2023 Montana Mining and Mineral Symposium

Presentation Guidelines, Schedule & Abstracts

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Montana Tech campus, Butte, MT

MBMG
Montana Bureau of Mines and Geology

2023 Montana Mining and Mineral Symposium
Presentation Guidelines

Oral Presentations

Oral Presentations will be given from a central Windows-based PC. Speakers need to bring their compatible-format presentation (Microsoft PC PowerPoint readable) on a thumb-drive to transfer to the central PC on the morning prior to their presentation. Please include your last name in the file name. Choice of handheld or lavalier microphone is available.

Oral Presentations have a 20-minute time slot. Ideally, the presentations are 15 minutes in length followed by 5 minutes of questions. In order to keep on schedule, presentations will be timed and speakers will be interrupted at 20 minutes to move on to the next speaker. A 2-minute time left warning (at 18 minutes) will be given to entice the speaker to wrap up remarks before the final interruption.

Poster Presentations

The poster presentations will be held in the Mineral Museum @ Montana Tech.

All posters will be hung with push pins on a double-sided moveable poster wall.

Maximum poster size is 7 feet in length x 5 feet tall. If you have a larger poster that is already printed and you wish to use it, please contact squane@mtech.edu to see if accommodations can be made.

Proceedings

A Proceedings volume will be published by the MBMG following the 2023 Symposium. Details regarding submission guidelines and dates will be announced at this year’s Symposium.

Montana Rhodochrosite from Mineral Museum @ Montana Tech Photo: S. Quane

Thursday, September 28, 2023 Copper Lounge, Montana Tech Student Union Building

TIME	SPEAKER	TITLE
9:00-9:20	INTRO	INTRODUCTION TO 2023 MINING & MINERAL SYMPOSIUM
9:20-10:20	Garrett Smith	Overview of Mining Operations in Montana
10:20-10:40	BREAK	BREAK
10:40-11:00	George Brimhall	Evidence for Hydrogen Diffusion in Porphyry Copper Deposit Ore Genesis and Alteration Mineral Zoning
11:00-11:20	Mario Guzman	Evidence for High-Level Porphyritic Intrusion Below the Sunnyside Epithermal Vein Deposit, Colorado
11:20-11:40	Jarred Zimmerman	Controlling Hydrothermal Fluid Flow and Changing Porosity in the Tuff of Sulphur Creek, Yellowstone National Park, Wyoming
11:40-12:00	BREAK	BREAK
12:00-12:20	Katharina Pfaff	Mineralogy Across Scales: An Example from the Idaho Copper Belt
12:20-12:40	Gregory Bell	Ruby Graphite Project - Early Exploration Results
12:40-13:00	Amanda Griffith	Update on Montana Resources
13:00-14:00	LUNCH	LUNCH
14:00-14:20	Adrian Van Rythoven	Critical Mineral Potential of the Phosphoria Formation in Southwestern Montana
14:20-14:40	Virginia Gillerman	Nd-enriched Lehmi Pass REE-Th-Fe District, Idaho-Montana: Mid-Paleozoic Mineralization from Crustal-scale Hydrothermal Circulation?
14:40-15:00	Reed Lewis	Critical Minerals Research Efforts by the Idaho Geological Society
15:00-15:20	BREAK	BREAK
15:20-15:40	Michael Gary	Using Indicator Minerals Taken from Stream Sediment Samples to Detect Rare Earth Element Deposits
15:40-16:00	Marisa Redgrave	Geophysical Survey in the Bearpaw Mountains on the Rocky Boy Reservation in Northeastern Montana
16:00-16:20	Sarah Risedorf	New Investigations of the Carbonate-related, REE-Nb Deposits in Southern Ravalli County, Montana
16:20-16:40	Alexei Rukhlov	Episodic Carbonatite Emplacement in the Canadian Cordillera from 810 to 330 Ma: From Supercontinent Breakup to Orogenic Convergence
16:40-17:00	John Metesh	Uno Sahinen Award Presentations
17:00-19:00	Posters/Reception	Poster presentations and reception in Mineral Museum @ Montana Tech

Friday, September 29, 2023 Copper Lounge, Montana Tech Student Union Building

TIME	SPEAKER	TITLE
9:00-10:00	Allen Andersen	Keynote: Earth MRI Program Overview and USGS Critical Mineral Research in the Northwestern United States
10:00-11:00	Eric Anderson	Keynote: Earth Mapping Resources Initiative - a Montana Perspective
11:00-11:20	BREAK	BREAK
11:20-11:40	Danie Grobler	Ni+Cu+PGE Mineralization within the Lower Ultramafic Series of the Stillwater Complex, Montana, USA
11:40-12:00	Chris Gammons	New Investigations of the Winston Gold Mining District, Montana
12:00-12:20	Celine Beaucamp-Stout	Trace Elements in Fluorescent Sphalerite of the Philipsburg Mining District, Granite County, Montana
12:20-12:40	Karen Lund	Structural Evolution of Gold-Bearing Cobalt-Copper Deposits of the Blackbird Mining District, East-Central Idaho
12:40-13:00	Kyle Nacey	Black Butte Copper Project Montana, USA
13:00-14:00	LUNCH	LUNCH
14:00-14:20	Kyle Eastman	Geology, Mineralization, and Critical Minerals Potential of the Radersburg and Giant Hill 7.5’ Quadrangles, Broadwater County, Montana
14:20-14:40	Kaleb Scarberry	Geologic Mapping and Mineralization of the Elkhorn 7.5’ Quadrangle and Historic Mining District, Jefferson County, Montana
14:40-15:00	Amanda Rossi	Upcoming MBMG Economic Geology Projects
15:00-15:20	BREAK	BREAK
15:20-15:40	John Sanford	Modern Data Delivery
15:40-16:00	Denise Herman & Connie Thomson	Standing on the Shoulders of Giants: Preserving Rock Collections for Future Study
16:00-16:20	Colleen Elliot	A New View of the Chief Joseph Plutonic-Metamorphic Complex, SW Montana
17:00-19:00	MAP CHAT	MAP CHAT and PIZZA at Butte Brewing Company 465 E. Galena St. Butte, MT

Abstracts

Oral Presentations

Garrett Smith

Update on Hard Rock Mining in Montana

This presentation will provide a brief overview about the categories of mining activities that are permitted and regulated through Montana DEQ and a summary of current hard rock mining projects around the state. Discussion will include the general duties of DEQ's Hard Rock Mining Section, statutory changes from the 2023 legislative session, and current permitting actions for new applications or modifications to existing permits. The presentation will conclude with a photo tour of selected sites that represent the wide range of active operations that are inspected by DEQ staff. Exploration projects and Small Miner Exclusion sites (<5 acres) will be included, although the larger Operating Permit mines are the primary focus. Site summaries may include a discussion of local geology, overlapping regulatory jurisdictions, and other factors that influence the development of mineral commodities in the Treasure State.

George Brimhall

Evidence for Hydrogen Diffusion in Porphyry Copper Deposit Ore genesis and Alteration Mineral Zoning

While critical minerals and copper are vital to attaining a carbon neutral society through electrification, decarbonization of heavy industries, transportation, and aviation systems may require molecular hydrogen which is a powerful emission-free combustible fuel with a higher energy density (35 watts/g) than lithium (0.2 watts/g). However, the minute molecular size of H_2 (0.27 nm) makes it readily subject to diffusion even through many but not all metals and rocks making conveyance and storage challenging. Such remarkably selective physical behavior raises the question as to where in nature hydrogen diffusion may have played a decisive role. Especially for an abundant element in gaseous form it's capability of affecting oxidation and reduction through migration could have major consequences on natural systems. This study explores the possibility that diffusion of molecular hydrogen gas (H_2) played a significant chemical and perhaps mechanical role during mineralization and wall rock alteration during porphyry copper deposit genesis. The basis of this research stem from recent field mapping in Montana and supportive theoretical calculations of equilibrium phase diagrams to explain the mineral assemblages and geological patterns observed in Brimhall (2021) designed to advance the Porphyry Copper paradigm used in exploration.

It is suggested that while chemical and mineralogical effects of hydrogen diffusion were described in this study, that the possible chemical-mechanical effects of abundant hydrogen gas not be overlooked. Hydrogen gas may have played a major role in the multi-stage fracturing characteristic of porphyry copper deposits. Conventionally, over-pressured aqueous fluids are invoked to explain fracture development with release of magmatic water which expands and does pressure-volume work causing brittle rock failure at depths where such expansion is accommodated. Hydrogen, recognized herein may dramatically enable this process through hydrolytic weakening of quartz and other minerals (Griggs, 1967; Rovetta et al. 1989; and Strauch et al, 2023).

