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Geochemical Characteristics of TP3 Mine Wastes at the Elizabeth Copper Mine Superfund Site, Orange Co., Vermont

by

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TABLE OF CONTENTS

INTRODUCTION 5
SAMPLES 6
CHARACTERISTICS OF TP3 9
METHODS 10
    Bulk geochemical analysis 10
    Mineralogical methods 10
    Acid-generating potential 11
        Paste pH 11
        Acid-base accounting 11
            Acid-producing Potential (AP) 12
            Neutralization Potential (NP) 12
            Guidelines for interpretation of ABA results 13
        Acid-base accounting for this study 13
    Leach study 14
RESULTS 15
    Bulk geochemistry 15
    Mineralogy 19
    Mineral textures and compositions 23
    Acid-base accounting 25
    Leach study 29
DISCUSSION 32
CONCLUSIONS 36
ACKNOWLEDGMENTS 37
REFERENCES 38

APPENDIX A. Sample information
    A-1. Surface samples
    A-2. Soil boring samples
APPENDIX B. Geochemical data
    B-1. Bulk geochemistry of TP3 mine waste
    B-2. QA/QC data.
APPENDIX C. Mineralogy of TP3 mine waste
APPENDIX D. Leachate results

FIGURES

Figure 1. Location map 6

Figure 2. Elizabeth mine site map showing locations of historic mine waste pile TP3 and flotation tailings piles TP1 and TP2. Surface runoff from TP3 flows downhill through a breach in TP2 to a pond on TP1. Pond water flows down though a decant system that discharges at the northeastern corner of TP1, where it joins seeps and surface runoff to form the main channel of Copperas Brook 7

Figure 3. Sketch map and photos of TP3. Dashed white lines separate subareas defined for preliminary planning of passive treatment systems (Hathaway and others, 2001). TB identifies URS soil boring sites. Boundaries and shapes of colored areas A through H are schematic. See Appendix A for latitude and longitude of sample sites 8

Figure 4. Copper concentration in surface mine waste plotted by pile. Bars are color-coded by dominant surface color as shown in Fig. 3 18

Figure 5. Total base-metal concentrations vs. iron content in TP3 mine waste 18

Figure 6. Variations of base metal concentrations in TP3 mine waste with depth. Surface samples plot at depth 0. Eastern US soil point is based on mean metal concentrations in soils reported by Shacklette and Boerngen (1984) 19

Figure 7. Mineralogy of TP3 surface material. Silicate minerals with neutralizing potentials (NP) greater than one include biotite, chlorite, tremolite, clay, talc, and calcic plagioclase. Silicate minerals that have little or no acid-neutralizing potential (NP~1) include sodic plagioclase, muscovite, and quartz 21-22

Figure 8. Variation of estimated percentages of potential acid-generating minerals (sulfides, jarosite, efflorescent salts) with depth in surface and soil boring samples from TP3 22

Figure 9. TP3 mineralogy. A, Photograph of efflorescent salts on oxidized ore cobbles on pile F. B, Photomicrograph of soil boring material from sample TB4-S2 (2- 4 ft depth) from pile C, the red area south and east of Copperas Road. The large grain in the center and the smaller grains outlined in yellow are all chalcopyrite (Ccp). C, Backscattered-electron SEM image of soil boring material from sample TB5-S2/S3 (2-6 ft [0.6-1.8 m] depth) from pile B, the black sintered waste rock pile. Hematite (Hem) is the dominant mineral. Minor amounts of sulfur are detected in some hematite grains and in goethite (Gt), which occurs with quartz (Qtz); plagioclase (Pl) and chalcopyrite (CCp) are also present. Scale bar in lower right corner is 10 micrometers long. D, Backscattered-electron SEM image of soil boring material from sample TB6-S4/S5/S6 (6-12 ft [1.8 –3.6m] depth) from pile H, the red bench overlooking Copperas Road. Pyrrhotite (Po, bright white) is partly altered to jarosite (Jrs, gray) and elemental sulfur resulting in a "swiss-cheese" texture. Silicate mineral grains include muscovite (Ms), plagioclase (Pl), chlorite (Chl), Mn-rich garnet (Grt) and quartz (Qtz). Scale bar in lower right corner is 100 micrometers long 24

Figure 10. Classification of TP3 mine wastes in terms of net neutalization potential (NNP) and paste pH. Materials that have paste pH <4 and NNP<0 are considered likely to generate acid. Only till samples plot in the "non-acid-generating" field on this diagram. 26

Figure 11. Effects of repeatedly washing TP3 surface mine waste with deionized water (DI) on leachate pH. Black line represents nominal pH (3.8) for jarosite equilibration. Lower pH values indicate dissolution of efflorescent sulfate salts 26

Figure 12. Leachable copper from surface samples of TP3 mine waste piles. Piles are coded by dominant surface color. Dashed lines show water quality standards for Vermont, assuming a hardness of 100 mg/L $CaCO_3$ for acute aquatic toxicity 30

Figure 13. Dissolved metal concentrations in leachate as a function of pH. Shaded field represents the range of surface water compositions in the upper Copperas Brook watershed (Seal and others, 2001). Points that plot above the dashed lines exceed drinking water and acute aquatic toxicity water quality standards 31

Figure 14. Change in net neutralization potential (NNP) as a function of jarosite content and ABA method. Open symbols, Method 1; solid symbols, Method 2. Method 2 is the more aggressive acid digest for sulfide sulfur determination (see

Table 7). NNP values are all negative (acid-generating), regardless of method. Note the very low NNP values for sample TB5-S2/S2, which represents the 2 to 6 ft (0.6 to 1.8m) soil-boring sample from pile B. All other samples are surface composites.......... 33

Figure 15. Profiles through yellow, jarosite-rich mine waste pile F based on all of the data for soil boring TB7. Note log scale for many of the plots. Net neutralization potential (NNP) for selected samples using ABA method 1. Units are mg/kg (ppm) for bulk geochemistry, weight percent for XRD mineralogy, and µg/L for leachates. Note the close agreement for leachate copper determined by two different methods (AES and MS). Depths are plotted at the midpoint of the interval sampled.......... 34

Figure 16. Profiles through black to red, hematite-rich clinker and waste from the copperas works in pile B, based on all of the data for soil boring TB5. Note log scale for many of the plots. Net neutralization potential (NNP) for selected samples using ABA method 1. Units are mg/kg (ppm) for bulk geochemistry, weight percent for XRD mineralogy, and µg/L for leachate. Note the close agreement for leachate copper determined by two different methods (AES and MS). Depths are plotted at the midpoint of the interval sampled 35

TABLES

Table 1. Soil boring depths.......... 9

Table 2. Sample splits 9

Table 3. Guidelines for interpretation of ABA results 13

Table 4. Selected metal concentrations in TP3 mine waste 16

Table 5. Mine waste minerals.......... 20

Table 6. Paste pH and acid-base accounting results.......... 27

Table 7. Comparison of acid-base accounting results using different methods.......... 29

INTRODUCTION

Remediation of the Elizabeth mine Superfund site in the Vermont copper belt poses challenges for balancing environmental restoration goals with issues of historic preservation while adopting cost-effective strategies for site cleanup and long-term maintenance. The waste-rock pile known as TP3, at the headwaters of Copperas Brook, is especially noteworthy in this regard because it is the worst source of surface- and ground-water contamination identified to date, while also being the area of greatest historical significance. The U.S. Geological Survey (USGS) conducted a study of the historic mine-waste piles known as TP3 at the Elizabeth mine Superfund site near South Strafford, Orange County, VT (Fig. 1). TP3 is a 12.3-acre (49,780 m^2) subarea of the Elizabeth mine site (Fig. 2). It is a focus area for historic preservation because it encompasses an early 19th century copperas works as well as waste from late 19th- and 20th century copper mining (Kierstead, 2001). Surface runoff and seeps from TP3 form the headwaters of Copperas Brook. The stream flows down a valley onto flotation tailings from 20th century copper mining operations and enters the West Branch of the Ompompanoosuc River approximately 1 kilometer downstream from the mine site. Shallow drinking water wells down gradient from TP3 exceed drinking water standards for copper and cadmium (Hathaway and others, 2001). The Elizabeth mine was listed as a Superfund site in 2001, mainly because of impacts of acid-mine drainage on the Ompompanoosuc River.

The environmental geochemistry and mining history of the Elizabeth mine is summarized in a series of papers in Hammarstrom and others (2001). Mineralogical and geochemical data on composite surface samples from six discrete subareas of TP3 were included in studies of solid mine wastes by Hammarstrom and others (1999; 2001). Seal and others (2001) showed that the TP3 area generates some of the most acidic and metal-laden drainage in the Copperas Brook watershed. Seeps from the base of TP3 have the lowest pH and the highest dissolved concentrations of Al, Cu, Zn, Cd, and Co and some of the highest concentrations of Fe of any waters on the site. Therefore, if parts or all of TP3 remain intact, reclamation strategies must address surface water diversion and treatment to achieve water quality objectives (Hathaway and others, 2001). Proposed reclamation strategies range from complete to partial to no removal of TP3. To assess the viability of preserving any part of TP3, several questions need to be answered:

1. What are the sources of metals and acidity in waters draining TP3?
2. Are there significant differences among the different colored piles?
3. How variable is the environmental impact among the various piles of TP3?
4. How does the environmental impact vary with depth in the piles?

No single approach or test exists to answer all these questions. Therefore, a multi-faceted study was designed to characterize the surface and subsurface materials on TP3 in terms of mine-waste geochemistry, mineralogy, acid-generation potential, and leachability of metals. Objectives for the study included the following:

- Subsurface and additional surface sampling of TP3,
- Determination of the mineralogical and bulk geochemical character of waste materials as a framework for understanding interactions between waters and solids,
- Paste pH measurements,
- Acid-base accounting to evaluate acid-producing capability of mine wastes,
- Leach studies to determine the relative mobility of acidity and metals from mine wastes.

These data thus provide multiple lines of evidence for assessing the environmental impacts associated with different parts of TP3. Part of this study was funded by the U.S. Army Corps of Engineers as part of the site evaluation for the U.S. Environmental Protection Agency (USEPA).

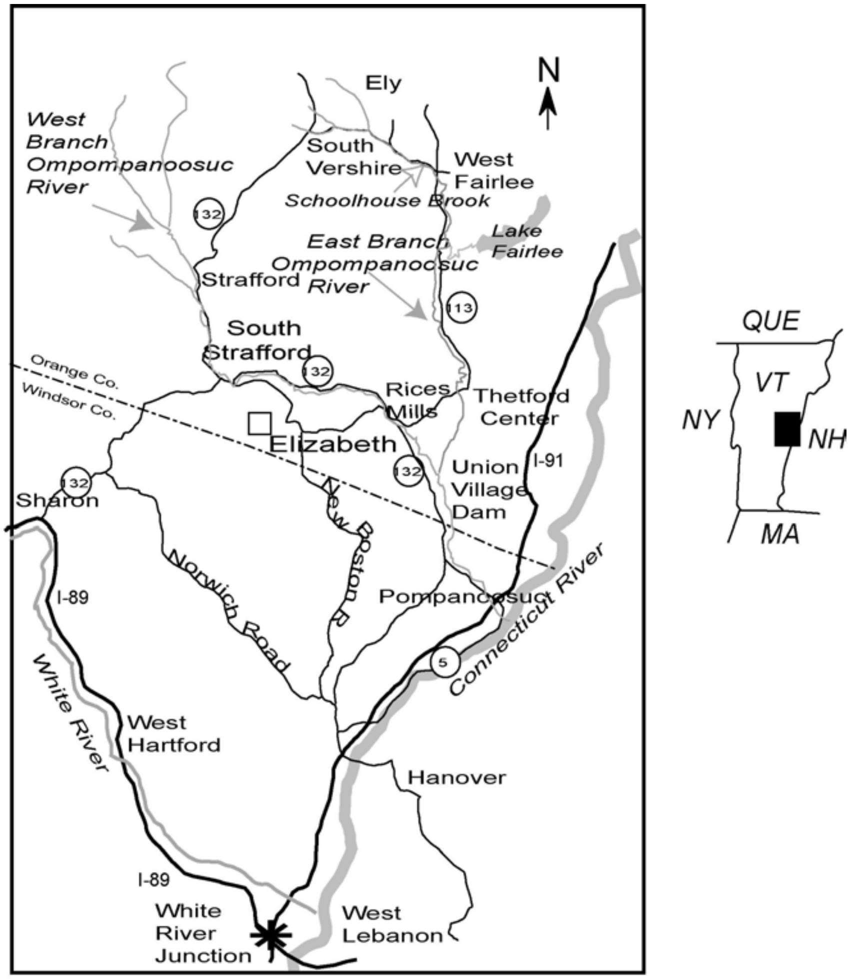

Figure 1. Location map.

SAMPLES

The U.S. Geological Survey collected surface samples of eight mine waste piles (Fig. 3, piles A through H). Surface-sample composites of soil (<2 mm) material were sampled by collecting a minimum of 30 sample increments over a designated, measured area on a random, stratified grid. An increment consists of a scoop of the 5 top cm using a U-Dig-It stainless steel trowel. The trowel was pre-contaminated prior to sampling. Samples from each pile were mixed to make a composite sample, sieved through a 10-mesh sieve into a plastic gold pan, labeled and stored in plastic bags for shipping to the lab. Dry, sieved samples weighed 2.5 kg or more. Piles A through F were sampled in 1998 (Hammarstrom and others, 1999; 2001). Piles G and H were sampled in duplicate in October of 2002; piles A, B, and C were resampled at the same time. All surface samples were subjected to geochemical and mineralogical analysis. Surface samples for piles A, B, C, E, F, G, and H were submitted to BC Research, Inc. for acid-base accounting. Pertinent data from the previously reported 1998 sampling are included in this report, along with data for a surface sample of TP4, a small area of mine waste produced from the South Pit (Fig. 2).

Subsurface samples were acquired as soil borings with a 2”(5 cm)-diameter split spoon coring device. Drilling, sampling, and core logging were conducted by URS Corporation, under contract to the U.S. Army Corps of Engineers and USEPA. Eight cores were acquired (see Fig.

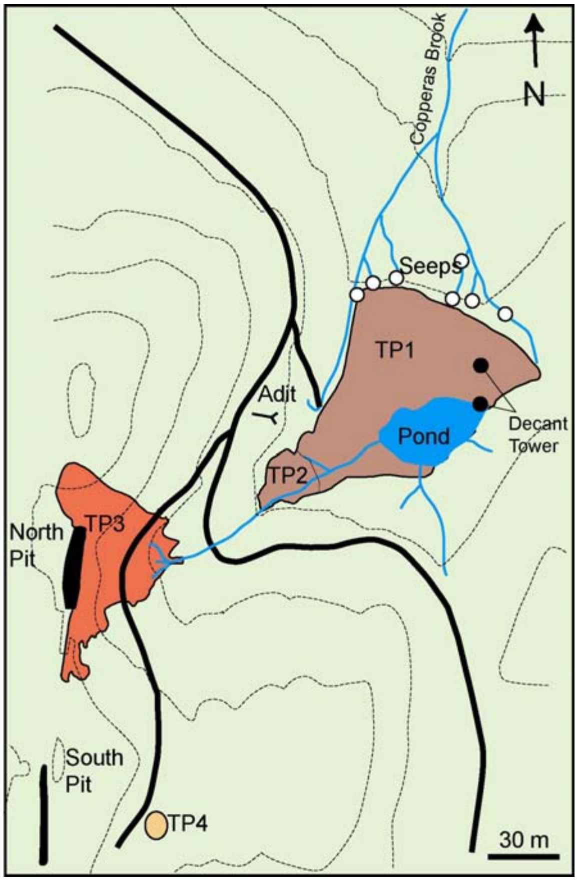

Figure 2. Elizabeth mine site map showing locations of historic mine waste pile TP3 and flotation tailings piles TP1 and TP2. Surface runoff from TP3 flows downhill through a breach in TP2 to a pond on TP1. Pond water flows down though a decant system that discharges at the northeastern corner of TP1, where it joins seeps and surface runoff to form the main channel of Copperas Brook.

3 for locations). The drilling method varied depending on the terrain. Where possible, borings advanced through the piles in 2-ft (0.61m) intervals. Boring depths ranged from 5.7' (1.7m) for a hand auger profile through pile E at TB20 to 28.3' (8.6 m) for a tripod-mounted boring through pile H at TB6. Borings ended in till, bedrock, or possibly on large buried boulders (Table 1).

Samples were removed from the spoon, logged in the field, and placed into Tyvek bags. In some cases, it was necessary to combine 2 or 3 sampling intervals to acquire sufficient sample for analysis due to poor recovery. For example, sample EMV-ROCTB1-S4/S5/S6 represents the combined samples recovered from the S4, S5, and S6 core retrievals. Fifty-one samples, including three duplicate samples (SQ) and one sample split for replicate analysis, were analyzed for chemistry and mineralogy. Twenty-eight samples were analyzed for acid-base accounting. Soil boring samples are numbered with the prefix EMV-ROC, followed by the boring number and the sampled interval(s). The EMV-ROC sample number prefix is omitted from data tables for clarity, with the exception of Appendix A (sample information), where the prefix is preserved in the "field number" column. Gaps in sample numbers represent boring intervals where inadequate sample was recovered.

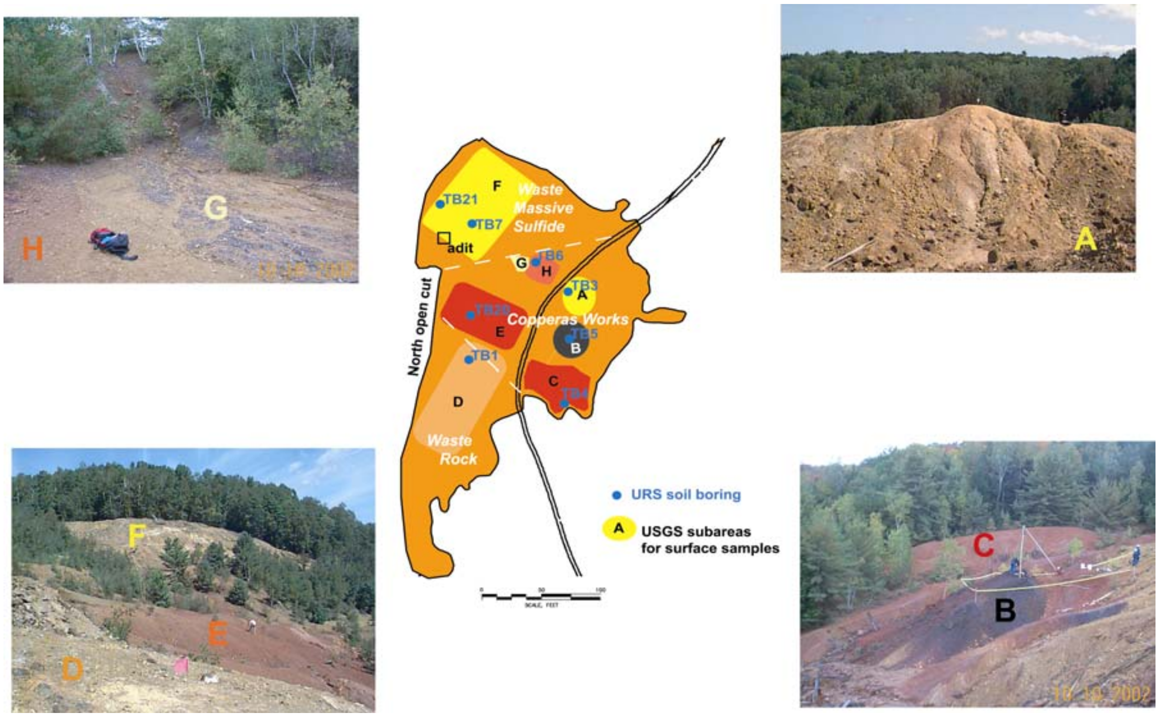

Figure 3. Sketch map and photos of TP3. Dashed white lines separate subareas defined for preliminary planning of passive treatment systems (Hathaway and others, 2001). TB identifies URS soil boring sites. Boundaries and shapes of colored areas A through H are schematic. See Appendix A for latitude and longitude of sample sites.

Soil boring material ranged from gravel to sand to silt in particle size. Most of the material was moist when logged in the field immediately after retrieval. The dominant material encountered in all borings is highly weathered waste rock. Rock fragments of weathered schist were encountered throughout the piles. Fragments of wood were observed in soil borings from 12 to 14 ft (3.6 to 4.3 m) depth in pile A and at 10 to 12 ft (3.0 to 3.6 m) depth in pile H (Appendix A).

In most of the borings, glacial till was encountered at depth, above bedrock. The glacial till is regionally extensive, and typically covers bedrock in valleys. The till is olive green to gray in color, dense, and feels like modeling clay to the touch. Till underlies TP1, crops out along the Copperas Brook bank below TP1, and is visible in gullies along the road at the northernmost edge of TP3. A sample of till (01JH26) was collected along Copperas Brook below TP1 and analyzed for comparison with material encountered in soil borings.

Samples were shipped from the field to the U.S. Geological Survey in Reston, VA following chain-of-custody procedures. In the lab, samples were air dried and weighed. Sample color was determined by comparison with Munsell soil color charts (Munsell, 1994). Coarse (>2 mm) material and debris were removed, and material was sieved to break up clots in soil borings, as necessary. Samples were split into aliquots by fractional shoveling (Pitard, 1993) for further analysis (Table 2).

Table 1. Soil boring depths.

Pile	Boring	Depth	Bottom material
D	TB1	26 ft (7.9 m)	Till
A	TB3	18 ft (5.5 m)	Bedrock?
C	TB4	6.6 ft (2.0 m)	Bedrock
B	TB5	10.25 ft (3.1 m)	Till
H	TB6	28.3 ft (8.6 m)	Till/boulder
F	TB7	24 ft (7.3 m)	Till/bedrock
E	TB20	5.7 ft (1.7 m)	Mine waste
F	TB21	10.3 ft (3.1 m)	Till/weathered rock

Table 2. Sample splits.

Sample size	Purpose
50 g	Leach study
100 g	Bulk geochemistry
100 g	Acid-base accounting
10g	Paste pH
15 g	Mineralogy
25 g (or more)	Archive

CHARACTERISTICS OF TP3

The TP3 area was heavily trafficked during 20th century copper mining as ore was transported from the South Pit along a road that cuts across the mine waste piles. Although parts of TP3 are distinct, much of the material may have been disturbed during the long period of activity (1790s to 1958). The design of any proposed treatment system for TP3 runoff depends on the nature of the water to be treated. Surface-runoff composition is a function of interactions between water (rain, snowmelt, groundwater) and the solid materials. Preliminary proposed reclamation strategies considered different options for preserving TP3 (Hathaway and others, 2001). Options include no preservation, partial preservation, or complete preservation. Subareas of TP3 defined by Hathaway and others (2001) included waste massive sulfide, two subareas of material thought to represent waste from the copperas works, and a subarea largely composed of waste rock.

The most striking feature about TP3 is its color (Fig. 3). Hammarstrom and others (1999) divided TP3 into six piles (A though F) on the basis of dominant color for composite surface sampling. Additionally, piles G and H were defined for the present study because of possible historic significance. Figure 3 outlines the footprint of TP3 and shows the generalized location of different color piles and the sites selected for soil borings. Bright red piles (C and E) represent partly roasted ore from the copperas works. Pile B is a cone of dark reddish brown to black sintered ore (clinker) from the copperas roast beds. Piatak and others (2003) reported geochemistry and leachate data for separate samples of red (oxidized) and black sintered ore from pile B. Pile D is a brownish-yellow pile of mixed material, mainly composed of waste rock. Yellow piles A and F represent waste piles from later copper mining. The upper parts of pile F are strewn with cobble to boulder-size blocks of waste rock and discarded ore, which partly overlie roast beds from the copperas works. The northwestern part of pile F, north of the North Open Cut, includes waste rock and hand-cobbed ore from the circa 1880s Tyson shaft (Kierstead, 2001). Efflorescent sulfate-salt minerals including melanterite (copperas), rozenite, and copiapite form on weathered ore and mine-waste soils, especially in the area of pile F (Hammarstrom and others, 2001). These minerals form by evaporation of extremely acidic water. Efflorescent minerals are very soluble; they repeatedly form during dry periods and dissolve with rain or snowmelt. Crowley and others (2001) used a remote sensing spectral reflectance technique known as AVIRIS to map the distribution of dominant surface minerals at the mine site. The

AVIRIS map showed that the iron oxide mineral hematite, the source of the bright red colors, is the dominant surface mineral in parts of the copperas works areas. The iron hydroxysulfate mineral jarosite, the source of much of the yellow color on TP3, is the dominant surface mineral over most of TP3. Boundaries of piles that can be associated with a particular color, surface mineral, or mining era are indistinct.

METHODS

Bulk geochemical analysis

All of the samples were analyzed for chemistry to determine the major-, minor-, and trace-element composition of the solid material. Sample splits were ground in U.S. Geological Survey sample preparation labs in Denver, CO (Taggart, 2002). All samples were analyzed for 40 elements by inductively coupled plasma-atomic emission spectrometry (ICP-AES). Analytical procedures, detections limits and an evaluation of analytical performance for a variety of geological materials are reported in Briggs (2002) and Briggs and Meier (2002). Composite mine-waste surface samples collected in 1998 were analyzed by inductively coupled plasma-mass spectrometry (ICP-MS), by LECO furnace for total sulfur, and by wavelength-dispersive x-ray fluorescence spectroscopy (WD-XRF); those data and analytical details were reported by Hammarstrom and others (1999).

NIST certified reference materials were analyzed to monitor accuracy and precision. In addition to replicate field samples, laboratory duplicates on separate aliquots of the same sample were analyzed. USGS job numbers and laboratory number entries in the National Geochemical Database (Smith, 2002) are listed in Appendix B-1. QA/QC data are included in Appendix B-2.

Mineralogical methods

The mineralogy of mine waste affects the choice of predictive tests of acid-mine drainage and the interpretation of test results (White and others, 1999; Jambor, 2003). Different minerals in mine waste have inherently different solubility characteristics, as well as acid-generating or acid-neutralizing potentials. The mineralogy of TP3 mine wastes was characterized by a number of methods, including powder x-ray diffraction (XRD), optical microscopy, scanning electron microscopy (SEM), and mineral separation.

For XRD, splits of all samples were pulverized in alcohol in a McCrone micronizer equipped with agate grinding pellets to reduce average particle size to 1 to 5 micrometers. Micronized samples were loaded into side-loading aluminum holders. Powder patterns were collected on a Scintag X1 automated diffractometer equipped with a Peltier detector using CuKa radiation. Patterns were interpreted with the aid of Scintag and MDI Applications JADE search/match software and compared with reference patterns in the Powder Diffraction File (ICDD, 2002). The relative amounts of different minerals in TP3 mine wastes were estimated by quantitative phase analysis using the Siroquant computer program (Taylor and Clapp, 1992). Siroquant utilizes the full XRD profile in a Rietveld refinement to estimate the weight percentages of different minerals in the mixture, based on a rigorous identification of minerals present prior to the refinement. Raudsepp and Pani (2003) summarized applications of Rietveld analysis for environmental studies of mine wastes. Small amounts (<5 weight percent) of a mineral are not always detectable by XRD.

Uncertainties in XRD interpretation were resolved by examining samples under a binocular microscope and by using electron microbeam techniques to confirm the presence and composition of suspected minerals. Epoxy grain mounts were prepared for selected mine-waste samples. Samples were carbon-coated and examined with a JEOL JSM-840 scanning electron microscope (SEM) equipped with a back-scattered electron (BSE) detector, a secondary electron (SE) detector, and a PGT x-ray energy-dispersive system (EDS). EDS spectra were collected to obtain qualitative analysis of mineral compositions to refine XRD identifications and choose appropriate starting minerals from the Siroquant mineral library for Rietveld refinement. The SEM typically was operated at an accelerating voltage of 15 kV and a specimen current of 1 to 2 nA. A JEOL electron microprobe was used to analyze selected silicate minerals.

Heavy-mineral concentrates were obtained by placing a few grams of mine waste into the heavy liquid methylene iodide (specific gravity of 3.3) to separate sulfides and other heavy minerals. The heavy mineral concentrate was extracted from the separatory funnel, washed with acetone, and air-dried. Smear mounts of the concentrates were prepared for XRD.

Small amounts of readily soluble efflorescent sulfate salts can have dramatic effects on paste pH and acid-base accounting results. These minerals have been identified on the surface of TP3 in previous studies (Hammarstrom and others, 1999; 2001). Salts typically are present in amounts that are too small to detect in XRD patterns of the bulk mine waste because they are diluted by the much higher concentrations of other minerals. Evidence for readily soluble salts was evaluated in a simple experiment on composite surface material from piles A, B, C, and G. The experiment was conducted by mixing 2.0 g of mine waste with 40 mL of deionized water in a plastic centrifuge tube. The tube was capped, shaken by hand for 2 minutes, and centrifuged for 30 minutes at 3,000 rpm. The water was decanted and the pH was measured with an Orion pH meter. The procedure was repeated with fresh deionized water each day for 5 days, when the pH changes with subsequent washings leveled off. The tendency for salts to form in TP3 mine waste was also evaluated by allowing leachate solutions from selected leach experiments (see below) to evaporate in open air. A 50 mL aliquot was extracted from stored leachate solutions from surface composite samples from piles A, B, and H and from soil borings from TB5 (pile B). The leachates were filtered with a 0.45-micrometer nitrocellulose filter into ceramic dishes and allowed to evaporate to dryness. Solids that precipitated from evaporation were scraped out and analyzed by XRD as smear mounts.

Acid-generating potential

Many different test methods have been developed to predict acid-mine drainage. Two of the most common and widely used test methods are paste pH and acid-base accounting. These are considered static tests because they are short-term. These tests are relatively inexpensive and provide an estimate of the inherent capacity of a mine waste to produce or neutralize acid (White and others, 1999). Paste pH is routinely measured as a part of the acid-base accounting procedure. Acid-base accounting was originally developed to evaluate potentially toxic overburden materials encountered in coal mining and highway construction (Sobek and others, 1978).

Paste pH

Paste pH is a commonly measured soil characteristic. Paste pH is measured in the laboratory on 10-gram splits of <2 mm material (nominal soil). Mine waste is placed in a plastic beaker and 10 mL of distilled water (pH 5.33) is added to make a paste. The paste is stirred with a wooden spatula to wet the powder. In this study, pH was measured with an Orion pH meter fitted with an Ag/AgCl epoxy electrode and temperature probe. This method, based on Price and others (1997) provides a quick measure of the relative acid-generating (pH<4) or acid-neutralizing (pH>7) potential of the material. Paste pH was also measured by BC Research, Inc. as part of the acid-base accounting procedure described below. Sobek and others (1978) defined materials that have a paste pH of less than 4.0 as being acid-toxic.

Acid-base accounting

The acid-base account (ABA) is the most widely used static test to predict acid-mine drainage. The test is a laboratory test that is widely used in metal mining and coal mining to classify mine wastes.

The acid-base account was popularized by Sobek and others (1978). The test consists of two measurements: (1) measurement of the amount of acidity a sample is likely to produce (AP) and (2) measurement of the inherent neutralization potential of the same sample (NP). The difference between these two measurements is defined as the net neutralization potential of the sample (NNP):

$$NP - AP = NNP$$

If NP>AP, then the resulting NNP will be a positive number. If NP<AP, NNP will be negative. The NP/AP ratio is also used to describe the acid-producing potential of mine wastes. The NNP

is used in coal mining and the NP/AP ratio is more widely used for metal mines. ABA provides a screening tool to determine the need for further lengthy and expensive kinetic tests that might better simulate natural weathering conditions.

ABA typically is used as an acid-generation prediction test to evaluate waste rock, ore, or overburden. A number of states and jurisdictions use ABA resting in their regulatory requirements for active mining. Guidelines for ABA exist to classify mine wastes as acid, uncertain, or non-acid. Guidelines vary slightly from jurisdiction to jurisdiction. Classification criteria based on NNP are somewhat controversial, especially for materials that fall in the "uncertain" ranges (White and others, 1999). The following discussion provides a brief overview of ABA. Detailed discussions are included in Sobek and others (1978), USEPA (1994), White and others (1999), and references therein.

Acid-producing Potential (AP): The AP of a sample is determined by measuring the amount of sulfur present, based on the assumptions that all of the sulfur in the sample is present as an iron sulfide mineral (pyrite or pyrrhotite) and that reaction of sulfide mineral with oxygen in air and water will produce 2 moles of acid (H^+) from each mole of sulfur present, according to the reactions:

For pyrite: $FeS_{2(s)} + (7/2)\ H_2O + (15/4)\ O_{2(g)} = Fe(OH)_3 + 4H^+_{(aq)} + 2SO_4^{2-}{}_{(aq)}$

For pyrrhotite: $FeS_{(s)} + (5/2)\ H_2O + (9/4)\ O_{2(g)} = Fe(OH)_3 + 2H^+_{(aq)} + SO_4^{2-}{}_{(aq)}$,

Where s= solid, g= gas, and aq = aqueous species.

The cheapest and most commonly used material to neutralize acid is limestone, which is mostly comprised of the mineral calcite, $CaCO_3$. The amount of calcite required to neutralize the acid produced by pyrite or pyrrhotite is based on the following equation:

$$CaCO_{3(s)} + 2H^+_{(aq)} = Ca^+_{(aq)} + H_2CO_3$$

Because the ratio of moles of sulfur in the sulfide minerals to moles of calcite needed to neutralize the acid is 1 to 1 for either pyrite or pyrrhotite (e.g., 2 moles of sulfur in pyrite generate 4 moles of H^+, which requires 2 moles of calcite for neutralization), the AP can be expressed as an equivalent of $CaCO_3$, as follows:

atomic mass of 1 molecule of $CaCO_3$ /atomic mass of 1 mole of S = 100.09/ 32.06 = 3.122 g

AP and NP are expressed in units of kg of $CaCO_3$ equivalent per metric ton of mine waste (or rock). These values are sometimes reported in the equivalent units of tons of $CaCO_3$ per 1,000 metric tons of mine waste, or parts per thousand. The AP is computed from the measured sulfur concentration of the sample by converting grams to kilograms, as follows:

$$\text{AP in kg/t } CaCO_3 = \text{wt.\% S} \times 31.22$$

Mine wastes typically contain sulfate minerals as well as sulfide minerals, especially wastes that have oxidized by weathering over a long period of time. Both total sulfur and sulfate sulfur are analyzed, and the difference represents the sulfide sulfur in a procedure known as the "modified ABA method" or the "modified Sobek method". Sulfate sulfur represents the amount of total sulfur that has already been oxidized to sulfate. Some sulfate minerals are acid-generating (efflorescent iron-sulfate salts such as melanterite (copperas), rozenite, and copiapite) and some are benign (gypsum).

Neutralization Potential (NP): The neutralization potential of a sample is determined by treating a sample with an excess of HCl, allowing the HCl to react with the sample so that any neutralizing materials can consume the acid, and then determining the amount of unconsumed acid (in terms of $CaCO_3$ equivalent) by titrating the solution with a base (Sobek and others, 1978). The procedure starts with a “fizz” test to visually estimate the reaction of a small amount (0.5 g) of sample to a 25% solution of HCl. The degree of effervescence provides an indication of the amounts of carbonate minerals present. Based on the “fizz” rating, which can range from none to strong, a specific volume and strength of HCl is added to the sample. The mixture is heated to boiling, diluted, boiled, cooled, and titrated with NaOH to a set pH endpoint. The amount of base (NaOH) added provides a measure of how much of the HCl was neutralized by the sample. The neutralization potential is reported as kg of $CaCO_3$ per metric ton of mine waste. In cases where the sample has no fizz rating, the amount of base added in the titration exceeds the amount of HCl added, and the NP is reported as a negative number.

Guidelines for interpretation of ABA results: A negative NNP or a NP/AP ratio <1 indicates a potential for a mine waste to form acid (USEPA, 1994). The issue of what values are “safe” to adopt to classify a mine waste as non-acid-generating is not clear-cut. Acid-base accounting has been used for over 20 years as a tool to predict overburden and water-quality characteristics on mined lands. In a review of interpretation of acid-base accounting, Perry (1998) concluded that a deficit of carbonate material or NP increases the likelihood of acid drainage. In cases where NNP falls between –20 and +20, or 1<NP/AP<3, the material may be classified as “uncertain” and further kinetic tests are warranted. However, mine wastes are always classified as having acid-producing potential if NNP<0 and NP/AP<1 and some materials with weakly positive NNP (up to +20) may still have the potential to produce net acidity (Chemex, 2000). Nevada, California, Minnesota, Idaho, and Montana have regulations for waste rock and overburden acid-generation prediction testing for active mining and mineral exploration (USEPA, 1994). ABA results that indicate acid-producing potential typically require further kinetic tests or development of waste disposal management plans in these states. Ratios are used in screening mine wastes as a measure of the relative margin of safety of a material for the prevention of acid generation. Generally, NP/AP ratios greater than 2 indicate a high probability the material will maintain a near-neutral pH as mining proceeds. Table 3 lists guidelines adopted by some jurisdictions for interpretation of ABA results based on data compiled by White and others (1999) and USEPA (1994). Note that these guidelines apply to new mines, rather than historic mine wastes. These criteria however, provide tools for assessing the TP3 historic mine wastes as potential acid-generating materials.

Table 3. Guidelines for interpretation of ABA results.

Criterion	Acid	Uncertain	Non-Acid	Reference
NNP	< -5	-	-	Sobek and others (1978) Appalachian coal mine criterion
NNP	≤ 0	-	-	Ferguson and Morin (1991) British Columbia metal-mine criterion
NNP	-	20<NNP<+20	-	Ferguson and Morin (1991)
NNP	<+10	-	-	Day(1989)
NP/AP	<1	1<NP/AP<3	>3	Brodie and others (1991)
NP/AP	<1	1<NP/AP<1.3 to 4.0	>1.3 to 4.0	Morin and Hutt (1994)
NP/AP	-	<3	>3	NP/AP <3 triggers requirements for further tests in California (U.S. EPA, 1994)
AP/NP	>2	-	-	AP/NP >2 triggers requirements for kinetic tests in Idaho (U.S. EPA, 1994)
NP/AP	-	If NP< (20%>AP), further testing	NP= 20%>AP	Nevada guidelines (U.S. EPA, 1994)
NP/AP	-	-	>2	Amira International (2002)

Acid-base accounting for this study

Thirty-five samples of TP3 mine waste and the till sample were submitted to BC Research, Inc. for acid-base accounting. The neutralization potential and total sulfur concentrations were determined by the Sobek procedure (Sobek and others, 1978). Sulfate sulfur was determined by the modified Sobek procedure described above, by treating 5 g of sample with 20 mL of 3N HCl in a beaker. The beaker is covered, heated to a boil, cooled, and diluted to a known volume. After overnight settling, the supernatant is analyzed for sulfate sulfur.

