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**GEOLOGICAL SURVEY OF CANADA**
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# Field survey plan and strategy of snow sampling for ecosystem cycling of metals near gold and diamond deposits of the Slave Geological Province, Northwest Territories: Implications for the release, cycling, and monitoring of potential contaminant metallic elements in a changing environment

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# Field survey plan and strategy of snow sampling for ecosystem cycling of metals near gold and diamond deposits of the Slave Geological Province, Northwest Territories: Implications for the release, cycling, and monitoring of potential contaminant metallic elements in a changing environment

**J. Zheng[1], C. Zdanowicz[1], P. Outridge[1] and H. Falck[2]**

[1] Geological Survey Canada, Earth Science Sector, Natural Resources Canada, Ottawa, Ontario
[2] Northwest Territories Geoscience Office, Yellowknife, Northwest Territories

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# 1. Introduction

## *1.1 Background*

Environmental regulations are determined as relatively static criteria and generally do not take account of changing environmental processes. This is particularly important for earth surface processes in northern Canadian ecosystems, where drivers such as climate-change may be forcing substantial modifications to metal cycling and dynamics. Therefore, characterization of the effects of ongoing climate change on the release, transport, and deposition of trace elements in northern ecosystems is essential for assessing the impacts of future metal mining operations in Canada's North.

Under the Environmental Geosciences Program, a three-year project, Ecosystem cycling of metals near gold and diamond deposits of the Slave Geological Province, NWT: Implications for the release, cycling, and monitoring of potential contaminant metallic elements in a changing environment, was set up to investigate the dynamics and fluxes of a wide variety of trace metals in different parts of the ecosystem comprising the catchment, tributaries and lake waters along the ice road, Northwest Territory. The project aims to characterize the processes that control the release, transport, and deposition of trace elements in the northern environment. Results from this project are intended to help improve environmental assessments throughout the Canadian North.

This three-year project will examine the dynamics and fluxes of metals of environmental concerns in the ecosystem surrounding areas of gold and diamond mineralization in the Slave Geological Province of the central Northwest Territories (NWT). In collaboration with partners, the study will investigate the cycling of metals in various parts of the ecosystem comprising the catchment, tributaries, and waters of lakes in a transect stretching from gold mining areas in the southwest to diamond mining activities in the northeast (Diavik and Ekati Mines near Lac de Gras) (from Yellowknife to Courageous Lake). The aim of this project is to provide environmental geosciences knowledge that can be used by policy makers, regulators, and other stakeholders to minimize the adverse environmental impacts of future metal mining activities on dynamic northern ecosystems of the Slave Geological Province (Modified and abstracted from the project proposal, Outridge et al., 2011).

This open file describes the field snow sampling under this project, including field trip preparation, equipment needed, field sampling methodology, sample handling on site and sample analysis in the base laboratories. It is hoped that this report will facilitate future snow sampling in northern Canada.

The sampling area covers the southern portion of the Winter Road between Yellowknife and Diavik mining camp. The Tibbitt to Contwoyto Winter Road is shown in Figure 1. Sampling sites are shown in Figure 2. Field trip started on 9$^{th}$ of March and was completed on 25$^{th}$ of March, 2012.

Sample analysis started about 2 months after field trip and carried out in several laboratories within Canada. Analysis of samples for total mercury (THg) was carried out at the Centre for

Earth Observation Science, Department of Environment & Geography, University of Manitoba. Quantification of samples for other metal was done at the Department of Chemistry, Trent University while sample analysis for ion chemistry analysis was carried out at the glaciology chemistry laboratory, Geological Survey of Canada, Natural resources Canada.

