DISTRIBUTION OF HEAVY METALS IN CONTAMINATED SURFACE WATERS AND ALKALINE TAILINGS WITH *TYPHA LATIFOLIA* IN A WETLAND ENVIRONMENT, CROSSWISE LAKE, COBALT, ONTARIO[1]

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Abstract: Crosswise Lake hosts the largest accumulation of alkaline tailings in the Cobalt silver mining camp. Tailings were deposited in the north end of the lake by at least five different mills operating between 1908 and 1970. Tailings now blanket the entire lake floor and a lowland through which Farr Creek drains Crosswise Lake and Mill Creek drains surface water bodies from the Cobalt Lake part of the camp. The northern portion of these tailings has been flooded by construction of a water-control dam to form a permanent wetland in which *Typha latifolia* is the dominant species.

Water flowing through this wetland carries elevated concentrations of arsenic and many heavy metals, including cobalt, copper, lead, molybdenum, nickel, and zinc. Sampling of *T. latifolia* leaves and roots in the wetland indicate that the plants are elevated in most elements compared to background samples, with the roots generally being higher than the leaves. Element concentrations in the roots were less than 15% of the average values for sediment surrounding the roots, while most metals in the leaves generally had concentrations less than 15% of the root values. Molybdenum concentrations were the exception, averaging 85% of the tailings sediment value in the roots and 5x the sediment value in the leaves. The average Mo concentration in the background sediment was twice that of the tailings sediment and leaf values averaged 50% of the sediment average value. For some elements (Ag, Cd, Cr, Cu, Pb, Sb and Zn) the concentrations in the background leaf samples were as high as the tailings leaf samples, even though the background sediment had lower concentrations than the tailings.

Key Words: passive treatment, natural attenuation, phytoremediation, alkaline mine drainage, arsenic

Introduction

The discovery in 1903 of silver-arsenide mineralization hosted in carbonate veins led to the development of Cobalt as a major mining camp. Initial high-grade mining and hand cobbing of ore resulted in silver concentrates being shipped elsewhere for processing, with localized piles of waste rock dumped at the individual mine sites. The construction of mills to process the ore, starting in 1907, in turn led to the discharge of mill effluent slurries (tailings), containing finely ground waste rock, unrecovered metals (Ag, Co, Cr, Cu, Fe, Ni, Pb, Sb, Zn), arsenic, and other chemicals used in the mills, into the local lakes and low-lying areas. Release of metals and arsenic from tailings can contaminate downstream environments and can affect the health of aquatic species and humans for long periods of time following the cessation of mill activities. Therefore, it is important to characterize the distribution of metals in aquatic environments and the geochemical and biological processes regulating the transformation of these metals.

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The deposition of tailings in low-lying areas that may become seasonally or perennially flooded makes wetlands an important component of the potentially affected ecosystem. Constructed and natural wetlands have been utilized by mining companies because of their ability to attenuate metal contamination (Berghorn and Hunzeker 2001).

Several studies examining metal distribution in the tailings and water of the Cobalt camp were undertaken during the 1990s (Dumaresq and Michel 1992, Dumaresq 1993, Percival et al. 1996, 2004). Kelly (2006) and Kelly et al. (2007) examined the distribution of metals in five different sediment fractions (exchangeable, carbonates, oxides, organic matter, and residuals) from cores collected in a wetland situated on the Crosswise Lake tailings at Cobalt, as well as local surface waters and pore waters from the tailings. Kelly found that metals were primarily bound in the residual, oxide, and organic matter fractions of the sediment. Iron and sulfate reduction led to the immobilization of metals through the formation of metal sulfides. Kelly also noted that detectable concentrations of metals were present in several leaf samples of *Typha latifolia* and suggested that metal uptake by plants had occurred throughout the wetland; however, no background soil and vegetation data was available at the time for comparison. Previous studies have shown that metal uptake by plant materials, such as *T. latifolia*, can be over 90% of the total metal mass distribution and that higher percentages of metals are associated with the roots than the leaves (Jackson et al. 1993, Mays and Edwards 2001).

