

# Nomenclature for the laueite supergroup

S. J. MILLS<sup>1,\*</sup> AND I. E. GREY<sup>2</sup>

<sup>1</sup> Geosciences, Museum Victoria, GPO Box 666, Melbourne, Victoria 3001, Australia

<sup>2</sup> CSIRO Mineral Resources, Private Bag 10, Clayton South, Victoria 3169, Australia

[Received 17 August 2014; Accepted 17 September 2014; Associate Editor: A. Christy]

## ABSTRACT

A new nomenclature scheme has been set up for the laueite supergroup of minerals, which have the general formula  $M1^{2+}M2^{3+}M3^{3+}(XO_4)_2(OH)_2 \cdot 8H_2O$ , where  $M1 = Fe^{2+}$ ,  $Mg^{2+}$  or  $Mn^{2+}$ ;  $M2/M3 = Al^{3+}$  or  $Fe^{3+}$ ; and  $XO_4 = PO_4$  or  $AsO_4$ . The laueite supergroup is divided into the laueite group ( $XO_4 = PO_4$ ) and the maghrebite group ( $XO_4 = AsO_4$ ). These groups are then subdivided into subgroups on the basis of the dominant atoms,  $Al^{3+}$  or  $Fe^{3+}$ , in octahedral sites  $M2/M3$ . The new nomenclature has been approved by the International Mineralogical Association Commission on New Minerals, Nomenclature and Classification, proposal 14-F.

**KEYWORDS:** laueite supergroup, laueite, maghrebite, crystal structure, group nomenclature.

## Introduction

THE term ‘laueite group’ has come into common usage recently (Krivovichev, 2004; Meisser *et al.*, 2012; Scholz *et al.*, 2014) to refer to minerals with structures based on so-called laueite-type heteropolyhedral sheets (Moore, 1965) and having the general formula  $M1^{2+}M2^{3+}M3^{3+}(XO_4)_2(OH)_2 \cdot 8H_2O$ , where  $M1 = Fe^{2+}$ ,  $Mg^{2+}$  or  $Mn^{2+}$ ;  $M2/M3 = Al^{3+}$  or  $Fe^{3+}$ ; and  $X = P^{5+}$  or  $As^{5+}$ . The sheet motif, parallel to (010) is shown in Fig. 1. It comprises 7 Å kinked chains of *trans*-connected octahedra along [001] containing alternately  $M2$  and  $M3$ . Adjacent chains are linked along [100] by corner connections with  $XO_4$  tetrahedra. The sheets are connected along [010] by corner connections of the  $XO_4$  tetrahedra with  $M1O_2(H_2O)_4$  octahedra as shown in Fig. 2. The minerals generally have a divalent cation in  $M1$ , although there is also an oxidized species, sigloite (Hawthorne, 1988), with  $Fe^{3+}$  in the  $M1$  site.

## Nomenclature considerations

Following the recent description of new members with  $XO_4 = PO_4$  (Segeler *et al.*, 2012) and  $AsO_4$

(Meisser *et al.*, 2012; Scholz *et al.*, 2014), there was a need to formalize the use of laueite as a supergroup, containing separate groups with  $X = PO_4$  and  $AsO_4$ . Using the procedures developed by Mills *et al.* (2009) for standardization of mineral-group hierarchies, a grouping of laueite-related minerals was proposed to the International Mineralogical Association Commission on New Minerals, Nomenclature and Classification (IMA-CNMNC) and was accepted on August 7, 2014 (proposal 14-F). The assignment of minerals to the laueite supergroup is summarized in Table 1.

Laueite was the first mineral in Table 1 to have its structure determined by Moore in 1965, and the term ‘laueite group’ has been used frequently in publications to refer to the minerals in this list (e.g. Krivovichev, 2004; Meisser *et al.*, 2012; Scholz *et al.*, 2014). Consistent with Mills *et al.* (2009), laueite is the name to be used for the supergroup, which is divided at the highest level on the basis of the main anion, into the laueite group (phosphates) and the maghrebite group (arsenates). These groups are then subdivided into subgroups on the basis of the dominant cation,  $Al^{3+}$  or  $Fe^{3+}$ , in the octahedral sites  $M2/M3$ . This is analogous to the jahnsite group in which the minerals are subdivided into whiteites and jahnsites based upon the dominance of  $Al^{3+}$  or  $Fe^{3+}$ , respectively, in the  $M3$  site (Moore and Ito, 1978).

