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Naturally Degraded Surface Waters Associated with Hydrothermally Altered Terrane in Colorado

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FOREWORD

Open-File Report 00-16 describes the water quality of several areas in Colorado that show the effects of naturally degraded surface water. This study focuses on areas where hydrothermally altered host rocks are the primary cause of degradation. Often, areas with naturally degraded water overlap mining districts, where mining-related degradation also occurs. This information will be useful for State and Federal agencies and private owners for developing realistic reclamation plans for active and abandoned mines in areas where natural degradation is a contributor to poor water quality.

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ABBREVIATIONS AND SYMBOLS

AMLIP	Abandoned Mined Land Inventory Project
~	approximate value
cm	centimeter(s)
CDPHE	Colorado Department of Public Health and Environment
CGS	Colorado Geological Survey
cps	counts per second
°	degree
DO	dissolved oxygen
EDR	Environmental Degradation Rating
EPA	Environmental Protection Agency
ft	foot (Feet)
4WD	four-wheel drive
gpm	gallons per minute
GPS	Global Positioning System
>	greater than
<	less than
≤	less than or equal to
µg/L	micrograms per liter
µ	microns
µS/cm	microSiemens per centimeter
mg/L	milligrams per liter
NOAMS	naturally occurring, acidic, metal-rich springs or seeps
n/a	not applicable
no.	number
#	number
p.	page(s)
ppm	parts per million
%	percent
PHR	Physical Hazard Rating
PBS	Primary Base Series
quad	quadrangle (7.5-minute)
QA/QC	Quality Assurance/Quality Control
TDS	total dissolved solids
trec	total recoverable
U.S.	United States
USFS	United States Department of Agriculture - Forest Service
BLM	United States Department of Interior - Bureau of Land Management
v.	volume

INTRODUCTION

During the field season of 1999, Colorado Geological Survey (CGS) personnel conducted a reconnaissance-level investigation of naturally degraded surface waters associated with hydrothermal alteration in Colorado (Figure 1). Data from this study may be useful when regulatory agencies set stream standards. This information could also be useful for determining remediation goals for past and/or future mining operations.

Many of these sites were initially identified by water testing done in conjunction with an abandoned mine inventory conducted by the CGS for the USFS from 1991 through 1998. Personnel from the U.S. Geological Survey, the Colorado Division of Minerals and Geology, and Colorado State University were also important sources of preliminary information. A publication on iron occurrences in Colorado (Harrer and Tesch, 1959) describes numerous bog-iron deposits, many which are associated with naturally degraded water.

A study of this scope cannot catalog and characterize every naturally degraded, metal-rich stream in Colorado. It may serve as a guide to identify areas of Colorado that are susceptible to these phenomena and provide general information regarding water chemistry at these occurrences. Many of the areas described in this report should be the foci of detailed watershed characterization studies to better understand the natural and anthropogenic processes involved in the surface-water chemistry.

METHOD OF INVESTIGATION

Sites with potential for naturally occurring surface-water degradation were identified using the sources discussed previously and by using a variety of literature references. Using published maps and information from the abandoned-mine inventory of USFS-administered lands, sites with little or no known upstream mining activity were selected. In the field, visual evidence such as the occurrence of precipitate, ferricrete/ferrosinter deposits, or turbid water, in conjunction with pH and conductivity tests, were used to screen streams for sampling. Many of the sample sites and the associated altered slopes above them were photographed. Unfortunately, for this state-wide, reconnaissance-level study, time did not allow detailed geologic mapping or analyses of the alteration types exposed at and near sample sites.

Filtered (0.45 µ) and unfiltered water samples for laboratory analyses were collected from selected streams and springs. Depending on a variety of factors, including weather, time of day, distance from the vehicle, etc., subsampling into filtered (dissolved) and raw (total recoverable) bottles was done on site, at the vehicle, or indoors. Samples and/or subsamples were refrigerated until delivery to the lab. Field sampling protocols, laboratory analytical methods, and QA/QC information are in the appendix of this report.

For consistency in reporting data from different stream segments, analytical results are compared to general state-wide standards established by the State Water Quality Control Commission.

Specific stream-segment standards are not used. The most stringent state-wide standards are shown in the tables in this text, usually either domestic-water-supply or aquatic-life standards.

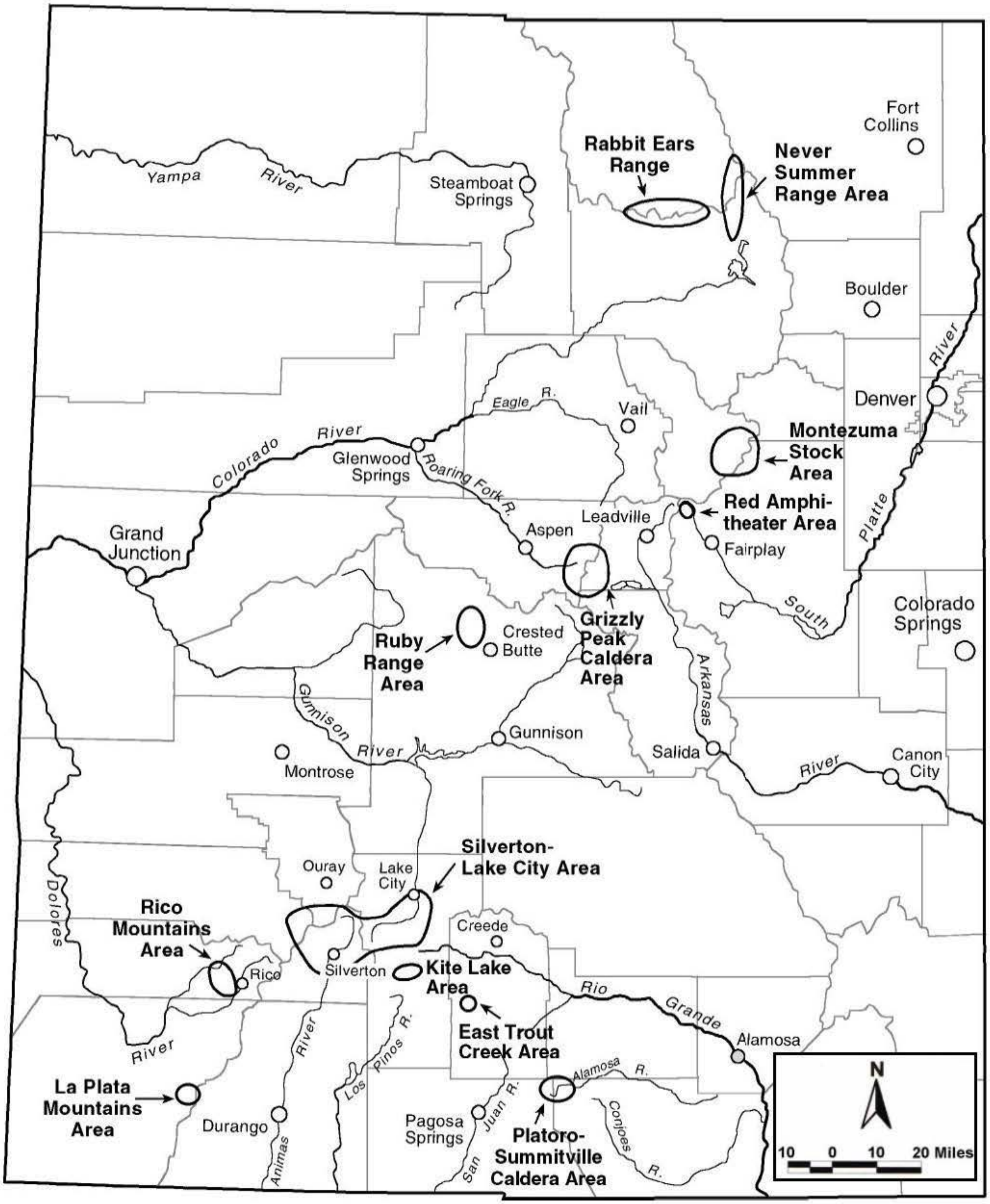

Figure 1. Index map showing areas described in this report.

Most domestic-water-supply standards are based on total recoverable metals, and most aquatic-life standards are based on hardness of the water and dissolved ion concentrations. Important exceptions to this generalization include iron and manganese. Both of these metals have aquatic-life standards of 1,000 µg/L (total recoverable). The much lower dissolved concentrations (300 µg/L for iron; 50 µg/L for manganese) shown as the standards on the tables in this report are for aesthetic purposes in drinking water.

Because of the software used for calculations and creation of the tables in this report, formats and use of significant figures do not conform to standardized methodology. Analytical values are reported in dissolved concentrations unless noted.

GEOLOGIC OVERVIEW

Most of the areas examined for this study are related to Laramide-age and later mineralization events. Frequently, naturally degraded streams are found in and on the margins of Tertiary-age calderas. Highly altered intrusive igneous rocks are also favorable host rocks for sources of naturally degraded streams. Acidic, metal-rich surface waters are often associated with mining districts. Hydrothermal fluids responsible for forming ore bodies also concentrated other metallic minerals, especially pyrite, within and on the margins of ore deposits. Oxidation of pyrite is the primary cause of naturally degraded, acidic, metal-rich streams. Oxidation of ferrous iron ions to ferric iron ions is another acid-generating reaction that exacerbates the problem.

SOUTHWESTERN COLORADO

Several areas of naturally degraded water occur in southwestern Colorado. Most are related to Tertiary-age calderas and related intrusive activity. Hydrothermal fluids associated with the igneous activity frequently formed ore deposits, mineral occurrences, and regional and localized altered zones. Mountain ranges such as the La Plata and Rico Mountains, formed by doming during emplacement of Tertiary-age intrusions, also host naturally degraded streams.

SAN JUAN MOUNTAINS

The San Juan Mountains comprise mostly Tertiary-age volcanic rocks that are remnants of a volcanic field that covered most of the southern Rocky Mountains. The initial volcanic activity began about 35 to 40 million years ago and was primarily andesitic in composition. Beginning about 30 million years ago, silicic ash flows, lavas, and breccias buried large areas of the older andesitic rocks. Throughout the San Juan volcanic field, rapid extrusion of large volumes of silicic rocks from near-surface magma chambers resulted in collapse of the overlying rocks and formed calderas. At least 15 calderas are well documented in the San Juan Mountains. Nesting and overlapping of the calderas are common. (See Steven and Lipman, 1976, p. 1-3.)

Silicic volcanism leading to caldera formation initially began in the northeastern (Bonanza) and southern parts (Summitville) of the San Juan volcanic field. In the western and central parts of the field, silicic eruptions and caldera formation began about 29 and 28 million years ago, respectively. Silicic volcanic activity and subsequent caldera formation may be related to emplacement of shallow, highly differentiated plutons above a batholith that is postulated to underlie most of the San Juan volcanic field. (See Steven and Lipman, 1976, p. 3.)

Varying degrees of mineralization and hydrothermal alteration are associated with the calderas and the related intrusive activity. In addition, nested and/or overlapping calderas create complex hydrologic, stratigraphic, and structural geologic conditions. Large areas of hydrothermally altered terrane are associated with the Silverton caldera, the Lake City caldera, and the Platoro-Summitville caldera complex. Other smaller, isolated areas with poor-quality water are scattered throughout the San Juan Mountains.

Silverton Caldera

The Silverton caldera is located in southwestern Colorado in the western San Juan Mountains. The town of Silverton lies near the southern boundary of the caldera, which is approximately 10 miles in diameter (Steven and Lipman, 1976, Figure 13). The caldera extends from about Mineral Creek on the west to the Animas River on the east, and reaches northward into the headwaters of the Uncompahgre River drainage basin.

This area has been extensively mined in the past for silver, gold, and base metals. Mining-related stream degradation is obvious in some areas of the mining district.

Within and adjacent to the Silverton caldera, the headwaters and tributaries of the Animas River have been extensively studied, and studies continue regarding water quality, abandoned mine and watershed characterization, reclamation technology and solutions, and the contribution of naturally acidic, metal-rich water to the degraded streams in the drainage basin. The U.S. Geological Survey is the primary agency conducting investigations, and other Federal and State agencies are involved. Church (2000) prepared a preliminary compilation that includes several of these reports.

Some previous studies are summarized in this section. The majority of the following discussion involves samples collected by CGS personnel during the 1999 field season, mostly in the headwaters of the Uncompahgre River drainage basin and one sample from the headwaters of Howard Fork of the San Miguel River.

Geology

The Silverton caldera is one of four closely spaced and/or overlapping calderas documented in the northwestern San Juan Mountains. The Silverton, San Juan, and Uncompahgre calderas extruded ash-flow tuffs of similar composition, and all three formed within 2 million years. The San Juan and Uncompahgre calderas formed simultaneously. The Silverton caldera is slightly younger and is mostly nested within the San Juan caldera. The Lake City caldera formed about 5 million years later and is mostly nested within the Uncompahgre caldera. (See Steven and Lipman, 1976, p. 7, 10-11, Figure 13.)

During and after formation of the San Juan caldera, small stocks, dikes, and sills intruded the volcanic rocks. Resurgent doming, followed by extrusion of the Crystal Lake Tuff from the San Juan caldera led to localized subsidence, forming the Silverton caldera and the related and highly mineralized Eureka graben. During the multiple episodes of subsidence, resurgence, and intrusive activity, numerous faults and fractures formed within and adjacent to the San Juan/Silverton calderas, providing zones of weakness for later intrusions and channels for ascending and recirculating hydrothermal fluids. (See Steven and Lipman, 1976, p. 10-14.)

About 6 to 10 million years after the Silverton caldera was structurally complete, silicic igneous rocks intruded zones of weakness along some of the caldera-related faults and fractures. These post-caldera igneous intrusions were the source for metal-rich, hydrothermal fluids responsible for most of the mineralization and alteration spatially related to the Silverton caldera. (See Steven and Lipman, 1976, p. 34.) Within and adjacent to the Silverton caldera, several mineral deposit types have been recognized, including veins, chimneys, replacements, stockworks, and disseminations. Sulfides and sulfosalts are abundant in all of these deposit types.

In addition to depositing economic grades of metallic minerals in some locations, hydrothermal fluids from post-caldera intrusions altered much of the surrounding host rock. In many instances, the original composition of the rock is difficult to ascertain because of the intensity of the alteration. Propylitic, argillic, phyllic, and acid-sulfate alteration types occur, and pyrite was added to host rocks in many localities.

Some of the pyrite has oxidized, a process continuing today, causing large areas of deep red staining, hence names such as Red Mountain. Oxidation of pyrite creates acidic conditions, causing more metals to dissolve and further degrade surface and ground water.

Previous Investigations

Results from selected studies involving the headwaters of the Animas River drainage basin are summarized. Discussion of ferricrete/ferrosinter deposits in the Animas, Uncompahgre, and Howard Fork of the San Miguel Rivers drainage basins follows. Data from the CGS abandoned-mine inventory and water-sampling program in Howard Fork in 1996 are also presented.

Wright and Janik (1995) sampled four springs and a stream unaffected by mining. The sample sites were in Topeka Gulch, a tributary of Cement Creek. Topeka Gulch drains a highly altered portion of the Silverton caldera in the vicinity of a postulated buried stockwork molybdenum deposit. Three of the four springs and the stream, all sites unaffected by mining, contained highly degraded water. Sample results from the three springs and the stream show pH ranged from about 2.9 to 4.4; dissolved aluminum ranged from about 5,000 to 22,000 µg/L; dissolved iron from 3,600 to about 50,000 µg/L; and dissolved zinc from about 80 to 1,000 µg/L. Mine effluent sampled in the same area had similar metal concentrations and pH values. Loading calculations suggest that naturally degraded water contributes about ½ of the dissolved metals discharging from the mouth of Topeka Gulch. (See Wright and Janik, 1995.)

CGS personnel collected a water sample from a tributary of Middle Mineral Creek in 1995. The stream was the easternmost major tributary draining into Middle Mineral Creek from the south and is unaffected by mining. More recent studies call this stream the "Red Trib" because of its distinctive color. Bedrock in the upper reaches of the tributary is stained red from oxidation of disseminated pyrite, and alteration is obvious. Water sampled from the tributary greatly exceeded state standards in aluminum and iron, and was slightly over the cadmium limit. Manganese, sulfate, and zinc concentrations were also elevated. The stream was flowing at an estimated rate of 500 gpm and had pH of 3.66. (See Sares, 1996, p. 226-227; Lovekin and others, p. 21-22, table 1.)

Bog-iron deposits related to the Silverton caldera are briefly described in the next paragraphs. For the most part, these deposits predate mining activity, but adits were driven into some of them during mineral exploration efforts. These bog-iron deposits are indicative of poor-quality water prior to mining, but it is likely that mining has exacerbated degradation in some areas. Severe water chemistry changes from pre-mining to post-mining may be indicated by compositional changes in the bog-iron deposits.

Limonite/ferricrete deposits line much of Cement Creek. Additional smaller, distinctly separate deposits are associated with springs along 4 miles of Cement Creek beginning near Gladstone. Active precipitation is ongoing at most of these sites. Limonite deposits associated with these springs are 500 to 1,000 feet long, 25 to 300 feet wide, and very thin. (See Harrer and Tesch, 1959, p. 68.) These deposits predate mining activity, indicating poor-quality water from natural sources. Undoubtedly, mine effluent affects some of the springs and surface flow and contributes substantially to degradation in Cement Creek. During the 1990's, U.S. Geological Survey personnel conducted numerous studies in the Cement Creek drainage basin. No further discussion of this basin is presented in this paper.

Limonite once used for flux at a nearby smelter is exposed at the Silverton Reservoir, elevation 9,500 feet, northeast of Silverton (Harrer and Tesch, 1959, p. 70). It is unknown if there are active seeps at this location.

Limonite/ferricrete deposits are associated with a spring at about 9,800 feet elevation near Burro Bridge, on the west side of Mineral Creek, 1½ miles south of Chattanooga. The spring water formed an apron of iron-rich precipitate that extends to Mineral Creek. (See Harrer and Tesch, 1959, p. 67.)

About ¾ mile south of Chattanooga, at an elevation of about 9,800 feet on the west side of Mineral Creek, an active spring has deposited a triangular-shaped deposit of ferrosinter. Deposition is still occurring, and the occurrence extends to Mineral Creek. The fan of precipitate associated with this spring is about 575 feet long and is 300 feet wide at the base. Thickness is 3 to 10 feet. (See Harrer and Tesch, 1959, p. 68.)

Much of Mineral Creek has alluvial bog-iron deposits in it (Harrer and Tesch, 1959, p. 70-71). Most of these deposits are probably related to upwelling of poor-quality groundwater and interaction with the highly degraded surface water. No individual springs are known in this area, although some probably exist. Similar to Cement Creek, Mineral Creek is presently strongly influenced by naturally and mining-related degraded water.

In Ouray County, on the north side of Red Mountain Pass in the Red Mountain Creek drainage basin, an iron-rich spring was discharging water on a hillside above the Guston Mine. The iron deposits were known prior to 1882 and presumably predate mining activity in this area. (See Harrer and Tesch, 1959, p. 52.)

Much of Ironton Park comprises a large limonite deposit that was formed by ferruginous springs prior to the onset of mining activity. The deposit covers a large area, but is thin. (See Harrer and Tesch, 1959, p. 53.)

Further north, iron-rich springs on the eastern side of Uncompahgre Park about 2 miles southeast of Ridgway have deposited a thin layer of ferricrete that covers several acres. (See Harrer and Tesch, 1959, p. 53.) These springs are probably not related to the Silverton caldera, but may be related to post-caldera igneous intrusions that were emplaced north of the caldera (Steven and Lipman, 1976, p. 34).

Metal-rich springs associated with the Silverton caldera occur in Howard Fork of the San Miguel River, in San Miguel County. Between Chapman Gulch and the town of Ophir, at least two metal-rich springs emerge. Although mines have been excavated above these springs, precipitate deposits associated with the springs predate mining. The Iron Springs mining district near Ophir was named for the spring with the largest precipitate deposit. The Iron Springs limonite deposit is about 1,500 feet long and extends to Howard Fork. Both the Ferric Oxide Limonite (adjacent to and west of Iron Springs) and the Iron Springs Limonite deposits are actively forming at present, and both have deposited precipitate into the Howard Fork streambed. (See Harrer and Tesch, 1959, p. 72-75.)

Chapman Gulch has several ferruginous springs and a discharging drill hole with metal-rich waters. Isolated, weathering ferricrete deposits line the banks in places. A sample of the drill hole water, which could be interpreted as groundwater, had 6.62 pH, 2,170 µS/cm conductivity, exceeded state standards in iron, sulfate, fluoride, and silver, and contained 1,400 mg/L calcium. (See Neubert and Harris, 1996, p. 21, 23-24.)

On the south side of Howard Fork, an unnamed tributary of Swamp Canyon shows evidence of natural degradation. The tributary drains highly altered rocks on the north side of South Lookout Peak. Ferricrete deposits line the stream channel upstream and downstream of a few small mines that were driven near the break-in-slope from the upper basin to the steep gulch that descends toward Swamp Canyon. Upstream of all the known mines, the 300-gpm stream had 3.88 pH and 288 µS/cm conductivity in June 1996. The same day, near the base of the steep gulch and upstream of a small mine that was draining about 0.2 gpm of degraded water, the stream was flowing at about 1,000 gpm and had 4.78 pH and 403 µS/cm conductivity. In August 1996 a water sample was collected from the stream at the latter test site. Stream flow was measured at

86 gpm, pH was 3.35, and conductivity was 515 µS/cm. Stream water exceeded standards in iron, aluminum, manganese, and zinc. Beaver ponds lying between the sample site and Swamp Canyon had white precipitate (aluminum hydroxide?) and the water had a bluish hue. The low volume of effluent discharging from the small mines in this drainage basin, and the existence of water with low pH and high conductivity above all known mines, suggests that the degraded water in this unnamed tributary is almost completely natural in origin. (See Neubert and Harris, 1996, p. 25-26.)

Present Investigation

In 1999, CGS work focused mainly in the headwaters of the Red Mountain Creek drainage basin. One sample was collected from the headwaters of Howard Fork of the San Miguel. The Animas River drainage basin was not included in this investigation because the U.S. Geological Survey is actively working on similar issues in that area.

Twenty samples were collected from the Red Mountain Creek drainage basin (Figure 2). Sample NW1, from the upper basin of Corkscrew Gulch, was <u>not</u> collected upstream of all significant and/or draining mines. During the 1999 sampling, a draining adit above the sample site was covered with snow. Fehlmann (1997, p. 33-35) reported that 20 gpm of extremely poor-quality water (pH of 2.2; conductivity of 5,600 µS/cm) emerged from this mine. Where sampled below the mine and associated waste-rock pile, the mine effluent contained exceptionally high concentrations of aluminum, iron, copper, sulfate, zinc, and arsenic (Fehlmann, 1997, p. 34-35).

Sample NW1 had 2.31 pH, conductivity of 821 µS/cm, and the stream was flowing at about 300 gpm in late June of 1999. Stream water was highly degraded and greatly exceeded state standards in copper, lead, silver, aluminum, and iron concentrations. Zinc, cadmium, sulfate, manganese, and nickel also exceeded standards (Table 1). Although some of the elevated metal concentrations are attributable to mine drainage, certainly the large exposures of acid-sulfate-altered bedrock and talus in the basin contribute acidic, metal-rich runoff and seepage. Metal and acid contributions from natural versus mine-related sources at sample site NW1 were not determined during this study.

Samples NW2 through NW8 are from the west and northwest side of Red Mountain #1, from tributaries of Corkscrew Gulch. No significant and/or draining mines are known above the sample sites, however, Red Mountain #1 is stained red, yellow, and brown from intense argillic and acid-sulfate alteration (Figures 3, 4). Disseminated pyrite was common in the gravel at most of these sample sites. In addition, fragments of ferricrete and traces of malachite were in the stream gravels at sample site NW3. In general, streams draining from Red Mountain #1 into Corkscrew Gulch carried clear water that showed no visual indications of degradation (Figure 5), but were quite acidic with pH of 2.59 to 4.73. Conductivities were usually low to moderate (less than 250 µS/cm), with the exception of NW8.

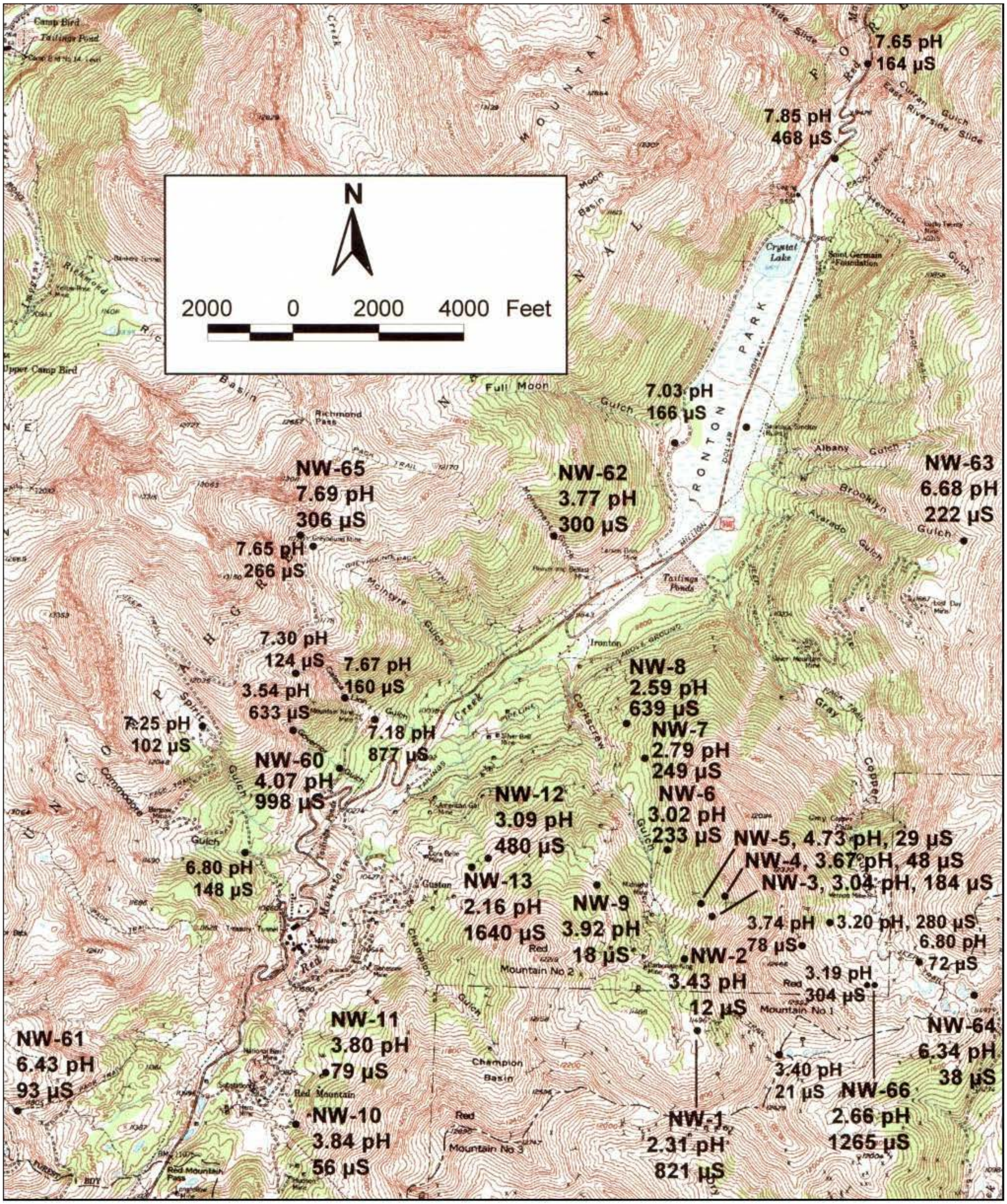

Figure 2. Map showing sample sites and test results in the Red Mountain Creek drainage basin.

Table 1. Analytical data for samples NW1-13, 60-66, 79 from the Silverton caldera area.

Sample	NW1, UPPER CORKSCREW (6/25/99)				NW2, WEST SIDE RED MOUNTAIN #1 (6/25/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	300.0				26.0			
pH (standard units)	2.31				3.43			
Conductivity (µS/cm)	821.0				12.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	11	None	N/A		6	None	N/A	
Aluminum (trec) (µg/L)	15,000	None	N/A	24,529.5	170	None	N/A	24.1
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	6.0	50.00	Below standard	9.8	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	36,000	1000.00	36.0	58,870.8	66	1000.00	Below standard	9.4
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	3,700	2000.00	1.9	6,050.6	< 10	2000.00	Below standard	N/A
Aluminum (µg/L)	15,000	87.00	172.4	24,529.5	160	87.00	1.8	22.7
Cadmium (µg/L)	0.7	0.21	3.4	1.1	< 0.3	0.12	Not detected	N/A
Calcium (mg/L)	3	None	N/A	4,905.9	2	None	N/A	283.5
Chloride (mg/L)	2.0	250.00	Below standard	3,270.6	< 10.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	790.0	1.85	427.5	1,291.9	< 4.0	1.05	Not detected	N/A
Fluoride (mg/L)	< 0.10	2.00	Below standard	N/A	< 0.10	2.00	Below standard	N/A
Iron (µg/L)	35,000	300.00	116.7	57,235.5	42	300.00	Below standard	6.0
Lead (µg/L)	70.0	0.18	390.6	114.5	< 1.0	0.07	Not detected	N/A
Magnesium (mg/L)	0.95	None	N/A	1,553.5	0.21	None	N/A	29.8
Manganese (µg/L)	73	50.00	1.5	119.4	5	50.00	Below standard	0.7
Nickel (µg/L)	26	18.34	1.4	42.5	< 20	11.07	Not detected	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	5.5	None	N/A	8,994.2	3.8	None	N/A	538.6
Silver (µg/L)	0.4	0.00	223.3	0.7	< 0.2	0.00	Not detected	N/A
Sodium (mg/L)	0.40	None	N/A	654.1	0.39	None	N/A	55.3
Sulfate (mg/L)	400	250.00	1.6	654,120.0	< 5	250.00	Below standard	N/A
Zinc (µg/L)	140	16.83	8.3	228.9	< 10	9.58	Not detected	N/A

Table 1. Analytical data for samples NW1-13, 60-66, 79 from the Silverton caldera area--continued.

Sample	NW3, NORTHWEST SLOPE OF RED MOUNTAIN #1 (6/25/99)				NW4, NORTHWEST FLANK OF RED MTN #1-HIGH (6/25/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	30.0				25.0			
pH (standard units)	3.04				3.67			
Conductivity (µS/cm)	184.0				48.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	17	None	N/A		6	None	N/A	
Aluminum (trec) (µg/L)	2,800	None	N/A	457.9	520	None	N/A	70.9
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	1,100	1000.00	1.1	179.9	550	1000.00	Below standard	75.0
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	40	2000.00	Below standard	6.5	< 10	2000.00	Below standard	N/A
Aluminum (µg/L)	2,800	87.00	32.2	457.9	160	87.00	1.8	21.8
Cadmium (µg/L)	< 0.3	0.28	Not detected	N/A	< 0.3	0.13	Not detected	N/A
Calcium (mg/L)	4	None	N/A	654.1	2	None	N/A	272.6
Chloride (mg/L)	< 50.0	250.00	Below standard	N/A	< 10.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	13.0	2.54	5.1	2.1	4.0	1.10	3.6	0.5
Fluoride (mg/L)	< 0.20	2.00	Below standard	N/A	< 0.10	2.00	Below standard	N/A
Iron (µg/L)	1,100	300.00	3.7	179.9	250	300.00	Below standard	34.1
Lead (µg/L)	< 1.0	0.30	Not detected	N/A	< 1.0	0.08	Not detected	N/A
Magnesium (mg/L)	1.60	None	N/A	261.6	0.30	None	N/A	40.9
Manganese (µg/L)	150	50.00	3.0	24.5	12	50.00	Below standard	1.6
Nickel (µg/L)	< 20	24.37	Below standard	N/A	< 20	11.59	Not detected	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	3.4	None	N/A	556.0	4.0	None	N/A	545.1
Silver (µg/L)	< 0.2	0.00	Not detected	N/A	< 0.2	0.00	Not detected	N/A
Sodium (mg/L)	0.24	None	N/A	39.2	0.28	None	N/A	38.2
Sulfate (mg/L)	45	250.00	Below standard	7,358.9	10	250.00	Below standard	1,362.8
Zinc (µg/L)	41	23.10	1.8	6.7	< 10	10.09	Below standard	N/A

Table 1. Analytical data for samples NW1-13, 60-66, 79 from the Silverton caldera area--continued.

Sample	NW5, NORTHWEST FLANK OF RED MOUNTAIN #1-LOW (6/25/99)				NW6, E. OF CORKSCREW, NW SIDE OF RED MTN #1 (6/26/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	50.0				15.0			
pH (standard units)	4.73				3.02			
Conductivity (µS/cm)	29.0				233.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	9	None	N/A		16	None	N/A	
Aluminum (trec) (µg/L)	190	None	N/A	51.8	4,600	None	N/A	376.1
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	110	1000.00	Below standard	30.0	1,200	1000.00	1.2	98.1
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	< 10	2000.00	Below standard	N/A	44	2000.00	Below standard	3.6
Aluminum (µg/L)	170	87.00	2.0	46.3	4,600	87.00	52.9	376.1
Cadmium (µg/L)	< 0.3	0.17	Not detected	N/A	< 0.3	0.26	Not detected	N/A
Calcium (mg/L)	3	None	N/A	817.7	5	None	N/A	408.8
Chloride (mg/L)	< 10.0	250.00	Below standard	N/A	< 10.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	< 4.0	1.48	Not detected	N/A	14.0	2.42	5.8	1.1
Fluoride (mg/L)	< 0.10	2.00	Below standard	N/A	< 0.10	2.00	Below standard	N/A
Iron (µg/L)	81	300.00	Below standard	22.1	1,100	300.00	3.7	89.9
Lead (µg/L)	3.0	0.12	24.1	0.8	< 1.0	0.28	Not detected	N/A
Magnesium (mg/L)	0.32	None	N/A	87.2	0.76	None	N/A	62.1
Manganese (µg/L)	8	50.00	Below standard	2.2	71	50.00	1.4	5.8
Nickel (µg/L)	< 20	15.09	Not detected	N/A	< 20	23.31	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	2.3	None	N/A	626.9	7.7	None	N/A	629.6
Silver (µg/L)	< 0.2	0.00	Not detected	N/A	< 0.2	0.00	Not detected	N/A
Sodium (mg/L)	0.30	None	N/A	81.8	0.21	None	N/A	17.2
Sulfate (mg/L)	5	250.00	Below standard	1,362.8	53	250.00	Below standard	4,333.5
Zinc (µg/L)	< 10	13.53	Below standard	N/A	45	21.98	2.0	3.7

Table 1. Analytical data for samples NW1-13, 60-66, 79 from the Silverton caldera area--continued.

Sample	NW7, NORTH RED MOUNTAIN #1 SPRING (6/26/99)				NW8, NW OF NORTH END OF RED MOUNTAIN #1 (6/26/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	10.0				13.0			
pH (standard units)	2.79				2.59			
Conductivity (µS/cm)	249.0				639.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	18	None	N/A		70	None	N/A	
Aluminum (trec) (µg/L)	4,000	None	N/A	218.0	16,000	None	N/A	1,133.8
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	380	1000.00	Below standard	20.7	4,700	1000.00	4.7	333.1
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	39	2000.00	Below standard	2.1	< 94	2000.00	Below standard	N/A
Aluminum (µg/L)	4,100	87.00	47.1	223.5	17,000	87.00	195.4	1,204.7
Cadmium (µg/L)	< 0.3	0.30	Not detected	N/A	< 0.3	0.86	Below standard	N/A
Calcium (mg/L)	5	None	N/A	272.6	14	None	N/A	992.1
Chloride (mg/L)	87.0	250.00	Below standard	4,742.4	< 10.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	8.0	2.76	2.9	0.4	38.0	8.70	4.4	2.7
Fluoride (mg/L)	< 0.10	2.00	Below standard	N/A		2.00	N/A	
Iron (µg/L)	360	300.00	1.2	19.6	4,700	300.00	15.7	333.1
Lead (µg/L)	< 1.0	0.35	Not detected	N/A	< 1.0	2.34	Below standard	N/A
Magnesium (mg/L)	1.40	None	N/A	76.3	8.50	None	N/A	602.3
Manganese (µg/L)	54	50.00	1.1	2.9	320	50.00	6.4	22.7
Nickel (µg/L)	< 20	26.23	Below standard	N/A	< 20	72.76	Below standard	N/A
Potassium (mg/L)	1.3	None	N/A	70.9	< 1.0	None	N/A	N/A
Silicon (mg/L)	21.0	None	N/A	1,144.7	25.0	None	N/A	1,771.6
Silver (µg/L)	< 0.2	0.00	Not detected	N/A	< 0.2	0.04	Not detected	N/A
Sodium (mg/L)	0.60	None	N/A	32.7	1.10	None	N/A	77.9
Sulfate (mg/L)	55	250.00	Below standard	2,998.1	170	250.00	Below standard	12,046.7
Zinc (µg/L)	21	25.07	Below standard	1.1	95	78.20	1.2	6.7

Table 1. Analytical data for samples NW1-13, 60-66, 79 from the Silverton caldera area--continued.

Sample	NW9, NORTHEAST RED MOUNTAIN #2 (6/26/99)				NW10, RED MOUNTAIN TOWN (6/27/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	200.0				280.0			
pH (standard units)	3.92				3.84			
Conductivity (µS/cm)	18.0				56.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	14	None	N/A		22	None	N/A	
Aluminum (trec) (µg/L)	230	None	N/A	250.7	650	None	N/A	992.1
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	150	1000.00	Below standard	163.5	170	1000.00	Below standard	259.5
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	< 10	2000.00	Below standard	N/A	20	2000.00	Below standard	30.5
Aluminum (µg/L)	180	87.00	2.1	196.2	690	87.00	7.9	1,053.1
Cadmium (µg/L)	< 0.3	0.25	Not detected	N/A	< 0.3	0.35	Below standard	N/A
Calcium (mg/L)	5	None	N/A	5,451.0	8	None	N/A	12,210.2
Chloride (mg/L)	< 10.0	250.00	Below standard	N/A	17.0	250.00	Below standard	25,946.8
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	< 4.0	2.24	Not detected	N/A	36.0	3.27	11.0	54.9
Fluoride (mg/L)	< 0.10	2.00	Below standard	N/A	< 0.10	2.00	Below standard	N/A
Iron (µg/L)	72	300.00	Below standard	78.5	160	300.00	Below standard	244.2
Lead (µg/L)	< 1.0	0.25	Not detected	N/A	2.0	0.46	4.3	3.1
Magnesium (mg/L)	0.44	None	N/A	479.7	0.55	None	N/A	839.5
Manganese (µg/L)	43	50.00	Below standard	46.9	85	50.00	1.7	129.7
Nickel (µg/L)	< 20	21.80	Below standard	N/A	< 20	30.51	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	2.5	None	N/A	2,725.5	3.0	None	N/A	4,578.8
Silver (µg/L)	< 0.2	0.00	Not detected	N/A	< 0.2	0.01	Not detected	N/A
Sodium (mg/L)	0.14	None	N/A	152.6	0.36	None	N/A	549.5
Sulfate (mg/L)	8	250.00	Below standard	8,721.6	20	250.00	Below standard	30,525.6
Zinc (µg/L)	< 10	20.40	Below standard	N/A	20	29.67	Below standard	30.5

Table 1. Analytical data for samples NW1-13, 60-66, 79 from the Silverton caldera area--continued.

Sample	NW11, RED MOUNTAIN TOWN EAST (6/27/99)				NW12, RED MOUNTAIN #2, NORTHWEST SIDE (6/27/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	200.0				50.0			
pH (standard units)	3.80				3.09			
Conductivity (µS/cm)	79.0				480.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	23	None	N/A		328	None	N/A	
Aluminum (trec) (µg/L)	1,100	None	N/A	1,199.2	5,700	None	N/A	1,553.5
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	15.0	50.00	Below standard	4.1
Iron (trec) (µg/L)	220	1000.00	Below standard	239.8	71,000	1000.00	71.0	19,351.1
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	4.0	0.50	8.0	1.1
Zinc (trec) (µg/L)	34	2000.00	Below standard	37.1	130	2000.00	Below standard	35.4
Aluminum (µg/L)	1,200	87.00	13.8	1,308.2	3,000	87.00	34.5	817.7
Cadmium (µg/L)	< 0.3	0.36	Below standard	N/A	0.4	2.88	Below standard	0.1
Calcium (mg/L)	8	None	N/A	8,721.6	110	None	N/A	29,980.5
Chloride (mg/L)	< 50.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	26.0	3.38	7.7	28.3	40.0	32.65	1.2	10.9
Fluoride (mg/L)	< 0.10	2.00	Below standard	N/A		2.00	N/A	
Iron (µg/L)	200	300.00	Below standard	218.0	5,400	300.00	18.0	1,471.8
Lead (µg/L)	< 1.0	0.49	Not detected	N/A	< 1.0	20.97	Below standard	N/A
Magnesium (mg/L)	0.76	None	N/A	828.6	13.00	None	N/A	3,543.2
Manganese (µg/L)	140	50.00	2.8	152.6	930	50.00	18.6	253.5
Nickel (µg/L)	< 20	31.40	Below standard	N/A	< 20	235.89	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	3.4	None	N/A	3,706.7	3.8	None	N/A	1,035.7
Silver (µg/L)	< 0.2	0.01	Not detected	N/A	< 0.2	0.58	Below standard	N/A
Sodium (mg/L)	0.24	None	N/A	261.6	0.46	None	N/A	125.4
Sulfate (mg/L)	79	250.00	Below standard	86,125.8	180	250.00	Below standard	49,059.0
Zinc (µg/L)	33	30.64	1.1	36.0	110	290.21	Below standard	30.0

Table 1. Analytical data for samples NW1-13, 60-66, 79 from the Silverton caldera area--continued.

Sample	NW13, RED MTN #2-NW SIDE, FURTHER SOUTH (6/27/99)				NW60, GOVERNORS GULCH (8/18/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	150.0				7.0			
pH (standard units)	2.16				4.07			
Conductivity (µS/cm)	1,640.0				998.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	254	None	N/A		1,066	None	N/A	
Aluminum (trec) (µg/L)	27,000	None	N/A	22,076.6	8,200	None	N/A	312.9
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	1.0	50.00	Below standard	0.8	1.0	50.00	Below standard	0.0
Iron (trec) (µg/L)	86,000	1000.00	86.0	70,317.9	900	1000.00	Below standard	34.3
Thallium (trec) (µg/L)	1.0	0.50	2.0	0.8	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	290	2000.00	Below standard	237.1	590	2000.00	Below standard	22.5
Aluminum (µg/L)	27,000	87.00	310.3	22,076.6	7,300	87.00	83.9	278.5
Cadmium (µg/L)	0.8	2.36	Below standard	0.7	2.0	7.27	Below standard	0.1
Calcium (mg/L)	88	None	N/A	71,953.2	400	None	N/A	15,262.8
Chloride (mg/L)	8.0	250.00	Below standard	6,541.2	41.0	250.00	Below standard	1,564.4
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 100	11.00	Not detected	N/A
Copper (µg/L)	150.0	26.26	5.7	122.6	< 40.0	89.30	Below standard	N/A
Fluoride (mg/L)	< 0.20	2.00	Below standard	N/A	1.40	2.00	Below standard	53.4
Iron (µg/L)	90,000	300.00	300.0	73,588.5	140	300.00	Below standard	5.3
Lead (µg/L)	< 1.0	14.61	Below standard	N/A	2.0	111.20	Below standard	0.1
Magnesium (mg/L)	8.40	None	N/A	6,868.3	16.00	None	N/A	610.5
Manganese (µg/L)	3,600	50.00	72.0	2,943.5	4,000	50.00	80.0	152.6
Nickel (µg/L)	< 20	194.36	Below standard	N/A	< 200	577.20	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	1.2	None	N/A	45.8
Silicon (mg/L)	12.0	None	N/A	9,811.8	13.0	None	N/A	496.0
Silver (µg/L)	< 0.2	0.37	Below standard	N/A	< 0.2	4.40	Below standard	N/A
Sodium (mg/L)	0.33	None	N/A	269.8	3.90	None	N/A	148.8
Sulfate (mg/L)	550	250.00	2.2	449,707.5	440	250.00	1.8	16,789.1
Zinc (µg/L)	270	233.84	1.2	220.8	590	786.96	Below standard	22.5

Table 1. Analytical data for samples NW1-13, 60-66, 79 from the Silverton caldera area--continued.

Sample	NW61, WEST OF RED MTN PASS (9/15/99)				NW62, MONUMENT GULCH (9/15/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	5.1				134.0			
pH (standard units)	6.43				3.77			
Conductivity (µS/cm)	93.0				300.0			
Alkalinity (mg/L CaCO3)	< 20.00							
Hardness (mg/L CaCO3)	95	None	N/A		217	None	N/A	
Aluminum (trec) (µg/L)	< 50	None	N/A	N/A	5,200	None	N/A	3,798.3
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	3.0	50.00	Below standard	2.2
Iron (trec) (µg/L)	< 10	1000.00	Below standard	N/A	16,000	1000.00	16.0	11,686.9
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	28	2000.00	Below standard	0.8	150	2000.00	Below standard	109.6
Aluminum (µg/L)	< 50	87.00	Below standard	N/A	2,800	87.00	32.2	2,045.2
Cadmium (µg/L)	< 0.3	1.09	Below standard	N/A	1.0	2.08	Below standard	0.7
Calcium (mg/L)	37	None	N/A	1,028.6	81	None	N/A	59,165.2
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	< 4.0	11.35	Below standard	N/A	120.0	22.91	5.2	87.7
Fluoride (mg/L)	< 0.10	2.00	Below standard	N/A	0.20	2.00	Below standard	146.1
Iron (µg/L)	< 10	300.00	Below standard	N/A	5,300	300.00	17.7	3,871.3
Lead (µg/L)	< 1.0	3.63	Below standard	N/A	1.0	11.65	Below standard	0.7
Magnesium (mg/L)	0.68	None	N/A	18.9	3.50	None	N/A	2,556.5
Manganese (µg/L)	< 4	50.00	Below standard	N/A	230	50.00	4.6	168.0
Nickel (µg/L)	< 20	92.13	Below standard	N/A	< 20	172.12	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	1.0	None	N/A	27.8	4.5	None	N/A	3,287.0
Silver (µg/L)	< 0.2	0.07	Not detected	N/A	< 0.2	0.28	Below standard	N/A
Sodium (mg/L)	0.31	None	N/A	8.6	1.40	None	N/A	1,022.6
Sulfate (mg/L)	27	250.00	Below standard	750.6	110	250.00	Below standard	80,347.7
Zinc (µg/L)	30	101.74	Below standard	0.8	120	204.22	Below standard	87.7

Table 1. Analytical data for samples NW1-13, 60-66, 79 from the Silverton caldera area--continued.

Sample	NW63, BROOKLYN GULCH (9/15/99)				NW64, LAKES ABOVE CEMENT CREEK (9/17/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	3.0				12.5			
pH (standard units)	6.68				6.34			
Conductivity (µS/cm)	222.0				38.0			
Alkalinity (mg/L CaCO3)	< 20.00				< 20.00			
Hardness (mg/L CaCO3)	202	None	N/A		37	None	N/A	
Aluminum (trec) (µg/L)	280	None	N/A	4.6	< 50	None	N/A	N/A
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	< 10	1000.00	Below standard	N/A	85	1000.00	Below standard	5.8
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	220	2000.00	Below standard	3.6	< 10	2000.00	Below standard	N/A
Aluminum (µg/L)	240	87.00	2.8	3.9	< 50	87.00	Below standard	N/A
Cadmium (µg/L)	1.4	1.97	Below standard	0.0	< 0.3	0.52	Below standard	N/A
Calcium (mg/L)	76	None	N/A	1,242.8	14	None	N/A	953.9
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	7.0	21.55	Below standard	0.1	< 4.0	5.02	Below standard	N/A
Fluoride (mg/L)	0.20	2.00	Below standard	3.3	< 0.10	2.00	Below standard	N/A
Iron (µg/L)	< 10	300.00	Below standard	N/A	37	300.00	Below standard	2.5
Lead (µg/L)	4.0	10.53	Below standard	0.1	< 1.0	0.94	Not detected	N/A
Magnesium (mg/L)	2.90	None	N/A	47.4	0.42	None	N/A	28.6
Manganese (µg/L)	20	50.00	Below standard	0.3	< 4	50.00	Below standard	N/A
Nickel (µg/L)	< 20	163.02	Below standard	N/A	< 20	44.64	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	4.1	None	N/A	67.0	1.1	None	N/A	75.0
Silver (µg/L)	< 0.2	0.25	Below standard	N/A	< 0.2	0.01	Not detected	N/A
Sodium (mg/L)	0.34	None	N/A	5.6	0.29	None	N/A	19.8
Sulfate (mg/L)	97	250.00	Below standard	1,586.2	10	250.00	Below standard	681.4
Zinc (µg/L)	190	192.22	Below standard	3.1	< 10	45.36	Below standard	N/A

Table 1. Analytical data for samples NW1-13, 60-66, 79 from the Silverton caldera area--continued.

