Parys Mountain

[SH 433 903]–[SH 449 907]

Introduction

Parys Mountain, on Anglesey (Figure 5.35), is the site of one of the finest examples of a volcanogenic massive sulphide (VMS)-type deposit in the Caledonides of the British Isles. Mining at Parys Mountain began in the Early Bronze Age (Jenkins, 1995), and it is thought likely that the Romans also worked the deposit (Manning, 1959). However, the most important phase of activity commenced in the early 1760s, with a major stimulus in 1768 following the discovery of a major orebody. This orebody came to be known as the 'Great Lode', sometimes referred to as the 'Opencast Lode', and made Parys Mountain Europe's premier copper producer. At this time in excess of 3000 tons of copper ore were being recovered per annum. At the end of the 18th century Parys Mountain was the largest copper mine in the world.

Several other orebodies were discovered following depletion of the Great Lode in the 1790s, the most significant being termed the 'North Discovery Lode', which provided considerable profit for the mine in the 1820s. Other notable discoveries included the Golden Venture Lode, the Carreg-y-doll Lode, Charlotte's Lode and the geographically more remote Morfa-du Lode (Greenly, 1919). Interestingly, it is thought that precipitation of copper in pits using scrap iron was trialed at Parys Mountain as early as 1579 (see Rowlands, 1981).

By the 1890s most mining at Parys Mountain had ended and It finally ceased in 1911, although copper precipitation continued until the 1950s. Although the full figures are not known precisely, Manning (1959) estimated that a total of more than 130 000 tons of copper metal were extracted from 2.6–3.7 x 10^6 tons of ore. The most recent phase of exploration commenced in 1948, and almost continually since that date a number of international mining companies have carried out extensive exploration programmes, involving not only drilling 150 holes, producing some 60 km of core, but also the sinking of 130 shafts. The most recent phase of exploration led to the sinking of the 300 m-deep Morris Shaft undertaken by Anglesey Mining plc.

Until comparatively recently, there was little literature describing the Parys Mountain mineral deposit, and detailed accounts of the nature of the orebody before large-scale extraction are not available. In addition, few mineral specimens are preserved from the early phase of mining. From the early description of Pennant (1783), there was undoubtedly a gossan capping to the Great Lode, and it was this gossan which hosted abundant anglesite, which was first described as a new species from Parys Mountain in 1832 (Beudant, 1832). However, as early as 1783, Withering (quoted in Dana, 1868) had described immense quantities of 'lead mineralized by sulphuric acid and iron' from the 'Island of Anglesea'. Probably the most important early account of Parys Mountain was that by Lentin (1800), a German technical specialist from the University of Leipzig who spent six years at Parys Mountain towards the end of the 18th century. In a series of 10 'letters', Lentin (1800) provided, amongst other things, an account of the mineralogy of the deposit, including a description of the form and occurrence of 'bleiglas', the old German term for anglesite.

Parys Mountain was later discussed by Ramsay (1866), who reported on the distribution of the principal lithologies present. It was Greenly (1919), however, who provided the first detailed geological synthesis. He concluded that the mineralization was epigenetic in origin, considering the deposit to be a series of mineral veins or 'lodes' hosted by rocks of Ordovician age related to 'mineral changes that took place during, but chiefly after, the great Post-Silurian earth-movements' Importantly, Greenly (1919) presented the first interpretation of the geological structure of the area. Further reports on the structure and stratigraphy were provided by Manning (1959), and Hawkins (1966), while Bates (1966) refined earlier models for the Parys Mountain deposit on the basis of faunas in adjacent sedimentary rocks, and on field mapping, work which he subsequently expanded (Bates, 1972, 1974).

