



Article

Nomenclature of the magnetoplumbite group

Dan Holtstam¹ and Ulf Hålenius¹

¹Department of Geosciences, Swedish Museum of Natural History, Box 50007, SE-104 05 Stockholm, Sweden

Abstract

A nomenclature and classification scheme has been approved by IMA–CNMNC for the magnetoplumbite group, with the general formula $A[B_{12}]O_{19}$. The classification on the highest hierarchical level is decided by the dominant metal at the 12-coordinated *A* sites, at present leading to the magnetoplumbite ($A = \text{Pb}$), hawthorneite ($A = \text{Ba}$) and hibonite ($A = \text{Ca}$) subgroups. Two species remain ungrouped. Most cations, with valences from 2+ to 5+, show a strong order over the five crystallographic *B* sites present in the crystal structure, which forms the basis for the definition of different mineral species. A new mineral name, chihuahuaite, is introduced and replaces hibonite-(Fe).

Keywords: magnetoplumbite group, plumboferrite, chihuahuaite, hexagonal ferrite, hexagonal aluminate, mineral nomenclature, mineral classification

(Received 13 February 2020; accepted 23 March 2020; Accepted Manuscript published online: 26 March 2020; Associate Editor: Anthony R Kampf)

Introduction

The mineral magnetoplumbite was described by Aminoff (1925) from the Långban iron-manganese mines, Värmland County, Sweden. The formula and the topology of the crystal structure was first correctly interpreted by Adelsköld (1938). The composition of this archetypal mineral is given as ideally $\text{Pb}[\text{Fe}_{12}]\text{O}_{19}$. It is isostructural with $\text{Ba}[\text{Fe}_{12}]\text{O}_{19}$ (barioferrite), a common synthetic permanent magnetic material (e.g. Pullar, 2012). They both belong to a wider family of compounds, the so-called hexagonal ferrites (or hexaferrites). The group members (Table 1) are rare as minerals, but are found in a variety of geological environments, including metasomatic skarns, high-grade metamorphic rocks (granulites), kimberlites, lherzolites, lamproites, volcanic and pyrometamorphic rocks and chondritic meteorites, altogether indicating significantly wide P – T – f_{O_2} stability conditions for the structure type. The minerals of the group, all possessing basic hexagonal crystal symmetry, are described by the general formula $AB_{12}O_{19}$, where *A* is a large cation (A^{2+} or A^{1+}) and *B* usually represents more highly charged cations of intermediate size. In the present paper, we announce the newly approved (by the Commission on New Minerals, Nomenclature and Classification of the International Mineralogical Association, IMA–CNMNC) nomenclature for the magnetoplumbite group (decision 95–SM/20, Miyawaki *et al.*, 2020). It should be noted that in this context, we use the commonly accepted formulae of mineral species; the exactness of some of them might be questioned, and a future revision based on reinvestigation of type specimens is desirable.

Author for correspondence: Dan Holtstam, Email: dan.holtstam@nrm.se

Cite this article: Holtstam D. and Hålenius U. (2020) Nomenclature of the magnetoplumbite group. *Mineralogical Magazine* 84, 376–380. <https://doi.org/10.1180/mgm.2020.20>

Crystal structure

Many detailed studies of the crystal structure exist (e.g. Obradors *et al.*, 1985; Utsunomiya *et al.*, 1988; Moore *et al.*, 1989; Wagner 1998). It is based on an essentially closest-packed arrangement of oxygen (O) and *A* atoms, with *B* metals occupying voids. One fundamental building block, *S*, forms a CCP two-layer sequence, $\cdot\text{cc}\cdot$. A fraction of the interstitial sites is occupied by metal atoms in the same fashion as in the spinel structure, which gives an overall composition $\{B_6O_8\}^{2+}$ of the block. A different block, denoted *R*, is built up of a three-layer HCP sequence, $\cdot\text{hhh}\cdot$. A quarter of the O atoms of the intermediate *h* layer is replaced by a large cation *A* (usually Ba^{2+} , Pb^{2+} , Ca^{2+} or K^+ in minerals). Taking the interstitial *B* atoms into consideration, *R* is equal to $\{AB_6O_{11}\}^{2-}$ in composition. By stacking of the blocks along the hexagonal *c* axis in the sequence $\cdot\text{RSR}^*\text{S}^*$, with a repeat of 22–23 Å, the magnetoplumbite unit cell with $Z = 2$ is obtained (Fig. 1). Starred blocks are rotated 180° in accordance with the space-group symmetry of the crystal structure, $P6_3/mmc$. The *a* unit-cell dimension is ~ 5.6 Å ($= 4 \times$ the radius of O^{2-}).

