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Physicochemical composition of wastes and co-located environmental designations at legacy mine sites in the south west of England and Wales: Implications for their resource potential

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ABSTRACT

This work examines the potential for resource recovery and/or remediation of metalliferous mine wastes in the south west of England and Wales. It does this through an assessment of the physicochemical composition of several key metalliferous legacy mine waste piles and an analysis of their co-location with cultural, geological and ecological designations. Mine waste samples were taken from 14 different sites and analysed for metal content, mineralogy, paste pH, particle size distribution, total organic carbon and total inorganic carbon. The majority of sites contain relatively high concentrations (in some cases up to several % by mass) of metals and metalloids, including Cu, Zn, As, Pb, Ag and Sn, many of which exceed ecological and/or human health risk guideline concentrations. However, the economic value of metals in the waste could be used to offset rehabilitation costs. Spatial analysis of all metalliferous mine sites in the south west of England and Wales found that around 70% are co-located with at least one cultural, geological and ecological designation. All 14 sites investigated are co-located with designations related to their mining activities, either due to their historical significance, rare species assemblages or geological characteristics. This demonstrates the need to consider the cultural and environmental impacts of rehabilitation and/or resource recovery on such sites. Further work is required to identify appropriate non-invasive methodologies to allow sites to be rehabilitated at minimal cost and disturbance.

1. Introduction

There are few locations world-wide where historic metal mining is more evident than in mainland Britain. Extensive mining of major ores for metals including Cu, Pb, Sn and Zn at locations such as the Devon Great Consols in SW Devon and Parys Mountain in NW Wales fuelled profound global societal and industrial change (particularly during the Industrial Revolution) but as a consequence created a significant legacy of waste. Most mine sites in the UK were in peak operation in the 18th and 19th centuries and, as a result, mine sites were not subject to restoration practices which have been required in more recent years. In England and Wales alone, it has been estimated that there are over 8,000 disused metal mines located predominately in 12 ore producing regions (Jarvis et al., 2007; Palumbo-Roe et al., 2010). Rather than simply rehabilitating such sites one option is to also recover any economically valuable metals that are present. Mine wastes and tailings are an obvious target for metals recovery as there are often significant quantities of such material in relatively easily accessible locations (i.e. above ground). To date, however, there is a paucity of studies that have characterised mine waste sites in terms of their metal content and extractability. This study is the first effort to present these data for prominent legacy mine sites in England and Wales.

Legacy mines also provide environmental or landscape 'resources'. This study examines the resource potential of these legacy mine wastes in the context of site rehabilitation. Further to the potential recovery of economically valuable metals, there are often other drivers. For example, site remediation may: enable the land to be developed; enhance the conservation of industrial heritage and the related tourism features; and/or decrease the release of pollutants from the site into the surrounding environment. Similarly, there are also often a range of existing services that the mine sites provide which must be considered when implementing site remediation, including: cultural, scientific and educational features (such as historic industrial ruins); and rare fauna and flora. Thus it

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is important to appreciate the multifaceted value, both positive and negative, depending on perspective, that these sites currently have and would have if remediated. Within this a cost benefit approach must be applied to accurately assess to what extent the economic gain (that can be made through metal extraction) can offset the economic cost of such an intervention. This study thus considers multifaceted characterisation of value and resource through various lenses and the authors use the word "resource" in a wide sense (e.g. Freeman et al., 2014) to cover both tangible resource of, for example, the metal/ore as well as functional and intangible resource stemming from the ecological, sociocultural and landscape value of the mine sites.

In this work key geological, ecological and cultural designations (herein grouped under the umbrella of "environmental designations") co-located with the mines of SW England and Wales and, in particular, the case study legacy mine sites are presented as a means of assessing the potential consequences of the remediation of these sites. The specific aims of this paper are therefore to: (i) present data from the physicochemical characterisation of mine wastes from 9 major sites in SW England and 5 major sites from Wales; (ii) delineate the co-located environmental designations of the case study sites; (iii) appraise broader considerations of value and resource relevant to metal mine sites; and (iv) consider potential decision making tools to determine appropriate methodologies for optimising resource value. Very few studies currently exist which have applied this holistic approach to mine waste characterisation and to our knowledge this is the first time that the co-location of UK mine waste with geological, ecological and cultural designations has been examined.

