

# Welshite, $\text{Ca}_2\text{Mg}_4\text{Fe}^{3+}\text{Sb}^{5+}\text{O}_2[\text{Si}_4\text{Be}_2\text{O}_{18}]$ , a new member of the aenigmatite group

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**SUMMARY.** Welshite, triclinic,  $\text{Ca}_2\text{Mg}_4\text{Fe}^{3+}\text{Sb}^{5+}\text{O}_2[\text{Si}_4\text{Be}_2\text{O}_{18}]$ ,  $a = 10.28 \text{ \AA}$ ,  $b = 10.69 \text{ \AA}$ ,  $c = 8.83 \text{ \AA}$ ,  $\alpha = 106.1^\circ$ ,  $\beta = 96.3^\circ$ ,  $\gamma = 124.8^\circ$ ,  $P\bar{1}$  with pseudo-monoclinic cell  $a_m = 9.68(1) \text{ \AA}$ ,  $b_m = 14.77(2) \text{ \AA}$ ,  $c_m = 5.14(1) \text{ \AA}$ ,  $\beta_m = 101.5(2)^\circ$ ,  $c$ -centred, occurs as lustrous subadamantine, thick prismatic reddish-black crystals up to 3 mm in greatest dimension associated with roméite, adelite, swedenborgite, berzeliite, manganooan phlogopite, richterite in crystalline dolomite from Långban, Sweden. Forms include  $b\{010\}$ ,  $a\{100\}$ ,  $k\{130\}$ ,  $m\{110\}$ ,  $j\{021\}$ ,  $p\{111\}$ ,  $q\{121\}$ ,  $v\{131\}$ ,  $r\{111\}$ ,  $s\{121\}$ ,  $t\{131\}$ , and  $w\{141\}$  (monoclinic setting). Streak pale-brown, hardness 6, specific gravity 3.77, fracture conchoidal, no cleavage,  $\alpha = 1.81(1)$ ,  $\gamma = 1.83(1)$ ,  $2E(\text{obs.}) \sim 45^\circ$ , no noticeable pleochroism.

Welshite is a new member of the aenigmatite-rhönite group and obtains from the substitution  $\text{Sb}^{5+} \rightarrow \text{Ti}^{4+}$  and  $\text{Be}^{2+} \rightarrow \text{Al}^{3+}$  in rhönite.

IN 1967, I announced eleven new minerals from Långban and Nordmark, Sweden of which two, numbers 10 and 11, were not yet named. Number 10 proved, by a circuitous route, to be magnusonite and investigation on that material was subsequently reported elsewhere (Moore, 1970a). Number 11, given the formula  $\text{Ca}_2(\text{Mg}, \text{Fe})_4\text{SbSi}_4\text{O}_{12}(\text{OH})_8$  in Moore (1967), was far less tractable. Further study on the material, including a qualitative determination of Be, a partial crystal structure analysis, and a suspected relationship with rhönite,  $\text{Ca}_2(\text{Mg}, \text{Fe})_4\text{Fe}^{3+}\text{Ti}^{4+}\text{O}_2[\text{Si}_3\text{Al}_3\text{O}_{18}]$ , completed the study. Unfortunately, neither quantitative Be nor a completed structure determination was obtained. A name, *welshite*, was subsequently announced (Moore, 1970b) and the formula was presented as  $\text{Ca}_2\text{Mg}_4\text{SbFeO}_2[\text{Be}_3\text{Si}_3\text{O}_{18}]$ , although neither description nor data were offered for the material. Dr. Michael Fleischer (U.S. Geological Survey) informed me that the species had never been reviewed by the International Commission on New Minerals and New Mineral Names. After further search for more material proved fruitless, I submitted the name and the data at hand to the Com-

mission in 1973, and the species and name were subsequently approved.

In the winter of 1975, I discovered twelve hand specimens of the new mineral in the Gustav Flink collection of Långban minerals at Harvard University and Professor Clifford Frondel kindly permitted the sacrifice of two specimens towards determination of BeO. The present communication is a formal description of the new species.

**Occurrence and paragenesis.** The only locality for welshite is the famous manganese and iron mines at Långban, Värmland, Sweden. The specimens originated from Dr. G. Flink who communicated these as unknowns Nos. 450 and 451 (Flink, 1927). But few specimens have been preserved; in addition to the Harvard specimens, the type (deposited in the collection at the U.S. National Museum of Natural History), one specimen presented to Mr. W. R. Welsh, and two paratypes in the Swedish Natural History Museum (Stockholm), the only other specimens to my knowledge are tiny fragments distributed upon request to a few other museums. Therefore, some discussion of associated minerals is desirable.

