Major sources of contamination in the waters draining the HI-YU Mine, Fairbanks Mining District, Alaska

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There are two major sources of contamination to Moose Creek; the "mill seep" emanating from below the old mill, and rock material containing high concentrations of harmful elements. Veins and their wallrocks serve as potential contaminants in two ways: through underground migration of water flowing through mine workings and through surface interactions with mine tailings. Hill (1933) documented 3 levels of underground workings and indicated that the steeply dipping veins are significantly faulted and fractured, creating zones which would be ideal conduits for subsurface water flow. The mill seep flows year-round with near constant composition (Table 1), it consequently must be a variety of groundwater, contaminated by interaction with subsurface materials. These contaminants potentially include metal left underground from past mining, vein material, and the wallrock surrounding the veins.

Table 1: Average concentrations of ore-related elements at each site. All values in ug/L. Gf = average values for Fairbanks-schist derived water in non-mineralized areas of the Fairbanks district, from Goldfarb, et. al., 1997. Values in bold are the highest for a given element; underlined values indicate significant decrease from site 7 to site 8.

st#	Zn	Cd	Cu	Mn	Ni	As	Co	Fe	Sb	Pb
Gf	0.70	<.02	<.5	0.20	0.50	3.00	0.02	22	0.30	<.05
1	7.53	0.04	0.70	1.42	0.64	15	0.05	19.7	1.52	0.11
2	70	0.67	0.99	116	2.68	17	0.79	28.5	1.43	0.09
3	57	0.51	1.00	73.3	2.27	21	0.52	31.1	1.68	0.17
4*	**2217**	**21.0**	**9.0**	**1032**	**127**	25	0.26	24	1.6	0.32
5	1009	6.4	3.0	539	64	**169**	**0.98**	**433**	**17.6**	0.74
6	519	3.62	1.94	325	31	100	0.726	183	9.24	0.39
7	318	2.10	1.6	225	19.3	76	0.67	93	14.3	0.32
8	33	0.17	0.7	266	2.6	80	0.53	298	12.5	0.26
9	201	1.41	1.4	190	12.1	69	0.53	110	9.3	0.19
10	206	1.50	1.3	167	12.7	56	0.40	70	7.9	0.13
11	201	1.41	1.4	190	12.1	69	0.53	110	9.3	0.19
12	14	0.03	1.1	60	2.0	35	0.30	64	10.3	0.08
13	4	0.02	1.3	62	1.7	32	0.29	62	9.8	0.11
14	0.9	0.01	0.3	0.2	0.1	28	0.01	4	0.2	0.03

4*: Mill seep sample location.

Sediments in Moose Creek and vicinity include what appear to be 'normal' stream sediments, mine tailings, and iron hydroxide precipitates. These materials can represent potential additional sources or sinks for elements in Moose Creek, depending on their compositions and abundance. Figure 1 shows the course of Moose Creek, the location of

tailings, waste rock piles, water and sediment samples locations, and location of the mill building.

Seven polished thin sections from vein and wallrock material from the waste dumps and from older Hi-Yu samples stored at the University of Alaska Fairbanks (UAF) were made and examined. Table 2 shows the sulfide minerals present and their approximate relative abundances in each of the seven sections. Gold was visible in three of the thin sections and is also noted in the table. Based on this work and that of Metz (1991), there appears to be three types of sulfide bearing veins present; a high stibnite, low sphalerite type (HY-1, 3, and 5), a high arsenopyrite/pyrite variety (HY-2 and 4), and a high sphalerite, low stibnite type (HY-6 and M1451).

Table 2: Sulfide minerals and relative abundance in vein thin sections, Hi-Yu deposit. Mineral abbreviations: Apy (arsenopyrite), Au (gold), Gal (galena), Py (pyrite), Sph (sphalerite), Stb (stibnite or other antimony sulfosalt). Sulfide minerals constitute 3-20% of the samples.

