PROCEEDINGS OF THE TWENTY-EIGHTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

April 2015
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Dr. Robert J. Varga, Editor
Director, Keck Geology Consortium
Pomona College

Dr. Holli Frey
Symposium Convener
Union College

Carol Morgan
Keck Geology Consortium Administrative Assistant

Christina Kelly
Symposium Proceedings Layout & Design
Office of Communication & Marketing
Scripps College

Keck Geology Consortium
Geology Department, Pomona College
185 E. 6th St., Claremont, CA 91711
(909) 607-0651, keckgeology@pomona.edu, keckgeology.org

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KECK GEOLOGY CONSORTIUM
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Robert J. Varga
Editor and Keck Director
Pomona College

Keck Geology Consortium
Pomona College
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Christina Kelly
Proceedings Layout & Design
Scripps College

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CHARACTERIZATION OF LEGACY MINE WASTE CONTRIBUTIONS TO FOURMILE CANYON, COLORADO

RACHEL SAMUELS, Washington and Lee
Research Advisors: Dave Harbor and Paul Low

INTRODUCTION

The history of 19th to mid-20th century mining and milling in Fourmile Canyon, Colorado has left the hillslopes and valley bottoms filled with potentially hazardous legacy sediment (Wohl, 2006). These sediments are unconsolidated and often close to waterways. The geochemical content and potential heavy metal risk that these legacy sediments pose is currently unknown and is the focus of this study. The companies that owned these piles have long since vanished, so the state of Colorado must remove the sediments where they are hazardous. One of the tailings pond sites in this study has already been removed by the state. Understanding the low potential hazard of the mine waste could save the state thousands of dollars where the sediment contamination is immobile; alternatively, where it is high and mobile, it could speed the removal of potentially dangerous sediments.

The bulk sediment and stream water content of mine wastes in the area have been analyzed (Beganskas, 2012), but the specific contribution of the mine wastes, particularly the differences between mill waste and the unprocessed waste rock left on the hillside, had been unexplored. Bulk sample analysis provides the maximum possible metal contamination, but geochemical analysis of leachates yields a comparative risk of these sediments (Salomans, 1995) by assuming that if water cannot remove the metals, it poses little risk.

The mining in the area began in the 1860s, and the milling process changed continuously over the decades until the gold mining finally stoppedafter U.S. involvement in World War II. At first, the ore was crushed and roasted; later, they amalgamated the ore using mercury. (Bailey, 1982) By analyzing the fluid mobility of the toxic metals in these sediments and the spatial relation of those heavy metals, we not only further our understanding of how dangerous these sediments are but also unlock some keys to interpreting the past.

Catastrophic flooding in September 2013 and lesser flooding in 2011-2012 severely eroded some areas of this sediment along Fourmile Creek, exposed it to future erosion, and transported significant volumes downstream. Regardless of what toxic metal ions could be transported by regular weather patterns, the force of the flood moved masses of tailings ponds downstream. An analysis of the amount of sediment removed from the major tailings pond in coordination with leachate and bulk geochemical analysis will give insight as to the total impact of the 2013 flood.

GEOLOGIC SETTING

Two different types of mine waste were examined: mill-processed waste and unprocessed waste rock. Processed waste is residual ore that was processed for gold and then piled below the mills in ponds resulting in thick layers of fine sediment. Two larger deposits of this processed waste were analyzed: the deposit in Salina and the deposit below the Wood Mountain Mine (Fig. 1). These two tailings ponds contained heavily oxidized material. In particular, Salina has layers of sediment more than five meters thick. The layers varied in thickness from less than 3 mm to more than half a meter, and varied in color from dark, gunmetal gray to bright red to bleached white. The

2013 flood changed the course of Fourmile Creek adjacent to this deposit and undercut the tailings. The adjacent streambed is a mixture of clay-rich mine waste and flood debris.

