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GSC-MITE FINAL REVIEW OF ACTIVITIES

FEBRUARY 25th-26th, 2002

**NATURAL RESOURCES CANADA
CAMSELL HALL, 588 BOOTH ST., OTTAWA**

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Program, Day 1

Monday, February 25th

- 08:15 Coffee & Muffins
- 08:45 Welcome - Bob Garrett; Murray Duke & Irwin Itzkovitch
- 08:55 Introduction to Smelter-Centred Studies - Graeme Bonham-Carter
- 09:05 Geological framework of Rouyn-Noranda and surroundings - Jean Veillette
- 09:25 Factors affecting metal distribution and mobility in soils near the Horne smelter: A regional perspective - Penny Henderson
Geochemical presentation for map production - Ross Knight
- 10:05 Coffee
- 10:20 A high resolution historical perspective on environmental changes related to the Horne smelter - Martine Savard
- 11:00 The atmospheric transport of smelter emissions: Constraints from snow chemistry - Kevin Telmer
- 11:40 A study of airborne trace metals accumulated in the seasonal snowpack of Winter 2001 in the Rouyn-Noranda region, Québec - Deb Kliza
- 12:10 Lunch, available in the 588 Booth St. canteen
- 13:00 Distribution patterns of smelter-related elements in peat from the Rouyn-Noranda region, Québec - Inez Kettles
- 13:40 Spatial distribution of metals in lake sediments: The relationship between emissions and lake sediment concentrations - Kevin Telmer
- 14:20 Vertical metal distributions in lacustrine sediments: Preliminary results from a novel multidisciplinary perspective - Sam Alpay
- 15:00 Coffee
- 15:15 Distribution, transport and sources of metals in marine sediments near a coastal lead smelter in northern New Brunswick - Mike Parsons
- 15:55 Deposition of trace elements on surface soil around the Trail smelter, British Columbia: Application of the passive collection moss monitoring method - Hamed Sanei
- 16:25 An empirical model for atmospheric metal deposition round Rouyn-Noranda, based on snow and peat surveys - Graeme Bonham-Carter
- 17:05 Close

Program, Day 2

Tuesday, February 26th

- 08:15 Coffee & Muffins
- 08:45 Development of the history of atmospheric metals deposition from the Devon Ice Cap using a clean drill: Progress and future perspectives - Christian Zdanowicz
- 09:10 Optimization of sample collection, preparation, digestion and analytical procedures for environmental studies - Gwendy Hall
- 09:50 Coffee
- 10:05 Introduction to Natural Sources Studies - Rod Klassen
- 10:10 The effects of weathering and soil forming processes on geochemical background - Rod Klassen
- 10:50 Mercury, antimony, nickel and zinc in soils near two past producing mercury mines, British Columbia - Alain Plouffe
- 11:15 Mercury cycling in soils underlain by permafrost, Kaminak Lake, Nunavut: An overview and directions for future research - Isabelle McMartin
- 11:40 Mercury cycling in modern boreal podzols and in paleosols of Northern Québec - Michel Parent
- 12:10 Lunch, available in the 588 Booth St. canteen
- 13:10 Mercury cycling in Kejimikujik Park: lessons learned - Andy Rencz
- 13:50 Panel Discussion: Outstanding Knowledge Gaps & Role of GSC in future MITE Research - Murray Duke, Susan Till, Advisory Committee Members, Bob Garrett
- 14:50 Close - Susan Till, Murray Duke & Bob Garrett

BACKGROUND

The Geological Survey of Canada (GSC) established its Metals in the Environment (MITE) Initiative in 1997 in order to provide a focus for several activities already underway and as a response to requests for action from both inside and outside the Department on science issues related to Canadian Environmental Protection Act (CEPA) Priority Substance List (PSL) risk assessments, the Toxic Substances Management Policy, and Canada's position in international fora such as the United Nations Economic Commission for Europe (UN-ECE), Organization of Economic Cooperation and Development (OECD) and the North American Free Trade Area (NAFTA).

GSC-MITE was also a specific response by the Department to calls for action on science issues defined by the Mining Association of Canada (MAC) - Canadian Network of Toxicology Centres (CNTC) multi-disciplinary multi-stakeholder (industry, government and university) workshop on metals in the environment issues held at Val Morin, Québec, October, 1996.

The goal of GSC-MITE was defined:

To improve the understanding of the biogeochemical cycle of metals and ultimately to ensure that there is a sound geoscientific basis for policy and regulatory decisions which will affect the production and use of metals.

The Initiative was implemented with five year funding at a level of \$0.5M p.a. to March 2002. The MITE funds have been annually levered to \$1.75M to \$2M with contributions of salary, O&M and capital funds from participating GSC Divisions, and through awards on linked science projects from the federal government's Toxic Substances Research Initiative and the Industry-NSERC funded Metals in the Environment Research Network (MITE-RN).

The specific objectives established at the beginning of the Initiative were:

- the resolution of science issues related to sources, transport and fate of metals in the surficial environment,
- the estimation of metal flux rates from natural sources,
- the development of criteria to differentiate between metals from natural and anthropogenic sources,
- to assess the validity of historical records in natural materials, and
- to provide sound science advice for policy and regulatory development.

The Final Review of Activities presents the key results of the MITE research undertaken by GSC staff from 1997 to 2002. Abstracts of the presentations to be given follow; as does a list of GSC-MITE formal project/subproject titles, with the names and divisional affiliation of their leaders, and the periods over which they were funded. Finally, a preliminary cumulative listing of project/subproject publications is provided.

With the establishment of a new funding and approval model for research within the GSC, GSC-MITE as a discrete entity will cease after March, 2002. MITE-related science will become integrated with the broader goals and objectives of the science delivered by GSC staff, under such issues as "A Clean Environment for Canadians".

Communication of GSC-MITE results and publication activities will continue beyond March, 2002. A symposium, "Distribution of metals in the environment around smelters", showcasing GSC-MITE results is being held at the 2002 GAC/MAC annual meeting in Saskatoon, May 27th - 29th. The proceedings will be published in a special issue of *Geochemistry: Exploration, Environment, Analysis*, and final reports and accumulated data for the smelter-centred projects will be published as a GSC Bulletin (CD-ROM). Other reports will follow, focussing on natural source, and other MITE issues, and will be published in appropriate peer-reviewed science journals.

GSC-MITE will continue to meet its final objective (above) as the knowledge gained is applied in future risk assessments concerning metals in the environment, and most importantly subsequent risk management decisions. The knowledge accrued in MITE science activities contributes to Sustainable Development decision making by providing sound science for the development of effective regulations which protect the environment but do not inhibit economic development.

ABSTRACTS OF PRESENTATIONS

AT THE

GSC-MITE FINAL REVIEW

February 25th and 26th, 2002

Bedrock and Surficial Geology of the Central Part of the Greenstone Belt, Québec and Ontario.

Veillette, J.

