Identification of rare earth element occurrences in mine waste throughout Montana

Jackson Quarles[1], Matthew Vitale[2], Michael Calhoun[3]

Montana Bureau of Mines and Geology, USA, 1jquarles@mtech.edu, 2mvitale@mtech.edu, 3mcalhoun@mtech.edu

Abstract

The demand for Rare Earth Elements (REE) and other critical elements continues to increase, to the point of exceeding their supply. Existing conventional deposits cannot satisfy domestic demand for the foreseeable future; intensive research on REE recovery from secondary sources is ongoing. Mining and industrial wastes are prime targets for assessing the presence of economically accessible REE and critical minerals. Montana has thousands of inactive and abandoned mines that could be an important source of REE's. These waste sources are regulated under several different remediation actions, i.e. CERCLA and RCRA and require close coordination with various stakeholders.

The waste material and seeps generated from mine sites, as well as past ore processing facilities, may contain rich sources of rare earth elements. We have developed and implemented an extensive sampling program to collect aqueous and solid samples for REE analysis at sites located throughout Montana. Results of reconnaissance mine waste (solids) sampling will guide future targeted sampling to obtain a more complete characterization of promising materials using sampling protocols developed for statistical characterization of resources.

Sample results show REE present in most of the samples collected. However, concentrations vary considerably between sites and waste sources. REE concentrations are higher in water where pH values are 4.0 or lower, while concentrations in sludge samples are highest when generated from sites treating acid mine water with lime. Solid waste samples have varied in concentrations and some possible correlations have been observed.

The large investment of time and money needed to permit a new mine is a deterrent for the exploration and development of new REEs deposits in the United States. Secondary recovery of REEs from existing waste material alleviates this time investment. Additionally, recovering REEs can contribute to environmental clean-up efforts by reducing and remediating waste piles that would otherwise be left in place. The relative composition of REE on the basis of total REE content was assessed through the use of an Outlook Coefficient (Coutl). This is a ratio of high-demand REE's to the more abundant REEs in the collected samples. The higher the coefficient, the greater the potential industrial value.

Keywords: Montana, rare earth elements, waste, solids, water, sludge, REE

Introduction

In recent years the demand for Rare Earth Elements (REEs) and other critical minerals has increased beyond the available supply that conventional deposits can satisfy in the U.S. Therefore, the intensive search for secondary sources has begun. With thousands of mines, tailings impoundments, and water treatment facilities possibly containing rich sources of REEs, the focus of the search was broken into two major areas; Southwest Montana and Central Montana. The counties sampled are shown in Fig. 1. Preliminary sampling was done at 52 different sites varying from current mining operations to abandoned mines and processing facilities. An estimated 400 water and solid samples were collected in total. These samples were sent to various laboratories for analysis and the results were compiled to help guide more intensive searches on the promising mines in the future.

