Structural and Hydrologic Characterization of Two Historic Waste Rock Piles

by

Aileen Cash

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

in

Geoenvironmental Engineering

Department of Civil and Environmental Engineering
University of Alberta

Abstract

Mine waste rock is one of the largest waste streams produced from precious metal mining that must be managed over the long-term. Of particular concern is the management of chemical oxidation of sulphide minerals termed acid rock drainage (ARD).

This thesis presents a field and laboratory investigation of two historic waste rock stockpiles at Detour Lake Mine in Ontario, Canada. 100 physical samples and *in situ* measurements of unsaturated conditions were collected. Laboratory analyses determined particle size distribution and unsaturated and hydraulic characteristics. Digital image processing techniques evaluated large scale grain size, porosity, and water storage capacity. The stockpiles were unsaturated, clast supported structures with features typical of end-tipped deposition. On average, 17% of the material was <4.75 mm, where unsaturated water flow dominates. For water flow in matric fines of <4.75 mm, the estimated average residence time was 200 days to 1.1 years assuming 100% infiltration. Observations can support geochemical mass transport models to assist in future ARD predictions.

Dedication

"Life is like laundry: you get out of it what you put into it."

Acknowledgements

I would like to acknowledge the many people who have provided invaluable assistance throughout this project. First, many thanks to my supervisor Dr. Ward Wilson, whose insight, encouragement, and support were invaluable throughout all stages of this research. He provided boundless enthusiasm towards all aspects of life and always left me feeling empowered after every meeting.

The research program has been a joint effort with many others. Our project partners at the University of Waterloo, Dr. David Blowes, Dr. Richard Amos, Jeff Bain, and Brayden McNeil, have been great collaborators with valuable expertise, guidance, and feedback. The Environmental Department staff at Detour Gold Corporation led by Jim Robertson and Marie-Hélène Turgeon has contributed significant experience, logistical help, and direction during the field program and beyond. In addition, the financial support of the National Sciences and Engineering Research Council and Detour Gold Corporation made this work possible.

Laboratory experiments were supported by the Department's technical support staff, specifically Christine Hereygers and Dr. Louis Kabwe. Their experience and resourcefulness were crucial in solving the myriad of problems encountered in the lab. Special thanks to Sally Petaske and Vivian Giang who are always willing to help and have solutions to many problems.

I am very fortunate to have amazing friends who have supported me and cheered me on throughout this process. Finally, to my family: your endless love, support, and encouragement have helped me on this journey and many others throughout my life – I could not have done it without you.

Table of Contents

List of Tables

List of Figures

Chapter 1.0 Introduction

The mining and extraction industry is an integral part of the Canadian economy, with a contribution of $124.6 billion to Canada's gross domestic product (GDP) in 2012 for mining, quarrying and oil and gas extraction (Industry Canada, 2012). Increasingly, environmental liability influences precious metal mining operations in all stages of operation, from permitting through to mine closure. The ongoing liability necessitates a more comprehensive understanding of the environmental impacts of mining practices to assist in the management of environmental risk. In modern mining operations, the demands on mining companies include environmental stewardship to reduce wastes, a reduction in the environmental impacts of their operations, and an understanding of the behaviour of mine waste over the long term (Lottermoser, 2010). Mining wastes and their management is an important aspect of this stewardship, as these materials can have elevated levels of metals and sulphur compounds, which can adversely affect the surrounding environment. The need for a detailed understanding of the behaviour and characteristics of mine waste is vital, as the size and scale of many global operations continue to increase and lower grade ore bodies are developed producing greater volumes of waste.

Mining activities produce metal ores or industrial minerals as well as mine waste streams generated from the mineral processing. Mine wastes include tailings and processed wastes that are produced through the milling of ore, which accumulate in an impoundment (Lottermoser, 2010). Overburden and waste rock is sub-economic material produced during operations and cannot be refined. This material is stored in engineered structures known as waste rock dumps (Aubertin, 2013). A waste rock dump must contain the material, maintain long-term stability, and prevent the migration of contaminants over its lifespan. Of primary concern is the reaction of sulphide-bearing minerals in mining waste rock and tailings with atmospheric water, oxygen, and microorganisms, resulting in acidic drainage and metal leaching (Lottermoser, 2010; Wilson, 2011). These phenomena are termed acid rock drainage (ARD) and metal leaching (ML). The estimated potential environmental liability for ARD in 2005 was $1.3 to $3.3 billion in Canada alone (Wickland & Wilson, 2005). A more comprehensive understanding of ARD generation in mine structures can minimize the financial assurance costs during the mine life and after closure.

A study on historic waste rock dumps was conducted at Detour Lake Mine in Ontario, Canada. Detour Lake Mine is a gold property currently owned and operated by Detour Gold Corporation. The 540 km^2 property is located approximately 300 km northeast of Timmins, Ontario, and 10 km west of the Ontario-Quebec border. Placer Dome Inc. initially opened Detour Lake Mine in 1983 and operated the mine until closure in 1999. The combined open pit and underground facility produced 1.8 million ounces of gold (Detour Gold Corporation, 2012b). After production ceased, the mine underwent closure and reclamation, until it was purchased in 2006 by Detour Gold Corporation (Detour Gold Corporation, 2013). From 2009 to 2012, the property underwent significant study and permitting to expand the existing open pit, and a new milling plant was constructed to support a new mining operation on the property. Gold production commenced in the first quarter of 2013, with an expected mine life of 21 years (Detour Gold Corporation, 2012a). The historic nature of the site presented an opportunity to evaluate past mine wastes produced on site and their evolution in the post-closure time period.

This thesis details a study on the historic waste rock piles located at Detour Lake Mine and analyses their characteristics with regard to structure, hydrology, and migration of water. Limited attention has been given to the historical behaviour and evolution of mine waste rock under field conditions over time and the relationship to the development of

ARD. Although previous field studies have evaluated flow and leaching of metals and acidic drainage, these studies are often completed after construction of waste rock piles or as small-scale laboratory experiments. It is useful to understand the behaviour of historical field-scale waste rock piles to gain an understanding of temporal influences and climate variability. A detailed field-scale characterization of historical waste rock, including physical characteristics, gas and water transport, and water chemistry, is valuable to provide a basis for managing sulfide-bearing waste rock from both past and future mining operations.

1.1 Research Program and Objectives

The goal of this research is to evaluate the geotechnical properties and hydrologic behaviour of mine waste rock to assist in water quality prediction, specifically for historic waste rock found under site conditions. The study consisted of a field and laboratory investigation conducted on two historic waste rock stockpiles at Detour Lake Mine. The stockpiles date from 1983 to 1999 and contain waste rock with some overburden material with a 10-year operating history and 16-year post-closure history.

The field testing program was focused on two historic waste rock stockpiles, Stockpile 1 and Stockpile 2, which were located in the footprint of the proposed open pit for the new mining operations. The waste rock material required relocation to a new storage facility, and a forensic excavation of the piles was conducted as part of this relocation during multiple field campaigns. Samples and field measurements were taken for subsequent analysis and detailed laboratory testing. Photographs of all sampling locations were collected, and select photos were utilized to identify the range of particles and their proportions within the waste rock profile. These data were evaluated to address research objectives to achieve the project goal.

The specific research objectives were:

1. To design and implement a field and laboratory program to evaluate the internal structure and physical properties of a historic waste rock dump. These data included detailed descriptions of qualitative and quantitative measurements of waste rock properties;

2. To collect a large sample inventory to accurately represent the heterogeneous properties present in the waste rock stockpiles and provide varied sample properties for laboratory testing;

3. To evaluate the unsaturated soil properties of the fine fraction of waste rock to assess the water storage within waste rock; and

4. To use digital image processing (DIP) analyses to evaluate grain size to assist in characterizing the full range of particle sizes, to evaluate the fine fraction percentage of the waste rock pile, and to evaluate the porosity and available water within the waste rock.

1.2 Thesis Organization

This thesis contains six chapters. Chapter 1 provides an introduction to the research program, a brief site history as well as the purpose and research objectives associated with the project. Chapter 2 presents a review of relevant literature outlining previous studies into waste rock structures, specifically unsaturated soil characteristics, hydrology, and physical characteristics. The site location and history of Detour Lake Mine are also described. Chapter 3 discusses the field and laboratory program and the methodology and scope of all tests conducted. The results of the research program are presented and discussed in Chapter 4. Chapter 5 presents the results of the DIP analyses as well as a discussion on estimating waste rock parameters using these data. Finally, Chapter 6 provides the conclusions of the research study as well as recommendations for future work.

Chapter 2.0 Literature Review and Background Studies

2.1 Introduction

The following section describes past studies of waste rock stockpiles in precious metal mining projects, including their structure, physical characteristics, and behaviour as it relates to the production of acid rock drainage risks for closure. A history of the Detour Gold Project is also discussed.

2.1.1 Mine Waste Production

Precious metal mining activities require the physical separation and concentration of an ore or mineral. In addition to this extraction, waste streams are produced from mining, mineral processing, and metallurgical processing. Overburden and waste rock must be removed from around the ore body as they do not meet the cut-off grade for mineral processing (Lottermoser, 2010). Consequently, waste rock, overburden, and tailings represent the highest volume waste streams that must be stored. The large volumes, typically millions or billions of tonnes in an engineered structure or pile, pose a challenge to mine operators to manage the geotechnical and environmental aspects of their storage during the mine lifetime and into perpetuity (Wilson, 2011). Waste rock dump construction and storage of these materials above ground require detailed understanding of their physical and chemical behaviour to properly manage these materials over the long term.

Waste rock dump construction typically takes into account five main factors: geometry and storage, stability, drainage, contamination, and economics. Typical configurations can include valley or side-hill fills, heaped fills, or ridge fills (Taylor & Greenwood, 1985). Construction methods for waste rock dumps often rely on end-dumping of material from large haul trucks, resulting in a loosely packed material at the angle of repose (O'Kane, Stoicescu, Januszewski, Mchaina, & Haug, 1998).

Construction can also occur through multiple lifts of end-dumped material ranging from 6 m to 60 m in thickness (Herasymuik, 1996).

Paddock dumps or heaped waste rock dumps are typically constructed using end-dumped material spread by a bulldozer. This construction technique is typically utilized in areas of flat terrain, and piles are built upwards in lifts and can have similar characteristics to end-dumped material with laminations of material within the lift at the angle of repose. Paddock or heaped dumps can also have a terraced configuration where subsequent lifts at a higher elevation do not reach the crest of the lower dump lift, creating a bench between the two lifts (Herasymuik, 1996).

Waste rock dumps are in operation throughout the entire mine life and require study of their behaviour over this period, including decommissioning and post-closure monitoring. In particular, management of waste over the long term is important for estimating risk, which influences the closure liability of a mine project. During the decommissioning phase, site reclamation and rehabilitation activities are performed. Monitoring and treatment may be required to ensure compliance with environmental regulations during this phase and into the post-closure phase (The International Network for Acid Prevention (INAP), 2009b). Consequently, a detailed assessment must be conducted to understand the environmental and geochemical characteristics of all aspects of the mine site, especially mining wastes containing sulphide minerals and metals. Specifically, to understand the environmental impact of a waste rock dump, the environment and properties must be understood as well as how these properties will evolve with time (Ritchie, 1994). This study will focus on the characterization, behaviour and management of historic waste rock from the Detour Gold Project. The following sections provide background on research into the physical and hydrologic characterization of waste rock and relevant studies in the literature.

2.1.2 Acid Rock Drainage and Metal Leaching

In the past, funds allocated for mine waste disposal were low due to minimal costs for haulage and storage of tailings or waste rock on dump sites or impoundments. Reclamation and decommission was not extensive, and often seepage from these structures was not considered an environmental concern (Jambor, 1994). Today, sulfide mineral oxidation within waste rock is an important process that has been studied and must be managed as it can result in environmental degradation.

Of particular concern related to the environment are the prediction, prevention, and ongoing management of sulfide minerals and their chemical oxidation within waste rock, commonly termed Acid Rock Drainage or ARD. ARD is produced through the reaction of sulfide-bearing minerals in waste rock or tailings with atmospheric water and oxygen (Lottermoser, 2010). Often, a complementary result of acid generation includes the release of metals, resulting in elevated metal and metalloids in effluent or seepage termed metal leaching (ML). In Canada alone, an estimated 750 million tonnes of mine waste rock is expected to be acid generating. This represents a \$0.4 billion to \$2.1 billion liability for adequate treatment and control of ARD (Mine Environment Neutral Drainage (MEND), 2001). Consequently, prevention and management of ARD is imperative during all stages of mine development and operation to minimize ongoing costs.

Chemical weathering (via oxidation of pyrite) is the primary process responsible for the production of ARD. The process is governed by chemical, biological, and electrochemical reactions where hydrogen ions are produced through a series of reactions. First, chemical oxidation of one mole of pyrite by atmospheric oxygen produces one mole of Fe^{2+}, two moles of SO_4^{2-}, and four moles of H^+ (Blowes & Ptacek, 1994; INAP, 2009b). The general equation for the oxidation of pyrite is given as:

$$FeS_2(s) + 7/2O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+ \quad (2.1)$$

This reaction predominates at higher pH conditions. The ferrous iron produced is further oxidized to produce ferric iron:

$$Fe^{2+} + \frac{1}{4}O_2 + H^+ \rightarrow Fe^{3+} + \frac{1}{2}H_2O \quad (2.2)$$

Precipitation of ferrous iron as oxyhydroxides can occur as ferrihydrite. Ferrihydrite compounds are simplified to a nominal composition of $Fe(OH)_3$ (INAP, 2009b):

$$Fe^{2+} + \frac{1}{4}O_2 + 2\frac{1}{2}H_2O \rightarrow Fe(OH)_3 + 2H^+ \quad (2.3)$$

The overall reaction for pyrite oxidation can therefore be described as:

$$FeS_2 + 15/4O_2 + 7/2H_2O \rightarrow Fe(OH)_3 + 2SO_4^{2-} + 4H^+ \quad (2.4)$$

In the above reactions, pyrite is oxidized primarily through atmospheric oxygen. It can also be oxidized by ferric iron produced in the above reactions (INAP, 2009b). The result is the generation of 16 moles of acid per mole of pyrite:

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \quad (2.5)$$

This reaction requires 14 moles of aqueous ferric iron and consequently occurs under acidic conditions. At lower pH conditions, pyrite oxidation follows Equation 2.1, and at a pH of 4.5 or lower, pyrite oxidation by ferric iron will predominate (Equation 2.5).

Pyrrhotite is another common sulfide mineral that contributes to ARD and is also found at the Detour Lake Project. Studies on pyrrhotite oxidation are less prevalent, and the oxidation products are not studied as significantly (Nicholson & Scharer, 1994). Pyrrhotite has the chemical formula $Fe_{1-x}S$. It can have varying crystal forms as the structure is iron deficient, resulting in chemical compositions ranging from Fe_9S_{10} to FeS.

With oxygen as the primary oxidant, pyrrhotite oxidation is described by Nicholson and Scharer (1994) as:

$$Fe_{1-x}S + (2-½x)O_2 + xH_2O \rightarrow (1-x)Fe^{2+} + SO_4^{2-} + 2xH^+ \quad (2.6)$$

Consequently, the acidic load H^+ is directly dependent on the chemical structure of the pyrrhotite or the 'x' in the formula (Janzen, Nicholson, & Scharer, 2000; Nicholson & Scharer, 1994). Similar to the reaction in Equation 2.3, ferrous iron can precipitate as a ferric oxide. Pyrrhotite can also be oxidized by ferric iron at low pH conditions:

$$Fe_{1-x}S + (8-2x)Fe^{3+} + 4H_2O \rightarrow (9-3x)Fe^{2+} + SO_4^{2-} + 8H^+ \quad (2.7)$$

Janzen et al. (2000) indicate that under some field or laboratory conditions, this reaction may not move to completion, and consequently, more iron rich pyrrhotite or elemental sulfur may be produced:

$$Fe_{1-x}S_{(s)} + 0.5(1-x)O_2 + 2(1-x)H^+ \rightarrow (1-x)Fe^{2+} + S^0 + (1-x)H_2O \quad (2.8)$$

Nicholson and Scharer (1994) indicate that at atmospheric concentrations of oxygen at ambient temperature, the rate of pyrrhotite oxidation was 100 times that of pyrite. It is believed that this increased rate is related to the iron deficient structure of the pyrrhotite mineral. The rate of oxidation for all sulfide minerals is dependent on numerous factors, including the type of sulfide mineral, ambient environment, and oxidant type. The principal factors include the surface area and grain size, morphology, pH, climate and temperature, redox potential, and water sources (INAP, 2009b). Typically, finer grained material will oxidize more quickly due to the larger surface area for reactions.

Sulfide minerals in waste rock are often accompanied by alkaline or acid-consuming minerals. Acid neutralization occurs through various alkaline minerals in different pH ranges (INAP, 2009b). The general reaction for the consumption or neutralization of ARD by calcite is provided in the following equation.

$$CaCO_3 + H^+ \rightarrow Ca^{2+} + HCO_3^- \qquad (2.9)$$

The reaction results in calcium cation release and bicarbonate, which increases pH (INAP, 2009b). The typical pH buffering series in mine wastes begins with the depletion of calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), ankerite ($Ca(Fe,Mg)(CO_3)_2$), and siderite ($FeCO_3$). After consumption of these minerals, hydroxide dissolution occurs followed by aluminiosilicate dissolution at low pH conditions (Blowes & Ptacek, 1994). Measurement of the acid generating and neutralization potential of waste rock is typically conducted through static and kinetic laboratory tests.

By accurately characterizing the geochemistry and environmental loadings associated with waste rock, ARD in the field can be better understood to minimize the financial assurance costs during the mine life and after closure. This necessitates an understanding of the internal structure of waste rock dumps and reactant pathways (water and atmospheric oxygen) through these materials.

2.2 Theory of Unsaturated Flow in Porous Media

Mine waste structures consist of well-graded rock ranging in size from boulders to silt and clay particles. The free-draining nature of these structures and their location above the local groundwater table results in waste rock that is unsaturated. Unsaturated soils contain both air and water phases in the particle voids. To understand the hydrologic behaviour of waste rock structures, the theory of unsaturated soil mechanics must be applied, as unsaturated behaviour is an extension of the theories and principles of saturated soil mechanics. Fredlund, Rahardjo, and Fredlund (2012) provide an extensive and in-depth textbook on unsaturated soils and their use in engineering. The following section provides a brief review related to the understanding of water flow in waste rock.

Unsaturated soils consist of defined phases with different properties and defined bounding surfaces. The three primary phases are air, water or pore fluid, and the soil or rock material. The interface between air and water, or the contractile skin, must also be taken into account as the properties of this interface are distinct from those of water. The unsaturated soil regime is therefore considered a four-phase system where the soil particles and air-water interface behave with respect to the applied stress regime. The flow of air and water phases occurs with respect to applied gradients. A soil is considered unsaturated when the pore fluid is compressible. This occurs when small air bubbles are occluded within the pores of a soil, causing the water pressure to be negative relative to the air phase. The water and air phase flow in response to stress gradients, and the soil and contractile skin come to equilibrium (Fredlund et al., 2012).

Soil suction is a state variable that is used to describe unsaturated media. It is described by the relationship of matric, osmotic, and total suction. The relationship between total, matric, and osmotic suction is given as:

$$\psi = (u_a - u_w) + \pi \qquad (2.10)$$

where, ψ is total suction, (u_a-u_w) is the matric suction, and π is osmotic suction. In soils, water rises above the water table due to capillaries or small voids within the medium, similar to the capillary rise seen in glass tubes when inserted into a large container. If a capillary tube is inserted into water from a soil, the partial pressure of water vapour above the meniscus of the tube would be less than the partial pressure of water vapour above the soil's water. Relative humidity (RH) is the ratio of the partial pressure of water vapour in a given mixture to the saturated vapour pressure of water at a given temperature. Consequently, as the radius of the capillary tube decreases, the partial pressure of water vapour and the relative humidity will also decrease. Therefore, matric suction can be defined as the difference between the air pressure, u_a, and the water pressure, u_w, at the meniscus (Fredlund et al., 2012).

Soil water typically has dissolved solutes such as salts or minerals. The vapour pressure of soil water will be less than that of pure water, and as the solute concentration increases, this causes the relative humidity to decrease. This behaviour is termed osmotic suction. Consequently, total suction is the sum of osmotic suction and matric suction.

2.2.1 The Soil Water Characteristic Curve and Hydraulic Conductivity

The typical method to estimate soil suction in engineering practice is the use of a Soil-Water Characteristic Curve (SWCC). The SWCC gives an indication of the volumetric or gravimetric water content of a soil as a function of the applied matric suction. The SWCC can indicate the distribution of water within voids and relates to the soil's gradation, texture, and void ratio (Fredlund et al., 2012).

A SWCC has three distinct zones, including the boundary effect zone, the transition zone, and the residual zone (Figure 2.1). At the intersection of the boundary effect and transition zone is the air-entry value (AEV) that represents the point at where water in the largest pores begin to drain and allow air entry. Residual conditions occur at the boundary of the transition and residual zones (Fredlund et al., 2012). All pore sizes that can drain have lost water and have been replaced by air, resulting in a discontinuous water phase around the soil particles. The residual zone ends at a soil suction of 10^6 that corresponds to oven dry.

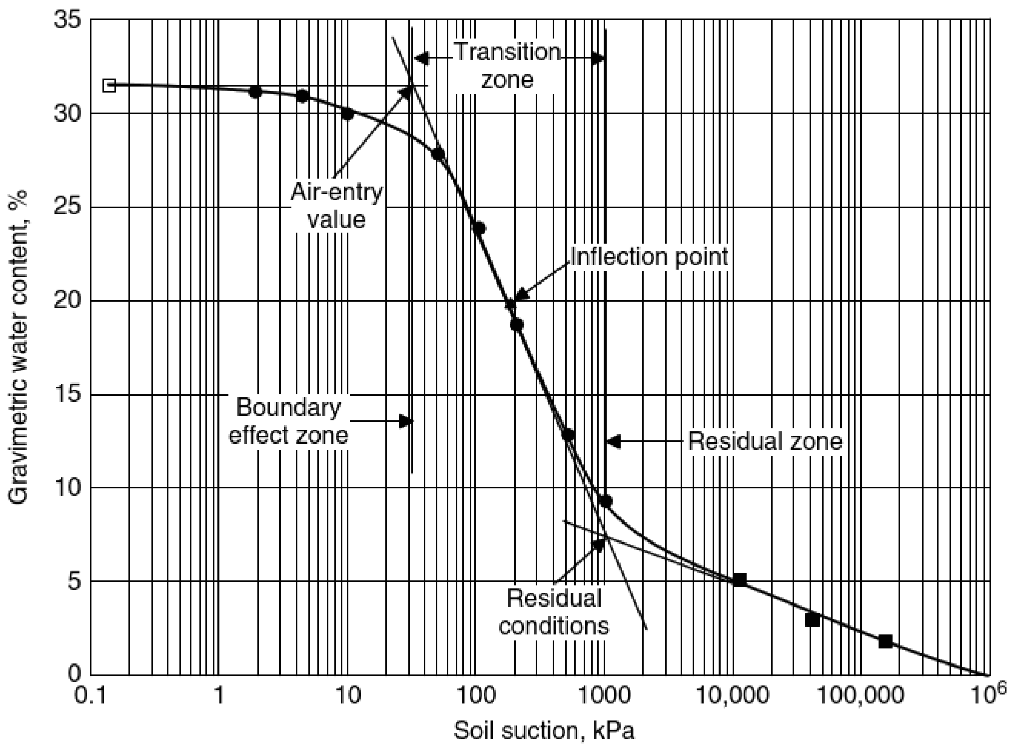


Figure 2.1- Typical Soil Water Characteristic Curve showing major zones of desaturation (from Fredlund et al., 2012)

Typically, SWCCs are constructed for the drying of a soil where the soil is initially saturated, with little or no occluded air, and then soil suction is increased. An adsorptive or wetting SWCC can also be generated where the soil moisture content increases to saturation. The resulting SWCCs are different due to hysteretic behaviour of the material, and consequently, an *in situ* material at a specific moisture content could have a wide range of suction values (Fredlund et al., 2012). Therefore, the SWCC can be used to assist in estimating unsaturated behaviour in engineering practice; however, values do not represent fixed or absolute conditions at a given soil suction.

Particle size distributions, or also termed grain size distribution, is a common method to classify soils and can also be used to assist in estimating unsaturated properties. The distribution of voids in a sample can be considered the inverse of a grain size distribution. The void distribution can be used to estimate the SWCC and is a common estimation method in practice. The grain size distribution can help indicate the primary drying zones for the SWCC using pedo-transfer functions (Fredlund et al., 2012).

2.2.2 Water Flow through Unsaturated Soils

Fluid flow in unsaturated porous media is proportional to the hydraulic conductivity. In saturated conditions, the hydraulic conductivity is a constant value as the area available for water flow within a soil remains constant, and is described by Darcy's Law (Lambe & Whitman, 2008). As a soil desaturates and air enters the pores of the soil, the cross-sectional area available for flow of water in the soil decreases, as entrapped air bubbles act similarly to a soil particle. As desaturation occurs, the hydraulic conductivity decreases. The decrease in hydraulic conductivity is largest after a soil has desaturated past the AEV. The changing relationship of the hydraulic conductivity with matric suction can be plotted similar to a SWCC and has similar hysteretic effects with wetting and drying of the soil. Fluid flow in unsaturated soils occurs in response to a total hydraulic head gradient, similar to saturated soils, and is not a function of the difference in matric suction (Fredlund et al., 2012).

Flow of water is described using Darcy's Law, which combines the components above where the flow rate of water is proportional to the hydraulic head gradient over a given distance and where the constant of proportionality for a given soil is the hydraulic conductivity, k_w (Lambe & Whitman, 2008). However, the hydraulic conductivity is not constant in unsaturated conditions as described above and must be represented as a function of the degree of saturation, S, or matric suction (Fredlund et al., 2012). Darcy's Law is expressed below where the hydraulic conductivity is a function of matric suction:

$$v_w = -k_w(u_a - u_w)\frac{\partial h_w}{\partial y} \quad (2.11)$$

where v_w is the flow rate, $k_w(u_a-u_w)$ is hydraulic conductivity as a function of matric suction, and $\partial h_w/\partial y$ is the hydraulic head gradient in a given direction, y.

Measurement of a hydraulic conductivity function for unsaturated soils is difficult, and numerous methods are available to estimate a suitable function. Methods include empirical, statistical, correlation, and regression models. Typically, the SWCC is utilized to estimate the hydraulic conductivity empirically. The typical relationship between the SWCC and hydraulic conductivity functions are provided in Figure 2.2 (Fredlund et al., 2012).

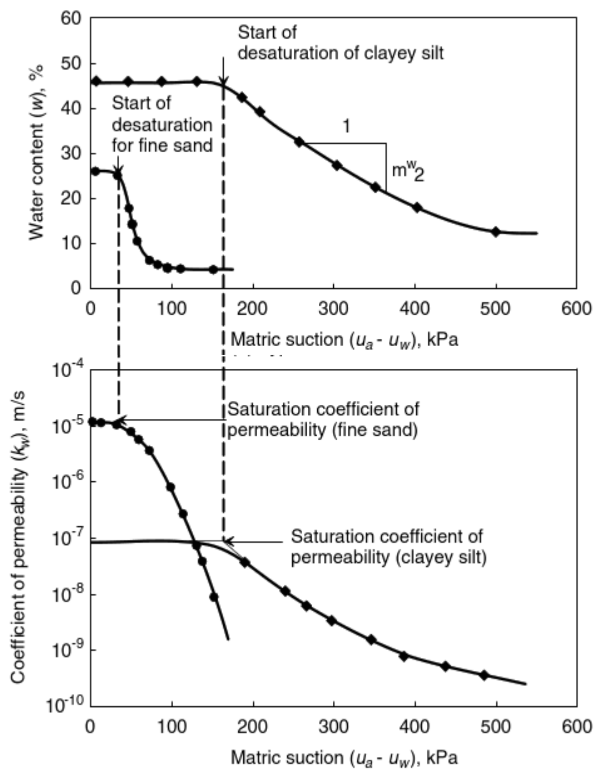


Figure 2.2 - A typical relationship between a Soil Water Characteristic Curve and hydraulic conductivity function in two different soils (from Fredlund et al., 2012)

One-dimensional flow through unsaturated soils can be used to understand vertical infiltration into a soil column where the water table is below the surface or a structure is built above the ground surface and is great in lateral extent. Ground surface moisture flux boundary conditions will alter the unsaturated profile above the water table. Considering a single soil element where flow is steady state, flow into the element will equal flow out. Using Darcy's Law to express flow as a function of hydraulic head gradient and the unsaturated hydraulic conductivity function, the non-linear differential equation for one-dimensional flow is given by:

$$k_w(u_a - u_w)\frac{d^2h_w}{dy^2} + \frac{dk_w(u_a - u_w)}{dy}\frac{dh_w}{dy} = 0 \tag{2.12}$$

where $dk_w(u_a-u_w)/dy$ is the change in the unsaturated hydraulic conductivity over a given distance, dy. The solution is non-linear due to the non-linear nature of the unsaturated hydraulic conductivity function. If the soil was saturated and homogeneous, k_w would be constant and the resulting differential equation would be linear. This equation can be analyzed using finite difference or finite element methods with appropriate boundary and initial conditions.

As described above, flow of water through waste rock is dependent on the unsaturated characteristics and the degree to which a soil is saturated. These properties will dictate the rate at which water will flow and the pathways taken during infiltration events. Typical AEVs for waste rock are less than 1 kPa; however, residual moisture contents are high due to the well-graded nature of the waste rock fines (Aubertin, 2013).

The particle size is also related to capillarity in a SWCC. Particles greater than 5 mm exhibit no capillarity or water retention. Materials greater than 5 mm will exhibit an AEV value that is similar to that of the fine fraction and the SWCC is shifted downward, as only the porosity changes. Consequently, the division between the coarse and fine fraction of the soil can be defined as 5 mm or, for convenience, to the No. 4 sieve (4.75 mm). In the case of waste rock, the AEV is controlled primarily by the fine fraction, and the SWCC including the coarse fraction can be estimated from knowing the relative proportions of fines and clasts (Yazdani, Barbour, & Wilson, 2000).

The following sections discuss studies completed to characterize waste rock dumps to understand the unsaturated flow behaviour of water through highly variable waste rock.

2.3 Hydrogeologic Characterization of Waste Rock Stockpiles

ARD production in mining is dependent on the structure of waste rock dumps as structural features allow oxygen and water ingress, promoting sulfide oxidation. In addition, to understanding the geochemical reactions in the waste, the physical structure of waste rock is critical to characterize pathways for reactant flow and to understand long-term behaviour.

To date, a moderate number of studies have evaluated the internal structure and hydrology of full-scale waste rock piles, and some studies are ongoing. Previous studies have been completed on waste rock to characterize their structure, the mechanisms of preferential flow, environmental loadings, and the importance of climate and site geology. This section will review studies on the physical and hydrologic behaviour of waste rock dumps.

2.3.1 Structural and Physical Characteristics of Waste Rock

Waste rock dumps are typically constructed by end dumping of material from a tipping face, resulting in a slope at the angle of repose or as a free-dumped structure. Materials dumped from tipping faces, typically higher than 5 m, result in segregation of the waste rock where the coarse material is found at the base of the waste rock dump and the finer material is nearest to the tipping face (Herasymuik, 1996; Smith et al., 1995). These dumps are often referred to as segregated dumps, as the waste rock material is coarsening downwards and forms distinct layers of fine and coarse rock at the angle of repose (Wilson, 2011). A free-dumped structure such as a paddock dump or push dump will not exhibit a significant segregation of material as end-dumped material (Smith et al., 1995). The structure of a waste dump and its environment can drive the production of ARD, and consequently, an understanding of the structure can assist in mitigation and prevention of ARD (INAP, 2009b). The geotechnical stability of waste rock piles must also be included in the structural design of waste rock (Aubertin, 2013); however, a discussion on geotechnical risk and long-term stability is outside the scope of this report.

A conceptual model of waste dump structure in segregated piles was determined by Herasymuik (1996) at the Golden Sunlight Mine. Structure mapping of a large waste rock dump was conducted in combination with evaluating the unsaturated behaviour of the waste rock dump. The conceptual model illustrates that the coarse material is located at the base of the dump, providing drainage and allowing the inflow of oxygen upward into the waste rock dump. The upper portion of the structure is interbedded fine and coarse layers of material at the angle of repose. Angle of repose slopes are approximately 37°, but vary based on particle shape and size, specific gravity, and the method and height of construction, among other factors (Aubertin, 2013). Material in waste rock dumps can range from silt- and clay-sized particles up to boulders that are metres in diameter. During infiltration, water flows along the fine layers as these materials retain the water in capillary tension (Fines, 2006; Wilson, 2011). Oxygen ingress by advection occurs at the base of the pile where large open voids are found due to the blocky nature (Figure 2.3).

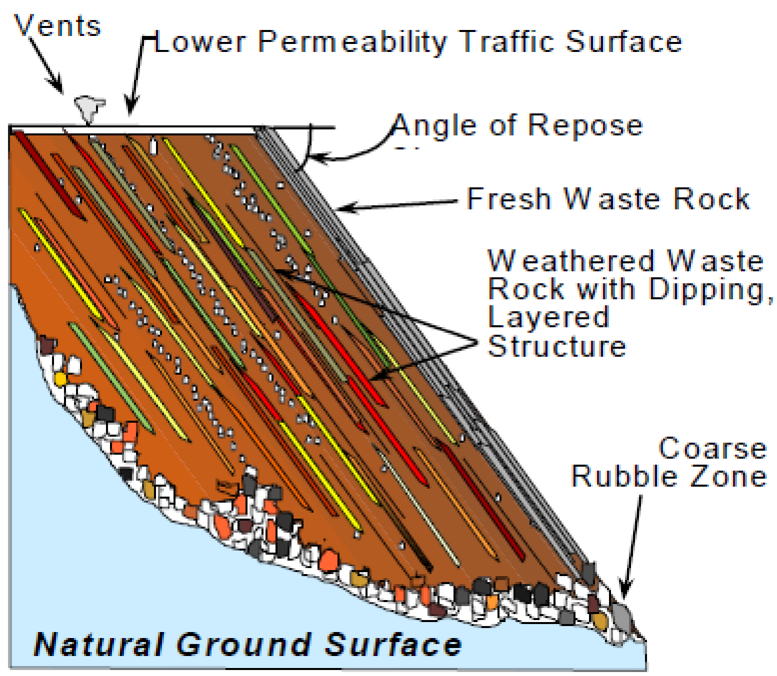


Figure 2.3 - Conceptual model of segregated waste rock dump with oxygen and water flow pathways (from Herasymuik, 1996)

The above diagram illustrates the process of air and water ingress and highlights the inherent heterogeneity of waste rock. Textures range from boulders with open voids and larger cobble clasts in matrix-supported fines to fines in a clast-supported structure and zones of strictly fine material. Furthermore, the effects of physical and chemical weathering (i.e. sulphide oxidation) continually alter the structure, even within short periods of time (Wilson, 2011). End-dumping techniques also cause significant segregation of particle sizes and results in a loose-packed structure.

Another common feature in waste dumps include traffic surfaces or ramps created by trucks that haul and dump material at the tipping face. This feature can also be created if the dump is constructed in smaller benches. The result is a compacted layer that can reach 1 m (Aubertin, 2013) within the dump, which often has low permeability and acts like a pavement between benches (INAP, 2009b).

These structural aspects created during construction directly influence water and oxygen flow. Often, they enhance the production of ARD due to the ease at which oxygen can ingress from the base and the conductive nature of water into fines at the top of a tip face (INAP, 2009b).

Excavation studies or the construction of research test piles have been used to characterize the physical and geotechnical properties of waste rock. Sample collections can be used to determine physical properties such as moisture content, grain size distribution, the SWCC, saturated hydraulic conductivity, and geochemical characterization. *In situ* testing can include density, temperature, soil suction, and relative humidity (Andrina, Miller, & Neale, 2003; Andrina, Wilson, Miller, & Neale, 2006; Fines, Wilson, Williams, Tran, & Miller, 2003; Herasymuik, 1996;). In instrumented studies, monitoring equipment is installed permanently to monitor waste rock properties continually. Past research programs to characterize physical characteristics will be discussed in further sections.

2.3.2 Digital Image Processing Analysis of Waste Rock

In addition to physical characterization, computer analysis of the physical properties of waste rock can also be conducted. Due to the large scale of mine waste and the significant range of particle sizes associated with dumps, it is often impossible to sample and characterize grain sizes greater than 10 cm (Chi, 2010). The use of standard screens and sieves for particle size distribution is standard for fine material and is a highly accurate method (Sudhakar, Adhikari, & Gupta, 2006). However, screens and sieves for material larger than 10 cm are uncommon and are expensive (Kemeny, Devgan, Hagaman, & Wu, 1993). Consequently, alternative methods like digital image processing (DIP) analysis have been employed to assist in evaluating grain size distribution and fragmentation. DIP analysis has been utilized in mining and geotechnical applications to characterize blast fragmentation to reduce expenses related to crushing and grinding for mineral recovery due to its low cost and simplicity (Hunter, McDermott, Miles, Singh, & Scoble, 1990; Kemeny, 1994; Kemeny et al., 1993; Maerz, Palangio, & Franklin, 1996). DIP analysis was utilized in this study and a brief review of the technology is discussed.

Multiple software packages utilize photographs of rock material to analyze particle size, including Split-Desktop, WipFrag, FRAGSCAN, and Fragalyst, (Hunter et al., 1990; Sudhakar et al., 2006). In addition, Chi (2010) at the University of Waterloo developed a program to obtain the spatial grain size distribution from photographs taken at the Diavik Waste Rock Project. Each software program provides a particle size distribution using different methods for edge detection and delineation of particles and fines (Sudhakar et al., 2006). SPLIT imaging software is reviewed in the following section. This program allows automatic input of an image where the particle boundaries are delineated and post-edited to ensure accurate interpretation of edges (Hunter et al., 1990).

The SPLIT image processing software, Split-Desktop, utilizes five steps for image analysis: determining an image scale, performing automatic delineation of the photograph, manual user editing of the delineations, calculation of the particle size distribution, and providing the graphical output of the results. During delineation, the software utilizes pre-processing greyscale equalization to sharpen particle boundaries and shadows (Kong, 2013) and will also assess particle boundaries in accordance with the resolution of the photograph as well as the scale and distance from the material (BoBo, 2001). After particle delineation, the program creates a best-fit ellipse for the particle and statistically based correction factors for fragment overlap and fines (Kong, 2013; Split Engineering LLC, 2011b). Kemeny (1994) provides a detailed discussion of image processing and statistic calculations as well as field validation studies, which are outside the scope of this study.

