24-1387

LABORATORY DRAINAGE QUALITY FROM MAFIC-INTRUSIVE, TUFFACEOUS-SEDIMENTARY, AND WEATHERED WASTE ROCKS

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Progress Report on Contract J910C82009 to the U.S. Bureau of Land Management Salt Lake City Office

30 November 1998

Kim A. Lapakko Minnesota Department of Natural Resources Division of Minerals 500 Lafayette Road, Box 45 St. Paul, MN 55155-4045

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1. INTRODUCTION

Tailings and waste rock, as well as the mine itself, are components of metal mining operations which remain long after mining has ceased. These remnants may be, relatively speaking, chemically inert and therefore environmentally innocuous. On the other hand, mining wastes may adversely affect water quality long after mining has ceased. For example, acidic drainage was observed in 1977 at a Norwegian mine which had been abandoned in 1833 (Iversen and Johannessen 1987). In the United States acidic drainage from mining areas has impacted thousand of miles of streams (U.S. Bureau of Mines 1985). Remediation of these problems can cost from tens to hundreds of millions of dollars (Biggs 1989).

As discussed by Lapakko (1990), governmental agencies have, in recent years, developed regulations to reduce the potential for problematic mine waste drainage and the associated financial liability. Plans for closure and post-closure care of mine wastes are an important aspect of these rules and must be submitted prior to mine development. This approach allows the costs of mine waste reclamation to be considered along with other mining costs in the assessment of mineral recovery economics.

In order to develop effective, efficient, and economical pre-development waste rock management plans it is necessary to estimate the quality of drainage generated by the lithologies excavated in order to access the ore. Mitgation techniques can then be scaled to the estimated potential for adverse impact. Existing data on a waste rock of similar composition, generated by similar mining methods, and exposed to environmental conditions for an extended time provide the best indicator of drainage quality. Since these data are rarely available, it is necessary to use other means of drainage quality prediction, such as compositional characterization and/or dissolution testing. Dissolution testing, however, can be expensive and may take several years to complete. In order to provide less expensive and time consuming method of predicting waste rock drainage quality, the U.S. Bureau of Mines Salt Lake City Research Center (USBM) initiated a program to develop a mathematical model to predict the quality of drainage from discrete rock types (individual lithologies; White and Jeffers 1994; White and others 1994; Lin 1996; Guard 1997; Lin and others 1997). Such a tool will assist regulatory agencies, mining companies, and the public in assessing potential water quality impacts of waste rock drainage.

Whereas literature values can provide dissolution rates for modeling individual isolated minerals present a given lithology, empirical data are needed to provide rates describing their dissolution within the specific rock matrix. Distinct to each lithology is the grain size, surface morphology, and extent of liberation of the individual minerals. Within each rock type the interaction with other minerals and their dissolution products will also be unique. Thus, dissolution testing on individual lithologies is a necessary step in developing the mathematical model for predicting the quality of drainage from individual lithologies. This dissolution testing will also provide, on a primary level, empirical data on drainage quality and dissolution rates for the lithologies tested.

As the number of lithologies subjected to dissolution testing increases, the integrity of the mathematical modeling output will increase, as will the catalogue of empirical data available to assist prediction of drainage quality from similar lithologies. The Duluth Complex is one lithology which has been subjected to several dissolution studies in both laboratory and field

(Lapakko 1988, 1994; Lapakko and Antonson 1994). In this rock type virtually all of the sulfur minerals occur as sulfides.

The present study examines the dissolution of eleven waste rock samples: seven mafic-intrusive samples, three tuffaceous-sedimentary samples, and a waste rock sample which had been weathered in the environment for 75 to 100 years. All samples tested were subjected to accelerated weathering using the MN DNR protocol, which is a modification of the "modified" humidity cell protocol described in ASTM Standard Method 5744-96 (White and Sorini 1996). In addition three of the samples, one from each rock type, were also subjected to the ASTM protocol.

2. **OBJECTIVES**

The objectives addressed in the present project are as follows.

- 1. Describe the variation of drainage quality, particularly pH, as a function of the sulfur content of seven mafic-intrusive and three tuffaceous-sedimentary rock samples.
- 2. Determine the rates of sulfate, calcium, and magnesium release as a function of the sulfur content of seven mafic-intrusive and three tuffaceous-sedimentary rock samples.
- 3. Relate the drainage pH and rates of release to the solid-phase composition of seven mafic-intrusive and three tuffaceous-sedimentary rock samples.
- 4. Describe the temporal variation of drainage quality and determine the rates of sulfate, calcium, and magnesium release for an waste rock sample which had oxidized in the environment for 75 to 100 years.

The drainage quality data presently available on these samples are presently limited and, consequently, so is the degree to which the objectives are addressed. The overall objectives of the present study also include examining the effects of protocol variations on drainage quality and interlaboratory comparison of ASTM Modified Humidity Cell results. These objectives are not discussed in the present report.

3. BACKGROUND

3.1. Mine Waste Dissolution

3.1.1. Sources of Acid

The dissolution of iron sulfide minerals such as pyrite and pyrrhotite is responsible for the majority of mine-waste acid production (Stumm and Morgan 1981). Equations 1 and 2 are commonly published reactions representing pyrite and pyrrhotite oxidation by oxygen (after Stumm and Morgan 1981; Nelson 1978):

$$FeS_2(s) + (7/2)H_2O + (15/4)O_2(g) = Fe(OH)_3(s) + 4H^+(aq) + 2SO_4^{2-}(aq)$$
 (1)

$$FeS(s) + (5/2)H_2O + (9/4)O_2(g) = Fe(OH)_3(s) + 2H^+(aq) + SO_4^{2-}(aq)$$
 (2)

The rate of oxidation and attendant acid production is dependent on solid-phase compositional variables. Oxidation rates vary among sulfide minerals, reportedly decreasing in the order marcasite > pyrrhotite > pyrite. For a given sulfide mineral, the oxidation rate increases with the reactive surface area available. It also varies with the crystal form of the mineral. For example, the oxidation of framboidal pyrite is reported to be much more rapid than that of euhedral pyrite.

The rate of sulfide mineral oxidation also increases as pH decreases into a range conducive to bacterial catalysis of ferrous iron oxidation. Nordstrom (1982) reported that as "pH decreases to 4.5, ferric iron becomes more soluble and begins to act as an oxidizing agent." As pH further decreases bacterial oxidation of ferrous iron becomes the rate limiting step in the oxidation of pyrite by ferric iron (Singer and Stumm 1970), which is the only significant oxidizing agent in this pH range (Nordstrom 1982; Singer and Stumm 1970; Kleinmann et al. 1981).

These weathering reactions produce acidic, iron- and sulfate-rich aqueous water which can 1) contact sulfide minerals and accelerate their oxidation, 2) evaporate partially or totally to precipitate hydrated iron-sulfate and other minerals and/or 3) contact host rock minerals which react to neutralize some or all of the acid. Acidic flow which migrates through the mine waste will exit as acid mine drainage (AMD).

Hydrated iron-sulfate minerals precipitate during the evaporation of acidic, iron- and sulfate-rich water within mine-waste materials and store (for potential subsequent release) acid generated by iron sulfide mineral oxidation. The more common hydrated iron-sulfate minerals that occur as efflorescent salts on the surfaces of weathering pyrite include melanterite, rozenite, szomolnokite, romerite and copiapite (FeSO₄·7H₂O, FeSO₄·4H₂O, FeSO₄·H₂O, Fe²⁺Fe₂³⁺(SO₄)₄·14H₂O, and Fe²⁺Fe₄³⁺(SO₄)₆(OH)₂·20H₂O, respectively) (Alpers et al., 1994). According to Nordstrom (1982) and Cravotta (1994), these sulfate salts are highly soluble and provide an instantaneous source of acidic water upon dissolution and hydrolysis. They are partially responsible for increased acidity and metals loadings in the receiving environment during rainstorm events.

As an example, equations 3, 4 and 5 summarize the step-wise dissolution of melanterite.

$$FeSO_4 \cdot 7H_2O(s) = Fe^{2+}(aq) + SO_4^{2-}(aq) + 7H_2O$$
 (3)

$$Fe^{2+}(aq) + (1/4)O_2(g) + H^+(aq) = Fe^{3+}(aq) + (1/2)H_2O$$
 (4)

$$Fe^{3+}(aq) + 3H_2O = Fe(OH)_3(s) + 3H^+(aq)$$
 (5)

The net result of equations 3 through 5 is summarized in equation 6, which shows a net production of two moles of acid produced for each mole of melanterite dissolved.

$$FeSO_4 \cdot 7H_2O(s) + (1/4)O_2(g) = Fe(OH)_3(s) + SO_4^2(aq) + (9/2)H_2O + 2H^+(aq)$$
 (6)

Cravotta (1994) showed that a similar aqueous dissolution of romerite produced six moles of acid for each mole of romerite dissolved. Their cumulative storage and incremental release may help explain the lag from mine-waste placement to AMD-formation particularly in arid climates.

According to Nordstrom (1982), the formation of hydrated iron sulfates is an important intermediate step that precedes the precipitation of the more common iron minerals such as goethite and jarosite. Jarosite is slightly soluble (Alpers et al. 1994) and can, therefore, contribute acid according to equation 7. For example, recent preliminary leach studies

$$KFe_{3}(SO_{4})_{2}(OH)_{6}(s) = K^{+} + 3FeOOH(s) + 2SO_{4}^{2^{-}}(aq) + 3H^{+}(aq)$$
(7)

on natural and synthetic jarosites conducted by USBM showed a drop in pH from 6 in the deionized water leachant to 3 or 4 after contact with the jarosites. Because of its relatively low solubility, the acid contributed by jarosite dissolution is probably small relative to that by dissolution of more soluble hydrated iron sulfates.

