TECHNIQUES FOR RECLAIMING METALLIFEROUS TAILINGS IN WALES[1]

by

John P. Palmer[2]

Abstract. Wales has a considerable legacy of abandoned metalliferous mine sites. These sites are often a landscape scar and pollution and public health hazard. Research into plant material tolerant of the high concentrations of metals found, covering systems preventing upward and downward migration of metals, public health aspects of metals in the environment and the movement of metals through ecosystems has provided a sound basis for land reclamation schemes. Adequately designed tailings movement, drainage, capping systems and vegetation cover and proper integration of these with land use are essential for successful reclamation schemes.

Additional Key Words: metal tolerance; covering systems

Introduction

Metal mining in the United Kingdom has been carried out since pre-Roman times. Production of metals has been subject to large fluctuations in demand even in the short term and many mines have been worked and reworked intermittently for centuries. The industrial revolution caused large numbers of metal mines to be opened up in the late seventeenth century and early eighteenth century but the great period of British metal production was between 1840 and 1890. After the decline in the 1890's many mines continued production until the early part of the twentieth century but very few remained operating after the 1940s. In 1989 there is one tin mine operating in Cornwall and intermittent gold production in very small quantities from mines in Wales.

The legacy of derelict land

The reclamation of metalliferous tailings in Wales is, therefore, a matter of reclaiming land at disused and abandoned mine sites. There has never been any reclamation of metalliferous spoil in Wales during the operation of a working mine and it has been estimated that there are 2000 ha of derelict land despoiled by metal mining and processing in Wales (Johnson et al 1977).

The techniques of ore treatment were such that there were never large tailings impoundments as we see at some modern mines but there were large tailings dumps and some mines did have small tailings dams.

Many of the problems associated with modern tailings are however found

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[2]John P. Palmer is Senior Environmental Scientist with Richards, Moorehead and Laing Ltd, Consulting Engineers and Environmental Scientists, 3 Clwyd Street, Ruthin, Clwyd, LL15 1HF, United Kingdom.

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at these abandoned mines. Figure 1 illustrates a flowsheet of ore treatment at the Goginan lead mine in Mid-Wales in 1848. It can be seen that there are three major types of waste:

* Coarse grained tailings
* Fine grained tailings
* Slime pit waste.

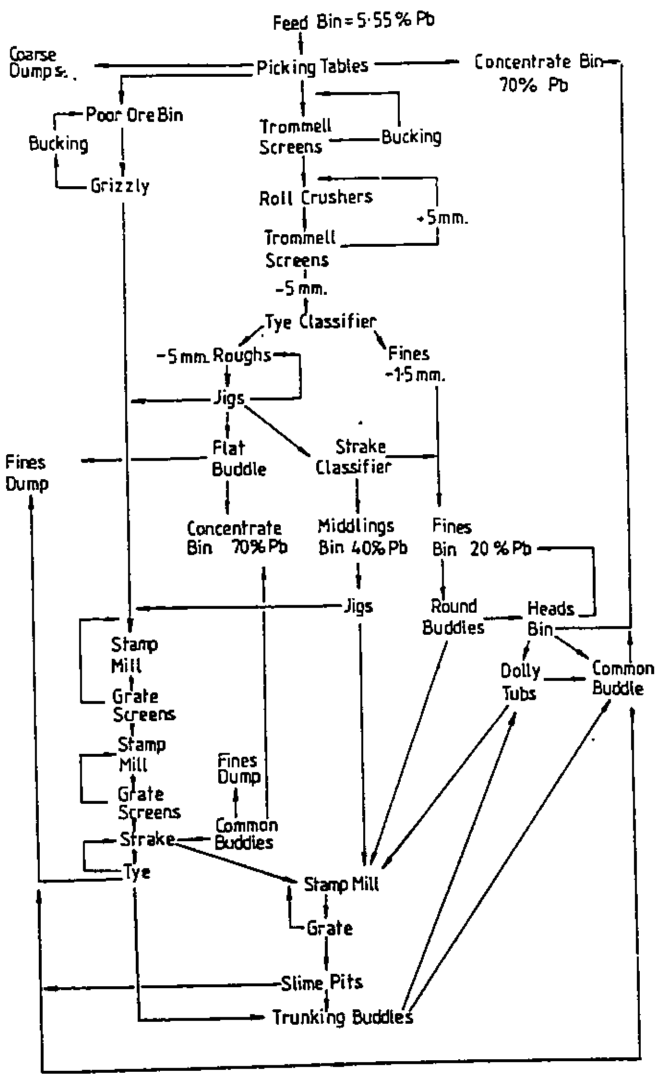

Figure 1 A flowsheet of processes at the Goginan Mine Mill in 1848 (from Hughes 1988)

