Potential for Uranium Mobility in a Sandstone Aquifer in the Bridgetown Area, Nova Scotia

Hayley D. Pothier

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Department of Earth Sciences
Dalhousie University, Halifax, Nova Scotia

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DALHOUSIE UNIVERSITY

Department of Earth Sciences
Halifax, Nova Scotia
Canada B3H 4J1
(902) 494-2358
FAX (902) 494-6889

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AUTHOR: Hayley D. Pothier

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Abstract

The town of Bridgetown, Nova Scotia is considering switching its municipal fresh water supply from surface water to groundwater to help lower operational and maintenance costs. Preliminary chemical analysis of the groundwater has shown elevated uranium concentrations. The purpose of this study is to determine if the source of uranium in the groundwater is within the Triassic Wolfville Formation aquifer, which underlies the Bridgetown region. Drill core from Paradise, near Bridgetown, and well cuttings from the test wells at Bridgetown, were analyzed and logged to better understand the stratigraphy of the Wolfville Formation and to determine which, if any, horizons have elevated uranium that can be leached into the groundwater. Spectrometer assays were conducted on Paradise drill core and results indicated that horizons within the core have up to twice the background levels of uranium. Samples from these horizons along with well cutting samples from the Bridgetown wellfield underwent both acid and aqueous leachate testing. Test results indicate that leachable uranium is present in the rock, although concentrations in the leachate are still below values previously measured in well waters. These results suggest that the Wolfville Formation may indeed be a source of leachable uranium in the groundwater. Further leachate testing on bulk rock samples should be done, as results from the study on >74µm sediment suggests that there is mobile uranium available even in these coarse grained fractions. The results of this study would also suggest that continued monitoring of uranium concentrations in production wells in Bridgetown be continued.

Keywords: Uranium, Groundwater, Bridgetown, Paradise, Leachate Testing, Wolfville Formation

1.0 INTRODUCTION

1.1 Statement of purpose

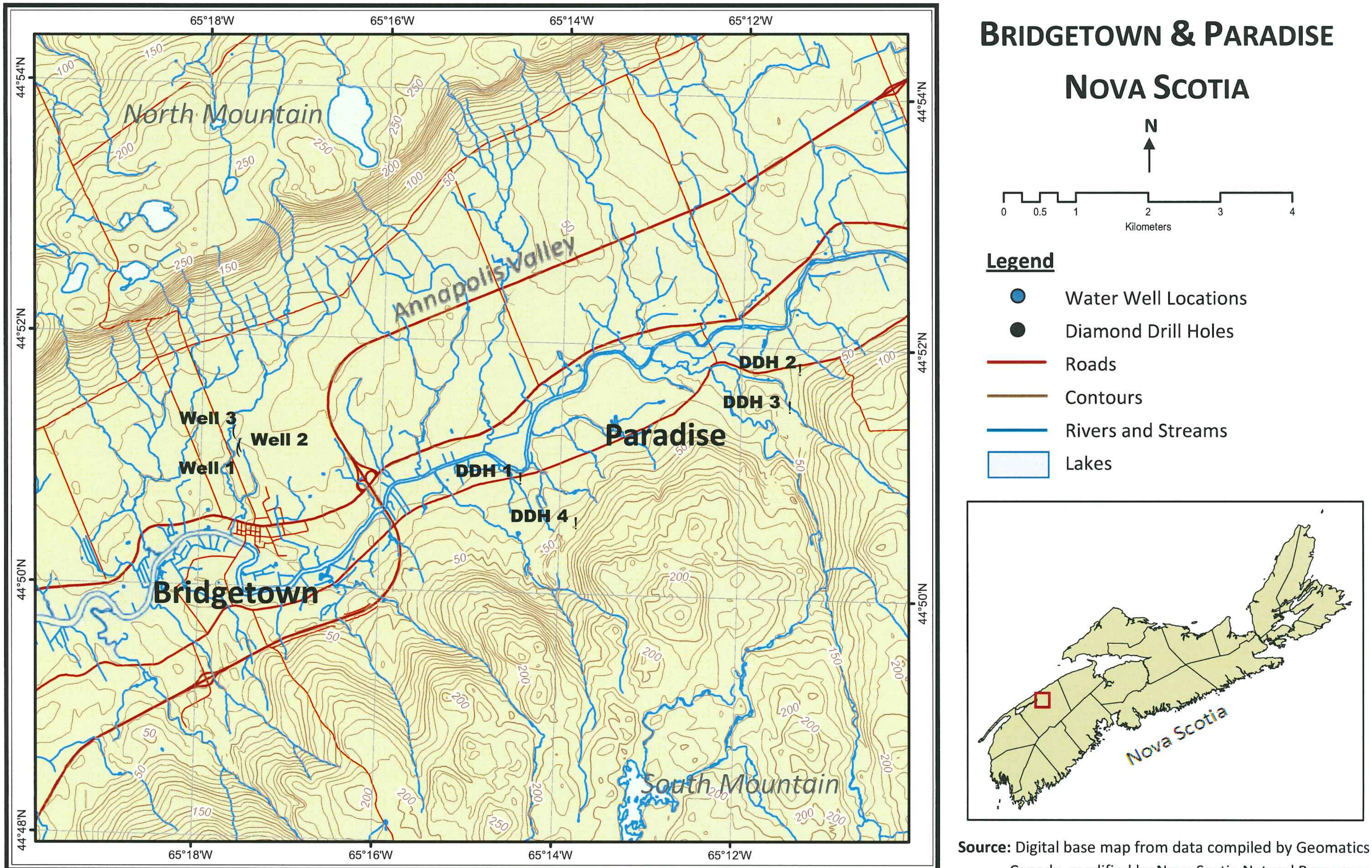
The town of Bridgetown, Nova Scotia is considering switching its municipal fresh water supply from surface water to groundwater to help reduce costs, but preliminary chemical analysis of the groundwater has shown elevated uranium concentrations. The purpose of this thesis is to determine if the source of uranium in the groundwater is the Wolfville Formation, which underlies the Bridgetown region and is the main aquifer for the region.

1.2 Study Area

1.2.1 Study Area Location

Bridgetown is located in the Annapolis Valley in southwestern Nova Scotia within the jurisdiction of Annapolis County (Figure 1.1). The elevation of the valley floor varies from 0-50 m above sea level and rarely exceeds a slope of 5% (Rivard et al., 2007). The surrounding uplands reach elevations up to 250 m above sea level. The North Mountain is located to the northwest and slopes down into the valley at about 20% to 35% and the South Mountain to the southeast with a slope into the valley ranging from 5% to 10% (Rivard et al., 2007). The local watershed surrounding Bridgetown has a surface area of 33 km^2 and is part of the larger Annapolis Valley watershed which drains an area of approximately 1600 km^2 into the Annapolis Basin via the Annapolis River (Rivard et al., 2007). The Nova Scotia climate is generally humid and temperate with an average annual temperature of approximately 6^{0}C (Trescott, 1968). The average rainfall for the Bridgetown area is 1279 mm/year (Rivard et al., 2007).

Figure 1.1: Bridgetown and Paradise, Nova Scotia



Source: Digital base map from data compiled by Geomatics Canada, modified by Nova Scotia Natural Resources.

1.2.2 Geologic Setting

Bridgetown is underlain by the Triassic Wolfville Formation and is bounded by the Triassic-Jurassic Blomidon Formation and the North Mountain Formation to the northwest, and by the South Mountain Batholith of Devonian age to the southeast (Figure 1.2). The Wolfville Formation was deposited unconformably on a basement of Cambrian-Ordovician rocks of the Meguma Supergroup and the South Mountain Batholith as alluvial fans and fluvial deposits in the Late Triassic (Trescott, 1968). It was subsequently buried by the Blomidon Formation, which is predominately composed of siltstones and claystones with minor interbedded sandstones (Trescott, 1968). The Wolfville and Blomidon Formations were in turn overlain by the North Mountain Formation, a series of basalt flows (Trescott, 1968). The Annapolis Valley was carved by glaciers during the last glacial period. The surficial sediments in the Bridgetown area rarely exceed a thickness of 5m (Rivard et al., 2007).

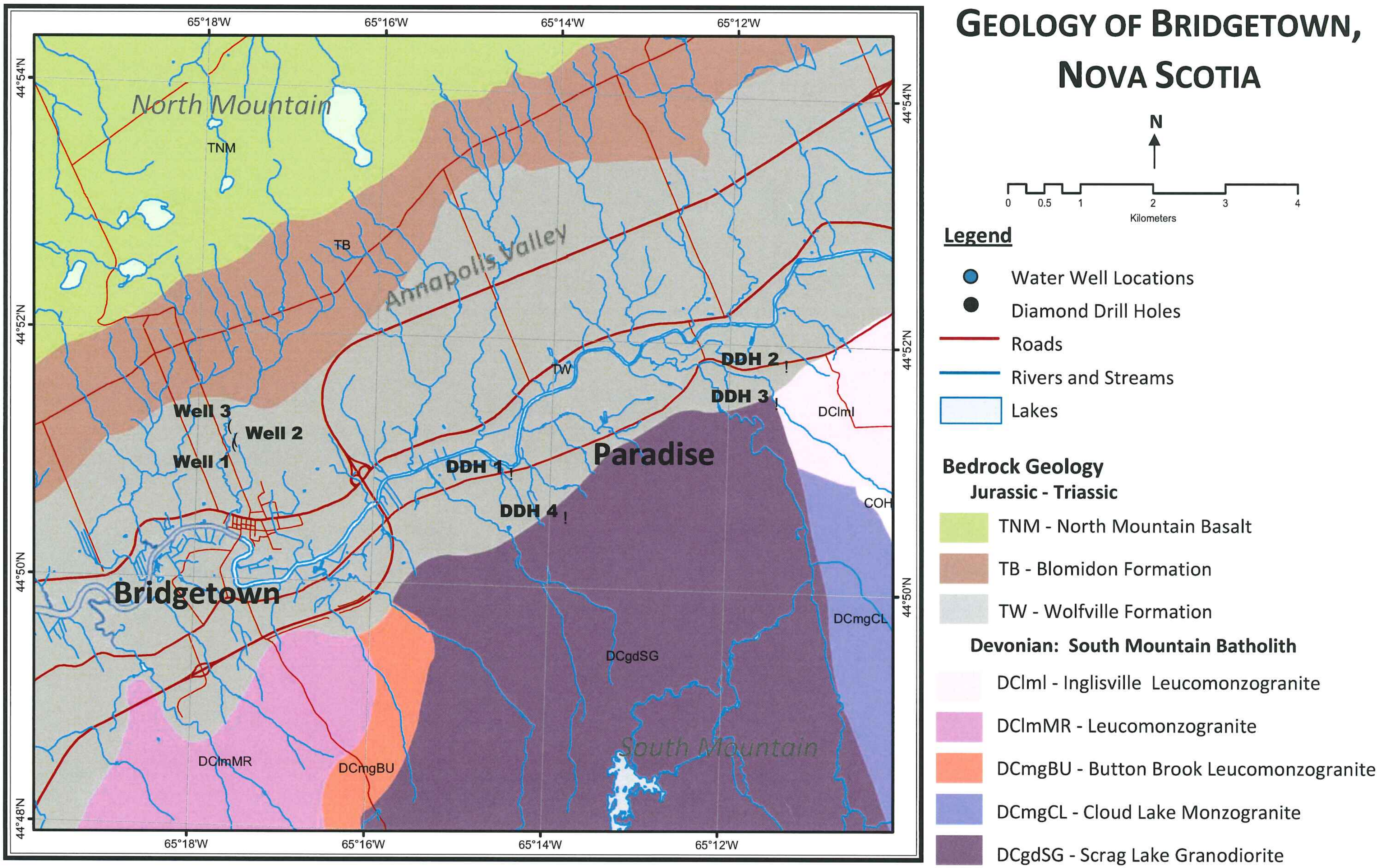
1.2.3 Wolfville Formation

The Wolfville Formation is composed of fluvial sediments deposited during the Triassic. The beds dip between 5-10 degrees to the northeast towards the Bay of Fundy and extend the entire length of the Annapolis Valley (Figure 1.2). The Formation reaches thicknesses of up to 833 m (Crosby, 1962), and is primarily composed of arenitic to subarkosic sandstones with minor pebble and conglomerate beds (Rivard et al, 2007). The rock is cemented with calcite, which is believed to be of secondary origin (Smitheringale, 1973). The clasts are mainly quartz and feldspars indicating that the source of the sediment supply would have been the adjacent metamorphic and granitic highlands (Rivard et al, 2007). A more detailed description of the rock composition is outlined in Table 1.1. The detrital matrix of the sandstone is made up of silt-sized quartz and feldspar, clay minerals, minor amounts of biotite, muscovite, and chlorite as well as clay sized hematite (Smitheringale, 1973). The majority of the rocks are reddish brown, but there are pale grey zones present as well (Smitheringale, 1973). In many beds colouring is irregular, with reddish brown patches found in grey zones and vice versa. The boundaries between colour changes are sharp and can be seen both crosscutting and parallel to bedding (Smitheringale, 1973).

Table 1.1: Modal composition of Wolfville Formation Sandstones (from Smitheringale, 1973).

Component	Approximate per cent composition	
	Range	Average
Quartz, quartzite, quartz grains containing pieces of feldspar	40-76	62
Feldspar	3-40	16
Sedimentary and metasedimentary rock fragments exclusive of quartzite	1-5	2
Detrital matrix	5-28	14
Calcite cement	0-25	6

Figure 1.2: Bedrock geology map of the Bridgetown and Paradise region



Source: Keppe, 2000; Trescott, 1968. Digital base map from data compiled by Geomatics Canada, modified by Natural Resources

1.2.4 Hydrogeology

The Wolfville Formation is considered the most important bedrock aquifer in the Annapolis Valley (Trescott, 1968). As mentioned earlier, the Wolfville Formation is a heterogeneous unit containing interbedded conglomerates and siltstones, but it is still considered one hydrostratigraphic unit since many of the water-bearing sandstones and conglomerate beds are interconnected and can be penetrated almost anywhere within the formation (Trescott, 1968).

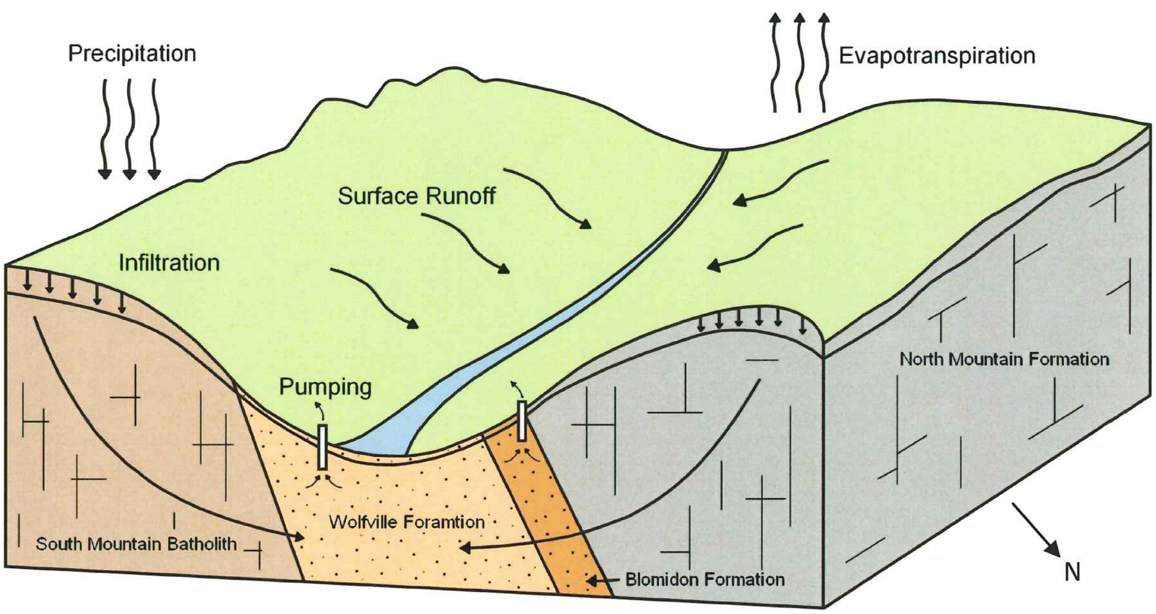
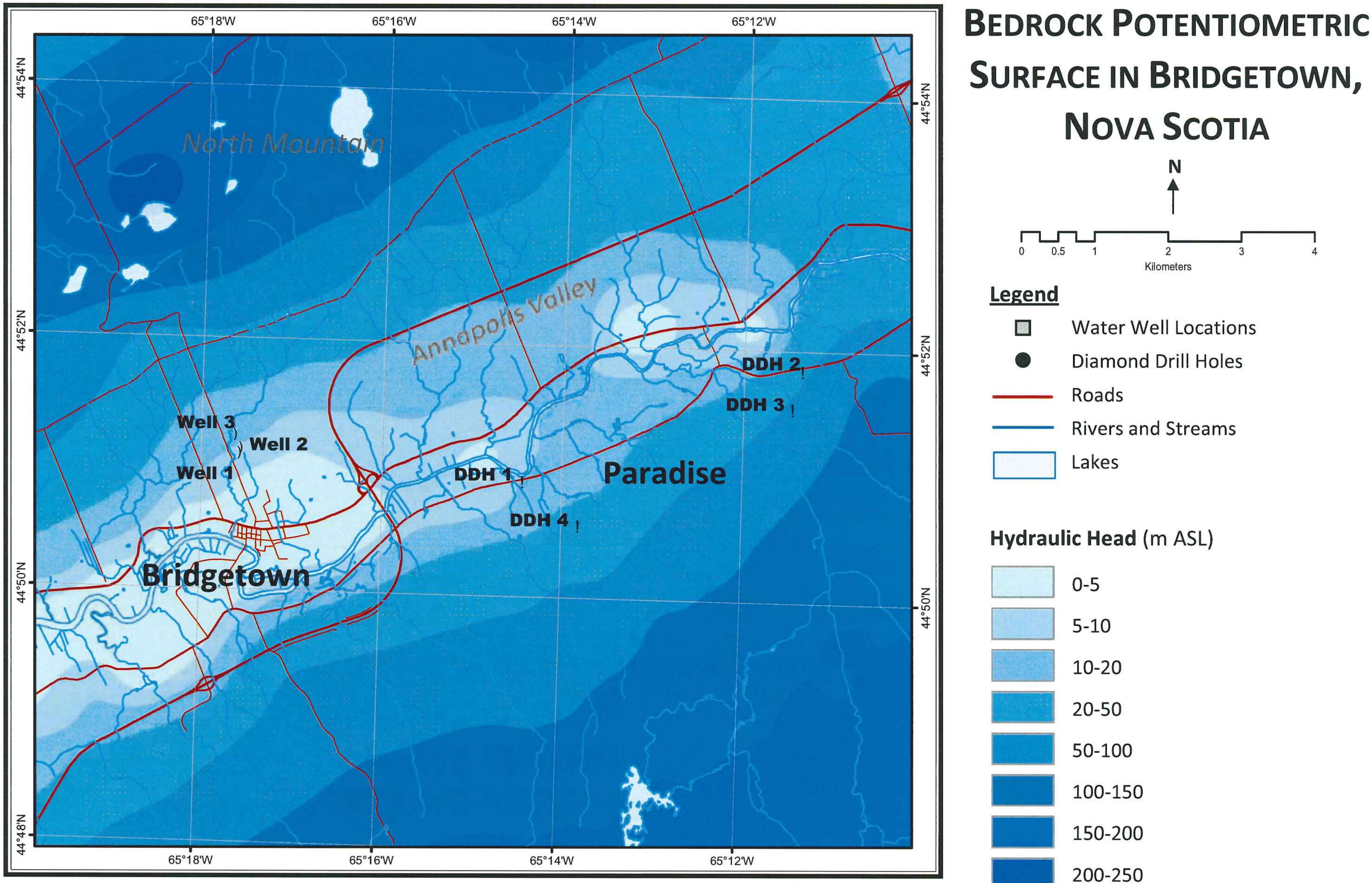


Figure 1.3: Groundwater movement in the Annapolis Valley (from Rivard et al., 2007)

Figure 1.3 illustrates a simplified version of movement of water in the region. Regionally, groundwater flow in the Annapolis Valley flows down gradient from the North and South Mountains towards the low lying valley floor where it eventually meets the Annapolis River and flows southwest into the Bay of Fundy. The watertable in the region follows the local topography (Trescott, 1986). Figure 1.4 shows the variability in hydraulic head in the Bridgetown region.

