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Geochemical Characterization of Mine Waste at the Ely Copper Mine Superfund Site, Orange County, Vermont

by

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INTRODUCTION

The abandoned Ely copper mine in the Vermont copper belt was placed on the U.S. Environmental Protection Agency (USEPA) National Priorities List (NPL) on September 13, 2001. The location of the mine is shown in Figure 1. Acidic drainage from the mine enters Ely Brook and has a major effect on the aquatic life. Ely Brook then flows into Schoolhouse Brook and eventually joins the East Branch of the Ompompanoosuc River approximately 2.8 km downstream from the site (Figs. 1 and 2). Currently, the USEPA is carrying out a Remedial Investigation/Feasibility Study (RI/FS) at the site to determine the nature and extent of contamination and to assess the potential threats to human health and the environment. Also, USEPA is performing a historical resource assessment to determine if the Ely mine is eligible for the National Register of Historic Places. To aid in the RI/FS, the U.S. Geological Survey (USGS) conducted a study of the mine-waste piles at the Ely mine Superfund site. To determine the extent of contamination at the site, the investigation focused on answering the following questions:

(1) What type of mine waste is present at the site?

(2) What is the chemical composition of the mine-waste piles?

(3) What is the acid-generating potential of the material?

(4) Are potentially toxic trace metals leached from the waste? If so, are the metals leached in quantities that may contaminate soils and streams and have a deleterious effect on the environment?

(5) How variable is the environmental impact among the various mine-waste piles?

(6) Is any of the material geochemically similar to mine waste at the near-by Elizabeth mine, a Superfund site in the initial stages of remediation?

This last question is important because if mine waste at the Ely mine is geochemically similar to the mine waste at the Elizabeth mine (Fig. 1), remediation technologies evaluated for the Elizabeth mine may be applicable to the Ely mine.

The Ely mine has been investigated by both State and Federal agencies. In 1988, the Vermont Department of Environmental Conservation inventoried fish species in Schoolhouse Brook and in 1991 stated that the macroinvertebrate community in Schoolhouse Brook was impacted by mine drainage due to high copper concentrations (USEPA, 2003a). In the early 1990's, the U.S. Bureau of Mines and the Vermont Department of Environmental Conservation conducted water sampling and benthic macroinvertebrate surveys and constructed an experimental passive treatment system using limestone and sulfate-reducing bacteria (McSurdy and others, 1995). The results of the macroinvertebrate survey indicated a slight impact on Schoolhouse Brook downstream of the confluence with Ely Brook (McSurdy and others, 1995). Holmes and others (2002) characterized spring runoff from the Ely mine as highly acidic and highly contaminated. The pH of seepage from the mine-waste piles was generally less than 3.5 and concentrations of metals including Cu, Al, Fe, Zn, Cd, Co, and Mn exceeded

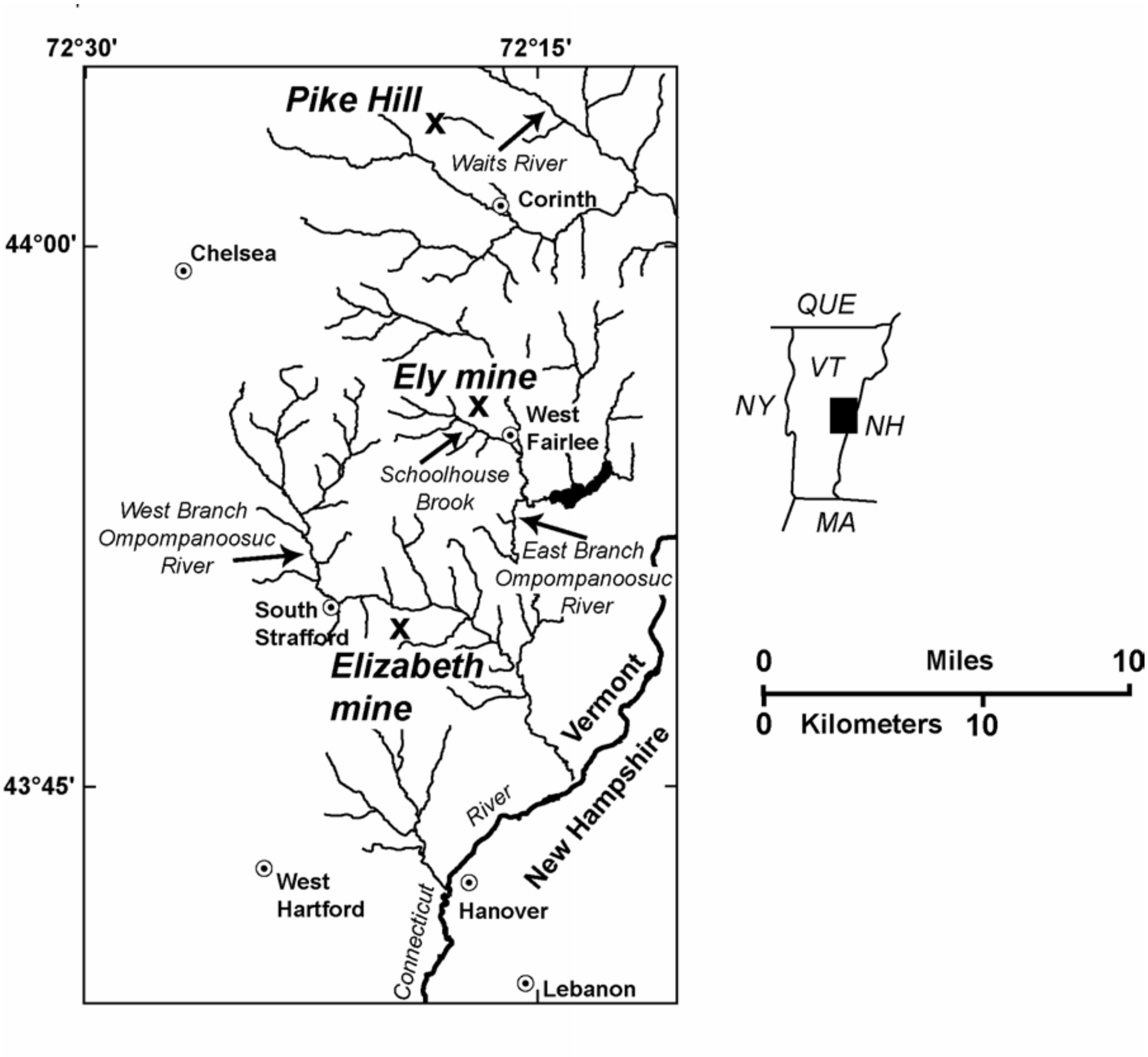


Figure 1. Location of the Ely, Elizabeth, and Pike Hill mines in Orange County, Vermont.

water-quality criteria. Holmes and others (2002) also found concentrations of copper in exceedance of water-quality criteria in Schoolhouse Brook over 10 km downstream of the mine. The geology, environmental geochemistry, and mining history of the Ely mine were summarized in a series of papers in the Society of Economic Geologists Guidebook Series, volume 35 (Crowley and others, 2001; Hammarstrom and others, 2001a, b; Hathaway and others, 2001; Kierstead, 2001; Seal and others, 2001a, b; Slack and others, 2001). Composite surface samples from the upper and lower mine-waste areas (Fig. 2) contain high concentrations of metals including up to 19 wt. % Fe, which is in excess of the preliminary remediation goal (PRG) for industrial soil, and up to 2,000 mg/kg Cu (Hammarstrom and others, 2001b). Also, a composite sample of the pot slag revealed concentrations of Cu greater than 7,000 mg/kg (Hammarstrom and others, 2001b) and grab samples of the slag reported by Piatak and others (2003) contain up to 6,940 mg/kg Cu. Leachate tests on the slag indicate Cu and Zn may be leached in excess of the water-quality guidelines for the protection of aquatic life (Piatak and others, 2003; 2004). Seal and others (2001b) reported acidic and metal-rich drainage at the Ely mine. For example, the pH of Ely Brook ranges from 3.3 to 3.4 and the water is dominated by Ca, Fe, Al, and sulfate and contains Cu concentrations between 1,300 and 2,200 µg/L, well in excess of the acute and chronic water-quality guidelines for the protection of aquatic life (Seal and others, 2001b). The previous studies, in conjunction with this current report, summarize the extent of contamination and aid the USEPA in determining a reclamation scheme for this Superfund site.

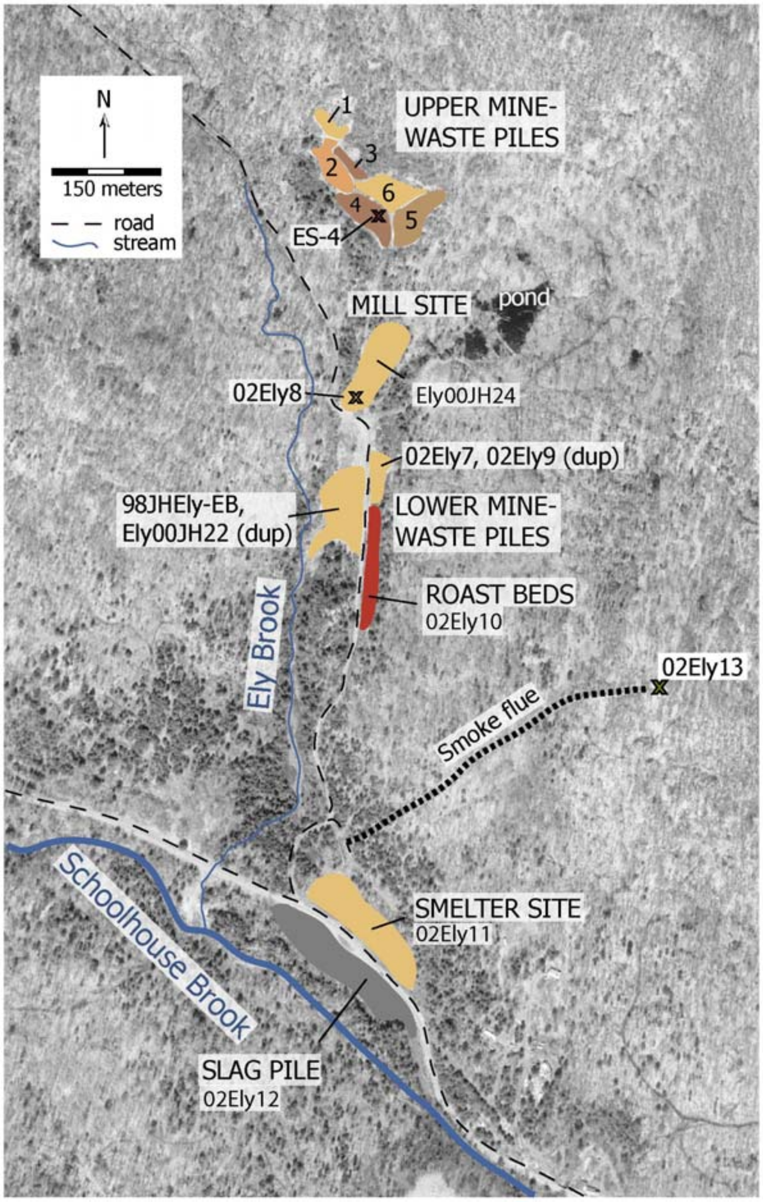


Figure 2. Ely mine site map showing mine-waste piles, the smoke flue, Ely Brook, and Schoolhouse Brook. Colored regions indicate composite samples and "x" indicates a grab sample. Colors for samples are based on an approximation of the dominant Munsell color. Boundaries for sample areas are schematic. Upper mine-waste samples 02Ely1 to 02Ely6 are abbreviated as "1" to "6". "dup" indicates field replicate samples.

METALLURGICAL OPERATIONS AND SAMPLING

The Ely mine was in operation from the 1850's to 1905 and exploited a Besshi-type massive sulfide deposit (Slack and others, 2001). Bedrock includes metasedimentary and minor mafic metaigneous rock of Silurian and Early Devonian age. Massive sulfide ore occurred as an elongate body and was composed of pyrrhotite, chalcopyrite, and minor sphalerite and pyrite (Offield and Slack, 1993; Slack and others, 2001). The Ely mine produced somewhere between 13.6 and 18.1 million kg of copper over the life of the mine, and was among the top ten U.S. producers of copper between 1866 and 1881 (Kierstead, 2001). The Ely mine was the only copper mine in Vermont where complete copper refinement, from mining of raw ore to smelting of refined ingot copper, was successfully integrated on a large scale (Kierstead, 2001).

The Ely site covers approximately 1,416,450 m^2 (350 acres) and includes shafts and adits, barren mine-waste piles, roast beds, flotation-mill tailings, the ruins of the World War I era flotation mill, remains of a smelter plant and slag heaps, and a smoke flue (Kierstead, 2001). As the ore was removed from the underground workings, accessed by at least six shafts and three adits, waste rock was deposited along the upper hillside. Six composite samples (02Ely1 to 02Ely6) of the upper mine waste collected for this study are shown in Figures 2 and 3. This area is characterized by fine-grained to boulder-sized waste rock. The predominantly boulder-sized surface of 02Ely3 is likely the remains from hand cobbing the ore and may include some low-grade ore (Fig. 3C). Also, several acidic seeps are found emerging from the upper waste pile, and the red hardpan crust (ES-4) around one of these seeps was also sampled. This is the same seep referred to as ES-4 by Holmes and others (2002).

During World War I, a small short-lived flotation mill recovered 1,633 kg (3,600 lbs) of copper from old ore dumps (Kierstead, 2001). Sample Ely00JH24 is the surface composite of the footprint of the flotation mill area, which is approximately 50 meters by 150 meters (Fig. 2). Within this area, the flotation-mill tailings cover an area of approximately 100 m^2 and are at least a meter deep. The tailings are stratified and samples include brownish yellow oxidized surface (02Ely8A), thin layers of pale yellow jarositic and gray muscovite-rich material at a depth of 35-46 cm (02Ely8B), and black unoxidized tailings below 71 cm (02Ely8C) (Fig. 4A). Composites of the lower mine waste include duplicates of waste rock west of the road (98JHEly-EB and Ely00JH22), duplicates of waste rock east of the road (02Ely7 and 02Ely9) and partially roasted ore from the roast beds (02Ely10) (Figs. 2 and 4B).

The Ely smelting plant was built in 1867, and eventually became a massive operation consisting of 24 smelting furnaces and spanning over 213 meters (Kierstead, 2001). Besides processing ore from the Ely mine, the Ely smelter processed ore between 1878 and 1882 from the Union mine, shown on Figure 1 at Pike Hill (Kierstead, 2001). Remnants of the smelting operation include foundation walls, masonry furnace bases, and a section of magnesite-coated rocks from the lining of a copper converter. The pot slag from the operation was deposited along the bank of Schoolhouse Brook, extends for more than 90 meters, and is locally up to several meters high. Samples for this study include surface composites of the smelter-plant soil (02Ely11) and of the slag material (02Ely12) (Figs. 2, 4C and 4D). A smoke flue built in 1877 is located north of the smelter plant (Fig. 2). The flue was built to draw smelter fumes out of the valley, which by the mid 1870's was denuded of most vegetation. A 24-meter tall draft chimney (not extant)

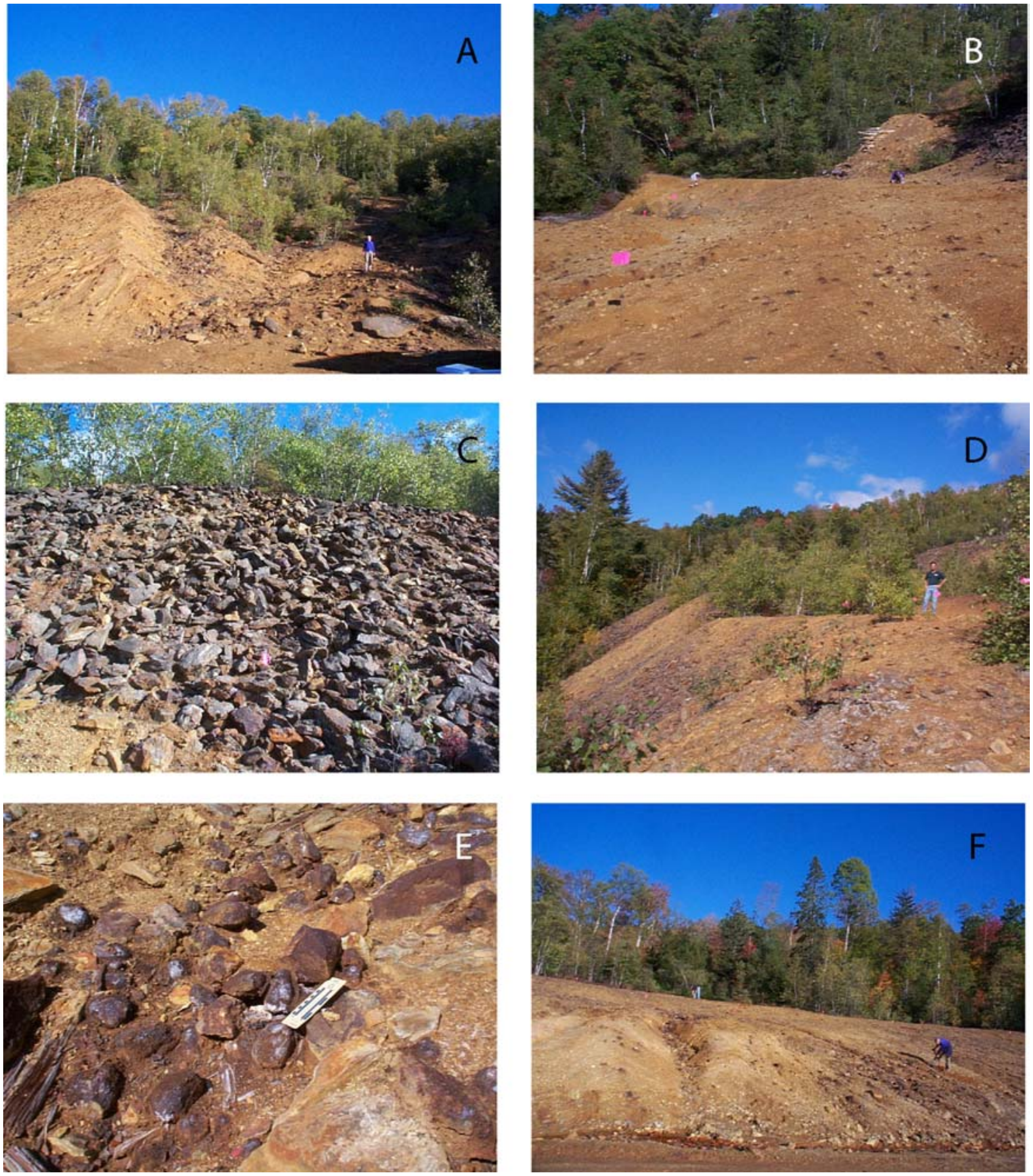


Figure 3. Photographs of upper waste piles sampled at the Ely mine. A. Composite sample area 02Ely1. B. Composite sample 02Ely2; note the pink flags which designate one sample of the composite. C. The soil between the boulders was sampled for composite sample 02Ely3. D. Looking west at composite sample area 02Ely4; note white efflorescent salts on boulders. E. White efflorescent salts on boulder in composite sample area 02Ely5. F. Composite sample area 02Ely6.

topped the flue. The flue never worked as intended (Abbott, 1964). A grab sample of the soil from the end of the smoke flue was also collected (02Ely13) (Fig. 2).

The types of mine waste found at the Ely mine are analogous to the types found at the Elizabeth mine. The upper and lower waste piles at the Ely mine include waste rock and partially roasted ore from copper extraction. The historic mine waste (TP3) at the

Figure 4. Photographs of sample areas at the Ely mine. A. Flotation-mill tailings; 02Ely8A is oxidized surface material, 02Ely8B is the pale yellow layer adjacent to the scale bar, and 02Ely8C is black unoxidized material. B. Composite sample area 02Ely10, roast beds. C. Smelter site and composite sample area 02Ely11. D. Weathered surface of slag pile; note the rounded casts of slag pots.

Elizabeth mine is a composite of waste piles from early 19th century copperas production, partially roasted beds, and hand-cobbed waste rock from late 19th and 20th century copper mining (Kierstead, 2001). Geochemical characteristics of TP3 mine waste are summarized in Hammarstrom and others (2003). The flotation-mill site and the smelter site sampled at the Ely mine are similar in color and grain size to TP3. Flotation tailings are also found at both mine sites. Flotation-mill tailings at the Elizabeth mine are discreet piles covering an area of over 100,000 m^2, whereas tailings at the Ely mine are spatially associated with other mine waste and are volumetrically minor covering an area of approximately 100 m^2. Small localized slag deposits are present at the Elizabeth site, whereas an extensive slag deposit is found at the Ely mine along Schoolhouse Brook. Most of the mine waste at the Ely mine (not including the tailings and slag) is similar in color, grain size, and/or degree of metal extraction to the TP3 area of the Elizabeth mine. Geochemical characterizations of mine waste at these two sites are compared in this report.

