Avoca Mine, a Volcanic Hosted Massive Sulphide Deposit in the Southwest of the European Caledonides

Dr. W.A. Sheppard

1 INTRODUCTION

The Avoca Mine in Southeast Ireland and the Parys Mountain Mine in Angelsey in North Wales are both hosted by volcanic sequences within the Caledonides of Western Europe. Massive, semi-massive, vein-style and disseminated sulphide mineralization occurs within both mining areas. The mineralization at each Mine is interpreted to be volcanogenic with a variable degree of structural overprinting, but at Avoca there is uncertainty in relation to structural modeling. At Avoca geochemical studies by B. McConnell has shed much light of the nature of the volcanic sequence and to a fair degree confirmed the stratigraphy established by detailed mapping and lithological correlation.

It is hoped that, whether you seek the assurance of the VHMS pigeonhole or you have come to explore the uniqueness found in every VHMS deposit, you enjoy the short visit to the Avoca mine area. The field trip will include a presentation, visits to the East Avoca Open Pit, the Cronebane Open Pit and selected outcrops. Drill core will be made available by the geological Survey of Ireland and inspected on site. Bold type within the text denotes drill core or field visit of relevance.

2 THE AVOCA MINE

There was a lengthy history of copper mining at Avoca Mine, 60km south of Dublin. The mineralization is hosted by the Duncannon Group a northeast-trending, Middle to Upper Ordovician sequence of basic to acid volcanics related to subduction along the southeast margin of the Iapetus Ocean. Two principal sequences have been mapped within the Avoca Mine area. First, there is Unit 2 consisting of rhyolites and lithic-dominated tuffs in approximately equal proportions lying within the structural hangingwall of the mineralized sequence to the southeast and east of the mineralized area. Second, a younger crystal-dominant sequence of typically sericitic volcanics that is referred to as Unit 3. This Unit is best developed to the northwest and west of the Mine and dominates the structural footwall of the mineralized sequence. The Avoca mineralization is interpreted to lie at the top of the Unit 3 sequence. Within the mine area, Unit 4, a sequence of upward-fining, lithic and crystal volcaniclastics sequence passing up into black shale overlies the massive sulphide mineralization.

The mine area had a complex structural history. Because of insufficient way-up evidence and difficulty in sequence recognition due the overprinting by alteration, a number of possible structural models must be considered to explain lithological distribution within the Avoca Mine area. However, a regional synclinal model is favoured by the author (Fig.2).

