caused the six minor octahedra to become dodecahedral. Furthermore, the minor octahedra (now dodecahedra) protected the major octahedron from being stripped at its vertices (the usual way that octahedral crystals of the diamond structure are dissolved; Moore and Lang, 1974). Consequently only {110} bevels (and not large rounded faces) were formed, together with the unusual high-index faces. In summary, this diamond grew as an octahedron, suffered some dissolution, grew again with minor octahedra on its corners, then suffered further dissolution.

Acknowledgements. We are very grateful to Dr Robert Burns (Diamond Research Laboratory) and Mr Dudley Holmes (Kimberley Open Mine Museum) for loan of this extraordinary specimen.

References

Lang, A. R. (1957) *Acta Metallurgica,* **5** 358–64.
—— (1958) *J. Applied Physics*, **29**, 597–8.
Moore, M. (1973) *Dissolution, Defects and Disorder in Diamond and Diamond-like Substances,* Ph.D. Thesis, University of Bristol.
—— (1988) *Industrial Diamond Review*, **48**, 59–64.
—— and Lang, A. R. (1974) *J. Cryst. Growth*, **26**, 133–9.
Williams, A. F. (1932) *The Genesis of the Diamond*, Vol. I and II, E. Benn.
Yacoot, A. (1990) *X-Ray Studies of Diamond: Morphology and Radiation Counting Behaviour,* Ph.D. Thesis, University of London.

[*Manuscript received 28 December 1990; revised 23 May 1991*]

KEYWORDS: crystal growth, diamond, morphology, X-ray topography.

Dept. of Physics, King's College, University of London, Strand, London WC2R 2LS — A. YACOOT*

Dept. of Physics, Royal Holloway and Bedford New College, University of London, Egham, Surrey TW20 0EX — M. MOORE

* *Now at National Physical Laboratory, Teddington, Middlesex TW11 0LW.*

MINERALOGICAL MAGAZINE, MARCH 1992, VOL 56, PP. 113–115

Manganoan–cadmian tetrahedrite from the Tunaberg Cu–Co deposit, Bergslagen, central Sweden

THE cobalt-bearing copper ores of Tunaberg, southeastern Bergslagen, central Sweden, occur in skarn-altered marbles in a metamorphosed volcano-sedimentary sequence. The ores generally consist of chalcopyrite with minor cobaltite, galena, bornite, cubanite, pyrrhotite and sphalerite. In this paper the occurrence of manganoan–cadmian tetrahedrite associated with alabandite, stannoidite and bismuth in a massive galena aggregate from the Tunaberg ore deposit is described. Cadmium-bearing tetrahedrites (Pattrick, 1978; Voropayev *et al.*, 1988; Dianwu Jia *et al.*, 1988) and manganese-bearing tetrahedrites (Basu *et al.*, 1984; Burkhart-Baumann, 1984) have been reported previously from a few localities, but manganoan–cadmian tetrahedrite has not been described before.

Electron-probe microanalyses (EPMA) were performed with a Cambridge Instruments Geoscan operated at an acceleration potential of 15 kV, a probe current of 40 nA, and equipped with a Link energy-dispersive system (EDS), and with a Microscan 9 instrument. Standards used were pure metals for Ag; synthetic CdS (for Cd); stibnite (for Sb, S), bismuthinite (for Bi), chalcopyrite (for Cu), troilite (for Fe), sphalerite (for Zn), and rhodonite (for Mn). To avoid errors in the analysis of Cd and Ag in tetrahedrite due to overlapping peaks of the Ag-$L\beta_1$ and Cd-$L\alpha$ peaks, the positions of these peaks were carefully

Table 1. Compositions and formulae of tetrahedrite.

Grain code	Weight %									
	Cu	Ag	Mn	Cd	Fe	Zn	Sb	Bi	S	Total
5687A	22.4	20.6	1.8	2.4	2.5	0.4	24.3	2.2	22.6	99.2
5687B	21.0	22.3	2.1	3.3	2.7	n.d	25.3	0.5	21.0	98.2
5687C	22.1	21.0	2.3	5.2	1.3	n.d	25.0	1.6	22.3	100.8
	20.8	21.7	2.5	4.8	1.3	n.d	23.9	1.8	21.9	98.8

	Atomic proportions based on 29 atoms								
	Cu	Ag	Mn	Cd	Fe	Zn	Sb	Bi	S
5687A	6.54	3.54	0.61	0.40	0.84	0.11	3.70	0.20	13.06
5687B	6.32	3.94	0.73	0.56	0.92		3.95	0.05	12.53
5687C	6.47	3.57	0.78	0.86	0.43		3.82	0.14	12.93
	6.21	3.82	0.86	0.81	0.44		3.73	0.16	12.97

checked by analysing synthetic silver with 0.8 wt.% Cd. Apparent concentrations were ZAF corrected with an on-line program.