All samples were collected in October 2002 with the exception of 98JHEly-EB, collected in August 1998, and Ely00JH22 and Ely00JH24, collected in June 2000

(Appendix A). The mine-waste piles were divided based on variation in waste type, color, and geographic location. Composites of soil (<2 mm) material consist of a minimum of 30 sample increments over a measured area divided into a stratified grid. Increments were collected with a stainless steel trowel from either the top 5 cm of soil (surface, designated with an A) or at a depth of 25 cm (depth samples, designated with a B). Samples were mixed and sieved through a 10-mesh sieve. Grab samples (ES-4, 02Ely8A, -B, -C, 02Ely13) were also collected using the stainless steel trowel. Composite and grab samples were stored in plastic bags for shipping to the laboratory, where they were air dried, and split into aliquots by fractional shoveling (Pitard, 1993). Splits of the samples were used to determine bulk geochemical composition, mineralogy, and acid-base accounting. In addition, laboratory-leaching tests assessed the reactivity of the material. Sample color was determined on dry material using Munsell soil color charts. Because of the variegated nature of the material, more than one color may have been chosen to describe each sample. For illustrative purposes in figures and graphs for this study, one color was chosen to represent the sample. The Munsell color and other sample information including sampling date, location description, and depth are in Appendix A.

METHODS

Bulk geochemical composition

The bulk chemical composition of samples was determined using inductively coupled plasma-atomic emission spectrometry (ICP-AES) following acid-digestion by a mixture of HCl-HNO_3-$HClO_4$-HF in USGS laboratories in Denver, Colorado (Briggs, 2002a). The USGS job number and laboratory sample number for entry into the National Geochemical Database (Smith, 2002) are listed in Appendix B-1. NIST certified reference materials were analyzed to monitor accuracy and precision (Appendix B-2). Analytical results of several duplicate splits are also presented in Appendix B-1.

Mineralogy

Mineralogical identification was determined using X-ray diffraction analysis (XRD) in USGS laboratories in Reston, Virginia. XRD was performed on samples pulverized in alcohol in a McCrone micronizer equipped with agate grinding pellets. Side-loading aluminum holders were used and the powder patterns were collected using a Scintag X1 automated powder diffractometer equipped with a Peltier detector with CuKα radiation. The XRD patterns were analyzed using Material Data Inc.'s JADE software and standard reference patterns. The relative amount of phases in each pattern was estimated using the Siroquant computer program that utilizes the full XRD profile in a Rietveld refinement (Taylor and Clapp, 1992). The accuracy of the Siroquant results is approximately ± 5 wt. %

Several mine-waste leachates (see below) were filtered through 0.45 µm pore-size nitrocellulose filters and allowed to evaporate to dryness to determine the tendency of trace amounts of salts to form from the mine waste. The presence of efflorescent sulfate salts can effect paste pH and acid-base accounting results; salts occur on the surface of mine waste from the Ely mine (Hammarstrom and others, 2001b). Leachate evaporates were evaluated using XRD.

Acid-base accounting

Acid-base account (ABA) was originally designed to estimate the inherent capacity of coal-mine waste to produce or to neutralize acid (Sobek and others, 1978). Currently, this method is used to evaluate metal-mine waste as well as coal-mine waste and typically includes the determination of paste pH (White and others, 1999). Paste pH for this study was determined both in USGS laboratories in Reston, VA, and by B.C. Research, Inc., as part of their acid-base accounting procedure. Paste pH determined in USGS laboratories was measured on a split of 10 g of < 2 mm diameter sample. The sample is combined with 10 mL of deionized water (pH 5.33), stirred with a wooden spatula, and the pH of the paste is measured using an Orion pH meter fitted with an Ag/AgCl epoxy electrode and temperature probe. This method, based on Price and others (1997), is a quick indication of the relative acid-generating (pH < 4) or acid-neutralizing (pH > 7) potential of the samples. Sobek and others (1978) defined material with a paste pH of less than 4.0 as acid-toxic.

ABA or net-neutralization potential (NNP) consists of two measurements: (1) neutralization potential (NP) and (2) the acid-generating potential (AP). NNP is defined as the difference between these two measurements (NNP = NP – AP). The NP/AP ratio is also used to describe the acid-producing potential of mine waste. ABA classifications for mine-waste samples are based on both NNP and NP/AP and are divided into three categories including acid-generating, uncertain, and non-acid generating. The definition of "acid-generating" based on NNP and NP/AP is variable from study to study and is outlined in White and others (1999) and Perry (1998). Morin and Hutt (1994) emphasized the need for site-dependent ABA criteria for estimating acidic drainage potential and the lack of certainty in universal criteria applicable to all sites. Although a single absolute ABA criterion does not exist, NNP or NP/AP values are useful in evaluating the potential of a material to be acid-generating or acid-neutralizing. For this study, NNP less than zero or NP/AP less than one are considered potentially acid-generating, but further quantification of the degree of acid generation can only be determined by kinetic tests and by detailed mineralogical and geochemical characterization of site-specific samples, which is beyond the scope of this study.

ABA analyses in this study were done by B.C. Research Inc. using a combination of the Sobek method to determine NP and the modified Sobek method to determine AP (Sobek and others, 1978; White and others, 1999). The first step in determining NP is to perform a "fizz" test by reacting the sample with diluted hydrochloric acid (HCl) at room temperature to estimate the calcium and magnesium carbonate content of the sample. Samples for this study had a fizz rating of "none." Therefore, 20 mL of 0.1 N HCl was added to 2 g of < 60-mesh material and boiled until the reaction ceased. The mixture is then cooled and titrated with sodium hydroxide (NaOH) to a pH of 7.0. The amount of NaOH added is a measure of how much HCl was neutralized and an indication of the neutralizing potential reported as kg of calcium carbonate ($CaCO_3$) per metric ton of mine waste.

AP was determined according to the modified Sobek procedure, which determines AP on the sulfide content rather than the total sulfur. Total sulfur was analyzed by LECO furnace and sulfate-sulfur was determined by heating 5.00 g of sample with 20 mL of 3 N HCl to a boil. The sample is allowed to cool and diluted with deionized water (DI) to a known volume. The solution is then analyzed for sulfate by a turbidimetric method. Sulfide-sulfur is calculated from the difference between total sulfur and sulfate-sulfur and is assumed to be present in the acid-generating iron-sulfide minerals pyrite and pyrrhotite. For these sulfides, two moles of acid are produced for each mole of sulfur and one mole of $CaCO_3$ will neutralize the two moles of acid. Thus, the AP is obtained by multiplying the weight percentage of sulfide-sulfur by 31.25 to yield AP in units of kg of $CaCO_3$ per metric ton (White and others, 1999).

For several mine-waste samples in this study, results for duplicate sulfate-sulfur analyses were poor. These samples contain jarosite, which is refractory in the 3 N HCl used in the procedure to determine sulfate-sulfur. Concentrated HCl and longer boiling times (30 minutes) were found to liberate the sulfate-sulfur in jarosite (Vos and O'Hearn, 2001). Thus, the sulfate-sulfur contribution of the jarosite can be underestimated and the AP based on sulfide-sulfur overestimated. Two samples were reanalyzed by this more aggressive method.

Leach test

The field-leach test developed by Hageman and Briggs (2000) was performed on splits of the samples in USGS laboratories in Reston, Virginia. Splits of samples (material < 2 mm in diameter) were combined with a solution that approximates eastern United States precipitation (ESP) at a solution to sample ratio of 20:1. A mixture of sulfuric acid and nitric acid was added to deionized water to adjust the pH to 4.2 ± 0.1 to produce synthetic eastern precipitation solution (USEPA, 1994). The mixtures were shaken for five minutes and after 24 hours the pH and specific conductivity were measured on unfiltered splits. The leachates were then filtered through 0.45 µm pore-size nitrocellulose filters and analyzed for cations by inductively coupled plasma- mass spectrometry (ICP-MS) and ICP-AES, and for anions (sulfate and chloride) by ion chromatography (IC) in USGS laboratories in Denver, Colorado, and Ocala, Florida, respectively. ICP-MS and ICP-AES analyses were performed according to USGS methods outlined in Lamothe and others (2002) and Briggs (2002b). Dissolved total iron and ferrous iron concentrations were determined using colorimetric kits containing 1, 10 phenanthroline indicator on a Hach DR/2000 spectrophotometer.

RESULTS AND DISCUSSION

Bulk geochemistry

The concentrations of major, minor, and trace elements in all samples are given in Appendix B-1. Duplicate splits of samples 02Ely2A, 02Ely6B, Ely00JH24, and 02Ely12 were analyzed separately and are included in Appendix B-1. The results of analyzing NIST standard reference material are presented in Appendix B-2.

The concentrations of selected metals and the USEPA preliminary remediation goals (PRGs) for residential and industrial soils are given in Table 1. PRGs are guidelines, not legally enforceable standards, used for initial evaluations of potentially contaminated sites. Concentrations of metals above these levels do not designate a site as contaminated but suggests that further evaluation of the potential risks posed by the contaminate may be necessary (USEPA, 2002). Concentrations of metals that exceed the PRGs are shown in bold in Table 1.

Table 1. Concentration of selected metals in mine waste from the Ely mine.

Sample	Al wt.%	As mg/kg	Cd mg/kg	Co mg/kg	Cr mg/kg	Cu mg/kg	Fe wt.%	Mn mg/kg	Mo mg/kg	Ni mg/kg	Pb mg/kg	V mg/kg	Zn mg/kg
PRG-residential[1]	7.6	22	37	900	210	3,100	2.3	1,800	390	1,600	400	550	23,000
PRG-industrial[1]	10	260	450	1,900	450	41,000	10	19,000	5,100	20,000	750	7,200	100,000
02Ely 1A	4.4	<10	<2	31	49	**3,680**	**17.5**	1,390	31	12	32	135	102
02Ely 1B	4.5	<10	<2	28	66	1,620	**15.7**	1,160	32	19	23	139	91
02Ely 2A	4.5	<10	<2	31	57	2,320	**17.4**	1,620	28	11	35	156	201
02Ely 2A DUP [2]	4.6	<10	<2	32	57	2,630	**17.6**	1,620	30	12	40	151	155
02Ely 2B	4.6	<10	<2	31	72	1,240	**16.5**	862	27	20	27	148	105
02Ely 3	5.7	<10	<2	39	149	**5,660**	**15.6**	667	18	11	78	268	341
02Ely 4A	5.3	<10	<2	37	107	2,050	**18.4**	1,050	33	13	49	212	194
02Ely 4B	5.3	<10	<2	38	102	1,530	**15.9**	1,020	21	16	42	183	151
02Ely 5A	4.6	<10	<2	39	75	**3,250**	**21.4**	890	34	12	46	202	269
02Ely 5B	4.5	<10	<2	31	86	1,440	**13.8**	998	14	20	27	143	160
02Ely 6A	4.7	<10	<2	39	73	**4,220**	**18.3**	1,340	34	12	52	172	223
02Ely 6B	5	<10	<2	39	98	2,560	**15.9**	1,440	21	18	42	162	184
02Ely 6B DUP	5	<10	<2	39	96	2,830	**16.2**	1,410	24	19	45	158	184
ES-4	1	<10	<2	27	1.3	2,640	**45.6**	134	5.3	11	<4	60	60
Ely00JH22	4.26	<10	<2	14	48	**5,100**	**19.4**	**2,180**	42	<3	69	197	149
Ely00JH24	4.31	<10	<2	19	71	2,400	**18.3**	**1,920**	69	<3	82	211	207
Ely00JH24 DUP	4.36	<10	<2	18	73	2,320	**17.4**	**2,220**	59	<3	79	207	210
02Ely 7A	4.1	<10	<2	34	45	**7,020**	**18.4**	**2,420**	46	11	57	145	216
02Ely 9A[3]	4.1	<10	<2	39	42	**6,940**	**19.5**	**2,330**	45	12	65	150	250
02Ely 7B	4	<10	<2	54	38	**6,540**	**19.6**	1,740	46	13	63	150	214
02Ely 9B[3]	4	<10	<2	53	42	**5,580**	**19.5**	1,730	48	14	71	163	228
02Ely 8A	3.8	<10	<2	25	38	2,240	**16.0**	**2,520**	28	7.2	50	139	219
02Ely 8B	5	<10	<2	20	68	1,510	**10.8**	**2,050**	20	7	46	144	113
02Ely 8C	4.9	11	**42**	**1,040**	103	**25,600**	**19.0**	**2,010**	18	237	52	132	3,960
02Ely 10A	3.9	<10	<2	50	68	2,040	**19.6**	1,210	41	18	47	169	447
02Ely 10B	4.4	<10	<2	31	86	1,630	**15.1**	915	24	19	21	129	235
02Ely 11	4	<10	<2	78	70	2,780	**16.0**	699	20	26	65	115	425
02Ely 12	4	<10	<2	431	35	**6,880**	**28.4**	878	34	32	93	104	3,440
02Ely 12 DUP	4	<10	<2	414	36	**6,750**	**27.4**	871	33	32	61	104	3,360
02Ely 13	6.5	<10	<2	14	101	45	**5.2**	750	2.2	34	120	171	81

[1] USEPA preliminary remediation goals (PRGs) for residential and industrial soils (USEPA, 2002). Samples in bold are in excess of either the industrial or residential soil PRG.

[2] DUP, duplicate analysis of the same sample.

[3] 02Ely9A and 02Ely9B are field replicate samples for sample 02Ely7A and 02Ely7B, respectively.

Mine-waste samples contain significant concentrations of Fe. All samples exceed the PRG for industrial soils (10 wt. % Fe), except 02Ely13 (smoke-flue soil), which exceeds the residential PRG of 2.3 wt. % Fe. The smoke-flue soil is not mine waste, but is organic-rich soil that may have been contaminated by smelter smoke exhausting from the flue. Thus, the 5.2 wt. % Fe of sample 02Ely13 may be an indication of the background concentrations of Fe in the soil around the site. The highest concentration of Fe, 45.6 wt. %, is found in the hardpan seep material, which is predominantly goethite (see below). Nearly half of the mass of the hardpan is Fe, nearly a third of the slag is Fe and between 10 and 21% of the mass of the other mine-waste samples is Fe (Table 1).

Copper is the dominant metal found in the samples, with the highest concentration reaching 25,600 mg/kg in the unoxidized flotation-mill tailings. The areas sampled at the site which do not exceed the PRG for Cu in residential soil either at the surface or at depth are the two south-west sections of the upper mine waste (02Ely2, 02Ely4), the hardpan seep (ES-4), the soil around the flotation mill (Ely00JH24), the roast beds (02Ely10), the soil around the smelter site (02Ely11), and the smoke-flue soil (02Ely13) (shown in blue and green in Figure 5). In general, waste-rock material (except for the two samples from the upper waste pile mentioned above), the flotation tailings, and the slag shown in yellow, orange, and red in Figure 5 exceed the EPA guideline of 3,100 mg/kg Cu for residential soils. All samples, except for the smoke-flue soil, contain anomalous concentrations (at least 1,200 mg/kg) of Cu when compared with the range of < 1 to 700 mg/kg Cu for soils in the eastern United States reported by Shacklette and Boerngen (1984). The reported value of 45 mg/kg Cu for the smoke-flue soil may be elevated when compared to background soil for the area due to contaminated exhaust from the smoke flue. The areal extent of such contamination is unclear.

The concentrations of Zn in the mine waste are significantly higher than the mean concentration of 40 mg/kg for soils in the eastern United States (Shacklette and Boerngen, 1984) but do not exceed the PRG for residential soil (Table 1). The highest concentrations of Zn are found in the unoxidized flotation tailings (02Ely8C) and the slag material (02Ely12) with 3,960 and 3,440 mg/kg Zn, respectively. The concentrations of Mn in the surface samples from the lower mine-waste pile (Ely00JH22, 02Ely7A, 02Ely9A), the soil surrounding the flotation mill (Ely00JH24), and the flotation-mill tailings also exceed the PRG for residential soil (Table 1).

Copper is the dominant base metal in all samples, constituting over 80% of the total (Cu+Cd+Co+Ni+Pb+Zn), except for in the slag and smoke-flue soil. For the slag sample, 63% of the base-metal total is Cu and 32% is Zn. In general, the trend in base-metal variation is a reflection of the Cu concentration in the sample. The total base-metal concentration decreases with depth for most samples (Fig. 6 and Table 1). For example, the concentration of Cu is at least 25% lower at depth for the upper mine-waste samples. The concentration of total base metals and Cu decreases in the transition zone of the flotation-mill tailings sampled at a depth of 35-46 cm, but increases significantly in the unoxidized material sample at 71-91 cm (Fig. 6). This is due to the high percentage of sulfides in this sample (see section below).

Color was one criterion used to distinguish between sampling locations and the concentrations of base metals do not appear to correlate with the dominant color of the material (Fig. 6). Similarly, Hammarstrom and others (2003) did not report a distinct trend between color and base-metal concentrations for TP3 samples from the Elizabeth mine. At the Ely mine, the color of the upper mine-waste piles (02Ely1 to 6) ranges from yellow to strong brown and the total base metal of these piles ranges from 1,400 to 6,100 mg/kg. The highest as well as one of the lowest base-metal sums are found in material that is reddish brown/brownish yellow.

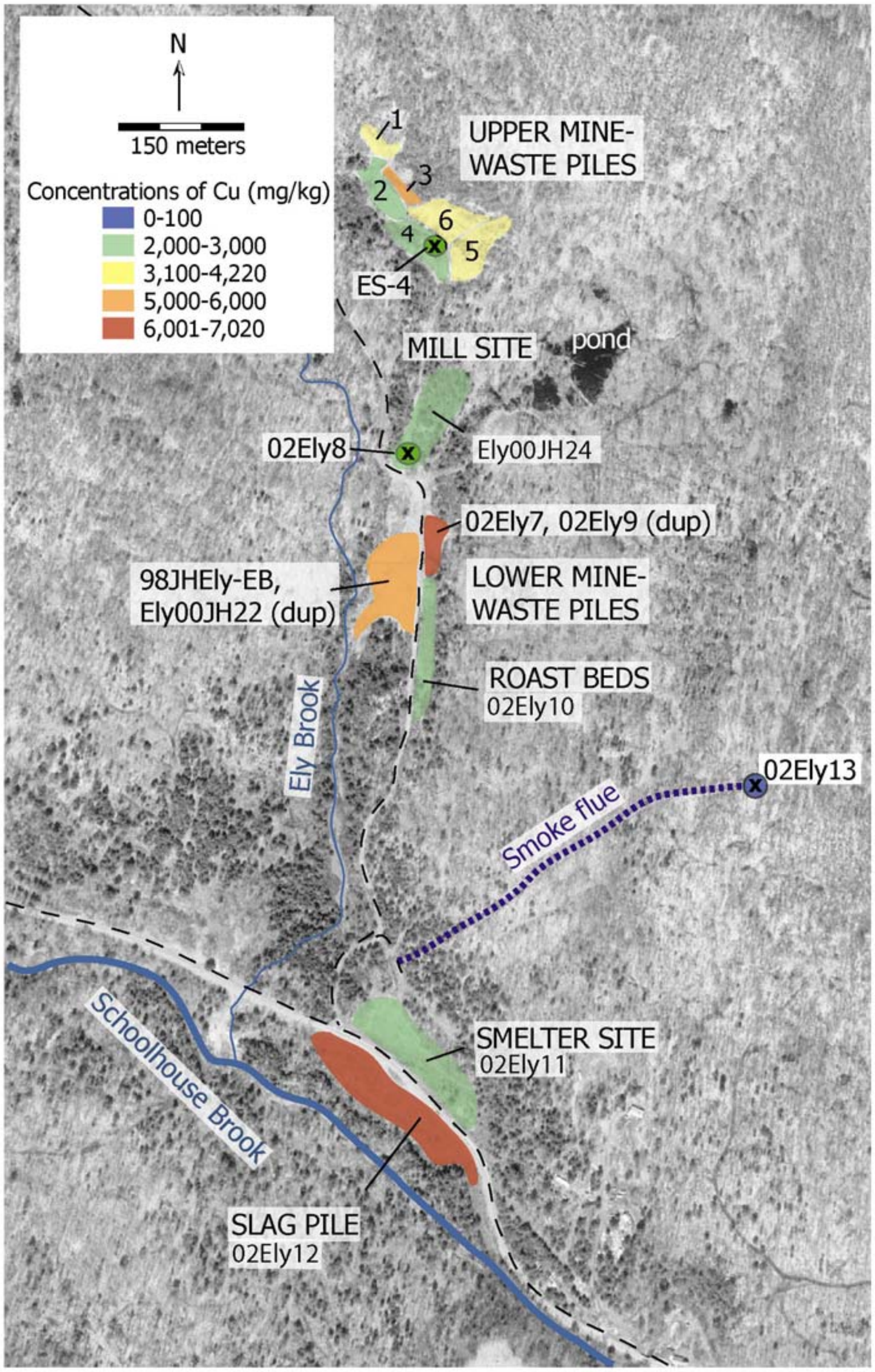


Figure 5. Concentration of Cu in surface samples from the Ely mine. Regions shaded in yellow, orange, and red exceed EPA preliminary remediation goals (PRG) for residential soil for Cu and all areas exceed the PRG for industrial soil for Fe, except the smoke-flue area.