Sample	NW65, ABOVE GREYHOUND (9/25/99)				NW66, UPPER GRAY COPPER (9/25/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	11.0				4.0			
pH (standard units)	7.69				2.66			
Conductivity (µS/cm)	306.0				1,265.0			
Alkalinity (mg/L CaCO3)	70.00							
Hardness (mg/L CaCO3)	278	None	N/A		< 28	None	N/A	
Aluminum (trec) (µg/L)	< 50	None	N/A	N/A	4,900	None	N/A	106.8
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	< 10	1000.00	Below standard	N/A	25,000	1000.00	25.0	545.1
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	13	2000.00	Below standard	0.8	39	2000.00	Below standard	0.9
Aluminum (µg/L)	< 50	87.00	Below standard	N/A	4,900	87.00	56.3	106.8
Cadmium (µg/L)	< 0.3	2.53	Below standard	N/A	< 0.3	<0.42	Not detected	N/A
Calcium (mg/L)	99	None	N/A	5,936.1	< 10	None	N/A	N/A
Chloride (mg/L)	120.0	250.00	Below standard	7,195.3	310.0	250.00	1.2	6,759.2
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	< 4.0	28.35	Below standard	N/A	160.0	<4	>40	3.5
Fluoride (mg/L)	< 0.10	2.00	Below standard	N/A	0.17	2.00	Below standard	3.7
Iron (µg/L)	< 10	300.00	Below standard	N/A	25,000	300.00	83.3	545.1
Lead (µg/L)	< 1.0	16.59	Below standard	N/A	22.0	<0.6	>34	0.5
Magnesium (mg/L)	7.50	None	N/A	449.7	0.71	None	N/A	15.5
Manganese (µg/L)	< 4	50.00	Below standard	N/A	47	50.00	Below standard	1.0
Nickel (µg/L)	1,700	208.03	8.2	101.9	< 20	<36	Not detected	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	1.7	None	N/A	101.9	4.7	None	N/A	102.5
Silver (µg/L)	< 0.2	0.44	Below standard	N/A	< 0.2	<0.01	Not detected	N/A
Sodium (mg/L)	2.00	None	N/A	119.9	0.28	None	N/A	6.1
Sulfate (mg/L)	74	250.00	Below standard	4,437.1	140	250.00	Below standard	3,052.6
Zinc (µg/L)	13	252.26	Below standard	0.8	37	<36	>1.0	0.8

Table 1. Analytical data for samples NW1-13, 60-66, 79 from the Silverton caldera area--continued.

Sample	NW79, HOWARD FORK LAKE (9/21/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	420.0			
pH (standard units)	4.70			
Conductivity (µS/cm)	343.0			
Alkalinity (mg/L CaCO3)				
Hardness (mg/L CaCO3)	275	None	N/A	
Aluminum (trec) (µg/L)	1,600	None	N/A	3,663.1
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	< 10	1000.00	Below standard	N/A
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	67	2000.00	Below standard	153.4
Aluminum (µg/L)	1,500	87.00	17.2	3,434.1
Cadmium (µg/L)	0.3	2.51	Below standard	0.7
Calcium (mg/L)	100	None	N/A	228,942.0
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A
Copper (µg/L)	< 4.0	28.10	Below standard	N/A
Fluoride (mg/L)	0.20	2.00	Below standard	457.9
Iron (µg/L)	< 10	300.00	Below standard	N/A
Lead (µg/L)	< 1.0	16.35	Below standard	N/A
Magnesium (mg/L)	6.20	None	N/A	14,194.4
Manganese (µg/L)	260	50.00	5.2	595.2
Nickel (µg/L)	< 20	206.42	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A
Silicon (mg/L)	7.5	None	N/A	17,170.7
Silver (µg/L)	< 0.2	0.43	Below standard	N/A
Sodium (mg/L)	2.30	None	N/A	5,265.7
Sulfate (mg/L)	110	250.00	Below standard	251,836.2
Zinc (µg/L)	67	250.08	Below standard	153.4

Samples had low hardness (6 to 18 mg/L) except for sample NW8, which was 70 mg/L. Low hardness “lowers the bar” for metals with hardness-related stream standards. For several metals, the low hardness created situations where the detection limit of the analytical method was higher than the state standard, and comparison between the samples and stream standards was not possible. However, if the metals were not detected, they are not contributing appreciably to metal loading into Corkscrew Gulch. Sample NW8 had the highest metal content. Samples NW3, 6, and 7 were moderately degraded; and samples NW2, 4, and 5 were slightly degraded.

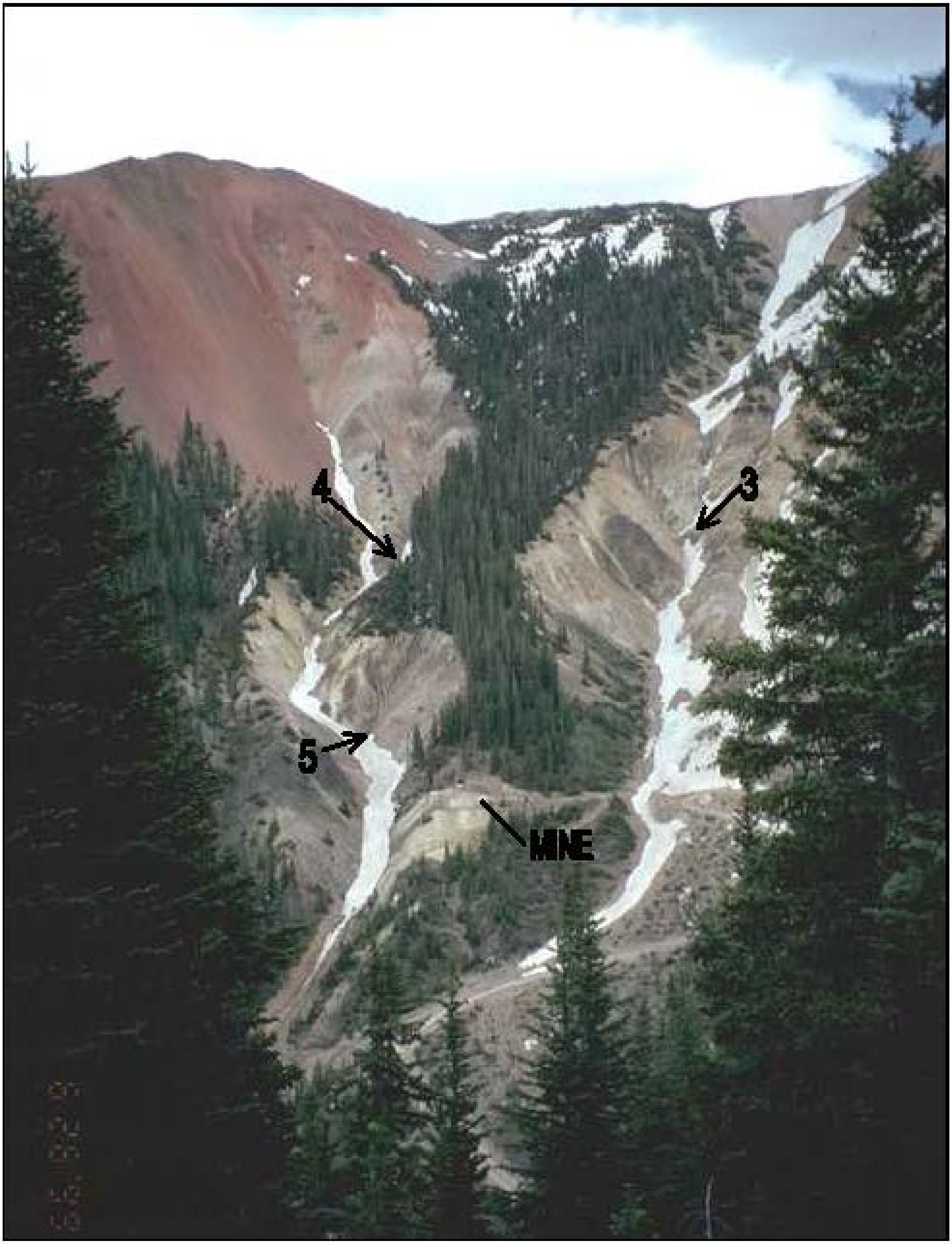

Figure 3. Photograph showing sample sites NW3-5 on the west side of Red Mountain #1.

Figure 4. Photograph showing sample site NW3 on the altered western slope of Red Mountain #1.

Only aluminum exceeded standards in all of the samples from the west and northwest side of Red Mountain #1. The variance in aluminum concentration was great, ranging from 160 to 16,000 µg/L. Copper exceeded its hardness-related standard in 5 of the 8 samples, but in general copper concentrations were low to moderate (<4 to 14 µg/L, except for 38 µg/L in sample NW8). Iron and manganese exceeded standards in four samples, ranging from 42 to 4,700 µg/L in iron and 5 to 320 µg/L in manganese. Zinc concentrations were generally low, but exceeded standards in three samples and ranged in value from <10 to 95 µg/L. Lead was only detected in one sample, but exceeded standards in sample NW5 with a value of 3 µg/L (Table 1).

On the east side of Red Mountain #1, in the upper reaches of Gray Copper Creek and above all known draining mines or mines of moderate size or larger, sample NW66 (Figure 2) was collected from a stream lined with well-indurated ferricrete. The mountainsides to the northwest are highly fractured and stained red, brown, and yellow (Figure 6). Upstream of the sample site, brown staining is prevalent. Disseminated pyrite commonly occurs in the fine-grained gravels in the streambed. The creek was flowing at 4 gpm and had 2.66 pH and 1,265 µS/cm conductivity. This water was extremely degraded, especially with respect to aluminum, iron, copper, lead, and chloride. Zinc concentration approached state standards (Table 1). The detection limit for calcium was elevated in this sample, and calcium was not detected. Because calcium was not detected, the hardness and the hardness-related water-quality standards, could not be calculated.

Figure 5. Photograph showing spring on the northwestern slope of Red Mountain #1 at sample site NW7.

Further to the south, and east of Red Mountain #1, sample NW64 was collected from the discharge of a tarn on the Cement Creek side of the drainage divide (Figure 2). Rocks in the stream channel had minor red-brown stain, flow was 12.5 gpm, pH was 6.34, and conductivity was 38 µS/cm (Table 1). The water was clean, possibly because of lack of groundwater contribution from the severely altered slopes of Red Mountain #1.

Figure 6. Photograph of the east side of Red Mountain #1. Sample NW66 was collected upstream of any influence from the mine shown at left.

Samples NW9 to NW13 were collected from streams flowing from Red Mountain #2 (Figures 2, 7). All samples were collected from above the known large and/or draining mines. Lab results indicate that most of the non-mining-related runoff from Red Mountain #2 is moderately to highly degraded. The sampled streams had flows ranging from 50 to 280 gpm, pH was 2.16 to 3.92, and conductivity ranged from 18 to 1,640 µS/cm (Table 1).

The stream of sample NW12, which flows on the northern edge of a large landslide with intense acid-sulfate alteration exposed on the fresh headwall (Figure 8), was milky and carried a large volume of suspended solids (Figure 9). Sample results suggest the solids were mostly iron and aluminum hydroxides. Orange-red and gray precipitates along the stream channel were plentiful.

Sample NW13 from a stream on the south side of the slide was the most degraded sample collected near Red Mountain #2, but the water was relatively clear and no precipitate was apparent. At the sample site, the high acidity apparently kept most metals in a dissolved state, however, ponds within 100 feet downstream of the site had abundant light-green precipitate coating their bottoms and attached to algae. The color of the precipitate may be related to the high copper content of the water (150 µg/L).

Sample sites NW10 and NW11 had moderate amounts of red-brown precipitate in the stream channels, but the water was clear. Sample NW9 was slightly murky, but had no associated precipitate.

Aluminum concentration was above standards in all of the samples, varying from 180 µg/L in the cleanest sample (NW9), to 27,000 µg/L in the most acidic and metal-rich sample (NW13). Copper and manganese exceeded standards in all of the samples except NW9, varying from <4 to 150 µg/L in copper and 43 to 3,600 µg/L in manganese. Iron, ranging from 72 to 90,000 µg/L, and zinc, ranging from <10 to 270 µg/L was above standards in two samples. Only sample NW10 contained lead above detection level. Because of the low hardness of that sample, lead concentration of only 2 µg/L exceeded standards. Thallium and sulfate concentrations were above standards in sample NW13.

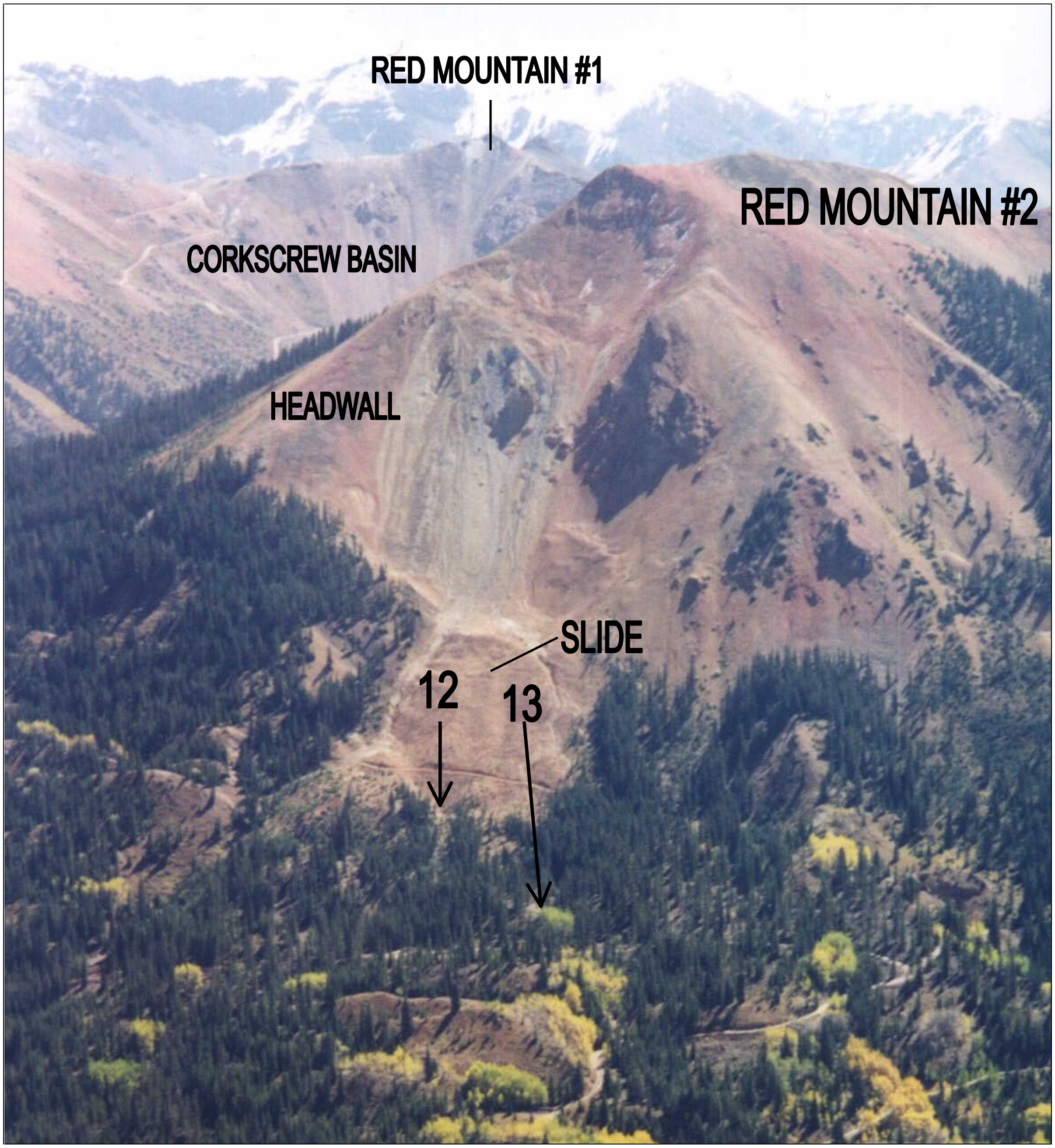

Figure 7. Photograph showing sample sites NW12-13 on the western slope of Red Mountain #2.

Figure 8. Photograph showing the headwall of the slide above sample sites NW12-13.


Figure 9. Photograph showing the milky water of NW12.

Samples from the west side of U.S. Highway 550 (Figure 2, samples NW60-62, 65) had widely varying compositions. The two seriously degraded and acidic samples were from the middle segments of deeply eroded gulches with altered wall rocks (NW60, 62). Both of these samples were murky and had high aluminum values with considerable differences between total and dissolved aluminum, suggesting high concentrations of aluminum hydroxides occurring as suspended solids (Table 1).

Intensely altered brown-yellow and light-yellow rocks with seams of white clay in fractures are exposed in upper Governor Gulch, above sample site NW60 (Figure 10). In addition to aluminum, sample NW60 contained high manganese (4,000 µS/cm), sulfate (440 mg/L), and zinc (590 µg/L), though zinc was below standards because of the high hardness of the sample (1,066 mg/L).

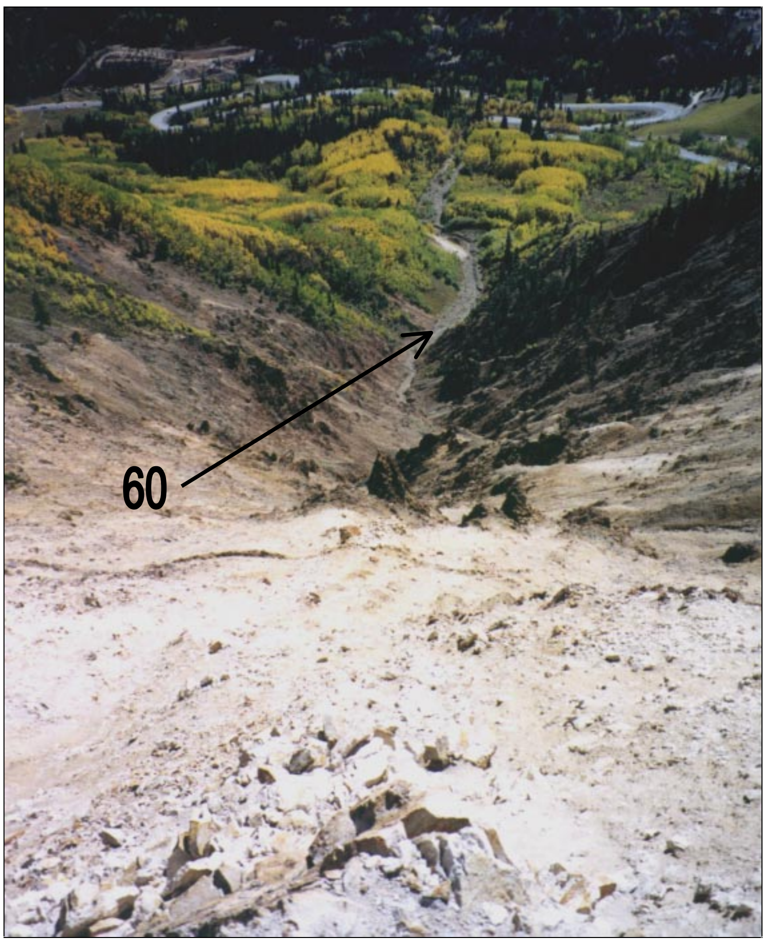

Figure 10. Photograph showing sample site NW60 and the headwaters of Governor Gulch.

Red precipitate occurred at sample site NW62 from Monument Gulch. Stream water contained high iron, with considerable differences between total and dissolved concentrations, and high copper content (120 µg/L).

Cleaner samples (NW61, 65) from west of U.S. 550 were collected at higher elevations, from areas surrounded by grassy slopes with less intensely altered bedrock. Sample NW61, from an unnamed stream west of Red Mountain Pass, was below standards in all of the analyzed parameters.

Sample NW65, from McIntyre Gulch just upstream of the Greyhound Mine, was notable because it contained abundant nickel (1,700 µg/L), well above standards. This high nickel concentration seems out of context with other samples from this area and may represent a lab error. Chloride was also high (120 mg/L), though within the standard of 250 mg/L. Rocks in the stream channel showed propylitic alteration and contained moderate amounts of calcite, chlorite, and epidote, and minor disseminated pyrite. Moderate amounts of white precipitate coated the gravel and algae in the stream.

The stream in the upper reaches of Brooklyn Gulch (Figure 2, sample NW63), above all significant mining activity, was flowing at 3 gpm, had 6.68 pH, and 222 µS/cm conductivity. The water was clear and no precipitate occurred. Nearby alluvium/colluvium included some hydrothermally altered rocks, but most of the upstream portion of this drainage basin was grass-covered and showed no obvious or intensely altered bedrock. Despite the pristine appearance, aluminum concentration (240 µg/L) exceeded standards. Zinc, copper, lead, and cadmium concentrations were elevated but within standards (Table 1).

In 1999, the southernmost sample associated with alteration related to the Silverton caldera was collected near the headwaters of Howard Fork of the San Miguel River, west of Ophir Pass (Figure 11). Sample NW79 was from a lake with a bluish tinge (Figure 12). No surface water was observed filling the lake, but it was discharging at about 420 gpm, indicating a large inflow of groundwater from the red-stained altered slopes surrounding Ophir Pass. Conductivity was 343 µS/cm and pH was 4.70 (Table 1). Aluminum and manganese exceeded state standards, however small brook trout were swimming in the lake. A small ferrosinter deposit seeping minor amounts of water is exposed north of the lake (Figure 11). This ferrosinter deposit is probably related to water originating from the red-stained, altered southwestern slopes of Lookout Mountain.

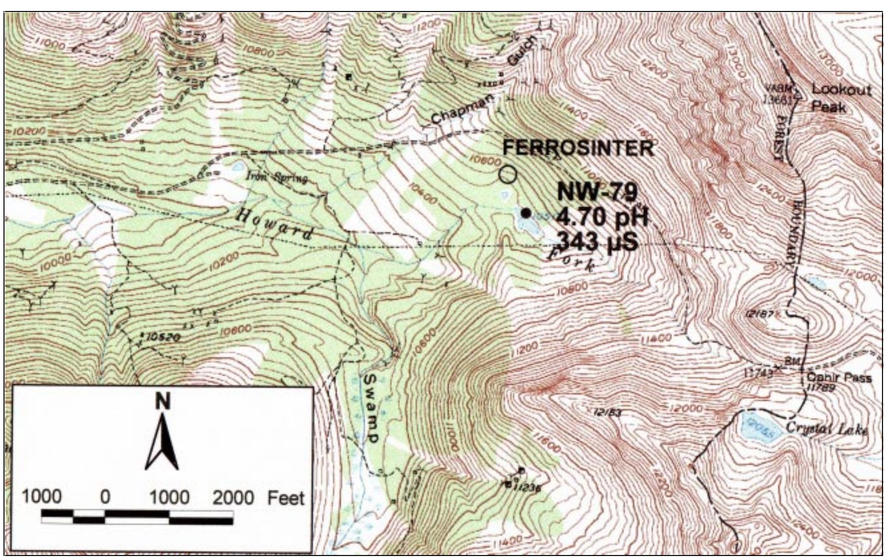

Figure 11. Map showing sample site NW79 and a nearby ferrosinter deposit in the headwaters of Howard Fork of the San Miguel River.

Figure 12. Photograph showing a lake with blue-green water at sample site NW79.

Lake City Area

Lake City is in the northwest part of the San Juan Mountains. Three possible sources of naturally degraded water were investigated on a reconnaissance level by CGS personnel in 1999. Previously, Miller (1998) conducted a detailed study of naturally degraded water in selected streams in the Redcloud Peak area. Most of the altered rocks associated with the degraded waters are spatially related to intrusions within and along the margins of the Uncompahgre/Lake City nested calderas.

The Lake City caldera is nested within the southern part of the Uncompahgre caldera, but formed about 5 million years later. Extrusion of the Sunshine Peak Tuff caused the initial collapse of the Lake City caldera. Emplacement of a shallow granite porphyry pluton caused resurgent doming within the caldera. (See Steven and Lipman, 1976, p. 7, 14-15.)

Several ages of mineralization are known in the Lake City area. Small, subeconomic base- and precious-metal deposits occur in the cores of the intermediate-composition volcanoes that predated the caldera-forming eruptions of the present San Juan volcanic field. Larger vein and disseminated occurrences were deposited in the northern part of the Uncompahgre caldera prior to development of the Lake City caldera. Younger, but undated, vein and disseminated occurrences formed in and adjacent to the Lake City caldera. Mineralized veins hosted in faults of the Eureka graben on the west side of the Lake City caldera probably postdate caldera formation and may be as young as 15 million years old. (See Steven and Lipman, 1976, p. 33.)

Much of the Uncompahgre/Lake City caldera complex and surrounding area show the effects of hydrothermal alteration. Within the Lake City caldera, the most intensely altered rocks are near the margins of the shallow granite porphyry intrusion that caused resurgent doming (Steven and Lipman, 1976, p. 15).

Redcloud Peak

Redcloud Peak is about eight miles southwest of Lake City and is within but near the margin of the Lake City caldera. It lies on the north side of Lake Fork of the Gunnison River.

Geology

In the Redcloud Peak area of the Lake City caldera, about 100 quartz veins have been identified. Of those 100 veins, 30 are more than 2,000 feet long. Quartz and disseminated pyrite are the primary vein constituents. Minor amounts of galena, chalcopyrite, sphalerite, tetrahedrite, and rhodochrosite occur sporadically. Although only a small amount of mining has been attempted near Redcloud Peak, this area is rated as having high mineral-resource potential for precious and base metals in veins and breccia pipes, and moderate potential for molybdenum and copper in porphyry-type deposits. (See Miller, 1998, p. 4-5.)

Previous Investigation

No significant acidic mine drainage is documented in the Redcloud Peak area of the Lake City caldera, however natural acid-rock drainage does occur. In July 1994, Miller (1998) conducted a water-sampling program near Redcloud Peak. The project included surface-water samples from 32 sites and one spring sample, and was designed to determine geochemical baselines in an intensely mineralized, but essentially unmined area.

White hydrous aluminum oxides coat the rocks in the streams at most of the sample sites with high aluminum concentrations. Iron precipitates occur at some localities, but are far less common than aluminum. Sample results showed that 5 of 33 samples had pHs of less than 5. Sulfate concentration generally ranged from 20 to 50 mg/L and was greater than 100 mg/L in two samples, including the spring sample. Aluminum concentration was greater than 1,000 µg/L in six samples; manganese was greater than 50 µg/L in nine samples; zinc was more than 50 µg/L in nine samples; and molybdenum was at least 2 µg/L in eight samples. Iron concentration was as high as 450 µg/L, but usually ranged from 10 to 40 µg/L. Many of the most degraded samples were collected from streams draining the northwest side of Redcloud Peak and from the spring in lower Alpine Gulch. (See Miller, 1998, p. 12, Table 1, Figure 3.)

Miller (1998, p. 12) suggests that low pH and high sulfate water results from near-surface oxidation of sulfides, and that neutral pH and high sulfate water results from subsurface oxidation. Acid produced by subsurface oxidation may be buffered by calcite formed during the widespread propylitic alteration of this area.

Present Investigation

In 1999, sample NW87 was collected from a south-flowing tributary of Lake Fork in Burrows Park (Figure 13), slightly west of the Miller (1998) study area. The slopes above the sample site had brown, red and yellow iron staining. Smaller areas showed bleaching indicative of argillic alteration. Flow was 5 gpm, pH was 5.98, and conductivity was 346 µS/cm. All of the tested parameters fell within state standards, and most metals were not detected. Zinc was slightly elevated (Table 2).

Water tested further upstream in the Lake Fork drainage basin showed neutral pHs and moderate conductivities, and did not indicate severe degradation. No additional samples were collected.

No large volumes of significantly degraded water were identified in the headwaters of Lake Fork upstream of the Miller (1998) study area.

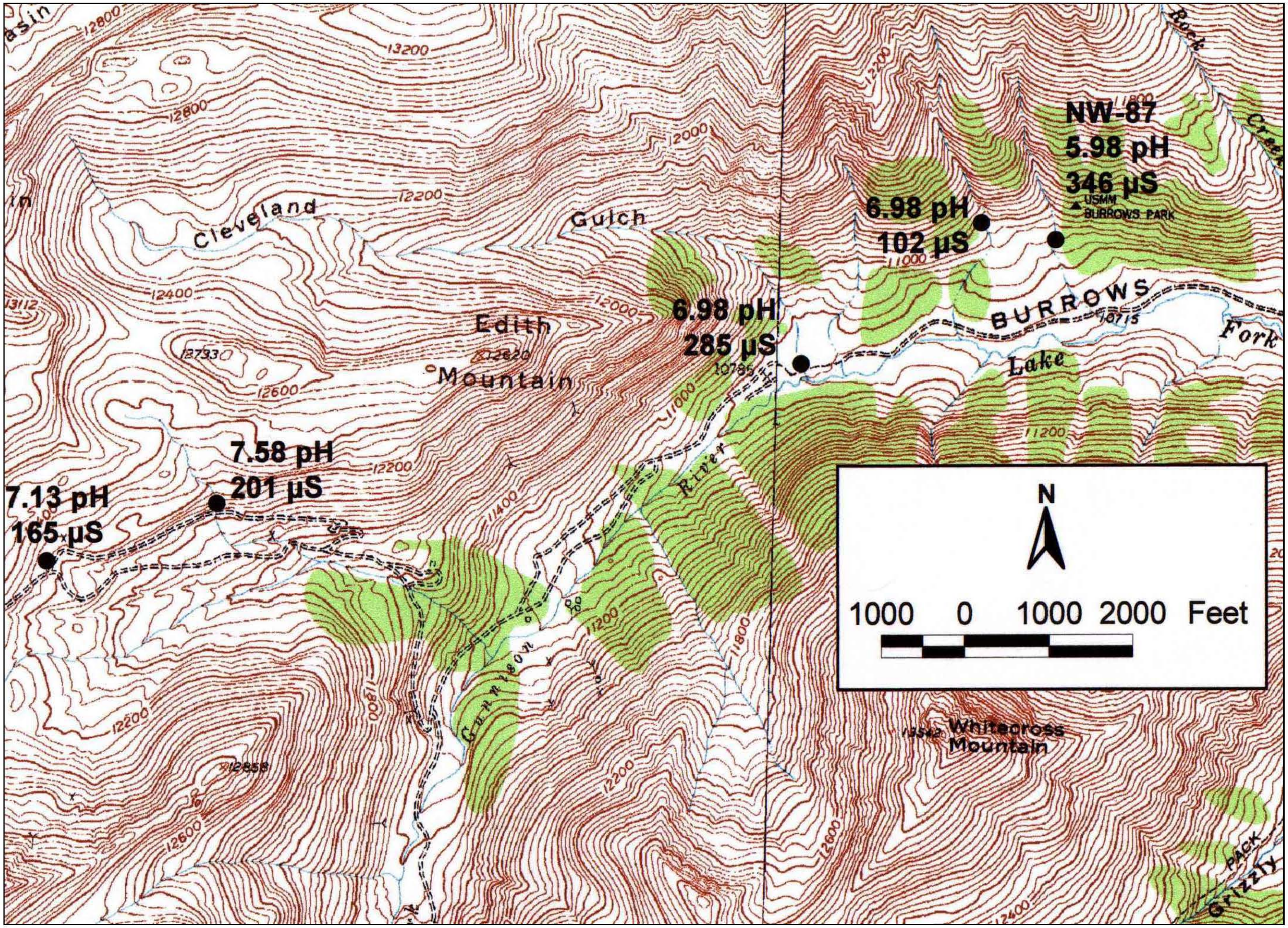

Figure 13. Map showing sample site NW87 and nearby water test results in the upper Lake Fork of the Gunnison River drainage basin.

Table 2. Analytical data for samples NW84-91 from the Lake City area.

Sample	NW84, LOST TRAIL CREEK EAST (10/5/99)				NW85, LOST TRAIL CREEK-UPPER (10/5/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	35.0				1.0			
pH (standard units)	7.19				5.89			
Conductivity (µS/cm)	289.0				122.0			
Alkalinity (mg/L CaCO3)	27.00				20.00			
Hardness (mg/L CaCO3)	219	None	N/A		87	None	N/A	
Aluminum (trec) (µg/L)	1,100	None	N/A	209.9	< 50	None	N/A	N/A
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	260	1000.00	Below standard	49.6	< 10	1000.00	Below standard	N/A
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	12	2000.00	Below standard	2.3	12	2000.00	Below standard	0.1
Aluminum (µg/L)	52	87.00	Below standard	9.9	< 50	87.00	Below standard	N/A
Cadmium (µg/L)	< 0.3	2.10	Below standard	N/A	< 0.3	1.02	Below standard	N/A
Calcium (mg/L)	71	None	N/A	13,545.7	30	None	N/A	163.5
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	< 4.0	23.06	Below standard	N/A	< 4.0	10.49	Below standard	N/A
Fluoride (mg/L)	0.23	2.00	Below standard	43.9	0.11	2.00	Below standard	0.6
Iron (µg/L)	< 10	300.00	Below standard	N/A	< 10	300.00	Below standard	N/A
Lead (µg/L)	< 1.0	11.78	Below standard	N/A	< 1.0	3.19	Below standard	N/A
Magnesium (mg/L)	10.00	None	N/A	1,907.9	2.90	None	N/A	15.8
Manganese (µg/L)	120	50.00	2.4	22.9	< 4	50.00	Below standard	N/A
Nickel (µg/L)	< 20	173.12	Below standard	N/A	< 20	85.90	Below standard	N/A
Potassium (mg/L)	1.2	None	N/A	228.9	2.0	None	N/A	10.9
Silicon (mg/L)	13.0	None	N/A	2,480.2	14.0	None	N/A	76.3
Silver (µg/L)	< 0.2	0.29	Below standard	N/A	< 0.2	0.06	Not detected	N/A
Sodium (mg/L)	6.60	None	N/A	1,259.2	3.40	None	N/A	18.5
Sulfate (mg/L)	62	250.00	Below standard	11,828.7	26	250.00	Below standard	141.7
Zinc (µg/L)	< 10	205.54	Below standard	N/A	12	94.09	Below standard	0.1

Table 2. Analytical data for samples NW84-91 from the Lake City area--continued.

Sample	NW86, WAGER GULCH (10/5/99)				NW87, BURROWS PARK (10/6/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	15.0				5.0			
pH (standard units)	3.45				5.98			
Conductivity (µS/cm)	554.0				346.0			
Alkalinity (mg/L CaCO3)					< 10.00			
Hardness (mg/L CaCO3)	380	None	N/A		284	None	N/A	
Aluminum (trec) (µg/L)	1,500	None	N/A	122.6	< 50	None	N/A	N/A
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	2,900	1000.00	2.9	237.1	21	1000.00	Below standard	0.6
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	160	2000.00	Below standard	13.1	78	2000.00	Below standard	2.1
Aluminum (µg/L)	1,500	87.00	17.2	122.6	< 50	87.00	Below standard	N/A
Cadmium (µg/L)	0.4	3.24	Below standard	0.0	< 0.3	2.57	Below standard	N/A
Calcium (mg/L)	140	None	N/A	11,447.1	100	None	N/A	2,725.5
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	8.0	37.03	Below standard	0.7	< 4.0	28.85	Below standard	N/A
Fluoride (mg/L)	0.49	2.00	Below standard	40.1	0.24	2.00	Below standard	6.5
Iron (µg/L)	2,800	300.00	9.3	228.9	< 10	300.00	Below standard	N/A
Lead (µg/L)	< 1.0	25.83	Below standard	N/A	< 1.0	17.08	Below standard	N/A
Magnesium (mg/L)	7.40	None	N/A	605.1	8.30	None	N/A	226.2
Manganese (µg/L)	1,100	50.00	22.0	89.9	< 4	50.00	Below standard	N/A
Nickel (µg/L)	< 20	263.80	Below standard	N/A	< 20	211.30	Below standard	N/A
Potassium (mg/L)	2.1	None	N/A	171.7	2.0	None	N/A	54.5
Silicon (mg/L)	24.0	None	N/A	1,962.4	6.8	None	N/A	185.3
Silver (µg/L)	< 0.2	0.75	Below standard	N/A	< 0.2	0.45	Below standard	N/A
Sodium (mg/L)	8.00	None	N/A	654.1	0.92	None	N/A	25.1
Sulfate (mg/L)	120	250.00	Below standard	9,811.8	46	250.00	Below standard	1,253.7
Zinc (µg/L)	160	328.74	Below standard	13.1	77	256.69	Below standard	2.1

Table 2. Analytical data for samples NW84-91 from the Lake City area--continued.

Sample	NW88, SLUMGULLION-WINDY POINT (10/6/99)				NW89, SLUMGULLION MILKY (10/6/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	4.0				340.0			
pH (standard units)	3.26				3.45			
Conductivity (µS/cm)	743.0				2,280.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	213	None	N/A		1,947	None	N/A	
Aluminum (trec) (µg/L)	25,000	None	N/A	545.1	84,000	None	N/A	155,680.6
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	4.0	50.00	Below standard	7.4
Iron (trec) (µg/L)	5,200	1000.00	5.2	113.4	55,000	1000.00	55.0	101,933.7
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	160	2000.00	Below standard	3.5	700	2000.00	Below standard	1,297.3
Aluminum (µg/L)	25,000	87.00	287.4	545.1	67,000	87.00	770.1	124,173.8
Cadmium (µg/L)	0.3	2.06	Below standard	0.0	1.8	11.67	Below standard	3.3
Calcium (mg/L)	77	None	N/A	1,678.9	700	None	N/A	1,297,338.0
Chloride (mg/L)	1,400.0	250.00	5.6	30,525.6	130.0	250.00	Below standard	240,934.2
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	33.0	22.60	1.5	0.7	100.0	149.45	Below standard	185.3
Fluoride (mg/L)	0.57	2.00	Below standard	12.4	2.10	2.00	1.1	3,892.0
Iron (µg/L)	5,300	300.00	17.7	115.6	15,000	300.00	50.0	27,800.1
Lead (µg/L)	< 1.0	11.39	Below standard	N/A	< 1.0	261.20	Below standard	N/A
Magnesium (mg/L)	5.10	None	N/A	111.2	48.00	None	N/A	88,960.3
Manganese (µg/L)	1,100	50.00	22.0	24.0	10,000	50.00	200.0	18,533.4
Nickel (µg/L)	< 20	170.04	Below standard	N/A	130	912.51	Below standard	240.9
Potassium (mg/L)	1.9	None	N/A	41.4	4.4	None	N/A	8,154.7
Silicon (mg/L)	29.0	None	N/A	632.3	42.0	None	N/A	77,840.3
Silver (µg/L)	< 0.2	0.28	Below standard	N/A	< 0.2	12.39	Below standard	N/A
Sodium (mg/L)	6.90	None	N/A	150.4	24.00	None	N/A	44,480.2
Sulfate (mg/L)	160	250.00	Below standard	3,488.6	1,300	250.00	5.2	2,409,342.0
Zinc (µg/L)	160	201.47	Below standard	3.5	480	1311.34	Below standard	889.6

Table 2. Analytical data for samples NW84-91 from the Lake City area--continued.

Sample	NW90, SLUMGULLION CREEK (10/6/99)				NW91, SLUMGULLION WEST (10/7/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	450.0				72.0			
pH (standard units)	4.21				3.79			
Conductivity (µS/cm)	236.0				805.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	118	None	N/A		562	None	N/A	
Aluminum (trec) (µg/L)	1,100	None	N/A	2,698.2	6,000	None	N/A	2,354.8
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	1,600	1000.00	1.6	3,924.7	1,200	1000.00	1.2	471.0
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	35	2000.00	Below standard	85.9	83	2000.00	Below standard	32.6
Aluminum (µg/L)	950	87.00	10.9	2,330.3	6,000	87.00	69.0	2,354.8
Cadmium (µg/L)	< 0.3	1.29	Below standard	N/A	< 0.3	4.40	Below standard	N/A
Calcium (mg/L)	43	None	N/A	105,476.9	200	None	N/A	78,494.4
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	< 4.0	13.64	Below standard	N/A	< 4.0	51.65	Below standard	N/A
Fluoride (mg/L)	0.26	2.00	Below standard	637.8	0.75	2.00	Below standard	294.4
Iron (µg/L)	540	300.00	1.8	1,324.6	1,200	300.00	4.0	471.0
Lead (µg/L)	< 1.0	4.93	Below standard	N/A	< 1.0	44.86	Below standard	N/A
Magnesium (mg/L)	2.60	None	N/A	6,377.7	15.00	None	N/A	5,887.1
Manganese (µg/L)	340	50.00	6.8	834.0	3,000	50.00	60.0	1,177.4
Nickel (µg/L)	< 20	108.50	Below standard	N/A	24	354.70	Below standard	9.4
Potassium (mg/L)	2.5	None	N/A	6,132.4	5.5	None	N/A	2,158.6
Silicon (mg/L)	21.0	None	N/A	51,512.0	25.0	None	N/A	9,811.8
Silver (µg/L)	< 0.2	0.10	Not detected	N/A	< 0.2	1.46	Below standard	N/A
Sodium (mg/L)	7.30	None	N/A	17,906.5	17.00	None	N/A	6,672.0
Sulfate (mg/L)	64	250.00	Below standard	156,988.8	160	250.00	Below standard	62,795.5
Zinc (µg/L)	33	122.09	Below standard	80.9	85	457.29	Below standard	33.4

Slumgullion Slide

The Slumgullion Slide is a large earthflow on the east side of Lake Fork of the Gunnison River. The headwall of the slide is about 5 miles east of Lake City, and State Highway 149 traverses and parallels the lower part of the slide.

The older and larger part of the slide formed about 700 years ago, damming Lake Fork of the Gunnison and creating Lake San Cristobal. The older slide is about 4 miles long and ¼ mile wide. At the toe of the slide in the valley of Lake Fork, material spread upstream about ¼ mile and downstream about ½ mile from the main body of the slide. (See Savage and others, 1992, p. 19.)

A younger and still-active portion of the slide lies within and above parts of the older slide. The active part of the slide is about 300 years old. It is about 2 miles long and 1/8 to 1/4 mile wide and is moving at a rate of about 7 to 20 feet per year. (See Savage and others, 1992, p. 19.)

Geology

Intensely clay-altered Tertiary-age volcanic rocks are exposed in the headwall of the slide (Figure 14). These intermediate-composition extrusive rocks are related to pre-caldera andesitic volcanoes. A small intrusion, probably of pre-caldera age, crops out within a mile south of the headwall. (See Lipman, 1976.) The headwall of the slide roughly corresponds to the eastern margin of the Uncompahgre caldera, and is about 5 miles east of the Lake City caldera margin. Intense alteration in the area of the slide may be related to the exposed pre-caldera intrusion, or perhaps to buried intrusions associated with margin faults of the Uncompahgre/Lake City caldera complex.

Much of the body of the slide comprises soft, wet, unstable clay cut by numerous gullies. Most of the clay is gray or light yellow, but streaks of red, iron-stained material are common.

Present Investigation

Sample NW88 was collected from a stream draining severely altered rocks south of the slide (Figures 14, 15). Samples NW89 to NW91 were collected from streams within or bordering the Slumgullion Slide. All of these samples were acidic, had moderate to high conductivity, and moderate to high hardness. Aluminum, iron, and manganese concentrations exceeded state standards in all of the samples (Table 2).

Figure 14. Photograph showing headwall and upper reaches of Slumgullion Slide. Sample NW88 was collected from the stream to the right and near the bottom of the barren, eroded gulch in foreground. The eroded gulch is not part of the slide, but shows the intensely clay-altered bedrock prevalent in this area.

At sample site NW88, partly eroded ferricrete formed the banks of the stream in some areas. Alluvium was mostly argillized porphyry with yellow and red stain. Fragments of ferricrete, brick-red, fine-grained volcanic(?) rock, and yellow- and brown-stained silicified rocks also occurred as alluvium. Flow was about 4 gpm, pH was 3.26, and conductivity was 743 µS/cm. Aluminum greatly exceeded standards; iron and manganese exceeded by more than an order of magnitude; and copper and chloride concentrations were also above standards. The chloride concentration was exceptionally high compared to most samples collected for this study.

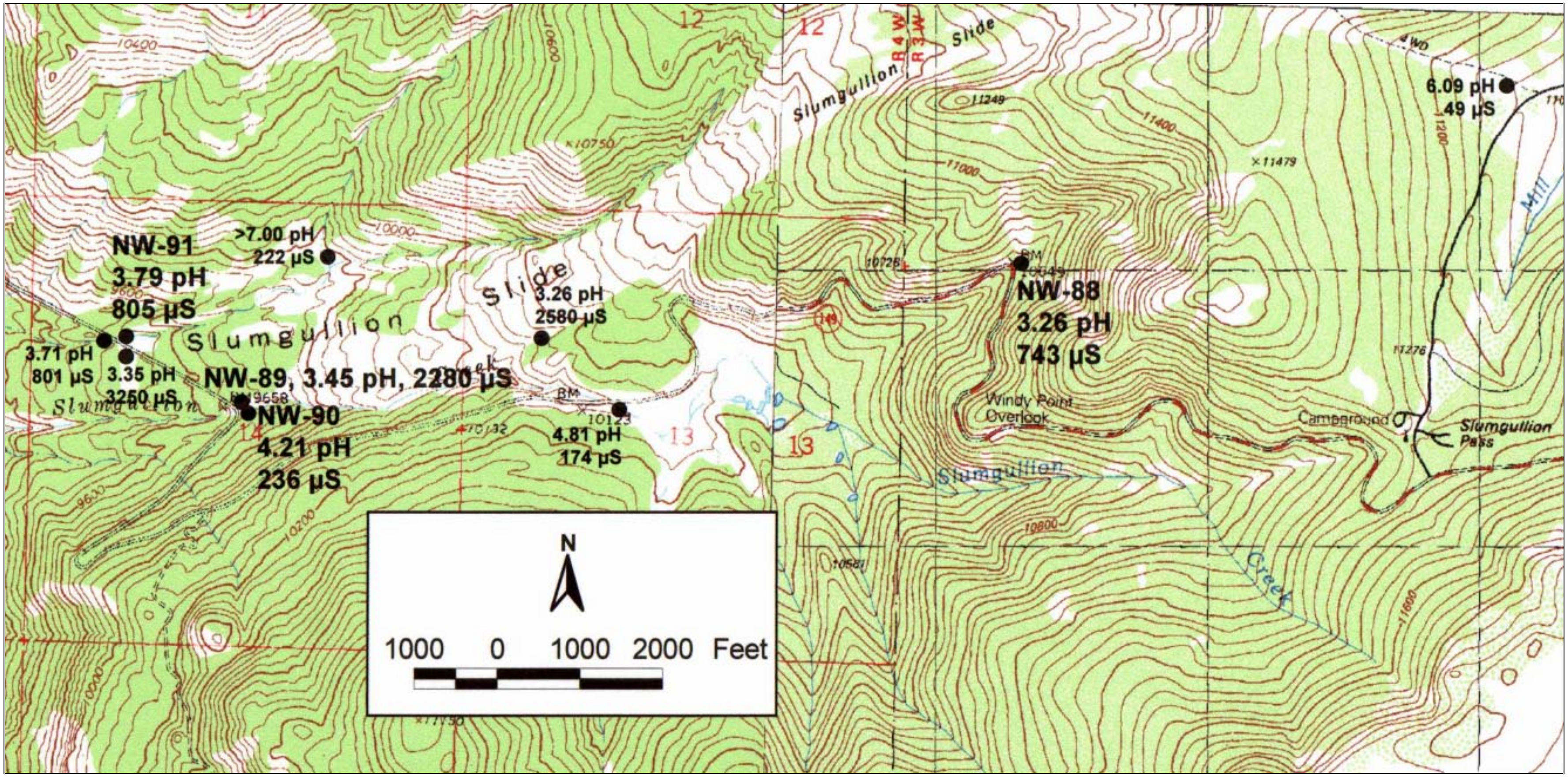

Figure 15. Map showing sample sites NW88-91 and water test results from the Slumgullion Slide area.

