



Geology of Metallic Mineral Deposits,  
Northern Rockies, USA  
PROCEEDINGS



Montana Mining and Mineral Symposium  
October 19–October 22, 2016  
Montana Bureau of Mines and Geology  
at Montana Tech, Butte, Montana

2017

MBMG Open-File Report 685  
Korzeb, S., and Scarberry, K.C.



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**MINING AND MINERAL SYMPOSIUM PLANNING COMMITTEE MEMBERS**

Luke Buckley	Katelyn McNamee
Peggy Delaney	John Metesh
Nancy Favero	Tom Patton
John Foley	Tony Roth
Denise Herman	Kaleb Scarberry
Stan Korzeb	

**ACKNOWLEDGMENTS**

The MBMG Mining and Mineral Symposium Committee thanks the following people and departments for their assistance in organizing and managing the 2016 Mining and Mineral Symposium. The field trips were made possible by the commitment of time and expertise by field trip leaders Chris Gammons, Ted Antonioli, and Pete Ellsworth. A special thanks to Great Harvest Bakery for providing field trip lunches, the Butte Brewing Company for hosting the Map Chat, and Montana Tech's Foundation and Career Services department, Lee's Office City, and the Butte Chamber of Commerce for donating supplies for registrant packets. We also extend a sincere thanks to our volunteers, Susan Leland, Kathlene McNamee, Jean Peterson, Ilene Greb, and Elyse Lewis for their assistance during the Symposium.

## FOREWORD

The Montana Bureau of Mines and Geology is proud to host the second Mining and Minerals Symposium on October 19–22, 2016 in Butte, Montana. Our goal is to provide a collegial annual meeting of geologists, mineralogists, mining engineers, and others who share a passion for “rock talks.” As was the case last year, there is a wide range of topics that include mineralogy, exploration, mining, and reclamation.

As the U.S. economy becomes much more reliant on imported non-fuel minerals to support new technology, we are challenged to provide information to improve that imbalance. In its Fact Sheet 2015-3082, the U.S. Geological Survey notes that the number of minerals for which we depend exclusively on imports more than doubled (8 to 19) between 1954 and 2014. Montana’s role in mineral development is long recognized, but has diminished in recent years in response to stronger competition in the world market. It is important for our geologic community to continue its efforts to explore new deposits and expand mineralogical research that can lead to the development of new mines as well as sustain interest in existing projects. Likewise, new technology in remote sensing, mapping techniques, and analytical tools continue to advance our ability to discover geologic features in Montana. Our understanding of the geologic processes has greatly expanded over the last few decades and we are excited to hear about them in this year’s symposium.

For those not fortunate enough to attend and experience the excitement and camaraderie of earth science and engineering, we offer these proceedings. For those who could attend, they will provide fond memories.

## MEETING SCHEDULE

### Wednesday, October 19, 2016

7:30 a.m.–9:00 a.m.	Field Trip Registration/Check-In	Natural Resources Building
9:00 a.m.–4:00 p.m.	Granite Bi-Metallic Mine Field Trip	
Noon–5:00 p.m.	General Registration, Check-In	Copper Lounge, SUB
5:00 p.m.–7:00 p.m.	MEET AND GREET	MBMG Mineral Museum

### Thursday, October 20, 2016

8:00 a.m.–8:50 a.m.	General Registration, Check-In	Copper Lounge, SUB
8:50 a.m.–9:00 a.m.	Welcome and Opening Remarks <i>Don Blacketter, Chancellor, Montana Tech and John Metesh, State Geologist, Montana Bureau of Mines and Geology, Butte, MT</i>	
9:00 a.m.–9:30 a.m.	History and Economic Potential of the Cable Mine, Cable Mountain Mining District, Deer Lodge County, Montana: with a 3D Model to Guide Exploration and Development <i>Bruce Cox, Consulting Geologist, Missoula MT. Henry Bogert, Mining Engineer, Sun Valley, ID</i>	
9:30 a.m.–10:00 a.m.	Supergene Mineralogy of the Continental Pit, Butte, Montana <i>Kyle Eastman, Graduate Student, Geological Engineering, Montana Tech, Butte, MT</i>	
10:00 a.m.–10:30 a.m.	Minerals of the Leonard Mine, Butte, Montana <i>Mike Goble, PE, Bureau of Reclamation, Denver, CO</i>	
10:30 a.m.–11:00 a.m.	<i>BREAK</i> Poster Sessions	Copper Lounge
11:00 a.m.–11:30 a.m.	Bucket Line Dredge Tails—Gold Asset or Gravel Asset? <i>Robin McCulloch, Consulting Mining Engineer, Butte, MT</i>	
11:30 a.m.–NOON	Natural Acid Rock Drainage and Ferricrete Deposit Chemistry of the Judith Mountains, Montana <i>Sara Edinberg, Hydrogeologist, Montana Department of Environmental Quality, Helena, MT</i>	
NOON–1:30 p.m.	<b>LUNCH</b>	Copper Lounge
	Mining History and Minerals, Bluebird Mine and Mill, Butte, Montana <i>Richard Gibson, Consulting Geologist and Historian, Butte, MT</i>	
1:30 p.m.–2:00 p.m.	Geology and Minerals of the Black Pine Mine, Granite County, Montana <i>Dave Waisman, Fine Mineral Show and SVL Analytical, Kellogg, ID</i>	

- 2:00 p.m.–2:30 p.m. In the Field with the Montana Hard Rock Mining Bureau: An Update on Mining in Montana  
*Garrett Smith, Geochemist, Montana Department of Environmental Quality, Helena, MT*
- 2:30 p.m.–3:00 p.m. Geology and Mining Methods on the J-M Reef Platinum and Palladium Mineralized Zone, Stillwater Complex, Nye, Montana  
*James Rose, Hydrogeologist, Montana Bureau of Mines and Geology, Butte, MT*
- 3:00 p.m.–3:30 p.m. **BREAK** Poster Sessions Copper Lounge
- 3:30 p.m.–4:00 p.m. Geology and Mineralization of the Stibnite Mining District, Central Idaho  
*Reed Lewis, Geologist, Idaho Geological Survey, Moscow, ID*
- 4:00 p.m.–4:30 p.m. Geology, Fluid Inclusions, and Stable Isotope Study of the Calvert Tungsten Mine, Pioneer Mountains, Montana  
*Joshua Messenger, Graduate, Geological Engineering, Montana Tech, Butte, MT, Chris Gammons, Professor, Geological Engineering, Montana Tech, Butte, MT*
- 5:00 p.m.–7:30 p.m. **MAP CHAT AND PIZZA** **Butte Brewery**

### Friday, October 21, 2016

- 8:00 a.m.–8:50 a.m. General Registration and Check-In Copper Lounge
- 8:50 a.m.–9:00 a.m. Opening Remarks and logistics  
*Stan Korzeb, Economic Geologist, Montana Bureau of Mines and Geology, Butte, MT*
- 9:00 a.m.–9:30 a.m. Montana Resources Permitting for the Future  
*Mark Thompson, Manager, Environmental Affairs, Montana Resources, Butte, MT*
- 9:30 a.m.–10:00 a.m. Pb Isotopic Compositions of Montana Ores Revisited  
*Francis Ö. Dudás, Researcher (retired), Radiogenic Isotope Laboratory, EAPS, Massachusetts Institute of Technology, Cambridge, MA*
- 10:00 a.m.–10:30 a.m. **BREAK** Poster Sessions Copper Lounge
- 10:30 a.m.–11:00 a.m. The Animas River (Gold King Mine) Spill in Colorado: Lessons for the Long Future  
*John Ridley, Professor, Geosciences Department, Colorado State University, Fort Collins, CO*
- 11:00 a.m.–11:30 a.m. Golden Sunlight Mine: Geology and Mineralization Overview  
*David Odt, Chief Geologist, Golden Sunlight Mine, Whitehall, MT*
- 11:30 a.m.–NOON Bull Mountain: A Miocene–Quaternary Fault Block that Preserves a Remnant of the Mesozoic Arc in Southwestern Montana  
*Kaleb C. Scarberry, Geologist, Montana Bureau of Mines and Geology, Butte, MT*



NOON–1:30 p.m.	<b>LUNCH</b>	Copper Lounge
	The Highland Mining District–Past and Present, Silver Bow County, Montana <i>Dave Stratton, Water Environmental Technologies, Butte, MT</i>	
1:30 p.m.–2:00 p.m.	Silver Mineralization of the Oro Fino Mining District, Powell and Deer Lodge Counties, Montana <i>Stan Korzeb, Economic Geologist, Montana Bureau of Mines and Geology, Butte, MT</i>	
2:00 p.m.–2:30 p.m.	Origin of Amethyst Overgrowths on Pegmatitic Quartz from the Boulder Batholith: Fluid Inclusion Evidence <i>Chris Gammons, Professor, Geological Engineering, Montana Tech, Butte, MT, Jon Szarkowski, Undergraduate Student, Geological Engineering, Montana Tech, Butte, MT, H. Peter Knudsen, Professor, Mining and Engineering, Montana Tech, Butte, MT</i>	
2:30 p.m.–3:00 p.m.	The World Class Talc Deposits of Southwestern Montana <i>John Childs, Childs Geosciences, Bozeman, MT</i>	
3:00 p.m.–3:30 p.m.	Mineralogy and Environmental Geochemistry of Slag in Lower Area One, Butte, Montana <i>Jenna Kaplan, Field Geologist, US Forest Service, Red Lodge, MT</i>	
3:30 p.m.–4:00 p.m.	Natural Amelioration in Flooded Mine Shafts and Related Changes in Arsenic Concentrations <i>Renee Schmidt, Graduate Student, Chemistry and Geochemistry, Montana Tech, Butte, MT</i>	
4:00 p.m.–5:00 p.m.	<b>BREAK</b>	
5:00 p.m.–6:00 p.m.	No-Host Bar	Copper Lounge
6:00 p.m.–8:00 p.m.	<b>BANQUET</b>	Copper Lounge

### Saturday, October 22, 2016

7:30 a.m.–9:00 a.m.	Field Trip Registration/Check-In	Natural Resources Building
9:00 a.m.–4:00 p.m.	Calvert Mine Field Trip	

## POSTERS

Origin of Bright Yellow Coatings of Secondary Cadmium Sulfide (Greenockite) on the Walls of the Orphan Boy Mine, Butte, Montana, **Chris Gammons**, *Professor, Geological Engineering, Montana Tech, Butte, MT*; **Jon Szarkowski**, *Undergraduate Student, Geological Engineering, Montana Tech, Butte, MT*

Mineralogy of Silver in the Ore Deposits of Butte: An Update with New Findings, **Jon Szarkowski**, *Undergraduate Student, Geological Engineering, Montana Tech, Butte, MT*

Geochemistry and Fluid Inclusion Study of the Unmined Heddleston Porphyry Copper Deposit, Lewis and Clark County, Montana, **Ben Schubert**, *Graduate Student, Geological Engineering, Montana Tech, Butte, MT*

Reexamination of the Historic Hecla Pb-Ag Mining District, Pioneer Mountains, Montana: Magmatic Fluids or Metamorphosed MVT Deposit?, **Kyle Eastman**, *Graduate Student, Geological Engineering, Montana Tech, Butte, MT*

Eruption History and Origins of Precious Metal Ore Deposits: The Eocene Lowland Creek Volcanic Field, Southwestern Montana, **Kaleb C. Scarberry**, *Geologist, Montana Bureau of Mines and Geology, Butte, MT*

## SUPPLEMENTARY INFORMATION

### Field Trips

*Wednesday, October 19, 2016*

**Granite Bi-Metallic Field Trip:** The trip will tour the renowned Philipsburg Mining District in Granite County, Montana, where attendees will have an opportunity to explore the historic town of Philipsburg before visiting the Granite Bi-Metallic Mine, once Montana's largest producer of high-grade silver. Consulting geologist and Philipsburg mining expert **Ted Antonioli** will describe the area's unique ore deposits, the development and production of the Granite Bi-Metallic, and its eventual closure. The site retains many original buildings and mine facilities and is a popular destination for history, mining, and mineral enthusiasts.

*Attendees will depart from the Natural Resources Building on the Montana Tech campus at 9 a.m. Preparation tips and instructions will be included in the symposium information packets of those who have pre-registered for this field trip.*

*Saturday, October 22, 2016*

**Calvert Mine Field Trip:** Between 1956 and 1962, the Calvert Mine, a now abandoned open pit mine located in the West Pioneer Mountains, 40 miles SW of Butte, produced over 100,000 tons of scheelite ore at 1.1% WO<sub>3</sub>. The pit is now filled with crystal clear water, and there are extensive waste rock dumps that are popular with mineral collectors as a source of epidote, garnet, rare beryl (aquamarine variety), and scheelite. The distribution of scheelite is hard to pick out by eye but is obvious at night with a black light. **Chris Gammons**, Professor, Geological Engineering, Montana Tech, will lead this trip examining the geology and mineralogy of the Calvert deposit, which consists of a calcic exoskarn (almost devoid of sulfide minerals) and an epidote-rich endoskarn. Chris will discuss the chemistry and hydrology of the pit lake, which is 90 feet deep, pH-neutral, and almost completely devoid of dissolved heavy metals. If time and weather allow, an inflatable kayak will be available for those who wish to view the mine walls along the shoreline.

*Attendees will depart from the Natural Resources Building on Montana Tech campus at 9 a.m. Preparation tips and instructions will be included in the symposium information packets of those who have pre-registered for this field trip.*

## Field Trip Instructions

*2016 MBMG Mining and Mineral Symposium*

*Field Trip Information*

*Granite Bi-Metallic Mine – October 19, 2016*

*Calvert Mine – October 22, 2016*

### Registration and Check-In

Registration and check-in tables are located in the second floor lobby of the Natural Resources Building, accessible through the building's north entrance. Please be at Registration by 8:00 a.m. If you will be parking in NRB visitor parking, you will be provided a visitor parking pass when you check in. Please display the pass on your dashboard where it will be clearly visible to our security officers.

### Information

- ✓ Please wear sturdy, comfortable shoes for the field trips; no open-toed shoes please.
- ✓ Montana weather is unpredictable can change quickly and dramatically. We suggest that you bring a coat, hat, gloves, and rain gear with you for the trip.
- ✓ It is hunting season in Montana. We will provide orange safety vests for each participant. Wearing the vest is required for you to participate in the field trip.
- ✓ Be sure to bring your favorite rock hammer and digging tools so you can collect samples.
- ✓ We anticipate returning from each field trip by 4:30 p.m. Transportation to the next symposium event or to local hotels will be available from the Natural Resources Building.
- ✓ If you need special assistance to participate in the tour, please see one of the Symposium staff.

### Meet and Greet, Wednesday, October 19, 2016

**5:00-7:00 p.m.**

Following the Granite Bi-Metallic field trip, join us for a Meet and Greet in the Mineral Museum on the Montana Tech campus. Examine the MBMG Mineral Museum's collection of impressive specimens and exhibits and meet fellow registrants while enjoying hors d'oeuvres and a no-host bar.

### Map Chat, Thursday, October 20, 2016

**5:00-7:30 p.m.**

Enjoy the spectacular view of the Highland Mountains from the Butte Brewery and sample some of Butte's finely crafted beers while you talk with the MBMG mapping geologists and learn about their recent projects. Pizza will be served. Free shuttle service will be provided to and from the Brewery.

### Parking and Shuttle Service

Due to several major construction projects, visitor parking on the Montana Tech campus is very limited. Complimentary shuttle service is available to and from local hotels, Symposium venues, and field trips. A shuttle service schedule is shown below. If you do plan on parking your own vehicle on campus, please inform one of the Symposium staff. A visitor parking pass will be issued to you.



## 2016 MBMG Mining and Mineral Symposium Shuttle Information and Visitor Parking

Due to several major construction projects, visitor parking on the Montana Tech campus is very limited. Complimentary shuttle service is available to and from local hotels, Symposium venues, and field trips. A shuttle service schedule is shown below

If you do plan on parking your own vehicle on campus, please inform one of the Symposium staff. A visitor parking pass will be issued to you. Shuttle service to the **Map Chat** will depart from the Student Union Building immediately following Thursday's talks. Shuttles will be available at the Butte Brewery at 6:00 p.m. and 7:30 p.m. for transportation to hotels.

### SHUTTLE SCHEDULE: (Pick-up times are best estimates)

Shuttle departs Montana Tech at 6:45 a.m.

### Shuttle Pick-up Times

#### South Route:

##### Shuttle 1

Quality Inn	7:00 a.m.
La Quinta Inn	7:10 a.m.
Holiday Inn Express	7:20 a.m.
Comfort Inn	7:30 a.m.
Super 8	7:40 a.m.
Best Western Plus	7:50 a.m.
Hampton Inn	8:00 a.m.
Toad Hall Manor	8:15 a.m.

#### North Route:

##### Shuttle 2

America's Best Value Inn	7:00 a.m.
Econo Lodge	7:10 a.m.
Copper King Mansion	7:30 a.m.
Finlen Hotel	7:40 a.m.
Miner's Inn	7:50 a.m.

Shuttle 2 will pick up folks who missed the first shuttle. Call 406-491-6620, 406-491-3362, or 406-498-2516 for help.

### Shuttle Departure Times

Shuttles depart from the Student Union Building (SUB) at the following times:

Wednesday, October 19, 2016	4:00 p.m.	7:15 p.m.	Last pick up at Museum
Thursday, October 20, 2016	4:45 p.m., 5:15 p.m.	7:45 p.m.	Last pick up at Brewery
Friday, October 21, 2016	4:15 p.m.	7:45 p.m.	Last pick up at SUB
Saturday, October 22, 2016	4:00 p.m.		

**MontanaTech**

**LEGEND**

1. Science and Engineering (S&E)	8. Health Sciences Building (HSB)	15. Natural Resources Research Center (NRRC)	<b>P</b> Parking
2. Engineering Hall (ENG)	9. Student Union Building (SUB)	16. Engineering Lab/Classroom Building (ELC)	<b>V</b> Visitor Parking
3. Main Hall	Bookstore	17. Frank and Ann Gilmore University Relations Center (URC)	<b>♿</b> Wheelchair accessible
4. Museum Building (MUS)	10. HPER Complex	18. Prospector Hall	
5. Chemistry and Biology Building (CBB)	11. Natural Resources Building (NRB)	19. Centennial Hall	
6. Physical Plant	12. Library	20. Highlands College	
7. Mill Building	13. Mining/Geology Building (MG)		
	14. Chancellor's Residence		

Montana Tech is a tobacco-free campus

7 miles south of Montana Tech's North campus

**SYMPOSIUM PROCEEDINGS:**  
**TECHNICAL PAPERS AND ABSTRACTS**



# History and Economic Potential of the Cable Mine, Cable Mountain Mining District, Deer Lodge County, Montana: A 3D Model to Guide Exploration and Development

Bruce Cox<sup>1</sup> and Henry Bogert<sup>2</sup>

<sup>1</sup>Consulting Geologist, Missoula, Montana; <sup>2</sup>Mining Engineer, Sun Valley, Idaho

## ABSTRACT

Mines bordering Cable Mountain in Deer Lodge County, Montana are renowned producers of high-grade gold ores but have seen minimal production since the War Powers Act of 1941.

Exploration drilling by several companies in the 1980s and 1990s has identified mineralized domains within a broad shear system and carbonate roof pendant. The targets exhibit gold grades and dimensions similar to the historic production stopes. A 21st-century evaluation of the Cable Mountain district has employed geological modeling software to merge data from the mining and exploration archive to generate a 3D model that can guide future exploration and development.

The following descriptions of Cable mine history and mine geology are summarized from Emmons and Calkins (1913), Lakes (1948), and excerpts from notes and maps in Cable Mountain Mine, Inc. company files.

### Cable Mine History Pre-WWII

Three prospectors working in the Georgetown placer deposits expanded their prospecting to the south side of Cable Mountain (fig. 1) and discovered the Cable lode in 1866. The next 4 years saw the erection of a 20-stamp mill and production estimated at \$400,000 (current gold price), but the principal stopes collapsed due to lack of structural support.

From 1871 to 1876, Conrad Kohrs financed construction of a ditch from Warm Springs Creek and began mining the High Bench placer downslope from the Cable lode. During this period, Salton Cameron assumed management of the underground mine, sunk a second shaft on the lode, and began mining ore northwest from the area of caved ground. This renewed lode production is estimated to have yielded \$1,000,000 in gold.

J.C. Savery gained control of the property in 1876. He supervised the erection of a 30-stamp mill (fig. 2), completion of a 1500-foot crosscut adit, and discovery of the cylindrical, and gently dipping, Lake orebody. The Cable mine was periodically active through 1891.

The mine reopened in 1901 under the direction of F.W. Bacorn and operated sporadically until 1941. During this period, longhole drilling from winze levels discovered a copper-gold orebody that has not been methodically defined or exploited.

### Exploration Since 1947

Minor underground development and exploration were performed through the 1950s, but no production was proposed or attempted. Joseph Aidlin purchased the property in 1976 and financed both placer and lode exploration into the 1990s under the banner of Cable Mountain Mine, Inc., the current owner. CMMI and its lessees performed rotary and core drilling—the results of which prompted the development of the geologic model described herein.

### Geology of Cable Ore Deposits

The Cable orebodies occur entirely within a roof pendant of Cambrian Hasmark dolomite at the northern margin of the Cable granodiorite stock. The carbonate mass measures approximately 2000 ft along strike, 200 ft average width, and 650 ft deep in the area of the historic stopes (fig. 3). In general, the carbonate bedding and intrusive contacts both dip steeply northeast. Hasmark strata display strong recrystallization to white marble with local domains of coarse rhombohedral calcite. Magnetite, chlorite, and calc-silicates are common accessory minerals in the replacement strata.



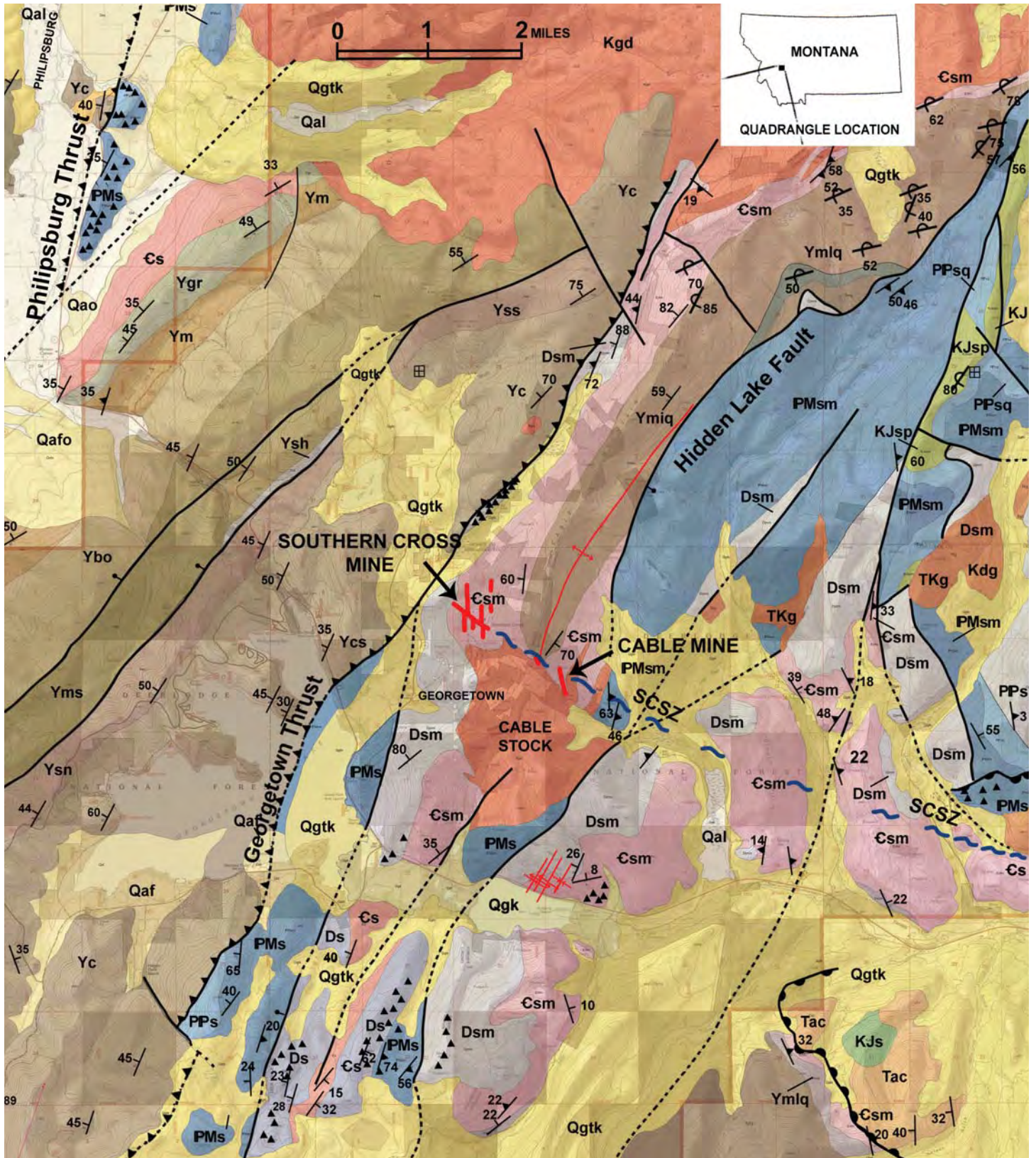


Figure 1. Geologic map of the Cable Mountain Mining District. (Modified from Plate 1, MBMG Open-File Report 483). Red bars denote vein trends; SCSZ, Southern Cross Shear Zone.



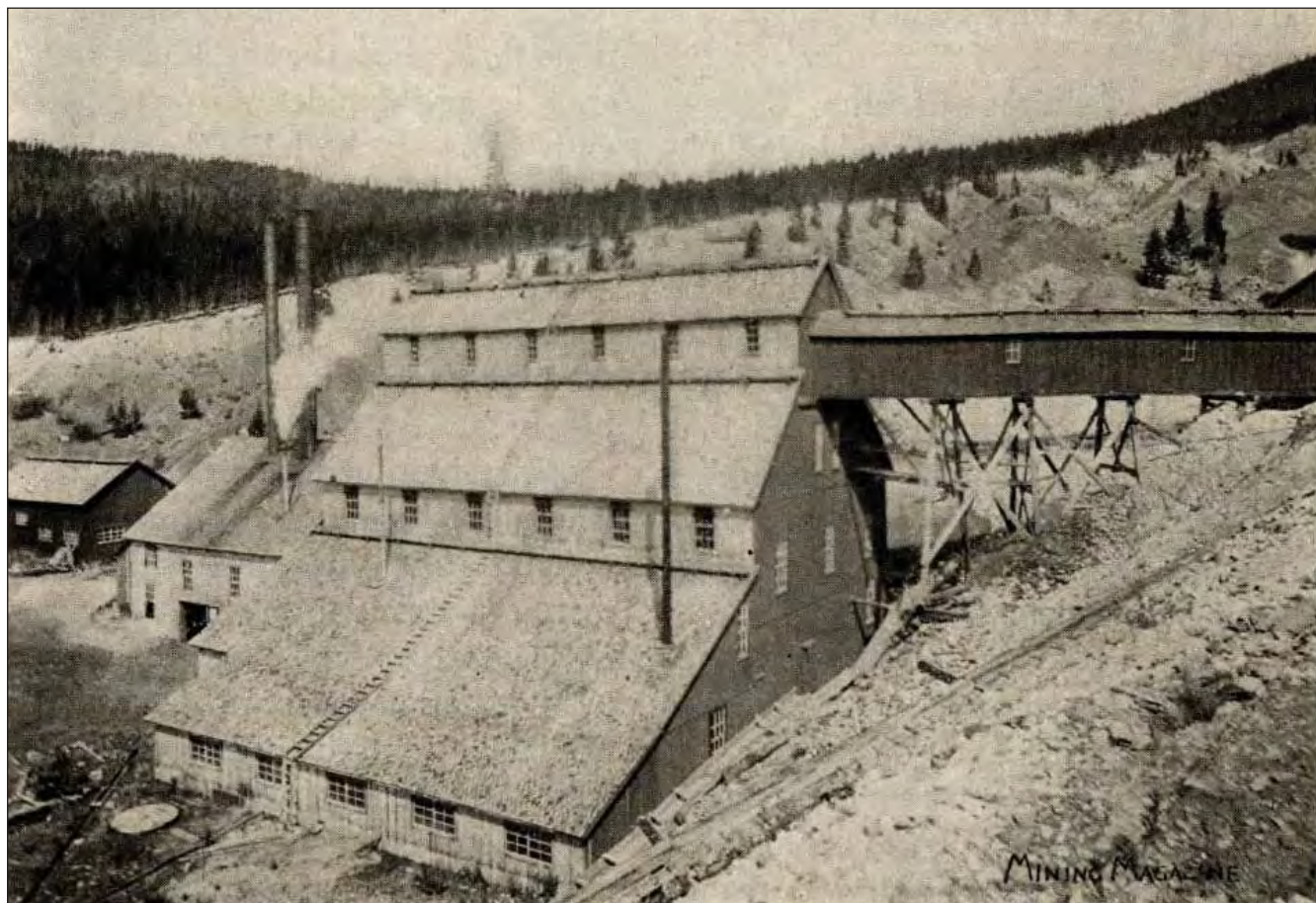


Figure 2. Cable Mill and Upper Placer. Reproduced from Bohm, 1906.

Gold occurs in the carbonate replacement bodies and in veins and breccias, but it is not uniformly distributed. Magnetite replacement bodies are common in the area of the most productive stopes, but magnetite deposition predates gold mineralization. Coarse crystalline gold is common, and museum-quality specimens are well documented. The most common gangue minerals are pyrite, pyrrhotite, and chalcopyrite.

The most evident ore control is the west–northwest-trending Southern Cross shear zone, which hosts vein and shear breccia mineralization at both Cable and Southern Cross mines. Shaley carbonate strata were encountered in some stopes and may represent part of the middle Hasmark section. This horizon also hosts replacement ore in the Southern Cross mine and other mines in western Montana.

### Modern Exploration

Rotary and core drilling at Cable during the 1980s and 1990s yielded multiple 5-ft intercepts grading greater than 0.3 ounces gold per ton. The intercepts cluster in two principal targets: (1) beneath the historic stopes and (2) along strike to the northwest. The first target also contains an area of underground longhole drilling that indicates potentially bulk-mineable copper–gold replacement mineralization. The second target appears to contain gold only and is associated dikes and a mapped splay of the SCSZ.

### 3D Perspective

Plans and cross sections on 50-ft centers depicting the old Cable Mine workings, drilling, and geology (figs. 4 and 5) were scanned and imported into AutoCAD, where they were scaled and oriented in 3D space. The historic workings were digitized, then imported into GEMS software and modeled. Drift solids were created by extruding the sill trace of the old level maps. Creating solids of the old stopes was more challenging, as the stope shape changed significantly from section to section. Consequently, the stope solids are considered more representative of the stope location than the actual stope geometry.



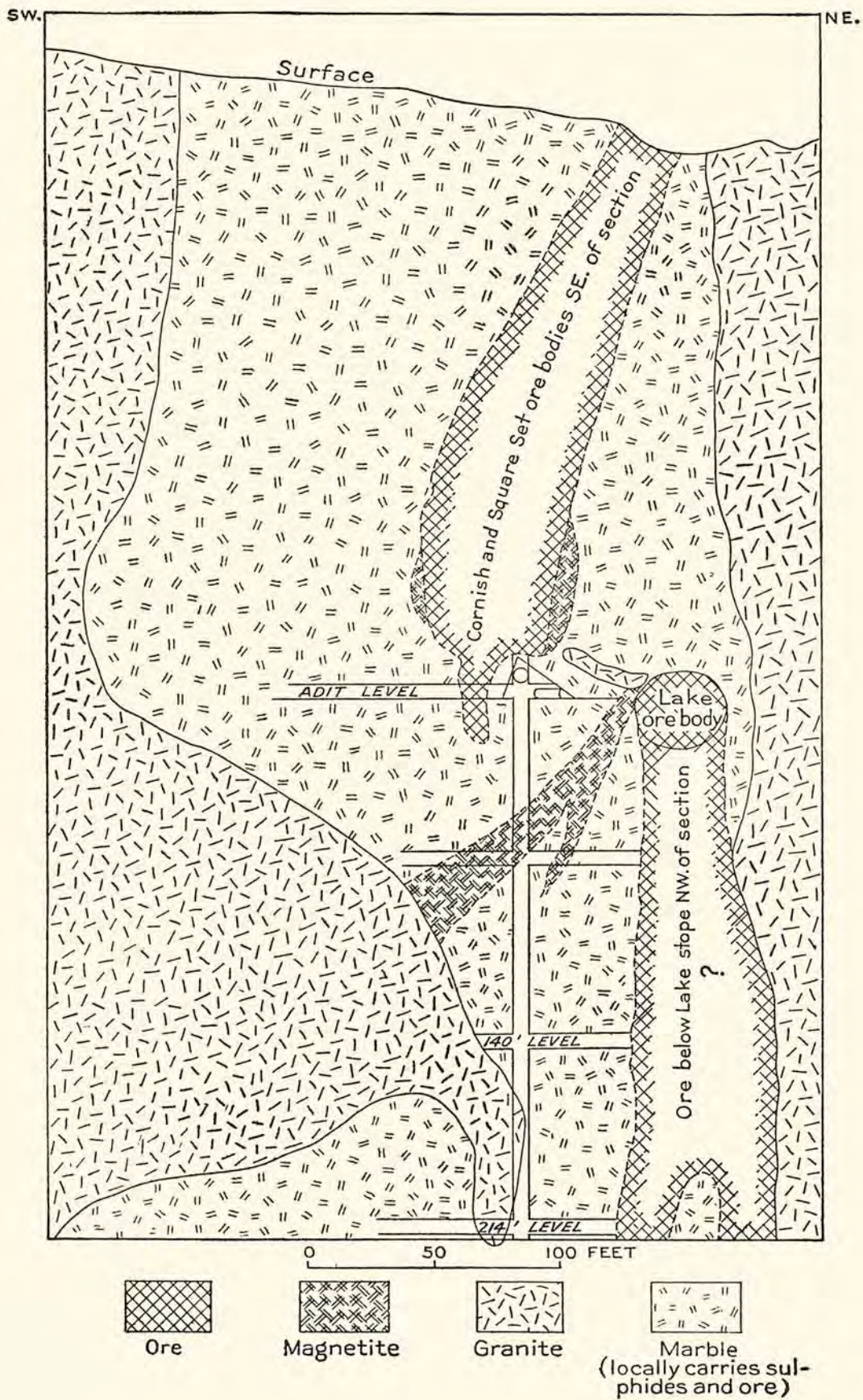


Figure 3. Cross-section through Cable mine workings and ore zones. Reproduced from Emmons and Calkins, 1913.

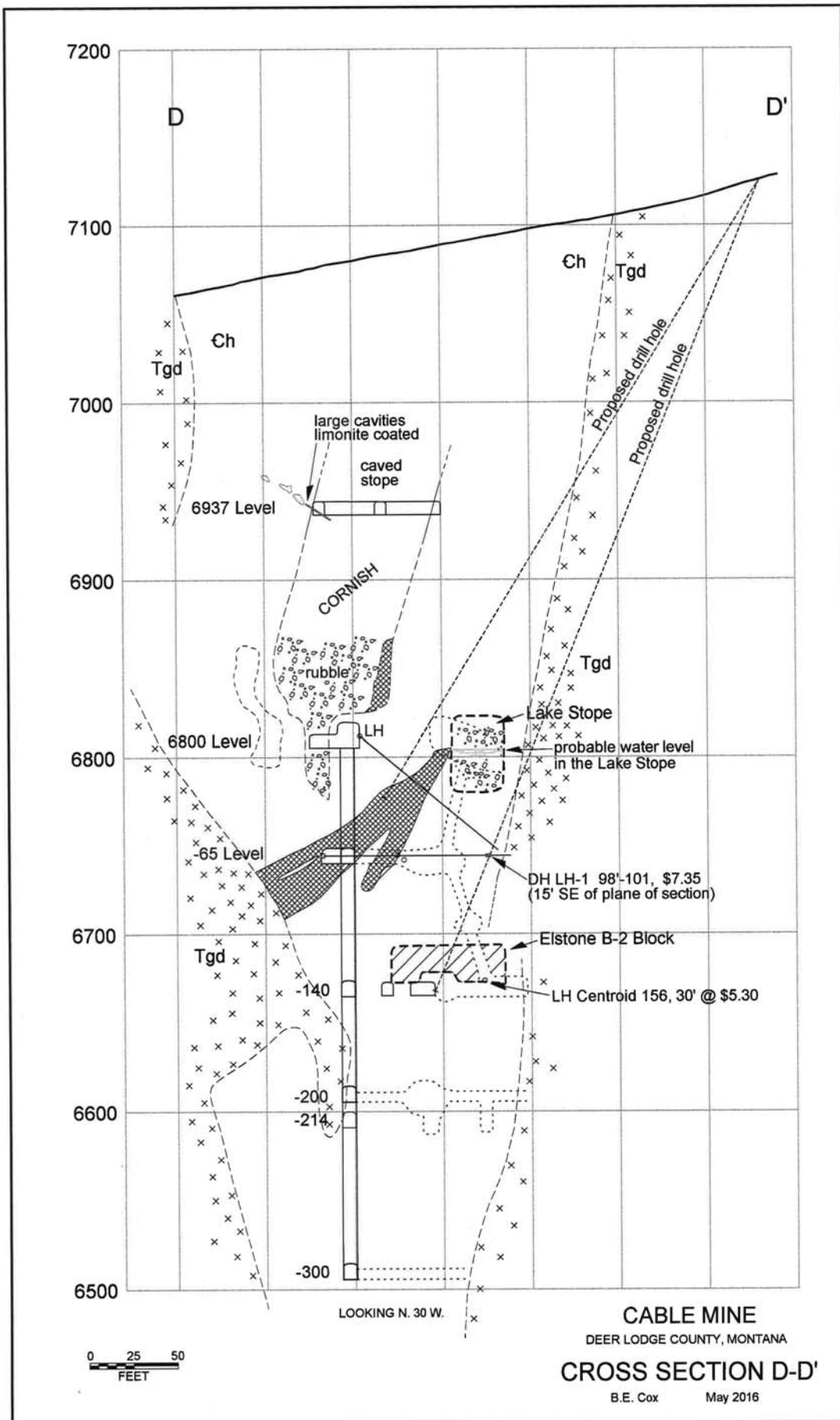


Figure 4. Cross-section D-D' through Cable mine workings. Line of section is oriented NE-SW and approximately parallel to the Emmons and Calkins section in figure 3.



