Synthetic leaching of uranium from South Mountain Batholith granites and Horton Group siltstones of south central Nova Scotia, using a suite of ionic complexes

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Abstract

Many rock formations in Nova Scotia, particularly granitic rocks and siltstones of Devono-Carboniferous age, may have an impact on the groundwater quality of surrounding areas. These geologic units have locally elevated uranium concentrations. Roll front type mineralization is responsible for the high uranium concentrations found in the Carboniferous Horton Group siltstones that are used in this study. The South Mountain Batholith (SMB) is a suite of peraluminous granitic rocks that contain locally high uranium concentrations in late-stage mica-rich granites and monzogranites. Uranium can also concentrate in late stage fracture and fault structures. Weathering and other geochemical processes can mobilize uranium, which allows the metal to accumulate in groundwater systems in concentrations above recommended guidelines established by Health Canada (20 μg/L).

This laboratory study focuses on the impact of calcium, chloride, carbonate and sulphate complexes on uranium mobilization, with a focus on geochemical conditions such as pH and Eh as well as lithologic characteristics of the samples. A synthetic leaching procedure using extraction fluids created with the ions listed above, is used to simulate natural weathering processes to try and identify the geochemical components that may be liberating uranium specifically from SMB granites and Horton Group siltstones. These experiments confirm the importance of Eh-pH conditions in mobilizing uranium from these rocks. The sulphate extraction fluids leach elevated U concentrations in oxidizing acidic conditions whereas the carbonate extraction fluids leach elevated U concentrations in oxidizing alkaline conditions. In general, the granites leach higher U levels than the siltstones even with lower U concentrations in the whole rock. It is concluded that, under consistently oxidizing conditions, numerous geochemical and geologic factors have an influence on U mobility, but pH, lithology and mineralogy seem to be the major controlling parameters behind U liberation in this study.

Key words: Uranium, Carbonate, Sulphate, Extraction, Leachate, pH, Eh, Granite, Siltstone

Acknowledgments

There are numerous individuals who contributed to the success of this study. First I would like to thank Meggie Letman, a graduate student who developed the extraction procedure that was used. She was always there for guidance and advise related to laboratory procedures and methods. I would also like to thank Rob Jamieson for providing access to his laboratory which was crucial for the success of this thesis. A big thanks goes out to Anne-Marie Ryan. This thesis would not have been possible without your encouragement, advice and support. I would also like to acknowledge the Nova Scotia Exploration Fund for providing funding for this thesis. Finally, I would like to thank Lawrence Plug and the ERTH 4200 class for their tremendous support which made this thesis possible.

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1.0 Introduction

1.1 Statement of Purpose

Uranium is a naturally occurring element found elevated in a number of geologic formations throughout Nova Scotia, in particular Devonian granitoids of the South Mountain Batholith (SMB) and clastic sedimentary sequences of Carboniferous age. Uranium in drinking water is deemed potentially hazardous when exposure surpasses Health Canada's (2014) drinking water guidelines. The acceptable concentration of uranium in Canadian Drinking water is 20 μg/L (Health Canada, 2014). Roughly 4% of Nova Scotia water wells contain uranium concentrations exceeding the Health Canada guidelines (Drage and Kennedy 2013). Uranium contaminated water can be attributed to groundwater that has been in contact with uranium-bearing geologic components for extensive time frames (Health Canada, 2014). It is common to find uranium in rocks and soils, but some formations contain higher uranium concentrations then others. As well, depending on the specific distribution of U within the rock or soil, the environmental conditions may enhance U mobility. Contaminated water wells pose a threat towards residents who rely on groundwater as their primary water source. Understanding why uranium is found in high concentrations throughout Nova Scotia water wells is necessary to best serve communities potentially impacted by elevated uranium in their well waters. This thesis explores the potential for U mobilization from a selection of Nova Scotia rocks under experimental conditions to deduce the geochemical influences that may be impacting U mobility.

1.2 Previous Research

A number of groundwater studies have been conducted across Nova Scotia to determine areas with elevated uranium concentrations. The community of Grand Pré relies on groundwater wells to produce water for local residents, and there is increased concern regarding uranium in their groundwater (Samolczyk et al., 2012). Groundwater samples from Grand Pré show that four out of the seventeen sampled wells contained uranium concentrations that exceeded the 20 μg/L Health Canada guideline (Samolczyk et al., 2012). High uranium concentrations in this region are thought to be related to leaching processes associated with the local geology and geochemical environment (Samolczyk et al., 2012). Other areas in Nova Scotia have elevated uranium concentrations, some of which may be associated with anthropogenic inputs. Road salt introduces chloride into groundwater systems contributing to the mobilization of uranium (Drage and Kennedy, 2013). Calcium and carbonate-ions are thought to have a strong correlation with uranium mobility (Drage and Kennedy, 2013). Calcium-uranyl-carbonates are considered mobile uranium complexes, believed to be responsible for the elevated uranium concentrations in many Nova Scotia water wells (Drage and Kennedy, 2013). Uranium reacts with sulphates, carbonates and silicate ions to produce soluble compounds (Kronfield et al. 2003). A study using computer modeling approaches concludes that the zero valent, calcium-uranyl-carbonate complex is associated with the majority of uranium found in the studied wells (Drage and Kennedy, 2013).

1.3 Format of Thesis

This thesis focuses on determining the geochemical process or processes responsible for uranium mobility in Nova Scotia. Chapter 2 addresses essential background information regarding Nova Scotia geology and uranium characteristics, summarizing uranium's complex chemical and geochemical properties. Chapter 3 summarizes the laboratory methods used throughout the study. The geochemical data acquired from laboratory experiments is presented in Chapter 4. A discussion regarding the geologic impact on groundwater quality is included in Chapter 5. The final chapter, Chapter 6 summarizes the key findings of the thesis and includes recommendations for future studies.

2.0 Background

2.1 Geologic Setting

Devono-Carboniferous sedimentary rocks of the Horton Group, and granitic rocks of the Devonian age South Mountain Batholith are known to contain numerous occurrences of uranium locally (Figure 2.1) (Ryan and O'Beirne-Ryan, 2006). MacDonald et al. (1992) describes the South Mountain Batholith (SMB) as a massive granitoid body, outcropping over 7300 km^2, classified as one of the largest igneous bodies related to the Appalachian Orogeny. One third of Nova Scotia is underlain by the SMB (McKenzie and Clarke, 1975) and approximately 50% of the SMB is comprised of biotite monzogranite (MacDonald et al., 1992). In a number of areas, the SMB is overlain by Carboniferous age clastic sedimentary rocks of the Horton Group (Ryan and O'Beirne-Ryan, 2006). The Horton Group is divided into two formations, the underlying Horton Bluff Formation (HBF) and the upper Cheverie Formation (Bell, 1929). The HBF consists of lacustrine deposits varying from conglomerates to sandstones, siltstones and shales (Bell 1929; Ryan and O'Beirne-Ryan, 2006). A sample of siltstone from this unit is used in my study. The Cheverie Formation is an arkosic sand-dominated sequence (Bell 1929; Ryan and O'Beirne-Ryan, 2006). This Horton Group is overlain by marine limestone and gypsum of the Windsor Group (Bell 1929; Ryan and O'Beirne-Ryan, 2006) which may introduce carbonate or sulphate into groundwater systems.

Within both the SMB and Horton Group sedimentary sequences there are known areas of elevated uranium in the bedrock which, in turn, may contribute to elevated U in groundwater systems (Figure 2.2). South central Nova Scotia is also draped by quaternary deposits of glacial origin (Stea et al, 1992; MacFarlane, 1983). The till deposits are dominated by sand and gravel derived from the underlying SMB and Carboniferous rocks (MacFarlane, 1983). The region has numerous drumlin features that have a northwest-southeast long axis orientation which is indicative of the direction of ice flow (MacFarlane, 1983). These drumlins are comprised of Lawrencetown Till and the Overlying Beaver River Till (Finck and Stea, 1995). Both of these tills include organic soil profiles (Finck and Stea, 1995). The Beaver River Till covers approximately 40% of the SMB (Finck and Stea, 1995) including the Harrietsfield region (Stea et al, 1992). These glacial deposits incorporate material from the Windsor Group (MacFarlane, 1983) indicating that they can include carbonates and sulphates derived from the Carboniferous gypsum and limestone deposits.

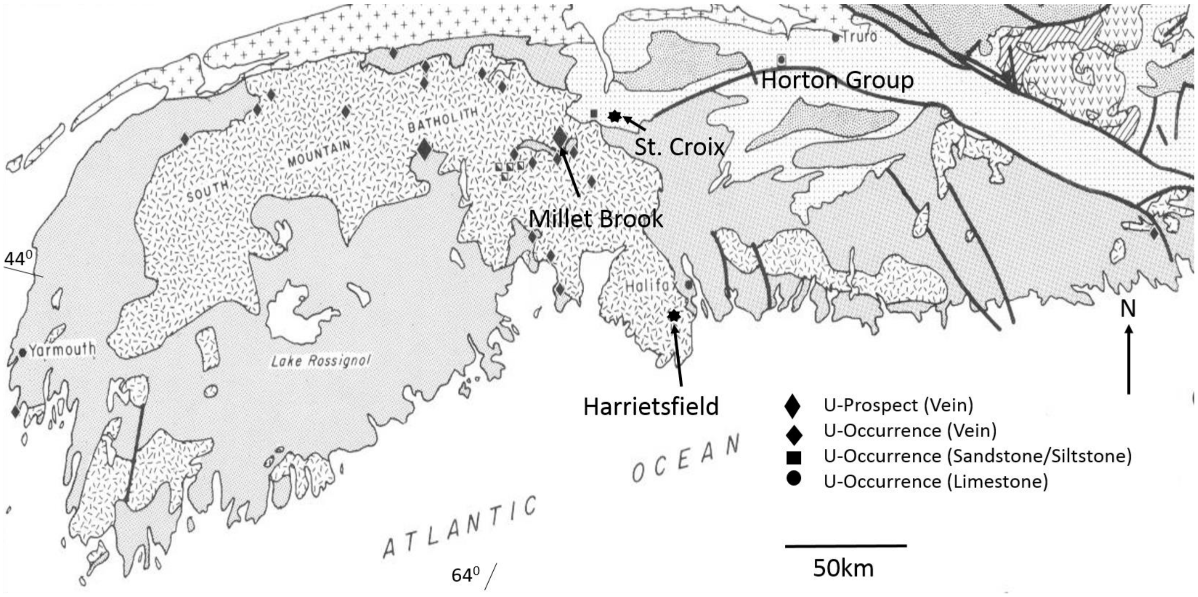

Figure 2.1. Map illustrating different geologic units and localities with known elevated uranium concentrations. Samples from these locations are used in my study. The sample from Millet Brook is from the C2-1 core taken from the Nova Scotia Department of Natural Resources core library. The other samples are taken from outcrops at St. Croix and Harrietsfield respectively. (Map Modified from the N.S. Department of Mines and Energy, 1982).

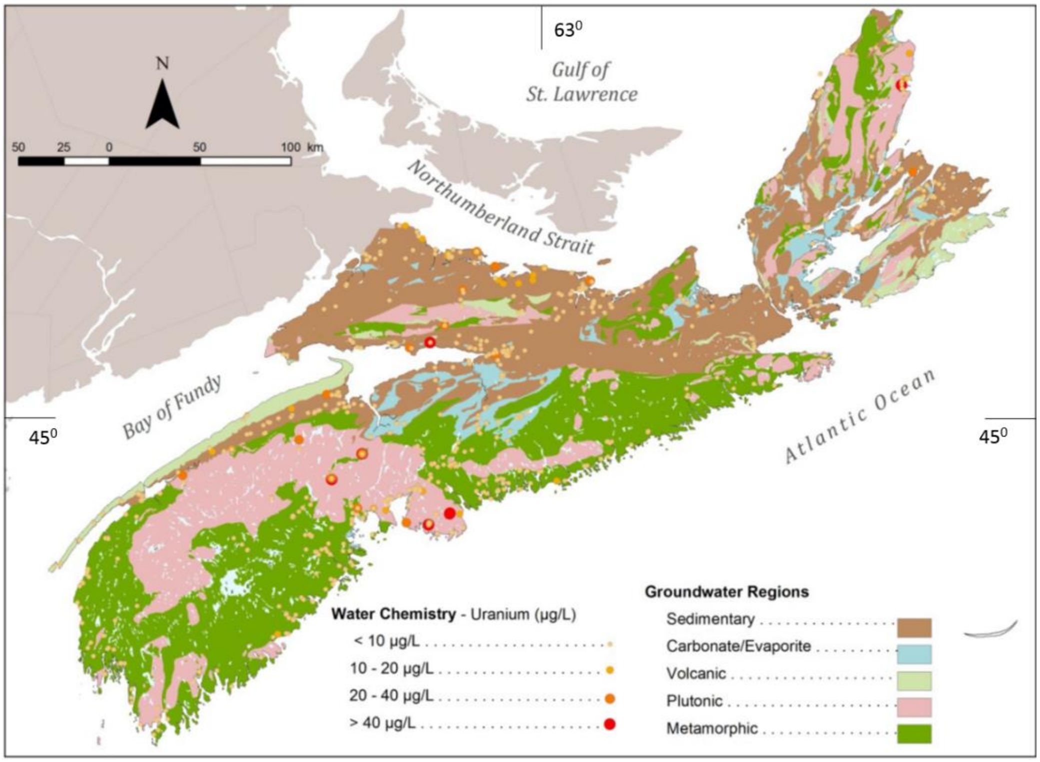

Figure 2.2. Basic geologic map of Nova Scotia illustrating U concentrations within groundwater wells. (Map modified from Drage and Kennedy, 2013).

2.2 Uranium-Bearing Rocks in South Central Nova Scotia

Two types of rock formations in south central Nova Scotia are considered to have higher than typical uranium concentrations. The Intrusive rocks such of the SMB have abnormal quantities of uranium, particularly in some locations (Chatterjee, 1982) as do the Horton Group rocks in certain areas (Durham and Little, 1971; Kronfield et al., 2004).

2.2.1 South Mountain Batholith

The SMB has uranium concentrations locally that exceed those of similar rocks elsewhere (Chatterjee, 1982). The locally-elevated U in the SMB can be divided into different deposit types, each with its own set of lithologic properties. The granite at Millet Brook (MBG) contains approximately 450,000 kg of uranium compounds, making it one of the largest uranium deposits in Eastern Canada (Figure 2.1) (Ryan and O'Beirne-Ryan, 2009). The MBG contains high concentrations of uranium within fracture zones, as uranium concentrated through fluid migration during late stage crystallization of the granite (Chatterjee et al., 1982). As an incompatible element, uranium is found in higher concentrations within late crystalizing rocks such as leucogranites and within fractures and veins within less evolved granites (Chatterjee, 1982). Much of the SMB is dominated by two mica granites such as biotite-muscovite monzogranites (McKenzie and Clark, 1975). The presence of micas indicate that the original magma contained a high content of a volatile phase which facilitated the deposition of uranium in high concentrations within specific areas of the rock (Chatterjee, 1982). Uranium concentrations vary throughout the SMB depending on the presence of volatiles during crystallization and post-crystallization.

2.2.2 Horton Group

High uranium concentrations within sedimentary rocks are usually credited to the erosion of uranium-bearing deposits (Barkhouse and Laffin, 1982). The uranium occurrences within the Maritimes Basin sedimentary rocks is attributed to the erosion of U-bearing highlands of the SMB (Figure 2.1) (Chatterjee, 1977; MacFarlane, 1983). Weathered granites release uranium into surface runoff, which eventually enters permeable Horton Group rocks through groundwater (Ryan et al., 2009). Uranium migrating through the sedimentary sequence is deposited at reduction-fronts such as carbon-rich horizons (Ryan and O'Beirne-Ryan, 2006).

2.3 Uranium in Groundwater

2.3.1 Nova Scotia

Nova Scotia groundwater has been known to contain high concentrations of uranium since 1978 and approximately half of all Nova Scotia residents rely on groundwater as their primary water source (Drage and Kennedy, 2013). Samolczyk et al. (2012) state that natural inputs are responsible for uranium mobility within the Grand Pré area, where Drage and Kennedy (2013) believe anthropogenic inputs also have an influence on U mobility. Kronfeld et al. (2004) found that there is a noticeable increase in uranium concentrations in groundwater in close proximities to uranium-bearing geology (Figure 2.2) due to weathering processes.

There are a number of ions that react with uranium and form soluble complexes. Soluble uranium complexes commonly include calcium carbonate, but other ions such as chloride may be responsible for chemical interactions that mobilize uranium (Drage and Kennedy, 2013) Sulphate is another ion that has the ability to influence uranium transport (Bachmaf et al., 2008). These ions can be introduced into Nova Scotia groundwater systems both naturally and anthroprogenically. Evaporites and limestones are widespread across the Province and may be introducing calcium, carbonate and sulphate into groundwater. Glacial till deposits across the Province may also have elevated levels of sulphate and carbonate within them. Drywall, a common construction waste made of gypsum ($CaSO_{4.}\cdot H_2O$), is a soluble compound, and improper disposal of such waste may liberate uranium as ions leach into groundwater systems. Similarly, Road salt and seawater are likely the primary sources of chloride in groundwater systems (Drage and Kennedy, 2013).

2.3.1.1 Harrietsfield Nova Scotia

Harrietsfield is a small community located to the southwest of Halifax (Figure 2.1) that has had an ongoing issue with high U concentrations within local groundwater wells. In recent years it has been suggested that a local waste disposal site may have aggravated this situation; the Supreme Court of Nova Scotia believes leachate from the disposal site may have negatively influenced groundwater quality (*3076525 Nova Scotia Ltd. v. Nova Scotia (Environment)*, 2015). MacFarlane (1983) and the Nova Scotia Uranium Task Force (1982) claim that local geology is the main influence on the elevated U levels in groundwater wells. MacFarlane's (1983) study sampled 322 wells and analyzed their U concentrations. The sampled wells are located within various geologic units such as the SMB and glacial tills (MacFarlane, 1983). MacFarlane (1983) concludes that water wells with elevated U concentrations are correlated to pH, redox environments, surrounding lithology and overburden. The report illustrates that Harrietsfield has had an ongoing issue with uranium contaminated groundwater prior to 1983. In recent years, homes in close proximity to the waste disposal site have experienced increased levels of U in their wells (*3076525 Nova Scotia Ltd. v. Nova Scotia (Environment)*, 2015).

2.3.2 United States of America

Many areas in the United States of America (USA) contain naturally occurring uranium in rocks and groundwater. Hess et al. (1985) states that western regions of the USA contain higher values of naturally occurring uranium in groundwater than eastern regions. The Colorado Plateau, Rocky Mountains and the West Central Platform are areas that have the highest uranium concentrations within local geologic units (Hess et al., 1985), thus influencing groundwater quality. The United States Environmental Protection Agency (EPA) deems that 20 μg/L is the acceptable concentration of uranium within drinking water, but this level is only enforced through public water systems (Orloff et al., 2003). Within Canada 20 μg/L is also the acceptable limit. Orloff et al., (2003) concludes that surrounding geologic units are responsible for the majority of uranium contaminated groundwater in the USA.

2.4 Properties of Uranium

2.4.1 Uranium as a Radioactive Element

Uranium is a radioactive element and has radioactive properties that are related to its decay chain. Native uranium occurs as three separate isotopes, ^{238}U, ^{235}U and ^{232}U, each having their own distinct decay series. However, ^{238}U is the most abundant U isotope as it makes up 99.3% of all natural uranium (Bourdon et al., 2003). Because ^{238}U dominates, the majority of radiation produced by U decay is associated with ^{238}U even though all three U isotopes produce radioactive products. Radioactive elements are atomically unstable and achieve stability by emitting energy in the form of radiation. Radiation is emitted through half-life decay which is defined as the amount of time required for half an element's atoms to decay to a new isotope. The half-life of ^{238}U is 4.47 Gyrs (Bourdon et al., 2003). The U-decay chain consists of many radioactive elements (e.g. radium and radon) but the decay series eventually ends by the formation of a stable isotope of lead. An illustration of the uranium decay chain is given in Appendix A (Bourdon et al., 2003).

2.4.2 Redox Environments and Valence States

Uranium consists of a two principle valence states U(VI) and U(IV), each defining various geochemical properties. The solubility of uranium is linked to its valence state (Kronfeld et al., 2003; Zhou and Gu, 2005), connecting uranium mobility to redox environments. The two oxidation states are related to different redox environments, which in turn affect the solubility of uranium. U(VI) is a soluble state of U found in oxidizing environments (Duff and Amerhein, 1996; Samolczyk et al., 2012). The reduced state of uranium, U(IV) is insoluble and found in anoxic environments (Duff and Amerhein, 1996; Samolczyk et al., 2012). In oxidizing conditions U(VI) forms soluble complexes with numerous anions including sulphate and carbonate (Kronfeld et al., 2004) (Figure 2.3). Uranium is found in aqueous solutions as the uranyl ion (UO_2^{2+}) (Barkhouse and Laffin, 1982; Bourdon et al., 2003). Uranyl carbonate complexes are the most common soluble uranium compound (Kronfeld et al., 2004) credited for U liberation within groundwater systems (Drage and Kennedy, 2013).

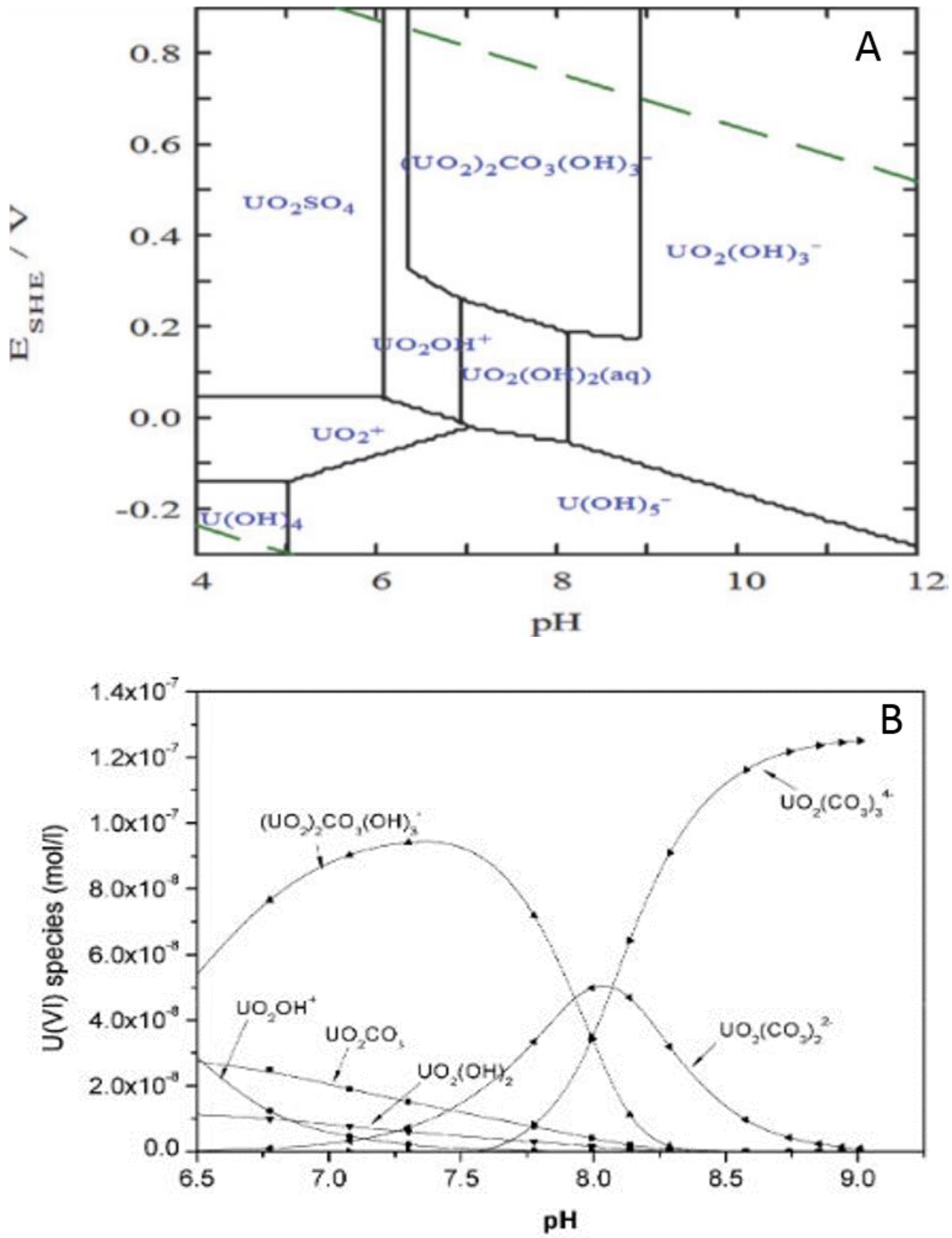

Figure 2.3. Stability phase diagram of soluble uranium complexes under varying geochemical conditions. These diagrams represent stability zones for a specific set of uranium rich solutions. These diagrams show general conditions that produce soluble uranium complexes, but stability zones may vary for different samples. (A) Soluble uranium complexes under certain Eh and pH conditions (Diagram from Kumar et al., 2014). (B) Soluble U complexes under varying pH conditions and their respective concentrations of U(VI) (Diagram from Nair and Merkel, 2011). It is important to note that these diagrams show information calculated for specific data sets, therefore stability zones and concentrations may change depending on the concentrations of additives.

3.0 Methods

This study uses a variety of lab procedures to investigate how different materials impact uranium mobility. The lab procedures were developed by Meggie Letman, a Masters candidate in the Department of Process Engineering and Applied Sciences, and were adapted from the U.S Environmental Protection Agency Synthetic Precipitation Leaching Procedure (Environmental Protection Agency, 1994). The lab procedures and analytical methods I used are adopted to be consistent with those of Letman's (personal communication, 2015) who is conducting a parallel study (MASc in progress). Essentially, the process involves a leaching experiment using natural earth materials with added solutions of varying compositions and concentrations.

There are three important phases associated with the laboratory procedures, the pre-extraction phase, the agitation sequence and the post-extraction phase. The three phases define the extraction process. Each extraction includes triplicate samples and one blank. Two extractions are conducted simultaneously.

3.1 Pre-Extraction Phase

The pre-extraction phase involves sampling, crushing (fine gravel to sand size) and analyzing the rocks that are being used for the extraction, creating extraction fluids, conducting measurements (pH, Eh and Alkalinity) and preparing the extraction vessels for the extraction. It is important to note that temperature was not monitored throughout the extractions, but is assumed to be relatively consistent between 20-25 °C.

3.1.1 Rock Samples

Three different rock samples are used in this study, two of which are from the SMB and the other from the Horton Group. The SMB samples are granite from Millet Brook and granite from Harrietsfield, NS (Figure 2.1 and Figure 2.2), both regions with known U-bearing groundwater. The Harrietsfield sample is taken from an outcrop located on Old Sambro Road. The Millet Brook Sample is taken from the C2-1 core from the Nova Scotia Department of Natural Resources (37.7-38.9 ft and 39.8-40.5 ft). It is important to note that there is a limited amount of the Millet Brook sample available, therefore granite from Harrietsfield is used as a sample replacement. The timeframe in which this study is conducted does not allow for more Millet Brook samples to be taken due to winter weather conditions which accounts for the limited data produced for the Millet Brook sample. Granite from Harrietfield is used because the area has current issues with elevated levels of uranium in groundwater. The Horton Group sample is siltstone from an outcrop at St. Croix, NS (Figure *2.1*). The samples are crushed to a grain size of approximately 2mm. 50-250 g of the crushed rock samples were sent to Maxxam Laboratories for metal analysis (Al, As, Ba, Cd, Cr, Co, Cu, Fe, Pb, Mn, Ni, Se, Sr, Ti, Sn, U V, ZN) conducted using ICP/MS analysis on a total digestion of the samples. It is important to note that the sample from Harrietsfield was not analyzed by Maxxam due to the time constraint of this thesis.

3.2.2 Extraction Fluids

Extraction Fluids are created by dissolving desired quantities of the chemical complex being studied into 4.1L of reverse-osmosis water (RO). The chemical complexes used are lab grade

NaCl, $NaHCO_3$, $CaCl_2 \cdot 2H_2O$, $CaSO_4$, naturally occurring gypsum from the Windsor area in NS and seashells (calcium carbonate). The chemical component of the extraction fluid is calculated using stoichiometric relationships and chemistry calculations to convert a desired concentration to a mass (Appendix B). The concentrations chosen are based on concentrations Letman is using to maintain consistency between the two studies. The extraction fluid is undisturbed for 20 minutes to achieve chemical equilibrium.

