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The presence of mercury and other trace metals in surface soils in the Norwegian Arctic

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HIGHLIGHTS

- Levels of Hg and other trace elements in soil samples from Svalbard are presented.
- Hg is strongly enriched in the surface soils.
- Hg levels are similar in other Arctic regions.

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ABSTRACT

Svalbard is an important study area for investigating the long-range transport of mercury (Hg) and other trace elements to the Arctic. Few studies have focused on their concentrations in Arctic soils. With ongoing climate change leading to thawing permafrost ground the soil compartment is of increasing importance in the Arctic. In this study, elemental composition and soil organic matter (SOM) content of surface and mineral soils in Svalbard are presented. The aim is to provide new data on soils in the Arctic and to gain more knowledge about the role of the soil in the biogeochemical cycle of mercury (Hg). Concentrations are reported for Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, S and Zn. Samples were taken in Adventdalen and in the area near Ny-Ålesund. We obtained a mean Hg concentration of 0.111 ± 0.036 μg/g in surface soils (range 0.041–0.254 μg/g). Hg levels in mineral soils (mean: 0.025 ± 0.013 μg/g; range: 0.004–0.060 μg/g) were substantially lower than in the corresponding surface soils. Hg strongly accumulates in the surface soil layer (upper 3 cm) and is associated with SOM (surface soil: 59 ± 14%). Hg concentrations in the surface soil were slightly lower than those in the humus layer in mainland Norway and were comparable to levels in soils elsewhere in the Arctic. An inverse association of Hg was found with elements attributed to the mineral soil, indicating that Hg is predominantly derived from atmospheric deposition.

1. Introduction

The Arctic is a particularly vulnerable ecosystem and is affected by anthropogenic activities occurring in temperate and industrial areas. As a remote archipelago in the Arctic, Svalbard (74–81°N) is subjected to long-range transport of contaminants. Organic-rich surface soils can be used to identify this contribution (Steinnes and Friedland, 2006). Few local sources emit contaminants in Svalbard (*e.g.* coal mining, power plant, airport and local traffic). Trace elements emitted at lower latitudes can be transported over great distances as a result of volatility and persistence in the atmosphere. The main sources for heavy metal emissions are fossil fuel combustion, non-ferrous metal production, and waste incineration (AMAP, 2005). These can increase the amount of contaminants cycling in the environment that exceed natural levels. Natural emissions of heavy metals to the atmosphere derive from biogenic sources, volcanic emissions, soil-derived dusts, and sea salt aerosols. Emitted as particulates or in their gaseous form, the metals follow air trajectories and can subsequently be deposited in the Arctic. Cold, dense air and darkness in winter time lead to an accumulation and increased possibility of their deposition. The AMAP assessment from 2002 (AMAP, 2005) postulated that the anthropogenic emissions both in and outside the Arctic account for more than 50% of the observed heavy metal concentrations in the

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Arctic. Accumulation of metals in biota and subsequent enrichment in higher trophic levels may give rise to hazards and risks for animals and people inhabiting the Arctic and consuming wildlife there (AMAP, 1998).

This study focuses in particular on the heavy metal mercury (Hg) in the Arctic. It is known as a global pollutant originating from release from anthropogenic activities (Lantzy and Mackenzie, 1979) such as fossil fuel combustion, coal and gold mining, cement production, and waste incineration. These have led to elevated concentrations of Hg in the environment (AMAP, 2011; Mason et al., 1994). Hg in its elemental state is highly volatile and its atmospheric lifetime of 6–12 months enables long-range transport in the atmosphere (Lamborg et al., 2002; Selin et al., 2007; Slemr et al., 2011). Further transport is possible via ocean currents or rivers. Hg may be easily reemitted in its elemental form from oceans, snow, and tundra (AMAP, 2011). Hg is measured in the Arctic atmosphere, *e.g.* at Ny-Ålesund in Svalbard (Berg et al., 2013). Elevated concentrations of mobile Hg are followed by increased risk for bioaccumulation and biomagnification, especially when transformed into methylmercury (MeHg), which is highly toxic (AMAP, 2011). Elevated Hg concentrations at higher trophic levels are reported (*e.g.* in humans, polar bears and Arctic marine wildlife) (AMAP, 2011). The main pathways for the entry of Hg into terrestrial environments in the Arctic are through weathering of rocks and atmospheric deposition (Gamberg et al., 2015). During spring time, atmospheric Hg depletion events (AMDEs) occur in the Arctic and Hg is deposited by oxidizing Hg(0) to Hg(II), as first reported in 1998 by Schroeder et al. (1998). Photochemically initiated reactions and the involvement of halogens presumably delivered from sea ice (Steffen et al., 2008) lead to a rapid decrease in the atmospheric gaseous concentrations of elemental Hg and an increase in oxidized species causing deposition on snow, ice, or ocean surfaces. Once deposited in surface snow or ice, Hg can be partly reemitted or be further retained, transformed and transported into other environmental media. Further pathways in soil and in the terrestrial ecosystems are the subject of debate (Poissant et al., 2008). Snow, ice, and soils on land function as “key reservoirs” (Gamberg et al., 2015) when Hg is deposited from the atmosphere. The reservoirs then supply Hg via soil erosion or melting during the spring/summer thaw to freshwater and marine ecosystems (Gamberg et al., 2015). Accumulation in soil may also lead to a possible terrestrial exposure route for biota. Knowledge about the role of soil in the biogeochemical cycling of Hg is limited and only few studies on Hg concentrations in Arctic soils have been reported (AMAP, 2011, 2005; Bełdowski et al., 2015). Therefore, the aims of this study are 1) to provide new background data on the composition of soils in Svalbard, in particular for Hg, for comparison with existing data for soils in the Arctic and Norway, and 2) to reveal possible sources of Hg in order to explain the observed levels. To investigate associative effects of different heavy metals and constituents of soil, concentration data for the following elements are presented and discussed: aluminum (Al), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), Hg, manganese (Mn), nickel (Ni), lead (Pb), sulfur (S) and zinc (Zn).