Figure 1.4: Bedrock potentiometric map of the Bridgetown and Paradise region (Rivard et al., 2007)



Source: Rivard et al. (2007); NSEL databases (2006); GSC field campaigns Trescott (1968). Digital base map from data compiled by Geomatics Canada, modified by Natural Resources Canada.

The primary mechanism for groundwater flow in the South Mountain Batholith and the North Mountain Basalts is through fractures in the bedrock. In the Wolfville and Blomidon Formations, groundwater movement is concentrated in the sandstone and conglomerates and flows through intergranular pore spaces while flow through joints is only secondary (Trescott, 1968). Groundwater flow will also move towards layers with higher permeability. The rate of movement across less permeable siltstones and claystones is likely to be slow in areas where vertical circulation is present, such as the upward movement beneath the major streams (Trescott, 1968).

Another mechanism that influences groundwater movement is the act of pumping. Extracting water from an aquifer causes the watertable surrounding the pumping well to decrease forming a cone of depression. This changes the local hydraulic head causing groundwater to move towards the pumping well. The rate of pumping and aquifer properties, such as transmissivity and storativity, will determine how far the watertable will decline and to what extent it influences local or regional groundwater flow (Cech, 2005).

When rainwater first reaches the ground it has little dissolved mineral matter, but as the water infiltrates through surficial deposits and bedrock its chemistry changes. The longer groundwater is in contact with the surrounding rock the more time it has to dissolve solids as it migrates through the aquifer, therefore groundwater chemistry is greatly influenced by the composition of the aquifer through which it moves and the contact time (Trescott, 1968). The main cementing agent within the Wolfville Formation is calcium carbonate, therefore calcium and bicarbonate are important cation and anion contributors, respectively, to the total dissolved solids. They are also the main contributors to the hardness and alkalinity. The resulting groundwater is slightly basic with a pH that is commonly less than 8.2 (Trescott, 1968). Generally though, the Wolfville Formation contains good quality waters as compared to Health Canada's Guidelines for Canadian Drinking Water Quality.

1.3 Organization of Thesis

Chapter 2 provides details about the history of the Bridgetown wellfield project, as well as information about the geochemistry of uranium as it relates to groundwater. Chapter 3 will outline the methods used in collecting and analyzing data that had been obtained previously and the data acquired as a part of this thesis. Chapter 4 provides a detailed account of all of the results from this study of the Bridgetown water well cuttings and the Paradise Drill Core and also the results of the leachate tests performed on samples collected from both the well cuttings and the drill core. Chapter 5 discusses the relevance of the results and how they relate to previously obtained data, as well as recommendations for future work.

2.0 BRIDGTOWN WELLFIELD PROJECT

2.1 Project History

This overview is based on the work of D'Eon, 2007. In 2001 a water treatment feasibility study was conducted by CBCL for the Town of Bridgetown to determine the options and costs associated with water treatment. The Town currently uses surface water as its freshwater supply, but after evaluating both surface water treatment and groundwater options, the Bridgetown Council decided to pursue groundwater as a source of fresh water for the town on the basis of lower capital, operational, and maintenance costs. In March 2006, three test wells were drilled to determine whether the quantity and quality of the water would meet the needs of the town and meet drinking water standards. Figure 1.1 shows the test well locations. Twenty-four hour pumping tests and water quality sampling were carried out on all three wells. The yield was determined to be sufficient, and met the water quality Guidelines for Canadian Water Quality; however, uranium levels were 15 μg/L, just 5 μg/L below the guidelines of 20 μg/L.

A water supply well just 600m away from the proposed wellfield location has shown uranium concentrations of 27 μg/L, indicating that uranium concentrations in groundwater vary not only regionally but locally as well. Further long term testing was recommended to evaluate the potential for uranium concentrations to change with continued pumping, as well as, temporal variation of uranium in the groundwater.

A long term pumping test was conducted on well 3 for 30 days in August 2006 and uranium levels remained below 14 μg/L. Based on the results of this testing, the Town Council decided to upgrade wells 2 and 3 to production wells, and they were drilled to a larger diameter and lined with casing and screens to accommodate this decision. Figure 2.1 illustrates a stratigraphic profile of the

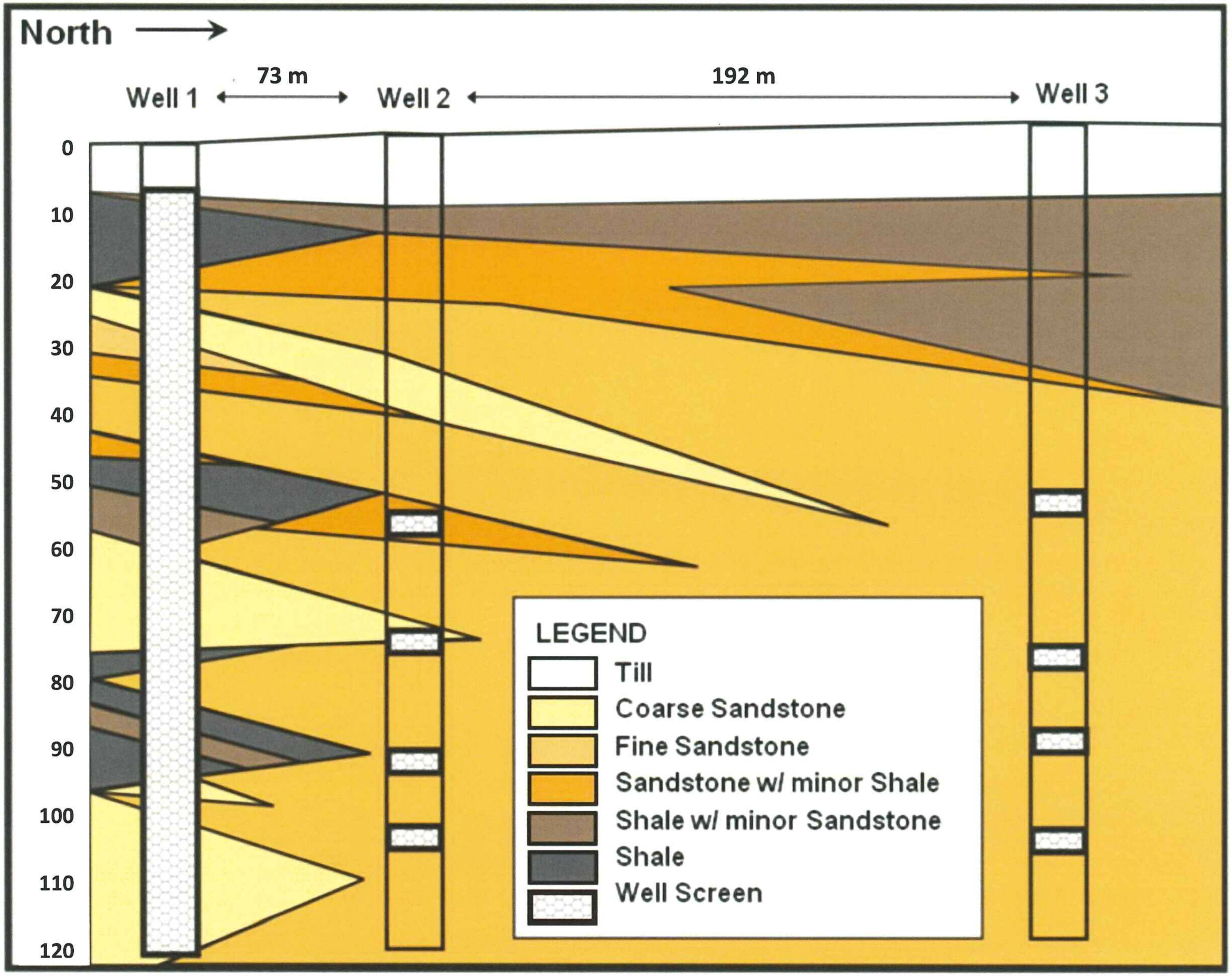


Figure 2.1: Stratigraphic profile of water wells in the proposed Bridgetown wellfield (CBCL, 2007).

wellfield site and the locations of the screens that were installed. Subsequent water quality samples were taken during a 72 hour pumping test on the two new production wells and elevated uranium was again detected, with levels as high as 19 µg/L in well 2 and 27 µg/L in well 3. The results are summarized in Table 2.1.

Table 2.1: Uranium concentration results from 72 hour pumping tests (D'Eon, 2007).

	Uranium (2 hr)	**Uranium (36 hr)**	**Uranium (72 hr)**
Well 2	16 µg/L	18 µg/L	19 µg/L
Well 3	20 µg/L	24 µg/L	27 µg/L

Screening only the production zones of fractured sandstone and sealing the rest of the borehole with casing causes preferential flow through the production zones. If these zones are associated with higher uranium concentrations then any apparent dilution from zones with lower uranium concentrations will be reduced.

Depth discrete sampling was conducted on the wells to determine if uranium concentrations were higher is specific horizons. The results of this sampling are located in Appendix A. If uranium concentrations are shown to be elevated at a certain depth, then that section of the well may be sealed off to reduce the input of water through that portion of the aquifer and as a result it may lower the uranium concentration in the well water. Figure 2.2 illustrates the results of the depth discrete sampling on the three wells. Uranium concentrations were all below the 20 µg/L guideline and only one was below 10 µg/L. The only horizon that was of concern was located near the deepest screen of well 3 between 103-105 m, which produced a uranium concentration of 14 µg/L. With the assumption that the elevated uranium concentration at this depth was contributing to the high uranium values during the 72 hour pumping test, well 3 was modified by sealing off the bottom screen.

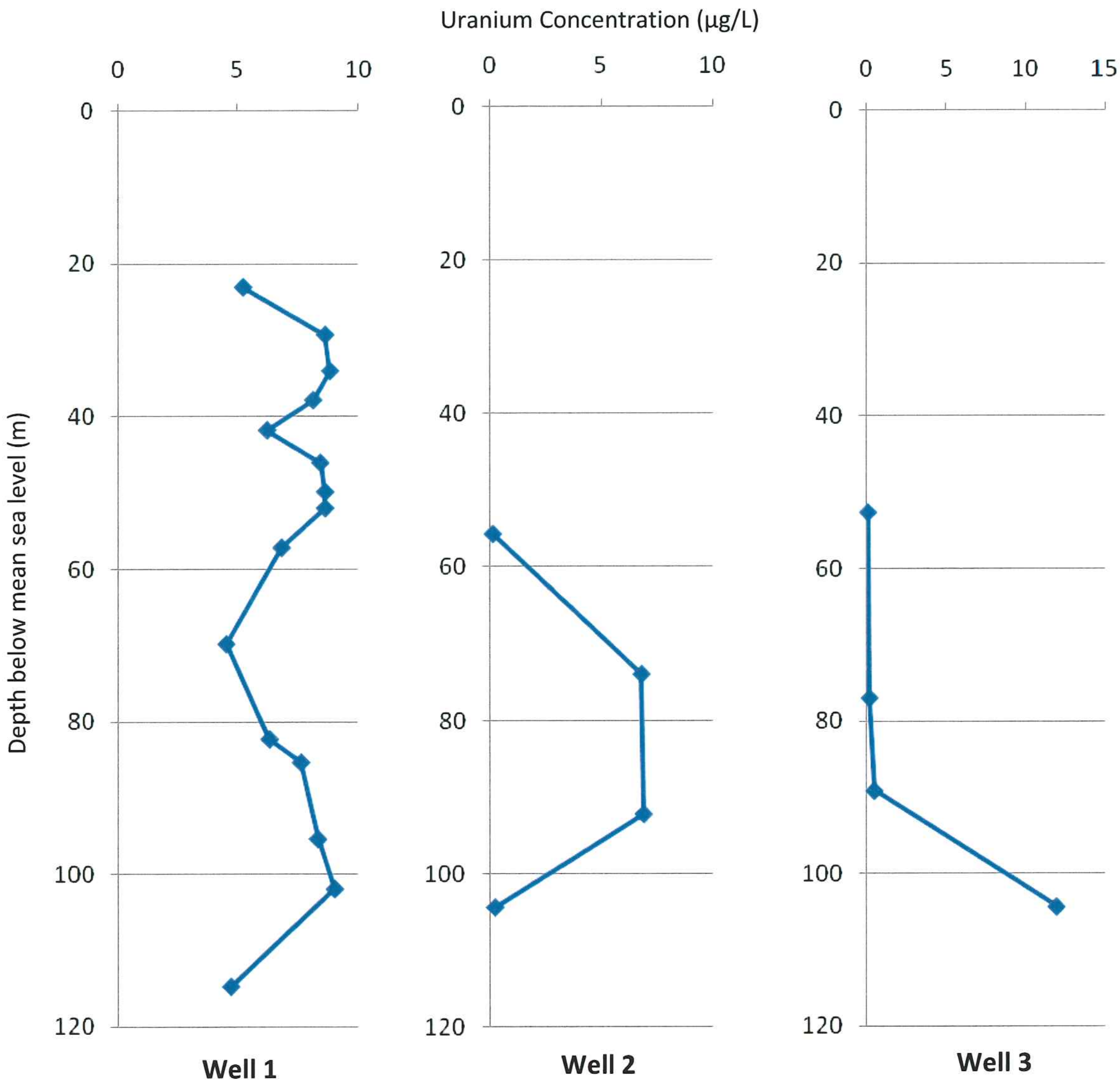


Figure 2.2: Depth discrete sampling for dissolved uranium on Well 1 was done while it was still an open borehole while sampling on Wells 2 and 3 were done once they had been screened (CBCL, 2007).

Another 72 hours pumping test was conducted on well 3, and it was found that uranium levels dropped below the guideline.

2.2 Physical and Chemical properties of Uranium

Uranium is a naturally occurring radioactive element that is commonly found in trace amounts in a variety of rock forming minerals. The solubility of uranium is determined by its valence state. Uranium occurs in the 4+ oxidation state in its reduced form where it remains stable and essentially immobile in reducing conditions (Ivanovich and Harmon, 1992). In near-surface environments uranium can be oxidized to either U^{5+} or more commonly U^{6+}. The more stable 6+ oxidation state forms the soluble uranyl complex ion (UO_2^{2+}), which plays the most important role in uranium transport in groundwater (Ivanovich and Harmon, 1992).

The uranium concentrations present in groundwater are influenced by variables such as contact time within the uranium-bearing horizon, uranium content of the horizon, amount of evaporation and the availability of complexing ions (Ivanovich and Harmon, 1992).

The uranyl ion forms a variety of soluble complexes with carbonate, phosphate, sulphate, fluoride, and silicate ions. In alkaline pH conditions, soluble carbonate complexes increase the solubility and mobility of uranium (Kronfeld et al, 2004). Uranium concentrations within an aquifer can vary from place to place depending upon changes in Eh-pH which can cause uranium to mobilize or precipitate from solution along its flow path (Ivanovich and Harmon, 1992). Figures 2.3 and 2.4 outline the relationship between the solubility of different uranyl complexes and the pH of the solution. The most common complex found in natural waters is the soluble uranyl carbonate complex (UO_2CO_3). We can see from Figure 2.3 shows that the presence of carbonate complexes in solutions with a pH greater than 5 will significantly influence the possible proportion of dissolved uranium.

Apart from uranium minerals such as uraninite, uranium is also common trace component of many other rock forming minerals. Uranium is released from rocks by weathering. Many minerals, such as zircon, that contain uranium, are often insoluble and isolate the uranium from the groundwater, but minerals, such as biotite, may have uranium present along grain boundaries and when weathered the uranium is easily mobilized under oxidizing conditions (O'Beirne-Ryan and Zentilli, 1999).

