GEOCHEMICALLY FINGERPRINTING SPATIAL AND TEMPORAL RECOVERY OF A HIGHLY ANTHROPOGENICALLY DISTURBED LAKE: TORCH LAKE, (UPPER PENINSULA) MICHIGAN, USA

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ABSTRACT

With the objective of monitoring the recovery of Torch Lake after cessation of mining and associated activities, sediment cores were taken spatially from four depositional basins of the lake during the summer of 1999. Cores were sectioned, total metal content extracted by microwave digestion and analyzed for 22 metals using hexapole inductively coupled mass spectrometry and atomic absorption spectroscopy. Sediment ages were determined via ^{210}Pb and ^{137}Cs. Our approach was to compare ratios of metal concentrations expected from surrounding rocks, sediments and soils, and values from a reference lake to assess recovery in Torch Lake. Results showed that 1) Torch Lake is coming to geochemical equilibrium with the watershed, 2) copper loadings have not decreased since mining activities have stopped and 3) a multi-elemental approach is an effective way to assess the recovery of ecosystems disturbed by human perturbation.

INTRODUCTION

Torch Lake is located in the Keweenaw Peninsula of Upper Michigan near the town of Linden. The lake measures 2.2 km wide and is 9.3 km long, with a maximum depth of 36 m and an average depth of 17m (Ellenberger et. al. 1994). For approximately 100 years (1860's-1960's) heavy metal concentrations in the sediments of the lake were dominated by anthropogenic inputs related to copper mining activities (e.g. Ellenberger et. al. 1994, Kerfoot et. al. 1994). Upper Michigan contained some of the largest deposits of native copper in the world, and that copper was mined heavily. Because of the need for steam power during copper extraction processes, the shores of Torch Lake were the preferred location of several stamp mill operations during the 1800's and early 1900's. These mills generated approximately 200 million tons of copper tailings during the processes of metal extraction from the host rock (Ellenberger et. al. 1994). In order for the copper to be separated out by floating or other techniques, large pieces of the parent rocks, which were composed of basalts and conglomerates, were crushed into sand sized particles known as "stamp sands" (Kerfoot et. al. 1994). These stamp sands were a byproduct and disposed of directly into Torch Lake and on the surrounding area. Intense mining activities stopped in the region during the 1960's, but the mining legacy still exists in the form of stamp sands lining the shores, continually affecting lake chemistry. A discharge of cupric ammonia carbonate (a commonly used copper leach liquor) occurred over the time span of October 1971 through June 1972, discharging nearly 27,000 gallons directly into the waters of Torch Lake (Wright et. al. 1973). As a result, in recent years much focus has been placed on the high amounts of copper found in the sediments.

The U.S. Environmental Protection Agency (EPA) placed Torch Lake and its surrounding areas on the Superfund list in 1986, and over the last four years, the EPA has begun remediation efforts in order to stop the continued direct input of stamp sands from shoreline sources. Efforts include the covering of the exposed stamp sands with sands and loams, which were then covered with seed, in hopes that grass will take root. Trees, shrubs, and other rooted plants have also been put in place to try to control the erosion of the stamp sands into the lake.

The goal of this research is to monitor how the lake is responding to less anthropogenic inputs, in order to better asses the future of recovery in the lake. Assessing the degree of recovery in disturbed environments can be done with different approaches. The first is a target specific approach designed to evaluate the trends of a single element of interest, for example, copper. Temporal changes in concentration are examined over time and an assessment is made about how the lake is responding by that trend. Another approach is done via a multi-elemental characterization. At Torch Lake, a multi-elemental approach was taken, which examined ratios of metals in a reference lake and in local rock types. This information may later be used to calculate an approximate date that the lake will be at or close to natural levels of heavy metal concentrations in the surface sediments.

METHODS

Torch lake cores were taken from four different proposed depositional basins including deepest point. These sites were located in areas where sediment actively accumulates, thus ensuring a good temporal record. Samples were collected using a MC-400 Lake/Shelf Multi-corer designed by Ocean Instruments. This multi-coring device was deployed from an EPA research vessel, the R/V Mudpuppy. On the boat, sediment cores were inspected in order to ensure a core taken is of good quality. Cores were considered to be good quality (undisturbed) if the core is horizontal at the sediment/water interface and the water present in the core tube is clear. After the cores were taken off the boat, sediments were extruded using a manual-extruding device. The cores were sectioned into slices approximately 0.5 to 1 cm in thickness. After sectioning, the sediment was placed into acid (10% HCl) washed sample containers, and were then cooled at 4° C until metal analysis.

To begin analysis, samples were homogenized and freeze-dried. Total metal content was determined in the samples using a nitric acid digestion in a CEM-MDS-81D microwave (Hewitt and Renolds 1990). In every microwave run, aliquots of a standard reference material (NIST Buffalo River Sediment standard #2704) and a blank were digested to satisfy QA/QC (Long et. al. 1995; Kolak et. al. 1998). After digestion, the sample were diluted and filtered with 0.40 µm acid washed nucliopore filter. HEX-ICP-MS was used to quantify the metal concentrations. Elements analyzed for included Cu, As, Pb, Ba, U, Al, Ca, Mo, Mn, Ni, Fe, Se, Sc, Ti, V, K, Cr, Co Zn, Sr, Hg and Mg. Some of the major cations (Ca, Mg, and Fe) were measured using a Perken-Elmer 5100 PC atomic absorption spectrometer. Ages of slices were determined using ^{210}Pb along with ^{137}Cs in three of the four cores. These samples were sent to The Freshwater Institute located in Winnipeg, Manitoba, Canada for analysis.

