# Vaughanite, $TlHgSb_4S_7$, a new mineral from Hemlo, Ontario, Canada[1]


DONALD C. HARRIS AND ANDREW C. ROBERTS

Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, Canada K1A 0E8

AND

ALAN J. CRIDDLE

Department of Mineralogy, British Museum (Natural History), Cromwell Road, London, England, SW7 5BD



## Abstract

Vaughanite, idealized formula $TlHgSb_4S_7$, is a very rare primary constituent of the Golden Giant orebody of the Hemlo gold deposit, Hemlo, Ontario, Canada. It was found in two polished sections from one drill core; as a 450 by 300 $\mu$m aggregate associated with pääkkönenite, stibnite, realgar, and native arsenic; and as a 40 $\mu$m anhedral grain associated with stibarsen and chalcostibite. Vaughanite is opaque with a metallic lustre and a black streak. No cleavage was observed but parting, produced by indentation, was detected as a series of weak parallel traces. It is brittle, with an even, occasionally arcuate, fracture. $VHN_{25}$ is 100–115, mean 104. Mohs hardness (calc.) = $3–3\frac{1}{2}$. In reflected plane-polarized light in air the bireflectance is weak to moderate; the pleochroism is also weak, from a somewhat greenish grey to slightly darker bluish grey. Anisotropism is moderate to strong, with rotation tints in shades of green, yellow, purplish brown to brown. Reflectance spectra and colour values are tabulated. The colour in air is light grey. Internal reflections are rare but are arterial-blood-red on indentation fractures. X-ray studies have shown that vaughanite is triclinic with refined unit-cell parameters *a* 9.012 (3), *b* 13.223 (3), *c* 5.906 (2) Å, $\alpha$ 93.27 (3)°, $\beta$ 95.05 (4)°, $\gamma$ 109.16 (3)°, *V* 659.46 (80) Å$^3$, $a:b:c = 0.6815:1:0.4466$ and Z = 2. The space group choices are *P*1 (1) or $P\bar{1}$ (2), diffraction aspect *P**. The five strongest lines in the X-ray powder pattern [*d* in Å (*I*) (*hkl*)] are: 4.343 (30) ($\bar{1}30$), 4.204 (100) ($\bar{1}21$), 3.313 (60) (130), 2.749 (40) ($02\bar{2}$, 131) and 2.315 (30) ($\bar{3}4\bar{1}$, $\bar{2}51$, 122). The average of five electron microprobe analyses gave Tl 18.3 (2), Hg 17.5 (2), Sb 43.4 (3), As 1.1 (1), S 20.5 (5), total 100.8 wt. %, corresponding, on the basis of total atoms = 13, to $Tl_{0.98}Hg_{0.95}(Sb_{3.90}As_{0.17})_{\Sigma 4.07}S_{7.00}$. The calculated density is 5.56 g/cm$^3$ for the empirical formula and 5.62 g/cm$^3$ for the simplified formula. The mineral is named for Professor David J. Vaughan.



KEYWORDS: vaughanite, pääkönenite, new mineral, Hemlo gold deposit, Ontario, Canada, reflectance data, X-ray data, electron microprobe analyses, thallium mercury antimony sulphide.


## Introduction

VAUGHANITE, ideally $TlHgSb_4S_7$, is a newly described thallium-bearing mineral from the Hemlo gold deposit, Hemlo, Ontario, Canada. The mineral is named for Professor David J. Vaughan (1946–), Manchester University, Manchester, England, for his many outstanding contributions to ore mineralogy and ore microscopy. The mineral and the mineral name have been approved by the Commission on New Minerals and Mineral Names, International Mineralogical Association. Type material, BM 1987, 95, is preserved at the British Museum (Natural History) as polished section E.1220. A second polished section containing a single grain of vaughanite from the same drill core sample is in the Systematic Reference Series of the National Mineral Collection, housed at the Geological Survey of Canada, Ottawa, Ontario, Canada, under catalogue number NMC 65497.

[1] Geological Survey of Canada Contribution Number 12388.


