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

A Proposal to the Montana NRDP

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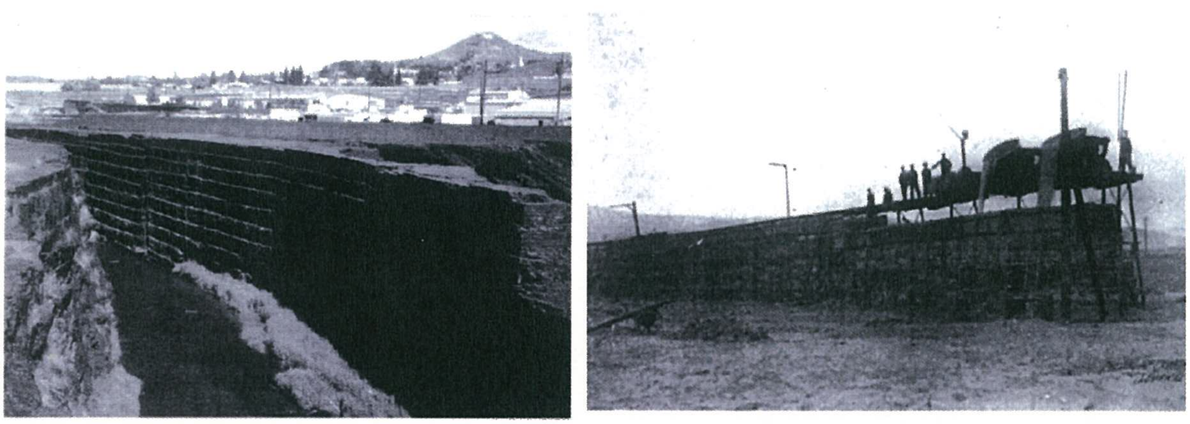
December 01, 2014



A) Silver Bow Creek passing through the Butte Reduction Works slag wall canyon (from Quivik, 2007); B) Men building the slag wall at Butte Reduction Works. (from Quivik, 2007; original photo published in Engineering and Mining Journal 89, March, 1910).

A. Project Summary

Title: Mineralogy and Environmental Geochemistry of Slag in Lower Area One, Butte
Sponsor: Montana NRDP
Location: Slag walls along Centennial Avenue
Total Dollar Amount = $16906 (NRDP = $13,000; Match = $3906)
Project Leader: Dr. Chris Gammons, Montana Tech
Begin Date: Jan 01, 2015 (or when funding is in place)

This is a proposal for a small amount of funding ($13,000) for the PI and a graduate student at Montana Tech to characterize the mineralogy and environmental geochemistry of the Butte Reduction Works slag walls. The better we understand the scientific complexities of "waste in place" in Butte Area One, the better position we are in to make informed decisions about the future of reclamation and restoration in Butte.