Duplicate analyses for total sulfur, sulfate sulfur, and analyses of standard materials were performed for quality insurance and quality control. Poor reproducibility was observed for duplicate sulfate sulfur determinations for some samples. Evaluation of the mineralogy of these samples showed that they are jarosite-rich. The highly oxidized nature of the TP3 mine waste introduced complications for applying the modified ABA method because the sulfate mineral jarosite is refractory in 3N HCl. The jarosite sulfur is not completely liberated as sulfate during the modified Sobek procedure (Vos and O'Hearn, 2001; R.Vos, written commun., 2003). Therefore, the sulfate sulfur contribution of the jarosite in the sample can be underestimated and the maximum potential acidity based on sulfide sulfur can be overestimated resulting in a more negative NNP value. To test this, five samples were reanalyzed using more aggressive procedures (concentrated HCl and longer boiling times) to liberate the sulfate sulfur in jarosite and evaluate the effects of mineralogy on ABA results.

Leach study

The U.S. Environmental Protection Agency (1992; 1994), state agencies, and industry commonly use the Toxicity Characteristic Leaching Procedure (TCLP, Method 1311) or the Synthetic Precipitation Leaching Procedure (SPLP, Method 1312) to assess the leachability of hazardous materials. These tests were not designed for mining wastes; rather, the TCLP was designed to simulate leaching in a sanitary landfill. The TCLP involves leaching the test material with acetic acid, which preferentially binds lead due to a strong complex between lead and acetate, and is required under the Resource Conservation and Recovery Act (RCRA) as one approach to defining a hazardous waste. The SPLP comes closest to simulating conditions in a waste-rock dump (Smith, 1997). The SPLP has been designated as an American Society for Testing and Materials (ASTM) method (D6234-98 Standard Test Method for Shake Extraction of Mining Waste by the Synthetic Precipitation Leaching Procedure). Hageman and Briggs (2000) developed a Field-Leach Test to provide on-site pH and conductivity information (for field prioritization) as well as a rapid, cost-effective means of acquiring leachate data. The field-leach test is based on the premise that the most chemically reactive material in weathered mine waste consists of relatively soluble components in the fine fraction (< 2 mm) of the waste. In general, higher concentrations of chemical constituents are leached from the smaller size fractions in the weathered mine-waste piles studied. The choice of the < 2 mm size fraction may tend to slightly overestimate the leachability of the mine-waste material as a whole, but this size-fraction cutoff does not appear to "miss" any readily leachable phases (Smith and others, 2000). The field-leach test produces the same geochemical trends as the SPLP and comparable pH and conductivity; absolute concentrations for some elements are typically lower by this test than data obtained using the SPLP.

The field-leach test was adapted as a laboratory procedure for this study. The test was conducted by combining 50 g of <2 mm sample with 1,000 g (1 liter) of synthetic eastern U.S. precipitation in a capped polyethylene bottle. The synthetic precipitation was prepared by adding a mixture of 60% H_2SO_4:40% HNO_3 (by weight) to deionized water; the solution pH was 4.2 ± 0.1. The sample was vigorously shaken for five minutes, and then allowed to settle for 24 hours. Specific conductance and pH were measured on unfiltered water samples and recorded. Aliquots were filtered through 0.45 micrometer pore size nitrocellulose filters. A filtered split (125 mL) was analyzed for sulfate and chloride by ion chromatography in USGS laboratories in Ocala, FL. A filtered split (125 mL) was acidified with 12 drops of Ultrex HNO_3 and submitted to USGS analytical laboratories for analysis by ICP-MS (Lamothe and others, 2002) and ICP-AES (Briggs, 2002, Briggs and Meier, 2002) using USGS methods for water samples. ICP-MS is most useful for trace elements in the parts-per-billion range. Analyses for major elements in the parts-per-million range are less accurate by ICP-MS; therefore, ICP-AES data should be used for major elements. Details of the leach protocol are available at:

http://crustal.usgs.gov/minewaste/pdfs/hageman1.pdf

RESULTS

Large data tables are included as a series of appendices to this report. Sample information is included in Appendix A. Appendix A-1 describes surface samples, grouped by subarea, along with sampling date, Munsell color, and dry sample weight. Appendix A-2 includes the field log descriptions, sampling intervals, drilling methods, and geotechnical data supplied by URS. Appendices B, C, and D include bulk geochemical data and QA/QC data, mineralogy, and leachate chemistry, respectively. For the boring logs, the source data are reported in feet or inches; these units are preserved in the appendices, tables, and plots throughout this report. Metric units are given in parentheses next to U.S. customary units in the text. To convert from feet to meters, multiply by 0.3048.

Bulk geochemistry

Geochemical data for 41 elements for all surface and soil boring samples are reported in Appendix B-1, arranged by mine-waste pile (A though H) and depth. QA/QC data are included as Appendix B-2. Comparison of measured values for standard reference materials to certified mass fractions indicates that all measured values are within two standard deviations of the certified mass value; in most cases, the measured values are within one standard deviation of accepted values (Appendix B-2).

Results for selected metals are listed in Table 4, along with USEPA preliminary remediation goals (PRGs) for residential and industrial soils. PRGs are screening guidelines intended as tools for evaluating and cleaning up contaminated sites (USEPA, 2002); concentrations at a site that are below PRG concentrations are used to identify areas and contaminants that do not warrant further federal attention (USEPA, 2002). Concentrations above PRGs do not necessarily designate a site as contaminated, but may warrant further evaluation of potential risks. Samples that are dominantly till are highlighted in italics in Table 4.

All of the TP3 mine waste is iron-rich. Except for the till encountered at depth in the soil borings, which contains <10 weight percent iron (Fe), all of the samples contain between 10 and 40 weight percent Fe. Copper (Cu) is the dominant metal; 23% of the TP3 samples exceed residential soil PRG concentrations. Arsenic (As) and cadmium (Cd) concentrations are below detection limits for about half of the samples. About 14% of the samples slightly exceed the residential soil PRG for arsenic. One sample exceeds industrial PRG soil guidelines for copper, any must samples exceed guidelines for iron. Zinc is the second most abundant metal in the mine waste, with concentrations that range from less than 100 to more than 2,000 mg/kg Zn. Lead concentrations are all <200 mg/kg. Duplicate surface samples for a given pile (surface composites and 0 to 2 ft (0 to 0.6 m) soil borings) indicate that despite the heterogeneity of mine waste material, the chemical signature of each pile is reproducible (Fig. 4). Yellow piles F and G have the highest surface concentrations of copper. Although the surface material of red pile E is lowest in Cu (<1,000 mg/kg Cu), other red (C) and black (B) piles that represent areas of the historic copperas works cannot be distinguished from other parts of TP3 on the basis of copper (Fig. 4) or other metals (Table 4). Piles A and H have nearly identical copper concentrations in surface material, despite color differences in the piles.

Total base metals (copper+cadmium+cobalt+nickel+lead+zinc) tend to increase with increasing iron content for mine-waste samples (Fig. 5). Till and mixed till and mine-waste samples encountered at depth in soil borings are distinct from mine waste by virtue of their lower Fe and metal concentrations. Metal concentrations vary over an order of magnitude (factor of 10) within individual mine waste piles. Similarly, individual waste piles are not distinct at depth (Fig. 6). Relative to surface samples, samples at depth can have higher or lower metal concentrations. All mine-waste samples contain at least ten times as much metal as typical eastern U.S. soil, and most contain much higher metal concentrations than the till. Although the till does contain some metals, the till contains about twice as much zinc as copper (Table 4), reflecting the very different composition and mineralogy of the till compared to the mine waste.

Table 4. Selected metal concentrations in TP3 mine waste.
[Till and mixed till and mine-waste samples in italics]

Pile	Sample[1]	Depth (ft)	(m)	Al	As	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	V	Zn
	Guidelines[2]			wt.%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	wt.%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	PRG-residential			**7.6**	**22**	**37**	**900**	**210**	**3,100**	**2.3**	**1,800**	**390**	**1,600**	**400**	**550**	**23,000**
	PRG-industrial			**10**	**260**	**450**	**1,900**	**450**	**41,000**	**10**	**19,000**	**5,100**	**20,000**	**750**	**7,200**	**100,000**
A	02TP3A	0	0	3.6	11	<2	20	69	1,860	17	277	31	4.2	40	80	391
A	98JHNPA* (Q)	0	0	3.3	4	0.2	5	100	1,800	16	170	27	<2	87	90	170
A	TB3-S1	1	0.3	3.9	<10	<2	15	88	1,300	15.7	80	72	3.6	46	65	187
A	TB3-S2	3	0.9	3.2	10	<2	20	80	763	19.5	87	62	4.8	34	74	224
A	TB3-SQ2 (Q)	3	0.9	3.3	11	2.4	18	80	615	17.7	83	58	4.9	37	74	202
A	TB3-S3	5	1.5	3.2	<10	2	25	60	779	16.9	89	33	5.8	26	70	300
A	TB3-S5/S6	10	3.0	3.7	<10	2.5	22	79	1,960	19	193	31	4.4	50	96	186
A	TB3-S7	13	4.0	2.3	17	12	99	25	15,300	26.9	198	24	15	50	107	1,010
A	TB3-S8/S9	16	4.9	3.7	<10	3.3	20	56	1,170	20.4	370	12	21	11	101	102
B	02TP3B	0	0	1.2	<10	<2	158	<1	2,380	36.6	50	34	41	29	34	1,170
B	98JHNPB* (Q)	0	0	1.3	10	2	100	41	2,100	36	65	34	26	51	32	1,200
B	TB5-S2/S3	4	0	1.5	<10	13	113	3.7	818	40.5	52	48	34	<4	58	666
B	TB5-S4/S5	7.5	2.3	2.3	20	8.3	85	31	1,480	31.8	173	50	25	45	72	691
B	TB5-S5	9.3	2.8	3.5	<10	<2	7.3	26	313	8.7	286	10	3	33	25	60
B	*TB5-S5/S6*	*9.9*	*3.0*	*5.8*	*<10*	*<2*	*12*	*124*	*416*	*7.2*	*558*	*4.7*	*19*	*18*	*54*	*103*
C	02TP3C	0	0	3.6	24	<2	53	54	1,110	22	207	80	13	59	89	384
C	98JHNPC* (Q)	0	0	3.7	25	0.8	30	81	1,100	24	220	100	8	120	84	350
C	TB4-S1	1	0.3	3.9	29	2.4	39	74	2,050	19.1	162	100	9.4	99	92	381
C	TB4-S1-R (Q)	1	0.3	4	17	<2	47	65	1,060	20.2	200	88	12	90	91	395
C	TB4-S2	3	0.9	3.6	29	<2	38	66	5,440	17.8	162	73	9.2	93	84	320
C	TB4-S3	4.5	1.4	3.4	36	11	257	64	70,000	14.3	132	84	40	101	74	1,370
D	98JHNPD*	0	0	3.6	8	0.3	9.2	65	3,200	17	230	47	<2	61	78	200
D	TB1-S1/S2	2	0.6	4.2	<10	3.8	25	89	3,160	19.3	158	30	5	38	116	203
D	TB1-S3	5	1.5	4	11	<2	15	89	1,050	16.8	106	26	3.6	46	82	148
D	TB1-SQ3 (Q)	5	1.5	4.1	10	2.4	16	96	1,150	17.5	137	33	4.1	45	96	184
D	TB1-S4/S5/S6	9	2.7	3.5	10	3.6	16	112	2,410	18.1	92	32	3.7	34	103	180
D	TB1-S7	13	4.0	4.3	<10	3.1	21	154	8,640	14.7	164	12	4	35	106	352
D	TB1-S8	15	4.6	5.9	<10	4.7	28	121	2,390	11	136	26	5.3	60	106	524
D	TB1-S9A	17	5.2	4	<10	2.5	18	77	1,020	11.2	74	7.5	4.7	42	77	280
D	TB1-S9B	17	5.2	1.7	13	7.5	44	24	2,150	31.9	71	35	11	54	72	456
D	*TB1-S10/S11/S12*	*21*	*6.4*	*2.8*	*14*	*4.1*	*33*	*39*	*3,120*	*20.4*	*223*	*33*	*6.9*	*74*	*58*	*371*
D	*TB1-S13*	*25*	*7.6*	*5.8*	*<10*	*<2*	*15*	*124*	*777*	*6*	*523*	*3.1*	*35*	*23*	*99*	*897*
E	98JHNPE*	0	0	3	20	1.1	41	68	850	23	170	67	9.2	84	70	440
E	TB20-S1 (HA)	1	0.3	3	24	4.3	76	35	844	27.6	130	86	16	48	72	905
E	TB20-S2 (HA)	3	0.9	3.6	15	3.5	57	67	1,490	21.1	141	95	14	53	72	450
E	TB20-S3 (HA)	4.9.	1.5	4	37	3	61	55	1,540	20	166	90	15	51	63	493
F	98JHNPF*	0	0	2.9	16	1.3	22	62	6,600	21	83	56	3	76	83	420
F	TB7-S1	1	0.3	3.8	17	3.2	32	56	3,740	22.1	86	68	6.7	43	89	305

Pile	Sample[1]	Depth		Al	As	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	V	Zn
		(ft)	(m)													
F	TB7-S2	3	0.9	3.3	16	<2	15	26	1,820	15.8	218	14	9.9	15	85	77
F	TB7-S3	5	1.5	3.7	<10	<2	11	40	629	11.8	214	4.5	12	6.7	91	31
F	TB7-S3-R (R)	5	1.5	3.6	<10	<2	10	39	583	11.8	228	3.1	12	10	90	31
F	TB7-S4	7	2.1	3.4	<10	<2	13	38	500	12	265	2	14	9.1	88	29
F	TB7-S5	8.8	2.7	3.4	<10	<2	14	40	430	10.9	305	<2	14	4.7	73	34
F	TB7-S6	11.5	3.5	3.2	<10	<2	26	27	484	13.2	259	<2	15	4.3	68	94
F	TB7-S7	13.3	4.0	3.4	<10	2	25	38	455	10.4	331	<2	16	6.2	68	90
F	TB7-S8	14.8	4.5	3.6	<10	<2	28	50	676	10.2	318	<2	16	6.5	72	120
F	TB7-S9	23	7.1	6.2	<10	<2	14	88	31	3.3	1,080	2.5	37	14	90	63
F	TB21-S1	1	0.3	3.2	13	4.5	30	44	5,980	23.6	100	62	7.2	42	100	215
F	TB21-S2	3	0.9	3.8	<10	<2	26	46	605	11.5	289	2.7	18	12	74	88
F	TB21-S3	5	1.5	4.2	<10	<2	20	66	1,120	12.4	314	7.8	20	14	94	85
F	*TB21-S4*	*6*	*1.8*	*6.3*	*<10*	*<2*	*17*	*117*	*396*	*7.7*	*425*	*2.3*	*36*	*14*	*114*	*86*
F	*TB21-S5*	*9.4*	*2.9*	*7.4*	*<10*	*<2*	*17*	*112*	*422*	*5.3*	*594*	*2.2*	*43*	*16*	*142*	*120*
G	02TP3G	0	0	4.2	<10	<2	29	61	4,570	15	272	45	11	28	97	224
G	02TP3G-R (Q)	0	0	4	<10	<2	26	62	4,110	13.7	269	35	11	27	96	185
H	02TP3H	0	0	3.3	<10	<2	29	35	1,810	22.7	229	32	9.8	26	94	205
H	02TP3H-R (Q)	0	0	3.2	14	<2	30	37	1,820	22.4	229	30	11	30	90	203
H	TB6-S1 (HA)	1	0.3	2.8	19	3.5	21	26	1,420	24.3	209	41	7.4	31	98	214
H	TB6-S2 (HA)	3	0.9	2.9	62	2.8	22	45	6,780	21.1	98	75	6	72	92	165
H	TB6-S2	3	0.9	2.5	21	26	123	12	2,560	27.4	152	34	24	96	82	2,650
H	TB6-S3 (HA)	4.4	1.3	2.5	31	3.6	68	17	3,540	26.3	134	37	15	179	82	202
H	TB6-S3	5	1.5	3.7	<10	11	44	56	1,490	22	432	18	18	22	107	1,220
H	TB6-S4/S5/S6	9	2.7	3.9	14	3	24	48	937	18	939	13	16	17	96	267
H	TB6-S7	14	4.3	6.5	<10	3	28	110	3,050	6	590	6.3	38	49	104	629
H	*TB6-S13/S14*	*26.6*	*8.1*	*6.6*	*12*	*<2*	*70*	*95*	*51*	*5.9*	*1,200*	*2.1*	*55*	*14*	*102*	*336*
TILL	*01 JH 26*	*0*	*0*	*6.5*	*<20*	*<4*	*20*	*92*	*41*	*3.6*	*1,000*	*<4*	*44*	*10*	*99*	*81*
TP4	02TP4	0	0	6.2	<10	<2	28	155	1,340	11.8	510	7.6	27	32	118	155

[1] (Q), duplicate sample for same area or boring interval; (R) replicate analysis of the same sample; *, ICP-MS data for 1998 samples (Hammarstrom and others, 1999); all other samples analyzed by ICP-AES

[2] Guidelines from USEPA Region 9 for Superfund/RCRA programs. Preliminary remediation goals (PRGs) are risk-based concentrations considered to be protective for humans. They are used for site screening, and are not cleanup standards. See http://www.epa.gov/region09/waste/sfund/prg/

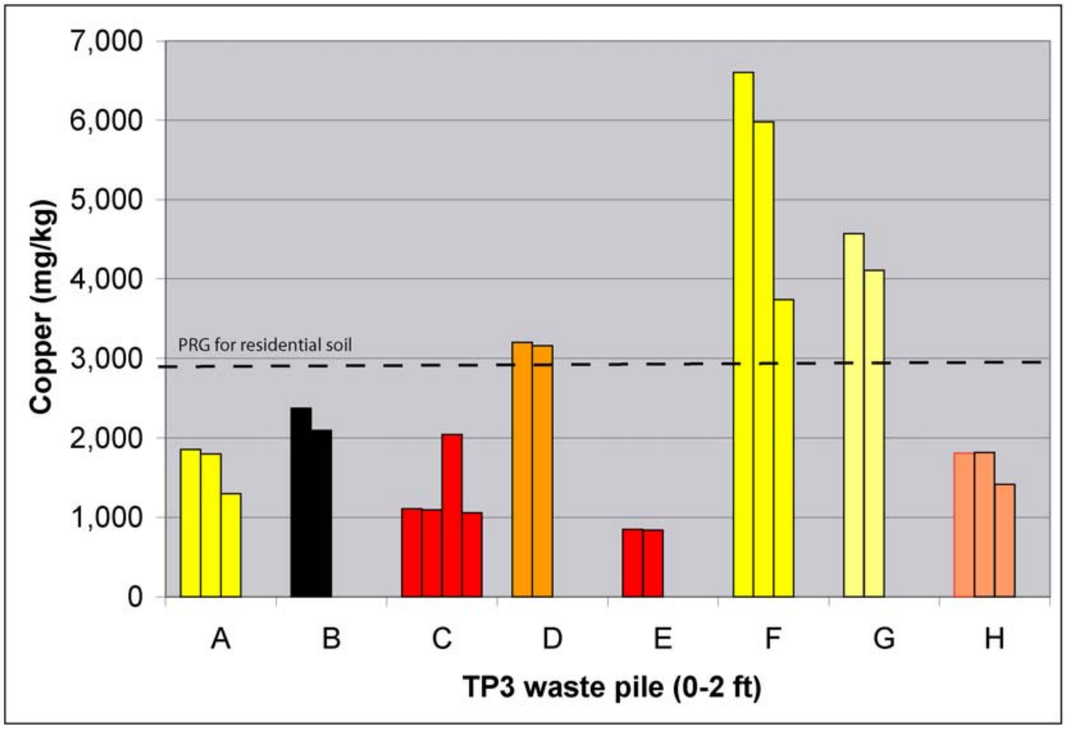

Figure 4. Copper concentration in surface mine waste plotted by pile. Bars are color-coded by dominant surface color as shown in Fig. 3.

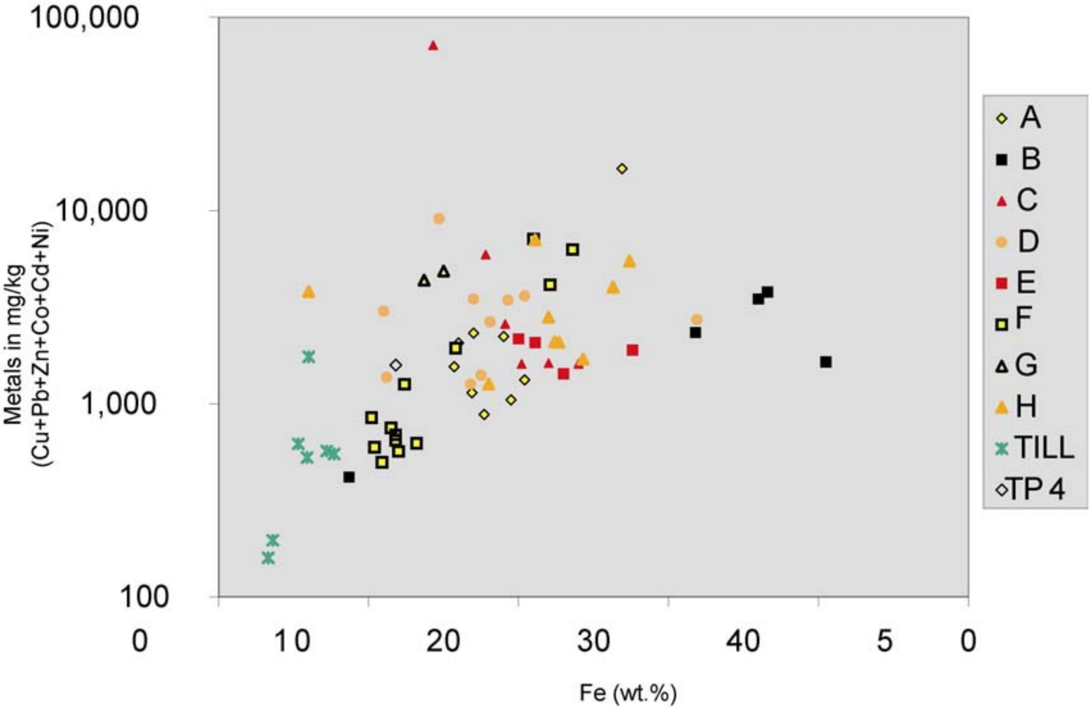

Figure 5. Total base-metal concentrations vs. iron content in TP3 mine waste.

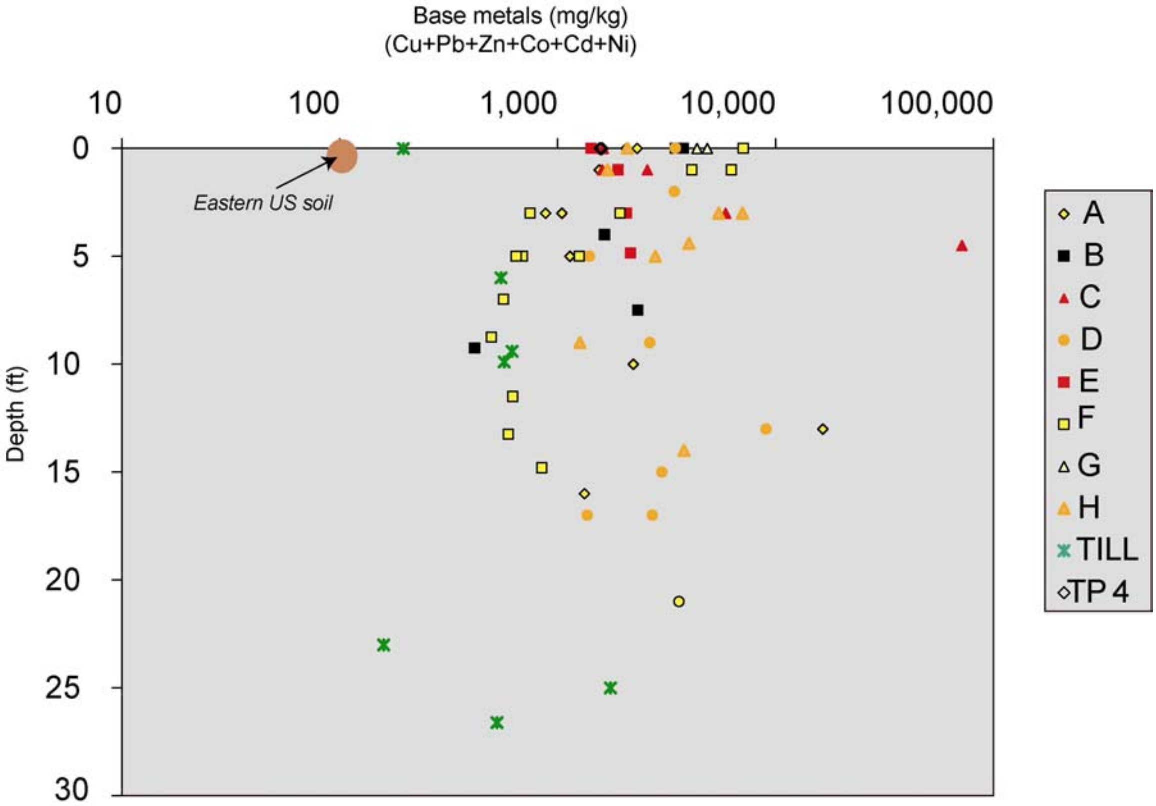

Figure 6. Variations of base metal concentrations in TP3 mine waste with depth. Surface samples plot at depth 0. Eastern US soil point is based on mean metal concentrations in soils reported by Shacklette and Boerngen (1984).

Mineralogy

TP3 mine wastes are composed of fragments of rocks and soil derived from physical and chemical weathering of ore and host rocks. Minerals present in TP3 mine waste include a variety of silicates, sulfides, sulfates, and oxides (Table 5). The distinct color differences of different piles reflect the dominant colored mineral present. Red and black piles are hematite-rich, yellow piles are jarosite-rich, and orange piles represent mixtures of different colored minerals. Hematite is present in areas dominated by waste materials produced by the copperas works. Roasting of the pyrrhotite-rich ores drove off much of the sulfur and left a residue of ferric oxide (hematite). Although hematite forms naturally in many environments, hematite is not present as a significant mineral in Elizabeth mine ore and host rocks.

Mineralogy of surface materials is presented as a series of pie diagrams that illustrate the dominant minerals in each pile (Figure 7). Minerals are grouped to illustrate their acid-generating, acid-neutralizing, or inert behavior with respect to their relative contribution to water quality. Variations in potential acid-generating minerals with depth are shown in Figure 8. Data plotted in Figures 7 and 8 are based on quantitative estimates of the mineralogical composition of TP3 mine waste from powder XRD diffraction data (Appendix C). These data are intended to show trends in mineralogy within and among piles, rather than absolute abundances of any given mineral. Calcite, the most effective short-term acid-neutralizing mineral, is present in some of the lithologies that make up the Elizabeth mine sequence (Slack and others, 2001). However, most of the calcite that was initially present in mine waste has been consumed in acid-neutralizing reactions that resulted in gypsum formation. Calcite is present in the glacial till in some of the soil borings at depth, where mine waste and till are mixed. Calcite is not detected in any of the surface samples. Some of the silicate minerals present in the mine waste are capable

Table 5. Mine waste minerals.

Mineral	Ideal Formula	Acid-producing NP=0	Inert NP$\leq$1	Acid-neutralizing NP>1
<u>Sulfide minerals</u>				
Pyrrhotite	$Fe_{1-x}S$	X		
Pyrite	FeS_2	X		
Chalcopyrite	$CuFeS_2$	X		
Sphalerite	ZnS		X	
<u>Efflorescent sulfate salts</u>				
Melanterite	$FeSO_4 \bullet 7H_2O$	X		
Rozenite	$FeSO_4 \bullet 4H_2O$	X		
Copiapite	$Fe^{2+}Fe_4^{3+}(SO_4)_6(OH)_2 \bullet 20H_2O$	X		
Alunogen	$Al_2(SO_4)_3 \bullet 17H_2O$		X	
<u>Other sulfate minerals</u>				
Jarosite	$K_2Fe_6^{3+}(SO_4)_4(OH)_{12}$	X		
Gypsum	$CaSO_4 \bullet 2H_2O$		X	
<u>Silicate minerals</u>				
Quartz	SiO_2		X	
Plagioclase	$NaAlSi_3O_8 - CaAl_2Si_2O_8$			
Muscovite	$KAl_2AlSi_3O_{10}(OH)_2$		X	
Biotite	$K(Fe_{2.1}Mg_{1.9})_3AlSi_3O_{10}(OH)_2$			X
Vermiculite	$(Mg,Fe^{2+},Al)_3(Si,Al)_4O_{10}(OH)_2 \bullet 4H_2O$			X
Chlorite	$(Mg,Fe^{2+})_5Al(Si_3Al)O_{10}(OH)_8$			X
Tremolite	$Ca_2Mg_5Si_8O_{22}(OH)_2$			X
Talc	$Mg_3Si_4O_{10}(OH)_2$			X
<u>Other minerals</u>				
Hematite	Fe_2O_3		X	
Calcite	$CaCO_3$			X

of contributing to long-term neutralization potential. Typical NP values for biotite range from 2.7 to 8.8 (Jambor, 2003). In contrast, muscovite contributes little or no NP (0.3 kg per metric ton $CaCO_3$ equivalent). Muscovite grains in mine waste are physically and chemically intact whereas biotite is highly altered to a mineral similar to vermiculite. The amount and nature of the acid-producing minerals exceeds the capacity of minerals that have some inherent NP to neutralize the mine waste.

The pie charts readily explain the different surface colors of the different piles (Fig. 7). Red and black piles B, C, and E are largely composed of the reddish-black mineral hematite whereas the yellowest pile (A) is largely composed of the straw-yellow mineral jarosite. No hematite is observed at the surface in piles A and D, and only minor amounts are present in piles F, G, and H; this is consistent with the historical evidence for concentration of the roast beds in the central part of TP3 (Kierstead, 2001). Small amounts of acid-generating sulfides, jarosite, and salts are present in all of the piles. These minerals contribute to the low paste pH values measured for all the surface materials. The relative percentage of acid-generating minerals is highly variable with depth within the piles (Fig. 8). Red piles C and E have less than 15% acid-generating minerals at the surface and at depth; hematite and quartz are the dominant minerals throughout the entire pile. However, the hematite content of black pile B (Fig. 3) decreases from over 70% at the surface to <5% at a depth of 9.5 ft (2.9 m) with a concomitant increase in jarosite content. Plots of the relative proportions of each mineral group as a function of depth in the pile are included in Appendix C.

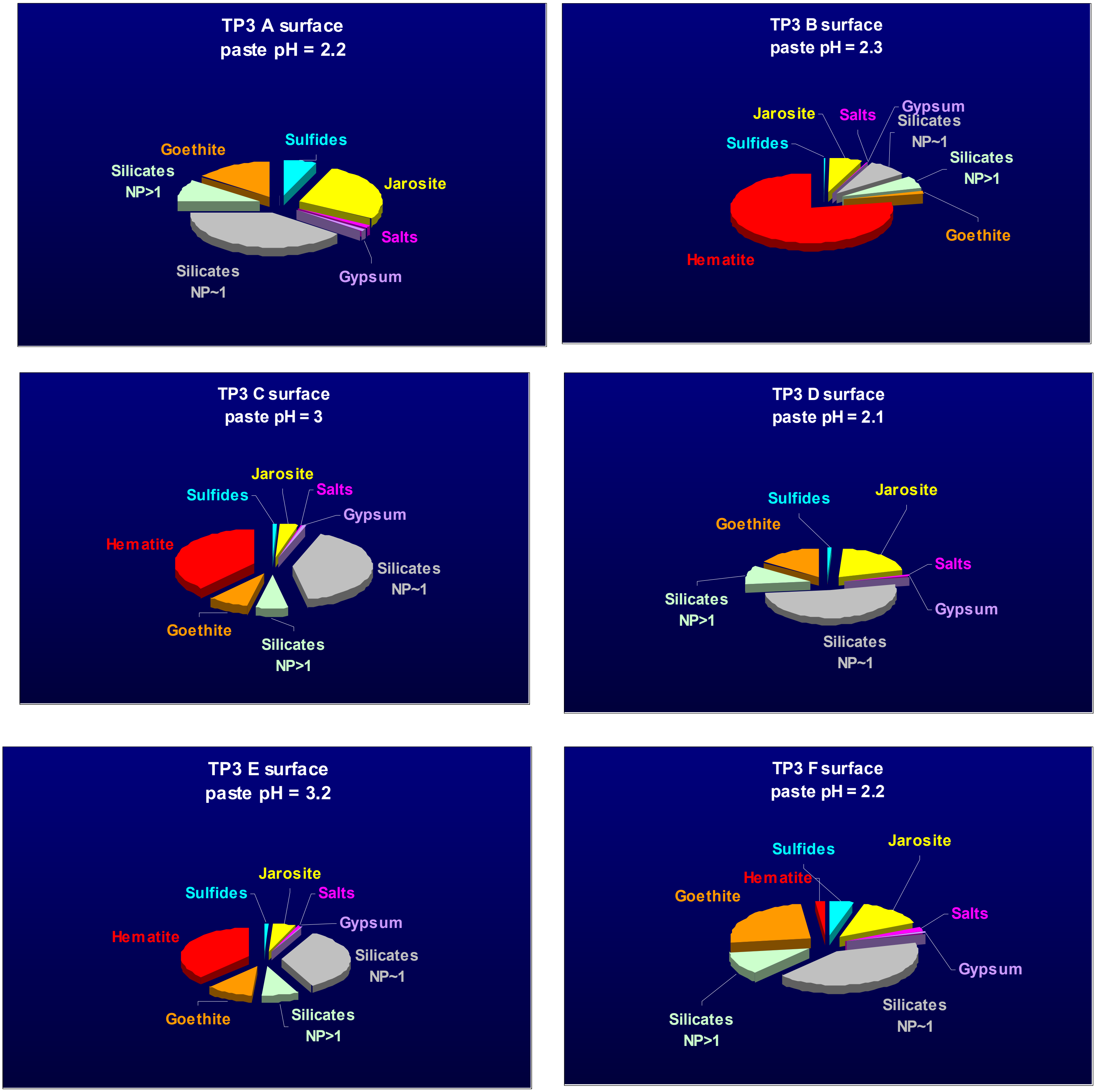

Figure 7. Mineralogy of TP3 surface material.

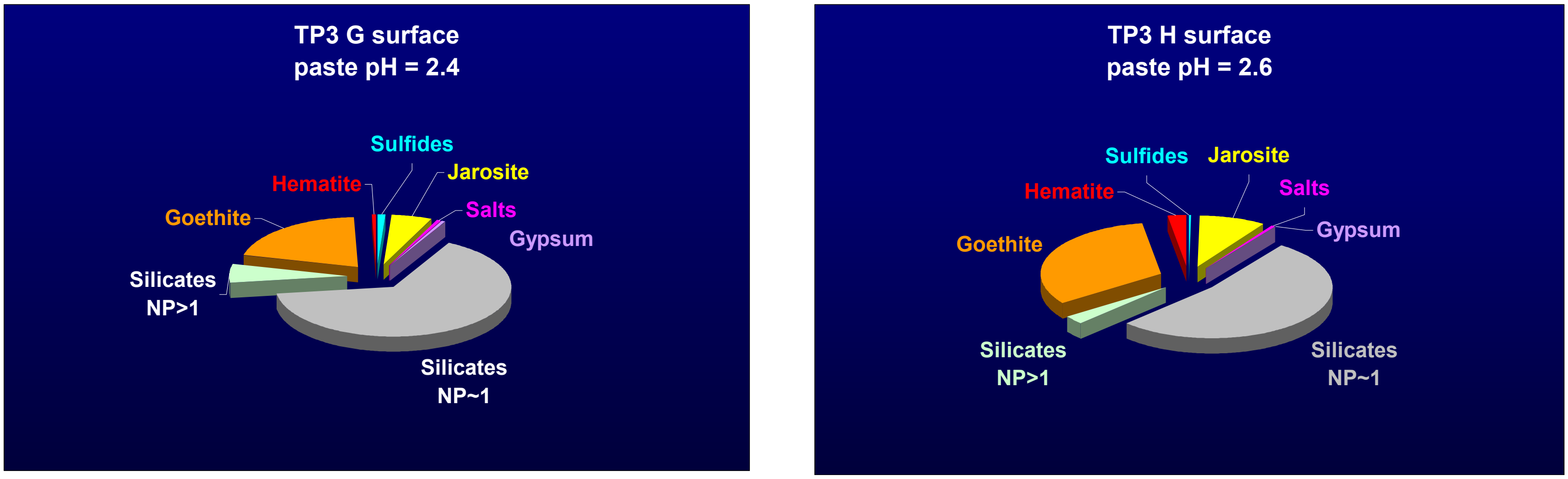

Figure 7. – Continued. Mineralogy of TP3 surface material. Silicate minerals with neutralizing potentials (NP) greater than one include biotite, chlorite, tremolite, clay, talc, and calcic plagioclase. Silicate minerals that have little or no acid-neutralizing potential (NP~1) include sodic plagioclase, muscovite, and quartz.

