GOLD AND SILVER DEPOSITS IN COLORADO SYMPOSIUM

ABSTRACTS, POSTERS AND PROGRAM

BERTHOUD HALL, COLORADO SCHOOL OF MINES
GOLDEN, COLORADO
JULY 20-24, 2017

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Principle Editors:

Lewis C. Kleinhans
Mary L. Little
Peter J. Modreski

Sponsors:

Colorado School of Mines Geology Museum
Denver Regional Geologists' Society
Friends of the Colorado School of Mines Geology Museum
Friends of Mineralogy – Colorado Chapter

Front Cover: Breckenridge wire gold specimen (photo credit Jeff Scovil). Cripple Creek Open Pit Mine panorama, March 10, 2017 (photo credit Mary Little). Design by Lew Kleinhans.

Back Cover: The Mineral Industry Timeline – *Exploration* (old gold panner); *Discovery* (Cresson "Vug" from Cresson Mine, Cripple Creek); *Development* (Cripple Creek Open Pit Mine); *Production* (gold bullion refined from AngloGold Ashanti Cripple Creek dore and used to produce the gold leaf that was applied to the top of the Colorado Capital Building. Design by Lew Kleinhans and Jim Paschis.

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Symposium Planning Committee Members:

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Additional thanks to: Bill Rehrig and Jim Piper.

Acknowledgements:
Far too many contributors participated in the making of this symposium than can be mentioned here. Notwithstanding, the Planning Committee would like to acknowledge and express appreciation for endorsements from the Colorado Geological Survey, the Colorado Mining Association, the Colorado Department of Natural Resources and the Colorado Division of Mine Safety and Reclamation.
Field trip leaders and organizers would also like to acknowledge the following for their contributions to the field trip efforts: Pat Farr, Dick Nielsen, Matt Collins, Matt Schreiner, and Jay Parker.

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WELCOME

Welcome to the 2017 Gold and Silver Deposits of Colorado Symposium. This conference will focus on precious metal deposits that occur in the Colorado Mineral Belt, which extends along the Front Range and as far west as Aspen, Colorado.

The Symposium's program includes a number of talks by experts which focus on the genesis of gold and silver deposits, the current economic environment for precious metals, Colorado's deep mining history and detailed economic geology of particular mines.

Eight field trips are planned to various sites and mines, some of which have not been accessible to the public for a number of years. The Field Trip Guide, to accompany the field trips, provides detailed historical as well as geological background which is as fascinating today as ever. We are fortunate to have access to key mining districts where considerable wealth was created in the 1800s and 1900s, and which were key elements to build Denver and the railroad which would eventually reach the west coast.. These include: Jamestown, Caribou, Cripple Creek, Central City and Idaho Springs, Georgetown, Aspen, the Alma region, and Leadville.

The Concept, planning and organization of the Symposium was all carried out by volunteers from four organizations: the Colorado School of Mines Geology Museum, Friends of the Colorado School of Mines Geology Museum, the Denver Regional Exploration Geologists Society and the Friends o Mineraalogy, Colorado Chapter.

The **Geology Museum** has the best mineral display in the state of Colorado and other Western states. It will be open to Symposium participants on the Opening Night (June 20th) and at other times. The collection dates back to the 1880s with specimens donated by or acquired from the pioneers of Colorado mineralogy.

The **Friends of the Colorado School of Mines Geology Museum** is a support group, formed in 2009, dedicated to promoting and assisting in the maintenance and expansion of the Geology Museum.

The **Friends of Mineralogy, Colorado Chapter** is a service organization that since 1977 has continued its tradition of planning symposiums and presentations dedicated to increasing the knowledge about minerals and their deposits.

The **Denver Region Exploration Geologists Society** is an Organization of mining and mineral exploration professionals with the mandate to meet monthly to cultivate mineral deposits-related presentations and professional camaraderie. Meetings are held on the first Monday of evey month except during the summer months. In addition, DREGS helps sponsor activities of students at the Colorado School of Mines and organizes independent field trips to areas of interest.

Program Schedule

Thursday, July 20, 2017 - Registration, Badge/ Package Pickup and Icebreaker Reception

5:00 – 8:00 p.m. OPENING RECEPTION at the CSM Geology Museum, Colorado School of Mines, 1310 Maple Street, Golden, CO.

Pick up Field Trip Information and Registration Packets at the Reception. You must pick up your Field Trip registration and Badge (or contact the Field Trip Leader, if meeting at site.)

PARKING: Parking is free on campus on the weekends, and from 5PM – 7AM on weekdays. On Friday and Monday at metered and spaces, fieldtrip participants can park for free using a code provided by their fieldtrip leader. Others must pay. In both cases, place ticket stub on your car dashboard. In town, free parking is available at various locations. In the Golden business district, free parking is available for 2 hour segments as indicated by the signs.

The talks on Saturday and Sunday will be at Berthoud Hall (#7 on the Map). The closest parking lot to Berthoud is Lot D, due W of the Student Center. This is also convenient to the CSM Geology Museum for Thursday's Reception and Registration. A small number of spots are available in Lots north and south of the Museum.

Friday, July 21, 2017 – Field Trips (see field trip guidebook and leaders)

Field Trip A ***Boulder County Trip # 1 – Jamestown***
Leader: Jim Paschis (jpaschis@yahoo.com; 303-817-6209)

Field Trip C ***Georgetown/ Empire Area***
Leader: Steve Zahony (szahony@comcast.net; 303-903-4078)

Field Trip E ***Alma/Airplay Area***
Leaders: L.J. Karr (ljkarr@comcast.net; 720-878-2552), or Dean Misantoni (dmisantoni@hotmail.com; 719-839-5008).

Field Trip G ***Central City/Blackhawk/ Idaho Springs***
Leader: Larry James (jamesgeoa@cs.com; 303-905-3754) or Jim Piper (geopros@clanmurray.org; 303-932-1209).

Program Schedule

Saturday, July 22, 2017 Presentations *(all presentation times inclusive of Q & A)*

(PLEASE NOTE: All Symposium talks will be in Berthoud Hall, Room 241, 2nd floor)

7:30 – 8:30 a.m.	Walk-in registration (Berthoud Hall, 2nd Floor Hallway)
8:00 – 5:00 p.m.	Poster papers open (Berthoud Hall, Room 243, across from 241)

8:15 a.m.	**Welcome, Opening Remarks & Announcements** (Berthoud Hall 241)
8:30 a.m.	**Richard Goldfarb**: The Origin of Gold Deposits. (**Keynote Speaker**)
9:05 a.m.	**Bill Atkinson**: How Gold Deposits Form: The Chemistry of Transport and Deposition.
9:40 a.m.	**Peter Bojtos** – Gold: Its past, the Present, and Its Future.
10:10 a.m.	Coffee break (20 min.)
10:30 a.m.	**Beth Simmons**: Colorado Gold and Silver Before 1859.
11:00 a.m.	**Ed Raines**: The Frederick Mayer Collection of Colorado Territorial Gold Coins, a History of the Coins and Coiners.
11:15 a.m.	**Stan Dempsey**: Mining Districts of the Northern Half of the Colorado Mineral Belt.
11:50 a.m.	**Lisa Dunn**: Clear Creek County's Mining Districts: Discovering Missing History from Primary Source Materials.

(12:00-2:00 and 3:00-5:00 PM: Special Drop-In Open House -Russell L. & Lyn Wood Mining History Archives, CSM Arthur Lakes Library, Room 184,downstairs, follow signs)

12:25 p.m.	Lunch break (80 min.)
1:45 p.m.	**Tommy Thompson**: The Precious-base Metal Manto Deposits of the Colorado Mineral Belt at Leadville, Gilman, Kokomo, & Aspen.
2:20p.m.	**Ralph Stegen**: Silver-rich Manto Deposits of Aspen, Colorado: Characteristics, discovery, and mining history.
2:55p.m.	**Vince Matthews**: Does the "Colorado Mineral Belt" Best Describe the Distribution of Tertiary Epithermal Ore Deposits in Colorado?
3:30 p.m.	Afternoon break + Poster Session (soft drinks, beer, snacks)
5:30 p.m.	Social hour begins at Table Mountain Inn. Pre-registration required.
6:30 p.m.	Dinner Banquet. Table Mountain Inn, 1310 Washington Ave., Golden. ("Kachina Fajita Buffet" - beef & chicken fajita strips, cheese enchiladas, southwestern Caesar salad, and much more). Pre-registration required.
7:45 p.m.	After-dinner presentation**: Ed Raines**: Silver as a precious metal: From the Greeks to today.

Program Schedule

Sunday, July 23, 2017 Presentations *(all presentation times inclusive of Q & A)*

(PLEASE NOTE: All Symposium talks will be in Berthoud Hall, Room 241, 2nd floor)

8:00 – 8:45 a.m. Walk-in registration (Berthoud Hall, 2nd Floor Hallway)
8:00 – 5:00 p.m. Poster papers open (Berthoud Hall, Room 243)

8:45 a.m. **Opening Remarks & Announcements**

9:00 a.m. **Paul Bartos**: The Breckenridge Mining District, Summit County, Colorado.
9:35 a.m. **Jim Paschis**: Cash Mine: 3rd level Mining, Milling, and Ore Microscopy.

10:10 Coffee break (20 min.)

10:30 a.m. **Larry James**: The Central City Mining district, Gilpin County, Colorado.
11:05 a.m. **Karen Wenrich**: The Sweet Home Mine—Silver to Rhodochrosite.

11:40 Lunch break (90 min.)

1:10 p.m. **Steve Veatch**: The World's Greatest Gold Camp: A Concise History of the Cripple Creek Mining District.
1:45 p.m. **Bob Carnein**: An Updated Introduction to Cripple Creek Geology and Minerals.
2:20 p.m. **Doug White**: Newmont North America: Cripple Creek.

3:05 p.m. Afternoon break (20 min.)

3:25 p.m. **Bruce Geller**: A Cursory Description of Telluride Occurrences in Boulder County, Colorado and Exploration Guides: Classic Examples of Epithermal Telluride Deposits in Boulder's Backyard.
4:00 p.m. **Pete Modreski** – A Mineralogical Look at Colorado's Gold and Silver Production.

4:30 p.m. **Closing Remarks**

Program Schedule

Poster Papers (Saturday & Sunday, Berthoud Hall Room 243)

Lee Alford and **Alexander Gysi** (Colorado School of Mines): Hydrothermal Evolution of Au-bearing Quartz-pyrite Veins and their Association to Base Metal Veins in Central City, Colorado.

Matthew D. Dye (Colorado School of Mines), **Nigel M. Kelly** (University of Colorado), **Thomas Monecke** (Colorado School of Mines), and **Karen D. Kelley** (U.S. Geological Survey): A Revised Paragenetic History of Gold Mineralizing Events at the Cripple Creek Gold-Telluride Deposit, Colorado.

Mario Guzman and **Thomas Monecke** (Colorado School of Mines): Mineralogy, Petrography and Mineral Chemistry of the North Amethyst Epithermal (Au-Ag) Deposit, Creede, Colorado: Insights into Precious and Base Metal Mineralization.

Irene Kadel-Harder and **Peter Price** (Front Range Community College): Remote Sensing of Alteration Signatures Associated with Epithermal Mineral Deposits using WorldView-3, ASTER, Landsat, and Hyperion Data.

Tommy B. Thompson: Theses/dissertations Completed along the Colorado Mineral Belt & Cripple Creek District.

Subaru Tsuruoka, Thomas Monecke, and **T. James Reynolds** (Colorado School of Mines, and Fluid, Inc.): Mineral Paragenesis of the Summitville High-sulfidation Epithermal Cu-Au Mineralization: Nature of the Mineralizing Hydrothermal Fluids.

Monday, July 24, 2017 – Field Trips (see field trip guidebook and leaders)

Field Trip B	***Boulder County Trip #2 – Caribou*** Leader: Steve Zahony (szahony@comcast.net; 303-903-4078)
Field Trip D	***Leadville*** Leader: Tommy Thompson (thompsontommyt@aol.com; 775-772-7899)
Field Trip F	***Cripple Creek/ Victor*** Leader: Bob Carnein (ccarnein@gmail.com; 719-687-2739) or Steve Veach (steven.veatch@gmail.com; 719-231-1475)
Field Trip H	***Aspen/ Smuggler Mine*** Leader: Ralph Stegan (rstegan@fmi.com; 520-429-4418)

The Origin of Gold Deposits

Richard J. Goldfarb
Colorado School of Mines

Global gold production today continues to be about 3200 tonnes per year, significantly below the growing global demand and stressing the need for new discoveries. Thus, gold continues to be the main target for explorationists, comprising about 40% of annual global exploration expenditures. Half a century ago, two-thirds of the World's gold was being recovered from the great Witwatersrand paleoplacers of South Africa; today they account for about just 5% of global production. Other deposit types now are making up the difference, commonly mined as low-grade, high-tonnage types of operations. An improved understanding of how gold deposits form is essential to target new deposits, particularly in the search for the more difficult ores that may be hidden under shallow cover.

Exclusive of placer and paleoplacer gold deposits, slightly more than 40% of our gold is mined from orogenic gold deposits, and slightly more than 40% from epithermal-porphyry-skarn deposits. Orogenic gold deposits are structurally controlled gold deposits that are inherent to metamorphic terranes and are essentially part of the regional metamorphic process. During the greenschist to amphibolite transition, 3-4% of the rock volume may change to the fluid phase (aqueous-carbonic metamorphic fluid). Metals and sulfur are released during devolatilization of diagenetic pyrite, and the crustally-derived fluids will be focused into major structures, and move upward during changing stresses and regional uplift. Gold ores will be deposited over dozens of seismic events at depths of anywhere between 3 and 20 km.

The prograde metamorphic heating may be controlled by a variety of processes in different active margin settings, including processes of crustal thickening, crustal thinning, ridge subduction, and slab devolatilization. These deposits are represented across geological time. In contrast, gold-rich porphyry, skarn, and epithermal deposits in arc environments form from fluids exsolved from shallow magmas and (or) from meteoric fluids convecting around such shallowly emplaced plutonic bodies. Gold-rich porphyries are typically formed from oxidized magmas in oceanic arcs due to the incompatible behavior of metals and volatiles which accumulate episodically, and are released at the apex of the causative intrusion. Rising acidic magmatic fluid or vapor will form higher-level, high sulfidation epithermal gold ores, whereas upwelling of near-neutral meteoric fluids will form low-sulfidation ores. These magmatic-related gold deposits may also have formed across geologic time, but known deposits are mainly of Cenozoic age, because older examples of these gold resources deposited in the upper few kilometers of crust have been lost to erosion.

In summary, despite a great deal of confusion in the literature and because many workers fail to look at the big picture, most of us agree that primary gold deposits form from crustal fluids of metamorphic (orogenic), magmatic (high sulfidation epithermal), or meteoric (low sulfidation epithermal) origin.

Other gold deposit types are globally of lesser economic significance and their genesis is less well understood. (1) Carlin-type gold deposits are of extreme economic importance in Nevada, but other economically important provinces are not recognized. Therefore, our present-day model for the origin of Carlin deposits is not a global model, but rather a model based solely for this gold deposit type in Nevada. Presently, a magmatic model is most popular for the formation of this ca. 40 Ma, shallow, replacement-style gold deposit type in unmetamorphosed(?) dirty carbonate rocks of central and northeastern Nevada. However, there are still many problems with such a model, and the importance of hydrocarbons in the ore-forming process of this deposit type needs further investigation. (2) Reduced intrusion-related gold deposits have received extensive attention in the economic geology literature in the past few decades. Unlike porphyry gold deposits that are associated with oxidized plutons, these very low grade gold-only sheeted vein systems occur in the apex of more reduced intrusions and form from aqueous-carbonic fluids exsolved at deeper (4-6 km) levels. They are poor exploration targets and Fort Knox (Alaska) may be the only economic example of this gold deposit type. (3) Iron oxide-copper-gold (IOCG) deposits are a very poorly understood group of deposits of all ages. Some of the larger examples of these probably magmatic deposits, such as Olympic Dam and Carajas, represent the only gold deposits that form in intracontinental settings during periods of continental break-up. There are actually very few unequivocal examples of IOCG deposits, as the majority of deposits classified as IOCGs are probably gold-bearing skarn deposits. Most models stress that volatiles and metals from these deposits formed over a wide range of crustal levels, which reflects enrichments in metasomatized subcontinental lithospheric mantle that is partially melted to form the causative magmas.

Biography

Richard J. Goldfarb is a senior research geologist with the Minerals Program of the U.S. Geological Survey, where he has been employed for more than 33 years. Rich's major expertise is the geochemistry and geology of ore deposits with emphasis on Phanerozoic lode gold. Much of his earlier career work was concentrated on the Tertiary gold deposits of southern Alaska. Results from this work were used to develop ore genesis models for giant gold deposits elsewhere in Alaska and in other parts of the North American Cordilleran. In recent years, Rich has conducted detailed studies on the understanding of the distribution of gold deposits through space and time, compiling the most comprehensive global description of their distribution and evaluating the controlling tectonic/geologic features. He has senior-authored and co-authored more than 200 refereed publications in economic geology. Rich has served as President of the Society of Economic Geologists, is a past Silver Medalist, International Exchange Lecturer, and Thayer Lindsley lecturer of the society, has served as chief editor of *Mineralium Deposita*, is presently on the editorial boards of *Economic Geology* and *Gondwana Research, and* was one of the co-editors of the *Economic Geology One Hundredth Anniversary Volume*. He received his BS in geology from Bucknell University, MS in hydrology from MacKay School of Mines, and PhD in geology in 1988 from the University of Colorado.

How Gold-Silver Deposits Form: The Chemistry of Transport and Deposition

W. W. Atkinson, Jr.
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Gold, silver and other heavy metals occur in the Earth's mantle in incredibly tiny traces, but they can be enriched many fold to reach the concentrations of economic ores. Perhaps the most important process of concentration is by partial melting. Most of the metals we wish to use, such as gold, silver, lead, zinc, copper and others, do not fit easily into the minerals that make up common rocks, so each time their host rock is partially melted, the heavy metals go into the melt. We can see this process on a continental scale (Figure 1).

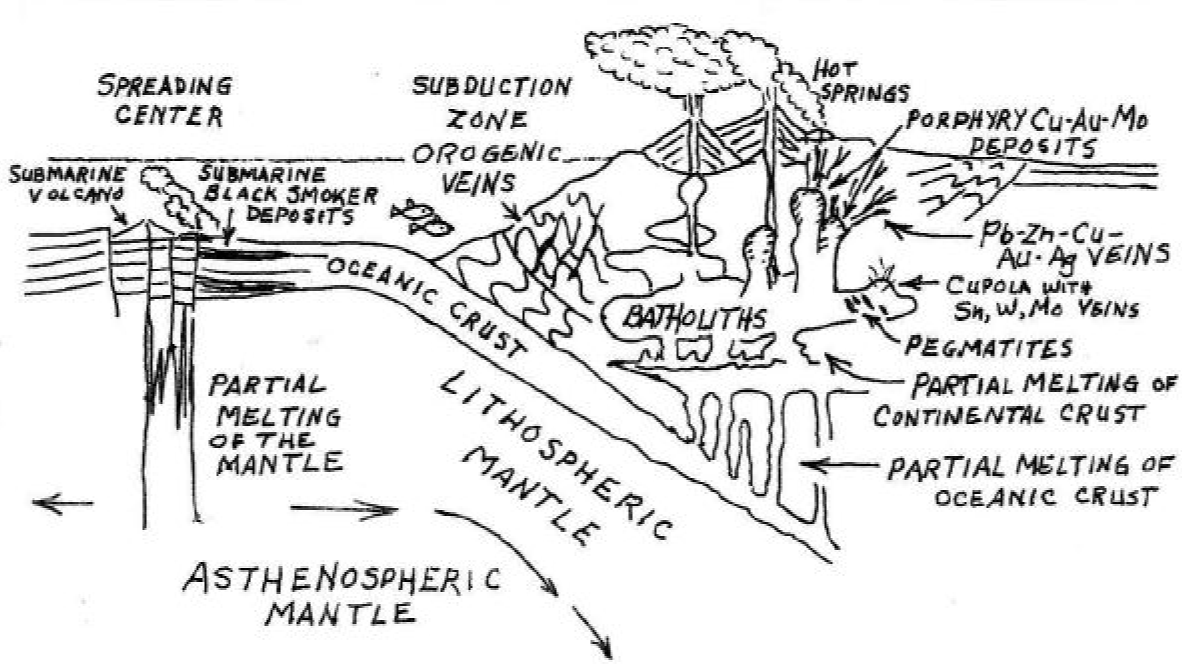


Figure 1. Plate tectonic model showing enrichment of heavy metals and sites of deposition.

The earth is being pulled apart along great rifts by convection in the plastic mantle, the oceanic spreading centers, responsible for submarine ridges of volcanoes. Pulling apart relieves high pressure at depth in the deep mantle, allowing mantle rocks to partially melt, producing basaltic magma, which flows out onto the sea floor to form the lava flows of the oceanic crust. This lava is richer in heavy metals than the original mantle rock. The continuing convection pulls oceanic crust to the continents, where it slides down under the lighter rocks, the process of subduction. It continues downward into hotter and hotter depths, where it begins to partially melt, producing new magma somewhat enriched in the heavy metals. This magma, still basaltic, rises until it reaches the continental crust, where it forms ponds, and begins to partially melt the overlying rocks. This new melt of the continental rocks has the composition of common granites and once again is richer in heavy metals than the previous melt. The granites form. huge intrusions, such as the Sierra Nevada batholith of California. Looking back a bit, we see that the oceanic lava flows have also incorporated small amounts of ocean water, containing salt and sulfur in sulfates. When the granitic melts begin to crystallize, the rock-forming minerals reject the heavy metals and most of the water, forming bubbles that rise to the tops of the intrusions. The last magma to crystallize is lighter than the just-formed granite, so that it rises to form finger-like and slab-like intrusions. The bubbles of water, rising in the fingers and slabs, are rich in salt, heavy metals and other elements that did not fit into the rock-forming minerals. The bubbles are now concentrated at the tops of the fingers of the last magma. As the last magma crystallizes, the water boils, cracks the surrounding rock and the heavy metals are carried out into the cracks to be deposited as veins. Thus we see a sequence of events that have concentrated the heavy metals into hot, saline water, a hydrothermal solution, capable of transporting the metals out into the surrounding rocks. We might imagine that all the metals will just be deposited together in the cracks, but now other processes separate the metals to form distinct zones of the different metals (Figure 2).

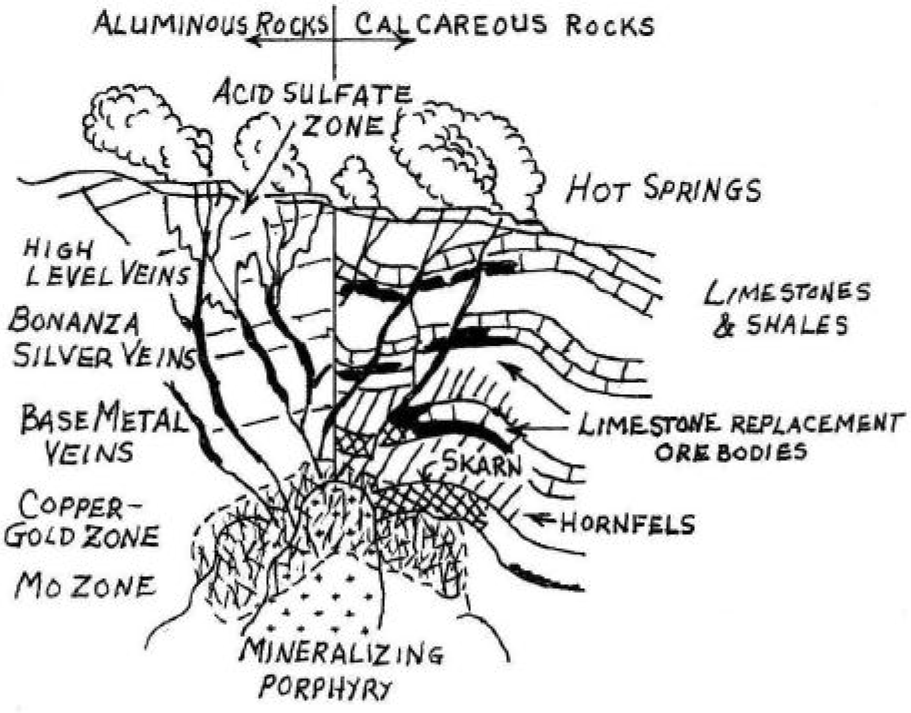


Figure 2. Type and locations of deposits above a mineralizing porphyry intrusion.

The first agent to carry the metals upward and outward through the cracks is the salt, specifically the chloride ions. They grab onto the heavy metals, forming combinations, or "complexes" in the solution, such as $AuCl_2$-, $CuCl^o$, $ZnCh_2^o$, $PbCl_2^o$ and $AgCh_2$- , that is, chloride combinations of gold, copper, zinc, lead and silver. Iron also forms such combinations, but its behavior is much more complex and it is neglected here. It happens that the combinations are sensitive to cooling, which causes them to break down to liberate the metals. The least stable complex is that of gold, followed by copper, then zinc, then lead and finally silver. As the hydrothermal solution moves away from the hot, mineralizing intrusion source, the chloride combinations cool, break down and deposit the metals in. the order given. This results in deposition of zones rich in each of the metals, in the order given (Figure 3).

Aluminous rocks, such as volcanic rocks, shales and other intrusions do not react significantly with the chloride combinations, so that cooling is the only influence on their stabilities. On the other hand, rocks containing carbonates, i.e., limestones and dolomites, contain easily available calcium, which forms a chloride complex much more stable than those of any of the heavy *metals.* Calcium *robs* the chloride, liberating the heavy metals, resulting in massive replacements of limestone by sulfides, with little regard for zoning.

This would be a nice simple scheme for explaining the zoning of metal deposits, except for the fact that gold is not usually confined to the deepest zone. 1n fact, gold often occurs in veins with lead, zinc, andsilver in many districts, such as Central City.

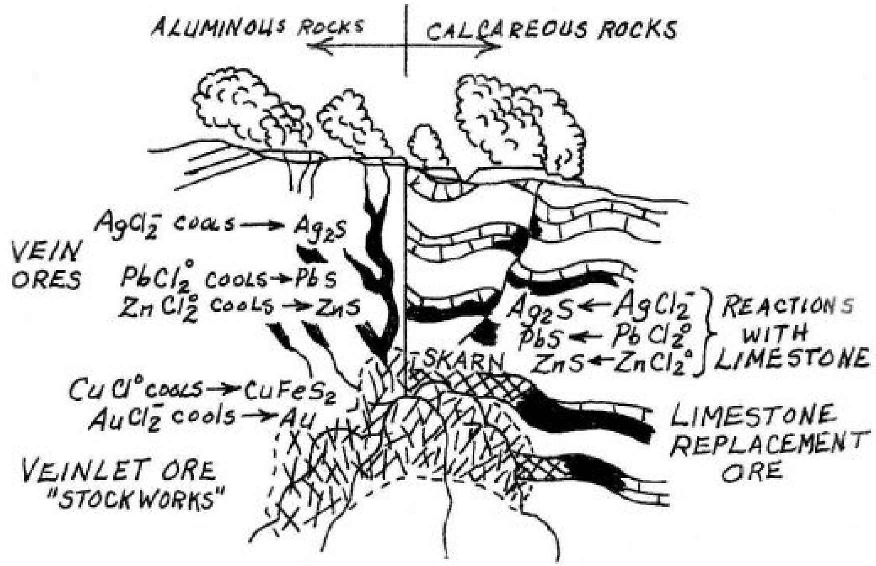


Figure 3. Deposition of metals from chloride complexes.

It also occurs in quartz veins above the lead and zinc, even up into high level veins and sometimes even into the hot springs themselves! So something else is going on. The answer is in the behavior of sulfur. Experimental work has shown that sulfur in slightly oxidized magmas occurs primarily as $S0_2$, sulfur dioxide. When the magmas cool and crystallize into rock, then cool further below 400°C, the $S0_2$ reacts abruptly with water, to form hydrogen sulfide and sulfuric acid, according to the following reaction: $4S0_2 + 4H_20 > H_2S + 3H_2S0_4$. This reaction changes the hydrothermal solution from nearly neutral, with a very low sulfide content, to one which is highly acid, altering feldspars to mica and clay, and biotite to pyrite and muscovite. For metal deposition, the H_2S provides sulfide to form chalcopyrite, sphalerite, galena, argentite and other sulfides. In the case of gold, it forms a very soluble sulfide complex, $Au(HS)_{2-}$. This combination is almost insensitive to cooling, so that is how gold can travel up a vein even to the hot spring level (Figure 4).

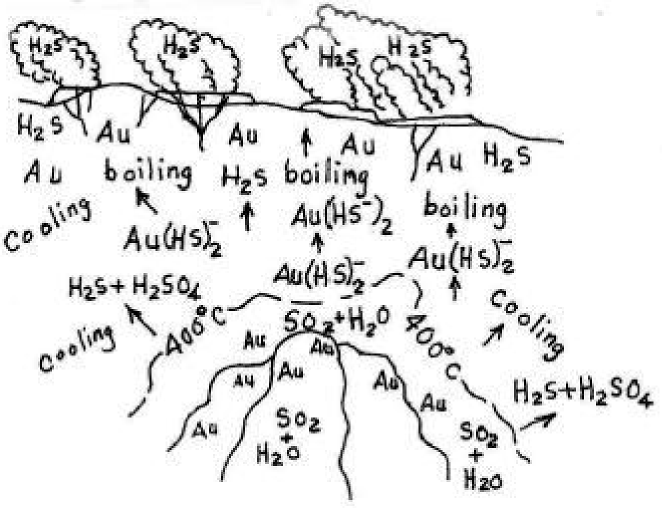


Figure 4. Behavior of sulfur in magmas, reaction $4S0_2 + 4H_20 > 3H_2S + H_2SO_4$ below

400°, transport and deposition of gold from $Au(HS)_2$ complex.

However, the distance the gold travels depends on the stability of the combination. Boiling drives off the H_2S, and it may also combine with iron in minerals in the surrounding rocks to form pyrite, depositing the gold. Where the solution cools sufficiently to decompose the lead, zinc and silver chloride complexes, the liberated metals can steal the sulfur to be deposited as sulfides, along with the gold. This is the situation with moderate to low amounts of sulfur in solution, referred to as "low sulfidation" (Figure 5).

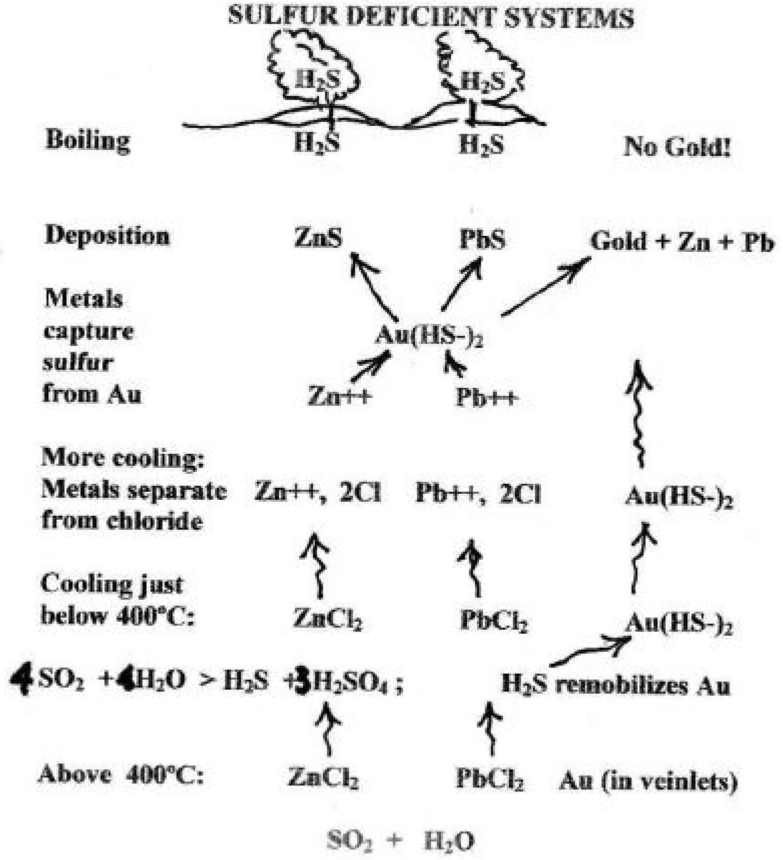


Figure 5. Deposition of Zn, Pb and Au in sulfur-deficient systems.

If the amount of sulfur in solution is high ("high sulfidation"), the gold complex will not be affected, since there is plenty of H2S to deposit the other metals as sulfides (Figure 6).

These are a poorly understood group of deposits of all ages. Some of the larger examples of these probably magmatic deposits, such as Olympic Dam and Carajas, represent the only gold deposits that form in intracontinental settings during periods of continental break-up. There are actually very few unequivocal examples of IOCG deposits, as the majority of deposits classified as IOCGs are probably gold-bearing skarn deposits.

Most models stress that volatiles and metals from these deposits formed over a wide range of crustal levels, which reflects enrichments in metasomatized subcontinental lithospheric mantle that is partially melted to form the causative magmas.

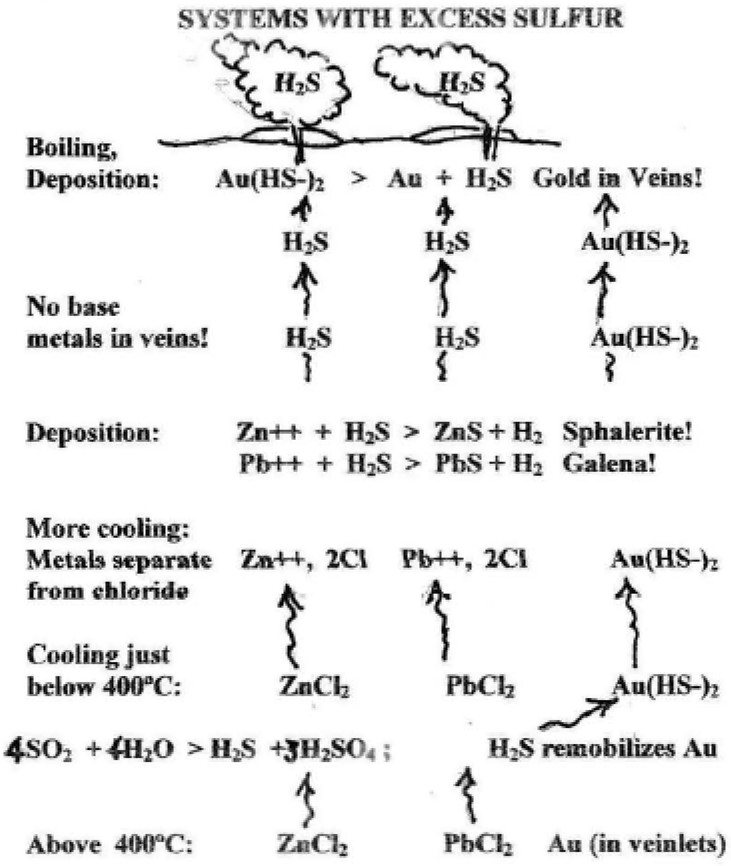


Figure 6. Deposition of Zn, Ph and Au in systems with excess sulfur.

So, the scenario goes from partial melting of the mantle, oceanic crust, and continental crust, followed by crystallization of granites. Salty water leaves the granites in the last crystallizing melt as bubbles, carrying the heavy metals as chloride combinations or complexes. Then sulfur enters the picture to carry gold as a sulfide complex, until it is broken down to deposit the other heavy metals and finally, gold.

Biography

Born in Albuquerque in 1935 and began collecting rocks & minerals in 1944. B.S. in chemistry, M.S. and Ph.D. in Geology. Work in geology: M.S. thesis - District geology, San Pedro Mts., (N.M., Pub. N.M. Bur Mines & Min. Res., 1961). Eleven in years in industry with Anaconda – Butte, Mont., Park City, Utah, Yerington, Nev., Tintic District, Utah, Carr Fork skarn, Bingham, Utah, Victoria Mine, skarn/breccia pipe, Nev., Sar Cheshmeh, Iran. Twenty-six years teaching economic geology at the University of Colorado, Boulder. Supervised 36 M.S., 17 Ph.D. theses in Colo., N.M., Ariz., Wyo. Mont., Nev. Calif., Alaska, Yukon, Mexico, Bolivia, and Chile, on porphyry Cu-Mo, skarns, Au, Ag, Pb, Zn, W epithermal deposits, etc.. Numerous consulting jobs in Quebec, Alaska, Nevada, Colorado, Mexico, Peru, Chile, and Spain and twenty-two seminars on geochemistry of gold deposits in Latin America and Spain.

Gold - Its Past, the Present and its Future

Peter Bojtos, P.Eng.
Geologist and Mining Engineer
2582 Taft Ct. Lakewood, CO 80215
peter@bojtos.com

The presentation will start by reviewing the history of gold; its origins, its cultural desirabilities and the uses that humankind has put it to.

As the presentation continues up to the present time, we will examine where the earth's patrimony of gold currently lies, how much of it has been produced and how much of it still lies in the ground; specifically where it all is at the moment both in its unmined and mined state. The presentation will also look at the current value placed on the yellow metal by peoples around the world.

Finally, the presentation will ponder over the future of gold; where it might be found, how present extraction methods could develop and what competition and competitors might lie ahead for gold.