Sample NW89 was from a milky and murky tributary of Slumgullion Creek, just upstream of its confluence with Slumgullion Creek and State Highway 149. This stream drains much of the body of the active portion of the earthflow. Mud in this area stained the vehicle tires blue, presumably because of the acidity. Flow was 340 gpm, pH was 3.45, and conductivity was 2,280 µS/cm. This water was extremely degraded. Aluminum and manganese exceeded standards by more than two orders of magnitude; iron exceeded by a factor of about 50, and sulfate and fluoride were above standards. Silica, chloride, sodium, zinc, nickel, and copper concentrations were elevated, and the water had extremely high hardness (Table 2). Large differences between the total and dissolved concentrations of aluminum and iron suggest that the suspended solids in the stream are largely composed of aluminum and iron hydroxides. Sulfate precipitates such as gypsum may form some of the solids, too. Because of the fairly high flow rate and high metal concentrations, this stream contributes significant metal loads to Slumgullion Creek and Lake Fork of the Gunnison.

Sample NW90 was from Slumgullion Creek immediately above its confluence with the milky tributary described above. At this sample site, Slumgullion Creek receives surface flow from the southern boundary of the slide, but slide run-off is considerably diluted by the much larger flow from the upper part of the Slumgullion Creek drainage basin that lies south of the slide. A test of upper Slumgullion Creek showed some evidence of natural degradation, with pH of 4.81 and 174 µS/cm conductivity (Figure 15), but no sample was collected in 1999. At sample site NW90, the water was slightly cloudy, and moderate amounts of red precipitate covered some of the stream gravel. Flow was 450 gpm, pH was 4.21, and conductivity was 236 µS/cm. In comparison to the nearby sample from the milky stream, this water was relatively clean. Aluminum, iron, and manganese exceeded standards, but the concentrations were considerably lower than in NW89. The large difference between total and dissolved iron concentrations suggests moderate volumes of iron hydroxides were in suspension (Table 2).

Sample NW91 was from a creek flowing near the northwestern border of the slide (Figure 15). Within this stream's drainage basin, a few small and dry mines were driven in bedrock north of the slide, but these probably do not significantly affect water quality. Red-orange precipitate coated the streambed (Figure 16). Flow was 72 gpm, pH was 3.79, and conductivity was 805 µS/cm. Aluminum and manganese significantly exceeded standards, and iron exceeded to a lesser extent. Much of the high conductivity may be explained by relatively high concentrations of sulfate and major cations such as calcium, magnesium, sodium, and silica. Sample NW91 was degraded despite the diluting effect of an unnamed tributary joining this stream from the north, about ½ mile upstream. A test from the northern tributary showed neutral pH and moderate conductivity A test in some wetlands near site NW91, on the south side of State Highway 149, showed acidic water with conductivity of more than 3,000 µS/cm (Figure 15).

Figure 16. Photograph showing sample site NW91 near the northwest margin of Slumgullion Slide. The eroded creek bank comprises yellow, moist clay typical of much of the slide.

Carson Camp Area

Carson Camp was a turn-of-the-century mining settlement near the headwaters of Wager Gulch, a tributary of Lake Fork of the Gunnison River. It is located about 10 miles south of Lake City. The Carson mining district straddles the Continental Divide, and large mines lie in the upper basins of Wager Gulch on the north side of the divide, and in a tributary of Lost Trail Creek on the south side of the divide (Figure 17).

Geology

Large areas of altered rocks are exposed along the Continental Divide in and near the Carson mining district. The alteration is spatially related to the Carson volcanic center, a 29-million-year-old volcano that predates the formation of the nearby Uncompahgre/Lake City and the inferred Lost Lake calderas. The core of the volcano is now exposed as a porphyritic andesite stock. Intermediate-composition lavas and volcaniclastic rocks surround the stock. Hydrothermal alteration has affected parts of the stock and the surrounding extrusive and volcaniclastic rocks. (See Lipman, 1976; Steven and Lipman, 1976.)

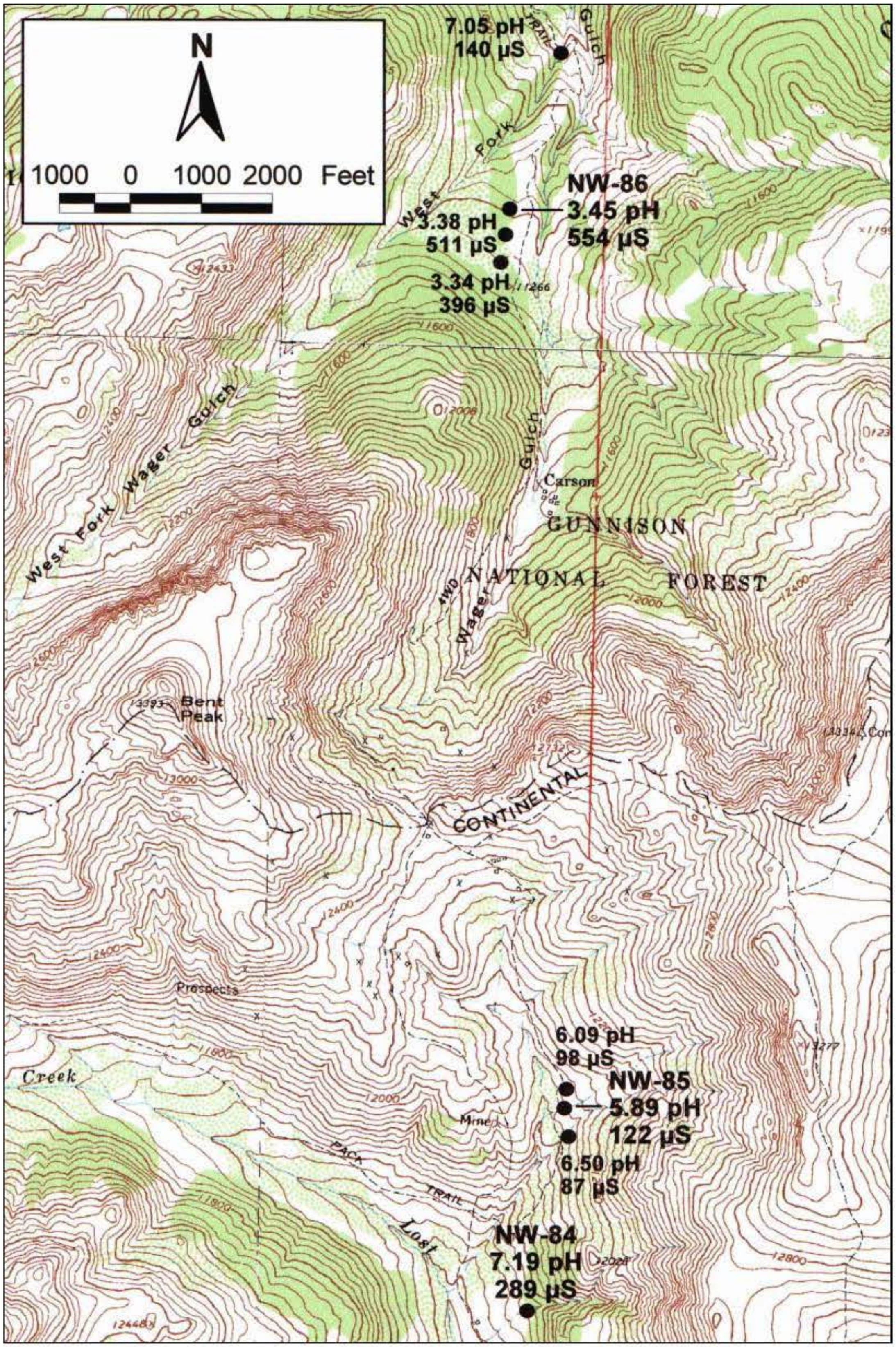

Figure 17. Map showing sample sites NW84-86 and water test results from the Carson area.

Mines in the Carson mining district explored numerous discontinuous veins that cut the stock and surrounding volcanic rocks. Minor amounts of gold and silver were produced from the veins, which also contained varying amounts of barite, quartz, enargite, pyrite, chalcopyrite, sphalerite, galena, and marcasite (Larsen, 1910). Mineralization and alteration in the Carson area may have resulted from late-stage hydrothermal activity associated with the pre-caldera Carson volcano, or it may be related to later caldera-forming events nearby.

Present Investigation

In upper Wager Gulch, iron-rich springs emerge in a wetland between Wager Gulch and the West Fork of Wager Gulch. No mines are known to exist above this series of springs. The spring water has formed a bog-iron deposit that is actively growing and contains yellow, red, and brown ferrihydrites. (See Harrer and Tesch, 1959, p. 44.) Bedrock exposed in the outcrops immediately above the springs is gray volcanic rock that does not appear severely altered. Lipman (1976) mapped altered volcanic rocks higher up on the ridge, not visible from the springs.

Sample NW86 was from a stream flowing across the bog-iron deposit (Figure 18). Within and near the stream channel, most of the ferrosinter was fresh and hard with a thin coating of soft precipitate. An oily sheen appeared on the ferrosinter surface in shallow areas of the stream and near seeps. Away from the channel, the deposit was weathered into dark, red-brown soil. Where sampled, flow was 15 gpm, pH was 3.45, and conductivity was 554 µS/cm. Aluminum, manganese, and iron concentrations significantly exceeded state standards (Table 2). Copper and zinc concentrations were elevated, but within standards because of the high hardness of the water. Water tests indicated that as the stream flowed across the active ferrosinter deposit, pH remained fairly constant, but conductivity gradually increased (Figure 17). Degraded water from the springs merged with West Fork of Wager Gulch. West Fork was tested below the confluence with the degraded springs and above its confluence with Wager Gulch and showed pH of 7.05 and 140 µS/cm conductivity. Additional sampling would be required to characterize the chemistry of this spring and its effects on Wager Gulch.

In a tributary of Lost Trail Creek on the south side of the Continental Divide, moderate-sized to large abandoned mines were operated almost to the ridgeline, therefore, this tributary may be tainted by past mining efforts. Because of the mining in the main tributary, two water samples were collected from smaller, unmined tributaries flowing from the ridge east of Lost Trail Creek (Figure 17). Bedrock exposed on the slopes above the sample sites include weakly altered and iron-stained volcaniclastic and extrusive rocks (Lipman, 1976). Stream gravel included argillized and propylitized rocks, along with fresh pieces of porphyry. Sample NW84 was collected from a stream with 35 gpm flow, 7.19 pH, and 289 µS/cm conductivity. Although the water appeared clear, minor amounts of light-yellow precipitate had settled into some of the pools and clogged the sample filter, indicating that some material was in suspension. This water exceeded state standards in manganese concentration (Table 2). Sulfate was slightly elevated. Dissolved and total aluminum and iron concentrations differed substantially, suggesting the presence of aluminum and iron hydroxides suspended in solution.

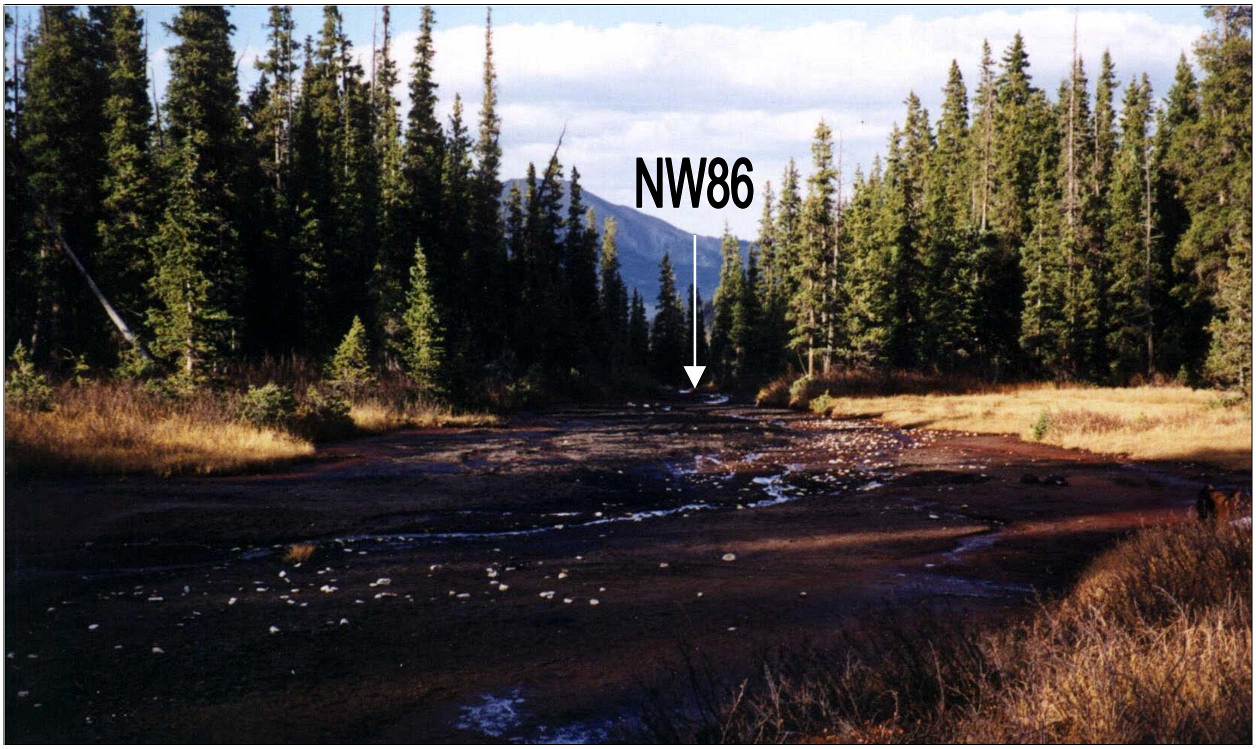

Figure 18. Photograph showing sample site NW86 and ferrosinter deposit near Wager Gulch.

Sample NW85 was from a smaller tributary; flow was 1 gpm, pH was 5.89, and conductivity was 122 µS/cm. Although pH was lower, this water was relatively clean and was within standards for the analyzed parameters. Water tests from other springs and streams in this area did not indicate severe degradation and were not sampled (Figure 17).

Platoro-Summitville Caldera Complex

This caldera complex is in the southeastern San Juan Mountains. Alamosa lies about 40 miles to the east; Pagosa Springs is about 20 miles to the west-southwest; and Wolf Creek Pass is about 10 miles to the west-northwest. Because of the well-documented and on-going environmental problems at the Summitville Mine, this area has been the focus of numerous water quality studies concerned with mining-affected and naturally occurring degraded water.

Geology

The Platoro caldera began forming about 30 million years ago and is one of the oldest of the San Juan volcanic field. Pre-caldera andesitic volcanoes of the Conejos Formation were deeply eroded and the terrain was relatively flat when extrusion of the silicic Treasure Mountain Tuff and caldera formation began. Resurgence within the caldera followed quickly, and the moat surrounding the resurgent core filled with lava and volcaniclastic rocks of the lower member of the Summitville Andesite. The Summitville Andesite is similar in composition to the Conejos

Formation and may represent a reactivation of the pre-caldera volcanism. (See Steven and Lipman, 1976, p. 4-6.)

When the Platoro caldera moat was nearly filled with Summitville Andesite, subsequent extrusion of upper members of the Treasure Mountain Tuff between 29 and 30 million years ago formed the Summitville caldera. The Summitville caldera is nested in the northern part of the Platoro caldera. The Summitville caldera probably had no resurgence and soon filled with upper members of the Summitville Andesite. (See Steven and Lipman, 1976, p. 6.)

Later extrusive and intrusive igneous activity and mineralization were concentrated near the margins of both calderas. At least five post-caldera igneous episodes occurred between 29 and 20 million years ago. Hydrothermal alteration and base- and precious-metal deposits are related to some of the post-caldera igneous events. (See Steven and Lipman, 1976, p. 6, 33.)

Faults associated with the Platoro-Summitville caldera complex served as structural zones of weakness for emplacement of intrusive stocks during post-caldera igneous episodes. The quartz monzonite Alamosa River stock and the andesite porphyry Jasper stock are responsible for extensive hydrothermal alteration in the upper Alamosa River drainage basin. The Alamosa River stock shows quartz-sericite-pyrite alteration that extends into the overlying Summitville Andesite in the drainage basins of Iron, Alum, and Bitter Creeks (Figure 19). Intrusion of the Jasper stock caused the alteration of bedrock in Jasper and Burnt Creeks. (See Bove and others, 1995, p. 36-38; Lipman, 1974; Meyer and others, 1996, p. 5.)

Figure 19. Photograph showing intense alteration on the south side of Lookout Mountain, in the Iron Creek drainage basin.

Previous Investigations

Because of the vast amount of information collected by numerous individuals and agencies during the last decade, no effort is made to document all of the studies involving water quality in the Alamosa River. A few examples of naturally degraded springs sampled by CGS personnel are described and tabulated in the following paragraphs.

Numerous tests for pH and conductivity were performed on mining-affected and natural waters during the course of an abandoned-mine inventory of USFS-administered land (Kirkham and Lovekin, 1995). A follow-up study (Kirkham and others, 1995) included collecting samples from five naturally degraded springs, or NOAMS (naturally occurring, acidic, metal-rich springs). Sample results showed pHs were all below 4, and all contained high metal concentrations. Aluminum, copper, iron, and zinc were the most commonly elevated metals, although manganese was quite high in two of the springs. Flow rates on these springs varied from less than 2 gpm to about 20 gpm (Table 3).

Table 3. Analytical data for selected samples collected in the Platoro-Summitville caldera area prior to 1999. [Results are shown in dissolved concentrations and µg/L unless noted. Blank columns indicate the parameter was not analyzed or the results are not known. The 1993 and 1994 samples were reported in Kirkham and others (1995); the 1995 samples are reported in Meyer and others (1996, table 2).]

Parameter	Upper Iron	Lower Iron	Bitter	FR-250 Seep	Main Burnt	Iron Creek ICW1	Iron Creek ICW2	Iron Creek ICW4	Pass-Me-By Mine
Date	8/5/93	8/27/93	6/18/94	8/11/93	8/31/93	9/14/95	9/14/95	9/14/95	9/14/95
Flow (gpm)	6.7	~20	1.6	3.9	~18				
pH	2.53	2.94	3.27	2.75	3.82	3.87	3.79	2.39	3.02
Conductivity (µS/cm)	2,590	622	214	2,600	2,040	433	624	3,610	1,225
Eh (millivolts)						173	175	247	214
Temperature (°C)						9.0	7.2	6.6	5.6
DO (mg/L)						0.6	0.1	0.4	0.5
TDS (mg/L)						218	314	1,810	613
Hardness (mg/L)	33	26	2	785	947				
Aluminum	120,000	9,000	1,422	38,000	31,000	7,500	18,000	270,000	59,000
Arsenic						4	<10	<10	33
Calcium (mg/L)	22.0	7.0	0.2	150.0	320.0	36	33	19	18
Cadmium	1.70	<20.00	<0.30	<20.00	<20.00	0.38	0.62	3	1.2
Copper	990.0	<40	77.0	350.0	58.0	<4	<8	2,500	110
Iron	160,000	26,000	1,920	70,000	72,000	48,000	90,000	500,000	160,000
Lead	7.0	<80.0	<3.0	<80.0	<80.0	<1	<1	<1	<1
Magnesium (mg/L)	2.6	2.0	0.3	100.0	42.0	5.9	5	3	2.4
Manganese	240.0	650.0	49	15,000	4,200	1,200	1,300	220	400
Mercury							<0.2	<0.2	<0.2
Nickel	<200	<40	<1	160.0	<40				
Potassium (mg/L)						4.6	5.1	<0.25	6.9
Silver	<0.2	<40	<0.6	<40	<40				
Sodium (mg/L)						2.7	0.94	0.14	0.30
Sulfate (mg/L)	1,380		25			180	310	3,200	640
Zinc	260	130	138	930	810	150	230	310	190

The Upper Iron NOAMS emerges from intensely altered Summitville Andesite. Water flows from a sub-horizontal fracture down a precipitate-covered slope that is about 200 feet wide and 300 feet long. (See Sares, 1996, p. 5-6.) The spring water had a flow rate of 6.7 gpm, pH of

2.53, and contained extremely high concentrations of aluminum, iron, and copper. Cadmium, lead, zinc, and sulfate concentrations also exceeded state water quality standards (Table 3).

The Lower Iron NOAMS occurs in a post-caldera monzonite intrusion immediately downslope from intensely altered Summitville Andesite and associated talus and colluvium. Water from the spring has formed a large ferrosinter mound. (See Sares, 1996, p. 6.) This spring is the largest identified NOAMS in this caldera complex and flowed at about 20 gpm. The pH was 2.94, and aluminum, iron, manganese, and zinc concentrations were high (Table 3).

Meyer and others (1996) collected additional samples from springs and seeps in the Iron Creek drainage basin and from the Pass-Me-By Mine, which lies in the Iron Creek drainage basin below the sampled seeps. Lab results show the waters from all of the seeps and the mine are extremely acidic and are highly degraded with aluminum and iron, and slightly degraded with zinc. Cadmium, copper, and sulfate are high in the most acidic seep and in the mine water. Manganese is high in the two seeps with slightly higher pHs (Table 3). Higher concentrations of calcium, magnesium, and sodium in the seeps with the higher pHs may indicate a mild buffering effect because of dissolution of carbonate and feldspar minerals. (See Meyer and others, 1996, p. 10-11.)

The Bitter NOAMS emerges from intensely altered Summitville Andesite in the upper reaches of the Bitter Creek drainage basin. Several other springs occur at approximately the same elevation in this gulch, suggesting a permeability boundary in the ash-flow units that compose the bedrock. (See Sares, 1996, p. 6.) This spring flowed at about 1.6 gpm, had pH of 3.27, and carried high concentrations of aluminum, copper, iron, and zinc (Table 3).

Several seeps emanate in a borrow pit along Forest Road #250 between Alum and Bitter Creeks. The borrow pit was excavated in a debris flow. Bedrock in this area is highly altered, post-caldera intrusive monzonite. (See Sares, 1996, p. 6.) The sampled seep flowed at about 3.9 gpm, had pH of 2.75, and significantly exceeded state standards in aluminum, copper, iron, manganese, and zinc concentrations. Magnesium, calcium, and nickel concentrations were also high (Table 3).

The Main Burnt NOAMS is in the middle to upper portion of the Burnt Creek drainage basin. This spring emerges from intensely altered, intrusive andesite porphyry of the Jasper stock. Precipitate deposited from the spring water has formed an overhanging ferrosinter mound composed of small, stair-stepped terraces holding shallow pools of water. (See Sares, 1996, p. 6.) The spring flowed at a rate of about 18 gpm, had pH of 3.82, and greatly exceeded state standards in aluminum, iron, manganese, and zinc concentrations. Calcium, magnesium, and copper concentrations were also elevated (Table 3).

To determine if the formation of precipitate mounds partly attenuates the waters of natural seeps and springs, Meyer and others (1996) sampled three of the mounds to analyze their metal content. The mounds were sampled immediately adjacent to the spring or seep to obtain “fresh” precipitate, and farther from the source for “older” material. With few exceptions, the “old” and “fresh” material in the same deposits were similar in composition. All of the mounds contained from 23% to 43% iron, and most of the cations and metals were 10 to 1,000 times more concentrated in the mounds than in the water. These analyses show that abundant iron and significant amounts of trace metals are precipitated during formation of the ferrosinter deposits, and that development of these deposits is the first step toward attenuation of these naturally degraded waters. (See Meyer and others, 1996, p. 15-17.)

Present Investigation

In 1999, two samples were collected from near the Platoro-Summitville caldera complex (Figure 20). NW83 was from Crater Creek, on the western side of the Continental Divide. Although alteration associated with intrusive activity reportedly occurs in this area (Neubert and others, 1992, p. 213), none was obvious in the vicinity of the sample location. Vein deposits containing zinc and other base metals were exposed and mined slightly downstream of the sample site. Stream gravel at the sample site included mostly relatively fresh andesite porphyry, with lesser amounts of argillic-altered porphyry, siliceous, light-brown aphanitic volcanic or volcaniclastic rock, and traces of quartz veins with pyrite stringers. The sample was relatively clean, and only showed the presence of a few trace metals in low concentrations. Sulfate was elevated but within standards (Table 4).

Sample NW95 was from a spring with an associated, actively forming ferrosinter deposit (Figure 21) near the headwaters of Iron Creek, on the eastern side of the Continental Divide. A nearby shallow prospect pit was not considered a factor in the water quality of the spring. Bedrock exposed at a small waterfall about 200 feet downstream of the sample site comprised silicified and pyritized, gray, aphanitic volcanic rock. Old, well-indurated ferricrete deposits (Figure 22) on both sides of Iron Creek adjacent to the sample site suggest a long history of degraded water emerging in this area. Both upstream and downstream of the spring, a thin layer of red precipitate coated much of the channel of Iron Creek. The sampled spring was flowing at 3 gpm, had 3.58 pH, and conductivity of 203 µS/cm. Aluminum concentration significantly exceeded state standards, and iron, copper, manganese, and thallium also exceeded standards (Table 4).

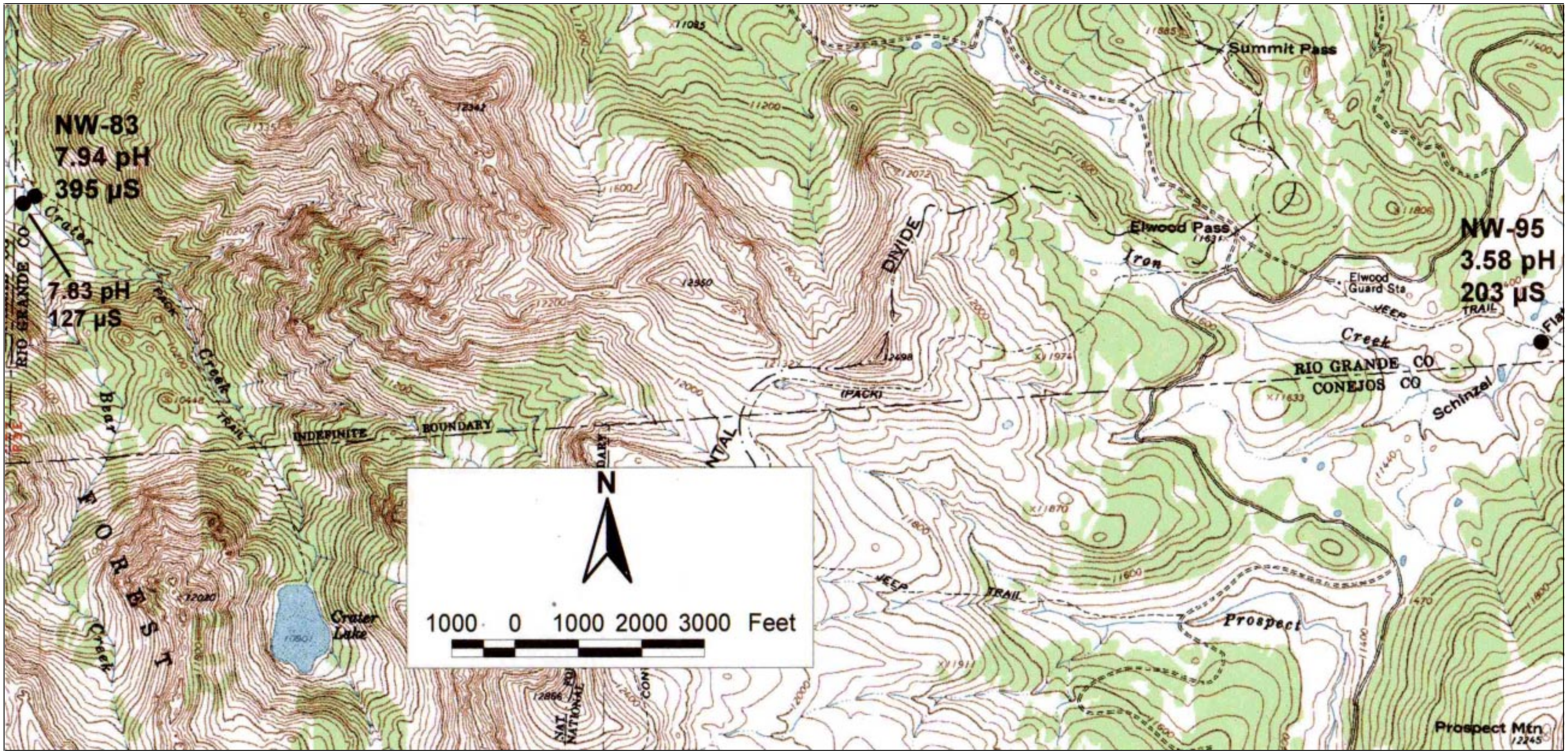

Figure 20. Map showing sample sites NW83, 95 from the Platoro-Summitville caldera area.

Table 4. Analytical data for samples NW83, 95 from the Platoro-Summitville caldera area.

Sample	NW83, CRATER CREEK (9/28/99)				NW95, SCHINZEL FLATS (10/12/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	215.0				3.0			
pH (standard units)	7.94				3.58			
Conductivity (µS/cm)	395.0				203.0			
Alkalinity (mg/L CaCO3)	100.00							
Hardness (mg/L CaCO3)	378	None	N/A		28	None	N/A	
Aluminum (trec) (µg/L)	71	None	N/A	83.2	3,000	None	N/A	49.1
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	1.0	50.00	Below standard	0.0
Iron (trec) (µg/L)	280	1000.00	Below standard	328.2	1,400	1000.00	1.4	22.9
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	2.0	0.50	4.0	0.0
Zinc (trec) (µg/L)	18	2000.00	Below standard	21.1	26	2000.00	Below standard	0.4
Aluminum (µg/L)	< 50	87.00	Below standard	N/A	3,100	87.00	35.6	50.7
Cadmium (µg/L)	< 0.3	3.22	Below standard	N/A	< 0.3	0.42	Below standard	N/A
Calcium (mg/L)	130	None	N/A	152,355.5	10	None	N/A	163.5
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	< 4.0	36.86	Below standard	N/A	7.0	4.00	1.7	0.1
Fluoride (mg/L)	< 0.10	2.00	Below standard	N/A	0.20	2.00	Below standard	3.3
Iron (µg/L)	< 10	300.00	Below standard	N/A	1,500	300.00	5.0	24.5
Lead (µg/L)	< 1.0	25.63	Below standard	N/A	< 1.0	0.65	Not detected	N/A
Magnesium (mg/L)	13.00	None	N/A	15,235.5	0.77	None	N/A	12.6
Manganese (µg/L)	16	50.00	Below standard	18.8	160	50.00	3.2	2.6
Nickel (µg/L)	< 20	262.73	Below standard	N/A	< 20	36.48	Below standard	N/A
Potassium (mg/L)	1.1	None	N/A	1,289.2	< 1.0	None	N/A	N/A
Silicon (mg/L)	2.5	None	N/A	2,929.9	7.9	None	N/A	129.2
Silver (µg/L)	< 0.2	0.74	Below standard	N/A	< 0.2	0.01	Not detected	N/A
Sodium (mg/L)	2.80	None	N/A	3,281.5	1.60	None	N/A	26.2
Sulfate (mg/L)	92	250.00	Below standard	107,820.8	44	250.00	Below standard	719.5
Zinc (µg/L)	16	327.24	Below standard	18.8	26	36.22	Below standard	0.4

Figure 21. Photograph showing ferrosinter deposit at sample site NW95, adjacent to Iron Creek.


Figure 22. Photograph showing ferricrete along upper Iron Creek near sample site NW95.

Kite Lake

Kite Lake is in the upper Rio Grande River drainage basin, near the headwaters of Bear Creek and close to the Continental Divide. Abandoned mines related to the ghost town of Beartown are nearby. Samples collected in 1999 are above the known large and/or draining mines.

Geology

Degraded water near Kite Lake emerges from Precambrian Uncompahgre Formation phyllite and quartzite. Pyrite commonly occurs in some of the weakly metamorphosed rocks of the Uncompahgre Formation. Volcanic rocks related to early Oligocene andesitic volcanism crop out to the north of an east-trending fault zone that lies immediately north of the sample sites. (See Steven and others, 1974.) The mode of occurrence of the pyrite suggests that it is related to the Precambrian depositional environment, rather than a Laramide or later mineralization event. The inferred Ute Creek caldera of Tertiary age is within about 3 miles to the northeast (Steven and Lipman, 1976, Figure 5). It is not known if degradation in this area is caldera related, but more likely it is a result of the weathering of Precambrian-age pyrite in the Uncompahgre Formation.

Previous Investigation

Kirkham (1993, p. 4-5) described degraded water in the stream draining into Kite Lake from the southwest. Although a few small mines lie on private land near this creek, the mines are apparently dry, and any drainage associated with them flows directly toward Kite Lake, rather than into the stream. The stream channel is lined with red-orange precipitate in its upper reaches, upstream of the observed mines. When tested slightly upstream of Kite Lake in 1992, this stream had 4.75 pH and 113 µS/cm conductivity.

Kirkham (1993, p. 6-7) also discusses degraded springs and associated ferrosinter deposits on the north-facing slope east-southeast of Kite Lake. In 1992, a 15-gpm spring was emerging from a shallow, caved adit or prospect pit hosted entirely within a ferrosinter deposit. It is doubtful that this shallow working affected water quality, and the prospect was probably driven to test the metal values of the ferrosinter deposit. This water had 4.33 pH, 346 µS/cm conductivity, and contained extremely high concentrations of iron and aluminum. Copper, manganese, zinc, cadmium, and nickel exceeded standards, and sulfate was elevated but within standards (unpublished data available at CGS). Samples were collected from the unnamed receiving stream above and below its confluence with the degraded spring water. From upstream to downstream, flow in the creek increased from 20 to 35 gpm, pH dropped from 6.53 to 4.15, and conductivity rose from 33 µS/cm to 174 µS/cm. The upstream sample was within standards for the analyzed parameters. The downstream sample was degraded, exceeding standards in aluminum, iron, copper, manganese, zinc, and cadmium (unpublished data available at CGS).

Present Investigation

The cliffs and talus slopes around Kite Lake comprise iron-stained phyllite and quartzite. Disseminated pyrite is common, and the rocks are stained brown, with lesser amounts of red and yellow staining. Sample NW92 was collected from the stream that feeds into Kite Lake from the southwest (Figure 23), and near the test site of Kirkham (1993, p. 4) described above. Flow was 2 gpm, pH was 3.80, and conductivity was 208 µS/cm. Aluminum, manganese, zinc, and copper exceeded state standards (Table 5). No large mines are known to exist in the drainage basin above the sample site.

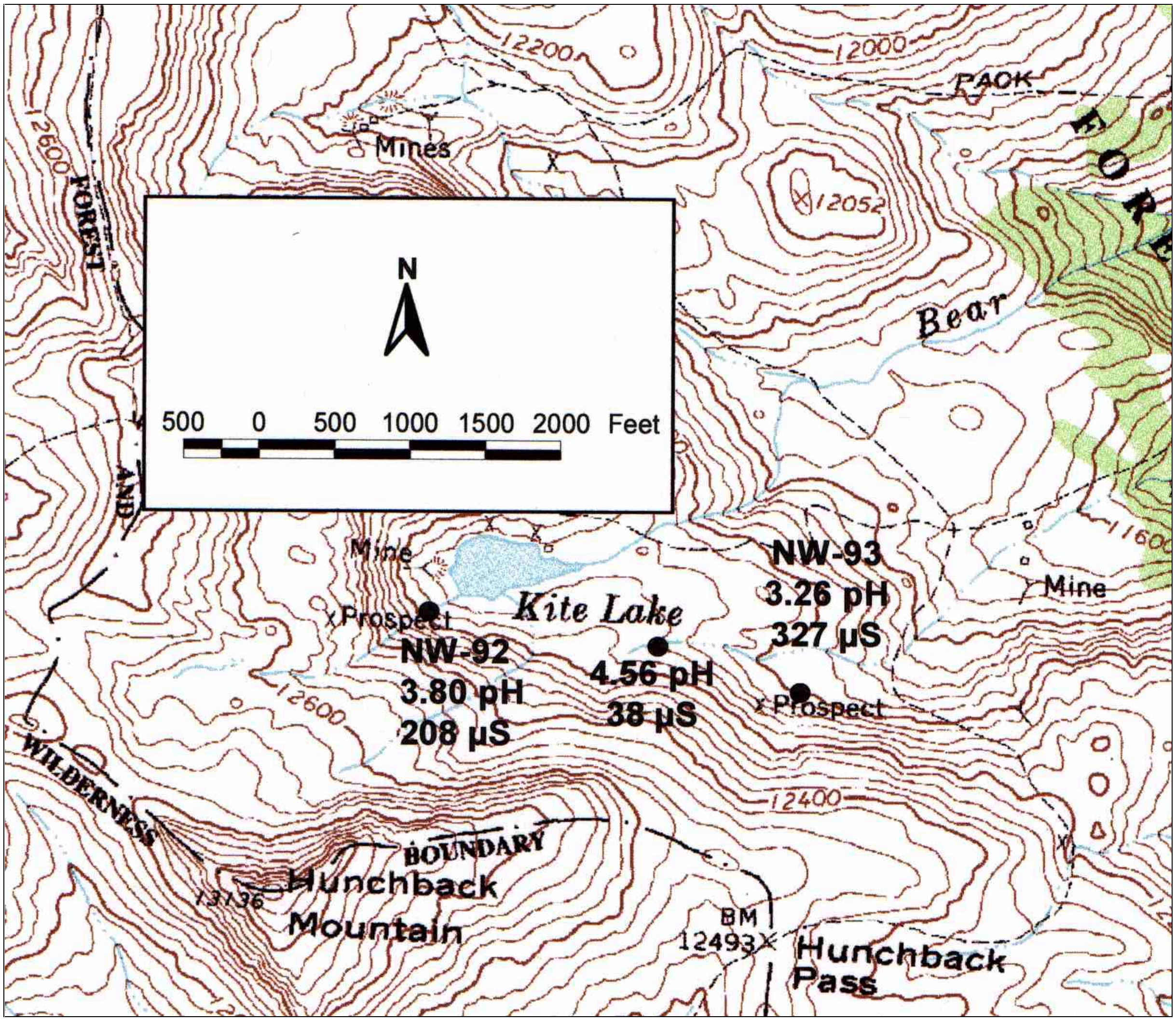

Figure 23. Map showing sample sites NW92-93 near Kite Lake and Hunchback Pass.

Small prospects and/or caved adits excavated in the ferrosinter deposits (Figure 24) described by Kirkham (1993, p. 6-7) east-southeast of Kite Lake probably do not affect the water quality of the springs that formed the deposits. Sample NW93 was collected from one of the seeps below an icy cliff. Flow was 2 gpm, pH was 3.26, and conductivity was 327 µS/cm. Aluminum and iron concentrations greatly exceeded state standards. Manganese, copper, and zinc also exceeded standards. Nickel and sulfate were elevated, but within standards (Table 5).

Table 5. Analytical data for samples NW92-94 from the San Juan Mountains.

Sample	NW92, KITE LAKE SOUTHWEST (10/11/99)				NW93, HUNCHBACK PASS NORTH (10/11/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	2.0				2.0			
pH (standard units)	3.80				3.26			
Conductivity (µS/cm)	208.0				327.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	66	None	N/A		50	None	N/A	
Aluminum (trec) (µg/L)	5,700	None	N/A	62.1	5,200	None	N/A	56.7
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	42	1000.00	Below standard	0.5	14,000	1000.00	14.0	152.6
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	300	2000.00	Below standard	3.3	86	2000.00	Below standard	0.9
Aluminum (µg/L)	5,800	87.00	66.7	63.2	4,700	87.00	54.0	51.2
Cadmium (µg/L)	0.4	0.82	Below standard	0.0	0.4	0.66	Below standard	0.0
Calcium (mg/L)	14	None	N/A	152.6	13	None	N/A	141.7
Chloride (mg/L)	27.0	250.00	Below standard	294.4	91.0	250.00	Below standard	992.1
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	10.0	8.31	1.2	0.1	31.0	6.51	4.8	0.3
Fluoride (mg/L)	0.13	2.00	Below standard	1.4	0.21	2.00	Below standard	2.3
Iron (µg/L)	40	300.00	Below standard	0.4	14,000	300.00	46.7	152.6
Lead (µg/L)	1.0	2.17	Below standard	0.0	< 1.0	1.45	Below standard	N/A
Magnesium (mg/L)	7.60	None	N/A	82.9	4.20	None	N/A	45.8
Manganese (µg/L)	670	50.00	13.4	7.3	270	50.00	5.4	2.9
Nickel (µg/L)	50	69.82	Below standard	0.5	42	56.20	Below standard	0.5
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	3.2	None	N/A	34.9	4.9	None	N/A	53.4
Silver (µg/L)	< 0.2	0.04	Not detected	N/A	< 0.2	0.02	Not detected	N/A
Sodium (mg/L)	0.27	None	N/A	2.9	0.30	None	N/A	3.3
Sulfate (mg/L)	78	250.00	Below standard	850.4	91	250.00	Below standard	992.1
Zinc (µg/L)	300	74.69	4.0	3.3	86	58.63	1.5	0.9

Table 5. Analytical data for samples NW92-94 from the San Juan Mountains--continued.

Sample	NW94, EAST TROUT CREEK EAST (10/12/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	80.0			
pH (standard units)	3.29			
Conductivity (µS/cm)	741.0			
Alkalinity (mg/L CaCO3)				
Hardness (mg/L CaCO3)	405	None	N/A	
Aluminum (trec) (µg/L)	14,000	None	N/A	6,105.1
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	6,000	1000.00	6.0	2,616.5
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	67	2000.00	Below standard	29.2
Aluminum (µg/L)	14,000	87.00	160.9	6,105.1
Cadmium (µg/L)	< 0.3	3.40	Below standard	N/A
Calcium (mg/L)	150	None	N/A	65,412.0
Chloride (mg/L)	110.0	250.00	Below standard	47,968.8
Chromium (µg/L)	< 10	11.00	Below standard	N/A
Copper (µg/L)	10.0	39.10	Below standard	4.4
Fluoride (mg/L)	0.12	2.00	Below standard	52.3
Iron (µg/L)	5,800	300.00	19.3	2,529.3
Lead (µg/L)	< 1.0	28.27	Below standard	N/A
Magnesium (mg/L)	7.40	None	N/A	3,227.0
Manganese (µg/L)	870	50.00	17.4	379.4
Nickel (µg/L)	< 20	276.88	Below standard	N/A
Potassium (mg/L)	1.8	None	N/A	784.9
Silicon (mg/L)	24.0	None	N/A	10,465.9
Silver (µg/L)	< 0.2	0.83	Below standard	N/A
Sodium (mg/L)	8.20	None	N/A	3,575.9
Sulfate (mg/L)	310	250.00	1.2	135,184.8
Zinc (µg/L)	69	346.96	Below standard	30.1

Figure 24. Photograph showing ferrosinter deposit near Kite Lake, near sample site NW93.

East Trout Creek

Naturally degraded water flows in a tributary of East Trout Creek, about ½ mile upstream from its confluence with West Trout Creek and about 20 miles south-southwest of Creede. East Trout Creek flows northward from the Continental Divide, eventually joining the Rio Grande about 10 miles upstream of Creede.

Geology

Altered ash-flow tuffs with a chalky appearance are exposed along the ridge on the east side of East Trout Creek. A Tertiary-age intrusion crops out about 3 miles downstream (Steven and others, 1974). The Creede caldera lies about 8 miles to the northeast, and the Mount Hope caldera is about 10 miles to the east (Steven and Lipman, 1976). Sulfur was mined from some of these altered rocks at the nearby Sulphur Tunnel (Figure 25). The presence of the nearby sulfur mine suggests fumarolic activity that could cause localized and intense hydrothermal alteration. The nearby Tertiary intrusion may have been the source for the hydrothermal fluids responsible for the alteration.

Present Investigation

Kirkham, (1993, p. 10) previously tested the unmined drainage basin north of the Sulphur Tunnel. In 1992, this stream had 3.88 pH and 744 µS/cm conductivity. In 1999 sample NW94 was collected from this stream, near the site of Kirkham's test (Figure 25). Stream gravel comprised gray andesite with minor brown and red staining; pinkish, aphanitic porphyry with sparse disseminated pyrite; propylitically altered, medium-grained intrusive(?) rock with chlorite; bleached porphyry with a strong sulfur odor; and fragments of ferricrete. Flow was about 80 gpm, pH was 3.29, and conductivity was 741 µS/cm. Aluminum concentration exceeded standards by more than two orders of magnitude; iron and manganese significantly exceeded standards; and sulfate concentration was slightly above standards (Table 5). Hardness was high, and chloride, silicon, and sodium concentrations were elevated. Moderate to high concentrations of major ions account for much of the high conductivity.

Although the alteration appeared to affect much of the ridge between Trout Creek and Copper Creek, water tests from tributaries of Trout Creek to the north, including Copper Creek, did not indicate severe degradation (Figure 25), and no additional samples were collected. Apparently the mineralizing fluids responsible for the sulfur mineralization and associated alteration were very localized.

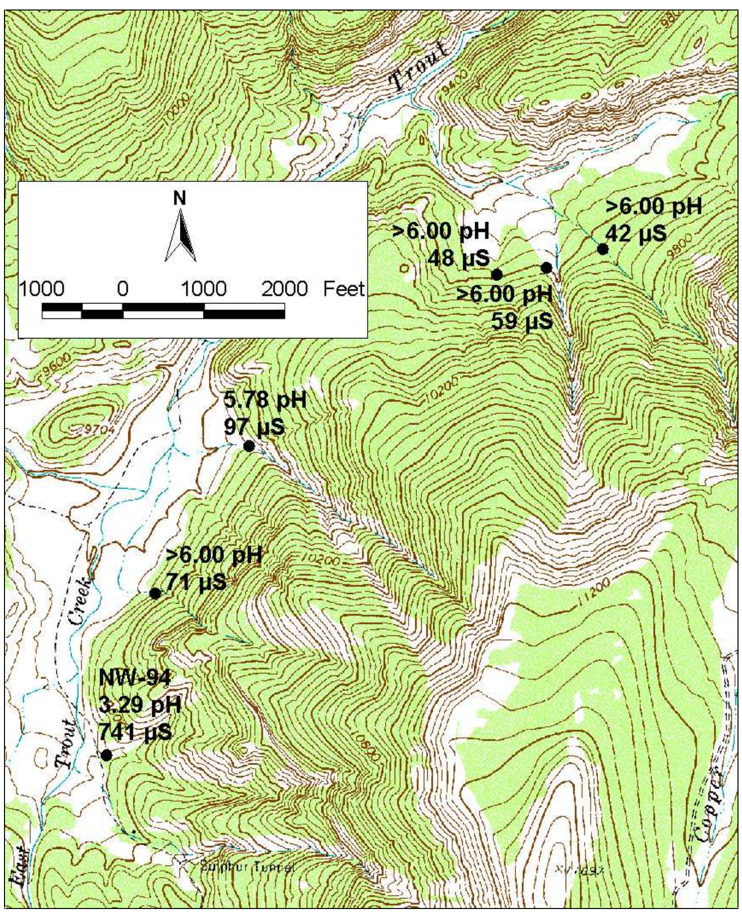

Figure 25. Map showing sample site NW94 and test results near East Trout Creek.

LA PLATA MOUNTAINS

The La Plata Mountains are about 10 miles northwest of Durango in southwestern Colorado. Naturally degraded water emerges from several locations near the drainage divide between the La Plata and East Mancos Rivers.

Geology

The La Plata Mountains represent the erosional remains of a domal uplift of about 6,000 feet and about 15 miles in diameter. Doming resulted from the intrusion of several intermediate-composition stocks and sills during the Laramide. In addition to the intrusive rocks, Pennsylvanian- to Cretaceous-age sedimentary rocks are exposed. The sedimentary sequence has been subjected to folding, faulting, and localized areas of contact metamorphism. (See Neubert and others, 1992, p. 64-65.)

The Allard stock, near the headwaters of Bedrock Creek, is one of the intrusions of the La Plata Mountains. This multi-phase, syenite stock hosts a sub-economic copper deposit that is partly exposed at the surface. Potassic and argillic alteration and pyritization are widespread and extend into country rock beyond the stock. Pyrite and chalcopyrite are abundant and are the dominant metallic minerals. Gold, silver, platinum, and palladium also occur, primarily as telluride minerals. (See Neubert and others, 1992, p. 138-140.)

Previous Investigations

Degraded water emerging in Rush Basin has formed an extensive bog-iron deposit along the East Mancos River. The deposit is up to 1,000 feet wide, 1½ miles long, and up to 10 feet thick. (See Harrer and Tesch, 1959, p. 51.) Although this limonite deposit occurs downstream of a few small mines, the deposit almost certainly predates mining activity. Water chemistry after the onset of mining may differ slightly from the pre-mining chemistry.

In the headwaters of the East Mancos River, on the north side of the Allard stock, Meyer and others (1996) collected a total of five samples from the East Mancos River, from some seeps, and from a small adit downstream of the other sample sites. With the exception of one of the natural seep samples that contained extremely high concentrations of most of the analyzed parameters, the natural waters and the adit effluent contained similar concentrations of most of the parameters. All of the pHs were between 3.5 and 4; aluminum and copper concentrations were high; and zinc concentrations were elevated. Iron concentrations were high, except in one of the in-stream samples.