Many sites still have large quantities of these wastes. They commonly contain up to 2% of metal and sometimes considerably more. The fine wastes are a particular problem because:

* they often contain high concentrations of metal (see Table 1).
* the fineness of the waste means that a high proportion of the total metal content is often 'available'.
* when dry they are subject to wind blow.
* they are easily subject to water erosion.
* many are permanently wet and have thixotrophic properties and are very difficult to handle.

Table 1 Total Concentrations of some metals in mine tailings in Wales (ug g^{-1})

Site (metals mined)	Pb	Zn	Cd	Cu
Minera (Pb/Zn)	14000	34000	435	625
Y Fan (Pb/Zn)	42400	6700	268	376
Halkyn (Pb/Zn)	22882	65187	380	174
Parys Mountain (Cu)	63	88	nd	1390
Goginan (Pb)	175000*	9600	16	nd
Drws-y-Coed (Cu)	800	660	nd	37000*

* Maximum levels; nd - not done

All metal mining sites in Wales are near water courses because of the widespread use of water as a source of power in the mines and in the treatment processes. Some major rivers are polluted, particularly with zinc, because they run through mining districts or are fed by mine drainage. In addition large areas of land adjacent to mine sites may have become polluted by wind blow of toxic waste. On some sites wastes have been reprocessed - this activity was particularly common with respect to the removal of zinc from lead mining waste at the beginning of this century. Generally because of the long history of mining at many sites they are a complex of ruined buildings, spoil heaps and open shafts.

Reclamation of these abandoned mines therefore has one or all of three aims:

1. To reduce a risk to public health through contamination of air, water and soil.
2. To make the sites safe.
3. To clean-up rivers which are polluted from mining activities.
4. To remove landscape scars.

Because mines are old there are two considerations which have to be taken into account during reclamation which may not feature in reclamation of more recent tailings operations. These are:

* the industrial archaeological value of some of the remains
* the nature conservation value of plants growing on the wastes.

These are dealt with in Richards (1989).

Research into the reclamation of metalliferous tailings

Research in the UK into the reclamation of metalliferous tailings has concentrated on spoils in Wales and has focussed on the following areas:

1. The tolerance of plant material growing on metalliferous spoils to the metals found in the spoils.
2. The movement of metals from spoils into the ecosystem.
3. The relationships between heavymetals in the environment and public health.
4. The use of covering materials aimed at preventing upward migration of metal ions.

Plant material tolerant of heavy metals

Much work has been done on the nature and mechanism of metal tolerance in grasses found on metalliferous spoils in Wales (Smith

Table 2 Metal tolerant cultivars of grasses commercially available in the UK

Grass	Source	Comments
Festuca rubra cv. Merlin	Trelogan Mine, North Wales	Tolerant of lead and zinc. Although selected from a mine in an area of calcareous rocks this cultivar can also be apparently successfully used on more acid tailings.
Agrostis capillaris cv. Goginan	Goginan Mine, Mid-Wales	Tolerant of lead and zinc. Suitable for use on acid spoils.
Agrostis capillaris cv. Parys	Parys Mountain North Wales	Tolerant of copper and lead. Suitable for use on acid spoils.

and Bradshaw 1972, Powell et al 1986, Humphries and Bradshaw 1976, Johnson, et al 1977). Three grasses have been selected and produced commercially for use on metal spoils (Table 2). There are few instances of research into metal tolerance in trees on metalliferous spoils. This may in part be due to the almost ubiquitous grazing of mine sites by sheep in Wales. There are however some mine sites supporting trees. These are most commonly birch (Betula pubescens or B.pendula) and Willow (usually Salix caprea). Work by Brown and Wilkins (1958 a,b) has established that Birch from Cwmrheidol mine in Mid-Wales is more tolerant of zinc than that from control sites and that this tolerance may be assisted by mycorrhizal infection. Among the advantages suggested for the use of tolerant species are the following:

* The ability to vegetate spoils of high metal content without covering of a non-toxic material.
* Better binding of a non-toxic cover material to the underlying toxic spoil because the roots of a tolerant species will penetrate the underlying spoil.
* Lower herbage concentration of metals in tolerant plant material than in non-tolerant.

