DOE/ET/28365-20

OPEN FILE REPORT 82-5

GEOTHERMAL IMPLICATIONS OF WARM MINE WATER DRAINAGE AT LAKE CITY AND CRIPPLE CREEK, COLORADO

by

Kevin P. McCarthy

PREPARED FOR THE
U.S. DEPARTMENT OF ENERGY
DIVISION OF GEOTHERMAL ENERGY
UNDER CONTRACT DE-FC07-79ID12018

COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
STATE OF COLORADO
DENVER, CO

1982

DOE/ET/28365-20

OPEN FILE REPORT 82-5

GEOTHERMAL IMPLICATIONS OF WARM MINE WATER DRAINAGE AT LAKE CITY AND CRIPPLE CREEK, COLORADO

by

Kevin P. McCarthy

PREPARED FOR THE
U.S. DEPARTMENT OF ENERGY
DIVISION OF GEOTHERMAL ENERGY
UNDER CONTRACT DE-FC07-79ID12018

COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
STATE OF COLORADO
DENVER, CO

1982

TABLE OF CONTENTS

FIGURES

TABLES

NOTICE

NOTICE

Reference to a company product name does not imply approval or recommendation of the product by the Colorado Geological Survey nor the U.S. Department of Energy to the exclusion of others that may be suitable.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to the following: The U.S. Geological Survey, Water Resources Division, Colorado District, who analyzed the mine water samples; Hydrologist Ted Hurr, who was most helpful in procuring the analysis; Norma Swanson and Al Goodwin who were very helpful in Lake City, and Alex Paul, Charlie Carlton, and Rod Proffitt for their invaluable help in the analysis at Cripple Creek. At the U.S.G.S., Ogden Tweto provided valuable advice, and Don Gautier reviewed a earlier draft of the manuscript. Becky Nelson was expedient and accurate as typist, and Cheryl Brchan drafted the figures with her usual precision.

GEOTHERMAL IMPLICATIONS OF WARM MINE WATER DRAINAGE AT LAKE CITY AND CRIPPLE CREEK, COLORADO

by

Kevin P. McCarthy

INTRODUCTION

During July, 1981, the Colorado Geological Survey sampled warm water draining from mines near Lake City and Cripple Creek (Fig. 1), as part of a statewide geothermal resource assessment program. Warm water (>20°C) was also observed at the Camp Bird mine near Ouray, but this could not be sampled due to the lack of proper safety clothing for approaching the mine. Although the mines sampled probably represent a fraction of the mines in Colorado issuing warm water, the discussion here of two conspicuous sites may prove useful for analogous areas. The most interesting result of this work was the discovery of several "hot" mines near Cripple Creek.

Due to the lack of data specific to the nature of this investigation, and the minimal time allotted for the study due to more pressing research, the hypotheses presented are quite speculative. This report is intended to provide stimulus for further research.

Lake City

The San Juan mountains are an eroded volcanic plateau in which at least 15 collapse calderas have been identified (Steven and Lipman, 1976). The main part of the volcanism occurred between 22 and 30 million years ago. Lake City lies in the west-central portion of the mountains, on the edge of the nearly obliterated Uncompahgre Caldera, which partially contains the younger Lake City Caldera.

The Gladiator and Golden Chain mines, and the TCM tunnel were sampled, although warm water is to be found in other local mines (Normal Swanson, oral comm., 1981). Figure 2 shows mine locations and structural margins of calderas. Table 1 presents the physical properties and chemical analysis of Lake City thermal waters.

Table 1. Lake City mine water analyses.
(in mg/l except where noted)

	TCM Tunnel	Gladiator	Golden Chain
Calcium	290	160	180
Chloride	76	110	87
Iron (UG/.L)	2,800	3,200	6,200
Magnesium	33	19	36
Manganese (UG/L)	670	1,300	39,000
Potassium	29	46	36
Silica	34	58	32
Sodium	300	420	360
Sodium, percent	42%	63%	55%
Sulfate	720	610	970
Total Alkalinity (As Calcium Carb.)	540	620	340
Hardness			
Noncarbonate	320	0	260
Total	860	480	600
Specific conductance (Micromohs):	2,200	2,360	2,690
Total Dissolved Solids	1,810	1,800	1,950
pH-field (lab)	7.5 (7.6)	8.0 (8.1)	7.7 (7.7)
Temperature - °C (°F)	26 (79)	26 (79)	24 (75)
Sodium adsorp. ratio	4.5	8.4	6.4

The TCM tunnel was driven in 1908 (Irving and Bancroft, 1911). The results of the endeavor probably were not encouraging, as evidenced by the tailings. According to Irving and Bancroft (1908), the prospects in this area (Larson Creek) encountered "very narrow veins of quartz, showing few metallic minerals, and these chiefly pyrite." The rock are hydrothermally altered, gray andesitic and rhyodacitic breccia, with phenocrysts of plagioclase, hornblende, and biotite (Lipman, 1976). Andesitic and rhyolitic porphyry dikes run parallel to the road. Currently, limonite and bog iron are being formed in a pool at the mouth of the tunnel, and the overflow cascades over the iron-stained, terraced, travertine crust which encases the tailings.