From the early 1970s through to the present day, a series of PhD and MSc studies have investigated the mineralogy and genesis of the Parys Mountain deposit. In addition, there have been numerous unpublished reports from mining exploration companies. Wheatley (1971b) provided the first paragenetic interpretation of Parys Mountain, and concluded that the mineralization had both syngenetic and epigenetic characteristics, but that it was certainly pre-deformation. Thanasuthipitak (1974) investigated the petrology and geochemical character of the associated volcanic rocks, and suggested that the mineralization was syngenetic, and related to the volcanism. Ixer and Gaskarth (1975) compared the mineralization to the Kuroko deposits of Japan, and linked it to Ordovician plate tectonics. Nutt *et al.* (1979) questioned this notion and, on the basis of K-Ar age determinations, suggested that the mineralization was of late Caledonian age. However, Pointon (1979), and Pointon and Ixer (1980) convincingly re-instated the idea that the Parys Mountain deposit was linked to volcanism, arguing that the deposit was related to the exhalation of mineral-rich fluids into seawater contemporaneous with submarine volcanism. They went on to argue that the mineral deposit was later deformed, which was accompanied by deformation and remobilization of sulphides, with the generation also of quartz and chlorite.

Southwood (1982, 1984) established the presence of basic volcanic rocks at Parys Mountain, overturning the previously held notion that the volcanic sequence was solely slide in character; critically, the potential for equating magmatism at Parys Mountain with that in central Snowdonia was advanced considerably. The most recent doctoral studies include those by Westhead (1993), and Tennant (1999); the former study conformed to the previously held view that the overall structure at Parys Mountain was that of an overturned syncline; in contrast the latter study suggested that the dominant structure represents a N-dipping homoclinal sequence. Tennant and Steed (1997) presented the results of an investigation into the lithogeochemistry of the various volcanic rocks at Parys Mountain and presented a new model which suggested that the volcanism was in part of early Silurian (Aeronian) age, in contrast to most earlier accounts which had considered the volcanism to be entirely of Ordovician (Caradoc) age. Finally, Barrett *et al.* (1998, 1999) have reviewed the findings of research undertaken by Anglesey Mining plc since 1995, which has focused on re-logging of available core, remapping of surface geology, and undertaking a lithogeochemical investigation. Their principal conclusion is that mineralization is controlled by the distribution of silicic eruptive centres and related volcanic facies.

Description

Parys Mountain forms a prominent whaleback hill which rises to 147 m OD, located 3 km south of Amlwch, in north-east Anglesey. The hill is orientated ENE–WSW and is approximately 2.5 km in length. The legacy of mining manifests itself in a devastated landscape over some 3 m^2, dominated by two large open-pits (Figure 5.36).

Greenly (1919) described the geology of Parys Mountain as being dominated by a central zone of shales of Silurian age flanked by intrusive 'felsite and shales both to the north and south and overstepped to the north of the mine by Precambrian rocks forming the hangingwall of the Carmel Head Thrust. The overall disposition of these strata and the identification of graptolites of supposed Silurian age in the southern shales led Greenly (1919) to infer the presence of a roughly E–W-trending antiformal structure through the area. He also identified the importance of a later phase of approximately N–S-trending oblique-slip faulting, the so-called 'cross-courses'. Bates (1966, 1972, 1974) reviewed the field evidence and faunas, and concluded that in fact the southern shales were of Ordovician age and hence the structure across Parys Mountain was actually synformal, with the northern limb being overturned to the south. This is a view that has until recently been widely accepted, for example by Pointon· and Ixer (1980), and Westhead (1991, 1993). 'The latter author also noted the importance of thrusting at Parys Mountain, particularly at depth. More recently, however, the structure of the Parys Mountain area has been re-appraised and the area is now considered to be underlain by a homoclinal structure with the sequences dipping more-or-less uniformly to the north (Tennant and Steed, 1997).