There have been very few instances where tolerant material has been sown directly onto spoil material in Wales. Tolerant material has however been used in many reclamation schemes in conjunction with a cover of non-toxic material.

The movement of metals through the ecosystem

These studies have included work on the metal content of invertebrate and vertebrate herbivores and carnivores on heavy metal sites (Coughtrey and Martin 1975, 1976, Roberts et al 1978, Roberts and Johnson 1978), the effect of heavy metals on aquatic ecosystems (McLean & Jones, 1975; Newton, 1944) and the effect of windblown dust on soil metal levels (Davies and White, 1981). This latter study provided the impetus for a reclamation scheme to control wind blown dust at Cwmsymlog in Mid-Wales.

Heavy metals in the environment and public health

Studies have been carried out in a metal mining district in Scotland and Wales to ascertain the extent to which blood levels are affected by heavy metals, particularly lead, in the environment. Anecdotal evidence from mining districts has suggested that lead in water supplies has caused brain damage to individuals in the past but the establishment of a relationship between lead in the environment and health in modern Britain has been less easy. Both water supply and household dust have been suggested as a principal route by which lead gets into the body (Elwood & Gallacher, 1983; Moffat, 1987). However in these studies in Wales and Scotland, in lead mining districts, blood lead levels were within EEC limits and lower than in some British cities. Work is currently being carried out on lead in dusts soils throughout Britain in order to assist the government to set acceptable standards for lead in soils and some initial survey work has been published (Culbard et al 1988).

The use of covering materials to prevent upward movement of metal ions

Relevant research on this topic has included field trials on metalliferous spoils in Wales using different capping materials, laboratory experiments simulating the field situation using columns of spoil, capping materials and break layers and specific research into the use of different types of break layers to prevent upward migration of metal ions (Jones et al 1982; Cairney 1987). Trials established by Liverpool University and the Robinson Jones Partnership Ltd in 1975 on lead/zinc spoil at Minera in Wales have been particularly informative in terms of the performance of the treatments used (Johnson et al 1977).

These trials were reviewed 12 years after their initiation in order to provide design criteria for the reclamation of lead/zinc wastes at Minera (Richards Moorehead and Laing Ltd 1988a).

Reclamation Techniques

The possible ways in which spoil contaminated by heavy metals can be reclaimed are:

1. By covering the waste in situ with uncontaminated material.
2. By excavation of the spoil and encapsulation in a previously prepared cell on site.
3. By amelioration of the wastes and vegetating them with metal tolerant plants.
4. By excavation of the spoil and removal off-site.
5. By on-site reprocessing of spoil to remove metals as a commercial exercise and incorporating restoration of the site.

Methods 1 to 3 have all been practised in Wales and 1 and 2 will be illustrated in the following case studies. Method 4 is rarely carried out because of the large quantities of material involved. Method 5 has been considered as an option at some sites in the UK (Richards Moorehead and Laing Ltd 1985) but has not recently been carried out successfully in Wales. There are sites however where substantial quantities of spoil exist and which could be reprocessed commercially. At one site the combination of reprocessing with a reclamation and development scheme is being given serious consideration.

Reprocessing as mean of reducing the 'contamination status' of a waste is not however as straightforward as might appear. The extent to which metal can be removed from spoil is dependent on the mineralogy of the spoil, the particle size of the feed material and the process used. Although much metal can be removed from a metal-rich spoil, for example reprocessing may extract 70% of the metal in a spoil containing 6% metal, the waste from the reprocessing activity may be no less contaminating. This is because its particle size may have been much reduced resulting in a much larger surface area and consequently greater availability of metal.