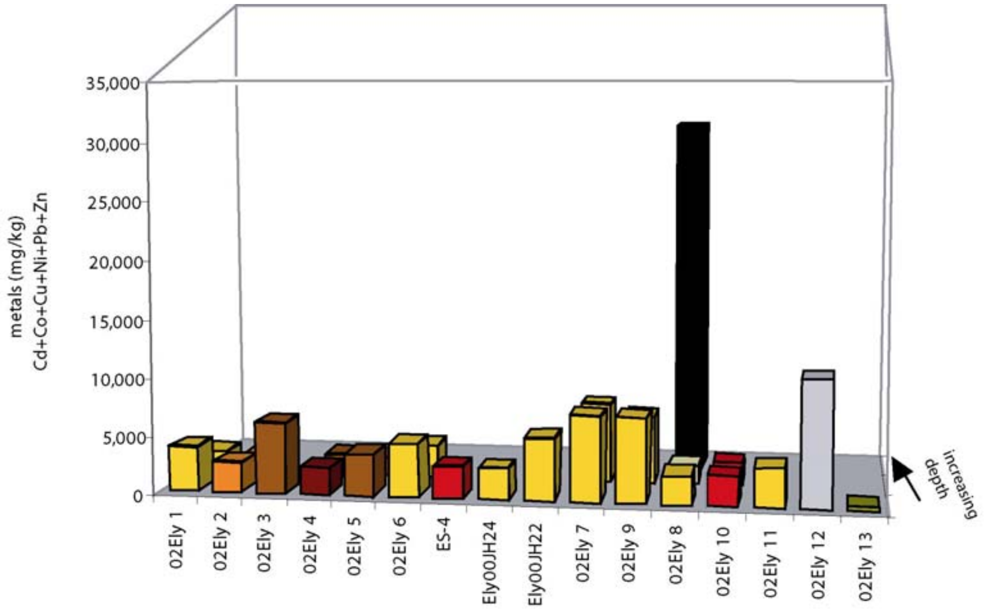


Figure 6. Total base metals in mine waste plotted according to pile and dominant color. The samples increase in depth along the Z-axis. Data from Table 1.

Total base metals do tend to increase with an increase in Fe content as shown in Figure 7. Although the lower and upper mine-waste piles cluster in the same area in Figure 7, lower mine-waste material is slightly more metal-rich than upper mine-waste material. Of the upper mine-waste piles, composite sample 02Ely3 contains the highest concentration of Cr (149 mg/kg), Cu (5,660 mg/kg), S (3.67 wt. %), and Zn (341 mg/kg). The surface of this area is covered with boulders and may be the remnants of a hand-cobbing area. The base-metal and Fe content of the flotation-mill soil, smelter soil, and roast beds are comparable to the upper mine-waste piles (Fig. 7). Slag contains high concentrations of base metals and is anomalously Fe-rich in Figure 7. Unoxidized tailings contain the only detectable As (11 mg/kg) and Cd (42 mg/kg) and the highest concentrations of Co (1,040 mg/kg), Cu (25,600 mg/kg), Ni (237 mg/kg), S (14.09 wt. %), and Zn (3,960 mg/kg; Fig. 7). The concentrations of Cd, Co, Cu, Fe, and Mn in this sample exceed the PRG for residential soils. In general, the most metal-rich samples at the Ely site, in decreasing base-metal content, are: the unoxidized flotation-mill tailings (02Ely8C), the slag material (02Ely12), the lower mine-waste pile east of the road (02Ely7 and 9), and area 02Ely3 in the upper waste piles (Figs. 6 and 7). The extremely high Fe content of the predominantly goethitic hardpan seep is distinct from the other samples. Smoke-flue soil has the lowest Fe and base metal concentrations (Fig. 7). This sample also contains significantly less Mo and S, but contains high Cr (101 mg/kg) and the highest concentrations of Al (6.5 wt. %), Ca (1.6 wt. %), Mg (1.5 wt. %), Pb (120 mg/kg), Sn (28 mg/kg), Sr (139 mg/kg), and rare earth elements including Ce (45 mg/kg), La (21 mg/kg), and Yb (2.3 mg/kg) compared to the other samples (Appendix B-1). The high Al, Ca, and Mg may be a reflection of the presence of silicate phases (see section below) and the high Pb and Sn may be a result of contamination from the fumes of the smelter. Also, the 24-meter tall lead-lined draft chimney that topped the smoke flue may be a source of anomalous Pb.

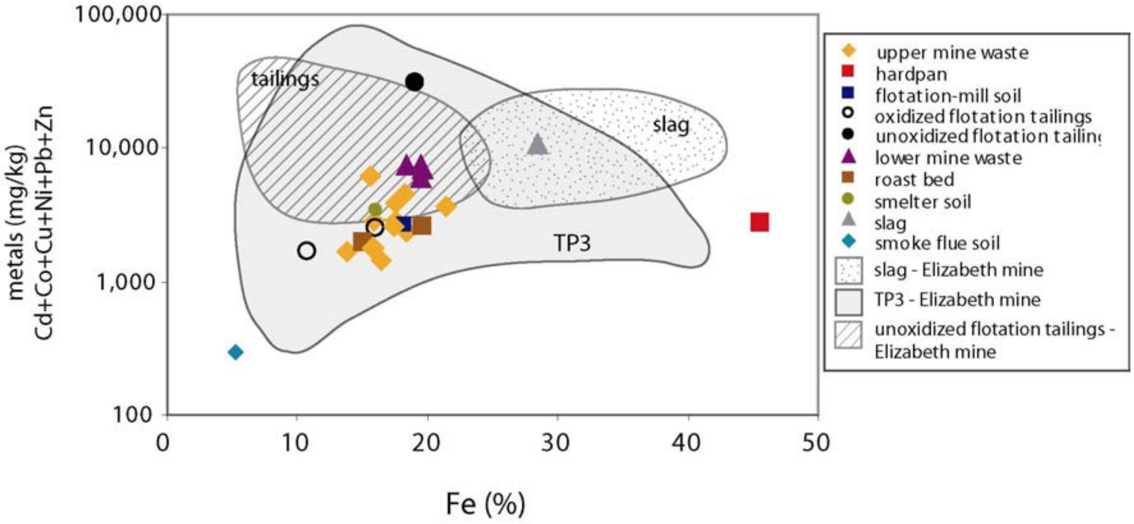
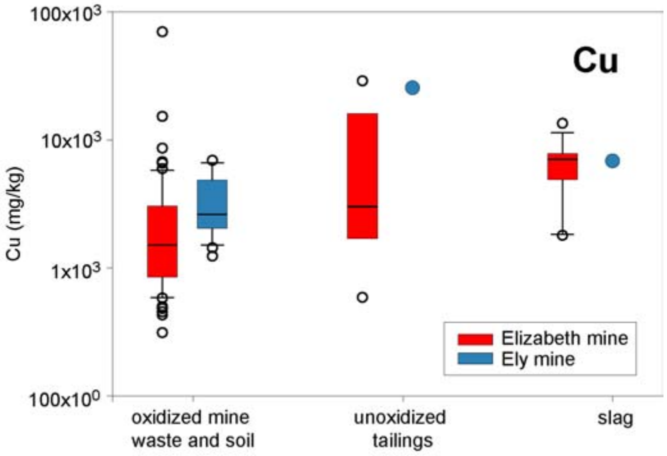


Figure 7. Total base-metal concentrations versus Fe content for mine-waste samples. The composition of the historic mine waste (TP3), unoxidized tailings, and slag at the Elizabeth mine are plotted for comparison (Hammarstrom and others, 2001a, 2003; Piatak and others, 2003, 2004). Note the logarithmic scale for the total base-metal concentrations.

Total base-metal concentrations in the historic mine-waste piles (TP3), the unoxidized tailings, and slag at the Elizabeth mine Superfund site are also plotted on Figure 7. TP3 samples containing the underlying till are not included in Figure 7 because no till has been found at the Ely mine. Iron content and base-metal concentrations in TP3 vary significantly and most samples from the Ely mine fall within this range. Unoxidized tailings from the Ely mine contain close to the maximum base-metal concentration found in unoxidized tailings from the Elizabeth mine (Fig. 7). The composite sample from the base of the slag pile at the Ely mine is within the range of compositions in grab slag samples from the Elizabeth mine (Fig. 7). Similar to the Ely samples, the dominant metals in the mine waste from the Elizabeth mine are Cu (313-70,000 mg/kg) and Zn (29-10,200 mg/kg) (Hammarstrom and others, 2001a, 2003; Piatak and others, 2003, 2004). Concentrations of these two metals from the Ely and Elizabeth mines follow trends similar to those found for the concentrations of total-base metals discussed above. The concentrations of Cu and Zn in oxidized mine waste and soil at both sites are similar; those in unoxidized tailings at the Ely mine are near the maximum for concentrations found at the Elizabeth mine; those in slag at both sites are comparable (Fig. 8). Generally, the concentrations of other metals follow similar trends. One exception is the slightly higher concentrations of Ni and Pb in slag from Ely mine. Concentrations of Co, Cr, Ni, and Pb in roast beds at the Ely mine are similar to those in surface samples of the red roasted material at the Elizabeth mine; concentrations of Cu, Mn, S, and Sr are higher in the Ely samples than the Elizabeth samples (Hammarstrom and others, 2003).



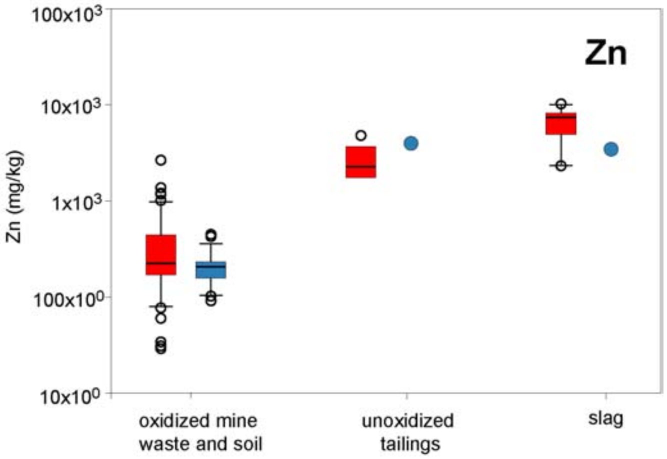


Figure 8. Box plots of Cu and Zn concentrations in mine waste from the Ely and Elizabeth mines. The median value is shown as the vertical bar in the center of the rectangular box whose ends represent the 25th and 75th percentiles. The ends of the "whiskers" that extend from the box represent the 10th and 90th percentiles; outlying points are also plotted. Concentrations for Ely unoxidized tailings and for Ely slag are displayed as points. Oxidized mine waste (TP3) at the Elizabeth mine does not include samples containing underlying till. Slag samples from the Elizabeth mine are grab samples, whereas the slag sample from Ely is a composite. Data for the Elizabeth mine (except one unoxidized tailings sample) are from Hammarstrom and others (2001a, 2003), and Piatak and others (2003, 2004).

Mineralogy

Although the Ely mine-waste samples are the products of a wide range of metallurgical processes, the samples were initially derived from the same set of host rock and ore. Thus, the same minerals are present in many samples and include a variety of silicates, sulfides, sulfates, and oxides (Table 2). Some minerals originally not present in significant quantities in host rock or ore were produced by the metal extraction processes (e.g., hematite from roasting, and fayalite from smelting). Estimates of the weight percentage of each phase were determined by a Rietveld refinement on a full XRD profile and are summarized in Appendix C. Rietveld results are illustrative with an accuracy of ±5 wt. %, but are not meant to represent absolute mineralogical content for each sample.

Table 2. Minerals in mine waste from the Ely mine. Neutralization potential (NP) ranges and averages (in parentheses) are for monomineralic samples from Jambor and others (2000, 2002). NP units are kg $CaCO_3$/ton.

Minerals	Ideal formula	Acid-generating NP < 0	Inert NP = 0-1	Acid-neutralizing NP > 1	Phase or range of phases	Reference
SILICATE MINERALS						
Quartz	SiO_2		x			
Albite	$NaAlSi_3O_8$ (An_{0-10})		0.5		Ab_{98}	Jambor and others (2000)
Anorthite	$CaAl_2Si_2O_8$ (An_{90-100})			10.7	An_{93}	Jambor and others (2000)
Labradorite	$(Ca,Na)Al_{1-2}Si_{2-3}O_8$ (An_{50} - An_{70})			2.6-11.5 (8.0)	An_{50-67}	Jambor and others (2002)
Biotite	$K(Mg, Fe)_3(AlSi_3O_{10})(OH)_2$			2.7-24.9 (10.5)	Mg_{2-94}	Jambor and others (2000)
Muscovite	$KAl_2(AlSi_3O_{10})(OH)_2$		0.3			Jambor and others (2000)
Chlorite	$(Mg,Fe^{2+})_5Al(Si_3Al)O_{10}(OH)_8$			0.8-21.6 (8.3)	$Mg_{0.37-0.95}$	Jambor and others (2000)
Kaolin	$Al_2Si_2O_5(OH)_4$		0		kaolinite	Jambor and others (2000)
Talc	$Mg_3Si_4O_{10}(OH)_2$			1.7		Jambor and others (2000)
Vermiculite-hydrobiotite	K-Mg-Fe-Al silicates			29.0		Jambor and others (2002)
Sepiolite [1]	$Mg_4(OH)_2Si_6O_{15}\bullet 6H_2O$					
Hornblende	$(Ca,Na)_{2-3}(Mg,Fe,Al)_5Si_6(Si,Al)_2O_{22}(OH)_2$			0.2-8.7 (3.7)	amphiboles	Jambor and others (2002)
Fayalite	Fe_2SiO_4			40.2, 38.8	Fa_{66} & Fa_{89}	Jambor and others (2002)
OTHER MINERALS						
Calcite	$CaCO_3$			49.9 [2]		Jambor and others (2002)
Goethite	FeO(OH)			1.5		Jambor and others (2002)
Hematite	Fe_2O_3			2		Jambor and others (2002)
Magnetite	$Fe^{2+}Fe_2^{3+}O_4$			1.7		Jambor and others (2002)
EFFLORESCENT SULFATE SALTS						
Alunogen	$Al_2(SO_4)_3\bullet 17H_2O$					
Copiapite	$Fe^{2+}Fe^{3+}(SO_4)_6(OH)_2\bullet 20H_2O$	x				
Melanterite	$FeSO_4\bullet 7H_2O$	x				
Rozenite	$FeSO_4\bullet 4H_2O$	x				
OTHER SULFATE MINERALS						
Gypsum	$CaSO_4\bullet 2H_2O$		x			
Jarosite	$K_2Fe_6^{3+}(SO_4)_4(OH)_{12}$	-3.9				Jambor and others (2002)
SULFIDES						
Chalcopyrite	$CuFeS_2$	x	x			Plumlee (1999)
Pyrite	FeS_2	x				Plumlee (1999)
Pyrrhotite	$Fe_{1-x}S$	x				Plumlee (1999)
Sphalerite	ZnS		x			Plumlee (1999)

[1] Phase identified as sepiolite in the Rietveld refinement is likely altered biotite, see discussion in text.

[2] Theoretical value of 50 kg $CaCO_3$/ton for 20 mL of 0.1M HCl used in ABA tests on Ely mine waste. The theoretical value is 1,000 for complete dissolution.

The Munsell color of some samples is a reflection of the dominant mineral present. This correlation was also reported by Hammarstrom and others (2003) for the TP3 samples at the Elizabeth mine. The variation in color found among piles at the Ely mine is not as distinct as the variation in color of TP3 samples from the Elizabeth mine. At Ely, the red color of ES-4 is due to the abundance of goethite (76 wt. %) (Appendix

C). The Ely roast beds (02Ely10) are red because the area is hematite-rich (up to 16 wt. %). At the Elizabeth mine, the partially roasted ore is red and black; red piles contain up to 41 wt. % hematite and black piles contain up to 77 wt. % hematite (Hammarstrom and others, 2003). Several minerals may be similar in color and thus the dominant mineral in a sample cannot be determined exclusively by color. The unoxidized tailings (02Ely8C) are black because of the dominance of pyrrhotite (29.6 wt. %), but the slag material is dark gray due to the presence of abundant fayalite (39.2 wt. %). The smoke-flue soil (02Ely13) is predominantly composed of silicates and contains only trace amounts of Fe-oxides, which contribute to the light olive brown color of this sample. 02Ely8B is pale yellow due to the presence of minor goethite (2.5 wt. %), no hematite, and significant jarosite (13.9 wt. %). The remaining mine-waste samples are mixtures of several colored minerals and vary from yellow to brownish yellow to reddish yellow to reddish brown to strong brown. A simple correlation between mineralogy and sample color was not found.

The major mineralogy of each sample is illustrated in Figure 9. Most silicates are grouped according to their acid-neutralizing potential (NP > 1) or their relatively inert behavior (NP ~ 0) (NP for individual minerals is given in Table 2). Sulfide fields represent the sum of pyrrhotite, pyrite, chalcopyrite, and sphalerite; salt fields represent efflorescent sulfate salts such as alunogen, copiapite, melanterite, and rozenite.

With the exception of the hardpan seep, the samples contain significant quartz ranging from 18.8 to 43.3 wt. %. Quartz is neither acid-generating nor acid-neutralizing with respect to contributions to water quality, and thus is grouped with other minerals with a NP ~ 0 (Fig. 9). For most samples, the second most abundant phase is feldspar (Appendix C). The compositions of the feldspars range from anorthite to albite, most commonly identified by XRD as albite and labradorite. Sodic feldspars are less acid-neutralizing than more calcic feldspars according to Jambor and others (2000 & 2002). Therefore, sodic feldspars are grouped with other relatively inert silicates (NP ~ 0) in Figure 9, whereas more calcic feldspars are grouped with acid-neutralizing silicates (NP > 1). In general, muscovite is the most common sheet silicate with lesser amounts of chlorite and/or biotite. Clay phases include kaolinite, talc, vermiculite, and a phase with a strong intensity, broad peak at a spacing of approximately 11.5 to 12 Å, identified as sepiolite in the XRD patterns. However, sepiolite is generally associated with low latitudes and semi-arid climates, commonly forming in shallow seas and lakes, and is unlikely to be found in mine waste. More likely, this peak may be ascribed to hydrous altered biotite. As reported by Rebertus and others (1986), biotite (strong intensity peak at 9.9 Å) weathers to interstratified biotite-vermiculite (hydrobiotite) (stong intensity peak in the range of 10 to 14 Å). The range in peak spacing for the phase in the mine-waste samples from approximately 11.5 to 12 Å may be a result of varying degrees of biotite alteration. Hornblende is found in most samples ranging from 0 to 7.9 wt. % for mine-waste samples and 16.2 wt. % for the smoke-flue soil.

Goethite is the dominant oxide in most samples; goethite abundance decreases with depth (Fig. 9). The hardpan seep (ES-4) contains 76 wt. % goethite and thus a calculated Fe content from the Siroquant results of 48 wt. % Fe. This is in good agreement with the concentration of Fe from ICP-AES analysis of 45.6 wt. %. Only a few samples contain hematite, including one surface section of the upper mine waste (02Ely4A), the roast beds (02Ely10A & B), the smelter soil (02Ely11), the slag pile (02Ely12), and the smoke-flue soil (02Ely13). Only the roast beds contain major

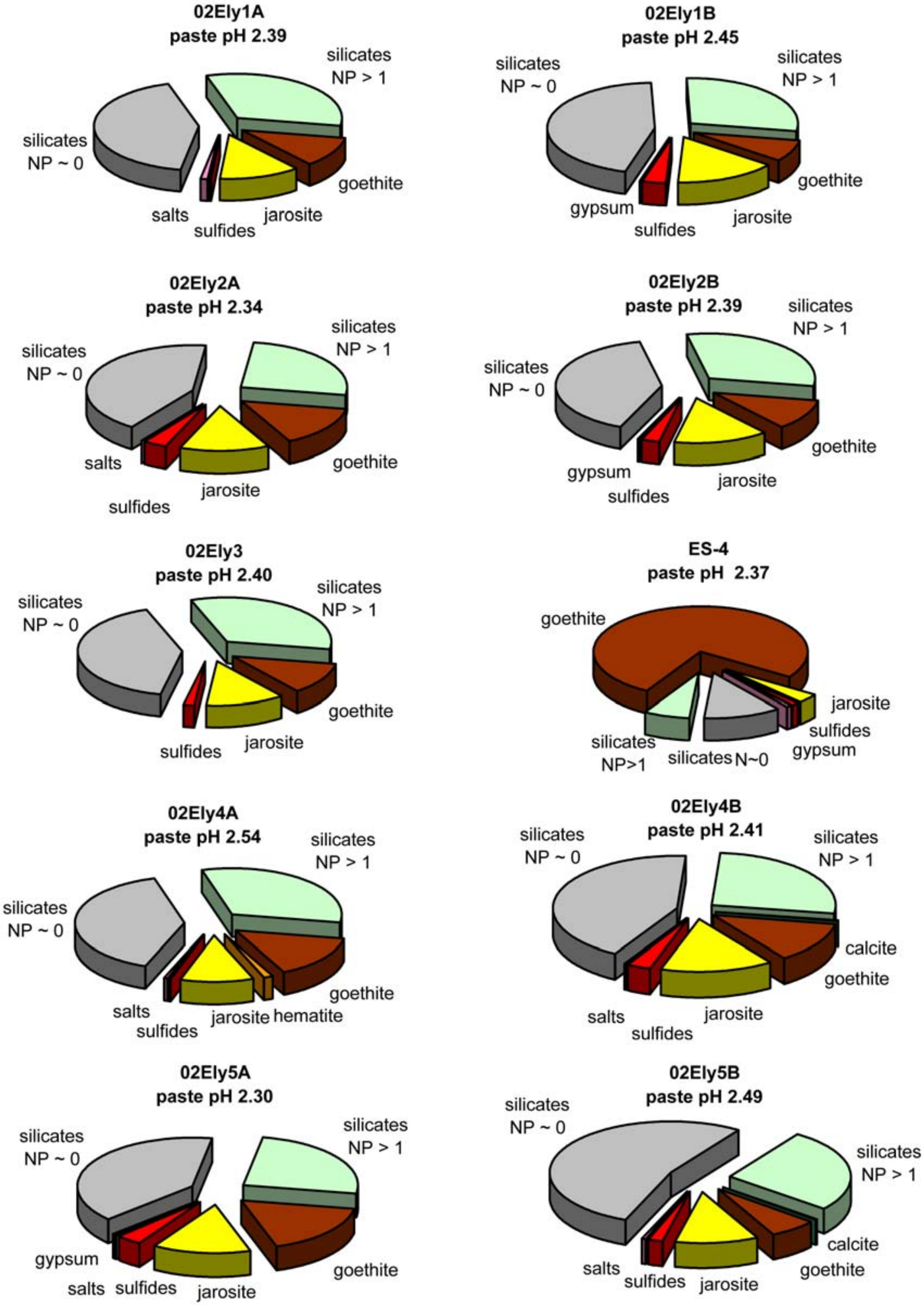


Figure 9. Mineralogy of Ely mine waste based on Rietveld refinements using the Siroquant computer program. "A" samples are surface samples; "B" and "C" are at depth.

