Younger, P., and Potter, H.A.B. (2012) *Parys in Springtime: Hazard Management and Steps Towards Remediation of the UK's Most Polluted Acidic Mine Discharge.* In: 9th International Conference on Acid Rock Drainage (ICARD), 20th-26th May 2012, Ottawa, Canada.

Copyright © 2012 The Authors

A copy can be downloaded for personal non-commercial research or study, without prior permission or charge

The content must not be changed in any way or reproduced in any format or medium without the formal permission of the copyright holder(s)

http://eprints.gla.ac.uk/69553/

Deposited on: 13 December 2012

Enlighten – Research publications by members of the University of Glasgow
http://eprints.gla.ac.uk

Parys in springtime: hazard management and steps towards remediation of the UK's most polluted acidic mine discharge

Paul L. Younger[1] and Hugh A.B. Potter[2]

[1] Newcastle Institute for Research on Sustainability, Devonshire Building, Newcastle University, Newcastle upon Tyne NE1 7RU, UK. paul.younger@ncl.ac.uk
[2] Environment Agency, National Operations - Geoscience Team, c/o NIReS, Devonshire Building, Newcastle University Campus, Newcastle upon Tyne NE1 7RU, UK. hugh.potter@environment-agency.gov.uk

Abstract
Mynydd Parys is a hill on the Isle of Anglesey in North Wales which is riven with old copper mine workings, dating back more than 3500 years. Continued movement of air and water through old workings generates extremely acidic water, though the average flow rate is only about 10 l/s. After the last underground workings closed in the early 20th Century, the interior of one of the adits was fitted with a concrete plug incorporating a valved pipe. Until about 1950, this valve was periodically opened to flush water into ponds filled with scrap metal, where copper was precipitated by the "cementation" process. When these operations ceased, the valve was left closed and the dam forgotten. In the late 1990s it was realised that failure of this dam could cause a devastating flood in the town which had since grown below the mine. A complex multi-stakeholder process was initiated to resolve this hazard. Removal of the dam diverted much flow from a second catchment, so most drainage now flows in a short channel to the sea; the impact on marine life is now being investigated. Pilot treatment trials recommended an HDS lime-dosing operation, for which funding is now being sought.

Key Words: acidity, dewatering, flooding, pollution, remediation, treatment.

Introduction
Mynydd Parys (UK National Grid Reference (NGR) SH441904), also known in English as Parys Mountain, is a relatively low hill (rising to 147 m above sea level) in the northern district of Ynys Môn (Isle of Anglesey) in North Wales, UK (Figure 1).

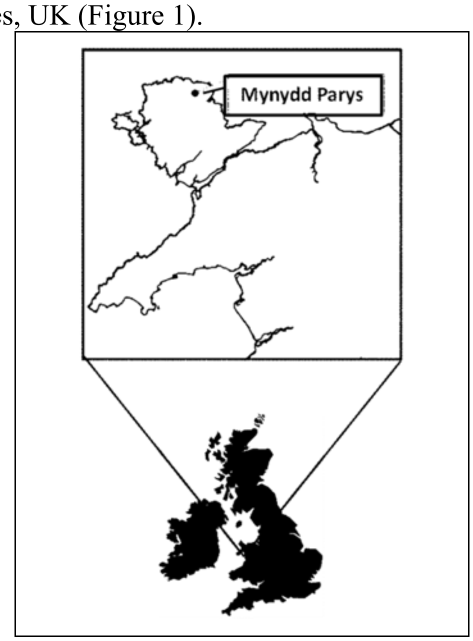

Figure 1. Location map of Mynydd Parys, North Wales, UK.

The nearest town is Amlwch, which lies 2 km to the north, and downstream of, Mynydd Parys. The hill has been a copper mining district for more than 3,500 years, and in the late 18th Century minerals worked here briefly dominated the world copper market (Rowlands 1966). No significant mining has taken place at Mynydd Parys for about a century, and the site would be largely forgotten by the mining community were it not that it has the distinction of giving rise to what can be reasonably claimed to be the most polluted acidic mine water in the UK. In addition to water pollution, the site has also posed a flooding threat to the town of Amlwch. This paper explains the background to this flooding threat, how it was resolved, and the steps that have since been taken to finally remediate the site drainage to restore a more natural freshwater ecology to the immediate receiving watercourse (the evocatively-named Afon Goch Gogledd, which translates in English as "Red River North") and to reduce the loadings of ecotoxic metals entering the Irish Sea, into which the Afon Goch Gogledd debouches at Amlwch. (For this reason, the Afon Goch Gogledd is sometimes called the Afon Goch Amlwch).