In the structure, the large *A* cation is ideally 12-coordinated to O, forming a triangular orthobicupola, at $(\frac{2}{3}, \frac{1}{3}, \frac{1}{4})$. The interstitial *B* atoms occupy five unique sites with designations *M1*–*M5*. (Table 2). The five-fold coordinated *M2* atom, ideally located at the centre of a trigonal bipyramid (*2b*), is in reality slightly displaced (split) into two statistically half-occupied, pseudotetrahedral *4e* sites (Obradors *et al.*, 1985). This kind of disorder is dynamic in most situations, i.e. a rapid diffusion of the metal atom takes place through the mirror plane of the bipyramid (Kimura *et al.*, 1990; Kreisel *et al.*, 1998; Du and Stebbins, 2004; Krz̄ała *et al.*, 2018). The *M4* coordination polyhedra are trigonally distorted octahedra that occur in pairs sharing a common face in a hematite-like arrangement, i.e. forming B_2O_9 dimers.

Table 1. The presently valid magnetoplumbite-group minerals.

Name	Formula	Type locality	References
Plumboferrite	Pb[Fe _{10.67} Mn _{0.33} Pb]O _{18.33}	Jakobsberg mine, Värmland, Sweden	Igelström (1881); Holtstam <i>et al.</i> (1995)
Magnetoplumbite	Pb[Fe ₁₂]O ₁₉	Långban mines, Värmland, Sweden	Aminoff (1925); Holtstam (1994)
Hibonite	Ca[Al ₁₂]O ₁₉	Esiva alluvial deposit, Madagascar	Curien <i>et al.</i> (1956); Bermanec <i>et al.</i> (1996)
Yimengite	K[Ti ₃ Cr ₅ Fe ₂ ³⁺ Mg ₂ ²⁺]O ₁₉	Yimeng Shan, Shangdong, China	Dong <i>et al.</i> (1983); Peng ad Lu (1985)
Hawthorneite	Ba[Ti ₃ Cr ₄ Fe ₂ ³⁺ Fe ₂ ²⁺ Mg]O ₁₉	Bultfontein diamond mine, Northern Cape, South Africa	Grey <i>et al.</i> (1987); Haggerty <i>et al.</i> (1989)
Nežilovite	Pb[Mn ₂ ⁴⁺ Fe ₇ AlZn ₂]O ₁₉	Nežilovo, North Macedonia	Bermanec <i>et al.</i> (1996)
Haggertyite	Ba[Ti ₅ Fe ₃ ³⁺ Fe ₂ ²⁺ Mg]O ₁₉	Crater of Diamonds State Park, Arkansas, USA	Grey <i>et al.</i> (1998)
Batiferrite	Ba[Ti ₅ Fe ₈ ³⁺ Fe ₂ ²⁺]O ₁₉	Üdersdorf, Eifel area, Germany	Lengauer <i>et al.</i> (2001)
Barioferrite	Ba[Fe ₁₂]O ₁₉	Mount Ye'elim, Hatrurim Complex, Israel	Murashko <i>et al.</i> (2011)
Hibonite-(Fe)*	Fe ²⁺ [Al ₁₂]O ₁₉	Allende carbonaceous chondrite, Mexico	Ma (2010)
Gorerite	Ca[AlFe ₁₁]O ₁₉	Hatrurim Complex, Israel	Galuskin <i>et al.</i> (2019)

*Here renamed chihuahuaite

The total unit-cell contents for an $AB_{12}O_{19}$ compound can thus be expressed as $A_2[{}^{6i}(M1)_2\ {}^{5i}(M2)_2\ {}^{4i}(M3)_4\ {}^{6i}(M4)_4\ {}^{6i}(M5)_{12}]_{\Sigma 24}O_{38}$.

The magnetic structure of magnetoplumbite can be described by the Néel model of ferrimagnetism. The spin orientation of Fe^{3+} at each site (Table 2) is a result of superexchange interaction through the O^{2-} ions. As the cation has a spin-only magnetic moment of $5\ \mu_B$ (Bohr magnetons), the total magnetisation per formula unit would be $(6-2-2+1+1) \times 5\ \mu_B = 20\ \mu_B$ at absolute temperature, which is in good agreement with experimental results (Kojima, 1982). Magnetoplumbite possesses a large magnetocrystalline anisotropy, which is related to a strong preference of the magnetic moments of the ions to align along c .

β -alumina (diaoyudaoite), ideally $Na[Al_{11}]O_{17}$, is a structural derivative of magnetoplumbite (Felsche, 1968) and a common solid-state ion conductor and catalyst. The three $O3$ atoms at $6h$ ($x, -x, \frac{1}{4}$) in the middle h layer of the R block have collapsed to a single point $2c$ ($\frac{1}{3}, \frac{2}{3}, \frac{1}{4}$), compensating for the total lower charge of the metal atoms in this compound. Consequently, R encompasses $\{AB_5O_9\}^{2-}$ and does not contain the nominally 5-coordinated $M2$ site. The mirror planes at $z = \frac{1}{4}$ and $\frac{3}{4}$ correspond to the ion conduction layer in β -alumina.

