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Geochemical classification of mine drainages and natural drainages in mineralized areas

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ABSTRACT: The Colorado Mineral Belt (CMB) hosts a broad spectrum of mineral deposits, each with characteristic ore and gangue minerals, trace metals, host rocks, wallrock alteration, and structural features. We are systematically characterizing the geological parameters that affect the chemistry of mine-impacted and natural drainages in and adjacent to the CMB. Water samples from throughout the state have been collected and analyzed. We have derived a classification for mine drainage and related natural drainage that summarizes the relationship between pH and metals.

1 INTRODUCTION

Numerous mineralized areas in Colorado, USA are found throughout and adjacent to a northeast trending belt termed the Colorado Mineral Belt (CMB) (Figure 1). Throughout this region, many mines and drainage tunnels produce water that is acidic and carries a burden of heavy metals and other toxic elements. The reactions producing acid in coal mines can be found in Stumm and Morgan (1981). Wentz (1974) discusses the geologic controls on mine drainage and, in turn, the effect of that mine drainage on many Colorado streams. However, the influence of both host rock geology and mineral deposit types is not usually considered in discussions of mine drainage. Our study systematically characterizes the geological parameters that affect the acidity and concentration of metals in mine drainage and mineral-impacted natural drainages in Colorado. In a series of three related papers, we report on the results of sampling 25 mines, tunnels and natural drainages. In this paper, we develop a classification scheme to summarize a large body of data on many mines and natural drainages. Plumlee et al. (1992) discuss in greater detail the processes and geologic controls on the pH and metal concentrations in mine drainage. Smith et al. (1992) discuss metal partitioning between drainage water and suspended sediment at several diverse deposit types.

2 SAMPLING, ANALYTICAL METHODS

Metal concentrations were determined from an acidified sample (0.1 micron filter) by atomic absorption spectrometry (Aruscavage and Crock, 1987), inductively coupled plasma emission spectroscopy (ICP-AES)(Lichte and others, 1987) and inductively coupled mass spectrometry (ICP-MS)(A.L. Meier, U.S. Geological Survey, pers. comm., 1992).

Water from mines and natural drainages throughout Colorado (Figure 1), has been collected and analyzed for pH, heavy metals, anions , specific conductance, and temperature. The names, and geological settings of the mines and drainages that we sampled are listed in table 1. For a more detailed discussion of the geology shown in Table 1, see Davis and Streufert (1990). The analytical results for representative water samples are listed in Table 2.

3 DISCUSSION

We have derived a classification scheme based on pH and metal concentrations (Figure 2).

Table 1. Mines and natural drainages sampled. Under "Type", M=mine-related, N=natural, H=historic drainage, R=under remediation, S=low-volume seep.

SAMPLE	Field ID	Region	Type	Type of Deposit	Host Rock
Alpha Corsair Mine	AL1	Creede	MH	Epithermal Ag,Pb,Zn	Ash flow tuff
Argo Tunnel	Argo1	Central City	MH	Pyrite veins gold	Metasediments
Bandora Mine	BAN1	Silverton	MH	Polymetallic veins	Sedimentary
Carlton Tunnel	CAR-1	Cripple Creek	MH	Au,Ag,Te,veins	Alkaline volcanics
Chapman Gulch 1	CHAP1	Ophir	N	Fringe porphyry Mo	Volcanics
Chapman Gulch 2	CHAP2	Ophir	N	Fringe porphyry Mo	Volcanics
Chapman Gulch 3	CHAP3	Ophir	N	Fringe porphyry Mo	Volcanics
Dauntless Mine	DAU-1	Leadville	MH	Carbonate replacement	Carbonates
Druid Mine	DRUID1	Central City	MHS	Pyritic veins	Metasediments
Tip-Top Mine	GAM-4	Central City	MH	Pyritic gold veins	Metasediments
Gamble Gulch 6	GAM-6	Central City	N	Pyritic gold veins	Metasediments
Garibaldi Mine	GAR-1	Leadville	MH	Polymetallic veins	Igneous and Carbonates
Leadville Drain	LD-1	Leadville	MHR	Carbonate replacement	Carbonates
Miner's Creek	MC1	Creede	MH	Epithermal Ag,Pb,Zn	Volcanics
Pass Me By	PMB1	Summitville	MH	Unmined epithermal Au	Volcanics
Rawley Tunnel	RAW-1	Bonanza	MH	Epithermal Ag,Pb,Zn	Volcanics
Ruby Mine	RUB-1	Leadville	MH	Silver-lead replacements	Carbonates
S. Mineral Creek	SMCB1	Silverton	N	Porphyry Mo	Volcanics
Smuggler Mine	GSM-1	Cental City	MH	Pyritic Au veins	Metasediments
Solomon Mine	SOL1	Creede	MH	Epithermal Ag,Pb,Zn	Volcanics
Dike 550	Dike 550	Summitville	MR	Epithermal Au	Volcanics
Blackstrap	Blackstrap1	Summitville	MS	Epithermal Au	Volcanics
Reynolds Tunnel	Reynolds1	Summitville	MH	Epithermal Au	Volcanics
Union Creek	WP2	Leadville	N	Possible carbonate replacement	Sediments
Yak Tunnel	YAK-1	Leadville	MHR	Polymetallic veins and carbonate replacements	Igneous and carbonates