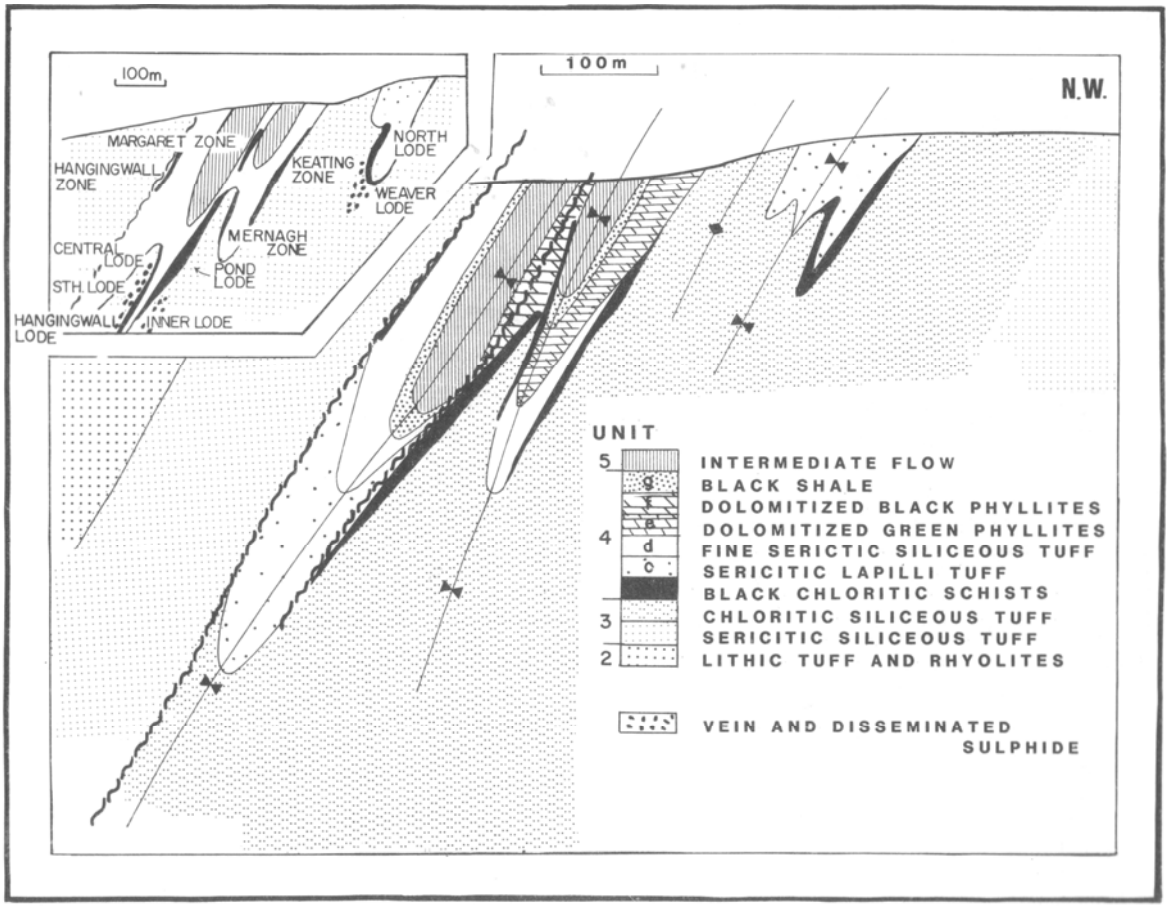

Figure 2 Geological Section of West Avoca

The mineralization at Avoca includes two principal styles. First, massive to banded cupriferous pyritic sulphide is hosted by black chloritic schist at the base of Unit 4. Pb-Zn massive sulphide is best developed on the structural hangingwall of this cupriferous massive sulphide and in the stratigraphic hangingwall rocks. Second, complex vein-style and disseminated mineralization referred to as 'stringer' mineralization occurs in strongly silicified and chloritized tuffs at the top of Unit 3.

Production from the Avoca Mine is estimated to have totaled 16Mt grading about 0.6% Cu. Mining dates from at least the 1700s with the most recent production in the years 1958 to 1962 and 1969 to 1982. In the latter period of mining, massive sulphide was mined at a grade of 1.0% Cu to 1.2% Cu and stringer sulphide at 0.8% Cu to 1.0% Cu. Within the mine area, mineralization is known to extend over a surface area of approximately 4km X 500m and to a depth of over 500m. The total *in situ* copper resource at Avoca is believed to have exceeded 100Mt at 0.2% Cu. Exploration of the Avoca Mine area is incomplete. There is potential for discovery of new base-metal sulphide deposits within and along strike from the known mineralized area. In addition to base metals, previous exploration by Riofinex intersected significant stringer gold mineralization including 30.1m at 3.74g/t Au. These intersections highlight the potential for the discovery of gold mineralization.

3 VOLCANIC CENTRES

The volcanics within the Avoca region were interpreted by McConnell to be derived from a zoned magma chamber developed from the mixing of two magma sources, one related to subduction and the other associated with rifting. Sampling for this study was based on the Unit 1 to Unit 5 geological framework presented here and lends much support to that geological interpretation. There were probably five volcanic centres in the Avoca Area.