Rouyn-Noranda is located in the central part of the Abitibi Subprovince which contains the largest granite-greenstone terrane in the world. It extends from the vicinity of Timmins, Ontario to the Chibougamau area in Quebec, and consists primarily of Archean sedimentary and volcanic sequences intruded by granitoids, and showing the east-west structural orientation typical of Superior Province. The geology discussed here lies within a radius of about 100 km from Rouyn-Noranda. Within this area, most lithological units are Archean in age but clastic Proterozoic rocks and Paleozoic carbonates are also present southwest of Rouyn-Noranda. About 70% of Canadian gold mines are located in the southern part of the Abitibi Subprovince. Since the early 1900s more than 145 mines have produced precious and base metals, many of these located along the Cadillac/Larder Lake and the Porcupine/Destor major fault systems. Thick glacial, glaciofluvial, and glaciolacustrine deposits from glacial lake Barlow-Ojibway, cover a large part of the Precambrian substrate. Natural exposures in Quaternary sediments show only one full glacial cycle, from base to top: till, glaciofluvial, fine-grained glaciolacustrine, and postglacial organic and eolian sediments. Boreholes drilled down to bedrock reveal in some locations, however, a much older and more complex stratigraphy which includes organics of probable interglacial age. The ice-flow sequences reconstructed through the systematic mapping of glacial striations and cross-striations on bedrock and glacial transport studies reflect this complexity. They reveal an earlier ice flow toward the northwest followed by a gradual counterclockwise shift toward the southwest and ending with convergent flows toward a major interlobate deglaciation landform, the Harricana Moraine, roughly oriented north-south across the region. This recent knowledge has proved beneficial to mineral exploration methods applicable in glaciated terrain. Glacial transport of materials from distant source areas is of special significance for the geochemical study of surficial deposits and lake bottom sediments in Abitibi-Timiskaming. The fine fraction of till, to a lesser extent, and glaciolacustrine silt and clay in the western part of the region, contain calcareous rock flour "imported" from the carbonate rocks of the Hudson Platform 200 km to the northwest, while these deposits are devoid of carbonate in the eastern part of the region. This difference of provenance in sediments of similar grain-size and origin is explained by the ice flow history of the region.

Factors Affecting Metal Distribution and Mobility in Soils near the Horne Smelter: a Regional Perspective

Henderson, P.J., Knight, R.D. and McMartin, I.

Soil sampling was undertaken near the Horne smelter at Rouyn-Noranda, Quebec, as part of the Geological Survey of Canada MITE initiative. The soil study was aimed at examining variations in trace metal concentrations in glacially-derived sediments, developing criteria for differentiating anthropogenic from geogenic metal enrichment, and determining the fate of smelter-derived metals in the environment.

Humus, B- horizon (10-15 cm depth) and C- horizon (80-90 cm depth) soil samples were collected at 106 sites within 100 km radius of the smelter. The <2mm sized fraction of both humus and mineral soil samples was analyzed geochemically using inductively coupled plasma atomic emission spectrometry after nitric-aqua regia digestion. In addition, humus samples were subjected to a sequential extraction scheme designed to nominally separate the following phases: (1) soluble organics, (2) amorphous and crystalline Fe oxides, (3) sulphides and insoluble organics, and (4) silicate and other resistant minerals. Mineral soils were analyzed using leaches selective for separation of amorphous Fe oxide phases and residual (silicate) mineral phases. Organic matter content and soil pH was measured.

Results indicate that smelter-derived metals (eg. Ag, As, Cd, Cu, Pb, Zn) are enriched in humus near the smelter and decrease in concentration with distance, depending on the element and dominant wind direction. The estimated metal load in humus, using a 3-parameter nonlinear radial decay model and fewer smelter-related elements, is $Pb > Cu = Zn > As$, while reported smelter emissions are in the order $Pb = Zn > As > Cu$. The discrepancy, particularly for Cu, suggests that metals behave differently in organic soils.

Sequential analytical results indicate that residence sites of metals in humus vary depending on the metal. For the smelter-derived metals Cd, Pb and Zn, >50% of the total metal is held in the labile, soluble organic phase, for Cu and As, ~25% is held in labile phases. Factors affecting metal mobility in humus include total concentration, soil pH, and the underlying parent material.

Metal concentrations in mineral soils vary depending on the soil horizon, effectiveness of downward leaching from contaminated humus, bedrock geology and parent material. Factors affecting metal mobility include the total concentration and mobility of the element in the overlying organic horizon, and the composition and texture of the parent material, which affects permeability and pH.

**Grid Interpolation and Modeling Techniques used in the Presentation of Geochemical Data
for Soils within a 100 km radius of the Horne Smelter, Rouyn-Noranda, Quebec:
The Progression from 1998 to 2001.**

Knight, R.D. and Henderson, P.J

The application of various grid interpolation and modeling techniques used in the presentation of geochemical data can affect the outcome of the map and influence the viewer's impression of the data. The evolution of our data presentation technique has been influenced by both technical and scientific elements, and has progressed from the basic proportional dot maps presented in 1998 to the final release geochemical maps depicting surfaces and point data. This progression included consideration of surfaces generated by kriging, natural neighbour, triangulation, rectangulation and, inverse distance weighting. Variations in colour representing background values are compared for two elements. Point data plots have also changed throughout the duration of the project and include a progression from proportional dot maps for all data to point maps incorporating a parent material classification with the geochemical data symbol.

A High Resolution Historical Perspective on Environmental Changes Related to the Horne Smelter

Savard, M.M., Bégin, C., Parent, M., Marion, J., Smirnov, A., Hou, X. and Sharp, Z.

The Questions: Can we distinguish between anthropogenic and geogenic sources of metals in surficial accumulations of mining districts? Can we monitor environmental changes induced by natural processes and anthropogenic activities?

Scientific approach: We have combined analyses of pedogeochemistry and dendrogeochemistry at selected sites, with emphasis on tree-ring standard parameter index, metal concentrations and isotope ratios of single-ring suites of long-lived trees near a smelter. The premiss of the research program was that, in addition to the usual climatic fluctuations, tree ring characteristics would also record pedogeochemical and atmospheric changes induced by smelter emissions.

Objectives: (1) Evaluate dendrogeochemistry as a monitoring tool for environmental changes near a point source; (2) Distinguish natural and anthropogenic accumulations of metals in the environment using tree rings of pre-smelter and of uncontaminated series, and pedogeochemical profiles; and (3) Provide, if possible, a historical perspective on environmental changes near the Horne smelter.

Results: During the 5 years of the project, we have: selected 7 sites along a SW-NE transect crossing Rouyn-Noranda; characterized 8 soil profiles with HCl, M-III and total extractions, analyzed 240 soil extracts with ICP-MS/AES, characterized 135 spruce trees for dendrochronology, selected 21 trees for dendrogeochemistry; mechanically separated 1582 ring pairs; performed 1580 elemental analyses of ring wood with ICP-MS/AES; produced 1126 isotopic Pb analyses; separated chemically 1317 cellulose samples from ring pairs; nitrated 817 cellulose samples; analyzed 1317 $\delta^{13}\text{C}$ values on cellulose using an Elemental Analyser (EA) in Continuous Flow (CF) with an IRMS; performed 817 $\delta^2\text{H}$ analyses with a Thermal Conversion (TC)/EA in CF with a IRMS.

Soils: At all sites, the geochemical soil profiles using the 3 types of extracts show a systematic decrease of concentrations and of $^{206}\text{Pb}/^{207}\text{Pb}$ isotopic ratios with depth. As seen in the [Me] and Pb isotope ratios, the point source metal contribution decreases with distance from the smelter.

Tree rings, natural sources: $\delta^2\text{H}$ first order trends vary inversely with the one in $\delta^{13}\text{C}$ values of ring pairs. Trees promptly respond to atmospheric point source pollution (SO_2) by reducing their stomatal aperture. Here again, anthropogenic effects diminish with distance from the smelter.

Tree rings, anthropogenic sources: [Me] and Pb isotope ratios reveal that there is a delay of about 18 years after the onset of smelter operations before trees record a significant increase in the rate of Me assimilation and the input of point source Pb. As expected, the amplitude of the increase as well as the proportion of point source Pb diminish with distance from the Horne smelter.

