

## SHORT COMMUNICATIONS

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### Lead-antimony mineralization at Bwlch Mine, Deganwy, Wales

LEAD sulphantimonide minerals are uncommon in the British Isles. Amongst the better known occurrences are those in the Padstow, Tintagel and Port Isaac areas of north Cornwall (see Greg and Lettsom, 1858; Dines, 1956; Hobson, 1972), at Glendinning Mine, in Dumfries and Galloway (Smith, 1919; Gallagher *et al.*, 1983), and also at Carrock Mine (Kingsbury and Hartley, 1956) and Wet Swine Gill (Fortey *et al.*, 1984), in the northern Lake District. Bwlch Mine, near Deganwy, Gwynedd, is one of the lesser known localities in the British Isles for lead sulphantimonide minerals, and recent work by the authors has identified a wider range of these than previously reported. All of the samples referred to in this paper are lodged in the mineral collection in the Department of Geology, National Museum of Wales, under accession numbers NMW 82.1G., NMW 83.44G. and NMW 85.70G.

#### Location and geological setting

Bwlch Mine (SH 7870 7944) is located some 200 m NW of Bwlch. Little is known of the early history of the mine, but it received a brief mention by Russell (1944) who investigated specimens of stibnite he had discovered in the collections of the Museum of Practical Geology and of the Royal Geological Society of Cornwall. During this work he also established the presence of semseyite and jamesonite. It was while attempting to verify these latter minerals that the present study developed.

The mine is driven into a small hill composed of highly altered, nodular ignimbrite of Caradoc (Ordovician) age, belonging to the Capel Curig Volcanic Formation (M. J. C. Nutt, pers. comm., 1986). At present there is no access to previously-worked levels and material can only be collected from a small overgrown waste dump.

At Bwlch Mine the antimony minerals occur typically in irregular patches, and in thin veins and stringers up to 2 cm (but more usually of the order

of 0.5 cm) in width, associated with quartz, cutting nodular ignimbrite. Sphalerite, galena and marcasite are associated sulphide phases. A brownish-yellow crust on stibnite and the lead sulphantimonide minerals was identified by Russell (1944) as bindheimite,  $Pb_2Sb_2O_6(O,OH)$ , while cherry-red coatings on stibnite, observed during the course of this study (NMW 85.70G.M34), are thought to be kermesite,  $Sb_2S_2O$ ; however X-ray diffraction investigations of these secondary minerals have not verified either identification.

Whereas stibnite forms typical bladed (often radial) masses of crystals and is relatively easy to identify in hand specimen, the lead sulphantimonide minerals present problems of identification in view of their physical and structural similarities (Jambor, 1969). In reflected light all the Sb-bearing phases show moderate to strong anisotropism and have similar optical properties (Ramdohr, 1980; Picot and Johan, 1982), which rules out confident mineral identification using this approach. Furthermore, the lead sulphantimonide phases are much finer grained than the stibnite and detailed microscopic observation has revealed complex intergrowths between the various phases. Jamesonite is the only other Sb-bearing phase which can sometimes be identified in hand specimen as it forms capillary crystals in quartz. The various lead sulphantimonide minerals do, however, have distinctive X-ray powder patterns, and a combination of X-ray diffraction and electron microprobe techniques was utilised in this study.

#### Methods

X-ray powder photographs were obtained using facilities at the National Museum of Wales, University College, Cardiff and Royal Holloway and Bedford New College (Cu-K $\alpha$  radiation and Ni filters were used throughout). These were compared with data given in the JCPDS Powder Diffraction File for Minerals, 1980.

Energy dispersive and wavelength dispersive electron microprobe analyses were obtained using facilities in the Department of Geology, University College, London (Cambridge Mark 5), and in the Faculty of Materials, University College, Cardiff (Cambridge Microscan III) respectively. Standards used were galena, lead metal and lead telluride (for Pb), antimony metal (for Sb), pyrite (for S and Fe), copper metal (for Cu) and zinc metal (for Zn). Confirmatory analyses were also carried out by Dr C. J. Stanley of the British Museum (Natural History) using a wavelength-dispersive Cambridge Instruments Microscan IX microprobe.