\* E-mail: smills@museum.vic.gov.au  
DOI: 10.1180/minmag.2015.079.2.02

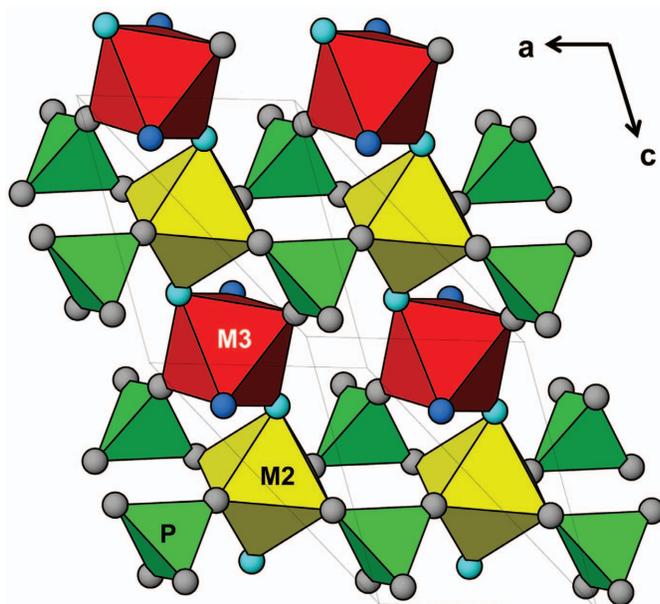


FIG. 1. Laueite heteropolyhedral sheet. Small grey, light blue and dark blue spheres are coordinated oxygen, hydroxyl and water, respectively.

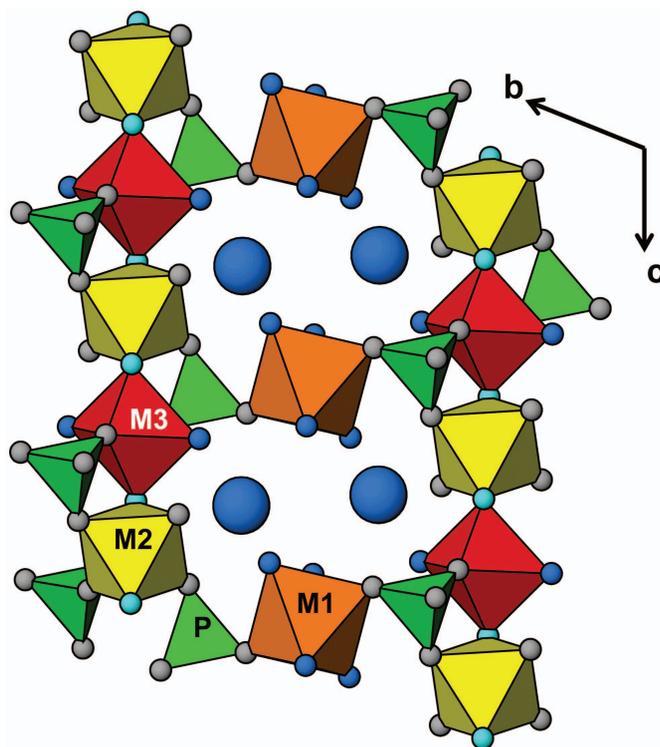


FIG. 2. Connectivity between laueite sheets. Small grey, light blue and dark blue spheres are coordinated oxygen, hydroxyl and water, respectively. Large blue spheres are interlayer water molecules.

TABLE 1. Hierarchy for the laueite supergroup.

