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Geochemical Baselines and Processes Affecting Surface Water, Redcloud Peak Area, Colorado

by

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Introduction

When precipitation, as rain and snow, falls within a drainage basin, water comes into contact with rock minerals and chemical weathering is initiated. Chemical weathering within a basin involves the congruent dissolution of minerals such as calcite or the incongruent dissolution and transformation of minerals such as plagioclase to clay minerals. These processes release elements to the natural water of a basin. Therefore the chemical composition of water that evolves within a basin that has not been affected by anthropogenic processes, is determined primarily by the chemical composition of rocks within the basin. Climate, mainly precipitation and temperature plays a role, particularly in the rates of water-rock reactions, but composition of the rocks is the fundamental control. The major element composition of most rock types is generally known from geologic maps, giving insight into the expected major element composition of natural waters of the basin in question. The same is not true with respect to trace elements which can vary two or more orders of magnitude within similar rock types.

This background geochemistry of the natural water of a basin can be modified by input from anthropogenic processes such as nuclear fallout, atmospheric emissions, or mining wastes. There is probably no place in the world in which the natural background composition of waters of an area have not been modified to some extent by anthropogenic processes; the effects of these processes are always superimposed on the natural background geochemistry. But areas can be selected which are only minimally affected by anthropogenic input. Geochemical baselines, at a particular point in time for stream waters, can thus be determined, and may approximate the natural background geochemistry, in areas of minimal anthropogenic input. This information is useful for understanding the processes responsible for the chemical composition of waters of a basin. In addition, because stream water geochemistry is sensitive to changes in the environment, by monitoring stream water geochemistry in the future, changes in the environment within the basin can be determined.

The purpose of this study is to determine the natural baseline geochemistry of stream waters in the Redcloud Peak area (fig. 1), in the Southern Rocky Mountains of Colorado, for one period of time. Recent advances in analytical technology, particularly inductively coupled plasma-mass spectrometry, allow for the determination of a wide range of major and minor elements at very low detection limits. The Redcloud Peak area was selected because the study area has been shown to have high and moderate potential of several deposit types (Sanford and others, 1987) and the area has not been significantly impacted by mining, although some mines and prospects exist in the area. Therefore the geochemical baselines of stream waters evolving in this mineralized area can be determined and approximates the natural background geochemistry.

The determination of geochemical baselines for the Redcloud Peak area establishes a range of element concentrations in stream waters for this minimally impacted mineralized area at the time of sampling.

Field and Laboratory Methods

Thirty-three samples of water were collected from streams and one spring in the Redcloud Peak area (fig. 2). Samples were collected in high density polyethylene bottles that

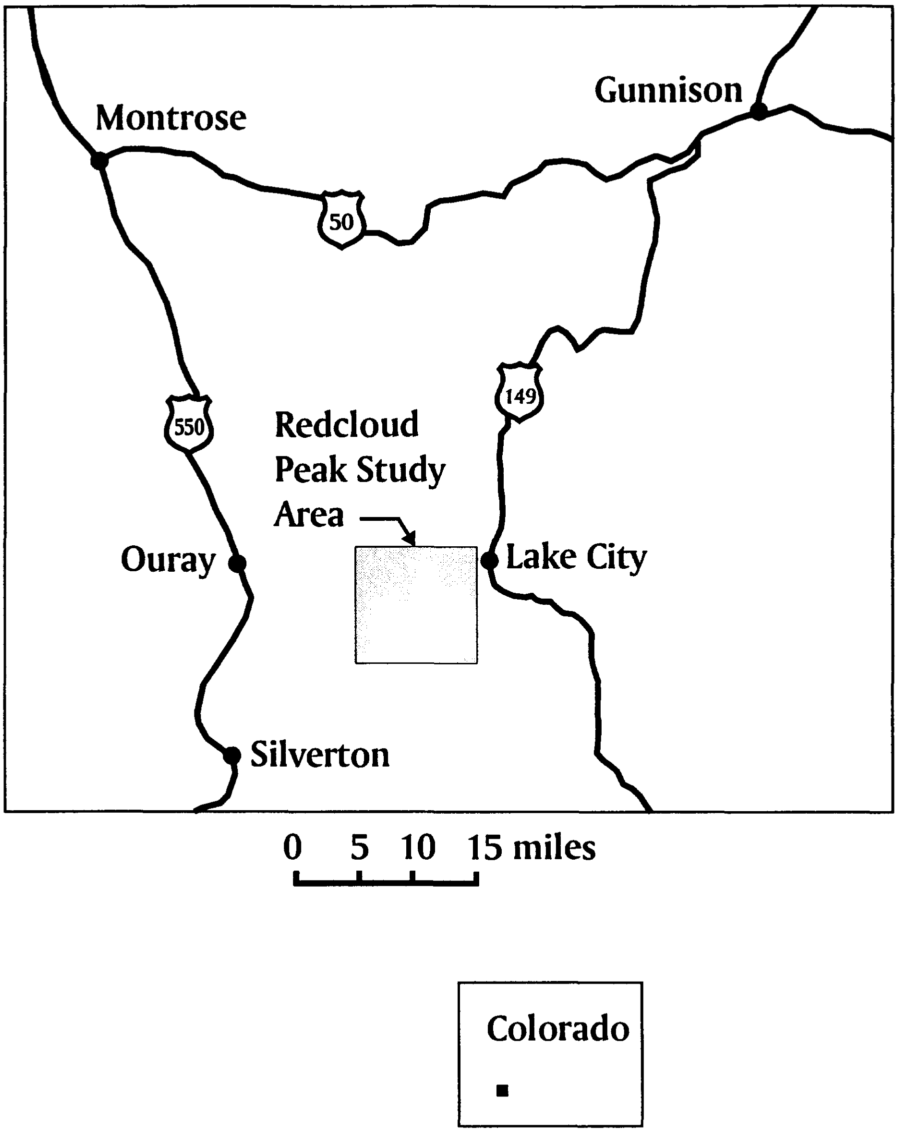

Figure 1. Map showing location of Redcloud Peak study area.