Sample	Mineral	% abundance
HY-1	Stb	72
	Py	20
	Sph	8
HY-5	Stb	79
	Py	15
	Apy	3
	Sph	3
HY-3	Stb	83
	Apy	10
	Sph	6
	Py	~1
	Au	<0.1(visible)
HY-4	Apy	87
	Py	7
	Stb	5
	Gal	<1

Sample	Mineral	% abundance
HY-2	Py	78
	Apy	15
	Sph	5
	Stb	2
M1451	Sph	87
	Apy	7
	Stb	5
	Py	<1
	Au	<0.1(visible)
HY-6	Sph	58
	Apy	40
	Stb	<2
	Au	<0.5(visible)

X-ray fluorescence (XRF) chemical analyses of vein material gathered from the waste rock dump and from ore samples donated to UAF (Table 3) show metal contents in agreement with the polished section identifications (Table 2), including overall sulfide contents ranging from 7 to 20%. These analyses also show the three different sulfide-bearing veins types along with a quartz-dominant variety. Copper is apparently present as tetrahedrite ($Cu_{12}Sb_4S_{13}$), as it is highest in the antimony-rich samples. Lead in the form of galena is also present and appears to be associated with the sphalerite-rich veins. In addition to the vein material these samples also include about 30% wallrock, consistent with the thin nature of the veins present and the inability of miners to only extract the vein material.

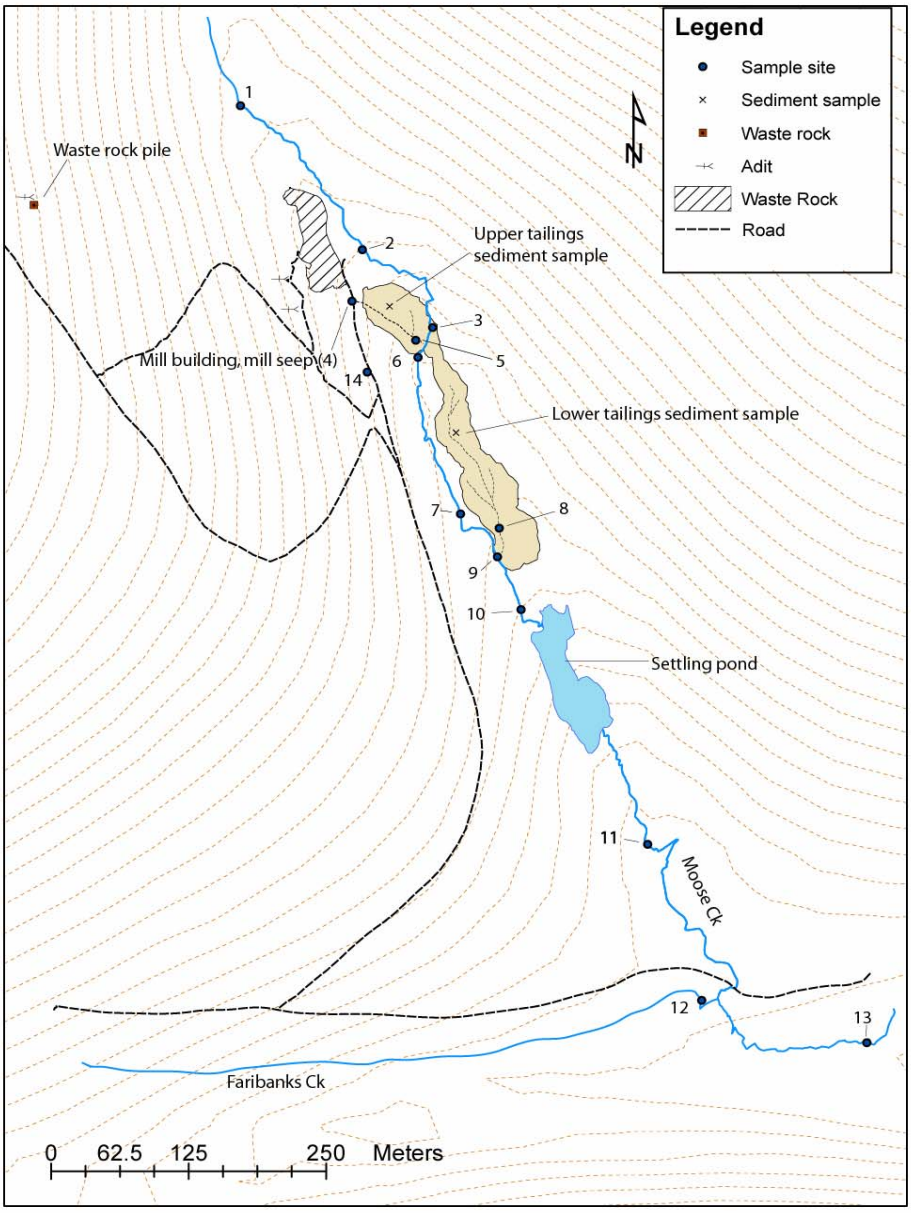

Figure 1: Sample location map, Hi-Yu area. Base map from U.S. Bureau of Land management, contour interval 10 feet. Sample locations and physical geography determined by hand-held gps positions, typical errors +/- 6 m.