Geology

The geology of Mynydd Parys is extremely complicated, and its interpretation is not made any easier by the fact that so much of the natural sequence has been disturbed and / or buried during several millennia of mining, both underground and at surface. The account which follows is adapted from a summary prepared with the assistance of geologically-trained mine explorers (Younger *et al.* 2004). The ore deposits of Mynydd Parys are considered to be volcanogenic massive sulphides ('VMS') of Kuroko type; while such orebodies are widespread worldwide, this is the only known example in the UK. The country rock comprises Ordovician-Silurian shales, rhyolites and pyroclastics, which are sharply folded into what appears to be an overturned syncline verging to the south; the fold core, comprising Silurian shales, is exposed in the opencuts. As the overall steep dip (50-60°) of both beds and cleavage is to the north, mining progressed to the north with increasing depth. The ore shoots comprise both large quartz bodies with abundant pyrite and relatively low grade (5%) chalcopyrite, and also massive fine-grained galena/sphalerite/chalcopyrite mixtures ('bluestone'), which have been proven over an area of some 6 km x 1 km extending ENE-WSW. These parallel lodes are interpreted to have been deposited by sea floor hydrothermal activity related to Ordovician / Silurian volcanism in a marginal basin near a convergent plate margin (Barrett *et al.* 2001). There was subsequent remobilisation of Cu as vein deposits during later tectonic activity. This has given rise to concentrations of sulphides of both syngenetic (e.g. the quartz-rich Carreg y Doll and the bluestone Opencast lodes) and invasive varieties (e.g. North Discovery Lode).

Summary of Site History

Prehistoric Parys

There are relatively few mine sites anywhere in the world for which any account of their prehistory can be given. However, over the last few decades the persistence and patience of teams of mine explorers, amongst whose ranks have numbered many eminent amateur and professional mining archaeologists, have revealed much about Bronze Age mining in North Wales (O'Brien 1996). Indeed, one of the Bronze Age copper mines excavated by these experts is now open to tourists (the Great Orme Mine, some twenty km to the east of Mynydd Parys). The copper orebodies at Great Orme are carbonate hosted, and themselves comprised mainly copper carbonate ore minerals. In contrast, as noted above, the copper mineralisation at Mynydd Parys is overwhelmingly sulphidic, and it was once considered that this chemistry might have deterred prehistoric miners, given the greater difficulties of refining the copper. However, O'Brien (1996) mentions tantalising old records of ancient workings and tools found in the 19th and early 20th Centuries, which *could* have been interpreted as being Bronze Age; however, no definitive evidence was available to him at the time he wrote. As it happens, at that very time (summer 1995) the Parys Underground Group (PUG) was excavating a buried access into the old workings on Mynydd Parys with a view to working back upwards to try and intercept shallow old working from the Bronze Age. This quest was successful, and large numbers of stone tools (termed mauls) were found in workings only a few tens of metres beneath the present land surface. PUG have gone on to document the old workings, and the abundant tools found in them, in great detail, with summaries being published on-line (**http://www.amlwchhistory.co.uk/bronze.html**). It would appear that the Mynydd Parys mines were worked as part of an extensive trading operation involving Cornish tin, with which the Welsh copper was blended to produce bronze.

Historic Mining at Mynydd Parys

The documented history of mining at Mynydd Parys dates back to the late 18th Century (Rowlands 1966), when surface outcrops were exploited by numerous shallow shafts which coalesced subsequently into large opencuts. In the 19th Century, the lodes were worked down to depths of about 300m by shafts, with over 20km of recorded passages in two separate major mines: Mona to the east, and Parys to the west. Conventional underground mining ceased towards the end of the 19th Century, but copper recovery continued up to the middle of the 20th Century by means of the so-called "cementation process", in which acidic, copper-rich mine drainage (both that draining naturally from the lowest adit and leachates generated by deliberate washing of surface spoils) was fed into an extensive system of brick-lined ponds, in which scrap iron was placed, which reduced the dissolved Cu^{2+} to elemental copper, which could then be scraped off the iron substrate. In this way, some 50 tonnes of copper were produced each year until the early 1950s (Manning 1959). Since then, the mining lease for Mynydd Parys has passed through the ownership of a sequence of mining companies, who have carried further prospection of the area by means of more than 20 km cumulative depth of boreholes. The current leaseholders, Anglesey Mining plc, have sunk a 285m shaft, from which 1.5km of exploratory lateral development has been undertaken. They have since extended exploration coverage to west and east using surface boreholes, the most recent of which were drilled in 2005-8 (Barrett 2009). Current total reserve estimates are around 7 million tonnes averaging 9% Cu+Pb+Zn. It should be emphasised that the recent exploration by Anglesey Mining plc at Mynydd Parys is restricted to virgin orebodies which are physically isolated from the old workings which give rise to the hazards discussed in this paper.

Hazard Identification and Assessment

There are two principal hazard categories associated with the old mine workings of Mynydd Parys: acidic drainage and flood hazard.

Acidic drainage

The volcanogenic massive sulphides of Mynydd Parys are subject to ongoing weathering due to circulation of air through innumerable old workings. This has resulted in extremely acidic waters, with pH values below 2 being recorded in some underground pools (unpublished data: PUG). This is accompanied by unusual secondary minerals and an impressive range of acidophilic bacteria, which produce abundant extra-cellular polysaccharide oozes, often forming mats and gelatinous draperies. Unusual flora is also associated with acidic leachate in the surface environment: rare lichen assemblages on the site are accorded formal protection as Sites of Special Scientific Interest (Jenkins *et al.* 2000).