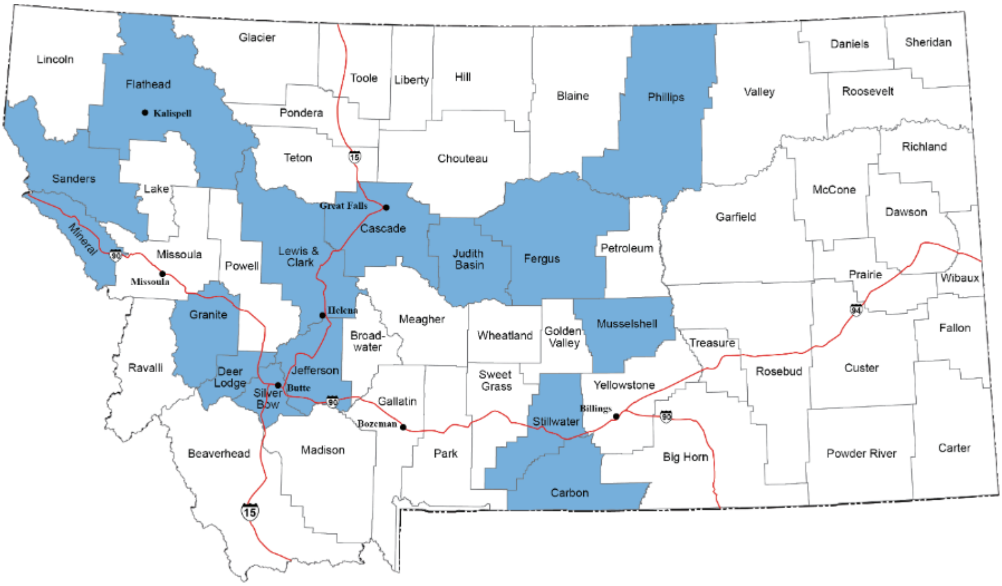

Figure 1 Montana counties where sampling occurred

Methods

Collection of water samples and water treatment samples followed the Montana Bureau of Mines & Geology (MBMG) Standard operation procedures (SOP) for water sampling (Gotkowitz, 2023).

For well sampling, the wells were purged until at least 3-bore volumes were removed and field parameters (pH, temperature, specific conductance, Eh, and oxidation-reduction potential) had stabilized. Field parameters were measured with a multiparameter Hach Datasonde. Unfiltered samples were collected directly from the discharge hose. A PVC valve and tubing were used to allow the use of a disposable in-line filter. Total recoverable and dissolved samples were collected in clean 500 mL polyethylene bottles. Total recoverable samples were acidified with 5 mL of concentrated nitric acid for preservation. For the dissolved samples a 0.45 µm disposable filter was used and the samples were preserved with 5 mL of concentrated nitric acid.

For surface water, samples were collected near the center of the deepest, flowing part of the stream or seep using a clean bucket. A peristaltic pump and polyethylene tubing were used to fill sample bottles. Two total recoverable and dissolved samples were collected per sample site. Field parameters were collected by using the Datasonde.

At sites with water treatment plants, influent and effluent and sludge samples were collected. Field parameters were taken by placing the Datasonde into a clean bucket filled with water; separate buckets were used for collecting samples and measuring of field parameters to avoid cross-contamination. Sludge samples were collected directly from the discharge in two 1 L plastic bottles.

Collection of waste rock and other forms of solid samples followed the MBMG's SOP for solid sampling. The field crew determined how many samples could be collected to obtain a representative sample. At each site, an approximately 1-ft-deep (30 cm) hole was dug; samples were collected at about 0.25 ft (8 cm) deep and at the hole bottom. Each sample was thoroughly mixed, and then transferred to a 1-gallon (3.8 L) plastic bag. Each bag was labelled with a sample ID and date.

Sample Analysis

The water samples were analysed for metals by the MBMG analytical laboratory; splits were sent to the University of West Virginia Energy Institute, where a modified U.S.

Environmental Protection Agency (EPA) method 200.8 was used to determine concentrations by inductively coupled plasma-mass spectrometry (ICP-MS). Solid and sludge samples were analysed as well. Solid samples were submitted to ALS Geochemistry, where the samples crushed and ground to 85% passing 75 µm, dried at high temperature (110 °C), calcined, and then decomposed by Li Borate fusion prior to ICP-MS analysis. Additionally, a 4-acid digestion and inductively coupled-atomic emission spectroscopy for additional metals was performed.

Results

Central Montana

Central Montana is home to some of the largest and historic mining districts in the state. The Little Rockies district as well as the Neiheart district being a large part of the focus. The Little Rockies are home to both the Zortman and Landusky mines which ceased operations in 1998 leaving behind thousands of cubic yards of waste and contaminated water (Mitchell 2004). The mine site has 4 water treatment facilities which continuously treat the contaminated water leaving the leach pads. Neiheart's mining district stopped operations in the late 40's with an estimated 50 mines being abandoned (Neiheart Montana). Access to the Neiheart mines was a challenge due to private land ownership. After working with U.S. Environmental Protection Agency (EPA) and U.S. Forest personnel (USFS), access was granted to most sites and sampling began. Other sites in central Montana with smaller footprints were also sampled and assayed for preliminary economic viability.

Solids

Solid samples from the Zortman-Landusky mine were a challenge to access as most of the waste piles left behind had been remediated and covered. Only one pile had exposed waste where the decomposing sulfides had produced a vent of exposed material. A sample from the vent was taken as well as spent carbon from the bio-plant treatment facility. The Neiheart district had solids taken from eight waste piles at different mines as well as samples from four mine waste repositories in the area. Preliminary results from solid sampling in Central Montana can be seen in Appendix A.