The Gladiator mine, south of town, is the only sampling site in this district still being mined. The country rock consists of bedded flows and tuffs of biotite quartz latite, with phenocrysts of plagioclase, biotite and augite (Lipman, 1976). Within the mine, limonite-stained tuff predominates, and iron and manganese sulfates are apparent throughout. The nature of the ore was not determined during this study, but in the adjacent Black Crook mine was described by Irving and Bancroft (1911). They stated: "The ore of the Black Crook consists of sphalerite, galena, a little tetrahedrite, pyrite, and very subordinate chalcopyrite with irregular bunches of pyrargite in a gangue of quartz, barite, and rhodochrosite." Water cress grows in the warm water flowing from the mouth of the mine.

The Golden Chain mine, further south, is just below the Golden Fleece, the most famous mine of the district. A description of the Golden Chain is not available, but the ore may be very similar to that in the Golden Fleece. The country rock here is the same as that at the Gladiator. Apparently, the main vein in the Golden Fleece consisted of broken country rock with interstices filled with gray and white quartz and silicified fragments impregnated with petzite, pyrite, argentiferous tetrahedrite, galena, hinsdalite, and pyrargite. Some rhodochrosite was present. Bog iron was more widespread at the mouth of the Golden Chain than at any of the mines visited.

Cripple Creek

The Miocene Cripple Creek volcano was formed by explosive eruptions along a network of fissures that had resulted from regional compression during the Laramide Orogeny (Loughlin and Koschmann, 1935). Most of the mines in the district are situated in the breccia-filled throat of this volcano, which is surrounded by Precambrian granite.

The warm mines at Cripple Creek include the El Paso, Chicken Hawk, Cresson, and the Camella (Rod Proffit, oral comm., 1981), although others probably exist. These mines are all in the western portion of the crater, topographically lower than most of the other mines. The Camella shaft, of unknown depth, is "steaming." On July 23, 1981, a temperature probe was lowered into the Camella shaft to a depth of 85 feet (26 m) where the air temperature was 46°C (115°F). Figure 3 shows the location of warm mines at Cripple Creek.

The volcanic breccia is quite permeable relative to the surrounding granite. This created great problems for mining, as water in the saturated breccia was impounded by the less permeable granite; a situation likened to "a wet sponge inside a glass" by Lindgren and Ransome (1906). The El Paso tunnel drained many of the mines prior to the completion of the Roosevelt Tunnel in 1911. The deeper Carlton Tunnel was driven much later to drain the large Ajax and Portland mines near Victor.

Due to the efficiency of the drainage tunnels, no surface mine drainage was available for sampling. The Roosevelt and Carlton tunnels were sampled, and the Roosevelt was found to be considerably colder, despite draining the warm mines. The analyses of the water from the two tunnels in shown in Table 2.

The Cresson mine is situated in highly altered breccia of the "Cresson Blowout." For many years, this mine was the largest single gold producer in the district. The ore was concentrated in pockets, being composed primarily of telluride minerals associated with disseminated pyrite. In 1915, an ore chamber was discovered which was 23 ft (7 m) by 13.5 ft (4 m) by about 40 ft (12 m) high, thickly covered with the gold telluride calaverite (Wolf and Patton, 1915).

Table 2. Cripple Creek drainage tunnels analyses (in mg/l except where noted).

	Roosevelt	Carlton
Calcium	250	500
Chloride	5.5	55
Iron (UG/L)	11	50
Magnesium	37	30
Manganese (UG/L)	12	420
Potassium	3.8	5.2
Silica	28	61
Sodium	42	120
Sodium percent	10	16
Sulfate	690	1,200
Alkalinity		
As Calcium Carbonate	110	160
Hardness		
Noncarbonate	670	1,200
Total	780	1,400
Specific conductance (Micromohos)	1,480	2,360
Total dissolved solids	1,120	2,700
pH - field (lab)	7.0 (7.5)	7.0 (7.8)
Temperature - °C (°F)	10 (50)	24 (75)
Sodium absorp. ratio	.7	1.4

The Chicken Hawk mine and the Camella shaft, on Guyot Hill, are probably merged into a single mine. The country rock is breccia, situated between intrusive phonolite to the north, and granite to the southwest. A description of the ore is not available.

The El Paso workings are in granite, outside the main crater, near a phonolite plug and associated dikes. The telluride ore occurs in veins of quartz, flourite, pyrite, and sphalerite (Lindgren and Ransome, 1906). A major fault of the district traverses the mine in a southwesterly direction (Wobus, Epis, and Scott, 1976).

DISCUSSION

Lake City and Cripple Creek share a Tertiary volcanic history, but are dissimilar in most respects. The ore in Cripple Creek is dispersed in veins and pods within breccia filling the crater. The massive sulfides at Lake City occur in ring faults and radial fractures associated with late-stage caldera collapse.