Beyond the site margins, acidic drainage is principally experienced as environmental degradation. Before 2003, the bulk of the drainage from the mine workings drained south, into the Afon Goch De (Red River South), which is a tributary of the Afon Dulas, which enters the sea through the otherwise high-quality estuarine environment of Bae Dulas (Dulas Bay). To the north, as noted in the introduction, the site drains to the Afon Goch Gogledd. This has not entered the sea by a natural channel in living memory; rather, it outfalls through a culvert. The total amount of drainage leaving Mynydd Parys is rather modest, averaging around 10 l/s, but it contains such high concentrations of many ecotoxic metals (Table 1) that, when the Environment Agency assessed several thousand abandoned metal mines in Wales, Parys Mountain was determined to be the highest priority for remedial action (Environment Agency Wales, 2002), and it is one of the most polluting mines in the UK (Mayes *et al.* 2009; Environment Agency, 2012). Certainly the Afon Goch Gogledd is devoid of any freshwater fauna.

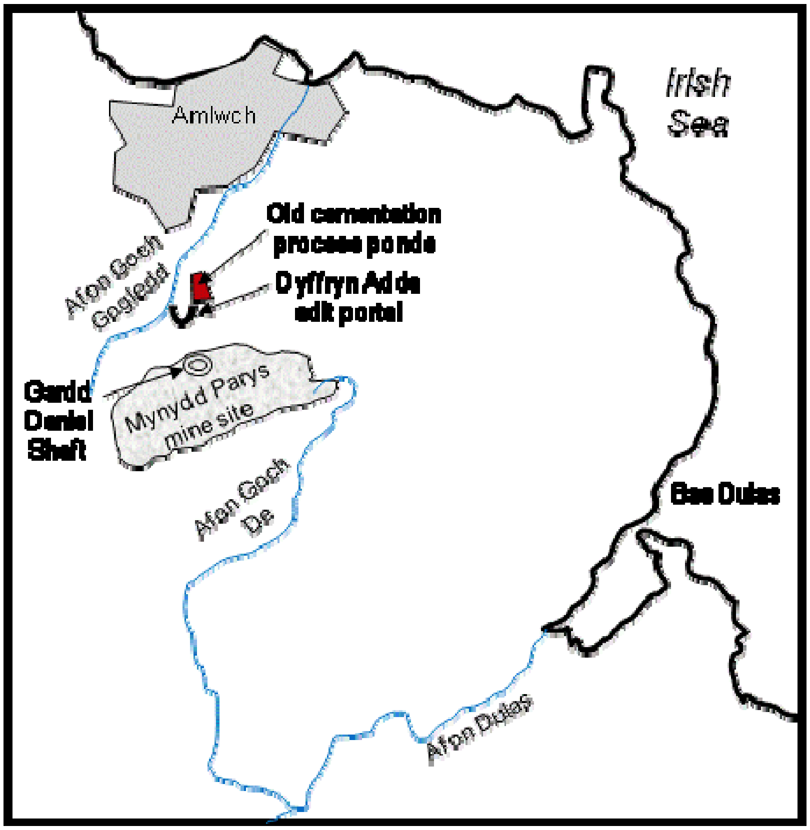

Figure 2. Sketch map of the vicinity of the Mynydd Parys mining district.

Flood hazard

During active mining in the 19th Century, the principal drainage of the Mynydd Parys workings was to the north, via an adit known as the 'Joint (45 Fathom) Level', which was driven in from the north side of the mountain at Dyffryn Adda (Figure 2), eventually forming the only connection between the two principal mines, the Parys Mine on the western half of the mountain and the Mona Mine on the eastern half (Figure 3). When deep mining ceased, a dam with valves was emplaced within this level, which allowed water to flood the workings almost up to the 20 fathom level. The perched water table was manifested as a lake in the bottom of the Great Opencast, with overflow then taking place through the Mona Adit to the Afon Goch De. When the valve was closed, only small amounts of residual drainage exited via Dyffryn Adda, Sequential opening and closing of the valves was undertaken as part of the cementation process operations until the early 1950s. After these ceased, however, the valves were apparently left closed and the Joint Level down-adit from the dam eventually became inaccessible through partial collapse and accumulations of ochre. In the late 1990s, access to the level was regained by PUG, who eventually accessed the dam, where the valves proved to be inoperative and the concrete showed signs of degradation. Figure 3 summarises the situation at that juncture, with a large volume of highly acidic (pH 2), metal-rich water impounded with a head of some 40m behind a dam of unknown stability. This clearly posed a potential hazard to the town of Amlwch downstream. This hazard was brought to the attention of Anglesey County Council and the Environment Agency Wales by the Amlwch Industrial Heritage Trust (the parent organisation of PUG) in late 2001, and a working group was set up to tackle the problem. The first author was retained as an expert advisor to help the group develop a strategy to deal with the issue.

