“TRACE ELEMENT ANALYSIS OF UTAH LAKE’S SEDMINETARY SLUDGE USING XRF AND PIXE TECHNIQUES”

By Remy Lamberts

Submitted to the Department of Physics and Astronomy in partial fulfillment
of graduation requirements for the degree of
Bachelor of Science

Brigham Young University
Aug 2005

Advisor: B. Lawrence Rees

Signature: _________________________

Capstone Coordinator: Branton Campbell

Signature: _________________________

Department Chair: R. Steven Turley

Signature: _________________________

Abstract

Thirty-six sediment samples were extracted from the bottom of Utah Lake in a grid-like pattern in the area of the former site of the Geneva Steel plant. A few of the samples were initially analyzed using an energy dispersive X-ray fluorescence spectrometer (EDXRF) to determine a rough estimate of the sediment matrix, which consisted mainly of calcium carbonate and silicon dioxide. All thirty-six samples were then analyzed with wavelength-dispersive XRF (WDXRF). The majority of the results were consistent with findings of previous investigations. However, higher counts of lead, arsenic, copper, and zinc were found in one of the samples. This was likely due to Geneva's pumping of materials into the lake. This local sample was then analyzed with Particle-induced X-ray emission (PIXE) spectroscopy, and similar results were found. PIXE was also used to show that the preparation of samples for the XRF was introducing some trace amounts of tungsten into the samples.

Acknowledgments

I would like to acknowledge Professor Lawrence B. Rees, my capstone advisor, who aided me greatly and gave me input on almost every aspect of my project. I would especially like to thank Dave Tingey for all the time he put into teaching about sample preparation and use of the XRF. I would also like to thank Eric Christiansen, Michael Dorais, and the rest of the Geology department for aiding me and letting me occupy my time with their XRF spectrometer. I also acknowledge Mark Jackson of the Geography department for lending me a GPS and aiding me with some of my aerial graphics. Thanks to Willis Brimhall for his studies in a similar area, and his communications and input to me for my report. I express gratitude to Alan Smith who kindly lent me his pride and joy, his zodiac boat, for 3 months. Finally thanks to the rest of the undergraduates in the PIXE group who helped me to complete my report.

Contents

Appendixes

List of Figures

List of Tables

Chapter I. Introduction

1.1 Overview

The main objective of this project was to determine what trace elements are currently residing in the sediment of Utah Lake, as well as to measure their relative concentrations. The project was conducted in hopes of identifying possible environmental hazards with the intent that any effects they might be having on recreationalists, local residents, and wildlife may be evaluated. It has been said that "The potential of Utah Lake as a healthy fish and wildlife habitat, water resource, and recreation area hangs in the balance—waiting to be nurtured into greatness"(Carter [1]). I initially began my research in hopes of helping to "nurture" the lake into a cleaner and healthier state by identifying any current hazards that might need attention. Due to time constraints and interests, I focused more specifically on the sediments near the Geneva Steel mill, where lots of byproducts were dumped into the lake. Beginning in the early 90s, Geneva Steel made an effort to restore the damage it had done to Utah Lake and the surrounding area (Carter). How well they have restored the damage, is something my project can be used to evaluate. Other objectives of my project were to restore a wavelength-dispersive XRF (WDXRF) to a functional state, and to utilize it in my research. Lastly, I made an assessment of the standard XRF pellet preparation technique, and the levels of contaminations it was introducing.

1.2 Background

1.2.1 Utah Lake

"Utah Lake is a mirror of our relationship to place over time. From native people to contemporary life along the Wasatch Front, this body of water is a reflection of subsistence, abuse, neglect, and restoration" said Terry Tempest Williams on reviewing the history of Utah Lake (Carter [1]). The lake suffered a long period of abuse in the 19th and 20th centuries with the implementation of railroads, livestock overgrazing, agriculture pesticides and fertilizers, sewage dumping, over-damming and dredging of the lake's tributaries, and my particular focus, the Geneva Steel mill. The abuse has had devastating effects on the wildlife of the area. For example, of the original thirteen species of fish in the lake, only two remain, as many of the others could no longer survive in the polluted environment. Trace element analysis of the sediments provides one way to monitor the lake for health hazards.

The normative mineral distribution of the lake is known and has been considerably mapped out already. In 1973 Sonerholm [3] collected 149 samples in a grid-like pattern over the entire lake and used atomic absorption spectrophotometry to determine the primary mineral distributions in the sediments. He concluded that of the seven metals he profiled (sodium, potassium, calcium, magnesium, aluminum, iron, and silicon), most of them existed in a carbonate or sulfate containing compound. If it was not a carbonate or sulfate form, it was usually part of some larger mineral. For example, he showed that the majority of calcium was in the form of calcium carbonate (calcite) and not in the form of calcium oxide (CaO). He also discovered that calcium carbonate (calcite) was the most prevalent compound in the sediments, making up the majority of sediment matrixes. In the area of Geneva Steel, he reported calcium carbonate levels ranging from 20 to 65% of the matrix, with the calcium carbonate levels increasing as you get further from the shore. He also found that silicon dioxide had an inverse relationship; it makes up 50% or more of the matrix as you get closer to the shore, and goes down to about 15% as you proceed further from the shore. Throughout my research, these numbers acted as controls for me as I was able to compare the numbers I obtained to previously reported data.

In 1976 Willis Brimhall [4] of the BYU Department of Geology did an extensive research project on the geology of Utah Lake, building off of Sonerholm's data. He found that impurities such as magnesium, strontium, iron (from the mill), and others were also found. Furthermore, he found that the silica levels rose near the mouths of rivers and shorelines; this was due to the waves generated during storms which have sufficient amplitude to cause turbidity in the water and to shift the sediments on the floor of the lake. Since the calcium carbonate was of a smaller particle size than the silica, it often moves much more than the silica which remains where it was originally deposited.

Other studies have indicated the major elements of focus for assessing water quality based on trace element analyses. In the 2002 water quality assessment report to Congress [5], lead, zinc, and chlorine were some of the trace elements found and monitored in the Utah Lake and Jordan River area. Therefore, these were a few of the elements I focused on the most. However I did as broad of a trace element analysis as procedures allowed in order to look for other elements such as copper, iron, calcium, magnesium, and potassium, because another report *Utah's 2004 303(d) List of Impaired Water* [2], indicated them as some more commonly found trace elements.

1.2.2 Wavelength-Dispersive X-Ray Fluorescence Spectroscopy

The WDXRF uses an x-ray source to ionize a sample. This in turn causes X-rays to be emitted with the specific energies characteristic of the elements in the sample. The scattered X-rays are then diffracted through a crystal and are then received by an X-ray detector positioned at some specific angle away from the crystal. The angle where the intensity of the scattered X-rays is maximum, is determined by the wavelength of the X-rays emitted from the sample and which are characteristic of the elements in the source. Some of the disadvantages are that the sample preparation for the WDXRF is demanding and the run times are long because the detector has to scan through the entire range of diffraction angles. However, WDXRF has a much higher resolution than the EDXRF, which allows for less spectral overlap and lower background [6], and the WDXRF system is routinely used by the Geology Department for samples similar to mine. For these advantages I chose to use WDXRF to do the majority of my trace element analysis.

1.2.3 Energy Dispersive X-Ray Fluorescence Spectroscopy

The EDXRF uses an x-ray tube with a rhodium target as its excitation source. These X-rays are incident on secondary targets to produce X-rays that are primarily restricted to the narrow range of energies corresponding to the characteristic X-rays of the secondary target. These secondary X-rays are then used to excite the sample which emits the characteristic X-rays of the elements in the sample. These energies are measured directly with a lithium-drifted silicon (Si)Li detector, and the energy spectrum is then analyzed to identify the elements present in the sample The main disadvantages of the EDXRF are its low resolution, overlap of spectrum, and lack of analysis of the spectrum by the computer. These disadvantages also led me to believe WDXRF would be a better technique for the majority of my research; however, the EDXRF does have its advantages: sample preparation is simple, running the machine is not difficult, and results can be obtained quickly. I therefore opted to use the EDXRF to do a preliminary analysis on some of the samples in order to determine an overall matrix, and give me an idea of what to look for when using the other methods for trace element analysis.

1.2.4 Particle-Induced X-ray Emission (PIXE) Spectroscopy

In my research, PIXE was done using a 2MEV van de Graff accelerator; protons from the accelerator strike the sample and cause inner-shell ionization of atoms in a specimen. As with the XRF spectrometers, X-rays with characteristic energies are produced by the sample, and are detected with a Si(Li) detector. The raw data are then analyzed with GUPIX, a software package produce by the University of Guelph. Since matrix compositions are needed when analyzing PIXE data, it is an advantage if PIXE can be combined with other methods that allow determination of the matrix composition. I therefore used PIXE in conjunction with the XRFs for my report. Although, the range of PIXE is not as great as the XRFs, its background is much lower than the EDXRF's, and it can be used to scan for heavy metals that the WDXRF might have trouble detecting. I used PIXE on a limited

Fig. 1. The Van De Graff accelerator used for PIXE spectrometry, The Si(Li) detector can also be seen towards the back.

number of samples to confirm their anomalies and to scan for other heavy metal that might be in the samples.

1.3 Combining Techniques to Measure Trace Element Concentrations

The three techniques described above were used in conjunction with each other in order to determine trace element concentrations in the sediments around Geneva. I initially planned to look for elemental gradients surrounding the mill. The idea was that as you got further from the mill you would see levels of metals present decreasing. This would require a much greater effort than I was able to undertake; however, I was still able to make reasonable and sustainable conclusions about Geneva Steel. I was able to assess what influence they might have had in adding to the trace elements, what environmental hazards might be in the lake, and what further research should be done in this area.

