Quartz-sulphide vein mineralization of Devonian and Variscan age in central Wales

Mining for a variety of minerals, principally the ores of lead, zinc, copper and silver, but also the minerals marcasite, barite and witherite, has taken place intermittently in the Central Wales Orefield over a considerable length of time. Copper was sought during the Early Bronze Age at a number of sites (Timberlake, 1988, 1989, 1992). The Romans were active militarily in the area and mined gold to the south, at the Dolaucothi Mine GCR site. Until recently, it was not known whether they had mined lead in Central Wales. However, excavations in 2004–2005 between Llancynfelyn and Talybont, on the western side of the orefield, revealed a Roman smelting site beneath a medieval trackway. Lead mining was certainly active during Monastic times (Hughes, 1981a), although details of operations in the Middle Ages are only fragmentary.

The first major documented boom of activity was during the 17th century, when silver was the main target, sought particularly at a group of mines between Talybont and Goginan, where the ordinarily argentiferous galena is accompanied by richly argentiferous tetrahedrite. However, the most intensive phase in the mining history of Central Wales came in the mid-19th century, when hundreds of workings, ranging from short trial adits through to full-scale mines, were prosecuted in search of lead and, particularly later in the century, for zinc, with silver and copper as by-products. Locally intense marcasite mineralization, which in places contaminated the lead and zinc ores sufficiently to render them unsaleable, was occasionally sold as 'pyrites' Uones, 1922) for sulphuric acid manufacture, while small amounts of barite and witherite were mined in the eastern part of the orefield.

Mining had declined considerably by the early 20th century, the industry finally fading away after the First World War, when the release of Government metal stocks (particularly zinc), coinciding as it did with the dramatic rise of Broken Hill in Australia, caused a major slump in prices. Apart from very minor trials and a number of exploration projects, the post-Second World War years have seen the industry in this area dormant.

Mineral production figures were only compulsorily recorded in the United Kingdom after 1845, so that the produce of the intensive 17th century years remains unknown. Therefore the preserved figures represent an unknown percentage of the total (Mason, 1997). From 1845 onwards, the Central Wales Orefield produced more than 450 000 tons of lead ore concentrates containing in excess of 2.5 million oz of recovered silver, more than 140 000 tons of zinc ore concentrates and more than 8000 tons of copper ore concentrates. Most of the production came from a small number of major mines, such as Van, which exceeded 125 000 tons of lead- and zinc-ore concentrates between 1866 and 1917 alone (Burt *et al.,* 1990).

Geologically, the Central Wales Orefield occurs in the deformed remnants of a structurally controlled marginal basin (the Welsh Basin), which developed on the south-eastern continental margin of the Iapetus Ocean during Lower Palaeozoic times (see Dewey, 1969). Turbidite-dominated sequences of Ashgill to Upper Llandovery age comprise the host rocks to the mineralization, the range of basinal facies present varying from coarse conglomeratic sandstones developed in proximal channels, to hemipelagic graptolitic black-shales deposited on the basin plain. Periodic facies variations were controlled by sediment availability, which was in turn related to transgressive and regressive phases of the Welsh Basin seas.

The Acadian deformation, responsible for inverting the Welsh Basin, occurred in early Devonian times (Soper *et al.,* 1987), with the development of a series of major open NNE–SSW-trending periclinal folds, the most important being represented by the Plynlimon, Machynlleth and Van inliers (Cave and Hains, 1986). Between these key structures, smaller parasitic folds occur on all scales. NNE–SSW-trending strike faults and thrusts commonly developed as compression accommodation structures, while cleavage, approximately axial planar to folds, Is only pervasive in the more argillic units, some of which have been worked for poor-quality slate.

Mineralization in Central Wales falls into two broad categories, namely minor but widespread pre-tectonic mineralization, and major, post-tectonic fracture-hosted vein mineralization. The pre-tectonic mineralization is partly diagenetic, comprising locally common framboidal, nodular or cubic pyrite, nodular apatite, silica, carbonate and monazite (see for example Read *et al.,* 1987; Milodowski and Zalasiewicz, 1991; Smith *et al.,* 1994). Additionally, pre-tectonic veins are widespread in all lithotypes and contain abundant quartz accompanied by variable amounts of chlorite, pyrite and ferroan dolomite (Fitches, 1987). Vein compositions directly reflect host-rock lithology, implying the localized derivation of fluids during an early stage of sediment dewatering. The veins are characteristically limited in extent, with strike lengths rarely exceeding 10 m, and are usually flat-lying and irregular in shape, due partly to later deformation. The post-tectonic metalliferous veins cut the pre-tectonic veins (Mason, 1994, 1997).

