Geochemical sources and long-term implications of mine waste weathering, Cwmystwyth Mine, Wales

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Fig.1: Cwmystwyth mine looking NW

Evaluation of the distribution and leaching potential of lead, cadmium, and zinc from the Cwmystwyth Mine (Fig.1) has been undertaken along with surface grab sample mineralogy. Metal concentrations and pH were evaluated respectively, in which a general weak association between these two factors was found. Using these two parameters, a Ficklin diagram was created to assess the type of drainage being produced at the Cwmystwyth Mine, which indicated that metal leaching neutral mine drainage is being generated.

Discharge water from mine workings (Fig.2), waste materials and outcrop generated some variations in terms of pH and metal concentration, with most samples showing alkaline results but higher metals from water that flows through the mine (Nant y Gwaith).

Given the extensive mining history at Cwmystwyth, it is no wonder that metals are finding their way through the environment, heavily exceeding the EQS set out by the European Commission. Lead concentrations in all samples but one exceeded the EQS range, and dissolved metal concentrations in the water samples significantly increased downstream. Zinc concentrations are uniformly high, reflecting the higher mobility of zinc over lead and secondary zinc minerals are much rarer than lead sulfate or lead carbonate phases. Cadmium geochemistry appears controlled by zinc mobility and secondary phases.

In summary, the mine is heavily contaminating the Ystwyth catchment, with high levels of Pb, Zn, Cd, and other transition metal(loids) are contributing to this contamination such as Mn and As. As proved to be leaching, but it still meets the EQS. Contamination in the river is attributed to the water discharge and perhaps seepage from different mine tailings, adits and underground workings (Fuge et al.1993).

It is very unlikely that the site will be remediated by cover or removal of mine waste or by using passive treatment due to its topographical complexity, and the sensitive nature of the site, being within a protected Site of Special Scientific Interest (SSSI). Moreover, the data suggests that there have not been any improvements in terms of dissolved metals in the water when data was compared to historic values; hence the mine remains a potential source of metals to the catchment.

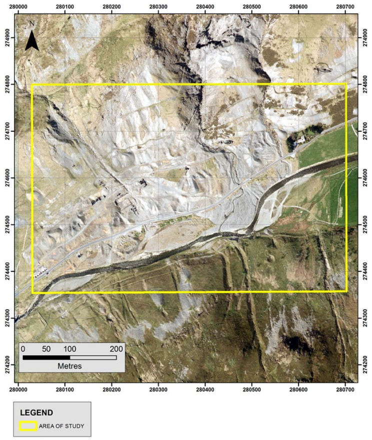

Fig.2: Study area and main mine facilities at the Cwmystwyth Mine. Insert shows location with respect to the British Isles (Digimap and ArcMap).

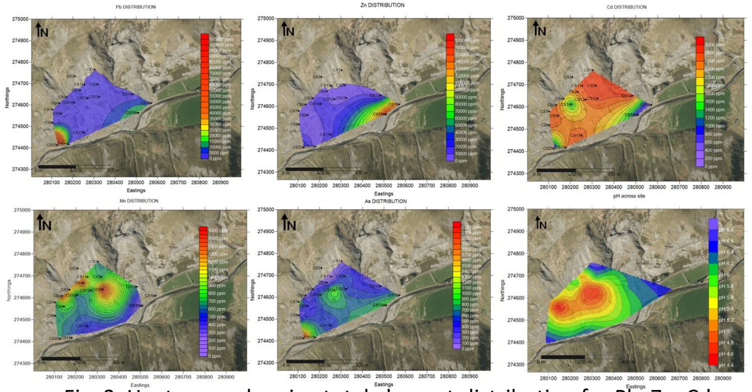

Fig. 3: Heat maps showing total element distribution for Pb, Zn, Cd, Mn, & As as well as paste pH for the area of study shown in Fig.2.

These results have been mapped and compared to in-situ pH data collected in the field from these dump materials. For the purpose of this paper only lead, cadmium, manganese, arsenic, and zinc are described in detail. The heat maps showing metal distribution for these elements and paste pH are provided in Figure 3.

The maps illustrate that high metal bearing material is present at the lower adit adjacent to Ystwyth river as reflected in the hot spots for lead and arsenic at the lower Gill adit (fig.3). By comparison zinc is most anomalous in the wash-out sediment from the Hugh adit and the higher elevation workings where it appears to have been transported (fig.3). Apart from the Pugh adit mouth arsenic shows elevation in more acidic soils and is antipathetic to cadmium and manganese which show a visual correlation to high pH