Main conclusions: (1) Dendrogeochemistry is a practical, informative and highly efficient approach to monitor geochemical changes in the environment. (2) The geochemical temporal series in tree rings combined with the Pb isotopic soil profiles clearly distinguish geogenic metals from these emitted by the smelter. (3) The methodology produced during DINAMITE constitutes a solid basis for the scientific approaches to be developed for the investigation of climatic changes and diffuse pollution.

The Atmospheric Transport of Metal Emissions: Constraints from Snow Geochemistry

Telmer, K.

Abundances of 57 elements and ions, including base and transition metals, REEs, major lithophile elements, and anions, were determined in samples of snowpack obtained along three 50 km radial transects emanating from the Horne base metal smelter in Rouyn-Noranda, Quebec, to constrain (1) what is emitted; (2) what chemical form the emissions take; (3) how far are emissions transported; and (4) what processes control their deposition. Using a method that can reproducibly detect between site differences in the chemical burden greater than 20%, it is shown that the deposition of emitted elements forms a bulls-eye around the smelter that rapidly decays with distance to near background levels at a distance of 40 to 50 km. The solubility of elements in meltwaters varies with distance from the smelter and is likely due to mineralogy. Metals and trace elements occur dominantly in the particulate phase and their solubility is unpredictable to quasi-predictable depending on the element. The effect of local geology on the chemical burden is detectable, but secondary to smelter emissions for trace elements. A gradient in enrichments, relative to upper crustal abundances, from proximal through to distal sites forms a binary mix with end members comprised of smelter emissions and regional background. This is used to determine that at least 30 elements are emitted by the smelter and that deposition is still roughly double the regional background levels at a distance of 50 km. The pattern of element deposition within the bulls-eye indicates that deposition inside 15 km radius occurs by wet+dry deposition, and outside 15 km by wet deposition only. This explains why a well fitting mathematical model can account for only ~50% of reported metal emissions within 50 km of the smelter. The remaining emissions are available for long range transport during dry weather and likely have an atmospheric residence time similar to that of water vapour.

Airborne Trace Metals in the Seasonal Snowpack of Rouyn-Noranda Region, Quebec, Winter 2001

**Kliza, D., Bonham-Carter, G.F., Zdanowicz, C., Hall, G.E.M., Vaive, J.E., Paktunc, D.
and Smith, D.**

During a second winter survey, snow was sampled in February 2001, 99 days after the onset of snow accumulation. Samples were collected from 57 sites at distances of 2 to 277 km from the smelter, primarily downwind. The soluble ($< 0.1\mu\text{m}$) and particulate ($> 0.1\mu\text{m}$) phases were separated and analyzed separately for total major and trace elements, including Pb, Cu, Zn, As and Cd. Results for all elements, after standardizing to an annual basis, are reported in ng per cm^2 per year.

Duplicate samples were collected at 26 sites to determine the size distribution and chemical composition of metal-bearing particles deposited in the snowpack. One thousand particles were analysed in each of these samples using an automated Variable Pressure Scanning Electron Microscope (VP-SEM) equipped with an Energy Dispersive X-Ray analyser (EDX). For each particle, the surface area was measured and X-ray counts were collected for 19 elements: Na, Mg, Al, Si, P, S, Pb, Cl, K, Ca, V, Cr, Fe, Ni, Cu, Zn, As, Se and Cd.

Plots of metal deposition rate versus distance from the smelter compare closely between 1998 and 2001, particularly for Cu. By fitting an empirical model to the 2001 metal concentration data versus distance from the smelter, estimates of ambient background deposition rate were made as follows: Cu ($44\text{ ng/cm}^2/\text{yr}$), Zn ($105\text{ ng/cm}^2/\text{yr}$) As ($12\text{ ng/cm}^2/\text{yr}$) and Pb ($30\text{ ng/cm}^2/\text{yr}$). The 2001 estimates are lower and better constrained than the 1998 estimates, because some samples were taken between 100-250 km from the smelter, whereas the 1998 data were restricted to 50 km. In both years, the model levels reached values within the standard error of background at less than 60 km from the smelter. The values are consistent with results reported from other snow studies in Canada, and from peat data (see Kettles, this session).

The particles range in size (area) from $0.3\mu\text{m}^2$ (SEM detection limit) to $1409\mu\text{m}^2$. The mode of the size distribution shows little variation between sample sites, and averages $2.9\mu\text{m}^2$ ($\pm 2.8\mu\text{m}^2$). There is no obvious relationship between maximum particle size and distance from smelter. In terms of elemental composition, particles fall into two broad categories: (1) those consisting primarily of common rock-forming elements such as Al, Si, Fe, Ca, K and Mg; and (2) those consisting primarily of metallic elements (typically Zn, Cu, Pb, and/or Cr with S) which are most likely smelter-derived. In all snow samples, the most abundant particles (75 to 85 %) are Al+Si. The most abundant metal-bearing particles are Fe+Cu+S (0.5 %), Fe+S (0.3 %), and Zn+S (0.2 %), but many other associations occur that include V, Se, As and Ni.

Distribution Patterns of Smelter-Related Metals in Peat from the Rouyn-Noranda region, Quebec

Kettles, I.M.

A peatland study was undertaken to investigate the value of peat as an historical record of smelter metal emissions. Profile samples were collected from peat hummocks and hollows from 37 peatlands located within a 100-km radius of the Horne copper smelter. Splits of 630 samples were digested with nitric-perchloric acid for a "near total" extraction prior to ICP-AES analysis for smelter-related (Cu, Pb, Zn, As) and other elements. Second splits from 24 samples from 5 sites (7, 10, 12, 15 and 25 km from the smelter) were subjected to a 4-step sequential extraction analysis to identify the main metal residence sites. The labile phases were selected with (1) sodium acetate (adsorbed and exchangeable metals, carbonates, etc) and (2) sodium pyrophosphate (soluble organics), and the non-labile phases with (3) aqua regia (near- total) and a multi-acid leach (total).

Peat in the hummocks is poorly decomposed and has low bulk density (around 0.01 g cm^{-3}) whereas peat from the hollow surface is more decomposed and has a bulk density commonly 2 or more times higher. Within each hummock, concentration levels of smelter-related elements were relatively low in the uppermost 20 cm and increased markedly between depths of 20 and 45 cm. In the tallest hummocks, metal concentrations decreased again below 50 cm from surface, reaching values less than those near the surface by depths of 60 to 75 cm. Profiles generated for multiple separate hummocks at the same site indicate a small amount of observable intra-site variation, with Cu having the least and Zn the greatest. Unlike the hummocks, smelter-related metals are consistently high in the uppermost 20 cm of the peat hollow but below 20 cm they are near background. Profiles show the diminishing effect of smelter emissions with increasing distance from the smelter. For example, Cu values in some samples below 20 cm in the hummocks are over 400 ppm at 7 km, but are at most 24 ppm at 63 km. When data for hummock surface growth are plotted, smelter-related metal levels decrease systematically with increasing distance from the smelter and spatially have a circular pattern, centred on the smelter but skewed to the predominant wind direction.

Results of selective phase leaching of peat from the 10 km and more distant hummocks show that about 75% of the Pb and Zn in the peat hummocks is labile compared to 25% of the Cu. Within the labile component, three-quarters of the Zn is in the easily-extractable fraction compared to half to two-thirds of the Pb. Metal distribution patterns change closer to the smelter in the 7 km hummock. Here there are larger amounts of metals in the easily-extractable fraction, with the relative proportions of Pb and Zn increasing by about 20 to 40 % and Cu by 2 to more than 10-fold.

This study shows that there are consistent patterns of smelter-related element variation in peat with increasing distance from the smelter. The hummock sequence can be divided into small enough vertical sample segments to see, within the resulting geochemical profile, small-scale variations in peat composition. Knowledge of the relative proportions of metals in the labile and non-labile phases provides further insight into interpreting the patterns of metal distribution within peat deposits.