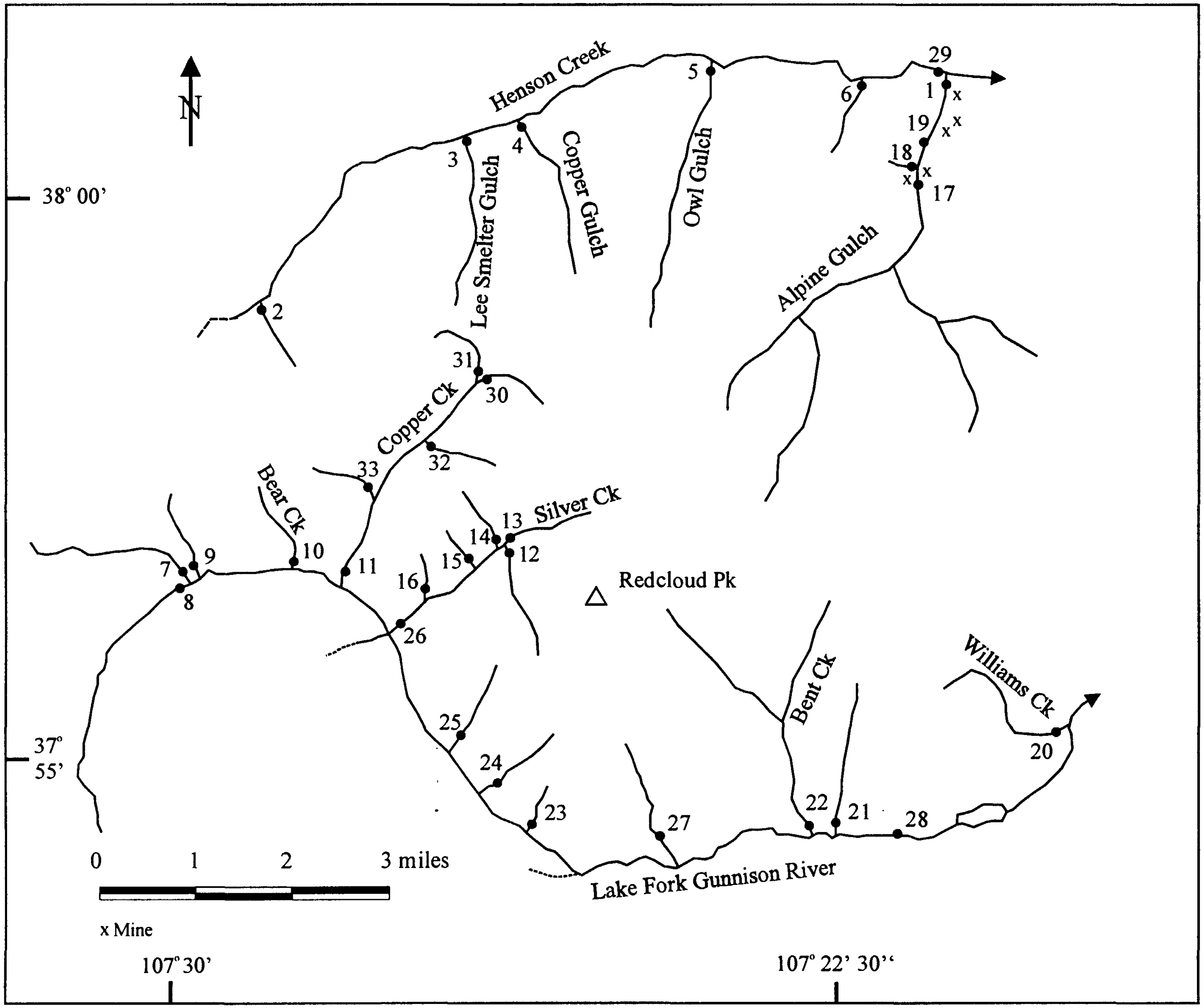

Figure 2. Map showing locations of sample sites, Redcloud Peak area, Colorado

had been rinsed with 10 % nitric acid. At each site, a 60-ml sample was collected and filtered through a 0.45 μm filter, and acidified to pH< 2 with nitric acid. An additional 500-ml raw sample was also collected. The methods and the data are shown in McHugh and others (1995).

At each site the temperature, pH, and conductivity were measured. The pH was measured using an Orion[1] model 250 pH meter with an Orion glass electrode with a Ag/AgCl junction. The conductivity was measured using an Orion model 120 conductivity meter. Ferrous iron was also determined at each site colorimetrically with a Hach DR/2000 spectrophotometer. Calcium, magnesium, sodium, potassium, silica, aluminum, manganese, and total iron were determined using the filtered, acidified samples by flame atomic absorption spectrophotometry (Perkins-Elmer, 1976). Fluoride, chloride, sulfate, and nitrate were determined by ion chromatography using the unacidified samples (Fishman and Pyen, 1979). Alkalinity, as bicarbonate, was determined on the raw samples by Gran's plot potentiometric titration (Orion Research, 1978). The remaining elements were determined using the filtered and acidified samples by inductively coupled plasma-mass spectrometry.