Biography

Peter was born and raised in Yorkshire, England where he started collecting rocks, mountaineering and spelunking from his early teens. He graduated from the University of Leicester, UK in 1972 and has since gained over 45 years of worldwide experience in both the exploration and operations side of the mining industry. He has been involved with both open-pit and underground operations; primarily mining precious and base metals, uranium, iron ore and diamonds.

For the first half of his career he worked with several junior and major mining companies in Africa, Canada, USA and Central America. For the past 22 years Peter has been an independent director of numerous Canadian, US, Australian, London or European listed mining and exploration companies. Peter has lived in the Denver area for the past 25 years.

Colorado Gold & Silver before 1859

Beth Simmons, Ph.D.
cloverknoll@comcast.net

In Colorado, the rush for gold and silver started long before 1859. The Spanish were in on the earliest action, exploring northwestward from Santa Fe and north into La Plata Mountains. The French came up the Missouri River; their trappers and traders spread westward into the mountains. They must have discovered gold because, in 1748, French explorer and trapper Le Page du Pratz, author of '*Historie de la Louisiana'* wrote of a *'min d'or'* (gold mine) along the upper Arkansas River, describing "a rivulet whose waters rolled down gold dust." In this, the first published mention of gold in the Rocky Mountains, a full century before the California Gold Rush, du Pratz was describing deposits at Cache Creek south of Leadville.

Then the Rivera brothers in New Mexico received word of a "silver nail" that had come from the La Plata Mountains. Twice, in 1761 and 1765, they led small exploring parties northwest from Santa Fe into La Plata ("the silver") Mountains. Along the way, they made many discoveries, but found no promising silver lode. The next jaunt came eleven years later when the priests Dominquez and Escalante journeyed along the Rivera route seeking a "bearded white man's colony" somewhere in northern Utah. They found neither precious metals nor the pale people, but did observe Natives in Arizona mining gypsum for plaster in their pueblos. By that time silver had been discovered in the San Francisco Mountains of Arizona.

In 1779, Governor de Anza came north from Santa Fe on an Indian-chasing mission as far as Florissant and down the Ute Pass to Colorado Springs. Some of his 800 soldiers must have gone AWOL because early American argonauts along the Fall River in Clear Creek County found Spanish helmets and cookware. The Spanish certainly found gold; the "Spanish Bar" in Idaho Springs was named after that!

By 1803, Thomas Jefferson made his famous Louisiana land deal with Napoleon. Then he sent out exploring parties to see what he had purchased. Zebulon Pike led three different excursions – one to the headwaters of the Mississippi, one up the Red River in Oklahoma, and one up the Arkansas River. Pike was "captured" by the Spanish in San Luis Valley where he had holed up for the winter, taken to Santa Fe and thrown in jail. An American trapper/carpenter, James Purcell, was wintering in Santa Fe. Purcell showed Pike two gold nuggets that he had collected "from the headwaters of the Platte." That was the first time an American showed another American any gold from Colorado. Pike reported the nuggets in his journal. About the same time, in January of 1807, another American trapper, Anthony Beatty, reported a "promising **silver** lode, 1700 miles up the Platte from St. Louis," to President Jefferson. He offered the President a cut of the action, but there is no evidence that Jefferson took him up on the deal.

In the time between those early reports and George Jackson's discovery in January of 1859, many reports of precious metals found their way into official American, Spanish, and Mexican government documents, plus tales were told by traders, trappers, and travelers. This presentation reviews the mostly ignored descriptions, dates, and places; it tells of the people who paved the way to Colorado's metallic riches.

Biography

Dr. Beth Simmons, one of the founding members of the Friends of the CSM Geology Museum, wrote "A Quick History of Idaho Springs" and is renowned for her historical research, writing, and historical movie making. Delving into the many early reports of gold discoveries, it is apparent that the early explorers weren't as gold -or land-hungry- as the Americans just before the Civil War.

The Frederick Mayer Collection of Colorado Territorial Gold Coins
A History of the Coins and Coiners

Ed Raines
Collections Manager, Colorado School of Mines Geology Museum

The Frederick Mayer Collection of Colorado Territorial Gold Coins has recently been loaned to the CSM Geology Museum. These coins are without question the most important artifacts extant that are directly linked to the Pikes Peak Gold Rush. And even more important to the world of mineralogists and geologists, they are the only metallurgical remnants with a legitimate provenance that is tied to the frontier mines.

The origins of the Colorado Gold Rush were born in the hard times of the Panic of 1857, and most 59ers came west with empty pockets. As Elliot West put it in “The Contested Plains” the average 59er didn’t have to think his way through a long series of pros and cons for a westward journey, *i.e.* “it wasn’t why should I go to Pikes Peak, it was why not?” But, those 59ers who found gold, still didn’t have any ***money*** with which to buy food, supplies, or a night on the town.

Into this vacuum stepped Clark, Gruber & Co. of Leavenworth, Kansas. The bankers (brothers Milton and Austin Clark in partnership with Emanuel Gruber) examined the circumstances of a frontier gold mining region located some 1700 miles from the mint where gold could be converted to cash and developed a business plan that called for the establishment of a private mint in Denver to coin the gold being mined.

The men acted out their plan most efficiently and were turning out $20, $10, $5, and $2.50 gold pieces within seven months from their decision to proceed with the plan. The business was an instant success as the coinage fulfilled a vital economic function to the development of the region.

Other men also coined gold on a small scale in the Gold Rush days, and the Mayer Collection contains important examples of these coins. The coins of John Parsons who operated for a short time at Tarryall are featured in the collection. Also represented are the coins of J.J. Conway who operated a mint in Georgia Gulch during the summer of 1861.

Biography

Ed Raines is the Collections Manager at the Colorado School of Mines Geology Museum. He has studied, written about, and spoken on Colorado Mineralogy, Geology and Mining History.

The Mining Districts of the Northern Half of the Colorado Mineral Belt

Stanley Dempsey

This paper describes the mining district governments that were formed in the northern half of the Colorado Mineral Belt, during and just after the Pikes Peak Gold Rush. Miners arrived before any federal mining law was passed by Congress, and they found themselves in a part of the United States where there was no territorial or state government or laws, and no courts. As they had done in California a decade before, miners made their own laws and set up their own courts. These home grown governments were spontaneous creations of the gold rush participants themselves. The laws they adopted drew upon a variety of legal traditions, including the California experience, German and Mexican mining law, and traditions of free mining tracing back to the Magna Carta and the United States Constitution. These district governments operated until the passage of federal mining laws in 1866 and 1872, and by and large they were effective in providing security of tenure for miners.

Miners at places like Idaho Springs and Black Hawk assembled, elected a presiding officer and a secretary, and adopted mining laws allowing individuals to stake claims, and to hold these claims by working them. They established boundaries for the district, set rules for the size of claims, and provided for recording of claim and claim transfer documents. Miners courts were convened from time to time to adjudicate claim disputes, and sometimes the miners assembled to hear criminal matters in a summary manner. Criminal sanctions included banishment, a practical choice in a rough and busy camp where no one had time to build a jail.

The paper will also discuss a revival of interest in mining district laws in recent years. Historians and economists have undertaken considerable research into the subject, searching for copies of mining district laws, and often examining diaries of participants in gold rush for evidence of how miners behaved in the mining district setting. They have done a particularly thorough job with respect to materials related to the California gold rush.

Many of these works are scholarly attempts to understand why miners were able to govern themselves, and investigations of the creation of property rights in the frontier setting. Other papers consider the relationship of mining district laws and the adoption of the prior appropriation doctrine in western U. S. water law. Some also examine the information to try shed more light on the subject of law and order on the frontier. Mining district experience suggests that the early western regions of the United States enjoyed more law and order than would suit writers of western fiction.

There has also been much scholarly examination of the formation and operation of mining district governments, and how they may be early examples of what is now called open source lawmaking. Much of the literature being developed in this tradition consider the mining district governments to be examples of the same kind of internet collaborative processes that have create such products as Wikipedia.

Finally, the paper will describe efforts of historians and archivists to preserve the records of these governments, and where they may be found.

Biography

Stan Dempsey, currently principal at Dempsey & Co. and retired Chairman of the Board of Royal Gold, Inc., a royalty and streaming company, headquartered in Denver, Colorado. Over the years, Stan has been a miner, a geologist, a lawyer, a mining company executive an investment banker, and authored the book, “Mining the Summit”. Mr. Dempsey received degrees in geology and law from the University of Colorado, and completed the Program for Management Development at the Harvard Business School.

His many awards include an Honorary Doctor of Engineering degree by the Colorado School of Mines in 2006, the 2007 William Lawrence

Saunders Gold Medal Award from the Society for Mining, Metallurgy and Exploration. He was the 33rd Gold Medal Recipient of the Mining and Metallurgical Society of America in 2011 and most recently was inducted into the Mining Hall of Fame and Museum in September of 2016.

His interests outside of his professional life include mountaineering, fly fishing, trains and libraries. He resides in Golden, Colorado with his wife Judy.

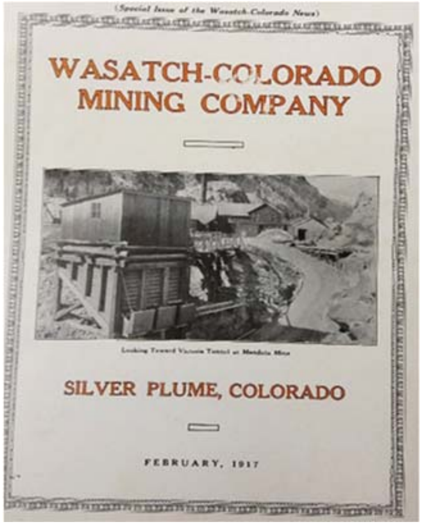
Clear Creek County’s mining districts:
Discovering missing history from primary source materials

Lisa G. Dunn
Special Collections, Arthur Lakes Library, Colorado School of Mines,
1400 Illinois St., Golden CO 80401, ldunn@mines.edu

With its rich history of gold and silver mining, Colorado has hundreds of areas identified in the published literature as mining districts. Clear Creek County, to the west of Golden (Jefferson County) and one of the original counties in Colorado, contains over 50 identified districts. Significant mining activity is described in publications from the US Geological Survey, US Bureau of Mines, Colorado Geological Survey and other organizations. These give us a picture of a district’s economic geology and mine operations and production but, as researchers know, that picture is often incomplete in its details. Most of Colorado’s mines are now abandoned, inaccessible, forgotten. Do the “details” still exist and, if so, how can we discover them?

Resources in the Russell L. & Lyn Wood Mining History Archive, Colorado School of Mines, can be used to illustrate the contribution of primary source materials (reports, maps, diagrams, etc.) to a fuller picture of the historic activity in Clear Creek County’s mining districts. The Mining History Archive houses a large collection of primary source materials and publications on the history and technology of mining. Archive items include those related to the Idaho Springs, Montana, Silver Plume and other districts. The Mining History Archive’s materials contain detail not available from the published literature. For example, in some cases assay records, underground workings diagrams, production figures, and even information on “what it was like” to operate a mine are available.

The *Mine Reports Collection* in the Archive consists of reports from mining engineers, geologists, and mine owners. These range from formal bound reports (Figure 1) to single typed sheets and handwritten notes.



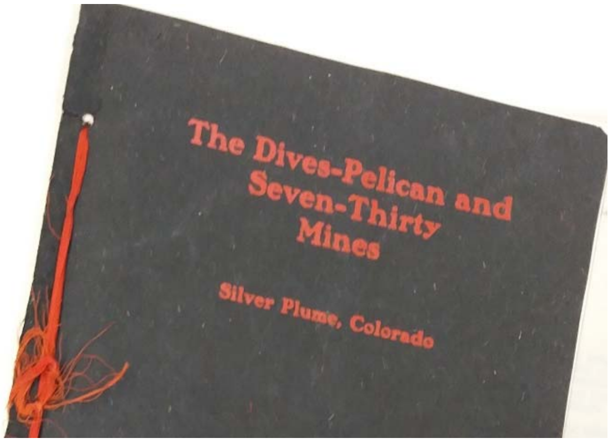
(Special Issue of the Wasatch-Colorado News)

WASATCH-COLORADO
MINING COMPANY

Looking Toward Victoria Tunnel at Mendota Mine

SILVER PLUME, COLORADO

FEBRUARY, 1917



The Dives-Pelican and
Seven-Thirty
Mines

Silver Plume, Colorado

Figure 1. Prospectus documents, Wasatch-Colorado Mining Company, operations in Silver Plume district, 1917 (Mine Reports Collection, Report 954); and the Dives-Pelican and Seven-Thirty Mines, Silver Plume district, 1903 (Mine Reports Collection, Report 760).

In addition to descriptions of the property, claim maps and maps showing portions of the associated mining districts are common, for example shown in Figure 2.

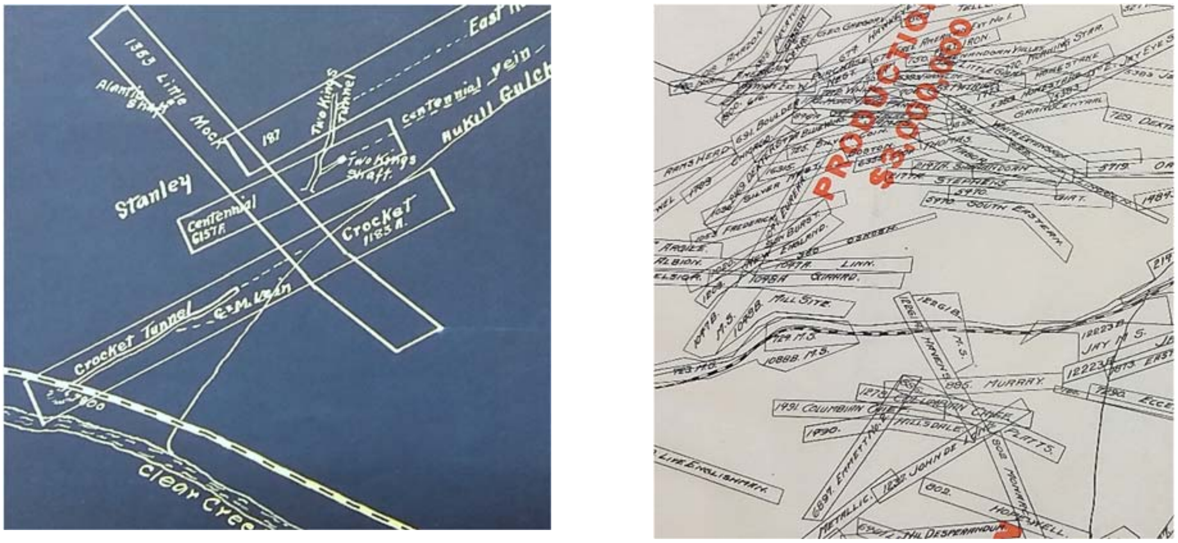
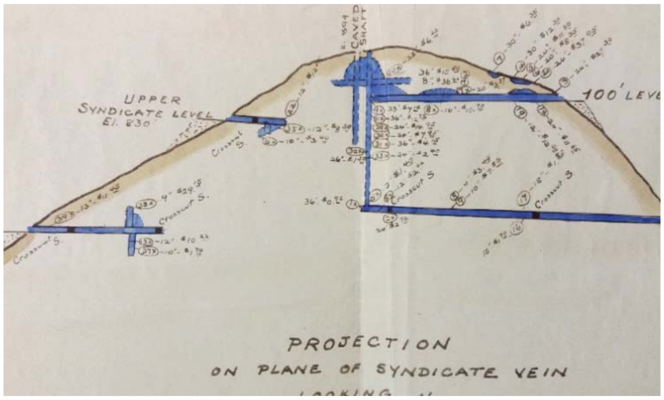


Figure 2. Maps showing claims—Hukill Group (left), Fall River district, 1934 (Mine Reports Collection, Report 746); and Freeland Development and Transportation Company properties (right), South Clear Creek, Freeland-Lamartine district [nd] (Mine Reports Collection, Mine Report 968).

Underground maps are much less common, but illustrate the extent of the workings and their relationships to the development of the properties (Figure 3). Some include data on assay sampling or notes on further development. Professionally drafted or hand drawn, this information is unlikely to appear in the published literature.



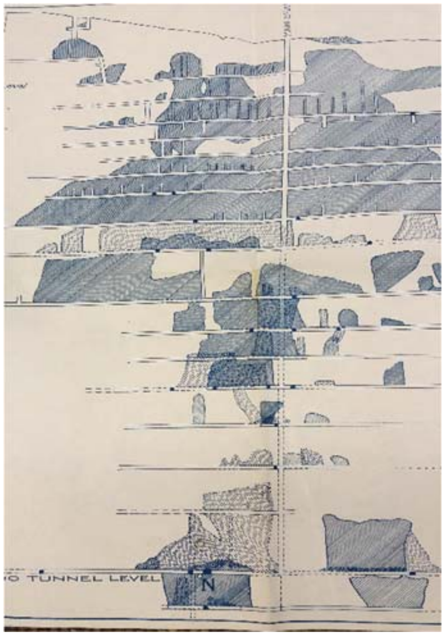


Figure 3. Maps of underground workings—Syndicate Mine (left), Montana district, c1910 (Mine Reports Collection, Report 805); Gem Mine (right), main shaft and Argo Tunnel, Idaho Springs district, 1915 (Mine Reports Collection, Report 990).

The contents of each mine report in the Collection reflect the issues of the time associated with mine activity. For those reports generated for promotional or investment purposes, relationships with neighboring proven producers or known ore deposits, assay and production data, and other information attractive to investors are common (Figures 4, 5).

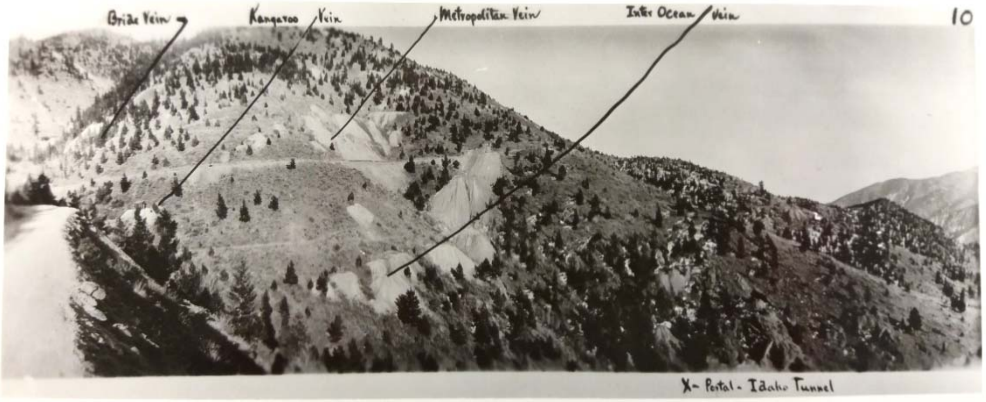
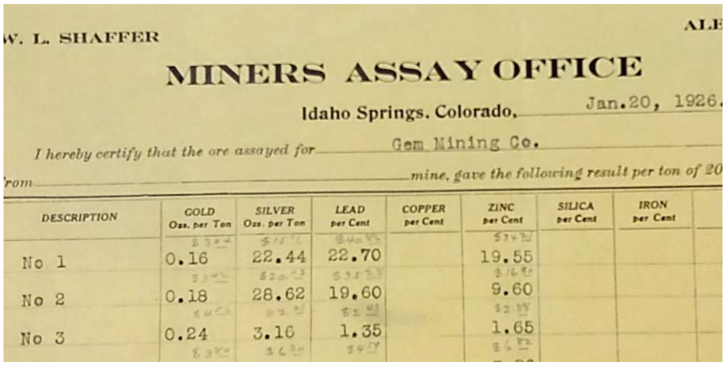


Figure 4. Proximity of the Bride, Kangaroo, Metropolitan and Inter Ocean veins, Idaho Springs district, 1930s (Mine Reports Collection, Report 993).



W. L. SHAFFER

ALE

MINERS ASSAY OFFICE

Idaho Springs. Colorado, Jan.20, 1926.

I hereby certify that the ore assayed for Gem Mining Co.

rom *mine, gave the following result per ton of 20*

DESCRIPTION	GOLD Ozs. per Ton	SILVER Ozs. per Ton	LEAD per Cent	COPPER per Cent	ZINC per Cent	SILICA per Cent	IRON per Cent
No 1	0.16	22.44	22.70		19.55		
No 2	0.18	28.62	19.60		9.60		
No 3	0.24	3.16	1.35		1.65		

Figure 5. Ore assay figures for the Gem Mining Company, Idaho Springs district, 1926 (Mine Reports Collection, Report 994).

Mine reports are primarily technical or promotional documents, and accompanying photographs usually illustrate the physical layout of the property, equipment, or nearby resources (towns, rail lines, water). However, a few of the reports include photographs of active mining scenes, miners and property owners (Figures 6, 7).

Figure 6. Men piling high-grade ore, Mendota Mine?, Wasatch-Colorado Mining Company, Silver Plume district, 1917 (Mine Reports Collection, Report 954).

Figure 7. Miners at the Marshall Tunnel, Aliunde Consolidated Mining Company, Argentine district?, 1896? (Mine Reports Collection, Report 2124).

In addition to the Mine Reports Collection, the Russell L. & Lyn Wood Mining History Archive's *document collections* are another source of unique information. One of these document collections, the Stanley Mine Company Collection (A0135), contains drafts of reports on the Stanley's successful properties in Clear Creek County, production figures, and unpublished maps from the 1940s-1952. The Percy P. Barbour Collection (A0117, 1867-1967) includes maps, survey notebooks and papers from Barbour and fellow surveyors on their work with mining and civil properties in Clear Creek County. The Archive's *photograph collections* include depictions of both surface and underground mining operations. While the Mining History Archive focuses on the technology and operational side of mining, it preserves a variety of records on related industries and experiences, including on the human experience. The Walter V. Berry Collection (A0133) records, along with Berry's successful life as an industrialist, his development of the Anglo Saxon Mine outside of Georgetown in his later years (1970s). The Anglo Saxon turned out to have no economic value for Berry, but the collection reflects Berry's work as a small miner and his engagement with the community of Georgetown.

"Grey literature" (items of limited distribution and availability, and not included in standard publications indexes) is another valuable resource but represents challenges for discovery and access. For decades the early academic thesis literature has been marginally discoverable to many researchers—*Colorado School of Mines' early theses* include works of original research on local mines including the Almaden Mine, Big Five Tunnel, Stevens Mine and Phoenix veins (Colorado School of Mines Thesis and Dissertation Collection). Product catalogs are everyday grey literature; but the Morse Brothers Equipment Catalogs (A0112) from the company's Denver office, include photos and specifications on mining equipment used throughout Colorado in the 1900s. Thanks to digitization projects, shared online catalogs and web browsers, access to these hidden materials is already much improved and benefits a wider audience. Discovery of primary source materials and grey literature is important for the researcher who needs to go further than mainstream published content.

Colorado's numerous *local and state archives* preserve collections of historic materials on mining; some of these organizations have finding aids and librarians or archivists who can work with users. These organizations' projects to develop open-access digital content are another critical component to support in-depth research. For example, CSM's Mining History Archive is making digital content available via *Digital Collections of Colorado,* Mines' institutional repository, including a reference on Colorado mining districts (Dunn, 2015). The archives and libraries of Colorado are key resources that the researcher should seek out to get a richer picture of Colorado's mining districts.

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Percy P. Barbour Collection (A0117). Russell L. & Lyn Wood Mining History Archive, Arthur Lakes Library, Colorado School of Mines.

Stanley Mines Company Collection (A0135). Russell L. & Lyn Wood Mining History Archive, Arthur Lakes Library, Colorado School of Mines.

Walter V. Berry Collection (A0133). Russell L. & Lyn Wood Mining History Archive, Arthur Lakes Library, Colorado School of Mines.

Biography: Lisa G. Dunn is the Special Collections Manager, Arthur Lakes Library, Colorado School of Mines. She received her BS in Geology from UW-Superior and her MA in Earth Sciences from Washington University. Since getting her MLS in Library Science, Dunn has worked in engineering libraries, first at the Montana College of Mineral Science and Technology in Butte, then at Colorado School of Mines. She manages the Russell L. & Lyn Wood Mining History Archive, and collaborates with users on research in economic geology, mining, and related mining industries. Dunn has authored several publications on information's role in geology and mining.

Leadville, Gilman, Kokomo & Aspen

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The mantos are massive sulfide-carbonate-quartz replacement deposits primarily in Paleozoic limestone-dolostone sequences. They commonly exhibit mineral-metal zoning centered on mid-Tertiary intrusive stocks and/or in up-dip settings that indicate stratigraphic control on ore fluid flow direction. Individual manto bodies at Leadville commonly have a pyritic zone outboard of the dominant base-precious metal central zone. Some skarn assemblages are present (*e.g.* Leadville and Kokomo); however, the mantos are outboard of the skarn zones. Paleo-karst breccia bodies are zones of increased permeability to ore fluids, and many orebodies exhibit near-vertical geometries of the karst bodies with nearly complete replacement of carbonate blocks-matrix and retaining only unreplaced chert relics within the massive sulfide body.

At Leadville the mantos close to the Breece Hill quartz monzonite porphyry stock contain elevated gold contents in addition to high concentrations of Zn, Pb, and Cu, principally in marmatite, galena, and chalcopyrite; with increased distance, primarily up-dip west in the Leadville and Dyer dolostones, the silver content increases substantially. In fact, supergene effects on the near-surface mantos at Fryer Hill yielded bonanza concentrations of wire silver. At Kokomo, the mantos exhibit mineralogical zoning up-dip to the southwest from the Tucker Hill intrusive-thermal center. Similarly, Gilman manto deposits exhibit zoning to the southwest from karst-hosted Cu-Ag chimney deposits transitioning up-dip to the southwest in to breccia-hosted, stratigraphically-bounded marmatite-galena bodies. No intrusive center is known for the Gilman deposits even though they are capped by the 70Ma Pando sill. Northeast-trending faults were important in localizing some karst zones and, thus, influencing ore fluid flow at Kokomo and Leadville. Post-ore hydrothermal breccia masses at Leadville are exposed in mine workings as well as at the surface; many of these bodies exhibited elevated metal contents due to ore fragment inclusion. As such, they were guides to deeper-level manto deposits in the down-dropped block that yielded ore to the Black Cloud mine-mill at the south end of the block.

The radiometric dates on alteration products as well as fission-track dates on apatite and zircon document that ore formation in these districts occurred between 36 and 40Ma. Ore fluid pressure-corrected temperatures based on fluid inclusion and sulfide-pair isotopic analyses ranged between early +500˚C low-salinity fluids ranging down to late-stages of low-salinity 150˚C fluids. A narrow range of $\delta^{34}S$ about O‰ in the manto and chimney sulfides indicates the sulfur was derived from a magmatic source. A range of +5.0 to +9‰ $\delta^{18}O$ for calculated ore fluid water responsible for alteration products indicates that the hydrothermal fluids were magmatically-derived; subsequent collapse of meteoric-formational waters on to the sulfide mantos yielded the late carbonate and local sulfate minerals in veinlets and vugs. Clearly, these manto districts owe their origin to emplacement of mid-Tertiary igneous bodies with subsequent magmatic, metal-rich fluid release. This summary will focus on the Leadville and Kokomo manto systems.

Total production of metals from these 4 districts is estimated to be $1.63X10^6$ metric tonnes Zn, $1.5X10^6$ metric tonnes Pb, 145,000 metric tonnes Cu, 502 Moz Ag, and 3.6 Moz Au. More than half of the precious metals came from the Leadville district; the gold at Leadville came principally from the discovery placers in California Gulch.

Many well-known people were involved with discovery and production in the Leadville district, including the Guggenheim family, the “Unsinkable” Molly Brown, and H.A.W. Tabor.

Introduction

The discovery of placer gold in 1860 in California Gulch at Leadville led to major production of complex ores for 140 years centered about a 43Ma quartz monzonite porphyry stock-laccolith complex at Breece Hill (**Fig. 1**). The ore bodies are localized in collapse breccias within Paleozoic limestones converted to regional dolostone with metal zonation from central complex pyrite-marmatite-galena-tetrahedrite-gold bodies outward to pyrite-sphalerite-galena-acanthite bodies. Within the central Breece Hill stock there are veins with wolframite-gold-bismuthinite, in a zone characterized by quartz-sericite-pyrite alteration in the Ibex mines. Undoubtedly, there is the potential for a bulk-tonnage system in that zone, but it has been tested with only a few drill holes.

Geologic Setting

The stratigraphic section and northeast-trending faults have localized the mantos around the Breece Hill intrusive center (**Figs. 1 & 2**). Additional control occurs at Leadville where a 72Ma Pando sill is localized at the top of the Leadville Dolomite section (**Fig. 3**), acting as a permeability barrier to ore fluids passing out of the intrusive center upward and outward along the faults.

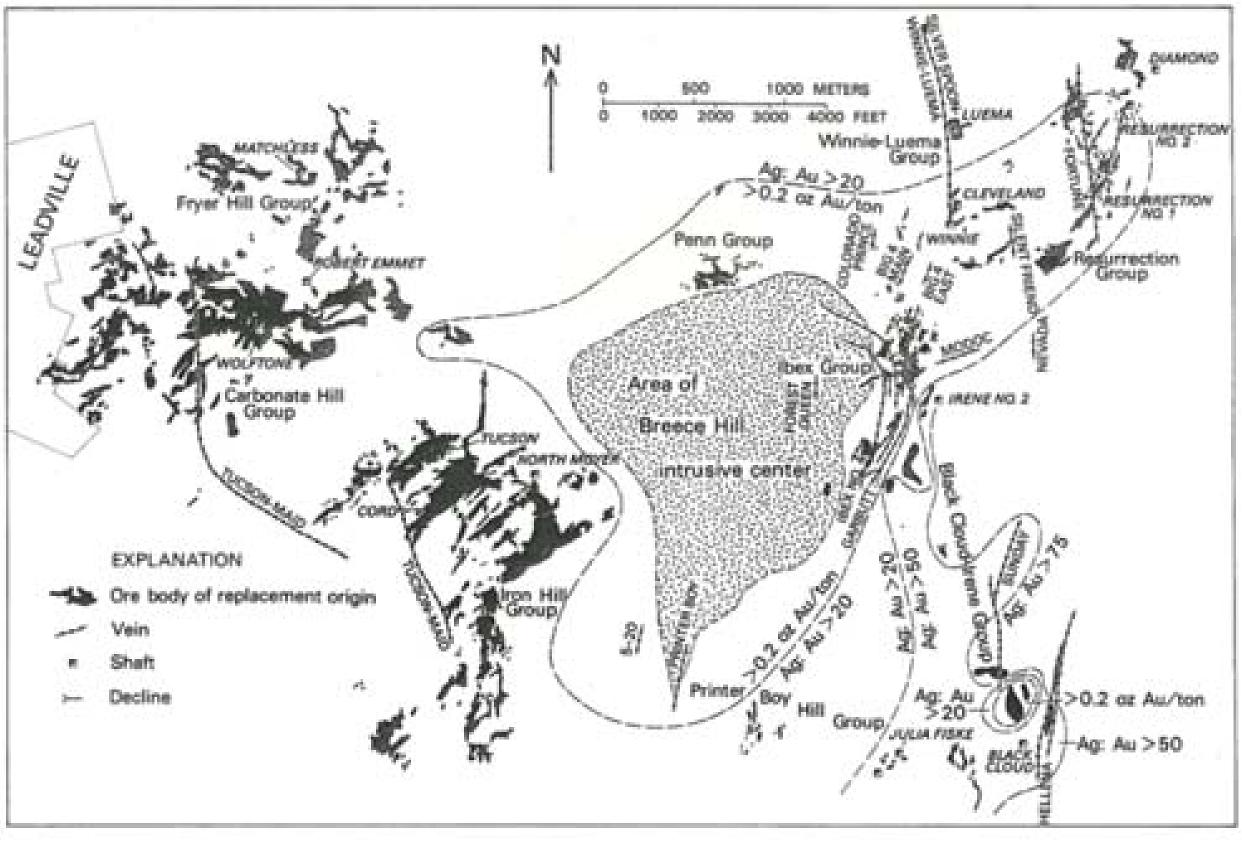

Figure 1. Leadville district orebodies around the Breece Hill intrusive center, showing the increase in silver values outboard of Breece Hill.

The ores at Leadville are localized in the Cambrian-Mississippian Manitou, Dyer, and Leadville Dolomites; however, the Kokomo mantos are found in the thin limestone units of the Minturn Formation. The ore at Kokomo commonly exhibits jasperoid either within the orebodies or as peripheral transitions into unaltered limestone or dolostone breccia.

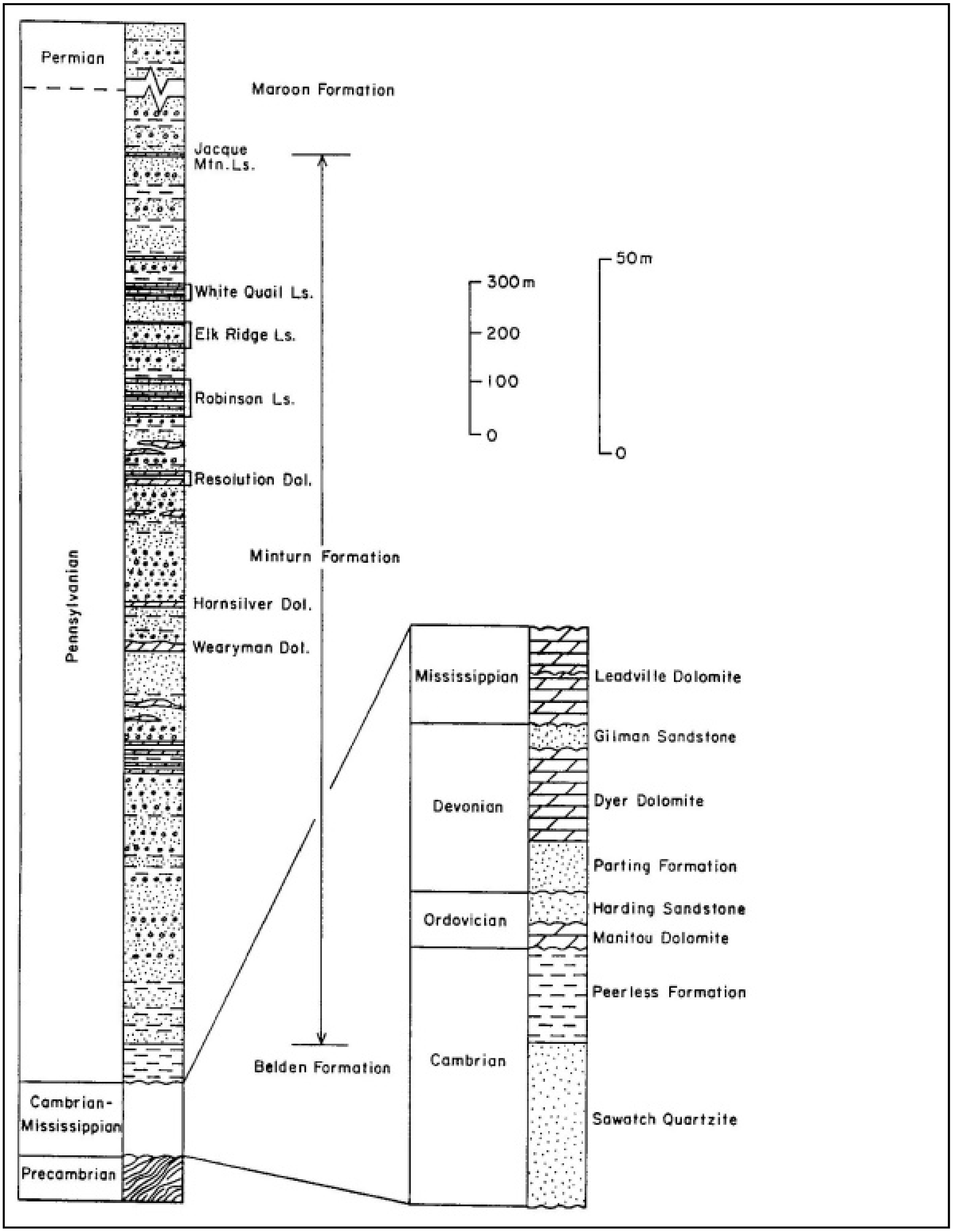

Figure 2. Stratigraphic section at Leadville and Kokomo (adapted from Mach and Thompson, 1998).