**Spatial Distributions of Metals in lake Sediments:
The Relationship between Emissions and Lake Sediment Concentrations**

Telmer, K.

Abstract not Provided by Author

Vertical Metal Distributions in Lacustrine Sediments: Preliminary Results from a Novel Multidisciplinary Perspective

Alpay, S.

Metals are commonly more concentrated near the sediment-water interface than in deeper lake sediments. These observations are widely reported and have been attributed to increased anthropogenic deposition and/or to vertical diagenetic remobilization. The Geological Survey of Canada - Metals in the Environment Initiative (GSC-MITE) has established a second phase of lake sediment studies in the Rouyn-Noranda region to explore the relative effects of chronological metal loading and diagenetic metal remobilization in lake sediment profiles. A multidisciplinary research team has been formed to integrate evidence from biological indicators, quantitative mineralogy, geochemistry, microbial populations, and numerical approaches to understanding the processes of early diagenesis in freshwater systems. The aims of this study are to:

- 1) combine traditional and advanced analytical techniques to identify the diagenetic processes that distribute or redistribute metals in lake sediments,
- 2) characterize the pre-industrial lake sediment record as well as lake response to mining and smelting operations, and
- 3) evaluate the effects of 1) and 2) in lakes with similar metal loading but in different geochemical settings.

Two kettle lakes, Lac Perron and Lac de la Pépinière, were selected from within the zone of influence of the Horne smelter in Rouyn-Noranda (Quebec) from 100 lakes studied in a reconnaissance survey (Phase I of the GSC-MITE lake sediment studies; Kliza and Telmer, 2001).

Preliminary data suggest that vertical metal mobility within the sediment column is probable, a historical record of sulphate loading from smelter emissions has been preserved, and the two lakes are geochemically distinct in their histories of increased acidification. These three conditions indicate that the two sites are suitable to address the original aims of this study. This presentation will highlight emerging results from diatom analysis, microbial enumerations, isotopic determinations, quantitative mineralogy, sediment and aqueous geochemistry.

As results continue to be generated and interpreted, an increased understanding of metal cycling and diagenetic metal remobilization in lake sediments is developing. Furthermore, new quantitative information that results from the multidisciplinary approach taken will enable development of more realistic geochemical reaction-transport models that can be used in government and industry in selecting appropriate risk management strategies to minimize deleterious ecosystem effects.

Reference:

Kliza, D. and Telmer, K., 2001. Phase I. Lake sediment studies in the vicinity of the Horne smelter in Rouyn-Noranda, Quebec. Geological Survey of Canada Open File D2952, CD-ROM

Distribution, Transport and Sources of Metals in Marine Sediments near a Coastal Lead Smelter in Northern New Brunswick

Parsons, M.B. and Cranston, R.E.

Significant variations in As, Cd, Cu, Hg, Pb and Zn concentrations occur in marine sediments from the Bay of Chaleur, an estuary located between northern New Brunswick and Québec's Gaspé Peninsula. The bay receives metals from a variety of sources including a lead smelter, two thermal generating stations, a mercury-cell chlor-alkali plant, and numerous mined and unmined base-metal deposits. The purpose of this study is to assess the fluxes and dispersal patterns of metals and metalloids released to the bay from both natural and anthropogenic sources, and to characterize the processes that collect and redistribute these elements.

Gravity cores and grab samples of marine sediments were collected from 130 sites in the Bay of Chaleur, in water depths of 2 to 95 m and at distances up to 100 km away from the smelter. The sediments were subsampled within 24 hours of collection for analyses of metal concentrations, lead isotope ratios, carbon contents, and grain size. Sediment pore waters were extracted from the cores using centrifugation and analyzed in the field for dissolved ammonium, sulfate, and salinity. These pore water data were used to estimate present-day sediment accumulation rates.

Chemical analyses of 925 sediment subsamples show the following ranges in metal and metalloid concentrations (mg/kg): As, 3–74; Cd, 0.02–69; Cu, 3–200; Hg, <0.01–2.4; Ni, 8–68; Pb, 0.3–2040; and Zn, 22–3200. The highest concentrations of these elements occur in surficial sediments within 5 to 10 km of the smelter. Metal concentrations in harbour sediments adjacent to the smelter are highest at approximately 5 cm depth and decrease progressively towards the sediment surface, which may reflect the significant reduction in smelter emissions since the mid-1970s. Anomalously high concentrations of Hg and Cd, Cu, Pb and Zn also occur within 1 km of the chlor-alkali plant and a decommissioned Cu-Zn concentrate loading facility, respectively. Analyses of ammonium and sulfate gradients in the sediment pore waters, vertical profiles of Fe, Mn and organic carbon in the solid phase, and grain size variations indicate that the metal profiles in most cores are not caused by sampling artifacts or diagenetic remobilization. Lead isotope ratios show that Pb in the contaminated surface sediments is less radiogenic than the natural background Pb. Comparison of Pb isotope ratios in the sediments with published isotopic data for geogenic and anthropogenic sources suggests that the surface enrichment of Pb throughout most of the bay is mainly derived from historical combustion of Canadian leaded gasoline and smelter emissions.

This study indicates that the flux of metals to most areas of the Bay of Chaleur has increased in recent years relative to pre-industrial times. This is especially true for Pb, which is present in surface sediments throughout the entire bay at concentrations that are at least three to four times background values (0.3–6 mg/kg). Dispersion of smelter effluents and emissions by wind and/or near-shore currents has resulted in an area of elevated As, Cd, Cu, Hg, Pb and Zn concentrations in surficial marine sediments within approximately 20 km of the Brunswick smelter.

Deposition of Trace Elements on Surface Soil around the Trail Smelter, British Columbia: Application of the Passive Moss Monitoring Method

Goodarzi, F., Sanei, H., Garrett, R.G. and Duncan, W.F.

The aerial deposition and accumulation of the elements As, Cd, Cu, Hg, Pb, and Zn on the surface soil was assessed using the passive collection moss-monitoring method in the area surrounding the Trail smelter, British Columbia, Canada. The monitoring of the deposition was performed by placing twenty-two flat moss-bags in the study area and allowing them to be exposed to the aerial deposition for 3-month periods over the two-year study (1998-2000). The main goal of this research was to determine the cumulative deposition of the "settleable" portion of elements on land, the extent of influence from the point source, and to study the seasonal variations in the pattern of elemental deposition in the Trail smelter's surrounding area.

After a two-year period of study, the results show that the deposition of these elements is greatest in proximity to the smelter and decreases with an increase in distance. The pattern of deposition generally varies seasonally, with the magnitude of variation being dependent on the element under study and the location of the monitoring station. Overall, the deposition of the studied elements (as registered by moss-monitoring stations) appears to be a complex phenomenon involving various factors such as meteorological conditions (prevailing wind direction and precipitation), physiography (topography, valley shape and orientation) and in-process activities at the smelter (production level, emission control efficiency, and the geochemistry of feed). Although, it appears that, on an annual basis, in-process activities particularly production levels of lead and zinc, and the quantity of emissions from the stack, are more directly related to the observed aerial deposition of elements than any of the other factors.

Estimation of the relative contribution of stack-emitted material versus material originating from the secondary sources (e.g. wind blown fugitive dust from storage piles and uncovered transportation of ore/slag, and historical dust) indicates that the secondary sources are the major contributor of lead and zinc deposited within a short distance from the smelter. Gradually, the stack emissions become the main source of Pb and Zn at greater distances from the smelter. The typical material originating from each source as characterized by SEM/EDX indicates a marked difference in their morphology and chemical composition.