DIP presents challenges for image processing due to a variation of factors. Variable lighting conditions, limited resolution of photographs, as well as errors due to perspective and the use of a two-dimensional photo for a three-dimensional particle analysis can present challenges during delineation (Chi, 2010; Hunter et al., 1990).

Void space or porosity accounts for 10% to 40% of the volume of the fragmented rock, which is identified as dark shapes formed by the meeting of convex particle edges (Kemeny, 1994). These shadowed areas can be detected during delineation, but often require some user correction. Finally, particle size distribution results using DIP techniques often underestimate the fines portion of the material analyzed (Sudhakar et al., 2006). However, results from the Diavik waste rock project combined sieve data with DIP data to create a composite particle size distribution of the full grain size range (Chi, 2010; Smith et al., 2011). The results from Chi (2010) indicate that the waste rock distribution is heterogeneous and non-uniform as the fines content ranged from 10% to 40% and will directly affect the rates of mineral oxidation and the production of ARD. A subsequent study by Kong (2013) compared the DIP program developed by Chi (2010) with two programs, WipFrag and Split-Desktop software, on select waste rock photographs. The comparison concluded that both WipFrag and Split-Desktop analyses required well-lit photographs and results were influenced by lighting conditions. Furthermore, auto-delineation performed by the program was less accurate in areas outside of the focus area of the photo and required greater manual editing. Overall, the particle size distributions generated by each of the three methods were consistent for the coarse fraction (Kong, 2013). The results of this comparison resulted in Split Desktop being utilized in this study to characterize large-scale waste rock.

2.3.3 Hydrologic Characteristics of Waste Rock

The physical properties of waste rock directly influence its hydrologic behaviour. Initial studies characterized waste rock as a porous media; however, a porous media has uniform properties and is not sophisticated enough due to the coarse and highly heterogeneous nature of waste rock. The inherent heterogeneity of a waste rock dump presents considerable difficulty in accurately modelling the flow pathways and predicting environmental loadings to the environment, as average material properties cannot accurately describe the behaviour (Fines, 2006; Smith et al., 1995).

The ingress of oxygen and water into waste dumps is illustrated in Figure 2.4. Precipitation as rain or through snowmelt is conducted into the pile or runs off the surface (INAP, 2009b). The infiltration moves through the pile typically under unsaturated conditions through various pathways: either fine grained matric material, through macropores, or preferential pathways (Aubertin, 2013). Seepage through the waste rock may exit at the toe or on the face of the pile. It may also interact with the groundwater below the structure.

The study of water flow through waste rock piles has previously been illustrated at two different scales: first, at a smaller scale to illustrate the internal process, and second, at a large scale to understand the drainage and infiltration relationship to flow paths within a full-scale pile. The production of ARD is influenced by saturated-unsaturated water flow, chemical interactions, heat transfer and flow in water and air, as well as the circulation of air within a waste pile (Smith et al., 1995).

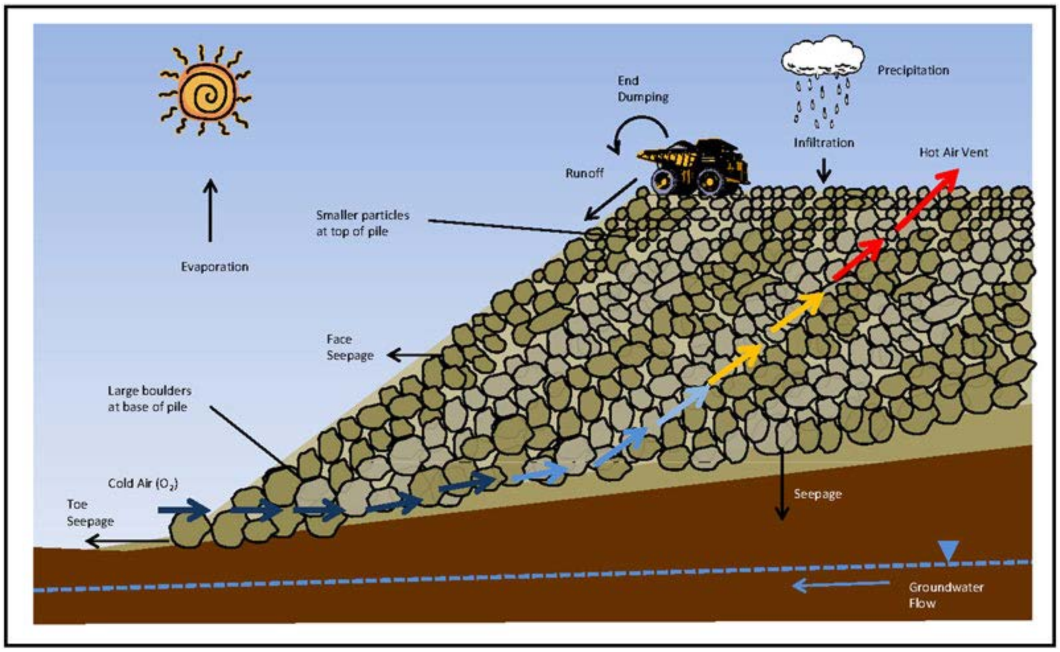


Figure 2.4 –Typical waste rock dump construction showing air and water pathways and receptors (from INAP, 2009)

The water flow in waste rock as described by Smith et al. (1995) indicates four factors that must be considered when understanding waste rock behaviour:

- Waste rock texture and the hydrostratigraphy of the pile. These properties can influence the structure of the waste rock and the paths in which both air and water flow. Larger particles conduct seepage through larger voids, and fine materials behave more as a porous medium;
- The water content profile of the waste rock and its variability in space and time;
- The temperature profile of the waste rock and its behaviour during infiltration events; and;
- Large-scale hydrologic behaviour as determined from outflow measurements taken.

These four factors are the main considerations that must be accounted for in the hydrogeology of waste rock, as the amount of fines and their water content influence the rate of transmission of water and the waste rock properties affect the production and transmission of ARD. However, other factors such as settlement, migration of fines, as well as preferential pathways in waste rock can influence flow (Smith et al., 1995). The grain size distribution and the proportions of matrix-supported or clast-supported material and their spatial relation significantly govern fluid flow. These properties are influenced primarily by the method of mining and the deposition of waste in the rock dumps as well as the rock type and its friability and behaviour during weathering (Smith & Beckie, 2003). Internal seepage within waste rock is also affected by channeled flow, segregation of materials, ponding of water tables on low permeability zones, and weathering (Smith et al., 1995).

Initially, waste rock dump material is deposited with availability for water storage as the material is at lower water content than what can be held due to capillarity (Smith & Beckie, 2003). This period can be referred to as the “wetting up” period. This period is dependent on the waste rock properties as well as climate. In upper regions of typical dumps, finer layers have soil-like behaviour. Flow in fine-grained material occurs as a function of grain size distribution. The division in waste rock between soil-like and rock-like behaviour has been related to the sand content and varies in the literature. Some previous divisions include a sand-sized content of 20% for 2 mm sand or 40% material passing the 4.75 mm sieve (Herasymuik, 1996; Smith & Beckie, 2003). Flow can be further complicated if fine layers above coarse units form a capillary barrier and the seepage cannot migrate into coarse material under low saturation (Fala, Molson, Aubertin, Bussiere, & Chapuis, 2006). In coarse areas with clast-supported structures, flow occurs between particle contacts (Smith & Beckie, 2003). Stratification and structural features within the dump creates zones of higher and lower permeability in relation to the degree of saturation. Stratification can occur due to the deposition method or directly from contact with equipment (Fala et al., 2003).

Local flow systems formed from macropores can create channels that are inclined, vertical, or horizontal (Fala et al., 2003), and water flow may by-pass fines in high infiltration scenarios. Conversely, with lower infiltration rates, fines may remain saturated due to higher AEVs and conduct the majority of flow.

Water tables within the dump are not common due to the free-draining nature of waste rock; however, traffic surfaces or low permeability at the base of a pile can result in water table development (Smith et al., 1995). The low permeability of these surfaces also causes the infiltration to move laterally, promoting distribution of infiltration within the dump (Smith & Beckie, 2003).

The amount of infiltration depends on the amount of rainfall, the capacity of the surface for infiltration during a precipitation event, topography and surface texture, surface vegetation or engineered covers, and the existing moisture conditions in the dump (Smith & Beckie, 2003). Precipitation will runoff the surface if the infiltration capacity is exceeded, and some precipitation will be lost to evaporation, both on the surface and from within the dump. The depth of the evaporative zone is dependent on climate as well as the surface characteristics (Smith & Beckie, 2003).

Long-term hydrologic simulations in Fala et al. (2006) analyze the period of time for a waste rock pile to allow the wetting front to move completely through the pile or the “wetting up” period. Analyses indicate that, under typical precipitation conditions, after this initial wetting up the long-term volumetric water content profiles within the pile become cyclical, with changes related to seasonality (i.e. wet and dry seasons). The time to reach this state varies depending on the dump properties. After this dynamic steady-state condition is achieved, changes in yearly precipitation do not alter the water contents (Fala et al., 2006).

Smith and Beckie (2003) identified important parameters for hydrogeological characterization, including moisture content, matric suction, SWCC, and the associated unsaturated hydraulic conductivity. Various studies on large-scale waste dumps (Andrina, 2009; Blackmore et al., 2012; Nichol, Smith, & Beckie, 2005; Stockwell, Beckie, & Smith, 2003; Stockwell, Smith, Jambor, & Beckie, 2006) cite the difficult process of measuring and predicting the hydrologic behaviour in the field due to macropore flow, wetting-up of dumps after construction, and internal structure created during construction.

2.4 Previous Waste Rock Characterization Studies

A number of waste rock investigations have been completed to assess and characterize the behaviour of mine waste rock with respect to physical, hydrologic, and geochemical properties. Details of prominent and ongoing studies are discussed primarily in relation to water flow and physical characteristics. Geochemical data are not discussed and are outside the scope of this study.

<u>Golden Sunlight Mine, Montana, USA</u>

A large-scale waste rock excavation study was conducted at the Golden Sunlight Mine, in southwest Montana in 1994. The study aimed to understand the major hydrogeological mechanisms and pathways within a waste rock dump as a large lateral slide occurred due to a foundation failure. The failure necessitated the relocation of waste rock material and allowed examination of the internal structure of the waste rock pile (Herasymuik, 1996). The waste rock dumps were constructed by end dumping from platforms on the sides of mountain slopes (McKeown, Barbour, Rowlett, & Herasymuik, 2000).

The study consisted of an excavation study and subsequent laboratory analysis of 242 samples. During the excavation study, interbedded layers of coarse and fine material were observed on each bench of material. The layers in the pile ranged from 20 cm to several meters at the angle of repose. The study identified that the upper 15 m of the waste rock pile held the majority of the liquid water within the pile (Herasymuik, 1996). Observations indicated that the coarse lower section of the waste rock pile did not hold significant water in tension and provided the primary pathway for oxygen and water vapour ingress. The fine fraction of the piles contained more water, and waste rock with more than 40% passing the 4.75 mm sieve had a greater ability to retain water than samples with less than 40% passing the same sieve (Herasymuik, 1996). In summary it was concluded water is stored and transported in the fines less than 4.75 mm under unsaturated conditions.

Cluff Lake Mine, Saskatchewan, Canada

The Cluff Lake uranium mine was an open pit and underground operation from 1980 to 2002 (Nichol, Smith, & Beckie, 2005). A test pile waste rock study was started in 1998 to study fluid pathways and infiltration mechanisms. The waste pile was 600 m x 900 m constructed by end dumping in 0.5 m to 3 m lifts to a height of 30 m. The pile had both compacted traffic surfaces and coarse non-trafficked surfaces. The test pile was constructed on top of the existing pile, and extended 8 m x 8 m to a height of 5 m. The core of the test pile was instrumented (8 m x 8 m) and 16-2 m x 2 m lysimeters were located at the base of the test pile. The instruments measured infiltration and outflow using actual precipitation events and man-made events (Smith & Beckie, 2003; Nichol et al., 2005). The material was characterized by particle size distribution and found to be on the boundary of a matrix- or clast-supported structure.

The study primarily evaluated infiltration using infiltrometer tests. In some areas, 90% infiltration was observed when neglecting evaporation (Smith & Beckie, 2003). During high intensity infiltration events, ponding was observed in low areas, and coarse waste rock promoted fast infiltration. Yearly net infiltration was 57% (Nichol, 2002; Nichol et al., 2005) for natural and applied rainfall and ranged from 55% to 85% for large events. Lysimeter responses were highly varied and had different response times and volumes with multiple arrival times of wetting fronts. The different arrival times of wetting fronts suggested multiple or preferential flow paths within the pile with different residence times. For the 5 m pile, the residence time for natural rainfall conditions were 4.4 years, and for tracer tests performed residence time was 2.8 years (Nichol et al., 2003). Macropore flow may also have contributed to reduced oxidation rates as water was conveyed away from fines (Smith & Beckie, 2003). The study also observed that low flow cover systems decreased the spatial variability of water flow due to reduced infiltration and limiting macropore flow (Smith & Beckie, 2003)

The variability of water flow under transient infiltration requires identification of features and pathways through the waste rock (Nichol, 2002). Water can be exchanged between channels or pathways depending on a given infiltration rate during a single infiltration event. The characterization of the internal structure of waste rock piles is difficult due to placement variability, but also the hydraulic conductivity. It was noted that even with extensive instrumentation, the mechanism that controls water flow through waste rock could not be determined from flow data alone. The length of rainfall events is often too short to obtain sufficient detail from instrumentation installed at study sites (Nichol et al., 2003). The water flow is further complicated as flow in macropores causes velocities to be three to four orders of magnitude higher than the mean water velocity, since the hydraulic conductivity of the large diameter material is high when saturated and their large diameter pores can conduct significant volumes of water (Nichol et al., 2005). From this study, it is clear that heterogeneous properties and the inconsistency of natural infiltration events result in a highly complex behaviour that is not easily characterized.

A companion study at Cluff Lake identified the effect of surface configuration on the outflow reported to the lysimeters and changes in runoff during artificial irrigation to prepared surfaces. Both an uncompacted, levelled surface free of depressions, and a compacted surface were compared (Marcoline, Beckie, Smith, & Nichol, 2003) using the surface of the constructed pile reported by Nichol (2002). This study emphasized how heterogeneities in waste rock directly influence the hydrogeologic behaviour. Creating a homogeneous surface free of depressions did not significantly decrease the outflow reported at the lysimeters; however, it prevented conditions like ponding in small catchments on the surface. This did not correspond to a more uniform distribution of flow from the lysimeters as the inner structure has a greater impact than the surface configuration. Marcoline et al. (2003) also illustrated that a compacted surface layer did effectively reduce the speed at which water migrated through the pile, but also appeared to block some macro-pores in the waste rock pile and resulted in better predictions of the internal flow mechanisms. With compaction, more homogeneous material, and elimination of large pathways, the behaviour of waste rock was much more easily predicted (Marcoline et al., 2003).

<u>Key Lake Uranium Mine, Saskatchewan, Canada</u>

An investigation at the Key Lake Operation north of Saskatoon, Saskatchewan, was conducted on a 12-m high waste rock dump that was deconstructed, sampled, and characterized. The climate was continental sub-arctic with significant temperature variations between -40 °C and +35 C (Stockwell et al., 2003). The dump was constructed using an end-dumping technique and was deconstructed after an unsuccessful infiltration study due to freezing within the pile preventing flow. Due to the complexity and transient nature of unsaturated flow in waste rock, physical measurements were taken to assist in characterization of the dump parameters. Measurements included grain size distribution, soil moisture content, and matric suction (Stockwell et al., 2003). Deconstructed was completed in 2 m lifts with construction of trenches for wall grab samples in both weathered areas and random sampling locations. Water content and suction were measured at the sampling points. During deconstruction, alternating layers of coarse and fine material were discovered oriented at the angle of repose, with a coarse rubble zone at the base of the structure with open air voids. Frozen material was found adjacent to the rubble zone with ice lenses up to 50 cm thick; however, the majority of the pile was not frozen. Stockwell et al. (2003) indicated no clear relationship between the suction and moisture content of samples collected, which may have resulted from limited samples collected or influences due to hysteresis and sample variability. Although various measurements were taken to assist in characterization, it was concluded that there were no relationships between the grain size, geochemical behaviour, and weathering variability (Stockwell et al., 2003).

INAP Waste Rock Dump Characterization Project

Two waste rock dumps were excavated to determine their *in situ* properties with differing geologies and climates. A combined field and laboratory investigation was completed at two sites: Site 1 in South-Eastern United States and Site 2 near Sudbury, Canada (Fines, 2006). The field program consisted of characterizing the *in situ* material in test pits through determining matric suction and density measurements as well as through collecting samples for paste pH testing, saturated hydraulic conductivity, determination of the SWCC, and particle size analysis. Deconstruction of both field sites illustrated similar interbedded layers associated with end-dumped waste rock. Site 1 experienced extensive weathering over the 10-year life of the dump, increased flushing of certain materials, and had greater seepage. The material was weathered and unsaturated with soil suctions ranging from 10 kPa to 50 kPa (Fines et al., 2003). Site 2 experienced less weathering in granitic type rocks, and some areas of the dump remained frozen throughout the year. Fines (2006) described that the particle size of the materials at Site 2 had a much coarser fraction that led to more complicated flow paths, and the pile was at residual water content. The climate differences indicate that the weathering process is enhanced in humid to sub-tropical environments, producing a larger proportion of fines and enhanced leaching. The water contents of the dumps were a function of the amount of fine materials, and the blocky nature of Site 2 resulted in high suction conditions at residual water content in comparison to partially saturated fines at Site 1.

Grasberg Mine, Papua Province, Indonesia

The Grasberg Mine is located in the equatorial mountains in the Papua Province of Indonesia, with temperatures between 2 °C and 14 °C. This area is a high rainfall environment with 4000 mm to 5000 mm of precipitation (Andrina et al., 2003). Investigation into ARD production of waste rock was investigated, and a series of trial waste rock dumps were constructed to evaluate methods to reduce ARD such as covers or *in situ* treatments to the waste rock. A 20-m high dump extending 480 m x 80 m was constructed consisting of eight 60-m panels. Instrumentation included lysimeters, gas sampling ports, and Thermistors to monitor temperature. Treatments of the waste rock included a high density polyethylene (HDPE) cover, a mud cover, weathered waste rock, and limestone cover. Some panels combined waste rock and limestone with various blending methods. Characterization of the piles was completed through sample collection and instrumentation monitoring (Andrina et al., 2003).

The waste rock dump was constructed by end dumping or push dumping, and segregation of the material was observed. The highest temperatures in the dump reached approximately 70 °C in the first 18 to 36 months, and panels blended with limestone had lower temperatures (Andrina et al., 2006). During decommissioning, the panels showed evidence of oxidation with the exception of one where blended reactive rock and limestone was placed with a stacker. Temperatures were around 20 °C and paste pH values remained neutral. Predictions indicated that full oxygenation of the dump may not occur due to high rainfall. However, observations and gas sampling data did not support this, and segregation during placement facilitated air entry (Andrina et al., 2006). Oxidation rates between leach columns, test pads, meso-scale experiments, and a trial dump were evaluated to understand the effect of scale and to understand if a scale up factor could be used (Andrina, Wilson, & Miller, 2012). Scale up factors for the trial dump, test pad, and leach columns ranged from 11% to 58%. A lower oxidation rate in the large trial dump was linked to the difference in particle size as well as hydrology and oxygen concentration (Andrina et al., 2012).

Diavik Diamond Mine, Northwest Territories, Canada

The Diavik Waste Rock Project is a laboratory and field-scale project to compare field and laboratory behaviour and to assist with the mine closure plan (Smith et al., 2012). The site has two test piles constructed in 2006 in northern Canada where continuous permafrost is found. The two piles are 15 m in height and are highly instrumented with lysimeters, thermistor cables, gas lines, soil water suction samplers, moisture content probes, and air permeability balls (Pham, Sego, Blowes, Smith, & Amos, 2012). Investigations into unsaturated flow in the piles into collection lysimeters, oxygen and heat transport, and geochemistry are currently being monitored. Hydraulic properties were scaled using the method by Yazdani et al. (2000) from small-scale samples.

Flow in the 15-m test piles suggest that matrix flow dominates in these piles due to low rainfall conditions typical of the climate, even though the pile would be best described as clast supported and rock-like (as opposed to soil-like properties). During high rainfall events, macropore flow and preferential flow paths occurred in the piles. Due to the climate, freezing within the piles influences drainage and flow (Neuner et al., 2009).

Antamina Mine, Ancash Region, Peru

The Antamina Mine initiated a comprehensive waste rock study in 2005 to understand and predict future effluent water quality (Harrison, Aranda, Sanchez, & Vizconde, 2012). Five large test piles were constructed with varying rock types and instrumented for study. The ongoing study also consists of laboratory testing, field cell kinetic column tests, and cover studies in addition to the test pile program to evaluate preferential flow and overall fluid flow characteristics (Blackmore et al., 2012; see also Javadi et al, 2012). These studies are ongoing to support an overall waste rock management strategy. The program is currently starting its secondary phase to relate the test piles to the full-scale waste rock piles, understand gas transport, and investigate cover solutions (Harrison et al., 2012).

Laboratory and Modelling Analyses of Waste Rock

A study conducted by Newman (1999) illustrated, in unsaturated column experiments and numerical modelling, that water flow occurs where water is already present. Columns of fine and coarse material were tested in the laboratory and subsequently simulated in a finite element mesh using

SEEP/W, a finite element seepage model. Laboratory-determined SWCCs and saturated hydraulic conductivity values were used in the analysis. The numerical modelling illustrated that as the flux rate applied to the system decreased, the percentage of total effluent discharging in the fine material increased, and at very low flux values, 100% of the effluent travelled through the fines. If the suction values were greater than the AEV, the pores of the unsaturated material would drain where the large grain size zones drain first, which decreases the permeability (Newman, 1999). As a result, at higher suction pressures, the permeability of the coarser grained material can be greater than that of the fines, and water will preferentially flow through the fine material. Fluxes greater than the saturated hydraulic conductivity of the coarser material result in preferential flow through the coarse pathway, and fluxes that are less than the saturated conductivity of the fine layer promote flow in the fines (Newman, 1999). These results indicate that the pathway in waste rock hydrogeology is not the same in all cases, but is a function of the infiltration rate.

This concept was further extended to numerically investigate the movement of water in alternating coarse and fine material in inclined soils, similar to the structure of an end-dumped waste rock pile. Wilson (2000) utilized SEEP/W to understand the influence of inclination on flow in a dump as well as how contact surfaces between layers influence flow. Solutions determined from parametric and sensitivity analyses indicated that the solutions to flow problems in inclined layers are highly non-linear, and the behaviour relies on multiple variables, each set of variables with a unique solution. The highly complex functions used to quantify the unsaturated behaviour of the soils and low fluxes are difficult and result in significant numerical errors and solution instability. Similar behaviour of pathway migration for water flow described by Newman (1999) was observed in inclined layers (Wilson, 2000).

The concept of flow in inclined layers was further modelled utilizing a meso-scale sized experiment by Andrina, Wilson, and Miller (2009). This study accompanied the large field-scale test pile program previously described at the Grasberg Mine. The columns consisted of three panels of layered fine and coarse acid waste rock at the angle of repose, and rainfall was simulated to achieve uniform constant flux in the entire panel. The outflow within the panel did not only vary with respect to the grain size of the layers, as described by Newman (1999) and Wilson (2000), but outflow was also found in different layers of the panel. At a low flux rate of 2 mm/day at the surface, water flow was concentrated in the middle of the panel, and when increased to 5 mm/day, outflow was measured at each of the layers (Andrina et al., 2009). At high infiltration rates, 10 mm/day, vertical flow occurred within the panel.

The study identifies the relationship between the infiltration rate and flow path. Low flow rates promoted flow at the angle of repose with water flow in fines due to capillary forces. At higher rainfall intensities, vertical flow dominated due to the influence of gravity, and outflow from the coarse layers increased due to decreases in matric suction and permeability in the fine layers (Andrina et al., 2009). This introduces further complexity in understanding the mechanisms and behaviour of water flow in waste rock dumps, as the movement does not only rely on the effects of material conductivity in unsaturated conditions, but the influence of gravity flow behaviour in high infiltration environments.

2.5 Detour Lake Mine Site Description and History

This study discusses a waste rock excavation project currently being conducted on a historic waste rock dump at Detour Lake Mine. The mine site has recently been reopened, and existing waste rock piles at the site must be relocated for pit expansion at the site. As a result, a unique opportunity was presented to evaluate existing waste rock piles.

Detour Lake Mine (DLM) is a gold deposit property that has been redeveloped from a previous open-pit and underground operation from 1983 to 1999 (Robertson, Barazzuol, & Day, 2012). Redevelopment and assessment of the property began in 2006 with mill and facilities construction from 2010 to 2012 and production beginning in early 2013.

The mine is located 180 km northeast of Cochrane, Ontario, Canada, in the James Bay glacial lowlands (Figure 2.5). The overburden consists of glacial tills and glaciofluvial materials that range from zero to 40 m in depth. Some peat is found in the upper 3 m of the profile (AMEC Earth & Environmental, 2010a). The bedrock consists of a portion of the Abitibi Greenstone Belt in the Superior Province of the Canadian Shield. The structure of the area consists of volcanic massive and pillow basalts with shear zones that have associated hydrothermal alteration with mineralization. Pyrrhotite is the primary sulphide mineral with additional pyrite and chalcopyrite, some pentlandite and arsenopyrite. Calcite is the primary carbonate with some dolomite (AMEC Earth & Environmental, 2010b; Robertson et al., 2012). A more detailed characterization of the area and deposit geology is provided in Robertson et al. (2012).

Climate data is unavailable for the DLM site; however, records from Cochrane, Ontario, provide comparable data. The climate is moist continental with an average annual precipitation of 880 mm, of which 583 mm are rainfall and 297 cm of snow. Temperatures range from average highs of 24 °C in summer months (July and August) to average lows of -25 °C (January and February) (Environment Canada, 2013). Evaporation values onsite are not available; however, evaporation values are available from stations near DLM, including Moosonee, Ontario, and Amos, Quebec. The mean annual lake evaporation is 485 mm (AMEC Earth & Environmental, 2009).

Figure 2.5 – Map of Detour Lake Mine location (from Detour Gold Corporation, 2012a)

The previous operations at DLM produced four waste rock stockpiles that were re-contoured and closed with a single layer cover during mine decommissioning. The stockpiles were in operation for 16 years, and have been in the post-closure phase for approximately 10 years. These stockpiles present an opportunity to assess and characterize waste rock dumps with a 26 year history with the aim to understand physical and geochemical behaviour. This knowledge can be applied to all aspects of the DLM including future waste management at the property and the treatment of tailings or pit walls (Robertson et al., 2012). An investigation into the waste rock piles began in 2011 to assess the behaviour of waste rock under site conditions.

2.5.1 Stockpile Locations and Composition

The original development at DLM produced four waste rock structures, Stockpiles 1 to 4. Each waste rock pile contains on the order of a few million tonnes of waste rock. Stockpile 1, Stockpile 2, and Stockpile 3 are located adjacent to the open pit from the original operation. Stockpile 4 is located to the east between the open pit and an existing tailings management area (TMA). The stockpiles cover areas up to 28 hectares and contain primarily waste rock with some local overburden. During closure of the first operation, the waste rock piles were re-sloped and covered and have a cover ranging from 0.3 m to 1.5 m. Stockpiles 1 and 2 are the focus of this research study, and Stockpiles 3 and 4 have been instrumented for an alternative study.

Stockpiles 1 and 2 are located in the proposed footprint of the open pit for the DLM operations and must be relocated to a dedicated potentially acid generating (PAG) waste rock facility. The relocation of the piles presented a unique opportunity to examine the internal characteristics and properties to determine the hydrological and geochemical conditions under site conditions over the past 11 to 27 years. The piles are approximately 15 m to 20 m high above the surrounding terrain.

2.6 Justification for Further Research

The prediction of ARD in the mining industry is challenging due to the heterogeneity of waste rock structure and properties as well as the scale of waste rock dumps on mine sites. Sampling programs are often limited due to limited access and neglect the coarse fraction of waste rock, skewing the relative proportions of the fine and coarse material. Limitations of previous studies in the literature include:

- Limited data sets of waste rock are available for parameters such as air filled porosity, soil suction, and SWCCs;

- Temporal effects on waste rock as studies are often conducted on newly constructed piles or test piles over limited time periods, resulting in a narrow view of waste rock behaviour;

- Difficulty in numerical modelling of water flow in waste rock as many necessary parameters that cannot be expressed accurately. Extending models to incorporate climate changes and understand long-term behaviour is also limited; and

- Detailed characterization of waste rock is difficult due to the heterogeneity of the structure and limited understanding of the proportion of coarse and fine material. Large grain size particles are not characterized or measured.

Data from past characterization studies therefore provide some information into the conceptual behaviour, but neglect the combined understanding of physical properties and hydrology with geochemistry, as obtaining representative samples from piles is rare.

In this thesis, a detailed forensic excavation project was completed on two waste rock stockpiles to assess the effects of weathering under natural field conditions for almost 30 years. The waste rock piles were constructed by typical mining methods and covered at the end of mine life. A detailed field and laboratory program was completed to collect representative physical samples to characterize physical and hydrologic properties over the long term under site conditions. Representative sampling from two stockpiles provided an extensive catalogue of physical parameters that form the basis for an assessment of the physical parameters that influence the hydrology of waste rock. These results are described and discussed in the following chapters. This program will provide a foundation for additional studies of water chemistry, microbiology, and gas transport with research partners at DLM and the

University of Waterloo to improve techniques for the prediction of long-term water quality in waste rock at Detour Lake Mine.

Chapter 3.0 Materials and Methods

3.1 Introduction

Investigation of the physical properties and characteristics of waste rock at Detour Lake Mine (DLM) located in Northern Ontario was conducted through a field investigation with subsequent laboratory analyses. The field program was conducted in two stages to characterize and collect samples from Waste Rock Stockpile 1 and 2 (WRS 1 and WRS 2, respectively). The first stage was conducted on the waste rock piles prior to relocation of the waste rock material in the configuration after closure to assess near surface characteristics. The second investigation stage occurred during excavation and relocation of the waste rock material during mine start-up activities. *In situ* testing and subsequent laboratory tests were also performed to assist in material characterization.

3.2 Field Program

The first stage of the field investigation involved a detailed test pit program to assist in characterization of the waste rock and cover material, followed by *in situ* testing and representative sampling for further study. The secondary stage involved the collection of grab samples from exposed waste rock profiles to assess the characteristics within the pile as well as to map the structure. The field investigation program is outlined in Sections 3.2.1 and 3.2.2.

3.2.1 Test Pitting Program

The first stage of the field program was conducted from July 30 to August 21, 2011, at DLM. Dr. G. Ward Wilson was present on site from July 28 to August 1 to assist with the initiation of the test pit program, to confirm sampling locations, and to provide guidance to the researcher on data collection procedures and techniques. Two days were utilized to excavate test pits on areas of interest on WRS 1 and WRS 2 to identify locations of interest requiring future study and to finalize the sampling procedure.

Three large test pits were completed on WRS 1 and one large and six small test pits were completed on WRS 2 during this initial site assessment. The remainder of the test pit investigation was conducted from August 12 to 21, in conjunction with equipment and contractor availability (WRS 1 was investigated from August 12 to 16, and WRS 2 was investigated from August 18 to 21). This portion of the investigation was assisted by Pablo Urrutia. A total of 28 test pits were excavated and logged to cover the spatial are of the pile and aimed to assess range of properties across the spatial area and . Samples collected in the test pit program were taken from both the cover material as well as the waste rock.

Test pit excavations were facilitated through on-site contractors and mine site staff. The test pit excavations were completed using a backhoe and consisted of 10 m x 10 m pits, to a depth of approximately 3 m to 4 m. Figure 3.1 provides an approximate schematic of the plan and cross section of a typical test pit. Fresh surfaces of waste rock were opened to evaluate any *in situ* structure within the piles and for sample collection. The test pits were constructed in approximately 1-m benches to result in an overall 1:1 slope in the pit with a ramp for access in and out of the excavation. Some sloughing of material occurred during construction, particularly in cases where waste rock particles were large (i.e. particle diameters in excess of 0.5 m). Test pits consisted of two benches with a larger opening at the base of the test pit to allow ingress to the bottom. Figure 3.2 and illustrates the excavation of a typical test pit with the creation of benches, and Figure 3.3 displays a typical test pit after construction. An orange stake located on the upper bench of the test pit represents 1 m.

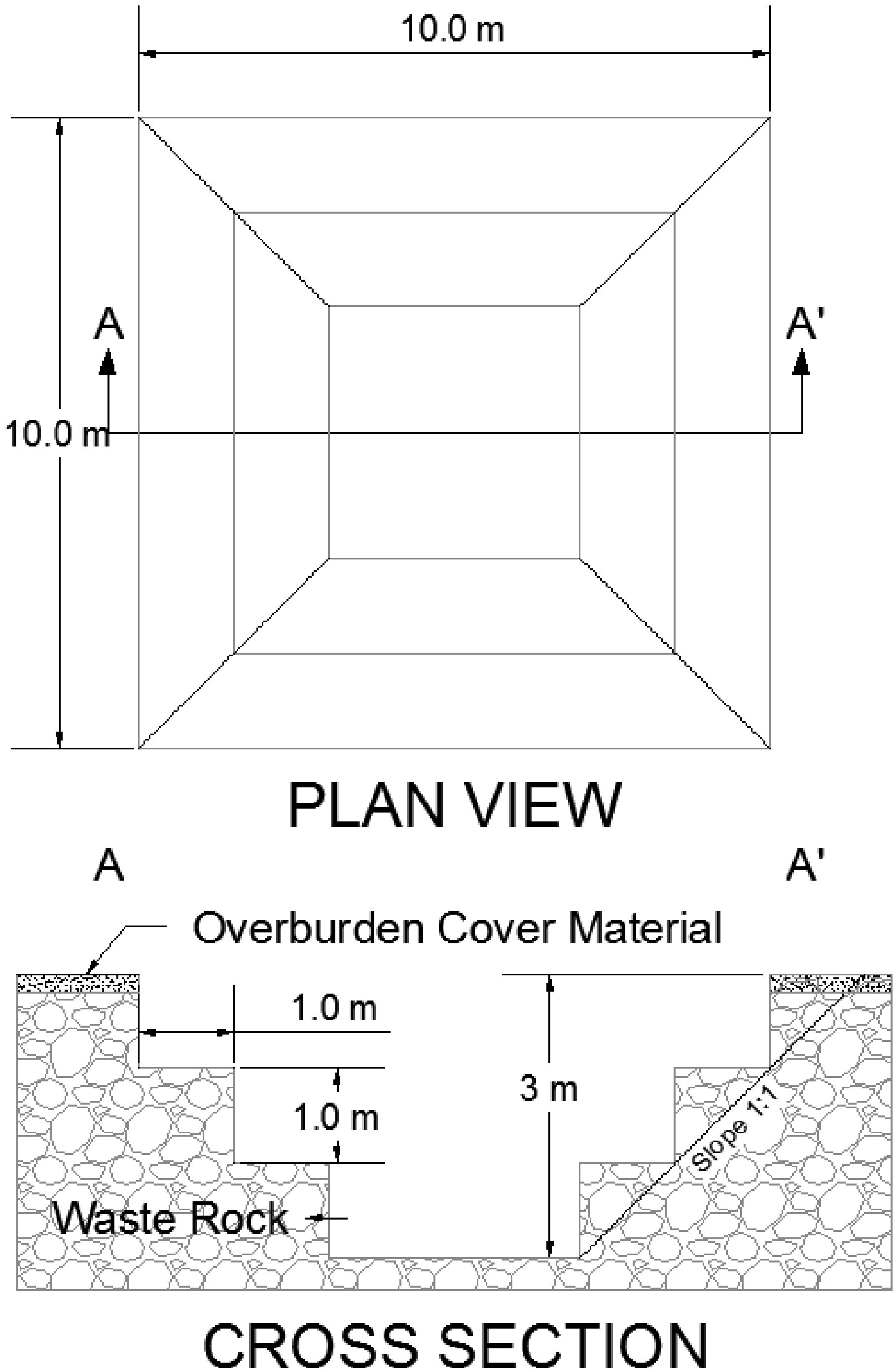


Figure 3.1 – Representation of test pit excavation plan and cross section

Figure 3.2 - Backhoe beginning construction of a test pit on WRS 1

Figure 3.3 – A typical completed test pit on WRS 2 with tensiometers installed

3.2.1.1 Test Pit Site Selection

To ensure the total waste dump area was sampled, a grid was constructed on both WRS 1 and WRS 2 to identify sampling locations. Thirteen test pits were excavated on WRS 1, spaced on a 100 m x 100 m grid. Fifteen test pits were completed on WRS 2 and were spaced on a 75 m x 75 m grid. The locations of the test pits were spaced to adequately investigate variations in geology and structure over the spatial area of the piles. Some test pit locations were relocated to avoid excavations on access roadways to the waste rock piles or to evaluate areas near previous drill holes for future data correlation. GPS readings for each test pit were recorded after excavation.

3.2.1.2 Field Tests Performed

After construction of each test pit, detailed logging of each test pit was completed identifying the physical characteristics of the waste rock and cover material. Test pit excavation, logging, and sampling procedures were consistent for the investigations on both waste rock piles. Parameters of interest within the test pit site included:

- Visual observations of geology, including or rock types, colour, presence and degree of oxidation, sulfide minerals visible, and associated crystal habit;
- Waste rock texture, visible structure, angularity, and degree of weathering;
- Soil suction measurements;
- Temperature profile;
- Representative samples for laboratory analysis; and

- Photos taken with a 1 m reference stake to assist in digital image processing analyses.

The test pit logging procedure involved the installation of three tensiometers (2725ARL Jet Fill Tensiometers, Soil Moisture Equipment) upon completion of the test pit in areas of fines. Typically, one tensiometer was installed in the cover material and two in waste rock material in areas of interest. The tensiometers were installed in a small hole cored to the size of the ceramic probe that permitted hydraulic contact with the soil (Figure 3.4). The tensiometers were allowed to equilibrate while other logging was performed. Tensiometers were installed on different benches in the test pit to understand the vertical suction profile. Highly oxidized or weathered areas were chosen to evaluate properties of oxidized waste as well as representative locations in the test pit. After equilibration, suction values were recorded. Influence of weather was noticed on some suction readings, as suctions would increase with sun exposure. Sampling areas were covered to reduce evaporative losses on days with no cloud cover, and suction readings were not taken on days where sampling occurred in the rain.