Study Area

The Redcloud Peak study area is located between the Uncompahgre and Gunnison National Forests on federal lands administrated by the Bureau of Land Management. Elevations range from around 9400 feet along the Lake Fork of the Gunnison River to 14,034 feet for Redcloud Peak. Precipitation ranges from around 20 inches along the lower portion of Henson Creek to greater than 40 inches surrounding Redcloud Peak (Colorado Climate Center, 1984). Most of the study area is in the alpine zone characterized by alpine tundra and the absence of trees. Below this zone, the remaining area is in the subalpine zone, dominated mainly by Engelmann spruce and subalpine fir.

Geology and Mineralization

The study area is located within the San Juan volcanic field of southwestern Colorado. The study area occurs mainly within the 23.1 Ma Lake City caldera (Lipman, 1976). The caldera formed in response to the eruption of the Sunshine Peak Tuff with subsequent eruption of dacite lavas and emplacement of felsic plutons and related rhyolitic intrusions (Hon and others, 1983 and Hon, 1987). Most of the exposed rocks within the study area are part of the caldera-fill sequence (Lipman, 1976 and Hon, 1987).

The Redcloud Peak area has approximately 100 quartz veins, of which 30 are more than 2000 feet long (Hon, 1987). The veins contain quartz and disseminated pyrite with minor amounts of galena, chalcopyrite, sphalerite, tetrahedrite, and rhodochrosite (Sanford and others, 1987). No significant acid-mine drainage occurs within the study area, although natural acid-rock drainage is present. The Galena mining district is located adjacent and northwest of the

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[1] The use of trade names in this report is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

Redcloud Peak area. Galena, sphalerite, and pyrite with minor chalcopyrite, silver bearing tetrahedrite and native silver occur in the Galena district (Sanford and others, 1987).

The mineral potential of the Redcloud Peak area was evaluated by (Sanford and others, 1987). They concluded that "much of the Redcloud Peak area has high mineral resource potential for precious (silver and gold) and base (principally lead, zinc, and copper, but also antimony, barite, bismuth, cadmium, fluorspar, manganese, mercury, selenium, tellurium, and tungsten) metals in vein-type and breccia-pipe-type epithermal deposits; the rest of the study area has moderate potential for these deposits. Part of the Redcloud Peak study area has high potential for uranium in vein-type deposits; other parts of the area have moderate potential for this commodity. Parts of the Redcloud Peak study area have moderate potential for molybdenum and copper in quartz monzonite-associated porphyry deposits " (Sanford and others, p. B1, 1987). The high to moderate potential for several deposit types and the lack of significant mining or acid drainage associated with mining allow the determination of geochemical baselines of this mineralized area that approximate the natural background geochemistry of stream waters at the time of year the sampling was carried out. This information can be used as collaborating data for establishing baselines at sites impacted by acid-mine drainage with similar deposit types, geology, and climate.

Results

Waters were collected from 32 streams and one spring during July 21-23, 1994 (fig. 2). The weather was stable and no precipitation occurred during this time. Spring runoff was over and stream flow was less than mean flow (Ugland and others, 1995). The chemical analyses of the 33 waters are shown in Table 1. The maximum values of remaining elements not shown in Table 1 are shown in Table 2. The quality of the waters ranges from excellent to degraded. The waters can be classified by the dominant cation and anion. Eighteen of the waters are calcium-sulfate dominant, 9 are calcium-sulfate-bicarbonate dominant and 6 are calcium-bicarbonate dominant in composition.

Waters from mineralized areas

The water data delineate four anomalous areas that are related to mineralization of the rocks (fig. 3). The northwest Redcloud Peak anomaly (sites 11, 12, 13, 14, 16, 20, 30, and 32) is located along the northwestern slope of Redcloud Peak and extends from Redcloud Peak to Cooper Creek (fig. 3). The waters in this area are anomalous in sulfate, Zn, rare-earth elements La, Ce, Pr, Nd, Sm, Eu, Gd, Dy, and Yb (REE), Mo, Li, U, Be, F, and low pH. The high values of sulfate and acid waters indicate surface and near surface oxidation of sulfides, mainly pyrite, and potential for epitheral base and precious metal deposits. Sanford and others (1987) concluded the most of the Redcloud Peak study area had high potential for precious and base metals in vein-type and breccia-pipe-type epithermal deposits. The anomalous values for Mo, Li, U, Be, REE, and F indicate the presence of highly evolved igneous rocks characteristic of porphyry Mo mineralization in the near surface.

The Alpine Gulch anomaly (fig. 3) is located along lower Alpine Gulch (sites 18 and 19).

