–Geochemistry of mine waste, mine drainage, and stream sediments from the Vermont Asbestos Group Mine, northern Vermont, USA[1]

Nadine M. Piatak[2], Robert R. Seal II[2], Denise M. Levitan[2], and Jane M. Hammarstrom[2]

[2] U.S. Geological Survey, Reston, VA 20192, USA, npiatak@usgs.gov

ABSTRACT

The Vermont Asbestos Group (VAG) mine consists of the Eden, C-area, and Lowell quarries where chrysotile asbestos was mined from serpentinized ultramafic rock intermittently from 1900 to 1993. The environmental impact of the approximately 9 km^2 landscape characterized by quarries, waste-rock piles, mill-tailings piles, and mine buildings is assessed through the geochemical characterization of mine waste, mine drainage, and stream sediments. Mine waste includes waste rock, mill tailings, and concentrated ore and is predominantly serpentine, pyroxene, olivine, chlorite, magnetite, quartz, brucite, and phlogopite. These samples contain up to 90% chrysotile and the concentrations of Co (95.3 to 125 mg/kg), Cr (1,190 to 1,570 mg/kg), Fe (6.91 to 12.3 wt. % Fe_2O_3), and Ni (1,820 to 2,230 mg/kg) in nearly all samples exceed the U.S. Environmental Protection Agency's (USEPA) remediation goal for residential soils. The concentrations of As (3 to 63 mg/kg) additionally exceed the USEPA's remediation goal for industrial soils. The concentrations of Ni in all stream sediments, of Cr in most sediments, and of As in some sediments exceed probable effect concentrations for sediment-dwelling organisms. The ultramafic source rock is high in Cr and Ni, which explains the high concentrations of these elements in the stream sediments. In contrast to stream sediments and mine waste, concentrations of As, Cr, and Ni in leachates and in waters draining the site are below aquatic toxicity guidelines. Overall, the mine waste and stream sediments at the VAG mine site contain concentrations of As, Co, Cr, Fe, and Ni that locally exceed environmental standards.

Additional Key Words: chrysotile, nickel, chromium, arsenic, Belvidere Mountain

INTRODUCTION

The Vermont Asbestos Group (VAG) mine produced asbestos intermittently from 1900 to 1993. The asbestos is slip-fiber chrysotile with minor cross-fiber chrysotile; the chrysotile variety of asbestos is thought to be less deleterious to human health compared to asbestiform amphibole minerals (i.e., crocidolite, amosite) (Van Baalen et al., 1999). The mine consists of the Eden, C-area, and Lowell quarries located on the east and south flanks of Belvidere Mountain in Orleans and Lamoille Countries, Vermont (Figure 1). The landscape includes open-pit quarries, one flooded pit, waste-rock and mill-tailing piles, mill buildings, and storage silos that cover approximately 9 km². During its peak, the mine was the source of as much as 96 to 98% of the chrysotile mined in the United States (Burmeister and Matthews, 1962). The mining activity resulted in massive waste piles, the largest of which is a tailings pile 900 meters long and over 150 meters high. The asbestos-contaminated waste is estimated to be over 26 million metric tons of material (Vermont Department of Health (VTDH), 2008).

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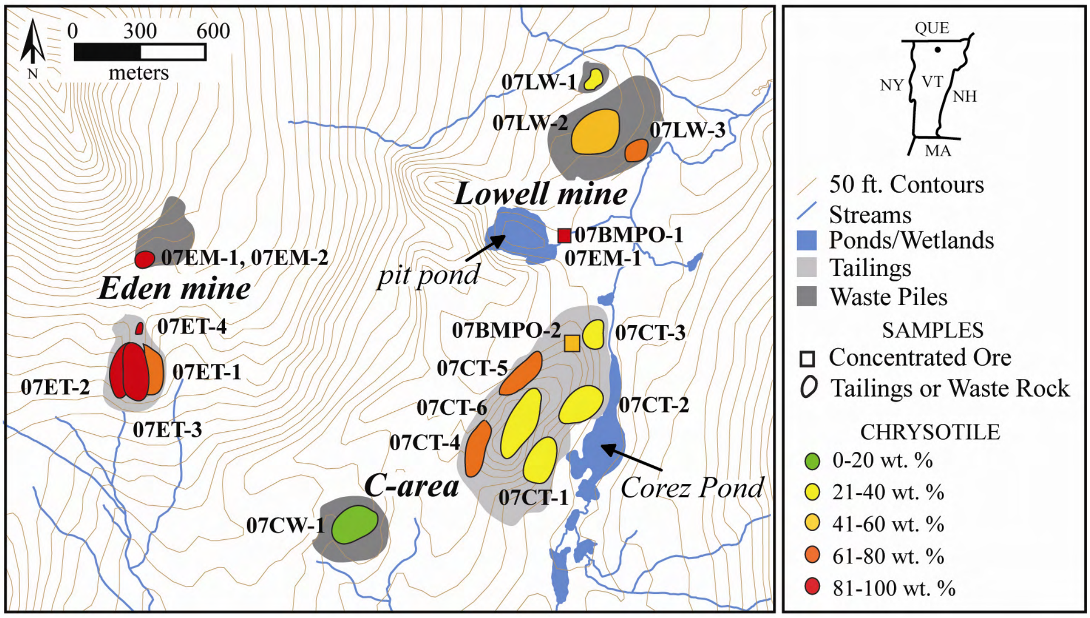