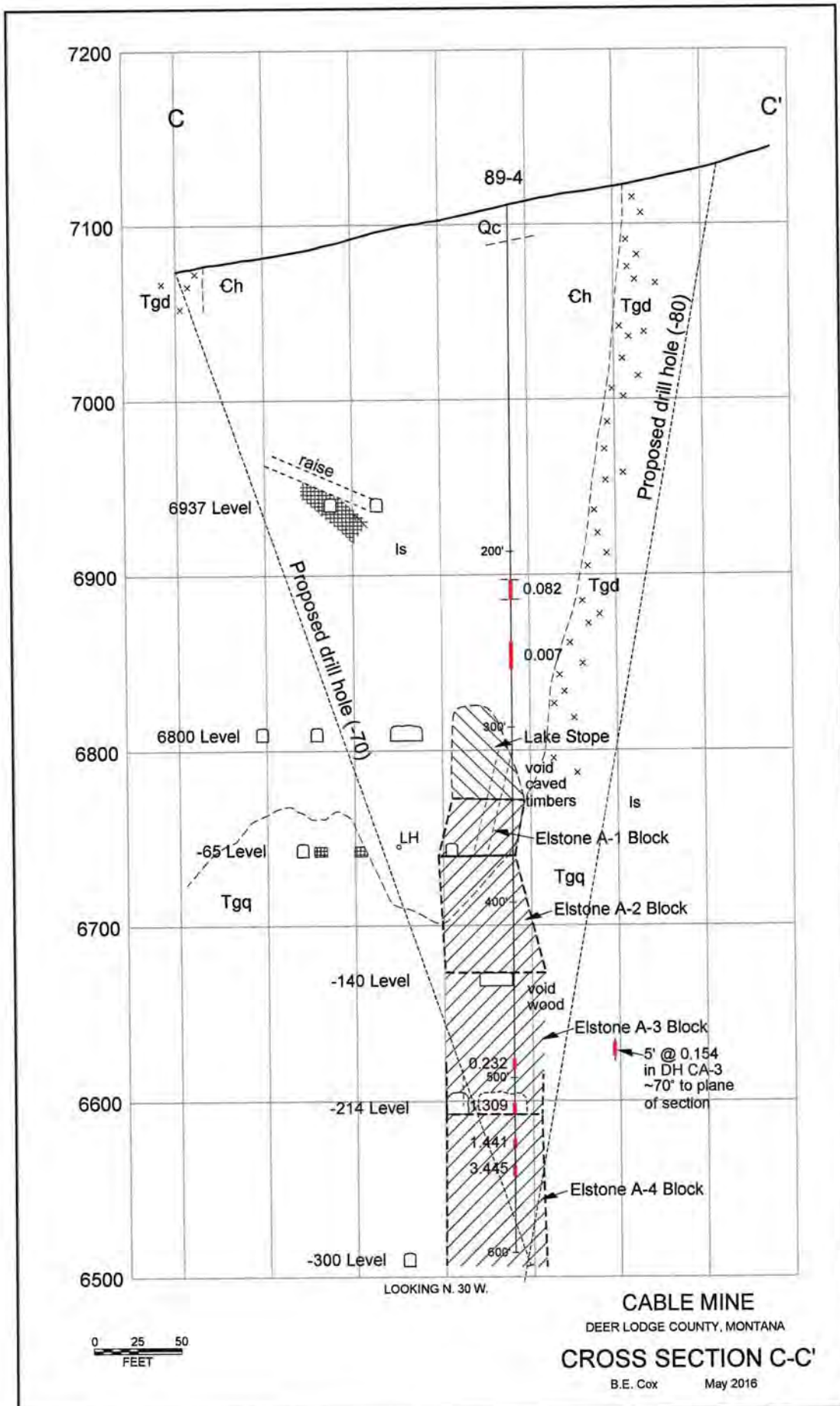


Figure 5. Cross-section C-C' through Cable mine workings. Line of section is oriented NE-SW, 50 ft NW from section D-D'.

Current geologic interpretations, summarizing the historic data and the results of the modern exploration, were added to help identify future drill targets. Potential mineralized zones were also modeled; however, as the mineralized zones are based on historic drilling, no resource was estimated.

#### REFERENCES

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## **Geochemical Investigation of the Hecla District; a Magmatic-Hydrothermal Pb-Zn-Ag Carbonate Replacement Deposit, Pioneer Mountains, Beaverhead County, Montana**

Eastman, K.A.,<sup>1</sup> Gammons, C.H.,<sup>1,\*</sup> Messenger, J.M.,<sup>1</sup> Zimmerman, J.,<sup>1</sup> Poulson, S.R.,<sup>2</sup> Gnanou, H.,<sup>1</sup>  
and Kaplan, J.M.<sup>1</sup>

<sup>1</sup>*Department of Geological Engineering, Montana Tech of the University of Montana, Butte, MT*

<sup>2</sup>*Department of Geological Sciences and Engineering, University of Nevada-Reno, Reno, NV*

*\*Corresponding author: Prof. Chris Gammons, cgammons@mtech.edu, 406-496-4763*

### **ABSTRACT**

The Hecla mining district in southwestern Montana produced 11.5 M oz Ag, 88 M lbs Pb, and lesser amounts of Cu, Zn, and Au, mainly in the late 19th century. In this study, we reexamine the district to determine the sources of metals and the nature of the mineralizing fluids. The carbonate-hosted ore bodies display structures (bedding parallel ore shoots) and mineral assemblages (sphalerite, galena, pyrite, tetrahedrite, quartz) that are consistent with an early Mississippi Valley Type (MVT) origin, a late Cretaceous magmatic-hydrothermal replacement origin, or some combination thereof. Reflected light microscopy, SEM-EDS, Raman micro-spectroscopy, and electron microprobe analysis document the paragenesis of hypogene and supergene mineralization. This is supplemented with data on fluid inclusions in quartz, and S-isotopic analyses of galena, sphalerite, and pyrite. Information from fluid inclusions in quartz suggests that the mineralizing fluids were rich in CO<sub>2</sub> (three phase inclusions), with salinities between 2 and 5 wt. % NaCl equivalent, and local evidence of boiling. Many fluid inclusions contain daughter minerals, likely dawsonite: NaAlCO<sub>3</sub>(OH)<sub>2</sub>. Sulfur stable isotope geothermometry is in close agreement with the fluid inclusion data, and suggests that mineralization occurred at peak temperatures between 300°-325°C. The most likely source for the magmatic fluids is a buried pluton in the center of the district. We conclude that the Hecla orebodies are the end result of a glacially eroded, supergene enriched, magmatic-hydrothermal event that most likely occurred in late Cretaceous time.

### **INTRODUCTION**

#### **Mining History**

The Pioneer Mountains in southwestern Montana have experienced a long history of mining and mineral exploration that stretches back well over 150 years. During the late 1800s and early 1900s, the Hecla District was a major producer of silver and lead, producing 11.5 M oz Ag, 88 M lbs Pb, 5.2 M lbs Cu, 11,700 oz Au, and an unknown quantity of Zn (Karlstrom, 1948). The district is located in a northeast-facing glacial valley at the head of Trapper Creek, approximately 45 miles south of Butte, Montana (fig. 1). The study area can be reached via Trapper Creek road, which is an unimproved two-track road that heads west out of the town of Melrose. The district was discovered in 1872 by William Spurr while on a trapping expedition. In the next year most of the major discoveries in the valley had been made and the first shipment of ore, assayed at 140 ounces of silver per ton along with considerable amounts of lead, was rail-headed to San Francisco and then shipped by water to smelters in Swansea, Wales. In 1875 a 40-ton lead smelter was built at Glendale, MT, approximately 10 miles down-valley. Word spread about the discovery, and soon Glendale was a bustling town with a population over 1000. In 1877, the Hecla Consolidated Mining Company was formed, and by 1881 it had purchased most of the better claims along with the smelter in Glendale.

During the next decade, production boomed, but soon gave way to a gradual decline during the 1890s and early 1900s. In 1904 the Hecla Consolidated Mining Company went out of business, and this signaled the end of significant production at Hecla. Several larger companies attempted to revive the district throughout the first half of the twentieth century, but by 1945 production had ceased (Karlstrom, 1948). The property is currently owned by the University of Mississippi Foundation, as part of the Julius Levine endowment.



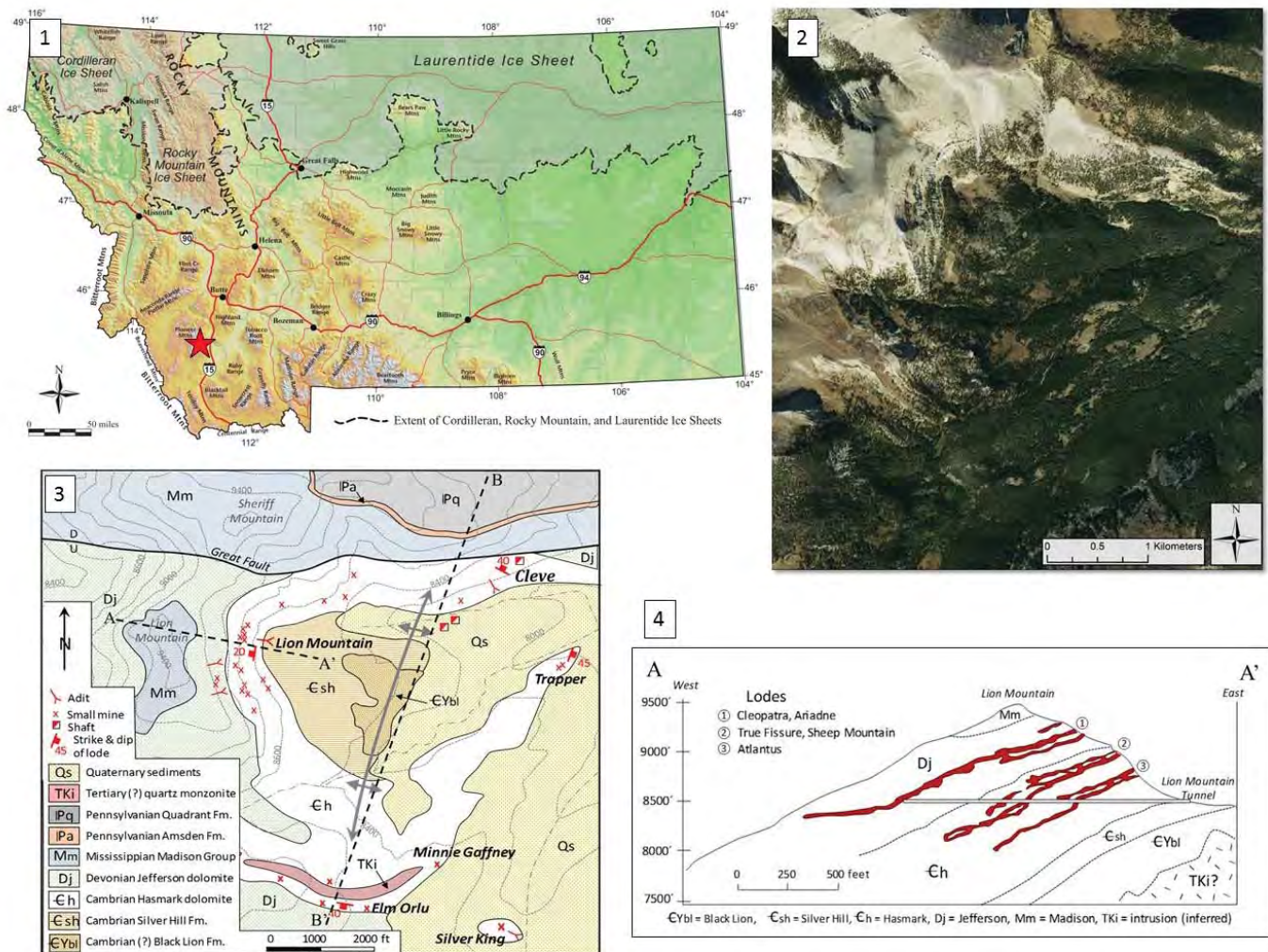


Figure 1. Insets: (1) location map; red star indicates location of the Hecla district in the Pioneer Mountains. (2) Satellite imagery of glacial valley that hosts the orebodies. (3) Geologic map, modified from Karlstrom (1948). (4) Cross section A–A', modified from Karlstrom (1948).

### Geologic Setting

The geology of the Pioneer Mountains consists primarily of Middle Proterozoic (Belt Supergroup) through Mesozoic sedimentary rocks, intruded by the late Cretaceous to early Tertiary silicic plutons of the Pioneer Batholith. The Hecla District is located within a structural dome of Precambrian (Black Lion Fm.) through Mississippian (Madison Group) sedimentary rocks. Most of the known deposits are in dolomite of the Cambrian Hasmark and Devonian Jefferson Formations. Mineralization is generally stratiform within the main dome structure, following a handful of preferred bedding planes and fracture networks. The district is bordered on the north by the Great Fault, an east-west trending, steeply north-dipping normal fault, and on the south by a quartz-diorite intrusion dated at 70.5 Ma (Zen et al., 1975). Contact metamorphism suggests that a shallow but unexposed pluton is present beneath the Hecla dome, and K-Ar dating of metamorphic biotite in the Cambrian Silver Hill Formation gave a similar age to the neighboring quartz diorite. Numerous deformation events before, during, and after the late Cretaceous magmatic activity have affected the sedimentary section in the area, resulting in complex large to small-scale structures.

The basin that hosts the Hecla District is a compound cirque, presently drained to the northeast by Trapper Creek. Glaciation prior to and during the Pleistocene is responsible for the exposure of many of the orebodies, and also produced large amounts of glacial till that currently obscures much of the bedrock of the valley floor. Karlstrom (1948) estimated that during the peak of the last glaciation, thicknesses of ice in the valley exceeded 1000 feet. Lateral, medial, and recessional moraines are readily identifiable in the district, along with areas of kame and kettle topography. Talus slopes and trimlines around the cirques clearly delineate the lateral extent of ice.

## Previous Studies

In 1948, as part of his Ph.D. dissertation at the University of Chicago, Thor N.V. Karlstrom published a report on the geology and mining history of the Hecla Mining District (Karlstrom, 1948). More recent work from the U.S. Geological Survey and Montana Bureau of Mines and Geology (Zen et al., 1975; Snee, 1982; Pearson et al., 1988; Zen, 1996; McDonald et al., 2012) included dating of the Pioneer Mountain plutons and updated geologic maps and stratigraphic interpretations of the area. Gravitational and aeromagnetic surveys of the region were conducted as part of the 1988 Pioneer Mountains Mineral Resource Assessment. An aeromagnetic high was located beneath the Hecla District that plunges northwestward, and is thought to indicate a plunge in the batholith contact, or a smaller separate pluton at depth (Pearson et al., 1988). These studies agree well with a private exploration program that was conducted in the late 1990s. Little information was available from this study, but Gignoux (2000) provides a similar aeromagnetic map, and references drilling that encountered trace mineralization at depth, leading to a suggestion that Hecla represents a glacially exposed cupola. At the time of this writing, the authors are not aware of any other stable isotope or fluid inclusion work performed on the Hecla district.

## METHODS

### Sample Collection and Petrography

The Hecla District was visited during September and October of 2015. Samples were taken from dumps and outcrops at the Cleve, Trapper, Elm Orlu, Minnie Gaffney, and Silver King Mines, as well as from the large dump at the entrance to the Lion Mountain tunnel (see Fig. 1 for locations). None of the underground workings were entered for safety reasons. A portable X-ray fluorescence spectrometer (pXRF) was used to confirm mineralogy in the field and to help selected samples for additional petrographic and stable isotope analysis. Samples containing visible mineralization were imbedded in epoxy mounts and polished for examination using reflected light microscopy and scanning electron microscopy (SEM-EDS). For SEM work, we used the LEO 1430VP instrument located at the Center for Advanced Mineral Processing (CAMP) lab at Montana Tech. Selected specimens of supergene minerals were mounted on a slide with putty and analyzed with a Renishaw InVia Raman microscope, also located at Montana Tech. A single sample of ore from the Silver King Mine containing sphalerite, galena, and tetrahedrite was analyzed by electron probe microanalysis (EPMA) at Washington State University's GeoAnalytical Lab on a JEOL JXA-8500F instrument.

### Fluid Inclusions

Samples of quartz intergrown with galena from the main Lion Mountain dump were chosen for fluid inclusion analysis. Polished plugs were glued to a glass slide, sliced, and repolished to create quartz disks roughly 100  $\mu\text{m}$  thick polished on both sides. The glue was dissolved in acetone, and the disk was cut into small pieces for fluid inclusion microthermometry. Fluid inclusions were analyzed at Montana Tech on a modified USGS-type gas-flow heating/freezing stage. Phase changes were recorded near the melting points of solid  $\text{CO}_2$  (near  $-56^\circ\text{C}$ ), water ice ( $-10^\circ$  to  $0^\circ\text{C}$ ), and  $\text{CO}_2$ -clathrate ( $0^\circ$  to  $+10^\circ\text{C}$ ), the homogenization of  $\text{CO}_2(\text{l})$  and  $\text{CO}_2(\text{v})$  ( $20^\circ$  to  $31^\circ\text{C}$ ), and the final homogenization of the fluid inclusion ( $> 200^\circ\text{C}$ ). Fluid inclusion salinities were determined for  $\text{H}_2\text{O}$ -rich inclusions based on the melting point depression of ice, using the equation of Potter et al. (1978). Salinities of  $\text{CO}_2$ -rich inclusions were determined based on the freezing point of  $\text{CO}_2$ -clathrate, following the methods of Darling (1991) and Diamond (1992).

### Stable Isotopes

Samples of galena, sphalerite, and pyrite were hand-picked and powdered using a mortar and pestle, and transferred to small glass vials. The samples were analyzed for S-isotopes at the University of Nevada-Reno using a dual inlet Micromass IsoPrime stable isotope ratio mass spectrometer. All S-isotope data in this study are reported in per mil (‰) relative to the VCDT. Estimated analytical uncertainty based on replicate measurements is  $\pm 0.1\%$ . Galena-sphalerite and galena-pyrite pairs from the Minnie Gaffney and Silver King mines were used for S-isotope geothermometry. This approach is valid only if the two minerals formed at the same time, at equilibrium. The stable isotope fractionation calculator hosted by the website "Alpha Delta" (Beaudoin and



Therrien, 2004, 2009) was used to calculate formation temperatures. Regressions based on data in Grootenboer and Schwerz (1969), Kiyosu (1973), Czamanske and Rye (1974), Rye (1974), Li and Liu (2006), and Liu et al. (2015) were all used for sphalerite-galena geothermometry and compared for internal consistency. A regression based on the data of Kajiwra and Krouse (1971) was used for pyrite-galena geothermometry calculations.

## RESULTS

### Petrography and Paragenesis

Mineralization occurs preferentially along bedding planes and fractures, pods, and pipe-like conduits within the Cambrian Hasmark dolomite and the unconformably overlying Devonian Jefferson dolomite (fig. 2), and near but not directly adjacent to an intrusive contact to the south. The ores exist as both hypogene sulfides and oxidized secondary minerals (figs. 3, 4, 5). Major hypogene sulfides include galena, sphalerite, tetrahedrite, pyrite, and chalcopyrite. Important secondary ore minerals, identified with SEM-EDX and/or Raman spectroscopy, include acanthite, chalcocite, covellite, malachite, azurite, aurichalcite, smithsonite, hemimorphite, cerrusite, and anglesite (figs. 3, 4). The principal gangue mineral is quartz, although some well-mineralized specimens consist of veins and replacements of Pb-Zn-Fe sulfides, with very little gangue (figs. 3.3, 3.4).



Figure 2. Fracture-filling secondary mineralization at Lion Mountain.

Associated alteration minerals include tremolite, as a replacement of silica-rich dolomites, and jasper/chalcedony, as botryoidal fracture fillings and fortification structures (fig. 3.2). This silica flooding is especially apparent in both barren dolomite and directly associated with primary sulfides at the Minnie Gaffney Mine. EPMA work confirmed the presence of high Ag in tetrahedrite from the Silver King mine, with concentrations up to 9.1 wt% Ag. EPMA found little to no silver in galena, suggesting that tetrahedrite is the primary hypogene Ag ore mineral. The district displays a large-scale zonation of supergene enrichment, with oxidized ores at higher, more topographically exposed elevations and hypogene sulfides present at lower elevations. In particular, greater amounts of hypogene sulfides were found at the Elm Orлу, Silver King, and Minnie Gaffney Mines. Also noted at several locations was the presence of “calamine”, an antiquated name for mixed light-colored zinc silicates and carbonates (hemimorphite and smithsonite, respectively). Figure 5B shows coarse galena being replaced by anglesite, with an intervening rim of acanthite + covellite. Other samples were found with partly oxidized galena rimmed by acanthite. This acanthite, certainly supergene in origin, may have significantly increased the tenor of silver in the ore of Hecla. As the mines were driven deeper into the mountain, this supergene-enriched ore would have diminished.

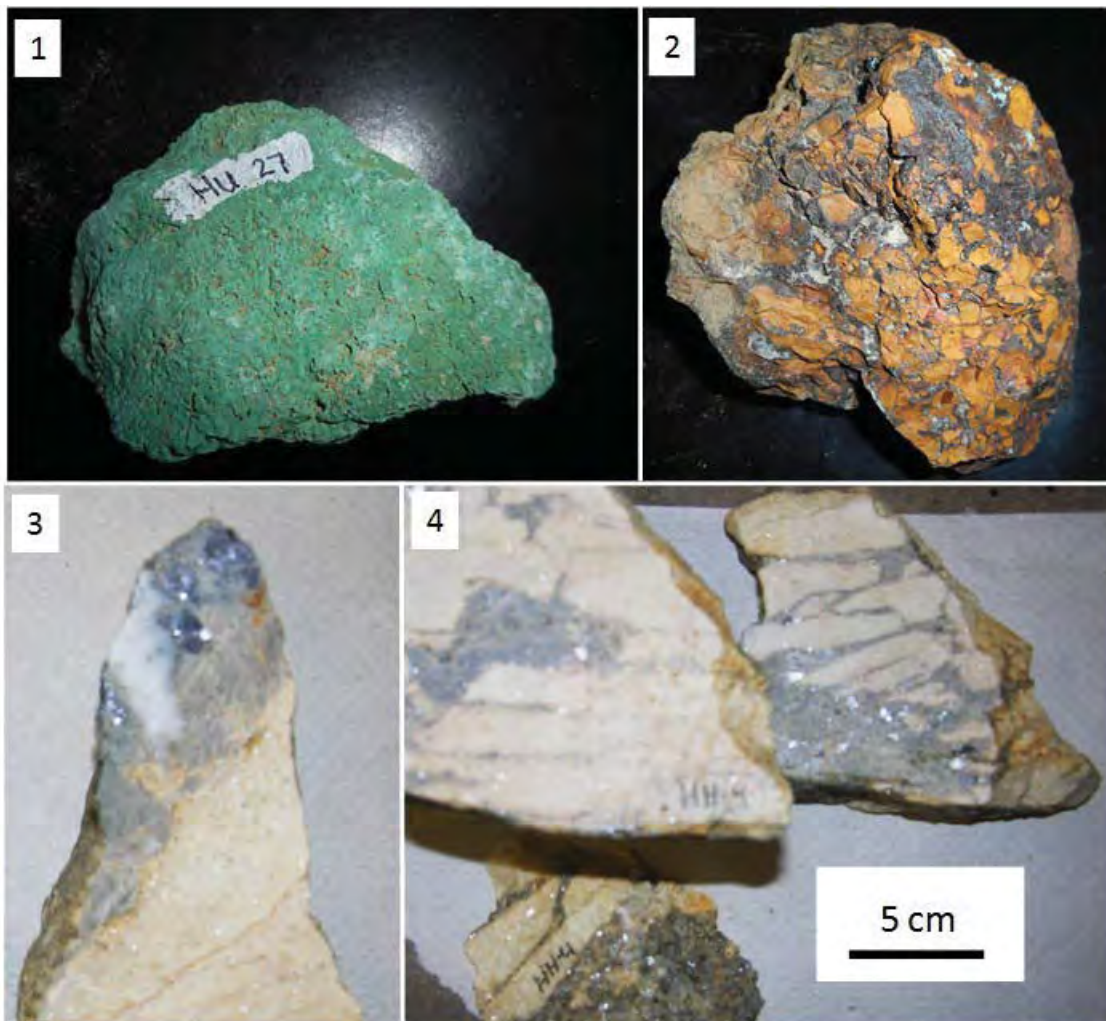


Figure 3. Top: secondary malachite (1) and jasper (2) from Lion Mountain. Bottom: sphalerite (medium brown), galena and quartz veining tan-colored dolomite at the silver king mine. Scale is similar for all photos.



Figure 4. Galena and quartz from the Cleopatra Mine waste piles.



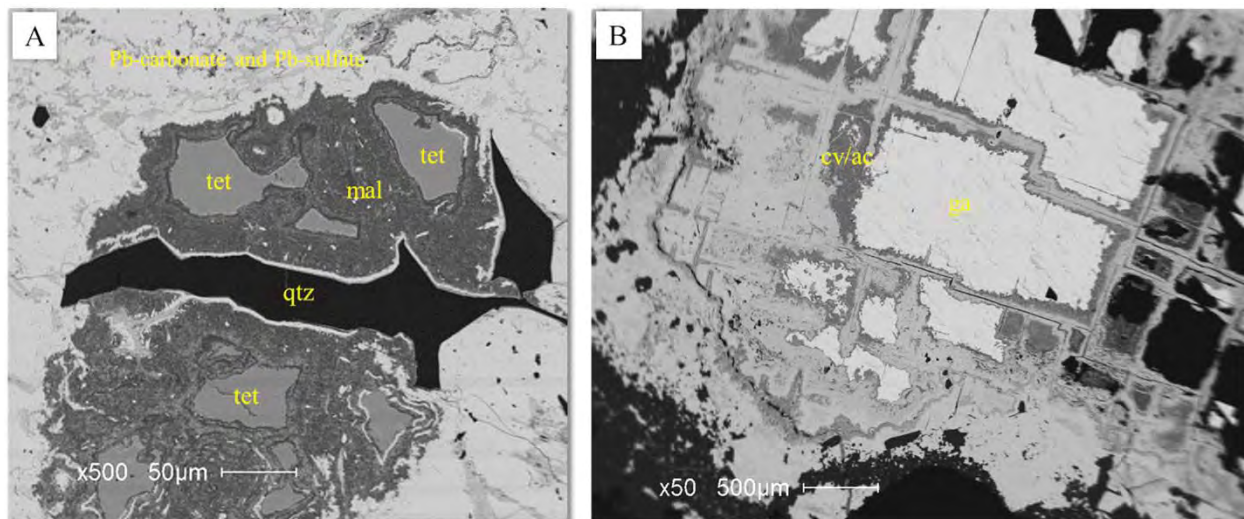


Figure 5. SEM-photographs: (A) Tetrahedrite partially replaced by malachite and other carbonates/sulfates. (B) Covellite/acanthite (dark gray) and anglesite (medium gray) replacing galena (white).

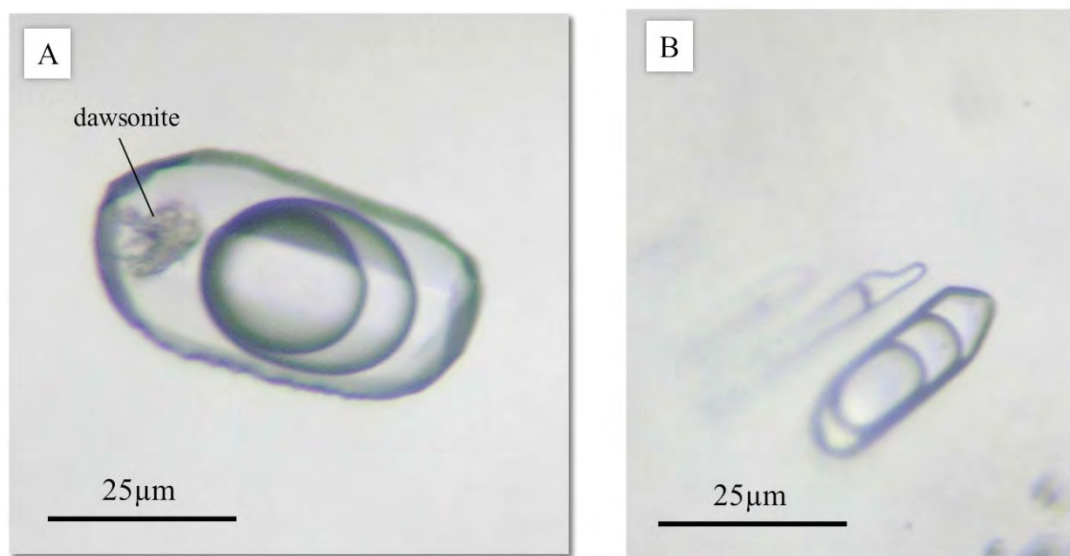


Figure 6. (A) Three-phase fluid inclusion in quartz from Lion Mountain, with daughter mineral, likely dawsonite. (B) Three-phase fluid inclusions in quartz.

### Fluid Inclusions

Because fluid inclusions were examined from only two samples of quartz, both from the Cleopatra Mine on Lion Mountain (fig. 4), the data presented in this study should be considered preliminary.

The majority of the fluid inclusions examined were simple, two-phase, water-rich inclusions with a moderate sized vapor bubble. A second population of fluid inclusions were CO<sub>2</sub>-rich, with liquid CO<sub>2</sub> visible at room temperature (fig. 6). Many of the CO<sub>2</sub>-rich inclusions contained a fibrous daughter mineral, thought to be dawsonite (NaAlCO<sub>3</sub>(OH)<sub>2</sub>) (fig. 6A). Both fluid inclusion populations (CO<sub>2</sub>-rich and H<sub>2</sub>O-rich) homogenized between 151°C and 346°C, with an average of 292°C. Some inclusions showed total homogenization to the vapor phase, whereas others in the same field of view showed total homogenization to the liquid phase, indicating that the hydrothermal fluids were episodically boiling.

Figure 7 shows the distribution of salinity values determined in this study. In general, the H<sub>2</sub>O-rich inclusions had higher salinity than the CO<sub>2</sub>-rich inclusions, although the two populations overlap. The average salinity for all of the inclusions examined is 4.85 wt% NaCl equivalent. Figure 8 plots salinity vs. homogenization temperature. The majority of the H<sub>2</sub>O-rich fluid inclusions plot on a possible mixing trend between a hotter, more saline fluid (~ 9 wt% NaCleq at 325°C) and a cooler, less saline fluid (~ 4 wt% NaCleq at 150°C). In contrast, the CO<sub>2</sub>-rich inclusions fall off the trend at lower salinity. It is possible that the salinity of the CO<sub>2</sub>-

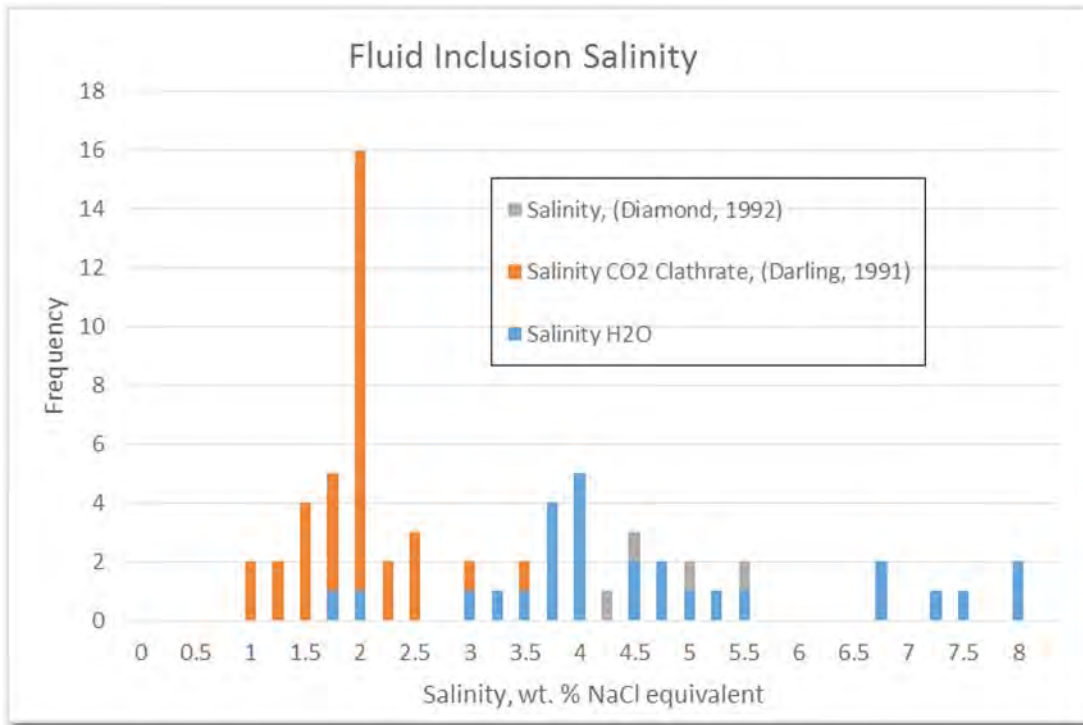


Figure 7. Histogram of fluid inclusion salinities.

rich inclusions has been underestimated. For example, if methane is present, then the clathrate that forms while a frozen inclusion thaws to room temperature could be a mixed  $\text{CH}_4\text{-CO}_2$  compound, complicating the salinity calculations. No attempt was made in this study to test for the presence of methane.

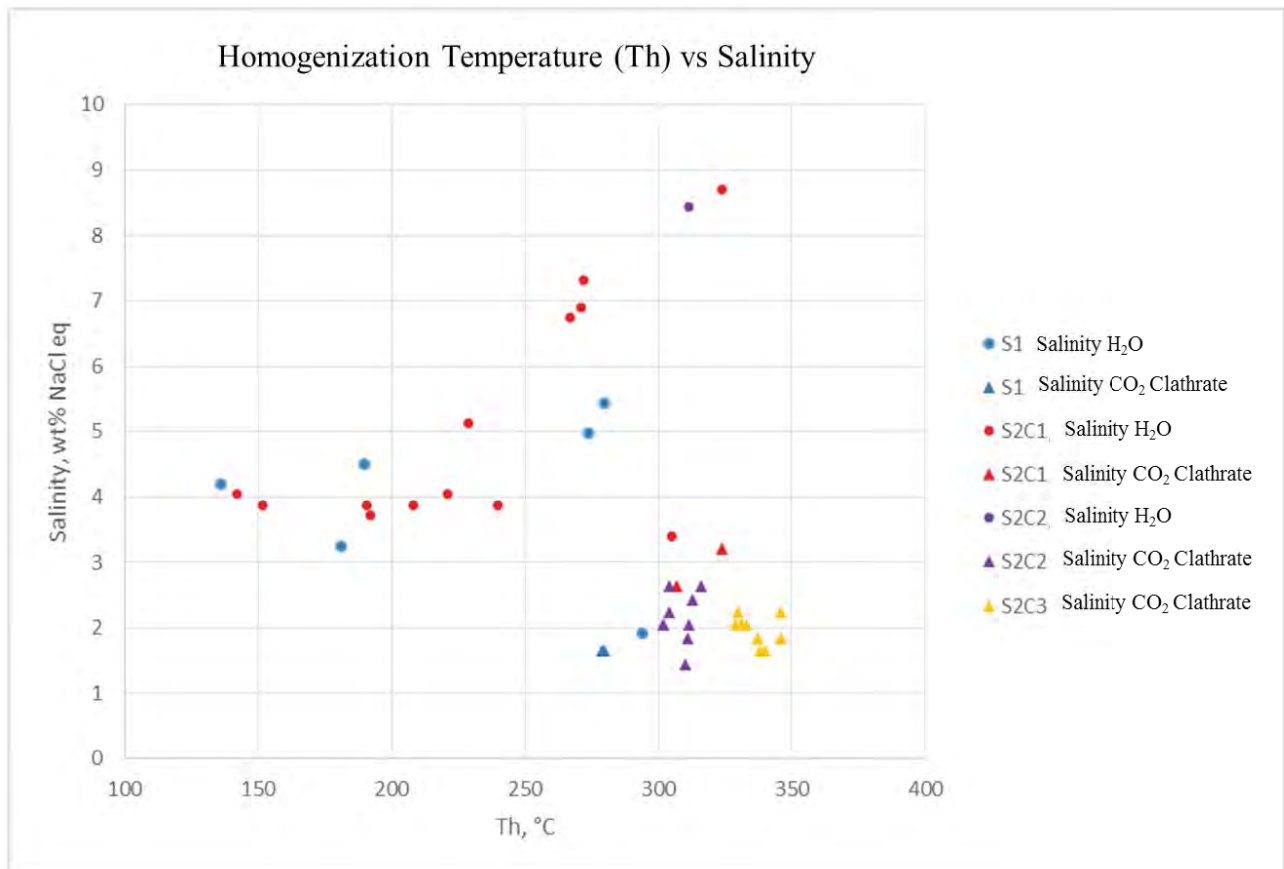


Figure 8. Plot of salinity vs. homogenization temperature for fluid inclusions in quartz.

Table 1. Sulfur isotope data (‰).

Mine - Sample No.	Mineral	$\delta^{34}\text{S}$ VCDT
Minnie Gaffney	galena	3.0
"	pyrite	6.3
Silver King-1	sphalerite	5.8
"	galena	3.4
Silver King-3	pyrite	5.9
Silver King-4	sphalerite	5.8
"	galena	3.5
Silver King-7	sphalerite	5.8
"	galena	3.6
Trapper	galena	1.3
Cleopatra	galena	2.4
Elm Orlu	galena	1.9

## Stable Isotopes

Sulfur isotope data (table 1) occupy a relatively narrow range between +1.3 to +6.3‰ that is slightly heavier than the accepted value for magmatic sulfur (i.e., close to 0‰). The average equilibrium temperature based on the three sphalerite-galena pairs is 291°C, and the calculated temperature for the single pyrite-galena pair is 301°C. The error in these temperature estimates attributed to analytical uncertainty ( $\pm 0.1$  ‰) is estimated to be  $\pm 6^\circ\text{C}$ . This is considerably less than the estimated uncertainty ( $\pm 39^\circ\text{C}$ ) obtained when the six different galena-sphalerite fractionation regressions listed in the methods section are used. This is consistent with Rye (1974), who suggested that, even under ideal circumstances, sulfur isotope geothermometry has an inherent error of at least  $\pm 20^\circ\text{C}$ .

