

Introduction

The Bismark Mine is located near the headwaters of the South Boulder River in Madison County, Montana (Figure 1). The bedrock of the area is predominantly metamorphic rock of the Archean Pony series, intruded by a tongue of the Cretaceous quartz monzonitic Tobacco Root batholith. The gneiss and the granite are both weakly fissured and mineralized near the contact. The mine is located on several of these fissure veins near the granite-gneiss contact. Additionally, numerous small veins of pyrite, chalcopyrite, and molybdenite with quartz are present. During its operation, over 58,000 lbs. of copper, more than 7,000 lbs. of lead, and almost 1,200 oz. of silver and smaller amounts of gold were removed. The mine was abandoned by 1963.

During the mining process mine tailings were discarded downslope from the mine adits. A wetland naturally developed on top of the tailings due to diffuse seepage of seasonal snowmelt from the surrounding area and discharge from the lower adit of the mine. Multiple unmapped seeps contribute flow to the wetland. The water emerging from the adit and seeps has a pH between 6.78 and 8.05 and contains measurable concentrations of major and trace elements, including Fe (up to 1.47 mg/L), Pb (up to 17.4 µg/L), Zn (15 – 36 µg/L), Cu (up to 116.7 µg/L), and As (up to 3.66 µg/L).

The purpose of this study, which is part of a more extensive wetland characterization, was to investigate metal retention and accumulation within the wetland soils and vegetation and to evaluate potential for metal release from the soils.

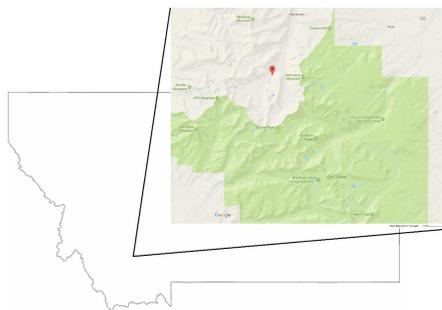


Figure 1. Map showing the location of the Bismark Mine in southwestern Montana

Methods

Soil trenches and pits (Figure 2) were dug at various locations across the wetland during the summers of 2014 – 2017. Samples were collected from each horizon and from any interesting features observed in the pit. This research is focused on the samples collected from 2015 and 2016. Textures of the samples were determined using the USDA Textural field flow chart. Splits of the samples were sent to Activation Laboratories in Ancaster, Ontario, Canada, for total metal analysis using a four-acid digestion followed by analysis with inductively coupled plasma optical emission spectrometry (ICP-OES). Soil organic matter (SOM) was determined through a loss-on-ignition (LOI) method, where the amount of organic matter in the soil is determined by the heated destruction of all organic matter present (Konen et al., 2002). Vegetation samples (sedges) were collected from the wetland during the summer of 2018. For comparison, additional sedge samples were collected along a nearby stream (Moose Creek) not impacted by drainage from abandoned mines. Metal concentrations in the sedge samples were determined using a dry ash procedure following that described by Tuzen (2003) for soil and plant material. Metal availability and mobility from one set of the soil samples were evaluated using a modified sequential extraction method (See Table 1) outlined by Rauret et al. (1998). Metal concentrations of the sequential extraction and the dry ash procedures were determined by either flame atomic adsorption spectrometry (FAAS) or graphite furnace atomic adsorption spectrometry (GFAAS) at Indiana University (Bloomington, Indiana).

Step/Reagent	Target Phase
1. Milli-Q Water	Readily Soluble
2. Acetic Acid (0.11 mol/L)	Exchangeable/Carbonate

Table 1. Procedure steps and target phase taken from the modified sequential extraction (from Rauret et al., 1998).



Figure 2. One of the soil pits excavated at the Bismark wetland.

Results and Discussion

Figure 3 a - c below shows the soil organic matter (SOM, %) for each of the samples. The highest SOM is seen in the near-surface samples for 2015 Pit 3 and 2016 Trench A. 2016 Trench B has the highest amount of SOM at the depth of 42 cm.