The post-tectonic metalliferous veins (or lodes) are hosted by a swarm of transverse fractures, which vary in magnitude from mineralized joints to major normal fault-zones with displacements of over 200 m (Figure 5.51). The predominant strike of the fractures is ENE–WSW, although localized north-west-southeast and north-east-south-west trends also occur. Transverse fracturing and mineralization were effectively synchronous, and fracture propagation and the accompanying brecciation were both assisted by the hydraulic properties of the mineralizing fluids. Indeed, the role of hydraulic fracturing in the formation of mineralized vein-breccias was first proposed by Phillips (1972), using the Central Wales Orefield as a model. The breccias consist of angular fragments of wall-rock cemented by the various ore and gangue minerals. Radial growths of minerals cementing matrix-supported rock clasts indicate that mineral nucleation on the rock fragments took place rapidly after brecciation. In addition to the mineralized breccias, some demonstrably late-stage veins consist of crustiform open fissure-fillings.

Prior to the 1970s, the detailed paragenesis of the metalliferous mineralization in the Central Wales Orefield had received little attention. The probable late Caledonian age of the mineralization was postulated by Jones (1922), although earlier Finlayson (1910b) had suggested that the Lower Palaeozoic sedimentary-hosted metalliferous veining occurring throughout Wales was of Hercynian age.

The first major paragenetic study of the Central Wales Orefield was by Raybould (1973, 1974), who reached the conclusion that the mineralization involved a single, generalized paragenetic sequence, showing a gradual change in mineralogy through successive cross-cutting and re-brecciation episodes. The sequence identified comprises sustained quartz deposition with associated minerals being precipitated in the order pyrite (first), ankerite, chalcopyrite, sphalerite, and galena (last). In addition, occurrences of marcasite, arsenopyrite and, at one locality, minor cobaltite were described. Raybould (1973, 1974) also perceived a zonation pattern, in which the proportion of galena in the ore-bodies increases while that of chalcopyrite decreases as the lodes on the western flank of the Plynlimon inlier are traced westwards.

The area was re-investigated in the late 1980s and early 1990s by Mason (1994, 1997). Preliminary fieldwork had led to the recognition that the mineralization of Central Wales is in fact polyphase and is mineralogically far more complex than had hitherto been believed. The subsequent detailed investigations, which resulted in the discovery of a number of rare ore minerals, such as the third worldwide occurrence of tucekite [$Ni_9Sb_2S_8$], also resulted in a re-appraisal of the paragenesis of the Central Wales Orefield. Mason (1994, 1997) identified that the post-tectonic metalliferous veining of Central Wales may be divided into two groups of assemblages, termed 'A1' and 'A2' (see (Table 5.1)), which were referred to as the 'Early Complex' and 'Late Simple' groups. In fact, many of the mineralized fractures of the Central Wales Orefield contain assemblages belonging to both groups, since they have been subjected to repeated episodes of tectonic activity; re-brecciation and mineralization. Spatially, the distribution of the two groups of assemblages is erratic, although in some areas one group is prevalent over the other.

Veins carrying assemblages belonging to the early or A1 group, which are commonly 'welded' to their walls, are compact and consist of numerous angular clasts of shattered sedimentary rock cemented by sulphide-bearing quartz (Mason, 1994, 1997). The quartz of the A1 group of assemblages is milky-white, close-grained and tough; occasional vugs contain slender prismatic crystals with water-clear terminations. The diverse sulphide minerals are usually fine-grained and complexly intergrown. Economically, Pb, Cu and Ag were the prime metals mined from the A1 group of assemblages. Other elements present in minor amounts comprise Zn, Sb, Fe, NI, Co, As, and Au, in estimated order of abundance. Varying facets of the A1 style of mineralization are best seen at the Darren Mine, Erglodd Mine, and Eaglebrook Mine GCR sites.

(Table 5.1) Classification of Central Wales Orefield mineralization into the 'Early Complex' A1 and 'Late Simple' A2 groups. Minor/trace species are in italics; major phases are underlined. After Mason (1994, 1997).

