NATURAL ACID ROCK DRAINAGE ASSOCIATED WITH HYDROTHERMALLY ALTERED TERRANE IN COLORADO[1]

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Extended Abstract

Introduction Acid mine drainage impacts on water quality from historic mining districts are well documented in Colorado's mountainous areas. It is less well known that natural acid rock drainage (ARD) adversely affects water quality in eleven different headwater areas of the state. The geology of these areas is characterized by hydrothermal alteration, commonly related to volcanic activity, post-volcanic mineralization, or igneous stock emplacement. Areas of Colorado known to exhibit natural acid rock drainage include the Silverton Caldera, Lake City Caldera, Platoro-Summitville Caldera west of Alamosa; Kite Lake and East Trout Creek in the central San Juan Mountains; the La Plata Mountains; the Rico Mountains; Red Mountain and East Red Mountain in the Grizzly Peak Caldera southwest of Leadville; the Ruby Range; the Montezuma Stock west of Keystone; Red Amphitheatre northwest of Alma; and the Rabbit Ears Range (Fig. 1).

Methods Water from streams and springs was sampled to characterize water quality in hydrothermally altered geologic terrain. A total of 86 water samples were obtained from the altered areas (Fig. 1) in locations that appear to have no mining-related influence. In mining districts, water samples were obtained upstream or topographically above the influence of mining activity to confirm the presence of non-anthropogenic, natural acid rock drainage.

Several of these areas were then mapped, based on field observations and aerial photography, to determine the characteristics and the extent of alteration and various hydrothermal alteration types (Fig. 2). Rock samples were analyzed to identify mineral assemblages. In the expansive altered terrain of the Silverton Caldera, remotely sensed hyperspectral spectroscopic data augmented detailed field mapping to identify hydrothermal alteration areas and types.

Additional Key Words: alteration, headwaters, map, metals, standards, water quality

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[1]Poster paper presented at the 7th International Conference on Acid Rock Drainage (ICARD), March 26-30, 2006, St. Louis MO. R.I. Barnhisel (ed.) Published by the American Society of Mining and Reclamation (ASMR), 3134 Montavesta Road, Lexington, KY 40502

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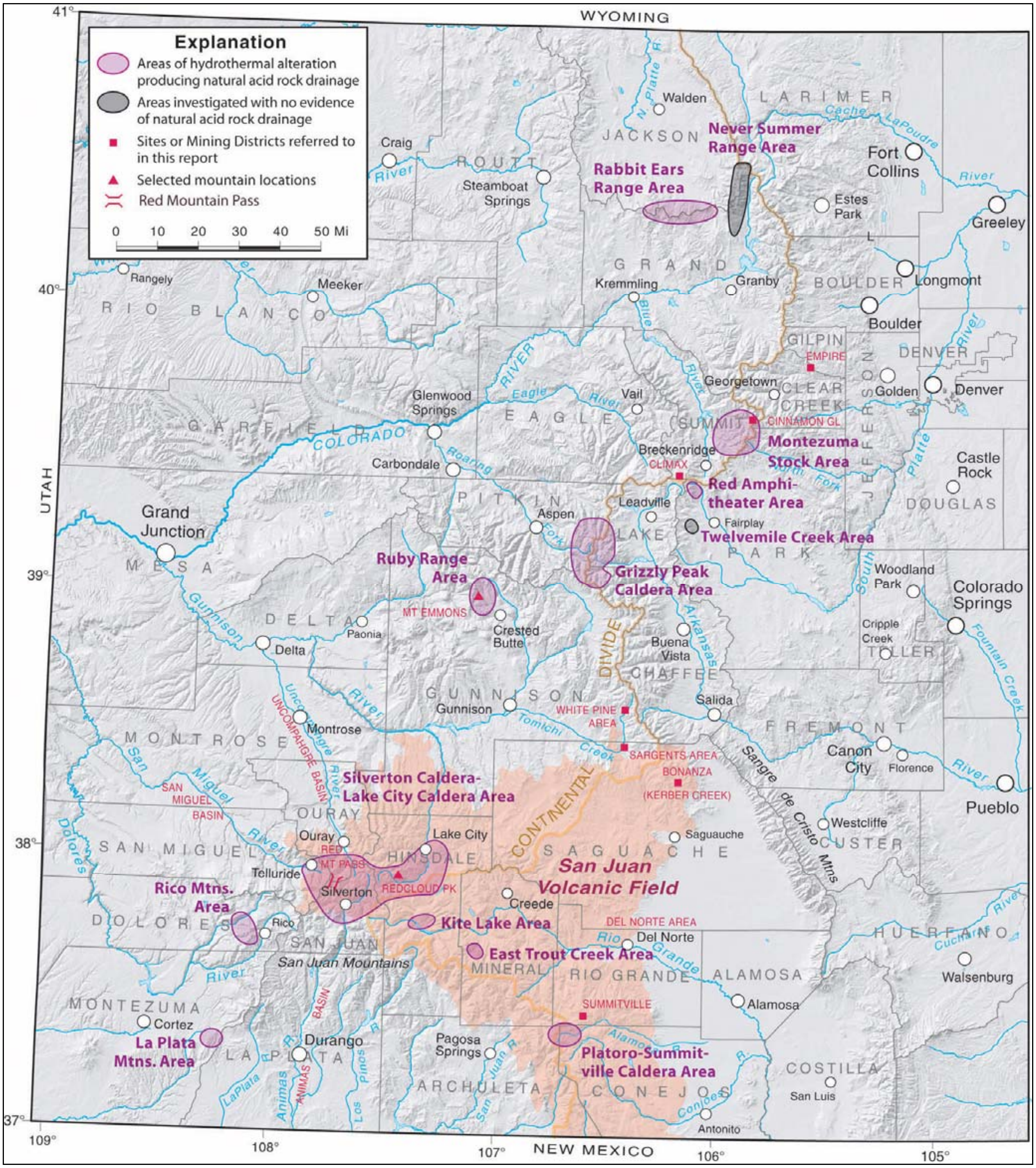