Figure 1. Location of mill tailings, waste rock, and concentrated ore samples from the Vermont Asbestos Group mine. Samples are color coded according to weight percentage of chrysotile fibers.

The degradation of a downstream wetland due to erosion of the waste piles and locally elevated concentrations of Ni, Cr, and As in surface waters has brought recent attention to the site. The erosion of fine-grained material has prompted limited excavations and construction on site. Also, the site has become a growing concern from the perspective of human-health effects, although a recent report found no significant increase in asbestos-related diseases among people living near the mine relative to residents of the rest of Vermont (VTDH, 2008, 2009). This study assesses potential environmental impacts associated with the site by characterizing the geochemistry and mineralogy of the waste material and by examining the chemistry of mine-drainage waters and stream sediments.

SAMPLE DESCRIPTION

Solid samples include composites (at least 30 increments) of the surfaces of the mill tailings and waste-rock piles and grab samples of concentrated processed ore. Composites were collected from the following locations shown in Figure 1: three areas from two waste-rock piles at the Lowell quarry; six areas of mill tailings at the C-area; one waste-rock pile at the C-area; four areas of mill tailings at the Eden quarry; two soils at the Eden quarry. The two grab samples of concentrated processed ore were collected from under a conveyer bucket near the pit pond and from a storage building on the C-tailings pile.

Composites of stream sediments were collected from two watersheds shown in Figure 2. The samples in the first watershed are from Hutchins Brook and tributaries, Dark Branch, and the Gihon River. These sample sites are downstream of the Eden mine quarry and part of the C-area except for two control sites that do not directly receive water from the mine site (Figure 2). Stream sediments from the second watershed are located near or downstream of the C-area and Lowell mine quarry and include Burgess Branch and tributaries, Corez Pond, and the Pit Pond. The control site in this watershed is shown in Figure 2.