3.3.3 Extraction Vessels

Each extraction includes four 1 L extraction vessels. 50 g of the crushed rock being analyzed is added into three of the four extraction vessels. The fourth extraction vessel does not contain a rock sample as it is used for quality control. 1 L of the desired extraction fluid is added to each of the four extraction vessels to create a 1 L mixture of the fluid and rock.

3.3 pH Measurements

The pH for each extraction fluid is measured prior to each extraction. The pH is measured before the extraction fluids are mixed with rock samples. The initial extraction fluid pH values are measured using an Accumet 13-620-631 probe which is connected to a Fisher Scientific Accumet Excel XL50 Dual Channel pH/Ion/Conductivity Meter. Calibration methods are given in Appendix C.

3.4 Oxidation-Reduction Potential Measurements

The oxidation reduction potential (ORP) for each extraction fluid is measured prior to each extraction. All ORP values are recorded using an Orion 9179BNMD triode low maintenance ORP probe connected to a Thermo Scientific Orion 5 star pH ISE Cond-DO Portable meter. The unit is calibrated to represent Eh, therefore the ORP readings are equivalent to Eh. The calibration methods are given in the appendix C.

3.5 Alkalinity Test

Approximately 0.1 L of the extraction fluid remains as it is not used to fill the four extraction vessels. This volume of the extraction fluid is used to conduct an alkalinity test. Alkalinity is tested by conducting a titration with the extraction fluid and 0.1 N H_2SO_4 or 0.02 N H_2SO_4 (personal communication, M. Letman, 2016; American Public Health Association, American Water Works Association, Water Environment Federation, 2012). The test is completed when the extraction fluid reaches a pH of 4.6. Alkalinity is determined using Equation 1.

$Alkalinity = \frac{\mathrm{A \times N \times 50000}}{\mathrm{Sample\ volume\ (ml)}}$ (A=acid volume, N=normality of acid). The alkalinity results show inconsistencies and may be inaccurate due to the normality of the acid used, therefore are not used for any analysis and are given in Appendix D.

3.2 Agitation Sequence

Following the preparation of the rock-extraction fluid mixture, the samples are agitated to encourage the leaching and extraction of labile uranium. The extraction vessels for each extraction are placed in a bucket, which is placed on the agitation device as shown in Figure 3.1. Two buckets fit on the rollers, therefore two extractions are conducted simultaneously. The machine is turned on, rotating the buckets at 30 (+/- 2) rpm (Environmental Protection Agency, 1994), causing the extraction vessels to tumble head over head. The agitation device runs for 72 (+/- 2) hours.

Figure 3.1. The agitation device with two rotating buckets. Each bucket contains four extraction vessels and represents one extraction.

3.3 Post-Extraction Phase

Extraction vessels are removed from the agitation device and pH and Eh measurements are taken again. Samples are filtered and sent to Maxxam Laboratories and the Dalhousie Water Lab for select metal analysis.

3.3.1 pH Measurements

The leachate pH values are measured using an Orion 9156BNWP refillable probe connected to a Thermo Scientific Orion 5 star pH ISE Cond-DO Portable meter. Calibration methods are given in Appendix C.

3.3.2 Oxidation-Reduction Potential Measurements

The leachate ORP values are measured using the same probe and meter as in the pre-extraction phase. Calibration methods are given in Appendix C.

3.3.3 Filtration

The leachate from each extraction vessel is filtered to remove all suspended matter. Approximately 500 mL of the leachate is filtered using a vacuum (Figure 3.2). The leachate is filtered twice, initially through a 47 mm microfiber glass filter then through a 45 µm gridded filter. Each filtered sample is poured into two 50 mL digestion tubes. Duplicate samples are necessary as the samples are being analyzed by two laboratories. Trace grade nitric acid is added to both samples until a pH < 2 is achieved in order to preserve the samples (American Public Health Association, American Water Works Association, Water Environment Federation, 2012).

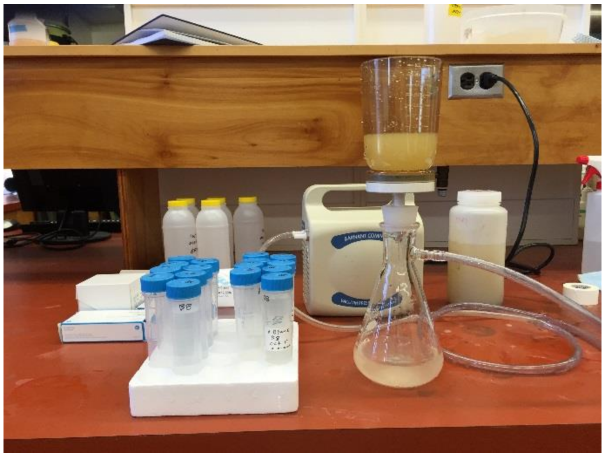

Figure 3.2. Illustrates the filtration procedure. The vacuum is connected to an Erlenmeyer flask and sucking the leachate through a glass filter.

3.3.4 Dalhousie Water Lab Analysis Preparation

An analysis of a full metal suite is conducted at the Dalhousie Water Lab using a Thermo Scientific XSeries 2 ICPMS machine. The blank and two randomly selected samples from each extraction are prepared for analysis. Their analysis requires that the samples are acid digested and diluted to specific concentrations. The samples are digested using standard Dalhousie Water Lab procedures. This includes adding an additional 2.5 mL of trace grade nitric acid to the samples and placing them in the digestion block where they are heated at 110°C for two hours (personal communication, M. Letman, 2015). Once the samples are digested they are diluted to 10x, 100x and 1000x dilutions. Each sample has four solutions, three dilute solutions as stated above as well as a non-dilute solution, all of which are submitted to the Dalhousie water lab for a major metal analysis.

3.3.5 Maxxam Laboratories U Analysis

A second set of samples are sent to Maxxam Laboratories for U analysis. The same sample numbers that are analyzed at the Dalhousie Water Lab are analyzed using ICP/MS by Maxxam.

3.4 Quality Control

This study is based on a limited number of extractions; therefore, quality control is a crucial component in ensuring that accurate data is produced. All lab equipment is thoroughly sanitized between uses. pH and ORP probes are calibrated before every use. Extractions include triplicate samples as well as a blank to ensure quality control. Two of the triplicate samples are randomly selected for analysis. The duplicate results are compared with each other to ensure data accuracy. Uranium analysis is conducted at two labs to ensure results are accurate. Comparing the uranium data from Maxxam and the Dalhousie water lab shows that they both produce similar results (within 1% of each other). Any extractions that appear to produce unreliable data are conducted again to ensure the data produced is accurate. Data is considered unreliable when duplicate samples produce variable results (>5% difference for the siltstone extractions; different order of magnitude for the granite extractions).

4.0 Results

4.1 Rock Results

Three rock types are used in the leaching experiments. Horton Group siltstones from St. Croix NS, granite from Millet Brook (MBG) are analyzed for original metal concentrations. The granite from Harrietsfield (HG) is not analyzed due to the time constraints of this thesis, but known uranium concentrations from similar samples near the sampling site are used to determine an approximate uranium concentration for the Harrietsfield sample.

4.1.1 Horton Group Siltstone

Table 4.1 shows the elemental concentrations within the Horton Group Siltstone. The sample contains 20 ppm of uranium. The sample used is defined as grey siltstone lenses interlayered with reddish arkosic sandstone (personal communication, A.M. Ryan, 2016). Black organic-rich mm sized fragments are evident in the siltstone. The siltstone lenses are separated from the sandstones and define the sample used in this study.

Metals	**Concentration (mg/kg)**
Molybdenum (Mo)	ND
Antimony (Sb)	ND
Cadmium (Cd)	ND
Thallium (Tl)	1.2
Cobalt (Co)	2.3
Beryllium (Be)	4.4
Selenium (Se)	4.7
Nickel (Ni)	7.1
Tin (Sn)	12
Uranium (U)	20
Arsenic (As)	22
Lead (Pb)	25
Zinc (Zn)	27
Chromium (Cr)	37
Copper (Cu)	39
Strontium (Sr)	76
Vanadium (V)	78
Manganese (Mn)	120
Barium (Ba)	190
Iron (Fe)	14000
Aluminum (Al)	98000

Table 4.1. Elemental concentrations within the Horton Group siltstone. The sample is comprised of 20 mg/kg U. ND defines an element that is not detected.

4.1.2 Granite from Millet Brook

Table 4.2 shows the elemental concentrations within the MBG. This sample has 8.2 ppm of uranium. Millet Brook is located within the Salmontail Lake Pluton (SLP). MacDonald (2001) states that the SLP is an early stage (phase 1) pluton which is comprised of biotite granodiorite, biotite monzogranite and fined grained leucomonzogranite. The granite in the area of Millet Brook is predominantly biotite granodiorite (Ham, 1990).

Metals	**Concentration (mg/kg)**
Molybdenum (Mo)	ND
Antimony (Sb)	ND
Selenium (Se)	ND
Cadmium (Cd)	0.23
Thallium (TI)	0.98
Beryllium (Be)	2.2
Tin (Sn)	3.1
Arsenic (As)	5.6
Cobalt (Co)	7.1
Uranium (U)	8.2
Nickel (Ni)	8.3
Chromium (Cr)	25
Lead (Pb)	37
Vanadium (V)	41
Copper (Cu)	74
Strontium (Sr)	120
Zinc (Zn)	120
Manganese (Mn)	500
Barium (Ba)	590
Iron (Fe)	26000
Aluminum (Al)	66000

Table 4.2. Elemental concentrations within the MBG. The sample is comprised of 8.2 mg/kg U. ND defines an element that is not detected.

4.2.3 Granite from Harrietsfield

Harrietsfield is located on the Halifax Pluton. MacDonald (2001) states that the pluton consists of biotite granodiorite, biotite monzogranite, leucomonzogranite, and muscovite-biotite monzogranite is the dominant lithology of the eastern pluton. The sample used in my study is as a muscovite-biotite monzogranite with noticeable weathering rinds (Figure 4.1.) Although the sample used in my study was not analyzed, it comes from an outcrop proximal to a sample analyzed by MacDonald (2001) with 3 ppm of uranium. Figure 4.2 illustrates the sampling site.

Figure 4.1. Sample of the muscovite-biotite monzogranite taken from Harrietsfield.

Figure 4.2. Sample site for the granite from Harrietsfield. There is evidence of weathering on the outcrop.

4.2 Extraction Results

Synthetic extractions are used to replicate the weathering processes of water on geologic units. Each extraction produces leachate that is analyzed for dissolved uranium as well as other dissolved metals.

4.2.1 Initial Extraction Components

Twelve extractions are conducted using various chemical additives dissolved in reverse osmosis water (RO) and mixed with different rock types. Table 4.3 displays the solutions and rock types used for each extraction: concentrations selected to be consistent with Letman's study (personal communication, M. Letman, 2015).

Extraction #	Solution Composition	Ion of Focus	Concentration of Ion of Focus (mg/L)	Rock Type
A	NaCl	Cl^-	500	Siltstone
B	NaCl	Cl^-	500	Granite (MBG)
C	$NaHCO_3$	HCO_3^-	500	Siltstone
D	$NaHCO_3$	HCO_3^-	500	Granite (MBG)
E	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	200	Siltstone
F	RO	N/A	N/A	Siltstone
G	$CaSO_4$	SO_4^-	300	Siltstone
H	$CaSO_4$	SO_4^-	500	Siltstone
I	$CaSO_4$	SO_4^-	500	Granite (HG)
K	RO	N/A	N/A	Granite (HG)
L	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	500	Siltstone
M	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	500	Granite (HG)
N	Gypsum($CaSO_4 \cdot 2H_2O$)	SO_4^-	500	Granite (HG)
O	Seashells($CaCO_3$)	CO_3^{2-}	500	Granite (HG)
P	RO	N/A	N/A	Granite (HG)
R	$NaHCO_3$	HCO_3^-	500	Granite (HG)

Table 4.3. Solution compositions and their ion of focus as well as the rock types used in each extraction. RO refers to an extraction that did not consist of additional ions. MBG represents granite from Millet Brook and HG represents granite from Harrietsfield. Each extraction number consists of duplicate samples.

4.2.2 pH Measurements

The pH of the extraction fluids is measured before and after each extraction. The extraction fluid and leachate pH measurements are given for the different rock types in Tables 4.4-4.6 and illustrated in Figures 4.3-4.5.

4.2.2.1 Siltstone Extractions

The siltstone extractions produce extraction fluids that have a higher pH than their respective leachates (Table 4.4). The NaCl extractions show an opposite trend as they produce leachates with a higher pH than the extraction fluid: that is, leaching of the siltstone by all fluids expect the NaCl extraction fluid, resulted in a decrease in pH. The changes in pH for the siltstone extractions are shown in Figure 4.3.

Extraction #	**Solution Composition**	**Ion of Focus**	**Concentration of Ion of Focus (mg/L)**	**Extraction Fluid pH**	**Leachate pH**
C2	$NaHCO_3$	HCO_3^-	500	7.80	5.33
C3 (duplicate)	$NaHCO_3$	HCO_3^-	500	7.80	5.34
F6	RO (water)	N/A	N/A	7.10	5.83
F7 (duplicate)	RO (water)	N/A	N/A	7.10	5.84
A2	NaCl	Cl^-	500	6.38	7.33
A4 (duplicate)	NaCl	Cl^-	500	6.38	7.56
L2	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	500	5.60	4.08
L4 (duplicate)	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	500	5.60	4.11
E3	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	200	5.99	4.03
E4 (duplicate)	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	200	5.99	4.07
G3	$CaSO_4$	SO_4^-	300	5.90	4.13
G4 (duplicate)	$CaSO_4$	SO_4^-	300	5.90	4.14
H6	$CaSO_4$	SO_4^-	500	6.51	4.12
H7 (duplicates)	$CaSO_4$	SO_4^-	500	6.51	4.09

Table 4.4. Extraction fluid and leachate pH measurements for the siltstone extractions. The leachate pH values decrease except for the NaCl extractions which increase. Duplicate extractions produce similar leachate pH values (<5% difference).

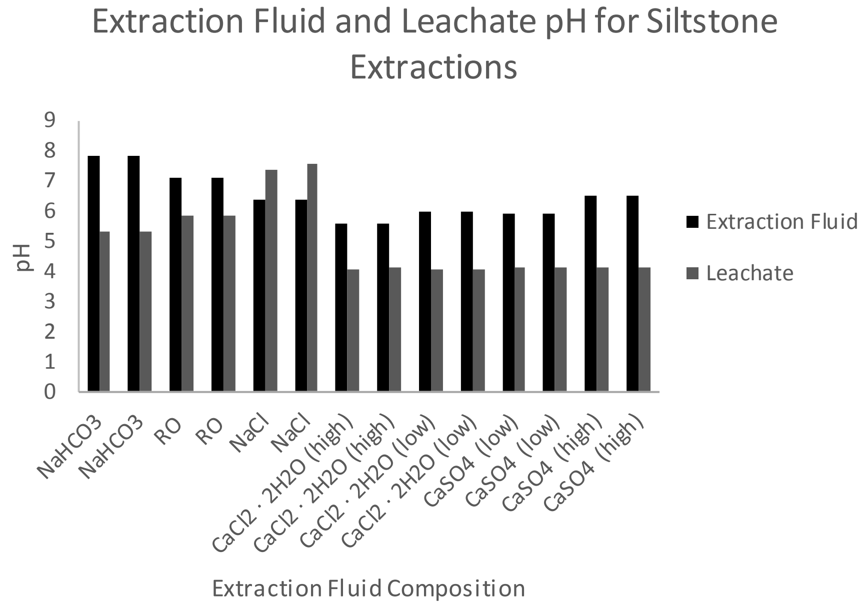

Figure 4.3. Changes in pH for the siltstone extractions. There is a decreasing trend in pH from the extraction fluid to the leachate values with the NaCl extractions showing an opposite trend. Each extraction consists of duplicate samples.

4.2.2.2 Millet Brook Extractions

The Millet Brook extractions produce extraction fluids with neutral to alkaline pH values: in both cases, the pH of the leachates have higher values than the original extraction fluids (Table 4.5). Table 4.5 displays the pH values associated with the various extractions and Figure 4.4 illustrates the pH changes between the extraction fluids and leachates for each extraction.

Extraction #	Solution Composition	Ion of Focus	Concentration of Ion of Focus (mg/L)	Extraction Fluid pH	Leachate pH
B7	NaCl	Cl^-	500	7.00	8.27
B8 (duplicate)	NaCl	Cl^-	500	7.00	8.27
D7	$NaHCO_3$	HCO_3^-	500	8.02	9.78
D8 (duplicate)	$NaHCO_3$	HCO_3^-	500	8.02	9.80

Table 4.5. Extraction fluid and leachate pH values for the Millet Brook extractions. The pH values range from neutral to alkaline. Duplicate extractions produce similar leachate pH values (<1% difference).

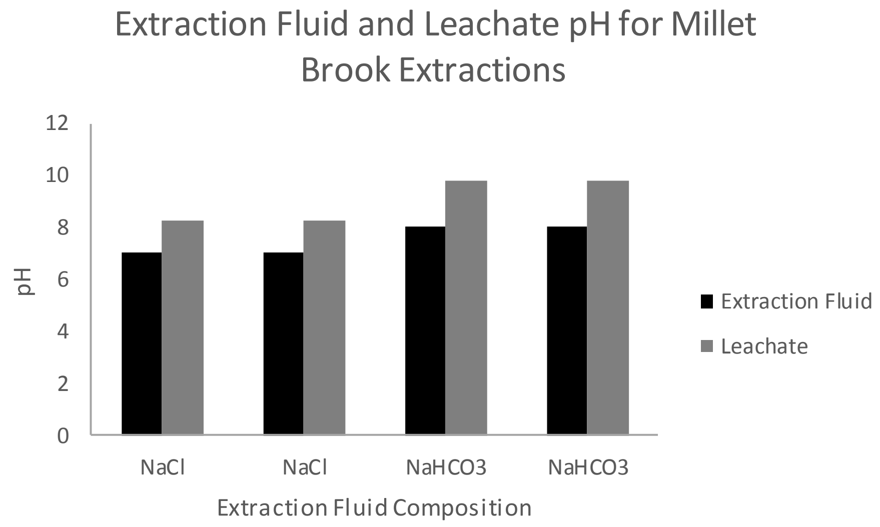

Figure 4.4. Changes in pH for the Millet Brook extractions. The figure illustrates the changes in pH showing an increase in pH from the extraction fluids to leachates. Each extraction consists of duplicate samples.

4.2.2.3 Harrrietsfield Extractions

There is an overall trend towards increasing pH from the extraction fluids to the leachates. Both the sulphate and calcium extractions produce leachates with slightly alkaline pH and the other extractions produce alkaline leachates. The pH values for the extraction fluids and leachates are given in Table 4.6 and illustrated in Figure 4.5.

Extraction #	Solution Composition	Ion of Focus	Concentration of Ion of Focus (mg/L)	Extraction Fluid pH	Leachate pH
N1	Gypsum ($CaSO_4 2H_2O$)	SO_4^-	500	5.32	7.92
N2 (duplicate)	Gypsum ($CaSO_4 2H_2O$	SO_4^-	500	5.32	8.23
P5	RO (water)	N/A	N/A	6.15	8.89
P6 (duplicate)	RO (water)	N/A	N/A	6.13	8.90
O3	Seashells ($CaCO_3$)	CO_3^{2-}	500	5.63	8.88
O4 (duplicate)	Seashells ($CaCO_3$)	CO_3^{2-}	500	5.63	8.93
I2	$CaSO_4$	SO_4^-	500	5.54	7.70
I3 (duplicate)	$CaSO_4$	SO_4^-	500	5.54	7.98
M7	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	500	5.53	7.04
M8 (duplicate)	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	500	5.53	7.20
K6	RO (water)	N/A	N/A	6.84	8.84
K8 (duplicate	RO (water)	N/A	N/A	6.84	8.79
R7	$NaHCO_3$	HCO_3^-	500	7.75	8.43
R8 (duplicate)	$NaHCO_3$	HCO_3^-	500	7.84	8.35

Table 4.6. Extraction fluid and leachate pH values for the Harrietsfield extractions. There is a trend in increasing pH from extraction fluids to leachates. Duplicate extractions produce similar leachate pH values (<5% difference)

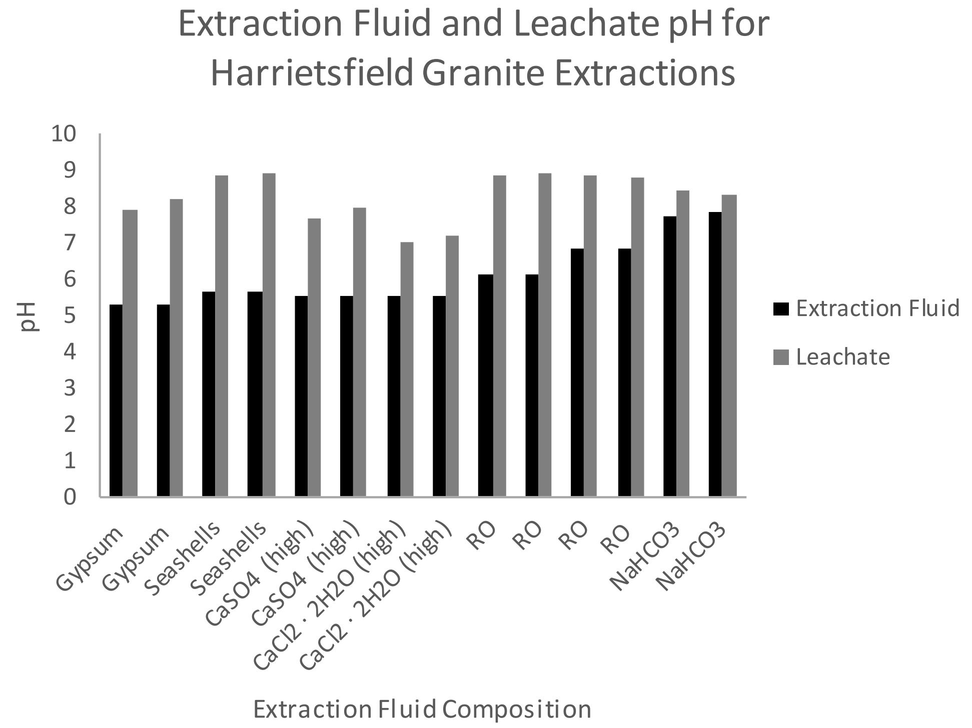

Figure 4.5. Changes in pH for the Harrietsfield extraction. There is an overall trend in increasing pH from extraction fluid to leachate values. Each extraction consists of duplicate samples.

4.2.3 Eh Measurements

Oxidation-reduction potential (ORP) measurements for each extraction fluid and leachate is calibrated to equate to Eh. The extraction fluid and leachate Eh values for the different rock type extractions are given in Tables 4.7-4.9 and illustrated in Figures 4.6-4.8.

4.2.3.1 Siltstone Extractions

The siltstone extractions did not show any significant changes between the extraction fluid and leachate Eh values. The Eh values range from approximately 300 mV to 450 mV (Table 4.7 and Figure 4.6). All Eh values indicate that the extraction fluids and the leachates are oxidizing.

Extraction #	**Solution Composition**	**Ion of Focus**	**Concentration of Ion of Focus (mg/L)**	**Extraction Fluid Eh (mV)**	**Final Eh (mV)**
C2	$NaHCO_3$	HCO_3^-	500	426.5	422.5
C3 (duplicate)	$NaHCO_3$	HCO_3^-	500	445.5	445.5
F6	RO (water)	N/A	N/A	321.1	334.3
F7 (duplicate)	RO (water)	N/A	N/A	321.1	312.0
A2	NaCl	Cl^-	500	293.9	309.0
A4 (duplicate)	NaCl	Cl^-	500	293.9	305.7
L2	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	500	584.3	492.8
L4 (duplicate)	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	500	580.0	449.7
E3	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	200	362.7	361.4
E4 (duplicate)	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	200	362.7	367.7
G3	$CaSO_4$	SO_4^-	300	320.4	320.8
G4 (duplicate)	$CaSO_4$	SO_4^-	300	320.4	309.6
H6	$CaSO_4$	SO_4^-	500	313.7	309.1
H7 (duplicate)	$CaSO_4$	SO_4^-	500	313.7	324.6

Table 4.7. Extraction fluid and leachate Eh values for the siltstone extractions. The values indicate that the solutions are oxidizing. Most duplicate extractions produce similar leachate Eh values (<5% difference), but C2-C3 and L2-L4 produce variable leachate Eh values (<10% difference).

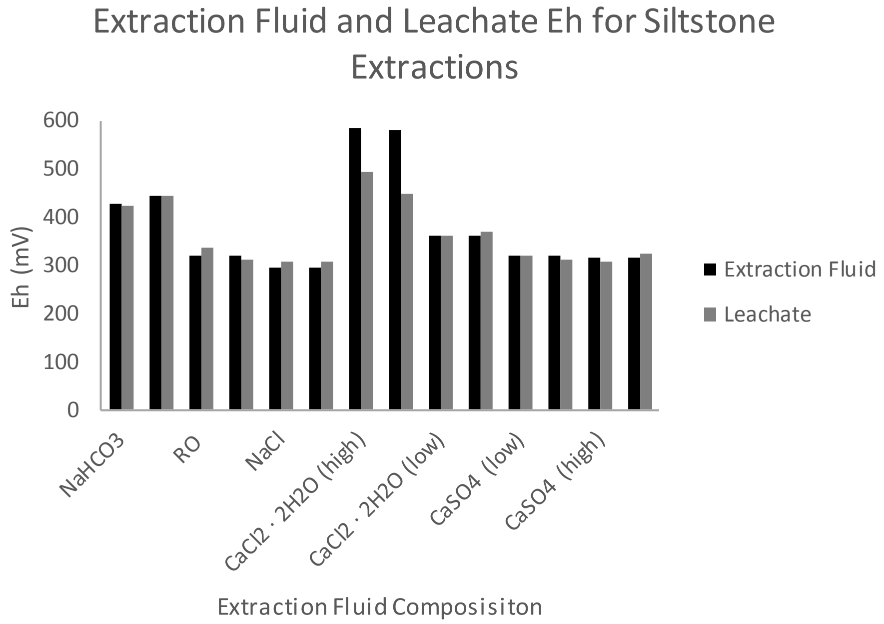

Figure 4.6. Changes in Eh for the siltstone extractions. There is not much variation between extraction fluid and leachate values except for the Ca^{2+} extractions. Each extraction consists of duplicate samples.

4.2.3.2 Millet Brook Extractions

The Eh values for the Millet Brook extractions show more significant changes between extraction fluid and leachate values than do the siltstones. The extraction fluid and leachate Eh values are given in Table 4.8. The chloride extractions display an increase in Eh from the extraction fluid to leachate values, whereas the bicarbonate extractions illustrate an opposite trend with decreasing Eh (Figure 4.7).

Extraction #	Solution Composition	Ion of Focus	Concentration of Ion of Focus (mg/L)	Extraction Fluid Eh (mV)	Leachate Eh (mV)
B7	NaCl	Cl^-	500	242.9	307.9
B8 (duplicate)	NaCl	Cl^-	500	242.9	305.7
D7	$NaHCO_3$	HCO_3^-	500	382.0	255.7
D8 (duplicate)	$NaHCO_3$	HCO_3^-	500	382.0	248.7

Table 4.8. Extraction fluid and leachate Eh values for the Millet Brook extractions. The Eh values are lower than those from the siltstone extractions, but still show that the Millet Brook extraction fluids and leachates are oxidizing. Duplicate extractions produce similar leachate Eh values (<3% difference).

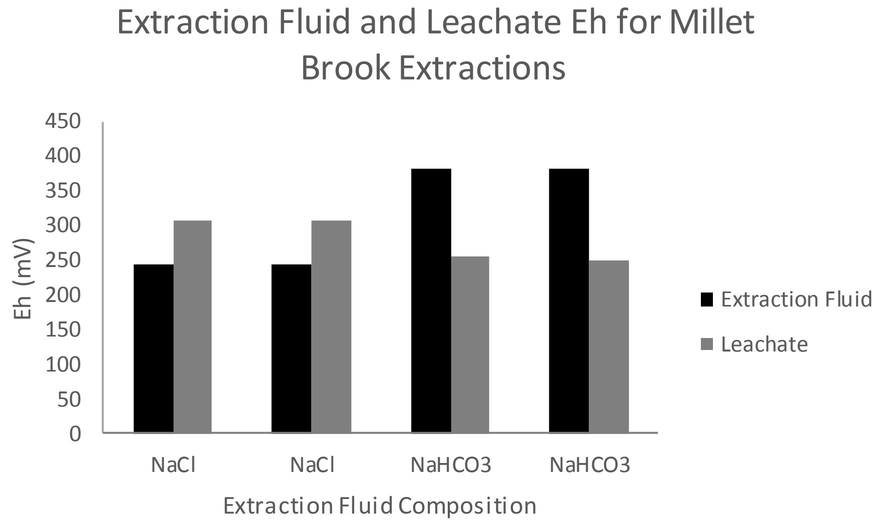

Figure 4.7. Changes in Eh for the Millet Brook extractions. Each extraction consists of duplicate samples.

