ANALYTICAL RESULTS FOR TOTAL-DIGESTIONS, EPA-1312 LEACH, AND NET ACID PRODUCTION FOR TWENTY-THREE ABANDONED METAL-MINING RELATED WASTES IN THE BOULDER RIVER WATERSHED, NORTHERN JEFFERSON COUNTY, MONTANA

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Table of Contents

Figures

Tables

INTRODUCTION

Metal-mining related wastes in the Boulder River basin study area in northern Jefferson County, Montana, have been implicated in their detrimental effects on water quality with regard to acid generation and toxic-metal solubilization during snow melt and storm water runoff events (Buxton and others, 1997). This degradation of water quality is defined chiefly by the "Class 1 Aquatic Life Standards" that give limits for certain dissolved metal concentrations according to water alkalinity (Montana Department of Health and Environmental Sciences, 1994).

Veins enriched in base- and precious metals were explored and mined in the Basin, Cataract Creek, and High Ore Creek drainages over a period of more than 70 years. Extracted minerals included galena, sphalerite, pyrite, chalcopyrite, tetrahedrite and arsenopyrite. Most of the metal-mining wastes in the study area were identified and described by the Montana Bureau of Mines and Geology (Metesh and others, 1994; Metesh and others, 1995; Marvin and others, 1996). In 1997, the U.S. Geological Survey collected 20 composite samples of mine-dump or tailings waste from ten sites in the Basin and Cataract Creek drainages, and two samples from one site in the High Ore Creek drainage. Desborough and Fey (1997) presented data concerning acid generation potential, mineralogy, concentrations of certain metals by energy-dispersive X-ray fluorescence (EDXRF), and trace-element leachability of mine and exploration wastes from the ten sites of the Basin and Cataract Creek drainages. The present report presents total-digestion major- and trace-element analyses, net acid production (NAP), and results from the EPA-1312 synthetic precipitation leach procedure (SPLP) performed on the same composite samples from the ten sites from the Basin and Cataract Creek drainages, and two composite samples from the site in the High Ore Creek drainage.