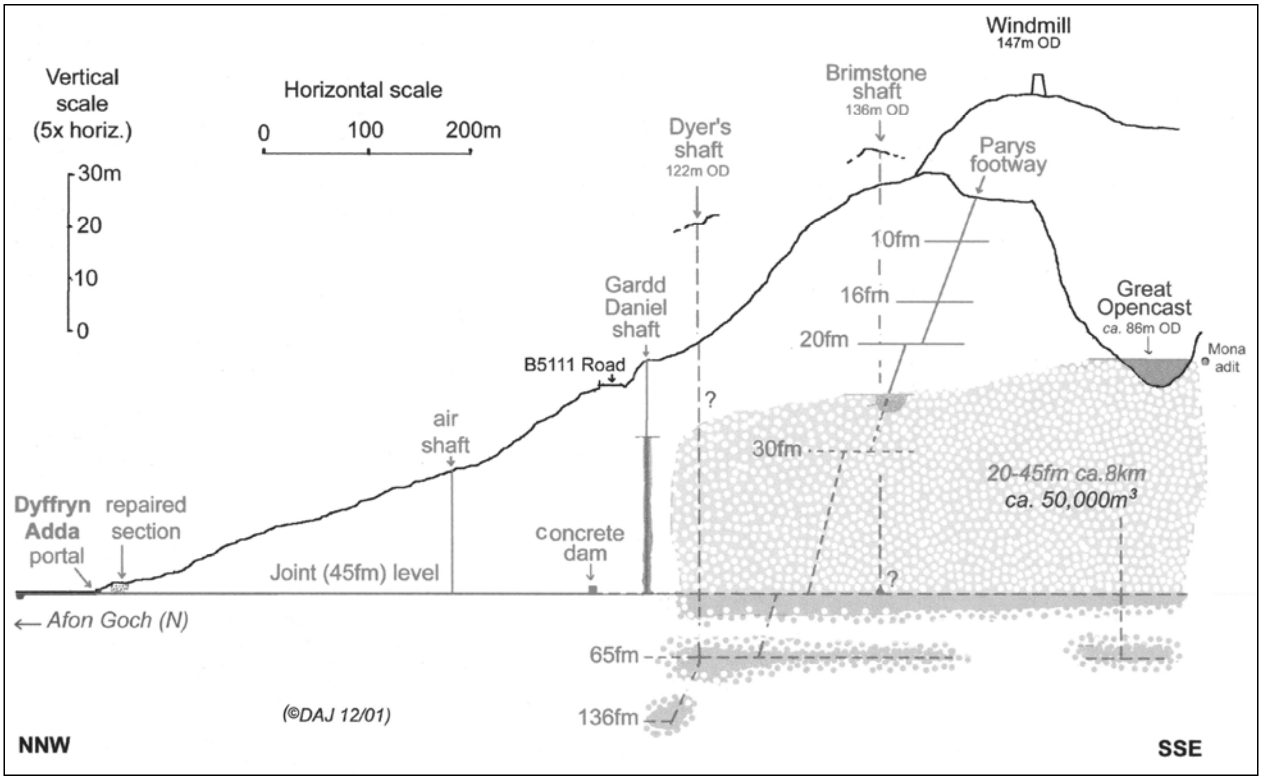

Figure 3. Hydrogeological cross-section of the old workings of Mynydd Parys, showing impounded water levels prior to the dewatering works implemented in 2003 (after Younger *et al.* 2004). The stippled areas show known areas of flooded workings prior to the drain-down of the mountain. "fm" = fathom.

Sequence of response

Having identified these two risks, the next stage was to identify a *modus operandi* to address them both. The public authorities responsible for the area – principally Anglesey County Council and the Environment Agency Wales – have powers and duties relating to both issues. As the pollution was an ongoing problem, there was no sense in which *preventative* action could be taken – only remedial action. In the case of the flood risk, however, there was a clear sense that swift action would be needed to eliminate the risk to life, limb and property in the event the underground dam should fail. A hydrological consultancy, Jeremy Benn Associates, were retained to assess whether failure of the dam would cause a flood of sufficient magnitude to warrant intervention. The approach they adopted was to parameterise the known dimensions of the Joint Level and the Afon Goch Gogledd, and then simulate the hydraulic consequences if the water retained behind the dam were to be released suddenly. In modelling terms, this amounted to assuming the dam was spontaneously replaced by easily erodible sand. The results were striking: the predicted flood would be about 2.5 times greater than the 100-year fluvial flood, and possibly as much as 6 times greater in a worst-case estimate. The velocities during such a flood event would be very high (4.3 - 9.2 m/s), with a correspondingly high potential for causing serious damage. It was clear that the flood wave that would hit Amlwch would have a very high probability of causing fatalities in the town. This galvanised thinking on the sequence of events: Phase I of any strategy had to be the elimination of this flood risk. Phase II would address the ongoing pollution issue. The safe removal of the dam would fulfil the needs of Phase I. In doing so, it was anticipated that it would result in virtual elimination of acidic drainage to the south of the mountain, but an increase in the pollutant loading to the north. This would be unequivocal good news for aquatic life in the valley of the Afon Goch De and Afon Dulas. However, the situation in the valley of the Afon Goch Gogledd would deteriorate. As the Afon Goch Gogledd was already devoid of aquatic life, there would be no immediate impact on the freshwater environment. It would also mean that a single water treatment system could in future be constructed just to deal with the water coming from Dyffryn Adda, without the need for a second treatment system to the south of the mine site. However, questions remained about the possible impact of the diverted waters on the marine environment.