Lake City

The warm water at Lake City could be produced by either normal geothermal energy or oxidation of sulfides. The heat flow in the entire San Juan region is relatively high. Zacharakis (1981) has interpolated a heat flow value of approximately 110 mw/m^2 for Lake City. Since the elevation difference between the groundwater recharge area (high peaks) and the mines is well over 5,000 feet (1,524 m), normal geothermal gradient could easily account for the elevated water temperature. Due to the age of the volcanic activity, it is unlikely that residual heat from this volcanism is present, unless recent, undetected, near-surface intrusions exist. Warm water may be brought to the surface via deep faults, but the subsurface extent of the many faults in the area is unknown. Local residents speak of warm springs in the vicinity (Norma Swanson, oral comm., 1981), but these have yet to be examined.

The oxidized gossan above the deposits is about 200 ft (61 m) thick at Lake San Cristobol, and about 100 feet (30 m) thick further north (Irving and Bancroft, 1911). The products of this natural process include limonite, hematite, pyrolusite, malachite, azurite, anglesite, cerusite, melanterite, and chalcanthite (Irving and Bancroft, 1911).

The sulfates in the mines attest to the extensive oxidation occurring presently. Touring the Gladiator mine, it was apparent that the iron and manganese sulfates and oxides present were being formed on the spot. No abrupt temperature changes were noticed, but the mine was comfortably warm on the early Spring day. Mine superintendent Albert Goodwin spoke of the year-round temperature of the mine being about 21°C (70°F). "Bad" air (perhaps caused by depletion of oxygen by oxidation) is present, but apparently not a major problem.

Figure 4 illustrates sampled water quality, and may provide some clues regarding the nature of the warm waters. The field pH values are normal for natural waters. The more basic lab values (perhaps caused by carbonate precipitation) suggest a buffering effect by the bicarbonate in solution. Thus, the H+ ion produced by sulphide oxidation is absorbed by carbonate, preventing the water from being acidic. The bicarbonate and sulfate in solution are apparently inversely related in the Lake City mine waters. This again may indicate sulfide oxidation, since as sulfate is produced, bicarbonate is altered to carbonic acid. The high iron and manganese content is probably due to oxidation of pyrite.

Sulfide oxidation is a complex natural process which can only be approximated by equation. Atmospheric oxygen is the strongest oxidizing reagent in the natural environment, but water serves as a catalyst for some reactions. Sato (1960) has shown that water may be oxidized in trace amounts to hydrogen peroxide, which serves as the primary reagent. The following sample equations approximate exothermic reactions that may be occurring at Lake City, given the ores present, and the oxides found in the gossans. Enthalpy changes for the reactions are included (from Krauskopf, 1979, and Garrels and Christ, 1965) to demonstrate heat production.

ΔH^o_o = Enthalpy change of each component
$\Delta H^o r$ = Enthalpy change of each reaction

Equation 1.

$$\begin{array}{lccccccccc} & 2FeS_2 & + & 15/2\ O_2 & + & 4H_2O & \rightleftharpoons & Fe_2O_3 & + & 4SO_4^{2-} & + & 8H^+ \\ \Delta H^o_o = & 2(-40.5) & & 15/2\ O_2 & & 4(-68.32) & & (-196.8) & & 4(-216.9) & & \end{array}$$

$\Delta H^o r = -710.12$ Kcal/mole

Equation 2.

$$\begin{array}{lccccccc} & PbS & + & 4H_2O_2 & \rightleftharpoons & PbSO_4 & + & 4H_2O \\ \Delta H^o_o = & (-22.5) & & 4(-45.68) & & (-219.5) & & 4(-68.32) \end{array}$$

$\Delta H^o r = -287.56$ Kcal/mole

Equation 3.

$$\begin{array}{lcccccccccccc} & PbS & + & H_2O & + & CO_2 & + & 2O_2 & \rightleftharpoons & PbCO_3 & + & SO_4^{2-} & + & 2H^+ \\ \Delta H^o_o = & (-22.5) & & (-68.32) & & (-94.05) & & & & (-167.3) & & (-216.9) & & \end{array}$$

$\Delta H^o r = -199.33$ Kcal/mole

Equation 4.

$$\begin{array}{lcccccccccccccc} & ZnS & + & 2Fe^{3+} & + & 3SO_4^{2-} & + & 3/2\ O_2 & + & H_2O_2 & \rightleftharpoons & Zn^{2+} & 2Fe^{2+} & 4SO_4^{2-} & + & 2H^+ \\ \Delta H^o_o = & (-48.2) & & 2(-11.4) & & 3(-216.9) & & & & (-68.32) & & (-36.4) & 2(-21) & 4(-216.9) & & \end{array}$$

$\Delta H^o r = -167.38$ Kcal/mole

Equation 5.

$$\begin{array}{lcccccccc} & MoS_2 & + & 11/2\ O_2 & \rightleftharpoons & MoO_3 & + & 2SO_4^{2-} \\ \Delta H^o_o = & (-55.5) & & & & (-180.3) & & 2(-216.9) \end{array}$$

$\Delta H^o r = -558.6$ Kcal/mole

Equation 6.

$$\begin{array}{lcccccccccccc} & Zn^{2+} & + & SO_4^{2-} & + & CaCO_3 & + & 2H_2O & \rightleftharpoons & CaSO_4 \cdot 2H_2O & + & ZnCO_3 \\ \Delta H^o_o = & (-36.4) & + & (-216.9) & + & (-288.3) & & 2(-68.32) & & (-483.1) & & (-194.2) \end{array}$$