The objectives of this study were to undertake a preliminary examination of the distribution of metals occurring in the root and leaf portions of *T. latifolia* in the Crosswise Lake tailings wetland relative to uncontaminated wetlands in the Cobalt area and to determine the degree of metal uptake.

Study Area

The Crosswise Lake tailings deposit is the largest single accumulation of tailings in the Cobalt area (Figure 1), where five mills discharged effluent to the lake and adjacent lowland from 1908 to 1970. Tailings can be found covering the entire floor of the entire present lake (over 2 km long) in addition to completely infilling the northern 800 m of the original lake and 1.7 km of downstream valley. Tailings also migrated to the lowland from mills operating upstream in the Mill Creek and Sasaginaga Creek watersheds. The water level of Crosswise Lake is regulated by a low concrete spillway across which water discharges to form Farr Creek. Mill (and Sasaginaga) Creek flow into Farr Creek approximately 150 m below the spillway.

Construction of a water level control dam on Farr Creek at the north end of the tailings deposit caused flooding of the lowland, creating a permanent wetland with areas of open water and a dense vegetation of *T. latifolia*. Wetlands containing *T. latifolia* also exist on tailings along Mill Creek and Sasaginaga Creek, with the Town of Cobalt recently constructing a wetland on the latter creek for municipal sewage treatment.

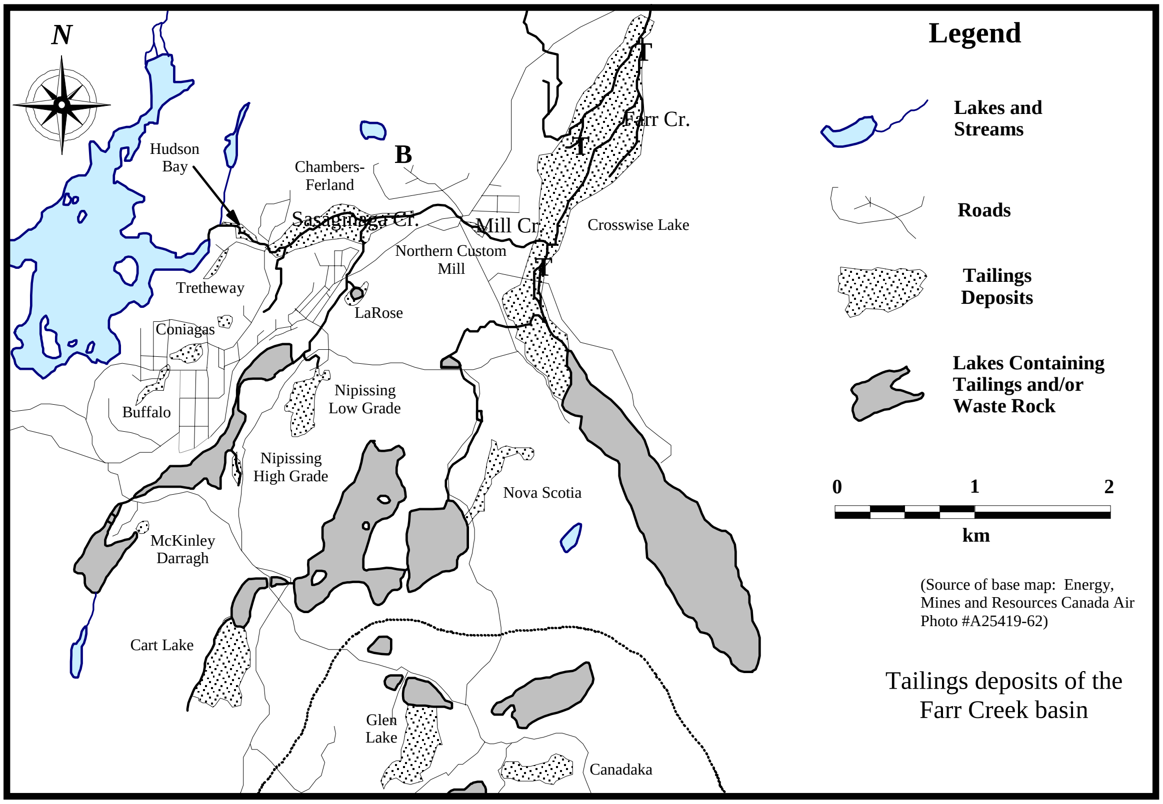

Figure 1: Distribution of tailings in the Cobalt area and the sampling sites on the Crosswise Lake tailings (T) and the background sites (B). Two of the background sites are to the west of the map, (modified from Dumaresq, 1993).