3.1.2. Sources of Neutralization

The balance between the rates of acid production by iron-sulfide mineral oxidation and host rock buffering will determine the acidity of mine-waste drainage. The most effective minerals for neutralizing acid are those containing calcium carbonate and magnesium carbonate. Examples include calcite, magnesite, dolomite, and ankerite (CaCO₃, MgCO₃, CaMg(CO₃)₂, and CaFe(CO₃)₂, respectively). Equation 8 represents the dominant dissolution reaction of calcite (CaCO₃) with iron-sulfide-generated acid (H⁺) above pH 6.4, while equation 9 is the dominant reaction below pH 6.4 (Drever, 1988):

$$CaCO_{3}(s) + H^{+}(aq) = HCO_{3}^{-}(aq) + Ca^{2+}(aq)$$
 (8)

The dissolution rates for the calcite reactions shown in equations 8 and 9 are relatively rapid. However, dissolution rates are not the same for all carbonates; for example, Rauch and White (1977) and Busenberg and Plummer (1986) have reported that the rates of magnesium carbonate

$$CaCO_{3}(s) + 2H^{+}(aq) = H_{2}CO_{3}(aq) + Ca^{2+}(aq)$$
 (9)

and calcium-magnesium carbonate (i.e., magnesite and dolomite) dissolution are substantially slower than that of calcium carbonate. Additionally, iron carbonates do not provide for net acid neutralization under oxidizing conditions, due to oxidation of the ferrous iron released, subsequent precipitation of ferric hydroxide, and the consequent acid production (reactions 4, 5).

Dissolution of silicates such as plagioclase-feldspar minerals (e.g., anorthite in equation 10, Busenberg and Clemency 1976) and olivine minerals (e.g. forsterite in equation 11, Hem 1970) can also neutralize acid under acidic conditions, but their dissolution rates (and consequent acid neutralization) are slow relative to the carbonate minerals.

$$CaAl_{2}Si_{2}O_{8}(s) + 2H^{+}(aq) + H_{2}O = Ca^{2+}(aq) + Al_{2}Si_{2}O_{5}(OH)_{4}(s)$$
(10)

$$Mg_{2}SiO_{4}(s) + 4H^{+}(aq) = 2Mg^{2+}(aq) + H_{4}SiO_{4}(aq)$$
(11)

The effectiveness of silicate-mineral neutralization is thought to be optimized by these factors: 1) the acid-production rate is relatively slow, 2) feldspar minerals comprise a significant percentage of the overall mineralogy, and 3) the available silicate-mineral surface area is large (Morin and Hutt 1994).

4. METHODS

4.1. Materials

The current study includes eleven waste-rock samples. Ten of the samples, seven mafic intrusive and three tuffaceous sedimentary rocks, were segregated from a "sulfide-carbonate mixed waste" bulk sample from an open-pit metal mine. The eleventh sample is a carbonate-hosted, base-metal-sulfide bearing waste rock from a 75- to 100-year old oxidized metal-mine waste-rock dump, and was provided by Kathleen Smith of the U.S. Geological Survey (USGS).

4.1.1. Mafic-Intrusive and Tuffaceous-Sedimentary Samples.

The seven mafic-intrusive and three tuffaceous-sedimentary samples were segregated from a runof-mine (ROM) bulk sample of "sulfide-carbonate mixed waste." The sample was collected from the face of a 20-foot-high mine bench where the mixed waste was exposed. To facilitate collection of a bulk sample that would meet the desired range of sulfide-sulfur and carbonate-carbon content for the study, four grab samples were collected from the "sulfide-carbonate mixed waste" and blended into a composite sample for preliminary chemical characterization. Chemical analyses of the blended grab samples showed that the mixed waste exhibited the following percentage ranges: $1.59 \le C_{tot} \le 1.89$, $6.24 \le CO_3 \le 7.00$, and $4.77 \le S^{2^-} \le 5.61$. Based on these values, an area of mixed waste exposed in the bench face was delineated, and the bulk sample was collected. The final bulk sample was placed into two 55-gallon drums and shipped to the mine metallurgical laboratory for sizing, crushing, splitting, and preliminary mineral characterization.

The bulk sample was screened through a 1.5-inch screen into two fractions. The minus 1.5-inch fraction was returned to the 55-gallon drums and sent to the USGS to become a standard reference material. The plus 1.5-inch fraction was washed to clean the sample surfaces of very-fine mine waste material that had accumulated during excavation, and consequently obscured surface mineralogy and texture. However, an unintended consequence of this rinsing resulted in removal of an unquantified amount of surface-oxidation products (e.g., sulfate-salt storage). Therefore, tests to quantify sulfate-salt storage, such as the hot-water leach, would be ineffective under these conditions and visually sorted into piles of similar rock types.

Guidance for the visual sorting was based on the fact that the mixed waste bulk sample was initially classified in the field to be approximately 50% gray, sulfidic, fine-grained, mafic-intrusive rock, and 50% black, carbonaceous and silicified tuffaceous-sedimentary rock. The initial visual sorting emphasized gross mineralogic and textural differences and produced five separate piles. Three of the piles were characterized by mafic intrusive rock that varied from massive, homogeneous material with abundant disseminated pyrite, to fractured material with densely-spaced fracture-filling quartz and pyrite veinlets. The other two piles consisted of dark-gray to black, sparsely pyritic sedimentary rock that varied from thin-bedded, carbonaceous material to fractured, silicified material with fracture-filling quartz veinlets. More rigorous sorting of the five piles, based on a binocular-microscope examination, produced ten samples; seven were mafic intrusive rocks with varying ranges of pyrite and carbonate content, and three were of dark-gray to black, silicified tuffaceous sedimentary rocks with little or no pyrite and carbonate present.

The ten samples (designated as numbers M-1 through M-10) were then each stage-crushed to 100% passing 0.25 inch. Subsequently, each crushed sample was split by rotary splitter into more than 12 aliquots of 0.25 kg each. Twelve aliquots from each of the ten samples comprise three 1-kg humidity-cell charges. After the 12 aliquots were set aside for humidity-cell charges, a portion of leftover material (about 0.25 kg) from the rotary splitting of each sample was pulverized by ring and puck to 80% passing 150 mesh (100 micron) for chemical analyses. The balance of leftover split material was re-combined and bagged as "reject". The 12 aliquots and "reject" comprising each sample were placed in plastic 5-gallon buckets and shipped to MDNR. As-received sample masses ranged from 6 to 14.5 kg. Upon receipt at MDNR, the "reject" portion of each sample was submitted for screen-fraction analysis at Lerch Brothers, Inc. in Hibbing, MN.

4.1.2. USGS Oxidized Waste-rock Dump Sample.

Broken waste-rock fragments ranging in size from 2 by 3 to 3 by 5 inches, selected from a 75- to 100-year old metal-mine waste-rock dump, comprise the USGS sample. A sample of approximately 25 kg was collected and shipped to the MDNR in a 5-gallon bucket. Because of the 75- to 100-year surface exposure on the dump, some of the individual sample fragments exhibit as-much-as an 1/8-inch thick oxidation rim. It was not possible to remove this oxidation rim during sample preparation. The sample is dominated by a coarsely crystalline matrix of dolomite that contains dispersed iron and base-metal sulfides. Iron sulfide as pyrite occurs in pods and some fracture fillings. Occasional visible grains of galena (PbS) and sphalerite (ZnS) comprise the base-metal sulfides. Some secondary calcite is also present.

Six hand specimens were selected from the USGS-sample population for gross mineralogic and petrologic exam. The remainder of the sample was stage-crushed to 100% passing 0.25 inch. The crushed USGS sample was subsequently blended by being passed three times through a Jones Splitter containing 0.75-inch chutes. After blending, the sample was split into aliquots of about 0.25 kg. Four of these aliquots were randomly selected from the sample-aliquot population to make up the USGS sample's 1-kg humidity-cell charge.

4.2 Accelerated Weathering "Modified-Humidity Cell" Protocol (ASTM Standard Method D-5744-96)

Three samples have currently been subjected to of accelerated-weathering tests conducted according to ASTM Standard Method 5744-96. A 16-cell array identical to that illustrated by figure 1 in the standard method is being used in this study. Four 0.25-kg aliquots (each in "ziplock bags) comprising each sample were used to load individual humidity cells; this "4-bag" loading method was used to minimize sample stratification and consequent fluid "channeling" in the cell. Because of the limited number of samples being subjected to the ASTM method in this study, the full complement of cell positions in the array were not used. The final 16-cell-array composition included a sample from the mafic-intrusive and tuffaceous-sedimentary rock types (M-2 and M-8), and a replicate of the USGS sample.

Following an initial 1.5-L week 0 rinse (see section 4.4., Modifications of the ASTM Protocol), the subsequent weekly accelerated-weathering cycles were comprised of the following:

- Tuesday previous week's leachant collected and weighed; each humidity cell weighed to determine amount of interstitial water present in the waste-rock sample after the leach; three-day dry-air period initiated (same time each cycle) NOTE: start of dry-air period begins the new week (i.e., week 1).
- Friday dry-air period ends; each humidity cell weighed to determine evaporation rate of interstitial water; three-day wet-air period initiated (same time each cycle).
- Monday wet-air period ends; each humidity cell weighed to determine gain/loss of interstitial water; 500-mL drip-trickle leach initiated.

• Tuesday - previous week's leachant collected and weighed; each humidity cell weighed to determine amount of interstitial water present in the waste-rock sample after the leach; three-day dry-air period initiated; start of new week (i.e., week 2).

Air-flow rates (L/min) and relative-humidity readings were taken once daily for each cell during the three-day dry-air period; these readings were also taken once daily for each cell on Friday and the following Monday during the wet-air period.