Mario Guzman

Evidence for a High-Level Porphyritic Intrusion Below the Sunnyside Epithermal Vein Deposit, Colorado

High-temperature quartz veins were identified in drill core at ~600 m below the Sunnyside epithermal base and precious metal deposit in southwestern Colorado. The veins consist of early anhedral quartz that shows a bluish cathodoluminescence emission and hosts heterogenous silicate melt inclusions. The early quartz is overgrown by a later generation of quartz that exhibits euhedral terminations with oscillatory growth zones showing a bright pink to purple cathodoluminescence emission. Both types of quartz are crosscut by ubiquitous planes of vapor-rich inclusions and some hypersaline liquid inclusions. In addition, secondary planes of intermediate-density inclusions occur. The petrographic characteristics of the two quartz types are similar to those in 'A' and 'B' veins encountered in shallow- and intermediate-depth porphyry deposits. The relationships at Sunnyside imply that these high-temperature veins formed from magmatic-hydrothermal fluids derived from an intrusion located not far below the lowest level of drilling. Sunnyside appears to be a rare example of an epithermal deposit that is directly connected to a high-level porphyritic intrusion.

Jarred Zimmerman

Controlling Hydrothermal Fluid Flow and Changing Porosity in the Tuff of Sulphur Creek, Yellowstone National Park, Wyoming

Regional faulting, local flow contacts, and unit fracture planes exert a strong control the permeability of the Pleistocene-aged volcanic units associated with the Yellowstone caldera. At Seven Mile Hole, local large-scale structures such as the trends of silicified ridgelines, siliceous sinter fields, and river valleys compare well with faulting inside and outside of the caldera, as well as the main caldera ring fault. The most prominent trends are N-S, NW-SE, and NE-SW, indicating the general E-W extension noted in the Basin and Range Province plays a key role in localization of the thermal area. Hydrothermal mineral assemblages indicate the increased permeability allowed alkaline-chloride and acid-sulfate fluids to infiltrate the unit, creating six assemblages, and one that appears to be a shallow modification of a deeper assemblage. Porosity in the unaltered Tuff of Sulphur Creek ranges from 7% and 26%, mean 17 ± 8% (n = 5). The exemplary alkaline-chloride alteration noted around Ridge 7741 as a quartz-illite aureole, shows little deviation from the unaltered porosity, with a mean of 25% (n = 2). However, the associated silicified ridgeline shows a nearly 40% porosity reduction relative to unaltered porosity, likely due to the precipitation of secondary quartz and other silica minerals infilling pore spaces and fractures. The shallowest assemblage (MA1: kaolinite-opal ± alunite) is interpreted as the steam-heated section and has a wide range of porosity, from 3% to 33% (n = 30), with most samples falling between 8% and 19%. Similar to silicified sections, the decrease in porosity is attributed to precipitation of opaline silica, potentially enhanced by clay production.

Katharina Pfaff

Mineralogy Across Scales: An Example from the Idaho Copper Belt

Understanding the mineralogy, geochemistry and petrophysical properties of rocks in the subsurface is key to mineral exploration and assessments of (critical) mineral resources, as well as to mine planning, mining, mineral processing, and reclamation. To achieve this goal, high-quality datasets of various types must be acquired, co-registered and interpreted across the range of scales in 3-D. We will present new developments in workflow development applied to the strata-bound Co-Cu Iron Creek deposit in the Idaho Cobalt belt as well as advances in understanding the occurrence, distribution and sequestration of critical minerals in known ore deposits.

Gregory, J. Bell

Ruby Graphite Project - Early Exploration Results

Located in the Ruby Range mountains in southwestern Montana near Dillon, a natural graphite deposit was operated from 1901 until 1948 by the Crystal Graphite Company. After having produced approximately 2,500 tons of vein graphite using artisanal mining methods more than 70 years ago, the location was abandoned and mostly forgotten.

Until now, the lands had never been properly explored with modern methods, and had never been drilled. The Ruby Graphite project was initiated in 2015 to turn the previously discovered mineral into a resource with new value under the current age of electric vehicles. A combination of private and Federal mineral rights totaling 1,945 acres (787 hectares) including 96 lode mining claims were acquired by Ruby Graphite Holdings LLC. Then, last year Reflex Advanced Materials Corp. agreed to fund a modern exploration program to demonstrate the extent and grade of the Ruby Graphite deposit.

The initial exploration effort concentrated on identifying potential graphite-bearing areas and developing a geological model of the stratigraphy and structure. Detailed geologic mapping was conducted which included chemical fingerprinting to support lithology and structure mapping, as well as a soil survey, UAV (drone) based detailed photogrammetry and elevation modeling, electromagnetic (EM) survey using a multifrequency, shallow-looking, handheld survey tool, and an Induced Potential (IP) survey to delineate conductivity trends indicative of graphite. Follow on EM surveys included an aerial TDEM survey and several lines of Min-Max survey.

The initial results implicate several conductive trends that correlate well among the shallow EM survey and progressively deeper Min-Max, IP and TDEM surveys. These potential graphite-bearing trends are more extensive than what was previously expected by Ruby Graphite management. Reflex mobilized a HQ core rig in early August to conduct the first drilling of the property, and as a result, the presence of vein and flake graphite has been proved by the bit.

This is exciting news, as the U.S. has not produced its own natural graphite for more than 40 years. With the growing demand for natural graphite for use as anodes in lithium-ion batteries, the material is recognized as a critical and strategic mineral resource by the U.S. government.

Amanda Griffith

Update on Montana Resources

The Butte Mining District has historically produced a little over 24 billion lbs of Copper, 4.9 billion lbs of Zinc, and 3.7 billion lbs of Manganese, along with Molybdenum, Lead, Silver, and Gold (through 2022). Historical mining of the underground and Berkeley Pit focused on the later “Main Stage” vein type hydrothermal mineralization. Montana Resources opened the Continental Pit in 1986 mining Cu and Mo from low grade ore consisting primarily of porphyry style mineralization.

Over the last 37 years the mine has contributed valuable revenue to the county and state through purchase orders and county and state taxes. The mine currently employs 392 people and operates 24 hours a day, 365 days a year. Ore and waste are mined at a rate of 84,900 tpd, and ore is milled up to 50,000 tpd. Montana Resources produces Cu and Mo Concentrates that are then sold to smelters around the world.

In November of 2022 a slide occurred on the D-East Pushback. The area was identified several months before the slide occurred and was caused by mining into the highly altered enrichment blanket. The supergene alteration lowered the rock strength resulting in a multi-bench, circular failure. Radar was utilized to monitor the area and the slide was predicted within a few hours of when it occurred. Prior to the slide, the highwall in which the slide occurred was the final highwall. Since the slide the decision has been made to add an additional pushback and shallowing the highwall angle through the enrichment zone to lower the potential of future slides.

The Continental Pit has 32 years of production remaining, with the potential to expand to the west into the “Central Zone”. Over the last 3 years Montana Resources has converted historical drill logs (pre 2015) to a digital format to aid in modeling the geology of the area. This model has been incorporated into our reserve model to better define waste areas.

Adrian Van Rythoven

Critical Mineral Potential of the Phosphoria Formation in Southwestern Montana

The Phosphoria Formation is a Permian (~265 – 274 Ma) sedimentary rock unit that occurs in Montana, Idaho, Utah, and Wyoming. Lithology is primarily phosphorite intermixed with terrigenous sediments and intervals of chert. There are two phosphatic members of economic interest: the Retort (upper) and the Meade Peak (lower). The younger Retort Member is much more prevalent in Montana, whereas the Meade Peak is a much more significant member to the south. No current P mines are operating in Montana since the later 1900s, but many abandoned phosphorous mines (some with significant mine dumps) remain. Significant mining of the Meade Peak Member occurs in southeast Idaho. In Montana, the Formation is present as subvertical to steeply dipping sections in Beaverhead, Powell, Granite, Silver Bow, and Madison counties.

In the phosphatic rocks, biogenic apatite (or carbonate-rich apatite: francolite) is the source of phosphorous. Diagenetic processes seem to have variably enriched the apatite in rare earth elements (REES). Grades of up to ~0.27 wt. % total REE (including Y) have been determining using modern analytical methods. Contrary to conventional REE deposits hosted in carbonatite, these members are enriched in heavy REEs, with 40 % to 50 % of the total REE grade being Y, Tb, and heavier REEs. Shaly intervals in the phosphatic members also have sporadic high V, Cr, Ni, and Zn. These are in addition to the known phosphorous resources in the Formation.