Chapter II. Experimental Setup and Methods

2.1 Sample Gathering

During May of 2005, I collected approximately 36 samples at known locations in Utah Lake. In order to move around the lake, I used an inflatable pontoon boat with a 25 horsepower motor. At each point, a homemade lead anchor was dropped on one side of the boat. The sediment samples were extracted by forcing a 10 foot PVC pipe into the lake floor, and extracting a plug of sediment approximately 2-3 inches long. Simultaneously, a GPS unit was calculating the point of extraction with an accuracy of within a 1 meter radius. The plugs were then forced from the PVC pipe into a 125 mL Nalgene jar, where they were labeled and stored. As shown fig.2., the first 28 samples were taken in a grid-like pattern near the shore of the mill. The other samples were taken

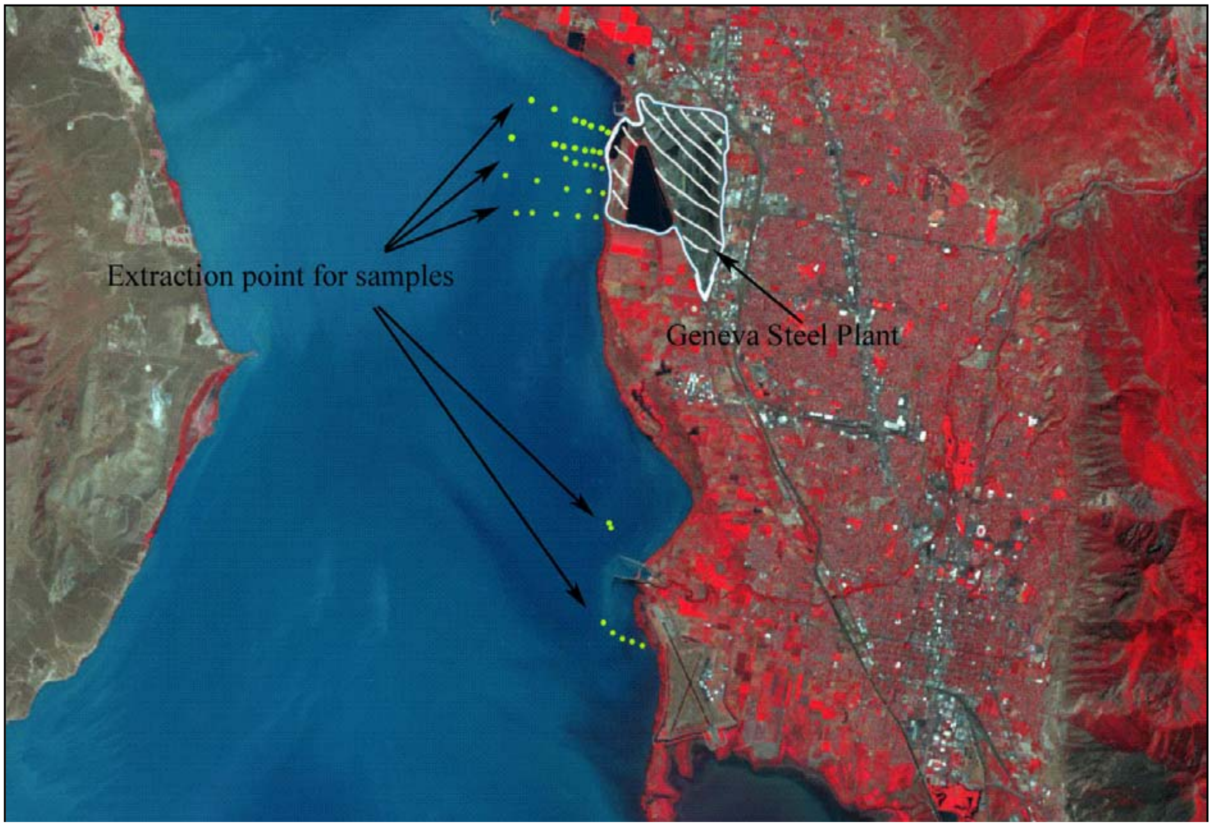


Fig. 2. An infrared satellite photo of Utah Lake marking every point on the lake where a sediment extraction was made. They are marked by the yellow-green dots on the lake. The white hash marked area is where the Geneva Steel plants location is at. Appendix B has the geographical data for the points.

at a different spot 5 miles south of the mill, acting as a control for my experiment. For more information on the extraction points see Appendices A and B which contain more maps and data points showing more specifically the points of extraction.

2.2 Analysis using the XRF spectrometers

2.2.1 Initial Analysis with the EDXRF

Using the EDXRF with a series of secondary targets, two types of sediment samples where analyzed: silt samples and sand samples. The samples were first dried in an oven for 3 days at 80°C. They were then homogenized by placing the sample in a Teflon vessel with an agate ball. The vessel was placed in a micro-dismembrator in order to pulverize the sample into a powdery homogenous sample as shown in Fig.3. The pulverized samples were then placed on a polycarbonate film slide. Since I was not worried about quantitatively measuring each element in the samples yet, I did not weigh the samples out in a specific manner, nor did I extend extraordinary precautions to assure that each sample was run *exactly* the same. I just wanted to run each one to find the basic elements that were making up the matrix.

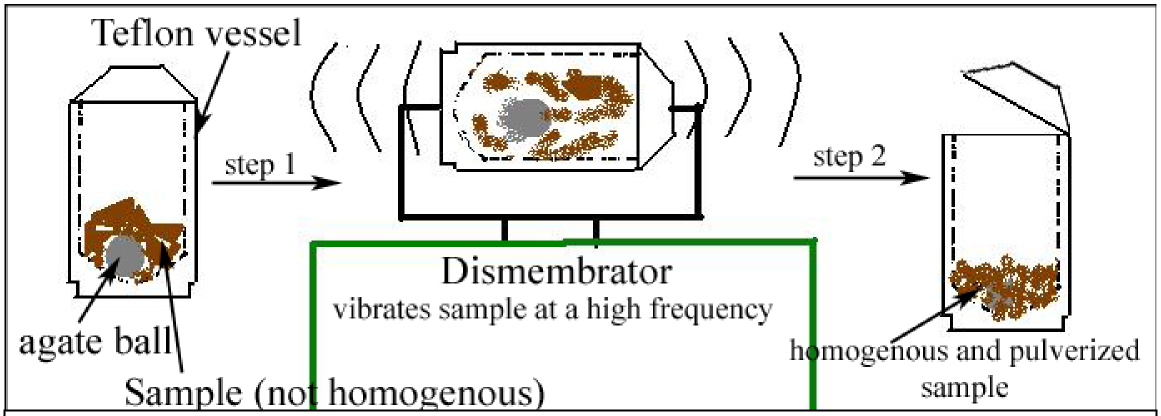


Fig. 3. Diagram showing the non homogenous sample place in the vessel with durable agate ball. The vessel is then placed in the dismembrator where it is vibrated at a high frequency, and the ball effectively pulverizes and homogenizes the sample.

The scans were done using five different secondary targets in order to complete a comprehensive scan of the trace elements in the samples.

2.2.2 Oxford WDXRF Attempts

Before I began even collecting samples, I worked on renovating an Oxford QX WDXRF that had been occupying the laboratory for a number of years, but had never been set up. I spent a couple of months providing the appropriate power to it, providing the right detector gas mixtures (at correct pressures), and getting the x-ray tube to hold voltage, and trying to calibrate it. Unfortunately that detector was set up for only 5 elements when the Physics Department received it. I had hoped to set up the XRF to scan for other elements after it was fully functional. However, with the help of Dr. Rees, we discovered that the QX Spectrometer had a series of monochromators installed that were element specific. This meant that there would be no way to configure the XRF to look for elements other than what it could already look for. So in the end, I decided against using this machine for the actual analysis of my samples; however, I spent lots of time making it a functional machine in hopes that it would be useful to my project.

Fig. 4. The Oxford QX spectrometer that was renovated over a period of two months.