A study of the effectiveness of reclamation methods for contaminated land in Wales has recently been completed (Richards Moorehead and Laing Ltd (1988b). This included metalliferous mines reclamation. It concluded that a major reason for unsuccessful schemes was a failure to adequately predict the movement of water in the completed schemes. This resulted in continued pollution of water courses and contamination of capping materials.

The following case studies illustrate current approaches to metalliferous tailings reclamation in Wales.

Parc Mine

At Parc Mine there was a 2.2 ha complex of fine tailings dumps, slimes ponds and derelict buildings remaining from mining in an area of calcareous Ordovician shales.

The reclamation scheme at Parc was carried out because of erosion of tailings dumps and pollution of the adjacent watercourses Nant Gwydr and the Afon Conwy and its flood plain. It had been estimated that 13000 tonnes of material had been removed from the tips by sheet and gulley erosion since the abandonment of the mine. The scheme involved regrading the site, burying fine material and slimes under coarser materials capping the whole site with a 375 mm layer of quarry waste and sowing with metal tolerant cultivars of grasses. Particular attention was paid to site drainage. Monitoring of suspended lead and zinc soon after reclamation showed that their levels had been much reduced compared to the situation prior to the reclamation scheme being carried out. This was particularly so in flood situations. Monitoring of lead and zinc levels in the Nant Gwydr by the Welsh Water Authority since the site was reclaimed has shown that the water quality has not deteriorated since then. Water quality in the Nant Gwydr has however never been good because the stream has its source in an old mine adit. The levels of zinc and lead in the Nant Gwydr are thus above those in EEC directives for supporting fish and other aquatic life and at about the EEC limit for the watering of livestock.

The vegetated area has mostly been managed for sheep grazing and 10 years after establishment is in good condition considering it is growing on quarry waste.

Goginan

Goginan mine is in an area of predominantly acid rocks of Silurian age in Mid-Wales. Goginan mine was worked for lead and silver from Roman times until about 1890 and on abandonment was a complex of spoil heaps, slime pits, shafts, adits and buildings. During the 1960's and 70's large quantities of spoil were removed for hardcore and country rock was quarried and removed. The site was again abandoned in the mid 1970's and subject to illegal fly tipping. Investigation of the site prior to reclamation commenced in 1987 and involved the following:

1. Characterisation of all the materials on site.
2. Investigation of industrial archaeological features and areas of nature conservation value.
3. Investigation of shafts, adits, structures and drainage.

Soils and spoils on most of the site had levels of lead or zinc above 'background' levels. Lead levels in spoil on the site ranged from 200 ug g^{-1} to over 17%. Uncontaminated subsoil suitable for covering was encountered at a depth of 1.5 m on part of the site. The reclamation scheme involved the following:

1. Removal of the most contaminated tailings to a containment cell excavated on site. The cell was lined and sealed with a polythene membrane.

2. Contaminated soils and tailings not placed in the cell were reprofiled and limed prior to capping with a 300 mm deep layer of granular material and 200 mm of subsoil.

3. Seeding with a grazing mixture and re-establishment of hedgerows.

4. Provision of new site drainage incorporating a bed of limestone to maintain a high pH.

5. Retention of some areas of natural vegetation because of their nature conservation interest.

6. Capping of shafts and provision of grilles in mine entrances. Particular regard was given to making the requirements of bats, which in the UK are a protected species under the Wildlife and Countryside Act.

There was not enough break layer material or subsoil on site so a substantial quantity was imported.

Minera

Minera is in an area of carboniferous limestone rocks in North Wales and was an important lead mining and smelting site which ceased operations in 1914. Because the area is in limestone country the natural colonised vegetation of some of the abandoned wastes was of considerable importance and some mining areas are now protected as nature reserves. The reclamation scheme was divided into two phases because of its size. An investigation similar to that at Goginan was carried out and was supplemented by the experience gained from the 12 year long trial of capping materials referred to previously. A particular problem at this site was the large quantities of fine tailings material spilling down a slope into the River Clwyedog and low lying areas of wet slimes. The scheme involved the following work:

1. The complete removal of fine tailings and underlying contaminated soil from the slopes down to the river. Deposition of this material in a fill area over existing slimes.