Present Investigation

In 1999, nine samples were collected from the Allard stock area, from both the La Plata River drainage basin and the headwaters of the East Mancos River drainage basin (Figure 26). Sample

NW70 was collected where the copper occurrence is exposed at the surface. The sample site was at the base of a conspicuous cascade where Bedrock Creek flows across mineralized intrusive rock with disseminated pyrite. The intrusive rock at the cascade had a thin coating of hard, red precipitate (Figures 27, 28). Stream gravel included mineralized intrusive rocks and fragments of ferricrete. Weathered fluorite occurred on some pieces. Flow was 214 gpm, pH was 4.48, and conductivity was 119 µS/cm. Copper concentration was quite high, greatly exceeding state standards. Aluminum, manganese, iron, lead, zinc, and fluoride also exceeded standards (Table 6). A tributary of Bedrock Creek, flowing from the northeast, showed test parameters suggesting clean water, probably similar to that sampled in the headwaters of Boren Creek, just across the drainage divide (Figure 26).

West of the ridgeline that forms the boundary between the La Plata River and East Mancos River drainage basins, samples and tests revealed several areas of natural degradation. Sample NW76 was from the headwaters of a small stream emerging from the heavily iron-stained talus on the south side of Rush Basin. The channel was lined with old, partly eroded ferricrete (Figure 29). Red precipitate occurred adjacent to seeps alongside the stream channel, but the stream bottom was not completely coated until further downstream. Flow was 18 gpm, pH was 3.59, and conductivity was 455 µS/cm. Aluminum and copper concentrations were exceptionally high. Manganese, zinc, cadmium, iron, and nickel also exceeded standards (Table 6).

Sample NW75 was collected a few hundred feet downstream in the same creek of NW76, but upstream of its confluence with a larger stream that drains much of Rush Basin. The streambed was lined and terraced with actively forming red, brown, and yellow ferrosinter (Figure 30). Flow had increased to 42 gpm, pH was nearly identical, but conductivity increased to 835 µS/cm. Concentrations of several metals increased dramatically: iron increased about two orders of magnitude; copper increased almost 5-fold; manganese, zinc, and cadmium roughly tripled; and aluminum and nickel doubled. In addition, thallium, sulfate, and chromium exceeded standards, and arsenic was elevated (Table 6). This was the most degraded sample collected from the Allard stock area.

Sample NW77 was collected from a stream draining the southwest side of Burwell Peak. The stream channel and banks were composed almost exclusively of loose material derived from the steep slopes above. Almost no vegetation grew, and the channel had the appearance of an active and unstable debris flow. Stream gravel included pyritized and altered porphyry and sandstone, relatively fresh diorite and hornfels, and broken pieces of ferricrete. Pyrite was common, chrysocolla and chalcopyrite were sparse. Flow was 65 gpm, pH was 4.23, and conductivity was 321 µS/cm. The water carried high concentrations of dissolved copper. Interestingly, dissolved copper exceeded aluminum, which was also significantly above state standards. Manganese, zinc, and cadmium also exceeded standards. Iron concentration was unusually low (Table 6).

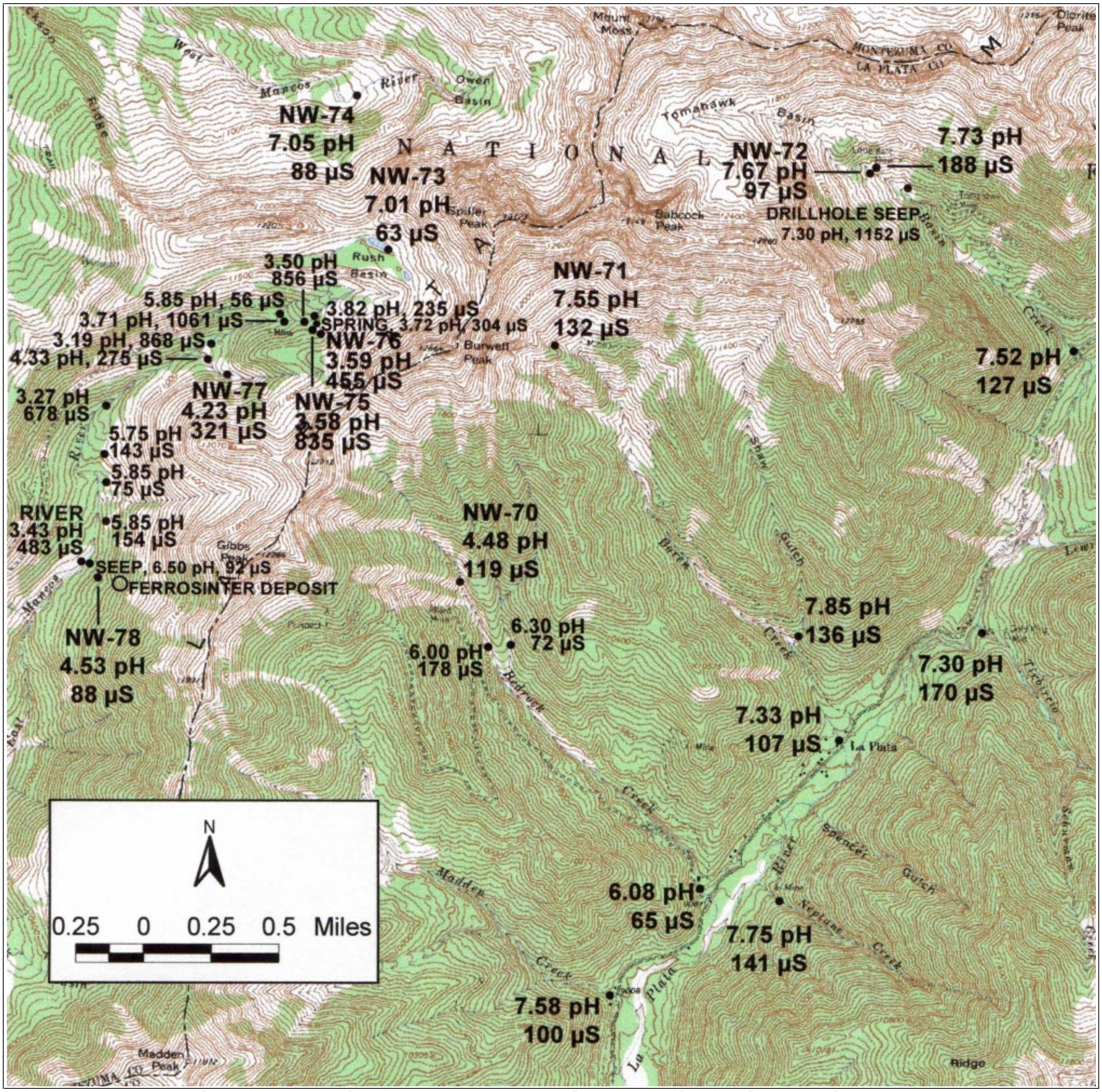

Figure 26. Map showing sample sites NW70-78 and test results in the La Plata Mountains.

A small, dark red-brown ferrosinter deposit is visible on the west side of Gibbs Peak (Figure 31). Sample NW78 was collected from a little stream that drains the deposit. Alluvial material included silicified siltstone and brown- and red-stained quartzite. The stream channel had abundant unconsolidated red precipitate. Flow was 28 gpm, pH was 4.83, and conductivity was 88 µS/cm. Copper concentration significantly exceeded standards, but was low compared to samples collected further north. Manganese and aluminum also exceeded standards. Zinc was elevated, but within standards (Table 6).

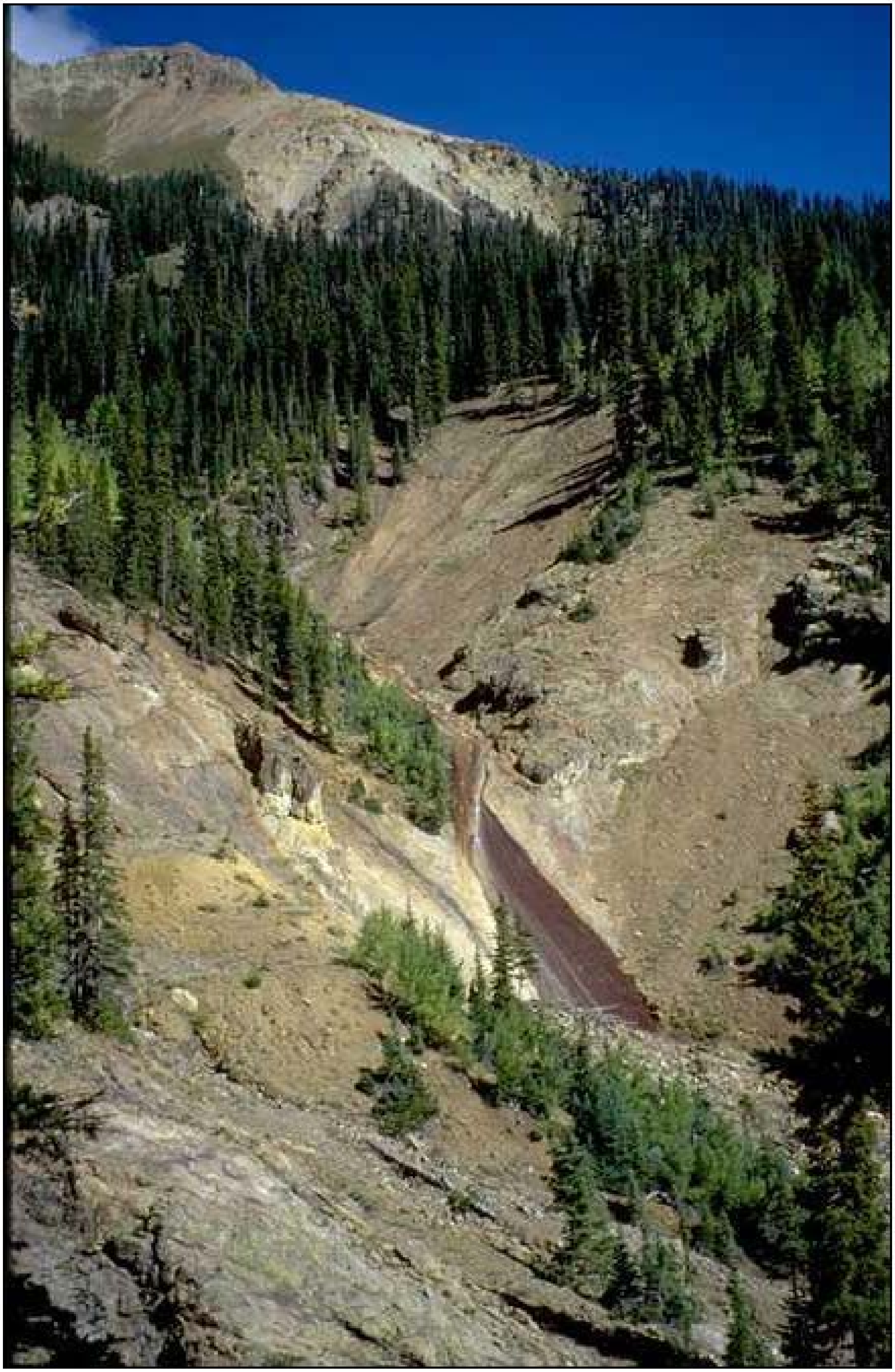

Figure 27. Photograph of Bedrock Creek showing cascade flowing across precipitate-coated, mineralized intrusive rock and altered slopes.

Figure 28. Photograph showing sample site NW70 at base of cascade in Bedrock Creek.

Numerous tests were conducted in the main branch of the East Mancos River and from side seeps and tributaries (Figure 26). These tests indicated that most of the seeps and tributaries in this part of the East Mancos drainage basin are slightly acidic and may carry moderate to high concentrations of metals. However, the main stem of the East Mancos River is highly degraded for an unknown distance downstream. At the lowest test site, the East Mancos had 3.43 pH and 483 µS/cm conductivity, and the streambed was coated with red precipitate. Past mining activities between this test site and the upper sample sites may affect water quality, but the effects are apparently dwarfed by the degraded runoff from the large exposures of altered bedrock and talus further upstream.

Table 6. Analytical data for samples NW70-78, near the Allard stock.

Sample	NW70, BEDROCK CREEK (9/18/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	214.0			
pH (standard units)	4.48			
Conductivity (µS/cm)	119.0			
Alkalinity (mg/L CaCO3)				
Hardness (mg/L CaCO3)	72	None	N/A	
Aluminum (trec) (µg/L)	2,000	None	N/A	2,333.0
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	730	1000.00	Below standard	851.6
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	150	2000.00	Below standard	175.0
Aluminum (µg/L)	1,900	87.00	21.8	2,216.4
Cadmium (µg/L)	0.5	0.88	Below standard	0.6
Calcium (mg/L)	27	None	N/A	31,495.9
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A
Copper (µg/L)	440.0	8.97	49.0	513.3
Fluoride (mg/L)	2.60	2.00	1.3	3,032.9
Iron (µg/L)	670	300.00	2.2	781.6
Lead (µg/L)	5.0	2.46	2.0	5.8
Magnesium (mg/L)	1.20	None	N/A	1,399.8
Manganese (µg/L)	330	50.00	6.6	384.9
Nickel (µg/L)	< 20	74.79	Below standard	N/A
Potassium (mg/L)	2.0	None	N/A	2,333.0
Silicon (mg/L)	8.4	None	N/A	9,798.7
Silver (µg/L)	< 0.2	0.04	Not detected	N/A
Sodium (mg/L)	0.94	None	N/A	1,096.5
Sulfate (mg/L)	40	250.00	Below standard	46,660.6
Zinc (µg/L)	150	80.64	1.9	175.0

Table 6. Analytical data for samples NW70-78, near the Allard stock--continued.

Sample	NW71, BOREN CREEK (9/18/99)				NW72, BASIN CREEK (9/18/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	4.0				100.0			
pH (standard units)	7.55				7.67			
Conductivity (µS/cm)	132.0				97.0			
Alkalinity (mg/L CaCO3)	< 20.00				< 20.00			
Hardness (mg/L CaCO3)	113	None	N/A		82	None	N/A	
Aluminum (trec) (µg/L)	< 50	None	N/A	N/A	< 50	None	N/A	N/A
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	30	1000.00	Below standard	0.7	< 10	1000.00	Below standard	N/A
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	19	2000.00	Below standard	0.4	16	2000.00	Below standard	8.7
Aluminum (µg/L)	< 50	87.00	Below standard	N/A	< 50	87.00	Below standard	N/A
Cadmium (µg/L)	< 0.3	1.25	Below standard	N/A	< 0.3	0.97	Below standard	N/A
Calcium (mg/L)	42	None	N/A	915.8	31	None	N/A	16,898.1
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	< 4.0	13.15	Below standard	N/A	< 4.0	9.98	Below standard	N/A
Fluoride (mg/L)	0.30	2.00	Below standard	6.5	< 0.10	2.00	Below standard	N/A
Iron (µg/L)	12	300.00	Below standard	0.3	< 10	300.00	Below standard	N/A
Lead (µg/L)	< 1.0	4.64	Below standard	N/A	< 1.0	2.94	Below standard	N/A
Magnesium (mg/L)	2.00	None	N/A	43.6	1.10	None	N/A	599.6
Manganese (µg/L)	22	50.00	Below standard	0.5	< 4	50.00	Below standard	N/A
Nickel (µg/L)	< 20	105.02	Below standard	N/A	< 20	82.20	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	2.4	None	N/A	52.3	2.4	None	N/A	1,308.2
Silver (µg/L)	< 0.2	0.09	Not detected	N/A	< 0.2	0.05	Not detected	N/A
Sodium (mg/L)	0.72	None	N/A	15.7	0.68	None	N/A	370.7
Sulfate (mg/L)	34	250.00	Below standard	741.3	21	250.00	Below standard	11,447.1
Zinc (µg/L)	18	117.73	Below standard	0.4	14	89.60	Below standard	7.6

Table 6. Analytical data for samples NW70-78, near the Allard stock--continued.

Sample	NW73, RUSH BASIN (9/19/99)				NW74, BELOW OWEN BASIN (9/19/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	10.0				300.0			
pH (standard units)	7.01				7.05			
Conductivity (µS/cm)	63.0				88.0			
Alkalinity (mg/L CaCO3)	< 20.00				< 20.00			
Hardness (mg/L CaCO3)	51	None	N/A		74	None	N/A	
Aluminum (trec) (µg/L)	< 50	None	N/A	N/A	210	None	N/A	343.4
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	38	1000.00	Below standard	2.1	18	1000.00	Below standard	29.4
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	< 10	2000.00	Below standard	N/A	23	2000.00	Below standard	37.6
Aluminum (µg/L)	< 50	87.00	Below standard	N/A	< 50	87.00	Below standard	N/A
Cadmium (µg/L)	< 0.3	0.67	Below standard	N/A	< 0.3	0.90	Below standard	N/A
Calcium (mg/L)	19	None	N/A	1,035.7	27	None	N/A	44,153.1
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	< 4.0	6.62	Below standard	N/A	< 4.0	9.15	Below standard	N/A
Fluoride (mg/L)	< 0.10	2.00	Below standard	N/A	< 0.10	2.00	Below standard	N/A
Iron (µg/L)	12	300.00	Below standard	0.7	< 10	300.00	Below standard	N/A
Lead (µg/L)	< 1.0	1.49	Below standard	N/A	< 1.0	2.54	Below standard	N/A
Magnesium (mg/L)	0.79	None	N/A	43.1	1.60	None	N/A	2,616.5
Manganese (µg/L)	< 4	50.00	Below standard	N/A	24	50.00	Below standard	39.2
Nickel (µg/L)	< 20	57.07	Below standard	N/A	< 20	76.07	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	0.08	None	N/A	4.4	2.4	None	N/A	3,924.7
Silver (µg/L)	< 0.2	0.02	Not detected	N/A	< 0.2	0.04	Not detected	N/A
Sodium (mg/L)	0.31	None	N/A	16.9	0.53	None	N/A	866.7
Sulfate (mg/L)	8	250.00	Below standard	436.1	27	250.00	Below standard	44,153.1
Zinc (µg/L)	< 10	59.65	Below standard	N/A	23	82.18	Below standard	37.6

Table 6. Analytical data for samples NW70-78, near the Allard stock--continued.

Sample	NW75, RUSH BASIN SOUTH (9/20/99)				NW76, RUSH BASIN SOUTH-UPPER (9/20/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	42.0				18.0			
pH (standard units)	3.58				3.59			
Conductivity (µS/cm)	835.0				455.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	44	None	N/A		29	None	N/A	
Aluminum (trec) (µg/L)	69,000	None	N/A	15,797.0	36,000	None	N/A	3,532.2
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	30.0	50.00	Below standard	6.9	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	43,000	1000.00	43.0	9,844.5	470	1000.00	Below standard	46.1
Thallium (trec) (µg/L)	5.0	0.50	10.0	1.1	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	480	2000.00	Below standard	109.9	170	2000.00	Below standard	16.7
Aluminum (µg/L)	72,000	87.00	827.6	16,483.8	34,000	87.00	390.8	3,336.0
Cadmium (µg/L)	1.9	0.60	3.2	0.4	0.7	0.43	1.6	0.1
Calcium (mg/L)	15	None	N/A	3,434.1	10	None	N/A	981.2
Chloride (mg/L)	150.0	250.00	Below standard	34,341.3	140.0	250.00	Below standard	13,736.5
Chromium (µg/L)	13	11.00	1.2	3.0	< 10	11.00	Below standard	N/A
Copper (µg/L)	5,700.0	5.87	971.1	1,305.0	1,200.0	4.12	291.4	117.7
Fluoride (mg/L)	< 1.00	2.00	Below standard	N/A	< 0.50	2.00	Below standard	N/A
Iron (µg/L)	46,000	300.00	153.3	10,531.3	440	300.00	1.5	43.2
Lead (µg/L)	< 1.0	1.22	Below standard	N/A	< 1.0	0.68	Not detected	N/A
Magnesium (mg/L)	1.60	None	N/A	366.3	1.00	None	N/A	98.1
Manganese (µg/L)	2,100	50.00	42.0	480.8	680	50.00	13.6	66.7
Nickel (µg/L)	100	51.27	2.0	22.9	42	37.40	1.1	4.1
Potassium (mg/L)	7.6	None	N/A	1,740.0	3.2	None	N/A	314.0
Silicon (mg/L)	15.0	None	N/A	3,434.1	14.0	None	N/A	1,373.7
Silver (µg/L)	< 0.2	0.02	Not detected	N/A	< 0.2	0.01	Not detected	N/A
Sodium (mg/L)	1.30	None	N/A	297.6	0.82	None	N/A	80.5
Sulfate (mg/L)	290	250.00	1.2	66,393.2	210	250.00	Below standard	20,604.8
Zinc (µg/L)	510	52.93	9.6	116.8	170	37.24	4.6	16.7

Table 6. Analytical data for samples NW70-78, near the Allard stock--continued.

Sample	NW77, BURWELL PEAK WEST (9/20/99)				NW78, GIBBS PEAK WEST (9/20/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	65.0				28.0			
pH (standard units)	4.23				4.83			
Conductivity (µS/cm)	321.0				88.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	189	None	N/A		57	None	N/A	
Aluminum (trec) (µg/L)	4,100	None	N/A	1,452.7	200	None	N/A	30.5
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	11	1000.00	Below standard	3.9	520	1000.00	Below standard	79.4
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	530	2000.00	Below standard	187.8	53	2000.00	Below standard	8.1
Aluminum (µg/L)	4,100	87.00	47.1	1,452.7	200	87.00	2.3	30.5
Cadmium (µg/L)	2.4	1.87	1.3	0.9	< 0.3	0.73	Below standard	N/A
Calcium (mg/L)	68	None	N/A	24,093.4	20	None	N/A	3,052.6
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	5,200.0	20.40	255.0	1,842.4	150.0	7.27	20.6	22.9
Fluoride (mg/L)	0.60	2.00	Below standard	212.6	0.40	2.00	Below standard	61.1
Iron (µg/L)	12	300.00	Below standard	4.3	170	300.00	Below standard	25.9
Lead (µg/L)	< 1.0	9.61	Below standard	N/A	< 1.0	1.74	Below standard	N/A
Magnesium (mg/L)	4.70	None	N/A	1,665.3	1.60	None	N/A	244.2
Manganese (µg/L)	1,200	50.00	24.0	425.2	340	50.00	6.8	51.9
Nickel (µg/L)	< 20	155.22	Below standard	N/A	< 20	61.98	Below standard	N/A
Potassium (mg/L)	1.0	None	N/A	354.3	1.3	None	N/A	198.4
Silicon (mg/L)	5.3	None	N/A	1,877.9	7.1	None	N/A	1,083.7
Silver (µg/L)	< 0.2	0.22	Below standard	N/A	< 0.2	0.03	Not detected	N/A
Sodium (mg/L)	1.40	None	N/A	496.0	0.70	None	N/A	106.8
Sulfate (mg/L)	110	250.00	Below standard	38,974.7	30	250.00	Below standard	4,578.8
Zinc (µg/L)	540	181.99	3.0	191.3	52	65.40	Below standard	7.9

Figure 29. Photograph showing weathered ferricrete at sample site NW76.

Although draining areas at least partly underlain with altered bedrock, four of the samples were relatively clean and within state standards for all analyzed parameters (samples NW71-74, table 6). An inactive, hard, and partly eroded ferricrete deposit occurred adjacent to the Boren Creek sample, and pyrite occurred in some of the alluvial material in Boren and Basin Creeks, but samples NW71-72 had similar metal concentrations and were relatively pure. Tests of many other tributaries of the La Plata River suggested no serious degradation, and no additional samples were collected (Figure 26).

Sample NW73 from a glacial lake at the headwaters of the East Mancos River above Rush Basin was clean. Sample NW74 was from the West Mancos River downstream from Owen Basin. Although iron-stained and silicified sandstone crop out above the sample site, and specularite and calcite occurred in the alluvium, the sample was clean. Downstream from site NW74, ferricrete/ferrosinter deposits and associated degraded springs reportedly occur (Benson and Nichols, 1998, p. 10-11). Although some of these springs are associated with small mines, in all likelihood the mines were driven to explore fault zones where degraded water emerged and formed precipitate deposits, an obvious mineral exploration target. These downstream sites were not visited during this study because of ambiguity concerning the origin of the degraded waters and the time required to access them.

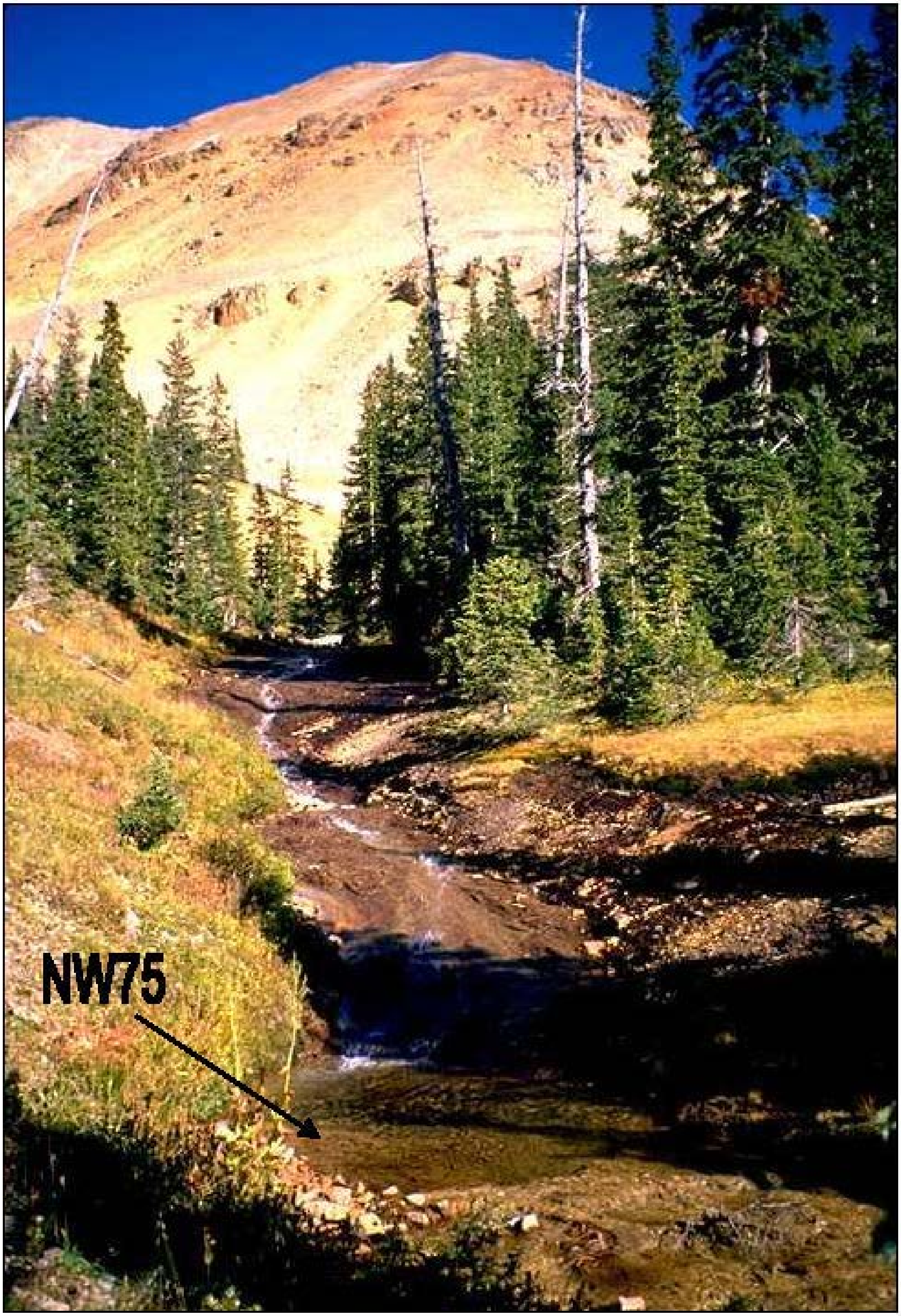

Figure 30. Photograph showing sample site NW75 and terracettes of ferrosinter.

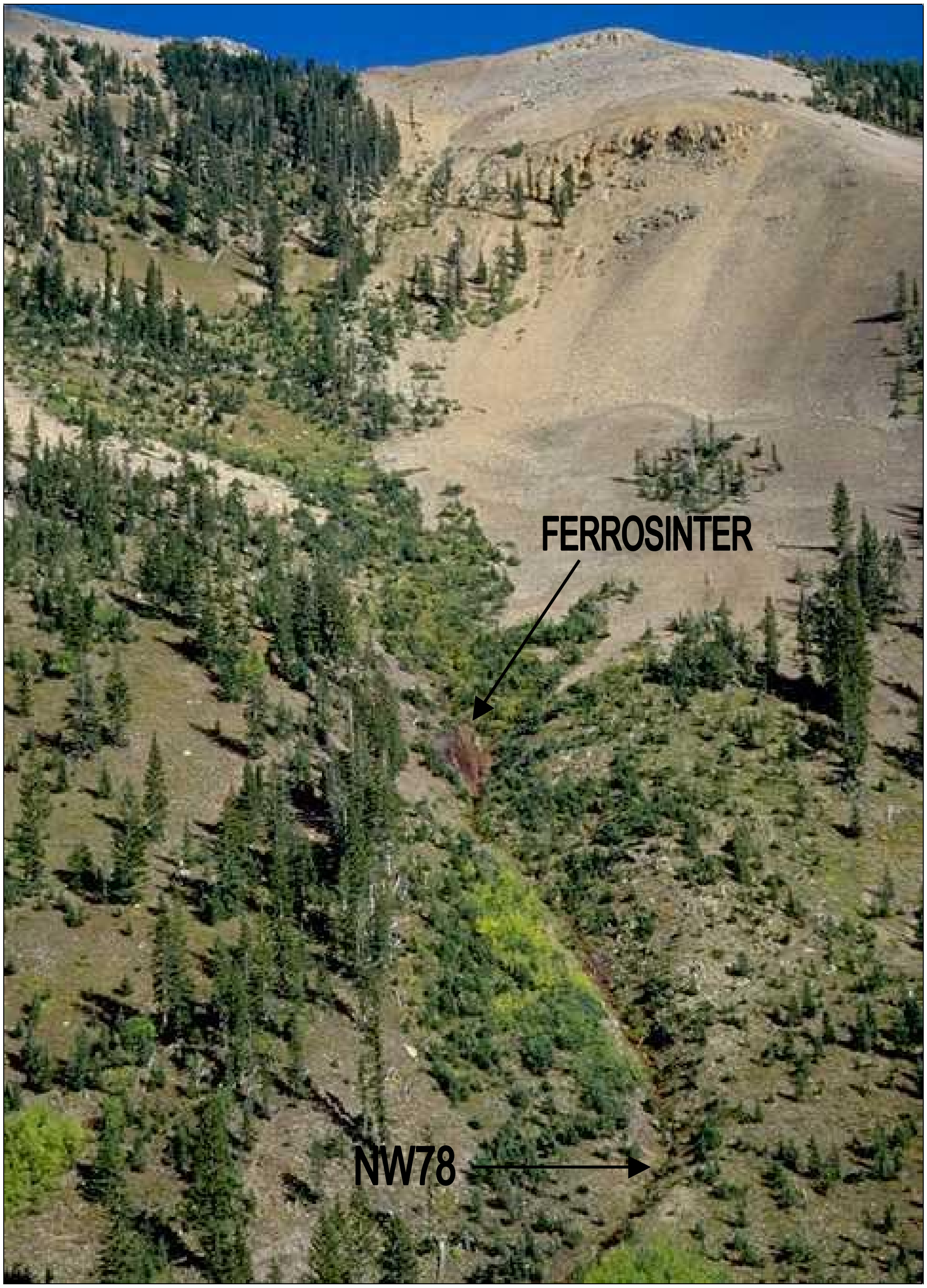

Figure 31. Photograph showing ferrosinter deposit on the west side of Gibbs Peak and sample site NW78.

RICO MOUNTAINS

The Rico Mountains are in southwest Colorado, near the headwaters of the East and West Dolores Rivers. The town of Rico and the Rico and Dunton mining districts are within the mountain range. Degraded waters sampled for this study emanate from the Calico Peak-Eagle Peak area, and from Darling Ridge, lying between Rico and Dunton.

Geology

Rocks exposed in the Rico area range in age from Precambrian to Tertiary. Precambrian rocks include greenstone and metadiorite overlain by Uncompahgre Quartzite. Paleozoic-age rocks are abundant and include the Leadville Limestone, Larson Quartzite, Hermosa Formation, Rico Formation, and Cutler Formation. The nearly 3,000-foot-thick Hermosa Formation is the most commonly exposed sedimentary rock and consists of interbedded sandstones, arkoses, shales, conglomerates, limestones, dolomites, and gypsum. (See Neubert and others, 1992, p. 30.)

At least three magmatic episodes have affected the Rico area. Laramide-age latite porphyry sills and dikes are common throughout the district. Later during Laramide time, a monzonite stock up to 2 miles wide intruded the rocks on the west side of the Dolores River. Intrusion of this monzonite stock and the associated hydrothermal fluids probably caused much of the replacement- and vein-type mineralization of the Rico mining district. Much younger, Pliocene-age dikes and small stocks of alaskite are presumably the source rocks for deeply buried stockwork molybdenum occurrences. (See Neubert and others, 1992, p. 31.)

Intrusion of the igneous rocks formed a structural dome about 6,000 feet high and 5 to 10 miles in diameter. The doming event was accompanied by associated faulting, folding, and tilting of the sedimentary rocks in the Rico area. (See Neubert and others, 1992, p. 31.)

Some of these faults provided channels for mineralizing fluids to replace adjacent sedimentary rocks and form vein deposits. Large quantities of silver, lead, zinc, and sulfuric acid (From pyrite) were produced from replacement and vein-type deposits in the Rico area. Gold and copper were byproducts. At least one deeply buried, sub-economic stockwork molybdenum deposit exists. (See Neubert and others, 1992, p. 31-32.)

At Calico Peak, about 3 miles west-northwest of Rico, Tertiary-age latite porphyry dikes and plugs intruded Paleozoic- and Mesozoic-age sedimentary rocks. The igneous plug at Calico Peak, and the surrounding faults and fractures in the sedimentary rocks have been intensely altered. The alteration occurred in at least two stages; an earlier episode of hydrothermal, probably epithermal alteration, followed by a late stage consisting of solfataric alteration. Many of the original minerals, especially the feldspars, have been changed to clay; and disseminated pyrite and/or oxidized pyrite (limonite, hematite) are common. Alunite and jarosite also occur. (See Pratt and others, 1969; Neubert and others, 1992, p. 16-18, A-5 - A-8.)

Springs in the Rico-Dunton area often have associated gases. Carbon dioxide and hydrogen sulfide gases are common in the mines. Small bubbles of gas were observed emerging from fractured bedrock exposed in some of the streambeds.

Previous Investigations

Ferruginous springs are reported in Silver Creek, in the northern and western branches of upper Horse Creek, and in lower Horse Creek. Horse Creek is northwest of Rico and drains the eastern side of the intensely altered terrain of Calico Peak and Johnny Bull Mountain. The springs have deposited limonite in swampy areas of the stream valley. Although mines are present in these drainage basins, the limonite deposits were recorded as early as 1900. (See Harrer and Tesch, 1959, p. 26-27.) These deposits are probably not a result of upstream mines, although upstream mining activity may have altered the chemistry of the springs to some extent.

Present Investigation

Sample NW67 was collected from Sulphur Creek, upstream of some small surface and underground sulfur mines (Figure 32). Flow was 90 gpm, pH was 8.11, and conductivity was 435 µS/cm. The water had high hardness and did not exceed state standards in any of the analyzed parameters (Table 7). Zinc concentration was slightly anomalous, but well within standards. No sample was collected downstream of the sulfur occurrences because mining-related versus natural degradation could not be determined.

Samples NW68 and NW69 were from the upper forks of Silver Creek, upstream of the Rosebud Mine and a few small sulfur occurrences (Figure 32). Bedrock adjacent to the sample sites included red beds cut by porphyry dikes (Figure 33) and sometimes overlain or flanked by secondary deposits of "claycrete", where pebbles and gravels of various compositions are cemented by light-colored clay. The "claycrete" is generally soft, but occasionally is indurated to some extent. Altered igneous rocks exposed upstream of the sample site contain alunite. Alluvium in the stream channels includes medium- to coarse-grained red arkose, fine-grained gray and nearly white sandstone with some calcite in the matrix, and porphyritic igneous rocks. The porphyry shows various degrees of alteration, from completely argillized into clay to fresher material with intense red stain and minor pyrite. A strong smell of sulfurous gas occurs throughout this area.

Sample NW68 was from the main fork of Silver Creek. Flow was 150 gpm, pH was 7.69, and conductivity was 638 µS/cm. The stream water had high hardness and alkalinity. Manganese concentration exceeded standards, and sulfate was elevated but within standards (Table 7). Perhaps because of the high calcium concentration in the sample, detection limits for copper and zinc were about 10 times higher than normal, and the concentrations of these metals is not known.

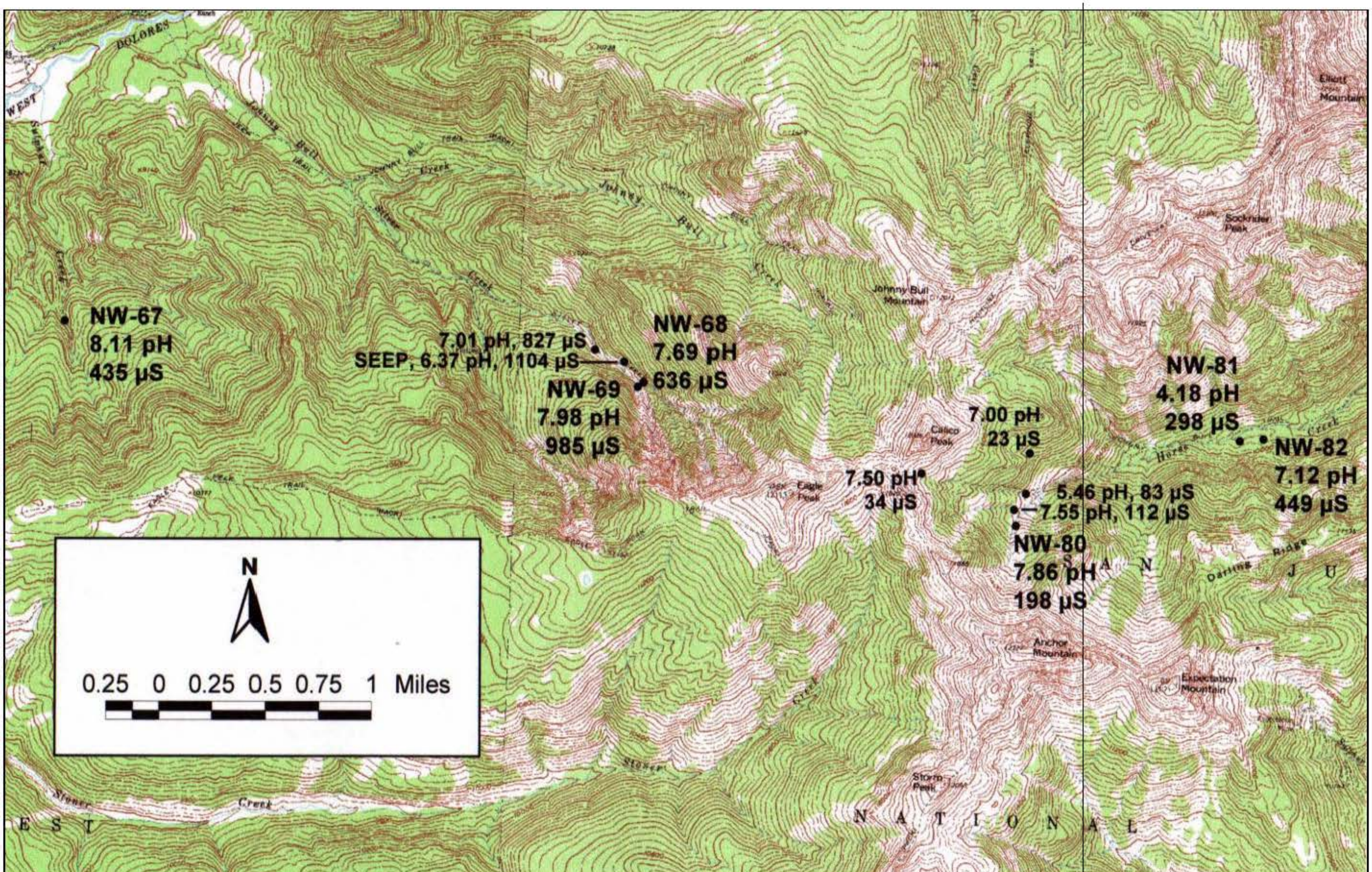

Figure 32. Map showing sample sites NW67-69, 80-82, and test results in the Rico-Dunton area.

Table 7. Analytical data for samples NW67-69, 80-82 from the Rico-Dunton area.

Sample	NW67, SULPHUR CREEK (9/26/99)				NW68, SILVER CREEK (9/26/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	90.0				150.0			
pH (standard units)	8.11				7.69			
Conductivity (µS/cm)	435.0				636.0			
Alkalinity (mg/L CaCO3)					125.00			
Hardness (mg/L CaCO3)	449	None	N/A		674	None	N/A	
Aluminum (trec) (µg/L)	< 50	None	N/A	N/A	170	None	N/A	139.0
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	50	1000.00	Below standard	24.5	390	1000.00	Below standard	318.9
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	16	2000.00	Below standard	7.8	< 100	2000.00	Below standard	N/A
Aluminum (µg/L)	< 50	87.00	Below standard	N/A	65	87.00	Below standard	53.1
Cadmium (µg/L)	< 0.3	3.69	Below standard	N/A	< 0.3	5.07	Below standard	N/A
Calcium (mg/L)	150	None	N/A	73,588.5	240	None	N/A	196,236.0
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	< 4.0	42.65	Below standard	N/A	< 40.0	60.36	Below standard	N/A
Fluoride (mg/L)	< 0.10	2.00	Below standard	N/A	< 0.10	2.00	Below standard	N/A
Iron (µg/L)	28	300.00	Below standard	13.7	18	300.00	Below standard	14.7
Lead (µg/L)	< 1.0	32.66	Below standard	N/A	< 1.0	58.08	Below standard	N/A
Magnesium (mg/L)	18.00	None	N/A	8,830.6	18.00	None	N/A	14,717.7
Manganese (µg/L)	13	50.00	Below standard	6.4	240	50.00	4.8	196.2
Nickel (µg/L)	< 20	299.17	Below standard	N/A	< 20	407.41	Below standard	N/A
Potassium (mg/L)	1.9	None	N/A	932.1	1.3	None	N/A	1,062.9
Silicon (mg/L)	3.0	None	N/A	1,471.8	3.5	None	N/A	2,861.8
Silver (µg/L)	< 0.2	0.99	Below standard	N/A	< 0.2	2.00	Below standard	N/A
Sodium (mg/L)	2.50	None	N/A	1,226.5	1.10	None	N/A	899.4
Sulfate (mg/L)	20	250.00	Below standard	9,811.8	130	250.00	Below standard	106,294.5
Zinc (µg/L)	19	378.23	Below standard	9.3	< 100	533.69	Below standard	N/A

Table 7. Analytical data for samples NW67-69, 80-82 from the Rico-Dunton area--continued.

Sample	NW69, SILVER CREEK WEST (9/26/99)				NW80, HORSE CREEK (9/27/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	18.0				150.0			
pH (standard units)	7.98				7.86			
Conductivity (µS/cm)	985.0				198.0			
Alkalinity (mg/L CaCO3)					50.00			
Hardness (mg/L CaCO3)	1,310	None	N/A		191	None	N/A	
Aluminum (trec) (µg/L)	1,000	None	N/A	98.1	< 50	None	N/A	N/A
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	1,500	1000.00	1.5	147.2	15	1000.00	Below standard	12.3
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	< 500	2000.00	Below standard	N/A	11	2000.00	Below standard	9.0
Aluminum (µg/L)	210	87.00	2.4	20.6	< 50	87.00	Below standard	N/A
Cadmium (µg/L)	< 0.3	8.55	Below standard	N/A	< 0.3	1.88	Below standard	N/A
Calcium (mg/L)	460	None	N/A	45,134.3	68	None	N/A	55,600.2
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	< 40.0	106.52	Below standard	N/A	< 4.0	20.51	Below standard	N/A
Fluoride (mg/L)	< 0.10	2.00	Below standard	N/A	0.26	2.00	Below standard	212.6
Iron (µg/L)	370	300.00	1.2	36.3	< 10	300.00	Below standard	N/A
Lead (µg/L)	< 1.0	148.98	Below standard	N/A	< 1.0	9.70	Below standard	N/A
Magnesium (mg/L)	39.00	None	N/A	3,826.6	5.00	None	N/A	4,088.3
Manganese (µg/L)	600	50.00	12.0	58.9	< 4	50.00	Below standard	N/A
Nickel (µg/L)	< 20	675.23	Below standard	N/A	< 20	155.98	Below standard	N/A
Potassium (mg/L)	3.0	None	N/A	294.4	< 1.0	None	N/A	N/A
Silicon (mg/L)	4.9	None	N/A	480.8	1.3	None	N/A	1,062.9
Silver (µg/L)	< 0.2	6.27	Below standard	N/A	< 0.2	0.23	Below standard	N/A
Sodium (mg/L)	4.70	None	N/A	461.2	0.69	None	N/A	564.2
Sulfate (mg/L)	210	250.00	Below standard	20,604.8	42	250.00	Below standard	34,341.3
Zinc (µg/L)	< 100	937.36	Below standard	N/A	< 10	182.99	Below standard	N/A

Table 7. Analytical data for samples NW67-69, 80-82 from the Rico-Dunton area--continued.

Sample	NW81, HORSE CREEK SOUTH (9/27/99)				NW82, DARLING RIDGE NORTH (9/27/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	100.0				23.0			
pH (standard units)	4.18				7.12			
Conductivity (µS/cm)	298.0				449.0			
Alkalinity (mg/L CaCO3)					22.00			
Hardness (mg/L CaCO3)	159	None	N/A		399	None	N/A	
Aluminum (trec) (µg/L)	2,700	None	N/A	1,471.8	2,300	None	N/A	288.4
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	400	1000.00	Below standard	218.0	830	1000.00	Below standard	104.1
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	360	2000.00	Below standard	196.2	270	2000.00	Below standard	33.9
Aluminum (µg/L)	2,700	87.00	31.0	1,471.8	< 50	87.00	Below standard	N/A
Cadmium (µg/L)	2.9	1.64	1.8	1.6	2.2	3.36	Below standard	0.3
Calcium (mg/L)	51	None	N/A	27,800.1	140	None	N/A	17,552.2
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	160.0	17.62	9.1	87.2	6.0	38.59	Below standard	0.8
Fluoride (mg/L)	0.65	2.00	Below standard	354.3	0.57	2.00	Below standard	71.5
Iron (µg/L)	380	300.00	1.3	207.1	130	300.00	Below standard	16.3
Lead (µg/L)	< 1.0	7.54	Below standard	N/A	< 1.0	27.66	Below standard	N/A
Magnesium (mg/L)	7.80	None	N/A	4,251.8	12.00	None	N/A	1,504.5
Manganese (µg/L)	3,600	50.00	72.0	1,962.4	2,500	50.00	50.0	313.4
Nickel (µg/L)	< 20	136.27	Below standard	N/A	< 20	273.69	Below standard	N/A
Potassium (mg/L)	1.3	None	N/A	708.6	1.2	None	N/A	150.4
Silicon (mg/L)	14.0	None	N/A	7,631.4	8.4	None	N/A	1,053.1
Silver (µg/L)	< 0.2	0.17	Not detected	N/A	< 0.2	0.81	Below standard	N/A
Sodium (mg/L)	3.40	None	N/A	1,853.3	2.50	None	N/A	313.4
Sulfate (mg/L)	120	250.00	Below standard	65,412.0	190	250.00	Below standard	23,820.9
Zinc (µg/L)	390	157.41	2.5	212.6	200	342.50	Below standard	25.1

Figure 33. Photograph showing sample site NW69 and porphyry dike in upper Silver Creek.

Figure 33. Photograph showing sample site NW69 and porphyry dike in upper Silver Creek.