Resolving the pollution conundrum

In the absence of site-specific information for a circumstance that had not yet been observed (i.e. all of the flow entering the Afon Goch Gogledd), an analogy was drawn with prior experiences at the Wheal Jane mine in Cornwall (Younger *et al.* 2005). When the mine water from Wheal Jane entered estuarine waters, iron rapidly precipitated to form suspended flocs of ferric hydroxide, which were restricted to the upper (fresher) stratum of the estuarine water column. The flocs remained in the top waters, and were gradually carried out to sea where they dispersed over the space of a day or two. Given that the sea near Amlwch is a known area of very high natural dispersion (Hoare and Hiscock, 1974), in stark contrast to the system in the Wheal Jane area, and given also that the loadings of untreated mine water discharged at Jane were substantially greater than those proposed to be discharged at Mynydd Parys, there were strong grounds for considering the Wheal Jane experience as essentially a "worst case" scenario if it is used as a yardstick against which to estimate the likely impacts of high concentrations of metals entering the sea from the Afon Goch Gogledd. From extensive modelling and monitoring in the Wheal Jane study, it was identified that the key indicator for unacceptable degradation of sea water quality varied with tidal conditions, but fell always in the range of 2 to 4 tonnes of iron per day (the other metals all followed the most abundant, iron, in impact patterns) (Younger *et al.* 2005).

In order to apply these findings to the Mynydd Parys case, it was necessary to calculate equivalent loadings of metals likely to leave the system during the period of drawdown of water levels in the old workings, and to compare these with the threshold for impact reported in the Wheal Jane case study. It must be stressed that loadings calculations for the Mynydd Parys system were unavoidably subject to significant uncertainties, not least because two key parameters were imperfectly known, namely (i) the total volume of impounded water and (ii) the heterogeneity in quality of the impounded water away from the few sampling points so far accessed. However, using the data available, maximum metals loads were estimated at about 3 tonnes (calculated from predicted volume of mine water multiplied by measured iron concentration). Even if this load were discharged over 12 days (the minimum feasible, given pumping constraints), this would amount to only 0.3 tonnes per day, or some 13% of the lowest of the thresholds for noticeable impact experienced in the far more sluggish estuarine system at Wheal Jane. It should also be noted that the figure of 0.3 tonnes of iron per day assumed no attenuation of mine water pollutants between the discharge of the pumped water to the surface ditch and its arrival at the outfall of the Afon Goch Gogledd to the sea. Clearly, significant attenuation can be expected, in the form of precipitation of ferric hydroxides within the Dyffryn Adda precipitation pits and within the channel of the Afon Goch Gogledd. The maximum loading cited above was therefore based on pessimistic (conservative) assumptions. This gave solid grounds for optimism that the removal of the dam could be undertaken without causing unacceptable degradation of marine water quality.

It was also observed that the Afon Goch Gogledd drains to the sea via an outfall into the mixing zone of a major (20 m^3/s, pH 3.5) industrial discharge from a bromine plant which was then still active. This enormous low pH discharge was not known to have had any significant effects on marine water quality and / or ecology (unpublished data, Countryside Council for Wales). Indeed, it is reported that the low pH is no longer detectable only a few tens of metres from the edge of the zone of turbulence arising from the discharge (*ibid.*). This underlines the highly dispersive hydraulic behaviour of marine currents in this area, further bolstering confidence in the deductions made above. To further put the proposed pumping activities in perspective, it should be noted that the maximum installed pump capacity would amount to only a quarter of one percent of the bromine plant discharge flow rate.

Stakeholder Engagement

As a historical site in an area of great natural beauty, and an area with great cultural richness as a stronghold of the Welsh language and its associated culture, Mynydd Parys was never going to be an easy area in which to undertake an industrial remediation project. The project leaders for the Phase I activities (draining the mountain) were Isle of Anglesey County Council, and the Environment Agency Wales were also an obvious key stakeholder. In addition, a whole host of other organisations had a very legitimate interest in any possible interventions on Mynydd Parys. A multi-stakeholder task force was therefore created to provide a forum in which the interests of all of these stakeholders could be aired and reconciled as the plans for drain down of the mountain were developed. The full list of invited stakeholders was as follows:

- Cyngor Sir Ynys Môn (Isle of Anglesey County Council)
- Asianteth yr Amgylchedd Cymru (Environment Agency Wales)
- Cadw (the Welsh agency for historical monuments)
- Cyngor Gefn Gwlad Cymru (The Countryside Council for Wales, which has nature conservation duties on both land and in marine waters)
- Anglesey Mining plc
- Amlwch Industrial Heritage Trust (a local voluntary group), and it's subsidiary, the
- Parys Underground Group
- Anglesey Estate (principal local landowners)
- Menter Môn (local enterprise development agency)
- University of Wales, Bangor (local scientific interests, including mine water biogeochemistry expert Barrie Johnson)
- Awdurdod Datblygu Cymru (the Welsh Development Agency)

The first author (Younger) was appointed as an expert advisor to this steering group, with principal responsibility for developing the method statements and supporting documents for environmental permits etc.