2. Covering of the deposited spoil in the fill area with a polythene membrane and a minimum of 500 mm of imported colliery spoil. A greater depth of colliery spoil was used in tree planting areas.

3. Sowing of a low maintenance grass mixture directly into the colliery spoil.

4. Protection and in some cases transplanting of vegetation of nature conservation value.

5. Capping of shafts.

6. Provision of site drainage.

The removal of fine tailings from the slopes down to the river enabled pollution of the river from this source to be minimised and tree planting on the slopes to take place into original ground. The importation of colliery spoil was facilitated by the proximity of a colliery spoil heap itself in need of reclamation. The covering of the metalliferous spoil with colliery spoil obviated the need for a separate scheme to deal with this material.

Major industrial archaeological remains were found underneath tailings when these were being excavated. These were carefully preserved under the direction of an industrial archaeologist.

More details of this aspect are given in Richards (1989).

Because of the large quantities of toxic fine material which were to be moved during the scheme, six static dust monitoring stations were set up to run continuously during the construction period. Construction personnel were required to wear personel dust monitors periodically during their work.

All water draining off the site during the construction period was routed through treatment areas to settle out suspended material in the water.

Thousands of cuttings of willows were taken from trees growing on the metalliferous spoil prior to the reclamation work starting in order to provide material for subsequent planting during the scheme. In addition mature willows which would otherwise be lost during the scheme were lopped and placed in a holding area for re-use.

Conclusions

The experience in Wales of dealing with metalliferous tailings is applicable to similar areas of abandoned mining and also to existing or future operations. Abandonment of tailings dumps without reclamation in Wales has had the following consequences.

* Pollution of major water courses to the extent that they support an impoverished fauna and flora.

* A public health hazard through wind blown dust contaminated with heavy metals.

* Pollution of farmland and gardens by wind blown dust and run off from contaminated heaps.

The techniques used in Wales for dealing with these problems have centred on:

* covering and containing the contaminated waste using coarse material to restrict the movement of heavy metals from the waste into the covering material or surrounding soil.

* the use of plants tolerant of heavy metals for revegetation.

Lessons that have been learned during reclamation of tailings in Wales are:

* Movement of weathered tailings will expose unweathered and unleached material. Great care has to be taken that the reclamation scheme does not cause greater pollution of water courses than was the case before the scheme commenced.

* Tailings should therefore only be removed if this is necessary to achieve the goals of the reclamation scheme.

* Covering of spoil material and incorporation of a break layer or membrane as a capillary break is an effective way of reclaiming metalliferous tailings. Restrictions may have to be placed on after use, however, to ensure that the capillary break is not disturbed. Monitoring of sward and soil metal levels should be carried out if the sward is to be grazed.

* The correct design of the drainage of a reclaimed site is crucial. Water should be prevented from draining through metalliferous tailings wherever possible by appropriate land form design and the use of cut-off drainage.

* Limestone beds are useful to reduce the dissolved metal loading of drainage water in acid areas but are not always long-term solutions - the limestone may quickly become coated with insoluble reaction products which impair its ability to neutralise the water.

* The interface between covering material and metalliferous spoil should be above the expected water table at all times. Containment cells encapsulated in a membrane should not be placed below the water table.

* Coarse material such as colliery spoil is suitable as a capping layer but should be infertile at depth to discourage the roots of the sward penetrating the underlying spoil.

* Deep rooting woody vegetation should not be used on the capping layer unless this layer is deep enough for the underlying spoil not to be penetrated by roots.

* Choice of species to be sown should be made carefully. Metal tolerant species may not be appropriate for non-contaminated covering material because the advantage of such species binding capping layer and spoil together by rooting into it has to be balanced against such roots being a means by which heavy metals can be transported to the uncontaminated capping layer. Some metal tolerant ecotypes are anyway outcompeted by non-tolerant ecotypes in uncontaminated soils.

* Some sites are of industrial archaeological and nature conservation value - these factors should be taken into account at the earliest stages of the design.

Links to papers are on the bottom of the next page see corresponding numbers.

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