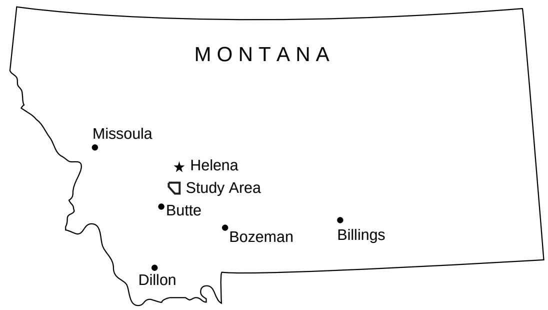
METHODS OF STUDY

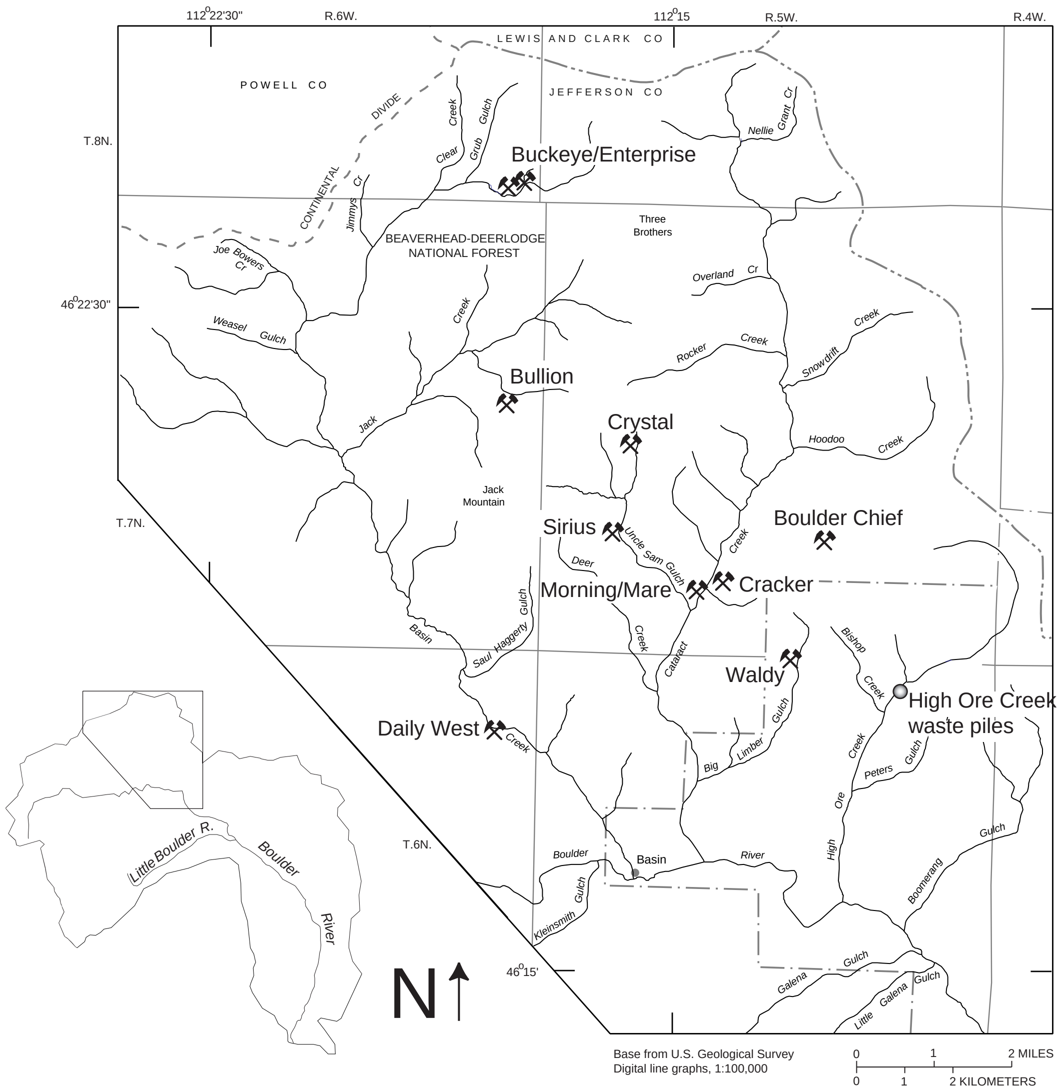
Sample Collection

Twenty-three mine waste samples (exploration waste, dump material, or mill tailings) were taken at eleven sites distributed in the Boulder River study area (see figure 1). Material from each site was collected from 30 or more randomly selected cells across the top and sides of a dump to a depth of about 5 cm using four to six randomly selected 50-80 g scoops. This material was passed through a 2-mm screen to remove coarse material, because the minus-2-mm fraction was deemed to be the most reactive to water in short-term exposures. The resulting composite sample typically contained 1 to 2 kg of mine-waste or dump material (Desborough and Fey, 1997; Smith and others, 2000).

Sample Preparation

In the laboratory, samples were dried at 40^{o}C, split using a Jones splitter, and recombined several times to achieve thorough mixing. Splits from the homogenized material were made for: 1) total-digestion inductively coupled plasma-atomic emission spectroscopy (ICP-AES), 2) EPA-1312 leach test, and 3) net acid production (NAP) determination. Material for the EPA-1312 leach did not require further processing; splits





⚒ mine site sampled (see table 1 for sample numbers and descriptions)

● High Ore Creek waste piles (since removed)

Figure 1. Index map of Montana showing Boulder River study area, and location map for mine-waste sample sites.

for ICP-AES and NAP determinations were ground to minus-200-mesh (75 microns) using a vertical pulverizer with ceramic plates.

Analytical Methods

Total-digestion ICP-AES method

A 0.2 gram portion of minus-200-mesh material was subjected to a mixed-acid total digestion using HCl, HNO_3, $HClO_4$ and HF acids (Briggs, 1996). The resulting solution was analyzed for 40 elements, using inductively coupled plasma-atomic emission spectroscopy (ICP-AES). Results for 32 selected elements are shown in table 2. This digestion is very effective in dissolving sulfides and most silicates and oxides; resistant or refractory minerals such as zircon, spinels, and some tin oxides are only partially dissolved. Standard reference materials (SRM's) were digested and analyzed with the samples. These standards were SRM-2704, SRM-2709, SRM-2710, and SRM-2711, available from the National Institute of Standards and Technology (NIST). A statistical summary of mean values, median values, and standard deviations for multiple analyses of these materials, and comparisons with certified values are given in Fey and others (1999).

EPA-1312 Leach Method (Synthetic Precipitation Leach Procedure-SPLP)

A 100-g sample of mine waste was placed in a 2.3L polyethylene bottle. Two liters of extract solution were added, resulting in a 1:20 sample/extract ratio, with 300 cc of headspace. The SPLP method mandates that an extract solution of pH 4.2 be used on soils from east of the Mississippi River and a solution with pH of 5.0 be used on soils from west of the Mississippi River. The more acidic pH 4.2 solution is to be used on mine-waste material; since the materials of this report are all mine wastes, the pH 4.2 solution was used here. The extract solution was made from de-ionized water acidified to a pH of 4.2 with a one-percent solution of 60/40 H_2SO_4/HNO_3. The capped bottles were placed on an end-over-end (tumbling) rotating agitator at 30 rpm for 18 hours. The leachates were then pressure-filtered through a 142 mm diameter-0.7 micron glass-fiber filter (US-EPA, 1986). A 100 mL aliquot of filtered solution was acidified with ultra-pure HNO_3 for analysis for 25 elements by ICP-AES (Briggs and Fey, 1996) and for sulfate by ICP-AES as sulfur. Conductivity and pH were determined on the bulk filtered leachate.