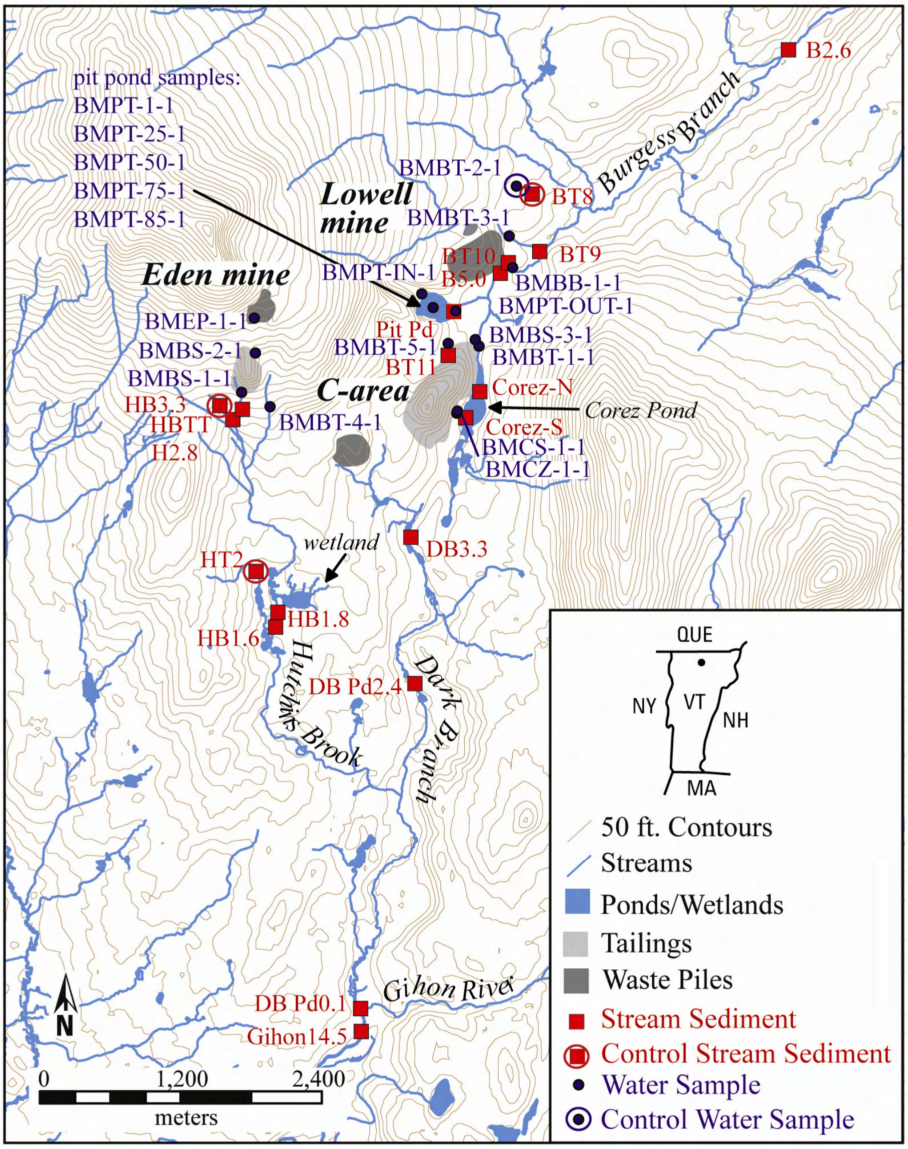

Figure 2. Location of stream sediment and water samples from the Vermont Asbestos Group mine and surrounding area. Tailings and waste piles are the same as in Figure 1.

Water samples were collected at 0.3 m (1 ft), 7.6 m (25 ft), 15.2 m (50 ft), 22.8 m (75 ft) and 25.9 m (85 ft) depths within the flooded pit (pit pond) at the Lowell quarry and from the pit's inflow and outflow (BMPT samples in Figure 2). Water samples also include Corez Pond (BMCZ-1-1), a seep draining into the pond (BMCS-1-1), and water in Burgess Brook downstream of the pond (BMBT-1-1). A tributary that flows along the north side of the Lowell waste piles (BMBT-3-1), one downstream of the C-area quarry (BMBT-5-1), one downstream of the C-area tailings (BMBS-3-1), and an unimpacted tributary (BMBT-2-1) were sampled. Burgess Brook sample directly downstream of the mine is BMBB-1-1. From the Eden quarry, seeps (BMBS-1-1, BMBS-2-1), a pond (BMEP-1-1), and a downstream tributary (BMBT-4-1) were sampled.

METHODS

The mill tailings, waste rock, and concentrated ore were dry sieved through 10 mesh (2 mm). The stream-sediment samples were wet sieved through 10 mesh (2 mm) and dry sieved through 80 mesh (180 µm). Mineralogy was determined by X-ray diffraction (XRD) in U.S. Geological Survey (USGS) laboratories in Reston, VA. Powder patterns were collected using a PANalytical X'Pert PRO automated powder diffractometer with CuKα radiation. XRD patterns were analyzed using PANalytical X'Pert HighScore Plus software and standard reference patterns. Chrysotile fibers were quantified by polarized light microscopy (PLM; USEPA Method 600/R-93/116; USEPA, 1993) by K-D Associates, Inc., South Burlington, VT.

The major element-oxide chemistry of the composite and concentrated ore samples was measured using wavelength dispersive X-ray fluorescence spectroscopy (XRF) following fusion in a mixture of $LiBO_2$ and $Li_2B_4O_7$. Loss on ignition (LOI) was determined as an estimate of organic, carbonate, and water content. All solid samples including stream sediments were analyzed by inductively coupled plasma-atomic emission spectrometry (ICP-AES) and inductively coupled plasma-mass spectrometry (ICP-MS) following acid-digestion with a mixture of HCl-HNO_3-$HClO_4$-HF. All analyses were done by SGS Laboratories, Toronto, Canada. Reproducibility for most elements based on the analysis of a laboratory replicate sample is approximately ±10%.