## DISCUSSION

### Conditions of Mineralization

Based on geologic reasoning, Karlstrom (1948) proposed formation temperatures for the Hecla mineral deposits of 175-300°C and depths of 4,000-12,000 feet (1.2 to 3.6 km) below the surface. Karlstrom's temperature estimates are in line with this study. Fluid inclusion homogenization temperatures were found to range from 150° to 325°C, and S-isotope geothermometry based on sphalerite-galena and pyrite-galena pairs fell in a tight range of 291 to 301°C. At this time we have no firm estimate of pressure for the Hecla deposit. The close agreement between the average fluid inclusion homogenization temperature and temperatures based on S-isotope geothermometry would suggest that any correction of the fluid inclusion data for pressure is likely to be small (Potter, 1977). However, some of the fluid inclusions contain a large fraction of liquid  $\text{CO}_2$  at room temperature, and therefore were likely trapped at pressures in excess of 1 kbar (e.g., Brown and Lamb, 1989; Diamond, 2001). Assuming lithostatic pressure, this corresponds to depths in excess of 3.5 km. Thus, our fluid inclusion data, although preliminary, are in reasonable agreement with Karlstrom's (1948) upper range of estimates for the temperature and depth of formation at Hecla.

Assuming that the fluid inclusions found in a single quartz sample from the Cleopatra Mine are representative of the entire district, the ore-forming fluids at Hecla had low- to moderate-salinity values of 1.3 to 8.8 wt% NaCleq. This range of salinity is consistent with a magmatic fluid that cooled to temperatures near 300°C without boiling (e.g., see Rusk et al., 2008).

### Possible Ore Deposit Models for Hecla

Initial observations of district geology, ore mineralogy and vein textures suggested that Hecla could be a metamorphosed Mississippi Valley Type (MVT) deposit. However, MVT deposits generally have fluid salinities of 10 to 30 wt% NaCleq and compositions similar to oil field brines (Leach et al., 2010). Although our fluid inclusion data are preliminary, the salinities obtained from Hecla are much lower, averaging less than 5 wt% NaCleq. MVT deposits typically have a wide spread in  $\delta^{34}\text{S}$  of the contained sulfide minerals, up to a 30‰ range within a single deposit, reflecting a variety of sulfur sources and/or kinetic fractionation during bacterial or thermochemical sulfate reduction (Leach et al., 2010). In contrast, the spread in  $\delta^{34}\text{S}$  of sulfide minerals at Hecla is very small (fig. 9), and is mostly attributable to equilibrium fractionation between different sulfide minerals. Finally, MVT deposits are thought to form at temperatures of 100 to 200°C, much lower than the temperatures obtained in this study based on fluid inclusions and S-isotope geothermometry. Some varieties of MVT deposit, such as the Irish Midlands deposits and the Rio Grand Rift deposits, are thought to form at temperatures as high



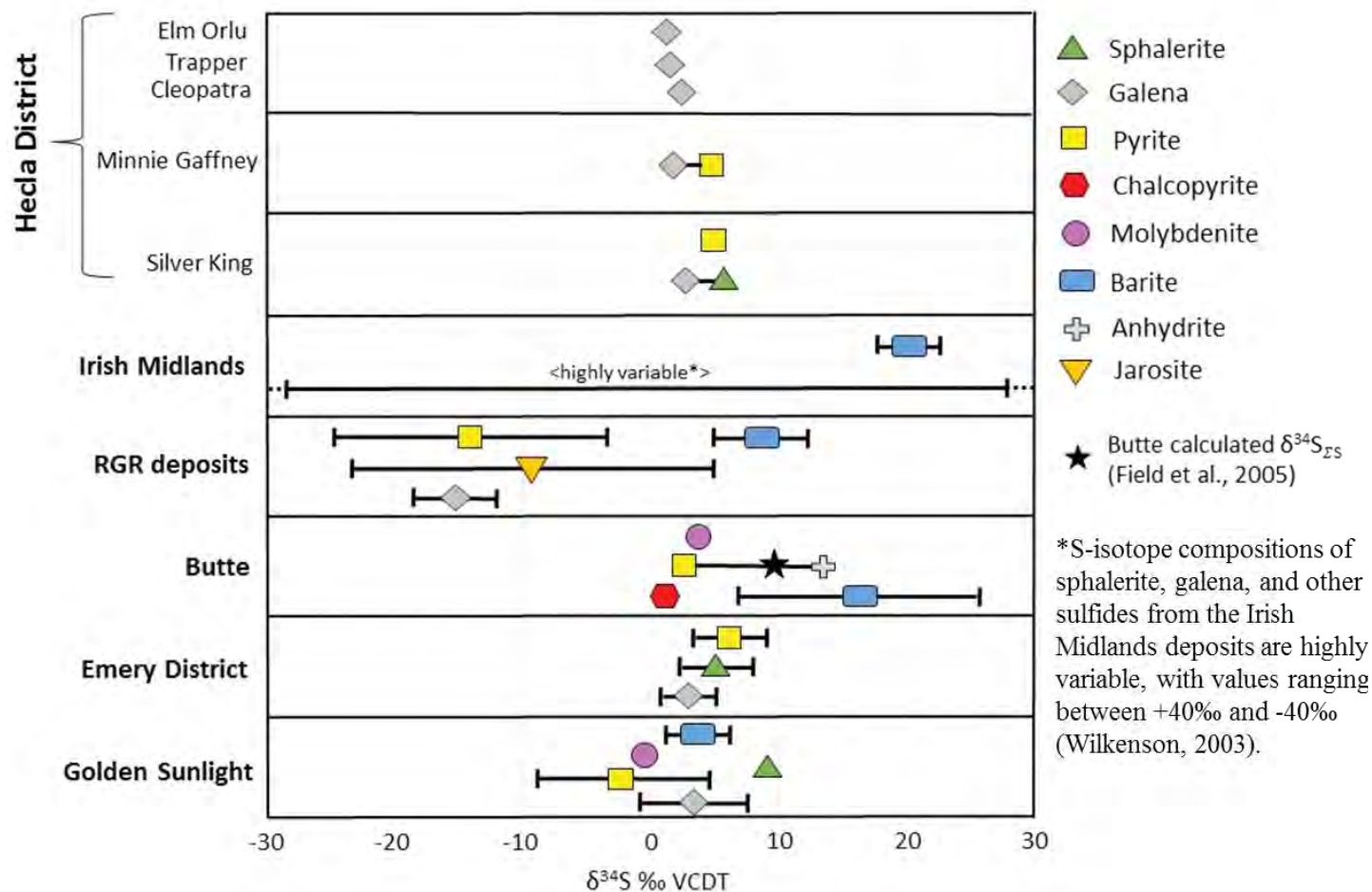


Figure 9. Sulfur isotopes from various nearby or mineralogically similar deposits compared to the Hecla district. Sources of data: this study (Hecla); Johnston (1999); Rakovan and Partey (2009); Field et al. (2005); Zimmerman (2016); Porter and Ripley (1985).

as 250°C. However, like MVT deposits, the Irish deposits contain high salinity fluid inclusions (10 to 15 wt% NaCl<sub>eq</sub>, Wilkinson, 2003) and a wide range in  $\delta^{34}\text{S}$  of sulfide minerals (Johnston, 1999). Rakovan and Partey (2009) suggest that the RGR deposits formed when rift-related magmatic fluids rich in fluorine, barium and base metals encountered Paleozoic limestones. Hecla lacks the tectonic setting and F- and Ba-rich mineralogy of the RGR deposits. Given these inconsistencies, it is very unlikely that the mineralization at Hecla could have been caused by any sort of MVT-style process.

Although skarn mineralization is well known from other locations in the Pioneer Mountains (e.g., Calvert, LenTung, Browns Lake, Indian Queen), the lack of high-temperature skarn minerals such as pyroxene and garnet precludes Hecla from having formed in close proximity to a magma. Instead, we suggest that the ore-forming magmatic fluids travelled a considerable distance from their source, cooling down to temperatures near 300°C before depositing the bulk of their base and precious metal when the carbonate rocks at the base of the Paleozoic section were encountered. The fact that the Hecla sulfide minerals have average  $\delta^{34}\text{S}$  values near +4‰ does not preclude a magmatic source for the hydrothermal S. Field et al. (2005) showed that the hydrothermal fluid that formed the rich deposits of Butte had a total S signature that was strongly enriched in  $^{34}\text{S}$ , possibly due to assimilation of heavy S from Proterozoic metasedimentary rocks into the porphyritic intrusions that were the source of the magmatic fluids. Zimmerman (2016) reached a similar conclusion for the polymetallic vein deposits of the Emery District, near Deer Lodge, MT, that are hosted by mafic volcanic rocks of the Elkhorn Mountain Volcanics. Perhaps not coincidentally, the fluid inclusions from Emery have many characteristics in common with those of Hecla, including a similar salinity and temperature range and the presence of 3-phase, CO<sub>2</sub>-rich inclusions, many of which have dawsonite daughter minerals (Zimmerman, 2016). Although hosted by entirely different rock types (andesitic-basalt lava flows vs. dolomite), the veins at Emery have similar narrow, low-angle, bedding-parallel characteristics to many of the veins at Hecla.

## SUMMARY

In summary, a genetic model for the formation of the Hecla deposits is given in Figure 10. This model is consistent with the results of this study, as well as the observations made by previous workers (e.g., Karlstrom, 1948) and more recent aeromagnetic data (Pearson et al., 1988) that indicate a north-plunging intrusive body underlying the core of the Hecla district. The unexposed magma chamber beneath the Hecla dome may have concentrated hydrothermal fluids into a cupola bounded at the top by the chemically unreactive clastic sediments of the Black Lion and Silver Hill formations. Fluid over-pressuring led to hydraulic fracturing, allowing fluids to ascend into joints and bedding planes in the overlying carbonates, where pH-neutralization resulted in ore mineral precipitation.

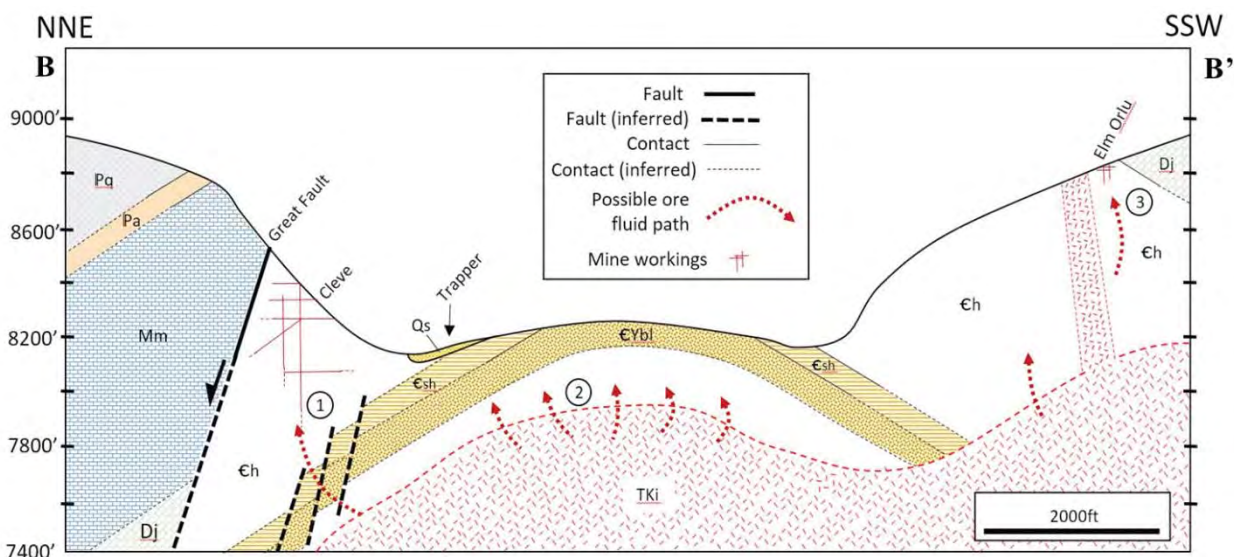


Figure 10. Simplified cross section (based on geologic map of Karlstrom, 1948, with updated stratigraphic interpretations) through the long axis of the major dome structure (B-B' of figure 1.3) Showing proposed intrusion and possible mineralizing fluid pathways. (1) Fluids followed faults into the northward-plunging anticlinal nose at the cleve mine. (2) Location of potential cupola source region. (3) Mineralization associated with smaller scale intrusions.

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## Silver Minerals of the Oro Fino Mining District, Powell and Deer Lodge Counties, Montana

Stanley Korzeb

*Economic Geologist, Montana Bureau of Mines and Geology, 1300 West Park Street, Butte, MT 59701,  
skorzeb@mtech.edu*

### ABSTRACT

#### History and Production

The Oro Fino Mining District is located in the Deer Lodge National Forest, 6 miles east of Galen and 13 miles north of Butte in Powell and Deer Lodge Counties. Placer deposits were discovered in 1867 and were mined until 1870, producing \$80,000 of gold (1800s gold price; Williams, 1951). Placer mining was renewed in 1889 with the discovery of sapphires in Dry Cottonwood Creek and continued until 1910. Gold was recovered with the sapphires and paid for the dredging operations. The sapphires were not gem grade and were sold for mechanical uses such as watch movements (Pardee and Schrader, 1951).

Lode deposits were discovered in 1886, with the Champion mine being the first mine to operate in the district from 1886 to 1888. The mine closed due to the expense of shipping ore to the mill located near Deer Lodge. It wasn't until 1916, when mining resumed in the district, that the Independence mine opened. The Champion mine was reopened in 1919 and became one of the largest silver producers in the district. Operations at the Champion mine continued until 1926 when it closed due to low silver prices (Pardee and Schrader, 1951; Williams, 1951).

From 1929 to 1930 the Cashier and Independence mines were in production, and in 1931 Williams (1951) reports only the Independence mine being in production. The Champion mine remained closed until 1938 when it was reopened, and by 1940 the American, Cashier, Grizzly Bear, Independence, and Champion mines were operating (Williams, 1951). Historical records on the Champion mine, preserved at the Montana Bureau of Mines and Geology archives, indicate the mine was in production in 1966. The mine operated intermittently until 1975 when mining operations in the Oro Fino district ended.

Accurate production records for the district were not reported until after 1933 and are summarized in table 1.

Table 1. Oro Fino production from 1933 to 1948 summarized by Williams (1951) from the Mineral Yearbook for the years 1933 to 1950. Production suspended from 1943 to 1946 by World War II.

Year	Producing Mines	Tons of Ore	Oz. Gold	Oz. Silver	Lbs. Copper	Lbs. Lead
1933	3	68	21	1,053	64	—
1934	3	22	9	2,183	16	—
1935	2	8	2	280	—	—
1936	8	158	83	3,854	265	200
1937	—	—	—	—	—	—
1938	3	105	21	1,383	112	—
1939	4	346	161	4,262	—	—
1940	4	1,429	131	16,252	—	—
1941	2	1,176	55	17,564	—	—
1942	2	518	10	4,815	1,000	—
1947	2	15	1	378	—	—
1948	1	3	—	94	—	—

## Geology

The Oro Fino mining district lies within the west side of the Boulder Batholith, mapped by Williams (1951). The east half of the district is included in the 1:24,000 scale Lockhart Meadows quadrangle, mapped by Hargrave and Berg (2013). The following discussion is a compilation of these two maps and field observations.

The entire district lies within the Butte granite of the Boulder Batholith and is the host rock for the epithermal veins. During the close of the Butte granite magmatism, pegmatite, aplite, and alaskite dikes with a preferred northeast orientation were intruded into the batholith (Berger and others, 2011). The Boulder Batholith was uplifted by basin and range faulting and Larimide–Eocene crustal extension. This uplifting event caused the exhumation of the batholith, exposing the Butte granite. Basin and range faulting and crustal extension caused a northeast-trending partial graben to develop, cutting across the batholith. East of the district, the Lowland Creek volcanic field erupted, filling the partial graben between 49 and 53 Ma (Scarberry and others, 2015; Dudas and others, 2010). The Lowland Creek volcanic rocks originated from caldera type eruptions within the graben, which were followed by single vent volcanos (Foster, 1987). On top of Cotton Wood Mountain, and at the head of Oro Fino Creek, the Butte granite is overlain by rhyolite that is attributed to the Avon volcanic event (Hargrave, 1990; Hargrave and Berg, 2013).

Basin and range uplifting and crustal extension caused a series of northeast-trending fractures and faults to develop in the Butte granite. At the same time, a few early north–south-trending fractures developed that are cut by northeast-trending faults. These faults and fractures are parallel to the aplite dikes and, in some locations, are adjacent to and follow the dikes. Development of the northeast- and north–south-trending faults probably coincides with the formation of the northeast-trending partial graben and the eruption of the Lowland Creek volcanic field. These faults and fractures are hosts for the northeast- and north–south-trending epithermal veins. The veins show evidence of the original faults being open fractures filled with brecciated Butte granite. Epithermal veins adjacent to the aplite dikes show the faults were filled with both brecciated aplite and Butte granite. Dating of the veins by  $^{40}\text{Ar}/^{39}\text{Ar}$  methods show the veins developed  $45.87 \pm 1.03$  Ma to  $50.73 \pm 1.21$  Ma at the close of the Lowland Creek volcanic field eruptions during the cooling phase.

## Vein Mineralogy

Minerals from the veins were identified from 36 polished sections, 38 polished thin sections, and 23 thin sections. The polished sections, polished thin sections, and thin sections were examined using reflected light and transmitted light microscopy and scanning electron microscopic-energy dispersive spectrum (SEM-EDS) techniques. The SEM-EDS analysis was performed at the Center for Advanced Mineral and Metallurgical Processing, Montana Tech. Minerals were also identified by examination of hand specimens and cut slabs. A total of 36 minerals from 10 groups were identified.

From the mineral identifications, a series of mineralizing events that developed the Oro Fino veins were identified. The mineralizing events can be broken down into a series of stages represented by host rock alteration, base-metal mineralization, silver-gold mineralization, and supergene alteration. Each mineralizing event has a unique mineralogy that was influenced by physical and chemical changes of the hydrothermal fluids that developed the veins. Physical events such as changes in fluid temperature, pressure, episodes of brecciation, wall rock reactions, and fluid boiling can influence the mineralogy of each stage. Chemical changes, such as the introduction of different metals, can be reflected in vein mineralogy.

## Silver Mineralization

Silver was the most important commodity produced from the Oro Fino mining district, along with gold as a minor commodity. Silver production came from a variety of silver-bearing minerals (table 2) identified from polished sections and polished thin sections. These minerals crystallized from hydrothermal fluids under specific geochemical and physical conditions.

The silver–gold mineralizing event overprints the base-metal mineral-

Table 2. Silver minerals identified from the Oro Fino veins.

Silver–Gold Mineralizing Event
Acanthite $\text{AgS}_2$
Electrum $X_{\text{Au}} 0.3\text{--}0.45 \text{ Au/Ag}$
Freibergite $\text{Ag}_6\text{Cu}_4(\text{Fe,Zn})_2\text{Sb}_4\text{S}_{13}$
Miargyrite $\text{AgSbS}_2$
Pyrrargyrite $\text{Ag}_3\text{SbS}_3$
Silver Ag

izing event and started after galena precipitation. Acanthite and pyrargyrite are found as intergrown grains (fig. 1) and crystallized simultaneously. Acanthite is a low-temperature monoclinic polymorph that inverts at 177.8°C from the high-temperature cubic argentite structure (Keighin and Honea, 1969). It has been demonstrated from experimental investigations that argentite and pyrargyrite will crystallize together at temperatures ranging from 178° to 465°C (Bryndzia and Kleppa, 1988). After argentite and pyrargyrite crystallize, argentite inverts to acanthite with dropping temperatures. Due to the inversion of argentite to acanthite, only acanthite will be found in the veins.

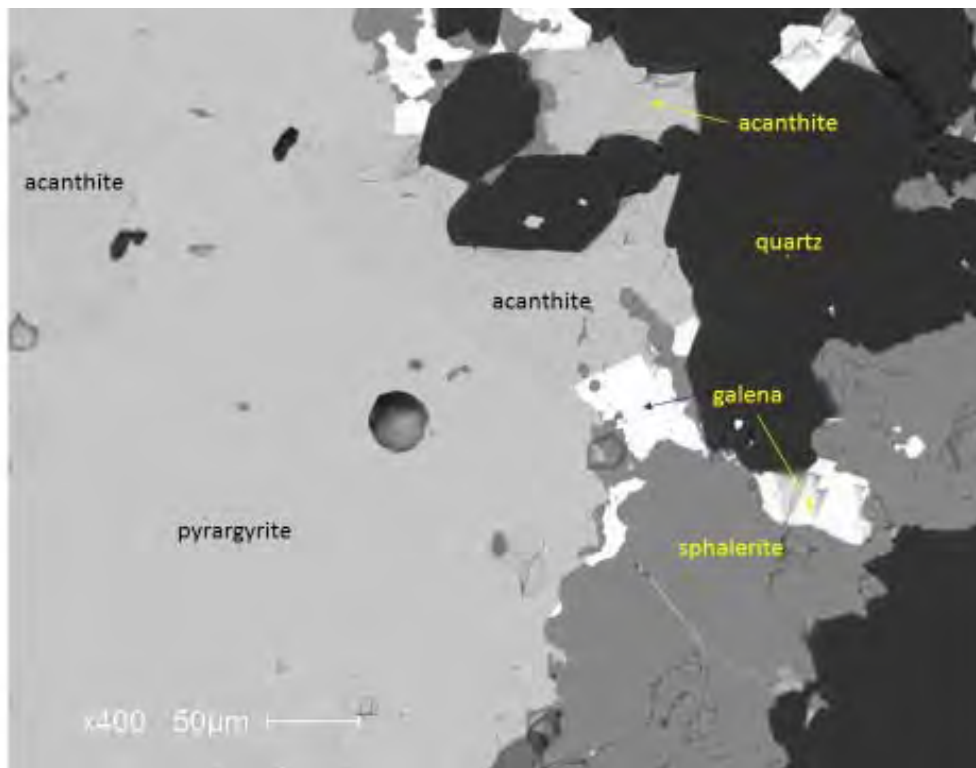


Figure 1. SEM-BS image of pyrargyrite and acanthite intergrowth.

Miargyrite is less common in the veins and crystallized at the same time as pyrargyrite but was not found in association with pyrargyrite. Experimental investigations by Keighin and Honea (1969) demonstrate miargyrite will crystallize at the same time as pyrargyrite at temperatures ranging from 192° to 455°C. The phase relations between pyrargyrite and miargyrite determined by Keighin and Honea (1969) indicate miargyrite will crystallize from a fluid that is deficient in silver with respect to pyrargyrite. At locations in the vein system that were depleted in silver and remained enriched in antimony, miargyrite will crystallize in favor of pyrargyrite.

Particles of a gold-silver alloy (variety electrum) are associated with acanthite and pyrargyrite (fig. 2). The textural relationships between electrum and the other silver minerals indicate electrum co-precipitated with acanthite and pyrargyrite. From SEM-EDX analysis, the Au mole fraction ( $X_{Au}$ ) for electrum was determined to vary from 0.3 to 0.45 mole percent. Thermodynamic constraints determined by Gammons and Williams-Jones (1995) indicate the solubility of gold is dependent on the composition of Au-Ag alloys. They determined the composition of Au-Ag alloys is a complex function of temperature, activity of sulfur ( $a_{S_2}$ ), activity of oxygen ( $a_{O_2}$ ), Cl<sup>-</sup> concentration, and total Au-Ag content of the hydrothermal system. Additional thermodynamic constraints on electrum composition are the co-precipitation with other Au-Ag-bearing minerals (e.g., sulfides, sulfosalts, tellurides, or selenides; Gammons and Williams-Jones, 1995). The composition of electrum in equilibrium with argentite can be used as a geothermometer if an independent estimate of  $a_{S_2}$  can be made (Gammons and Williams-Jones, 1995).

Using the thermodynamic constraints established by Gammons and Williams-Jones (1995), a temperature range was determined for the precipitation of the Au-Ag alloy during the development of the silver-gold mineralizing event. The temperature range was extrapolated from a diagram that shows the mole weight % of electrum ( $X_{Au}$ ) in equilibrium with argentite as a function of temperature and the relationship between  $a_{S_2}$  for the

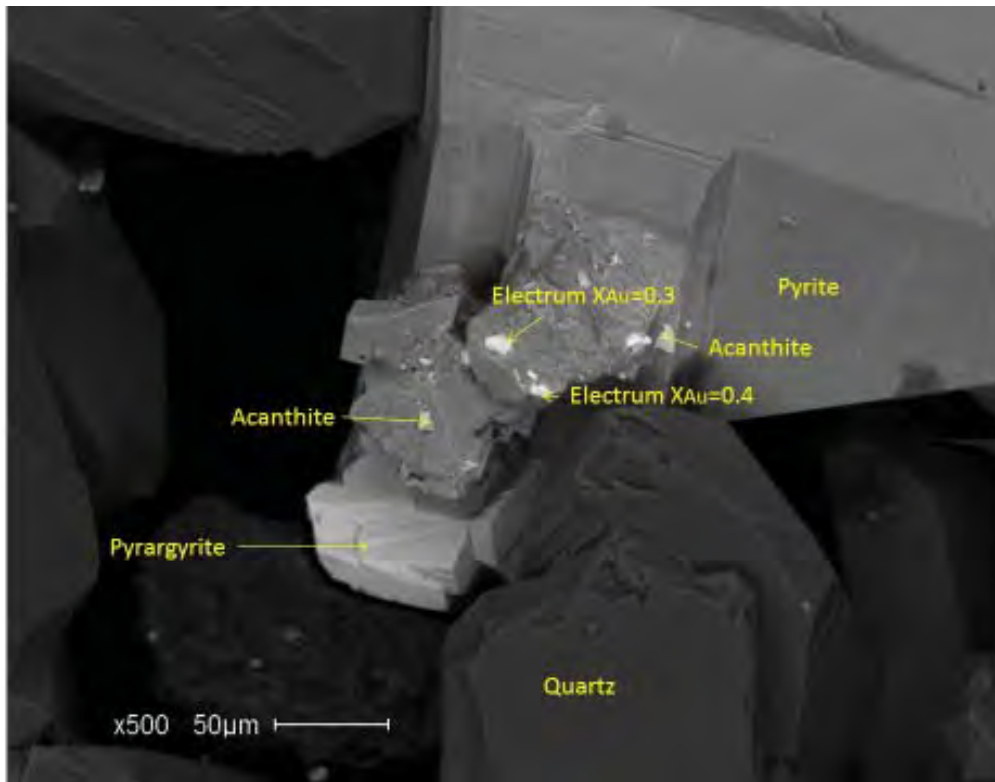


Figure 2. SEM-BS image of electrum particles on pyrite associated with acanthite and pyrargyrite.

buffering mineral assemblage pyrite–sphalerite. By applying the parameters for  $X_{Au}$  0.3–0.4 mole % for electrum and  $(X_{FeS})_{sph}$  0.04 to 0.1 mole % for sphalerite to the diagram (Gammons and Williams-Jones, 1995) the crystallization temperature for electrum was determined to vary from 230° to 325°C.

Native silver had both a hypogene and supergene origin. Silver that had a hypogene origin occurs as particles attached to acanthite and pyrargyrite grains and can be associated with electrum. The silver precipitated at the same time as the electrum from fluids saturated in silver with respect to gold. Silver with a supergene origin resulted from the replacement of pyrargyrite by senarmontite (fig. 3). The replacement process freed silver from the replaced pyrargyrite, which in turn precipitated as rounded grains included in the antimony oxide mineral senarmontite.

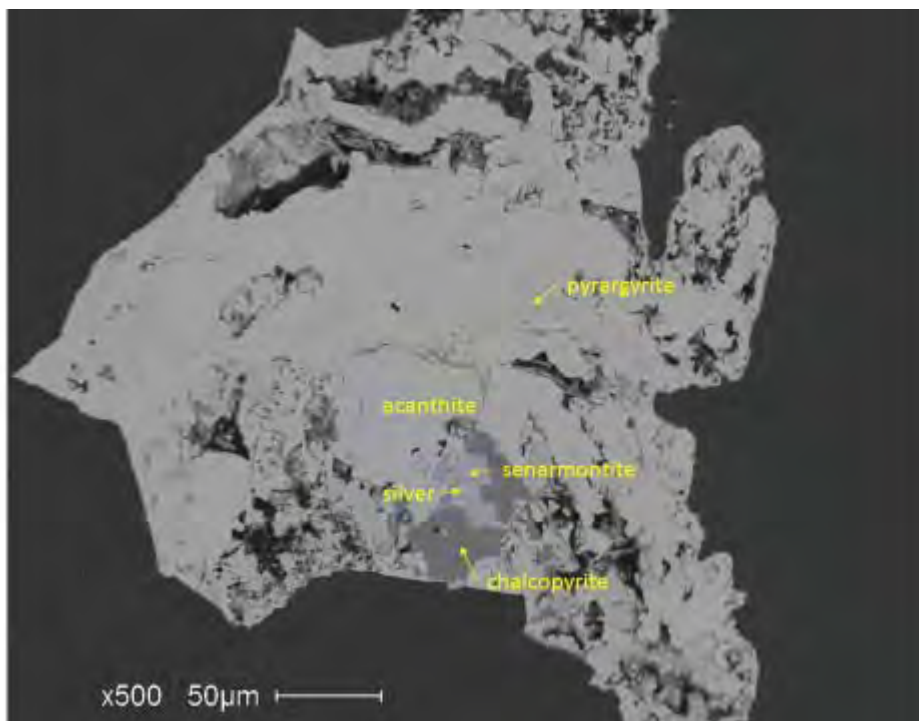


Figure 3. SEM-BS image of pyrargyrite being replaced by senarmontite with supergene silver inclusions.



Freibergite was the last silver mineral to crystallize by replacing pyrrargyrite and is found along the margins of pyrrargyrite grains displaying replacement textures (fig. 4). Freibergite developed when late-stage hydrothermal fluids containing copper, iron, and zinc were introduced near the close of the gold–silver mineralizing event and at the beginning of the supergene alteration event. By using the molar ratios  $\text{Ag}/(\text{Ag}+\text{Cu})$  and  $\text{Zn}/(\text{Zn}+\text{Cu})$ , it is possible to determine the temperature for precipitation of freibergite (Sack and Ebel, 2006). The molar ratios are plotted on a diagram generated by Sack and Ebel (2006) that shows the relationship between  $\text{Ag}/(\text{Ag}+\text{Cu})$  and  $\text{Zn}/(\text{Zn}+\text{Cu})$  molar ratios and temperature. Using the molar ratios determined from SEM-EDS analysis of 0.41 and 0.33 for  $\text{Ag}/(\text{Ag}+\text{Cu})$  and 0.41 and 0.33 for  $\text{Zn}/(\text{Zn}+\text{Cu})$ , a temperature range of 160° to 215°C was determined for the replacement of pyrrargyrite by freibergite.

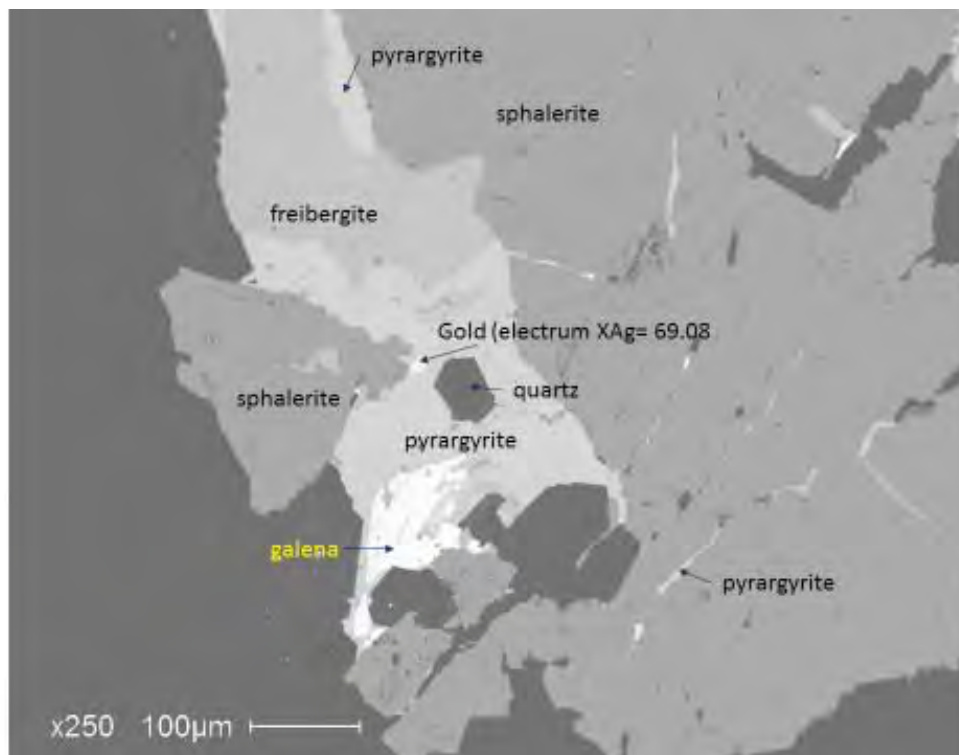


Figure 4. SEM-BS image of freibergite replacing pyrrargyrite.

## DISCUSSION

Hypogene silver–gold mineralization took place from a boiling low-salinity hydrothermal fluid that was chemically and physically evolving over time. The silver–gold mineralizing event for the Oro Fino veins took place at temperatures ranging from over 300°C to less than 160°C. The first mineralizing event, the precipitation of pyrrargyrite with argentite, took place at temperatures between 200°C and 465°C shown on the Ag–Sb–S phase diagram (Keighin and Honea, 1969). Miargyrite precipitation takes place from silver-deficient fluids at the same temperatures as argentite and pyrrargyrite (Keighin and Honea, 1969). The precipitation of native silver and electrum following the crystallization of miargyrite, argentite, and pyrrargyrite took place within the same 200° to 465°C temperature range. Electrum precipitation constrains the temperature of gold–silver mineralization to 230°–325°C, overlapping the 200° to 465°C range shown on the Ag–Sb–S phase diagram (Keighin and Honea, 1969).

Acanthite, pyrrargyrite, miargyrite, native silver, and electrum precipitated from a hydrothermal fluid that was saturated in antimony, silver, and gold. Antimony and arsenic are known to scavenge gold and silver from hydrothermal fluids (Cooke and Simmons, 2000). In modern geothermal systems that were studied in New Zealand, gold and silver were found to precipitate with amorphous antimony sulfide (Weissberg, 1969; Cooke and Simmons, 2000).

There is a strong correlation between the presence of antimony and gold and silver mineralization in the Oro Fino veins with one of the first silver minerals to precipitate being pyrrargyrite (a silver antimony sulfosalt). This

correlation suggests gold and silver was scavenged by antimony and transported together in the hydrothermal fluids.

Later with dropping temperatures and changing fluid chemistry, the mineralization process changed from direct precipitation to replacement. The final hypogene silver mineral, freibergite, developed by replacing pyrargyrite at a temperature range of 160° to 215°C. At temperatures below 160°C, supergene mineralization will take place (Hedenquist and others, 2000), causing hypogene minerals to be replaced by supergene minerals. Supergene-native silver was generated as a result of pyrargyrite being replaced by senarmontite. This replacement reaction put silver and antimony in solution, allowing native silver to precipitate as inclusions in senarmontite.

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## Geology, Fluid Inclusion, and Stable Isotope Study of the Calvert Tungsten Mine, Pioneer Mountains, Montana

Joshua Messenger,<sup>1</sup> Christopher H. Gammons,<sup>1,\*</sup> and Simon R. Poulson<sup>2</sup>

<sup>1</sup>*Department of Geological Engineering, Montana Tech of the University of Montana, Butte, MT*

<sup>2</sup>*Department of Geological Sciences and Engineering, University of Nevada-Reno, Reno, NV*

\*Corresponding author: [cgammons@mtech.edu](mailto:cgammons@mtech.edu)

### ABSTRACT

The Calvert tungsten skarn deposit is located in the northern extent of the West Pioneer Mountains, approximately 40 miles southwest of Butte, Montana. The orebody occurs within skarn developed in the Pennsylvanian Amsden Formation near or in contact with a satellite pluton of the Late Cretaceous Pioneer Batholith. At least three stages of skarn and ore formation have been recognized: stage I, early prograde metasomatism characterized by diopside, forsterite, and trace grossular garnet; stage II, main-stage prograde metasomatism characterized by grossular, diopside(?), epidote, calcite, and quartz together with scheelite, hematite, zircon, magnetite, apatite and sphene; stage III, retrograde alteration caused local replacement of early mineral assemblages by actinolite, calcite, and quartz together with scheelite, hematite, magnetite, phlogopite, chlorite, and muscovite.

Fluid inclusion microthermometric measurements of the Calvert skarn minerals show that the main prograde mineral assemblage was formed at temperatures between 400°–450°C and pressures between 2 and 2.5 kbar which correspond to a depth of 7–8.75 km. The salinity of these fluid inclusions increases from 3.2 wt.% to 11.2 wt.% NaCl eq., suggesting either a mixing between a high salinity magmatic fluid and a dilute fluid of meteoric origin, or an increase in salinity due to loss of water to the formation of hydrous skarn minerals.

The protolith marble has  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  values that average +0.6‰ (VPDB) and +25.2‰ (VSMOW), respectively. These isotopic values are depleted relative to unmetamorphosed marine limestone values of +0.0‰ and +30.6‰. The  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  values of the skarn calcite range from -5.0‰ to -9.4‰ for carbon and from +7.7‰ to +14.0‰ for oxygen. The observed depletion towards isotopic magmatic values indicates an interaction between the marble and metasomatic fluids derived from the source igneous body. Mineral stability relationships combined with fluid inclusion data suggest that during formation of the metasomatic skarn the mole fraction  $\text{CO}_2$  of the fluid was approximately 0.01. Scheelite precipitation most likely resulted from cooling coupled with an increase in the activity of calcium due to fluid/rock interaction with the calcite-marble host rock.

Mineral paragenesis, mineral chemistry, fluid inclusion and stable isotope studies are consistent with the hypothesis that the Calvert deposit is a distal skarn. The source of the hydrothermal fluids is not known but could include the Foolhen Mountain Tonalite or the Bryant Creek Granite which outcrop in the study area. An alternative possible source is a buried pluton at greater depth. This could account for the large amounts of water and temperatures involved with the formation of the Calvert skarn.