Table 3: Ore-element contents of representative Hi-Yu vein material by XRF. Samples include approximately 30% wallrock adjacent to vein. Weighted average of the vein material = 1part each of Asp-, Stb-, and Sph- rich veins+ 2 parts quartz-rich vein.

Sample	Type	As wt %	S wt %	Pb wt %	Sb wt %	Cu wt %	Zn wt %	Fe wt %	Total sulfide
HY-2	Py-rich	6.9	2.7	0.8	0.7	0.2	0.3	4.7	16.4
HY-3/5	Stb-rich	0.7	1.8	0.6	1.4	0.9	0.4	1.2	7.1
HY-QV	Qtz-rich	1.5	0.4	0.2	0.1	0.001	0.02	1.5	3.8
HY-SLV	Spl-rich	3.4	11	1.4	0.6	0.1	5.5	6.7	28.3
HY-4	Asp-rich	4.4	7.5	2.6	0.8	0.03	2.4	7.7	25.3
Weighted Average		2.9	2.9	0.8	0.6	0.2	0.9	3.2	11.6

Partial trace element analyses of the vein materials by XRF (Table 4) show significant enrichments in bismuth, tin, gallium, and nickel. Mineralogically, nickel is commonly enriched in arsenopyrite; gallium and tin in sphalerite; and bismuth in galena [1]. Such associations can explain the observed enrichments. One sample contains anomalous tungsten, presumably due to scheelite, a common vein mineral in the Fairbanks district [2]. Molybdenum is present at barely detectible concentrations.

Table 4: Trace element contents (in ppm) of representative Hi-Yu vein material by XRF. Samples include approximately 30% wallrock adjacent to vein. Weighted average = 1part each of Asp-, stb-, and sph- rich veins+ 2 parts quartz-rich vein

Sample	type	Bi	Mo	Sn	W	Ga	Ni
HY-2	Asp-rich	7	3	52	<1	46	50
HY-3/5	Stb-rich	<1	1	262	<1	23	13
HY-QV	Qtz-rich	3	<1	5	<1	8	14
HY-SLV	Spl-rich	8	2	341	520	37	85
HY-4	Spl-rich	11	3	79	<1	146	105
Weighted Average		5	2	107	52	35	37

Because sphalerite is a potential host for several important elements that contaminate Moose Creek, I performed electron microprobe analysis on 4 sphalerite samples from the Hi-Yu mine and waste piles (Table 5). The sphalerites contain a modest amount of iron, small—but significant—amounts of Cd, and virtually undetectable Mn. The average Zn/Cd ratio of the sphalerite (~300:1) compares favorably with that reported for Moose Creek (~100:1) by Goldfarb et al. (1997), indicating that Hi-Yu sphalerite is a source for Zn and Cd in Moose Creek. Although Mn is a common element in sphalerite, the Mn contents of the Hi-Yu sphalerite are barely above detection and are unlikely to be the source for anomalous Mn in Moose Creek.

Table 5: Average microprobe compositions of sphalerites. Note: number in () is 1σ, values for Mn and As below detection limits

Sample #	S Elemental Percents	Mn Elemental Percents	Fe Elemental Percents	Zn Elemental Percents	As Elemental Percents	Cd Elemental Percents
HY-2 (a)	33.94 (0.22)	<0.03	1.97 (0.55)	63.57 (0.70)	<0.09	0.24 (0.03)
HY-3 (a)	33.85 (0.32)	<0.03	2.31 (0.69)	62.80 (2.53)	<0.09	0.27 (0.07)
HY-6 (a)	34.11 (0.20)	<0.03	3.80 (1.17)	62.69 (1.45)	<0.09	0.32 (0.05)
HY-7	34.10 (0.29)	<0.03	1.94 (0.40)	64.78 (0.45)	<0.09	0.15 (0.04)