2.2.3 Sample Preparation for the WDXRF

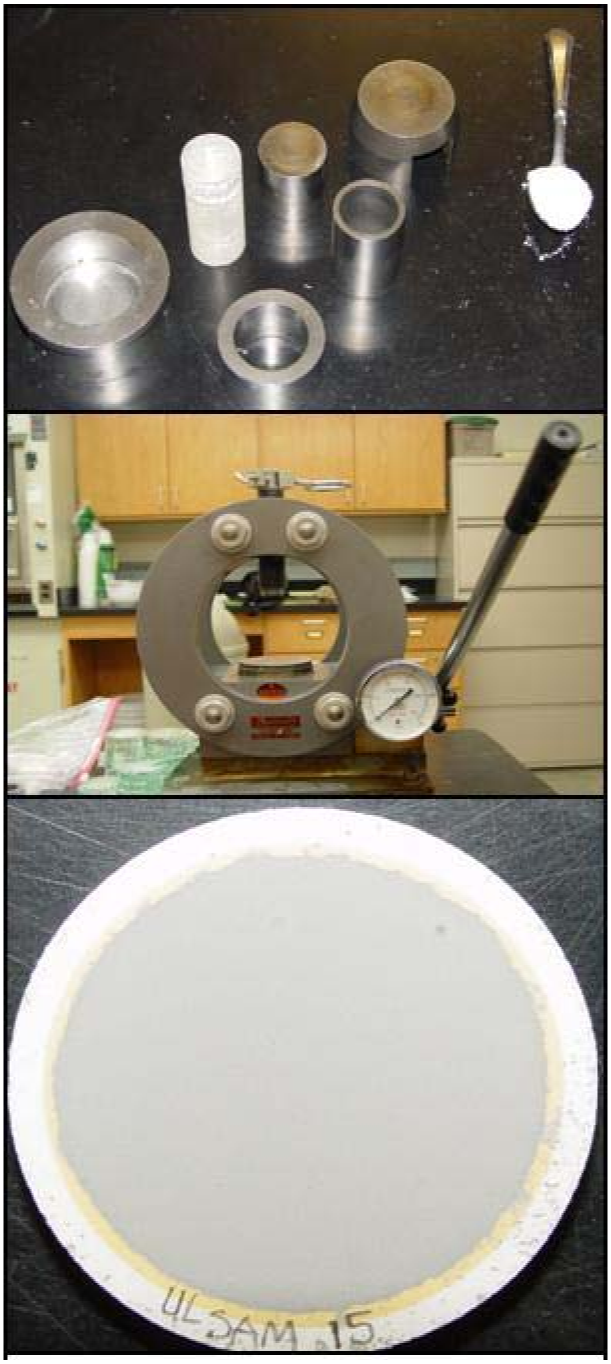


Fig. 5. Top: shows the set of dies, and a spoonful of the cellulose. **Middle:** the hydraulic press used to compress the sample using a seven ton force. **Bottom:** the final pressed pellet ready for WDXRF.

At this point, I considered doing the entire report with the EDXRF when Dave Tingey, who was giving me some advice on sample preparation, offered to lend me the BYU Geology Department's WDXRF to analyze my samples. I accepted the offer and used their WDXRF to run my samples, which expedited much of my analysis time because their WDXRF gives outputs of the data in a very practical and usable form. Before I could use the XRF, though, I first had to prepare all samples to be run using the standard preparation techniques that geologists use in the preparation of XRF samples. I began by drying the samples as I had done with the EDXRF (3 days @ 80˚C). The samples were then pulverized using a mechanism similar to the one depicted in Fig.2.; the difference was the vessel in which they were crushed was much larger and was made of tungsten carbide (Fig. 8). I had some initial reservations in using this vessel as I suspected it might introduce some levels of contamination, but I was assured that the contamination was low and predictable. After the samples had been pulverized, I created pressed pellets by placing 2.000 grams of the sample with some amount of cellulose into a set of standard dies, and compressed them with a hydraulic press (see Fig.5). With this process I was able to produce 34 pellets with uniform composition, density, and mass per unit area. All of these traits make the analysis of the sample an easier process.

2.2.4 Analysis with the Geology WDXRF

Beginning on April 30th, the pressed pellets were analyzed with Department of Geology's Siemens SRS 303 WDXRF shown in Fig.6. 9 samples were run at a time along with one standard sample; the standard sample is used in order to indicate which elements the spectrometer is seeing correctly, and which elements are being seen with some inaccuracy. The run time per sample was about 3.5 hours per sample, and all runs had been completed by the 14th of July. All of the samples were analyzed properly except for one sample, ULSAM-23 which had a convergence error. This implied that the pressed pellet prepared was releasing an overload of X-rays for a particular element, and the detector couldn't handle it. The sample was rerun once, but failed due to the same error. After the rest of the runs were over, all data were extracted to a spreadsheet file, where they were converted into there most convenient forms. For matrix elements they were

Fig. 6. A picture of the Siemens SRS 303 Wavelength-dispersive XRF, and the analysis computer.

converted to percent weights, while for trace elements they were displayed as parts per million.

2.3 PIXE

2.3.1 Sample Preparation

After the results from the WDXRF had been interpreted, I selected 5 samples of particular interest to be analyzed using PIXE. I did this to see if there were any other trace elements that were not being seen with the XRF spectrometers. My first priority was to analyze ULSAM05 as it had some interesting abnormalities compared to other data. In order to assess the contamination levels incurred from using the tungsten carbide chatter box, I decided to run two different samples: one that had been pulverized using the tungsten carbide chatterbox, and one that had been pulverized using the micro-dismembrator and a Teflon vessel as described in Fig. 2. Pulverized samples were accurately weighed and spiked with a solution containing an precisely known concentration of Yttrium. The samples were then dried again in the oven at 80°C for 24 hours. After this drying process, 1 to 1.5 milligrams of the dried, spiked, and pulverized samples were adhered to polycarbonate slides using a toluene polystyrene mixture. 3 slides per sample were created, so 6 slides total had been created for the sample ULSAM05. My next goal was to analyze ULSAM23 because it could not be analyzed using the WDXRF. So 3 slides were prepared for it in the same manner

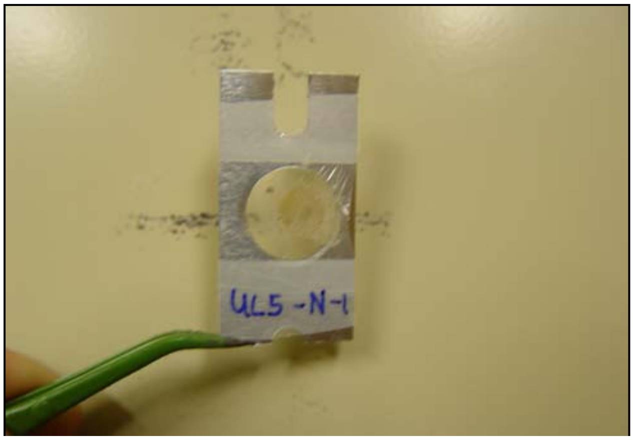


Fig. 7. one of the prepared PIXE slides for ULSAM-5

described above; however due to time constraints I failed to spike it with the Yttrium spike. Slides for ULSAM6, ULSAM25, and ULSAM10, were also created.

2.3.2 Analysis with PIXE

As mentioned earlier, ULSAM-5 was my first priority to analyze with the PIXE as it had the most outstanding abnormalities. This was done using the 2.1 MeV Van de Graff accelerator to ionize the samples. The two different filters that precede the detector are a pinhole filter made of a sheet of .014 inch mylar with a small hole, sandwiched between two layers of Beryllium of width 46 µm, and a .028 inch mylar filter. They are X-ray absorber filters and are used to attenuate the dominant peaks and allow greater trace element sensitivity [7], allowing the user to see different ends of the spectrum better. As aforementioned, the raw data are analyzed using GUPIX, a statistical software package designed for analyzing PIXE data. The data from GUPIX were then normalized using the iron concentrations because it is an element that both PIXE and XRF both see with accuracy. Due to time constraints, not all of the slides that were prepared were analyzed with PIXE.

Chapter III. Results

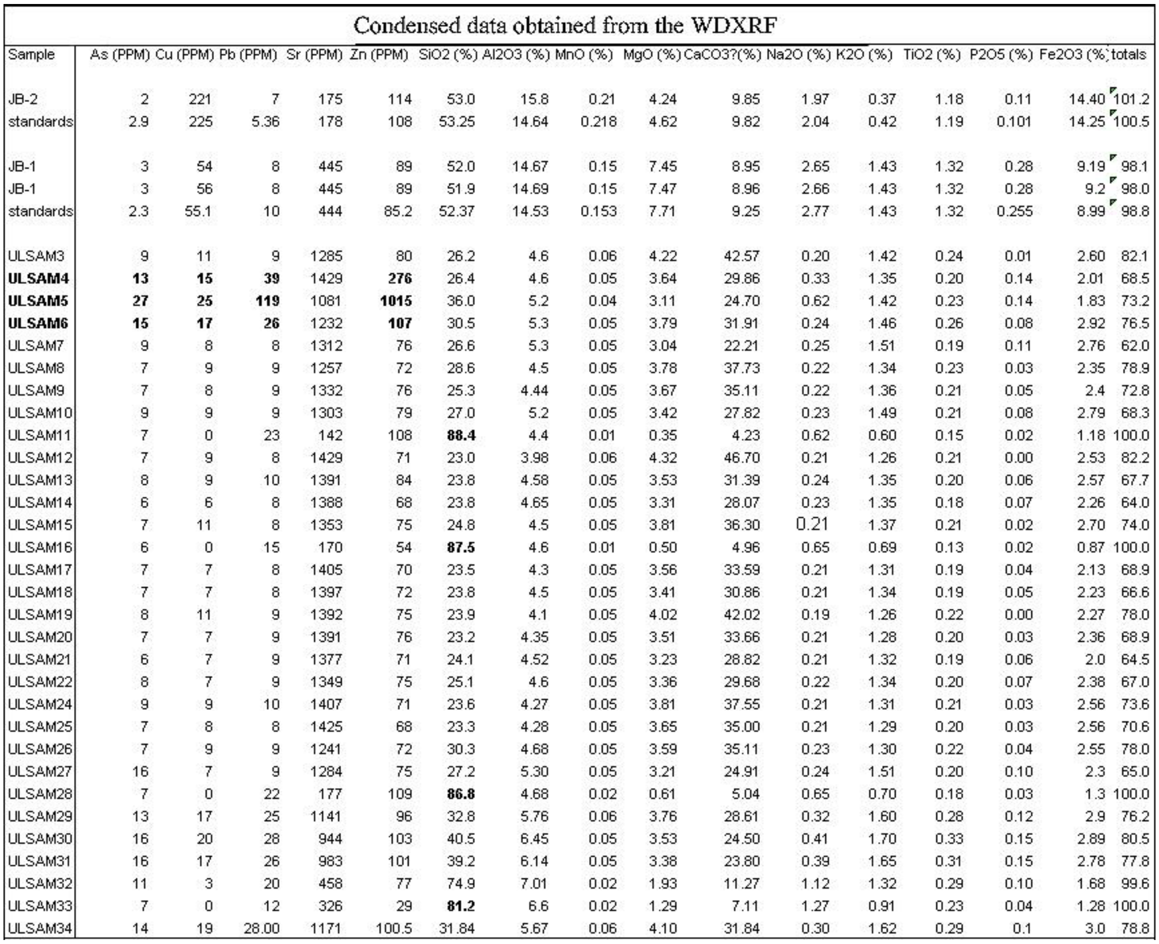
3.1 Summary of Results

3.1.1 XRF Results

The EDXRF runs allowed me to see what the main elements were and gave me an idea of what other elements might be of interest. In the siltier sample from deeper waters, I detected the presence of mainly calcium, iron, and strontium. Zinc, barium, zirconium, and titanium were other minor contributors in that sample. The sandier sample, which was obtained from shallower waters near the shore, had the same major contributors of calcium, iron, and strontium, but also, as expected, heavy levels of silicon (presumed to be silicon dioxide).