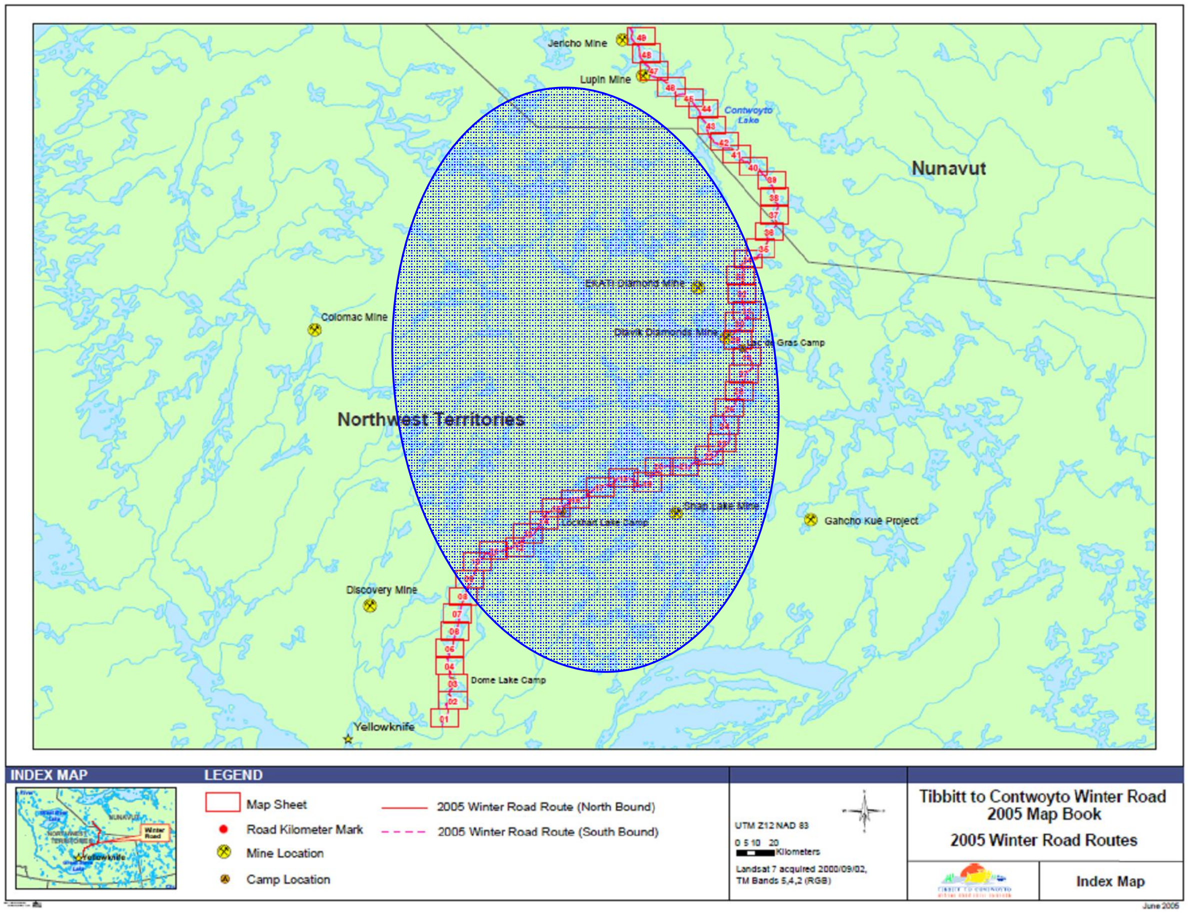


Figure 1. Diagram of the Tibbitt to Contwoyto Winter Road located in Northwest Territory and Nunavut Territory. This figure is directly taken from the 2005 Winter Road Routes by EBA Engineering Consultants Ltd. July 2005 (EBA, 2005), with an addition of the shaded area showing the approximate snow sampling area.

### *1.2 Working Group Members of the project*

Peter Outridge, GSC Ottawa
James Zheng, GSC Ottawa
Christian Zdanowicz, GSC Ottawa
Jennifer Galloway, GSC Calgary
Hendrik Falck, Northwest Territories Geoscience Office, Yellowknife, NT
Andrew Macumber, PhD candidate, Carleton University, Ottawa
Robert Mercredi, North Slave Métis Alliance
Hamed Sanei, GSC Calgary

Timothy Patterson, Carleton University, Ottawa
Gary Stern, DFO (Arctic Region)
Robin Staples, AANDC, Water Resources Division
Steve Kokelj, Northwest Territories Geoscience Office
Christopher Spence, Environment Canada
Brent Murphy, Seabridge Gold Inc.
Ron Near, Rio Tinto Group
Sheryl Grieve, North Slave Métis AllianceINAC/CARD

## 2. Field snow sampling transect design and site selections

### *2.1. Purpose of snow sampling for this project*

- To assess the contribution of mercury and other metals from the atmospheric snow deposition;
- To estimate the natural background of mercury and other metals in the snowfalls in the study area; and
- To contribute the information of mercury and other metals input from atmospheric snow fall to the project "Ecosystem cycling of metals near gold and diamond deposits of the Slave Geological Province, NWT" under management of Environmental Geosciences Program.

### *2.2 Factors affecting the transects and sampling site selection*

- Mining sites;
- Radial distance from the Winter Road that may be a local source of transportation pollution;
- Accessibility via available transportation vehicles;
- Scientific requirements for this study;
- The position of the tree line; and
- Lakes that are aimed to be sampled by sediment core.

### *2.3 Site design and selection for snow sampling*

Snow sampling for THg and other metals took place in the catchments of lakes selected for sediment sampling. Co-sampling locations with sediment coring sites can facilitate data analysis and source assessment of those elements in the study area.