Table 1. Analytical data for 33 water samples from Redcloud Peak area, Colorado

Site	Temp deg. C	pH	Cond µS/cm	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	SiO2 mg/l	Alkalinity mg/l	SO4 mg/l	Cl mg/l
RW01	15	6.86	128	15	2.4	2.1	0.9	9	13	42	0.17
RW02	8	7.09	110	15	1.7	0.7	0.5	3	29	32	0.15
RW03	12	5.92	230	31	3.3	1.5	0.8	9	<1	93	0.11
RW04	9	7.55	119	17	1.3	1	0.4	6	10	28	0.14
RW05	7	7.14	132	19	1.5	1	0.5	6	20	34	0.11
RW06	7	7.65	105	14	1.9	1.7	0.4	8	23	20	0.12
RW07	11	7.1	195	25	5.3	0.4	0.5	3	18	70	<0.1
RW08	9	7.37	120	18	1.8	0.4	0.4	3	26	28	<0.1
RW09	11	6.87	87	13	1	0.5	0.4	4	21	22	<0.1
RW10	9	6.73	117	14	2.5	0.4	0.9	6	12	42	<0.1
RW11	10	5.17	117	12	1.5	1	1.2	10	15	45	<0.1
RW12	8	4.92	127	12	2	0.6	1.9	9	<1	49	0.15
RW13	11	7.18	143	17	2.9	1.6	1.1	9	17	49	0.11
RW14	13	3.58	320	22	4.5	2.2	4.5	29	<1	106	0.14
RW15	5	6.08	70	7.8	1.2	0.6	1.7	16	13	23	0.14
RW16	9	4.17	148	11	2	0.5	3.6	25	<1	53	0.15
RW17	10	7	128	15	2.4	2	0.9	10	18	43	0.1
RW18	8	7.92	208	28	4.3	4.4	0.5	12	86	37	0.29
RW19	10	7.81	622	85	10	26	1.1	14	179	176	0.82
RW20	9	6.8	95	13	1.2	4	0.4	9	40	9	0.17
RW21	12	6.91	93	12	1.4	1.2	0.7	6	29	23	0.13
RW22	12	7	94	12	1.4	1.2	0.7	6	15	23	0.11
RW23	11	7.42	121	18	1.6	2.3	0.3	7	45	16	0.15
RW24	11	7.6	210	33	2	4.4	1.2	8	94	24	0.17
RW25	8	7.57	87	11	1.2	1.1	1	8	13	24	0.11
RW26	14	6.06	129	14	2.4	1.1	1.7	10	<1	50	0.13
RW27	11	7.05	44	6.3	0.5	0.9	0.5	6	23	6.9	0.13
RW28	16	7.12	115	16	1.8	1.7	0.8	7	28	23	0.19
RW29	14	7.53	136	18	2.1	2.3	0.6	10	35	31	0.22
RW30	10	4.42	140	12	1.4	1.2	1.2	10	<1	52	<0.1
RW31	8	6.4	55	7.6	0.7	0.4	0.4	3	15	13	0.18
RW32	6	3.9	194	14	2.3	1.1	2.3	17	<1	74	0.17
RW33	10	6.6	47	6.7	0.7	0.4	0.5	4	20	10	<0.1

Site	F mg/l	NO3 mg/l	Al mg/l	Mn mg/l	Fe mg/l	Fe2+ mg/l	Cu µg/l	Zn µg/l	Co µg/l	Ni µg/l	Mo µg/l	As µg/l
RW01	0.23	<0.2	<0.1	0.02	0.03	0.01	<1	<5	1	1	1	<1
RW02	0.12	2	<0.1	<0.01	0.02	<0.01	<1	<5	<1	<1	1	<1
RW03	0.41	<0.2	0.4	0.18	0.02	<0.01	1	60	1	5	<1	<1
RW04	0.2	<0.2	<0.1	<0.01	0.01	0.01	<1	<5	<1	<1	7	<1
RW05	0.18	<0.2	<0.1	<0.01	-0.01	<0.01	<1	<5	<1	<1	3	<1
RW06	0.16	<0.2	<0.1	<0.01	0.01	<0.01	<1	<5	<1	<1	1	<1
RW07	0.15	<0.2	<0.1	<0.01	0.02	0.02	<1	67	<1	1	<1	<1
RW08	0.11	<0.2	<0.1	<0.01	0.02	<0.01	<1	22	<1	<1	1	<1
RW09	0.11	<0.2	<0.1	<0.01	0.01	0.01	3	6	<1	<1	1	<1
RW10	0.09	<0.2	<0.1	<0.01	0.01	<0.01	<1	7	<1	<1	<1	<1
RW11	0.27	0.32	1.2	0.5	0.04	0.04	1	90	1	2	<1	<1
RW12	0.19	1.1	1.6	0.52	-0.01	<0.01	4	110	<1	2	<1	<1
RW13	0.2	0.32	0.1	0.15	0.01	0.01	<1	10	1	1	2	<1
RW14	0.96	<0.2	2.62	2	0.45	0.21	3	280	12	7	<1	<1
RW15	0.15	<0.2	<0.1	<0.01	0.02	<0.01	<1	10	<1	<1	<1	<1
RW16	0.33	<0.2	1.7	1.2	0.07	0.07	3	83	4	3	<1	<1
RW17	0.18	<0.2	<0.1	0.02	0.27	0.27	<1	5	2	1	1	<1
RW18	0.1	<0.2	<0.1	<0.01	-0.01	<0.01	<1	<5	<1	<1	2	<1
RW19	0.39	<0.2	<0.1	<0.01	0.01	<0.01	<1	<5	<1	1	29	11
RW20	0.1	<0.2	<0.1	<0.01	-0.01	<0.01	<1	5	<1	<1	1	<1
RW21	0.07	<0.2	<0.1	<0.01	0.01	<0.01	<1	<5	<1	<1	<1	<1
RW22	0.08	<0.2	<0.1	<0.01	0.03	0.02	<1	<5	<1	<1	<1	<1
RW23	0.32	<0.2	<0.1	<0.01	0.02	<0.01	<1	<5	<1	<1	6	<1
RW24	0.28	<0.2	<0.1	<0.01	0.02	<0.01	<1	<5	<1	<1	9	<1
RW25	0.09	<0.2	<0.1	<0.01	0.01	0.01	<1	<5	<1	<1	1	<1
RW26	0.2	0.59	0.3	0.26	0.03	0.01	3	100	1	2	<1	<1
RW27	0.08	<0.2	<0.1	<0.01	0.04	<0.01	<1	<5	<1	<1	2	<1
RW28	0.16	<0.2	<0.1	0.01	0.03	0.01	<1	<5	<1	<1	1	<1
RW29	0.14	<0.2	<0.1	0.02	0.02	0.01	2	26	<1	<1	1	<1
RW30	0.26	0.37	2.1	0.67	0.07	0.05	2	130	3	2	<1	<1
RW31	0.12	<0.2	<0.1	<0.01	0.01	<0.01	<1	<5	<1	<1	<1	<1
RW32	0.69	<0.2	4.4	0.53	0.04	0.04	6	93	3	<1	<1	1
RW33	<.05	<0.2	<0.1	<0.01	0.02	0.01	<1	<5	<1	<1	<1	<1

