Acid coal mine drainage in the Arctic

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INTRODUCTION

Acid mine drainage (AMD) is a well-known environmental problem resulting from the oxidation of sulfidic mine waste. In cold regions, AMD is often considered limited by low temperatures during most of the year and the observed environmental impact thought to be related to pollution generated during the warm summer period. However, within the investigated oxidizing, sulfidic coal mine waste rock pile in Svalbard (78° N) it has been shown that heat generation is high enough to keep the pile warm (roughly 5 °C throughout the year) despite mean annual air temperatures below -5 °C. Consequently, weathering processes continue year-round within the waste rock pile. During the winter, weathering products accumulate within the pile because of a frozen outer layer on the pile and are released as a flush during soil thawing in the spring. Consequently, spring runoff water contains elevated concentrations of metals. Several of these metals are taken up and accumulated in plants where they reach phytotoxic levels, including aluminum and manganese. Laboratory experiments document that uptake of Al and Mn in native plant species is highly correlated with dissolved concentrations. Therefore, future remedial actions to control the adverse environmental impacts of cold region coal-mining need to pay more attention to winter processes including AMD generation and accumulation of weathering products. Focus of this presentation is the chemistry of the AMD released from the waste pile during the high arctic summer period.

Picture 1. The abandoned coal mine waste pile in Bjørndalen near Longyearbyen, Svalbard (78°N). The pile is 20 m high and comprises roughly 200,000 m³ of pyritic waste rock (<1% FeS_2) deposited between 1986 and 1996.

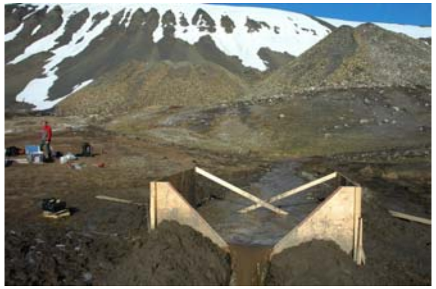
PUBLICATIONS

Jens Søndergaard, Bo Elberling and Gert Asmund (2008). Metal speciation and bioavailability in acid mine drainage from a high Arctic coal mine waste rock pile: temporal variations assesed through high-resolution water sampling, geochemical modelling and DGT. Cold Regions Science and Technology: in press, doi:10.1016 /j.coldregions. 2008.01.003.

Jens Søndergaard (2007). In situ measurements of labile Al and Mn in acid mine drainage using diffusive gradients in thin films. Analytical Chemistry: 79; 6419-6423.

Jens Søndergaard, Bo Elberling, Gert Asmund, Claus Gudum and Karl M. Iversen (2007). Temporal trends of dissolved weathering products released from a high Arctic coal mine waste rock pile in Svalbard (78°N). Applied Geochemistry: 22; 1025-1038.

Bo Elberling, Jens Søndergaard, Louise A. Jensen, Lea B. Schmidt, Birger U. Hansen, Gert Asmund, Tonci Balić-Žunić, Jørgen Hollesen, Susanne Hanson, Per-Erik Jansson and Thomas Friborg (2007). Arctic Vegetation Damage by Winter-generated Coal Mining Pollution Released upon Thawing. Environmental Science and Technology: 41; 2407-2413.



Picture 2. The waste rock pile with the drainage trench and the constructed weir used to quantify the discharge throughout the summer 2005. The trench was designed to collect all runoff coming from the pile. Daily measurements of element concentrations and continuously measured discharge made is possible to estimate the flux of dissolved weathering products from the pile.

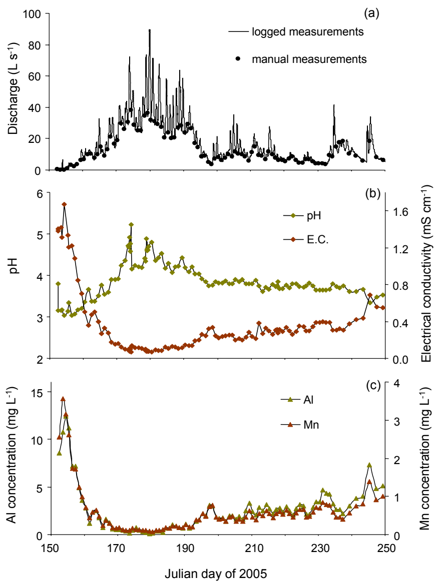


Figure 1. Temporal variations in flow rate and dissolved runoff chemistry measured at the location of the weir. (a) Flow rate of runoff; (b) pH and electrical conductivity and (c) Al and Mn concentrations.