Welshite occurs as lustrous, subadamantine, thick prismatic reddish-black crystals up to 3 mm in greatest dimension. The crystals occur very locally, densely sprinkled in rather compact crystalline (1-2 mm grain size) dolomite, which fills fractures in dense fine-grained hematite ore. Accessory minerals in the dolomite include berzeliite, manganooan phlogopite, richterite, and occasional hausmannite grains. In close association with the welshite are orange roméite (var. *weslienite*) as rounded octahedra, pale greenish-yellow waxy grains of adelite, and, very rarely, swedenborgite.

Welshite is yet another example of an antimony-bearing skarn product from Långban. It occurs in a paragenesis similar to the other antimony-bearing minerals roméite,  $\text{Ca}_2\text{Sb}_2\text{O}_6\text{F}$ ; swedenborgite,  $\text{NaSbBe}_4\text{O}_7$ ; katoptrite,  $\text{Mn}_{13}\text{Sb}_2\text{Al}_4\text{Si}_2\text{O}_{28}$ ; långbanite,  $\text{Mn}_4^{2+}\text{Mn}_3^{3+}\text{SbSi}_2\text{O}_{24}$ ; manganostibite,  $\text{Mn}_7\text{SbAsO}_{12}$ ; and stenhuggarite,

$\text{CaFe}^{3+}\text{Sb}^{3+}\text{As}_2^3+\text{O}_7$ . In addition, it is allied chemically to the beryllsilicate clin amphibole joersmithite,  $\text{PbCa}_2\text{Mg}_4\text{Fe}^{3+}(\text{OH})_2[\text{Si}_6\text{Be}_2\text{O}_{22}]$ , although the two minerals have not been found together. Moore (1970b) has interpreted these curious minerals as products of thermal recrystallization of local concentrations of antimony- and arsenic-bearing complexes admixed in the iron and manganese oxide proto-ores. The presence of beryllium is unusual; it probably derived from a separate source in which case the peculiar combination of As, Sb, and Be is of 'accidental' occurrence, accounting for the extreme rarity of these minerals outside this extremely local source.

**Physical properties.** Welshite is deep reddish-brown to reddish-black, brownish-orange in transmitted light. The colour varies somewhat probably resulting from variations in the oxidation grade of the iron in the mineral. The crystals closely resemble clinopyroxenes in habit but differ in possessing a much higher luster. The streak is pale brown, hardness 6, specific gravity 3.77 (Berman torsion balance,  $T = 21.0^\circ\text{C}$ , toluene as the displaced fluid). The fracture is conchoidal; no evidence of cleavage could be produced. The crystals are insoluble in dilute to strong HCl solutions and remain unaltered even after a period of one week.

Optically, welshite shows low birefringence and lack of cleavage did not admit orientation of the indicatrix. The isogyres are broad and the interference figures sufficiently blurred to inhibit interpretation of the sign. Biaxial,  $\alpha = 1.81(1)$ ,  $\gamma = 1.83(1)$ ,  $2E(\text{obs}) \sim 45^\circ$ . The grains are not discernibly pleochroic.

**Crystallographic properties.** Welshite is a member of the aenigmatite group and enjoys the same complex cell-pseudocell relationships and persistent polysynthetic twinning of that triclinic phase. Crystals are usually stout prismatic parallel to the  $c_m$ -axis although occasional individuals thick tabular parallel to  $b\{010\}$  are also encountered. The facets are lustrous and remarkably free from etching, presenting excellent signals on the two-circle reflection goniometer. Forms observed include  $b\{010\}$ ,  $a\{100\}$ ,  $k\{130\}$ ,  $m\{110\}$ ,  $j\{021\}$ ,  $p\{111\}$ ,  $q\{121\}$ ,  $v\{131\}$ ,  $r\{111\}$ ,  $s\{121\}$ ,  $t\{131\}$ , and  $v\{141\}$ . The indexing of the forms adopts the linear elements of the pseudo-monoclinic cell ( $a_m$ ,  $b_m$ ,  $c_m$ ,  $\beta_m$ ) owing to obvious pseudo-monoclinic development of the crystals. The pseudo-monoclinic axial ratios are  $0.6554:1:0.3480$ ,  $\beta = 101^\circ 30'$ , adopted from the X-ray study. All crystals examined were polysynthetically twinned on  $\{010\}$ . Two typical habits are shown in fig. 1.