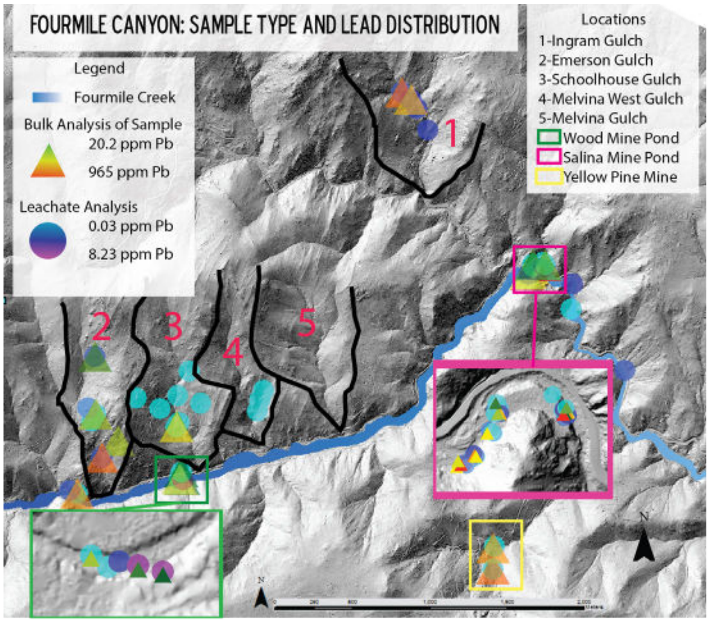

Figure 1. The investigated areas of Fourmile Canyon, with samples analyzed for their bulk content as triangles and samples analyzed for leachate content as circles. The color of the symbol represents the relative amount of lead extracted from the sample.

Unprocessed waste mainly consists of piles of rocks downslope of a mine adit or shaft in sizes of varying magnitude. These unconsolidated piles generally lack vegetation, are heavily oxidized, and demonstrate downslope motion. Some of the mines have evidence of mine reclamation work like debris barriers, but most of the deposits appear to be creeping downslope. The deposits varied in sediment size, the size of the deposit, and the level of oxidation, often varying excessively in the same deposit.

METHODS

Processed Rock

We collected 40 samples from the tailings pond at Salina and 16 from the one at Wood Mine (Fig.1). At Salina, we focused on six sites approximately 30-50 meters apart along the exposed pond sediment wall (Fig. 2). At each site, we took either four to eight 250-500 g samples from 50-100 cm swathes as representative samples or three to five samples from layers of particular interest, such as those of a distinct color or texture, and recorded the height above the stream of the sample location. For Wood Mine, we