$\Delta H^o r = +0.99$ Kcal/mole

Formulas of mineral used:

FeS_2	Pyrite	$PbCO_3$	Cerussite	$CaSO_4$	Gypsum
Fe_2O_3	Hematite	ZnS	Sphalerite	$ZnCO_3$	Smithsonite
PbS	Galena	MoS_2	Molybdenite		
H_2O_2	Hydrogen Peroxide	MoO_3	Molybdite		
$PbSO_4$	Anglesite	$CaCO_3$	Calcite		

Cripple Creek

Evidence of typical geothermal processes is less apparent at Cripple Creek. At an elevation of about 9,500 feet (2,896 m), recharge through the Precambrian granite is probably quite limited. Zacharakis (1981) has estimated a near normal heat flow of 80 mw/m2 for the area. Some warm water convection may be occurring within the crater, but unless very recent intrusions have been emplaced following volcanism, the volcano should be too old to produce a high geothermal gradient. Denny and others (1930) and Lindgren and Ransome (1906) spoke of normal gradients measured in several mines (1.7°F/100 ft, 13°C/Km), with a high temperature of 83°F (28°C) at the 30 level of the Portland mine. No warm springs are evident, but a cold spring to the east (George and others, 1920) is high in silica, which could indicate that the water was hot at depth. The presence of cinnabar and native sulphur (Sharps, 1965) is significant, but these minerals may simply be well preserved, older epithermal deposits.

Temperature anomalies were recorded by Denny and others (1930) in the Cripple Creek mines. On the 8 level of the Midget mine, a temperature of 96.5°F (dry bulb) (36°C) was recorded by them, while temperatures at the 7 and 9 levels were around 65°F (18°C). Any references to heat in the mines in the literature refer to warm air, or mine walls, rather than water. There is no correlation between depth of the mines and temperature anomalies, and some of the warm mines are quite shallow.

The dangerous gas problem at the Cripple Creek mines has been discussed by many. Lindgren and Ransome (1905, 1906) and McCarn (1894) suggested that the gases are "the last exhalations from the throat of the extinct Cripple Creek volcano." However, careful experiments and analyses done by Denny and others (1930) showed that the gas usually has a composition that would be expected of ordinary air with the oxygen removed. This led them to the conclusion that the mine gas is produced by the oxidation of sulfides. No empirical correlation of temperature and gas could be made, however.

The waters are of a calcium-sulfate type, as shown in Figure 4. The large difference between field and lab pH is once again evidence for carbonate buffering. The Roosevelt Tunnel water is apparently similar to water from the Carlton Tunnel, but more diluted. Dilution may account for the temperature difference also, although some warmth in the deep Carlton Tunnel may be due to geothermal gradient.

The comprehensive report by Lindgren and Ransome (1906) lists over 50 carbonates, oxides, sulphates, and silicates which could be produced from oxidation of primary minerals. In addition to the equations written for the Lake City mines, some further, more unusual reactions apparently occur at Cripple Creek. Equation 6 represents a later stage reaction. Many other reactions probably take place which are not represented here.

Lindgren and Ransome (1906) reported witnessing the alteration of molybdenite to molybdite in air, which is the basis for Equation 5. Gypsum and calcite are quite common in the veins, so Equation 6 may be reasonable. Lindgren and Ransome (1906) also mention oxidation of calaverite in air.

CONCLUSIONS

Strong cases can be made for both exothermic reactions, and geothermal phenomena providing the heat at Lake City. Geothermal gradients may be higher than normal at this site, but sulfide oxidation is certainly taking place and probably providing some heat.

Several clues provided indirectly by water and air problems at Cripple Creek suggest sulphide oxidation may cause the high temperatures in the mines. These facts are summarized as follows:

1.) "Bad" air: Denny and others (1930) showed convincingly that unbreathable air in the mines is probably due to extensive oxidation of sulphides. Charlie Carlton (oral comm., 1982) indicated that miners say "warm air is bad air" in this district.

2.) High, "standing" water: The original water table ranged from 9500 to 9700 feet in elevation. Locals say that the warm mines were not particularly hot in the past (Charles Carlton, oral comm., 1981). This suggests that trapped, unaerated water was slowing exothermic reactions in the sulphide veins, until the water was drained by the two tunnels. Further, all warm mines known are in the topographically lowest portion of the crater, where the water level was highest. Lindgren and Ransome (1906) mention rather deep, oxidized telluride minerals to the northeast, while near-surface, unoxidized calaverite occurred in the Beacon Hill area, near the El Paso mine (figure 2). Loughlin and Koschman (1935) suggested that some iron sulfates may be carried down and reprecipitated as pyrite and marcasite in the deeper, reducing zone within the groundwater.

Equations 7 and 8 below illustrate a potential retarding effect of water low in dissolved oxygen.

G r = Free energy of the reaction.

Equation 7.

PbS + 4H O PbSO + 4H O
Go = (-23.6) 4(-31.27) (-194.4) 4(56.69)
G r = -271.68 Kcal/mole

PbS	Galena	PbSO	Anglesite
H O	Hydrogen Peroxide		

H O represents aerated water. Reaction goes to completion, releasing energy

Equation 8.