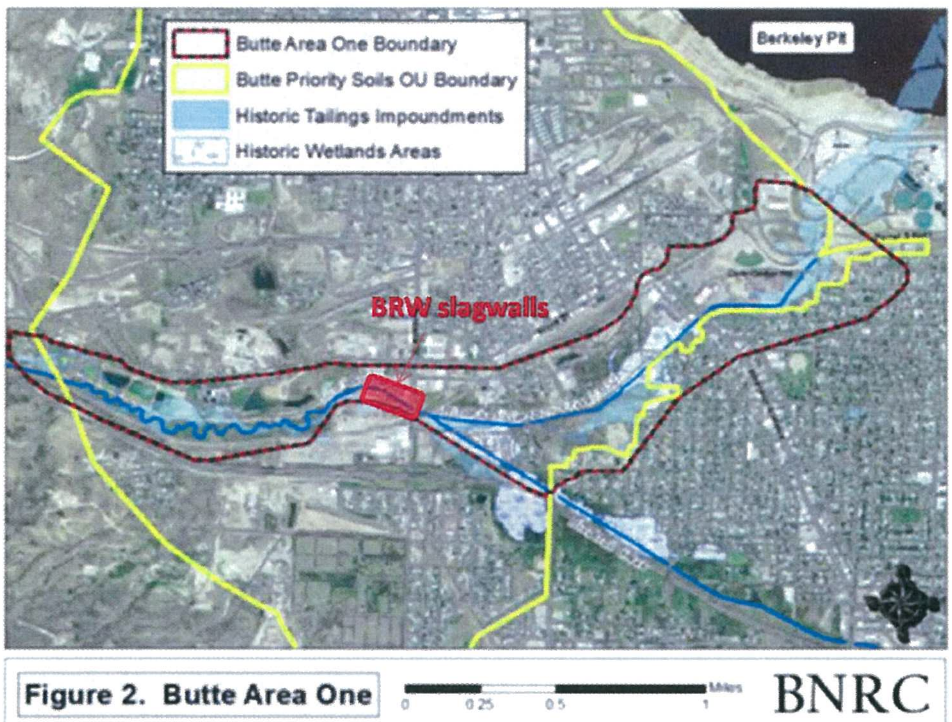


Figure 1: Map of Butte Area One showing the location of the easily accessible slag walls of the Butte Reduction Works (BRW), near the intersection of Montana and Front Streets.

A.2. Background

The slag canyon walls shown on the title page of this proposal (located in Fig. 1) are one of the icons of the Butte industrial landscape. They were built during the early 1900's as a byproduct of smelting of copper ore at the Butte Reduction Works (BRW). The *slag* was a lava-like mixture of silica and various metals that was separated from the molten copper *matte* and then poured into wooden forms and allowed to air-cool. As discussed by Quivik (2007), the operators of the Butte Reduction Works constructed the slag walls in this way to help contain the much larger volume of pyrite-rich mill tailings (crushed ore from which the valuable copper minerals had been separated), and also to more easily divert surface water (Missoula Gulch, Silver Bow Creek) around the tailings impoundment, thereby lessening environmental damage to the stream and its floodplain. This is an example of environmental foresight that was rare in the Butte-Anaconda area at this time.

Today, the slag walls are one of the first things that interested observers see when they get off the Interstate at Montana Street on their way Uptown or to the Visitor's Center. And yet, there is very little information on the mineralogy or geochemistry of this slag deposit. I have led tours addressing Butte geology for students and professors from across the country, and one of the questions they invariably ask is: "What's in that black stuff"? Good question. That is the crux of the present proposal. Although there have been some Montana Tech M.S. theses on characterization of granulated slag from Anaconda and the East Helena smelter through the Dept. of Metallurgical Engineering (Pande, 1993; Jarvis, 2003; Filius, 2007), the author could find no information on the chemical or mineralogical makeup of the BRW slag. A recent study characterized the sediment *under* the slag walls (TREC, 2013), but not the slag itself.

During the past 15 years there has been a sharp increase in the number of detailed studies on the mineralogy and geochemistry of ferrous (steel-related) and non-ferrous (heavy metals, phosphorous) slags (Fig. 2). This work was recently summarized in the excellent review paper of Piatak et al. (2014). Long dismissed as being an ugly waste product, these recent studies have shown the sometimes fascinating mineralogy present in slag, and also highlight the potential (sometimes high, sometimes low) for slag wastes to leach metals into the environment.