Table 2. Analytical results for selected mine and natural drainage samples. Cu and Zn values greater than 1000 μg/L were obtained by atomic absorption spectrophotometry. Detection limits in μg/L by ICP-AES are 200 for Cu, 40 for Zn, 20 for Cd, 100 for Ni, 60 for Co, and 200 for Pb. All values listed below these limits were obtained using ICP-MS. Sulfate was determined by ion chromatography

SAMPLE	Cu μg/L	Zn μg/L	Cd μg/L	Ni μg/L	Co μg/L	Pb μg/L	Spec. Cond. μS	pH	SO4 mg/L
Argo Tunnel	4500	30000	130	120	100	40	4000	2.93	2100
Blackstrap	500000	700000	4400	28000	17000	60	38000	1.75	128000
Carlton Tunnel	1	110	1	20	5	<5	2800	7.66	1200
Chapman Gulch 1	1	40	<1	10	5	<5	1400	7.9	600
Rawley Tunnel	1200	33000	150	40	50	5	900	5.96	600
Reynolds Tunnel	9300	18300	210	720	530	210	3200	2.94	1900
Ruby Mine	<1	20	<1	<5	<5	<5	230	7.83	5
Solomon Mine	40	26000	160	10	80	1100	790	4.5	310
Yak Tunnel	2400	69000	290	40	20	10	980	4.44	640

Pyrite oxidation is responsible for the acidity seen in many of the mine waters (Nordstrom and others, 1979). Metals are more soluble in solutions of low pH, but we found many mine drainages with relatively high pH and yet a large concentration of metals. Zn, Cu, Cd, Ni, Co and Pb constitute the major heavy metals (other than Mn, Al, and Fe) that we found in the mine

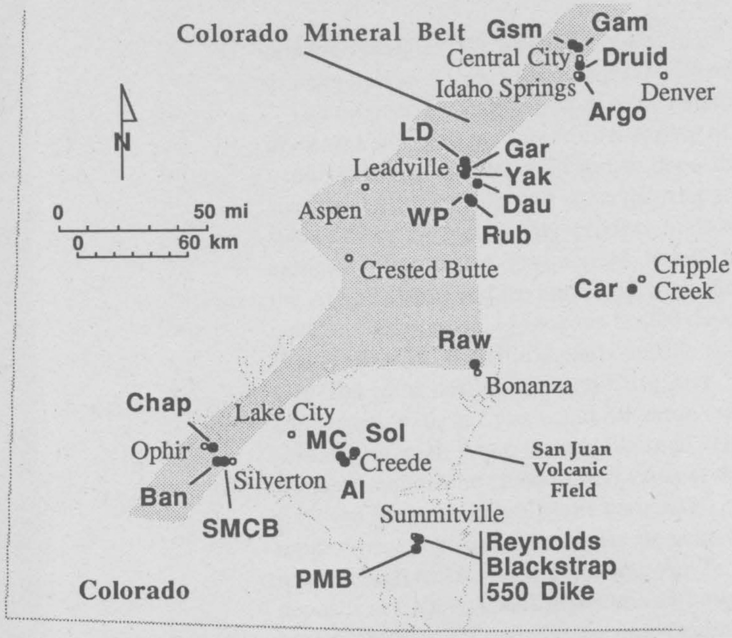

Figure 1. Map of western Colorado showing the location of drainage sites sampled relative to the Colorado Mineral Belt and the San Juan volcanic field.