4.3 MN DNR Cell Accelerated-Weathering Protocol

An accelerated-weathering test method similar to ASTM Standard Method D-5744-96 has been designated as the MN DNR protocol (Lapakko 1998, p. 8). The MN DNR protocol uses the same humidity-cell size, waste-rock charge, and leachant volume and application method as described in ASTM D-5744-96. However, instead of subjecting the humidity cell apparatus to the humid- or dry-air flow into the cell, the cells were simply stored in a controlled temperature and humidity room between weekly rinses.

One-kg charges of seven mafic-intrusive waste-rock samples (samples M-1 through M-7) and three tuffaceous-sedimentary waste-rock samples (M-8 through M-10) were loaded into 12 MN DNR cells and subjected to initial rinsing (week 0) 11 August 1998. Samples M-2 and M-8 were run in duplicate. To date (17 November 1998) these 10 samples have been subjected to 15 weeks of accelerated weathering. A 1-kg charge of USGS sample was loaded into a MN DNR cell on 19 August 1998, and has subsequently been subjected to five weeks of accelerated weathering.

4.4. Modifications to the ASTM and MN DNR Accelerated-Weathering Protocols

Samples tested were either subjected to humidity cell testing using the "Modified Humidity Cell" designated as ASTM Standard Method 5744-96 (White and Sorini 1996) or the MN DNR protocol. The only departure from the standard-method protocol was the volume of de-ionized water used for the initial leach (week 0); instead of a single 500-mL leach, three 500-mL rinses totaling 1.5 L were performed on each sample to flush it of residual sulfate salts produced by natural weathering prior to sample collection. The same initial-rinse technique (1.5 L vs 0.5 L week-0 rinse) is used in the MN DNR protocol.

The 3-rinse procedure consisted of an initial 500-mL drip-trickle leach to wet the 1-kg sample, a 500-mL flooded leach to saturate the sample (after sample was flooded, leachant was in contact with sample for 5 minutes prior to being drained), and a final 500-mL drip-trickle leach to complete the rinse. Recovered volumes from each of the three rinses were weighed, and composited. Samples (approximately 60 mL) from the composite were preserved and submitted for analyses so that selected cation/anion loads could be calculated.

The discussions which follow address initial results from the cells employing the MN DNR protocol and the ASTM Standard Method. Comparison these methods will be discussed more extensively in an upcoming report.

4.5. Analyses

The mine waste samples were analyzed for sulfur, sulfide, sulfate, evolved carbon dioxide, as well as whole rock and trace constituent concentrations by ACTLABS, Inc. (Wheat Ridge, CO). Mineralogic analyses using x-ray diffraction, optical microscopy, and SEM will be conducted by Barry Frey of Midland Research and Louis Mattson of Nashwauk, MN.

Water samples were analyzed for specific conductance, pH, alkalinity, acidity, and Eh at the MN DNR in Hibbing. Specific conductance was analyzed using a Myron L conductivity meter, and an Orion SA720 meter, equipped with a Ross combination pH electrode (8165), was used for pH analyses. Alkalinity (for pH \ge 6.3) and acidity were determined using standard titration techniques for endpoints of 4.5 and 8.3, respectively (APHA et al. 1992). Eh readings were taken using a Beckman model 11 meter with an Orion electrode (9678BN).

Composite samples from week 0 rinses of two mafic-intrusive (M-1, M-3) and one tuffaceoussedimentary (M-8) sample were analyzed by inductively coupled plasma mass spectrometry (ICP-MS, Perkin Elmer mode-SCIEX-Elan 5000) at the University of Minnesota Department of Geology to identify trace parameters released to drainage. Based on these scans (Appendix 1), trace parameters were selected for subsequent determination at the Minnesota Department of Agriculture (MN DA). Metals were determined with a Varian 400 SPECTRAA; a Zeeman GFAA furnace was attached for low concentrations. Sulfate concentrations were determined using a Technicon AA2 automated colorimeter or, for $[SO_4] < 5 \text{ mg/L}$, a Dionex ion chromatograph.

5. **RESULTS**

5.1. Introduction

Particle size distribution and solid-phase chemistry data are available for all mafic-intrusive and tuffaceous sedimentary samples. Since the experiment is yet in its early stages, limited data on drainage quality are available.

5.2. Solid-phase Analyses

5.2.1. Particle Size Distribution

Particle size distribution determinations on the mafic-intrusive samples indicated roughly 50 percent of the particles were in the -4/+20 mesh Tyler fraction (4.75 mm \le d \le 0.850 mm), 75 percent were coarser than 48 mesh (0.300 mm \le d), and 10 percent were in the -200 mesh fraction (d \le 0.074 mm; Table 1). The tuffaceous-sedimentary samples were coarser, with about 65 percent in the -4/+20 mesh fraction, 80 percent coarser than 48 mesh, and 7 percent in the -200 fraction (Table 2). The USGS sample was coarsest, with 76 percent in the -4/+20 fraction, 84 percent coarser than 48 mesh, and 6 percent finer than 200 mesh (Table 2). Dry sieving was used for the -100 fraction, since there was little difference between results of dry- and wet-sieving the -100 mesh fraction (Tables 1, 2).

5.2.2. Solid-Phase Chemistry

The key variables with regard to generation of acidic drainage are the surfaces areas of iron sulfide, calcium carbonate, and magnesium carbonate minerals. As discussed in section 2, the oxidation of iron sulfide minerals leads to acid production, and dissolution of calcium and magnesium carbonate minerals neutralizes acid. Whether drainage from a sample is acidic is dependent upon the balance of these reactions.

Mineralogic analyses are necessary to quantify the available sulfide and carbonate minerals, and all samples will be submitted for these analyses. Chemical data can be used as a preliminary indicator of mineral contents. Assuming all of the sulfide is present as iron sulfide and the carbon dioxide (CO₂) is present solely as calcium and magnesium carbonates, the potentials for acid production $[AP(S^{2-})]$ and neutralization $[NP(CO_2)]$ can be estimated.

The **mafic-intrusive samples** have sulfide contents (total sulfur minus sulfur present as sulfate) of ranges from roughly six to nine percent, and evolved CO_2 contents from roughly two to six percent (Table 3). Assuming all of the sulfide is present as iron sulfide and the CO_2 is present solely as calcium and magnesium carbonates yields net neutralization potential values of -204 to -60 g/kg CaCO₃. These values indicate that the estimated potential to produce acid [AP(S²⁻)] exceeds that to neutralize acid [NP(CO₂)]. If these potentials are entirely available, the samples will ultimately produce acidic drainage. However, the implied neutralization potentials of the samples range from about 50 to 130 g/kg CaCO₃, indicating that drainage may be neutral for a long time prior to acidification.

The tuffaceous-sedimentary samples have lower contents of sulfide (1.3 to 3.75 percent) and evolved CO_2 (1.92 to 4.05 percent). Using the same approach as above, the estimated net NP values for samples M-10, M-9, and M-8 are 3, 33, and -25 g/kg CaCO₃, respectively. If the [AP(S²-)] and [NP(CO₂)] are entirely available, only sample M-8 will produce acidic drainage. The [NP(CO₂)] of this sample is 92 g/kg CaCO₃, indicating that drainage would be neutral for a long time prior to acidification.

The sulfide content of the **USGS sample** is 13 percent as compared to an evolved CO_2 content of 20.9 percent (Table 3). However, it is likely that the elevated lead and zinc in the sample (1.7 and 4.2 percent, respectively) are present as sulfides. The respective mole percentages of sulfide, lead, and zinc are 0.405, 0.0068, and 0.064. This indicates that 82 percent of the sulfur (10.7 percent of rock) is associated with iron, and the resultant AP(FeS) is 334 g/kg CaCO₃. Similarly, the NP(CO₂) must be adjusted since the calculated value requires more calcium and magnesium than is present in the rock. Calculating neutralization potential based on the observed concentrations of calcium and magnesium yields an NP(Ca + Mg) of 60.5 g/kg CaCO₃. This represents an upper bound for the NP present as calcium and magnesium carbonate, since some of the calcium and magnesium may occur in silicate minerals. The remaining carbonate is associated with iron and possibly manganese, since both are present at fairly high levels (Table 3). In an oxidizing environment, dissolution of these carbonates will not contribute to acid neutralization.

5.2.3. Trace Metal Chemistry

Arsenic is the major parameter of concern in the mafic-intrusive and tuffaceous sedimentary rocks. Arsenic concentrations range from 1200 to 2100 ppm in the former and from 250 to 500 ppm in the latter (Table 4). Most other trace metal concentrations are below 100 ppm. Notable exceptions for the mafic-intrusive samples are barium (270 ppm average), rubidium (140 ppm average), vanadium (120 ppm average), and zirconium (260 ppm average). Exceptions for the tuffaceous-sedimentary rocks are barium (120 ppm average) and chromium (170 ppm average).

As previously mentioned, the USGS sample has extremely elevated levels of lead and zinc, measuring 1.7 and 4.2 percent, respectively. Copper and cadmium are also relatively high, with reported levels of 460 and 350 ppm, respectively. Concentrations of other trace metals are typically lower than 10 ppm.

5.2.4. Mineralogy

Visual descriptions of the mafic-intrusive, tuffaceous-sedimentary, and USGS samples are presented in Appendix 1. The samples will be submitted for more detailed mineralogic characterization by x-ray diffraction, optical microscopy, and scanning electron microscope.

5.3. Drainage Quality Results

For the mafic-intrusive and tuffaceous sedimentary samples, 15 weeks of data are presented for pH, net alkalinity (alkalinity - acidity), Eh, and specific conductance. Eight weeks of data are presented metals and six weeks for sulfate. For the USGS sample, five weeks of data are presented for pH, net alkalinity, Eh, and specific conductance.