The flux of elements into an unit area and the subsequent enrichment of elements in surface soil after exposure to the atmospheric deposition was also calculated by extrapolating the concentration data obtained from the known dimensions of the flat-square moss bags to the measured elemental quantities of the surface soil. The results can be used to predict the long-term degree of trace elements accumulation in the soil assuming that the deposition rate persists over times and that all the elements accumulate on the soil surface with no post-depositional remobilization of elements.

An Empirical Model for Atmospheric Metal Deposition round Rouyn-Noranda, based on Snow and Peat Surveys

Bonham-Carter, G.F., Kliza, D., Kettles, I.M. and Daneshfar, B.

The distance at which the deposition of metals of smelter origin are indistinguishable from ambient background levels, as determined from ombotrophic peat and snow surveys are: Cu - 50 to 60 km; Pb - 56 to 66 km; Zn - 38 to 39 km. This is one measure of the distance at which the influence of the smelter can be determined on the ground from single-element geochemical data. Some indication of smelter materials can be detected at distances out to about 130 km by multivariate analysis.

The amount of metal in excess of the ambient background determined by integrating the concentration-distance model over radial area is compared with reported emissions from the Horne smelter. This smelter 'loading' as estimated from snow and peat is then compared to actual emissions reported for the Horne smelter. The range of estimated proportions of total emissions deposited within 150 km of the smelter are: Cu- 14 to 73%, Pb- 10 to 32%, and Zn- 52 to 65%, depending on the year and sampling medium. Even though these estimates are associated with various assumptions and sources of error, they give an approximate measure of how much smelter-emitted metal is transported beyond 150 km, and provide 'ground-truth' for comparison with numerical atmospheric transport modelling to be carried out by Environment Canada.

Principal components analysis of snow and peat data illustrates that the atmospheric deposition of metals can be considered in terms of two end-members: PC-1 is a metal-rich 'smelter' end-member dominated by Cu, As, Zn, Pb and PC-2 is a 'natural background' end-member comprising rock-forming elements such as Al, Mn, Mg, Fe. Sulphur does not fall on this mixing curve, and appears to behave independently.

The snow data contain information of potential value for determining the biological availability of smelter metals. In both sampling years, the snow was thawed and filtered in the laboratory (0.1 μm for 2001, 0.45 μm for 1998), with the subsequent independent analysis of the 'soluble' and 'particulate' fractions. The median (particulate/total) ratio for metals for the 2 years are: Cu- 0.32 to 0.30; Pb- 0.28 to 0.26; Zn- 0.30 to 0.28; As- 0.23 to 0.33; Cd- 0.18 to 0.06; Sb- 0.62 to 0.62; Ag to 0.74, 0.69. Therefore about 60% of the deposited metals Cu, Pb, Zn and As are readily available as soon as the snow melts (or rain falls), 40% of Sb, 30% of Ag and about 10% of Cd. Although the 'soluble' fraction is in a readily available state, some of the 'particulate' fraction may also be readily available, depending on other factors—therefore these values should be considered conservative.

The Effects of Weathering and Soil Forming Processes on Geochemical Background

Klassen, R.A.

To establish trace metal associations and residence sites in terms of mineralogy and weathering, mineralogical and geochemical soil profiles in different geological terrains were characterized. Analytical approaches on sand-silt-clay-sized ($< 2\text{mm}$), silt and clay-sized ($< 0.063\text{mm}$), and clay-sized ($< 0.002\text{mm}$) fractions were varied, including microbeam techniques, and geochemical analysis using wet chemical (hydrofluoric-nitric-perchloric, aqua regia, and hydroxylamine hydrochloride acid digestions), and Instrumental Neutron Activation analysis. Soil parent materials are derived from sulphide-bearing marble, black shale, and ultramafic igneous rock, and are enriched in one or more of the trace elements, As, Zn, Hg, Ni, Cr.

A new approach to mineralogical analyses of fine sand and silt-sized minerals was developed based on Scanning Electron Microscopy (SEM) linked to an Energy-Dispersive X-ray Spectrometer with mapping capabilities (SEM-EDS). In addition to mineralogy, diverse physical and chemical properties of mineral grains can be analyzed, including size, shape and coatings, etc., that demonstrate weathering changes in profiles.

In soil profiles, trace element concentrations vary systematically with depth, with the greatest rate of change in the uppermost 50 cm of the solum (A and B soil horizons). Four geochemical profile types reflect the dominant weathering processes leading to differences among A and B, and C soil horizons. Mineral weathering and leaching is associated with trace elements that increase downward to maximum values in the C soil horizon. For Cu, Ni, Pb, and Cr, strong linear relations with lithophile elements (Al, K, Mg) indicate that they are held in Mg-bearing phyllosilicates, and the weathering of those minerals controls the transformation of metal to more labile and bioavailable forms. The identification of an important mineralogical control for trace element geochemistry provides a tool for the interpretation of natural geochemical background variations and assessing environmental risk. Elements whose concentrations decrease downward in the upper solum (e.g., Zn, and possibly Hg) are more controlled by organic matter than by inorganic minerals.

Empirical respiration studies show that soil geochemistry affects biological activity, with significant differences among horizons, with Mn and Ni affecting the transformation of nitrogen compounds in Ni-Cr-rich soils of the eastern Townships. The work has significant implication for chemical and biological transformations in soils influenced by agricultural and forestry practices.

A new approach to characterizing metal speciation using the competing ligand exchange method was examined. Differences in the temporal release of trace elements indicate the method can distinguish kinetically different species of Ni and Cu, and potential differences among soil horizons. Although the approach holds promise for environmental studies, its application to soils has proven premature. Electrothermal vapourization can characterize Hg forms and complexes soils, showing differences among soil horizons.

Mercury, Antimony, Nickel, and Zinc in Soils near two Past-Producing Mercury Mines, British Columbia

Plouffe, A., Hall, G.E.M., and Pelchat, P.

The Pinchi fault region, located in central British Columbia, is naturally enriched in mercury because of the abundance of cinnabar (HgS) mineralization in bedrock. Two mercury mines were active in the region: Bralorne Takla and Pinchi Lake mines. Between 40 and 249 tonnes of Hg were emitted from the Pinchi Lake mine during the operation periods which extended from 1940 to 1944 and from 1968 to 1975. Emission data are not available for the Bralorne Takla mine which was only active from 1943 to 1944.

The aim of this study is to identify the source of mercury in soils, i.e. to determine if the observed high mercury levels are related to natural processes (e.g. metal cycling in soil, glacial dispersal from the mineralized bedrock) or to anthropogenic activities (mining).

Humus, B-horizon and C-horizon soil samples were collected along sampling transects which start in the vicinity of both mines and extend up to 85 km from the mines, into regions with naturally elevated mercury concentrations. The <2mm size fraction of all samples was analyzed by a combination of ICP-AES and ICP-MS following two leaches applied in sequence and designed to estimate the metal concentrations held in labile and non-labile phases of humus and sediments. The clay-sized fraction (<0.002 mm) of the C-horizon samples was analyzed by ICP-AES.

Mercury concentrations are highest in humus in both labile and non-labile phases near Pinchi Lake and Bralorne Takla mines and rapidly decrease with increasing distance from the mines. Such enrichment in humus is not observed in regions distant from the mines where the mercury concentrations are naturally elevated in the underlying soil parent material. Consequently, the mercury enrichment in humus near both mines is thought to be in part due to anthropogenic contamination. On average, 95% of the mercury in humus is held in a non-labile phase which is dominantly HgS dust (cinnabar ?) as identified with a variable pressure scanning electron microscope. The remainder of the mercury is likely loosely bound to organic matter. Elevated mercury concentrations in the B- and C-horizons (80% in non-labile phases on average) are related to the presence of cinnabar derived from bedrock.