The X-ray study on welshite, initiated in 1966, presented problems that were not resolved until it

was discovered that the mineral is a member of the aenigmatite group. Walenta (1969), in a detailed study on the member rhönite,  $\text{Ca}_2(\text{Mg}, \text{Fe})_4\text{Fe}^{3+}\text{Ti}^{4+}\text{O}_2[\text{Si}_3\text{Al}_3\text{O}_{18}]$ , pointed out that a pronounced pseudo-monoclinic cell for aenigmatite could be discerned, which is  $c$ -centred and which is the orientation adopted for the present study. Weak extra reflections require that the  $b_m$ - and  $c_m$ -axes be doubled. Adopting the convention of Walenta (1969), the relationship of the pseudo-monoclinic cells for welshite and aenigmatite can be readily discerned:

	Welshite	Aenigmatite
$a_m$ (Å)	9.68(1)	9.888
$b_m$ (Å)	14.77(2)	14.814
$c_m$ (Å)	5.14(1)	5.203
$\beta_m$	$101^\circ 30'(10')$	$102^\circ 21'$

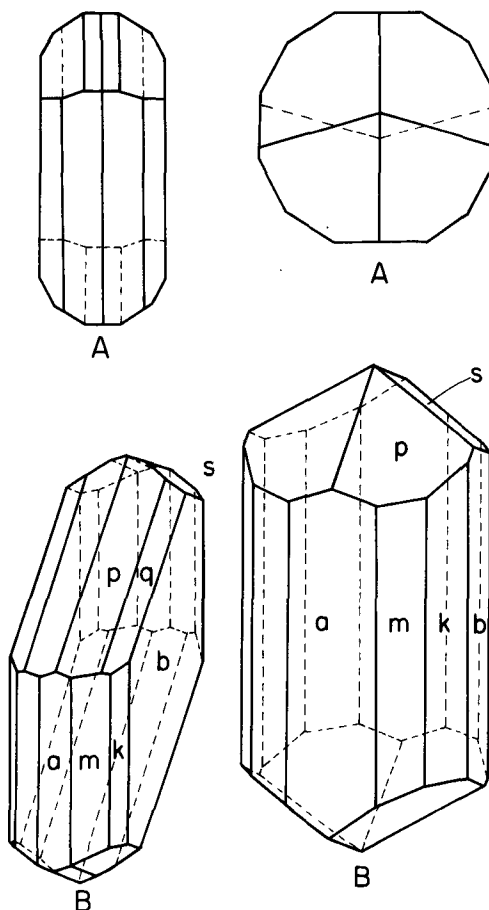


FIG. 1. Two typical habits for welshite, Långban, Sweden, showing the forms  $b\{010\}$ ,  $a\{100\}$ ,  $k\{130\}$ ,  $m\{110\}$ ,  $p\{111\}$ ,  $q\{121\}$ , and  $s\{121\}$ . A, plan. B, clinographic projection.

The data for welshite were obtained from  $a_m$ -,  $b_m$ -, and  $c_m$ -axis rotation photographs (Cu- $K\alpha$  radiation) and  $b_m$ - and  $c_m$ -axis precession photographs (Mo- $K\alpha$  radiation) of the zero levels.

Machin and Süssse (1974), in a detailed crystal structure analysis on serendibite, another member of the aenigmatite group of structures, list the triclinic reduced cells for welshite and six other members of that group. Their study is sufficiently complete and detailed discussion here is unnecessary. They applied the transformation matrix  $(002/\frac{1}{22}\bar{1}/\frac{1}{22}0)$  to the pseudo-monoclinic cell of welshite, obtaining  $a = 10.28 \text{ \AA}$ ,  $b = 10.69 \text{ \AA}$ ,  $c = 8.83 \text{ \AA}$ ,  $\alpha = 106.1^\circ$ ,  $\beta = 93.3^\circ$ , and  $\gamma = 124.8^\circ$ , space group  $P\bar{1}$ , for the true welshite cell. In addition to the serendibite structure study by these scientists, Merlini (1970) and Cannillo, Mazzi, Fang, Robinson, and Ohya (1971) have published detailed accounts of the aenigmatite crystal structure.

The pseudo-monoclinic cell was adopted for indexing the powder data in Table I. Owing to coincidence of non-equivalent planes, the three-dimensional single-crystal intensities were used to unambiguously select the appropriate plane. It was not necessary to double the  $b_m$ - and  $c_m$ -axes since the extra reflections are sufficiently weak that they would not contribute to the powder photographs. Owing to detailed accounts of the aenigmatite and serendibite crystal structures, further work on the structure of welshite has been abandoned. A future study on this problem is warranted, however, since the ordering scheme for the cations in welshite is not yet known.