Eliminating the Flood Risk

The following strategy was developed, and then formally adopted by the task force:

- Pump water from the Gardd Daniel Shaft (Figure 2 and 3 – NGR SH440907), and to discharge the water into the adjoining roadside drainage channel. This channel runs alongside the B5111 road, before passing under the road in a culvert at NGR SH442910. After passing beneath the road, the pumped water was to be diverted via one or more of the old cementation process ponds in the vicinity of Dyffryn Adda (Figure 2). As these were extensively vegetated, they offered some filtration and settling of suspended solids before the water finally discharged to the Afon Goch Gogledd at around NGR SH437914.
- Lower water levels within the mine workings sufficiently for the dam in the Joint 45 Fm Level (Figure 3) to be safely breached. Then maintain pumping at the minimum rate needed to keep the water level down at the required level (about 10 l/s) while miners entered the adit and mined out the dam. Thereafter, pumping was halted and the drainage of the mines continued by gravity outflow along the Joint 45 Fm Level, flowing out at surface at Dyffryn Adda (Figure 3).

To offer comfort to the various stakeholders and minimise potential visual impact on the sea, the following operating plan was agreed before pumping commenced:

- The maximum pumping capacity to be provided at the site was 50 l/s. Although prior analysis strongly suggested that degradation of sea water quality from receipt of the drainage via the Afon Goch Gogledd would not prove to be a problem (even if the maximum pumping rate were to be applied) pumping was instigated in a staged manner, so that the true performance of the system could be demonstrated beyond reasonable doubt, and various levels of contingency measures implemented, before the top rate of pumping was attained.

- Pumping therefore commenced at 20 l/s, with visual inspection of the sea from a vantage point near where the culverted Afon Goch Gogledd enters the seas (at NGR SH448938) after 24 hours of pumping. As no significant discoloration was visible, pumping rate was increased in 10 l/s steps to ~50 l/s.
- As a precaution against any unexpected changes in mine water quality, conductivity, pH and turbidity of the pumped water were monitored at least once a day at the shaft head. Had any abrupt change of more than 50% occurred in any of these parameters, the representative of the steering committee would have been immediately notified, and they would have the authority to reduce or suspend pumping.

In the event, the pumping operation at the shaft went smoothly (Figure 4) and no contingency measures were triggered.

Figure 4. Pumping operations at Gardd Daniel Shaft in 2003.

Unfortunately, and despite the open consultation process, some stakeholders broke ranks with the consensus approach and made a public fuss, demanding that the Council place several tonnes of limestone gravel in the path of the mine water where it entered the old cementation process ponds (Figure 3). The first author advised that the contact time of the acidic water with the limestone would be insufficient to yield any rise in pH, but that it would result in the clear acidic waters (Figure 4), which were essentially inconspicuous in the ditch downstream of the shaft, precipitating highly conspicuous orange iron hydroxysulfates on the surface of the limestone chippings, thus establishing a visual impact without any benefit. This is precisely what happened. Another anticipated effect was a reprise of the old-time cementation operations, as water splashing on the steel casing of the pump outlet deposited native copper.

The only real surprise was the total volume of water that had to be pumped before the water level dropped down to the level of the dam. When the pumping operation was being designed, efforts were made to estimate how much water would need to be removed from storage before the adit would be drained to the floor. This was fundamentally difficult, as the flooded workings were largely unmapped, and their state of backfilling or otherwise) not recorded. By analogy with what was known of voids above the water line (as observed by PUG) the consensus estimate was about 50,000 m^3. In reality, 270,000m^3 had to be pumped continuously for 3 months (Apr – Jul 2003) before the water level settled at the foot of the shaft. The deep flooded mine workings were therefore far more extensive than predicted which underlines the case for the retention of accurate mine plans; obviously a challenge when deep mining started in the Bronze Age and peaked in the 19th Century.

Towards the Final Remediation Strategy

Quantification of metal loading from Parys Mountain

While removal of the dam eliminated the risk of flooding of the town of Amlwch, it made little difference to the significant pollution caused by the Mynydd Parys mines: in effect it removed most of the pollution (save that from old mine waste leachates) from the catchment of the Afon Goch De, but transferred all of this to Afon Goch Gogledd (Figure 2). Subsequent monitoring confirms that the Afon Goch Gogledd is the single largest source of copper entering the Irish Sea (Cu: 10,241 kg/yr; Zn: 24,268 kg/yr: 2003 data) with extremely high concentrations (Cu: 5,490 µg/l; Zn: 13,000 µg/l) even after dilution between the adit and sea (Environment Agency 2008). This tiny stream, around 2 m wide with mean flow of 0.06 m^3/s, has the fifth highest flux of Cu in England and Wales (Environment Agency 2008), comparable to the Thames (flow = 67 m^3/s; Cu = 11,080 kg/yr), Severn (71 m^3/s; 10,430 kg/yr) and Mersey (27 m^3/s; 5,100 kg/yr) .