Synthetic precipitation leaching procedure (USEPA Method 1312; USEPA, 1994) was conducted in USGS laboratories in Reston, VA, on splits of samples. Fifty grams of <2 mm in diameter sample were combined with one liter of a solution that approximates western United States precipitation. The western synthetic precipitate (WSP) solution was made by combining a mixture of sulfuric acid and nitric acid with deionized water to adjust the pH to 5.0 ± 0.1 (USEPA 1994). The sample and solution mixtures were agitated in a rotary extractor apparatus for 18 hours. Specific conductance and pH were measured using a YSI multi-parameter meter and alkalinity was determined by titration. Filtered (0.45 µm nitrocellulose filter) acidified splits were analyzed for cations by ICP-MS and ICP-AES and filtered splits for anions by ion chromatography (IC) in USGS laboratories in Denver, CO. Reproducibility for most elements based the analysis of a laboratory replicate sample is generally better than ±10%. The accuracy of the analyses was generally within one standard deviation for major cations (ICP-AES), trace elements (ICP-MS), and anions (IC) for standard reference waters certified by the USGS.

Surface water samples were filtered through 0.45 µm pore-size nitrocellulose filters, and splits were acidified and analyzed by ICP-AES and ICP-MS for dissolved cations. Filtered and unacidified aliquots were analyzed by IC for anions and for alkalinity by titration. Specific conductance and pH were measured on site using Orion meters. ICP-AES, ICP-MS, and IC were performed in USGS laboratories in Denver, CO. Reproducibility for most elements based the analysis of a field duplicate sample is generally better than ±10%. The accuracy of the analyses was generally within one standard deviation for major cations (ICP-AES), trace elements (ICP-MS), and anions (IC) for standard reference waters certified by the USGS.

This paper focused on selected elements that are potentially environmentally significant at the site.

RESULTS AND DISCUSSION

Mine Waste

Bulk geochemistry

The samples are mainly composed of SiO_2 (34.4 to 40.3 wt. %) and MgO (35.2 to 38.8 wt. %) with significant Fe_2O_3 (6.91 to 12.3 wt. %) and lesser amounts of Al_2O_3 (1.06 to 1.84 wt. %) and CaO (0.49 to 1.62 wt. %) (Table 1). Nearly all of the samples contain Fe in excess of the USEPA Preliminary Remediation Goal (PRG) for residential use (5.5 wt. % Fe) but are below that for industrial use (72 wt. % Fe) (USEPA, 2008). The LOI determined by XRF ranges from 10.7 to 15.8 wt. % and is likely due to H_2O in chrysotile and to the presence of carbonate minerals such as calcite, dolomite, and hydrotalcite discussed below. Major element variations among piles are subtle with the concentrated ore (07BMPO samples) containing the highest concentrations of CaO and the highest Al_2O_3, Na_2O, K_2O, and TiO_2 in waste rock samples from the Lowell (07LW-1), C-area (07CW-1), and Eden (07EM-1, 07EM-2) quarries. Overall, the major element compositions of the VAG samples are comparable to the average composition of ultramafic rocks (Faure, 1991) (Table 1). This suggests that the asbestos extraction process did not change the overall bulk composition significantly.

Table 1. Select bulk chemistry of mine-waste samples from VAG. Bold values exceed the PRG.