Net Acid Production (NAP) method

A 1.0-g sample of pulverized, minus-200-mesh material was digested with a solution of 30 percent hydrogen peroxide to oxidize pyrite, thereby producing sulfuric acid (Lapakko and Lawrence, 1993). This acidic solution reacted with the bulk of the sample, releasing additional acidity from water-soluble salts, and reacted with acid-consuming minerals such as carbonates and some non-carbonate minerals (e.g. biotite, chlorite and epidote). The solutions were heated for one hour, cooled, and filtered. The acidic filtrate was then titrated to a pH of 7 with 0.1M NaOH. A calculated net acid production (NAP) is expressed in terms of kg-equivalent $CaCO_3$ per metric ton of mine waste. This NAP is meant to represent the net long-term or total potential of a material to produce acid over an unspecified period of weathering.

DISCUSSION OF RESULTS

Site descriptions, tonnages, and localities are given in table 1. The estimated tonnages are from Desborough and Fey (1997). The results for total-digestion analyses (ICP-AES) are presented in table 2. The results for leachable metals in the EPA-1312 leach are in table 3. The pH, sulfate, and conductivities of EPA-1312 leach solutions, and the net acid production determinations are also in table 3.

A systematic comparison of results between the passive leach utilized and described in Desborough and Fey (1997) and the EPA-1312 leach is discussed in Fey and others (2000). A chemical method for ranking wastes by plotting net acid production against dissolved elements iron, arsenic, cadmium, copper, lead, and zinc in the EPA-1312 leach is presented in figure 2 and figure 3.

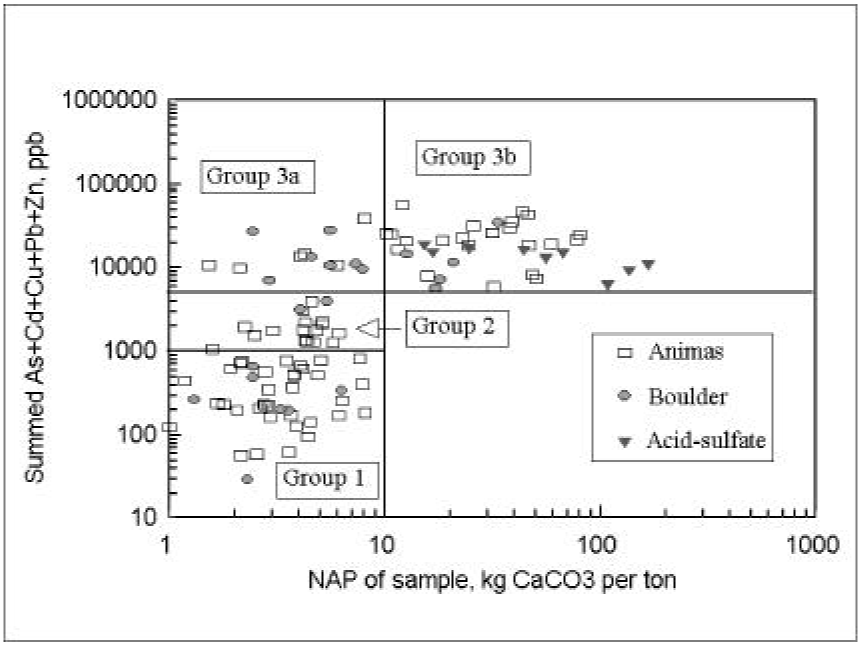


Figure 2. Relationship between NAP (net acid production) of mine waste and sum of dissolved metals As+Cd+Cu+Pb+Zn in EPA-1312 leach. From Fey and others (2000).

These figures were generated from data obtained from NAP measurements and EPA-1312 leaches of 109 mine wastes collected from the Boulder River study area and from the upper Animas River study area in southwest Colorado (Fey and others, 2000). The samples from both areas are similar polymetallic vein mine wastes (shown by the symbols for Animas and Boulder), plus nine acid-sulfate wastes from the Animas River study area (shown by symbol for Acid-sulfate). The figures show that the wastes can be segregated into three or four classes, based on the NAP and the dissolved metals in the leach. Referring to figure 2, Group 1 consists of wastes with less than 1,000 µg/L summed toxic metals (As+Cd+Cu+Pb+Zn). This group contains nine samples from the Boulder River study area. Group 2 consists of wastes with the summed metals between

1,000 and 5,000 µg/L. Group 2 contains two samples from the Boulder River study area. Group 3 consists of wastes with summed dissolved metals greater than 5,000 µg/L, and is subdivided into Groups 3a and 3b. The distinction between the latter two groups is based on the NAP; Group 3a has a NAP of less than 10 kg per ton $CaCO_3$ equivalent, and Group 3b has a NAP of greater than 10 kg per ton $CaCO_3$ equivalent. Waste materials in Group 3b have the greatest potential for degrading water quality, should waters produced from these wastes migrate to ground or surface waters. Groups 3a and 3b contain seven and five samples, respectively, from the Boulder River study area.