3.1 RATHDRUM

A few lines of evidence indicate that the volcanics within Unit 1 include the earliest volcanics in the area (Fig.1). They consist of a diverse sequence of intermediate lavas and coarse polymict volcaniclastics with minor shale intercalations centred on the Rathdrum area in the northwest. Rhyolites are not common and largely restricted to small dykes. The rocks within the Unit lack strong alteration or strong foliation development. These Unit 1 volcanics include basic rocks of arc affinity and acid rocks that show a fractional crystallization trend but they did not reach peralkaline compositions.

3.2 BALLYMOYLE

To the far northeast of the Avoca mine area, the Ballymoyle Volcanics are a geochemically distinct sequence that, like the Rathdrum volcanics lack strong alteration or foliation development and are not peralkaline in nature. Only very limited deposition from this centre extended into the Avoca area, but a few sample localities within Units 2 and Unit 3 have been demonstrated by McConnell to have a Ballymoyle geochemical signature.

3.3 AVOCA UNIT 2 AND UNIT 3

The Unit 2 and Unit 3 lithologies relate to a volcanic centre that lay within a few kilometres to the northeast of the Avoca mine. Unit 2 contains a series of peralkaline, potassic rhyolites, some of which are magnetic **(DDH R-4)**. They include massive, flow banded and brecciated rhyolites. The strike continuity of these rhyolites is generally good, certainly exceeding 500m in a number of areas, suggesting an origin as high level intrusive but more likely as flows, yet evidence of welding is rarely seen. Sperulitic textures and partial devitrification are common features in thin section. The rhyolites lie within moderately to strongly siliceous, moderately foliated chloritic lithic volcaniclastics. These generally lack clear bedding and are polymict with some possible chloritic pumiceous clasts. They are usuallydominated by irregularly shaped rhyolitic clasts dominate. Shale intercalations are very rare. It is speculated that these volcaniclastics were rapidly deposited possibly as mass flow units. Some coarse-tail grading has been reported in drill core.

Unit 3 extends for about 2km to the northeast and for over 5km to the southwest of the mine (Fig.1). It is dominated by sericitic crystal-dominated volcaniclastics that include quartz-eye tuffs typical of many VHMS deposits within the Caledonides. The lithologies low in the sequence are feldspathic with embayed quartzes, but towards the top of the sequence feldspar dies out as the silica content of the sequence increases **(DDH WL-14)**.

Close to the mine footwall, lithic volcaniclastics are present, chlorite replaces sericite as the foliation forming mineral and there are possible chert horizons **(DDH 1040-67, DDH 1040-7, DDH KG-10)**. The sericite is a 2M1 muscovite polymorph, while the chlorite is chamosite. The top of the Unit in East Avoca is marked by a distinctive white rhyolite with a pyritic breccia.

The view that Unit 2 is older than Unit 3 is supported geochemically by evidence that the Unit 3 rocks are less evolved and correspond to a general waning of volcanic activity and an associated reducing magma evolution. Unit 3 includes some non-peralkaline rhyolites. The general lack of basic rocks is thought to be due to a low density rhyolitic cap developing in the magma chamber to inhibit eruption of basic to intermediate magmas (McConnell). Within the wall rocks to mineralization, the Unit 3 volcanics show depletion in TiO_2, K_2O, Sr and LREE elements and possible depletion in MgO, CaO and Na_2O.

3.4 AVOCA UNIT 4

The nature of Unit 4 supports the presence of a local volcanic centre in the vicinity of East Avoca that developed soon after the deposition of the main massive sulphide bodies in the Avoca area. At the base of Unit 4 is massive sulphide hosted by black chloritic schist **(DDH 1040-67)**. This horizon is overlain by an upward fining sequence of volcaniclastics and volcanic sediments. These lithologies include both strongly chloritic and strongly sericitic schistose to phyllitic volcaniclastics (Fig.2). The top of the unit is marked by black shales. The coarsest lithology within the unit is found in East Avoca where a agglomerate containing bleached rhyolite clasts is spatially associated with the white brecciated rhyolite at the top of Unit 3 (Fig.3) **(Cronebane Open Pit)**. The agglomerate includes large blocks of this rhyolite, some of which are brecciated and pyritic. A feature of the Unit 4 sequence is the development of vein and disseminated dolomite.