Using the data from the EDXRF, I was able to choose appropriate standard samples to run along with my pressed pellets in the WDXRF. A table of summarized results from the WDXRF is given on the following page in Fig. 4, while the entire list of results is given in Appendix D. The most notable results were in ULSAM-5 where abnormal levels of lead, zinc, copper, and arsenic were found. The average amounts of zinc, lead, copper, and arsenic in all other samples was 14 ppm, 9 ppm, 9 ppm, and 86 ppm, respectively, while in ULSAM-5 the counts were 119 ppm, 27 ppm, 25 ppm, and 1015 ppm, respectively. The two samples on either side of it, ULSAM-6 and ULSAM-4 showed above average concentrations of the same elements.

ULSAM-11, ULSAM-16, ULSAM-28, and ULSAM-33 were all sandy samples that were taken very close to shore, and thus the primary compound in their matrix was silicon dioxide which constituted from 81% to 88% of these shoreline samples. ULSAM-23, a sandier sample with a darker color, would have been likely classified in this range, but since it was having convergence errors, we never obtained a clear reading with



Condensed data obtained from the WDXRF

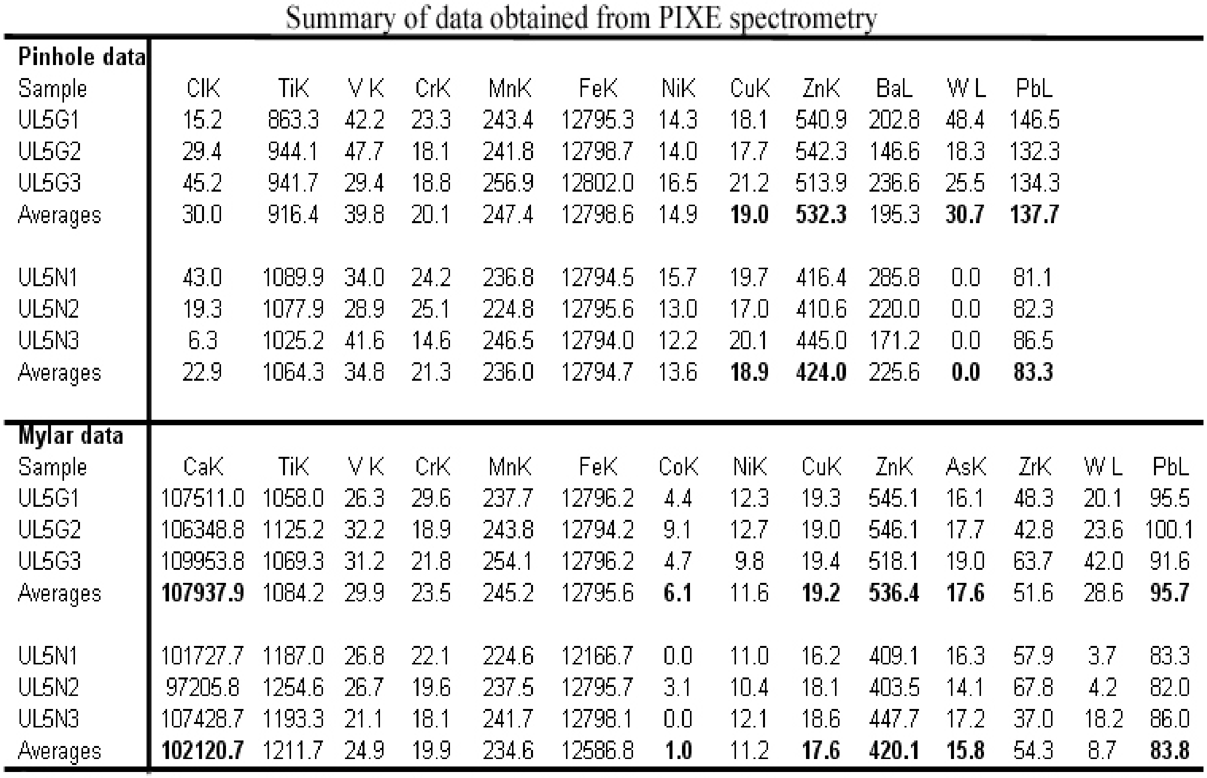
Sample	As (PPM)	Cu (PPM)	Pb (PPM)	Sr (PPM)	Zn (PPM)	SiO2 (%)	Al2O3 (%)	MnO (%)	MgO (%)	CaCO3?(%)	Na2O (%)	K2O (%)	TiO2 (%)	P2O5 (%)	Fe2O3 (%	totals
JB-2	2	221	7	175	114	53.0	15.8	0.21	4.24	9.85	1.97	0.37	1.18	0.11	14.40	101.2
standards	2.9	225	5.36	178	108	53.25	14.64	0.218	4.62	9.82	2.04	0.42	1.19	0.101	14.25	100.5
JB-1	3	54	8	445	89	52.0	14.67	0.15	7.45	8.95	2.65	1.43	1.32	0.28	9.19	98.1
JB-1	3	56	8	445	89	51.9	14.69	0.15	7.47	8.96	2.66	1.43	1.32	0.28	9.2	98.0
standards	2.3	55.1	10	444	85.2	52.37	14.53	0.153	7.71	9.25	2.77	1.43	1.32	0.255	8.99	98.8
ULSAM3	9	11	9	1285	80	26.2	4.6	0.06	4.22	42.57	0.20	1.42	0.24	0.01	2.60	82.1
ULSAM4	**13**	**15**	**39**	1429	**276**	26.4	4.6	0.05	3.64	29.86	0.33	1.35	0.20	0.14	2.01	68.5
ULSAM5	**27**	**25**	**119**	1081	**1015**	36.0	5.2	0.04	3.11	24.70	0.62	1.42	0.23	0.14	1.83	73.2
ULSAM6	**15**	**17**	**26**	1232	**107**	30.5	5.3	0.05	3.79	31.91	0.24	1.46	0.26	0.08	2.92	76.5
ULSAM7	9	8	8	1312	76	26.6	5.3	0.05	3.04	22.21	0.25	1.51	0.19	0.11	2.76	62.0
ULSAM8	7	9	9	1257	72	28.6	4.5	0.05	3.78	37.73	0.22	1.34	0.23	0.03	2.35	78.9
ULSAM9	7	8	9	1332	76	25.3	4.44	0.05	3.67	35.11	0.22	1.36	0.21	0.05	2.4	72.8
ULSAM10	9	9	9	1303	79	27.0	5.2	0.05	3.42	27.82	0.23	1.49	0.21	0.08	2.79	68.3
ULSAM11	7	0	23	142	108	**88.4**	4.4	0.01	0.35	4.23	0.62	0.60	0.15	0.02	1.18	100.0
ULSAM12	7	9	8	1429	71	23.0	3.98	0.06	4.32	46.70	0.21	1.26	0.21	0.00	2.53	82.2
ULSAM13	8	9	10	1391	84	23.8	4.58	0.05	3.53	31.39	0.24	1.35	0.20	0.06	2.57	67.7
ULSAM14	6	6	8	1388	68	23.8	4.65	0.05	3.31	28.07	0.23	1.35	0.18	0.07	2.26	64.0
ULSAM15	7	11	8	1353	75	24.8	4.5	0.05	3.81	36.30	0.21	1.37	0.21	0.02	2.70	74.0
ULSAM16	6	0	15	170	54	**87.5**	4.6	0.01	0.50	4.96	0.65	0.69	0.13	0.02	0.87	100.0
ULSAM17	7	7	8	1405	70	23.5	4.3	0.05	3.56	33.59	0.21	1.31	0.19	0.04	2.13	68.9
ULSAM18	7	7	8	1397	72	23.8	4.5	0.05	3.41	30.86	0.21	1.34	0.19	0.05	2.23	66.6
ULSAM19	8	11	9	1392	75	23.9	4.1	0.05	4.02	42.02	0.19	1.26	0.22	0.00	2.27	78.0
ULSAM20	7	7	9	1391	76	23.2	4.35	0.05	3.51	33.66	0.21	1.28	0.20	0.03	2.36	68.9
ULSAM21	6	7	9	1377	71	24.1	4.52	0.05	3.23	28.82	0.21	1.32	0.19	0.06	2.0	64.5
ULSAM22	8	7	9	1349	75	25.1	4.6	0.05	3.36	29.68	0.22	1.34	0.20	0.07	2.38	67.0
ULSAM24	9	9	10	1407	71	23.6	4.27	0.05	3.81	37.55	0.21	1.31	0.21	0.03	2.56	73.6
ULSAM25	7	8	8	1425	68	23.3	4.28	0.05	3.65	35.00	0.21	1.29	0.20	0.03	2.56	70.6
ULSAM26	7	9	9	1241	72	30.3	4.68	0.05	3.59	35.11	0.23	1.30	0.22	0.04	2.55	78.0
ULSAM27	16	7	9	1284	75	27.2	5.30	0.05	3.21	24.91	0.24	1.51	0.20	0.10	2.3	65.0
ULSAM28	7	0	22	177	109	**86.8**	4.68	0.02	0.61	5.04	0.65	0.70	0.18	0.03	1.3	100.0
ULSAM29	13	17	25	1141	96	32.8	5.76	0.06	3.76	28.61	0.32	1.60	0.28	0.12	2.9	76.2
ULSAM30	16	20	28	944	103	40.5	6.45	0.05	3.53	24.50	0.41	1.70	0.33	0.15	2.89	80.5
ULSAM31	16	17	26	983	101	39.2	6.14	0.05	3.38	23.80	0.39	1.65	0.31	0.15	2.78	77.8
ULSAM32	11	3	20	458	77	74.9	7.01	0.02	1.93	11.27	1.12	1.32	0.29	0.10	1.68	99.6
ULSAM33	7	0	12	326	29	**81.2**	6.6	0.02	1.29	7.11	1.27	0.91	0.23	0.04	1.28	100.0
ULSAM34	14	19	28.00	1171	100.5	31.84	5.67	0.06	4.10	31.84	0.30	1.62	0.29	0.1	3.0	78.8