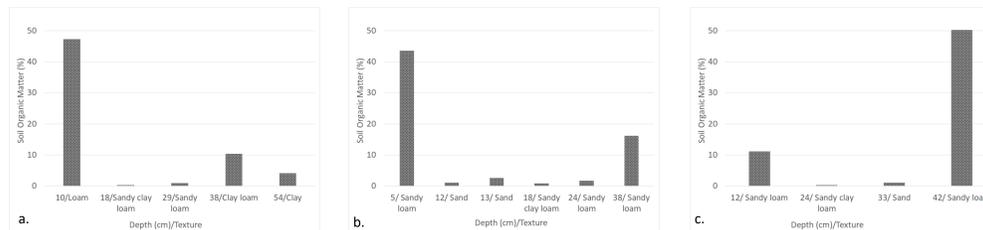


Figure 3. Soil organic matter compared to depth and texture for (a) 2015 Pit 3, (b) 2016 Trench A, and (c) 2016 Trench B.

In Figure 4, the concentrations of Ca, Mg, and Na are compared to depth and texture. The highest concentrations of these elements seem to be somewhat associated with the presence of loam and clay textures, which makes sense given the cation-holding capacity of clay minerals.

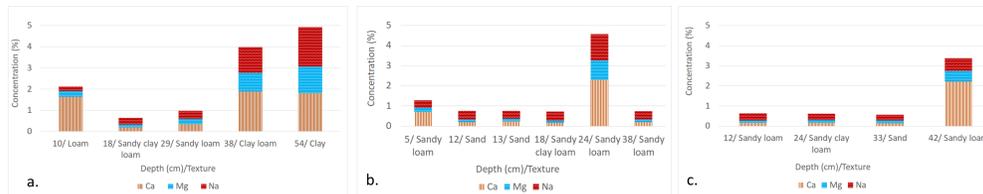


Figure 4. Concentrations of Ca, Mg, and Na compared to depth and texture for (a) 2015 Pit 3, (b) 2016 Trench A, and (c) 2016 Trench B.

Figure 5 a-c shows the concentrations of Al, Fe, S, and Cu in the soil samples. 2015 Pit 3 has Al concentrations that increase with depth, while the other metals are present in lower concentrations and remain constant with depth and texture. 2016 Trench A and B have similar concentrations of Al. No obvious trend in concentration is apparent when compared to depth or texture.

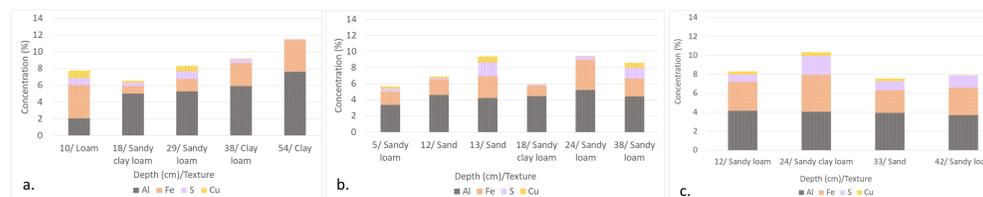


Figure 5. Concentrations of Al, Fe, S, and Cu compared to depth and texture for (a) 2015 Pit 3, (b) 2016 Trench A, and (c) 2016 Trench B.

As, Cr, Mn, Mo, Ni, Pb, and Zn concentrations are shown in Figure 6. Elemental concentration did not vary notably between 2015 Pit 2 and 2016 Trench A and B and there were no obvious connections between concentration and texture. It should be noted that trace element concentrations in the soils are 10 to more than 1000 times greater than concentrations in the wetland water samples, indicating that the soils accumulate and concentrate these elements. Trace metal cations are commonly held on the negatively charged surfaces of clays, soil organic matter and iron oxides.