Figure 5. The Dyffyrn Adda adit.

Concentrations of other metals and metalloids including Cd, As, Fe, Mn are also very high (see Table 1). The European Water Framework Directive requires countries to reduce inputs of priority pollutants including metals, and to improve the quality of all rivers and groundwater to “good” by 2027. Abandoned metal mines are the most significant source of metals to rivers in England and Wales (Mayes *et al.*. 2010), and cause pollution in ~8% of rivers. Dealing with this pollution is now a high priority for the UK Government (Defra, 2011) and phased programmes of work are being developed in Wales and England.

Following removal of the dam, the bulk of the pollution is discharged to the north via the Dyffryn Adda adit (Figure 5) into the Afon Goch Gogledd; however the Afon Goch De remains contaminated primarily due to run-off from the very extensive mine wastes and former precipitation ponds. In 2004, a scoping study reviewed available water quality and flow data to establish the metal loadings from the site. Results for key pollutants are given in Table 1 (unpublished report for Environment Agency). The scoping study concluded that active treatment was required for the main Dyffryn Adda adit discharge (Figure 5) which enters the Afon Goch Gogledd, and that further monitoring was needed to fully characterise the variation in flows and water quality. On the south side, the Afon Dulas now has the potential to support fish and so efforts should be made to control the input of metals from diffuse sources.

Table 1 – Selected water quality parameters in the two streams draining the Mynydd Parys mine site following removal of the dam in 2003 (see Figure 2 for locations)

Watercourse	Parameter	Mean concentration (µg/l)	Load (kg/d) [Flow = 10 l/s]	Environmental Quality Standard (µg/l)
Afon Goch Gogledd	Cu	43,000	37.2	1
	Zn	71,370	61.7	8
	Cd	167	0.14	0.08
	As	450	0.38	50
	Ni	150	0.13	20
	Fe	599,000	517	1,000
	SO_4	2,747,000	2,373	n/a
Afon Goch De	Cu	299	n/a	1
	Zn	1,850	n/a	8

Pilot scale treatment plant

In 2007, a number of potential treatment technologies were reviewed (lime dosing, sulphide precipitation) and a pilot-scale field trial was carried out to establish the feasibility of treating the mine water. Monitoring data do not show any significant change in water quality since the dewatering operation but this will be reviewed prior to detailed design of a full-scale plant. The technology tested was a high density sludge hydroxide system designed and operated by Siltbuster Ltd. A series of jar tests were carried out to establish dosing rates using either sodium hydroxide or lime, and air requirements. These were followed by running the pilot-plant using initially lime (and subsequently sodium hydroxide) plus a polymer flocculent for 3-4 weeks to assess metal-removal effectiveness. The pilot plant has a series of lamellar plates to remove solids. A consistent sludge was generated and subjected to a comprehensive characterisation process to determine whether it was inert, non-hazardous or hazardous waste for disposal.

Figure 6. Mynydd Parys pilot active treatment plant.

The results showed that treatment should remove between 96 and 99% of the dissolved metals (Cd = 96.2%; Cu = 99.9%; Fe = 99.9%; Zn = 98.3%) except Mn (35.6%), and raised water from pH 3 to pH 7, with little difference in performance between lime and sodium hydroxide. The mine water contains very little carbon dioxide and so there is no requirement to install a de-gassing stage. The sludge generated was primarily iron hydroxide with small amounts of calcium, sulphate and carbonate compounds. A good high density sludge was formed and after filter pressing, the sludge should be at least 40% solids. At full scale, around 500 tonnes per year of dry solids would be generated. The sludge was characterised using Environment Agency guidance and found to be non-hazardous.

The pilot plant results were used to develop indicative design of a full-scale plant. Mine water would be transferred by gravity from the adit portal, and pumped into two parallel process streams. Treated water would be returned back to the Afon Goch Gogledd. Sludge would be taken off site for disposal to non-hazardous landfill. Indicative costs were estimated at £1.5m capital and £250k/yr for operation, including sludge management. However, these costs were based on a relatively limited set of flow data and so continuous flow monitoring equipment has been installed. The potential blockage of the adit due to collapses within the workings is being assessed to avoid any further build-up of water within the mine.

Contaminated land

The old cementation process ponds (Figure 2) once used to extract copper from the mine water now contain sediments which are highly contaminated with metals and metalloids. Since these ponds are no longer actively flooded, there are periods when the ponds dry up and there is the potential for contaminated dust to blow off site. In 2009, it was determined that dust containing lead and arsenic from a 4 hectare section of ponds, the Henwaith Precipitation Ponds, posed an unacceptable risk to the health of local residents (Anglesey, 2010). Remediation works by the local authority, Isle of Anglesey County Council, with Welsh Government funding have sealed the exposed ochre with soil and a geosynthetic barrier, and water is being pumped into these ponds to prevent the generation of dust.