Table 1. Samples run with the WDXRF are shown with their concentrations of selected elements. The sample JB-1 and JB-2 were standard samples that were run with my samples. The samples labeled standard are the accepted values for the standards. Most of the results discussed have been placed in bold faced print. ULSAM-23 was not included because it produced no data due to convergence errors.

the XRF of what elements were in it. The levels of calcium carbonate in the sample range from 5% in the samples close to shore up to about 40% in the samples that were taken the furthest from the shore. It is also of some importance to note that most of the samples that do not have silicon dioxide as their major component have a total percent weight that is much lower than 100%.

3.1.2 PIXE Results

PIXE yielded results comparable to those of XRF, and matrix data appeared similar. For example, the average percent weight of calcium carbonate in the ULSAM-5 came out to be 26.5%, whereas with the XRF the percent weight was 24.6%. Much of the trace element analysis also showed similar data. For Example, the lead in ULSAM-5 came out to be an average of 110.7 ppm with the pinhole filter, and 90.5 ppm with the mylar filter. These results are close to the 119 ppm seen with the WDXRF. Yet, other data were not fully consistent with the WDXRF. The Zinc composition in ULSAM5 came out to be about 480 ppm using PIXE. This number is about than half of what was reported with the WDXRF. Arsenic results were slightly different as well; PIXE reported 37 % less arsenic then with the XRF. Comparing the amounts of tungsten in the samples that were prepared using the tungsten carbide chatterbox to those that were prepared using the teflon vessel, there was a noticeable rise in the concentration of tungsten when the tungsten vessel was used. There was also an unexpected rise in the level of lead, zinc, and cobalt in the samples that had been prepared using the tungsten vessel.



Summary of data obtained from PIXE spectrometry

Pinhole data

Sample	ClK	TiK	V K	CrK	MnK	FeK	NiK	CuK	ZnK	BaL	W L	PbL
UL5G1	15.2	863.3	42.2	23.3	243.4	12795.3	14.3	18.1	540.9	202.8	48.4	146.5
UL5G2	29.4	944.1	47.7	18.1	241.8	12798.7	14.0	17.7	542.3	146.6	18.3	132.3
UL5G3	45.2	941.7	29.4	18.8	256.9	12802.0	16.5	21.2	513.9	236.6	25.5	134.3
Averages	30.0	916.4	39.8	20.1	247.4	12798.6	14.9	**19.0**	**532.3**	195.3	**30.7**	**137.7**
UL5N1	43.0	1089.9	34.0	24.2	236.8	12794.5	15.7	19.7	416.4	285.8	0.0	81.1
UL5N2	19.3	1077.9	28.9	25.1	224.8	12795.6	13.0	17.0	410.6	220.0	0.0	82.3
UL5N3	6.3	1025.2	41.6	14.6	246.5	12794.0	12.2	20.1	445.0	171.2	0.0	86.5
Averages	22.9	1064.3	34.8	21.3	236.0	12794.7	13.6	**18.9**	**424.0**	225.6	**0.0**	**83.3**

Mylar data

Sample	CaK	TiK	V K	CrK	MnK	FeK	CoK	NiK	CuK	ZnK	AsK	ZrK	W L	PbL
UL5G1	107511.0	1058.0	26.3	29.6	237.7	12796.2	4.4	12.3	19.3	545.1	16.1	48.3	20.1	95.5
UL5G2	106348.8	1125.2	32.2	18.9	243.8	12794.2	9.1	12.7	19.0	546.1	17.7	42.8	23.6	100.1
UL5G3	109953.8	1069.3	31.2	21.8	254.1	12796.2	4.7	9.8	19.4	518.1	19.0	63.7	42.0	91.6
Averages	**107937.9**	1084.2	29.9	23.5	245.2	12795.6	**6.1**	11.6	**19.2**	**536.4**	**17.6**	51.6	28.6	**95.7**
UL5N1	101727.7	1187.0	26.8	22.1	224.6	12166.7	0.0	11.0	16.2	409.1	16.3	57.9	3.7	83.3
UL5N2	97205.8	1254.6	26.7	19.6	237.5	12795.7	3.1	10.4	18.1	403.5	14.1	67.8	4.2	82.0
UL5N3	107428.7	1193.3	21.1	18.1	241.7	12798.1	0.0	12.1	18.6	447.7	17.2	37.0	18.2	86.0
Averages	**102120.7**	1211.7	24.9	19.9	234.6	12586.8	**1.0**	11.2	**17.6**	**420.1**	**15.8**	54.3	8.7	**83.8**

Table 2.The samples run with PIXE are listed on the verical axis while the selected elements for the two different filters are labeled on the horizontal axis. All numbers are given in units of parts per million(ppm). The samples labled with a G were pulverized using the tungsten vessesl while the samples that were pulverized using the cleaner teflon vessel are labeled with an N. The rows labeled "averages" are averages of the three slides for each sample. The number in bold faced print denote figures that are discussed in the interpretations.

For ULSAM6 and ULSAM23, which were run using PIXE, there was some significant error incurred due to high background. This was because the count rate I used when ionizing the samples was too great and there were too many X-rays coming into the detector. High count rates can cause two or more X-rays to be processed by the electronics a single X-ray of higher energy. This results in pile-up peaks in the spectrum that can interfere with real data. After being run through GUPIX it was determined that these data were no longer reliable; however, the results for the ULSAM-5 are still acceptable.

3.2 Interpretations of Results

Discrepancies between WDXRF and PIXE can be explained by statistical error. Accuracy of the WDXRF can be assessed using the standard samples that were run simultaneously. For many elements it does a fairly good job, but for some elements, such as chlorine or sulfur where the XRF obtains a number different from what is actually in the standard, the number might not be valid. Some of the discrepancies between PIXE data and WDXRF data are due to this reason. For example, the difference between counts for zinc was reported to be greater by a factor of two for the WDXRF. If you look at the standards for zinc you can see that the XRF was reading numbers higher than actually obtained. There is also some inherent statistical error associated with both techniques. Since computer programs fits a curve to data, there will naturally be some statistical in error when fitting data. Furthermore, the thickness of the slides for PIXE may not have been completely accurate because it was difficult to spread the pulverized sample evenly over the slide as the particle sizes were still too large to be of even thickness. Since the slides for PIXE are quite thin, and the samples I looked at were fairly large, there could also be some statistical error in the homogeneity of the sample. In addition, the PIXE samples are quite small compared to the WDXRF samples. Because of this, the PIXE data are more subject to variations caused by the inhomogeneity of the sample material. For these reasons, I rely more on the data obtained from the WDXRF which can be used to analyze a larger sample and which is run with standards to ensure the accuracy of the measurements.

Moreover, some of the differences are due to human error. One of the problems was that the samples ranged in depth from 2 to 3 inches. Since 1mm of sediment per year is accumulating on the floor of Utah Lake, this tells the history of 50-76 years (Brimhall [4]). Making one homogenous mixture of the sediment plugs could possibly be including some sediment that was there before Geneva Steel existed. Another problem is that not all of the samples were completely homogenized because they could not completely fit in the vessel. This reason could contribute to some of the discrepancies between samples.

The levels of contamination from the tungsten vessel, although small, are real. The average level of tungsten in the 3 slides that were prepared using the Teflon vessel was 4.4 ppm according to the pinhole filter and mylar results. The average level of tungsten in the 3 slides that were prepared using the tungsten carbide vessel was 29.7 ppm. The level of contamination is not completely accurate because you do not know how well the sample has been normalized for the tungsten, but it can be shown that

Fig. 8. The tungsten vessel used for pulverizing the majority of the samples for production of pressed pellets.

there was definitely more tungsten in those samples. It is also clear from the data that there was some contamination of lead, zinc and cobalt from the process. I noticed that some metal filings on top of the vessel had rubbed off from somewhere during the pulverization process. I had been careful to try and blow these off using pressurized air before opening vessel, but must be recognized as a likely source of the contamination levels of the specified metals.

