *CNMMN*) in setting up the nomenclature proposal is highly acknowledged. Members of *CNMMN* improved and completed the original proposal by their constructive and encouraging comments. Clivia Hejny is thanked for her contributions to the understanding of polysomatic structures.

References

- Anderson, B.W., Payne, C.J., Claringbull, G.F., Hey, M.H. (1951): Taaffeite, a new beryllium mineral, found as cut gemstone. *Mineral. Mag.*, **29**, 765-772.

- Arakcheeva, A.V., Pushcharovskii, D. Yu., Rastsvetaeva, R.K., Kas-haev, A.A., Nadezhina, T.N. (1995): Crystal structure of nigerite-6H. *Crystallogr. Rep.*, **40**, 587-592.
- Armbruster, Th. (1998): Zincohögbomite-8H from Samos (Greece): crystal structure, polysomatism, and polytypism in högbomite related structures. *Schweiz. Mineral. Petrogr. Mitt.*, **78**, 461-468.
- Armbruster, Th., Bermanec, V., Zebec, V., Oberhänsli, R. (1998): Titanium and iron poor zincohögbomite-16H, $Zn_{14}(Al,Fe^{3+},Ti,Mg)_8Al_{24}O_{62}(OH)_2$, from Nezilovo, Macedonia: occurrence and crystal structure of a new polysome. *Schweiz. Mineral. Petrogr. Mitt.*, **78**, 469-477.
- Bannister, F.A., Hey, M.H., Stadler, H.P. (1947): Nigerite, a new tin mineral. *Mineral. Mag.*, **28**, 128-136.
- Burke, E.A.J., Lof, P., Hazebroek, H.P. (1977): Nigerite from the Rosendal pegmatite and aplite, Kemiö island, southwestern Finland. *Bull. Geol. Soc. Finland*, **49**, 151-157.
- Burke, E.A.J. & Lustenhouwer, W.J. (1981): Pehrmanite, a new beryllium mineral from Rosendal pegmatite, Kemiö Island, southwestern Finland. *Can. Mineral.*, **19**, 311-314.
- Čech, F., Rieder, M., Novák, F., Novotny, J. (1978): Accessory nigerite in a granite from central Bohemia, Czechoslovakia. *N. Jb. Mineral. Mh.*, **1978**, 337-346.
- Chen, J., Shi, Y., Pan, Zh., Zhizhong, P. (1989): The crystal structure and crystal chemistry of a new mineral, penzhizongite-6H. *Earth Sci. J. Wuhan College Geol.*, **14**, 413-422.
- Gatehouse, B.M. & Grey, I.E. (1982): The crystal structure of högbomite-8H. *Am. Mineral.*, **67**, 373-380.
- Gatehouse, B.M., Grey, I.E., Nickel, E.H. (1983): The crystal structure of nolanite, $(V,Fe,Ti,Al)_{10}O_{14}(OH)_2$ from Kalgoorlie, Western Australia. *Am. Mineral.*, **68**, 833-839.
- Gavelin, A. (1916): Über Högbomit. *Bull. Geol. Inst. Univ. Uppsala*, **15**, 289-316.
- Grey, I.E. & Gatehouse, B.M. (1979): The crystal structure of nigerite-24R. *Am. Mineral.*, **64**, 1255-1264.
- Guinier, A., Bokij, G.B., Boll-Dornberger, K., Cowley, J.M., Đurovič, S., Jagodzinski, H., Krishna, P., De Wolff, P.M., Zvyagin, B.B., Cox, D.E., Goodman, P., Hahn, Th., Kuchitsu, K., Abrahams, S.C. (1984): Nomenclature of polytype structures. Report of the International Union of Crystallography Ad-Hoc Committee on the Nomenclature of Disordered, Modulated and Polytype Structures. *Acta Cryst.*, **A40**, 399-404.
- Hejny, C. & Armbruster, Th. (2002): Polysomatism in högbomite: The crystal structures of 10T, 12H, 14T, and 24R polysomes. *Am. Mineral.*, in press.
- Hudson, D.R., Wilson, A.F., Threadgold, I.M. (1967): A new polytype of taaffeite – a rare beryllium mineral from the granulites of central Australia. *Mineral. Mag.*, **36**, 305-310.
- Jacobson, R. & Webb, J.S. (1947): The occurrence of nigerite, a new tin mineral in quartz-sillimanite-rocks from Nigeria. *Mineral. Mag.*, **28**, 118-128.
- Makovicky, E. (1997). Modularity – different types and approaches. In Merlino, S. (ed.): Modular aspects of minerals. *EMU Notes in Mineralogy*, **1**, 315-344.
- McKie, D. (1963): The högbomite polytypes. *Mineral. Mag.*, **33**, 563-580.
- Moor, R., Oberholzer, W.F., Gübelin, E. (1981): Taprobanite, a new mineral of the taaffeite group. *Schweiz. Mineral. Petrogr. Mitt.*, **61**, 13-21.
- Neiva, A.M.R. & Champness, P.E. (1997): Nigerite and gahnite from the granitic pegmatite veins of Cabanas, Ponte do Lima, northern Portugal. *N. Jb. Mineral. Mh.*, **1997**, 385-409.
- Nel, H.J. (1949): Hoegbomite from the corundum fields of the eastern Transvaal, Union of South Africa. *Geol. Surv. Mem.*, **43**, 1-7.
- Nickel, E.H. (1993): Standardization of polytype suffixes. *Can. Mineral.*, **31**, 767-768.
- Nuber, B. & Schmetzer, K. (1983): Crystal structure of ternary Be-Mg-Al oxides: taaffeite, $BeMg_3Al_8O_{16}$, and musgravite, $BeMg_2Al_6O_{12}$. *N. Jb. Mineral. Mh.*, **1983**, 393-402.
- Ockenga, E., Yalçin, Ü., Medenbach, O., Schreyer, W. (1998): Zincohögbomite, a new mineral from eastern Aegean metabauxites. *Eur. J. Mineral.*, **10**, 1361-1366.
- Peacor, D.R. (1967): New data on nigerite. *Am. Mineral.*, **52**, 864-866.
- Peng, C.C. & Wang, K.J. (1963): Discovery of a compact structure with 8-layers. Crystal structure analysis of taaffeite (in Russian). *Scientia Sinica*, **12**, 276-278.
- Petersen, E.U., Essene, E.J., Peacor, D.R., Marcotty, L.A. (1989): The occurrence of högbomite in high-grade metamorphic rocks. *Contrib. Mineral. Petrol.*, **101**, 350-360.
- Schmetzer, K. (1983): Crystal chemistry of natural Be-Mg-Al-oxides: taaffeite, taprobanite, musgravite. *N. Jb. Mineral. Abh.*, **146**, 15-28.
- Schmetzer, K. & Berger, A. (1990): Lamellar iron-free högbomite-24R from Tanzania. *N. Jb. Mineral. Mh.*, **1990**, 401-412.
- Thompson, J.B., Jr. (1978): Biopyriboles and polysomatic series. *Am. Mineral.*, **63**, 239-249.
- Tindle, A.G. & Breaks, F.W. (1998): Oxide minerals of the Separation Rapids rare-element granitic pegmatite group, northwestern Ontario. *Can. Mineral.*, **36**, 609-635.
- Yvon, K., Jeitschko, W., Parthé, E. (1977): LAZYPULVERIX, a computer program, for calculating X-ray and neutron diffraction powder patterns. *J. Appl. Cryst.*, **10**, 73-74.

Received 27 July 2001

Modified version received 21 August 2001

Accepted 19 September 2001