4.2.3.3 Harrietsfield Extractions

The Eh values for the Harrietsfield extractions range from approximately 250 mV to 600 mV, indicating a fairly large range in Eh (Table 4.9). The extractions show a decrease in Eh from the extraction fluids to leachates except for the bicarbonate extractions which shows an opposite trend (Figure 4.8). The Ca^{2+} extractions display the greatest decrease in Eh.

Extraction #	Solution Composition	Ion of Focus	Concentration of Ion of Focus (mg/L)	Extraction Fluid Eh (mV)	Leachate Eh (mV)
N1	Gypsum ($CaSO_4 2H_2O$)	SO_4^-	500	365.2	267.1
N2 (duplicate)	Gypsum ($CaSO_4 2H_2O$	SO_4^-	500	365.2	253.9
P5	N/A	N/A	N/A	308.0	266.1
P6 (duplicate)	N/A	N/A	N/A	395.7	264.3
O3	Seashells ($CaCO_3$)	CO_3^{2-}	500	344.7	262.6
O4 (duplicate)	Seashells ($CaCO_3$)	CO_3^{2-}	500	344.7	265.7
I2	$CaSO_4$	SO_4^-	500	310.3	268.6
I3 (duplicate)	$CaSO_4$	SO_4^-	500	310.3	261.5
M7	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	500	580.0	309.3
M8 (duplicate)	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	500	580.0	298.3
K6	RO (water)	N/A	N/A	325.7	265.2
K8 (duplicate	RO (water)	N/A	N/A	325.7	268.0
R7	$NaHCO_3$	HCO_3^-	500	241.7	280.0
R8 (duplicate)	$NaHCO_3$	HCO_3^-	500	246.4	283.5

Table 4.9. Extraction fluid and leachate Eh values for the Harriestfield extractions. Oxidizing solutions are produced in each extraction. Duplicate extractions produce similar leachate Eh values (<5% difference).

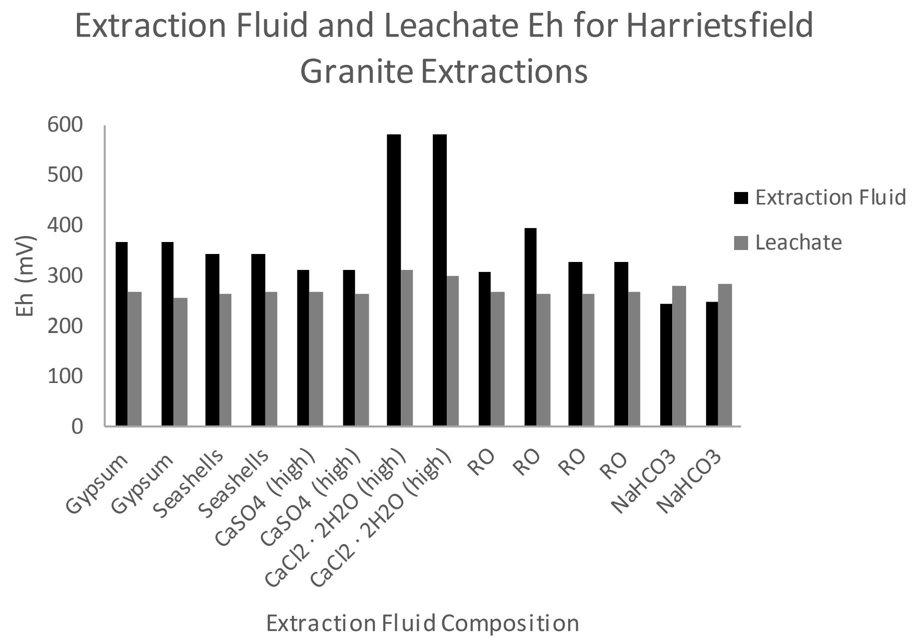

Figure 4.8. Changes in Eh for the Harritefield extractions. The extraction fluid Eh values are lower than the leachate values except for the bicarbonate extractions. Each extraction consists of duplicate samples.

4.2.4 Concentration of Dissolved Uranium in Leachate

Dissolved uranium concentrations are measured for the leachates produced by the extractions. There are variations in the results depending on the solutions and rock types used. In general, the granites leach more uranium than the siltstone despite having lower U concentrations. The dissolved uranium results are given in the Tables 4.10-4.12 and illustrated in Figures 4.9-4.11.

4.2.4.1 Siltstone Extractions

The quantities of dissolved uranium for the siltstone extractions are displayed in Table 4.10. The sulphate extractions produce the greatest concentrations of dissolved U within the leachate, whereas the bicarbonate extractions produce the least. The extractions are listed in order from the lowest concentration of dissolved U to the highest (Table 4.10). Figure 4.9 illustrates the changes in dissolved U concentrations for the different extractions.

Extraction #	Solution Composition	Ion of Focus	Concentration of Ion of Focus (mg/L)	Dissolved U (ppb)
C2	$NaHCO_3$	HCO_3^-	500	0.15
C3 (duplicate)	$NaHCO_3$	HCO_3^-	500	0.15
F6	RO (water)	N/A	N/A	0.18
F7 (duplicate)	RO (water)	N/A	N/A	0.16
A2	NaCl	Cl^-	500	0.66
A4 (duplicate)	NaCl	Cl^-	500	0.46
L2	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	500	0.93
L4 (duplicate)	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	500	0.95
E3	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	200	1.00
E4 (duplicate)	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	200	1.00
G3	$CaSO_4$	SO_4^-	300	1.8
G4 (duplicate)	$CaSO_4$	SO_4^-	300	1.8
H6	$CaSO_4$	SO_4^-	500	2.4
H7 (duplicates)	$CaSO_4$	SO_4^-	500	2.5

Table 4.10. Concentrations of dissolved U for the siltstone extractions. The concentrations of dissolved U range from 0.15 ppb to 2.5 ppb. Most duplicate extractions produce similar leachate dissolved U concentrations (<5% difference), but A2-A4 produce 30% variations in dissolved U concentrations and F6-F8 produce 12% variations in dissolved U concentrations. These variable results from Maxxam are compared with the Dalhousie Water Lab results which confirms that they are accurate (Appendix G and Appendix H).

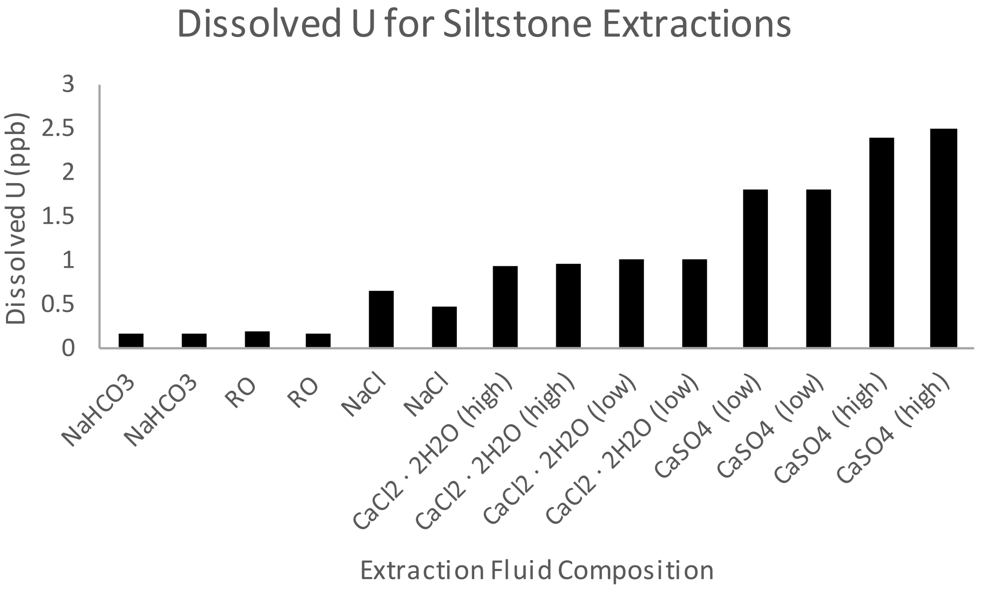

Figure 4.9. Variations of dissolved U for the siltstone extractions. Dissolved U concentrations increase from left to right. Each extraction consists of duplicate samples.

4.2.4.2 Millet Brook Extractions

The quantities of dissolved uranium within Millet Brook leachates vary from 4.9 ppb to 8.7 ppb (Table 4.11). The bicarbonate extractions produce higher concentrations of dissolved U than the chloride extractions. The changes in dissolved U concentrations for the different extractions are illustrated in Figure 4.10.

Extraction #	**Solution Composition**	**Ion of Focus**	**Concentration of Ion of Focus (mg/L)**	**Dissolved U (ppb)**
B7	NaCl	Cl^-	500	4.9
B8 (duplicate)	NaCl	Cl^-	500	6.7
D7	$NaHCO_3$	HCO_3^-	500	7.5
D8 (duplicate)	$NaHCO_3$	HCO_3^-	500	8.7

Table 4.11. Concentrations of dissolved U for the Millet Brook extractions. The concentration of dissolved U varies between the chloride and bicarbonate extractions. The duplicate extractions produce leachate dissolved U concentrations that are variable from each other (14% difference for B7-B8 and 23% difference for D7-D8). These variable results from Maxxam are compared with the Dalhousie Water Lab results which confirms that they are accurate (Appendix G and Appendix H).

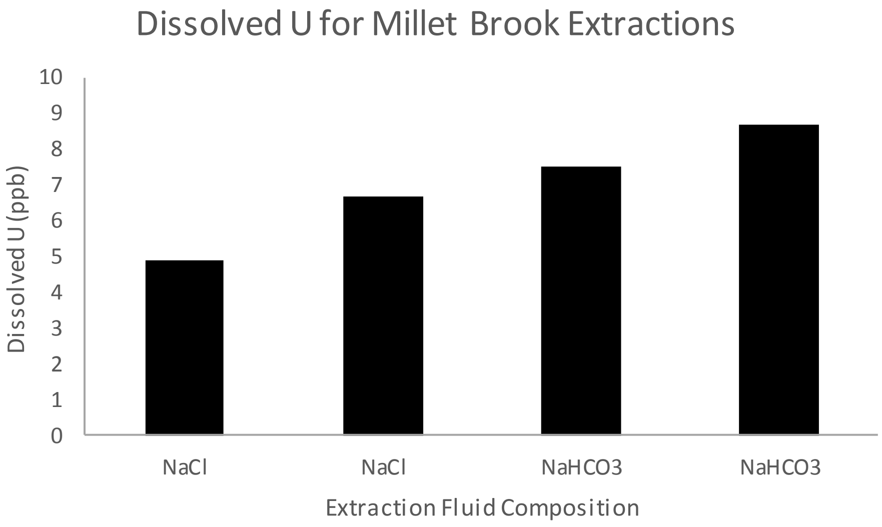

Figure 4.10. Variations in dissolved U concentrations for the Millet Brook extractions. There is an increasing trend in dissolved uranium from left to right. Each extraction consists of duplicate samples.

4.2.4.3 Harrietsfield Extractions

The Harrietsfield extractions produce the highest concentrations of dissolved U out of the three rock type extractions. The Harriesfield extractions produce dissolved U concentrations ranging from 2.72 ppb to 29.25 ppb (Table 4.12). The bicarbonate extractions produce the highest concentrations of dissolved U. The changes in dissolved U concentrations for the different Harrietsfield extractions are illustrated in Figure 4.11.

Extraction #	**Solution Composition**	**Ion of Focus**	**Concentration of Ion of Focus (mg/L)**	**Dissolved U (ppb)**
N1	Gypsum ($CaSO_4 2H_2O$)	SO_4^-	500	2.90
N2 (duplicate)	Gypsum ($CaSO_4 2H_2O$	SO_4^-	500	3.10
P5	RO (water)	N/A	N/A	3.30
P6 (duplicate)	RO (water)	N/A	N/A	2.60
O3	Seashells ($CaCO_3$)	CO_3^{2-}	500	3.40
O4 (duplicate)	Seashells ($CaCO_3$)	CO_3^{2-}	500	3.60
I2	$CaSO_4$	SO_4^-	500	4.51
I3 (duplicate)	$CaSO_4$	SO_4^-	500	4.28
M7	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	500	4.40
M8 (duplicate)	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	500	4.72
K6	RO (water)	N/A	N/A	6.70
K8 (duplicate)	RO (water)	N/A	N/A	6.01
R7	$NaHCO_3$	HCO_3^-	500	31.0
R8 (duplicate)	$NaHCO_3$	HCO_3^-	500	31.0

Table 4.12. Concentrations of dissolved U for the Harrietsfield extractions. The concentrations of dissolved U are approximately between 2-6 ppb for all extractions except the HCO_3^- extractions (approximately 29 ppb). Most duplicate extractions produce similar concentrations of dissolved uranium (≤ 7% difference), but the P5-P6 and K6-K8 extractions produce variable concentrations of dissolved U (25% difference and 10% difference respectively). It is important to note that the RO extractions are conducted twice for quality control. *These variable Maxxam results are compared with the Dalhousie Water Lab results which confirms that they are accurate (Appendix G and Appendix H).*

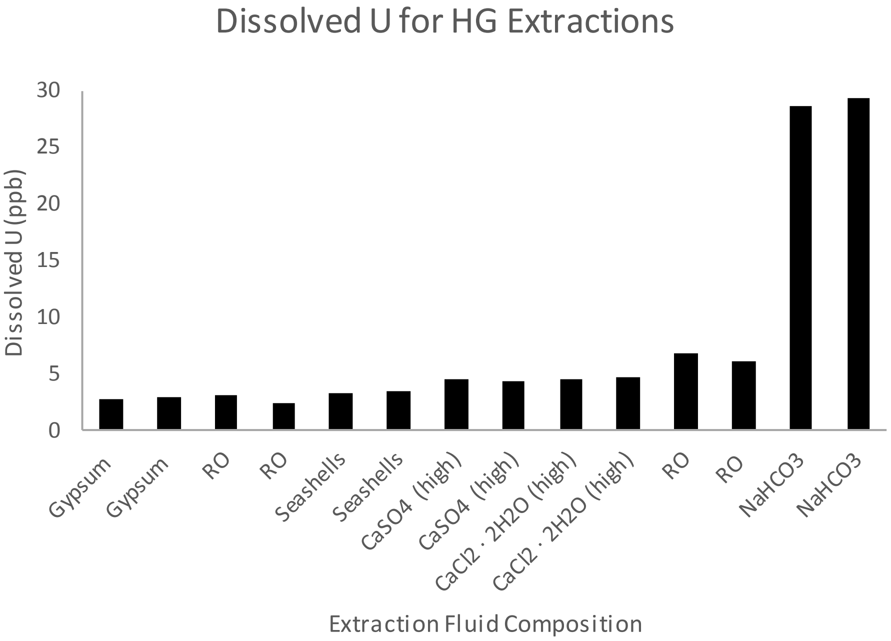

Figure 4.11. Variations in dissolved U concentrations for the Harrietsfield Extractions. The bicarbonate extractions produce the highest concentrations of dissolved U. Each extraction consists of duplicate samples. RO extractions are conducted twice for quality control and produce variable results. The Maxxam results are compared to the Dalhousie Water Lab results which confirms that the results are accurate.

4.2.5 Concentration of Dissolved U vs. pH

Concentrations of dissolved uranium are plotted against the pH of the leachates for the different extractions. The relationship between the concentrations of dissolved U and pH for the siltstone extractions are illustrated in Figure 4.12, Figure 4.13 for the MBG extractions and Figure 4.14 for the HG extractions. The siltstone extractions produce higher concentrations of dissolved U in acidic conditions whereas the MBG and HG extractions produce higher concentrations of dissolved U in alkaline conditions.

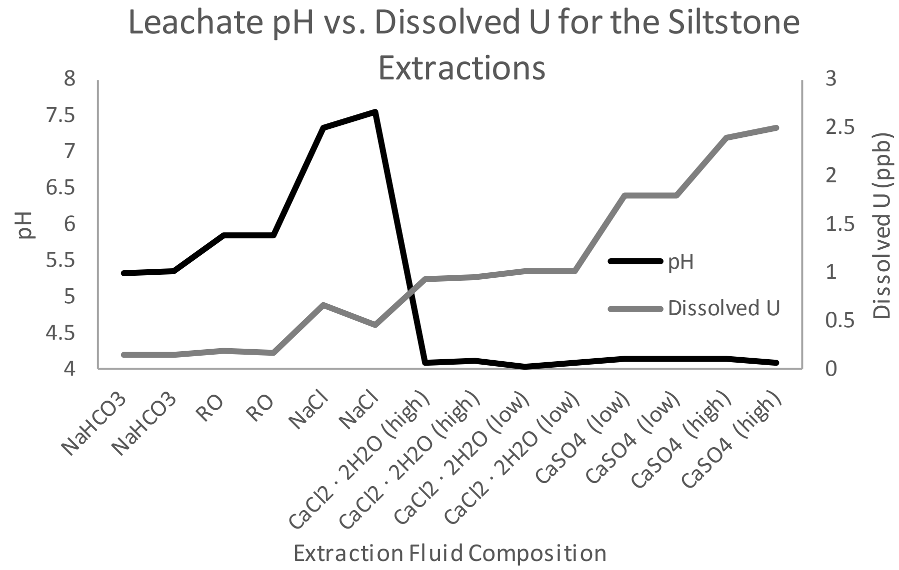

Figure 4.12. Relationship between pH and dissolved U for the siltstone extractions. The siltstone extractions produce higher concentrations of dissolved U when pH conditions are acidic (approximately pH 4). SO_4 has the greatest impact on U mobility. Each extraction consists of duplicate samples.

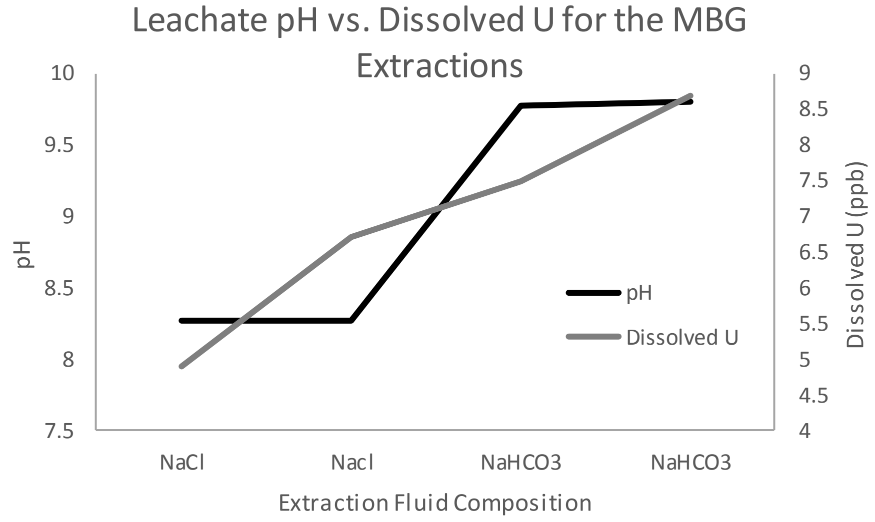

Figure 4.13. Relationship between pH and dissolved U for the MBG extractions. The MBG extractions produce higher concentrations of dissolved U when pH conditions are alkaline (approximately pH 9.8). Each extraction consists of duplicate samples.

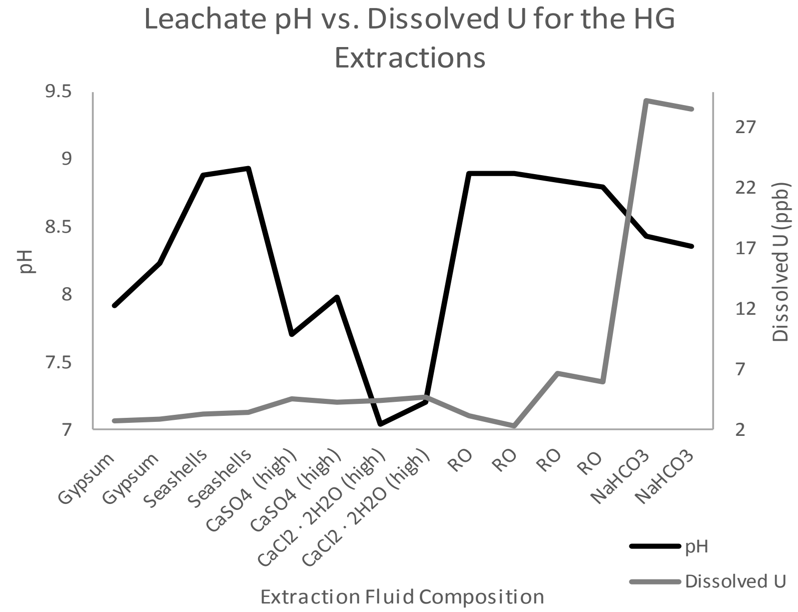

Figure 4.14. Relationship between pH and dissolved U for the HG extractions. The HG extractions produce slightly alkaline to alkaline leachates. Each extraction consists of duplicate samples.

4.2.6 Concentration of Dissolved U vs. Eh

Concentrations of dissolved uranium are plotted against the Eh of the leachates for the different extractions. The relationship between dissolved U and Eh for the siltstone extractions is illustrated in Figure 4.15, Figure 4.16 for the MBG extractions and Figure 4.17 for the HG extractions. There is no correlation between the trends in dissolved U concentrations and Eh.

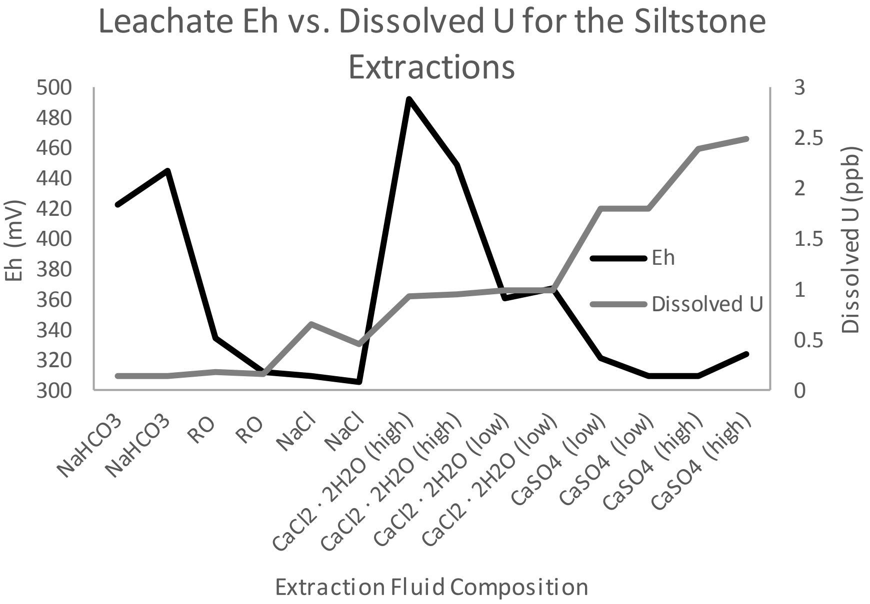

Figure 4.15. Relationship between Eh and dissolved U for the siltstone extractions. Eh varies from 300 mV to 500 mV, but does not show as similar trend as the concentrations of dissolved U. Each extraction consists of duplicate samples.

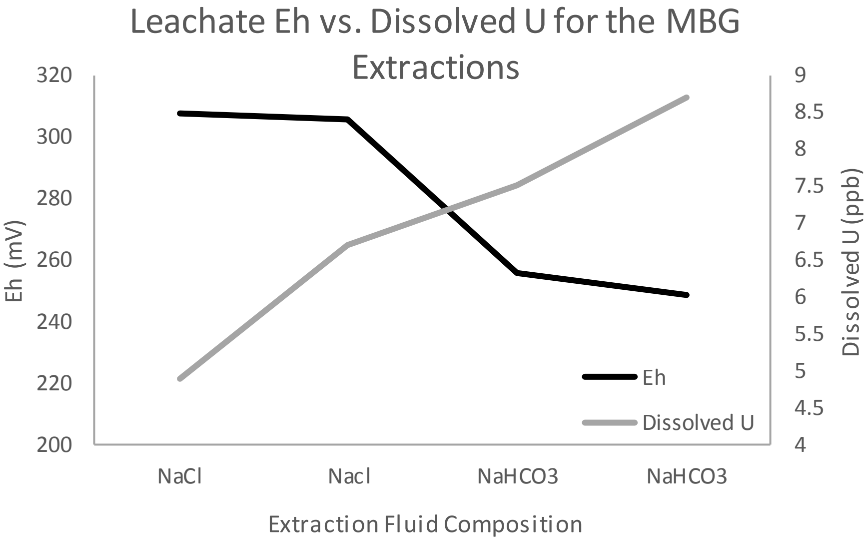

Figure 4.16. Relationship between Eh and dissolved U for the MBG extractions. Eh slightly decreases as concentrations of dissolved U increase, but due to the small data set and minimal variation in Eh, there is not conclusive evidence that they are related. Each extraction consists of duplicate samples.

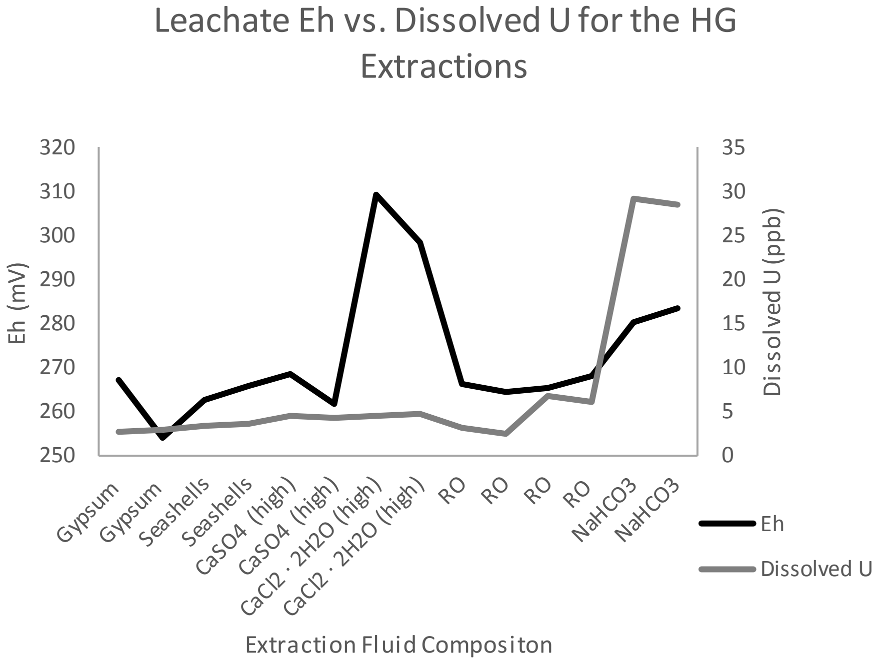

Figure 4.17. Relationship between Eh and dissolved U for the HG extractions. Eh values vary for the different extractions but do not correlate to the variations in dissolved U. Each extraction consists of duplicate samples.

4.2.7 Concentration of Dissolved Metals in Leachate

A number of metals are analyzed to determine if they react with the extraction fluids similarly to uranium. The full suite of metal analysis is conducted for all three rock type extractions. The dissolved metal results are given in Table 4.13 for the siltstone extractions, Table 4.14 for the MBG extractions and Table 4.15 for the HG extractions. Full data tables are given in Appendix G. It is important to note that this study focuses on the geochemical parameters that drive U mobility. Dissolved metal analysis is conducted to determine if there are any distinct trends between U and other metals, but is not the primary focus of the study.