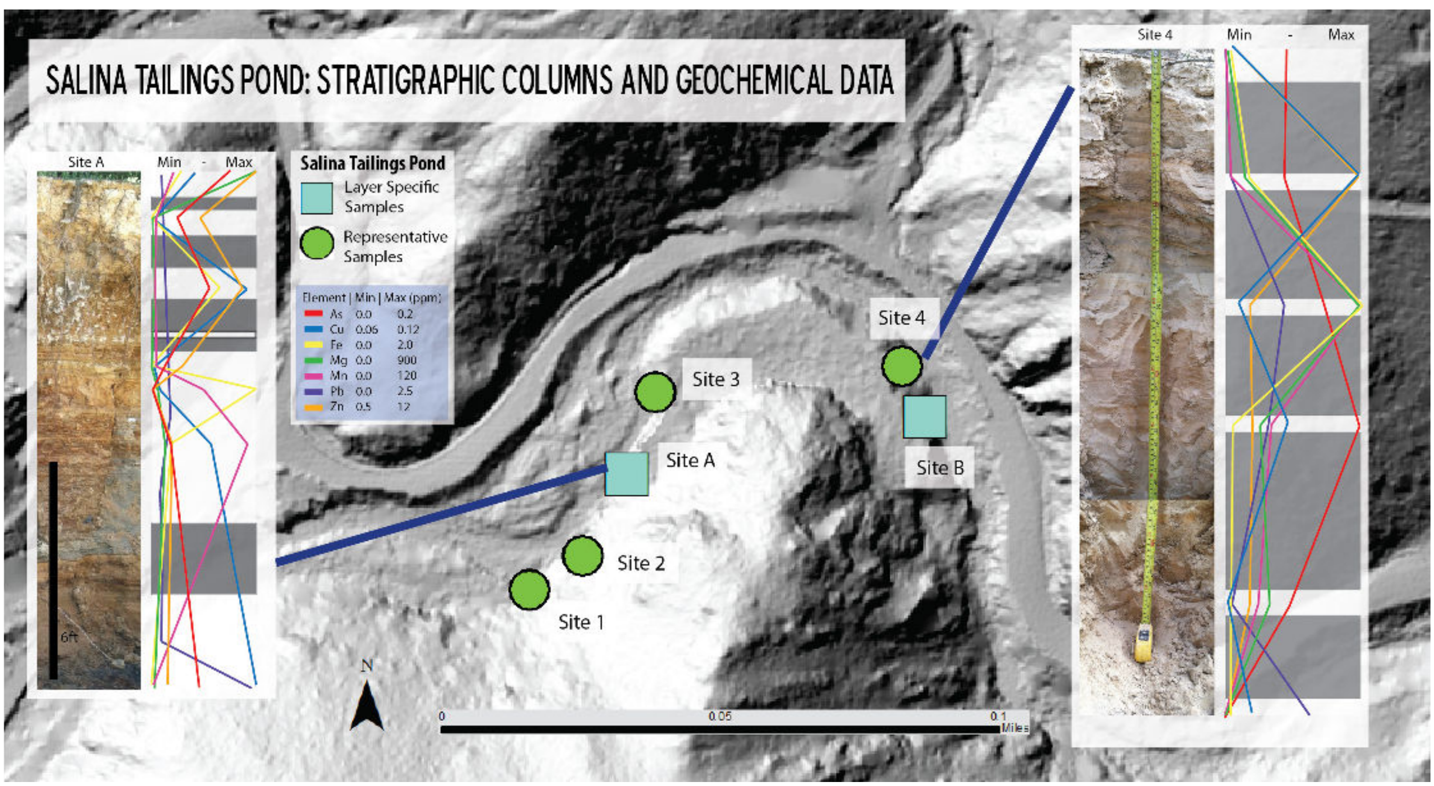

Figure 2. The sample sites at the Salina Tailings pond, showing representative and distinctive layer sampling methods. The stratigraphic columns for Site A and Site 4 show the min-max trends of arsenic, copper, iron, magnesium, manganese, lead, and zinc.

took two to four representative samples from three sites.

Unprocessed Rock

We selected sites close to Fourmile Creek by using old mine roads to explore the remains of the adits and shafts. We collected 44 unprocessed waste rock samples, including samples fromIngram, Emerson, and Schoolhouse Gulch. The largest unprocessed mine waste piles were found near the Nancy, Ingram, and Yellow Pine Mines (Fig. 1). We took one sample at smaller deposits, two at larger deposits and up to four at the largest. We cleared away the top 5-10 cm of sediment before using a hand trowel to take a 250-500 g sample of the waste rock.

Laboratory Methods

The Toxicity Characteristic Leaching Procedure (TCLP) is a widely utilized procedure for determining the potential leaching of hazardous materials from sediments. Developed and used by the EPA, the procedure is intended to determine the liquid mobility of organic and inorganic hazardous material (EPA, 1972). The procedure involves placing 5 g of sample in 100 ml of mild acid and agitating for 18±2 hours. The TCLP is the main procedure used by national and state agencies to assess the hazard of soils (Al-Abed et al., 2006). A total of 103 samples were analyzed using this leachate procedure.

After following the TCLP, the filtered leachate was analyzed using Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES), using QCS-27 as our standard. To constrain the maximum contaminant content, a subset of thirty-one samples of processed and unprocessed waste were sent to Acme Lab for bulk elemental analysis using ICP and ICP-MS.

Spatial relationships were analyzed using ArcGIS. Lidar DEMs from 2013 and 2010 were subtracted to determine erosion. The total mass lost from the Salina tailings pond over the three year period was determined from a sum of the negative elevation change values in the tailings pond area.