Sample NW69 was from the west fork of Silver Creek, about 100 feet downstream of the outcrop of an argillic-altered porphyry dike that crosses the stream channel. The water was slightly murky, and moderate amounts of red and yellow precipitate were in the stream channel. Flow was 18 gpm, pH was 7.98, and conductivity was 985 µS/cm. Hardness of the sample was over 1,000 mg/L. Manganese, aluminum, and iron concentrations exceeded state standards, and sulfate was elevated (Table 7). Similar to NW68, detection limits for copper and zinc were about 10 times higher than normal, and these elements were not detected. Large differences between total and dissolved aluminum and iron concentrations suggest that compounds of these elements occurred as suspended solids.

Sample NW80 was from near the headwaters of Horse Creek. Minor red staining occurs on the bedrock and talus above the sample site. Flow was 150 gpm, pH was 7.86, and conductivity was 198 µS/cm. Despite the weakly altered rock above the site, this water was relatively clean and did not exceed standards in any of the tested parameters.

Sample NW81 was from one of several springs emerging in and adjacent to an iron bog on the south side of Horse Creek (Figure 34). Flow was estimated at 100 gpm for the series of springs. At the sample site, pH was 4.18 and conductivity was 298 µS/cm. Manganese, aluminum, and copper significantly exceeded standards; and zinc, cadmium, and iron also exceeded standards.

Sample NW82 was from a steep gulch that borders the east side of the iron bog. Exposed bedrock(?) higher in the gulch appeared altered and was stained dark brown to almost black (Figure 35). This area was mapped as a landslide deposit (Pratt and others, 1969). Alluvial material at the sample site included fresh diorite and altered porphyry. Some of the altered rocks were bleached, chalky, and crumbly; others were silicified with pyrite occurring in veinlets or disseminated. Flow was 23 gpm, pH was 7.12, and conductivity was 449 µS/cm. Hardness was quite high at 449 mg/L. Manganese concentration was 50 times higher than the state standard. Sulfate was elevated, but within standards. Zinc and cadmium were also elevated, but within their hardness-related standards (Table 7). Yellow precipitate accumulated on the filter during the sampling, and large differences between the total and dissolved aluminum and iron concentrations suggest that significant volumes of these elements occur as suspended solids. This sample site was above a nearby caved adit that was draining obviously degraded effluent with 6.03 pH and 388 µS/cm conductivity. The effluent was forming a terraced ferrosinter deposit on the associated waste-rock pile.

Figure 34. Photograph showing sample site NW81 at wetlands with iron bog along Horse Creek.

Figure 35. Photograph showing sample site NW82 at altered gulch draining into Horse Creek. This entire mountainside is mapped as a landslide deposit (Pratt and others, 1969).

WEST-CENTRAL COLORADO

Areas sampled in west-central Colorado include altered areas associated with the Grizzly Peak caldera in the Sawatch Range, and parts of the Ruby Range near Crested Butte (Figure 1).

GRIZZLY PEAK CALDERA

The Grizzly Peak caldera straddles the Continental Divide, extending about 12 miles southward from Independence Pass. The caldera is about 10 miles wide. "East Red Mountain" is near the eastern boundary, and the headwaters of New York and Bowman Creeks are near the western boundary. (See Fridrich and others, 1991; Tweto and others, 1978.) Degraded water emerges on both sides of the Continental Divide, affecting Lincoln Creek on the west side, and South Fork of Lake Creek on the east side.

Geology

About 39 million years ago, prior to formation of the Grizzly Peak caldera, numerous rhyolitic stocks and dikes were emplaced in an arcuate zone of fractures that encircled and included the site of the future caldera. Circulation of hydrothermal fluids related to this pre-caldera magmatism caused widespread alteration and formed porphyry molybdenum occurrences and gold-bearing quartz-pyrite veins. (See Fridrich and others, 1991, p. 1160-1161, 1167.)

The Grizzly Peak caldera resulted from eruption of the rhyolitic Grizzly Peak Tuff between 37 and 32 million years ago and is slightly older than the calderas of the San Juan Mountains. During subsidence, an inner ring-fracture zone formed because of substantial differences in depths of collapse within the caldera. Caldera resurgence caused by emplacement of a granodiorite laccolith resulted in a complexly faulted dome. Fault zones in the resurgent dome were later intruded by post-caldera, intermediate-composition dikes and small stocks. (See Fridrich and others, 1991, p. 1160.)

Previous Investigations

In 1994, Colorado Geological Survey personnel collected a water sample from one of a series of springs on the northwest side of Peekaboo Gulch, about ½ mile below its headwaters (Figure 36). The springs emerge near a ring fracture that separates older, intracaldera collapse breccias and lavas on the northwestern side of the fault from younger Grizzly Peak Tuff on the southeastern side of the fault. The ring fracture is a reverse fault with 3,000 to 4,000 feet of displacement that formed during resurgent doming within the caldera. Emplacement of intrusions during the resurgent doming episode caused extensive and pervasive hydrothermal alteration and metal-sulfide mineralization in the overlying rocks. (See Sares, 1996, p. 6; Fridrich and others, 1991, p. 1173.)

Figure 36. Photograph showing west side of Peekaboo Gulch. Ferrosinter deposits are on the lower right. White stream shows where aluminum hydroxides precipitate when clean water from upstream begins diluting the acidic, metal-laden spring waters seeping from the walls of the gulch.

Although a few small- to moderate-sized mines and prospects lie upslope from this spring, they drain no water and probably do not affect the Peekaboo Gulch springs. Water sampled in 1994 from a Peekaboo Gulch spring greatly exceeded state standards in aluminum, cadmium, copper, iron, and zinc concentrations. Silver and sulfate concentrations also exceeded standards. Spring water had pH of 2.17 and an estimated flow of 25 gpm. Water from this series of springs had an obvious impact on Peekaboo Gulch. Above the springs the water in the stream was clear, and pH was nearly neutral. Below the springs the stream water was red with iron hydroxide precipitate, and the pH was about 3.5. (See Sares, 1996, p. 7.) Where dilution of the acidic spring water initially begins, white precipitate (aluminum hydroxide?) forms (Figure 36).

The altered rocks of Red Mountain and the ridge to the south also affect water on the west side of the Continental Divide near the ghost town of Ruby. Lincoln Creek, a tributary of the Roaring Fork River, is the affected stream. An unmarked and unnamed tributary of Lincoln Creek originating from the ridge south of Red Mountain was sampled in 1997. The stream was sampled above all the known mines. The active channel was lined with well-indurated ferricrete and ferrosinter; and a weathered ferrosinter deposit comprising brown powdery material occurred adjacent to and north of this stream. At the sample site, conductivity was more than 2,000 µS/cm, and pH was about 3. Aluminum and iron concentrations were greater than 150,000 µg/L, copper was 6,300 µg/L, and manganese, sulfate, zinc, cadmium, chromium, and nickel also exceeded stream standards. Lincoln Creek had red precipitate beginning at the confluence with the unnamed stream. Interestingly, test results from a marked, but unnamed, stream draining the west side of Red Mountain and only about 800 feet north of the degraded stream did not indicate significant degradation. (See Neubert and others, 1998b, p. 16-18.)

Present Investigation

In 1999, seven samples were collected in the vicinity of the Grizzly Peak caldera, all in the South Fork Lake Creek drainage basin (Figure 37). Sample and water test results are discussed beginning with the upstream sites.

Tests were performed on some of the numerous springs that emerge on the west side of Peekaboo Gulch, near the break in slope between the steep walls of the lower part of the gulch and a relatively flat bench (Figures 36, 37). The slopes above the springs comprise intensely altered and fractured volcanic rocks with red, brown, and yellow staining and some bleaching. Disseminated pyrite is common. Although one moderate-sized and a few small mine workings penetrate the slope above the bench, these mines were dry and probably do not affect groundwater in this area. Tests showed pH values between 2.61 and 3.12 and conductivities between 585 µS/cm and 1,960 µS/cm. Abundant fresh and older, hard, red-brown ferrosinter occurs throughout the areas with springs, indicative of a long history of poor water quality.

Sample NW29 was from the upper reaches of the Peekaboo Gulch stream, where degraded water from the springs starts to reveal its influence through the appearance of moderate to abundant light gray-green precipitate (Figure 36). Flow was estimated at 800 gpm, pH was 4.30, and conductivity was 79 µS/cm. This water exceeded state standards in concentrations of aluminum, copper, and zinc (Table 8). Total aluminum concentration was more than double the dissolved concentration, suggesting that much of the precipitate consists of aluminum hydroxides.

Sample NW33 was from the lower portion of a large ferrosinter/ferricrete deposit, below the convergence of several small springs (Figure 38). This is the same general area where the 1994 sample was collected. Some of the ferricrete is stained yellow-green (copiapite?). Flow was measured at 30 gpm, pH was 2.85, and conductivity was 1,764 µS/cm. This water was extremely degraded, exceeding state standards by more than two orders of magnitude in aluminum, iron, and copper concentrations. Manganese, zinc, cadmium, and sulfate also exceeded standards (Table 8).

Several similar springs join Peekaboo Gulch from the west side in the area extending from a few hundred feet south of sample site NW33 to the stream that serves as the outlet of Herschel Lake. This zone of degraded seeps corresponds with the highly altered red-stained bedrock and talus that forms the southeastern slopes of Red Mountain. The stream draining Herschel Lake derives most of its water from less severely altered bedrock on the northeastern side of Red Mountain; pH was 6.80 and conductivity was 117 µS/cm (Figure 37). Water tested in a ravine about 100 feet south of the Herschel Lake outlet stream had pH of 3.88 and 98 µS/cm conductivity. This ravine originates in the highly altered slopes on the southeast side of Red Mountain, and a small mine was visible adjacent to the stream above the test site.

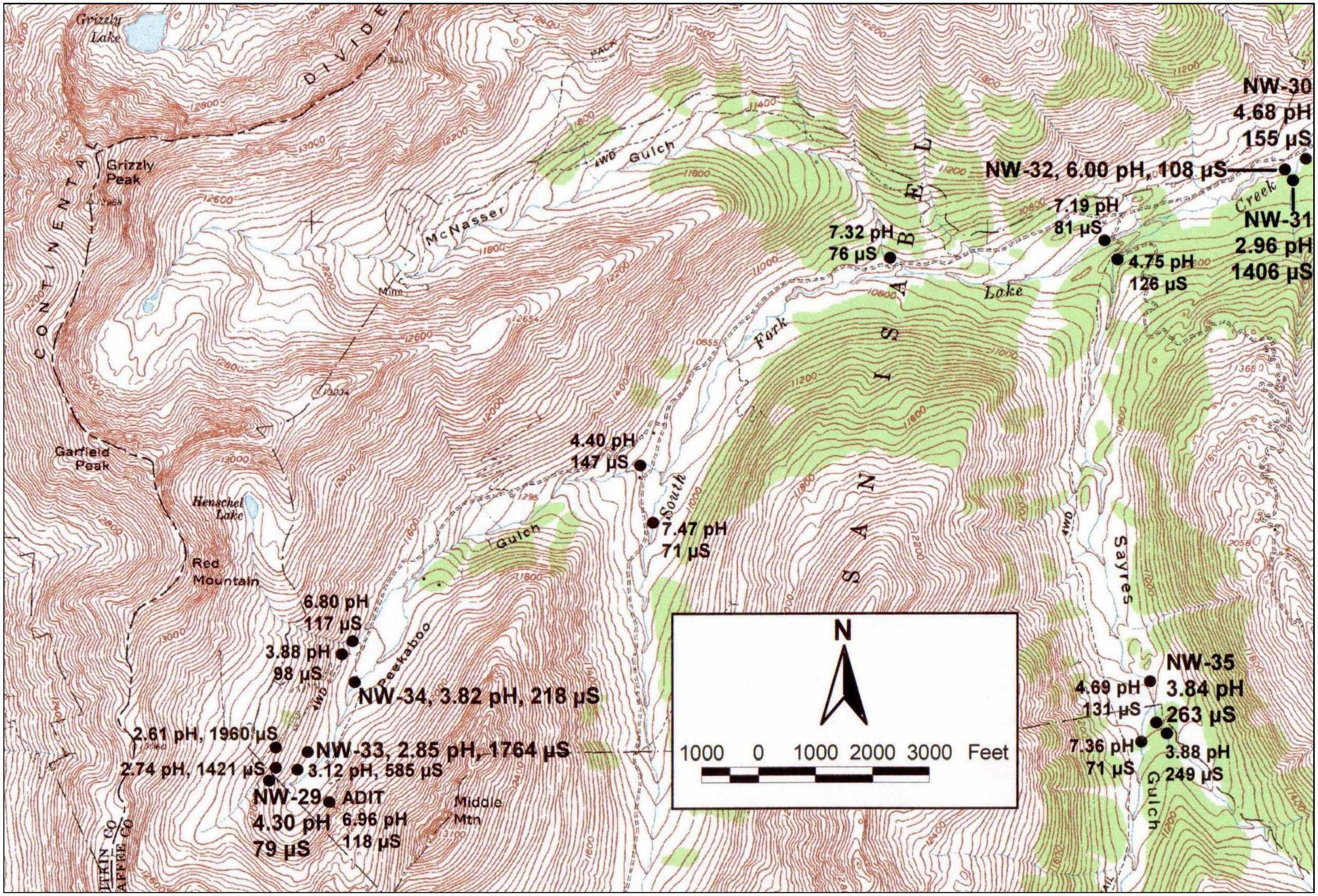

Figure 37. Map showing sample sites and test results in the South Fork of Lake Creek drainage basin.

Table 8. Analytical data for samples NW29-35 from the Grizzly Peak caldera area.

Sample	NW29, UPPER PEEKABOO (8/12/99)				NW30, S. FORK LAKE CREEK-DOWNSTREAM (8/13/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	800.0				7,000.0			
pH (standard units)	4.30				4.68			
Conductivity (µS/cm)	79.0				155.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	26	None	N/A		91	None	N/A	
Aluminum (trec) (µg/L)	1,800	None	N/A	7,849.4	4,300	None	N/A	164,075.1
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	81	1000.00	Below standard	353.2	3,100	1000.00	3.1	118,286.7
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	31	2000.00	Below standard	135.2	57	2000.00	Below standard	2,174.9
Aluminum (µg/L)	700	87.00	8.0	3,052.6	2,500	87.00	28.7	95,392.5
Cadmium (µg/L)	< 0.3	0.39	Below standard	N/A	< 0.3	1.05	Below standard	N/A
Calcium (mg/L)	9	None	N/A	39,247.2	32	None	N/A	1,221,024.0
Chloride (mg/L)	< 1.0	250.00	Below standard	N/A	11.0	250.00	Below standard	419,727.0
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	110.0	3.69	29.8	479.7	180.0	10.87	16.6	6,868.3
Fluoride (mg/L)	< 0.10	2.00	Below standard	N/A	< 0.10	2.00	Below standard	N/A
Iron (µg/L)	20	300.00	Below standard	87.2	660	300.00	2.2	25,183.6
Lead (µg/L)	< 1.0	0.56	Not detected	N/A	< 1.0	3.39	Below standard	N/A
Magnesium (mg/L)	0.76	None	N/A	3,314.2	2.60	None	N/A	99,208.2
Manganese (µg/L)	29	50.00	Below standard	126.5	64	50.00	1.3	2,442.0
Nickel (µg/L)	< 20	33.95	Below standard	N/A	< 20	88.71	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	3.1	None	N/A	13,518.5	2.7	None	N/A	103,023.9
Silver (µg/L)	< 0.2	0.01	Not detected	N/A	< 0.2	0.06	Not detected	N/A
Sodium (mg/L)	0.82	None	N/A	3,575.9	1.10	None	N/A	41,972.7
Sulfate (mg/L)	17	250.00	Below standard	74,133.6	53	250.00	Below standard	2,022,321.0
Zinc (µg/L)	39	33.43	1.2	170.1	55	97.54	Below standard	2,098.6

Table 8. Analytical data for samples NW29-35 from the Grizzly Peak caldera area--continued.

Sample	NW31, UNNAMED E. OF SAYRES GULCH (8/13/99)				NW32, S. FK. LAKE CK BELOW SAYRES (8/13/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	500.0				7,000.0			
pH (standard units)	2.96				6.00			
Conductivity (µS/cm)	1,406.0				108.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	270	None	N/A		86	None	N/A	
Aluminum (trec) (µg/L)	78,000	None	N/A	212,589.0	2,200	None	N/A	83,945.4
Antimony (trec) (µg/L)	< 3.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 3.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	68,000	1000.00	68.0	185,334.0	1,200	1000.00	1.2	45,788.4
Thallium (trec) (µg/L)	< 3.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	390	2000.00	Below standard	1,062.9	49	2000.00	Below standard	1,869.7
Aluminum (µg/L)	78,000	87.00	896.6	212,589.0	< 50	87.00	Below standard	N/A
Cadmium (µg/L)	3.4	2.47	1.4	9.3	< 0.3	1.01	Below standard	N/A
Calcium (mg/L)	80	None	N/A	218,040.0	31	None	N/A	1,182,867.0
Chloride (mg/L)	32.0	250.00	Below standard	87,216.0	1.0	250.00	Below standard	38,157.0
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	2,300.0	27.60	83.3	6,268.7	62.0	10.41	6.0	2,365.7
Fluoride (mg/L)	1.00	2.00	Below standard	2,725.5	< 0.10	2.00	Below standard	N/A
Iron (µg/L)	67,000	300.00	223.3	182,608.5	230	300.00	Below standard	8,776.1
Lead (µg/L)	< 3.0	15.87	Below standard	N/A	< 1.0	3.15	Below standard	N/A
Magnesium (mg/L)	17.00	None	N/A	46,333.5	2.10	None	N/A	80,129.7
Manganese (µg/L)	1,100	50.00	22.0	2,998.1	32	50.00	Below standard	1,221.0
Nickel (µg/L)	97	203.15	Below standard	264.4	< 20	85.31	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	10.0	None	N/A	27,255.0	2.5	None	N/A	95,392.5
Silver (µg/L)	< 0.6	0.41	Not detected	N/A	< 0.2	0.06	Not detected	N/A
Sodium (mg/L)	5.30	None	N/A	14,445.2	1.00	None	N/A	38,157.0
Sulfate (mg/L)	620	250.00	2.5	1,689,810.0	31	250.00	Below standard	1,182,867.0
Zinc (µg/L)	390	245.67	1.6	1,062.9	42	93.38	Below standard	1,602.6

Table 8. Analytical data for samples NW29-35 from the Grizzly Peak caldera area--continued.

Sample	NW33, PEEKABOO WEST (8/13/99)				NW34, PEEKABOO UPSTREAM OF HERSCHEL (8/13/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	30.0				500.0			
pH (standard units)	2.85				3.82			
Conductivity (µS/cm)	1,764.0				218.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	98	None	N/A		72	None	N/A	
Aluminum (trec) (µg/L)	100,000	None	N/A	16,353.0	6,400	None	N/A	17,443.2
Antimony (trec) (µg/L)	< 5.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 5.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	190,000	1000.00	190	3,107.1	3,900	1000.00	3.9	10,629.5
Thallium (trec) (µg/L)	< 5.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	610	2000.00	Below standard	99.8	62	2000.00	Below standard	169.0
Aluminum (µg/L)	100,000	87.00	1,149.4	16,353.0	6,200	87.00	71.3	16,898.1
Cadmium (µg/L)	6.4	1.12	5.7	1.0	0.4	0.88	Below standard	1.1
Calcium (mg/L)	32	None	N/A	5,233.0	26	None	N/A	70,863.0
Chloride (mg/L)	29.0	250.00	Below standard	4,742.4	3.0	250.00	Below standard	8,176.5
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	1,500.0	11.63	129.0	245.3	200.0	8.93	22.4	545.1
Fluoride (mg/L)	1.20	2.00	Below standard	196.2	0.10	2.00	Below standard	272.6
Iron (µg/L)	190,000	300.00	633.3	31,070.7	3,200	300.00	10.7	8,721.6
Lead (µg/L)	< 5.0	3.78	Not detected	N/A	< 1.0	2.44	Below standard	N/A
Magnesium (mg/L)	4.40	None	N/A	719.5	1.70	None	N/A	4,633.4
Manganese (µg/L)	520	50.00	10.4	85.0	62	50.00	1.2	169.0
Nickel (µg/L)	< 20	94.15	Below standard	N/A	< 20	74.44	Below standard	N/A
Potassium (mg/L)	7.7	None	N/A	1,259.2	< 1.0	None	N/A	N/A
Silicon (mg/L)	27.0	None	N/A	4,415.3	4.6	None	N/A	12,537.3
Silver (µg/L)	< 1.0	0.07	Not detected	N/A	< 0.2	0.04	Not detected	N/A
Sodium (mg/L)	3.00	None	N/A	490.6	1.10	None	N/A	2,998.1
Sulfate (mg/L)	1,000	250.00	4.0	163,530.0	63	250.00	Below standard	171,706.5
Zinc (µg/L)	620	104.23	5.9	101.4	57	80.21	Below standard	155.4

Table 8. Analytical data for samples NW29-35 from the Grizzly Peak caldera area--continued.

Sample	NW35, EAST FORK OF SAYRES GULCH (8/13/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	1,200.0			
pH (standard units)	3.84			
Conductivity (µS/cm)	263.0			
Alkalinity (mg/L CaCO3)				
Hardness (mg/L CaCO3)	96	None	N/A	
Aluminum (trec) (µg/L)	10,000	None	N/A	65,412.0
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	4,500	1000.00	4.5	29,435.4
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	110	2000.00	Below standard	719.5
Aluminum (µg/L)	9,800	87.00	112.6	64,103.8
Cadmium (µg/L)	0.4	1.10	Below standard	2.6
Calcium (mg/L)	31	None	N/A	202,777.2
Chloride (mg/L)	7.0	250.00	Below standard	45,788.4
Chromium (µg/L)	< 10	11.00	Below standard	N/A
Copper (µg/L)	640.0	11.41	56.1	4,186.4
Fluoride (mg/L)	0.40	2.00	Below standard	2,616.5
Iron (µg/L)	1,400	300.00	4.7	9,157.7
Lead (µg/L)	< 1.0	3.67	Below standard	N/A
Magnesium (mg/L)	4.50	None	N/A	29,435.4
Manganese (µg/L)	130	50.00	2.6	850.4
Nickel (µg/L)	27	92.62	Below standard	176.6
Potassium (mg/L)	< 1.0	None	N/A	N/A
Silicon (mg/L)	4.5	None	N/A	29,435.4
Silver (µg/L)	< 0.2	0.07	Not detected	N/A
Sodium (mg/L)	1.10	None	N/A	7,195.3
Sulfate (mg/L)	88	250.00	Below standard	575,625.6
Zinc (µg/L)	110	102.34	1.1	719.5

On the east side of Peekaboo Gulch, bedrock does not appear highly altered, and water shows no apparent degradation. A test of water draining from an adit across the gulch from sample site NW33 showed pH of 6.96 and 118 µS/cm conductivity (Figure 37).

Sample NW34 was from Peekaboo Gulch below the influence of most of the degraded springs described above, and above the diluting influence of the Herschel Lake stream. Stream water was slightly murky, and abundant light red, red-brown, and orange precipitate lined the streambed. The precipitate extended onto the banks of the stream and included ferrosinter and ferricrete. Most was somewhat hardened, however within the flowing water a thin layer of soft, fresh orange precipitate overlay the older, hardened material. Above the banks of the stream, some of the older precipitate was weathering into dark brown soil. At the sample site, flow was measured at 500 gpm, pH was 3.82, and conductivity was 218 µS/cm. This water greatly exceeded standards in aluminum and copper concentrations. Iron and manganese also exceeded

Figure 38. Photograph showing sample site NW33 and ferrosinter deposit.

standards. Aluminum, iron, copper, and manganese concentrations and loads all increased substantially compared to sample NW29, about ½ mile upstream (Table 8).

A test from Peekaboo Gulch a few hundred feet upstream of its confluence with South Fork of Lake Creek revealed pH of 4.40 and conductivity of 147 µS/cm. Minor white precipitate coated the rocks of the streambed. South Fork of Lake Creek was tested about 1,000 feet upstream of its confluence with Peekaboo Gulch. The stream showed no obvious evidence of degradation, pH was 7.47, and conductivity was 71 µS/cm. Immediately below the confluence of South Fork and Peekaboo, minor amounts of red precipitate appeared in the stream. Minor red precipitate occurred in South Fork downstream continuously beyond McNasser Gulch (which tested at 7.32 pH, 76 µS/cm conductivity) to Sayres Gulch. About 1,000 feet upstream of the confluence with Sayres Gulch, and below the confluence with McNasser Gulch, South Fork of Lake Creek had 7.19 pH and 81 µS/cm conductivity (Figure 37).

A large red- and yellow-stained altered area crops out to the east of Sayres Gulch (Figure 39). Fridrich and others (1991, Figure 2) labeled this area "East Red Mountain," although it has no name on the 1:24,000 topographic maps. East Red Mountain is a pre-caldera intrusion that was altered and weakly mineralized prior to caldera formation (Fridrich and others, 1991, Figure 2, p. 1161). No large and/or draining mines are known to exist in the east fork of Sayres Gulch drainage basin, but at least two tributaries of the east fork, draining the altered western slopes of East Red Mountain, were lined with precipitate. Water tests from these tributaries during the CGS abandoned mine inventory in 1994 showed pHs of less than 3.6 and conductivities of about 250 to 1,150 µS/cm. Upstream of the influence of these degraded tributaries, east fork of Sayres Gulch had no precipitate, pH was neutral, and conductivity was less than 100 µS/cm. (See USFS-AMLIP inventory forms #12-01-368/4319-1 and #12-01-367/4319-1, available at CGS, Denver, Colorado.)

In 1999 several tests and a sample were collected in Sayres Gulch. Sample NW35 was from east fork of Sayres Gulch, below the influence of the degraded water from the west side of East Red Mountain, and upstream of the diluting influence of the apparently clean west fork of Sayres Gulch. Where sampled, the channel was lined with abundant light yellow-red precipitate, weakly cementing some of the stream gravel and cobbles. Partially weathered ferricrete/ferrosinter is exposed on the stream banks, suggesting a long history of degraded water. The east fork was flowing at about 1,200 gpm and was slightly murky. Conductivity was 263 µS/cm and pH was 3.84. Aluminum and copper concentrations greatly exceeded state standards; iron, manganese, and zinc also exceeded standards. The substantial difference between total and dissolved iron concentrations suggests that suspended iron precipitates are responsible for the murky water (Table 8).

The west fork of Sayres Gulch was tested about 400 feet upstream of its confluence with the east fork. The water appeared clean and had 7.36 pH and 71 µS/cm conductivity. At the confluence of the presumably clean west fork and the obviously degraded east fork, white precipitate appeared and the stream water became considerably cloudier (Figure 40). A test conducted about 500 feet downstream of the confluence showed 4.69 pH and 131 µS/cm conductivity. The increase in pH because of the influence from the west fork may be causing aluminum hydroxides to precipitate, lining the stream channel and remaining in suspension. About 1½ miles further downstream and about 1,000 feet upstream from its confluence with South Fork of Lake Creek, moderate amounts of white and light red precipitate were in Sayres Gulch, and the murky water had pH of 4.75 and conductivity of 126 µS/cm (Figure 37). Test parameters suggest little chemical change in Sayres Gulch from the mixing zone of the east and west forks downstream to South Fork of Lake Creek.

Figure 39. Photograph showing "East Red Mountain" at the headwaters of the first tributary east of Sayres Gulch along South Fork Lake Creek.

A large volume of extremely degraded water enters South Fork of Lake Creek from an unnamed gulch east of Sayres Gulch (Figure 39). This stream drains the northwest slopes of "East Red Mountain". A few small- to moderate-sized, dry mines exist in this sub-basin, but they probably do not significantly affect the runoff, especially in comparison to the large exposures of altered rocks. In 1994, a water test conducted from a precipitate-laden stream near the headwaters of this sub-basin showed pH of less than 3 and conductivity of 923 µS/cm. (See USFS-AMLIP inventory forms #12-01-367/4320-1 and #12-01-368/4319-1.)

In 1999, sample NW31 was collected from the unnamed creek about 100 feet upstream from its confluence with South Fork. The creek flowed across terraces of red precipitate that are soft on the top and harder at depth. Although this water was slightly clearer in appearance than the water of South Fork, it was considerably more degraded. The flow was estimated at 500 gpm, pH was 2.96, and conductivity was 1,406 µS/cm. Concentrations of aluminum and iron were more than two orders of magnitude above state standards; copper and manganese exceeded standards by more than an order of magnitude; and sulfate, zinc, and cadmium also exceeded standards (Table 8). High concentrations combined with the relatively high flow rate create a situation where this tributary was contributing a large proportion of the metal load to the South Fork drainage basin.

Figure 40. Photograph showing mixing zone of east fork and Sayres Gulch, looking downstream.

Sample NW32 was collected from South Fork of Lake Creek above the influence of the unnamed tributary, and downstream of Sayres Gulch. The stream channel had minor light-red precipitate, and the water was murky. Flow was estimated at 7,000 gpm, pH was 6.00, and conductivity was 108 µS/cm. Although the addition of acidic, metal-rich Sayres Gulch water had a noticeable effect on South Fork, the sample only exceeded state standards in iron and copper concentrations. Large differences between total and dissolved aluminum and iron suggest the precipitate and the suspended solids in South Fork are composed primarily of aluminum and iron hydroxides.

Sample NW30 was collected from South Fork of Lake Creek downstream of the confluence with the highly degraded stream of NW31. The stream channel had more light-red precipitate than at NW32 and was murky. Streamflow was estimated at 7,000 gpm, pH had dropped to 4.68, and conductivity increased to 155 µS/cm. Concentrations of aluminum and copper exceeded state standards by more than an order of magnitude; and iron and manganese also exceeded standards. Values for dissolved and total iron and aluminum suggest that similar to site NW32, the precipitate lining the channel and the suspended solids are probably iron and aluminum complexes.

No additional inflows of degraded water were observed downstream of sample site NW30 during this brief reconnaissance study.

RUBY RANGE

The Ruby Range lies northwest of Crested Butte and south of Marble, in west-central Colorado. The West Elk Mountains are adjacent on the south, and the Elk Mountains lie to the north and east.

Geology

The crest of the Ruby Range comprises a series of Oligocene-age, intermediate-composition stocks, with related sills, dikes, and laccoliths. These igneous rocks intruded a sequence of Cretaceous- and Tertiary-age sedimentary rocks that consist of shale, siltstone, and sandstone. Felsic-composition igneous rocks were emplaced late in the Tertiary. Hydrothermal alteration and mineralization in the range are related to the intrusive events, especially to the younger, felsic intrusions. Disseminated pyrite is abundant in many of the altered areas. Vein deposits of precious and base metals have been mined in the past, and exploration and possible development of a stockwork molybdenum deposit at Mt. Emmons continues. Another known stockwork molybdenum occurrence underlies Redwell Basin, and others are postulated to exist further north in the range. (See Ludington and Ellis, 1983.)

Numerous ferruginous springs emerge in the Ruby Range. Although past mining has affected many of the drainage basins, the springs and associated limonite deposits existed prior to mining, and deposition of limonite and other ferrihydrites continues at present.

Previous Investigations

Keystone Spring

Limonite and other ferrihydrites have been deposited on a swampy hillside below the Keystone Spring, about 3 miles west of Crested Butte. The deposit is 3,000 feet long, 800 to 2,200 feet wide, up to 15 feet thick, and extends to Coal Creek. (See Harrer and Tesch, 1959, p. 34-35.) The spring emerges below the nearby Keystone lead-zinc-copper mine. A large volume of water flows from the Keystone Mine and is diverted to a water treatment plant between the mine and Coal Creek. Although the limonite deposit predates the mining activity, and deposition of limonite presumably continues at present, the mine has probably significantly affected local hydrology, and possibly water chemistry. The Keystone bog-iron deposit, or fen, has recently drawn attention because it is the southernmost documented occurrence of the Roundleaf Sundew carnivorous plant.

Redwell Basin

The Redwell Basin springs are about 10 miles northwest of Crested Butte. The Red Well is a spring near the head of Redwell Basin. The spring emerges from Cretaceous-age rocks and is depositing hydrous iron oxides. Lower in the basin, another iron-rich spring emerges from a shallow shaft. The spring predates the shaft, which was sunk as an exploration effort in this bog-iron deposit. Hematite is actively being deposited in the swampy portions of Redwell Basin. Iron precipitates form a deposit about 600 feet long, 75 feet wide, and up to 5 feet thick. (See Harrer and Tesch, 1959, p. 40-41.)

In October 1996, CGS personnel collected a sample from the pool of water that fills the depression in the ferrosinter deposit at the "Redwell." The water had pH of 3.51, conductivity of 304 µS/cm, and exceeded state standards in lead by more than three orders of magnitude (1,600 µg/L). Standards were exceeded by more than two orders of magnitude in zinc (6,900 µg/L) and cadmium (61 µg/L). Iron (23,000 µg/L), aluminum (3,900 µg/L), and manganese (1,900 µg/L) were more than an order of magnitude above standards; and copper (14 µg/L) slightly exceeded. (See Fehlmann and others, 1998, p. 53-54.) Although the spring predates mining activity in the basin, its position below many large mines, and the occurrence of high concentrations of trace metals suggests that groundwater may be contaminated by subsurface mine drainage. Tracer tests or ferrosinter samples could help determine if mine-related water affects Redwell Spring.

Present Investigation

In 1999 samples were collected from some of the degraded springs that are above all known significant mines in the Ruby Range.

Paradise Basin lies in the headwaters of the Crystal River drainage basin and is a tributary of Rock Creek. The Tertiary-age Paradise stock intruded this area, and much of the exposed bedrock and talus is altered and stained red (Figure 41). Hydrothermal fluids related to the intrusion mineralized and altered the stock and surrounding rocks. The basin has been an exploration target for a stockwork molybdenum deposit and hosts a few small- to moderate-sized mines. For this study, two samples were collected from Paradise Basin, above all known mines.

Sample NW46 was collected from the eastern part of Paradise Basin, above the Paradise Mine (Figure 42). The stream disappeared beneath iron-stained alluvium and colluvium about 200 feet downstream from the sample site, and flow rate was slightly higher upstream of the sample site. Alluvium and colluvium in this area comprised baked dark shale and light-colored, fine-grained intrusive rock. Disseminated pyrite and pyrite veinlets were common in both rock types. Where sampled, flow was 25 gpm, pH was 4.27, and conductivity was 359 µS/cm. Aluminum, manganese, and copper exceeded standards (Table 9). Sulfate was elevated but within standards. Because of the high hardness of the sample, elevated concentrations of zinc, cadmium, and lead were within standards.

Sample NW47 was from a stream a few hundred feet upstream from wetlands where intermingling waters cause abundant white precipitate to form (Figure 43). Moderate amounts of gray precipitate lined the stream channel at the sample site. Colluvium and alluvium consisted of baked shale and intrusive rock with only minor pyrite and iron staining. Flow was 25 gpm, pH was 7.25, and conductivity was 793 µS/cm. This exceptionally hard water slightly exceeded standards in sulfate and aluminum, but was much purer than NW46 (Table 9).

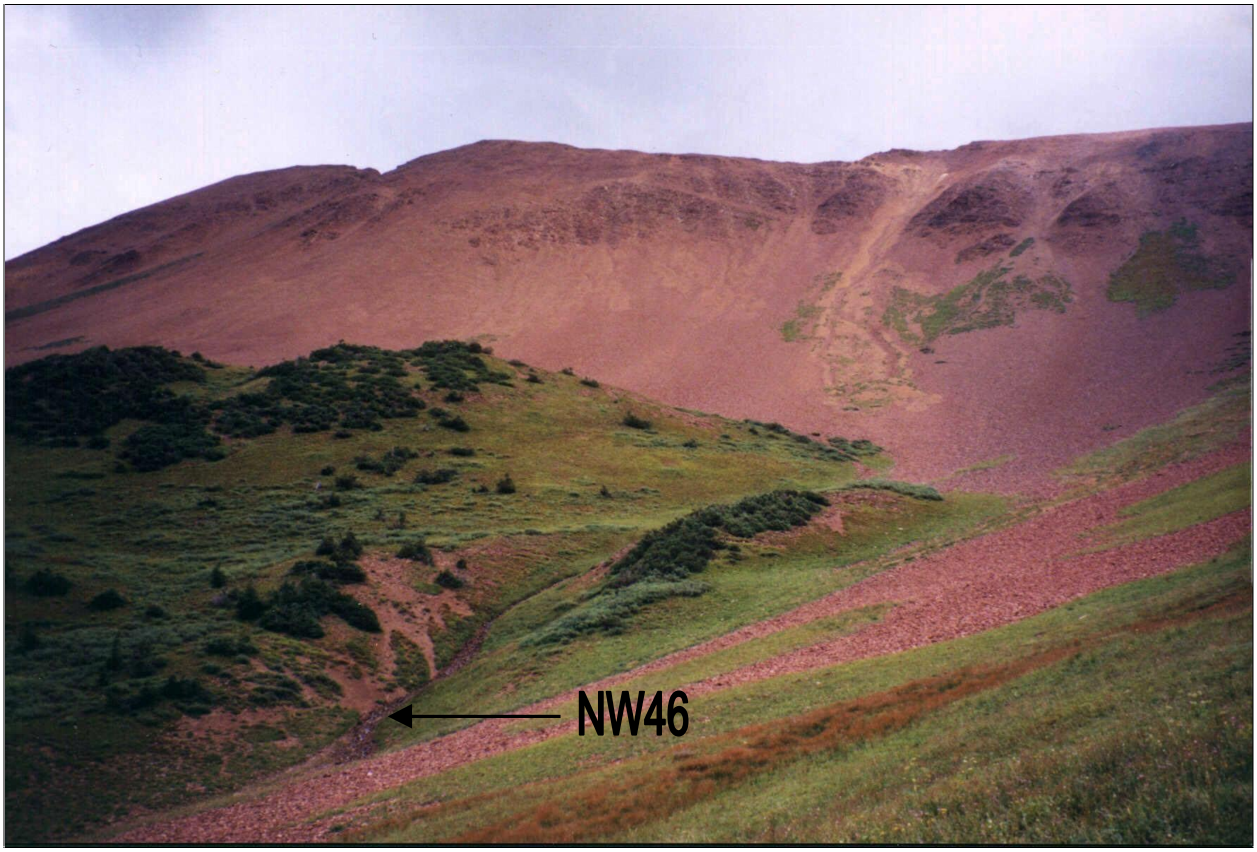

Figure 41. Photograph showing sample site NW46 and the altered bedrock and talus of Paradise Basin.

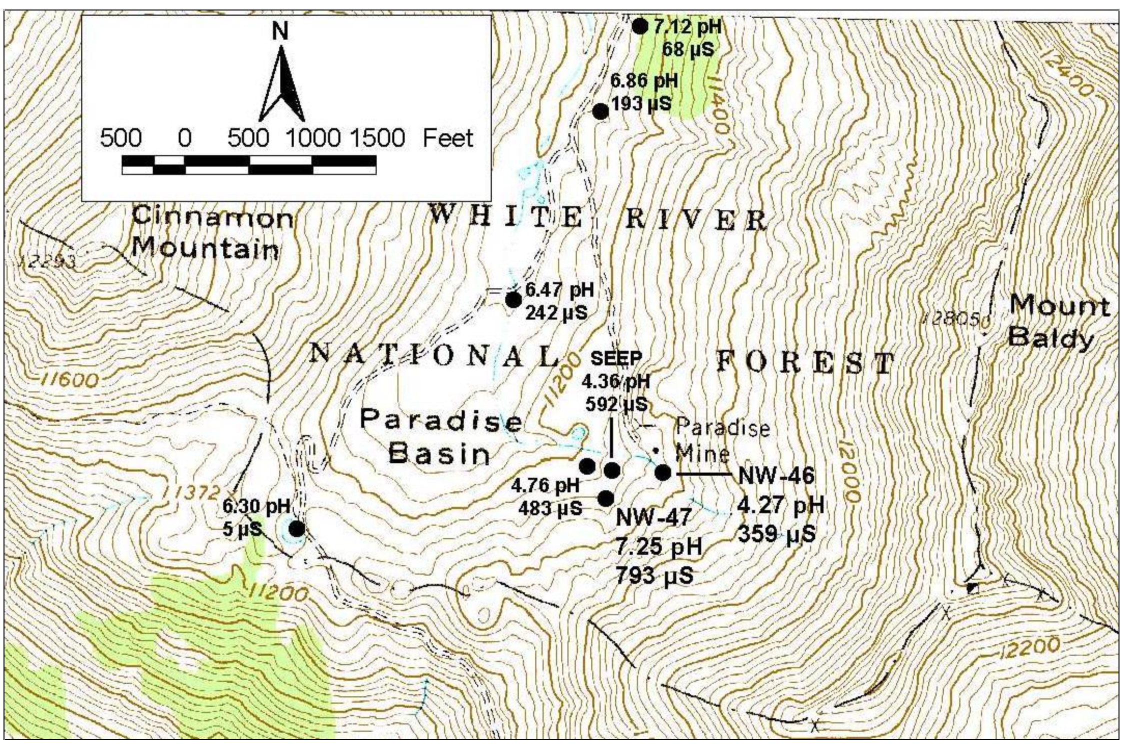

Figure 42. Map showing samples sites NW46-47 in Paradise Basin.

Table 9. Analytical data for samples NW46-47, 49-51 from the Ruby Range.

Sample	NW46, PARADISE EAST (8/25/99)				NW47, PARADISE SOUTH (8/25/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	25.0				25.0			
pH (standard units)	4.27				7.25			
Conductivity (µS/cm)	359.0				793.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	308	None	N/A		778	None	N/A	
Aluminum (trec) (µg/L)	1,600	None	N/A	218.0	54	None	N/A	7.4
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	< 10	1000.00	Below standard	N/A	< 10	1000.00	Below standard	N/A
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	150	2000.00	Below standard	20.4	46	2000.00	Below standard	6.3
Aluminum (µg/L)	1,600	87.00	18.4	218.0	89	87.00	1.0	12.1
Cadmium (µg/L)	1.3	2.75	Below standard	0.2	< 0.3	5.68	Below standard	N/A
Calcium (mg/L)	110	None	N/A	14,990.3	270	None	N/A	36,794.3
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	150.0	30.94	4.8	20.4	5.0	68.21	Below standard	0.7
Fluoride (mg/L)	< 0.10	2.00	Below standard	N/A	0.20	2.00	Below standard	27.3
Iron (µg/L)	< 10	300.00	Below standard	N/A	10	300.00	Below standard	1.4
Lead (µg/L)	5.0	19.17	Below standard	0.7	< 1.0	71.14	Below standard	N/A
Magnesium (mg/L)	8.10	None	N/A	1,103.8	25.00	None	N/A	3,406.9
Manganese (µg/L)	270	50.00	5.4	36.8	17	50.00	Below standard	2.3
Nickel (µg/L)	< 20	224.84	Below standard	N/A	< 20	454.24	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	5.1	None	N/A	695.0	3.6	None	N/A	490.6
Silver (µg/L)	< 0.2	0.52	Below standard	N/A	< 0.2	2.56	Below standard	N/A
Sodium (mg/L)	1.60	None	N/A	218.0	2.00	None	N/A	272.6
Sulfate (mg/L)	140	250.00	Below standard	19,078.5	320	250.00	1.3	43,608.0
Zinc (µg/L)	150	275.09	Below standard	20.4	49	602.51	Below standard	6.7

Table 9. Analytical data for samples NW46-47, 49-51 from the Ruby Range--continued.

Sample	NW49, S. FK. GOLD CREEK-HIGH (8/26/99)				NW50, RED LADY SOUTH (8/26/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	18.0				6.0			
pH (standard units)	2.49				3.76			
Conductivity (µS/cm)	1,788.0				23.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	566	None	N/A		9	None	N/A	
Aluminum (trec) (µg/L)	34,000	None	N/A	3,336.0	350	None	N/A	11.4
Antimony (trec) (µg/L)	< 2.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	86.0	50.00	1.7	8.4	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	130,000	1000.00	130.0	12,755.3	21	1000.00	Below standard	0.7
Molybdenum (trec) (µg/L)	< 10	None	N/A	N/A				
Thallium (trec) (µg/L)	< 2.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	13,000	2000.00	6.5	1,275.5	110	2000.00	Below standard	3.6
Aluminum (µg/L)	34,000	87.00	390.8	3,336.0	340	87.00	3.9	11.1
Cadmium (µg/L)	100.0	4.42	22.6	9.8	0.4	0.17	2.4	0.0
Calcium (mg/L)	200	None	N/A	19,623.6	3	None	N/A	98.1
Chloride (mg/L)	290.0	250.00	1.2	28,454.2	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	4,600.0	51.97	88.5	451.3	5.0	1.45	3.4	0.2
Fluoride (mg/L)	< 0.10	2.00	Below standard	N/A	0.10	2.00	Below standard	3.3
Iron (µg/L)	120,000	300.00	400.0	11,774.2	14	300.00	Below standard	0.5
Lead (µg/L)	14.0	45.32	Below standard	1.4	3.0	0.12	24.9	0.1
Magnesium (mg/L)	16.00	None	N/A	1,569.9	0.27	None	N/A	8.8
Manganese (µg/L)	8,800	50.00	176.0	863.4	74	50.00	1.5	2.4
Nickel (µg/L)	< 20	356.66	Below standard	N/A	< 20	14.82	Not detected	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	8.3	None	N/A	814.4	2.2	None	N/A	72.0
Silver (µg/L)	0.7	1.48	Below standard	0.1	< 0.2	0.00	Not detected	N/A
Sodium (mg/L)	2.60	None	N/A	255.1	0.52	None	N/A	17.0
Sulfate (mg/L)	890	250.00	3.6	87,325.0	6	250.00	Below standard	196.2
Zinc (µg/L)	13,000	460.12	28.3	1,275.5	110	13.27	8.3	3.6

Table 9. Analytical data for samples NW46-47, 49-51 from the Ruby Range--continued.

Sample	NW51, REDWELL MIDDLE (8/26/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	10.0			
pH (standard units)	3.91			
Conductivity (µS/cm)	61.0			
Alkalinity (mg/L CaCO3)				
Hardness (mg/L CaCO3)	26	None	N/A	
Aluminum (trec) (µg/L)	830	None	N/A	45.2
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	< 10	1000.00	Below standard	N/A
Molybdenum (trec) (µg/L)	< 10	None	N/A	N/A
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	660	2000.00	Below standard	36.0
Aluminum (µg/L)	830	87.00	9.5	45.2
Cadmium (µg/L)	5.2	0.39	13.2	0.3
Calcium (mg/L)	9	None	N/A	490.6
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A
Copper (µg/L)	43.0	3.74	11.5	2.3
Fluoride (mg/L)	< 0.10	2.00	Below standard	N/A
Iron (µg/L)	< 10	300.00	Below standard	N/A
Lead (µg/L)	410.0	0.58	709.8	22.3
Magnesium (mg/L)	0.86	None	N/A	46.9
Manganese (µg/L)	560	50.00	11.2	30.5
Nickel (µg/L)	< 20	34.36	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A
Silicon (mg/L)	3.8	None	N/A	207.1
Silver (µg/L)	0.6	0.01	80.9	0.0
Sodium (mg/L)	0.99	None	N/A	54.0
Sulfate (mg/L)	21	250.00	Below standard	1,144.7
Zinc (µg/L)	670	33.88	19.8	36.5

The wetlands consists of a series of acidic seeps, probably representing the re-emergence of some of the flow of the stream of NW46. The abundant white precipitates that appeared downstream of sample site NW47 are probably mostly aluminum and sulfate (gypsum?) compounds that form as the aluminum-rich, acidic waters of the seeps are partly neutralized by the slightly alkaline, calcium- and sulfate-rich waters of the stream of NW47.

Sample NW49 was from the uppermost headwaters of the south fork of Gold Creek (Figure 44), about 100 feet downstream of where the water emerges from talus. Bedrock and talus in this area consist of highly pyritized intrusive rocks. A layer of ferricrete overlies the bedrock about 8 feet above the active stream channel, and blocks of broken ferricrete are within and alongside the streambed (Figure 45). Minor amounts of red precipitate coated the channel, flow was 18 gpm, pH was extremely low at 2.49, and conductivity was exceptionally high at 1,788 µS/cm. Although the water was very acidic, the hardness was more than 500 mg/L (Table 9). This water was extremely degraded. Aluminum, manganese, and iron concentrations exceeded standards by more than two orders of magnitude. Copper, zinc, and cadmium were quite concentrated, exceeding their high, hardness-related standards by more than an order of magnitude. Sulfate, arsenic, and chloride also exceeded standards. Lead and silver were elevated, but within their hardness-related standards.

Figure 43. Photograph showing mixing of waters in Paradise Basin. Sample NW47 was collected from the tributary on the left, above the mixing zone. The series of seeps to the right are acidic.