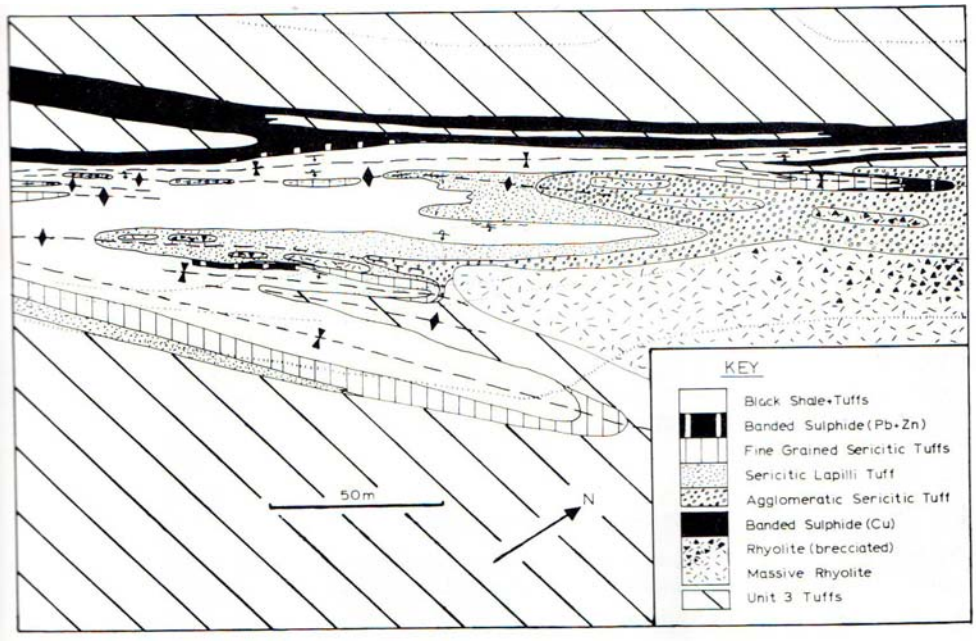

Figure 3 Geological Plan of the Central Part of Cronebane Open Pit

The volcanics of Unit 4 are distinguished from the footwall Unit 2 and Unit 3 lithologies by their negative Zr to Nb relationship and low Zr indicating derivation from a different magmatic source (McConnell).

3.5 AVOCA UNIT 5

Unit 5 **(DDH R-4)**, an intermediate lava flow with in excess of 50% albite and containing tremolite after pyroxene, directly overlies Unit 4 black shale (Fig.2). It was best exposed in West Avoca during mining where subophitic textures were noted in thin section of samples away from the tectonized base of the flow. Unit 5 was also intersected in drillholes at Rockstown. **(DDH R4)** some 4km north of the mine area (Fig.1). This lithology is geochemically distinct from others in the Mine area and was shown to be related to pre-D_1 dolerites northeast of Rockstown. They mark a new, post-mineralization volcanic cycle with associated early dolerites. The Unit 5 lava flow is enriched in TiO_2, Al_2O_3 and MgO and depletion in Fe_2O_3, MnO, CaO, Na_2O and K_2O, reflecting a change in alteration within the post massive ore lithologies.