Manganoan–cadmian tetrahedrite occurs as anhedral grains up to 50 μm wide in aggregates up to 200 μm across with bismuth and locally, breithauptite and ullmannite enclosed in galena. Moreover, the galena contains smaller composite aggregates locally, with anhedral grains of bismuth, stannite, stannoidite, chalcopyrite and locally with breithauptite, alabandite and the manganoan–cadmian tetrahedrite. Bismuth occurs also as isolated, commonly cube-like inclusions in galena. Close to the galena grain boundaries, bismuth is replaced by intergrowths of bismuthinite and the sulphosalts matildite, pavonite and gustavite.

Electronprobe microanalyses of the manganoan–cadmian tetrahedrite were performed on three grains. The tetrahedrite structure, as described by Wuensch (1964), can be written as ${}^{IV}M1_6{}^{III}M2_6[{}^{III}X{}^{IV}Y_3]_4{}^{VI}Z$ where $M1$ is (Cu, Fe, Zn, Hg, Cd), $M2$ is (Cu, Ag), X is (Sb, As, Bi, Te), and Y and Z are (S, Se). Johnson *et al.* (1986) give a general compositional formula of the form $(Cu,Ag)_6Cu_4(Fe,Zn,Cu,Hg,Cd)_2(Sb,As,Bi,\text{-}Te)_4(S,Se)_{13}$, and suggest from the meagre data available on Mn-bearing tetrahedrites that Mn substitution in tetrahedrite is analogous to that of Fe, Zn, Hg and Cd. The compositional formulae calculated on the basis of 29 atoms per formula unit from the four analyses of manganoan–cadmian tetrahedrite (Table 1) can be expressed in the form suggested by Johnson *et al.* (1986) as: $(Cu_{2.06-2.46}Ag_{3.54-3.94})_{\Sigma 6.00}Cu_{4.00}(Fe_{0.43-0.92}\text{-}Zn_{0.00-0.11}\ Cu_{0.03-0.26}Cd_{0.40-0.86}Mn_{0.61-0.86})\text{-}_{\Sigma 2.04-2.47}(Sb_{3.70-3.95}Bi_{0.05-0.20})_{\Sigma 3.90-4.00}\text{-}S_{12.53-13.06}$. This result is consistent with the suggestions of Johnson *et al.* (1986) that the $M2$ position in the tetrahedrite structure as described by Wuensch (1964) is occupied by four Cu and two (Fe, Zn, Hg) atoms, and that Cd and Mn substitute for Fe and Zn in the $M1$ position. The highest Mn- and Cd-contents in natural tetrahedrite that have been recorded previously are 5.74 wt.% Mn in tetrahedrite from Basu *et al.* (1984) and 11.97 wt.% Cd from Dianwu Jia *et al.* (1988). The most Mn- and Cd-rich tetrahedrite is recorded in this study from Tunaberg and is represented by manganoan–cadmian tetrahedrite grain 5687C, in which Mn (2.4 wt.%) and Cd (5.0 wt.%) predominate over Fe and Zn; the compositional formula (average of 2 analyses, Table 1) of this manganoan–cadmian tetrahedrite shows a Mn/Cd atomic ratio around 1 and can be written as $(Cu_{2.30}Ag_{3.70})_{\Sigma 6.00}Cu_{4.00}\ (Fe_{0.43}Zn_{0.00}\text{-}Cu_{0.04}Cd_{0.83}Mn_{0.82})_{\Sigma 2.12}(Sb_{3.78}Bi_{0.15})_{\Sigma 3.93}S_{12.95}$.

Acknowledgements. Prof. I. S. Oen and an anonymous reviewer are acknowledged for critically reading the manuscript. Electronprobe microanalyses were performed at the electron-microprobe laboratory of the Institute of Earth Sciences, Free University, Amsterdam, with financial support by N.W.O.-W.A.C.O.M. (Research Group for Analytical Chemistry of Minerals and Rocks, subsidised by the Netherlands Organization for Scientific Research).