Group name	Mineral name	M1*	M2	M3	X	Structure reference
Laueite group	laueite	Mn <sup>2+</sup>	Fe <sup>3+</sup>	Fe <sup>3+</sup>	P <sup>5+</sup>	Moore (1965)
	ushkovite	Mg <sup>2+</sup>	Fe <sup>3+</sup>	Fe <sup>3+</sup>	P <sup>5+</sup>	Galliski and Hawthorne (2002)
	ferrolaueite	Fe <sup>2+</sup>	Fe <sup>3+</sup>	Fe <sup>3+</sup>	P <sup>5+</sup>	Segeler <i>et al.</i> (2012)
	manganogordonite	Mn <sup>2+</sup>	Al <sup>3+</sup>	Al <sup>3+</sup>	P <sup>5+</sup>	Leavens and Rheingold (1988)
	gordonite	Mg <sup>2+</sup>	Al <sup>3+</sup>	Al <sup>3+</sup>	P <sup>5+</sup>	Leavens and Rheingold (1988)
	paravauxite	Mg <sup>2+</sup>	Al <sup>3+</sup>	Al <sup>3+</sup>	P <sup>5+</sup>	Baur (1969b)
	sigloite	Fe <sup>2+</sup>	Al <sup>3+</sup>	Al <sup>3+</sup>	P <sup>5+</sup>	Hawthorne (1988)
	curetonite	Fe <sup>3+</sup>	Al <sup>3+</sup>	Al <sup>3+</sup>	P <sup>5+</sup>	Cooper and Hawthorne (1994)
	unnamed	Ba <sup>2+</sup>	Al <sup>3+</sup>	Al <sup>3+</sup>	P <sup>5+</sup>	Cooper and Hawthorne (1994)
		Mn <sup>2+</sup>	Fe <sup>3+</sup>	Al <sup>3+</sup>	P <sup>5+</sup>	Grey <i>et al.</i> (2015)
Maghrebite group	césarferreiraite	Fe <sup>2+</sup>	Fe <sup>3+</sup>	Fe <sup>3+</sup>	As <sup>5+</sup>	Scholz <i>et al.</i> (2014)
	maghrebite	Mn <sup>2+</sup>	Al <sup>3+</sup>	Al <sup>3+</sup>	As <sup>5+</sup>	Meisser <i>et al.</i> (2012)

\* See text for explanation of differing coordinations for the M1 cations in sigloite and curetonite.

All currently accepted laueite-group minerals have the same dominant trivalent cation, Al<sup>3+</sup> or Fe<sup>3+</sup>, in both the M2 and M3 sites of the 7 Å chain; however, considering that the M2 and M3 sites have different coordinations, M2O<sub>4</sub>(OH)<sub>2</sub> and M3O<sub>2</sub>(OH)<sub>2</sub>(H<sub>2</sub>O)<sub>2</sub>, there appears to be no reason why each site could not contain a different dominant cation. Indeed, two synthetic phases with heteropolyhedral sheets that are topologically identical to those in laueite, but with M2 and M3 sites containing different cations, have been reported by Wang *et al.*, (2000): (enH<sub>2</sub>)NbFeOF(PO<sub>4</sub>)<sub>2</sub>(H<sub>2</sub>O)<sub>2</sub> [en = ethylenediamine] with Nb<sup>5+</sup> in site M2 and Fe<sup>3+</sup> in site M3 and (enH<sub>2</sub>)Ti(Fe,Cr)(F,O)(H<sub>0.3</sub>PO<sub>4</sub>)<sub>2</sub>(H<sub>2</sub>O)<sub>2</sub> with Ti<sup>4+</sup> in site M2 and Fe<sup>3+</sup>/Cr<sup>3+</sup> in site M3. We have also reported recently on intergrowths between laueite and mangangordonite at Hagendorf Süd, in which a single-crystal refinement on one of the compositions gave dominant Fe in site M2 and dominant Al in site M3 and would correspond to a new mineral species (Grey *et al.*, 2015).

The mineral curetonite, Ba(Al,Ti)(PO<sub>4</sub>)(OH,O)F (Cooper and Hawthorne, 1994) is included in Table 1, even though it has a different symmetry (monoclinic) and a different arrangement of interlayer cations from the other laueite supergroup members. The reason for its inclusion is that its sheet is topologically identical to the sheet in laueite. In addition, although the sheets are cross-linked by Ba<sup>2+</sup> cations rather than by M<sup>2+</sup>O<sub>2</sub>(H<sub>2</sub>O)<sub>4</sub> octahedra, the valence-matching principle (Brown, 1981) is maintained in both cases, as described by Cooper and Hawthorne (1994).