Figure 1. Map of western Colorado showing areas of hydrothermal alteration investigated for natural acid rock drainage.

Results and Discussion An understanding of water quality related to hydrothermally altered terrane in Colorado is acquired when the data gathered from the above investigations is synthesized. Eighty-one percent of the water samples were acidic (i.e., pH < 7) and/or had metal concentrations exceeding the Colorado Water Quality Control Commission's statewide surface-water-quality standards (Table 1). Only 19 percent of the samples met statewide water quality standards for all or most of the tested parameters (e.g., pH, metal content). Of the 86 samples with no apparent anthropogenic influence, 66 had pH below the standard of 6.5. Concentrations of dissolved Al exceeded the State standard of 87 μg/L in 77 of the 86 samples, and dissolved Mn exceeded the secondary (aesthetic) drinking water standard of 50 μg/L in 58 samples. Dissolved Cu and Zn concentrations exceeded hardness-related State water quality standards in 50 and 47 samples, respectively. Dissolved Fe exceeded the secondary (aesthetic) drinking water standard of 300 μg/L in 38 of 86 samples. Total recoverable Fe exceeded the water quality standard of 1,000 μg/L in 35 samples. Sulfate (SO_4^{-2}) exceeded the secondary drinking-water standard of 250 mg/L in 14 samples, and Cd and Pb exceeded their hardness-related standards in 25 and 10 samples, respectively. Nickel exceeded its hardness-related standard in 14 samples. Other parameters such as Tl, Cl^-, Cr, F^-, and Ag exceeded standards ≤5 times each; these analytes were not detected in most samples. Arsenic exceeded the recently adopted USEPA standard of 10 μg/L in three samples (Table 1). The most common constituents exceeding statewide water quality standards in areas of natural acid rock drainage are pH, Al, Fe, Cu, Mn, and Zn.

The chemical composition of natural acid rock drainage is a function of the geologic characteristics of the specific area of interest. The most important features influencing water composition are the mineralization type, structural setting, size of the alteration system, and host rock compositions. All these factors play a part in determining water composition and the complex relationships between constituents in solution. The water quality of natural acid rock drainage for different hydrothermally altered areas in Colorado was characterized by determining aqueous metal and anion concentrations that exceeded water quality standards (Table 2).

Natural ARD waters that commonly exceed statewide water quality standards are often spatially associated with altered and mineralized rocks in caldera-related settings (Silverton, Lake City, Summitville-Platoro, Grizzly Peak). Most of the other areas with poor water quality are associated with extensive altered areas around disseminated, porphyry-type, molybdenum-Cu or molybdenum systems (Montezuma, La Platas, Ruby Range, Rico, Red Amphitheater, and Rabbit Ears Range).