A temperature profile was completed primarily for test pits on WRS 2 due to the availability of equipment (Figure 3.5). Temperature was measured with depth in the side walls of the test pit from the surface in locations where the temperature probe had sufficient contact to output a reliable reading. The temperature probe was inserted in approximately 0.5 m intervals.

Figure 3.4 - Typical tensiometer installation in fine material.

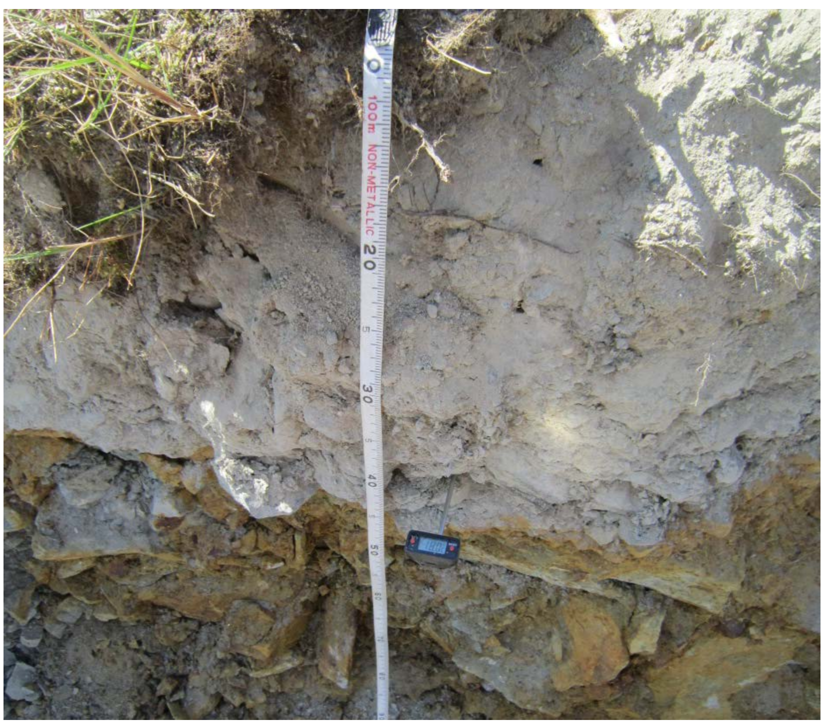


Figure 3.5 – Measurement of soil and waste rock temperature in a test pit wall

Visual logs of each test pit included observations of material or rock types present. Detour Gold Corporation geologists provided instruction on major rock types found in waste rock, which were identified during logging. Detailed geological logging was outside of the scope of this study; however, some preliminary rock identification was included. Major rock groups identified included:

- Footwall Mafic Volcanic (FMV) – fine grained homogenous volcanic unit resembling basalt with some areas of porphyritic feldspar and plagioclase phenocrysts, quartz veinlets and chloritic alteration. This lithology is estimated to include 42% of waste rock.

- Talc Chlorite Schist (TC) and Chloritic Greenstone (CG) – includes amphibole, chlorite and talc, plagioclase, pyroxene potassium feldspar and mica. Sulfides account for 2% to 5% of the material and some calcite and dolomite.

- Felsic Intrusive (FI) and Mafic Intrusive (MI) –intrusive lithologies included quarts and potassium feldspar in the felsic intrusives, with some pyrite accounting for 3% by weight with some calcite and dolomite.

- Chert (CMH) – the chert marker horizon is a fine grained felsic to intermediate dyke. The material was misidentified as chert and has retained the classification for consistency. The material has a high sulfide content and associated quartz veining.

A detailed description of DLM geology and major lithologies can be found in AMEC Earth & Environmental (2010b). Cover material on the waste rock piles consisted of overburden material placed during closure. The material is fine grained with some cobble- and boulder-sized rounded glacial material. Vegetation on the waste rock piles was not sampled, but was present in the upper 10 cm to 15 cm of the cover profile with rootlets extending into the cover material.

Some identification of sulphide minerals was recorded during logging. Sulphide mineral distribution ranged from disseminated within the host rock to along fracture planes as well as forming small clusters. No significant relation of sulphide presence was linked to rock type or to degree of oxidation. To quantitatively describe oxidation and weathering within the pile, estimates of the proportion of exposed rock within the test pit that showed evidence of surface oxidation or clasts or oxidation of fines was recorded.

Figure 3.6 - Location showing fresh surface of waste rock material with highly oxidized fine matrix and oxidation on surfaces of clasts.

Photos were taken of each test pit and sampling location with a 1 m reference stake or reference square. These photos were taken for visual records of each sampling location as well as for use in digital image processing (DIP) techniques to determine large-scale grain size. DIP analysis is discussed in Section 3.3.5.3.

3.2.1.3 Representative Sampling and Sample Handling

Test pit sampling occurred in conjunction with soil suction measurements. After the tensiometers equilibrated, bag samples were extracted from the material surrounding the ceramic cup. Samples of 1 L to 2 L of matric material from around the tensiometers were collected by trowel, placed into plastic bags, sealed with cable ties, and double bagged to prevent moisture loss. Larger 20-L samples were collected in plastic pails at the same sampling location using a larger shovel (Figure 3.7). The size of waste rock material collected was limited by the plastic pails, and material was typically less than 10 cm in diameter.

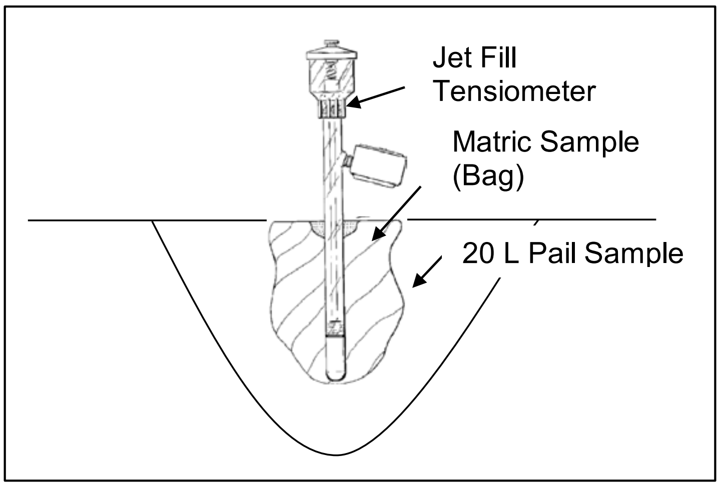


Figure 3.7 - Schematic of typical tensiometer installation during test pit sampling, and samples collected around the tensiometer.

Samples of both cover material and waste rock were stored during the sampling period in a large refrigerator to reduce loss of moisture and shipped to the University of Alberta (UA). After arrival at UA, both small matrix samples and the 20-L samples were oven-dried to evaluate moisture content. A total of 39 and 28 samples were collected on WRS 1 and WRS 2, respectively, during this sampling program.

3.2.2 Profile Sampling Program

The second stage of the field program involved the collection of grab samples over two sampling periods. As previously discussed, WRS 1 and

WRS 2 are located in the footprint of the new open pit, and the material must be excavated and relocated. The relocation of the waste rock material provided an opportunity to collect grab samples in the interior of the waste rock piles and visually examine the structural attributes.

Sampling on WRS 2 was conducted over a period from October 20 to November 8, 2011. The sampling program was conducted by Pablo Urrutia, and grab samples were taken with a shovel or front-end loader along an exposed excavated face within the waste rock dump (Figure 3.8). The excavated slopes were exposed to ambient conditions for an unknown period of time, and the moisture content of the samples was determined to be unrepresentative of the *in situ* conditions and was not measured.

Figure 3.8 – Typical excavated waste rock face on Waste Rock Stockpile 2 with a 1 m reference square

Sampling on WRS 1 was conducted on July 20, 2012, with the assistance of Jeff Bain and Adam Lentz from the University of Waterloo. An exposed North-South excavated face of WRS 1 was sampled using an excavator (Figure 3.9). Similar to WRS 2, moisture content data was determined to be unusable.

Figure 3.9 – Profile investigation on Waste Rock Stockpile 1 using an excavator. Note the person for scale and excavator holding reference square for photos taken.

Profile logging and sampling procedures were consistent for the investigations on both waste rock piles and followed a similar procedure to that set out for test pit logging. Heavy equipment utilized in sampling was facilitated through on-site contractors and mine site staff.

3.2.2.1 Site Selection

Areas of interest were selected based on accessibility to the waste rock piles throughout the sampling period and were concentrated along an excavation face. Locations on WRS 2 were limited to areas newly excavated and where activity of mining equipment was not occurring. Locations on WRS 1 were chosen along the length of the exposed slope in approximately 20 m to 50 m intervals in areas without sloughing that were safe for heavy equipment to access. The sampling locations were chosen to adequately investigate the total lateral extent of the excavated slope to investigate changes in geology and structure. Furthermore, due to the height of the exposed slopes in WRS 1 and 2, samples were taken along a vertical profile at a given point. The samples aimed to investigate vertical variations in structure and the texture of the pile with elevation. For example, at a given location, multiple sampling points were chosen at differing elevations to investigate rubble zones, traffic surfaces, or layered zones. GPS readings were taken approximately 5 m to 10 m from the toe of the slope near the sampling locations as direct access to the face of the slope was restricted due to safety concerns.

3.2.2.2 Field Tests Performed

Profile logging and sampling procedures were consistent for the investigations on both waste rock piles. Parameters of interest were similar to those evaluated in the test pits and included:

- Visual observations of geology, including or rock types, colour, presence and degree of oxidation, sulfide minerals visible, and associated crystal habit;
- Waste rock texture, visible structure, angularity, and degree of weathering;
- Representative samples for laboratory analysis; and;
- Photos taken with a 1 m reference square to assist in DIP analyses.

Due to the instability of the excavated slopes and their exposure to ambient conditions, soil suction and temperature profile measurements were not completed. Cover samples were not collected during the profile investigations on WRS 1 and WRS 2. Logging procedures were the same as test pits as described in Section 3.2.1.2. A 1 m reference square was attached to the bucket of the excavator to provide scale reference in photos taken at each sampling location for future DIP analysis, illustrated in Figure 3.9.

3.2.2.3 Representative Sampling and Sample Handling

20-L pail samples were collected from each sampling location. On WRS 2, samples were collected utilizing a shovel or front-end loader. A representative sample was collected in a 20-L pail from the sampling area. Samples on WRS 1 were collected using an excavator that placed material from the sampling location at the base of the slope face, and a representative subsample was taken in a 20-L pail with a shovel (Figure 3.10). Material was limited to less than 10 cm in size due to the size of the sampling pail. Large material in excess of 1 m was observed during sampling (Figure 3.11). Pail samples were shipped to UA where they were oven dried. Due to the length of time the stockpile faces were exposed to the atmosphere, moisture content of the samples were determined to be unrepresentative of *in situ* conditions and not measured. After oven drying, the samples were re-stored in the 20-L pails. During the profile sampling program, 21 and 12 samples were collected on WRS 1 and WRS 2, respectively.

Figure 3.10 – Material placed by an excavator from three sampling locations during the WRS 1 profile investigation. Subsamples were taken in 20-L plastic pails. Note differing waste rock sizes, textures, and colours.

Figure 3.11 - 20-L pail samples were limited to fine material. Grain size was observed in excess of 1 m.

Table 3.1 summarizes the total samples collected from both the test pit and profile sampling programs. From the combined field programs, a total of 16 cover samples and 83 waste rock samples were collected. A sand lens was located in the southwest corner WRS 1 during the test pit program and an additional sample was collected for study.

Table 3.1 - Total physical samples collected on stockpile test pits and profile sampling programs

Waste Rock Pile	Material Type	Number of Samples
Waste Rock Stockpile 1	Cover	10
	Waste Rock	49
	Sand	1
Waste Rock Stockpile 2	Cover	6
	Waste Rock	34
Total Samples		**100**

3.3 Laboratory Testing

Post-processing of samples collected from the test pitting and profile sampling program was conducted at UA. The following sections discuss testing performed on the samples collected as well as detailed characterization performed on select samples.

3.3.1 Moisture Content

Upon arrival at UA, samples collected from the test pitting program were evaluated for moisture content. Small matric bag samples from material sampled from around the installed tensiometers and the 20-L pail samples were measured separately to evaluate differences in moisture content between primarily soil-like matric samples and larger scale samples with rock-like material. Moisture content was conducted as outlined in ASTM Standard D2216 (2010). Entire samples were tested to ensure bias from migration of moisture in cohesionless particles did not affect testing results. ASTM Standard D2216 (2010) recommends for material with a maximum particle size of 75.0 mm and that specimen mass be 5 kg for accuracy within ±1%. The 10-L pail sample material contained particles with a typical maximum of 10 mm, and sample masses were in excess of 7 kg. Specimens were oven dried at 110±5 °C for approximately 24 hours. Note that moisture content was only determined for samples collected from test pits as they represent *in situ* conditions. Samples from the second stage profile sampling were unreliable and not measured. However, samples were oven-dried to prevent further geochemical reactions.

3.3.2 Particle Size Distribution using Sieve Analysis

Particle size distribution was completed for the matric bag samples and 20-L pails collected during the sampling programs. Sieve testing of matric bag samples followed ASTM Standard D6913 (2009).

Matric bag samples contained 1 kg to 2 kg of material, and a representative subsample (261 g to 629 g) was obtained using a riffle box sample splitter. The sample was split a maximum of two times. ASTM Standard D6913 Method A (2009) was performed using a single sieve set for a maximum particle size of 4.75 mm (No. 4 sieve). To prevent overloading, samples were sieved in multiple batches if necessary. Material was passed through standard sieves of mesh sizes 4.75, 2.00, 0.85, 0.425, 0.25, 0.15, 0.106, and 0.075 mm and placed in a mechanical sieve shaker for 10 minutes. The cumulative mass retained was measured and recorded to determine percent passing each sieve.

After completion of particle size distribution of the matric bag samples, the bag sample was combined with the 20-L pail sample to create a composite sample that was representative of the sample location. Particle size distribution of the pail samples was conducted by composite sieve analyses (ASTM Standard D6913; Method B, 2009). A chute splitter was utilized to mechanically split each pail sample a maximum of two times, creating four representative subsamples. One subsample was utilized for composite sieve analysis, one quarter was retained for paste pH testing, and two quarters were retained as representative samples for additional geochemical testing performed at UW.

The representative quarter sample was manually separated into the coarse and fine fraction using a 19.0 mm wire sieve. The coarse fraction was processed in one batch in a TS-2 Gilson Testing Screen (Figure 3.12b) for 10 minutes with sieve sizes of 75.0, 50.0, 37.5, 25.0, and 19.0 mm. ASTM Standard D6913 (2009) provides sieve designations to a maximum size of 75 mm. For oversized material above the 75.0 mm sieve, 152 mm (6 inch) and 203 mm (8 inch) templates were constructed for manual evaluation of these large size particles. No particles over 152 mm were found in the representative samples.

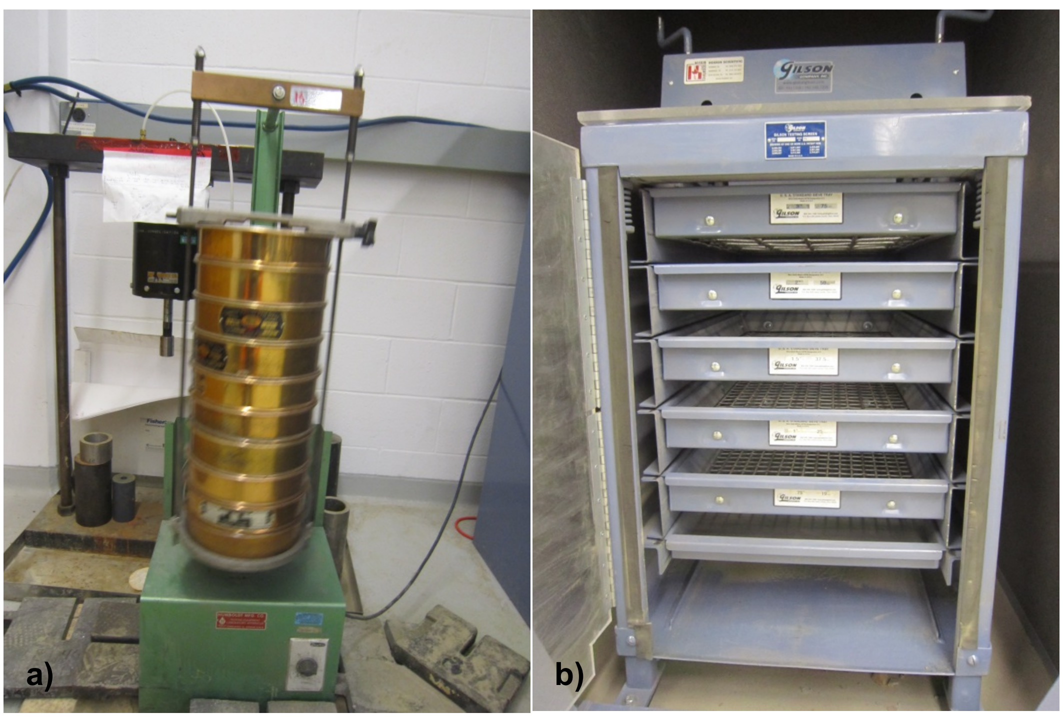


Figure 3.12 - Sieve analysis a) Standard mesh sieves for fine grained fraction, b) TS-2 Gilson Testing Screen for coarse fraction

The fine fraction subsample was processed in multiple batches of approximately 300 g to 500 g on a mechanical sieve shaker using standard sieves of sizes 9.5, 4.75, 2.00, 0.85, 0.425, 0.25, 0.15, 0.106, and 0.075 mm (Figure 3.12a). Washing of the coarse and fine fraction was not employed as the influence of washing can alter the geochemical properties of the waste rock. Cumulative mass retained on each sieve was measured and recorded by combining the mass of the fine and coarse fractions to determine percent passing each sieve. Hydrometer analyses were not performed on any samples due to the small proportion of sample < 0.075 mm.

3.3.3 Paste pH

Paste pH is used as a screening tool to indicate the presence of readily available neutralizing potential (NP) and stored acidity from surface oxidation of the waste rock and cover material. Paste pH testing was performed in accordance with ASTM Standard D4972 (2007) to determine the pH of a solution of waste rock and water. One quarter representative sample from each pail was utilized to produce a subsample for testing. The oven-dried material was sieved through a 2.0 mm (No. 10) sieve to remove the coarse fraction. 10 g of waste rock fines were mixed with 10 mL of ultrapure deionized water, mixed thoroughly, and allowed to stand for one hour (Figure 3.13). The pH was determined using a Fisher Scientific AR50 Dual channel pH/Ion/Conductivity meter (ASTM Standard D4972; Method A, 2007). Calibration of the pH probe using pH 4, 7, and 10 pH buffers was conducted at the start of each day of paste pH testing with additional pH checks (using a pH 7 buffer) performed periodically through the day. Paste pH readings that were less than 4 (acidic) were retested using the pH meter with buffer calibrations of pH 2, 4, and 7 to ensure results were within the range of the calibration buffers.

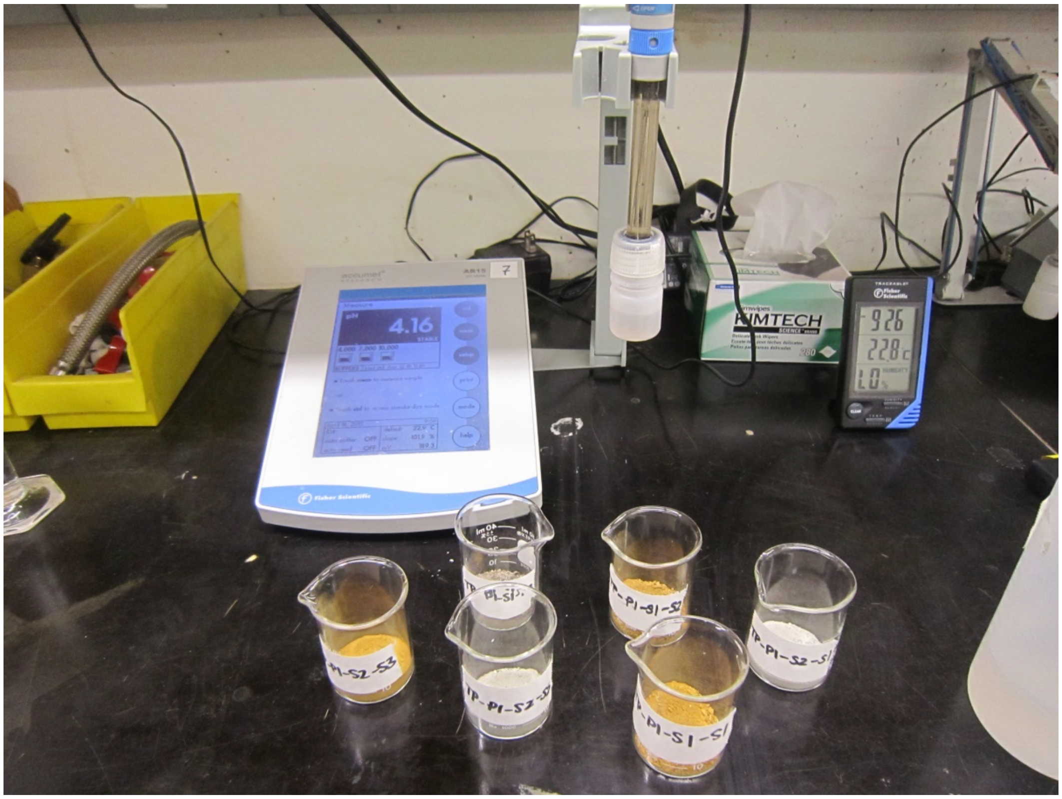


Figure 3.13 – Paste pH testing with various waste rock samples

3.3.4 Munsell Color System

The Munsell Color System is a systematic method to accurately describe a soil's colour through identification of the hue, value, and chroma. Hue indicates the relation of a soil colour to red, yellow, green, blue, or purple. Value denotes the lightness, and chroma indicates the strength. Specimens are compared to standard colour chips that provide a notation identifying these three dimensions in the order of hue, value/chroma. A typical notation example is 5Y 6/3, where 5Y is a yellow hue with a value of 6 and a chroma of 3 (Soil Survey Staff Division, 1993).

Samples of material less than the 2.0 mm (No. 10) sieve were used to identify soil colour as the fines had a uniform colour in comparison to the coarse fraction that typically had multiple tones. Comparison to both rock and soil colour chips was conducted with dry samples in natural light conditions. The waste rock samples were primarily identified using soil colour chips due to their weathered nature.

3.3.5 Sample Selection for Detailed Laboratory Testing

Due to the large volume of samples collected, a select set of samples were chosen to complete detailed laboratory testing. Samples were selected to represent the range of grain sizes present for both the cover and waste rock material. The samples were also selected to be representative of other variables, including the degree of surface oxidation, spatial location, sampling period (i.e. test pit and profile samples), and stockpile number. A total of 13 samples were selected to perform additional tests (Table 3.2). Three cover samples were selected due to three distinct particle-size envelopes, and 10 waste rock samples were selected to represent the range of grain sizes within the plotted envelope of curves. More samples were selected from WRS 1 as the spatial area is larger and more samples were required for characterization.

Table 3.2 - Samples selected for detailed laboratory testing

Stockpile Number	Sample Identification	Sample Type
WRS 1	TP-P1-S4-S1	Cover
	TP-P1-S14-S1	Cover
	TP-P1-S5-S3	Waste Rock
	TP-P1-S6-S3	Waste Rock
	TP-P1-S9-S1	Waste Rock
	TP-P1-S11-S2	Waste Rock
	P1-P6-S1	Waste Rock
	P1-P3-S2	Waste Rock
WRS 2	TP-P2-S11-S1	Cover
	TP-P2-S10-S3	Waste Rock
	TP-P2-S13-S3	Waste Rock
	TP-P2-S16-S3	Waste Rock
	WRS-2-12	Waste Rock

Detailed laboratory testing for the above samples involved determining saturated hydraulic conductivity, determining the SWCC, and using DIP to construct a detailed grain size curve. These analyses are discussed in the following sections.

3.3.5.1 Saturated Hydraulic Conductivity

Saturated hydraulic conductivity measurements were performed using a constant head test due to the high permeability of the soils. The test procedure is modified from ASTM Standard D2434 (2006). The apparatus utilizes an acrylic walled specimen cylinder with an 100-mm internal diameter with an outflow valve located 21.5 cm from the base of the cell, which allows the phreatic surface in the cell to remain constant. The top of the cell is open to ambient laboratory temperatures of approximately 22 °C. A capillary tube with measuring tape was placed horizontally and attached to the inlet valve of the cell. The capillary tube was de-aired and placed above the free surface of the permeability cell to create an approximate gradient of 0.3. Material was placed in a plexiglass cell with a 100-mm internal diameter. The bottom of the cylinder contained a saturated porous plate with nylon filter paper. A representative subsample of material less than 4.75 mm (No. 4 sieve) was placed in the cell, saturated with distilled water from the bottom up, and left at saturation for a period of 24 hours. Material was place loosely in the cell, and samples were not saturated under vacuum pressure. Figure 3.14 illustrates a typical set up of a constant head permeability cell with capillary tube and measuring tape.

The inlet valve was opened, and the location of the meniscus of the capillary tube on the measuring tape was recorded with time. Readings were taken every 1 cm to 20 cm over a length of approximately 40 cm. Hydraulic conductivity values were not temperature corrected to 20 °C.

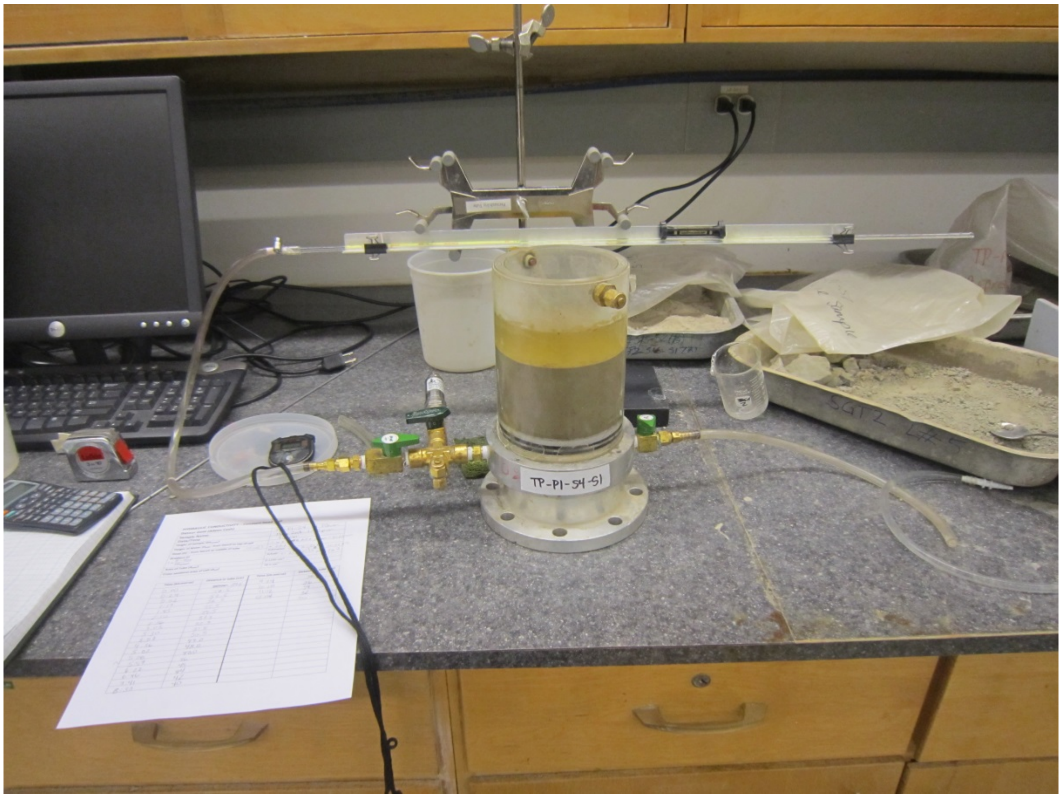


Figure 3.14 - Setup of a typical constant head permeability test

3.3.5.2 Soil-Water Characteristic Curves

Soil-water characteristic curves (SWCC) describe the unsaturated behaviour of soils through measurement of the change in volumetric or gravimetric water content with changes in suction. SWCCs were measured using Tempe cell pressure chambers to measure the change in volumetric water content with soil suction. Two types of Tempe cells were utilized for the 13 samples tested: three 180-mm tall Plexiglas Tempe cells with an internal diameter of 70 mm and 10 60-mm tall 1405 Tempe pressure cells (Soilmoisture Equipment Corp.) with internal diameters of 88 mm (Figure 3.15). All cells utilized 1 bar ceramic stones.

Figure 3.15 - Typical Tempe cell pressure chamber

Representative subsamples of the same material from saturated hydraulic conductivity tests (less than 4.75-mm material) were placed in the Tempe cells loosely as density measurements were not measured. Each specimen was saturated from the bottom up with distilled water at ambient laboratory temperature. The specimen remained saturated for a minimum of 24 hours, and then excess water was removed. Initial moisture content, sample height, and cell weight were recorded.

Due to the free-draining nature of coarse waste rock, samples were tested using a combination of a hanging column method and pressure chamber method (adapted from ASTM Standard D6836 (2008)). Clear flexible tubing was attached to the bottom water outlet drain tube with a capillary needle and drain bottle to permit drainage. The top outlet of the Tempe cell was covered with aluminum foil to allow atmospheric pressure within the cell and to limit evaporation. For the hanging column method, the drain tube and capillary needle was lowered below the bottom outlet to create negative water pressure or increase the matric suction (Figure 3.16a). The bottom outlet was considered the datum or zero reference point. The needle was lowered by 30 mm or 0.3 kPa intervals, and outflow of water due to drainage was measured daily through measurement of the reduction in cell weight. When the cell weight remained constant, the system was assumed to be at equilibrium with the applied matric suction, and the weight was recorded. The capillary needle was lowered in 0.3 kPa to 0.5 kPa intervals until approximately 4 kPa, or approximately 40 cm below the outlet drain of the Tempe cell.

Samples were then transferred to a pressure chamber where matric suction was increased through applied air pressure (Figure 3.16b). Air pressure was adjusted using a pressure regulator, and outflow of water was measured daily through measurement of the reduction in cell weight. Air pressure was increased initially in 1.7 kPa (0.25 psi) increments, then increased to 6.9 kPa (1 psi) and 13.8 kPa (2 psi) increments at higher pressures.

Figure 3.16 – a) Hanging column testing method, b) Pressure regulator apparatus

Data was plotted continuously throughout the test to ensure the complete characterization of the SWCC for each sample. After completion of the test, the final sample height and weight were measured, and each sample was oven dried to calculate the final gravimetric moisture content. Calculation of volumetric moisture content at each suction increment was completed to plot the SWCCs.

3.3.5.3 Digital Image Processing

DIP techniques were applied using Split Desktop software (Split Engineering LLC, 2011a) to delineate the particle size distribution for the large-scale material at the location of the 13 samples chosen for detailed investigations. Due to the limited sampling size of 20-L pails, large-scale waste rock material could not be measured, and DIP techniques were utilized to characterize the large grain size fraction above 75 mm (3 inches). A high-resolution photo was selected from each sampling location that best represented the sampling area. Photos were not adjusted for perspective, as limited image distortion was observed; however, brightness in some photos was adjusted.

A grid was superimposed on each photo to evaluate the variability of grain size within sections of a photo. A comparison of particle size curves from different sections of the photo and the photo in its entirety were evaluated. Auto-delineation of particles was applied to the photographs, and delineations of particles were adjusted manually for accuracy as well as delineation of areas of fine material. Poor lighting conditions and shadows influenced the accuracy of delineation, and the researcher’s best judgement was used to correctly identify particle boundaries. In addition to delineation of solid particles and fine matrix material, open void space was also delineated to estimate the air filled porosity as well as the volume of particles. A detailed overview and results from the DIP analyses are presented in detail in Chapter 5.

Chapter 4.0 Field and Laboratory Results and Discussion

4.1 Introduction

The following subsections present the field and laboratory results from the investigation at the Detour Lake Mine. A discussion of the field program outcomes and major trends are discussed as well as laboratory testing on selected samples. The data gathered in the field program is in Appendix A and laboratory program results are found in Appendix B.

4.2 Field Investigation Results

The multi-stage field program on WRS 1 and WRS 2 permitted the investigation of the waste rock in both the undisturbed state, as well as investigation after excavation and deconstruction. The test pit sampling program allowed initial in-situ measurements to be taken under site conditions. These measurements characterized the interface of the cover with the atmosphere, as well as the upper portion of the waste rock prior to any disturbance. The secondary profile program was conducted after the stockpiles had been partially excavated that allowed visual examination of the internal structure.

A total of 100 samples were collected on WRS 1 and WRS 2 during the test pitting program: 39 samples from WRS 1 and 28 samples from WRS 2. During the profile sampling program, 21 samples were collected on WRS 1, and 12 samples on WRS 2. The locations of the samples taken on WRS 1 and WRS 2 are illustrated in Figure 4.1 and Figure 4.2, respectively. Test pit and profile locations were recorded using a commercial grade hand-held Global Positioning System (GPS) unit.

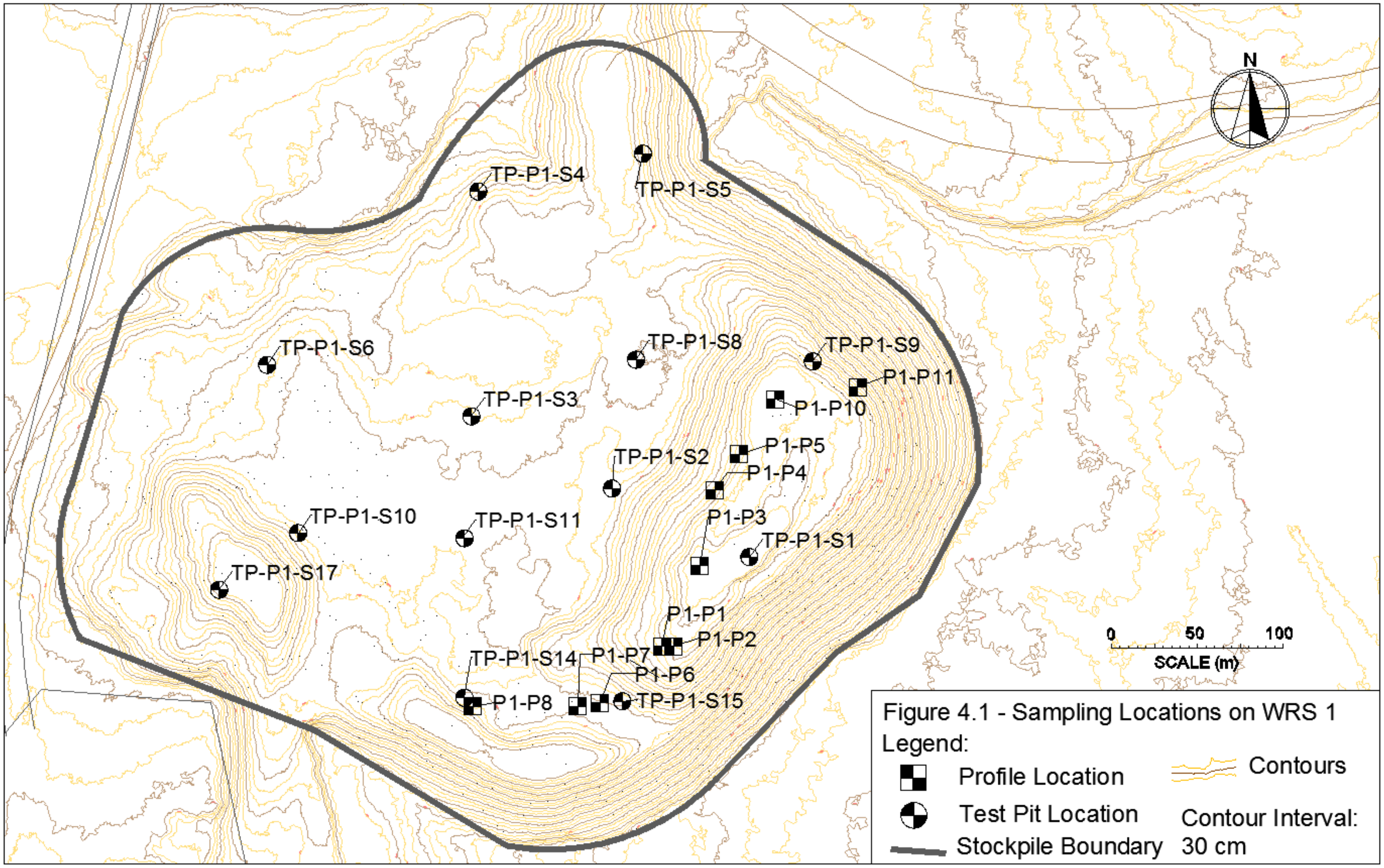


Figure 4.1 - Test pit and profile sampling locations on WRS 1

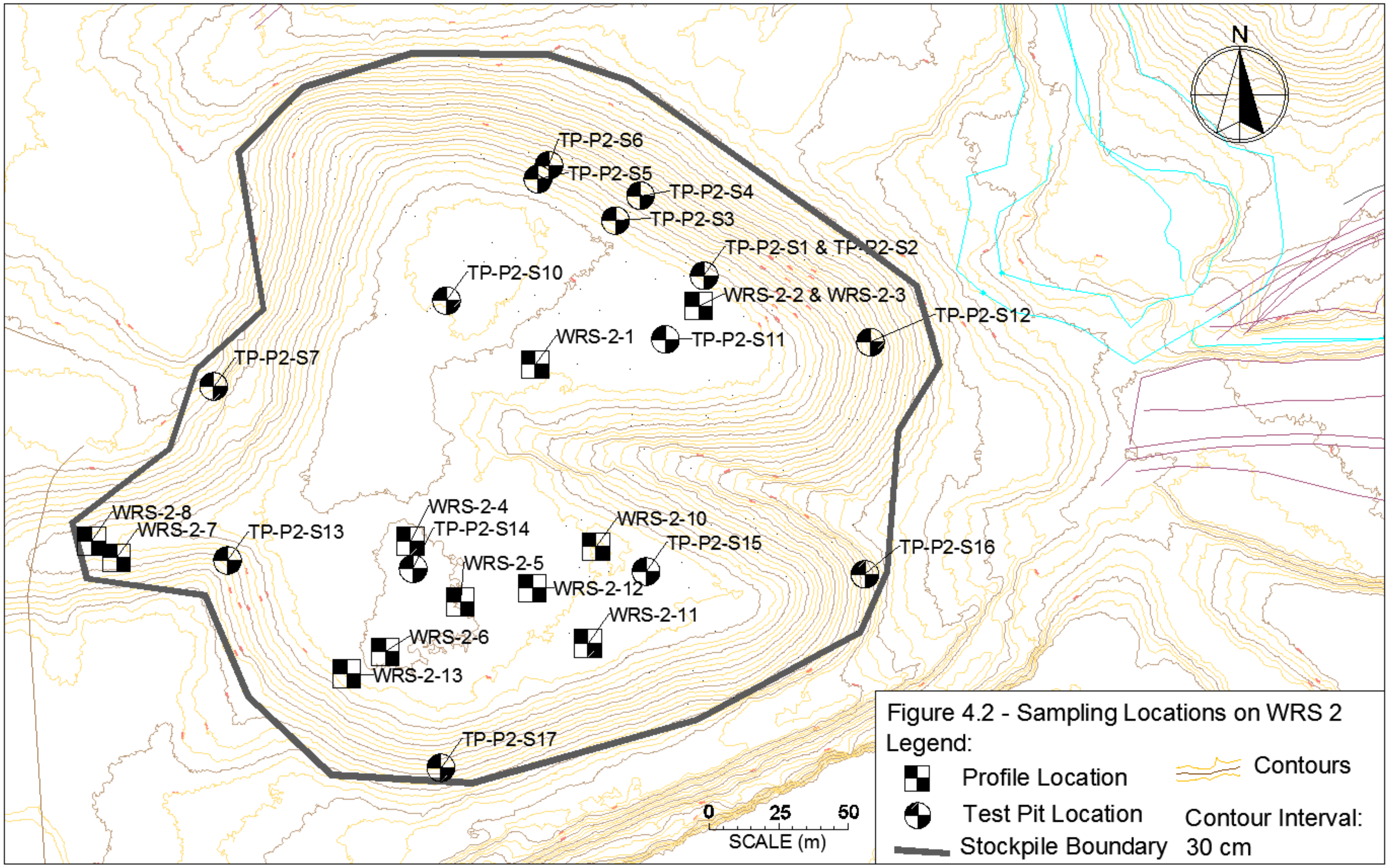


Figure 4.2 - Test pit and profile sampling locations on WRS 2

The specific method of construction of the Detour Lake stockpiles was unknown prior to the sampling programs conducted on WRS 1 and 2. All stockpiles were covered at closure with a single layer overburden soil cover that typically ranges from 30 cm to 1 m in thickness. Vegetation, shrubs and grasses, have grown on the cover with roots extending into the upper 10 cm to 15 cm of the profile. The underlying waste rock was varied in gradation throughout the stockpiles, from clay-sized particles up to boulders approximately 2 m in diameter.