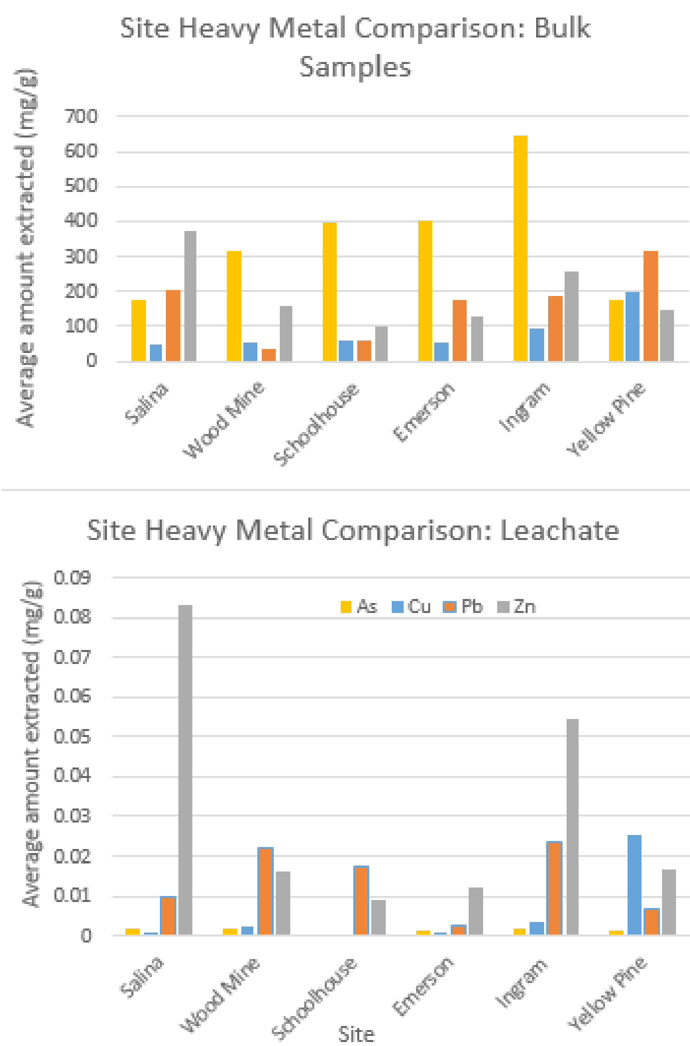

Figure 3. The average amount of arsenic, copper, lead and zinc per gram of sample extracted via bulk analysis and leachate analysis at each site.

RESULTS

Geochemical analysis

The bulk arsenic content of the samples far exceeded the EPA limit of 75ppm. Howerver, the leachate contained relatively low levels of heavy metals. Six samples exceeded the limits for lead, but no other EPA thresholds were exceeded. Leachate content varied substantially for calcium, iron, and magnesium. Generally, unprocessed rock contains more heavy metals than processed tailings. Unprocessed waste rock from Ingram Mine contains the highest average bulk arsenic content; the waste rock outside of Yellow Pine Mine contains the highest average bulk lead.

Salina tailings leached large amounts of zinc, but the leached lead and leached copper were lower than that of Wood Mine, Schoolhouse, and Ingram. The most contaminated samples for both leached and bulk toxic metals were from Ingram (Fig. 3).

The distribution of hazardous material in leachate varies greatly between and within sites. Iron appears evenly distributed across the landscape; copper has a high spatial variability and appears concentrated in a select few areas. Neighboring layers and waste rock piles contain substantially different elements. Some samples with similar bulk contents leached dissimilar elements. Zinc, copper and lead had high levels of correlation between bulk and leachate calculations, but arsenic and barium had relatively low correlation.

The samples contain economically viable amounts of gold, particularly in the samples from Wood Mine and the unprocessed waste rock in Schoolhouse Gulch.