*Mineralogical Magazine, March 1989, Vol. 53, pp. 79–83*

## Occurrence

Vaughanite occurs within the Golden Giant orebody at the Hemlo gold deposit, near the northeast shore of Lake Superior, 35 km east of Marathon, Ontario, Canada, adjacent to the Trans-Canada Highway #17, at latitude 48° 40′ N and longitude 86° 00′ W. Preliminary reports on the mineralogy of the Hemlo deposit have been published by Harris (1986*a*, *b*, *c*). Vaughanite is an extremely rare primary constituent of this epithermal–hydrothermal deposit and has been identified in only two polished sections of one drill core sample from hole GG 25, 324.9 m.

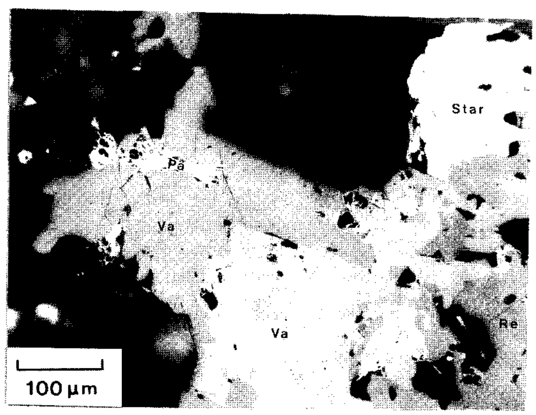


FIG. 1. Photomicrograph of vaughanite (Va) aggregate surrounding a fibrous bundle of pääkkönenite (Pä) and associated with stibarsen (Star) and realgar (Re). Oil immersion. Polished section BM 1987, 95, E.1220. Repolished after extraction of fragment for X-ray diffraction studies.

In polished section BM 1987, 95, E.1220, vaughanite occurs as a 450 by 300 $\mu$m aggregate composed of two distinct angular grains in different optical orientation. This aggregate encloses a 150 $\mu$m long fibrous bundle of pääkkönenite (Fig. 1). The pääkkönenite was identified by quantitative electron microprobe analyses and by residual X-ray lines in the vaughanite powder pattern. Stibnite, realgar and native arsenic are associated metallic minerals in a quartz–calcite matrix. In polished section NMC 65497, vaughanite occurs as a 40 $\mu$m anhedral grain in stibarsen, associated with chalcostibite, within a similar quartz–calcite matrix. This grain was initially 200 $\mu$m, but most of it was used for the initial X-ray powder diffraction identification. This polished section also contains criddleite (Harris *et al.*, 1988) but the two minerals are more than one centimetre apart.

## Optical properties

In polished section, in plane-polarized light (at about 3200 K), vaughanite is weakly to moderately bireflectant and weakly pleochroic from slightly greenish grey to a slightly darker bluish grey. When immersed in oil ($N_D$ 1.515), the bireflectance and reflectance pleochroism are enhanced. Internal reflections were not observed in plane-polarized light. Between crossed polars, the mineral is moderately to strongly anisotropic, with vivid and characteristic rotation tints. The sequence of rotation tints, for the more anisotropic of the two grains in the polished section, are: from extinction; purple; purplish brown–grey; brownish yellow; greenish yellow; sage green (at 45°); bluish green; deep 'blue-bottle' green. With the polars (analyser) uncrossed by 3°, the sequence is: dark, slightly yellowish green; bluish green; deep green; dark, brownish grey; light purplish grey; bright, pale grey; to bright, creamy grey. Rare, arterial-blood-red internal reflections are evident between crossed polars, on fractures produced by the micro-hardness tester. Immersion in oil enhances these effects.

In comparison with the minerals with which it is associated, vaughanite is much lower reflecting than pääkkönenite and native arsenic, and is slightly lower reflecting than the $R_2$ vibration direction of stibnite. It is, however, almost identical, in colour and brightness, to the $R_1$ vibration direction of stibnite.

## Reflectance data and colour values

Reflectance measurements were made using the equipment and procedures described by Criddle *et al.* (1983). A WTiC reflectance standard (Zeiss no. 314) was used, with Zeiss oil ($N_D$ 1.515) for immersion measurements. The effective numerical apertures of the × 16 air and oil objectives were adjusted to 0.15.