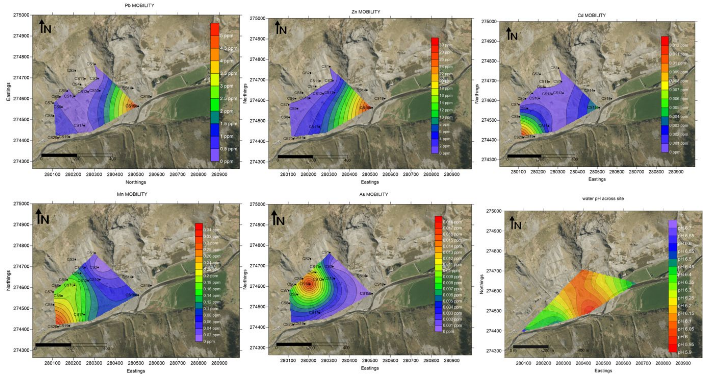

Figure 4: Heat maps for leachable metals in EN12457 leachate and site water map

Using the results of the BS EN 12457 testwork, interpolated heat maps were derived to analyse the spatial distribution of the soluble metals that have potential to leach into the environment and cause serious harm (fig 4). These results portray the potential labile nature of the metals from surface material. Cadmium and manganese show similar trends and are most labile in the area of Gill's lower adit in the south west of the map. Lead and zinc are most labile in the sediments associated with Hugh adit whilst arsenic shows a hot spot on the side of the hill where pH is neutral and from other data total iron content is low. In the pH map of the River Ystwyth upstream and downstream from the mine, where acidic to neutral waters can be observed (fig 4). This indicates most of the acidic waters are coming from the Nant Y Gwaith which travels through the mine and waste dump located closer to the Ystwyth river (Fig.5). Regression analysis on water chemistry indicated that lead and zinc have an antipathetic relationship to pH whilst arsenic is positively correlated. Manganese and cadmium show a stronger relationship to alkalinity than pH

Fig.5: Looking east at the mine

A useful visualization for mine water chemistry-pH interactions is the Ficklin diagram (Ficklin et al., 1992). The plot defines fields of different water chemistry based on concentration of divalent cations and pH. The results in the Cwmystwyth mine are plotted in Figure 6, where it can be inferred that Neutral Mine Drainage (NMD) could be taking place, as most samples lie within the near-neutral/high-metal and near-neutral/low-metal zones. However, this diagram is not yet used as a formal guideline to define AMD or NMD, and due to the small number of samples this could be rather inconclusive. However, if more samples had been collected similar results could be expected

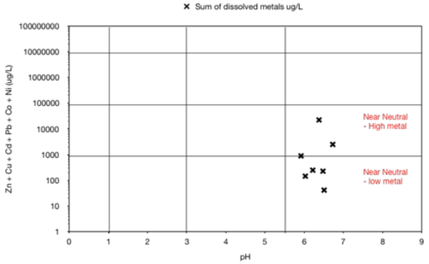

Fig. 6: Ficklin plot, Cwmstwyth mine waters

Neutral pH in the mine could be attributed to the lack of pyrite as evidenced by the XRD results, where only sample CS10 contained less than 1% pyrite. The majority of sulfides comprise, galena and sphalerite that are both non-acid generating. According to the XRD and Carbonate Rating test, buffering is coming from silicate minerals rather than calcite, such as Albite (NaAlSi3O8) and Muscovite (KAl2(AlSi3O10)(OH)2). Carbonate minerals generate significantly more neutralisation potential than silicate minerals, which means that the extremely low concentration of carbonate in the sample after the carbonate test indicates that there is no neutralisation potential for the studied samples, as this is directly related to the abundance of non-Fe/Mn carbonate minerals. This can be compared to a study by Jambor (2003) where it is stated that certain silicate minerals are known to buffer mine effluents at a neutral pH.

A site conceptual model of the Cwmystwyth mine (fig.7) has been developed using literature resources from a desk study and field observations. The conceptual model aims to identify and highlight the environmental linkage for the studied transition metals, which are causing the River Ystwyth to be severely contaminated.

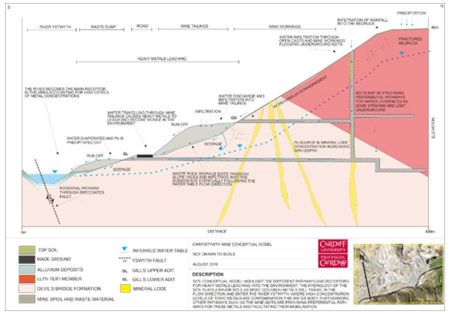

Fig.7: Conceptual model, Cwmystwyth mine waters

The mineral lodes containing Pb and Zn underground may be a great source of contamination as the ore is being exposed to water The regulation of mine waste in the UK is managed by the Coal Authority in collaboration with the Environment Agency and Natural Resources Wales (Environment Agency, 2016). However, due to the diverse opinions of stake holders to the site and its designation as a Site of Special Scientific Interest it is highly unlikely to be remediated in the near future

Ficklin WH, Plumlee GS, Smith KS, McHugh JB (1992) Geochemical classification of mines drainages and natural drainages in mineralized areas. Proc 7th International Symposium on Water-Rock Interaction, Park City, 13-18 July 1992 V1, P381-384. Rotterdam: A A Balkema, 1992

Fuge R, Pearce FM, Pearce NJ, Perkins WT (1993) The geochemistry of cadmium in the secondary environment near abandoned metalliferous mines, Wales. Applied Geochemistry 2: 29-35.

Jambor, J.L., (2003) Mine-Waste Mineralogy and Mineralogical Perspectives of Acid-Base Accounting. In: J.L. Jambor, D.W. Blowes and A.I.M. Ritchie (Eds.), Environmental Aspects of Mine Wastes, Short Course Series Vol. 31, Mineralogical Association of Canada, 117-146.