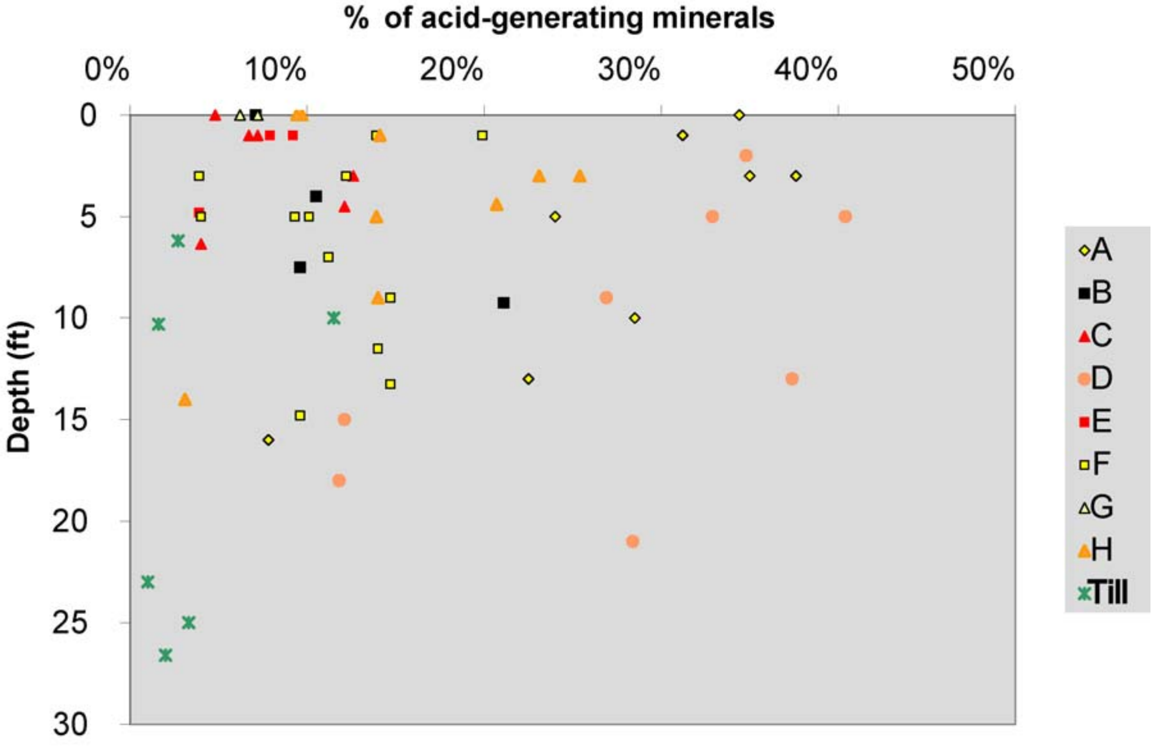

Figure 8. Variation of estimated percentages of potential acid-generating minerals (sulfides, jarosite, efflorescent salts) with depth in surface and soil boring samples from TP3.

Mineral textures and compositions

Efflorescent sulfate salts have been observed during site visits made over the course of several years. Although the salts are a minor component of the overall mine waste of TP3 (Fig. 7), salts are locally abundant on the surface of TP3 in the area of piles F, G, and H (Fig. 9A). XRD and previous mineralogical studies of the TP3 salts (Hammarstrom and others, 1999; 2001) show that the blue salts are copper-bearing melanterite, which dehydrates to white rozenite; alunogen and gypsum are also white and the yellow salts are copiapite (Table 5). The colored sulfate salts readily dissolve during rainstorms and add iron, aluminum, copper, and sulfate to surface runoff. Although this process has been ongoing for at least fifty years, there is a sufficient supply of iron and metal in the near-surface material for the process of salt formation to continue.

Photomicrographs and SEM images of polished grain mounts of soil boring samples from piles B, C, and H illustrate the size and shape of the mine waste materials at depth (Fig. 9 B, C, D). Biotite alteration is identified by XRD, SEM, and electron microprobe analysis. In XRD patterns, the presence of altered biotite is determined by a shift of the strong intensity 9.9 Å peak towards a spacing of 12 Å; in many cases, the XRD pattern best matches a pattern for the clay mineral sepiolite, $(Mg, Fe^{2+})_4Si_6O_{15}(OH)_2 \bullet 6H_2O$, which has its strongest intensity XRD peak at 11.9 Å. Sepiolite however, is a marine clay mineral unlikely to be found in mine waste. SEM and microprobe probe data show that altered biotite has highly variable but depleted potassium content, is hydrated, and relatively iron- rich with Fe/(Fe+Mg) = 0.7 to 0.9. The biotite is weathering towards hydrobiotite (strong XRD peak at 12.30 Å), a mixture of biotite and K-free vermiculite, which demonstrates that biotite reacts in the acidic environment present in the TP3 mine wastes. Biotite breakdown under acidic conditions provides a ready source of potassium for jarosite. SEM data confirm the XRD identification of minor amounts of chalcopyrite, sphalerite, and galena in addition to pyrite and altered pyrrhotite in the mine wastes. Thus, sources of metals and acid remain within the piles despite the weathered character of the material. Unless the material is removed, or isolated from further contact with air and water, oxidative weathering will continue to form the jarosite and efflorescent sulfate salts that generate acidic conditions within the piles.

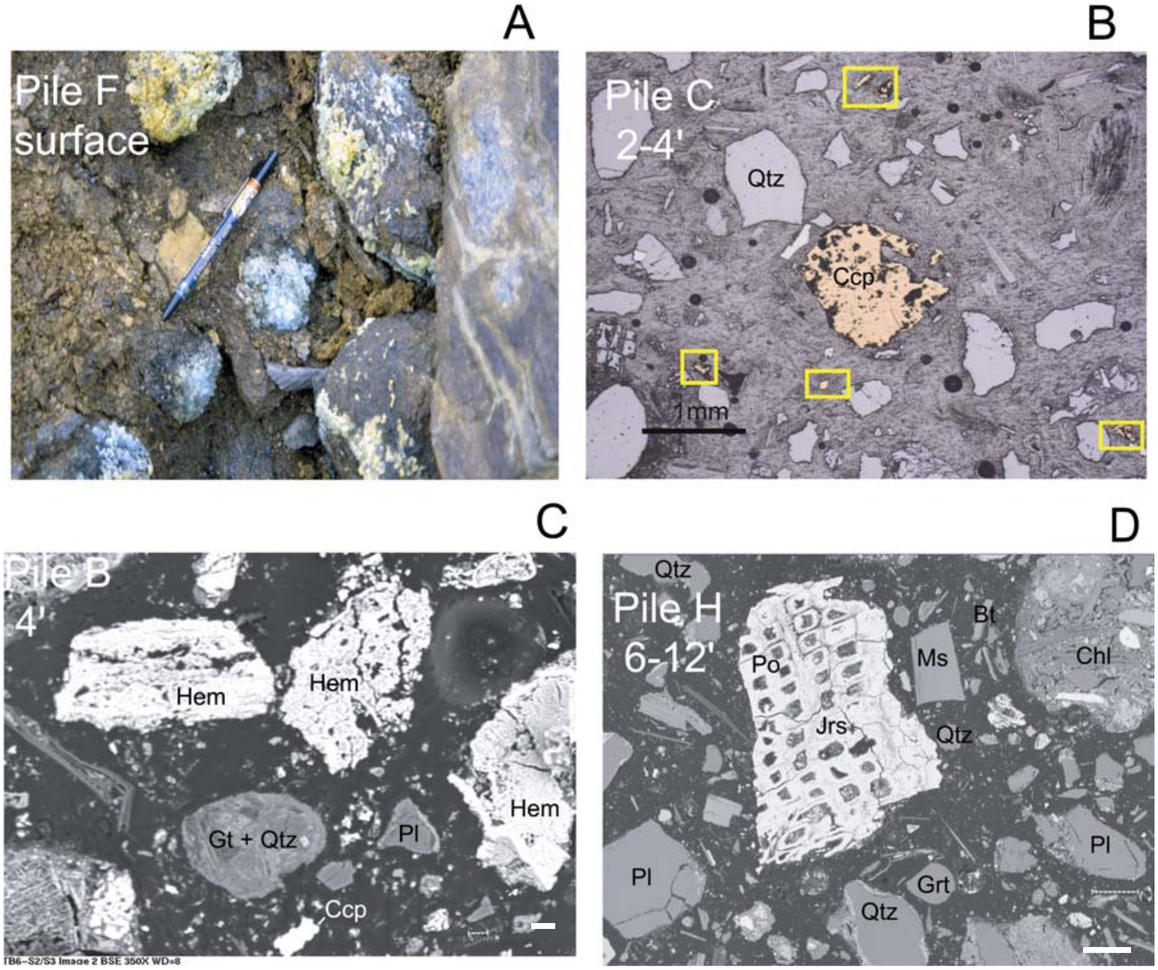

Figure 9. TP3 mineralogy. A, Photograph of efflorescent salts on oxidized ore cobbles on pile F. B, Photomicrograph of soil boring material from sample TB4-S2 (2- 4 ft depth) from pile C, the red area south and east of Copperas Road. The large grain in the center and the smaller grains outlined in yellow are all chalcopyrite (Ccp). C, Backscattered-electron SEM image of soil boring material from sample TB5-S2/S3 (2-6 ft [0.6-1.8 m] depth) from pile B, the black sintered waste rock pile. Hematite (Hem) is the dominant mineral. Minor amounts of sulfur are detected in some hematite grains and in goethite (Gt), which occurs with quartz (Qtz); plagioclase (Pl) and chalcopyrite (CCp) are also present. Scale bar in lower right corner is 10 micrometers long. D, Backscattered-electron SEM image of soil boring material from sample TB6-S4/S5/S6 (6-12 ft [1.8 –3.6m] depth) from pile H, the red bench overlooking Copperas Road. Pyrrhotite (Po, bright white) is partly altered to jarosite (Jrs, gray) and elemental sulfur resulting in a “swiss-cheese” texture. Silicate mineral grains include muscovite (Ms), plagioclase (Pl), chlorite (Chl), Mn-rich garnet (Grt) and quartz (Qtz). Scale bar in lower right corner is 100 micrometers long.

Acid-base accounting

Paste pH and acid-base accounting results (Table 6) show that all of the TP3 mine wastes are classified as acid-generating material. The till samples at the bottom of some soil borings are the only samples that are non-acid-generating. Mine waste paste pH values are all less than 4; till is neutral to slightly alkaline (7.2 to 7.7). Samples of mixed till and mine waste near the interface between mine waste and till have NNP near 0 and paste pH near 4, reflecting the mixed nature of the samples. No measurements fell between 4 and 7. USGS and BCRI determinations of paste pH are in excellent agreement. The only samples that have any measurable fizz ratio and neutralization potential are till-rich samples. Maximum potential acidity values are highly variable due to the complex mixture of different sulfur-bearing minerals in the mine waste. In some samples, most of the sulfur is present as sulfide; in others, most of the sulfur has been oxidized to sulfate. The mineralogy of the samples (Appendix C) shows that in most cases, the dominant sulfate mineral is acid-producing jarosite rather than gypsum (inert). XRD and SEM data confirm that sulfide minerals are present; thus, the detection of sulfide sulfur in the highly oxidized mine waste is independently confirmed. Because of the lack of sufficient inherent neutralizing potential in the mine waste, all of the samples have negative net neutralization potentials as well as NP:AP ratios less than zero. Therefore, the mine wastes are classified as acid-generating by all of the accepted criteria (Figure 10).

Effects of varying the strength of HCl and boiling time used in the determination of sulfate sulfur are summarized in Table 7, along with replicate data for total sulfur determinations for four samples. In all cases, the more vigorous acid treatment dissolves more of the refractory sulfate sulfur and increases the NNP. Although NNP “improves”, NNP values are still negative and paste pH values do not change, so the data points still plot in the “acid-generating” field on Figure 10.

Jarosite comprises a significant part of most of the surface mine wastes (Fig. 7). Effloresecnt sulfate salts are observed on weathering ore cobbles and along gullies, especially in the area of piles F, G, and H as the piles dry out after rainstorms (Hammarstrom and others, 1999; 2001) and as a localized, shallow subsurface layer on TP3-F. The salts form a very small, but consistent mass fraction of the surface mine-waste soil (Fig. 7). Results of washing experiments to test the effects of these minor amounts of salts on pH (Fig. 11) show that upon exposure to deionized water (pH 5.5), dry splits of the surface material for piles A,B,C, and G cause the solution pH to drop to a value of 3.5 or less. The dashed line at pH=3.8 represents the equilibrium pH for stoichiometric dissolution of jarosite as described by the reaction(Langmuir, 1995):

$$KFe_3(SO_4)_2(OH)_6 + 3H_2O = K^+ + 3Fe(OH)_{3(ppt)} + 2SO_4^{2-} + 3H^+$$

After one wash, sample 02TP3C reached the jarosite equilibrium pH. XRD analysis did not detect any salts (Appendix C) and the small amount of salts that dissolved upon initial exposure to water were apparently removed by the single wash. XRD analysis also indicates that the other samples, which all had 0.4 to 1% salts, took repeated washings to remove the salts. By day 7 however, all of the samples approached the jarosite-water equilibrium pH. Gypsum and the iron sulfate mineral rhomboclase crystallized from evaporation of the initial wash solution from sample 02TP3A. Therefore, very minor amounts of sulfate salts (<1 % of the sample mass) are sufficient to significantly depress pH.

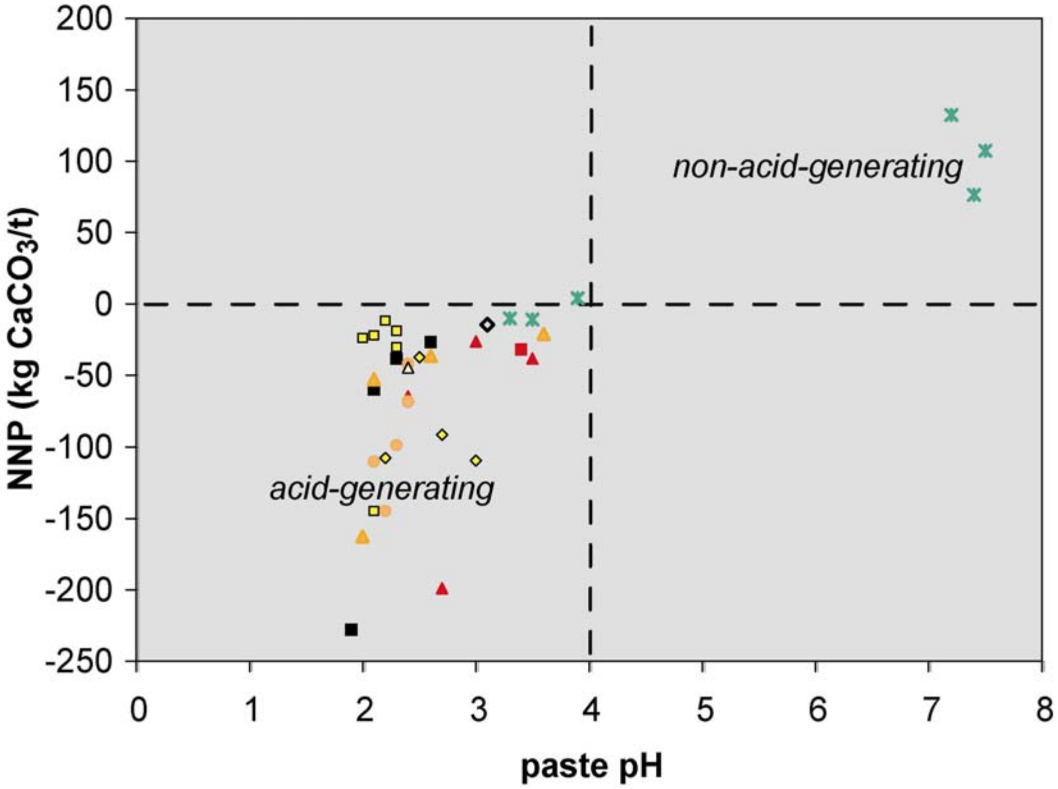

Figure 10. Classification of TP3 mine wastes in terms of net neutalization potential (NNP) and paste pH. Materials that have paste pH <4 and NNP<0 are considered likely to generate acid. Only till samples plot in the “non-acid-generating” field on this diagram.

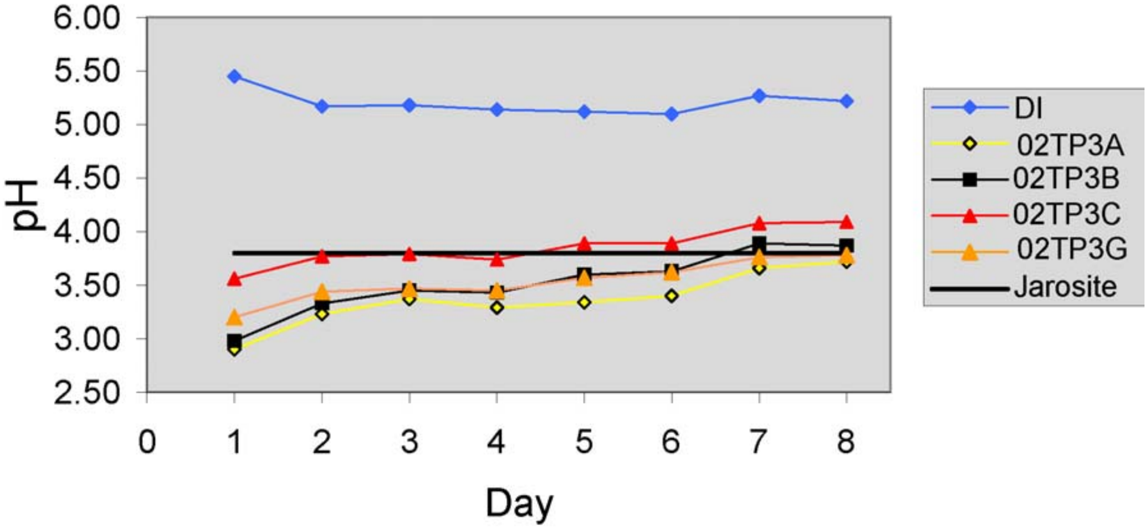

Figure 11. Effects of repeatedly washing TP3 surface mine waste with deionized water (DI) on leachate pH. Black line represents nominal pH (3.8) for jarosite equilibration. Lower pH values indicate dissolution of efflorescent sulfate salts.

Table 6. Paste pH and acid-base accounting results.
[Italics, till and mixed samples of till-mine-waste]

Sample	Paste pH	Paste pH	Total S	Sulfate S	Sulfide S	Maximum Potential Acidity[1] (AP)	Neutralization Potential (NP)	Net Neutralization Potential (NNP)	Fizz Rating	NP/AP
	(USGS)	(BCRI)	(Wt.%)	(Wt.%)	(Wt.%)	kg $CaCO_3$/t	kg $CaCO_3$/t	kg $CaCO_3$/t		
Pile A										
02TP3A	2.2	2.2	4.27	1.13	3.14	98	-10	-108	none	-0.1
TB3-S1	3.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB3-S2	2.8	3.0	4.46	1.29	3.17	99	-10	-109	none	-0.1
TB3-SQ2	2.6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB3-S3	2.6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB3-S5/S6	2.5	2.7	4.04	1.43	2.61	82	-10	-91	none	-0.1
TB3-S7	2.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB3-S8/S9	2.4	2.5	1.58	0.83	0.75	23	-14	-37	none	-0.6
Pile B										
02TB3B	2.2	2.3	1.92	0.93	0.99	31	-8	-38	none	-0.2
TB5-S2/S3	2.1	1.9	8.26	1.51	6.75	211	-17	-228	none	-0.1
TB5-S4/S5	2.2	2.1	2.87	1.31	1.56	49	-11	-60	none	-0.2
TB5-S5	2.5	2.6	2.82	2.1	0.72	23	-4	-27	none	-0.2
TB5-S5/S6	*2.6*	*3.3*	*1.4*	*1.16*	*0.24*	*8*	*-3*	*-10*	*none*	*-0.4*
Pile C										
02TP3C	2.8	3.0	1.21	0.49	0.72	23	-4	-26	none	-0.2
TB4-S1	3.0	3.5	1.92	0.85	1.07	33	-5	-38	none	-0.1
TB4-S1 Rep	3.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB4-S2	2.3	2.4	2.84	0.98	1.86	58	-7	-65	none	-0.1
TB4-S3	2.7	2.7	6.83	1.05	5.78	181	-18	-199	none	-0.1
Pile D										
TB1-S1/S2	2.6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB1-S3	2.4	2.4	5.13	3.15	1.98	62	-7	-68	none	-0.1
TB1-SQ3	2.5	2.3	4.78	1.92	2.86	89	-9	-99	none	-0.1
TB1-S4/S5/S6	2.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB1-S7	2.4	2.2	5.54	1.38	4.16	130	-15	-145	none	-0.1
TB1-S8	2.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB1-S9A	2.6	2.4	3.15	1.95	1.2	38	-5	-42	none	-0.1
TB1-S9B	2.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB1-S10/S11/S12	2.4	2.1	4.89	1.78	3.11	97	-13	-110	none	-0.1
TB1-S13	*3.2*	*3.5*	*0.46*	*0.23*	*0.23*	*7*	*-4*	*-11*	*none*	*-0.5*
Pile E										
98JHNPE	3.2	2.9	1.27	0.41	0.86	27	-3	-30	none	-0.1
TB20-S1 (HA)	3.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB20-S2 (HA)	3.1	3.4	1.76	0.83	0.93	29	-3	-32	none	-0.1
TB20-S3 (HA)	3.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Pile F										
98JHNPF	2.2	2.1	5.12	1.29	3.83	120	-25	-145	none	-0.2
TB7-S1	2.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Sample	Paste pH	Paste pH	Total S	Sulfate S	Sulfide S	Maximum Potential Acidity[1] (AP)	Neutralization Potential (NP)	Net Neutralization Potential (NNP)	Fizz Rating	NP/AP
TB7-S2	2.3	2.3	1.75	1.39	0.36	11	-8	-19	none	-0.7
TB7-S3	2.4	2.3	1.49	0.82	0.67	21	-10	-30	none	-0.5
TB7-S3	2.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB7-S4	2.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB7-S5	2.4	2.2	1.82	1.57	0.25	8	-4	-12	none	-0.5
TB7-S6	2.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB7-S7	2.4	2.1	2.27	1.94	0.33	10	-12	-22	none	-1.1
TB7-S8	2.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB7-S9	*7.7*	*7.5*	*<0.02*	*<0.02*	*<0.02*	*<0.6*	*107*	*107*	*moderate*	
TB21-S1	2.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB21-S2	2.2	2.0	1.12	0.98	0.14	4	-20	-24	none	-4.5
TB21-S3	2.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB21-S4	*2.4*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*
TB21-S5	*3.3*	*3.9*	*0.4*	*0.37*	*0.03*	*1*	*5*	*4*	*none*	*5.1*
Pile G										
02TP3G	2.5	2.4	1.84	0.6	1.24	39	-6	-45	none	-0.1
02TP3G-R	2.6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Pile H										
02TP3H	2.5	2.6	1.78	0.97	0.81	25	-11	-37	none	-0.4
02TP3H-R (SB6)	2.6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB6-S1 (HA)	2.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB6-S2 (HA)	2.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB6-S3 (HA)	2.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB6-S2	2.2	2.0	5.72	1.57	4.15	130	-33	-163	none	-0.3
TB6-S3	2.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TB6-S4/S5/S6	2.2	2.1	2.5	1.19	1.31	41	-12	-53	none	-0.3
TB6-S7	3.3	3.6	0.87	0.28	0.59	18	-3	-21	none	-0.2
TB6-S13/S14	*7.2*	*7.2*	*1.17*	*1.02*	*0.15*	*5*	*137*	*132*	*moderate*	*29.2*
Till										
01 JH 26	*n.d.*	*7.4*	*0.04*	*<0.02*	*0.04*	*1*	*78*	*76*	*moderate*	*62.0*
TP4										
02TP4	3.1	3.1	1.23	0.76	0.47	15	0	-15	none	0.0

[1] Maximum potential acidity based on sulfide sulfur.

Table 7. Comparison of acid-base accounting results using different methods.

Sample	Total S wt. %	Sulfate S wt. %		Sulfide S wt. %		Maximum Potential Acidity kg $CaCO_3$/t		Neutralization Potential (NP) kg $CaCO_3$/t	NNP kg $CaCO_3$/t	NNP kg $CaCO_3$/t	Fizz Rating
AP Method[1]:		1	2	1	2	1	2		1	2	
02TP3A	4.27	1.13	3.67	3.14	0.60	98.1	18.8	-9.5	-107.6	-28.3	none
02TB3B	1.92	0.93	1.49	0.99	0.43	30.9	13.4	-7.5	-38.4	-20.9	none
02TP3C	1.21	0.49	0.98	0.72	0.23	22.5	7.2	-3.8	-26.3	-11.0	none
98JHNPE	1.27	0.14	1.13	0.86	0.14	26.9	4.4	-2.7	-29.6	-7.1	none
98JHNPF	5.12, 4.97	1.29, 2.59	n.d.	3.83, 2.38	n.d.	119.7, 74	n.d.	-25.1, -28	-144.8, -102	n.d.	none
TB1-S3	5.13	3.15	n.d	1.98	n.d	62	n.d.	-6.5	-68	n.d	none
TB4-S1	1.92, 1.91	0.85	n.d	1.07	n.d	33	n.d	-5	-38	n.d	none
TB4-S3	6.83	1.05	n.d	5.78	n.d	181	n.d	-18.3, -18.8	-199	n.d	none
TB5-S2/S3	8.26	1.51	2.12	6.75	6.14	210.9	191.8	-17.0	-227.9	-208.8	none
TB6-S13/S14	1.17, 1.13	1.02	n.d	0.15	n.d.	4.7	n.d.	137.0	132.3	n.d.	moderate
TB7-S2	1.75	1.39	n.d	0.36	n.d	11.3	n.d	-7.8	-19.1	n.d	none
01 JH 26	0.04, 0.04	<0.02	n.d	0.04	n.d	1.3	n.d	77.5	76.3	n.d	moderate

[1] Method 1: 5 g samples, 20 mL 3N HCl, std.boil
Method 2: 5 g sample, conc. HCl, 30 min. boil

Leach study

The leach study approximates the chemical composition of runoff from the mine- waste piles. The synthetic precipitation solution simulates the composition of rain and snow in the eastern U.S. Dissolved copper concentrations leached from surface samples (composites and soil borings from the upper 2 ft (0.6 m) of the pile) indicate that surface runoff from all of the piles is likely to exceed acute aquatic toxicity standards for copper (Fig. 12). Dissolved metal concentrations (copper, zinc, cadmium) in all leachate solutions are plotted as a function of leachate pH along with the surface water composition for Copperas Brook headwaters below TP3 at Mine Road and the range of water compositions observed in the upper Copperas Brook watershed (Fig. 13). The complete leachate data set is tabulated in Appendix D. All of the leachates have pH <4.0, with the exception of two till-rich samples. Thus, interaction of the synthetic precipitation (pH 4.2) with mine waste lowers pH. Almost all of the leachates overlap the observed range of surface waters in the upper part of the Copperas Brook watershed, which indicates that the surface runoff from TP3 is dominated by waters that have reacted with readily soluble materials in the mine waste. All of the leachates, and all of the analyzed surface waters exceed the acute aquatic toxicity standard for copper; more than half of the leachates also exceed the drinking water standard for copper. Samples from the red, hematite-rich piles tend to have the least acidic leachate pH and the lowest copper concentrations; however, the most extreme copper concentration of any leachate is from one of the red piles. No pattern is observed in the data that would indicate that one pile is less likely to contribute acid and (or) copper to surface runoff than any other pile. Zinc and cadmium partly overlap the observed range of surface water compositions; some samples exceed water quality guidelines for these metals and some do not (Fig. 13). In the Elizabeth mine ores, zinc and cadmium tend to be associated in the mineral sphalerite, ZnS, where minor amounts of cadmium substitute for zinc. The presence of dissolved cadmium in TP3 surface runoff and leachates is noteworthy because cadmium is the

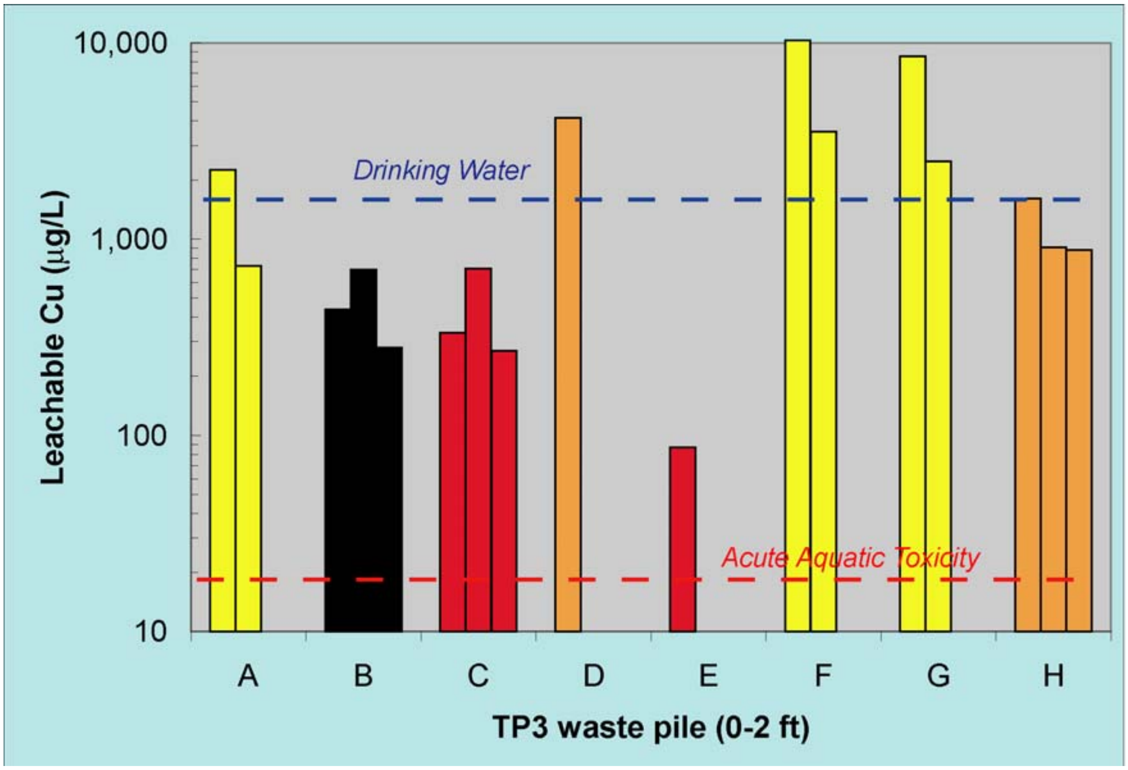

Figure 12. Leachable copper from surface samples of TP3 mine waste piles. Piles are coded by dominant surface color. Dashed lines show water quality standards for Vermont, assuming a hardness of 100 mg/L $CaCO_3$ for acute aquatic toxicity.

only element present at Elizabeth that is currently regulated in sludges produced by acid-neutralization in treatment systems. Any sludge produced in a water treatment system would be subjected to toxicity characteristics leaching procedures (TCLP) to determine if the sludge is classified as a hazardous or non-hazardous waste. The costs of sludge disposal increase significantly if sludge is classified as hazardous waste. Most samples from the red and the black piles (B, C, and E) contribute less zinc and cadmium to leachates than yellow and orange piles (A, D, F, G, H), but some of the samples from red and black piles produce leachates that exceed water quality standards for these elements. Based on leachate pH and metal concentration, the data indicate that all of the piles contribute to acid-mine drainage in Copperas Brook and no individual pile can be classified as non-acid-forming.

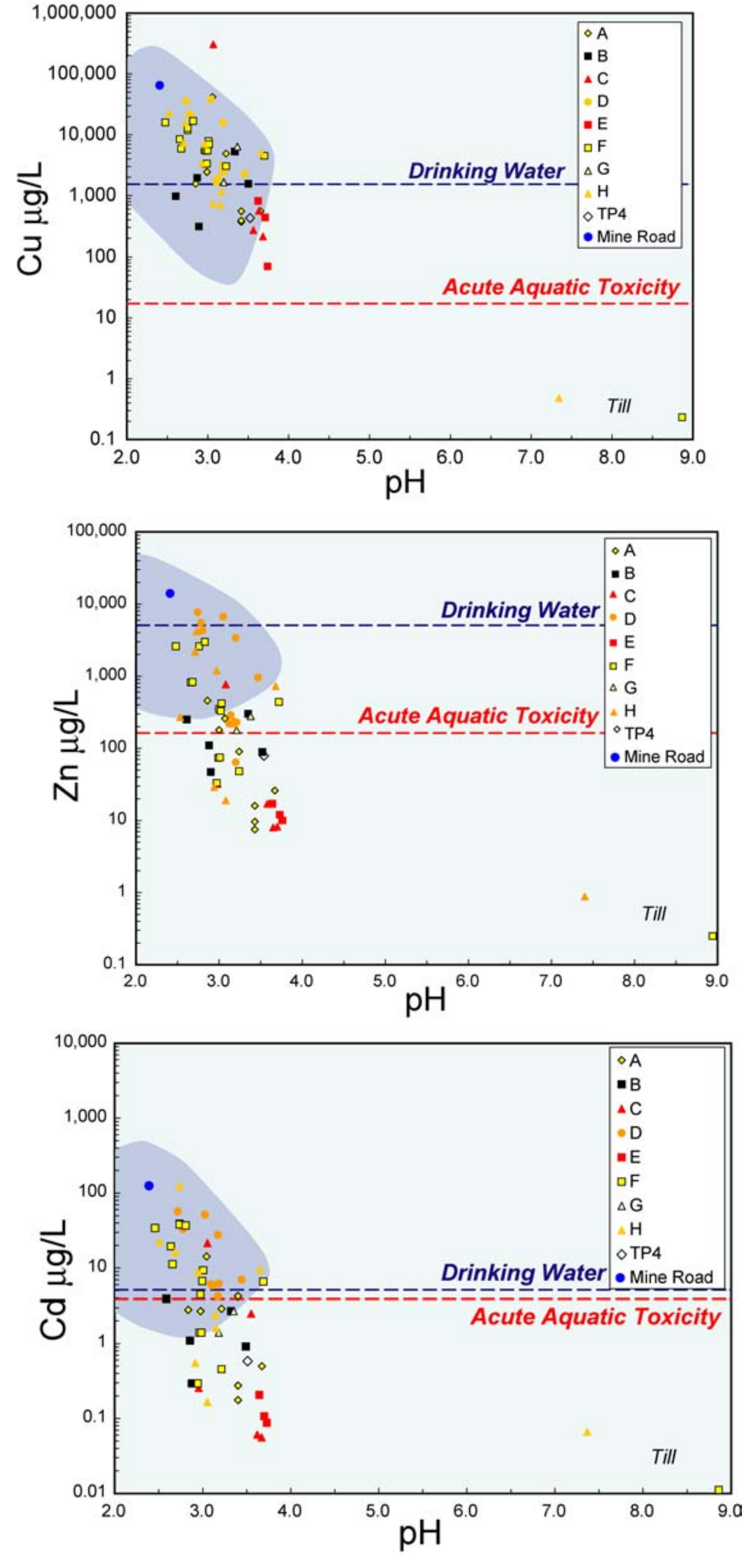

Figure 13. Dissolved metal concentrations in leachate as a function of pH. Shaded field represents the range of surface water compositions in the upper Copperas Brook watershed (Seal and others, 2001). Points that plot above the dashed lines exceed drinking water and acute aquatic toxicity water quality standards.

DISCUSSION

TP3 mine waste includes partially weathered pyrrhotite-rich ore, fragments to boulder-size pieces of rock, soil derived from weathering of ore and host rock, and weathered processed ore from the copperas works. Although the materials are highly oxidized, soil borings show that sand- to silt- particle sizes and moisture are present at depth in the piles (Appendix A). Therefore, air and infiltrating waters can penetrate the piles at depth.

Because of the interest in carefully documenting the environmental signature of the historically significant copperas roast piles below the road, replicate surface composites of piles A, B, and C collected in 2002 were analyzed for chemistry. The 2002 samples were subjected to more aggressive acid treatment for sulfide sulfur determination for ABA, as well as to detailed mineralogical study to evaluate the effects of the roasting on the environmental fingerprint of the resulting red and black, hematite-rich waste piles. Although the more aggressive acid treatment results in a more accurate net neutralization potential (NNP) because it liberates the sulfate sulfur in jarosite, the net result is still acid-generating. The "improvement" in NNP varies as a function of the jarosite content of the sample (Fig. 14). Very little change in NNP is observed for samples from piles B, C, and E. These samples contain less than 10 percent jarosite. For jarosite-rich pile A, a large change in NNP is observed. However, the NNP for all samples is still net negative, the paste pH is less than 4, and the leach study shows that these piles readily release copper when they interact with simulated precipitation. The roasting process liberated most, but not all, of the sulfide sulfur in the ore and left an iron-rich, oxidized residue. Individual fist-size pieces of red and black sintered ore (clinker) from the surface of pile B each contain 1 percent total sulfur, more than 2,000 mg/kg copper, and more than 1,000 mg/kg zinc (see Hammarstrom and others (2001), Table 4), in good agreement with the composite soil-size material collected over the surface of the pile. Mineralogy, additional geochemistry, and leachate data for the red and black sintered ore from the surface of pile B are comparable to the composite surface and soil boring samples in this report. Both sintered ore samples contain jarosite and readily leach copper (Piatak and others, 2003).

TP3 mine wastes can be divided into subareas on the basis of surface color. Different colors correlate with different mineralogy. The red and black piles (B, C, E) represent remnants of roasted ore from the copperas works; these piles mainly are composed of the iron-oxide mineral hematite. Other piles contain little to no hematite. In general, the surface materials of the red and black piles have lower sulfide mineral content, higher net neutralization potentials, and lower concentrations of readily leachable metals than the other piles. However, all of the criteria examined in this study (paste pH, metal content, mineralogy, total sulfur and sulfide sulfur content, acid-base accounting, and leaching behavior) indicate that these piles contribute enough acid-forming material to contribute to acid-mine drainage. NNP plots indicate that all of the TP3 piles have high acid-generating potential. The only non-acid forming materials encountered on TP3 are till-rich samples encountered in soil borings from the lower parts of the piles.

Variations with depth for all of the parameters measured for this study are illustrated in a series of depth profiles for soil borings. Till was encountered at the bottom of boring TB7, which penetrated yellow pile F (see Fig. 3 for location) in the waste massive sulfide area of TP3 (Fig. 15). Metal concentrations in the mine waste are highest near the surface and generally decrease (with some reversals) with depth. Cadmium is below the detection limit of 2 mg/kg (ppm), except in the near-surface sample. At a depth of about 5 ft (1.5 m), pyrrhotite content shows a sharp increase coincident with a decrease in sulfate salts. The mineralogical trends show that pile F is (1) heterogeneous at depth, (2) contains pyrrhotite that could oxidize if exposed to air and water, and (3) contains acid-generating soluble efflorescent salts and jarosite at depth. Jarosite and salts are not present in the bottommost sample that contains till. Although the bulk geochemistry shows that total metal concentrations tend to decrease with depth, the leachable metals tend to increase with depth. In terms of the variability of acid-generating potential with depth in the pile, no trends in NNP are apparent, paste pH is uniformly between 2 and 3, and except for the till which has neutralization potential, all of the samples plot in the "acid-producing" field in terms of guidelines for evaluation acid-base accounting data. TB5 penetrated the black pile (B on Fig. 3) in the center of the copperas works area. The core bottomed out in glacial till at 10.25 ft (3.1 m), and the bottommost interval sampled represents a mixture of till and mine waste.