A1 ('Early Complex') assemblages	**A2 ('Late Simple') assemblages**
Early Devonian isotopic age Post-Caledonian relaxation?	Early Carboniferous to Permian isotopic ages Mainly Variscan extension?
WEAK BRECCIATION	**MAJOR BRECCIATION**
A1-a Minor early Cu qtz + chalcopyrite + ferroan dolomite	**A2-a Pb-Zn assemblage** qtz + sphalerite + chalcopyrite + galena
BRECCIATION	**MAJOR BRECCIATION**
A1-b Early sphalerite assemblage + pyrite + sphalerite (with chalcopyrite disease) + ferroan dolomite + chlorite	A2-b Ullmannite-bearing Pb-Cu assemblage qtz + chalcopyrite + ullmannite + galena
MAJOR BRF.CCIATION	**CRUSTIFORM OVERGROWTH**
A1-c Polymetallic assemblage w_z + pyrite + siegenite + cobalt pentlandite + millerite + chalcopyrite + *pyrrhotite* + tucekite + ullmannite + *gersdorffite* + *electrum* + tetrahedrite + bournonite + *boulangerite* + galena	A2-c Calcite-dominated assemblage qtz + galena + sphalerite + calcite + *chalcopyrite* + *pyrite*
SHEARING OF SULPHIDES	**CRUSTIFORM OVERGROWTH**
A1-d Minor late veining chalcopyrite + galena + "honey-blende" sphalerite	**A2-d Coarsely crystalline quartz** qtz + *chalcopyrite* + *pyrite* lerite
LOCALLY MAJOR BRECCIATION	**RELATIONSHIP UNKNOWN**
A1-e Ferroan dolomite influx qtz + ferroan dolomite	**A2-e Barium minerals assemblage** *qtz* + sphalerite + galena + calcite + barite + witherite
LOCAL FRACTURING	**MAJOR BRF.CCIATION AND TECTONISM**
A1-f Late cavity-filling qtz + *siegenite* + *cobalt pentlandite* + millerite + chalcopyrite + galena	**A2-f Iron sulphides assemblage** + sphalerite + pyrite + marcasite
Important economic assemblages: A1-b (moderate Zn); A1-c (major Pb-Ag, moderate Cu); A1-f (minor Pb-Cu)	**Important economic assemblages: A2-a (major Pb-Zn, minor Ag); A2-b (moderate Pb, Ag, Cu); A2-c (locally major Pb-Zn); A2-e (locally major Pb, barite)**

The A2 or later group of assemblages contrasts strongly with the A1 group, with a simple mineralogy of generally less than five mineral species in each assemblage being characteristic (Mason, 1994, 1997). The A2 assemblages have a much coarser grain-size compared to A1 assemblages. The sulphides are optically 'clean', under high-powered magnification, in striking contrast to the complex, microscopic intergrowths of the A1 assemblages. The A2 assemblages occur in both previously unmineralized and re-activated A1 mineralized fractures, and form breccia cements, banded fissure-fill and composite vein deposits, often separated from their wall-rocks by bands of clay-gouge. The coarsely crustiform textures exhibited in many cases are reminiscent of some of the 'Pennine-type' deposits. The chief gangue mineral is, again, quartz, but it is relatively friable compared to the A1-type quartz; colourless to greyish-white in colour, it forms common, squat, stumpy crystals. Calcite is widespread and locally occurs in large amounts, but ferroan dolomite is very rare. Contrasting features of the A2 style of mineralization are best seen at the Ceulan Mine Opencast and Nantiago Mine GCR sites.