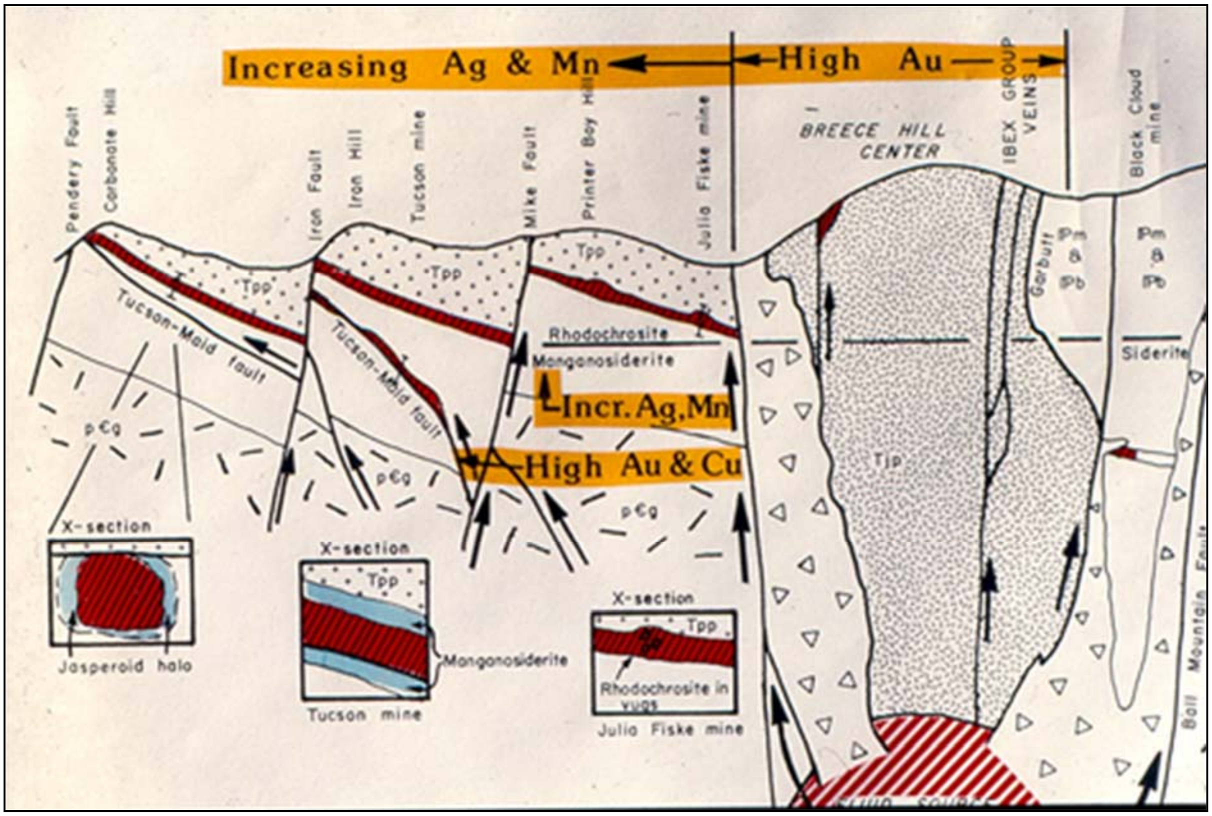

Figure 3 Vertical and lateral metal zoning in the Leadville district with changes in the presence of jasperoid laterally, and variation in manganese mineralogy. Tpp is the Pando sill that occurs along the unconformity at the top of the Leadville Dolomite.

Both Leadville and Kokomo districts exhibit skarn systems at the margins of stocks; at Kokomo the skarn is dominated by epidote while the Leadville skarn is dominated by magnetite. The stocks at Kokomo are quartz monzonite porphyry bodies at the northern part of the district. Mineral-metal zoning at Kokomo is from central pyrrhotite-pyrite outward to sphalerite-galena-chalcopyrite, commonly with jasperoid coatings, into barren jasperoid, hydrothermal dolomite and ultimately into unaltered limestone country rock.

At Leadville the zoning consists of central base-precious metals with a pyrite-rich margin (**Fig. 4**) passing outboard into dissolution tubes that have white dolomite coatings with disseminated interior quartz and pyrite. District metal zoning is illustrated by both Figures 1 and 3.

The orebodies are massive sulfide aggregates or occur as banded sulfide masses (**Fig. 5**) with interstitial dolomite or siderite. Marmatite contains up to 19.3% FeS at Leadville (Thompson and Beaty, 1990) and up to 15% at Kokomo (Mach and Thompson, 1998).

Geochemistry

Metal concentrations in orebodies can be highly variable but will be in the generally range of 8% Zn, 4% Pb, 2-4 ounces/ton Ag, and 0.05 to 0.5 ounces/ton Au; the ores are clearly zinc-dominate. With increasing distance from the heat-fluid source the FeS content of marmatite decreases from the "black-jack" to green to yellow sphalerite. Accessory siderite to manganosiderite is present from higher temperature, respectively, to lower temperature settings.

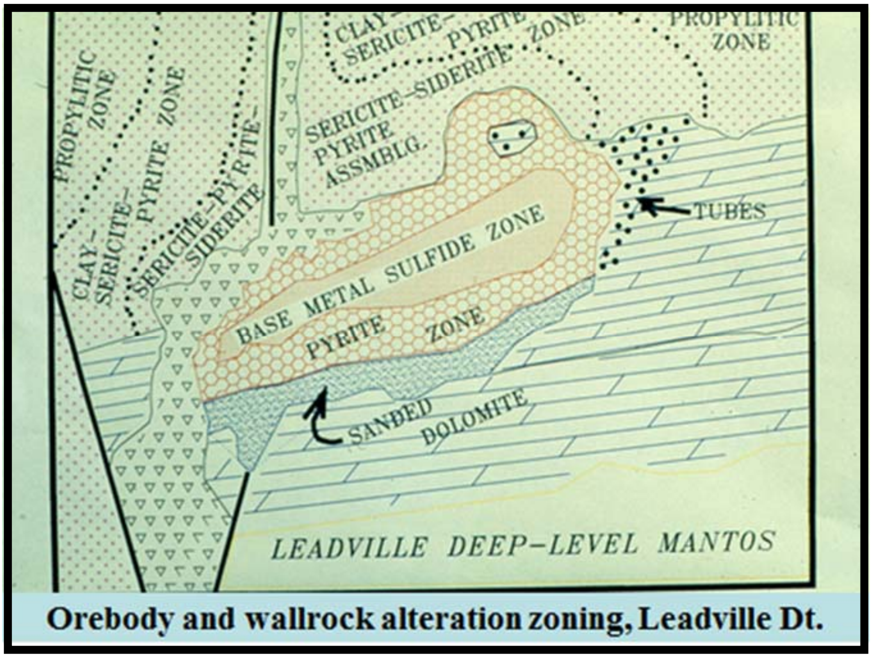

Figure 4. Sulfide mineral zoning in mantos of the Black Cloud mine. Note the discordant breccia mass (triangular symbol) that cuts the manto sulfide body, transporting orebody fragments away and generally above the body. Dissolution tubes are indicated out in the regional dolostone. Wallrock alteration in the Breece Hill quartz monzonite porphyry is zoned about ore fluid feeder structures. This zonal alteration and the transport of ore fragments by the post-mineral breccia bodies were important exploration guides even in outcrops but also in the mine workings at Black Cloud.

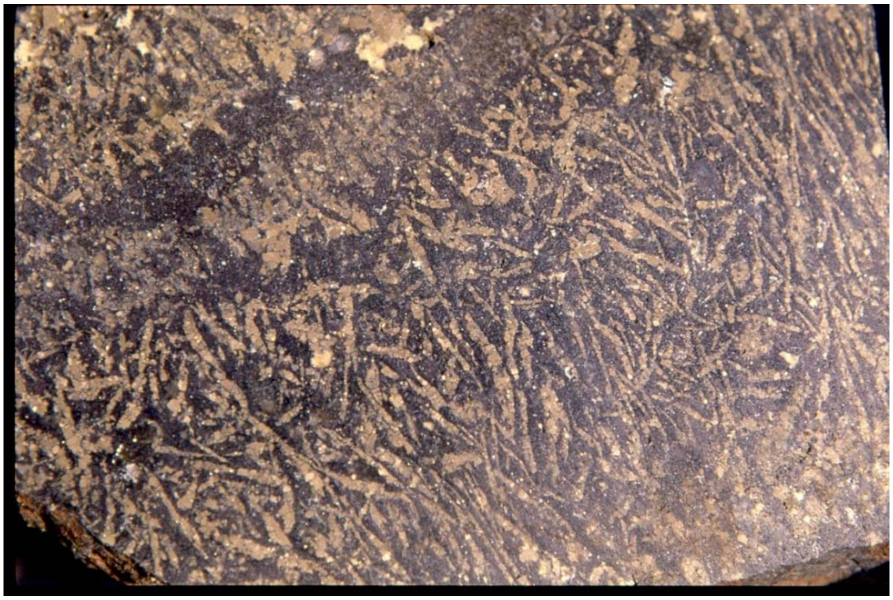

Figure 5. Typical textures in many Leadville and Kokomo orebodies with platy pyrrhotite (referred to in the literature as “rod” texture), replaced by pyrite and/or marcasite with interstitial marmatite-galena-tetrahedrite-(gold). Banding is typically parallel to dolostone-limestone bedding, and the iron sulfide rods are commonly perpendicular to bedding.

Stable isotope geochemistry and fluid inclusion analyses at Leadville (Thompson and Arehart, 1090) and Kokomo (Mach and Thompson, 1998) have been completed on quartz, sphalerite, and carbonate minerals in the mantos. At Leadville filling temperatures range from >350˚C near Breece Hill to slightly >200˚C on the fringes at Fryer Hill (Thompson and Beaty, 1990). With pressure correction from sphalerite geobarometry, an additional 90˚C must be added to the filling temperature to establish the actual ore fluid temperatures during ore deposition, indicating maximum tempereatures near 500˚C near the Breece Hill center. At Kokomo the temperatures with pressure corrections are slight >400˚C to below 200˚C in the latest stages of yellow sphalerite. Ore fluid salinities from freezing point depression in both districts indicates fluids had NaCl contents < 7.0 equivalent weight percent (Thompson and Beaty, 1990).

Sulfur, carbon, and oxygen stable isotope geochemical analyses have been completed in both districts, indicating that ore fluids interacted with the regional dolostones and limestones, reducing their regional values from δ^{18}O values of 22-24 ‰ to <19.5‰ and reducing igneous whole rock values from 10.4-12.2‰ in outcrops to 8.7-10.9‰ on the Yak drainage tunnel level some 2,500ft below the surface. Changes in igneous whole δD values range from surficial 9.8-10.2‰ to 9.1-9.3‰ on the Black Cloud 1250 level. Ore fluid isotopic values are calculated to be within the magmatic water field (Thompson and Beaty, 1990) (**Fig. 6**). Similar interpretation is reached from the sulfur isotopic analyses of pyrite, galena, sphalerite, and chalcopyrite; the δ^{34}S values cluster around 0‰, indicating a magmatic sulfur source (**Fig. 7**; Thompson and Beaty, 1990). Using isotope geothermometry, ore fluid temperature values virtually identical to the pressure-corrected fluid inclusion analyses were obtained (Thompson and Beaty, 1990).

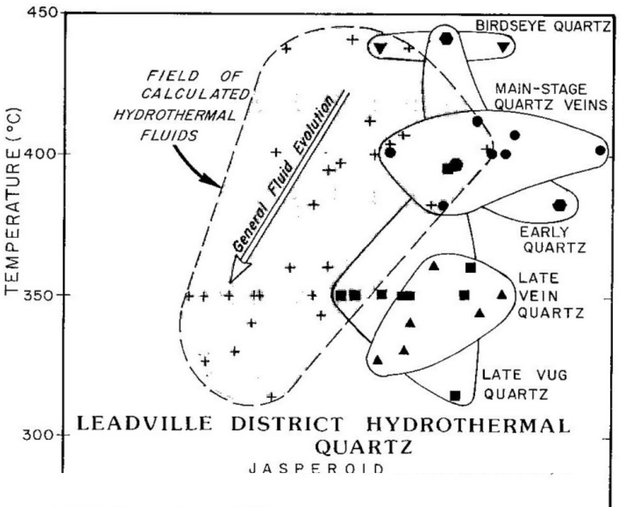

Figure 6. Variation in δ^{18}O value and temperature for hydrothermal quartz, Leadville district. Quartz associated with ore deposition precipitated from fluids isotopically similar to that which altered the porphyry (5-8‰); paragenetically later fluids are isotopically lighter (1-6‰).

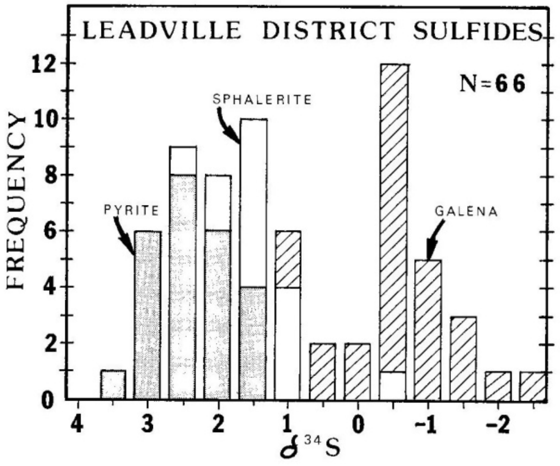

Figure 7. Sulfur isotopic values for Leadville district sulfides with values decreasing in ^{34}S from pyrite to sphalerite to galena in agreement with the paragenetic sequence of sulfide mineral precipitation.

Conclusions

The evidence indicates that the manto deposits at Leadville and Kokomo were derived from magmatic hydrothermal fluids coming from the multi-phase stocks. Post-mineral breccias, locally associated with rhyolitic plugs, dated at 38.5Ma, document ore formation between 43Ma and 38.5Ma. Similar data from other manto districts along the Colorado

Mineral Belt make the strong case that magmatic ore fluids are responsible for manto Zn-Pb-Cu-Ag-(Au) orebodies formation.

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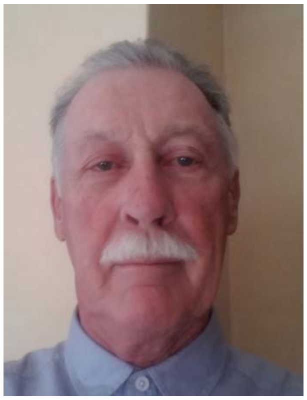
Biography



Tommy Thompson received his B.S. (1961), M.S. (1963) and Ph.D. (1966) from the University of New Mexico. He has served as a faculty member at 4 universities: Oklahoma State University (1966-1973); Colorado State University (1973-1995); Mackay School of Mines (UNR: 1997-2014); Universidad Nacional de San Juan, Argentina (2004-2005), for a total of 47.5 years. He is Emeritus at both CSU & Mackay. He was the first Director, Ralph J. Roberts Center for Research in Economic Geology (CREG), serving in that capacity for 16 years. He is a CPG (#10875) and has consulted throughout the western Hemisphere.

The Silver-Rich Manto Deposits of Aspen, Colorado: Characteristics, Discovery, and Mining History

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The Aspen mining district, located about 170 km southwest of Denver and situated along the west margin of the Sawatch Range produced significant Ag with accessory Pb and Zn from manto deposits associated with carbonate rocks. The district is recognized for its high-grade silver deposits having these attributes: silver-rich mineralogy occurring as sulfosalts, sulfides, and native metal, produced significant silver over relatively short timeframe (~50 million oz. in eight years), and for the numerous large boulders of silver. The ores of the district were discovered in 1879. The boom years of mining were 1888-1895 when Aspen was one of the leading silver producers in the world.

The characteristics of the Aspen manto deposits and geology of the district were described by Henrich (1889) and Spurr (1898) when access to the high-grade stopes was available. Bastin (1925) provided mineralogical and textural observations of the rich silver ores. Revisions to the stratigraphy, breccia formation, and ore controls are by Vanderwilt (1935) and Rohlfing (1938). The most recent comprehensive geologic description of the Aspen area is by Bryant (1971; 1979). The mines were not accessible from the 1950s until the Smuggler mine and Compromise tunnel were re-opened in the early 1980s. This allowed access to mine levels and stopes in the Smuggler and Aspen Mountain areas. Utilizing this new access, all available mine workings were detailed mapped, sampled, and supplemented by laboratory studies that resulted in a published genetic model for the district (Stegen et al., 1990).

Geologic Setting of the Aspen Area

Aspen is located near the intersection of the northwestern boundary of the Colorado mineral belt and the western margin of the Sawatch uplift. In this area, Proterozoic gneiss, schist, and quartz monzonite is overlain by a think sequence of Paleozoic and Mesozoic sedimentary rocks. The sedimentary rocks of Cambrian through Mississippian age are 200 to 320 m thick and comprise a thin belt that denotes the margin of the Sawatch uplift and passes beneath the city of Aspen (Fig. 1). The uppermost unit of this sequence is the Mississippian Leadville Limestone. The Leadville is disconformably overlain by black shale and limestone of the Belden Formation that is the basal unit of thick series (>4 km) of Pennsylvanian through Cretaceous clastic sedimentary rocks.

In the Aspen district, virtually all of the manto deposits are contained within rocks associated with the Leadville Limestone. The Leadville consists of two members, a thinly laminated dolostone (Red Cliff Dolomite) and an upper massive limestone (Castle Butte Limestone). Both of these members have significant thickness variations that have been attributed to post-depositional carbonate dissolution (De Voto, 1983). Two stratabound breccia bodies were described by Spurr (1898) because of their importance in hosting much of the mineralization: the Contact breccia within the Leadville that separates the Red Cliff and Castle Butte Members and another (Silver breccia) localized between the Leadville Limestone and Belden Formation. These breccias were interpreted by Spurr (1898) as of tectonic origin, but subsequently reinterpreted as related to sedimentary (Rohlfing, 1938) or karst – dissolution processes (De Voto, 1983).

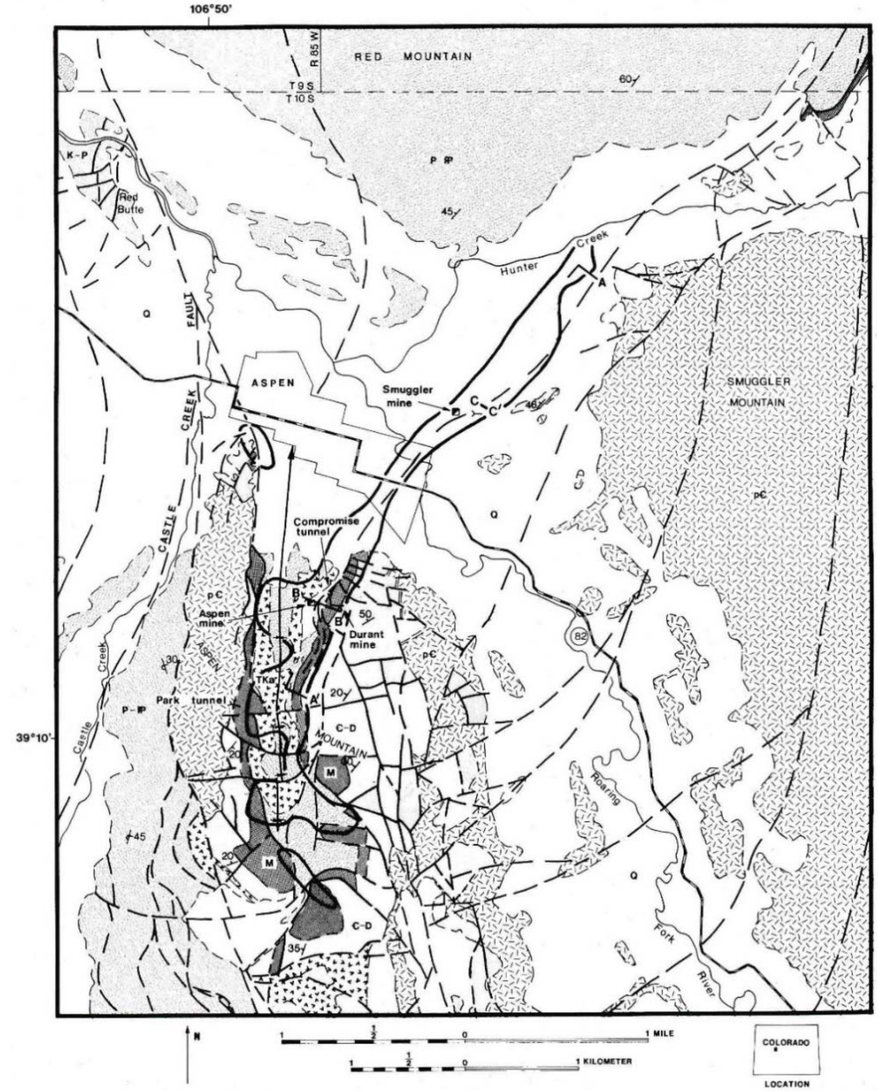

Figure 1. Simplified geologic map of the Aspen area (modified from Bryant, 1971; 1972). Symbols used with map: Q – Quaternary deposits, TKa – Aspen Mountain sill, P-IP – Permian & Pennsylvanian rocks, M – Leadville Limestone, C–D – Devonian, Ordovician and Cambrian rocks, pC – Proterozoic rocks. Area of significant Ag-Pb-Zn production within bold solid line.

Four igneous rocks of Late Cretaceous or early Paleocene age were intruded as sills or dikes in the Aspen region (Bryant, 1971; 1979). Three of these occur south of the productive part of the district, but one (Aspen Mountain sill) has a distribution that approximately coincides within the area of significant mineralization (Figure 1). The Aspen Mountain sill is an aplite porphyry (Bryant, 1979) emplaced within the lower part of the Belden Formation. The aplite porphyry contains phenocrysts of sericitized feldspar and mafites set within a fine-grained sericitically-altered groundmass; pyrite is disseminated and also found within sparse thin veinlets with quartz (Stegen, 1988). Fission track dating of zircon from three of the rocks including the aplite porphyry have dates of about 52 Ma, but apatite dates are about 30 Ma (Bryant et al., 1990) and do not furnish definitive evidence for the age of the manto deposits.

The Castle Creek fault zone bisects the Aspen area and is the main structure bounding this part of the Sawatch uplift (Bryant, 1979). The sedimentary rocks are tilted to a moderate-dipping monocline north of Aspen, but south are within a north-plunging syncline (Fig. 1). Numerous faults displace the sedimentary rocks and sill in the Aspen and Smuggler Mountains area. A number of north-trending faults with steep dips parallel the Castle Creek fault and are cut by a series of cross faults having west – northwest orientations that dip moderately to the south in Smuggler Mountain and are steep in Aspen Mountain. The intersections of cross faults with the semiconcordant breccia bodies were a loci for the silver-rich mantos (Spurr, 1898).

Characteristics and Mineralogy of the Manto Deposits

The manto deposits were localized principally within two breccia masses atop and within the Leadville Limestone (Fig. 2). The breccia bodies are semiconcordant to bedding, but diverse in character, origin, age, and the type of mineralization they host. The principal silver-rich orebodies are hosted by the Contact breccia composed entirely of dolostone fragments set within a finer matrix of dolomite sand grains indistinguishable from the Red Cliff Dolomite. The lower contact is undulatory and marked by cuspate incisions into the underlying dolostone.

The Contact breccia contains mantos that are laterally continuous, stratabound, and tabular. The ore minerals are found in two main settings: as open-space filling between breccia fragments and as infilling and replacement of a basal bed of stratified dolomite sand. The mineralogic and paragenetic relations of the mantos define three major stages of mineralization. An early stage is characterized by open-space growth of abundant barite with lesser amounts of pyrite, marcasite, sphalerite, and galena. The intermediate stage contains tennantite that is relatively abundant and typically massive. Tennantite is extensively replaced by galena and sphalerite, both occurring in greater abundance than the early stage and are traversed by chalcopyrite, bornite, and sparse aikinite replacement veinlets. Pearceite, acanthite, stephanite, and native silver replace earlier sulfide and sulfosalt minerals and are locally abundant (Bastin, 1925; Stegen, 1988). Texturally the sulfides have a range from discontinuous “crisscross” within barite (Spurr, 1898) to large masses of sulfide. Native silver is of two major occurrences: as compact, irregular masses intergrown with sulfide and sulfosalt minerals interpreted as hypogene in origin. Silver also consists of dendrites, wires, and massive nuggets associated with minerals derived from supergene processes (malachite, cerussite, smithsonite, various iron oxides). Other notable characteristics of the mantos is their low pyrite content, contain minimal amount of quartz, are not anomalous in gold, and the alteration of dolostone wall rock surrounding the mantos is visibly recrystallized to form a continuous zone up to 0.3 m thick.

In contrast, the Silver breccia is located at the top of the Leadville Limestone within Aspen Mountain but in Smuggler Mountain area it is situated atop the Contact breccia. The fragments within the Silver breccia are heterolithic, random oriented, poorly sorted, and matrix supported. The most common fragment is dolostone, but limestone, shale, sericitically-altered aplitic porphyry of the Aspen Mountain sill, and barite-rich sulfides are set within a matrix of black carbonaceous shale apparently derived from the overlying Belden Formation. The matrix of the Silver breccia is variably mineralized consisting of galena, sphalerite, and pyrite ranging from complete replacement of the matrix to sparse, fine-grained sulfide disseminations. The galena and sphalerite in Silver breccia constituted the bulk of the milling ores of the district. The breccia characteristics indicate the Silver breccia clearly post-dated manto formation in the Contact breccia and sericitic alteration of the aplite sill, but contains sulfides as a massive replacement of the breccia matrix. This breccia is interpreted to have formed by a hydrothermal-related process.

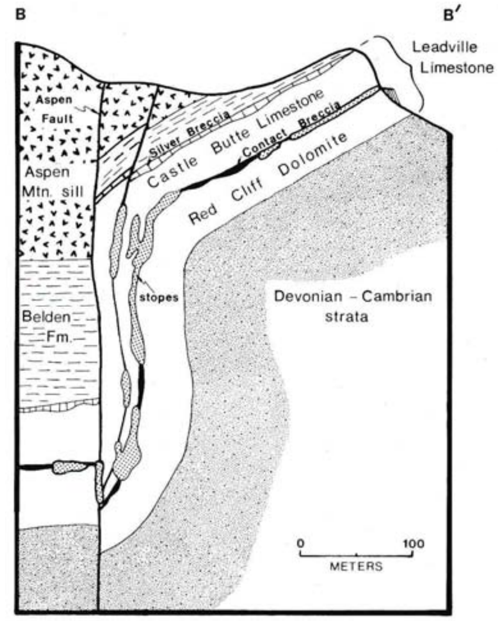

Figure 2. West – East cross section view to the north through Aspen Mountain showing Red Cliff and Castle Butte Members and the Contact and Silver breccias. Modified from Spurr (1898).

Discovery and Mining History

Prospectors knowledgeable of the ore host rocks at Leadville utilized geologic maps of the Hayden Survey (1877) by following limestone to what is now the Aspen area. The discovery site was a silver, malachite, and barite occurrence on a ridge west of Spar Gulch on Aspen Mountain. Following was another discovery nearby and at the base of Smuggler Mountain. Claims were then located north and south of present Aspen; the first ore was shipped in 1880 via pack animals to Leadville and later to an Aspen smelter (started 1882) for processing. Aspen was a small town until the discovery in 1884 of very rich ore in the Aspen and Emma mines. During a six month period, the Emma mine produced 11 metric tons (354k ounces) of silver. Two railroad companies arrived in 1887-8 that provided greater availability of transportation and lower shipping costs; the ores were then railed to Leadville for smelting. This resulted in a dramatic increase in district production and from 1887 through 1892 totaled about 985 metric tons of silver. The town also experienced population and city growth that included opening of the Wheeler Oprah House and Hotel Jerome in 1889. Repeal of the Sherman Act in 1893 significantly impacted production that never returned to prior amounts. As mining progressed deeper, the amount of direct-shipped ores to smelters declined and by the later 1890s the district was producing lower-grade milling ores processed by concentrators in the Aspen area. During this period, long tunnels were completed within the Aspen Mountain (Durant, Veteran, Park, Traynor, Newman, and Midnight) and Smuggler Mountain (Cowenhoven) areas for mine dewatering, haulage, and exploration. There was a minor increase in production during World War I and during the 1920s metal production fluctuated greatly. There has been very little mining in the district since 1952.

The district mine workings extend from Hunter Creek (north) beneath the city of Aspen to Tourtelotte Park (south) over a horizontal distance of about 5 km and have a vertical range of 850 meters. The district produced about 3,151 metric tons of Ag, 266,700 metric tons of Pb, and 10,000 metric tons of Zn from an estimated 4 million metric tons of ore. Since the production records are a total for the district, little is actually known of the actual tons, grades, and metal production amounts from individual mines.

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Biography

Ralph J Stegen is vice president of mine site exploration with Freeport-McMoRan Exploration based in Tucson, Arizona. He is responsible for exploration and resource modeling activities for Freeport's operating and inactive mines or deposits in North and South America. He obtained his M.S. degree under Tommy Thompson at Colorado State University completing research on the manto deposits of the Aspen district, Colorado.

Does the ‘Colorado Mineral Belt’ Best Describe the Distribution of Tertiary Epithermal Ore Deposits in Colorado?

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Lovering (1930) and Tweto and Sims (1963) explain the distribution of epithermal ore deposits in Colorado in different ways. GIS analyses tested the efficacy of their models. The results reveal that Lovering’s (1930) model, when applied statewide, is superior to the Colorado Mineral Belt concept of Tweto and Sims (1963). Lovering’s model provides the best correlation with Colorado’s gold-mining districts and known metallic mineral resources (gold, silver, copper, lead, molybdenum, zinc, tellurium, and bismuth).

The mining districts of Rosita-Westcliffe, Cripple Creek-Victor, Rito Seco, and Hahns Peak, along with others, did not lie within Tweto and Sims’ (1963) “maximum extent” of the Colorado Mineral Belt. The statewide application of Lovering’s (1930) model shows that those supposedly ‘anomalous’ mining districts -- are not anomalous. The results of this study are also consistent with the detailed work of Caine (2007, 2008), Klein et al. (2008), and Wessel and Ridley (2010) showing that the Proterozoic shear zones are not the primary control for ore deposits in the Front Range.

Our study demonstrates that the Proterozoic metamorphic rocks in Colorado provided the first-order, geologic control for the upward migration of Laramide, and post-Laramide, magmas and ore-forming fluids. Additionally, the analysis confirms Lovering’s (1930) conclusion that Proterozoic granitic plutons acted as barriers to upward migration of magmas and ore-forming fluids during the Tertiary. Moreover, our analysis indicates that the Proterozoic granitic barriers probably diverted and concentrated the ascending fluids near the pluton margins. A high percentage of gold mining districts and metallic mineral resources in Colorado occur in metamorphic rocks within one mile of Proterozoic pluton-metamorphic boundaries.

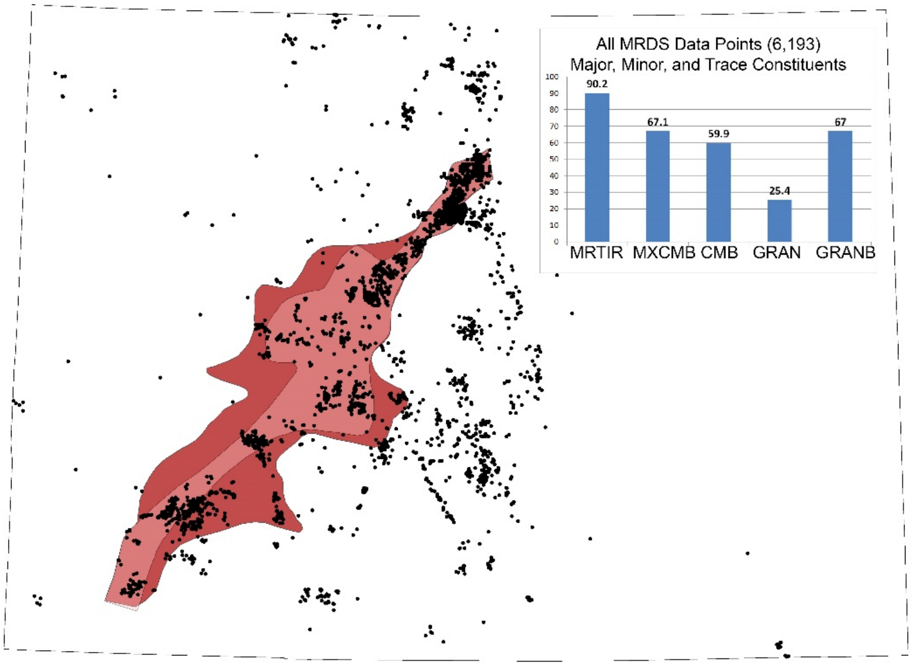

Figure 1. Map of Colorado showing the distribution of data (black dots) from the USGS Mineral

Resource Data System (MRDS) for gold, silver, copper, lead, zinc, bismuth, tellurium, and molybdenum. Tweto and Sim's (1963) Colorado Mineral Belt (CMB) is shown in light red and their Maximum Extent of the Colorado Mineral Belt (MXCMB) is shown in dark red. The graph statistically illustrates the percentage of the 6,193 MRDS data points that fall within the tested polygons (MRTIR = Proterozoic metamorphic rocks and Tertiary igneous rocks; GRAN = Proterozoic granitic plutons; and GRANB = Proterozoic granitic plutons with a one-mile buffer.

Note the large number of points that fall outside both CMB polygons. The polygon with a one-mile buffer around the Proterozoic granitic plutons (GRANB) contains as many MRDS points as the MXCMB of Tweto and Sims (1963). The MRTIR polygon contains considerably more points than the MXCMB polygon. This analysis confirms Lovering's concept that most of the mineral deposits are found in metamorphic rocks associated with Tertiary igneous rocks.

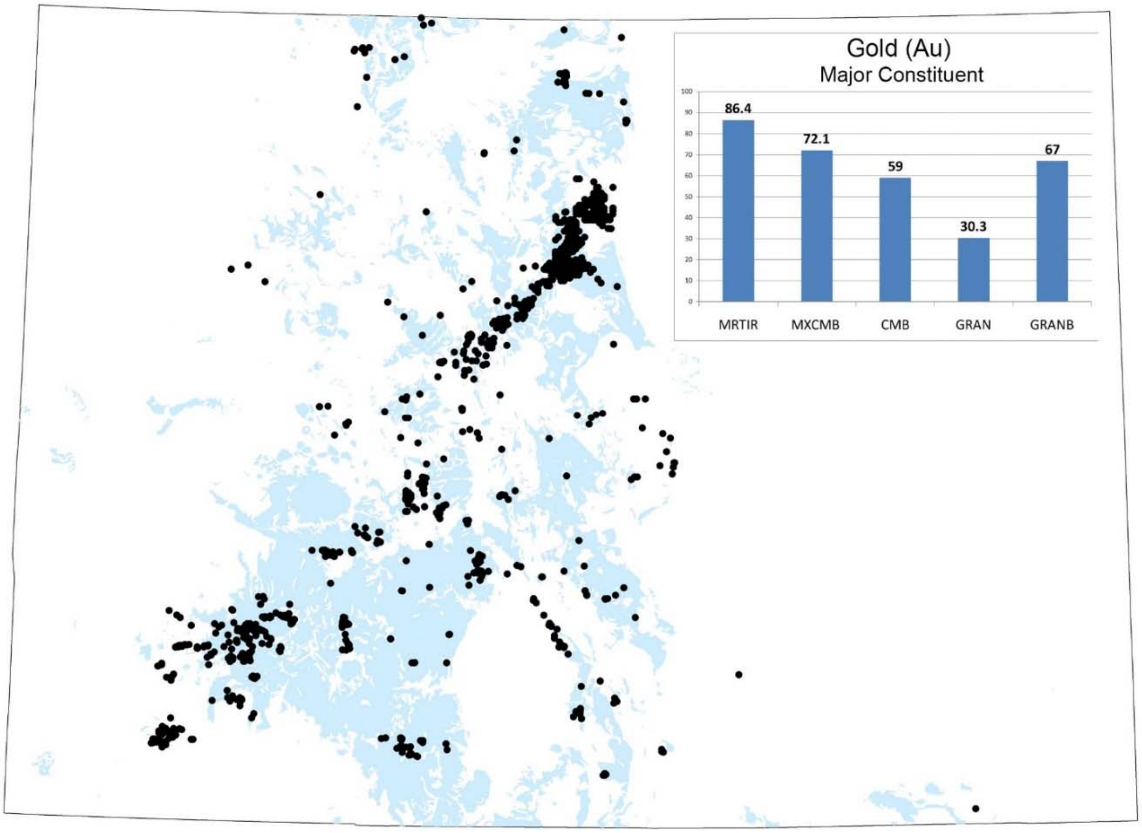

Figure 2. Map showing distribution of MRDS data points (1,187) where gold (Au) is a major constituent. The blue areas are the MRTIR polygons. Note in the summary graph that the GRANB polygon contains a higher percentage of points than the CMB and nearly as high as the MXCMB polygon. However, the MRTIR polygon contains the highest percentage.

