

GSC Scientific Presentation 88 – Presenter’s notes

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Slave Geological Province

Hope Bay (TMAC; qz-carbonate vein Au)

Tundra/Salmita (legacy contamination; new claims by Seabridge; qz vein Au)

Giant Mine (legacy contamination; new claims by TerraX; shear zone hosted Au)

During the first decade (~1947-1957) of operations at Giant Mine thousands of kg of As₂O₃ were emitted per day (estimated total 24,566,040 kg) directly to the atmosphere until emission controls were implemented in the early 1950s. These included first an electrostatic precipitator and then a baghouse. 2500 tonnes of As₂O₃ were produced from the Con Mine Roaster.

Giant: The site is 950 ha (2,300 acres) in size. It contains 8 open pits, 4 tailings ponds, 325,000 m³ of contaminated soils and approx. 100 buildings. Most of which, including the roaster and baghouse, have now been taken down.

A major challenge is the safe long term storage of 233,000 tons of arsenic trioxide dust. Currently this is back filled in the stopes to be kept frozen in perpetuity by thermo-siphons, that are similar to what is used in hockey rinks. This approach is known as the “Frozen Block Method”.

The site is owned by the Federal Government of Canada and remediation is estimated to be about 900 million to 1 billion dollars.

Other mines: Beaulieu Mine 1947-1948

Burwash Mine 1935

Camlaren Mine 1962-63, 1980-81

Con Mine 1938-2003

Discovery Mine 1950-1969

Giant Mine 1948-2004

Negus Mine 1939-1952

Outpost Is Mine 1941-42, 1951-52

Ptarmigan & Tom Mine 1941-42, 1985-97

Ruth Mine 1942, 59

Thompson-Lundmark Mine 1941-43, 1947-49

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Geochemical background refers to natural variations in the concentration of elements in the environment, whereas “baseline” may include both geogenic and anthropogenic inputs (Salminen and Tarvainen, 1997; Salminen and Gregorauskiene, 2000; Reimann and Garrett, 2005). Careful determination of both geochemical background and baseline is necessary to assess chemical change in the environment and provide guidelines for regulation and policy.

“Temperature anomalies with respect to 1901 to 1950 for the whole Arctic for 1906 to 2005 (black line) as simulated (red envelope) by MMD models incorporating known forcings; and as projected for 2001 to 2100 by MMD models for the A1B scenario (orange envelope). The black line is dashed where observations are present for less than 50% of the area in the decade concerned.” Source: courtesy of: IPCC WG1 AR4 Report Fig 11.18. ARC = Arctic

“... changes in surface air temperature ($^{\circ}\text{C}$, left), precipitation (mm day^{-1} , right) ... for winter (DJF, top) and summer (JJA, bottom) predicted by climate change models for 2080-2099 relative to 1980-1999. Stippling denotes areas of uncertainty in the models. The largest increase is predicted for the Arctic, where winters will be more than 7.5°C warmer on average in 100 years. Source: courtesy of: IPCC WG1 AR4 Report Fig. 10.9. Partial.

In the natural environment, bioavailability and mobility of As controlled by pH and redox conditions

Solubility, mobility, and toxicity of As depend on concentration and speciation (reduced As III more soluble and toxic than As V, inorganic As more toxic than organic forms). Depends on redox conditions and pH that affect speciation (AsV stable in oxic waters and As III predominate species in reduced redox environments) and precipitation/dissolution of solid-phases (As-Fe and Mn oxides) and sorption and desorption on mineral surfaces

Solid-phase AsV (arsenate) released from sediments as AsIII (arsenite) that diffuses upwards through porewater and is released to overlying surface waters or re-precipitate in oxic sediments.

What affects redox conditions? Lake stratification, oxygen consumption by decaying OM, microbial-mediated redox processes in sediments, etc.

As cycling in sediments makes it precarious to infer contamination from sediment interface As enrichments

But serves as a warning that alteration of the organic geochemistry of aquatic sediments by enhanced OM fluxes may have unanticipated effects for As mobility

OM compounds are redox reactive and can mediate the release and redox transformation of solid-phase As(V) at depth in the sediment column to As(III), which can diffuse upward to be released to overlying waters or re-precipitate in oxic sediments (Lovely et al., 1996; Redman et al., 2002; van Geen et al., 2004). These processes can result in substantial surface sediment enrichment of As (Martin and Pedersen, 2002). Interactions between As and OM also include competitive adsorption (Grafe et al., 2001; Redman et al., 2002), stabilization and physical

coating of As-bearing colloids (Neubauer et al., 2013), OM and dissolved OM-Fe complexation with As (Langner et al., 2012, 2014) and carbon-limited microbially mediated precipitation of As-bearing minerals (Kirk et al., 2004).

Macdonald, and Fyfe. 2005. Recent climate change in the Arctic and its impact on contaminant pathways and interpretation of temporal trend data. *Sci Total Environ* 342: 5-86.

Sullivan and Aller 1996. Diagenetic cycling of As in Amazon shelf sediments. *Geochim Cosmochim Acta* 60: 1465-77

Example: Martin and Pedersen, 2002. *Environ Sci Tehcnol* 36: 1516-23.

Temperate ice-covered lake impacted by Cu, Zn, Ni, As. Reduced metal loading promoted lake recovery □ inc. phytoplankton production. Enhanced OM flux □ reduced oxygen through metabolism in sediment. Mediated conversion of As(V) to As(III) that diffused back into lake's bottom water

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To answer the question – but are elevated As concentrations in the YK area due to mining or mineralization? We used a meta-analytical approach and tested the hypotheses that sedimentary As concentrations were related to the following variables: lake order (Strahler stream order), lake connectivity, lake area, catchment area, catchment vegetation, bedrock geology, distance from Giant Mine, direction from Giant Mine, sedimentary particle size, and organic matter constituents as measured using Rock Eval pyrolysis.