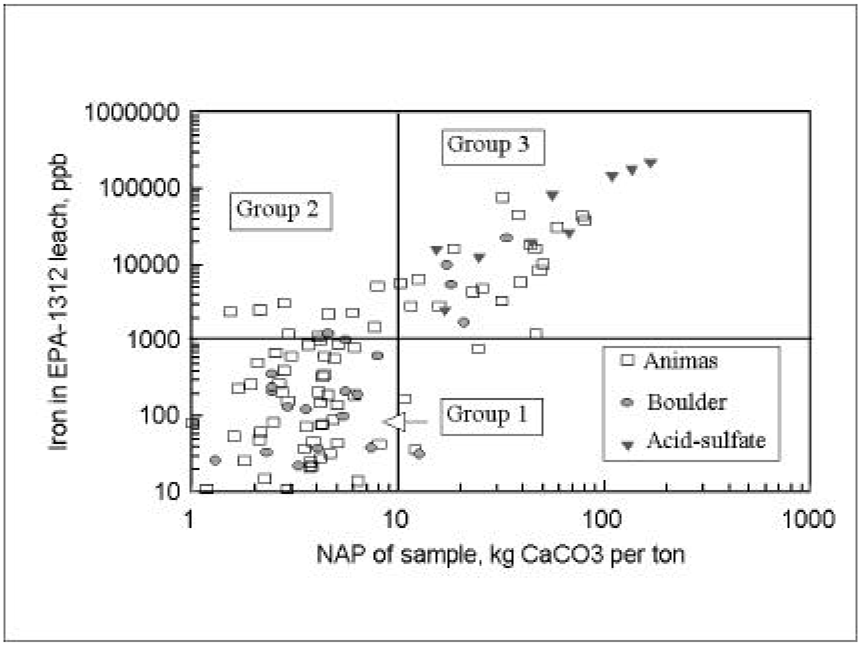


Figure 3. Relationship between NAP (net acid production) of mine waste and dissolved iron in EPA-1312 leach. From Fey and others (2000).

Figure 3 shows the relationship between the net acid production and the dissolved iron in the EPA-1312 leach solutions. This figure is derived from the same samples as figure 2. This figure segregates the waste materials into three groups. The group boundaries are determined on the basis of dissolved iron in the leach solutions, because dissolved iron in waters can also have a toxic effect on aquatic life (Nordstrom and others, 1999). Group 1 consists of wastes with dissolved iron less than 1,000 µg/L, and contains fifteen samples from the Boulder River study area. Group 2 consists of wastes with dissolved iron greater than 1,000 µg/L and NAP less than 10 kg per ton $CaCO_3$ equivalent; this group has two samples from the Boulder River study area. Group 3 consists of wastes with dissolved iron greater than 1,000 µg/L and NAP greater than 10 kg per ton $CaCO_3$ equivalent. This group contains four samples from the Boulder River study area.

The NAP, summed dissolved toxic metals, dissolved iron, and sample ranks are in table 4. Note that when the rank based on the dissolved summed metals is compared with the rank based on dissolved iron, there is not a simple one-to-one correspondence. Some samples with a rank of 3a or 3b based on the dissolved summed toxic metals may have a low rank of 1 or 2 based on dissolved iron. This can occur in samples whose dissolved summed toxic metals are dominated by dissolved zinc. These samples may have low amounts of iron, or generate leach solutions whose pH values are sufficiently high (greater than about 3.5) that iron is removed by precipitation (Smith and others, 1993), and zinc remains in solution. It is therefore important to note that *either* the summed dissolved toxic metals *or* the dissolved iron generated in a leach solution indicate potential for water quality degradation by acidic drainage generated by these mine wastes.

Desborough and Fey (1997) also developed a qualitative ranking method, utilizing the pH of a passive leach, summed toxic metals (As+Cd+Cu+Pb+Zn) from the passive leach, and the estimated size of dumps as additive factors. This resulted in a ranking scale ranging from one (low potential for water quality degradation) to nine (highest potential for water quality degradation). In table 4, the size classes from Desborough and Fey (1997) are in column 6, and are incorporated into a final ranking of the samples of this study by adding both chemistry-based ranks (columns 3 and 5) and the size ranks. This final ranking approach (column 7) yields values between three (lowest) and nine (highest). The division of chemical ranking based on the NAP of samples (as derived from figure 2) is reflected by carrying the letter suffix **a** or **b** (**a**: NAP less than 10 kg per ton $CaCO_3$ equivalent; **b**: NAP greater than 10 kg per ton $CaCO_3$ equivalent). Samples with no letter suffix were in either Group 1 or 2 in figure 2, and contain NAP less than 10 kg per ton $CaCO_3$ equivalent. The method of this report yields rankings similar to the method presented in Desborough and Fey (1997).

Evaluating the combined ranking scores, one can divide the samples into three broad classes. The first class, with a combined score of three to four, would represent material with a relatively low potential for water quality degradation. The middle class, with a combined score of five to six, would represent material with a moderate potential for water quality degradation. The third class, with a combined score of seven, eight, or nine, represents material with a high potential for water quality degradation. Absent from these chemical ranks, however, is consideration of whether adit or surface water is present and flowing across waste material, which can have an important influence on the desirability of removing material. For example, material from the upper and lower tailings impoundments below the Bullion Mine are placed in the class with low potential for degradation, but these impoundments were placed in a tributary to Jack Creek, which bisects them. Clearly these two sites have a greater impact on stream water quality than their low chemical ranking would imply. For each site, it is important to combine knowledge of local hydrologic conditions that may provide transport pathways for dissolved metals, with chemistry-based and size ranks.