Considering the known economics of the Phosphoria for P, the Formation might produce significant critical mineral byproducts given the appropriate metallurgy.

Virginia S. Gillerman

Nd-Enriched Lemhi Pass REE-Th-Fe District, Idaho-Montana: Mid-Paleozoic Mineralization from Crustal-Scale Hydrothermal Circulation?

Three spatially and petrologically distinct groups of rare earth element (REE)–bearing deposits are aligned in a northwest belt across Lemhi County, Idaho, and adjoining portions of Montana. The Lemhi Pass district is located in the Beaverhead Mountains along the Idaho/Montana border at the southeast end of the belt. Mesoproterozoic clastic metasedimentary rocks at Lemhi Pass host multiple quartz veins and biotite-rich shears and replacements containing specular hematite, thorite [ThSiO4] and rare earth minerals, principally monazite. As noted by early workers (Staatz, 1972, 1979), the veins are unusually enriched in neodymium (Nd), a valuable REE for the green economy. Monazite in one deposit contains up to 35 weight percent Nd oxide (EMPA analysis), and in general, REE patterns of district vein samples show a middle rare earth (MREE) hump on chondrite-normalized REE diagrams. Early Cambrian (ca. 530 Ma) syenite and mafic lamprophyre intrusive rocks are present in the district, but the age of the REE-Th mineralization is constrained as Late Devonian (ca. 355 Ma with a broad range) by EMPA chemical ages on monazite and thorite. A similar age (315 Ma) was obtained from ID-TIMS U-Pb age determinations on zircon in an ultramafic sill near one of the dated deposits. Lead isotopes of minerals in the Fe-Th-REE vein deposits are highly radiogenic, and single crystal determinations (ID-TIMS) on Nd-monazite from the Lucky Horseshoe mine returned values of Epsilon Nd from -6 to -7 (model ages of ca. 1.3 – 1.4 Ga), suggesting derivation of rare earths from ancient crustal sources. Still, the unusual chemistry of the deposits has remained unexplained. Lemhi Pass is situated near a Precambrian to Mississippian/Tertiary unconformity, and late Paleozoic-age anoxic strata and SEDEX deposits are present elsewhere in central Idaho. Studies of REEs in sedimentary phosphorites over geologic time suggest a new hypothesis. Shale-normalized REE patterns of marine phosphorites of different ages and locations world-wide typically show flat to hump-shaped patterns (Emsbo et al., 2015), partly due to redox and iron scavenging. The REE patterns of the Lemhi Pass rocks are more similar to those of the Devonian to Carboniferous phosphorites of the Mid-Continent region than to the very different LREE-enriched pattern of mantle-derived carbonatites. Did hydrothermal circulation through anoxic, REE-enriched Devonian strata as well as underlying, oxidized continental basement mix fluids of continental and marine origin, resulting in the unique rare earth concentrations at Lemhi Pass?

Reed S. Lewis

Critical Minerals Research Efforts by the Idaho Geological Survey

The Idaho Geological Survey (IGS) has increased its research efforts on critical minerals thanks to funding from the U.S. Geological Survey's Earth-MRI Program, the University of Idaho, and industry. The objective of our work is to provide detailed geologic maps, geochemical and geochronological analyses of samples, and surface measurements of magnetic susceptibility and radiometric U-Th-K to better understand the distribution, age, and controls of mineralization. To date, much of the work has been in the Salmon area, where we have mapped and refined the Mesoproterozoic stratigraphy of the Idaho cobalt belt (ICB). In addition, we have mapped Mesoproterozoic intrusive rocks thought to be related to copper-cobalt mineralization and investigated Cambrian and Ordovician syenitic rocks for REE potential. Thus far, the IGS has published three 1:24,000-scale geologic maps and a 1:16,000-scale map compilation within the ICB. Additional sampling and geologic mapping in two adjacent quadrangles were completed in September, and a new mapping project north and west of the historic Blackbird mine commenced. The IGS also conducted stream sediment sampling to provide baseline compositional data for Cu-Co and REE concentrations. Historic stream-sediment sampling results have been digitized and published. New Earth-MRI funding in 2023 expanded our mapping efforts to the Mineral Hill REE-Nb district immediately northeast of the ICB. The IGS has also conducted various analyses of a recent cooperative USGS-Industry airborne geophysical survey in this area, including statistical clustering techniques and band ratios of potassium to thorium concentrations. The results inform geologic mapping and identify areas where the radiometric response is discordant with known lithology and may represent alteration, mineralization, or regional-scale contact metamorphism. Several areas identified as anomalous from the airborne survey share a similar radiometric signature to known REE occurrences within the area and represent targets for further investigation. A second Earth-MRI project area is in the western phosphate field in southeast Idaho and adjoining states. Although not currently part of the recovery process, the scale of the western phosphate mining industry suggests that byproduct REE production has the potential to produce a significant part of current U.S. demand, along with other critical minerals such as vanadium and fluorine. Our focus is on the Meade Peak and Retort members of the Permian Phosphoria Formation. The collection strategy has been to measure, describe, and sample vertical sections from suitable outcrops, mine exposures, or core. Geologic and geochemical data for each location will be evaluated and characterized regarding its sedimentology (lithology, grain size, sedimentary structures, degree of bioturbation), gross composition (organic, detrital, chemical), and concentrations of redox-sensitive trace elements, such as Mo, Ni, and V, that assist in characterizing the depositional and early diagenetic setting and identifying flooding surface boundaries between major facies associations. The project is a four-state cooperative effort involving state surveys from Idaho, Wyoming, Utah, and Montana and is administered by the Idaho Geological Survey.

Michael Gary

Using Indicator Minerals Taken From Stream Sediment Samples to Detect Rare Earth Element Deposits

Rare earth elements (REEs) play a vital role in numerous technologies, including electronics, renewable energy, motor vehicles, aerospace, and medicine. However, with a limited supply and the rising global demand for REEs, the exploration and extraction of new REE deposits becomes increasingly crucial for sustaining our modern way of life. This study investigates using indicator minerals in stream-sediment samples as a potentially efficient and cost-effective tool for REE exploration. Stream-sediment samples from the Sheep Creek area (southern Ravalli County, MT) were dried, sieved, gravity separated using a Wilfley table, and separated using a hand magnet. The "heavy, non-magnetic" fraction of the sediment was mounted in epoxy and polished for automated SEM-EDS mineralogical analysis. Results (in progress) confirm the hypothesis that higher concentrations of indicator minerals are found in stream sediment immediately below known REE-Nb-rich carbonatite deposits, with the most useful indicator minerals in the Sheep Creek area being columbite and monazite. Several detritral monazite grains in one of the stream-sediment samples were analyzed by the USGS LTrace laboratory in Denver, using LA-ICP-MS and the Th-Pb dating method. The results show that the age range of detrital monazites in stream sediments is very similar to the age range of monazites collected from the carbonatite outcrops. This confirms that the monazites found in the stream sediment samples are likely derived from carbonatites (the target rock type), and not from Precambrian granite or amphibolite country rock. The results of this study will be combined with new airborne radiometric and magnetic data being flown by the USGS in 2023 in order to get a complete comprehension of the efficacy of utilizing indicator minerals for REE deposit exploration in the Sheep Creek area.

Marisa Redgrave

Geophysical Survey in the Bearpaw Mountains on the Rocky Boy Reservation in Northeastern Montana

The Bearpaw Mountains are located on the Rocky Boy Reservation, approximately 15 miles south of Havre, Montana. This area is known to have abundant natural resources like oil, natural gas, and minerals. The fieldwork in this area comprised two central geophysical data collection systems using the Alta X drone. The first is the Medusa (MS-1000), which detects gamma rays through gamma decay radiation. This is used to identify radioactive minerals like uranium and thorium. The second type of equipment used was a hyperspectral sensor called the Headwall. The Headwall detects spectral signatures using sunlight in the electromagnetic spectrum's visible, near-infrared, and short-wave infrared portions. These signatures are like thumbprints for all materials on Earth and can be used to identify minerals, vegetation, soil, etc. Hand samples were collected from this site and will be used to create a database of spectral signatures with their corresponding chemical composition. The library will allow for easy identification of rocks using spectral signatures. These surveys were conducted to locate and collect data on critical minerals and rare earth elements. The main rock types specified at the site are biotite pyroxenite, shonkinite, monzonite, porphyritic potassic syenite, and assorted pegmatites. The data processing for this fieldwork is ongoing and will be published later.
The rocks in this area have been known to contain rare earth elements and critical minerals. The United States depends on foreign nations to import REE and critical minerals. The dependence on foreign countries leaves the US vulnerable to supply chain shortages, devastatingly affecting the US economy. Locating sites of REE and critical minerals is a matter of national security and has been given the highest priority by the US government.