Sample	CaO wt. %	Fe_2O_3 wt. %	LOI wt. %	MgO wt. %	SiO_2 wt. %	As mg/kg	Co mg/kg	Cr mg/kg	Ni mg/kg	Zn mg/kg
PRG resid.[1]	-	7.8	-	-	-	0.39	23	280	1,600	23,000
PRG ind.[1]	-	100	-	-	-	1.6	300	1,400	20,000	310,000
ultramafic[2]	2.24	**13.8**	-	38.47	42.36	0.8	**175**	**1,800**	**2,000**	40
07LW-1	0.64	**10.2**	10.9	35.6	39.7	**6**	**111**	**1,380**	**1,980**	123
07LW-2	0.78	**9.83**	11.1	36.8	38.3	**5**	**113**	**1,370**	**2,050**	37
07LW-3	0.62	**10.5**	10.7	37.5	38.9	**3**	**110**	**1,570**	**2,140**	40
07CT-1	0.91	**9.21**	11.6	36.6	39.5	**26**	**112**	**1,540**	**2,010**	39
07CT-2	1.13	**8.66**	11.8	38.4	38.8	**12**	**108**	**1,390**	**2,080**	37
07CT-3	0.82	**9.7**	11.6	37.4	38.3	**6**	**111**	**1,370**	**1,970**	41
07CT-4	1.18	**12.3**	12.9	35.2	35.5	**7**	**125**	**1,470**	**2,230**	90
07CT-5	0.92	**9.37**	11.9	37.6	37.7	**9**	**124**	**1,440**	**2,040**	37
07CT-5 Dup	0.99	**9.54**	11.9	37	37.1	**8**	**111**	**1,400**	**1,980**	37
07CT-6	1.33	**10**	12	37.6	37.3	**15**	**121**	**1,380**	**2,070**	43
07CW-1	0.94	**9.2**	11	36.5	40.3	**14**	**95.3**	**1,360**	**1,990**	40
07ET-1	0.55	**9.79**	12.7	37.2	36.9	**63**	**118**	**1,460**	**2,110**	34
07ET-2	0.59	**10.1**	12.3	38	38.4	**29**	**119**	**1,470**	**2,180**	36
07ET-3	0.61	**10.4**	12.6	36.9	37.1	**45**	**122**	**1,390**	**2,190**	36
07ET-4	0.8	6.91	14.8	38.8	37.5	**3**	**107**	**1,190**	**1,820**	29
07EM-1	0.49	**10.3**	12	35.8	39.6	**13**	**121**	**1,340**	**2,120**	46
07EM-2	0.72	**9.63**	12.2	35.4	39.3	**22**	**103**	**1,420**	**2,000**	48
07BMPO-1	1.51	**9.44**	13.1	37.5	36.4	**19**	**107**	**1,310**	**2,090**	36
07BMPO-2	1.62	**8.25**	15.8	36.9	34.4	**12**	**99.9**	**1,230**	**1,840**	30

[1] Preliminary Remediation Goals (PRG) for residential (resid.) and industrial (ind.) soils are for noncancer-based (Co, Cu, Fe, Ni, Zn) and cancer-based (As, Cr) chronic exposure (USEPA, 2008). PRG for Fe converted to oxide percent.

[2]Average chemical composition for ultramafic rocks from Faure (1991). Oxide percent calculated from elemental concentration.

Several trace elements are present in the mine waste in significant concentrations (Table 1). Arsenic concentrations exceed USEPA industrial use PRGs, whereas Co, Cr, and Ni concentrations exceed the PRG for residential use (USEPA, 2008). The average concentrations of these elements in ultramafic rock from Faure (1991) also exceed the remediation goals and are similar to concentrations found in the mine waste (Table 1). The concentrations of elements in ultramafic rock in Table 1 are generally higher than in the VAG samples because the mine samples have been metamorphosed and contain hydrated minerals as indicated by LOI. Among the samples, the range in concentrations of Cr (1,190 to 1,570 mg/kg) and Ni (1,820 to 2,230 mg/kg) is limited whereas As shows more variability (3 to 63 mg/kg). The concentrations of As correlate with the concentrations of Sb in the mine-waste samples with the samples from the Eden quarry area generally having the highest concentrations. Other trace elements present include Cu (up to 19.4 mg/kg) and Zn (up to 123 mg/kg), none of which exceed USEPA guidelines. Trace-element concentrations reported by Faure (1991) for the average composition of ultramafic rocks are similar to those found in the mine waste (Table 1).

Mineralogy

All mine-waste samples contain serpentine, chlorite, magnetite, and pyroxene and most contain quartz, olivine, and brucite. Calcite and/or dolomite and hydrotalcite are present in many samples and phlogopite was identified in a few samples. Overall, the mineralogy of the samples reflects the mineralogy of the serpentinized ultramafic rock from which the chrysotile asbestos was mined. Antigorite was reported to be the most abundant serpentine group mineral in the deposit but chrysotile was the mineral of economic interest (Van Baalan et al., 1999). The amount of chrysotile fibers in the mine waste is illustrated in Figure 1. The tailings and soils from the Eden quarry, the earliest mined area, and one sample of concentrated ore contain the highest amount of chrysotile fibers. The C-area and Lowell tailings contain intermediate amounts, and the C-area waste rock contains the least.

Trace amphibole was identified by XRD by scanning a limited 2θ range for an extended count time (Gunter et al., 2007; Levitan et al., *in press*). The only samples that did not contain traces of amphibole were the Eden quarry tailings, and one of the concentrated ore samples. The amphibole in the mine-waste samples is not in a fibrous form, which is significant because amphibole asbestos is thought to be more deleterious to human health than chrysotile asbestos. Fibrous amphibole was reported in a host rock sample from the site (Levitan et al., *in press*).