KEY FINDINGS

Field investigations of AMD from a high Arctic coal mine waste rock pile were carried out during the summers of 2005 and 2006. The most abundant metals in the AMD (apart from alkali- and alkaline earth metals) were iron (Fe), aluminum (Al), manganese (Mn), zinc (Zn), and nickel (Ni). The pH varied between 2.8 and 5.2. Aluminum and Mn concentrations were observed above phytotoxic levels (up to 13 and 4 mg L^{-1}, respectively) and were considered the most critical elements in terms of environmental impact (Figure 1).

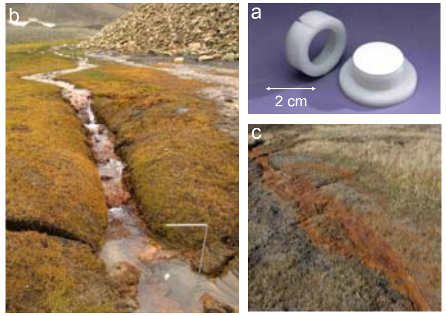
The highest concentrations of all dissolved metals, the lowest pH values, and a very high daily release of sulfuric acid (up to twice as high as the following month) were observed in AMD during the first two weeks of thaw (Figure 1). This is considered the result of a release of pollutants slowly generated and accumulated within the pile during winter but released as a flush upon thawing. Similar presumed accumulation/flush sequences were observed later in the summer, where rain events followed relatively long dry periods.

The analytical metal speciation technique of diffusive gradients in thin films (DGT) was evaluated for the first time for measuring labile Al and Mn in AMD. Initial laboratory tests in standard solutions showed that DGT can be used below the previously reported pH working range for Al (no corrections needed down to pH 3.0). For Mn measurements, it was found necessary to apply a simple linear correction with respect to pH below pH 4.0.

Taking this correction into account and using the method in the field revealed that 84-100% of the dissolved Al and Mn in the runoff (pH 3.1- 4.2) was labile and potentially biologically available (Figure 2). Measurements of Al and Mn using DGT agreed fairly well with predictions of dissolved inorganic/'bioavailable' Al and Mn species using the speciation model WHAM VI (Figure 2). This demonstrates that DGT can be successfully applied for monitoring time-integrated labile metal concentrations at AMD sites.

Model predictions for the entire summer period revealed that the highest concentrations of dissolved inorganic/'bioavailable' metal species including 'free' metal ions were found in runoff during the initial two-week 'spring-flush'. This emphasizes that spring runoff is especially critical in terms of environmental impact. Later in the summer, both the concentrations of 'bioavailable' metals and 'free' metal ions decreased markedly. These results show that a change in deposition strategy aiming to reduce the winter production of pollutants, and/or a treatment/collection of spring runoff, is necessary to reduce the vegetation damage caused by coal mine waste rock piles situated in the Arctic.

Picture 3. Fieldwork during 2005 and 2006 included daily water sampling and in situ measurements of pH, electrical conductivity, dissolved oxygen, and redox potential.



Picture 4. (a) Labile and potentially 'bioavailable' Al and Mn concentrations in the drainage water were measured using the in situ speciation technique of diffusive gradients in thin films (DGT). (b) A DGT sampler hangs suspended from a rod in a small runoff stream. (c) Vegetation damage in the area down-stream from the waste pile (c) is presumably mainly due to high Al and Mn concentrations in the runoff as well as Fe(III) precipitates.

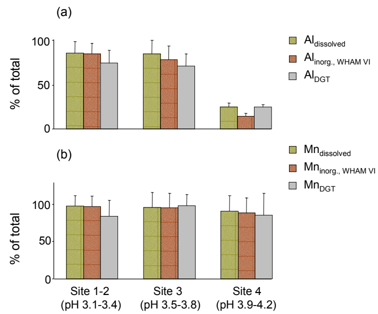


Figure 2. Speciation of Al (a) and Mn (b) in runoff from the coal mine waste rock pile as measured and modelled at four polluted study sites during July and August 2006. Bars represent mean values ± one std. deviation of: 1) dissolved concentrations; 2) concentrations of total inorganic species predicted using the WHAM VI speciation model; and 3) DGT-labile concentrations. All are expressed as a percentage of the total metal concentration (particulate bound + dissolved metal). N=12, 14, 12, and 10 at Site 1, 2, 3, and 4, respectively.

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