Table 1. Sample numbers, localities, estimated size, and site descriptions for mine-waste samples collected in Boulder River watershed study area, 1997. Given coordinates are approximate; sample sets collected at one mine site are not all from exact same point. See descriptions for relative locations.

Basin Creek drainage

Sample No.	Latitude dec. deg.	Longitude dec. deg.	estimated size (tons)	description
D97B017	46.3561	112.2944	6,000	Bullion Mine, upper waste dump, from upper adit
D97B018			7,000	Bullion Mine, middle waste dump, from middle adit
D97B019			12,000	Bullion Mine, lower waste dump, from lower adit
D97B002			500	Bullion Mine, lowest small dump, lowest adit near tailings impoundment
D97B001			1,200	Bullion Mine, upper tailings impoundment
D97B003			3,600	Bullion Mine, lower tailings impoundment
D97B004	46.398	112.2944	5,000	Buckeye/Enterprise Mines, brown waste on east side (Enterprise)
D97B005			10,000	Buckeye/Enterprise Mines, light-gray waste on west side (Buckeye)
D97B006			16,000	Buckeye/Enterprise Mines, flotation tailings near Basin Creek
D97B012	46.2955	112.2952	300	Daily West Mine, yellow waste at creek bed

Cataract Creek drainage

Sample No.	Latitude dec. deg.	Longitude dec. deg.	estimated size (tons)	description
D97MT007	46.3305	112.2094	3,500	Boulder Chief Mine, waste from open cut above mine adit
D97MT008			3,500	Boulder Chief Mine, waste from below mine adit
D97MT009	46.3228	112.2364	4,000	Cracker Mine, waste from adit
D97MT009D				Cracker Mine, waste dump, re-sample
D97B014	46.3500	112.2606	20,000	Crystal Mine, waste along east side of large open cut on hilltop
D97B015			10,000	Crystal Mine, waste along west side of large open cut on hilltop
D97B016			4,000	Crystal Mine, waste at ore bins near Uncle Sam Gulch

Table 1. (cont.) Sample numbers, localities, estimated size, and site descriptions for mine-waste samples collected in Boulder River watershed study area, 1997. Given coordinates are approximate; sample sets collected at one mine site are not all from exact same point. See description for relative locations.

Cataract Creek drainage (cont)

Sample No.	Latitude dec. deg.	Longitude dec. deg.	estimated size (tons)	description
D97MT013	46.3128	112.2400	1,000	Morning/Mare Mines, waste piles from adit
D97MT010	46.3361	112.2444	5,000	Sirius Mine, waste dump at adit
D97MT011	46.3039	112.2175	700	Waldy Mine, waste dump at adit

High Ore Creek drainage

Sample No.	Latitude dec. deg.	Longitude dec. deg.	estimated size (tons)	description
97BMF-132A				dredged tailings/gravel mix from High Ore Creek
97BMF-132B				approximately 1 km below Comet Mine

Dredged material from High Ore Creek (samples 97-BMF-132A and 97-BMF-132B) has since been removed by the U.S. Bureau of Land Management.

Table 2. Total-digestion ICP-AES analyses for mine waste samples collected from the Boulder River watershed study area, Jefferson County Montana.

SAMPLE NO.	Al %	Ca %	Fe %	K %	Mg %	Na %	P %	Ti %	Mn ppm	Ag ppm	As ppm	Ba ppm
D-97-B001	4.3	0.04	1.8	1.9	0.15	0.06	0.05	0.14	93	34	3200	300
D-97-B002	7.1	0.06	5.7	3.3	0.28	0.08	0.04	0.17	460	5	3100	300
D-97-B003	4.1	0.05	1.7	1.8	0.15	0.06	0.05	0.14	84	32	3300	260
D-97-B004	7.2	0.23	7.4	3.2	0.39	0.94	0.05	0.24	220	6	8200	840
D-97-B005	6.9	0.05	4.4	3.4	0.20	0.18	0.02	0.13	160	32	13000	520
D-97-B006	4.7	0.04	2.1	2.2	0.16	0.08	0.02	0.10	170	98	13000	350
D-97-B0012	5.7	0.07	6.1	3.5	0.23	0.08	0.05	0.16	390	14	77	220
D-97-B0014	7.6	0.74	3.9	3.6	0.49	0.73	0.07	0.22	1800	31	3200	700
D-97-B0015	8.1	0.97	5.3	3.7	0.67	0.84	0.08	0.34	1800	6	2500	700
D-97-B0016	6.1	0.16	3.4	3.2	0.23	0.32	0.03	0.10	890	41	4400	390
D-97-B0017	6.2	0.25	4.0	3.1	0.31	0.35	0.04	0.18	240	56	8700	300
D-97-B0018	6.9	0.19	3.8	3.3	0.28	0.18	0.06	0.22	330	45	4400	420
D-97-B0019A	5.7	0.36	4.7	2.8	0.34	0.31	0.06	0.17	490	49	4900	500
D-97-B0019B	6.1	0.22	3.6	2.8	0.26	0.18	0.06	0.18	470	48	3200	420
D-97-MT007	8.7	1.2	2.5	3.3	0.47	0.48	0.07	0.33	1300	15	70	1100
D-97-MT008	6.9	0.13	2.5	3.2	0.42	0.37	0.08	0.20	320	32	87	520
D-97-MT009	7.6	0.10	3.1	3.5	0.49	0.13	0.04	0.29	740	48	200	310
D-97-MT009D	7.4	0.16	3.1	3.7	0.43	0.20	0.04	0.24	790	43	220	410
D-97-MT0010	7.4	0.25	3.8	3.4	0.27	0.56	0.04	0.16	210	34	8600	480
D-97-MT0011	6.6	0.90	4.3	3.0	0.37	0.54	0.05	0.12	3300	16	340	520
D-97-MT0013	7.6	0.12	2.8	4.1	0.36	0.19	0.06	0.25	810	43	220	500
97-BMF-132A	7.0	0.88	3.5	2.6	0.44	1.4	0.07	0.21	590	36	2500	850
97-BMF-132B	6.9	0.92	3.4	2.9	0.36	1.5	0.06	0.20	790	28	2200	860