The two grains of vaughanite were orientated for measurement at their sharply defined (and straight) extinction positions. Grain 1 (Fig. 2) is visibly more anisotropic and measurably more bireflectant than Grain 2. This is a consequence of the different crystallographic orientation of the grains and is not related to any compositional difference—they have the same composition. The reflectance data for the more bireflectant grain are summarized in Table 1, together with the corresponding colour values; the complete data are available at the British Museum (Natural History).

Colour values relative to the CIE Illuminant A (2856 K), which is reasonably close in colour temperature to that of the light-source used for

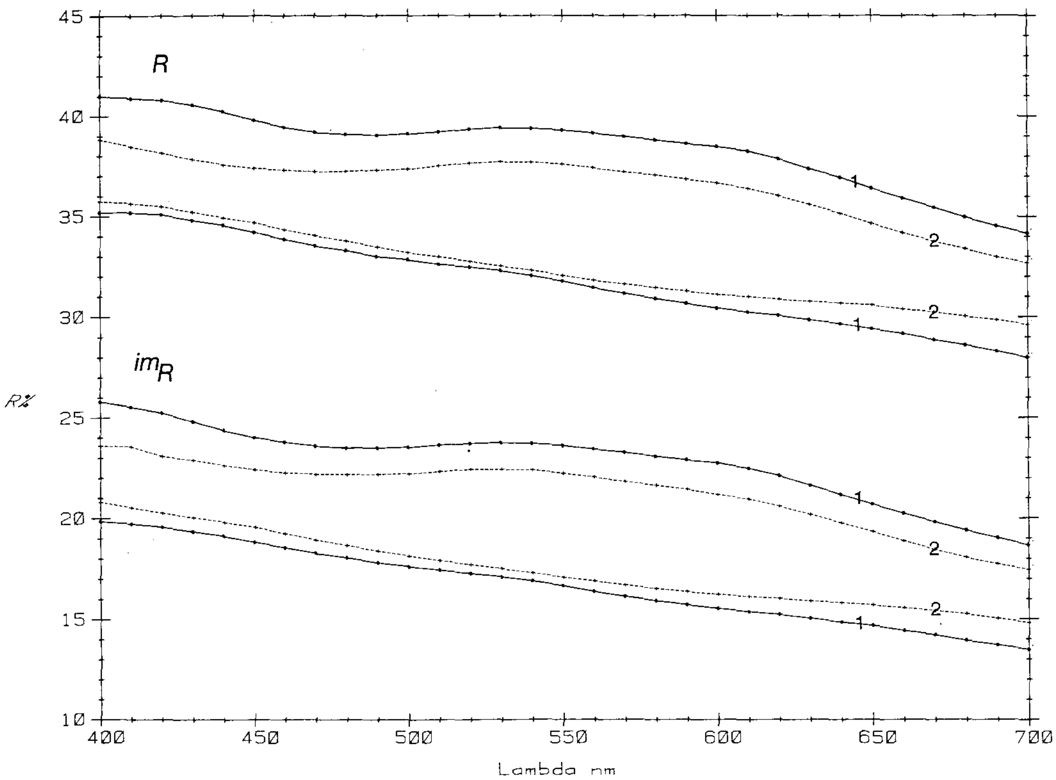


FIG. 2. Reflectance spectra for vaughanite in air and in oil (Specimen BM 1987, 95, E.1220).