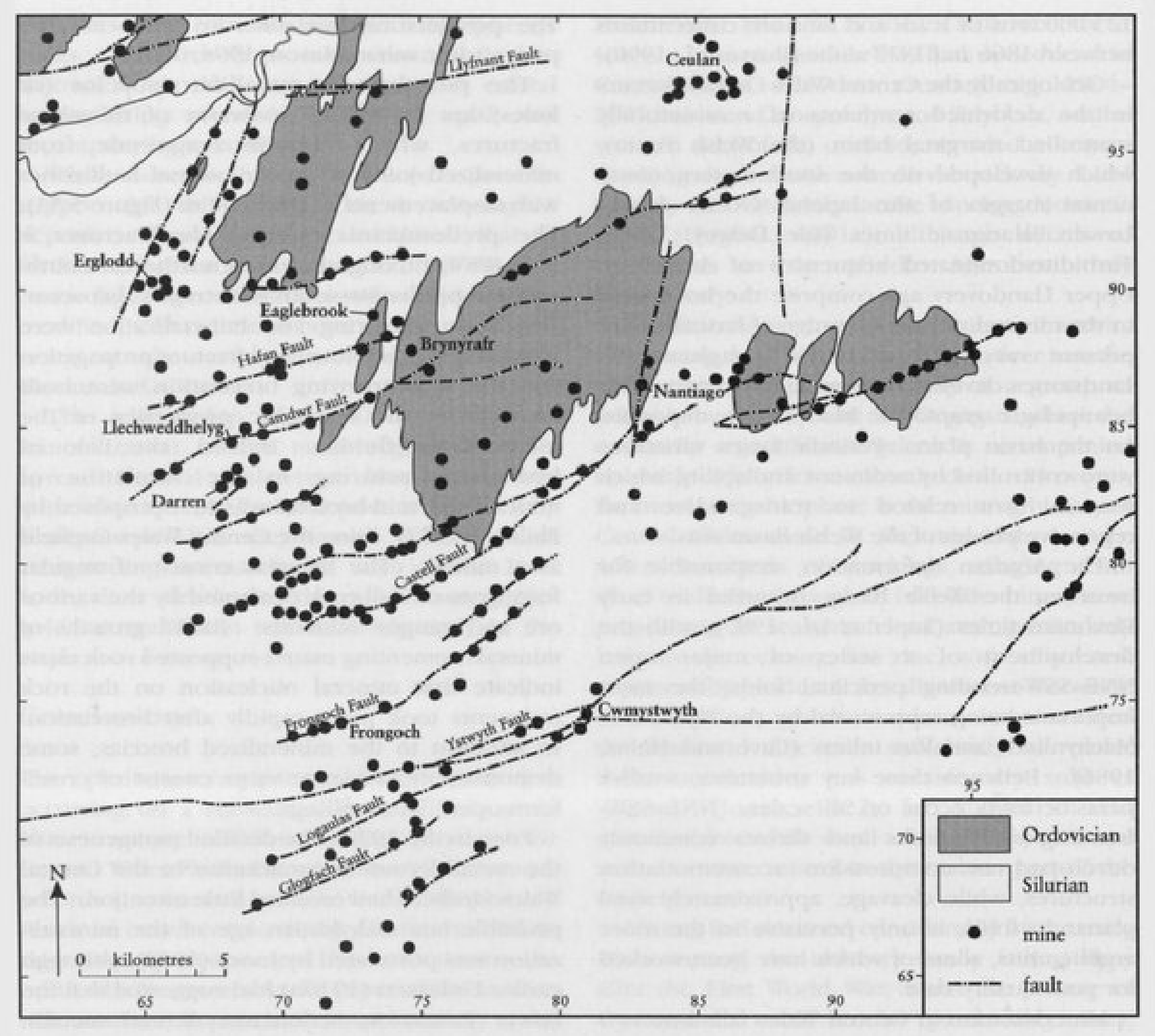
The Cwmystwyth Mine and Brynyrafr Mine GCR sites provide classic sites where the textural features of the mineralization belonging to both the A1 and A2 episodes are dearly demonstrated, while the Nantymwyn GCR site emphasizes the highly regional nature of the mineralization.

Secondary mineralization, the detailed paragenesis of which is as complex as that of the primary mineralization, is widespread throughout the Central Wales Orefield, and there has been considerable research on the subject (see, for example, Rust, 1990a,b, 1992; Mason, 1992, 2004; Mason and Rust, 1995; Green *et al.,* 1996). Many rare secondary minerals have been reported from Central Wales in recent years, often occurring in complex, post-mining assemblages formed within dumps of sulphide-rich material. The suite of minerals which formed *in situ* is simpler. In common with many base-metal mining districts, cerussite, pyromorphite, wulfenite, bindheimite, hemimorphite, malachite, cuprite, native copper, chalcocite, goethite and limonite are of frequent occurrence, although typically only in small quantities.