In contrast to curetonite, the minerals stewartite (Moore and Araki, 1974) and kastningite (Adiwidjaja *et al.*, 1999), which have similar compositions and symmetries to laueite-supergroup minerals, cannot be considered to belong to the laueite supergroup because their heteropolyhedral sheets are not topologically identical to those in laueite. In particular, the orientation of the PO<sub>4</sub> groups relative to the sheets differs from that in laueite, and they are classed as geometrical isomers (Moore, 1970, 1975; Krivovichev, 2004). Similarly, the structure layers of pseudolaueite (Baur, 1969a), metavauxite (Baur and Rao, 1967) and strunzite (Fanfani *et al.*, 1978) have a topologically different connectivity between the octahedra and tetrahedra and are thus topological isomers, while geometrical isomerism further separates pseudolaueite from metavauxite and strunzite (Krivovichev, 2004).

## Acknowledgements

We thank Tony Kampf and an anonymous reviewer for comments on the manuscript and members of the CNMNC for comments during the proposal process.

## References

- Adiwidjaja, G., Friese, K., Klaska, K.H. and Schlüter, J. (1999) Inorganic crystal structures – The crystal structure of kastningite (Mn,Fe,Mg)(H<sub>2</sub>O)<sub>4</sub>[Al<sub>2</sub>(OH)<sub>2</sub>(H<sub>2</sub>O)<sub>2</sub>(PO<sub>4</sub>)<sub>2</sub>]·2H<sub>2</sub>O – a new hydroxyl aquated orthophosphate hydrate mineral. *Zeitschrift für Kristallographie*, **214**, 465–468.
- Baur, W.H. (1969a) A comparison of the crystal structures of pseudolaueite and laueite. *American Mineralogist*, **54**, 1312–1323.
- Baur, W.H. (1969b) The crystal structure of paravauxite, FeAl<sub>2</sub>(PO<sub>4</sub>)<sub>2</sub>(OH)<sub>2</sub>(H<sub>2</sub>O)<sub>2</sub>. *Neues Jahrbuch für Mineralogie Monatshefte*, **1969**, 430–433.
- Baur, W.H. and Rao, B.R. (1967) The crystal structure of metavauxite. *Naturwissenschaften*, **54**, 561.
- Brown, I.D. (1981) The bond-valence method: An empirical approach to chemical structure and bonding. Pp. 1–30 in: *Structure and Bonding in Crystals, Vol. 2* (M. O’Keeffe and A. Navrotsky, editors). Academic Press, New York.
- Cooper, M. and Hawthorne, F.C. (1994) The crystal structure of curetonite, a complex heteropolyhedral sheet mineral. *American Mineralogist*, **79**, 545–549.
- Fanfani, L., Tomassini, M., Zanazzi, P.F. and Zanzari, A.R. (1978) The crystal structure of strunzite, a contribution to the crystal chemistry of basic ferric-manganous hydrated phosphates. *Tschermaks mineralogische und petrographische Mitteilungen*, **25**, 77–87.
- Galliski, M.A. and Hawthorne, F.C. (2002) Refinement of the crystal structure of ushkovite from Nevados de Palermo, Republica Argentina. *The Canadian Mineralogist*, **40**, 929–937.
- Grey, I.E. Keck, E., Mumme, W.G., MacRae, C.M., Price, J.R., Glenn, A.M. and Davidson, C.J. (2015) Crystallographic ordering of aluminium in laueite at Hagendorf Süd. *Mineralogical Magazine*, (in press).
- Hawthorne, F.C. (1988) Sigloite: The oxidation mechanism in [M<sub>2</sub><sup>3+</sup>(PO<sub>4</sub>)<sub>2</sub>(OH)<sub>2</sub>(H<sub>2</sub>O)<sub>2</sub>]<sup>2-</sup> structures. *Mineralogy and Petrology*, **38**, 201–211.