As stated in the results, the samples that were not composed of mostly silicon dioxide had total percent weights that were significantly less than 100%. The WDXRF actually has no way of determining which oxidation states the metals are in, nor does it truly know if they are simple oxides. For Utah Lake, as pointed out in the introduction, most of these are carbonates, sulfates, or other mineral crystals. If exact states of all the metals were known, the totals would come out closer to 100%. However, since the numbers given still indicate how much of the given metal is in the solid, it was not necessary to change these numbers around.

Of particular interest are the abnormal element reports in ULSAM-5. The location at which this point was extracted was relatively close to the shore. It is actually where I tried to centralize my grid around Geneva Steel. The reason I chose this area as a central point was because I saw a pipe of large diameter running from the mill out into the lake, which is illustrated in Fig.9 on the following page. About 50 yards west from where this pipe enters the water, in the approximate area of ULSAM-5, there is a “Water Hazard sign” indicating to water users that there may be underwater hazard in the area.

Fig. 9. The lower left hand corner shows a close up image of the shoreline where a presumed waste pipe coming from the mill enters the water. It shows the relative proximity of ULSAM5 and ULSAM6 to the pipe. Geneva's property is also shown in the white hash-marked area.

It is probable that this is the location where the mill dumped their wastes into the lake with the use of this pipe. As discussed above, there were high levels of lead, copper, arsenic, and zinc found in this area, all of which had been reportedly dumped into the lake [1].

The elevated levels of these elements seem to have been a local phenomenon. As reported ULSAM-4 and ULSAM-6 also had mildly elevated levels of the same elements, but elsewhere the levels of these elements seemed to be fairly consistent. It is hypothesized that the organics that were being dumped into the lake may have caused lead, zinc, and copper precipitates due to local changes in pH. Although this is a possibility it is also possible that they were dumping these metals directly into the lake.

3.3 Conclusions and Future Outlook

I found the WDXRF spectrometer to be a more efficient tool for doing trace element analysis of larger samples than PIXE. When using the tungsten vessel for the pulverization process, I discovered that levels of contamination were detectable; I believe that they could be predictable with further studies. In cases where a geologist or other researcher may be looking at a sample where tungsten, lead, zinc, or cobalt is of significant importance, it would be advised to know exactly what levels of contamination are being introduced or to use some other process to pulverize the sample.

Elevated levels of zinc, lead, and copper were found locally, near a presumed waste pipe coming from the mill. The results obtained make it seem probable that Geneva Steel is ultimately responsible for the phenomenon. If these results were due to the mill, then its presence in the valley is having some continuing effects on the sediments of Utah Lake, and further study into this local phenomenon would be encouraged. It is possible that other points have even higher levels of the specified elements and could be health hazards. A future study that would be very interesting would be to do a trace element analysis as a function of the depth of the sample. This type of depth profiling could reveal fluctuations in trace elements as time progressed.

References:

[1] R. Carter, *Utah Lake: Legacy.* June Sucker Recovery Implementation program (2003).

[2] Utah Division of Water Quality, "Utah's 2004 303(d) List of Impaired Waters," (2004).

[3] P. A. Sonerholm, "Normative distribution in Utah Lake sediments: a statistical analysis," Provo: Brigham Young University geology studies, v. 21, pt.3 (1974).

[4] W. H. Brimhall, L. B. Merrit, "The geology of Utah Lake: implications for resource management / prepared for Mountainland Association of Governments," Provo, Utah: Eyring Research Institute, (1976).

[5] Utah Division of Water Quality, "Utah Water Quality Assessment Report to Congress," (2002).

[6] http://www.learnxrf.com/index.htm

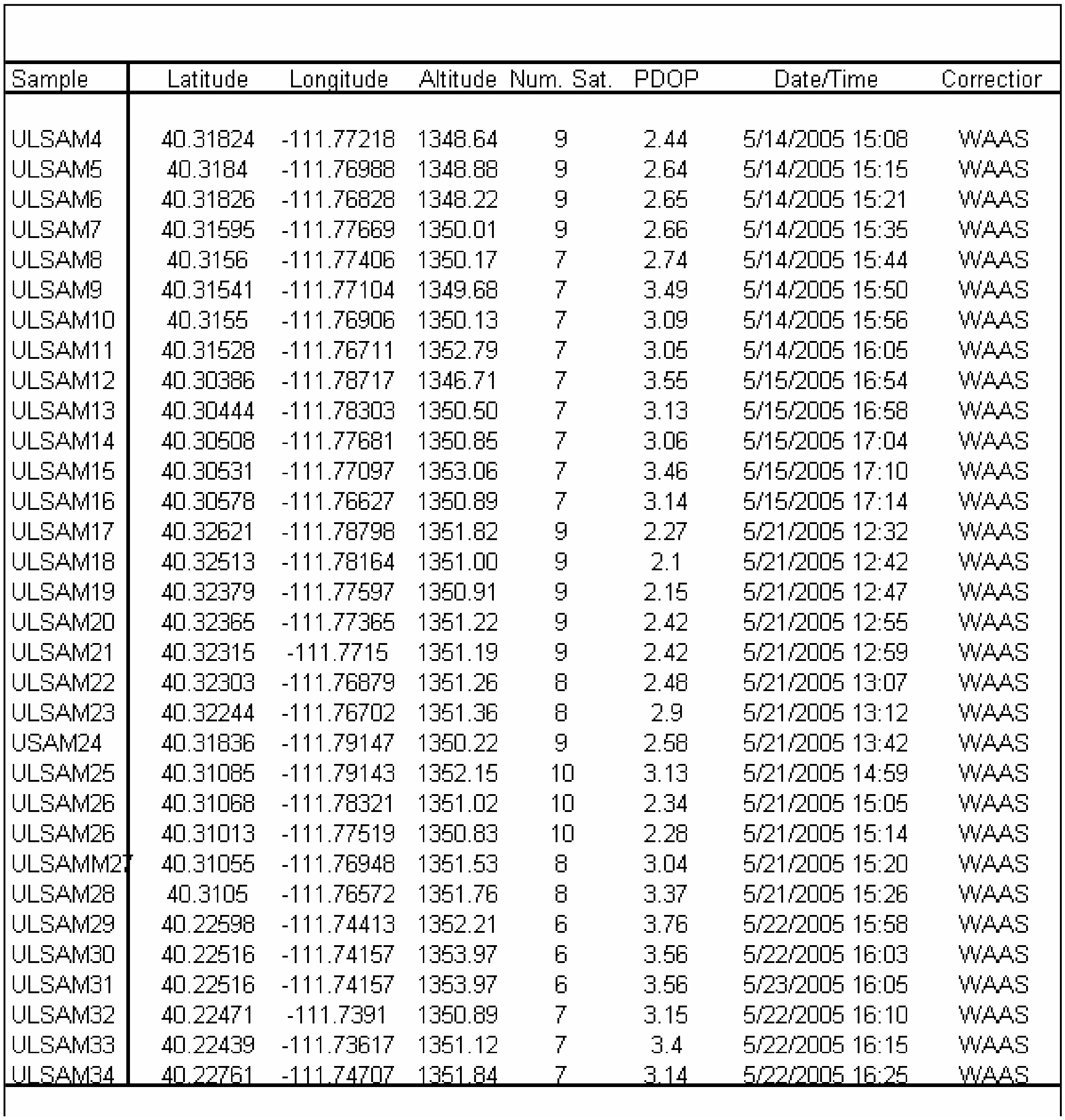
[7] S.A.E Johansson, "Particle induced X-ray emission and complementary nuclear methods for trace element determination. Plenary lecture," ***The Analyst***, 1992, **117**(3), 259 – 265, (1992).

Appendix A: Maps labeled with extraction points

A figure showing the labeled points of extraction at the Northern part of lake adjacent to the steel mill

A figure showing the points of extraction at a different eastern shoreline, 7 miles south of the mill