2. Material and methods

2.1. Study area

Sampling was conducted in August 2014 and 2015 in Spitsbergen. Sampling sites were selected in Adventdalen and near Ny-Ålesund (Fig. 1). Spitsbergen is the largest island in the Svalbard archipelago. Svalbard is located in the High Arctic between 74 and 81 °N and 10 to 28 °E. In 2015 2667 inhabitants lived in Svalbard (ssb.no, 2015). Longyearbyen, located at Isfjorden, represents the largest settlement. The climate is influenced by the latitude and the North Atlantic current. The latter effect leads to generally higher temperatures than in the Russian or Canadian Arctic at similar latitudes. Average temperatures above zero can be observed from June through September (Svalbard.nordicvisitor.com). The annual mean temperature in 2015 was −2.2 °C (yr.no). The land surface in Svalbard features a continuous permafrost and thus is characterized by little vegetation, poorly developed soil, and no forests or agricultural areas. Soils in Svalbard are covered with bryophytes, lichens, grasses, and different sedges (Bekku et al., 2004; Major et al., 2001; Singh et al., 2013). Soil development is determined by freeze-thaw cycles (Nieder and Benbi, 2008). An active layer thickness of 1.6–2.0 m was observed near Ny-Ålesund in 2008 (Westermann et al., 2010) and of 1.0–1.6 m in Adventdalen and Janssondalen in 2000 (Brown et al., 2000; CALM-project). In the Soil Atlas of Circumpolar Regions (Jones et al., 2009) soils in Adventdalen are characterized as Leptic Cryosols (CRle). Bekku et al. (2004) characterized the soil near the Bayelva river as a Regosolic Cryosol.

The sampling area Adventdalen, classified as a periglacial landform, is a 40-km long valley on the west coast of Spitsbergen opening into Adventfjorden and later into Isfjorden. Longyearbyen, the largest settlement in Svalbard, is situated in Adventdalen. This includes an all-year operated airport, a small coal-fired power plant, and the operation of the coal mine Gruve 7. The Adventdalen Group is built of two clastic sediment sequences: the lower Janusfjellet subgroup and the upper Carolinefjellet formation. The latter is present in the sampling areas and is comprised of sandstone, siltstone, and shale. It ends in fluvial and glacifluvial deposits (Major et al., 2001). Soil development was observed to be more pronounced in Adventdalen compared to Ny-Ålesund. This goes along with a relatively mild climate in Adventdalen resulting in richer high Arctic tundra vegetation compared to other parts of Svalbard (Major et al., 2001). A total of 16 samples were taken in Adventdalen. Further samples were taken in the area surrounding Ny-Ålesund: the Bayelva catchment (n = 26), London (n = 10) and close to the glacier Bøtnbreen (n = 5). The settlement of Ny-Ålesund is located at Kongsfjorden about 110 km further north than Isfjorden. “In the Ny-Ålesund area metamorphic rocks of Caledonian Age are overlain by Late Palaeozoic to Tertiary sedimentary rocks.” (Haldorsen and Heim, 1999) Sampled soils were mainly developed on limestone and glauconitic sandstone.

2.2. Sample collection

Suitable sample locations were chosen based on the following four criteria: (i) remoteness from local anthropogenic pollution sources, (ii) not part of intertidal zone and at least 500 m away from the sea, (iii) full coverage of surface soil with vegetation, and (iv) state of soil layer development (organic-rich surface layer at least 3 cm thick and with a total depth of at least 20 cm). Soils were sampled at moss-covered hummocks developed on dry terrain, where the development of organic-rich surface soil was more complete than elsewhere in the sampling areas. All soil samples were taken by cutting squares with an area of approximately 18 × 18 cm and 5 cm thickness in the soil surface using a normal stainless steel breadknife. Surface soil samples were cut in half and stored in paper bags without removing the vegetation (mostly mosses). Mineral soil samples were taken separately with a small plastic shovel at a depth of ca. 20 cm where no influence of the vegetation was apparent and stored in polyethylene bags.