Antimony is found in association with the mercury mineralization in bedrock at Pinchi Lake mine. Consequently, antimony might have been emitted during the mining operations. There is an antimony enrichment in humus (95% in non-labile form) near both mines which decreases with increasing distance. The enrichment is probably related to anthropogenic contamination since slightly elevated labile:non-labile Sb ratios in the humus are only found near Pinchi Lake mine and not at Bralorne Takla. The potential anthropogenic Sb enrichment only present at Pinchi Lake mine could be related to the longer operation period at that mine compared to Bralorne Takla mine. Zinc and nickel were not processed or emitted at the mines. Zinc and nickel enrichments in the soils are derived from bedrock and glacial sediments naturally enriched in these metals.

Mercury Cycling in Soils Underlain by Permafrost, Kaminak Lake area, Nunavut: an Overview and Directions for Future Research

**McMartin, I., Hall, G.E.M., Kerswill, J.A., Douma, S., Goff, S.P., Sangster, A.L.
and Vaive, J.E.**

The Kaminak Lake project (2.1c) was carried out in the Kivalliq Region of Nunavut to study the cycling of mercury (Hg) in soils underlain by permafrost. In Kaminak Lake, Hg levels are high in lake trout and above background in lake water in areas underlain by Archean greenstone belt rocks and/or the Proterozoic Hurwitz Group. Hg enrichments in both lake fish and water have therefore been considered as a classic example of "natural" contamination by Hg in a remote, unpopulated region of Canada. The objectives of this project were to (1) determine the source(s) and occurrence of Hg in local bedrock and mineralization, (2) evaluate the distribution of Hg in the surficial environment, (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 concentrations of Hg in soils and the pathways by which Hg may become bio-available to fish.

Field work was undertaken during the summers of 1997 and 1999. In total, 100 till, 30 humus, 18 peat, 18 dwarf birch leaf, 26 bedrock and 40 lake water samples were collected across the Kaminak Lake drainage basin. The geochemical, mineralogical and lithological composition of the samples were determined. In addition, during metallogenic investigations completed as part of the Western Churchill NATMAP Project, 142 bedrock samples from mineral showings or deposits were collected in the greenstone belt and analysed for Hg and other trace and major elements.

Results suggest that several Hg sources reside in Zn-bearing massive sulphide accumulations and polymetallic veins that are distributed throughout the Archean Kaminak greenstone belt. In contrast, bedrock lithologies within the Proterozoic Hurwitz Group (including the shales from the Ameto Formation) are not enriched in Hg. Additional local sources (gaseous Hg⁰) may exist along faults and unconformities in exposed outcrops or directly under Kaminak Lake. Glacial sediments (e.g., till) partly derived from mineralization zones and from local bedrock lithologies cover about 67% of the watershed and form a discontinuous mantle overlying the bedrock surface. Repeated exposure of till to oxidation above the permafrost table and vertical mixing of surface organic matter by cryoturbation have resulted in the continuous release of Hg from sulphide-rich debris and its subsequent accumulation in the finest organic-rich clay fraction of till. The transportation of Hg bound to fine-grained humic matter in soils through surface runoff may play important roles in bringing bio-available Hg species to the lake and their concentration in the fish. In addition, runoff from shallow peatlands may also represent a significant source of Hg since about 16% of the drainage basin is covered by fibrous peat.

Future research and publications will be directed towards the role of organic matter and the importance of cryoturbation processes in the mineral soils of cold climate regions for the transport of Hg and other metals to lacustrine environments.

Mercury Cycling in Modern Boreal Podzols and in Paleosols of Northern Quebec

Parent, M.

The interpretation that the cycling of organic matter in boreal podzols is the main process controlling the cycling of mercury has now gained widespread acceptance. However since this interpretation lacks the direct support of isotopic tracers, unequivocal demonstration has yet to come. Typically, mesic soil profiles developed on till in the northern boreal forest show Hg enrichments in two sets of horizons: (1) the surface organic and organic-rich horizons (L, F, H, Ah) and (2) the spodic horizons (Bhf, Bf). At depth, the parent material (C horizon) of these soils is characterized by very low [Hg], commonly on the order of 5 ppb in Archean terrains, which is in sharp contrast with the 200-250 ppb typically observed in the surface organic horizons and with the 50-75 ppb commonly observed in organic-rich spodic horizons. Hence the question: are these Hg enrichments a by-product of industrial activities or are they natural?

In the surface organic horizons, mercury is only slightly enriched in labile phases (0.25 M HCl extraction) and is largely concentrated in the non labile phases, e.g., in the insoluble organics. This contrasts with Pb, which is essentially concentrated in labile phases and which can be assigned to anthropogenic sources on the basis of Pb isotope signatures. This suggests that litter fall and decomposition are the key processes by which Hg is incorporated into the soil, while direct deposition from the atmosphere is the main process of incorporation for Pb. In the B horizon, Hg is almost entirely associated with the labile phases, where its concentration is proportional to the organic matter content, e.g., to [C]. Since the residence time of humic compounds in the B horizon, as provided by radiocarbon dating of humic and fulvic acids, generally exceeds 1000 years, it seems safe to conclude that the elevated Hg concentrations in these soils cannot result from the cumulative biogenic/pedogenic cycling of Hg derived from their parent material. Enrichment factors of that order of magnitude are simply not observed in such young soils. Elevated [Hg] in soils are therefore derived from natural, Hg-rich litter fall, a conclusion that is supported by the high Hg concentrations hitherto observed in Holocene paleosols; Hg derived from atmospheric sources had indeed been accumulating in boreal podzols since long before the industrial era.

One recommended avenue for future research on Hg and Pb cycling is to refine and develop this multiple criteria approach to a larger set of Late Quaternary paleosols.

Mercury Cycling in Kejimikujik Park: Lessons Learned

A. Rencz

Kejimikujik Park, Nova Scotia, is noted for having the highest mercury concentrations in loon blood in North America. Atmospheric deposition, geologic sources, trophic effects and the physical and chemical characteristics of the ecosystem have all been suggested as important factors that may contribute to this problem.

The project objective was to develop a mass balance budget describing the relevant sources and fluxes (deposition, volatilization, rock weathering, etc.) of mercury species (including total and methyl mercury). The results show that the sources of mercury to the Kejimikujik ecosystem are not unusually different from other areas in North America; indicating that the processes controlling mercury cycling and speciation within the ecosystem are the primary factors. Among other things, our research has shown the importance of wetlands within the catchment basin for the production and distribution of methyl mercury. The wetlands are responsible, in large part, for the production of Dissolved Organic Carbon (DOC), which promotes the retention of mercury in the system and its conversion to methyl mercury. The project has shown the relevance of spatial variation in mercury levels across the Park. Although the level of DOC appears to be the driving force there is a positive relationship between mercury in yellow perch and levels of mercury across the drainage basin. Other areas of research include: importance of microbiological processes in mercury cycling and transformations, sedimentation processes as a sink for mercury, and the significance of ground water as a potential source for mercury, and possibly for methyl mercury. The research also indicates the potential for using remote sensing to identify lakes with high DOC that are at risk for mercury bioaccumulation.

The GSC MITE project in Kejimikujik Park has successively shown the importance of including geoscience in multi-disciplinary environmental projects.

Development of the History of Atmospheric Metals Deposition from the Devon Ice Cap: Progress and Future Perspectives

Zheng, J., Fisher, D., Zdanowicz, C., Blake, E., Hall, G.E.M., Vaive, J.E., and Lawson, G.