Sarah Risedorf

New Investigations of the Carbonatite-Related, REE-Nb Deposits in Southern Ravalli County, Montana

The Sheep Creek district in southernmost Ravalli County contains a large number (> 30) of thin (< 4 m) carbonate bodies hosted by deformed and metamorphosed igneous rocks (amphibolite, meta-gabbro, augen gneiss) previously dated to circa 1.37 Ga. The meta-igneous complex and associated REE-rich carbonatite bodies extend into Idaho, and are on strike with the Lemhi Pass Th-REE district, circa 100 km to the southeast. The carbonate bodies, which were mined at a small scale for niobium in the late 1950s and early 1960s, contain a number of REE-rich minerals, including monazite, allanite, ancylite, bastnaesite, and many others. Columbite is the principle Nb mineral. Gangue minerals include ferroan dolomite, calcite, apatite, barite, quartz, actinolite, magnetite, and Ba-rich feldspar. Sparse sulfides include pyrite, pyrrhotite, chalcopyrite, Co-Ni-As sulfides, and molybdenite. Strongly mineralized carbonate bodies are bordered by an albite-phlogopite-calcite rich alteration zone, which is interpreted as a type of fenite. Geochemical analyses of bulk samples from outcrops and mine dumps (n = 40) show a strong enrichment in light REE and depletion in heavy REE, with a lack of europium or cerium anomalies. This pattern is typical of carbonatites, worldwide. Stable isotopes of carbonate minerals are consistent with a primary magmatic origin overprinted by a high-temperature hydrothermal event.   Th-Pb dating of monazite and Re-Os dating of molybdenite indicate a late Jurassic to early Cretaceous age for the mineralization at Sheep Creek. More geochronological studies are planned. To date, the work described above has been funded by a grant from the DEVCOM Army Research Laboratory to Montana Tech. Other agencies, including the Montana Bureau of Mines and Geology, the Idaho Geological Survey, and the U.S. Geological Survey, are commencing scientific work in the Sheep Creek/Mineral Hill area, and the USGS plans to fly airborne geophysics (magnetics and radiometrics) over the region in 2023. The company that owns the mineral rights in the Sheep Creek area is collecting stream-sediment and soil geochemistry. As of this writing, there are no immediate plans to commence mining in the district.

Alexei S. Rukhlov

Episodic Carbonatite Emplacement in the Canadian Cordillera from 810 to 330 Ma: From Supercontinent Breakup to Orogenic Convergence

Carbonatites are igneous rocks containing abundant primary carbonate minerals. As the exclusive source of critical metals such as niobium (e.g., St. Honoré, Quebec) and rare earth elements (e.g., Mountain Pass, California), these rare rocks have become important exploration targets. In the Canadian Cordillera, carbonatites were emplaced episodically at ca. 810-700, 500, and 360-330 Ma, forming part of the Cordilleran alkaline province, a long (at least 4,600 km), narrow (ca. 200 km) orogen-parallel belt. Like carbonatites globally, which are typically restricted to intracratonic settings as part of crustal-scale doming and extensional systems, the Neoproterozoic and Cambrian carbonatites were injected during the protracted breakup of the supercontinent Rodinia and subsequent passive margin development on the western flank of Laurentia. In contrast, the more numerous late Paleozoic carbonatites, which host Nb-Ta deposits (e.g., Fir in the Blue River area and Aley) and REE deposits (e.g., Wicheeda) are unusual because they were emplaced near the continental margin while subduction was taking place to the west rather than in the cratonic interior during continental breakup.

In the Blue River area of east-central British Columbia, at least 18 carbonatite and two alkaline, silica-undersaturated-rock bodies are exposed, including at the Fir deposit, one of the largest and best studied Nb-Ta occurrences in the Canadian Cordillera. The Fir carbonatite contains an NI 43-101-compliant resource of 48.4 million tonnes (Indicated) grading 1,610 ppm Nb2O5 and 197 ppm Ta2O5 plus 5.4 million tonnes (Inferred) averaging 1,760 ppm Nb2O5 and 191 ppm Ta2O5. The carbonatites, consisting mainly of ferroan dolomite or calcite, are hosted by metamorphosed Neoproterozoic pelitic, arenaceous, and amphibolitic rocks of the Mica Creek assemblage. Both the carbonatites and host rocks experienced multiple episodes of deformation and metamorphism during Mesozoic to Cenozoic accretionary tectonics while outboard terranes welded to each other and to Laurentia. The carbonatites form isoclinally folded sill-like tabular bodies up to 72 m thick. Metamorphosed up to amphibolite grade, they display diverse fabrics including coarse-grained, granoblastic to fine-grained, foliated, and porphyroclastic varieties. The unusual Ta-rich Nb minerals are spatially associated with coarse molybdenite. Despite the metamorphism and deformation, most carbonatites in British Columbia, except the late Paleozoic Nb-Ta and REE carbothermal rocks, retain primary mantle carbon and oxygen isotopic signatures. Furthermore, in Sr-Pb-Nd isotopic correlation diagrams, the British Columbia carbonatites define mixing trends involving FOZO (FOcus ZOne), HIMU (high-$^{238}U/^{204}Pb$ or μ), and EM1 (enriched mantle 1) mantle end members found in oceanic basalts, young (<200 Ma) carbonatites worldwide, and the plume-related Kola alkaline province (ca. 370 Ma), and a high- $^{3}He/^{4}He$ FOZO component indicates a relatively deep-seated source. Notably, the depleted, mid-ocean ridge mantle (DMM) end member, representing the upper mantle, is excluded from the mixing trends defined by the carbonatite data from British Columbia and elsewhere. Paleogeographic reconstructions place the western margin of Laurentia, and hence the 810-330 Ma British Columbia alkaline province, above the equatorial large low shear wave velocity province (LLSVP) marked by a long-lived reservoir at the core-mantle boundary ('plume-generation zone' or PGZ). These data indicate that parental magmas of Cordilleran carbonatites and related rocks were derived from a long-lived, deep-level mantle reservoir that was tapped episodically since the Neoproterozoic. We suggest that the 810-700 and 500 Ma intrusions record tapping during the breakup of Rodinia, and that the 360-330 Ma bodies record tapping triggered by lithospheric extension resulting from the late Paleozoic subduction along the western flank of Laurentia that created the Slide Mountain ocean as a back-arc basin.

Allen K. Andersen

Earth MRI Program Overview and USGS Critical Mineral Research in the Northwestern United States

The Earth Mapping Resources Initiative (Earth MRI) is a nationwide effort led by the U.S. Geological Survey and its state and private sector partners to improve our knowledge of the geologic framework in the United States and to identify areas that have potential to contain undiscovered critical mineral resources. The project aims to enhance our domestic mineral supply and decrease the Nation's reliance on foreign sources of minerals that are fundamental to our security and economy. Since its inception in 2019, Earth MRI has funded major geoscience projects including airborne magnetic and radiometric surveys, detailed geologic mapping, geochemical reconnaissance surveys, high-resolution elevation (lidar) surveys, and mine waste characterization studies.

In the Northwest region, three major airborne geophysical surveys have been completed and additional surveys are planned in 2024. The Idaho Cobalt belt survey completed in 2022 covers an area with known cobalt, copper, and gold resources in Proterozoic metasedimentary rocks. These baseline data provide a regional context to more local data collection efforts including unpiloted aerial system hyperspectral, field magnetic susceptibility, X-ray fluorescence, and radiometric measurements collected in ground campaigns. The Boulder Batholith geophysical survey covers the Late Cretaceous Boulder Batholith and co-magmatic Elkhorn Mountains Volcanics, located along the Continental Divide in southwestern Montana. This well-preserved example of continental arc magmatism hosts several different mineral systems and deposit types including porphyry copper-molybdenum, skarn, auriferous breccia-pipe, and polymetallic vein deposits with the potential to contain byproduct critical commodities. Ore mineral systems are present in northeast Washington state where the Paleozoic western margin of North America has experienced periods of terrane accretion, deformation, metamorphism, and intrusion. The recently completed Republic survey covers 12,700 square kilometers with critical mineral potential in basin brine path, metamorphic, porphyry tin (granite-related), reduced intrusion-related, and volcanogenic seafloor mineral systems, among others.