In general, the internal structure of the stockpiles was characteristic of a combination of a push or paddock dump construction technique, with some areas constructed by end-tipped deposition. The end-tipped construction structure is consistent with that of a segregated dump proposed by Herasymuik (1996). The segregated dump conceptual model characteristics include coarser material toward the base of a bench, forming a rubble zone, and the upper area of the bench with distinct layers of fine and coarse rock at the angle of repose. During the excavation of waste rock from WRS 1, traffic surfaces and angle of repose slopes were visible in the excavated profile. During the excavation program on WRS 1, angle of repose slopes were primarily identified on exposed slope faces that trended East-West. The majority of exposed waste rock on WRS 1 during the profile sampling program trended North-South, and it was assumed the direction of this cut face obscured some were visible and extended approximately 10 m to 15 m, separated by compacted traffic surfaces. Coarse zones of waste rock were visible above compacted traffic surfaces; however segregation of waste rock particle sizes was not well-defined.

4.2.1 Test Pit Investigation Results

The test pit investigation was successful for the characterization of the upper profile of the waste rock stockpiles. A total of 13 test pits were constructed on WRS 1 and 15 test pits on WRS 2 (Figure 4.3). Sample logs for each test pit are included in Appendix A, each detailing major units and rock types within each test pit, as well as photographs and samples taken. Overviews of the major observations and trends from the data are discussed in the following section.

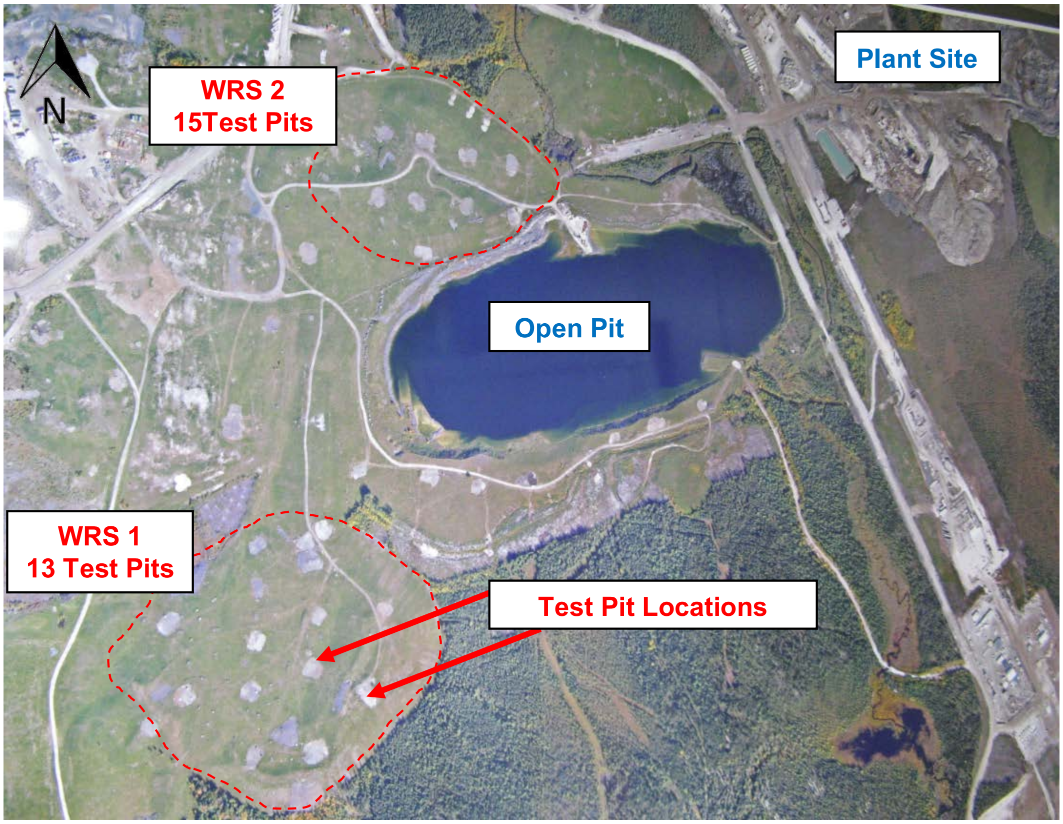


Figure 4.3 - Aerial view of the Detour Lake Mine showing outlines of the approximate area of investigation for WRS 1 and WRS 2 with the visible locations of constructed test pits

Sloughing during construction of the test pits caused some difficulties during excavation and sampling. Sloughing typically occurred in test pits where grain size material of >0.5 m was encountered. Consequently, observation of any significant structure was difficult during the test pit program due to sloughing as well as the limited depth of the test pits. The primary structural feature observed in the test pit program was a compacted waste rock layer at the interface of the cover and waste rock. The compacted traffic surface may have resulted from placement of the cover. The waste rock appeared to be closely packed with a cemented-like structure typically of approximately 30 cm to 50 cm (Figure 4.4).

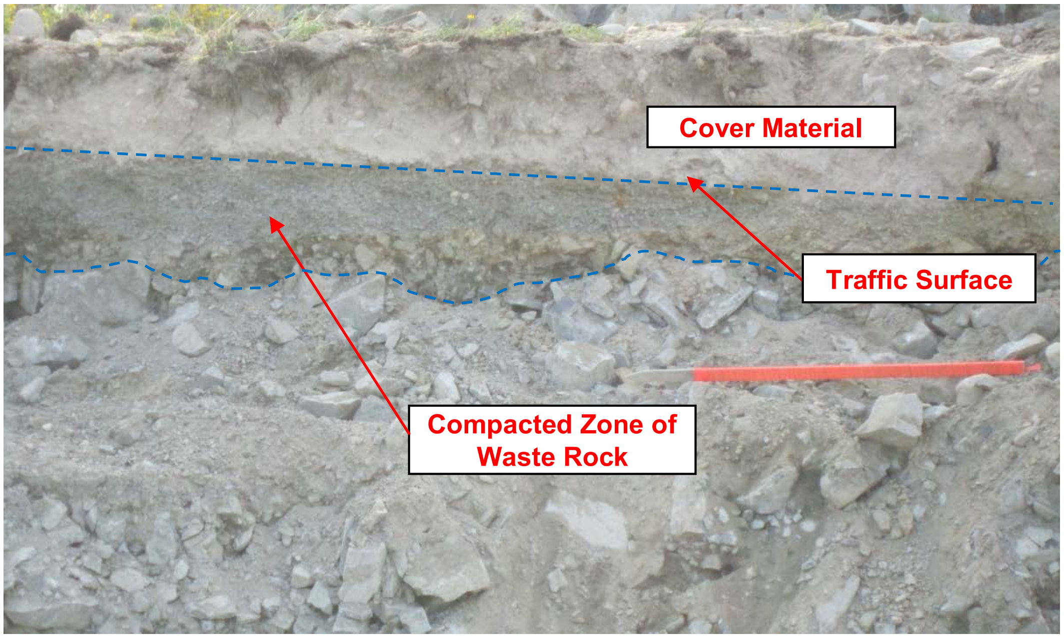


Figure 4.4 - Waste rock profile showing cover material with underlying traffic surface and zone of compacted waste rock

Both cover material and waste rock samples were collected during the test pit program. Cover samples were collected to assess the material type and the hydrologic properties controlling water ingress. Waste rock samples were taken within the test pit and formed the majority of samples collected.

The cover material consists of a till overburden material with some organics in the upper 0.10 m of the profile. The material was a light brown-grey with a silty sand texture with rounded glacial boulders and cobbles from 0.15 m to 0.20 m. The proportion of sand and clay sized material varied by location, and some locations with greater clay and fines contents had greater cohesion and water retention. Some waste rock particles were found in the cover material, however these particles were assumed to have mixed into the cover material during its placement. The cover thickness ranged from 0.0 to 1.0 m, and some gullies were observed on the sloped batters of the piles. The cover was discontinuous in some areas with small areas of exposed waste rock.

Waste rock in the test pits had heterogeneous properties, including grain size, oxidation, texture, and presence of sulphide minerals. Grain size ranged from silt and clay sized to boulders greater than 2 m. The grain size profile of the test pits generally increased in particle size with depth. The upper benches of the waste rock often had a higher proportion of fines, and lower benches in the test pit showed clast supported structure (Figure 4.5). The clast supported structure had voids infilled with sand and silt sized matric material, or the voids were open and were air filled. WRS 1 and 2 did not show evidence of significant rock degradation and weathering consistent with many waste rock excavation projects with operating histories of similar length (Herasymuik, 1996).

The dominant rock types found in the test pits were footwall mafic volcanic, and talc chlorite schist/chloritic greenstone. Other rock types found include mafic and intermediate intrusive rocks. Some of the chert marker horizon (CMH) lithology was encountered, and was the least prevalent rock type. The dominant sulfide minerals were pyrrhotite and pyrite, and they were difficult to differentiate due to the fine dissemination and lack of crystal form. The sulfides were often weakly disseminated and found on fracture surfaces or associated with veins within the rock. Some crystal clusters were observed. Cementation of waste rock was visible and resulted in the aggregation of smaller particles, typically in areas with greater evidence of oxidation. Potassic alteration and some mineral precipitation were also observed and were often associated with the agglomeration of smaller particles (Figure 4.6).

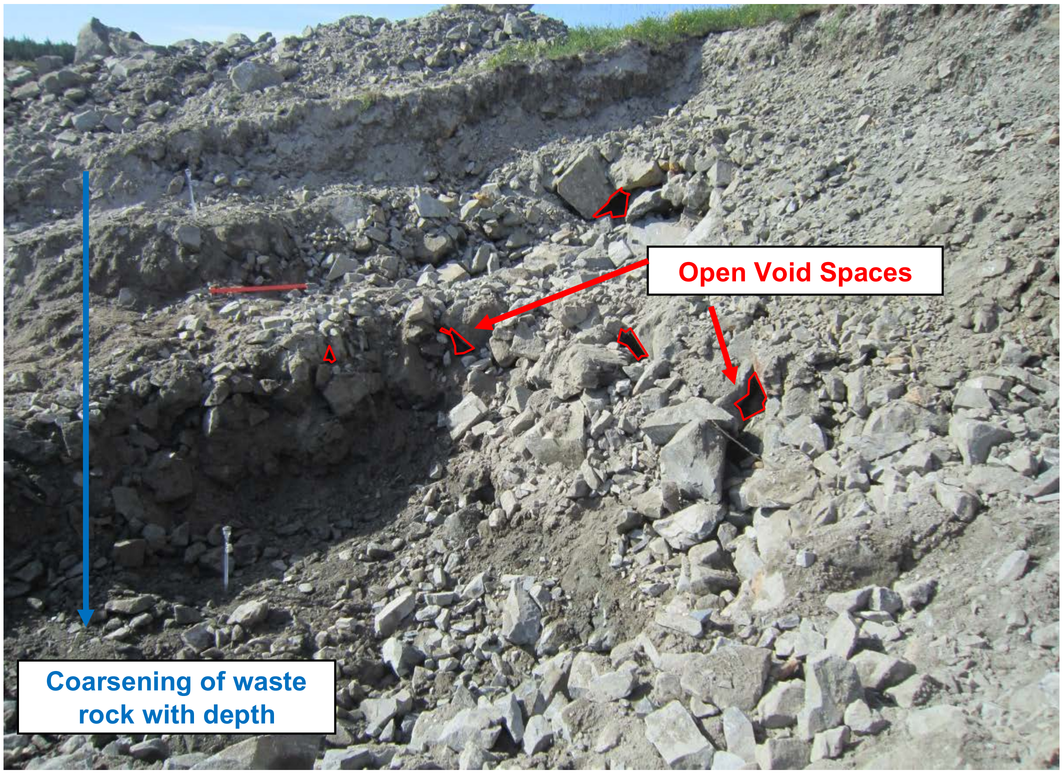


Figure 4.5 – Test pit TP-P2-S16 showing a coarser waste rock as depth increases with open void spaces in clast supported structure

Figure 4.6 - Oxidation of waste rock on WRS 1 resulting in agglomeration and cementation of smaller particles

The degree of oxidation of the waste rock within the test pits and profiles investigated was highly variable. All of the waste rock in the stockpiles has indications of oxidation on the surface of particles or in the fine grained material. The oxidation of particles was evident through sharp colour change in comparison to the unweathered or fresh surfaces of rock, which were typically grey to black. The oxidation colours ranged from yellow-orange dark red-orange and purple zones. In general, oxidation was observed more frequently and to a greater degree on WRS 1. Some test pits had complete oxidation of the surface of clasts as well as oxidation of the matric material. The presence of a cover has not prevented oxidation within the waste rock pile, however it may limit oxygen advection into the piles.

4.2.1.1 Matric Suction and Moisture Content Measurements

In addition to the qualitative observations within the test pits, *in situ* measurements were also collected to assess the unsaturated properties of the waste rock material. A total of 51 tensiometer (2725ARL Jet Fill Tensiometer, Soil Moisture Equipment) readings were taken in *in situ* waste rock after excavation. Matric suction values ranged from 3 kPa to 53 kPa in the cover material, and 1 kPa to 39.5 kPa in the waste rock material. Figure 4.7 illustrates the relationship of the logarithm of matric suction with increasing depth. The depths of the tensiometers are relative to the surface elevations, which were normalized for comparison. The suction profile is erratic, and in some areas appears to decrease with increasing depth into the waste rock profile. This may be the result of the movement of wetting fronts or greater moisture in the matric material at depth. Test pit TP-P1-S15 was not included due to precipitation during sampling that resulted in saturation and alteration of the *in situ* matric suction conditions.

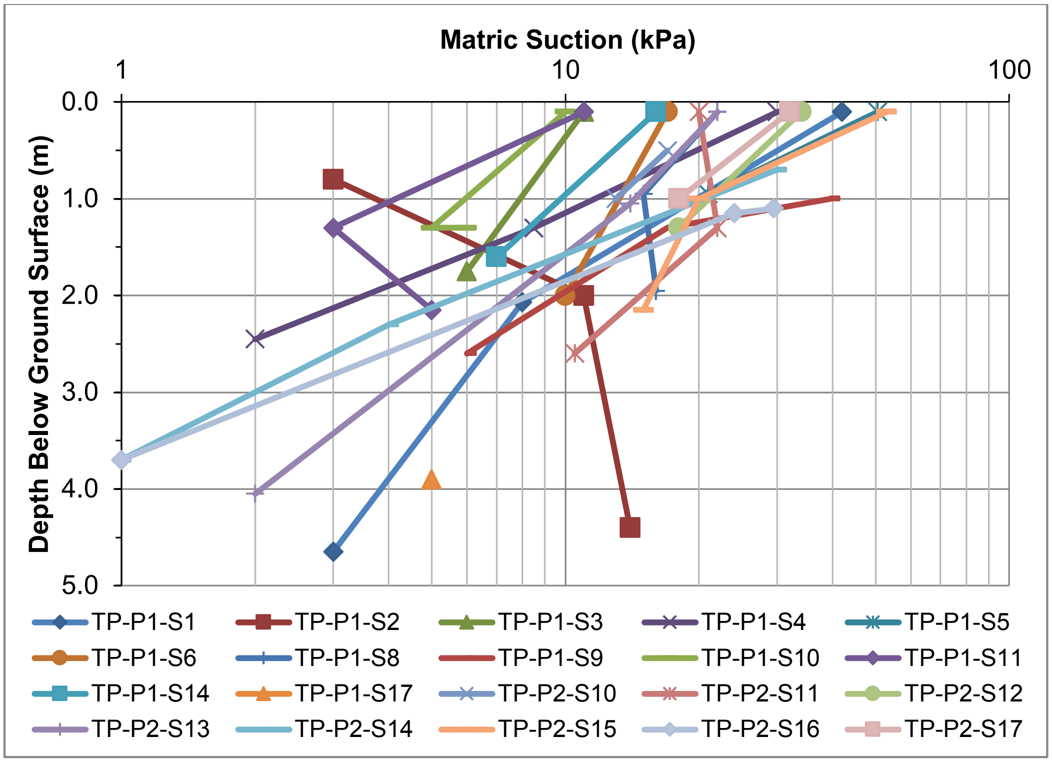


Figure 4.7 - In-situ soil suction with increasing depth for test pit samples

Gravimetric moisture contents were completed on test pit samples after shipment to the laboratory at the University of Alberta. Bag samples of matric material and 20-L pail samples were dried separately to characterize the moisture content variation in the matric fines and coarser grain size samples. A summary of the results are presented in Table 4.1.

Table 4.1 - Gravimetric moisture contents for matric bag samples and 20-L pail samples

	Gravimetric Moisture Content (wt %)		
Sample Type	**Average**	**Maximum**	**Mimimum**
Cover (Matric Sample)	6.8%	16.7%	2.6%
Cover (20-L Pail)	5.5%	12.5%	2.1%
Matric Bag Sample	4.3%	7.5%	2.3%
20-L Pail Sample	2.3%	8.2%	0.3%

The moisture content of the fine-grained matrix had an average of 4.3 wt% and was higher than the large pail samples, where water contents averaged 2.3 wt%. Higher moisture content within the fines is expected due to the higher air entry value and ability to retain more water under unsaturated conditions than coarse grained material. Plots of moisture content with depth for the matric samples and 20-L pail samples are provided in Figure 4.8 and Figure 4.9. Similar to matric suction data, the moisture content profile is variable due to heterogeneity in structure and composition typical of waste rock material. As expected, cover samples have higher moisture contents than waste rock due to the predominantly fine grained material that can hold more moisture. The 20-L pail cover samples had a slightly lower moisture contents due to the inclusion of larger particles that did not contribute significantly to the moisture content.

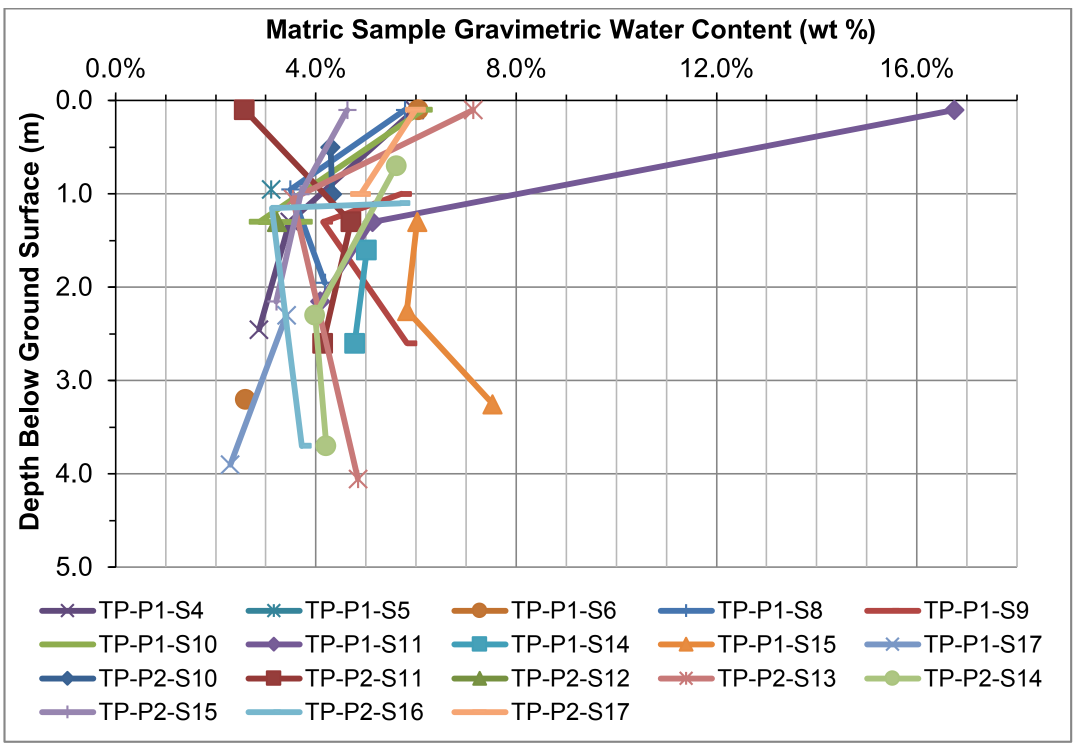


Figure 4.8 –Moisture content profile with increasing depth for test pit matric samples

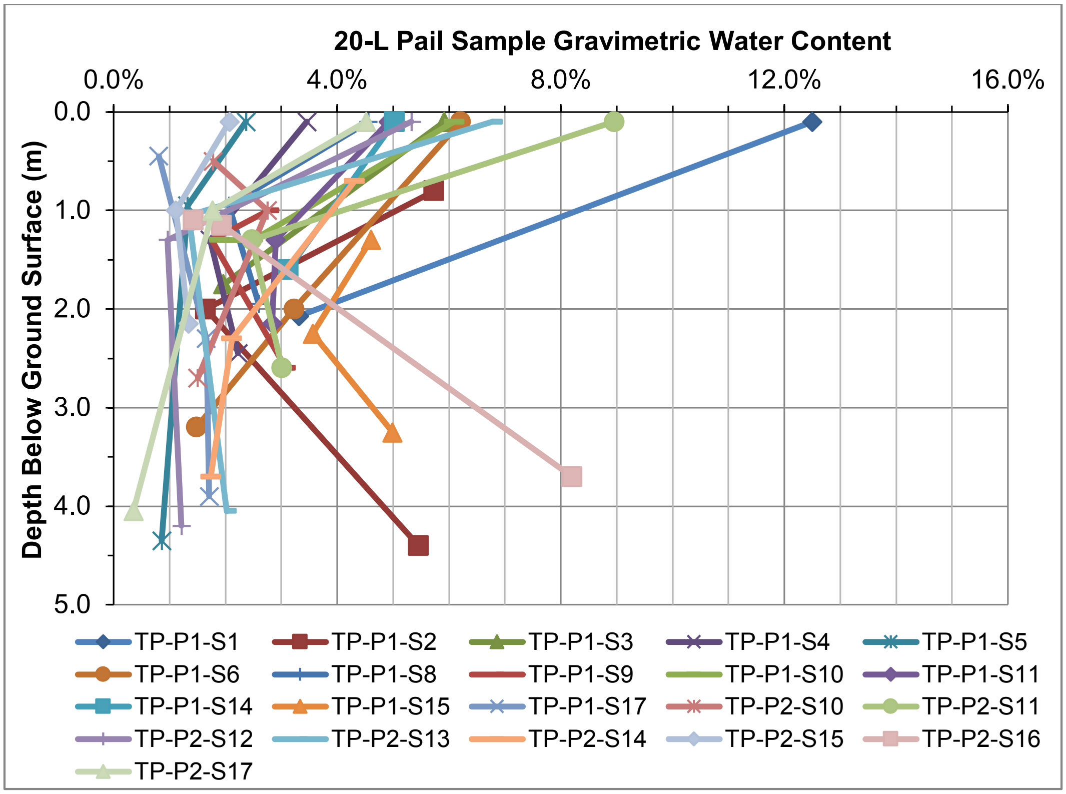


Figure 4.9 - Moisture content profile with increasing depth for test pit 20-L pail samples

Plots of the gravimetric moisture content and *in situ* tensiometer matric suction values are plotted for the cover material in Figure 4.10. The field conditions of much of the cover material are similar with matric suction values typically ranging from 20 to 30 kPa and moisture content of approximately 6 wt%. A similar plot for the waste rock material illustrates a much larger range of matric suction and water content values (Figure 4.11).

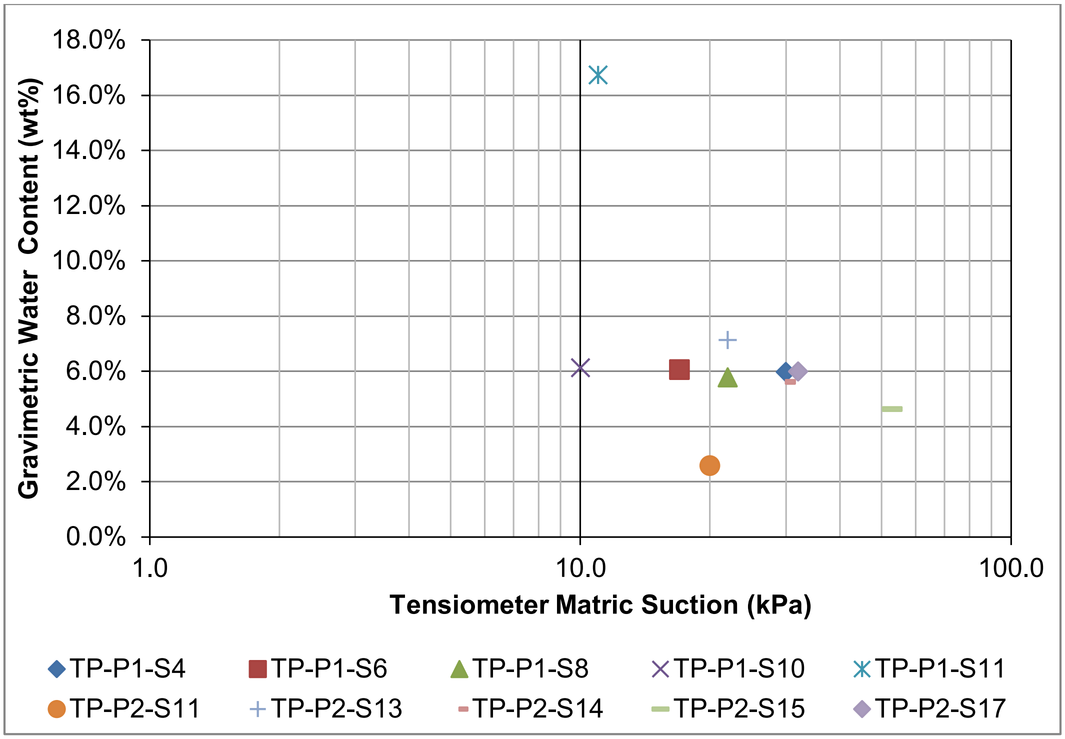


Figure 4.10 – Gravimetric moisture content versus matric suction for field readings from test pit program

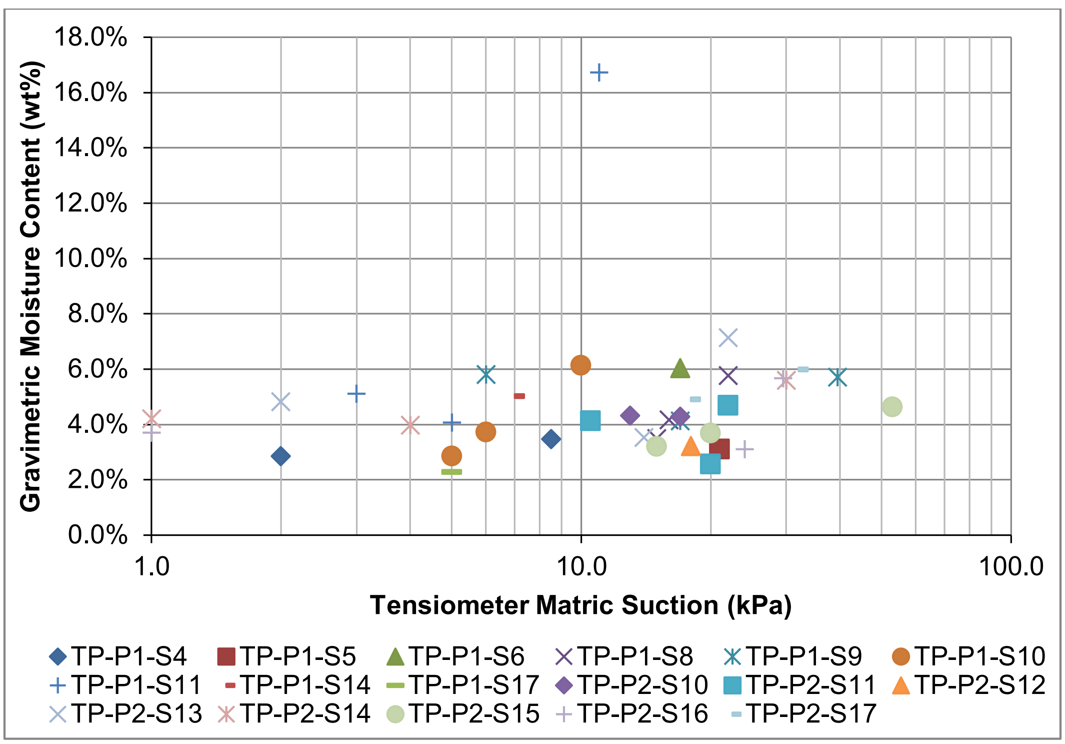


Figure 4.11 - Gravimetric moisture content versus matric suction for field readings from test pit program

No standing water or running water were observed in any of the test pits on WRS 1 or WRS 2 indicating that the piles are free draining structures and the material is unsaturated. Traffic surfaces may reduce the water flow velocity through the compacted layers, however no perched water tables were observed. A perched water table is a water table found in the unsaturated zone caused by a low permeability layer above the regional ground water table. In waste rock, a low permeability zone of fines can reduce permeability such that a perched water table is created. This phenomenon did not occur due to the coarse, clast-supported structure of the DLM waste rock.

Table 4.2 presents a summary of the matric suction values from tensiometer readings and moisture contents obtained during the field program. Matric suction readings and matric bag samples were not taken in some sampling locations due to the coarse nature of the waste rock in the sample location and are indicated as not applicable. During the drying process, five samples were mislabelled and are also denoted N/A. Tensiometer readings "not taken due to rain", are also indicated.

Table 4.2- Matric suction and gravimetric water content data for test pit samples

Sample Name	Matric Suction (kPa)	Gravimetric Water Content (wt%)	
		Matric Sample	20-L Pail Sample
TP-P1-S1-S1	8.0	N/A	0.0
TP-P1-S1-S2	3.0	N/A	3.3
TP-P1-S1-S3	42.0	N/A	12.5
TP-P1-S2-S1	3.0	N/A	5.7
TP-P1-S2-S2	11.0	N/A	1.6
TP-P1-S2-S3	14.0	N/A	5.5
TP-P1-S3-S1	6.0	N/A	2.0
TP-P1-S3-S2	11.0	N/A	5.9
TP-P1-S4-S1	30.0	6.0	3.5
TP-P1-S4-S2	8.5	3.5	1.7
TP-P1-S4-S3	2.0	2.9	2.2
TP-P1-S5-S1	50.5	N/A	2.4
TP-P1-S5-S2	21.0	3.1	1.3

Sample Name	Matric Suction (kPa)	Gravimetric Water Content (wt%)	
		Matric Sample	20-L Pail Sample
TP-P1-S5-S3	N/A	N/A	0.9
TP-P1-S6-S1	17.0	6.0	6.2
TP-P1-S6-S2	10.0	N/A	3.2
TP-P1-S6-S3	N/A	2.6	1.5
TP-P1-S8-S1	22.0	5.8	4.6
TP-P1-S8-S2	15.0	3.5	2.1
TP-P1-S8-S3	16.0	4.2	2.6
TP-P1-S9-S1	39.5	5.7	2.8
TP-P1-S9-S2	17.0	4.1	1.8
TP-P1-S9-S3	6.0	5.8	3.1
TP-P1-S10-S1	10.0	6.1	6.1
TP-P1-S10-S2	5.0	2.9	2.5
TP-P1-S10-S3	6.0	3.7	1.9
TP-P1-S11-S1	11.0	16.7	4.9
TP-P1-S11-S2	3.0	5.1	2.9
TP-P1-S11-S3	N/A	4.1	2.8
TP-P1-S11-S4	5.0	N/A	0.3
TP-P1-S14-S1	16.0	N/A	5.0
TP-P1-S14-S2	7.0	5.0	3.1
TP-P1-S14-S3	N/A	4.8	N/A
TP-P1-S15-S1	Not taken - rain	6.0	4.6
TP-P1-S15-S2	Not taken - rain	5.8	3.6
TP-P1-S15-S3	Not taken - rain	7.5	5.0
TP-P1-S17-S1	N/A	0.0	0.8
TP-P1-S17-S2	N/A	3.4	1.7
TP-P1-S17-S3	5.0	2.3	1.7
TP-P2-S1 & S2	N/A	N/A	N/A
TP-P2-S3	N/A	N/A	1.8
TP-P2-S4	N/A	N/A	N/A
TP-P2-S5	N/A	N/A	N/A
TP-P2-S6	N/A	N/A	N/A
TP-P2-S7	N/A	N/A	2.1
TP-P2-S10-S1	17.0	4.3	1.8
TP-P2-S10-S2	13.0	4.3	2.7
TP-P2-S10-S3	N/A	0.0	1.5
TP-P2-S11-S1	20.0	2.6	9.0
TP-P2-S11-S2	22.0	4.7	2.5
TP-P2-S11-S3	10.5	4.1	3.0
TP-P2-S12-S1	34.0	N/A	5.3
TP-P2-S12-S2	18.0	3.2	1.0

Sample Name	Matric Suction (kPa)	Gravimetric Water Content (wt%)	
		Matric Sample	20-L Pail Sample
TP-P2-S12-S3	N/A	N/A	1.2
TP-P2-S13-S1	22.0	7.1	6.8
TP-P2-S13-S2	14.0	3.5	1.3
TP-P2-S13-S3	2.0	4.8	2.0
TP-P2-S14-S1	30.0	5.6	4.3
TP-P2-S14-S2	4.0	4.0	2.1
TP-P2-S14-S3	1.0	4.2	1.7
TP-P2-S15-S1	53.0	4.6	2.1
TP-P2-S15-S2	20.0	3.7	1.1
TP-P2-S15-S3	15.0	3.2	1.3
TP-P2-S16-S1	29.5	5.7	1.4
TP-P2-S16-S2	24.0	3.1	1.9
TP-P2-S16-S3	1.0	3.7	8.2
TP-P2-S17-S1	32.0	6.0	4.5
TP-P2-S17-S2	18.0	4.9	1.8
TP-P2-S17-S3	N/A	N/A	0.4

4.2.1.2 Temperature Measurement

Finally, a thermal profile was completed in test pits on WRS 2. Temperature readings in the cover and root zone ranged from approximately 14°C to 21°C, and the mean ambient air (MAA) temperature for August, when sampling was conducted, was 15.9°C (Figure 4.12).