Go = (-23.6) 4(-56.59) (-194.4)
G r = +55.96 Kcal/mole

Reaction will not occur without energy input.

3.) Localized temperature anomalies: Lindgren and Ransome (1906) mention a temperature change of several degrees fahrenheit within 100 feet (30 m) horizontally in a tunnel. Alex Paul, geologist for the Ajax Mine (oral comm., 1981), mentioned much cooler mines adjacent to and deeper than the steaming Camella shaft.

4.) High negative enthalpy: The equations written should all go quickly to completion and produce heat (except Eq. 6) due to the extreme negative values for the reaction enthalpy changes. Also, Lindgren and Ransome (1906) mention witnessing several "energetic" reactions upon exposing sulfides to air. High temperatures are not uncommon in sulfide mines, and fires have even been reported due to exothermic reactions (Ogden Tweto, oral comm., 1982).

These factors suggest that the heat in Cripple Creek mines may be due to sulfide oxidation, after a long period of reducing conditions. The large amount of timber required for mining in the loose volcanic breccia may also provide "fuel" for oxidation (Ogden Tweto, oral comm., 1982). Upon draining stagnant water, the exposed sulphides may have begun oxidizing to depth quickly. Much of the heat in the Lake City mines is probably due to sulfide oxidation also, although favorable conditions exist for typical geothermal energy processes.

Further work should be done to determine the heat source and amount of heat at both of these sites, but particularly at Cripple Creek. A useful method may be to examine sulfur isotope fractionation due to kinetic effects during oxidation as described by Ohmoto and Rye in Barnes (1979). Careful dating of late-stage hydrothermal activity is also recommended.

Regardless of the heat source the phenomena of these areas may be classified as geothermal energy, in a broad sense. The energy may be harnessed in much the same way as geothermal energy is developed today.

References

Barnes, H. L., ed., 1979, Geochemistry of hydrothermal ore deposits, 2nd edition: John Wiley and Sons, Inc., 798 p.

Denny, E. H., Marshall, K. C., Fieldner, A. C., 1930, Rock-strata gases of the Cripple Creek District, and their effect on mining: U.S. Bur. Mines Bull. 317, p. 1-64.

Garrels, R. M., and Christ, C. L., 1965, Solution, minerals, and equilibria: Harper & Row, 450 p.

George, R. D., Curtis, H. A., Lester, O. C., Crook, J. K., and Yeo, J. M., 1920, Mineral waters of Colorado: Colorado Geol. Survey Bull. 11, 474 p.

Irving, J. D., and Bancroft, H., 1911, Geology and ore deposits near Lake City, Colorado: U.S. Geol. Survey Bull. 478, 123 p.

Krauskopf, K.B., 1979, Introduction to geochemistry: McGraw-Hill Book Co., N.Y., N.Y., 721 p.

Lindgren, W., and Ransome, F. L., 1905, The geological resurvey of the Cripple Creek district, Colorado: U.S. Geol. Survey Bull. 260, p. 85-98.

______1906, Geology and gold deposits of the Cripple Creek district, Colorado: U.S. Geol. Survey Prof. Paper 54, 516 p.

Lipman, P. W., 1976, Geologic map of the Lake City Caldera area, western San Juan Mountains, Southwestern Colorado: U.S. Geol. Survey Misc. Investigations Series, Map I-962.

Loughlin, G. F., and Koschmann, A. H., 1935, Geology and ore deposits of the Cripple Creek district, Colorado: Colorado Scientific Society Proceedings, v. 13, no. 6, 435 p.

McCarn, H. L., 1894, Notes on the geology of the gold field of Cripple Creek, Colorado: Science (A.A.A.S.), v. 23, p. 31-35.

Sato, M., 1960, Oxidation of sulfide minerals at 25°C: Economic Geology, v. 55, p. 1202-1231.

Sharps, T. I., 1965, Sulfur deposits in Colorado: Colorado School of Mines Mining Industry Bulletin, v. 8, no. 6, p. 1-8.

Steven, T. A., and Lipman, P. W., 1976, Calderas of the San Juan Volcanic Field, Southwestern Colorado: U.S. Geol. Survey Professional Paper 958, 35 p.

Wobus, R. A., Epis, R. C., and Scott, G. R., 1976, Reconnaissance geologic map of the Cripple Creek - Pikes Peak area, Teller, Fremont, and El Paso Counties, Colorado: U.S. Geol. Survey Map MF-805.

Wolf, H. J., and Patton, H. B., 1915, Preliminary report on the Cresson gold strike at Cripple Creek, Colorado: Colorado School of Mines Quarterly, v. 19, no. 4, p. 1-15.