Appendix B: geographical information for extraction points



Sample	Latitude	Longitude	Altitude	Num. Sat.	PDOP	Date/Time	Correctior
ULSAM4	40.31824	-111.77218	1348.64	9	2.44	5/14/2005 15:08	WAAS
ULSAM5	40.3184	-111.76988	1348.88	9	2.64	5/14/2005 15:15	WAAS
ULSAM6	40.31826	-111.76828	1348.22	9	2.65	5/14/2005 15:21	WAAS
ULSAM7	40.31595	-111.77669	1350.01	9	2.66	5/14/2005 15:35	WAAS
ULSAM8	40.3156	-111.77406	1350.17	7	2.74	5/14/2005 15:44	WAAS
ULSAM9	40.31541	-111.77104	1349.68	7	3.49	5/14/2005 15:50	WAAS
ULSAM10	40.3155	-111.76906	1350.13	7	3.09	5/14/2005 15:56	WAAS
ULSAM11	40.31528	-111.76711	1352.79	7	3.05	5/14/2005 16:05	WAAS
ULSAM12	40.30386	-111.78717	1346.71	7	3.55	5/15/2005 16:54	WAAS
ULSAM13	40.30444	-111.78303	1350.50	7	3.13	5/15/2005 16:58	WAAS
ULSAM14	40.30508	-111.77681	1350.85	7	3.06	5/15/2005 17:04	WAAS
ULSAM15	40.30531	-111.77097	1353.06	7	3.46	5/15/2005 17:10	WAAS
ULSAM16	40.30578	-111.76627	1350.89	7	3.14	5/15/2005 17:14	WAAS
ULSAM17	40.32621	-111.78798	1351.82	9	2.27	5/21/2005 12:32	WAAS
ULSAM18	40.32513	-111.78164	1351.00	9	2.1	5/21/2005 12:42	WAAS
ULSAM19	40.32379	-111.77597	1350.91	9	2.15	5/21/2005 12:47	WAAS
ULSAM20	40.32365	-111.77365	1351.22	9	2.42	5/21/2005 12:55	WAAS
ULSAM21	40.32315	-111.7715	1351.19	9	2.42	5/21/2005 12:59	WAAS
ULSAM22	40.32303	-111.76879	1351.26	8	2.48	5/21/2005 13:07	WAAS
ULSAM23	40.32244	-111.76702	1351.36	8	2.9	5/21/2005 13:12	WAAS
USAM24	40.31836	-111.79147	1350.22	9	2.58	5/21/2005 13:42	WAAS
ULSAM25	40.31085	-111.79143	1352.15	10	3.13	5/21/2005 14:59	WAAS
ULSAM26	40.31068	-111.78321	1351.02	10	2.34	5/21/2005 15:05	WAAS
ULSAM26	40.31013	-111.77519	1350.83	10	2.28	5/21/2005 15:14	WAAS
ULSAMM27	40.31055	-111.76948	1351.53	8	3.04	5/21/2005 15:20	WAAS
ULSAM28	40.3105	-111.76572	1351.76	8	3.37	5/21/2005 15:26	WAAS
ULSAM29	40.22598	-111.74413	1352.21	6	3.76	5/22/2005 15:58	WAAS
ULSAM30	40.22516	-111.74157	1353.97	6	3.56	5/22/2005 16:03	WAAS
ULSAM31	40.22516	-111.74157	1353.97	6	3.56	5/23/2005 16:05	WAAS
ULSAM32	40.22471	-111.7391	1350.89	7	3.15	5/22/2005 16:10	WAAS
ULSAM33	40.22439	-111.73617	1351.12	7	3.4	5/22/2005 16:15	WAAS
ULSAM34	40.22761	-111.74707	1351.84	7	3.14	5/22/2005 16:25	WAAS

Table listing the geographical locations of each individual sample. The data was gathered using a GPS unit. The points were extracted to satellite and aerial photographs using the software ERDAS.

Appendix C: XRF Data

Sample	As (PPM)	Ba (PPM)	Ce (PPM)	Cl (PPM)	Cr (PPM)	Cu (PPM)	Ga (PPM)	La (PPM)	Nb (PPM)	Nd (PPM)	Ni (PPM)	Pb (PPM)	Rb (PPM)	S (PPM)	Sc (PPM)	Sm (PPM)
JB-2	2	211	13	439	27	221	18	0	0	0	18	7	6	91.00	50	6
standards	2.9	222	6.76	281	28.1	225	17	2.35	1.58	6.63	16.6	5.36	7.37	17.9	53.5	2.31
JB-1	3	505	72	195	431	54	19	39	34	30	139	8	40.60	147	23	6
JB-1	3	502	74	198	430	56	19	43	33	29	137	8	40.10	145	25	7
standards	2.3	493	67.8	176	425	55.1	17.9	38.6	33.3	26.8	133	10	41.3	19.4	27.5	5.13
ULSAM3	9	245	33	96	44	11	9	12	4	0	3	9	57	3869	31	6
ULSAM4	13	238	22	109	31	15	9	0	3	0	2	39	45	5419	31	7
ULSAM5	27	262	29	131	37	25	9	13	3	0	5	119	51	5228	27	8
ULSAM6	15	249	35	106	37	17	10	18	5	22	5	26	56	4726	29	8
ULSAM7	9	218	20	187	26	8	9	0	4	18	4	8	48	6314	34	9
ULSAM8	7	236	24	103	38	9	9	0	4	0	3	9	51	4219	29	7
ULSAM9	7	214	27	152	34	8	8	0	3	0	2	9	49.20	4909	29	7
ULSAM10	9	225	37	163	32	9	10	19	4	22	4	9	50	5624	33	10
ULSAM11	7	226	28	98	11	0	4	15	5	0	6	23	14	364	0	0
ULSAM12	7	229	26	230	40	9	9	0	3	18	1	8	51.60	3841	31	7
ULSAM13	8	218	23	205	29	9	9	0	3	18	1	10	47.00	5421	33	6
ULSAM14	6	209	21	195	26	6	8	0	3	0	2	8	43.70	5844	34	5
ULSAM15	7	224	33	168	35	11	9	15	3	20	3	8	51	4788	31	8
ULSAM16	6	247	23	85	11	0	3	0	4	0	3	15	15	782	0	0
ULSAM17	7	213	22	145	30	7	8	0	3	0	0	8	45	5268	32	8
ULSAM18	7	207	21	154	28	7	8	0	3	0	1	8	45	5558	34	6
ULSAM19	8	222	25	124	36	11	8	0	4	0	1	9	49	4219	30	7
ULSAM20	7	212	22	171	29	7	8	0	3	17	1	9	44.30	5196	33	10
ULSAM21	6	214	22	142	27	7	9	0	3	0	0	9	42.90	5676	33	11
ULSAM22	8	210	24	144	28	7	8	0	3	0	2	9	44	5550	33	4
ULSAM24	9	215	22	128	34	9	9	0	4	18	1	10	48.60	4777	32	6
ULSAM25	7	209	24	209	31	8	8	0	3	18	2	8	46.50	5117	31	5
ULSAM26	7	230	24	132	35	9	9	0	4	18	3	9	49.40	4396	28	8
ULSAM27	16	230	30	135	28	7	9	12	4	0	3	9	48.20	5956	33	9
ULSAM28	7	239	28	76	13	0	4	15	4	0	5	22	14.90	1284	0	1
ULSAM29	13	264	35	173	38	17	10	17	6	20	6	25	59.40	4891	28	9
ULSAM30	16	314	26	145	41	20	10	0	6	19	7	28	63.80	4652	25	9
ULSAM31	16	300	32	171	37	17	10	17	6	20	7	26	58.80	4957	25	11
ULSAM32	11	445	37	125	22	3	8	17	6	0	6	20	34.00	2653	10	6
ULSAM33	7	398	35	77	16	0	6	16	5	0	2	12	23	940	7	0
ULSAM34	14	265	38	161	41	19	10	17	6	22	6	28.00	64	4571	30	8

Sample	Sm (PPM)	Sr (PPM)	Th (PPM)	U (PPM)	V (PPM)	Y (PPM)	Zn (PPM)	Zr (PPM)	SiO_2 (%)	Al_2O_3 (%)	MnO (%)	MgO (%)	$CaCO_3$ (%)	Na_2O (%)	K_2O (%)	TiO_2 (%)
JB-2	6	175	3	0	573	19	114	54	53.0	15.8	0.21	4.24	9.85	1.97	0.37	1.18
standards	2.31	178	0.35	0.18	575	24.9	108	51.2	53.25	14.64	0.218	4.62	9.82	2.04	0.42	1.19
JB-1	6	445	9	3	205	24	89	140.0	52.0	14.67	0.15	7.45	8.95	2.65	1.43	1.32
JB-1	7	445	8	3	207	24	89	138.8	51.9	14.69	0.15	7.47	8.96	2.66	1.43	1.32
standards	5.13	444	9.3	1.67	211	24.3	85.2	141	52.37	14.53	0.153	7.71	9.25	2.77	1.43	1.32
ULSAM3	6	1285	3	0	49	14	80	41	26.2	4.6	0.06	4.22	42.57	0.20	1.42	0.24
ULSAM4	7	1429	4	1	37	10	276	31	26.4	4.6	0.05	3.64	29.86	0.33	1.35	0.20
ULSAM5	8	1081	7	2	43	11	1015	57	36.0	5.2	0.04	3.11	24.70	0.62	1.42	0.23
ULSAM6	8	1232	5	0	44	14	107	53	30.5	5.3	0.05	3.79	31.91	0.24	1.46	0.26
ULSAM7	9	1312	2	2	35	11	76	25	26.6	5.3	0.05	3.04	22.21	0.25	1.51	0.19
ULSAM8	7	1257	3	0	41	13	72	56	28.6	4.5	0.05	3.78	37.73	0.22	1.34	0.23
ULSAM9	7	1332	3	0	36	12	76	33.2	25.3	4.44	0.05	3.67	35.11	0.22	1.36	0.21
ULSAM10	10	1303	3	1	36	13	79	32	27.0	5.2	0.05	3.42	27.82	0.23	1.49	0.21
ULSAM11	0	142	3	0	29	2	108	182	88.4	4.4	0.01	0.35	4.23	0.62	0.60	0.15
ULSAM12	7	1429	3	0	41	12	71	33.6	23.0	3.98	0.06	4.32	46.70	0.21	1.26	0.21
ULSAM13	6	1391	2	0	34	12	84	26.3	23.8	4.58	0.05	3.53	31.39	0.24	1.35	0.20
ULSAM14	5	1388	2	1	31	11	68	19.1	23.8	4.65	0.05	3.31	28.07	0.23	1.35	0.18
ULSAM15	8	1353	3	0	38	12	75	32	24.8	4.5	0.05	3.81	36.30	0.21	1.37	0.21
ULSAM16	0	170	3	0	20	2	54	125	87.5	4.6	0.01	0.50	4.96	0.65	0.69	0.13
ULSAM17	8	1405	2	0	34	11	70	22	23.5	4.3	0.05	3.56	33.59	0.21	1.31	0.19
ULSAM18	6	1397	2	0	33	11	72	21	23.8	4.5	0.05	3.41	30.86	0.21	1.34	0.19
ULSAM19	7	1392	3	0	38	12	75	34	23.9	4.1	0.05	4.02	42.02	0.19	1.26	0.22
ULSAM20	10	1391	2	0	33	12	76	25.5	23.2	4.35	0.05	3.51	33.66	0.21	1.28	0.20
ULSAM21	11	1377	1	0	30	11	71	21.3	24.1	4.52	0.05	3.23	28.82	0.21	1.32	0.19
ULSAM22	4	1349	2	0	33	11	75	28	25.1	4.6	0.05	3.36	29.68	0.22	1.34	0.20
ULSAM24	6	1407	2	0	36	12	71	29.9	23.6	4.27	0.05	3.81	37.55	0.21	1.31	0.21
ULSAM25	5	1425	2	0	33	11	68	25.4	23.3	4.28	0.05	3.65	35.00	0.21	1.29	0.20
ULSAM26	8	1241	3	0	38	13	72	51.6	30.3	4.68	0.05	3.59	35.11	0.23	1.30	0.22
ULSAM27	9	1284	2	1	35	11	75	30.5	27.2	5.30	0.05	3.21	24.91	0.24	1.51	0.20
ULSAM28	1	177	3	0	29	4	109	226.6	86.8	4.68	0.02	0.61	5.04	0.65	0.70	0.18
ULSAM29	9	1141	5	1	44	15	96	62.7	32.8	5.76	0.06	3.76	28.61	0.32	1.60	0.28
ULSAM30	9	944	5	2	49	17	103	108.2	40.5	6.45	0.05	3.53	24.50	0.41	1.70	0.33
ULSAM31	11	983	5	2	45	16	101	103.1	39.2	6.14	0.05	3.38	23.80	0.39	1.65	0.31
ULSAM32	6	458	4	0	39	9	77	270.5	74.9	7.01	0.02	1.93	11.27	1.12	1.32	0.29
ULSAM33	0	326	3	0	31	5	29	175	81.2	6.6	0.02	1.29	7.11	1.27	0.91	0.23
ULSAM34	8	1171	5	0	49	15	100.5	56.2	31.84	5.67	0.06	4.10	31.84	0.30	1.62	0.29