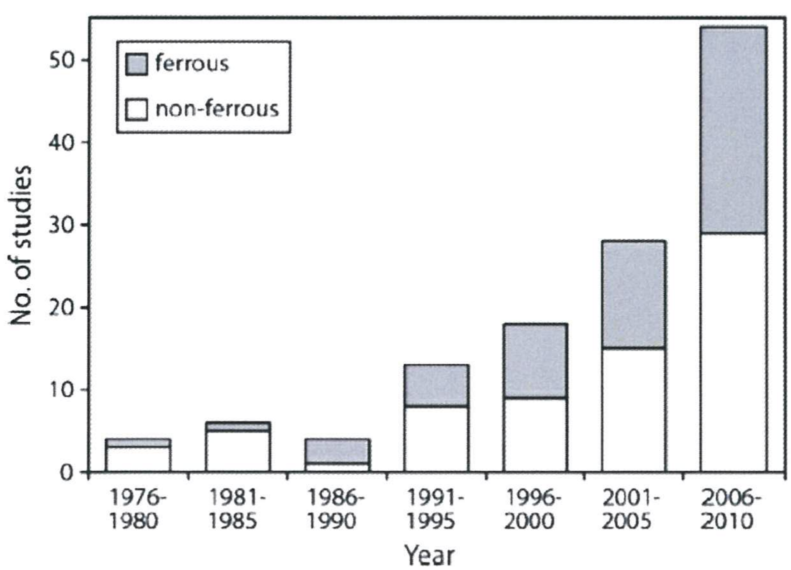


Figure 2. Number of mineralogical and geochemical studies of slag deposits published between 1976 and 2010 (Fig. 1 of Piatak et al., 2014).

B. Project Goals and Objectives

The main goal of this project is to characterize the *mineralogy* and *chemical composition* of the Butte Reduction Works slag. Because the slag was air-cooled, it is likely to have a high percentage of crystalline minerals and a lower percentage of amorphous glass. As reviewed by Piatak et al. (2014), air-cooled slag deposits contain mineral textures seen in natural basaltic or ultra-mafic lava flows (see also Tatarinov, 2002). Therefore, to study slag, one can apply the same types of characterization methods used for decades by geologists who study natural igneous rocks.

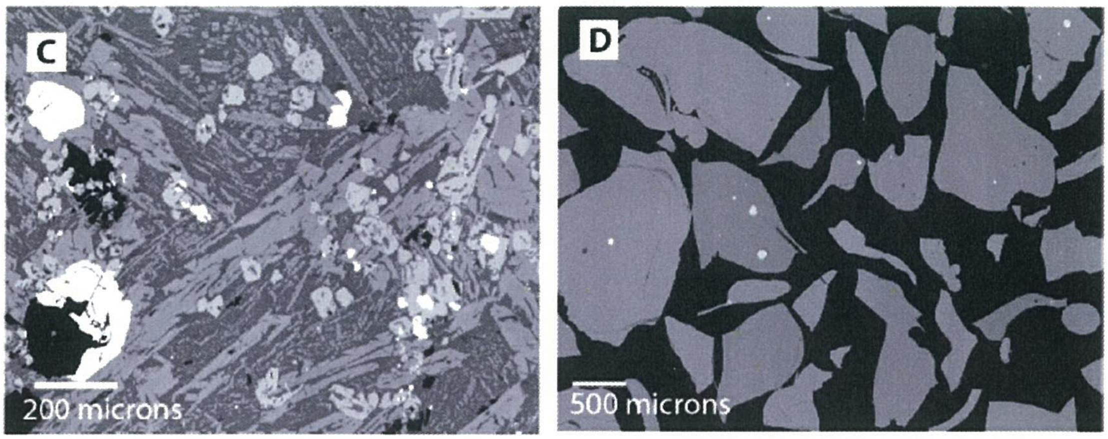


Figure 2. Backscattered scanning electron photomicrographs of A) crystalline, air-cooled slag from an abandoned copper mine in Vermont; and B) granulated, glassy slag from an abandoned copper mine in Tennessee (from Piatak et al., 2014). The different gray shades in "A" show the presence of different silicate minerals (olivine, pyroxene, spinel), the white patches are metal sulfides, and the black areas are holes in the slide. Most of the material in "B" is glass.

A second goal of the project is to characterize the *environmental geochemistry* of the BRW slag. Given its conspicuous location, it is reasonable to address the question of whether the BRW slag could be a source of contamination to Silver Bow Creek. To this end, we will use two non-aggressive leaching procedures (SPLC, TCLP) to determine the range in dissolved concentrations of various metals and metalloids in waters that could come in contact with the slag. Based on the review of Piatak et al. (2014) there are a number of trace elements that might be released during leaching of non-ferrous Cu slags, including arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn) (Table 1).

Table 1: Elements that may be an environmental concern in various types of slags. (Copied from Piatak et al., 2014).