Growing concerns about long-range transport of atmospheric pollutants into the Arctic relate to adverse effects of certain pollutants (e.g., toxic metal species) on the health of Arctic ecosystems and human residents, and to trans-border pollution legislation issues. Ice cores drilled from ice caps can be used to develop archives of atmospheric pollution in the Arctic, allowing for modern depositional trends to be viewed in a long-term perspective. As part of the Geological Survey of Canada's Metals in the Environment (MITE) initiative, a 65m ice core was drilled in April 2000 on Devon Island (75°N; 82°W; 1860 m). The core is estimated to span a period extending back to ca 1800 AD, with annual to multi-annual temporal resolution. The ice core will be used to develop a modern to pre-industrial record of atmospheric trace metal deposition for the Canadian High Arctic.

The Devon Island core was drilled with a new titanium auger (diam. 8.2. cm) custom-designed to minimize metal contamination of the ice. Trace metals in polar snow are typically present at sub-ppb to low ppt levels. Hence, stringent quality-control procedures are needed to ensure that concentrations measured in ice cores truly reflect atmospheric deposition. A decontamination protocol was developed for the Devon Island core that involves stepwise removal of concentric ice layers with pre-cleaned titanium tools. The successive layers were analysed at the GSC by ICP-MS for a range of metal species including Cd, Cu, Pb and Zn. Results show a rapid decrease in the concentration of all metal species of interest between the outermost layer (1 cm) and inner cores. Metal levels in the inner 6-7 cm of cores show constant or near-constant values, indicating that any contamination is limited to the outermost layers. A comparison between inner core concentrations for Cu, Cd, Pb and Zn and published data from other polar snow and ice cores reveals a good agreement in the range of values observed. Our findings demonstrate that the new drill and the stepwise decontamination procedure allow for accurate measurement of ice-core trace metal concentrations that reflect true atmospheric deposition levels. Some typical metal concentrations found in test cores dating from the late 1960s to late 1970s are: 65-240 ppt Zn, 10-300 ppt Pb, 20-50 ppt Cu, and 1-5 ppt Cd. That some metals are only present at a few ppt in ice that formed during a decade of heavy industrial activity anticipates the difficulties of establishing meaningful trends over longer time periods.

Sampling of the Devon Island ice core is expected to be completed by then end of 2002. The 200-yr record of atmospheric trace metal deposition developed from the Devon Island core will be the first of its kind ever obtained in the Canadian Arctic.

Optimization of Sample Collection, Preparation, Digestion and Analytical Procedures for Environmental Studies

Hall, G.E.M.

This presentation summarizes the work carried out under the GSC-MITE program by the Analytical Method Development laboratory in the Applied Geochemistry and Mineralogy Subdivision. This work falls into two categories: 'specialized' analyses in support of other MITE scientists and analytical research and development aimed at providing the information and tools necessary to collect different geological media for accurate elemental analysis required in environmental studies. The research carried out focuses on the development of: protocols for sampling, filtering and preserving surface waters for elemental analysis including Hg (a separate study); recommendations for preserving lake sediment cores for sequential extraction analysis; protocols for the sampling, preservation and analysis of snow and ice samples for melt and particulate phases; and sequential leach design for the determination of Hg in soils and sediments. Some examples of recent results will be presented in this overview.

NOTES

**List of GSC-MITE Initiative Project/Subproject Formal Titles, their leaders
and periods of funding**

1. Point Sources Program

1.1 Smelter Studies Project - Terrestrial Component

- 1.1a Smelter emission characterization studies - F. Goodarzi (GSC-Calgary) 1997-2000
- 1.1b Impact of heavy metals on soils in the vicinity of two Canadian smelters: Humus and Soil studies - P.J. Henderson (Terrain Sciences Division) 1997-2002
- 1.1c Dendrochemical studies: Dendrochemical investigations of natural and anthropogenic metals in the environment [DINAMITE] - M.M. Savard (GSC-Quebec) 1997-2002
- 1.1d Interpretation of trace metals from natural and anthropogenic sources: Lake sediment studies - K. Telmer (Mineral Resources Division) 1997-2000; S. Alpay (Mineral Resources Division) 2000-2002
- 1.1e Impact of metal emissions on the hydrogeochemical cycle in the vicinity of selected smelters: Hydrogeochemical studies - K. Telmer (Mineral Resources Division) 1997-2000; D. Kliza (Mineral Resources Division) 2000-2002
- 1.1f The historical record of smelter emissions in peat: Peat studies - I. Kettles (Terrain Sciences Division) 1997-2002
- 1.1g Project Coordination/GIS data integration and model management: GIS and modelling studies - G.F. Bonham-Carter (Mineral Resources Division) 1997-2002

1.2 Smelter Studies Project - Marine Component

- 1.2 Natural and anthropogenic metal fluxes to marine sediments off Belledune, New Brunswick - R.E. Cranston (GSC-Atlantic) 1997-2002

2. Natural Sources and Weathering Processes Program

2.1 Trace Metals in the Environment Project

- 2.1a Weathering processes and trace metal flux in the surficial environment: trace elements in soils of eastern and central Canada - R.A. Klassen (Terrain Sciences Division) 1997-2002
- 2.1b Weathering processes and trace metal flux in the surficial environment: Pinchi Fault, British Columbia - A. Plouffe (Terrain Sciences Division) 1997-2002
- 2.1c Weathering processes and trace metal flux in the surficial environment: Kaminak Lake, Nunavut - I. McMartin (Terrain Sciences Division) 1997-2002
- 2.1d Weathering processes and trace metal flux in the surficial environment: Grande Baleine, Quebec - M. Parent (GSC-Quebec) 1997-2002

**Formal list of GSC-MITE Initiative Projects, Subprojects, their leaders
and periods of funding (continued)**

2. Natural Sources and Weathering Processes Program (continued)

2.2 Mercury Projects

- 2.2 Measurement of mercury fluxes to the atmosphere from natural sources -
P.E. Rasmussen (Mineral Resources Division) 1997-2000
- 2.3 Source apportionment of trace elements (Hg) in loons, Eastern Canada -
A.N. Rencz (Mineral Resources Division) 1997-2002

3. Arctic Studies Program

- 3.1 Atmospheric deposition of trace elements in Arctic regions - D. Koerner (Terrain Sciences Division) 1997-2000; D. Fisher (Terrain Sciences Division) 2000-2002
- 3.2 Composition of mineral dust in Arctic snow and ice: A pilot project - R.A. Klassen (Terrain Sciences Division) 1998-1999

4. Analytical Chemistry and Coordination Program

4.1 Analytical Chemistry Project

- 4.1a MITE-related analytical geochemistry, research and method development -
G.E.M. Hall (Mineral Resources Division) 1997-2002
- 4.1b Mineralogical investigations of Canadian till and lake sediment standard reference materials - J.B. Percival (Mineral Resources Division) 1999-2000
- 4.1c Lead isotope characteristics of lead ore deposits of environmental significance - W.J. Davis (Continental Geosciences Division) 1999-2000

4.2 Coordination

- 4.2 Program Coordination and Secretariat - R.G. Garrett (Mineral Resources Division) 1997-2002

**Geological Survey of Canada Metals in the Environment
(GSC-MITE) Initiative, 1997-2002**

Cumulative Publications List by Project/Subproject

Note: Contributions marked [*] are of the form of extended abstracts in proceedings volumes

1. Point Sources Program

1.1 Smelter Studies Project - Terrestrial Component

Subproject 1.1a: Smelter emission characterization studies (F. Goodarzi)

Goodarzi, F., Sanei, H. and Duncan, W.F.