Table 1. Reflectance data and colour values in air and oil for vaughanite

| λnm | $R_1$ | $R_2$ | $imR_1$ | $imR_2$ | λnm | $R_1$ | $R_2$ | $imR_1$ | $imR_2$ |
|---|---|---|---|---|---|---|---|---|---|
| 400 | 35.2 | 41.0 | 19.85 | 25.8 | 560 | 31.4 | 39.15 | 16.4 | 23.4 |
| 420 | 35.1 | 40.8 | 19.6 | 25.2 | 580 | 30.9 | 38.8 | 15.9 | 23.1 |
| 440 | 34.6 | 40.2 | 19.1 | 24.4 | ***589*** | 30.65 | 38.6 | 15.7 | 22.9 |
| 460 | 33.9 | 39.45 | 18.5 | 23.8 | 600 | 30.4 | 38.5 | 15.5 | 22.7 |
| ***470*** | 33.5 | 39.2 | 18.3 | 23.6 | 620 | 30.1 | 37.9 | 15.2 | 22.1 |
| 480 | 33.3 | 39.1 | 18.0 | 23.5 | 640 | 29.7 | 36.9 | 14.8 | 21.15 |
| 500 | 32.8 | 39.1 | 17.6 | 23.5 | ***650*** | 29.4 | 36.4 | 14.7 | 20.7 |
| 520 | 32.5 | 39.35 | 17.25 | 23.7 | 660 | 29.2 | 35.9 | 14.4 | 20.2 |
| 540 | 32.05 | 39.4 | 16.9 | 23.7 | 680 | 28.6 | 35.9 | 13.9 | 19.4 |
| ***546*** | 31.6 | 39.3 | 16.75 | 23.65 | 700 | 28.0 | 34.2 | 13.5 | 18.7 |

Colour values:

| | Illuminant *C*: | | | | Illuminant *A*: | | | |
|---|---|---|---|---|---|---|---|---|
| *x* | .300 | .306 | .293 | .303 | .437 | .442 | .431 | .439 |
| *y* | .308 | .314 | .302 | .313 | .406 | .409 | .405 | .409 |
| Y% | 31.5 | 38.9 | 16.45 | 23.2 | 31.2 | 38.7 | 16.1 | 23.0 |
| $\lambda_d$ | 480 | 485 | 480 | 486 | 481 | 487 | 481 | 487 |
| $P_e$% | 4.7 | 1.7 | 7.7 | 2.9 | 2.5 | 1.2 | 4.2 | 2.0 |

observation (about 3200 K), are in complete agreement with the description of the appearance of the mineral.

It has already been noted that there are similarities in the appearance of vaughanite to that of the $R_1$ vibration direction of stibnite. Comparison of the data in Table 1 with those of stibnite (Simpson, 1975; in QDF 2, 1986) confirm this, but also show that stibnite is more bireflectant and that its $R_2$ values are differently dispersed. In terms of reflectance, the only mineral with which vaughanite might be confused is cylindrite (Criddle and Stanley, QDF 2.94, 1986) but, here again, the spectral dispersion of the $R_2$ values of the two minerals is different. Any confusion that might arise from the appearance of the three minerals in plane-polarized light can be quickly dispelled between crossed polars–all three are quite distinctive.

### Microhardness and physical properties

Vaughanite has a microhardness $VHN_{25}$ in the range 100–115 based on five indentations on two grains with a Leitz Miniload 2 micro-hardness tester. The mean is 104 which corresponds to a Mohs hardness of 3–3½. The mineral is opaque with a metallic lustre and a black streak. The megascopic colour could not be observed owing to the small grain size and the fact that vaughanite was observed only in polished section. Cleavage was not observed but parting, produced by indentation, was detected as a series of weak parallel traces. The fracture is even, occasionally arcuate and the tenacity is brittle. The paucity of material and small grain size precluded a Berman balance specific gravity determination.

### Electron microprobe analyses

The quantitative analyses were performed with a CAMEBAX electron microprobe operated at 20 kV with a beam current of 30 nA and a 15 $\mu$m beam spot. The X-ray lines and standards used were Tl-$M\alpha$, Sb-$L\alpha$, S-$K\alpha$ (synthetic $TlHgSbS_2$); Hg-$M\alpha$ (natural cinnabar) and As-$L\alpha$ (synthetic $FeAs_2$). The average of five analyses gave Tl 18.3 (2), Hg 17.5 (2), Sb 43.4 (3), As 1.1 (1), S 20.5 (5), total 100.8 wt. %. The empirical formula based on the total atoms = 13, is $Tl_{0.98}Hg_{0.95}(Sb_{3.90}As_{0.17})_{\Sigma 4.07}S_{7.00}$. The simplified formula is $TlHgSb_4S_7$.