Sample NW50 was from Red Lady Basin, above the Keystone Mine and bog-iron deposit described previously. No major mines are known above this elevation in this vicinity. The walls of Red Lady Basin are altered sedimentary rocks that are stained red and brown (Figure 46). A ferrosinter deposit occurs within the basin (Figure 47). When examined for this study, no water was flowing through the ferrosinter deposit. Most of the deposit appeared to be inactive and was weathering into dark brown soil. Sample NW50 was from an unmarked stream on the west side of the basin and was peripheral to the ferrosinter deposit. Minor red precipitate occurred, flow was 6 gpm, pH was 3.76, and conductivity was only 23 µS/cm. Lead, zinc, aluminum, copper, cadmium, and manganese exceeded standards (Table 9). Standards for lead, zinc, copper, and cadmium were very low because of the exceptionally low hardness of the sample. Metal loads at this sample locale are not substantial because of the low flow rate and moderate to low trace-metal concentrations.

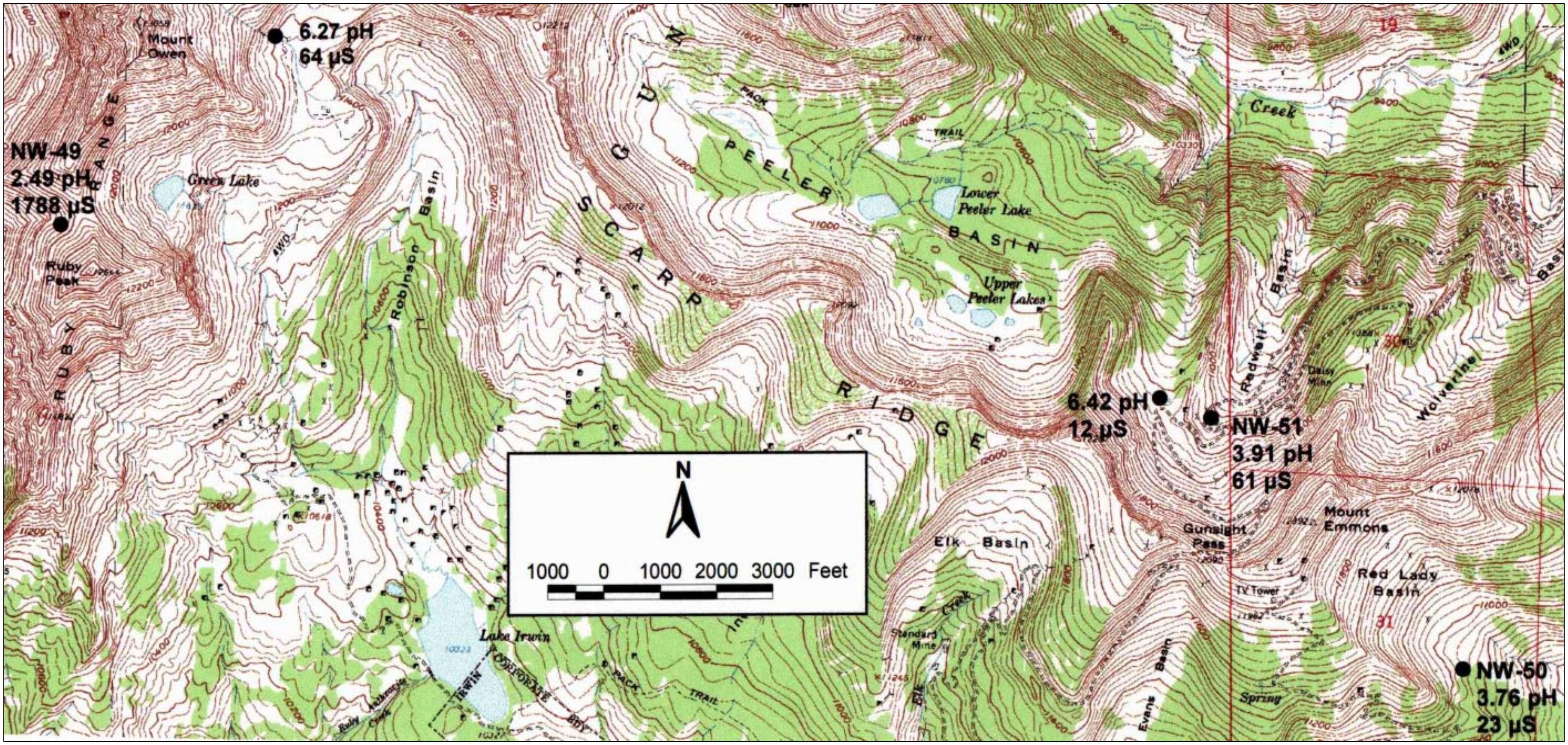

Figure 44. Map showing sample sites NW49-51 and test results in the southern part of the Ruby Range.

Figure 45. Photograph showing sample site NW49 and ferricrete cap rock about 8 feet above the present stream channel in upper Gold Creek.

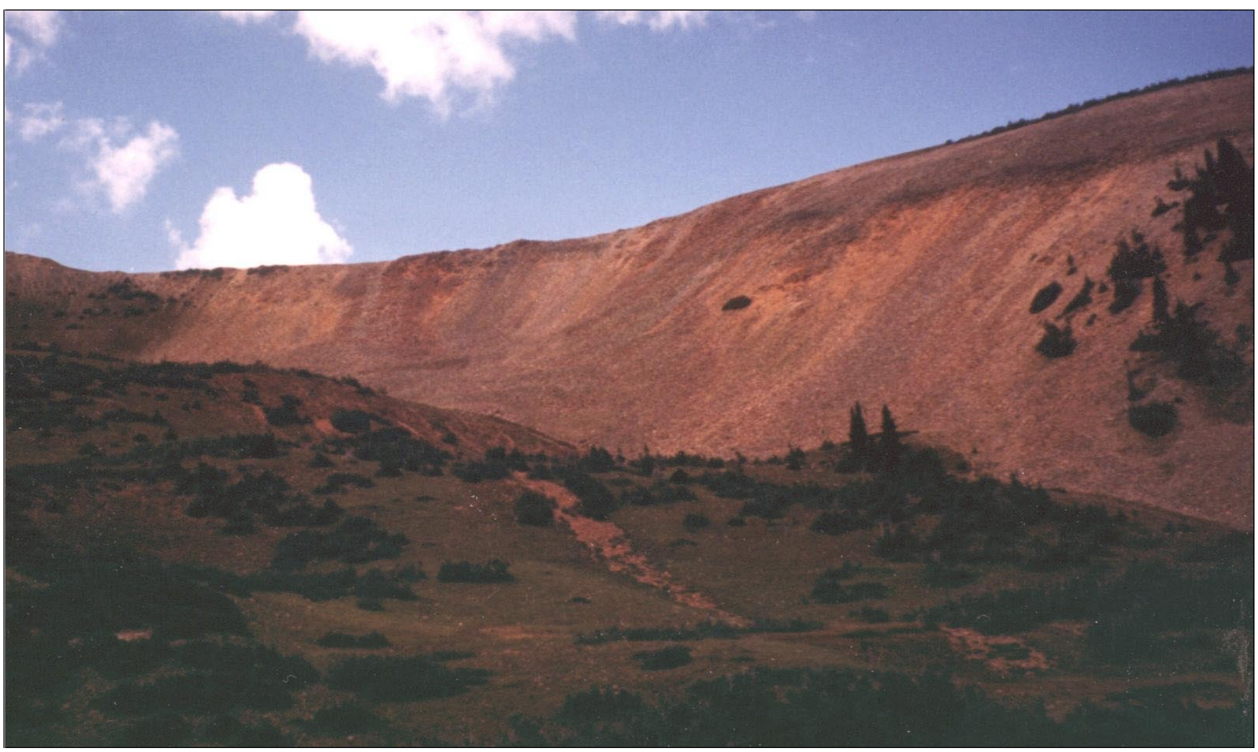

Figure 46. Photograph showing altered bedrock and talus in Red Lady Basin.

Figure 47. Photograph showing partly weathered ferrosinter deposit in Red Lady Basin.

Sample NW51 was from the upper part of Redwell Basin, above the Red Well and all of the large, draining mines. However, this basin has been extensively mined and drilled, so the sample may not be completely without the influence of past mining activity. Nevertheless, the presence of iron bogs and the Red Well, a ferrosinter deposit, indicates the existence of degraded water prior to mining activity in the basin. Sample NW51 was from a spring near the middle of the upper part of Redwell Basin (Figures 44, 48), and no known draining mines are upstream of this site. The spring emerges from grass and talus near the access road that traverses the basin. Flow was 10 gpm, pH was 3.91, and conductivity was 61 µS/cm. Lead was almost three orders of magnitude above standards; silver, zinc, cadmium, copper, manganese, and aluminum exceeded standards by about an order of magnitude or more (Table 9). Compared to most samples collected for this study, the trace-metal concentrations compared to aluminum and iron were quite high, suggesting that this water may be influenced by past mining activity. However, sulfate concentration was lower than most mining-affected waters, suggesting minimal anthropogenic impact to the spring. More detailed studies may reveal how much, if any, change in water quality has occurred since mining began in the basin.

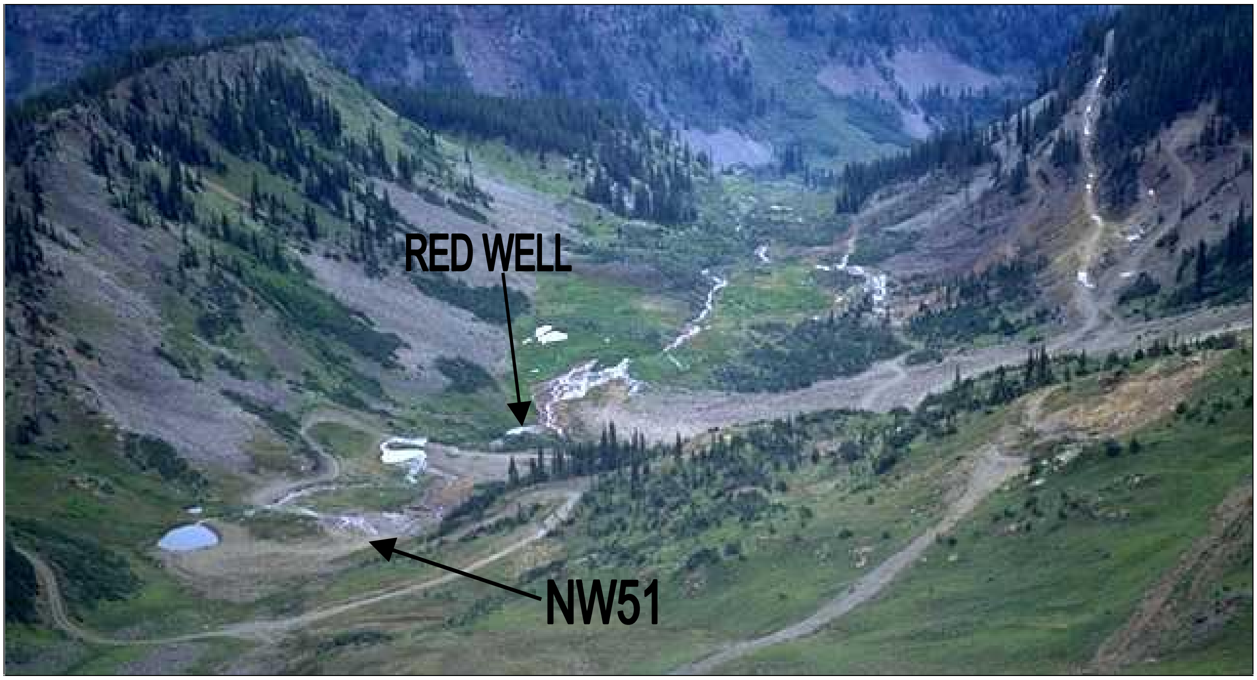

Figure 48. Photograph showing sample site NW51 and Redwell Basin.

CENTRAL COLORADO

The Montezuma stock between Breckenridge and Georgetown, and Red Amphitheatre between Alma and Leadville were sampled for this study. Twelvemile and Sheep Creeks draining parts of the Buffalo Peaks were tested, but no samples were collected. Unlike many of the areas sampled to the southwest, these degraded waters are related to alteration resulting from emplacement of intrusive igneous rocks, rather than caldera formation.

MONTEZUMA STOCK

The Montezuma stock and its associated alteration straddle the Continental Divide in Park, Clear Creek, and Summit Counties. Breckenridge is about 10 miles to the west-southwest, Georgetown is about 10 miles to the northeast, and Grant is about 12 miles to the east-southeast.

Degraded water associated with the altered rocks affects stream basins on both sides of the Continental Divide. Handcart Gulch, a tributary of North Fork of the South Platte River, and the headwaters of the Snake River were the focus of work in this area. Bruno Gulch and tributaries of Peru Creek were sampled, too.

Geology

Emplacement of the Montezuma stock was the primary factor causing extensive fracturing and mineralization in the Montezuma mining district. The heated, metal-rich fluids that formed economic mineral deposits also created a widespread area of hydrothermally altered terrane with abundant disseminated pyrite. The Oligocene-age Montezuma stock is composed primarily of quartz monzonite. It intruded Precambrian-age Swandyke hornblende gneiss that comprises gneiss, schist, pegmatite, and aplite. Faults, fractures, and pyrite-rich alteration associated with the stock extend into the surrounding gneiss. (See Meyer and others, 1996, p. 5.)

At the surface, the stock only extends south to about the town of Montezuma, except for a sliver exposed in the headwaters of the North Fork of the South Platte River, on the southwestern side of Hall Valley. The stock broadens at depth, as determined in maps of the Roberts Tunnel. A band of argillized, sericitized, and pyritized altered rocks about 1 to 2 miles wide covers the southeastern part of the stock, and extends southward and eastward into the overlying Precambrian rocks. (See Neuerburg, 1971.)

Pyrite, galena, and sphalerite are the major sulfide minerals in veins associated with the Montezuma stock. Chalcopyrite and copper sulfosalts are common. Quartz, manganiferous carbonates, and barite occur as gangue minerals. (See Neuerburg, 1971.)

Ferricrete and ferrosinter deposits are common in the areas underlain and flanked by altered rocks.

Previous Investigations

Water samples were collected from streams on the south and east side of the Continental Divide in the Red Cone area in 1992 and 1995 (Streufert, 1993, p. 2-3; Meyer and others, 1996). In 1992, a water sample was collected from Handcart Gulch, in the upper part of some ferricrete and bog-iron deposits. A small exploration adit was driven in the higher reaches of the western tributary of this drainage basin. This adit had a shallow pool of standing water, but no water was discharging, and the adit was deemed to have negligible impact on local water quality. Water in upper Handcart Gulch exceeded state standards in iron and manganese; copper, zinc, and cadmium concentrations were also high. The stream had pH of 3.80 and flow rate of about 1,350 gpm. (See Sares, 1996, p. 7.)

Field measurements from 1992 suggest that water quality worsens downstream in Handcart Gulch, where acidity and metal concentrations increase. Natural interactions of the acidic stream water with the extensive bog-iron deposits that line Handcart Gulch may cause this further degradation, but disturbance of the deposits during placer mining and small-scale iron mining attempts probably exasperates the problem. (See Sares, 1996, p. 7.)

In 1995, water samples were collected from Handcart Gulch by Meyer and others (1996) as part of a study comparing naturally acidic stream and spring waters to mine discharges in three mining districts in Colorado. Sample results indicate that Handcart Gulch water contains lower concentrations of trace metals than the other drainage basins in their study (Iron Creek near the Alamosa River and the East Mancos River). Major cation (calcium, magnesium, potassium, and sodium) concentrations correlated well with sulfate and pH, suggesting that as acidity increases minerals such as calcite, dolomite, feldspars, pyroxenes, and amphiboles are dissolving and neutralizing some of the acid. Water from the Whale Mine in Hall Valley, about 1 mile west of Handcart Gulch, was considerably different in character from the natural waters of Handcart Gulch. Although the pH was higher in the mine water, so were concentrations of cadmium, manganese, lead, and zinc. Aluminum, copper, iron, and sulfate concentrations fell within the ranges found in the natural waters. (See Meyer and others, 1996, p. 9-11.)

In 1992, two samples were collected from Bruno Gulch. (On the newest U.S. Geological Survey topographic map of the Montezuma quadrangle this feature is labeled as “Buno”, and that is how it is reported in Sares, 1996, and Streufert, 1993. Older U.S. Geological Survey publications use “Bruno”, as does the newest version of the Mount Evans quadrangle immediately to the east.) Bruno Gulch is a tributary of Geneva Creek and drains the eastern side of Red Cone. No known mines are within this drainage basin. Water in upper Bruno Gulch exceeded state standards in aluminum, copper, and zinc. Inflows of relatively pure water from unaltered areas diluted the low quality water so that a sample from lower Bruno Gulch only slightly exceeded standards in cadmium. The upstream sample had pH of 5.50 on an estimated flow of 900 gpm. The downstream water was flowing at an estimated rate of 2,250 gpm and had pH of 8.20. (See Sares, 1996, p. 7.)

Extensive bog-iron deposits occur north of Webster Pass in the upper reaches of the Snake River drainage basin. This swampy, iron-rich feature is called the Snake River fen by more recent researchers. Numerous naturally degraded springs and seeps draining to the northwest from the northwest slope of Red Cone Peak have deposited ferrihydrites on the mountain slope and along the bottom of the Snake River. The precipitates have formed deposits that extend about 1,000 feet along the slopes of Red Cone and are about 100 feet wide along the marshy drainage bottoms. Discontinuous deposits occur for about 1 mile along the Snake River. Thicknesses of up to 10 feet have been observed. (See Harrer and Tesch, 1959, p. 75-76.)

Limonite deposits formed by ferruginous spring water occur in West Geneva Creek northwest of Grant. The source of the iron is pyrite associated with the altered Montezuma stock and surrounding country rock. Although mines have been driven in veins above these iron-rich springs, the limonite deposits predate the mining operations, and are still forming today. The limonite occurs in at least five distinct deposits, 700 to 4,200 feet long, 200 to 500 feet wide, and up to 15 feet or more in thickness. (See Harrer and Tesch, 1959, p. 20.) Degraded water has probably emerged from these springs for thousands of years. Upstream mining may have modified the water chemistry, however.

Present Investigation

In 1999, most samples were collected from the Handcart Gulch drainage basin and tributaries of the Snake River. In addition, a few samples were collected from tributaries of Peru Creek and from Bruno Gulch.

Red Cone Peak Area -- Handcart and Bruno Gulches

Bedrock at Red Cone consists of Precambrian schist and gneiss that was intensely altered during the emplacement of the Montezuma stock. Disseminated pyrite is abundant in the bedrock and in the talus slopes (Figure 49).

Below the talus slopes, extensive bog-iron and ferricrete deposits occur in Handcart Gulch and Hall Valley, near the headwaters of the North Fork South Platte River. In Handcart Gulch, the deposits extend from near Red Cone Peak and Webster Pass downstream to its confluence with Hall Valley, then a short distance further downstream in Hall Valley. The deposit is about 100 feet wide and 6 feet or more in thickness. Composition of the deposit varies considerably, from older and well-indurated, hard material to soft, freshly precipitated ferrihydrites. (See Harrer and Tesch, 1959, p. 54-56; Streufert, 1993, p. 4.)

Figure 49. Photograph showing the headwaters of Handcart Gulch and Red Cone.

In August 1999 samples were collected from the two uppermost tributaries of Handcart Gulch (NW36-37, figure 50). The eastern tributary drains the south side of Webster Pass. Minor ferricrete occurs in the basin above sample site NW36, and the exposed bedrock is stained bright red. Alluvium in the channel comprises iron-stained, propylitized and argillized granitic and metamorphic rocks, some with disseminated pyrite. Stream water flowing at 48 gpm had 3.59 pH and 201 µS/cm conductivity. Aluminum, copper, and manganese concentrations exceeded state standards (Table 10).

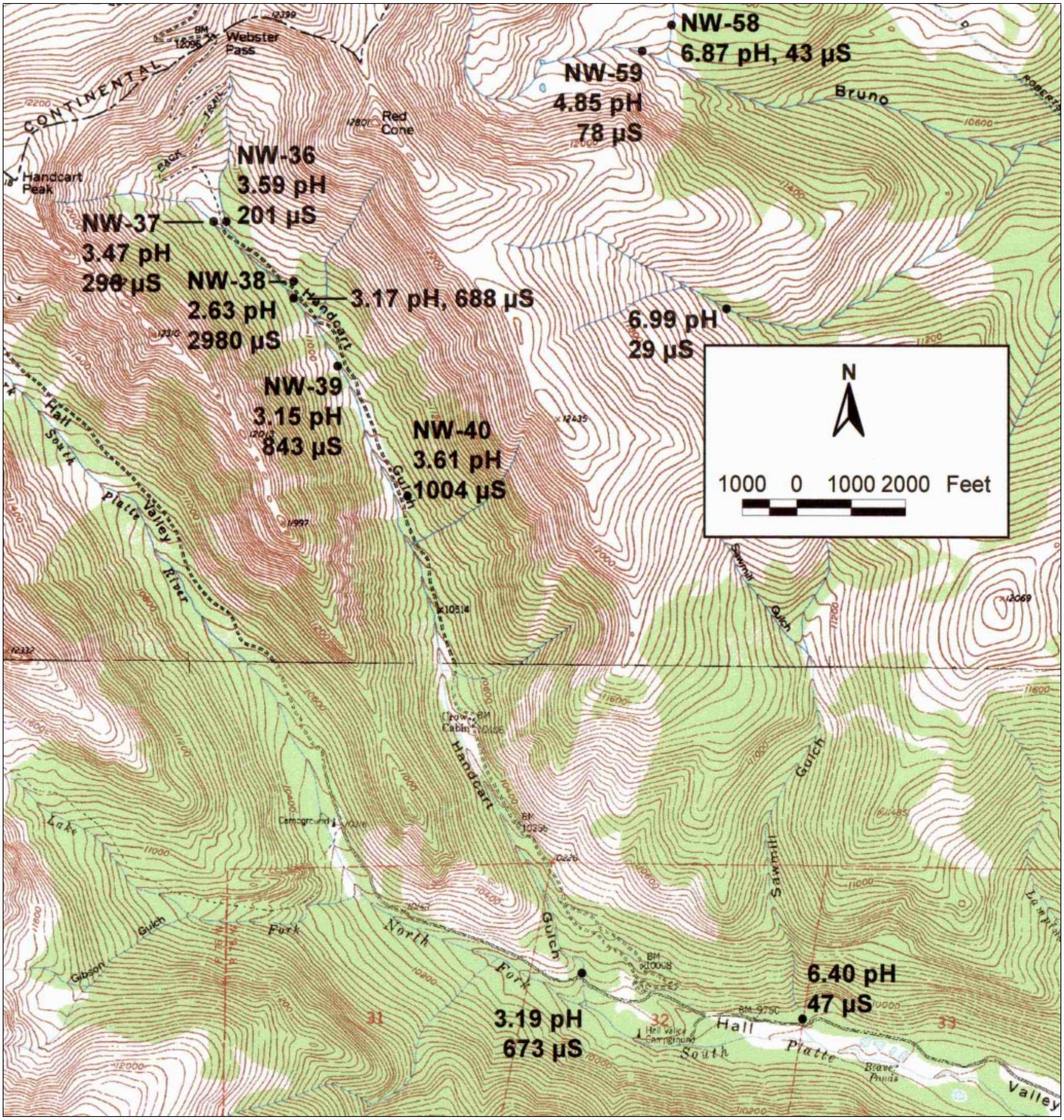

Figure 50. Map showing sample sites NW36-40, 58-59 from south and east of Red Cone.

Table 10. Analytical data for samples NW14-28, 36-43, 45, 58-59 from the Montezuma stock area.

Sample	NW14, WEBSTER PASS NORTH-SEEP (8/4/99)				NW15, WEBSTER PASS NORTH-CREEK (8/4/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	7.0				150.0			
pH (standard units)	3.55				4.19			
Conductivity (µS/cm)	80.0				51.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	13	None	N/A		13	None	N/A	
Aluminum (trec) (µg/L)	1,300	None	N/A	49.6	720	None	N/A	588.7
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	77	1000.00	Below standard	2.9	180	1000.00	Below standard	147.2
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	60	2000.00	Below standard	2.3	33	2000.00	Below standard	27.0
Aluminum (µg/L)	1,300	87.00	14.9	49.6	660	87.00	7.6	539.6
Cadmium (µg/L)	0.5	0.23	2.2	0.0	< 0.3	0.22	Not detected	N/A
Calcium (mg/L)	4	None	N/A	152.6	4	None	N/A	3,270.6
Chloride (mg/L)	29.0	250.00	Below standard	1,106.6	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	7.0	2.06	3.4	0.3	6.0	2.03	3.0	4.9
Fluoride (mg/L)	< 0.10	2.00	Below standard	N/A	< 0.10	2.00	Below standard	N/A
Iron (µg/L)	68	300.00	Below standard	2.6	130	300.00	Below standard	106.3
Lead (µg/L)	3.0	0.21	14.0	0.1	< 1.0	0.21	Not detected	N/A
Magnesium (mg/L)	0.72	None	N/A	27.5	0.66	None	N/A	539.6
Manganese (µg/L)	50	50.00	Below standard	1.9	50	50.00	Below standard	40.9
Nickel (µg/L)	< 20	20.22	Below standard	N/A	< 20	19.93	Not detected	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	3.8	None	N/A	145.0	3.8	None	N/A	3,107.1
Silver (µg/L)	< 0.2	0.00	Not detected	N/A	< 0.2	0.00	Not detected	N/A
Sodium (mg/L)	0.67	None	N/A	25.6	0.93	None	N/A	760.4
Sulfate (mg/L)	22	250.00	Below standard	839.5	16	250.00	Below standard	13,082.4
Zinc (µg/L)	59	18.76	3.1	2.3	31	18.45	1.7	25.3

Table 10. Analytical data for samples NW14-28, 36-43, 45, 58-59 from the Montezuma stock area--continued.

Sample	NW16, WEST OF PEAK 13,214 (8/4/99)				NW17, LANDSLIDE PEAK SOUTHWEST-LOW (8/5/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	80.0				800.0			
pH (standard units)	3.91				3.79			
Conductivity (µS/cm)	74.0				89.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	28	None	N/A		23	None	N/A	
Aluminum (trec) (µg/L)	1,300	None	N/A	566.9	1,500	None	N/A	6,541.2
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	56	1000.00	Below standard	24.4	1,200	1000.00	1.2	5,233.0
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	24	2000.00	Below standard	10.5	130	2000.00	Below standard	566.9
Aluminum (µg/L)	1,300	87.00	14.9	566.9	1,500	87.00	17.2	6,541.2
Cadmium (µg/L)	< 0.3	0.42	Below standard	N/A	0.6	0.36	1.7	2.6
Calcium (mg/L)	8	None	N/A	3,488.6	7	None	N/A	30,525.6
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	9.0	4.01	2.2	3.9	31.0	3.40	9.1	135.2
Fluoride (mg/L)	0.10	2.00	Below standard	43.6	0.20	2.00	Below standard	872.2
Iron (µg/L)	12	300.00	Below standard	5.2	1,100	300.00	3.7	4,796.9
Lead (µg/L)	< 1.0	0.65	Not detected	N/A	< 1.0	0.49	Not detected	N/A
Magnesium (mg/L)	2.00	None	N/A	872.2	1.40	None	N/A	6,105.1
Manganese (µg/L)	96	50.00	1.9	41.9	240	50.00	4.8	1,046.6
Nickel (µg/L)	< 20	36.52	Below standard	N/A	< 20	31.53	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	4.0	None	N/A	1,744.3	5.5	None	N/A	23,984.4
Silver (µg/L)	< 0.2	0.01	Not detected	N/A	< 0.2	0.01	Not detected	N/A
Sodium (mg/L)	0.86	None	N/A	375.0	1.30	None	N/A	5,669.0
Sulfate (mg/L)	24	250.00	Below standard	10,465.9	37	250.00	Below standard	161,349.6
Zinc (µg/L)	24	36.26	Below standard	10.5	130	30.78	4.2	566.9

Table 10. Analytical data for samples NW14-28, 36-43, 45, 58-59 from the Montezuma stock area--continued.

Sample	NW18, LANDSLIDE PEAK SOUTHWEST-FERRICRETE (8/5/99)				NW19, LANDSLIDE PEAK SOUTHWEST-HIGH (8/5/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	30.0				300.0			
pH (standard units)	3.30				4.81			
Conductivity (µS/cm)	233.0				18.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	29	None	N/A		10	None	N/A	
Aluminum (trec) (µg/L)	3,000	None	N/A	490.6	220	None	N/A	359.8
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	1,200	1000.00	1.2	196.2	< 10	1000.00	Below standard	N/A
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	280	2000.00	Below standard	45.8	25	2000.00	Below standard	40.9
Aluminum (µg/L)	3,000	87.00	34.5	490.6	220	87.00	2.5	359.8
Cadmium (µg/L)	2.3	0.43	5.3	0.4	< 0.3	0.18	Not detected	N/A
Calcium (mg/L)	8	None	N/A	1,308.2	3	None	N/A	4,905.9
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	79.0	4.16	19.0	12.9	< 4.0	1.58	Not detected	N/A
Fluoride (mg/L)	0.30	2.00	Below standard	49.1	< 0.10	2.00	Below standard	N/A
Iron (µg/L)	700	300.00	2.3	114.5	< 10	300.00	Below standard	N/A
Lead (µg/L)	< 1.0	0.69	Not detected	N/A	< 1.0	0.14	Not detected	N/A
Magnesium (mg/L)	2.30	None	N/A	376.1	0.49	None	N/A	801.3
Manganese (µg/L)	450	50.00	9.0	73.6	41	50.00	Below standard	67.0
Nickel (µg/L)	< 20	37.73	Below standard	N/A	< 20	15.99	Not detected	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	8.3	None	N/A	1,357.3	3.0	None	N/A	4,905.9
Silver (µg/L)	< 0.2	0.01	Not detected	N/A	< 0.2	0.00	Not detected	N/A
Sodium (mg/L)	1.60	None	N/A	261.6	0.80	None	N/A	1,308.2
Sulfate (mg/L)	96	250.00	Below standard	15,698.9	10	250.00	Below standard	16,353.0
Zinc (µg/L)	290	37.60	7.7	47.4	24	14.44	1.7	39.2

Table 10. Analytical data for samples NW14-28, 36-43, 45, 58-59 from the Montezuma stock area--continued.

Sample	NW20, LANDSLIDE PEAK SOUTHWEST-SEEP (8/5/99)				NW21, HEADWATERS OF SNAKE RIVER (8/4/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	10.0				62.0			
pH (standard units)	3.84				5.79			
Conductivity (µS/cm)	163.0				82.2			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	30	None	N/A		59	None	N/A	
Aluminum (trec) (µg/L)	4,100	None	N/A	223.5	< 50	None	N/A	N/A
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	7,300	1000.00	7.3	397.9	< 10	1000.00	Below standard	N/A
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	330	2000.00	Below standard	18.0	< 10	2000.00	Below standard	N/A
Aluminum (µg/L)	3,900	87.00	44.8	212.6	< 50	87.00	Below standard	N/A
Cadmium (µg/L)	2.4	0.44	5.4	0.1	< 0.3	0.75	Below standard	N/A
Calcium (mg/L)	8	None	N/A	436.1	21	None	N/A	7,097.2
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	110.0	4.26	25.8	6.0	< 4.0	7.54	Below standard	N/A
Fluoride (mg/L)	0.30	2.00	Below standard	16.4	< 0.01	2.00	Below standard	N/A
Iron (µg/L)	5,000	300.00	16.7	272.6	< 10	300.00	Below standard	N/A
Lead (µg/L)	< 1.0	0.71	Not detected	N/A	< 1.0	1.84	Below standard	N/A
Magnesium (mg/L)	2.50	None	N/A	136.3	1.60	None	N/A	540.7
Manganese (µg/L)	410	50.00	8.2	22.3	< 4	50.00	Below standard	N/A
Nickel (µg/L)	< 20	38.52	Below standard	N/A	< 20	64.05	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	9.1	None	N/A	496.0	2.0	None	N/A	675.9
Silver (µg/L)	< 0.2	0.01	Not detected	N/A	< 0.2	0.03	Not detected	N/A
Sodium (mg/L)	1.80	None	N/A	98.1	0.79	None	N/A	267.0
Sulfate (mg/L)	72	250.00	Below standard	3,924.7	30	250.00	Below standard	10,138.9
Zinc (µg/L)	280	38.48	7.3	15.3	12	67.84	Below standard	4.1

Table 10. Analytical data for samples NW14-28, 36-43, 45, 58-59 from the Montezuma stock area--continued.

Sample	NW22, WEST OF CLIMAX MINE (8/5/99)				NW23, CREEK EAST OF CLIMAX MINE (8/5/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	80.0				180.0			
pH (standard units)	4.41				3.84			
Conductivity (µS/cm)	258.0				289.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	121	None	N/A		91	None	N/A	
Aluminum (trec) (µg/L)	5,500	None	N/A	2,398.4	11,000	None	N/A	10,793.0
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	< 10	1000.00	Below standard	N/A	3,400	1000.00	3.4	3,336.0
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	3,500	2000.00	1.8	1,526.3	1,300	2000.00	Below standard	1,275.5
Aluminum (µg/L)	5,700	87.00	65.5	2,485.7	11,000	87.00	126.4	10,793.0
Cadmium (µg/L)	14.0	1.32	10.6	6.1	7.7	1.05	7.3	7.6
Calcium (mg/L)	33	None	N/A	14,390.6	20	None	N/A	19,623.6
Chloride (mg/L)	20.0	250.00	Below standard	8,721.6	54.0	250.00	Below standard	52,983.7
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	250.0	13.92	18.0	109.0	67.0	10.91	6.1	65.7
Fluoride (mg/L)	0.30	2.00	Below standard	130.8	0.70	2.00	Below standard	686.8
Iron (µg/L)	10	300.00	Below standard	4.4	3,300	300.00	11.0	3,237.9
Lead (µg/L)	13.0	5.10	2.5	5.7	< 1.0	3.40	Below standard	N/A
Magnesium (mg/L)	9.40	None	N/A	4,099.2	10.00	None	N/A	9,811.8
Manganese (µg/L)	4,000	50.00	80.0	1,744.3	4,100	50.00	82.0	4,022.8
Nickel (µg/L)	34	110.50	Below standard	14.8	48	88.97	Below standard	47.1
Potassium (mg/L)	< 1.0	None	N/A	N/A	1.4	None	N/A	1,373.7
Silicon (mg/L)	5.6	None	N/A	2,442.0	9.6	None	N/A	9,419.3
Silver (µg/L)	< 0.2	0.10	Not detected	N/A	< 0.2	0.06	Not detected	N/A
Sodium (mg/L)	1.90	None	N/A	828.6	2.00	None	N/A	1,962.4
Sulfate (mg/L)	120	250.00	Below standard	52,329.6	180	250.00	Below standard	176,612.4
Zinc (µg/L)	3,500	124.61	28.1	1,526.3	1,300	97.85	13.3	1,275.5

Table 10. Analytical data for samples NW14-28, 36-43, 45, 58-59 from the Montezuma stock area--continued.

Sample	NW24, 2ND CREEK EAST OF CLIMAX MINE (8/5/99)				NW25, CREEK EAST OF WARDEN GULCH (8/5/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	200.0				50.0			
pH (standard units)	3.77				4.29			
Conductivity (µS/cm)	197.0				117.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	31	None	N/A		35	None	N/A	
Aluminum (trec) (µg/L)	5,900	None	N/A	6,432.2	3,600	None	N/A	981.2
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	1,100	1000.00	1.1	1,199.2	25	1000.00	Below standard	6.8
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	120	2000.00	Below standard	130.8	200	2000.00	Below standard	54.5
Aluminum (µg/L)	5,800	87.00	66.7	6,323.2	3,600	87.00	41.4	981.2
Cadmium (µg/L)	0.7	0.46	1.5	0.8	1.5	0.50	3.0	0.4
Calcium (mg/L)	8	None	N/A	8,721.6	11	None	N/A	2,998.1
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	45.0	4.40	10.2	49.1	31.0	4.81	6.4	8.4
Fluoride (mg/L)	0.11	2.00	Below standard	119.9	0.20	2.00	Below standard	54.5
Iron (µg/L)	1,100	300.00	3.7	1,199.2	17	300.00	Below standard	4.6
Lead (µg/L)	< 1.0	0.76	Not detected	N/A	< 1.0	0.87	Not detected	N/A
Magnesium (mg/L)	2.80	None	N/A	3,052.6	1.80	None	N/A	490.6
Manganese (µg/L)	220	50.00	4.4	239.8	520	50.00	10.4	141.7
Nickel (µg/L)	< 20	39.71	Below standard	N/A	< 20	42.92	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	6.0	None	N/A	6,541.2	8.5	None	N/A	2,316.7
Silver (µg/L)	< 0.2	0.01	Not detected	N/A	< 0.2	0.01	Not detected	N/A
Sodium (mg/L)	1.40	None	N/A	1,526.3	1.00	None	N/A	272.6
Sulfate (mg/L)	73	250.00	Below standard	79,584.6	42	250.00	Below standard	11,447.1
Zinc (µg/L)	140	39.81	3.5	152.6	210	43.42	4.8	57.2

Table 10. Analytical data for samples NW14-28, 36-43, 45, 58-59 from the Montezuma stock area--continued.

Sample	NW26, CK BETWEEN CINNAMON AND WARDEN (8/6/99)				NW27, CINNAMON GULCH WEST (8/6/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	15.0				5.0			
pH (standard units)	3.89				3.65			
Conductivity (µS/cm)	179.0				143.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	56	None	N/A		22	None	N/A	
Aluminum (trec) (µg/L)	3,700	None	N/A	302.5	2,100	None	N/A	57.2
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	81	1000.00	Below standard	6.6	250	1000.00	Below standard	6.8
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	1.0	0.50	2.0	0.0
Zinc (trec) (µg/L)	910	2000.00	Below standard	74.4	570	2000.00	Below standard	15.5
Aluminum (µg/L)	3,700	87.00	42.5	302.5	2,100	87.00	24.1	57.2
Cadmium (µg/L)	4.2	0.72	5.9	0.3	4.2	0.35	12.0	0.1
Calcium (mg/L)	19	None	N/A	1,553.5	6	None	N/A	163.5
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	82.0	7.17	11.4	6.7	360.0	3.29	109.4	9.8
Fluoride (mg/L)	0.20	2.00	Below standard	16.4	0.20	2.00	Below standard	5.5
Iron (µg/L)	140	300.00	Below standard	11.4	250	300.00	Below standard	6.8
Lead (µg/L)	< 1.0	1.70	Below standard	N/A	36.0	0.47	77.2	1.0
Magnesium (mg/L)	2.00	None	N/A	163.5	1.80	None	N/A	49.1
Manganese (µg/L)	1,100	50.00	22.0	89.9	920	50.00	18.4	25.1
Nickel (µg/L)	< 20	61.26	Below standard	N/A	< 20	30.64	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	8.8	None	N/A	719.5	6.0	None	N/A	163.5
Silver (µg/L)	< 0.2	0.03	Not detected	N/A	0.8	0.006	139.9	0.0
Sodium (mg/L)	1.70	None	N/A	139.0	1.50	None	N/A	40.9
Sulfate (mg/L)	60	250.00	Below standard	4,905.9	40	250.00	Below standard	1,090.2
Zinc (µg/L)	910	64.56	14.1	74.4	570	29.81	19.1	15.5

Table 10. Analytical data for samples NW14-28, 36-43, 45, 58-59 from the Montezuma stock area--continued.

Sample	NW28, CINNAMON GULCH EAST (8/6/99)				NW36, WEBSTER PASS SOUTH (8/20/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	300.0				48.0			
pH (standard units)	4.54				3.59			
Conductivity (µS/cm)	142.0				201.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	153	None	N/A		31	None	N/A	
Aluminum (trec) (µg/L)	1,100	None	N/A	1,798.8	4,800	None	N/A	1,255.9
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	590	1000.00	Below standard	964.8	210	1000.00	Below standard	54.9
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	440	2000.00	Below standard	719.5	25	2000.00	Below standard	6.5
Aluminum (µg/L)	1,100	87.00	12.6	1,798.8	4,700	87.00	54.0	1,229.7
Cadmium (µg/L)	1.8	1.58	1.1	2.9	0.3	0.45	Below standard	0.1
Calcium (mg/L)	53	None	N/A	86,670.9	9	None	N/A	2,354.8
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	5.0	250.00	Below standard	1,308.2
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	75.0	17.01	4.4	122.6	17.0	4.31	3.9	4.4
Fluoride (mg/L)	0.40	2.00	Below standard	654.1	< 0.10	2.00	Below standard	N/A
Iron (µg/L)	220	300.00	Below standard	359.8	210	300.00	Below standard	54.9
Lead (µg/L)	< 1.0	7.11	Below standard	N/A	< 1.0	0.73	Not detected	N/A
Magnesium (mg/L)	5.00	None	N/A	8,176.5	2.00	None	N/A	523.3
Manganese (µg/L)	1,700	50.00	34.0	2,780.0	95	50.00	1.9	24.9
Nickel (µg/L)	< 20	132.04	Below standard	N/A	< 20	38.96	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	5.0	None	N/A	8,176.5	7.2	None	N/A	1,883.9
Silver (µg/L)	< 0.2	0.16	Not detected	N/A	< 0.2	0.01	Not detected	N/A
Sodium (mg/L)	1.80	None	N/A	2,943.5	0.70	None	N/A	183.2
Sulfate (mg/L)	82	250.00	Below standard	134,094.6	41	250.00	Below standard	10,727.6
Zinc (µg/L)	440	151.97	2.9	719.5	28	38.97	Below standard	7.3

Table 10. Analytical data for samples NW14-28, 36-43, 45, 58-59 from the Montezuma stock area--continued.

Sample	NW37, HANDCART PEAK EAST (8/20/99)				NW38, RED CONE SOUTHWEST (8/20/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	165.0				6.0			
pH (standard units)	3.47				2.63			
Conductivity (µS/cm)	296.0				2,980.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	43	None	N/A		106	None	N/A	
Aluminum (trec) (µg/L)	3,500	None	N/A	3,148.0	170,000	None	N/A	5,560.0
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 5.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 5.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	4,300	1000.00	4.3	3,867.5	180,000	1000.00	180.0	5,887.1
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 5.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	150	2000.00	Below standard	134.9	400	2000.00	Below standard	13.1
Aluminum (µg/L)	3,500	87.00	40.2	3,148.0	170,000	87.00	1,954.0	5,560.0
Cadmium (µg/L)	1.1	0.59	1.9	1.0	2.6	1.18	2.2	0.1
Calcium (mg/L)	11	None	N/A	9,893.6	16	None	N/A	523.3
Chloride (mg/L)	3.0	250.00	Below standard	2,698.2	66.0	250.00	Below standard	2,158.6
Chromium (µg/L)	< 10	11.00	Below standard	N/A	91	11.00	8.3	3.0
Copper (µg/L)	< 4.0	5.80	Below standard	N/A	990.0	12.39	79.9	32.4
Fluoride (mg/L)	0.20	2.00	Below standard	179.9	< 0.10	2.00	Below standard	N/A
Iron (µg/L)	4,000	300.00	13.3	3,597.7	140,000	300.00	466.7	4,578.8
Lead (µg/L)	< 1.0	1.20	Below standard	N/A	< 5.0	4.20	Not detected	N/A
Magnesium (mg/L)	3.90	None	N/A	3,507.7	16.00	None	N/A	523.3
Manganese (µg/L)	310	50.00	6.2	278.8	490	50.00	9.8	16.0
Nickel (µg/L)	26	50.76	Below standard	23.4	310	99.62	3.1	10.1
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	10.0	None	N/A	8,994.2	23.0	None	N/A	752.2
Silver (µg/L)	< 0.2	0.02	Not detected	N/A	< 1.0	0.08	Not detected	N/A
Sodium (mg/L)	2.40	None	N/A	2,158.6	1.40	None	N/A	45.8
Sulfate (mg/L)	54	250.00	Below standard	48,568.4	1,300	250.00	5.2	42,517.8
Zinc (µg/L)	170	52.35	3.2	152.9	420	111.00	3.8	13.7

Table 10. Analytical data for samples NW14-28, 36-43, 45, 58-59 from the Montezuma stock area--continued.

Sample	NW39, HANDCART BELOW ALTERATION (8/20/99)				NW40, HANDCART FERROSINTER (8/20/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	500.0				25.0			
pH (standard units)	3.15				3.61			
Conductivity (µS/cm)	843.0				1,004.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	53	None	N/A		176	None	N/A	
Aluminum (trec) (µg/L)	29,000	None	N/A	79,039.5	27,000	None	N/A	3,679.4
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	30,000	1000.00	30.0	81,765.0	84,000	1000.00	84.0	11,447.1
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	180	2000.00	Below standard	490.6	200	2000.00	Below standard	27.3
Aluminum (µg/L)	28,000	87.00	321.8	76,314.0	27,000	87.00	310.3	3,679.4
Cadmium (µg/L)	1.2	0.68	1.8	3.3	0.6	1.77	Below standard	0.1
Calcium (mg/L)	12	None	N/A	32,706.0	41	None	N/A	5,587.3
Chloride (mg/L)	13.0	250.00	Below standard	35,431.5	13.0	250.00	Below standard	1,771.6
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 100	11.00	Not detected	N/A
Copper (µg/L)	200.0	6.82	29.3	545.1	370.0	19.19	19.3	50.4
Fluoride (mg/L)	0.20	2.00	Below standard	545.1	1.00	2.00	Below standard	136.3
Iron (µg/L)	29,000	300.00	96.7	79,039.5	110,000	300.00	366.7	14,990.3
Lead (µg/L)	< 1.0	1.56	Below standard	N/A	< 1.0	8.69	Below standard	N/A
Magnesium (mg/L)	5.50	None	N/A	14,990.3	18.00	None	N/A	2,453.0
Manganese (µg/L)	280	50.00	5.6	763.1	520	50.00	10.4	70.9
Nickel (µg/L)	66	58.61	1.1	179.9	< 200	147.06	Not detected	N/A
Potassium (mg/L)	1.0	None	N/A	2,725.5	2.3	None	N/A	313.4
Silicon (mg/L)	14.0	None	N/A	38,157.0	27.0	None	N/A	3,679.4
Silver (µg/L)	< 0.2	0.02	Not detected	N/A	< 0.2	0.20	Not detected	N/A
Sodium (mg/L)	2.10	None	N/A	5,723.6	6.00	None	N/A	817.7
Sulfate (mg/L)	210	250.00	Below standard	572,355.0	320	250.00	1.3	43,608.0
Zinc (µg/L)	150	61.45	2.4	408.8	200	171.36	1.2	27.3

Table 10. Analytical data for samples NW14-28, 36-43, 45, 58-59 from the Montezuma stock area--continued.

Sample	NW41, PEAK 13,214 WEST-LOW (8/5/99)				NW42, WEBSTER PASS NORTH-LOW (8/5/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	500.0				400.0			
pH (standard units)	3.32				3.68			
Conductivity (µS/cm)	274.0				113.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	47	None	N/A		17	None	N/A	
Aluminum (trec) (µg/L)	4,500	None	N/A	12,264.8	2,100	None	N/A	4,578.8
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	3,700	1000.00	3.7	10,084.4	1,400	1000.00	1.4	3,052.6
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	230	2000.00	Below standard	626.9	90	2000.00	Below standard	196.2
Aluminum (µg/L)	4,500	87.00	51.7	12,264.8	2,100	87.00	24.1	4,578.8
Cadmium (µg/L)	1.0	0.63	1.6	2.7	0.5	0.28	1.8	1.1
Calcium (mg/L)	12	None	N/A	32,706.0	5	None	N/A	10,902.0
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	32.0	6.23	5.1	87.2	4.0	2.60	1.5	8.7
Fluoride (mg/L)	0.30	2.00	Below standard	817.7	< 0.10	2.00	Below standard	N/A
Iron (µg/L)	3,600	300.00	12.0	9,811.8	1,400	300.00	4.7	3,052.6
Lead (µg/L)	< 1.0	1.34	Below standard	N/A	< 1.0	0.32	Not detected	N/A
Magnesium (mg/L)	4.20	None	N/A	11,447.1	1.10	None	N/A	2,398.4
Manganese (µg/L)	480	50.00	9.6	1,308.2	110	50.00	2.2	239.8
Nickel (µg/L)	23	54.04	Below standard	62.7	< 20	24.87	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	7.1	None	N/A	19,351.1	5.6	None	N/A	12,210.2
Silver (µg/L)	< 0.2	0.02	Not detected	N/A	< 0.2	0.00	Not detected	N/A
Sodium (mg/L)	1.50	None	N/A	4,088.3	0.88	None	N/A	1,918.8
Sulfate (mg/L)	68	250.00	Below standard	185,334.0	27	250.00	Below standard	58,870.8
Zinc (µg/L)	230	56.13	4.1	626.9	92	23.63	3.9	200.6

Table 10. Analytical data for samples NW14-28, 36-43, 45, 58-59 from the Montezuma stock area--continued.