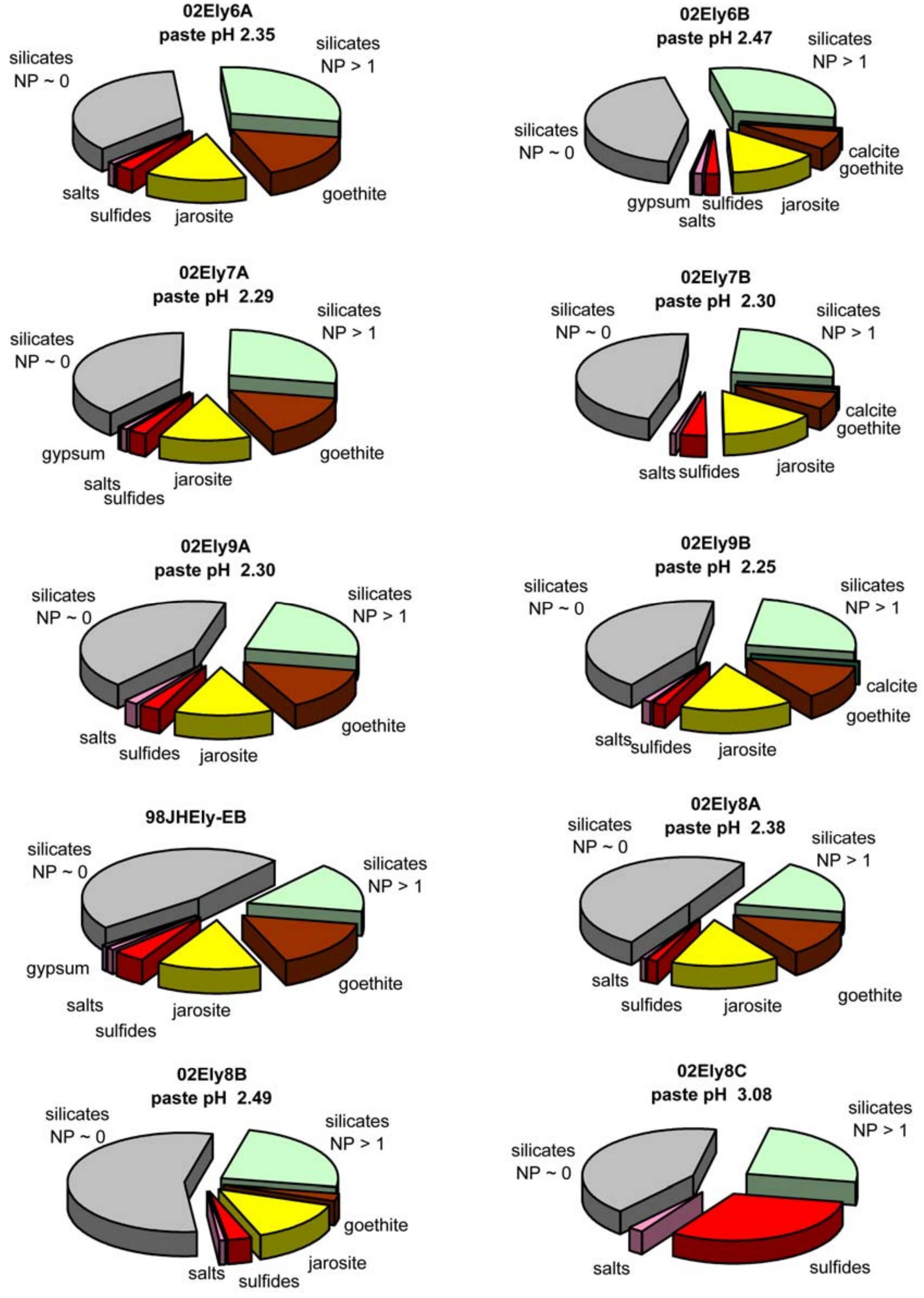


Figure 9. (cont.)

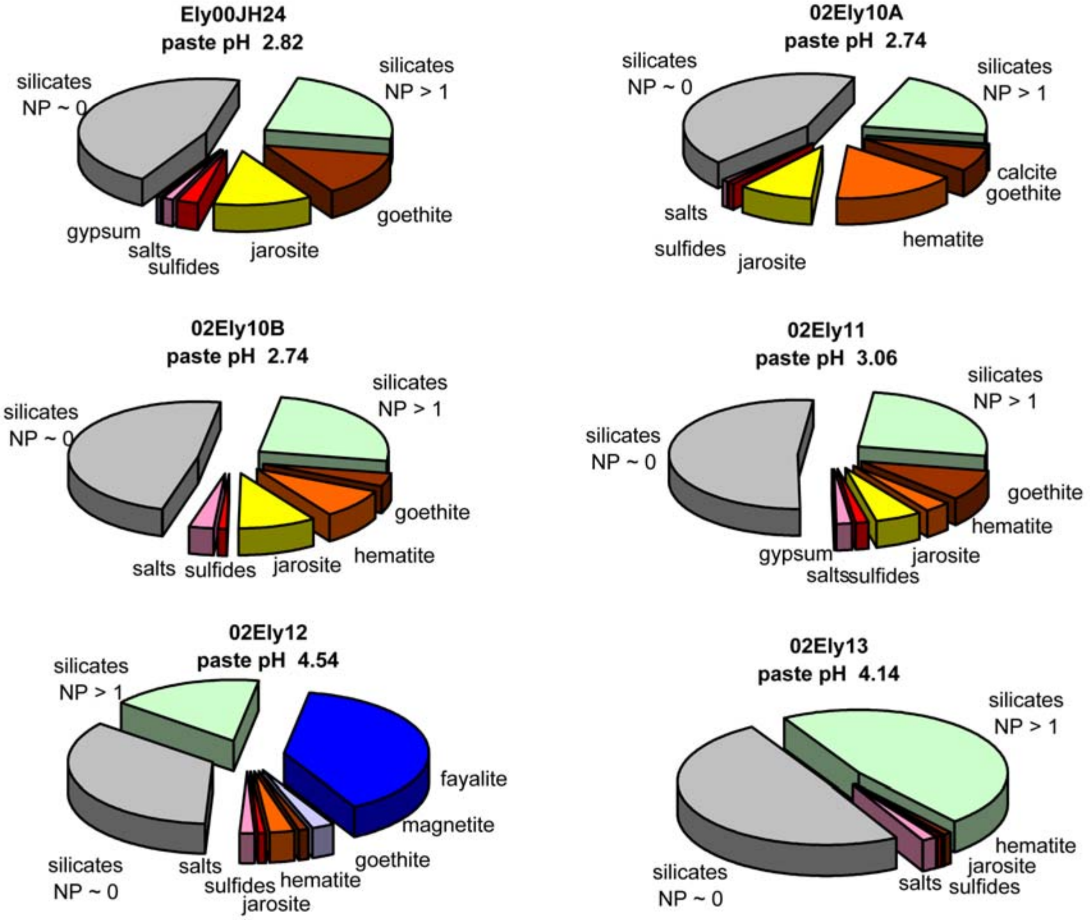


Figure 9. (cont.)

amounts of hematite (15.9 and 8.8 wt. % for surface and depth samples, respectively). Hematite was a product of the roasting process, during which the pyrrhotite-rich ores were burned to drive off sulfur. The slag sample also contains magnetite (2.6 wt. %). These iron oxides (goethite, hematite, and magnetite) have a slight acid-neutralizing potential with NP values ranging from 1.5 to 2 kg $CaCO_3$/ton. In contrast, jarosite is potentially acid-generating with a NP of –3.9 kg $CaCO_3$/ton (Jambor and others, 2002) and the upper mine-waste piles, lower mine-waste piles, surface soil around the mill site, and the roast beds contain at least 10 wt. % jarosite. Localized, jarosite-rich, yellow layers were found at depth within the roast beds. The jarosite content increases or remains approximately the same at depth for most of the areas sampled at depth.

Pyrrhotite and chalcopyrite were positively identified in several mine waste XRD profiles. The Rietveld-determined abundances of these minerals are up to 3.7 wt. % for pyrrohtite, except for the anomalously high concentration of 29.6 wt. % pyrrhotite in the unoxidized flotation tailings, and up to 1.6 wt. % for chalcopyrite. Chalcopyrite was positively identified by electron microprobe analyses in mine waste from the upper mine-waste piles by Hammarstrom and others (2001b). The Rietveld-determined concentrations of pyrite and sphalerite are 0.5 wt. % or less. Overall, the total sulfide concentrations ranged from 0.1 to 4.5 wt. % for all samples, except for the unoxidized flotation tailings. Pyrrhotite and pyrite oxidation is acid-generating; chalcopyrite oxidation can be acid-generating depending on the oxidizing agent; the oxidation of pure sphalerite is not acid-generating if oxygen is the oxidizing agent (Plumlee, 1999).

The Rietveld-determined abundances of the sulfate salts including alunogen, copiapite, melanterite, rozenite, and gypsum are less than 1.6 wt. % (Appendix C). These results are also near the detection limit for the XRD profile. The presence of sulfate salts including gypsum, melanterite, rozenite, and chalcanthite in mine waste was investigated because these phases occur on the surface of mine waste at the Ely mine (Hammarstrom and others, 2001b). Sulfate salts found on the slag pile include chalcanthite, rozenite, siderotil, brochantite, and gypsum (Piatak and others, 2003; 2004). Filtered leachate water was evaporated (procedure discussed above in methods) and the resulting evaporates were identified as gypsum, rhombclase ($FeH(SO_4)_2 \bullet 4H_2O$), and szomolnokite ($FeSO_4 \bullet H_2O$). The results imply that soluble sulfate salts are present in the mine-waste samples, although potentially in quantities less than the detection limit of XRD.

Calcite is the most effective acid-neutralizing mineral and therefore was included in the Siroquant analyses. The Rietveld-determined abundance of calcite in these mine-waste samples is minimal (0 to 0.8 wt. %) and likely below the reliable detection limit for the XRD profiles. Therefore, calcite is included as a phase in Figure 9 with questionable reliability.

Acid-base accounting

Paste pH and acid-base accounting results (Fig. 10 and Table 3) indicate that most mine-waste samples from the Ely mine are acid-generating. The hardpan seep (ES-4) and slag sample (02Ely12) were not analyzed for ABA. According to paste pH, ES-4 is potentially acid-toxic (paste pH < 4), but the slag is not. The paste pH values were determined both by the USGS and B.C. Research, Inc., and are in excellent agreement (Table 3).

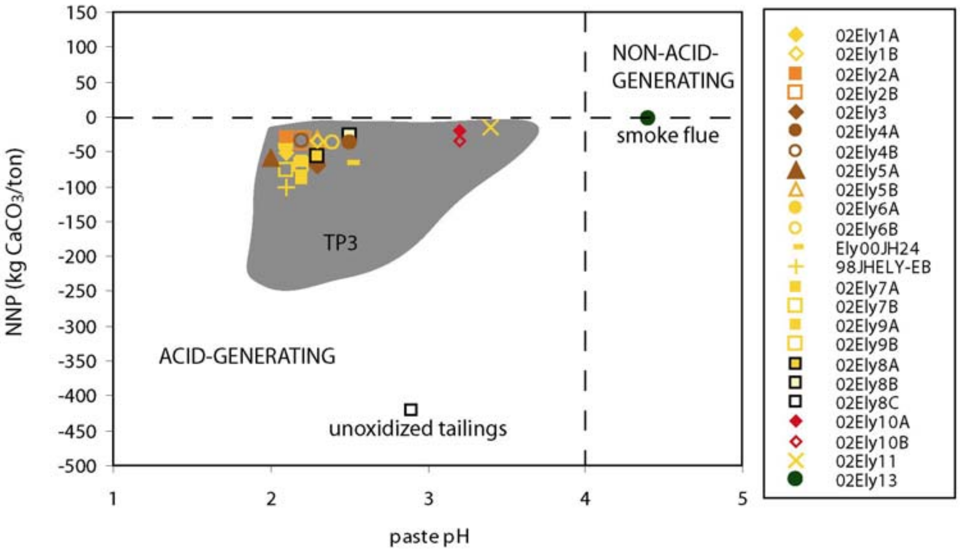


Figure 10. Acid-base accounting results for mine waste from the Ely mine. Material with a paste pH < 4 and NNP < 0 are considered likely to generate acid. ABA results for historic mine waste (TP3) at the Elizabeth mine are shown as the shaded region (data from Hammarstrom and others, 2003).

Table 3. Paste pH and acid-base accounting results.

	Paste pH (USGS)	Paste pH (B.C. Research)	Total S (LECO) wt. %	Sulfate S wt. %	Sulfide S wt. %	Maximum Potential Acidity (AP) kg $CaCO_3$/t	Neutralization Potential (NP) kg $CaCO_3$/t	Net Neutralization Potential (NNP) kg $CaCO_3$/t	Fizz Rating	NP/AP
02Ely 1A	2.4	2.1	2.56	1.28	1.28	40.0	-9.5	-49.5	none	-0.2
02Ely 1B	2.5	2.3	2.18	1.36	0.82	25.6	-8.3	-33.9	none	-0.3
02Ely 2A	2.3 *(2.3)*[1]	2.1	2.48	1.84	0.64	20.0	-9.8	-29.8	none	-0.5
02Ely 2B	2.4	2.2	2.05	1.21	0.84	26.3	-8.8	-35.1	none	-0.3
02Ely 3	2.4	2.3	3.67	1.55	2.12	66.3	-4	-70.3	none	-0.1
02Ely 4A	2.5	2.5	2.09	1.11	0.98	30.6	-7	-37.6	none	-0.2
02Ely 4B	2.4	2.2	2.49	1.63	0.86	26.9	-8.3	-35.2	none	-0.3
02Ely 5A	2.3	2	2.88	1.35	1.53	47.8	-11.8 *(-10.5)*	-59.6	none	-0.2
02Ely 5B	2.5	2.3	1.77	1.08	0.69	21.6	-8	*-29.6*	none	-0.4
02Ely 6A	2.4	2.1	2.76	1.67	1.09	34.1	-8.5	-42.6	none	-0.2
02Ely 6B	2.5 *(2.5)*	2.4	2.53	1.45	1.08	33.8	-4.3 *(-5)*	-38.1	none	-0.1
ES-4	2.4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Ely00JH24	2.8	2.5	2.30	0.37	1.93	60.3	-5.5	-65.8	none	-0.1
Ely00JH24[2]	2.8	2.5	2.30	1.8	0.50	15.6	-5.5	-21.1	none	-0.4
98JH-ELY-EB	n.a.	2.1	3.10	0.34	2.76	86.3	-14.7	-101.0	none	-0.2
98JH-ELY-EB[2]	n.a.	2.1	3.10	2.3	0.80	25.0	-14.7	-39.7	none	-0.6
02Ely 7A	2.3	2.2	3.33	1.61	1.72	53.8	-10.8	-64.6	none	-0.2
02Ely 9A[3]	2.3	2.2	3.74	1.34	2.4	75.0	-12.8	-87.8	none	-0.2
02Ely 7B	2.3	2.1	3.62 *(3.71)*	1.6	2.02	63.1	-13	-76.1	none	-0.2
02Ely 9B[3]	2.3	2.2	3.37	1.54	1.83	57.2	-12	-69.2	none	-0.2
02Ely 8A	2.4	2.3	2.69	1.11	1.58	49.4	-8.5	-57.9	none	-0.2
02Ely 8B	2.5	2.5	2.24	1.55	0.69	21.6	-4.5 *(-4.3)*	-26.1	none	-0.2
02Ely 8C	3.1	2.9	14.09	0.83	13.26	414.4	-7.5	-421.9	none	0.0
02Ely 10A	2.7	3.2	1.84	1.42	0.42	13.1	-7.3 *(-7.5)*	-20.4	none	-0.6
02Ely 10B	2.7	3.2	2.19	1.28	0.91	28.4	-5	-33.4	none	-0.2
02Ely 11	3.1	3.4	1.28	0.93	0.35	10.9	-3.5	-14.4	none	-0.3
02Ely 12	4.5 *(4.6)*	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
02Ely 13	4.1	4.4	0.07 *(0.08)*	0.03	0.04	1.3	-1.8	-3.1	none	-1.4

[1] Italic numbers in parentheses are duplicates.

[2] More aggressive method used to determine AP.

[3] 02Ely9A and 02Ely9B are field replicate samples for sample 02Ely7A and 02Ely7B, respectively.

The NNP values range from –421.9 to –3.1 kg $CaCO_3$/ton (Fig. 10). The acid-generating potential of the samples does not vary on the basis of the Munsell soil color as shown in Figure 10. The soil from the top of the smoke flue (02Ely13) is the only sample that does not plot within the acid-generating area in Figure 10. This material has a slightly negative NNP value (-3.1) and a paste pH above 4. Of the remaining samples, most form a cluster of points in Figure 10 with paste pH values between 2.0 and 2.5 and NNP values ranging from –101 to –26.1 kg $CaCO_3$/ton. The outlying samples include the partially roasted ore (02Ely10) and the smelter-site soil (02Ely11), both of which have higher paste pH, 3.2 and 3.4, respectively, and slightly less negative NNP (Fig. 10). The most negative NNP value, –421.9 kg $CaCO_3$/ton, is for the unoxidized tailings, which contains nearly 30 wt. % pyrrhotite according to the Siroquant results. This value is four times lower than the lowest NNP reported for the other samples.

Acid-base accounting results for historic mine-waste piles at the Elizabeth mine are shown as the gray shaded region in Figure 10. Carbonate till underlying the Elizabeth mine waste and mixtures of this till and the mine waste are not shown in Figure 10. The NNP of most mine waste from the Ely mine plots in the upper range of NNP values for the historic mine waste from the Elizabeth mine (TP3 in Figure 10). Unoxidized tailings at the Ely mine are more acid-generating than the historic mine waste from the Elizabeth mine (Fig. 10).

The NNP of the mine-waste samples is based on the amount of acid-generating minerals and acid-neutralizing minerals in a given sample. The amounts of these minerals present and their ability to counteract each other should result in the net-neutralization potential. Table 2 lists the neutralization potentials (NP) for rock-forming minerals found in mine waste from the Ely mine. The NP values were derived from the results of static tests by Jambor and others (2000; 2002). In general, the silicates and oxides contribute minimal acid neutralization because of the slow dissolution kinetics of most of these phases compared to the oxidation of sulfides. The Ely samples lack acid-neutralizing carbonate gangue minerals. Pyrrhotite is the most abundant sulfide and alters even more rapidly than pyrite. Also, these samples are composed of particles of various sizes, which may facilitate the access of oxygen and increase oxidation rates. Therefore, determination of the quantity of sulfides and acid-generating sulfates, such as jarosite and efflorescent sulfate salts, is the best indication of the acid-generating potential of the samples.

The AP for acid-base accounting is calculated based on the quantity of sulfides present, but most mine-waste samples from the Ely mine contain significant jarosite. For this study, the more aggressive procedure required to liberate sulfate-sulfur in jarosite was conducted on two samples from the Ely mine (Table 3). The AP determined by this more aggressive procedure is less than a third of the AP determined by the standard method. The NNP for both these samples is negative, although less negative, indicating the material is still classified as acid-generating.