- Krivovichev, S.V. (2004) Topological and geometrical isomerism in minerals and inorganic compounds with laueite-type heteropolyhedral sheets. *Neues Jahrbuch für Mineralogie Monatshefte*, **2004**, 209–220.
- Leavens, P.B. and Rheingold, A.L. (1988) Crystal structures of gordonite, MgAl<sub>2</sub>(PO<sub>4</sub>)<sub>2</sub>(OH)<sub>2</sub>(H<sub>2</sub>O)<sub>6</sub>(H<sub>2</sub>O)<sub>2</sub>, and its Mn analog. *Neues Jahrbuch für Mineralogie Monatshefte*, **1988**, 265–270.
- Meisser, N., Brugger, J., Krivovichev, S., Armbruster, T. and Favreau, G. (2012) Description and crystal structure of maghrebite, MgAl<sub>2</sub>(ASO<sub>4</sub>)<sub>2</sub>(OH)<sub>2</sub>·8H<sub>2</sub>O, from Aghbar, Anti-Atlas, Morocco: first arsenate in the laueite mineral group. *European Journal of Mineralogy*, **24**, 717–726.
- 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.
- Moore, P.B. (1965) The crystal structure of laueite, Mn<sup>2+</sup>Fe<sup>3+</sup>(OH)<sub>2</sub>(PO<sub>4</sub>)<sub>2</sub>(H<sub>2</sub>O)<sub>6</sub>·6H<sub>2</sub>O. *American Mineralogist*, **50**, 1884–1892.
- Moore, P.B. (1970) Structural hierarchies among minerals containing octahedrally coordinating oxygen. I. Stereoisomerism among corner-sharing octahedral and tetrahedral chains. *Neues Jahrbuch für Mineralogie Monatshefte*, **1970**, 163–173.
- Moore, P.B. (1975) Laueite, pseudolaueite, stewartite and metavauxite: A study in combinatorial polymorphism. *Neues Jahrbuch für Mineralogie Abhandlungen*, **1975**, 148–159.
- Moore, P.B. and Araki, T. (1974) Stewartite, Mn<sup>2+</sup>Fe<sup>3+</sup>(OH)<sub>2</sub>(H<sub>2</sub>O)<sub>6</sub>[PO<sub>4</sub>]<sub>3</sub>·2H<sub>2</sub>O: Its atomic arrangement. *American Mineralogist*, **59**, 1272–1276.
- Moore, P.B. and Ito, J. (1978) I. Whiteite, a new species, and a proposed nomenclature for the jahnsite-whiteite complex series, II. New data on xanthoxenite. III. Salmonsite discredited. *Mineralogical Magazine*, **42**, 309–323.
- Scholz, R., Chukanov, N.V., Menezes Filho, L.A.D., Attencio, D., Lagoeiro, L., Belotti, F.M., Chaves, M.L.S.C., Romano, A.W., Brandao, P.R., Belakovskiy, D.I. and Pekov, I. (2014) Césarferreirite, Fe<sup>2+</sup>Fe<sup>3+</sup>(AsO<sub>4</sub>)<sub>2</sub>(OH)<sub>2</sub>·8H<sub>2</sub>O, from Eduardo mine, Conselheiro Pena, Minas Gerais, Brazil: Second arsenate in the laueite mineral group. *American Mineralogist*, **99**, 607–611.
- Segeler, C.G., Moore, P.B., Dyar, M.D., Leans, F. and Ferraiolo, J.A. (2012) Ferrolaueite, a new mineral from Monmouth County, New Jersey, USA. *Australian Journal of Mineralogy*, **16**, 69–76.
- Wang, X., Liu, L., Cheng, H., Ross, K. and Jacobson, A.J. (2000) Synthesis and crystal structures of [H<sub>3</sub>N(CH<sub>2</sub>)<sub>2</sub>NH<sub>3</sub>]NbMOF(PO<sub>4</sub>)<sub>2</sub>(H<sub>2</sub>O)<sub>2</sub>, M = Fe, Co and [H<sub>3</sub>N(CH<sub>2</sub>)<sub>2</sub>NH<sub>3</sub>]Ti(Fe<sub>0.9</sub>Cr<sub>0.1</sub>)F<sub>1.3</sub>O<sub>0.7</sub>(H<sub>0.3</sub>PO<sub>4</sub>)<sub>2</sub>(H<sub>2</sub>O)<sub>2</sub>. *Journal of Materials Chemistry*, **10**, 1203–1208.