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Late Holocene climate and chemical change at high latitudes: case studies from contaminated sites in subarctic and arctic Canada

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Climate variability is occurring at unprecedented rates in northern regions of the Earth, yet little is known about the nature of this variability or its influence on chemical cycling in the environment, particularly in areas with a legacy of contamination from past resource development. We use a paleolimnological approach to reconstruct climate and chemical change over centuries and millennia at two sites in the mineral-rich Slave Geologic Province in Northern Canada heavily impacted by gold mining. Such an approach is necessary to define the cumulative effects of climate change on metal loading and can be used to define anthropogenic release of contaminants to support policy and regulation due to a paucity of long-term monitoring data.

The Seabridge Gold Inc. Courageous Lake project is a gold exploration project 240 km north of Yellowknife in the central Northwest Territories, Arctic Canada. Mining operations took place within the claim area at the Tundra (1964-1968) and Salmita (1983-1987) mines. Giant Mine is located in the subarctic near the City of Yellowknife and mining at this site represents the longest continuous gold mining operation in Canada (1938 to 2002). Due to the refractory mineralogy of ore, gold was extracted from arsenopyrite by roasting, which resulted in release of substantial quantities of highly toxic arsenic trioxide to the environment. Arsenic (As) is also naturally elevated at these sites due its occurrence in Yellowknife Supergroup greenstone belts and surficial geologic deposits. To attempt to distinguish between geogenic and anthropogenic sources of As and characterize the role of climate change on metalloid mobility we used a freeze coring technology to capture lake sediments from the properties. Sediments were analyzed for sedimentary grain size and bulk geochemistry using ICP-MS to reconstruct climate and chemical change. Micropaleontological analyses are on-going. Interpretations of the physical, chemical, and biological archive preserved in the lake sediment cores are informed by our characterization of sediments from over 50 lakes in the region.

In the longer record obtained from the Giant Mine area we show that the concentration of aqua regia leached As increases prior to resource development and that concentrations are variable over millennia. Lowest concentrations of As in the $\sim$3500 cal yr BP record are coincident with regional Neoglacial cooling. As concentrations begin to increase from concentrations near 100 ppm to over 1000 ppm in the lastest Holocene, coincident with a period of regional warming associated with the Medieval Warm period, although at this point we cannot rule out post-depositional remobilization of As from higher in the sediment column. Concentrations in excess of 10,000 ppm at the top of the sediment core are likely associated with anthropogenic release of this contaminant. At the more northern Courageous Lake site, the sediment record extends back about a hundred years, and reveals that concentrations of As in lake sediments prior to development of the area were about 40 ppm. Increases in As are associated with drilling and mine production but continued increases after 1999 may be due to remobilization of As due to on-going climate warming, recent remediation efforts, or vertical movement of this element in the sediment column.