

## MERCURY CYCLING IN PERENNIALY FROZEN SOILS OF ARCTIC CANADA, KAMINAK LAKE AREA, NUNAVUT

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### **Abstract**

In the Kaminak Lake area, Hg is associated with local Zn-bearing massive sulphide accumulations and polymetallic veins that are distributed throughout the Kaminak greenstone belt. Glacial sediments (e.g. till) partly derived from these mineralization zones and from local bedrock lithologies form a discontinuous mantle overlying the bedrock surface. Repeated exposure of till to oxidation above the permafrost and recycling of organic matter by cryoturbation have resulted in the release of Hg from the sulphide-rich debris and its subsequent accumulation in the finest organic-rich clay fraction of till. The transportation of Hg bound to humic matter on land (in mineral and organic soils) through surface runoff, and possibly the long residence time of organic matter in soils of cold climates, may play important roles in the creation of bio-available Hg species (methylation) and ultimately concentration in the fish.

### **Introduction**

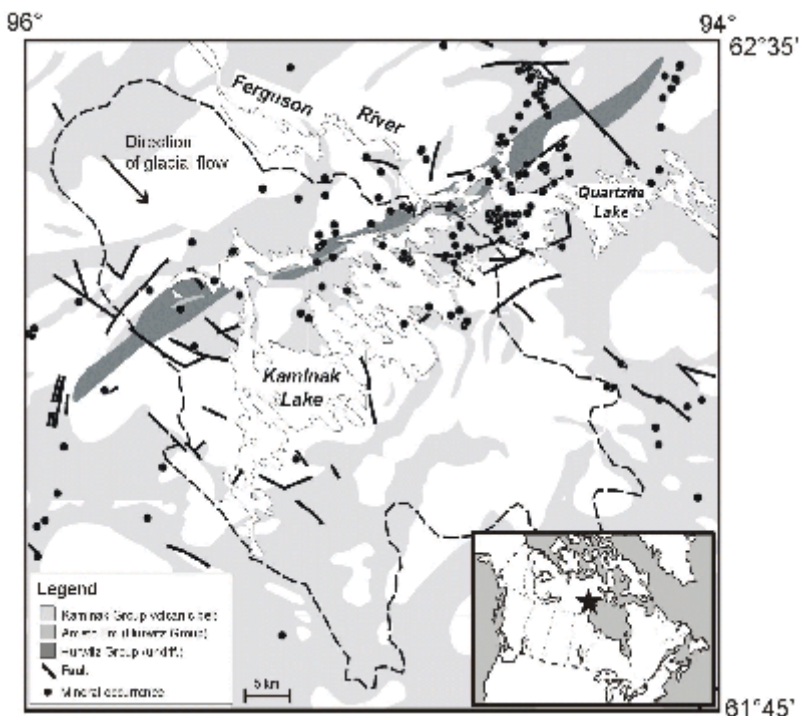
As part of the Metals In The Environment (MITE) Program initiated by the Geological Survey of Canada (GSC) in 1997, a project to study the cycling of Hg in soils underlain by permafrost was undertaken in the Kaminak Lake area. The area is located in the Kivalliq Region of Nunavut on the northwestern side of Hudson Bay (Fig. 1). The Kaminak Lake drainage basin is extensively covered by recent sediments deposited during the last glaciation from the northwest (McMartin and Henderson, 1999). In places, particularly in the northwestern part of the watershed, organic soils predominate. Kaminak Lake trout are known to contain high Hg levels, above the national consumption guideline of 0.5 ppm (Sherbin, 1979). Furthermore, analysis of lake water collected by the GSC in the region showed Hg concentrations above background in areas underlain by Archean greenstone belt rocks and/or the Proterozoic Hurwitz Group (Hornbrook and Jonasson, 1971). Variations in Hg concentrations were therefore assumed to reflect the presence of slates (Ameto Fm - Hurwitz Group) and/or country rocks and local sulphide mineralization in the Kaminak Group volcanic belt (Hornbrook and Jonasson, 1971; Shilts and Coker, 1995). The objectives of this project are to (1) determine the source(s) of Hg in the Kaminak Lake area and document Hg abundance in bedrock and sulphide mineralization, (2) evaluate the distribution of Hg in perennially frozen surficial sediments, (3) examine the residence sites of Hg in surficial sediments collected in the active layer and shallow permafrost, and (4) determine the factors which control the observed concentrations of Hg in sediments and the pathways through which Hg becomes bio-available.

### **Methodology**

Glacial sediments, e.g. till, were sampled in soil profiles in the active layer above the permafrost near mineralization and potential Hg-rich rocks. The thin, organic rich layer (humus) was also collected from the surface at each site. Till samples were air-dried and separated at <2 mm and <0.063 mm by dry sieving; the clay-sized fraction (<0.002 mm) was separated by centrifugation and decantation (Lindsay and Shilts, 1995). Humus samples were air-dried and sieved to <2 mm. All size fractions were analyzed for Hg by CV-AAS and for a suite of major and trace elements by ICP-AES, following an aqua regia

digestion. On selected samples, Hg was also determined directly by CV-AAS with a Milestone AMA-254 (Hall and Pelchat, 1997). Analysis of duplicate samples and laboratory standards was used to monitor analytical accuracy and precision. Organic matter content was determined by LECO, and by loss-on-ignition (LOI) at 550° C (Sheldrick, 1984); soil pH was determined in the laboratory (Knight et al., 2000). The mineralogy of the fine sand fraction of till (heavy and light minerals) was determined by visual examination under a binocular microscope; the clay fraction was analyzed by x-ray diffraction. The lithologies of the pebble fraction of till (2-4 mm) were visually determined (n=250 clasts/sample). Chemical partitioning studies of selected till and humus samples were completed to determine the Hg residence sites. A simplified scheme was developed to separate labile from non-labile phases (modified from Hall et al., 1996). Representative bedrock samples from the Kaminak and Hurwitz Groups and mineralized bedrock zones were also collected across the area (Goff and Kerswill, 1999). These samples were analyzed for Hg by CV-AAS (after aqua regia leach) and the ones that contained the most Hg were examined under the scanning electron microscope to determine Hg minerals.