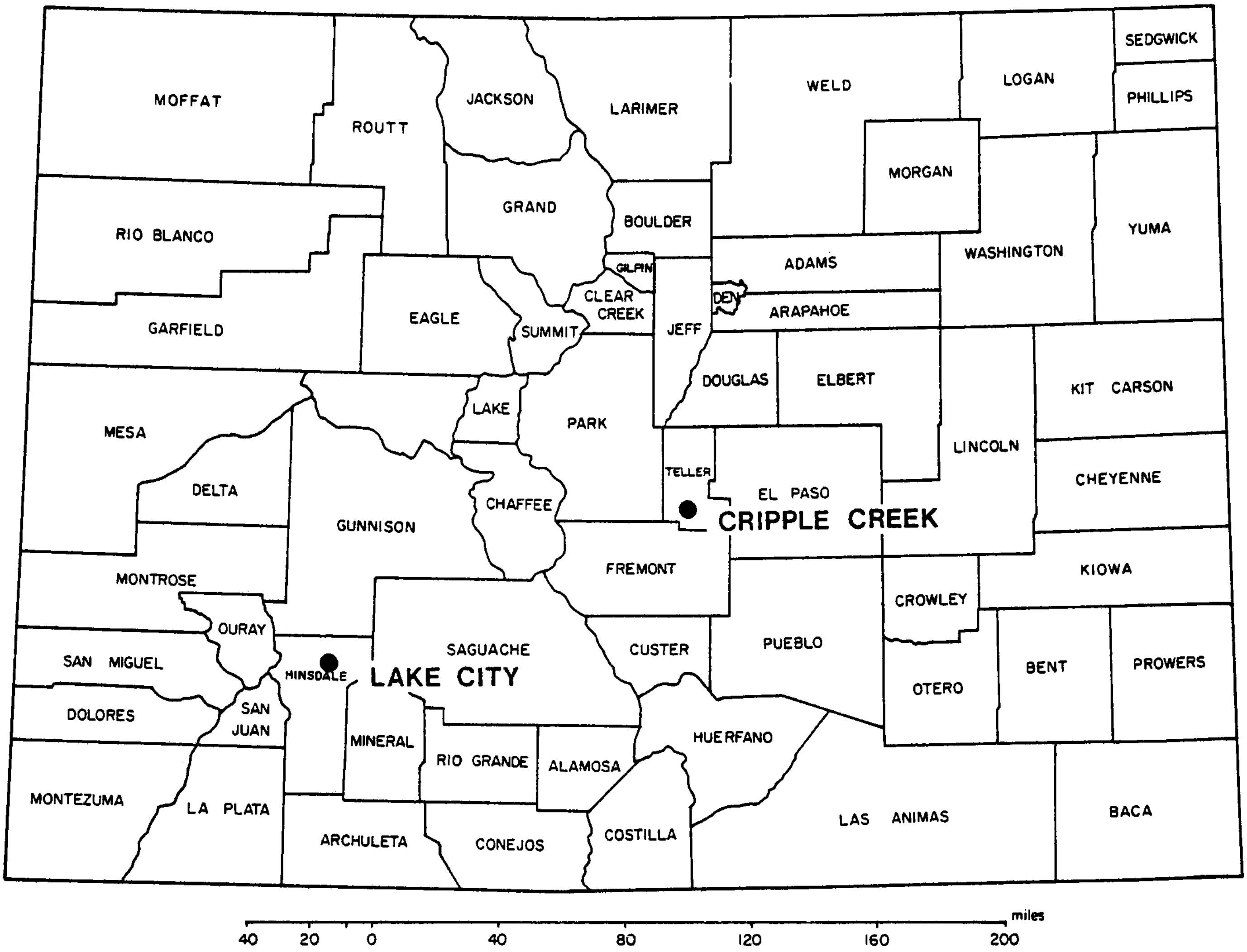


Figure 1. Index map.