5.3.1. Mafic-intrusive Samples

Drainage quality from the mafic-intrusive samples indicated that, while iron sulfides were oxidizing, pH and alkalinity were controlled by the dissolution of calcium and magnesium carbonate minerals. At week 6, sulfate concentrations typically ranged from 120 to 240 mg/L. Values for the 7.4- and 8.1-percent sulfur samples were lower than this range (85 and 95 mg/L, respectively).

Typically pH ranged from 7.9 to 8.1, with values from the 7.3-percent sulfur sample slightly below this range and those from the 9.05-percent sulfur sample slightly above this range (drainage quality tables in Appendix 2). Alkalinities typically ranged from 80 to 110 mg/L as CaCO₃. Examination of the calcium and magnesium concentrations indicate that calcium carbonate dissolution was 1.5 to 2.0 times that of magnesium carbonate dissolution (molar basis). This ratio was slightly higher for the 7.4-percent sulfur sample.

Trace metal release was limited to relatively low levels of manganese, antimony, and zinc. The approximate concentration ranges for these parameters at week 4 were 0.3-3, 0.07-0.2, and 0.01-0.1 mg/L, respectively. The high release of antimony relative to arsenic is somewhat surprising

since the solid-phase concentrations of antimony were roughly three percent those of arsenic (Table 4). Apparently the arsenic is in a fairly stable form in these rocks.

5.3.2. Tuffaceous-sedimentary Samples

As with the mafic-intrusive rocks, despite the oxidation of iron sulfides in the tuffaceous sedimentary rocks, the initial drainage quality was controlled by the dissolution of calcium and magnesium carbonates. Sulfate concentrations at week six ranged from about 80 to 160 mg/L, reflecting the oxidation of iron sulfide minerals. This range is similar to that observed for four of the seven mafic-intrusive samples (Appendix 2). This is notable since the sulfur contents of the tuffaceous-sedimentary samples is roughly 20 to 60 percent of the lowest sulfur content of the mafic-intrusive rocks. That is, the tuffaceous-sedimentary samples generated more sulfate per unit mass sulfide minerals than the mafic-intrusive samples in the initial stage of the experiment.

Typically pH ranged from 7.9 to 8.1, with the 1.31-percent sulfur sample generating slightly lower values. Alkalinities ranged from 25 to 90 mg/L. The calcium and magnesium concentrations indicate that the calcium carbonate dissolution was roughly 1.4 times that of the magnesium carbonates, on a molar basis.

Manganese, antimony, and arsenic were the only trace metals regularly detected in the drainages. Typical concentration ranges at week 4 were 0.2-0.7, 0.02-0.04, and 0.001-0.01 mg/L, respectively. As with the mafic-intrusive rocks, the elevated antimony concentrations relative to the arsenic concentrations in the drainages is notable; solid-phase antimony concentrations were roughly 10 percent those of arsenic (Table 4).

5.3.3. USGS Sample

Little can be said regarding the USGS samples as the present data are limited. Drainage pH was typically in the range of 6.9 to 7.0, the lowest of all samples examined. The typical range for alkalinity was less than 5 to 10 mg/L as $CaCO_3$. These relatively low values suggest, preliminarily, that the majority of the carbonate may be associated with iron and manganese.

5.4. Comparison of MN DNR and ASTM Methods

Three samples are being subjected to dissolution by both MN DNR and ASTM methods: the 7.05-percent sulfur mafic-intrusive sample, the 3.75-percent sulfur tuffaceous-sedimentary sample, and the USGS sample. There are presently no sulfate or metals data for drainage from the USGS sample.

While the data are presently limited, a few preliminary observations can be made. First, the sulfate concentrations produced by the two methods were similar for the mafic-intrusive and tuffaceous-sedimentary samples. Second, the pH for the ASTM method was slightly lower than that for the MN DNR method for all three samples. Third, the alkalinities produced by the ASTM method are substantially lower for all three samples. Fourth, the calcium and magnesium concentrations produced with the ASTM method were lower than those with the MN DNR

method. These sulfate concentrations suggest that the sulfide oxidation is similar by both methods, but the dissolution of calcium and magnesium carbonates is slower with the ASTM method (as indicated by lower pH, alkalinity, as well as calcium and magnesium concentrations). The data are presently too limited to make definitive conclusions. These observations and their implications will be further examined in the future.

6. ACKNOWLEDGMENTS

Bill White of the U.S BLM Salt Lake City Office was largely responsible for segregating the mafic-intrusive and tuffaceous-sedimentary rock samples, as well as providing initial descriptions of the mineralogy of the samples. John Folman conducted laboratory dissolution experiments, with assistance from Anne Jagunich and supervision from David Antonson. Gregory Walsh input data and Mr. Folman was responsible for tabular output. Sue Backe provided clerical assistance in assembling tables within the report body.

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SAMPLE	MS-1		MS-2		MS-3		MS-4		MS-5		М	S-6	MS-7	
NUMBER	%R	∑%P	%R	∑%Р	%R	∑%Р	%R	∑%Р	%R	∑%P	%R	∑%Р	%R	∑%P
+ 1/4"	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
- 1/4+4M	. 0.0	100.0	0.0	100.0	0.0	100.0	0.1	99.9	0.1	99.9	0.0	100.0	0.0	100.0
-4+10M	19.8	80.2	17.5	82.5	20.8	79.2	19.0	80.9	18.3	81.6	18.5	81.5	23.0	77.0
-10+20M	34.1	46.1	33.4	49.1	31.5	47.7	32.0	48.9	34.2	47.4	36.1	45.4	37.6	39.4
-20+28M	7.8	38.3	7.9	41.2	7.4	40.3	7.4	41.5	7.6	39.9	7.7	37.7	7.3	32.1
-28+35M	6.0	32.3	6.4	34.8	5.9	34.4	5.8	35.7	5.7	34.2	5.7	32.0	5.1	27.0
-35+48M	7.1	25.2	8.4	26.4	7.2	27.2	6.2	29.5	6.1	28.1	6.1	25.9	5.2	21.8
-48+65M	3.9	21.3	2.9	23.5	4.5	22.7	4.7	24.8	4.7	23.4	4.2	21.7	3.3	18.5
-65+100M	5.3	16.0	5.9	17.6	5.7	17.0	5.9	10.9	5.3	18.1	4.8	16.9	4.6	13.9
-100+150M	3.0	13.0	3.8	13.8	2.8	14.2	3.2	15.7	3.1	15.0	3.2	13.7	2.2	11.7
-150+200M	3.5	9.5	3.0	10.8	4.0	10.2	3.5	12.2	3.0	12.0	3.3	10.4	2.6	9.1
-200M	9.5	-	10.8	-	10.2	-	12.2	-	12.0	_	10.4	-	9.1	-

Table 1. Particle size distribution for mafic intrusive rock (Analysis by Lerch Brothers, Inc.)

%R - Percent retained.

 \sum %P - Cummulative percent passing.

Wet vs dry sieving of MS-3, percent retained.

	MS - 3	
	DRY	WET
-100M+150	2.8	1.2
-150M+200	4.0	2.0
-200M	10.2	13.8

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SAMPLE	MS-8		MS-9		MS-10		U	SGS
FRACTION	%R	∑%P	%R	∑%P	%R	∑%Р	%R	∑%P
+ 1/4"	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
- 1/4+4M	0.1	99.9	0.6	99.4	0.4	99.6	19.2	80.8
-4+10M	34.4	65.5	35.8	63.6	41.1	58.5	42.6	38.2
-10+20M	28.3	37.2	26.6	37.0	26.8	31.7	14.1	24.1
-20+28M	7.0	30.2	7.5	29.5	6.9	24.8	4.3	19.8
-28+35M	5.0	25.2	5.5	24.0	4.8	20.0	3.1	16.7
-35+48M	4.7	20.5	5.0	19.0	4.3	15.7	2.9	13.8
-48+65M	1.9	18.6	3.6	15.4	3.1	12.6	2.1	11.7
-65+100M	4.9	13.7	3.8	11.6	2.7	9.9	2.0	9.7
-100+150M	3.1	10.6	2.8	8.8	2.4	7.5	1.8	7.9
-150+200M	1.8	8.8	1.8	7.0	1.7	5.8	1.5	6.4
-200M	8.8	-	7.0	-	5.8	-	6.1	-

Table 2. Particle size distribution for sedimentary rock and USGS sample. (Analysis by Lerch Brothers, Inc.)

%R - Percent retained Σ %P - Cummulative percent passing

Wet vs dry sieving of MS-9, percent retained.

FRACTION	MS - 9			
	DRY	WET		
-100M+150	2.8	1.9		
-150M+200	1.8	1.4		
-200M	7.0	8.3		

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			Mafic-	Intrusive	2			Tufface	ous-Sedin	nentary	
	M-5	M-4	M-2	M-1	M-7	M-3	M-6	M-10	M-9	M-8	USGS
S	6.50	6.75	7.05	7.3	7.40	8.10	9.05	1.31	1.37	3.90	13.7
SO4	0.90	0.90	0.45	<0.05	< 0.05	0.15	1.50	< 0.05	<0.05	0.45	2.15
CO ₂	5.85	4.45	4.10	4.45	2.84	2.15	2.62	1.92	3.35	4.05	20.90
CaO	6.01	4.92	4.29	3.04	4.33	3.76	4.17	1.69	2.45	3.34	0.45
MgO	2.02	1.72	1.40	1.21	1.23	1.04	1.13	0.80	1.34	1.68	2.12
Na ₂ O	0.09	0.08	0.07	0.07	0.09	0.09	0.09	0.03	0.04	0.05	< 0.01
K ₂ O	4.62	4.01	4.52	4.45	5.24	4.86	5.48	0.87	1.05	1.56	0.04
$Fe_2 O_3$	10.31	9.71	11.95	14.98	10.49	11.24	12.43	2.28	2.29	4.52	43.68
MnO	0.12	0.10	0.15	0.27	0.07	0.05	0.06	0.04	0.06	0.08	9.53
TiO ₂	2.81	2.55	3.08	3.04	3.38	3.31	3.39	0.14	0.14	0.60	0.04
P ₂ O ₅	1.47	1.38	1.38	1.52	1.77	1.67	1.73	0.35	0.15	0.49	0.05
Al ₂ O ₃	12.99	11.87	14.50	14.39	15.66	15.21	15.68	2.20	2.66	3.97	0.84
SiO ₂	47.66	52.89	47.08	44.28	46.64	47.60	44.06	88.81	85.50	76.16	3.45

Table 3. Whole rock chemistry (percent) of mafic intrusive, sedimentary, and USGS rocks (analysis by Actlabs, Inc.).