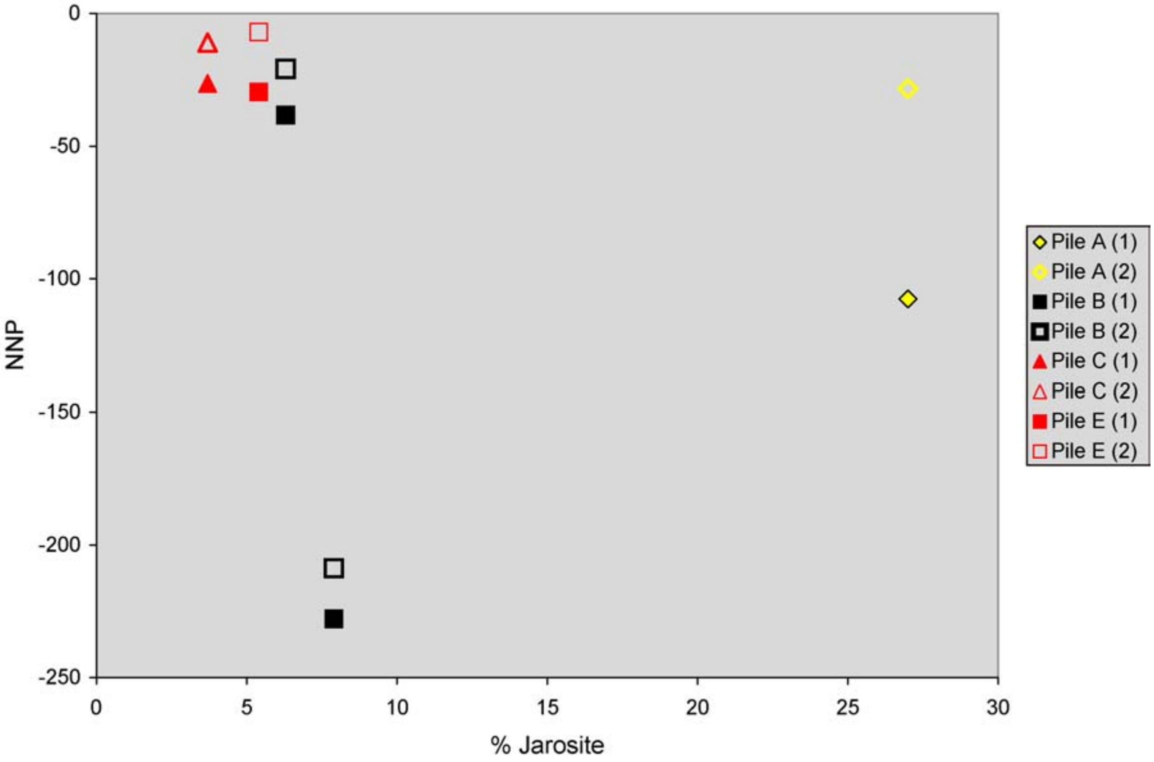

Figure 14. Change in net neutralization potential (NNP) as a function of jarosite content and ABA method. Open symbols, Method 1; solid symbols, Method 2. Method 2 is the more aggressive acid digest for sulfide sulfur determination (see Table 7). NNP values are all negative (acid-generating), regardless of method. Note the very low NNP values for sample TB5-S2/S2, which represents the 2 to 6 ft (0.6 to 1.8m) soil-boring sample from pile B. All other samples are surface composites.

In terms of bulk composition, the surface samples contain relatively more copper and zinc and less cadmium than samples at shallow (4 ft) depths (Fig. 16). Results for the 1998 and 2002 surface samples are nearly identical for chemistry. The 1998 surface composite had no detectable pyrrhotite (by XRD) and over 1% efflorescent sulfate salts. The 2002 surface composite for the same sample area had 0.2% pyrrhotite and 0.4 % salts. Such differences probably reflect the ephemeral nature of the salts at the surface. The 1998 sample was collected in August during a period of intermittent rain when salts were observed. The 2002 sample was collected on a dry day in November when salts were less prominent at the site. Leachate copper tends to increase with depth in the pile; zinc and cadmium are erratic. NNP values all plot below 0 and paste pH values are all below 4. Note differences in the NNP scales between Figures 15 and 16; TB5 NNP values predict a much worse case for acid-generation than is observed in TB7. The extreme (-228) NNP value for the 4 ft (1.2 m) depth sample from TB5 was also analyzed by the more aggressive ABA method (Table 7), which resulted in an NNP value of –209. In addition to sulfide and sulfate minerals, this sample also contains elemental sulfur, which probably contributes to the extreme NNP values.

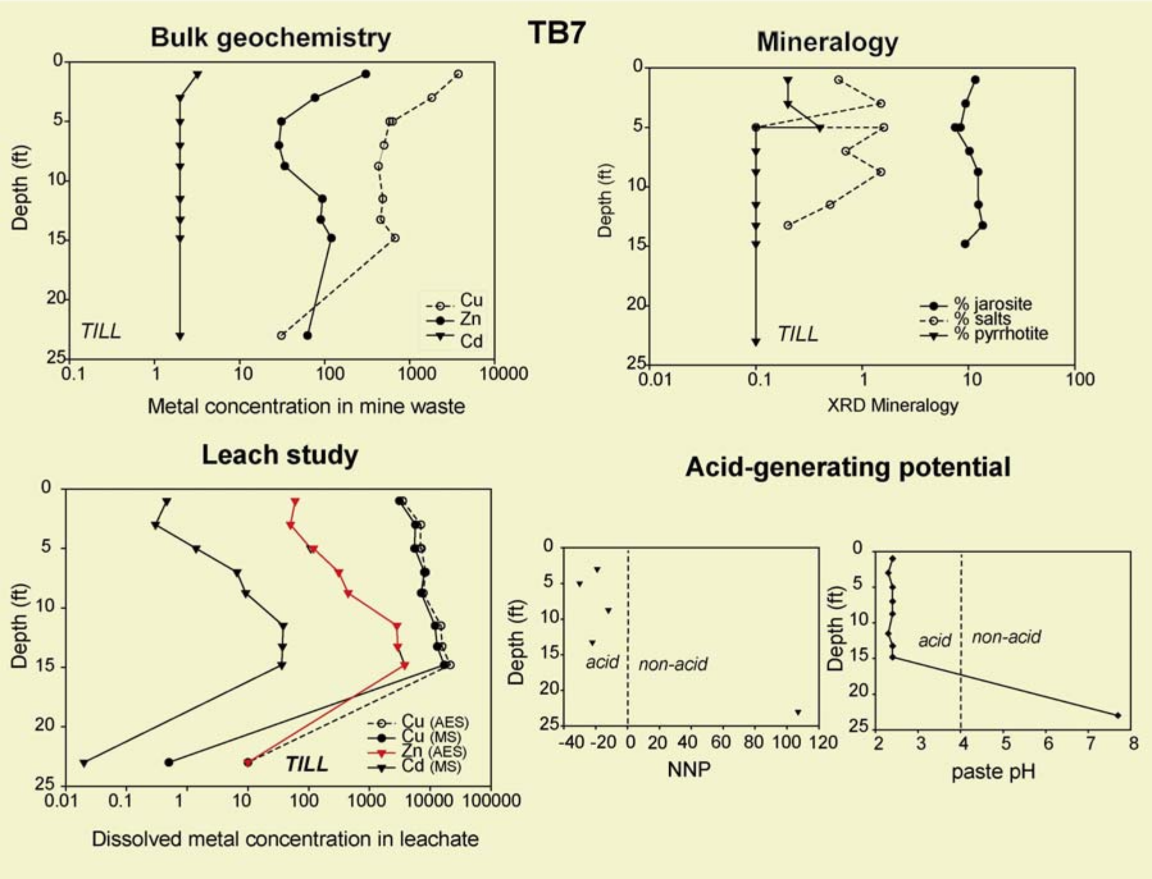

Figure 15. Profiles through yellow, jarosite-rich mine waste pile F based on all of the data for soil boring TB7. Note log scale for many of the plots. Net neutralization potential (NNP) for selected samples using ABA method 1. Units are mg/kg (ppm) for bulk geochemistry, weight percent for XRD mineralogy, and µg/L for leachates. Note the close agreement for leachate copper determined by two different methods (AES and MS). Depths are plotted at the midpoint of the interval sampled.

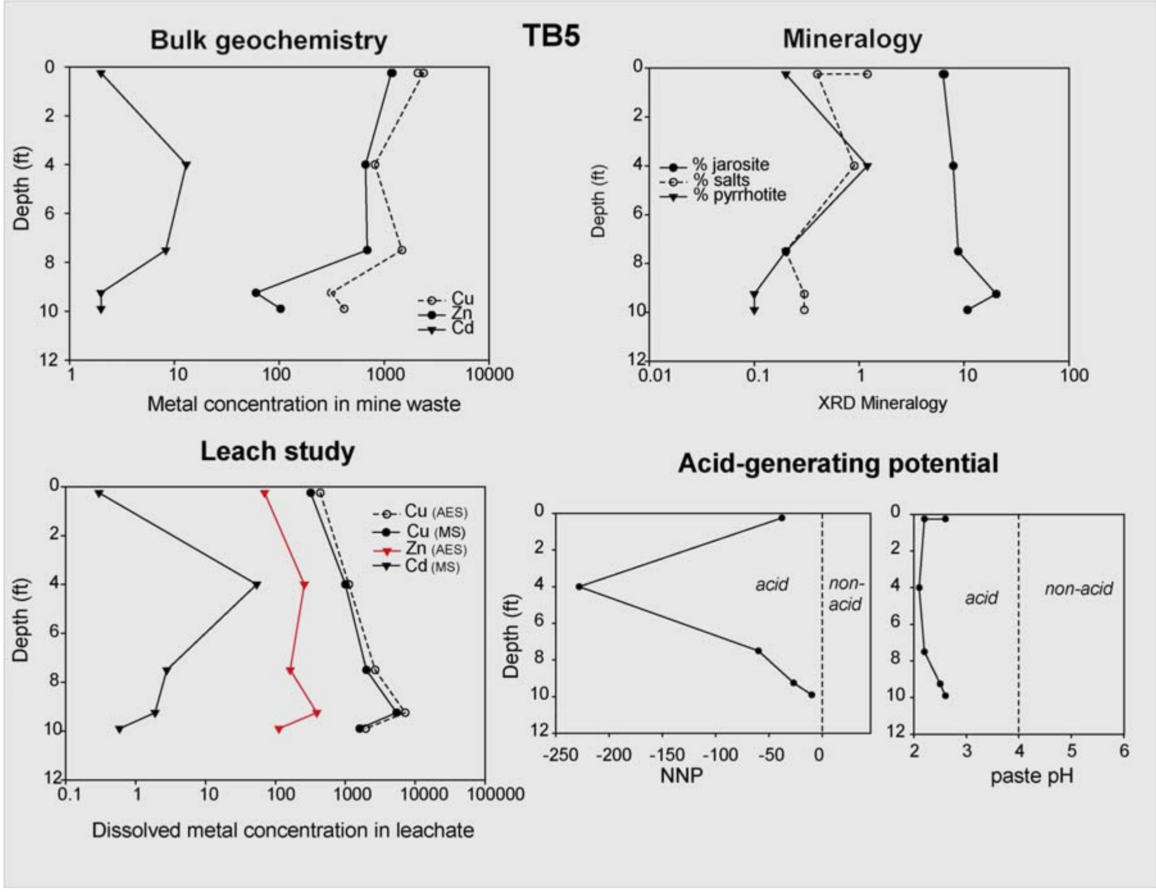

Figure 16. Profiles through black to red, hematite-rich clinker and waste from the copperas works in pile B, based on all of the data for soil boring TB5. Note log scale for many of the plots. NNP, net neutralization potential for selected samples using ABA method 1. Units are mg/kg (ppm) for bulk geochemistry, percent for XRD mineralogy, and µg/L for leachate. Note the close agreement for leachate copper determined by two different methods (AES and MS). Depths are plotted at the midpoint of the interval sampled.

CONCLUSIONS

In conclusion, the data support the following answers to the questions posed at the outset of this study:

(1) What are the sources of metals and acidity in waters draining TP3?

The sources of metals and acidity in waters draining TP3 are the mine wastes. Surface and ground water interact with remnants of the primary ores and secondary minerals that form by weathering of iron sulfides and other minerals in and on the mine wastes and pick up metals and acidity. Simulated precipitation leached metals from the TP3 mine wastes and produced solutions that mimic observed surface-water compositions in acidity and dissolved metal concentrations. The only non-acid-generating material encountered on TP3 is the glacial till that underlies the mine waste.

(2) Are there significant differences among the different colored piles?

There are differences among the different colored piles. Yellow piles (A, F, and G) in the massive sulfide waste area are jarosite-rich, have the lowest paste pH values at the surface (~2.2), and contain significant amounts of copper (>1,000 mg/kg). Red and black piles (B, C, and E) in the copperas works areas owe their color to the iron-oxide mineral hematite. Red areas generally contain lower concentrations of base metals at the surface of the piles and slightly higher paste pH (2.2 to 3). Waste rock area D and pile H are heterogeneous in color, acidic (paste pH ~2.6), contain little or no hematite, owe their color to a mixture of goethite and jarosite, and contain a lot of silicate minerals derive from weathering of host rock. The geochemical fingerprint of surface material from each pile is reproducible (Fig. 4).

(3) How variable is the environmental impact among the various piles of TP3?

All of the piles are classified as “acid-producing” by acid-base accounting and paste-pH criteria. This includes surface as well as subsurface samples. All of the piles contain some soluble, acid-forming minerals and some sulfide minerals that are likely to oxidize as weathering of the piles proceeds. Copper is readily leached from all of the piles in concentrations that exceed acute aquatic toxicity water-quality standards; some of the leachates exceed drinking water standards. The environmental impact of the different piles, as indicated by all of the studies undertaken, suggest a high potential for acid generation and metal release from all of the piles on TP3.

(4) How does the environmental impact vary with depth in the piles?

Soil boring samples show that the piles are heterogeneous in texture (silty to sandy with gravel, rock, and debris), color, mineralogy, and chemical composition. The only materials encountered in this study that can be classified as non-acid-forming are the till-rich materials that underlie the TP3 mine waste piles. The till is a natural material unrelated to mining. Till covers bedrock in most stream valleys in the region and is observed along Copperas Brook and in wooded areas adjacent to the mine site. Analysis of the soil boring samples shows that the waste piles all contain metals, readily leachable metals, acid-generating minerals, and are potentially acid-forming from top to bottom. Unless the piles are isolated from access of air and water by removal or capping to prevent continued erosion, all parts of the piles are likely to continue to have a negative environmental impact on Copperas Brook.

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APPENDIX A

Sample information
[Till samples in italics]

A-1: Surface samples

Pile	Field number	Date collected	Sampling Location	Description	Latitude °N	Longitude °W	Munsell color	Dry sample mass (kg)
A	02TP3A	10-Oct-02	Yellow pile east of Copperas Rd (TP3-A); top of pile is location for TB-3. Same area as sampled in 1998. See sample TP3-A, Table 6, p. 29 of OFR 99-564.	Yellow surface material; note orange-brown zones at depth and some sandy gray material. This may represent 1830s-era copper-mine waste dumped over copperas waste.	43.82139	72.33611	Yellow	3.07
A	98JHNPA	19-Aug-98	Yellow pile east of Copperas Rd (TP3-A)	North Pit area (tailings pile 3) Pile A . Pile A is the yellow, deeply eroded, unvegetated pile below the road. Soil composite of yellow-brown surface soil; 30 increments, -10 mesh	43.82186	72.33667	Yellow	>1
B	02TB3B	10-Oct-02	Black pile east of Copperas Rd (TP3-B); top of pile is location for TB-5. See sample TP3-B, Table 6, p. 29 of OFR 99-564.	Replicate for 1998 sample.	43.82111	72.33611	Dark Yellowish Brown	3.86
B	98JHNPB	19-Aug-98	Black pile east of Copperas Rd (TP3-B); top of pile is location for TB-5.	North Pit area (tailings pile 3) Pile B . Pile B is the black and red pile of sintered material below the road.	43.82086	72.33672	Dark reddish brown	>1
C	02TP3C	10-Oct-02	Red pile east of Copperas Rd (TP3-C); center of area is location for TB-4. See sample TP3-C, Table 6, p. 29 of OFR 99-564.	Replicate for 1998 sample.	43.82056	72.33639	Yellowish Red	3.07

Pile	Field number	Date collected	Sampling Location	Description	Latitude °N	Longitude °W	Munsell color	Dry sample mass (kg)
C	98JHNPC	19-Aug-98	North Pit area (tailings pile 3) Pile C. Pile C is the easternmost area north of the road.	Soil composite of red to black surface soil; 30 increments, -10 mesh. Surface runoff from this area directly affects surface water sample site LIZM13.	43.82019	72.33639	Reddish Brown	>1
D	98JHNPD	20-Aug-98	North Pit area (tailings pile 3) Pile D. Pile D is the southernmost area west of the road.	Mine waste, waste rock and ore; 30 increments, -10 mesh	43.82114	72.33772	Brownish Yellow	>1
E	98JHNPE	20-Aug-98	North Pit area (tailings pile 3) Pile E. Pile E is the red, central area above (west of) the road.	Mine waste, waste rock and ore; 30 increments, -10 mesh	43.82161	72.33783	Red	>1
F	98JHNPF	20-Aug-98	North Pit area (TP3) Pile F. Pile F is the northernmost area of TP3, N of the North Open Cut. 30 increments, -8 mesh	Most of the soil is yellowish brown in this area and the area is strewn with rocks and boulders. Rounded rocks on the order of 20 cm in diameter that litter upper parts of the hillside may represent hand-cobbed ore from Tyson-era copper mining. These rocks develop white efflorescent salt crusts. Yellow and blue salts form intermittently on the soil surface in gullies, and locally form a layer a few cm thick below the soil surface.	43.82253	72.33750	Yellowish brown	>1
G	02TP3G	10-Oct-02	Gully and flat at upper adit(?) west of Copperas Rd; yellow area just west of TB-6 location. Area sampled at request of Ed Hathaway during site tour with J. Johnnson and M. Kierstead. This area may include waste from a closed adit (the gully).	Yellow sandy surface material in gully (J. Johnnson thinks this is waste from the closed upper adit). Sampled a 30' x 10' area that includes a small 4' high mound (3 of 30 increments) at the N edge of the sample area and a lobe at the east end of the area.	43.82167	72.33639	Brownish Yellow	2.95

Pile	Field number	Date collected	Sampling Location	Description	Latitude °N	Longitude °W	Munsell color	Dry sample mass (kg)
G	02TP3G-R	10-Oct-02	Gully and flat at upper adit(?) west of Copperas Rd; yellow area just west ofTB-6 location. Area sampled at request of Ed Hathaway during site tour with J. Johnnson and M. Kierstead. This area may include waste from a closed adit (the gully).	Yellow sandy surface material in gully (J. Johnnson thinks this is waste from the closed upper adit). Sampled a 30' x 10' area that includes a small 4' high mound (3 of 30 increments) at the N edge of the sample area and a lobe at the east end of the are	43.82167	72.33639	Brownish Yellow	2.53
H	02TP3H	10-Oct-02	Red area around TB-6 and slope above the road. This area is adjacent to the yellow area sampled for 02TP3G. Note a marked color distinction between these two areas.	Red-brown soil around TB-6 includes 25' wide relatively flat area and 20' E-facing slope above the road. Notes deep erosion gullies, wood, rusted metal, and boulders of country rock and oxidized ore. Sampled 20 increments at top, 10 on slope. Heterogeneous.	43.82167	72.33639	Yellowish Brown	2.61
H	02TP3H-R	10-Oct-02	Red area around TB-6 and slope above the road. This area is adjacent to the yellow area sampled for 02TP3G. Note a marked color distinction between these two areas.	Red-brown soil around TB-6 includes 25' wide relatively flat area and 20' E-facing slope above the road. Notes deep erosion gullies, wood, rusted metal, and boulders of country rock and oxidized ore. Sampled 20 increments at top, 10 on slope. Heterogeneous.	43.82167	72.33639	Yellowish Brown	2.5
TP4	02TP4	10-Oct-02	TP4 surface material. Sampled from flat, oval (27 m x 17 m) area on top of pile as well as from upper parts of the 15 m high eastern slope boulder field.	The boulders are large blocks (up to a meter across) of waste rock and ore.	43.81511	72.33675	Brownish Yellow	4.53

Pile	Field number	Date collected	Sampling Location	Description	Latitude °N	Longitude °W	Munsell color	Dry sample mass (kg)
TILL	*01 JH 26*	*9-Nov-01*	*Glacial till layer exposed along bank of Copperas Brook downstream from seep at base of TP1*	*Glacial till*			*Olive green*	*>1*

A-2. Soil boring samples.

Pile	Field number	Date collected	Sampling Location	Description	Soil boring log sample description	Latitude °N	Longitude °W	Drill method	Interval (ft)	Avg. depth (ft)	Blows/6" (140 lb or 300 lb hammer); Wt of hammer (WOH)[1]	Munsell color	Dry sample mass (kg)
D	EMV-ROC-TB1-S1/S2	29-Oct-02	Bluff east of North cut	Boring of TB1. Combined samples of S1 (0 to 2 ft) and S2 (2 to 4 ft).	BROWNISH YELLOW SILTY SAND,very fine sand, frequent layers 1/2" thick - 2" thick YELLOW SILTY SAND, fine to coarse sand (moist) (medium dense) [WASTE ROCK] Exhibits high degree of chemical weathering	43.82083	72.33750	Yanmar rubber track KDT150; split spoon 2" OD	0 - 4'	2	7 11 6 1 1 1 1 1	Yellow	0.35
D	EMV-ROC-TB1-S3	29-Oct-02	Bluff east of North cut	Boring of TB1 4' - 6'	YELLOW SILT CLAY (medium plasticity) (moist), frequent 1/2" to 1" layers of dark BROWN TO FINE COARSE SAND, (MOIST) (LOOSE) [WASTE ROCK] high degree of chemical weathering	43.82083	72.33750	Yanmar rubber track KDT150; split spoon 2" OD	4' - 6'	5	1 2 8 7	Yellow	0.45
D	EMV-ROC-TB1-SQ3	29-Oct-02	Bluff east of North cut	Duplicate sample for boring of TB1 4' - 6'	YELLOW SILT CLAY (medium plasticity) (moist), frequent 1/2" to 1" layers of dark BROWN TO FINE COARSE SAND, (MOIST) (LOOSE) [WASTE ROCK] high degree of chemical weathering	43.82083	72.33750	Yanmar rubber track KDT150; split spoon 2" OD	4' - 6'	5	1 2 8 7	Yellow	0.48

Pile	Field number	Date collected	Sampling Location	Description	Soil boring log sample description	Latitude °N	Longitude °W	Drill method	Interval (ft)	Avg. depth (ft)	Blows/6" (140 lb or 300 lb hammer); Wt of hammer (WOH)[1]	Munsell color	Dry sample mass (kg)
D	EMV-ROC-TB1-S4/S5/S6	29-Oct-02	Bluff east of North cut	Boring of TB1. Combined samples of S4 (6 to 8 ft), S5 (8 to 10 ft) and S6 (10 to 12 ft).	6 - 8' Interval: BROWNISH YELLOW SILTY SAND, fine to coarse sand (moist) (medium dense). 8 - 10' Interval: BROWNISH YELLOW SILTY SAND, fine sand, occasional layer of YELLOW SILT CLAY (medium plasticity) (moist) (medium)	43.82083	72.33750	Yanmar rubber track KDT150; split spoon 2" OD	6' - 12'	9	1 5 8 9 1 6 7 4 2 4 3 7	Yellow	0.42
D	EMV-ROC-TB1-S7	29-Oct-02	Bluff east of North cut	Boring of TB1 12' - 14'	BROWN YELLOW TO YELLOW SILTY SAND, fine sand, occasional 1/2" layer of DARK BROWN FINE TO COARSE SAND, trace subangular gravel (weathered ore) (moist) (very dense) [WEATHERED WASTE ROCK]	43.82083	72.33750	Yanmar rubber track KDT150; split spoon 2" OD	12' - 14'	13	12 40 50 38	Yellow	0.45
D	EMV-ROC-TB1-S8	29-Oct-02	Bluff east of North cut	Boring of TB1 14' - 16'	LIGHT GRAY FINE TO COARSE SAND, trace silt, frequent oxidized zones characterized by brownish yellow color 1-2" and 5"-7" in spoon-(moist) (very dense) [WASTE ROCK] Extremely weathered with foliation of parent rock visually apparent.	43.82083	72.33750	Yanmar rubber track KDT150; split spoon 2" OD	14' - 16'	15	43 76 74 105	Yellow	0.48
D	EMV-ROC-TB1-S9A	29-Oct-02	Bluff east of North cut	Boring of TB1 16' - 18'. Sample from upper 6"	BROWNISH YELLOW SILTY SAND, very fine to fine sand, trace coarse sand (moist) (very dense) [WASTE ROCK]	43.82083	72.33750	Yanmar rubber track KDT150; split spoon 2" OD	16' - 18'	17	40 48	Yellow	0.28

Pile	Field number	Date collected	Sampling Location	Description	Soil boring log sample description	Latitude °N	Longitude °W	Drill method	Interval (ft)	Avg. depth (ft)	Blows/6" (140 lb or 300 lb hammer); Wt of hammer (WOH)[1]	Munsell color	Dry sample mass (kg)
D	EMV-ROC-TB1-S9B	29-Oct-02	Bluff east of North cut	Boring of TB1 16' - 18'. Sample from lower 6"	Transitions to YELLOWISH RED TO REDDISH BROWN FINE TO COARSE SAND, trace silt, trace fine angular gravel (moist) (very dense) [WASTE ROCK] 17 - 18'	43.82083	72.33750	Yanmar rubber track KDT150; split spoon 2" OD	16' - 18'	17	50 38	Yellowish Brown	0.2
D	EMV-ROC-TB1-S10/S11/S12	29-Oct-02	Bluff east of North cut	Boring of TB1. Combined samples of S10 (18 to 20 ft), S11 (20 to 22 ft) and S12 (22 to 24 ft).	18 - 20' Interval: BROWNISH YELLOW SILTY SAND, very fine to fine sand, coarse sand (moist) (dense) [WASTE ROCK] (1/4" zones and 3" and 5". Color is reddish brown). Bottom 3" of sample YELLOW SILT/CLAY (wet) (stiff) (medium plasticity) [WASTE ROCK] (high	43.82083	72.33750	Yanmar rubber track KDT150; split spoon 2" OD	18' - 24'	21	10 16 23 20 7 60 45 30 16 21 38 33	Yellow	0.66
D	*EMV-ROC-TB1-S13*	*29-Oct-02*	*Bluff east of North cut*	*Boring of TB1 24' - 26'*	*OLIVE GRAY SILTY SAND, fine sand, trace coarse sand (moist) (very dense) [GLACIAL TILL]*	*43.82083*	*72.33750*	*Yanmar rubber track KDT150; split spoon 2" OD*	*24' - 25' 8"*	*25*	*34 33 66 120/4" 120/2"*	*Light Yellowish Brown*	*0.64*
A	EMV-ROC-TB3-S1	17-Oct-02	Yellow waste rock east of Copperas Rd	Boring of TB3 0 - 2'	BROWNISH YELLOWISH SAND, medium to fine sand, little silt, trace fine gravel (moist) (medium dense) [FILL-TAILINGS PILE]	43.82139	72.33611	Yanmar rubber track KDT150; split spoon 2" OD	0 - 2'	1	1 4 7 4	Yellow	0.56
A	EMV-ROC-TB3-S2	17-Oct-02	Yellow waste rock east of Copperas Rd	Boring of TB3 2 - 4'	Same as above; at 2' becomes loose, little to some silt	43.82139	72.33611	Yanmar rubber track KDT150; split spoon 2" OD	2' - 4'	3	WOH 4 4 8	Yellow	0.54
A	EMV-ROC-TB3-SQ2	17-Oct-02	Yellow waste rock east of Copperas Rd	Duplicate sample for boring of TB3 2 - 4'	Same as above; at 2' becomes loose, little to some silt	43.82139	72.33611	Yanmar rubber track KDT150; split spoon 2" OD	2' - 4'	3	WOH 4 4 8	Yellow	0.39

Pile	Field number	Date collected	Sampling Location	Description	Soil boring log sample description	Latitude °N	Longitude °W	Drill method	Interval (ft)	Avg. depth (ft)	Blows/6" (140 lb or 300 lb hammer); Wt of hammer (WOH)[1]	Munsell color	Dry sample mass (kg)
A	EMV-ROC-TB3-S3	17-Oct-02	Yellow waste rock east of Copperas Rd	Boring of TB3 4' - 6'	Same as above; at 4' trace of coarse gravel (medium dense)	43.82139	72.33611	Yanmar rubber track KDT150; split spoon 2" OD	4' - 6'	5	9 16 9 12	Yellow	0.56
A	EMV-ROC-TB3-S5/S6	17-Oct-02	Yellow waste rock east of Copperas Rd	Boring of TB3. Combined samples of S5 (8 to 10 ft) and S6 (10 to 12 ft). Note: no sample from S4 interval (6 to 8 ft) described in log as yellowish red with some gravel	8' trace fine gravel, BROWNISH YELLOW; 10' becomes medium dense, trace medium sand	43.82139	72.33611	Yanmar rubber track KDT150; split spoon 2" OD	8' - 12'	10	21 3 4 4 6 9 6 4	Yellow	0.4
A	EMV-ROC-TB3-S7	17-Oct-02	Yellow waste rock east of Copperas Rd	Boring of TB3 12' - 14'	12.6' DARK GRAY TO BLACK 2" seam of decomposed rock, abundant mica flakes 12.8'- wood	43.82139	72.33611	Yanmar rubber track KDT150; split spoon 2" OD	12' - 14'	13	12 14 53 100	Brownish Yellow	0.57
A	EMV-ROC-TB3-S8/S9	17-Oct-02	Yellow waste rock east of Copperas Rd	Boring of TB3. Combined samples of S8 (14 to 16 ft) and S9 (16 to 18 ft).	13' REDDISH BROWN MEDIUM TO FINE SAND, little fine gravel, little silt (moist) (dense) [FILL - TAILINGS] 13.3'- trace wood 13.5' becomes BROWNISH YELLOW 14'- wood fragments, little coarse to fine gravel (very dense) 16' YELLOWISH RED SILTY SAND, medium	43.82139	72.33611	Yanmar rubber track KDT150; split spoon 2" OD	14' - 18'	16	79 68 19 25 24 100/3" 30/2"	Yellowish Brown	0.51
C	EMV-ROC - TB4-S1	11-Oct-02	Red area south and east of Copperas Rd.	Boring of TB4 0-2'	YELLOWISH RED SILTY FINE TO COARSE SAND (very loose) (moist) [WASTE ROCK]	43.82056	72.33639	Tripod 3" steel casing, 2'; split spoon 2" OD	0 - 2'	1	WOH	Yellowish Red	0.4

Pile	Field number	Date collected	Sampling Location	Description	Soil boring log sample description	Latitude °N	Longitude °W	Drill method	Interval (ft)	Avg. depth (ft)	Blows/6" (140 lb or 300 lb hammer); Wt of hammer (WOH)[1]	Munsell color	Dry sample mass (kg)
C	EMV-ROC - TB4-S1 Rep	11-Oct-02	Red area south and east of Copperas Rd.	Replicate of boring of TB4 0-2'	YELLOWISH RED SILTY FINE TO COARSE SAND (very loose) (moist) [WASTE ROCK]	43.82056	72.33639	Tripod 3" steel casing, 2'; split spoon 2" OD	0 - 2'	1	WOH	Yellowish Red	0.38
C	EMV-ROC-TB4-S2	11-Oct-02	Red area south and east of Copperas Rd.	Boring of TB4 2' - 4'	2 - 4' Interval YELLOWISH RED SILTY FINE TO COARSE SAND (moist) (very loose) (traces of yellow mineral jarosite(?) and gray to black coloration [WASTE ROCK]	43.82056	72.33639	Tripod 3" steel casing, 2'; split spoon 2" OD	2 - 4'	3	WOH 3/6"	Yellowish Red	0.4
C	EMV-ROC-TB4-S3	11-Oct-02	Red area south and east of Copperas Rd.	Boring of TB4 4' - 6'	4' - 5'1" Interval DARK GRAY VERY FINE TO MEDIUM SILTY SAND (very dense) (high degree of chemical weathering) transitioning to OLIVE GRAY FINE SAND w trace gravel (angular) (moist) (very dense) [GLACIAL TILL] @4.5 FT.	43.82056	72.33639	Tripod 3" steel casing, 2'; split spoon 2" OD	4' - 5'1"	4.5	3 75 120/1"	Reddish Brown	0.42
C	EMV-ROC-TB4-S4	11-Oct-02	Red area south and east of Copperas Rd.	Boring of TB4 6' - 6'7"	Refusal @ 6' 7" on bedrock	43.82056	72.33639	Tripod 3" steel casing, 2'; split spoon 2" OD	6' - 6' 7"	6.3	120/3"	Light Yellowish Brown	0.076
B	EMV-ROC-TB5-S2/S3	9-Oct-02	Composite of samples S2 and S3 (2 - 6') from boring TB5	Pile of black waste rock TP3	2-4' Interval YELLOWISH RED VERY FINE TO COARSE SAND, little with silt (moist) (very loose) [WASTE ROCK] 2-4' marled- red with yellow coatings on partings 4-6' Interval REDDISH BROWN VERY FINE TO COARSE SAND, with silt (moist) (loose)	43.82111	72.33611	Tripod 3" steel casing, 2'; split spoon 2" OD	2' - 6'	4	1 1 2 3 2 2 5 5	Yellowish Brown	0.38

Pile	Field number	Date collected	Sampling Location	Description	Soil boring log sample description	Latitude °N	Longitude °W	Drill method	Interval (ft)	Avg. depth (ft)	Blows/6" (140 lb or 300 lb hammer); Wt of hammer (WOH)[1]	Munsell color	Dry sample mass (kg)
B	EMV-ROC-TB5-S4/S5	10-Oct-02	Composite of samples S4 and S5 (6 - 9') from boring TB5	Pile of black waste rock TP3	6 -8' Interval 1st 1" upper spoon BROWN FINE TO COARSE SAND, trace silt (loose) transitions to REDDISH BROWN FINE TO COARSE SAND with silt (loose) [WASTE ROCK] 8-9' Interval REDDISH BROWN FINE TO COARSE SAND	43.82111	72.33611	Tripod 3" steel casing, 2'; split spoon 2" OD	6' - 9'	7.5	2 2 5 5 4 (all 140 lb) Switch to 300 lb at 6.5' 2 3 3 9 6	Red	0.36
B	EMV-ROC-TB5-S5	10-Oct-02	Boring of TB5 9.0' - 9.5'	Chemically weathered rock zone	9.0 - 9.5' Interval Transition to alternating layers of LIGHT GRAY AND YELLOW VERY FINE TO FINE SAND (moist) (very dense) (platelike structure) [CHEMICALLY WEATHERED ROCK]	43.82111	72.33611	Tripod 3" steel casing, 2'; split spoon 2" OD	9.0' - 9.5'	9.25	35 120/4"	Pale Yellow	0.27
B	*EMV-ROC-TB5-S5/S6*	*10-Oct-02*	*Boring of TB5 9.5' - 10.25'*	*Glacial till at bottom of TB5*	*OLIVE GRAY VERY FINE TO FINE SILTY SAND (very dense) (moist) [GLACIAL TILL] Bottom of boring 10.25'*	*43.82111*	*72.33611*	*Tripod 3" steel casing, 2'; split spoon 2" OD*	*9.5' - 10.25'*	*9.9*	*175/3"*	*Light Brown*	*0.16*
H	EMV-ROC-TB6-S1 (HA)	22-Oct-02	0 - 2 ft: Yellow bench west of Copperas Rd	Hand auger soil sample of upper part of TB6 0 - 2'	YELLOWISH RED (WITH BROWNISH YELLOW LENSES) SILTY SAND, medium to fine sand, trace coarse sand, little silt, with fine gravel, trace coarse gravel, moist [FILL - TAILINGS PILE]	43.82167	72.33639	Stainless steel hand auger	0 - 2'	1	NA	Brownish Yellow	0.52
H	EMV-ROC-TB6-S2 (HA)	22-Oct-02	2 - 4 ft: Yellow bench west of Copperas Rd	Hand auger soil sample of upper part of TB6 2' - 4'	Little coarse to fine gravel	43.82167	72.33639	Stainless steel hand auger	2 - 4'	3	NA	Yellow	0.48

Pile	Field number	Date collected	Sampling Location	Description	Soil boring log sample description	Latitude °N	Longitude °W	Drill method	Interval (ft)	Avg. depth (ft)	Blows/6" (140 lb or 300 lb hammer); Wt of hammer (WOH)[1]	Munsell color	Dry sample mass (kg)
H	EMV-ROC-TB6-S3 (HA)	22-Oct-02	4 - 4.8 ft: Yellow bench west of Copperas Rd	Hand auger soil sample of upper part of TB6 4' - 4.8'	Trace debris (brick fragments) At 4.8' Refusal (possible cobble or bedrock)	43.82167	72.33639	Stainless steel hand auger	4 - 4.8'	4.4	NA	Brownish Yellow	0.47
H	EMV-ROC-TB6-S2	1-Nov-02	Red bench overlooking Copperas Rd	Boring of TB6 2' - 4'	0 - 3" BROWN FINE-MEDIUM SAND with tan silt, trace gravel. 3 - 7" BROWN, RED BROWN MEDIUM SAND with gravel. 7-8" as above with black fine-medium SAND [WASTE ROCK]	43.82167	72.33639	Tripod 3" steel casing, 2'; split spoon 2" OD	2' - 4'	3	3 12 11 35	Brownish Yellow	0.47
H	EMV-ROC-TB6-S3	1-Nov-02	Red bench overlooking Copperas Rd	Boring of TB6 4' - 6'	0 - 2" LARGE COBBLE/FERRICRETE, GRAY TO BLACK with amber mineralization. 2-15" BROWN TO RED BROWN FINE SAND with silt, trace sand (moist) (dense) [WASTE ROCK]	43.82167	72.33639	Tripod 3" steel casing, 2'; split spoon 2" OD	4' - 6'	5	23 10 12 15	Yellowish Brown	0.38
H	EMV-ROC-TB6-S4/S5/S6	1-Nov-02	Red bench overlooking Copperas Rd	Boring of TB6. Combined samples of S4 (6 to 8 ft), S5 (8 to 10 ft) and S6 (10 to 12 ft).	BROWN TO YELLOW BROWN MEDIUM SAND, little gravel, some silt (yellow) (moist) (loose). 10 - 12' Interval: BROWN TO YELLOW BROWN FINE SAND with silt, trace gravel/medium sand (dry). Wood fragments.	43.82167	72.33639	Tripod 3" steel casing, 2'; split spoon 2" OD	6' - 12'	9	5 10 15 15 2 10 10 15 10 25 100/X 120/X	Brownish Yellow	0.66
H	EMV-ROC-TB6-S7	1-Nov-02	Red bench overlooking Copperas Rd	Boring of TB6 13' - 15'	GRAY FINE SAND AND SILT, GRAVEL, black coloration to base (moist) (medium dense) [NATIVE]	43.82167	72.33639	Tripod 3" steel casing, 2'; split spoon 2" OD	13' - 15'	14	15 25 35 40	Light Brownish gray	0.47