Nomenclature

Name of the group

Prior to this work, the group had not been formally approved by CNMNC. However the term 'magnetoplumbite group' is prevalent in the literature. Strunz and Nickel (2001) denominated the oxide subclass 4.CC.45 as the magnetoplumbite group, which included diaoyudaoite, plumboferrite and lindqvistite. In recent editions of Fleischer's Glossary of Mineral Species (Back, 2018) the 'plumboferrite group', covering the same group of minerals (Table 1), has been introduced. It was then in principle used as a synonym of the magnetoplumbite group.

Although plumboferrite has historical precedence over magnetoplumbite (discovered in 1881 and 1925, respectively), there are several good arguments to keep magnetoplumbite in the group name. In chemistry and materials science, the concept of magnetoplumbite (or simply 'M') type compounds for substances possessing a certain crystal structure is extremely well established (e.g. Collongues *et al.*, 1990; Pullar, 2012). It would be misleading if the mineralogical nomenclature deviated from other areas of science. The true interpretation of the composition of plumboferrite, and its close relationship to magnetoplumbite is in fact a relatively late insight (Holtstam *et al.*, 1995). Furthermore, plumboferrite is atypical in its formula and slightly different in atomic arrangement compared to other members, including positional disorder of Pb atoms and oxygen vacancies (related to $6s^2$ lone electron-pair effects of the Pb^{2+} ion) in the region of $z = \frac{1}{4}$ that give rise to weak superstructure reflections in X-ray diffraction data. This species is thus not ideal as an archetype for the group as a whole, although the deviations do not support it to be kept outside the group. The present choice agrees with the statement by Mills *et al.* (2009): "a group or a supergroup name can be selected contrary to the precedence rule because the name of this group (supergroup) is very firmly established in the literature."

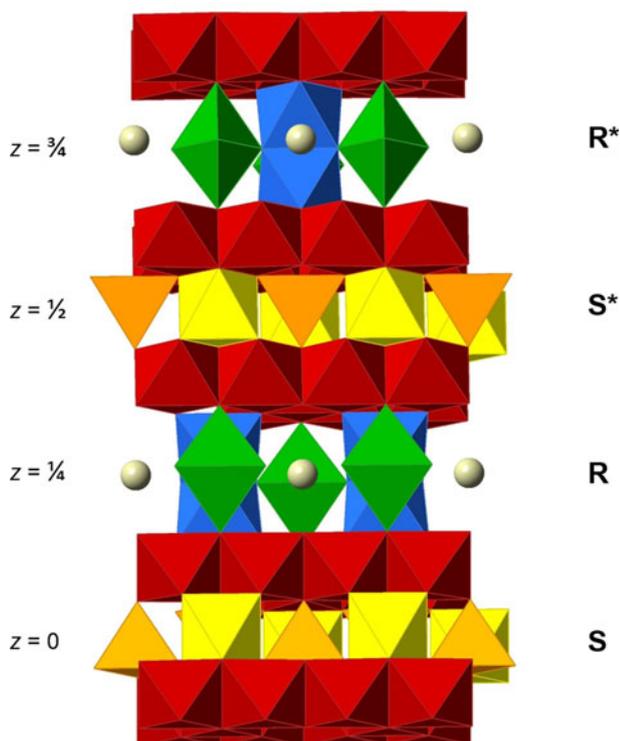


Fig. 1. Polyhedral representation of the ideal magnetoplumbite-type structure viewed approximately along [310]. The $M1$ octahedra (yellow) and the $M3$ tetrahedra (orange) are in the central section of the S block. The trigonal bipyramidal $M2$ positions (green), face-sharing $M4$ octahedra (blue) and the large A atoms (grey spheres) belong to the central part of the R block. Layers of edge-sharing $M5$ octahedra (red) are sandwiched between the cores of blocks.

Table 2. Properties of crystallographic sites for *A* and *B* metal atoms in magnetoplumbite-group minerals.

Site	Wyckoff position	CN	Point symmetry	Block	Magnetic spin (Fe ³⁺)
<i>A</i>	2 <i>d</i>	12	$\bar{6}m2$	R	
<i>M1</i>	2 <i>a</i>	6	$\bar{3}m$	S	↑
<i>M2</i>	2 <i>b</i> (4 <i>e</i>)	5 (4 + 1)	$\bar{6}m2$ (3 <i>m</i>)	R	↑
<i>M3</i>	4 <i>f</i>	4	3 <i>m</i>	S	↓
<i>M4</i>	4 <i>f</i>	6	3 <i>m</i>	R	↓
<i>M5</i>	12 <i>k</i>	6	<i>m</i>	R-S	↑

CN – coordination number

Table 3. Classification of the magnetoplumbite group.**Magnetoplumbite subgroup, A = Pb**

Magnetoplumbite

Plumboferrite

Nežilovite

Hawthorneite subgroup, A = Ba

Hawthorneite

Haggertyite

Batiferrite

Barioferrite

Hibonite subgroup, A = Ca

Hibonite

Gorerite

Members that do not belong to a subgroup

Yimengite, A = K

Chihuahuaite [previously hibonite-(Fe)], A = Fe²⁺**Consequences**

Although the β-alumina-type minerals, presently diaoyudaite (Shen *et al.*, 1986) and kahlenbergite, K[Al₁₁]O₁₇ (Krüger *et al.*, 2019), were included in a previous grouping, they are not part of the present nomenclature because of the requirement of isostructurality.