NOTE: SO_4 reported as SO_4 as opposed to as sulfur.

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			Mafic	intrusive				Tuffac	eous Sedim	entary	
	M-5	M-4	M-2	M-1	M-7	M-3	M-6	M-10	M-9	M-8	USGS
Ag	2.3	2.2	1.9	0.7	2.6	1.5	2.8	1.3	1.1	2.1	20.0
As	1330	1230	1530	1350	1850	1820	2070	245	260	494	94
Au (ppb)	1470	1930	1420	1120	1590	1370	1400	451	489	1230	18
Ba	268	244	256	233	314	290	311	87	104	156	7
Be	2	2	2	3	2	2	2	<1	<1	- 1	<2
Bi	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	7
Br	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cd	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	351.7
Со	16	16	19	20	17	20	19	4	3	7	2
Cr	38	58	38	21	27	38	32	229	141	137	43
Cs	15.6	14.0	20.2	21.6	22.1	20.9	22.3	2.3	2.9	4.1	<0.5
Cu	15	17	19	23	16	20	17	10	11	14	464
Hf	6.0	5.6	6.6	6.6	6.7	6.8	6.2	0.7	0.9	1.6	<0.5
Ir (ppb)	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Мо	<5	<5	<5	<5	<5	<5	<5	<5	5	7	<2
Ni	14	13	19	23	20	19	21	10	12	15	4
Pb	<5	<5	<5	<5	5	7	<5	<5	<5	5	17117
Rb	117	115	138	161	145	139	145	<20	23	43	<20
Sb	38.7	40.8	43.9	48.5	41.0	50.3	43.7	22.3	24.8	24.3	5.7
Se	<3	4	<3	<3	<3	<3	<3	<3	<3	<3	<3

 Table 4. Page 1 of 2.
 Trace metal analysis of mafic intrusive, sedimentary, and USGS rocks (analysis by Actlabs, Inc., concentrations in ppm unless otherwise noted).

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			Mafic	intrusive				Tuffac	eous Sedim	entary	
	M-5	M-4	M-2	M-1	M-7	M-3	M-6	M-10	M-9	M-8	USGS
Sr	67	59	61	54	67	59	67	25	25	38	4
Та	<1	<1	1	1	<1	<1	1	<1	<1	<1	<1
v	109	112	116	107	120	128	127	53	75	60	4
w	26	23	36	50	28	29	29	5	7	7	4
Y	50	47	-58	58	62	59	65	10	9	15	6
Zn	23	23	65	118	23	27	23	28	24	25	42070
Zr	274	251	245	287	273	262	255	38	37	79	9
Се	107	96	120	122	147	124	132	25	24	39	5
Eu	4.0	3.7	4.3	4.1	4.3	4.3	4.1	0.9	0.7	1.4	0.2
La	51.3	45.3	57.0	59.3	72.0	59.7	68.9	13.6	14.4	21.2	2.7
Lu	0.57	0.48	0.63	0.63	0.68	0.61	0.62	0.07	0.08	0.18	0.09
Nd	54	52	67	71	86	70	77	11	11	21	<5
Sc	16.4	14.5	20.6	22.0	19.0	18.2	18.2	1.7	2.3	5.9	1
Sm	12.0	11.0	13.4	13.6	14.9	14.0	14.0	2.2	2.2	4.0	0.5
Tb	1.4	1.5	1.8	1.6	2.0	1.7	1.9	<0.5	<0.5	<0.5	<0.5
Th	4.6	4.3	5.2	5.4	5.7	5.4	5.3	1.4	1.6	2.0	1.3
U	2.2	<0.5	<0.5	<0.5	<0.5	<0.5	1.3	1.1	1.6	0.9	0.8
ΥЪ	3.4	3.3	4.2	4.6	4.5	4.3	4.7	0.5	0.5	1.1	0.4

 Table 4. Page 2 of 2.
 Trace metal analysis of mafic intrusive, sedimentary, and USGS rocks (analysis by Actlabs, Inc., concentrations in ppm unless otherwise noted).

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Appendix 1

Solid-Phase Composition and Week 0 Drainage Quality Scan

Table A1.1. Carbon and sulfur content of 1999 BLM project samples.

- Table A1.2. Mafic-intrusive waste rock descriptions based on binocular microscope examination.
- Table A1.3. Tuffaceous-sedimentary waste rock descriptions based on binocular microscope examination.
- Table A1.4. Mafic-intrusive and tuffaceous sedimentary rock: week 0 composite rinse concentrations.

No.	ID ¹	CAI	CAP	СТОТ	SAP	STOT	CaCO ₃ ²	S ²⁻³	NP^4	AP ⁵	NP/AP
	MAFIC										
1	257	0.245	0.214	1.376	1.241	7.32	9.42	6.08	94	190	0.49
2	259	0.191	0.609	1.328	1.096	6.99	9.48	5.89	95	184	0.52
3	260	0.224	0.412	0.815	0.919	7.89	4.92	6.97	49	217	0.23
4	261	0.223	0.997	1.487	0.872	6.60	10.53	5.72	105	178	0.59
5	262	0.197	1.351	1.924	0.926	6.44	14.39	5.52	144	172	0.84
6	263	0.163	0.502	0.924	0.826	8.83	6.34	8.01	63	250	0.25
7	264	0.187	0.611	1.041	0.835	7.59	7.12	6.76	71	211	0.34
					SEDIM	IENTAR	Y		-		
8	265	0.35	0.961	1.545	0.558	3.99	9.96	3.44	100	107	0.93
9	291	0.525	0.825	1.418	0.084	1.41	7.44	1.33	74	41	1.80
10	292	0.34	0.385	0.868	0.262	1.41	4.40	1.15	44	36	1.22
					CO	NTROL					
Cn ⁶	311	0.49	4.869	5.895	0.759	1.42	45.04	.66	45	21	2.14

Table A1.1. Carbon and sulfur content of 1999 BLM project samples. CAI: carbon, acid insoluble (noncarbonate); CAP: carbon after pyrolysis (no organic C); SAP: sulfur after pyrolysis (sulfate sulfur).

¹ All numbers preceded by 200146 ² (CTOT - CAI) x 100/12 ³ (STOT - SAP) ⁴ CaCO₃ x 10, NP in kg/t as CaCO₃ ⁵ AP in kg/t as CaCO₃ = S²⁻ x 31.2

⁶ Control

Ordered NP/AP

0.25 0.34 0.49 0.52 0.59 0.84 Mafic 0.23 Sedimentary 0.93 1.22 1.80

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FeS₂ abundance, morphology Carbonate Presence¹ Alteration Fracture type, No Texture abundance Argillic Abundant (+) to sparse dissem. Dense, fine-gr., equigranular Isolated hairline None observed M-1 veinlets euhedral py. Dense, fine-gr., equigranular Argillic Isolated hairline Abundant (++) dissem. None observed M-2 veinlets euhedral py. Slight argillic. Abundant (++) dissem. M-3 Dense, fine-gr., equigranular Isolated hairline Minimal - some minor fizz feldspars altered euhedral py. veinlets observed to clay Abundant (++) dissem. Fractured, fine-gr., Slight argillic, Stockworks of Present as spherical-vug M-4 equigranular, w/frax filled feldspars altered euhedral py. & some frax fillings and as hairlinehairline-qtz w/qtz & some py. to clay veinlets filled w/py. fracture fillings Abundant (+) dissem. euhedral Slight argillic, Present as spherical-vug M-5 Fractured, fine-gr., Stockworks of equigranular, w/frax filled feldspars altered py. & some frax filled w/py. fillings and as hairlinehairline-qtz fracture fillings w/qtz & some py. to clay veinlets Abundant (++) dissem. Fractured, fine-gr., Slight argillic. Stockworks of Present as some spherical-M-6 equipranular, w/ dark feldspars altered hairline-gtz euhedral py. & some frax vug fillings, as selvage on inclusions & frax filled to clay veinlets filled w/py.; pyritic margin frax-filling qtz veinlets, and bounds some dark inclusions as hairline-fracture fillings w/qtz & some py. Slight argillic, Abundant (+) dissem. euhedral Fractured, fine-gr., Stockworks of M-7 Present as some sphericalequigranular, with dark feldspars altered hairline-qtz py. & some frax filled w/py.; vug fillings, as selvage on inclusions & frax filled to clav pyritic margin bounds some frax-filling qtz veinlets, and veinlets w/qtz & some py. as hairline-fracture fillings dark inclusions

Table A1.2. Mafic-intrusive waste rock descriptions based on binocular microscope examination

¹Qualitatively determined by placing drop of 10% HCI on rock surfaces and observing presence or absence of fizz (i.e., CO₂ generation from CaCO₃ dissolution)

frax : fractures

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gr : grained

py: pyrite

 $qtz: \; quartz \;$

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No.	Texture	Alteration	Fracture type, abundance	FeS ₂ abundance, morphology	Carbonate Presence ¹
M-8	Black, fractured, silicified, and carbon-bearing sediment; fractures filled with cryptocrystalline qtz	Silicified (+)	Stockworks of 1/8th-inch wide cryptocrystalline-qtz veinlets	Pyrite as sparse disseminations	None observed
M-9	Thin-bedded, silicified and carbon-bearing sediment; carbon present as graphitic slickensides	Silicified (++)	None	Pyrite as very thin coating on bedding planes	None observed
M-10	Thin-bedded, silicified and carbon-bearing sediment; carbon present as graphitic slickensides	Silicified (+++)	None	Pyrite as very thin coating on bedding planes	None observed

Table A1.3. Tuffaceous-sedimentary waste rock descriptions based on binocular microscope examination.