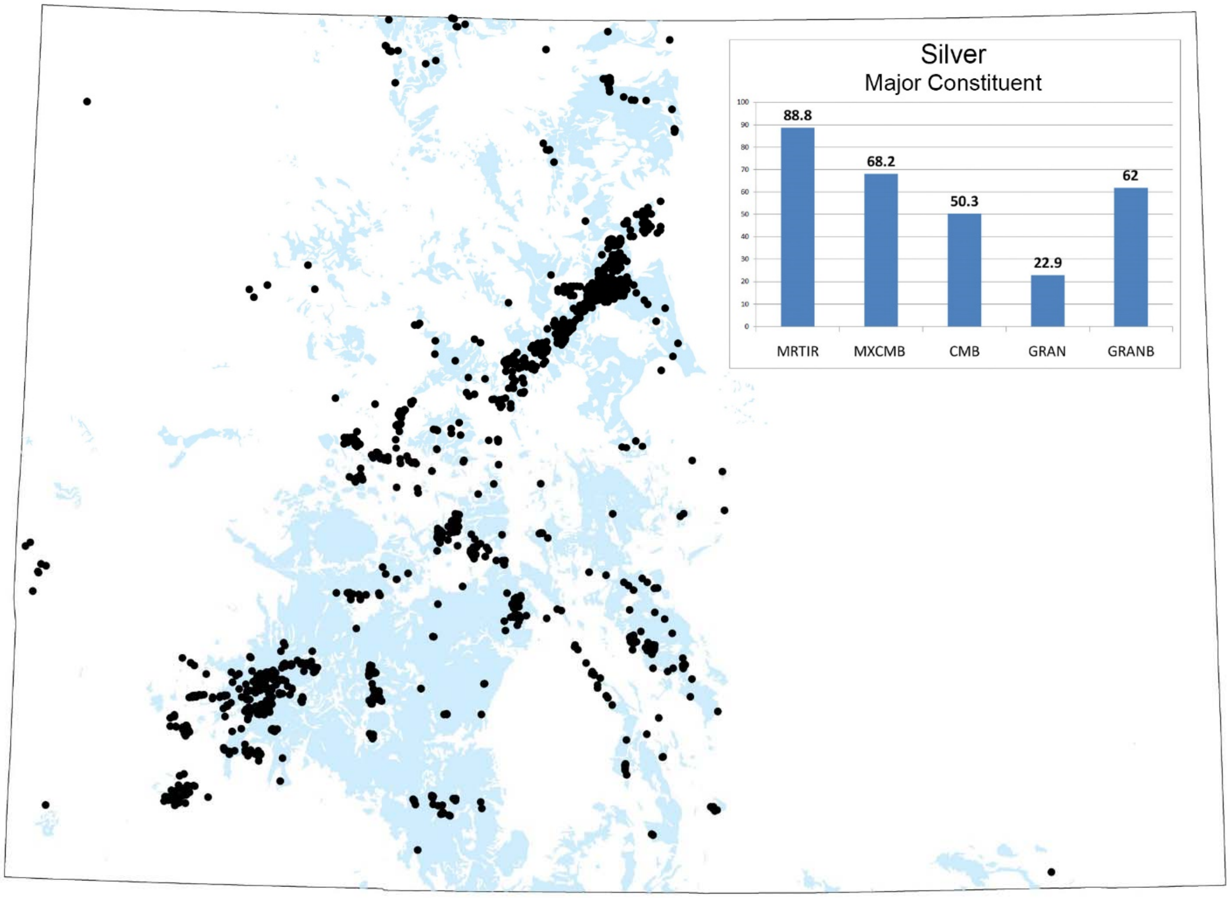

Figure 3. Map showing distribution of MRDS data points (1,504) where silver (Ag) is a major constituent. The blue areas are the MRTIR polygons. Note in the summary graph that the GRANB polygon contains a higher percentage of points than the CMB and nearly as high as the MXCMB polygon. However, the MRTIR polygon contains the highest percentage.

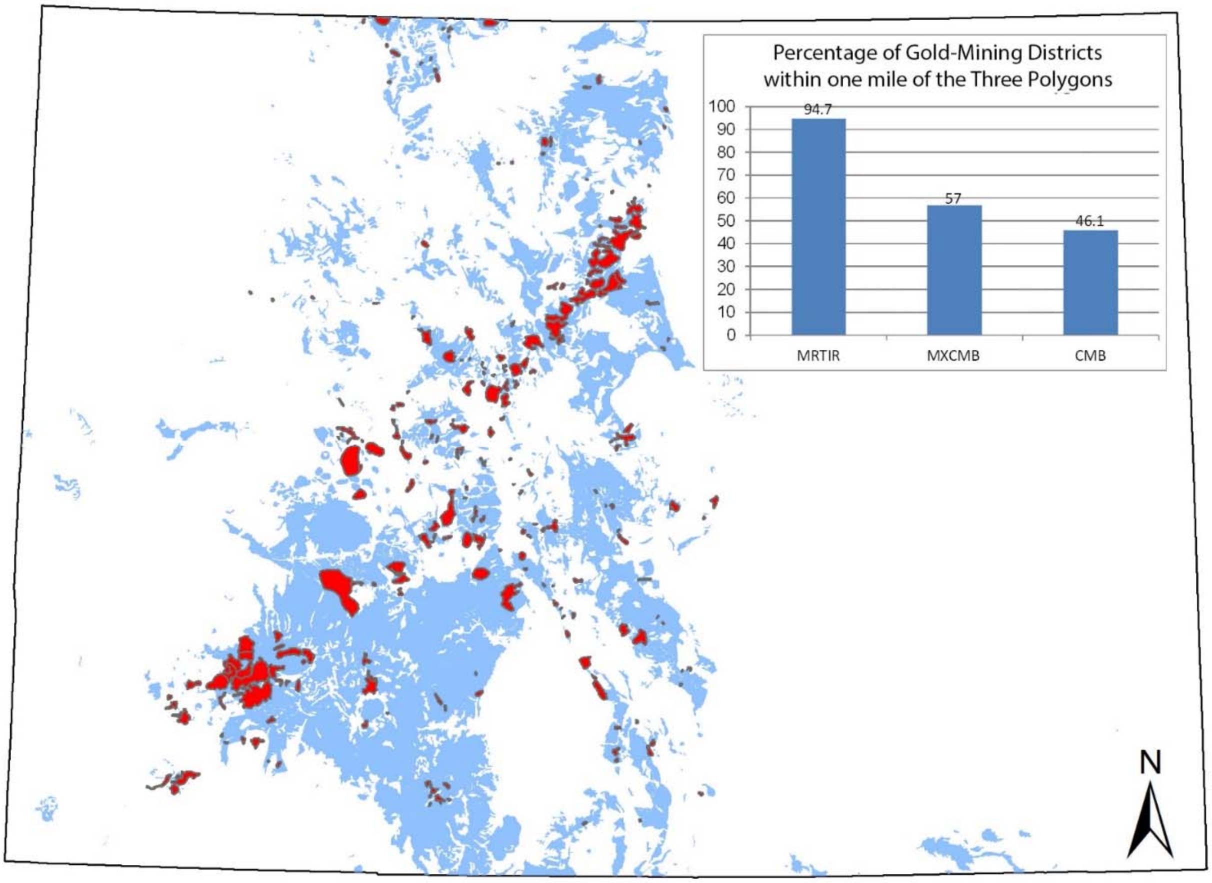

Figure 4. Correlation of gold-district outlines from Davis and Streufert (1990) with three polygons. A one-mile buffer was put around the gold-district polygons to account for their subjective nature. The percentage falling within MRTIR is more than double those falling within the CMB polygon and significantly greater than the MXCMB polygon.

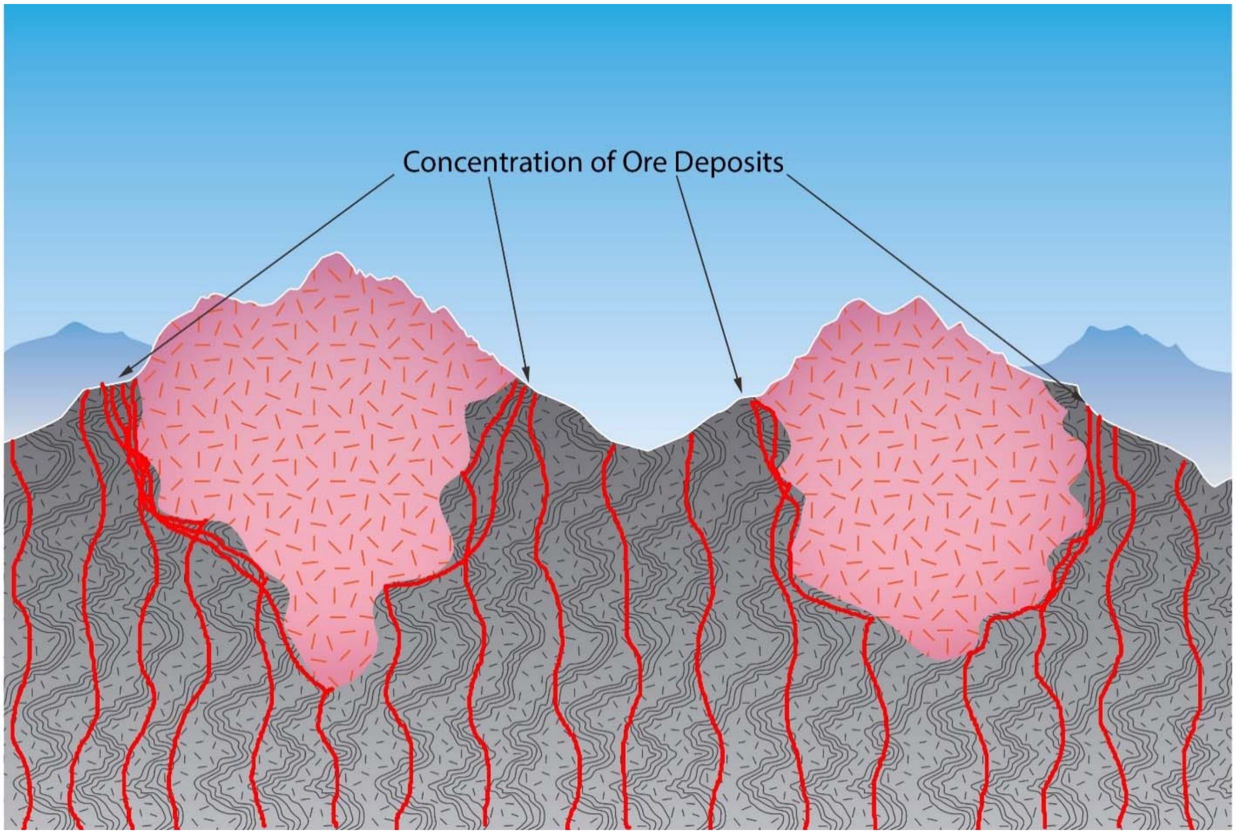

Figure 5. Conceptual model of how Proterozoic plutons can act as barriers to rising ore fluids and possibly divert the fluids to the metamorphic rocks near their margins.

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Biography

Dr. Vince Matthews retired as State Geologist and Director of the Colorado Geological Survey at the beginning of 2013. He then served as Interim Executive Director of the National Mining Hall of Fame and Museum and still serves on the Board of Directors.

Vince received Bachelors and Masters degrees in Geology from the University of Georgia and a Ph. D. from the University of California, Santa Cruz and holds Outstanding Alumnus Awards from both institutions. He taught at five institutions of higher education and served as an executive in four, publicly-held, natural-resource companies.

Matthews is a Senior Fellow in the Geological Society of America where he served as General Chair of the 125th Anniversary Meeting in 2013. He is the 2014 recipient of the Pioneer Award from the American Association of Petroleum Geologists.

Silver as a Precious Metal from the Greeks to Today

Ed Raines

Only a multi-disciplinary approach produces a real understanding of the precious metals story. Geology and mineralogy combine with mining and metallurgy to provide four of the pillars which support civilization. In addition the art and technology of metals processing allows a manufacturing effort to provide products for the market. And finally, economics provides the glue that sticks it all together. Did I say finally? My mistake--nothing is final in a political world.

While many sources seem to settle on a date of around 6000 BC for man's first use of gold, the exact date is unknown. Gold jewelry was in use by the Egyptians by 3000 BC, but it should be noted that at that time the Egyptians used barley as a medium of exchange! It was not until around 700 BC that the Greeks began to manufacture tokens that could be exchanged in place of barter. Scattered Greek archaeological sites have produced irregular lumps of metal mostly gold, silver, or electrum (a naturally occurring mineral alloy containing at least twenty percent silver). Even though a merchant or buyer would be a fool to deal in such tokens without weighing them, these tokens were probably used as an accessory to bartering for several centuries before true coins came into use. Herodotus tells us that King Croesus struck standardized (98%) gold coins embossed with an image of a lion's head beginning around 650. BC. Croesus's source for the gold was electrum nuggets recovered from placer mines on the Pactolus River along the base of Mount Tmolus in Lydia (located in the western present-day Turkey).

In the search for and exploitation of precious metals, gold has always led the way with silver following. Perhaps a better way to put it is that gold placers are easier to find, easier to work, and require less up front capital than underground silver deposits. Gold is also easier to work than silver, and maybe the most under-appreciated contrasting characteristic is that people seem to like shiny yellow more than shiny gray-white. Never-the-less, within a short time, the Greeks were soon mining and coining silver.

Greece

Lead-silver deposits in carbonate rocks were discovered at Laurion (aka Lavrion or Laurium) on the Attic Peninsula in the city-state of Athens around 3200 BC, and by the 5th century BC silver was a very important part of the Athenian economy.

Shortly before the second Persian invasion of Greece, the Athenian state discovered a rich, new horizon of silver mineralization in 483 BC. Themistocles insisted that the silver would be used to finance the construction of 200 trireme style ships instead of simply distributing it to Athenian citizens. Ultimately, this fleet defeated the Persian fleet at the Battle of Salamis in 480 BC, a victory which isolated the invading Persian army and helped lead to its defeat at Plataea in 479. Production declined during the Peloponnesian War (431-404 BC) and was shut down completely by the Spartans when they captured the fort of Dekelia in 413 BC. Laurion's total production has been estimated at 500,000,000 oz. (Marion Butler 1999 and Silver institute)

Rome

Italy does not contain silver deposits that even approach those of Greece. As Rome grew and prospered, it inevitably found itself in conflict with Carthage, the leading power in the western Mediterranean. Conflict erupted between the two powers in 264 BC and evolved into what we now refer to as the three Punic Wars (264-241, 218-201, and 149-146 BC). In 238, during the first Punic War, Rome occupied Sardinia. The Island's base metal carbonate deposits produced enough silver for coinage for the time being, but Rome soon turned an eye toward Spain which had furnished the Carthaginians with a tremendous supply of silver that they used in coinage that circulated throughout the Mediterranean. By the end of the second Punic War, Rome and Carthage were involved in a continuous conflict in Spain, and by about 100 AD, Rome had won control over and was operating Spanish mines that quickly became the leading source of silver in the Mediterranean World.

Spain and Great Britain

Spanish mines were a critically important source of silver for Rome until the fall of the western Empire in 476 A.D. At the same time European trade with the Orient in spices and silk was growing in spurts and bounds, punctuated by screaming halts such as the Moorish conquest of Spain in the 8th century A.D. During next six or seven centuries, discoveries of new silver deposits in Central and Eastern Europe (Schemnitz, Rammelsburg, Freiburg, Joachimsthal, and Kongsburg) supplemented and then surpassed Spain's production. But Spain had an even greater future in precious metals ahead.

Columbus's discovery voyage was meant to get around the invasions and the expansionist Muslim Caliphate that constantly seemed to interrupt the European-Oriental trade. Following the discovery of a "new" land, Ferdinand and Isabella committed Spain to an aggressive quest for various natural resources with gold at the top of their list. After their deaths their daughter Johanna and then their grandson Carlos I (Charles V—Hapsburg King of Austria and Holy Roman Emperor) continued to push the quest for gold to supplement the Spanish Treasury.

What they found was silver. First at Potosi, Peru (now Bolivia) and then in Mexico, the mines of Spanish colonies expanded world silver production by nearly an order of magnitude. Between 1500 and 1800 Mexico, Peru, and Bolivia produced around eighty-five percent of the world's supply of the white metal. The Spanish eight reales (the pieces of eight of pirate movies) coin came to a prominence never achieved by any other coin issue.

Colonial America was silver poor; so was its overlord, Great Britain. The British solution to a lack of precious metals was systematic warfare with Spain that really amounted to nothing more than grand theft or legalized piracy via the British Navy. The British solution continued through the Napoleonic Wars until a revitalized colonial imperialism in India and Australia solved their shortage of precious metals problem.

USA

During the American Revolution, Alexander Hamilton adopted a more civilized solution to the precious metal shortage. The first issue of Continental Currency authorized by Congress on May 10, 1775, carries the words "this bill entitles the Bearer to receive [fill in the denomination of the bill] Spanish milled DOLLARS." Spanish milled dollars were the aforementioned eight reales. The Spanish eight reales was legal tender in the US until the passage of the Coinage Act of 1857.

During the 19th westward migration of the US, numerous richly mineralized areas were exploited from California and Nevada to Colorado and South Dakota. First at the Comstock Lode, then at Leadville, and finally in the Coeur d'Alene the US found so much silver that it became an economic problem that forced a political solution.

Addenda / Thoughts

Throughout the world, exploitable silver occurrences vary from carbonate-hosted lead-zinc-silver deposits to polymetallic vein deposits. The mineralization has usually required beneficiation techniques unique to the ores from cupellation to amalgamation to flotation to smelting. The industrial revolution has vastly improved metals processing technology. Our understanding of economics has evolved into various schools of thought, each competing in the political arena, but often in detriment to the economic well-being of mankind.

Biography

Ed Raines is the Collections Manager at the Colorado School of Mines Geology Museum. He has studied, written about, and spoken on Colorado Mineralogy, Geology and Mining History.

The Breckenridge Mining District, Summit County, Colorado

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There has been one hundred years of mining in the Breckenridge mining district, starting from 1859 and ending in 1959. This has generated on the order of one to one and a half million ounces of gold, nearly one million ounces of silver, and tens to hundreds of millions of pounds of zinc and lead from gold lodes, placers, and Zn-Pb-Ag veins.

The dominant mining operation in the district was placers. More than $15.5 million worth of gold (at historical prices of $17.50 to $35 per ounce) were recovered from district placers. Ransome (1911) described three types of placers: shallow gravels in gulches, bench or high level placers, and deep or low-level placers. The gulch gravels were the first worked with simple sluices and gold pans. These gravels could be quite rich. For example, the Gold Run Gulch placer was known in the early days of the district as the "Pound Diggings", as it was said to have yielded no less than a pound of gold per miner per day (Ransome, 1911). In today's prices, this would be on the order of $18,000/day. Placers at the mouth of Barney Ford Gulch in 1861 were said to yielding $3.64 a pan or more than 0.1 oz/ton (Parker, 1974). Some of the district's richest placer ground occurred at the mouth of Galena Gulch where a 29 ¼ oz nugget was reported (Ransome, 1911).

Hydraulic mining of bench gravels soon followed. By 1870, French Gulch had 27 km of ditches, 2,000 m of flumes, and 5 hydraulic monitors mining the stream gravels (Parker, 1974). The bench gravels were largely mined out by 1900. Attention then turned to the deep gravels of the Blue and Swan Rivers. Initially, these placer were treated with hydraulic elevators with unsatisfactory results owing to very large boulders clogging the operation. This was solved through the use of dredges which were successfully employed in the district beginning in 1906. At least eight dredges operated in the district; these were of multiple generations, including an early steam type. One of the earlier dredges cost an estimated $35,000 to construct; it was soon yielding $1,000 a day in gold (Parker, 1974). The heyday of dredge mining was from 1906 to 1924. In the late 1930s, dredging activity declined, and after 1947, there was only small scale sporadic activity (Parker, 1974). Dredging activity ceased in 1959. The remains of one of these dredges (known as Reiling gold dredge) can still be seen in French Gulch about 300 m west of the Country Boy mine.

Lode gold mining started in 1869 and continued until 1959. Lodes were the chief source of gold in the district from about 1885 to 1908 when their production was superseded by large scale placer dredging operations. On the order of twenty-five to thirty veins were exploited throughout the district.

In 1880, the railroad arrived in the district. This allowed cheap transport of base metal ores to Denver smelters, and production of zinc, lead, and silver ores became economically feasible. The Wellington mine, on the north side of French Gulch approximately 2.5 km east of Breckenridge, was the largest lode mine in the district. At the Wellington, there are over 20,000 m of tunnels and shafts through a vertical range of 238 m. From 1887, when production started, to 1929, over 737,000 tons of ore were produced, yielding 165 million pounds of zinc, 41 million pounds of lead, 750,000 ounces of silver, and 6,500 ounces of gold. (Lovering and Goddard, 1950). This leads to estimated grades of 0.01 oz/t Au, 1 oz/t Ag, 3% Pb, and 11% Zn. The Wellington mine was inactive from 1929 to 1948. Between 1948 and 1958, production occurred in the portion of mine above the water table. Over 58,000 tons of ore were mined with grades on the order of 0.04 oz/ton gold, 3 oz/ton silver, 10 per cent lead, 14.5 per cent zinc, and 0.4 per cent copper (Wallace et al, 2003). There was some minor exploratory drilling toward the end of the mine's life. In 1960, a core hole was drilled and said to contain eight feet of high grade material (exact values unknown; Asarco private report, 1990). This intercept was interpreted as the faulted extension of the Great Northern vein, which was the principal producer in the mine during the period 1910-1926. As far as is known, the intercept was not followed up.

The general geology of the Wellington Mine consisted of a vein complex within a hornblende biotite monzonite stock. Sections drawn by Lovering (1934) show considerable structural complexity. In general, veins at the Wellington mine strike northeasterly and dip 60 to 65 degrees, typically to the southeast. The main vein consisted of irregular shoots of sphalerite and galena scattered through a strike length of 900 m. Ore shoots tended to occur at strike changes or where the vein steepened (Lovering and Goodard, 1950). These were sulfide veins (pyrite-sphalerite-galena) with minimal quartz gangue. Much of the sphalerite is dark brown to black and iron rich. Sulfides tend to be massive with no crustification or depositional banding. Gangue is dominated by siderite and ankerite and appears to be late relative to the sulfides. At depth, the veins became more pyritic and non-commercial. Vein widths varied from a few cm to 10 m; 1.5 m was the approximate average (Lovering, 1934).

Adjacent to the veins, the igneous wallrock was converted to an aggregate of sericite, quartz, ankerite, and minor disseminated pyrite. Garnet-epidote-magnetite skarn occurs in the calcareous portion of the Morrison Formation near the Wellington mine; there is also significant bleaching/hornfels of sandstone and siltstones.

The northern part of the district contains a series of small, intensely sericitized, quartz monzonite porphyry stocks containing stockworks of gold-bearing iron-oxide quartz veinlets, typically 0.2-0.5 cm wide. Individual veinlets typically have limited extent along strike (less than 10 m) and contain quartz as druse or crystals parallel to the plane of the veinlet, commonly overgrowing the original quartz phenocryst. Subparallel arrays of these veinlets were mined in bulk in glory holes with stope widths up to 18 m (Ransome, 1911). At some occurrences, the Jumbo mine for example, there were true veins up to 1 m wide containing high grade gold values, 1-8 oz/T Au (Summit County Journal, 1927); at other localities, only irregular veinlets are present.

The largest mine of this type was Jessie, with an estimated production of $800,000 to $1.5 million worth of gold prior to 1909 (Ransome, 1911). Stopes at the Jumbo mine are similar in size to those of Jessie, suggesting a similar amount of production. Other occurrences of porphyry quartz monzonite with stockwork iron oxide-Au veinlets include the Hamilton, Cashier, and I.X.L. mines with estimated production on the order of $200,000 to $500,000 worth of gold (Ransome, 1911). At depth, the Fe-oxide –quartz veinlets transition to sulfide veinlets containing, in decreasing order of abundance, pyrite, sphalerite, and galena. Grades of the hypogene material could be quite high. For example, ore shipped from the Cashier averaged 0.55 oz/ton Au, 10 oz/ton Ag, and 5% Zn (Ransome, 1911).

At Jessie, the quartz monzonite porphyry was pervasively altered to sericite; even K-spar megacrysts have been converted to sericite. This occurs in areas associated with greater than 10% veinlets. In areas containing lesser quantities of veinlets, the accompanying wallrock alteration is less. Relict K-feldspar is present and kaolinite shows up in the ground mass. Propylitic alteration with only minor conversion of K-feldspar to sericite and biotite altered to chlorite (instead of sericite) is found at the margin and fringes of the intrusion. The adjacent

Pierre shale is typically unaltered and unmineralized even where adjacent to stockwork veining in the intrusive.

At the I.X.L. mine, located 1 km east of Browns Gulch, irregular veinlets of pyrite, sphalerite and galena in a quartz monzonite porphyry were accompanied by strong sericitic alteration and local hornfels and skarn (garnet-pyroxene-pyrite-pyrrhotite) of Niobrara Formation limestone. Secondary biotite and K-feldspar were reported in drill holes at depth beneath the I.X.L. workings (FMC private report, 1989) and there were rare quartz–molybdenite-pyrite veinlets reported within the workings (Stednick and other, 1987).

The Gibson Hill area, in the northwestern part of the district, featured veinlets, replacement, and disseminations of Fe-oxide–Au contained within bedding plane shears and fractures in Dakota Sandstone. These were known as blanket deposits (Lovering and Goddard, 1950). Similar deposits were also noted from Shock Hill and Little Mountain. Unoxidized dump samples revealed stockwork veinlets of pyrite-sphalerite-galena-quartz and calcite. Gold and silver were distributed among many small fractures or segregated into local high grade pockets. Lovering (1934) described "mud" seams consisting of altered rock selvages along bedding plane slips in quartz-rich sandstone which assayed 0.5 to 2 oz/t Au. The abundance of skarn and hornfels coupled with a near-radial array of faults suggests that an intrusion at shallow depth underlies the sedimentary rocks at Gibson Hill.

The Breckenridge district is noted among mineral collectors for the specimens of leaf and wire gold from Farncomb Hill in the southeastern part of the district. Here thin veins, rarely exceeding 1 cm in width, occur in Pierre shale near quartz monzonite porphyry sills (Ransome, 1911). The veins had remarkable continuity given their extremely narrow widths, with a maximum strike length on the order of 90 m. The pockets of native gold were restricted to the oxide zone and occurred as small pockets of crystalline native gold in a limonitic matrix. Occasional remnants of calcite were found suggesting that is was the principal gangue mineral. Traces of pyrite, sphalerite, galena, and chalcopyrite were found in the veins at depth. The typical occurrence was as a thin barren fracture, which on rare occasions would contain a pocket perhaps 0.5 to 1 meter long and up to 2.5 cm wide, containing a nearly continuous mass of hackly gold within a matrix of limonite (Ransome, 1911). The gold appears to be a supergene enrichment effect. The specimen value of the Farncomb Hill gold was appreciated early on; much remains from the discoveries. The Denver Museum of Science and Nature has an extensive collection of specimens from Farncomb Hill; the largest one is termed "Tom's Baby". Discovered in 1887, it weighs approximately 13 pounds (Ransome, 1911).

The overall geology of the district is dominated by Jurassic-Cretaceous sedimentary rocks which have been intruded by small stocks, dikes and sills of monzonite and quartz monzonite porphyry. PreCambrian gneiss is only locally exposed in the far western portion of the district; this is directly overlain by the Maroon and Chinle Formations of Pennsylvanian and Permian age. (Lower Paleozoic rocks, which are highly productive units in nearby districts, were eroded off here following uplift of the ancestral Rockies.) The Maroon and Chinle Formations are overlain by the Jurassic Morrison and Entrada Formations and the Cretaceous section of Dakota Sandstone, Benton Shale, Niobrara Formation, and Pierre Shale. The sedimentary rocks were folded and complexly faulted during the Laramide. At the northwest end of the district, the sedimentary rocks strike N-S with eastward dips. Further east, they strike E-W with shallow northerly dips. Just east the Blue River on the west side of the district, there is a large, highly faulted, north-south trending anticline (see A-A' in Wallace et al, 2002) which may be the continuation of the Hoosier anticline mapped further south.

Intrusion of Eocene age sills, dikes, and small stocks of first, monzonite and then slightly later, two varieties of quartz monzonite porphyry, followed Laramide folding and faulting. Locally accompanying the quartz monzonite porphyry were intrusion and hydrothermal explosion breccias; these are typically seen in the eastern part of the district. Cocker and Pride (1979) suggested some of the igneous intrusives may have vented to the surface; however, coeval volcanics are not present in the district and presumably have been eroded away (if they ever existed). From oldest to youngest, based on crosscutting field relations, the igneous units include a hornblende biotite monzonite, a quartz monzonite porphyry, and a quartz monzonite megacrystic porphyry; the latter with K-feldspar megacrysts up to eight centimeters in length. All three igneous rock types are considered to have been emplaced close together in time (Ransome, 1911; Lovering, 1934; Wallace et al, 2003). The monzonite porphyry tends to occur as sills. The quartz monzonite porphyries occur as dikes, sills, laccoliths, and small stocks. Mineralization at Jessie, Jumbo, Hamilton, I.X.L., and Cashier is directly related to the megacrystic quartz monzonite porphyry. This unit has been dated at 43-45 Ma (Bryant et al, 1975; Simmons and Hedge, 1978).

Cocker and Pride (1979), among others, have proposed that the district is underlain by a Climax-type porphyry molybdenite system; this is viewed as unlikely. The only known occurrence of potassic alteration (at the I.X.L. mine) was drilled to depths of 240 m; no molybdenite mineralization was encountered (FMC private report, 1987). Three deep drillholes in the Wirepatch area (near Farncomb Hill) were said to have been drilled in 1977 in search of molybdenum; no molybdenum mineralization was encountered (FMC private report, 1987). Moreover, age dating suggest that the igneous/hydrothermal mineralization events at Breckenridge are significantly older than known molybdenite mineralization elsewhere in Colorado (Bryant et al, 1975).

The deposits at Breckenridge are believed to represent telescoped porphyry Zn-Au deposits. A closer analog may be the Fe-rich sphalerite-galena-pyrite veins at St. Kevin or Central City, Colorado which have a similar metal suite (Lovering and Goddard, 1950).

The last significant period of exploration in the district occurred in 1983-1990, focusing on gold. Anaconda and FMC both had drill programs in the eastern part of the district; ASARCO, under the direction of the author, had a two-year drill program in the western part of the district. Some details of the exploration results can be found in Kellogg et al, (2002); Wallace et al, (2003); and Widmann et al, (2003). In general, although some interesting intercepts were encountered, overall continuity was lacking. This, coupled with the then relatively low gold price ($386/oz Au), caused the curtailment of exploration activities.

In 1961, the Breckenridge ski resort opened on the lower slopes of Peak 8, west of the town. In that first year of operation, there were approximately 17,000 skier visits. Over the years, the ski resort has expanded to encompass five peaks, with over 1.6 million ski visits per year (Breckenridge Ski Resort web site {www.gobreck.com}, 2017). Accompanying the expansion of the ski resort has been the conversion of patented mining claims to summer homes and ski chalets; these have been increasingly upscale. This activity accelerated in the mid to late 1980s, continuing to this day. The community is now solidly anti-mining, except where its mining history is concerned. In 2005, the Summit County commissioners (Breckenridge is the county seat) passed an anti-cyanide initiative, this, in an effort to preclude modern open pit gold mining. The cyanide initiative was overturned by the Colorado Supreme Court in 2009. Nonetheless, additional mining of metallic resources in the district is viewed as extremely unlikely.

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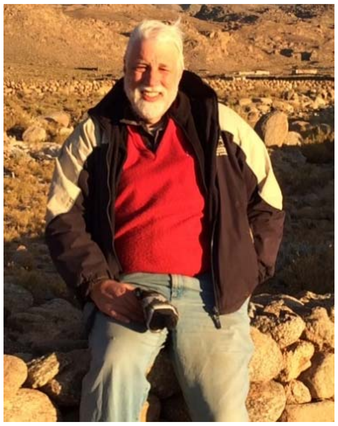
Biography



In my career as an exploration geologist, I have been involved in six discoveries including porphyry and skarn copper-gold, bonanza gold-silver veins, high sulfidation, and Carlin-type deposits and have worked throughout the U.S. and Latin America, employed by major and junior mining companies, as a consultant, and as an academic. While at the Colorado School of Mines, I designed and had built the new Geology Museum. I am the author of 27 scientific publications and co-author of 5 geologic quadrangle maps. I'm currently Chief Geologist Americas, Greenfields Exploration for AngloGold Ashanti. I was involved in exploration of the Breckenridge district in 1988-1990, and am a co-author of the three published quadrangle maps that cover the district, having written the economic geology section in all three supplemental reports.

Cash Mine: 3rd level Mining, Milling and Ore Microscopy

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This gold-silver telluride mine is in the Gold Hill Mining District, Boulder County, Colorado, USA at 9145 Sunshine Canyon Drive. Placer gold was first discovered in the county in 1859 at Gold Run whose watershed includes the Cash Gulch. The gold-silver telluride veins were discovered later and staked in 1872.

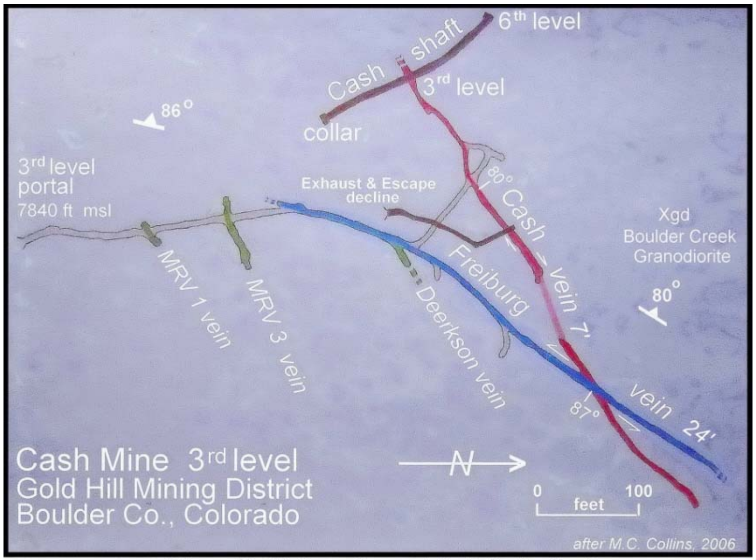

Figure 1. Major veins and their fault offset .

Amphibolite grade metamorphic units were intruded and assimilated by the Boulder Creek Granodiorite, a 1.70 Ga (Gable, 1980) catazonal pluton. The continental scale 1st order Colorado lineament extends to Lake Superior and includes the Precambrian Idaho Springs – Ralston shear zone 14 miles south of the district (Warner, 1980). This trend finds a very wide variety of hydrothermal ore deposits and a series of post-Laramide shallow intrusives. The mining district is one of several gold-silver telluride and tungsten districts in the northern end of the NE-SW trending Colorado Mineral Belt. This orientation is cross-cut by the 2nd order northwest trending, Laramide-reactivated, Precambrian faults or breccia reef structures including the Hoosier breccia reef west of the mine. The possible age of the Cash ore may be extrapolated from the Eureka Mine four miles south at 48 myr (Paschis, 1973). Both deposits contain scheelite. Tungsten and telluride minerals are locally coeval (Kelly and Goddard, 1969) and support that timing for the Cash Mine mineralization. Ore deposit emplacement was beneath at least 2,000 feet of the Boulder Creek pluton topped by the Eocene Flattop peneplain of the Colorado Front Range. The Cash shaft followed the steep northwest dipping vein to the 9th level.

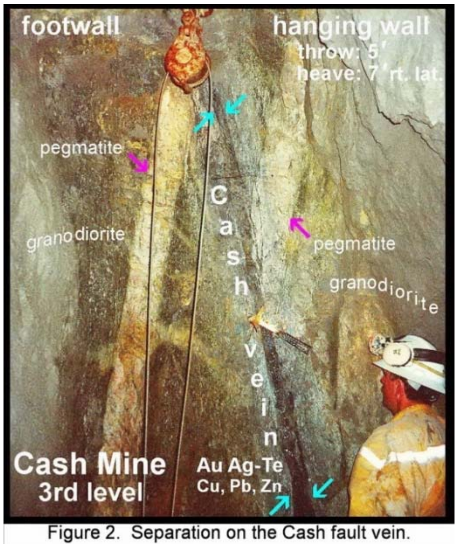

Figure 2. Separation on the Cash fault vein.

Mine mapping by Russ McClellan in the 1950's with assays guided ore reserve demarcation into the 1960's. Where accessible, those reserves were rechecked and found credible. This encouraged Mount Royale Ventures to lease and develop the 3rd level adit (Collins, 2006) and mine farther and peripheral in several of the veins shown in Fig. 1. The Cash fault vein separation maybe seen in Fig. 2. Open spaces created in the pre-veinfault were the important ore-hosting feature. Note that the vein width widens as the pre-vein fault steepens. Cash pre-vein fault geometry (right lateral and normal throw components) controlled ore localization. Details of ore mineralogy may be seen using ore microscopy. An example of mineralization in a narrow quartz vein is shown in Fig. 3. The left half is shown in plane polarized light (PPL). Under crossed polarized light (+PL) the major mineral hessite is last in the paragenesis of this mineral association. It is identified by anisotropic blue

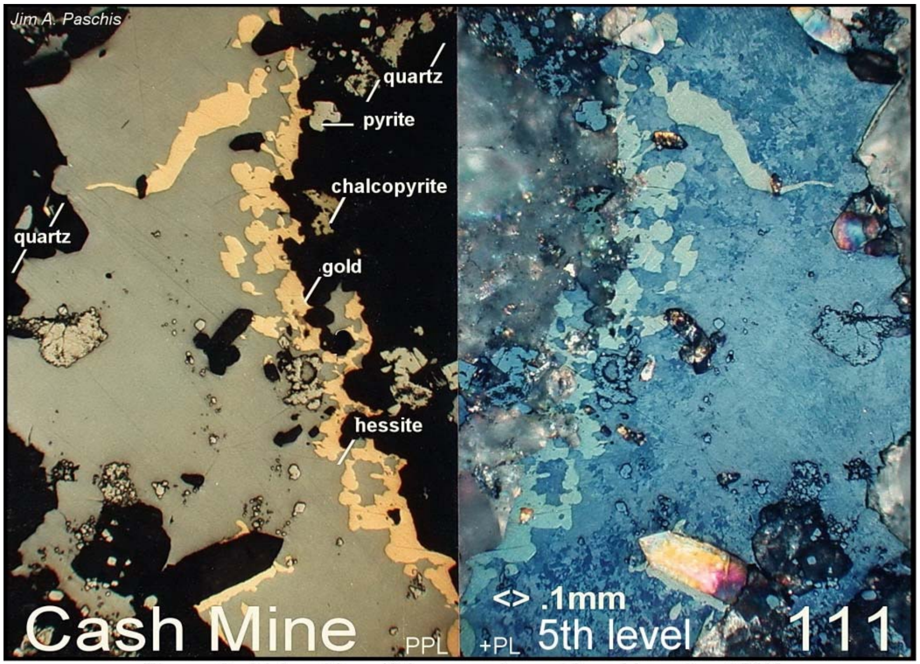

Figure 3. Vein with sulfides, quartz, gold and hessite. 150X

colors. Early sulfides of pyrite, galena, sphalerite and chalcopyrite and very late rare scheelite are associated with the tellurides. Gold in vugs is found as fine leaves, rarely as striated, curled horns or as inclusions in the common silver telluride – hessite, with petzite on the 3rd level. Fine-grained, dull to dark gray, quartz locally known as "horn quartz" is the common chalcedonic gangue with subordinate carbonates and clays. Underground vein sampling widths for assaying included the vein and the argillic alteration flanks. Mining and milling included these components to reduce acid-generating pyrite in the tailings impoundment.