Pile	Field number	Date collected	Sampling Location	Description	Soil boring log sample description	Latitude °N	Longitude °W	Drill method	Interval (ft)	Avg. depth (ft)	Blows/6" (140 lb or 300 lb hammer); Wt of hammer (WOH)[1]	Munsell color	Dry sample mass (kg)
H	*EMV-ROC-TB6-S13/S14*	*2-Nov-02*	*Red bench overlooking Copperas Rd*	*Boring of TB6 25' - 28.3'*	*GRAY MEDIUM SAND WITH SURROUNDING GRAVEL (moist) (medium dense to dense) [NATIVE]. 28 - 28.3' same, clayey (moist) (dense) OLIVE GRAY. Boulder on till at bottom of boring.*	*43.82167*	*72.33639*	*Tripod 3" steel casing, 2'; split spoon 2" OD*	*25' - 28.3'*	*26.6*	*32 32 15 120/5" BOUNCE 50 100/x boulder*	*gray*	*0.56*
F	EMV-ROC-TB7-S1	24-Oct-02	0-2 ft: Amber bench NE of North cut	Amber plateau/bench NE of North cut	BROWNISH YELLOW VERY FINE SILTY SAND, trace coarse sand (moist) (medium dense) (yellow silt layer - weathered minerals at 6"-7" in spoon) [WASTE ROCK]	43.82194	72.33694	Yanmar rubber track KDT150; split spoon 2" OD	0 - 2'	1	6 10 7 4	Brownish Yellow	0.45
F	EMV-ROC-TB7-S2	24-Oct-02	2 - 4 ft: Amber bench NE of North cut	Amber plateau/bench NE of North cut	YELLOWISH GRAY SILTY FINE SAND, trace coarse sand (moist) (very dense) (yellowish red oxidized layer upper part of spoon 2-3" and traces of yellow weathered minerals occasionally <1/foot) [WASTE ROCK]	43.82194	72.33694	Yanmar rubber track KDT150; split spoon 2" OD	2 - 4'	3	10 17 42 27	Brownish Yellow	0.56
F	EMV-ROC-TB7-S3	24-Oct-02	4 - 6 ft: Amber bench NE of North cut	Amber plateau/bench NE of North cut	YELLOWISH RED VERY FINE SILTY SAND, trace coarse sand (moist) (dense) [WASTE ROCK]	43.82194	72.33694	Yanmar rubber track KDT150; split spoon 2" OD	4 - 6'	5	11 12 19 28	Brownish Yellow	0.6
F	EMV-ROC-TB7-S3	24-Oct-02	4 - 6 ft: Amber bench NE of North cut	Amber plateau/bench NE of North cut	YELLOWISH RED VERY FINE SILTY SAND, trace coarse sand (moist) (dense) [WASTE ROCK]	43.82194	72.33694	Yanmar rubber track KDT150; split spoon 2" OD	4 - 6'	5	11 12 19 28	Brownish Yellow	0, Splits taken from TB7-S3

Pile	Field number	Date collected	Sampling Location	Description	Soil boring log sample description	Latitude °N	Longitude °W	Drill method	Interval (ft)	Avg. depth (ft)	Blows/6" (140 lb or 300 lb hammer); Wt of hammer (WOH)[1]	Munsell color	Dry sample mass (kg)
F	EMV-ROC-TB7-S4	24-Oct-02	6 - 8 ft: Amber bench NE of North cut	Amber plateau/bench NE of North cut	BROWN VERY FINE SILTY SAND, trace coarse sand (moist) (very dense) (weathered schist 8-10" from top of sample) [WASTE ROCK] (tr. White salt crystals)	43.82194	72.33694	Yanmar rubber track KDT150; split spoon 2" OD	6 - 8'	7	27 120/5"	Brownish Yellow	0.67
F	EMV-ROC-TB7-S5	25-Oct-02	8 - 9.5 ft: Amber bench NE of North cut	Amber plateau/bench NE of North cut	BROWNISH YELLOW VERY FINE SILTY SAND, trace coarse sand (moist) (very dense) [WASTE ROCK] (one piece fine weathered gravel in spoon)	43.82194	72.33694	Yanmar rubber track KDT150; split spoon 2" OD	8 - 9.5'	8.75	100 120/4"	Yellow	0.61
F	EMV-ROC-TB7-S6	25-Oct-02	11 - 12 ft: Amber bench NE of North cut	Amber plateau/bench NE of North cut	BROWNISH YELLOW VERY FINE SILTY SAND, trace coarse sand (moist) (very dense) [WASTE ROCK OR TILL]	43.82194	72.33694	Yanmar rubber track KDT150; split spoon 2" OD	11 - 12'	11.5	120 /3"	Olive Yellow	0.4
F	EMV-ROC-TB7-S7	25-Oct-02	12.3 - 14.3 ft: Amber bench NE of North cut	Amber plateau/bench NE of North cut	BROWNISH YELLOW VERY FINE SILTY SAND, trace coarse sand (moist) (very dense) [WASTE ROCK OR TILL]	43.82194	72.33694	Yanmar rubber track KDT150; split spoon 2" OD	12.3 - 14.2'	13.25	77 120/5"	Olive Yellow	0.6
F	EMV-ROC-TB7-S8	25-Oct-02	14.3 - 15.3 ft: Amber bench NE of North cut	Amber plateau/bench NE of North cut	BROWNISH YELLOW TO OLIVE GRAY SILTY FINE SAND, trace coarse sand, trace weathered schist 1/8" - 1/4", some yellowish mineralized/ decomposed rock 1/2" (moist) (very dense) [WASTE ROCK] Possible GLACIAL TILL in bottom 3" of spoon	43.82194	72.33694	Yanmar rubber track KDT150; split spoon 2" OD	14.3 - 15.3'	14.8	55 110/1"	Olive Yellow	0.6

Pile	Field number	Date collected	Sampling Location	Description	Soil boring log sample description	Latitude °N	Longitude °W	Drill method	Interval (ft)	Avg. depth (ft)	Blows/6" (140 lb or 300 lb hammer); Wt of hammer (WOH)[1]	Munsell color	Dry sample mass (kg)
F	*EMV-ROC-TB7-S9*	*25-Oct-02*	*22 -24 ft: Amber bench NE of North cut*	*Amber plateau/bench NE of North cut*	*OLIVE GRAY SILT with fine sand, trace coarse sand, trace fine gravel (very dense) (moist) [GLACIAL TILL]* *Bottom of boring at 27'3" where spoon not advancing (rock?)* *Intervening material all in till*	*43.82194*	*72.33694*	*Yanmar rubber track KDT150; split spoon 2" OD*	*22 - 24'*	*23*	*58 88 120/4"*	*gray*	*0.64*
E	EMV-ROC-TB20-S1 (HA)	22-Oct-02	0 - 2 ft: Red pile between Copperas Rd. and North cut	Red spine east on North cut (between Copperas Rd. and North cut)	YELLOWISH RED SILTY SAND, fine to coarse sand (moist), traces of black and yellow sand	43.82111	72.33694	Stainless steel hand auger	0 - 2'	1	NA	Yellowish Red	0.55
E	EMV-ROC-TB20-S2 (HA)	22-Oct-02	2 - 4 ft: Red pile between Copperas Rd. and North cut	Red spine east on North cut (between Copperas Rd. and North cut)	YELLOWISH RED SILTY SAND, fine to coarse sand (moist), traces of black and yellow sand	43.82111	72.33694	Stainless steel hand auger	2 - 4'	3	NA	Yellowish Red	0.62
E	EMV-ROC-TB20-S3 (HA)	22-Oct-02	4 - 5.7 ft: Red pile between Copperas Rd. and North cut	Red spine east on North cut (between Copperas Rd. and North cut)	Same as above, but contains fine sunrounded gravel	43.82111	72.33694	Stainless steel hand auger	4 - 5.7'	4.85	NA	Red	0.57
F	EMV-ROC-TB21-S1	23-Oct-02	0 - 2 ft: Amber pile north of North cut	Amber pile N of North cut	BROWNISH YELLOW SILTY SAND, fine to coarse sand, trace subrounded gravel (moist) (loose) [WASTE ROCK]	43.82222	72.33750	Yanmar rubber track KDT150; split spoon 2" OD	0 - 2'	1	4 3 2 4	Brownish Yellow	0.27
F	EMV-ROC-TB21-S2	23-Oct-02	2 - 4 ft: Amber pile north of North cut	Amber pile N of North cut	BROWN SILT, VERY FINE SILTY SAND, AND VERY FINE SAND (moist) (dense) [TILL OR WASTE ROCK] low plasticity	43.82222	72.33750	Yanmar rubber track KDT150; split spoon 2" OD	2 - 4'	3	2 16 41 45	Yellowish Brown	0.5

Pile	Field number	Date collected	Sampling Location	Description	Soil boring log sample description	Latitude °N	Longitude °W	Drill method	Interval (ft)	Avg. depth (ft)	Blows/6" (140 lb or 300 lb hammer); Wt of hammer (WOH)[1]	Munsell color	Dry sample mass (kg)
F	EMV-ROC-TB21-S3	23-Oct-02	4- 6 ft: Amber pile north of North cut	Amber pile N of North cut	BROWN SILT, VERY FINE SILTY SAND, AND VERY FINE SAND (moist) (very dense) [TILL OR WASTE ROCK] low plasticity	43.82222	72.33750	Yanmar rubber track KDT150; split spoon 2" OD	4 - 6'	5	19 58 56 62	Olive Yellow	0.54
F	*EMV-ROC-TB21-S4*	*23-Oct-02*	*6- 8 ft: Amber pile north of North cut*	*Amber pile N of North cut*	*OLIVE GRAY SILT, trace coarse sand (very dense) (moist) [GLACIAL TILL] Weathered rock in top of spoon at 8'*	*43.82222*	*72.33750*	*Yanmar rubber track KDT150; split spoon 2" OD*	*6' - 6'4"*	*6*	*120/4"*	*Light Olive Brown*	*0.4*
F	*EMV-ROC-TB21-S5*	*23-Oct-02*	*8.5 - 10.3 ft: Amber pile north of North cut*	*Amber pile N of North cut*	*OLIVE GRAY SILT, trace coarse sand (very dense) (moist) [GLACIAL TILL] Piece of black weathered schist at 9.5-9.8' Drove core to 10.5 ft with 300 lb hammer. Bottom of core at 10.3 ft*	*43.82222*	*72.33750*	*Yanmar rubber track KDT150; split spoon 2" OD*	*8.5' - 10.3'*	*9.4*	*31 50 60 120/4"*	*Light Olive gray*	*0.48*

[1] Refers to number of blows to advance the split spoon 2 feet; various hammer weights were used to penetrate the mine waste piles. “Refusal” refers to a penetration of less than 1 ft per 100 blows.

APPENDIX B

B-1: Bulk Geochemistry of TP3 mine wastes

Pile	Sample[1]	Depth	Ag	Al	As	Au	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cu	Eu	Fe	Ga	Ho	K	La	Li	Mg	Mn	Mo
		(ft)	ppm	wt.%	ppm	ppm	ppm	ppm	ppm	wt.%	ppm	ppm	ppm	ppm	ppm	ppm	wt.%	ppm	ppm	wt.%	ppm	ppm	wt.%	ppm	ppm
A	02TP3A	0	6.9	3.6	11	<8	20	<1	<10	0.6	<2	<4	20	69	1,860	<2	17	<4	<4	1	<2	5.3	0.59	277	31
A	98JHNPA*	0	3.3	3.3	4	n.d.	32	0.2	3.8	0.4	0.2	1.5	5	100	1,800	n.d.	16	11	n.d.	1.2	0.9	9.7	0.55	170	27
A	TB3-S1	1	6.8	3.9	<10	<8	13	<1	<10	0.69	<2	<4	15	88	1,300	<2	15.7	<4	<4	1.3	<2	4.2	0.56	80	72
A	TB3-S2	3	6.9	3.2	10	<8	11	<1	<10	0.54	<2	<4	20	80	763	<2	19.5	<4	<4	1.3	<2	5.6	0.29	87	62
A	TB3-SQ2	3	6.9	3.3	11	<8	13	<1	<10	0.53	2.4	<4	18	80	615	<2	17.7	<4	<4	1.3	<2	5.2	0.28	83	58
A	TB3-S3	5	6.1	3.2	<10	<8	71	<1	<10	0.9	2	<4	25	60	779	<2	16.9	<4	<4	1.6	2.2	10	0.33	89	33
A	TB3-S5/S6	10	5.2	3.7	<10	<8	30	<1	<10	2	2.5	<4	22	79	1,960	<2	19	<4	<4	1.3	<2	7.5	0.7	193	31
A	TB3-S7	13	7.9	2.3	17	<8	10	<1	<10	0.61	12	<4	99	25	15,300	<2	26.9	<4	<4	1.1	<2	9.3	0.46	198	24
A	TB3-S8/S9	16	<2	3.7	<10	<8	209	<1	<10	0.75	3.3	<4	20	56	1,170	<2	20.4	<4	<4	1.1	2.8	16	0.64	370	12
B	02TB3B	0	11	1.2	<10	<8	2.6	<1	<10	0.072	<2	<4	158	<1	2,380	<2	36.6	<4	<4	0.54	<2	3.7	0.06	50	34
B	98JHNPB*	0	8.9	1.3	10	n.d.	14	0.1	3.7	0.09	2	0.4	100	41	2,100	n.d.	36	4.4	n.d.	0.48	0.3	4.9	0.06	65	34
B	TB5-S2/S3	4	9.7	1.5	<10	<8	<1	<1	<10	0.29	13	<4	113	3.7	818	<2	40.5	<4	<4	0.64	<2	5.2	0.12	52	48
B	TB5-S4/S5	7.5	9.8	2.3	20	<8	10	<1	<10	0.3	8.3	<4	85	31	1,480	<2	31.8	<4	<4	0.96	<2	6.4	0.2	173	50
B	TB5-S5	9.25	<2	3.5	<10	<8	196	1.2	<10	1	<2	<4	7.3	26	313	<2	8.7	14	<4	1.2	<2	3.8	0.057	286	10
B	TB5-S5/S6	9.9	<2	5.8	<10	<8	347	1.7	<10	1.3	<2	8.3	12	124	416	<2	7.2	26	<4	1.5	7.2	12	0.57	558	4.7
C	02TP3C	0	14	3.6	24	<8	30	<1	<10	0.35	<2	<4	53	54	1,110	<2	22	<4	<4	1	<2	9.1	0.28	207	80
C	98JHNPC*	0	24.2	3.7	25	n.d.	44	0.2	10	0.3	0.8	2.4	30	81	1,100	n.d.	24	10	n.d.	1	1.5	12	0.26	220	100
C	TB4-S1	1	20	3.9	29	<8	25	<1	<10	0.31	2.4	<4	39	74	2,050	<2	19.1	<4	<4	1.4	<2	9.2	0.3	162	100
C	TB4-S1 Rep	1	18	4	17	<8	34	<1	<10	0.37	<2	<4	47	65	1,060	<2	20.2	5.4	<4	1.2	<2	9.5	0.31	200	88
C	TB4-S2	3	14	3.6	29	<8	24	<1	<10	0.33	<2	<4	38	66	5,440	<2	17.8	<4	<4	1.4	<2	8.6	0.31	162	73
C	TB4-S3	4.5	18	3.4	36	<8	35	<1	<10	0.32	11	<4	257	64	70,000	<2	14.3	<4	<4	0.98	<2	9	0.27	132	84
D	98JHNPD*	0	7	3.6	8	n.d.	65	0.2	4.1	0.51	0.3	2.9	9.2	65	3,200	n.d.	17	8.7	n.d.	1.2	2	8.7	0.41	230	47
D	TB1-S1/S2	2	11	4.2	<10	<8	32	<1	<10	0.43	3.8	<4	25	89	3,160	<2	19.3	<4	<4	1.6	<2	9.9	0.72	158	30
D	TB1-S3	5	7.1	4	11	<8	21	<1	<10	1	<2	<4	15	89	1,050	<2	16.8	<4	<4	1.5	<2	8.8	0.43	106	26

Pile	Sample[1]	Depth	Ag	Al	As	Au	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cu	Eu	Fe	Ga	Ho	K	La	Li	Mg	Mn	Mo
D	TB1-SQ3	5	8	4.1	10	<8	25	<1	<10	1.1	2.4	<4	16	96	1,150	<2	17.5	<4	<4	1.6	<2	9.8	0.45	137	33
D	TB1-S4/S5/S6	9	7.6	3.5	10	<8	16	<1	<10	1.2	3.6	<4	16	112	2,410	<2	18.1	<4	<4	1.4	<2	7.1	0.69	92	32
D	TB1-S7	13	6.9	4.3	<10	<8	14	<1	<10	1.1	3.1	<4	21	154	8,640	<2	14.7	<4	<4	2	3.9	8.1	0.91	164	12
D	TB1-S8	15	<2	5.9	<10	<8	169	<1	<10	2.3	4.7	8.9	28	121	2,390	<2	11	5.4	<4	2.8	6.9	27	0.81	136	26
D	TB1-S9A	17	<2	4	<10	<8	108	<1	<10	1.8	2.5	12	18	77	1,020	<2	11.2	6	<4	2.2	8.3	18	0.37	74	7.5
D	TB1-S9B	17	7.4	1.7	13	<8	14	<1	<10	0.22	7.5	<4	44	24	2,150	<2	31.9	<4	<4	0.99	<2	8.3	0.12	71	35
D	TB1-S10/S11/S12	21	8.4	2.8	14	<8	22	<1	<10	0.76	4.1	<4	33	39	3,120	<2	20.4	<4	<4	1.6	<2	8.2	0.2	223	33
D	TB1-S13	25	<2	5.8	<10	<8	370	1.5	<10	0.77	<2	20	15	124	777	<2	6	13	<4	1.8	12	32	1.2	523	3.1
E	98JHNPE*	0	11.8	3	20	n.d.	30	0.2	7.7	0.3	1.1	1.5	41	68	850	n.d.	23	8.4	n.d.	0.76	0.8	12	0.24	170	67
E	TB20-S1 (HA)	1	16	3	24	<8	12	<1	<10	0.28	4.3	<4	76	35	844	<2	27.6	<4	<4	0.97	<2	9.3	0.23	130	86
E	TB20-S2 (HA)	3	16	3.6	15	<8	24	<1	<10	0.3	3.5	<4	57	67	1,490	<2	21.1	<4	<4	1.3	<2	11	0.27	141	95
E	TB20-S3 (HA)	4.85	17	4	37	<8	26	<1	<10	0.44	3	<4	61	55	1,540	<2	20	<4	<4	0.96	<2	11	0.32	166	90
F	98JHNPF*	0	10.7	2.9	16	n.d.	55	0.2	6.5	0.4	1.3	2.3	22	62	6,600	n.d.	21	9.1	n.d.	1	1.4	9.6	0.23	83	56
F	TB21-S1	1	9.2	3.2	13	<8	78	<1	<10	0.32	4.5	<4	30	44	5,980	<2	23.6	<4	<4	1.5	<2	9.1	0.33	100	62
F	TB21-S2	3	<2	3.8	<10	<8	301	1.3	<10	0.7	<2	12	26	46	605	<2	11.5	<4	<4	0.94	7.6	14	0.48	289	2.7
F	TB21-S3	5	<2	4.2	<10	<8	303	1.3	<10	0.75	<2	11	20	66	1,120	<2	12.4	<4	<4	1.2	7.2	19	0.71	314	7.8
F	TB21-S4	6	<2	6.3	<10	<8	530	1.8	<10	0.98	<2	13	17	117	396	<2	7.7	12	<4	2.1	7.4	42	1.4	425	2.3
F	TB21-S5	9.4	<2	7.4	<10	<8	494	2.3	<10	1.7	<2	37	17	112	422	<2	5.3	14	<4	2	18	63	2.1	594	2.2
F	TB7-S1	1	9.6	3.8	17	<8	71	<1	<10	0.36	3.2	<4	32	56	3,740	<2	22.1	<4	<4	1.7	<2	9.2	0.24	86	68
F	TB7-S2	3	2.7	3.3	16	<8	249	1.2	<10	0.53	<2	<4	15	26	1,820	<2	15.8	<4	<4	1.1	3	10	0.29	218	14
F	TB7-S3	5	<2	3.7	<10	<8	310	1.2	<10	0.54	<2	<4	11	40	629	<2	11.8	8.8	<4	1.2	2.6	11	0.32	214	4.5
F	TB7-S3	5	<2	3.6	<10	<8	316	1.2	<10	0.54	<2	<4	10	39	583	<2	11.8	6.8	<4	1.2	3.1	11	0.33	228	3.1
F	TB7-S4	7	<2	3.4	<10	<8	290	1.3	<10	0.72	<2	<4	13	38	500	<2	12	4.9	<4	1.1	2.5	13	0.38	265	2
F	TB7-S5	8.75	<2	3.4	<10	<8	278	1.3	<10	1.1	<2	<4	14	40	430	<2	10.9	<4	<4	1.1	2.6	14	0.44	305	<2
F	TB7-S6	11.5	<2	3.2	<10	<8	238	1.4	<10	1.3	<2	<4	26	27	484	<2	13.2	<4	<4	1.1	2.5	15	0.45	259	<2
F	TB7-S7	13.25	<2	3.4	<10	<8	198	1.3	<10	1.4	2	7.1	25	38	455	<2	10.4	7.6	<4	1.1	4.6	15	0.5	331	<2
F	TB7-S8	14.8	<2	3.6	<10	<8	190	1.5	<10	3	<2	11	28	50	676	<2	10.2	<4	<4	1.2	7.7	18	0.54	318	<2
F	TB7-S9	23	<2	6.2	<10	<8	388	2.3	<10	4.7	<2	58	14	88	31	<2	3.3	10	<4	1.7	30	49	1.5	1,080	2.5

Pile	Sample[1]	Depth	Ag	Al	As	Au	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cu	Eu	Fe	Ga	Ho	K	La	Li	Mg	Mn	Mo
G	02TP3G	0	4.6	4.2	<10	<8	161	<1	<10	0.63	<2	4.8	29	61	4,570	<2	15	12	<4	1.3	3.6	13	0.43	272	45
G	02TP3G-R	0	4.6	4	<10	<8	154	<1	<10	0.62	<2	<4	26	62	4,110	<2	13.7	12	<4	1.2	2.8	14	0.46	269	35
H	02TP3H	0	6.7	3.3	<10	<8	122	<1	<10	0.51	<2	<4	29	35	1,810	<2	22.7	<4	<4	1.1	2.5	8.7	0.31	229	32
H	02TP3H-R	0	6.4	3.2	14	<8	126	<1	<10	0.48	<2	<4	30	37	1,820	<2	22.4	<4	<4	1	<2	9.5	0.32	229	30
H	TB6-S1 (HA)	1	8.2	2.8	19	<8	88	<1	<10	0.43	3.5	<4	21	26	1,420	<2	24.3	<4	<4	1.2	<2	7.3	0.22	209	41
H	TB6-S2 (HA)	3	16	2.9	62	<8	98	<1	<10	0.22	2.8	<4	22	45	6,780	<2	21.1	<4	<4	1.8	<2	9.1	0.17	98	75
H	TB6-S3 (HA)	4.4	9.1	2.5	31	<8	76	<1	<10	0.28	3.6	<4	68	17	3,540	<2	26.3	<4	<4	1.3	<2	6.7	0.19	134	37
H	TB6-S2	3	6.1	2.5	21	<8	73	<1	<10	0.34	26	<4	123	12	2,560	<2	27.4	<4	<4	1.3	<2	8	0.28	152	34
H	TB6-S3	5	2.6	3.7	<10	<8	148	<1	<10	0.69	11	<4	44	56	1,490	<2	22	<4	<4	1.2	4.3	12	0.53	432	18
H	TB6-S4/S5/S6	9	2	3.9	14	<8	207	<1	<10	0.71	3	7.5	24	48	937	<2	18	<4	<4	1.5	8	15	0.56	939	13
H	TB6-S7	14	<2	6.5	<10	<8	378	2	<10	1	3	50	28	110	3,050	<2	6	11	<4	1.3	18	81	1.4	590	6.3
H	TB6-S13/S14	26.6	<2	6.6	12	<8	466	2	<10	6.2	<2	64	70	95	51	<2	5.9	9.6	<4	2.1	35	64	1.9	1,200	2.1
TP4	02TP4	0	<2	6.2	<10	<8	148	<1	<10	1.3	<2	16	28	155	1,340	<2	11.8	7.9	<4	1.4	9.3	22	1.7	510	7.6
TILL	01 JH 26	0	<4	6.5	<20	<20	400	2	<20	2.4	<4	60	20	92	41	<4	3.6	20	<8	1.7	32	48	1.5	1,000	<4

Pile	Sample	Depth	Na	Nb	Nd	Ni	P	Pb	S	Sc	Sn	Sr	Ta	Th	Ti	U	V	Y	Yb	Zn	Job No.	Lab No.
		(ft)	wt.%	ppm	ppm	ppm	wt.%	ppm	wt.%	ppm	ppm	ppm	ppm	ppm	wt.%	ppm	ppm	ppm	ppm	ppm		
A	02TP3A	0	2.3	<4	9.6	4.2	0.022	40	4.27	10	<5	25	<40	<4	0.048	<100	80	<2	<1	391	MRP-04326	C-215162
A	98JHNPA*	0	1.7	< 0.2	n.d.	<2	n.d.	87	4.02	7.8	n.d.	29	n.d.	< 0.06	n.d.	0.2	90	1.8	n.d.	170	MRP-01252	C-125895
A	TB3-S1	1	2.1	<4	8.2	3.6	0.026	46	n.d.	11	5.4	28	<40	<4	0.09	<100	65	<2	<1	187	MRP-04327	C-215207
A	TB3-S2	3	1.6	<4	11	4.8	0.022	34	4.46	10	5	24	<40	<4	0.12	<100	74	<2	<1	224	MRP-04327	C-215208
A	TB3-SQ2	3	1.6	<4	9.9	4.9	0.019	37	n.d.	10	<5	22	<40	<4	0.14	<100	74	<2	<1	202	MRP-04327	C-215210
A	TB3-S3	5	1	<4	10	5.8	0.019	26	n.d.	10	<5	21	<40	<4	0.11	<100	70	<2	<1	300	MRP-04327	C-215211
A	TB3-S5/S6	10	1.7	<4	12	4.4	0.039	50	4.04	11	<5	38	<40	<4	0.084	<100	96	<2	<1	186	MRP-04327	C-215212
A	TB3-S7	13	1	<4	16	15	0.15	50	n.d.	12	<5	41	<40	<4	<0.005	<100	107	<2	<1	1,010	MRP-04327	C-215213
A	TB3-S8/S9	16	0.99	<4	12	21	0.072	11	1.58	12	<5	105	<40	<4	0.27	<100	101	3.8	1.3	102	MRP-04327	C-215209
B	02TB3B	0	0.29	<4	24	41	0.022	29	1.92	9	6.4	<2	<40	<4	<0.005	<100	34	<2	<1	1,170	MRP-04326	C-215163
B	98JHNPB*	0	0.28	< 0.2	n.d.	26	n.d.	51	1.69	2	n.d.	7.7	n.d.	< 0.06	n.d.	0.3	32	0.7	n.d.	1,200	MRP-01252	C-125896
B	TB5-S2/S3	4	0.47	<4	26	34	0.014	<4	8.26	12	7.6	<2	<40	<4	0.046	<100	58	<2	<1	666	MRP-04327	C-215217
B	TB5-S4/S5	7.5	0.87	<4	20	25	0.029	45	2.87	12	8.1	14	<40	<4	0.058	<100	72	<2	<1	691	MRP-04327	C-215218
B	TB5-S5	9.25	1.5	<4	<4	3	0.054	33	2.82	5.1	<5	139	<40	<4	0.48	<100	25	2.6	<1	60	MRP-04327	C-215219
B	TB5-S5/S6	9.9	2	4.3	4.7	19	0.038	18	1.40	9.5	<5	190	<40	<4	0.37	<100	54	4.2	1.1	103	MRP-04327	C-215220
C	02TP3C	0	1.4	<4	13	13	0.016	59	1.21	12	<5	18	<40	<4	0.061	<100	89	<2	<1	384	MRP-04326	C-215164
C	98JHNPC*	0	1.2	0.5	n.d.	8	n.d.	120	1.8	10	n.d.	26	n.d.	0.1	n.d.	0.4	84	1.5	n.d.	350	MRP-01252	C-125897
C	EMV-ROC -TB4-S1	1	1.2	<4	10	9.4	0.026	99	1.92	16	<5	21	<40	<4	0.024	<100	92	<2	<1	381	MRP-04327	C-215214
C	EMV-ROC -TB4-S1 Rep	1	1.3	<4	12	12	0.015	90	n.d.	14	<5	20	<40	<4	0.055	<100	91	<2	<1	395	MRP-04326	C-215161
C	TB4-S2	3	1.1	<4	9.6	9.2	0.064	93	2.84	14	<5	22	<40	<4	<0.005	<100	84	<2	<1	320	MRP-04327	C-215215
C	TB4-S3	4.5	1.1	<4	5.6	40	0.63	101	6.83	12	<5	22	<40	<4	<0.005	<100	74	<2	1	1,370	MRP-04327	C-215216
D	98JHNPD*	0	1.4	0.5	n.d.	<2	n.d.	61	3.77	6.9	n.d.	28	n.d.	0.38	n.d.	0.2	78	2.3	n.d.	200	MRP-01252	C-125898
D	TB1-S1/S2	2	2.4	<4	10	5	0.05	38	n.d.	14	<5	24	<40	<4	0.089	<100	116	<2	<1	203	MRP-04327	C-215197
D	TB1-S3	5	2.1	<4	9.6	3.6	0.036	46	5.13	11	5.3	38	<40	<4	0.12	<100	82	<2	<1	148	MRP-04327	C-215198
D	TB1-SQ3	5	2.1	<4	9.8	4.1	0.038	45	4.78	12	5	37	<40	<4	0.14	<100	96	<2	<1	184	MRP-04327	C-215199
D	TB1-S4/S5/S6	9	2.1	<4	11	3.7	0.051	34	n.d.	11	<5	33	<40	<4	0.063	<100	103	<2	<1	180	MRP-04327	C-215200

Pile	Sample	Depth	Na	Nb	Nd	Ni	P	Pb	S	Sc	Sn	Sr	Ta	Th	Ti	U	V	Y	Yb	Zn	Job No.	Lab No.
D	TB1-S7	13	1.8	<4	9	4	0.098	35	5.54	18	5.1	36	<40	<4	<0.005	<100	106	4.4	1.1	352	MRP-04327	C-215201
D	TB1-S8	15	0.77	<4	11	5.3	0.04	60	n.d.	16	<5	31	<40	<4	0.12	<100	106	4.4	<1	524	MRP-04327	C-215202
D	TB1-S9A	17	0.34	<4	13	4.7	0.028	42	3.15	11	<5	21	<40	<4	0.082	<100	77	4.6	1	280	MRP-04327	C-215203
D	TB1-S9B	17	0.86	<4	19	11	0.043	54	n.d.	11	7.5	12	<40	<4	0.019	<100	72	<2	<1	456	MRP-04327	C-215204
D	TB1-S10/S11/S12	21	1.4	<4	11	6.9	0.046	74	4.89	11	5.3	21	<40	<4	0.022	<100	58	<2	<1	371	MRP-04327	C-215205
D	TB1-S13	25	1	9.1	9.8	35	0.054	23	0.46	15	<5	148	<40	6.4	0.37	<100	99	9	1.3	897	MRP-04327	C-215206
E	98JHNPE*	0	1	0.3	n.d.	9.2	n.d.	84	1.2	7.3	n.d.	18	n.d.	0.09	n.d.	0.4	70	1.3	n.d.	440	MRP-01252	C-125899
E	TB20-S1 (HA)	1	1.2	<4	16	16	0.014	48	n.d.	13	5	14	<40	<4	0.063	<100	72	<2	<1	905	MRP-04327	C-215239
E	TB20-S2 (HA)	3	1.4	<4	12	14	0.02	53	1.76	14	<5	20	<40	<4	0.04	<100	72	<2	<1	450	MRP-04327	C-215240
E	TB20-S3 (HA)	4.85	1.5	<4	11	15	0.026	51	n.d.	12	<5	22	<40	<4	0.065	<100	63	<2	<1	493	MRP-04327	C-215241
F	98JHNPF*	0	0.85	0.6	n.d.	3	n.d.	76	4.96	6.5	n.d.	24	n.d.	0.23	n.d.	0.4	83	1.9	n.d.	420	MRP-01252	C-125900
F	TB21-S1	1	0.82	<4	15	7.2	0.078	42	n.d.	13	6.5	30	<40	<4	<0.005	<100	100	<2	<1	215	MRP-04327	C-215242
F	TB21-S2	3	0.91	<4	10	18	0.053	12	1.12	9.1	<5	124	<40	<4	0.33	<100	74	4.7	<1	88	MRP-04327	C-215243
F	TB21-S3	5	0.92	<4	11	20	0.068	14	n.d.	12	<5	130	<40	<4	0.29	<100	94	5.1	1.2	85	MRP-04327	C-215244
F	TB21-S4	6	1	9.6	7.6	36	0.057	14	n.d.	14	<5	182	<40	4	0.38	<100	114	6.9	1.1	86	MRP-04327	C-215245
F	TB21-S5	9.4	1.2	13	15	43	0.089	16	0.40	18	<5	227	<40	14	0.55	<100	142	14	1.8	120	MRP-04327	C-215246
F	TB7-S1	1	1	<4	12	6.7	0.047	43	n.d.	13	7.7	22	<40	<4	<0.005	<100	89	<2	<1	305	MRP-04327	C-215229
F	TB7-S2	3	0.87	<4	9.8	9.9	0.046	15	1.75	9.8	<5	115	<40	<4	0.2	<100	85	2.9	<1	77	MRP-04327	C-215230
F	TB7-S3	5	0.91	<4	6.2	12	0.032	6.7	1.49	8.8	<5	140	<40	<4	0.32	<100	91	2.5	<1	31	MRP-04327	C-215231
F	TB7-S3	5	0.9	<4	6	12	0.033	10	n.d.	8.8	<5	141	<40	<4	0.34	<100	90	3.3	<1	31	MRP-04327	C-215232
F	TB7-S4	7	0.87	<4	6.8	14	0.041	9.1	n.d.	9.6	<5	177	<40	<4	0.28	<100	88	3.2	<1	29	MRP-04327	C-215233
F	TB7-S5	8.75	0.94	<4	6.2	14	0.043	4.7	1.82	9.1	<5	182	<40	<4	0.29	<100	73	3.8	<1	34	MRP-04327	C-215234
F	TB7-S6	11.5	0.92	<4	8.8	15	0.052	4.3	n.d.	9.2	<5	215	<40	<4	0.26	<100	68	3.2	<1	94	MRP-04327	C-215235
F	TB7-S7	13.25	0.9	<4	8.6	16	0.047	6.2	2.27	9.8	<5	206	<40	<4	0.29	<100	68	5	1	90	MRP-04327	C-215236
F	TB7-S8	14.8	0.88	<4	10	16	0.068	6.5	n.d.	9.5	<5	248	<40	<4	0.27	<100	72	6	1	120	MRP-04327	C-215237
F	TB7-S9	23	1.2	7.8	25	37	0.061	14	<0.02	13	<5	368	<40	7.8	0.37	<100	90	21	2.4	63	MRP-04327	C-215238
G	02TP3G	0	1.1	<4	10	11	0.054	28	1.84	12	<5	72	<40	<4	<0.005	<100	97	3.2	<1	224	MRP-04326	C-215166

Pile	Sample	Depth	Na	Nb	Nd	Ni	P	Pb	S	Sc	Sn	Sr	Ta	Th	Ti	U	V	Y	Yb	Zn	Job No.	Lab No.
G	02TP3G-R	0	1.1	<4	9.4	11	0.051	27		11	<5	79	<40	<4	0.013	<100	96	3.1	<1	185	MRP-04326	C-215165
H	02TP3H	0	1	<4	15	9.8	0.042	26	1.78	11	5.3	57	<40	<4	0.12	<100	94	2.3	<1	205	MRP-04326	C-215167
H	02TP3H-R	0	0.96	<4	15	11	0.044	30		12	6.2	58	<40	<4	0.12	<100	90	<2	<1	203	MRP-04326	C-215168
H	TB6-S1 (HA)	1	0.91	<4	15	7.4	0.038	31	n.d.	11	<5	45	<40	<4	0.12	<100	98	<2	<1	214	MRP-04327	C-215221
H	TB6-S2 (HA)	3	0.78	<4	12	6	0.08	72	n.d.	12	<5	41	<40	<4	<0.005	<100	92	<2	<1	165	MRP-04327	C-215222
H	TB6-S3 (HA)	4.4	0.86	<4	16	15	0.057	179	n.d.	11	<5	39	<40	<4	<0.005	<100	82	<2	<1	202	MRP-04327	C-215223
H	TB6-S2	3	0.98	<4	17	24	0.048	96	5.72	11	7	44	<40	<4	0.034	<100	82	<2	<1	2,650	MRP-04327	C-215224
H	TB6-S3	5	0.98	<4	14	18	0.057	22	n.d.	14	<5	64	<40	<4	0.24	<100	107	4	1	1,220	MRP-04327	C-215225
H	TB6-S4/S5/S6	9	0.91	<4	14	16	0.07	17	2.50	12	<5	96	<40	<4	0.24	<100	96	6.3	1.3	267	MRP-04327	C-215226
H	TB6-S7	14	0.93	12	35	38	0.085	49	0.87	17	<5	194	<40	9.8	0.23	<100	104	17	3.5	629	MRP-04327	C-215227
H	TB6-S13/S14	26.6	0.93	<4	29	55	0.058	14	1.17	14	<5	388	<40	7.1	0.36	<100	102	23	2.4	336	MRP-04327	C-215228
TP4	02TP4	0	1.9	<4	12	27	0.051	32	1.23	19	5.8	71	<40	<4	0.23	<100	118	8.4	1.1	155	MRP-04326	C-215169
TILL	01 JH 26	0	1.2	10	27	44	0.06	10	0.04	10	<10	280	<80	10	0.36	<200	99	22	2	81	MRP-03762	C-200689

[1] The prefix "EMV-ROC" for soil boring filed numbers is omitted from the sample number for clarity. Soil borings, 02 series surface samples and till were analyzed by 40-element inductively coupled plasma-atomic emission spectrometry (ICP-AES) in USGS analytical laboratories. Analytical procedures and detection limits are reported by Briggs (2002) at: http://pubs.usgs.gov/of/2002/ofr-02-0223/G01fortyelementICP-AESsolid_M.pdf.
Samples marked with an "*" were analyzed by ICP-MS, as reported by Hammarstrom and others (1999). SQ samples are replicates for soil borings; -R samples are replicates for surface composites.