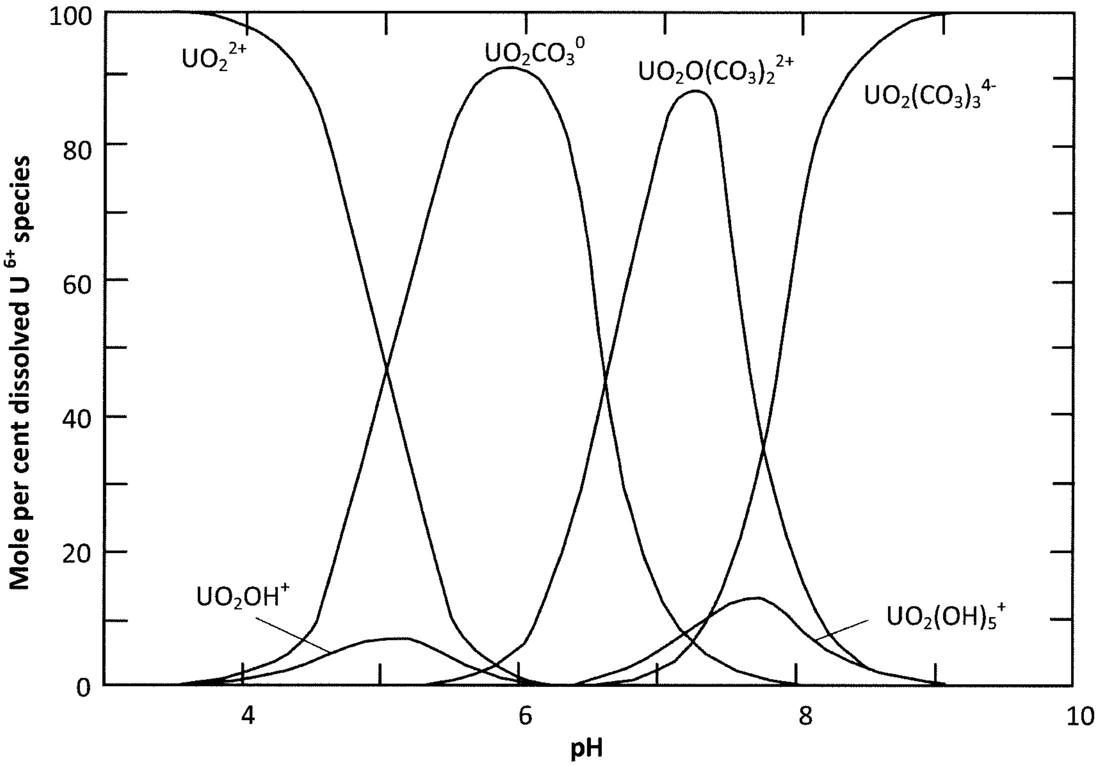


Figure 2.3: Distribution of uranyl-hydroxy and carbonate complexes plotted against pH for $p_{CO2} = 10^{-2}$ atm, and total uranium concentration of 10^{-8} M at 25°C (from Ivanovich and Harmon, 1992).

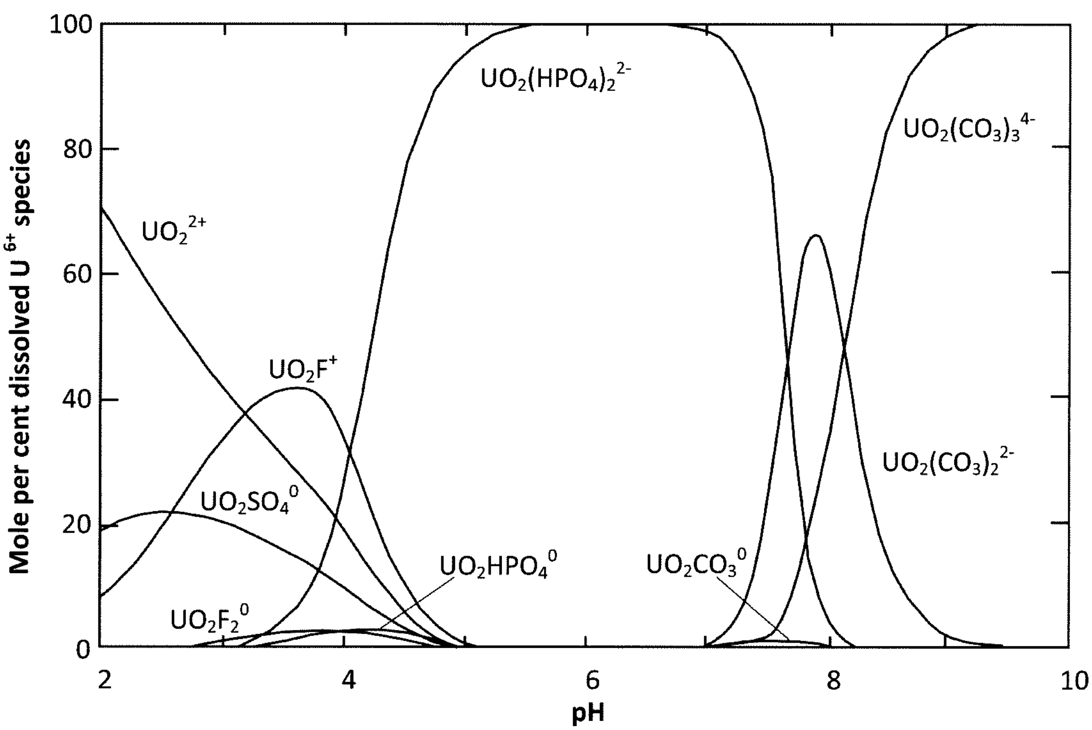


Figure 2.4: Distribution of uranyl complexes plotted against pH at 25°C for total uranium concentration of 10^{-8} M, in the presence of other ions: $\sum F = 0.3$ ppm, $\sum Cl = 10$ ppm, $\sum SO_4 = 100$ ppm, $\sum PO_4 = 0.1$ ppm and $\sum SiO_2 = 30$ ppm (from Ivanovich and Harmon, 1992).

3.0 METHODS

A number of techniques were used to obtain data to help better understand the stratigraphy of the Wolfville formation and to determine if the Wolfville Formation could be the source of uranium found in the groundwater in the Bridgetown area.

3.1 Bridgtown Water Well Cuttings Analysis

Water well cuttings were collected by CBCL Limited in 2006 (D'Eon, 2007) at 1.5 or 3 metre intervals while the test wells in Bridgetown were being drilled. As the material was brought up to the surface it passed through a 74 µm sieve and was placed in plastic bags on site. The samples were collected in an attempt to locate coarse grained sandstone and conglomerate horizons within the well bore hole. Depending on the degree of cementation, sandstones and conglomerates typically form good aquifers because of high porosity and permeability values.

This study subsequently worked with the cutting samples collected. They were laid out at room temperature to air dry, and then examined using a x4 microscope to determine grain size, grain composition, and grain shape for each of the samples.

3.2 Paradise Drill Core Analysis

In 1999, three diamond drill cores were drilled in Paradise by Hibernia Minerals Inc. (Wightman, 1999). They are located approximately 6 km from the Bridgetown wellfield as shown in Figure 1.1. Grain size, grain composition, degree of consolidation and colour were all recorded. The core was assessed with a scintillometer to determine if any horizons had elevated radiation levels. A scintillometer is an instrument that detects gamma radiation from radioactive materials, such as uranium, thorium and potassium. Gamma rays are detected when they encounter the sodium iodide crystal within the instrument. This results in free electrons and light emissions which are converted into electrical pulses. The number of pulses or counts is related to the quantity of radioactive material in the sample (O'Reilly, 1982). The distance at which the instrument is held from the sample will influence the total counts per minute. All the measurements were taken with the scintillometer resting up against the sample to help minimize any error. Horizons with measurements higher than background levels of radiation can be said to contain elevated radioactive material.

Assays were conducted using a gamma ray spectrometer approximately every 1.2 m to determine minimum uranium concentrations in the Paradise drill core. A gamma ray spectrometer operates the same way as a scintillometer, but it is more sophisticated in that it can detect the amount of radiation emitted by different elements. The gamma ray emissions of different elements have different energies associated with the radioactive decay. With this method radioactive emissions from uranium can be distinguished from other radioactive elements, such as potassium, and a minimum uranium concentration can be determined for each sample (O'Reilly, 1982).

3.3 Acid Leachate Testing

Three well cutting and 3 drill core samples were sent to Maxxam Analytics in Bedford, NS where they underwent the synthetic precipitation leaching procedure (SPLP). This involves immersing the sediment sample into a mildly acidic solution with a pH of 4.2. This testing method simulates leaching that would occur in acid rain conditions and evaluates the potential for leaching metals including uranium under these and similar conditions. A summary of the SPLP method by Maxxam Analytics is contained in Appendix B.

Three 50 g samples were taken from cuttings from well 1 between 15-18 m, 39-42 m, and 48-51 m. These samples were chosen based on the depth in the well, grain size, shape and type. To perform the leachate tests a minimum of a 250 mL sample was needed which significantly reduced the number of cutting samples to choose from. All cutting samples from wells 2 and 3 were too small, but the majority of the cutting samples from well 1 were large enough. Well 1 was also an ideal well to sample as it is the only well that has screen installed the entire length of the well, while wells 2 and 3 only have screens located at 4 specific sandstone horizons indicated in Figure 2.1. Three samples were then chosen based on grain size and composition. Samples that were entirely coarse grained sand or entirely silt were avoided. Uranium would be less likely to be present in the coarse grained samples that were almost entirely composed of quartz with little feldspar because these minerals do not readily incorporate uranium into their crystal structure (Tieh and Ledger, 1981). The fine grained material may contain mineral or clay grains that contain uranium, but since the fine grained material has a low permeability, there is likely limited groundwater flow through these horizons. For these reasons samples were chosen from horizons that contained both a coarser grained fraction as well as some finer grained material.

Three samples were also taken from drill core 1 in the Paradise region close to Bridgetown. These samples were chosen based on the results from the scintillometer readings. Sample 4 was taken from a horizon at 65 m depth that read the highest values of up to 220 cps, sample 5 was taken from a horizon at 71 m depth with intermediate values of approximately 120 cps, and sample 6 was taken from a horizon at 36 m depth that read only slightly above background levels of approximately 90 cps.

3.4 Aqueous Leachate Testing

Three samples from the Bridgetown well cuttings and 4 samples from the Paradise drill core were chosen for aqueous leachate testing. The cutting samples were taken from well 1 between 18-21 m, 33-36 m, and 52-55 m in depth and were chosen based on the same criteria outlined in the acid leachate testing section 3.3. Four samples were taken from the drill core. Two samples were selected from drill core 1 at 38 m and 71 m depth respectively and the other two samples were selected from drill core 3 at 26 m and 44 m depth. These samples were chosen based on assay results with the spectrometer that showed uranium concentration above background levels and by similarities in grain size and colour to those of the well cuttings.

One hundred grams was collected from each sample and was lightly crushed and placed in a glass beaker along with 300 mL of distilled water. Distilled water was used because the pH of groundwater in the Wolfville Formation has been recorded as being slightly basic (Trescott, 1968) and a neutral pH would be closer to natural conditions than the pH of 4.2 in the acid leachate testing method. It also meant that there was little or no addition of ions from the water.

The samples were placed on an agitator table rotating at 100 revolutions per minute for 14 hours. The time from was chosen based on experiments previously done by Parsons (2007) on similar uranium mobility testing from Carboniferous sandstones in the region surrounding Windsor, NS. Using this method, Parsons (2007) concluded that the total dissolved solids in the leachate reached relatively constant values after approximately 8 hours.

The samples were then sent to Maxxam Analytics in Bedford, NS where they were filtered at 45 μm and underwent water quality analysis for metals, total alkalinity ($CaCO_3$), dissolved chloride (Cl^-) and dissolved sulphate (SO_4^{2-}).

3.5 Core Washing Experiment

In an attempt to correlate the mineralogical composition of water well cuttings to the drill core 23 samples (including those collected for the aqueous leachate tests) were placed in glass flasks and placed on an agitator table for 14 hours. These samples were then passed through a 63 μm sieve to mimic the sieve used to collecting the cuttings from the water wells. The washed samples were then analyzed using the same method outlined in section 3.1. The drill core samples selected for washing were chosen because they appeared to have the most similar grain size, grain type, and colour as the well cuttings.

3.6 Methods Summary

The mineralogical composition of both the well cuttings and drill core was determined and these findings along with the scintillometer and assay results were used in order to choose appropriate samples for both leachate test methods.

4.0 RESULTS

4.1 Bridgetown Water Well Cutting Analysis

The 74 μm sieve removed a considerable amount of the fine grained material from the well cutting samples collected. The cutting samples that still contained some fine-grained material were typically reddish brown, which can be attributed to the reddish brown colour of the fine-grained silt and clay. Coarse grained samples that lacked significant fine material appeared more pinkish grey. The most abundant clast type in the samples was quartz which made up 50% of the clasts and approximately 80% of the lithic clasts in the form of sandstone clasts or quartzite. About 75% of the cuttings samples were quartz. Feldspars made up 20% of the clasts and the remainder was composed of granite and metasedimentary rock clasts as well as mica, and unidentified black minerals, which may be a type of oxide. A detailed description of the water well cutting samples is given in Appendix C. Table 4.1 summarizes the average composition for the samples taken from all three water wells.

Table 4.1: Modal composition of water well cuttings from wells 1, 2, and 4 from the Bridgetown wellfield site

	Approximate per cent composition	
Component	Range	Average
Quartz	10-85	50
K-Feldspar	0-50	13
Plagioclase	0-10	4
Lithics (including sandstone, siltstone, quartzite, granite)	0-90	32
Other	0-5	1

The grain size varied from silt to very coarse-grained sandstone, with clasts as large as 13 mm and the majority of the samples appeared to be relatively poorly sorted. Figure 2.1 outlines the stratigraphic profile complied by CBCL Limited that was produced at the time of drilling.

Figure 4.1: Stratigraphic log of cuttings from water well 1

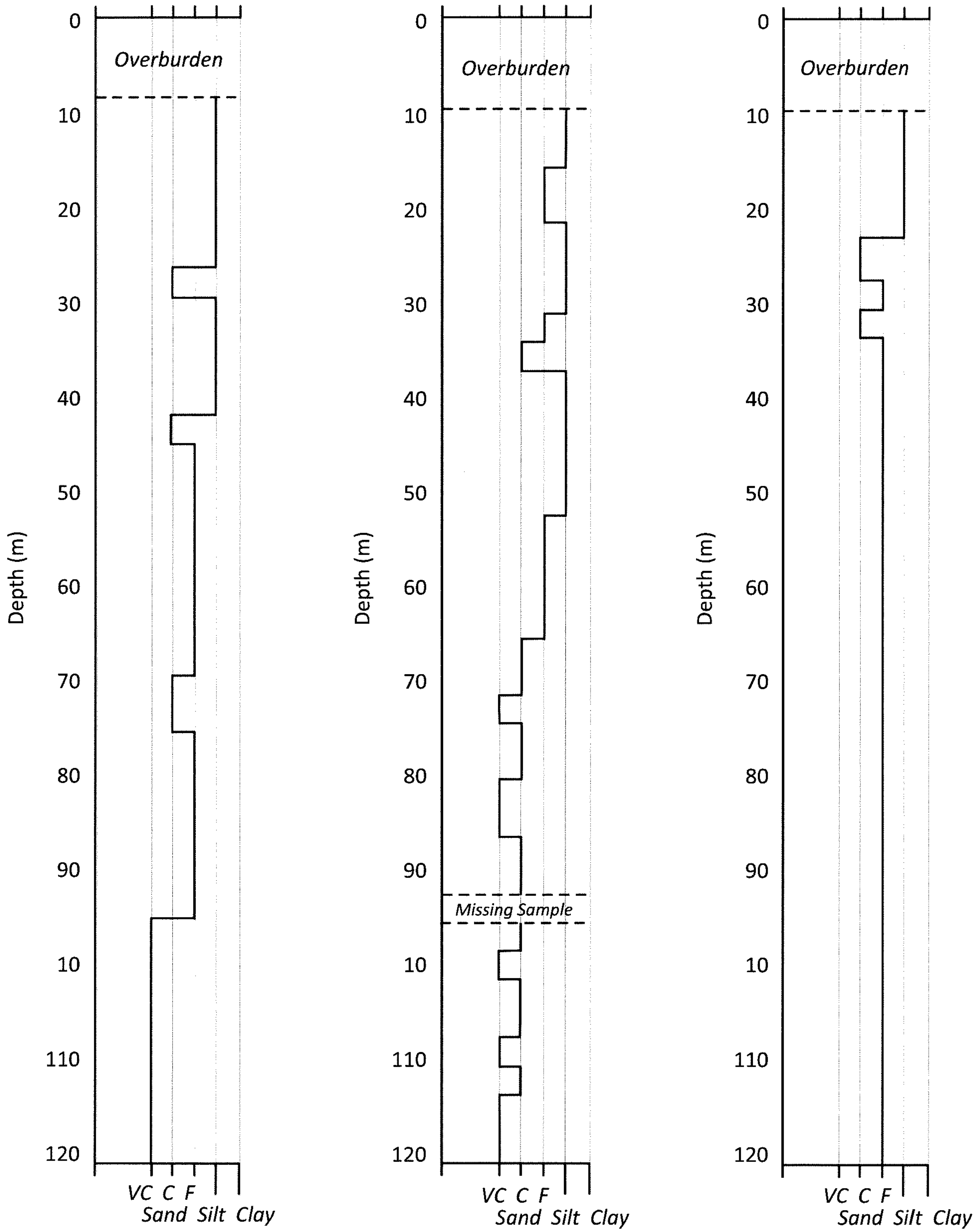


Figure 4.1 illustrates the grain size logs for the cuttings taken from the Bridgetown water wells that were produced as a result of this study. The clasts were typically sub-rounded, but sub-angular to rounded grains were commonly found in the same sample. Coarse grained (>2 mm) were also typically better rounded than the fine-grained (<2 mm) clasts.