During 2009 3rd level stopes were in production to provide 50 tons-per-day to the Gold Hill Mill at the property entrance. The mill used flotation and gravity methods for ore mineral concentration. The flotation circuit concentrate was assayed prior to shipping to the smelter. One check using XRF analysis confirmed fire assay values for the -60 mesh flotation product gave 12 ounces gold per ton. An example of the concentrate may be seen in Fig. 4, using ore microscopy. Note that in this example a gold grain appears closely associated with sphalerite. More commonly gold was deposited after the base metal sulfides. This concentrate was in much greater amount than the gravity circuit. Concentration by gravity was accomplished using a Knelson centrifugal concentrator to recover gold-tellurides and sulfides. It operated under 60g and is shown in Fig. 5. The inset presents concentrate with six dense minerals in various stages of abrasion from the ball mill and passing through the Knelson. The apparent lack of abrasion to most of the galena fraction is a result of final in-situ cleavage during traverse under high acceleration.

Figure 4. Selected view of minerals recovered by flotation. 200X

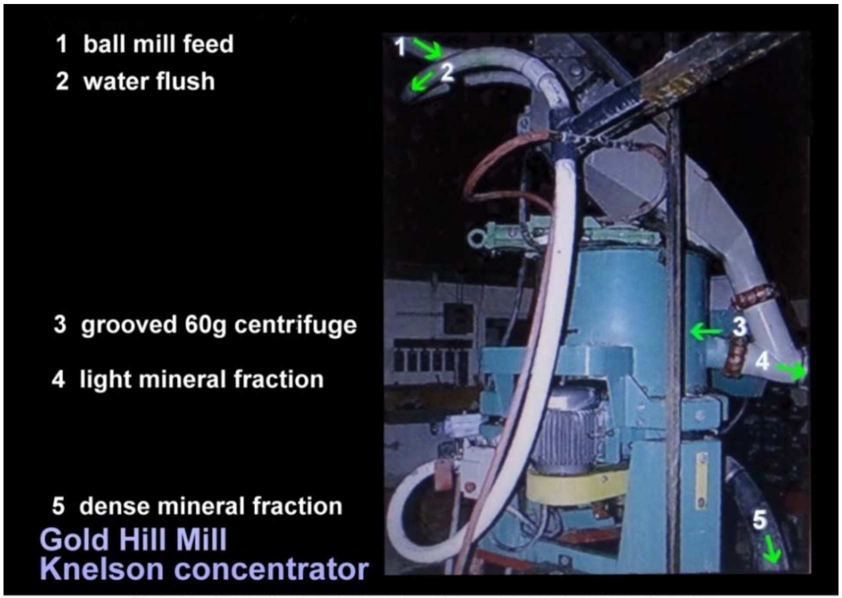

Figure 5. Inset showing dense mineral concentrate: 1. galena, 2. pyrite, 3. sphalerite, 4. hessite, 5. gold, 6. pearceite. 100X

In Fig. 6, shown under PPL, gray hessite follows dark gray euhedral quartz. Quite conspicuous is the gold filling many fractures. These range in shape and width. As (originally cubic) hessite cooling takes place below 155º C, it reduces density and becomes monoclinic (Palache and others, 1944) resulting in anisotropism previously shown in Fig. 3. This dimorphic expansion results in very fine curvilinear fractures. In this ore sample hessite was apparently confined in a quartz vug. The ensuing expansion under confinement generated broad stress on the hessite resulting in greater strain and larger fractures. These fractures are occupied by coarser gold. This microscopically integral structural association with deposition gives inference that the hessite was deposited above 155º C and gold in this ore was deposited below 155º C. Kelly and Goddard, 1969, concluded that the Boulder County telluride deposits with native gold were deposited at 100 +/- 10º C.

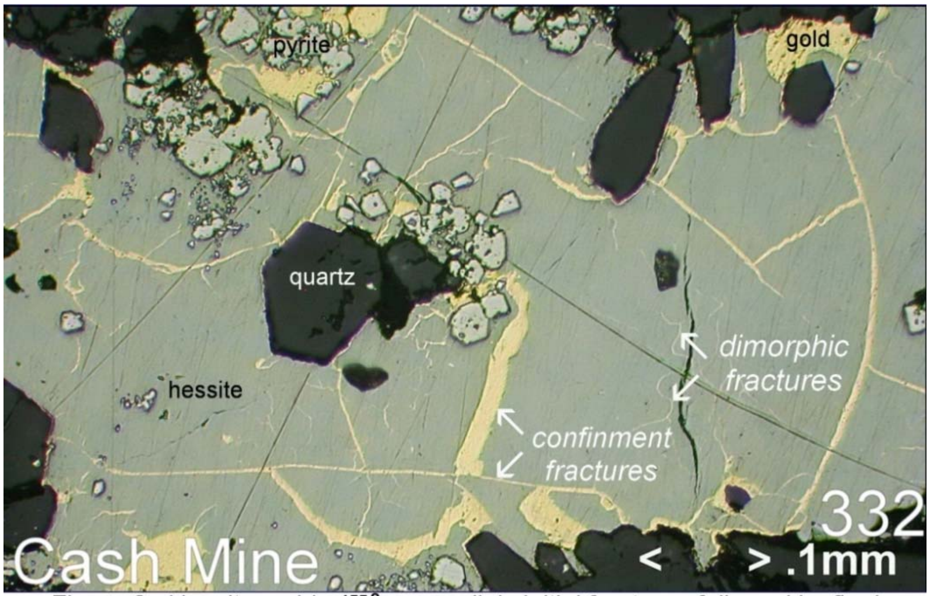

Figure 6. Hessite: cubic $\xrightarrow{155°}$ monoclinic initial fractures followed by final stress confinement fractures with gold in-filling.

On the macroscopic scale shown by the Cash vein, it diminishes in width and heave as the workings progressed to the northeast. The Freiberg vein appears the more dominating structure toward that trend. Precambrian textural control is suggested where the ore-hosting veins are within shears often subparallel to narrow granitic pegmatites.

The concentrates were shipped to Torreon, Mexico for pyrometallurgical recovery of gold and silver. Cash Mine ore has a general elemental ratio of Au : Ag = 1 : 7 which is consistent with the historical record. The production by MRV was 1,600 oz gold and 11,470 oz silver.

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Biography

Jim won his Brunton compass in a single jack contest and earned his MS degree at Colorado School of Mines. He provided geologic input for deeper development at the Schwartzwalder Mine north of Golden. He supported the profession as the Denver Region Exploration Geologists’ Society field trip chairman and volunteered as a field guide and lecturer to the Colorado Mining Association Education Foundation for 45 years. Jim was senior mine geologist at the Cash Mine and is nearing completion of the Atlas of Gold Ore Microscopy.

Central City District: $100 Billion in Au+Ag, 3 shaky models, 4 unsolved mysteries, and consequences

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This presentation first outlines great accomplishments and failures during the 19th century: the 40 years that yielded most of the precious metals from the Central City District (CCD). Situated in Gilpin County, this wide band of gold, silver and base metal mines became the largest early-day metal producer of the Colorado Territory. It attracted a large transient population and spectacular sums of foreign and domestic capital during the decade following discovery in 1859. In the American Civil War era, the U.S. Government worked quickly to codify new law and provide pioneer agency assistance, hoping to keep this source of hard currency out of enemy hands. An early "boom and bust" environment gave way to steady production, but little application of available geological science was attempted. The laws from local miners determined how exploration had been done since the 19th Century.

In 1859 the CCD, the first lode gold and silver discovery in Colorado Territory, stimulated great domestic and foreign interest. The surge in metal production and underground exploration in the "wild West" not far from American Civil War activity, provided material for tabloid news. Intense interest in finding lode deposits led to significant issuance of speculative mining stock, notably in London. Overseas capital was spent lavishly on both sides of the Atlantic Ocean. The largest sums changed hands on property purchases and leases.

New mining laws, in l865 and l872, soon legalized fee ownership of mineral rights, a requirement of most investors. Provisions of the "Apex law", (an 1872 departure from non-mineral real estate law) became troubling to landowners and investors. A lack of large ore bodies, similar to "world class" resources identified by discovery of nearby Leadville and (later) Cripple Creek, became evident. Three eras of limited government surveys recorded some conflicting conclusions for public interpretation. A prevalence of tiny lode claims clustered around the best lodes, held by multiple scattered owners and leased to locals, also detracted from spending money on geologic studies and drilling.

This presentation, based on the author's experience mapping surface geology and past involvement with underground mining of small, scattered ore bodies in the CCD, describes a few unusual geologic features in the district. These interpretations need further study; if correct, there are future applications in this unusual district. History of the district began with brief success of placer "exploration" after years of finding nothing. It led to near-surface, hard-rock discoveries, and the founding of Central City. Although information is lacking about those quickly "eradicated" placers, retracing them simulates an effective geochemical exploration technique for today.

The best discovery outcrops of veins showed a heavy brown iron-rich material bearing metallic gold. Soon miners termed this "top quartz". California-trained mining people, certain that gold always occurs in quartz veins, likely coined the term. In search of richer "quartz", entire hillsides were stripped of soil. Few notes on mineralogy and grade of ore sub-croppings of the discovery years are known. Significant coarse metallic gold nuggets came from supergene-enriched outcrop; however, the primary precious metal-bearing ores were not encountered by shallow holes into underlying outcrops. A misconception that most precious metal content could be recovered by simple crushing and mercury amalgamation quickly led to erecting stamp mills the first season. Consequences included failed investments in heavy machinery, and discharge of significant metallic mercury into drainages. Samples and ore body descriptions were poorly recorded or lost during post Civil War economic turmoil and mine abandonment.

Geologic controls of ore were discovered by "exploration during mining" in the next decades, and first focused on veins. Land ownership over any structure came first, and exploration was made by sinking shallow shafts. CCD operators employed little geoscience, and their small claims restricted work to one direction: “straight down” for nearly a century of mining. Ore body character and genesis ideas became partly enshrined by federal survey studies (completed in l918 and 1968). In the 20th century, economic geologic information was generated by early workers with limited prior experience in metal mines, and many later geologists were seeking uranium.

The federal work did not lead to new ore bodies. They found a lack of adequate information regarding mined out, inaccessible or barely accessible inactive underground ore bodies. Almost no exploration drilling, a usual constraint of reality in many big districts had ever been conducted. Synthesis of size, depth extent, metals produced from combinations of old mines, and variations in mineralization across the district suggests some creative alternate models.

The first “unanswered question” or discussion topic starts with striking differences in igneous dikes of different texture and (only pre-alteration) composition, injected widely across the district. Localization of precious metal ores in many mines occurs near a visually –distinct, fine-grained porphyry “type”, typically altered. This has been described and mapped as bostonite. There is no quantitative or modal analysis and this rock name is obsolete in petrography. Dike-ore relationships exposed in several mines involving this “porphyry” describe it as soft, highly altered, argillized (?), color grey to white in freshly broken rock, or as hard, weakly altered lilac-pink rock that fractures randomly, not orthogonally. P. K. Sims and others’ Plate 1 (1963) distinguished bostonite and quartz bostonite. Poorly studied outcrops in wooded areas are noted not far from major mines of the district. Ore in these mines reportedly occurs adjacent to, surrounded by, or terminating against such dikes. Significance of a very hard, altered, tan variety of “bostonite” with visible trains of gas cavities and vesicles is a topic of this discussion. The toughness of boulders of this “vesicular bostonite” is unusual. A very hard blow from a big hammer shatters pieces from edges only. Also, its blocky form and resistance to surficial decay may suggest it was “work-hardened” by “magma kneading” -this needs study. Figure 1 shows an example from Hidden Treasure 1 claim on Quartz Hill.

The Quartz hill bostonite is similar to somewhat altered rocks nearby described as bostonite on USGS maps. Banding and vesicle holes/ texture are evident. Definite fine quartz druses inside some cavities. Shafts following steeply dipping veins encountered this dike (shown in Figure. l), one of multiple magma emplacements into the same structures. USGS authors note an association of bostonite dikes with ore bodies here. Further textural variations in dikes are common here and from dumps from the California mine (Figure 2, see below). Vesicular textures are also seen in dike outcrops near mines at Black Hawk, Colorado.

Figure 1. Fine grained porphyritic dike rock from dump on Hidden Treasure #1 claim on Quartz Hill.

The fluid needed to form expanded vesicles could develop from trapped magmatic gas phase or steam. Field review of more dikes in the district may reveal whether the hot magma was moving when the vesicles expanded. Could gas cavities suggest fluid exsolution, related to alteration or precious metal deposition? If strong flow banding exists, does that suggest that a shallow subvolcanic environment existed not far above this ore zone? Certain patterns might be evident from dump rocks over distances, for example along the trace of the California Dike. The deepest ore bodies in several mines show repeated crosscutting by dikes, by syn-ore age faults through dikes, and faulting of dike-post ore contacts.

A second "mystery" is, whether several overlapping "groups" of ore minerals that occur together really define several distinct "stages" or mineralization events occurred over a period of time. Seen in mines and vein samples, no two groups mutually exclude any assemblages. Classical paragenetic models, some noted by other authors in the CCD trip guidebook, require a specific sequence of events or stages of mineralization, and state it can be documented with polished sections. Arrivals of somehow different fluids, spaced by (unconstrained) time intervals, each depositing a different "stage", are widely claimed. Two observations question this. First, what hydrothermal system could maintain the same stages (in same order? at same time?) of mineral deposition at hundreds of specific veins, and in the structural zones where larger productive vein swarms (lodes) extend across this huge district? The model of "many paragenetic stages" may be documentable at micro scale in a few veins vein over time, but the concept of one ongoing sequence of injections that generated ore throughout the district is problematic. Also, erosion and fault displacement which postdate ore deposition are not considered in the paragenetic sequence questioned here. An alternative concept is local evolution of similar ore fluids controlled by heat flow, where evolving fluid chemistry controls mineral deposition. Observed basement rock mineralogy also is discussed in terms of reactions affecting gold solubility. How might one fluid precipitate these multiple mineral suites which are affected by changes in temperature, elevation, host rock iron mineral content etc.

In addition, mining downward and laterally along structural zones, especially in the most productive areas of the district, frequently revealed bodies of multiple mineralogical (or 'ore deposition stage') character. The intense faulting within many vein exposures at the scale of a stope or mine level makes identification of the "paragenetic sequence" difficult. Alternate, more realistic models of 'ore deposition over time' could also explain sequences.

As at many new and old discoveries elsewhere, geophysics or drilling to seek indications of underlying magma as a source of hydrothermal ores is lacking., But, the presence of such a magma, or a major central plutonic heat source, is a near-standard explanation (except in France) for ore origins at CCD. No sizeable cooling igneous mass somewhere in the vicinity at the proper time has been documented.

The best ore shoots or ore bodies defined beneath near-surface, secondary enrichment zones have generally proven to be small tonnage, steeply to vertically oriented, and widely spaced. Mining of these follows irregular vertical ore columns downward and leads to zones containing pyritic low-grade material, where ore may pinch out along locally complex fault structures. The observed downward development of ore shoots may relate partially to narrow claims or land rights along a mineralized structure. Essentially all CCD ore has been mined from within a series of narrow belts of discontinuous vein zones extending east-northeast across the district. Ore bodies occur as veins within the broader belt or lode, which may not maintain continuity on strike. An example of "horse-tail pattern", in which mineralization shifted between adjacent veins or structures within the width of a single narrow claim, was documented in the Mammoth mine, 1981-1982. This small gold- copper producer needed more ore where a vein, mined eastward and explored over a period of months, vanished within one meter. The ore zone shrank in width, disappeared from the heading, and seemed to split into tiny fingers that bent northeastward into the drift wall. Fortunately, a raise into a new level punched through a wall of barren rock. There, a new parallel vein structure was found that widened to the east. Ore grades died out west of the raise, and small "fingers" of ore angled southwestward. The mineralizing system had "shifted" northward to another nearby parallel structure. Poddy, good grade ore was diluted by least two generations of thin dikes that also shifted position between the structures. One was typically very hard, fine grained porphyritic quartz monzonite, impregnated with gold-bearing pyrite. The other was decomposed "bostonite" altered to white clay and possibly sericite. Mineralization is pyrite predominated accompanied by Cu values. Old workings revealed the l9th century miners had encountered similar "cymoid" displacement of ore veins. Such ore bodies, commonly diluted by similar internal dikes. were difficult to mine cleanly (especially if breaking mine rock were guided by candle light). Potential investors dismissed such CCD veins as unlikely to become large mines.

A poorly- documented, but fortunate reality over time, also decorates CCD mining history. Laws originated locally, and in other early mining districts during the wild western frontier years led to consequences when mineral deposits were sold and mined. At CCD, when impressive ore grades were coming from "the top quartz", expectation was that high value, easily extracted ores would be present downward as continuous gold-quartz veins, as happened in California. This was widely hyped, and the potential for lucrative returns attracted large and small investors. After buying into an unseen "mine", situated across the ocean and halfway beyond into North America (managed from an office London), some investors received their first dividend check shortly after purchasing stock. And, in that unregulated market, they bought more, often at a higher price. They soon discovered they had just received the only dividend ever to be paid by that stock entity. Stock companies promoted building of new mills using unproven technology, and some were built to treat ore not yet discovered.

Potential investors and prospectors were alarmed by such failures, and also upon learning that land tenure for gold claims was maintained mainly by armed possession. After half a decade of underground success, including significant discoveries of deeper primary ores, economic collapse and failure of metallurgical extraction struck. The dose of reality drove away investors in droves. British and European capital retreated back across the Atlantic. Mine workings in the CCD caved in or filled with water. Information on ore bodies and past production was lost over time**.**

Soon thereafter, other new developments benefited miners and everyone else in the the Western United States. Some failures demanded changes. The flows of capital into the country first went through American banks. Gilpin County, Colorado, a region with more gold and silver than was held by banks, became the true “birth mother “, the catalyst leading to Colorado’s rapid assimilation as a U S Territory. Statehood came later. Meanwhile, security was ramped up around America’s new treasure territory. Significant military presence was rapidly provided. Troops set up forts and won skirmishes. Military concerns included hostile neighbors such as Mexico, with government and leadership tied to land- hungry European monarchies that surely hoped to acquire the “Richest Square Mile on Earth”, the name coined by Gen. Ulysses S. Grant, in a speech at Central City. There were warring native tribes, and a semi-independent Mormon territory to the west had already fought off the U S Army once. To the south, the massive military efforts of the Confederacy badly needed “hard” currency that gold provided.

The federal government realized that citizens and mine operations needed access to private land ownership which would benefit the Nation. When remote mountain areas were sold off for very little, everyone benefited. The Union military also needed “hard” money for foreign exchange. The federal government became innovative, and the U S Treasury Department set up the Denver Mint. Cash purchase of any and all of the Territory’s two largest industrial products, unrefined gold and silver, was promised upon delivery to a government mint, with only a small deduction for high quality assaying in a state-of-the-art laboratory. Delivery of monetary metal to distant banks was via Wells Fargo armored couriers. Government ownership of gold and silver was not mandated, but the simple purchase by the mint directly from mines was a bargain.

Another problem appeared: the Central City “ore field” in the l860s was divided into at least 9 little sub-kingdoms, each a separate mining district defined by local statutes and local boundaries. New governments and laws were established in each little camp at Miners Meetings, where a local “congress” of citizen claim owners was empowered to write law. These new democratic entities based on U. S. law developed in California, is the reason the Central City “district” land records are still subdivided and taxes are levied based on those small mining districts with varied legal names. These adjoining districts joined along survey-defined boundaries agreed on long ago. They cluster, to this day, around the seat of Gilpin county government. Variations in district regulations for claim specifications, and the early day granting of fee ownership of surface and mineral rights to U S territorial land using power of “city title” by local officials had consequences felt even today in Gilpin County.

The First Colorado Territorial Legislature, met hurriedly, in the face of threats of a Civil War. It quickly codified law for land ownership, drawing from rules created democratically in numerous “Miners Meetings”. The federal government legalized territorial property assignments on newly federalized land. Many claims, some only 50 feet wide but a few thousands of feet long, were sold and deeded to individuals by the General Land Office in Washington. The mosaic of tiny claims, overlapping and held by local and absentee owners, rapidly limited the scale of exploration for concealed ore bodies.

By the end of 1867, mines in the CCD, including a few veins that extended into Clear Creek County, had produced about 45% of recorded gold production and 80 percent of silver production from Colorado. Government stimulus played a significant role, and provided currency metals.

Gradual success followed some lean early years. In 1871 Gilpin County produced 71% of the base and precious metals in Colorado. Several mining communities gained permanence. In earliest years, frenzied investments created thousands of local labor jobs. But Gilpin County ore rarely yielded good recoveries of gold and silver to the simple stamp mills with mercury amalgamation process brought from California. Soon sales appeared of devices and processes alleged to improve recovery. Much wasted expenditure was followed by successful development of copper smelting in Black Hawk. Gold could be recovered with the copper, for the first time in American history. But the success rate of mining operations, many quite small, remained low. There were no million-ounce mines, although perhaps some produced a half million ounces or equivalent Au-+Ag ounces. A parallel reality was that, unlike in districts developed under later federal mining laws, many significant mines in CCD produced from very small acreage. Those small claims were patented by the federal General Land Office. Many competing mining companies in the district built steam plants and sank inclined shafts in close proximity on many steeply-dipping, subparallel veins. Divided ownership of the district’s thousands of overlapping patented mining claims, commonly miniscule in size, led to hundreds of small under-capitalized operations. Secrecy was encouraged by threats of apex litigation. Deep shafts, with the latest hoisting and pumping equipment of the times, were sunk only a short distance from similar production facilities on adjacent properties. Land owners did not benefit from these inefficiencies. Economies of scale, with shared facilities and information, might have led to success instead of to many corporate failures.

The California mine on Quartz Hill exemplifies the land problems of the district. Its owners erected a multi-story plant on a single small claim, shown here with some surrounding land ownership as Figure 2.

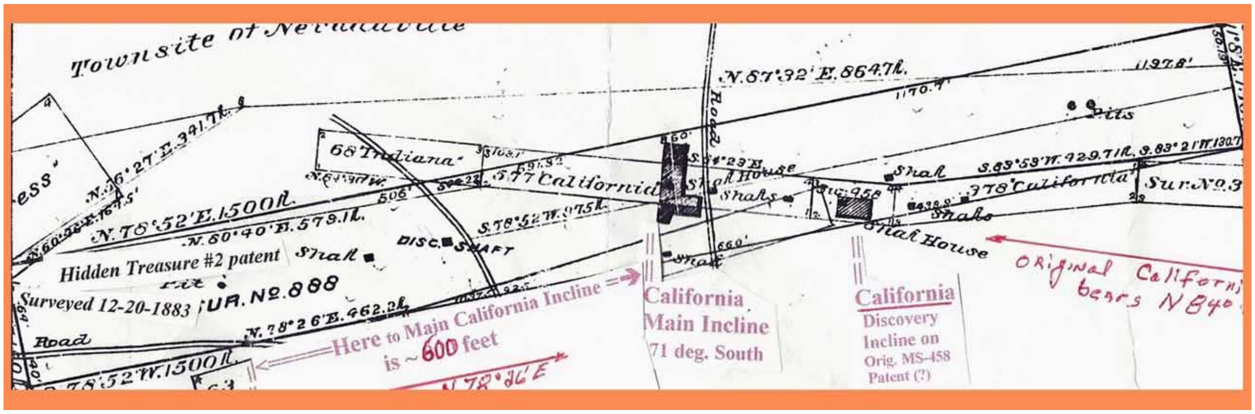

Figure 2. Plan of the California #557 claim, at center. The claim is 50 feet wide. The shaft immediately to the right (east), on discovery claim 958, followed low grade base metal ore downward.

At the California claim, high grade Au-Ag ore bodies were first encountered below 500 feet in. The sub-vertical exploration incline soon became the mine's production shaft. Shaft work was conducted by candle light, was labor intensive and in a confined poorly-ventilated dark space. That narrow claim was surrounded by adjacent claims of generally hostile competitors, concerned by potential theft of ore, if there were any discovery beneath their properties. The company tended to release few physical details about its subterranean bonanza. Instead of joining with a neighbor and sinking a larger common shaft, the California mine produced its hundreds of tons of ore and greater quantities of waste rock monthly through the tiny shaft, hoisting it to surface with a bucket dragged up a wooden slide. The miners also raised large quantities of water, which flowed in constantly using a longer "water barrel" or "bailing skip". By the l880s this became the deepest mine in Colorado.

In l891 local mine operator T.A. Rickard, later Colorado's first state geologist, mapped relationships of veins, faulting and dike emplacement on the 2100 level of the mine and in the neighboring Indiana claim. They appeared in Transactions of the AIME (Vol. XXVI, 1896). He observed that ore of grade similar to that found in the mine's higher levels persisted to that depth. Some was mined, at great cost, but the best shoot projected downward beneath the property of a different landowner. This ore body, and perhaps others of similar nature deep beneath adjacent claims with adverse owners, was never developed. Rickard's sketches of mine faces on the 900 level show multiple dikes cut by, cutting, and adjacent to a wall of narrow, high grade veins of sulfides and precious metals. The California mine ceased operations in 1902, a decade before lower cost access and better ventilation reached its 2000 level through the Argo drainage tunnel. In the l890s there was no pump technology operable by steam piped deep underground, or by mechanical pump rods somehow curving to pass down that narrow crooked incline. The mine closed permanently because the cost of raising each ton of rock (including ore), and of numerous bailers full of water during many months of the year, greatly exceeded the economic value of the deep ore. Economics of silver, a major CCD co-product were strongly affected by government subsidy programs under populist government administrations which preceded the next election of "gold standard" administrations. The result for silver-rich mine operations, in times of huge swings in metal prices, was frequently catastrophic. Bastin and Hill (1917) describe the silver price crashes from 1861 to 1913 in Figure 3.

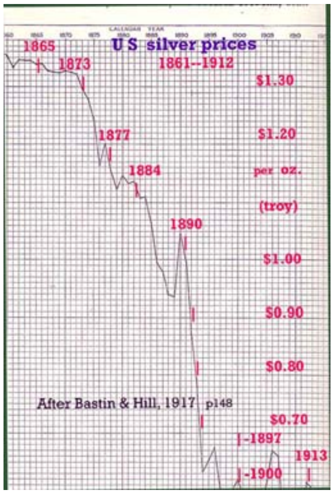

Figure 3.

The impressive 19th century Au - Ag production of the CCD declined year by year to low levels by early decades of the 20th century. Some resumption of gold production accompanied price increases for that metal in the 1930s era. The district has seen little production, and no systematic exploration by large mining companies, since the Second World War. Small-scale labor intensive underground work largely stopped by 1935 or earlier, failed to produce great finds.

Some ideas are presented here as to a few differences between CCD geology and some ore districts observed elsewhere, based on field work, historical data collection, and economic evaluations undertaken during intervals between l978 and 2014. Specific features include the degree of small scale faulting within veins. The possible occurrence of a few faults at wide angles to the vein systems could cause offsets, perhaps leaving potential for undiscovered extensions. In addition, the documentable igneous-intrusion sequence, rock types and related events do not closely resemble those found in many metal districts in northern Colorado.

One exceptional deposition environment in the CCD is columnar breccias found in/near a few vein deposits. One mineralized example, exposed at surface, is “The Patch”, site of recent surface and underground extraction from the Glory Hole mine. This sub-vertical ellipsoidal “pipe” of breccia carries mineable gold and silver values at some levels. Untested zones have long exuded promise and generated human adventures and misfortunes, as noted in this Symposium’s Field Trip G guide (July 2017) and several appendices by Alers, McCoy, and James. Component clasts include ZnS, py, Au-Ag (by assay), veined Pre-C host rock, ash-like matrix.

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Figure 4. is an atypical breccias pit wall, (rock pick for scale): coarse sand-size grains surround both angular and rounded rock fragments, which are red from decades of weathering, as also seen in Figure 5.

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Figure 5, above, shows part of a southerly wall of Glory Hole pit, which cut through an old underground stope (center right) mined long ago for oxidized (formerly pyritic sulfide) ore, probably part of a vein. A low angle structure at the lower limit of stope is underlain by coarse breccia, with sub-rounded clasts of marble size and larger, in a hard siliceous(?) matrix that contains goethite (after sulfides?). The clasts have harder (siliceous?) rims. Centers of some clasts were soft material, now removed. Zoning of clasts was probably caused by hydrothermal alteration during high energy “milling” of the breccia. (Photo by L. James, 2012, with permission).

Recent thinking about the district benefits from ongoing geology research. The estimated depth beneath a paleosurface when The Patch apparently vented upward at CCD is discussed elsewhere. It might differ from the thickness of Paleozoic to possible Tertiary volcanic rocks above the district when the more abundant veins formed. 20th Century assumptions for depth of cover in some northern Colorado ore districts include most of the thick Paleozoic section (with its basal rock units hosting mineralization) plus Mesozoic formations. All of these Phanerozoic rock units are exposed today not far north and south of the CCD. However, 21st Century depth estimates might be improved by use of fluid inclusion data for selected samples, or by modeling of paleotopography at time of ore formation. Present understanding of faulting and sedimentation sequences in the Front Range has improved in recent years. Paleo-erosion rate estimates and computer modeling also were scarce when former depth estimates for ore formation (some stated, “at least 0.5 mi.”) were published.

Placer gold historically mined downstream may help estimate initial size of the CCD ore system, and the history of its unroofing. Significant areas of Tertiary volcanic rock and detritus eroded from rock units similar to those at CCD are found south of Denver Basin along the foot of the Front Range. The age range and composition of some volcanic detritus is similar to the Tertiary igneous rocks that crop out elsewhere in the Mineral Belt. A cursory search for bostonite clasts was inconclusive. If accompanying traces of placer gold, eroded clasts carried down-river from CCD outcrops pieces of could define marker units. Extensive placer gold in major streams in the Denver Basin, derived from erosion up-river is known only in a few identifiable sedimentary units and channels in the basin. The age of some placers, and thus the CCD unroofing, must be bracketed by earlier and later age-dateable barren gravels. Estimation of the timing of unroofing, hence erosion, of CCD gold deposits should also improve estimation of depth of emplacement.

New ore targeting ideas will have to deal with 150 years of land ownership fractionation, as well as undocumented mining from out of ore zones inaccessible for more than a century. More new applied geoscience will still lure some of us to continue learning in that 13 x 15 km x 1.5km space containing thousands of veins.

Biography

Larry has worked in metals and uranium exploration geology and in mine evaluation and development. Since 2009, as a consultant based in Golden, Colorado, he has conducted field work and mine evaluation on several continents. He has worked for several major and junior companies.

Corporate employment for major companies and governments included assignments in geology and program management in Southeast Asia, Latin America, Eastern Europe/ Soviet republics, Egypt and Mongolia. He has worked extensively in Utah, Nevada, Colorado and Wyoming, and for several years in Midcontinent Precambrian rocks. His two daughters began their education in rural Japan as‘the only blondes in the class’. He published maps and papers on mineral deposits in the Great Basin, Colorado, South Korea, Philippines, and Indonesia, as well as mining history in Utah. He works on modeling of formation of metal ore deposits using ample field observations. Larry served as adjunct professor in Economic Geology under Prof. Bill Atkinson at University of Colorado, Boulder for eight years. He enjoys the outdoors, interaction with other scientists, some foreign languages and occasional extreme sports.

He received a BSc. (Hons) at Stanford University, and a Ph.D. from Pennsylvania State University. His dissertation focused on alteration in calcareous sediments adjacent to the Ely (Robinson) porphyry Cu –Au system. In the Central City district of Colorado, he has worked on underground precious metals projects and mapped surface areas at times over three decades.

The Sweet Home Mine—Silver to Rhodochrosite

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The Sweet Home Mine is nestled at timberline (11,600') near the head of Buckskin Gulch in the Alma Mining District in the Mosquito Range, central Colorado. The mine's veins lie within Precambrian granite gneiss intruded by Tertiary monzonite porphyry. Paleozoic formations, mostly limestone/dolomite, have hosted most of the precious and base-metal production from the Alma district. However, the Sweet Home mine vein system is not in Paleozoic formations. “A possibility exists that this vein system continues updip into the Paleozoic units capping Mount Bross above the mine and to the east.” (Misantoni & others, 1998).

Pb-Ag mining began in 1872--the mine holds U.S. Patent #106--one of the 1872 Mining Law's oldest. Like so many of Colorado's old silver mines, the Ag-bearing veins were elusive and yielded no bonanza. “As silver mines go, the Sweet Home mine was a failure. It was a hole in the ground that devoured hopes and money, and gave very little in return. Based solely on its unimpressive silver output, the Sweet Home should have faded into obscurity and abandonment a century ago, joining many others that became nothing more than collapsed portals and flooded workings” (Voynick, 1998). However, the tenacity of miners allowed this mine to operate intermittently for over 120 years. From the 1870’s to the 1890’s, the silver miners also mined rhodochrosite specimens, which were sold to museums in the United States and Europe. Rugged topography, extreme elevation, poor roads, and long, bitter winters finally put the end to the marginal silver mining. The last Ag mining occurred in 1966, when a specimen of rhodochrosite ($MnCO_3$) was sold by miners for $2500; that specimen, now in the Houston Museum of Natural Science, was estimated to have a value of $250,000 in 1998. Far more money has been made from Sweet Home rhodochrosite than was ever made from silver. Early production records for silver at the Sweet Home Mine have not been located. This was not the case for some of the other mines on the side of Mt. Bross and Mt. Lincoln, which by 1878 had produced more than $3 million in silver (Voynick, 1998). Beeler (1933) estimated the extent of the original 5 tunnels of the Sweet Home Mine at 1,040 feet and that “these ores were sometimes almost unbelievably rich, there can be no doubt, and there is no doubt as to the haphazard manner in which they were mined and the product scattered, often leaving no record except a local legend of what had been found.”

In 1991, with an investment capital of $300,000, the mine was reopened by Sweet Home Rhodo, Inc., but silver was hardly the target; instead, cherry-pink, gemmy rhodochrosite was the commodity of interest. Like most mining, times got rough and Sweet Home Rhodo, Inc. went broke after 1.5 years, just as they hit a pocket of gemmy rhodochrosite. Borrowing more money, they were able to mine the material, which included "museum grade" rhodochrosite along with fluorite, tetrahedrite, sphalerite, and hübnerite. The Coors Foundation bought the biggest of these specimens, the Alma King, and donated it to the Denver Museum of Nature and Science.

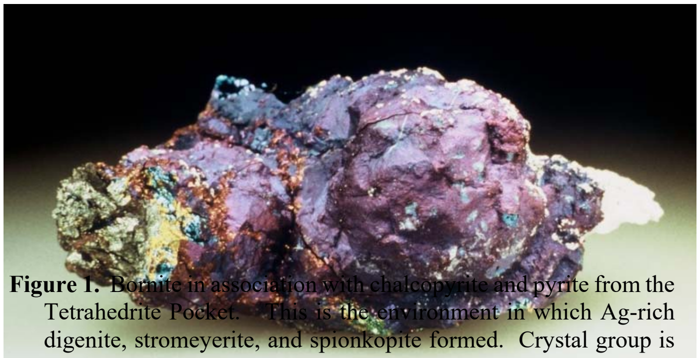

Figure 1. Bornite in association with chalcopyrite and pyrite from the Tetrahedrite Pocket. This is the environment in which Ag-rich digenite, stromeyerite, and spionkopite formed. Crystal group is 7.6 cm in length. Sweet Home Rhodo, Inc. collection; photo by Jeff Scovill.

SILVER

For over a century silver was believed to occur in argentiferous galena (Patton, 1912). However, in

1998 microprobe analyses (Wenrich, 1998) showed little Ag in the galena. Rather it occurs in small crystals of the Ag-Cu-sulfide, stromeyerite, and in Cu-sulfides, such as digenite, bornite, and tetrahedrite (Table 1, Fig. 1). Had previous miners been privy to this information they may have been more successful in their quest for silver.

RHODOCHROSITE

Figure 2. Rhodochrosite on quartz, 10.4 cm, from the Blueberry Pocket, found through GPR exploration work. Photo by Jeffrey Scovil.

Although the early Sweet Home miners failed to find a silver bonanza, they did find well-developed, deeply colored, euhedral crystals of rhodochrosite as early as the 1870's (Voynick, 1998). 100 years later in the 1970's, Leonard Beach, the owner at that time, realized that if the Sweet Home Mine was to have a future it was in rhodochrosite, not silver. Over the past 100 years the Sweet Home Mine has produced rhodochrosite of extraordinary beauty--it is unrivaled in its striking color by rhodochrosite from any other locality in the world (Fig. 2).