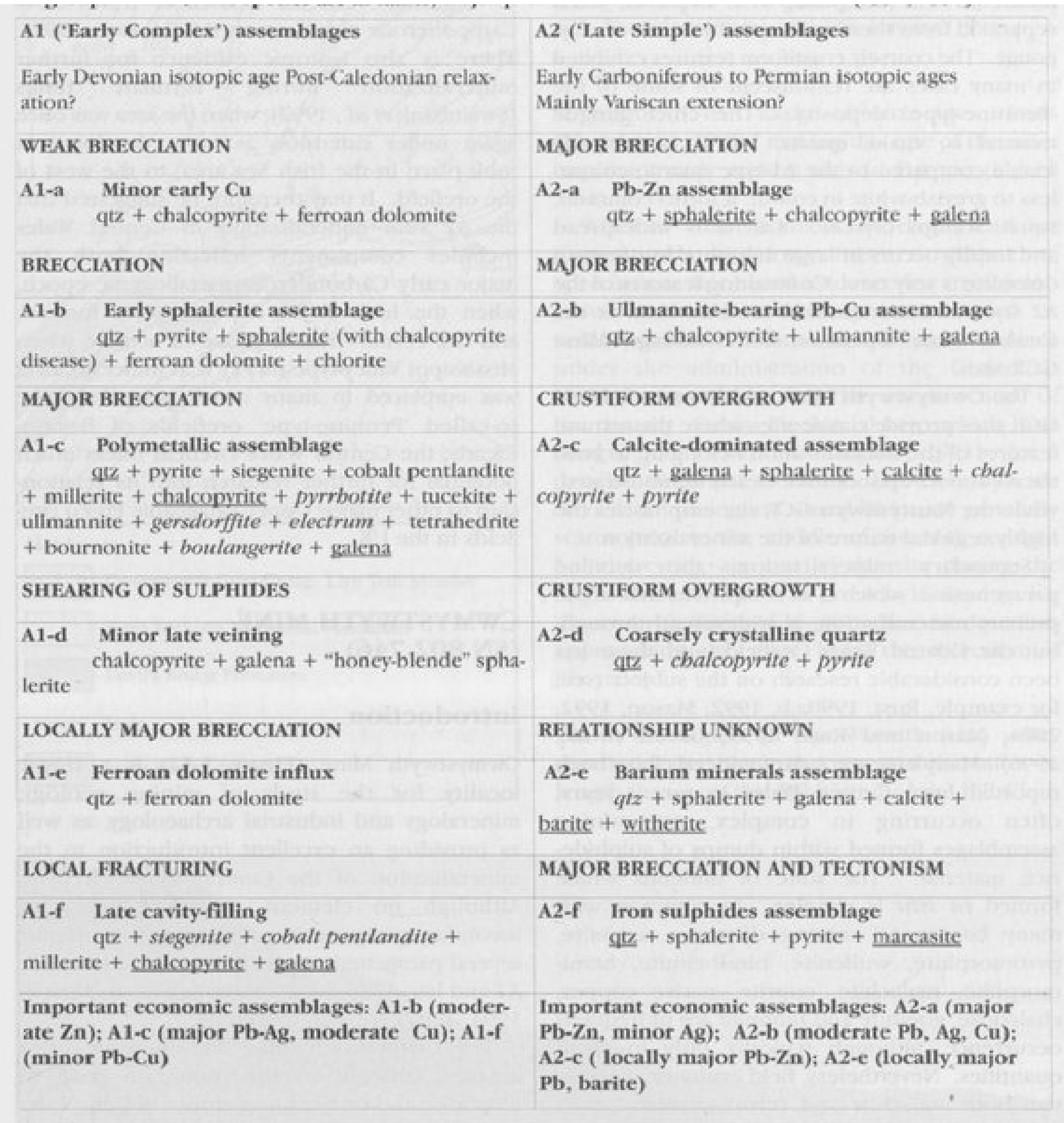
Nevertheless, field evidence suggests that both malachite and cerussite were locally worked at vein outcrops. The Frongoch Mine, Llechweddhelyg Mine and Eaglebrook Mine GCR sites reflect aspects of this secondary paragenesis.

In summary, two major episodes of mineralization resulted in the emplacement of the A1 and A2 groups of assemblages, a point reinforced by both tectonic (Mason, 1994) and Isotopic evidence (Fletcher *et al.,* 1993). Post-orogcnic relaxation has been proposed as the mechanism for the development of fractures carrying the A1 assemblages in early Devonian times, while fractures carrying the A2 assemblages are believed to have formed in response to regional Variscan extension from early Carboniferous times onwards (Mason, 1997). There is also isotopic evidence for further mineralization during Permian times (Swainbank *et al.,* 1992), when the area was once again under extension as basin development took place in the Irish Sea area, to the west of the orefield. It may therefore be suggested that the A2 vein mineralization in Central Wales includes components reflecting both the major early Carboniferous metallogenic epoch, when the Irish Pb-Zn deposits were formed, and the Permo-Triassic phase of activity, when Mississippi Valley-type (MVI) vein mineralization was emplaced in many areas, generating the so-called 'Pennine-type' orefields of Britain. Clearly, the Central Wales Orefield offers much potential for further research into its relationship to other major Upper Palaeozoic Pb-Zn ore-fields in the UK.

References



(Figure 5.51) Map showing the distribution of old metal mines in the Central Wales Orefield. The location of the GCR sites are highlighted. After Ball and Nutt (1976).



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