	Steel	Fe	Ni laterite	Ni sulfide	Cu	Pb	Zn
As	**	**			**	**	**
Ba						**	
Cd					*		
Co				**	**	**	
Cr	**	*	**		**		**
Cu					**		
Mn	**	**	**			**	
Ni			*	*			
Pb					**	**	**
Zn					**	**	**

Symbols: * = concentrations occasionally exceed criteria, ** = concentrations commonly exceed criteria, criteria are USEPA soil screening levels for all elements except for Cr, which was from CCME (USEPA, 2010; CCME, 2007).

C. Project Benefits

There are a number of benefits, both short-term and longer-term, that will stem from this project. These include:

- We will collect new scientific data on a prominent mine waste feature in the middle of Butte Area One. This will benefit NRDP, the Montana DEQ, the US-EPA, BP-ARCO, the city of Butte, and any other stakeholders who are concerned with the past, current, and future well-being of the headwaters of Silver Bow Creek and the Clark Fork River.
- By publishing our results in a technical journal we will reach a broader scientific audience, thereby placing our findings within the context of what is known, world-wide, about non-ferrous slags. A journal publication on this topic will also reinforce the reputation of Montana Tech, its faculty, and its students.
- Funding from this project will help support a graduate student research project at Montana Tech.
- Information obtained in this project will be used to construct a poster that could be displayed at the Butte Visitor's Center, the Montana Tech Mineral Museum, or another venue. The poster will be written in non-technical language, and will include information on the history and metallurgy of the site, as well as the mineralogy and geochemistry of the slag itself.

Although many people feel that mine waste has little purpose other than to be removed or monitored, there is a lot of scientific complexity associated with the wastes. The better we understand these complexities, the better position we are in to make informed decisions about the future of reclamation and restoration in Butte.

D. Project Implementation

D.1. Collection of Samples

The BRW slag is easily accessed for sampling from Centennial Avenue, where it forms a 10 foot high wall separating the street from Silver Bow Creek. Effort will be made to collect representative samples without damaging the appearance of outcrop. This can be done with a rock hammer and chisel, exploiting pre-existing planes of weakness (joints, bedding surfaces) to collect "fist-sized" samples. We will collect samples near the bottom, middle, and top of individual flow layers. As well, any secondary minerals forming along cracks or on the surfaces of the slag will be collected for later examination.

D.2. Solids Characterization

We will employ a number of methods to characterize the slag deposits (see Table 2). Some of these, such as optical microscopy and portable X-ray fluorescence (pXRF) give a wealth of information at relatively little cost. For example, Table 3 summarizes a pXRF analysis of a piece of slag float collected by the author along Centennial Ave. Like many copper slags (Piatik et al., 2014), this sample was rich in Fe, Si, and Ca, as well as Cu, Mn and Zn. Because the results of the pXRF are semi-quantitative, we will submit selected samples of slag in the form of crushed and homogenized powders to a commercial lab for bulk chemical analysis. Other methods of characterization, such as scanning electron microscopy (SEM), X-ray diffraction (XRD) and electron microprobe analysis (EMPA) are common tools used by geologists to verify mineralogy and document mineral composition. With the exception of EMPA, all of these instruments are present at Montana Tech. For EMPA analysis (usually required for publication-quality data on mineral compositions), we will make a trip to Washington State University (Pullman, WA).

Table 2: Methods that will be used to characterize the slag samples in this study.

method	capability	cost
Portable XRF (pXRF)	Semiquantitative trace metal scan. Excellent reconnaissance tool	No cost
Bulk digestion, ICP-MS	Bulk chemical analysis, including trace metals	Moderate
Optical microscopy	Identification of major minerals, glass, and textural relationships	Low
SEM-EDS	Mineral and glass composition (not good for trace elements)	Moderate
XRD	Mineral identification	Moderate
EMPA	Mineral and glass composition, including trace elements	Moderate