4.2 Paradise Drill Core Analysis

4.2.1 Core Description

The four cores drilled in the Paradise region were all predominately coarse-grained sandstone with minor fine-grained sandstone and siltstone layers. Clast composition remained relatively consistent throughout and was dominated by quartz and feldspar. Mica, including biotite and muscovite was also visible in much of the core. There also appeared to be significant amounts of white clay minerals, presumably kaolinite, which may have originated from weathered feldspar grains (White et al., 2001). Due to the somewhat patchy record of the core and the lack of any distinctive beds, it was not possible to correlate the cores with one another.

Core 1 represented an interval from 29.5 m to 99.5 m in depth for a total of 70 m. There were numerous locations throughout the drill core that were missing, leaving only 46 m of core present but in place. The majority of this core was light grey in colour with limited red or red and grey mottled horizons. Figure 4.2 shows a log of the core including locations of the finer grained layers. Unlike drill Cores 2-4, Core 1 did not penetrate into the weathered granite below.

Core 2 represented the interval from 8 m to 33.5 m in depth for a total of 25.5 m. This section was predominately red in colour with some red and grey mottled horizons. This core penetrated into the granite unit below and showed a gradual contact. There were some large boulder- sized granite clasts near the base of the contact.

Core 3 represented the interval from 26.5 m to 61.5 m in depth for a total of 35 m. Colouring within the core was either light grey or red with significant mottling throughout. Similar to Core 2, this core showed a gradual contact between the sandstone unit and the underlying granite. There were also large boulder-sized granite clasts near the base of the contact.

Core 4 represented the interval from 20.5 m to 90.5 m in depth for a total of 70 m. The majority of this core was light grey in colour with limited red or red and grey mottled horizons. The fine-grained sandstones and siltstones were all a red to reddish brown colour. The contact with the underlying granite was also gradual in this core.

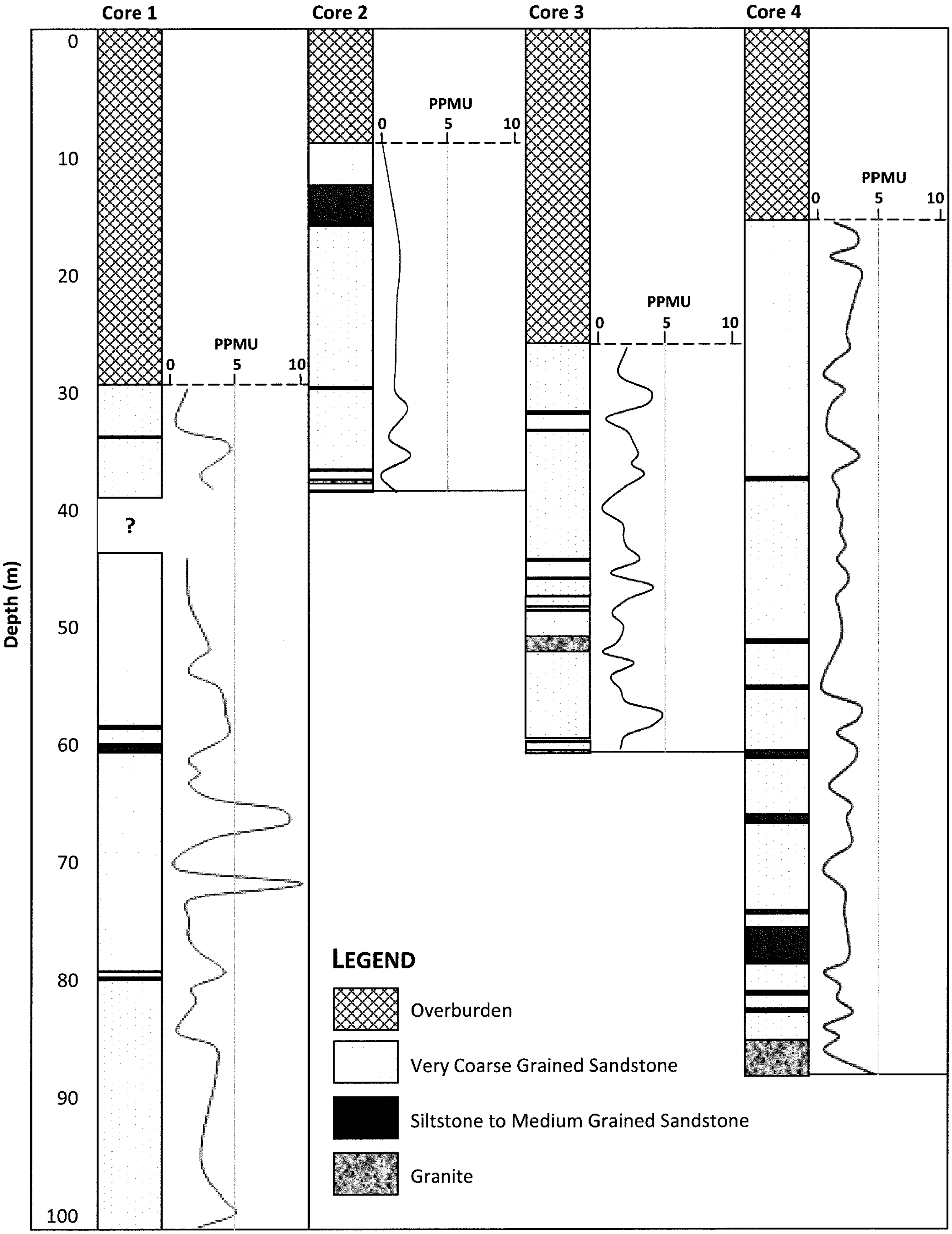
4.2.2 Scintillometer Results

Background count was determined to be approximately 90 cps. The majority of the core gave background values. There were slightly higher values found in some parts of core 1. Between 61-62 m and 64-68 m values reached approximately 100 cps, and between 64.5-65.5 m values reached up to 225 cps, which is over twice background. This latter section consisted of light grey and red mottled coarse-grained sandstone. Core 3 also had some sections that were only very slightly above average at about 110 cps between 40-43 m and 50-54 m. There was no evident relationship between grain size or colour and the variations in cps found within the core.

4.2.3 Spectrometer Assay Results

The assay results were consistent with those found with the scintillometer. Most of the assays conducted produced uranium concentrations within the range of background levels. The background level ranged from 0 ppmU to 7 ppmU with an average of 1.8 ppmU. From these results, it can be concluded that any reading giving values higher than our maximum background level will have elevated uranium present in the rock. In Core 1, there were 3 assays with significant results; 8.4 ppmU at 65 m

Figure 4.2: Stratigraphic log and parts per million uranium (PPMU) of diamond drill core from Paradise, Nova Scotia.



depth, 8.7 ppmU at 66 m depth, and 10.0 ppmU at 71 m depth. In Core 2 no results gave values above 4.7 ppmU. In Core 3 there was only one reading of 5.1 ppmU at 55.5 m depth. In drill core 4 there was also only one reading of 4.9 ppmU at 87 m in depth (Figure 4.2).

4.3 Acid Leachate Testing

Information about the samples that underwent acid leachate testing, using the synthetic precipitation leachate procedure, is outlined in Table 4.2 and the results of the chemical analysis of the leachate using the synthetic precipitation leaching procedure are listed in Table 4.3. Leachable uranium was present within 5 of the 6 samples. The values recorded ranged from less than 1 μg/L to 2 μg/L. There was a significant different in the final pH of the leachate from the Bridgetown well cutting samples, which were slightly basic, and the Paradise drill core samples, which were slightly acidic. There were no visible trends with the leachability of other metals that were tested as well.

4.4 Aqueous Leachate Testing

Information about the samples that underwent the aqueous leachate testing is outlined in table 4.4 and the results of the chemical analyses are listed in Table 4.5. Leachable uranium was present in all seven of the samples. The values recorded ranged from 0.3 μg/L to 5.7 μg/L. As with the acid leachate tests, there was a significant difference in the final pH of the leachate from the Bridgetown well cutting samples, which were again basic, and the Paradise drill core samples, which were again acidic.

Figure 4.5 illustrates a variety of leachable metals plotted against leachable uranium concentrations. There were no significant trends with any of the metals except vanadium which had an r-squared value of 0.95 indicating that there may be a relationship. This positive linear relationship with vanadium was also visible when looking at the depth discrete sampling data collected from water well 1

(Figure 4.6). In addition to vanadium there was also a negative linear relationship between uranium and manganese that was not visible in the leachate tests that were performed as part of this project.

Table 4.2: Chemical analysis results of acid leachate tests

Sample Number	Units	1	2	3	4	5	6	RDL
Location		Well 1	Well 1	Well 1	Core 1	Core 1	Core 1	
Depth	m	15-18	39-42	48-51	65	71	36	
Final pH	pH	9.43	9.37	9.44	6.68	5.84	5.92	N/A
Dissolves Metals								
Leachable Aluminum (Al)	µg/L	6200	3200	890	4200	990	1500	100
Leachable Antimony (Sb)	µg/L	ND	ND	ND	ND	ND	ND	20
Leachable Arsenic (As)	µg/L	ND	ND	ND	ND	ND	ND	20
Leachable Barium (Ba)	µg/L	190	110	74	ND	ND	ND	50
Leachable Beryllium (Be)	µg/L	ND	ND	ND	ND	ND	ND	20
Leachable Boron (B)	µg/L	ND	ND	ND	ND	ND	ND	500
Leachable Cadmium (Cd)	µg/L	ND	ND	ND	ND	ND	ND	3
Leachable Chromium (Cr)	µg/L	ND	ND	ND	ND	ND	ND	20
Leachable Cobalt (Co)	µg/L	ND	ND	ND	ND	ND	ND	10
Leachable Copper (Cu)	µg/L	25	ND	ND	ND	ND	ND	20
Leachable Iron (Fe)	µg/L	2100	1300	ND	1200	510	1200	500
Leachable Lead (Pb)	µg/L	ND	ND	ND	ND	ND	ND	5
Leachable Lithium (Li)	µg/L	ND	ND	ND	ND	ND	ND	20
Leachable Manganese (Mn)	µg/L	34	28	ND	48	62	57	20
Leachable Molybdenum (Mo)	µg/L	ND	ND	ND	ND	ND	ND	20
Leachable Nickel (Ni)	µg/L	ND	ND	ND	ND	ND	ND	20
Leachable Selenium (Se)	µg/L	ND	ND	ND	ND	ND	ND	20
Leachable Silver (Ag)	µg/L	ND	ND	ND	ND	ND	ND	5
Leachable Strontium (Sr)	µg/L	ND	96	120	ND	ND	ND	50
Leachable Thallium (Tl)	µg/L	ND	ND	ND	ND	ND	ND	1
Leachable Tin (Sn)	µg/L	ND	ND	ND	ND	ND	ND	20
Leachable Uranium (U)	µg/L	2	2	1	1	2	ND	1
Leachable Vanadium (V)	µg/L	27	ND	22	ND	ND	ND	20
Leachable Zinc (Zn)	µg/L	ND	ND	ND	ND	ND	ND	50

RDL = Readable detectable limit

ND = Not detected

Table 4.3: Chemical analysis results of aqueous leachate testing

Sample Number	Units	10	16	24	26	27	28	29	RDL
Location		Core 3	Core 3	Core 1	Core 1	Well 1	Well 1	Well 1	
Depth	m	44	26	71	37	52-55	18-21	33-36	
Spectrometer Result	ppmU	4.4	4.2	10.0	8.4	-	-	-	
Inorganics									
Total Alkalinity ($CaCO_3$)	mg/L	25	27	15	22	36	39	35	5
Dissolved Chloride (Cl)	mg/L	1	2	1	1	3	3	2	1
Dissolved sulphate (SO_4)	mg/L	ND	2	ND	ND	6	12	15	2
Final pH	pH	6.97	6.90	6.60	6.76	9.08	8.95	8.84	N/A
Dissolves Metals									
Aluminum (Al)	µg/L	620	900	370	110	2100	4900	2400	10
Antimony (Sb)	µg/L	ND	ND	ND	ND	ND	ND	ND	2
Arsenic (As)	µg/L	11	3	2	ND	16	8	4	2
Barium (Ba)	µg/L	21	21	9	19	90	170	100	5
Beryllium (Be)	µg/L	ND	ND	ND	ND	ND	ND	ND	2
Bismuth (Bi)	µg/L	ND	ND	ND	ND	ND	ND	ND	2
Boron (B)	µg/L	24	110	12	14	19	30	28	5
Cadmium (Cd)	µg/L	ND	ND	ND	ND	ND	ND	ND	0.3
Chromium (Cr)	µg/L	ND	ND	ND	ND	ND	3	ND	2
Cobalt (Co)	µg/L	ND	ND	ND	ND	ND	1	ND	1
Copper (Cu)	µg/L	ND	ND	5	3	ND	6	ND	2
Iron (Fe)	µg/L	300	620	83	ND	1200	2300	1300	50
Lead (Pb)	µg/L	ND	ND	ND	ND	ND	1.1	0.5	0.5
Manganese (Mn)	µg/L	14	32	150	210	17	32	18	2
Molybdenum (Mo)	µg/L	ND	ND	ND	ND	ND	2	ND	2
Nickel (Ni)	µg/L	ND	ND	ND	ND	ND	ND	ND	2
Selenium (Se)	µg/L	ND	ND	ND	ND	ND	ND	ND	2
Silver (Ag)	µg/L	ND	ND	ND	ND	ND	ND	ND	0.5
Strontium (Sr)	µg/L	37	45	13	21	120	53	88	5
Thallium (Tl)	µg/L	ND	ND	ND	ND	ND	ND	ND	0.1
Tin (Sn)	µg/L	ND	ND	ND	ND	ND	ND	ND	2
Titanium (Ti)	µg/L	15	16	24	4	34	56	26	2
Uranium (U)	µg/L	0.3	0.3	0.4	0.3	5.7	2.8	1.3	0.1
Vanadium (V)	µg/L	ND	ND	ND	ND	42	20	17	2
Zinc (Zn)	µg/L	ND	ND	ND	ND	ND	8	ND	5

RDL = Readable detectable limit

ND = Not detected

Figure 4.3: Correlation of uranium with other dissolved metals in aqueous leachate test (Well sample: ◆ Core sample: ◇).

