Preserving the Legacy of Historic Metal-Mining Industries in the Light of the Water Framework Directive and Future Environmental Change in mainland Britain: Challenges for the Heritage Community

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Contemporary global metal mining is a source of environmental pollution, but in Britain it is our historic mining industry that has left a legacy of contamination in the landscape, around both the immediate mine sites as well as within the river valley floors that drain these orefields. It has been estimated that the levels of lead and zinc stored within some northern British river systems represent values comparable to present-day reserves of economically viable ore deposits and exposure to them can be detrimental to human health. Despite the prevalence and significance of these deposits, they have been neglected by the cultural heritage community, in favour of more easily interpretable remains such as mine buildings, technologies of ore procurement and processing, and the final products of manufacture. This paper argues that in the light of future climate change and legislation associated with the EU Water Framework Directive, heritage managers and industrial archaeologists have to start investigating these deposits as part of their studies and to engage with the environmental science and geomorphological communities who are, at present, setting the agenda in terms of strategies for pollution mitigation and landscape remediation.

KEYWORDS Metal Mining, Water Framework Directive, Climate Change, Heritage Management

Introduction

Across the globe, ore deposits have been exploited for their metalliferous minerals since later prehistory, a process that has shaped the social, economic and political development of contemporary human society. Nowhere is this more evident than in Britain, where the origins of mining for the major ores of copper, tin and lead and other associated metals date back beyond the Roman period to the Bronze Age, although its precise character and timing is still the focus of much debate.[1] What is unequivocal is the intensification and peak output of this activity was during the Industrial Revolution of the 18th and 19th centuries.

In England and Wales, it has recently been estimated that there are over 3000 abandoned metal mines,[2] concentrated in 12 main ore producing regions (Figure 1). Many of these remains form an important component of our landscape of industrial heritage[3] and are often used as part of a wider portfolio of historic assets to promote conservation, tourism and education.[4] Whilst the economic boost that this legacy provides is undoubtedly beneficial, particularly in regions that have long suffered industrial decline, the preservation of these remains has also left a significant legacy of industrial contamination associated with extraction, ore processing and smelting, around both the immediate sites and across the wider landscape, posing significant risks to natural ecosystems and human health.[5]

Despite the prevalence of industrial remains associated with metal mining across the orefields of Britain and the formation of the *Industrial Archaeology Society* in 1973, until recently few practicing archaeologists have sought to consider the implications of metal mining contamination upon the wider environment. This is despite the fact that archaeologists are probably the best placed profession to understand the intricacy of these remains and likely spatial variability in contamination levels across former mining sites; for example, the ability to identify crushing and dressing floors, which are likely to be highly contaminated. However, despite this expertise, traditional archaeological approaches to this environment have largely focused on recording the fabric of the built environment, the technologies of ore extraction, power, processing and manufacture, and the final metal products themselves.[6] In the past two decades environmental archaeologists have sought to redress this balance by investigating the link between pollution histories, the historic environmental record and palaeoecology, particularly the exploitation of woodland, which was a source of fuel for ore processing.[7] Such environmental studies are starting to view geochemical contamination from metalworking processes as an artefact in its own right and a resource to be studied and utilised, for example, Romano-British metalworking geochemistry.[8] Such concepts have already been established by the osteoarchaeological and geochemical communities who have combined forces to consider the human health effects of historical contamination.[9]

Whilst there is no doubt that this important aspect of our industrial heritage should be preserved, the combined predicted effects of future climate change[10] and, in Europe, stricter pollution control associated with the Water Framework Directive[11] provide significant challenges for its longer-term sustainable management. The aim of this paper is to explore these issues by highlighting the scale of potential problems, possible solutions and to consider how the wider heritage community can contribute to this debate.

The Legacy of Pollution

Although the heritage community has shown limited interest in the wider contamination associated with metal mining, it is the geomorphological, geochemical and environmental science communities that have long recognized the importance of these industries for environmental pollution and the sensitivity of these landscapes to change. A number of geomorphological studies have considered specific physical processes of erosion, for example by wind and water around discrete mine sites,[12] whilst the link between geomorphology and wider contamination studies was established in the mid 1970s;[13] since then, numerous empirical investigations across the orefields of Britain have demonstrated the levels of contamination and the importance of river systems in facilitating the dispersal, storage and remobilisation of metals transported as particulate fractions or binding to sediments in a variety of chemical forms.[14] In addition to sediment transport processes, the spatial distribution and hence concentration of contaminated sediments within valley floors is intimately linked to river planform and style of sedimentation as well as flood regime; these factors have led geomorphologists to distinguish between valley floors characterised by ‘passive dispersal’ where the addition of contaminated materials seems to have a negligible impact on the natural system and those ‘actively transformed’, though both are merely end members of a continuous spectrum.[15] Therefore, archaeologists need to be aware of the contaminants within the mine sites themselves as well as those that have already been dispersed, but are stored within the wider catchment environment (Plate 1a&b).