Table 3. Preliminary pXRF analysis of a slag sample from the BRW slag wall

Fe	21.0%	Cu	0.29%
Si	18.9%	Mn	0.23%
Ca	15.1%	Ba	0.21%
Al	6.40%	W	700 ppm
Zn	1.7%	Cr	340 ppm
K	1.1%	Pb	285 ppm
S	0.47%	As	273 ppm

D.3. Leachate Characterization

The leachate tests will be carried out in the PI's lab at Montana Tech (CBB Room 209). Representative bulk samples of slag will be crushed, homogenized, and sieved to appropriate size fractions, following standard methods (USEPA, 2008) for the synthetic precipitation leaching procedure (SPLC) and the toxicity characteristic leaching procedure (TCLP). Starting solutions, contact time, and liquid-to-solid ratios will follow standard protocols. For comparison, additional tests will employ non-crushed slag (i.e., pieces of slag collected from the outcrop). Leachate solutions will be analyzed at the lab of the Montana Bureau of Mines and Geology for the same set of major and trace elements that is run on other Butte-related waters, e.g., mine shaft or pit-lake waters. All experiments will be performed in triplicate to obtain results that are more easily reviewed for internal consistency and repeatability.

D.4. Dissemination of Results

All mineralogy and geochemistry data, along with an interpretation of the results, will be submitted to the NRDP in the form of a technical report, written by the graduate student and/or myself. It is unlikely that this report will take the form of a Montana Tech thesis. More likely it will be a non-thesis research project, or simply a report co-authored by myself and the student. This report will include all raw laboratory data as appendices. In addition, the PI hopes that the results will lead to publication of a paper in a technical journal, such as Applied Geochemistry, Mineralogical Magazine, or Canadian Mineralogist. One or both of us would be happy to present our findings at a public meeting. Finally, we will put together a poster that summarizes our major findings within the context of the history of mining and reclamation that has taken place around the slag deposit. This poster will be presented to the Butte Chamber of Commerce and a copy could be made available to other interested parties on request.

E. Project Schedule

The proposed project will begin as soon as funding is arranged. Much of the characterization work will be performed during the summer of 2015. Laboratory leach tests will be completed in the summer or fall of 2015. A draft of the final report, as well as an electronic copy of the poster, will be submitted to NRDP by June 01, 2016.

F. Monitoring Activities

There will be no monitoring activities associated with this project.

G. Budget

	NRDP	Match	Total project
1. Salary			
Gammons	0	2500	2500
Grad student	4000	0	4000
2. Benefits			
Gammons	0	625	625
Grad student	400	0	400
3. Supplies	1000	0	1000
4. Analytical	4000	0	4000
5. Travel	1000	0	1000
6. Total Direct	10400	3125	13525
7. IDCs	2600	787	3387
8. Total Project	**$13000**	**$3906**	**$16906**

1. Two months of summer salary is requested for a Montana Tech graduate student who will perform much of the work described in this proposal. $2500 of my own salary is included as an in-kind match: this is roughly 1 week of time at my research salary rate.
2. Benefits for summer work are 10% of salary for students, 25% of salary for faculty.
3. The biggest cost item for supplies is the preparation of a suite of 20 polished thin sections of the slag samples. This can be done by several commercial labs in the western U.S., at a typical price of $30/sample. The polished sections will be used for optical petrography, SEM-EDS, and EMPA analysis. $400 additional money is requested for miscellaneous consumable supplies needed to set up and perform the laboratory leach tests, as well as to print out at least 2 copies of our poster.
4. Analytical costs are summarized in the following table:

Analytical method	quantity	Estimated cost
Bulk chemistry	5 to 10 samples	500
SEM-EDS	10 hours	1000
XRD	10 samples	500
EMPA	2 days	1000
ICP-MS of leachate	20 samples	1000
	Subtotal	$4000

5. Travel expenses are requested for the PI and graduate student to spend 2 days on the EMPA facility at Washington State (Pullman, WA). The estimated cost of $1000 includes 2 nights lodging, 3 days meals, and mileage for a state vehicle (800 miles round-trip).
7. IDC's at Montana Tech are 25% of total direct costs for State-funded projects.

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