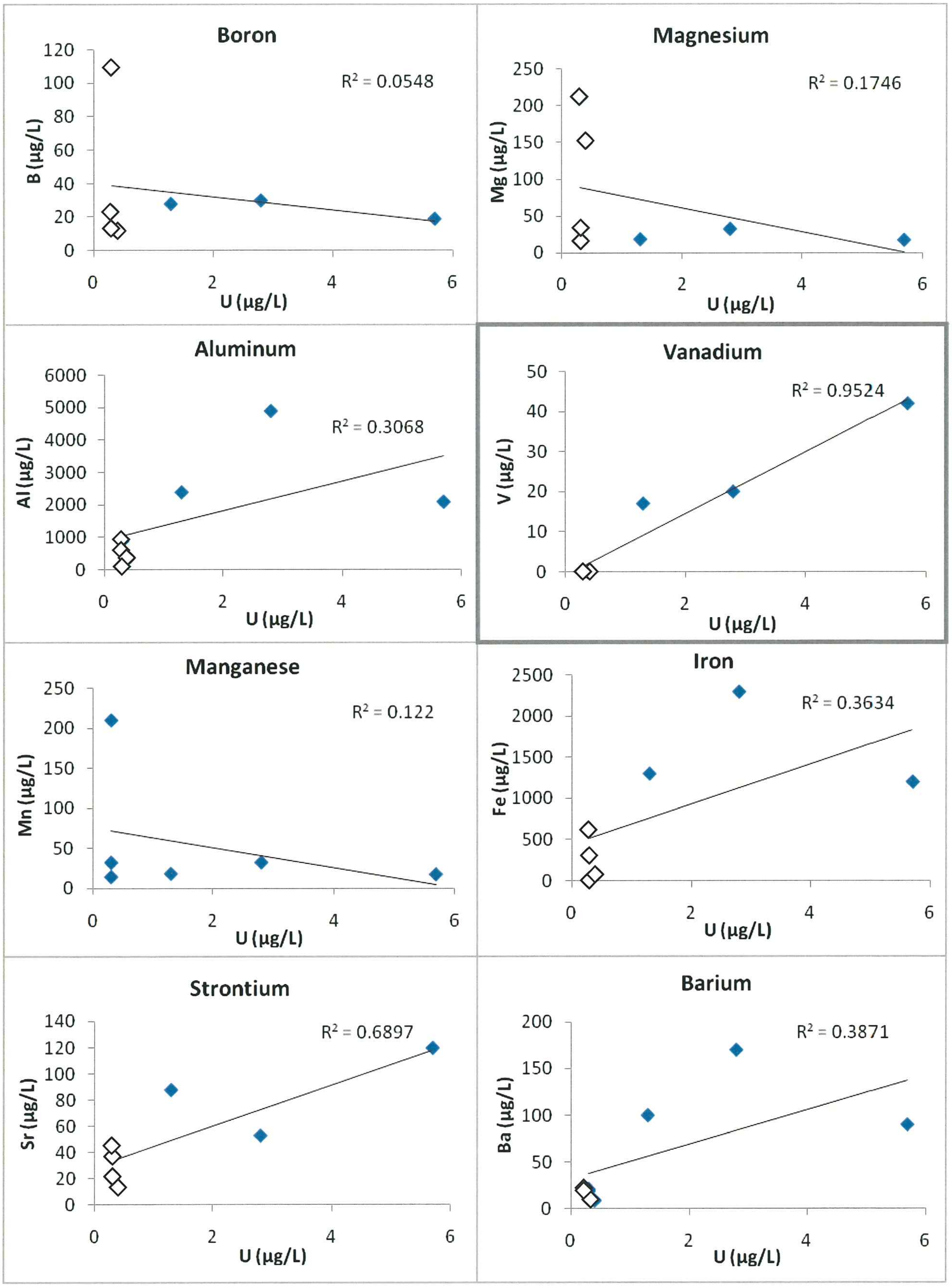
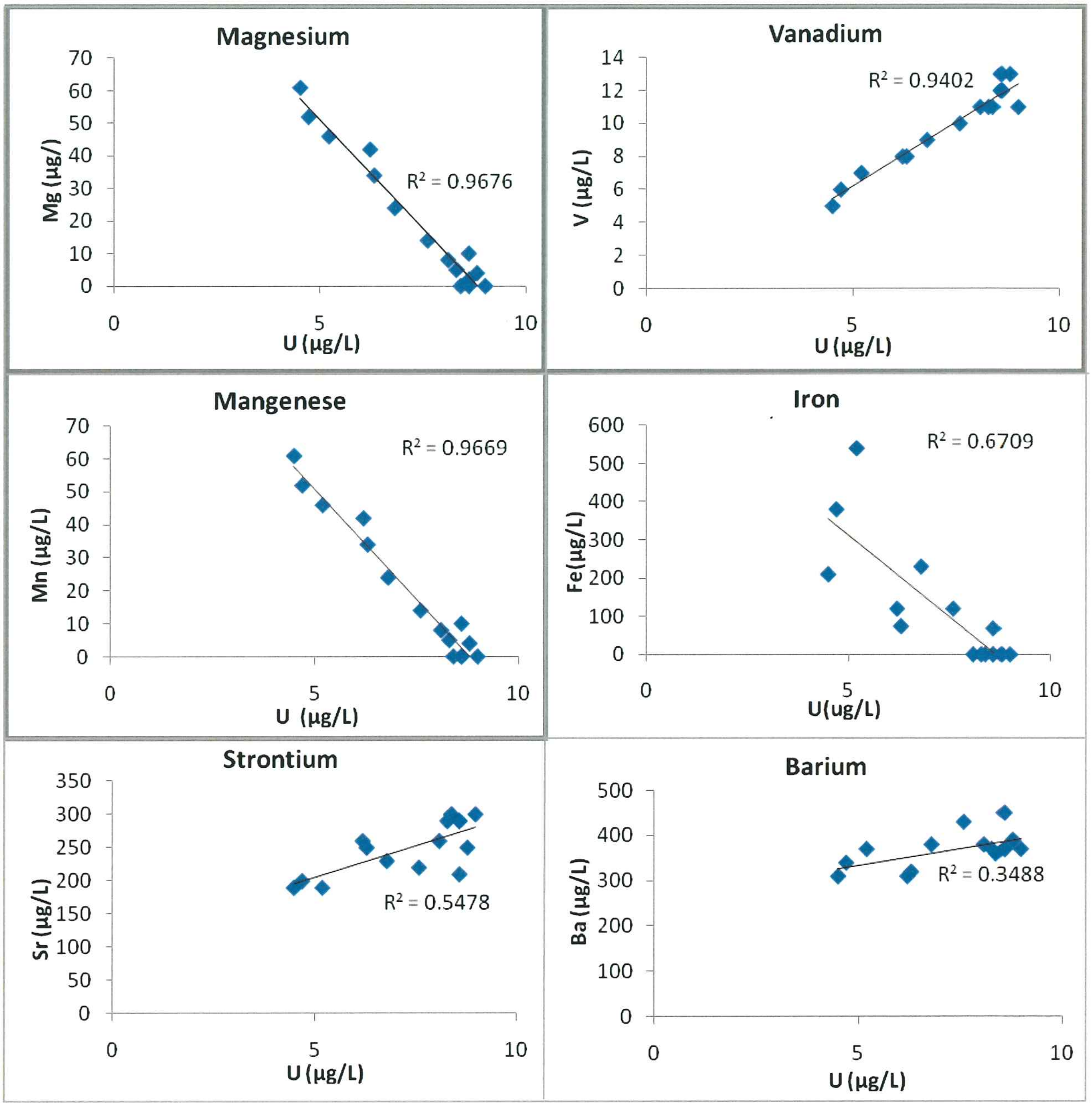


Figure 4.4: Correlation of uranium with other dissolved metals in depth discrete sampling performed on well 1.



4.5 Drill Core Wash Analysis

A 63 μm sieve was used to remove the fine grained portion of the core samples collected for washing. The colour of the samples varied considerably from red to light grey which reflected the colour of the clay portion of the core before the sample was washed. The most abundant clast type in the samples was quartz which made up approximately 45% of the clasts, followed closely by the feldspars which made up 42% of the clasts. The remainder was composed of mica and other unidentified black minerals, which may be a type of oxide. Table 4.6 summarizes the average components for the samples taken from all four core from the paradise region. A detailed description of the washed core samples is given in Appendix D.

Table 4.4: Modal composition of Paradise Core wash samples.

	Approximate per cent composition	
Component	Range	Average
Quartz	35-75	45
K-Feldspar	15-55	37
Plagioclase	0-10	8
Biotite	3-10	5
Muscovite	2-8	4
Other	0-1	1

5.0 DISCUSSION

The positive linear relationship between uranium and vanadium concentrations may provide some insight to the source of the uranium in the groundwater. Both uranium and vanadium are soluble in oxidizing conditions and they will be transported in groundwater in a similar fashion and will also precipitate out of solution when they encounter a reduced zone in the aquifer. If this reduced zone where uranium and vanadium were deposited were to become re-oxidized this relationship in the elements concentrations in the groundwater would be expected.

The negative linear relationship between manganese and magnesium with uranium concentrations may provide information about the redox state of the groundwater. Manganese becomes soluble in reducing environments while uranium is more likely to precipitate under these conditions (Gounot, 1994). Horizons where manganese concentrations are high and uranium concentrations are low may be interpreted as reduced zones while horizons where uranium concentrations are high and manganese concentrations are low may be interpreted as oxidized zones. This relationship was not visible in the acid or aqueous leachate test results.

The sampling method for which the well cuttings were collected makes it difficult to determine the true composition of the rock. The use of the sieve when collecting samples also reduced the amount of fine-grained material that may have been retained in the samples. A significant portion of the calcite cement would have also been removed in this process. The total alkalinity values determined in the aqueous leachate test show low levels of $CaCO_3$. The mobility of uranium in groundwater is significantly increased in the presence of carbonate, so the amount of leachable uranium may increase if a bulk sample, and not just the coarse fraction retrieved during drilling, were to undergo leachate analysis. This could have possible implications for potential elevated uranium levels in some horizons, so future studies should consider the sampling protocol if uranium content is to be precisely determined.

The sedimentary units described in the Bridgetown water wells could not be correlated to the sedimentary units present in the drill core from the Paradise region due to a lack of any distinguishable layers. In addition, the sediments from the well cuttings are more mature than the samples taken from the drill core. The well cuttings samples are finer grained are more rounded and contained higher quartz to feldspar ratios than the drill core samples. This increase in maturity may be a result of their greater distance of the wells from the South Mountain Batholith which was the primary sediment source for the Wolfville Formation.

The difference in pH between the water well cuttings samples and the drill core samples in the acid leachate testing may be in part the result of the difference in grain composition. The presence of clays and a higher proportion of feldspar, biotite and muscovite may lead to higher pH values in the drill core samples that the water well samples. The difference in pH between the water well cuttings samples and the drill core samples in the aqueous leachate testing method is likely to be in part the same reason as in the acid leachate testing with a pH slightly higher due to the higher starting pH.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Drill core from Paradise, near Bridgetown, and well cuttings from the test wells at Bridgetown were analyzed and logged to better understand the stratigraphy of the Wolfville Formation and to determine which, if any, horizons have elevated uranium that can be leached into the groundwater. Spectrometer assays on Paradise drill core indicated that horizons within the core have uranium levels up to twice the background levels. Samples from these horizons, along with well cutting samples from the Bridgetown wellfield, underwent both acid and aqueous leachate testing. Test results indicate that leachable uranium is present in the rock although concentrations in the leachate are still below values previously measured in well waters. These results suggest that the Wolfville Formation may indeed be a source of leachable uranium in the groundwater.

Further leachate testing on bulk rock samples would be useful, as results from the study on >74 µm sediment suggests that there is mobile uranium available even in these coarse grained fractions. Further research could be carried out on well water chemistry which may help to determine the various uranium species and complexing ions present in the groundwater and which aid or hinder the mobility of uranium. It would also be useful to determine how water chemistry changes from non-pumping to different pumping conditions for the act of pumping may influence the redox state of the groundwater and therefore influence the mobility of uranium. The results of this study would also suggest that there be continued monitoring of uranium concentrations in productions wells in Bridgetown. Should the wells go into municipal production, monitoring will be carried out as required by the Guidelines for Monitoring Public Drinking Water Supplies.

7.0 REFERENCES

CBCL Limited (2007) Bridgewater Groundwater Supply Development. Discrete Interval Sampling. CBCL Job # 60805.02. December 7, 2007.

Cech, T.V. (2005) Principles of Water Resources, History, Development, Management, and Policy. 2nd Edition. John Wiley & Sons, Inc.

Crosby, D.G. (1962) Wolfville Map Area, Nova Scotia, (21 H 1). Geological Survey of Canada, Memoir 325.

D'Eon, W. (2007) CBCL Limited Consulting Engineers. Memo to John Langmead, Mayor Art Marshall, John Drage, Judy MacDonald, Gavin Kennedy, Aileen Waller-Hebb. "Bridgetown Wellfield – Uranium", November 9, 2007.

Destination Nova Scotia (n.d.) Weather History. Retrieved October 19, 2008, http://www.destination-ns.com/content/weatherhistory.asp.

Garrels, R.M., Christ, C.L., (1965) Solutions, Minerals, and Equilibria. Harper & Row Publishers.

Gounot, A-M., (1994) Microbial oxidation and reduction of manganese: Consequences in groundwater and applications. Elsevier. FEMS Microbiology Reviews. Volume 14 pp. 339-350.

Ivanovich, M. and Harmon, R.S. (1992) Uranium-series disequilibrium: Applications to Earth, Marine, and Environmental Sciences, Second Edition, Clarendon Press.

Keppe, J.D., (2000) Geological Map of the Province of Nova Scotia, Scale 1:500 000, digital version of Nova Scotia Department of Natural Resources Map ME 2000-1 complied by B.E. Fisher and J.C. Poole, Scale 1:500 000.

Kronfeld, J., Godfrey-Smith, D.I., Johannessen, D., Zentilli, M. (2004) Uranium series isotopes in the Avon Valley, Nova Scotia. Journal of Environmental Radioactivity. Elsevier Ltd. Volume 73. pp.335-352.

Maynard, J.B. (1983) Geochemistry of Sedimentary Ore Deposits. Springer-Varlag New York Inc. pp. 148-179.

O'Beirne-Ryan, A.M. and Zentilii, M. (1999) Distribution of Uranium in Selected Rock Types in Centralmainland, Nova Scotia: Implications for the Occurrence of High Levels of Radon in Domestic Well Waters and Indoor Air. AGS Colloquium and Annual Meeting. Abstract, p32.

O'Reilly, G. (1982) Uranium in Nova Scotia: A Background Summary for the Uranium Inquiry, Nova Scotia. Department of Mines and Energy. Report 82-7.

Parsons, A. (2007) Potential for Uranium mobilization from weathered outcrops of Uranium-Bearing Sedimentary Strata, Southern Nova Scotia. Department of Earth Sciences, Reference Thesis, Dalhousie University.

Porcelli, Donald; Swarzenski, Peter W. (2003) "The Behavior of U- and Th-series Nuclides in Groundwater". Reviews in Mineralogy and Geochemistry , Uranium-Series Geochemistry Volume 52. pp 317-361.

Rivard, C. Deblonde, R. Boivin, R., Bolduc, A., Paradis, S. J., Paradis, D., Liao, S., Gauthier, M.-J., Blackmore, A., Trépanier, S., Castonguay, S., Drage, J., Michaud, Y. (2007) Canadian Groundwater Inventory Hydrogeological Atlas of the Annapolis Valley, Nova Scotia. Geological Survey of Canada. Open File 5541.

Smitheringale, W.G. (1973) Geology of Parts of Digby, Bridgetown, and Gaspereau Lake Map-Areas, Nova Scotia. Geological Survey of Canada, Department of Energy, Mines and Resources. Memoir 375.

Tieh, T.T. and Ledger, E.B. (1981) Fission Track Study of Uranium in Two Granites of Central Texas. Contrib. Mineral Petrol. 76:12-16.

Trescott, P.C. (1968) Groundwater Resources and hydrogeology of the Annapolis-Cornwallis Valley, Nov Scotia, Province of Nova Scotia Department of Mines, Memoir 6.

White, A.F., Bullen, T.D., Schulz, M.S., Blum, A.E., Huntinton, T.G., Peters, N.E., (2001) Differential rates of feldspar weathering in granitic regoliths. Geochimica et Cosmochimica Acta, Vol. 65, No. 6, pp. 847–869.

Wightman, J. (1999) Nova Scotia Department of Natural Resources Unpublished Report. Number 1999-040. Nova Scotia.

APPENDIX A: Depth discrete sampling results for total and dissolved elements from water wells in proposed Bridgetown wellfield. Work conducted by CBCL Limited, December 2007.

Well 1: Depth Discrete Sampling while still an open bore hole

Parameter	Units															
Elements (ICP-MS)																
Dissolved Aluminum (Al)	ug/L	<10	<10	<10	<10	<10	<10	<10	13	13	12	22	14	14	19	19
Dissolved Antimony (Sb)	ug/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Dissolved Arsenic (As)	ug/L	3	4	3	3	2	3	3	3	3	<2	2	3	3	3	<2
Dissolved Barium (Ba)	ug/L	370	450	390	380	310	360	370	370	380	310	320	430	370	370	340
Dissolved Beryllium (Be)	ug/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Dissolved Bismuth (Bi)	ug/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Dissolved Boron (B)	ug/L	14	13	12	11	13	10	9	8	13	14	12	13	10	10	15
Dissolved Cadmium (Cd)	ug/L	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Dissolved Chromium (Cr)	ug/L	<2	<2	<2	<2	<2	3	3	3	<2	<2	2	<2	2	3	<2
Dissolved Cobalt (Co)	ug/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Dissolved Copper (Cu)	ug/L	<2	<2	<2	<2	<2	<2	2	2	2	2	4	2	2	3	3
Dissolved Iron (Fe)	ug/L	540	68	<50	<50	120	<50	<50	<50	230	210	74	120	<50	<50	380
Dissolved Lead (Pb)	ug/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Dissolved Manganese (Mn)	ug/L	46	10	4	8	42	<2	<2	2	24	61	34	14	5	<2	52
Dissolved Molybdenum (Mo)	ug/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Dissolved Nickel (Ni)	ug/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Dissolved Selenium (Se)	ug/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Dissolved Silver (Ag)	ug/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Dissolved Strontium (Sr)	ug/L	190	210	250	260	260	300	290	290	230	190	250	220	290	300	200
Dissolved Thallium (Tl)	ug/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Dissolved Tin (Sn)	ug/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Dissolved Titanium (Ti)	ug/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Dissolved Uranium (U)	ug/L	5.2	8.6	8.8	8.1	6.2	8.4	8.6	8.6	6.8	4.5	6.3	7.6	8.3	9	4.7
Dissolved Vanadium (V)	ug/L	7	13	13	11	8	11	12	12	9	5	8	10	11	11	6
Dissolved Zinc (Zn)	ug/L	<5	<5	<5	<5	14	<5	<5	<5	<5	<5	10	9	<5	19	7

Well 2: Depth Discrete Sampling after well was upgraded to a screened production well.

Parameter	Units				
Elements (ICP-MS)					
Dissolved Aluminum (Al)	ug/L	<10	10	<10	<10
Dissolved Antimony (Sb)	ug/L	<2	<2	<2	<2
Dissolved Arsenic (As)	ug/L	<2	2	3	<2
Dissolved Barium (Ba)	ug/L	250	340	340	170
Dissolved Beryllium (Be)	ug/L	<2	<2	<2	<2
Dissolved Bismuth (Bi)	ug/L	<2	<2	<2	<2
Dissolved Boron (B)	ug/L	8	10	10	8
Dissolved Cadmium (Cd)	ug/L	<0.3	<0.3	<0.3	<0.3
Dissolved Chromium (Cr)	ug/L	<2	2	2	<2
Dissolved Cobalt (Co)	ug/L	<1	<1	<1	<1
Dissolved Copper (Cu)	ug/L	<2	<2	<2	<2
Dissolved Iron (Fe)	ug/L	440	76	84	310
Dissolved Lead (Pb)	ug/L	<0.5	<0.5	<0.5	<0.5
Dissolved Manganese (Mn)	ug/L	53	8	5	41
Dissolved Molybdenum (Mo)	ug/L	<2	<2	<2	<2
Dissolved Nickel (Ni)	ug/L	<2	<2	<2	<2
Dissolved Selenium (Se)	ug/L	<2	<2	<2	<2
Dissolved Silver (Ag)	ug/L	<0.5	<0.5	<0.5	<0.5
Dissolved Strontium (Sr)	ug/L	350	320	330	330
Dissolved Thallium (Tl)	ug/L	<0.1	<0.1	<0.1	<0.1
Dissolved Tin (Sn)	ug/L	<2	<2	<2	<2
Dissolved Titanium (Ti)	ug/L	<2	<2	<2	<2
Dissolved Uranium (U)	ug/L	<0.1	6.8	6.9	0.2
Dissolved Vanadium (V)	ug/L	<2	9	9	<2
Dissolved Zinc (Zn)	ug/L	<5	83	<5	47

Well 3: Depth Discrete Sampling after well was upgraded to a screened production well.