The scale of particulate contamination of the environment is considerable; it has been estimated that in northern England alone, over 12,000 km^2 of catchments are affected by the legacy of historic metal mining.[16] Within the Yorkshire Ouse basin, which drains the North Pennine Orefield and is without doubt the most intensely studied metilliferous region of Britain, it is estimated that 620 million tonnes of lead and 640 million tonnes of zinc are stored within its floodplains, representing values comparable to present day reserves of economically viable ore deposits.[17] Within the sub-catchment of the River Swale, it is estimated that approximately 55% of the agriculturally important floodplain is significantly contaminated and that 28% of the lead produced within the catchment remains stored within the valley floor.[18] Scenarios developed using computational modelling suggest that 70% of contaminants deposited within the Swale system have remained for more than 200 years following mine closure[19] and more generally, contamination from historic 'low-scale' mining can still be detected in alluvial sediments over 1000 years after deposition.[20]

In addition to the particulate load deposited upon the valley floors, metal contaminants can be carried in suspension and solution and are known collectively as 'acid mine drainage'.[21] A comprehensive government-funded inventory of pollution discharges across England and Wales identified 338 discharges from 4923 abandoned metal mines.[22] Whilst contaminant profiles were only available for around 30% of those discharges, they suggested a minimum of 193 tonnes of zinc, 18.5 tonnes of lead, 0.64 tonnes of cadmium, 19.1 tonnes of copper, 551 tonnes of iron, 72 tonnes of magnesium and 5.1 tonnes of arsenic are discharged into surface waters annually.[23]

However, other studies have demonstrated the complexity of unravelling the sources of pollution showing that during periods of low flow, diffuse sources are relatively unimportant with more contaminations being released from point source mine waters; in contrast, during periods of higher flow 90% of contaminants are attributed to diffuse sources with contributions from waste materials and groundwater discharge.[24]

The Impact of Climate Change and the Implementation of the Water Framework Directive

Recent geological history demonstrates that the earth's climate has been shaped by natural cycles of climate change,[25] but it is now widely acknowledged that human adaptation of the planet is causing significant changes to current and future climate,[26] leading geoscientists to define this period as the Anthropocene.[27] Although challenges remain in refining predictions, it seems likely that both the frequency and intensity of weather events will become more pronounced, with extremes of both temperature and rainfall common place.[28]

Despite levels of contamination being shown to be high, at present the majority of these mining age sediments in northern and western Britain are 'locked down' in the landscape, protected from erosion by vegetation (predominantly rough pasture or improved grassland). However, the autumn 2001 floods in the Yorkshire Ouse basin provided an insight into the potential problems that might occur as a result of future climatic conditions with post-flood point sampling at 35 sites along the River Swale recording lead, zinc and cadmium concentrations exceeding government safety levels.[29]

In addition to the issues of climate change, the challenges of dealing with the legacy of metal mining have been compounded further by the requirements of the Water Framework Directive.[30] Although this significant piece of legislation, which provides a structure for the protection, improvement and sustainable management of the water environment came into effect in December 2000, and has therefore been on the statute books for a considerable period of time, the ramifications of this legislation for heritage are only now beginning to take shape since there is a need for all surface waters to maintain 'good status' by 2015. This status is measured using a range of criteria including ecological targets across 12 River Basin Districts, which provide the strategic level of management and those that fail will need to achieve good status by 2021 or 2027 and the challenges are considerable. [31]