Table 2. (cont.) Total-digestion ICP-AES analyses for mine waste samples collected from the Boulder River watershed study area, Jefferson County Montana.

SAMPLE NO.	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	La ppm	Li ppm	Mo ppm	Nb ppm	Nd ppm	Ni ppm
D-97-B001	< 2	30	2	16	170	10	16	39	12	17	11	4
D-97-B002	< 2	36	10	12	19	17	20	16	19	22	15	9
D-97-B003	< 2	25	2	15	150	10	14	35	12	15	9	4
D-97-B004	< 2	28	4	4	91	19	15	25	5	34	10	10
D-97-B005	< 2	58	3	3	100	16	34	43	3	26	22	5
D-97-B006	5	40	1	5	81	11	24	27	5	18	15	2
D-97-B0012	50	45	8	20	880	18	27	18	7	22	17	10
D-97-B0014	8	63	15	13	300	13	35	76	11	33	24	12
D-97-B0015	2	63	20	27	180	14	34	34	6	35	24	16
D-97-B0016	9	50	9	4	380	13	27	49	15	32	18	7
D-97-B0017	2	54	13	14	170	14	30	36	8	27	21	8
D-97-B0018	4	45	10	18	300	15	25	35	10	29	16	8
D-97-B0019A	10	38	9	12	440	12	21	28	10	24	15	9
D-97-B0019B	6	42	8	17	400	14	24	29	11	27	16	8
D-97-MT007	8	64	7	2	73	16	36	19	3	36	26	8
D-97-MT008	12	58	4	20	120	16	34	30	7	31	23	10
D-97-MT009	12	56	4	18	94	18	33	29	17	40	19	6
D-97-MT009D	4	42	3	16	110	17	25	32	20	32	15	6
D-97-MT0010	3	49	4	6	180	17	28	22	15	37	17	6
D-97-MT0011	4	59	11	13	68	8	35	28	21	22	22	13
D-97-MT0013	< 2	66	5	16	49	15	38	23	14	34	24	8
97-BMF-132A	17	54	9	21	450	15	31	28	8	30	22	10
97-BMF-132B	15	49	10	15	360	14	26	25	6	27	18	9

Table 2. (cont.) Total-digestion ICP-AES analyses for mine waste samples collected from the Boulder River watershed study area, Jefferson County Montana.

SAMPLE NO.	Pb ppm	Sc ppm	Sr ppm	Th ppm	V ppm	Y ppm	Yb ppm	Zn ppm
D-97-B001	3400	6	32	10	66	4	< 1	200
D-97-B002	740	9	47	14	94	4	< 1	340
D-97-B003	3300	5	28	8	61	3	< 1	150
D-97-B004	690	7	210	19	53	4	< 1	200
D-97-B005	5200	4	77	6	36	3	< 1	220
D-97-B006	20000	4	46	7	30	2	< 1	610
D-97-B0012	16000	8	140	9	89	6	< 1	6900
D-97-B0014	3200	8	210	18	73	13	1	1100
D-97-B0015	480	12	240	14	120	14	1	420
D-97-B0016	4800	5	76	20	38	8	< 1	1000
D-97-B0017	3500	8	110	16	70	7	< 1	280
D-97-B0018	3400	9	76	10	93	5	< 1	560
D-97-B0019A	8200	8	94	14	72	7	< 1	1300
D-97-B0019B	5600	8	70	10	83	7	< 1	800
D-97-MT007	630	8	200	6	52	20	2	1200
D-97-MT008	3800	6	100	16	60	17	2	1700
D-97-MT009	11000	10	62	10	100	5	< 1	1800
D-97-MT009D	5700	9	83	8	100	5	< 1	780
D-97-MT0010	8700	6	140	28	44	6	< 1	630
D-97-MT0011	2000	6	120	12	46	16	1	900
D-97-MT0013	730	10	73	18	92	9	< 1	240
97-BMF-132A	4400	8	330	12	62	13	1	2300
97-BMF-132B	2500	6	340	10	54	10	< 1	2200

Table 3. pH and conductivities of EPA-1312 leach solutions, net acid production (Acidity), and ICP-AES analyses for sulfate and 25 elements from EPA-1312 leach solutions for mine waste samples collected from the Boulder River watershed study area, Jefferson County Montana.