In all of the areas studied, changes in water chemistry, from essentially unimpacted (circum-neutral pH/low metal) to ARD (low pH/high metal) are readily related to changes in hydrothermal alteration type and intensity (degree of replacement of host rock). In particular, changes from propylitic or unaltered rocks to acid-sulfate, QSP, or argillic altered zones are commonly reflected in dramatic changes in the local chemistry of tributaries and springs (e.g., Red Amphitheatre, Grizzly Peak, La Platas). Such behavior is expected based on inherent variations in acid generating capacity and acid neutralizing potential of the different alteration assemblages. In general, the water samples from all of the altered areas show strong positive correlations between Al, Fe, Mn, Cu, Cd, Zn, Ni, Si and SO_4^{-2} with decreasing pH.

Many of the areas examined during this study are in watersheds where both natural ARD and historic mining have affected water quality. Where warranted, these watersheds should be characterized in detail to: 1) better understand the natural ARD and anthropogenic processes affecting stream water quality, and 2) more objectively document or rank site characteristics with respect to possible contributions from anthropogenic sources.

Acknowledgements

The authors would like to thank Rebecca Miller, Sharon Diehl, and Harry Posey for reviewing this extended abstract and for their helpful suggestions. The Colorado Department of Natural Resources Severance Tax Operational Fund provided funding for this project. Severance taxes are derived from the production of gas, oil, coal, and minerals.

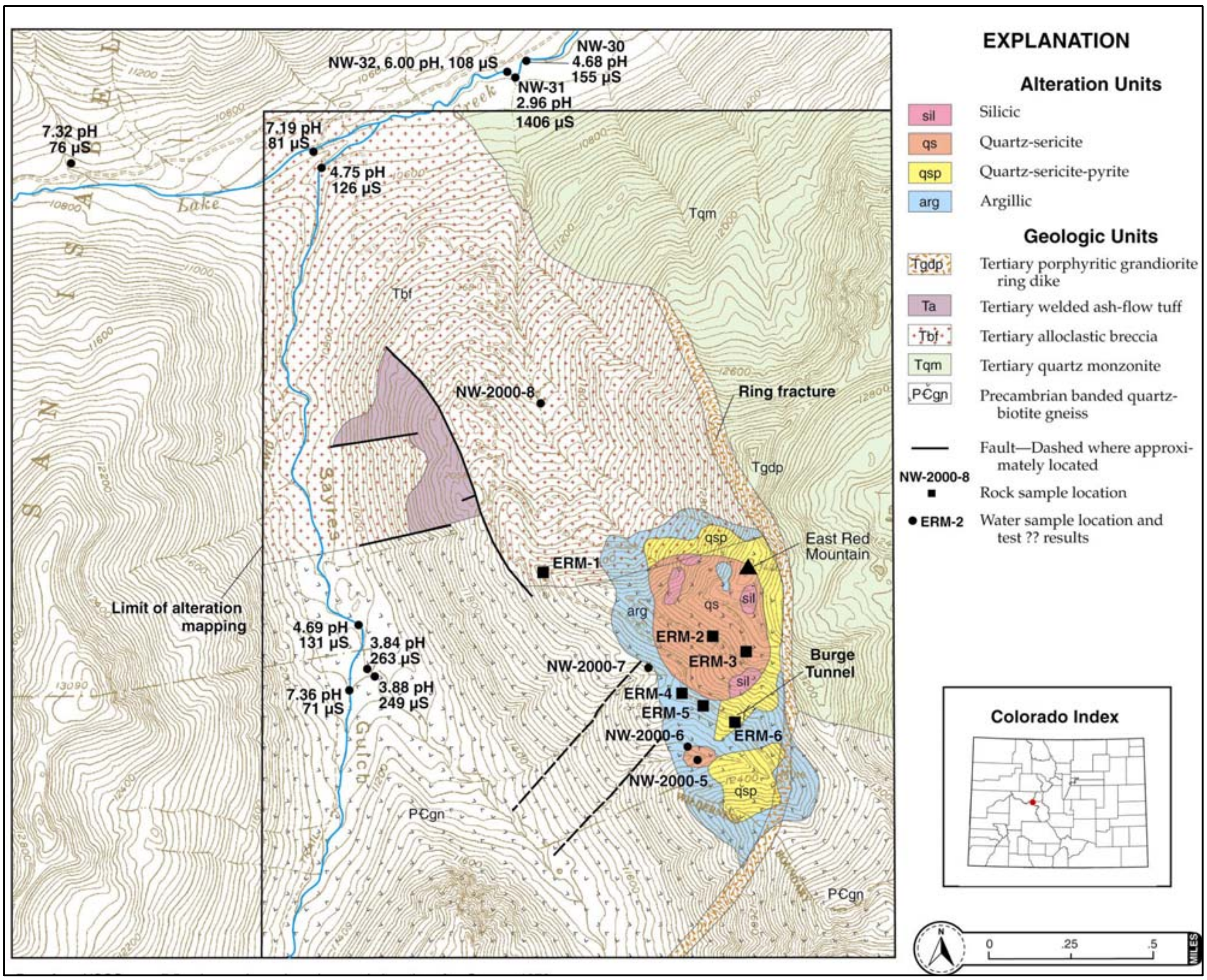

Figure 2. The East Red Mountain area of the Grizzly Peak Caldera – an example of mapping zoned, hydrothermally altered terrane in Colorado. (after Cruson, 1973)