The mineral name hibonite-(Fe), for Fe[Al₁₂]O₁₉ (Ma, 2010), does not fit well in this scheme as it does not belong to the same subgroup as the parent mineral, hibonite. In addition, suffixes tend to make nomenclature unnecessarily complex. Hibonite-(Fe) is thus assigned a new root name, 'chihuahuaite', after the state (estado) of Mexico where Allende, the holotype host meteorite fell in 1969 (King *et al.*, 1969). Levison modifiers may, however, be used if rare earth element (REE) dominant species are to be approved (with new root names).

Lindqvistite, Pb[Fe₁₆Pb(Mn,Mg)]O₂₇, is a related mineral (Holtstam and Norrestam, 1993). It has the block stacking

sequence ·RSSR*S*S* and thus a different topology than magnetoplumbite. Lindqvistite is consequently not counted as a member of the magnetoplumbite group. Galuskin *et al.* (2018) have reported closely related Ba- and K-dominant ferrites from Jabel Harmun, West Bank, Palestinian Territories. Further discoveries could motivate the creation of a supergroup, covering different stacking themes among naturally occurring ferrites.

Subdivision

The nomenclature is devised to be simple and flexible at the same time. The group is divided into subgroups based on composition, specifically the dominant *A*-type cation (Table 3). The rationale for this scheme is that variations in *A* atom composition tend to be less complex compared to that of *B* atoms, and information on the precise stoichiometry, including any structural vacancies at cation or anion sites that might be present, is not necessary to determine the position at the highest hierarchical level in the group.

Definition of species

Individual species of the magnetoplumbite group are further defined from their composition and distribution of cations over the *B*-type positions (Table 4). Monovalent, divalent, tetravalent and pentavalent cations are incorporated in the magnetoplumbite structure by charge-coupled substitutions of A²⁺ or B³⁺ ions (Table 5). It is evident that a large number of theoretically possible combinations of cation arrangements exist. However, studies on both minerals and synthetic materials show that most cations exhibit preferential ordering depending on their ionic size, charge and electronic configuration (Grey *et al.*, 1987; Wagner and O'Keefe, 1988; Xie and Cormack, 1990; Bermanec *et al.*, 1996; Holtstam, 1996; Nagashima *et al.*, 2010). An important trend observed is that divalent *B*-type ions strongly prefer the tetrahedrally coordinated *M3* sites (Batlle *et al.*, 1991), whereas highly charged species, like Ti⁴⁺, Mn⁴⁺ and Sb⁵⁺, become enriched in the *M4* octahedra (Doyle *et al.*, 2014; Nemrava *et al.*, 2017). For compositions with a high degree of replacement of trivalent ions, divalent species also become concentrated at octahedrally coordinated sites, preferentially *M5* (Cabañas *et al.*, 1994). Some trivalent *d* cations (Cr³⁺ and Mn³⁺) are ordered at the distorted *M5* octahedra (e.g. Katlakunta *et al.*, 2015; Shlyk *et al.*, 2015; Nemrava *et al.*, 2017). This behaviour is explained largely by crystal-field effects. The Fe³⁺ cation, in cases when diluted in the compound and less abundant among *B* positions, e.g. in hibonite, is accumulated at *M2* and *M3* (Holtstam, 1996; Medina and Subramanian, 2017). Al³⁺ in turn, when competing with other trivalent species, tends

Table 4. Major components at the cation sites of magnetoplumbite-group minerals. Species-defining elements are given in bold.