Extraction #	Ion of Focus	Dissolved Metals (μg/L)										
		U	**Li**	**Al**	**P**	**Ti**	**V**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**
C2	HCO$_3^-$	0.150	18.86	154.4	36.08	0.878	0.885	0.138	124.6	811.4	2.021	3.131
C3	HCO$_3^-$	0.150	21.13	156.9	22.64	1.717	1.240	0.262	131.7	893.9	2.157	3.309
F6	N/A	0.180	4.333	52.11	23.64	2.144	0.452	0.169	2.415	76.25	0.075	0.368
F7	N/A	0.160	9.004	91.90	27.94	3.883	0.490	0.324	3.681	85.11	0.116	0.239
A2	Cl$^-$	0.660	1.099	83.60	30.78	1.959	0.358	0.102	2.012	89.79	0.028	0.094
A4	Cl$^-$	0.460	0.785	75.51	31.68	1.286	0.273	0.143	1.876	62.62	0.023	0.115
L2	Ca^{2+}	0.804	21.04	4982	36.27	1.109	1.021	0.542	408.7	4523	5.507	11.94
L3	Ca^{2+}	0.819	20.83	5104	14.68	0.995	0.921	0.537	415.2	4681	5.529	11.24
E3	Ca^{2+}	1.000	26.20	2575	33.25	1.459	0.565	0.411	273.9	3890	4.657	8.737
E4	Ca^{2+}	1.000	25.40	2591	26.65	1.375	0.502	0.408	275.6	4206	4.674	8.707
G3	SO$_4^-$	1.800	24.56	2066	26.75	1.158	0.135	0.471	277.4	2907	4.749	7.670
G4	SO$_4^-$	1.800	24.53	2113	28.39	1.152	0.119	0.539	288.4	3211	4.941	7.808
H6	SO$_4^-$	2.400	23.19	3069	28.52	1.122	0.102	0.602	288.4	3179	4.699	7.941
H7	SO$_4^-$	2.500	22.74	3053	26.37	1.102	0.095	0.631	306.1	3338	4.88	7.790
		U	**Cu**	**Zn**	**As**	**Se**	**Ag**	**Cd**	**Sb**	**Ba**	**Ce**	**Pb**
C2	HCO$_3^-$	0.150	5.860	11.58	0.199	0.242	0.653	0.079	0.000	88.2	0.188	1.574
C3	HCO$_3^-$	0.150	6.056	7.547	0.154	0.229	0.115	0.072	0.000	89.54	0.359	0.618
F6	N/A	0.180	1.656	2.561	0.573	0.577	0.026	0.000	0.000	1.193	0.113	0.352
F7	N/A	0.160	1.707	3.039	0.693	0.629	0.037	0.000	0.000	1.620	0.159	0.611
A2	Cl$^-$	0.660	1.653	2.694	0.826	0.525	0.222	0.000	0.011	2.074	0.157	0.665
A4	Cl$^-$	0.460	1.078	6.486	0.605	0.363	0.174	0.000	0.000	2.187	0.083	0.451
L2	Ca^{2+}	0.804	36.70	16.46	0.417	0.088	0.134	0.190	-0.061	261.5	3.404	7.771
L3	Ca^{2+}	0.819	36.82	17.22	0.446	0.182	0.091	0.225	-0.14	272.3	3.412	8.126
E3	Ca^{2+}	1.000	23.60	15.94	0.342	0.166	0.152	0.154	0.000	202.2	1.729	4.491
E4	Ca^{2+}	1.000	18.21	13.63	0.391	0.201	0.072	0.160	0.000	202.7	1.639	4.266
G3	SO$_4^-$	1.800	13.23	12.31	0.69	0.315	0.100	0.127	0.000	156.0	2.167	3.251
G4	SO$_4^-$	1.800	12.07	11.05	0.744	0.474	0.128	0.125	0.152	146.8	2.279	3.358
H6	SO$_4^-$	2.400	10.44	12.95	0.688	0.445	5.241	0.124	0.000	126.3	3.891	4.287
H7	SO$_4^-$	2.500	10.05	10.51	0.688	0.497	0.155	0.141	0.000	136.9	3.596	5.219

Table 4.13. Concentrations of dissolved U, Li, Al, P, Ti. V, Cr, Mn, Fe. Co, Ni CU, Zn, As, Se, Ag, Cd, Sb, Ba, Ce and Pb for each siltstone extraction.

Extraction #	**Ion of Focus**	**Dissolved Metals (μg/L)**										
		U	**Li**	**Al**	**P**	**Ti**	**V**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**
B7	Cl^-	4.900	2.238	28.66	30.95	0.994	0.061	0.112	10.17	18.03	0.138	0.856
B8	Cl^-	6.700	3.433	31.48	33.42	1.120	0.075	0.103	12.47	8.762	0.186	0.587
D7	HCO_3^-	7.500	23.44	961.6	45.65	7.789	4.560	0.260	2.557	93.08	0.076	0.302
D8	HCO_3^-	8.700	24.85	1023	35.67	10.11	5.005	0.260	2.958	118	0.069	0.271
		U	**Cu**	**Zn**	**As**	**Se**	**Ag**	**Cd**	**Sb**	**Ba**	**Ce**	**Pb**
B7	Cl^-	4.900	6.009	5.631	2.782	0.122	0.08	0.015	0.000	5.985	0.083	0.291
B8	Cl^-	6.700	3.736	3.946	4.167	0.211	0.088	0.014	0.000	6.202	0.121	0.262
D7	HCO_3^-	7.500	1.597	3.503	21.05	0.711	0.182	0.015	0.350	10.00	0.080	0.249
D8	HCO_3^-	8.700	1.598	2.74	21.39	0.711	0.069	0.000	0.146	12.62	0.063	0.236

Table 4.14. Concentrations of dissolved U, Li, Al, P, Ti. V, Cr, Mn, Fe. Co, Ni CU, Zn, As, Se, Ag, Cd, Sb, Ba, Ce and Pb for the MBG extractions.

Extraction #	Ion of Focus	Dissolved Metals (μg/L)										
		U	**Li**	**Al**	**P**	**Ti**	**V**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**
N1	CO_3^{2-}	2.714	22.81	517.9	42.44	1.897	0.626	0.054	4.834	30.88	0.704	0.328
N2	CO_3^{2-}	2.857	21.64	508.2	33.19	1.092	0.569	0.114	3.898	25.35	0.069	0.372
P5	N/A	3.147	21.01	1140	67.67	40.02	2.446	0.988	13.43	598.9	0.554	0.846
P6	N/A	2.352	21.54	1153	60.00	36.82	2.501	0.342	10.49	507.0	0.170	0.376
O3	Cl^-	3.278	20.82	1140	70.75	38.8	2.385	0.461	11.40	559.2	0.262	0.333
O4	Cl^-	2.451	19.26	1255	68.74	45.66	2.514	1.419	18.28	661.7	0.433	0.998
I2	Ca^{2+}	4.010	29.95	237.0	34.08	0.388	0.325	0.002	24.40	-17.83	0.087	1.669
I3	Ca^{2+}	3.992	30.32	254.9	43.56	0.671	0.281	-0.002	24.60	-21.96	0.084	1.755
M7	SO_4^-	3.789	26.67	178.3	39.52	0.541	1.439	0.145	51.52	61.62	0.298	4.706
M8	SO_4^-	4.011	26.55	175.6	17.13	0.278	1.328	0.085	55.27	48.45	0.277	4.660
K6	N/A	6.233	21.62	1086	82.66	32.76	2.238	0.276	9.688	456.6	0.166	0.730
K8	N/A	5.749	24.01	1042	74.26	30.82	2.299	0.288	9.256	447.4	0.140	0.487
R7	$HC0_3^-$	29.25	19.05	640.3	67.07	33.06	1.968	0.349	16.05	400.7	0.536	0.510
R8	$HC0_3^-$	28.59	18.26	592.7	64.84	29.68	1.570	0.288	13.36	349.1	0.101	0.259
		U	**Cu**	**Zn**	**As**	**Se**	**Ag**	**Cd**	**Sb**	**Ba**	**Ce**	**Pb**
N1	CO_3^{2-}	2.714	0.025	0.035	0.032	0.100	0.003	0.002	0.008	0.034	0.002	0.002
N2	CO_3^{2-}	2.857	1.512	3.542	0.094	-0.149	0.008	-0.014	-0.163	2.975	0.045	0.145
P5	N/A	3.147	8.957	14.18	1.337	-0.161	0.015	-0.003	0.185	3.197	1.356	1.316
P6	N/A	2.352	6.394	4.863	1.067	-0.103	-0.002	-0.005	-0.178	2.863	1.085	0.692
O3	Cl^-	3.278	3.206	4.635	1.307	-0.159	0.016	0.0430	-0.144	4.521	1.315	0.903
O4	Cl^-	2.451	2.952	5.583	1.129	-0.121	0.039	-0.010	-0.151	2.94	1.432	1.299
I2	Ca^{2+}	4.010	4.450	4.264	-0.076	-0.125	-0.008	0.001	-0.164	13.57	0.019	1.018
I3	Ca^{2+}	3.992	2.628	5.498	-0.104	-0.092	-0.007	0.003	-0.161	8.913	0.029	0.132
M7	SO_4^-	3.789	1.862	2.713	-0.106	0.052	0.007	0.004	-0.130	28.51	0.036	0.472
M8	SO_4^-	4.011	1.329	2.409	-0.190	0.049	-0.008	-0.002	-0.153	29.70	0.029	0.476
K6	N/A	6.233	5.387	8.174	1.596	-0.044	0.016	-0.011	0.091	8.939	1.059	9.552
K8	N/A	5.749	3.828	6.785	0.998	-0.182	0.010	-0.012	-0.117	5.570	0.930	0.794
R7	$HC0_3^-$	29.25	8.387	5.424	0.685	-0.048	0.028	-0.01	-0.159	3.908	0.845	0.706
R8	$HC0_3^-$	28.59	5.576	4.141	0.572	-0.074	-0.008	-0.015	-0.179	3.521	0.740	0.454

Table 4.15. Concentrations of dissolved U, Li, Al, P, Ti. V, Cr, Mn, Fe. Co, Ni CU, Zn, As, Se, Ag, Cd, Sb, Ba, Ce and Pb for the HG extractions.

5.0 Discussion

Uranium mobility is influenced by numerous geologic and geochemical factors. Variations in lithology and mineralogy as well as pH and Eh conditions are particularly significant in the case of U mobility.

5.1 Uranium Concentration in Rock vs. Leachate

There is no correlation between the quantities of U within the rock samples and the concentrations of dissolved U produced by each extraction. The granite from Millet Brook (MBG) contains less U than the St. Croix siltstone (8.2 ppb vs. 20 ppb respectively), yet the MBG leaches more dissolved U than the siltstone (4.9-8.7 ppb vs. 0.15-2.5 ppb respectively). The granite from Harrietsfield was not analyzed for U, however likely contains approximately 3 ppm of uranium, the approximate value of uranium concentrations within muscovite-biotite monzogranites in the Harrietsfield region (MacDonald, 2001). MacFarlane (1983) states that higher U concentrations within groundwater systems in Nova Scotia are related to granitic bodies. The analysis of my results suggests that U mobility is strongly correlated to mineralogic, textural and lithologic properties as the different rock types leached different concentrations of dissolved uranium. Where the uranium is situated within the rock itself may account for some of the variations in dissolved uranium between the Siltstone, MBG and HG extractions.

The composition of the MBG plays a major role in U mobilization. Mica-rich granites usually contain higher concentrations of U as they are formed by magmas consisting of a high volatile phase (Chatterjee, 1982). Uranium as an incompatible element can become concentrated in these more volatile components. As well, because U is soluble in oxidizing environments (Duff and Amerhein, 1996; Samolczyk et al., 2012) uranium can be re-deposited within biotite cleavage planes during weathering or alteration (O’Beirne-Ryan, 2006). Ryan and O’Beirne-Ryan (2006) state that weathered granitoid bodies of the SMB are somewhat depleted of biotite. My study is meant to simulate weathering processes, therefore it is reasonable to consider that the elevated levels of dissolved U from the MBG and HG extractions are related the presence and weatherability of biotite or other easily weathered U-bearing phases: combined with changes in pH and or Eh, this loosely bonded U may be remobilized.

The granite at Millet Brook hosts the largest U deposit in Eastern Canada (Ryan and O’Beirne-Ryan, 2009). The mechanism in which U is concentrated within the MBG may explain the U mobilization observed in my study. The MBG is locally fractured allowing U-rich fluids to mineralize within and close to fracture zones (Chatterjee et al., 1982). The high concentrations of U found in the MBG is the result of secondary mineralizing processes caused by water interactions. Meteoric water entered the granitic body, mobilized U and re-deposited the element within fracture zones (Chatterjee et al., 1982). Similarly, in my study I propose that this uranium is weakly adsorbed within the granitic body and is easily liberated by solution interactions.

The siltstone did not leach high concentrations of uranium. One possible explanation is that the presence of organic matter within the siltstone results in U-reduction causing U to strongly adsorb to these organics, even in the presence of an oxidizing environment. Uranium content within Horton Group rocks is credited to roll front mineralization (Ryan and O’Beirne, 2009). Uranium mineralizes within reducing layers, which is suggests that uranium may be found in association with organic material. Kumar et al. (2014) and MacFarlane (1982) indicate that uranium has strong sorption to organic material, supporting my interpretation that U within the siltstone is strongly adsorbed to organic material, which may explain why the siltstone leached relatively low concentrations of U.

5.2 Geochemical Influences on U Mobility

Uranium mobility is also influenced by numerous geochemical factors. Variations in pH and redox environment in turn influence the U-complexes that form within groundwater systems (MacFarlane, 1983). Analyzing the pH and Eh conditions for the extractions gives further insight into the geochemical processes that drive U mobility from the different geologic units studied.

5.2.1 pH Effect on U Mobility

The concentrations of dissolved U is influenced by pH: concentrations of dissolved uranium increase when pH decreases for the siltstone extractions and increase when pH increases for the granite extractions (Figure 4.12, Figure 4.13 and Figure 4.14). The variations in dissolved uranium between the three rock type extractions shows that there is a strong relationship between U mobility and pH conditions (Figure 4.12, Figure 4.13 and Figure 4.14). The relationship between pH and dissolved U concentrations suggests that uranium forms different soluble complexes under varying pH conditions.

Sulphate has the greatest influence on U mobility with respect to the siltstone extractions. The sulphate extraction fluids produced approximately 200% more dissolved uranium than the other extraction fluids for the siltstone extractions (Figure 4.12). Sulphate had an opposite impact on the HG extractions as it produced the lowest quantities of dissolved uranium with respect to the other extraction fluids. Bachmaf et al. (2007) states that sulphate can impact uranium sorption depending on geochemical conditions. Analyzing the results from the sulphate extractions suggests that uranyl-sulphate complexes form under acidic conditions.

The sulphate extraction fluids produce the lowest concentrations of dissolved U for the HG extractions, contrary to the highest concentrations for the siltstone extractions (Figure 4.14 and Figure 4.12). The sulphate-siltstone extractions produce an acidic leachate as opposed to the alkaline leachate of the sulphate-HG extractions. A recent study of groundwater composition related to uranium content found that uranyl-sulphate complexes form in acidic conditions (pH < 6) (Kumar et al., 2014). My study shows similar results, as sulphate has the greatest impact on uranium liberation in an acidic solution (Figure 4.12).

Carbonate forms soluble complexes with uranium and plays a major role in U mobilization (Drage and Kennedy, 2013; MacFarlane, 1983). Carbonate is used in extraction fluids for the siltstone, MBG and HG extractions, but only leaches elevated levels of uranium when pH conditions are alkaline (Figure 4.12, Figure 4.13 and Figure 4.14). Carbonate leaches the highest concentrations of uranium for the MBG and HG extractions. MacFarlane (1983) states that Nova Scotia Granites have an influence on increasing the pH of groundwater which contributes to the elevated concentrations of dissolved U. Previous studies conclude that uranium-carbonate complexes are soluble under alkaline conditions as carbonate is a strong ligand (Figure 2.3) (Bachmaf et al., 2007; Kumar et al., 2014). The results from my study support this observation, as the carbonate extractions leached higher quantities of uranium under alkaline conditions.

5.2.2 Eh effect on U mobility

The analysis of the relationship between Eh and U mobility suggests that there is little correlation between the two in my study. Each extraction produces variable concentrations of dissolved U under different Eh conditions (Figure 4.15, Figure 4.16 and Figure 4.17). Kumar et al. (2014) states that oxidizing waters (Eh > 200mV) contain higher concentrations of uranium complexes. Every extraction conducted in my study produces oxidizing leachates with an Eh > 200, however there is no evidence that Eh variations measured contribute to the liberation of uranium (Table 4.7, Table 4.8 and Table 4.9). Figure 4.15, Figure 4.16 and Figure 4.17 illustrate that there is not a trend between Eh and dissolved U. Even though the slight variations in Eh did not drastically influence U mobility, the fact that the leachate is oxidizing in every case does have an influence U mobility. The general oxidizing nature of the leachate allowed uranyl complexes to form (UO_2^{2+}): uranyl-sulphate and uranyl-carbonate complexes are soluble in oxidizing environments (Kumar et al., 2014). Interpretations of the dissolved U results shows that an oxidizing environment alone is not enough to liberate uranium. The fact that the $NaHCO_3$ and $CaSO_4$ extractions have varying effects on U mobility even though they both produce oxidizing leachates is indicative that other factors such as pH are responsible for U mobility.

5.3 Natural vs Lab Grade Additives

The HG extractions include extraction fluids that are comprised of both natural and anthropogenic additives. The lab grade compounds have a greater influence on U mobility than the natural materials (Figure 5.1). This may be credited to the grain size variations between the lab grade and natural additives as well as compositional differences. There may be other constituents within the natural materials that have an influence on U mobility; for example, the gypsum used also has mud lenses present. It may be that sulphate strongly adsorbs to these clay particles, therefore does not form uranium-sulphate complexes. It is possible that synthetic sulphate additives may have a greater influence on U mobility as they do not contain other material that may impact sulphates sorption potential. The seashell extractions have a lesser influence on U mobility than other Ca^{2+} or CO_3^{2-} bearing compounds (CaCl2 · 2H2O and NaHCO3). As well the CaCl2 · 2H2O and NaHCO3 extractions both have a greater influence on U mobility than the seashells ($CaCO_3$). This may be credited to the variations in chemical formulas between the materials. To accurately state that natural occurring carbonate has a varying effect on U mobility than synthetic carbonate, one must conduct extractions using similar material (Seashells and lab grade calcium carbonate). Interpretations from the results suggest that seashells used (or limestone) may have a lesser influence on U mobility than other carbonate materials, but further investigation must be conducted to confirm this hypothesis.

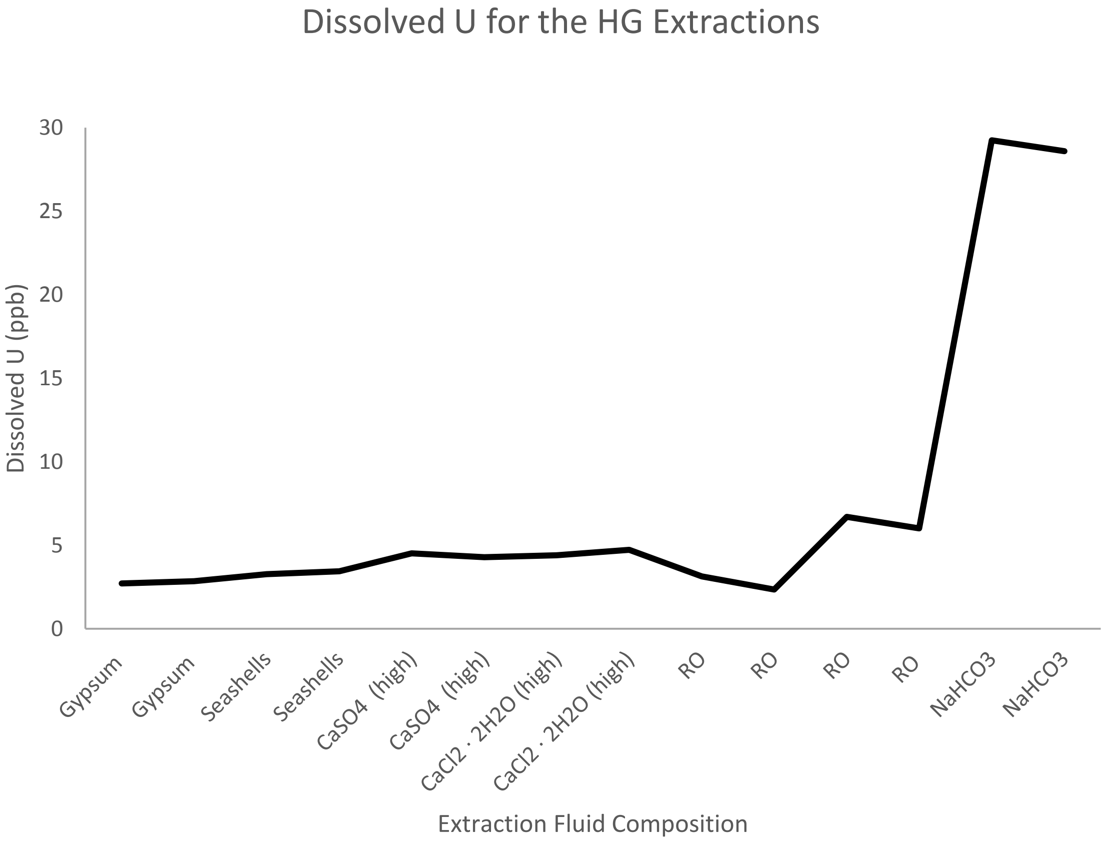

Figure 5.1. Variations in dissolved U for the HG extractions. The overall trend shows an increase in dissolved U from left to right. The natural materials (gypsum and seashells) produce the lowest concentrations of dissolved U. Two RO extractions are conducted producing four results as each extraction consists of duplicate samples. There are differences in dissolved U concentrations between the two RO extractions. It is possible that grain size variations or compositional differences between the crushed rocks used for the two extraction is causing this discrepancy.

5.4 Dissolved U and Other Metals

Preliminary assessment from this thesis suggests there is no direct correlation between U mobility and any other metal (Table 4.10, Table 4.11 and Table 4.12). It is worth noting that the scope of this study is to determine the geochemical influences that drive U mobility, therefore the materials and methods used are geared towards highlighting uranium mobility.

5.5 Variability Between Duplicate Extractions

Each extraction consists of duplicate samples, but some duplicates show variations in dissolved uranium concentrations. This is most evident with the MBG and HG extractions illustrated in Table 4.11 and Table 4.12. This is likely related to the spatial variations of uranium within the samples credited to both the abundance and weathering of biotite. The siltstone extractions show much stronger correlation between duplicate samples (Table 4.10) which may suggest that uranium is more uniformly distributed within the rock than the granites. The siltstone is also crushed to a more uniform grain size, therefore duplicate extractions are comprised of more identical crushed rock samples.

6.0 Conclusion and Future Recommendations

Groundwater systems are complex environments which are influenced by numerous geochemical factors. Nova Scotia has several geologic units that contain elevated levels of uranium. Uranium can be mobilized from rocks through geologic and weathering processes, or by the interaction with anthropogenic inputs. Carbonates form soluble complexes with uranium in oxidizing alkaline solutions. Sulphates can also form soluble complexes with uranium, but under oxidizing acidic conditions. Lithology and mineralogy play a crucial role in uranium liberation as well as pH and Eh conditions in this study. The Horton Group siltstone contain higher whole rock quantities of uranium than the MBG and HG samples yet they leach lower concentrations of uranium during the leaching procedure. Nova Scotia has had a history of uranium groundwater contamination which is believed to be the result of the local geology. MacFarlane (1983) and the Nova Scotia Uranium Task Force (1982) discuss that many regions within Nova Scotia have been subjected to groundwater uranium levels that surpassed Health Canada guidelines in the past. Many water wells still contain elevated uranium levels (Drage and Kennedy, 2013), but it is still unclear if anthropogenic inputs have increased the quantities of uranium within groundwater systems. My study has concluded that the differences in lithologic and mineralogic properties between the rock samples likely have a significant impact on U mobilization. The siltstone extractions suggest that uranium strongly adsorbs to organic particles within the rock, therefore the siltstone leaches low concentrations of uranium under the conditions of my experiments. The weatherability of biotite within the granites allows intruding extraction fluids to mobilize uranium from within cleavage planes, which may be why these extractions leach higher concentrations of uranium. It is important to note that my study includes a small sample size only focusing on three rock types. Future work should analyze a wider variety of geology with a focus on glacial till as MacFarlane (1983) credits high levels of dissolved U to glacial features such as drumlins. These drumlins can incorporate sulphates and carbonates from the Windsor Group. Glacial till in Southern Nova Scotia may contain organic material locally, which my study has shown can have an influence on U-mobility. Surficial geology consists of re-worked older geology, therefore the glacial features found throughout Nova Scotia can incorporate material derived from the SMB and Carboniferous sediments. It is important to consider the inputs these glacial features may have on groundwater systems and their impact on uranium mobility.

In conclusion, the results from my study confirm that uranium in Nova Scotia is mobilized in oxidizing environments and forms a variety of soluble complexes dependent on pH, Eh and regional geology.

7.0 References

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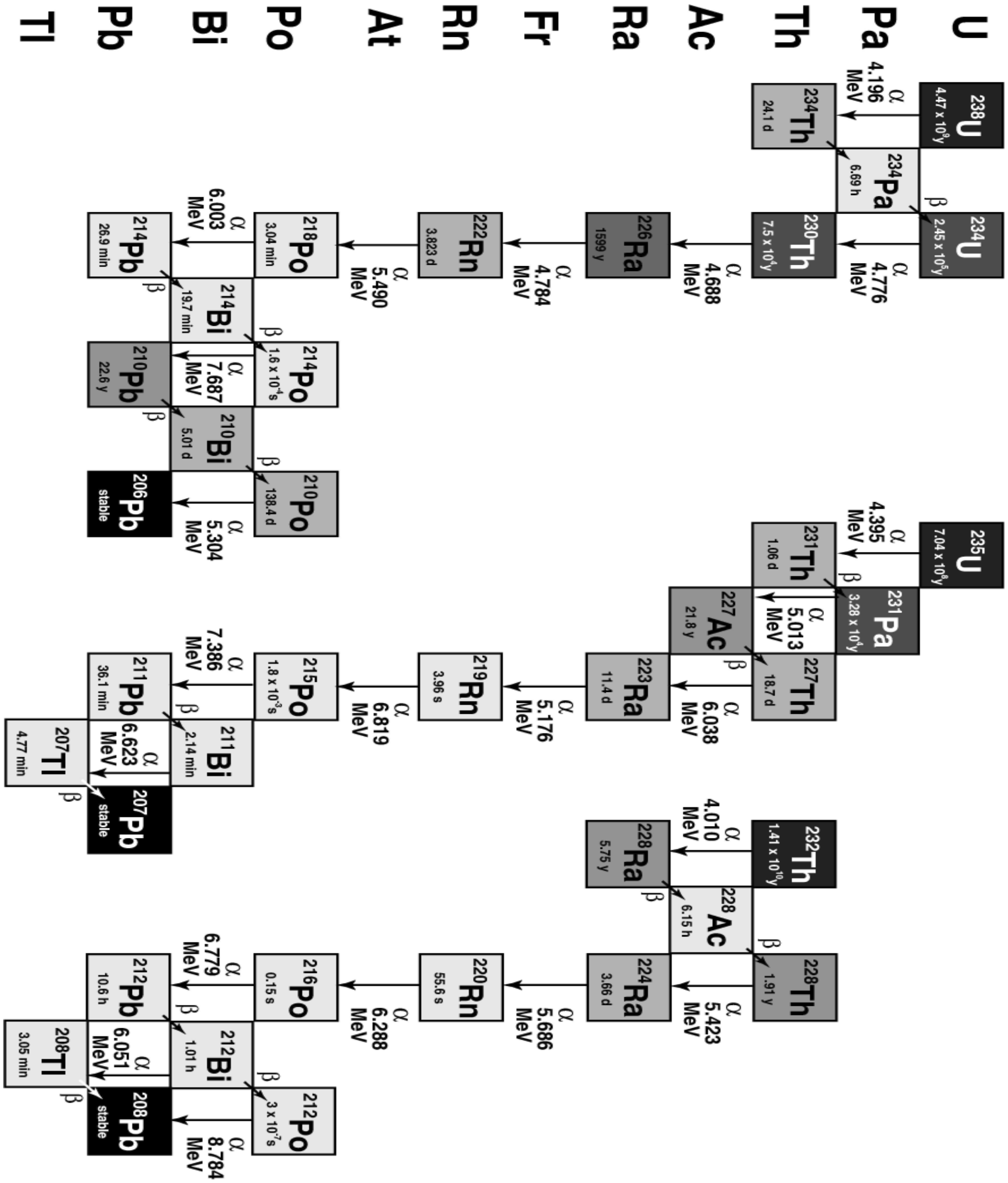
Appendices

Appendix A - Uranium Decay Chain



(From Bourdon et al., 2003)

Appendix B - Mass Calculations for Extraction Fluid Compounds

Extraction #	**Extraction Fluid Composition**	**Ion of Focus**	**Concentration of Ion of Focus (mg/L)**	**Molar Mass of Extraction Fluid Compound (g/mol)**	**Molar Mass of Ion of Focus (g/mol)**	**Mass of Extraction Fluid Compound (g)**
A1,A2,A3,A4	NaCl	Cl^-	500	58.4400	35.4530	3.3796
B5,B6,B7,B8	NaCl	Cl^-	500	58.4400	35.4530	3.3796
C1,C2,C3,C4	$NaHCO_3$	HCO_3^-	500	84.0060	61.0160	2.8224
D5,D6,D7,D7	$NaHCO_3$	HCO_3^-	500	84.0060	61.0160	2.8224
E1,E2,E3,E4	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	200	147.0160	40.0780	3.0080
F5,F6,F7,F8	RO	N/A	N/A	N/A	N/A	N/A
G1,G2,G3,G4	$CaSO_4$	SO_4^-	300	136.1400	96.0626	1.7432
H5,H6,H7H8	$CaSO_4$	SO_4^-	500	136.1400	96.0626	2.9053
I1,I2,I3,I4	$CaSO_4$	SO_4^-	500	136.1400	96.0626	2.9053
K5,K6,K7,K8	RO	N/A	N/A	N/A	N/A	N/A
L1,L2,L3,L4	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	500	147.0160	40.078	7.5225
M5,M6,M7M8	$CaCl_2 \cdot 2H_2O$	Ca^{2+}	500	147.0160	40.078	7.5225
N1,N2	Gypsum($CaSO_4 \cdot 2H_2O$)	SO_4^-	500	172.1710	96.063	3.6741
O3,O4	Seashells($CaCO_3$)	CO_3^{2-}	500	100.0870	60.010	3.4190
P5,P6	RO	N/A	N/A	N/A	N/A	N/A
R7,R8	$NaHCO_3$	HCO_3^-	500	84.0060	61.016	2.8224

Formulas Used to Calculate Mass of Extraction Fluid Compound

$$m\ (Ion\ of\ Focus) = \frac{Concentration\ of\ Ion\ of\ focus}{Volume\ of\ Extraction\ Fluid\ (1000mL)}$$

$$n\ \ (Ion\ of\ Focus) = \frac{m\ (Ion\ of\ Focus)}{M\ (Ion\ of\ Focus)}$$

$$mol\ of\ Ion\ of\ Focus = mol\ of\ Extraction\ Fluid\ Compound$$

$$m\ (extraction\ Fluid\ Compound) =\ n\ (Extraction\ Fluid\ Compound)\ X\ M\ (Extraction\ Fluid\ Compound)$$

$$m\ (4.1L\ solution) = m\ (Extraction\ Fluid\ Compound$$

(n=mol, m=mass, M=molar mass)

*All extraction fluids are prepared as 4.1L extraction fluids.