The volcanic rocks which host the mineralization are predominantly silicic, and were described initially as lelsite' (Greenly, 1919). A range of volcanic and pyroclastic rocks has now been identified at Parys Mountain, although many descriptions are from drill-core samples and only a relatively restricted range of lithologies is recognizable in weathered surface outcrops. In addition, the rocks have been affected by extensive alteration, comprising early recrystallization of primary volcanic products, such as volcanic glass and pumice, intense hydrothermal alteration, and later low-grade regional metamorphism. Consequently, the nomenclature of the primary character of the volcanic rocks has been both variable and controversial.

Pointon and Ixer (1980) described the presence of rhyolitic and dacitic lavas, intrusive rhyolite, siliceous sinter, chert, chloritic chert and shale, tuffs and volcaniclastic rocks. They recorded rhyolitic flows and flow breccias from the western and eastern ends of Parys Mountain, occurring as slabs several metres long and averaging 1 m in thickness, with breccias containing blocks 0.1–1.0 m across set in a fine-grained matrix. The lavas show well-developed spherulitic and perlitic recrystallization textures after primary volcanic glass. The rhyolites are dominated by recrystallization textures characterized by granular quartz with minor chlorite and white mica. Phenocrysts are rare, being typically quartz and less commonly feldspar. Dacitic lavas, described by Thanasuthipitak (1974), are both porphyritic and non-porphyritic, the former containing plagioclase feldspar phenocrysts up to 10 mm in length. The aphyric rocks show plagioclase feldspar laths in a fine-grained matrix dominated by quartz aggregates showing a primary perlitic texture.

One of the most interesting units described by Pointon and Ixer (1980) is the so-called siliceous sinter, a unit established originally by Thanasuthipitak (1974). This unit occurs in the Carreg-y-doll Lode zone (at [SH 445 905]) and at the western extremity of the outcrop, at Morfa-du (at [SH 433 903]). It is essentially stratiform and comprises a rock showing fine-scale, colour-dominated layering, with evidence of repeated brecciation. The rock is composed of very fine-grained aggregates of quartz, clay and white mica, with chalcedony or recrystallized quartz-filled voids, although recrystallization is extensive. Locally, as at Morfa-du, the rock shows polyphase brecciation.

Interestingly, Pointon and her (1980) recorded only minor tuff horizons within the Parys Mountain volcanic succession, noting that Thanasuthipitak (1974) had recorded pyro-clastic rocks from the western end of the outcrop. Pointon and her (1980) also described the presence of various volcaniclastic rocks, derived from the volcanic horizons of the Parys Mountain area. Basic volcanic rocks were later identified from the western end of Parys Mountain (Southwood, 1982, 1984).

The most recent investigations of Parys Mountain, by Tennant and Steed (1997), adopted a different approach to previous studies. Accepting the problems posed by secondary alteration in interpretation of primary mineralogy, textures and chemistry, they utilized concentrations of those trace elements typically considered to be immobile during such alteration events in order to establish a chemostratigraphy. On this basis, they identified a tripartite compositional structure for the Parys Mountain volcanic rocks, comprising comendite/ pantellerite-rhyolite, rhyolite-dacite, and sub-alkaline basalt-andesite. More significantly, critical immobile element plots have identified five discrete rhyolite units at Parys Mountain (A, B, C–1, C–2, and D), along with two thin mafic units (Barrett *et al.,* 1998).

Rhyolite A shows both pyroclastic, fiamme-bearing rhyolitic tuffs, exposed to the south-west of the Great Open Pit, and a flow-banded facies with overlying rubble, which is exposed at the western end of the Great Open Pit. Pyroclastic facies of C–2 rhyolite are also seen in the Great Open Pit, for example forming the small knoll at the western end of the pit and also forming parts of the northern wall. Flow-banded rhyolites of Rhyolite D are exposed in the vicinity of Ty'n-y-mynydd, this rhyolite being interpreted as a dome facies. This same facies is also seen in the east of the area, at Pensarn, occurring in association with pyroclastic blocky breccias and lapilli tuffs. Significantly, Barrett *et al.* (1998) interpreted the 'White Rock', considered by Pointon and her (1980) to be siliceous sinter, to be in fact mainly silicified mudstone, with a small percentage representing silicified rhyolitic rocks.