Leachate

Leaching tests conducted on the < 2 mm size fraction of each sample using a solution which approximates eastern United States precipitation indicate that significant concentrations of metals may be released from the mine waste (Appendix D). The leaching tests simulate weathering of the waste piles and approximate the composition of runoff. The surface runoff and seepage waters at this site funnel downhill from the upper mine workings towards Ely Brook, where water quality is impacted (McSurdy and others, 1995; USEPA, 2003a). Results from the leaching tests were compared with water-quality guidelines for the protection of aquatic life and drinking water standards (Fig. 11). The toxicity guidelines for aquatic life for Cu, Cd, and Zn are based on a hardness of 100 mg/L $CaCO_3$. This hardness is slightly higher than the hardness reported by Seal and others (2001b) of between 64.2 to 87.3 mg/L $CaCO_3$ for Schoolhouse Brook upstream of

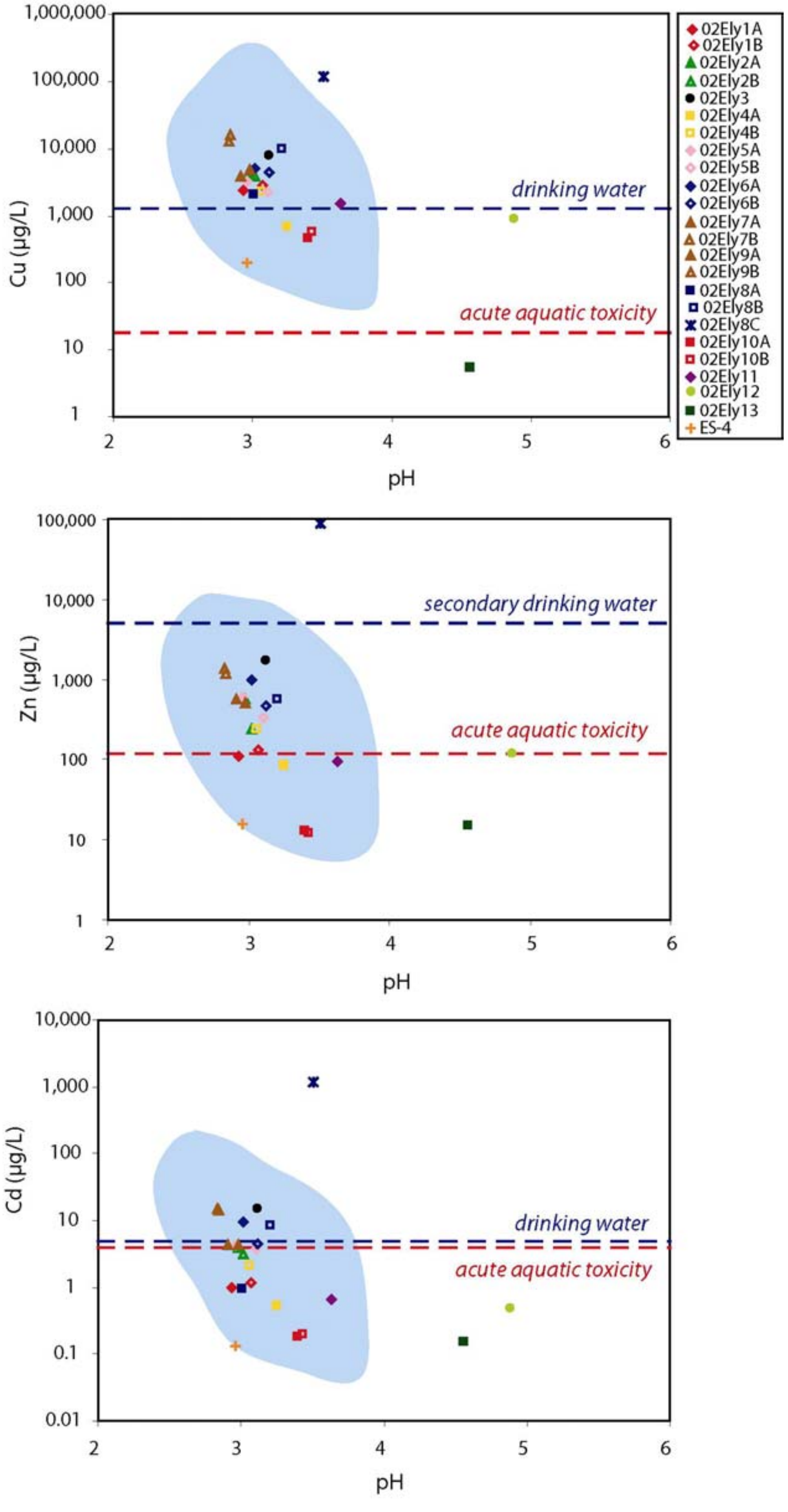


Figure 11. Dissolved metal concentrations in leachate as a function of pH. Shaded fields represent the composition of leachate from the historic mine-waste pile (TP3) at the Elizabeth mine (data from Hammarstrom and others, 2003). Points that plot above the dashed lines exceed drinking water and acute toxicity water-quality standards (standards from USEPA, 2003b and 1993, respectively).

the confluence with Ely Brook. In general, an inverse relationship exists between hardness and the toxicity of these metals with regards to impacts on aquatic life. Therefore, aquatic life is adversely affected by a lower concentration of the metal in water with a lower hardness.

The major anion in all leachate samples is sulfate. For most samples, Al, Ca, Cu, Fe, and Mg dominate the cations; Co, Cd, K, Ni, Mn, and Zn are significant in some samples (Appendix D). Concentrations of Cu in all leachates, except in the smoke-flue leachate, exceed the acute water-quality guidelines for the protection of aquatic life: Concentrations of Cu in all but six of the leachates exceed the USEPA drinking water standard (Fig. 11). The lowest amount of Cu was leached from smoke-flue soil (5.5 µg/L), which contains the least Cu in bulk geochemical analysis (Fig. 12). The highest amount of Cu was leached from unoxidized flotation-mill tailings (120,000 µg/L), which contains the most Cu in bulk geochemical analysis (Fig. 12). Leachate produced from the lower mine-waste pile east of the road (02Ely7B) contains 16,000 µg/L Cu. This composite sample was collected at a depth of 25 cm. Samples from this area also have some of the highest concentrations of Cu, according to the bulk chemical analysis (Fig. 12). Overall, the concentration of Cu in the bulk geochemical analysis correlates with the concentrations of Cu in leachate (Figure 12). An exception is the slag pile, which contains high concentrations of Cu in bulk analysis and relatively low concentrations of Cu in leachate, perhaps due to the more resistant nature of slag material. Samples which exceed the toxicity guidelines and do not exceed the drinking water standard for Cu include the slag pile, the roast beds, the hardpan seep, and one surface composite from the upper waste piles (02Ely4A).

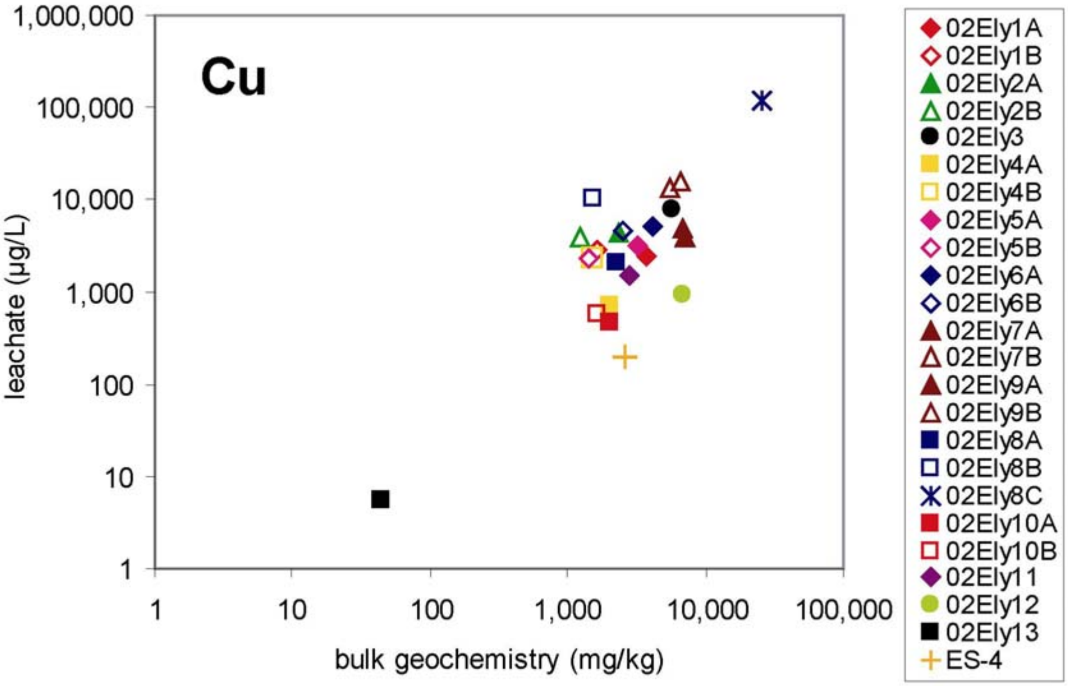


Figure 12. Bulk geochemical results for Cu concentrations versus the concentration of Cu in leachate. Note log scale.

The concentrations of Zn in most leachates from the Ely mine exceed the acute aquatic toxicity guideline but are less than the secondary drinking water standard for Zn (Fig. 11). Leachate from the unoxidized tailings contains anomalous Zn (91,000 µg/L), nearly twenty times greater than the drinking water standard. In general, leachate which contains the least amount of Cu, also contains the least amount of Zn and Cd (Fig. 11), including leachate from slag, soil at the smelter site, smoke-flue soil, roast beds, hardpan seep, and upper mine-waste sample 02Ely4A. Cadmium concentrations in leachate from surface composites from the upper mine-waste piles 02Ely3 and 02Ely6A, lower waste-pile composite sample 02Ely7B, and the flotation-mill tailings sampled at 35-46 cm and 71-91 cm exceed the USEPA drinking water standard. The pH of the leachate from all samples except slag material and smoke-flue soil is less than 4.2, the pH of the eastern synthetic precipitation leaching solution. This decrease in leachate pH implies that precipitation interacting with most mine waste at the site will produce acidic runoff.

The most extreme leachate composition is from the unoxidized flotation-mill tailings, which contains the highest concentrations of Cu, Cd, and Zn, as previously mentioned, as well as the highest concentrations of Al (24.7 mg/L), Co (13,000 µg/L), Fe (90.6 mg/L), Ni (3,000 µg/L), Pb (5.9 µg/L), and U (70 µg/L). Trace metals such as Cd, Co, Cr, Cu, Ni, and Zn are leached from the depth composite sample from the lower mine-waste pile east of the road (02Ely7B and 9B) and the surface composite 02Ely3 from the upper waste pile in higher amounts relative to most other Ely samples. Leachates with the lowest concentrations of trace metals (Cd, Co, Cu, Ni, and Zn) are from the surface and at depth composite samples from the roast beds and from the soil at the top of the smoke flue. In contrast, leachate from smoke-flue soil contains the second highest concentration of Pb (3.8 µg/L). Leachate from the hardpan-seep samples contains low concentrations of some trace metals including Cd (0.13 µg/L), Cu (200 µg/L), Ni (1.7 µg/L), and Zn (16 µg/L).

Concentrations of Cu, Cd, and Zn in leachate from the historic mine waste at the Elizabeth mine are shown as shaded regions in Figure 11. The leachate data are from Hammarstrom and others (2003) and the same leachate test was conducted on both suites of samples. Concentrations of Cu, Cd, and Zn in leachate from most Ely mine samples are similar to those in leachate from the historic mine-waste piles at the Elizabeth mine. The pH of the leachates from smoke-flue soil and slag material are higher than the pH of the leachate from the Elizabeth samples; the concentrations of metals in the leachate from smoke-flue soil and slag material are within the range of concentrations found in the leachate from the Elizabeth samples. Also, unoxidized tailings leachate contains higher concentrations of these metals than oxidized mine waste at the Elizabeth mine. In general, runoff from the Ely mine-waste piles are expected to be similar in composition to runoff from the historic waste piles at the Elizabeth mine on the basis of the results of the leaching experiments.

CONCLUSIONS

The data presented in this report support the following conclusions regarding these initially proposed questions:

(1) What type of mine waste is present at the site?
The mine waste present at the Ely mine is a combination of host rock and discarded ore, some of which has undergone various stages of metallurgical processing. The barren landscape consists of host rock and discarded ore removed from underground workings, partially roasted ore, flotation-mill tailings (including an oxidized surficial layer and the unoxidized material at depth), the ruins of the World War I era flotation mill, and remains of a smelter plant and slag heaps. A partially intact smoke flue begins near the smelter site and runs to the top of a hillside east of the mine site.

(2) What is the chemical composition of the mine-waste piles?
In general, the bulk geochemical composition of the mine waste is Fe >> Al > S> K > Ca > Mg. Based on modal mineralogy, silicon is a dominant element in the samples but was not directly measured in this study. The samples contain significant Fe; all samples except smoke-flue soil exceed the PRG for industrial soils. Minor and trace element concentrations are generally characterized by Cu > Mn > Ba ~ V ~ Zn > Cr ~ Sr > Co ~ Mo ~ Pb. Concentrations of Cu, the dominant metal, are significantly higher than the average concentration of Cu in soils in the eastern United States. Also, the concentrations of Cu in the following samples exceed the PRG for residential soils: 1. four of the six surface composite samples from the upper mine-waste piles, 2. two composite samples from the lower mine-waste piles, 3. unoxidized flotation-mill tailings, and 4. slag. Several samples from the lower mine-waste piles contain concentrations of Mn that are greater than the PRG for residential soils. Also, all samples contain anomalous Zn when compared to the average concentrations of Zn in soils from the eastern United States. The concentrations of As and Cd are below the detection limits for all samples except the unoxidized flotation-mill tailings.

(3) What is the acid-generating potential of the material?
Low paste pH and negative net-neutralization potential (NNP) indicate that mine waste (excluding the smoke-flue soil) analyzed by acid-base accounting (ABA) is "acid-generating," with NNP values ranging from -421.9 to -14.4 kg $CaCO_3$/ton. These samples contain a variety of minerals that may generate acid upon weathering including sulfides, jarosite, and efflorescent sulfate salts. Hardpan seep and slag were not analyzed by ABA. Smoke-flue soil has only a slightly negative NNP (-3.1 kg $CaCO_3$/ton) and paste pH > 4 and is the only sample considered "non-acid-generating."

(4) Are potentially toxic trace metals leached from the waste? If so, are the metals leached in quantities that may contaminate soils and streams and have a deleterious effect on the environment?
The dominant trace metals leached from the mine waste are Cd, Co, Cu, Ni, and Zn. Copper was leached in concentrations that exceed the water-quality guideline for the protection of aquatic life from all samples except the smoke-flue soil. Also, concentrations of Cu in most leachates are higher than the drinking water standard. For most samples, Zn was leached in concentrations that exceed the acute aquatic toxicity standard but are lower than the secondary drinking water standard. Leachates from several samples exceed the acute aquatic toxicity and drinking water standards for Cd. There is no USEPA toxicity guideline established for Co, but the concentration of Co in

leachates (excluding the smoke-flue leachate) exceeds the New York water criterion. Also, the concentration of Ni in the leachate from the unoxidized tailings is higher than the acute aquatic toxicity guideline. Therefore, several potentially toxic trace metals are leached from the mine waste in quantities that may contaminate soils and streams and have a deleterious effect on the environment.

(5) How variable is the environmental impact among the various mine-waste piles?

Based on the parameters examined in this study, unoxidized flotation-mill tailings have the highest potential to produce metal-laden acidic water, which may have a negative environmental impact. This sample contains the highest concentrations of many trace metals including Cd, Co, Cu, Ni, and Zn and leaching tests indicate these metals are leached in concentrations that may be harmful to aquatic life. Also, this sample contains significant quantities of sulfides and has the lowest NNP. The unoxidized flotation-mill tailings are not usually exposed to weathering. Spring runoff can erode the overlying oxidized tailings and expose the unoxidized tailings to weathering, which may lead to the formation of efflorescent sulfate salts and may produce metal-laden acidic runoff.

Slag material contains high concentrations of Co, Cu, and Zn, but leachate tests indicate these metals are not readily leached, although concentrations of Cu and Co do exceed water-quality standards. The boulder slope on the upper mine-waste pile (Fig. 2, area 02Ely3) contains the highest concentrations of several trace metals out of the six samples collected from the upper waste piles. The lower waste piles (sample areas 02Ely7/02Ely9 and 98JHEly-EB/Ely00JH22) are also of environmental concern based on their bulk geochemistry, acid-base accounting, and leachate test results.

In contrast, smoke-flue soil contains the lowest concentrations of most trace metals, is “non-acid-generating” based on ABA, and does not leach metals in significant quantities. Thus, this area, which was once denude of vegetation and is currently reforested, does not appear to contain acid-generating material that is having a significant impact on the environment. The smoke-flue soil does contain elevated concentrations of Pb, Cr, and Sn, which may be the result of contamination from fumes of the smelter. The areal extent of this contamination is unknown.

(6) Is any of the material geochemically similar to mine waste at the Elizabeth mine Superfund site?

In general, the bulk geochemistries of the Ely and Elizabeth samples are similar. For example, the concentration of Fe in samples from the Ely mine is within the range of similar type mine waste (i.e. oxidized mine waste, tailings, slag) at the Elizabeth mine. Smoke-flue soil contains lower concentrations of Fe and the hardpan from the seep contains higher concentrations of Fe compared to the Elizabeth samples. Also, Ely samples contain comparable total base-metal concentrations, with the exception of the smoke-flue soil, which contains less. Concentrations of Cu and Zn in oxidized mine waste and soil at both sites are similar. Concentrations of Cu and Zn in unoxidized tailings at the Ely mine are near the maximum for concentrations found at the Elizabeth mine; and the concentrations of Cu and Zn in slag at both sites are similar. In general, the concentrations of other metals such as Cd, Co, Cr, Mo, Ni, and Pb in mine waste at the Ely mine are within the range of concentrations of these metals in analogous mine waste at the Elizabeth mine. The roast beds at the Ely mine contain similar concentrations of

Co, Cr, Ni, and Pb and slightly higher concentrations of Cu, Mn, S, and Sr compared to the surface of the roasted red piles at TP3. As for the acid-base accounting results, overall both suites of samples are considered “acid-generating” with paste pH < 4 and negative net-neutralization potentials. Also, the composition of the leachate produced from most Ely mine samples is within the range found for the historic mine waste at the Elizabeth mine. Based these parameters, the mine waste at the Ely mine is geochemically similar to the historic mine waste at the Elizabeth mine.

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Appendix A. Sample information.

Sample number	Date collected	Sample type	Area	Sampling Location	Description	Depth (cm)	Munsell color	Munsell color #
02Ely 1A	10/08/02	surface composite of soil	upper waste piles	Northernmost upper waste pile at west end of upper waste area. Area measures about 14.6 m (48 ft) (E-W) by 38.4 m (126 ft) (N-S); includes small pile at 24.4 m (80 ft) east of A1 beyond stand of trees. A1-A6-E1-E6 defines roughly rectangular area; A7 is location of small pile 24.4 m (80 ft) E of A1.	Surface is littered with fist- to boulder-size oxidized ore and waste rock (subequal amounts). Country rock is shaley, greenish schist that forms smaller particles.	surface	yellow to brownish yellow	10YR 7/8 to 6/8
02Ely 1B	10/08/02	composite of soil at depth	upper waste piles	same as above	At depth, material is mostly sandy with mottled yellow patches and dark red-brown patches, which represent completely acid-leached rocks. Some large rocks at depth. No changes in soil character apparent in upper 25 cm and below.	25	yellow to brownish yellow	10YR 7/8 to 6/8
02Ely 2A	10/08/02	surface composite of soil	upper waste piles	Southwestern upper waste pile below road. Samples 10 across x 3 high. At center line, area is about 43 m (140 ft) across by 15 m (50 ft) wide.	Locally at west end area includes dump area below timber loading platform(?), wet areas, clayey at depth, white salts around base of rocks and on soil.	surface	reddish yellow	7.5YR 6/8
02Ely 2B	10/08/02	composite of soil at depth	upper waste piles	same as above		25	reddish yellow	7.5YR 6/8
02Ely 3	10/08/02	surface composite of soil	upper waste piles	Boulder slope below road above flat top of area 02Ely2. Traversed across length and height of pile.	Average boulder size 30 cm by 5 cm. Black, schistose ore with red oxidized surfaces and rusty-colored lichen coatings.	surface	reddish brown strong brown	5YR 4/3 7.5YR 5/8
02Ely 4A	10/08/02	surface composite of soil	upper waste piles	South-central part of upper waste dumps. Stonewall gully is the east end (break between waste rock on area 4 and more ore on area 5). Traversed 10 rows across ~EW (43 m) and 3 rows high (~NS). Top 2 rows on bench, 3rd row on accessible parts of slope. Trees at base of slope.	Mine waste pile with abundant waste rock and little ore. Parts of slope covered with boulders; other parts are bare soil.	surface	reddish brown strong brown	5YR 5/4 7.5YR 5/8
02Ely 4B	10/08/02	composite of soil at depth	upper waste piles	same as above		25	reddish brown brownish yellow	5YR 5/4 10YR 6/8

Appendix A. (cont.)

Sample number	Date collected	Sample type	Area	Sampling Location	Description	Depth (cm)	Munsell color	Munsell color #
02Ely 5A	10/08/02	surface composite of soil	upper waste piles	South-east corner of upper waste pile. Sampled 5 across (23 m across EW) x 6 vertical (49 m NS).	Waste pile with ore, decomposed ore forms local black soil. Note salts forming on soil surface at east end (Relative Humidity 27%, Temperature ~17°C (63 °F)	surface	strong brown brownish yellow	7.5YR 4/6 10YR 6/8
02Ely 5B	10/08/02	composite of soil at depth	upper waste piles	same as above		25	brownish yellow	10YR 6/8
02Ely 6A	10/08/02	surface composite of soil	upper waste piles	Irregular, diamond-shaped area above the seeps. See air photo for extent. Sampled 6 x 5 stations.	Heterogeneous area, local trees and roots, bare slope with ore, gray areas, yellow areas.	surface	brownish yellow	10YR 6/8
02Ely 6B	10/08/02	composite of soil at depth	upper waste piles	same as above		25	brownish yellow	10YR 6/8
ES-4	10/08/02	ochre at seep	upper waste piles	ES-4 seep (Holmes and others, 2002)	Red seep crusts. Note red-black crust over more orange hardpan material. Dry when sampled.	surface	red	2.5YR 4/6
Ely00JH24	06/27/00	surface composite of soil	lower waste piles	Flotation mill area.		surface	brownish yellow	10YR 6/6
98JH-Ely-EB	08/25/98	surface composite of soil	lower waste piles	Lowest mine dump directly along Ely Brook on both sides of the road.		surface	brownish yellow	10YR 6/8
Ely00JH22	06/27/00	surface composite of soil	lower waste piles	Lowest mine dump directly along Ely Brook on both sides of the road. Replicate sample of 98JH-Ely-EB sample area.		surface		
02Ely 7A	10/08/02	surface composite of soil	lower waste piles	Lower waste piles above the road sampled 10 stations parallel to the road by 3 stations perpendicular to the road. Sample 02Ely9 is a replicate sample of the same area.		surface	yellowish brown	10YR 5/8
02Ely 7B	10/08/02	composite of soil at depth	lower waste piles	same as above		25	brownish yellow	10YR 6/6

Appendix A. (cont.)