An ambitious petrographic/electron microprobe study was undertaken at the Sweet Home Mine, supported by Sweet Home Rhodo, Inc. Analyses of 127 rhodochrosites containing 28 elements each were completed from 13 pockets in the Sweet Home Mine. Likewise, extensive analyses of the associated sulfides were completed. Geochemical halos and geographic trends in the mineral chemistry were helpful for rhodochrosite exploration. Although tetrahedrite (high Sb) is higher in silver than is tennantite (high As -- Table 1), high quality cherry red rhodochrosite tends to be associated more with tennantite (Wenrich, 1998).

SULFIDES

Ag-bearing Tetrahedrite/Tennantite **$(Cu,Fe,Ag,Zn)_{12}(Sb,As)_4S_{13}$**

Tetrahedrite/tennantite is closely associated with rhodochrosite at the Sweet Home Mine. Tetrahedrite is more common at the Sweet Home Mine than tennantite. An almost complete solid solution exists between tennantite (100% arsenic) and tetrahedrite (100% antimony) at the Sweet Home Mine. Forty-nine analyses show the tetrahedrite/tennantite spans a range from $Sb_{02}As_{98}$ to $Sb_{91}As_{09}$ (Table 1, Fig. 3). Such compositional variation occurs not only on a large scale throughout the mine, but also on a small scale as well; individual crystal clusters vary through as much as 60% of the solid solution series.

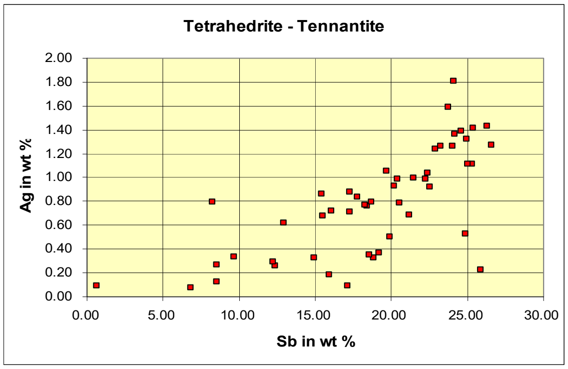

Figure 3. The concentration of silver increases with increasing antimony in the zincian tetrahedrite/tennantite series. Electron microprobe chemical analyses of 49 tennantite/tetrahedrite crystals from samples collected throughout the Sweet Home Mine.

Some of the silver mined from the Sweet Home Mine from 1872 until 1966 undoubtedly was extracted from the tetrahedrite (Fig. 3). A direct linear correlation exists between the concentration of silver and that of antimony in tetrahedrite/ tennantite (Fig. 3) because Ag substitutes for Cu more readily in Sb-rich tetrahedrite than in the As-rich members of the tetrahedrite/tennantite series. The concentration varies from 1.8 wt. % (18,000 ppm) Ag in Sb-rich tetrahedrite down to 0.08 wt. % (800 ppm) in As-rich tennantite.

An average of 15 atomic % of the copper in the tennantite/tetrahedrite structure is replaced by Zn. Few samples contain Zn concentrations that deviate more than 2% from this 15% substitution for copper. Therefore, this sulfosalt series at the Sweet Home Mine is most properly named zincian tetrahedrite or zincian tennantite.

Bornite (Cu_5FeS_4), **Digenite** (Cu_9S_5), **Spionkopite** ($Cu_{39}S_{28}$), **Stromeyerite** (AgCuS), and **Jalpaite(?)** (Ag_3CuS_2)

All five of these copper sulfides contain silver at the Sweet Home Mine and were probably the major source of silver for the mining operations from 1872 to 1966, although the early miners may have thought it was coming from the associated "argentiferous" galena (see Table 1 and Fig 4 for galena/copper sulfide associations). Stromeyerite is sparse, but where present, it is a major silver mineral (Table 1) and would have contributed significantly to the Ag ore. Four analyses were made of a Ag-rich copper sulfide that was very fine grained (2 microns); the electron microprobe results for all 4 analyses gave low totals, which was probably a result of the very small size of the grains and the minerals slightly oxidized nature. The stoichiometry of this phase is not clear because of the poor totals and partial oxidation, but it is not stromeyerite. It has tentatively been identified as jalpaite(?)--Ag_3CuS_2--(Table 1), but the stoichiometry works out to an oxidized jalpaite(?)--$Ag_{1.56}Cu_{0.41}S_{1.36}O_{0.62}$.

A bluish copper sulfide that petrographically used to be called blaubleibender covellite was described in 1981 as spionkopite ($Cu_{39}S_{28}$). Covellite was identified petrographically by Honea (1992), and a bluish mineral from the Main Stope that appears to be covellite was also observed petrographically during this study. However, this "covellite" was analyzed on the microprobe (4 analyses) and all results closely calculate stoichiometrically to $(Cu,Ag,Fe)_{39}S_{28}$. They are therefore referred to here as spionkopite (Table 1). They contain significant amounts of silver, 23-38% (weight percent).

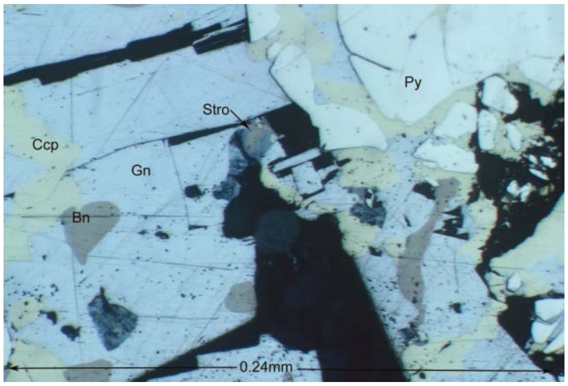

Figure 4. Reflected light photomicrograph of pyrite (Py-yellow), chalcopyrite (Ccp-gold), galena (Gn-light gray), digenite (surrounding Stro-blue-gray), bornite (Bn-maroon), stromeyerite (Stro-purplish pink—small grain in center of photo). Sample from the Main Stope. Horizontal field of view is 0.24mm. Photo by Karen Wenrich.

No native silver was observed during these petrographic and electron microprobe studies. All of these copper sulfides have anomalous Hg concentrations, which in one case is over 4 wt.%. None of these copper sulfides are as common at the Sweet Home as sulfides such as pyrite, galena, sphalerite, or chalcopyrite. However, some nice samples have been discovered in the mine (Fig. 1). Figure 4 shows the association of all of these copper sulfides plus galena, pyrite, and chalcopyrite.

A graph of silver versus copper in bornite (Fig. 208, Wenrich and Modreski, 1998) illustrates a direct inverse correlation between the two elements, indicating that silver has substituted for copper in the crystal lattice. These copper sulfides occur late in the paragenetic sequence and have apparently replaced earlier sulfides (Fig. 209, Wenrich and Modreski, 1998). Locally they fill skeletal tetrahedrite crystals, and, as also shown in Fig 209, Wenrich and Modreski (1998), wormy galena can be observed to lie within bornite that has partially replaced the galena.

Chalcopyrite $CuFeS_2$

The chalcopyrite formed distinctly later than the pyrite as can be seen in Figure 201, Wenrich and Modreski (1998), where the chalcopyrite fills fractures in the pyrite. A significant amount of Zn and Ag have substituted into the chalcopyrite structure in a few samples (Table 1), although in general, the chalcopyrite is pure $FeCuS_2$ for most of the 32 analyses (Wenrich and Modreski, 1998).

Galena PbS

Galena forms cubes and octahedrons (Fig. 5) at the Sweet Home Mine, and is associated with copper sulfides, particularly chalcopyrite, bornite, and the sulfosalt tetrahedrite/tennantite. Although most of the 31 galena analyses show pure PbS, a few contain over a percent Zn. According to Patton and others (1912, pp. 226-227) "argentiferous galena is the principal mineral mined where the ore is unoxidized." Although

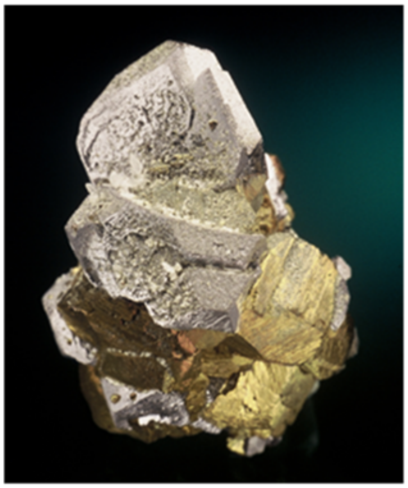

Figure 5. Galena octahedron coated with later chalcopyrite. Galena crystal, from the Rainbow Pocket, is 3.1 cm high. Photo by Jeff Scovil.

electron microprobe analyses show that some galenas from the Tetrahedrite Stope, Main Stope, and Red and Blue Pocket do contain silver, galenas from other areas of the mine contain little to no silver (Table 1). Even where the galena is "argentiferous", the concentration of silver is <0.45 wt.%--significantly lower than that contained in most of the copper sulfides, bornite, digenite, and tetrahedrite (Table 1), and certainly less than in the Ag-Cu-sulfides, stromeyerite, spionkopite, and jalpaite(?). Modreski (1988) analyzed several galena crystals on the scanning electron microscope from the Sweet Home Mine and found no samples with Ag >0.48%.

SULFIDES—Non-Ag-bearing Pyrite FeS_2

Pyrite is by far the most common of the sulfides and also the earliest formed. The crystals are generally euhedral and associated with quartz or other sulfides. The pyrite is surprisingly pure FeS_2 with little substitution of other elements. Electron microprobe analyses of 31 pyrite crystals indicate the concentrations of As, Ni, Pb, Cd, Sb, Ca, Mn, Mg, P, Ba, V, Si, Al, K, Ti, Se, and W are <0.02.

Sphalerite ZnS

The sphalerite is moderately pure ZnS in all 56 sphalerite analyses, except for very minor substitution of Cd and Fe for Zn (Table 1). The compositionally pure sphalerite commonly formed gemmy golden orange (Fig. 6) to gemmy golden yellow crystals. Amazingly, only a very small amount of Fe replacing the Zn caused the sphalerite to be opaque (Fig. 202, Wenrich and Modreski, 1998). Zones of submicroscopic (<1 micron) opaque needles are aligned within some sphalerite. Other sphalerite is clear and colorless, with wispy golden patches. Electron microprobe analyses did not detect any compositional differences (Table 1) between the clear inclusion-free sphalerite and the golden sphalerite.

Minor increases in Fe in sphalerite occur in areas where the rhodochrosite is likewise contaminated by Fe, such as in the Tetrahedrite Stope, whereas the Main Stope, where some of the purest rhodochrosite resides, contains some of the purest sphalerite.

Figure 6. Golden orange sphalerite crystal, 9 mm, intergrown with quartz crystals. Photo by Jeff Scovil.

OXIDES, FLUORIDES, and PHOSPHATES

Hübnerite $MnWO_4$

The hübnerite from the Sweet Home Mine is very close to the pure end member of the hübnerite-ferberite solid solution, so much so that in thin section the color is a gemmy orange. This orange translucent color is visible along the thin edges of large hübnerite blades (Fig. 7). When a thin slice of the crystal is cut and the slice is viewed with transmitted light in a microscope, distinct compositional banding is obvious (Fig. 7). The gemmy orange bands are essentially pure $MnWO_4$. Only a very small amount of iron (around 0.35 weight percent) substituting for the Mn is required to turn the orange hübnerite into black bands. The hübnerite in several samples is associated with muscovite and with chalcopyrite (Fig. 8).

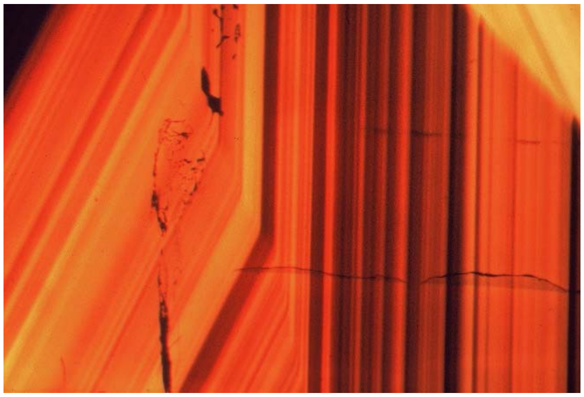

Figure 7. Transmitted plane light photomicrograph of a single gemmy orange hübnerite blade from the Coors Pocket. Note the compositional banding. Gemmy orange bands are essentially pure $MnWO_4$. Only a very small amount of iron (<0.35 wt. %) substituting for the Mn is required to turn the orange hübnerite into the black bands. Horizontal field of view is 1.05 mm. Photo by Karen Wenrich.

Figure 8. Large single blade of hübnerite associated with chalcopyrite from the Rainbow Pocket, 2.5 cm. Photo by Jeff Scovil.

Fluorite CaF_2

Fluorite formed during two distinct separate stages: (1) an early green fluorite, and (2) a later purple fluorite. Electron microprobe analyses of the fluorite indicate that these minerals are very pure and stoichiometric. As is normally the case, the color in fluorite is not due to any detectable changes in trace element impurities. The late stage purple fluorite is wispy in places, but microprobe analyses do not show any compositional variations between the purple wisps in and the colorless wisps. This is not surprising, because the color in fluorite has generally been attributed to physical properties other than compositional variation. However, extensive studies on the color in fluorite indicate that some colors appear to be attributable to trace concentrations of rare-earth-elements well below the lower detection limit of these elements on the electron microprobe.

Fluorapatite $Ca_5(PO_4)_3F$

Elongate doubly terminated apatite grains were found as inclusions within the rhodochrosite in samples from both the Empty and Red & Blue Pockets. Electron microprobe analyses indicate that they are fluorapatite (Table 14, Wenrich and Modreski, 1998).

Triplite $(Mn,Fe,Mg,Ca)_2(PO_4)(F,OH)$

Three grains of triplite occur as small inclusions (about 20 microns each) in fluorapatite that rims a large rhodochrosite crystal from the Empty Pocket. The electron microprobe analyses of the triplite were very stoichiometric considering the size of the grains that were analyzed (Table 14, Wenrich and Modreski, 1998)

SILICATES

Muscovite $KAl_2(Si_3Al)O_{10}(OH,F)_2$

Muscovite books are not uncommon in the Sweet Home Mine. Electron microprobe analyses were made of muscovite from the Corner Pocket, Coors Pocket, Watercourse Drift, and the Red and Blue Pocket (Table 15, Wenrich and Modreski, 1998). The most common occurrence of the muscovite is in radiating aggregates in association with hübnerite (Fig. 213, Wenrich and Modreski, 1998).

Topaz $Al_2SiO_4(F,OH)_2$

Topaz inclusions are very common in the quartz crystals associated with rhodochrosite, fluorite, sphalerite, and tetrahedrite/tennantite. Although much of the quartz contains no such inclusions, the quartz that does contains many topaz inclusions. Electron microprobe analyses of two topaz crystals indicate that the mineral is stoichiometric and has almost no detectable trace elements.

Quartz SiO_2

Quartz was the earliest formed mineral in the Sweet Home Mine suite and formed well-developed terminated crystals onto which many of the subsequent minerals grew. Large quartz crystals are commonly surrounded by sulfides, particularly tetrahedrite, chalcopyrite, and sphalerite.

Dickite $Al_2Si_2O_5(OH)_4$

Very fine-grained clusters of greenish crystals of dickite were found and analyzed on the electron microprobe (Table 16, Wenrich and Modreski, 1998).

CARBONATES

Rhodochrosite $MnCO_3$

Rhodochrosite commonly occurs as a gangue mineral in mines throughout the world. However, it rarely occurs in a gemmy, lustrous red form like that from the Sweet Home Mine in the Mosquito Range. Unfortunately, not all rhodochrosite that comes from the Sweet Home Mine is as red and gemmy as those in the Good Luck Pocket and Watercourse Drift, because a rind of lighter pink rhodochrosite coats the gorgeous cherry-red interior of many specimens from the Sweet Home Mine. The lower quality rhodochrosite fills fractures in the cherry rhodochrosite, and forms rinds around many crystals, demonstrating that it is clearly later than the cherry rhodo (Fig. 9). This indicates that rhodochrosite in the Sweet Home Mine formed in two distinctly different stages of mineralization. Pink material contains as much as 7% (atomic) Fe+Mg+Ca replacing Mn in the rhodochrosite structure, whereas the cherry-red gemmy material is consistently <1% total Fe+Mg+Ca (Fig. 11). Such pure $MnCO_3$ is rare in nature and relatively unique to the Sweet Home Mine. It is clear that there are areas within the mine that consistently show the low Fe+Mg+Ca signatures in rhodochrosite. The low Fe:Mg:Ca signatures signify areas where higher temperature and higher value, cherry-red rhodo may be found (Fig. 10).

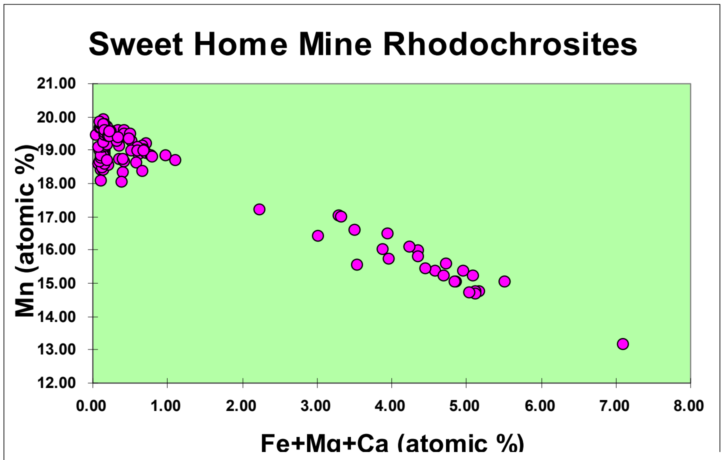

Figure 10. Summary of 127 electron microprobe results showing Mn versus Mg+Fe+Ca in atomic percent. There is a distinct break in composition between the two stages of rhodochrosite. The gemmy, cherry-red rhodochrosite consistently has Mg+Fe+Ca contents that are <1%, whereas the lower quality pink rhodochrosite has >2% up to 7% Mg+Fe+Ca. Fig. 9 shows color result of impurities.

Figure 9. The gemmy rhodochrosite in the center of the specimen formed earlier at a higher temperature and is essentially pure $MnCO_3$, whereas the later, lower-temperature, lighter pink rhodochrosite contains several percent Ca+Fe+Mg in substitution for Mn in the rhodochrosite structure. Sweet Home Rhodo, Inc. collection.

CRYSTAL CHEMICAL ZONING IN THE SWEET HOME MINE

Most minerals in the Sweet Home Mine are relatively pure stoichiometric end members. However, tetrahedrite/tennantite and rhodochrosite are not. Tetrahedrite/tennantite spans most of the solid solution series between the two end members - from $Sb_{02}As_{98}$ to $Sb_{91}As_{09}$. Although rhodochrosite does not have such extensive solid solution, the content of Fe+Ca+Mg substitutes significantly for Mn, such that the color of rhodo is dramatically altered (Fig. 11) (Wenrich, 1998). Likewise, sphalerite shows very minor enrichment of Fe.

Coincidentally the "contamination" of rhodochrosite, tetrahedrite, and sphalerite generally occur within the same areas of the Sweet Home Mine. High antimony tetrahedrite/tennantite, higher-Fe+Ca+Mg rhodochrosite, and higher-iron sphalerite all occur in the Tetrahedrite Stope whereas these same minerals in the Main Stope remain relatively pure. The Coors Pocket and the Watercourse Raise contain some low and some moderate trace-element substitution in their crystals.

Higher As tetrahedrite/tennantite and low Fe sphalerite correlate nicely with the areas of the highest quality, gemmy cherry-red rhodochrosite: The best comes from the Main Stope, and if these four areas are ranked, the Tetrahedrite Stope is fourth in quality. Figure 214 in Wenrich and Modreski, 1998 shows mine drift cross sections; if these cross sections are studied, one can see that the purer material comes from pockets along 2 parallel structural trends.

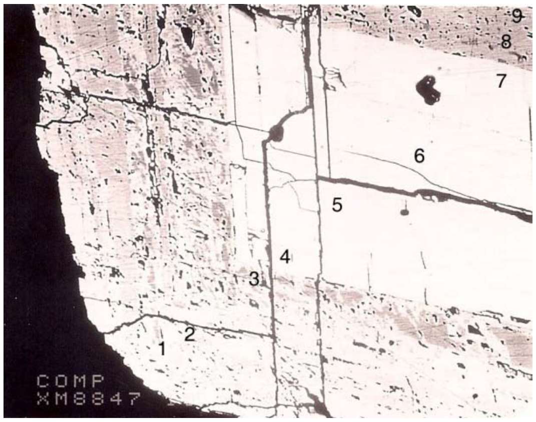

Figure 11. Cherry rhodochrosite is transparent in thin section whereas the lower-quality pink rhodochrosite forms rims and fills fractures that are dark and cloudy. Electron backscatter image; horizontal field of view is 250 µm. A traverse of spot chemical analyses was made across this sample, providing an excellent demonstration of the substantial variation in Fe, Ca, and Mg content between the cherry and pink rhodochrosite. The spots are recorded by number on the photograph and correspond to the sample numbers in the following table of Fe, Ca, and Mg contents in weight percent. Note the low Fe content for spots 4-7 and the associated clear purity in the backscatter image.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Fe	8.8	8.6	9.2	1.2	1.2	1.3	1.3	9.1	9.0
Ca	0.7	0.6	0.7	0.1	0.1	0.1	0.1	1.1	1.1
Mg	0.6	0.6	0.7	0.1	0.1	0.1	0.1	0.8	0.8

PARAGENESIS

The most prominent minerals at the Sweet Home Mine have been placed into a paragenetic sequence of formation based on their interrelationships as observed in hand specimen, and their decreasing temperature of formation measured by T. James Reynolds (1998). Minerals that can have their temperature of formation calculated from fluid inclusions, such as rhodochrosite, fluorite, topaz, quartz, and sphalerite can be placed into such a diagram as shown in Fig. 12 with a fair degree of accuracy. However, the opaque minerals such as pyrite, galena, chalcopyrite, and tetrahedrite/tennantite had to be worked into the paragenetic sequence based on their interrelationships as observed in hand specimen, and with those minerals that have measured fluid-inclusion filling temperatures.

Fluid inclusion temperatures determined by Reynolds (1998) indicate that the early cherry stage of rhodochrosite formed at about 325°C, whereas the later, lower-quality pink stage formed at temperatures <200°C.

CONCLUSIONS

The electron microprobe has provided quantitative chemical analyses of most mineral phases known to be present in the Sweet Home Mine, including some that are a mere 2-3 microns in size. Owners of Sweet Home sulfide specimens can feel more confident in the mineral identifications put on the labels for their specimens than is often possible from other mines where no specimens have been chemically analyzed.

Overall, the samples analyzed during this study indicate that there is twice as much tetrahedrite as tennantite and that the two phases are intricately intergrown in many samples.

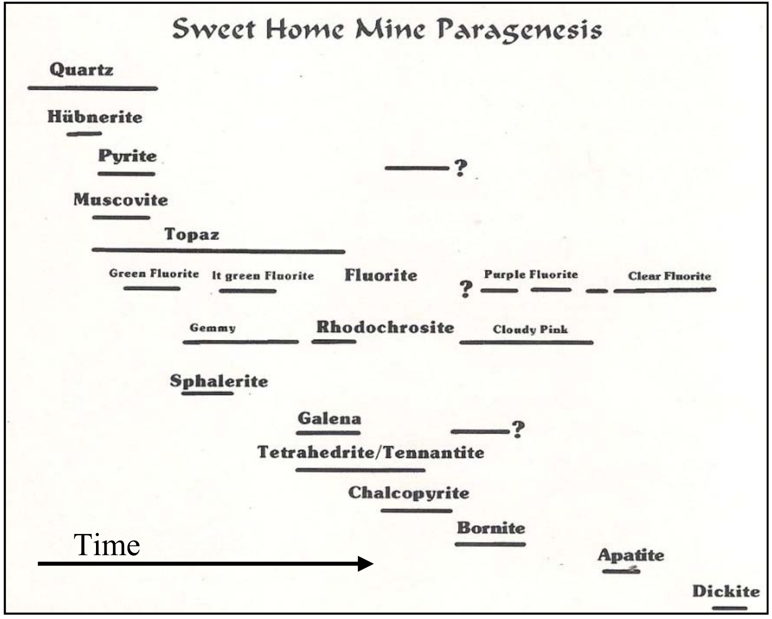

Figure 12. Graph showing the paragenetic sequence for the dominant minerals found at the Sweet Home Mine. Note that quartz and pyrite are the earliest-formed minerals, while rhodochrosite and fluorite appear to have formed over a longer period of time and at much lower temperatures. Fluid inclusion filling-temperatures were determined for rhodochrosite, fluorite, quartz, and sphalerite (see Reynolds, 1998); hence, these minerals are more firmly established on the paragenesis sequence than are the remainder of the minerals.

Analyzed veins and pockets that show elevated iron contamination in the sphalerite and high antimony to arsenic ratios in the tetrahedrite/tennantite (toward the tetrahedrite end member) match up with the same veins and pockets that contain Fe+Ca+Mg contamination in the rhodochrosite. Areas that contain such trace-element contamination of sphalerite, tetrahedrite, and rhodochrosite have historically produced lower quality rhodochrosite. The cherry-red rhodochrosites were deposited early from moderately high temperature Mn-rich fluids that were very different from the late, low-temperature, Mn+Fe+Ca+Mg-rich fluids that deposited the pink rhodochrosites.

Sweet Home Rhodo, Inc. used this information successfully as an exploration tool. When a sulfide vein was encountered and contained higher As tetrahedrite/tennantite and low Fe sphalerite, it was explored further, because the probability of discovering a pocket with high quality, gemmy cherry rhodochrosite is much greater than with high Sb and Fe sulfides veins, which were avoided.

Alteration ages of 28-31 Ma were determined by K-Ar dating of sericite vein selvages adjacent to quartz-pyrite-hübnerite veins and polymetallic, base-metal, rhodochrosite veins (Missantoni & others, 1998). These ages are similar to mineralization ages at the Climax Mine, <7 km to the NW. Lüders and others (2009) believe that "mineralization at the Sweet Home Mine occurred coeval with the final stage of magmatic activity and ore formation at the nearby world-class Climax molybdenum deposit about 26 to 25 m.y. ago." The abundant sulfide mineralization associated with fluorite and rhodochrosite as gangue minerals, and occasional quartz-pyrite molybdenite veins, are similar to peripheral epithermal mineralization at the Climax and Henderson Mo deposits. So, it is possible that the Sweet Home Mine mineralization is the uppermost expression of a deeper-seated molybdenum deposit. Stable isotopes and fluid inclusion results suggest early stages of alteration/mineralization took place in a high temperature, magmatic-dominated hydrothermal system at 375-400°C (Reynolds, 1998). These fluids later cooled and became increasingly meteoric in origin. No phase separations (boiling, etc.) occurred and no high-salinity fluids were present (Reynolds, 1998). Open-space euhedral quartz began growing at 350-375°C (Reynolds, 1998), followed by topaz, muscovite, hübnerite, tetrahedrite/tennantite, fluorite, sphalerite, and rhodochrosite. Rhodochrosite formed in two stages: (1) The earliest at about 325°C resulting in a pure, gemmy, cherry-colored $MnCO_3$, and (2) A later <200°C impure stage that has up to 16% Fe+Mg+Ca replacing Mn. This cation substitution significantly reduces the value of the specimens. The Sweet Home Mine has produced millions of dollars in mineral specimens since 1991--a far better bonanza than was ever reaped by silver production.

Table 1. Selected electron microprobe chemical analyses of Sweet Home sulfides. Values are in weight percent. Al, Ca, Cd, Co, K, Mg, Mn, Ni, P, Se, Si, Ti, V, and W were also determined, but all were less than

0.03%.

A. Sample Location	**Ag**	**As**	**Sb**	**Cu**	**Zn**	**Fe**	**Pb**	**Ba**	**Hg**	**S**	**Total**
Tennantite-Good Luck	0.0	19.	0.6	43.	8.7	0.2	<.0	<.0	<.0	28.	102.
Tennantite-Main Stope	0.1	13.	8.6	41.	7.8	0.2	0.1	<.0	<.0	26.	98.0
Tetrahedrite-Watercourse	0.6	9.2	15.	40.	7.2	0.6	<.0	<.0	<.0	26.	100.
Tetrahedrite-Watercourse	1.4	1.9	26.	37.	7.0	0.2	<.0	<.0	<.0	25.	97.7
Tetrahedrite-Coors Pocket	0.5	5.5	19.	39.	7.8	0.4	<.0	<.0	<.0	26.	99.8
Tetrahedrite-Museum Pocket	1.8	2.7	24.	38.	7.7	0.1	<.0	<.0	<.0	25.	101.
Tetrahedrite-Empty Pocket	0.8	3.7	17.	38.	7.8	0.1	<.0	<.0	<.0	26.	98.7
Bornite--Good Luck Pocket	1.6	<.0	<.0	58.	0.0	12.	<.0	0.1	0.4	25.	99.7
Bornite--Main Stope	5.2	<.0	<.0	55.	0.0	10.	<.0	0.2	0.4	24.	97.1
Digenite--Empty Pocket	0.2	<.0	0.1	75.	0.0	3.3	<.0	0.1	0.6	22.	101.
Jalpaite(?)--Museum Pocket	65.	<.0	<.0	9.8	<.0	0.2	0.0	<.0	--	8.4	86.6
Jalpaite(?)--Museum Pocket	65.	<.0	0.1	9.9	<.0	0.2	<.0	0.1	--	8.5	87.0
Spionkopite--Main Stope	23.	<.0	<.0	46.	0.0	5.4	0.2	0.2	0.1	24.	100.
Spionkopite--Main Stope	25.	<.0	0.0	47.	0.0	1.1	0.1	0.1	<.0	24.	98.7
Stromeyerite--Main Stope	50.	<.0	<.0	29.	0.0	0.0	<.0	0.2	4.1	16.	101.
Stromeyerite--Main Stope	52.	<.0	<.0	33.	0.1	0.0	<.0	<.0	0.4	19.	105.
Chalcopyrite-Coors Pocket	<.0	<.0	<.0	33.	3.0`	29.	<.0	<.0	<.0	34.	100.
Chalcopyrite-Museum	1.3	<.0	<.0	34.	0.2	29.	<.0	<.0	<.0	34.	100.
Chalcopyrite-Red+Blue	<.0	<.0	<.0	33.	<.0	30.	<.0	<.0	<.0	35.	99.3
Galena-Corner Pocket	<.0	<.0	<.0	0.0	0.0	<.0	86.	<.0	<.0	13.	100.
Galena-Coors Pocket	<.0	<.0	<.0	0.2	0.7	0.2	85.	<.0	<.0	13.	101.
Galena-Museum Pocket	0.0	<.0	<.0	0.0	<.0	0.0	87.	<.0	<.0	13.	100.
Galena-Pyrite Pocket	0.3	<.0	0.0	<.0	0.7	0.0	84.	<.0	<.0	13.	99.5
Galena-Red & Blue Pocket	0.4	<.0	0.0	0.0	0.0	0.0	84.	<.0	<.0	13.	99.7

*Jalpaite(?): This mineral identification is very tenuous. The analysis is suspect because of the low totals. However, the approximate proportion of silver to copper should be reasonably accurate, roughly 3:1. The mineral is partially oxidized--the samples contain 1.56% and 1.98% oxygen respectively, and the totals are very low indicating an unreliable analysis. Such oxygen concentrations calculate to about 8.5 atomic % oxygen. Both samples also contain Al: 0.53% and 0.71%, respectively.

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Biography

Dr. Karen Wenrich graduated from Penn State with a Ph.D. in geology/volcanology. Karen worked for 25 years for the USGS, followed by a career consulting for the mining industry; during this time she published over 170 papers. She is a specialist in the geology and mineralogy of uranium deposits. From 2002-2005 Karen worked for the International Atomic Energy Agency in Vienna, Austria, as their senior uranium geologist traveling worldwide studying uranium deposits. As IAEA staff she shared in the 2005 Nobel Peace Prize "For their efforts to prevent nuclear energy from being used for military purposes". She has done extensive studies on breccia-pipe uranium deposits. In 2008, 2010, and 2011 Karen testified on Capitol Hill before the U.S. House Natural Resources Committee against a bill to permanently bar mining claims on 1.1 million acres of land in northern Arizona.

In Vulture Gold Mine Headframe, Arizona

The World's Greatest Gold Camp: A Concise History of the Cripple Creek Mining District

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The Cripple Creek Mining District is situated on the southwestern flank of 14,115 foot (4,302 m) - high Pikes Peak in southern Colorado. It was at this location, about 30 million years ago, that volcanic events ripped through billion-year-old rocks forming a seven-square-mile (18 sq. km) volcanic-intrusive complex with significant gold deposits (Hunter et al., 2009).

The story of Cripple Creek begins in a pasture of grazing cattle where a cowboy, Bob Womack (1844-1909), searched for gold while he tended herds. He was a broad-shouldered and weather-beaten man who endured long days of wind, rain, and cold. Womack had a small log cabin at the fringe of the pines. Inside, like similar cabins, there was a little cast-iron stove with a neat stack of kindling in a wooden dynamite box, and against the wall was a cot covered with a blanket. A kerosene lamp sat on a table. From this modest cabin, Womack searched for gold. The sound of his pick and the worried chatter of squirrels in the pine trees were the only sounds that disturbed the meadows. Womack was at ease in his cow pasture—it was his oyster—and he had the feel of things as he rode horseback over the land.

After digging countless prospect pits into the hills of Cripple Creek, Womack finally discovered gold that all the other prospectors had missed. Acting quickly, Womack established the El Paso Lode on October 20, 1890. Although Womack's claim was initially ignored because of his hard drinking and storytelling nature, the news of his strike—flung like gold dust—got out. Mining claims by other prospectors soon followed.

The discovery of rich gold veins, combined with rumors of wealth that went unchecked, brought a rush of prospectors by the thousands. They were fueled by furious hunger and an impossible desire—more than they have ever known—as they carried their picks and led surly donkeys into the district. Many of the prospectors were farmers, ranchers, or tradesmen with little or no experience in mining (Reynolds, 1892). United in the dream of striking it rich, and bolstered by no other knowledge of mining than that which they learned themselves by reading, watching, or listening, these men established prospect holes in every available piece of ground as they eagerly searched for gold.

The gold rush to Cripple Creek forever changed the grassy hills where mountain men once explored, the Ute Indians roamed, round-bellied birds tweeted, and wildflowers bloomed. Within days Cripple Creek became an instant city of tents, wooden shacks, and log cabins. The high concentrations of gold telluride minerals made this place like no other in North America, and the area soon became known as the World's Greatest Gold Camp.

The allure of gold and adventure was unrelenting. Within three years the population of Cripple Creek and numerous smaller towns surged from a handful of prospectors to over 5,000 people who traveled to the district over three wagon roads that entered the gold camp.

In those early days, Concord stagecoaches with red and yellow wheels rumbled into town day and night, lurching to a standstill as passengers stepped out, adding to the number of fortune seekers. Teamsters drove six horse- or mule-drawn wagons over winding dirt roads littered with rocks and up steep grades to bring supplies, food, building materials, and mining machinery to the district while muleskinners hauled out loads of ore to smelters. Prices of goods and materials were high due to the long journey over mountain roads. The streets were in poor condition, and dumps from the mines often spilled onto the streets. Houses and one-room cabins were quickly built from lumber or pine logs.

This brawling, raucous, free-for-all mining camp had a "Wild West" atmosphere and was an odd cabal of gamblers, dreamers, miscreants, miners, and gentlemen. There were lots of men and fewer women. Saloons and dance halls were numerous. According to one report, "Men were rough . . . fearless, and ready to cast everything on a single die. They were not the kind of men to be caught napping, not to be turned from their purpose (Rastall, 1906, p 23)."

On April 5, 1891, miners formed the Cripple Creek Mining District to provide some form of government through mining law (Taylor, 1966). The city of Cripple Creek began as two separate towns: Fremont, platted November 4, 1891, and Hayden Placer, platted February 15, 1892 (Levine, 1994). The town of Hayden Placer formally changed its name to Cripple Creek on May 31, 1892 (Ubbelohde et al., 2015). In a special election on February 23, 1893, the Town of Freemont and the town of Cripple Creek combined into one city—Cripple Creek (Levine, 1994).

The *Cripple Creek Crusher* and *The Prospector* newspapers first printed in 1891. Writers for both papers banged away at typewriters in narrow, smoke-filled rooms on flat-topped desks. Both papers published reports on the tremendous growth and development of the district: Every week new veins of gold were being opened and fortunes dug out of Cripple Creek's bowl of riches,

One writer observed, "Every hill for miles came to be lined with roads dotted with dumps and shaft houses, and thickly sprinkled with prospect holes (Rastall, 1906 p. 6)." These newspaper articles, published in streams of sheeted print, fueled the electric excitement across the goldfields. It seemed as if a new world had burst out of the land. The streets were busy with life and energy.

Ore production increased and mine development expanded in 1892. The town of Victor was established by the Woods Brothers in 1893. Both Cripple Creek and Victor retained much of their rough frontier appearance in those early days. It was reported, "There is scarce a level piece of ground in the country and . . . the houses straggle over the hills with hardly a semblance of order (Rastall, 1906, p. 62)."

The nationwide Silver Panic of 1893 brought brutally difficult economic times to everyone. Cripple Creek, though, made a difference: it was a golden beacon of promise that shone across the nation as newspapers carried exciting stories of gold discoveries. Hardly a week went by without a new gold vein was discovered. Scarcely an issue of the *Crusher* appeared without a new article about a new strike was given, fueling the goldrush madness. And not a month passed that there was not a new influx of people. With every revolution of the clock more shafts were sunk while underground blasts extended drifts through solid rock. And through it all fortunes were made.