Early records of the mineralogy of the Parys Mountain deposit are patchy, concentrating upon particularly unusual discoveries, such as the formerly abundant anglesite (Lentin, 1800; Beudant, 1832). The first attempt to systematically describe the nature of the primary mineralization was made much later, by Greenly (1919). The importance of this account is that it was based not only on field observations but also on contemporary local knowledge and mine reports. Greenly (1919) noted that the chief sulphide minerals present are pyrite, chalcopyrite, chalcocite, sphalerite and galena. He distinguished between a pyrite-chalcopyrite-quartz assemblage and a dense rock, called 'bluestone', consisting of galena and sphalerite with minor pyrite and chalcopyrite. Note was also made of the 'accumulations' of silica, including the 'quartz rock' of the Carreg-y-doll Lode, the siliceous sinter of Pointon and Ixer (1980).

Importantly, Greenly (1919) noted the 12 'lodes' that he described to dip a little west of north at around 45°, and, critically, depicted them as concordant features. He considered the Great Lode to be the most economically important of the ore deposits, describing it to be an enormous 'aggregate' or 'bunch', with a broad zonation of sulphides comprising pyrite to the north, chalcopyrite in the central zone and bluestone to the south.

Later studies revealed a hitherto greater complexity to the sulphide mineralogy at Parys Mountain. Wheatley (1971b), and Sivaprakash (1977) reported electron microprobe analyses on polished sections of Parys Mountain ores, which confirmed the presence of both tetra-hedrite and tennantite, accompanied by minor bournonite. In addition, a suite of bismuth-bearing minerals was identified by Sivaprakash (1977), including native bismuth, bismuthinite, kobellite and galenobismuthite.

Pointon and Ixer (1980) did not recognize either the broad classification of ores or their zonation as proposed by Greenly (1919). Instead, they established a paragenetic sequence based on the textural relationships of the ore minerals observed in numerous polished sections. Four generations of pyrite (A–D) were recognized, each with or without a diagnostic suite of associated minerals. Pyrite A is a minor phase comprising often euhedral crystals in altered volcanic and sedimentary rocks. Pyrite B, the main pyrite generation, is ubiquitous in its occurrence as euhedral crystals, and contains an inclusion assemblage of pyrrhotite, hematite and rutile. Pyrite B is frequently zoned, and has also been abundantly replaced by later sulphides comprising chalcopyrite, galena and sphalerite. Pyrite C is framboidal, occurring as a surround to pyrite B, and is frequently replaced or cemented along fractures by galena and chalcopyrite, accompanied in places by tetrahedrite, sphalerite, arsenopyrite and bismuth minerals. Pyrite D is directly associated with the poly-metallic mineralization and is both unzoned and inclusion-free, occurring as subhedral to anhedral grains intimately intergrown with chalcopyrite and marcasite.

Clearly, the pyrite generations A–C pre-dated the polymetallic mineralization, and Pointon and Ixer (1980) recognized that both types of mineralization have been extensively modified, possibly by regional metamorphism. Late quartz-chlorite and quartz-carbonate-barite veins, which cross-cut the pyritic and polymetallic mineralization and which carry pyrite, arsenopyrite, marcasite, chalcopyrite, galena, sphalerite and hematite, are interpreted by these authors to indicate a post-depositional remobilization process. Other features which may be attributed to later deformation are polygonal grain boundaries in recrystallized galena and extensively developed twinning in chalcopyrite.

More recently, exploration work by Anglesey Mining plc has focused on the western part of the site, and, through a combination of diamond drilling and underground development, two significant zones of stratiform mineralization have been investigated, known as the 'Engine Zone' and the 'White Rock Zone'. The Engine Zone consists of a series of massive sulphide-rich debris-flows dominated by sphalerite (Tennant and Steed, 1997), resting mainly on shales and silicic pyroclastic rocks. It is much disturbed by the later cross-course faulting. Within the White Rock Zone, a series of massive, Zn-Pb-Cu-dominated sulphide lenses occurs within a larger zone of quartzose breccia, extending to surface as the Morfa-du siliceous sinter. The mineralization intersected during this exploration also contains 78 g/t silver and 0.66 g/t gold (Charter, 1995).