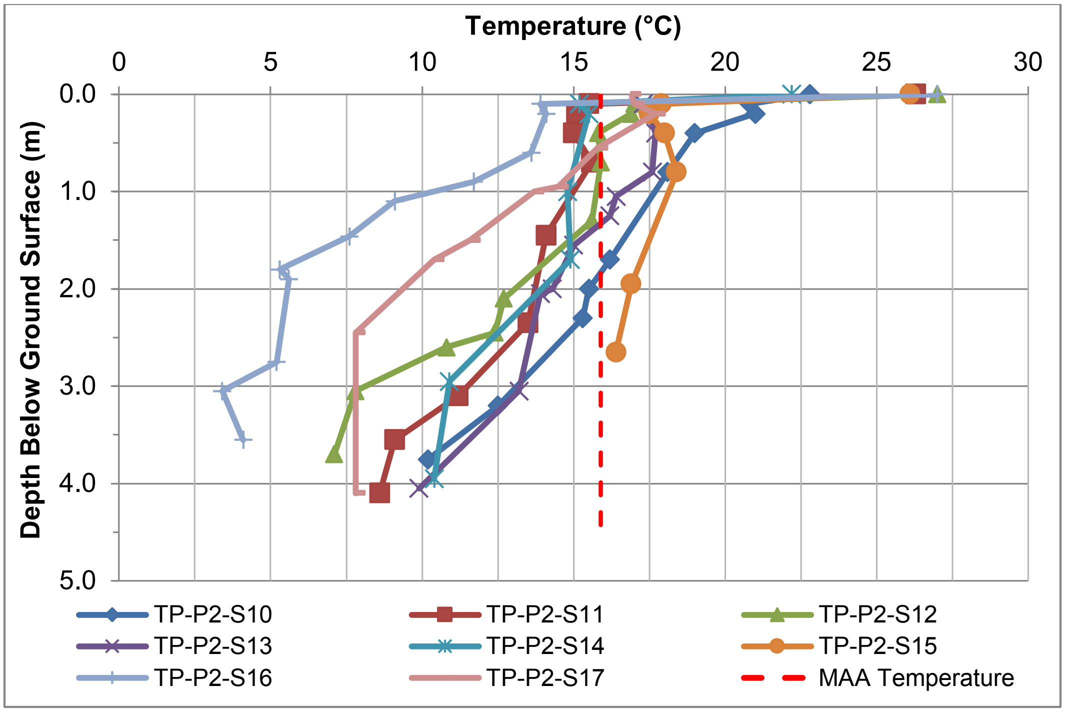


Figure 4.12 – Waste rock temperature with depth below ground surface for WRS 2 test pits

Temperatures decreased with depth within the test pit, and at the base, temperatures ranged from approximately 4°C to 11°C. Hot spots or thermal zones were not observed in the WRS 2 test pits during sampling, however Detour Environment technicians did report seeing steam vents during the winter of 2012 to early 2013.

4.2.2 Profile Investigation Results

The profile investigation provided an opportunity to examine the inner characteristics of WRS 1 and WRS 2. A total of 11 profiles on WRS 1 and 13 profiles on WRS 2 were examined. Sample logs for each location are included in Appendix A, which provides a sketch, description of major units within each test pit, as well as photos and samples taken. The cover material was not studied in this stage of the investigation, and waste rock material was the primary focus. Samples were collected in 20-L pails. Gravimetric moisture content data for the profile samples was not conducted due to the length of time that the excavated waste rock face was exposed. However, samples were dried to facilitate further testing and to halt any additional geochemical weathering.

Excavation and relocation of waste rock by DLM from WRS 1 was ongoing through late 2011 and into mid-2012. The relocation of the waste rock to another facility created a continuous face typically trending North-South. This exposed face was used to examine the inner structure of the pile. The excavated face ranged from approximately 7 m to 20 m in height from toe to crest. Figure 4.13 provides a detailed view of a section of the WRS 1 face and visible structural elements. Figure 4.14 provides a larger view of the excavated face through the pile. Two traffic surfaces were visible in the exposed face with angle of repose layering. Each lift had finer waste rock near the crest, and a rubble zone of larger material at the base of the lift. The coarse rubble zone was clast supported and was primarily infilled with fine matrix material, and some open void space.

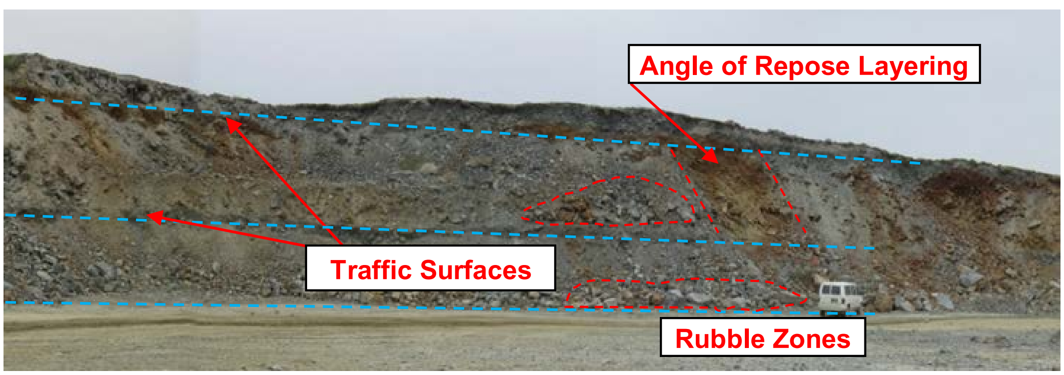


Figure 4.13 - Excavated face of WRS 1 showing evidence of layered structure, traffic surfaces and rubble zones

A similar degree of oxidation encountered during the test pit program was also identified in the profile campaign, with some orange-red coloured surface oxidation throughout. The extent of oxidation however had significant spatial variability. Figure 4.14 and Figure 4.15 present images of the profiles of WRS 1 and WRS 2 during excavation for relocation. The varied range of oxidation colour from grey to orange is evident as well as structural features described in Figure 4.13. Structural features in WRS 2 were less evident than WRS 1 as the excavated face was not exposed to the same height.

4.2.3 Discussion

In general, the structure and features observed in WRS 1 and WRS 2 were consistent with other waste rock dumps excavations such as Golden Sunlight Mine (Herasymuik, 1996) and the INAP study in Northern Ontario (Fines et al., 2003). Vertical and horizontal variation in particle size was observed, however the dipping bed structure observed in the profile sampling campaign was at times difficult to distinguish.

From field observations, it was determined that the primary North-South trending excavation face on WRS 1 was not perpendicular to the direction of material placement during construction of the dump. Therefore, the angle of repose dumping structure was difficult to distinguish. On East-West trending portions of the excavation, dipping beds were more evident. Other reasons for less identifiable bedding structure could be the results of smaller tip faces of only 10 m to 15 m or the method of construction was more similar to paddock dumping.

The degree of weathering of waste rock in WRS 1 and WRS 2 after 27 year history is less than expected for a waste dump of this age. The Golden Sunlight Mine excavation study noted the degree of weathering that had taken place was highly varied between material located adjacent to one another, as some areas would appear unweathered and others with significant rock degradation. The amount of sulfide minerals, geology, and climate (colder winters) may influence the rate of weathering in the waste rock.

Figure 4.14 – Excavated North-South face of WRS 1 showing internal structure and variability of oxidation

Figure 4.15 - Excavated face of WRS 2 for sampling locations WRS-2-4, WRS-2-5, and WRS-2-6

4.3 Laboratory Results

Laboratory testing was completed in stages. First, particle size distribution data was collected as the method of initial characterization. The following stages included preliminary geochemical testing and colour classification and finally, detailed laboratory testing to characterize hydraulic properties. The following section presents the results of the laboratory results.

4.3.1 Grain Size Distribution

Grain size distribution was conducted on the 100 20 L pail samples from both the test-pit sampling program and profile-sampling program. In addition, 35 bag samples of matrix materials, collected during the test-pit program were also characterized for grain size separately to evaluate differences in grain-size distribution with sample scale. Testing of matrix samples was completed in August 2012 and the 20 L pail samples were analyzed in January and February 2013. The stockpile cover material was primarily sand sized with varying amounts of silt and clay and some glacial highly rounded cobbles or waste rock particles. The underlying waste rock material had a varied gradation based on rock type and location. Appendix B provides the matric bag sample and 20-L pail sample particle size distributions for each sampling location.

4.3.1.1 20-L Pail Samples

All samples were classified by grain size analysis utilizing the method detailed in Section 3.3.2. Cover samples were well graded with less than 50% passing the No. 200 sieve, indicating a coarse-grained soil. A plot of all cover grain size curves is provided in Figure 4.16. These data illustrated that material from multiple sources or different borrow sources were used for the cover, as the distributions plot in groups. Four samples, TP-P1-S2-S1, TP-P1-S5-S1, TP-P1-S11-S1, and TP-P1-S14-S1, form a distinct group of particle size distribution curves with a higher content of gravel-sized material. Gravel clasts found in samples were typically glacial cobbles, or waste rock mixed in to the cover. These curves are from samples found on Stockpile 1 only. The remainder of the samples are primarily sand with fines, with greater than 50% passing the No. 4 (4.75 mm) sieve. Three cover samples were selected for additional testing and were selected to represent the range of material sampled.

The particle size distributions for 84 pail waste rock samples are presented in Figure 4.17. Samples collected during the test pit program have a higher proportion of fines as samples were collected in the near surface areas of the waste rock pile. Coarser particles were typically observed at the base of a bench. Profile samples were taken from varied depths and the coarse fraction was better represented. The envelope of grain size curves generated from testing was similar to other field investigations reviewed by McKeowan et al (2000) and the Golden Sunlight Mine waste rock investigation (Herasymuik, 1996).

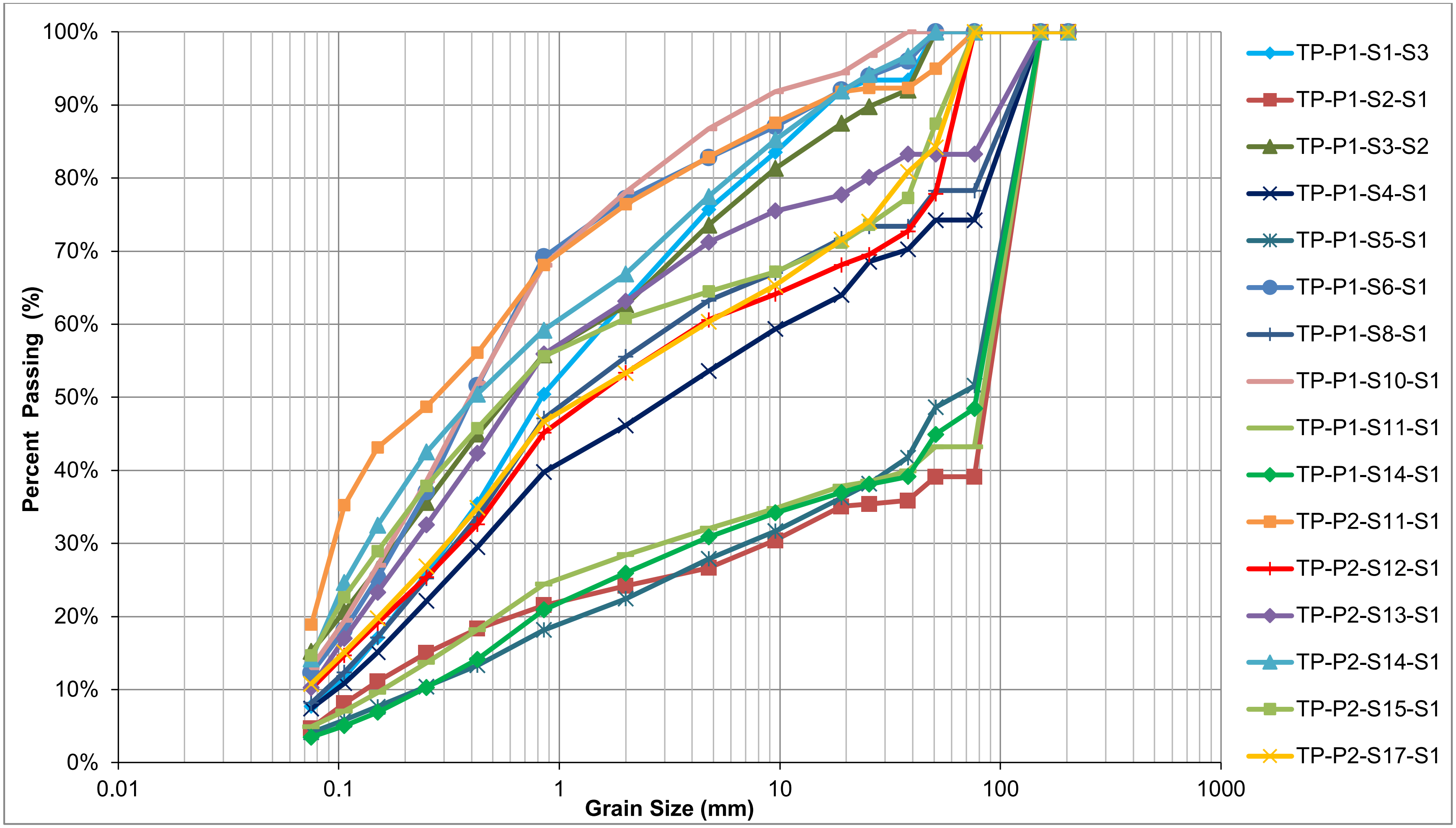


Figure 4.16 - Particle size distribution curves for all 16 cover samples on WRS 1 and WRS 2

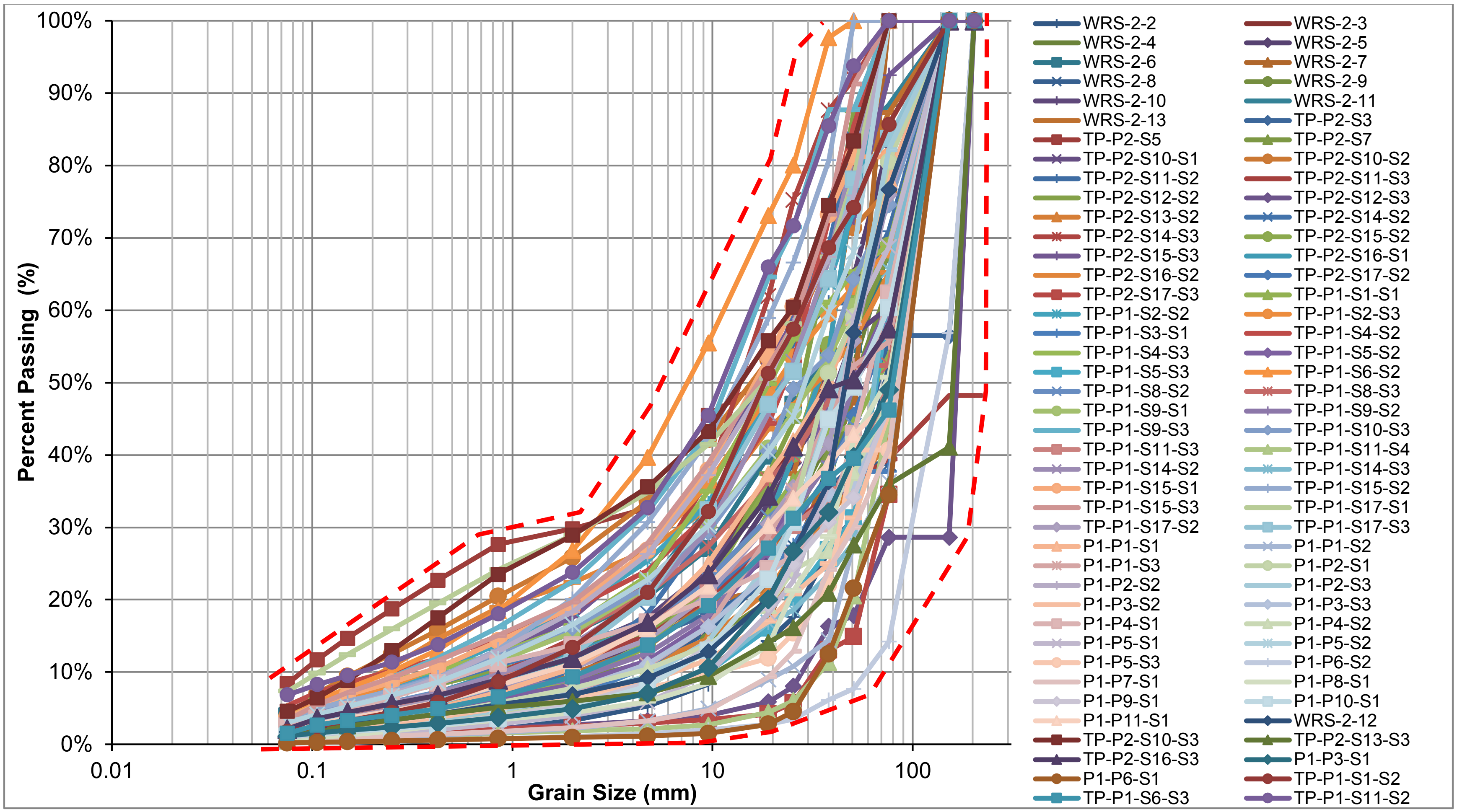


Figure 4.17 - Particle size distribution curves for 84 waste rock samples on WRS 1 and WRS 2

The samples were well graded and had a characteristic long “tail” of fines is particular to waste rock. Particle size distribution data from physical samples was effective in characterizing the fine grained portion of waste rock at the DLM. Due to the limited container size that was used to collect samples, the upper range of particle sizes was not characterized accurately. The typical maximum size of particles sampled was 75 mm. As a result, the upper portion of the measured distribution is gap graded. It should be noted that during sampling, very large particles were observed up to 2 m to 3 m in diameter and consequently the range of particles sampled did not represent the full grain size distribution within the waste rock. Herasymuik (1996) described this limited grain size characterization as the fine grained endpoint distribution. The fine fraction was well characterized during the grain size distribution tests and is invaluable for understanding the water storage capacity of waste rock and its hydraulic behaviour (McKeown et al., 2000). To characterize the coarse grained endpoint, digital image processing is explored in Chapter 5, as well as the volume of fines within the waste rock pile.

The following set of figures (Figures 4.18 to 4.21) present waste rock samples further classified into groups containing 0% to10%, 10% to 19%, 20% to 29% and 30% to 39%, passing the No. 4 (4.75 mm) sieve. Typically, material with greater than 40% passing the No. 4 sieve is considered to be soil-like, with clasts surrounded by fine material (Herasymuik, 1996). No samples collected during the study had greater than 40% passing the No. 4 sieve. This indicates that the waste rock piles will behave as a rock-like material and a clast supported structure with open voids or matrix material infilling would be expected. The largest number of samples is in the range of 20% to 29% passing the #4 sieve.

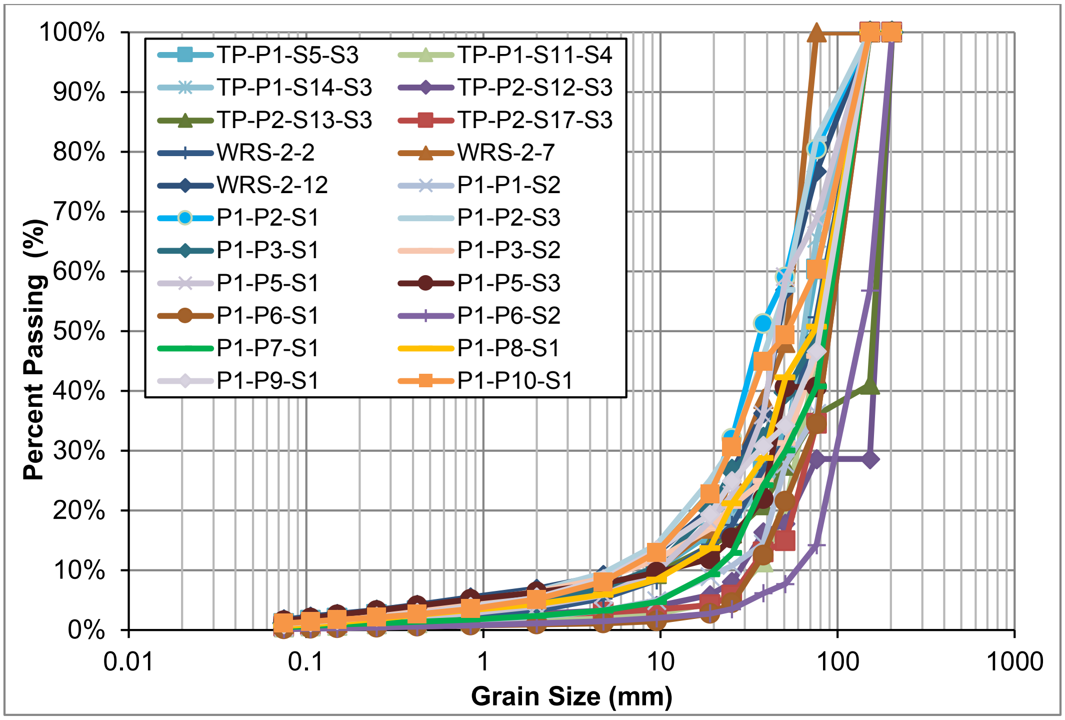


Figure 4.18 – Particle size distribution curves containing less than 10% passing the #4 sieve

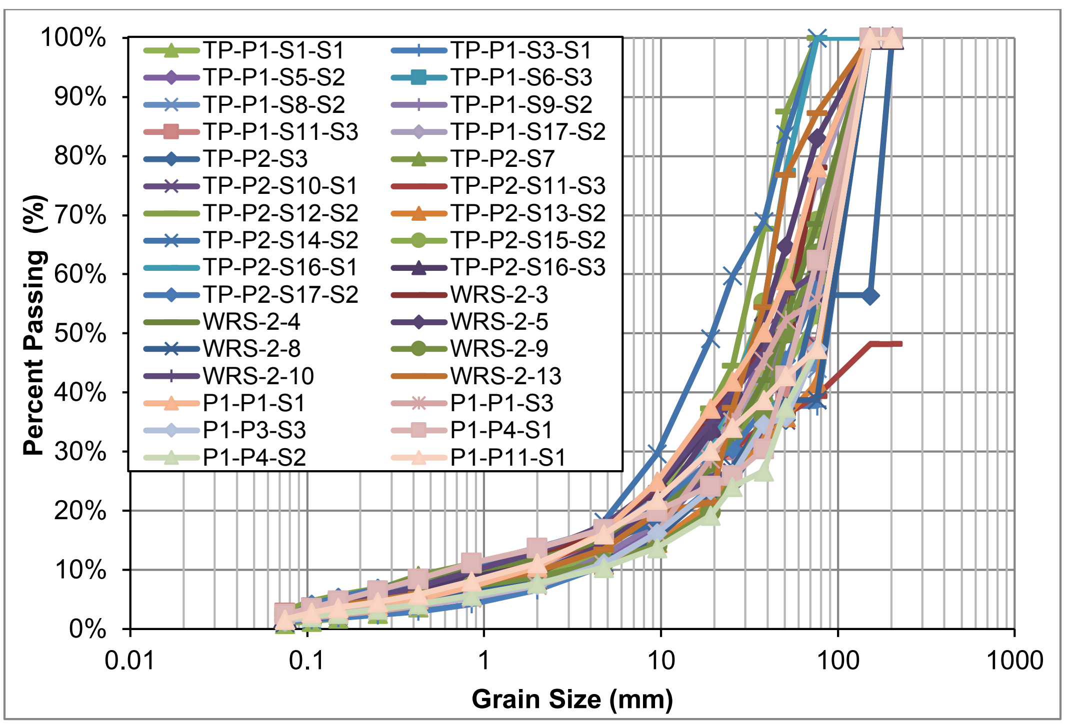


Figure 4.19 - Particle size distribution curves containing less than 20% passing the #4 sieve

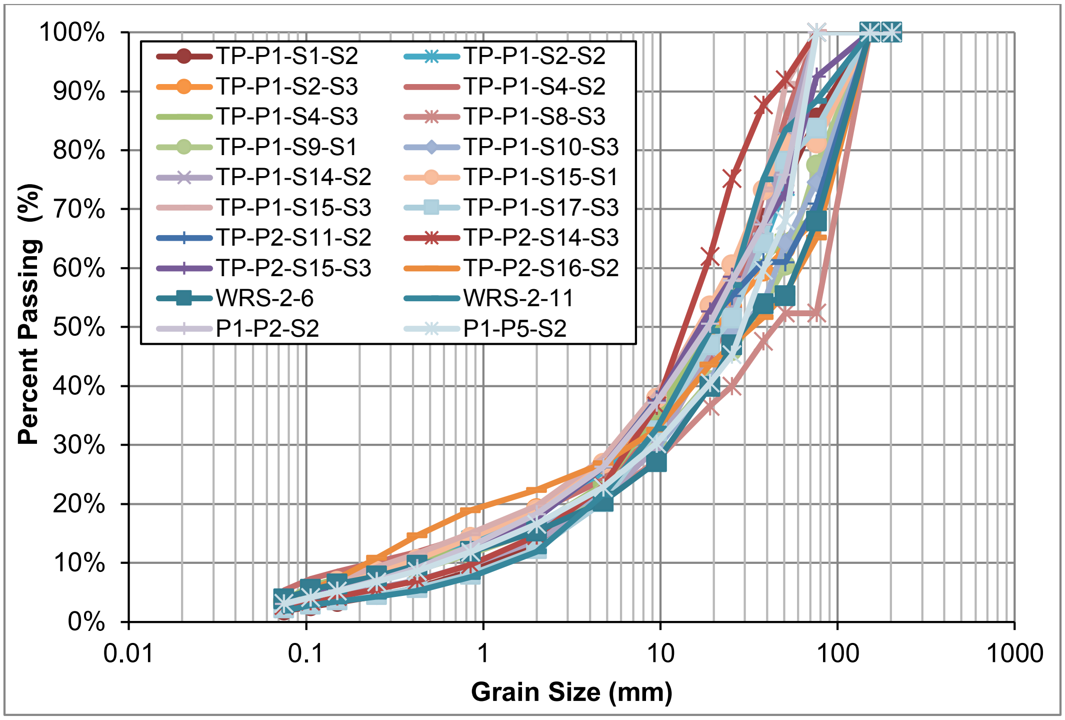


Figure 4.20 - Particle size distribution curves containing less than 30% passing the #4 sieve

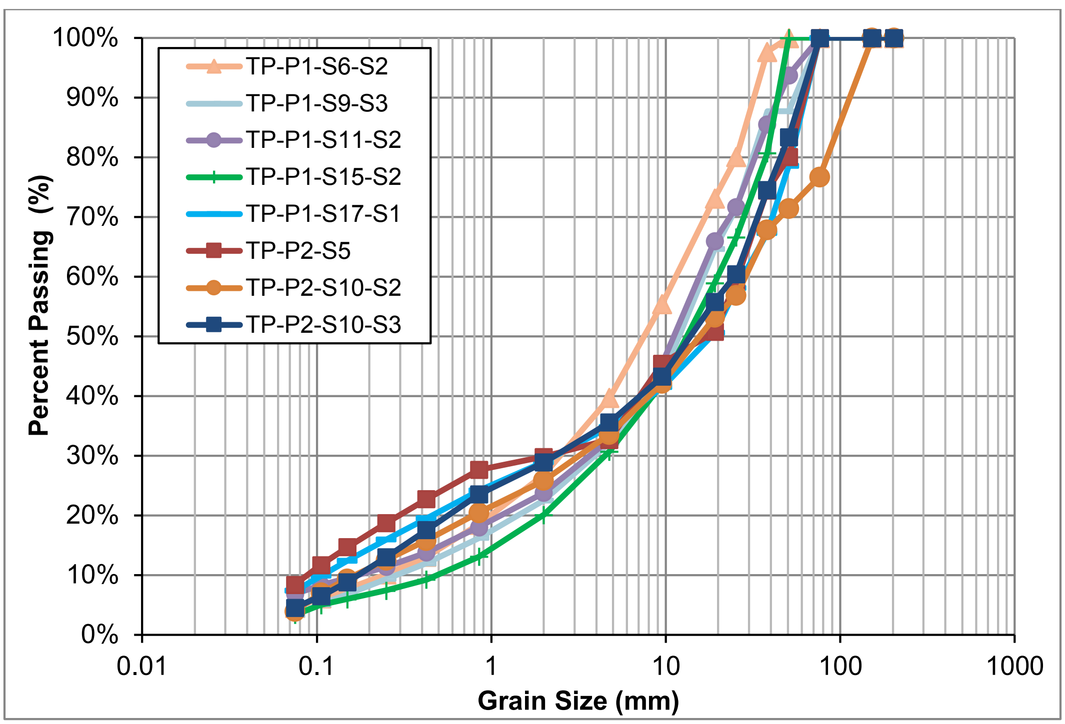


Figure 4.21 - Particle size distribution curves containing less than 40% passing the #4 sieve

4.3.1.2 Matric Samples

All matric bag samples were sieved separately from pail samples to characterize the fine fraction. Matric samples were only collected during the test pit program at each sampling location as described in Section 3.3.2, and a total of 67 were collected. Due to the high volume of samples that were processed and incorrect labelling during testing, data from 34 matric samples was determined to be reliable. The matric grain size distributions of 9 cover samples and 25 waste rock samples are shown in Figure 4.22 and Figure 4.23, respectively. The maximum sieve size tested was 9.5 mm.

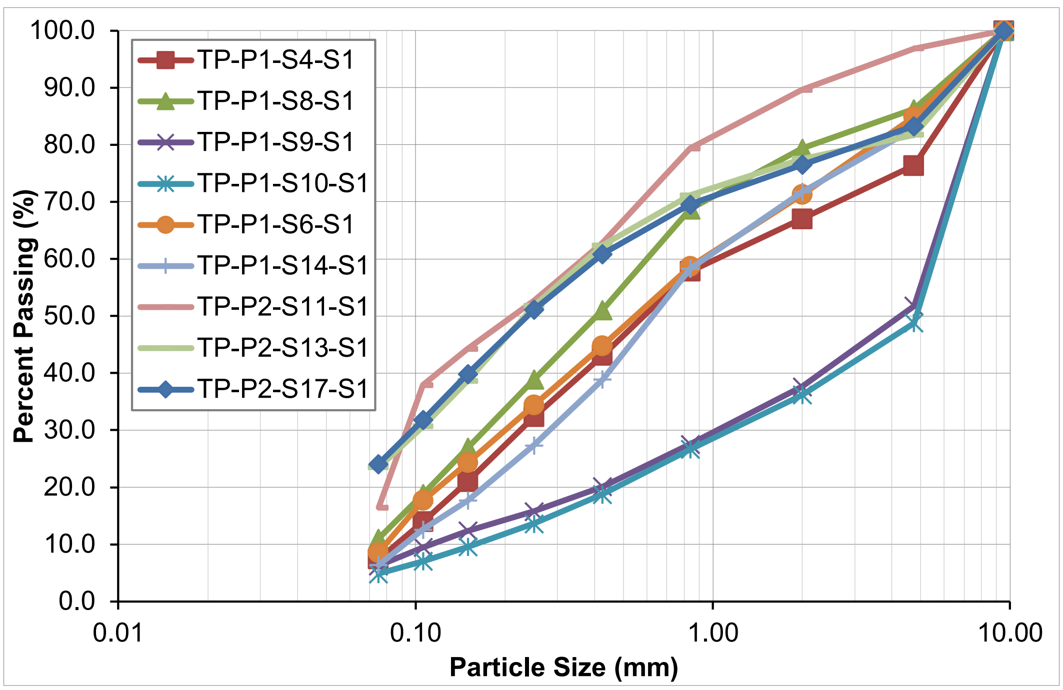


Figure 4.22 - Particle size distribution curves for cover material passing the 9.5 mm sieve

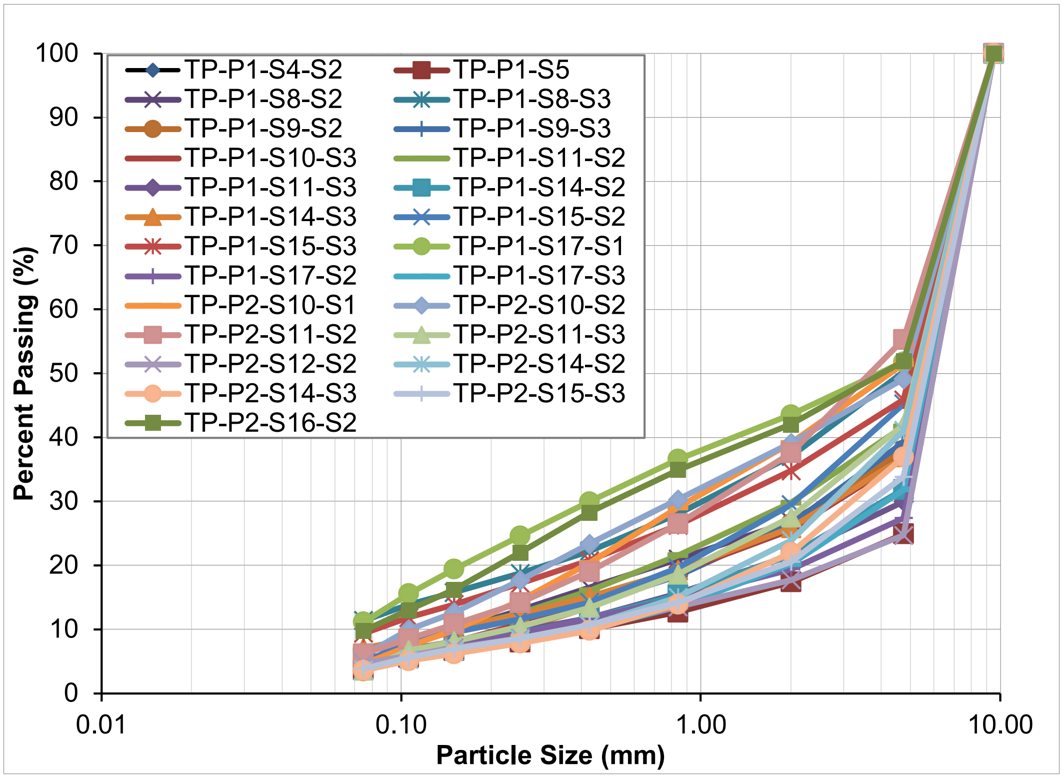


Figure 4.23 - Particle size distribution curves for waste rock material passing the 9.5 mm sieve

The grain size distributions of matric material for the cover samples are similar to the large bucket samples, as groups of similar soil materials are evident. The matric material of the waste rock samples has a similar tail of fines that is well graded. At the time of testing, material up to 9.5 mm was included in the sieve analysis, and in future studies it is recommended that this material is not included to better understand the distribution of the less than 4.5 mm material.

4.3.1.3 Discussion

The grain size distributions of all samples created an envelope of wide ranging gradations. The location of the sample, the degree of weathering, rock type and handling during mine operations all influence the particle size distribution. Consequently the grain size within waste rock is highly heterogeneous, however a well graded "tail" fine fraction is consistent for most samples. The waste rock structure at the Detour Lake Mine has rock-like properties, and the proportion of fines found in samples support visual observations that open void spaces and a clast supported structure dominate despite the age of the pile.

In this study, similar particle size distributions did not indicate that other properties will also be similar. Three particle size distributions from Test Pit 15 on WRS 1 are presented in Figure 4.24 that have very similar particle size distributions. Table 4.3 lists properties observed during the investigation, including observed degree of weathering, moisture content and paste pH. The field observations of oxidation are highly varied for samples taken within an area of approximately 10 m x 10 m indicating grain size does not give a substantial indication of oxidation processes or geochemical properties.

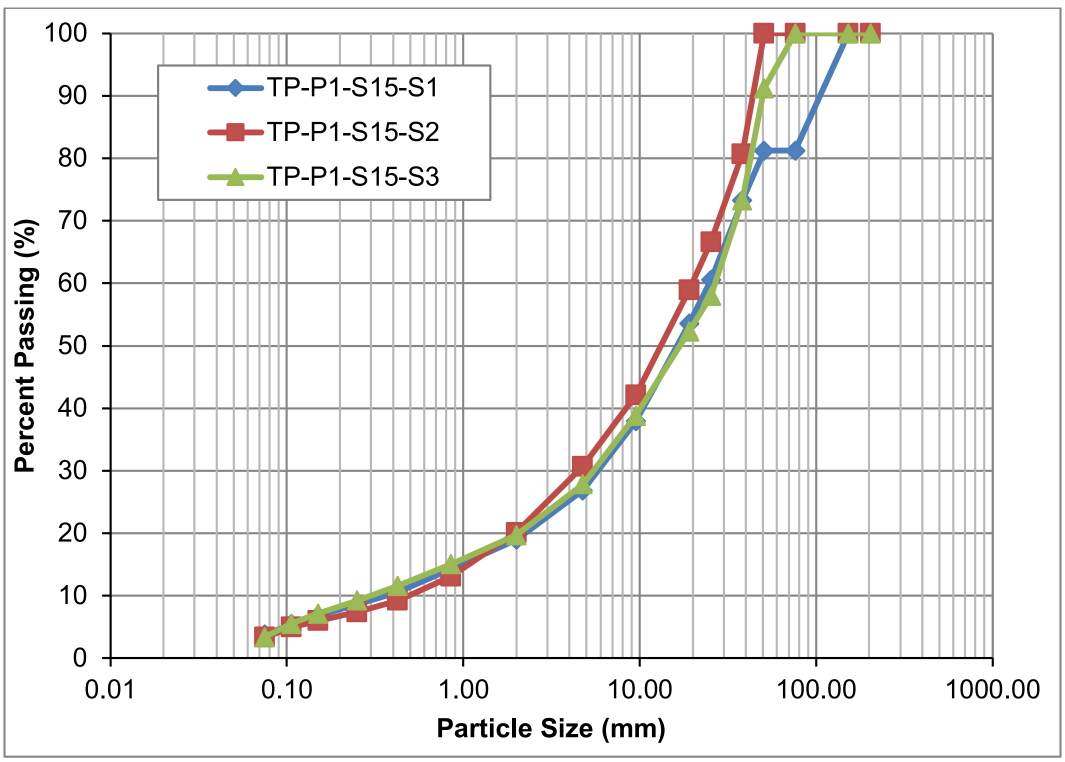


Figure 4.24 – Particle size distribution curves for TP-P1-S15

Table 4.3- Variation in sample properties found in test pit number 15

Sample Number	Level of Oxidation	Moisture Content of Fines	Paste pH
TP-P1-S15-S1	Very High	6.0%	2.9
TP-P1-S15-S2	Moderate	5.8%	4.9
TP-P1-S15-S3	Low	7.5%	6.8

No indication or record of the age of material or date of placement was available. Therefore, the study was not able to assess differences in grain size distribution with ageing or weathering. Few inferences can be made about changes to the waste rock gradation over the 26 year post-closure period and how the distribution may have changed over time.

4.3.2 Paste pH

Paste pH testing was conducted on the fines of all samples collected. The frequency of paste pH values from all samples are shown in Figure 4.25. The pHs of the cover samples were neutral, and fell in the range of 6 to 8. Waste rock sample pH values were bimodal, with a peak between 3 and 3.5 and 6.5 and 7. Approximately 20% of waste rock samples have a pH of less than 4, and most samples fall within the neutral pH range. Similar distributions were found on WRS 1 and 2 (Figure 4.26). A summary of paste pH data is provided in Table 4.4. The paste pH results support on site observations that ARD has not yet developed on site.