Parameter	Units				
Elements (ICP-MS)					
Dissolved Aluminum (Al)	ug/L	<10	<10	<10	<10
Dissolved Antimony (Sb)	ug/L	<2	<2	<2	<2
Dissolved Arsenic (As)	ug/L	<2	<2	<2	3
Dissolved Barium (Ba)	ug/L	170	180	210	220
Dissolved Beryllium (Be)	ug/L	<2	<2	<2	<2
Dissolved Bismuth (Bi)	ug/L	<2	<2	<2	<2
Dissolved Boron (B)	ug/L	7	7	7	9
Dissolved Cadmium (Cd)	ug/L	<0.3	<0.3	<0.3	<0.3
Dissolved Chromium (Cr)	ug/L	<2	<2	<2	4
Dissolved Cobalt (Co)	ug/L	<1	<1	<1	<1
Dissolved Copper (Cu)	ug/L	<2	<2	<2	<2
Dissolved Iron (Fe)	ug/L	290	150	93	<50
Dissolved Lead (Pb)	ug/L	<0.5	<0.5	<0.5	<0.5
Dissolved Manganese (Mn)	ug/L	120	94	75	2
Dissolved Molybdenum (Mo)	ug/L	<2	<2	<2	<2
Dissolved Nickel (Ni)	ug/L	<2	<2	<2	<2
Dissolved Selenium (Se)	ug/L	<2	<2	<2	<2
Dissolved Silver (Ag)	ug/L	<0.5	<0.5	<0.5	<0.5
Dissolved Strontium (Sr)	ug/L	400	410	420	450
Dissolved Thallium (Tl)	ug/L	<0.1	<0.1	<0.1	<0.1
Dissolved Tin (Sn)	ug/L	<2	<2	<2	<2
Dissolved Titanium (Ti)	ug/L	<2	<2	<2	<2
Dissolved Uranium (U)	ug/L	<0.1	0.2	0.5	12
Dissolved Vanadium (V)	ug/L	<2	<2	<2	14
Dissolved Zinc (Zn)	ug/L	5	12	<5	61

Well 1: Depth Discrete Sampling while well was still an open bore hole.

Parameter	Units															
Elements (ICP-MS)																
Total Aluminum (Al)	ug/L	11	<10	51	<10	13	<10	<10	16	40	31	35	25	70	290	24
Total Antimony (Sb)	ug/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Total Arsenic (As)	ug/L	<2	3	3	3	3	3	3	3	3	3	3	4	3	4	<2
Total Barium (Ba)	ug/L	320	450	390	370	360	370	370	370	400	370	350	450	370	390	290
Total Beryllium (Be)	ug/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Total Bismuth (Bi)	ug/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Total Boron (B)	ug/L	15	12	10	11	10	9	10	10	12	13	10	13	10	9	14
Total Cadmium (Cd)	ug/L	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Total Chromium (Cr)	ug/L	<2	<2	<2	2	3	3	2	2	<2	<2	2	<2	2	2	<2
Total Cobalt (Co)	ug/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Total Copper (Cu)	ug/L	<2	<2	<2	<2	<2	<2	<2	2	3	3	4	2	2	<2	3
Total Iron (Fe)	ug/L	4800	520	490	580	330	380	420	360	1200	1300	870	850	410	1000	4900
Total Lead (Pb)	ug/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Total Manganese (Mn)	ug/L	120	10	10	8	7	3	8	5	21	40	23	14	6	38	120
Total Molybdenum (Mo)	ug/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Total Nickel (Ni)	ug/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Total Selenium (Se)	ug/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Total Silver (Ag)	ug/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Total Strontium (Sr)	ug/L	180	200	230	270	280	300	290	290	260	210	270	260	290	290	180
Total Thallium (Tl)	ug/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total Tin (Sn)	ug/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Total Titanium (Ti)	ug/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	5	<2
Total Uranium (U)	ug/L	3.9	9.2	8.8	8.7	8.8	9	8.7	8.9	8.4	6.9	7.7	9.4	8.7	8.4	3.1
Total Vanadium (V)	ug/L	7	14	14	13	13	14	12	13	13	12	11	15	13	12	7
Total Zinc (Zn)	ug/L	5	<5	<5	<5	<5	<5	6	<5	<5	6	6	<5	<5	18	7

Well 2: Depth Discrete Sampling after well was upgraded to a screened production well.

Parameter	**Units**				
Elements (ICP-MS)					
Total Aluminum (Al)	ug/L	<10	13	14	<10
Total Antimony (Sb)	ug/L	<2	<2	<2	<2
Total Arsenic (As)	ug/L	<2	4	3	<2
Total Barium (Ba)	ug/L	250	400	370	170
Total Beryllium (Be)	ug/L	<2	<2	<2	<2
Total Bismuth (Bi)	ug/L	<2	<2	<2	<2
Total Boron (B)	ug/L	9	8	9	9
Total Cadmium (Cd)	ug/L	<0.3	<0.3	<0.3	<0.3
Total Chromium (Cr)	ug/L	<2	5	4	<2
Total Cobalt (Co)	ug/L	<1	<1	<1	<1
Total Copper (Cu)	ug/L	<2	<2	<2	<2
Total Iron (Fe)	ug/L	29000	9700	4600	7500
Total Lead (Pb)	ug/L	<0.5	<0.5	<0.5	1.3
Total Manganese (Mn)	ug/L	120	120	58	85
Total Molybdenum (Mo)	ug/L	<2	<2	<2	<2
Total Nickel (Ni)	ug/L	<2	<2	<2	<2
Total Selenium (Se)	ug/L	<2	<2	<2	<2
Total Silver (Ag)	ug/L	<0.5	<0.5	<0.5	<0.5
Total Strontium (Sr)	ug/L	340	340	340	340
Total Thallium (Tl)	ug/L	<0.1	<0.1	<0.1	<0.1
Total Tin (Sn)	ug/L	<2	<2	<2	<2
Total Titanium (Ti)	ug/L	<2	<2	<2	<2
Total Uranium (U)	ug/L	1.2	7.8	7.2	2.1
Total Vanadium (V)	ug/L	9	28	18	<2
Total Zinc (Zn)	ug/L	11	<5	<5	24

Well 3: Depth Discrete Sampling after well was upgraded to a screened production well.

Parameter	Units				
Elements (ICP-MS)					
Total Aluminum (Al)	ug/L	27	<10	12	13
Total Antimony (Sb)	ug/L	<2	<2	<2	<2
Total Arsenic (As)	ug/L	<2	<2	<2	5
Total Barium (Ba)	ug/L	170	170	200	280
Total Beryllium (Be)	ug/L	<2	<2	<2	<2
Total Bismuth (Bi)	ug/L	<2	<2	<2	<2
Total Boron (B)	ug/L	7	8	7	9
Total Cadmium (Cd)	ug/L	<0.3	<0.3	<0.3	<0.3
Total Chromium (Cr)	ug/L	<2	<2	<2	10
Total Cobalt (Co)	ug/L	<1	<1	<1	<1
Total Copper (Cu)	ug/L	<2	<2	<2	<2
Total Iron (Fe)	ug/L	7700	9700	12000	6400
Total Lead (Pb)	ug/L	<0.5	<0.5	<0.5	<0.5
Total Manganese (Mn)	ug/L	180	190	190	62
Total Molybdenum (Mo)	ug/L	<2	<2	<2	<2
Total Nickel (Ni)	ug/L	2	<2	<2	<2
Total Selenium (Se)	ug/L	<2	<2	<2	<2
Total Silver (Ag)	ug/L	<0.5	<0.5	<0.5	<0.5
Total Strontium (Sr)	ug/L	400	400	400	480
Total Thallium (Tl)	ug/L	<0.1	<0.1	<0.1	<0.1
Total Tin (Sn)	ug/L	<2	<2	<2	<2
Total Titanium (Ti)	ug/L	<2	<2	<2	<2
Total Uranium (U)	ug/L	1.4	1.9	2.2	14
Total Vanadium (V)	ug/L	<2	2	8	35
Total Zinc (Zn)	ug/L	46	20	55	13

APPENDIX B: Synthetic Precipitation Leachate Procedure Method Summary from Maxxam Analytics.

Scopes and Application:

Leachate is liquid produced from the natural degradation of waste as well as liquid runoff produced by rainwater falling directly on the waste or filtering through the surrounding soil. The content of the leachate depends upon the content of the waste, the moisture of the waste, the amount of rainfall and the pH of the rainwater. Leachate tests simulate the natural leaching process and are used to determine the concentration of contaminants from soil, solid materials and multi-phase wastes that would enter the environment. The SPLP extraction procedure is intended to imitate surface leachate conditions where solids are contacted with weak inorganic acids typically found in acid rain.

Summary:

A homogeneous (reduced to < 9.3 mm) sample is extracted over an 18-hour period. The concentration of the extraction fluid to be used is determined based on geographical location and required testing parameters. A very dilute sulphuric acid / nitric acid solution (Extraction Fluid A) is used to simulate acid rain composition east of the Mississippi River for most inorganic and non-volatile organic parameters. Reagent grade water is used as the extraction fluid when cyanide or volatile organic parameters are requested. For non-volatile parameters, 50g of sample (as received) is required for leachate extraction. A minimum 200g – 250g of material should be provided. All leachate analysis is performed on the "as received" material. The client must ensure that the material submitted is representative and request any additional pre-treatment (i.e. removal from substrate).

Quality Assurance:

A minimum of one method blank, sample preparation check and a sample duplicate is performed every twenty samples.

APPENDIX C: Bridgetown Wellfield Water Well Cuttings Descriptions

Water Well 1

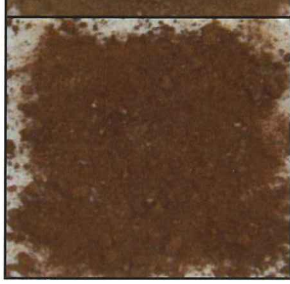
DEPTH: 9 - 12 m
Colour - light brown
Grain Size - 15 mm max; ave. 1 mm
Grain Type - qtz (55%) kfeld (19%) plag (5%) lithics (20%) other (1%)
Grain Shape - sub-angular to rounded; ave. sub-rounded

DEPTH: 12 - 15 m
Colour - orange-brown with some grey mottling
Grain Size - 1.5 mm max; ave. 100 µm
Grain Type - qtz (69%) kfeld (20%) plag (10%) lithics (0%) other (1%)
Grain Shape - angular to sub-rounded; ave. sub-angular

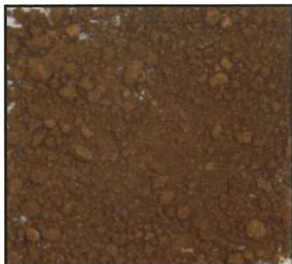
DEPTH: 15 - 18 m
Colour - reddish-brown
Grain Size - 1.5 mm max; ave. 250 µm
Grain Type - qtz (60%) kfeld (25%) plag (10%) lithics (5%) other (<1%)
Grain Shape - sub-rounded to rounded; ave. sub-rounded

DEPTH: 18 - 21 m
Colour - orange-brown with some grey mottling
Grain Size - 2 mm max; ave. 100 µm
Grain Type - qtz (69%) kfeld (15%) plag (10%) lithics (5%) other (1%)
Grain Shape - sub-rounded to rounded; ave. sub-rounded

DEPTH: 21 - 24 m
Colour - orange-brown with some grey mottling
Grain Size - 2 mm max; ave. 200 µm
Grain Type - qtz (%) kfeld (%) plag (%) lithics (%) other (%)
Grain Shape - sub-angular to well rounded; ave. sub-rounded



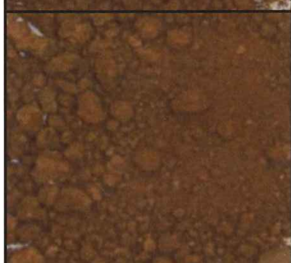
DEPTH: 24 - 27 m
Colour - orange-brown
Grain Size - 2 mm max; ave. 100 µm
Grain Type - qtz (60%) kfeld (25%) plag (9%) lithics (5%) other (1%)
Grain Shape - sub-angular to well rounded; ave. rounded



DEPTH: 27 - 30 m
- Colour - orange-brown with some grey mottling
- Grain Size - 1.5 mm max; ave. 250 µm
- Grain Type - qtz (65%) kfeld (15%) plag (5%) lithics (14%) other (1%)
- Grain Shape - sub-angular to well rounded; ave. sub-rounded

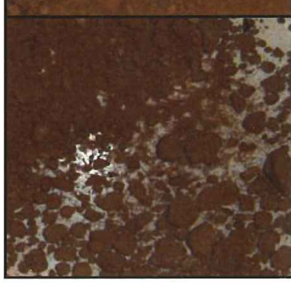
DEPTH: 30 - 33 m
- Colour - pink
- Grain Size - 3 mm max; ave. 350 µm
- Grain Type - qtz (80%) kfeld (10%) plag (5%) lithics (0%) other (5%)
- Grain Shape - sub-rounded to rounded; ave. sub-rounded

DEPTH: 33 - 36 m
- Colour - reddish-brown
- Grain Size - mm max; ave. 100 µm
- Grain Type - qtz (65%) kfeld (20%) plag (9%) lithics (5%) other (1%)
- Grain Shape - angular to rounded; ave. sub-rounded



DEPTH: 36 - 39 m
- Colour - reddish-brown
- Grain Size - 2 mm max; ave. 250 µm
- Grain Type - qtz (59%) kfeld (15%) plag (10%) lithics (15%) other (1%)
- Grain Shape - angular to rounded; ave. sub-rounded

DEPTH: 39 - 42 m
- Colour - reddish-brown with some grey mottling
- Grain Size - 10 mm max; ave. 250 µm
- Grain Type - qtz (70%) kfeld (15%) plag (10%) lithics (4%) other (1%)
- Grain Shape - sub-angular to well rounded; ave. rounded



DEPTH: 42 - 45 m
- Colour - reddish-brown with some grey mottling
- Grain Size - 6 mm max; ave. 0.5 mm
- Grain Type - qtz (69%) kfeld (20%) plag (10%) lithics (0%) other (1%)
- Grain Shape - angular to well rounded; ave. sub-rounded

DEPTH: 45 - 48 m

Colour - reddish-brown

Grain Size - 6 mm max; ave. 0.5 mm

Grain Type - qtz (70%) kfeld (15%) plag (10%) lithics (5%) other(<1%)

Grain Shape - angular to well rounded; ave. sub-rounded

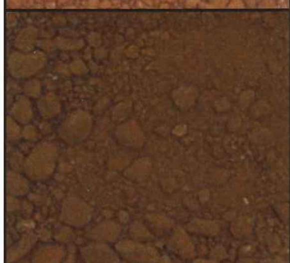
DEPTH: 48 - 51 m

Colour - reddish-brown with some grey mottling

Grain Size - 8 mm max; ave. 100 µm

Grain Type - qtz (17%) kfeld (2%) plag (1%) lithics (80%) other (<1%)

Grain Shape - sub-angular to rounded; ave. sub-rounded



DEPTH: 51 - 54 m

Colour - reddish-brown

Grain Size - 8 mm max; ave. 100 µm

Grain Type - qtz (17%) kfeld (2%) plag (1%) lithics (80%) other (<1%)

Grain Shape - sub-angular to rounded; ave. sub-rounded

DEPTH: 54 - 57 m

Colour - orange brown

Grain Size - 3 mm max; ave. 0.5 mm

Grain Type - qtz (75%) kfeld (15%) plag (5%) lithics (4%) other(1%)

Grain Shape - sub-angular to rounded; ave. sub-rounded

DEPTH: 57 - 60 m

Colour - reddish-brown with some grey mottling

Grain Size – 6 mm max; ave. 1 mm

Grain Type - qtz (75%) kfeld (10%) plag (10%) lithics (4%) other (1%)

Grain Shape - sub-angular to rounded; ave. sub-rounded

DEPTH: 60 - 63 m

Colour - reddish-brown with some grey mottling

Grain Size – 5 mm max; ave. 1 mm

Grain Type - qtz (79%) kfeld (10%) plag (5%) lithics (5%) other (1%)

Grain Shape - sub-angular to well rounded; ave. rounded

DEPTH: 63 - 65 m

Colour - pink with grey mottling

Grain Size - 3 mm max; ave. 1 mm

Grain Type - qtz (80%) kfeld (10%) plag (9%) lithics (0%) other (1%)

Grain Shape - sub-angular to well rounded; ave. sub-rounded

DEPTH: 65 - 67 m

Colour -pink

Grain Size - 6 mm max; ave. 2 mm

Grain Type - qtz (85%) kfeld (7%) plag (7%) lithics (0%) other (1%)

Grain Shape - angular to rounded; ave. sub-rounded

DEPTH: 67 - 70 m

Colour - pink

Grain Size - 5 mm max; ave. 2 mm

Grain Type - qtz (69%) kfeld (10%) plag (10%) lithics (10%) other (1%)

Grain Shape - angular to well rounded; ave. sub-rounded

DEPTH: 70 - 73 m

Colour - pink

Grain Size - 8 mm max; ave. 2.5 mm

Grain Type - qtz (64%) kfeld (20%) plag (15%) lithics (0%) other (1%)

Grain Shape - sub-angular to rounded; ave. sub-rounded

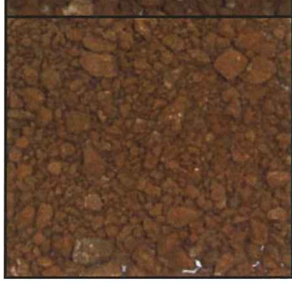
DEPTH: 73 - 76 m

Colour - pink with grey mottling

Grain Size - 5 mm max; ave. 1 mm

Grain Type - qtz (64%) kfeld (20%) plag (15%) lithics (0%) other (1%)

Grain Shape - angular to rounded; ave. sub-rounded



DEPTH: 76 - 79 m

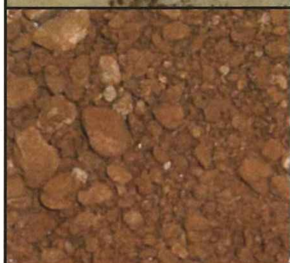
Colour - reddish brown

Grain Size - 3 mm max; ave. 250 μm

Grain Type - qtz (60%) kfeld (10%) plag (10%) lithics (17%) other (3%)