Site	U µg/l	Li µg/l	Be µg/l	Sc µg/l	Cr µg/l	Rb µg/l	Sr µg/l	Y µg/l	Cs µg/l	Ba µg/l	La µg/l	Ce µg/l
RW01	<0.1	2	<0.2	3	0.3	2.1	170	<0.1	<0.2	18	12	<0.1
RW02	0.1	3	<0.2	2	0.3	1.5	120	<0.1	0.2	3.4	66	<0.1
RW03	0.3	4	0.8	3	<0.2	2.3	190	4.9	0.2	22	12	3.2
RW04	1.1	3	<0.2	4	0.3	1.2	140	<0.1	<0.2	2.9	75	<0.1
RW05	0.5	2	<0.2	2	0.2	0.7	160	<0.1	<0.2	14	3.5	0.1
RW06	0.1	3	<0.2	3	0.2	0.9	130	<0.1	<0.2	17	0.3	<0.1
RW07	<0.1	2	<0.2	2	<0.2	1.8	83	<0.1	<0.2	9.3	0.3	<0.1
RW08	0.1	1	<0.2	3	0.3	0.6	81	0.1	<0.2	9.3	0.2	0.1
RW09	0.4	<1	<0.2	2	<0.2	1	37	0.1	<0.2	3.2	0.4	<0.1
RW10	<0.1	3	0.2	3	<0.2	4.1	55	<0.1	<0.2	4.9	0.2	<0.1
RW11	2.6	3	1.7	2	<0.2	3.6	54	8.8	<0.2	14	7	14
RW12	6.6	5	2.9	3	<0.2	6.8	39	9.2	<0.2	8.9	5.8	10
RW13	0.6	2	<0.2	4	<0.2	3.2	170	0.3	0.2	16	0.4	0.4
RW14	3.4	16	6.9	7.1	<0.2	21	56	9.2	1.8	6.5	2.9	6.7
RW15	0.2	2	0.6	4.7	<0.2	6.2	29	0.2	<0.2	7.5	0.2	<0.1
RW16	3.5	8.7	4.3	6.1	<0.2	18	35	3.5	2.5	26	1	2.1
RW17	<0.1	2	<0.2	5	<0.2	1.9	160	<0.1	<0.2	18	0.2	<0.1
RW18	1	4.6	0.3	5.6	0.5	0.6	430	<0.1	<0.2	49	0.2	<0.1
RW19	2.2	170	<0.2	7.2	0.5	4.8	>1000	<0.1	3.1	19	0.2	<0.1
RW20	0.2	4	<0.2	5.4	0.2	0.6	130	<0.1	<0.2	11	0.3	<0.1
RW21	0.3	4	<0.2	4.8	<0.2	1.9	140	<0.1	<0.2	4.3	<0.1	<0.1
RW22	0.2	3	<0.2	4.3	<0.2	1.8	140	<0.1	<0.2	4.1	<0.1	<0.1
RW23	2.1	11	<0.2	5.4	0.2	1.2	190	<0.1	0.2	2.4	0.1	<0.1
RW24	8.1	21	<0.2	5.2	0.5	2.4	320	<0.1	0.4	32	<0.1	<0.1
RW25	0.1	2	<0.2	6.9	<0.2	2.1	38	<0.1	<0.2	5.1	0.2	0.1
RW26	2.6	4	2.5	6.6	0.3	6.6	110	4	0.2	14	2.2	3.5
RW27	0.6	4.7	<0.2	7	0.2	1.8	39	0.1	0.7	0.9	<0.1	0.1
RW28	0.5	2	0.3	8.2	0.5	1.4	140	<0.1	<0.2	15	<0.1	<0.1
RW29	0.3	2	<0.2	7.6	0.3	1.3	190	<0.1	<0.2	16	<0.1	0.1
RW30	5.2	3	3.3	8.9	<0.2	4	49	13	<0.2	14	9.8	21
RW31	<0.1	<1	<0.2	8.2	<0.2	0.8	42	<0.1	<0.2	13	0.2	<0.1
RW32	4.6	5.7	1	8.2	0.2	9.5	44	13	1.1	7.2	4.1	13
RW33	<0.1	<1	<0.2	8.1	<0.2	1.1	79	<0.1	0.2	14	<0.1	0.1

Site	Pr µg/l	Nd µg/l	Sm µg/l	Eu µg/l	Gd µg/l	Dy µg/l	Yb µg/l
RW01	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RW02	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RW03	0.8	3.4	0.7	0.2	1.1	0.6	0.2
RW04	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RW05	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RW06	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RW07	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1
RW08	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1
RW09	<0.1	0.3	<0.1	<0.1	<0.1	<0.1	<0.1
RW10	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RW11	2.2	8.7	1.8	0.2	2	1.6	0.6
RW12	1.7	5.8	1.4	0.2	1.8	1.5	0.7
RW13	<0.1	0.3	<0.1	<0.1	<0.1	<0.1	<0.1
RW14	1	4.7	1.2	0.2	1.6	1.3	0.6
RW15	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RW16	0.4	1.6	0.3	<0.1	0.4	0.4	0.2
RW17	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RW18	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RW19	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RW20	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RW21	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RW22	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RW23	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RW24	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RW25	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RW26	0.6	2.4	0.5	<0.1	0.7	0.5	0.2
RW27	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RW28	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RW29	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RW30	2.8	10	2.2	0.2	2.4	2	0.9
RW31	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1
RW32	2	9	2.1	0.3	2.9	2.2	0.8
RW33	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Table 2. Maximum values for selected elements.