In general, two transects, covering about three degrees in latitude by two degrees in longitude, were sampled, one from North to South (N-S) and the other, from East to West (E-W) as shown in Figure 2. This design is aimed to extend the coverage of study area, trying to distinguish the contributions of atmospheric contaminants from the local mining sites and from long range transportation. For background and comparison purpose, a remote site in a Canadian High Arctic ice cap, the Agassiz Ice Cap, was also sampled. This remote site was sampled with a depth profile covering a full year snow accumulation, which will serve an estimation of the annual flux and a mean sample concentration of the selected metals with no local mining sites and with no (or very limited if any) anthropogenic contribution.

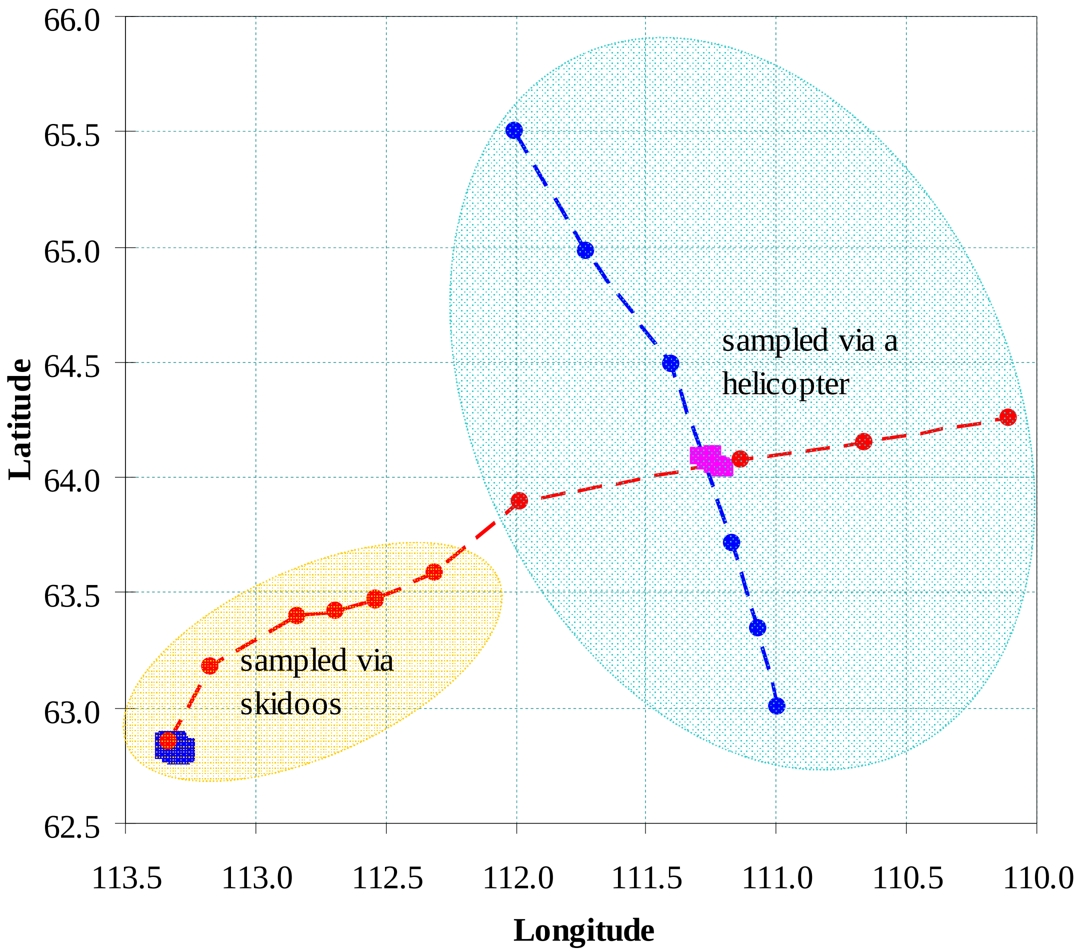


Figure 2. Two transects, one from North to South (N-S) and the other from East to West (E-W), designed for snow sampling for study of THg and other metals. In the figure, S-N transect sites: solid blue circles; E-W transect: solid red circles with detailed sampling lakes: Waite Lake (solid blue squares) and Mathews Lake (solid pink squares). Light blue shaded sites were sampled via a helicopter while those shaded by light yellow were sampled via skidoos.