The sediments in the Moose Creek valley are a final source of chemical components to Moose Creek. These sediments consist of a mixture of naturally eroding rocks, of sulfide-rich mine tailings, and of secondary precipitates. Interactions between the water of Moose Creek and the underlying fine-grained sediments is expected to be a two-way process, with some elements precipitated from water and others dissolving into the water. A particular concern with regards to water quality stems from the fact that mine tailings—crushed rock from which the gold had been extracted—were dumped into the valley. Reports and some physical evidence indicate that a retaining dam was built to contain the tailing material, but it is long gone. Presumably some of the tailings, especially the finer-grained portion, physically migrated downstream and continue to migrate downstream. Materials from the valley were sampled and analyzed in order to better assess sources and sinks of metal into Moose Creek. Figure 1 shows the general locations of sediments analyzed and Table 6 describes the physical characteristics of the samples

Table 6: Physical characteristics of sediment samples

Site	Location	Appearance	% grain size distribution, mm		
			>0.7	.07-0.2	<0.2
S2	Moose Ck below waste	'normal'-looking stream sediment	24	39	37
S4	mill seep	soil (?) under seep	20	56	24
UT	upper tailings	heavily orange-stained to dark brown	13	66	21
LT	lower tailings	pale to dark brown	9	41	50
S7	Moose Ck below UT	abd sed (from tailings?) on rocks	18	55	27
S8FE	drainage through LT	FeOx precipitate + trapped sediment	20	44	36
S8fe	drainage through LT	sediment + FeOx preciptate	19	63	17
S9	Moose Ck below LT	sed on top of rocks--from Tailings?	5	80	15
S11	Moose Ck below pond	sediment trapped in organic mat	mostly <0.2mm?		
S12	Fbx Crk above Moose	'normal'-looking stream sediment	not available		
S13	Fbx Crk below Moose	'normal'-looking stream sediment	38	24	38

The sample collected at site 4 (S4) is most likely soil from the mill area. This area adjacent to the mill is potentially contaminated with processed ore material and mine tailings. At site 8 two samples were collected: S8FE--which contains a greater abundance of the <0.2 mm fraction--is presumably iron oxide precipitate with some sediment, and S8fe—which contains a much larger percentage of 0.7-0.2 mm fraction--is comprised of sediment with minor iron oxide precipitate (Table 6). Sample S11 was collected about 50 m upstream of site 11 (Fig. 1) below the old settling pond. This sample consisted of organic material with trapped fine-grained sediment. The remainder of the samples (S2, S7, S9, S12, and S13) were stream sediments collected from Moose Creek and Fairbanks Creek.

To assess elemental variation as a function of grain size, both the fine-grained (<0.2 mm) and a split of the entire sample for four of the upper tailings samples (UTT, UT-Ox, UT-B, and UT-R, see figure 2 for sample designation) were analyzed. Table 7 shows the comparison for many representative elements, listed in decreasing order of greatest average difference of enrichment in the fine-grained fraction. For most elements, the difference in concentration between the fine-grained fraction and the entire sample is

<20% and apparent differences may be due to analytical error. Especially notable is that the sulfur, arsenic, and silicon contents are indistinguishable between the two size fractions.

A reasonable explanation for the elemental variations versus grain size comes from the physical nature of the sulfide minerals concerned: galena, sphalerite, and stibnite are relatively soft minerals with strong cleavages, whereas pyrite and arsenopyrite are hard minerals, lacking cleavage. During the grinding preliminary to treatment of the ore one would expect that the softer minerals with cleavage would grind to finer sizes than the harder minerals lacking cleavage. This apparent grain size difference would have significant impact both on the mineral reaction rates (finer minerals react more quickly) and on the physical transportability of the sulfides (finer-grained minerals are more readily transported).