Water

A majority of the mines assessed had seeps associated with them and samples were collected whenever available. In Neiheart there were seven adit discharges sampled as well as 16 wells and seeps at the Black Eagle smelter in Great Falls. Some of the samples were a combination of multiple seeps. The analytical results can be found in Appendix A.

Water Treatment

Water treatment facilities are an imperative part of mine reclamation and an aid to the REE search due to sludge being generated from these facilities often being rich in critical minerals and REE's. All four treatment plants at Zortman-Landusky had samples taken from their influent and effluent flows as well as their sludge discharge. The results of the sampling can be seen in Appendix A.

Southwest Montana

The Butte mining district, known for its 150-year history of hard rock mining, is home to 10,000 mi of underground mining tunnels and two open pit mines. The Berkeley Pit is the lowest point in the flooded mining complex and acts a sump for all underground mines in the area (Gammons and Duaime 2020). As part of the Superfund investigation in Butte, frequent water-level measurements and water-quality sampling occurs. The sampling profile of these sources was expanded to include rare earth elements.

Southwest Montana is also home to the 300 mi^2 Anaconda Company Smelter site, the center of which is located in Anaconda, MT (EPA Region 8 Montana Office 2021). The smelter is surrounded by large piles of slag covering approximately 195 acres and contains high concentrations of metals (EPA 2023). The Phillipsburg district is another prominent district in the area that is home to dozens of mining claims that were sampled as well.

Solids

Opportunistic solid samples were taken from numerous sites in Southwestern Montana.

Samples from the Butte Mining District were largely taken from tailings and sludge surrounding the Butte Mine Flooding Operable Unit (BMFOU) Superfund site. The slag piles surrounding the smelter in Anaconda, MT were sampled at 8 different locations as well as 37 samples taken from the mines in the Philipsburg District. Additionally, multiple cores were taken from the Contact Mill (Philipsburg) and sampled. Preliminary results from solid sampling in Southwestern Montana can be seen in Appendix A.

Water and Water Treatment

The bulk of the aqueous samples taken from Southwestern Montana originate from the BMFOU. Mines that contained water treatment plants like Golden Sunlight and Beal Mountain were sampled extensively. In addition to aqueous samples, sludge from the clarifier of the Horseshoe Bend Water Treatment Plant (BMFOU) was sampled for REEs. Preliminary results from water sampling in Southwestern Montana can be seen in Appendix A.

Conclusion

The preliminary sampling of mine waste(s) for REE's in Montana is promising. It quickly became apparent that mines with acidic water discharge had higher concentrations of REEs. More sampling will need to be conducted in order to draw conclusions between different solid wastes and REE concentrations. With over 400 aqueous and solid samples collected from different waste sources at these mines, it is clear that this is an important resource that needs to be examined further for economic feasibility.

A coutl number or outlook coefficient for each sample was calculated. Showing the ratio between heavy and light REEs. A higher coefficient represents a greater potential industrial value. Central Montana had an average of 1.73 while Southwest Montana had an average coutl of 1.54. In general, solid samples reported higher values than aqueous.

The beneficial effects from the removal and utilization of mining waste is advantageous for not only economic purposes but environmental remediation. A large portion of the sampled sites are considered contaminated and designated as superfund sites with waste piles that would otherwise remain in place. When processing the wastes problems could be present due to contaminants such as arsenic and uranium that could affect recovery. Southwest Montana trending higher in both while central Montana has lower amounts.

Acknowledgements

The authors wish to thank the various individuals and companies who allowed access for sampling, their cooperation is greatly appreciated. Numerous state and federal agencies also assisted with site access for sampling, including the MT Department of Environmental Quality, EPA, USFS, and Bureau of Land Management.

Research was sponsored by the Combat Capabilities Development Command Army Research Laboratory and was accomplished under Cooperative Agreement Number W911NF-22-2-0015. The views and conclusions contained in this document are those of the authors, and should not be interpreted as representing the official policies, either expressed or implied, of the Combat Capabilities Development Command Army Research Laboratory or the U.S. Government. The U.S. Government is authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation herein.