Element	Concentrations
Ti	2
V	0.4
Ga	0.2
Ge	0.2
Zr	<0.1
Nb	<0.3
Ag	<0.1
Cd	<2
Sn	<0.3
Sb	0.4
Te	<1
Eu	0.2
Tb	0.4
Ho	0.5
Er	0.6
Tm	0.2
Hf	<0.1
Ta	<0.1
W	<0.1
Re	<0.1
Au	<0.1
Tl	0.2
Pb	<5
Bi	<0.6
Th	<0.4

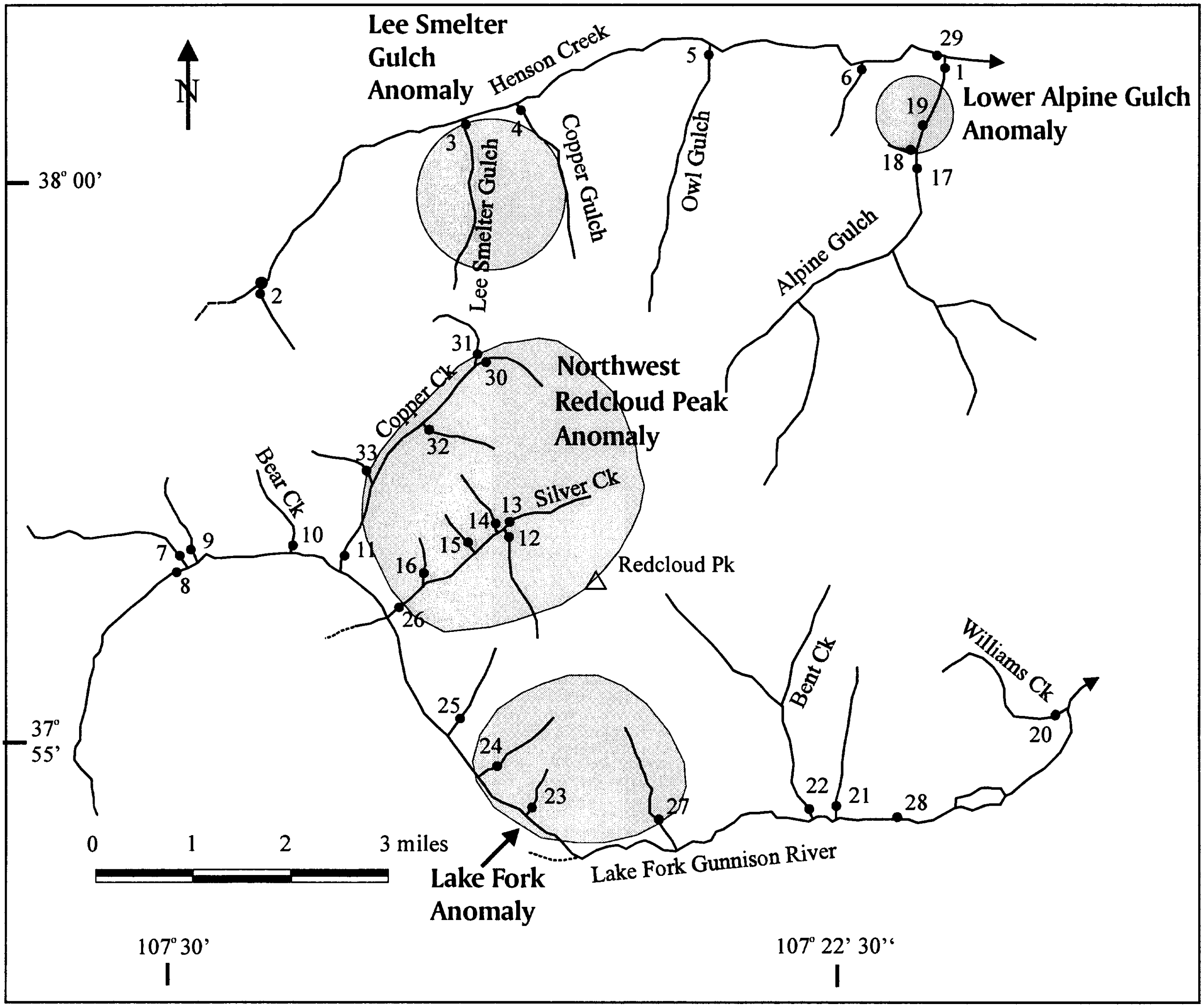

Figure 3. Map showing locations of anomalies, Redcloud Peak area, Colorado

The waters of the area are anomalous in Mo, As, Li, U, F, sulfate, and conductivity. The high concentrations of sulfate indicates that oxidation of sulfides has taken place in the subsurface, but not the surface. If sulfide oxidation was occurring at the surface, the acid generated by the oxidation would not have time to be buffered and the waters would be acidic. The alkaline pH values and the higher alkalinity values indicate that natural acid generated by the oxidation of the sulfides has been buffered, probably by calcite present in the subsurface. Calcite is probably associated with propylitic alteration of the rocks. The water chemistry indicates porphyry Mo mineralization in the subsurface. This area was considered to have high potential for porphyry Mo deposits by Sanford, and others (1987).

The Lee Smelter Gulch anomaly (fig. 3) is located along Lee Smelter Gulch and Copper Gulch (sites 3 and 4). The waters of the area are anomalous in sulfate, REE, Zn, Mo, U, F and low pH values. The acid waters and the high sulfate concentrations indicate that the area is undergoing oxidation of pyrite in the surface and near surface and indicates potential base and possibly precious metal mineralization. The anomalous Mo, U, F, and REE indicate the waters are in contact with evolved igneous rocks with moderate porphyry Mo mineralization in the subsurface. This area was considered to have moderate potential for porphyry Mo deposits by Sanford and others (1987).