Mineral	<i>A</i>	<i>M1</i>	<i>M2</i>	<i>M3</i>	<i>M4</i>	<i>M5</i>
Magnetoplumbite	Pb	Fe³⁺	Fe³⁺	Fe³⁺ , Mn ²⁺	Fe³⁺ , Ti ⁴⁺ , Sb ⁵⁺	Fe³⁺ , Mn ³⁺
Plumboferrite	Pb	Fe³⁺	Pb²⁺	Fe³⁺ , Mn ²⁺	Fe³⁺	Fe³⁺
Nežilovite	Pb	Al	Fe³⁺	Zn	Mn⁴⁺ , Ti ⁴⁺	Fe³⁺ , Mn ³⁺
Hawthorneite	Ba	Cr³⁺	Fe³⁺	Fe²⁺ , Mg	Ti⁴⁺	Cr³⁺ , Fe³⁺
Haggertyite	Ba , K	Ti⁴⁺ , Fe³⁺	Fe³⁺	Fe²⁺	Ti⁴⁺	Ti⁴⁺ , Fe²⁺
Batiferrite	Ba	Fe³⁺	Fe³⁺	Fe²⁺	Ti⁴⁺ , Fe³⁺	Fe³⁺ , Ti⁴⁺
Barioferrite	Ba	Fe³⁺	Fe³⁺	Fe³⁺	Fe³⁺	Fe³⁺
Hibonite	Ca	Al	Al	Al	Al	Al
Gorerite	Ca	Al	Fe³⁺	Fe³⁺	Fe³⁺	Fe³⁺
Yimengite	K	Fe³⁺	Fe³⁺	Mg²⁺ , Fe²⁺	Ti⁴⁺	Cr³⁺
Chihuahuaite	Fe²⁺ , Mg	Al	Al	Al	Al	Al

Table 5. Significant types of substitution in the magnetoplumbite group.

Generalised substitution	Example
Homovalent	
$A^{2+} \rightarrow A^{2+}$	$Pb^{2+} \rightarrow Ba^{2+}$
$B^{3+} \rightarrow B^{3+}$	$Fe^{3+} \rightarrow Cr^{3+}$
Heterovalent	
$2B^{3+} \rightarrow B^{2+} + B^{4+}$	$2Al^{3+} \rightarrow Mg^{2+} + Ti^{4+}$
$3B^{3+} \rightarrow 2B^{2+} + B^{5+}$	$3Fe^{3+} \rightarrow 2Mn^{2+} + Sb^{5+}$
$A^{2+} + B^{3+} \rightarrow A^{1+} + B^{4+}$	$Ba^{2+} + Fe^{3+} \rightarrow K^{+} + Ti^{4+}$
$A^{2+} + B^{3+} \rightarrow A^{3+} + B^{2+}$	$Ca^{2+} + Al^{3+} \rightarrow REE^{3+} + Mg^{2+}$
$2B^{3+} + O^{2-} \rightarrow B^{2+} + B^{2+} + \square$	$2Fe^{3+} + O^{2-} \rightarrow Pb^{2+} + Mn^{2+} + \square$

*Describes the relation between magnetoplumbite and plumboferrite, and explains non-stoichiometry in some synthetic magnetoplumbite samples (Holtstam, 2003).

to be concentrated at M1 (Bermanec *et al.*, 1996), with the smallest octahedral volume.

New or unaccredited mineral compositions

In the literature, analytical data are available that suggest the existence of new, yet officially unrecognised members of the group. Titanium-rich analogues of yimengite and hawthorneite (~5 Ti atoms per formula unit) were analysed by Lu and Chou (1994). Lu *et al.* (2007) have described a “Ca analogue to yimengite” or rather a Ca analogue to hawthorneite, which would fit into the hibonite subgroup. Rezvukhin *et al.* (2019) recently found yimengite with high Al (>1 atom per formula unit) contents. Sandiford and Santosh (1991) described zoned ‘hibonite’ grains with REE-rich cores ($\Sigma REE > 0.6$ atoms per formula unit). Holtstam (1994) reported a Ti-rich magnetoplumbite sample for which Ti > Fe³⁺ at M4 could be inferred (a possible Pb analogue to batiferite). A Mn³⁺-analogue to plumboferrite was detected by Chukanov *et al.* (2016). Furthermore, Chukanov *et al.* (2019) recently published analyses of a Ba-dominant analogue to nežilovite and of an Al analogue to yimengite.

From a vast amount of studies of synthetic compounds, it can be speculated that many new natural members exist with, for example: $A = Sr^{2+}$, REE (Ce³⁺, La³⁺ etc.), Mg²⁺, Rb⁺, Cs⁺ or Ag⁺ along with enrichment in the B positions (non-exhaustive list) of: Si⁴⁺, Sc³⁺, Ti³⁺, V²⁺, V³⁺, V⁴⁺, Co²⁺, Ni²⁺, Cu²⁺, Ga³⁺, Ge⁴⁺, Zr⁴⁺, Nb⁵⁺, In³⁺, Sn⁴⁺, Te⁴⁺, Ta⁵⁺ or Bi³⁺ (e.g. Coutellier *et al.*, 1984; Morgan and Miles, 1986; Li *et al.*, 2016). The range of possible cation valences seem to be limited to 1–3 for A and 2–5 for B sites, which has implications when casting formulae of uncharacterised members of the group. Particular caution is needed for samples containing some of the divalent ionic species, as Fe²⁺, Mg²⁺ and Pb²⁺ have been shown to enter both kinds of sites. Substitutions at anion sites seem to be limited for this structure type.

Acknowledgements. Constructive comments on the original nomenclature proposal by members of the Commission on New Minerals, Nomenclature and Classification (CNMNC), and on the manuscript by two reviewers, are appreciated.