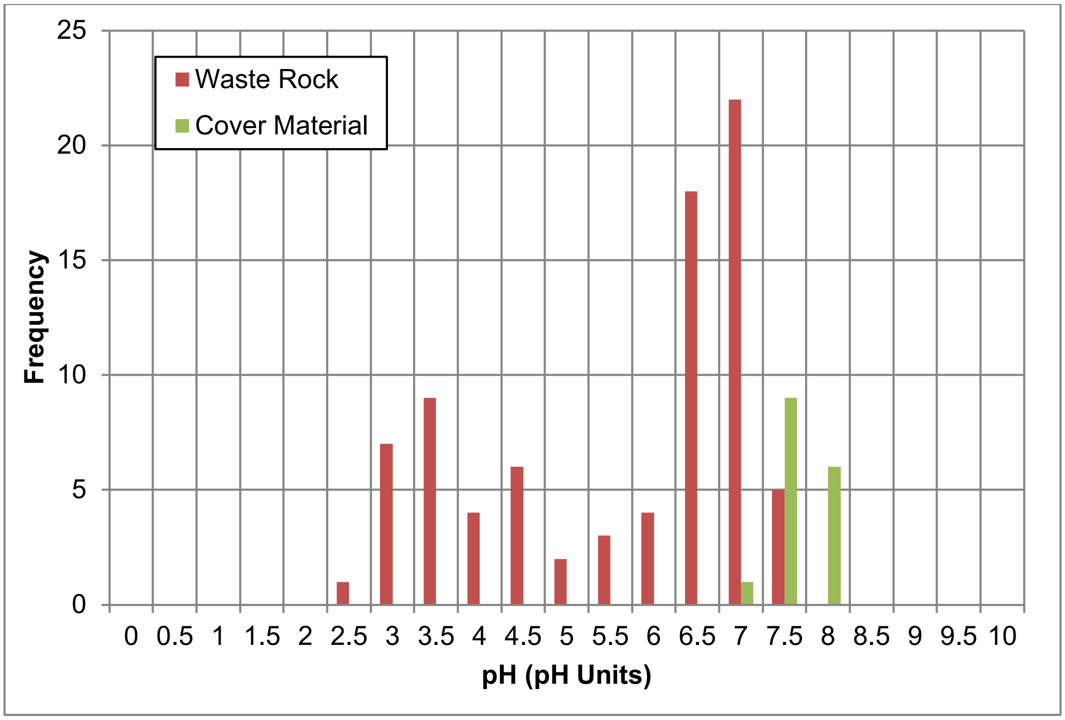


Figure 4.25 - Frequency distribution of paste pH results for waste rock and cover samples

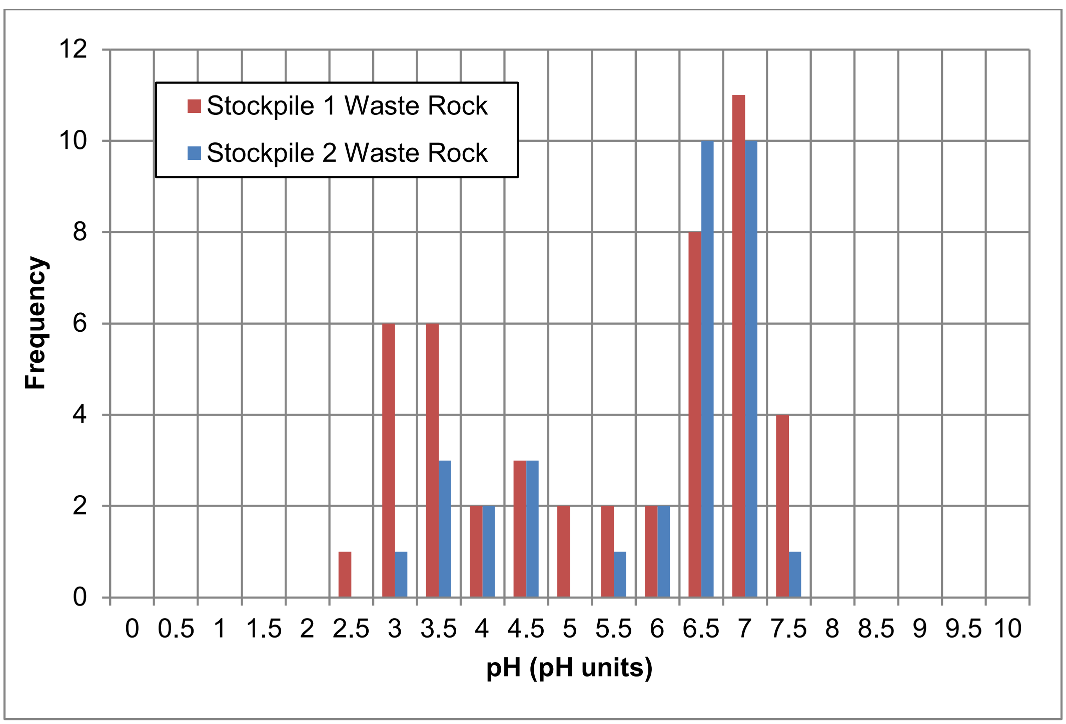


Figure 4.26 – Frequency distribution of paste pH results for WRS 1 and WRS 2

Table 4.4- Paste pH results

Sample Name	Paste pH	Sample Name	Paste pH
TP-P1-S1-S1	2.8	TP-P2-S12-S2	6.7
TP-P1-S1-S2	2.7	TP-P2-S12-S3	6.9
TP-P1-S1-S3	7.0	TP-P2-S13-S1	8.0
TP-P1-S2-S1	7.5	TP-P2-S13-S2	5.6
TP-P1-S2-S2	6.8	TP-P2-S13-S3	6.7
TP-P1-S2-S3	2.5	TP-P2-S14-S1	7.8
TP-P1-S3-S1	6.8	TP-P2-S14-S2	3.0
TP-P1-S3-S2	7.8	TP-P2-S14-S3	2.9
TP-P1-S4-S1	7.5	TP-P2-S15-S1	7.5
TP-P1-S4-S2	7.1	TP-P2-S15-S2	3.6
TP-P1-S4-S3	7.3	TP-P2-S15-S3	3.9
TP-P1-S5-S1	7.2	TP-P2-S16-S1	5.2
TP-P1-S5-S2	6.5	TP-P2-S16-S2	6.2
TP-P1-S5-S3	6.4	TP-P2-S16-S3	6.9
TP-P1-S6-S1	7.5	TP-P2-S17-S1	7.4
TP-P1-S6-S2	3.5	TP-P2-S17-S2	6.3
TP-P1-S6-S3	7.1	TP-P2-S17-S3	6.7
TP-P1-S8-S1	7.7	WRS-2-1	N/A
TP-P1-S8-S2	6.7	WRS-2-2	3.3
TP-P1-S8-S3	6.8	WRS-2-3	6.5
TP-P1-S9-S1	3.3	WRS-2-4	6.3
TP-P1-S9-S2	4.4	WRS-2-5	6.4
TP-P1-S9-S3	2.3	WRS-2-6	6.4
TP-P1-S10-S1	7.5	WRS-2-7	4.3
TP-P1-S10-S2	7.0	WRS-2-8	6.6
TP-P1-S10-S3	3.0	WRS-2-9	6.6
TP-P1-S11-S1	7.7	WRS-2-10	3.2
TP-P1-S11-S2	4.4	WRS-2-11	6.1
TP-P1-S11-S3	6.0	WRS-2-12	4.1
TP-P1-S11-S4	N/A	WRS-2-13	6.6
TP-P1-S14-S1	7.3	P1-P1-S1	2.8
TP-P1-S14-S2	2.9	P1-P1-S2	2.9
TP-P1-S14-S3	4.0	P1-P1-S3	3.4
TP-P1-S15-S1	2.9	P1-P2-S1	6.8
TP-P1-S15-S2	4.9	P1-P2-S2	6.0
TP-P1-S15-S3	6.8	P1-P2-S3	6.1
TP-P1-S17-S1	7.2	P1-P3-S1	6.8
TP-P1-S17-S2	5.1	P1-P3-S2	6.1
TP-P1-S17-S3	6.5	P1-P3-S3	6.8
TP-P2-S1 & S2	N/A	P1-P4-S1	6.3

Sample Name	Paste pH	Sample Name	Paste pH
TP-P2-S3	6.4	P1-P4-S2	4.4
TP-P2-S4	N/A	P1-P5-S1	6.7
TP-P2-S5	7.2	P1-P5-S2	4.8
TP-P2-S6	N/A	P1-P5-S3	6.6
TP-P2-S7	6.5	P1-P6-S1	6.3
TP-P2-S10-S1	5.8	P1-P6-S2	N/A
TP-P2-S10-S2	6.4	P1-P7-S1	3.2
TP-P2-S10-S3	6.7	P1-P8-S1	5.1
TP-P2-S11-S1	8.0	P1-P9-S1	3.1
TP-P2-S11-S2	4.3	P1-P10-S1	6.7
TP-P2-S11-S3	6.7	P1-P11-S1	6.5
TP-P2-S12-S1	7.4		

4.3.3 Munsell Soil Colour

Munsell soil colour was evaluated for the fines used in paste pH testing (<2 mm material). Munsell soil colour chips are divided into both rock and soil colour chips. All samples were identified using soil colour chips, and were classified into five hues, 10Y, 5Y, 2.5Y, 10YR, and 7.5YR. These hues are yellow (Y) or yellow red (YR), and the preceding number in the notation notes the location or degree from 0 to 10 within that hue. The full colour classification of hue, chroma and value is summarized for the samples in Table 4.5 using the format of 'Hue Value/Chroma'. Most samples have similar hues of 5Y, 2.5Y and 10YR, which are consecutive on the hue scale.

Table 4.5 - Munsell soil colour results

Sample Name	Munsell Soil Colour	Sample Name	Munsell Soil Colour
TP-P1-S1-S1	10YR 6/8	TP-P2-S12-S2	10Y 6/1
TP-P1-S1-S2	10YR 5/6	TP-P2-S12-S3	2.5Y 6/1
TP-P1-S1-S3	10YR 4/1	TP-P2-S13-S1	2.5Y 7/1
TP-P1-S2-S1	5Y 7/1	TP-P2-S13-S2	2.5Y 5/2
TP-P1-S2-S2	10Y 6/1	TP-P2-S13-S3	2.5Y 6/1
TP-P1-S2-S3	10YR 5/8	TP-P2-S14-S1	2.5Y 7/2
TP-P1-S3-S1	10Y 5/1	TP-P2-S14-S2	10YR 5/4
TP-P1-S3-S2	2.5Y 7/2	TP-P2-S14-S3	10YR 5/6

Sample Name	Munsell Soil Colour	Sample Name	Munsell Soil Colour
TP-P1-S4-S1	5Y 7/1	TP-P2-S15-S1	5Y 7/1
TP-P1-S4-S2	5Y 5/1	TP-P2-S15-S2	10YR 5/6
TP-P1-S4-S3	10Y 5/1	TP-P2-S15-S3	10YR 5/4
TP-P1-S5-S1	5Y 6/2	TP-P2-S16-S1	5Y 6/2
TP-P1-S5-S2	10Y 6/1	TP-P2-S16-S2	2.5Y 6/1
TP-P1-S5-S3	10Y 6/1	TP-P2-S16-S3	5Y 6/1
TP-P1-S6-S1	5Y 7/1	TP-P2-S17-S1	2.5Y 6/2
TP-P1-S6-S2	10YR 5/4	TP-P2-S17-S2	5Y 7/1
TP-P1-S6-S3	10Y 6/1	TP-P2-S17-S3	5Y 6/2
TP-P1-S8-S1	2.5Y 6/1	WRS-2-1	N/A
TP-P1-S8-S2	5Y 6/2	WRS-2-2	7.5YR 4/6
TP-P1-S8-S3	5Y 5/2	WRS-2-3	5Y 5/1
TP-P1-S9-S1	10YR 5/8	WRS-2-4	10YR 6/3
TP-P1-S9-S2	10YR 5/6	WRS-2-5	5Y 5/1
TP-P1-S9-S3	7.5YR 5/8	WRS-2-6	5Y 2/6
TP-P1-S10-S1	2.5Y 6/2	WRS-2-7	10YR 5/3
TP-P1-S10-S2	2.5Y 7/2	WRS-2-8	5Y 6/1
TP-P1-S10-S3	10YR 5/6	WRS-2-9	2.5Y 6/2
TP-P1-S11-S1	2.5Y 6/2	WRS-2-10	10YR 5/6
TP-P1-S11-S2	10YR 4/3	WRS-2-11	2.5Y 5/1
TP-P1-S11-S3	5Y 5/1	WRS-2-12	10YR 5/6
TP-P1-S11-S4	N/A	WRS-2-13	5Y 6/1
TP-P1-S14-S1	5Y 6/2	P1-P1-S1	10YR 5/6
TP-P1-S14-S2	10YR 5/6	P1-P1-S2	10YR 4/6
TP-P1-S14-S3	10YR 5/4	P1-P1-S3	10YR 5/6
TP-P1-S15-S1	10YR 5/6	P1-P2-S1	10Y 6/1
TP-P1-S15-S2	5Y 5/2	P1-P2-S2	2.5Y 6/2
TP-P1-S15-S3	5Y 7/1	P1-P2-S3	2.5Y 6/2
TP-P1-S17-S1	5Y 6/2	P1-P3-S1	10Y 6/1
TP-P1-S17-S2	2.5Y 5/3	P1-P3-S2	2.5Y 5/4
TP-P1-S17-S3	5Y 5/2	P1-P3-S3	10Y 6/1
TP-P2-S1 & S2	N/A	P1-P4-S1	2.5Y 7/2
TP-P2-S3	2.5Y 6/1	P1-P4-S2	2.5Y 5/3
TP-P2-S4	N/A	P1-P5-S1	5Y 6/2
TP-P2-S5	10YR 6/1	P1-P5-S2	10YR 6/4
TP-P2-S6	N/A	P1-P5-S3	2.5Y 6/3
TP-P2-S7	10YR 5/1	P1-P6-S1	2.5Y 6/1
TP-P2-S10-S1	10YR 6/4	P1-P6-S2	N/A
TP-P2-S10-S2	2.5Y 5/3	P1-P7-S1	10YR 5/6
TP-P2-S10-S3	2.5Y 6/2	P1-P8-S1	10YR 5/4
TP-P2-S11-S1	2.5Y 7/2	P1-P9-S1	10YR 5/4

Sample Name	Munsell Soil Colour	Sample Name	Munsell Soil Colour
TP-P2-S11-S2	10YR 5/6	P1-P10-S1	2.5Y 5/2
TP-P2-S11-S3	10Y 6/1	P1-P11-S1	10Y 6/1
TP-P2-S12-S1	2.5Y 7/1		

The relationship between Munsell soil colour and paste pH was assessed to determine if the soil colour of the fines provided an indication of the geochemical reactivity. Paste pH is plotted versus chroma and value for each of the five hues found in Figures 4.27 to Figure 4.31. Samples with 10Y, 5Y, and 2.5Y hues typically had paste pH values in the neutral range of 6 to 8. For these three hues, lower value and higher chroma parameters of the soil colour were associated with lower pH values, which were all above pH 4. For the 10YR hue, much higher chroma numbers in the range of six to eight were associated with lower pH values between 4.5 and 2. Paste pH results for the 7.5YR hue were below 3.5, however only two samples were classified in this group. In general, as samples become redder in hue, the paste pH decreases and the degree of oxidation increases. The Munsell soil colour and paste pH data are summarized in Table 4.6.

Paste pH provides a preliminary indication of the readily available acid and neutralizing potential on the surface of the sample particles. These data can be used as a screening test and can be correlated with future geochemical testing. Munsell soil colour classification could also be used in future to correlate with rock type for identification of potentially acid generating material or to qualify degree of weathering. The relationship between Munsell soil colour and paste pH could be beneficial as it provides a simple method for field staff to identify the waste rock colour and identify if the material will be potentially acid generating (PAG), or if the material could be used for construction due to low reactivity.

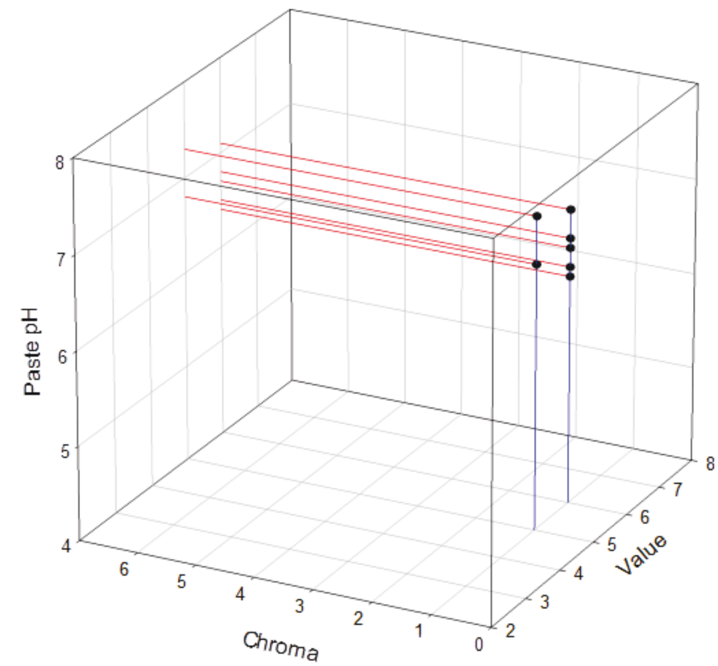


Figure 4.27 –Relationship of paste pH and Munsell soil colour for the 10Y hue

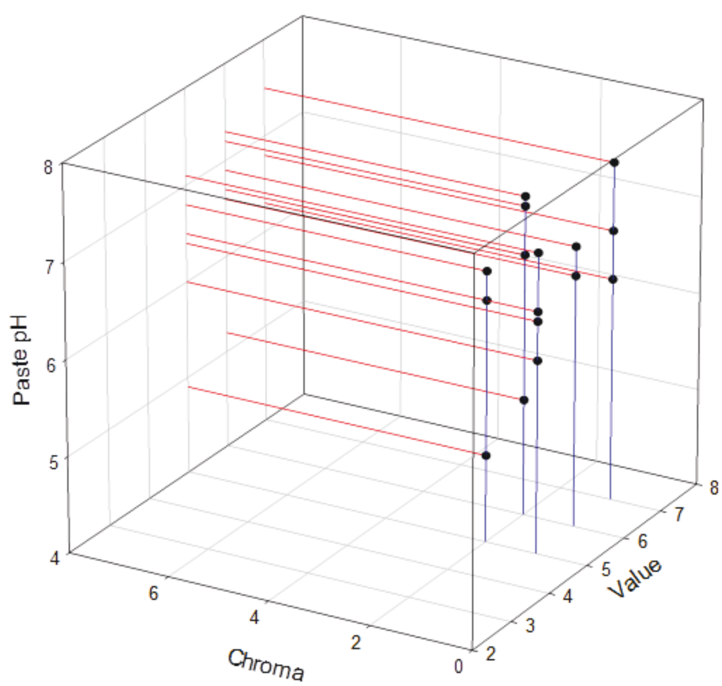


Figure 4.28 - Relationship of paste pH and Munsell soil colour for the 5Y hue

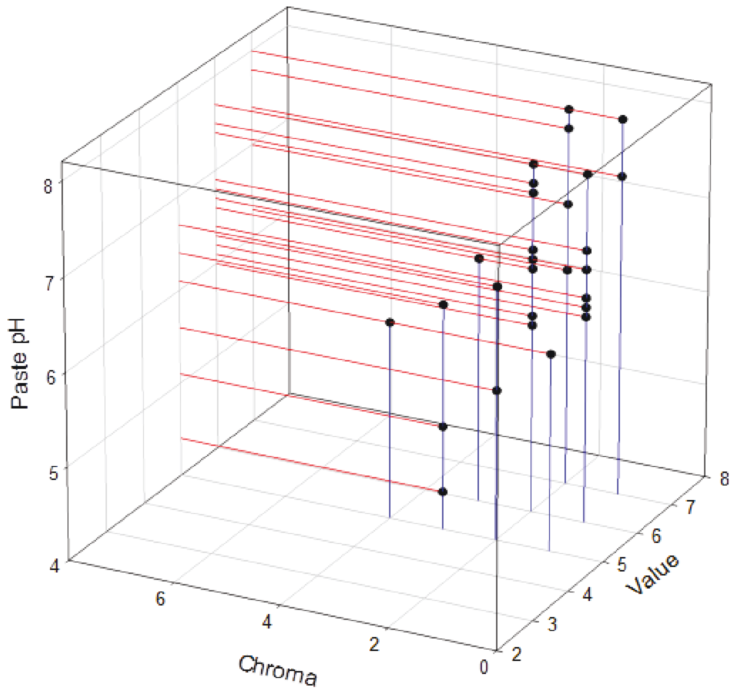


Figure 4.29 - Relationship of paste pH and Munsell soil colour for the 2.5Y hue

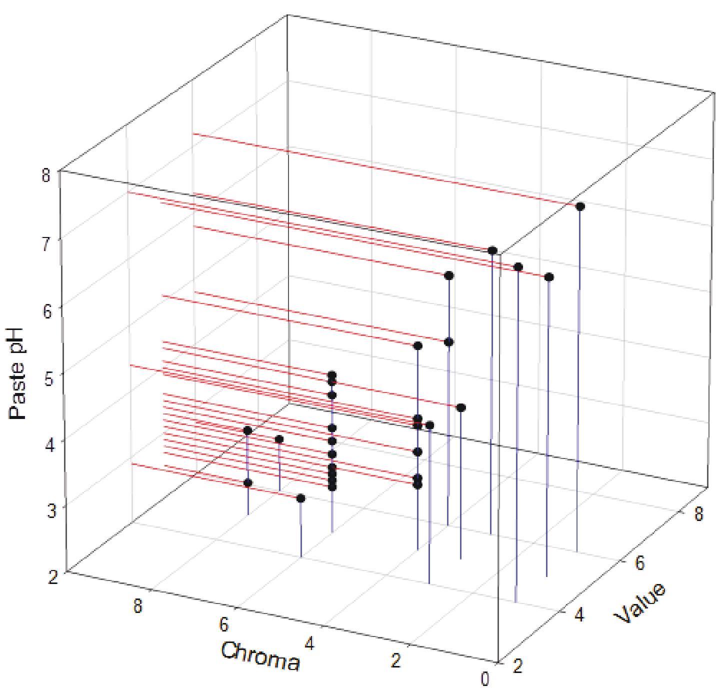


Figure 4.30 - Relationship of paste pH and Munsell soil colour for the 10YR hue

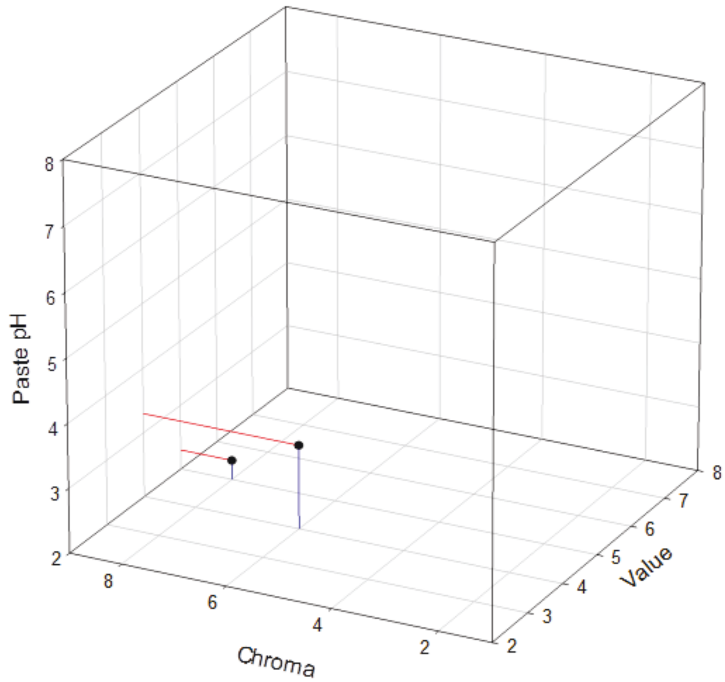


Figure 4.31 - Relationship of paste pH and Munsell soil colour for the 7.5YR hue

Table 4.6 - Summary of Munsell Soil Colour and paste pH values

Hue	Value/Chroma	Paste pH values of samples for the given soil colour (pH units)	Average pH for Value/Chroma
10Y	5/1	7.3, 6.8	7.1
	6/1	6.8, 6.5, 6.4, 7.1, 6.8, 6.8, 6.8, 6.5, 6.7, 6.7	6.7
5Y	2/6	6.4	6.4
	5/1	7.1, 6, 6.5, 6.4	6.5
	5/2	6.8, 4.9, 6.5	6.1
	6/1	6.9, 6.6, 6.6	6.7
	6/2	7.2, 6.7, 7.3, 7.2, 5.2, 6.7, 6.7	6.7
	7/1	7.5, 7.5, 7.5, 6.8, 7.5, 6.3	7.2
2.5Y	5/1	6.1	6.1
	5/2	5.6, 6.7	6.2
	5/3	5.1, 6.4, 4.4	5.3

Hue	Value/Chroma	Paste pH values of samples for the given soil colour (pH units)	Average pH for Value/Chroma
	5/4	6.1	6.1
	6/1	6.4, 6.9, 6.7, 6.2, 6.3	6.5
	6/2	7.5, 7.7, 6.7, 7.4, 6.6, 6, 6.1	6.9
	6/3	6.6	6.6
	7/1	7.4, 8.0	7.7
	7/2	7.8, 7, 8, 7.8, 6.3	7.4
10YR	4/1	7.0	7.0
	4/3	4.4	4.4
	4/6	2.9	2.9
	5/1	6.5	6.5
	5/3	4.3	4.3
	5/4	3.5, 4.0, 3, 3.9, 5.1, 3.1	3.8
	5/6	2.7, 4.4, 3, 2.9, 2.9, 4.3, 2.9, 3.6, 3.2, 4.1, 2.8, 3.4, 3.2	3.3
	5/8	2.5, 3.3	2.9
	6/1	7.2	7.2
	6/3	6.3	6.3
	6/4	5.8, 4.8	5.3
	6/8	2.8	2.8
7.5YR	4/6	3.3	3.3
	5/8	2.3	2.3

4.4 Detailed Laboratory Results

Ten waste rock samples and three cover samples were selected to represent the range within the particle size distributions, degree of oxidation, the sampling program where the waste rock was collected and spatial location on the stockpiles. Table 4.7 provides a summary of the results from the preliminary laboratory program for the 13 samples selected. The grain size curves for the waste rock material are highlighted in Figure 4.32, and cover material curves are found in Figure 4.16. Note that material types listed are abbreviated and detailed descriptions of lithology are provided in Section 3.2.1.2. The samples represent a range of soil colours, paste pH and moisture content. Detailed testing included analysis of constant head saturated hydraulic conductivity and the determination of the soil water characteristic curve. The results of these tests are provided in the following sections.

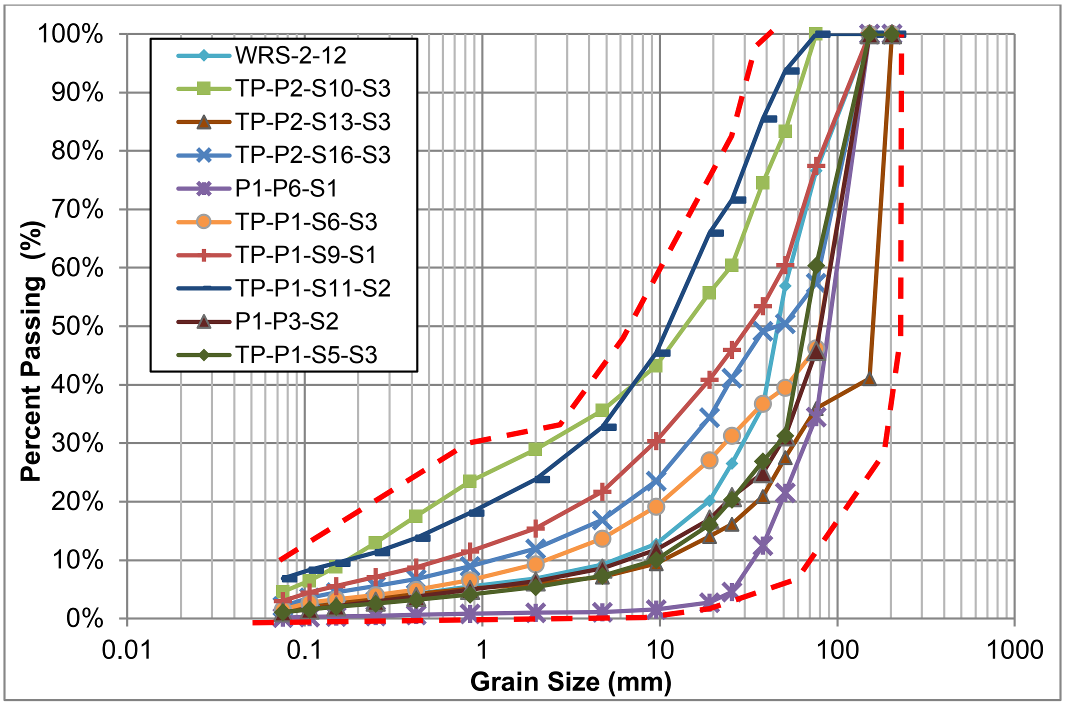


Figure 4.32 – Ten select 20-L pail samples selected to represent both the range of grain size distributions range and physical properties

Table 4.7 - Results of preliminary tests for samples selected for detailed testing

Sample Type and Location	Sample Number	Material Type	Matric Suction	Gravimetric Water Content (%) Matric Bag Sample	Gravimetric Water Content (%) 20-L Pail Sample	Paste pH	Munsell Soil Colour
WRS 1 and WRS 2 Cover	TP-P1-S4-S1	OVB	30.0	6.0	3.5	7.5	5Y 7/1
	TP-P1-S14-S1	OVB	16.0	0.0	5.0	7.3	5Y 6/2
	TP-P2-S11-S1	OVB	20.0	2.6	9.0	8.0	2.5Y 7/2
WRS 1 Waste Rock	TP-P1-S5-S3	FI,FMV,TC	N/A	0.0	0.9	6.4	10Y 6/1
	TP-P1-S6-S3	FMV	N/A	2.6	1.5	7.1	10Y 6/1
	TP-P1-S9-S1	FMV, TC, FI	39.5	5.7	2.8	3.3	10YR 5/8
	TP-P1-S11-S2	FMV/MI, FI	3.0	5.1	2.9	4.4	10YR 4/3
	P1-P3-S2	TC, FI	N/A	N/A	N/A	6.1	2.5Y 5/4
	P1-P6-S1	FMV, FI, TC	N/A	N/A	N/A	6.3	2.5Y 6/1
WRS 2 Waste Rock	TP-P2-S10-S3	FMV, TC	N/A	0.0	1.5	6.7	2.5Y 6/2
	TP-P2-S13-S3	TC, FMV	2.0	4.8	2.0	6.7	2.5Y 6/1
	TP-P2-S16-S3	TC, FMV	1.0	3.7	8.2	6.9	5Y 6/1
	WRS-2-12	TC	N/A	N/A	N/A	4.1	10YR 5/6

4.4.1 Constant Head Saturated Hydraulic Conductivity Analysis

Saturated hydraulic conductivity was determined using a constant head permeability test. A constant head test utilizes a steady state head to measure the outflow volume with time. Water flow occurs primarily in the <4.75 mm size fraction in unsaturated conditions and the select samples were screened to remove material greater than the No. 4 (4.75 mm). The fine fraction used in permeability testing was the same as material used in Tempe cell testing to determine SWCC's. Table 4.8 presents the results of the constant head tests. Sample P1-P6-S1 was not tested due to limited fine material, which was insufficient to fill the specimen cylinder with an appropriate depth for reliable results.

Table 4.8 – Constant head saturated hydraulic conductivity values for select samples

Sample Type and Location	Sample Number	Saturated Hydraulic Conductivity (k, m/s)
WRS 1 and WRS 2 Cover	TP-P1-S4-S1	2.4×10^{-4}
	TP-P1-S14-S1	4.1×10^{-5}
	TP-P2-S11-S1	1.3×10^{-6}
WRS 1 Waste Rock	TP-P1-S5-S3	7.6×10^{-5}
	TP-P1-S6-S3	1.5×10^{-5}
	TP-P1-S9-S1	5.4×10^{-6}
	TP-P1-S11-S2	1.2×10^{-5}
	P1-P3-S2	1.4×10^{-5}
	P1-P6-S1	N/A
WRS 2 Waste Rock	TP-P2-S10-S3	1.8×10^{-5}
	TP-P2-S13-S3	3.1×10^{-6}
	TP-P2-S16-S3	2.2×10^{-5}
	WRS-2-12	7.3×10^{-6}

The hydraulic conductivity values for the three cover samples ranged over two orders of magnitude. The permeability range of 10^{-6} m/s to 10^{-4} m/s is characteristic of glacial tills and mixtures of sand, silt and clay (Terzaghi, Peck, & Mesri, 1996), which is consistent with the observed material properties during sampling and post processing.

The <4.75 mm waste rock samples were in the range of 10^{-5} m/s to 10^{-6} m/s. Results of hydraulic conductivity testing from Fines et al. (2003) were in the range of 10^{-6} m/s to 10^{-9} m/s, and Herasymuik (1996) reported saturated hydraulic conductivity values of 2.3×10^{-5} m/s. The test results of the Detour Lake Mine material are consistent with this range of values in the literature. In-situ values would likely be lower due to mineral precipitates causing cementation as well as the difference between in-situ density and that of the uncompact material tested in the laboratory.

4.4.2 Soil Water Characteristic Curves

Soil water characteristic curves were determined for the thirteen select samples. The material <4.75 mm was placed into Tempe pressure cells and the material was initially saturated. The drainage SWCC was measured as matric suction was increased. The waste rock and cover samples were not compacted as *in situ* density was not measured in the field and consolidation effects were not investigated.

The SWCCs of volumetric water content and matric suction for the three cover samples are provided in Figure 4.33. The SWCCs for the waste rock material is presented for WRS 1 in Figure 4.34, and for WRS 2 in Figure 4.35. Curve fitting of the sample data was completed using the SoilVision SVFLUX computer program (SoilVision Systems Ltd., 2012) through application of the Fredlund and Xing (1994) model. The AEVs and residual volumetric saturation from these curve fitting solutions are provided for each sample in Table 4.9.