Appendix C - Calibration Methods

pH Calibration

The pH probes are calibrated prior to every set of measurements. The probe is calibrated using three buffer solutions with varying pHs. The three solutions had a pH of 4, 7 and 10. Approximately 20 mL of each Buffer solution was poured into a 50 mL beaker. The initial calibration step involves placing the pH electrode into the pH 4 buffer solution. The calibration is conducted by pressing the calibration button on the pH meter and adjusting the reading until the meter displays a pH reading of 4. The same calibration procedure is conducted for the other buffer solutions. The pH electrode is rinsed with RO between each calibration.

Eh Calibration

The Eh probes are calibrated prior to each set of measurements. The probe is calibrated using an oxidation-reduction (ORP) potential buffer solution. Approximately 20 mL of the buffer solution is poured into a 50 mL beaker. The ORP electrode is placed in the buffer solution and the calibrate button is pressed on the ORP meter. The Eh calibration is temperature dependent so the Eh reading is adjusted until it displays the correct Eh measurement for the appropriate solution temperature (424 mV at 20°C)

Appendix D - Alkalinity Values

Extraction #	**Extraction Fluid Composition**	**Rock Type**	**Extraction Fluid Volume (mL)**	**Initial Burette Volume (mL)**	**Initial pH**	**Final Burette Volume (mL)**	**Normality of H_2SO_4 Used**	**Volume of H_2SO_4 Used (mL)**	**Alkalinity**
A1,A2,A3,A4	NaCl	Siltstone	100	0	6.50	0.5	0.1	0.5	25.0
B5,B6,B7,B8	NaCl	Granite (MBG)	70	0.5	8.52	1.1	0.1	0.6	42.9
C1,C2,C3,C4	$NaHCO_3$	Siltstone	100	1) 2.0 2) 0	8.22	1) 25 2) 12.5	0.02	35.5	355.0
D5,D6,D7,D7	$NaHCO_3$	Granite (MBG)	100	1) 0 2) 11.0	8.22	1) 25 2) 22	0.02	36	360.0
E1,E2,E3,E4	$CaCl_2 \cdot 2H_2O$	Siltstone	71	12.7	4.91	12.8	0.1	0.2	14.1
F5,F6,F7,F8	RO	Siltstone	81	13.9	6.95	14.1	0.1	0.2	12.3
G1,G2,G3,G4	$CaSO_4$	Siltstone	99	9.7	6.04	9.9	0.1	0.2	10.1
H5,H6,H7H8	$CaSO_4$	Siltstone	99	9.9	6.84	10.1	0.1	0.2	10.1
I1,I2,I3,I4	$CaSO_4$	Granite (HF)	100	10	5.98	9.82	0.1	0.18	9.0
K5,K6,K7,K8	RO	Granite (HF)	100	9.82	7.01	9.61	0.1	0.21	10.5
L1,L2,L3,L4	$CaCl_2 \cdot 2H_2O$	Siltstone	100	1) 0 2) 10	5.63	1) 25 2) 12	0.02	27	270.0
M5,M6,M7 M8	$CaCl_2 \cdot 2H_2O$	Granite (HF)	100	1) 0 2) 10	5.52	1) 25 2) 16	0.02	29	290.0
N1,N2	Gypsum($CaSO_4 \cdot 2H_2O$)	Granite (HF)	100	1) 1 2) 10	5.31	1) 25 2) 14	0.02	28	280.0
O3,O4	Seashells($CaCO_3$)	Granite (HF)	100	1) 2 2) 9	5.64	1) 25 2) 18	0.02	32	220.0
P5,P6	RO	Granite (HF)	Not Measured	Not Measured	Not Measured	Not Measured	Not Measured	Not Measured	Not Measured
R7,R8	$NaHCO_3$	Granite (HF)	Not Measured	Not Measured	Not Measured	Not Measured	Not Measured	Not Measured	Not Measured

Equation 1 $$Alkalinity = \frac{\mathrm{A}\times\mathrm{N}\times 50000}{\text{Sample volume (ml)}}$$ (A=acid volume, N=normality of acid)

It is important to note that the normality of the acid used has an impact on the accuracy of alkalinity measurements. The 0.1 N H_2SO_4 is very strong and rapidly changes pH, therefore it is difficult to get an accurate measurement of the volume of acid required to achieve a pH of 4.6. The 0.02 N H_2SO_4 alkalinity tests require larger volumes of acid to achieve a pH of 4.6, therefore the burette is filled multiple times and is represented in the table by volumes 1 and 2.

Appendix E - Rock Results

Maxxam ID		BFH862		BFH863		BFH865			
Sampling Date		10/15/2015		10/15/2015		10/15/2015			
	UNITS	**TMP**	**RDL**	Siltstone	**RDL**	Granite (MBG)	**RDL**	**MDL**	**QC Batch**
Metals									
Total Aluminum (Al)	mg/kg	40000	10	98000	100	66000	10	N/A	4247978
Total Antimony (Sb)	mg/kg	ND	2.0	ND	2.0	ND	2.0	N/A	4247978
Total Arsenic (As)	mg/kg	ND	2.0	22	2.0	5.6	2.0	N/A	4247978
Total Barium (Ba)	mg/kg	120	5.0	190	5.0	590	5.0	N/A	4247978
Total Beryllium (Be)	mg/kg	ND	2.0	4.4	2.0	2.2	2.0	N/A	4247978
Total Cadmium (Cd)	mg/kg	ND	0.15	ND	0.15	0.23	0.15	N/A	4247978
Total Chromium (Cr)	mg/kg	4.8	2.0	37	2.0	25	2.0	N/A	4247978
Total Cobalt (Co)	mg/kg	1.9	1.0	2.3	1.0	7.1	1.0	N/A	4247978
Total Copper (Cu)	mg/kg	7.2	2.0	39	2.0	74	2.0	N/A	4247978
Total Iron (Fe)	mg/kg	5300	50	14000	50	26000	50	N/A	4247978
Total Lead (Pb)	mg/kg	33	0.50	25	0.50	37	0.50	N/A	4247978
Total Manganese (Mn)	mg/kg	680	2.0	120	2.0	500	2.0	N/A	4247978
Total Molybdenum (Mo)	mg/kg	ND	2.0	ND	2.0	ND	2.0	N/A	4247978
Total Nickel (Ni)	mg/kg	6.2	2.0	7.1	2.0	8.3	2.0	N/A	4247978
Total Selenium (Se)	mg/kg	ND	2.0	4.7	2.0	ND	2.0	N/A	4247978
Total Strontium (Sr)	mg/kg	26	5.0	76	5.0	120	5.0	N/A	4247978
Total Thallium (Tl)	mg/kg	0.30	0.10	1.2	0.10	0.98	0.10	N/A	4247978
Total Tin (Sn)	mg/kg	4.3	2.0	12	2.0	3.1	2.0	N/A	4247978
Total Uranium (U)	mg/kg	13	0.10	20	0.10	8.2	0.10	N/A	4247978
Total Vanadium (V)	mg/kg	15	2.0	78	2.0	41	2.0	N/A	4247978
Total Zinc (Zn)	mg/kg	ND	5.0	27	5.0	120	5.0	N/A	4247978

RDL = Reportable Detection Limit
QC Batch = Quality Control Batch
ND = Not Detected
N/A = Not Applicable

Appendix F - Extraction Measurements

Extraction #	Solution Composition	Mass of Solution Compound (g)	Rock Type	Rock Mass (g)	Extraction Fluid		Leachate	
					pH	Eh	pH	Eh
A1	NaCl	3.3769	Siltstone	N/A	6.38	293.9	8.25	300.8
A2	NaCl	3.3769	Siltstone	49.964	6.38	293.9	7.33	309.0
A3	NaCl	3.3769	Siltstone	50.048	6.38	293.9	7.45	307.9
A4	NaCl	3.3769	Siltstone	49.974	6.38	293.9	7.56	305.7
B5	NaCl	3.3795	Granite (MBG)	N/A	7.00	242.9	8.21	301.9
B6	NaCl	3.3795	Granite (MBG)	50.042	7.00	242.9	8.30	288.0
B7	NaCl	3.3795	Granite (MBG)	50.037	7.00	242.9	8.27	285.7
B8	NaCl	3.3795	Granite (MBG)	50.082	7.00	242.9	8.27	287.6
C1	$NaHCO_3$	2.8223	Siltstone	N/A	7.80	426.5	10.04	143.6
C2	$NaHCO_3$	2.8223	Siltstone	49.960	7.80	426.5	5.33	422.5
C3	$NaHCO_3$	2.8223	Siltstone	49.990	7.80	426.5	5.30	445.5
C4	$NaHCO_3$	2.8223	Siltstone	50.007	7.80	426.5	5.34	446.9
D5	$NaHCO_3$	2.8220	Granite (MBG)	N/A	8.02	382.0	10.04	121.0
D6	$NaHCO_3$	2.8220	Granite (MBG)	49.994	8.02	382.0	9.87	230.7
D7	$NaHCO_3$	2.8220	Granite (MBG)	50.012	8.02	382.0	9.78	255.7
D8	$NaHCO_3$	2.8220	Granite (MBG)	49.975	8.02	382.0	9.80	248.7
E1	$CaCl_2 \cdot 2H_2O$	3.0043	Siltstone	N/A	5.99	362.7	6.79	309.1
E2	$CaCl_2 \cdot 2H_2O$	3.0043	Siltstone	49.997	5.99	362.7	3.99	389.6
E3	$CaCl_2 \cdot 2H_2O$	3.0043	Siltstone	49.999	5.99	362.7	4.03	361.4
E4	$CaCl_2 \cdot 2H_2O$	3.0043	Siltstone	49.990	5.99	362.7	4.07	367.7
F5	RO	N/A	Siltstone	N/A	7.10	321.1	8.89	237.5
F6	RO	N/A	Siltstone	49.967	7.10	321.1	5.83	334.3
F7	RO	N/A	Siltstone	49.988	7.10	321.1	5.84	312.0
F8	RO	N/A	Siltstone	49.943	7.10	321.1	5.80	318.2
G1	$CaSO_4$	1.7420	Siltstone	N/A	5.90	313.7	6.58	322.2
G2	$CaSO_4$	1.7420	Siltstone	49.990	5.90	313.7	4.10	357.6
G3	$CaSO_4$	1.7420	Siltstone	50.008	5.90	313.7	4.13	320.8
G4	$CaSO_4$	1.7420	Siltstone	50.015	5.90	313.7	4.14	309.6
H5	$CaSO_4$	2.9040	Siltstone	N/A	6.51	313.7	7.13	270.6
H6	$CaSO_4$	2.9040	Siltstone	50.009	6.51	313.7	4.12	309.1
H7	$CaSO_4$	2.9040	Siltstone	50.014	6.51	313.7	4.09	324.6
H8	$CaSO_4$	2.9040	Siltstone	49.955	6.51	313.7	4.14	324.7
I1	$CaSO_4$	2.9066	Granite (HG)	N/A	5.54	310.3	5.45	348.3
I2	$CaSO_4$	2.9066	Granite (HG)	50.083	5.54	310.3	7.70	268.6
I3	$CaSO_4$	2.9066	Granite (HG)	50.079	5.54	310.3	7.98	261.5
I4	$CaSO_4$	2.9066	Granite (HG)	49.992	5.54	310.3	8.17	262.4
K5	RO	N/A	Granite (HG)	N/A	6.84	325.7	8.56	258.6
K6	RO	N/A	Granite (HG)	50.012	6.84	325.7	8.84	263.2
K7	RO	N/A	Granite (HG)	50.026	6.84	325.7	8.93	265.2
K8	RO	N/A	Granite (HG)	50.025	6.84	325.7	8.79	268.0
L1	$CaCl_2 \cdot 2H_2O$	7.5228	Siltstone	N/A	5.60	584.3	4.94	554.4
L2	$CaCl_2 \cdot 2H_2O$	7.5228	Siltstone	49.920	5.60	584.3	4.08	492.8
L3	$CaCl_2 \cdot 2H_2O$	7.5228	Siltstone	49.996	5.60	584.3	4.08	456.4
L4	$CaCl_2 \cdot 2H_2O$	7.5228	Siltstone	50.086	5.60	584.3	4.11	449.7
M5	$CaCl_2 \cdot 2H_2O$	7.5225	Granite (HG)	N/A	5.53	580.0	5.48	410.8
M6	$CaCl_2 \cdot 2H_2O$	7.5225	Granite (HG)	49.991	5.53	580.0	6.55	283.5
M7	$CaCl_2 \cdot 2H_2O$	7.5225	Granite (HG)	49.999	5.53	580.0	7.04	309.3
M8	$CaCl_2 \cdot 2H_2O$	7.5225	Granite (HG)	50.075	5.53	580.0	7.20	298.3
N1	Gypsum ($CaSO_4 \cdot 2H_2O$)	3.6770	Granite (HG)	49.973	5.32	365.2	7.92	267.1
N2	Gypsum ($CaSO_4 \cdot 2H_2O$)	3.6770	Granite (HG)	49.969	5.32	365.2	8.23	253.9
O3	Seashells ($CaCO_3$)	3.4178	Granite (HG)	49.975	5.63	344.7	8.88	262.6
O4	Seashells ($CaCO_3$)	3.4178	Granite (HG)	49.987	5.63	344.7	8.93	265.7
P5	RO	N/A	Granite (HG)	49.68	6.15	308.0	8.89	266.1
P6	RO	N/A	Granite (HG)	50.011	6.13	395.7	8.90	264.3
R7	$NaHCO_3$	0.6872	Granite (HG)	49.986	7.75	241.7	8.43	280.0
R8	$NaHCO_3$	0.6873	Granite (HG)	49.985	7.84	246.4	8.35	283.5

Appendix G - Dalhousie Water Lab Results (ICP/MS)

Run	Time	4.5Bkg	7Li	27Al	31P	45Sc	47Ti	51V	52Cr	55Mn	56Fe	59Co	60Ni	65Cu	66Zn	75As	77Ar Cl	82Se	107Ag	111Cd	115In	121Sb	137Ba	140Ce	159Tb	208Pb	220.5Bkg	238U
		ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
		OB A1 NaCl blank 12/7/2015 1:28:27 PM																										
1	13:28:27	0	0.234	11.48	38.78	0.92014	0.415	0.038	0.091	3.992	6.073	0.039	0.56	11.28	6.511	0.178	0	-0.051	0.482	0.01	0.88101	0.221	1.999	0.021	0.94343	0.754	0	0.003
2	13:29:04	0	0.241	11.7	33.22	0.94868	0.315	0.048	0.08	4.003	1.464	0.043	0.517	11.42	6.556	0.175	0	0.139	0.541	0.012	0.90945	0.207	2.015	0.021	0.97621	0.764	0	0.006
3	13:29:40	0	0.234	11.61	30.61	0.95669	0.36	0.042	0.056	4.013	-0.023	0.043	0.525	11.53	6.431	0.113	0	0.02	0.486	0.008	0.92142	0.171	2.012	0.022	0.97786	0.759	0	0.004
x		0	0.236	11.6	34.2	0.94183	0.363	0.043	0.076	4.003	2.504	0.042	0.534	11.41	6.499	0.155	0	0.036	0.503	0.01	0.90396	0.2	2.009	0.021	0.96583	0.759	0	0.004
s		0	0.004	0.111	4.174	0.01921	0.05	0.005	0.018	0.011	3.178	0.002	0.023	0.124	0.064	0.037	0	0.096	0.033	0.002	0.02076	0.026	0.008	0.001	0.01942	0.005	0	0.001
%RSD		0	1.88	0.96	12.2	2.04	13.85	11.85	23.84	0.265	126.9	5.617	4.292	1.084	0.978	23.77	0	267.4	6.604	23.84	2.296	13.01	0.412	3.697	2.011	0.617	0	26.26
		OB A2 NaCl Siltstone 12/7/2015 1:31:17 PM																										
1	13:31:17	0	1.104	83.68	34.52	0.96327	1.852	0.357	0.113	2.004	92.46	0.029	0.094	1.651	2.752	0.82	0	0.628	0.198	-0.005	0.91894	-0.001	2.057	0.154	0.97331	0.664	0	0.612
2	13:31:53	0	1.1	83.6	27.48	0.97989	1.934	0.364	0.094	2.034	89.59	0.027	0.101	1.649	2.799	0.87	0	0.432	0.244	-0.001	0.93621	0.013	2.097	0.159	0.98769	0.669	0	0.618
3	13:32:30	0	1.093	83.51	30.33	0.99103	2.092	0.351	0.098	1.998	87.33	0.028	0.087	1.66	2.694	0.826	0	0.517	0.224	-0.008	0.94097	0.02	2.069	0.156	0.99999	0.661	0	0.61
x		0	1.099	83.6	30.78	0.97806	1.959	0.358	0.102	2.012	89.79	0.028	0.094	1.653	2.749	0.839	0	0.525	0.222	-0.005	0.93204	0.011	2.074	0.157	0.98699	0.665	0	0.614
s		0	0.006	0.086	3.539	0.01397	0.122	0.006	0.01	0.02	2.571	0.001	0.007	0.006	0.053	0.027	0	0.098	0.023	0.003	0.01159	0.011	0.021	0.002	0.01335	0.004	0	0.004
%RSD		0	0.523	0.103	11.5	1.428	6.236	1.809	9.755	0.973	2.864	3.363	7.605	0.345	1.92	3.232	0	18.71	10.42	66.82	1.244	100.4	0.992	1.584	1.353	0.578	0	0.693
		OB A4 NaCl Siltstone 12/7/2015 1:34:07 PM																										
1	13:34:07	0	0.8	74.83	37.82	0.97343	1.317	0.27	0.166	1.861	65.79	0.026	0.119	1.064	6.428	0.603	0	0.337	0.152	-0.005	0.9205	-0.045	2.155	0.089	0.97756	0.442	0	0.452
2	13:34:43	0	0.79	75.9	27.86	0.9846	1.3	0.272	0.134	1.882	61.28	0.021	0.101	1.058	6.485	0.623	0	0.454	0.192	-0.005	0.94037	-0.038	2.227	0.08	0.99018	0.457	0	0.464
3	13:35:20	0	0.765	75.81	29.35	0.98874	1.241	0.277	0.13	1.885	60.8	0.023	0.124	1.112	6.545	0.59	0	0.299	0.179	-0.009	0.94345	-0.019	2.178	0.083	0.99546	0.455	0	0.463
x		0	0.785	75.51	31.68	0.98226	1.286	0.273	0.143	1.876	62.62	0.023	0.115	1.078	6.486	0.605	0	0.363	0.174	-0.006	0.93478	-0.034	2.187	0.084	0.98773	0.451	0	0.459
s		0	0.018	0.595	5.375	0.00792	0.04	0.004	0.02	0.013	2.753	0.003	0.012	0.029	0.058	0.017	0	0.081	0.02	0.002	0.01246	0.014	0.037	0.005	0.0092	0.008	0	0.007
%RSD		0	2.262	0.788	16.97	0.807	3.083	1.284	13.96	0.692	4.396	11.14	10.86	2.737	0.901	2.789	0	22.26	11.59	38.46	1.332	39.93	1.691	5.716	0.931	1.809	0	1.42
		OB B5 NaCl blank 12/7/2015 1:36:57 PM																										
1	13:36:57	0	0.188	5.033	34.43	0.97805	0.416	0.018	0.08	1.843	7.495	0.014	0.31	2.147	3.935	0	0	0.039	0.185	-0.005	0.92781	-0.068	0.876	0.008	0.97766	1.123	0	-0.003
2	13:37:33	0	0.189	5.184	30	1.00208	0.301	0.012	0.042	1.861	2.169	0.013	0.325	2.195	3.833	0	0	-0.012	0.209	-0.004	0.95203	-0.062	0.902	0.008	1.00595	1.139	0	-0.003
3	13:38:10	0	0.177	4.964	28.63	1.00678	0.408	0.014	0.039	1.855	0.457	0.015	0.323	2.179	3.872	-0.056	0	-0.177	0.209	-0.009	0.95548	-0.057	0.915	0.007	1.01237	1.122	0	-0.004
x		0	0.185	5.06	31.02	0.99564	0.375	0.015	0.054	1.853	3.373	0.014	0.32	2.174	3.88	-0.019	0	-0.05	0.201	-0.006	0.94511	-0.062	0.898	0.008	0.99866	1.128	0	-0.003
s		0	0.007	0.113	3.033	0.01541	0.064	0.003	0.022	0.009	3.67	0.001	0.008	0.024	0.052	0.032	0	0.113	0.014	0.002	0.01508	0.006	0.02	0	0.01847	0.009	0	0
%RSD		0	3.607	2.227	9.777	1.548	17.1	21.06	41.75	0.5	108.8	6.999	2.566	1.12	1.33	173.9	0	225.8	6.96	40.27	1.595	9.236	2.238	5.08	1.849	0.8	0	14.26
		OB B7 NaCl Granite from Millet Brook 12/7/2015 1:39:46 PM																										
1	13:39:46	0	2.411	28.38	33.63	0.99492	0.944	0.061	0.123	10.08	21.16	0.134	0.863	5.952	5.612	2.88	0	0.166	0.068	0.015	0.94252	-0.053	6.017	0.084	0.98747	0.288	0	4.184
2	13:40:23	0	2.33	28.67	30.94	1.01642	1.034	0.061	0.107	10.18	16.88	0.142	0.844	5.964	5.613	2.678	0	0.007	0.085	0.015	0.96035	-0.051	5.978	0.084	1.01032	0.291	0	4.213
3	13:40:59	0	2.392	28.95	28.28	1.01227	1.004	0.062	0.107	10.26	16.06	0.137	0.861	6.11	5.667	2.788	0	0.195	0.086	0.017	0.96476	-0.044	5.961	0.08	1.013	0.296	0	4.265
x		0	2.378	28.66	30.95	1.00787	0.994	0.061	0.112	10.17	18.03	0.138	0.856	6.009	5.631	2.782	0	0.122	0.08	0.015	0.95587	-0.049	5.985	0.083	1.00359	0.291	0	4.221
s		0	0.043	0.285	2.672	0.0114	0.046	0	0.009	0.09	2.738	0.004	0.01	0.088	0.031	0.101	0	0.101	0.01	0.001	0.01177	0.005	0.028	0.002	0.01403	0.004	0	0.041
%RSD		0	1.79	0.995	8.634	1.131	4.598	0.681	8.166	0.888	15.18	2.817	1.189	1.459	0.556	3.645	0	82.64	13.07	7.828	1.232	9.33	0.474	2.44	1.398	1.349	0	0.973
		OB B8 NaCl Granite from Millet Brook 12/7/2015 1:42:36 PM																										
1	13:42:36	0	3.443	31.12	36.41	1.00692	1.128	0.075	0.117	12.35	11.89	0.18	0.58	3.693	3.895	4.181	0	0.218	0.075	0.011	0.94678	-0.068	6.111	0.117	0.99656	0.263	0	6.124
2	13:43:12	0	3.419	31.77	30.35	1.02212	1.096	0.08	0.095	12.52	8.083	0.187	0.583	3.711	3.95	4.185	0	0.237	0.092	0.015	0.96588	-0.063	6.239	0.122	1.0129	0.261	0	6.19
3	13:43:49	0	3.436	31.55	33.51	1.0319	1.136	0.071	0.097	12.54	6.309	0.19	0.598	3.803	3.993	4.135	0	0.178	0.097	0.016	0.96571	-0.056	6.255	0.123	1.02347	0.261	0	6.19
x		0	3.433	31.48	33.42	1.02031	1.12	0.075	0.103	12.47	8.762	0.186	0.587	3.736	3.946	4.167	0	0.211	0.088	0.014	0.95946	-0.063	6.202	0.121	1.01098	0.262	0	6.168
s		0	0.012	0.328	3.028	0.01259	0.021	0.004	0.012	0.102	2.854	0.005	0.01	0.059	0.049	0.028	0	0.03	0.011	0.003	0.01098	0.006	0.079	0.003	0.01356	0.001	0	0.038
%RSD		0	0.352	1.042	9.059	1.234	1.897	5.616	11.83	0.819	32.58	2.725	1.624	1.573	1.241	0.664	0	14.15	12.79	19.66	1.144	9.65	1.272	2.584	1.341	0.549	0	0.619