References

Adelsköld V. (1938) X-ray studies on magneto-plumbite, PbO·6Fe₂O₃, and other substances resembling “beta-alumina”, Na₂O·11Al₂O₃. *Arkiv för Kemi, Mineralogi och Geologi, Serie A-12*, **29**, 1–9.

Aminoff G. (1925) Über ein neues oxydisches mineral aus Långban. (Magnetoplumbit.) *Geologiska Föreningens i Stockholm Förhandlingar*, **47**, 283–289.

Back M. (2018) *Fleischer's Glossary of Mineral Species 2018*. Mineralogical Record Inc., Tucson, USA, 424 pp.

Battle X., Obradors X., Rodríguez-Carvajal J., Pernet M., Cabañas M.V. and Vallet M. (1991) Cation distribution and intrinsic magnetic properties of Co-Ti-doped M-type barium ferrite. *Journal of Applied Physics*, **70**, 1614–1623.

Bermanec V., Holtstam D., Sturman D., Criddle A.J., Back M.E. and Scavnicar S. (1996) Nežilovite, a new member of the magnetoplumbite group, and the crystal chemistry of magnetoplumbite and hibonite. *The Canadian Mineralogist*, **34**, 1287–1297.

Cabañas M.V., González-Calbet J.M., Rodríguez-Carvajal J. and Vallet-Regi M. (1994) The solid solution BaFe_{12-2x}Co_xTi_xO₁₉ (0 ≤ x ≤ 6): cationic distribution by neutron diffraction. *Journal of Solid State Chemistry*, **111**, 229–237.

Chukanov N.V., Aksenov S.M., Jančev S., Pekov I.V., Göttlicher J., Polekhovskiy Y.S., Rusakov V.S., Nelyubina, Y.V. and Van K.V. (2016) A new mineral species ferricronadite, Pb[Mn₆⁴⁺(Fe³⁺, Mn³⁺)₂]O₁₆; mineralogical characterization, crystal chemistry and physical properties. *Physics and Chemistry of Minerals*, **43**, 503–514.

Chukanov N.V., Vorobei, S.S., Ermolaeva V.N., Varlamov D.A., Plechov P.Y., Jančev, S. and Bovkun A.V. (2019) New data on chemical composition and vibrational spectra of magnetoplumbite-group minerals. *Geology of Ore Deposits*, **61**, 637–646.

Collongues R., Gourier D., Kahn-Harari A., Lejus A.M., They J. and Vivien, D. (1990) Magnetoplumbite-related oxides. *Annual Review of Materials Science*, **20**, 51–82.

Coutellier J.M., Ferrand B., Daval J., Grange, Y. and Joubert J.C. (1984) Research of substituted hexagallate substrates for the epitaxy of hexaferrite films. *Materials Research Bulletin*, **19**, 1037–1046.

Curien H., Guillemin C., Oorcel J.T. and Sternberg M. (1956) La hibonite, nouvelle espèce minérale. *Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences*, **242**, 2845–2847.

Dong Z., Zhou J., Lu Q. and Peng Z. (1983) Yimengite, K(Cr,Ti,Fe,Mg)₁₂O₁₉, a new mineral from China. *Kexue Tongbao*, **15**, 932–936 [in Chinese].

Doyle P.M., Schofield P.F., Berry A.J., Walker A.M. and Knight K.S. (2014) Substitution of Ti³⁺ and Ti⁴⁺ in hibonite (CaAl₁₂O₁₉). *American Mineralogist*, **99**, 1369–1382.

Du L.S. and Stebbins J.F. (2004) Calcium and strontium hexaluminates: NMR evidence that “pentacoordinate” cation sites are four-coordinated. *Journal of Physical Chemistry B*, **108**, 3681–3685.

Felsche J. (1968) The alkali problem in the crystal structure of beta alumina. *Zeitschrift für Kristallographie*, **127**, 94–100.

Galuskin E.V., Galuskina I.O., Widmer R. and Armbruster, T. (2018) First natural hexaferrite with mixed β''-ferrite (β-alumina) and magnetoplumbite structure from Jabel Harmun, Palestinian Autonomy. *European Journal of Mineralogy*, **30**, 559–567.

Galuskin E.V., Krüger B., Galuskina I.O., Krüger H., Nejbert K., Vapnik Ye. and Tomizaki, T. (2019) Gorerite, IMA 2019-080. CNMNC Newsletter No. 52, December 2019, page 892; *Mineralogical Magazine*, **83**, 887–893.

Grey I.E., Madsen, I.C. and Haggerty S.E. (1987) Structure of a new upper-mantle, magnetoplumbite-type phase, Ba[Ti₃Cr₄Fe₄Mg]O₁₉. *American Mineralogist*, **72**, 633–636.