SAMPLE NO.	Leach pH @ 18 hrs	Leach cond. @ 18 hours µS/cm	NAP (acidity) kg $CaCO_3$ per ton	[sulfate] SO_4 mg/L	Al µg/L	As µg/L	B µg/L	Ba µg/L	Be µg/L	Ca µg/L	Cd µg/L
D-97-B001	3.79	60	2.45	8.8	17	320	10	94	< 10	290	< 10
D-97-B002	3.5	107	3.6	20.8	49	20	16	25	< 10	1400	< 10
D-97-B003	3.85	61	2.45	7.9	20	540	< 10	82	< 10	280	< 10
D-97-B004	3.48	106	6.32	15.9	84	140	29	50	< 10	360	< 10
D-97-B005	3.18	240	20.9	43.6	110	230	28	78	< 10	1600	< 10
D-97-B006	3.23	210	4.59	37.3	270	800	< 10	55	< 10	470	< 10
D-97-B0012	2.71	1090	33.7	277.1	5600	< 20	18	24	< 10	13000	220
D-97-B0014	6.26	87	0.5	31.4	64	62	26	81	< 10	12000	< 10
D-97-B0015	4.45	60	1.31	23.7	15	30	11	51	< 10	6400	< 10
D-97-B0016	4	78	4.09	28.5	41	< 20	12	61	< 10	5400	43
D-97-B0017	2.92	597	17.3	117.8	5100	140	< 10	87	< 10	2600	< 10
D-97-B0018	3.3	315	18.1	127.6	940	< 20	12	82	< 10	20000	34
D-97-B0019A	3.63	238	2.93	82.6	130	< 20	< 10	45	< 10	19000	70
D-97-B0019B	3.68	227	5.42	86.7	140	< 20	30	64	< 10	20000	46
D-97-MT007	7.69	119	0.23	15.4	220	< 20	72	220	< 10	21000	< 10
D-97-MT008	3.13	333	5.61	66.9	910	< 20	47	94	< 10	6500	70
D-97-MT009	3.37	163	12.7	40.3	240	< 20	10	38	< 10	3400	12
D-97-MT009D	3.31	210	7.4	53.5	170	< 20	12	41	< 10	7700	16
D-97-MT0010	3.7	240	7.95	55	270	95	14	35	< 10	5400	14
D-97-MT0011	7.41	202	2.32	54.8	26	< 20	19	59	< 10	40000	< 10
D-97-MT0013	3.67	96	3.3	18.3	55	< 20	14	88	< 10	1900	< 10
97-BMF-132A	3.98	247	2.45	88.4	570	160	160	310	< 10	12000	240
97-BMF-132B	3.24	498	5.61	134.7	1200	100	80	270	< 10	25000	230

Table 3. (cont.) pH and conductivites of EPA-1312 leach solutions, net acid production (Acidity), and ICP-AES analyses for sulfate and 25 elements from EPA-1312 leach solutions for mine waste samples collected from the Boulder River watershed study area, Jefferson County Montana.

SAMPLE NO.	Co µg/L	Cr µg/L	Cu µg/L	Fe µg/L	K µg/L	Li µg/L	Mg µg/L	Mn µg/L	Mo µg/L	Na µg/L	Ni µg/L
D-97-B001	< 10	< 10	37	210	2800	< 10	95	25	< 20	460	< 10
D-97-B002	12	< 10	< 10	120	3500	< 10	470	880	< 20	430	< 10
D-97-B003	< 10	< 10	29	360	3800	< 10	99	15	< 20	620	< 10
D-97-B004	< 10	< 10	43	190	3500	< 10	160	160	< 20	780	< 10
D-97-B005	< 10	< 10	29	1700	4000	< 10	160	94	< 20	500	< 10
D-97-B006	< 10	< 10	120	1200	3700	< 10	130	16	< 20	370	< 10
D-97-B0012	30	< 10	1700	22000	1600	< 10	3200	5100	< 20	130	32
D-97-B0014	< 10	< 10	15	190	3000	< 10	1800	610	< 20	280	< 10
D-97-B0015	< 10	< 10	31	26	2600	< 10	1300	470	< 20	250	< 10
D-97-B0016	< 10	< 10	330	37	2000	< 10	1300	1300	< 20	150	< 10
D-97-B0017	53	< 10	950	9700	1800	< 10	2600	2200	< 20	150	23
D-97-B0018	60	< 10	1500	5400	2000	< 10	6300	4400	< 20	69	18
D-97-B0019A	18	< 10	350	130	2200	< 10	3800	2500	< 20	75	15
D-97-B0019B	26	< 10	190	97	2400	< 10	4200	3400	< 20	130	11
D-97-MT007	< 10	< 10	12	80	4400	< 10	1400	130	< 20	1400	< 10
D-97-MT008	< 10	< 10	540	1000	3000	< 10	1300	1200	< 20	570	11
D-97-MT009	< 10	< 10	60	31	3800	< 10	450	2000	< 20	410	< 10
D-97-MT009D	< 10	< 10	85	38	3200	< 10	520	1900	< 20	270	< 10
D-97-MT0010	< 10	< 10	120	620	4600	< 10	740	900	< 20	550	< 10
D-97-MT0011	< 10	< 10	< 10	33	3000	< 10	1500	32	< 20	420	< 10
D-97-MT0013	< 10	< 10	20	22	3600	< 10	280	790	< 20	290	< 10
97-BMF-132A	28	< 10	670	240	3600	23	2800	5200	< 20	2100	11
97-BMF-132B	30	< 10	980	210	2900	10	3300	6500	< 20	700	13