B-2: QA/QC data

QA/QC was monitored by analyzing NIST standard reference materials, field replicate samples, and laboratory duplicates. Field replicates are included as separate entries in Appendix B-1. Other reference materials are reported in Appendix B-2, along with 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). For laboratory duplicates, averages and standard deviations are reported.

		NIST Standard Reference Material SRM 2709				NIST Standard Reference Material SRM 2711				Laboratory duplicates				Laboratory duplicates			
Element	Units			CMF	(±)			CMF	(±)	C-215197	C-215197	Mean	(±)	C-215161	C-215161	Mean	(±)
		MRP-04326	MRP-04327	IMF		MRP-04326	MRP-04327	IMF		MRP-04327	MRP-04327			MRP-04326	MRP-04326		
Ag	ppm	< 2	< 2	0.41	0.03	5	5	4.63	0.39	11	11	11	0	16	17	17	1
Al	wt.%	7.5	7.4	7.5	0.06	6.5	6.5	6.5	0.09	4.2	4.2	4.2	0.0	4.1	4.0	4.1	0.1
As	ppm	19	19	17.7	0.8	95	94	105	8	< 10	< 10			22	12	17	7
Ba	ppm	950	950	968	40	720	730	726	38	30	33	32	2	35	35	35	0
Be	ppm	4	3			2	2	ND		< 1	< 1			< 1	< 1		
Bi	ppm	< 10	< 10			< 10	< 10	ND		< 10	< 10			< 10	< 10		
Ca	wt.%	1.9	1.9	1.89	0.05	2.8	2.9	2.88	0.08	0.43	0.42	0.43	0.01	0.38	0.36	0.37	0.01
Cd	ppm	< 2	< 2	0.38	0.01	42	42	41.70	0.25	4	4	4	0	< 2	< 2		
Ce	ppm	47	46	42		75	75	69		< 4	< 4			< 4	< 4		
Co	ppm	13	14	13.4	0.7	10	10	10		25	24	25	1	44	45	45	1
Cr	ppm	120	120	130	4	42	44	47		90	88	89	1	66	63	65	2
Cu	ppm	32	33	34.6	0.7	110	110	114	2	3200	3100	3150	71	1000	1100	1050	71
Eu	ppm	< 2	< 2			< 2	< 2	1.1		< 2	< 2			< 2	< 2		
Fe	wt.%	3.5	3.6	3.5	0.11	2.8	2.9	2.89	0.06	20	19	20	1	20	20	20	0
Ga	ppm	12	13	14		13	12	15		< 4	< 4			6	4	5	1
Ho	ppm	< 4	< 4	0.54		< 4	< 4	1		< 4	< 4			< 4	< 4		
K	wt.%	1.9	2.0	2.03	0.06	2.3	2.5	2.45	0.08	1.7	1.6	1.7	0.1	1.2	1.2	1.2	0.0
La	ppm	24	24			39	39	40		< 2	< 2			< 2	< 2		
Li	ppm	55	55			27	27	ND		10	10	10	0	10	10	10	0
Mg	wt.%	1.5	1.5	1.51	0.05	1.0	1.0	1.05	0.03	0.74	0.72	0.73	0.01	0.31	0.31	0.31	0.00
Mn	ppm	540	550	538	17	620	640	638	28	160	160	160	0	200	200	200	0
Mo	ppm	3	4	2		4	4	1.6		29	31	30	1	88	89	89	1
Na	wt.%	1.2	1.2	1.16	0.03	1.2	1.2	1.14	0.03	2.4	2.4	2.4	0.0	1.3	1.3	1.3	0.0

		NIST Standard Reference Material SRM 2709				NIST Standard Reference Material SRM 2711				Laboratory duplicates				Laboratory duplicates			
Nb	ppm	19	16			26	24	ND		< 4	< 4			< 4	< 4		
Nd	ppm	18	18	19		31	31	31		10	10	10	0	12	12	12	0
Ni	ppm	73	75	88	5	19	19	20.6	1.1	5	5	5	0	12	12	12	0
P	wt.%	0.063	0.064	0.062	0.005	0.083	0.081	0.086	0.007	0.050	0.049	0.050	0.001	0.015	0.015	0.015	0.000
Pb	ppm	16	18	18.9	0.5	1100	1100	1162	31	40	36	38	3	92	93	93	1
Sc	ppm	12	12	12		10	10	9		14	14	14	0	14	14	14	0
Sn	ppm	< 5	< 5			8	< 5	ND		< 5	< 5			5	< 5		
Sr	ppm	220	220	231	2	240	240	245.3	0.7	24	24	24	0	20	20	20	0
Ta	ppm	< 40	< 40			< 40	< 40	ND		< 40	< 40			< 40	< 40		
Th	ppm	10	11	11		14	15	14		< 4	< 4			< 4	< 4		
Ti	wt.%	0.34	0.34	0.342	0.024	0.29	0.28	0.306	0.023	0.095	0.084	0.090	0.008	0.059	0.058	0.059	0.001
U	ppm	< 100	< 100	3		< 100	< 100	2.6		< 100	< 100			< 100	< 100		
V	ppm	110	110	112	5	80	80	81.6	2.9	120	120	120	0	91	91	91	0
Y	ppm	19	17	18		29	26	25		< 2	< 2			< 2	< 2		
Yb	ppm	2	2	1.6		3	3	2.7		< 1	< 1			< 1	< 1		
Zn	ppm	110	110	106	3	350	350	350.4	4.8	200	200	200	0	420	420	420	0

Mineralogy of TP3 mine waste
Quantitative estimates of mineral percentages based on Rietveld refinement of powder X-ray diffraction patterns using Siroquant.
Concentrations reported in weight %.

Pile	Sample	Depth (ft)	Quartz	Albite	Anorthite	Labradorite	Biotite	Muscovite	Chlorite	Clay	Talc	Hydrobiotite	Tremolite	Calcite	Goethite	Hematite
A	02TP3A	0	15.70	19.30	7.10		0.00	3.00	0.10	1.10	2.70		0.00		15.20	0.00
A	98JHNPA*	0	17.90	20.50	4.40		0.00	6.60	0.00					0.00		0.10
A	TB3-S1	1	15.30	15.90	9.60	0.00	0.00	6.80	0.00	0.80	5.20	0.10	1.80	0.00	11.80	0.80
A	TB3-S2	3	13.60	12.40	10.10	0.00	0.00	6.10	0.00	0.90	1.70	0.00	2.60	0.00	14.50	0.00
A	TB3-SQ2	3	17.40	9.60	11.10	0.00	0.00	6.40	0.00	1.20	1.60	0.10	1.80	0.00	15.60	0.00
A	TB3-S3	5	20.50	3.80	6.80	0.00	0.00	16.70	0.00	1.00	2.10	0.00	3.90	0.00	19.10	0.00
A	TB3-S5/S6	10	8.80	10.00	7.50	2.10	0.00	7.50	0.90	1.20	0.10	0.10	4.50	0.00	19.90	0.00
A	TB3-S7	13	19.00	3.60	8.00	0.20	5.70	7.00	11.30	0.20	0.00	0.10	0.60	0.00	19.50	1.30
A	TB3-S8/S9	16	35.10	2.70	0.00	16.60	0.60	7.10	0.00	1.60	1.10	11.20	0.30	0.00	15.40	0.00
B	02TB3B	0	5.20	2.10	2.40		0.00	0.10	0.40	0.20	1.20	0.10	2.40		1.20	77.30
B	98JHNPB*	0	7.70	2.50	0.50	0.70	0.20	0.80	0.00	0.90	0.70	0.00	1.50	0.10	1.30	74.50
B	TB5-S2/S3	4	6.60	0.00	1.80	4.20	0.00	0.00	1.00	1.80	1.30	0.10	0.00		13.70	58.30
B	TB5-S4/S5	7.5	15.40	2.50	4.10	2.00	0.50	2.30	0.00	1.80	1.50	0.00	3.70		1.50	54.40
B	TB5-S5	9.25	37.50	2.10	3.90	21.50	1.50	2.60	0.00	0.50	0.00	0.00	3.90		0.00	4.70
B	TB5-S5/S6	9.9	34.20	4.40	1.80	29.30	9.10	3.10	0.10	0.40	0.70	0.90	2.20		0.00	2.30
C	02TP3C	0	21.00	10.30	0.10	1.00	0.50	8.90	0.80	0.00	2.90	0.10	3.00		8.10	38.00
C	98JHNPC*	0	13.00	13.70	0.00	1.30	0.00	7.00	0.00		3.70	0.00	3.50	0.10	12.60	34.50
C	TB4-S1	1	25.40	9.30	0.00	0.40	0.00	10.40	0.00	1.00	0.80	0.10	4.50		8.30	32.90
C	TB4-S1 Rep	1	24.50	13.20	0.00	1.40	0.10	10.40	0.00	1.30	2.40	0.10	2.30		7.30	29.50
C	TB4-S2	3	26.00	9.20	0.00	1.80	0.00	9.50	0.00	1.10	0.30	0.10	3.70	0.00	6.60	28.60
C	TB4-S3	4.5	24.80	6.40	0.00	6.20	0.40	10.20	0.00	0.40	0.30	0.00	4.30	2.00	2.20	29.60
C	TB4-S4	6.3	38.20	0.00	0.00	28.40	21.20	3.70	0.00	0.50	1.10	1.80	0.00		1.00	0.00
D	98JHNPD*	0	22.70	21.70	0.00	1.30	0.30	7.00	0.40	0.70	2.50	0.10	4.60	0.00	16.10	0.00
D	TB1-S1/S2	2	8.30	23.70	1.30	0.00	0.00	8.80	0.90	0.10	0.00	6.80	1.50	0.00	13.80	0.00
D	TB1-S3	5	8.10	17.20	4.80	0.00	0.00	7.20	0.00	1.10	5.60	0.30	2.20	0.00	9.50	1.30
D	TB1-SQ3	5	9.00	17.10	10.10	0.00	0.00	7.70	0.00	1.10	4.90	0.30	0.80	0.00	13.20	0.00
D	TB1-S4/S5/S6	9	8.30	22.00	5.70	0.00	0.00	5.00	0.00	1.20	8.30	3.30	0.30	0.00	11.80	0.00

Pile	Sample	Depth (ft)	Quartz	Albite	Anorthite	Labradorite	Biotite	Muscovite	Chlorite	Clay	Talc	Hydrobiotite	Tremolite	Calcite	Goethite	Hematite
D	TB1-S7	13	12.20	9.30	2.00	15.40	0.00	0.00	0.00	0.30	5.00	0.20	5.50	5.80	5.80	0.00
D	TB1-S8	15	31.90	5.70	4.60	0.00	0.00	25.50	2.40	1.50	0.00	0.00	0.00	0.00	6.60	0.00
D	TB1-S9A	17	45.90	2.60	0.10	0.00	0.00	25.30	0.50	1.00	0.70	0.00	0.00	0.00	2.10	1.50
D	TB1-S10/S11/S12	21	24.30	10.00	9.30	0.00	0.00	6.90	0.00	0.40	0.00	0.00	0.70	0.00	10.70	7.00
D	TB1-S13	25	53.70	6.70	7.80	1.00	3.40	11.80	1.70	0.10	0.00	5.70	3.70	0.00	0.40	0.70
E	98JHNPE*	0	19.50	12.50	0.00	1.90	0.00	3.60	0.30	0.40	1.30	0.00	4.50	0.00	11.30	37.40
E	TB20-S1 (HA)	1	16.80	4.00	0.00	4.70	0.80	8.90	2.40	1.00	2.30	0.00	4.50	0.50	5.30	40.30
E	TB20-S2 (HA)	3	22.70	9.30	4.50	1.70	1.10	8.30	0.30	0.70	1.40	0.10	2.90	0.00	4.10	33.70
E	TB20-S3 (HA)	4.85	25.00	10.10	4.60	1.40	0.60	6.70	0.00	0.40	1.00	0.00	2.70	0.00	2.40	41.10
F	98JHNPF*	0	20.00	11.50	0.00	1.40	0.00	8.90	0.00	1.10	5.40	0.20	3.00	0.00	25.10	1.90
F	TB7-S1	1	26.30	8.80	0.80	0.70	1.70	9.60	0.00	2.20	0.00	0.10	1.30	0.00	28.30	5.60
F	TB21-S1	1	26.30	8.00	1.70	0.00	0.00	13.50	1.20	0.40	2.80	0.10	0.90	0.00	24.60	0.00
F	TB7-S2	3	46.40	2.80	0.00	7.20	0.50	10.10	0.00	1.50	0.00	0.10	3.80	0.00	15.40	0.00
F	TB21-S2	3	56.80	4.40	0.50	10.80	0.70	12.00	0.30	0.70	2.80	0.40	2.60	0.20	3.20	0.00
F	TB7-S3	5	50.80	3.80	0.50	8.30	1.30	15.10	0.00	1.60	2.60	0.10	4.00	0.00	1.90	0.00
F	TB7-S3	5	53.70	3.00	1.00	7.20	1.40	13.30	0.80	1.70	1.90	0.20	3.30	0.00	1.90	0.00
F	TB21-S3	5	49.00	3.40	0.00	12.20	0.80	10.20	0.20	0.10	1.40	8.10	3.70	0.00	6.70	0.00
F	TB21-S4	6	43.50	3.80	0.00	11.30	3.70	17.60	2.00	0.50	1.10	8.60	3.60	0.00	1.30	0.00
F	TB21-S5	9.4	44.00	4.30	2.50	11.00	7.20	16.40	2.00	0.00	0.90	0.40	9.30	0.00	0.00	0.00
F	TB7-S4	7	52.90	1.80	1.30	8.60	1.70	11.60	0.40	0.40	2.10	0.10	4.90	0.00	2.40	0.00
F	TB7-S5	8.75	52.50	1.70	1.40	10.30	0.00	8.80	0.90	0.20	0.60	0.60	4.90	0.00	2.40	0.00
F	TB7-S6	11.5	51.20	1.70	0.90	7.50	1.30	6.90	0.30	1.20	1.10	0.10	4.70	0.00	2.50	0.00
F	TB7-S7	13.25	46.50	1.00	1.00	9.40	2.10	10.50	0.00	2.50	0.70	0.20	5.50	0.00	1.30	0.00
F	TB7-S8	14.8	43.30	2.70	0.00	9.80	1.60	9.40	0.00	2.50	2.30	0.10	5.60	0.00	2.70	0.00
F	TB7-S9	23	48.20	3.10	0.30	14.30	6.50	11.60	0.30	3.20	1.80	0.20	4.60	4.90	0.00	0.00
G	02TP3G	0	39.10	5.10	2.00	7.30	0.60	12.80	0.00	0.50	0.00	0.10	3.50		20.40	0.60
G	02TP3G-R	0	39.80	4.90	1.70	7.70	0.80	9.20	0.30	0.10	1.80	0.30	4.80		21.60	0.30
H	02TP3H	0	27.70	9.90	0.00	4.20	0.30	9.80	0.00	1.20	0.90	0.10	1.40		32.30	2.40
H	02TP3H-R (SB6)	0	29.30	12.10	0.00	0.10	0.00	10.90	1.70	2.10	0.40	0.00	2.20		28.90	3.00
H	TB6-S1 (HA)	1	28.20	10.40	0.00	1.20	0.80	7.50	0.00	0.70	0.00	0.20	2.80		33.00	0.80

APPENDIX C

Pile	Sample	Depth (ft)	Quartz	Albite	Anorthite	Labradorite	Biotite	Muscovite	Chlorite	Clay	Talc	Hydrobiotite	Tremolite	Calcite	Goethite	Hematite
H	TB6-S2 (HA)	3	28.00	5.60	0.10	0.30	0.90	12.10	1.40	0.60	0.00	0.10	1.60	0.00	23.30	0.00
H	TB6-S2	3	21.00	6.30	4.30	3.90	1.00	6.10	2.10	2.00	0.90	0.20	1.60		25.60	1.20
H	TB6-S3 (HA)	4.4	27.30	8.00	0.00	0.00	0.50	8.60	0.80	1.00	0.00	0.00	1.60		30.00	0.70
H	TB6-S3	5	30.50	7.00	0.00	7.00	0.60	9.80	0.00	2.50	0.00	0.00	3.50		24.50	0.00
H	TB6-S4/S5/S6	9	36.90	6.20	0.90	2.80	0.20	11.50	1.10	0.00	2.90	4.50	2.30		16.50	0.00
H	TB6-S7	14	52.60	5.00	0.00	9.90	1.50	12.60	2.20	0.00	3.20	0.30	6.20	1.20	1.70	0.00
H	TB6-S13/S14	26.6	41.90	1.90	1.60	10.20	6.00	18.00	2.80	0.60	1.10	0.20	4.90	2.90	0.40	0.00

Pile	Sample	Depth (ft)	Jarosite	Alunogen	Copiapite	Melanterite	Rozenite	Gypsum	Chalcopyrite	Pyrite	Pyrrhotite	Sphalerite	chi^{2} [1]
A	02TP3A	0	27.00	0.00		0.40	0.60	1.30	1.90	0.00	3.00	1.50	6.26
A	98JHNPA*	0	24.60	0.60	0.60	0.50		1.20	1.20				6.28
A	TB3-S1	1	30.10	0.00	0.00	0.00	0.00	0.80	0.50	0.00	0.10	0.50	6.22
A	TB3-S2	3	36.20	0.20	0.00	0.00	0.00	0.60	0.40	0.00	0.20	0.60	5.47
A	TB3-SQ2	3	34.10	0.00	0.10	0.00	0.00	0.00	0.40	0.00	0.20	0.20	5.25
A	TB3-S3	5	21.20	0.00	0.30	0.00	0.10	2.00	1.00	0.00	0.20	1.20	5.01
A	TB3-S5/S6	10	27.30	0.20	0.00	0.00	0.00	8.90	0.30	0.00	0.20	0.50	4.61
A	TB3-S7	13	20.90		0.00	0.00	0.00	0.90	0.90	0.00	0.20	0.50	4.85
A	TB3-S8/S9	16	5.80	0.30	0.60	0.40	0.00	0.60	0.20	0.00	0.20	0.30	5.11
B	02TB3B	0	6.30	0.00	0.30	0.00	0.10	0.20	0.00	0.00	0.20	0.20	3.17
B	98JHNPB*	0	6.50	0.30	0.20	0.30	0.40	0.30	0.00	0.00	0.00	0.20	3.00
B	TB5-S2/S3	4	7.90	0.30	0.00	0.30	0.30	0.80	0.00	0.00	1.20	0.50	3.53
B	TB5-S4/S5	7.5	8.80	0.00	0.20	0.00	0.00	0.80	0.10	0.00	0.20	0.30	3.26
B	TB5-S5	9.25	20.30	0.00	0.00	0.00	0.20	0.50	0.10	0.00	0.10	0.40	5.25
B	TB5-S5/S6	9.9	10.80	0.00	0.00	0.00	0.30	0.00	0.10	0.00	0.10	0.20	6.38
C	02TP3C	0	3.70	0.00	0.30	0.00	0.00	0.60	0.30	0.30	0.00	0.20	4.19
C	98JHNPC*	0	7.40	0.00		0.00	0.00	0.20	0.30	0.50	0.80	0.10	4.07
C	TB4-S1	1	5.80		0.20	0.00	0.00	0.20	0.40	0.00	0.10	0.20	3.91
C	TB4-S1 Rep	1	5.30	0.50	0.10	0.10	0.30	0.30	0.20	0.60	0.10	0.00	3.89

Pile	Sample	Depth (ft)	Jarosite	Alunogen	Copiapite	Melanterite	Rozenite	Gypsum	Chalcopyrite	Pyrite	Pyrrhotite	Sphalerite	chi^2 [1]
C	TB4-S2	3	10.30	0.40	0.00	0.10	0.00	0.40	1.30	0.00	0.10	0.40	4.23
C	TB4-S3	4.5	3.70	0.90	0.50	0.30	0.40	1.00	4.00	1.90	0.10	0.30	4.50
C	TB4-S4	6.3	2.90	0.00	0.30	0.50	0.20	0.00	0.00	0.00	0.10	0.00	5.28
D	98JHNPD*	0	19.90	0.70	0.20	0.00	0.00	0.50	0.50	0.00	0.00	0.60	4.59
D	TB1-S1/S2	2	32.40	0.00	0.60	0.40	0.00	0.00	0.60	0.00	0.20	0.60	4.16
D	TB1-S3	5	36.80	0.00	0.30	0.30	0.00	2.40	0.90	0.00	0.20	1.90	5.63
D	TB1-SQ3	5	30.40	0.00	0.20	0.00	0.00	2.90	0.80	0.00	0.20	1.30	5.33
D	TB1-S4/S5/S6	9	25.50	0.00	0.00	0.00	0.00	7.20	1.00	0.00	0.20	0.20	5.75
D	TB1-S7	13	33.70	0.00	0.00	0.40	0.30	1.00	2.80	0.00	0.20	0.00	5.11
D	TB1-S8	15	10.40	1.00	0.00	0.00	0.00	9.60	0.30	0.00	0.10	0.30	5.34
D	TB1-S9A	17	10.20	0.00	0.30	0.40	0.20	8.50	0.20	0.00	0.10	0.40	4.43
D	TB1-S10/S11/S12	21	26.60	0.00	0.20	0.00	0.00	2.20	0.80	0.00	0.20	0.60	4.73
D	TB1-S13	25	2.10	0.00	0.00	0.30	0.70	0.00	0.00	0.00	0.10	0.10	5.73
E	98JHNPE*	0	5.40	0.60	0.00	0.00	0.00	0.40	0.20	0.60	0.10	0.00	4.03
E	TB20-S1 (HA)	1	6.90	0.00	0.00	0.40	0.00	0.50	0.00	0.00	0.50	0.10	4.53
E	TB20-S2 (HA)	3	7.90	0.00	0.10	0.00	0.00	0.10	0.40	0.70	0.10	0.00	3.97
E	TB20-S3 (HA)	4.85	2.80	0.00	0.60	0.00	0.00	0.00	0.30	0.10	0.10	0.00	4.01
F	98JHNPF*	0	13.60	0.90	0.60	0.50	0.00	1.10	1.70	0.00	2.60	0.40	5.42
F	TB7-S1	1	11.60	0.40	0.20	0.00	0.00	0.70	1.20	0.00	0.20	0.30	3.84
F	TB21-S1	1	16.80	0.30	0.30	0.30	0.00	0.40	1.90	0.00	0.20	0.10	4.12
F	TB7-S2	3	9.40	0.00	0.40	0.50	0.60	0.00	0.60	0.00	0.20	0.50	4.62
F	TB21-S2	3	3.10	0.30	0.30	0.00	0.00	0.60	0.10	0.00	0.10	0.00	4.03
F	TB7-S3	5	8.40		0.00	0.10	0.00	0.70	0.30	0.00	0.10	0.40	4.44
F	TB7-S3	5	7.50		0.40	0.30	0.90	0.50	0.30	0.00	0.40	0.30	4.53
F	TB21-S3	5	3.30	0.30	0.30	0.00	0.00	0.20	0.00	0.00	0.10	0.00	5.02
F	TB21-S4	6	1.50	0.50	0.30	0.00	0.00	0.30	0.30	0.00	0.10	0.00	5.44
F	TB21-S5	9.4	0.70	0.00	0.00	0.00	0.00	0.20	0.40	0.00	0.40	0.10	5.48
F	TB7-S4	7	10.20	0.00	0.60	0.00	0.10	0.40	0.10	0.00	0.10	0.10	4.72
F	TB7-S5	8.75	12.30	0.20	1.00	0.20	0.10	0.90	0.30	0.00	0.10	0.50	4.55
F	TB7-S6	11.5	12.40		0.00	0.50	0.00	6.50	0.40	0.00	0.10	0.60	4.88

Pile	Sample	Depth (ft)	Jarosite	Alunogen	Copiapite	Melanterite	Rozenite	Gypsum	Chalcopyrite	Pyrite	Pyrrhotite	Sphalerite	chi^2 [1]
F	TB7-S7	13.25	13.60	0.20	0.00	0.00	0.00	4.60	0.30	0.00	0.10	0.50	5.19
F	TB7-S8	14.8	9.30		0.00	0.00	0.00	10.10	0.10	0.00	0.10	0.10	5.44
F	TB7-S9	23	0.00	0.00	0.00	0.10	0.00	0.10	0.70	0.00	0.10	0.10	5.66
G	02TP3G	0	5.60	0.00	0.60	0.00	0.00	0.70	0.60	0.00	0.30	0.10	5.01
G	02TP3G-R	0	4.90		0.20	0.00	0.20	0.30	0.30	0.00	0.50	0.10	4.57
H	02TP3H	0	8.90		0.20	0.00	0.20	0.10	0.00	0.00	0.20	0.20	4.76
H	02TP3H-R (SB6)	0	7.40	0.50	0.60	0.00	0.00	0.00	0.30	0.00	0.20	0.40	4.65
H	TB6-S1 (HA)	1	12.90		0.40	0.10	0.00	0.50	0.20	0.00	0.20	0.30	4.14
H	TB6-S2 (HA)	3	23.00	0.30	0.00	0.00	0.00	0.50	1.60	0.00	0.20	0.30	4.26
H	TB6-S2	3	21.80		0.00	0.00	0.00	0.60	0.40	0.00	0.20	0.70	4.01
H	TB6-S3 (HA)	4.4	19.10	0.50	0.00	0.30	0.00	0.50	0.20	0.00	0.20	0.40	3.96
H	TB6-S3	5	11.90	0.60	0.40	0.50	0.00	0.60	0.00	0.00	0.20	0.30	4.43
H	TB6-S4/S5/S6	9	13.20	0.00	0.10	0.00	0.00	0.30	0.20	0.00	0.20	0.30	4.79
H	TB6-S7	14	1.00	0.90	0.00	0.40	0.00	0.60	0.60	0.00	0.10	0.10	5.95
H	TB6-S13/S14	26.6	0.00	0.80	0.00	0.30	0.40	5.10	0.30	0.00	0.20	0.00	4.81

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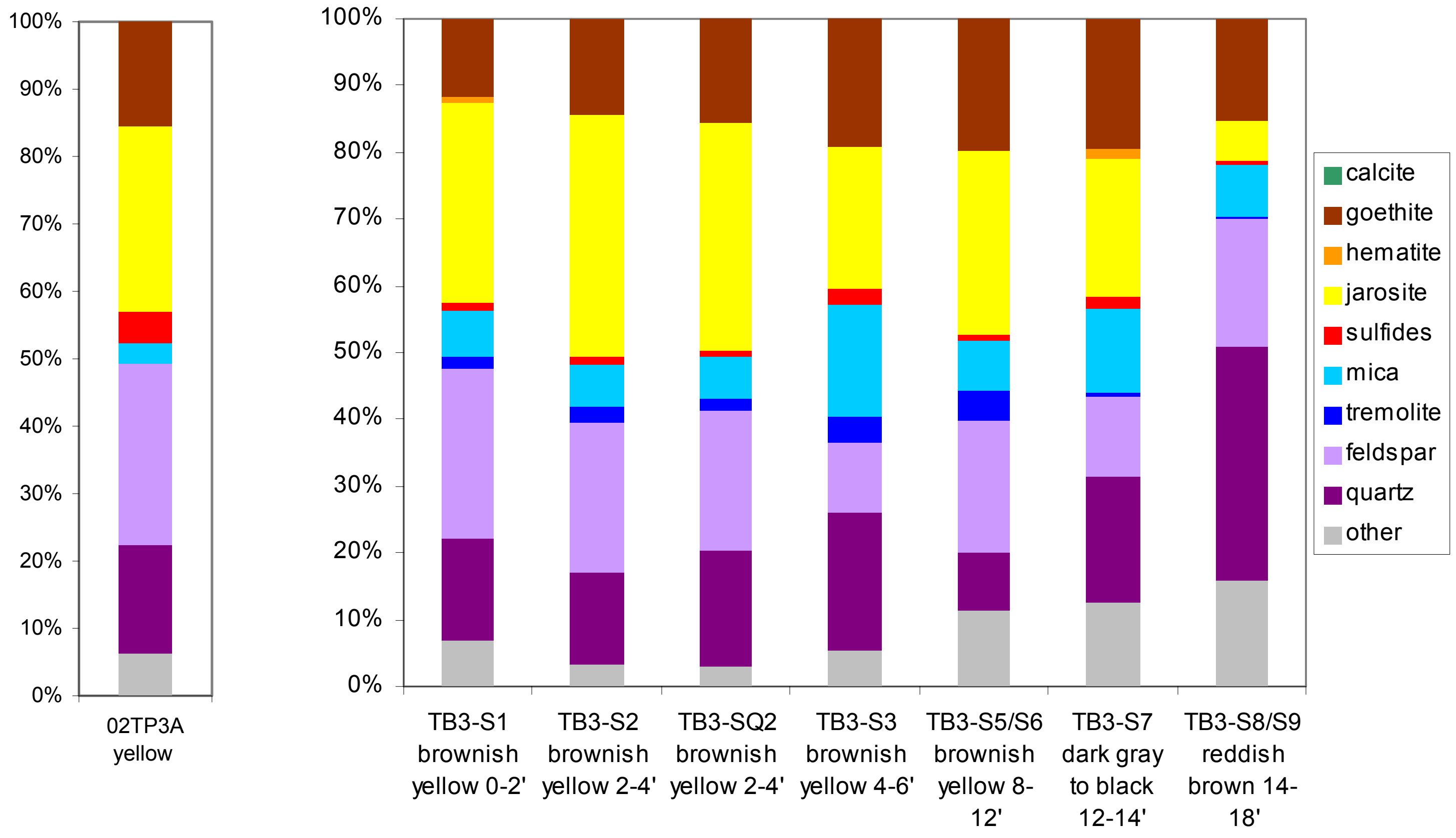
[1] Chi^2 is a computed statistical residual, which is used as a measure of the fit of the refinement. Chi^2 =1 for a perfect correlation between the least-squares model and the observed data. In complex natural mixtures, ideal values are almost never observed due to systematic errors and imperfect physical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

APPENDIX C

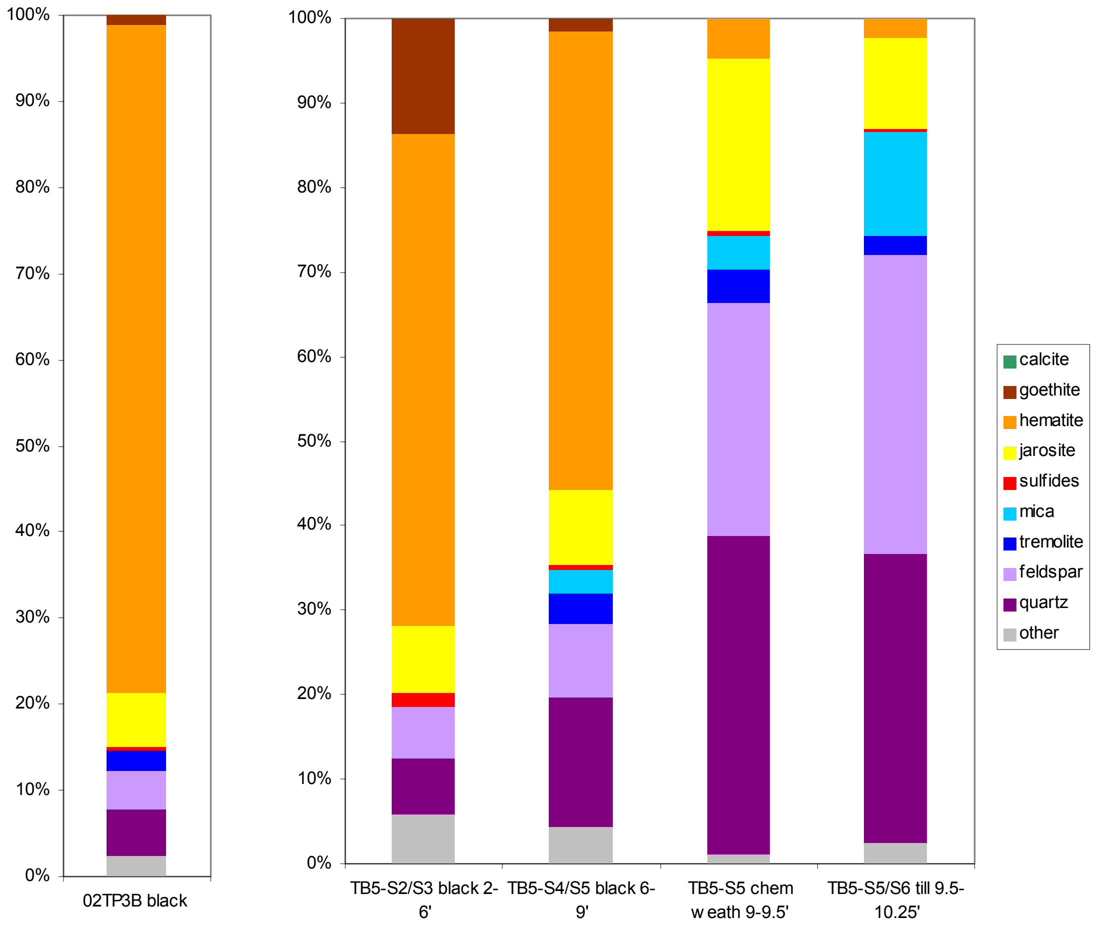
Bar charts

The following pages contain a series of colored bar charts showing the relative percentage of different minerals present in TP3 mine waste. Results for the surface composite sample are shown on the left. Results for soil borings are shown with color and depth interval indicated at the bottom of each column of the bar chart. Changes in the height of a color band show the relative changes in the amount of a given mineral through the pile. Talc, chlorite, gypsum, and efflorescent salts are grouped as “other” on the bar charts.