2001: Monitoring the distribution and deposition of trace elements associated with a zinc-lead smelter in the Trail area, British Columbia, Canada. *Journal of Environmental Monitoring*, 3(5):515-525.

Goodarzi, F., Sanei, H., Garrett, R.G. and Duncan, W.F.

In press: Accumulation of trace elements on the surface soil around the Trail smelter, British Columbia, Canada. *Environmental Geology*.

Subproject 1.1b: Impact of heavy metals on soils in the vicinity of two Canadian smelters: Humus and Soil studies (P.J. Henderson)

Henderson, P.J., Knight, R. and McMartin, I.

1999: Heavy-metal concentrations in soils surrounding Canadian base-metal smelters: a comparative study. *In Current Research 1999-D*, Geological Survey of Canada, pp. 17-26.

Knight, R.D., Lapointe, M., Kyer, T. and Henderson, P.J.

2000: Some observations on the effects of length of sample storage, sample type, and sample depth on the determination of pH in soils collected in the vicinity of the Horne smelter at Rouyn-Noranda, Quebec. *In Current Research 2000-C24*, Geological Survey of Canada, 7 p.

Henderson, P.J., Knight, R.D. and McMartin, I.

2000: Geological and geochemical controls on trace metal distribution in soils near a base-metal smelter, northern Canada. *In Conference Abstracts 5th International Conference on Environmental Geochemistry*, University of Cape Town, South Africa, pp. P5-24. [*]

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2001: Regional distribution of trace metals in soils surrounding a Cu smelter in the Boreal Shield Ecozone, Northern Quebec, Canada. *In Proceedings 6th International Conference on the Biogeochemistry of Trace Elements* (Ed. K. Bolton), University of Guelph, Guelph, Ontario, pp. 538. [*]

McMartin, I., Henderson, P.J., Plouffe, A. and Knight, R.D.

2001: Comparison of Cu-Hg-Ni-Pb concentrations in soils adjacent to four Canadian anthropogenic point sources. *In Proceedings 6th International Conference on the Biogeochemistry of Trace Elements* (Ed. K. Bolton), University of Guelph, Guelph, Ontario, pp. 537. [*]

Henderson, P.J., Knight, R. and McMartin, I.

2002: Geochemistry of soils within a 100 km radius of the Horne smelter, Rouyn-Noranda, Quebec. Geological Survey of Canada, Open File 4169, 398 p. or CD-ROM.

McMartin, I., Henderson, P.J., Plouffe, A. and Knight, R.D.

In press: Comparison of Cu-Hg-Ni-Pb concentrations in soils adjacent to anthropogenic point sources: examples from four Canadian sites. *Geochemistry: Exploration, Environment, Analysis*, 2(1).

Subproject 1.1c: *Dendrochemical studies: Dendrochemical investigations of natural and anthropogenic metals in the environment [DINAMITE] (M.M. Savard)*

Marion, J., Savard, M.M., Bégin, C. and Parent M.

2001: Assimilation du carbone, des nutriments et des métaux lourds par l'épinette noire à proximité de la fonderie Horne, Rouyn-Noranda (Québec). *In Current Research 2001-C22*, Geological Survey of Canada, 9 p.

Savard, M.M., Bégin, C. and Parent, M.

2001: A high resolution historical perspective on anthropogenic accumulation of metals in the environment using H, C and Pb isotopic dendrochemistry. *In Proceedings 6th International Conference on the Biogeochemistry of Trace Elements* (Ed. K. Bolton), University of Guelph, Guelph, Ontario, pp. 304. [*]

Savard, M. M., Bégin, C., Parent, M.

In press: Are industrial SO₂ Emissions Reducing CO₂ Uptake by the Boreal Forest? *Geology*-17502.

**Subproject 1.1d: *Interpretation of trace metals from natural and anthropogenic sources:
Lake sediment studies (K. Telmer, 1997-2000; S. Alpay, 2000-2002)***

Kliza, D., Telmer, K., Hall, G.E.M., Bonham-Carter, G.F. and Alpay, S.

2000: Preliminary results from a study of metals in lake sediments around the smelter at Rouyn-Noranda, Quebec. *In* Proceedings of 11th Annual International Conference on Heavy Metals in the Environment (Ed. J. Nriagu). University of Michigan School of Public Health, Ann Arbor, MI. CD-ROM, Contribution #1141, 1 p. [*]

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2001: Phase I. Lake sediment studies in the vicinity of the Horne smelter in Rouyn-Noranda, Quebec. Geological Survey of Canada Open File D2952, CD-ROM.

Bonham-Carter, G., Kliza, D., Buckle, J. and Telmer, K.

2001: Exploratory spatial data analysis of regional lake-sediment data from the Rouyn-Noranda region, Quebec. *In* Proceedings 6th International Conference on the Biogeochemistry of Trace Elements (Ed. K. Bolton), University of Guelph, Guelph, Ontario, pp. 541. [*]

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2001: Diagenetic metal remobilization versus chronological metal loading in lake sediments. *In* Proceedings 6th International Conference on the Biogeochemistry of Trace Elements (Ed. K. Bolton), University of Guelph, Guelph, Ontario, pp. 70. [*]

**Subproject 1.1e: *Impact of metal emissions on the hydrogeochemical cycle in the vicinity of
selected smelters: Hydrogeochemical studies (K. Telmer, 1997-2000; D.
Kliza, 2000-2002)***

Kliza, D., Telmer, K., Bonham-Carter, G.F. Hall, G.E.M., and Garrett, R.G.

2000: Recent emissions detected in natural snowpack around the smelter at Rouyn-Noranda, Quebec. *In* Proceedings of 11th Annual International Conference on Heavy Metals in the Environment (Ed. J. Nriagu). University of Michigan School of Public Health, Ann Arbor, MI. CD-ROM, Contribution #1413, 1 p. [*]

Kliza, D., Telmer, K.T., Bonham-Carter, G.F. and Hall, G.E.M.

2001: Geochemistry of snow from the Rouyn-Noranda region of Western Quebec: An environmental database. Geological Survey of Canada Open File 3869, 169 p.

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Kliza, D. and Bonham-Carter, G.F.

In press: Geochemistry of snow from the Rouyn-Noranda region of Western Quebec: An environmental database, Part II. Geological Survey of Canada Open File 4205, CD-ROM

Subproject 1.1f: *The historical record of smelter emissions in peat: Peat studies (I. Kettles)*

Kettles, I.M. and Dion, K.M.

2000: Geochemical composition of hummock and hollow peat and feather moss in the vicinity of the Horne Smelter, Rouyn-Noranda, Quebec. Geological Survey of Canada Open File 3882, 185 p.

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Subproject 1.1g: *Project Coordination/GIS data integration and Model management: GIS and modelling studies (G.F. Bonham-Carter)*

Bonham-Carter, G.F. and Kettles, I.M.

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Project 1.2: *Natural and anthropogenic metal fluxes to marine sediments off Belledune, New Brunswick (R.E. Cranston)*

Cranston, R.E.

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2. Natural Sources and Weathering Processes Program

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Plouffe, A and Hall, G.E.M.

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Subproject 2.1d: *Weathering processes and trace metal flux in the surficial environment: Grande Baleine, Quebec (M. Parent)*

Contributions reported under Subproject 1.1c

2.2 Mercury Project

Project 2.2: *Measurement of mercury fluxes to the atmosphere from natural sources (P.E. Rasmussen, 1997-2000)*

Rasmussen, P.E., Friske, P.W.B., Azzaria, L.M. and Garrett, R.G.

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Subproject 4.1b: *Mineralogical investigations of Canadian till and lake sediment standard reference materials (J.B. Percival, 1999-2000)*

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Garrett, R.G.

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