Sample	NW43, WEBSTER PASS NORTH-GULCH (8/5/99)				NW45, CINNAMON GULCH-UPPER (8/6/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	400.0				220.0			
pH (standard units)	3.68				4.37			
Conductivity (µS/cm)	113.0				29.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	17	None	N/A		10	None	N/A	
Aluminum (trec) (µg/L)	2,100	None	N/A	4,578.8	590	None	N/A	707.5
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	1,400	1000.00	1.4	3,052.6	56	1000.00	Below standard	67.2
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	93	2000.00	Below standard	202.8	110	2000.00	Below standard	131.9
Aluminum (µg/L)	2,100	87.00	24.1	4,578.8	560	87.00	6.4	671.6
Cadmium (µg/L)	0.5	0.28	1.8	1.1	1.1	0.19	5.8	1.3
Calcium (mg/L)	5	None	N/A	10,902.0	3	None	N/A	3,597.7
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	< 4.0	2.60	Not detected	N/A	10.0	1.69	5.9	12.0
Fluoride (mg/L)	< 0.10	2.00	Below standard	N/A	< 0.10	2.00	Below standard	N/A
Iron (µg/L)	1,400	300.00	4.7	3,052.6	< 10	300.00	Below standard	N/A
Lead (µg/L)	< 1.0	0.32	Not detected	N/A	1.0	0.15	6.5	1.2
Magnesium (mg/L)	1.10	None	N/A	2,398.4	0.67	None	N/A	803.5
Manganese (µg/L)	110	50.00	2.2	239.8	280	50.00	5.6	335.8
Nickel (µg/L)	< 20	24.87	Below standard	N/A	< 20	16.92	Not detected	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	0.4	None	N/A	479.7
Silicon (mg/L)	5.5	None	N/A	11,992.2	2.7	None	N/A	3,237.9
Silver (µg/L)	< 0.2	0.00	Not detected	N/A	< 0.2	0.00	Not detected	N/A
Sodium (mg/L)	0.87	None	N/A	1,896.9	0.53	None	N/A	635.6
Sulfate (mg/L)	26	250.00	Below standard	56,690.4	11	250.00	Below standard	13,191.4
Zinc (µg/L)	92	23.63	3.9	200.6	110	15.38	7.2	131.9

Table 10. Analytical data for samples NW14-28, 36-43, 45, 58-59 from the Montezuma stock area--continued.

Sample	NW58, BRUNO GULCH-N. FORK (9/16/99)				NW59, BRUNO GULCH (9/16/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	100.0				80.0			
pH (standard units)	6.87				4.85			
Conductivity (µS/cm)	33.0				78.0			
Alkalinity (mg/L CaCO3)	< 20.00							
Hardness (mg/L CaCO3)	< 29	None	N/A		49	None	N/A	
Aluminum (trec) (µg/L)	< 50	None	N/A	N/A	890	None	N/A	388.1
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	< 10	1000.00	Below standard	N/A	770	1000.00	Below standard	335.8
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	< 10	2000.00	Below standard	N/A	40	2000.00	Below standard	17.4
Aluminum (µg/L)	< 50	87.00	Below standard	N/A	800	87.00	9.2	348.9
Cadmium (µg/L)	< 0.3	<0.43	Not detected	N/A	< 0.3	0.64	Below standard	N/A
Calcium (mg/L)	< 10	None	N/A	N/A	16	None	N/A	6,977.3
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	< 4.0	<4.07	Not detected	N/A	6.0	6.38	Below standard	2.6
Fluoride (mg/L)	< 0.10	2.00	Below standard	N/A	0.20	2.00	Below standard	87.2
Iron (µg/L)	< 10	300.00	Below standard	N/A	520	300.00	1.7	226.8
Lead (µg/L)	< 1.0	<0.66	Not detected	N/A	< 1.0	1.40	Below standard	N/A
Magnesium (mg/L)	0.91	None	N/A	496.0	2.10	None	N/A	915.8
Manganese (µg/L)	< 4	50.00	Below standard	N/A	210	50.00	4.2	91.6
Nickel (µg/L)	< 20	<37.04	Not detected	N/A	< 20	55.24	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	< 1.0	None	N/A	N/A
Silicon (mg/L)	2.8	None	N/A	1,526.3	4.7	None	N/A	2,049.6
Silver (µg/L)	< 0.2	<0.01	Not detected	N/A	< 0.2	0.02	Not detected	N/A
Sodium (mg/L)	0.98	None	N/A	534.2	1.50	None	N/A	654.1
Sulfate (mg/L)	6	250.00	Below standard	3,434.1	30	250.00	Below standard	13,082.4
Zinc (µg/L)	< 10	<36.84	Not detected	N/A	42	57.52	Below standard	18.3

The western tributary drains the eastern side of Handcart Peak and is lined with brown and orange-red ferrosinter and ferricrete. Fresh and older, partly decomposed ferricrete and ferrosinter deposits cover much of this valley floor, which lies in a wetland environment. Altered bedrock exposed on the walls of this drainage basin is stained red, yellow, and brown. At sample site NW37, the creek flowed at about 165 gpm, had 3.47 pH, 296 µS/cm conductivity, and contained much higher metal concentrations than the eastern tributary. Aluminum, iron, manganese, zinc, and cadmium values exceeded state standards (Table 10).

The addition of poor-quality groundwater from numerous visible and subsurface seeps probably plays an important role in downstream degradation in Handcart Gulch. Samples NW38 and NW40 are from springs and/or seeps on the east side of Handcart Gulch (Figure 50). Sample NW38 is from one of several seeps that emerge near the toe of a large rock glacier comprising brown and yellow altered metamorphic rocks on the southwestern side of Red Cone. This water was severely degraded, showing 2.63 pH and 2,980 µS/cm conductivity. Iron, aluminum, and copper concentrations greatly exceeded state standards. Manganese, chromium, sulfate, nickel, zinc, and cadmium values also exceeded standards. Above this area of numerous seeps, Handcart Gulch had some ferricrete and precipitate. Below the confluence with the seeps, Handcart Gulch water had 3.17 pH, 688 µS/cm conductivity, and precipitate lining the streambed was more abundant, especially orange-red precipitate.

Sample NW40 was from a spring that emerges at a 10-foot-long prospect adit situated in the midst of a large ferrosinter deposit on the east side of Handcart Gulch. This small adit is completely hosted in ferrosinter and has no effect on water quality. Several smaller springs emerged within this brown and yellow-green ferrosinter deposit, but NW40 represents the largest, flowing at about 25 gpm. Conductivity was 1,004 µS/cm, and pH was 3.61. This sample was slightly cleaner than NW38, but greatly exceeded state standards in aluminum and iron concentrations. Manganese and copper concentrations significantly exceeded standards, and sulfate and zinc values were slightly above standards (Table 10).

Sample NW39 was collected from Handcart Gulch downstream of the group of seeps near NW38 and upstream of the springs at NW40. The stream channel was lined with ferricrete and abundant orange-red precipitate, and lesser amounts of gray-yellow precipitate (Figure 51). In this area the ridge lying southwest of Handcart Gulch that forms the drainage divide between Handcart Gulch and Hall Valley is fractured, altered, and stained brown-yellow. Stream water flowed at 500 gpm, had pH of 3.15 and conductivity of 843 µS/cm. Aluminum, iron, and copper greatly exceeded standards; manganese, zinc, cadmium, and nickel values also exceeded standards (Table 10). A few hundred feet downstream of this sample site, orange-red precipitate increased and formed terraces that the stream flowed over, around, and through.

Near the mouth of Handcart Gulch, precipitate was abundant, and stream water had 3.19 pH and 673 µS/cm conductivity (Figure 50) suggesting similar water quality to NW39. No sample was collected because some small draining mines about ¼ mile downstream of sample site NW40 may have some affect on water quality.

Figure 51. Photograph showing sample site NW39 and Handcart Gulch.

In the fall of 1999, the main branch and the north fork of Bruno Gulch were sampled (Figure 50). Sample NW58 is from the north fork that drains the southeastern side of Landslide Peak. The headwater area of this stream appears altered and is stained dark brown, but most of the stream reach lies outside of the altered area mapped by Neuerburg (1971). This water was quite pure with no significant metal concentrations (Table 10). NW59 was from Bruno Gulch upstream of its confluence with the north fork, at approximately the same location as a 1992 sample discussed in the **Previous Investigations** section. The streambed and algae had minor amounts of light-brown precipitate, and the pH was moderately acidic. Although the flow was considerably different, the 1999 and 1992 samples had similar metal concentrations. The 1999 sample exceeded state standards in aluminum, iron, and manganese. Copper and zinc concentrations were elevated, but within standards.

A test of the south fork of Bruno Gulch indicated high quality water with neutral pH and 29 µS/cm conductivity (Figure 50). Most of the gently sloping terrain above this test site was covered with alpine vegetation, and severe alteration was not obvious. Sawmill Gulch was tested near its mouth and showed 6.40 pH and 47 µS/cm conductivity, suggesting no significant degradation of the surface waters in this area.

Snake River

Extensive iron bogs that lie within and adjacent to the alteration zone associated with the Montezuma stock (Neuerburg, 1971) suggest the occurrence of metal-rich drainage near the headwaters of the Snake River. Numerous water tests and samples were collected in this area (Figure 52), which is essentially devoid of mines or prospects in its upper reaches. Samples collected further north have small mines above some of the sites, but the mines and associated waste-rock piles are not draining and probably have no significant effect on water quality.

Sampling and testing confirmed the presence of naturally degraded stream and spring water in the southern portion of the Snake River drainage basin, primarily on the east side of the river. From the southern slopes of Santa Fe Peak to Webster Pass, sampled and/or tested surface water had pH between 3.30 and 5.31, with most pHs below 5. Conductivity ranged from 18 to 289 µS/cm.

Sample NW14 was from a 7-gpm seep about 2,000 feet north of Webster Pass, and NW15 was from the adjacent stream flowing at 150 gpm, upstream of the seep (Figure 52). Seep water was slightly more acidic and had more conductivity than the stream, but most metal concentrations were similar (Table 10). Both samples exceeded state standards in aluminum, copper, and zinc. Seep water also exceeded standards in cadmium and lead.

Downstream in the same tributary, samples NW42 and NW43 were replicate samples collected from a site adjacent to a 4WD trail (Figure 52). At this downstream site, flow had increased from 150 to 400 gpm, pH had dropped to 3.68, and conductivity had increased to 113 µS/cm. The stream channel was steep with moderate amounts of red precipitate, some relatively indurated and some quite soft and muddy. Terracettes of ferrosinter/ferricrete had formed, but were not as well developed as those in tributaries to the north, described in the following paragraphs. Concentrations of aluminum, iron, and zinc increased substantially compared to the upstream sample, and the stream water significantly exceeded state standards in aluminum and exceeded standards in iron, zinc, manganese, and cadmium (Table 10). Copper was not detected in one of the replicates, but occurred at the detection limit in the other sample. If actually present at the detection limit, copper also exceeded standards. All of the samples contained little hardness (<20 mg/L), therefore hardness-related standards for copper, zinc, and cadmium were quite low.

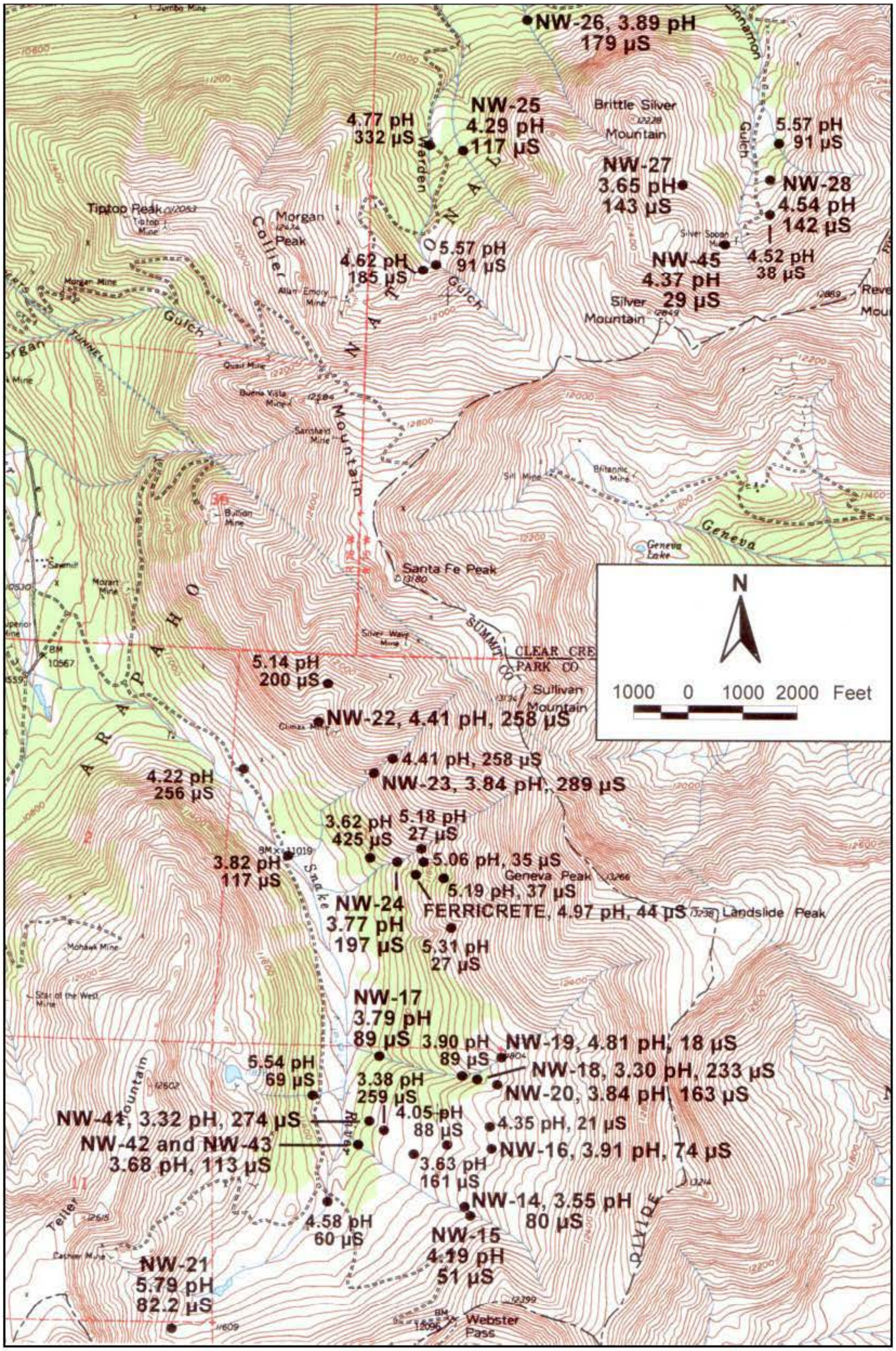

Figure 52. Map showing sample sites NW14-28, 41-43, 45, and nearby test results in the Snake River and Peru Creek drainage basins.

Samples NW16 and NW41 were from the adjacent tributary to the north of sample NW42 (Figure 52). This tributary drains a large area of altered granitic rock and amphibolite with dark brown, light brown, and yellow stains. At sample site NW16, flow was 80 gpm, pH was 3.91, and conductivity was 74 µS/cm. Aluminum, copper, and manganese concentrations exceeded state standards (Table 10). At sample site NW41, the stream flows over terracettes of red precipitate, flow was 500 gpm, pH had dropped to 3.32, and conductivity had increased to 274 µS/cm. Aluminum greatly exceeded state standards, and iron, manganese, copper, zinc, and cadmium concentrations were also above standards. Similar to the previously described tributary, pH decreased, and metal concentrations and conductivity increased from upstream to downstream. Sequential tests from upstream to downstream showed a general pattern of decreasing pH and increasing conductivity (Figure 52). At the test site with pH of 3.63, a large, partly weathered ferrosinter deposit is exposed. From this limited, reconnaissance-level sampling and testing, it is not clear if the ferrosinter deposit is changing the surface water chemistry, or if the deposit indicates an area of poor-quality groundwater emerging at the surface.

Samples NW17 to 20 are from the drainage basin on the southwest side of Landslide Peak (Figure 52). The upper slopes of the drainage basin are altered (Neuerburg, 1971) and show brown and yellow staining. A large, actively forming ferrosinter deposit is exposed on the slope (Figure 53). Numerous springs emerge in and near this ferrosinter deposit. Shallow prospect pits excavated within the bog-iron deposit presumably have no effect on water quality.

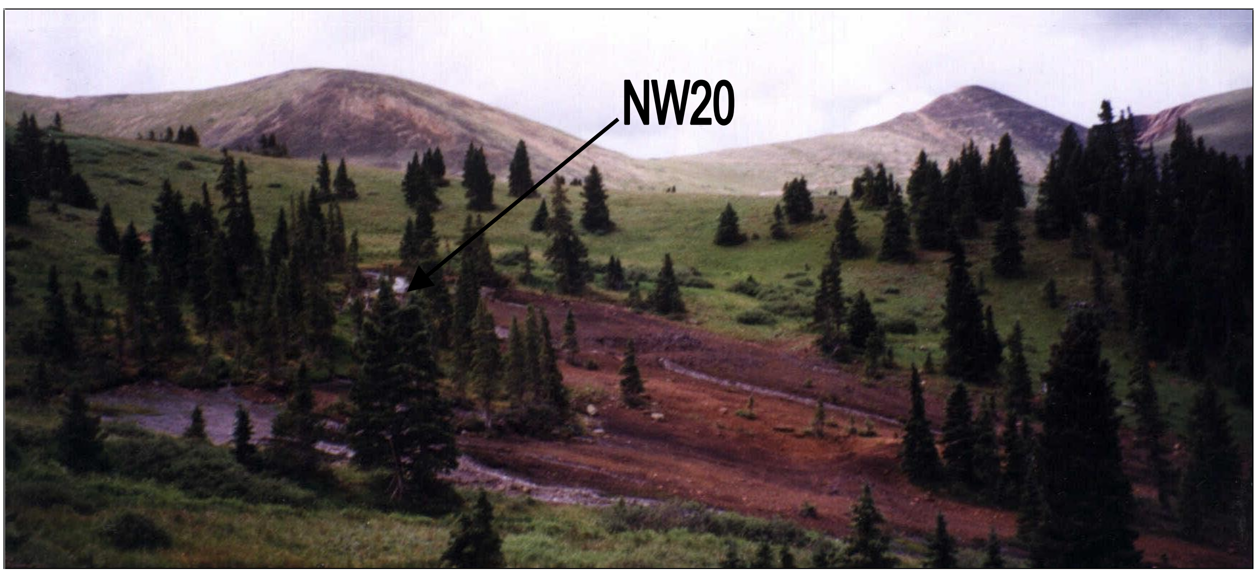

Figure 53. Photograph showing sample site NW20 at ferrosinter deposit.

Two samples were collected at this ferrosinter deposit. Sample NW20 was from a pool of clear water near the upper part of the deposit. Hardened, red-brown precipitate formed the walls of the pool, which was about 2 feet deep (Figure 54). Flow from the pool was dispersed and not measurable, but was estimated at about 10 gpm. Conductivity was 163 µS/cm, and pH was 3.84. Aluminum, copper, and iron concentrations significantly exceeded state standards; and manganese, zinc, and cadmium also exceeded standards.

Figure 54. Photograph showing pool of water in ferrosinter at sample site NW20.

Sample NW18 was collected near the lowest part of the exposed portion of the ferrosinter deposit, just upstream of the confluence of the ferrosinter drainage with the marked stream flowing from the southwest side of Landslide Peak. Several of the springs and seeps associated with the ferrosinter had coalesced into a few larger streams. Sample NW18 was from the largest of these streams, which flowed at 30 gpm. Conductivity had increased to 233 µS/cm, and pH dropped to 3.30. Although test parameters of pH and conductivity suggest that water near the base of the ferrosinter deposit was more degraded than the spring near the summit, lab analyses show most trace-metal concentrations were noticeably lower in the water at the base of the deposit. Although still above standards, aluminum and iron concentrations were greatly reduced, and copper was somewhat reduced (Table 10). Zinc and cadmium concentrations showed minor change, and manganese concentration increased slightly. Higher conductivity probably resulted from additional sulfate in the water, although sulfate concentrations still met state standards. The acidity increase may be attributable to dissolved ferrous iron ions combining with water to form iron hydroxide precipitate and free hydrogen ions. Water sample results suggest that lab analyses of material from the ferrosinter deposit would reveal abundant iron and aluminum, with anomalous concentrations of copper.

Sample NW19 was from the marked tributary draining the southwest side of Landslide Peak, upstream of any obvious influence from the degraded springs at the ferrosinter deposit. Flow rate was 300 gpm, pH was 4.81, and conductivity was 18 µS/cm. The stream channel had no precipitate. Aluminum and zinc concentrations slightly exceeded state standards, but iron, copper, and cadmium levels were below detection limits (Table 10).

A water test downstream of the confluence of the relatively clean water of NW19 with the degraded water associated with the ferrosinter deposit showed 3.90 pH and 89 µS/cm conductivity (Figure 52). Below the confluence, the main stream channel is lined with smooth, hard, red, iron-rich precipitate that creates a flume-like appearance.

Sample NW17 was collected from this same marked stream about 2,000 feet downstream of the ferrosinter deposit. Flow was 800 gpm, pH was 3.79, and conductivity was 89 µS/cm. Abundant red precipitate, some that is well indurated, lined the stream channel, occasionally forming terracettes. Aluminum and copper significantly exceeded state standards; and manganese, iron, zinc, and cadmium also exceeded standards (Table 10).

Numerous seeps with associated red precipitate emerge throughout the area between sample sites NW42 and NW17. Tests from some of these seeps showed similar pH and conductivity as the samples collected nearby, suggesting large volumes of water with similar chemistry flow beneath and at the surface, eventually draining into the Snake River. These degraded tributaries and innumerable seeps and springs contribute substantially to metal loads in the upper Snake River, above all known significant mining activity.

Upstream of sample NW42, and above all of the large bog-iron deposits, sample NW21 was collected in the headwaters of the Snake River (Figure 52), near the western boundary of the altered area (Neuerburg, 1971). Although rocks on the north side of Handcart Peak showed brown staining, this 62-gpm stream had pH of 5.79 and conductivity of 82 µS/cm. Much of the gravel had a red, iron-oxide coating. Most metals were not detected, and none exceeded standards (Table 10). Acidic or metal-rich waters associated with the altered rocks on the north side of Handcart Peak are probably low in volume and/or are diluted by runoff from the relatively unaltered rocks west of the sample site. Also, fractured bedrock on Handcart Peak may provide conduits for water with significant residence time in the altered rocks to descend and eventually emerge in the upper reaches of Handcart Gulch and Hall Valley, contributing to degradation described previously in the **Handcart Gulch** section of this report.

The alteration zone shown by Neuerburg (1971) extends northward, but past mining activities increased in that area, as well. Numerous tests and samples (NW22-24) were collected from the Snake River and its tributaries draining from the Continental Divide from Geneva Peak northward to the southwest side of Santa Fe Peak (Figure 52). Efforts were made to select sample sites draining areas where previous mining activity was limited or non-existent. Some small, dry mines lie above some of the sample sites, however impacts on water quality by these mines is believed to be minimal. Some of the water tests shown on figure 52 are from streams that may be affected by past mining activities.

Sample NW24 was from a marked stream lying between Geneva Peak and Sullivan Mountain. The sample was collected near the lower end of a ferricrete/ferrosinter deposit, immediately below the confluence of an unmarked stream flowing from the east and the marked stream. Flow was 200 gpm, pH was 3.77, and conductivity was 197 µS/cm. Aluminum concentration greatly exceeded state standards; and copper, manganese, iron, zinc, and cadmium also exceeded standards (Table 10). Water tests conducted upstream of the ferricrete/ferrosinter deposit showed pHs greater than 5 and less than 40 µS/cm conductivities (Figure 52).

Sample NW23 was from a marked stream draining southwest from Sullivan Mountain. Heavily iron-stained gneiss and igneous rocks compose the slopes of this drainage basin, and the stream channel is lined with ferricrete. Yellow precipitate that clogged the water filter indicated that the stream was carrying moderate volumes of suspended solids. Flow was 300 gpm, pH was 3.84, and conductivity was 289 µS/cm. Aluminum and manganese concentrations greatly exceeded state standards; and zinc, iron, cadmium, and copper also exceeded standards (Table 10). Water tested near the upper extent of the exposed ferricrete channel had 4.41 pH and 258 µS/cm conductivity (Figure 52).

The Snake River was tested downstream of its confluence with the streams of samples NW23 and NW24. The stream channel had abundant red precipitate, pH was 3.82, and conductivity was 117 µS/cm (Figure 52).

Sample NW22 was from an unmarked stream draining the southwest side of Santa Fe Peak (Figure 52). The sample was collected upstream of the influence of water associated with the Climax Mine. A few small, presumably dry mines lie on the south side of Santa Fe Peak above this sample site. Most of the alluvium consisted of gneissic rocks with red iron-oxide and black manganese(?)-oxide coatings. Flow was 80 gpm, pH was 4.41, and conductivity was 258 µS/cm. Aluminum and manganese concentrations greatly exceeded state standards; and zinc, copper, cadmium, and lead significantly exceeded standards (Table 10). Water tested upstream of this sample site, from a south-flowing tributary, showed 5.14 pH and 200 µS/cm conductivity (Figure 52).

Peru Creek

The north-facing slopes of the Continental Divide drain toward Peru Creek and are within the altered area mapped by Neuerburg (1971), and the Montezuma stock crops out at lower elevations on these slopes. Samples NW25-28, and NW45 were collected from some of these north-flowing tributaries (Figure 52). Numerous mines have been driven into the red- and yellow-stained slopes in this area, but most of the large ones are at lower elevations. For this study, efforts were made to sample streams above all of the known large and/or draining mines.

Sample NW25 was from an eastern tributary of Warden Gulch that drains the northwest side of Silver Mountain (Figure 52). Rocks in the streambed had a red stain, but no precipitate occurred. Water was flowing at 50 gpm, pH was 4.29, and conductivity was 117 µS/cm. Aluminum concentration was high, and manganese, copper, zinc, and cadmium also exceeded standards (Table 10).

Sample NW26 was from a tributary of Peru Creek that drains the northwest side of Brittle Silver Mountain (Figure 52). The streambed contained fresh, yellow- and red-stained granitic rocks of the Montezuma stock. Flow was 15 gpm, pH was 3.89, and conductivity was 179 µS/cm. This water exceeded standards in the same parameters as NW25, but the concentrations of most trace metals were 2 to 5 times higher (Table 10). Aluminum was about the same.

Sample NW27 was from a 5-gpm spring that drains into an unmarked, northeast-flowing tributary of Cinnamon Gulch (Figure 52). This spring was one of several on the north-facing slope of a grassy, swampy basin. About 20 feet to the west, another spring emerged from an 8-foot-deep prospect pit. Many of the springs, including the one at the prospect pit, emerged from a sub-horizontal fracture in the bedrock. Bedrock and talus on the slopes above show brown iron-staining, but the alteration does not appear severe. The springs showed no visible indications of degradation, but pH was 3.65 and conductivity was 143 µS/cm. This water was highly degraded, exceeding state standards for copper and silver by two orders of magnitude. Lead, aluminum, zinc, manganese, and cadmium exceeded standards by more than an order of magnitude, and thallium slightly exceeded standards (Table 10). It is reasonable to assume that the other springs emerging from this fracture have similar degraded water. If so, this series of springs may be a significant metal loading source for upper Cinnamon Gulch.

Sample NW28 was from a large spring emerging near the base of a steep slope on the eastern side of Cinnamon Gulch (Figure 52). Moderate amounts of light yellow precipitate coat the rocks in the stream channel of the spring. The yellow precipitate coating continues downstream for about 500 feet, until the spring water merges with the main stream of Cinnamon Gulch. Bedrock and talus exposed on the slopes above this 300-gpm spring are intensely altered and are stained brown, red-brown, and yellow. Conductivity was 142 µS/cm, and pH was 4.54. Manganese and aluminum concentrations significantly exceeded standards, and copper, zinc, and cadmium also exceeded standards (Table 10). The water was moderately hard, so standards for zinc, copper, and cadmium were higher than for most of the samples collected near the Montezuma stock.

Sample NW45 was collected from the upper basin of Cinnamon Gulch, not far above the Silver Spoon Mine (Figure 52). Bedrock and talus on the slopes above are intensely altered and stained brown, red-brown, and yellow. The stream was slightly turbid and was flowing at 220 gpm. Conductivity was only 29 µS/cm and pH was 4.37. No precipitate was in the channel here. Although the water was not substantially degraded with high metal concentrations, zinc, lead, aluminum, copper, cadmium, and manganese exceeded standards (Table 10). Zinc, lead, copper, and cadmium had exceptionally low standards because of the low hardness of the sample.

Beginning a few hundred feet downstream of NW45 in the upper basin of Cinnamon Gulch at about the elevation of the Silver Spoon Mine, Cinnamon Gulch has moderate to abundant red precipitate that coats the streambed. Water was not sampled in the precipitate-lined portion of Cinnamon Gulch because multiple abandoned mines in and along the flanks of this upper basin unquestionably contribute to degradation beginning at about the Silver Spoon Mine. Most likely, the abundant red precipitate occurring in upper Cinnamon Gulch is caused by a combination of natural springs that emerge in this basin, such as the spring of NW28, and effluent from some of the abandoned mines that evidently intersected water-bearing, mineralized fractures.

RED AMPHITHEATRE

An area of naturally occurring degradation occurs in Red Amphitheatre, above the Sweet Home Mine and about 5 miles northwest of Alma. Red Amphitheatre is about ½ mile long and ¼ mile wide (Figure 55). The unnamed stream that drains this basin merges with Buckskin Creek, eventually flowing into the Middle Fork of the South Platte River near Alma.

Geology

Bedrock in Red Amphitheatre consists of Precambrian granitic rocks, overlain by Paleozoic-age sedimentary rocks. All of these rocks were intruded by a Laramide-age stock. (See Tweto and others, 1978.) A few mineralized veins were prospected and/or mined below and in the lower part of Red Amphitheatre..

Much of Red Amphitheatre consists of iron-stained talus and colluvium that flank steep ridges (Figure 56). Hydrothermal alteration and mineralization in this area is probably related to the Laramide igneous activity.

Present Investigation

This area was included in an abandoned mine inventory conducted for the USFS by CGS in 1992 (White and Sares, 1995). A caved and dry adit was inventoried on the north side of Red Amphitheatre drainage basin. The associated waste-rock pile was less than 1,500 cubic yards, suggesting a moderate length of underground workings (USFS-AMLIP inventory form #12-10-403/4352-1, available at CGS). The surface area of the iron-stained rock and talus exposed in Red Amphitheatre dwarfs the surface area of rocks exposed by this caved underground mine.

Water tested near the mouth of Red Amphitheatre in October 1992 had pH of 6.3 and conductivity of 100 µS/cm on an estimated flow of 450 gpm (USFS-AMLIP inventory form #12-10-403/4352-1). No sample was collected.

In 1999 sample NW52 was collected from near the mouth of Red Amphitheatre (Figure 55). Above the sample site, the stream flowed beneath loose, iron-stained talus and a snowbank and could not be sampled. Alluvium and colluvium at and near the sample site included limestone, sandstone, and intrusive igneous rocks, all with varying degrees of iron staining. One piece contained molybdenite.

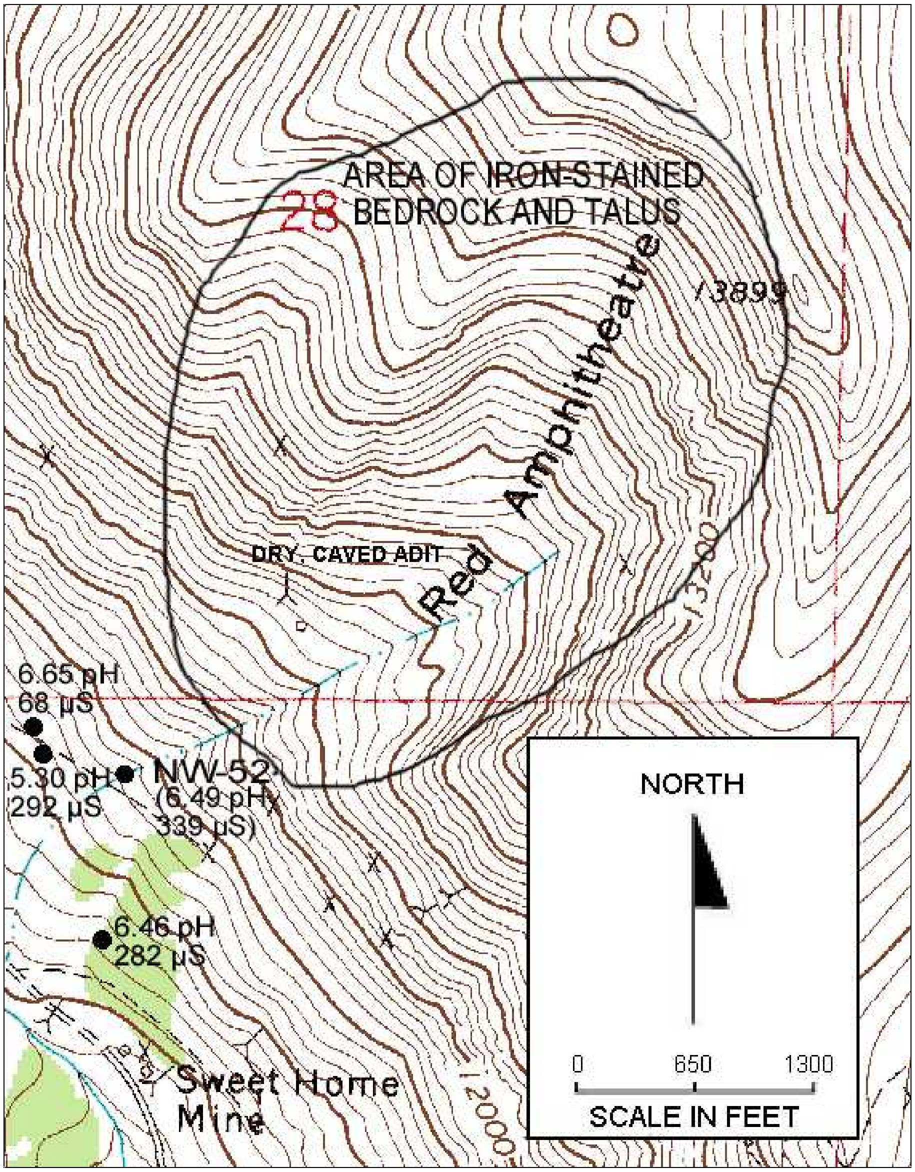

Figure 55. Map showing sample site NW52 and Red Amphitheatre.

Stream flow was 70 gpm; pH was 6.49; and conductivity was 339 µS/cm. White and light-brown precipitate lined the stream channel. Although the stream water appeared fairly clear, the water filter caught white suspended solids. The sample greatly exceeded state standards for dissolved manganese, and moderately exceeded the standards for dissolved aluminum, cadmium, and zinc. Because the water contained high hardness, the water-quality standards for zinc and cadmium were higher than in most alpine environments. Dissolved aluminum was about 1/5 the concentration of total aluminum, suggesting that the precipitate and the suspended solids are dominantly aluminum hydroxides (Table 11). Contact with limestone may neutralize any acidic drainage forming in Red Amphitheatre and explain the high hardness.

Other water test results from near Red Amphitheatre are inconclusive. Two tests showed evidence of degradation, with similar or lower pH and similar conductivities as NW52 (Figure 55). Water at the most northwestern site shows low conductivity and is probably not degraded.

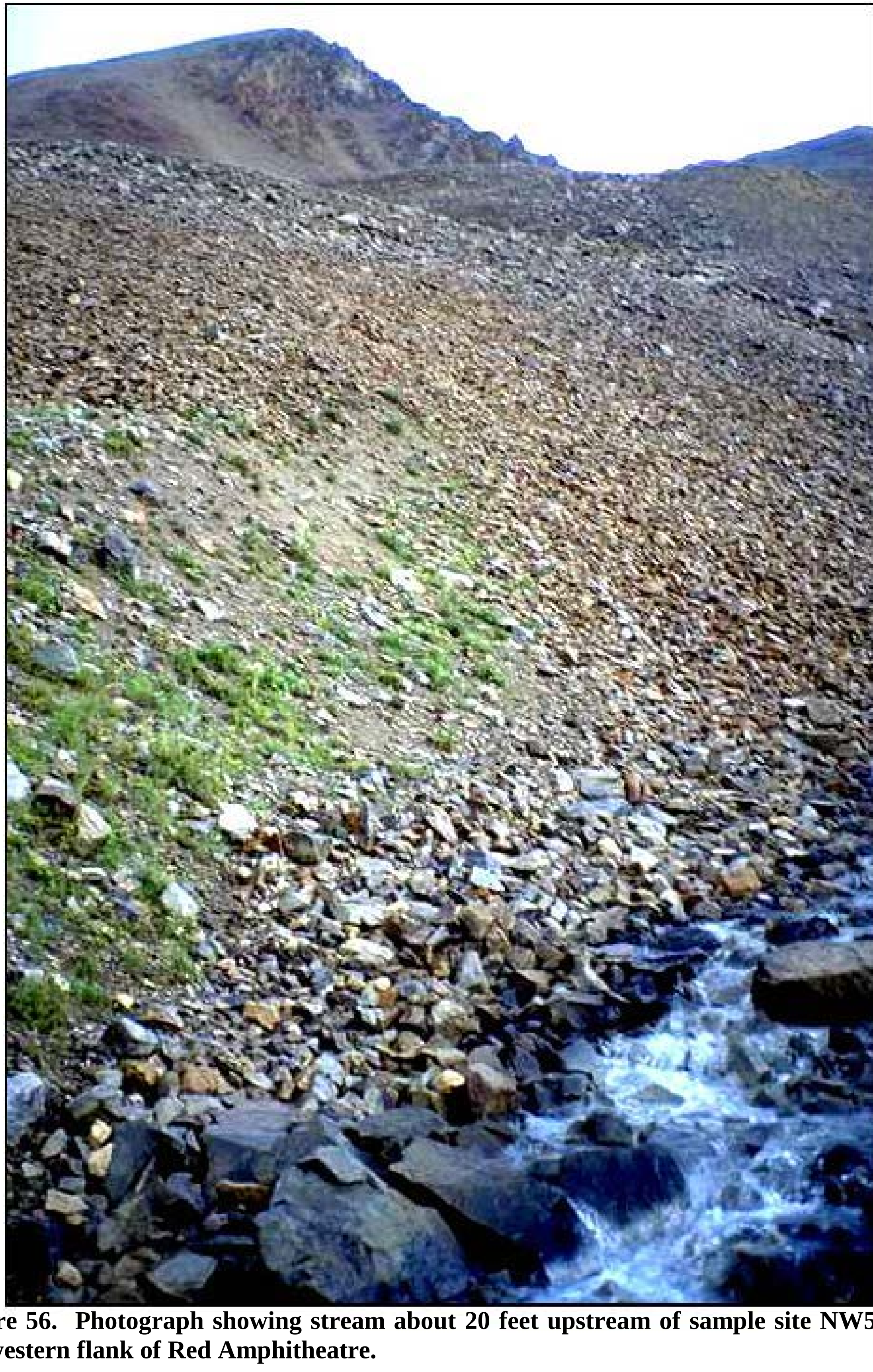

Figure 56. Photograph showing stream about 20 feet upstream of sample site NW52 and the western flank of Red Amphitheatre.

Table 11. Analytical data for water sample NW52 from Red Amphitheatre.

Sample	NW52, RED AMPHITHEATRE (8/27/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	70.0			
pH (standard units)	6.49			
Conductivity (µS/cm)	339.0			
Hardness (mg/L CaCO3)	262	None	N/A	
Aluminum (trec) (µg/L)	660	None	N/A	251.8
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	22	1000.00	Below standard	8.4
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	870	2000.00	Below standard	332.0
Aluminum (µg/L)	140	87.00	1.6	53.4
Cadmium (µg/L)	4.9	2.41	2.0	1.9
Calcium (mg/L)	85	None	N/A	32,433.5
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A
Copper (µg/L)	< 4.0	26.90	Below standard	N/A
Fluoride (mg/L)	1.80	2.00	Below standard	686.8
Iron (µg/L)	< 10	300.00	Below standard	N/A
Lead (µg/L)	< 1.0	15.21	Below standard	N/A
Magnesium (mg/L)	12.00	None	N/A	4,578.8
Manganese (µg/L)	780	50.00	15.6	297.6
Nickel (µg/L)	< 20	198.56	Below standard	N/A
Potassium (mg/L)	1.1	None	N/A	419.7
Silicon (mg/L)	2.0	None	N/A	763.1
Silver (µg/L)	< 0.2	0.39	Below standard	N/A
Sodium (mg/L)	0.98	None	N/A	373.9
Sulfate (mg/L)	66	250.00	Below standard	25,183.6
Zinc (µg/L)	850	239.48	3.5	324.3

TWELVEMILE CREEK

A report by CDPHE suggests that Twelvemile Creek, in the western part of South Park, may contribute to elevated cadmium concentrations in the South Platte upstream of Antero Reservoir (CDPHE, 1988, p. 38). Brief reconnaissance in the area revealed no large, obviously altered terranes. A water test in Twelvemile Creek showed slightly alkaline pH and extremely low conductivity (Figure 57). No sample was collected. Tests nearby in Sheep Creek showed near-neutral or alkaline pHs and moderately high conductivities. Much of the Sheep Creek drainage basin is underlain with the Minturn and Belden Formations (Tweto and others, 1978). The Belden contains black calcareous shales, which probably explains the high pH and conductivity in the surface runoff. No samples were collected because of the lack of obvious indications of degradation and the high pHs.

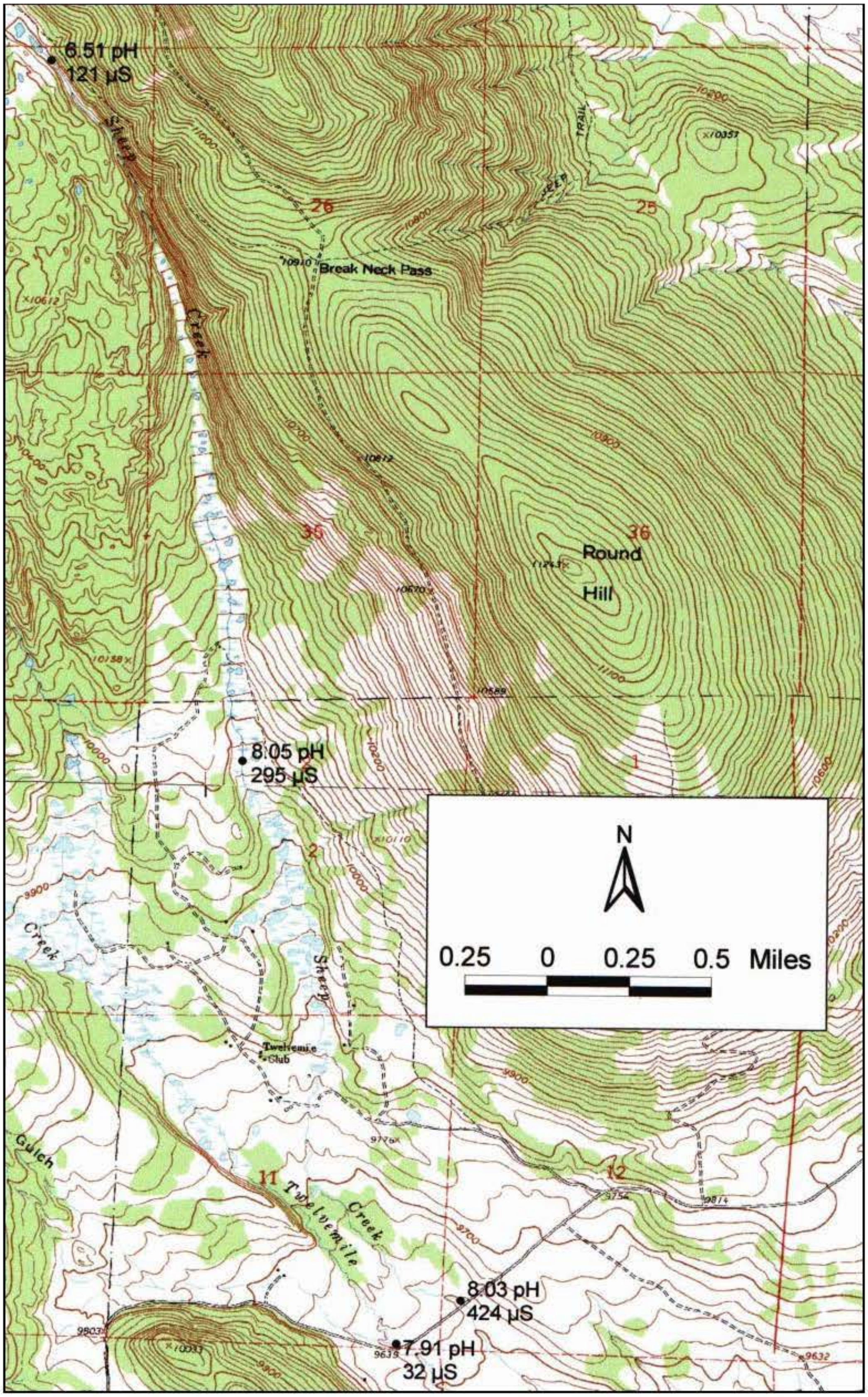

Figure 57. Map showing water test results in South Park in the Twelvemile Creek area.

NORTH-CENTRAL COLORADO

North-central Colorado has few highly mineralized areas, and large areas showing intense alteration are rare. In the isolated areas where streams are contaminated, dilution rapidly mitigates the problem. Natural stream degradation occurs, but is not a serious dilemma in this area.

RABBIT EARS RANGE

The Rabbit Ears Range is an east-west trending range along the Continental Divide and forms the boundary between Middle Park to the south and North Park to the north. The Rabbit Ears Range is about 30 to 40 miles long, extending from the Park Range and Rabbit Ears Peak on the west to Bowen Pass and the Never Summer Mountains on the east. The nearest towns are Granby to the south and Rand to the north.

Alteration of the intrusive rocks that form the range is obvious in a few localities. Areas investigated for this report include the Poison Ridge area in the central part of the range; Parkview Mountain near Willow Creek Pass, and the headwaters of Willow Creek (draining into Middle Park).

Geology

The Rabbit Ears Range comprises a belt of intrusive and extrusive, intermediate- to felsic-composition igneous rocks of Tertiary age that have intruded and/or overlie older Tertiary sedimentary rocks. Sedimentary rocks include sandstones, siltstones, and shales. Some of the intrusions and the surrounding sedimentary rocks have been brecciated, mineralized, and altered. (See Neubert, 1994, p. 42.)

The altered intrusions host subeconomic porphyry copper/molybdenum occurrences. Little, if any production has resulted however. (See Neubert, 1994, p. 41-43.)

Present Investigation

Poison Ridge

The highly altered Poison Ridge stock crops out in Sheep Creek, close to the Continental Divide. Disseminated pyrite is common to abundant throughout much of the altered stock. In addition to pyrite, part of the stock contains subeconomic concentrations of copper, mostly as chalcopyrite. Previous studies have identified more than 50 million tons of mineralized rock averaging more than 0.2% copper. The only evidence of mining is a small prospect in the oxidized portion of the occurrence near Sheep Creek. (See Neubert, 1994, p. 42-43.)

Two water samples were collected in this area (Figure 58). NW54 was from the lowest in a series of beaver ponds in a meadow alongside a drill road about 1½ miles downstream of the headwaters of Sheep Creek, on the southwest side of Poison Ridge. Bedrock on the slopes above the pond and the talus pile alongside the pond consisted of brown- and red-stained, fine-grained intrusive rocks or baked shale and altered porphyry. Some of the rocks had yellow stain, and a few pieces contained minor amounts of disseminated pyrite.

Water in the pond had a bluish hue and an oily sheen on the surface. Although the pH was neutral at 6.93, the pond water had a high conductivity of 1,140 µS/cm. Water bugs skimmed the surface. Lab results showed water in the pond slightly exceeded state standards in iron, manganese, and sulfate concentrations. High levels of calcium, magnesium, silicon, and sodium probably cause the high conductivity (Table 12).