4 STRUCTURAL COMMENT

Regional Caledonian deformation in the post-Wenlock to early Devonian produced a moderate to very strong, penetrative to spaced S_1 fabric is developed within the Unit 3 volcaniclastic lithologies. Shearing sub-parallel to strike is a major feature of the deformation within the Avoca mine area. The immediate footwall rocks to massive sulphide have been referred to as blastomylonites. Silica was highly mobile during D_1. There is a strong stretching lineation, best seen in West Avoca, defined by mineral and clast elongation. This plunges to the southeast and is parallel to the axis of the main F_1 folds in West Avoca. A spaced S_2 is present, best displayed in finer grained lithologies. Close to the footwall of massive sulphide the history of quartz veining is very complex ranging from pre-D_1 to very late in the structural history of the mine area. Review of regional geology indicates that the Mine lies on a north-10^o-east structural linear.

At the time of mining within the Cronebane open pit in East Avoca, there was abundant and clear way up evidence in support of folding with overturned limbs the strongest developed. Elsewhere within the mine area, way up criteria are rare and often ambiguous. With the benefit of both surface and underground exposure and of drill core within the immediate mine area, however, the structural controls on lithological distribution could be demonstrated to be both folding and shearing. In West Avoca, detailed lithological correlation defines a series of synclinal axis disrupted by shearing along their limbs (Fig.3). In contrast to East Avoca, it is the right-way-up limbs that are best preserved in West Avoca. In East Avoca, folds tighten northwestwards towards this main shear which lies towards the structural footwall of Unit 4. In West Avoca the main shear lies at the structural hangingwall of Unit 4. Both in the Rockstown area and at Kilmacoo in the extreme east of East Avoca, drill core interpretation supports lithological repetition by tight folding.

The key question is whether the strong folding at Avoca is of regional significance or solely related to the major shear development within the Mine area. Publications include models with all lithologies younging to the northwest, all younging to the southeast and the synclinal model preferred here. While there is little evidence to conclusively establish

the correct model, mapping by the author and geochemical interpretation by McConnell support the presence of a regional syncline. However, in the absence of any modern regional structural studies there can be little further progress in resolving this issue. Thrust repeats remain an alternative possibility to explain the apparent degree of lithological Unit symmetry on either side of the Avoca Syncline.

5 MINERALIZATION

5.1 THE MASSIVE MINERALIZATION

The average grade of mined massive sulphide was about 1.2% Cu. The sub-level caving method of mining used at Avoca in the final period of mining meant that development was largely restricted to the massive sulphide footwall, thus good exposure of massive sulphide was not common. The main body of the deposit was genuinely massive, of moderate grain size and had a laminated appearance. It was, however, totally recrystallized and lacked any primary textures. Hangingwall exposures on 1040 Level show an anastomosing relationship with discontinuous black chlorite schist bands and lenses separating continuous undulating massive sulphide bands. Close to the hangingwall of a number of the massive sulphide bodies identified, a marked increase in Pb-Zn content was noted which by analogy with other VHMS deposits is indicative of way up. All such occurrences support the synclinal model for the mine area.

A number of discontinuous Pb-Zn lenses and bands occur within the Unit 4 sequence both in East and West Avoca. These would appear to occur in some of the finer grained lithologies and some contain blocks of rhyolite and volcaniclastic rocks, not all of which can be interpreted as boudins **(Cronebane Open Pit)**.

5.2 THE STRINGER MINERALIZATION

The mineralization referred to as stringer mineralization is a very complex vein and disseminated low-sulphide (6% S to 10% S) vein quartz system **(East Avoca Open Pit, Cronebane Open Pit)**. The average grade of stringer sulphide mined from underground was about 0.8% Cu. This stringer mineralization is hosted by volcaniclastics at the top of Unit 3. It lies in both the structural footwall and hangingwall of the massive sulphide horizon (inset Fig.2). The mineralization is vein quartz hosted chalcopyrite, however, locally high sulphide zones are present. These are banded and best interpreted as areas where margins of a massive sulphide body have been incorporated into the stringer complex. Remobilization of chalcopyrite into vein quartz is seen within these areas and early research by Wheatley concluded from ore microscopy study that much of the stringer zone chalcopyrite was derived in this way. Of note regarding grade distribution within the stringer mineralization are i) the low but significant galena and sphalerite contents within the stringer zones in East Avoca where chloritization is less extreme **(East Avoca Open Pit)** and ii) the early interpretation by Murphy that the Cu zones within the West Avoca stringer mineralization were arranged in and en echelon pattern. Exploration by RTZ at Kilmacoo intersected a modest Au Resource hosted by silicified Unit 3 volcaniclastics and associated with finely banded white quartz veining **(DDH KG-10)**.