### INTRODUCTION

The Calvert deposit is located in the north Pioneer Mountains, approximately 40 miles SW of the city of Butte in southwestern Montana (fig. 1). It is centered on 45.854°N latitude and 113.158°W longitude at an elevation of approximately 7,100 feet, with a vertical relief of about 37 meters.

Access to the mine can be gained from Butte by travelling south on Interstate 15 to exit 102, then west on Montana HW-43 to the Big Hole River bridge. Take a left onto Bryant Creek Road and continue to Calvert Loop Road, which merges with Forest Service Rd 70648 and leads to the southeast corner of Calvert Mine property. Unimproved roads allow access around the entire site.

The Calvert deposit was discovered by W.I. Ferguson and George Henderson who located two lode claims which later became the site of the Calvert open pit. The orebody was a significant tungsten producer between 1956–1957 and 1960–1962 during which time the mine produced a total of approximately 113,000 tons of ore averaging 1.1%  $\text{WO}_3$  (Walker, 1963), with a measured reserve of 128,000 tons at 1.1%  $\text{WO}_3$ . When mining operations ceased, groundwater and snowmelt created a pit lake of exceptional clarity and chemical purity (Gammons et al., 2013).



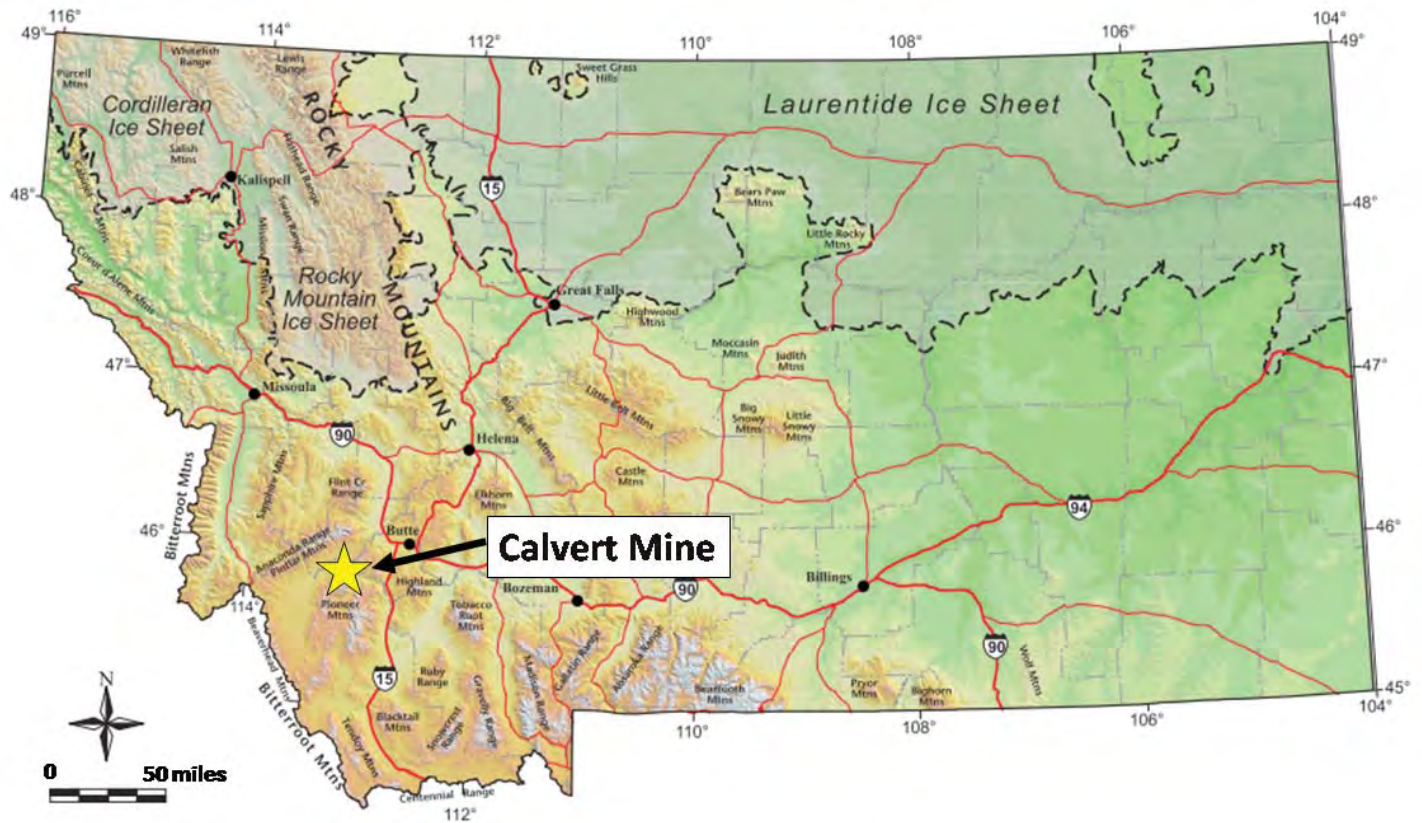


Figure 1. Location of the Calvert mine in the Pioneer Mountains. Montana image adapted from the Montana Bureau of Mines and Geology Geologic Map 62.

The purpose of this paper is to present and document the geology, carbonate stable isotope compositions, and to discuss the evolution of skarn and ore formation using the isotopic and microthermometric constraints.

## GEOLOGIC SETTING

The Pioneer Mountains are located near the eastern extent of the Sevier fold and thrust belt which is a region of overlapping thrust faults displacing middle Proterozoic to Cretaceous sedimentary rocks. These rocks have been intruded by granitic rocks of the Pioneer Batholith. Snee (1982) described the Pioneer Batholith as a composite body made up of plutons ranging in composition from granite to tonalite, with minor pyroxenite and gabbro, emplaced in the epizone during the time span of 83-65 Ma.

Throughout the Pioneer Mountains, granitic rocks consistently intrude to the stratigraphic level of the Hasmark, Madison, Jefferson and/or Amsden carbonate-bearing formations. This combination of reactive carbonate sediments and input of magma and associated hydrothermal activity is an ideal environment to create skarns, base and precious metal veins/replacement deposits, and stockwork or porphyry deposits.

The Pioneer Batholith is situated within the Great Falls Tectonic Zone (GFTZ), a northeast-trending, 1.85 Ga suture zone between the Archean Medicine Hat Terrain to the north and the Archean Wyoming Terrain to the southeast. Sims et al. (2004) interpreted the GFTZ to contain accreted crust of the Wallace Terrain, as well as the Trans-Montana fold and thrust belt of Paleoproterozoic age.

The geology surrounding the Calvert Hill area was mapped and described by Truckle (1988), who inferred at least two periods of folding and thrusting in the area. The earliest event produced the high-angle northwest striking and southwest dipping Foolhen thrust fault and placed Precambrian paragneiss over Phanerozoic metasediments. Truckle (1988) postulated that the Foolhen thrust fault was later folded until rupture during the second compressional event that created the Calvert thrust fault. Later tensional stress caused left-lateral movement along the Bryant Creek tear fault. The Calvert mine is situated near the intersection of the Calvert and Bryant Creek faults.



## DEPOSIT GEOLOGY

Precambrian and Phanerozoic rocks crop out in the study area and are interpreted as Proterozoic paragneiss, Pennsylvanian Amsden Formation, Cretaceous igneous intrusions (tonalite, granite, aplite and pegmatite), as well as mineralized and barren skarn (fig. 2). The dominant strike of the metasedimentary rocks is to the WNW, dipping to the SW, and parallels many of the intrusive contacts. The orebody has a similar orientation and plunges south at approximately 50 degrees. The map shows the likely location of a fault which separates the Paleozoic metasediments to the west from Precambrian gneiss to the east.

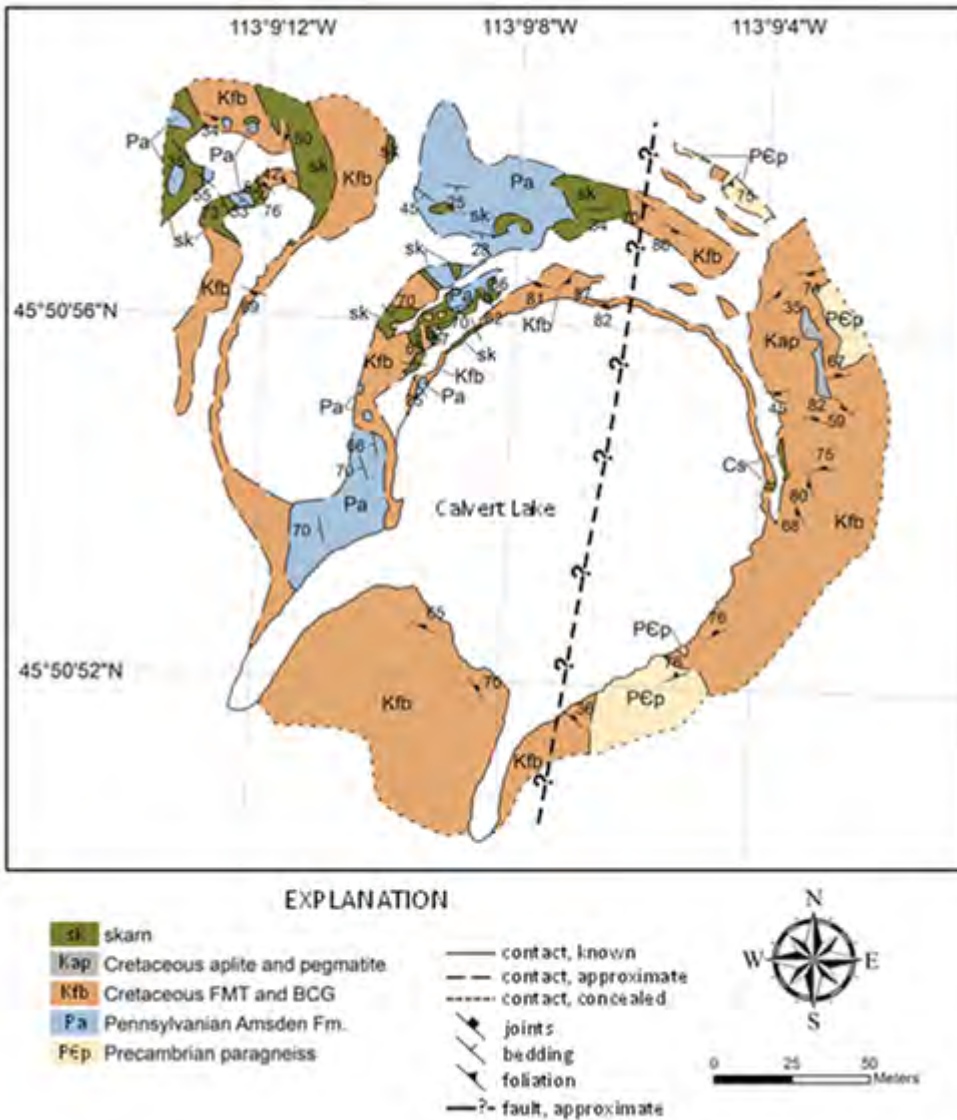


Figure 2. Geologic map of the Calvert mine (Messenger, 2016).

The Foolhen Mountain Tonalite (FMT) is the dominant intrusive rock at the Calvert mine. Snee and Sutter (1982) used Ar/Ar age-spectrum and conventional K/Ar dating methods on hornblende to yield a date of  $72.06 \pm 1.07$  Ma for the FMT. An outcrop of granitic rock exposed in the western workings at Calvert is tentatively correlated to the Bryant Creek Granite (BCG) of Snee and Sutter (1982). The BCG intrudes the FMT and is therefore younger than the tonalite.

Two northwest-trending dikes of apatite and pegmatite intrude the tonalite in the eastern portion of the study area and have been mapped as a single unit (Kap). The dikes have not been metamorphosed suggesting that emplacement followed regional metamorphism.

The marble host of the skarn ore at Calvert has been interpreted to be part of the Pennsylvanian Amsden Formation which represents a shallow marine to coastal facies. The Amsden Fm. is exposed as outcrops and in trenches in the western half of the mine where it exists in sharp contact with igneous rock and skarn.

Emplacement of the intrusive rock(s) caused contact metamorphism which recrystallized the Paleozoic limestone to marble. The contact between the marble and limestone was not observed at the Calvert mine; therefore, the extent of the metamorphic aureole is not known.

At the Calvert mine, skarns developed in the FMT (endoskarn) and in the marble (exoskarn). The principal

The paragneiss outcrops as northwest-trending blocks located in the eastern portion of the study area and is bordered by coarse-grained tonalite. The paragneiss in the Calvert Hill area has been presumed to be of Precambrian age by Berger et al. (1983) because of its amphibolite grade of metamorphism and polydeformed character. Truckle (1988) described the paragneiss as being a fine-medium-grained, foliated and compositionally layered quartzo-feldspathic gneiss.

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skarn minerals at Calvert are garnet, epidote, actinolite, calcite and quartz together with forsterite, diopside, scheelite, magnetite, zircon, sphene, apatite, phlogopite, muscovite, hematite and chlorite as accessory minerals. Scheelite can be difficult to recognize in outcrop, but is visible when the sample is under UV light (fig. 3).

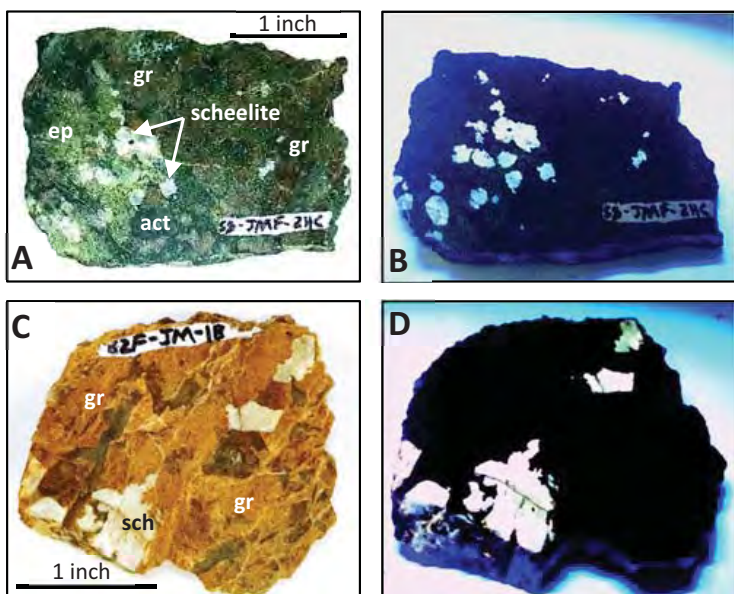


Figure 3. Rock slabs of Calvert samples. A & C under normal light, B & D under UV light, showing scheelite fluorescence.

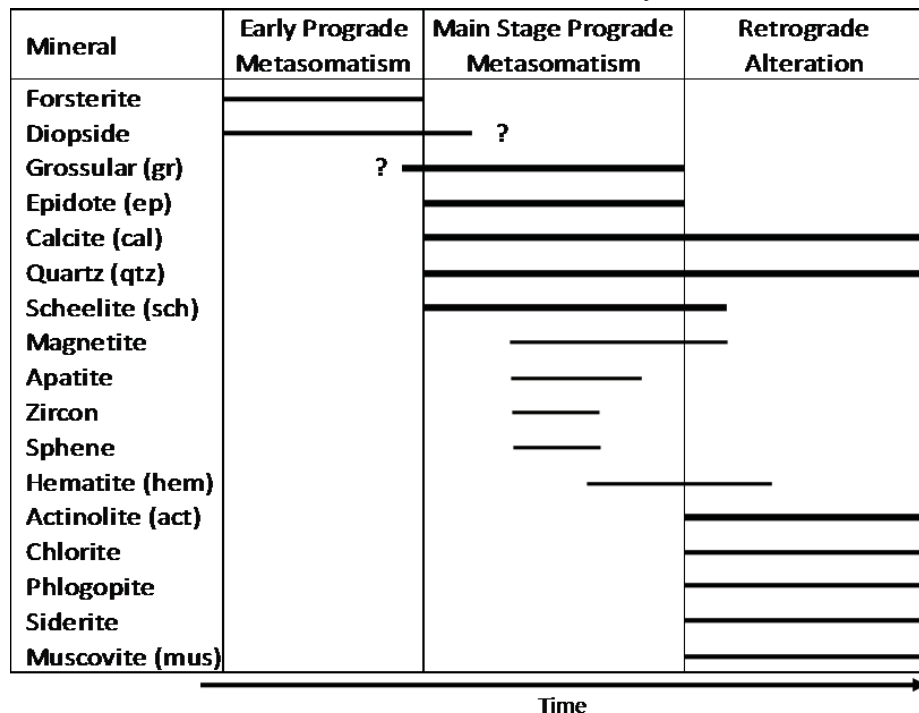
Four subtypes of rock have been distinguished within the Amsden Formation at Calvert: 1) a calcite-forsterite-diopside-garnet(?) - phlogopite marble; 2) a garnet-epidote-calcite-quartz prograde skarn with coarse-grained scheelite (up to 2 cm in diameter); 3) an actinolite-calcite-quartz skarn with fine- to medium-grained scheelite; and 4) late retrograde skarn with chlorite and muscovite with no scheelite. Many of the garnets contain scheelite as inclusions, along with quartz, calcite and epidote. The Calvert skarn is notable for being nearly completely absent of sulfide minerals or other evidence of base metal mineralization.

Although not observed in this study, others have reported trace amounts of beryl, chalcopyrite, pyrrhotite, molybdenite and cuprotungstite (Gobla, 2012). The occurrence of aquamarine beryl, highly sought by local mineral collectors, was first described by King (1966).

### PARAGENESIS OF SKARN AND ORE MINERALS

The sequence of skarn mineralization of the Calvert deposit is shown in figure 4. The minerals formed during three stages: 1) early prograde metasomatism; 2) main-stage prograde metasomatism; and 3) retrograde alteration.

An early period of prograde metasomatism is indicated by the formation of a bleached marble between the skarn and marble. This zone consists of mainly calcite with minor forsterite, diopside, trace garnet(?) and



secondary phlogopite and chlorite. The bleached zone varies in thickness from 5 cm to about one meter. The bleached marble furthest from the skarn contact is nearly completely white and consists of granoblastic calcite with disseminations of diopside and phlogopite. Closer to the skarn contact the marble is darker and consists of calcite, forsterite, diopside, garnet(?), phlogopite, fine-medium-grained subhedral chlorite, and chalcedony filling vugs and veins.

The main-stage prograde skarn assemblage is dominated by garnet, diopside(?), epidote, calcite and quartz together with scheelite, zircon, magnetite, apatite, hematite and sphene as accessory minerals. Coarse garnet (up to 8 cm) and epidote are typically

Figure 4. Paragenetic sequence of mineralization at the Calvert mine. Thicknesses of lines represent extent of mineralization.

found fractured and intergrown (Figure 5, A). Coarse-grained scheelite is also commonly intergrown with garnet and epidote, and occurs as fine-grained inclusions in garnet.

The garnet is light red-brown, and in thin section is commonly anisotropic with multiple growth zones, sector zoning and local oscillatory zoning. Besides scheelite, garnet hosts inclusions of calcite, quartz, epidote and accessory minerals such as zircon and sphene.

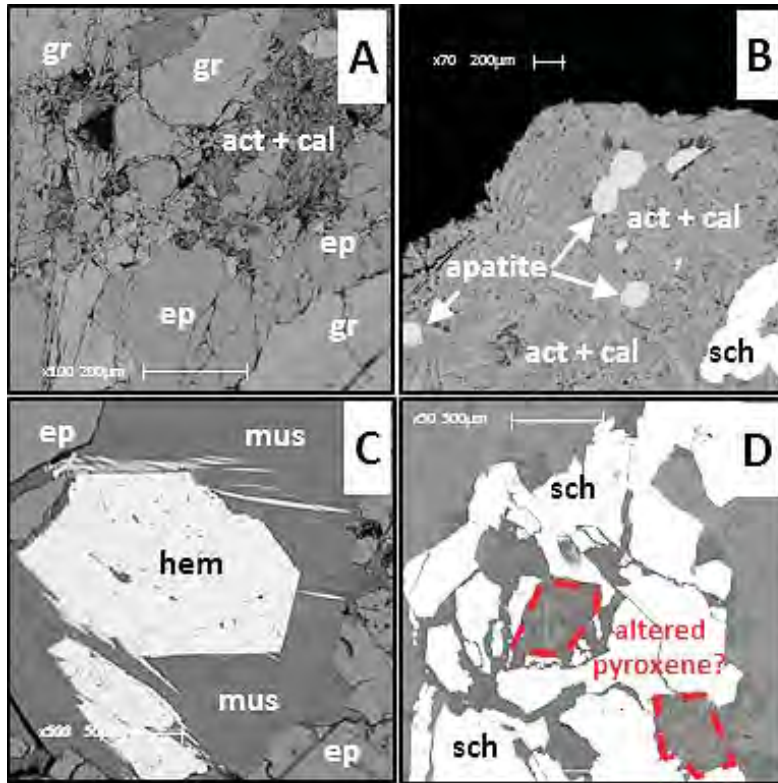


Figure 5. Backscatter electron (SEM-BSE) images that show the relationship between prograde and retrograde minerals. Garnet is commonly intergrown with epidote (A). Remnant scheelite in a retrograde matrix of actinolite, calcite and quartz (B). Fractured epidote altered to muscovite and hematite (C). Pyroxene (?) inclusions in scheelite altered to actinolite and calcite (D, red outlines).

ranged from  $-3.0^{\circ}$  to  $-1.4^{\circ}\text{C}$  for garnet,  $-4.9^{\circ}$  to  $-4.2^{\circ}\text{C}$  for quartz, and  $-8.1^{\circ}$  to  $-1.2^{\circ}\text{C}$  for scheelite. All the inclusions exhibited noncritical homogenization to the liquid phase upon heating. Homogenization temperatures ( $T_h$ ) ranged from  $248.8^{\circ}$  to  $267.8^{\circ}\text{C}$  for garnet,  $209.0^{\circ}$  to  $264.0^{\circ}\text{C}$  for quartz, and  $200.5^{\circ}$  to  $288.6^{\circ}\text{C}$  for scheelite. Figure 7 shows a dominant population of fluid inclusions with a homogenization temperature range of  $250^{\circ}$ - $260^{\circ}\text{C}$ .

Salinities (wt.% NaCl eq.) were determined using the freezing point depression after Potter et al. (1978). A plot of salinity vs. homogenization temperature (fig. 8) shows three clusters, possibly an artifact of sampling bias, centered at salinities of 3.2 wt.%, 7.3 wt.%, and 11.2 wt.% NaCl eq. Salinities of inclusions in quartz and garnet average 7.2 wt.% and 3.4 wt.% NaCl eq., respectively. The clusters in salinities may represent different degrees of mixing between a saline magmatic fluid and less saline groundwater. Alternatively, an increase in salinity could have occurred as a result of the formation of abundant epidote (a hydrous mineral) in the skarn assemblage.

#### Fluid Inclusion Leachate

Five scheelite samples were selected for leaching of cations from opened fluid inclusions. The samples were analyzed for major cations (e.g., K, Mg, Na, Ca) with an inductively coupled plasma-atomic emission spectrometer (ICP-AES) located at the Montana Bureau of Mines and Geology (MBMG). It should be noted that this method can only be used to determine cation ratios, not concentrations.

Retrograde alteration at the Calvert mine is extensive, with a mineral assemblage dominated by actinolite, calcite and quartz together with scheelite, hematite, muscovite, phlogopite, chlorite, magnetite and siderite as accessory minerals. Retrogression of the skarn is significant with pyroxene(?) inclusions in early scheelite altering to calcite and actinolite, garnet altering to calcite, quartz and hematite, and epidote altering to muscovite and hematite (fig. 5, B-D). Hematite occurs as subhedral-euhedral crystals in garnet and epidote, as well as an alteration product at grain boundaries and intergrown with muscovite.

#### FLUID INCLUSIONS

Fluid inclusions were analyzed from garnet, scheelite and quartz. Primary inclusions ranged from 6.5 to 50  $\mu\text{m}$  in diameter and at  $25^{\circ}\text{C}$  consisted of two phase liquid + vapor (L+V) with the vapor phase occupying 7 to 12% volume (fig. 6). In all cases, no solid phases or other fluid phases (e.g.,  $\text{CO}_2$  or  $\text{CH}_4$ ) were observed. In addition, no evidence of boiling was noted.

#### Final ice melting temperatures ( $T_m$ )



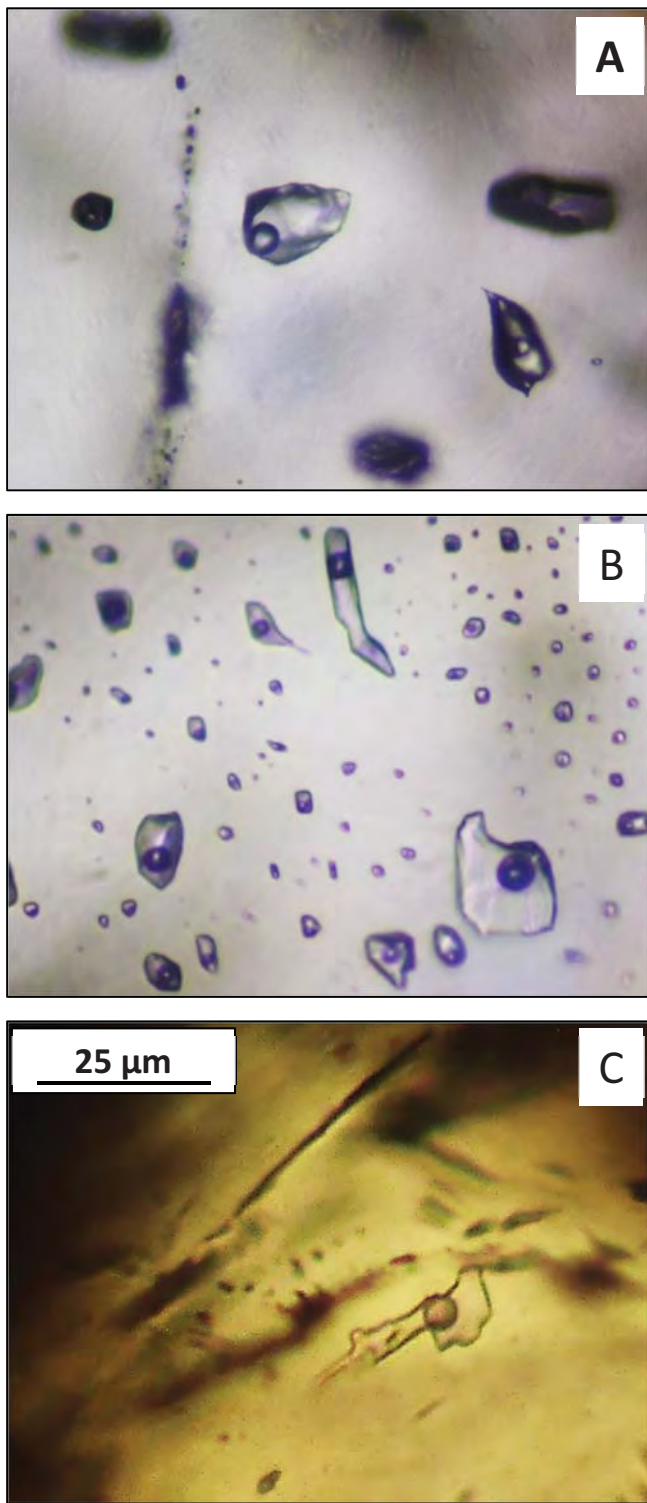


Figure 6. Two phase fluid inclusions in scheelite (A), quartz (B), and garnet (C). Microphotographs are taken in PPL at 320x magnification. Scale is the same for all photographs.

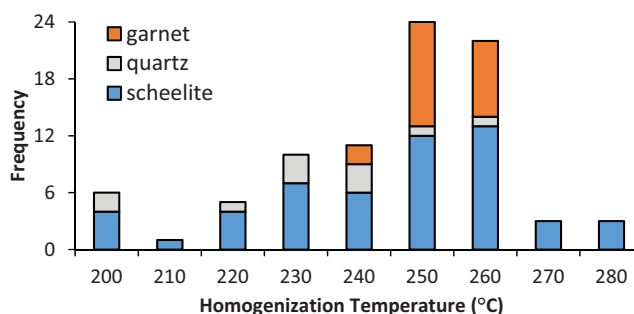


Figure 7. Histogram of homogenization temperatures for all fluid inclusions in this report.

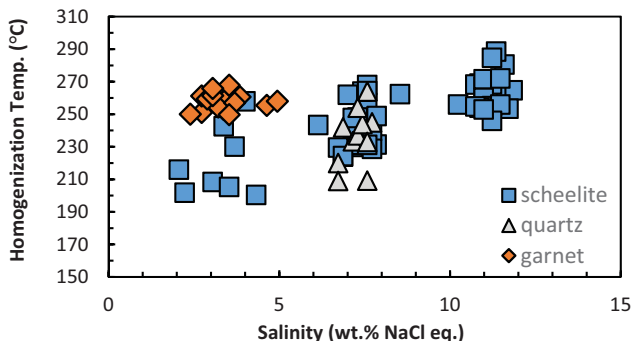


Figure 8. Plot of homogenization temperature vs. salinity.

As summarized by Truesdell (1984), the Na/K ratio of geothermal waters above about 180°C can be used as a geothermometer. Temperatures of entrapment of the leached fluid inclusions in scheelite were estimated using equations after Fournier (1981, Equation 1) and Truesdell (1984, Equation 2):

$$T = 1217 / (\log (\text{Na}/\text{K}) + 1.483) - 273.15 \quad (1)$$

$$T = 855.6 / (\log (\text{Na}/\text{K}) + 0.8573) - 273.15 \quad (2)$$

in which T is in Celsius and Na/K is the mass ratio in the inclusion leachates. The results (table 1) yield entrapment temperatures near 400°C (Equation 1) to 450°C (Equation 2). It should be noted that this geothermometer assumes equilibrium between the fluid and two feldspars (plagioclase and alkali-feldspar). This assumption would be valid for a high temperature fluid equilibrated with granite, but not necessarily with a tonalite.

### Pressure of Entrapment

Using data from Potter (1977), a pressure correction was determined using a homogenization temperature of 250°C and an estimated temperature of entrapment of 400° to 450°C from the leachate analyses (fig. 9). Since salinities ranged from 3.2 wt.% to 11.2 wt.% NaCl eq., pressure determinations were made using T-P diagrams of the H<sub>2</sub>O-NaCl system at 5 wt.% and 10 wt.% NaCl equivalent. Both diagrams predict a corresponding pressure of formation between 2 and 2.5 kbars. If it is assumed that fluid pressures were lithostatic, then this corresponds to a depth of 7 to 8.75 km, assuming a geobaric gradient of 3.5 km/kbar.



**STABLE ISOTOPES**

Table 1. Measured Na/K ratios (ppm basis) and calculated entrapment temperatures for leachate samples. The shaded data are anomalous and were discarded.

Field ID	Na/K	Fournier T (°C)	Truesdell T (°C)
7304-1	2.23	392	437
JH-FM	1.04	538	704
B2F-JM	1.97	411	469
CAL-IS	2.24	390	435
JMSF	2.03	407	462

Stable isotope studies provide important constraints for the source(s) of ore fluids (e.g., seawater, meteoric water, magmatic hydrothermal fluids, metamorphic fluids, etc.). In this study, thirty samples of calcite were collected from skarn, unaltered and altered marble and analyzed for  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  at the University of Nevada-Reno. Estimated analytical uncertainties are  $\pm 0.2\text{‰}$  for  $\delta^{13}\text{C}$  and  $\pm 0.2\text{‰}$  for  $\delta^{18}\text{O}$ . All C-isotope values

are referenced to the Vienna Pee Dee Belemnite (VPDB) standard. All O-isotope values are referenced to the Vienna Standard Mean Ocean Water (VSMOW) standard. Results of the isotopic analyses are summarized in Figure 10. Average  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  values of the unaltered marble are  $+25.2\text{‰}$  and  $+0.6\text{‰}$ , respectively. Average  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  values of the bleached marble are  $+18.0\text{‰}$  and  $-0.6\text{‰}$ , respectively. Average  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  values of the skarn calcite are  $+11.2\text{‰}$  and  $-7.0\text{‰}$ , respectively.

Figure 10 shows a large depletion of both  $^{18}\text{O}$  and  $^{13}\text{C}$  in the skarn calcite relative to the calcite in the marble protolith. These data also show that the marble underwent minimal  $^{18}\text{O}$  or  $^{13}\text{C}$  depletion except within close proximity to the skarn (largest zone of bleached marble observed at Calvert was  $\sim 1\text{ m}$ ). The bleached zones are slightly depleted in  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  with respect to the country rock. Samples collected from completely metasomatized country rock exhibit large depletions in  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$ .

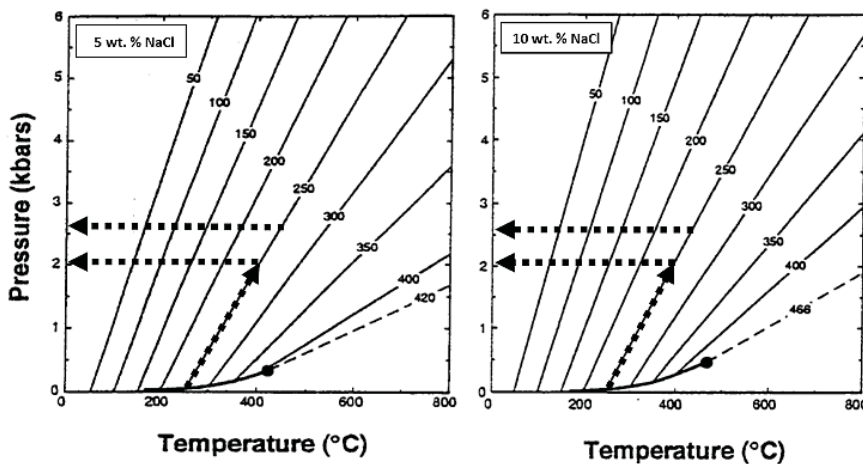


Figure 9. Pressure correction diagrams for the  $\text{H}_2\text{O}$ -NaCl system at 5 wt.% (left) and 10 wt.% NaCl (right).

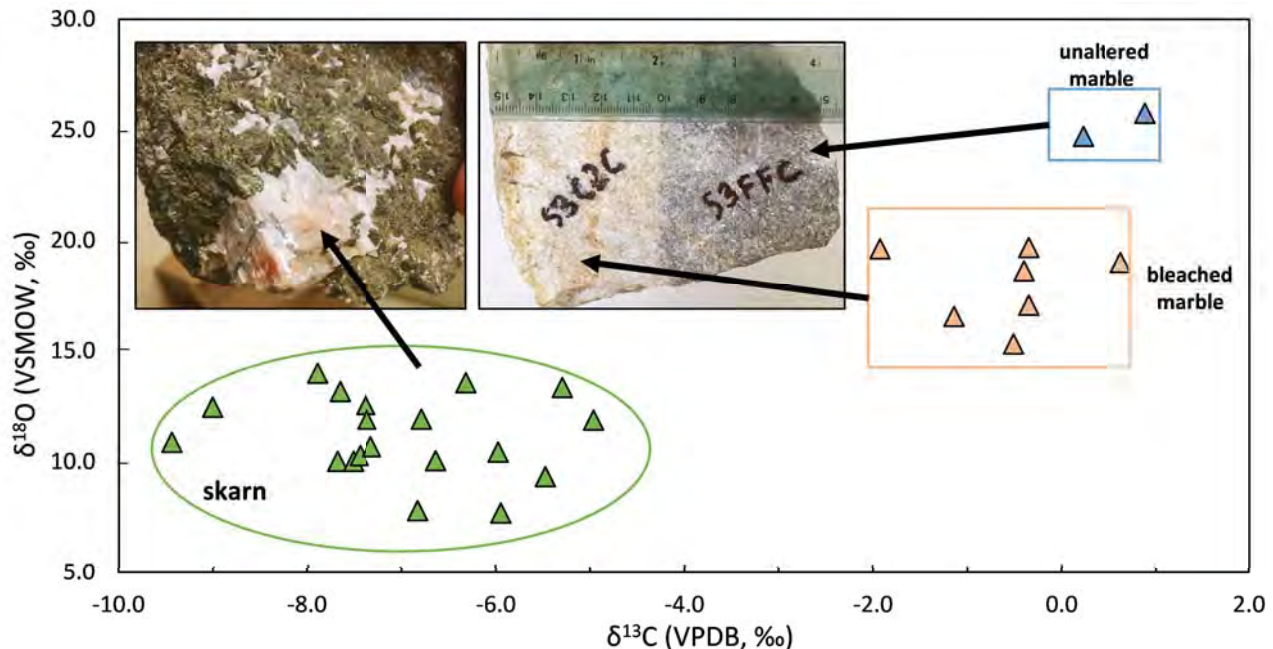


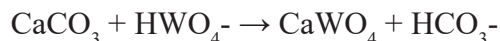
Figure 10. Results of isotopic analysis on calcite samples and representative photographs of sample locations.

Messenger (2016) used the stable isotope results to calculate the extent of fluid-rock interaction during skarn formation. It was concluded that the entire range in isotopic composition of calcite from Calvert can be explained by interaction of a magmatic fluid with  $\delta^{13}\text{C} = -5.5\text{‰}$  and  $\delta^{18}\text{O} = +7.5\text{‰}$  with Paleozoic limestone with an initial isotopic composition of  $\delta^{13}\text{C} = 0.0\text{‰}$  and  $\delta^{18}\text{O} = +30.6\text{‰}$ . The interested reader is referred to Messenger (2016) for more details.

### FLUID CHEMISTRY

No  $\text{CO}_2$  vapor, liquid or clathrate crystals (upon cooling) were observed in any of the fluid inclusions, which suggests a mole fraction  $\text{CO}_2 < 0.015$  (Diamond, 1992). This information, along with the prograde mineral assemblage, can be used to further constrain the physical and chemical conditions prevalent during prograde skarn formation. Figure 11 is a T- $X_{\text{CO}_2}$  diagram from Klemd (2004) showing the stability of epidote as a function of temperature and  $X_{\text{CO}_2}$  in the fluid phase. According to this phase diagram, the prograde skarn mineral assemblage consisting of garnet, epidote, quartz and calcite is stable at low  $X_{\text{CO}_2}$  ( $< 0.015$ ) and within the estimated entrapment temperatures from leachate experiments (400° to 450°C), and is therefore consistent with the observations made in this study.