At surface, the complexity of the mineralization can be readily appreciated. Although the common lead, copper and zinc minerals are seen, accompanied by ubiquitous pyrite, the rarer primary phases require ore microscopy for their determination, many occurring as grains only a few microns across. The presence of much 'gossan' is also evident, although since the 19th century searches by many mineralogists have failed to re-discover the large (> 10 mm) gemmy, yellow to colourless anglesite crystals, discovered in the 18th century, for which the site is now justly famous (Southwood and Bevins, 1995). In addition to anglesite, accounts by Pennant (1783), and Lentin (1800) strongly suggest the presence of pyromorphite, native copper, 'melaconite' (presumably tenorite) and native sulphur as components of the gossan. More recently, Pointon and Ixer (1980) recorded, from polished section investigations, chalcopyrite being replaced by bornite, chalcocite, covellite and cuprite.

Within the underground workings at Parys Mountain, an extensive suite of post-mining secondary minerals, formed primarily by bacteriogenic pyrite decay in a highly acidic environment (pH as low as 2), is the subject of an ongoing investigation (Jenkins and Johnson, 1993; Jenkins, 1999). The post-mining mineralogy is dominated by a variety of rare sulphate minerals in addition to ferrous hydrous oxides. The sulphates are dominated by yellow jarosite and possibly hydronium jarosite, accompanied by an extensive range of other species including chalcanthite, halotrichite, cuprian melanterite (Bor, 1950), antlerite, basaluminite, copiapite, coquimbite, fibroferrite, jarosite, gunningite, römerite(?), siderotil and rozenite (Jenkins, 1999; Jenkins *et al.,* 2000). Jenkins *et al.* (2000) provided a description of the occurrence of these various post-mining sulphate minerals, in both surface and underground environments. They noted that underground the commonest alteration product of chalcopyrite is the bright-green hydroxy-sulphate antlerite, which often overlies blue-green brochantite, reflecting a drop in pH. Basaluminite, a rare aluminium hydroxysulphate, also occurs as an efflorescence on the mine walls, along with allophane. Above ground the rare species fibroferrite, coquimbite and copiapite occur in overhangs and recesses in the open-pit walls. Unfortunately, a unique occurrence of the rare hydrated zinc sulphate gunningite coating sphalerite has been destroyed in recent years.

Interpretation

A critical discussion relating to the Parys Mountain ore deposit has focused on whether the primary mineralization is of epigenetic or syngenetic origin. Probably the first interpretation was forwarded by Greenly (1919), who proposed that the orebody was principally epigenetic in origin. However, on a key structural cross-section in Greenly (1919), he clearly showed the Carreg-y-doll and Charlotte's lodes as being concordant with their host shales and 'felsite'. Manning (1959) also supported a syngenetic origin for the mineralization, while Wheatley (1971b) suggested that the deposit included both epigenetic and syngenetic elements, but that it certainly preceded deformation.

Thanasuthipitak (1974) was the first to propose that the Parys Mountain mineralization is entirely of syngenetic origin, and linked to rhyolitic volcanism. Ixer and Gaskarth (1975) later suggested that it was similar to the Kuroko-type deposits of Japan, and related to the exhalation of metal-rich brines into the sea in Ordovician times. This theory was re-inforced by the studies of Pointon (1979), and Pointon and Ixer (1980).

Nutt *et al.* (1979) challenged the syngenetic origin and, on the basis of K-Ar age determinations, argued that the mineralization was epigenetic, being of late Caledonian (Acadian) age. Bearing in mind the degree of metamorphic remobilization, it is highly likely that the K-Ar ages are in fact reset ages, and hence do not reflect the true age of mineralization.