In addition to the efforts funded by Earth MRI, the USGS Mineral Resources Program funds additional critical mineral research projects throughout the northwestern U.S. Through the project, Evaluation of Critical Elements in Carbonatites, researchers are examining rare-earth element (REE) enrichment in mineralogically similar carbonatite intrusions of the Bearpaw Mountains, Montana and Bear Lodge Mountains, Wyoming, that occur along the northern and eastern margins of the Archean Wyoming craton, respectively. Intrusion of the carbonatite magmas was likely contemporaneous (~50-53 Ma), but the disparate epsilon-neodymium values (0 and -10) indicate potentially different mantle and crustal source components, and thus a different magmatic evolution toward a similarly REE-enriched carbonatite composition. Critical mineral resource potential is also being investigated along the lower contact of the Stillwater Complex in Sweet Grass County, Montana. Potential ore-grade enrichments of nickel, copper, and platinum-group elements (PGE) occur in disrupted portions of the Peridotite zone and Basal series within discordant dunite masses, pyroxenite pegmatoids, magmatic breccias, and structurally controlled vermiculite-rich rock. The highest PGE grades within the lower stratigraphy are commonly found for samples containing sulfide globules in proximity to disaggregated chromitite schlieren. Mineralogical studies of chromite-rich samples show that PGE are hosted mainly by bismuth tellurides, arsenides, antimonides, arsenic-sulfides, and platinum-iron alloys.

Eric Anderson

Earth Mapping Resources Initiative – A Montana perspective

The Earth Mapping Resources Initiative (Earth MRI) is a partnership between the USGS, State Geological Surveys, and other Federal, State, and private sector organizations. The fundamental goal is to improve the three-dimensional geologic framework of the Nation and identify potential critical mineral resources. Earth MRI provides support for state-of-the-art geologic mapping, high-resolution airborne geophysics, and topographic (lidar) surveys and in Montana, an airborne geophysical survey was flown in June 2022 over part of the Boulder batholith with a second survey currently being flown west of the initial survey. Together these surveys cover 14,500 km2 with new surveys near the Montana-Idaho border scheduled in 2024. All surveys collect magnetic and radiometric data, are flown along east-west flight lines spaced 200 m at a nominal terrain clearance of 100 m, and are publicly available through the USGS ScienceBase data repository.

The USGS Mineral Resource Program provides project support for research and mineral assessments. A five-year project "Porphyry Copper Systems of the Boulder batholith, Montana" began in 2023 that leverages the Earth MRI-funded geophysical data to support field-based geologic mapping and mineral resource potential of significant mineral systems of the Boulder batholith. The overarching project objectives include: 1) development of new geophysical, geological, and metallogenic interpretations that are informed by new airborne geophysical data, 2) development of geologic characterization to provide broader scale geologic, geochronologic, and petrogenetic interpretations in support of detailed geologic mapping conducted by the Montana Bureau of Mines and Geology, and 3) development of new interpretations of the relationships between volcanic and plutonic rocks and accompanying mineral systems.

A summary of the high-resolution geophysical data from the 2022 survey will be compared to previous geophysical data, with examples highlighting their potential for integration with existing geologic and mineral resource information. The magnetic data were reduced-to-the-pole so that anomalies are better aligned over causative sources. The first vertical derivative, tilt derivative, and analytic signal were applied to highlight components of the magnetic field. The radiometric data were processed to show changes in potassium, thorium, and uranium concentrations in the upper few centimeters of the Earth's surface. Some of the preliminary results from the 2022 geophysical survey clearly indicate intrusions having a pronounced magnetic character occur beneath basin-fill sediments and within sedimentary and volcanic rock packages. In addition, map patterns in both the radiometric and magnetic anomaly maps highlight folds within the Paleozoic and Mesozoic rock sequences. Finally, strong contrasts will be shown within the radioelement concentration and magnetic field maps along the eastern geologic contact between the Butte granite and volcano-plutonic rocks of the Elkhorn Mountains for over 80 km along strike. These combined observations underscore the potential of using the newly acquired, high-resolution, airborne geophysical survey data in geological framework mapping and for the exploration of critical mineral resources.

Danie Grobler

Ni+Cu+PGE Mineralization within the Lower Ultramafic Series of the Stillwater Complex, Montana, USA

Stillwater Critical Minerals (SCM) is exploring for base and precious metals within the Archaean Stillwater Igneous Complex. The SCM exploration properties cover the largest part of the stratigraphic lower third of the central and western portion of the layered intrusion, from the Basal Series, at the footwall contact, upwards into the Peridotite and Bronzitite Zones of the Ultramafic Series (UMS).

Rocks of the Peridotite Zone are conventionally interpreted to be repetitive, laterally continuous with layered cyclical units of olivine, orthopyroxene (bronzite), and chromite cumulates. This textbook stratigraphic model was developed in the eastern portion of the Stillwater Complex, some distance from SCM's focus areas to the west.

In general, the lower Stillwater Complex exhibits a very similar stratigraphy to that of the Platreef with ultramafics and chromitites near its base grading into predominantly pyroxenites higher up. It further displays the same metal distribution pattern as the Platreef, with PGE-enrichment towards the top of the Ultramafic Series, and base metal sulfide enrichment into the footwall contact zone. However, stratigraphic correlations within the central to western part of the lower Stillwater Complex (Chrome and Iron Mountain area) are complicated by structural complexity, lateral lithological variations and late- to post-magmatic assimilation and alteration processes. Furthermore, recent geological mapping point to a very different picture for the Chrome Mountain and Iron Mountain areas where only part of the Peridotite Zone is developed compared to that in the eastern part of the Stillwater Complex. Importantly, the upper portion of Chrome Mountain appears to be represented by PGE+Ni+Cu-bearing pegmatoidal orthopyroxenite with associated chromitite stringers probably of Bronzitite Zone affinity. This may be of significant exploration importance since historic descriptions of mineralisation within the lower Stillwater Complex have always been correlated with the Peridotite Zone.

The Platreef represents the textbook example of Contact-Style Ni+Cu+PGE deposits. Historically, the Platreef is defined as a 100-400m thick interval of mineralized pyroxenitic to harzburgitic intrusives that represents the Upper Critical Zone (UCZ) of the Bushveld Complex abutting/stoping into a series of platform sediments. Grobler et al proposed a new hybrid exploration model where the higher-grade PGE+Ni+Cu mineralized Upper Platreef is modelled to represent the Bastard and Merensky reefs with a UG2 chromitite reef developed down-dip away from the magma-sediment assimilation zone.

This model explains the broad zones of mineralisation found at specific stratigraphic positions within the contact zone of layered intrusions. Of much importance is that the broad magmatic layered stratigraphy is still preserved in the contact assimilation environment but exhibit more diffuse and disturbed contacts and have abundant xenoliths and more sulfide. It was shown on the Platreef that the three PGE+Ni+Cu mineralised zones represented by the Bastard, Merensky and chromitite seams can be identified within the contact zone of the shallow Platreef where it forms a broad zone of sulfide-rich mineralisation, disrupted, and concentrated in places by partially assimilated country rock xenoliths. It explains the high-grade mineralisation ("Merensky") found at the upper contact of the Platreef as well as the base metal-enriched basal contact zone associated with external sulfur assimilation from footwall sediments. Application of the above "contact-style stratiform reef model" in combination with a detailed structural interpretation forms an important exploration strategy to identify continuous high-grade zones of mineralisation within the lower part of mafic-ultramafic layered complexes. These disrupted contact-style layers (including the Merensky equivalent on the Platreef) are more sulfide rich than the internal layers because the former assimilated sulfidic sediments that formed the immediate host rocks to the intrusion.

The SCM exploration team has also identified a new style of Ni+Cu+PGE+Au enriched mineralisation within the Chrome Mountain area. This mineralisation is enriched in nickel-pge's and occurs within NNW-trending cross-cutting structures. At leas three of these mineralised structures have been drill intersected during the current exploration season. The structures are identified by their orientation, mineralisation and alteration styles and geophysical anomaly characteristics.