For more detailed assessment of metal contaminants into lakes, multi sites were selected for two of the freeze coring lakes, Mathews Lake (8 sites) and Waite Lake (13 sites). For the other freeze coring lakes, one sampling site for each lake was selected. However, whenever the distance between two sediment coring lakes is more than 30 km, an extra snow sampling site was added in between.

In areas where no sediment coring was planned (e.g. the S-N transect), sampling sites are assigned about every 0.5 degrees to provide a reasonable coverage of snow sampling across the lake catchments.

### *2.4 Special sites for snow sampling on slope, near trees and on the lakes*

When sampling on and near Mathews Lake and Waite Late, some special sites were selected. Those special sites include sites on slope and under the trees within the lake's catchment.

As trees and/or shrub vegetation might possibly affect total metal content in the snow near their growing site, special sites with no trees (north of the tree line) were also included. During this field trip, although about 10 sampling sites could be categorized as sites below the tree line (indicated by Dowings (2008) and Huang et al. (2005)), small numbers of trees were still visibly distributed even 10s of kilometres north of the tree line. In order to collect snow samples that have no tree effect, three special sites beyond the area of visible trees were selected at ~65.5N 112.0W (within Nunavut territory), 65.0N 111.7W and 64.5N 111.4W (Within Northwest Territories) respectively, on the north side of the N-S transect.

## 3. Field equipment

Field equipment for snow sampling is separated into three categories: field sampling equipment, field safety equipment and transportation vehicles. Some of the equipment serves more than one purpose, such GPS and camera. In this case, the equipment is included under the category that appears first.

### *3.1 The field sampling equipment*

AA Batteries: 10 pairs (for GPS)
Aluminum foil: two rolls (100' each)
Bottles: Glass (60 for total Hg, pre-cleaned)
HDPE (60 for metals, pre-cleaned)
Coolers: five for sample storage.
Digital cameras: two units
Field notebook: one
Field computer: one
Goggles: two pairs
Gloves: polyethylene (100 pairs, large size)
Nylon (20 pairs, large size)
Working (4 pairs, large size)
GPS unit: two units
Maps: Local maps/Winter Road maps
Pencils: two
Plastic scoops: five units (pre-cleaned)
Plastic bags: 200 (8x10")

Ruler: folding measure (two meter size)
Sharpies: three
Shovels: Steel (one)
Aluminum (one)
Skidoo safety hamlet: two (large size)
Skidoo insulated gloves: one large size and one medium size
Snow probe: one
Snow shoes: two pairs
Tarps: two pieces (for covering skidoo during storm)
Titanium plate: two (Pre-cleaned)
Tool box: one
Tyvek clean jackets: 10 suites (XXX-large size)
Whirl-Pak bags: 100 (Size: 6x9")

### *3.2 Safety and cold clothing equipment*

Bag: dunnage (for carrying sleeping gear)
Boots
Emergency tent (must be able to fit two persons or more)
First aid kit: standard (Stay in the truck)
portable (for snowmobilers)
Float/survival suits
Foam mats
Hearing protection
Insoles for matching boots
Insulated gloves
Insulated pants
Large garbage bags
Liner for mitten
Lipsticks
Emergency location responder (with 12 Li-batteries)
Parker
Pillow
Pull over cap
Radio (Communication with Winter Road authority during field sampling)
Sat phone with a SIM card (for emergency)
Sleeping bags
Socks for matching boots
Sun cream
Sunglasses

### *3.3 Transportation vehicles*

- Helicopters (12 hours of flying time was kindly provided by Seabridge Gold Inc.)

- Truck one, 4 wheel drive, a loan from the Aboriginal Affairs and Northern Development Canada, NWT Geoscience Office, Yellowknife, NWT.
- Truck two, 4 wheel drive, a commercial rental truck from a Yellowknife truck rental company.
- Snowmobiles, two for safety purpose. A loan from the Water Survey of Canada, Environment Canada, Yellowknife, NT.
- Trailer: for carrying snowmobiles. A loan from Water Survey of Canada, Environment Canada, Yellowknife, NT.
- Straps and spare parts for the trailer and skidoos.

## 4. Field snow sampling

Samples for total Hg and other metal contaminants as well as ion samples in snow packs were taken separately in two sets of sample bottles and one set of Whirl-Pak bags. This means they were replicated at each site. No chemicals were added into snow samples because the samples were intended to be kept in frozen state till analysis. A major emphasis was place on contamination control because the concentrations of many metals in snow are often orders of magnitude below the one in lake waters and sediments. A similar sampling procedure was used for sampling on ice caps (Zheng et al. 2006).