Chemical analyses of minerals from the Calvert skarn deposit (Messenger, 2016) show that a large proportion of the skarn minerals are calcium-rich (diopside, grossular, actinolite, epidote, calcite, apatite). This observation suggests high calcium activity during skarn formation, most likely due to reaction with the calcic marble protolith. The presence of calcite may also have triggered precipitation of scheelite, as shown by the following reaction:



It is possible that the skarn-forming hydrothermal fluids transported dissolved tungsten some distance from its magmatic source until scheelite was eventually deposited when the first carbonate rock was encountered.

### CONCLUDING REMARKS

The Calvert scheelite-bearing skarn developed in the Pennsylvanian Amsden Formation during the emplacement and cooling of one or more satellite plutons of the Pioneer Batholith. The estimated conditions of the main-stage prograde metasomatic skarn formation at Calvert are as follows:

Pressure: 2 to 2.5 kbar (7 to 8.75 km depth)

Temperature: 400° to 450°C

Mole fraction  $\text{CO}_2$ : 0.01

Salinity: 3.2 to 11.2 wt.% NaCl eq.

The W-bearing ore fluids could have originated from the Foolhen Mountain Tonalite, the Bryant Creek Granite, or possibly from a deeper intrusion that is below the present mine workings. Because of the relatively low temperature of formation and abundance of calcite and epidote in both prograde and retrograde skarn, we suggest that the Calvert deposit is an example of a distal skarn. The hydrothermal fluids must have migrated away from their source magma and cooled several hundred degrees before encountering the carbonate rocks

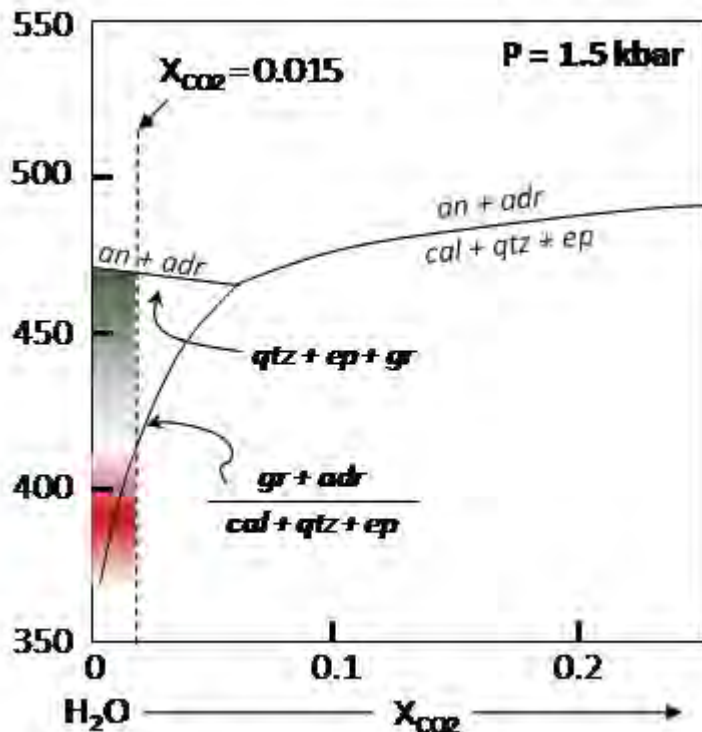


Figure 11. T- $X_{\text{CO}_2}$  projection calculated at 1500 bars in the CF\*SCH system for  $0 < X_{\text{CO}_2} < 0.25$ . Red shaded region shows equilibrium for garnet, quartz and epidote in the presence of calcite at  $X_{\text{CO}_2} < 1.5\%$ . Green shaded region shows the upper stability of epidote in the presence of garnet and quartz (no calcite). Abbreviations are grossular (gr), andradite (adr), epidote (ep), anorthite (an), quartz (qtz), and calcite (cal). Modified from Klemd, 2004.

necessary to precipitate scheelite and the associated skarn minerals. The major amounts of retrograde alteration at Calvert suggests a possible late influx of meteoric water.

### ACKNOWLEDGMENTS

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## Bull Mountain: A Miocene–Quaternary Fault Block that Preserves a Remnant of the Mesozoic Arc in Southwestern Montana

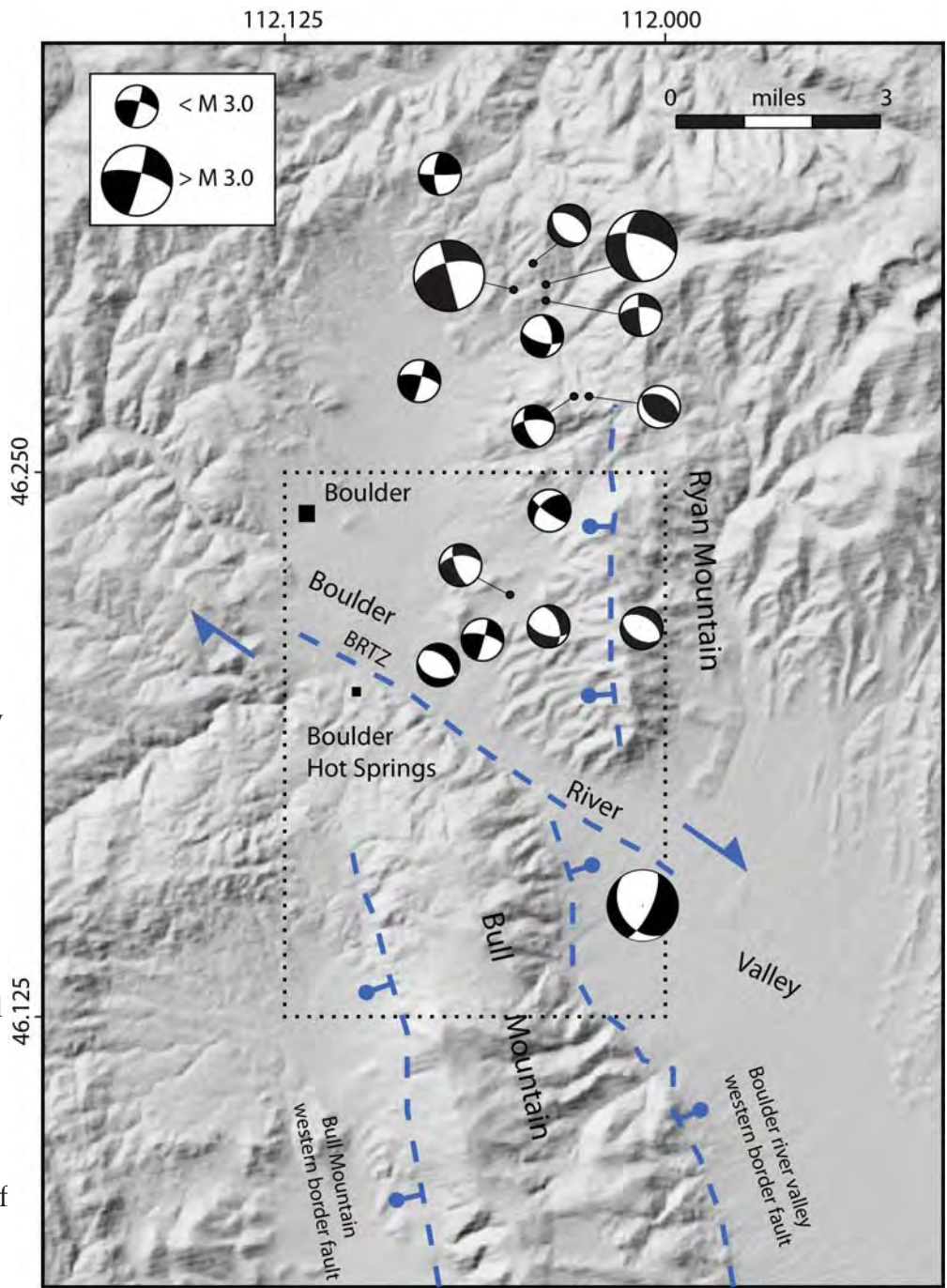
Kaleb C. Scarberry

*Geologist, Montana Bureau of Mines and Geology, 1300 W. Park Street, Butte, MT 59701,  
kscarberry@mtech.edu*

### ABSTRACT

Bull Mountain is a Miocene–Quaternary Basin and Range horst that extends from Whitehall north to Boulder, Montana. The horst is 10 miles wide, 20 miles long, and bound by Quaternary normal faults (Stickney and others, 2000) that terminate where they merge with a NW-striking transverse fault zone that tracks the Boulder River Valley (fig. 1). The transverse fault is named here the Boulder River Transverse Zone (BRTZ). Several small earthquakes (magnitude 0.5–3.5) occurred near the north end of the fault block since 1982 (M.C. Stickney, written commun., 2016), and first ground motions indicate that the region is undergoing active northeast–southwest-directed crustal extension. The northwest-striking BRTZ is favorably oriented to accommodate right-lateral slip (fig. 1) and, in this respect, is similar to clusters of northwest-striking, right lateral faults that constitute the Lewis and Clark Zone located 30 miles to the north. The Boulder Hot Springs lie within the BRTZ, and chemistry of the 54–74°C geothermal water (Metesh, 2000) suggests slow circulation to a depth of nearly 5 km within the fault zone.

Miocene–Quaternary uplift at Bull Mountain presented a remnant of the Mesozoic Cordilleran arc magma system and exposed the contact between arc plutons (Boulder Batholith) and arc volcanic rocks (Elkhorn Mountains Volcanics). New field and analytical data (Scarberry, 2016; Scar





berry and others, in review; Olson and others, 2016) provide a clearer picture of arc-related deformation and magmatism at Bull Mountain. Dacite lavas, domes, and auto-brecciated lavas formed at around 85 Ma. Three rhyolite ignimbrite (fig. 2) sheets, each 100 to 200 m thick, formed over the dacite lavas and domes between 85 and 82 Ma. Diorite and quartz granodiorite porphyry intrusions locally metamorphosed and mineralized the volcanic units between 80 and 78 Ma. The main pluton of the Boulder Batholith, the Butte Granite, intruded volcanic rocks between 76 and 74 Ma and coincided with a regional ore-bearing hydrothermal event. Juxtaposition of arc plutons and arc volcanics may have, in part, been accommodated by a thrust fault that spans the north–south length of Bull Mountain. The magnitude of displacement on the structure is not yet known, but there is evidence that the structure is mineralized (Scarberry, 2015; Scarberry and others, 2016).

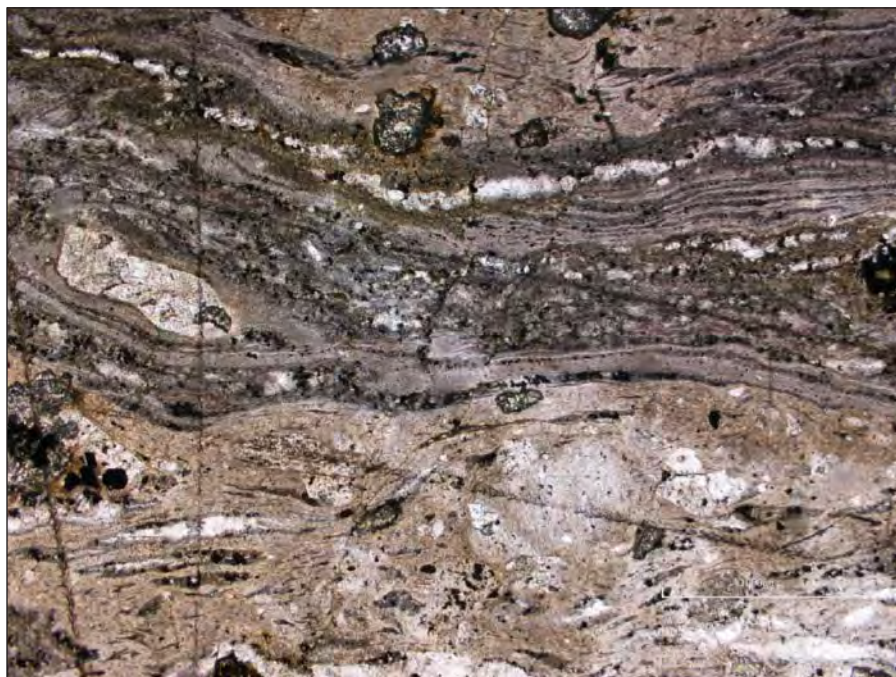


Figure 2. Photomicrograph of fiammé in rhyolite ignimbrite of the Elkhorn Mountains Volcanics.

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## Eruption History and Origin of Precious Metal Ore Deposits: The Eocene Lowland Creek Volcanic Field, Southwest Montana

Kaleb C. Scarberry

*Geologist, Montana Bureau of Mines and Geology, 1300 West Park Street, Butte, MT 59701*

### ABSTRACT

The 53–49 Ma Lowland Creek Volcanic field (fig. 1; Smedes, 1962; Dudas and others, 2010) contains suites of andesite–rhyolite that formed during two main eruptive cycles (Foster, 1987). The volcanic pile is about 3,000 ft thick between Butte and Anaconda and records products of both eruption cycles (fig. 2). The first cycle is represented by rhyolitic outflow tuff from a distal eruption, whereas the second cycle consists of near-vent and intracaldera deposits of andesite–rhyolite tuffs, lavas, breccia, intrusions and lava domes. Epithermal gold–silver mineralization formed after caldera collapse (Foster, 1987) and occurs throughout the volcanic field (fig. 1). Gold-bearing diatreme and fumarole deposits at Montana Tunnels and the Ruby Mine, respectively, are intracaldera deposits (Sillitoe and others, 1985; Foster, 1987) and gold–silver mineralization at the Tuxedo and Flume Gulch Mines resulted from fluid circulation along a caldera vent wall.

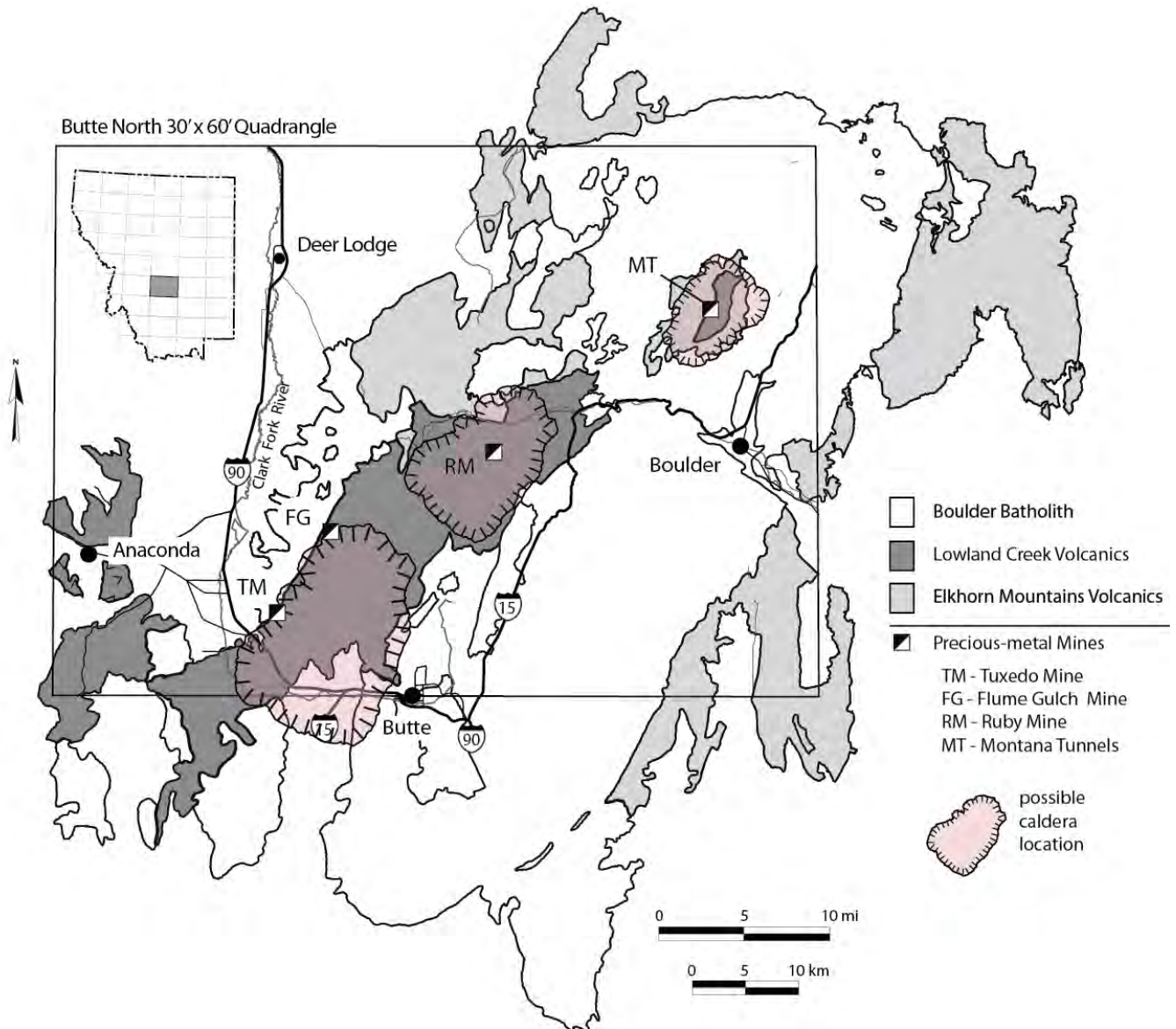


Figure 1. The Lowland Creek Volcanic field in southwestern Montana with speculative Eocene caldera locations shown.



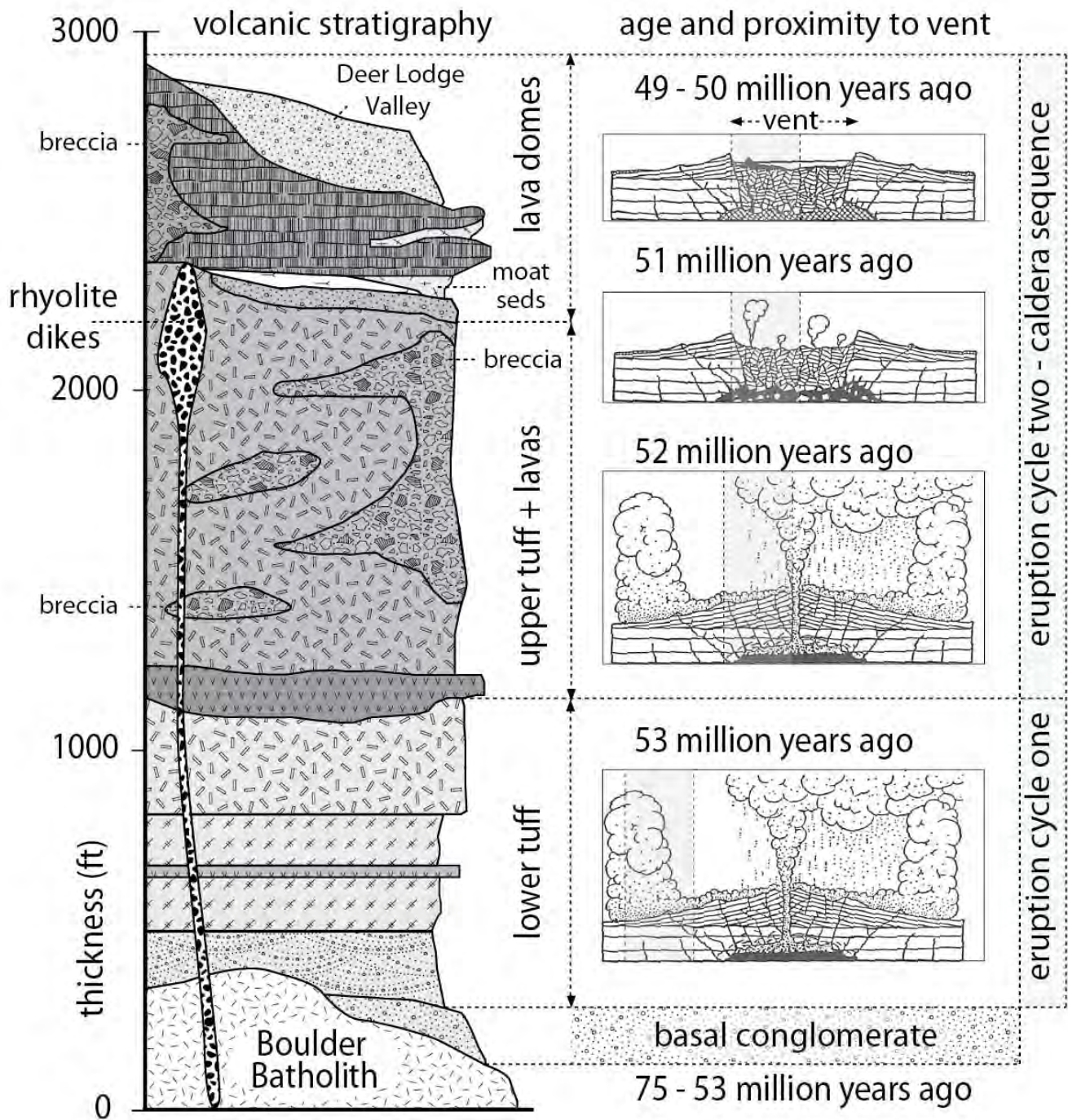


Figure 2. Volcanic section exposed between Butte and Anaconda.

The timing of caldera formation and mineralization is constrained by new isotopic ages (fig. 3). A caldera formed west of Butte (fig. 1) between ~ 52 and 51 Ma. Dikes of the upper tuff + lava unit crystallized at 51.8 Ma (<sup>40</sup>Ar–<sup>39</sup>Ar on plagioclase) and cut the 53.0 Ma (<sup>40</sup>Ar–<sup>39</sup>Ar on biotite) lower rhyolite tuff unit. Rhyolite dikes intruded a ring fault at 51.1 Ma (ID-TIMS <sup>206</sup>Pb–<sup>238</sup>U on zircon) and are brecciated and mineralized at the Tuxedo and Flume Gulch mines (fig. 2). Epithermal fluids likely circulated in the caldera vent wall by ~ 51 Ma and continued during the resurgence of the doming of the caldera floor and emplacement of the Hackney Lava dome in the caldera at 49 Ma (<sup>40</sup>Ar–<sup>39</sup>Ar, Dudas and others, 2010).

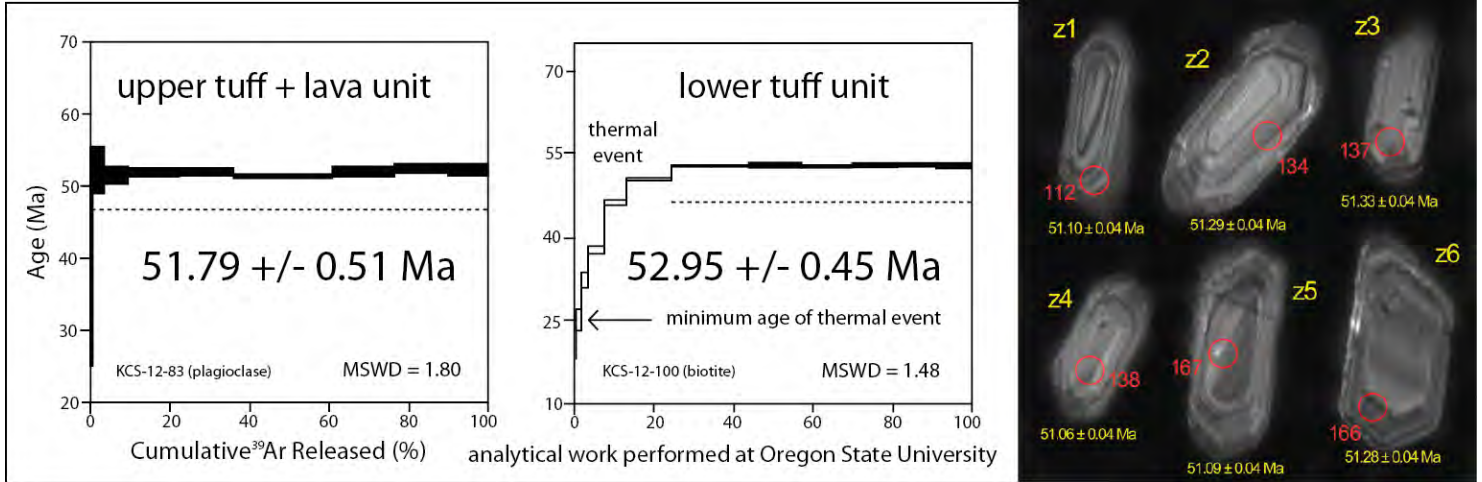


Figure 3. Plateau ages from <sup>40</sup>Ar–<sup>39</sup>Ar step-heating experiments (left) and zircon grains subjected to ID-TIMS <sup>206</sup>Pb–<sup>238</sup>U analysis (right).

Eocene volcanism and extensional faulting occurred at roughly the same time near Butte (Houston and Dilles, 2013). I propose that the Lowland Creek Volcanic field originated as a series of “graben volcanoes” (e.g., Aguirre-Diaz and others, 2008) that collapsed to create N45°E trending basins in Cretaceous igneous rocks (fig. 4). In this tectonic setting, large-volume ignimbrites of the Lowland Creek Volcanic field erupt during graben collapse, and post-ignimbrite rhyolite domes and dikes are aligned with graben master faults.

### Eocene graben volcanoes

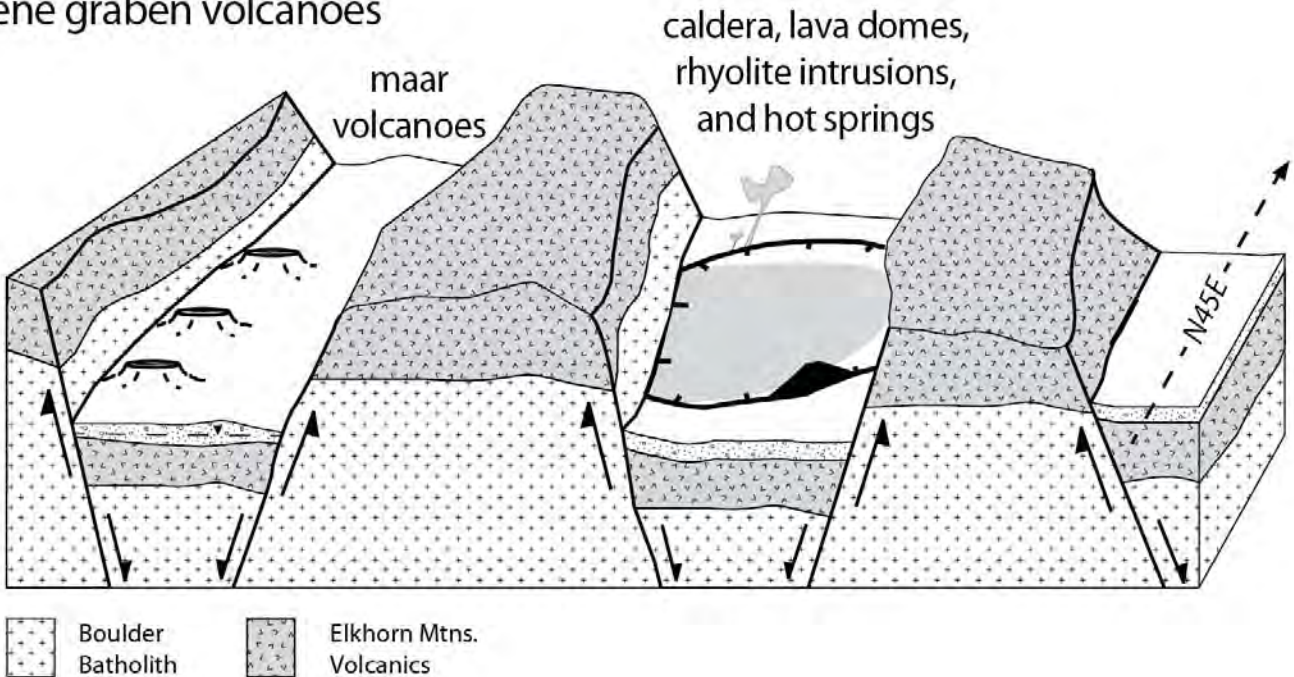


Figure 4. Proposed volcano-tectonic setting for Eocene graben volcanoes of the Lowland Creek volcanic field.



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**SUMMARY ARTICLES**



## Mining History and Minerals, Bluebird Mine and Mill, Butte, Montana

Richard I. Gibson

*Consulting Geologist and Historian, Butte, MT 59701*

### ABSTRACT

Archibald Primrose, Fifth Earl of Rosebery and Prime Minister of Great Britain from 1894–1895, married Hanna de Rothschild in 1878, at a time when she was the richest woman in Britain. Rosebery was a celebrated Scottish imperialist, anti-Socialist and philanthropist, first president of the London Scottish Rugby Football Club, and so well known that his image adorned cigar boxes. The combined Rosebery–Rothschild fortunes allowed them to invest widely, even as far afield as Butte, Montana Territory.

Rosebery's American business interests were developed by a dashing young New Yorker, Ferdinand Van Zandt. The growing silver mines at Burlington, a few miles west of Butte, led him to encourage Rosebery to invest in the Bluebird Mine in 1885, and on November 22, 1886, Van Zandt's 90-stamp mill opened there, helping yield the remarkable output of 1.4 million ounces of silver in 1888 alone.

But success was short lived. Litigation contending claim encroachment in 1889 tied things up for several years. George Tyng, Rosebery's manager at the White Deer Cattle Ranch in the Texas Panhandle, settled most of the lawsuits by 1891, but another that same year, a \$2 million case, resulted in the authorities seizing the mine, anticipating the need for payment, effectively shutting down production indefinitely. When the news reached London, Van Zandt shot himself in his room at the Brown Hotel in upscale Mayfair. The mine began to fill with water and was ultimately sold off piecemeal. The crash in the price of silver in 1893 was the final nail in the coffin: the Bluebird hoist went to the Diamond and the headframe was transported to the Blue Jay Mine (the Blue Jay was due east of the Steward, about half way between the Kelley and Parrot Mines). Extensive ruins of the mill (closed permanently March 1, 1892) can still be found out west of Butte, east of Rocker, about a half-mile south of the mine. The stone hoist platform remains at the mine site, together with extensive dumps and the caved shaft.

Burlington itself suffered because the Bluebird Mine and mill were the town's primary employers, even though a number of smaller mines were in the vicinity, including the Great Republic, Champion, and Moody & Sankey. All were primarily silver producers, and all suffered mightily in the collapse of 1893.

Burlington had begun in a big way in 1885 when the post office was established. Within a few years, some 2,000 residents called the place home, making for a flourishing community supporting at least seven saloons, two groceries, several hotels, a church, a community library, and a school. In 1887 the Bluebird was the only non-union operation in the Butte District; on June 13 that year (Miner's Union Day), union leaders from Butte hiked out the Bluebird Trail (the westward extension of Park Street) and intimidated workers at the Bluebird Mine, bringing them back to Butte where they were initiated into the union, making Butte a closed shop, with all mines unionized.

Following the crash of 1893, at least 60 houses were loaded onto wagons and relocated into Butte. The town died a decade-long death. The post office closed in 1901, and the last business, a saloon and roadhouse, shut down in 1905. Twelve families were still hanging on in 1906. For a time early in the 20th century, Burlington's dairy cows reportedly provided as much as 25 wagons of milk to Butte daily.

The area of the mine and mill is mapped as aplite, interpreted by Houston and Dilles (2013) as a thick sub-horizontal dike-like body within the Butte Granite. Especially around the mill site and less so at the Bluebird shaft, aplite outcrops include abundant small clots and cavities of coarser-grained quartz and feldspar and occasional tourmaline. Smoky quartz crystals around 1 cm are common, with occasional crystals to 4 cm, similar in size to feldspars.

Many of the smoky quartz crystals contain or have relict surface impressions of asteroidal and bow-tie clusters of a soft greenish-white phyllosilicate mineral. Muscovite would be expectable but does not usually occur

in such forms. Raman spectroscopy was inconclusive. The habit is reminiscent of pyrophyllite, which would imply a greater acidity than is likely. Other possibilities include something in the talc-chlorite family. Work continues.

At the mine site, the dumps include occasional galena and sphalerite, probably representative of the later mining effort when zinc began to interfere with silver production that had been free-milling. Interesting blue chalcedony is also present.

Thanks to Chris Gammons for the Raman spectroscopy and Mary McCormick for pointing me to additional historical resources.

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The Story of Butte, special issue of the Butte Bystander, April 15, 1897 (figure 1).

## Minerals of the Leonard Mine: Butte, Montana

Michael J. Gobla

*PE, Bureau of Reclamation, PO Box 25007, D-83111, Denver, CO 80225, mgobla@do.usbr.gov*

### ABSTRACT

The Leonard mine in Butte is a world-renowned mineral locality that has produced prolific amounts of crystal specimens. It is known for well-crystalized specimens of copper minerals, including several rare mineral species, and is a co-type locality for two minerals new to science: colusite and djurleite. As a copper mine, it was an economic powerhouse providing some of Butte's richest copper ores during 83 years of mining operations. The principal ore minerals were chalcocite and enargite, with lesser amounts of covellite, bornite, colusite, digenite, and djurleite. Developed in 1890, the mine became known for producing copper minerals. By the 1950s, the mine was famous for producing prolific quantities of crystalized enargite, pyrite, and quartz along with occasional finds of crystals of over a dozen other mineral species. The specimens were brought out in the miners' lunch boxes and sold for extra income. The Anaconda company called it "a mineral collector's paradise" (Miller, 1973). In August 1974, the company entered the mineral specimen business by employing geologist Duane Johnson to collect mineral specimens from the underground mines in Butte and place them in the specimen market for sale.

The Butte ores formed as a disseminated copper-molybdenum porphyry deposit. The upper deposit was fractured, and massive quartz-pyrite veins formed due to hydrothermal action (Rusk, 2008). The veins, called "Main Stage" mineralization (Sales, 1914), are east-west-trending mineralized fissures up to 100 ft wide. The world had never seen such massive veins filled with high-grade ore. Butte became known as "The Richest Hill on Earth" as it dominated world copper production (Weed, 1912). In the areas near the Leonard mine a series of closely spaced southeast-striking fractures formed and were also filled by the Main Stage

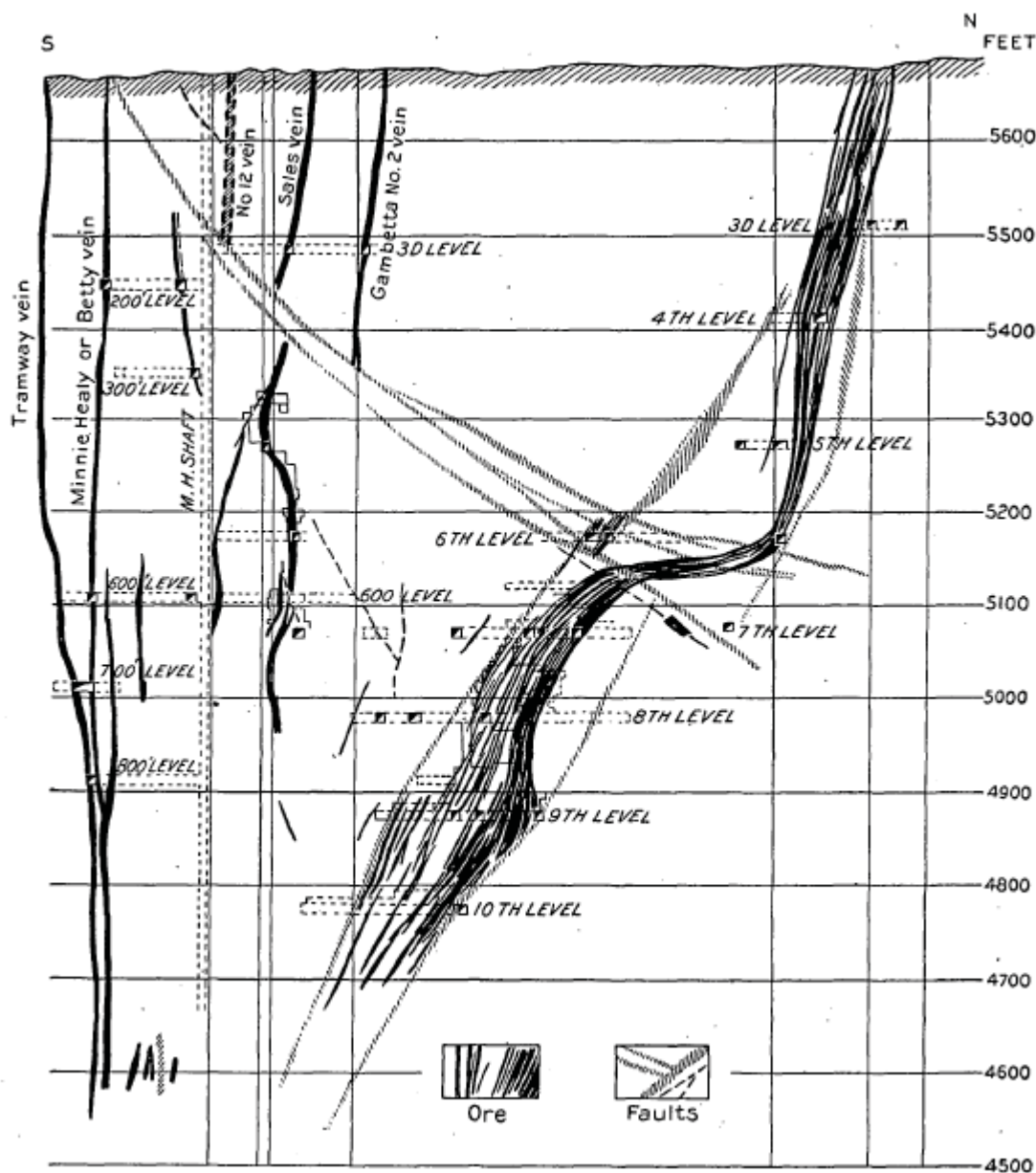


Figure 1. Cross section through the Leonard and adjacent mines (Weed, 1912).

mineralization. In some areas, the fracturing and splitting of the veins were so intense that it became known as the “horse tail zone” because the trace of the many veins on mine maps resembled the many parallel hairs in the tail of a horse (Sales, 1914). The Leonard and adjacent mines exploited these rich ores.