Methodology

For this study, samples of leaf, main root, and soil surrounding the roots of *T. latifolia* were collected from three sites along the length of the Crosswise Lake tailings between the spillway and control dam. In addition, samples of T. latifolia were collected from three tailings-free background sites located at the outlets of Gillies Lake and Girioux Lake, and a small tributary valley of Sasaginaga Creek (Figure 1).

Samples were placed in plastic bags and refrigerated until prepared for analysis at Carleton University. Leaf and root samples were washed, dried and crushed. Soil samples were washed, screened to remove small rootlets, and dried. All samples were analysed by ICPMS at Queen's University.

Results and Discussion

The mineralogy of the Cobalt deposits is complex, but the main elements associated with the silver-arsenide mineralization that were analyzed in this study include Ag, As, Co, Fe, and Ni. The silver deposits contain only minor sulfides; however, small massive sulfide lenses do occur with local Archean-age volcanics and may be a source of Cu, Fe, Mo, Pb, and Zn. Minor Cr may be associated with the intrusive Nipissing diabase. Both the volcanics and diabase were mined as wall rock adjacent to the narrow silver-arsenide bearing carbonate veins and, therefore, some of the associated metals can be expected to occur in the tailings.

Kelly (2006) investigated the distribution of metals in the sediment fractions, pore water, and surface water of the Crosswise Lake tailings in 2004 and 2005, Table 1 provides a summary of the average concentrations reported for select elements. The sediment values represent 12 tailings samples cut from cores at a depth of 25 +/- 2.5 cm, which is well below the root zone of plants present and below the accumulation of organic matter in the wetland. The pore water data included 21 samples extracted from core sections at various depths (0.15 to 1.35 m) and 7 samples from piezometers installed to a depth of up to 1.25 m. The surface water data represent 13 samples collected from Farr Creek and the wetland.

Table 1: Average concentrations of select elements for tailings sediment, pore waters and surface waters at the Crosswise Lake tailings deposit (data in ppm from Kelly 2006).

Element	Ag	As	Cd	Co	Cr	Cu	Fe	Mo	Ni	Pb	Sb	Zn
Tailings	n.a.[1]	23.8	n.a.	792	303	453	63728	n.a.	445	489	74	519
Pore Water (core)	0.036 (9)[2]	2.73	<0.006	0.272	0.058 (15)	0.109	9.70	0.274 (6)	<0.059	0.379 (6)	1.41	0.201
Pore Water (piez)[3]	<0.014	2.04	<0.006	0.176	<0.016	<0.012	2.81	<0.036	<0.059	<0.213	<0.166	0.035
Surface Water	<0.0001	0.275	<0.0001	0.008	0.0006	0.003	0.084	0.001	<0.01	0.0007 (8)	0.0037	<0.005

1: element not analysed; 2: number of samples used to calculate average; 3: piezometer samples

The tailings contained a wide array of metals in significant concentrations. The surface and pore water samples contained detectable levels of many metals, but Ag, Cd, Ni and Pb were below the detection limit in most if not all water samples. Pore water concentrations were generally one to two orders of magnitude higher than the surface waters, but one to three orders of magnitude less than the sediments. Kelly also analysed several leaf samples from *T. latifolia* and concluded that they contained elevated concentrations of As, Co, Cr, Cu, Fe, and Zn; however, background data were not available for comparison at that time.