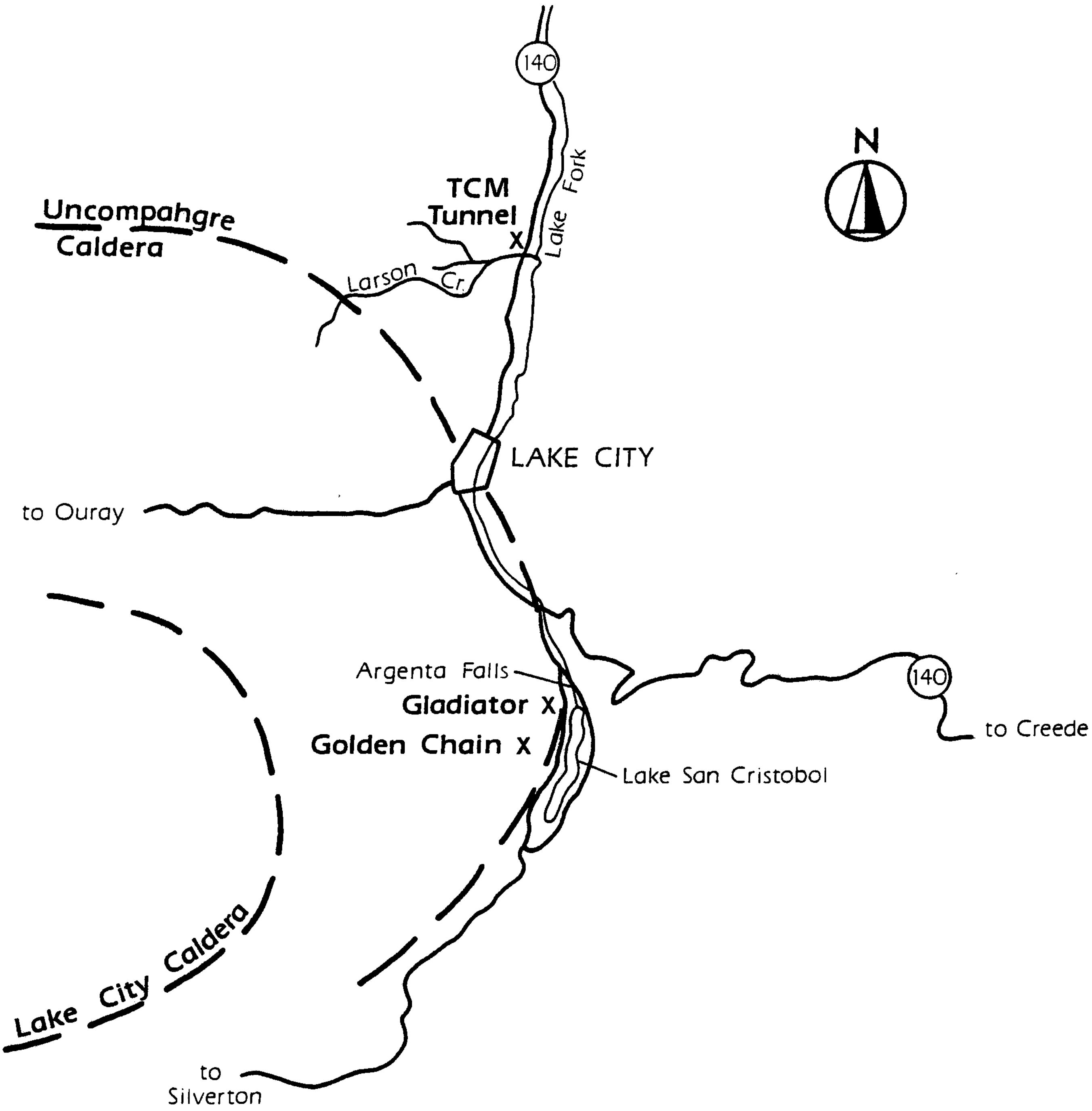
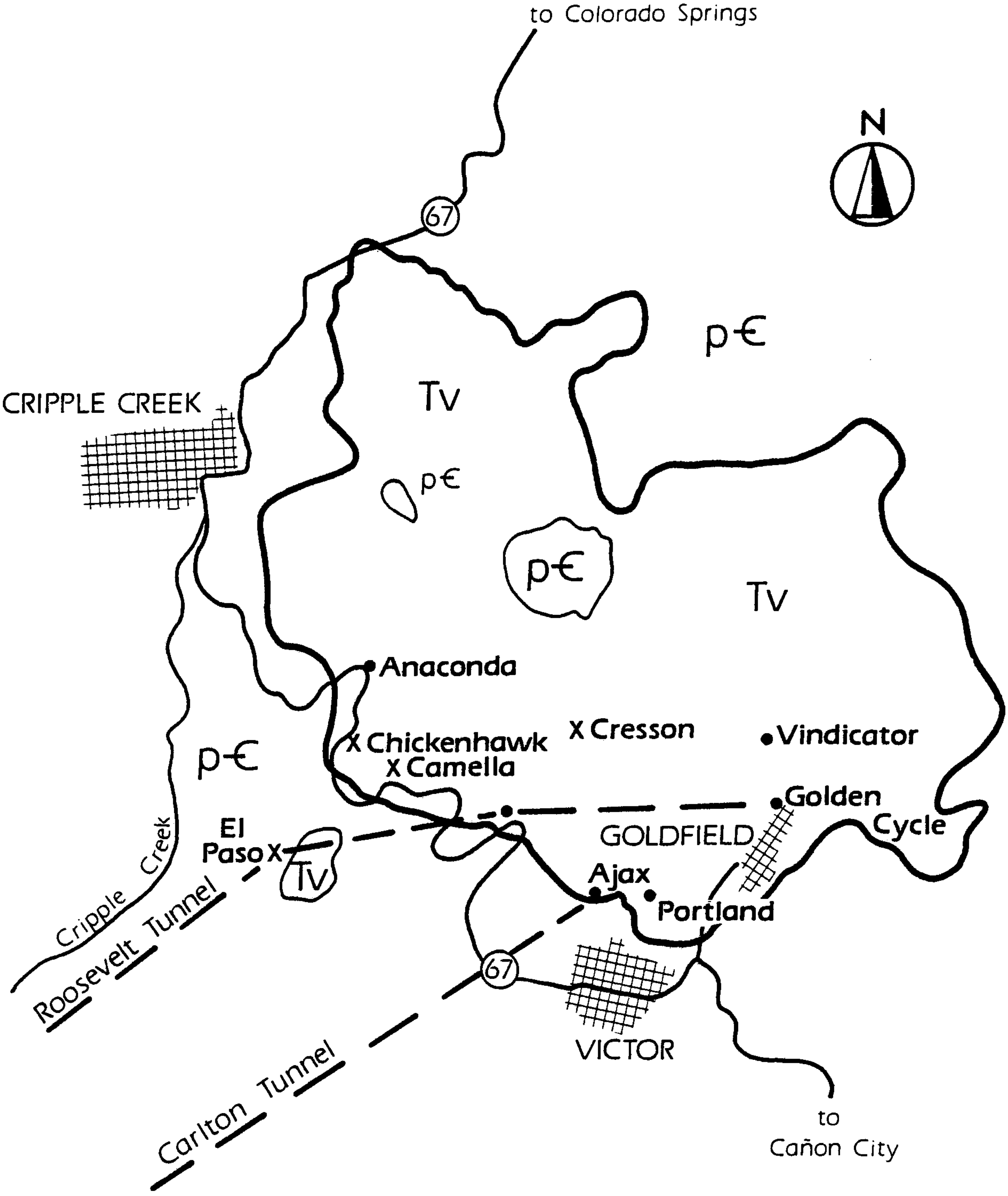