### *4.1 Sample containers used for snow pack sampling*

Glass bottles (400-ml, Fisherbrand Clear French Squares with PTFE-Faced PE-Lined Closures) and high density polyethylene (HDPE) bottles (500 ml, Nalgene®, Fisher Scientific, Canada) were used for THg samples and other trace metals in this study respectively. Whirl-Pak bags were used for ion samples, which served for data analysis,

### *4.2 Decontamination procedure for sample containers and utensils*

The procedure used for cleaning HDPE bottles was: soaking in 30% HNO3 (trace metal grade) at 50 °C for two weeks, then in new 7% HNO3 (trace metal grade) at room temperature for another two weeks, and finally filled with 0.5% BASELINE® HNO3 for at least two more weeks (Zheng et al., 2006). The bottles were rinsed with RO-DI water between each cleaning step. Before HDPE bottles were shipped for field sampling, they were rinsed three times with 0.5% BASELINE® HNO3 followed by three RO-DI rinses.

The glass bottles were rinsed with RO-DI water at least three times and let dry on a Class-100 bench.

All utensils including polyethylene scoops and titanium plates used for field sampling and/or sample processing in laboratories were treated and cleaned in a procedure similar to HDPE bottles before they were used.

### *4.3 Sample blanks*

One set of eight glass bottle blanks for THg and one set of eight HDPE bottle blanks for other metals were taken during the field trip in different locations, and one set of three HDPE bottle blanks in base laboratory were taken during sample processing in the Class-10 working station. This procedure was designed to identify possible sources of any metal contamination during the field and laboratory stages of the study.

### *4.4 Sampling spot selection, pit digging and preparation for sampling*

In general, snow pack sampling spot was carefully selected towards wind and away from any possible and/or obvious contamination sources nearby. All bottles were labelled on site before sampling.

Common practice for snow pack sampling is as follows:

a. Once arriving at the site, a quick visual reconnaissance of the site was carried out to find a representative spot facing towards the wind with no direct contamination sources upwind;
b. Walk to the sampling spot from downwind with a shovel (Figure 3a);
c. Use aluminum or steel shovel to dig a pit and create a working area. Note: never approach the sampling spot from upwind side;
d. Label sample bottles and bags with a sharpie and take detailed note of the snow pit, including pit depth, snow stratigraphy, sizes of snow grain, weather conditions (Temperature, sunshine condition et al.);
e. Arrange sample containers and tools on left or right side of the personnel who is working in the pit and then create a new clean surface of the pit wall. (Figure 3b)
f. Take samples towards the wind and away from any visible contamination, such as visible black detritus (as indicated by the red arrow in Figure 3c).

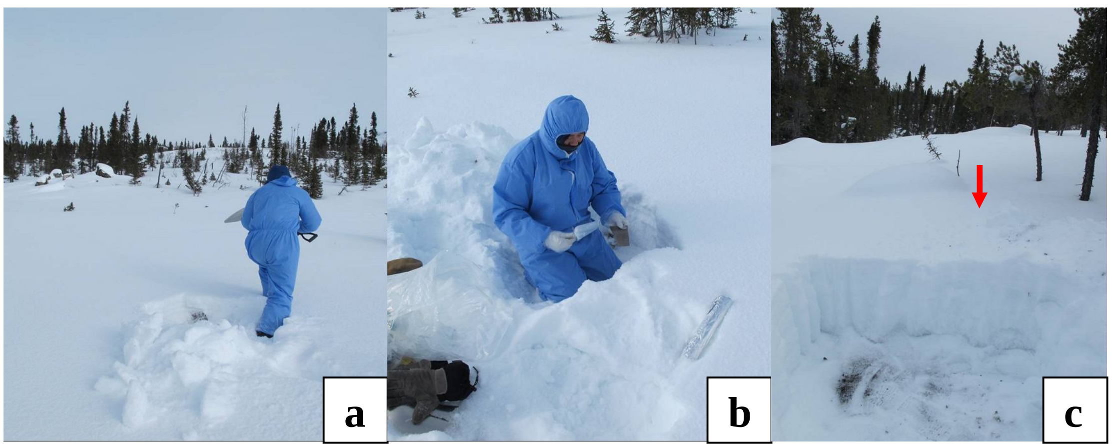


Figure 3. Snow sampling strategy to minimize sample contamination. a. Approach the sampling spot from downwind; b. Keep gear downwind from sampling pit wall but within easy reach during sampling. Tyvek overall jackets and polyethylene gloves should be used by the personnel taking samples with a plastic scoop and a titanium chisel.; and c. always create a new surface from the pit wall and take samples on the newly created surface.

a. Towards the sampling spot from downwind; b. Keep gear downwind from sampling pit wall but within easy reach during sampling. Tyvek overall jackets and polyethylene gloves should be used by the personnel taking samples with a plastic scoop and a titanium chisel.; and c. always create a new surface from the pit wall and take samples on the newly created surface.