Remediation, its cost and the impact on Heritage

Whilst metal mining is not the only issue driving water quality,[32] the empirical evidence described above clearly demonstrates that it has resulted in the introduction of significant volumes of industrial pollutants into the natural environment, but that the environmental science community has developed a thorough understanding of levels of toxicity, as well as current and future pathways of contaminant delivery. However, in contrast to other countries where contemporary mining is causing significant environmental problems,[33] the majority of contamination in Britain is associated with historic mining remains and whilst as point sources they are no longer directly contributing contaminants into the environment, waste tips and mine drainage continue to provide a source of pollutants. In the UK, this historical context creates a key management dilemma since it is only since 1999 that mine operators have been under a legal obligation to mitigate pollution from abandoned mines.[34] Even if obligations were met, the financial burden is considerable; a series of joint reports commissioned by DEFRA and the Welsh Government in collaboration with the Environment Agency estimates that at present-day economic rates the total cost to remediate all of the water-related environmental problems associated with abandoned non-coal mines would be around 370 million over an initial 10 year period, excluding operating costs.[35]

Given the lack of contemporary workings, greater emphasis is placed in the literature on diffuse sources, recognising the importance of contaminants already distributed beyond the mines themselves,[36] a point corroborated by a range of empirical studies. For example, analysis of flood sediments after the 2003 floods on the River Swale indicated that the highest concentrations of contaminants were found at the mouths of heavily mined tributaries with elevated levels continuing for 5-10km downstream of those inputs.[37]

However, whilst focusing on diffuse sources within the floodplains and wider valley floors is important, there seems to have been little attempt to explore diffuse pollution sources within the perimeters of mining sites themselves. This is certainly an area of research where the input of heritage specialists would be exceedingly valuable, especially if levels of contamination could be correlated with industrial processes and archaeological features. Recent work using a combination of multi-spectral satellite imagery, lidar and aerial photography, augmented by ecological survey and geochemical analysis has been undertaken to assess the condition of industrial archaeological remains on Alston Moor in the North Pennines.[38] The results indicated extensive processes of gullying, mass movement and deflation all contributing to environmental degradation and acting as pathways for pollutant dispersal. The study also highlighted the importance of water management features within the landscape, including sites of hushing, a hydraulic mining technique used to expose and clear overburden from above ore deposits[39]. Whilst water management features were important at the time of mining they clearly have a contemporary role to play as pathways of pollutant movement. This study[40] demonstrates the potential for detailed large-scale survey and provides an exemplar of how combining geomorphological, geochemical and heritage methodologies can provide a much greater understanding of the landscape rather than considering a mine site as one simple, large point source of pollution. Understanding slope-channel coupling and sediment storage is of paramount importance and Lidar clearly offers a valuable technique to assist in landscape analysis.

As English Heritage note on their website, they have been protecting 'industrial sites' since the early 1950s through a combination of both scheduling and listing. This approach has been augmented by initiatives such as the annual '*Heritage at Risk*' programme (established 2008), which has a sub-theme specifically devoted to industrial remains (http://www.english-heritage.org.uk/caring/heritage-at-risk/industrial-heritage-at-risk/protecting-industrial-sites/) and the publication of other literature aimed at informing protection and conservation strategies for the industrial environment.[41] However, current protection measures invariably provide a best-fit designation for all site types, periods and locations and in the case of metal mining they don't consider contaminants although this does come under the umbrella of 'associated site issues'. At present, with funding from English Heritage, the *National Association of Mining History Organisations* (NAHMO) are in the process of producing 'The *Research Framework for the Archaeology of the Extractive Industries of England*' with the aim of informing decision–making with respect to future archaeological research and heritage (management) of mining landscapes. This 18 month programme offers the heritage community a real opportunity to engage with the wider contamination issues of historic metal mining, which is considered as a discrete theme and the research agenda does mention the wider landscape impacts; however, draft chapters available via the NAHMO website (http://www.namho.org/research.php) suggest that this opportunity to take a holistic assessment of such remains may not be realized fully.

Having specifically led the way with contaminant studies, the published literature indicates that it is the environmental science community who are largely driving the agenda focused around strategies for mitigation and remediation. To date, the majority of this work has been undertaken to reduce the effects of pollution from coal mines; in 2008, the Environment Agency reported that together with the Scottish Environmental Protection Agency and Coal Authority 54 mine-water treatment plants had been built preventing 2500 tonnes of iron and other metals from entering the hydrological system.[42] With respect to metal mines, progress has been slower but is now considered a priority with the treatment plant at Wheal Jane tin mine (Cornwall), which prevents 670 tonnes of iron and 150 tonnes of zinc from entering the tidal Restronguet Creek annually, providing an exemplar of what can be achieved.[43]

Whilst the environmental community has the technological ability to undertake these important schemes, it is unclear from the literature as to how heritage stakeholders are contributing their specialist knowledge to remediation proposals; solutions can be active or passive, dividing into those dealing with particulate waste and those focused upon acid mine drainage.[44] Where pollution can be identified to a discrete point source, active solutions usually use chemical reagents to facilitate cleaning within treatment plants, whereas passive solutions use a combination of gravity and natural biogeochemical processes operating across artificial lagoons and wetlands to achieve the same outcome, though in reality, most solutions include a combination of the two.