Table 3. (cont.) pH and conductivites of EPA-1312 leach solutions, net acid production (Acidity), and ICP-AES analyses for sulfate and 25 elements from EPA-1312 leach solutions for mine waste samples collected from the Boulder River watershed study area, Jefferson County Montana.

SAMPLE NO.	P µg/L	Pb µg/L	Si µg/L	Sr µg/L	Ti µg/L	V µg/L	Zn µg/L
D-97-B001	16000	< 50	410	2.4	< 50	< 10	120
D-97-B002	8800	< 50	1100	4.2	< 50	< 10	170
D-97-B003	19000	< 50	400	2.4	< 50	< 10	78
D-97-B004	4500	< 50	2800	4.2	< 50	< 10	150
D-97-B005	2300	11000	990	26	< 50	< 10	130
D-97-B006	12000	12000	630	56	< 50	< 10	230
D-97-B0012	12000	4300	1200	30	< 50	< 10	28000
D-97-B0014	23000	83	2200	65	< 50	< 10	550
D-97-B0015	14000	< 50	2000	83	< 50	< 10	200
D-97-B0016	4700	340	2100	18	< 50	< 10	2400
D-97-B0017	< 50	4000	1400	24	< 50	< 10	590
D-97-B0018	< 50	2000	1400	31	< 50	< 10	3600
D-97-B0019A	12000	920	2300	21	< 50	< 10	5600
D-97-B0019B	6200	650	1900	31	< 50	< 10	3000
D-97-MT007	35000	< 50	3400	42	< 50	< 10	54
D-97-MT008	15000	3300	1300	17	< 50	< 10	6600
D-97-MT009	3500	13000	1300	32	< 50	< 10	1300
D-97-MT009D	9200	9000	1600	31	< 50	< 10	1800
D-97-MT0010	3200	7500	1400	43	< 50	< 10	1700
D-97-MT0011	8700	< 50	3500	110	< 50	< 10	28
D-97-MT0013	9500	< 50	1800	9.3	< 50	< 10	180
97-BMF-132A	45000	460	3600	120	< 50	< 10	25000
97-BMF-132B	13000	91	2600	110	< 50	< 10	26000

Table 4. NAP (acidity), summed As+Cd+Cu+Pb+Zn from EPA-1312 leach, chemical rank based on summed As+Cd+Cu+Pb+Zn, dissolved iron in EPA-1312 leach, chemical rank based on dissolved iron, size classes of mine-waste sites, and composite rank based on combination of chemical ranks and size classes.

column	1	2	3	4	5	6	7
SAMPLE NO.	Acidity kg $CaCO_3$ per ton	summed dissolved metals µg/L	chemical rank based on dissolved summed metals	dissolved iron µg/L	chemical rank based on dissolved iron	size class from Desborough and Fey (1997)	rank based on combining chemistry ranks and size rank
D-97-B001	2.5	477	1	210	1	2	4
D-97-B002	3.6	190	1	120	1	1	3
D-97-B003	2.5	647	1	360	1	3	5
D-97-B004	6.3	333	1	190	1	3	5
D-97-B005	20.9	11,389	3b	1,700	3	3	9b
D-97-B006	4.6	13,150	3a	1,200	2	3	8a
D-97-B0012	33.7	34,220	3b	22,000	3	1	7b
D-97-B0014	0.5	710	1	190	1	3	5
D-97-B0015	1.3	261	1	26	1	3	5
D-97-B0016	4.1	3,113	2	37	1	3	6
D-97-B0017	17.3	5,680	3b	9,700	3	3	9b
D-97-B0018	18.1	7,134	3b	5,400	3	3	9b
D-97-B0019A	2.9	6,940	3a	130	1	3	7b
D-97-B0019B	5.4	3,886	2	97	1	3	6
D-97-MT007	0.2	66	1	80	1	3	5
D-97-MT008	5.6	10,510	3a	1,000	2	3	8a
D-97-MT009	12.7	14,372	3b	31	1	3	7b
D-97-MT009D	7.4	10,901	3a	38	1	3	7a
D-97-MT0010	8.0	9,429	3a	620	1	3	7a
D-97-MT0011	2.3	28	1	33	1	2	4
D-97-MT0013	3.3	200	1	22	1	2	4
97-BMF-132A	2.5	26,530	3a	240	1	removed	--
97-BMF-132B	5.6	27,401	3a	210	1	removed	--

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