Leachate

Mine waste leached with the acidic WSP solution (pH 5.0) resulted in alkaline leachates with pH ranging from 8.8 to 10.2, specific conductance from 35 to 621 µS/cm, alkalinity ranging from 12 to 111 mg/L $CaCO_3$, and hardness from 16 to 405 mg/L $CaCO_3$. The pH, specific conductance, alkalinity, and hardness generally are positively correlated; the highest values for all are from the tailings and concentrated ore leachates. The concentrations of many elements, including Al, Cd, Fe, Mn, Pb, and the rare earth elements, are below the detection limits in the leachates. For detectable trace elements, As and Zn are below or near their detection limits of 1 and 0.5 µg/L, respectively; Co ranges from <0.02 to 0.16 µg/L, Cr from <1 to 4.40 µg/L, Cu from <0.5 to 0.92 µg/L, Ni from <0.4 to 2.7 µg/L, and Sb from <0.3 to 2.33 µg/L. Calcium ranges from 0.93 to 5.80 mg/L and Mg from 2.1 to 97 mg/L. Anions include NO_3 (up to 35 mg/L), and SO_4 (up to 175 mg/L); the leaching solution (WSP) contains 1.6 and 1.2 mg/L of these elements, respectively, from the sulfuric and nitric acids added to adjust pH. The ore concentrate sample 07BMPO-2 contains high or the highest concentrations of many of the elements. However, overall the leachates contained low concentrations of most metals, none of which exceeded USEPA drinking water or aquatic ecosystem toxicity guidelines (USEPA, 2003, 2006).

Sediments

Stream sediments collected proximal to the site contain high concentrations of some of the elements associated with the chrysotile deposit such as Fe and Mg. The concentrations of Mg and Fe correlate and are generally highest in samples collected from the mine site, with concentrations decreasing with increasing distance from the mine (Figure 3). The exception is sediment collected from the northern end of Corez Pond (Corez-N) in the Burgess Branch watershed (Figure 3B). The concentrations of other major elements such as Ca and Al do not follow these trends.

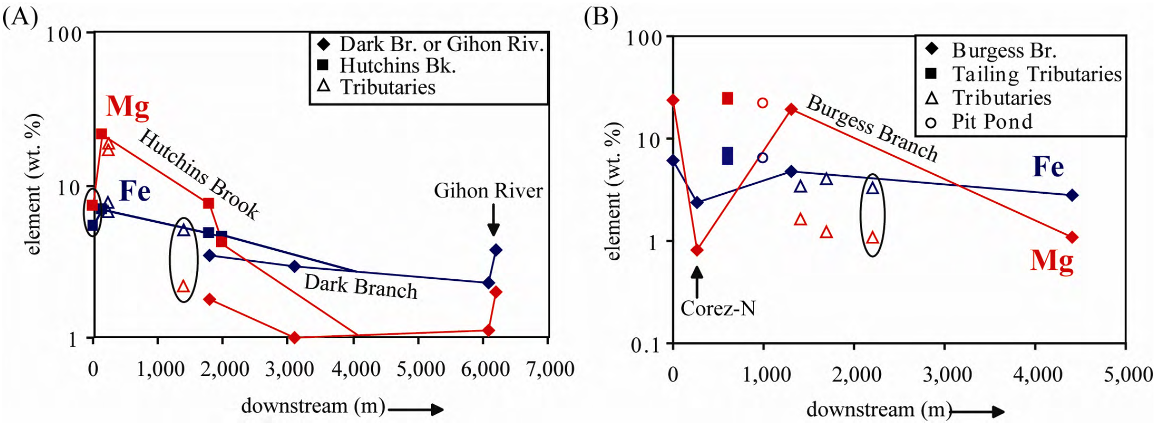

Figure 3. Concentrations of Fe (blue) and Mg (red) in stream sediments from Hutchins Brook, Dark Branch, and the Gihon River (A), and from Burgess Branch (B). Downstream distances are approximate and measured from the furthest upstream site. Circled sites are control sites not impacted by the mine.

The concentrations of several trace elements follow the Mg and Fe trends. The concentrations of the potentially toxic elements As, Co, Cr, Ni, and Sb all generally decrease with increasing distance from the mine (Figure 4). The concentrations of these elements are low in the sample from the northern end of Corez Pond (Figure 4B). This site, compared to the southern end of the pond, is slightly sheltered from the mine waste in that there is a road and wooded riparian area between the tailing and the site. The highest concentrations of As, Co, Cr, Ni, and Sb principally are found in sediment collected directly from the mine site or from a wetland in Hutchins Brook which has been partially filled by fine-grained mine waste. In general, the concentrations of these elements are significantly lower in streams not impacted by the mine.