Ongoing works

Most of the metal mines in the UK closed many decades ago and so a major barrier to remediation works is the absence of any responsible party. The costs of dealing with these mines therefore falls to the Government which is keen to deliver environmental improvements and ensure compliance with European Union legislation (e.g. Water Framework and Mining Waste Directives). At Mynydd Parys, Environment Agency Wales is working in partnership with the Coal Authority, the County Council and other local stakeholders (including the Amlwch Industrial Heritage Trust) to design environmental improvements that are sympathetic to the unique ecology, geology and industrial heritage at the site, and deliver benefits for the wider community. Detailed bids are being prepared for a full-scale treatment plant at Parys Mountain with funding decisions expected early in 2012. If successful, it is hoped that a treatment plant would be commissioned by 2015.

Conclusions

Mines at Mynydd Parys have been generating acidic drainage for more than 3500 years. Still today, an average of about 10 l/s of water is so highly charged with metals that it is the greatest source of metal pollution to the Irish Sea. After abandonment of the "cementation" process operations in the early 20th Century, the underground dam that was used to control water flow to the precipitation ponds was left closed, and by the turn of the new Millennium it was realised that it represented a major flood risk to the town of Amlwch, which had since grown up below the Dyffryn Adda mine portal. A successful “pump and dig” strategy removed this risk in 2003, and in the intervening years a sporadic programme of characterisation and testing has identified what needs to be done to finally remediate the polluted waters: is it finally springtime for Parys?

Acknowledgements

We are extremely grateful to David Jenkins – the real hero of Mynydd Parys – who first highlighted the flooding issue, led the archaeological investigations underground, and played a pivotal role in keeping lots of different stakeholders happy.

References

Anglesey County Council (2010) *Remediation Statement – Version 2.* Available on-line athttp://www.anglesey.gov.uk/upload/public/attachments/132/2_2010V2_Remediation_Statement1.pdf; last accessed 19-03-2012).

Barrett, T.J. (2009) *Summary of 2005-2008 Drilling Results at Parys Mountain: Lithogeochemistry, Petrography and Geological Relations*. Report for Anglesey Mining plc by Ore Systems Consulting, Markdale Ontario. 20pp. (available on-line at: www.angleseymining.co.uk/old/old-website/amplc/ParysMine/ParysBarrettJan09report.pdf; last accessed 20-11-2011)

Barrett, T.J., MacLean, W.H. and Tennant, S.C. (2001) Volcanic sequence and alteration at the Parys Mountain volcanic-hosted massive sulphide deposit, Wales, United Kingdom: applications of immobile element lithogeochemistry. *Economic Geology*, vol. 96, pp. 1279-1305.

Defra (2011) *Water for Life*. The Stationery Office., London, UK. www.defra.gov.uk/environment/quality/water/legislation/whitepaper/

Environment Agency Wales (2002) *Metal Mine Strategy for Wales*. Environment Agency, Bristol, UK.

Environment Agency (2012) *Prioritisation of abandoned non-coal mine impacts on the environment: the national picture.* http://publications.environment-agency.gov.uk/PDF/SCHO1111BUBX-E-E.pdf Environment Agency, Bristol, UK.

Hoare, R., and Hiscock, K. (1974) An ecological survey of the rock coast adjacent to a bromine extraction works. *Estuarine and Coastal Marine Science,* **2,** 329-348.

Jenkins, D.A., Johnson, D.B., and Freeman, C. (2000) The Cu-Pb-Zn mines on Mynydd Parys: mineralogy, microbiology and acid mine drainage. In Cotter-Howells, J., *et al.* (eds) *Environmental Mineralogy*. Mineralogical Society. London. pp. 161 - 179.

Manning, W. (1959) The Parys and Mona Mines in Anglesey. In *The Future of non-Ferrous Mining in Great Britain and Ireland.* Institution of Mining and Metallurgy, London. pp. 313 – 328.

Mayes, W.M., Johnston, D.**,** Potter, H.A.B., & Jarvis, A.P. (2009) A national strategy for identification, prioritisation and management of pollution from abandoned non-coal mine sites in England and Wales. I. Methodology development and initial results. *Science of the Total Environment*, **407(21),** 5435-5447.

Mayes, W.M., Potter, H.A.B., & Jarvis, A.P. (2010) Inventory of aquatic contaminant flux arising from historical metal mining in England and Wales. *Science of the Total Environment,* **408,** 3576-3583.

O'Brien, W. (1996) *Bronze Age copper mining in Britain and Ireland*. Shire Publications Ltd, Princes Risborough. 64pp.

Younger, P.L., Coulton, R.H. and Froggatt, E.C. (2005) The contribution of science to risk-based decision-making: lessons from the development of full-scale treatment measures for acidic mine waters at Wheal Jane, UK. *Science of the Total Environment*, 338: 137 – 154.

Younger, P.L., Jenkins, D.A., Rees, S.B., Robinson, J., Jarvis, A.P., Ralph, J., Johnston, D.N. and Coulton, R.H. (2004) Mine waters in Wales: pollution, risk management and remediation. In Nichol, D., Bassett, M.G. and Deisler, V.K. (Editors), *Urban Geology in Wales.* National Museums and Galleries of Wales Geological Series Number 23. Cardiff, September 2004. 138 – 154.

Acronyms

EAW – Environment Agency Wales
PUG – Parys Underground Group