### X-ray powder and single-crystal study

A single fragment, dug out of polished section BM 1987, 95, E.1220, was mounted and studied by single-crystal precession methods employing Zr-filtered Mo radiation. The fragment was orientated with $b^*$ parallel to the dial axis and the reciprocal lattice levels collected were: $0kl \rightarrow 2kl$, $hk0$, $hk1$, $101^* \wedge b^*$, $\bar{1}01^* \wedge b^*$, $201^* \wedge b^*$, $\bar{2}01^* \wedge b^*$, $102^* \wedge b^*$, $\bar{1}02^* \wedge b^*$, $301^* \wedge b^*$, $\bar{3}01^* \wedge b^*$, $302^* \wedge b^*$ and $\bar{3}02^* \wedge b^*$.

Vaughanite is triclinic with space-group choices $P1$ (1) or $P\bar{1}$ (2) and diffraction aspect $P^*$. The refined unit-cell parameters: $a$ 9.012 (3), $b$ 13.223 (3), $c$ 5.906 (2) Å, $\alpha$ 93.27 (3)°, $\beta$ 95.05 (4)°, $\gamma$ 109.16 (3)°, $V$ 659.46 (80) Å$^3$ and $a:b:c = 0.6815:1:0.4466$ are based on 24 reflections, between 4.94 and 1.903 Å, in the X-ray powder pattern for which unambiguous indexing was possible. All possible reflections down to 1.80 Å were visually examined on single-crystal precession films. These unit-cell parameters are in their reduced form as indicated by a cell reduction computer program.

Table 2. X-ray powder data for vaughanite

| Iest. | d Åmeas. | dÅcalc. | hkl |
|---|---|---|---|
| 20 | 12.5 | 12.4 | 010 |
| 20 | 8.42 | 8.46 | 100 |
| | | 8.43 | $\bar{1}10$ |
| 10 | 5.88 | 5.86 | 001 |
| 10 | 5.14 | 5.12 | 011 |
| | | 5.09 | $\bar{1}01$ |
| 15 | 4.935 | 4.930 | $\bar{1}11$ |
| 30 | 4.343 | 4.342 | $\bar{1}30$ |
| 100 | 4.204 | 4.201 | $\bar{1}21$ |
| 5 | 3.726 | 3.724 | $12\bar{1}$ |
| 10 | 3.649 | 3.649 | 210 |
| 20 | 3.545 | 3.553 | $\bar{1}3\bar{1}$ |
| | | 3.540 | $03\bar{1}$ |
| 10 | 3.417 | 3.422 | $\bar{2}1\bar{1}$ |
| 60 | 3.313 | 3.310 | 130 |
| 5 | 3.282 | 3.286 | $21\bar{1}$ |
| 5 | 3.260 | 3.258 | 201 |
| 10 | 3.110 | 3.110 | $\bar{2}31$ |
| 5b | 3.053 | 3.054 | 220 |
| 20 | 2.971 | 2.973 | $\bar{3}10$ |
| | | 2.969 | $\bar{3}20$ |
| 10 | 2.938 | 2.941 | $\bar{1}4\bar{1}$ |
| | | 2.937 | 211 |
| 15 | 2.912 | 2.911 | $01\bar{2}$ |
| 20 | 2.812 | 2.810 | $\bar{3}30$ |
| 5 | 2.781 | 2.782 | $11\bar{2}$ |
| 40 | 2.749 | 2.749 | $02\bar{2}$ |
| | | 2.747 | 131 |
| 10 | 2.729 | 2.733 | $\bar{3}21$ |
| | | 2.724 | $\bar{1}1\bar{2}$ |