Grain Shape - angular to sub-rounded; ave. sub-angular

DEPTH: 79 - 81 m
Colour - Red with grey mottling
Grain Size - 8mm max; ave. 250µm
Grain Type - qtz (40%) kfeld (10%) plag (10%) lithics (30%) other (10%)
Grain Shape - angular to sub-rounded; ave. sub-angular

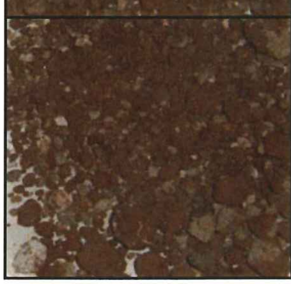


DEPTH: 81 - 84 m
Colour - reddish brown with grey mottling
Grain Size - 3 mm max; ave. 0.5 mm
Grain Type - qtz (64%) kfeld (10%) plag (5%) lithics (20%) other (1%)
Grain Shape - angular to rounded; ave. sub-rounded

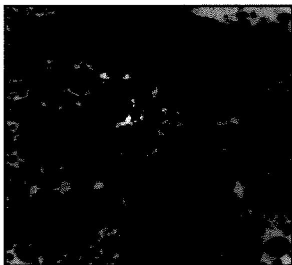
DEPTH: 84 - 85 m
Colour - reddish-brown with some grey mottling
Grain Size - 4 mm max; ave. 2.5 mm
Grain Type - qtz (45%) kfeld (9%) plag (5%) lithics (40%) other(1%)
Grain Shape - sub-angular to rounded; ave. sub-rounded

DEPTH: 85 - 86.5 m
Colour - reddish brown
Grain Size - 8 mm max; ave. 500 µm
Grain Type - qtz (54%) kfeld (15%) plag (10%) lithics (20%) other(1%)
Grain Shape - sub-angular to rounded; ave. sub-rounded

DEPTH: 86.5 - 88 m
Colour - red with grey mottling
Grain Size - 7 mm max; ave. 1.5 mm
Grain Type - qtz (60%) kfeld (20%) plag (20%) lithics (0%) other (0%)
Grain Shape - angular to rounded; ave. sub-rounded



DEPTH: 88 - 89.5 m
Colour - red with grey mottling
Grain Size - mm max; ave. µm
Grain Type - qtz (60%) kfeld (5%) plag (5%) lithics (20%) other (10%)
Grain Shape - sub-angular to well rounded; ave. sub-rounded

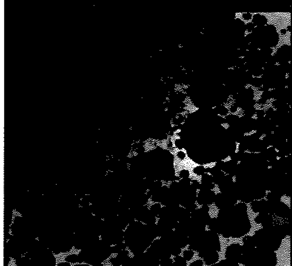


DEPTH: 89.5 - 91 m

Colour - red
Grain Size - 6 mm max; ave. 2 mm
Grain Type - qtz (70%) kfeld (5%) plag (2%) lithics (20%) other (3%)
Grain Shape - sub-rounded to well rounded; ave. rounded

DEPTH: 91 - 94 m

Colour - pinkish-brown with some grey mottling
Grain Size - 8 mm max; ave. 0.5 mm
Grain Type - qtz (59%) kfeld (10%) plag (10%) lithics (20%) other (1%)
Grain Shape - sub-angular to rounded; ave. sub-rounded



DEPTH: 94 - 95.5 m

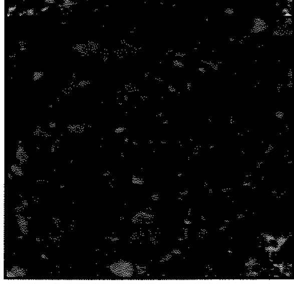
Colour - red with some grey mottling
Grain Size - 6 mm max; ave. 2 mm
Grain Type - qtz (67%) kfeld (5%) plag (2%) lithics (25%) other (1%)
Grain Shape - angular to sub-rounded; ave. sub-rounded

DEPTH: 95.5 - 97 m

Colour -
Grain Size - 4 mm max; ave. 2 mm
Grain Type - qtz (68%) kfeld (10%) plag (10%) lithics (10%) other (2%)
Grain Shape - angular to well rounded; ave. sub-rounded

DEPTH: 97 - 98.5 m

Colour - pink with grey mottling
Grain Size - 5 mm max; ave. 2 mm
Grain Type - qtz (69%) kfeld (15%) plag (10%) lithics (5%) other (1%)
Grain Shape - angular to well rounded; ave. sub-rounded



DEPTH: 98.5 – 100 m

Colour - pink with grey mottling
Grain Size - 6 mm max; ave. 2.5 mm
Grain Type - qtz (54%) kfeld (25%) plag (10%) lithics (10%) other (1%)
Grain Shape - angular to sub-rounded; ave. sub-angular

DEPTH: 100 - 103 m
Colour - Red
Grain Size - 7 mm max; ave. 2.5 mm
Grain Type - qtz (54%) kfeld (25%) plag (20%) lithics (0%) other (1%)
Grain Shape - angular to rounded; ave. sub-rounded

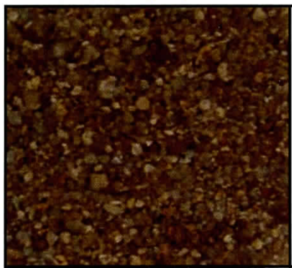
DEPTH: 103 - 106 m
Colour - pink
Grain Size - 11 mm max; ave. 2 mm
Grain Type - qtz (54%) kfeld (20%) plag (20%) lithics (5%) other (1%)
Grain Shape - angular to rounded; ave. sub-rounded

DEPTH: 106 - 109 m
Colour - pink
Grain Size - 7 mm max; ave. 3 mm
Grain Type - qtz (50%) kfeld (30%) plag (20%) lithics (0%) other (0%)
Grain Shape - angular to sub-rounded; ave. sub-angular

DEPTH: 109 - 112 m
Colour - red
Grain Size - 7 mm max; ave. 3 mm
Grain Type - qtz (50%) kfeld (25%) plag (20%) lithics (5%) other (0%)
Grain Shape - angular to sub-rounded; ave. sub-angular

DEPTH: 112 - 115 m
Colour - pink
Grain Size - 5 mm max; ave. 2 mm
Grain Type - qtz (50%) kfeld (25%) plag (20%) lithics (5%) other (0%)
Grain Shape - angular to rounded; ave. sub-angular

DEPTH: 115 - 118 m
Colour - pink
Grain Size - 8 mm max; ave. 3 mm
Grain Type - qtz (65%) kfeld (20%) plag (15%) lithics (0%) other (0%)
Grain Shape - angular to rounded; ave. sub-rounded



DEPTH: 118 - 120 m

Colour - pink

Grain Size - 7 mm max; ave. 3 mm

Grain Type - qtz (70%) kfeld (15%) plag (15%) lithics (0%) other (0%)

Grain Shape - angular to rounded; ave. sub-rounded

DEPTH: 120 - 121.5 m

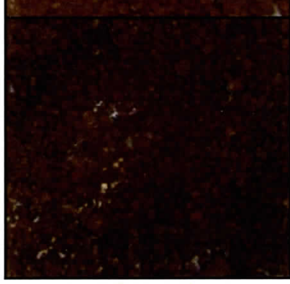
Colour - pinkish-red

Grain Size - 5 mm max; ave. 2.5 mm

Grain Type - qtz (65%) kfeld (15%) plag (14%) lithics (5%) other (1%)

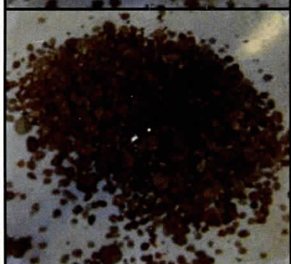
Grain Shape - angular to rounded; ave. sub-rounded

Well 2

	**DEPTH: 11 – 14 m** Colour - reddish-brown Grain Size - 5 mm max; ave. 1 mm Grain Type - - qtz (20%) kfeld (10%) plag (1%) lithics (68%) other (1%) Grain Shape - angular to rounded; ave. sub-angular
	**DEPTH: 14 – 17 m** Colour - orange-brown Grain Size - 10 mm max; ave. 500 μm Grain Type - qtz (60%) kfeld (12%) plag (5%) lithics (20%) other (3%) Grain Shape - sub-angular to well rounded; ave. rounded
	**DEPTH: 17 – 20 m** Colour - orange-brown Grain Size - 1 mm max; ave. 0.5 mm Grain Type - qtz (20%) kfeld (1%) plag (1%) lithics (78%) other (0%) Grain Shape - sub-angular to rounded; ave. sub-rounded
	**DEPTH: 20 – 23 m** Colour - pink Grain Size - 3 mm max; ave. 1.5 mm Grain Type - qtz (60%) kfeld (10%) plag (5%) lithics (20%) other (2%) Grain Shape - angular to sub-rounded; ave. sub-angular
	**DEPTH: 23.5 – 26.5 m** Colour - reddish pink Grain Size - 4mm max; ave. 2 mm Grain Type - qtz (60%) kfeld (13%) plag (5%) lithics (20%) other (2%) Grain Shape - sub-angular to well rounded; ave. rounded
	**DEPTH: 26.5 – 29.5 m** Colour - brown Grain Size - 3 mm max; ave. 0.5 mm Grain Type - qtz (60%) kfeld (5%) plag (3%) lithics (30%) other (2%) Grain Shape - angular to sub-rounded; ave. sub-angular

DEPTH: 29.5 – 32.5 m

Colour - pinkish orange
Grain Size - 2 mm max; ave. 0.2 mm
Grain Type - qtz (40%) kfeld (3%) plag (0%) lithics (55%) other (2%)
Grain Shape - sub-angular to rounded; ave. sub-rounded



DEPTH: 32.5 – 35.5 m

Colour - pink
Grain Size – 2 mm max; ave. 0.5 mm
Grain Type - qtz (40%) kfeld (15%) plag (5%) lithics (40%) other (0%)
Grain Shape - sub-angular to well rounded; ave. rounded

DEPTH: 35.5 - 39 m

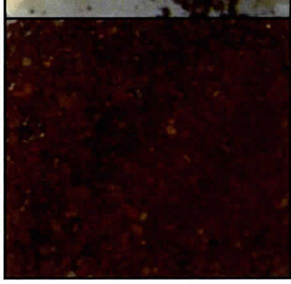
Colour - pink
Grain Size - 5 mm max; ave. 1 mm
Grain Type - qtz (35%) kfeld (50%) plag (0%) lithics (15%) other (0%)
Grain Shape - sub-angular to well rounded; ave. sub-rounded

DEPTH: 39 - 42 m

Colour - pinkish brown
Grain Size - 4 mm max; ave. 2 mm
Grain Type - qtz (20%) kfeld (0%) plag (0%) lithics (80%) other (0%)
Grain Shape - sub-angular to well rounded; ave. rounded

DEPTH: 42 - 45 m

Colour - red
Grain Size - 2.5 mm max; ave. 1 mm
Grain Type - qtz (10%) kfeld (10%) plag (0%) lithics (80%) other (0%)
Grain Shape - sub-rounded to well rounded; ave. rounded

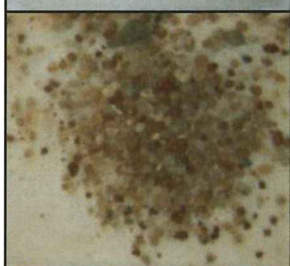


DEPTH: 45 - 48 m

Colour - red
Grain Size - 3 mm max; ave. 0.2 mm
Grain Type - qtz (10%) kfeld (10%) plag (0%) lithics (80%) other (0%)
Grain Shape - sub-angular to well rounded; ave. rounded

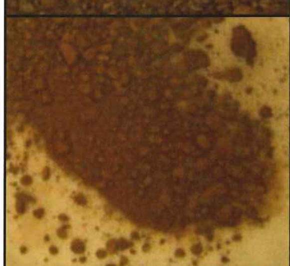
DEPTH: 48 - 51 m
Colour - red with some grey mottling present
Grain Size - 3 mm max; ave. 2 mm
Grain Type - qtz (48%) kfeld (0%) plag (0%) lithics (50%) other (2%)
Grain Shape - sub-angular to well rounded; ave. sub-rounded

DEPTH: 51 - 54 m
Colour - red
Grain Size - 3 mm max; ave. 2 mm
Grain Type - qtz (7%) kfeld (1%) plag (2%) lithics (90%) other (0%)
Grain Shape - angular to well rounded; ave. rounded

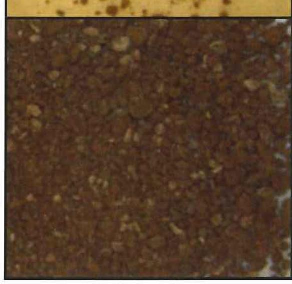


DEPTH: 54 - 57 m
Colour - reddish grey, with some grey mottling present
Grain Size - 3 mm max; ave. 1 mm
Grain Type - qtz (70%) kfeld (5%) plag (3%) lithics (20%) other (2%)
Grain Shape - sub-angular to well rounded; ave. rounded

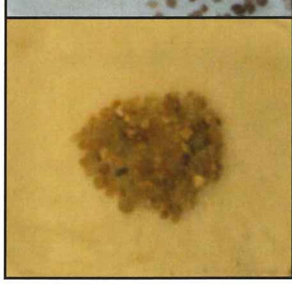
DEPTH: 57 - 60 m
Colour - reddish orange
Grain Size - 2 mm max; ave. 0.5 mm
Grain Type - qtz (29%) kfeld (5%) plag (5%) lithics (60%) other (1%)
Grain Shape - sub-rounded to well rounded; ave. rounded

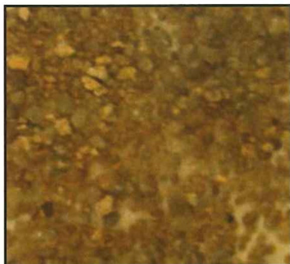
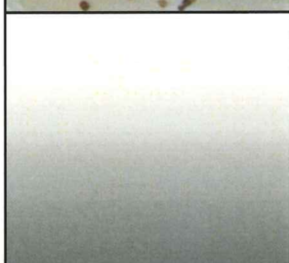
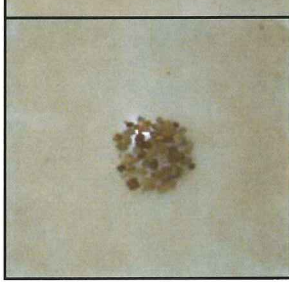


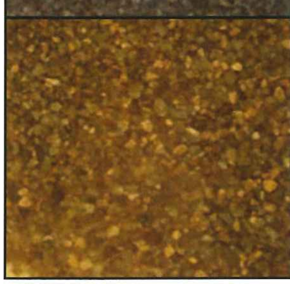
DEPTH: 60 - 63 m
Colour - reddish orange
Grain Size - 3 mm max; ave. 1 mm
Grain Type - qtz (5%) kfeld (0%) plag (0%) lithics (94%) other (1%)
Grain Shape - angular to sub-rounded; ave. sub-angular



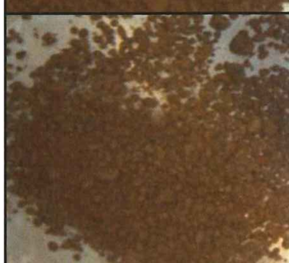
DEPTH: 63 - 66 m
Colour - reddish orange
Grain Size - 3 mm max; ave. 1 mm
Grain Type - qtz (10%) kfeld (2%) plag (2%) lithics (85%) other (1%)
Grain Shape - sub-angular to well rounded; ave. rounded

	**DEPTH: 66 - 69 m** Colour - pink Grain Size - 4 mm max; ave. 2 mm Grain Type - qtz (50%) kfeld (0%) plag (5%) lithics (45%) other (0%) Grain Shape - sub-angular to well rounded; ave. rounded
	**DEPTH: 69 - 72 m** Colour - pink Grain Size - 3 mm max; ave. 2 mm Grain Type - qtz (40%) kfeld (5%) plag (5%) lithics (50%) other (0%) Grain Shape - sub-angular to well rounded; ave. sub-rounded
	**DEPTH: 72 - 75 m** Colour - pink Grain Size - 7 mm max; ave. 2 mm Grain Type - qtz (55%) kfeld (15%) plag (10%) lithics (15%) other (5%) Grain Shape - sub-angular to sub-rounded; ave. sub-rounded
	**DEPTH: 75 - 78 m** Colour - pinkish grey Grain Size - 3 mm max; ave. 2 mm Grain Type - qtz (70%) kfeld (10%) plag (5%) lithics (15%) other (0%) Grain Shape - angular to well rounded; ave. sub-rounded
	**DEPTH: 78 - 81 m** Colour - pink Grain Size - 7 mm max; ave.2 mm Grain Type - qtz (45%) kfeld (10%) plag (10%) lithics (35%) other (0%) Grain Shape - sub-angular to well rounded; ave. sub-rounded
	**DEPTH: 81 – 84 m** Colour - pinkish grey Grain Size - 5 mm max; ave. 3 mm Grain Type - qtz (75%) kfeld (5%) plag (10%) lithics (10%) other (0%) Grain Shape - sub-angular to well rounded; ave. sub-rounded

	**DEPTH: 84 – 87.5 m** Colour - pink Grain Size - 7 mm max; ave. 3 mm Grain Type - qtz (55%) kfeld (27%) plag (5%) lithics (10%) other (2%) Grain Shape - sub-angular to well rounded; ave. sub-rounded
	**DEPTH: 87.5 – 90.5 m** Colour - light brown Grain Size - 4 mm max; ave. 1 mm Grain Type - qtz (50%) kfeld (5%) plag (5%) lithics (35%) other (5%) Grain Shape - angular to sub-rounded; ave. sub-angular
	**DEPTH: 90.5 – 93.5 m** Colour - pinkish grey Grain Size - 5 mm max; ave. 2.5 mm Grain Type - qtz (58%) kfeld (5%) plag (5%) lithics (20%) other (2%) Grain Shape - sub-angular to well rounded; ave. rounded
	**Missing Sample DEPTH 93.5 – 97 m**
	**DEPTH: 97 – 100 m** Colour - pinkish grey Grain Size - 4 mm max; ave. 1.5 mm Grain Type - qtz (60%) kfeld (0%) plag (0%) lithics (40%) other (0%) Grain Shape - sub-rounded to well rounded; ave. rounded
	**DEPTH: 100 – 103 m** Colour - pinkish grey Grain Size - 4 mm max; ave. 2 mm Grain Type - qtz (50%) kfeld (5%) plag (0%) lithics (45%) other (0%) Grain Shape - sub-angular to rounded; ave. sub-rounded