Sample number	Date collected	Sample type	Area	Sampling Location	Description	Depth (cm)	Munsell color	Munsell color #
02Ely 8A	10/08/02	grab sample	lower waste piles	Flotation mill tailings at north end of lower waste piles and east of mine access road intersection, downhill from cement foundation. Area of tailings appears to extend over a distance of about 25 m E-W along the mine access road and about 4 m in a N-S direction across the road to the stream edge.	Oxidized surface material.	surface	brownish yellow	10YR 6/8
02Ely 8B	10/08/02	grab sample	lower waste piles	Flotation mill tailings	Grey and yellow layered and mottled material sampled at a depth of 35 to 46 cm (below oxidized surface material and above unoxidized black tailings).	35-46	pale yellow	2.5Y 8/4
02Ely 8C	10/08/02	grab sample	lower waste piles	Flotation mill tailings	Black, unoxidized tailings. Auger used to find unoxidized tailings at depth of 71 to 91 cm. Limit of auger was 91 cm; tailings may be thicker.	71-91	black	5Y 2.5/1
02Ely 9A	10/08/02	surface composite of soil	lower waste piles	Replicate of 02Ely7A		surface	yellowish brown	10YR 5/8
02Ely 9B	10/08/02	composite of soil at depth	lower waste piles	Replicate of 02Ely7B		25	brownish yellow	10YR 6/8
02Ely 10A	10/08/02	surface composite of soil	roast beds	Partially roasted ore sampled 10 stations long by 3 stations wide (long = parallel to the road). Note that the old road runs through this area.	Mostly red surface area. Locally, especially at the north end, very bright red.	surface	red	2.5YR 4/8
02Ely 10B	10/08/02	composite of soil at depth	roast beds	same as above	Some yellow, jarosite-rich layers at depth.	25	red	2.5YR 6/6
02Ely 11	10/09/02	surface composite of soil	smelter site	Sampled 10 stations (parallel to the road) x 3 stations perpendicular to the road. Sampled in clearing between the stone wall and the road.		surface	yellowish brown	10YR 5/6
02Ely 12	10/09/02	surface composite	slag pile	Composite of small pieces of slag at base of the pile.		surface	dark grey	2.5Y 4/1
02Ely 13	10/08/02	grab soil sample	soil around top of smoke flue	Soil in wooded area at the top of the smoke flue.		surface	light olive brown	2.5Y 5/4

Appendix B

B-1: Bulk geochemistry of Ely mine waste.

Sample	Depth (cm)	Ag mg/kg	Al wt. %	As mg/kg	Au mg/kg	Ba mg/kg	Be mg/kg	Bi mg/kg	Ca wt. %	Cd mg/kg	Ce mg/kg	Co mg/kg	Cr mg/kg	Cu mg/kg	Eu mg/kg	Fe wt. %	Ga mg/kg	Ho mg/kg
02Ely 1A	0	6.4	4.4	<10	<8	163	1.1	<10	1.2	<2	11	31	49	3,680	<2	17.5	8.6	<4
02Ely 1B	25	5.7	4.5	<10	<8	164	1.1	<10	1.2	<2	16	28	66	1,620	<2	15.7	12	<4
02Ely 2A	0	5.8	4.5	<10	<8	160	1	<10	1	<2	16	31	57	2,320	<2	17.4	14	<4
02Ely 2A DUP[1]	0	5.5	4.6	<10	<8	195	1	<10	1.1	<2	12	32	57	2,630	<2	17.6	12	<4
02Ely 2B	25	6	4.6	<10	<8	158	1.1	<10	1.1	<2	20	31	72	1,240	<2	16.5	10	<4
02Ely 3	0	6.6	5.7	<10	<8	126	<1	<10	0.98	<2	32	39	149	5,660	<2	15.6	14	<4
02Ely 4A	0	6.2	5.3	<10	<8	171	<1	<10	1.1	<2	21	37	107	2,050	<2	18.4	18	<4
02Ely 4B	25	5	5.3	<10	<8	169	<1	<10	1	<2	24	38	102	1,530	<2	15.9	16	<4
02Ely 5A	0	8	4.6	<10	<8	127	<1	<10	0.93	<2	14	39	75	3,250	<2	21.4	14	<4
02Ely 5B	25	3.6	4.5	<10	<8	239	1.1	<10	0.98	<2	25	31	86	1,440	<2	13.8	15	<4
02Ely 6A	0	9.7	4.7	<10	<8	139	<1	<10	0.91	<2	22	39	73	4,220	<2	18.3	11	<4
02Ely 6B	25	7.6	5	<10	<8	151	1	<10	1.1	<2	25	39	98	2,560	<2	15.9	15	<4
02Ely 6B DUP	25	8.3	5	<10	<8	149	1	<10	1	<2	26	39	96	2,830	<2	16.2	12	<4
ES-4	0	4.2	1	<10	<8	71	<1	<10	0.15	<2	<4	27	1.3	2,640	<2	45.6	<4	<4
Ely00JH22	0	8	4.26	<10	<8	283	<1	<50	0.877	<2	<5	14	48	5,100	<2	19.4	17	<4
Ely00JH24	0	9	4.31	<10	<8	254	<1	<50	1.003	<2	8	19	71	2,400	<2	18.3	15	<4
Ely00JH24 DUP	0	10	4.36	<10	<8	241	<1	<50	1.029	<2	<5	18	73	2,320	<2	17.4	14	<4
02Ely 7A	0	10	4.1	<10	<8	121	1	<10	1	<2	8.5	34	45	7,020	<2	18.4	9	<4
02Ely 9A[2]	0	11	4.1	<10	<8	108	<1	<10	1	<2	10	39	42	6,940	<2	19.5	13	<4
02Ely 7B	25	13	4	<10	<8	106	<1	<10	0.83	<2	13	54	38	6,540	<2	19.6	12	<4
02Ely 9B[2]	25	14	4	<10	<8	140	<1	<10	0.75	<2	17	53	42	5,580	<2	19.5	18	<4
02Ely 8A	0	8.4	3.8	<10	<8	178	<1	<10	0.91	<2	11	25	38	2,240	<2	16	10	<4
02Ely 8B	35-46	6.8	5	<10	<8	179	1	<10	1.1	<2	12	20	68	1,510	<2	10.8	17	<4
02Ely 8C	71-91	5.4	4.9	11	<8	140	<1	<10	0.96	42	11	1,040	103	25,600	<2	19	9.6	<4
02Ely 10A	0	19	3.9	<10	<8	182	<1	<10	0.91	<2	11	50	68	2,040	<2	19.6	7	<4
02Ely 10B	25	12	4.4	<10	<8	161	1	<10	1.1	<2	17	31	86	1,630	<2	15.1	9.3	<4
02Ely 11	0	11	4	<10	<8	228	1.2	<10	0.77	<2	17	78	70	2,780	<2	16	7.4	<4
02Ely 12	0	4.8	4	<10	<8	191	1.4	<10	1	<2	23	431	35	6,880	<2	28.4	<4	<4
02Ely 12 DUP	0	4.6	4	<10	<8	181	1.5	<10	0.98	<2	24	414	36	6,750	<2	27.4	<4	<4
02Ely 13	0	<2	6.5	<10	<8	239	1.6	<10	1.6	<2	45	14	101	45	<2	5.2	18	<4

[1] DUP indicates duplicate analysis of same sample.

[2] 02Ely9A and 02Ely9B are field replicates of 02Ely7A and 02Ely7B, respectively

Appendix B-1. (cont.)

Sample	K wt. %	La mg/kg	Li mg/kg	Mg wt. %	Mn mg/kg	Mo mg/kg	Na wt. %	Nb mg/kg	Nd mg/kg	Ni mg/kg	P wt. %	Pb mg/kg	S wt. %	Sc mg/kg	Sn mg/kg	Sr mg/kg	Ta mg/kg	Th mg/kg	Ti wt. %
02Ely 1A	1.2	7.8	8.9	0.74	1,390	31	1.4	<4	12	12	0.08	32	2.56	15	5.2	87	<40	<4	0.22
02Ely 1B	1.3	8.6	14	0.96	1,160	32	1.4	<4	12	19	0.074	23	2.18	16	<5	100	<40	<4	0.33
02Ely 2A	1.5	10	8.9	0.54	1,620	28	1.4	<4	13	11	0.07	35	2.48	16	<5	80	<40	<4	0.29
02Ely 2A DUP	1.5	8.5	8.6	0.53	1,620	30	1.4	<4	12	12	0.07	40		15	<5	82	<40	<4	0.26
02Ely 2B	1.6	12	16	0.84	862	27	1.3	<4	15	20	0.078	27	2.05	16	<5	104	<40	4.1	0.34
02Ely 3	2.1	18	18	0.97	667	18	1.6	<4	19	11	0.15	78	3.67	22	<5	71	<40	4	0.19
02Ely 4A	1.9	13	13	0.95	1,050	33	1.5	<4	16	13	0.087	49	2.09	20	<5	80	<40	<4	0.32
02Ely 4B	2	16	15	1	1,020	21	1.5	<4	15	16	0.075	42	2.49	18	8.5	78	<40	4	0.33
02Ely 5A	1.8	10	10	0.57	890	34	1.4	<4	16	12	0.089	46	2.88	17	<5	68	<40	<4	0.27
02Ely 5B	1.5	11	16	0.82	998	14	1.2	<4	13	20	0.068	27	1.77	15	<5	94	<40	<4	0.32
02Ely 6A	1.8	14	12	0.79	1,340	34	1.3	<4	17	12	0.091	52	2.76	18	6.9	69	<40	<4	0.16
02Ely 6B	1.8	15	15	1	1,440	21	1.4	<4	15	18	0.079	42	2.53	18	<5	82	<40	<4	0.28
02Ely 6B DUP	1.9	16	15	0.98	1,410	24	1.3	<4	15	19	0.086	45		18	<5	78	<40	5.4	0.26
ES-4	0.51	<2	2.9	0.19	134	5.3	0.25	<4	33	11	0.047	<4		12	9.1	2.3	<40	<4	<0.005
Ely00JH22	1.66	8	9	0.49	2,180	42	1.36	32	<9	<3	0.06	69	3.29	10	<50	72	<40	<6	0.27
Ely00JH24	1.56	7	11	0.625	1,920	69	1.3	36	10	<3	0.05	82	2	14	<50	79	<40	<6	0.374
Ely00JH24 DUP	1.46	6	11	0.64	2,220	59	1.31	33	<9	<3	0.05	79	1.96	15	<50	79	<40	<6	0.385
02Ely 7A	1.3	6.9	8.4	0.7	2,420	46	1.2	<4	12	11	0.088	57	3.33	14	7.2	61	<40	<4	<0.005
02Ely 9A	1.4	7.8	8.4	0.67	2,330	45	1.3	<4	14	12	0.089	65	3.74	14	5.4	58	<40	<4	<0.005
02Ely 7B	1.5	9.8	8.8	0.69	1,740	46	1.2	<4	15	13	0.093	63	3.62	13	<5	58	<40	<4	<0.005
02Ely 9B	1.7	12	9.9	0.71	1,730	48	1.2	<4	17	14	0.092	71	3.37	13	6.1	57	<40	<4	0.008
02Ely 8A	1.3	7.5	6	0.3	2,520	28	1.4	<4	11	7.2	0.059	50	2.69	15	6.2	61	<40	<4	0.22
02Ely 8B	1.7	8	8.4	0.46	2,050	20	1.7	<4	6.7	7	0.048	46	2.24	16	<5	80	<40	4.2	0.33
02Ely 8C	1.3	6.3	23	0.99	2,010	18	1.2	<4	14	237	0.2	52	14.09	22	7.4	55	<40	4.2	<0.005
02Ely 10A	1.2	7.1	10	0.55	1,210	41	1.1	<4	14	18	0.06	47	1.84	16	5.3	70	<40	<4	0.29
02Ely 10B	1.3	11	14	0.67	915	24	1.2	<4	14	19	0.062	21	2.19	14	<5	106	<40	<4	0.29
02Ely 11	1.1	9.1	21	0.69	699	20	0.93	<4	14	26	0.073	65	1.28	12	<5	106	<40	<4	0.19
02Ely 12	0.92	14	29	0.71	878	34	0.74	<4	29	32	0.09	93		15	9	109	<40	<4	<0.005
02Ely 12 DUP	0.9	14	28	0.71	871	33	0.76	<4	29	32	0.088	61		14	12	111	<40	<4	<0.005
02Ely 13	0.84	21	34	1.5	750	2.2	1.6	17	14	34	0.08	120	0.07	18	28	139	<40	6.4	0.84

Appendix B-1. (cont.)

Sample	U mg/kg	V mg/kg	Y mg/kg	Yb mg/kg	Zn mg/kg	Job No.	Lab No.
02Ely 1A	<100	135	9	1.7	102	MRP-04326	C-215170
02Ely 1B	<100	139	10	1.5	91	MRP-04326	C-215171
02Ely 2A	<100	156	9	1.8	201	MRP-04326	C-215172
02Ely 2A DUP	<100	151	8.3	1.6	155	MRP-04326	C-215173
02Ely 2B	<100	148	7.7	1.1	105	MRP-04326	C-215174
02Ely 3	<100	268	8.5	1.3	341	MRP-04326	C-215175
02Ely 4A	<100	212	6.9	1.1	194	MRP-04326	C-215176
02Ely 4B	<100	183	7	1.1	151	MRP-04326	C-215177
02Ely 5A	<100	202	5.7	1	269	MRP-04326	C-215178
02Ely 5B	<100	143	8.4	1.4	160	MRP-04326	C-215179
02Ely 6A	<100	172	8.4	1.3	223	MRP-04326	C-215180
02Ely 6B	<100	162	8.5	1.4	184	MRP-04326	C-215181
02Ely 6B DUP	<100	158	8.6	1.3	184	MRP-04326	C-215182
ES-4	<100	60	<2	<1	60	MRP-04326	C-215183
Ely00JH22	<100	197	9	<1	149	MRP-03747	C-200345
Ely00JH24	<100	211	9	<1	207	MRP-03747	C-200346
Ely00JH24 DUP	<100	207	10	<1	210	MRP-03747	C-200347
02Ely 7A	<100	145	10	1.8	216	MRP-04326	C-215184
02Ely 9A	<100	150	9.7	1.7	250	MRP-04326	C-215189
02Ely 7B	<100	150	7.2	1.4	214	MRP-04326	C-215185
02Ely 9B	<100	163	7.5	1.2	228	MRP-04326	C-215190
02Ely 8A	<100	139	10	1.7	219	MRP-04326	C-215186
02Ely 8B	<100	144	10	1.6	113	MRP-04326	C-215187
02Ely 8C	<100	132	10	1.8	3,960	MRP-04326	C-215188
02Ely 10A	<100	169	6.4	1.1	447	MRP-04326	C-215191
02Ely 10B	<100	129	8.8	1.3	235	MRP-04326	C-215192
02Ely 11	<100	115	7.4	1.2	425	MRP-04326	C-215193
02Ely 12	<100	104	13	1.7	3,440	MRP-04326	C-215194
02Ely 12 DUP	<100	104	12	1.8	3,360	MRP-04326	C-215195
02Ely 13	<100	171	21	2.3	81	MRP-04326	C-215196

Appendix B

B-2: Standard reference material [1].

		NIST Standard Reference Material					
			SRM 2709			**SRM 2711**	
			CMF			**CMF**	
Element	**Units**	MRP-04326	*IMF*	(±)	MRP-04326	*IMF*	(±)
Ag	**mg/kg**	< 2	**0.41**	**0.03**	5	**4.63**	**0.39**
Al	**%**	7.5	**7.5**	**0.06**	6.5	**6.5**	**0.09**
As	**mg/kg**	19	**17.7**	**0.8**	95	**105**	**8**
Ba	**mg/kg**	950	**968**	**40**	720	**726**	**38**
Be	**mg/kg**	4			2	**ND**	
Bi	**mg/kg**	< 10			< 10	**ND**	
Ca	**%**	1.9	**1.89**	**0.05**	2.8	**2.88**	**0.08**
Cd	**mg/kg**	< 2	**0.38**	**0.01**	42	**41.7**	**0.25**
Ce	**mg/kg**	47	*42*		75	*69*	
Co	**mg/kg**	13	**13.4**	**0.7**	10	*10*	
Cr	**mg/kg**	120	**130**	**4**	42	*47*	
Cu	**mg/kg**	32	**34.6**	**0.7**	110	**114**	**2**
Eu	**mg/kg**	< 2			< 2	1.1	
Fe	**%**	3.5	**3.5**	**0.11**	2.8	**2.89**	**0.06**
Ga	**mg/kg**	12	*14*		13	*15*	
Ho	**mg/kg**	< 4	*0.54*		< 4	*1*	
K	**%**	1.9	**2.03**	**0.06**	2.3	**2.45**	**0.08**
La	**mg/kg**	24			39	*40*	
Li	**mg/kg**	55			27	**ND**	
Mg	**%**	1.5	**1.51**	**0.05**	1	**1.05**	**0.03**
Mn	**mg/kg**	540	**538**	**17**	620	**638**	**28**
Mo	**mg/kg**	3	*2*		4	*1.6*	
Na	**%**	1.2	**1.16**	**0.03**	1.2	**1.14**	**0.03**
Nb	**mg/kg**	19			26	**ND**	
Nd	**mg/kg**	18	*19*		31	*31*	

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[1] QA/QC was monitored by analyzing NIST standard reference materials, field replicate samples, and laboratory duplicates. Field replicates and laboratory duplicates are included as separate entries in Appendix B-1. Certified mass fractions (CMF) for NIST standards reference materials (in boldface with standard deviations), and information mass fractions (IMF) for NIST standard reference materials (shown in italics) are given.

Appendix B-2. (cont.)

			NIST Standard Reference Material				
			SRM 2709			**SRM 2711**	
			CMF	**(±)**		**CMF**	**(±)**
Element	**Units**	MRP-04326	*IMF*		MRP-04326	*IMF*	
Ni	**mg/kg**	73	**88**	**5**	19	**20.6**	**1.1**
P	**%**	0.063	**0.062**	**0.005**	0.083	**0.086**	**0.007**
Pb	**mg/kg**	16	**18.9**	**0.5**	1100	**1162**	**31**
Sc	**mg/kg**	12	*12*		10	*9*	
Sn	**mg/kg**	< 5			8	**ND**	
Sr	**mg/kg**	220	**231**	**2**	240	**245.3**	**0.7**
Ta	**mg/kg**	< 40			< 40	**ND**	
Th	**mg/kg**	10	*11*		14	*14*	
Ti	**%**	0.34	**0.342**	**0.024**	0.29	**0.306**	**0.023**
U	**mg/kg**	< 100	*3*		< 100	*2.6*	
V	**mg/kg**	110	**112**	**5**	80	**81.6**	**2.9**
Y	**mg/kg**	19	*18*		29	*25*	
Yb	**mg/kg**	2	*1.6*		3	*2.7*	
Zn	**mg/kg**	110	**106**	**3**	350	**350.4**	**4.8**

Appendix C

C-1: Quantitative estimates of mineral weight percentages based on Rietveld refinement of powder X-ray diffraction patterns using Siroquant.

	Quartz	Albite	Anorthite	Labradorite	Biotite	Muscovite	Chlorite	Kaolin	Talc	Vermiculite	Sepiolite	Hornblende	Fayalite	Calcite
02Ely1A	29.8	6.3	0	17.5	0	6.6	3	0	1.3		4.7	5.9		
02Ely1B	28.8	9.8	0	13.6	0.3	5.5	2.2	1	1.6		3.4	7.2		0
02Ely2A	24.7	5.4	0	17.1	0	9.2	0	2.9	1.6		2.5	4.5		0
02ELy2B	30	3.4	0	16.7	0	6.4	0.4	0.5	1		7.1	5.8		0
02Ely3	22.3	9.5	0	11.9	4.9	8.6	2.4	0.8	0		12.6	1.5		
02Ely4A	27.2	5.6	0	19.9	0.3	6.5	0.7	0.5	0.5		6.9	3.9		0
02Ely4B	25.7	8.9	0	17.4	0.6	7.3	0	0.6	0.6		5.5	2.3		0.3
02Ely5A	24.6	8.1	0	15.2	0	5.6	2.3	1.5	1.9		3.3	2.2		0
02Ely5B	34.4	9.3	0	11.9	0	9	5.6	0.8	1		5.4	2.3		0.4
02Ely6A	18.8	7.1	0	14.5	0	8.7	2.3	0.9	0.6		7.2	4.5		0
02Ely6B	27.3	9.1	0	18	0	6.6	4.1	0.4	0		8	1.1		0.2
02Ely6B DUP[1]	20.2	9.4	0	18.6	0	7.5	4.7	0.8	0		6.9	2.1		0.2
ES-4	3.1	0	2.1	0.4	1.8	7.1	2.1	1.6			0.5	0		0
02Ely7A	22	11.7	0	14.2	0	5.2	1.4	0	0		3.9	7.9		0
02Ely9A[2]	23.4	9.9	0	9.1	0	9.1	4.3	0.2	0		2.7	7.2		0
02Ely7B	29.2	11.7	0	13.7	0.1	5.4	3.2	0.4	0		6.1	2.4		0.8
02Ely9B[2]	26.8	9.4	0	15.1	0	5.8	0.9	0.4	0		6.4	2.6		0.3
02Ely8A	32.3	9.9	0	13.7	0.3	6.3	0.2	0.8			3.1	2.2		
02Ely8B	32.6	10.5	0	13.7	0	12.4	3.3	0	0.7		5.5	0.8		
02Ely8C	28.6	8.7	9.3	1.2	9.7	3.8	3.1	0.9	0		0.2	1		0
Ely00JH24	28.6	4.9	0.5	13.3	0	11.2	5.1	1.3	0.3		4.3	0		
98JH-Ely-EB	20.5	14.2	1.9	0	0	12	6.3	0	0.6		3.5	4.1		
02Ely10A	29.9	2.2	1.1	8.7	0	11.3	3.2	0	0		2.5	5.9		0.2
02Ely10B	36.1	2.1	0	11.3	0.2	10.2	4.5	0	0.1		2.7	6.2		0
02Ely11	43.2	3.1	0	11.4	0	4.5	4.7	1.4	0		5.8	3.9		
02Ely12	28	0.9	6.6	2.5	2.6	4.5	1.8	1.5	0.7	2.3	0.5	0	39.2	
02Ely12 DUP	43.3	5.6	0.5	9	1.7	7.2	0	0.6	0	4.3	0.4	1.2	15	
02Ely13	35.5	4	0	15.4	0.9	9.6	7.1	0.3	0.3	7	0.2	16.2		0

[1] DUP indicates duplicate analysis of same sample.