In 2006, the sediment samples collected included the material encompassing the roots of *T. latifolia* and often contained a mixture of organic matter and tailings or uncontaminated mineral sediment. The average results for a suite of elements are given in Table 2 for both the background and Crosswise Lake tailings samples. Elemental concentrations for sediment collected from the root zone tailings sediment in 2006 were generally two to three times less than the deeper tailings values reported by Kelly, but were similar to the tailings values when compared to the background sediment values. The tailings sediment has higher average concentrations than the background sediments for every element with the exception of Cd and Mo, for which the background samples were almost twice as high as the 2006 tailings sediment samples. Unfortunately, Cd and Mo concentrations were not determined for the tailings collected by Kelly. For the 2006 samples, silver was below detection in all of the background samples, while Cu and Zn concentrations were marginally higher in the tailings.

Table 2: Average concentrations of select elements for background and tailings samples of sediment adjacent to roots, main root and leaves of *Typha latifolia*. All data in ppm.

Element	Background			Crosswise Lake Tailings		
	Sediment	Root	Leaf	Sediment	Root	Leaf
Ag	b.d.[1]	0.03	0.15	33.8	1.39	0.21
As	41.3	6.38	5.20	1644	199	27.6
Cd	1.9	0.08	0.05	1.05	0.11	0.04
Co	11.3	0.49	0.99	302	48.8	6.30
Cr	23.4	1.78	1.64	101	7.24	2.57
Cu	120	6.49	7.80	174	9.57	6.37
Fe	10260	1269	150	37970	2024	328
Mo	6.80	1.77	3.68	3.95	3.36	20.3
Ni	22.6	1.58	1.70	121	17.7	8.57
Pb	33.7	2.47	6.50	163	15.5	2.59
Sb	3.99	0.23	0.13	22.4	2.77	0.16
Zn	170	19.1	22.9	211	30.7	25.9

1: below detection

Examination of the 2006 vegetation data for the tailings samples shows that the elemental concentrations were generally lower than in the sediment, and root concentrations were higher than the leaf values. Root values were generally less than 10% of the sediment concentration; Ni and Zn are closer to 15%. Molybdenum was an exception, with an average root concentration value that was 85% of the sediment value and leaf sample concentrations averaging six times the root concentration and five times the sediment average. For all other elements, the average leaf concentration was usually less than 15% of the root average value, although Cr, Cu, Ni and Zn range from 30 to 85%.

The data for background samples of sediment and vegetation were typically lower than the tailings data, thus confirming that *T. latifolia* vegetation growing on the tailings at Crosswise Lake is enriched in numerous elements. As noted for the tailings vegetation, the background data show that the roots generally contained less than 10% of the sediment element concentrations; arsenic was 15% and molybdenum was 26%. Although silver was below detection in all background sediment samples, it was present at low concentrations in both sampled parts of the vegetation. Although the element concentrations were generally higher in the root samples than the leaf samples for the tailings vegetation, approximately 2/3 of the background vegetation samples had equal or higher average concentrations in the leaves; with Ag, Co, Mo and Pb at least twice as high in the leaf than the root. In fact, the background leaf samples had average elemental concentrations similar to (difference < 1.5x) or higher than the tailings leaf samples for Ag, Cd, Cr, Cu, Pb, Sb and Zn.

For the background samples, Mo again exhibited high concentrations which were present in the vegetation relative to the sediment, and in both the tailings and background samples the average leaf concentrations were higher than the root values. As noted earlier for the tailings vegetation, the leaf samples averaged 6x the root values, while for the background samples the leaf average was twice the root value. The reason for this high uptake of Mo into the leaves of *T. latifolia* in the Cobalt area is unknown at present.

Conclusions

Vegetation samples collected from *T. latifolia* growing on the tailings of Crosswise Lake contain elevated elemental concentrations relative to samples collected from *T. latifolia* growing in uncontaminated sites of the Cobalt area. Root concentrations were generally less than 15% of the sediment values and the leaf values are usually less than 15% of the root values for samples from the tailings. However, average leaf and root values for background samples were similar for many elements. Sampling either the roots of *T. latifolia* or the sediment surrounding the roots would have provided anomalies for the tailings in all of the elements reported. However, sampling and analysis of only the leaves of *T. latifolia* would have resulted in As, Co, Mo, and Ni anomalies for the tailings. The uptake of Mo by *T. latifolia* requires further study.

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