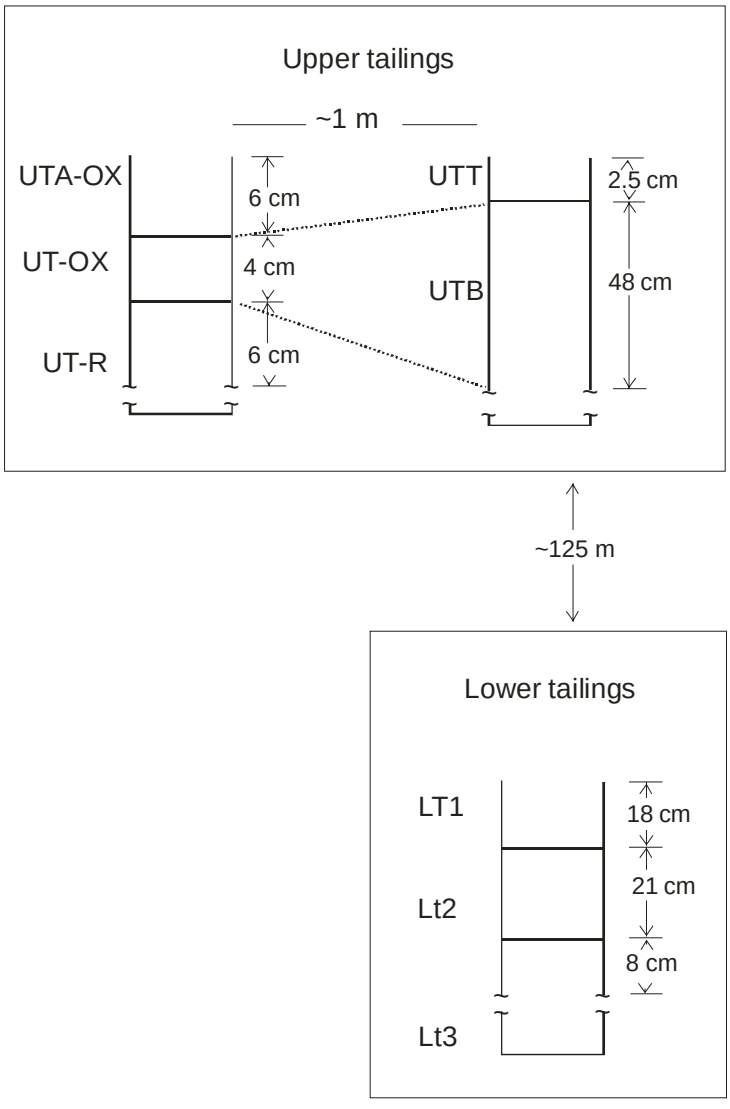

Figure 2: Cross section of upper and lower tailings, showing thickness of layers sampled.

Table 7: Comparison of fine-grained fraction to entire sample for upper tailing samples. f = fine-grained fraction; w = split of entire sample; all values in ppm unless noted otherwise.

	UTTf	UTTw	% diff	UTOf	UTOw	% diff	UTBf	UTBw	% diff	UTRf	UTRw	% diff	AVG DIFF
Pb	706	468	51	1580	267	492	514	490	5	610	546	12	140
Cd	2.22	1.44	54	4.96	0.94	428	1.7	1.68	1	1.52	1.5	1	121
Sb	281.7	154.3	83	78.5	28.1	179	130.4	107.3	22	80.8	57.4	41	81
Ag	14.4	8.02	80	28.5	12.25	133	11.8	9.72	21	27.6	22.7	22	64
Zn	126	80	58	76	44	73	144	84	71	98	70	40	60
Bi	1.77	1.67	6	2.69	0.92	192	1.55	1.7	-9	3.32	2.95	13	51
Cu	26.6	13.8	93	24.2	25.4	-5	22.8	12	90	43.6	38.8	12	48
Tl	0.48	0.3	60	0.26	0.2	30	0.5	0.28	79	0.4	0.36	11	45
Li	14.8	8.2	80	6.8	7.2	-6	14.8	7.8	90	9.8	8.8	11	44
Mn	50	25	100	20	25	-20	40	25	60	45	35	29	42
Rb	56	33.6	67	22.8	24.3	-6	55.4	29.7	87	46.6	41.1	13	40
Ga	8.3	5.25	58	3.2	4.3	-26	8.15	4.6	77	7.55	6.6	14	31
%K2O	1.1	0.72	53	0.47	0.57	-18	1.04	0.65	60	1.07	0.84	27	31
Cs	1.75	1.2	46	0.9	1	-10	1.65	1.05	57	1.55	1.4	11	26
W	1.3	6.4	-80	1.3	0.4	225	1.5	6.9	-78	0.5	0.4	25	23
%MgO	0.61	0.44	39	0.14	0.17	-18	0.54	0.43	26	0.34	0.24	42	22
U	1.6	1.4	14	2.5	1.7	47	1.5	1.4	7	3.3	2.9	14	21
%Al2O3	5.46	3.73	46	2.39	3.29	-27	5	3.7	35	5.4	4.32	25	20
Ba	298.5	271	10	92.5	115.5	-20	284	159.5	78	193.5	182.5	6	19
Co	1.4	0.9	56	0.6	1	-40	1.3	0.9	44	2.4	2.2	9	17
Sr	44.4	32.8	35	22.4	32.8	-32	43.6	30.4	43	49	43.6	12	15
Ni	7.8	4.6	70	2.6	4.6	-43	6.2	5.4	15	9.2	8.2	12	13
La	22	17.5	26	10.5	14	-25	20.5	16	28	23	20.5	12	10
%Fe2O3	4.15	3.55	17	2.22	2.85	-22	3.89	3.45	13	4.69	3.91	20	7
Mo	0.35	0.3	17	0.2	0.2	0	0.35	0.7	-50	0.4	0.25	60	7
Ce	40.3	34.5	17	20.9	28	-25	37.9	31.5	20	46.3	41.5	12	6
Cr	20	17	18	14	16	-13	18	19	-5	24	20	20	5
As	>10000	>10000	0	3410	3230	6	>10000	>10000	0	5820	5300	10	4
%S	0.1	0.12	-17	0.06	0.05	20	0.14	0.13	8	0.05	0.05	0	3
%SiO2	81.58	86.28	-5	92.14	89.63	3	83.49	85.9	-3	84.63	86.05	-2	-2