In previous studies there have been problems in obtaining reliable analyses for the various lead sulphantimonide phases, and quoted totals from electron microprobe analyses are often quite variable. For instance Janković *et al.* (1977) presented analyses with totals varying between 98 and 104% but recalculated all to 100% before determining formulae. Similar problems were also noted by Ayora and Gali (1981). In this study all analyses with totals outside the range 99–101% have been rejected. Recalculations of mineral formulae have been carried out on the basis of ideal formulae quoted by Fleischer (1983). No Bi, Ag, As or Cl was detected in any of the lead sulphantimonide analyses in this study.

### Mineralogy

*Stibnite* was identified in most specimens of ore and was confirmed by X-ray diffraction techniques (e.g. in specimen NMW 82.1G.M1). In addition stibnite was analysed in a number of polished sections, and the results gave a formula close to stoichiometric  $Sb_2S_3$  (see Table 1).

*Semseyite* was confirmed in numerous specimens (e.g. NMW 83.44G.M5 and NMW 83.44G.M10) by X-ray diffraction, while reliable analyses of semseyite were obtained by electron microprobe analysis in a number of specimens (e.g. specimen NMW 83.44G.M8). Electron microprobe results are presented in Table 1, with recalculation on the basis of  $S = 21$ , assuming an ideal formula  $Pb_9Sb_8S_{21}$ . Little variation in chemistry is present between analyses from different laboratories, although the analysis presented in column 6 shows the closest approximation to the ideal formula. Overall the analyses indicate compositions in the range of  $Pb_{9.12-9.57}Sb_{8.06-8.64}S_{21}$ . All Bwlch Mine semseyites, however, have Sb/Pb atomic ratios in the range 0.88–0.90, compared to the ideal ratio of 0.89.

*Zinckenite* was identified by X-ray diffraction analysis in specimens NMW 83.44G.M4 and NMW 83.44G.M6, and, although difficult to quantify, it appears to be more common than semseyite. This is

also indicated by the frequency of zinckenite analyses amongst electron microprobe data. Reliable electron microprobe analyses of zinckenite were obtained from specimen NMW 83.44G.M13. Results are presented in Table 1, with recalculation on the basis of  $S = 27$ , assuming an ideal formula  $Pb_6Sb_{14}S_{27}$ . The compositional range  $Pb_{6.24-6.63}Sb_{14.66-15.00}S_{27}$  gives Sb/Pb ratios in the range 2.22–2.38 (mean 2.32), which compares closely with the ideal ratio of 2.33.

*Jamesonite*. Readily observable capillary crystals have been identified as jamesonite on the basis of X-ray diffraction and electron microprobe analysis in specimen NMW 83.44G.M7. The result of one analysis is presented in Table 1. Recalculation on the basis of  $S = 14$ , assuming an ideal formula  $Pb_4FeSb_6S_{14}$ , gives a formula for the Bwlch Mine jamesonite of  $Pb_{3.72}Fe_{0.71}Sb_{5.89}S_{14}$ .

*Plagionite*. Two analyses, from specimens NMW 83.44G.M4 and NMW 83.44G.M13, presented in Table 1, have chemistries close to that of plagionite. The two analyses recalculate as  $Pb_{5.49}Sb_{8.62}S_{17}$  and  $Pb_{5.15}Sb_{8.12}S_{17}$ , close to the ideal formula  $Pb_5Sb_8S_{17}$ , and have Sb/Pb ratios of 1.57 and 1.58 respectively, compared with the ideal ratio of 1.60. The presence of plagionite was confirmed in specimen NMW 83.44G.M13 by X-ray diffraction on a small grain isolated from the area of the polished block analysed by electron microprobe methods. This represents the first verified occurrence of plagionite in the British Isles.