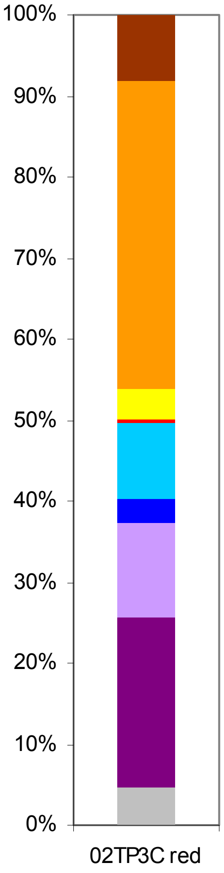
TP3 A

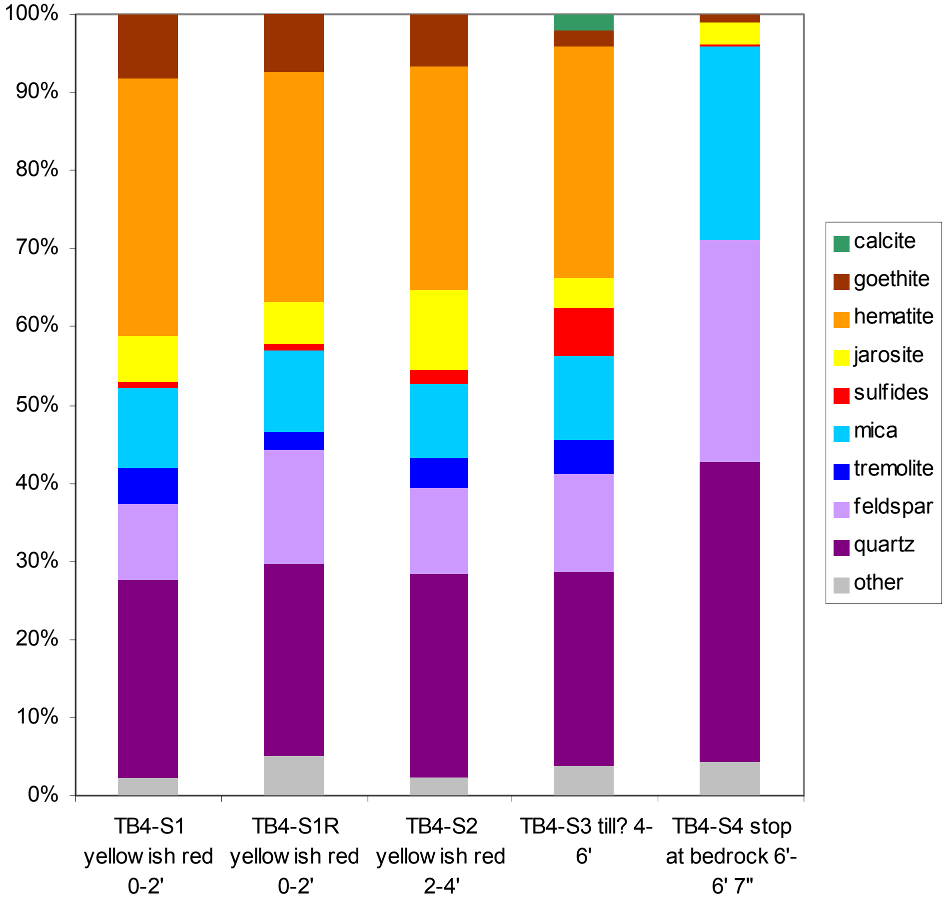

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
02TP3A yellow
TB3-S1 brownish yellow 0-2'
TB3-S2 brownish yellow 2-4'
TB3-SQ2 brownish yellow 2-4'
TB3-S3 brownish yellow 4-6'
TB3-S5/S6 brownish yellow 8-12'
TB3-S7 dark gray to black 12-14'
TB3-S8/S9 reddish brown 14-18'
calcite
goethite
hematite
jarosite
sulfides
mica
tremolite
feldspar
quartz
other

TP3 B

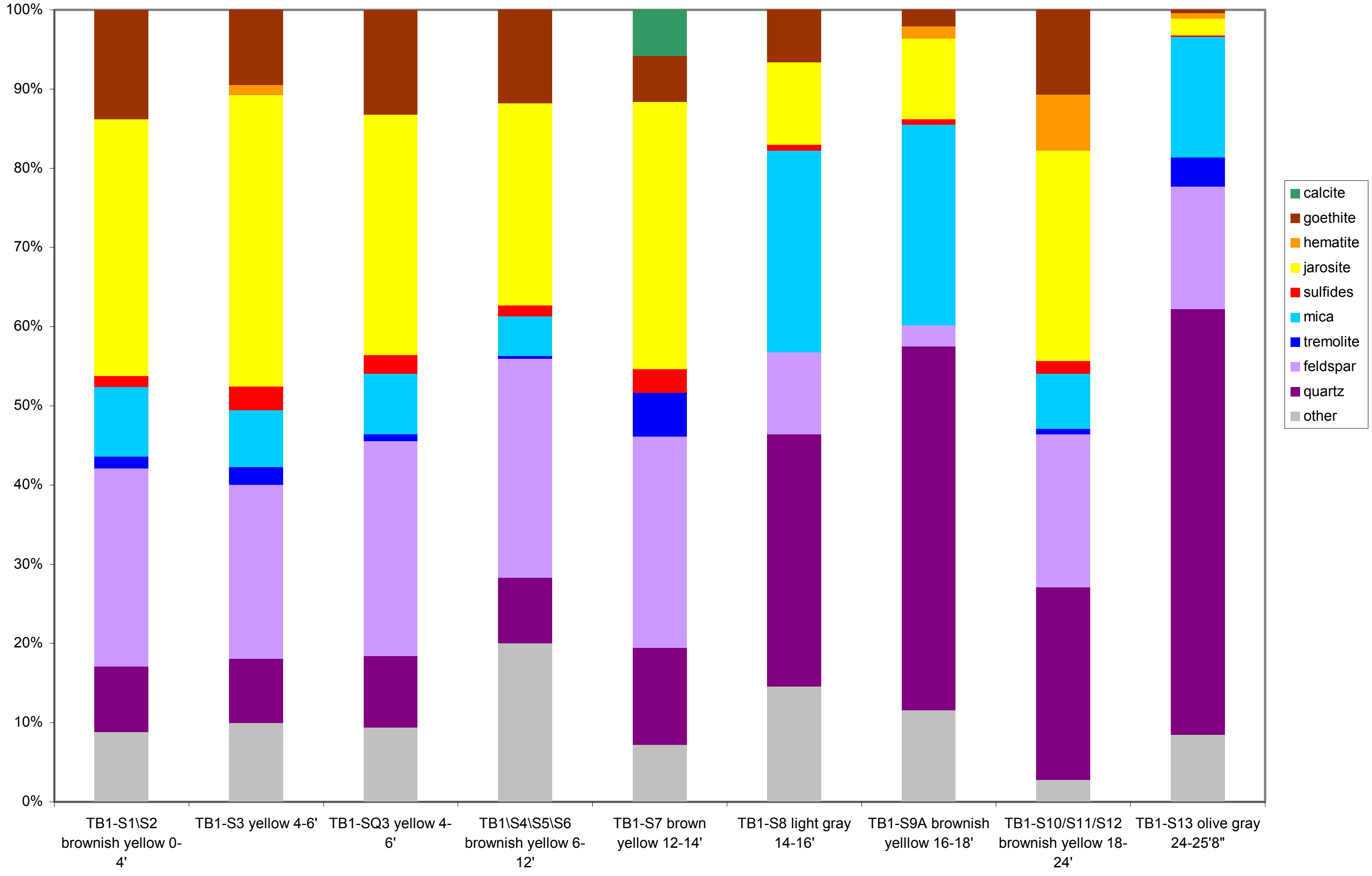

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
02TP3B black
TB5-S2/S3 black 2-6'
TB5-S4/S5 black 6-9'
TB5-S5 chem w eath 9-9.5'
TB5-S5/S6 till 9.5-10.25'
calcite
goethite
hematite
jarosite
sulfides
mica
tremolite
feldspar
quartz
other

TP 3 C

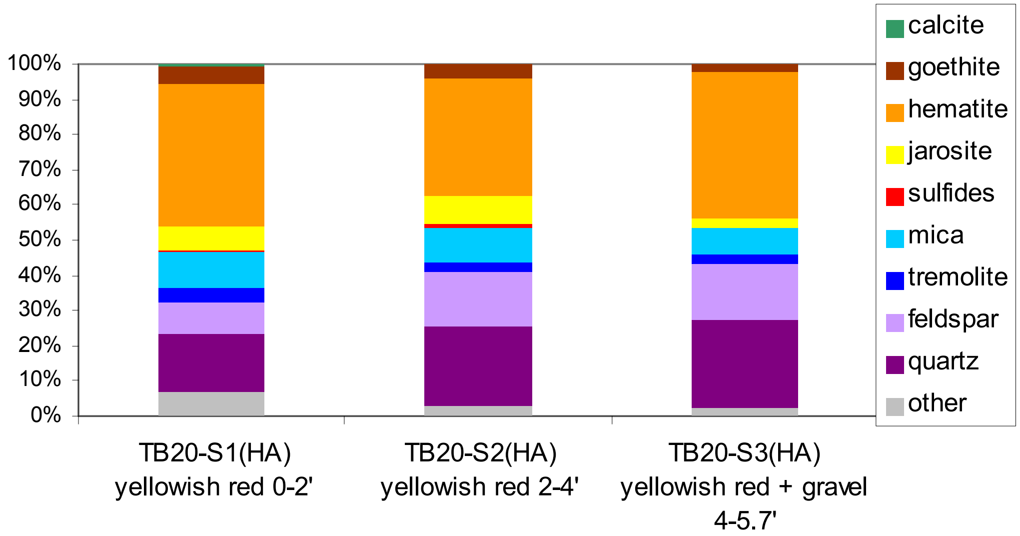

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
02TP3C red

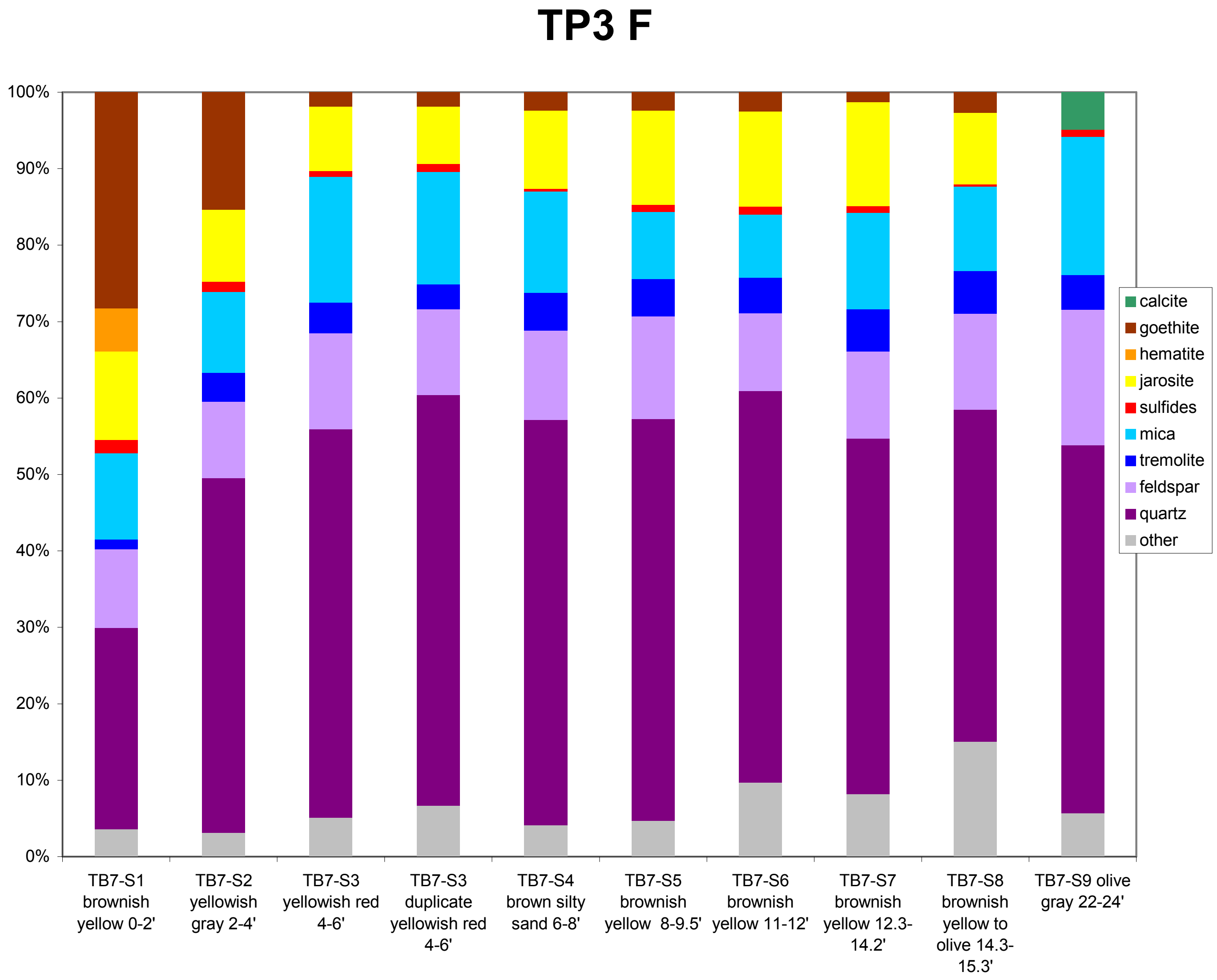

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
TB4-S1 yellow ish red 0-2'
TB4-S1R yellow ish red 0-2'
TB4-S2 yellow ish red 2-4'
TB4-S3 till? 4-6'
TB4-S4 stop at bedrock 6'-6' 7"
calcite
goethite
hematite
jarosite
sulfides
mica
tremolite
feldspar
quartz
other

TP3 D

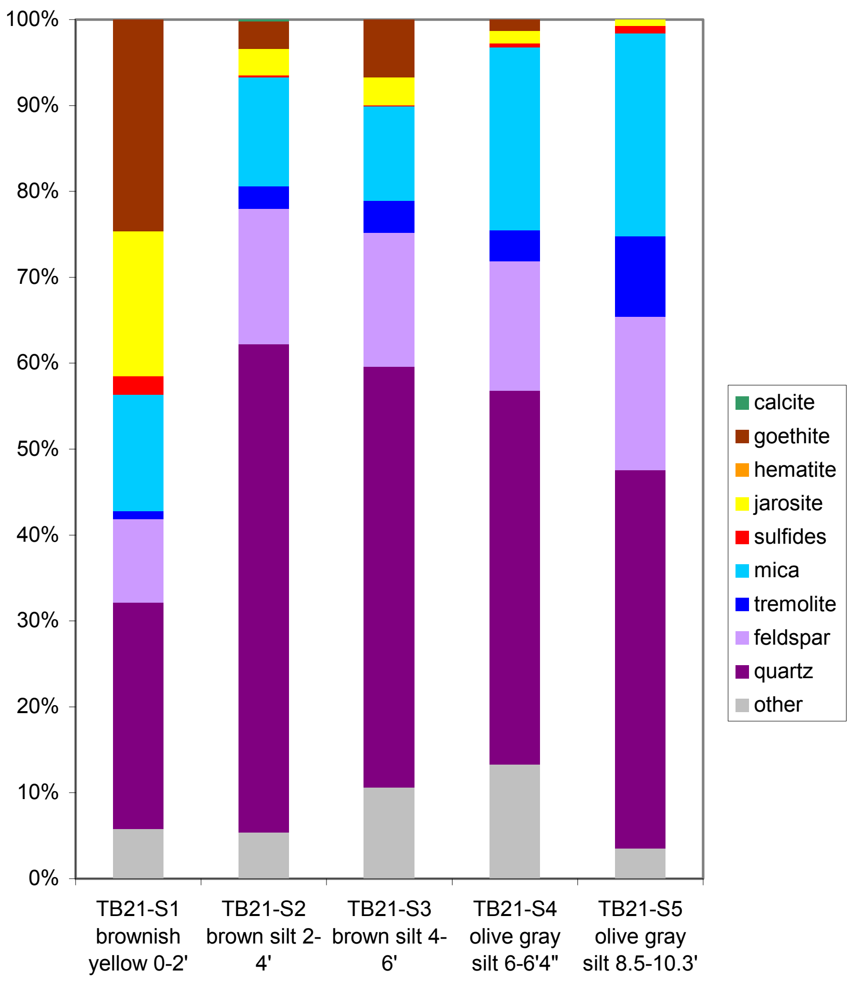

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
TB1-S1\S2 brownish yellow 0-4'
TB1-S3 yellow 4-6'
TB1-SQ3 yellow 4-6'
TB1\S4\S5\S6 brownish yellow 6-12'
TB1-S7 brown yellow 12-14'
TB1-S8 light gray 14-16'
TB1-S9A brownish yelllow 16-18'
TB1-S10/S11/S12 brownish yellow 18-24'
TB1-S13 olive gray 24-25'8"
calcite
goethite
hematite
jarosite
sulfides
mica
tremolite
feldspar
quartz
other

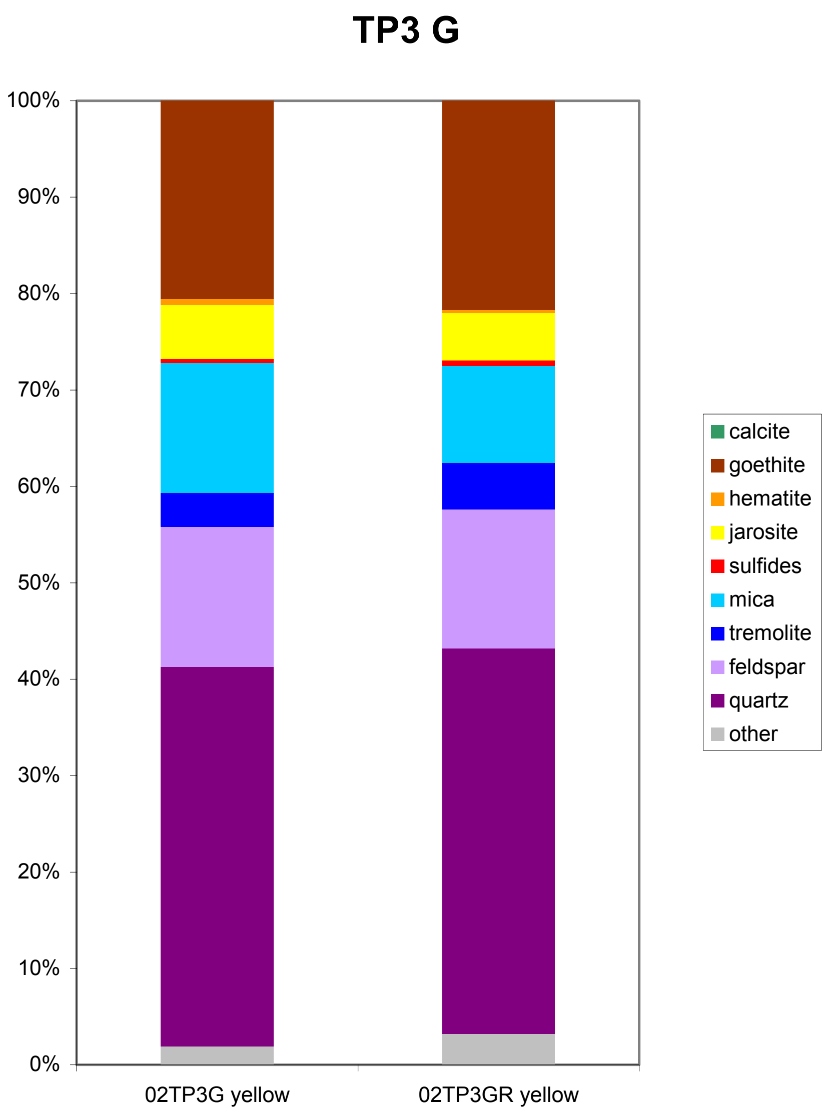
TP3 E


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
TB20-S1(HA) yellowish red 0-2'
TB20-S2(HA) yellowish red 2-4'
TB20-S3(HA) yellowish red + gravel 4-5.7'
calcite
goethite
hematite
jarosite
sulfides
mica
tremolite
feldspar
quartz
other

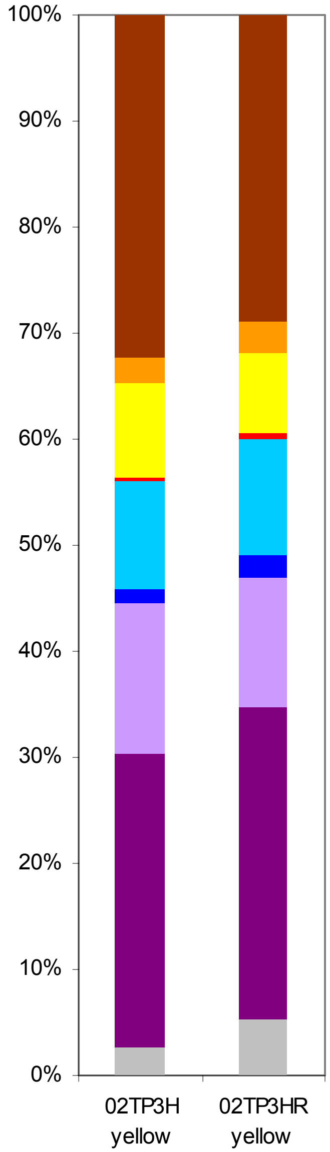

TP3 F
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
calcite
goethite
hematite
jarosite
sulfides
mica
tremolite
feldspar
quartz
other
TB7-S1 brownish yellow 0-2'
TB7-S2 yellowish gray 2-4'
TB7-S3 yellowish red 4-6'
TB7-S3 duplicate yellowish red 4-6'
TB7-S4 brown silty sand 6-8'
TB7-S5 brownish yellow 8-9.5'
TB7-S6 brownish yellow 11-12'
TB7-S7 brownish yellow 12.3-14.2'
TB7-S8 brownish yellow to olive 14.3-15.3'
TB7-S9 olive gray 22-24'

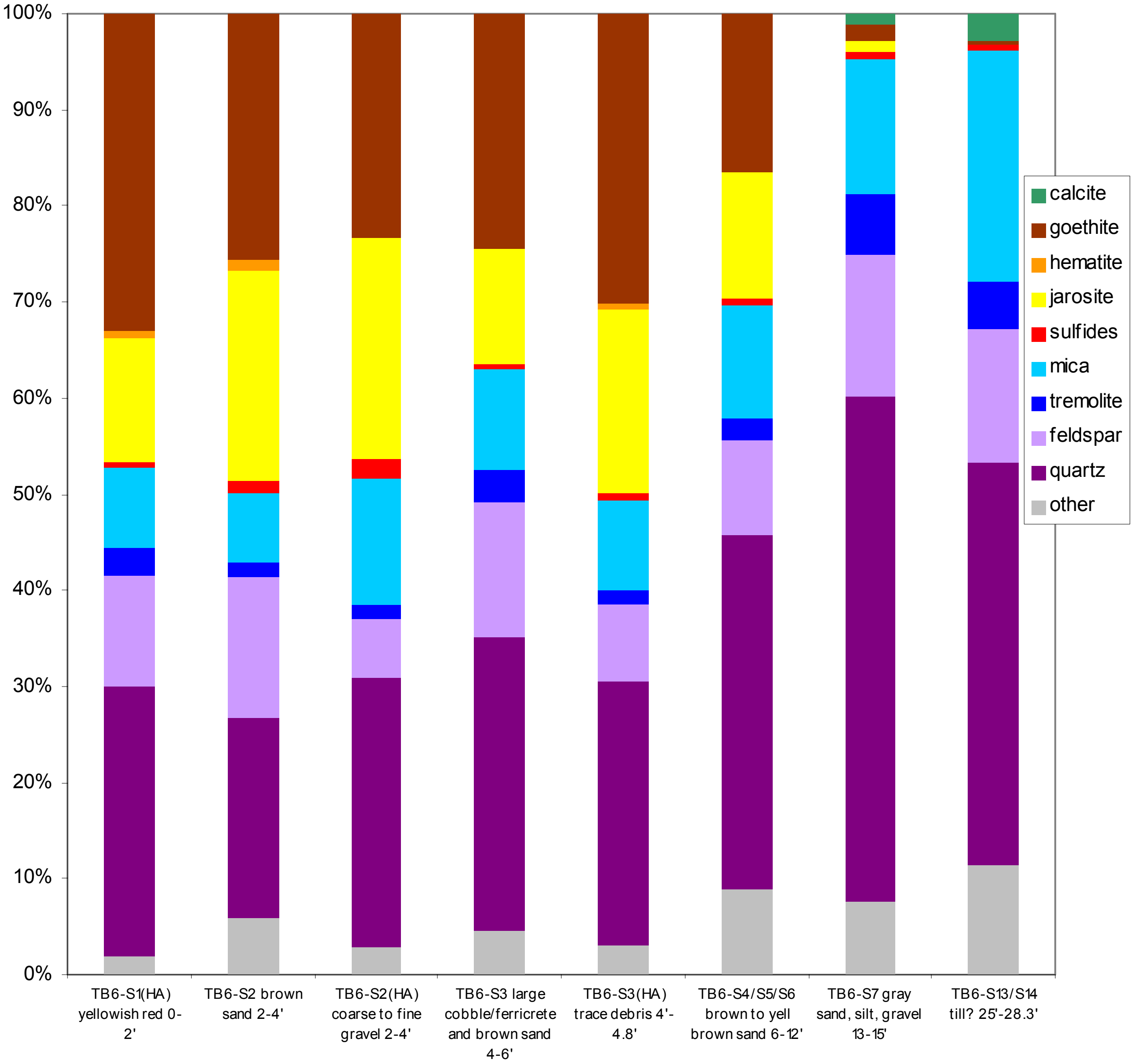
APPENDIX C


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
TB21-S1 brownish yellow 0-2'
TB21-S2 brown silt 2-4'
TB21-S3 brown silt 4-6'
TB21-S4 olive gray silt 6-6'4"
TB21-S5 olive gray silt 8.5-10.3'
calcite
goethite
hematite
jarosite
sulfides
mica
tremolite
feldspar
quartz
other


TP3 G
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
02TP3G yellow
02TP3GR yellow
calcite
goethite
hematite
jarosite
sulfides
mica
tremolite
feldspar
quartz
other

TP 3H


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
02TP3H yellow
02TP3HR yellow


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
TB6-S1(HA) yellowish red 0-2'
TB6-S2 brown sand 2-4'
TB6-S2(HA) coarse to fine gravel 2-4'
TB6-S3 large cobble/ferricrete and brown sand 4-6'
TB6-S3(HA) trace debris 4'-4.8'
TB6-S4/S5/S6 brown to yell brown sand 6-12'
TB6-S7 gray sand, silt, gravel 13-15'
TB6-S13/S14 till? 25'-28.3'
calcite
goethite
hematite
jarosite
sulfides
mica
tremolite
feldspar
quartz
other

LEACHATE RESULTS[1]

D-1: Field parameters, IC data for anions, and ICP-AES data for cations.

Field No.	pH	sp cond	ORP	Fe^{2+}	Fe total	Cl	SO_4	Ag	Al	As	B	Ba	Be	Ca	Cd	Co	Cr	Cu
Units		uS/cm	mV	mg/L	mg/L	mg/L	mg/L	ug/L	mg/L	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L	ug/L	ug/L	ug/L
02TP3A	2.86	560	556.3	0.16	1.18	0.2	180	<1	3.3	<100	<5	<1	<10	38	8.1	12	23	2,250
02TP3B	2.90	512	593.4	0.09	3.03	0.1	98	<1	1.4	<100	<5	<1	<10	4.7	5	<10	<10	438
02TP3C	3.58	74.4	578.4	0.01	0.03	<0.1	15	<1	0.039	<100	<5	<1	<10	0.1	<5	<10	<10	333
02TP3G	3.38	373	584.6	0.06	0.46	0.2	120	<1	7	<100	<5	<1	<10	0.92	8	79	11	8,510
02TP3G-R	3.21	251	583.1	0.11	0.13	0.1	61	<1	2.8	<100	<5	<1	<10	1.1	<5	36	<10	2,480
02TP3H	3.18	301	584.5	0.03	0.09	0.1	63	<1	2	<100	<5	<1	<10	0.76	<5	20	<10	1,610
02TP3H-R	3.17	248	583.4	0.05	0.08	0.1	46	<1	0.54	<100	<5	<1	<10	0.54	<5	20	<10	905
02TP4	3.54	134.9	601.4			<0.1	32	<1	0.51	<100	<5	<1	<10	2.3	<5	24	<10	535
TB1-S1/S2	3.20	240	583.2	0.73	1.05	0.1	51	<1	0.073	<100	<5	<1	<10	0.99	5	122	<10	4,150
TB1S10/11/12	2.80	1432	662.4	24	48.4	0.7	780	<1	9.1	<100	<5	<1	<10	176	34	315	65	25,100
TB1-S13	3.47	208	624.6	9.2	9.3	0.2	78	<1	2.8	<100	<5	<1	<10	7.5	8	51	<10	3,180
TB1-S3	3.12	992	590.4	0.46	0.54	0.2	570	<1	1.7	<100	<5	<1	<10	191	5.6	40	<10	1,850
TB1-S4/S5/S6	3.21	1139	593.2	0.3	0.38	<0.3	730	<1	1.8	<100	<5	<1	<10	256	5.8	25	<10	2,810
TB1-S7	2.74	1160	677.4	5.5	91.5	0.7	500	<1	9.4	<100	<5	<1	<10	36	57	208	99	44,700
TB1-S8	3.05	2220	643.2	7.9	30.1	0.9	1770	<1	22.3	<100	<5	<1	<10	569	56	552	152	50,500
TB1-S9A	3.20	1997	625.1	6.3	8.1	0.6	1560	<1	11.3	<100	<5	<1	<10	536	27	279	43	20,400
TB1-S9B	2.78	907	687.0	3.3	29	0.6	340	<1	11.6	<100	<5	<1	<10	12.9	36	355	60	25,500
TB1-SQ3	3.14	890	591.2	0.6	0.73	<0.2	480	<1	2.1	<100	<5	<1	<10	160	6.1	48	<10	2,140
TB20-S1 (HA)	3.76	77.5	620.9			0.1	15	<1	0.04	<100	<5	<1	<10	<0.1	<5	<10	<10	87
TB20-S2 (HA)	3.73	77.5	621.0			0.1	16	<1	0.085	<100	6.1	<1	<10	0.11	<5	<10	<10	587
TB20-S3 (HA)	3.64	95.5	621.4			<0.1	20	3.2	0.17	<100	<5	<1	<10	0.16	<5	<10	<10	1,030
TB21-S1	2.66	1348	677.6	5.2	34	0.7	340	<1	3.9	<100	<5	<1	<10	0.74	22	485	22	10,300
TB21-S2	2.48	1567	727.8	5	96.5	1.2	570	<1	8.6	<100	6.9	16	<10	2.6	39	910	55	19,500
TB21-S3	2.68	985	693.4	3.4	13.2	0.2	250	<1	6.3	<100	<5	18	<10	4.6	11	271	28	6,240
TB21-S4	3.00	557	670.6	0.49	0.95	0.2	170	<1	2.4	<100	<5	25	<10	28.9	9.4	100	<10	4,550
TB21-S5	3.72	438	648.8	0.73	1.54	0.2	240	1.2	6	<100	<5	6.2	<10	59	13	79	<10	6,230
TB3-S1	3.67	359	548.9			<0.1	170	<1	0.16	<100	<5	<1	<10	59.5	5.2	<10	<10	729
TB3-S2	3.43	227	551.6			0.1	67	<1	0.2	<100	<5	<1	<10	16.3	<5	<10	<10	524
TB3-S3	3.43	917	560.7	0.16	0.2	<0.2	550	<1	0.76	<100	<5	<1	<10	200	<5	<10	<10	658

APPENDIX D

Field No.	pH	sp cond	ORP	Fe^{2+}	Fe total	Cl	SO_4	Ag	Al	As	B	Ba	Be	Ca	Cd	Co	Cr	Cu
Units		uS/cm	mV	mg/L	mg/L	mg/L	mg/L	ug/L	mg/L	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L	ug/L	ug/L	ug/L
TB3-S5/S6	3.24	1316	566.4	0.27	0.48	0.3	840	<1	0.96	<100	<5	<1	<10	285	<5	<10	<10	5,420
TB3-S7	3.07	835	572.3	8.9	16.7	0.4	380	<1	1.3	<100	<5	<1	<10	82.1	14	1080	<10	44,500
TB3-S8/S9	3.00	453	584.8	1.57	2.31	0.2	93	1.2	0.36	<100	<5	<1	<10	4.5	8.1	75	<10	2,900
TB3-SQ2	3.43	236	554.5			0.1	74	<1	0.24	<100	<5	<1	<10	18.8	<5	<10	<10	537
TB4-S1	3.65	75.3	585.5			0.1	16	<1	0.034	<100	<5	<1	<10	0.8	<5	<10	<10	710
TB4-S1 Rep	3.70	68.4	483.7			<0.1	13	<1	0.041	<100	<5	<1	<10	0.18	<5	<10	<10	270
TB4-S2	2.98	434	613.7	1.44	2.56	0.2	82	<1	1.5	<100	<5	<1	<10	0.22	5	<10	<10	4,480
TB4-S3	3.08	1207	607.6	18.5	120.5	0.6	770	<1	3	<100	5.5	<1	<10	0.48	29	3750	<10	307,000
TB5-S2/S3	2.61	1382	663.3			0.6	440	<1	4.3	<100	14	<1	<10	64	<5	48	23	1,120
TB5-S4/S5	2.88	547	633.2			0.3	110	<1	1.9	<100	7.2	<1	<10	3.5	6.2	19	16	2,670
TB5-S5	3.35	200	625.0			0.2	51	<1	1.6	<100	<5	13	<10	2.2	<5	37	10	7,180
TB5-S5/S6	3.52	114.4	620.7			0.3	22	<1	0.023	<100	<5	3	<10	0.65	<5	<10	<10	1,960
TB6-S1 (HA)	3.08	341	623.0			0.2	54	<1	0.16	<100	<5	<1	<10	0.26	<5	<10	<10	879
TB6-S13/S14	7.40	874	606.6	0.01	0.01	0.3	520	<1	<0.01	<100	<5	3.5	<10	208	<5	<10	<10	<10
TB6-S2	2.73	1648	619.6	196	256	1.2	740	<1	5	<100	15	<1	<10	0.98	127	2820	24	17,900
TB6-S2 (HA)	2.94	456	628.8			0.2	79	1.1	0.52	<100	<5	<1	<10	0.34	<5	15	<10	4,090
TB6-S3	2.71	1110	621.2	46.5	54.5	0.5	310	<1	4.8	<100	<5	<1	<10	1.9	17	499	16	8,290
TB6-S3 (HA)	2.53	1660	628.1	116	164.5	0.9	590	<1	2.4	<100	10	<1	<10	0.52	31	1370	13	26,900
TB6-S4/S5/S6	2.97	753	614.7	10.4	12.6	0.3	200	<1	3.3	<100	<5	<1	<10	14.7	9.8	144	11	7,350
TB6-S7	3.68	258	607.9			0.2	120	<1	7.6	<100	<5	25	<10	15.1	12	272	<10	7,620
TB7-S1	3.24	439	610.9	0.39	0.36	0.2	76	1.2	0.75	<100	<5	<1	<10	2.1	<5	<10	<10	3,520
TB7-S2	2.97	543	611.8	0.33	1.18	0.2	100	<1	1.2	<100	<5	<1	<10	1.5	<5	<10	<10	7,010
TB7-S3	2.99	543	614.2	0.2	1.01	0.2	110	<1	1.2	<100	<5	<1	<10	1.9	6	24	<10	6,870
TB7-S3 DUP	3.01	521	616.8	0.27	0.9	0.2	100	<1	1.4	<100	<5	<1	<10	2	6	26	<10	7,170
TB7-S4	3.02	638	618.0	0.4	2.27	0.2	180	<1	3.2	<100	<5	<1	<10	25.8	6.1	123	<10	8,370
TB7-S5	3.03	941	618.2	0.4	1.73	0.3	410	<1	3.8	<100	<5	<1	<10	112	8.1	189	10	7,660
TB7-S6	2.76	1622	650.2	17.5	38.5	0.7	780	<1	9.3	<100	<5	<1	<10	174	41	780	35	15,000
TB7-S7	2.76	1638	652.6	28	54.2	0.8	810	<1	10.5	<100	<5	<1	<10	174	39	778	28	15,700
TB7-S8	2.83	2170	650.9	47	76	1	1400	<1	18.4	<100	<5	1.8	<10	390	40	950	48	21,400
TB7-S9	8.94	68	613.2			0.2	14	<1	0.086	<100	<5	<1	<10	11.2	<5	<10	<10	<10

Field No.	Fe	K	Li	Mg	Mn	Mo	Na	Ni	P	Pb	Sb	Si	Sr	Ti	V	Zn
Units	mg/L	mg/L	ug/L	mg/L	ug/L	ug/L	mg/L	ug/L	mg/L	ug/L	ug/L	mg/L	ug/L	ug/L	ug/L	ug/L
02TP3A	1	<0.1	5.7	1	32	<20	<0.1	<10	<0.1	<50	<50	0.17	3.2	<50	<10	704
02TP3B	2.9	<0.1	3.9	0.18	<10	<20	<0.1	<10	<0.1	<50	<50	0.13	<1	<50	<10	70
02TP3C	<0.02	0.38	<1	<0.1	<10	<20	<0.1	<10	<0.1	<50	<50	0.21	1.9	<50	<10	18
02TP3G	0.27	<0.1	15	4.5	90	<20	<0.1	22	0.12	<50	<50	0.36	2.1	<50	<10	399
02TP3G-R	0.11	<0.1	6.6	2.3	73	<20	<0.1	12	<0.1	<50	<50	0.28	3.8	<50	<10	248
02TP3H	0.066	<0.1	3.7	1.5	45	<20	0.13	<10	<0.1	<50	<50	0.46	2.9	<50	<10	259
02TP3H-R	0.06	0.2	2.3	0.95	50	<20	0.38	<10	<0.1	<50	<50	0.52	3.4	<50	<10	296
02TP4	0.025	0.37	1.7	1.1	258	<20	<0.1	14	<0.1	<50	<50	0.36	3.1	<50	<10	81
TB1-S1/S2	1.1	0.66	2.2	0.46	36	<20	0.19	13	<0.1	<50	<50	0.72	1.8	<50	<10	78
TB1S10/11/12	35.5	<0.1	9.8	5.3	158	<20	<0.1	58	0.18	<50	<50	<0.1	11	<50	<10	4690
TB1-S13	7.7	0.2	13	1.7	82	<20	<0.1	19	<0.1	<50	<50	0.38	1.7	<50	<10	1170
TB1-S3	0.45	<0.1	1.1	1	32	<20	0.25	<10	<0.1	<50	<50	<0.1	16	<50	<10	229
TB1-S4/S5/S6	0.3	<0.1	<1	0.79	46	<20	0.37	<10	<0.1	<50	<50	<0.1	19	<50	<10	242
TB1-S7	60.7	<0.1	3.6	3.5	120	<20	<0.1	37	0.54	<50	<50	<0.1	2.4	87	<10	8050
TB1-S8	25.4	1.4	48	21.9	357	<20	<0.1	82	0.44	<50	<50	<0.1	40	<50	<10	9350
TB1-S9A	7.8	<0.1	14	9.7	202	<20	<0.1	51	0.21	<50	<50	<0.1	73	<50	<10	4250
TB1-S9B	25.3	<0.1	9.1	7.5	160	<20	<0.1	52	0.25	<50	<50	<0.1	<1	<50	<10	5750
TB1-SQ3	0.62	<0.1	1.3	1.4	38	<20	0.13	10	<0.1	<50	<50	<0.1	14	<50	<10	300
TB20-S1 (HA)	0.044	1.1	<1	<0.1	<10	<20	0.14	<10	<0.1	<50	<50	0.31	1.1	<50	<10	14
TB20-S2 (HA)	0.05	1.5	<1	0.1	<10	<20	0.25	<10	<0.1	<50	<50	0.27	2.2	<50	<10	16
TB20-S3 (HA)	0.1	0.76	<1	0.15	<10	<20	0.31	<10	<0.1	<50	<50	0.28	4.7	<50	<10	22
TB21-S1	32.2	<0.1	3.2	1.6	84	<20	<0.1	69	<0.1	<50	<50	0.41	1.7	<50	<10	828
TB21-S2	97.4	<0.1	8.9	4.4	156	<20	<0.1	144	0.16	<50	<50	0.54	7.5	72	<10	2630
TB21-S3	11.7	0.17	11	3.6	166	<20	0.12	51	<0.1	<50	<50	0.62	14	<50	<10	788
TB21-S4	0.83	0.72	20	6.3	248	<20	0.39	39	0.14	<50	<50	1	41	<50	<10	527
TB21-S5	1.3	1.5	33	4.2	328	<20	0.5	24	0.18	<50	<50	1	139	<50	<10	664
TB3-S1	0.051	0.51	3.5	0.42	34	<20	0.35	<10	<0.1	<50	<50	0.37	9.7	<50	<10	30
TB3-S2	0.11	0.51	<1	<0.1	<10	<20	0.39	<10	<0.1	<50	<50	0.36	7.3	<50	<10	<10
TB3-S3	0.16	0.12	<1	<0.1	18	<20	0.48	<10	<0.1	<50	<50	0.18	29	<50	<10	14
TB3-S5/S6	0.36	<0.1	1.2	0.9	55	<20	0.37	<10	<0.1	<50	<50	0.29	32	<50	<10	94
TB3-S7	14.6	3.6	6.5	1.4	70	<20	0.21	110	0.39	<50	<50	0.3	7.2	<50	<10	275