	**DEPTH: 103 – 106 m** Colour - pink Grain Size - 6 mm max; ave. 2.5 mm Grain Type - qtz (55%) kfeld (25%) plag (9%) lithics (10%) other (1%) Grain Shape - sub-angular to rounded; ave. sub-rounded
	**DEPTH: 106 – 109 m** Colour - pink Grain Size - 5 mm max; ave. 2 mm Grain Type - qtz (60%) kfeld (30%) plag (7%) lithics (3%) other (0%) Grain Shape - sub-angular to rounded; ave. sub-rounded
	**DEPTH: 109 – 112 m** Colour - pink Grain Size - 5 mm max; ave. 3mm Grain Type - qtz (55%) kfeld (30%) plag (5%) lithics (8%) other (2%) Grain Shape - sub-angular to sub-rounded, ave. sub-rounded
	**DEPTH: 112 – 115 m** Colour - pinkish Grey Grain Size - 4 mm max; ave. 2 mm Grain Type - qtz (70%) kfeld (25%) plag (2%) lithics (3%) other (0%) Grain Shape - angular to sub-rounded, ave. sub-angular
	**DEPTH: 115 – 118 m** Colour - pink Grain Size - 9 mm max; ave. 3 mm Grain Type - qtz (50%) kfeld (39%) plag (5%) lithics (5%) other (1%) Grain Shape - angular to sub-rounded, ave. sub-rounded
	**DEPTH: 118 – 121 m** Colour - pink Grain Size - 6 mm max; ave. 3 mm Grain Type - qtz (50%) kfeld (35%) plag (9%) lithics (5%) other (1%) Grain Shape - angular to sub-rounded, ave. sub-angular

Well 3

	**DEPTH: 11 – 17 m** Colour - orange brown Grain Size - 7 mm max;, ave. 0.5 mm Grain Type - qtz (80%) kfeld (5%) plag (2%) lithics (8%) other (5%) Grain Shape - sub-angular to rounded, ave. sub-rounded
	**DEPTH: 17 – 23 m** Colour - orangish brown Grain Size - 6 mm max; ave. 0.5 mm Grain Type - qtz (68%) kfeld (2%) plag (5%) lithics (20%) other (5%) Grain Shape - sub-angular to well rounded, ave. sub-rounded
	**DEPTH: 23 – 25 m** Colour - reddish brown Grain Size - 4 mm max; ave. 1 mm Grain Type - qtz (73%) kfeld (2%) plag (5%) lithics (15%) other (5%) Grain Shape - sub-angular to well rounded, ave. sub-rounded
	**DEPTH: 25 – 29 m** Colour - light orange brown Grain Size - 7 mm max; ave. 0.5 mm Grain Type - qtz (70%) kfeld (5%) plag (10%) lithics (10%) other (5%) Grain Shape - angular to well rounded, ave. rounded
	**DEPTH: 29 – 32 m** Colour - light orange brown Grain Size - 2 mm max; ave. 0.2 mm Grain Type - qtz (45%) kfeld (2%) plag (1%) lithics (50%) other (2%) Grain Shape - sub-angular to well rounded, ave. sub-rounded
	**DEPTH: 32 – 35 m** Colour - pink Grain Size - 5 mm to max; ave. 0.5 mm Grain Type - qtz (35%) kfeld (1%) plag (2%) lithics (60%) other (2%) Grain Shape - angular to well rounded, ave. subrounded

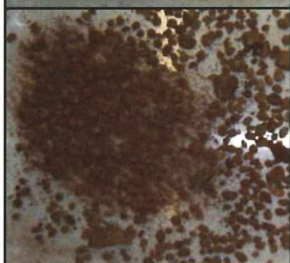
DEPTH: 35 – 38 m

Colour - reddish brown

Grain Size - 3 mm max; ave. 0.2 mm

Grain Type - qtz (66%) kfeld (1%) plag (2%) lithics (30%) other (0%)

Grain Shape - sub-angular to well rounded; ave. rounded



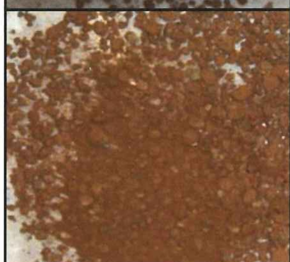
DEPTH: 38 – 41.5 m

Colour - orange brown

Grain Size - 4 mm max; ave. 0.5 mm

Grain Type - qtz (30%) kfeld (5%) plag (5%) lithics (60%) other (<1%)

Grain Shape - sub-angular to well rounded; ave. rounded



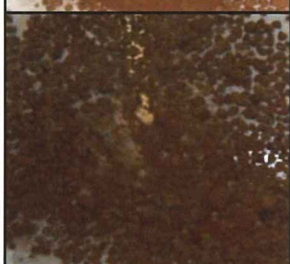
DEPTH: 41.5 – 44.5 m

Colour - reddish brown

Grain Size - 2 mm max; ave. 200 µm

Grain Type - qtz (5%) kfeld (0%) plag (0%) lithics (95%) other (<1%)

Grain Shape - sub-angular to rounded; ave. sub-rounded



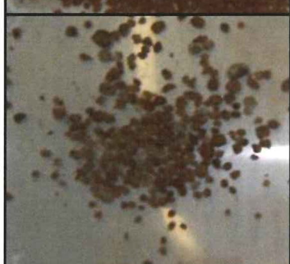
DEPTH: 44.5 – 47.5 m

Colour - reddish brown

Grain Size - 3 mm max; ave. 0.5 mm

Grain Type - qtz (15%) kfeld (0%) plag (1%) lithics (79%) other (5%)

Grain Shape - sub-angular to rounded; ave. sub-rounded



DEPTH: 47.5 – 50.5 m

Colour - pink

Grain Size - 4 mm max; ave. 0.5 mm

Grain Type - qtz (33%) kfeld (2%) plag (5%) lithics (60%) other (0%)

Grain Shape - sub-angular to rounded; ave. sub-rounded

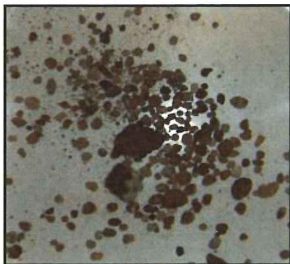
DEPTH: 50.5 – 53.5 m

Colour - pink

Grain Size - 4 mm max; ave. 1 mm

Grain Type - qtz (50%) kfeld (7%) plag (3%) lithics (40%) other (0%)

Grain Shape - sub-angular to well rounded; ave. rounded



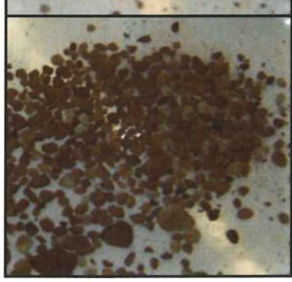
DEPTH: 53.5 – 57 m
Colour - pink
Grain Size - 3 mm max; ave. 0.5 mm
Grain Type - qtz (13%) kfeld (0%) plag (0%) lithics (85%) other (2%)
Grain Shape - sub-angular to rounded; ave. sub-rounded

DEPTH: 57 – 60 m
Colour - pink
Grain Size - 5 mm max; ave. 250 μm
Grain Type - qtz (15%) kfeld (2%) plag (2%) lithics (76%) other (5%)
Grain Shape - sub-rounded to well rounded; ave. rounded

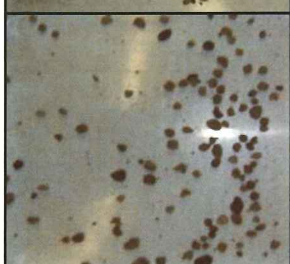
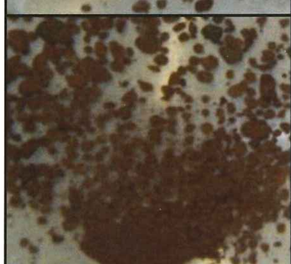
DEPTH: 60 – 63 m
Colour - pink
Grain Size - 3 mm max; ave. 0.5 mm
Grain Type - qtz (15%) kfeld (3%) plag (0%) lithics (82%) other (<1%)
Grain Shape - sub-rounded to well rounded; ave. rounded

DEPTH: 63 – 66 m
Colour - red
Grain Size - 3 mm max; ave. 1 mm
Grain Type - qtz (44%) kfeld (10%) plag (5%) lithics (40%) other (1%)
Grain Shape - sub-angular to well rounded; ave. rounded

DEPTH: 66 – 69 m
Colour - pink
Grain Size - 3 mm max; ave. 0.5 mm
Grain Type - qtz (15%) kfeld (2%) plag (1%) lithics (80%) other (2%)
Grain Shape - sub-angular to well rounded; ave. rounded



DEPTH: 69 – 72 m
Colour - reddish brown
Grain Size - 3 mm max; ave. 0.5 mm
Grain Type - qtz (15%) kfeld (5%) plag (0%) lithics (79%) other (1%)
Grain Shape - sub-angular to rounded; ave. sub-rounded

	**DEPTH: 72 – 75 m** Colour - reddish brown Grain Size - 2 mm max; ave. 0.5 mm Grain Type - qtz (12%) kfeld (1%) plag (0%) lithics (85%) other (2%) Grain Shape - sub-angular to well rounded; ave. sub-rounded
	**DEPTH: 75 – 78 m** Colour - reddish brown Grain Size - 6 mm max; ave. 0.5 mm Grain Type - qtz (9%) kfeld (0%) plag (0%) lithics (90%) other (1%) Grain Shape - sub-angular to rounded; ave. sub-rounded
	**DEPTH: 78 – 81 m** Colour - reddish brown Grain Size - 3 mm max; ave. 0.5 mm Grain Type - qtz (15%) kfeld (2%) plag (0%) lithics (82%) other (1%) Grain Shape - sub-angular to well rounded; ave. sub-rounded
	**DEPTH: 81 – 84 m** Colour - pink Grain Size - 3 mm max; ave. 1 mm Grain Type - qtz (56%) kfeld (2%) plag (0%) lithics (40%) other (2%) Grain Shape - sub-angular to rounded; ave. sub-rounded
	**DEPTH: 84 – 87 m** Colour - reddish brown Grain Size - 5 mm max; ave. 0.5 mm Grain Type - qtz (10%) kfeld (4%) plag (0%) lithics (85%) other (1%) Grain Shape - sub-angular to rounded; ave. sub-rounded
	**DEPTH: 87 – 90 m** Colour - red Grain Size - 4 mm max; ave. 0.5 mm Grain Type - qtz (2%) kfeld (0%) plag (0%) lithics (96%) other (2%) Grain Shape - sub-angular to rounded; ave. sub-rounded

APPENDIX D: Washed Paradise Drill Core Sample Descriptions

SAMPLE 7: Drill Core 4 – 87 m (2.8 ppmU)
Colour - Red
Grain Size – 8 mm max; ave. 250 μm
Grain Type - qtz (40%) kfeld (50%) plag (2%) biot (5%) musc (3%) other(<1%)
Grain Shape - angular to sub-rounded; ave. sub-angular

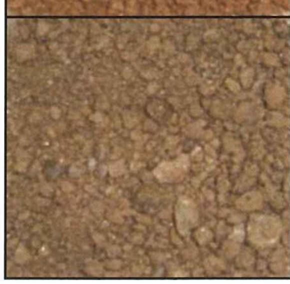
SAMPLE 8: Drill Core 4 – 66 m (1.6 ppmU)
Colour - Pinkish brown
Grain Size - 10 mm max; ave. 4 mm
Grain Type - qtz (60%) kfeld (30%) plag (0%) biot (5%) musc (5%) other (<1%)
Grain Shape - angular to sub-rounded; ave. angular

SAMPLE 9: Drill Core 3 – 182' (5.1 ppmU)
Colour - Light brown
Grain Size - 17mm max; ave. 5mm
Grain Type - qtz (45%) kfeld (35%) plag (10%) biot (8%) musc (2%) other (<1%)
Grain Shape - angular to sub-rounded; ave. angular

SAMPLE 10: Drill Core 3 – 55.5 m (4.4 ppmU)
Colour - Pinkish grey
Grain Size - 10 mm max; ave. 3 mm
Grain Type - qtz (65%) kfeld (30%) plag (<1%) biot (3%) musc (2%) other (<1%)
Grain Shape - angular to sub-rounded; ave. sub-angular

SAMPLE 11: Drill Core 2 – 30 m (3.9 ppmU)
Colour - Light grey
Grain Size - 9 mm max; ave. 0.5 mm
Grain Type - qtz (75%) kfeld (15%) plag (<1%) biot (3%) musc (2%) other (<1%)
Grain Shape - angular to sub-rounded; ave. sub-angular

SAMPLE 12: Drill Core 4 – 60 m (2.7 ppmU)
Colour - Pink
Grain Size - 8 mm max; ave. 2 mm (well sorted)
Grain Type - qtz (50%) kfeld (30%) plag (15%) biot (3%) musc (2%) other (<1%)
Grain Shape - angular to rounded; ave. sub-rounded

	**SAMPLE 13**: Drill Core 2 – 18.5 m (2.4 ppmU) Colour - Reddish brown Grain Size - 11 mm max; ave. 1 mm Grain Type - qtz (50%) kfeld (35%) plag (5%) biot (5%) musc (5%) other (<1%) Grain Shape - angular to rounded; ave. sub-angular
	**SAMPLE 14**: Drill Core 3 – 49 m (1.2 ppmU) Colour - Red Grain Size - 15 mm max; ave. 0.5 mm Grain Type - qtz (50%) kfeld (40%) plag (<1%) biot (4%) musc (4%) other (2%) Grain Shape - angular to sub-rounded; ave. sub-angular
	**SAMPLE 15**: Drill Core 3 – 33.5 m (3.6 ppmU) Colour - Pink Grain Size - 10 mm max; ave. 0.5 mm Grain Type - qtz (50%) kfeld (35%) plag (<1%) biot (10%) musc (3%) other (2%) Grain Shape - angular to sub-rounded; ave. sub-angular
	**SAMPLE 16**: Drill Core 3 – 26 m (4.2 ppmU) Colour - Pink Grain Size - 10 mm max; ave. 0.5 mm Grain Type - qtz (45%) kfeld (40%) plag (5%) biot (6%) musc (5%) other(<1%) Grain Shape -
	**SAMPLE 17**: Drill Core 4 – 51 m (1.2 ppmU) Colour - Grayish pink Grain Size - 12 mm max; ave. 1 mm Grain Type - qtz (50%) kfeld (35%) plag (5%) biot (6%) musc (2%) other(<1%) Grain Shape - angular to sub-rounded; ave. sub-angular
	**SAMPLE 18**: Drill Core 4 – 76 m (2.0 ppmU) Colour - Pinkish gray Grain Size - 11 mm max; ave. 1 mm Grain Type - qtz (40%) kfeld (45%) plag (5%) biot (4%) musc (4%) other(<1%) Grain Shape - angular to sub-rounded; ave. sub-angular

	**SAMPLE 19**: Drill Core 4 – 82 m (2.4 ppmU) Colour - Red Grain Size - 9 mm max; ave. 250 µm Grain Type - qtz (35%) kfeld (50%) plag (<1%) biot (7%) musc (8%) other(<1%) Grain Shape - angular to sub-rounded; ave. sub-angular
	**SAMPLE 20**: Drill Core 4 – 23 m (3.1 ppmU) Colour - Pinkish brown Grain Size - 14 mm max; ave. 0.5 mm Grain Type - qtz (35%) kfeld (55%) plag (2%) biot (7%) musc (3%) other(1%) Grain Shape - angular to sub-rounded; ave. sub-angular
	**SAMPLE 21**: Drill Core 4 – 31 m (2.0 ppmU) Colour - Reddish pink Grain Size - 10 mm max; ave. 1 mm Grain Type - qtz (43%) kfeld (50%) plag (<1%) biot (4%) musc (3%) other(<1%) Grain Shape - angular to sub-rounded; ave. sub-angular
	**SAMPLE 22**: Drill Core 1 – 97 m (3.7 ppmU) Colour - Pinkish gray Grain Size - 7 mm max; ave. 2 mm Grain Type - qtz (60%) kfeld (30%) plag (5%) biot (3%) musc (2%) other(<1%) Grain Shape - angular to sub-rounded; ave. sub-angular
	**SAMPLE 23**: Drill Core 1 – 66 m (8.7 ppmU) Colour - Light gray Grain Size - 12 mm max; ave. 2 mm Grain Type - qtz (47%) kfeld (35%) plag (15%) biot (2%) musc (1%) other(<1%) Grain Shape - angular to sub-rounded; ave. sub-angular
	**SAMPLE 24**: Drill Core 1 – 71 m (10.0 ppmU) Colour - Yellowish gray Grain Size - 15 mm max; ave. 1 mm Grain Type - qtz (40%) kfeld (40%) plag (12%) biot (5%) musc (3%) other(<1%) Grain Shape - angular to sub-rounded; ave. sub-angular

	**SAMPLE 25**: Drill Core 1 – 35 m (4.2 ppmU) Colour - Light gray Grain Size - 11 mm max; ave. 1 mm Grain Type - qtz (55%) kfeld (35%) plag (5%) biot (3%) musc (2%) other(<1%) Grain Shape - angular to sub-rounded; ave. sub-angular
	**SAMPLE 26**: Drill Core 1 – 66 m (8.4 ppmU) Colour - Light gray Grain Size - 12 mm max; ave. 2 mm Grain Type - qtz (55%) kfeld (35%) plag (5%) biot (3%) musc (2%) other(<1%) Grain Shape - angular to sub-rounded; ave. sub-angular