Run	Time	4.5Bkg	7Li	27Al	31P	45Sc	47Ti	51V	52Cr	55Mn	56Fe	59Co	60Ni	65Cu	66Zn	75As	77Ar Cl	82Se	107Ag	111Cd	115In	121Sb	137Ba	140Ce	159Tb	208Pb	220.5Bkg	238U
		ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
		OB C1 NaHCO3 blank 12/7/2015 1:45:26 PM																										
1	13:45:26	0	0.284	11.15	38.03	1.05076	0.613	0.484	0.081	0.74	11	0.067	0.107	2.132	4.378	0.049	0	0.153	0.091	-0.005	0.96493	-0.09	0.835	0.021	1.0289	0.27	0	-0.006
2	13:46:02	0	0.272	11.24	35.33	1.10391	0.552	0.501	0.061	0.734	6.286	0.067	0.115	2.126	4.375	0.009	0	0.012	0.11	-0.005	1.01297	-0.078	0.852	0.019	1.0714	0.272	0	-0.006
3	13:46:39	0	0.278	11.13	34.82	1.11738	0.461	0.554	0.055	0.748	4.372	0.064	0.094	2.103	4.393	-0.065	0	-0.141	0.109	-0.004	1.01902	-0.078	0.864	0.021	1.08596	0.277	0	-0.006
x		0	0.278	11.17	36.06	1.09068	0.542	0.513	0.065	0.741	7.219	0.066	0.106	2.12	4.382	-0.002	0	0.008	0.103	-0.005	0.99897	-0.082	0.85	0.021	1.06209	0.273	0	-0.006
s		0	0.006	0.059	1.724	0.03522	0.076	0.036	0.014	0.007	3.411	0.002	0.01	0.015	0.01	0.058	0	0.147	0.011	0.001	0.02964	0.007	0.014	0.001	0.02964	0.004	0	0
%RSD		0	2.072	0.526	4.782	3.23	14.11	7.05	20.65	0.945	47.25	2.748	9.863	0.73	0.227	2432	0	1821	10.47	17.83	2.967	8.787	1.667	4.813	2.791	1.345	0	1.486
		OB C2 NaHCO3 siltstone 12/7/2015 1:48:15 PM																										
1	13:48:15	0	18.99	153.1	39.33	1.05667	0.915	0.779	0.14	124.3	817.2	2.025	3.161	5.834	11.65	0.184	0	0.306	0.628	0.079	0.97665	-0.076	87.67	0.188	1.03519	1.564	0	0.124
2	13:48:52	0	18.98	155.6	35.89	1.08798	0.928	0.872	0.138	124.8	810.9	2.016	3.086	5.893	11.49	0.241	0	0.218	0.654	0.084	1.00405	-0.075	88.48	0.193	1.06578	1.575	0	0.123
3	13:49:29	0	18.61	154.4	33.03	1.10567	0.791	1.005	0.134	124.7	806	2.022	3.146	5.851	11.6	0.172	0	0.201	0.676	0.075	1.01603	-0.066	88.45	0.184	1.07669	1.583	0	0.123
x		0	18.86	154.4	36.08	1.08344	0.878	0.885	0.138	124.6	811.4	2.021	3.131	5.86	11.58	0.199	0	0.242	0.653	0.079	0.99891	-0.072	88.2	0.188	1.05922	1.574	0	0.123
s		0	0.219	1.215	3.158	0.02481	0.076	0.114	0.003	0.286	5.636	0.004	0.04	0.03	0.082	0.037	0	0.056	0.024	0.004	0.02018	0.006	0.458	0.005	0.02151	0.01	0	0
%RSD		0	1.159	0.787	8.752	2.29	8.613	12.84	2.245	0.229	0.695	0.212	1.274	0.516	0.705	18.62	0	23.23	3.673	5.259	2.021	8.035	0.519	2.427	2.031	0.633	0	0.163
		OB C3 NaHCO3 Siltstone 12/7/2015 1:51:05 PM																										
1	13:51:05	0	21.36	156.6	24.4	1.07463	1.737	1.202	0.271	130.7	892.1	2.151	3.328	6.039	7.628	0.162	0	0.214	0.104	0.067	0.98385	-0.076	88.82	0.356	1.04485	0.613	0	0.123
2	13:51:41	0	20.96	157.1	23.16	1.11859	1.693	1.24	0.259	131.9	895	2.181	3.313	6.116	7.459	0.126	0	0.244	0.116	0.071	1.02172	-0.067	89.66	0.358	1.07839	0.62	0	0.123
3	13:52:18	0	21.08	157.2	20.35	1.11954	1.72	1.277	0.255	132.5	894.7	2.14	3.286	6.014	7.555	0.172	0	0.229	0.123	0.079	1.02866	-0.06	90.12	0.364	1.09409	0.621	0	0.124
x		0	21.13	156.9	22.64	1.10425	1.717	1.24	0.262	131.7	893.9	2.157	3.309	6.056	7.547	0.154	0	0.229	0.115	0.072	1.01141	-0.068	89.54	0.359	1.07244	0.618	0	0.123
s		0	0.205	0.327	2.076	0.02566	0.022	0.037	0.008	0.927	1.612	0.021	0.022	0.054	0.084	0.024	0	0.015	0.01	0.006	0.02412	0.008	0.659	0.004	0.02515	0.004	0	0
%RSD		0	0.969	0.208	9.17	2.324	1.275	3.008	3.233	0.704	0.18	0.989	0.652	0.884	1.119	15.71	0	6.593	8.422	7.951	2.385	11.96	0.736	1.124	2.345	0.671	0	0.374
		OB D5 NaHCO3 blank 12/7/2015 1:53:54 PM																										
1	13:53:54	0	0.497	9.064	76.61	1.08986	0.525	1.348	0.107	0.33	6.501	0.031	0.005	0.734	2.739	-0.057	0	0.101	47.32	-0.006	0.98928	-0.093	1.237	0.001	1.05089	0.847	0	0.009
2	13:54:31	0	0.503	9.094	71.71	1.12752	0.589	1.169	0.084	0.344	2.986	0.03	0.008	0.748	2.821	-0.12	0	-0.082	47.02	-0.005	1.02874	-0.083	1.243	0.002	1.08967	0.846	0	0.009
3	13:55:08	0	0.511	9.127	70.67	1.14158	0.605	1.094	0.081	0.337	0.786	0.032	0.02	0.742	2.787	-0.118	0	-0.223	47.34	-0.003	1.03397	-0.076	1.245	0.003	1.0994	0.845	0	0.008
x		0	0.504	9.095	73	1.11965	0.573	1.203	0.091	0.337	3.424	0.031	0.011	0.741	2.782	-0.098	0	-0.068	47.22	-0.005	1.01733	-0.084	1.242	0.002	1.07999	0.846	0	0.008
s		0	0.007	0.032	3.173	0.02674	0.042	0.131	0.014	0.007	2.883	0.001	0.008	0.007	0.041	0.036	0	0.162	0.178	0.001	0.02443	0.008	0.004	0.001	0.02566	0.001	0	0.001
%RSD		0	1.36	0.347	4.346	2.388	7.344	10.86	15.39	2.052	84.19	2.366	73.17	0.978	1.48	36.52	0	238.1	0.378	29.9	2.402	9.822	0.349	39.59	2.376	0.156	0	9.313
		OB D7 NaHCO3 Granite from Millet Brook 12/7/2015 2:02:20 PM																										
1	14:02:20	0	23.37	950.7	50.69	1.08419	7.755	4.534	0.268	2.534	96.49	0.081	0.322	1.611	3.481	21.1	0	0.93	0.178	0.016	0.99066	0.399	9.795	0.085	1.06096	0.248	0	6.829
2	14:02:57	0	23.53	965.1	44.67	1.12286	7.805	4.564	0.264	2.562	91.98	0.077	0.29	1.62	3.534	21.09	0	0.54	0.203	0.016	1.02667	0.349	10.09	0.082	1.09083	0.253	0	7.015
3	14:03:34	0	23.42	968.9	41.6	1.13332	7.806	4.581	0.247	2.574	90.77	0.07	0.293	1.559	3.494	20.96	0	0.662	0.166	0.011	1.03641	0.302	10.12	0.074	1.10444	0.247	0	6.984
x		0	23.44	961.6	45.65	1.11346	7.789	4.56	0.26	2.557	93.08	0.076	0.302	1.597	3.503	21.05	0	0.711	0.182	0.015	1.01791	0.35	10	0.08	1.08541	0.249	0	6.943
s		0	0.082	9.595	4.62	0.02588	0.029	0.023	0.011	0.021	3.015	0.005	0.018	0.033	0.028	0.078	0	0.199	0.019	0.003	0.0241	0.048	0.18	0.006	0.02224	0.003	0	0.1
%RSD		0	0.349	0.998	10.12	2.324	0.372	0.514	4.353	0.811	3.239	6.885	5.85	2.067	0.795	0.373	0	28.05	10.24	19.91	2.368	13.84	1.797	7.06	2.049	1.266	0	1.435
		OB D8 NaHCO3 Granite from Millet Brook 12/7/2015 2:05:10 PM																										
1	14:05:10	0	25.05	1022	37.4	1.10963	9.927	5.039	0.272	2.943	121.6	0.071	0.281	1.584	2.721	21.47	0	0.726	0.062	-0.003	1.01753	0.141	12.56	0.061	1.08171	0.229	0	7.968
2	14:05:47	0	24.92	1027	36.4	1.14629	10.06	5.003	0.266	2.957	118	0.07	0.269	1.616	2.737	21.33	0	0.577	0.074	-0.003	1.04565	0.142	12.6	0.063	1.11869	0.235	0	8.017
3	14:06:24	0	24.58	1020	33.2	1.16051	10.34	4.975	0.243	2.975	114.4	0.067	0.263	1.593	2.761	21.38	0	0.829	0.071	-0.002	1.05582	0.156	12.7	0.064	1.12388	0.243	0	8.091
x		0	24.85	1023	35.67	1.13881	10.11	5.005	0.26	2.958	118	0.069	0.271	1.598	2.74	21.39	0	0.711	0.069	-0.003	1.03967	0.146	12.62	0.063	1.10809	0.236	0	8.025
s		0	0.244	3.447	2.195	0.02625	0.21	0.032	0.015	0.016	3.642	0.002	0.009	0.016	0.021	0.069	0	0.127	0.007	0.001	0.01983	0.008	0.071	0.002	0.023	0.007	0	0.062
%RSD		0	0.981	0.337	6.153	2.305	2.081	0.647	5.678	0.537	3.086	2.48	3.358	1.03	0.749	0.324	0	17.84	9.464	22.04	1.908	5.734	0.562	3.019	2.075	2.896	0	0.768

Run	Time	4.5Bkg	7Li	27Al	31P	45Sc	47Ti	51V	52Cr	55Mn	56Fe	59Co	60Ni	65Cu	66Zn	75As	77Ar Cl	82Se	107Ag	111Cd	115In	121Sb	137Ba	140Ce	159Tb	208Pb	220.5Bkg	238U
		ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
		OB E1 CaCl2 2H2O blank 12/7/2015 2:08:00 PM																										
1	14:08:00	0	0.188	10.06	40.09	137.02%	0.532	0.462	0.117	0.453	36.57	0.13	1.976	3.628	4.161	-0.028	0	-0.135	0.408	0.035	124.36%	-0.073	2.9	0.007	124.74%	1.067	0	0.01
2	14:08:37	0	0.195	10.16	35.9	140.02%	0.476	0.448	0.092	0.459	32.39	0.12	1.844	3.666	4.162	-0.038	0	-0.076	0.423	0.029	127.62%	-0.066	2.909	0.008	127.47%	1.068	0	0.009
3	14:09:14	0	0.19	10.03	33.46	140.69%	0.434	0.444	0.088	0.452	28.74	0.124	1.842	3.663	4.14	-0.012	0	-0.008	0.436	0.032	127.32%	-0.065	2.956	0.01	128.24%	1.064	0	0.01
x		0	0.191	10.08	36.48	139.24%	0.481	0.451	0.099	0.455	32.57	0.125	1.888	3.652	4.154	-0.026	0	-0.073	0.422	0.032	126.43%	-0.068	2.922	0.009	126.82%	1.066	0	0.01
s		0	0.003	0.065	3.351	1.96%	0.049	0.009	0.016	0.004	3.915	0.005	0.077	0.021	0.013	0.013	0	0.064	0.014	0.003	1.80%	0.005	0.03	0.002	1.84%	0.002	0	0
%RSD		0	1.684	0.64	9.185	140.40%	10.21	2.104	15.97	0.778	12.02	4.01	4.067	0.575	0.305	49.92	0	86.83	3.341	8.859	142.60%	6.682	1.037	20.17	145.30%	0.174	0	4.94
		OB E3 CaCl2 2H2O siltsone 12/7/2015 2:10:50 PM																										
1	14:10:50	0	26.18	2548	36.83	122.17%	1.451	0.612	0.443	269.7	3835	4.609	8.775	23.3	15.83	0.308	0	0.11	0.146	0.158	114.63%	-0.084	199.8	1.711	116.88%	4.476	0	0.935
2	14:11:27	0	26.2	2593	29.41	123.15%	1.443	0.558	0.396	275.3	3911	4.706	8.722	23.81	15.99	0.353	0	0.256	0.153	0.152	116.41%	-0.076	203.4	1.732	118.71%	4.494	0	0.952
3	14:12:04	0	26.21	2582	33.5	122.33%	1.483	0.524	0.395	276.6	3924	4.657	8.713	23.68	16.01	0.365	0	0.132	0.157	0.15	117.18%	-0.07	203.3	1.745	119.37%	4.505	0	0.945
x		0	26.2	2575	33.25	122.55%	1.459	0.565	0.411	273.9	3890	4.657	8.737	23.6	15.94	0.342	0	0.166	0.152	0.154	116.07%	-0.076	202.2	1.729	118.32%	4.491	0	0.944
s		0	0.015	23.45	3.715	0.53%	0.021	0.044	0.027	3.645	48.03	0.048	0.034	0.265	0.098	0.03	0	0.078	0.006	0.004	1.31%	0.007	2.021	0.017	1.29%	0.015	0	0.009
%RSD		0	0.058	0.911	11.17	42.80%	1.464	7.855	6.631	1.331	1.235	1.033	0.385	1.122	0.615	8.764	0	47.3	3.922	2.884	112.60%	9.342	1	0.992	109.10%	0.325	0	0.929
		OB E4 CaCl2 2H2O siltstone 12/7/2015 2:13:41 PM																										
1	14:13:41	0	25.52	2580	29.85	119.84%	1.389	0.531	0.435	273.8	4182	4.679	8.795	18.15	13.6	0.421	0	0.193	0.06	0.153	114.03%	-0.088	200	1.631	116.73%	4.214	0	0.931
2	14:14:18	0	25.42	2594	25.89	122.45%	1.406	0.499	0.393	275.9	4216	4.684	8.781	18.23	13.64	0.354	0	0.172	0.075	0.162	116.96%	-0.084	203.3	1.645	118.88%	4.3	0	0.956
3	14:14:54	0	25.27	2598	24.2	122.47%	1.331	0.478	0.394	277.2	4221	4.659	8.545	18.26	13.64	0.399	0	0.236	0.08	0.166	116.41%	-0.082	204.6	1.641	119.12%	4.283	0	0.958
x		0	25.4	2591	26.65	121.59%	1.375	0.502	0.408	275.6	4206	4.674	8.707	18.21	13.63	0.391	0	0.201	0.072	0.16	115.80%	-0.085	202.7	1.639	118.24%	4.266	0	0.949
s		0	0.127	9.287	2.902	1.51%	0.04	0.027	0.024	1.721	21.44	0.013	0.141	0.055	0.022	0.034	0	0.033	0.011	0.007	1.56%	0.003	2.345	0.007	1.32%	0.046	0	0.015
%RSD		0	0.499	0.358	10.89	124.50%	2.881	5.336	5.878	0.624	0.51	0.285	1.616	0.3	0.162	8.787	0	16.35	14.95	4.254	134.40%	3.663	1.157	0.433	111.40%	1.074	0	1.585
		OB F5 RO blank 12/7/2015 2:16:31 PM																										
1	14:16:31	0	0.139	6.168	39.85	113.32%	0.336	0.229	0.117	0.653	12.65	0.014	0.138	0.936	2.767	-0.042	0	0.079	0.299	-0.007	113.61%	-0.101	0.441	0.086	112.96%	0.192	0	-0.008
2	14:17:08	0	0.129	6.304	34.57	115.71%	0.282	0.214	0.08	0.684	6.898	0.016	0.134	0.927	2.756	-0.053	0	-0.104	0.32	-0.005	115.93%	-0.099	0.447	0.089	116.13%	0.193	0	-0.007
3	14:17:45	0	0.138	6.141	33.98	116.46%	0.311	0.197	0.07	0.674	5.312	0.013	0.129	0.955	2.772	0	0	0.195	0.314	-0.007	115.75%	-0.092	0.443	0.09	115.36%	0.198	0	-0.008
x		0	0.135	6.205	36.13	115.16%	0.31	0.213	0.089	0.67	8.286	0.014	0.134	0.94	2.765	-0.031	0	0.057	0.311	-0.007	115.10%	-0.097	0.444	0.089	114.82%	0.195	0	-0.007
s		0	0.005	0.087	3.235	1.64%	0.027	0.016	0.025	0.016	3.86	0.001	0.004	0.014	0.008	0.028	0	0.151	0.01	0.001	1.29%	0.005	0.003	0.002	1.65%	0.003	0	0
%RSD		0	3.965	1.407	8.954	142.30%	8.688	7.491	28.08	2.317	46.58	9.348	3.214	1.51	0.299	89.8	0	266.9	3.359	16.69	112.20%	5.016	0.737	2.414	143.60%	1.7	0	4.352
		OB F6 RO siltstone 12/7/2015 2:19:21 PM																										
1	14:19:21	0	4.365	52.08	26.89	106.63%	2.163	0.432	0.185	2.407	81.47	0.075	0.351	1.62	2.578	0.511	0	0.474	0.018	-0.009	107.03%	-0.042	1.198	0.11	108.29%	0.346	0	0.195
2	14:19:58	0	4.327	51.98	24.19	109.32%	2.196	0.458	0.162	2.419	74.73	0.075	0.382	1.667	2.525	0.595	0	0.613	0.031	-0.006	109.84%	-0.045	1.194	0.116	110.25%	0.355	0	0.198
3	14:20:34	0	4.308	52.29	19.82	109.07%	2.072	0.467	0.16	2.42	72.55	0.074	0.372	1.683	2.579	0.614	0	0.644	0.03	-0.007	109.81%	-0.034	1.187	0.115	110.25%	0.354	0	0.199
x		0	4.333	52.11	23.64	108.34%	2.144	0.452	0.169	2.415	76.25	0.075	0.368	1.656	2.561	0.573	0	0.577	0.026	-0.007	108.90%	-0.04	1.193	0.113	109.59%	0.352	0	0.197
s		0	0.029	0.16	3.568	1.49%	0.065	0.018	0.014	0.007	4.651	0	0.016	0.033	0.031	0.055	0	0.09	0.007	0.002	1.61%	0.006	0.005	0.003	1.13%	0.005	0	0.002
%RSD		0	0.669	0.307	15.1	137.30%	3.015	3.96	8.15	0.307	6.099	0.504	4.239	1.974	1.219	9.533	0	15.67	27.04	21.46	148.00%	14.66	0.454	3.004	103.40%	1.305	0	0.965
		OB F7 RO siltstone 12/7/2015 2:22:11 PM																										
1	14:22:11	0	8.983	90.84	32.6	106.76%	3.906	0.485	0.332	3.608	88.6	0.112	0.234	1.704	3.04	0.725	0	0.656	0.035	-0.004	107.27%	-0.029	1.583	0.15	107.59%	0.609	0	0.23
2	14:22:47	0	9.003	92.29	25.42	109.11%	3.786	0.498	0.323	3.728	83.37	0.119	0.25	1.698	3.058	0.667	0	0.621	0.038	-0.004	110.27%	-0.019	1.637	0.167	110.41%	0.613	0	0.235
3	14:23:24	0	9.025	92.57	25.82	109.47%	3.956	0.487	0.316	3.708	83.34	0.118	0.235	1.72	3.02	0.687	0	0.611	0.036	-0.003	110.48%	-0.02	1.639	0.161	110.91%	0.612	0	0.234
x		0	9.004	91.9	27.94	108.45%	3.883	0.49	0.324	3.681	85.11	0.116	0.239	1.707	3.039	0.693	0	0.629	0.037	-0.004	109.34%	-0.023	1.62	0.159	109.64%	0.611	0	0.233
s		0	0.021	0.924	4.037	1.47%	0.087	0.007	0.008	0.064	3.028	0.004	0.009	0.011	0.019	0.029	0	0.024	0.002	0.001	1.79%	0.006	0.032	0.009	1.79%	0.002	0	0.002
%RSD		0	0.235	1.006	14.45	135.90%	2.244	1.443	2.369	1.749	3.558	3.223	3.664	0.649	0.63	4.24	0	3.752	4.964	15.1	164.00%	26.25	1.979	5.363	163.30%	0.37	0	1.056

Run	Time	4.5Bkg	7Li	27Al	31P	45Sc	47Ti	51V	52Cr	55Mn	56Fe	59Co	60Ni	65Cu	66Zn	75As	77Ar Cl	82Se	107Ag	111Cd	115In	121Sb	137Ba	140Ce	159Tb	208Pb	220.5Bkg	238U
		ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
		OB G1 CaSO4 (low) blank 12/7/2015 2:25:01 PM																										
1	14:25:01	0	0.23	19.91	32.64	1.14862	0.413	0.063	0.093	0.599	33.88	0.085	1.195	5.031	3.199	-0.018	0	0.042	17.9	0.001	1.11414	-0.1	2.01	0.206	1.12592	0.622	0	0.016
2	14:25:38	0	0.28	20.38	32.32	1.20036	0.438	0.057	0.078	0.615	29.34	0.078	1.13	5.124	3.291	-0.01	0	0.042	17.96	-0.001	1.15977	-0.096	2.068	0.215	1.17046	0.633	0	0.017
3	14:26:14	0	0.302	20.35	28.17	1.22274	0.431	0.05	0.064	0.612	27.44	0.076	1.166	5.039	3.277	-0.049	0	-0.091	17.97	-0.004	1.18304	-0.096	2.051	0.219	1.18559	0.631	0	0.016
x		0	0.271	20.21	31.05	1.19058	0.427	0.057	0.078	0.608	30.22	0.08	1.164	5.065	3.256	-0.026	0	-0.002	17.95	-0.001	1.15232	-0.097	2.043	0.213	1.16065	0.629	0	0.016
s		0	0.037	0.267	2.495	0.03802	0.013	0.006	0.015	0.008	3.311	0.005	0.033	0.052	0.049	0.02	0	0.076	0.036	0.003	0.03505	0.002	0.03	0.006	0.03102	0.006	0	0.001
%RSD		0	13.75	1.319	8.038	3.193	2.998	11	18.64	1.377	10.95	6.206	2.796	1.026	1.512	78.76	0	3145	0.203	214.5	3.042	2.068	1.472	2.987	2.672	0.963	0	3.541
		OB G3 CaSO4 (low) siltstone 12/7/2015 2:27:51 PM																										
1	14:27:51	0	24.64	2048	30.74	1.13254	1.159	0.134	0.476	273.4	2879	4.71	7.705	13.11	12.24	0.659	0	0.193	0.097	0.124	1.09639	-0.075	154.4	2.14	1.12741	3.207	0	1.688
2	14:28:28	0	24.76	2075	24.28	1.14709	1.143	0.133	0.475	279.8	2923	4.778	7.618	13.34	12.44	0.704	0	0.406	0.1	0.126	1.12444	-0.074	156.4	2.182	1.15782	3.259	0	1.726
3	14:29:04	0	24.58	2076	25.23	1.15058	1.171	0.136	0.464	279.2	2918	4.761	7.689	13.24	12.24	0.707	0	0.346	0.103	0.13	1.1247	-0.067	157.3	2.178	1.15991	3.288	0	1.749
x		0	24.66	2066	26.75	1.1434	1.158	0.135	0.471	277.4	2907	4.749	7.67	13.23	12.31	0.69	0	0.315	0.1	0.127	1.11517	-0.072	156	2.167	1.14838	3.251	0	1.721
s		0	0.094	15.89	3.486	0.00957	0.014	0.002	0.007	3.529	23.94	0.035	0.046	0.116	0.12	0.026	0	0.11	0.003	0.003	0.01627	0.004	1.504	0.023	0.01819	0.041	0	0.031
%RSD		0	0.38	0.769	13.03	0.837	1.226	1.288	1.432	1.272	0.824	0.747	0.605	0.878	0.978	3.833	0	34.95	3.234	2.575	1.459	5.708	0.964	1.064	1.584	1.274	0	1.796
		OB G4 CaSO4 (low) siltsone 12/7/2015 2:39:05 PM																										
1	14:39:05	0	24.21	2093	33.86	1.0989	1.107	0.124	0.559	283.8	3174	4.944	7.809	11.99	10.94	0.834	0	0.707	0.124	0.132	1.07515	0.188	144.4	2.239	1.11698	3.319	0	1.731
2	14:39:41	0	24.38	2122	25.77	1.1307	1.125	0.116	0.545	291.1	3247	4.994	7.933	12.21	11.11	0.735	0	0.438	0.132	0.123	1.10849	0.15	147.7	2.305	1.15239	3.385	0	1.763
3	14:40:18	0	24.53	2122	25.53	1.14187	1.225	0.116	0.512	290.2	3211	4.885	7.683	12	11.09	0.664	0	0.278	0.128	0.12	1.11677	0.119	148.3	2.294	1.16521	3.372	0	1.787
x		0	24.37	2113	28.39	1.12382	1.152	0.119	0.539	288.4	3211	4.941	7.808	12.07	11.05	0.744	0	0.474	0.128	0.125	1.10014	0.152	146.8	2.279	1.14486	3.358	0	1.76
s		0	0.161	16.78	4.74	0.02229	0.063	0.005	0.024	3.976	36.27	0.055	0.125	0.121	0.097	0.086	0	0.217	0.004	0.006	0.02203	0.035	2.114	0.035	0.02498	0.035	0	0.029
%RSD		0	0.66	0.794	16.7	1.984	5.502	3.923	4.51	1.379	1.13	1.106	1.601	1.003	0.88	11.5	0	45.71	3.341	4.755	2.003	22.75	1.44	1.544	2.182	1.044	0	1.619
		OB H5 CaSO4 (high) blank 12/7/2015 2:41:55 PM																										
1	14:41:55	0	0.574	48.71	31.05	1.23287	0.318	0.023	0.278	0.633	33.87	0.099	1.875	1.281	7.839	-0.059	0	-0.016	0.258	0	1.18152	-0.061	1.289	0.121	1.20242	0.242	0	-0.007
2	14:42:32	0	0.63	49.5	27.97	1.28802	0.345	0.019	0.272	0.67	28.35	0.097	1.759	1.331	7.726	0.014	0	0.044	0.261	0.003	1.23189	-0.047	1.273	0.122	1.25433	0.246	0	-0.007
3	14:43:09	0	0.607	49.43	25.97	1.31238	0.335	0.02	0.258	0.667	26.14	0.088	1.759	1.265	7.784	0.015	0	0.083	0.267	0	1.25613	-0.045	1.304	0.122	1.28223	0.243	0	-0.007
x		0	0.604	49.22	28.33	1.27776	0.333	0.021	0.269	0.656	29.46	0.095	1.797	1.293	7.783	-0.01	0	0.037	0.262	0.001	1.22318	-0.051	1.289	0.122	1.24633	0.244	0	-0.007
s		0	0.028	0.435	2.56	0.04074	0.014	0.002	0.011	0.021	3.983	0.006	0.067	0.035	0.056	0.042	0	0.049	0.004	0.001	0.03806	0.009	0.015	0	0.0405	0.002	0	0
%RSD		0	4.662	0.883	9.035	3.188	4.057	10.98	3.907	3.143	13.52	6.292	3.717	2.68	0.724	408.2	0	133.9	1.684	129.9	3.112	16.82	1.191	0.176	3.25	0.966	0	1.255
		OB H6 CaSO4 (high) siltstone 12/7/2015 2:44:45 PM																										
1	14:44:45	0	23.06	3036	33.88	1.23612	1.119	0.1	0.598	285	3146	4.675	8.102	10.38	12.99	0.703	0	0.361	5.23	0.124	1.19183	-0.044	125.5	3.833	1.22529	4.205	0	2.349
2	14:45:22	0	23.3	3090	26.7	1.25057	1.138	0.104	0.61	290.4	3206	4.746	7.864	10.49	12.88	0.662	0	0.438	5.286	0.126	1.22196	-0.04	126.8	3.915	1.25717	4.333	0	2.404
3	14:45:58	0	23.2	3081	24.98	1.25522	1.109	0.102	0.598	289.8	3186	4.676	7.857	10.44	12.98	0.698	0	0.537	5.206	0.122	1.22288	-0.035	126.8	3.924	1.2577	4.322	0	2.436
x		0	23.19	3069	28.52	1.2473	1.122	0.102	0.602	288.4	3179	4.699	7.941	10.44	12.95	0.688	0	0.445	5.241	0.124	1.21222	-0.04	126.3	3.891	1.24672	4.287	0	2.396
s		0	0.118	28.76	4.723	0.00996	0.015	0.002	0.007	2.956	30.68	0.041	0.139	0.052	0.065	0.023	0	0.088	0.041	0.002	0.01767	0.004	0.75	0.05	0.01856	0.071	0	0.044
%RSD		0	0.51	0.937	16.56	0.799	1.325	2.226	1.155	1.025	0.965	0.863	1.755	0.495	0.503	3.301	0	19.81	0.784	1.514	1.457	11.32	0.594	1.283	1.489	1.655	0	1.842
		OB H7 CaSO4 (high) siltstone 12/7/2015 2:47:35 PM																										
1	14:47:35	0	22.74	3020	31.01	1.23454	1.033	0.097	0.641	300.9	3302	4.865	7.754	10.02	10.5	0.647	0	0.362	0.148	0.134	1.20657	-0.065	135.8	3.542	1.24627	5.157	0	2.439
2	14:48:12	0	22.74	3066	25.03	1.25981	1.169	0.094	0.632	307.2	3350	4.901	7.804	10.1	10.54	0.718	0	0.544	0.159	0.149	1.23489	-0.052	137.4	3.632	1.28504	5.227	0	2.464
3	14:48:49	0	22.74	3072	23.06	1.25103	1.103	0.094	0.621	310.3	3361	4.874	7.813	10.02	10.5	0.699	0	0.584	0.158	0.14	1.23651	-0.055	137.4	3.615	1.27816	5.273	0	2.504
x		0	22.74	3053	26.37	1.24846	1.102	0.095	0.631	306.1	3338	4.88	7.79	10.05	10.51	0.688	0	0.497	0.155	0.141	1.22599	-0.057	136.9	3.596	1.26983	5.219	0	2.469
s		0	0.001	28.55	4.138	0.01283	0.068	0.002	0.01	4.762	31.42	0.019	0.032	0.046	0.025	0.037	0	0.118	0.006	0.008	0.01684	0.007	0.954	0.048	0.02069	0.059	0	0.033
%RSD		0	0.006	0.935	15.69	1.028	6.194	1.953	1.63	1.556	0.942	0.389	0.411	0.461	0.233	5.343	0	23.79	3.913	5.485	1.374	11.5	0.697	1.332	1.629	1.121	0	1.325