¹ Qualitatively determined by placing drop of 10% HCI on rock surfaces and observing presence or absence of fizz (i.e., CO_2 generation from CaCO₃ dissolution)

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qtz : quartz

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Parameter	M-1	M-3	M-8	HRL ¹
Al	6.48	3.29	8.38	
As	39.8	28.6	5.73	56 ³
В	485	471	64.8	600
Ba	66.1	51.7	29.2	2000 ²
Br	5.08	8.62	4.21	
Cd	6.88	3.73	0.51	4
Cl, mg/L	18.7	15.9	3.06	
Со	883	853	69.9	100
Cr	0.225	0.107	0.106	100
Cs	183	169	36.5	
Cu	4.72	1.45	0.563	1300 ²
Fe	1480	1550	4.60	
Li	54.1	29.9	17.2	
Mn	21,940	10,690	2770	
Mo	0.761	7.00	16.5	
Ni	2127	2000	207	100
Pb	0.0294	0.0483	1.73	15 ³
Rb .	296	246	57.5	
SO ₄ , mg/L	1300	1694	997	500 ²
Se	33.0	64.8	25.3	30
Sr	909	874	363	
Tl	7.44	7.30	1.83	
U	0.127	1.210	0.210	
W	0.00	3.63	3.28	
Zn	159	32.9	18.1	2000

Table A1.4. Mafic intrusive and tuffaceous sedimentary rock: week 0 composite rinse concentrations, μ g/L except where noted (analysis by ICP-MS at University of Minnesota, Department of Geology)

¹ Human health risk limit

² MCL=Maximum contaminent level ³ Project to be decreased to 2-10 μ g/L

Appendix 2 Drainage Quality Data

Table A2.1.	MN DNR method drainage quality from 6.20% sulfide mafic-intrusive rock
Table A2.2.	MN DNR method drainage quality from 6.45% sulfide mafic-intrusive rock
Table A2.3.	MN DNR method drainage quality from 6.90% sulfide mafic-intrusive rock
Table A2.4.	MN DNR method drainage quality from 6.90% sulfide mafic-intrusive rock
Table A2.5.	ASTM method drainage quality from 6.90% sulfide mafic-intrusive rock
Table A2.6.	MN DNR method drainage quality from 7.29% sulfide mafic-intrusive rock
Table A2.7.	MN DNR method drainage quality from 7.39% sulfide mafic-intrusive rock
Table A2.8.	MN DNR method drainage quality from 8.05% sulfide mafic-intrusive rock
Table A2.9.	MN DNR method drainage quality from 8.55% sulfide mafic-intrusive rock
Table A2.10.	MN DNR method drainage quality from 1.30% sulfide tuffaceous-sedimentary rock
Table A2.11.	MN DNR method drainage quality from 1.36% sulfide tuffaceous-sedimentary rock
Table A2.12.	MN DNR method drainage quality from 3.75% sulfide tuffaceous-sedimentary rock
Table A2.13.	MN DNR method drainage quality from 3.75% sulfide tuffaceous-sedimentary rock
Table A2.14.	ASTM method drainage quality from 3.75% sulfide tuffaceous-sedimentary

rock

Table A2.15. MN DNR method rainage quality from 12.99% sulfide USGS rock sample

Table A2.16. ASTM method drainage quality from 12.99% sulfide USGS sample

Concen	oncentrations are in mg/L unless otherwise noted. pH is in standard units, net alkalinity is in mg/L as CaCO3. Blank indicates no analysis. Net															
			Net	•	-											
week	Eh(mv)	pH	Alkalinity	Cond(uS)	SO4	Ca	Mg	As	Co	Fe	K	Mn	Na	Ni	Sb	Zn
0	NA	7.46	NA	1641	1302	314	205	0.004	0.3	< 0.10	45	5.65	6.8	1.1	0.064	0.02
1	157.2	7.71	95.0	1100	418	167	36.8	0.009	< 0.10	< 0.10	9	0.9	0.6	< 0.10	0.114	0.02
2	143.9	7.91	90	900	340	142	32.9				8.2		0.3		0.113	
3	166	8.05	98	750	283	119	28.4				5.1		0.2		0.098	
4	106.1	8.06	110	650	200	101	26.9	0.01	< 0.10	< 0.10	•5.4	0.48	0.1	< 0.10	0.086	< 0.02
5	134.5	8.18		600												
6	155.6	8.13	90	550	162	83.4	25.8	0.005			3.1		0.1			
7	142.2	8.10		550												
8	131	8.12	110	550		79.9	22.8	0.004			3.8		< 0.10			
9	143	8.13		600 .										•		
10	126.6	8.08	120	525												
11	126.4	8.08		500												
12	63.9	8.09	110	485												
13	109.7	8.11		460												
14	165.4	8.03	105	465												
15	116.2	8.15		475												

Table A2.1. MN DNR method drainage quality from 6.20% sulfide mafic-intrusive rock (6.50% sulfur, ms-5, cell m-34).

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Concent	entrations are in mg/L unless otherwise noted. pH is in standard units, net alkalinity is in mg/L as CaCO3. Blank indicates no analysis. Net															
			Net													
week	Eh(mv)	pН	Alkalinity	Cond(uS)	SO4	Ca	Mg	As	Co	Fe	K	Mn	Na	Ni	Sb	Zn
0	NA	7.29	NA	1676	1340	297	199	0.007	0.4	0.8	35.4	7.5	5.8	1.3	0.06	0.03
1	157.6	7.68	95.0	1700	854	300	78.9	0.003	< 0.10	< 0.10	9.4	1.9	0.6	0.1	0.086	0.02
2	143.7	7.83	75	1150	534	180	44.7				6		0.2		0.075	
3	166.2	7.99	83	950	416	153	44.4	0.003			5.2		0.2			
4	103.8	8.05	85	750	333	124	35.1	0.003	< 0.10	<0.10	4.1	0.6	0.1	< 0.10	0.075	< 0.02
5	134.2	8.13		650												
6	174.9	7.90	85	650	218	92.2	30.5	0.003			3.8		0.1			
7	134.1	8.11		650												
8	126	8.10	82.5	650		78.6	24.5	0.003			3		< 0.10			
9	138	8.13		500												
. 10	123.1	8.08	80	500												
11	123.1	8.09		500												
12	61.5	8.10	75	490												
13	112.9	8.10		440												
14	161.4	8.04	80	475												
15	108.3	8.16		460												

Table A2.2. MN DNR method drainage quality from 6.45% sulfide mafic intrusive rock (6.75% sulfur, ms-4, cell m-35).

Concen	trations are	in mg/I	unless othe	erwise noted	. pH is i	n standar	d units, n	et alkalin	ity is in n	ng/L as C	aCO3. Bl	lank indic	ates no a	nalysis.		
			Net													
week	Eh(mv)	pН	Alkalinity	Cond(uS)	SO4	Ca	Mg	As	Co	Fe	K	Mn	Na	Ni	Sb	Zn
0	ŇΙΛ	7 77	NA	1638	2062	317	361	0.015	0.0	03	157	22.7	18	3	0.053	0.08
1	160.4	7.22		1038	2002	144	15 1	0.015	-0.10	0.5	157	25.7	10	<i>-</i> 0.10	0.055	0.00
1	159.4	1.30	80.0	1100	465	144	45.4	0.007	<0.10	<0.10	26.2	2.35	1.5	<0.10	0.148	0.03
2	· 143.8	7.63	77.5	750	279	93.3	32				17.5		0.6		0.139	
3	165.4	7.93	75	650	238	80.4	30.3	0.028			12.4		0.3			
4	103.8	8.01	80	650	261	88.1	31.3	0.042	< 0.10	< 0.10	12	1.2	0.2	< 0.10	0.108	< 0.02
5	133.7	8.01		600												
6	151.2	7.79	90	550	213	80.7	29.6	0.032			7.7		0.1			
7	142.4	7.85		750												
8	127.7	7.86	75	650		87.8	32.9	0.019			6.1		0.1			
9	143.4	7.91		650												
10	128.5	7.96	82.5	675												
11	128.4	7.95		700												
12	67.2	7.97	90	750												
13	118.2	7.86		650												
14	168.0	7.88	80	650												
15	113.8	8.02		650												

Table A2.3. MN DNR method drainage quality from 6.90% sulfide mafic intrusive rock (7.05% sulfur, ms-2, cell m-36).