There were two Leonard mines in Butte, and neither mine was associated with the nearby Leonard claim, which was a smelter site. The original Leonard mine was later referred to as the old Leonard when a new shaft and mine plant were developed in 1906. Being outfitted with the largest and finest equipment (headframe, hoist, and pumps), the new Leonard mine became the principal shaft from which nearby mines such as the Minnie Healey, East Colusa, West Colusa, Tramway, and many others were worked as the other mine shafts were abandoned.

The Leonard mine and the smelter claim were named after Butte’s Silent Copper King, Mr. Leonard Lewisohn. Butte’s three famous Copper Kings, Marcus Daly, William Clark, and Augustus Heinze, were flamboyant and involved in bitter economic and political fights. Although Leonard Lewisohn is not as well known, he and his younger brother Adolph had as much control of rich Butte copper mines and a far greater influence in the copper industry than the famous Copper Kings.

Leonard Lewisohn was born on October 10, 1847, in Hamburg, Germany. In 1865, Leonard joined his older brother Julius in New York City to represent the family business as merchants selling feathers, wool, bristles, and horse hair (Engineering and Mining Journal, 1891, p. 383).

In 1867, younger brother Adolph left Germany to join the firm of Lewisohn Brothers. The firm was invited to speculate in the purchase of some lead ingots, which they later resold at a good profit. Their trading of metals grew to include copper and zinc. By 1878 they were earning large profits from trading copper, the metal of the growing electric age. In 1878 they sent Charles T. Meader to Butte to look for investments in copper mining.

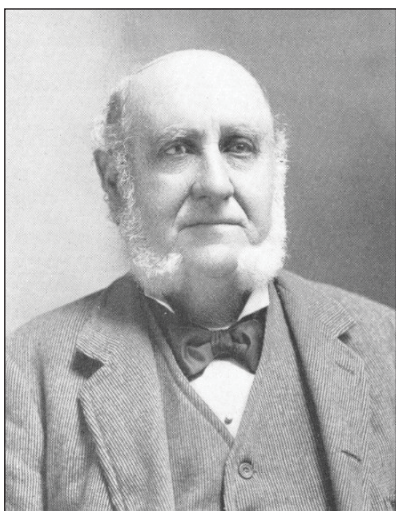


Figure 2. Charles T. Meader came to Butte in 1878. The Leonard mine is located in the former Butte suburb of Meaderville which was later consumed by the development of the Berkeley Pit.

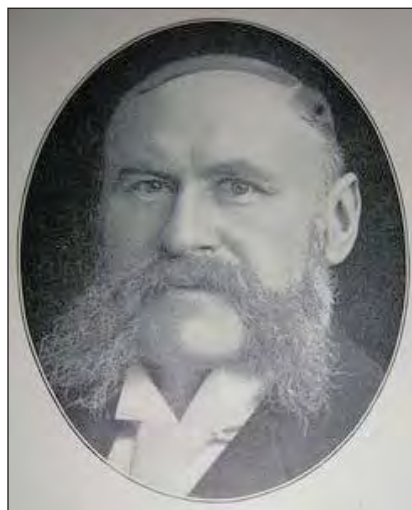


Figure 3. Leonard Lewisohn, Butte’s Silent Copper King, was the economic force behind the development of the Leonard mine and the Great Falls smelter.

Meader, a forty-niner, had successfully built a copper smelter in California. He purchased a number of mining claims including the Silverite, which was renamed the Colusa. Initial operations in 1879 were under the name of the New York Copper Company. Meader sold out his interest giving full control to the Lewisohn Brothers. In 1880 the Montana Copper Company was formed with Meader as manager and Leonard Lewisohn as president of the company.

With \$75,000 capital investment, construction of the Montana smelter was initiated on the Leonard claim in 1880. The smelter initially treated 30 tons per day and was profitable from the start. A new Butte enclave grew up around the smelter that became known as Meaderville. Once the operation was running smoothly, Mr. Mead



er left the company to develop the Bell mine that he purchased for \$100,000.

The Montana Company was reorganized in 1887 as the Boston and Montana Consolidated Copper and Silver Mining Company with a capitalization of \$3.75 million. Mr. A.S. Bigelow of Boston joined his capital with the Levisohn's properties to form the second largest copper producer in Butte. Clark's Colusa mine and smelter were purchased along with many other mine claims from other parties including the Piccolo. The West Colusa mine was developed with a deep shaft. The old Colusa mine then became known as the East Colusa. The Montana smelter was renamed the Boston and Montana's Upper Works.

The Leonard mine was established on the Piccolo claim, which was originally located by Mr. J.N. Collins on January 24, 1879. The claim was first worked through a shaft on the Piccolo Discovery vein producing ore for the company by 1888. The Piccolo claim was patented on August 16, 1889. In 1890 a new shaft called the Leonard with a 95-ft-tall headframe was developed. The Leonard mine soon became the company's most productive operation outperforming the Colusa.

In 1901 a 1,000 gallons per minute pump, the largest in the district, was installed on the 1,200-ft level of the mine. Lying adjacent to F.A. Heinze's Minnie Healy claim, the Leonard was caught up in the infamous underground warfare associated with the apex litigation at Butte until 1906. Although the Heinze forces battled underground, when the discharge pipes of the mighty Leonard pumps were turned into the Minnie Healy claim, the flooding was so great that Heinze finally gave in and ordered his men to stop the underground sabotage (Sales, 1964).

In 1906 a new shaft was developed further to the east. The "Old Leonard" shaft was renamed the Leonard No. 1, and the new shaft was called the Leonard No. 2 shaft. At the time of its erection, it was the biggest hoisting operation in the district. The steel headframe weighed 346,425 pounds and used a 3,000 hp engine with 1.5-inch diameter steel cable to hoist 5-ton skips. The new shaft provided more ventilation, which lowered temperatures in the mine by 20 degrees.

A fire broke out in 1906 on the 1,100-ft level of the Minnie Healy mine due to spontaneous combustion. The fire eventually spread to the 1,300 through the 2,000-ft levels of the Tramway, West Colusa, and Leonard mines and up to the 600 level in the Minnie Healy mine. The fire zones were sealed off using bulkheads, but a huge amount of good ore was abandoned by doing this. The worst day for the Leonard mine was April 24, 1911, when the hoist dropped 14 men 1,500 ft to the bottom of the shaft. Five of the men were killed; the other nine crippled by severe injuries.

In 1912 the No. 2 shaft of the Leonard mine was sunk another 294 ft to a depth of 2,000 ft, and the old No. 1 shaft was extended 194 ft to the same level. A new ventilation shaft was sunk to 1,400 ft to provide more air to the workings. About 1 million board feet per month of timber was used to support the underground workings where 522 men worked. Another 383 men worked on the surface of this mine.

In 1917 it was decided to fill the fire zone with mill tailings to extinguish the fire and allow mining to reenter the areas where millions of dollars of high-grade copper ore remained.

The filling work was conducted by drifting or drilling into the fire zone and pumping in the tailings from the Black Rock mill. The hydraulic filling was one of the most tremendous undertakings in the history of underground mining. The work had to be conducted carefully; blasting near the fire zone was held to a minimum due to the danger of the heat in the rocks setting off the explosive charges prematurely. The water content of the fill had to be drained off and pumped out of the mine so no underground reservoirs of water could collect that might later flood men in underlying workings. About 1,700 tons per day of tailings were being pumped into the Leonard mine. After 5 years the fire was extinguished and over 200,000 ft of diamond drilling had been conducted and more than 4,000,000 tons of tailings had been placed (Rice and Sayers, 1925). The abandoned areas were reopened and mined. Fires eventually returned to portions of the Leonard mine many years later.

The mine remained productive until May 1958. Low copper prices and declining grades led the Anaconda Company to close the Leonard mine. Workers were shifted to the Mountain Con mine where operations were restarted.

The Leonard mine was re-activated in 1962 for development work as part of the \$11 million deep mining program, which utilized the Kelly shaft for ore hoisting from deep levels. A 1,000 ton per day mining operation was planned for the Leonard. One hundred men were working in the mine; however, this was far below the number of miners needed to replace the production lost from shutting down the block caving operation at the Kelly mine. Anaconda decided on a temporary closure of the Leonard mine and moved the men to the Steward and Mountain Con mines. The company then began a program to recruit men from other mining districts in the western United States. In January 1963, the Leonard mine resumed production when an additional 350 contract miners were hired and placed at the Leonard and Steward mines. The men were put on 6-days-per-week shifts in order to produce as much copper ore as possible. Mining operations continued until 1967.

The mine was re-opened in January 1972 to produce 4% copper ore at a rate of 650 tons per day. On September 18, 1973, the headframe was blasted down to provide room for the expanding Berkeley pit. The underground mine was then accessed from the Kelly shaft. It shut down in February of 1975. With the abandonment and subsequent flooding of the Berkeley Pit, the Leonard mine workings are now flooded and inaccessible.

Table 1. Minerals of the Leonard Mine.

Atacamite	Copper	Galena*	Pyrophyllite
Baryte*	Cornwallite	Gold	Quartz*
Betekhtinite*	Covellite*	Gypsum*	Scheelite*
Bornite*	Diaspore	Hinsdalite*	Silver
Brochantite	Dickite	Hidalgoite	Sphalerite*
Calcite*	Digenite*	Hubnerite*	Tennantite*
Chalcanthite*	Djurleite*	Kaolinite	Tetrahedrite
Chalcocite*	Enargite*	Luzonite*	Topaz
Chalcopyrite	Fluorapatite*	Muscovite	Wavellite
Colusite*	Fluorite*	Pyrite*	Wurtzite*

\* Indicates that crystal specimens or microcrystals have been recovered.

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**FIELD TRIP GUIDE:  
PHILIPSBURG MINING DISTRICT**



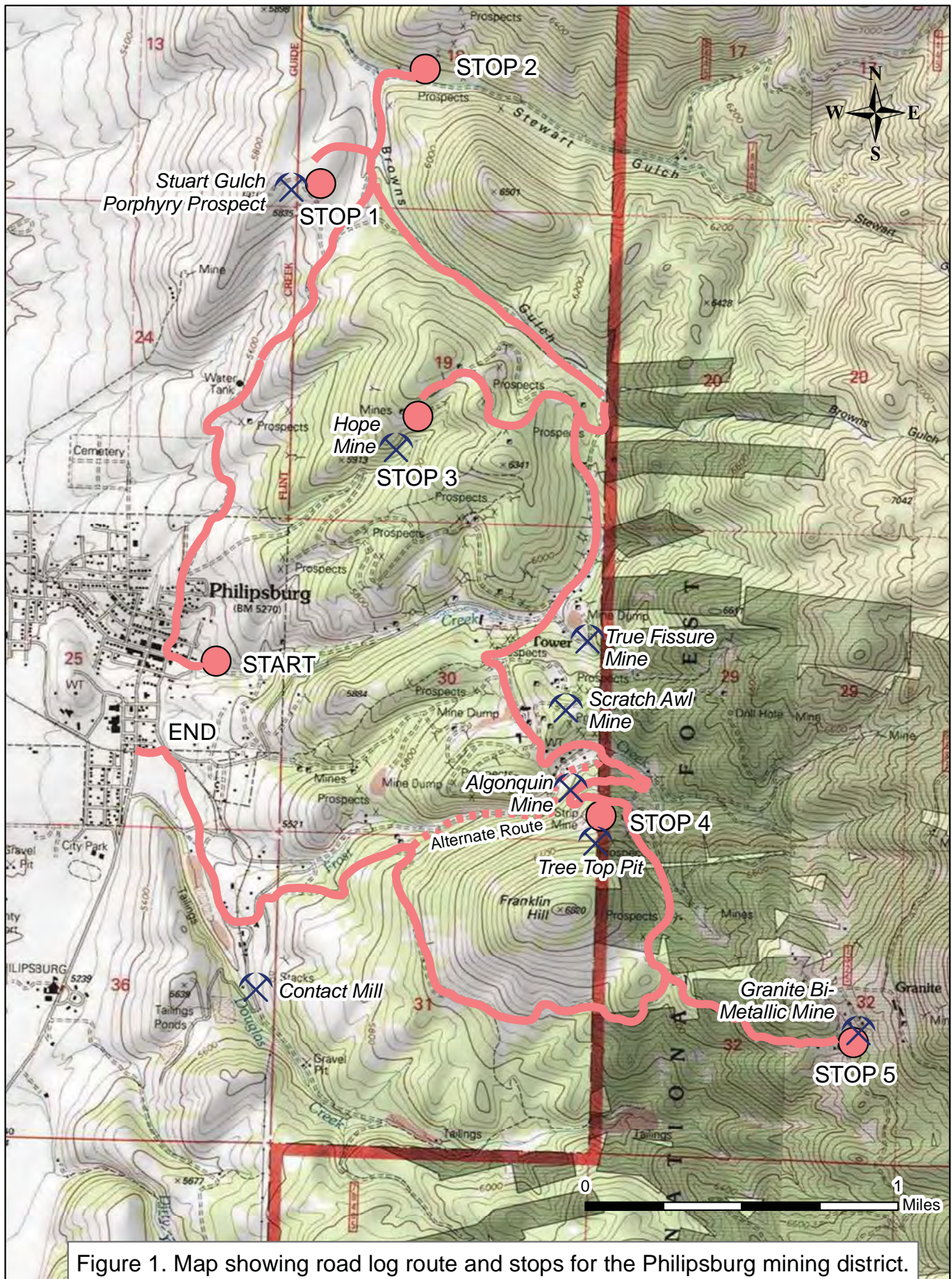


Figure 1. Map showing road log route and stops for the Philipsburg mining district.



**Guidebook for Field Trip to Philipsburg Mining District****Mining and Mineral Symposium 2016****October 19, 2016**Ted Antonioli<sup>1</sup> and Peter Ellsworth<sup>2</sup><sup>1</sup>*Geologist, Contact Mining Company, ted.antonioli@gmail.com*<sup>2</sup>*Peter Ellsworth, Consulting Geologist, Ellsworth Geological, PC, ellsgo@charter.net***INTRODUCTION**

The Philipsburg Mining District is one of the most historically productive silver and manganese districts in Montana. The field trip is planned to visit five important stops to point out mines and prospects that exhibit district genesis and zonation with routes, stops and principal mines shown on figure 1. The regional geology is summarized in the figure 2 geologic map windowed from the Philipsburg 30'x60' geologic map published by the Montana Bureau of Mines and Geology Open File Report 483 (Lonn, J.D et al.,2010) with the road log trace. The current mapping confirms much of the early work by the USGS accomplished by horseback more than 100 years ago (Emmons and Calkins, 1913), with the noted improvement of delineating a Tertiary detachment system along the eastern and northern flanks of the Flint Range outlining the eastern margin of the Sapphire Allochthon.

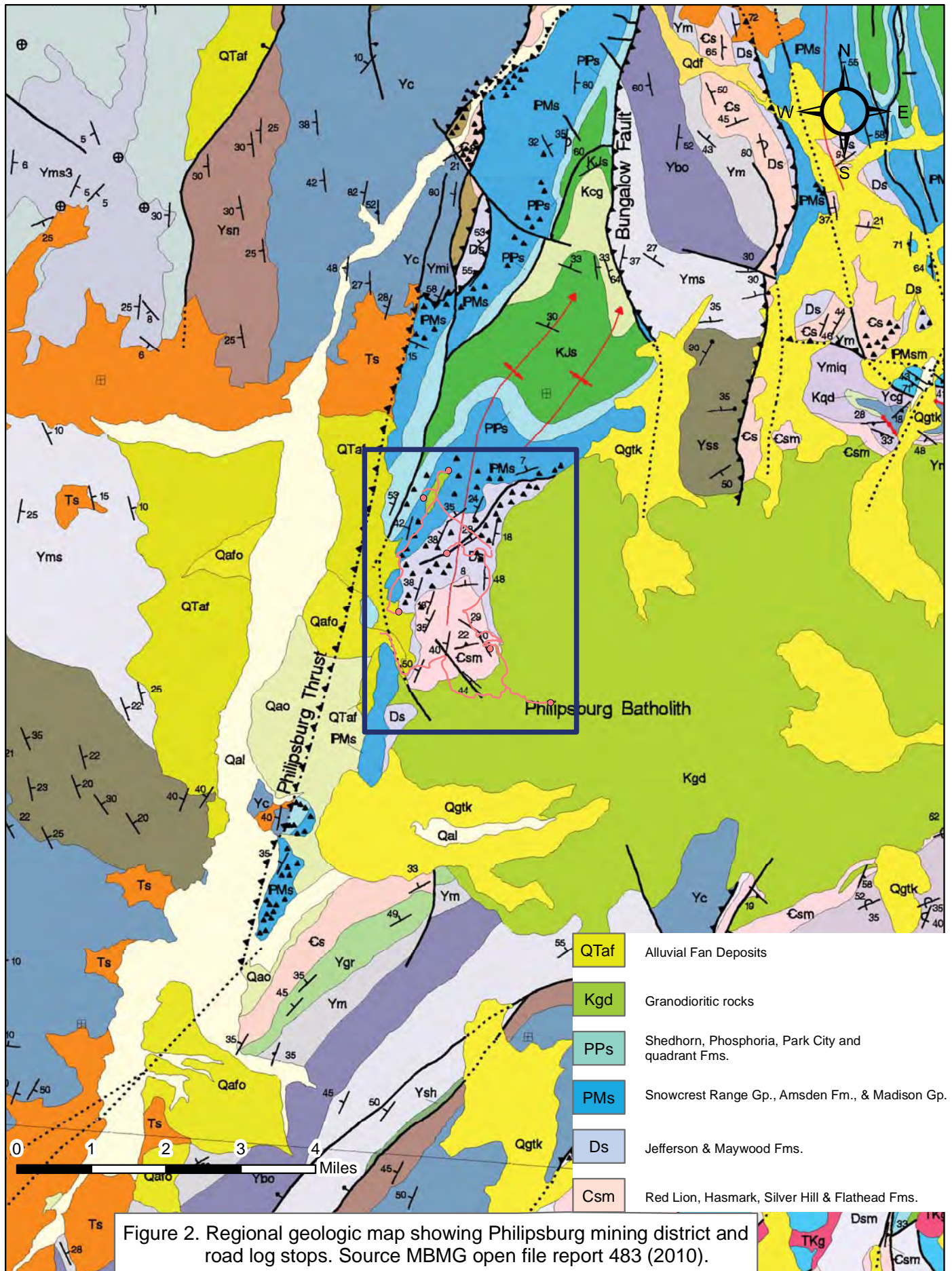
The Philipsburg batholith is aligned along a series of Late Cretaceous-Eocene magmatic events that form an arcuate pattern extending south of the Lewis and Clark Line from the Garnet stock in the Garnet Range to the Flint Creek mountains and southwesterly to the Anaconda Range toward the Idaho batholith. Eocene extension and erosion expose granitic intrusions within Paleozoic and Belt strata creating contact metamorphic aureoles across much of the Flint Creek range. Sears (2016) proposes that much of the igneous emplacement is controlled by syn-tectonic events forming low angle igneous bodies along detachment and thrust faults across southwest Montana. Ore deposits form a multitude of gold, copper and silver mining districts associated with late stage magmatism hosted in Mesozoic and Paleozoic sedimentary rocks and crystallized granitic rocks.

Figure 3 shows the Philipsburg district geology, comprised of veins, carbonate replacement deposits and molybdenum copper porphyry. These ore deposits are hosted in a north plunging anticline composed of sedimentary rocks ranging from Mesoproterozoic to Paleozoic in age, and in Cretaceous granodiorite in the eastern and southern parts of the district marked by the Philipsburg batholith. Mineralized veins primarily trend east-west across both the sedimentary and intrusive rocks; however, metal zonation from north to south suggests the district source of mineralization is the Stuart Gulch porphyry (Mo-Cu). Hydrothermal fluids were channeled from the Stuart Gulch porphyry stock along north-south fractures, precipitating ore deposits as far south as the Granite Bimetallic mine.

**BEGIN ROAD LOG**

The field trip will meet at the James Stuart/Hope stamp mill just east of downtown Philipsburg on the north side of East Broadway Street. The namesake of the original mill, mining entrepreneur James Stuart, has had the misfortune of having his name mis-spelled on several geographic features, including Stewart (Stuart) gulch and Stewart (Stuart) lake. This is perhaps karmic payback for Stuart's decision to fire the superb mining engineer who designed the mill, Philipp Deidesheimer, who is also the namesake of the town he laid out below the mill.

**START James Stuart/Hope Stamp Mill.** Meet at the site of Philipsburg's first mill – the reason, indeed, for the town's founding in 1867, located just east of downtown Philipsburg on Broadway. A stamp mill was recently removed from its original location near Maxville and is being restored next to the site of the original mill by the Granite County Historical Society and local volunteers. With luck the operator will have some ore to process for a demonstration!





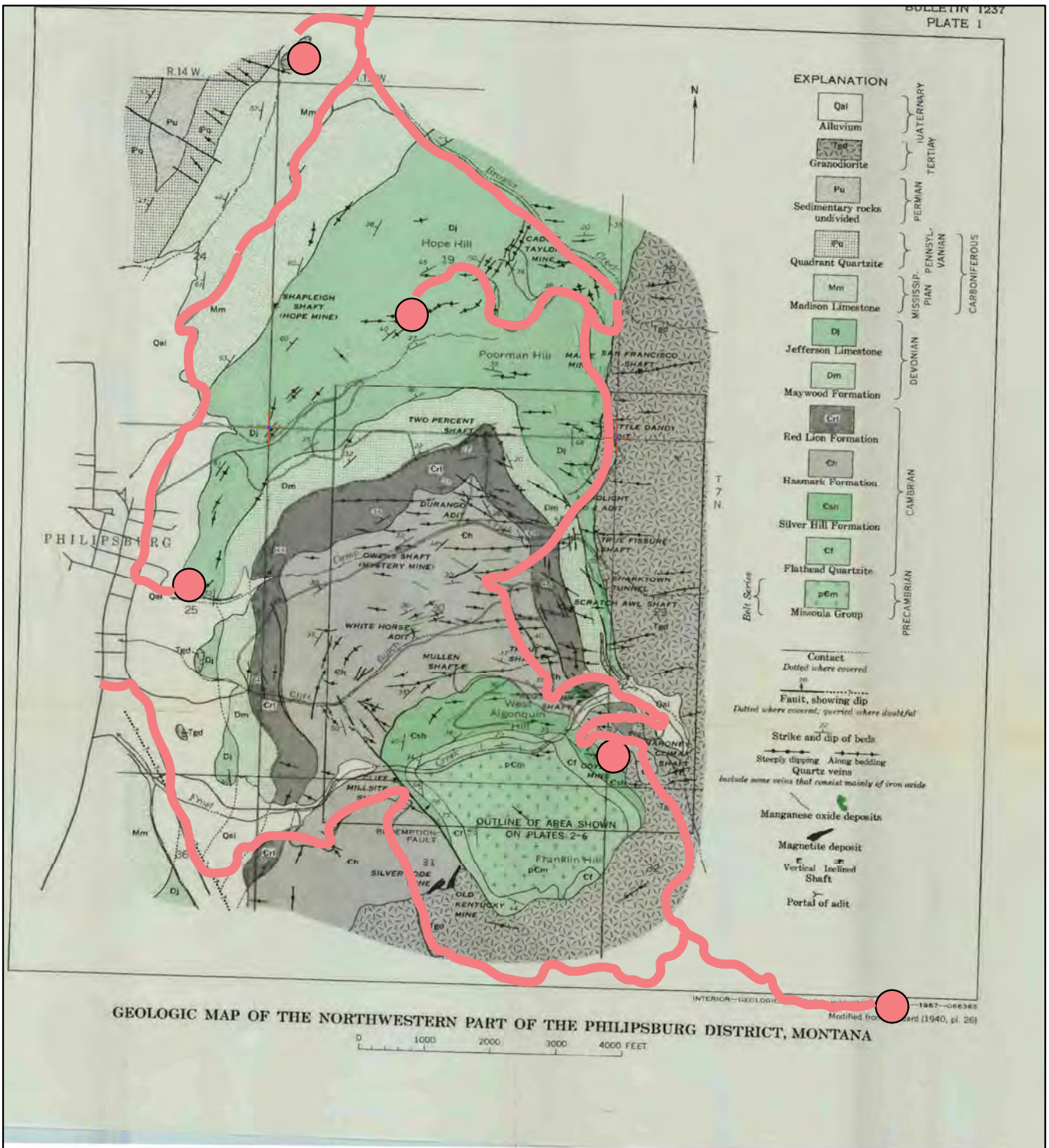


Figure 3. Geologic Map of the Northwestern part of the Philipsburg mining district, from Prinz (1967, Plate 1).



0.1 Go west on Broadway to the Kaiser House (built by Hector Horton, the district's discoverer) and take a right on Montgomery Street heading north toward Stuart Gulch.

0.9 View to east of the Hope mine dump where silver-copper ore vein and replacements deposits are hosted in the Devonian Jefferson Dolomite.

1.0 Passing the water tank used for Philipsburg water supply.

2.1 Note outcrop of Mississippian Madison Formation limestone with quartz vein and skarn alteration. A distinct airborne magnetic high anomaly beneath the ridge to east suggests there is a buried intrusive stock here.

2.2 Take left jeep track up Red Hill to STOP 1:

## **STOP 1**

Stuart Gulch porphyry complex. Extensive skarn is developed in contact with several porphyritic intrusive bodies that intrude Madison Formation (and possibly Amsden Fm., if the garnet-rich portion of the skarn had an Amsden protolith). The skarn contains sub ore-grade molybdenum mineralization and minor copper (Worthington, 2007). The Stuart Gulch stock, mapped by Emmons and Calkins (1913), was recognized by Charles C. Goddard, of Bear Creek Mining who recommended an exploration program on the porphyry target (Worthington, 2007). Bear Creek (Kennecott), Cyprus, and Dennison Mines all conducted exploration during the 1960s through early 1980s. A thrust fault in the Stuart Gulch area possibly controls emplacement of the intrusive rocks. High temperature mineralization (with molybdenum, tungsten and/or copper) and occasional "granitic" float occurs in several locations southward along the west side of the Philipsburg district, indicating porphyry mineralization potential southward along or near the Stuart Gulch thrust fault.

Recognizing a porphyry "engine" to mineralization in Philipsburg allows the entire district to be considered as a smaller version of Butte, with the major exception that the Butte system is dominated by copper, which is either minor or concealed at Philipsburg. At Butte, molybdenum-copper mineralization on the east edge of the district zones westward to predominantly copper mineralization, then silver-lead-zinc-manganese veins, and finally to a distal zone west of Butte where veins have high precious metal, but low base metal values (Meyer, et al, 1968). Similarly, Philipsburg zonation extends from molybdenum-copper in the north, to silver-copper-manganese in the Hope workings, to silver-lead-zinc-manganese mineralization in the central part of the district, to high precious metal, low base metal mineralization at the southern Granite-Bimetallic vein system. A slight variant of this zonation scheme was presented in Worthington and Robertson (1981).

Look at prospect pit on Red Hill exposing altered porphyry adjacent to skarn mineralization. Drive back to main road in Browns Gulch, reset odometer and turn left.

0.4 Park next to long open cut trench to examine STOP 2.

## **STOP 2**

Trench exposing skarn mineralization. Extensive exploration trenching exposes Madison Formation carbonate rocks exhibiting skarn mineralization where the limestone is altered by contact metamorphism from emplacement of the Stuart Gulch stock. Reset Odometer and backtrack.

Drive back toward south on main road 0.5 miles and turn west up Browns Gulch.

1.6 Turn right toward Hope mine

2.1 Cadgie Taylor mine orebin and headframe. Early miners exploited low grade vein and carbonate replacement ore bearing quartz-barite-silver at this location. Continue down road.

2.4 Park at hairpin turn and walk down road to STOP 3.

### STOP 3

Hope Discovery. After passing the former site of the Hope boardinghouse walk down the hill to look at exposures of Hope-style mineralization near the original discovery of the Hope mine. The Hope mine developed lenses of high-grade silver mineralization in bodies of quartz that were arranged in two parallel east-west trends called ore channels (fig. 4, Cole, 1949). An east-west striking vertical quartz vein and bedding-planes control mineralization along favorable horizons in the Devonian Jefferson formation limestone and dolomite. Several north-south striking veins displace the mineralization. Remarkably, the old-timers missed the continuation of high-grade ore exposed in the Comanche workings when the ore was cut off by the east-dipping Sweet Home fault. The high-grade, faulted-off ore body was discovered and mined by Philipsburg miner James Young in the early 1970s (fig. 5). Early miners coined the term “turkey eggs” to describe hanging wall yellow-black spotted texture in the dolomite used as an ore guide.

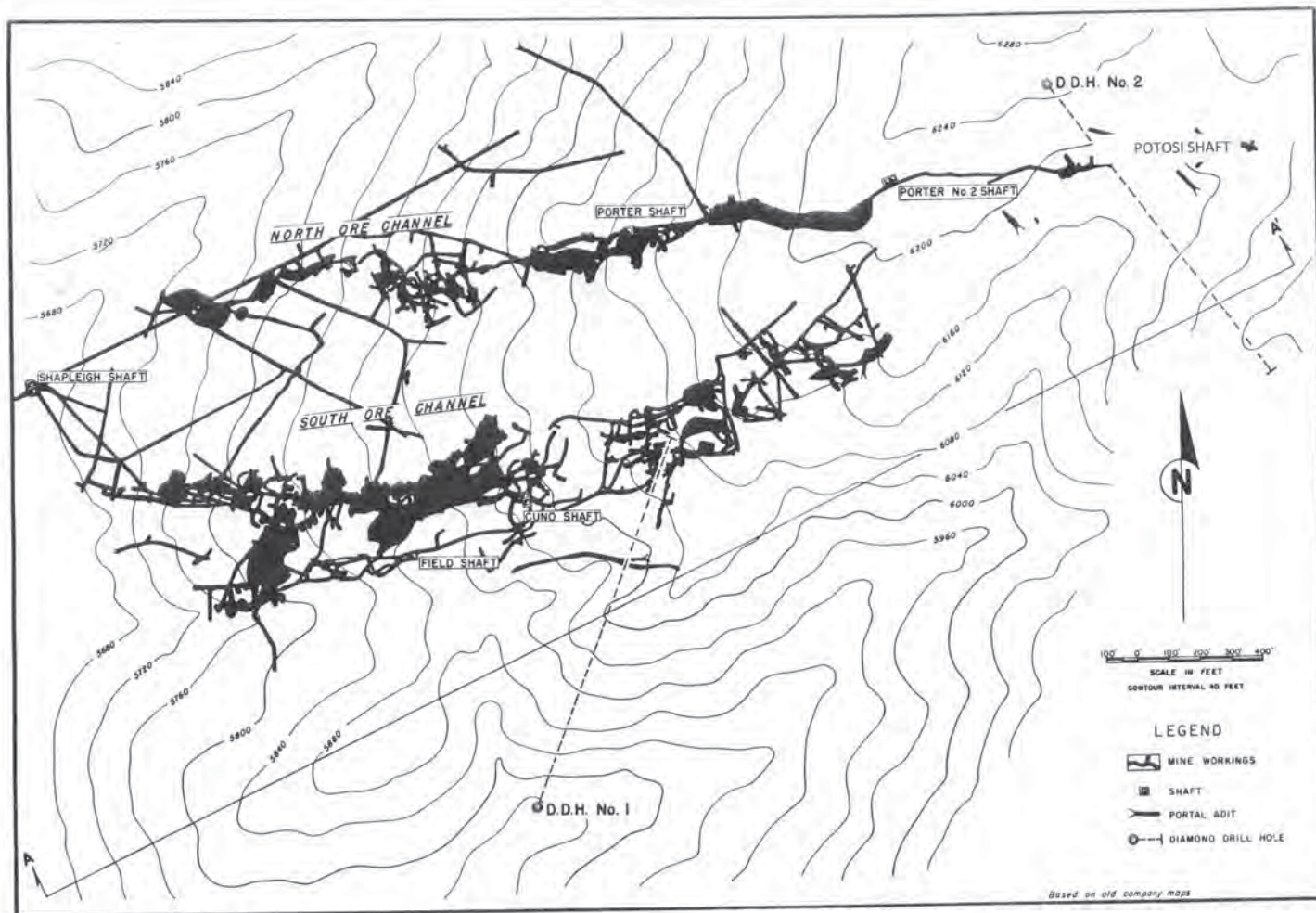


Figure 4. Hope Mine workings in plan view, modified from Cole, 1949, Figure 3

Return to the road junction at 0.8 mile mark. Reset trip meter and curve to the right.

0.8 On the left is an abandoned cyanide heap leach operation that extracted gold and silver from the dumps of the Frisco mine, to the east of the pads.

1.3 Road junction. On the left is the True Fissure mine, which developed the Horton and associated veins. The True Fissure was the principal mine of the Taylor-Knapp Company, which operated in Philipsburg in the 1940's through 1960s.

1.6 Road junction. Keep to right. Road to left goes to the Scratch Awl mine, which developed silver-lead-zinc and manganese deposits related to the Cliff Vein. The Cliff is one of several veins offset along bedding plane faults in the shaly parts of the Paleozoic section (Prinz, 1967). Displacement is normal, with the greatest

displacement in the upper part of the Maywood and lower part of the Jefferson (200-250 feet).

1.8 Trout ore bin with manganese mill ahead to the left. Foundations of the silver-lead-zinc flotation plant are on the right. The light colored tailings are from the flotation mill, and the black tailings in separate piles are from the manganese mill.

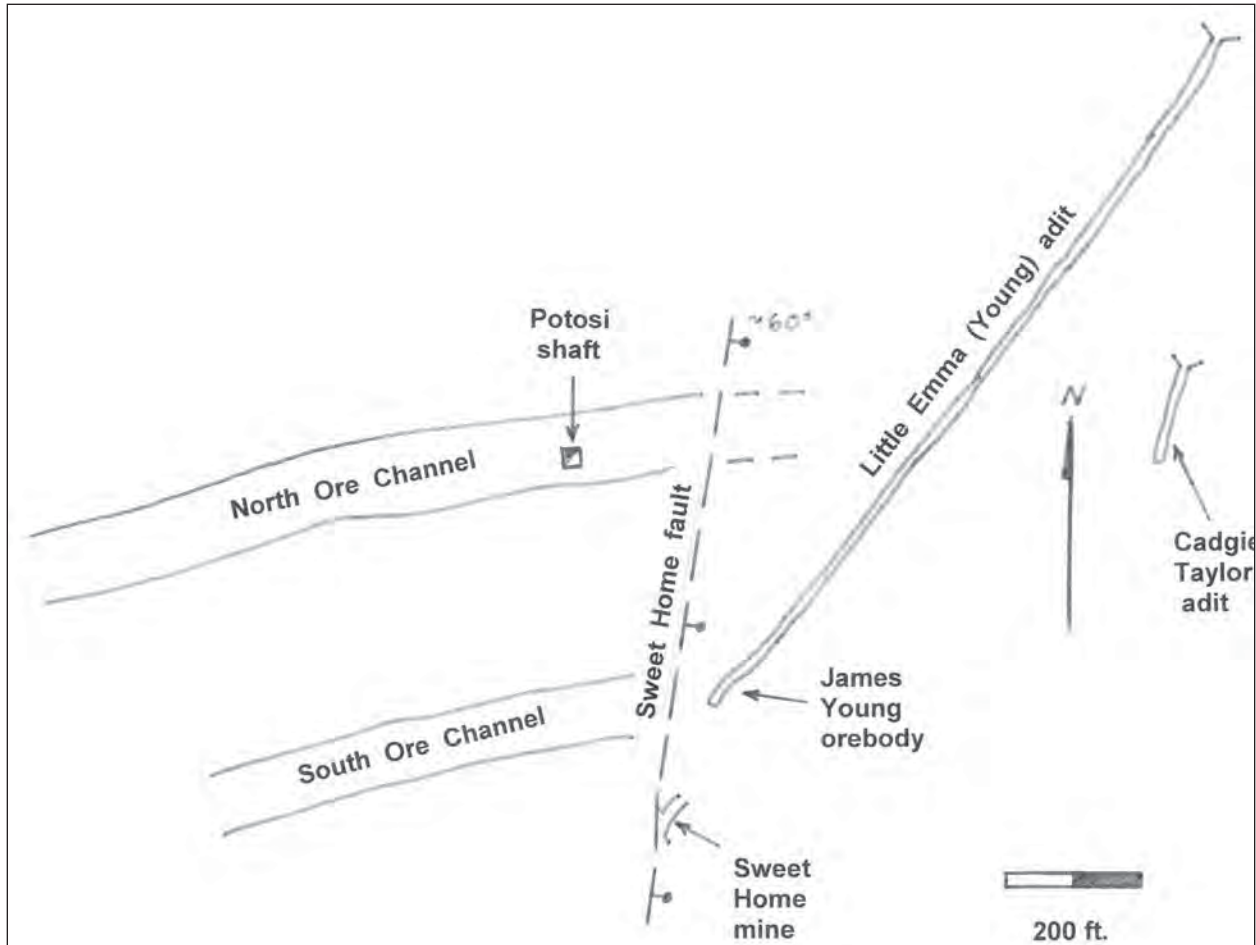


Figure 5. Geologic relationship in the eastern part of the Hope mine, modified from Contact Mining Co. map by J. Adler, 1973.

Drive 2.2 miles and park vehicle next to pit.