Chris Gammons

New Investigations of the Winston Gold-Mining District, Montana

The Winston mining district, located in the Elkhorn Mountains 20 miles southeast of Helena, produced over 100,000 oz of lode gold between 1906 and 1957. The district contains several dozen small to medium-sized lode mines, the majority of which exploited steep, east-west trending quartz-sulfide veins cutting Elkhorn Mountains Volcanics near a set of porphyry intrusions. From north to south, the latter include the Edna, Frieburg, January, and Vosburg (Olga) stocks. The stocks themselves are hydrothermally altered and locally contain abundant sulfides (pyrite, pyrrhotite, galena, sphalerite, chalcopyrite and trace molybdenite). Between 1984 and 1995, extensive drilling campaigns were conducted in the Winston District in an effort to define one or more large, bulk-tonnage gold deposits. The author made several visits to the district in 2019-2023, which included examination of the underground workings exposed in the new Carrabba Tunnel. New data are herein reported on the ore mineralogy, S-isotope geochemistry, and fluid inclusions contained in two of the larger mines in the district (Carrabba Tunnel/Custer Vein and the East Pacific Mine). In the Custer Vein, gold occurs as electrum in grains up to 50 microns in diameter in association with abundant pyrite and arsenopyrite, with lesser base metal sulfides and local scheelite. Veins at East Pacific are rich in sphalerite, galena, chalcopyrite, and Ag-rich tetrahedrite in addition to pyrite and arsenopyrite. The S-isotope composition of sulfides ranges between +1.1 and +6.3 ‰ (VCDT), values that are typical for polymetallic veins associated with the Boulder Batholith. Fluid inclusions in quartz are abundant. The majority are 3-phase, CO2-rich inclusions with moderate salinity (3 to 8 wt% NaCleq) that show final homogenization to the brine (liquid water) phase at temperatures of 250 to 370°C. Many CO2-rich inclusions decrepitated at T > 280°C before final homogenization. Overall, the characteristics of the fluid inclusions indicate a high pressure and depth of trapping that is inconsistent with an epithermal origin. Instead, it is speculated that the mineralization at Winston may belong to the “Reduced Intrusion-Related Gold System” (RIRGS) category of gold-rich, polymetallic vein deposits. Other gold-rich deposits in the Elkhorn Mountains may also be RIRG systems, including Radersburg (e.g., the Keating Mine) and Diamond Hill, as well as the Elkhorn mining district itself. Across Canyon Ferry Reservoir in the Big Belt Mountains, the Miller Mine (aka Miller Mountain Mine) has been listed by previous workers as a likely RIRGS deposit. Geochronological studies (in progress) are needed to establish the age of the porphyry stocks that are believed to be responsible for the mineralization in each of these districts.

Celine Beaucamp-Stout

Trace Elements in Fluorescent Sphalerite of the Philipsburg Mining District, Granite County, Montana

Sphalerite is a mineral known to regularly contain trace elements, many of them being valuable as critical commodities. Some sphalerite samples from the Philipsburg mining district, Granite County, Montana, display unusually bright fluorescence (red, orange, yellow, blue, purple, green) under longwave UV light (365nm). They were analyzed for trace elements and compared to low-to-non-fluorescent samples from the same district to understand which elements produce specific fluorescent responses. The Philipsburg mining district has been identified as a cordilleran polymetallic Ag-Cu-Zn±Pb lodes district, associated with a Mo-Cu porphyry of unknown extent.

Sphalerite samples from Philipsburg were analyzed with Laser Ablation Inductively Coupled Mass Spectroscopy. The data were filtered to remove solid inclusions and reflect only lattice-bound substitutions. All the fluorescent samples come from a high-sulfidation central zone where the low-Fe sphalerite coexists with enargite and tennantite. Fluorescent samples contain variable amounts of Cd, Cu, Ga, ± In, Hg, Ge, and W. Gallium averages 525 ppm (max value of 4997 ppm), and indium aver ages 114 ppm. Iron is Iron is remarkably low (average of ~100 ppm), while copper is high (average of 907 ppm). Also, up to ~2000 ppm of tungsten was detected in the sphalerite lattice of four fluorescent samples (average of the four samples: 152 ppm). When separated by fluorescence color, the data revealed that samples with the lowest amount of trace elements systematically fluoresce blue and green, while samples with the highest amount systematically fluoresce bright red. Orange and yellow fluorescence are intermediate colors with intermediate content of trace elements.

In comparison, low-to-non-fluorescent samples come from both high-sulfidation and low-sulfidation areas. The trace elements in these samples are Fe, Mn, Ag, Cd, Cu, As, Pb, Sb, Sn ± Ge, and Hg. Notable values are high silver (>1000 ppm) and high germanium (average of 255 ppm). Copper also remains high in these samples (average of 2280 ppm), while iron is variable (generally low with an average of ~100 ppm except for the Granite Bi-Metallic Mine which averages at ~ 50,000 ppm).

Some elements have the same valence as Zn^{2+} and can substitute directly into the ZnS lattice, including Fe, Mn, Cd, Hg, Pb, and Sn. Other elements require coupled substitution to maintain the overall charge balance: Cu, Ag, As, Ga, In, Sb, Ge, and W. In fluorescent sphalerite, the following coupled substitutions are proposed: $Cu^{+} + (Ga^{3+}, In^{3+}) = 2Zn^{2+}$ and $2Cu^{+} + Ge^{4+} = 3Zn^{2+}$. The valence for tungsten is suggested to be 6+, allowing for the coupled substitution of tungsten and copper for zinc as follows: $4Cu^{+} + 6W^{6+} = 5Zn^{2+}$ without the need for vacancies. In the low-to-non-fluorescent samples, the following coupled substitutions are proposed: $(Cu^{+} + Ag^{+}) + (As^{3+}, Ga^{3+}, In^{3+}, Sb^{3+}) = 2Zn^{2+}$ and $2(Cu^{+} + Ag^{+}) + (Ge^{4+}, Te^{4+}) = 3Zn^{2+}$.

Trace elements in sphalerite have been studied extensively, but associated fluorescence is usually not reported. These preliminary results indicate a correlation between fluorescence and specific elements, although the fundamental mechanisms creating the fluorescence are unclear, and should be investigated further.

Karen Lund

Structural Evolution of Gold-bearing Cobalt-Copper Deposits of the Blackbird Mining District, East-Central Idaho

Structural evolution of sediment-hosted, Au-bearing, Co-Cu deposits of the Blackbird mining district is elucidated by regional studies integrating the Mesoproterozoic depositional setting and stratigraphy with the subsequent tectonic history. Stratigraphic revisions show that the Blackbird deposits are unique to thick turbiditic, Fe-enriched successions of the Mesoproterozoic banded siltite unit of the Apple Creek Formation, upper part of the underlying coarse siltite unit of the Apple Creek, and basal part of the overlying Gunsight Formation. Regionally, exposure of mineralized host rocks is controlled by parallel northwest-trending thrust faults that are dated at 83 Ma by 40Ar/39Ar cooling data on white mica from cleavage. The Blackbird district lies within the Blackbird Mountain oblique thrust ramp where locally intense deformation resulted in three imbricate subplates that are stacked in inverted metamorphic sequence. Subsequent Eocene normal faults juxtaposed different structural levels side-by-side.

(1) The Indian Creek subplate is structurally highest, composed of compositionally layered chloritoid-garnet-biotite schist that reached 400-520o C and contains lowest Cl and K2O values. Mineral deposits are in sheared quartz-rich zones and contain relatively low sulfide and high As and Au. (2) The structurally central Blackbird subplate is characterized by bedded biotite phyllite and transposed biotite schist that was metamorphosed at 250-350o C. These rocks are characterized by intermediate Cl and K2O values. Co-Cu sulfides are in layered packages, quartz veins in fold hinge and shear zones, and ductility-contrast durchbewegung zones. Relative proportion of Co:Cu decreases and secondary sulfide mineral increases with greater evidence of metamorphism and deformation.

(3) The structurally lowest Haynes-Stellite subplate has the youngest strata. These rocks are gently folded, lower greenschist facies, bedded biotite phyllite having highest Cl and K2O values.

These contain high Co:Cu ratio and little evidence of secondary sulfide mineral formation.
Variations in metamorphic character, sulfide mineral paragenesis, and halogen contents in individual structural domains at Blackbird are products both of different mineral deposit origins and of heterogeneous tectonic processes.

Kyle Nacey

Black Butte Copper Project Update, MT, USA

The Black Butte Copper Project is a sediment hosted copper deposit located 15 miles north of White Sulphur Springs, MT and is estimated to be the second highest grade copper deposit in the world. The deposit is hosted within the Helena Embayment of the Belt Basin. Not including copper, the deposit hosts a wide variety of critical minerals including cobalt, barite, germanium, arsenic, and zinc. The Johnny Lee upper copper zone resource contains 9,658kt of copper while the lower copper zone contains 1,222kt of copper for a combined 10,880kt of copper.