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XRF: A synchrotron-based micro-analytical approach used to characterize target grains in thin sections of selected lake sediment samples. Micro XRD, micro X-ray absorption near edge spectroscopy (microXANES; solid phase speciation) and electron probe microanalysis (EPMA) permits semi-quantitative determination of proportions of As⁵, As³, and As¹. These proportions and the crystalline structure of roaster derived particles is now known and can be compared to particles in soils and sediments outside of mine lease area (our research). In this way, we may be able to determine if As in lake sediments are geogenic or anthropogenic in source.

XRD: The bottom slide shows the microXRD information for the target particle that appear red (As-rich) in the previous slide's element map. We use a focused X-ray beam generated by the synchrotron to do X-ray diffraction on a small area. It is similar to regular XRD except focused on a spot. The rings are a 2D representation of the diffraction pattern. The upper right shows the 1D xrd pattern for that spot, and the lower right box shows the fit to three minerals - gypsum, quartz and arsenolite. This proves that the particle is arsenic trioxide.

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extended X-ray absorption fine structure (EXAFS) spectroscopic studies have revealed that reduced organic sulfur (S) and oxygen/nitrogen (O/N) groups are involved in the complexation of Hg(II) to humic substances extracted from organic soils

Nanoscale secondary ion mass spectrometry (nanoSIMS or nano secondary ion mass spectrometry) is a nanoscopic scale resolution chemical imaging mass spectrometer based on secondary ion mass spectrometry. [

Advanced analytical tools with the capability to visualize and characterize organic matter at the submicrometer scale, such as Nano Secondary Ion Mass Spectrometry (NanoSIMS) and Scanning Transmission X-ray Microscopy (STXM) coupled to Near Edge X-ray Absorption Fine Structure Spectroscopy (NEXAFS), may be combined to locate and characterize mineral-associated organic matter.

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Figure 2 Wind rose depicting wind energy, frequency of direction and mean wind speed at the Yellowknife airport using data from Environment Canada (2001-2007). The shaded rose shows the relative wind energy by direction, and the outlined rose is the wind frequency of occurrence by direction. The mean wind speed by direction sector is indicated at the end of each axis. From Pinard et al. 2008.

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Background arsenic concentrations in lake sediment range from 34 – 111 mg/kg

Mining-related impacts extend to 5 – 10 cm depth in lake sediments and post-depositional mobility of arsenic is evident in all lakes.

Mineral hosts and form of arsenic in sediments depends on the source of arsenic and distance from the mine site.

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TK and Inuit Qaujimagatunangit studies on past climate and environmental change and mine-related impacts to communities and ecosystems. Combined with western science □ knowledge assemblage that includes human contextual information

TK is a holistic knowledge system (e.g., Tłı̄chǫ concept of ndè)

TK and paleontology are complementary: both are synchronic

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In near-surface sediments at shallow water sites, the dominant host of As is Fe-oxyhydroxide. Congruent pore water profiles for As and Fe show that post-deposition mobilization of As is governed by reductive dissolution of As-bearing Fe-oxyhydroxide.

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Figure 6 Concentrations of dissolved arsenic in lake waters from 98 lakes in the Yellowknife area with distance from the roaster stack at Giant Mine. Individual lakes are symbolized according to underlying bedrock geology according to Wright et al. (2006). The dashed line at 10 µg/L represents the Health Canada Drinking Water Guideline for arsenic. The dashed and dotted line at 5 µg/L represents the CCME Guideline for the Protection of Aquatic Life for arsenic. The relation between the two variables is represented by the following equation: $y = 437.28x - 1.57$; $r^2 = 0.58$; $N = 98$; $p < 0.01$; $F_{1,97} = 128.87$.

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Conceptual diagram showing processes controlling As cycling within lakes impacted by roaster emissions. Aerially transported As aerosols settle into the lake and slowly dissolve during burial, releasing As^{III}. Elevated concentration of As in reducing porewaters leads to both in-situ precipitation of As-bearing sulfides and diffusion of As to lake waters. Arsenic in oxic lake waters oxidizes and sorbs onto available particulate matter such as Fe-oxyhydroxides, that precipitate in the sediment-water interface. Sorbed As is subject to reductive dissolution during burial and re-mobilization in porewaters. Arsenic hosts also weather from surrounding soils and bedrock, but this is a minor source of As to sediments. Arsenic sulphides precipitates, as well as rare geogenic As hosts, are considered relatively stable in anoxic sediments.

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A number of different geologic settings are suitable for CO₂ storage including..... Large-scale implementation of CCS will require CO₂ storage in saline aquifers which have by far the largest capacity amongst the options listed. The Aquistore project where we are conducting our studies is a pilot project demonstrating CO₂ storage in a saline formation.

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The Aquistore CO₂ Storage site is located in SE Sask in the northern Williston. It is ~80 km from the Weyburn EOR field.

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The CO₂ Capture Plant is shown here after completion in 2013.

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What is our role? We are focusing on two specific areas of research: monitoring methods and induced seismicity. The expected outcomes are as listed.

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At the Aquistore site, a permanent array of 630 geophones (green dots) was deployed to 1) monitor the migration of CO₂ in the subsurface and 2) listen for any induced seismicity at the site.

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Based on this assessment, the deepest well in SK was drilled to a total depth of 3400 m. This is the CO₂ injection well.

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110 ktonnes