The Parys Mountain deposit, comprising a series of massive layers, lenses and disseminations of sulphide mineralization, has many features which are most compatible with a syn-sedimentary origin, contemporaneous with submarine volcanism in mid-Ordovician to early Silurian times. The strongest evidence comes from the occurrence of syn-sedimentary disturbances within the sulphide bodies, such as slump structures and debris flows. The difficulty in recognizing the syngenetic nature of the deposit has been due to the fact that the mineralization has not only been modified by regional low-grade metamorphism, but also it has been tilted 45° to the NNW and much disturbed by faulting.

In their genetic model, Pointon and Ixer (1980) envisaged mineralization both contemporaneous with volcanism, in which slumped masses of sulphide were mixed in debris flows with clastic and pyroclastic material, and continuing with fumarolic activity as volcanism waned, resulting in the massive sulphides of the Great Lode and Carreg-y-doll Lode, occurring with cherts and shales in the upper part of the sequence. Fumarolic activity finally ceased in early Silurian times, with a return to fine-grained clastic sedimentation.

In their conclusions, Tennant and Steed (1997) indicated that minor volcanism continued into early Silurian (Aeronian) times, and also that the degree of structural modification during Acadian deformation was much less than had previously been thought. They concluded that when the Parys Mountain succession was tilted to the NNW the shale units took up much of the strain, with reversed shearing along lithological contacts and the development of localized and, importantly, disharmonic drag-folding. These conclusions may go a long way towards explaining why anomalous bedding-cleavage relationships are so frequently observed within the shales at Parys Mountain.

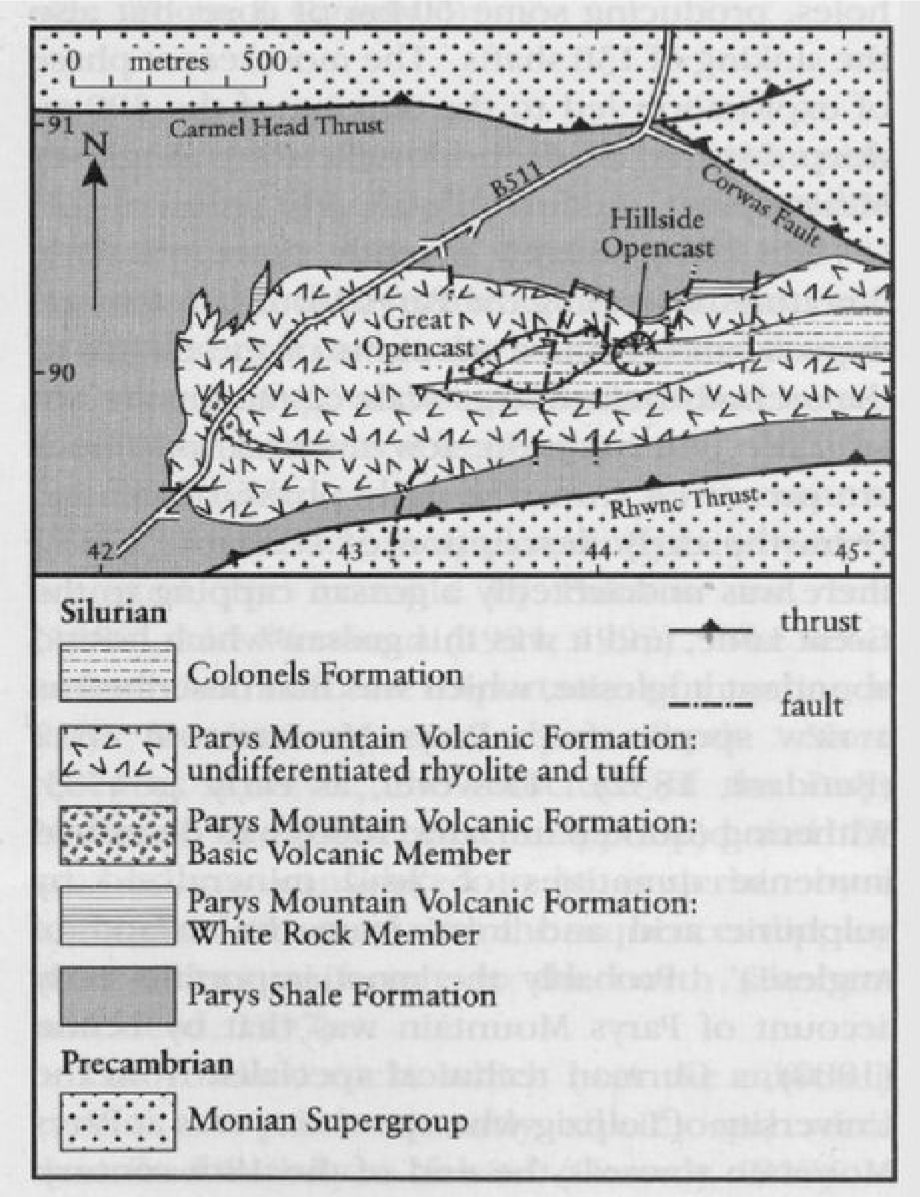
There has been much debate regarding the age of the sedimentary rocks to the north of the mine; whether they are Ordovician (as previously believed) or Silurian (as suggested by Tennant and Steed, 1997) is clearly a critical factor in determining which structural model is correct. The Ordovician age of these reportedly structureless sedimentary rocks, in which macrofossils have been found, is based on micropalaeontological data, obtained by the former Institute of Geological Sciences and summarized in Bates (1972). However, the micropalaeontological evidence is based entirely on poorly preserved acritarchs, which Tennant and Steed (1997) suggest may have been reworked during Silurian sedimentation. Although this could feasibly be the case, it would be extremely difficult to prove, and further detailed examination of the northern shales is required in order to fully assess their age, and thereby confirm which structural model is most reliable.