Hope, once lost from the silver panic and economic distress, was found in Cripple Creek. The repeal of the Sherman Silver Purchase Act resulted in the closure of silver mines while making gold mining a promising investment. This state of affairs brought thousands of out-of-work men, fortune seekers, and fortune makers who poured into Cripple Creek in an endless flow—lured by the golden splendor of that rich bonanza just waiting below the surface. By 1893 the Cripple Creek mining district emerged as the premier mining district in Colorado.

In 1894, the U.S. Geological Survey (USGS) sent two geologists to conduct fieldwork and prepare a report on the geology and mines of the Cripple Creek goldfields. The geologists were Whitman Cross (1854-1949) and Richard A.F. Penrose Jr. (1863-1931), both well-regarded men of science (Veatch, 2010).

These two geologists labored over the rocks they collected in Cripple Creek like Italian stonemasons, finishing them into standard sizes for study. This rock collection, now on display in the Cripple Creek District Museum, formed the foundation of their report. The Cross and Penrose report on Cripple Creek was published in 1895 and included a geologic map based on the representative rock collection they made (Cross and Penrose, 1895). The report was the first scientific publication on the district and was used by mine owners to raise capital for the expansion of their mining operations (Veatch, 2010).

The Cross and Penrose rock collection was remarkable in another way; it brought together in Cripple Creek the principal investors of what would become the Utah Copper Company and Daniel Jackling (1869-1956), the inventor of the technique that made the processing of low-grade copper ore profitable. Jackling, while working in a Cripple Creek mill from 1894 to 1895, developed relationships with Richard Penrose, his brother Spencer, and other mine owners (Veatch et al., 2006).

Spencer Penrose, his geologist brother Richard, and several mining men gathered around a large table to meet with Jackling. One of the men poured out a staggering slug of scotch in each of the glasses on the table. The room quickly subsided into silence when Jackling began, with inspired authority and knowledge of conviction, to reveal his plans: a new process that included mining with enormous open pits, using large mechanical shovels, and having steam locomotives haul ore cars to the mill (Veatch, 2010).

Richard Penrose knew that with the dawn of the age of electricity that the demand for copper would be endless. According to Richard Penrose, this would make a sound investment. Based on what Jackling had to say, the Penrose brothers and the other investors provided the funds to establish the Utah Copper Company that would mine copper ore in Utah's Bingham Canyon. The canyon's ore values became greater than the worth of the Comstock Lode, the California and Klondike gold rushes combined, and eventually made the Bingham Canyon mining operation the richest hole on Earth (Veatch, 2010). The investors were drenched in wealth.

The life of the mining camps came to an abrupt halt several times. The business sections of Cripple Creek burned to the ground by two destructive fires in 1896. And in 1899, a fire spread through Victor. These fires destroyed the quickly built wooden buildings of the early boom days. Brick and stone buildings rose from the ashes in their place. Some of these buildings still stand today, especially in Victor.

The continuous influx of people into the district led to the formation of Teller County, carved from parts of El Paso and Fremont Counties in 1899. A brick courthouse was built in Cripple Creek for civil actions and criminal trials; and where lawyers filed writs, summonses, appearances, and pleadings. Property taxes were paid to the County Treasurer and the County Clerk and Recorder maintained records.

By 1900, 500 mines had been located and more than a dozen towns established—including Cripple Creek, Victor, Altman, Independence, Elkton, Anaconda, Arequa, Eclipse, Midway, Beacon, Lawrence, Cameron, Mound City, Goldfield, and Gillett. Many of the gold mines were located either in or near the City of Victor. During that peak year, 8,000 miners produced more than 878,000 ounces of gold. Some of the mines were well-capitalized business operations with large payrolls. The Portland Mine, for instance, boasted 700 workers who worked in three shifts.

Rapid growth continued. The district's population in 1900 climbed to 50,000 people served by hotels, restaurants, lawyers, and brokerage houses. Cripple Creek was now the fourth largest city in Colorado with 13,000 people within the city limits and became the financial and business center of the district (Levine, 1994).

Streets bubbled with activity from curb to curb while the pace of business filled the air with whispering motes of gold dust. Each morning the sun greeted Bennett Avenue—illuminating outdoor advertising of patent medicines painted onto the bricks of commercial buildings—and brought the promise of activity, commerce, and hope for the day. A number of assay offices, overflowing with samples, operated in the district. Bankers had long lunches with mine owners in restaurants, graced with china plates, white napkins, and sparkling glasses. Children attended crowded schools, and newspapers printed the headlines of the day. Lawyers worked their cases. Together the miners, mine owners, merchants, and all the people of the mining district consumed life at a fever pitch.

The people who traveled to the Cripple Creek Mining District brought their institutions and customs, including fraternal organizations, band concerts, opera, theater, and religion. Sunday church services were an important part of life in the gold camp. Miners celebrated the Fourth of July with enthusiasm that included parades and games. Sporting events were essential as a cup of coffee and were a big draw in Cripple Creek with the townspeople attending baseball games, firemen's races, wrestling events, and boxing matches.

Jack Dempsey was training to be the top prizefighter. The so-called "Manassa Mauler" had a number of fights in the district. Dempsey's fights drew crowds. He would advance out of his corner, surrounded by a roaring mob, ducking, feinting, and bobbing against opponents. He was a powerful man, having worked in deep levels of the mines, and he could punch with a dynamite-laden glove.

A notorious red-light district on the bawdy Meyers Avenue sprang to life each evening when the sun slid behind Mount Pisgah. Busy mining men took time out for a drink of whiskey or to smoke a cigar in saloons; business was brisk at dance halls, pool halls, and theaters. Pleasure seeking and wickedness multiplied by the minute as raucous cries and shouts filled the night air.

By 1910, the mines of the district produced 22.4 million ounces of gold. Cripple Creek was unlike most of the other western mining camps in that its gold was contained in telluride minerals. These telluride minerals, which do not look like gold, contributed to why the district remained overlooked so long. Gold production required the use of the chlorination process rather than the stamp milling and amalgamation methods previously used in other mining districts. By 1911 gold extraction through cyanide leaching, a more efficient process, replaced chlorination in the gold camp.

As the gold camp grew, it took three railroads to serve the needs of the rip-roaring mining district. The railroads linked the area to the outside and kept the district provided with food, supplies, and equipment. Two trolley car lines provided transportation between the mines and towns.

The first railroad to reach Cripple Creek, started in 1893, was the narrow-gauge Florence and Cripple Creek Railroad that came to Cripple Creek up through the rugged Phantom Canyon from Florence. The Midland Terminal Railroad was the second railroad to Cripple Creek, and it was a spur of the standard-gauge Colorado Midland Railway that connected Colorado Springs to Leadville. The Cripple Creek spur originated at the depot in the hamlet of Divide and went south to Cripple Creek. The two railroads controlled freight rates and kept the costs of hauling ore to the mills high.

A third railroad, the narrow-gauge Colorado Springs and Cripple Creek District Railroad, (called the Short Line), was built along what is now the Gold Camp Road (Henry et al., 2004). By 1901, the train ran all the way from Colorado Springs to Cripple Creek. Powerful locomotives, with puffs of smoke billowing from their engines, hauled heavy cars of ore out of the district. The solid clacking tempo of the running wheels faded with the train as it vanished around the bend. This new railroad caused haulage rates drop, and these reduced rates allowed low-grade ore to ship. The Short Line, traveling through spectacular scenery, made this route a favorite tourist line.

The Cripple Creek Mining District is known for its large and celebrated mines that produced at least 30 millionaires. Spencer Penrose was one. He carried himself in a gentlemanly manner during the day and quite otherwise during the night. Spencer Penrose's mine, the C.O.D., was featured in the Cross and Penrose (1895) report and soon sold that same year for $250,000—the largest amount ever paid for mining property at that time in the district (Veatch et al., 2006). Penrose used his share of the profits to build the famous Broadmoor Hotel in Colorado Springs and to invest in Utah copper mining.

The Utah investment brought Penrose and his fellow investors unimaginable wealth. Spencer Penrose used his profits from the Utah Copper Company to establish the El Pomar Foundation which has benefited people the Pikes Peak region and Colorado to this day. Richard Penrose's interest in the Utah Copper Company brought him a fortune. In 1931, the estate of Richard Penrose left the Geological Society of America (GSA) an endowment of nearly $4 million. His bequest transformed the small scientific society into the largest and most productive geological organizations today (Veatch, 2010).

Winfield Scott Stratton, a Colorado Springs carpenter, prospected in the hills of the Cripple Creek area for 15 years and struck it rich on the 4th of July 1891 when he claimed the Independence Mine. He later sold it for $11 million. Stratton used some of his wealth to establish the Myron Stratton Home in Colorado Springs for orphans and the poor.

It was the Cresson Mine that held, deep underground, the storied "Cresson vug." On November 24, 1914 miners, working the 12th level, broke into the "vug" or cavity in solid rock measuring 40 feet (12.1 m) high, 20 feet (6 m) long, and 15 feet (4.5 m) high. This vug was covered with telluride minerals of sparkling sylvanite and calaverite that produced 60,000 oz. of gold and valued at $1.20 million—a huge amount, when the price of gold was $20 per ounce (Henry et al., 2004).

But not all was golden. Labor strife shook the area. First, in 1894 the Western Federation of Miners held a five-month long strike in response to mine owners increasing the workday from 8 hours to 10 hours. Violence erupted between striking miners and an armed militia of sheriff's deputies who were on the payroll of the mines. The governor declared martial law and sent in troops to restore order in the district. The union prevailed, and the strike ended when the mines returned to the 8-hour day with no reduction in the $3 per day wage (Ubbelohde et al., 2015).

Then in 1903 through 1904 labor strife erupted again—when anger gloomed into a violent quarrel. There was a lengthy period of violence between the union and non-union groups. Gun battles broke out and scores of men were killed, and 225 miners were run out of the district “on a rail.” The National Guard was sent to Cripple Creek to restore order (Ubbelohde et al., 2015). The mine owners prevailed, and the Federation of Miners was forced out of Colorado mines in 1904 (Cripple Creek & Victor Colorado Mining History n.d).

During the early twentieth century, the population and ore production declined as the gold ore became exhausted and the cost of mining rose. However, in 1934 there was a flurry of mining when the federal government raised the price of gold.

Water became a serious problem as underground workings deepened and encountered water. To mitigate these water problems, drainage tunnels were driven to drain the mines. The Carlton Tunnel, completed in 1941, was the longest of these drainage tunnels and drained the deepest levels of the Vindicator Mine. World War II caused the closure of mines and limited the effectiveness of the Carlton Tunnel.

After WWII, most of the mines were not profitable and closed. In 1976, Texasgulf and Golden Cycle formed a joint venture, the Cripple Creek & Victor Mining Company (CC&CV) to resume mining in the district. Through several mergers and acquisitions, ownership of CC&V changed hands. CC&V’s Cresson Mine, near the town of Victor, was permitted in 1994 as an open pit mine and gold production has continued since that date. In 2011 CC&V poured 266,000 ounces of gold, including its four millionth ounce. In 2013 CC&V donated 65 ounces of 24 karat gold to resurface the capitol dome in Denver. In 2015 CC&V poured its five millionth ounce of gold.

On August 3, 2015, Newmont Mining Company purchased CC&V from AngloGold Ashanti Limited. Newmont’s Cripple Creek process facilities include a rod and ball mill, two valley leach facilities, and two gold recovery units. Heap leaching recovers gold from the surface of lower-grade ore with a dilute sodium cyanide solution. The rod and ball mill is used to reduce the size of the high-grade ore to create more surface for the cyanide from which to strip the gold. CC&V’s mining fleet includes three shovels and 31 haul trucks with the capacity to haul ore ranging from 85 tons to 240 tons.

By the close of 2016, CC&V had poured 396,000 ounces of gold and calculated the value of CC&C’s mine assets to be $791 million (Newmont Mining CorporationAnnual Report, 2016). CC&V’s geologists use Brownfield exploration methods to identify new ore deposits near or adjacent to previously identified reserves, and in 2016 reported 3.4 million ounces of gold reserves. Under a recent mine life extension, mining is expected to continue in the until district 2025.

The end product of CC&V’s operations are doré bars, an alloy of gold and lesser amounts of silver that that is then transported to a refinery to produce bullion that meets the market standard of 99.95 percent gold. Cripple Creek’s gold is used for both fabrication or investment. Fabricated gold is used in electronics, dentistry, jewelry, medals, and coins. Investors purchase gold bullion, coins, and jewelry as part of their investment portfolios.

Cripple Creek’s gold mines contributed to the economic development of the Pikes Peak region and Colorado at the turn of the 20th century and beyond. Today, modern mining in the district continues to contribute to the economy of Colorado and the Pikes Peak region.

The splendors of Cripple Creek have not faded. Today, Cripple Creek thrives in the nostalgic atmosphere of the gold rush days, where limited stakes gambling is allowed in casinos that line Bennet Avenue. An active historic preservation program in the district works to save the old buildings whose bricks drip with history, and to preserve the old mining headframes and surface buildings that stand silently at abandoned claims. These structures promote heritage tourism as they draw the visitor back in time.

In the end, Womack did not cash in on his mine. It was a cruel trick of fate that landed Womack in poverty—a broken man when he was the one who discovered the rich bonanzas of the Cripple Creek’s goldfields. Womack’s only comfort was that he knew his discovery wrote him onto the pages of Colorado’s history.

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Biography

Steven Veatch is a geoscientist and former adjunct professor of Earth Science at Emporia State University in Kansas where he received an MS in Earth Science. He also has an MA from Webster University, St. Louis in management. Veatch has been involved in geoscience education initiatives for over 25 years. His family came to Cripple Creek in the 1890s from England and worked in the district's mines for over 40 years. Veatch has contributed chapters to 3 books: *Field Trips in the Southern Rocky Mountains, USA, Field Guide 5*, *The Paleontology of the Upper Eocene Florissant Formation, Colorado*, and *The World's Greatest Gold Camp: An Introduction to the History of the Cripple Creek and Victor Mining District.*

An Updated Introduction to Cripple Creek Geology & Mineral

Carl R. (Bob) Carnein

In a state containing many notable mineral localities, the Cripple Creek/Victor district stands out. Although it didn't produce specimens as spectacular as the Alma rhodochrosites or Breckenridge golds, Cripple Creek has yielded a steady stream of outstanding telluride minerals, as well as more limited but distinctive amethyst crystals and a suite of unusual minerals that includes gearksutite, creedite, rhodochrosite, and celestine.

The Cripple Creek/Victor district has an assemblage of over 120 minerals (Carnein and Bartos, 2005). Typical of any mining area, most of those are either rock forming minerals or things that are inconspicuous or of relatively low quality. However, all of these minerals, whether of collector interest or not, are important to the geologist trying to understand the origin of this complex deposit.

Scientific study of the district began 140 years ago, with F.V. Hayden's Territorial Survey of 1873 (Hayden, 1874). U.S.G.S. geologists dominated the early years, starting with Whitman Cross and R.A.F. Penrose, Jr. (1894, 1895) and continuing into the mid-20th century. More recently, geologists and graduate students at the University of Colorado, Colorado School of Mines, Colorado State University and at the Cripple Creek and Victor Gold Mining Co. (CCV) and elsewhere have completed dozens of studies that contribute to an impressive body of knowledge on a relatively small but economically prodigious area. Some noteworthy examples are Jensen (2003), Jensen and Barton (2007), and Dye (2015).

Like most scientists, geologists like to group things by their similarities. So Cripple Creek is usually classed as an alkalic-type epithermal gold deposit having at least some similarities with other world-class deposits (e.g. Emperor, Fiji; Porgera and Ladolam, Papua New Guinea). Characteristics of such deposits, although somewhat variable, include the following (Richards, 1998; Schroeter and Cameron, 1996):

- Sheeted quartz veins and hydrothermal breccia systems that, potentially, may host bonanza-grade gold mineralization (up to kg/tonne for short intervals);
- Common presence of Au/Ag tellurides, vanadium-rich mica (roscoelite), and fluorite;
- Silicic, potassic, and argillic alteration of wall rocks, with adularia, illite, sericite, and jarosite;
- Ore deposition during explosive discharge of overpressured fluids along convenient conduits (especially normal faults and volcanic edifices);
- Arc-collisional, post-subduction, or back-arc-basin tectonic settings.

Of these, only Cripple Creek's tectonic setting could be described as anomalous.

General descriptions of Cripple Creek's geology are available in many sources, the most recent being Jensen (2003); Jensen and Barton (2007), and Dye (2015). The deposit occupies an area where 4 Precambrian units intersect (Figure 1). The oldest of these is part of the 1.75Ga "Idaho Springs Formation", consisting of high grade metasediments and metavolcanics. These rocks are mostly biotite gneiss and mica schist and are best exposed on the east side of the town of Cripple Creek. The second oldest rocks belong to the Ajax granodiorite (informal name), dated at 1.7 to 1.65 Ga. They consist of hornblende or biotite granodiorite, some of it a pink to gray augen gneiss, that envelope most of the deposit, from southwest of the former town of Anaconda, through Victor, Goldfield, and along the east side of the north and east sub-basins (Figure 2).

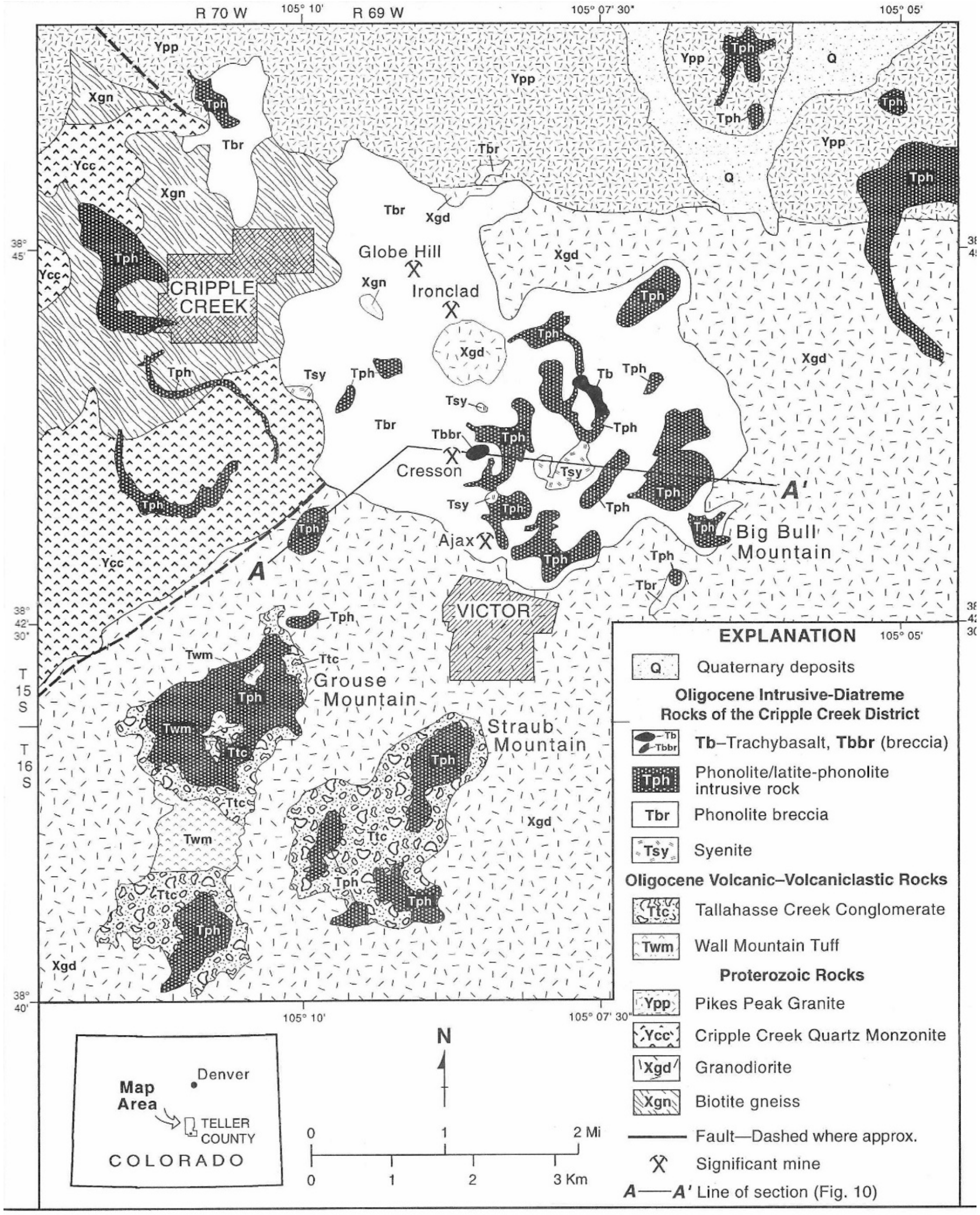

Figure 1. Geology of the Cripple Creek/Victor gold mining district (Cappa, 1998; modified from Wobus, *et al.*, 1976)

An isolated, nearly circular exposure, nearly 0.5 km across, occurs near the center of the basin. Next youngest is the Cripple Creek quartz monzonite, whose age is 1.4 to 1.45Ga. This unit, exposed between Cripple Creek and Anaconda, consists of reddish biotite-muscovite quartz monzonite and is probably equivalent to the Silver Plume Granite seen elsewhere in Teller County. Finally, the youngest Precambrian unit is the Pikes Peak Granite, dated at about 1Ga. Locally, the Pikes Peak consists of a relatively coarse biotite or hornblende granite that weathers to form rounded masses and a gravelly grus. Exposures are limited to the northern edge of the northern sub-basin.

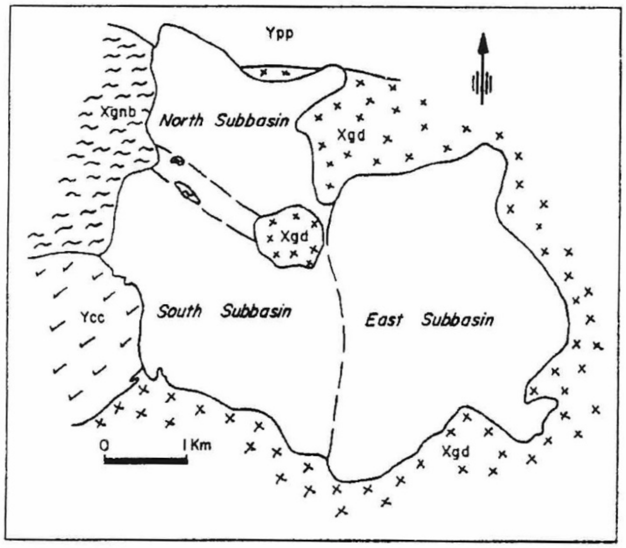

Figure 2. Sub-basins and Precambrian rocks of the Cripple Creek/Victor district (Thompson, 1992).

Near their intersection, the Precambrian host rocks were intruded by an Oligocene alkaline diatreme complex that includes hundreds of (early) phonolitic to (late) lamprophyric to silicocarbonatite alkaline rocks (Jensen and Barton, 2007). The latter are temporally closest to the gold mineralization. The location of the diatreme may relate to old areas of structural weakness.

Alkaline magmatism is widespread in CO, NM, UT, and WY, but compositions of individual bodies vary widely. In Colorado, it more or less coincides with relaxation of Laramide compression and commencement of extension in the Rio Grande rift (circa 30Ma). This and more widespread calc-alkaline magmatism (San Juan and Thirtynine Mile volcanics) probably relate to rifting and to processes in the upper mantle and lower crust. In the Cripple Creek area, the Oil Creek and Fourmile faults may relate to this rifting.

The diatreme complex, measuring about 5 km across and more or less carrot shaped in cross section, includes 3 sub-basins filled with (mostly) poorly sorted heterolithic volcanic agglomerate and breccia in a matrix of pulverized rock and crystal fragments. Fragments of Precambrian rocks are common near the diatreme borders (Jensen and Barton, 2007); most of the breccia consists of angular to sub-rounded pieces of various volcanic rocks and older breccias. Textures, structures, and the presence of lacustrine and other sedimentary rock fragments suggest multiple stages of explosive volcanic activity and subsidence, with the development of a maar at the surface. All traces of a tuff ring are gone, but its diameter was probably not much larger than that of present-day exposures of the eroded diatreme. Phreatomagmatic events both pre- and post-date the alkaline intrusives.

Total gold production from the Cripple Creek/Victor district has probably reached over 25 million ounces. This has come from two major types of deposit: (1) narrow, high grade quartz veins in which gold (and silver) occur as various telluride minerals (e.g. calaverite, sylvanite, krennerite, petzite) and (2) low grade, disseminated deposits, in which precious metals occur as microcrystalline gold and gold-bearing arsenic rich pyrite (Dye, 2015). The high grade (commonly 0.5 to 2 opt) quartz-telluride veins were exploited mostly early in the deposit's history, while low grade (average 0.02 to 0.03 opt) material has dominated since the 1980s and especially since 1994, when CCV opened the massive Cresson operation that has produced over 5 million ounces of gold to date. The narrow, steeply dipping, sheeted quartz veins trend mostly northwest or northeast and continue downward into the deepest underground mining levels (about 1000m). The low grade disseminated deposits are concentrated mostly within 300 meters of the surface.

Many workers have tried to unravel the complex series of structural and hydrothermal events that led to and included Au/Ag mineralization at Cripple Creek. For example, Thompson, *et al.* (1985) and Dwelley (1984) discussed paragenesis and structural sequences for both the vein systems (e.g. Ajax mine) and the low grade deposits of the Globe Hill area (northern sub-basin). They recognized five stages of mineralization in the veins of the Ajax mine and four mineral assemblages associated with a four-stage sequence of structural events in the Globe Hill area.

Other workers have proposed their own sequences (for examples, see Carnein and Bartos, 2005). The most recent attempt to develop a deposit-wide paragenesis is that of Dye (2015), who recognized seven distinct stages of mineralization. Hydrothermal fluids for each stage had their own compositions and physical/chemical characteristics. Interestingly, unlike most previous workers, Dye concluded that the relatively shallow deposits of microcrystalline hypogene gold and gold- and arsenic-bearing pyrite now being mined at Cresson are unrelated paragenetically to the gold-telluride deposits in the vein systems. Intense K-feldspar alteration occurred between the gold and gold-telluride mineralization stages, rather than simultaneously.

Dye also recognized that quartz mineralization is more complex than previously thought. Fluid-inclusion studies of quartz have been used in the past to work out P-T conditions for gold mineralization, the assumption being that they all occurred more or less together. This may be only partially valid, because three different types of quartz may represent separate mineralization stages. Finally, Dye also notes a sequence of pyrite compositional changes during the mineralization stages, including an association between Au-bearing and As-bearing pyrite. He recognized five generations of pyrite and determined that most pyrite associated gold occurs in solid solution, rather than as distinct nano-scale particles.

The Cripple Creek/Victor district is unusual for the wide variety of minerals found there. This, however, may result more from the number of studies done (especially in the late 19th and early 20th centuries) than from any real differences between Cripple Creek and other deposits of similar origin and size. Neither current mass mining and processing methods nor modern demands for safety and efficiency, both of operations and of employees, favor mineral discovery or preservation. However, modern prospecting tools allow identification of some minerals without expensive analytical work.

A few new finds have occurred in the last 10 to 15 years. Fine specimens of creedite, gearksutite, celestine, and rhodochrosite turned up in the Cresson open pit, north of Victor, in 2001. More recently, attractive specimens of small fluorite crystals and/or gray quartz crystals on elongate barite pseudomorphs after laumontite have been coming out of an undisclosed location south of Cripple Creek. Nice amethyst crystals, different from the old-time ones whose source is unknown, have been found at the site of the abandoned David Leighton mine, near the west edge of Cripple Creek. The author, along with Steven Veatch and John Rakowski of the Lake George Gem & Mineral Club, has identified, cataloged, and photographed several hundred specimens in the Cripple Creek District Museum. Although nothing truly new was found, we identified an old specimen of creedite that pre-dates what was thought to be the first (2001) find. Also noteworthy is the recent receipt by the CCDM of a 46-pound turquoise "nugget" from a claim on the northeast edge of Cripple Creek. New finds may also come from the future re-examination of old collections.

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Biography

An Ohio State grad, C.R. (Bob) Carnein taught geology at Waynesburg University (1970-1989) and Lock Haven University of PA (1989-2007). Teaching Waynesburg's geology field course in Florissant, CO, introduced him to central Colorado geology and minerals, and he retired to Teller County in 2007. Since then, he regularly volunteers at the Florissant Fossil Beds National Monument, the Cripple Creek District Museum, and the Pikes Peak Historical Society Museum, among others, as well as doing occasional geological consulting. Bob's interest in mineralogy began when he was 12, and he maintains a collection that is especially rich in material from the Cripple Creek/Victor district, Franklin/Sterling Hill, NJ, and Chuquicamata, Chile.

Newmont North America Cripple Creek

Douglas White
Area Geology Manager Cripple Creek Operation

Newmont Mining Corporation acquired the CC&V operation in August of 2015. The operation is part of Newmont's North American Region, which is headquartered in Elko, Nevada. Newmont has continued and has enhanced the project commitment to safe operations, historic preservation, reclamation, community relations, regulatory compliance, agency engagement, and recycling. Newmont was the only mining company on *Corporate Responsibility Magazine's* (*CR Magazine*) annual 100 Best Corporate Citizens List. Ranking 43rd overall in 2017 (click here to view the full list), this achievement represents the sixth time in the last 18 years that Newmont has been selected for this recognition, further affirming Newmont's lead in safety, environmental stewardship and social responsibility.

Exploration activities continue in the district to optimize surface reserves, resources and evaluation of underground potential. The current focus is on the surface open cut operations. To extend mine life Newmont provides regional and cooperate support to the CC&V Geology team. Working within a regional network of mines provides opportunities that previously did not exist.

Gold has been produced from the Cripple Creek Mining District since its discovery in 1891. Historic production from underground mines and small, shallow surface mines is approximately 20 million ounces of gold. Recent surface gold production, since 1995, is nearly 5.5 million ounces. During 2016 production reached 396k ounces as processing capacity increased from a single valley leach facility to two and an addition of a flotation and Carbon in Leach mill circuit to process higher grade ores. Expected mine life is 2025. Sustaining mining for over 127 years is a product of exploration success and expanding the understanding of the deposit and evolving lower cost mining and processing methods. There is a long list of geologists, students, government and university contributions.

Low grade ore tons are processed on the Valley Leach Facilities where a dilute solution of sodium cyanide is percolated through the crushed rock. The gold goes into solution and this pregnant solution is collected and pumped to the recovery facilities. Gold production continues on VLF1 and ADR1. VLF2 with a capacity of 218 million tons were brought into production in 2016. The new mill has designed capacity of 2.0 million tpa to process higher grade ore and improve recovery. The mill includes a gravity, flotation, and CIP circuit. Sulfide concentrate produced by flotation may be shipped to Newmont facilities in Nevada to optimize gold production in the region. The mill ore is mixed and stacked on VLF 2 for additional gold recovery.

Biography

Douglas White is the Area Geology Manager for Newmont Mining's Cripple Creek operations in Colorado. He assumed his current role in the Fall of 2015, upon Newmont's purchase of the mine. He is responsible for the management of near mine exploration and drill services, and has an advisory role for production geology. Doug White has 26 years' exploration and mine geology experience at Cripple Creek:

- Began work in the exploration department rig geologist for Nerco Minerals 1991;
- Progressed to Exploration project geologist;
- Moved to production geology in 1998 work included: ore control, geotechnical, reserve development, resource estimation management and reconciliation functions..

Mr. White attended Western State Colorado University where he received a degree in Comprehensive Geology in 1989. In 1989 he was chosen as a USGS NAGT intern, followed by a position with Tenneco Minerals as exploration geologist in 1990, working at Silver Cliff, Colorado and Nome, Alaska.

A Cursory Description of Telluride Occurrences in Boulder County, Colorado and Exploration Guides: Classic Examples of Epithermal Telluride Deposits in Boulder, Colorado's Backyard

Bruce Geller
Director of the Colorado School of Mines Geology Museum

Despite tellurium's scarcity in the earth's crust, telluride minerals are known in more deposits and deposit types than ever before, as a result of detailed microscopic and microanalytical techniques. Tellurium is ever more important in today's high-tech applications. Luckily, tellurium's rarity does not correlate with its price, or it would be more expensive than platinum.

Telluride minerals have been known in Colorado for over 145 years (Kelly and Goddard, 1969) and some species were first found here. Colorado hosts more tellurium occurrences per square kilometer than any area known on earth (Geller, 2014). Many of these are hosted in, but certainly not restricted to, the Colorado Mineral Belt (though the vastly important Cripple Creek district is not in this belt). Ore deposits in this belt loosely range in age from Proterozoic through Recent, but most resulted from hydrothermal activity related to Laramide-age plutons.

The northeast end of the Colorado Mineral Belt was the focus of field studies into the genesis of epithermal, vein-hosted telluride ores first undertaken by E. N. Goddard (1935, 1936, and 1940). Years later, the primary telluride-bearing area became known as the Boulder Telluride belt (BTB) and the focus was on laboratory studies (Kelly and Goddard, 1969). Some key questions raised by Lovering and Goddard (1950) concerned the relationship of telluride ores to other economic deposits of Ag-base metals, pyritic Au, tungsten, and fluorite, and the relationship of telluride-bearing veins to major structures which they designated as "breccia reefs".

Other unanswered questions involved the age and depositional conditions of the tellurides. W. C. Kelly, who worked as an ore petrographer with E. N. Goddard, described the diversity of telluride species found in the BTB (1969). He realized that no other known deposits contained these telluride suites in equal abundance or diversity, at that time. In short, Kelly and Goddard found many interesting points that called for further investigation.

The intention of this paper is not to exhaustively cover the many implications of years of telluride research, but rather to recap some of the conclusions derived from that research. First, the telluride deposits in Boulder County occur in narrow epithermal veins that are genetically related to alkali rocks of 55 Ma age at Jamestown (Sharaky, 2000) and 55 Ma age south and west of Gold Hill (Geller, 1993), but not found in those host rocks. Second, the same mineralized structures seen in hand specimens mimic those on mine- and district- scales. Third, the paragenetic sequence of telluride-stage ore is fairly similar throughout the BTB and emulated elsewhere in the world. Fourth, telluride mineral recognition in the field is extremely difficult, but is greatly facilitated by ore petrography and/or microanalytical imaging methods.

Guides to prospecting, recognizing, and differentiating telluride minerals will be offered, as well as a discussion of detractions.

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Biography

Bruce holds a B.S. degree from Dickinson College, an M.A. degree from the State University of New York at Binghamton, an A.M. degree from Harvard University, and a Ph.D. degree from the University of Colorado – all in geological sciences. He has worked in the mineral industry since 1981 as an explorationist, research consultant, journalist, business manager, and served as a consulting mineralogist for many large and small mining companies. Bruce taught earth science courses for seven years at Metropolitan State College and was a technical editor for the journal Mining Engineering for six years. He has served as the Director of the Colorado School of Mines Geology Museum since 2007. Bruce has authored many publications on telluride minerals, with a lesser number dedicated to non-telluride topics.

He has served as a Research Associate at the Denver Museum of Nature and Science, Secretary for the Denver Region Exploration Geologists' Society; is presently a Councilor for the Colorado Scientific Society and has been a board member of the The Denver Mining Club since 1994.

A mineralogical look at Colorado's gold and silver production

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Native gold and native silver are the best-known forms of these elements that are represented in the production of these metals from Colorado's mines. But they are, of course, not the only mineralogical form in which gold and silver occur in the ores that were mined.

Aside from native gold, the gold-silver telluride minerals accounted for a significant amount of the early production from Cripple Creek and from Boulder County. Sylvanite, $AgAuTe_4$; calaverite, $AuTe_2$; and krennerite, Au_3AgTe_8, were the most abundant telluride minerals mined in Colorado (Eckel, 1961, 1997; Geller, 1993, 1997; Kelly and Goddard, 1969.

Substantial amounts of native silver were produced in mining districts such as Aspen and Creede, as well as at Leadville and elsewhere. Silver also occurs as an alloyed element with gold, in which the silver content can vary from trace to considerable, so that much of Colorado's gold production also accounted for significant silver. The alloy is formally known as electrum, (Au,Ag), only when the silver content exceeds 20 weight percent Ag, but this is rare. Silver also occurs as silver sulfide (argentite/acanthite, Ag_2S), silver halides (chlorargyrite, AgCl; bromargyrite, AgBr; iodargyrite, AgI), and sulfosalts, including the tennantite-tetrahedrite-freibergite series, proustite, pyrargyrite, pearceite, polybasite, and others. Galena from Colorado's mines ranged from low in silver content to (less commonly) significantly silver-bearing (Modreski, 1988; Wenrich, 2017). When galena is high in silver content, the silver, which may have originally been in solid solution via coupled substitution of Ag + Bi or Ag + Sb for lead, is usually now present as microscopic inclusions of sulfosalts or argentite. Likewise, silver-bearing cerussite, such as occurred in abundance at Leadville, contained silver due to inclusions of the silver sulfides or sulfosalts. Other ore minerals, such as bornite, may contain minor silver as well (Wenrich, 2017).