2. Key drivers/deterrents for the reclamation of legacy mine waste

2.1. Environmental pollution

A large number of historic metal mine sites world-wide are responsible for the release of metals and metalloids into surface and groundwater (Hudson-Edwards et al., 2011; Plumlee and Morman, 2011). For example, a preliminary national assessment in 2009 revealed that as much as 6 of surface water bodies in England and Wales are currently adversely affected by pollution from historic metalliferous mines (Mayes et al., 2009). In the UK ore extraction ceased at the majority of mine sites by the first half of the twentieth century, and as such ownership and/or legal liabilities for clean-up are often either unclear or orphaned (Palumbo-Roe et al., 2010). This is also the case in many of the ore fields of North America (e.g. the USA and Canada have approximately 35,000 and 10,000 legacy metal mine sites respectively), Asia (e.g. Japan has approximately 5500 legacy metal mines) and Europe (e.g. Sweden has approximately 1000 legacy metal mines) (Mayes et al., 2009). The financial cost of remediating and rehabilitating these mine wastes is significant. For example, in 2012 a series of joint reports commissioned by the Department for Environment, Food and Rural Affairs (DEFRA) and the Welsh Government in collaboration with the Environment Agency estimated that the total cost to remediate all of the water-related environmental problems associated with abandoned non-coal mines in the UK would be approximately £370 million, excluding operating costs, and take upwards of ten years (Jarvis and Mayes, 2012a,b). Moreover, the pollutant discharge from such sites often continues for many decades or even centuries, before water quality recovers to the pre-mining baseline. For example, despite ceasing major operations in the late 18th century Parys Mountain in NW Wales remains a major contributor of Cu and Zn to the Irish Sea, discharging an estimated 24 and 10 tonnes of each element respectively each year (Mullinger, 2003).

2.2. Ecological resource

The unique (and often extreme) physicochemical conditions and lack of disturbance has resulted in the development of a rich ecological resource on many different metalliferous mine wastes world-wide (Bradshaw, 2000). For example, legacy mine sites often contain numerous species of rare metal-tolerant plants and lichens (Rodwell et al., 2007), grasslands, wildflowers, orchids and important invertebrates, birds and mammals (e.g. the lesser horseshoe bat) (Barnatt and Penny, 2004). In the UK this has resulted in specific recognition and protection for some mine waste sites. Examples include: the designation of Sites of Special Scientific Interest (SSSI) status for rare metal-tolerant plants, and lichens, and two priority habitats: Calaminarian grasslands (BRIG, 2008) and Open Mosaic Habitats on Previously Developed Land (OMH) (BRIG, 2010).

2.3. Geological and mineralogical resource

The amount of metal produced at major UK mine sites has generally been relatively well recorded over the peak production years (i.e. during the Industrial Revolution), however, definitive figures for the quantity and type of waste produced are often lacking, with estimates typically calculated from predictions on the mineral to waste ratios, which are often highly variable, even for the same commodity (Palumbo-Roe et al., 2010). To date a number of studies have attempted to quantify the mass, distribution and composition of mine waste located at specific sites across the UK, however, a conclusive inventory is yet to be created due to the large number of mine waste sites and the inherent complexity of differentiating between the mine waste and the natural ground surface. As such a first estimate (e.g. to within an order of magnitude) for the mass and composition of mining waste present at many major legacy metal mine sites in the UK has not yet been conducted with their associated economic value therefore unknown.

Globally, historic ore beneficiation processes were typically less efficient than today and as such it is likely that appreciable concentrations of economically valuable metals were discarded as waste and are currently stored at legacy metal mine sites. Furthermore, the material has often already undergone size reduction during historic ore beneficiation and is often stored as unconsolidated material in relatively accessible locations (in piles above ground). Mine waste (in particular mine tailings waste) is also often of a relatively homogenous physical and chemical composition compared to other waste streams such as municipal solid waste. These extraction and processing activities have often resulted in the occurrence of rare and unusual geological, mineralogical or physiographical features deemed worthy of protection. Many mine wastes in the UK are therefore designated, for example, as Sites of Special Scientific Interest (SSSIs) because of these characteristics. Similarly, where relics demonstrate technological advancement of the mining industry they may also be designated as, for example, Scheduled Monuments.

2.4. Sociocultural resource

The cultural heritage of many mine sites is considerable and the waste piles themselves are an intrinsically valuable component of this heritage landscape, i.e. in addition to remnant buildings and processing equipment (Howard et al., 2015). As such many landscape-scale historic mining districts have been granted official conservation status, for example the Cornwall and West Devon Mining Landscape World Heritage Sites as well as the numerous individual Scheduled Monuments and Listed Buildings that are associated with a rich legacy of mining. Physical features such as hushing scars; prospection pits and mine shafts; roads, tramways and leats linking the mines and settlements as well as the spoil tips