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Procedia Earth and Planetary Science 17 (2017) 284 – 287

Procedia Earth and Planetary Science

15th Water-Rock Interaction International Symposium, WRI-15

Weathering of Zinc-(Zn)-bearing Mine Wastes in a Neutral Mine Drainage Setting, Gunnerside Gill, Yorkshire

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Abstract

Numerous areas throughout the world are affected by circum-neutral pH, low iron (Fe) drainage with high concentrations of zinc (Zn) arising from discharges from, and weathering of, mine wastes. Gunnerside Gill, a small upland tributary in the headwaters of the River Swale in Yorkshire, is such a site affected by historic lead and zinc mining. The aim of the study is to assess the controls on Zn mobilisation from the mine tailings and floodplain sediments to the river water through a column leaching experiment. Sphalerite has been identified as the primary Zn mineral in the bedrock within Gunnerside Gill. However, there is more evidence of secondary phases of Zn were including Fe oxides and phosphates present within the samples and the BCR data suggests it is these phases that appear to be undergoing the majority of the Zn dissolution.

Peer-review under responsibility of the organizing committee of WRI-15

Keywords: neutral mine drainage; Zn; mining; Yorkshire

1. Introduction

Numerous areas throughout the world are affected by circum-neutral pH, low iron (Fe) drainage with high concentrations of zinc (Zn) arising from discharges from, and weathering of, mine wastes. Several historical mining areas in the UK are characterised by such circum-neutral, low Fe drainage, with high levels of dissolved Zn[1]. Gunnerside Gill, a small upland tributary in the headwaters of the River Swale in Yorkshire, is such a site affected by historic lead and zinc mining in the Northern Pennines. The aim of the study is to determine the controls on Zn mobility from Gunnerside Gill mine tailings and river bank sediments using column leaching experiments and

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Peer-review under responsibility of the organizing committee of WRI-15
doi:10.1016/j.proeps.2016.12.056

aqueous field data.

2. Site setting

Gunnerside Gill (54.3994° N, 2.0922° W) is a small upland tributary in the headwaters of the River Swale Gunnerside Gill is underlain by a series of Carboniferous strata comprising silica cemented sandstones, limestones and cherts[2]. Hydrothermal Pb, Zn, barium and fluorine-rich fluids were introduced into the Carboniferous strata by the intrusion of the Wensleydale Granite at depth, during the late Carboniferous or early Permian[3]. The volume of Zn produced from Gunnerside Gill is not well documented; although sphalerite was present with galena in Swaledale it was not commercially worked[4]. However, it has been estimated that 17796 tonnes of Pb were produced from mining in Gunnerside Gill[5]. The upper reaches of the River Swale, including Gunnerside Gill, were often mined by 'hushing'. Hushing is a hydraulic from of mining in which dams were constructed upslope of the shallow mineral veins and sluices were opened to erode the overburden and expose the mineral veins. This practice resulted in the mobilisation of significant amounts of fine-grained metal contaminated sediments to the catchment[6]. In a previous study conducted by[7] following flooding in 2000, samples of overbank and channel-edge flood sediment were recovered from along the River Swale. In the silt and sand sized fraction of the channel edge flood sediment recorded concentrations of Zn were found to be 4500 mg/kg as a result of the sediment input from Gunnerside Gill. Zinc concentrations in the clay and silt sized fraction of the overbank flood sediment were found to be 14000 mg/kg.

3. Materials and methods

Four samples of mine waste and floodplain sediment (mine waste: Gun 1, 2, 3; floodplain sediment Gun 9) from Gunnerside Gill were characterized by X-ray diffraction, electron microprobe analysis, total metal extraction and geochemical analysis and chemical sequential extraction. These samples were then used to model 10 years of weathering by undertaking a column leaching experiment. The columns comprised clear plastic tubes with acid washed quartz sand at the base and 1400 g of sample added in uniform layers of 1 to 2 cm. High-purity water was added on a weekly basis to mimic seasonal rainfall and the resulting leachate was sampled and subsequently analysed by ICP-AES.

4. Results and discussion

Gun 1, Gun 2 and Gun 3 are mixtures of waste rock and tailings, and Gun 9 is floodplain sediment from the lower reaches of Gunnerside Gill near its confluence with the River Swale. The general mineralogy of the samples is shown in Table 1. The Fe oxides contain variable proportions of Mn, Pb and Zn.

Table 1. Mineralogy of pre column experiment samples (X = major component, x = minor component, x_g = individual grains identified by EMP)

Sample	Quartz	Barite	Calcite	Fluoride	Clays	Cerussite	Galena	Fe Oxides	Sphalerite	Pb/Zn Phosphate	Pyrite
Gun 1	X	X	X		x	x		x_g			x_g
Gun 2	X	X	X	x	x		x_g	x_g			
Gun 3	X	X		x	x		x		x_g		x_g
Gun 9	X	X		x	x			x_g		x_g	

Based on the results of the BCR sequential extraction, as shown in Figure 1, the proportion of Zn in all four samples was found to be present mostly in the acid extractable or soluble/carbonate/cation exchange fraction, followed by the reducible or Fe/Mn oxihydroxide fraction in the case of Gun 1, Gun 2 and Gun 9 and the oxisible or organic matter/sulphide fraction in Gun 3. This is reflected in the original mineralogy of the samples, Fe oxides were