### *4.5 Sample taking and sample protection from contamination*

Personnel taking the samples wore Tyvek overall jackets and polyethylene gloves. All samples were taken with a pre-cleaned plastic scoop and a titanium plate (Figure 3b). Do not sample by pushing a bottle into the snow there is a choice.

Snow samples for trace metal study were taken into HDPE bottles carefully. Once sufficient volume of snow was taken, the sample was capped tight immediately and then sealed in double plastic bags.

Snow samples for THg study were taken and immediately capped tight, wrapped with foil to minimize exposure to light and sealed in two plastic bags. However, no preserving agents were added due to difficulties in using them in the field. The difficulties are resulted from the low temperature. In cold regions where temperature is much lower than freezing point, any preserving agent may freeze or half-freeze which alter its concentration of an agent. In addition of the difficulties to use preserving agents in samples, less surface contact and interaction between sample and the sample container surfaces could be more beneficial to the integrity of the sample as the samples are intended to be maintained frozen till they are analyzed. This procedure was used for snow sampling on ice caps and proven to be effective and practical (Zheng et al. 2013).

Snow samples for ion chemistry were taken with a titanium plate and a scoop, the same sampling procedure as for THg and other metals. Ion chemistry sample containers were Whirl-Pak bags instead of bottles.

All bottled samples and ion chemistry samples were stored in coolers after taken and kept under shade with coverage of snow layers outside of building at the camp sites. Samples were shipped back to Ottawa base laboratory via frozen cargo shipping from Yellowknife. In Ottawa, samples were stored in deep freezers ($-18^{o}C$ or lower) until analysis.

### *4.6 Sampling depth*

Depths of snow packs in the region were found between 15 cm and 71 cm. It is common that snow depth was shallower in open-flat locations, such as on a lake and deeper in a bay or in area with vegetation surrounding and overhead. When snow depth was less than 20 cm, one sample covering the whole profile from surface to the bottom was taken. For snow packs deeper than 20 cm, the snow depth profile was sampled in two or three layers.

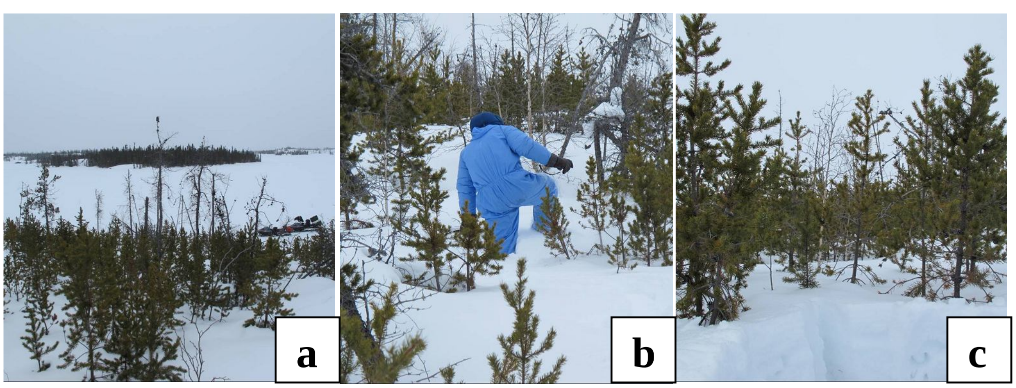


Figure 4. Snow sampling strategy in wooded areas. a. Leave skidoo behind and access the site on foot; b. Access the sampling spot carefully; and c. Take samples under trees.

### *4.7 Sampling under the trees*

To evaluate the effect of trees on the THg concentration in snow packs, special sites for snow pack sampling was planned and sampled. As accessibility via skidoo was difficult, site accessing was on foot (Figure 4). When taking samples in a bush or woods, try to avoid taking detritus of the tree leaves into the sample as detritus may totally alter the concentration of THg and trace metals in snow.

### *4.8 List of sampling sites*

A total 40 sampling sites were visited for this study, 33 sites were mainly located along the Winter Road, which extends from South-West to North-East. Six sites that were not along the Winter Road were set up for the S-N transect. One remote site at Agassiz Ice Cap, Nunavut was selected as the natural flux background evaluation of the contaminants concerned. Three sets of parallel samples were taken for studies of THg, trace metals and ion chemistry. A total of 266 samples were analyzed for this study. Details of the sapling sites are listed below.