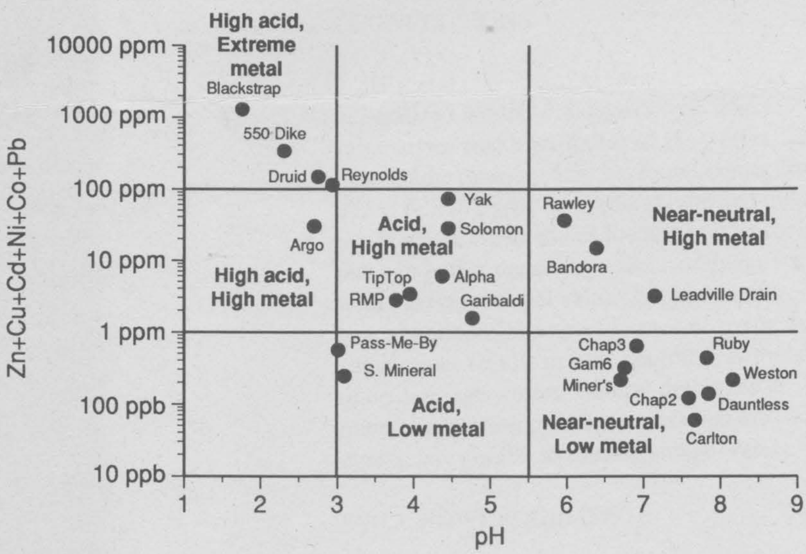

Figure 2. Variations in aqueous base metal concentrations (given as the sum of base metals Zn, Cu, Cd, Co, Ni, and Pb) as a function of pH for waters draining diverse ore deposit types in Colorado. Proposed classes for these waters are bounded by heavy lines and labeled with bold text. Sample locations and deposit types given in Table 1.

n= 24

drainage samples. We have used the sum of these metals as a parameter in our classification.

The proposed classification of mine natural drainages summarizes data from a variety of geologic environments. Acid sulfate deposits, such as at Summitville, and some quartz-pyrite sulfide veins at Central City, produce high-acid, extreme-metal waters. Pyrite veins drained by the Argo Tunnel produce high-acid, high-metal waters. Waters draining igneous-hosted deposits (Yak Tunnel at Leadville), quartz-sulfide veins (Tip-Top Mine north of Central City), and epithermal veins at Creede and Silverton are acid, high-metal. Water from epithermal veins at Bonanza, sandstone-shale-hosted veins at the Bandora Mine, and high-pyrite carbonate-replacement deposits at Leadville are near-neutral, high metal. Waters draining Au-Te deposits at Cripple Creek and some carbonate-hosted deposits at Leadville are near-neutral, low metal. The acid-sulfate epithermal deposit at the Pass-Me-By Mine and a natural iron-spring near Silverton produce acid, low metal waters.

4 CONCLUSIONS

A pH-metal classification for mine drainage and mineralized natural drainage conveniently summarizes major attributes of the waters. The most acidic drainage that we found comes from mines rich in pyrite or pyrite-alunite and quartz pyrite veins. Other mines located in host rocks that can buffer the acid, produce drainage water with near-neutral pH values but high metal concentrations. The near absence of pyrite in some mines results in near-neutral, low metal mine drainage waters. Natural drainages in mineralized areas produce waters that are chemically similar to mine drainage waters.

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REFERENCES

Aruscavage, P.J. and Crock, J.G., 1987, Atomic absorption methods, in Methods for Geochemical Analysis: P. A. Baedecker, ed., U.S. Geol. Survey Bulletin 1770. pp C1-C6.

Davis, M. W., and Streufert, R. K., 1990, Gold occurrences of Colorado: Colorado Geological Survey Resource Series 28, 101 p.

Lichte, F.E., Golightly, D.W., and Lamothe, P.J., 1987, Inductively coupled plasma atomic-emission spectrometry, in Methods for Geochemical Analysis: P.A. Baedecker, ed., U.S. Geol. Survey Bulletin 1770, pp B1-B10.

Nordstrom, D.K., Jenne, E.A. and Ball, J.W., 1979, Redox equilibria of iron in acid mine waters, in E.A. Jenne, ed., Chemical Modeling in Aqueous Systems: Speciation, Sorption, Solubility, and Kinetics, ACS Symposium Series 93: Washington, D.C., American Chemical Society, p. 51-79.

Plumlee,G.S., Smith, K.S., and Ficklin, W.H., 1992, Geological and geochemical controls on the composition of mine drainage and natural drainages in mineralized areas: Proceedings, 7th International Symposium on Water-Rock Interactions, Park City, Utah, 1992.

Smith, K.S., Ficklin, W.H., Plumlee, G.S., and Meier, A.L., 1992, Metal and arsenic partitioning between water and suspended sediment at mine-drainage sites in diverse geologic settings: Proceedings, 7th International Symposium on Water-Rock Interactions, Park City, Utah, 1992.

Stumm, Werner, and Morgan, J.J., 1981, Aquatic Chemistry, 2nd edition: New York, John Wiley and Sons, Inc.

Wentz, D.A., 1974, Effect of mine drainage on the quality of streams in Colorado, 1971-72: Colorado Water Conserv. Board Water-Resources Circ. 21, 117p.