Figure 1. Location map of study area showing major bedrock units, faults and mineral occurrences (modified from Tella et al., 1997). Kaminak Lake watershed is indicated by a dotted line.



## Results

### *Hg in bedrock*

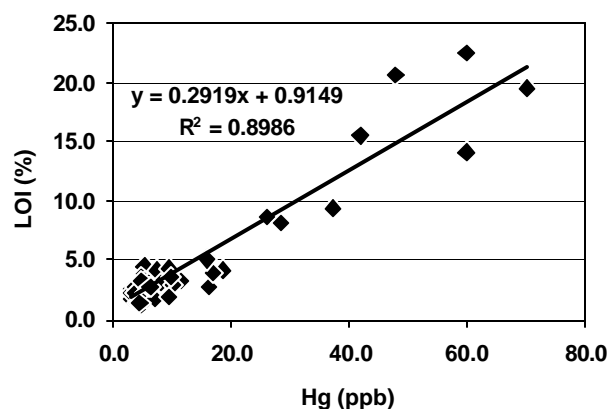
Several bedrock samples collected near and from mineralized zones within the Kaminak Group, specifically from Zn-bearing massive sulphide accumulations and polymetallic veins, are relatively high in Hg (up to 1280 ppb). On the other hand, none of the Hurwitz Group (including the slates from the Ameto Fm) and the Kaminak Group country rocks showed significant Hg concentrations (all <60 ppb). This suggests that local Hg sources likely reside in the mineral occurrences that are distributed throughout the Kaminak greenstone belt. Hg is presumably concentrated in sulphides like sphalerite, due to the geochemical affinity of Hg to Zn, and possibly galena, since these sulphides dominated the Hg-rich bedrock samples examined under the SEM. The low Hg values of the slates (<10 ppb), together with their low

organic contents (H. Sandeman, GSC, per. com.), indicate that the Ameto Fm does not represent a significant source of Hg for the area. On the other hand, additional local sources of Hg (gaseous Hg<sup>0</sup>) may exist along faults and unconformities in exposed outcrops or directly under Kaminak Lake.

### *Hg in soils*

Hg and other base metal concentrations are relatively low in all fractions of till in the Kaminak Lake area. The lithological analysis shows that far-traveled debris (50 km) comprise the bulk of the pebble fraction of till, which probably depresses the local geochemical signature in the fine fractions. The distal provenance of till is also reflected in the mineralogy of the heavy mineral fraction which is dominated by hematite and that of the clay fraction, dominated by quartz, feldspar, and hematite. Although occurring in relatively low levels, Hg in till is concentrated in the clay fraction and directly proportional to the content of organic matter (Fig. 2). The organic matter content varies considerably from site to site, and with depth in the active layer. Discrete organic rich layers can be found directly above the permafrost, reflecting the recycling of surface organic layers by cryoturbation. Most of the organic matter is fine grained, with contents reaching up to 25% LOI (7% organic C by LECO) in the clay fraction of till. In surface humus, organic contents average 78% LOI and Hg levels are up to 57x the concentrations in the <2 mm fraction of till (up to 330 ppb). Major elements and pH do not vary significantly with depth. On the other hand, trace metals such as Cu and Zn are slightly higher in humus than in till (up to 2x), and generally slightly increase down-profile. Similar to Hg, abrupt variations and increased concentrations are observed in organic rich layers.

Figure 2. Relationship between total Hg and total organic content (% LOI) in the clay fraction of till. Hg (ppb) was determined directly by CV-AAS with the Milestone AMA-254. A fitted linear regression and associated correlation coefficient are also shown.



### **Discussion**

Turbid cryosols present in the Kaminak Lake area are characterized by intense vertical mixing of material by frost heaving such that weathered bedrock, oxidized drift, and organic matter can be mixed together throughout the profile. Repeated exposure of till to oxidation at the surface causes most labile minerals such as sulphides to be destroyed in the active layer above the permafrost. Cryoturbation, on land and probably in the shallow areas of lakes underlain by permafrost, participates in the transfer of particulate and dissolved drift constituents to surface waters (Edwards et al., 1987). On the other hand, the cold temperatures likely restrain the degradation of organic matter in perennially frozen mineral soils. In the Kaminak Lake area, results show that organic matter plays a major role in the control of trace metal

concentrations in the near-surface environment. Hg released by the oxidation of sulphides, although in relatively low levels, is adsorbed or chelated with organic matter recycled in the active layer through frost-turbation and enters the lake through surface runoff. In addition, runoff from peatlands may also represent a significant source of Hg. These processes play important roles in bringing bio-available Hg species to the lake and concentration in the fish. Kaminak Lake is not the only lake where the fish contain high Hg concentrations in the Kivalliq Region. Nearby Maguse Lake has fish with up to 1.8 ppm of Hg; Ferguson Lake has fish with Hg values averaging greater than 1 ppm (Sherbin, 1979). All these lakes are underlain by mineralized greenstone belt rocks (Tella et al., 1997).

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