[2] 02Ely9A and 02Ely9B are field replicates of 02Ely7A and 02Ely7B, respectively.

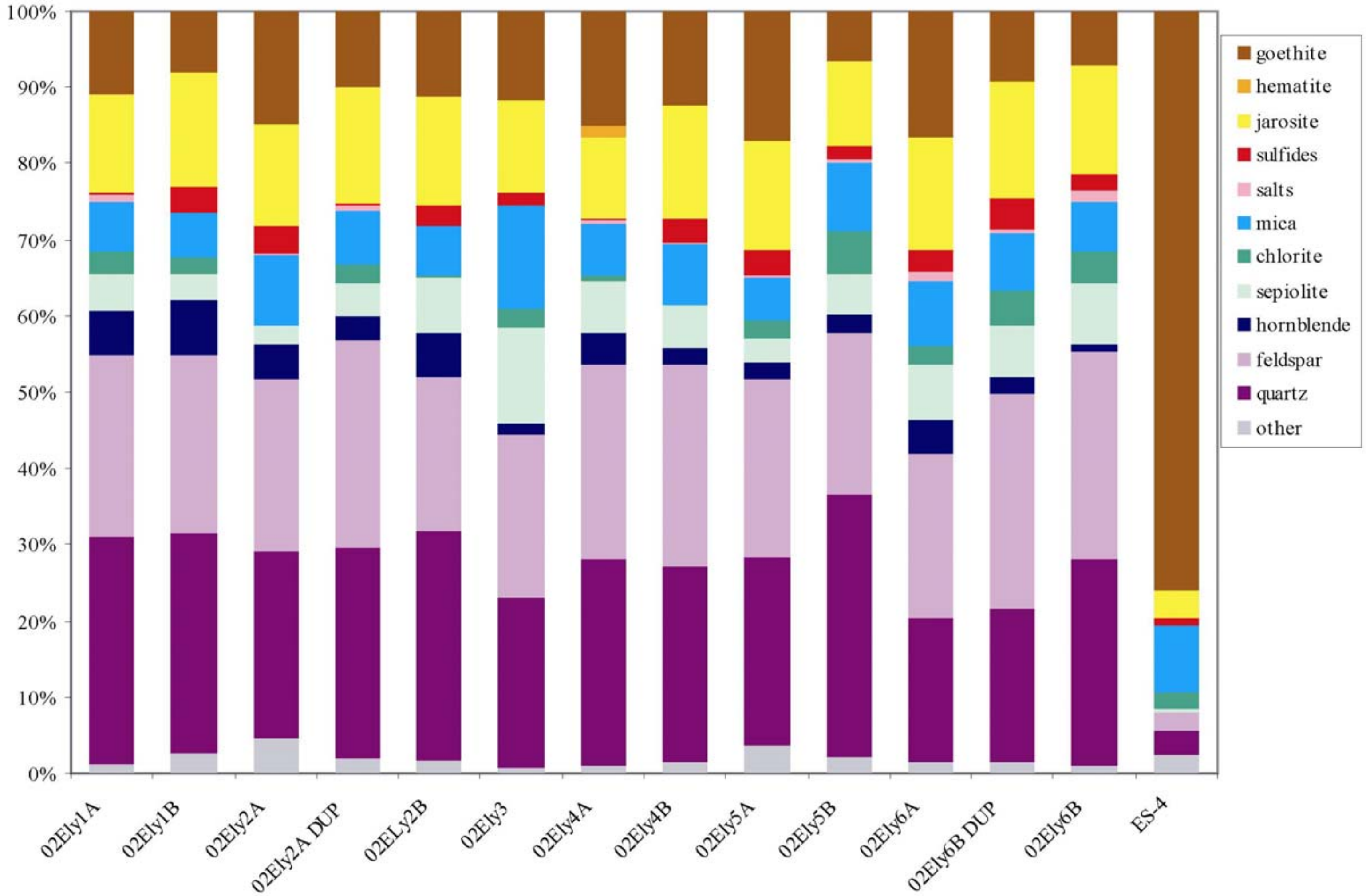
[3] Chi^2 is a computed statistical residual, which is used as a measure of the fit of the refinement. Chi^2 = 1 for a perfect correspondence between the least-squares model and the observed data. In complex natural mixtures, ideal values are almost never observed due to systematic errors and imperfect physical corrections. Values below 6 are considered reasonable fits for these complex mine wastes.

Appendix C-1. (cont.)

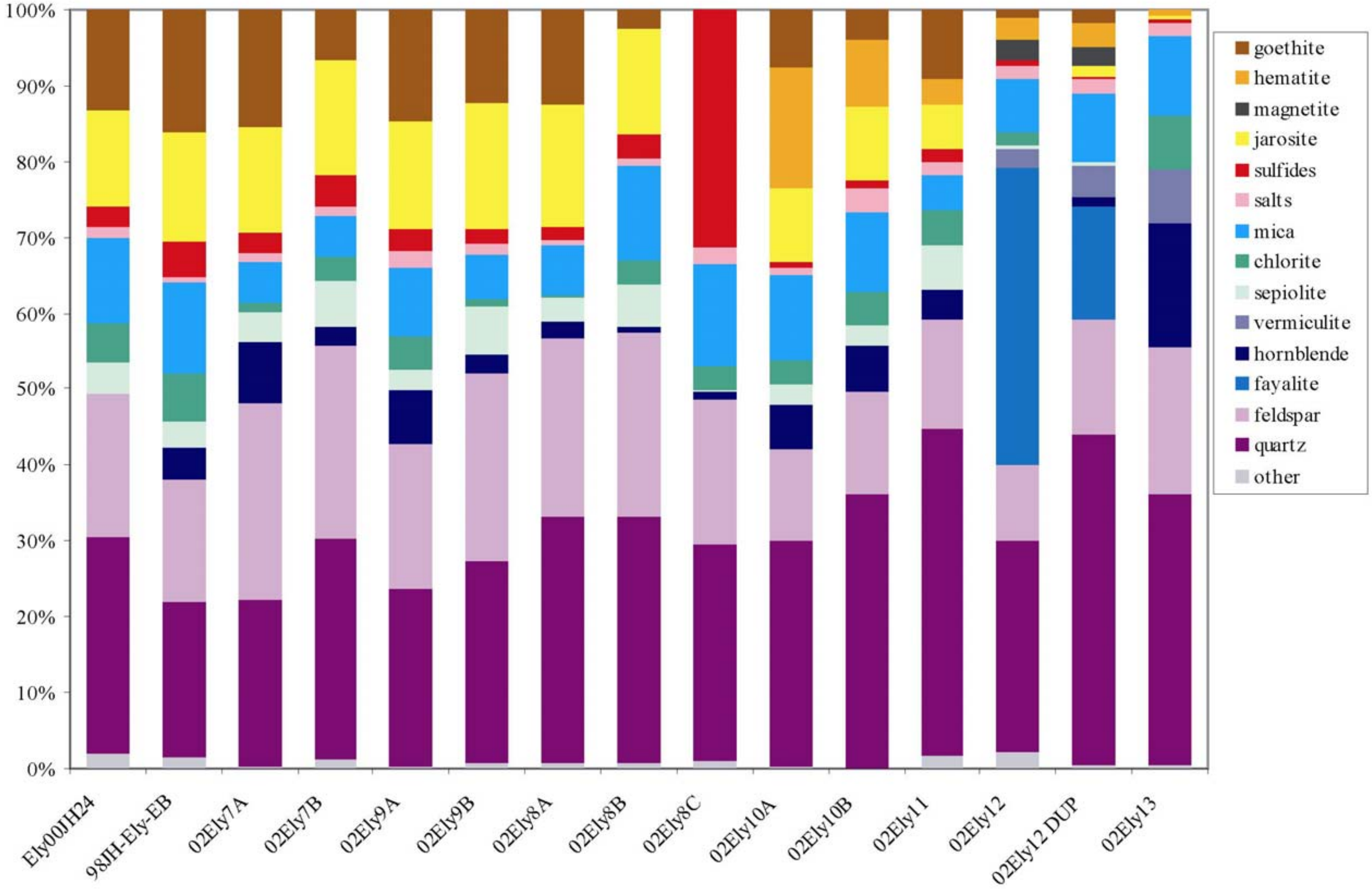
	Goethite	Hematite	Magnetite	Jarosite	Alunogen	Copiapite	Melanterite	Rozenite	Gypsum	Chalcopyrite	Pyrite	Pyrrhotite	Sphalerite	chi^{2}[3]
02Ely1A	11	0		12.7	0.3	0.2	0.4	0	0	0.2	0	0	0.1	5.08
02Ely1B	7.9	0		15.1	0	0	0	0	0.1	0.2	0	3	0.4	5.18
02Ely2A	14.8	0		13.4	0	0	0.2	0	0	0.3	0	3.1	0.2	6.31
02ELy2B	11.1	0		14.3	0	0	0	0	0.3	0.1	0	2.5	0.2	5.17
02Ely3	11.6	0		12.3	0	0	0	0	0	0.8	0	0.9	0	5.27
02Ely4A	15.1	1.4		10.6	0.2	0.1	0.1	0	0	0	0	0.2	0.2	5.29
02Ely4B	12.4	0		14.7	0	0.3	0	0	0	0	0	3.1	0.1	5.33
02Ely5A	17.1	0		14.1		0.2	0.2	0	0.3	0.3	0	3	0.1	5.32
02Ely5B	6.5	0		11.1	0	0.3	0.1	0	0	0	0.2	1.5	0.2	5.14
02Ely6A	16.5	0		14.9	0	1.2	0	0	0	1.1	0	1.5	0.1	5.78
02Ely6B	7.1	0		14.2	0	1.1	0.3	0	0.3	0.2	0	1.7	0.3	5.41
02Ely6B DUP	9.2	0		15.4	0	0.4	0	0	0.5	0	0	3.7	0.3	5.59
ES-4	76	0		3.5			0	0	0.8	0.4	0	0.3	0.3	5.38
02Ely7A	15.5	0		13.9	0.3	0.6	0.3	0	0.3	1.2	0	1.2	0.3	5.5
02Ely9A	14.6	0		14.2	0	1.4	0.6	0	0	1.6	0	1.1	0.3	4.71
02Ely7B	6.7	0		15.2	0	0.5	0.6	0	0	0.8	0.1	3.1	0.1	5.22
02Ely9B	12.2	0		16.7	0	0.9	0.6	0	0	0.6	0	1.1	0.2	5.02
02Ely8A	12.5	0		16	0	0.1	0.8	0	0	0.3	0.3	1.1	0	4.79
02Ely8B	2.5	0		13.9	0	0.2	0.7	0	0	0.1	0	3.2	0	6.86
02Ely8C	0	0		0	1	0	1.1	0	0	1.6	0.2	29.6	0	5.85
Ely00JH24	13.3	0		12.5	0	0.6	0.9	0	0.4	0.3	0	2.2	0.3	5.22
98JH-Ely-EB	16.1	0		14.5	0	0.9	0	0	0.9	1.2	0	3.1	0.2	6.25
02Ely10A	7.6	15.9		9.8	0	0.3	0.6	0	0	0	0.2	0.2	0.4	4.78
02Ely10B	4	8.8		9.7	0.6	1.6	0.9	0	0	0.1	0	0.7	0.3	4.91
02Ely11	9.1	3.4		5.8	0.6	0.9	0.3	0	0.2	0	0	1.8	0	4.91
02Ely12	1.1	2.8	2.6	0.1	0	1.1	0.6	0		0	0.5	0.2	0	3.89
02Ely12 DUP	1.8	3.2	2.3	1.6	0.9	0.9	0.3	0	0	0.1	0	0	0	4.12
02Ely13	0	0.8		0.4	0	0.5	1	0	0	0.1	0.5	0	0	6.43

Appendix C

C-2: Colored bar charts of relative weight percentages of minerals based on Siroquant results. Efflorescent sulfate salts are "salts" and calcite, kaolin, talc, and gypsum are grouped as "other."



Appendix C-2. (cont.)



Appendix D. Analytical results of leachate tests.

	pH	sp.	ORP	ORP	ORP	Fe^{2+}	Fe total						
parameter/element		cond.						Ag	Ag	Al	Al	As	As
units		µS/cm		corrected	mV	mg/L	mg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L
method[1]						Hach	Hach	ICP-AES	ICP-MS	ICP-AES	ICP-MS	ICP-AES	ICP-MS
02Ely 1A	2.93	577	458.4	671.3	671.3	1.06	2.68	<1	<0.01	5.1	4,200	<100	<0.9
02Ely 1B	3.07	451	450.3	663.2	663.2	0.29	0.63	<1	<0.01	3.9	3,800	<100	<0.9
02Ely 2A	2.98	587	451.2	664.1	664.1	0.36	1.33	<1	<0.01	6.3	5,600	<100	<0.9
02Ely 2A DUP[2]	2.96	593	452.2	665.1	665.1	0.19	1.07	<1	<0.01	7.4	6,100	<100	<0.9
02Ely 2B	3.02	467	351.4	565.5	565.5	0.34	0.92	<1	<0.01	4.9	4,900	<100	<0.9
02Ely 3	3.12	526	356.6	570.7	570.7	0.17	1.26	<1	<0.01	13.2	11,000	<100	<0.9
02Ely 4A	3.25	241	357.1	571.2	571.2	n.a.	n.a.	<1	<0.01	0.7	480	<100	<0.9
02Ely 4B	3.06	428	360.2	574.3	574.3	0.58	1.23	<1	<0.01	3.9	3,200	<100	<0.9
02Ely 5A	2.96	547	363.6	577.7	577.7	0.59	1.38	<1	<0.01	6.8	5,700	<100	<0.9
02Ely 5B	3.11	422	373.9	588.0	588.0	0.49	0.84	<1	<0.01	3.4	2,900	<100	<0.9
02Ely 6A	3.02	557	382.7	596.8	596.8	0.27	1.64	<1	<0.01	8.4	7,000	<100	<0.9
02Ely 6B	3.12	501	375.1	589.2	589.2	0.22	0.63	1.1	<0.01	2	1,900	<100	<0.9
02Ely 6B DUP	3.11	490	377.1	591.2	591.2	0.11	0.65	1.1	<0.01	2	1,900	<100	<0.9
ES-4	2.96	528	393.1	607.2	607.2	1.25	2.84	<1	<0.01	0.42	360	<100	<0.9
02Ely 7A	2.91	612	407.9	622.0	622.0	2.4	5.2	<1	<0.01	4.6	3,800	<100	<0.9
02Ely 9A[3]	2.98	601	402.3	616.4	616.4	0.58	2.44	<1	<0.01	13.2	11,000	<100	<0.9
02Ely 7B	2.84	822	418.2	632.3	632.3	10	18.6	<1	<0.01	9.7	8,500	<100	<0.5
02Ely 9B[3]	2.83	840	421.7	635.8	635.8	8.8	18.9	<1	<0.01	9	7,300	<100	<0.5
02Ely 8A	3.01	429	391.1	605.2	605.2	0.4	0.58	<1	<0.01	2.2	1,800	<100	<0.9
02Ely 8B	3.21	323	391	605.1	605.1	n.a.	n.a.	<1	<0.01	3.8	2,500	<100	<0.9
02Ely 8C	3.51	1,090	368.7	582.8	582.8	29.5	95	<1	<0.01	24.7	19,000	<100	0.6
02Ely 10A	3.40	146.1	401.4	615.5	615.5	n.a.	n.a.	<1	0.063	0.14	120	<100	<0.9
02Ely 10B	3.43	146.9	399.8	613.9	613.9	n.a.	n.a.	<1	0.04	0.19	160	<100	<0.9
02Ely 11	3.63	163.5	400	614.1	614.1	n.a.	n.a.	<1	0.027	0.41	330	<100	<0.9
02Ely 12	4.88	33.8	397.2	611.3	611.3	n.a.	n.a.	<1	<0.01	0.011	7.9	<100	<0.9
02Ely 12 DUP	4.89	29.7	395.7	609.8	609.8	n.a.	n.a.	<1	<0.01	0.01	7.9	<100	<0.9
02Ely 13	4.56	14.8	391.5	605.6	605.6	n.a.	n.a.	<1	<0.01	0.47	390	<100	<0.9

[1] Hach: colorimetric method using Hach spectrophotometer; IC: ion chromatography; ICP-AES: inductively coupled plasma-atomic emission spectrometry; ICP-MS: inductively coupled plasma-mass spectrometry.

[2] DUP indicates duplicate analysis of same sample.

[3] 02Ely9A and 02Ely9B are field replicates of 02Ely7A and 02Ely7B, respectively.

Appendix D. (cont.)

	Au µg/L ICP-MS	B µg/L ICP-AES	Ba µg/L ICP-AES	Ba µg/L ICP-MS	Be µg/L ICP-AES	Be µg/L ICP-MS	Bi µg/L ICP-MS	Ca mg/L ICP-AES	Ca µg/L ICP-MS	Cd µg/L ICP-AES	Cd µg/L ICP-MS
02Ely 1A	< 0.01	<5	<1	0.52	<10	0.05	< 0.04	1.8	1.6	6.2	0.99
02Ely 1B	< 0.01	<5	<1	0.86	<10	0.12	< 0.04	10.2	9.8	5.5	1.2
02Ely 2A	< 0.01	<5	<1	0.08	<10	0.12	< 0.04	4.8	4.2	8.5	4
02Ely 2A DUP	< 0.01	<5	<1	0.069	<10	0.14	< 0.04	5.4	4.3	9.2	4.2
02Ely 2B	< 0.01	<5	<1	0.85	<10	0.21	< 0.04	11.6	11	8.3	3.1
02Ely 3	< 0.01	<5	<1	0.21	<10	0.18	< 0.04	10.2	8.7	24	15
02Ely 4A	< 0.01	<5	<1	0.82	<10	<0.05	< 0.04	1.9	1.4	<5	0.52
02Ely 4B	< 0.01	<5	<1	0.17	<10	0.1	< 0.04	6.3	5.2	7.4	2.1
02Ely 5A	< 0.01	<5	<1	0.092	<10	0.054	< 0.04	2.2	1.8	10	4.3
02Ely 5B	< 0.01	<5	3.8	4.2	<10	0.14	< 0.04	15.2	14	8.5	3.8
02Ely 6A	< 0.01	<5	<1	0.12	<10	0.2	< 0.04	6.4	5.2	17	9.4
02Ely 6B	< 0.01	<5	<1	0.33	<10	0.2	< 0.04	30.5	29	9.4	4.5
02Ely 6B DUP	< 0.01	<5	<1	0.35	<10	0.14	< 0.04	27	26	10	4.5
ES-4	< 0.01	<5	<1	0.52	<10	<0.05	< 0.04	0.2	0.16	5	0.13
02Ely 7A	< 0.01	<5	<1	1.3	<10	0.077	< 0.04	1.4	1.2	9.4	4.3
02Ely 9A	< 0.01	<5	<1	0.26	<10	0.26	< 0.04	2.2	1.8	10	4.3
02Ely 7B	< 0.01	<5	1.6	2.6	<10	0.26	< 0.04	4.6	4.2	14	14
02Ely 9B	< 0.01	<5	3	3.7	<10	0.19	< 0.04	4.2	3.6	17	15
02Ely 8A	< 0.01	<5	<1	0.098	<10	0.085	< 0.04	2	1.6	5	0.93
02Ely 8B	< 0.01	<5	24	21	<10	0.099	< 0.04	2.2	1.7	9.8	8.4
02Ely 8C	< 0.01	<5	10	9.6	<10	0.57	< 0.04	1.3	1	1,280	1,200
02Ely 10A	< 0.01	<5	3.9	4.5	<10	<0.05	< 0.04	0.55	0.53	<5	0.18
02Ely 10B	< 0.01	<5	<1	0.67	<10	<0.05	< 0.04	1.9	1.7	<5	0.2
02Ely 11	< 0.01	<5	3.9	4.3	<10	<0.05	< 0.04	1.8	1.6	<5	0.66
02Ely 12	< 0.01	<5	16	16	<10	<0.05	< 0.04	3.4	3.3	<5	0.49
02Ely 12 DUP	< 0.01	<5	14	14	<10	<0.05	< 0.04	3	3	<5	0.48
02Ely 13	< 0.01	<5	14	12	<10	<0.05	< 0.04	0.12	0.13	<5	0.15

Appendix D. (cont.)