The concentrations of As, Cr, and Ni in some or all of the sediment samples exceed the probable effect concentration (PEC), a basis for predicting sediment toxicity (MacDonald et al. 2000). The samples that significantly exceed the guidelines of 111 mg/kg for Cr and 48.6 mg/kg for Ni are sediments from Hutchins Brook (HB 1.6, HB 1.8, H 2.8, HB 3.1), a tributary of Hutchins Brook draining Eden-quarry tailings (HBTT), southern end of Corez pond (Corez-S), the pit pond (Pit Pd), a tributary of Burgess Branch (BT11), and Burgess Branch directly downstream of the site (B 5.0) (Figures 2 and 4). One sample, HB 3.1, is a control sample and does not directly receive drainage from the mine. Arsenic exceeds the PEC in sediment from Hutchins Branch (HB 1.6, HB 1.8, H 2.8, HB 3.1) and in two of its tributaries (HBTT, HT2). Two of these samples, HB 3.1 and HT2, are control sites. The high concentrations of these metals in stream sediments not impacted by the mine indicate the source is not exclusively the mine.

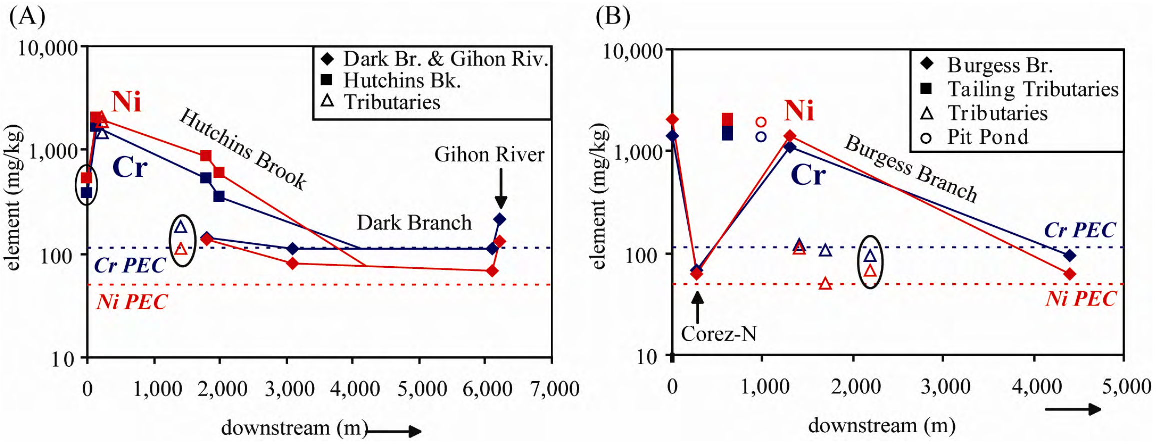

Figure 4. Concentrations of Cr (blue) and Ni (red) in stream sediments from Hutchins Brook, Dark Branch, and the Gihon River (A), and from Burgess Branch (B). Downstream distances are approximate and measured from the furthest upstream site. Circled sites are control sites not impacted by the mine. Probable effect concentrations (PEC) for Ni and Cr from MacDonald et al. (2000).

Mine drainage

The pH and specific conductance of the water samples are positively correlated and range from 6.9 to 10.1 and from 29.8 to 533 µS/cm, respectively (Table 2). Alkalinity and hardness are also positively correlated and range from 14.5 to 320 mg/L $CaCO_3$ and from 30.1 to 627 mg/L $CaCO_3$, respectively. The lowest pH, conductivity, alkalinity, and hardness are for the unimpacted tributary (BMBT-2-1), whereas the highest values are for the seep at Corez Pond (BMCS-1-1).

The concentrations of elements in the mine-drainage samples are below the USEPA drinking water standards and aquatic ecosystem toxicity guidelines (Table 2) (USEPA, 2003, 2006). The pH of most samples is higher than the acceptable range of 6.5 to 8.5 based on the USEPA secondary drinking water standard USEPA, 2003). The concentrations of As in several samples nearly reach the drinking water standard of 10 µg/L. Other metals detected but at low concentration include Al (up to 42 µg/L), Co (up to 2.89 µg/L), Cr (up to 3.4 µg/L), Cu (up to 8.7 µg/L), Fe (up to 89 µg/L), Mn (up to 27.9 µg/L), Ni (up to 31.1 µg/L), Sb (up to 12.4 µg/L) and Zn (up to 13.2 µg/L) (Table 2). Magnesium concentrations range from 2.4 mg/L for the unimpacted tributary to 132 mg/L in the Corez Pond seep (BMCS-1-1). The high Mg is likely related to the leaching of Mg from the ultramafic minerals. Overall, these waters contain low concentrations of most metals, which is consistent with the results of the leachate tests.