Apendix A: Southwest & Central Montana Figures

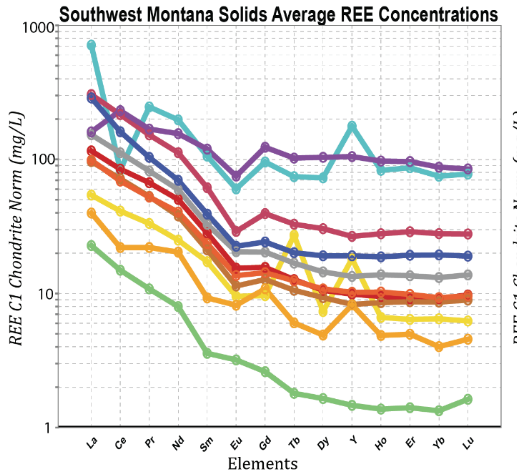

Figure A1 average REE concentrations by sample site

Figure A1 Legend

- Anaconda
- Butte Treatment Lagoon
- Golden Sunlight
- HSB
- Mammoth
- Montana Resources
- Montana Resources Mill
- Opportunity Ponds
- Philipsburg
- Pipestone
- Solvay

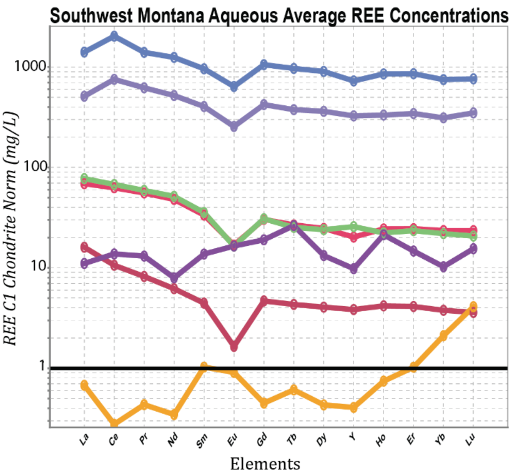

Figure A2 average REE concentrations by sample site

Figure A2 Legend

- Beal Mountain
- Berkeley Pit
- Butte Flooded Mines
- Crystal
- HSB
- Lower Bullion
- Upper Bullion

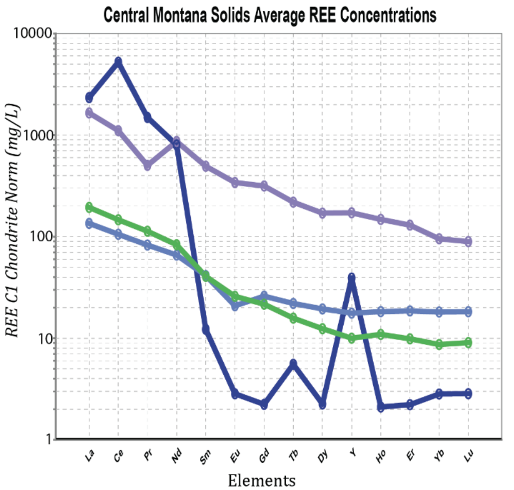

Figure A3 average REE concentrations by sample site

Figure A3 Legend

- Carpenter-Snow Creek
- Flat Creek
- Stillwater
- Zortman

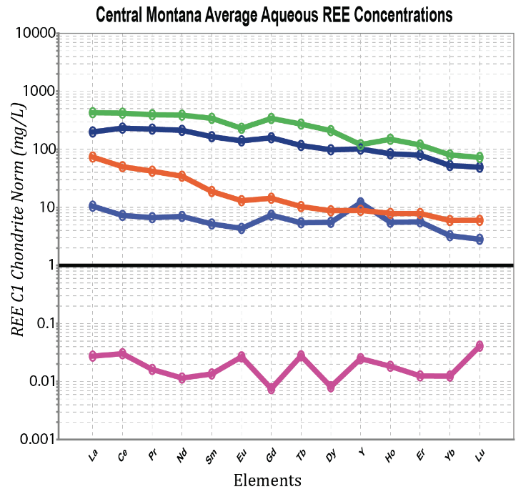

Figure A4 average REE concentrations by sample site

Figure A4 Legend

- Carpenter-Snow Creek
- Flat Creek
- Stillwater
- Zortman