Concent	entrations are in mg/L unless otherwise noted. pH is in standard units, net alkalinity is in mg/L as CaCO3. Blank indicates no analysis.															
			Net													
week	Eh(mv)	pH	Alkalinity	Cond(uS)	SO4	Ca	Mg	As	Co	Fe	К	Mn	Na	Ni	Sb	Zn
<u>^</u>		- 10			1005	105	1.60	0.014	o -	o r		10 -	.			
0	·NA	7.10	NA	1517	1025	195	169	0.014	0.5	0.5	90.6	10.7	8.4	1.5	0.027	0.06
1	158.4	7.48	95.0	1000	414	129	42.4	0.005	< 0.10	<0.10	25.4	2.17	1.2	< 0.10	0.127	0.02
2	. 141.7	7.74	77.5	700	262	90	31.8				18		0.6		0.145	
3	163.6	7.95	68	600	210	71.1	26.4	0.028			12.7		0.3			
4	99.9	8.06	80	550	197	65.6	23.4	0.051	< 0.10	< 0.10	11.9	1	0.3	< 0.10	0.122	< 0.02
5	135.3	7.97		550												
6	149.2	7.91	60	600	124	55.6	20.9	0.033			6.9		0.1			
7	137.5	7.98		550												
8	128.8	7.96	75	500		61.3	23.7	0.024			5.8		0.6			
9	137.2	8.01		500												
10	125.8	8.02	80	500												
11	114.7	7.94		600												
12	64.5	7.98	85	600												
13	110.5	7.97		550												
· 14	166.3	7.93	112.5	575												
15	111.0	8.07		550												

Table A2.4. MN DNR method drainage quality from 6.90% sulfide mafic intrusive rock (7.05% sulfur, ms-2, cell m-37).

Concen	oncentrations are in mg/L unless otherwise noted. pH is in standard units, alkalinity is in mg/L as CaCO3. Blank indicates no analysis.															
			Net													
week	Eh(mv)	pH_	Alkalinity	Cond(uS)	SO4	Ca	Mg	As	Co	Fe	K	Mn	Na	Ni	Sb	Zn
-									<u>.</u>							
0	NA	7.20	NA	1478	9 77	186	158	0.013	0.4	0.1	87.9	10.2	8.2	1.4	0.047	0.03
1	175.3	7.60	40	1550	795	231	81.4	0.006	< 0.10	0.1	28.9	3	1.3	0.6	0.11	0.2
2	145.5	7.58	30	1450	722	222	70				18		0.6		0.085	
3	222.2	7.42	12	750	358	101	37.7	0.009			9.2		0.2			
4	155	7.72	30	850	436	129	48.2	0.013	< 0.10	< 0.10	11	1.06	0.2	< 0.10	0.073	< 0.02
5	133.3	7.80		650												
6	144.1	7.84	30	550	217	70.3	26.2	0.01			6.1		0.1			
7	148.7	7.71		470												
8	110.7	7.80	30	385		43.1	16.6	0.01			3.9		0.1			
9	135.5	7.94		550												
10	135.5	7.65	30	450												
11	102.8	7.78		850												
12	65.5	7.80	30	550												
13	114.8	7.90		460												
14	159.8	7.87	37.5	465												
15	120.3	7.96		410												

Table A2.5. ASTM method drainage quality from 6.90% sulfide mafic intrusive rock (7.05% sulfur, ms-2, cell n-2).

Concent	icentrations are in mg/L unless otherwise noted. pH is in standard units, net alkalinity is in mg/L as CaCO3. Blank indicates no analysis.															
			Net													
week	Eh(mv)	pН	Alkalinity	Cond(uS)	SO4	Ca	Mg	As	Со	Fe	K	Mn	Na	Ni	Sb	Zn
0	NA	6.72	NA	1540	906	212	148	0.032	0.8	1.3	118	22.5	8.1	2.5	0.055	0.18
1	168.5	7.12	65.0	1300	821	193	52.6	0.001	<0.10	< 0.10	35.2	6.35	1.6	<0.10	0.085	0.03
2	154.5	7.47	65	1100	479	146	47.1				25.3		0.8		0.077	
3	175.7	7.73	68	900	399	131	39.4				19.2		0.5		0.08	
4	117.2	7.73	65	750	330	105	33.8	0.021	< 0.10	< 0.10	16.1	3.2	0.3	< 0.10	0.065	0.02
5	147.1	7.78		675												
6	160.5	7.71	60	650	239	86.6	32.3	0.036			10		0.2			
7	150.9	7.76		650												
8	130.9	7.77	57.5	600		74.4	26.2	0.03			7.5		0.1			
9	152.1	7.77		575												
10	130.4	7.60	57.5	575												
11	134	7.74		575												
12	66.4	7.80	60	475												
13	118.2	7.82		450												
14	171.9	7.74	95	460												
15	124.3	7.79		500												

Table A2.6. MN DNR method drainage quality from 7.29% sulfide mafic intrusive rock (7.30% sulfur, ms-1, cell m-33).

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Concen	oncentrations are in mg/L unless otherwise noted. pH is in standard units, net alkalinity is in mg/L as CaCO3. Blank indicates no analysis.															
			Net													
week	Eh(mv)	pH_	Alkalinity	Cond(uS)	SO4	Ca	Mg	As	Co	Fe	K	Mn	Na	Ni	Sb	Zn
0	27.4	= 16	27.4	1866	10/7	200	011	0.000	0.0		50.0	0 (0.2	2.0	0.007	0.07
0	NA	7.16	NA	1766	1367	289	211	0.008	0.8	0.4	59.8	8.6	8.3	2.8	0.037	0.07
1	148	7.87	110.0	600	165	86.1	17	0.016	<0.10	< 0.10	13.2	0.66	0.6	<0.10	0.211	0.02
2	132.2	8.03	95	350	74.5	37.9	10.8				9.1		0.3		0.26	
3	154.7	8.15	85	310	64	41.5	11.1	0.051			7.2		0.2			
4	95	8.13	80	350	84.5	50.3	13	0.104	<0.10	< 0.10	7.8	0.3	0.1	< 0.10	0.216	0.02
5	128.2	8.17		410												
6	143.9	8.05	100	385	85.2	56.9	15	0.056			5.5		0.1			
7	133.2	8.12		425												
8	121.7	8.13	95	380		50	12.6	0.034		4	3.9		0.1			
9	- 132.7	8.20		365												
10	118.7	8.12	82.5	255												
11	99.8	8.11		225												
12	54.9	8.13	87.5	320												
13	103.5	8.13		340												
14	152.6	8.06	80	265												
15	106.0	8.21		395												

Table A2.7. MN DNR method drainage quality from 7.39% sulfide mafic intrusive rock (7.40% sulfur, ms-7, cell m-38).

Concen	ncentrations are in mg/L unless otherwise noted. pH is in standard units, alkalinity is in mg/L as CaCO3. Blank indicates no analysis.															
			Net													
week	Eh(mv)	pH	Alkalinity	Cond(uS)	SO4	Са	Mg	As	Co	Fe	K	Mn	Na	Ni	Sb	Zn
								0.016						~ ~		
0	NA	6.92	NA	1970	1378	264	225	0.016	0.8	1.4	97.7	10.2	8.2	2.3	0.052	0.04
1	150.2	7.88	75	900	403	142	35.1	0.016	<0.10	0.1	23.4	1.3	1	< 0.10	0.199	0.02
2	135.2	8.01	70	600	200	78.7	19.8				15.9		0.4		0.214	
3	160.8	8.09	70	460	150	57.5	18.9	0.082			11.3		0.3			
4	95.1	8.12	70	415	132	52.3	17.4	0.105	< 0.10	< 0.10	8.6	0.59	0.2	< 0.10	0.185	0.02
5	126.5	8.18		385												
6	144.2	8.03	60	340	95	45.1	16.4	0.09			5.9		0.1			
7	131	8.05		365												
8	114.6	8.07	65	350		41.8	13.9	0.082			4.2		0.1			
9	132.6	8.10		360												
- 10	125.2	8.10	67.5	395												
11	99.3	8.09		385												
12	55.5	8.15	70	390												
13	104.1	8.14		390												
14	155.3	8.09	75	450												
15	106.9	8.20		410												

Table A2.8. MN DNR method drainage quality from 8.05% sulfide mafic intrusive rock (8.10% sulfur, ms-3, cell m-39).

Concent	ncentrations are in mg/L unless otherwise noted. pH is in standard units, alkalinity is in mg/L as CaCO3. Blank indicates no analysis.															
			Net			-			_							
week	Eh(mv)	pH	Alkalinity	Cond(uS)	SO4	Ca	Mg	As	Co	Fe	<u> </u>	Mn	Na	Ni	Sb	Zn
0	NA	6.99	NA	1833	1721	352	275	0.009	1.2	1	52.2	13.7	7.8	3.6	0.042	0.04
1	146.1	8.07	100	1000	434	178	28.3	0.012	0.1	< 0.10	13	1.4	0.7	0.1	0.17	0.02
2	131.5	8.16	100	650	226	108	18.6				9		0.3		0.158	
3	161	8.25	100	550	166	81.8	19.3	0.036			6.7		0.2			
4	92.3	8.25	110	500	159	81.4	20.7	0.03	< 0.10	< 0.10	5.6	0.7	0.1	< 0.10	0.133	< 0.02
5	125.4	8.19		600												
6	145	8.08	110	550	163	82.3	24.6	0.01			4.6		0.1			
7	132.5	8.17		550												
8	114	8.19	110	490		70	19.6	0.009			3.3		< 0.10			
9	134.5	8.16		475												
10	121.8	8.16	100	315												
11	93.7	8.13		265												
12	48.0	8.17	75	240												
13	95.4	8.15		210												
14	145.7	8.08	67.5	235												
15	99.9	8.20		225												

Table A2.9. MN DNR method drainage quality from 8.55% sulfide mafic intrusive rock (9.05% sulfur, ms-6, cell m-40).