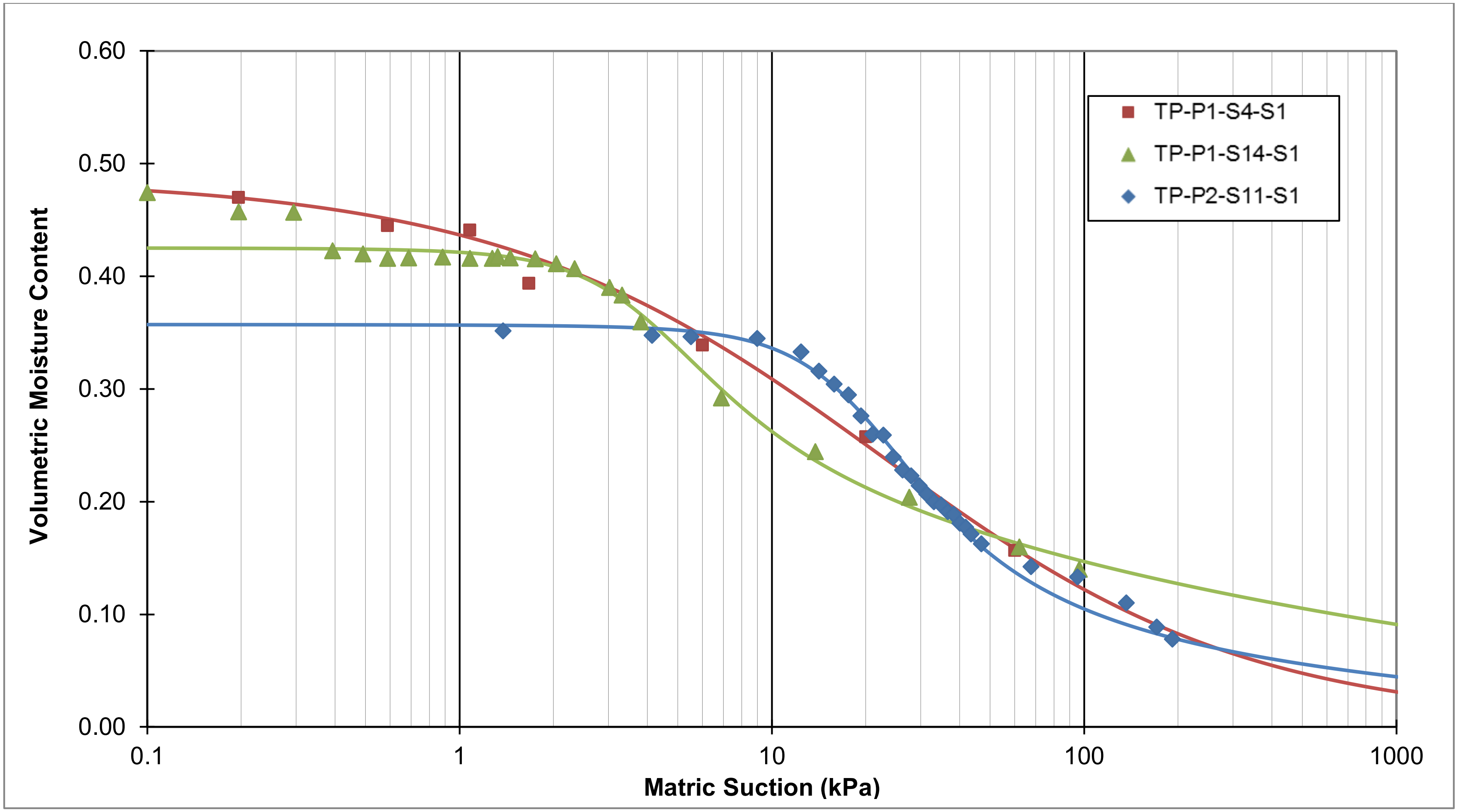


Figure 4.33 - Soil water characteristic curves for select cover samples with fitted Fredlund and Xing (1994) curves

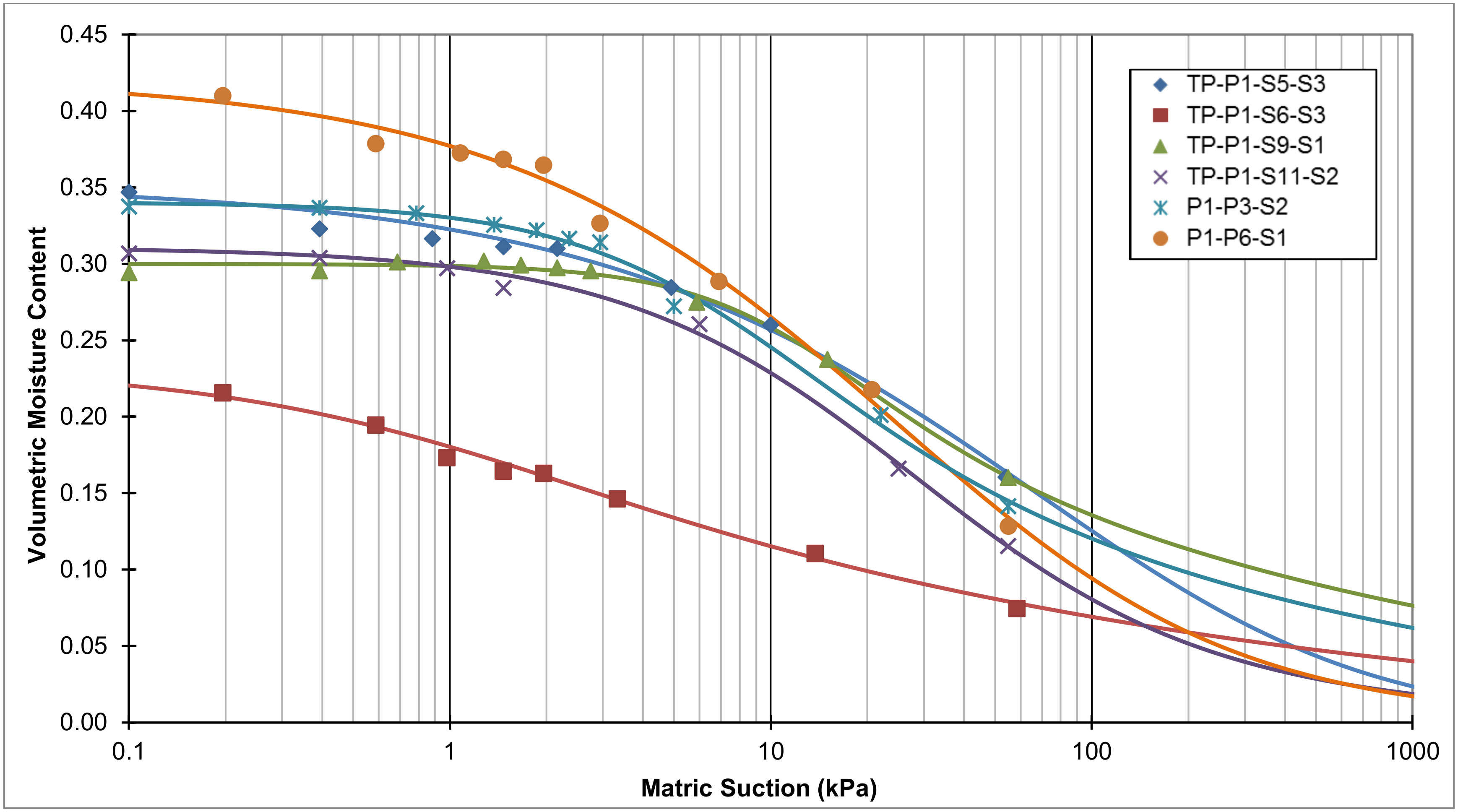


Figure 4.34 - Soil water characteristic curves for WRS 1 select samples with Fredlund and Xing (1994) curve fit

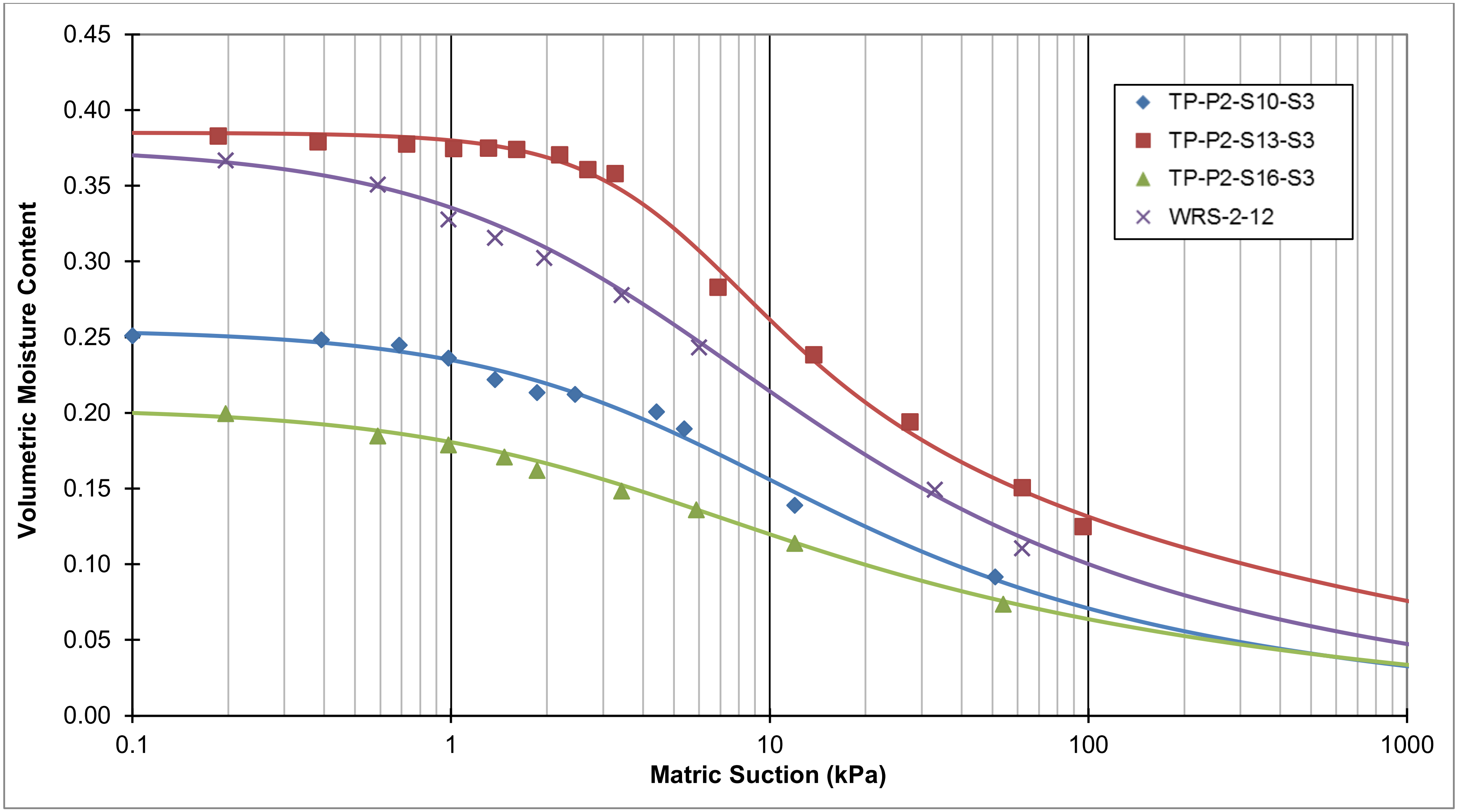


Figure 4.35 - Soil water characteristic curves for WRS 2 select samples with Fredlund and Xing (1994) curve fit

Table 4.9 - Air Entry Values and Residual Saturation values from Fredlund and Xing (1994) curve fitting to experimental data

Sample Type and Location	Sample Number	Air Entry Value (kPa)	Residual Saturation (vol. %)
WRS 1 and WRS 2 Cover	TP-P1-S4-S1	1.4	3.6
	TP-P1-S14-S1	2.3	17.0
	TP-P2-S11-S1	11.3	7.2
WRS 1 Waste Rock	TP-P1-S5-S3	2.8	5.5
	TP-P1-S6-S3	0.2	7.0
	TP-P1-S9-S1	5.4	12.0
	TP-P1-S11-S2	3.4	2.4
	P1-P3-S2	2.4	8.3
	P1-P6-S1	1.6	1.8
WRS 2 Waste Rock	TP-P2-S10-S3	1.2	5.5
	TP-P2-S13-S3	2.5	13.5
	TP-P2-S16-S3	0.8	5.2
	WRS-2-12	0.9	7.9

The SWCCs for the cover material typically have a wide range of AEVs due to the varying proportion of fines (silts and clays) and little gravel sized material. TP-P2-S11-S1 has greater than 50% passing the No. 4 sieve and the higher proportion of fine grained material results in a higher AEV. The residual degree of saturation ranged from 3.6 vol% to 17.0 vol%. The desaturation of the cover samples after reaching the air entry value is well-defined and the transition zones of the curves have a greater slope than the waste rock samples. Volume change within the samples was also larger than the waste rock samples, and water storage in the cover is higher than that for the waste rock materials.

In contrast, the transition zone of the waste rock SWCCs are very large and extend over a wide range of matric suctions with very small boundary effect zones. AEVs for WRS 1 samples ranged from 0.2 to 5.4, and the WRS 2 sample AEVs were also low, ranging from 0.8 kPa to 2.5 kPa (Table 4.9). The rock-like characteristics of the DLM waste rock piles illustrate that with small applied matric suction, near immediate drainage of the material occurs. The AEVs for the waste rock samples are lower than the *in situ* matric suction values measured using tensiometers during the test pit program, which fell within the range of 1 kPa to 53 kPa. Consequently, the *in situ* waste rock fines (<4.75 mm material) were typically unsaturated in the field. Residual volumetric saturation for the WRS 1 samples ranged from 1.8% to 12%, and for WRS 2, the samples ranged from 5.2% to 13.5%. For samples with higher residual volumetric water contents, including TP-P1-S9-S1 and TP-P2-S13-S3, the discrepancy may be related to the mineralogy. Both sample locations indicated the test pit contained the Talc Chloride/Chloritic Greenstone lithology. Detailed correlation of mineralogy with each of the SWCC was not completed, however in future may provide greater insight into the water retention behaviour of different lithologies found at DLM.

The volumetric SWCCs illustrate two groups of curves that are distinguished by their saturated volumetric water content. The first group of curves encompasses the majority of the samples tested, with saturated volumetric water contents of 30% to 40% and a smaller and higher sloped transition zone of the curve. The second group of curves contains three samples (TP-P1-S6-S3, TP-P2-S10-S3, and TP-P2-S16-S3) with saturated volumetric water contents of 20% to 25% with low AEVs and wider transition zones. These differences in curve shape do not have any apparent correlation to other measured properties such as grain size distribution, paste pH or material type.

SWCC plots of the gravimetric water content and matric suction were also generated to correlate with *in situ* values of matric suction and gravimetric moisture content presented in Figure 4.11. The SWCC plots are overlaid with the field results for the cover material and waste rock in Figure 4.36 and Figure 4.37.

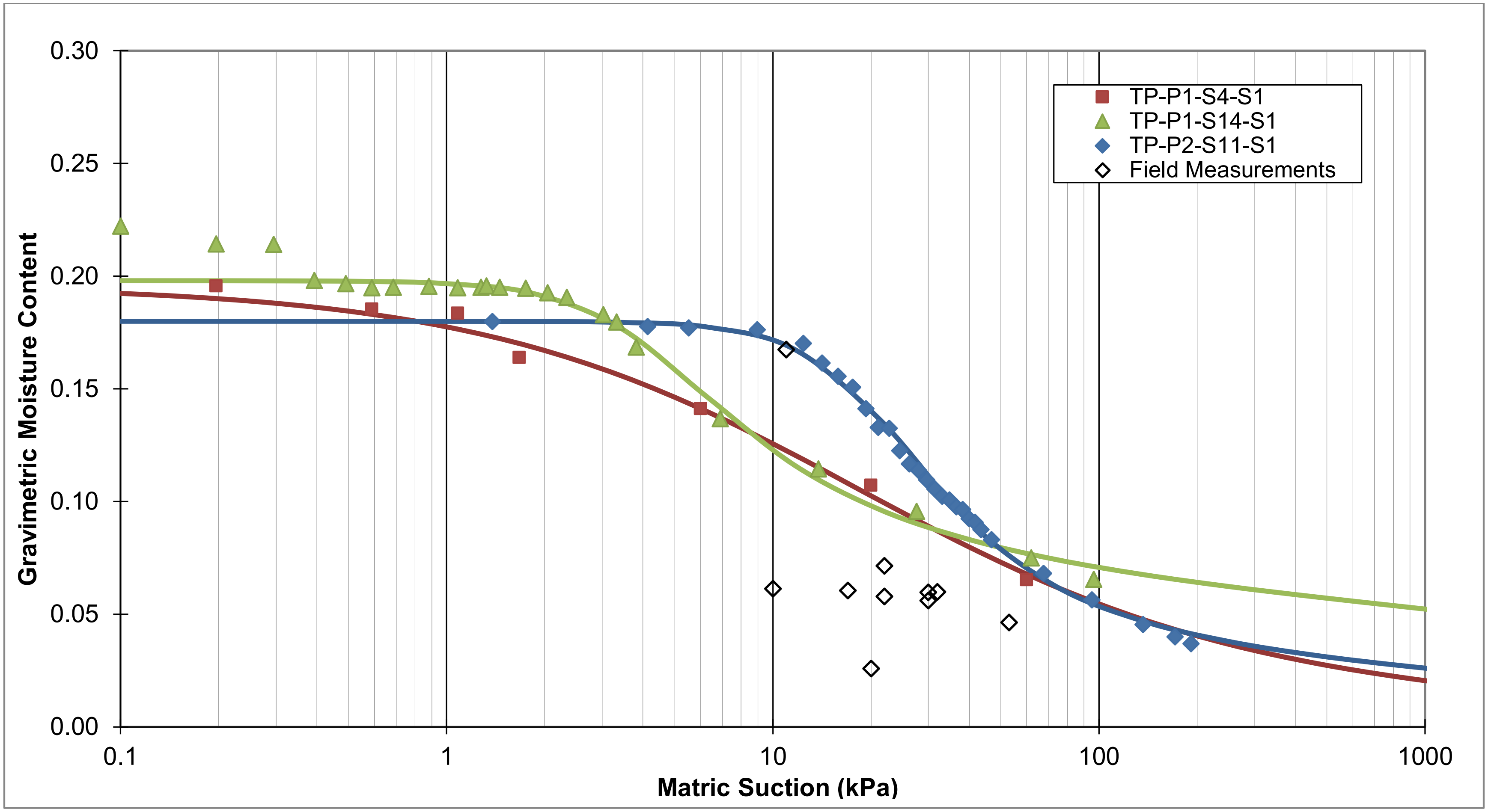


Figure 4.36 - Soil water characteristic curves of gravimetric water content and suction with field measurements for cover samples

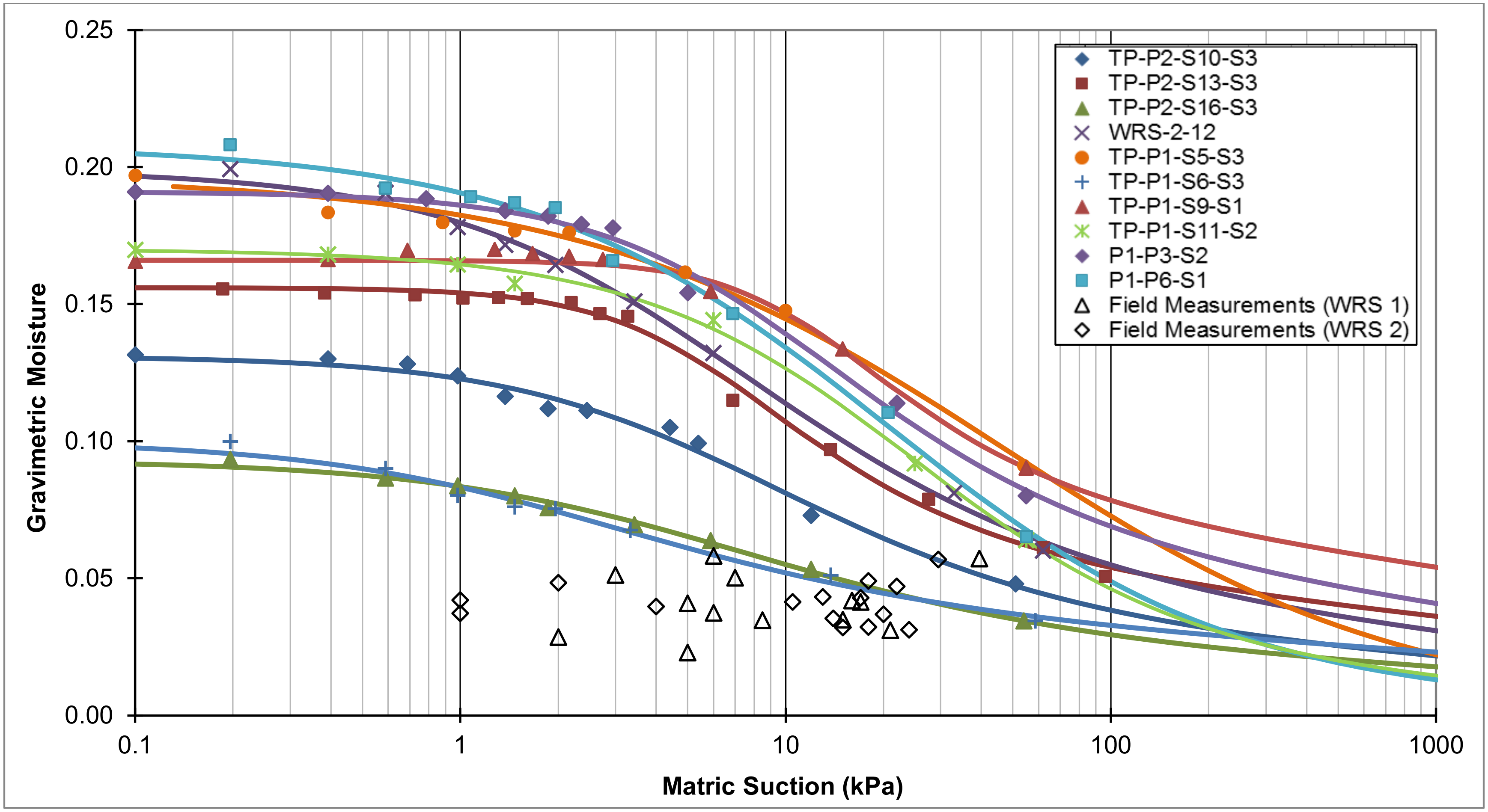


Figure 4.37 - Soil water characteristic curves of gravimetric water content and suction with field measurements for waste rock samples

Curve fits were generated with SoilCover software (Geo-Analysis 2000 Ltd., 1998). For the *in situ* field data, the gravimetric moisture content at a given suction is lower than gravimetric moisture contents of the SWCCs with the same range of suctions. The discrepancy in these data is likely related to the coarser particles (>4.75 mm) that surrounded the ceramic cup during measurements of matric suction. Tensiometers were preferentially placed in areas of test pits containing fines to assist in defining the range of matric suction within the fine fraction; however, particles larger than 4.75 mm were present in the measurement locations. The coarser waste rock fragments would not have the capacity to hold water, and the inclusion of larger particles in the matrix affects the porosity of the soil (Yazdani et al., 2000). As a result, the inclusion of larger particles in the matrix during measurement decreases the porosity and also decreases the gravimetric water content. Therefore, gravimetric moisture contents determined from the field investigation cannot be used to validate the SWCCs, however the matric suction value range can be used to determine a range of gravimetric and volumetric water contents that would be expected *in situ*.

Chapter 5.0 Large Scale Grain Size and Water Flux Predictions Using Digital Image Processing

5.1 Introduction

Due to the limit on particle size that can be practically sampled during field investigations, the upper particle size range of waste rock material is not often fully characterized. Digital image processing (DIP) techniques utilizing images of rock material are used in the mining industry to primarily for analysis of grain size of blasted material. DIP techniques have more recently been applied in determining the grain size distribution of *in situ* waste rock (Chi, 2010).

The following chapter presents the grain size analysis results of DIP analysis of waste rock material from images taken during the field campaigns of this study. In addition to grain size analysis, particle volumes, porosity, and volumetric water content relationships are explored to investigate overall water content in the unsaturated waste rock medium. Due to the unsaturated nature of waste rock, water flow dominates in matric material where water is retained under applied matric suctions. Porosity and water content provide valuable insight into the volume of water in the matric material and consequently the available water that can flow in waste rock. These parameters are valuable, as water flow within waste rock is the primary pathway where dissolved constituents such as metals and low pH drainage are transmitted. When coupled with geochemical data, water flux can assist in determining contaminant loadings to the environment, and therefore assist in the prediction of ARD.

5.2 Methodology for DIP Analyses

Photographs from the ten waste rock select samples outlined in Section 4.4 were analyzed using Split Desktop software (Split Engineering LLC, 2011a). The reference scale in each photograph was manually set using a reference stake or reference square that was placed in the photographed area during the field study. Common distortion problems, including trapezoidal distortion due to sloping of piles (Kong, 2013), were not encountered as photographs were taken in close proximity to the sample area and distortion effects were not significant. Images were selected with the best possible exposure and lighting conditions, however some areas of shadow and over exposure were encountered due to weather conditions and the sun location during sampling.

Photographs from the test pit study were taken of the *in situ* test pit walls or benches at a specific sample location. For the profile investigation samples, photographs were taken of the material excavated by the front end loader after it was placed on the ground. Due to the instability of the excavated face on WRS 1, direct photos of the stockpile face could not be taken as access to the face was restricted due to safety concerns.

The ten images selected were imported to Split Desktop. The image scale was set in the software using the reference stake or square within the image. Auto delineation was applied to each image and delineation improvements were completed by hand with manual edits. Manual edits corrected incorrect particle boundaries, identified open void spaces and areas of fines where no individual particles were visible. Areas of sloughed material and areas that could not be accurately delineated due to overexposure or shadow were masked and not included in the outputted grain size distribution. Figure 5.1 and 5.2 present an example image before and after particle delineation. The particle delineations for each of the ten analyses are presented in Appendix C.

Figure 5.1- Photo of sampling location TP-P1-S6-S3 using in DIP analysis prior to delineations with orange reference stake indicating 1 m

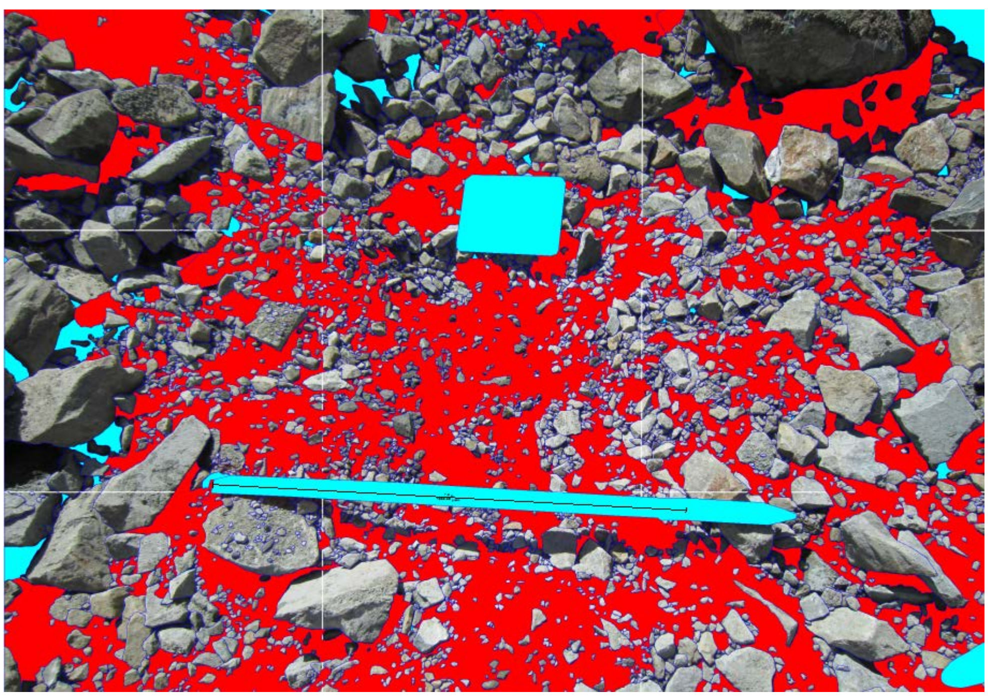


Figure 5.2 - Photo of sampling location TP-P1-S6-S3 after delineation of particles. Dark blue lines outline individual particles, light blue shaded areas indicate masked areas not included in the analysis and red shaded areas indicate areas of fines

The estimation of the delineated fragments is determined from the major and minor axis of particles that have been outlined in the image. A best fit ellipse is determined for each particle with an equivalent area. Additional compensation is made for particles that may be overlapping or only one axis of the particle is visible in the photograph (Kemeny, Girdner, BoBo, & Norton, 1999). Estimation of fines within the photograph utilizes the quantity of black pixels within an image as well as the size of the smallest delineated particle. A histogram of different particle sizes is plotted to determine a fines cut-off size that is located at 75% of the peak of the histogram (Kemeny et al., 1999). The fines cut-off value is related to the pixel size of the photograph, as larger pixels will limit the minimum detectable particle size (Split Engineering LLC., 2011b). After the fines cut-off particle size is determined, a calculation of the volume of material less than this size is completed. The volume of fines as a percentage of the total particle volume in the image is then utilized in the calculation of the fines distribution.

The distribution of fines is generated using two methods, a Schuhmann or a Rosin-Rammler distribution. In various studies, the Schuhmann distribution typically provides an accurate description of the fines content within 10% (Kemeny et al., 1999). The fines distribution can be correlated or adjusted through the 'fines factor' parameter that is a percentage between zero and 200. The fines factor can affect the outputted grain size distribution and was determined for each image through comparison with the sieve results (Split Engineering LLC., 2011b). The fines factor was selected such that the DIP curve had a similar fines distribution to the measured sample and follows a similar curve shape.

Sieve sizes used in the DIP analysis matched those used in the laboratory up to the 76.2 mm (3 inch) size. Standard sieve sizes greater than 75 mm were not found in the available literature, and consequently, sieve sizes were assumed to increase incrementally by 25.4 mm (1 inch). The largest sieve size was a maximum of 482.6 mm (19 inches).

5.3 DIP Grain Size Analysis Results and Discussion

Results from the DIP grain size analysis were completed for the ten select samples and distributions were compared to curves from the laboratory analysis. The full photographs from each location as well as the photographs after delineation are provided in Appendix C. The DIP results and sieve results for each of the ten images are presented for WRS 1 in Figure 5.3 and for WRS 2 in Figure 5.4. The fines factors determined through correlation of DIP data with measured data are listed in Table 5.1.

The DIP analysis increased the detected particle size from 76 mm in the laboratory analysis up to a maximum of 482.6 mm. The curves measured in the laboratory are poorly graded in the particle size range of the 50.8 mm and 76.2 mm sieve range, which indicates the 20-L pail samples were not large enough to representatively sample these particle sizes. The DIP curve results provide a better evaluation of these larger particle sizes.

Table 5.1- Fines factors selected in Split Desktop for DIP analysis

Sample Name	Sample Number	Fines Factor (%)
WRS 1 Waste Rock	TP-P1-S5-S3	20
	TP-P1-S6-S3	10
	TP-P1-S9-S1	20
	TP-P1-S11-S2	80
	P1-P3-S2	20
	P1-P6-S1	10
WRS 2 Waste Rock	TP-P2-S10-S3	80
	TP-P2-S13-S3	80
	TP-P2-S16-S3	50
	WRS-2-12	50

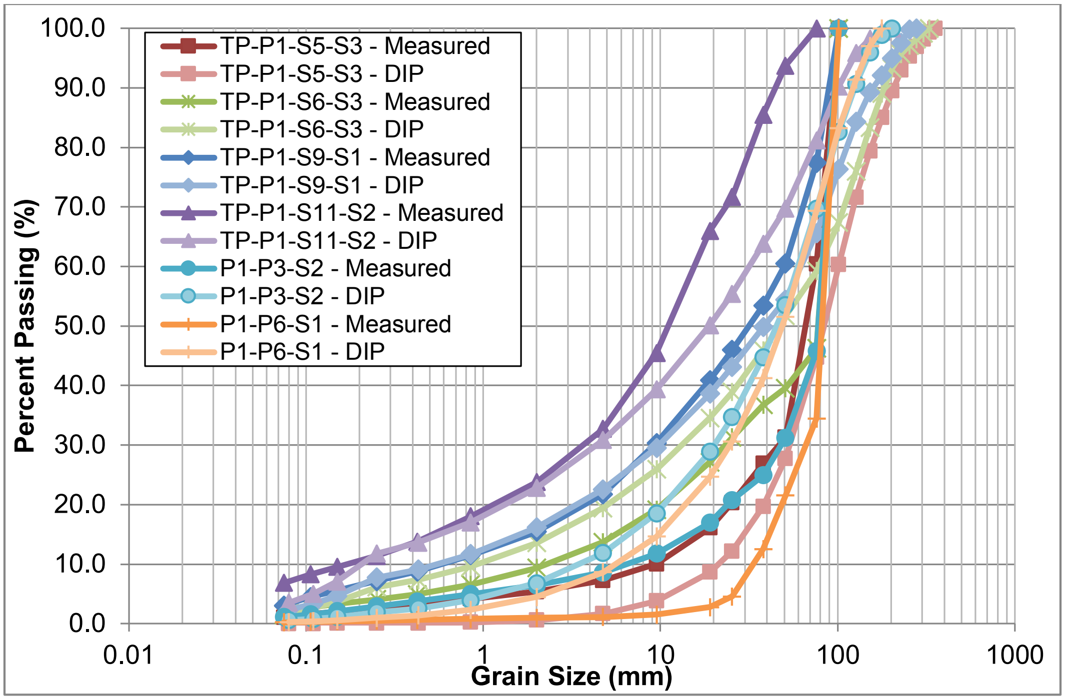


Figure 5.3- Laboratory and digital image processing curves from Split Desktop for select samples from WRS 1. Note 'Measured' indicates the sieve results and 'DIP' indicates Split Desktop results.

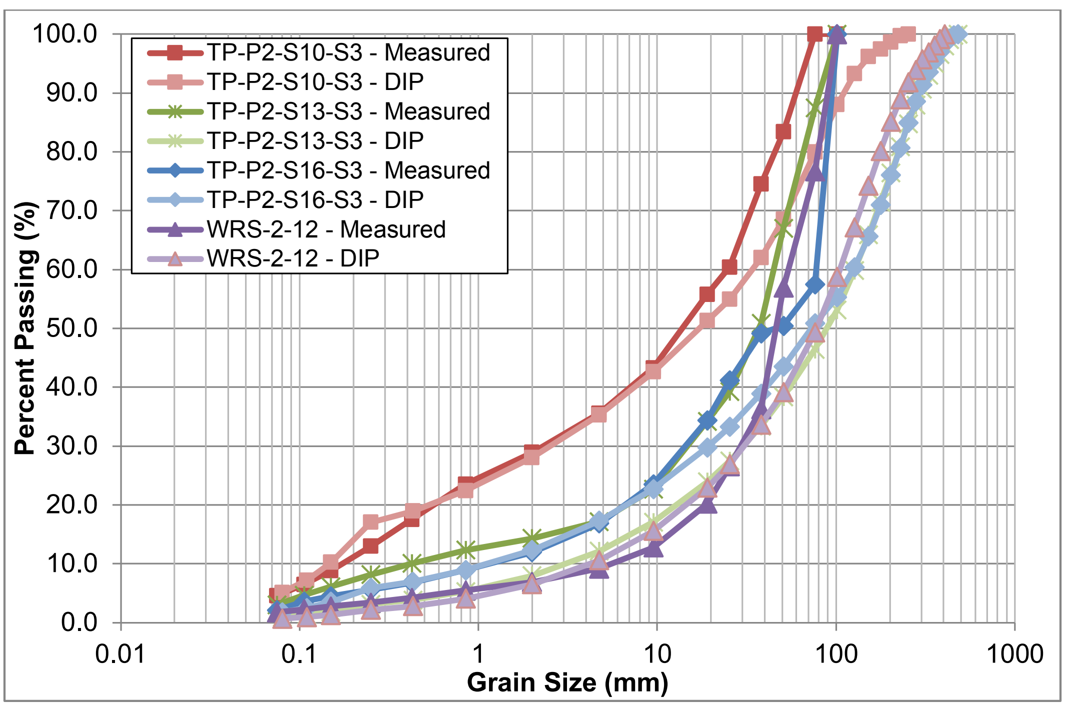


Figure 5.4 - Laboratory and digital image processing curves from Split Desktop for select samples from WRS 2. Note 'Measured' indicates the sieve results and 'DIP' indicates Split Desktop results.

The fines factor had an important role in correlation of the DIP analysis to the measured results. Samples TP-P1-S9-S1, TP-P1-S11-S2, TP-P2-S10-S3, TP-P2-S16-S3, and WRS-2-12 showed excellent correlation of the measured and DIP curves.

The remaining curves, TP-P1-S5-S3, TP-P1-S6-S3, P1-P3-S2, P1-P6-S1, and TP-P2-S13-S3 had similar shaped grain size distributions from the DIP analysis in comparison to the measured curve; however the correlation was not as close. Four possible reasons for these discrepancies were noted:

1. As the proportion of fines within a sample decreased, it was more difficult to apply an appropriate fines factor parameter. Samples P1-P3-S2 and P1-P6-S1 are coarser samples taken from the profile sampling campaign from coarse areas of the pile. The corresponding DIP curves for these two samples generate a fines profile that has a more gradual gradational change in comparison to the measured curve. It is important to note that the fine fraction in the DIP analyses were estimated through use of a particle distribution function related to the photo resolution. The method of fines estimation may account for the discrepancies noted in these images. Low fines factors were selected for these samples, however, the proportion of fines may be overestimated if the sample is taken from a rubble zone with open voids where the amount of fines is typically low.

2. The maximum particle size from the DIP analysis is much larger than that of the laboratory analysis. The proportionally larger weight of large diameter particles results in a shift in the grain size curve when compared to the laboratory analysis. The shape of the grain size curves is similar, but the DIP analysis curve is shifted to the right. Samples on WRS 2 were well graded and generally

showed a reasonable correlation between measured sieve data and photo grain size results. Sample TP-P2-S13-S3 had a higher proportion of fines in the measured analysis in comparison to the DIP results, and a higher fines factor was selected. This divergence is attributed to the significant range in grain size at this location, where particles up to 482.6 mm were identified. These particles have a large mass and consequently reduce the overall fines proportion within the sample.

3. Unrepresentative sampling in the field or extreme heterogeneity in the sampling area may result in differences between the measured and DIP grain size curve.

4. The Split Desktop software has difficulty delineating images with large areas of fines (Kemeny et al., 1999). Caution should be used when applying this method of analysis to areas where significant rock degradation has occurred.

In general, the DIP was most successful for samples with a well graded grain size distribution. Images of *in situ* slope faces or test pit walls provided a better representation of the true grain size range. Similar to the physical sample collection, no samples collected during the study had greater than 40% passing the No. 4 sieve. This supports the results presented in Chapter 4 that the waste rock piles behave as a rock-like material and have a clast supported structure. Images also identified open void space that will be analyzed in following sections. Finally, although the DIP images presented in Figure 5.3 and Figure 5.4 increased the range of particle sizes measured, the photograph scale is not sufficient to capture the total range of particles within the stockpiles. In future investigations, larger exposed faces may be required to assess the scale required to obtain a representative area to capture the full grain size range.

5.3.1 Composite Grain Size Analysis Results and Discussion

Results from the DIP analyses were combined with the results of the measured grain size analysis curves, similar to Chi (2010). The resulting grain size distribution utilizes data from the fines measured in the laboratory and includes the coarse fraction generated from the DIP analysis. The curves were combined through utilizing the image analysis percent passing values for particle sizes greater than 76.2 mm, or the largest particle size measured in the laboratory (i.e. all laboratory specimen particles had 100% passing 101.6 mm sieve size). To modify the percent passing values from the measured data, a simulated sample weight was calculate that would represent the equivalent sample volume needed to generate the grain size curve from the digital image analysis. The weight of the sample used in the laboratory test was increased by multiplying by the percent passing of the 101.6 mm sieve from the digital image processing. Using the simulated sample weight, the percent passing values from the laboratory sieve analysis were recalculated and integrated with the DIP results. A sample calculation is provided in Appendix C.

Figure 5.5 and Figure 5.6 present the combine curves with the digital image analysis curve for comparison. The distribution of fines decreases with the composite curve, although the shapes of the curves are consistent. The results identify that the assumed distribution of fines generated in the digital image analysis is different from the tail of fines distributions typically observed in the waste rock samples collected during the field program.

As previously discussed, the physical samples were poorly graded in the size range of the 50.8 mm and 76.2 mm. The unrepresentative volume of particles in these size ranges resulted in inconsistencies when combining the particle size data, particularly in sample TP-P2-S16-S3.

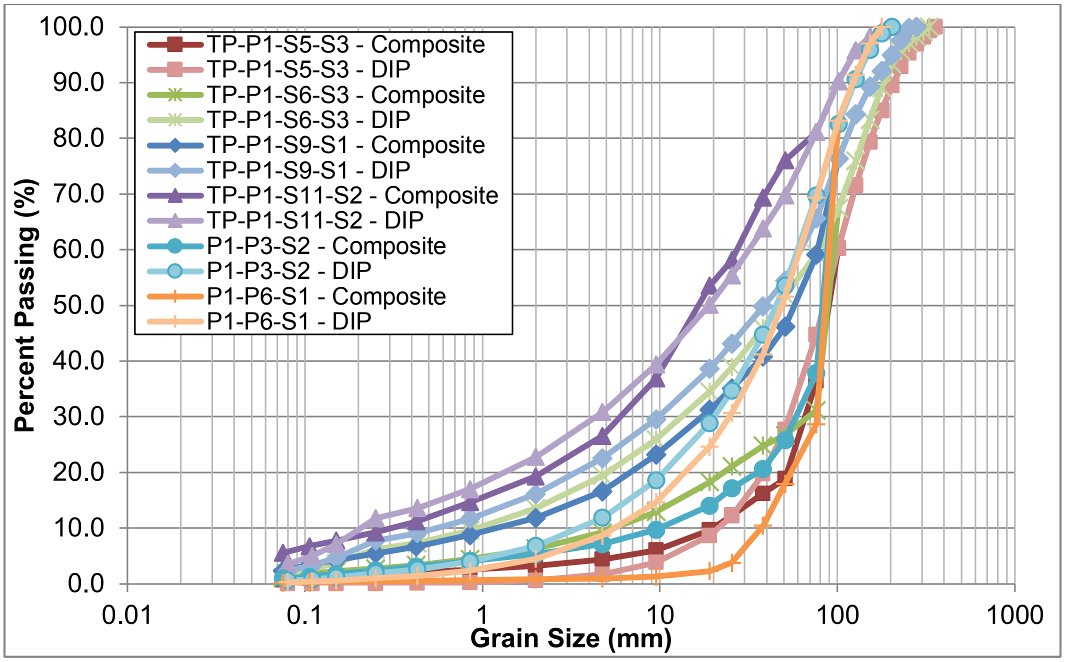


Figure 5.5 - Digital image processing curves from Split Desktop and combine curves using sieve and image data for select samples from WRS 1. 'Composite' indicates the combine sieve results and digital image data and DIP indicates results from image analysis.