References

Basu, K., Bortnikov, N. S., Mookherjee, A., Mozgova, N. N., Sivtsov, A. V., Tsepin, A. I., and Vrublevskaja, Z. V. (1984) *Neues Jahrb. Mineral. Abh.*, **149**, 105–12.

Burkhart-Baumann, I. (1984) Ibid., **150**, 37.

Dianwu Jia, Zengyou Fu, Huiwen Zhang, and Chunpei Zhao (1988) *Acta Mineral. Sinica*, **8**, 136–7 [*Am. Mineral.*, **75**, 710].

Johnson, N. E., Craig, J. R., and Rimstidt, J. D. (1986) *Can. Mineral.*, **24**, 385–97.
Pattrick, R. A. D. (1978) *Mineral. Mag.*, **42**, 286–8.
Voropayev, A. V., Spridonov, E. M., and Shibrik, V. I. (1988) *Dokl. Akad. nauk SSR*, **300**, 1446–8 [*Am. Mineral.*, **75**, 710].
Wuensch, B. J. (1964) *Z. Kristallogr.*, **119**, 437–53.

[*Manuscript received 18 March 1991: revised 30 May 1991*]

KEYWORDS: tetrahedrite, Cd-Mn substitution, Tunaberg, Sweden

Institute of Earth Sciences,
Free University, De Boelelaan 1085,
1081 HV Amsterdam, The Netherlands

RENÉ T. M. DOBBE

MINERALOGICAL MAGAZINE, MARCH 1992, VOL 56, PP. 115–116

Zoned manganiferous garnets of magmatic origin from the Southern Uplands of Scotland

MANGANESE-ENRICHED garnets of magmatic origin have been reported as occurring in the Newer Caledonian Cairngorm Granite of Scotland; the garnets ranged in composition from 32 to 52 mol.% spessartine, and were found within the granite itself, and an aplitic sheet associated with the granite (Harrison, 1988). There are only four other known localities of spessartine garnet in Scotland: two localities on south Harris, both of which are in pegmatites; one locality in Glen Cosaidh Inverness-shire in segregation pods in gneiss; finally in eulysite at a locality at Loch Duich in Ross and Cromarty (Nicholson, 1989). Manganiferous garnets have also been noted in the Caledonian Donegal Granite and its associated pegmatites and aplites (Hall, 1965).

Small garnets (<1 mm) have now been found in a pegmatitic and aplitic vein associated with the Cairnsmore of Fleet Granite, in the Southern Uplands of Scotland. The Cairnsmore of Fleet Granite is a late Devonian granite that is thought to have formed by a complex series of magmatic injection processes, which in turn produced a hybrid biotite and biotite–muscovite granite (Gardiner and Reynolds, 1937). Pegmatite and aplite veins were noted coming from, and passing through, the granite itself, and garnets were noted in both the pegmatites and the aplites (Gardiner and Reynolds, 1937). The vein outcrops in a small disused quarry (NX546754), near to Loch Clatteringshaws, and consists of a pegmatitic vein up to 1 m in thickness containing a thin (25 cm) band of fine grained aplitic material. Although the garnets can be found within the pegmatite they are mostly concentrated in the aplite.

Studied in transmitted light the garnets are commonly blood red, but are occasionally dark yellow. They range in size from 95 μm to 400 μm and are commonly subhedral but occasionally euhedral (Fig. 1). The garnets are often seen to be lined up in a row, almost touching (Fig. 1). The length of the line of garnets can be up to thirteen separate garnet crystals, and is an unusual texture within igneous rocks. A similar texture for chromite grains has been called the train texture, and is thought to be related to the magnetic properties of the grains (A. J. Hall, pers. comm., 1991). The garnets hosted within the aplite are held in a matrix of mainly quartz, albite and microcline, with occasional oligoclase, biotite and muscovite. Secondary chlorite is also present in the matrix. The aplite matrix displays a typical micrographic texture. The lack of muscovite may be due to the pegmatite being derived from the muscovite-deficient granitic magma of the Cairnsmore of Fleet pluton.

The garnets are gradually zoned, and an electron microprobe analysis of the 20 garnets, based on 24 oxygen atoms, gives an average composition for the cores of 59.4 mol.% spessartine, 35.8 mol.% almandine, 1.1 mol.% pyrope and 3.7 mol.% andradite. A similar averaged composition for the rim of the garnets is 48.4