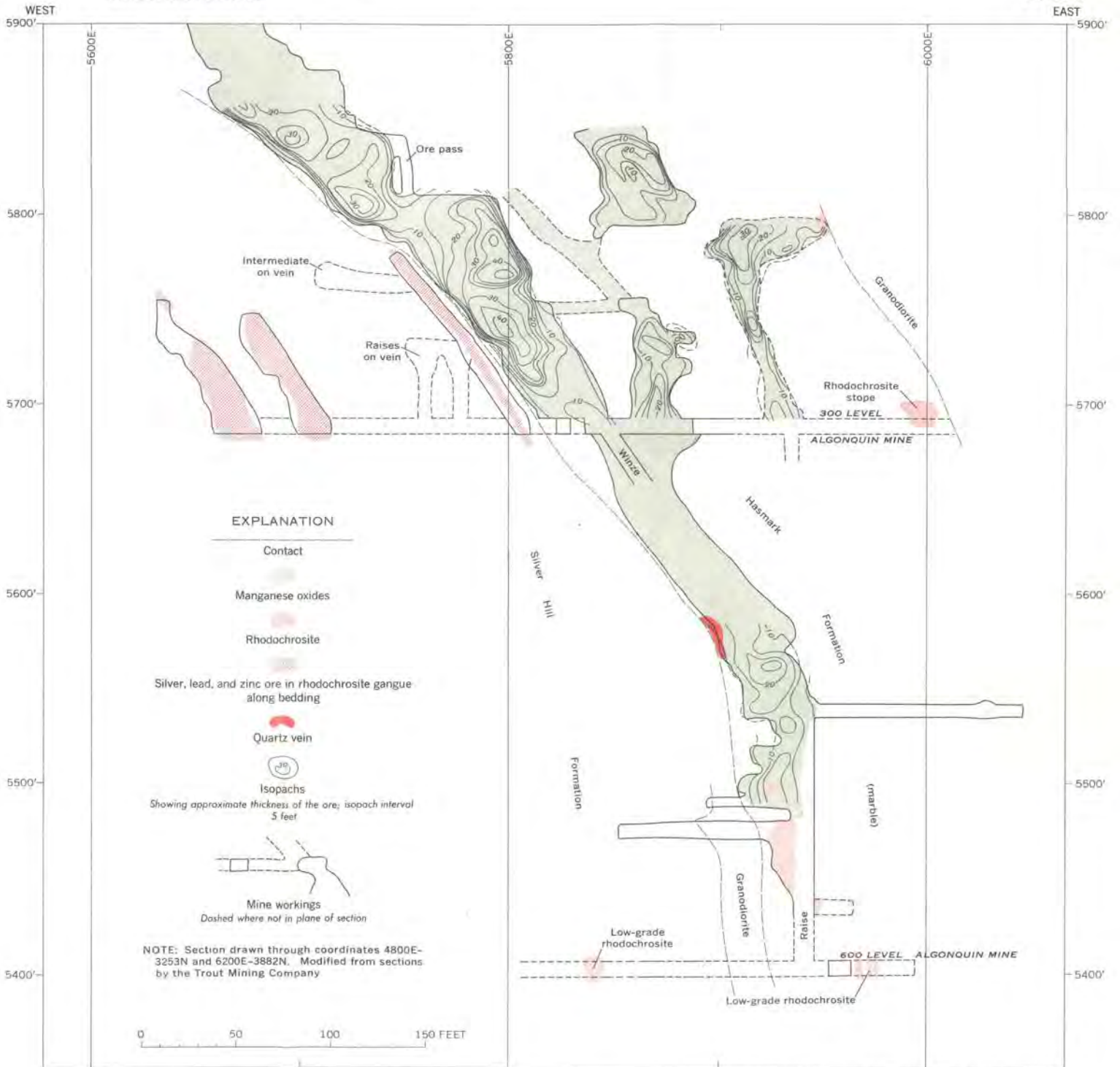
#### STOP 4

**Tree Top Pit.** The Tree Top pit mined the upper portion of the Coyle vein and replacement deposit (see fig. 6), and was the first and last place mined for manganese in Philipsburg. This mine was still operating in 1965 when the Montana Geological Society held its field conference in Philipsburg. Rhodochrosite forms replacements in calcareous Silver Hill Formation beds and basal Hasmark dolomite and oxidized to manganese dioxide near surface. The manganese dioxide in Philipsburg has the comparatively rare battery-active characteristic in the natural state. The manganese was first used in alloying steel and in the telephone system of the late 19th and early 20th century, which was powered by large batteries at the receiver set. Later the manganese was used for conventional dry cells, until the development of large, high grade African mines put Philipsburg at a competitive disadvantage in the 1960's. The manganese in this part of the district has a high gold content and was the focus of gold exploration efforts by Newmont in the late 1980's. Gold is confined to the manganese deposits and is not present in the broader skarn visible at this stop.

Reset odometer head back up road and turn right toward south crossing over east flank of Franklin Hill.

0.8 Turn left toward Granite then drive 1.5 miles to Granite Bimetallic mine site, park vehicle at STOP 5.





LONGITUDINAL SECTION OF THE LOWER PART OF THE COYLE ORE BODY  
PHILPSBURGH DISTRICT, MONTANA

Figure 6.

### STOP 5

Granite Bimetallic mine. The Granite-Bimetallic lode forms an east-west striking fissure vein within the Philipsburg batholith (see fig. 7, a plan and section from Emmons and Calkins, 1913). The vein on surface yields very low values, generally only an ounce or two of silver per ton and 0.01 ounces per ton of gold per ton. The mine was first located in the 1870's, and by this time the general idea of supergene enrichment was known from the development of the silver mines at Butte. The real potential of the deposit was first recognized by C.D. McClure, who operated the Hope mill, which processed silver ore from the northern part of the district. In 1880 he picked up a small specimen of high grade silver ore from the dump of a tunnel on the Granite Mountain claim, on the hill to the east. He convinced several of the St. Louis investors in the Hope to purchase the Granite, and later the Bimetallic, with himself as a partner. At approximately 200 feet below the surface, the tunneling encountered bonanza silver ore assaying hundreds of ounces of silver per ton. Unusually, gold was leached from the outcrop of the vein and enriched along with the silver, often exceeding one ounce of gold per ton in the richer silver ore. Therefore, gold was not weathered off the outcrop and gold placers did not develop. W.H. Emmons (Emmons and Calkins, 1913) deduced that the dissolution of gold in the weathering zone was facilitated by the presence of manganese in the vein. An excellent modern discussion of the chemistry of this relationship is found in Krauskopf, 1967, p. 525, where he explains that the function of the MnO<sub>2</sub> is to oxidize the gold, and the function of Chlorine in the system is to tie up the oxidized gold in a soluble gold-chloride complex ion. Re-deposition of both gold and silver takes place as solutions descend from the weathering zone and encounter

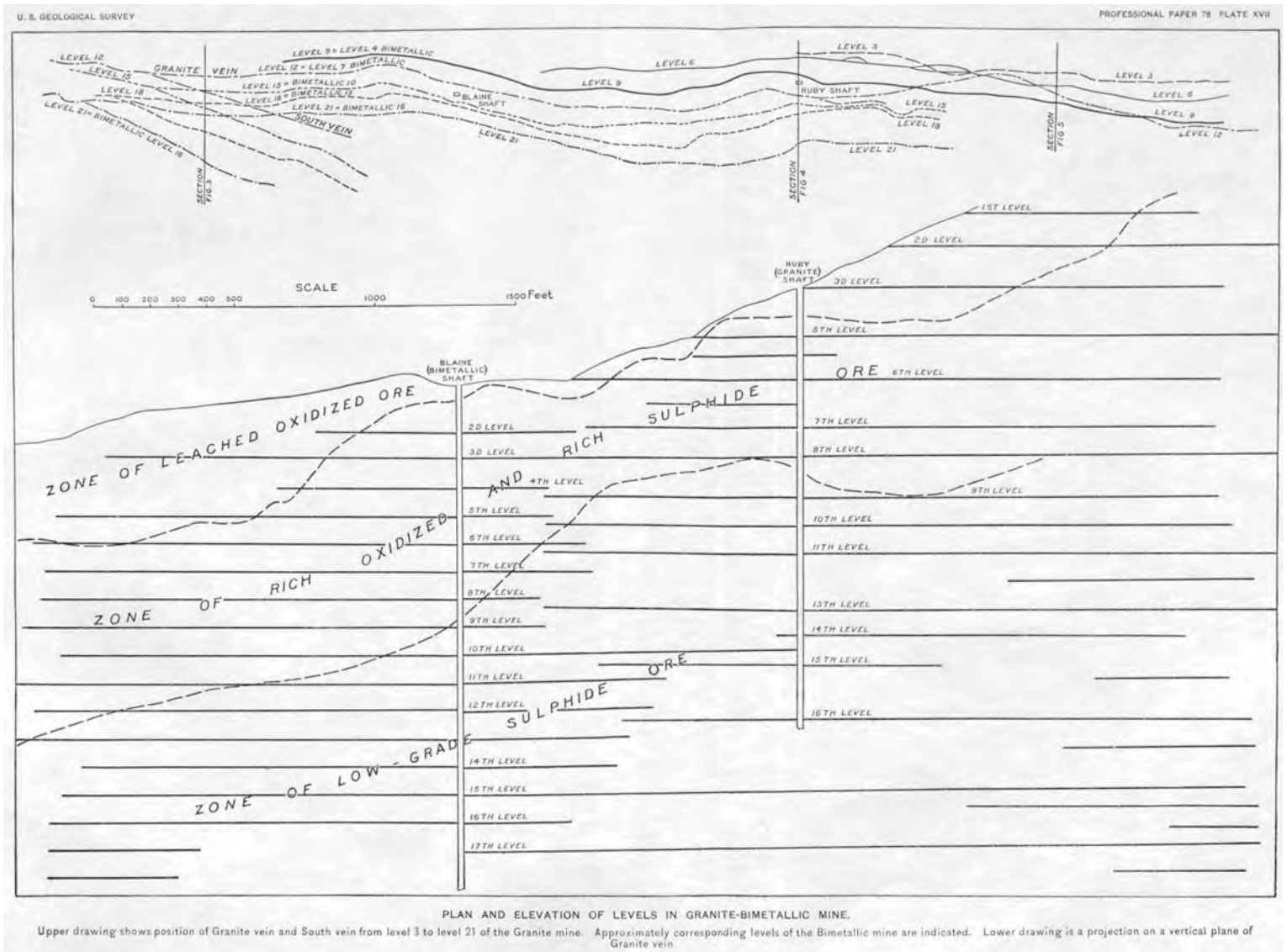


Figure 7. Plan map and long-section of Granite-Bimetallic mine, Emmons and Calkins, 1913, Plate XVII.

primary sulfide minerals at and below the water table, forming supergene minerals such as proustite and pyrrhotite (ruby silver). The silver-gold mineralization in the southern part of the Philipsburg district is interpreted to represent distal mineralization emanating from porphyry in the northern part of the district, in a zonation pattern similar to that seen in many porphyry systems, particularly Butte (Meyer, et al, 1968). However, the veins in Philipsburg strike east-west, across the district zonation, and there is no obvious pathway for the fluids to travel from the northern part of the district to the Granite-Bimetallic lode. This is the cue for arm waving – feel free to join in! Figure 8 shows sequential relationships of Granite-Bimetallic veins and the eastern Philipsburg batholith margin.

Retrace route from Granite then head back towards Philipsburg.

Note the collapsed house at mine turn off. Mae Waring, last resident of Granite, lived in this house in the 1960s, which is being rapidly reduced to rubble by the weight of heavy winter snows here at Granite.

Travel towards west on Granite ghost town road toward the Flint Creek Valley.

Down the road on left is the tramway tower for aerial tram from Granite to the mill and Philipsburg batholith granodiorite exposed in roadcuts. Then 0.2 miles down road from tram tower is an iron mine in skarn. The magnetite bodies do not contain the precious metal mineral assemblages characteristic of the Philipsburg mining district. The contact metamorphism seen here coincides with the Bimetallic stock emplacement, part of the composite Philipsburg batholith. K-Ar dates the Bimetallic stock to about 76.7-74 Ma (Hyndman, et al, 1982). The Bimetallic stock is interpreted to predate the base and precious metal mineralization in the district.

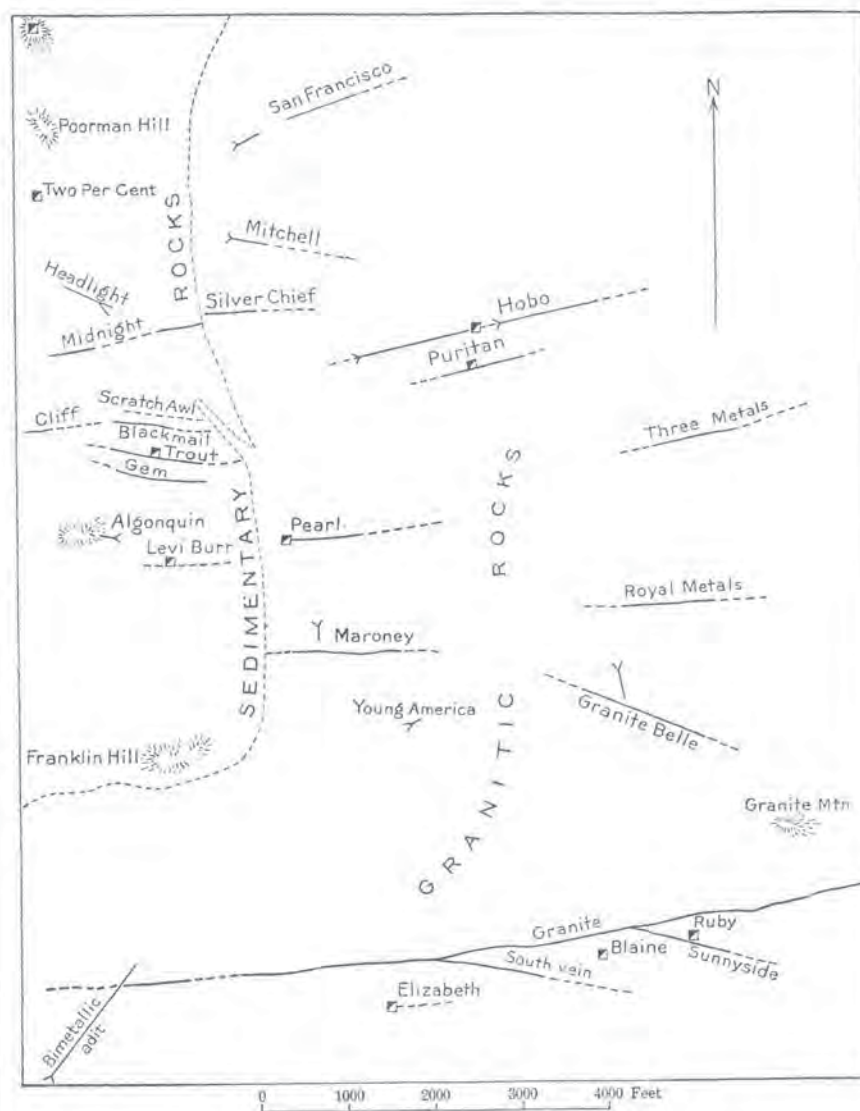


Figure 8. Veins in the SE part of Philipsburg District, Emmons and Calkins, 1913, figure 17.



Down off the mountain towards Philipsburg note on left is the road to Clark (named for the Bimetallic superintendent), the old site of the Granite-Bimetallic mill, and currently, Contact Mining Company's flotation mill, which has processed ore from several area mines including the dumps of the Granite and Bimetallic, from 1981 to the present. Keep straight.

To left is the site of the Philipsburg Mining Company mill and tailings pond. The pond is empty because most manganese tailings in Philipsburg were eventually shipped to consumers and stockpiles during and after World War II.

### ACKNOWLEDGMENTS

Our thanks to Bruce Cox for his assistance with several figures and advice on the geology. Views on the Philipsburg district are shaped by extensive discussions about district geology with Paul and Frank Antonioli, Charlie Goddard, Joe Worthington, and Dan Robertson; however, interpretations of the district are the opinions of the authors and they alone are entitled to the blame for any errors!

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## **ABSTRACTS**





**Local and Regional Geologic Settings of the World-Class Talc Deposits of Southwestern Montana**

John F. Childs

*President, Childs Geoscience Inc., 1700 West Koch Street, Suite 6, Bozeman, MT 50715, jfchildsgeo@msn.com, www.childsgeoscience.com*

**ABSTRACT**

The talc deposits of southwestern Montana are hosted by Archean to early Proterozoic(?) dolomitic marbles. Three major deposits are presently being mined in the Ruby and Gravelly Ranges, and a fourth historical producer has been reclaimed in the Ruby Range east of Dillon, MT. Several smaller deposits have produced minor amounts of talc. The talc is a co-product of hydrothermal processes that have also produced chlorite and sericite in the adjacent gneiss and schist. A hydrothermal origin for the talc is supported by the restricted areal extent of the individual deposits, the relatively sharp borders between talc/chlorite and high-grade metamorphic host rock assemblages, and by fluid inclusion and other geochemical data. Radiometric dating of sericite in gneiss adjacent to talc indicates a mid-Proterozoic age for much of the talc. Stable isotope and paleothermometric studies suggest that the talc-forming fluids could have been, at least in part, derived from basin brines that formed during the development of the mid-Proterozoic Belt Basin. Recent work by Underwood (2016) suggests that talc may have developed due to a crack-seal mechanism similar to that proposed for epithermal gold deposits. This new work may provide a better understanding of the complex cross-cutting and textural relationships recognized previously in the talc deposits.

Controls on mineralization recognized to date include a source of fluids enriched in magnesium, conduits such as fault zones that may have been periodically reactivated, and the presence of receptive carbonate host rocks. Distribution of the more significant deposits suggests control by a regional structural corridor possibly related to the southern margin of the Belt Basin. Exploration methods have consisted primarily of geologic mapping and outcrop and soil sampling. Some experimentation has been done on the use of geochemical and geophysical exploration methods, but these remain largely untested. Ongoing research of stable isotopes and structural controls by Childs Georesearch Inc. (Underwood, 2016) and on the geometry and structure of the Belt Basin by the Montana Bureau of Mines and Geology and other groups are providing new insights into the origin and structural controls of talc mineralization.

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## Pb Isotopic Compositions of Montana Ores Revisited

Francis Ö. Dudás

*Researcher (retired), Radiogenic Isotope Laboratory, EAPS, Massachusetts Institute of Technology, Cambridge, MA 02139*

### ABSTRACT

Early Pb isotopic studies, including several thousand analyses completed by the USGS on US ores, were targeted toward understanding ore formation and large-scale tectonic processes. More recently, isotopic analyses have traced the environmental impact of Pb pollution and support archaeological studies of prehistoric peoples. Here, I report a preliminary Pb isotopic inventory for Pb production in Montana over the period 1900–1980. This constitutes part of a broader study to determine the potential of isotopic data for tracing the origins of Pb-bearing paints, a major source of Pb pollution in urban environments. Using literature data, I have reconstructed the isotopic composition of the U.S. Pb supply for this time period. Montana contributed 745,000 short tons of Pb, 2.2% of the total U.S. Pb production between 1900–1980, and ranked sixth among all states. Montana's total recorded production, including that before 1900, is 846,000 short tons.

Within Montana, 20 of 56 counties have recorded Pb production from 86 districts. Over half of Montana's production came from Butte. A total of 42 of the 86 districts have published Pb isotopic data. I report 18 new Pb isotopic analyses from the Barker, Black Pine, Blue Eyed Nellie, Castle, Hecla, Heddleston, Neihart, and Philipsburg districts. The 47 districts for which we now have Pb isotopic data account for 94% of total Pb production. A total of 84 new analyses of samples from Butte span the range of vein and ore types, including late-stage minerals like barite and calcite.

The limitations of this isotopic inventory include: (1) incomplete records, particularly prior to 1930; (2) inconsistent production data in different sources; (3) duplication of records or incorrect source assignments; and (4) inadequate Pb isotopic data (21 districts have only one analysis). The overlap of Pb isotopic compositions between multiple locations makes the tracing of sources, even to the level of mining districts, impossible.

The data from the Castle Mountains district are surprising. The ores are associated with Eocene intrusive rocks and lie east of the Belt Basin, but have isotopic compositions similar to those from Neihart, located within the Paleoproterozoic and Archean metamorphic basement. The samples from Butte show a tight clustering of values ( $^{206}\text{Pb}/^{204}\text{Pb} = 17.95 \pm 0.10$ ,  $^{207}\text{Pb}/^{204}\text{Pb} = 15.57 \pm 0.02$ ,  $^{208}\text{Pb}/^{204}\text{Pb} = 38.23 \pm 0.10$ ;  $N = 67$ ), with outliers at both less and more radiogenic compositions. The radiogenic compositions ( $^{206}\text{Pb}/^{204}\text{Pb} > 18.9$ ) in pyrite and barite reflect elevated U/Pb in these samples, but the less radiogenic compositions ( $^{206}\text{Pb}/^{204}\text{Pb} < 17.7$ ) in pyrite and bornite are not easily interpreted. They may reflect the interaction of some ores with later fluids related to Lowland Creek volcanism.

**Supergene Mineralogy of the Continental Pit, Butte, Montana**

Kyle Eastman

*Graduate Student, Geological Engineering, Montana Tech, keastman@mtech.edu***ABSTRACT**

The Butte Porphyry Cu-Mo-Ag deposit has been considerably affected by supergene processes that enriched Cu and Ag and mobilized other metals. Supergene enrichment provided early miners with excellent ore grades and contributes heavily to current mining operations in Butte. The Continental Pit exhibits the classic leached and enriched vertical zonation that is common in near-surface porphyry systems around the world. Although studied by the Anaconda Copper Mining Company during the mid-20th century, significant and economically relevant questions remain regarding this deposit's supergene heavy metal geochemistry and its relationship to the local hydrology and tectonic history.

New research investigates the paragenesis of supergene and leach cap mineralogy and its distribution throughout the Continental Pit and provides recommendations for future mining. Mineral compositions and textures were determined using modern analytical techniques including portable X-ray fluorescence, shortwave infrared spectroscopy, Raman micro-spectroscopy, X-ray diffraction, and scanning electron microscopy/energy dispersive spectroscopy. Structural control of supergene geochemical zonation is apparent throughout the deposit; the distribution of hypogene veins and alteration assemblages, as well as faults and joints, leads to varying degrees of enrichment both vertically and horizontally in the Butte system. Intense supergene argillic alteration has resulted in areas of near-total replacement of feldspars by clay minerals. Major supergene ore minerals include chalcocite, acanthite, and native copper, with minor amounts of Cu-carbonates, oxides, and sulfates. Significant exposures of secondary fracture-filling phosphates were identified, including the minerals turquoise and chalcocite. Arsenic has been released from hypogene arsenic-bearing sulfosalts and incorporated into clays and secondary phosphates with measured concentrations up to 0.5 wt% arsenic in turquoise from the supergene enrichment blanket of the Continental Pit.



**Natural Acid Rock Drainage and Ferricrete Deposit Chemistry of the Judith Mountains, Montana**Sara C. Edinberg<sup>1</sup> and Christopher H. Gammons<sup>2</sup><sup>1</sup>*Hydrogeologist, Montana Department of Environmental Quality, Helena, MT 59620;* <sup>2</sup>*Professor, Department of Geological Engineering, Montana Tech, Butte, MT 59701, cgammons@mtech.edu***ABSTRACT**

The Judith Mountains are a low-elevation “island” mountain range in east-central Montana composed of a series of laccoliths and stocks cut by coarse-grained alkali granite and tinguaitite dikes. The geology of the Judith Mountains in the vicinity of Red Mountain and Judith Peak, two of the tallest mountains in the range, is conducive to the creation of headwater streams that are naturally acidic. Extensive limonite staining on Red Mountain attests to the widespread presence of disseminated pyrite in hydrothermally altered porphyry rock. However, no major historical mining operations are known to the area. The acidic streams undergo neutralization in pH as they travel downstream due to the influx of alkaline groundwater and tributary streams. The change in the character of the water is related to a change in geology from mineralized porphyry intrusions at the summit of the range to Paleozoic and Cretaceous sediments, including the Madison Limestone, in the foothills.

This study is the conclusion of a multiple-year project in the Judiths, quantifying the relationship between stream chemistry and local geology in three streams sourced from the Red Mountain porphyry. Chicago Gulch (aka Fords Creek) is the primary focus of this project. Although Collar Gulch and Armells Creek have been previously analyzed, some data are included in this thesis to compare to Chicago Gulch. The local Bureau of Land Management (BLM) office plans to use this thesis to guide decisions regarding future land-use issues in the Judith Mountains.

Results from ICP-AES, ICP-MS, and IC analysis of synoptic water samples quantify trends in metal concentrations and loads, pH, and distance downstream. White Al-hydroxide flocs are actively forming where the stream pH transitions from <5 to >5. This white precipitate is rich in trace metals, including Cu, Pb, and Zn. Precipitates in headwater reaches with pH <4 have higher iron content (approximately 25% Fe), with abundant pre-modern ferricrete deposits next to the stream. Alluvial ferricrete forms where pH transitions from <3.5 to >3.5, whereas broad ferricrete terraces form where Fe<sup>2+</sup>-rich groundwater emerges as springs and is oxidized to ferric hydroxide. All water samples collected in the upper reaches of Chicago Gulch exceed Montana water-quality standards for the protection of aquatic life for lead, cadmium, zinc, and copper, and human health standards for thallium. Lead concentrations are especially high in the headwaters of Chicago and Collar Gulches, indicating the possible presence of a weathered lead-sulfide deposit in the subsurface. Concentrations and loads of all metals decrease in all the streams once pH exceeds 5.5, and the lower reaches support a small population of trout. Prediction of pre-modern pH using the methods of Nimick and others (Nimick, D.A., Gurrieri, J.T., and Furniss, G., 2009, An empirical method for estimating instream pre-mining pH and dissolved Cu concentration in catchments with acidic drainage and ferricrete: *Applied Geochemistry*, v. 24, p. 106–119). indicates that the current pH regime is broadly similar to conditions when ancient ferricretes were deposited.

## Origin of Bright Yellow Coatings of Secondary Cadmium Sulfide (Greenockite) on the Walls of the Orphan Boy Mine, Butte, MT

Christopher H. Gammons

*Professor, Department of Geological Engineering, Montana Tech, Butte, MT 59701, cgammons@mtech.edu*

### ABSTRACT

Greenockite and hawleyite (polymorphs of CdS) are known to occur as supergene minerals in weathered, metal-sulfide deposits, where they often form bright yellow coatings on sphalerite and other minerals (fig. 1). Although apparently common, little is known about how these “blooms” of cadmium sulfide are formed. In Butte, Montana, yellow coatings of greenockite are actively forming on the walls of the underground Orphan Boy mine due to the interaction of dissolved  $\text{Cd}^{2+}$  with trace quantities of  $\text{H}_2\text{S}(\text{g})$  in the atmosphere. Dissolved  $\text{Cd}^{2+}$  is supplied by seepage from the mine walls where active weathering of Cd-bearing sphalerite is taking place.  $\text{H}_2\text{S}(\text{g})$  comes from two nearby flooded mine shafts where bacterial sulfate reduction has produced dissolved sulfide concentrations in excess of 10 mg/L  $\text{S}^{2-}$ .

Although the yellow coatings in the mine are visually striking, the individual CdS crystals are nano-sized, and cannot be imaged by conventional SEM. Positive identification of CdS was made by portable X-ray fluorescence (pXRF) and Raman microspectroscopy. Laboratory beakers containing  $\text{CdCl}_2$  and mixed  $\text{CdCl}_2$ - $\text{ZnCl}_2$  solutions developed a yellow precipitate of CdS within days to weeks of exposure to air in the mine. Other beakers containing Ag-nitrate precipitated acanthite ( $\text{Ag}_2\text{S}$ ). The presence of the vividly colored CdS coatings on the walls of the mine alerts the observer to the presence of a dangerous gas, hydrogen sulfide. Cadmium sulfide and other supergene metal-sulfide minerals may form in natural settings by the interaction of dissolved metal with trace amounts of gaseous  $\text{H}_2\text{S}$  supplied by sulfate-reducing bacteria or dissolution of metal-sulfide minerals by acidic pore waters.

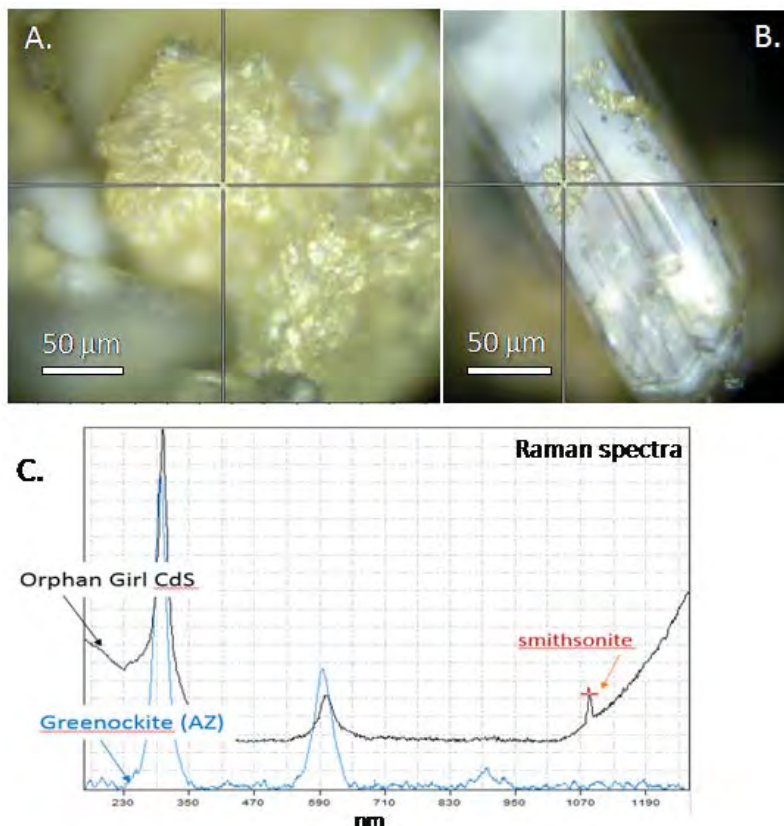


Figure 1. (A and B) Reflected light images of CdS (yellow) coating gypsum (silvery-white) collected from the mine wall. (C) Raman spectrum of CdS from the Orphan Girl mine compared to a reference spectrum of greenockite from Arizona.

## Origin of Amethyst Overgrowths on Pegmatitic Quartz from the Boulder Batholith: Fluid Inclusion Evidence

Christopher H. Gammons,<sup>1</sup> Jon Szarkowski,<sup>2</sup> and H. Peter Knudsen<sup>3,\*</sup>

<sup>1</sup>*Professor, Department of Geological Engineering, Montana Tech, Butte, MT 59701;* <sup>2</sup>*School of Mines and Engineering, Montana Tech, Butte, MT 59701;* and <sup>3</sup>*Dean, School of Mines and Engineering, Montana Tech, Butte, MT 59701*

*\*Corresponding author*

### ABSTRACT

Fine specimens of amethyst can be found in the Boulder and Pioneer Batholiths of southwest Montana. Locations immediately east of Butte, including the Little Gem mine, are currently being investigated by the authors. At Little Gem, a thick sill of pegmatite cuts granite of the late Cretaceous Butte Pluton. Pockets of amethyst are found in cavities between meter-sized crystals of pegmatitic quartz and alkali feldspar. The amethyst grows mainly from the hanging wall of the cavities, often in fist-sized clusters that terminate downwards. The roots of individual amethyst grains are often in crystallographic continuity with pegmatitic quartz, suggesting that the amethyst grew slowly under conditions of low silica supersaturation. Besides amethyst, a pale green mica is commonly found in the pegmatite cavities. Examination of the mica with an SWIR (short wave infrared) mineral analyzer shows it is K-illite (“sericite”) with high crystallinity, a variety of white mica that probably formed at  $T > 200^{\circ}\text{C}$ .

One of the unusual characteristics of amethyst from Little Gem is that it is found to crack, often with a loud “pop!,” when left out in the sun. In thin section, most of the amethyst is completely devoid of fluid inclusions, explaining its excellent transparency. Most fluid inclusions that are found are quite small and occur along healed fractures (i.e., secondary). However, a second population of much larger (up to 0.5 mm) primary fluid inclusions can also be found in roughly  $\frac{1}{4}$  of the thin sections examined. These inclusions are dark and typically contain a small central bubble of  $\text{CO}_2$  vapor rimmed by a larger bubble of liquid  $\text{CO}_2$ , in turn surrounded by a small amount of water. Some of the darkest inclusions are a single  $\text{CO}_2(\text{l})$  phase at room temperature but nucleate a small  $\text{CO}_2$  vapor bubble upon cooling below  $10^{\circ}\text{C}$ . These big,  $\text{CO}_2$  liquid-rich inclusions explain why the amethyst pops. When a cluster of amethyst is left in the sun, the temperature of the fluid in the inclusions goes up. Since liquid  $\text{CO}_2$  is nearly incompressible, once it fills up the entire volume of the inclusion any further increase in temperature causes the pressure inside the inclusion to increase rapidly to the point where the inclusion breaks, or “decrepitates.” Because the inclusions are so large, the amount of energy released when this happens is considerable: thus, the popping phenomenon.

Although we are still collecting data, preliminary results show that most of the fluid inclusions from Little Gem amethyst homogenize at temperatures between  $120^{\circ}$  and  $230^{\circ}\text{C}$ . However, because many of the large,  $\text{CO}_2$ -rich inclusions decrepitate during heating runs, these data are skewed towards the smaller, secondary inclusions. A few  $\text{CO}_2$ -rich primary inclusions that survived heating homogenized at temperatures as high as  $280^{\circ}\text{C}$ . This indicates that the amethyst is hydrothermal in origin, and not a product of the circulation of warm groundwater. Furthermore, thermodynamic calculations based on the fluid inclusion compositions and phase behaviors indicate that the liquid  $\text{CO}_2$ -rich inclusions were trapped at pressures  $>2$  kbar. Assuming lithostatic pressure, this means a depth of  $>7$  km. Where and when did these deep, hot,  $\text{CO}_2$ -rich fluids come from? Our current guess is that they bubbled out of a deep magma. Age-dating and further fluid inclusion work should help refine this idea.



**Mineralogy and Environmental Geochemistry of Slag in Lower Area One, Butte, Montana**

Jenna M. Kaplan

*Field Geologist, USDA Forest Service, Red Lodge, MT***ABSTRACT**

Butte, Montana, is the host to a Cu-Mo porphyry deposit and has been a location of mining interest since 1864. Once copper ore is removed from this deposit, it goes through a smelting process. Copper smelting processes consist of roasting, smelting, concentrating, and fire refining. During smelting, metals are separated from the waste, or gangue, material. Slag is the waste material from these processes. Non-ferrous slag, such as a copper ore, removes iron and silica from the original ore. There is much interest in slag postproduction, for there is often still a significant weight percent of metals trapped within a silica matrix. Slag in this study is from the Butte Reduction Works (BRW) copper smelter that started operation in 1886.

The slag walls were constructed alongside Silver Bow Creek starting in 1894, in a now superfund site called Lower Area One, and have never been geochemically analyzed. The main goals of this study were to characterize the mineralogy, chemical composition, and environmental geochemistry of the slag walls in Lower Area One. The composition of BRW slag is dominated by Fe, Ca, and Si. Silicates in the olivine and pyroxene groups, glass, and magnetite are the most abundant solid phases found in BRW slag. Olivine occurs as feather-shaped crystals that often grew within interstitial spaces. Some samples contain more than one olivine-type: a Fe-rich olivine approximating fayalite ( $\text{Fe}_2\text{SiO}_4$ ) and an Fe-Ca olivine approximating kirschsteinite ( $\text{CaFeSiO}_4$ ). Pyroxenes occur as prismatic crystals that often radiate out from sulfide droplets like sunrays. More than one pyroxene type was consistent throughout these samples, a hedenbergite ( $\text{CaFeSi}_2\text{O}_6$ ) as well as a Ca-Fe-rich pyroxene with the approximate formula  $\text{Ca}_3\text{FeSi}_4\text{O}_{12}$ . The olivines and pyroxenes are rich in metal impurities, including Zn, Mn, and Cu.

Magnetite is abundant as euhedral grains disseminated through the slag, and the slag itself is magnetic. Sulfides and other metallic compounds occur as tiny spheres, or “prills,” which are remnants of the molten Cu-sulfide matte that failed to separate from the slag during smelting. The main sulfides in the prills are bornite and chalcocite, commonly intergrown in an exsolution texture. Other prill phases include chalcopyrite, sphalerite, galena, and pyrrhotite. Based on bulk chemical composition, some metals in the slag, including Fe, As, Co, Mn, Pb, Zn, and W, exceed U.S. EPA screening levels for residential and/or urban soils. The BRW slag is not acid-generating, and instead has significant acid-neutralizing potential in the form of Ca-olivine and Ca-pyroxene. TCLP and SPLP tests indicate an overall low potential to leach metals from the slag, although one sample exceeded the TCLP standard for lead. Concentrations of dissolved As and W were elevated in the SPLP leachates, possibly due to the high pH of the solutions after interaction with the slag.

Interaction of BRW slag with Silver Bow Creek water gave variable results: some metals (e.g., Zn, Fe) showed a decrease in dissolved concentration, whereas others (e.g., As, W) increased. Dissolved copper concentration increased after Silver Bow Creek water interacted with one slag sample but decreased slightly in the other two samples. These contrasting results are explained by heterogeneity in the composition and mineralogy of the BRW slag. Because Silver Bow Creek passes directly through the BRW slag walls, there is a possibility of the release of certain metals from the slag to the stream water.

**Geology and Mineralization in the Stibnite Mining Area, Central Idaho**Reed S. Lewis<sup>1</sup> and Virginia S. Gillerman<sup>2</sup><sup>1</sup>*Geologist, Idaho Geological Survey, 875 Perimeter Drive, MS3014, Moscow, ID 83844, reedl@uidaho.edu;*<sup>2</sup>*Idaho Geological Survey, 322 E. Front Street, Suite 242, Boise, ID 83702, vgillerm@uidaho.edu***ABSTRACT**

The Stibnite Mining District of central Idaho has produced nearly a million ounces of gold plus substantial tungsten and antimony. Host rocks include the Cretaceous-age Idaho batholith, a small outlying granitic body (Stibnite stock), and a large metasedimentary roof pendant of Neoproterozoic to Ordovician age (Stewart and others, in press). Detrital zircon U-Pb analyses have been instrumental in establishing ages for the metasedimentary rocks (Lewis and others, 2014, 2016). Most importantly, earlier speculation that the district contains lower Paleozoic strata (Shenon and Ross, 1936) is substantiated by zircon ages as young as 500 Ma. Several Eocene calderas related to Challis volcanism are present immediately east and northeast of the district.