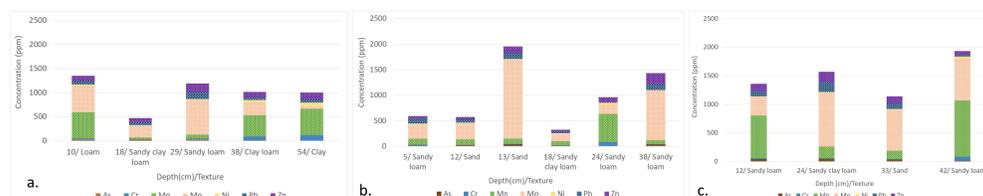


Figure 6. Concentrations of As, Cr, Mn, Mo, Ni, Pb, and Zn compared to depth and texture for (a) 2015 Pit 3, (b) 2016 Trench A, and (c) 2016 Trench B.

The results of the sequential extraction for 2016 Trench B are shown in Figure 7. Elements easily removed in the MQW step of the sequential extraction are Cu, Zn, Mn, and Cd, indicating a portion of these elements are loosely held on the surface of the soil particles (likely through electrostatic interactions) and are most easily mobilized. In the acetic acid extraction, additional amounts of Cu, Zn, Mn, and Cd are released, along with Pb. Elements released in this step would be easily mobilized with a decrease in pH. Measurable amounts of iron and aluminum are not seen in either of these steps, indicating they are more tightly held in iron oxides and aluminosilicate minerals not dissolved by the extraction.

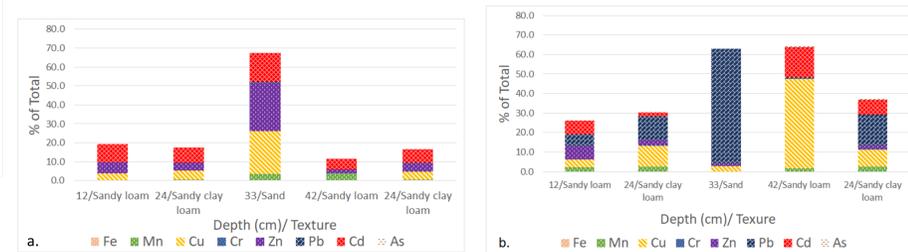


Figure 7. Sequential extraction results for 2016 Trench B samples showing metal release as % of total concentration for the (a) MQW step, and (b) the acetic acid step.

The results of the dry ash procedure for the sedge samples are shown in Figure 8. It is evident that the sedges accumulate certain metals, with the highest concentrations of Fe, Mn, Cu, and Zn seen in the samples collected from the Bismark site. The Moose Creek 2 sample shows higher concentrations of Pb and Cr compared to all but one of the Bismark samples. Given that the bedrock in this region is highly mineralized, this is not a complete surprise.

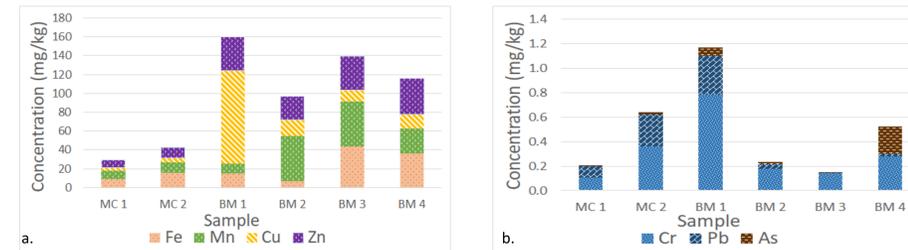


Figure 8. Concentrations of major (a) and minor (b) metals in vegetation samples from within the wetland.

Conclusion

Although there was no obvious trend between sample locations, depth, or texture, it can be said that trace element concentrations are 10-1000 times greater in soil samples compared to wetland water samples, indicating that the soils accumulate and concentrate these elements. Elements such as Cu, Zn, Mn, and Cd that were easily removed in the MQW step of sequential extraction are the elements most easily mobilized. Elements including Cu, Zn, Mn, Cd, and Pb that were released during the acetic acid extraction would be easily mobilized with a change in pH. Metals such as Fe, Mn, Cu, and Zn were found to accumulate in sedges within the Bismark wetland.

References

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