APPENDIX D

Field No.	Fe	K	Li	Mg	Mn	Mo	Na	Ni	P	Pb	Sb	Si	Sr	Ti	V	Zn
Units	mg/L	mg/L	ug/L	mg/L	ug/L	ug/L	mg/L	ug/L	mg/L	ug/L	ug/L	mg/L	ug/L	ug/L	ug/L	ug/L
TB3-S8/S9	2	0.86	11	2.3	81	<20	0.28	19	<0.1	<50	<50	0.55	8.3	<50	<10	249
TB3-SQ2	0.12	0.4	<1	<0.1	10	<20	0.48	10	<0.1	<50	<50	0.39	7.8	<50	<10	10
TB4-S1	0.14	1	<1	<0.1	<10	<20	<0.1	<10	<0.1	<50	<50	0.26	2.8	<50	<10	<10
TB4-S1 Rep	0.031	1.1	<1	<0.1	<10	<20	<0.1	<10	<0.1	<50	<50	0.28	1.8	<50	<10	11
TB4-S2	2.4	<0.1	3.4	0.11	<10	<20	<0.1	<10	0.11	<50	<50	0.14	1.6	<50	<10	52
TB4-S3	98.8	0.16	4.9	0.83	27	<20	<0.1	490	1.9	98	<50	<0.1	3.7	<50	<10	1260
TB5-S2/S3	23.3	<0.1	1.5	0.49	60	<20	<0.1	11	<0.1	<50	<50	0.14	3	<50	<10	259
TB5-S4/S5	2.6	<0.1	3.8	0.34	92	<20	<0.1	<10	0.1	<50	<50	0.17	1.3	<50	<10	163
TB5-S5	0.38	<0.1	<1	0.45	73	<20	0.13	13	<0.1	<50	<50	0.33	4	<50	<10	391
TB5-S5/S6	0.072	0.25	7.8	0.65	35	<20	0.28	<10	<0.1	<50	<50	0.4	<1	<50	<10	112
TB6-S1 (HA)	0.18	0.25	3.5	0.1	<10	<20	0.21	<10	<0.1	<50	<50	0.54	1.6	<50	<10	21
TB6-S13/S14	<0.02	3.2	5.1	6.7	140	<20	0.38	<10	<0.1	<50	<50	0.76	606	<50	<10	<10
TB6-S2	235	0.54	13	2.7	95	<20	<0.1	456	<0.1	<50	<50	0.27	1	<50	<10	4090
TB6-S2 (HA)	0.52	<0.1	3.7	0.18	<10	<20	0.22	<10	0.1	<50	<50	0.34	2	<50	<10	43
TB6-S3	50.6	0.58	10	3.2	154	<20	<0.1	86	<0.1	<50	<50	0.77	1.9	<50	<10	2120
TB6-S3 (HA)	155	<0.1	2.4	1.2	31	<20	<0.1	194	0.16	<50	<50	0.43	2.5	<50	<10	308
TB6-S4/S5/S6	10.1	<0.1	8.6	3.5	166	<20	<0.1	33	<0.1	<50	<50	0.7	3.6	<50	<10	1170
TB6-S7	5.1	2.8	21	2.2	186	<20	0.51	55	<0.1	<50	<50	1.6	162	<50	<10	913
TB7-S1	0.26	0.13	3.3	0.15	19	<20	0.19	<10	<0.1	<50	<50	0.41	2.8	<50	<10	60
TB7-S2	0.88	<0.1	4.1	0.54	59	<20	0.36	<10	0.16	<50	<50	0.75	6.2	<50	<10	50
TB7-S3	0.69	<0.1	5.5	1.1	58	<20	0.29	<10	0.19	<50	<50	0.71	8.4	<50	<10	108
TB7-S3 DUP	0.71	<0.1	5.3	1.2	60	<20	0.24	<10	0.2	<50	<50	0.7	8.7	<50	<10	120
TB7-S4	1.8	<0.1	2.6	1.8	104	<20	0.11	42	0.12	<50	<50	0.65	17	<50	<10	312
TB7-S5	1.3	<0.1	4.3	2.1	97	<20	<0.1	31	0.12	<50	<50	0.81	66	<50	<10	445
TB7-S6	39.3	<0.1	12	4.1	132	<20	<0.1	123	0.12	<50	<50	0.62	101	<50	<10	2820
TB7-S7	52.3	<0.1	13	4.3	115	<20	<0.1	116	0.1	<50	<50	0.72	131	<50	<10	2920
TB7-S8	53.1	<0.1	26	8.1	225	<20	<0.1	161	0.31	<50	<50	0.69	584	<50	<10	3800
TB7-S9	0.02	1.4	1	0.9	<10	<20	0.12	<10	0.12	<50	<50	1.1	36	<50	<10	<10

D-2: ICP-MS data

Field No.	Ag	Al	As	Au	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs	Cu	Dy	Er	Eu	Fe	Ga	Gd	Ge	Ho
Units	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
02TP3A	<0.01	2600	<0.9	< 0.01	<0.02	<0.05	< 0.04	32	2.8	1.3	10	17	2	1,600	0.21	0.084	0.079	920	0.12	0.29	0.031	0.033
02TP3B	<0.01	1200	<0.9	< 0.01	0.059	<0.05	< 0.04	3.9	0.3	0.55	5.3	3.1	0.49	320	0.083	0.041	0.029	2,400	0.09	0.1	< 0.02	0.017
02TP3C	0.049	34	<0.9	< 0.01	0.59	<0.05	< 0.04	0.11	2.5	0.021	1.2	<1	0.16	280	< 0.005	< 0.005	< 0.005	9	< 0.02	< 0.005	< 0.02	< 0.005
02TP3G	<0.01	5700	<0.9	< 0.01	0.17	0.11	< 0.04	0.7	2.7	8.4	64	7.8	0.61	6,500	0.35	0.18	0.11	230	< 0.02	0.45	< 0.02	0.064
02TP3G-R	<0.01	1900	<0.9	< 0.01	0.43	0.067	< 0.04	0.86	1.4	4.1	27	<1	0.6	1,700	0.18	0.098	0.046	82	< 0.02	0.23	< 0.02	0.036
02TP3H	<0.01	1400	<0.9	< 0.01	0.46	<0.05	< 0.04	0.62	1.6	1.8	18	<1	0.48	1,200	0.13	0.07	0.036	54	< 0.02	0.16	< 0.02	0.024
02TP3H-R	<0.01	420	<0.9	< 0.01	1	<0.05	< 0.04	0.48	2.4	0.93	20	<1	0.41	720	0.06	0.036	0.018	54	< 0.02	0.064	< 0.02	0.011
02TP4	0.11	440	<0.9	< 0.01	0.51	0.054	< 0.04	2.2	0.59	0.89	24	<1	0.29	440	0.093	0.056	0.021	26	< 0.02	0.12	< 0.02	0.018
TB1-S1/S2	<0.01	56	<0.9	< 0.01	0.12	<0.05	< 0.04	0.86	4.2	0.042	110	<1	1.1	3,200	0.0073	< 0.005	< 0.005	910	< 0.02	< 0.005	< 0.02	< 0.005
TB1S10/11/12	0.01	7200	<0.5	< 0.01	0.048	0.18	< 0.04	150	32	16	260	60	11	21,000	1.1	0.42	0.47	29,000	0.98	1.6	0.054	0.18
TB1-S13	<0.01	2000	<0.9	< 0.01	0.26	0.17	< 0.04	6.3	6.9	1.6	43	5.5	2.6	2,300	0.17	0.086	0.049	5,800	< 0.02	0.21	< 0.02	0.031
TB1-S3	<0.01	1500	<0.5	< 0.01	<0.02	<0.05	< 0.04	180	6	11	35	4	4	1,700	1.2	0.38	0.57	560	< 0.02	2	0.056	0.18
TB1-S4/S5/S6	0.01	1500	<0.5	< 0.01	0.024	<0.05	< 0.04	240	6.1	11	21	5.9	2.8	2,500	1.4	0.47	0.6	490	< 0.02	2.1	0.059	0.2
TB1-S7	<0.01	7200	<0.5	< 0.01	0.022	0.094	< 0.04	28	55	3.7	160	85	22	36,000	0.46	0.19	0.18	46,000	1.7	0.63	0.12	0.081
TB1-S8	<0.01	16000	<0.5	< 0.01	0.62	0.17	< 0.04	500	50	54	420	140	26	38,000	3.8	1.3	1.4	19,000	0.17	5.7	< 0.02	0.6
TB1-S9A	<0.01	8600	<0.5	< 0.01	0.14	0.13	< 0.04	490	27	84	230	36	5.2	16,000	3.5	1.2	1.7	6,300	< 0.02	5.2	< 0.02	0.55
TB1-S9B	<0.01	9200	<0.5	< 0.01	0.02	0.12	< 0.04	11	36	5.1	280	50	12	22,000	0.46	0.22	0.16	19,000	0.74	0.51	0.022	0.087
TB1-SQ3	<0.01	1800	<0.5	< 0.01	<0.02	<0.05	< 0.04	160	5.8	9.8	44	4.6	4.6	2,000	1.1	0.34	0.49	680	< 0.02	1.8	0.052	0.16
TB20-S1 (HA)	0.13	34	<0.9	< 0.01	0.56	<0.05	< 0.04	0.099	0.09	0.012	0.75	<1	0.17	73	< 0.005	< 0.005	< 0.005	40	< 0.02	< 0.005	< 0.02	< 0.005
TB20-S2 (HA)	0.15	71	<0.9	< 0.01	0.086	<0.05	< 0.04	0.12	0.11	0.013	0.99	<1	0.41	450	< 0.005	< 0.005	< 0.005	43	< 0.02	< 0.005	< 0.02	< 0.005
TB20-S3 (HA)	0.52	150	<0.9	< 0.01	0.62	<0.05	< 0.04	0.18	0.21	0.019	1.7	<1	0.65	840	< 0.005	< 0.005	< 0.005	91	< 0.02	< 0.005	0.02	< 0.005
TB21-S1	<0.01	3000	<0.5	< 0.01	0.98	<0.05	< 0.04	0.55	19	0.71	380	19	1.9	8,600	0.1	0.053	0.021	24,000	0.48	0.086	0.076	0.018
TB21-S2	<0.01	6700	<0.5	< 0.01	14	0.078	< 0.04	2.2	33	5	720	50	7.9	16,000	0.41	0.22	0.13	72,000	0.93	0.46	0.054	0.079
TB21-S3	<0.01	5400	<0.5	< 0.01	20	0.17	< 0.04	4.1	11	12	230	25	3.6	6,000	0.73	0.38	0.27	9,500	0.17	0.97	< 0.02	0.14
TB21-S4	<0.01	1800	<0.9	< 0.01	22	0.58	< 0.04	24	4.4	5	87	5.4	0.72	3,400	0.49	0.25	0.12	730	< 0.02	0.53	< 0.02	0.092
TB21-S5	<0.01	4800	<0.9	< 0.01	6.3	1	< 0.04	53	6.5	40	70	4.1	0.023	4,600	2.3	1	0.79	1,200	< 0.02	3.1	< 0.02	0.4
TB3-S1	<0.01	140	<0.9	< 0.01	0.04	<0.05	< 0.04	57	0.46	1.2	0.42	<1	1.9	570	0.19	0.078	0.071	120	< 0.02	0.28	0.033	0.03
TB3-S2	<0.01	150	<0.9	< 0.01	0.039	<0.05	< 0.04	14	0.18	0.31	0.32	<1	2.7	380	0.05	0.019	0.017	110	< 0.02	0.076	< 0.02	0.0058
TB3-S3	<0.01	630	<0.5	< 0.01	0.042	<0.05	< 0.04	180	4.2	18	0.41	<1	3	570	1.8	0.78	0.57	310	< 0.02	2.3	0.026	0.32

Field No.	Ag	Al	As	Au	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs	Cu	Dy	Er	Eu	Fe	Ga	Gd	Ge	Ho
Units	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
TB3-S5/S6	<0.01	810	<0.5	< 0.01	0.044	<0.05	< 0.04	280	2.9	19	2.8	2.4	7	5,000	2.4	0.8	0.88	560	< 0.02	3.8	0.061	0.39
TB3-S7	<0.01	1200	<0.5	< 0.01	0.18	<0.05	< 0.04	79	14	2.7	970	6.1	7.9	42,000	0.34	0.12	0.1	13,000	0.02	0.45	0.066	0.046
TB3-S8/S9	<0.01	340	<0.9	< 0.01	1.4	0.06	< 0.04	4.2	2.7	0.52	76	<1	1.2	2,500	0.056	0.026	0.016	1,800	< 0.02	0.056	< 0.02	0.0095
TB3-SQ2	<0.01	180	<0.9	< 0.01	0.022	<0.05	< 0.04	16	0.28	0.4	0.42	<1	2.6	400	0.068	0.03	0.022	120	< 0.02	0.096	0.035	0.013
TB4-S1	0.12	25	<0.9	< 0.01	0.12	<0.05	< 0.04	0.8	0.063	0.012	0.81	<1	0.11	580	< 0.005	< 0.005	< 0.005	130	< 0.02	< 0.005	< 0.02	< 0.005
TB4-S1 Rep	0.14	35	<0.9	< 0.01	0.96	<0.05	< 0.04	0.2	0.058	0.016	0.53	<1	0.098	220	< 0.005	< 0.005	< 0.005	29	< 0.02	< 0.005	< 0.02	< 0.005
TB4-S2	<0.01	1200	<0.9	< 0.01	<0.02	<0.05	< 0.04	0.19	0.26	0.2	4.1	3.4	0.67	3,400	0.018	0.0098	0.005	1,900	0.078	0.016	0.027	< 0.005
TB4-S3	<0.01	2300	<0.5	< 0.01	0.37	<0.05	< 0.04	0.39	21	0.24	2700	7.7	2.3	>200000	0.056	0.033	0.015	66,000	0.079	0.062	0.19	0.013
TB5-S2/S3	<0.01	3400	<0.5	< 0.01	0.11	<0.05	< 0.04	54	3.9	2.3	36	18	5	1,000	0.66	0.28	0.14	19,000	0.39	0.81	0.038	0.11
TB5-S4/S5	<0.01	1600	<0.9	< 0.01	<0.02	<0.05	< 0.04	2.8	1.1	0.55	13	12	1.7	2,000	0.077	0.045	0.014	2,200	0.028	0.09	< 0.02	0.015
TB5-S5	<0.01	1200	<0.9	< 0.01	12	<0.05	< 0.04	1.9	2.7	0.82	35	10	1.7	5,400	0.071	0.042	0.019	310	< 0.02	0.082	< 0.02	0.016
TB5-S5/S6	0.31	18	<0.9	< 0.01	3.6	<0.05	< 0.04	0.59	0.92	< 0.01	10	<1	1.1	1,600	< 0.005	< 0.005	< 0.005	61	< 0.02	< 0.005	< 0.02	< 0.005
TB6-S1 (HA)	<0.01	150	<0.9	< 0.01	0.15	<0.05	< 0.04	0.24	0.17	0.17	5.5	<1	0.36	760	0.013	0.0088	< 0.005	180	< 0.02	0.014	0.04	< 0.005
TB6-S13/S14	<0.01	6.5	<0.5	< 0.01	4.8	<0.05	< 0.04	200	0.065	0.07	0.12	<1	< 0.01	1	< 0.005	< 0.005	< 0.005	190	< 0.02	< 0.005	0.02	< 0.005
TB6-S2	<0.01	3800	<0.5	< 0.01	0.56	0.1	< 0.04	0.86	120	1.1	2400	22	10	16,000	0.32	0.14	0.071	190,000	0.66	0.27	0.15	0.057
TB6-S2 (HA)	<0.01	500	<0.9	< 0.01	0.16	0.06	< 0.04	0.31	0.56	0.27	16	<1	1.5	3,500	0.028	0.016	< 0.005	480	< 0.02	0.027	0.031	0.0068
TB6-S3	<0.01	3800	<0.5	< 0.01	0.54	0.14	< 0.04	1.6	16	1.5	410	11	7.2	7,400	0.23	0.14	0.051	38,000	0.34	0.2	0.047	0.044
TB6-S3 (HA)	<0.01	1900	<0.5	< 0.01	0.66	0.073	< 0.04	0.43	22	1.1	1100	9.7	5.3	23,000	0.1	0.056	0.033	120,000	0.75	0.12	0.21	0.023
TB6-S4/S5/S6	<0.01	2800	<0.5	< 0.01	0.47	0.23	< 0.04	14	8.8	6.3	130	6.7	5.8	7,200	0.57	0.26	0.16	8,400	0.033	0.62	0.02	0.1
TB6-S7	<0.01	5100	<0.9	< 0.01	21	2	< 0.04	12	9.5	53	200	1.3	0.4	5,100	4.7	2.7	1.3	3,600	< 0.02	6	< 0.02	0.92
TB7-S1	<0.01	740	<0.9	< 0.01	0.095	<0.05	< 0.04	2	0.46	0.38	8.7	1.2	0.42	3,100	0.037	0.025	0.0086	260	< 0.02	0.043	< 0.02	0.0086
TB7-S2	<0.01	1100	<0.9	< 0.01	0.22	0.05	< 0.04	1.3	0.3	0.54	4	<1	3.2	5,700	0.057	0.03	0.014	780	< 0.02	0.044	< 0.02	0.014
TB7-S3	<0.01	1100	<0.9	< 0.01	0.17	0.09	< 0.04	1.6	1.4	0.56	22	3.2	6.4	5,500	0.055	0.036	0.016	590	0.035	0.054	< 0.02	0.011
TB7-S3 DUP	<0.01	1200	<0.9	< 0.01	0.15	0.079	< 0.04	1.6	1.4	0.56	23	3	6.7	5,600	0.052	0.031	0.014	620	0.029	0.061	< 0.02	0.011
TB7-S4	0.18	2800	<0.5	< 0.01	0.12	0.086	< 0.04	25	6.6	6.8	110	9	11	8,000	0.28	0.16	0.12	1,600	0.059	0.33	0.02	0.059
TB7-S5	<0.01	3200	<0.5	< 0.01	0.16	0.093	< 0.04	100	9.2	24	160	8.3	9.8	7,100	0.55	0.24	0.28	1,200	< 0.02	0.71	0.034	0.095
TB7-S6	<0.01	7300	<0.5	< 0.01	0.97	0.34	< 0.04	150	38	36	640	31	22	12,000	0.84	0.28	0.51	31,000	0.66	1.4	0.028	0.14
TB7-S7	<0.01	8300	<0.5	< 0.01	0.67	0.25	< 0.04	160	37	35	650	26	23	13,000	0.92	0.36	0.53	41,000	0.87	1.5	0.051	0.15
TB7-S8	<0.01	14000	<0.5	< 0.01	2.5	0.49	< 0.04	340	36	68	780	38	16	17,000	3.1	1.2	1.1	42,000	0.68	4.2	< 0.02	0.54
TB7-S9	<0.01	74	<0.9	< 0.01	1	<0.05	< 0.04	11	<0.02	0.047	0.032	<1	< 0.01	<0.5	< 0.005	< 0.005	< 0.005	27	0.073	0.0059	< 0.02	< 0.005

Field No.	In	K	La	Li	Mg	Mn	Mo	Na	Nd	Ni	P	Pb	Pr	Rb	Re	Sb	Se	SiO2	Sm	SO4	Sr	Tb	Th	Tl	Tm
Units	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L	ug/L	mg/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L	mg/L	ug/L	ug/L	ug/L	ug/L	ug/L
02TP3A	0.015	<20	0.39	1.7	0.72	27	< 0.02	0.071	1.3	2.4	< 3	<0.05	0.24	0.16	0.02	<0.03	4.7	< 0.5	0.36	200	3.1	0.038	0.04	<0.05	0.01
02TP3B	0.011	<20	0.21	0.4	0.16	7.6	< 0.02	0.018	0.43	1.2	< 3	1.6	0.084	0.07	< 0.02	<0.03	3.3	< 0.5	0.11	120	1	0.016	0.04	<0.05	0.005
02TP3C	< 0.01	410	0.013	0.3	0.078	5.4	0.1	0.12	0.01	0.58	< 3	1.9	< 0.01	2.3	< 0.02	<0.03	2.7	< 0.5	< 0.01	16	2	< 0.005	< 0.03	0.069	< 0.005
02TP3G	0.022	<20	2	9.6	3.3	71	0.071	0.046	2.7	18	< 3	<0.05	0.62	2.2	< 0.02	<0.03	2.5	0.5	0.54	120	2.4	0.058	0.05	<0.05	0.026
02TP3G-R	< 0.01	40	1.1	4.8	1.8	55	< 0.02	0.086	1.2	8.5	< 3	<0.05	0.29	3.1	< 0.02	<0.03	1.6	< 0.5	0.21	62	3.2	0.028	< 0.03	<0.05	0.014
02TP3H	< 0.01	30	0.79	2.7	1.2	35	< 0.02	0.19	0.81	4.7	< 3	0.18	0.21	2.3	< 0.02	<0.03	0.35	0.6	0.16	60	2.8	0.019	< 0.03	<0.05	0.01
02TP3H-R	< 0.01	130	0.37	1.8	0.9	43	< 0.02	0.2	0.34	5.1	< 3	0.36	0.081	4.2	< 0.02	<0.03	0.3	0.82	0.067	46	3.4	0.0079	< 0.03	<0.05	0.0051
02TP4	< 0.01	340	0.36	1.4	1.2	230	0.044	0.12	0.47	13	< 3	0.087	0.12	4.1	< 0.02	<0.03	0.28	0.64	0.12	36	3.2	0.016	< 0.03	<0.05	0.0068
TB1-S1/S2	< 0.01	560	0.018	2	0.4	30	< 0.02	0.25	0.024	12	15	0.18	< 0.01	7.3	< 0.02	0.16	1.8	1.2	< 0.01	52	1.8	< 0.005	< 0.03	<0.05	< 0.005
TB1S10/11/12	0.37	<5	4.5	8.7	4	150	0.047	0.032	11	45	9	<0.05	2.5	1.2	0.23	<0.03	3.1	< 0.5	2.6	810	9.7	0.21	1.1	<0.05	0.048
TB1-S13	< 0.01	170	0.79	10	1.4	68	0.02	0.16	1	17	18	<0.05	0.23	10	< 0.02	<0.03	< 0.2	0.54	0.21	79	1.6	0.027	< 0.03	<0.05	0.013
TB1-S3	< 0.01	23	2.8	0.74	0.84	31	0.063	0.3	11	6.8	12	<0.05	2.1	1.7	< 0.02	<0.03	7	< 0.5	3.1	640	17	0.24	< 0.03	<0.05	0.043
TB1-S4/S5/S6	< 0.01	40	2.9	0.61	0.63	43	0.04	0.41	11	4.6	18	0.08	2.1	1.9	0.039	<0.03	7.7	< 0.5	2.8	830	19	0.26	< 0.03	<0.05	0.052
TB1-S7	0.7	<5	1.2	3	2.6	110	0.066	0.024	3.6	28	29	<0.05	0.69	0.051	0.45	<0.03	6.9	< 0.5	0.94	510	2	0.084	0.49	<0.05	0.025
TB1-S8	0.14	1100	16	40	16	320	0.081	0.069	41	58	17	0.44	8.7	7.1	0.29	<0.03	1.1	< 0.5	9	1800	34	0.71	1.6	<0.05	0.14
TB1-S9A	0.066	8	28	11	7.2	180	0.036	0.016	51	38	10	0.5	12	0.48	0.16	<0.03	0.91	< 0.5	8.9	1600	63	0.65	1.1	<0.05	0.15
TB1-S9B	0.23	<5	1.5	8.6	6.1	140	0.067	0.015	3.3	46	4	<0.05	0.76	0.026	0.23	<0.03	0.99	< 0.5	0.75	360	0.58	0.08	0.81	<0.05	0.034
TB1-SQ3	< 0.01	33	2.4	1	1.2	37	0.11	0.23	9.8	8	8	0.057	1.8	1.7	0.02	<0.03	5.8	< 0.5	2.6	570	15	0.22	< 0.03	<0.05	0.037
TB20-S1 (HA)	< 0.01	1100	< 0.01	< 0.1	0.072	2.8	0.074	0.23	< 0.01	1.4	< 3	0.77	< 0.01	3.8	< 0.02	<0.03	1.2	0.58	< 0.01	16	1.1	< 0.005	< 0.03	0.096	< 0.005
TB20-S2 (HA)	< 0.01	1400	< 0.01	0.1	0.11	3.9	0.071	0.31	< 0.01	1.4	< 3	0.097	< 0.01	4.1	< 0.02	<0.03	4.6	< 0.5	< 0.01	17	2.1	< 0.005	< 0.03	0.053	< 0.005
TB20-S3 (HA)	< 0.01	760	0.015	0.2	0.16	5.5	0.065	0.41	< 0.01	1.9	3	0.14	< 0.01	3.7	0.021	<0.03	4.9	0.5	< 0.01	21	4.8	< 0.005	< 0.03	<0.05	< 0.005
TB21-S1	0.16	<5	0.36	2.6	1.2	72	0.043	0.088	0.36	59	11	0.069	0.089	0.64	0.066	<0.03	5.8	0.54	0.082	320	1.5	0.014	0.33	<0.05	0.0079
TB21-S2	0.33	28	2.2	7.9	3.4	140	0.05	0.12	2.9	120	20	0.19	0.71	2.4	0.19	<0.03	3.9	0.94	0.62	560	6.6	0.066	1.9	<0.05	0.033
TB21-S3	0.091	150	4.9	11	3.1	160	0.064	0.18	6.2	49	13	0.11	1.6	6	0.053	<0.03	1.2	1	1.2	240	14	0.13	0.91	<0.05	0.058
TB21-S4	< 0.01	660	2.1	14	4.9	210	< 0.02	0.42	2.6	34	32	<0.05	0.65	6.8	< 0.02	<0.03	< 0.2	1.8	0.54	190	41	0.074	0.095	<0.05	0.034
TB21-S5	< 0.01	1300	14	24	3.1	280	0.054	0.47	20	20	33	<0.05	4.9	3.8	< 0.02	<0.03	< 0.2	1.7	4.2	260	140	0.39	0.21	<0.05	0.14
TB3-S1	< 0.01	540	0.38	< 0.1	0.34	30	0.13	0.41	1.2	1.4	< 3	0.069	0.23	5.1	< 0.02	<0.03	3.7	0.66	0.34	220	11	0.038	< 0.03	<0.05	0.0078
TB3-S2	< 0.01	400	0.12	< 0.1	0.076	6.6	0.024	0.43	0.31	6.2	< 3	0.072	0.05	6.8	< 0.02	<0.03	2.8	0.5	0.071	69	6.9	0.0088	< 0.03	<0.05	< 0.005
TB3-S3	< 0.01	100	4.9	< 0.2	0.072	16	0.06	0.5	15	0.75	< 4	0.055	3	3	0.027	<0.03	7.4	< 0.5	3.2	620	28	0.32	< 0.03	<0.05	0.094
TB3-S5/S6	0.01	95	4.8	0.99	0.73	53	0.044	0.39	18	2.4	< 4	0.1	3.4	3.8	0.095	<0.03	9.2	0.55	4.8	940	32	0.47	< 0.03	<0.05	0.094
TB3-S7	0.013	3400	0.68	6.7	1.2	68	0.11	0.28	2.2	100	< 4	<0.05	0.45	24	0.14	<0.03	3.2	0.56	0.63	460	7	0.066	0.17	0.45	0.014
TB3-S8/S9	< 0.01	920	0.25	7.9	2.1	73	0.022	0.35	0.31	20	6	<0.05	0.067	9.7	0.035	<0.03	< 0.2	1	0.073	100	8.7	0.0098	< 0.03	<0.05	< 0.005

Field No.	In	K	La	Li	Mg	Mn	Mo	Na	Nd	Ni	P	Pb	Pr	Rb	Re	Sb	Se	SiO2	Sm	SO4	Sr	Tb	Th	Tl	Tm
Units	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L	ug/L	mg/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L	mg/L	ug/L	ug/L	ug/L	ug/L	ug/L
TB3-SQ2	< 0.01	350	0.15	< 0.1	0.076	8.1	< 0.02	0.53	0.37	9.2	4	0.054	0.069	7	< 0.02	<0.03	2.7	0.57	0.11	76	7.3	0.013	< 0.03	<0.05	< 0.005
TB4-S1	< 0.01	970	< 0.01	0.1	0.041	4.8	0.075	0.18	< 0.01	0.98	< 3	5.5	< 0.01	2.5	0.032	<0.03	3.6	< 0.5	< 0.01	17	2.8	< 0.005	< 0.03	0.11	< 0.005
TB4-S1 Rep	< 0.01	980	0.01	0.1	0.032	4.8	0.18	0.17	< 0.01	2.1	< 3	3	< 0.01	2.5	< 0.02	<0.03	3.2	0.5	< 0.01	14	1.7	< 0.005	< 0.03	0.081	< 0.005
TB4-S2	0.049	<20	0.13	< 0.1	0.082	6	0.047	0.076	0.076	2.7	< 3	0.063	0.025	0.74	0.022	<0.03	6.3	< 0.5	0.015	84	1.8	< 0.005	< 0.03	<0.05	< 0.005
TB4-S3	0.3	110	0.097	4.2	0.62	27	0.17	0.04	0.22	370	< 4	0.1	0.042	2.7	0.22	<0.03	33	< 0.5	0.074	760	2.4	0.0095	1	<0.05	0.0054
TB5-S2/S3	0.041	10	0.59	1.2	0.37	53	0.03	0.026	2.4	6.1	8	<0.05	0.42	0.48	0.02	<0.03	4.1	< 0.5	0.82	450	2.7	0.12	< 0.03	<0.05	0.033
TB5-S4/S5	0.017	<20	0.26	0.3	0.26	76	< 0.02	0.14	0.28	9	23	<0.05	0.071	0.23	< 0.02	0.04	0.91	< 0.5	0.068	110	1.5	0.011	< 0.03	<0.05	0.0058
TB5-S5	< 0.01	<20	0.52	0.61	0.39	59	0.031	0.16	0.37	12	30	<0.05	0.1	0.14	0.033	<0.03	2.2	< 0.5	0.067	50	3.9	0.013	< 0.03	<0.05	0.0062
TB5-S5/S6	< 0.01	240	< 0.01	6.5	0.64	30	0.038	0.35	< 0.01	4.9	< 3	0.07	< 0.01	3	< 0.02	<0.03	2.1	0.7	< 0.01	24	0.7	< 0.005	< 0.03	<0.05	< 0.005
TB6-S1 (HA)	< 0.01	300	0.089	< 0.1	0.088	6.3	0.2	0.28	0.073	1.6	14	0.2	0.02	3.2	< 0.02	0.07	1.3	0.94	0.013	61	2.1	< 0.005	< 0.03	<0.05	< 0.005
TB6-S13/S14	< 0.01	3100	0.063	5.1	5.7	140	0.67	0.44	0.014	<0.1	33	<0.05	< 0.01	1.6	< 0.02	0.04	0.63	1.5	< 0.01	660	610	< 0.005	0.07	<0.05	< 0.005
TB6-S2	0.35	440	0.44	12	2.1	110	0.099	0.075	0.81	400	9	0.61	0.17	5.2	0.28	<0.03	10	0.78	0.26	740	0.83	0.046	1	<0.05	0.023
TB6-S2 (HA)	< 0.01	40	0.15	0.3	0.15	7.7	0.02	0.3	0.11	3.5	16	0.22	0.03	1.2	0.063	<0.03	3.6	0.55	0.027	88	2.4	< 0.005	< 0.03	<0.05	< 0.005
TB6-S3	0.089	490	0.7	9.5	2.6	140	0.061	0.096	0.74	76	20	0.12	0.18	4.6	0.087	<0.03	2.9	1.3	0.2	320	1.7	0.038	0.1	<0.05	0.02
TB6-S3 (HA)	0.18	<5	0.55	2.2	0.9	28	0.067	0.051	0.53	170	< 4	28	0.14	0.6	0.17	<0.03	29	0.9	0.12	630	2	0.016	0.85	<0.05	0.0086
TB6-S4/S5/S6	0.036	85	3	8.6	3	160	0.27	0.076	3.3	32	11	0.055	0.82	2.7	0.083	<0.03	1.1	1.2	0.71	210	3.5	0.089	0.3	<0.05	0.04
TB6-S7	< 0.01	2000	14	16	1.7	140	0.02	0.42	30	44	9.2	2.3	7.4	7.4	0.043	<0.03	0.23	2.4	6.1	130	140	0.83	0.06	0.071	0.39
TB7-S1	< 0.01	190	0.18	0.1	0.14	18	0.026	0.27	0.18	2.8	17	0.15	0.048	1.7	0.03	<0.03	2	0.77	0.037	88	3.3	0.0069	< 0.03	<0.05	< 0.005
TB7-S2	0.012	97	0.3	0.87	0.44	51	< 0.02	0.4	0.22	4.3	20	<0.05	0.062	3	0.07	<0.03	0.96	1.3	0.034	110	6.6	0.0089	< 0.03	<0.05	0.0067
TB7-S3	0.013	83	0.28	1.8	0.91	48	< 0.02	0.32	0.26	7.6	27	<0.05	0.068	3	0.041	<0.03	0.31	1.2	0.063	110	8.8	0.009	< 0.03	<0.05	0.0071
TB7-S3 DUP	0.013	74	0.29	1.9	0.98	50	< 0.02	0.29	0.27	8	29	<0.05	0.067	2.9	0.041	<0.03	0.25	1.2	0.054	110	8.7	0.0066	< 0.03	<0.05	< 0.005
TB7-S4	0.039	48	1.9	2.6	1.6	99	1.4	0.24	2.4	40	25	<0.05	0.6	2.8	0.027	0.09	1.1	1.2	0.44	210	18	0.046	< 0.03	<0.05	0.026
TB7-S5	0.021	42	5.1	4.4	1.8	90	0.076	0.15	8.6	29	27	<0.05	2.1	2.6	0.027	<0.03	2.3	1.5	1.5	450	66	0.098	< 0.03	<0.05	0.035
TB7-S6	0.22	<5	8.7	10	3.2	120	0.048	0.052	19	100	10	<0.05	4.5	0.58	0.1	<0.03	3	1.2	3.2	820	87	0.16	0.95	<0.05	0.045
TB7-S7	0.22	<5	9.4	11	3.4	110	0.042	0.045	19	100	9	<0.05	4.5	0.77	0.094	<0.03	1.9	1.4	3.3	870	110	0.17	1.3	<0.05	0.048
TB7-S8	0.24	32	37	22	5.8	210	0.056	0.033	39	130	7	0.05	11	2.1	0.11	<0.03	1.1	1.3	6.3	1400	530	0.55	2.4	<0.05	0.15
TB7-S9	< 0.01	1300	0.024	1.2	0.91	2	1.8	0.24	0.022	<0.1	110	<0.05	< 0.01	0.42	< 0.02	0.25	< 0.2	2.3	< 0.01	20	35	< 0.005	< 0.03	<0.05	< 0.005

Field No.	U	V	W	Y	Yb	Zn
Units	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
02TP3A	0.04	<0.1	< 0.02	0.71	0.064	460
02TP3B	0.028	<0.1	< 0.02	0.32	0.03	47
02TP3C	< 0.005	<0.1	1.6	< 0.01	< 0.01	17
02TP3G	0.21	<0.1	< 0.02	1.5	0.16	280
02TP3G-R	0.1	<0.1	0.021	0.83	0.089	180
02TP3H	0.088	<0.1	0.03	0.6	0.063	220
02TP3H-R	0.056	<0.1	< 0.02	0.27	0.024	250
02TP4	0.14	<0.1	0.23	0.47	0.043	79
TB1-S1/S2	0.039	<0.1	< 0.02	0.029	< 0.01	64
TB1S10/11/12	0.65	<0.1	0.028	3.5	0.3	4,300
TB1-S13	0.44	<0.1	0.062	0.83	0.072	960
TB1-S3	0.052	<0.1	0.044	3.4	0.25	220
TB1-S4/S5/S6	0.042	<0.1	0.041	4	0.28	230
TB1-S7	0.27	<0.1	< 0.02	1.6	0.14	7,700
TB1-S8	0.89	<0.1	< 0.02	11	0.77	6,700
TB1-S9A	0.45	<0.1	0.025	11	0.8	3,400
TB1-S9B	0.44	<0.1	0.048	2	0.2	5,500
TB1-SQ3	0.064	<0.1	0.072	2.9	0.2	290
TB20-S1 (HA)	0.01	<0.1	0.67	< 0.01	< 0.01	10
TB20-S2 (HA)	0.011	<0.1	0.5	< 0.01	< 0.01	12
TB20-S3 (HA)	0.0057	<0.1	0.37	0.021	< 0.01	17
TB21-S1	0.31	<0.1	< 0.02	0.4	0.05	820
TB21-S2	0.74	<0.1	0.02	1.8	0.22	2,600
TB21-S3	0.67	<0.1	0.029	2.9	0.36	830
TB21-S4	0.49	<0.1	< 0.02	2.3	0.2	350
TB21-S5	1.3	<0.1	< 0.02	9.5	0.84	440
TB3-S1	0.011	<0.1	0.031	0.76	0.047	26
TB3-S2	0.0093	<0.1	0.059	0.18	0.013	8
TB3-S3	0.019	<0.1	0.038	6.7	0.49	16
TB3-S5/S6	0.057	<0.1	0.021	7.3	0.48	90
TB3-S7	1.3	<0.1	0.065	1.1	0.088	260
TB3-S8/S9	0.15	<0.1	< 0.02	0.25	0.021	180

Field No.	U	V	W	Y	Yb	Zn
Units	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
TB3-SQ2	0.0088	<0.1	0.038	0.24	0.017	10
TB4-S1	< 0.005	<0.1	0.86	< 0.01	< 0.01	8
TB4-S1 Rep	0.012	<0.1	3.8	< 0.01	< 0.01	8
TB4-S2	0.064	<0.1	< 0.02	0.087	0.01	32
TB4-S3	0.66	<0.1	< 0.02	0.24	0.024	770
TB5-S2/S3	0.077	<0.1	< 0.02	2.2	0.18	250
TB5-S4/S5	0.084	<0.1	< 0.02	0.41	0.04	110
TB5-S5	0.061	<0.1	0.11	0.46	0.042	300
TB5-S5/S6	0.024	<0.1	0.32	< 0.01	< 0.01	89
TB6-S1 (HA)	0.024	<0.1	0.027	0.081	0.01	19
TB6-S13/S14	0.096	<0.1	0.09	0.057	< 0.01	1
TB6-S2	5.9	4.8	0.022	1.1	0.16	4,200
TB6-S2 (HA)	0.034	<0.1	< 0.02	0.15	0.012	29
TB6-S3	1	<0.1	0.025	1.1	0.12	2,200
TB6-S3 (HA)	0.91	1.4	< 0.02	0.49	0.06	270
TB6-S4/S5/S6	0.55	<0.1	0.11	2.4	0.22	1,200
TB6-S7	2.3	<0.1	0.064	18	2.6	730
TB7-S1	0.029	<0.1	< 0.02	0.21	0.023	48
TB7-S2	0.042	<0.1	< 0.02	0.34	0.027	33
TB7-S3	0.061	<0.1	< 0.02	0.32	0.039	74
TB7-S3 DUP	0.059	<0.1	< 0.02	0.33	0.039	75
TB7-S4	0.15	<0.1	0.24	1.4	0.18	330
TB7-S5	0.19	<0.1	0.046	2	0.22	420
TB7-S6	0.67	<0.1	0.022	2.6	0.22	2,600
TB7-S7	0.73	<0.1	< 0.02	3.1	0.27	2,600
TB7-S8	1.1	<0.1	< 0.02	16	0.83	3,000
TB7-S9	0.053	0.64	33	0.021	< 0.01	<0.5

[1] Sp. Cond., specific conductance measured in microsiemens per cm^2 ; ORP, oxidation-reduction potential; IC, ion chromatography for anions in water; ICP-AES, inductively coupled plasma-atomic emission spectroscopy for water samples; ICP-MS, inductively coupled plasma mass spectrometry for water samples.