However, it is estimated that some 60% of metal mining pollution in England and Wales is from diffuse sources.[45] A popular mitigation proposal in the literature is for relatively discrete areas such as spoil heaps to be capped with solid, inert materials such as waste rock, clay, organic waste or neutralizing agents such as limestone with an optional vegetative cover.[46] Where spoil heaps are being directly eroded next to adjacent stream channels, rock-filled gabions have been used to reduce erosion, but this is at a considerable cost; approximately £3 million for a 1-2km stretch of the River Nent in Cumbria; where diffuse pollution is shown to be concentrated along particular pathways of runoff, buffer strips (e.g. grassed waterways, infiltration trenches) can be used to prevent runoff entering the river system.[47]

The potential of extreme rainfall events to flush contaminated waters out from mine systems was highlighted by the events at Wheal Jane tin mine in 1992,[48] a problem that could be amplified under scenarios of future climate change and exacerbated if adits are blocked. Mayes and Jarvis[49] note the need for precise and accurate mapping of all mines to mitigate this issue but this plea highlights the lack of overlap between the environmental and heritage communities; much of this information is readily available via local authority Historic Environment Records (HERs), the National Mapping Programme (NMP) and volunteer groups such as the Northern Mine Research Society (http://www.nmrs.org.uk/).

Whilst the approaches to mitigation are well-developed, the challenges these provide for heritage are many and some scenarios may not be desirable to preservation of the historic environment. For example, technologies designed to deal with point sources require relatively large spaces for infrastructure, which is often lacking within the metal-rich uplands of northern and western Britain. As well as impacting directly on heritage designations (e.g. Scheduled Monuments, Listed Buildings), solutions for both point source and diffuse pollution may impact significantly on other designations related to the aesthetics, ecology and wilderness value (e.g. ANOB, SSSI), especially since many of the areas sit within National Parks and those in Devon and Cornwall have World Heritage Site status. Furthermore, phytotoxic plant communities, which have evolved to withstand high metal concentrations, are well-research phenomena with Calaminarian Grasslands now recognized as a Biodiversity Action Plan habitat type.[50] Consequently, remediation of heavy metal pollution in these areas would result in the destruction of areas of unique biodiversity (Plate 2), whilst maintenance of these habitats requires a degree of ongoing contamination to be maintained within the environment.

There are further conflicts of interest that may arise from mitigating pollution sources and remediation of existing pollution deposition. Primarily, the metal pollution, whilst a contaminant is also an historic artefact. It provides an insight to the past, in terms of environmental consideration, environmental legislation and economic activities. Indeed, geochemical pollution from the past is actively sought after as a key artefact with which to understand the past.[51]

As noted earlier, many of these waste deposits contain higher levels of metal than many commercially extracted ore deposits;[52] therefore, in a world of diminishing resources, increasing technological innovation, and the need to remove contaminants, it is not inconceivable to consider that future proposals might include the re-mining of deposits, which can have a variety of uses in addition to their metal content.[53] Furthermore, in the North Pennines over 1 million US dollars is currently being invested by one company who believe that '*there is significant untested potential for such mineralisation approximately 300-400m below previous, adit-accessed workings, and such deposits could be significantly larger than any previously discovered*' (http://www.minco.ie/projects/North%20Pennine%20Project.html). If proven, such developments would offer significant economic opportunities for this area, which might be difficult to resist and offer significant challenges for the historic environment.

Conclusions

This paper has sought to highlight the challenges facing the metal mining heritage of Britain in the light of future climate change and ever tightening pollution legislation; in Europe, this is associated with the implementation of the Water Framework Directive, but in other parts of the World may involve comparable legislation. These challenges are considerable; in the Swale catchment alone, it is estimated that it will take in excess of 5000 years for all this metal-rich sediment to be removed by natural processes.[54]