Sample	TiO2 (%)	P2O5 (%)	Fe2O3 (%)	totals	Co (PPM)
JB-2	1.18	0.11	14.40	101.2	
standards	1.19	0.101	14.25	100.5	38
JB-1	1.32	0.28	9.19	98.1	23
JB-1	1.32	0.28	9.2	98.0	26
standards	1.32	0.255	8.99	98.8	38
ULSAM3	0.24	0.01	2.60	82.1	0
ULSAM4	0.20	0.14	2.01	68.5	
ULSAM5	0.23	0.14	1.83	73.2	15
ULSAM6	0.26	0.08	2.92	76.5	0
ULSAM7	0.19	0.11	2.76	62.0	0
ULSAM8	0.23	0.03	2.35	78.9	0
ULSAM9	0.21	0.05	2.4	72.8	0
ULSAM10	0.21	0.08	2.79	68.3	0
ULSAM11	0.15	0.02	1.18	100.0	39
ULSAM12	0.21	0.00	2.53	82.2	0
ULSAM13	0.20	0.06	2.57	67.7	0
ULSAM14	0.18	0.07	2.26	64.0	0
ULSAM15	0.21	0.02	2.70	74.0	0
ULSAM16	0.13	0.02	0.87	100.0	28
ULSAM17	0.19	0.04	2.13	68.9	0
ULSAM18	0.19	0.05	2.23	66.6	0
ULSAM19	0.22	0.00	2.27	78.0	0
ULSAM20	0.20	0.03	2.36	68.9	0
ULSAM21	0.19	0.06	2.0	64.5	0
ULSAM22	0.20	0.07	2.38	67.0	0
ULSAM24	0.21	0.03	2.56	73.6	0
ULSAM25	0.20	0.03	2.56	70.6	0
ULSAM26	0.22	0.04	2.55	78.0	0
ULSAM27	0.20	0.10	2.3	65.0	0
ULSAM28	0.18	0.03	1.3	100.0	31
ULSAM29	0.28	0.12	2.9	76.2	0
ULSAM30	0.33	0.15	2.89	80.5	0
ULSAM31	0.31	0.15	2.78	77.8	0
ULSAM32	0.29	0.10	1.68	99.6	21
ULSAM33	0.23	0.04	1.28	100.0	53
ULSAM34	0.29	0.1	3.0	78.8	0

Appendix D: PIXE data (ppm)

Mylar data

Element	UL5G1	UL5G2	UL5G3	Averages	UL5N1	UL5N2	UL5N3	Averages
K K	4648.5	4348.7	5854.9	4950.7	4776.0	5059.7	4364.6	4733.4
CaK	107511.0	106348.8	109953.8	107937.9	101727.7	97205.8	107428.7	102120.7
ScK	0.0	0.0	0.0	0.0	0.0	0.0	16.3	5.4
TiK	1058.0	1125.2	1069.3	1084.2	1187.0	1254.6	1193.3	1211.7
V K	26.3	32.2	31.2	29.9	26.8	26.7	21.1	24.9
CrK	29.6	18.9	21.8	23.5	22.1	19.6	18.1	19.9
MnK	237.7	243.8	254.1	245.2	224.6	237.5	241.7	234.6
FeK	12796.2	12794.2	12796.2	12795.6	12166.7	12795.7	12798.1	12586.8
CoK	4.4	9.1	4.7	6.1	0.0	3.1	0.0	1.0
NiK	12.3	12.7	9.8	11.6	11.0	10.4	12.1	11.2
CuK	19.3	19.0	19.4	19.2	16.2	18.1	18.6	17.6
ZnK	545.1	546.1	518.1	536.4	409.1	403.5	447.7	420.1
AsK	16.1	17.7	19.0	17.6	16.3	14.1	17.2	15.8
SeK	1.1	0.5	0.9	0.8	1.0	0.2	0.0	0.4
BrK	1.6	25.2	3.7	10.2	4.5	2.8	3.2	3.5
RbK	38.9	32.9	31.2	34.3	32.9	34.8	41.6	36.4
SrK	626.4	615.1	575.2	605.6	560.0	568.1	610.0	579.4
Y K	5204.9	5170.0	4850.7	5075.2	5121.0	5077.2	5549.6	5249.3
ZrK	48.3	42.8	63.7	51.6	57.9	67.8	37.0	54.3
BaL	234.0	258.8	371.0	287.9	0.0	249.5	247.4	165.6
W L	20.1	23.6	42.0	28.6	3.7	4.2	18.2	8.7
PbL	95.5	100.1	91.6	95.7	83.3	82.0	86.0	83.8

Pinhole data

Element	UL5G1	UL5G2	UL5G3	Averages	UL5N1	UL5N2	UL5N3	Averages
AlK	699.4	1820.9	3865.1	2128.5	2391.3	2979.6	2093.2	2488.1
SiK	6499.9	12312.9	25638.6	14817.1	16192.1	21444.5	15578.5	17738.4
P K	0.0	0.0	107.6	35.9	0.0	0.0	0.0	0.0
S K	149.2	372.6	681.1	401.0	458.3	511.1	404.0	457.8
ClK	15.2	29.4	45.2	30.0	43.0	19.3	6.3	22.9
K K	1785.9	2104.4	2756.7	2215.7	2489.7	2512.8	2378.9	2460.5
CaK	75981.4	79915.0	88605.6	81500.7	102839.9	77914.7	82183.9	87646.2
ScK	501.4	536.7	309.5	449.2	343.9	358.0	382.4	361.4
TiK	863.3	944.1	941.7	916.4	1089.9	1077.9	1025.2	1064.3
V K	42.2	47.7	29.4	39.8	34.0	28.9	41.6	34.8
CrK	23.3	18.1	18.8	20.1	24.2	25.1	14.6	21.3
MnK	243.4	241.8	256.9	247.4	236.8	224.8	246.5	236.0
FeK	12795.3	12798.7	12802.0	12798.6	12794.5	12795.6	12794.0	12794.7
NiK	14.3	14.0	16.5	14.9	15.7	13.0	12.2	13.6
CuK	18.1	17.7	21.2	19.0	19.7	17.0	20.1	18.9
ZnK	540.9	542.3	513.9	532.3	416.4	410.6	445.0	424.0
AsK	1.5	4.7	0.0	2.1	12.7	9.0	12.0	11.2
SeK	4.5	4.0	9.5	6.0	6.8	4.4	4.5	5.2
BrK	4.8	0.0	6.0	3.6	0.0	0.0	3.8	1.3
RbK	40.1	35.9	28.4	34.8	35.7	55.7	31.1	40.8
SrK	572.7	584.6	519.4	558.9	562.9	519.9	519.2	534.0
Y K	4664.3	4575.4	4465.4	4568.4	4772.8	4526.8	4924.7	4741.4
Y L	0.0	283.6	1103.7	462.4	687.0	913.0	702.8	767.6
BaL	202.8	146.6	236.6	195.3	285.8	220.0	171.2	225.6
W L	48.4	18.3	25.5	30.7	0.0	0.0	0.0	0.0
PbL	146.5	132.3	134.3	137.7	81.1	82.3	86.5	83.3