Kyle Eastman

Geology, Mineralization, and Critical Minerals Potential of the Radersburg and Giant Hill 7.5' Quadrangles, Broadwater County, Montana

The Montana Bureau of Mines and Geology (MBMG) has received federal funding through the USGS Earth Mapping Resources Initiative (E-MRI) to conduct geologic mapping and critical minerals research in the Radersburg and Giant Hill 7.5' quadrangles. This area includes the historic Radersburg and Park mining districts, which have experienced significant magmatic activity related to the eastern margin of the Late Cretaceous Boulder Batholith. This magmatic activity is recognized within the region as the source of mineralizing hydrothermal fluids, and detailed mapping of volcanic and intrusive rocks will aid in the understanding of ore-forming processes and critical minerals prospectivity.
Mineralization in the Radersburg and Park districts consists of Au-bearing pyrite veins, polymetallic epithermal veins, porphyry Cu-Mo prospects, skarns (Cu-Au), and Pb-Zn±Ag carbonate replacement deposits. These deposit types may contain critical commodities such as Ge, Ga, In, V, Mo, Mn, W, Bi, P, U, As, Sb, and Te (Hofstra and Kreiner, 2020).
Activities supported by this grant include geologic mapping at the 1:24,000 scale, detailed geologic mapping at 1:12,000, geochemical sampling and analysis, optical petrography and scanning electron microscopy, and geochronology. These quadrangles are included in a 2022 E-MRI geophysical survey, and this geologic mapping project supports geophysical ground truthing.
This project intends to provide actionable information regarding the critical minerals prospectivity of the region, with primary stakeholders including state and federal land management agencies, local landowners, and the exploration/mining industry. Geologic mapping and geochemical sampling will also provide useful context for geohazards, groundwater, and geo-environmental investigations. Also supported by this project are salaries for student field and lab assistants, which provides valuable research experience with a critical minerals project.

Kaleb Scarberry

Geologic Mapping and Mineralization of the Elkhorn 7.5' Quadrangle and Historic Mining District, Jefferson County, Montana

The first USGS Earth Mapping Resources Initiative (E-MRI) geologic mapping project in Montana was the Elkhorn 7.5' quadrangle, competed in 2020-2022. The two major science goals of this project were to (1) refine the understanding of the Boulder Batholith magmatic system and (2) assess the critical commodity potential of mineral deposits in the Elkhorn quadrangle. Here we present our results that are focused on critical commodity and resource occurrences, and geologic relationships between the Late Cretaceous magma system (Boulder Batholith – Elkhorn Mountains Volcanics, or EMV's) and magmatic-hydrothermal mineral deposits. This project included 100 whole-rock geochemical analyses and additional geochronology, which adds to the available data on the Boulder Batholith region.
The association of metallic mineral deposits with igneous rocks has been a long-known fact for mineral prospectors in Montana at least since the gold strikes at Grasshopper Creek (1862), Alder Gulch (1863) and Last Chance Gulch (1864). The discovery of silver 35 miles (50 km) northeast of Butte led to establishment of a mining camp at Elkhorn in 1872 (Fig. 1) (Albright, 2004). The Elkhorn mines produced over $15 million in ore from deposit types that included Ag, Pb, Zn (Au) carbonate replacements, Fe-oxide skarns, sulfide-rich and sulfide-poor Au-Bi skarns, tourmaline-bearing breccia pipes and an unmined porphyry Mo (Cu) system (Brown and others, 2019). Earth-MRI Phase II critical metals, Platinum Group Elements (PGE's) and tungsten (W), are associated with the types of magmatic hydrothermal base metal replacement/skarns and porphyry Au mineral systems that are known in the Elkhorn 7.5'.

Amanda Rossi

Upcoming MBMG Economic Geology Projects

The rapidly growing economic geology program at the MBMG has a number of upcoming projects, with research focused on critical minerals prospectivity assessments of historically important mining districts. During the 2023 field season, MBMG conducted reconnaissance sampling of mine sites within the Boulder Batholith region, including the Butte District, and expects to ramp up fieldwork in the Boulder Batholith during 2024. Following on the Boulder Batholith, research will expand to cover other areas including the Pioneer Batholith, the Philipsburg District, and the Central Montana Alkalic Province. The Stillwater layered mafic PGE deposit is a well-known example of a critical minerals resource in Montana, and is also a target for future E-MRI geologic mapping and geophysical studies. A preliminary critical minerals prospectivity assessment has been conducted for the Boulder Batholith region, based on methodology from Hofstra and Kreiner (2020). This assessment includes historic mining districts throughout the region, active and recently active mine sites, and areas with ongoing exploration activity. Of the critical minerals determined by the USGS, the elements arsenic (As), bismuth (Bi), manganese (Mn), antimony (Sb), tellurium (Te), and zinc (Zn) are most well-represented in the Boulder Batholith. Zinc is common as the mineral sphalerite (ZnS), and may contain trace but important levels of the critical elements indium (In), gallium (Ga), germanium (Ge), as well as cadmium (Cd, not currently a critical element). Manganese, antimony, arsenic, and zinc are all common components of polymetallic epithermal vein systems and can be byproduct commodities at porphyry deposits. Bismuth occurs at some skarn deposits, carbonate replacement deposits may contain supergene vanadium (V), and molybdenum (Mo) deposits may contain rhenium (Re). Tellurium (Te) occurs at some epithermal gold-silver and polymetallic mines, and may be associated with

bismuth.
Ongoing geological mapping, geochemical sampling, and geophysical surveys in Montana supported by the USGS Earth Mapping Resources Initiative (E-MRI) program and other grants will yield new insights into critical minerals ore-forming processes.

John Sanford

Modern Data Delivery

The MBMG has long had large and complex databases of geologic and hydrogeologic data. The main focus going forward is to make that data available to staff and to the public in GIS format. Translation of the data into ArcGIS enterprise level databases began in February 2022, and the GIS team has made significant strides in spatializing data that was otherwise only available in tabular fashion.
The goals of spatialization of data, the enterprise data management process, and modernization are to be able to create 2D maps, 3D maps, and statistical and analytical dashboards that will better visualize the MBMG data in a more modernized and scientific look and feel. ESRI states that 65% of people understand data better when they can visualize it, whether as maps or as charts and graphs. The GIS staff have built 30+ new applications as web maps, in both 2D and 3D space, and as a suite of analytical dashboards that allow for a statistical look at our data.
Part of the modernization process is to provide better and more streamlined access for our public constituents. We want the public to have easier access to our maps, apps and data. MBMG's new GIS Open Data Hub Site, built on the ArcGIS Hub Site platform, was released early this summer. The "Hub" site for GIS is exactly that, a one stop shop for all web maps, analytical dashboards, and story maps, along with direct download access to the MBMG GIS data.

Denise Herman and Connie Thomson

Standing on the Shoulders of Giants: Preserving Rock Collections for Future Study

The MBMG's Data Preservation Program preserves the legacies of past, current, and future geology giants by archiving and managing their collections of documents, maps, photographs, and geologic materials.
While paper documentation can be digitized, the value of physical specimens lies in visual examination and consumptive analyses. Some geologic exploration areas represented by samples are no longer accessible, which makes preserving samples from those sites of even greater importance. The MBMG manages these samples not as museum pieces, but as assets to be used as the foundation for future research.
The MBMG also preserves incoming samples from our field geologists to facilitate future research. The Mineral Separation Lab sets aside a portion of each new raw sample and its analysis residue. These materials are labeled and inventoried to permit easy retrieval from our repository.
Our new in-house data management system streamlines our inventory, tracking, and analysis. Selected information from this database is printed onto QR labels for each sample container to provide immediate reference of its provenance and processes.
Aided by a U.S. Geological Survey National Geologic and Geophysical Data Preservation Program (NGGDDP) grant matched with State funding, we have archived several important collections, including the Anaconda Research Collection, and will soon be working on collections from Bob Chadwick and Todd Feeley.

We are nearing completion of a building dedicated to our archived geologic materials. This building includes both storage space and work space to stage and examine samples on site. Funding for this was also provided by NGGDDP funds with matching State funds. Collaboration between the MBMG's Mineral Separation Lab and the Data Preservation program expands our ability to successfully preserve the work of individual field geologists and to inform future investigations.