The structural complexity of the stringer zone rules out any definitive evidence regarding its early geometry and nature. The mineralized veins are typically syn-D1 or post-D1, but an early feeder system may well have been present within the stringer mineralization. Grey chert within the stringer mineralization may be early, however, it is analogous to grey chert in the CSA Mine in Cobar, New South Wales, Australia which was formed solely by epigenetic processes. Overall the best analogies with the Avoca stringer mineralization are found within Canadian Archean shear-hosted Au deposited, emphasising the major impact of its structural history on the Avoca mineralization.

5.3 ISOTOPIC STUDY

Sulphur isotopic data from the research by Williams showed no distinction between the massive and stringer mineralization and no trend within or between different bodies of such mineralization. Values typically ranged between $+6.8^0/_{oo}$ and $+12.3^0/_{oo}$. However, the samples from the Cronebane pyritic rhyolitic breccia showed a much wider range of $+0.2^0/_{oo}$ to $+17.4^0/_{oo}$ interpreted to indicate a greater proportion of magmatic sulphur within the rhyolite-hosted pyrite. Carbonate veins and lenses from Unit 4 lithologies gave $\delta^{13}C$ values from $-5.3^0/_{oo}$ to $-8.8^0/_{oo}$ and $\delta^{18}O$ values typically of from $+11.2^0/_{oo}$ to $+20.9^0/_{oo}$.

References

A comprehensive list of relevant references is available in McArdle 1993. The key references to note include:

Badham, J.P.N. 1978. Slumped sulphide deposits at Avoca, Ireland and their significance. Trans. Instn Min. Metall, (Sect. B: Appl. Earth sci.), 87, pp21 -26.

McArdle, P. 1993. Evolution and preservation of volcanogenic sulphides at Avoca, southeast Ireland. Trans. Instn Min. Metall, (Sect. B: Appl. Earth sci.), 102, pp149 -163.

McConnell, B.J. 1987. Geochemistry of Ordovician peralkaline volcanics at Avoca, County Wicklow, and their regional associations. Ph.D. thesis, University of Dublin.

Milner, A.L. and McArdle, P. 1992. Gold mineralization in Ordovician volcanic rocks at Kilmacoo, County Wicklow: its exploration and geological controls. *In* The Irish minerals industry – a review of the decade. Bowden. A.A. et al eds (Dublin: IAEG) pp51 - 63.

Murphy, G.J. 1959. The Avoca Enterprise, 2: the geology of the mineralised area. Mine and Quarry Engineering, 25 pp 330 – 338.

Platt, J.W. 1977. Volcanogenic mineralization at Avoca, Co. Wicklow, Ireland and its regional implications. *In* Volcanic processes in ore genesis. (London: Instn Min. Metall, and Geol. Soc.) pp163 – 170.

Sheppard, W.A. 1981. The host rock geology and geochemistry of the Avoca mines, County Wicklow, Ireland. Ph.D. thesis, University of Dublin.

Wheatley, C.J. 1971. Economic geology of the Avoca mineralised belt, southeast Ireland, and Parys Mountain, Anglesey. Ph.D. thesis, University of London.

Williams, F.M., Sheppard, W.A. and McArdle, P. 1986. Avoca Mine, County Wicklow: a review of geological and isotopic studies. *In* Geology and genesis of mineral deposits in Ireland. Andrew, C.J. et. al. eds. (Dublin: IAEG) pp49 – 69.