To assess compositional changes in the tailings taking place due to oxidation, samples were collected at different depths determined by color changes in the tailings (Fig. 2). Data (Table 8) are listed by increasing depth (right to left) for the upper (UT) and lower (LT) tailings and by decreasing ratio of average concentration in upper layers/lowest layer (top to bottom of table). The patterns exhibited in Top/Bottom ratios (T/B, Table 8) differ somewhat between the upper and lower tailings, but for many elements show remarkably uniform patterns. The most obvious pattern not shown is a uniform leaching of elements from the upper layers. Sulfide minerals are expected to rapidly dissolve through oxidation, yet the concentrations of arsenic are twice as high in upper than lower layers. Antimony shows inconsistent patterns (in part due to poor analyses?) and sulfur shows virtually no change. The increase in arsenic (± antimony) is not due to secondary precipitation is shown by the absence of the striking yellow-green of scorodite ($FeAsO_4 \cdot 2H_2O$) and stibiconite ($Sb_3O_6(OH)$), the principal secondary arsenic and antimony minerals of the Fairbanks area. Similarly, the absence of significant manganese enrichment from the upper layers indicates that secondary elemental precipitation is not a major factor.

The high arsenic content in UTT is likely chemically sorbed onto Fe(III) oxides which are present. This results from the oxidation of Fe(II) from pyrite and other iron bearing minerals and precipitation of Fe oxyhydroxides. These Fe oxyhydroxides are poorly crystalline and have large surfaces areas which result in significant adsorption capacity. Arsenate (As(V)) adsorption has been found to be the greatest at low pH values, 2.2 to 6.9, with the predominant As(V) species being $H_2AsO_4^-$ [2-6].

These elemental patterns, combined with the patterns seen as functions of grain size (Table7) are compatible with physical leaching of the tailings. Both the 'clean' appearance of the uppermost tailings layers and their high arsenic contents suggest that they have been physically winnowed by wind and water, with removal of finer minerals (muscovite, fine-grained sulfide minerals) and consequent enrichment in coarser minerals (quartz, other silicate minerals, and arsenopyrite). A pattern such as this explains both the vertical zoning in many elements and the changes between the upper and lower tailings. In particular, the average concentration of arsenic is 2-3 times higher in the upper than lower tailings, whereas the concentrations of lead, zinc, copper, bismuth, antimony, and cadmium either show little change or are higher in the lower than the upper tailings. The lower tailings also contain a much higher proportion of <0.2 mm particles (Table 6), and higher average concentrations of the muscovite-associated elements aluminum and potassium (Table 8), consistent with these elemental abundances. In sum, the lower tailings apparently formed by selective down-slope movement of tailings after the tailings dam failed. Further, both tailings have been selectively winnowed of finer-grained particles that presumably have been transported downstream by Moose Creek. Finally, much of the valley is most likely contaminated by fine-grained, wind- and snow/ice- borne tailings particles.