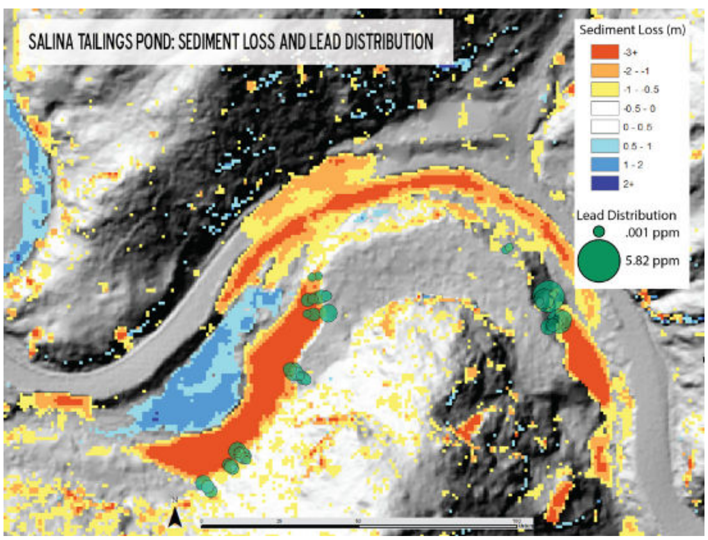

Figure 4. Elevation change near the Salina tailings pond from 2010 to 2013 lidar DEMs, with areas of red signifying loss (erosion) and areas of blue signifying gain (deposition). The green circles show increasing leachate lead content with increasing circle size.

The Salina Tailings Pond

At both Wood Mine and the Salina tailings pond, the severity of heavy metal contamination increased downstream from the start of the tailings. Although the heavy metal contamination increased downstream, the amount of gold present in the samples decreased downstream at Salina.

The more recent layers in the tailings ponds have a trend of greater contamination, for both representative layers and layers of interest. The very top layer, mostly a pale, chalky white, was not as contaminated, but most spikes in heavy metal contamination occurred about 70-150 cm below that layer. Copper and zinc spikes are correlated in these layers, as are iron, magnesium, and manganese (Fig. 2).

In terms of the loss of mine waste at the Salina waste pile from 2010-2013, we used GIS to determine an approximate loss of -4,470 ± 50 m^3 in the area (Fig. 4). Combined with the average amount of lead and arsenic leached per gram of Salina tailings, there is the potential for nearly 60 kg of lead and 10 kg of arsenic to leach from the transported tailings.

DISCUSSION

The leachate and the bulk geochemical analyses describe two possibilities. The first says that, although the samples are heavily contaminated, the heavy metals are trapped in minerals with low solubility and do not appear to be at risk of fluid mobility. The second is that the TCLP is not a comprehensive test for determining the relevant risk of sediments, especially where the sediment is not leached in place but is remove by erosion. We used the TCLP because it was recommended as a common and widely spread sediment toxicity analysis for government agencies. That said, there are a number of issues that have been raised regarding the applicability of the procedure to mine sediments (Hayes, 2014). While the procedure was originally developed to analyze substances in landfill conditions, and the test itself has been found less informative than a more involved sequential analysis, its prevalence in government agencies and the amount of existing literature regarding the process make it worthwhile. Additionally, analyses of its applicability specific to heavy metals have found it adequate in mine environments without substantial pH variability (Al-Abed et al., 2006) like that of Fourmile Canyon (Beganskas, 2012). A sequential analysis would shed more light on the fate of the transported sediments and the possibility of further contaminant leaching.

Spatial analysis showed that toxic metals tended to be present in small areas across Fourmile Canyon.

Despite the colorful appearance and fineness of the tailings pond sediments, however, the unprocessed waste rock in areas just outside of large mines, such as the Yellow Pine and the Ingram Mine, have equal and sometimes greater levels of contamination. However, these deposits are not very mobile. Even though Salina sediments did not leach as much contamination, a sediment loss of 4,470 m^3 downstream has a much higher potential contribution to the watershed.

CONCLUSION

TCLP leach analysis shows that, for the tested parameters, the sediments from the mining in Fourmile Canyon contribute minor toxicity relative to EPA safety guidelines, barring six samples that exceeded the lead threshold. However, significant erosion of processed mine waste yields a large quantity of metal waste to potential downstream contamination.

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