RESULTS AND DISCUSSION

Sediment cores were dated with ^{210}Pb using a constant flux sedimentation model and confirmed with ^{135}Cs. However, dates younger than 1955, or only the top sediments (about 10 cm) could only be reliably dated. ^{210}Pb dating methods are not considered valid beyond that date, due to the inputs of the ^{210}Pb deficient mine tailings and disturbance of the ^{210}Pb record by dredging operations (Kerfoot et. al. 1994). Cores from Torch Lake consisted of two layers, which were composed of two very different sediment types. Distinct differences both visually, and for most elements, geochemically, existed between them. The top layer, approximately 10cm thick, consisted of a fluffy brown material. This is sediment that has presumably been deposited since 1955 or about the time when the direct inputs of mining related sediments had stopped. This layer is thought to represent inputs of local sediments and referred to as the "cap layer". Fine particles of stamp sands and other mining related sediments such as slags (material generated from the copper smelting process) comprised the rest of the core, this material was a pinkish-purple color.

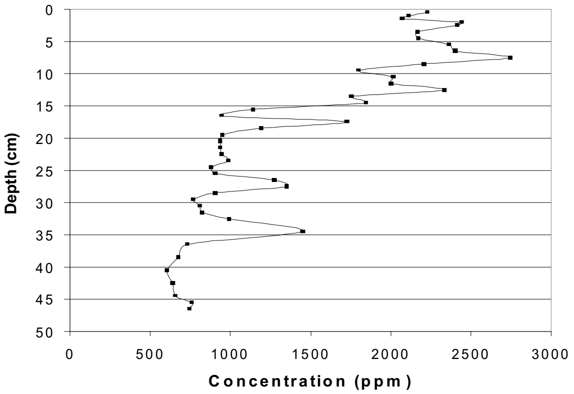

Figure 1. A Graph of Copper concentrations with depth, showing an increasing trend.

Copper values in the cores of Torch Lake have a trend of increasing concentrations towards the surface sediments (Figure 1). Mine tailings seem to have been more deficient in copper than what is coming into the lake presently. This is an opposite trend from expected for copper values in this core.

Since cores were analyzed for twenty-two metals, trends of other metals could be examined. For example, titanium (Ti) has a very sharp decrease in concentration towards the surface sediments (figure 2). This is due to the Ti present in the parent rock, which comprise the stamp sands. As the stamp sands were being discharged into the lake, there was enrichment in Ti concentrations. As stamp sands discharge decreased, Ti values rapidly decreased.

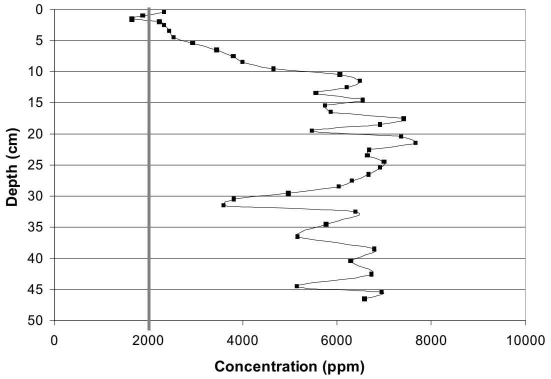

Figure 2. A graph showing the trend of Ti values. 2000 ppm is the estimated background concentration for local rocks.

Ratios of metals were assessed to determine the degree of perturbation and in turn recovery of the lake since mining activities stopped. However, background values were not reached. According to Wright et. al., 1973 approximately 20% of the lake volume had been filled between 1946 and 1970. Prior to 1946, the amount of volume filled is not known. Since background values for heavy metals could not be taken from these cores, a lake in the northern Keweenaw Peninsula, Gratiot Lake, was chosen to be a reference lake. This lake was chosen to be a representative reference lake for three important reasons, 1) both Torch Lake and Gratiot Lake have the same surfacial geology, (Jacobsville Sandstone) (Reimann and Caritat, 1998), 2) land cover (Maple Birch) and 3) Gratiot Lake has not been impacted so heavily by copper mining activities.

These lakes could not be compared with absolute concentration values. This is presumed to be the result of the high productivity of Gratiot Lake, and organic carbon dilutes the heavy metal concentration in the sediments. As a result, ratios of elements were examined in order to test the degree of recovery in Torch Lake (Table 1).

	Co/V	Ba/Ti	Cu/V
Local rocks "natural"	.06	.2	.9
Gratiot Lake	.09	.23	.9
Torch Lake "cap"	.26	.07	14
Torch Lake "stamp sands"	.40	.01	12

Table 1. Values for heavy metal ratios

The ratios of heavy metal concentrations in Gratiot Lake are close to the expected natural levels for the western Keweenaw Peninsula. Data from the table demonstrates the Gratiot Lake watershed had not been disturbed by mining activities and can be used to represent background concentrations of heavy metals for Torch Lake. Values from Torch Lake were examined to assess the degree of recovery from mining related sediments to natural sediments. As a result of less anthropogenic burdens, levels of heavy metal ratios are approaching that of Gratiot Lake. For example, the Ba/Ti ratio has increased by a factor of seven and the Co/V has been decreased by half, these values are becoming more reflective of Gratiot Lake. Values for Cu/V ratios indicate sediments still remain high in copper concentrations at Torch Lake years after mining activities stopped. Although copper concentrations remain high in Torch Lake, other metals exhibit trends that demonstrate the lake is recovering, and suggest the entire watershed is coming back to geochemical equilibrium.

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