The Lake Fork anomaly (fig. 3) is located along the lower southern slope of Redcloud Peak, above the Lake Fork of the Gunnison River (sites 23, 24, and 27). This anomaly is the weakest of the four. The waters of the area are anomalous in Mo, Li, U, and F. The area probably contains evolved igneous rocks with weak porphyry Mo mineralization in the subsurface.

Other elements associated with the four anomalous areas are Al, Fe, Mn, Co, Ni and Cu. The highest values are Al with a maximum value of 4.4 mg/l at site 32 (fig. 2). Sites 14, 30, 16, 12, and 11 (fig. 2) have Al concentrations >1 mg/l (Table 1). At many of these sites, hydrous Al oxides are actively precipitating in the stream channel. The oxidation of the sulfides, mainly pyrite, releases acid which dissolves the Al from rock minerals. When the acid waters mix with more neutral to alkaline waters, the resulting higher pH values of the mixed waters cause hydrous Al oxides or sulfates to precipitate forming white coatings along the stream bottoms and rock surfaces. Fe and Mn concentrations in the waters are less than Al. Much less hydrous Fe oxide precipitate is present in the stream channels than hydrous Al precipitates. Co and Ni concentrations are low; the maximum for both occur within the northwest Redcloud Peak anomaly (site 14) with 12 and 7 µg/l respectively. Cu concentrations are also low with a maximum of 6 µg/l at site 32, which suggests that the waters are not in contact with rocks containing Cu-rich minerals.

Alkalinity, which provides acid-buffering capacity to the waters, is highest at sites 19, 24, and 18 (fig. 2) with values of 179, 94, and 86 mg/l respectively (Table 1). These sites occur in the lower Alpine Gulch anomaly and the Lake Fork anomaly. The mainly felsic compositions of the bedrocks in the study area provide low alkalinity to the waters. Therefore the source of the higher values of alkalinity is probably due to calcite present as an alteration mineral in the surface or subsurface of the watersheds.

Anomalous concentrations of nitrate occur at sites 2 and 12 (fig. 2) with values of 2 and 1.1 mg/l respectively (Table 1). The source of the anomalous nitrate is not the mineralized rocks of the study area but is probably due to anthropogenic sources. The mostly likely cause is air pollution from the west. Another possibility is contamination by large animals.

Low ionic-strength waters

Low ionic strength waters are also present in the study area. Low values of conductivity, which is a measure of the total dissolved solids, occur at sites 27, 33, 31, and 15 with values of 44, 47, 55, and 70 µS/cm. These sites are located along a tributary draining the southeast slope of Redcloud Peak, along lower Copper Creek, upper northwestern portion of Copper Creek basin, and along lower Silver Creek (fig. 2). These sites contain the most dilute waters in the study area. These waters have elevated concentrations of sulfate and pH values that are slightly acid to neutral with low alkalinity, probably because of the oxidation of pyrite which is pervasive within the study area.

Comparison of Henson Creek with the Lake Fork of the Gunnison River

Comparisons of the water quality can be made of Henson Creek with the Lake Fork of the Gunnison River (the two major streams of the study area) by comparing the water quality at sites 29 and 28 (fig. 2 and Table 3). Henson Creek is higher in pH and alkalinity (which improves water quality), but higher in sulfate, Zn, and Cu than the Lake Fork. Fe, Al, and Mn concentrations were low at both sites, and As, Ni, and Co concentrations were <1 ug/l at both sites (Table 3). Zn concentration of 26 µg/l at site 29 on Henson Creek is the only elevated metal in the waters. Both streams are of overall good quality at sites 29 and 28, at the time of sampling.

Chemical modeling of the waters

To gain understanding of processes such as speciation of elements and identification of minerals that may control the concentration, mobility, and attenuation of elements in the stream waters, chemical modeling of the stream waters was carried out using PHREEQC (Parkhurst, 1995). The modeling program assumes mineral-solution equilibrium. For some chemical reactions, particularly with slow kinetics, this may not be the case. The cations in the stream waters occur mostly as simple cations or sulfate, carbonate, and bicarbonate complexes. The dominate anions are SO_4^{2-}, HCO_3^-, and Cl^-. The dominant species for selected elements are shown in Table 4.

The oxidation potential (Eh) is calculated using PHREEQE, assuming equilibrium of iron species in water with ferrihydrite with log K_T=17.91 at 25°C. The Eh values were all oxidizing and ranged from 0.099 to 0.826 volts. The high values of Eh at sites 14, 32, 16, 12, and 11 (Eh from 0.543 to 0.826 volts) are typical of waters in contact with oxidizing sulfide minerals, particularly pyrite. These waters are from the northwest Redcloud Peak anomaly. The lowest values occur at sites 18, 19, 6, 24, and 29 (Eh from 0.099 to 0.128 volts) and are typical for waters out of contact with the atmosphere. Because these are stream waters, except for site 19 which is a spring, groundwater inflow is probably a major component of flow at these sites.