Whichever structural model proves to be correct, the evidence for a major centre of exhalative seafloor hydrothermal activity being established in conjunction with volcanism in mid- to late Ordovician (and probably early Silurian) times is compelling. Continuation of volcanism into early Silurian times (Tennant and Steed, 1997) is a particularly important hypothesis given that in the remainder of North Wales volcanic activity, although widespread, had ceased by the end of Caradoc times. It may be the case (Barrett *et al.,* 1998) that basement-related structures in northern Anglesey acted as particularly influential conduits both to ascending magmas and to circulating hydrothermal fluids. A basement connection is in fact supported by the findings of Fletcher *et al.* (1993), in which the lead isotope ratios in galena from Wales were determined and interpreted. For Parys Mountain, the galenas have variable and radiogenic $^{206}Pb/^{204}Pb$ ratios, and consistently high $^{207}Pb/^{204}Pb$ compared both to other galenas from Wales and to global model growth-curves, leading to the inference that the lead may have been sourced, at least in part, from the Monian basement which underlies Anglesey.

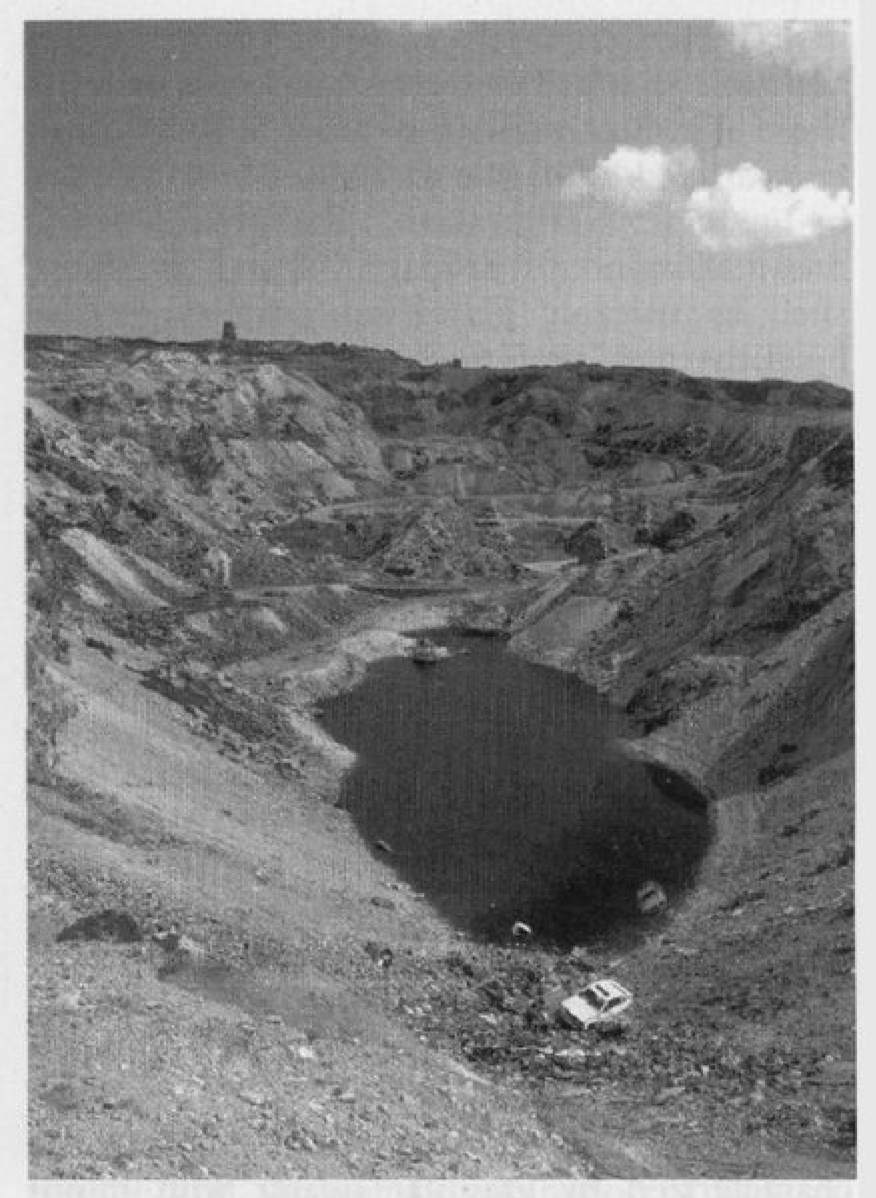
Conclusions

The Cu-Pb-Zn mineralization at Parys Mountain, in north-east Anglesey, worked since Bronze-Age times, represents, in its currently favoured interpretation, one of the finest examples of a volcanic-related submarine exhalative 'Kuroko-type' deposit in the British Caledonides. Becoming Europe's largest copper producer with the development of the Great Lode in the late 1700s, the origin of the deposit has been, and remains, the subject of much debate. Current evidence strongly points away from a model of epigenetic 'lodes' emplaced into the strata in fractures, and more towards mineral deposition taking place during the eruption and accumulation of the associated Lower Palaeozoic volcanic and sedimentary succession. Of additional interest, not least because the site is the type locality for the lead sulphate anglesite, is the former presence of a considerable gossan capping to the deposit containing a variety of secondary copper and lead minerals. Formerly present in abundance, anglesite specimens are now rarely found. The microbiological■ biochemical systems involved in the post-mining oxidation of pyrite in the old underground workings are also of considerable importance and are still under investigation.

References



(Figure 5.35) Map of the Parys Mountain GCR site. After Westhead (1991, 1993).



(Figure 5.36) Photograph of the Parys Mountain GCR site. (Photo: S. Campbell.)