Table 1. Coordinates of each sampling site visited for this study.

| **Transect sites** | | | **Waite Lake sites** | | | **Mathews Lake sites** | | |
|---|---|---|---|---|---|---|---|---|
| Site ID | Lat | Long | Site ID | Lat | Long | Site ID | Lat | Long |
| Control Lake | 64.07 | 111.14 | WL1 | 62.86 | 113.33 | M1 | 64.09 | 111.30 |
| P34-1 | 63.47 | 112.54 | WL2 | 62.86 | 113.33 | M2 | 64.09 | 111.27 |
| P34-2 | 63.48 | 112.54 | WL3 | 62.86 | 113.32 | M3 | 64.10 | 111.25 |
| P39 | 63.59 | 112.31 | WL5 | 62.84 | 113.35 | M4 | 64.07 | 111.27 |
| P49 | 64.26 | 110.11 | WL6 | 62.84 | 113.33 | M5 | 64.05 | 111.24 |
| A | 63.18 | 113.17 | WL7 | 62.85 | 113.31 | M6 | 64.05 | 111.22 |
| B | 63.89 | 111.98 | WL8 | 62.83 | 113.35 | M7 | 64.04 | 111.22 |
| C | 64.15 | 110.66 | WL9 | 62.83 | 113.33 | M8 | 64.05 | 111.21 |
| D | 63.01 | 111.00 | WL10 | 62.83 | 113.31 | M9 | 64.04 | 111.19 |
| E | 63.35 | 111.07 | WL11 | 62.83 | 113.28 | P28 | 63.40 | 112.84 |
| F | 63.71 | 111.17 | WL13 | 62.81 | 113.32 | P30 | 63.42 | 112.69 |
| G | 64.49 | 111.40 | WL14 | 62.81 | 113.30 | | | |
| H | 64.98 | 111.73 | WL15 | 62.82 | 113.29 | | | |
| I | 65.50 | 112.00 | | | | | | |

**Agassiz ice cap (80.7$^o$N and 73.1$^o$W, 1670 masl):** a site for natural flux background evaluation: A total of 14 samples from a 70-cm snow pit were taken. This depth of ice accumulation covered about 1.5 years (with half year overlapping) based on the summer layer found in the pit and the 50 year average of annual precipitation rate on the ice cap. These samples from Agassiz ice cap will be used for estimation of natural background of THg and trace metals directly deposited from the atmosphere as there is no local contribution of both THg and trace metals on Agassiz ice cap.

## 5. Field notes, temporary sample storage, pre-shipping preparation and shipping

Once field sampling was completed, the field notes were immediately checked and confirmed their accuracy and correctness. Then, all notes were input into computer after returning to the base camp. Photos of all the field note pages were taken with a digital camera as well.

All samples were preserved in coolers that were stored in a non-heated location or garage at the Northwest Territories Geoscience Office, Yellowknife, NT. Temperature inside the garage was found to be varying from -5$^oC$ to -19$^oC$ during storage time period.

Before shipping the samples, all the coolers were packed and strapped. Cooler's condition was carefully examined before packing.

Samples were shipped back to Ottawa base labs via First Air freezer cargo shipping. All samples were found in frozen state and intact when they arrived at the base laboratory in Ottawa.

## 6. Sample Preparation and analysis in base laboratories

### *6.1 Snow sample preparation and treatment at GSC for trace metal quantification.*

Samples for trace metal analysis needed preparation before they were sent for analysis. First, they were removed from the freezer and weighed in a class-100 workbench to estimate the volume. The samples were then transferred to a class-10 clean hood where an amount of 50% concentrated SEASTAR BASELINE® $HNO_3$ was added to each sample to give pH= ~3. The samples were capped and shaken to make sure the acid is well mixed before taking aliquot for trace metal analysis. Sample aliquots for trace metals were then frozen in -25$^oC$ freezer until they were frozen-shipped for analysis.

Analysis of trace metal quantification was carried out using a Thermo-Fisher (XSeries II) ICP-MS at the Laboratory of Aquatic Sciences and Biogeochemistry, Department of Chemistry, Trent University.

### *6.2 Snow samples for THg quantification*

Samples for total Hg analysis, contained in glass bottles with aluminum foil wrapping, were kept frozen in the -25$^oC$ freezer until they were sent for analysis at the Centre for Earth Observation Science, Department of Environment & Geography, University of Manitoba. Quantification of total Hg was carried out using an atomic fluorescence spectrometry. No sample pre-treatment at GSC laboratories were carried out.

### *6.3 Snow sample for ion chemistry analysis at GSC Laboratory*

Samples for ion chemistry analysis were preserved in the -25$^oC$ freezer until they were analysed at GSC glaciology laboratories. At the beginning of analysis, samples for ion concentrations were taken out the freezer and hanged on strings to thaw in a regular glaciology chemistry laboratory where a dust particle remover with a HEPA filter was installed and ran continuously. Once the samples were thawed, an aliquot from each sample was taken into an analytical tube and analyzed using a Dionex IC 110 that was also installed in the laboratory.