The intent of this present paper is to try to use published data on gold and silver production of Colorado's mining districts and the literature on the mineralogy of the ore deposits to reconstruct the proportions of the different gold and silver minerals that actually accounted for the production of the two metals. One earlier attempt at such a breakdown was a list of minerals produced in Colorado from 1858-1957, in terms of dollar value, prepared by Eckel (1961) and also adapted in Pearl (1969). Eckel's version of list gave for Colorado's top metallic mineral commodities in decreasing dollar amount:

Molybdenite	$542 million
Native gold	400 million
Sphalerite	295 million
Galena	260 million
Calaverite	250 million
Krennerite	150 million
Argentiferous galena	150 million
Silver halides	145 million
Argentiferous tetrahedrite-tennantite	100 million
Sulfosalts, chiefly polybasite-pearceite	100 million
Argentite	75 million
Auriferous sulfides	66 million
Chalcopyrite	58 million
Cerussite	50 million
Other tellurides	40 million
Smithsonite	35 million

Native silver	25 million
Anglesite	5 million

Pearl's (1969) version of this list combines the figure for galena (for the value of its lead content) with that of argentiferous galena (for its silver) for a total of $410 million, thus placing galena in second place on Pearl's list.

Finding all the data needed to compile an accurate (or even an approximate) update of this list of mineral production has proven to be a more daunting challenge than I might have anticipated. Some overall figures are easy to come by. For example, total Colorado gold production through 1965 is given as 40,775,923 troy ounces (Koschmann and Bergendahl, 1969). The major addition needed to bring this figure up to the present day is the production from Cripple Creek; its production through 1965 is given as 19,101,000 troy ounces by Koschmann and Bergendahl, and White (2017) also quotes historic (before 1995) Cripple Creek production as being about 20 million ounces, with production since then at the Cripple Creek & Victor gold mine being "nearly 5.5 million ounces". These combine for a total gold production from Cripple Creek of approximately 25.5 million troy ounces. As to silver, the Cripple Creek & Victor gold mine has been a significant producer of byproduct silver; it was ranked the 20th silver producer in the U.S. in 2014, the latest year for which production rankings are available from the USGS, out of 26 mines or districts thus ranked (USGS Mineral Yearbook, 2016). Total U.S. silver production between 2011-2015 has been 1040-1180 metric tons per year (Mineral Commodity Summaries, 2016). Some other sources of useful data on gold and silver production in Colorado include Baillie (1962); Henderson (1926); Lovering and Goddard (1950); and Williamson (1961).

However, to arrive at all the production figures *by mineral species* that I might hope to find, would require finding such data as silver content (and recovered amount of silver) in mined gold from Colorado, both historically and from current mining; the amount of native silver mined in Colorado post-1957, as well as the amounts of all the other silver-bearing sulfide and sulfosalt minerals; and the amount of gold (and silver) recovered from all the post-1957 gold, silver, and polymetallic mining operations in the Colorado, including mines in the San Juan Mountains, Boulder County and all the rest of the Colorado Mineral Belt. In my oral presentation I will endeavor to share at least some of this kind of data.

Appendix

Here are a few figures and conversion factors that are useful to have at hand to interpret the kind of statistics I have been trying to arrive at:

1. 1 troy ounce = 31.1 grams
2. 1 gram = 0.033154 troy ounces
3. 1 metric ton = 1000 kilograms = 10^6 grams = 32,154 troy ounces
4. Historic U.S. prices of gold: 1858-1861, $20.67; 1870, $22.88; 1879-1932, $20.67; 1934-1939, $35.00; 1941-1942, $35.50; 1950, $40.25; 1960, $36.50; 1970, $38.90; 1980, $594.90; 1990, $386.20; 2000, $272.65; 2010, $1420.25 . Source of data, http://onlygold.com/Info/Historical-Gold-Prices.asp .
5. Current spot price of gold (7/10/2017) = $1213.30/troy ounce = $39,008.47/kilogram
6. Historic U.S. prices of silver: 1834, $1.29; 1864, $2.94; 1877, <$1.29; 1900, $0.62; 1910, $0.54; 1920, $1.02; 1930, $0.38; 1940, $0.35; 1950, $0.74; 1960, $0.91; 1970, $1.77; 1980, $20.63; 1990, $4.82; 2000, $5.00; 2010, $20.20. Source of data for post-1900, USGS (2013); earlier years, various sources.
7. Current spot price of silver (7/10/2017) = $16.97/troy ounce = $545.60/kilogram.

I appreciate the help of Ed Raines and Bruce Geller in pointing out the list of minerals produced in Colorado that appeared in Eckel (1961) and Pearl (1969).

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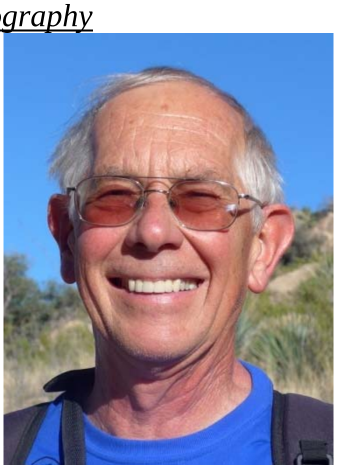
Biography



Dr. Peter J. Modreski has been a geochemist since 1979 with the U.S. Geological Survey, Lakewood, Colorado. He has a B.A. (chemistry) from Rutgers College and an M.S. and Ph.D. from Penn State (geochemistry). His research interests include mineralogy, gemstones, luminescence, Colorado geology, ore deposits, pegmatites, meteorites and impacts, alkaline igneous rocks, kimberlites, and volcanology. He is presently responsible for public and educational outreach at the USGS. Pete was a co-author of *Minerals of Colorado* (1997) and he is a Consulting Editor of Rocks and Minerals magazine and a Department Associate with the Earth Sciences Department, Denver Museum of Nature and Science.

Hydrothermal evolution of Au-bearing quartz-pyrite veins and their association to base metal veins in Central City, Colorado

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The Central City district in Colorado, just 25 miles west of Golden, was once a thriving mining district in the late 19th and early 20th century. This district provided a major source of gold and silver as well as lead, zinc, and uranium with the total output exceeding $100 million during the time of production [1]. The host rock lithology is dominantly composed of Precambrian quartzofeldspathic schists and gneisses that display structurally controlled hydrothermal quartz-pyrite veins with varying degrees of phyllic and silicic alteration. Several decades ago, this deposit was interpreted to be related to the upper part of a Laramide alkaline porphyry molybdenum system at the intersection of the Dory Hill fault and the Idaho Springs shear zone [2]. However, no clear textural relationships have been shown that relate the molybdenum mineralization to the later Au, Ag and base metal mineralized zones. Two significant stages of veining and mineralization have been recognized by [1], including: i) a higher temperature stage containing Au within dominantly quartz-pyrite veins, and ii) a lower temperature stage containing galena-sphalerite veins with base metal mineralization (i.e. Pb and Zn), Ag and rare gold. These two significant stages have been spatially separated into a central and peripheral zone, respectively, with a transitional intermediate zone and an uneconomic barren zone. The central zone contains quartz-pyrite veins that can be subdivided into Type A veins devoid of base metals and sulfosalts, and Type B veins containing abundant copper minerals [1]. The transitional intermediate zone contains pyrite veins (Type C) with significant quantities of sphalerite, galena, and copper minerals. The peripheral zone, with sparse quantities of pyrite, contains the sphalerite-galena veins where silver is ubiquitous, and accompanied by carbonates, chalcedony, quartz and barite. The outermost barren zone, is recognized as containing uneconomic quartz veins with galena, carbonates, and barite. These concentric zonal patterns are presumed to indicate a decrease in hydrothermal fluid temperatures from the central to the barren zone [1, 2]. Even though the mineralization was recognized to be spatially related to Tertiary intrusives [2], many aspects of the Central City district remain unclear. In particular, the relation between the quartz-pyrite veins and their association to base metal veins needs to be described in more detail for building an adequate genetic ore formation model for this deposit. This study will investigate the mineralogical and textural relationships in quartz-pyrite veins (Types A, B, and C) and their association to base metal veins with focus on the central and intermediate zones. The major goal of this research is to determine a genetic model for the Central City district and delineate in more detail the key ore forming processes responsible for the veining and observed metal zoning in the district. A mineral paragenesis will be established, and different pyrite and quartz generations will be characterized and related to the rock alteration types and base metal mineralization by combining textural observations at the field and thin section scale. Preliminary results indicate the pseudomorphic replacement of phyllosilicates by pyrite and muscovite. In addition, pyrite has been found in veins and disseminated in the host rock indicating that there are at least 3 different pyrite mineralization events. Cathodoluminescence will be utilized to determine the different quartz vein/veinlet generations, and LA-ICP-MS will be used to determine the trace element geochemistry of pyrite and Ti in quartz for using the TitaniQ geothermometer. The outcome of this study is expected to provide insight into the physiochemical conditions in which hydrothermal fluids mobilized and mineralized Au and base metals.

[1] Sims et al. (1963a), U.S. Geol. Survey Prof. Paper 359, 231 p.
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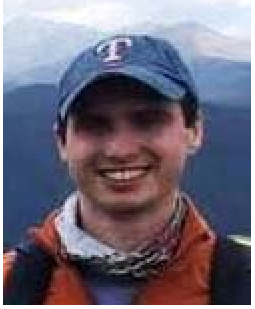
Lee Alford biography:

I am currently a second year master's student at Colorado School of Mines studying economic geology under the supervision of Dr. Alexander Gysi. My thesis is titled: Evolution of hydrothermal gold bearing pyrite veins and their association to base metal mineralization in Central City, CO. This summer I am working in Denver as a geology intern for the exploration division of The Electrum Group. Upon graduation in May 2018 I intend to enter the mining industry as a geologist utilizing the skills and passion for minerals and metals that I have developed here at Mines.



A Revised Paragenetic History of Gold Mineralizing Events at the Cripple Creek Gold-Telluride Deposit, Colorado.

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The world-class Cripple Creek gold-telluride deposit in central Colorado is the third largest gold deposit in the United States and has produced >24 million ounces of gold. Although research on the Cripple Creek deposit has been carried out since shortly after its discovery in 1891, several different and contradictory models have been proposed for the paragenetic sequence of mineralizing events and the magmatic and hydrothermal evolution of the deposit. The focus of the research presented here is on refining the paragenetic sequence and developing a new model that describes the evolution of hydrothermal fluids involved in mineralizing events.

Geological Background

The Cripple Creek deposit is hosted within an Oligocene alkaline-magmatic diatreme complex that developed at the structural intersection of four Precambrian units (**Figure 1**) beginning at ~32.5 Ma (Kelley et al., 1998). The diatreme hosts large volumes of heterolithic breccia that are intruded by alkaline sub-volcanic dikes and sills that have compositions that range from phonolite to lamprophyre (Lindgren and Ransome, 1906; Loughlin and Koschmann, 1935; Thompson et al., 1985; Kelley et al., 1998; Jensen, 2003). Intrusive bodies evolved to become progressively more mafic with time (Kelley et al., 1998; Jensen, 2003), and culminated with the emplacement of localized late stage lamprophyre breccia pipes. Gold mineralization within the deposit largely postdates the formation of the lamprophyre breccia pipes, and there is no clear evidence genetically linking mineralization to any of the intrusive bodies that are present within the upper 1000 m of the deposit (Jensen, 2003).

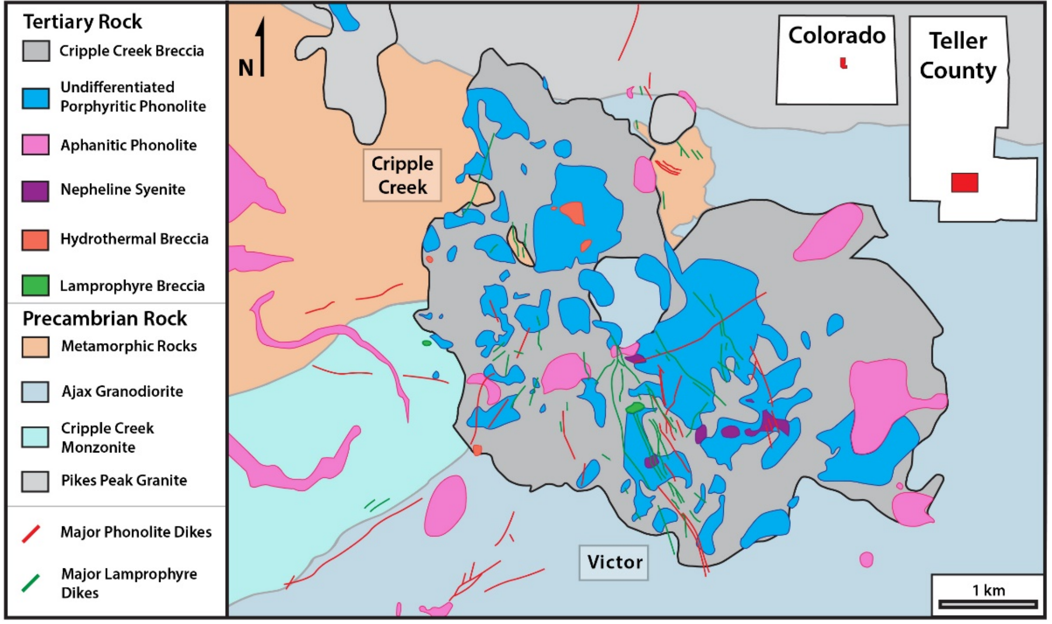

Figure 1: Geological map of the Cripple Creek deposit, Teller County, Colorado. *Modified after Jensen (2003)*

Gold production comes from high-grade gold-telluride veins, as well as broad low-grade zones that surround high-grade structures (Kelley et al., 1998; Jensen, 2003). Previous research has shown that gold occurs in three dominant forms: 1) gold-bearing telluride minerals within high-grade fissure-fill veins located within sheeted fracture zones (Cross and Penrose, 1895; Lindgren and Ransome, 1906; Loughlin and Koschmann, 1935; Koschmann, 1949; Thompson et al., 1985; Kelley et al., 1998; Jensen, 2003); 2) disseminated' free gold associated with pyrite within broad low-grade zones (Pontius, 1992; Burnett, 1995; Kelley et al., 1998); and 3) 'refractory' gold in trace element-rich pyrite that is locally associated with high-grade ores (Jensen, 2003).

Although several previous studies have focused on the history of mineralizing events within the deposit, there is disagreement among portions of the previously proposed paragenetic sequences and the relationship between high-grade gold-telluride veins and 'disseminated' gold-pyrite type mineralization remains unclear. Much of the previous research was performed prior to the discovery of bulk tonnage low-grade deposits. As a result, many of the proposed paragenetic sequences have a narrow focus on differences in mineralogy among individual telluride veins and were not able to account for the relationship between telluride veins and other forms of gold within the deposit.

A New Look at Cripple Creek

Approach

To explore the relationships between different forms of gold mineralization within the deposit, a combination of assay data and whole rock geochemical data from historic diamond drill core, blast pattern drilling chips, and on-site channel sampling were used to identify a series of high-grade ore zones that contained variable geochemical and mineralogical profiles. Specific target zones were selected for sampling based on macroscopic differences in ore mineral associations, morphological differences in quartz gangue (where present), the degree and type of associated alteration, and the extent of surface weathering and oxidation.

A suite of samples were collected from each target zone and characterized using hand sample observations, whole rock geochemical analysis, and transmitted and reflected light microscopy of thin sections produced from each sample. Based on differences in the mineral and alteration assemblages present among different thin sections, a subset of samples were further characterized using scanning electron microscopy (SEM), electron probe microanalysis, SEM-based automated mineralogical scanning, and optical, hot-cathode cathodoluminescence (CL) imaging. Data compiled from these analytical techniques were combined with field observations to develop a revised paragenetic sequence of the deposit, and the revised sequence was used to develop a new model for the hydrothermal evolution of the deposit.

Mineral relationships

Seven distinct mineralizing stages (**Table 1**) were identified based on relationships between individual ore, gangue, and alteration minerals. In relative order, these stages are:

1) Pervasive development of trace element-poor pyrite (Pyrite1) through the process of sulfidation of preexisting iron-rich minerals such as hematite and biotite across broad zones of host rock; this stage was accompanied by pervasive alteration of susceptible host rock to sericite (white mica).

2) Formation of trace element-rich gold-bearing arsenian pyrite (Pyrite2) within sets of micro-fractures that cut broad zones of Pyrite1; this stage culminated in a shift to the formation of microcrystalline hypogene native gold.

3) Development of micron-scale Ag-Pb-(Au) telluride minerals and galena within micro-fractures that cut grains of Pyrite2.

4) Formation of tetrahedrite-bearing quartz veins that cut mineralized zones formed during stages 1-3. This stage marks the first time that quartz was deposited in association with any of the ore minerals and the host rock surrounding these veins has generally been pervasively altered to secondary potassium feldspar.

5) Formation of hydrothermal quartz (± fluorite) and additional trace element-poor and trace element-rich pyrite (Pyrite3) within open fractures and veins that cut veins formed during the previous stage; Pyrite3 does not occur in the wall rocks adjacent to veins and the wall rock of these veins has been pervasively altered to secondary potassium feldspar.

6) Deposit-wide development of gold telluride minerals within quartz ± fluorite ± carbonate veins that may or may not contain Pyrite2 and/or Pyrite3.

7) Development of molybdenum, copper, and silver-rich base metal sulfide minerals and additional trace element-poor pyrite (Pyrite4) within veins of quartz ± fluorite ± barite ± anhydrite that cut all previously formed minerals.

Within mineralized zones, progressive mineralizing stages either cut or overprint the minerals formed during previous stages, and it is common for minerals from more than one stage to be present in hand samples. However, it is rare for minerals from all stages to be present. In addition, samples containing gold telluride minerals locally preserve textures that indicate cyclical deposition between telluride minerals and quartz gangue.

Table 1: *Revised paragenetic sequence of the Cripple Creek deposit. (alt=alteration)*

Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7
sericite	Pyrite2	petzite	tetrahedrite	purple fluorite	calaverite	quartz (Q1)
Pyrite1	hypogene gold	hessite	quartz 1 (Q1)	quartz 2 (Q2)	coloradoite + hypogene gold (localized)	molybdenite
		altaite	K-feldspar alt?	Pyrite3	sylvanite (rare)	tetrahedrite
		galena		K-feldspar alt?	krennerite (rare)	galena
						sphalerite
						acanthite
						Ag-sulfosalts
						Pyrite4

A key observation within the paragenetic sequence is that the different stages of pyrite growth have distinct spatial relationships with respect to wall rock, fractures, and veins. Pyrite1 is widespread and hosted within large volumes of rock across the deposit. In contrast, gold-bearing Pyrite2 is more restricted and only occurs within and immediately adjacent to fractures which cut host rock that contains Pyrite1. Pyrite2 most commonly occurs as overgrowths on irregular cores of Pyrite1, and Pyrite2 does not occur in rock that does not host Pyrite1. Occurrences of gold-bearing forms of Pyrite3 are even more restricted and only occur within the interior of fractures and not within adjacent wall rock. Pyrite3 locally occurs as overgrowths on irregular cores of Pyrite2.

Quartz Morphologies

Optical microscopy and CL imaging of quartz crystals in mineralized samples has revealed that at least three distinct types of quartz occur in association with gold-bearing ores. These are: “Q1” radial quartz which occurs as subhedral grains composed of individually aligned quartz crystallites that radiate from a common center and exhibit crossed-polar extinction in opposite quadrants within cross sections of grains; “Q2” prismatic quartz, which occurs as coherent euhedral to subhedral crystals with a distinctly prismatic hexagonal habit; and “Q3” chalcedonic amorphous quartz which occurs as layered and/or hemispherical masses that locally coat the interiors of vug space.

The CL images of radial Q1 quartz reveal oscillatory growth zoning that parallels the hexagonal outline of the crystals and cuts the aligned quartz crystallites. The CL images of Q2 quartz reveal locally complex oscillatory zoning patterns. The CL images of Q3 quartz reveal that the different habits of chalcedonic quartz have different optical CL color signatures. In addition, some crystals of Q1 and Q2 quartz preserve densely packed bands of fluid inclusions with uniform thickness, which run parallel to growth faces. These bands have variable color in CL and contain features that mimic tightly packed and oriented quartz crystallites.

Discussion

A New Perspective on Mineralizing History

The specific mineral associations of each paragenetic stage have several important implications for understanding the formation of the Cripple Creek deposit. Key relationships include the association between Pyrite2 and hypogene gold with rock that has been sericitically altered but not pervasively altered to secondary potassium feldspar. This demonstrates that the earliest of the gold mineralizing events preceded the development of potassium feldspar alteration. Gold-telluride veins, in contrast, are ubiquitously associated with host rock that has been altered to potassium feldspar. Therefore, the absence of potassium feldspar alteration in rock that hosts Pyrite2 and hypogene gold indicates these minerals formed prior to the gold-telluride mineralizing event.

A second key relationship involves the spatial distribution of different pyrite types within progressively more restrictive environments. The earliest forms of pyrite (Pyrite1) are broadly distributed through large volumes of host rock and occur both within fractures and as disseminations. Pyrite2 is confined to fractures and their immediately adjacent wall rock within zones of Pyrite1, and Pyrite3 is restricted solely to the interiors of fractures. The restriction of Pyrite2 most likely involves chemical gradients and desulfidation of fluids as they penetrated wall rock. Pyrite3 is associated with rock that has been altered to potassium feldspar which suggests that the development of this alteration style led to the reduced wall rock permeability involved in the spatial restriction of Pyrite3. Pyrite3 is restricted to veins that also host gold telluride minerals, but textural relationships indicate that Pyrite3 predates the formation of the telluride minerals. Therefore, although potassium feldspar alteration is ubiquitously associated with gold-telluride veins, it appears that potassium feldspar alteration began to develop prior to the formation of the gold telluride minerals.

The revised paragenetic sequence suggests that the Cripple Creek deposit likely started as a simple epithermal gold-pyrite system that evolved into a system capable of depositing large volumes of gold telluride minerals. This evolution requires significant changes in both the physiochemical conditions and compositions of the mineralizing hydrothermal fluids with time, potentially indicating that early gold-pyrite type mineralization and late gold-telluride-type mineralization were the result of an influx of distinct parental fluids that were derived from magma bodies intruded at different times during the mineralizing history of the deposit. Late cross-cutting molybdenite and base metal sulfide veins were likely derived from a third distinct pulse of fluid and indicate that the mineralizing history of the Cripple Creek deposit likely involved the influx of at least three chemically distinct parental fluids as opposed to a single fluid that evolved with time.

Implications of Quartz Textures

The CL images of radial Q1 quartz reveal myriad aligned quartz crystallites that radiate from a common center. Oscillatory growth zoning patterns that run perpendicular to the axis of the crystallites suggest the growth features were developed incrementally in layers. This texture infers that Q1 quartz was formed through successive deposition of quartz crystallites and chalcedony, followed by periods of quartz recrystallization to form individual composite quartz crystals.

Densely packed bands of fluid inclusions with uniform thickness in Q1 and Q2 quartz contain features that mimic the form of aligned quartz crystallites, and are interpreted to represent layers of chalcedonic quartz that became recrystallized either during or between periods of crystalline quartz deposition. The net result of these recrystallization episodes is the formation of single, coherent quartz crystals that are in fact composites representing several generations of quartz deposition and crystallization. These observations illustrate that quartz formation is significantly more complex than previously thought and indicates that fluid inclusions within individual quartz crystals may locally represent several distinct cycles of quartz deposition. It is thereby extremely difficult to correlate any one set of fluid inclusions with the associated ore minerals present within a quartz vein. This has important implications for future fluid inclusion studies as well as implications in drawing conclusions from previously published fluid inclusion data.

Conclusions

Recently performed mineralogical characterization of gold ores from the Cripple Creek deposit has provided evidence for seven distinct mineralizing stages that indicate the system started as a simple epithermal gold-pyrite type deposit and evolved to become a system capable of depositing large volumes of gold telluride minerals through the introduction of distinct parental hydrothermal fluids. The development of pyrite growth stages with distinct trace element profiles within progressively more restrictive environments demonstrates that the host rock became progressively less permeable with time and provides constraints on the timing of secondary potassium feldspar alteration. Further, the presence of gold as a trace element in some generations of pyrite indicates that pyrite may be an important economic resource within at least some zones of the deposit. Characterization of quartz gangue has provided evidence that multiple generations of chalcedonic and crystalline quartz may have undergone recrystallization to form individual composite quartz crystals that contain fluid inclusions representing several generations of quartz growth.

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Author Biography, Matthew Dye

Matthew Dye graduated Magna Cum Laude with a BA in Geology from the University of Colorado (2011), and his honors research on the Au-Te mineral Krennerite was published in the Canadian Mineralogist (2012). He received his MSc in Geology from the Colorado School of Mines (2015) with thesis work focused on the mineralizing history of the Cripple Creek Gold Telluride Deposit in Colorado. In addition to field work at Cripple Creek, Matthew also has extensive experience in automated mineralogy through work at the Colorado School of Mines QEMSCAN Facility. He enjoys mineral collecting with an emphasis on gold and silver.

Mineralogy, Petrography and Mineral Chemistry of the North Amethyst epithermal (Au-Ag) Deposit, Creede, Colorado: Insights into Precious and Base Metal Mineralization

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The Oligocene Creede mining district represents one of the most prolific intermediate sulfidation-state epithermal silver and base metal mining districts worldwide. The district is located in the Central San Juan Mountains of southwestern Colorado. Since 1889, the mining at Creede yielded approximately 4.1 million tonnes of ore containing 2,400 t Ag and approximately 139,000 t Pb, 41,000 t Zn, and 2,500 t Cu. The base metal and silver production has come from a number of major base metal and silver rich deposits in the central and southern parts of the Creede district located close to the town of Creede. However, the North Amethyst deposit, located at the northern end of the Creede district is known to contain significant precious metal (Au-Ag) mineralization.

The ores of the North Amethyst deposit are crustiform banded, intermediate sulfidation-state epithermal veins. Macroscopic study of exploration drill core and microanalytical techniques resulted in the definition of multiple epithermal vein stages. Four sulfide-bearing vein stages were observed at the North Amethyst deposit and are each punctuated by a breccia or a gangue stage. The earliest of the four is a manganese-rich gangue stage known as Alpha followed by a fine-grained precious metal rich stage known as Beta which consists of electrum, uytenbogaarditie, tetrahedrite, Ag-sulfosalts, native silver and base metal sulfides. The two subsequent vein stages are dominantly base metal sulfide-rich and are referred to as Stage-1 and Stage-2.

The mole percent FeS concentrations in sphalerite from each of the four sulfide bearing veins allowed for the interpretation of mineralization processes. The hydrothermal liquids forming the Alpha stage are interpreted to have cooled as they ascended from deep to shallow levels of the deposit, acquiring a higher sulfidation state (1.3 to 0.24 mole % FeS). Following the Alpha stage, the precious metal (Au-Ag) Beta stage was formed. The compositional variations in the sphalerite of Beta stage are less pronounced. However, the paragenesis of Beta stage indicates a shift from high to low sulfidation states through the transition from argentite-acanthite to native silver at the end of the mineral deposition sequence. The late base metal sulfide-rich Stage-1 was observed only in the deep part of the deposit and Stage-2 was observed at mid-elevation of the North Amethyst deposit. These two base metal and silver stages correlate with those recognized in the central and southern parts of the Creede mining district.

Remote sensing of alteration signatures associated with epithermal and porphyry-related mineral deposits using WorldView-3, ASTER, and Hyperion data

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NASA's Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite imagery has been used extensively in remote sensing studies for a variety of applications, including mineral and alteration mapping. DigitalGlobe's WorldView-3 (WV-3) satellite was launched in 2014 and has similar but expanded spectral capability when compared with ASTER in the VNIR (visible and near infrared) and SWIR (short wave infrared) bands, but at much higher resolution (DigitalGlobe, 2014). This study has been done to apply WV-3 data to an area which has a wealth of previous image data for comparison and to investigate the unique capabilities of the WV-3.

The Cuprite District, located in Esmeralda County, Nevada, was selected as a site for data processing evaluation because of its long history of evaluation by remote sensing techniques, including WV-3 validation. It is the site of Miocene hydrothermal alteration and shows distinct sillicified, opalized, and argillized alteration signatures (NASA Jet Propulsion Lab, 2002). Radiometrically calibrated ASTER data and WV-3 Supercube data were acquired and used to create band ratios for alteration mineral assemblages, including clay minerals, dolomite, amphibole, kaolinite, muscovite, sericite/muscovite/illite/smectite, and phengite/host rock.

The Cripple Creek District, located in Teller County, Colorado, was selected as a comparison and research site. Cripple Creek, a large alkalic-type epithermal Au-Te deposit, is an active open pit mine and has a large heap leach pad. The character of the alteration and the current emphasis on features requiring high spatial resolution suggest the Cripple Creek deposit is an excellent candidate for WV-3 applications. Peters, Livo, and Hauff (1996) and Peters and Hauff (2000) used Landsat Thematic Mapper (TM) and Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data to sense the mineralogy and extent of mine tailings and waste. They were able to identify illite/sericite and kaolinite, and between clay and iron minerals. Geophysical and Environmental Research Imaging Spectrometer (GERIS) data and field mapping were used to locate iron oxides in the district and could distinguish hematite, goethite/jarosite mixtures, and hematite/goethite mixtures (Taranik, Kruse, and Goetz, 1991). More recent work has used near infrared (NIR) data to identify argillic and potassic alteration minerals and differentiate the minerals of the oxide, transition, and sulfide zones of the deposit (Leichliter, 2015).

The WorldView-3 Supercube data, generously provided by the DigitalGlobe Foundation, has been calibrated and processed for band combinations and band ratios indicative of epithermal alteration mineral assemblages. The results have been compared with previous geological and image analysis studies and reprocessed ASTER multispectral and Hyperion hyperspectral data, with emphasis placed on comparisons with the recent paragenesis and mineral distribution studies. Comparison were also made with pit and stockpile mineralogy; additionally, work focused on categorizing ore types - oxide, transition, and sulfide - which could provide significant benefits for processing management.

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Theses-Dissertations Completed Along the Colorado Mineral Belt & Cripple Creek District

(Tommy B. Thompson, Advisor)

Abstract

Geologic mapping followed by petrographic analyses of host rocks with supporting geochemistry has been completed at sites shown on the Index Map. Radiometric dates, stable isotope geochemistry, fluid inclusion analyses, and comparisons with other mineralized systems, regionally and internationally, are parts of the graduate students' research.

Systems researched include carbonate rock-hosted Zn-Pb-Ag-Au vein and replacement deposits (Leadville, Gilman, Kokomo, Aspen, Italian Mountain, London & Big Four mines, Tincup), epithermal low-sulfidation vein- and breccia-hosted gold systems (Cripple Creek, Sultan Mountain, Engineer Pass), porphyry-related molybdenum systems with peripheral precious-metal vein systems (Climax, Henderson, Turquoise Lake, Red Mountain), uranium veins with late-stage precious metal overprint (Mena mine), silver-dominant epithermal veins and related fluvial sedimentary rocks (Creede), volcanogenic gold deposits (Vulcan mine, Gold Brick), and Hot Springs (San Luis Hills).

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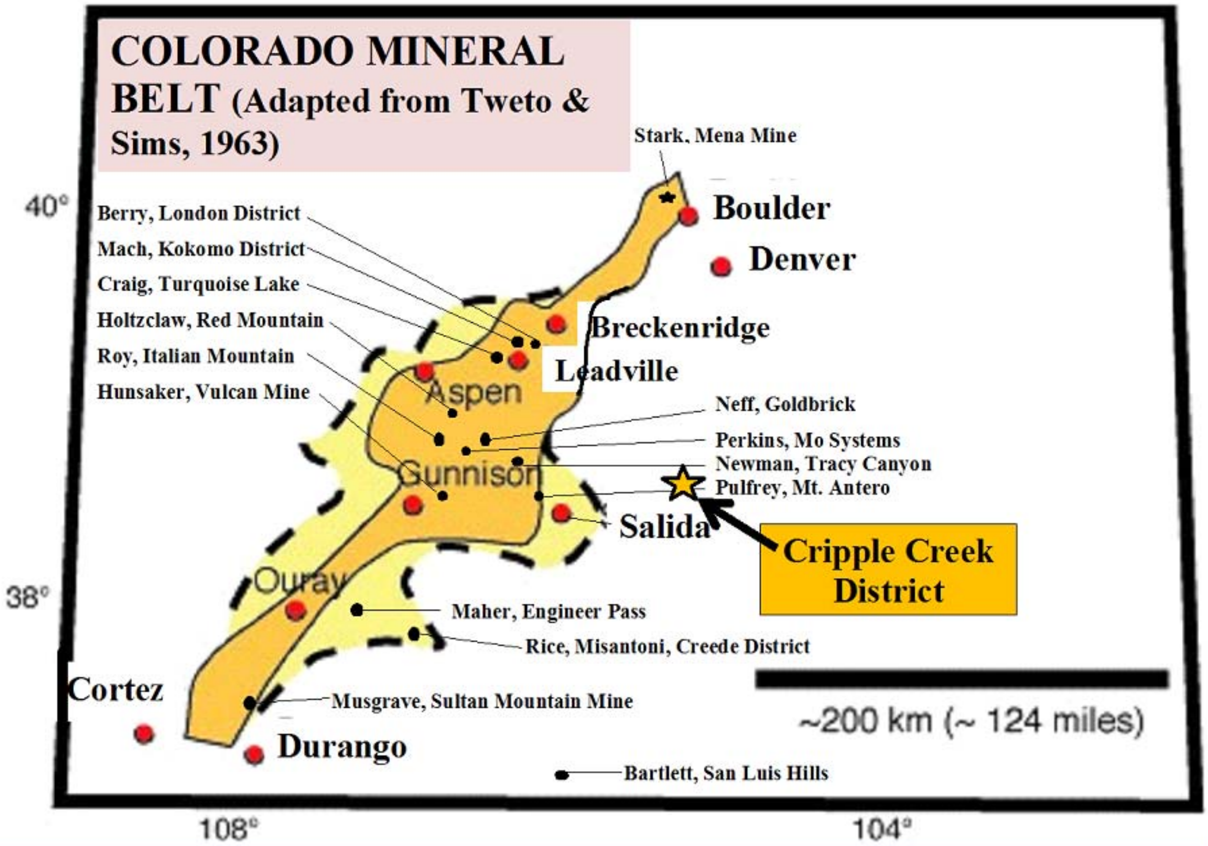

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Mineral Paragenesis of the Summitville high-sulfidation epithermal Cu-Au mineralization: Nature of the mineralizing hydrothermal fluids

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The Summitville high-sulfidation epithermal Au deposit is located in the San Juan Mountains of southwestern Colorado. The deposit is comparably small (560,000 oz Au), but preserves a transition in mineralization style from porphyry-type veins at depth (ca. 400 m) to surficial sinter deposits [2]. As Summitville represents one of the first shallow magmatic-hydrothermal systems studied in detail [1, 2], now it is known as the archetype of high-sulfidation epithermal deposits. Early workers have suggested that the deposit formation involved early alteration of the host rocks by a high-temperature vapor and subsequent mineralization of the Cu and Au minerals from a low-temperature liquid [3]. In contrast, more recent workers proposed that a vapor caused both alteration and mineralization, emphasizing the importance of metal transport by vapors [4]. The present study utilized a combination of optical microscopy, fluid inclusion petrography and microthermometry, and CL microscopy to clarify the nature of the mineralizing fluids.

Residual quartz at Summitville is early in the paragenesis and retains some textural characteristics of the original host rocks, despite the intense acid alteration. The precipitation of large euhedral enargite crystals postdated the residual quartz formation. Primary liquid inclusions recognized in the enargite show salinities of 7.3–7.7 wt% NaCl and homogenization temperatures of 260–280°C. Small euhedral quartz crystals line vugs and casts of former feldspar phenocrysts. They locally overgrow the enargite crystals. Primary liquid inclusions in these crystals have salinities of 0.9–2.6 wt% NaCl and homogenize at 195–245°C. Microthermometric data on one euhedral quartz crystal suggests a cooling trend from the core of the crystal towards its rim. The quartz crystals are overgrown by euhedral pyrite containing Au-bearing growth bands and copper-rich bands. This Au- and Cu-bearing pyrite is further overgrown by intergrown luzonite and enargite. A distinct late barite - native gold association, which includes the famous Summitville Boulder, is the latest phase in the paragenesis.

The present study concludes that the mineralization at Summitville was caused by a liquid, not a vapor. It is also envisaged here that this mineralizing liquid formed late in the history of the evolving system, exsolving directly from a magma so deep that the liquid never experienced a phase separation on its path to shallow levels [3].

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Biography

Subaru Tsuruoka is a Ph.D. candidate at the Colorado School of Mines.
He was born and raised in the northernmost island of Japan, Hokkaido. His educational background is a B.A. in geology and M.Sc. on stable isotope geochemistry from the Tokyo Institute of Technology, Tokyo, Japan.
After receiving his M.Sc., he proceeded to work in the mining industry and entered Japan Oil, Gas and Metals National Corporation (JOGMEC). He worked for 2 years as a market analyst and 4 years as a project geologist taking care of exploration projects, mainly in Australia.
In January 2014, he moved to Colorado to pursue his doctoral research in economic geology at the Colorado School of Mines. He is currently working on the Summitville high-sulfidation epithermal deposit, Colorado, the Santa Rita porphyry copper deposit, New Mexico, and gold porphyry deposits in the Maricunga belt, Chile. The ultimate goal of his doctoral research is to understand how a porphyry-epithermal hydrothermal system evolves from exsolution from crystallizing magma(s) to formation of porphyry and epithermal deposits.

GOLD AND SILVER DEPOSITS IN COLORADO SYMPOSIUM

BERTHOUD HALL, COLORADO SCHOOL OF MINES
GOLDEN, COLORADO
JULY 20-24, 2017