CONCLUSIONS

Several elements found at VAG are present in concentrations that may be of environmental concern. These elements include As, Co, Cr, Fe, and Ni. Waste rock, mill tailings, and concentrated ore left on site all contain concentrations of these elements that exceed USEPA preliminary remediation goals for industrial and some for residential land use. These samples also contain significant amounts of chrysotile fibers. Stream sediments from downstream of the mine contain concentrations of As, Cr, and Ni that may be harmful to sediment-dwelling organisms. The chemistry of the mine waste and stream sediments is a reflection of the serpentinized ultramafic rock from which the asbestos was mined. Although the solids contain high concentrations of these metals, leachate tests and waters collected on site contain low concentrations of As, Cr, and Ni suggesting these elements are not readily released into the aqueous environment.

Table 2. Select chemistry of filtered water samples from VAG. Bold values exceed the criteria.

Parameter Units	pH	Sp. Cond. µS/cm	Alkalinity mg/L $CaCO_3$	As µg/L	Cr µg/L	Cu µg/L	Mg mg/L	Ni µg/L	Sb µg/L	Zn µg/L
MCL[1]	>8.5	-	-	10	100	1,300	-	-	6	5,000
CCC[2]	-	-	-	340	16	25.8	-	842	-	211
CMC[2]	-	-	-	150	11	16.2	-	93	-	213
BMPT-1-1	**8.8**	351	205	8.2	1.3	1.1	47.3	2.7	2.71	2.2
BMPT-25-1	**8.9**	388	232	9.2	1.5	1.4	55.1	3.6	2.6	0.8
BMPT-50-1	**9.0**	383	231	8.7	1.1	1.2	56.4	3.4	3.34	0.5
BMPT-75-1	**9.2**	387	199	8.2	2.2	0.98	61.5	2.7	2.8	0.7
BMPT-85-1	**9.3**	393	189	9.3	1.9	1.1	63.1	3	3.05	0.8
BMPT-OUT-1	**9.2**	326	214	7.6	1.8	1	47.7	2.4	2.62	0.8
BMPT-IN-1	**9.6**	340	197	5.4	1.1	0.86	55.6	1.6	2.14	1.2
BMCZ-1-1	**8.7**	252	102	1	1	0.78	26	5.1	1.28	2.1
BMCS-1-1	**10.0**	533	320	8.6	3.1	1.4	132	2.1	10.5	1.5
BMBT-1-1	7.9	191	101	<1	<1	0.7	19.2	5.2	0.48	0.9
BMBT-2-1	6.9	29.8	15	<1	1.2	1.4	2.4	3.5	<0.3	13.2
BMBT-3-1	7.4	97.1	75	<1	2.6	1.4	15.6	2.6	0.69	2.4
BMBB-1-1	**8.5**	322	217	2	<1	0.92	50.5	8.2	1.46	0.7
BMBS-1-1	**8.9**	316	264	5	3	1	65.4	11.1	12.4	0.9
BMBS-2-1	7.5	210	151	<1	2.2	1.2	34.5	10.9	2.51	2.7
BMEP-1-1	**8.8**	163.8	96	3.1	2.6	8.7	21.5	19.9	1.59	1.8
BMBT-4-1	8.3	177.9	130	3.3	3.4	1.8	30.1	31.1	1.51	1.7
BMBT-5-1	**9.0**	320	237	3.5	1.2	1.6	51.7	6.4	1.94	<0.5
BMBS-3-1	**10.1**	294	162	<1	<1	<0.5	60.4	0.7	4.49	<0.5
BMBS-3-1 Dup	**10.1**	294	154	<1	<1	<0.5	59.3	0.6	4.19	<0.5

[1] Maximum Contaminant Level (MCL) from USEPA (2003). Values for pH and Zn are secondary standards.

[2] Criterion Continuous Concentrations (CCC) and Criterion Maximum Concentrations (CMC) for USEPA (2006). Criterion for As, Cr (VI), Cu. Ni, and Zn are hardness dependent and calculated based on 200 mg/L CaCO3.

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