*Other analyses*. In addition to the phases listed above, certain analyses presented in Table 1 possibly indicate the presence of other lead sulphantimonide minerals. Analyses 20–24, from specimen NMW 83.44G.M13, approximate closely to robinsonite, with an ideal formula of  $Pb_4Sb_6S_{13}$ . Although the Bwlch Mine analyses give compositions in the range  $Pb_{4.28-4.35}Sb_{6.30-6.55}S_{13}$ , their Sb/Pb ratios (range 1.45–1.51; mean 1.49) correspond to that of ideal robinsonite (1.50). If confirmed, this would be the first record of this mineral in the British Isles. Analysis 25 from specimen NMW 83.44G.M7 shows a very low Sb/Pb ratio, falling slightly below that of ideal semseyite. It is possible that this represents boulangerite, although the Sb/Pb ratio of 0.85 is slightly higher than that for boulangerite (0.80), assuming an ideal formula of  $Pb_5Sb_4S_{11}$ .

As it was not possible to extract sufficient material for X-ray powder diffraction at this stage, the presence of robinsonite and boulangerite at Bwlch Mine can only be considered as tentative.

### Discussion

This study has shown that the range of lead

TABLE 1. Analyses of antimony minerals from Bwlch Mine

	specimen no.	Sb	Pb	Fe	Cu	Zn	S	Total	
1.	stibnite	NMW 83.44G.M14	72.22	n.d.	0.03	0.15	n.d.	27.13	99.53
2.	stibnite	NMW 83.44G.M14	71.89	0.78	0.01	0.20	0.34	27.07	100.29
3.	stibnite	NMW 83.44G.M14	72.42	n.d.	n.d.	0.21	0.03	27.35	100.01
4.	stibnite	NMW 83.44G.M14	71.79	0.59	n.d.	0.22	0.15	26.94	99.69
5.	semseyite	NMW 83.44G.M12	28.38	53.49	0.02	0.11	0.07	18.14	100.21
6.	semseyite	NMW 83.44G.M12	27.71	53.52	n.d.	0.30	0.18	18.87	100.58
7.	semseyite	NMW 83.44G.M12	28.03	52.96	n.d.	n.d.	n.a.	18.38	99.37
8.	semseyite	NMW 83.44G.M12	27.77	53.14	0.02	n.d.	n.a.	18.25	99.18
9.	semseyite	NMW 83.44G.M12	28.20	53.24	0.07	n.d.	n.a.	18.27	99.78
10.	semseyite	NMW 83.44G.M12	27.74	53.55	n.a.	n.a.	n.a.	19.04	100.33
11.	zinckenite	NMW 83.44G.M13	45.63	33.00	0.02	0.32	0.14	21.65	100.76
12.	zinckenite	NMW 83.44G.M13	45.19	32.68	0.12	0.32	0.18	21.71	100.20
13.	zinckenite	NMW 83.44G.M13	45.08	32.98	0.12	0.31	0.08	21.53	100.10
14.	zinckenite	NMW 83.44G.M13	45.69	32.72	0.04	0.31	n.d.	21.94	100.70
15.	zinckenite	NMW 83.44G.M13	44.25	34.04	n.d.	0.36	0.13	21.43	100.21
16.	zinckenite	NMW 83.44G.M13	44.56	32.99	n.d.	0.50	0.17	21.60	99.82
17.	jamesonite	NMW 83.44G.M7	36.60	39.32	2.08	n.a.	n.a.	22.92	100.92
18.	plagiionite	NMW 83.44G.M13	38.55	41.90	n.d.	n.d.	n.a.	20.03	100.48
19.	plagiionite	NMW 83.44G.M4	38.16	41.03	n.a.	n.a.	n.a.	20.99	100.18
20.	?robinsonite	NMW 83.44G.M13	37.04	42.36	0.08	0.37	0.19	19.69	99.73
21.	?robinsonite	NMW 83.44G.M13	37.22	43.01	n.d.	0.24	0.18	19.99	100.64
22.	?robinsonite	NMW 83.44G.M13	37.76	42.68	0.04	0.29	0.06	20.08	100.91
23.	?robinsonite	NMW 83.44G.M13	37.70	42.53	n.d.	0.24	0.15	19.72	100.34
24.	?robinsonite	NMW 83.44G.M13	36.90	43.21	n.d.	0.33	0.12	20.03	100.59
25.	?boulangerite	NMW 83.44G.M7	27.69	55.06	n.a.	n.a.	n.a.	17.27	100.02