Grey I.E., Velde, D. and Criddle A.J. (1998) Haggertyite, a new magnetoplumbite-type titanate mineral from the Prairie Creek (Arkansas) lamproite. *American Mineralogist*, **83**, 1323–1329.

Haggerty S.E., Grey I.E., Madsen I.C., Criddle A.J., Stanley, C.J. and Erlank A.J. (1989) Hawthorneite, Ba[Ti₃Cr₄Fe₄Mg]O₁₉; a new metasomatic magnetoplumbite-type mineral from the upper mantle. *American Mineralogist*, **74**, 668–675.

Holtstam D. and Norrestam R. (1993) Lindqvistite, Pb₂MeFe₁₆O₂₇, a novel hexagonal ferrite mineral from Jakobsberg, Filipstad, Sweden. *American Mineralogist*, **78**, 1304–1312.

Holtstam D. (1994) Mineral chemistry and parageneses of magnetoplumbite from the Filipstad district, Sweden. *European Journal of Mineralogy*, **6**, 711–724.

Holtstam D., Norrestam R. and Sjödin A. (1995) Plumboferrite: new mineralogical data and atomic arrangement. *American Mineralogist*, **80**, 1065–1072.

Holtstam D. (1996) Iron in hibonite: a spectroscopic study. *Physics and Chemistry of Minerals*, **23**, 452–460.