Recent exploration work by Midas Gold, Inc., has outlined a multimillion-ounce gold (plus antimony and tungsten) resource. Mineralization is hosted by granodiorite, leucogranite (alaskite), schist, calc-silicate rocks, carbonate, and quartzite, principally within the north-trending Meadow Creek fault, northeast-trending splays, and the northeast-trending West End fault. Gold is present in disseminated pyrite and quartz-carbonate veins and breccias with pyrite, stibnite, arsenopyrite, and scheelite. Zircons of ~89 Ma define the granodiorite as an older batholith phase. Zircon rims in the muscovite-bearing Stibnite stock are  $85.7 \pm 0.1$  Ma and zircon tips in the leucogranite are  $83.6 \pm 0.1$  Ma (Gillerman and others, 2014). Post-mineral porphyry dikes intrude along faults and biotite from one has been dated by <sup>40</sup>Ar/<sup>39</sup>Ar step heating methods at  $46.8 \pm 0.3$  Ma (Gillerman and others, 2014). Vein relationships are complex, but potassic alteration and K-feldspar envelopes are locally common. Hydrothermal K-feldspar in three veins in schist and granite from the West End area have been dated at  $51.7 \pm 0.3$  Ma,  $51.0 \pm 0.4$  Ma, and  $50.8 \pm 0.3$  Ma (<sup>40</sup>Ar/<sup>39</sup>Ar; Gillerman and others, 2014). While not totally definitive of all mineralization in the district, the assemblage of quartz-carbonate-K-feldspar-sulfides is present in at least the historic Yellow Pine pit and West End deposits. These ages are compatible with observed mineral assemblages in the ores and suggest the bulk of mineralization is early Eocene (~51 Ma), probably associated with the onset of tectonic extension, faulting, and uplift that preceded continental volcanism.

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**Bucket Line Dredge Tails—Gold Asset or Gravel Asset?**

Robin McCulloch

*Consulting Mining Engineer, Butte, MT***ABSTRACT**

The mining industry is replete with talks of the inefficiencies of the recovery systems of the dredges of the 1920s and the 1930s. The recovery is likely more of a function of the deposit than the technology of the time. If the bedrock is hard and fractured or an extensive large boulder system existed on bedrock, there is a chance resources remain under the tails. If the gravel tail is dirty and full of clay, it may not have released the gold to the recovery system. A couple of test pits should answer the question quickly.

Dirt or fines on the top of the dredge tails may only indicate a soft bedrock easily excavated by the dredge. Often the tops of the piles are covered by the angular bedrock the dredge easily broke up while penetrating it for the gold in the fractures.

Another potential loss of gold from the dredge is if the deposit is skarn hosted and contains large volumes of black sand and the recovery system utilized riffles and sluices. Black sand can pack in the riffles and prevent the gold from being caught. In these situations, the test should be focused on the sluice waste that underlies the cobbles. Often the sluice waste is sized ½ inch minus and may exceed 10 ft in depth and be comprised of pea gravel and sand, with a few boulders mixed in to possibly stabilize the spud or the pivot for the dredge.

In many situations, the dredge may be reprocessed as an aggregate mine. If the sand fraction is washed and the heavy fraction is recovered there is a potential that the values recovered will offset some of the fuel costs or even some of the mining costs.

It is rare that sufficient gold remains in the tails to generate enough of a profit to justify reprocessing. To determine the profit potential, the tails must undergo a very detailed sampling program requiring large equipment to penetrate piles that may be over 100 ft thick, half of that being sluice waste composed of wet sand.



## Golden Sunlight Mine: Geology and Mineralization Overview

David Odt

*Chief Geologist, Golden Sunlight Mine, Whitehall, MT*

### ABSTRACT

Golden Sunlight mine is 25 miles ESE of Butte, in the Whitehall mining district, Jefferson County, Montana. Anthony Hedly located the first leached outcrop on the Sunlight vein in 1890, marking the start of mining and exploration in the district. American Exploration Company (AMEX) acquired the property in 1958 and held the ground until mining began in 1982 by AMEX's successor, Placer Amex, Inc. Since the first gold pour in 1983, Golden Sunlight has produced over 3 million troy oz gold during 34 years of operation. In 2006, Barrick acquired Placer Dome. The area is underlain by a homoclinal sequence of Proterozoic Belt Supergroup metasedimentary rocks (quartzite, siltite, and argillite) and lower Paleozoic sedimentary rocks. These rocks have been intruded by Cretaceous intrusions and later mantle-derived dikes and sills. Cretaceous intrusive latite is dated at  $84.4 \pm 2.1$  Ma, and post-mineral Cretaceous intrusive dikes and sills are all dated at approximately  $76.9 \pm 0.5$  Ma, forming a time bracket constraining the mineralization events. To the north, Elkhorn Mountain volcanics and diorite intrusions overlie the Proterozoic/ Paleozoic package along a structural contact.

Middle Proterozoic deposition of Belt rocks in the mine area is considered to represent a prograding shelf-slope-fan complex. Locally, soft sediment deformation and synsedimentary exhalative mineralization are observed. Past workers have defined a lower deep-sea fan facies transitioning into submarine canyon or inner fan channel fill facies (LaHood Formation), overlain by slope facies silts and muds (Bull Mountain Group).

The structure has been active since Precambrian time; Late Cretaceous events set the stage for key mineralization events. The Great Falls tectonic zone wrench faulting is interpreted to have created a district stress field, controlling the emplacement of sub-alkaline to alkaline melts at depth. Vein development, latite sill emplacement, depressurization, collapse of magma chamber, and formation of a pipe-shaped breccia body all occurred during Late Cretaceous time. Economic geology is dominated by Mineral Hill breccia, a pipe-shaped breccia 600 ft in diameter dipping 2000 ft WSW.

Tertiary and Quaternary block faulting, tilting, and folding occurred in response to Tertiary extension. Up-throw and tilting of Bull Mountain resulted in detachment on low-angle structures, mass wasting along the east range front of Bull Mountain, and offset along a steep range-bounding structure east of the Mineral Hill breccia.

Alteration of the Mineral Hill and APEX deposits include propylitic, argillic, phyllic, potassic, and silicic styles. Alteration zonation at Mineral Hill is dominated by the breccia geometry, stratigraphic controls, and structural controls along ENE-trending high-angle structure. Alteration zonation at APEX is controlled by high-angle feeding structure, stratigraphic controls, and structural controls along ENE, NE, and north trend. Both systems display stratiform mineralization control at the intersection of steeply dipping structural feeders.

In the Mineral Hill deposit, pyrite is the dominant sulfide with lesser chalcopyrite, covellite, bornite, and telluride minerals calaverite, buckhornite, hessite, krennerite, sylvanite, and petzite also present. Sericite, kaolinite, quartz, barite, dolomite, magnesite, dickite, orthoclase, and albite form gangue mineralogy.

In the APEX deposit, pyrite is the dominant sulfide with chalcopyrite, bornite, chalcocite, tetrahedrite, tennantite, sphalerite, galena, pearcite, aikinite, and telluride minerals tetradymite and goldfieldite appearing as well. Sericite, quartz, barite, siderite, anhydrite, rutile, altausite, magnetite, and adularia form gangue mineralogy. Other gangue minerals identified at APEX using the TerraSpec Halo mineral identifier include illite, kaolinite, buddingtonite, palygorskite, halloysite, phengite, chlorite, and various supergene Fe- minerals.

Sulfur isotope data from APEX were compared to data from the Mineral Hill, and results essentially overlap (Gammons and Gnanou, written commun., 2016). The hydrothermal S in both deposits appears to have a similar source. What that source "is" is open for debate.

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## The Animas River (Gold King Mine) Spill in Colorado: Lessons for the Long Future

John Ridley

*Professor, Geosciences Department, Colorado State University, Fort Collins, CO 80523-1482*

### ABSTRACT

The Animas River (Gold King Mine) Spill in August 2015 in the San Juan Mountains of southwest Colorado released over a period of about 2 days a slug of about 3 million gallons (104 tons) of low pH water into the headwaters of the Animas River. This water had built up in a pond in the mine workings over the previous few months. The slug carried about 400 tons of metals in solution and as suspended mineral particles, amounts that would normally seep out of the mine over about 6 months. This spill has been touted as the worst mining related environmental disaster in U.S. history, although it was small compared to tailings dam failures elsewhere in the world over the past few years and small even compared to earlier events in the Animas River watershed. In 1978, the bed of glacial Lake Emma breached in the workings of the nearby Sunnyside mine and drained an estimated 10 million gallons of lake water down through the mine workings, which then streamed at high pressure out of the American Tunnel into Cement Creek and the Animas River. The river ‘ran black’ 80 miles downstream into New Mexico and measured zinc loadings were up to an order of magnitude higher in the river than at the peak of the 2015 spill.

Active mining of sulfidic ores in the Animas River watershed in the San Juan Mountains lasted from the 1870s to 1991. Throughout this period, the Animas River had been a severely affected stream, although there are few data on the degree of contamination. The first tailings ponds were not installed in the watershed until the 1930s. Since the cessation of mine and mill activity, and as a result of site by site remediation by various groups, including the Animas River Stakeholders Group, water quality in the river had been generally improving, although this trend had recently reversed. The Gold King Mine was one of several hundred mines, dumps, and mill sites in the watershed and had not been identified in the early assessments in the 1990s as a priority site for treatment. Even though the mine was one of the largest in the district and its ores and wallrock have high acid-producing capacity as a result of high pyrite contents and relatively low acid-neutralizing capacity of enclosing hydrothermally altered host rock, discharge was low. Adit discharge, however, increased many fold around 2002 after installation of bulkheads in the underlying American Tunnel. The Gold King Mine had thus become a site of investigation, monitoring, and consideration for remediation even before the spill.

Could a similar event recur? The metal load in the Animas as a result of this spill and earlier loading will reside essentially permanently in stream bed precipitates and sediments, presumably along the whole length downstream to Lake Powell, and it has the potential to be chemically and physically remobilized. Minor remobilization of sediment was inferred during spring run-off this year. Potential for acid production in this and other abandoned mines, and in waste rock and tailings, will remain so long as pyrite is available for oxidative dissolution.

Despite the visual prominence of iron-oxide staining on weathered pyritic rock and waste, pyrite dissolution in the cool and semi-arid climate of the Mountain West is slow relative to our historic time frame. Estimated rates of pyrite dissolution based on natural acid rock drainage and petrology of historical mine waste imply that an order of magnitude drop in rate of acid production, and hence an increase in pH of water draining sulfidic rock, requires on order 1,000 years. Reaction rates may be different inside mine workings as a result of temperature, dissolution into a near stagnant partially deoxygenated mine pool, and other factors, but order of magnitude estimates of metal flux indicate that similar time spans would be required for ‘reactive flushing’ of pyrite in the Gold King Mine workings by through-flow of meteoric waters. We thus need to consider how we plan and engineer remediation for this time scale of potential contamination.

## **Geology and Mining Methods on the J-M Reef Platinum and Palladium Mineralized Zone, Stillwater Complex, Stillwater Mine, Nye, Montana**

James Rose

*Geologist, Montana Bureau of Mines and Geology, 1300 West Park Street, Butte, MT 59701, jrose@mtech.edu*

### **ABSTRACT**

The Stillwater Complex is a mafic layered igneous intrusive located in the Beartooth Mountains of south-central Montana. The economic mineral potential of the Complex has attracted prospectors, major mining companies, and research geologists since the discovery of copper and nickel-bearing massive sulfides in 1883. Chromite bands were discovered in 1930. Several attempts were made to mine the metallic ores from 1883 through 1962, but none proved profitable.

In 1930, Ed Sampson, a Princeton University geology professor, recognized the geologic similarities between the Stillwater Igneous Complex and the Bushveld Igneous Complex in South Africa. The Bushveld Complex contains the platinum-bearing Merensky Reef. Platinum minerals were first identified in the Stillwater Complex in 1936 by two Princeton graduate students, Joe Peoples and Art Howland.

Interest in the platinum mineralization was renewed by H.K. Conn of the Johns-Manville Corporation in 1961. By 1967, Johns-Manville geologists began an exploration program for a platinum-rich mineralized zone. The platinum- and palladium-bearing J-M Reef was identified through mapping and geochemical sampling in 1973.

Stillwater PGM Resources, now jointly owned by Manville Corporation and Chevron Oil, joined with the Anaconda Company to form the Stillwater Mining Company in 1982. The new company began a feasibility program of test mining and core drilling on the J-M Reef to determine ore grade and prove reserves. In 1985, the company committed to production mining in the Stillwater Valley, near the community of Nye. The Company currently operates two mines on the J-M Reef: one at the original mining site at Nye, and the second in the East Boulder Valley south of Big Timber, Montana.



## Natural Amelioration in Flooded Mine Shafts and Related Changes in Arsenic Concentrations

Renee Schmidt<sup>1</sup> and Alysia Cox<sup>2</sup>

<sup>1</sup>Graduate Student, Chemistry and Geochemistry, Montana Tech, 1300 West Park Street, Butte, MT 59701, [rschmidt@mtech.edu](mailto:rschmidt@mtech.edu); <sup>2</sup>Professor, Chemistry and Geochemistry, Montana Tech, 1300 West Park Street, Butte, MT 59701, [acox@mtech.edu](mailto:acox@mtech.edu)

### ABSTRACT

Metal and sulfate concentrations have decreased in nine flooded mine shafts in Butte, Montana, since mining operations ceased in 1982. In addition to our data, 30 years of groundwater monitoring data provided by the Montana Bureau of Mines and Geology (MBMG) indicated that each site continues to undergo natural amelioration—defined as a reduction in dissolved metal and sulfate concentrations and an increase in pH without assisted remediation or water treatment. Microbiological and water samples taken from these nine mines represented three distinct geochemical zones. The groundwater divide located between these zones separates differences in sulfate and carbonate bedrock composition, which contributes to changes in water–rock interactions. The MBMG recorded sulfate levels as high as 100 mM and metal concentrations at 375, 2.69, and 10,800 mM for Cu, Fe, and Zn, respectively, upon initial shutdown of the mines. Over time, pH values have increased by 0.5 to 2 and metal concentrations have decreased by several orders of magnitude.

Notable exceptions to amelioration were three mines (Anselmo, Steward, and Kelley) located east of the groundwater divide. These mines were lower in pH (between 3.5 and 6.5) than those in the west (between 6.0 and 7.5), contained trace amounts of sulfide (0.3–0.5  $\mu\text{M}$ ), were lower in dissolved inorganic carbon concentrations than the west side (an average of 100 mg/L vs. 200 mg/L), and contained reduced iron (II) and arsenic (III) species. In the Anselmo and Steward, arsenic levels have been increasing at rates of 0.2 and 1.4  $\mu\text{Myr}^{-1}$  and iron levels at 29.5 and 105.3  $\mu\text{Myr}^{-1}$ , respectively. Increasing arsenic concentration at a rate of 5.3  $\mu\text{Myr}^{-1}$  were also measured in the Kelley, but iron concentrations were decreasing at a rate of 1,392  $\mu\text{Myr}^{-1}$ . In addition, the pH in the Kelley mine has continuously decreased since 1990 for a total change of one pH unit, and the temperature has increased by 18°C. Combining aqueous geochemistry and microbial diversity analysis with the historical groundwater monitoring framework provides insight into natural amelioration rates as well as long-term water–rock–microbe interactions in mine shafts hosted in both carbonate and sulfate bedrock.

## Geochemistry and Fluid Inclusion Study of the Unmined Heddleston Porphyry Copper Deposit, Lewis and Clark County, Montana

Benjamin Schubert<sup>1</sup> and Christopher H. Gammons<sup>2,\*</sup>

<sup>1</sup>Graduate Student, Geological Engineering, Montana Tech, Butte, MT 59701; <sup>2</sup>Professor, Department of Geological Engineering, Montana Tech, Butte, MT 59701

\*Corresponding author: [cgammons@mtech.edu](mailto:cgammons@mtech.edu)

### ABSTRACT

The Heddleston deposit is a large porphyry Cu-Mo system located near the historic Mike Horse mine at the headwaters of the Blackfoot River. This deposit was drilled out by the Anaconda Mining Company (AMC) in the 1960s and early 1970s but was never mined. Although very little has been written on Heddleston, published grade/tonnage information (93 Mt at 0.48% Cu) suggest that it is probably the second largest known porphyry Cu deposit in Montana. Several hundred feet of sawed and polished drill core specimens (“skeleton core”) from Heddleston were archived by AMC and are accessible through the AMC collection on the Montana Tech campus. These rocks are currently being examined by the first author as an M.S. thesis that will incorporate vein and alteration mineral petrography, hydrothermal alteration studies, fluid inclusions, and possibly stable isotopes.

The local geology of the Heddleston deposit consists of several bodies of quartz monzonite porphyry that have intruded into the Precambrian Spokane Formation and associated mafic sills. Early prograde mineralization is widespread but low in grade (0.1% Cu) and consists of disseminated chalcopyrite in potassically altered wallrock. Several generations of thin (0.1 to 3 cm) quartz veins cut the protore, some of which are barren, and some of which contain sparse molybdenite, pyrite, and chalcopyrite. The porphyry-style mineralization was enriched by supergene weathering, with the replacement of primary sulfides by chalcocite, covellite, and digenite. Most of the archived core samples show some degree of secondary enrichment down to depths as great as 1000 ft or more.

Around the periphery of the deposit are several much thicker quartz-carbonate lodes containing abundant polymetallic sulfides similar to the “main stage” veins of Butte. The Mike Horse mine exploited one of these lodes. Sulfide minerals that we have identified from polished slabs of Mike Horse ore include pyrite, pyrrhotite (minor), sphalerite, galena, chalcopyrite, bornite, and Ag-rich tetrahedrite.

Preliminary examination of centimeter-wide, quartz–molybdenite veins from Heddleston shows an abundance of hypersaline fluid inclusions (liquid-rich, with halite ± sylvite ± chalcopyrite (?) daughter minerals) that coexist with an equally abundant population of dark, vapor-rich inclusions. Both types of inclusions homogenize at temperatures in the range of 300° to 450°C and may represent the brine and vapor phases, respectively, of a boiled magmatic fluid. This observation suggests that Heddleston formed at a shallower depth than Butte, which was too deep to allow widespread boiling of the magmatic-hydrothermal fluids. Heddleston is also probably much younger, as the inferred age of the host intrusions is Tertiary.

**In the Field with the Montana Hard Rock Mining Bureau: An Update on Mining in Montana**

Garrett Smith

*Geochemist, Montana Department of Environmental Quality, Helena, MT, 406-444-1967*

**ABSTRACT**

This presentation will provide a summary of recent hard rock mining activity around the State and a brief overview of the types of mining projects that are permitted through Montana DEQ. Discussion topics will include a description of the duties of the Hard Rock Mining Bureau, an outline of the typical permitting process, and an update on pending applications and projects currently under review. The presentation will conclude with a whirlwind tour of active operating permits that are inspected by DEQ staff. Selected sites will be used to represent the wide range of metals, industrial minerals, and rock products that are produced around Montana.

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**The Highland Mining District—Past and Present**

Dave Stratton

*Water Environmental Technologies, Butte, MT 59701*

**ABSTRACT**

Dave Stratton's family first moved to the Highland Mining District in 1872, and they mined that district for over 140 years. Mr. Stratton has lived the majority of his life in the Highland Mountains. He will share a brief history of the Highland Mining District, including the discovery of the Montana Centennial Nugget, and highlight some colorful aspects of early Montana Mining Camps. Additionally, he will discuss current developments in the district.



## Mineralogy of Silver in the Ore Deposits of Butte: An Update with New Findings

Jon Szarkowski<sup>1</sup> and Christopher H. Gammons<sup>2,\*</sup>

<sup>1</sup>Undergraduate Student, Geological Engineering, Montana Tech, Department of Geological Engineering, Butte, MT 59701, jszarkowski@mtech.edu; <sup>2</sup>Professor, Department of Geological Engineering, Montana Tech, Butte, MT 59701

\*Corresponding author: cgammons@mtech.edu

### ABSTRACT

Butte is one of the largest and most mineralogically complex porphyry-lode systems in the world. We continue to investigate the mineralogy of silver in the veins and lodes of Butte. Previous work showed that there are three main forms of silver in the district: (1) as solid solutions within other minerals; (2) as discrete, hypogene Ag-bearing minerals; and (3) as supergene Ag minerals. In addition to Ag-rich tetrahedrite, argentite, pearceite, and stromeyerite, all of which are fairly common at Butte, we have found six new silver minerals previously not known to be present in the district: larosite (Cu,Ag)<sub>21</sub>(Pb,Bi)<sub>2</sub>S<sub>13</sub>; furutobeite (Cu,Ag)<sub>6</sub>PbS<sub>4</sub>; jalpaite (Ag<sub>3</sub>CuS<sub>2</sub>); electrum (Au-Ag solution); matildite (AgBiS<sub>2</sub>); and cupropearceite (Cu<sub>6</sub>As<sub>2</sub>S<sub>7</sub>)(Ag<sub>9</sub>CuS<sub>4</sub>). Larosite, furutobeite, and cupropearceite were found in Ag-Cu-rich ore from the Mountain Con mine, located in the “Intermediate Zone” of the main stage veins at Butte. The other minerals were found in veins of the Peripheral Zone, e.g., the Marget Ann and Goldsmith mines. Specimens from Marget Ann are particularly rich in argentite, electrum, and jalpaite, which occur as fine disseminations with galena, sphalerite, chalcopyrite, and pyrite in a complex gangue including vuggy quartz, chalcedony, rhodochrosite, rhodonite, and adularia. Some textures displayed at Marget Ann resemble banded epithermal veins, and the occurrence of adularia, previously not reported from Butte, is consistent with this idea. We suggest that some of the silver (and gold) mineralization in the Peripheral Zone of Butte may be late, possibly Tertiary in age, and probably shallower in origin than the main porphyry-lode deposits in the district.

Electron microprobe analysis (EPMA) has confirmed the presence of very high concentrations of silver in several important hypogene copper minerals of Butte, especially chalcocite/digenite and bornite. By contrast, chalcopyrite is much less enriched in silver. Chalcocite and bornite, along with enargite, were the most abundant Cu-minerals in the rich Central Zone lodes. Most of the silver mined from the Central Zone, including the Berkeley Pit, probably came from impurities (solid solutions) in these minerals. Hypogene chalcocite and bornite are much less common relative to chalcopyrite towards the periphery of the district, allowing discrete, Ag-bearing minerals to form. Weathering of Butte Hill over tens of millions of years enriched the tops of the lodes in silver, mainly in the form of acanthite (low-temperature Ag<sub>2</sub>S) coatings and replacements of pre-existing sulfide minerals. Elemental silver is also found in the weathered Ag-rich veins.

Our study has identified several other rare minerals that were not previously known to occur in Butte, or whose occurrence was poorly documented. These include mawsonite (Cu<sub>6</sub>Fe<sub>2</sub>SnS<sub>8</sub>), kiddcreekite (Cu<sub>6</sub>SnWS<sub>8</sub>), and goldfieldite (Cu<sub>10</sub>(Te,Zn)<sub>4</sub>S<sub>13</sub>).

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**Montana Resources Permitting for the Future**

Mark Thompson

*Manager of Environmental Affairs at Montana Resources, Butte, MT***ABSTRACT**

Montana Resources, LLP (MR) is an open-pit copper and molybdenum mining company located in Butte, Montana. MR operates the Yankee Doodle Tailings Impoundment (YDTI), an area comprised of a massive rockfill embankment with a maximum height of approximately 650 ft and approximately 1,450 acres of tailings beach and supernatant pond. Under its current permit, MR's mine has ore reserves in excess of 25 years. Tailings storage capacity, however, is limited by the permitted embankment height, which will be reached within the next 4 years.

In reaction to the Mount Polley tailings impoundment failure, the 2015 Montana State Legislature passed new regulations for the construction, operation, and closure of tailings impoundments in Montana. Many believe that these statutes are the most comprehensive and robust legislated in the country. This presentation will discuss the approach taken by Montana Resources to permit additional tailings storage under the new requirements.

## **Geology and Minerals of the Black Pine Mine, Granite County, Montana**

Dave Waisman

*Fine Mineral Show and SVL Analytical, Kellogg, ID*

### **ABSTRACT**

The Black Pine Mine, Granite County, Montana, exploited the Combination Vein, one of four sub-parallel veins in the Mount Shields Formation of the Belt Supergroup. The veins are described in older studies as bedding plane structures, but actually occupy thrust faults as illustrated in this presentation. The series of sub-parallel veins is a common structural element of the tectonic block and may provide a model for future exploration for silver and gold in the region. The number of minerals in the mine has reached over 75 species. The Black Pine mine is the type locality for the mineral philipsburgite, and the mine is well-known by mineral collectors as producing large, high-quality crystals of veszelyite. Japan-law twinned quartz, also prized by the collector, are common in the mine. Other collector-quality specimens found in the mine include tetrahedrite, cerussite, and stolzite.

## **In the Field with the Montana Hard Rock Mining Bureau: An Update on Mining in Montana**

Garrett Smith

*Geochemist, Montana Department of Environmental Quality, Helena, MT, 406-444-1967*

### **BACKGROUND AND DUTIES**

The Hard Rock Mining Bureau (HRMB) is the program within the Montana Department of Environmental Quality (DEQ) that regulates the mechanized exploration and development of all ore, rock, or mineral substances from hard rock sources. Although that definition encompasses a wide variety of operations, the resources that are excluded from the HRMB's authority include bentonite, clay, coal, natural gas, oil, peat, sand and gravel (alluvium), scoria, soil materials, and uranium. Formerly known as the Environmental Management Bureau, this program was renamed following a reorganization of the internal structure at DEQ in early 2016. However, the responsibilities of the bureau and the range of operations that are regulated did not change as a result of the reorganization. In general, the HRMB oversees the operations conducted under small miner exclusion statements (SMES,  $\leq 5$  acres), exploration licenses, and operating permits.

The administrative duties and the permitting procedures that apply to the HRMB originate primarily from the Metal Mine Reclamation Act (MMRA) and Montana Environmental Policy Act (MEPA), see 82-4-301, MCA and 75-1-101, MCA. These duties include issuing timely and complete decisions for permit applications and modifications, and ensuring permitted mineral development occurs with adequate protection of other resources. This is often coordinated with other permits obtained through state or federal agencies. The bureau also reviews the annual reports or renewal statements submitted by the operators, and conducts annual inspections to review the mining and reclamation status at each site and to offer compliance assistance. Performance bonds (i.e. financial assurances) are held for operating permits, exploration projects, and some SMES sites, in order to perform any potential reclamation work that is not completed by the operator. The bonds are reviewed annually and they are recalculated at a minimum of every five years or following significant permit modifications.

The operating permit application process typically begins when an operator meets with the HRMB to discuss the proposed project and any special considerations that may be needed for potentially impacted resources. After developing an application and draft operating and reclamation plan, the operator submits their proposal to the HRMB. The bureau has 90 days to review the application and determine whether it is complete and compliant with applicable regulations, and may then respond to the operator with deficiency questions and comments. This exchange may go back and forth a number of times, but the review period for HRMB is reduced to 30 days for any subsequent responses or revisions to the application.

Proposed projects and site locations often have unique circumstances, so operating and reclamation plans can be quite variable between different applications. In each instance though, the HRMB considers the baseline information that is available for the site, the scope of the proposed work, and the operational flexibility that is allowed through the MMRA. When the proposal is deemed complete and compliant, the environmental review and document preparation processes begin. Depending on the significance of potential impacts, an Environmental Assessment (EA) or an Environmental Impact Statement (EIS) will be prepared by the HRMB or designated contractor. Unless federal agencies are also involved in the environmental review, the HRMB is limited to 12 months to complete the process. The bureau ensures appropriate public involvement through compliance with MEPA, which involves providing public notice, holding scoping meetings, developing potential alternatives for the project, and considering public comments on the draft document before it is finalized and published with a Record of Decision (ROD).

Assuming those permitting steps are completed without litigious delays, the operator is then able to carry out the proposed project after providing a performance bond (i.e. financial assurance) for any reclamation work that may be required. Modifications may be made to the permit over the life of the operation, but the process is dependent on the surface area and/or significance of the proposed modification. Small changes to the operating



plan or permit area may be permitted through a “minor revision,” while more substantial changes or “amendments” may require an in-depth review, resulting in another EA or EIS process. Despite some public perception, the HRMB does not regulate or adjudicate air quality, mining on tribal lands, mining claims, property or civil disputes, surface water quality, or water rights. These issues are often resolved through permitting and/or consultation with other state and federal agencies.

## **OPERATING PERMIT UPDATES**

The following discussion focuses primarily on hard rock operating permits and proposed projects which are currently under review, and does not address the hundreds of SMES and exploration projects underway across the state. As of August 2016, there are currently 66 operating permits administered by HRMB, with 8 additional permits under the bureau’s review or awaiting actions from the operator before work can begin. There are also several permits that include multiple mining sites under one operating and reclamation plan. This is more common with quarries and surficial rock picking operations, which typically acquire specific types of rock from relatively small locations spread over a large region. Considering these additional locations, there are currently 222 sites covered by operating permits and inspected by HRMB staff.

The total land area that is permitted for hard rock mining and milling operations is approximately 85,000 acres (<0.1% of Montana), but a smaller fraction of that land is actually disturbed by the operations. Many of the sites contain a disturbance area within a relatively larger permit area, which often corresponds to property ownership boundaries. The operators that produce rock products (e.g. rip rap, railroad ballast, construction and decorative stone) comprise the vast majority of sites, and account for 44% of all land permitted for hard rock mining. Base metal mines (e.g. Cu, Pb, Zn) cover 23% of all permitted land, while precious metal mines (e.g. Au, Ag, Pt, Pd, Rh) cover just under 20%. The remaining land is permitted for mining, milling, and processing a wide variety of products, including cement materials, talc, limestone, garnets, and sapphires.

However, when reviewing the number of operations which are currently active (i.e. generating product), it is clear that the markets for rock products and industrial minerals are less volatile than those for base and precious metals. As a result of fluctuations in commodity prices, most of the metal mines are currently in care and maintenance status or in the process of final closure. In contrast, many industrial mineral mines are following and amending long-term production plans, while quarries and rock picking operations continue to expand and experience increasing competition from neighboring operators. Detailed updates about the remaining major metal producers and pending projects were requested by the Montana Bureau of Mines and Geology earlier in 2016, and are included below.

### **Continental Pit Mine, Montana Resources (Cu, Mo, Ag)**

Despite generally declining copper and molybdenum prices in 2015 and 2016, Montana Resources of Butte continued to produce ore from the D-North area of the Continental Pit, while stripping overburden in the D-East expansion area to expose additional ore reserves. The overburden is being used as construction material around the site, particularly for raising the tailings embankment to an elevation of 6,405 feet (approved in early 2015). Copper concentrates were also produced from leach pad solutions at the Horseshoe Bend precipitation plant, and the nearby water treatment plant continued to treat the effluent stream for re-use in the mill circuit.

Later in 2015, the company submitted a revision to their operating permits to allow for salvaging soil around the tailings pond and stockpiling the soil along a nearby county road. Another revision was submitted to allow for the construction of “Tailings Booster Station #3.” This facility will allow the company to spigot tailings along the west side of the impoundment, which would establish a wider beach along the western embankment and provide better hydrologic containment. Montana Resources continues drilling investigations around the tailings impoundment and on the ridge to the west of the mine boundary. This work is being conducted to aid the models and construction designs for an upcoming application to raise the embankment to a final elevation of 6,500 feet.

### **Golden Sunlight Mine, Barrick Gold Corp. (Au, Ag)**

Barrick Gold Corp. submitted a number of revisions to their permit in 2015, in order to increase efficiency and maintain production during a period of decreasing gold prices. These measures included rehabilitating and expanding the underground workings located within Mineral Hill Pit and removing material from low-grade stockpiles created in the 1990s. These resources were added to the mill-feed to supplement the ore being produced in the North Area and South Area satellite pits. As part of their underground development, the company also constructed additional office and dry facilities for the underground mining contractors. Other permit revisions included expansions of the Southwest and Northeast Rock Disposal Areas, in order to optimize the haul routes for waste rock disposal.

In late 2015, Golden Sunlight reduced its workforce by over 50 percent and shifted the focus to producing ore from only the underground workings, putting a hold on production from the smaller pits and low-grade stockpiles. The mill then continued to operate in batch mode, processing ore from the underground workings, as well as ore brought in from off-site by third parties. The company also continued exploration and resource definition for the Apex area deposit (formerly the “Bonnie”), located on the ridge to the north of the current pits. An application for that project is expected sometime in 2016.

### **Stillwater Mine (Nye), Stillwater Mining Co. (Pt, Pd, Rh, Au, Cu, Ni, Co)**

Production continued steadily in 2015 at the Stillwater Mine near Nye, despite decreasing prices for platinum group metals and difficult labor agreement negotiations between union employees and Stillwater Mining Co. A Tunnel Boring Machine continued to be utilized for advancing the underground workings as part of the Blitz project. In mid-2015, the land application disposal (LAD) pond expansion was completed and in full operation, while the Stage 3 Hertzler tailings impoundment raise continued, with material being placed along the southern and western sides and liner being installed across the expanded area. A tear in the impoundment liner was also repaired, and leakage is being captured by a nearby infiltration trench and returned to the impoundment. Expansion of the East Waste Rock Dump also continued, with waste rock being placed and then contoured, soiled, and seeded. A minor revision to the permit was submitted for the construction of a concrete pad to support fuel tote filling activities.

### **East Boulder Mine, Stillwater (Pt, Pd, Rh, Au, Cu, Ni, Co)**

Similar to the Stillwater Mine, the East Boulder Mine continued underground production through 2015, despite decreasing prices for platinum group metals. Work on the tailings impoundment expansion continued, with the completion of the Stage 3 embankment lining and the associated stability analysis. The impoundment raise permitted as Stages 4 and 5 continued through the year. Preliminary investigations began for the Stage 6 expansion, which would increase the storage area to the west of the current impoundment footprint. Stillwater Mining Co. also acquired approximately 100 acres land on the opposite side of the East Boulder River for a potential waste rock storage site in the future. A minor revision to the permit was submitted to incorporate final slope cover design for the approved nitrogen source reduction measures at the tailings impoundment. Additional minor revisions were submitted for the construction of a parts/equipment storage building, and for a geotechnical drilling investigation to delineate and characterize glacial deposits to the west of the tailings impoundment.

### **Troy Mine, Hecla Mining Co. (Cu, Ag)**

Hecla Mining Co. acquired the Troy Mine from Revett Minerals, Inc. in early 2015, and soon announced that they would be permanently closing the Troy Mine. Hecla began the closure process by removing the remaining mining equipment, water pumps, ventilation system, and electrical infrastructure from the underground workings. Water will be allowed to flood the workings, beginning with the decline to the lower “I Beds” deposit that was never completed during operations. Hecla will continue to implement their reclamation plan, by eventually removing the mill and other surface structures, maintaining the tailings pipeline to convey mine water to the impoundment, and by covering and vegetating other portions of the impoundment.

### **Butte Highlands Gold Project, Butte Highlands Joint Venture LLC (Au)**

In early 2015, the Montana DEQ published a ROD on the Final Environmental Impact Statement for the Butte Highlands Gold project. This authorized Butte Highlands Joint Venture (BHJV) to construct and operate an underground gold mine approximately 15 miles south of Butte. Later in the year, the U.S. Forest Service released its Final Decision Notice on the haul road alternatives for the project, with a Finding of No Significant Impacts. This allows BHJV to use different roads for mine access and ore haulage (Highland Road west or Highland Road north/Roosevelt Drive). Future development is contingent upon the company submitting the appropriate reclamation performance bond and developing detailed plans for either hauling ore off-site or processing ore at the mine.

### **Montanore Project, Mines Management Inc. (Ag, Cu)**

Mines Management, Inc. continued the re-permitting process for the Montanore project on the east side of the Cabinet Mountains Wilderness. Montana DEQ and the U.S. Forest Service issued a Final Environmental Impact Statement (FEIS) in late 2015. Upon completion of the ROD in 2016, the company must then submit a reclamation performance bond, resource monitoring plans, and mitigation plans as part of the evaluation phase of their project. The evaluation phase will provide more information about hydrogeologic conditions, resource definition, and mine feasibility. This phase will include rehabilitating and extending the existing adit, replacing infrastructure, and establishing hydrologic monitoring points. In 2016, Hecla Mining Co. announced an agreement to acquire the Montanore Project from Mines Management Inc. The transfer was finalized in Q3 of 2016.

## **PENDING OPERATING PERMIT UPDATES**

### **Black Butte Copper Project, Tintina Resources Inc. (Cu) Pending**

After withdrawing plans to develop an exploration decline at the Black Butte project in 2014, Tintina Resources focused their efforts to submit a full operating permit application to Montana DEQ in late 2015. The project is based on the development of the upper and lower Johnny Lee deposits to the north of White Sulphur Springs, through underground “cut and fill” methods that utilize cemented paste tailings backfill. The submitted plan also includes a surface impoundment that would contain waste rock and cemented paste tailings, ponds for process water and storm water collection, a water treatment plant, groundwater infiltration galleries for water disposal, and crushing, flotation, and cement plant facilities. The HRMB provided deficiency questions and comments for the application in March 2016, and the company responded to questions and submitted an updated application in September 2016. The HRMB will now review and assess the updated documents.

### **Rock Creek Project, Hecla Mining Co. (Ag, Cu) Pending**

Hecla Mining Co. also acquired the Rock Creek project from Revett Minerals Inc. in 2015. The Rock Creek project will become the company’s focus for permitting and production in northwestern Montana, following the closure of the Troy Mine. The Rock Creek Project would begin with an evaluation adit, prior to the development of an underground room and pillar mine, with conventional on-site crushing and flotation processing. Although DEQ completed a ROD in December 2001, the permitting process is still on-going, with a draft Supplemental Environmental Impact Statement (SEIS) being published by the U.S. Forest Service in early 2016, followed by a public comment period. The USFS expects to complete the Final SEIS and ROD in late 2016.

### **Montana Limestone Resources (Limestone/Lime) Pending**

Montana Limestone Resources, LLC (MLR) is proposing to develop a quarry and plant to extract and process limestone. The permit area would cover 546 acres and it is located approximately 2.5 miles west of Drummond, in Granite County. The permit area includes the mine site and access road from State Highway 1 to the mine. The MLR project will consist of: an open pit mine producing 7,000 tons of limestone per week, a crushing and screening plant, a preheater rotary kiln that processes limestone into lime, storage/loading/shipping facilities to transport the lime, infrastructure to support project (e.g. roads, natural gas, power line, water wells, sediment BMPS, etc.). The application was received in late 2014, and HRMB provided deficiency questions and comments in early 2015. The review process is currently on hold, pending a response from the operator.

**Venture Stone (Rock products) Pending**

Venture Stone, LLC is proposing to develop multiple locations for decorative rock picking and processing. Surficial sandstone and “moss rock” would be removed from five sites located approximately 12 miles south-southeast from Great Falls, in Cascade County. Rock would be hauled to a separate mill and office site to the west of Great Falls, where the rock would be cut, shaped, and stored before shipping to consumers. The total permit area would be just over 10,000 acres, although a much smaller area would be disturbed by the operation at any given time. The application was received in mid-2016, and HRMB provided deficiency questions and comments one month later. The review process is currently on hold, pending a response from the operator.