Run	Time	4.5Bkg	23Na	39K	44Ca	45Sc	115In	159Tb	220.5Bkg
		ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
		OB A1 1000x 11/26/2015 5:26:48 PM							
1	17:26:48	0	218500	3899	4194	1.00188	1.01115	1.01372	0
2	17:27:02	0	203500	2443	3575	1.03544	1.03781	1.042	0
3	17:27:14	0	200200	976.8	2663	1.05921	1.05934	1.06706	0
x		0	207400	2440	3477	1.03218	1.0361	1.04093	0
s		0	9709	1461	770.5	0.02881	0.02414	0.02669	0
%RSD		0	4.681	59.89	22.16	2.791	2.33	2.564	0
		OB A2 1000x 11/26/2015 5:28:24 PM							
1	17:28:24	0	228200	23730	6026	1.00874	1.00301	1.01775	0
2	17:28:37	0	211400	20560	4925	1.04598	1.04707	1.05047	0
3	17:28:50	0	209300	19260	4573	1.06537	1.07293	1.07743	0
x		0	216300	21180	5175	1.04003	1.041	1.04855	0
s		0	10350	2300	758.1	0.02878	0.03535	0.02989	0
%RSD		0	4.788	10.85	14.65	2.767	3.396	2.851	0
		OB A4 1000x 11/26/2015 5:30:00 PM							
1	17:30:00	0	203500	8307	3042	1.00051	1.00904	1.021	0
2	17:30:13	0	189200	5873	1892	1.04935	1.04448	1.04329	0
3	17:30:26	0	186400	4815	789.6	1.07455	1.08301	1.0851	0
x		0	193000	6332	1908	1.04147	1.04551	1.0498	0
s		0	9140	1790	1126	0.03764	0.03699	0.03254	0
%RSD		0	4.735	28.27	59.04	3.614	3.538	3.1	0
		OB B5 1000x 11/26/2015 5:31:36 PM							
1	17:31:36	0	189100	5040	3791	0.99952	0.99915	1.00872	0
2	17:31:49	0	172700	2871	2801	1.04657	1.04178	1.04575	0
3	17:32:02	0	171400	1568	1961	1.08275	1.08085	1.07954	0
x		0	177700	3160	2851	1.04295	1.04059	1.04467	0
s		0	9871	1754	916.3	0.04173	0.04086	0.03542	0
%RSD		0	5.554	55.5	32.14	4.001	3.927	3.391	0
		OB B7 1000x 11/26/2015 5:33:12 PM							
1	17:33:12	0	252400	41080	23020	1.01844	1.01272	1.01368	0
2	17:33:25	0	236400	36830	20250	1.04497	1.04426	1.04312	0
3	17:33:38	0	233600	35060	20200	1.08379	1.07595	1.07171	0
x		0	240800	37660	21150	1.04907	1.04431	1.04284	0
s		0	10180	3095	1614	0.03287	0.03161	0.02902	0
%RSD		0	4.226	8.219	7.629	3.133	3.027	2.783	0
		OB B8 1000x 11/26/2015 5:34:48 PM							
1	17:34:48	0	191300	8221	32200	1.00882	1.00805	1.01689	0
2	17:35:01	0	176800	6344	28590	1.04482	1.04049	1.0385	0
3	17:35:14	0	173600	4602	27100	1.07518	1.07028	1.06616	0
x		0	180600	6389	29300	1.04294	1.03961	1.04052	0
s		0	9411	1810	2621	0.03322	0.03112	0.0247	0
%RSD		0	5.212	28.33	8.944	3.185	2.994	2.374	0

Run	Time	4.5Bkg	23Na	39K	44Ca	45Sc	115In	159Tb	220.5Bkg
		ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
		OB C1 1000x 11/26/2015 5:36:24 PM							
1	17:36:24	0	355400	14490	9838	1.02488	1.01322	1.0211	0
2	17:36:37	0	329900	12390	8851	1.05047	1.0426	1.04168	0
3	17:36:50	0	324500	10850	8555	1.07867	1.07566	1.08276	0
x		0	336600	12580	9081	1.05134	1.04383	1.04851	0
s		0	16480	1827	671.6	0.0269	0.03124	0.03139	0
%RSD		0	4.897	14.53	7.395	2.559	2.993	2.994	0
		OB C2 1000x 11/26/2015 5:38:00 PM							
1	17:38:00	0	331000	18080	499.6	1.0195	1.01839	1.02637	0
2	17:38:13	0	306800	15260	-595.7	1.05801	1.05677	1.04631	0
3	17:38:26	0	301900	13820	-886.7	1.08855	1.08342	1.09361	0
x		0	313200	15720	-327.6	1.05535	1.05286	1.05543	0
s		0	15590	2167	731	0.0346	0.03269	0.03454	0
%RSD		0	4.978	13.79	223.1	3.279	3.105	3.272	0
		OB C3 1000x 11/26/2015 5:39:36 PM							
1	17:39:36	0	459700	88960	33970	1.02816	1.02109	1.03005	0
2	17:39:49	0	424500	80520	31270	1.06485	1.05505	1.06228	0
3	17:40:02	0	418200	78540	30190	1.08612	1.0791	1.08679	0
x		0	434100	82670	31810	1.05971	1.05175	1.05971	0
s		0	22340	5532	1945	0.02932	0.02915	0.02846	0
%RSD		0	5.147	6.692	6.114	2.767	2.771	2.686	0
		OB D5 1000x 11/26/2015 5:41:13 PM							
1	17:41:13	0	386300	54010	7738	1.01362	1.01872	1.02246	0
2	17:41:26	0	345700	46850	5895	1.06307	1.05325	1.04503	0
3	17:41:39	0	343800	44840	5721	1.08993	1.07415	1.07329	0
x		0	358600	48570	6451	1.05554	1.04871	1.04693	0
s		0	24040	4822	1118	0.03871	0.02799	0.02547	0
%RSD		0	6.702	9.929	17.33	3.667	2.669	2.433	0
		OB D7 1000x 11/26/2015 5:46:03 PM							
1	17:46:03	0	392600	21860	9536	1.01457	1.00983	1.02015	0
2	17:46:16	0	364000	18390	8727	1.06106	1.05344	1.0494	0
3	17:46:29	0	358900	16970	8450	1.09509	1.08749	1.08562	0
x		0	371800	19070	8904	1.0569	1.05025	1.05172	0
s		0	18120	2514	564.2	0.04042	0.03893	0.03279	0
%RSD		0	4.874	13.18	6.337	3.824	3.706	3.118	0
		OB D8 1000x 11/26/2015 5:47:41 PM							
1	17:47:41	0	401500	24920	14480	1.02944	1.02387	1.02866	0
2	17:47:54	0	373500	21880	12630	1.05708	1.05186	1.0431	0
3	17:48:07	0	370000	20520	11910	1.08924	1.08533	1.08832	0
x		0	381700	22440	13010	1.05859	1.05369	1.05336	0
s		0	17280	2251	1325	0.02993	0.03077	0.03112	0
%RSD		0	4.527	10.03	10.19	2.827	2.92	2.955	0

Run	Time	4.5Bkg	23Na	39K	44Ca	45Sc	115In	159Tb	220.5Bkg
		ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
		OB E1 1000x	11/26/2015 5:49:18 PM						
1	17:49:18	0	36480	8794	213600	1.02301	1.0145	1.01925	0
2	17:49:30	0	33350	6604	201800	1.05513	1.04414	1.04052	0
3	17:49:43	0	32560	5128	198000	1.08853	1.07986	1.07708	0
x		0	34130	6842	204400	1.05555	1.04616	1.04561	0
s		0	2073	1845	8128	0.03276	0.03273	0.02925	0
%RSD		0	6.073	26.96	3.976	3.104	3.128	2.797	0
		OB E3 1000x	11/26/2015 5:50:54 PM						
1	17:50:54	0	76410	50630	189900	1.02069	1.01555	1.01563	0
2	17:51:06	0	69460	45010	173700	1.05667	1.04596	1.0418	0
3	17:51:20	0	68290	42720	171100	1.09006	1.07919	1.08034	0
x		0	71390	46120	178200	1.0558	1.0469	1.04592	0
s		0	4391	4072	10160	0.03469	0.03183	0.03255	0
%RSD		0	6.151	8.829	5.702	3.286	3.04	3.112	0
		OB E4 1000x	11/26/2015 5:52:30 PM						
1	17:52:30	0	92530	45610	193500	1.03175	1.0242	1.02678	0
2	17:52:42	0	84630	40550	181100	1.05458	1.03971	1.04017	0
3	17:52:56	0	83260	38650	175600	1.09017	1.08317	1.07437	0
x		0	86810	41600	183400	1.05883	1.04903	1.04711	0
s		0	5007	3594	9163	0.02944	0.03057	0.02454	0
%RSD		0	5.768	8.638	4.995	2.78	2.914	2.344	0
		OB F5 1000x	11/26/2015 5:54:06 PM						
1	17:54:06	0	57750	20500	6455	1.02005	1.00784	1.00011	0
2	17:54:19	0	53050	17610	5099	1.05541	1.044	1.04474	0
3	17:54:31	0	51960	16020	5256	1.09187	1.08432	1.08268	0
x		0	54250	18040	5603	1.05578	1.04539	1.04251	0
s		0	3075	2270	741.9	0.03591	0.03826	0.04133	0
%RSD		0	5.668	12.58	13.24	3.401	3.66	3.964	0
		OB F6 1000x	11/26/2015 5:55:42 PM						
1	17:55:42	0	27580	4652	-49.41	1.01942	1.01211	1.0192	0
2	17:55:54	0	24520	2893	-573	1.05577	1.05879	1.04856	0
3	17:56:08	0	23580	1190	-900.7	1.09469	1.08516	1.08728	0
x		0	25230	2912	-507.7	1.05663	1.05202	1.05168	0
s		0	2096	1731	429.4	0.03764	0.03699	0.03415	0
%RSD		0	8.307	59.45	84.58	3.563	3.516	3.247	0
		OB F7 1000x	11/26/2015 5:57:18 PM						
1	17:57:18	0	29770	5455	765.8	1.02493	1.01096	1.01002	0
2	17:57:31	0	26020	3842	-310.7	1.04726	1.03272	1.02372	0
3	17:57:44	0	25360	2126	-558.7	1.08713	1.07657	1.07436	0
x		0	27050	3808	-34.53	1.05311	1.04008	1.03603	0
s		0	2374	1665	704.1	0.03151	0.03342	0.03389	0
%RSD		0	8.775	43.72	2039	2.992	3.213	3.271	0

Run	Time	4.5Bkg	23Na	39K	44Ca	45Sc	115In	159Tb	220.5Bkg
		ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
		OB G1 1000x	11/26/2015 5:58:54 PM						
1	17:58:54	0	77040	37110	136400	1.02361	1.01267	1.00727	0
2	17:59:07	0	70290	32960	125200	1.05528	1.04527	1.04689	0
3	17:59:20	0	67500	30210	121400	1.09873	1.09108	1.08658	0
x		0	71610	33420	127700	1.05921	1.04968	1.04691	0
s		0	4901	3475	7760	0.03772	0.03939	0.03965	0
%RSD		0	6.845	10.4	6.078	3.561	3.753	3.788	0
		OB G3 1000x	11/26/2015 6:00:30 PM						
1	18:00:30	0	57190	27470	94900	1.0209	1.01744	1.03132	0
2	18:00:43	0	51060	23600	88500	1.06225	1.04463	1.04822	0
3	18:00:56	0	49550	21650	85670	1.08751	1.08156	1.07263	0
x		0	52600	24240	89690	1.05689	1.04788	1.05072	0
s		0	4047	2960	4731	0.03363	0.03218	0.02077	0
%RSD		0	7.693	12.21	5.275	3.182	3.071	1.976	0
		OB G4 1000x	11/26/2015 6:06:56 PM						
1	18:06:56	0	49330	23680	105400	1.02087	1.01211	1.02348	0
2	18:07:09	0	44820	20860	99230	1.04899	1.03636	1.03069	0
3	18:07:22	0	43880	19040	94790	1.08201	1.07561	1.07753	0
x		0	46010	21190	99810	1.05062	1.04136	1.0439	0
s		0	2915	2335	5327	0.0306	0.03204	0.02935	0
%RSD		0	6.336	11.02	5.337	2.913	3.077	2.811	0
		OB H5 1000x	11/26/2015 6:08:33 PM						
1	18:08:33	0	52370	16920	194500	1.02958	1.01962	1.03128	0
2	18:08:45	0	46790	14080	181800	1.0654	1.048	1.05426	0
3	18:08:58	0	45420	12330	175400	1.10258	1.09112	1.09474	0
x		0	48190	14450	183900	1.06585	1.05291	1.06009	0
s		0	3684	2315	9734	0.0365	0.036	0.03213	0
%RSD		0	7.645	16.03	5.292	3.424	3.419	3.031	0
		OB H6 1000x	11/26/2015 6:10:10 PM						
1	18:10:10	0	50020	25730	195300	1.0364	1.02429	1.0316	0
2	18:10:23	0	45400	22250	181800	1.05953	1.05118	1.04801	0
3	18:10:36	0	43440	20020	172800	1.10382	1.09558	1.0906	0
x		0	46290	22670	183300	1.06658	1.05702	1.05674	0
s		0	3377	2876	11310	0.03426	0.036	0.03045	0
%RSD		0	7.296	12.69	6.17	3.212	3.406	2.882	0
		OB H7 1000x	11/26/2015 6:11:48 PM						
1	18:11:48	0	44170	21420	201900	1.04131	1.0204	1.02187	0
2	18:12:00	0	40280	18840	189400	1.0666	1.05877	1.05752	0
3	18:12:13	0	38400	16500	181700	1.10682	1.09978	1.08571	0
x		0	40950	18920	191000	1.07158	1.05965	1.05503	0
s		0	2943	2460	10210	0.03304	0.0397	0.03199	0
%RSD		0	7.185	13	5.346	3.083	3.746	3.032	0

Run	Time	4.5Bkg	7Li	27Al	31P	45Sc	47Ti	51V	52Cr	55Mn	56Fe	59Co	60Ni	65Cu	66Zn	75As	82Se	107Ag	111Cd	115In	121Sb	137Ba	140Ce	159Tb	208Pb	220.5Bkg	238U
		ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
		L1 CaCl2 · 2H2O blank 3/9/2016 9:29:53 PM																									
1	21:29:53	0	0.308	5.985	33.9	1.39684	0.311	1.076	0.145	0.523	68.48	0.252	5.158	2.774	7.534	0.266	0.111	0.1	0.056	1.21129	0.053	2.811	0.015	1.22268	0.449	0	0.003
2	21:30:30	0	0.31	6.014	30.69	1.52012	0.332	1.123	0.114	0.532	62.33	0.239	4.939	2.746	7.414	0.259	0.142	0.116	0.063	1.31005	0.071	2.799	0.017	1.30959	0.445	0	0.012
3	21:31:07	0	0.278	5.955	29.01	1.56402	0.307	1.177	0.106	0.521	58.75	0.231	4.676	2.738	7.425	0.129	-0.007	0.122	0.059	1.33544	0.063	2.845	0.016	1.32673	0.44	0	0.006
x		0	0.298	5.984	31.2	1.49366	0.317	1.125	0.122	0.525	63.19	0.241	4.924	2.752	7.457	0.218	0.082	0.113	0.059	1.28559	0.062	2.818	0.016	1.28633	0.445	0	0.007
s		0	0.018	0.029	2.485	0.08667	0.014	0.051	0.021	0.006	4.924	0.011	0.241	0.019	0.066	0.077	0.079	0.011	0.003	0.06559	0.009	0.024	0.001	0.05579	0.004	0	0.004
%RSD		0	5.966	0.493	7.965	5.803	4.305	4.515	17.15	1.165	7.794	4.364	4.898	0.687	0.888	35.38	95.52	9.95	5.466	5.102	15.1	0.853	6.632	4.337	0.976	0	62.28
		L2 CaCl2 · 2H2O Siltstone 3/9/2016 9:32:40 PM																									
1	21:32:40	0	20.99	4955	41.25	1.34525	1.137	1.117	0.565	406.3	4518	5.506	12.32	36.5	16.44	0.462	0.125	0.126	0.185	1.20735	-0.107	259.8	3.381	1.21727	7.739	0	0.791
2	21:33:17	0	21.1	5017	32.61	1.34439	1.08	1.009	0.537	410.1	4536	5.546	11.81	36.94	16.51	0.402	0.008	0.136	0.194	1.22224	-0.044	261.4	3.408	1.23783	7.765	0	0.809
3	21:33:53	0	21.03	4975	34.96	1.33174	1.109	0.938	0.525	409.7	4514	5.468	11.68	36.66	16.43	0.387	0.131	0.141	0.19	1.20244	-0.031	263.3	3.424	1.23142	7.809	0	0.81
x		0	21.04	4982	36.27	1.34046	1.109	1.021	0.542	408.7	4523	5.507	11.94	36.7	16.46	0.417	0.088	0.134	0.19	1.21068	-0.061	261.5	3.404	1.22884	7.771	0	0.804
s		0	0.054	31.4	4.464	0.00756	0.028	0.09	0.02	2.126	11.64	0.039	0.334	0.222	0.043	0.04	0.069	0.007	0.004	0.01031	0.041	1.747	0.022	0.01052	0.035	0	0.011
%RSD		0	0.255	0.63	12.31	0.564	2.563	8.826	3.762	0.52	0.257	0.716	2.796	0.605	0.26	9.536	78.55	5.502	2.344	0.852	67.19	0.668	0.642	0.856	0.453	0	1.327
		L3 CaCl2 · 2H2O Siltstone 3/9/2016 9:35:27 PM																									
1	21:35:27	0	20.89	5091	17.12	1.28456	1.004	1.02	0.577	413.2	4677	5.568	11.57	37.2	17.4	0.542	0.179	0.088	0.226	1.17464	-0.179	270.8	3.4	1.1912	8.083	0	0.811
2	21:36:04	0	20.77	5097	13.95	1.30075	1.003	0.882	0.51	414.2	4678	5.486	11.12	36.64	17.15	0.406	0.155	0.092	0.226	1.2051	-0.136	273.7	3.4	1.21187	8.15	0	0.827
3	21:36:41	0	20.84	5122	12.96	1.28204	0.979	0.861	0.526	418.1	4688	5.532	11.04	36.63	17.11	0.39	0.212	0.093	0.223	1.19524	-0.106	272.4	3.436	1.21528	8.144	0	0.818
x		0	20.83	5104	14.68	1.28912	0.995	0.921	0.537	415.2	4681	5.529	11.24	36.82	17.22	0.446	0.182	0.091	0.225	1.19166	-0.14	272.3	3.412	1.20611	8.126	0	0.819
s		0	0.057	16.21	2.175	0.01015	0.014	0.087	0.035	2.607	6.096	0.041	0.282	0.327	0.156	0.083	0.029	0.002	0.002	0.01554	0.037	1.456	0.021	0.01303	0.037	0	0.008
%RSD		0	0.276	0.318	14.82	0.788	1.407	9.397	6.525	0.628	0.13	0.742	2.512	0.889	0.905	18.63	15.77	2.71	0.904	1.304	26.19	0.535	0.618	1.08	0.455	0	0.961
		M5 CaCl2 · 2H2O blank 3/9/2016 9:38:15 PM																									
1	21:38:15	0	0.21	15.14	78.33	1.3972	0.545	1.329	0.172	1.308	71.06	0.292	5.248	3.311	3.134	-0.268	0.07	0.055	0.067	1.22857	-0.15	4.034	0.009	1.25191	0.111	0	-0.011
2	21:38:51	0	0.208	15.38	72.03	1.45165	0.599	1.474	0.187	1.316	63.67	0.269	5.377	3.339	3.153	-0.196	0.061	0.077	0.062	1.28246	-0.13	4.085	0.014	1.29474	0.116	0	-0.003
3	21:39:28	0	0.232	15.18	68.3	1.47908	0.507	1.557	0.179	1.304	59.72	0.264	5.255	3.347	3.145	-0.31	-0.089	0.078	0.073	1.29662	-0.111	4.061	0.019	1.30426	0.122	0	0
x		0	0.217	15.23	72.89	1.44264	0.55	1.453	0.179	1.309	64.82	0.275	5.293	3.332	3.144	-0.258	0.014	0.07	0.067	1.26922	-0.13	4.06	0.014	1.28364	0.116	0	-0.005
s		0	0.013	0.128	5.07	0.04167	0.046	0.115	0.008	0.006	5.756	0.015	0.073	0.019	0.009	0.058	0.089	0.013	0.006	0.03591	0.02	0.026	0.005	0.02788	0.006	0	0.006
%RSD		0	6.011	0.842	6.956	2.889	8.388	7.929	4.195	0.464	8.88	5.43	1.376	0.566	0.299	22.47	638.5	19	8.321	2.829	15.2	0.629	33.67	2.172	4.93	0	121.4
		M7 CaCl2 · 2H2O Granite from Harrietsfield 3/9/2016 9:41:02 PM																									
1	21:41:02	0	26.68	177.3	42.64	1.38108	0.555	1.562	0.17	51	69.46	0.318	4.982	1.843	2.72	-0.154	0.044	0.002	0.004	1.23001	-0.149	28.14	0.035	1.23894	0.458	0	3.713
2	21:41:39	0	26.73	178.6	37.25	1.3878	0.481	1.386	0.135	51.91	58.86	0.3	4.736	1.882	2.748	-0.182	0.086	0.01	0.005	1.25402	-0.123	28.76	0.036	1.24794	0.477	0	3.831
3	21:42:15	0	26.59	179	38.67	1.37364	0.586	1.369	0.13	51.66	56.53	0.278	4.398	1.861	2.671	0.02	0.027	0.009	0.003	1.24119	-0.118	28.64	0.038	1.25125	0.481	0	3.825
x		0	26.67	178.3	39.52	1.38084	0.541	1.439	0.145	51.52	61.62	0.298	4.706	1.862	2.713	-0.106	0.052	0.007	0.004	1.24174	-0.13	28.51	0.036	1.24604	0.472	0	3.789
s		0	0.073	0.893	2.791	0.00708	0.054	0.107	0.022	0.469	6.894	0.02	0.293	0.02	0.039	0.109	0.03	0.005	0.001	0.01201	0.017	0.327	0.001	0.00637	0.012	0	0.066
%RSD		0	0.272	0.501	7.064	0.513	9.97	7.422	14.95	0.91	11.19	6.732	6.225	1.054	1.443	103.6	57.98	67.33	21.65	0.967	12.71	1.147	3.248	0.511	2.61	0	1.752
		M8 CaCl2 · 2H2O Granite from Harrietsfield 3/9/2016 9:43:49 PM																									
1	21:43:49	0	26.68	174.2	19.93	1.32594	0.303	1.397	0.113	54.88	57.03	0.296	4.991	1.34	2.454	0.002	0.164	-0.008	0	1.20427	-0.17	29.45	0.03	1.20341	0.478	0	3.972
2	21:44:26	0	26.56	177	17.43	1.36585	0.269	1.322	0.078	55.55	45.63	0.274	4.48	1.346	2.449	-0.249	0.016	-0.008	-0.004	1.24317	-0.151	29.79	0.028	1.24359	0.479	0	4.029
3	21:45:02	0	26.4	175.7	14.03	1.37043	0.261	1.266	0.063	55.38	42.68	0.26	4.509	1.301	2.323	-0.323	-0.035	-0.008	-0.002	1.24449	-0.137	29.86	0.029	1.24809	0.472	0	4.032
x		0	26.55	175.6	17.13	1.35407	0.278	1.328	0.085	55.27	48.45	0.277	4.66	1.329	2.409	-0.19	0.049	-0.008	-0.002	1.23064	-0.153	29.7	0.029	1.2317	0.476	0	4.011
s		0	0.141	1.405	2.965	0.02447	0.023	0.066	0.026	0.348	7.58	0.018	0.287	0.024	0.074	0.17	0.103	0	0.002	0.02285	0.017	0.219	0.001	0.0246	0.004	0	0.034
%RSD		0	0.53	0.8	17.31	1.807	8.126	4.941	30.13	0.631	15.64	6.437	6.16	1.831	3.084	89.69	212.7	1.837	92.46	1.857	10.94	0.736	2.705	1.997	0.812	0	0.843