- Holtstam D. (2003) Synthesis and nonstoichiometry of magnetoplumbite. *Neues Jahrbuch für Mineralogie-Monatshefte*, **2003**, 55–73.
- Igelström L.J. (1881) Plumboferrit, ett nytt mineral från Jakobsbergs manganmalmsgrufva vid Nordmarken i Wermland. *Öfversigt af Kongliga Vetenskaps-Akademiens Förhandlingar*, **38**, 27–31.
- Katlakunta S., Meena S.S., Srinath S., Bououdina M., Sandhya R. and Praveena K. (2015) Improved magnetic properties of Cr³⁺ doped SrFe₁₂O₁₉ synthesized via microwave hydrothermal route. *Materials Research Bulletin*, **63**, 58–66.
- Kimura K., Ohgaki M., Tanaka K., Morikawa H. and Marumo F. (1990) Study of the bipyramidal site in magnetoplumbite-like compounds, SrM₁₂O₁₉ (M = Al, Fe, Ga). *Journal of Solid State Chemistry*, **87**, 186–194.
- King E.A., Richardson K.A., Schonfeld E. and Eldridge J.S. (1969) Meteorite fall at Pueblito de Allende, Chihuahua, Mexico-Preliminary information. *Science*, **163**, 928–929.
- Kojima H. (1982) Fundamental properties of hexagonal ferrites with magnetoplumbite structure. Pp. 305–391 in: *Handbook of Ferromagnetic Materials, Volume 3* (E.P. Wohlfarth, editor). North-Holland, Amsterdam.
- Kreisel J., Lucazeau G. and Vincent H. (1998) Raman spectra and vibrational analysis of BaFe₁₂O₁₉ hexagonal ferrite. *Journal of Solid State Chemistry*, **137**, 127–137.
- Krüger B., Galuskin E.V., Galuskina I.O., Krüger H. and Vapnik Y. (2019) Kahlenbergite, IMA 2018-158. CNMNC Newsletter No. 49, June 2019, page 480; *Mineralogical Magazine*, **83**, 479–493.
- Krzatęła A., Panikorovskii T., Galuskina I. and Galuskin E. (2018) Dynamic disorder of Fe³⁺ ions in the crystal structure of natural barioferrite. *Minerals*, **8**, 340.
- Langgauer C. L., Tillmanns E. and Hentschel G. (2001) Batiferrite, Ba[Ti₂Fe₁₀]O₁₉, a new ferrimagnetic magnetoplumbite-type mineral from the Quaternary volcanic rocks of the western Eifel area, Germany. *Mineralogy and Petrology*, **71**, 1–19.
- Li J., Medinam E.A., Stalick J.K., Sleight A.W. and Subramanian M.A. (2016) Colored oxides with hibonite structure: A potential route to non-cobalt blue pigments. *Progress in Solid State Chemistry*, **44**, 107–122.
- Lu Q. and Chou H. (1994) Newly discovered members of yimengite isomorphous series: K(Ti₅Fe₃Cr₂Mg₂)O₁₉ and Ba(Ti₅Fe₄Mg₂Cr)O₁₉. *Acta Mineralogica Sinica*, **14**, 228–233.
- Lu Q., Liu H. and Xiao P. (2007) Ca-yimengite, another new mineral in kimberlite, Shandong Province. *Geological Science and Technology Information*, **26**, 1–7.
- Ma Ch. (2010) Hibonite-(Fe), (Fe, Mg)Al₁₂O₁₉, a new alteration mineral from the Allende meteorite. *American Mineralogist*, **95**, 188–191.
- Medina E.A., Li J. and Subramanian M.A. (2017) Colored oxides with hibonite structure II: structural and optical properties of CaAl₁₂O₁₉-type pigments with chromophores based on Fe, Mn, Cr and Cu. *Progress in Solid State Chemistry*, **45**, 9–29.
- Mills S.J., Hatert F., Nickel E.H. and Ferraris G. (2009) The standardisation of mineral group hierarchies: application to recent nomenclature proposals. *European Journal of Mineralogy*, **21**, 1073–1080.
- Miyawaki R., Hatert F., Pasero M. and Mills S.J. (2020) New minerals and nomenclature modifications approved in 2019. IMA Commission on New Minerals, Nomenclature and Classification (CNMNC), Newsletter 54. *Mineralogical Magazine*, **84**, doi:10.1180/mgm.2020.21
- Moore P.B., Sen Gupta P.K. and Le Page Y. (1989) Magnetoplumbite, Pb²⁺Fe₁₂³⁺O₁₉: Refinement and lone-pair splitting. *American Mineralogist*, **74**, 1186–1194.
- Morgan P.E. and Miles J.A. (1986) Magnetoplumbite-type compounds: Further discussion. *Journal of the American Ceramic Society*, **69**, C-157.
- Murashko M.N., Chukanov N.V., Mukhanova A.A., Vapnik E., Britvin S.N., Polekhovskiy Y.S. and Ivakin Y. D. (2011) Barioferrite BaFe₁₂O₁₉: A new mineral species of the magnetoplumbite group from the Haturim Formation in Israel. *Geology of Ore Deposits*, **53**, 558–563.
- Nagashima M., Armbruster T. and Hainschwang T. (2010) A temperature-dependent structure study of gem-quality hibonite from Myanmar. *Mineralogical Magazine*, **74**, 871–885.
- Nemrava S., Vinnik D.A., Hu Z., Valldor M., Kuo C.Y., Zhrebtsov D.A., Gudkova S.A., Chen C.-T., Tjeng L.-H. and Niewa, R. (2017) Three oxidation states of manganese in the barium hexaferrite BaFe_{12-x}Mn_xO₁₉. *Inorganic Chemistry*, **56**, 3861–3866.
- Obassadors X., Collomb A., Pernet M., Samaras D. and Joubert J.C. (1985) X-ray analysis of the structural and dynamic properties of BaFe₁₂O₁₉ hexagonal ferrite at room temperature. *Journal of Solid State Chemistry*, **56**, 171–181.
- Peng Z. and Lu Q. (1985) The crystal structure of yimengite. *Science in China Series B-Chemistry, Biological, Agricultural, Medical & Earth Sciences*, **28**, 882–887.
- Pullar R.C. (2012) Hexagonal ferrites: a review of the synthesis, properties and applications of hexaferrite ceramics. *Progress in Materials Science*, **57**, 1191–1334.
- Rezvukhin D.I., Alifirova T.A., Korsakov A.V. and Golovin A.V. (2019) A new occurrence of yimengite-hawthorneite and crichtonite-group minerals in an orthopyroxenite from kimberlite: Implications for mantle metasomatism. *American Mineralogist*, **104**, 761–774.
- Sandiford M. and Santosh M. (1991) A granulite facies kalsilite-leucite-hibonite association from Punalur, Southern India. *Mineralogy and Petrology*, **43**, 225–236.
- Shen S., Chen L., Li A., Dong T., Huang Q. and Xu W. (1986) Diaoyudaoite – a new mineral. *Acta Mineralogica Sinica*, **6**, 224–227 [in Chinese with English abstract].
- Shlyk L., Vinnik D. A., Zhrebtsov D. A., Hu Z., Kuo C.Y., Chang C.F., Lin H.J., Yang L.Y., Semisalovaeh A.S., Perov N.S. and Langer T. (2015) Single crystal growth, structural characteristics and magnetic properties of chromium substituted M-type ferrites. *Solid State Sciences*, **50**, 23–31.
- Strunz H. and Nickel E.H. (2001) *Strunz Mineralogical Tables: Chemical-Structural Mineral Classification System (9th edition)*. Schweizerbart, Stuttgart, Germany, 870 pp.
- Utsunomiya A., Tanaka K., Morikawa H., Marumo F. and Kojima H. (1988) Structure refinement of CaO-6Al₂O₃. *Journal of Solid State Chemistry*, **75**, 197–200.
- Wagner T.R. and O'Keeffe M. (1988) Bond lengths and valences in aluminates with the magnetoplumbite and β-alumina structures. *Journal of Solid State Chemistry*, **73**, 211–216.
- Wagner T.R. (1998) Preparation and crystal structure analysis of magnetoplumbite-type BaGa₁₂O₁₉. *Journal of Solid State Chemistry*, **136**, 120–124.
- Xie, L. and Cormack A.N. (1990) Cation distribution in magnetoplumbite and β''-alumina structures. *Materials Letters*, **9**, 474–479.