Table 1. Summary of water chemistry data from hydrothermally altered areas with no known anthropogenic influence.

Parameter	Exceedances of water quality standards (out of 86 samples)	Water Quality Standard (in µg/L unless specified)
pH	66	6.5-9.0 standard units
Antimony (trec)	0	6
Arsenic (trec)	3	10
Iron (trec)	35	1,000
Thallium (trec)	4	0.5
Zinc (trec)	2	2000
Aluminum (diss)	64	87
Cadmium (diss)	25	$(1.10167 – [\ln(\text{hardness}) \times (0.04184)]) \times e^{(0.7852[\ln(\text{hardness})]-2.715)}$
Chloride (diss)	2	250 mg/L
Chromium (diss)	2	11
Copper (diss)	50	$e^{(0.8545[\ln(\text{hardness})]-1.7428)}$
Fluoride (diss)	3	2 mg/L
Iron (diss)	38	300
Lead (diss)	10	$(1.46203 – [\ln(\text{hardness}) \times (0.145712)]) \times e^{(1.273[\ln(\text{hardness})]-4.705)}$
Manganese (diss)	58	$e^{(0.3331[\ln(\text{hardness})]+5.8743)}$
Nickel (diss)	14	$e^{(0.846[\ln(\text{hardness})]+0.0554)}$
Silver (diss)	14	$e^{(1.72[\ln(\text{hardness})]-10.51)}$
Sulfate (diss)	17	250 mg/L
Zinc (diss)	57	$e^{(0.8473[\ln(\text{hardness})]+0.8699)}$

trec= total recoverable; diss= dissolved; several metals have hardness dependent water quality standards represented by equations

Table 2. Summary of metal exceedances by area.

Area	Drainage Basin	Standard Exceedances
Silverton Caldera – Red Mountain Pass	Red Mountain Creek	Al, Mn, Fe, Cu, Zn, Cd, Pb, As, Tl, Ag
Western San Juan Mountains	San Miguel River	Al, Mn (limited sampling)
Lake City Area – Red Cloud	Lake Fork of the Gunnison	Al, Mn, Fe, Zn, Mo (Miller, 1998)
Lake City Area – Slumgullion	Lake Fork of the Gunnison	Al, Mn, Fe, Cu, Zn, SO_4, F, Cl
Lake City Area – Carson Camp	Lake Fork of the Gunnison	Al, Mn, Fe, Cu, Zn
Platoro-Summitville	Alamosa River	Al, Mn, Fe, Cu, Zn, Cd, Tl, SO_4
Kite Lake	Rio Grande	Al, Mn, Fe, Cu, Zn, Cd, Ni
East Trout Creek	Rio Grande	Al, Mn, Fe, SO_4
La Plata Mountains – Allard Stock	La Plata	Al, Mn, Fe, Cu, Zn, Cd, F, Pb
La Plata Mountains – Allard Stock	East Mancos	Al, Mn, Fe, Cu, Zn, Cd, As, Tl, Ni, Cr, SO_4
Rico Mountains	East & West Dolores	Al, Mn, Fe, Cu, Zn, Cd, SO_4
Grizzly Peak Caldera	S. Fork Lake Creek	Al, Mn, Fe, Cu, Zn, Cd, Ni, SO_4
Ruby Range	Gunnison River	Al, Mn, Fe, Pb, Cu, Zn, Cd, As, Ag, Cl, SO_4
Montezuma Stock	N. Fork South Platte	Al, Mn, Fe, Cu, Zn, Cd, Ni, Cr, SO_4
Montezuma Stock	Snake River	Al, Mn, Fe, Cu, Zn, Cd, Pb, Ag
Red Amphitheatre	Middle Fork S. Platte	Al, Mn, Zn, Cd, F
Rabbit Ears Range	Colorado River	Al, Mn, Fe, As
Never Summer Mountains	Illinois River	As (limited sampling)