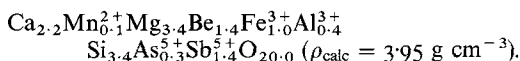
TABLE I. *Welshite. Powder data\**

$I/I_0$	$d_{\text{obs}}$	$d_{\text{calc}}$	$hkl$	$I/I_0$	$d_{\text{obs}}$	$d_{\text{calc}}$	$hkl$
5	7.99 Å	7.98 Å	110	1	2.212 Å	2.224 Å	421
7	7.32	7.38	020	1	2.164	2.159	350
3	5.05	5.04	001	6	2.098	2.090	351
6	4.73	4.74	200	4	2.069	2.060	202
3	4.35	4.37	130	3	1.979		
5	4.16	4.16	021	3	1.943		
3	3.87	3.86	201	+ 20 lines < 1.90-1.65			
2	3.67	3.69	040	1	1.622		
4	3.456	3.462	131	3	1.607		
4	3.158	3.160	131	3	1.587		
3	3.095	3.092	310	2	1.551		
7	2.910	2.914	240	1	1.528		
3	2.813	2.820	150	7	1.489		
6	2.670	2.668	241	2	1.478		
10	2.530	2.535	331	7	1.460		
2	2.440	2.432	311	+ 30 lines < 2			
3	2.402	2.398	241				

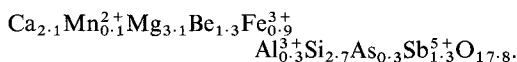
\* Fe/Mn radiation, 114.6 mm camera diameter, film corrected for shrinkage. Indexed on the pseudo-monoclinic cell.

*Chemical composition.* Owing to the meagre quantity of welshite available, a complete chemical analysis was not possible. Emission spectrographic analysis revealed major Be, Ca, Si, Mg, Mn, Sb, As, Fe, minor Al, and a trace of B. A crystal of the type specimen was sacrificed for quantitative electron-probe analysis, performed in 1966, but it was not until 1975 that sufficient material from two specimens in the Harvard collection was available for BeO determination. The probe data were corrected for absorption and efficiency-of-generation effects and utilized the following standards: anorthite (Ca, Al, Si); diopside (Ca, Mg, Si); knebelite (Fe, Mg, Mn); and arsenic and antimony metals. Twenty sample points over three crystals afforded, after correction: CaO 14.2(0.3), MnO 1.0(0.1), MgO 15.3(0.3), Fe<sub>2</sub>O<sub>3</sub> 9.1(0.8), Al<sub>2</sub>O<sub>3</sub> 2.1(0.2), SiO<sub>2</sub> 19.6(0.2), As<sub>2</sub>O<sub>5</sub> 3.6(0.4), Sb<sub>2</sub>O<sub>5</sub> 24.8(2.8) wt%. The determination of BeO = 4.0% was obtained from 40.0 mg of crystals and I am indebted to Dr. Jun Ito for this datum. Not enough material was available for oxidation grade of Fe or for water determination and the former was reported as Fe<sub>2</sub>O<sub>3</sub>. The oxide sum is low (= 93.7%); since no other cations were present, it is believed that this reflects uncertainties in the corrections owing to the unusual composition of welshite and to its matrix which is grossly different than those of the metal standards.

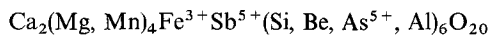
Computation of the formula unit for the pseudo-monoclinic cell ( $Z = 2$ ) based on  $\Sigma O = 20$  yields:



Computation based on cell volume and specific gravity affords:



In the absence of a thorough crystal structure analysis, assignment of sites is uncertain. The first formula suggests that the analysed Sb<sub>2</sub>O<sub>5</sub> is high since the calculated density is high although the sum of cations is close to that for an aenigmatite (13.6 vs. 14); second formula also suggests Sb<sup>5+</sup> may be too high and some of the lighter elements too low. Thus, only an approximate formula can be given. I propose,



by analogy with the aenigmatite group. The end-member composition  $\text{Ca}_2\text{Mg}_4\text{Fe}^{3+}\text{Sb}^{5+}\text{O}_2[\text{Si}_4\text{Be}_2\text{O}_{18}]$  is suggested. This is not only balanced but also yields a calculated density of 3.71 g cm<sup>-3</sup>, which is in reasonable accord with the observed specific gravity of 3.77. Thus, welshite may be most closely related to rhönite and

obtains by the substitution  $\text{Sb}^{5+} \rightarrow \text{Ti}^{4+}$  and  $\text{Be}^{2+} \rightarrow \text{Al}^{3+}$  in that mineral.

*Name.* The new species honours Mr. Wilfred R. Welsh of Upper Saddle River, New Jersey, dedicated teacher of the natural sciences and amateur mineralogist. Type material is preserved in the U.S. National Museum of Natural History, Smithsonian Institution.

*Acknowledgements.* It is a pleasure to thank Professor Clifford Frondel for loan of specimens and the Swedish Natural History Museum (Stockholm) for the opportunity to study the unusual Långban parageneses, which eventually led to the discovery of several new species.

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