Review of the published literature demonstrates the environmental science community has led the way in engaging with the pollution challenges created by the legacy of mining, but that these initiatives appear to take little account of the detailed heritage record. For example, the development of a national strategy for the identification, prioritisation and management of pollution from abandoned non-coal mine sites in England and Wales using a GIS framework to capture mine data from geological and Ordnance Survey maps fails to consider local authority Historic Environment Records[55]; as the authors acknowledge, stakeholder engagement is critical and it is important for the heritage community to engage with and contribute to such initiatives. Where large stakeholder consultations have been undertaken, they have yielded significant results; for example, the mining strategy for Wales, which bought together 20 stakeholder groups to consider the top 50 polluting metal mining sites in the country.[56]

Of course, contaminant problems are not restricted to mainland Britain; historic metal mining is a feature of a number of countries[57] and climate change will certainly affect all parts of the globe. In Europe, the WFD adds an additional dimension to these issues and is acute where mobilisation of contaminants is transnational[58], but if metal mining remains across the globe are to be managed in a sustainable way for the long term, heritage professionals need to set an agenda beyond simply preservation.

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LIST OF FIGURES

Figure 1. The major orefields of mainland Britain

Plate 1 a&b. Examples of erosion of mine tailings around Dunfell Hush, river Tees catchment, North Pennines (photographs, M. Kincey).

Plate 2. Spring sandworth on spoil at Whitesike Mine, river South Tyne catchment, North Pennines. Also known as Vernal sandwort or Leadwort, it is frequently found associated with Calaminarian Grassland habitats (photograph, M. Kincey).

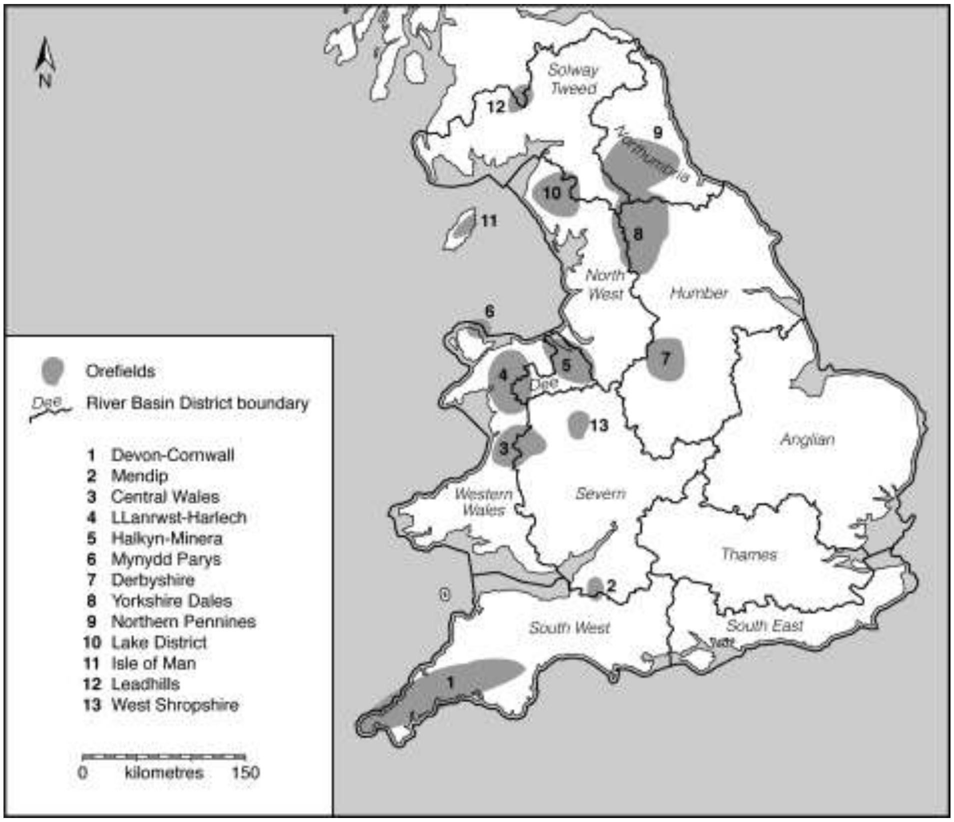
N
Solway
Tweed
Northumbria
North
West
Humber
Dee
Anglian
Western
Wales
Severn
Thames
South West
South East
Orefields
River Basin District boundary
1 Devon-Cornwall
2 Mendip
3 Central Wales
4 LLanrwst-Harlech
5 Halkyn-Minera
6 Mynydd Parys
7 Derbyshire
8 Yorkshire Dales
9 Northern Pennines
10 Lake District
11 Isle of Man
12 Leadhills
13 West Shropshire
0 kilometres 150

Figure 1