Figure 2. Location of mines sampled--Lake City area.



EXPLANATION

p€ Precambrian rocks
Tv Tertiary volcanic rocks
● Mines of interest
X Warm mines
╱ Crater rim

Figure 3. Warm mines at Cripple Creek.

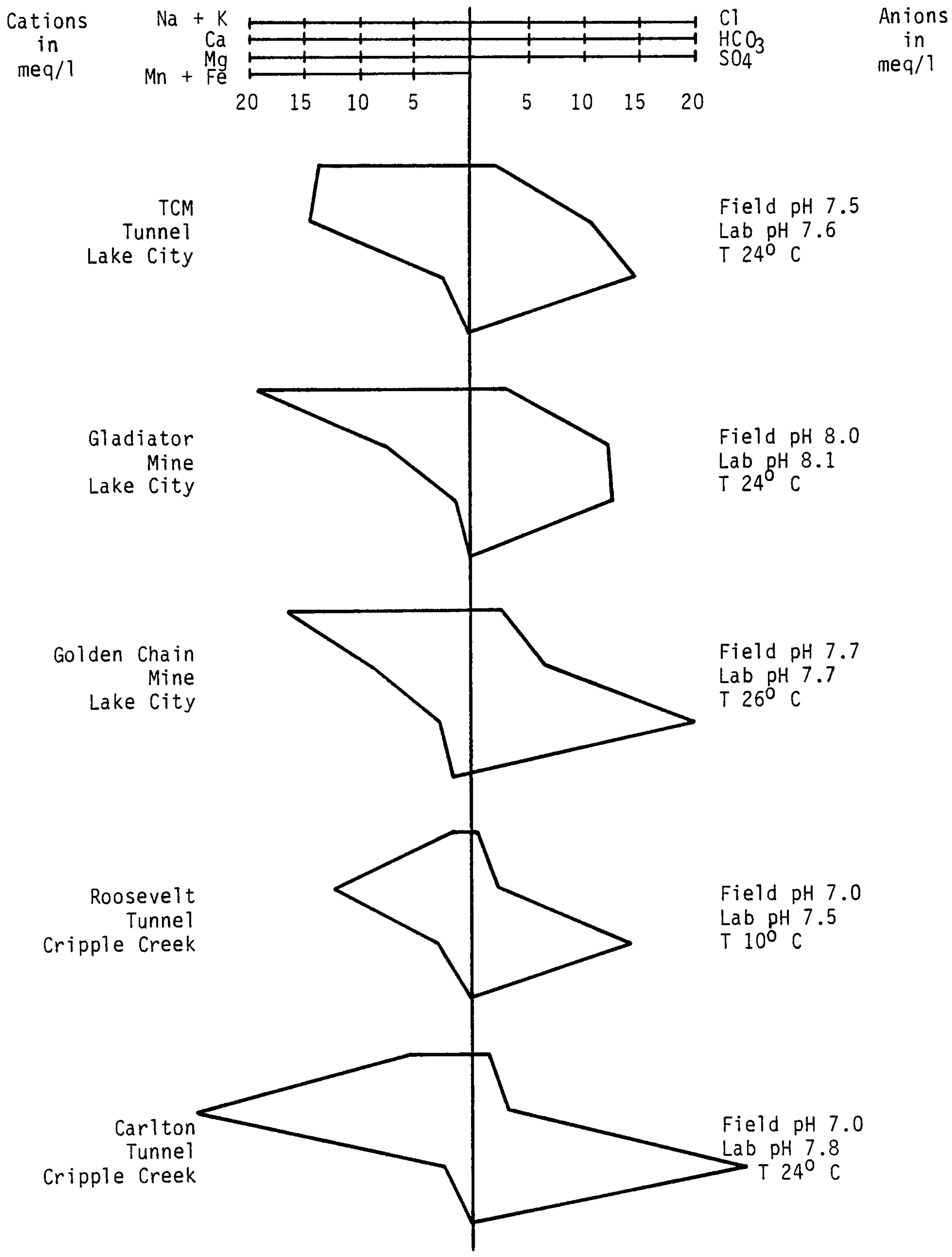


Figure 4. Stiff diagram of warm mine waters at Cripple Creek and Lake City.