Colleen Elliot

A New View of the Chief Joseph Plutonic-Metamorphic Complex, SW Montana

The Chief Joseph Plutonic and Metamorphic Complex (CJPMC) was defined in 1983 as the complex geologic terrane at the eastern end of the Bitterroot Lobe of the Idaho Batholith by Neal Desmarais in his PhD dissertation. The CJPMC occupies the topographically non-descript area between the Anaconda, Bitterroot, and Beaverhead ranges, is made up of WNW-trending lenses of amphibolite facies metasedimentary rocks surrounded by late Cretaceous and Paleogene plutonic and volcanic rocks. New MBMG mapping at 1:24,000- and 1:100,000-scale reveals that the Foolhen metamorphic complex and most of the Pioneer Batholith are also part of the complex, giving it an outline that extends roughly WNW from Hecla in the East Pioneer Mountains to the Bitterroot Valley.

The metasedimentary rocks of the CJMPC have Mesoproterozoic through Cretaceous protoliths that have reached amphibolite facies through partial melting pressures and temperatures. They are structurally complex and typically reflect three generations of ductile deformation structures. The youngest ductile generation is a broad shear zone that is roughly parallel to the Lewis and Clark Zone that creates a left-lateral jog in the structure of the Cordilleran fold and thrust belt.

The igneous rocks of the CJPMC can be roughly divided into three groups: 76-72 Ma biotite-hornblende granodiorite that is commonly foliated, 68-60 Ma peraluminous granite and granodiorite, and 53-48 Ma volcanic and hypabyssal dacite and rhyolite associated with the Challis and Lowland Creek volcanic suites. The 68-60 Ma peraluminous "two-mica" granites were once thought to represent the igneous metamorphic core of the Anaconda Complex, but pre-date extension and are found in both the footwall and hangingwall of the detachment. On a regional scale, the two-mica granites are part of a the North American Cordilleran Anatectic Belt of muscovite-bearing S-type granitic rocks.

The CJPMC is dissected by the Upper Big Hole Valley segment of the Anaconda Detachment Zone. The east half is in the Pioneer Mountains and the west half makes up the footwall of the Anaconda Detachment. The detachment dies out at near the edge of the CJMPC, and extension is transferred to a massive dike swarm along the continental divide.

The association between the CJPMC and mineral deposits has not been examined, though the complex is within the Idaho-Montana Porphyry Belt. The newly-recognized expanded footprint of the CJPMC encompasses the Hecla, Cannivan Gulch, Calvert, and Crystal Mountain mines, as well as a number of small gold and silver mines and placers. Our new understanding of the shape, extent, and age of the CJPMC suggests that it is a regionally significant structure that warrants a closer look.

Poster Presentations

Madeline A. Murchland

Mineralogical and Geochemical Investigation of the Mineral Hill Carbonatites, East-Central Idaho

The Mineral Hill district, in northern Lemhi, County, Idaho, hosts anomalous amounts of several critical minerals, namely rare earth elements, Ti, Nb, Ta, and Ba. The majority of this mineralization occurs in a belt of tabular carbonatite bodies that trends northwest into Montana, to become the Sheep Creek mining district. Several historic studies have generally characterized these deposits; however, their potential as hosts critical mineral sources warrants current research with updated methods. Our initial work focuses on the Upper and Lower Roberts, Lee Buck, and Cardinal prospects. These areas have been recently sampled, and optical petrography, scanning electron microscopy with energy dispersive spectroscopy, and powder X-ray diffraction are being utilized to determine the mineralogy, main rare earth-bearing phases, and phase relationships in both the carbonatites and their host rocks. Preliminary study with these methods has revealed that for each of the localities, the primary carbonate is intermixed calcite and dolomite, with accessory magnetite, amphibole, and monazite. Additional accessory phases vary by property; however, the Lee Buck and Cardinal properties show abundant allanite, fluorapatite, and barite.
This work has created a foundation for a more in-depth study on the geochemistry and paragenesis of the carbonatites by providing a general mineralogy and identifying minerals for dating. In addition to continued mapping and sampling efforts by the Idaho Geological Survey, electron probe microanalysis (EPMA) will be used to better characterize the chemistry of the rare earth-bearing phases, while wavelength dispersive X-ray fluorescence (WDXRF) and inductively-coupled plasma mass spectrometry (ICP-MS) will provide major, minor, and trace element analyses. EPMA and laser ablation ICP-MS methods will be used to date multiple phases, including apatite, monazite, and baddeleyite. Stable isotope analysis using carbon and oxygen will also be conducted for the purpose of confirming the deposits have an igneous origin. Overall, this research will support the United States Geological Survey's efforts to identify domestic critical mineral sources with the Earth Mapping Resource Initiative, as well as aiding in modern exploration efforts in the state of Idaho.

Cody J. Steven

Petrologic Characteristics of Cambro-Ordovician Intrusions in East-Central Idaho: Rare Earth Element Anomalies and Mineralization Potential

Trending along the western Laurentian rift margin is a series of Cambrian to Ordovician intrusions, several of which are in Idaho. The intrusions are relatively small, with map expressions frequently spanning roughly four square miles for each stock. In general, each intrusion is composed of several lithologies but dominated by syenite. Lithologies from the Deep Creek complex include hornblende syenite and gabbro, a lamprophyre dike, a theralite sill, and allanite-rich breccias along the contacts. Primitive compositions from the Cambro-Ordovician intrusions are typically sills and dikes that are enriched in compatibles while stocks are comprised of syenite enriched in incompatibles. In contrast with subduction-related syenites and granitoids of the Idaho batholith, Cambro-Ordovician intrusions have exceptionally high total alkalis and Ce+Zr+Y+Nb, and are interpreted as anorogenic melts. Small-volume partial melting, crustal metasomatism, and fractionation from the Cambro-Ordovician magmatic event has concentrated incompatibles in the Deep Creek intrusive suite, which has potential for rare earth element occurrences.

Liam D. Knudsen

Geologic Investigation of an Airborne Gamma Radiometric Survey, Salmon River Mountains, Idaho

Airborne gamma radiation surveys measure the concentrations of potassium, uranium, and thorium in the top 30cm of the Earth's surface. Because individual rock lithologies typically have unique concentrations of potassium, uranium, and thorium, airborne gamma radiation data is used to delineate the distribution of geologic map units and to identify areas of anomalous gamma radiation signals, which may be related to alteration or mineralization.

An airborne gamma radiation survey was recently published for a region of the Salmon River Mountains which hosts significant deposits of cobalt and rare earth elements, both of which are listed as critical minerals. The airborne gamma radiation survey was collected due to the prospect for undiscovered critical mineral deposits within the region.

Analyses of the survey were carried out to provide information for the improvement of the geologic framework and to identify areas where the gamma radiation data is anomalous for the mapped rock lithology. K-means clustering, principal component analysis, Kohonen self-organizing maps, and band ratios were used to analyze the airborne gamma radiation data. The clustering techniques were largely successful in delineating lithologies within the study area. Band ratios highlighted areas which may be altered. Through the clustering techniques, anomalous areas were identified, including both areas known to be mineral deposits and areas which warrant further investigation for the refinement of the geologic framework and for the possibility of mineralization.

Jasmine Singh

Mineralogy of high-grade drill core from the Golden Sunlight gold mine

A box of high-grade drill core from the Golden Sunlight Mine in Cardwell, Montana, was donated to Montana Tech when the mining operation shut down in 2020. As part of an undergraduate research project, the authors have begun examination of the drill core by reflected light microscopy, portable X-ray fluorescence (XRF), and SEM-EDS. The drill hole in question, which passed through the heart of the Mineral Hill breccia pipe, consists of nearly massive pyrite with a gangue of quartz, barite, and K-feldspar. Calaverite ($AuTe_2$) and gold of high fineness are locally abundant. Other minerals identified so far include tetradymite (Bi_2Te_2S), goldfieldite ($Cu_{10}(Te,As,Bi)_4S_{13}$), wittichenite ($Cu_3BiS_3$), hodrusite ($Cu_8Bi_{12}S_{22}$), mawsonite ($Cu_6Fe_2SnS_8$), and chalcopyrite. These minerals occur in abundance as rounded inclusions in pyrite, either by themselves or as complex intergrowths of two or more minerals. In places, up to 25% of the area of a given pyrite grain is comprised of these mineral inclusions. The rounded nature of the inclusions and the complex mineral intergrowths suggest the possibility that the minerals were originally trapped in the host pyrite as drops of molten Bi-Te-Cu-Au-S alloy that later solidified into the textures we see under the microscope. This idea is similar to the "liquid bismuth collection model" that has been proposed for concentration of gold in certain hydrothermal mineral deposits by droplets of liquid bismuth. More microscopy work is planned.

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