analyses 1-6, 11-16, 20-24, D.H.M. Alderton at University College, London  
 analyses 7-9, 18, C.J. Stanley at British Museum (Natural History), London  
 analyses 10, 17, 19, 25, P. Fisher at University College, Cardiff

n.d. = not detected  
 n.a. = not analysed for

sulphantimonide minerals at Bwlch Mine is greater than previously reported. The presence of stibnite, semseyite and jamesonite, as described by Russell (1944), has been verified, the additional presence of zinckenite and plagiionite has been determined, while the occurrences of robinsonite and boulangerite have been tentatively identified.

Other occurrences of lead sulphantimonide minerals in Great Britain show a variety of environments of formation and emplacement. The antimonian veins at Glendinning cross cut Silurian greywackes and are thought to have been derived by mobilization of antimony from syn-sedimentary antimonian arsenopyrite (Gallagher *et al.*, 1983). The quartz-antimony vein from Wet Swine Gill is located within the aureole of the Skiddaw Granite, and Fortey *et al.* (1984) remarked on the possibility that the later sulphosalt assemblage at Wet Swine Gill is related to remobilization of primary Sb by later Pb-bearing fluids. However, there is no evidence of primary arsenic-bearing phases at Bwlch Mine. In contrast, the occurrence is associated with a volcanic sequence and thus shows some affinity with the north Cornwall occurrences. It is now generally agreed that the Ordovician volcanic rocks of Wales developed in an ensialic extensional basin, the Welsh Basin. This formed as a result of lithospheric attenuation in a back arc environment related to southeasterly subduction of Iapetus Ocean lithosphere beneath the northwestern margin of Gondwanaland (Kokelaar *et al.*, 1984). In the North Wales area, during Caradoc times, a thick

bimodal sequence of acidic and basic magmas were both extruded, commonly explosively to form extensive ash-flow or ignimbrite units, and intruded at a high level to form thick sills and small bosses, leading to the development of the Llewelyn and Snowdon Volcanic Groups (see Kokelaar *et al.*, 1984, and Howells *et al.*, 1986). In such environments today, hydrothermal circulation is commonly present, such as in North Island, New Zealand, and epithermal mineral deposits are typically developed (Hedenquist, 1986). Antimony, along with mercury, gold and silver, is present in these New Zealand epithermal fluids and associated deposits (Weissberg, 1969; Browne, 1971) and indeed epithermal mineralization with antimony as a major component is characteristic of volcanic areas underlain by attenuated continental crust, such as Peninsular Malaysia (see Hutchison, 1983). We consider therefore, that the Bwlch Mine deposit is an epithermal mineral deposit, associated with development of the Llewelyn Volcanic Group. Although the ash-flow tuffs at Bwlch Mine, in which the mineralization is presently hosted, are probably quite distal from source, heat required to drive hydrothermal fluids would probably have been provided by nearby contemporary high level intrusions such as that at Penmaenmawr, located only 8 km to the southwest. Indeed much of the vein copper mineralization in Central Snowdonia has been related to hydrothermal circulation associated with volcanism, high-level intrusion and caldera collapse during development of the Ordovician volcanic pile

(Reedman *et al.*, 1985). More detailed work on the Bwlch Mine assemblage is currently in progress and further occurrences of antimony mineralization in North Wales are being investigated, particularly with a view to testing their epithermal nature and volcanic association.

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## Chloritoid from low-grade pelitic rocks in North Wales

MN-RICH chloritoid has been found in low-grade metamorphic slates of Ordovician age near Rhyd-Ddu (NH 565528) in Snowdonia, Gwynedd, North Wales. To the author's knowledge this is the first reported occurrence of chloritoid in the para-

tectonic Caledonides of the Welsh Basin and has important implications for the metamorphic history of the area which will be discussed elsewhere (Brearley, in prep.).

Chloritoid occurs in black slates of the Nant