Table 3. Comparison of Henson Creek to Lake Fork of the Gunnison River

	Henson Creek (site 29)	Lake Fork of the Gunnison River (site 28)
pH	7.53	7.12
Conductivity	136	115
Ca	18	16
Mg	2.1	1.8
Na	2.3	1.7
K	0.6	0.8
SiO2	10	7
Alkalinity as HCO3	35	28
Sulfate	31	23
Cl	0.22	0.19
F	0.14	0.16
Al	<0.1	<0.1
Mn	0.02	0.01
Fe	0.02	0.03
Cu	2	<1
Zn	26	<5
Mo	0.3	0.5
Cr	1	1
U	0.3	0.5

All speicies in mg/l except Cu, Zn, Mo, Cr, and U which are in ug/l, conductivity in uS/cm, and pH dimensionless

Table 4. Dominant dissolved species for selected elements

Element	Dominant Specie	Less Dominant Specie
Al	Al+3, Al(OH) 4-	AlF2+, AlSO4+
Alkalinity	HCO3-	
Ca	Ca2+	CaSO4
Cl	Cl-	
Cu	Cu(OH), Cu2+	Cu+
F	F-, AlF2+	
Fe	Fe2+	Fe(OH)2+, Fe(OH)+
K	K+	
Mg	Mg2+	MgSO4
Mn	Mn2+	MnSO4
Na	Na+	
S	SO42-	CaSO4, MgSO4
Si	H4SiO4	
Zn	Zn2+	ZnSO4, ZnCO3

Saturation indexes were calculated for a suite of minerals to determine if concentrations of trace metals in water were controlled by mineral phases. The saturation index is a convenient means of expressing saturation states of minerals (Barnes and Clark, 1969 where:

$$SI=\log_{10} IAP/K_T.$$

In the expression, SI is the saturation index, IAP is the ion activity product, and K_T is the equilibrium constant of the dissolution reaction at the temperature in question. Mineral phases are supersaturated at $SI>0$, saturated at $SI=0$, and undersaturated at $SI<0$.

The waters are supersaturated with respect to calcite only at site 19 (Table 5). Sites 18 and 24 are slightly undersaturated with respect to calcite. The remaining sites are all significantly undersaturated with respect to calcite. Pyrite is common in the rocks of the study area, so the oxidation of the pyrite generates acid which will dissolve any calcite present and then consume the alkalinity of the water. The felsic composition of the rocks provides low buffering capacity to neutralize the acid generated by the oxidation of the pyrite. Therefore the waters should be undersaturated with respect to calcite. Site 19 and to a lesser extent sites 18 and 24 are unusual in that they are supersaturated or slightly undersaturated with respect to calcite. Site 19 is a spring sample. The most likely explanation is that the waters are in contact with abundant calcite. The sulfate concentration at site 19 is 176 mg/l and can be explained by the oxidation of pyrite which would generate sulfate and acid. The amount of calcite in which the waters are in contact at this site is great enough to neutralize the acid and buffer the pH to 7.81. The presence of significant calcite is most likely due to propylitic alteration in the subsurface in the vicinity of site 19.

Other minerals which have an influence on the control of species in water is chalcedony. Most of the waters are near saturation with respect to chalcedony (Table 5). Therefore, chalcedony appears to control the amount of dissolved silica in the waters.

Conclusions and Summary

Waters in contact with mineralized rocks generate natural-acid drainage from two areas, the northwest Redcloud Peak and the Lee Smelter Gulch anomalous areas. The natural-acid drainage is mostly buffered in downstream Henson Creek and the Lake Fork of the Gunnison River and metals have been reduced to low levels. The quality of the waters, as they emerge from the area at sites 20 (Henson Creek) and 28 (Lake Fork of the Gunnison River) is good.

Waters from two other anomalous areas, the lower Alpine Peak Gulch area and the Lake Fork area (fig. 3), have alkaline pH with moderate concentrations of alkalinity, because of the presence of calcite, most likely from propylitic alteration in the subsurface. These waters have high concentrations of Mo, Li, U, and F. Arsenic concentration is also high at site 19.

Low-ionic strength waters are also present in the study area. These waters have elevated concentrations of sulfate and pH values that are slightly acid to neutral with low alkalinity, probably because of the oxidation of pyrite which is pervasive within the study area.

These baselines establish an approximation of background geochemistry of stream waters for the time of year in which the sampling was done. These data can be used along with other

Table 5. Saturation index values of mineral phases for waters collected in the Redcloud Peak area

Site No.	pE	Eh	Calcite	Chalcedony
1	3.95	0.233	-2.36	-0.48
2	3.62	0.214	-1.89	-0.87
3	7.13	0.421	—	-0.45
4	2.51	0.148	-1.81	-0.59
5	4.54	0.268	-1.92	-0.56
6	1.96	0.116	-1.46	-0.44
7	3.54	0.209	-1.86	-0.91
8	2.77	0.163	-1.56	-0.89
9	4.51	0.266	-2.24	-0.78
10	4.99	0.294	-2.65	-0.58
11	9.21	0.543	-4.17	-0.37
12	11	0.649	—	-0.35
13	3.6	0.212	-1.97	-0.43
14	14	0.826	—	0.06
15	6.73	0.397	-3.55	-0.1
16	13	0.767	—	0.04
17	2.71	0.160	-2.17	-0.37
18	1.67	0.099	-0.36	-0.27
19	1.92	0.113	0.25	-0.23
20	4.94	0.291	-2.07	-0.41
21	4.36	0.257	-2.09	-0.62
22	3.62	0.214	-2.3	-0.62
23	2.57	0.152	-1.24	-0.54
24	2.08	0.123	-0.51	-0.49
25	2.47	0.146	-1.89	-0.45
26	6.41	0.378	—	-0.42
27	3.33	0.196	-2.32	-0.61
28	3.15	0.186	-1.72	-0.6
29	2.17	0.128	-1.21	-0.42
30	12	0.708	—	-0.37
31	6	0.354	-3.12	-0.87
32	14	0.826	—	-0.09
33	5.02	0.296	-2.82	-0.77

information to establish geochemical baselines prior to mining at acid-mine drainage sites in areas of similar deposit types, geology, and climate. Caution must be exercised when estimating trace elements in waters from similar sites because variations in similar rock type can vary up to several orders of magnitude.

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