## 7. Quality Assurance/Quality Control

### *7.1 Analytical precision and accuracy*

As results achieved in this study are used for environmental evaluation and assessment of lake waters, aiming to understand the local background, the contribution from long range transportation and the effect from the regional mining activities, accuracy of the results directly affects the quality of study. Therefore, special attention has been paid to data quality control throughout this study.

To guarantee sound precision and accuracy for data achieved in this study, a multi level control has been adapted, including

1). Use of world-wide recognized certified reference materials. These materials were used for monitoring the accuracy of analytical instruments and methods during quantification of samples.

For other metal analysis, SRM 1643e (Trace metals in water) from the National Institute of Standards and Technology (NIST) was used to monitor the method and instrument response.

2). Multi-level ICP standards are used for concentration calculation in samples. Multi-level standards are needed in order to more precisely calculate sample concentrations, especially for elements with less linear responding signals. To verify the analyzer's recovery, internal standards, Rh and In, were used. The overall percentage recovery was 93 +/-7%.

3). Duplicate sampling and replicate sample analysis. Replicate samples help reduce random sampling errors and increase precision (and therefore accuracy); and

4). Laboratory and field blank control and monitoring. Blanks help estimate the background contribution of concerned elements from the container, analytical system and the analytical method.

### *7.2 Contamination control in the field*

Relevant historical data were collected and reviewed before field trip. Those historical data help design sampling site assignment and to judge the correctness of data range and trends found in this study;

Fair representative of sampling sites to reflect the field reality is critical for the quality of results. Therefore, two lakes and their nearby area were sampled in a higher space resolution. And sites far behind the tree line were planned and sampled. Those sites can not only provide the local background level but also can serve as a rough measure of concentrations of metals in the other sites south of the tree line where more activities occurred.

In this study, precaution has also been taken from sampling tools, field instrument preparation, sample container preparation and protection to contamination protection facility such clean jackets and gloves. To estimate the sample background from containers and field air contribution, field blanks were taken when possible and feasible.

To increase sampling precision and therefore to increase field sampling accuracy, duplicate or replicate samples were taken in a certain interval depending on field situation and capacity available.

Special sampling site assignment. Special and careful sampling site assignment helps increase the representative of the reality by a fair amount of samples taken in the filed;

Special sites for natural background assessment. Background samples are necessary for apportion of anthropogenic contribution;

## 8. Acknowledgements

This snow sampling activity of the GSC project “Ecosystem cycling of metals near gold and diamond deposits of the Slave Geological Province, NWT”, operating in the “Environmental Impact Assessment in the Northern Environment” Project of the “Environmental Geoscience” Program is to collect snowpack samples from along and out from the Tibbitt to Contwoyto Winter Road (TCWR) spanning a latitudinal gradient that crosses treeline.

The field sampling was supported by in-kind support from the Tibbitt to Contwoyto Winter Road Joint Venture (TCWR-JV), DeBeers, Seabridge Gold, Northwest Territories Geoscience Office (NTGO), Carleton University, Ottawa, Queen’s University, Belfast, and the North Slave Métis Alliance, and the Yellowknives Dene. Direct funding is provided by the Geological Survey of Canada.

We like to thank the Northwest Territories Geoscience Office and the Tibbitt to Contwoyto Winter Road Joint Venture for their kind support. Their knowledge, direct support and equipment were valuable and critical to this study. The mining company, Seabridge Gold Ltd. and its staff is specially thanked for their kind support of helicopter flight time, lodgings and transportation between Yellowknife and Diavik site. Mt. Bob Reid and Mr. Derek Forsbloom with Water Survey of Canada (Yellowknife) Environment Canada is thanked for their 2 snowmobiles and trailer loan. We also like to thank our team members, especially Dr. Jenifer Galloway, who helped much work on coordination and logistics for this field trip.

Sample analysis was carried out and supported by collaborators listed below:

Prof. Gary Stern

Centre for Earth Observation Science
Dept. of Environment & Geography, University of Manitoba
474 Wallace Building, 125 Drysart Road

Winnipeg, MB Canada, R3T 2N2
Tel: (204) 474-9084
Prof. Celine Gueguen
Canada Research Chair in Aquatic Sciences and Biogeochemistry
Trent University, Chemistry Dpt.
1600 West Bank Drive, Peterborough, ON, K9J 7B8
Phone: (705) 748-1011 Ext 7859 or 6315
Fax: (705) 748-1625

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