| Iest. | d Åmeas. | dÅcalc. | hkl |
|---|---|---|---|
| 5 | 2.688 | 2.688 | $\bar{2}41$ |
| 10 | 2.649 | 2.648 | 041 |
| | | 2.647 | $\bar{1}2\bar{2}$ |
| | | 2.582 | $12\bar{2}$ |
| 15 | 2.572 | 2.577 | 221 |
| | | 2.570 | 310 |
| 5 | 2.521 | 2.521 | $14\bar{1}$ |
| | | 2.520 | 112 |
| 10 | 2.464 | 2.463 | $\bar{1}5\bar{1}$ |
| | | 2.321 | $\bar{3}4\bar{1}$ |
| 30 | 2.315 | 2.317 | $\bar{2}51$ |
| | | 2.305 | 122 |
| 3 | 2.193 | 2.196 | $\bar{3}12$ |
| 5 | 2.172 | 2.171 | $\bar{2}60$ |
| | | 2.169 | $\bar{3}22$ |
| 5 | 2.115 | 2.115 | 400 |
| 5 | 2.073 | 2.073 | 060 |
| | | 1.988 | $05\bar{2}$ |
| 10b | 1.982 | 1.978 | $\bar{3}3\bar{2}$ |
| | | 1.978 | 410 |
| 15 | 1.903 | 1.903 | 013 |
| | | 1.901 | $\bar{3}4\bar{2}$ |
| | | 1.861 | $25\bar{1}$ |
| | | 1.858 | $15\bar{2}$ |
| 15b | 1.856 | 1.855 | $\bar{2}03$ |
| | | 1.852 | 331 |
| | | 1.851 | $\bar{2}13$ |
| | | 1.816 | 052 |
| 15 | 1.816 | 1.815 | $\bar{4}60$ |
| | | 1.813 | $\bar{2}7\bar{1}$ |

- 114.6 mm Gandolfi camera, Co radiation, Fe filter ($\lambda$Co K$\alpha$ = 1.79021Å)
- run at CANMET by Mr Paul Carrière
- b = broad line, intensities visually estimated
- indexed with $a$=9.012, $b$=13.223, $c$=5.906Å, $\alpha$=93.27°, $\beta$=95.05°, $\gamma$=109.16°

Fully indexed 114.6 mm Gandolfi camera X-ray powder data are presented in Table 2. Two lines which are ascribable to pääkkönenite contamination have been omitted. The data are unique and do not bear resemblance to any mineral listed in the PDF file up to and including Set 37.

Assuming the empirical formula and Z = 2, the calculated density is 5.56 g/cm$^3$; assuming the simplified formula of $TlHgSb_4S_7$, the calculated density increases to 5.62 g/cm$^3$.


### Acknowledgements

The authors thank Mr P. Carrière (CANMET) for running the 114.6 mm Gandolfi camera film of vaughanite.


### References


Criddle, A. J., Stanley, C. J., Chisholm, J. E., and Fejer, E. E. (1983) Henryite, a new copper-silver telluride from Bisbee, Arizona. *Bull. Minéral.* **106**, 511–7.

———(1986) QDF 2.94, Cylindrite. In *The Quantitative Data File for Ore Minerals* (A. J. Criddle and C. J. Stanley, eds.) 2nd iss. British Museum (Natural History).

Harris, D. C. (1986*a*) The minerals in the main Hemlo gold deposit, Ontario. *Current Research, Part A, Geol. Survey of Canada*, Paper 86-1A, 49–54.

——(1986*b*) Mineralogy of the main Hemlo gold deposit. In *The Hemlo gold deposits, Ontario* (D. C. Harris, ed.). Geological Association of Canada, Mineralogical Association of Canada, Canadian Geophysical Union, Joint Annual Meeting, Ottawa '86, *Field Trip 4: Guidebook*, 74 pp. Also in *Gold '86 Excursion Guidebook: Toronto, 1986* (J. Pirie and M. J. Downes, eds.), 158–65.

——(1986*c*) Mineralogy and geochemistry of the main Hemlo gold deposit, Hemlo, Ontario, Canada. In *Proceedings of Gold '86*, an International Symposium on the Geology of Gold, Toronto, 1986 (A. J. Macdonald, ed.), 297–310.

——Roberts, A. C., Laflamme, J. H. G., and Stanley, C. J. (1988) Criddleite, $TlAg_2Au_3Sb_{10}S_{10}$, a new gold-bearing mineral from Hemlo, Ontario, Canada. *Mineral. Mag.* **52**, 691–7.

Simpson, P. R. (1986) QDF 2.350, Stibnite (1975). In *The Quantitative Data File for Ore Minerals* (A. J. Criddle and C. J. Stanley, eds.) 2nd iss. British Museum (Natural History).


[*Manuscript received 4 May 1988; revised 24 May 1988*]