Chemical processes, however, are also likely in the tailings, as suggested by the iron oxide staining and elemental patterns not solely explainable by physical winnowing. For example, significant uranium depletion from upper relative to lower layers is most readily explained by the high solubility of uranium under oxidizing conditions; that the commonly associated element thorium does not show enrichment can be attributed to redox-independent solubility similar to arsenic. In addition, some of the variable

depletion in silver, bismuth, copper, lead, and antimony from the upper layers (Table 7) is probably caused by simple chemical leaching. If this is the case, one would expect enrichment of these elements in water that interacts with the tailings. Water quality of Moose Creek is presumably reflected by both the physical transport of sediments and the interaction of water with these sediments.

Table 8: Vertical compositional zoning in Tailings samples, arranged by enrichment in top layers. Notes: T/B = top/bottom = average upper layers/lower layer; oxides in wt%, others in ppm

	UTT	UTM	UTB	T/B	LTU	LTM	LTB	T/B	AVG
W	3.9	2.5	0.5	7.1	15.8	4.0	1.3	7.9	7.5
As	>10000	9000	5560	2.7	4170	4080	1815	2.3	2.5
CaO	0.05	0.06	0.05	1.2	0.10	0.07	0.05	1.7	1.5
MgO	0.34	0.32	0.29	1.1	0.37	0.61	0.28	1.8	1.4
TiO2	0.44	0.41	0.43	1.0	0.52	0.49	0.28	1.8	1.4
Na2O	0.22	0.32	0.18	1.5	0.30	0.37	0.28	1.2	1.4
Sb	185	86	69	2.0	63	197.2	214.675	0.6	1.3
S	900	930	1000	0.9	900	1000	600	1.6	1.2
Rb	38	33	44	0.8	58	106	53	1.6	1.2
Be	0.8	0.6	1.0	0.7	1.0	1.7	0.9	1.5	1.1
Zn	89	75	84	1.0	96	122	93	1.2	1.1
Th	6.7	5.4	9.4	0.6	8.0	14.2	7.5	1.5	1.1
Cs	1.3	1.2	1.5	0.8	1.7	3.9	2.2	1.3	1.1
V	18	16	26	0.7	21	51	25	1.4	1.0
Ba	207	163	188	1.0	270	530	375	1.1	1.0
P2O5	0.04	0.03	0.06	0.6	0.07	0.07	0.05	1.4	1.0
SiO2	87.4	87.8	84.3	1.0	87.9	80.1	85.1	1.0	1.0
MnO	0.04	0.03	0.04	1.0	0.04	0.04	0.04	1.0	1.0
La	20	15	22	0.8	23	38	26	1.2	1.0
Ce	35	30	44	0.7	41	69	45	1.2	1.0
Al2O3	3.82	3.60	4.86	0.8	5.24	8.51	5.84	1.2	1.0
Cr	17.3	16.8	22.0	0.8	16.0	23.0	17.0	1.1	1.0
K2O	0.72	0.68	0.96	0.7	1.05	2.09	1.46	1.1	0.9
Cd	1.8	2.3	1.5	1.4	0.4	1.5	3.0	0.3	0.8
Ni	6.2	4.7	8.7	0.6	8.4	8.8	8.1	1.1	0.8
Sr	34	32	46	0.7	42	63	56	0.9	0.8
Fe2O3	3.44	3.10	4.30	0.8	2.52	3.11	3.18	0.9	0.8
Co	1.0	1.0	2.3	0.4	1.4	2.0	1.7	1.0	0.7
Pb	587	713	578	1.1	97	308	975.5	0.2	0.7
U	1.5	1.8	3.1	0.5	1.0	1.9	2.1	0.7	0.6
Cu	20.2	21.1	41.2	0.5	9.8	14.4	35.3	0.3	0.4
Ag	11.2	15.6	25.2	0.5	2.4	5.0	12.6	0.3	0.4
Bi	1.7	1.7	3.1	0.5	0.7	1.1	11.5	0.1	0.3

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