Sample NW55 was from Sheep Creek, near a drill pad with at least two drill holes and about 1,000 feet downstream of NW54 (Figure 58). At NW55, abundant red precipitate was caught in algae. Red precipitate coated the creek bed beginning in the wetlands about 1,000 feet upstream of NW54 and continuing for at least 1,000 feet downstream of NW55. The creek had a 150-gpm flow, pH was 7.04, conductivity was 343 µS/cm, and alkalinity was 13 ppm. Aluminum, iron, and manganese concentrations slightly exceeded standards. Concentrations of calcium, magnesium, sulfate, and sodium were significantly lower than in NW54, but the silicon value was noticeably higher. Copper and zinc concentrations were elevated, but below state standards. (See table 12.)

Several water tests were conducted near Poison Ridge for this study (Figure 58). A test from Sheep Creek immediately upstream of Forest Road 107 and about ½ mile upstream of NW54 showed pH of 7.20 and 95 µS/cm conductivity. No precipitate was observed in the channel at this site. Progressing downstream in Sheep Creek, stream water conductivity slightly increased, and pH dropped slightly. Two beaver ponds in the wetlands on the north side of Sheep Creek were tested in addition to the pond where sample NW54 was collected. Both had neutral pH between 6.5 and 7.0 and high conductivities of 900 to 1,100 µS/cm. An unmarked tributary of Sheep Creek was tested about 800 feet northwest of NW55. Conductivity was 80 µS/cm and pH was 5.56.

Parkview Mountain

A quartz latite stock or plug is centered in the cirque on the east side of Parkview Mountain. Later intrusion of a granitic or monzonitic stock altered the quartz latite and the surrounding sedimentary rocks. In the altered rock, feldspar has decomposed to clay, and pyrite and its oxidation products are common. (See Neubert, 1994, p. 43.)

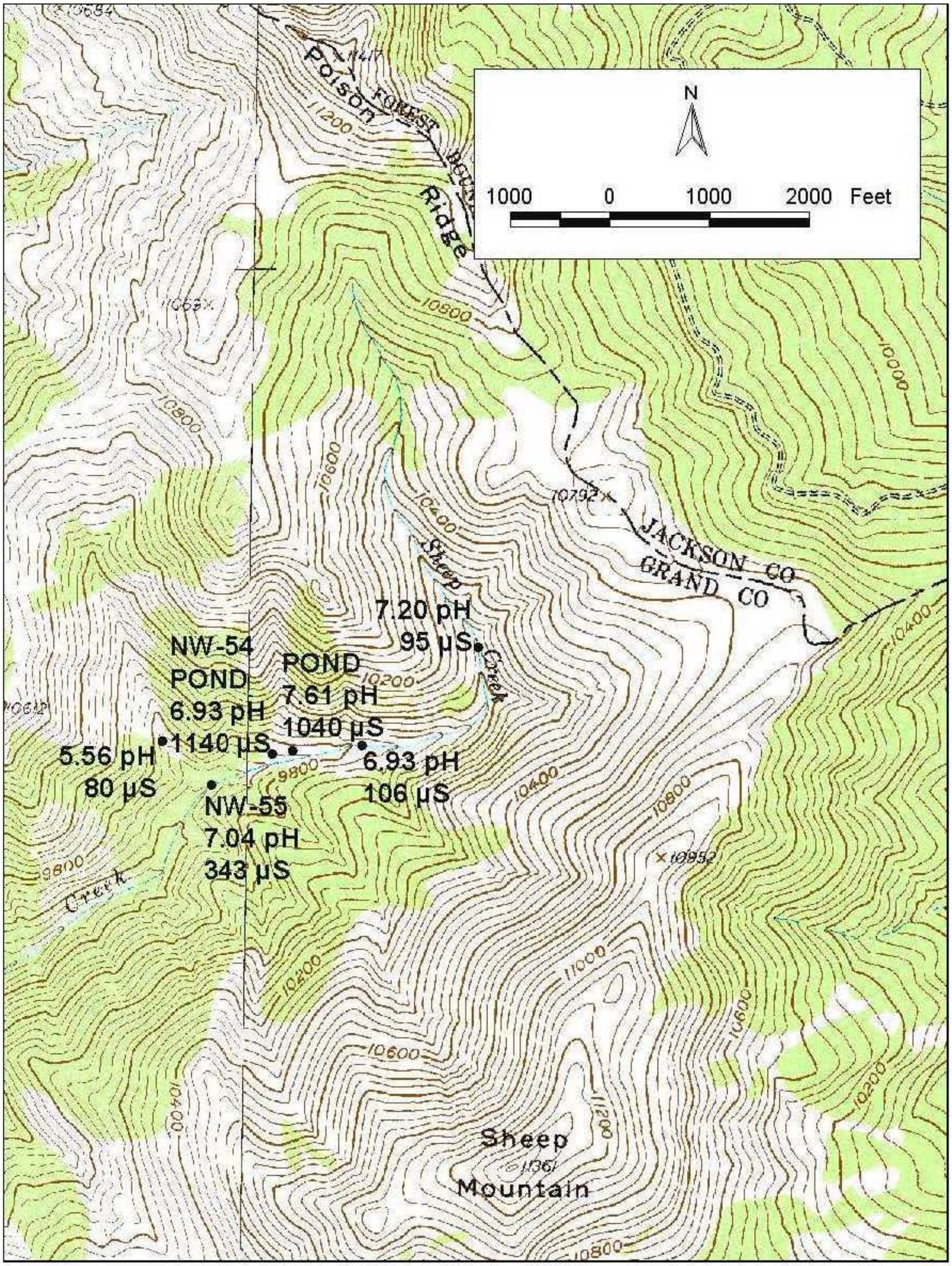

Figure 58. Map showing sample sites NW54-55 and test results near Poison Ridge.

Table 12. Analytical data for samples NW53-57 and a drill hole in north-central Colorado.

Sample	NW53, PARKVIEW EAST (9/7/99)				NW54, POISON POND (9/7/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	40.0							
pH (standard units)	6.65				6.93			
Conductivity (µS/cm)	106.0				1,140.0			
Alkalinity (mg/L CaCO3)								
Hardness (mg/L CaCO3)	86	None	N/A		1,399	None	N/A	
Aluminum (trec) (µg/L)	< 50	None	N/A	N/A	< 50	None	N/A	N/A
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	< 10	1000.00	Below standard	N/A	1,200	1000.00	1.2	0.0
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	20	2000.00	Below standard	4.4	< 10	2000.00	Below standard	N/A
Aluminum (µg/L)	< 50	87.00	Below standard	N/A	< 50	87.00	Below standard	N/A
Cadmium (µg/L)	< 0.3	1.00	Below standard	N/A	< 0.3	9.00	Below standard	N/A
Calcium (mg/L)	31	None	N/A	6,759.2	540	None	N/A	0.0
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	< 4.0	10.36	Below standard	N/A	< 4.0	112.70	Below standard	N/A
Fluoride (mg/L)	< 0.10	2.00	Below standard	N/A	0.70	2.00	Below standard	0.0
Iron (µg/L)	< 10	300.00	Below standard	N/A	170	300.00	Below standard	0.0
Lead (µg/L)	< 1.0	3.13	Below standard	N/A	< 1.0	163.57	Below standard	N/A
Magnesium (mg/L)	2.00	None	N/A	436.1	12.00	None	N/A	0.0
Manganese (µg/L)	< 4	50.00	Below standard	N/A	58	50.00	1.2	0.0
Nickel (µg/L)	< 20	85.00	Below standard	N/A	< 20	709.94	Below standard	N/A
Potassium (mg/L)	< 1.0	None	N/A	N/A	1.3	None	N/A	0.0
Silicon (mg/L)	5.8	None	N/A	1,264.6	11.0	None	N/A	0.0
Silver (µg/L)	< 0.2	0.06	Not detected	N/A	< 0.2	7.02	Below standard	N/A
Sodium (mg/L)	1.80	None	N/A	392.5	9.40	None	N/A	0.0
Sulfate (mg/L)	24	250.00	Below standard	5,233.0	520	250.00	2.1	0.0
Zinc (µg/L)	20	93.00	Below standard	4.4	< 10	991.23	Below standard	N/A

Table 12. Analytical data for samples NW53-57 and a drill hole in north-central Colorado--continued.

Sample	NW55, SHEEP CREEK (9/7/99)				NW56, JACK CREEK (9/8/99)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	150.0				650.0			
pH (standard units)	7.04				7.30			
Conductivity (µS/cm)	343.0				75.0			
Alkalinity (mg/L CaCO3)	13.00				30.00			
Hardness (mg/L CaCO3)	319	None	N/A		75	None	N/A	
Aluminum (trec) (µg/L)	500	None	N/A	408.8	58	None	N/A	205.5
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 1.0	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	< 1.0	50.00	Below standard	N/A
Iron (trec) (µg/L)	1,100	1000.00	1.1	899.4	250	1000.00	Below standard	885.8
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 1.0	0.50	Not detected	N/A
Zinc (trec) (µg/L)	60	2000.00	Below standard	49.1	< 10	2000.00	Below standard	N/A
Aluminum (µg/L)	180	87.00	2.1	147.2	< 50	87.00	Below standard	N/A
Cadmium (µg/L)	< 0.3	2.82	Below standard	N/A	< 0.3	0.91	Below standard	N/A
Calcium (mg/L)	120	None	N/A	98,118.0	25	None	N/A	88,578.8
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	< 20.0	250.00	Below standard	N/A
Chromium (µg/L)	< 10	11.00	Below standard	N/A	< 10	11.00	Below standard	N/A
Copper (µg/L)	8.0	31.85	Below standard	6.5	< 4.0	9.27	Below standard	N/A
Fluoride (mg/L)	0.50	2.00	Below standard	408.8	< 0.10	2.00	Below standard	N/A
Iron (µg/L)	560	300.00	1.9	457.9	200	300.00	Below standard	708.6
Lead (µg/L)	< 1.0	20.12	Below standard	N/A	< 1.0	2.60	Below standard	N/A
Magnesium (mg/L)	4.60	None	N/A	3,761.2	3.10	None	N/A	10,983.8
Manganese (µg/L)	230	50.00	4.6	188.1	18	50.00	Below standard	63.8
Nickel (µg/L)	< 20	230.72	Below standard	N/A	< 20	76.97	Below standard	N/A
Potassium (mg/L)	1.1	None	N/A	899.4	< 1.0	None	N/A	N/A
Silicon (mg/L)	16.0	None	N/A	13,082.4	2.4	None	N/A	8,503.6
Silver (µg/L)	< 0.2	0.55	Below standard	N/A	< 0.2	0.05	Not detected	N/A
Sodium (mg/L)	5.60	None	N/A	4,578.8	0.91	None	N/A	3,224.3
Sulfate (mg/L)	130	250.00	Below standard	106,294.5	8	250.00	Below standard	28,345.2
Zinc (µg/L)	58	283.12	Below standard	47.4	11	83.26	Below standard	39.0

Table 12. Analytical data for samples NW53-57 and a drill hole in north-central Colorado--continued.

Sample	NW57, BOWEN PASS NORTH (9/8/99)				PARKVIEW DRILL HOLE (7/8/98)			
Parameter	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)	Concentration/ measurement	Standard	Factor above standard	Load (grams/day)
Flow (gpm)	60.0				0.8			
pH (standard units)	8.14				6.20			
Conductivity (µS/cm)	153.0				532.0			
Alkalinity (mg/L CaCO3)					100.00			
Hardness (mg/L CaCO3)	166	None	N/A		255	None	N/A	
Aluminum (trec) (µg/L)	< 50	None	N/A	N/A	110	None	N/A	0.5
Antimony (trec) (µg/L)	< 1.0	6.00	Below standard	N/A	< 0.24	6.00	Below standard	N/A
Arsenic (trec) (µg/L)	< 1.0	50.00	Below standard	N/A	32.0	50.00	Below standard	0.1
Iron (trec) (µg/L)	< 10	1000.00	Below standard	N/A	13,900	1000.00	13.9	63.6
Thallium (trec) (µg/L)	< 1.0	0.50	Not detected	N/A	< 0.1	0.50	Not detected	N/A
Zinc (trec) (µg/L)	< 10	2000.00	Below standard	N/A	140	2000.00	Below standard	0.6
Aluminum (µg/L)	< 50	87.00	Below standard	N/A	83	87.00	Below standard	0.4
Cadmium (µg/L)	< 0.3	1.69	Below standard	N/A	< 0.18	2.37	Below standard	N/A
Calcium (mg/L)	61	None	N/A	19,950.7	71	None	N/A	325.1
Chloride (mg/L)	< 20.0	250.00	Below standard	N/A	0.5	250.00	Below standard	2.3
Chromium (µg/L)	< 10	11.00	Below standard	N/A	0.7	11.00	Below standard	0.0
Copper (µg/L)	< 4.0	18.27	Below standard	N/A	0.3	26.35	Below standard	0.0
Fluoride (mg/L)	0.20	2.00	Below standard	65.4	1.50	2.00	Below standard	6.9
Iron (µg/L)	< 10	300.00	Below standard	N/A	12,800	300.00	42.7	58.6
Lead (µg/L)	< 1.0	8.01	Below standard	N/A	< 0.1	14.69	Below standard	N/A
Magnesium (mg/L)	3.40	None	N/A	1,112.0	19.00	None	N/A	87.0
Manganese (µg/L)	< 4	50.00	Below standard	N/A	1,050	50.00	21.0	4.8
Nickel (µg/L)	< 20	140.77	Below standard	N/A	1.5	194.91	Below standard	0.0
Potassium (mg/L)	< 1.0	None	N/A	N/A	2.7	None	N/A	12.4
Silicon (mg/L)	1.8	None	N/A	588.7		None	N/A	
Silver (µg/L)	< 0.2	0.18	Not detected	N/A	< 0.06	0.38	Below standard	N/A
Sodium (mg/L)	0.70	None	N/A	228.9	6.20	None	N/A	28.4
Sulfate (mg/L)	29	250.00	Below standard	9,484.7	150	250.00	Below standard	686.8
Zinc (µg/L)	< 10	163.21	Below standard	N/A	12	234.59	Below standard	0.1

The only significant mine working in this area is the El Kebir adit, which is now caved but was about 350 feet long (Neubert, 1994, p. 41). No water was draining from this mine working, but a drill hole slightly above and to the west of the adit was discharging 1 to 2 gpm of water with pH of 6.73 and 563 µS/cm conductivity during an abandoned mine inventory in 1992 (Sares, 1993, p. 1). Drill-hole water flowing at 0.8 gpm was sampled in July of 1998 and had pH of 6.20 and 532 µS/cm conductivity. Iron and manganese concentrations exceeded state standards, and arsenic was elevated (Table 12, Parkview Drill Hole). The water was depositing abundant red-brown precipitate along its drainage path. Although this discharge seeped into the ground within about 200 or 300 feet of the drill hole prior to reaching a stream at the surface, the precipitate trail continued downhill, indicating higher flow rates intermittently. However, the precipitate deposit did not extend to the creek, suggesting that even during times of higher flow, drill-hole water either seeps in to the colluvium/alluvium prior to reaching the stream, or the metals have mostly precipitated from the water prior to its confluence with surface water. Water from the drill hole was tested again in September of 1999; pH was 6.68 and conductivity was 587 µS/cm. The discharge seeped into the ground about 100 feet downhill from the drill hole. This drill-hole discharge probably closely approximates the groundwater quality in this area, although it is possible that the El Kebir adit may have some effect.

Sample NW53 was from an unnamed tributary of Pass Creek that drains the cirque on the east side of Parkview Mountain (Figure 59). Because the creek was dry within the cirque, this sample was collected almost a mile downstream. Within and immediately downstream of the cirque, water evidently flowed beneath the surface of talus, colluvium, and alluvium. At the sample site, the creek was flowing at about 40 gpm, pH was 6.65, and conductivity was 106 µS/cm. The water looked clean, and none of the measured parameters exceeded state standards (Table 12). Any degraded water emanating from the exposed altered rocks or from the drill hole at Parkview Mountain was apparently diluted quickly by clean water.

Iron-stained rocks crop out on the ridge that forms the Continental Divide northeast of Haystack Mountain and northwest of Parkview Mountain. Most of the streams draining the altered area were dry in September 1999, but two tests of flowing streams showed pH of more than 7 and conductivities less than 200 µS/cm (Figure 59). None of the observed streams showed visible evidence of degradation, and no samples were collected.

NEVER SUMMER RANGE

The Never Summer Mountains are a north-trending range, part of which forms the Continental Divide. Much of the eastern slope of the Never Summer Mountains is within the northwest part of Rocky Mountain National Park. The range extends from about Porphyry Peaks on the south to Cameron Pass on the north. The Medicine Bow Mountains adjoin the range to the north. The nearest towns are Grand Lake, about 7 miles east-southeast, and Gould, about 7 miles to the west.

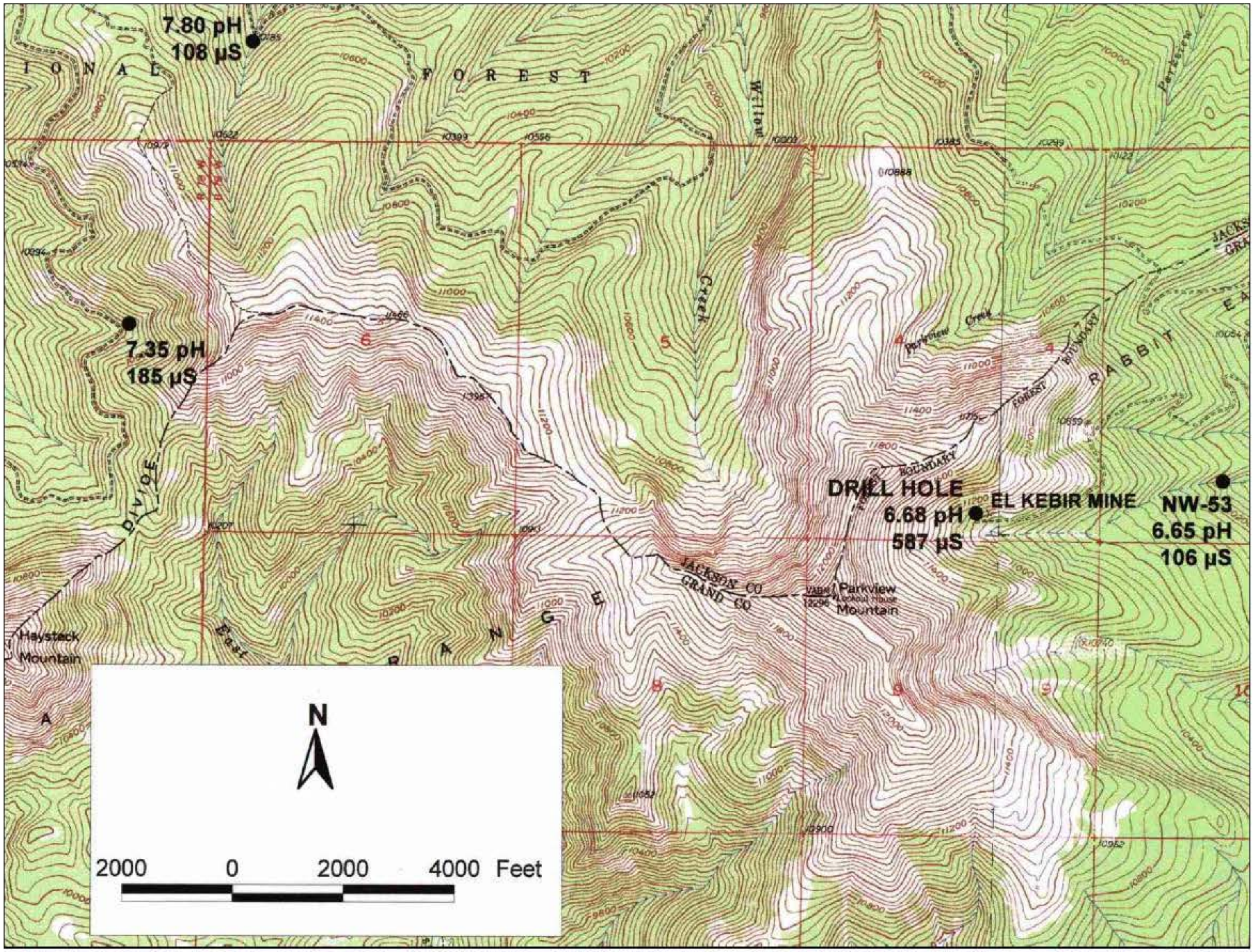

Figure 59. Map showing sample sites NW53 and Parkview Drill Hole, and water test results from near Parkview Mountain.

Geology

The Never Summer Range comprises a belt of Tertiary-age intermediate- to felsic-composition intrusions. These stocks, plugs, sills and dikes intruded Precambrian-age granofels, gneiss, schist and amphibolite, and Tertiary-age clastic sedimentary rocks. Lying west of the crest of the range, the north-trending Never Summer thrust fault juxtaposes Precambrian metamorphic rocks against and above part of the Tertiary-age sedimentary sequence. (See Neubert, 1994, p. 39-41; Tweto, 1979; O'Neill, 1981; Braddock and Cole, 1990.)

The Teller mining district is on the west side of the Never Summer Range, straddling the Never Summer thrust fault. Small-displacement faults associated with the thrust fault host small base- and precious-metal vein deposits that were mined in the past. In addition, weakly mineralized breccia pipes and breccia zones crop out in this area. Buried intrusive rocks were drilled during molybdenum exploration efforts. (See Neubert, 1994, p. 38-40.)

Present Investigation

Illinois River and Jack Creek

Near the headwaters of the Illinois River, near the intersection of the north-trending Never Summer Range intrusive belt with the eastern end of the east-trending Rabbit Ears Range, a breccia pipe with common disseminated pyrite intruded Precambrian-age rocks. This Tertiary-age pipe contains anomalous concentrations of arsenic, silver, and gold. Fissures related to the pipe are mineralized with galena and chalcopyrite. (See Neubert, 1994, p. 40.)

This breccia pipe was briefly examined in 1999. The pipe is highly fractured and moderately iron-stained, but no surface runoff or seeps were observed. Sample NW57 was collected nearby to determine if the reported mineralization at the breccia pipe affected surface-water quality in this area. The sample was from an unmarked tributary about 1,000 feet north of Bowen Pass (Figure 60) where the flow was about 60 gpm, pH was 8.14, and conductivity was 153 µS/cm. This stream emerged from an area underlain by amphibolite with minor iron staining. Most trace metals were not detected, and none of the detected metals occurred in concentrations above state standards. The relatively high conductivity for a headwaters stream may result from moderate concentrations of calcium and magnesium in the water (Table 12). Water tested at several locations in this area showed neutral to slightly alkaline pH and moderate conductivity (Figure 60). No obvious indications of degraded water were observed, and no other samples were collected.

About 2 miles to the west of those tests, within the Illinois River drainage basin, about 200 acres of Tertiary-age sedimentary rocks cut by northwest-trending breccia zones are underlain by rocks and soil with concentrations of more than 300 ppm arsenic and anomalous concentrations of gold, silver, antimony, and thallium. (See Neubert, 1994, p. 40.) During an abandoned mine inventory in 1997, samples were collected of water emerging from two small mine workings in this area. Both samples exceeded state standards in arsenic, iron, fluoride, and manganese. (See Ellis and Wood, 1998, p. 6-8.) High metal concentrations in host rock and soils suggest that some of the degradation associated with these small mines probably results from natural causes. However, the presence of precipitate associated with the mine discharges and the lack of precipitate in the receiving streams upstream of the mines imply that a significant percentage of the degradation is mine related. No samples were collected upstream of the mines during the inventory or for this study.

A buried Tertiary-age rhyolite plug presumably underlies the upper portion of Jack Creek in the vicinity of the Teller mining district. The north-trending Never Summer thrust fault also cuts this area. (See Neubert, 1994, p. 39.) Although surface expression of regional-scale alteration was not obvious, a sample was collected because of minor iron staining coating the gravels of Jack Creek.

NW56 was from Jack Creek, in the area of the buried intrusion and Never Summer thrust fault, and upstream of the significant mines of the Teller mining district (Figure 60). Many of the rocks in the streambed had a minor red coating that may be precipitate or may be caused by oxidation of iron minerals within the rocks. Where sampled, the creek was flowing at 650 gpm, pH was 7.30, conductivity was 75 µS/cm, and alkalinity was 30 ppm. Most metals were not detected or occurred in low concentrations. Iron was moderately high, but still within state standards (Table 12). Tests conducted further upstream in unmarked tributaries near the headwaters of Jack Creek showed neutral pHs and conductivities of less than 60 µS/cm (Figure 60). No obvious indications of degradation were observed, and no additional samples were collected.

Porphyry Peaks

Rocks exposed on the northwest side of Porphyry Peaks, near Lost Lake in the headwaters of Willow Creek, are severely altered, fractured, and decomposed. The alteration type is probably argillic, and iron staining is not intense. Numerous active landslides demonstrate the instability of the clay-rich bedrock between Porphyry Peaks and Lost Lake. Water tests conducted in this area showed nearly neutral pHs and conductivities of less than 120 µS/cm (Figure 61). No precipitate or other obvious indications of degradation were observed, and no samples were collected.

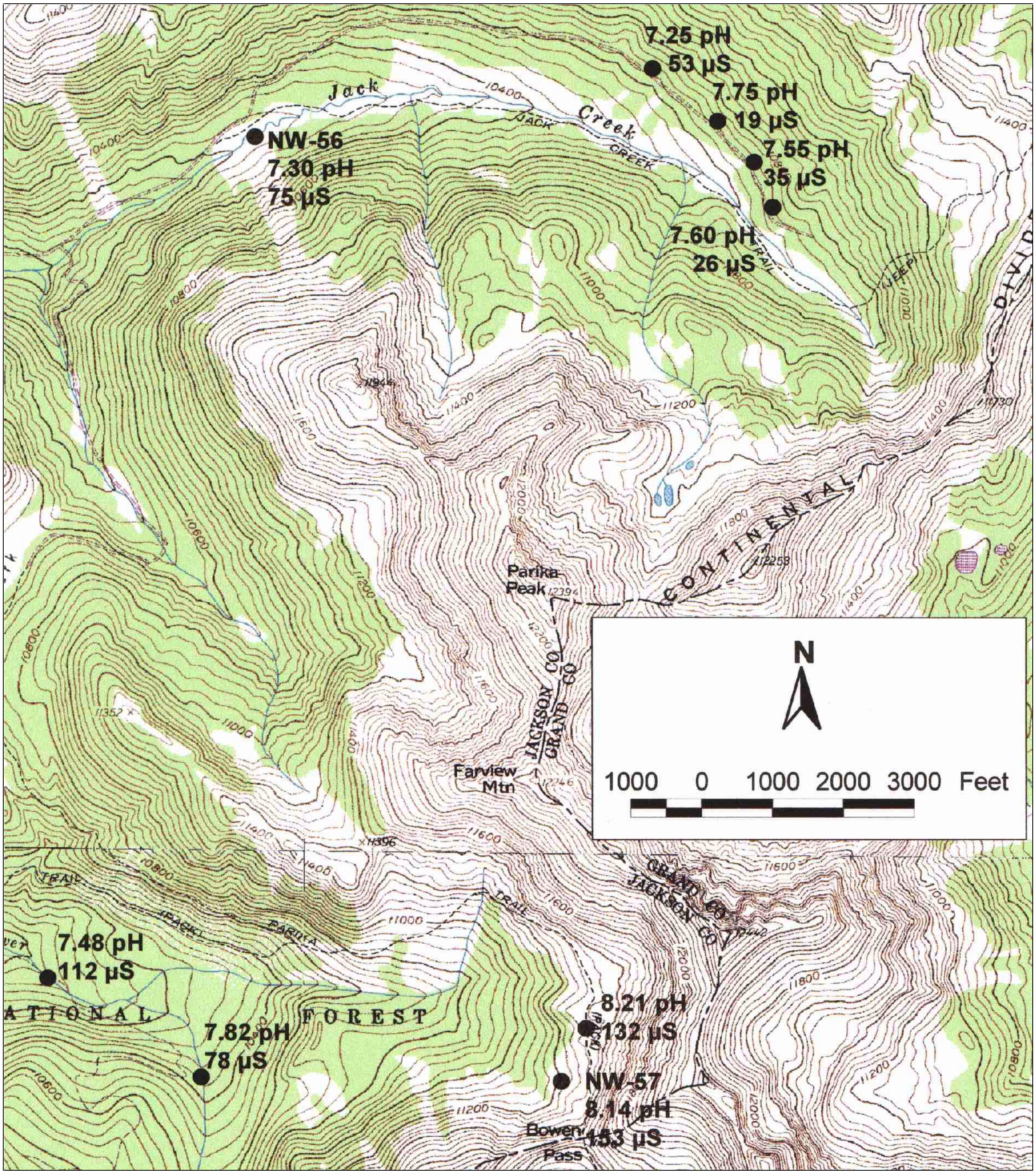

Figure 60. Map showing sample sites NW56-57 and water test results in the Illinois River and Jack Creek drainage basins.

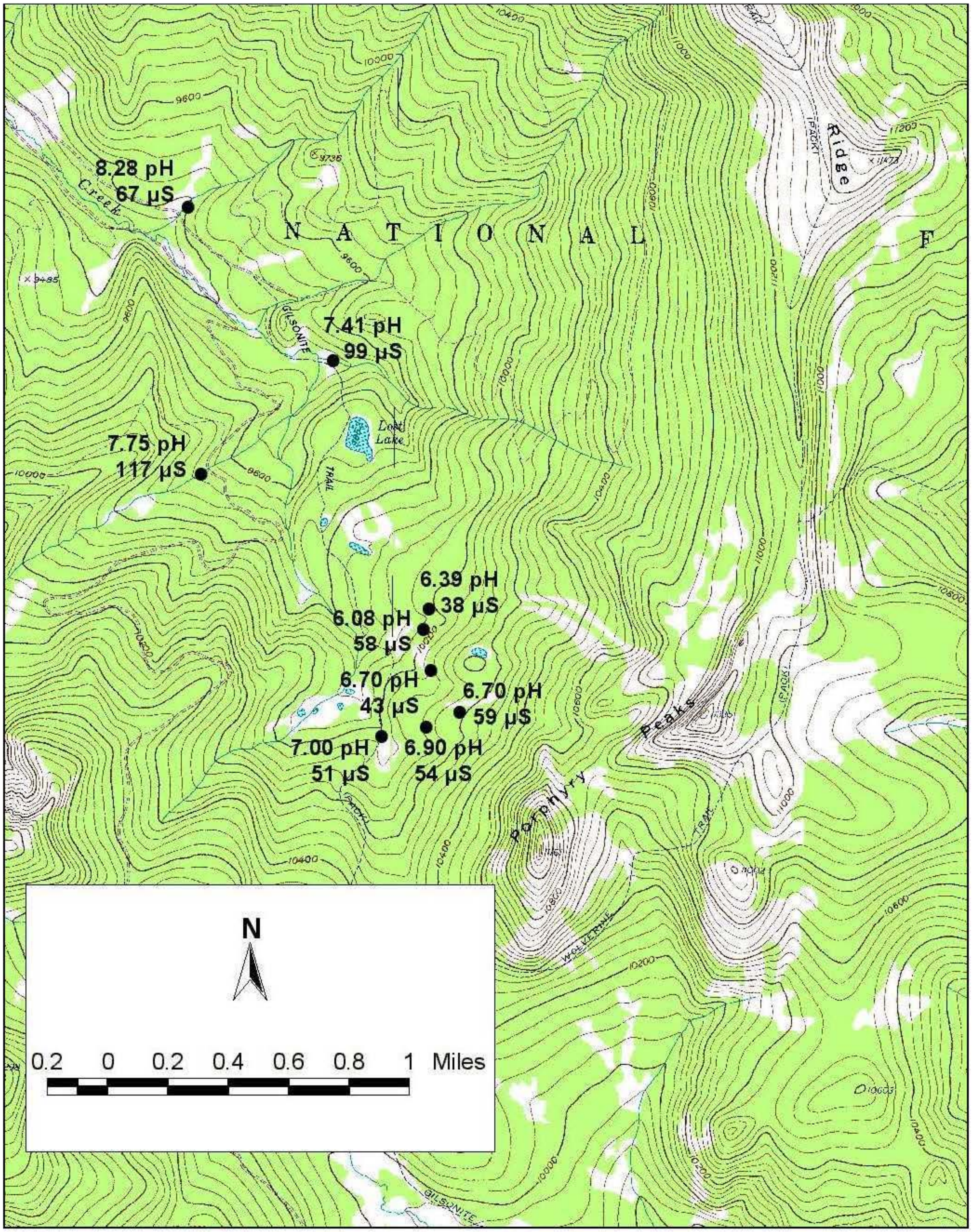

Figure 61. Map showing water test results near Porphyry Peaks.

UNSAMPLED AREAS OF INTEREST

Several areas with bog-iron deposits occur throughout Colorado. Springs and streams associated with these bog-iron deposits are often degraded, and many of these waters were sampled during the course of this investigation. A few smaller occurrences were briefly visited and either had no associated water, or water testing did not indicate degradation. Some of the more remote sites, or sites where literature descriptions did not sound promising were not visited

WHITEPINE AREA

A small bog-iron deposit is exposed near Tomichi Creek about 1½ miles upstream of Whitepine. The iron was deposited in the swampy parts of Tomichi Creek by springs carrying iron-rich water. (See Harrer and Tesch, 1959, p, 44.) This site was not visited, and it is not known if the springs are still active. In addition, it is not known if mining activity has affected the springs.

SANGRE DE CRISTO MOUNTAINS

Limonite occurs in the north and south branches of Decker Creek, on the west slope of the Sangre de Cristo Mountain south of Poncha Pass. This bog-iron deposit is about 800 feet long, 100 feet wide, and 8 feet or more in thickness. (See Harrer and Tesch, 1959, p. 59.) No active seeps were found in the limonite deposit during a brief examination in 1999.

Limonite occurs at and near the Major Mine in Major Creek, about 2 miles southeast of Valley View Hot Springs, on the west slope of the Sangre de Cristo Mountains. This bog-iron deposit has a few workings on it. (See Harrer and Tesch, 1959, p. 62-63.) It is unknown if any springs are active at this location, but it is unlikely. Mines inventoried in this area by CGS for the USFS were dry, and this site was not visited during 1999.

DEL NORTE AREA

Limonite occurs in flat layers along a ridge about 7 miles north of Del Norte and 2½ miles north-northwest of East Butte. This bog-iron deposit trends N.60°W. for 1,500 feet. It is about 800 feet wide and 5 feet or more in thickness. (See Harrer and Tesch, 1959, p. 61.) In 1999, brief reconnaissance in this area revealed no active springs.

SARGENTS AREA

Small bog-iron limonite deposits occur along Indian Creek, east of Sargents. The largest deposit is in sections 17 and 18, and is exposed for 800 feet along a roadcut and is 10 feet thick. (See Harrer and Tesch, 1959, p. 62.) This site was not visited in 1999, and it is unknown if there are any active springs at this location.

KERBER CREEK

Ferricrete occurs along the Kerber Creek-Bonanza Road about 7 miles west of Villa Grove. This deposit is about 350 feet long, 50 feet wide, and 7 feet or more in thickness. (See Harrer and Tesch, 1959, p. 62.) No significant active springs were observed in the ferricrete during brief reconnaissance in 1999. Soda Springs, an alkaline spring with no associated ferricrete is nearby, but was not sampled.

SUMMARY AND CONCLUSIONS

For this study, a total of 92 samples were collected from sources that are believed to have little or no mining-related influences on water quality. A few of the samples were clean or were not significantly degraded, and met stream standards for all or most of the tested parameters.

Depressed pH of less than 6 occurred in 68 of the samples, aluminum was greater than the state standard of 87 µg/L in 68 samples; and manganese was greater that the state standard of 50 µg/L in 62 of the samples. Zinc and copper concentrations exceeded hardness-related state standards or were greater than 50 µg/L in 58 and 53 samples, respectively; and iron exceeded the drinking-water standard of 300 µg/L in 43 samples. Sulfate exceeded 100 mg/L (standard is 250 mg/L) in 32 samples; and cadmium and lead exceeded their hardness-related standards in 24 and 10 samples, respectively. Other analyzed parameters, such as, thallium, chloride, chromium, fluoride, nickel, and silver, exceeded their standards fewer than 10 times each, and usually were not detected. Arsenic exceeded the present standard of 50 µg/L in one sample, and exceeded the EPA-recommended standard of 5 µg/L in a total of 4 samples.

The highest metal concentrations analyzed during this study, excluding sample NW1, which is affected by upstream mining, are briefly described in the following paragraphs. The lowest pH was 2.16 in sample NW13 from the northwest side of Red Mountain #2 within the Silverton caldera.

Water draining altered rocks associated with the Montezuma stock provided many of the highest ion concentrations of this study. Sample NW38 from seepage at the toe of a rock glacier on the southwest side of Red Cone was extremely degraded and contained the highest concentrations of aluminum (170,000 µg/L), iron (180,000 µg/L), sulfate (1,300 mg/L), nickel (310 µg/L), and chromium (91 µg/L). The highest silver concentration (0.8 µg/L) was from a spring in an unmined western tributary of Cinnamon Gulch (sample NW27).

Sample NW49 from the south fork of Gold Creek on the west side of the Ruby Range was highly degraded and provided the highest concentrations of arsenic (86 µg/L), cadmium (100 µg/L), and zinc (13,000 µg/L). Also in the Ruby Range, a spring in Redwell Basin (sample NW51) had the highest lead (410 µg/L). The Redwell Basin sample may be influenced to some extent by mining, although the low sulfate concentration suggests otherwise.

Water draining from the Allard stock in the La Plata Mountains contained the highest copper (5,700 µg/L) and thallium (5.0 µg/L) in sample NW75 from Rush Basin, and fluoride (2.6 mg/L) in sample NW70 from Bedrock Creek.

In the Lake City area, samples NW88 and NW89 from adjacent to and within the Slumgullion Slide provided the highest concentrations of chloride (1,400 mg/L) and manganese (10,000 µg/L), respectively.

This reconnaissance-level sampling program shows that aluminum and manganese concentrations nearly always exceed state water-quality standards in areas of naturally degraded surface waters. Copper, iron, and zinc are frequently elevated, especially near large, regional-scale mineralized systems and those associated with porphyry copper/molybdenum occurrences, such as the Montezuma and Allard stocks, the Grizzly Peak, Silverton, and Summitville calderas, and the igneous stocks of the Ruby Range.

Waters associated with regional-scale alteration and mineralized areas vary significantly in character. Some are extremely acidic, but have low conductivity and generally low metal concentrations. Despite the low concentrations, some of the metals exceed state standards because of low hardness. In general, these types of waters are found in tributaries high on mountain slopes and probably result from short residence times for water-rock reactions to occur. These tributaries add acidity to the receiving stream, but metal loading is minimal.

Springs emerging at lower elevations in regionally altered terranes are frequently acidic, but have high conductivity and moderate hardness. Major and trace ion concentrations are usually increased, and these sources add considerable metal loads to receiving streams. The increase in total dissolved solids and trace metals is probably a result of longer subsurface residence time, allowing percolating acidic water to react with the altered and mineralized host rocks.

Natural degradation associated with hydrothermally altered terrane is not always acidic. In some cases, such as in the Rabbit Ears Range and in the western part of the Rico area, pH is nearly neutral or slightly alkaline. Buffering by unaltered country rock or by calcite, chlorite, feldspars, or other alteration products has partly mitigated acidity, but significant concentrations of aluminum, iron, manganese, and sulfate remain in the water. In general, trace metals are not highly concentrated in these situations, but exceptions are common.

Waters of the Slumgullion Slide are especially interesting. They are extremely acidic, but have high hardness and contain high concentrations of most of the major cations and anions, and elevated concentrations of some trace metals. These waters are a significant loading source into Lake Fork of the Gunnison River.

Many of the areas examined during this study are in watersheds where both natural degradation and historic mining has impacted drainage basins. These watersheds should be characterized in detail to better understand the hydrologic and anthropogenic processes involved in stream degradation. Detailed characterization is especially important in drainage basins slated for major mine-reclamation projects. Information derived from watershed characterizations is useful for determining realistic remediation goals, and for prioritizing mine sites for cost-effective reclamation that provides measurable improvements to downstream water quality.

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APPENDIX

WATER SAMPLING PROTOCOLS AND QA/QC RESULTS

AT SAMPLE SITE:

1. **Calibration**

Check pH and conductivity meter calibration. Re-calibrate if necessary. Log date, time, and calibration results into field notebook.

2. **Data Sheet**

Begin filling out a Water Sample Data Sheet. Perform requisite measurements of GPS location, pH, conductivity, temperature, physical description, etc.

3. **Water Sample**

1) Put on gloves.

2) If sub-sampling at a location other than the sample site, rinse a clean, unused 1000-mL sample bottle with the sample water *3 times*. Then fill it with sample water. If water flow at the site is too low to allow using the sample bottle without stirring up the bottom sediment, use a syringe **--rinsed with sample water 3 times** to transfer the water into the sample bottle. *Do not touch the inside of the bottle, the lid, or the sample water.*

3) Label the 1000-mL bottle with the sample number. If a syringe is used to transfer sample water into the sample bottle, the same syringe can be used for the subsequent sub-sampling of this sample. Therefore, return the syringe to its packaging and label the packaging with the sample number as well. Place the labeled syringe into a ziplock bag.

4) Place sample bottle(s) and any syringes to be re-used for sub-sampling into separate ziplock bags.

4. **Flow measurement or estimation**

After sampling and/or on-site subsampling is completed, use a flume to measure the flow volume. In many cases, use of a flume is not practical. A flowmeter may be a viable option in larger streams. In small streams or streams with a steep gradient, using a liter bottle or 5-gallon bucket as a catchment may be effective. Depending on site conditions, these methods should be accurate to about 20%. Flow estimation is the last alternative, if none of the other options are practical.

AT THE SUBSAMPLING LOCATION:

1) Label each sub-sample bottle before the subsampling procedure is begun.

Record the following:

1) Name of sample site
2) Sample number
3) Subsample type
   The subsamples will be one of the following:
      a) Filtered metals acidified (FMA)
      b) Unfiltered metals acidified (MA)
      c) Unfiltered unacidified (NEUT)
4) Time
5) Date

2) Put on gloves and safety goggles.

3) Begin subsampling:

A) **Unfiltered metals acidified (MA) sample**

This sample **is not** filtered, and has acid added. It is for analysis of total metals. (***Note:** If the samples are to be sent to the State Inorganic Lab, acid will not be added in the field. It will already be in the FMA and MA bottles.*)

1. **(Do this step only if the lab has not added acid to the bottle)**
   Rinse the new acid-cleaned 250-mL MA plastic bottle with 10-20 mL of raw sample water three times.

2. After shaking the 1000-mL sample bottle to adequately mix any sediment or suspended material, pour the water into the 250-mL "MA" subsample bottle to just below the neck of the bottle.

3. **(Do this step only if the lab has not added acid to the bottle)**
   Add 20 drops of concentrated (16 molar) nitric acid to this sample if the pH is greater than 4.5. If pH is less than 4.5 only ten drops are needed. (must be preserved to a pH=2 or lower, so if sample is very basic it may need more nitric acid) **Use care when working with nitric acid.**

4. After tightly securing the lid, lightly shake the bottle to mix the acid with the subsample.

B) **<u>Filtered metals acidified (FMA)</u>**

This sample is filtered and has acid added. It is used for analysis of dissolved metals. (***Note:** If the samples are to be sent to the State Inorganic Lab, acid will not be added in the field. It will already be in the MA and FMA bottles.*****)

1. Put on new gloves (only if necessary)

2. Rinse a new 60-cubic centimeter (cc) syringe (or, if a syringe was used on site, rinse and re-use this syringe) by drawing in 10 mL of raw sample water. Then pull up on the syringe so that the entire syringe barrel can be exposed to the 10 ml of sample. Shake, discard and repeat twice. Then fill the syringe with sample water from the 1,000-mL bottle. Purge the syringe of any air bubbles to prevent an "air-lock" in the filter.

3. Rinse a new 0.45 μm disposable filter. This is done by attaching the filter to the rinsed syringe and forcing 20 cc of sample water through the filter. Point the syringe away from the subsampling area.

4. **(Do this step only if the lab has not added acid to the bottle)**
   Rinse the new acid-cleaned 250-mL FMA plastic bottle with 10 mL of filtered sample water three times.

5. Filter sample water into a new acid-cleaned 250-mL FMA plastic bottle. Fill the bottle to just below the neck of the bottle. If pushing water through the filter becomes difficult, place the syringe with the filter into a caulking gun (covered with plastic tape). The filter should be outside the end of the gun with the syringe barrel inside the gun. If filtering in the caulking gun becomes difficult, attach a new filter, rinse this filter with 20 mL of sample, and then resume filtering into bottle.

6. **(Do this step only if the lab has not added acid to the bottle)**
   Add 20 drops of concentrated (16 molar) nitric acid to this sample if the pH is greater than 4.5. If pH is less than 4.5 only ten drops are needed. (must be preserved to a pH = 2 or lower, so if sample is very basic it may need more nitric acid) **<u>Use care when working with nitric acid.</u>**

7. After tightly securing the lid, lightly shake the bottle to mix the acid with the subsample.

C) **Unfiltered unacidified sample (NEUT)**
This sample is **not** filtered and does **not** have acid added. It is used for analysis of anions.

1. Put on new gloves (only if necessary)

2. Rinse a new, **non**-acid cleaned, 250 mL "NEUT" plastic bottle three times with about 10 mL of sample water and discard.

4. Pour sample water into the "NEUT" bottle to just below the bottle neck. Preserve by refrigeration (at 4 degrees C) in a cooler.

D) **Alkalinity Determination**-(Only done on samples with a pH of 4.8 or greater.)

1. Use a CHEMetrics, Inc. K-9810 (10 to 100 ppm) or K-9815 (50-500 ppm) total alkalinity titration kit.

2. Fill a syringe from the 1,000 mL bottle and inject 20 mL of sample water through a 0.45 μm filter into the small cylinder supplied with the kit.

3. Add six drops of actuator solution to the filtered water sample, which will turn the sample water green.

   Note: The water is turned green, titrated to pink/red, and then to green again, at which time the meniscus is read. See below.

4. Attach the soft, pliable end of the short tubing piece to the ampule.

5. Break the scored tip of the ampule by hand and insert it into the device supplied in the titration kit. This device allows the user to admit small volumes of sample water into the evacuated ampule.

6. Immerse the stiff end of the tubing in the sample water.

7. Carefully add sample water to the ampule until a pink/red color appears. This is done by squeezing the plastic ball in the pliable tubing by pressing the control bar on the device supplied with the titration kit. Mix the solution thoroughly in the ampule between additions. Add sample water until the solution just turns green.

8. Once the solution turns green, invert the ampule and read the number at the meniscus. This number is the alkalinity as calcium carbonate expressed as milligrams per liter (mg/L) or ppm of $CaCO_3$. Multiplying by 1.2 will convert this to mg/L bicarbonate (HCO_3).

QA/QC Samples

Field duplicate sample - a field duplicate is an independent sample of the same medium (water, solids) collected at the same time and same location as another sample. This is used to confirm the reproducibility of the analysis results.

Lab duplicate sample - a lab duplicate is a split from a sample done in the lab. This is used to confirm the reproducibility of the lab analyses.

Equipment Blanks - This is created by reproducing the entire sampling process with de-ionized water (reagent grade). The same unused sampling equipment is used.

QA/QC RESULTS

Two equipment blanks were collected during the course of this water sampling program. Both blanks contained sodium and traces of silicon. No trace metals were detected in either blank, and sodium concentration in most of the samples was less than the sodium in the "blanks." Sodium concentration in samples exceeded that in the blanks only if the natural water had high conductivity/salinity. For these reasons, sodium and silicon in the blanks is interpreted to be caused by contaminated de-ionized water, not contaminated sampling equipment. Sample results are assumed to be valid representations of the water chemistry at the sample sites.

One field duplicate was collected, and parameters were nearly identical (samples NW42 and NW43, Table 10).

Samples were analyzed by the Colorado Department of Public Health and Environment laboratory. This is an EPA certified lab and follows QA/QC procedures required by the EPA. Some of these procedures include running spikes on 10% of the samples and running duplicates on 10% of the samples. Calibration of the analytical equipment is also checked every 10 samples. All of the spikes, lab duplicates, and calibration parameters fell within lab requirements. Original lab QA/QC documentation may be viewed, upon request, at the CGS offices.

ANALYTICAL METHODS

EPA Method 200.7 (ICP/Atomic Emission Spectrometry) was used to analyze most parameters (aluminum, arsenic, calcium, chromium, copper, iron, magnesium, manganese, molybdenum, nickel, potassium, silicon, sodium, and zinc). Antimony, cadmium, lead, silver, and thallium were analyzed by EPA Method 200.8 (ICP/Mass Spectrometry). EPA Method 300.0 (Ion Chromatography) was used for chloride and sulfate. Fluoride was analyzed by Method SM 4500-F-E (Complexone Method).