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Concent	centrations are in mg/L unless otherwise noted. pH is in standard units, net alkalinity is in mg/L as CaCO3. Blank indicates no analysis.															
			Net	· ·												
week	Eh(mv)	pН	Alkalinity	Cond(uS)	SO4	Ca	Mg	As	Co	Fe	К	Mn	Na	Ni	Sb	Zn
				•												
0	NA	7.72	NA	594	394	110	48.4	0.008	<0.10	0.1	13.5	1.35	1.9	0.2	0.038	0.05
1	158.1	7.73	32.5	1150	375	106	44.7	0.003	< 0.10	< 0.10	3.6	1.1	0.5	< 0.10	0.024	0.02
2	163.6	7.85	30	500	193	43.8	26.3				3.1		0.2		0.036	
3	178.2	7.90	35	380	142	35.2	21.4				2.3		0.1		0.033	
4	127.6	7.86	35	310	119	65.4	21.9	0.01	< 0.10	< 0.10	2	0.25	0.1	< 0.10	0.033	< 0.02
5	158.7	7.93		285												
6	164	7.73	40	245	77.3	28.8	13.3	0.008			1.2		< 0.10			
7	158.8	7.87		255												
8	139.3	7.93	32.5	225		24.9	10.6	0.006			0.9		< 0.10			
9	155.7	7.94		220												
10	149.2	7.34	35	210												
11	138.3	7.63		210												
12	95.1	7.80	55	200												
13	128.6	7.92		190												
14	175.9	7.84	35	190												
15	135.8	7.92		200												

Table A2.10. MN DNR method drainage quality from 1.30% sulfide tuffaceous-sedimentary rock (1.31% sulfur, ms-10, cell m-29).

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Concen	trations are	in mg/L	unless othe	rwise noted.	pH is in	n standard	units, ne	t alkalinit	y is in mg	g/L as CaC	CO3. Bla	nk indic	ates no a	nalysis.		
•			Net													
week	Eh(mv)	pH	Alkalinity	Cond(uS)	SO4	Ca	Mg	As	Co	Fe	K	Mn	Na	Ni	Sb	Zn
0	NA	7 01	NΔ	830	573	146	833	0.000	<0.10	<0.10	21.5	0.07	25	0.2	0.042	0.04
1	157.2	7.91	45.0	1100	125	120	50.1	0.009	<0.10	<0.10	21.5	0.97	2.5	<0.10	0.042	0.04
1	157.2	7.90	45.0	1100	433	152	39.1	0.007	<0.10	<0.10	5.9	0.8	0.7	<0.10	0.030	0.02
2	152.1	8.03	50	500	177	45.2	24				4.5		0.2		0.041	
3	167.3	8.11	52.5	390	130	42.1	20.5				3.2		0.2		0.047	
4	115.4	8.13	55	335	107	41.2	15.8	0.014	< 0.10	<0.10	2.9	0.16	0.1	< 0.10	0.045	< 0.02
5	151.9	8.13		295												
6	156.1	7.94	52.5	260	89.7	31	13.7	0.014			1.9		0.1			
7	149.5	8.10		275												
8	132.5	8.16	55	250		30	10.2	0.008			1.5		< 0.10			
9	149.1	8.13		230												
10	134	7.55	50	215												
11	130.5	7.89		220												
12	82.1	8.01	50	220			•									
13	119.7	8.1		200												
14	169.6	7.99	50	210												
15	126.0	8.10		215												

Table A2.11. MN DNR method drainage quality from 1.36% sulfide tuffaceous sedimentary rock (1.37% sulfur, ms-9, cell m-30).

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Concent	ncentrations are in mg/L unless otherwise noted. pH is in standard units net alkalinity is in mg/L as CaCO3. Blank indicates no analysis.															
•			Net													
week	Eh(mv)	pН	Alkalinity	Cond(uS)	SO4	Ca	Mg	As	Со	Fe	Κ	Mn	Na	Ni	Sb	Zn
0	NA	7.78	NA	1139	459	200	95.3	0.005	< 0.10	< 0.10	20.6	2.4	2.6	0.2	0.038	0.02
1	163.4	7.55	50.0	1550	777	243	91.8	0.003	< 0.10	< 0.10	5.4	3.2	0.6	0.1	0.018	0.02
2	152	7.84	65	950	397	120	44.1				5		0.2		0.021	
3	170.4	7.95	60	750	288	96	35.9				3.6		0.1		0.021	
4	114.9	8.00	65	625	244	80.7	31.8	0.001	< 0.10	0.1	2.9	0.7	0.1	< 0.10	0.021	0.03
5	150.8	8.06		525												
6	154.1	7.99	60	465	158	56.8	24.7	0.002			1.9		< 0.10			
7	150.4	8.07		460												
8	132.7	8.06	60	410		49.2	19.9	0.001			1.5		< 0.10			
9	147.6	8.09		395												
10	131	7.63	55	380												
11	130.1	7.89		365												
12	65.0	7.97	55	360												
13	115.8	8.06		325												
14	169.0	7.97	60	335												
15	121.6	8.07		335												

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Table A2.12. MN DNR method drainage quality from 3.75% sulfide tuffaceous sedimentary rock (3.90% sulfur, ms-8, cell m-31).

Concentrations are in mg/L unless otherwise noted. pH is in standard units, net alkalinity is in mg/L as CaCO3. Blank indicates no analysis.																
Net																
week	Eh(mv)	pH	Alkalinity	Cond(uS)	SO4	Ca	Mg	As	Со	Fe	K	Mn	Na	Ni	Sb	Zn
0		7 60	NT A	1125	460	206	00.0	0.004	<0.10	0.1	22.4	255	27	0.7	0.020	0.06
0	NA	7.08	INA	1123	409	200	99.9	0.004	\0.10	0.1	22.4	2.55	2.1	0.5	0.039	0.00
1	161.8	7.65	60.0	1550	666	213	76.3	0.007	<0.10	<0.10	5.3	2.86	0.6	0.1	0.026	0.04
2	· 147.4	7.83	65	900	330	110	38				5		0.2		0.031	
3	167.4	8.03	65	700	312	102	38.5				4.2		0.1		0.027	
4	111.2	7.95	90	600	221	72.6	28.4	0.002	< 0.10	< 0.10	2.9	0.7	0.1	< 0.10	0.024	< 0.02
5	144.4	8.02		550												
6	152.5	7.98	90	475	163	57.6	25	0.003			2		0.1			
7	146.9	8.07		500												
8	127.9	8.08	87.5	440		54.3	22.7	0.002			1.6		< 0.10			
9	145.9	8.07		420												
10	124.7	7.78	80	405												
11	128.3	7.89		380												
12	61.5	8.04	60	375												
13	114.7	8.04		345												
14	168.8	7.97	50	370												
15	117.5	8.08		360												

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Table A2.13. MN DNR method drainage quality from 3.75% sulfide tuffaceous sedimentary rock (3.90% sulfur, ms-8, cell m-32).

Concentrations are in mg/L unless otherwise noted. pH is in standard units, alkalinity is in mg/L as CaCO3. Blank indicates no analysis.																
Net																
week	Eh(mv)	pH	Alkalinity	Cond(uS)	SO4	Ca	Mg	As	Со	Fe	K	Mn	Na	Ni	Sb	Zn
0	NA ⁻	7.43	NA	1257	746	205	102	0.004	0.1	< 0.10	22	2.5	2.7	0.2	0.027	0.03
1	183	7.53	30.0	1550	862	253	93.6	0.004	< 0.10	< 0.10	5.2	1.36	0.5	0.1	0.022	0.04
2	133.8	7.82	30	850	423	122	44.3				3.2		0.2		0.158	
3	216.4	7.53	25	750	356	101	42.2	0.005			3.4		0.1			
4	207.1	7:73	30	600	273	79.6	33	0.005	< 0.10	< 0.10	2.9	0.26	0.1	< 0.10	0.02	< 0.02
5	122.3	7.69		500												
6	138	8.01	35	420	164	55.2	24.2	0.004			2		0.1			
7	145.4	7.87		385												
8	105.3	8.01	35	320		34.8	16.6	0.004			1.4		< 0.10			
9	127.1	8.01		405												
10	135.7	7.66	30	405												
11	106.9	7.75		385												
12	62.8	7.90	30	385												
13	108.8	7.99		325												
14	· 159.0	7.90	55	365												
15	116.5	8.06		360												

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Table A2.14. ASTM method drainage quality from 3.75% sulfide tuffaceous-sedimentary rock (3.90% sulfur, ms-8, cell n-1).

Concentrations are in mg/L unless otherwise noted.						pH is in standard units, alkalinity is in mg/L as CaCO3. Blank indicates no analysis.										
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week	Eh(mv)	pН	Alkalinity	Cond(uS)	SO4	Ca	Mg	As	Со	Fe	К	Mn	Na	Ni	Sb	Zn
				•												
0	153.9	6.75	10	1650												
1	122.3	6.96	<5.0	1550												
2	74	6.99	15	1200												
3	123.9	7.04	20	1000												
4	170.7	6.97	10	850												
5	131.8	7.07		750												

Table A2.15. MN DNR method drainage quality from 12.99% sulfide USGS rock sample (13.70% sulfur, cell m-41).

Concen	trations are	e in mg/	L unless oth	erwise noted	. pH is ii	pH is in standard units, alkalinity is in mg/L as CaCO3. Blank indicates no analysis.										
Net														_		
week	Eh(mv)	pН	Alkalinity	Cond(uS)	SO4	Ca	Mg	As	Со	Fe	K	Mn	Na	Ni	Sb	Zn
				•												
0	158.2	6.70	10	1450												
1	116.8	7.02	<5.0	1850												
2	80.6	6.93	<5.0	1350												
3	122.8	6.94	5	1050												
4	172.9	6.78	5	1050												
5	131.6	6.91		1000												

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Table A2.16. ASTM method drainage quality from 12.99% sulfide USGS sample (13.70% sulfur, cell n-3).