Run	Time	4.5Bkg	7Li	27Al	31P	45Sc	47Ti	51V	52Cr	55Mn	56Fe	59Co	60Ni	65Cu	66Zn	75As	82Se	107Ag	111Cd	115In	121Sb	137Ba	140Ce	159Tb	208Pb	220.5Bkg	238U
		ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
		I1 CaSO4 blank 3/9/2016 9:46:37 PM																									
1	21:46:37	0	0.295	11.32	39.2	1.06811	0.325	0.338	0.131	1.32	58.75	0.09	1.808	1.824	3.717	-0.286	-0.29	-0.01	0.003	1.07842	-0.23	1.284	0.242	1.11418	0.476	0	-0.022
2	21:47:13	0	0.333	11.44	32.37	1.11498	0.276	0.242	0.1	1.345	51.7	0.081	1.723	1.85	3.722	-0.186	-0.008	-0.009	0.003	1.12557	-0.22	1.284	0.241	1.15649	0.476	0	-0.022
3	21:47:50	0	0.303	11.27	32.45	1.15238	0.33	0.193	0.098	1.319	48.13	0.077	1.618	1.82	3.724	-0.208	-0.163	-0.007	0.003	1.15433	-0.219	1.318	0.239	1.18369	0.478	0	-0.023
x		0	0.311	11.34	34.67	1.11183	0.311	0.258	0.11	1.328	52.86	0.083	1.717	1.831	3.721	-0.227	-0.154	-0.009	0.003	1.11944	-0.223	1.296	0.24	1.15145	0.476	0	-0.022
s		0	0.02	0.085	3.918	0.04222	0.03	0.074	0.019	0.015	5.406	0.007	0.095	0.016	0.004	0.052	0.141	0.001	0	0.03833	0.006	0.02	0.002	0.03503	0.001	0	0
%RSD		0	6.327	0.746	11.3	3.798	9.548	28.7	17.06	1.113	10.23	7.915	5.553	0.894	0.102	23.04	91.65	15.94	11.29	3.424	2.858	1.527	0.652	3.042	0.249	0	1.808
		I2 CaSO4 Granite from Harrietsfield 3/9/2016 9:49:24 PM																									
1	21:49:24	0	30.16	236.3	38.87	1.04714	0.471	0.318	0.033	24.24	-18.45	0.092	1.806	4.484	4.296	-0.134	-0.129	-0.01	0.003	1.06726	-0.17	13.53	0.019	1.11174	1.014	0	3.953
2	21:50:01	0	29.73	236.7	33.51	1.06076	0.361	0.335	-0.018	24.53	-18.37	0.092	1.614	4.455	4.335	-0.018	-0.061	-0.008	-0.001	1.09215	-0.163	13.7	0.019	1.13626	1.015	0	4.041
3	21:50:38	0	29.95	238.1	29.85	1.04686	0.33	0.323	-0.009	24.44	-16.65	0.076	1.587	4.412	4.163	-0.075	-0.187	-0.007	0	1.08686	-0.159	13.48	0.019	1.13543	1.027	0	4.036
x		0	29.95	237	34.08	1.05159	0.388	0.325	0.002	24.4	-17.83	0.087	1.669	4.45	4.264	-0.076	-0.125	-0.008	0.001	1.08209	-0.164	13.57	0.019	1.12781	1.018	0	4.01
s		0	0.215	0.982	4.536	0.00794	0.074	0.009	0.027	0.149	1.02	0.009	0.119	0.037	0.09	0.058	0.063	0.002	0.002	0.01311	0.005	0.115	0	0.01393	0.007	0	0.049
%RSD		0	0.716	0.414	13.31	0.756	19.12	2.733	1294	0.609	5.724	10.5	7.148	0.821	2.114	76.42	50.28	20.24	293.2	1.212	3.258	0.848	0.865	1.235	0.721	0	1.224
		I3 CaSO4 Granite from Harrietsfield 3/9/2016 9:52:12 PM																									
1	21:52:12	0	30.44	253.5	47.93	1.02123	0.677	0.287	0.026	24.39	-21.2	0.095	1.887	2.651	5.509	-0.077	0.019	-0.007	0.004	1.04469	-0.162	8.947	0.03	1.10279	0.133	0	3.946
2	21:52:49	0	30.29	255.9	42.97	1.04258	0.721	0.278	-0.008	24.71	-21.93	0.08	1.719	2.623	5.58	-0.104	-0.177	-0.009	0.002	1.07205	-0.166	8.845	0.028	1.13334	0.133	0	4.012
3	21:53:26	0	30.24	255.2	39.76	1.04295	0.615	0.28	-0.023	24.71	-22.74	0.077	1.66	2.609	5.405	-0.13	-0.12	-0.007	0.003	1.07449	-0.153	8.948	0.028	1.13528	0.13	0	4.017
x		0	30.32	254.9	43.56	1.03559	0.671	0.281	-0.002	24.6	-21.96	0.084	1.755	2.628	5.498	-0.104	-0.092	-0.007	0.003	1.06375	-0.161	8.913	0.029	1.1238	0.132	0	3.992
s		0	0.101	1.248	4.115	0.01243	0.053	0.005	0.025	0.183	0.771	0.01	0.118	0.021	0.088	0.027	0.101	0.001	0.001	0.01654	0.006	0.059	0.001	0.01822	0.002	0	0.04
%RSD		0	0.334	0.49	9.449	1.201	7.92	1.712	1510	0.742	3.51	11.45	6.723	0.812	1.599	25.8	109.4	13.41	34.07	1.555	4.001	0.664	5.134	1.622	1.159	0	1.002
		K5 RO blank 3/9/2016 9:55:00 PM																									
1	21:55:00	0	0.204	21.96	44.2	1.02389	0.319	0.057	0.036	0.57	12.92	0.015	0.317	0.872	2.395	-0.275	-0.253	0.001	-0.017	1.06795	-0.248	9.663	-0.008	1.11513	36.41	0	-0.016
2	21:55:37	0	0.186	22.09	35.77	1.08039	0.316	0.061	-0.004	0.572	7.164	0.014	0.306	0.876	2.361	-0.221	-0.21	0.002	-0.018	1.12221	-0.241	9.704	-0.008	1.15863	36.76	0	-0.016
3	21:56:14	0	0.173	22	36.45	1.08487	0.234	0.06	-0.005	0.57	6.03	0.014	0.316	0.897	2.405	-0.26	-0.293	0.002	-0.02	1.12624	-0.239	9.733	-0.009	1.16629	36.52	0	-0.016
x		0	0.188	22.02	38.81	1.06305	0.289	0.059	0.009	0.57	8.703	0.014	0.313	0.881	2.387	-0.252	-0.252	0.002	-0.018	1.10546	-0.242	9.7	-0.008	1.14668	36.56	0	-0.016
s		0	0.015	0.066	4.685	0.03399	0.049	0.002	0.023	0.001	3.692	0	0.006	0.013	0.023	0.028	0.041	0	0.002	0.03255	0.004	0.035	0	0.02759	0.182	0	0
%RSD		0	8.148	0.301	12.07	3.197	16.76	3.565	252.2	0.222	42.42	2.358	1.928	1.516	0.963	11.07	16.3	23.47	9.324	2.945	1.818	0.361	4.812	2.406	0.497	0	0.441
		K6 RO Granite from Harrietsfield 3/9/2016 10:03:25 PM																									
1	22:03:25	0	21.63	1081	88.53	0.94618	32.76	2.229	0.294	9.621	460.5	0.167	0.722	5.357	8.205	1.731	0.093										
2	22:04:02	0	21.62	1089	82.53	0.9706	32.69	2.237	0.269	9.695	456.2	0.166	0.742	5.39	8.115	1.582	-0.158	-0.004	-0.001	1.02188	-0.201	0.004	0	1.04155	-0.001	0	-0.008
3	22:04:38	0	21.6	1088	76.91	0.9736	32.84	2.249	0.266	9.749	453.1	0.165	0.725	5.415	8.201	1.474	-0.067	-0.008	-0.001	1.07787	-0.201	0.001	0.001	1.10281	0.002	0	-0.009
x		0	21.62	1086	82.66	0.96346	32.76	2.238	0.276	9.688	456.6	0.166	0.73	5.387	8.174	1.596	-0.044	-0.005	-0.003	1.07916	-0.199	0.004	0.001	1.09379	0.009	0	-0.007
s		0	0.018	4.459	5.81	0.01504	0.075	0.01	0.015	0.064	3.733	0.001	0.011	0.029	0.051	0.129	0.127	-0.006	-0.002	1.05963	-0.201	0.003	0.001	1.07938	0.004	0	-0.008
%RSD		0	0.085	0.411	7.029	1.561	0.229	0.444	5.444	0.662	0.818	0.632	1.486	0.546	0.624	8.083	289.7	0.002	0.001	0.0327	0.001	0.002	0.001	0.03307	0.005	0	0.001
																41.3	52.3	3.086	0.536	51.23	104.8	3.064	146.1	0	16.98
		K8 RO Granite from Harrietsfield 3/9/2016 10:06:14 PM																									
1	22:06:14	0	23.84	1033	81.39	0.93473	30.36	2.276	0.303	9.203	447.5	0.136	0.488	3.816	6.767	0.956	-0.235										
2	22:06:51	0	23.79	1046	72.75	0.96913	31.24	2.316	0.288	9.276	448.6	0.141	0.488	3.826	6.757	1.039	-0.102	70.21	75.46	1.03455	69.98	71.8	69.7	1.06237	71.79	0	73.01
3	22:07:28	0	24.4	1048	68.66	0.97238	30.84	2.305	0.273	9.289	446.2	0.142	0.486	3.842	6.831	0.999	-0.209	69.99	75.51	1.08671	71.02	71.76	70.55	1.11847	72.63	0	73.45
x		0	24.01	1042	74.26	0.95875	30.82	2.299	0.288	9.256	447.4	0.14	0.487	3.828	6.785	0.998	-0.182	70.11	75.44	1.074	71.71	72.31	70.66	1.10362	73.15	0	74.47
s		0	0.34	8.121	6.499	0.02086	0.441	0.021	0.015	0.047	1.21	0.003	0.001	0.013	0.04	0.042	0.07	93.47%	100.63%	1.06509	94.54%	95.94%	93.74%	1.09482	96.70%	0	98.19%
%RSD		0	1.416	0.779	8.752	2.176	1.432	0.91	5.2	0.505	0.271	2.266	0.269	0.343	0.59	4.185	38.69	n/a	n/a	0.0272	n/a	n/a	n/a	0.02906	n/a	0	n/a
																		0.158	0.047	2.554	1.228	0.422	0.752	2.655	0.944	0	1.012

Run	Time	4.5Bkg	23Na	24Mg	39K	44Ca	45Sc	115In	159Tb	220.5Bkg
		ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
		L1 1000x	3/9/2016 6:41:39 PM							
1	0.778924	0	245700	2042	10860	563500	0.94704	0.96168	0.97117	0
2	0.779086	0	228700	1902	8324	533700	0.99867	1.01082	1.01586	0
3	0.779259	0	224700	1839	6920	524800	1.03316	1.04806	1.04753	0
x		0	233000	1928	8702	540700	0.99296	1.00686	1.01152	0
s		0	11200	103.6	1998	20280	0.04334	0.04333	0.03837	0
%RSD		0	4.805	5.375	22.96	3.751	4.365	4.303	3.793	0
		L2 1000x	3/9/2016 6:43:18 PM							
1	0.780069	0	96440	1636	12580	495800	0.94573	0.95403	0.96848	0
2	0.780231	0	87650	1473	9589	468500	1.00071	1.01253	1.01547	0
3	0.780394	0	85950	1422	7943	461900	1.0408	1.0525	1.04814	0
x		0	90010	1511	10040	475400	0.99575	1.00635	1.0107	0
s		0	5628	111.5	2348	17950	0.04773	0.04953	0.04005	0
%RSD		0	6.253	7.38	23.4	3.776	4.793	4.921	3.962	0
		L3 1000x	3/9/2016 6:44:56 PM							
1	0.781204	0	76490	1498	11460	505800	0.95855	0.96595	0.97472	0
2	0.781366	0	65540	1361	8888	472800	1.01429	1.02755	1.0201	0
3	0.781528	0	64450	1339	7188	464400	1.04758	1.05613	1.05582	0
x		0	68820	1400	9179	481000	1.00681	1.01654	1.01688	0
s		0	6657	86.24	2152	21840	0.04498	0.04609	0.04064	0
%RSD		0	9.673	6.162	23.44	4.541	4.468	4.534	3.997	0
		M5 1000x	3/9/2016 6:46:35 PM							
1	0.78235	0	113800	916	9997	528900	0.95742	0.969	0.97103	0
2	0.782512	0	102700	855.4	7490	496900	1.00815	1.01662	1.0137	0
3	0.782674	0	99750	787.1	5957	492000	1.05248	1.06335	1.05929	0
x		0	105400	852.8	7814	505900	1.00602	1.01632	1.01467	0
s		0	7414	64.53	2039	20010	0.04757	0.04718	0.04414	0
%RSD		0	7.034	7.567	26.1	3.955	4.728	4.642	4.35	0
		M7 1000x (100x)	3/9/2016 6:48:15 PM							
1	0.783507	0	64020	1525	9376	502700	0.95979	0.96891	0.97508	0
2	0.783669	0	57040	1449	6992	480300	1.02478	1.02826	1.02518	0
3	0.783831	0	56950	1444	5506	474200	1.05483	1.06706	1.06385	0
x		0	59340	1472	7291	485700	1.01313	1.02141	1.02137	0
s		0	4055	45.28	1952	15030	0.04858	0.04943	0.04451	0
%RSD		0	6.834	3.075	26.78	3.094	4.795	4.84	4.358	0
		M8 1000x	3/9/2016 6:49:55 PM							
1	0.784664	0	83140	1803	10070	532100	0.96706	0.97477	0.98054	0
2	0.784826	0	70570	1640	7395	500400	1.02314	1.03415	1.03125	0
3	0.784988	0	69240	1625	6465	484500	1.05341	1.06614	1.06694	0
x		0	74320	1689	7976	505700	1.01454	1.02502	1.02624	0
s		0	7672	98.67	1871	24240	0.04381	0.04637	0.04342	0
%RSD		0	10.32	5.841	23.45	4.794	4.318	4.524	4.231	0

Run	Time	4.5Bkg	23Na	24Mg	39K	44Ca	45Sc	115In	159Tb	220.5Bkg
		ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
		J1 1000x	3/9/2016 6:51:35 PM							
1	0.785822	0	116700	908.1	2930	182100	0.95412	0.95923	0.96267	0
2	0.785984	0	102700	785	617.8	171400	1.01068	1.01632	1.01341	0
3	0.786146	0	98710	745.6	-845.9	166600	1.04804	1.05322	1.05062	0
x		0	106000	812.9	900.6	173400	1.00428	1.00959	1.0089	0
s		0	9443	84.78	1904	7917	0.04728	0.04736	0.04414	0
%RSD		0	8.905	10.43	211.4	4.566	4.708	4.691	4.375	0
		J2 1000x	3/9/2016 6:53:16 PM							
1	0.786991	0	58250	1656	8265	162500	0.95497	0.95343	0.96221	0
2	0.787153	0	50190	1510	5359	153500	1.01316	1.01271	1.00724	0
3	0.787315	0	49730	1468	4207	148600	1.04607	1.05298	1.05018	0
x		0	52720	1545	5944	154900	1.00473	1.00637	1.00654	0
s		0	4788	98.71	2091	7032	0.04613	0.05007	0.04399	0
%RSD		0	9.082	6.389	35.19	4.54	4.591	4.976	4.37	0
		J3 1000x	3/9/2016 6:54:56 PM							
1	0.788148	0	153000	2457	11220	186000	0.95618	0.96525	0.96566	0
2	0.78831	0	143900	2328	8783	176600	1.01669	1.01901	1.01561	0
3	0.788472	0	142200	2280	7331	173800	1.05115	1.048	1.04739	0
x		0	146400	2355	9112	178800	1.00801	1.01075	1.00956	0
s		0	5813	91.66	1966	6391	0.04808	0.04199	0.0412	0
%RSD		0	3.972	3.891	21.57	3.575	4.77	4.154	4.081	0
		K5 1000x	3/9/2016 6:56:37 PM							
1	0.789317	0	111700	1478	2855	19030	0.95406	0.9557	0.96212	0
2	0.789479	0	99660	1369	352.8	17880	1.00905	1.01787	1.01154	0
3	0.789641	0	96970	1337	-916.2	17070	1.04824	1.05595	1.0471	0
x		0	102800	1394	763.8	17990	1.00378	1.00984	1.00692	0
s		0	7850	74.02	1919	986.4	0.04731	0.0506	0.04268	0
%RSD		0	7.638	5.309	251.2	5.482	4.713	5.011	4.239	0
		K6 1000x	3/9/2016 7:01:37 PM							
1	0.792789	0	108700	1286	12230	16130	0.95369	0.95928	0.96436	0
2	0.792951	0	95930	1134	9314	14820	1.01263	1.01435	1.00966	0
3	0.793113	0	94020	1109	8336	14170	1.04122	1.05153	1.04461	0
x		0	99560	1176	9961	15040	1.00251	1.00838	1.00621	0
s		0	7992	95.45	2028	1000	0.04463	0.04641	0.04024	0
%RSD		0	8.027	8.113	20.36	6.653	4.452	4.603	3.999	0
		K8 1000x	3/9/2016 7:03:18 PM							
1	0.793958	0	99310	1338	6411	15330	0.95969	0.96346	0.96668	0
2	0.79412	0	89370	1250	4208	14640	1.00646	1.01003	1.01239	0
3	0.794282	0	88290	1227	2607	13700	1.04873	1.05974	1.06162	0
x		0	92330	1272	4409	14550	1.00496	1.01108	1.01356	0
s		0	6072	58.32	1910	820.5	0.04454	0.04815	0.04748	0
%RSD		0	6.576	4.585	43.31	5.637	4.432	4.762	4.684	0

Run	Time	4.5Bkg	23Na	24Mg	39K	44Ca	45Sc	115In	159Tb	220.5Bkg
		ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
		N1 1000x	3/9/2016 7:04:58 PM							
1	0.795116	0	100300	3570	8958	84400	0.95797	0.96806	0.961	0
2	0.795278	0	88660	3411	6214	78540	1.02295	1.02624	1.02638	0
3	0.79544	0	86330	3306	4937	76200	1.05973	1.05767	1.04908	0
x		0	91770	3429	6703	79710	1.01355	1.01732	1.01215	0
s		0	7487	132.9	2055	4222	0.05153	0.04546	0.04573	0
%RSD		0	8.159	3.875	30.65	5.297	5.084	4.469	4.518	0
		N2 1000x	3/9/2016 7:06:36 PM							
1	0.79625	0	100300	3143	6408	67170	0.96924	0.96641	0.97189	0
2	0.796412	0	90310	3022	3727	62870	1.02496	1.02044	1.01775	0
3	0.796574	0	90550	2979	2769	61810	1.05369	1.05933	1.05786	0
x		0	93730	3048	4302	63950	1.01597	1.01539	1.01583	0
s		0	5712	84.98	1886	2839	0.04294	0.04666	0.04302	0
%RSD		0	6.094	2.788	43.85	4.44	4.226	4.595	4.235	0
		O3 1000x	3/9/2016 7:08:14 PM							
1	0.797384	0	92350	2532	6578	35930	0.96725	0.96055	0.96704	0
2	0.797546	0	82590	2318	4031	33260	1.02475	1.02095	1.01835	0
3	0.797708	0	81650	2288	2783	32080	1.05386	1.05979	1.04974	0
x		0	85530	2379	4464	33760	1.01529	1.01376	1.01171	0
s		0	5923	132.9	1934	1971	0.04408	0.05001	0.04175	0
%RSD		0	6.925	5.588	43.32	5.839	4.341	4.933	4.127	0
		O4 1000x	3/9/2016 7:09:52 PM							
1	0.798519	0	112600	2673	6437	34690	0.95409	0.95465	0.96	0
2	0.798681	0	104200	2559	4449	33140	1.00932	1.01349	1.01226	0
3	0.798854	0	101400	2524	2989	32530	1.04689	1.05125	1.0487	0
x		0	106000	2585	4625	33450	1.00343	1.00646	1.00699	0
s		0	5875	77.86	1731	1110	0.04668	0.04868	0.04458	0
%RSD		0	5.54	3.012	37.42	3.319	4.652	4.837	4.428	0
		P5 1000x	3/9/2016 7:11:32 PM							
1	0.799676	0	73550	1769	7682	23210	0.9582	0.95469	0.95884	0
2	0.799838	0	62590	1698	5259	21810	1.01341	1.01097	1.00795	0
3	0.8	0	59710	1578	3556	20540	1.05176	1.05214	1.04736	0
x		0	65290	1682	5499	21850	1.00779	1.00593	1.00472	0
s		0	7305	96.52	2074	1334	0.04703	0.04892	0.04435	0
%RSD		0	11.19	5.739	37.71	6.106	4.667	4.863	4.414	0
		P6 1000x	3/9/2016 7:13:11 PM							
1	0.800822	0	138500	1802	13170	31130	0.97154	0.97023	0.96973	0
2	0.800984	0	123500	1596	10320	29500	1.01434	1.00962	1.01049	0
3	0.801146	0	119900	1582	8578	27970	1.06085	1.06056	1.05025	0
x		0	127300	1660	10690	29540	1.01557	1.01347	1.01016	0
s		0	9890	123.4	2316	1582	0.04467	0.04529	0.04026	0
%RSD		0	7.769	7.434	21.67	5.356	4.398	4.469	3.986	0

Run	Time	4.5Bkg	23Na	24Mg	39K	44Ca	45Sc	115In	159Tb	220.5Bkg
		ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
		N1 1000x	3/9/2016 7:04:58 PM							
1	0.795116	0	100300	3570	8958	84400	0.95797	0.96806	0.961	0
2	0.795278	0	88660	3411	6214	78540	1.02295	1.02624	1.02638	0
3	0.79544	0	86330	3306	4937	76200	1.05973	1.05767	1.04908	0
x		0	91770	3429	6703	79710	1.01355	1.01732	1.01215	0
s		0	7487	132.9	2055	4222	0.05153	0.04546	0.04573	0
%RSD		0	8.159	3.875	30.65	5.297	5.084	4.469	4.518	0
		N2 1000x	3/9/2016 7:06:36 PM							
1	0.79625	0	100300	3143	6408	67170	0.96924	0.96641	0.97189	0
2	0.796412	0	90310	3022	3727	62870	1.02496	1.02044	1.01775	0
3	0.796574	0	90550	2979	2769	61810	1.05369	1.05933	1.05786	0
x		0	93730	3048	4302	63950	1.01597	1.01539	1.01583	0
s		0	5712	84.98	1886	2839	0.04294	0.04666	0.04302	0
%RSD		0	6.094	2.788	43.85	4.44	4.226	4.595	4.235	0
		R7 1000x	3/9/2016 7:14:51 PM							
1	0.801979	0	266300	1917	6267	23810	0.96903	0.97282	0.97485	0
2	0.802141	0	243100	1761	3609	21420	1.02424	1.02208	1.01752	0
3	0.802303	0	240500	1697	2390	20690	1.06509	1.06307	1.05852	0
x		0	250000	1791	4089	21970	1.01945	1.01932	1.01696	0
s		0	14210	112.9	1983	1632	0.04821	0.04519	0.04184	0
%RSD		0	5.684	6.3	48.49	7.427	4.729	4.433	4.114	0
		R8 1000x	3/9/2016 7:16:32 PM							
1	0.803148	0	228200	2115	7683	27330	0.97781	0.98095	0.97393	0
2	0.80331	0	210800	1927	5038	24800	1.03459	1.0316	1.02473	0
3	0.803472	0	206800	1891	3575	24220	1.07212	1.07098	1.05992	0
x		0	215300	1978	5432	25450	1.02818	1.02785	1.01953	0
s		0	11360	120.4	2082	1652	0.04748	0.04513	0.04323	0
%RSD		0	5.279	6.086	38.33	6.49	4.618	4.391	4.24	0

Appendix H - Maxxam Results (ICP/MS)

Maxxam ID		BIK079	BIK080	BIK081	BIK082	BIK083	BIK084	BIK085	BIK086	BIK087	BIK088	BIK089	BIK090	BIK092	BIK093	BIK094	BIK095	BIK096	BIK097	BIK098	BIK099	BIK100	BIK101	BIK102	BIK103			
Sampling Date		#######	#######	#######	#######	#######	#######	#######	#######	#######	#######	#######	#######	#######	#######	#######	#######	#######	#######	#######	#######	#######	#######	#######	#######			
COC Number		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A			
	UNITS	**A1**	**A2**	**A4**	**B5**	**B7**	**B8**	**C1**	**C2**	**C3**	**D5**	**D7**	**D8**	**E1**	**E3**	**E4**	**F5**	**F6**	**F7**	**G1**	**G3**	**G4**	**H5**	**H6**	**H7**	**RDL**	**MDL**	**QC Batch**
Metals																												
Dissolved Aluminum (Al)	ug/L	ND	120	95	ND	23	21	9.0	170	150	18	1000	1100	ND	2800	2800	7.4	94	68	12	2200	2300	52	3300	3200	5.0	N/A	4276063
Dissolved Antimony (Sb)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.0	N/A	4276063
Dissolved Arsenic (As)	ug/L	ND	ND	ND	ND	3.8	5.3	ND	ND	ND	ND	28	27	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.0	N/A	4276063
Dissolved Barium (Ba)	ug/L	ND	2.2	2.1	1.3	5.5	6.8	ND	94	92	1.6	9.9	10	1.9	200	200	ND	1.8	1.4	1.1	150	150	1.1	120	130	1.0	N/A	4276063
Dissolved Beryllium (Be)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.5	2.4	ND	ND	ND	ND	1.7	1.6	ND	1.9	1.9	1.0	N/A	4276063
Dissolved Bismuth (Bi)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.0	N/A	4276063
Dissolved Boron (B)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	61	ND	ND	ND	ND	ND	ND	50	N/A	4276063
Dissolved Cadmium (Cd)	ug/L	ND	ND	ND	ND	0.030	0.035	0.011	0.094	0.091	ND	ND	ND	0.041	0.20	0.20	ND	ND	ND	ND	0.15	0.16	0.014	0.16	0.16	0.010	N/A	4276063
Dissolved Calcium (Ca)	ug/L	250	310	200	1400	2500	2800	5100	780	920	5100	7700	7700	200000	180000	180000	1800	1200	1500	120000	91000	98000	190000	170000	170000	100	N/A	4276063
Dissolved Chromium (Cr)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.0	N/A	4276063
Dissolved Cobalt (Co)	ug/L	ND	ND	ND	ND	ND	ND	ND	2.2	2.3	ND	ND	ND	ND	4.8	4.7	ND	ND	ND	ND	4.8	5.1	ND	5.2	5.3	0.40	N/A	4276063
Dissolved Copper (Cu)	ug/L	11	ND	ND	2.4	6.4	3.9	2.3	6.6	7.4	ND	ND	ND	4.3	25	20	ND	ND	ND	4.0	14	14	ND	13	12	2.0	N/A	4276063
Dissolved Iron (Fe)	ug/L	ND	69	ND	ND	ND	ND	ND	900	960	ND	79	110	ND	4100	4300	ND	53	56	ND	3000	3400	ND	3300	3500	50	N/A	4276063
Dissolved Lead (Pb)	ug/L	ND	6.1	ND	0.72	ND	ND	ND	0.75	0.60	ND	ND	ND	ND	5.0	4.7	ND	ND	0.71	ND	3.5	3.3	ND	14	4.1	0.50	N/A	4276063
Dissolved Magnesium (Mg)	ug/L	ND	ND	ND	ND	140	170	ND	480	500	ND	780	870	ND	930	920	ND	ND	ND	ND	860	850	ND	880	910	100	N/A	4276063
Dissolved Manganese (Mn)	ug/L	3.6	2.0	ND	2.2	11	12	ND	130	140	ND	2.3	2.7	ND	280	270	ND	2.9	3.9	ND	270	290	ND	280	300	2.0	N/A	4276063
Dissolved Molybdenum (Mo)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	4.3	4.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.0	N/A	4276063
Dissolved Nickel (Ni)	ug/L	ND	ND	ND	ND	ND	ND	ND	3.8	3.9	ND	ND	ND	ND	8.1	8.8	ND	ND	ND	ND	8.8	7.7	ND	8.1	8.0	2.0	N/A	4276063
Dissolved Phosphorus (P)	ug/L	ND	ND	ND	ND	ND	130	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	100	N/A	4276063
Dissolved Potassium (K)	ug/L	190	1400	1000	ND	740	77000	410	8600	9400	130	7900	8500	250	9800	9800	150	1400	1700	1000	8900	9100	210	11000	9300	100	N/A	4276063
Dissolved Selenium (Se)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.0	N/A	4276063
Dissolved Silver (Ag)	ug/L	ND	ND	ND	ND	ND	48	ND	0.16	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.24	ND	ND	ND	3.8	ND	0.10	N/A	4276063
Dissolved Sodium (Na)	ug/L	180000	160000	170000	180000	180000	170000	300000	290000	290000	330000	330000	330000	630	1000	920	560	740	790	620	900	880	550	930	910	100	N/A	4276063
Dissolved Strontium (Sr)	ug/L	ND	ND	ND	ND	9.7	11	ND	7.0	8.3	ND	29	28	61	67	67	ND	ND	2.5	63	55	59	94	91	95	2.0	N/A	4276063
Dissolved Thallium (Tl)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.18	0.18	ND	ND	ND	ND	0.16	0.16	ND	0.17	0.16	0.10	N/A	4276063
Dissolved Tin (Sn)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.0	N/A	4276063
Dissolved Titanium (Ti)	ug/L	ND	8.5	4.2	ND	ND	ND	ND	ND	ND	ND	7.4	11	ND	ND	ND	ND	8.5	2.6	ND	ND	ND	ND	ND	ND	2.0	N/A	4276063
Dissolved Uranium (U)	ug/L	ND	0.66	0.46	ND	4.9	6.7	ND	0.15	0.15	ND	7.5	8.7	ND	1.0	1.0	ND	0.18	0.16	ND	1.8	1.8	ND	2.4	2.5	0.10	N/A	4276063
Dissolved Vanadium (V)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.8	4.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.0	N/A	4276063
Dissolved Zinc (Zn)	ug/L	ND	ND	ND	ND	6.5	ND	6.1	14	10	ND	6.0	ND	6.8	23	18	ND	5.8	6.4	ND	14	15	ND	15	14	5.0	N/A	4276063

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Success Through Science®

Maxxam Job #: B612314
Report Date: 2016/01/26

Dalhousie University
Sampler Initials: OB

ELEMENTS BY ICP/MS (DRINKING WATER)

Maxxam ID		BRQ636	BRQ637	BRQ638	BRQ639	BRQ640	BRQ641	BRQ642		
Sampling Date		2016/01/12	2016/01/12	2016/01/12	2016/01/12	2016/01/12	2016/01/12	2016/01/15		
COC Number		N/A	N/A	N/A	N/A	N/A	N/A	N/A		
	UNITS	**L1**	**L2**	**L4**	**M5**	**M7**	**M8**	**I1**	**RDL**	**QC Batch**
Metals										
Dissolved Uranium (U)	ug/L	ND	0.926	0.946	ND	4.40	4.72	ND	0.100	4354336

RDL = Reportable Detection Limit
QC Batch = Quality Control Batch
ND = Not detected

Maxxam ID		BRQ643	BRQ644	BRQ645	BRQ646	BRQ647		
Sampling Date		2016/01/15	2016/01/15	2016/01/15	2016/01/15	2016/01/15		
COC Number		N/A	N/A	N/A	N/A	N/A		
	UNITS	**I2**	**I3**	**K5**	**K6**	**K8**	**RDL**	**QC Batch**
Metals								
Dissolved Uranium (U)	ug/L	4.51	4.28	ND	6.70	6.01	0.100	4354336

RDL = Reportable Detection Limit
QC Batch = Quality Control Batch
ND = Not detected

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Maxxam Job #: B643985
Report Date: 2016/03/08

Dalhousie University
Sampler Initials: OB

ELEMENTS BY ICP/MS (WATER)

Maxxam ID		BYQ540	BYQ541	BYQ542	BYQ543	BYQ544	BYQ545	BYQ546		
Sampling Date		2016/03/01	2016/03/01	2016/03/01	2016/03/01	2016/03/01	2016/03/01	2016/03/01		
COC Number		N/A	N/A	N/A	N/A	N/A	N/A	N/A		
	UNITS	**N1**	**N2**	**O3**	**O4**	**P5**	**P6**	**R7**	**RDL**	**QC Batch**
Metals										
Dissolved Uranium (U)	ug/L	2.9	3.1	3.4	3.6	3.3	2.5	31	0.10	4407294

RDL = Reportable Detection Limit
QC Batch = Quality Control Batch

Maxxam ID		BYQ547		
Sampling Date		2016/03/01		
COC Number		N/A		
	UNITS	**R8**	**RDL**	**QC Batch**
Metals				
Dissolved Uranium (U)	ug/L	31	0.10	4407294

RDL = Reportable Detection Limit
QC Batch = Quality Control Batch