	Ce µg/L ICP-MS	Cl mg/L IC	Co µg/L ICP-AES	Co µg/L ICP-MS	Cr µg/L ICP-AES	Cr µg/L ICP-MS	Cs µg/L ICP-MS	Cu µg/L ICP-AES	Cu µg/L ICP-MS	Dy µg/L ICP-MS	Er µg/L ICP-MS
02Ely 1A	12	0.2	63	56	11	9.7	1.7	3,140	2,400	0.6	0.3
02Ely 1B	26	0.2	65	64	<10	3.3	1.6	3,250	2,800	0.97	0.46
02Ely 2A	7.9	0.3	94	92	15	13	3.6	5,130	4,300	0.75	0.4
02Ely 2A DUP	8.3	0.3	104	91	19	14	3.3	5,890	4,500	0.81	0.39
02Ely 2B	20	0.2	135	140	<10	3.5	2.3	4,370	3,800	1	0.47
02Ely 3	11	0.4	194	190	20	17	1.6	10,200	7,900	2.5	1.2
02Ely 4A	1.3	<0.1	20	13	<10	<1	0.72	1,030	690	0.14	0.058
02Ely 4B	12	0.2	144	130	<10	5.4	2.1	2,990	2,300	0.79	0.39
02Ely 5A	6.8	0.3	60	56	24	18	1.8	4,150	3,200	0.57	0.27
02Ely 5B	22	0.2	130	120	<10	3.6	1.9	2,880	2,300	1.1	0.47
02Ely 6A	15	0.3	154	140	11	11	3.4	6,580	5,100	1.5	0.65
02Ely 6B	8.8	0.1	93	90	<10	2.9	3.6	5,510	4,500	0.84	0.39
02Ely 6B DUP	8.4	0.1	91	89	<10	3.1	3.3	5,450	4,500	0.84	0.36
ES-4	1.7	0.2	<10	5.9	<10	<1	0.32	263	200	0.13	0.051
02Ely 7A	7.4	0.3	107	96	<10	5.6	2.1	5,090	3,900	0.85	0.34
02Ely 9A	18	0.4	229	210	<10	6.5	1.4	6,120	4,900	2.3	1
02Ely 7B	38	0.5	941	810	15	15	2.9	17,300	16,000	2.8	1.1
02Ely 9B	40	0.4	792	650	18	15	3.6	14,500	13,000	3	1.2
02Ely 8A	3.8	0.2	35	32	<10	3.2	3.5	2,660	2,100	0.35	0.18
02Ely 8B	5.5	0.2	248	190	<10	3.7	2.3	15,500	10,000	0.54	0.23
02Ely 8C	9.6	0.6	16,300	13,000	34	30	13	149,000	120,000	2	0.86
02Ely 10A	0.26	<0.1	<10	0.96	<10	<1	0.26	591	460	0.009	0.0053
02Ely 10B	0.35	<0.1	<10	1.7	<10	<1	0.68	727	570	0.021	0.011
02Ely 11	1.4	<0.1	28	25	<10	<1	0.23	1,980	1,500	0.075	0.035
02Ely 12	0.044	<0.1	19	16	<10	<1	0.016	1,110	900	0.005	< 0.005
02Ely 12 DUP	0.039	<0.1	19	17	<10	<1	0.017	1,020	850	< 0.005	< 0.005
02Ely 13	0.6	0.2	<10	1.3	<10	<1	0.068	<10	5.5	0.065	0.029

Appendix D. (cont.)

	Eu	Fe	Fe	Ga	Gd	Ge	Ho	In	K	K	La
	µg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L
	ICP-MS	ICP-AES	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-AES	ICP-MS	ICP-MS
02Ely 1A	0.2	2.5	2,100	0.038	0.77	< 0.02	0.11	0.039	<0.1	20	2.5
02Ely 1B	0.28	0.5	490	< 0.02	1.2	< 0.02	0.18	0.012	<0.1	<20	3.3
02Ely 2A	0.22	1.1	1,000	0.02	0.9	0.021	0.15	0.022	<0.1	<20	2.9
02Ely 2A DUP	0.23	0.96	810	0.026	0.95	< 0.02	0.15	0.022	<0.1	<20	3
02Ely 2B	0.33	0.65	640	< 0.02	1.3	< 0.02	0.17	0.012	<0.1	30	4.4
02Ely 3	0.74	0.88	770	< 0.02	3.2	< 0.02	0.45	0.012	0.1	130	1.6
02Ely 4A	0.035	0.11	90	< 0.02	0.17	< 0.02	0.025	< 0.01	0.22	180	0.48
02Ely 4B	0.24	1.1	900	< 0.02	1.1	< 0.02	0.14	0.014	<0.1	51	2.5
02Ely 5A	0.21	1.2	1,000	< 0.02	0.78	< 0.02	0.1	0.037	<0.1	<20	2.2
02Ely 5B	0.38	0.67	620	< 0.02	1.6	< 0.02	0.19	0.011	0.12	140	4.3
02Ely 6A	0.45	1.3	1,100	< 0.02	2	< 0.02	0.25	0.042	<0.1	<20	4.4
02Ely 6B	0.23	0.5	500	< 0.02	1	< 0.02	0.15	0.01	0.32	350	2.8
02Ely 6B DUP	0.21	0.42	440	< 0.02	1	< 0.02	0.14	0.01	0.28	320	2.7
ES-4	0.036	2.7	2,200	< 0.02	0.18	< 0.02	0.021	0.011	<0.1	72	0.68
02Ely 7A	0.21	4.7	3,900	0.076	1	< 0.02	0.14	0.051	<0.1	40	3.7
02Ely 9A	0.55	2.2	1,800	< 0.02	2.8	< 0.02	0.39	0.055	<0.1	<20	8.9
02Ely 7B	0.84	16.4	14,000	0.14	3.8	< 0.02	0.48	0.19	<0.1	<5	19
02Ely 9B	0.89	18.1	14,000	0.065	4.1	< 0.02	0.51	0.17	<0.1	28	21
02Ely 8A	0.09	0.5	420	< 0.02	0.39	0.033	0.065	< 0.01	<0.1	54	1.8
02Ely 8B	0.14	0.44	320	< 0.02	0.62	< 0.02	0.086	< 0.01	<0.1	71	2.9
02Ely 8C	0.61	90.6	66,000	0.038	2.7	0.15	0.34	0.33	2.3	1,800	3.4
02Ely 10A	0.005	0.12	100	< 0.02	0.015	< 0.02	< 0.005	< 0.01	1.3	1,200	0.15
02Ely 10B	0.0073	0.044	39	< 0.02	0.03	< 0.02	< 0.005	< 0.01	0.95	860	0.16
02Ely 11	0.02	0.081	67	< 0.02	0.093	< 0.02	0.015	< 0.01	0.4	360	0.56
02Ely 12	< 0.005	<0.02	<6	< 0.02	< 0.005	< 0.02	< 0.005	< 0.01	0.49	440	0.024
02Ely 12 DUP	< 0.005	<0.02	<6	< 0.02	0.0053	< 0.02	< 0.005	< 0.01	0.42	430	0.022
02Ely 13	0.017	0.084	69	< 0.02	0.068	< 0.02	0.01	< 0.01	0.96	890	0.28

Appendix D. (cont.)

	Li µg/L ICP-AES	Li µg/L ICP-MS	Mg mg/L ICP-AES	Mg mg/L ICP-MS	Mn µg/L ICP-AES	Mn µg/L ICP-MS	Mo µg/L ICP-AES	Mo µg/L ICP-MS	Na mg/L ICP-AES	Na mg/L ICP-MS	Nd µg/L ICP-MS
02Ely 1A	8.1	4.4	3.6	2.9	179	150	<20	< 0.02	<0.1	0.054	4.1
02Ely 1B	8	4.4	3.3	3	502	480	<20	0.027	<0.1	0.069	5.3
02Ely 2A	9.8	6.2	5.7	4.7	267	240	<20	< 0.02	<0.1	0.052	4.4
02Ely 2A DUP	11	6.7	6.6	4.9	306	250	<20	< 0.02	<0.1	0.05	4.5
02Ely 2B	10	6.3	3.8	3.6	417	400	<20	0.031	<0.1	0.061	7.6
02Ely 3	20	15	14.9	12	1110	940	<20	< 0.02	<0.1	0.023	13
02Ely 4A	2.1	1.8	1.6	1.2	169	130	<20	< 0.02	<0.1	0.11	0.73
02Ely 4B	9.3	5.3	3.5	2.7	293	240	<20	0.053	<0.1	0.071	5.4
02Ely 5A	9.8	5.2	5	3.9	191	160	<20	< 0.02	<0.1	0.044	4.2
02Ely 5B	11	6.6	3.3	2.7	458	410	<20	0.06	<0.1	0.1	7.9
02Ely 6A	14	8.3	8	6.1	407	340	<20	< 0.02	<0.1	0.04	9.7
02Ely 6B	14	9.8	4.2	3.8	569	520	<20	0.03	<0.1	0.12	4.9
02Ely 6B DUP	14	9.8	4.1	3.8	532	500	<20	0.029	<0.1	0.12	4.7
ES-4	4	0.4	0.35	0.26	28	23	<20	< 0.02	<0.1	0.048	1
02Ely 7A	5.6	1.9	2.2	1.7	145	120	<20	< 0.02	<0.1	0.059	4.4
02Ely 9A	5.8	2.1	3.2	2.5	245	210	<20	< 0.02	<0.1	0.046	11
02Ely 7B	5.4	5	5.4	4.5	708	660	<20	0.14	<0.1	0.018	21
02Ely 9B	6.6	5.8	5.4	4.3	612	550	<20	0.12	<0.1	0.036	23
02Ely 8A	7.2	3	2.3	1.8	243	200	<20	0.042	0.14	0.17	1.8
02Ely 8B	4.9	4	2.9	2.2	260	200	<20	0.022	<0.1	0.096	3.1
02Ely 8C	22	19	2.9	2.2	235	210	<20	0.54	<0.1	0.068	11
02Ely 10A	<1	< 0.1	0.2	0.19	24	21	<20	0.045	<0.1	0.14	0.097
02Ely 10B	<1	0.4	0.16	0.15	26	22	<20	0.039	0.12	0.21	0.18
02Ely 11	1.6	1.2	8.4	7.6	112	92	<20	0.051	<0.1	0.12	0.52
02Ely 12	<1	0.85	0.24	0.24	48	43	<20	0.1	0.19	0.15	0.024
02Ely 12 DUP	<1	0.73	0.25	0.26	62	56	<20	0.12	<0.1	0.14	0.019
02Ely 13	<1	0.4	0.26	0.24	27	23	<20	0.16	<0.1	0.12	0.33

Appendix D. (cont.)

	Ni	Ni	P	P	Pb	Pb	Pr	Rb	Re	Sb	Sb
	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
	ICP-AES	ICP-MS	ICP-AES	ICP-MS	ICP-AES	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-AES	ICP-MS
02Ely 1A	12	13	<0.1	< 3	<50	<0.05	0.94	1.9	0.031	<50	<0.03
02Ely 1B	32	16	<0.1	< 3	<50	<0.05	1.2	1.4	0.045	<50	<0.03
02Ely 2A	20	21	0.12	< 3	<50	<0.05	1	0.74	0.056	<50	<0.03
02Ely 2A DUP	24	22	0.13	< 3	<50	<0.05	1.1	0.63	0.055	<50	<0.03
02Ely 2B	23	28	0.1	< 3	<50	<0.05	1.8	1.4	0.045	<50	<0.03
02Ely 3	51	42	0.23	< 3	<50	0.12	2.3	3.1	0.05	<50	<0.03
02Ely 4A	<10	4.2	<0.1	< 3	<50	<0.05	0.17	4.6	0.021	<50	<0.03
02Ely 4B	26	23	<0.1	< 3	<50	<0.05	1.2	3	0.023	<50	<0.03
02Ely 5A	13	13	0.1	< 3	<50	<0.05	0.96	0.9	0.028	<50	<0.03
02Ely 5B	26	26	<0.1	< 3	<50	0.2	1.8	4.7	0.027	<50	<0.03
02Ely 6A	37	30	0.14	< 3	<50	<0.05	2.2	1.3	0.052	<50	<0.03
02Ely 6B	29	28	0.11	< 3	<50	0.1	1.2	8	0.036	<50	<0.03
02Ely 6B DUP	29	27	0.12	< 3	<50	0.82	1.1	7.5	0.038	<50	<0.03
ES-4	<10	1.7	<0.1	< 3	<50	0.16	0.25	1.3	< 0.02	<50	<0.03
02Ely 7A	18	14	<0.1	< 3	<50	0.31	1.1	1.6	0.048	<50	<0.03
02Ely 9A	36	33	0.12	< 3	<50	0.23	2.9	0.32	0.05	<50	<0.03
02Ely 7B	120	110	0.15	< 4	<50	0.054	5.5	0.68	0.096	<50	<0.03
02Ely 9B	100	91	0.13	< 4	<50	0.33	6.1	2.3	0.081	<50	<0.03
02Ely 8A	<10	8.5	<0.1	< 3	<50	<0.05	0.47	2.8	0.046	<50	0.03
02Ely 8B	48	39	<0.1	< 3	<50	0.35	0.79	2.9	0.041	<50	<0.03
02Ely 8C	3,460	3,000	1	< 4	<50	5.9	2.1	16	2.9	<50	0.09
02Ely 10A	<10	0.89	<0.1	3	<50	1.1	0.026	6.4	< 0.02	<50	<0.03
02Ely 10B	<10	0.7	<0.1	< 3	<50	0.059	0.045	5.9	< 0.02	<50	<0.03
02Ely 11	<10	6.5	<0.1	< 3	<50	0.41	0.13	3.6	0.045	<50	<0.03
02Ely 12	<10	3.5	<0.1	3	<50	0.71	< 0.01	1.3	< 0.02	<50	0.03
02Ely 12 DUP	<10	3.5	<0.1	4	<50	0.58	< 0.01	1.4	< 0.02	<50	0.06
02Ely 13	<10	1.7	<0.1	43	<50	3.8	0.072	4.1	< 0.02	<50	0.07

Appendix D. (cont.)

	Se µg/L ICP-MS	Si mg/L ICP-AES	SiO_2 mg/L ICP-MS	Sm µg/L ICP-MS	SO_4 mg/L IC	SO_4 mg/L ICP-MS	Sr µg/L ICP-AES	Sr µg/L ICP-MS	Tb µg/L ICP-MS	Th µg/L ICP-MS	Ti µg/L ICP-AES
02Ely 1A	2.7	0.37	0.54	0.9	140	140	<1	1.1	0.1	0.23	<50
02Ely 1B	2.2	0.52	0.98	1.2	120	140	1.9	2.4	0.16	< 0.03	<50
02Ely 2A	2.6	0.43	0.66	0.97	160	180	1.2	1.5	0.13	0.16	<50
02Ely 2A DUP	2.6	0.49	0.71	1	160	180	1.2	1.5	0.13	0.16	<50
02Ely 2B	1.3	0.34	0.65	1.6	140	170	3.6	4.2	0.18	0.03	<50
02Ely 3	3.9	0.3	< 0.5	3.3	230	250	<1	1.1	0.43	0.12	<50
02Ely 4A	2.2	0.45	0.6	0.17	49	47	1.2	1.1	0.02	< 0.03	<50
02Ely 4B	1.7	0.38	0.53	1.1	110	120	<1	0.92	0.14	0.1	<50
02Ely 5A	2.5	0.36	0.5	0.9	140	160	<1	0.52	0.094	0.18	<50
02Ely 5B	0.89	0.58	1	1.9	130	130	4.8	5	0.2	0.09	<50
02Ely 6A	4.4	0.29	< 0.5	2.2	170	180	<1	0.75	0.26	0.27	<50
02Ely 6B	2.4	0.52	0.98	1	160	200	2.9	3.3	0.14	0.08	<50
02Ely 6B DUP	2.3	0.49	0.93	0.99	160	190	2.6	3.1	0.14	0.07	<50
ES-4	< 0.2	0.74	1.2	0.22	89	92	<1	0.5	0.026	0.2	<50
02Ely 7A	3.3	0.69	1.1	0.99	140	150	3.6	3.6	0.15	0.18	<50
02Ely 9A	3.7	0.44	0.65	2.5	180	200	2.1	2.4	0.41	0.16	<50
02Ely 7B	4.6	0.37	0.6	4	260	290	3.7	3.5	0.51	2.3	<50
02Ely 9B	4.7	0.36	0.53	4.3	250	270	4.4	4	0.56	2.6	<50
02Ely 8A	3.5	0.37	0.53	0.38	87	91	1.7	1.9	0.056	< 0.03	<50
02Ely 8B	2.3	0.54	0.71	0.63	93	91	2.8	2.5	0.082	< 0.03	<50
02Ely 8C	10	0.78	1.4	2.9	800	790	<1	0.52	0.36	3.3	<50
02Ely 10A	1.3	0.59	1	0.014	26	26	4.2	4.2	< 0.005	< 0.03	<50
02Ely 10B	0.99	0.49	0.84	0.039	28	30	7.1	6.8	< 0.005	< 0.03	<50
02Ely 11	2.2	0.8	1.4	0.087	68	63	8.3	7.7	0.012	< 0.03	<50
02Ely 12	1.6	0.44	0.88	< 0.01	12	15	15	14	< 0.005	< 0.03	<50
02Ely 12 DUP	1.3	0.42	0.84	< 0.01	11	14	13	13	< 0.005	< 0.03	<50
02Ely 13	1.6	0.46	0.84	0.082	1.8	< 4	1.6	1.3	0.013	< 0.03	<50

Appendix D. (cont.)

	Tl µg/L ICP-MS	Tm µg/L ICP-MS	U µg/L ICP-MS	V µg/L ICP-AES	V µg/L ICP-MS	W µg/L ICP-MS	Y µg/L ICP-MS	Yb µg/L ICP-MS	Zn µg/L ICP-AES	Zn µg/L ICP-MS
02Ely 1A	<0.05	0.039	0.53	<10	<0.1	< 0.02	2.4	0.26	170	110
02Ely 1B	<0.05	0.064	0.72	<10	<0.1	< 0.02	4.1	0.4	168	130
02Ely 2A	<0.05	0.056	0.64	<10	<0.1	< 0.02	3.3	0.34	767	560
02Ely 2A DUP	<0.05	0.052	0.67	<10	<0.1	< 0.02	3.4	0.33	869	570
02Ely 2B	<0.05	0.067	0.86	<10	<0.1	< 0.02	4.3	0.4	322	240
02Ely 3	<0.05	0.16	1.1	<10	<0.1	< 0.02	11	0.85	2,510	1,700
02Ely 4A	<0.05	0.0066	0.11	<10	<0.1	0.038	0.6	0.042	110	83
02Ely 4B	<0.05	0.049	0.62	<10	<0.1	< 0.02	3.3	0.3	350	240
02Ely 5A	<0.05	0.037	0.31	<10	<0.1	< 0.02	2.3	0.2	894	610
02Ely 5B	<0.05	0.065	1.3	<10	<0.1	< 0.02	3.7	0.41	477	340
02Ely 6A	<0.05	0.077	1	<10	<0.1	< 0.02	6.2	0.45	1510	1,000
02Ely 6B	<0.05	0.049	0.99	<10	<0.1	< 0.02	3.5	0.28	654	470
02Ely 6B DUP	<0.05	0.05	0.99	<10	<0.1	< 0.02	3.5	0.27	627	480
ES-4	<0.05	0.0066	0.1	<10	<0.1	< 0.02	0.47	0.04	23	16
02Ely 7A	<0.05	0.048	0.65	<10	<0.1	< 0.02	3.3	0.28	798	560
02Ely 9A	<0.05	0.12	1.2	<10	<0.1	< 0.02	8.6	0.79	741	510
02Ely 7B	<0.05	0.14	2.2	<10	<0.1	0.053	11	0.82	1110	1,200
02Ely 9B	<0.05	0.15	2	<10	<0.1	0.058	12	0.83	1410	1,400
02Ely 8A	<0.05	0.026	0.17	<10	<0.1	< 0.02	1.6	0.16	258	180
02Ely 8B	<0.05	0.034	0.45	<10	<0.1	0.037	2	0.2	744	560
02Ely 8C	0.39	0.12	70	<10	<0.1	0.043	6.6	0.73	94,700	91,000
02Ely 10A	<0.05	< 0.005	0.024	<10	<0.1	0.25	0.057	< 0.01	17	13
02Ely 10B	<0.05	< 0.005	0.03	<10	<0.1	0.23	0.098	< 0.01	14	12
02Ely 11	<0.05	< 0.005	0.079	<10	<0.1	0.21	0.34	0.025	122	93
02Ely 12	<0.05	< 0.005	< 0.005	<10	<0.1	< 0.02	0.022	< 0.01	150	120
02Ely 12 DUP	<0.05	< 0.005	< 0.005	<10	<0.1	0.022	0.021	< 0.01	137	120
02Ely 13	<0.05	< 0.005	0.042	<10	0.42	0.027	0.26	0.025	16	15