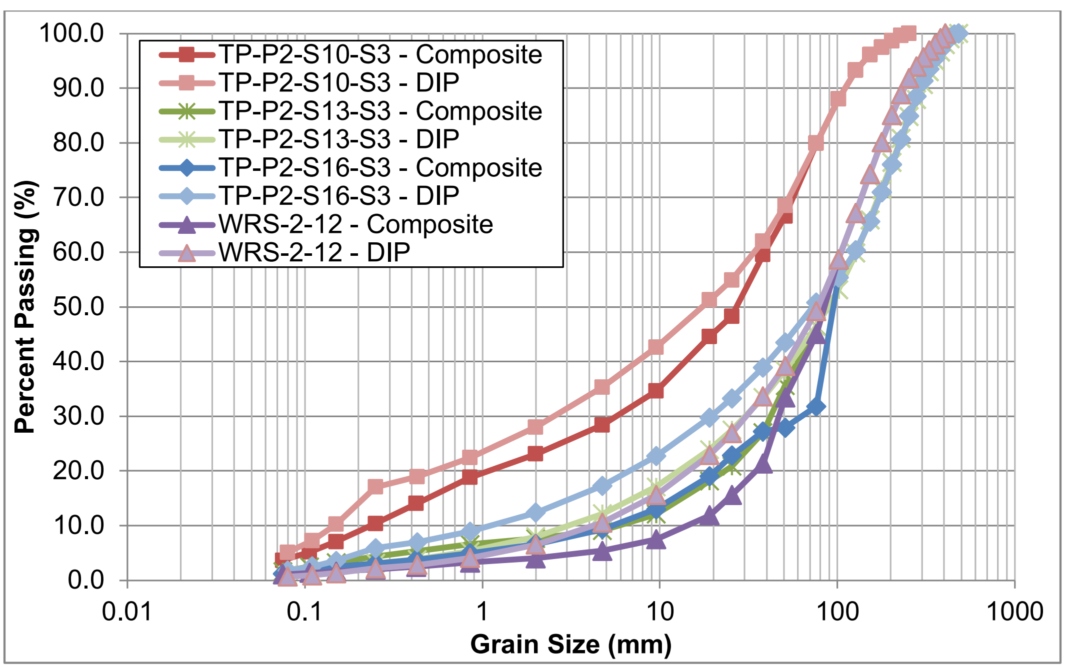


Figure 5.6 - Digital image processing curves from Split Desktop and combine curves using sieve and image data for select samples from WRS 2. 'Composite' indicates the combine sieve results and digital image data and DIP indicates results from image analysis.

The coefficient of uniformity (C_u) and coefficient of gradation (C_c) were calculated for the digital image output curves. All C_u values are greater than four, and the C_c values are between one and three, indicating well graded gravel (Table 5.2).

Table 5.2 - Coefficient of Uniformity and Coefficient of Gradation for digital image processing grain size curves

Sample Number	Coefficient of Uniformity (C_u)	Coefficient of Gradation (C_c)
TP-P1-S5-S3	4.70	1.37
TP-P1-S6-S3	82.87	2.45
TP-P1-S9-S1	116.45	2.78
TP-P1-S11-S2	152.19	2.88
P1-P3-S2	16.56	1.86
P1-P6-S1	10.77	1.86
TP-P2-S10-S3	229.80	1.30
TP-P2-S13-S3	40.17	2.29
TP-P2-S16-S3	108.03	2.60
WRS-2-12	24.47	2.12

5.3.2 Section Analysis Results and Discussion

Each of the ten images was divided into sections to determine the range of grain size distributions within a given photograph. Figure 5.7 provides a typical example of how photographs were subdivided. Numbers 1 through 9 indicate nine rectangular subareas of each image. Numbers 10 through 13 indicate the group of four rectangular areas that were analyzed together, for example, Section 10 includes subareas 1, 2, 4, and 5. Subdividing the photograph was used to investigate the range of grain sizes that could be found within a given area as well as the influence of the image area used in the digital image processing process. For each grain size curve generated, the fines factor must be kept consistent to allow comparison between outputted distributions.

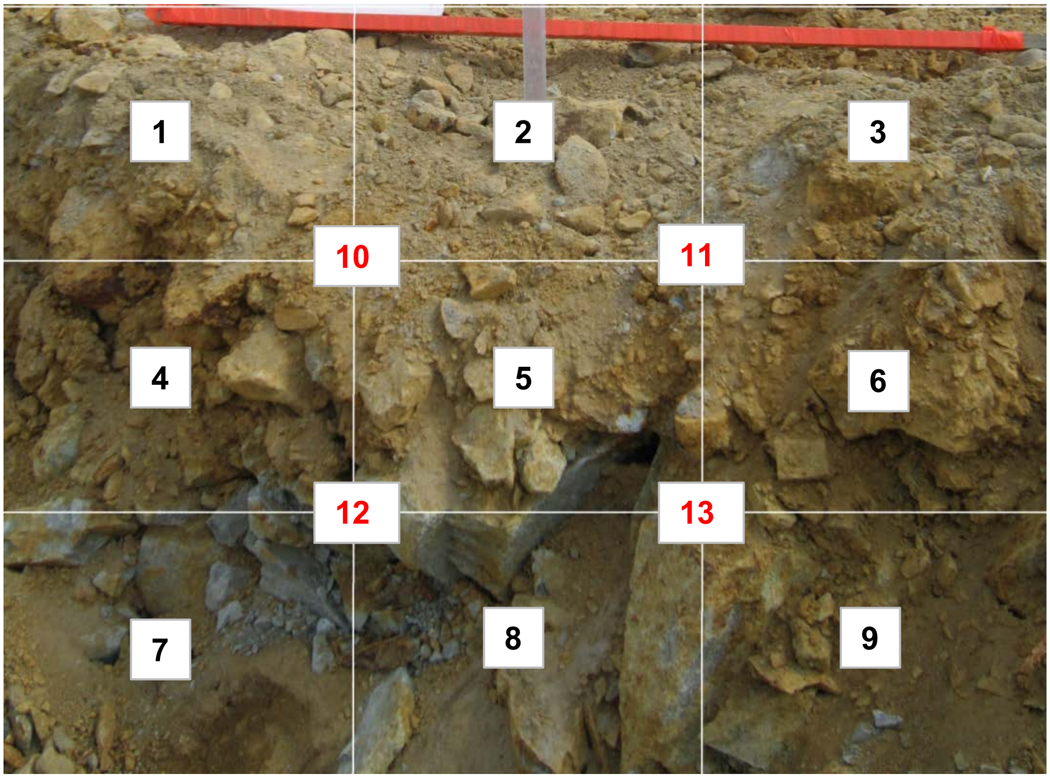


Figure 5.7 - Image of sample location TP-P1-S9-S1. Numbers indicate sections of the photograph that were analyzed individually.

Plots of the grain size distributions of individual rectangular sections, one through nine, are presented together with the grain size distribution from laboratory testing and the DIP grain size distribution from the full image area. A second plot of sections 10 through 13 are presented on a second plot. This procedure was repeated for each of the ten sample locations. Image P1-P3-S2 had a total of nine sections, and WRS-2-12 had a total of eight, due to areas of the photograph that were masked. The results are presented in Figure 5.8 through Figure 5.26.

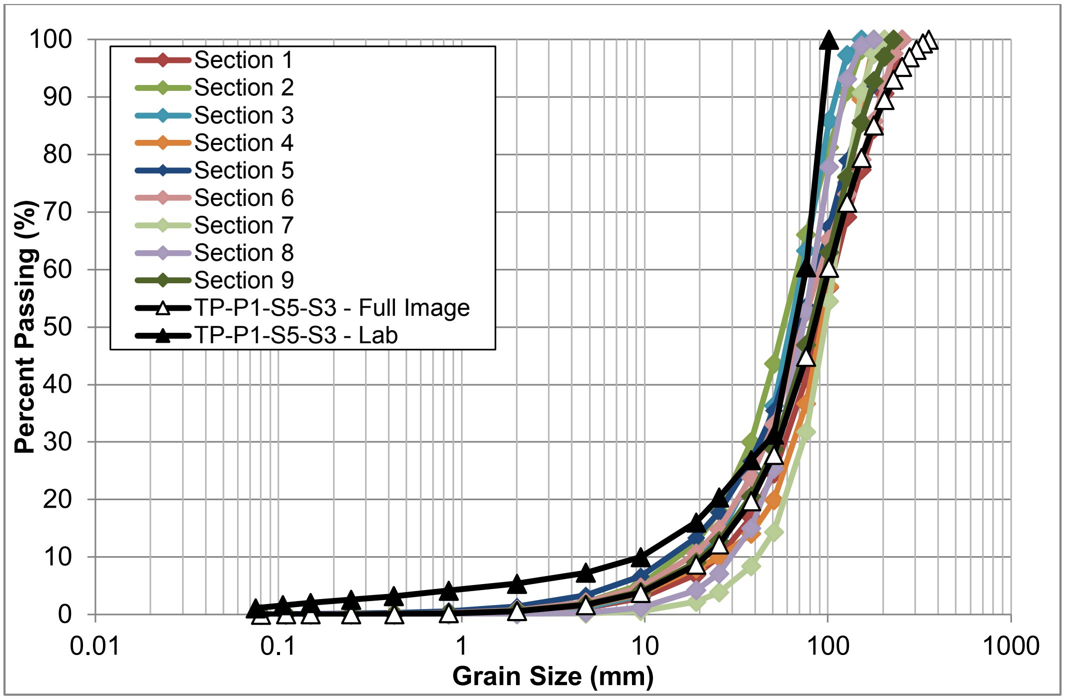


Figure 5.8 – Digital image processing grain size curves for TP-P1-S5-S3 Sections 1 through 9 with laboratory data and full image results.

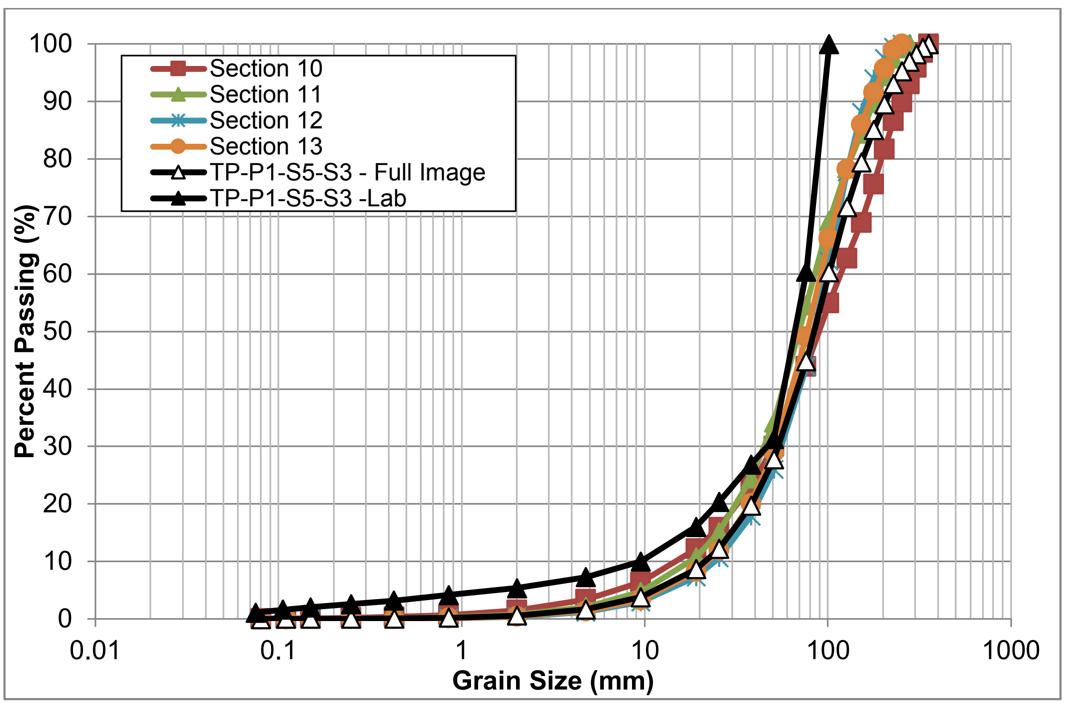


Figure 5.9 - Digital image processing grain size curves for TP-P1-S5-S3 Sections 10 through 13 with laboratory data and full image results.

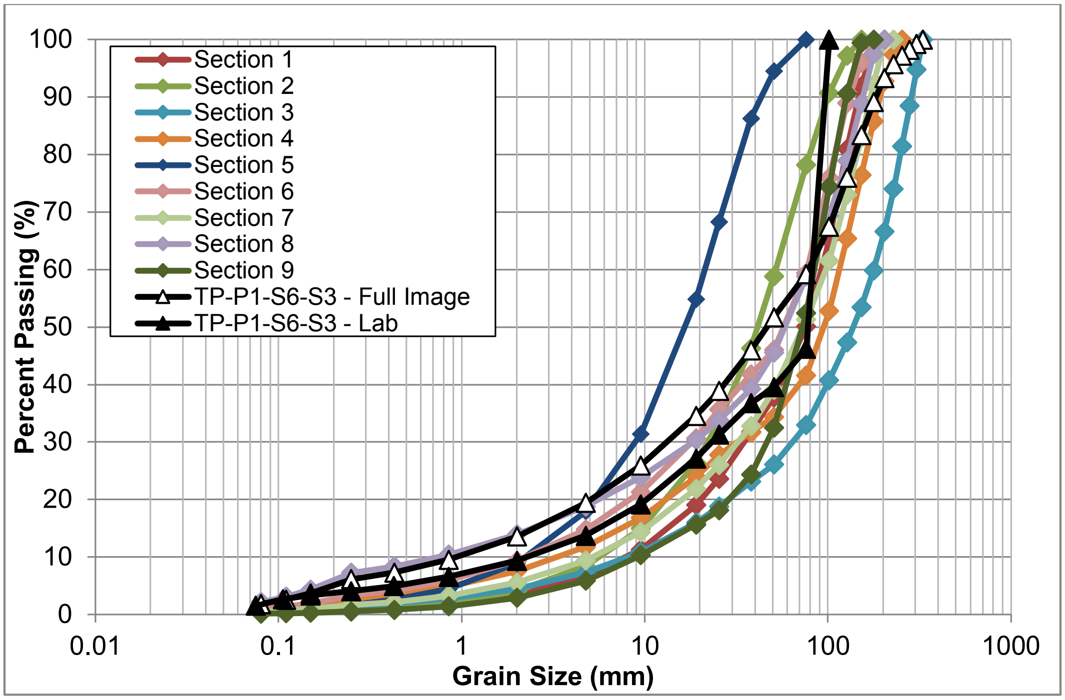


Figure 5.10 - Digital image processing grain size curves for TP-P1-S6-S3 Sections 1 through 9 with laboratory data and full image results.

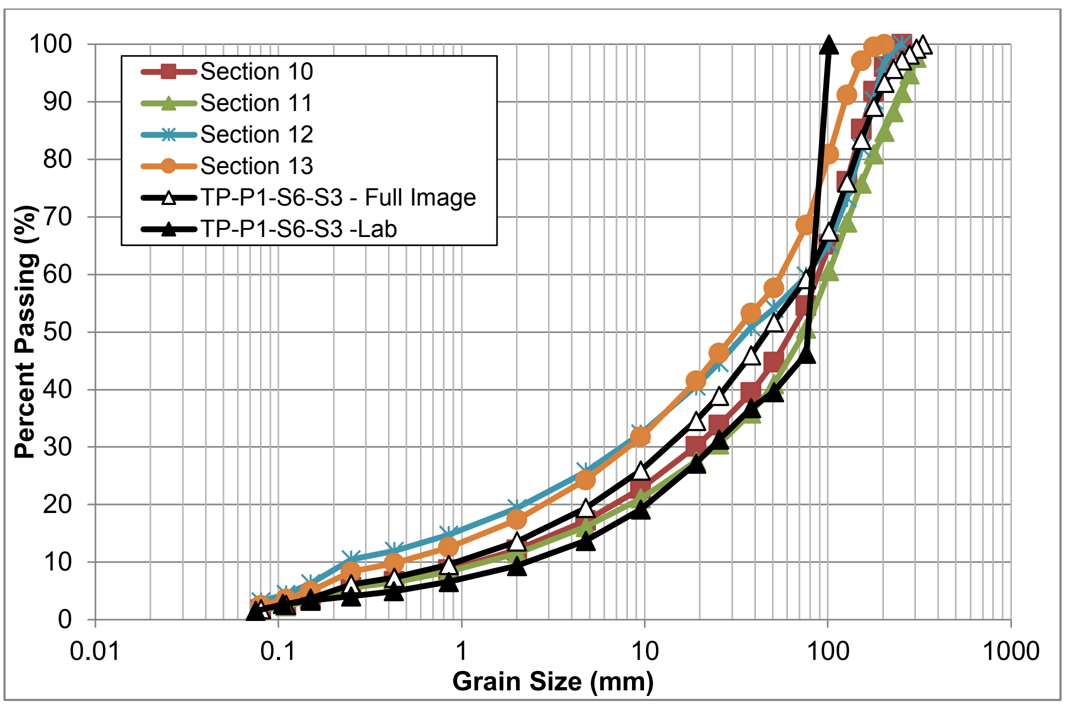


Figure 5.11 - Digital image processing grain size curves for TP-P1-S6-S3 Sections 10 through 13 with laboratory data and full image results.

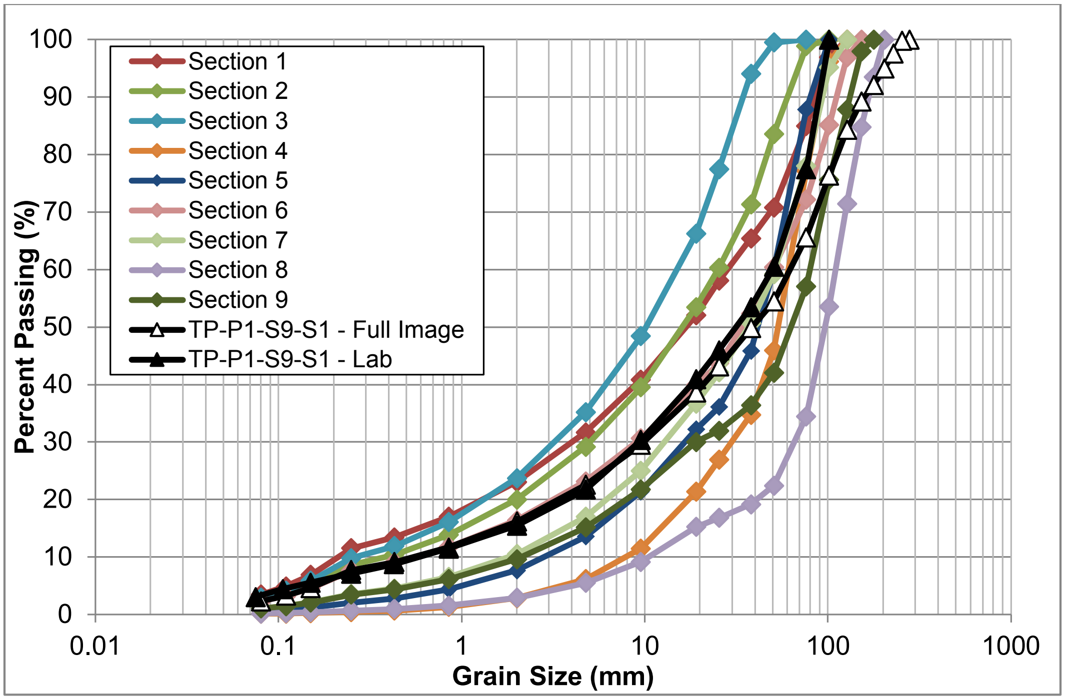


Figure 5.12 - Digital image processing grain size curves for TP-P1-S9-S1 Sections 19 through 9 with laboratory data and full image results.

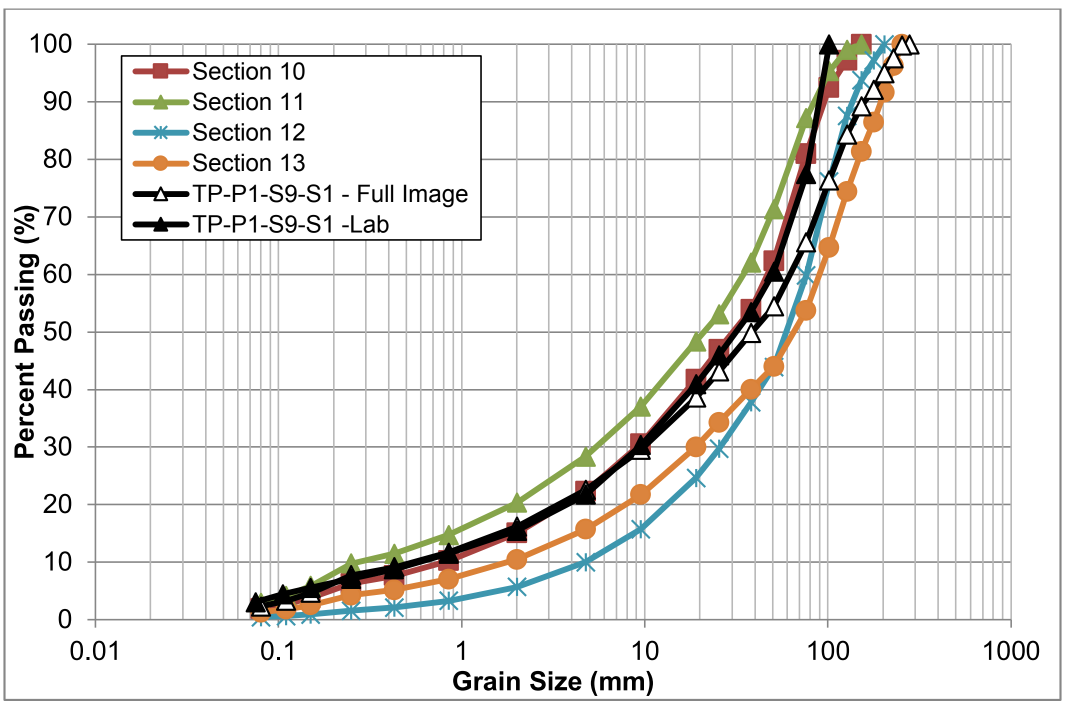


Figure 5.13 - Digital image processing grain size curves for TP-P1-S9-S1 Sections 10 through 13 with laboratory data and full image results.

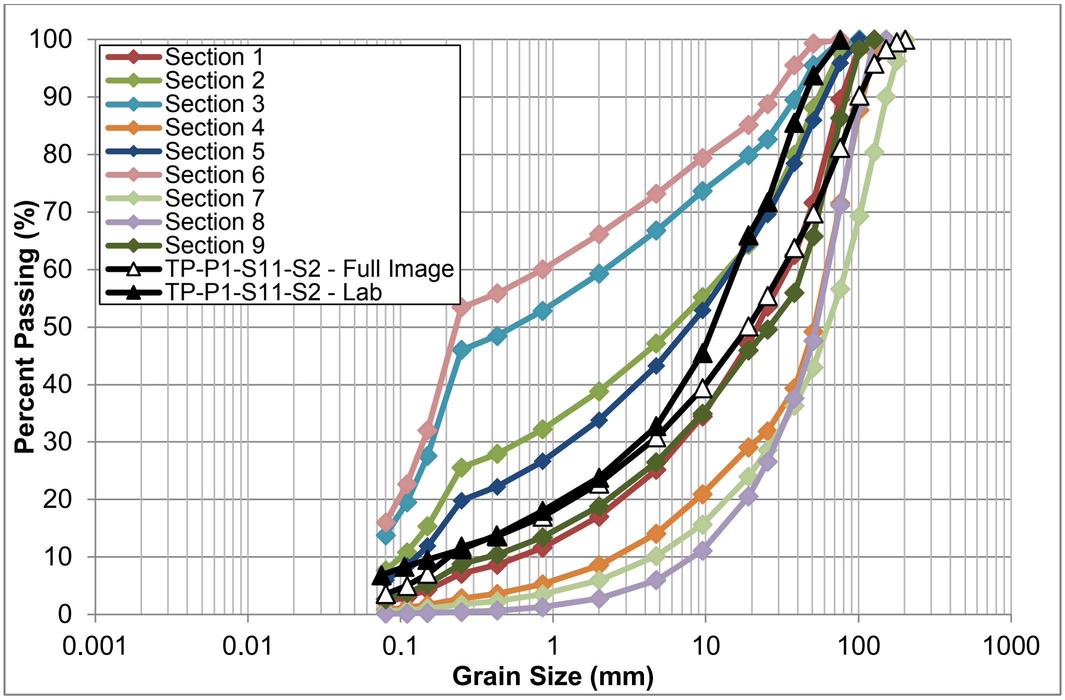


Figure 5.14 - Digital image processing grain size curves for TP-P1-S11-S1 Sections 1 through 9 with laboratory data and full image results.

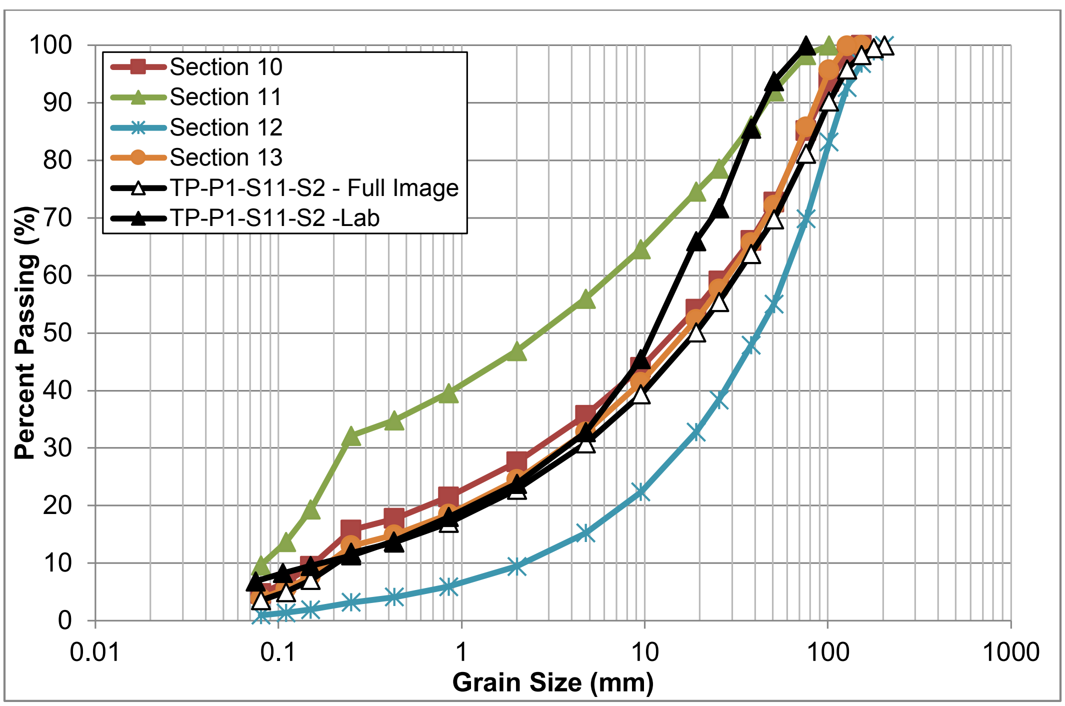


Figure 5.15 - Digital image processing grain size curves for TP-P1-S11-S2 Sections 10 through 13 with laboratory data and full image results.

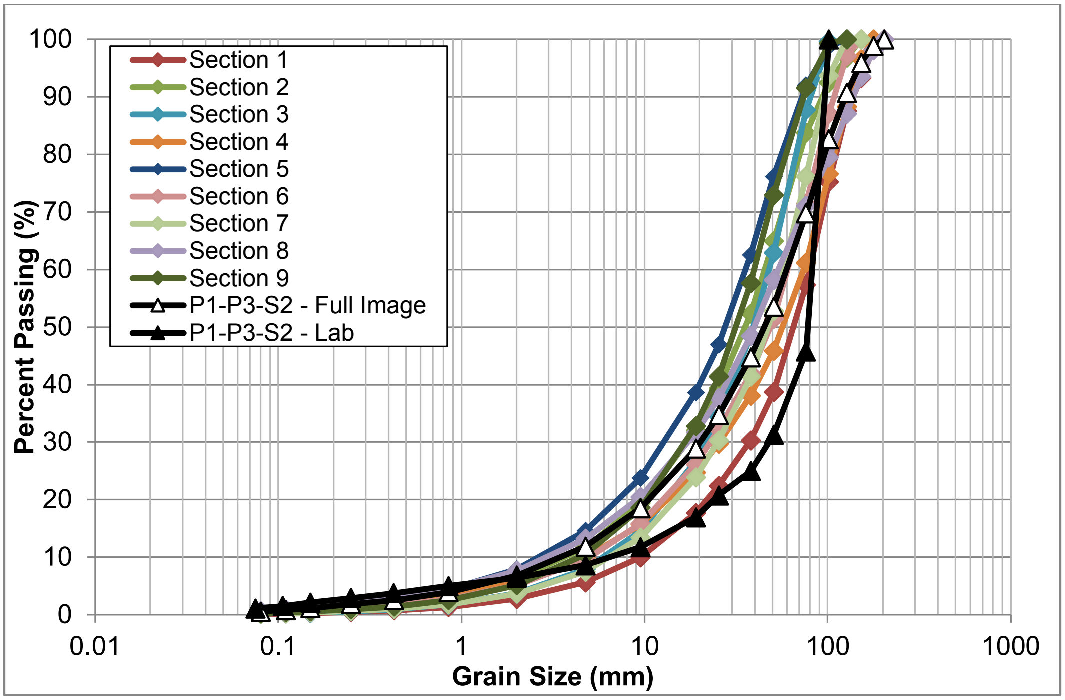


Figure 5.16 - Digital image processing grain size curves for P1-P3-S2 Sections 1 through 9 with laboratory data and full image results.

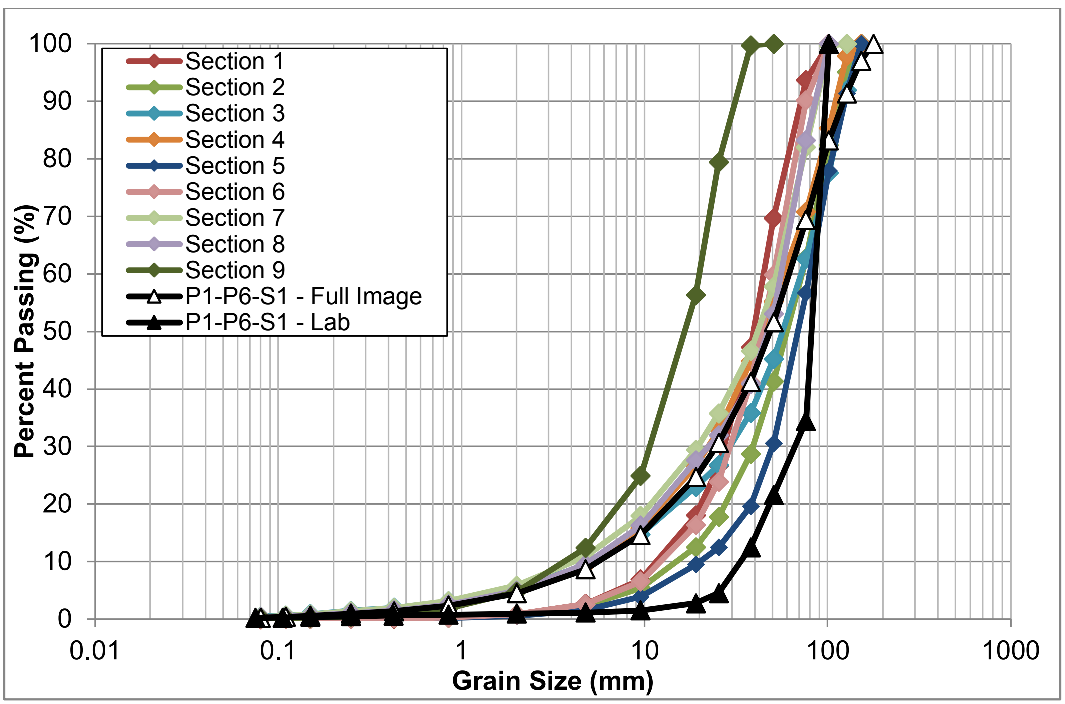


Figure 5.17 - Digital image processing grain size curves for P1-P6-S1 Sections 1 through 9 with laboratory data and full image results.

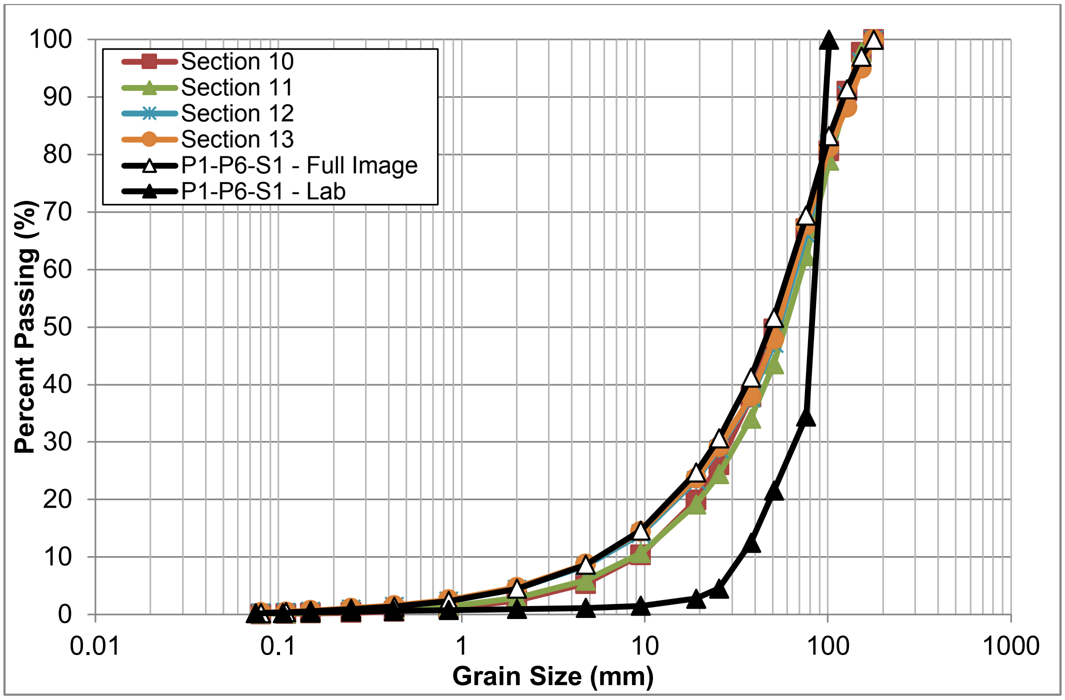


Figure 5.18 - Digital image processing grain size curves for P1-P6-S1 Sections 10 through 13 with laboratory data and full image results.

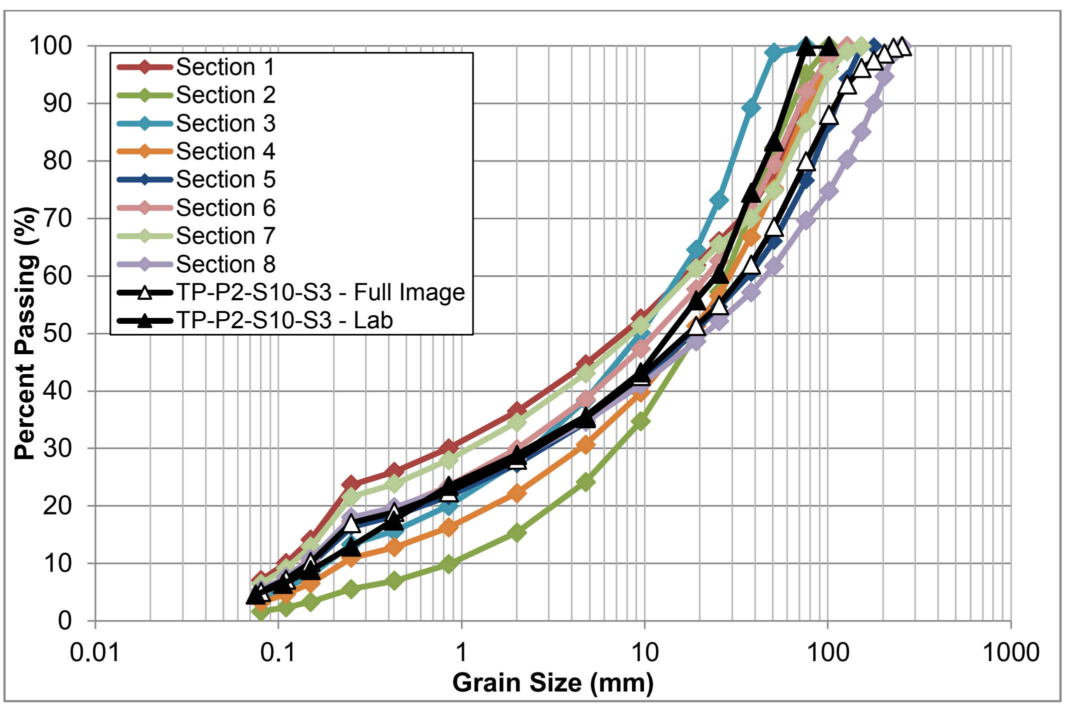


Figure 5.19 - Digital image processing grain size curves for TP-P2-S10-S3 Sections 1 through 8 with laboratory data and full image results.

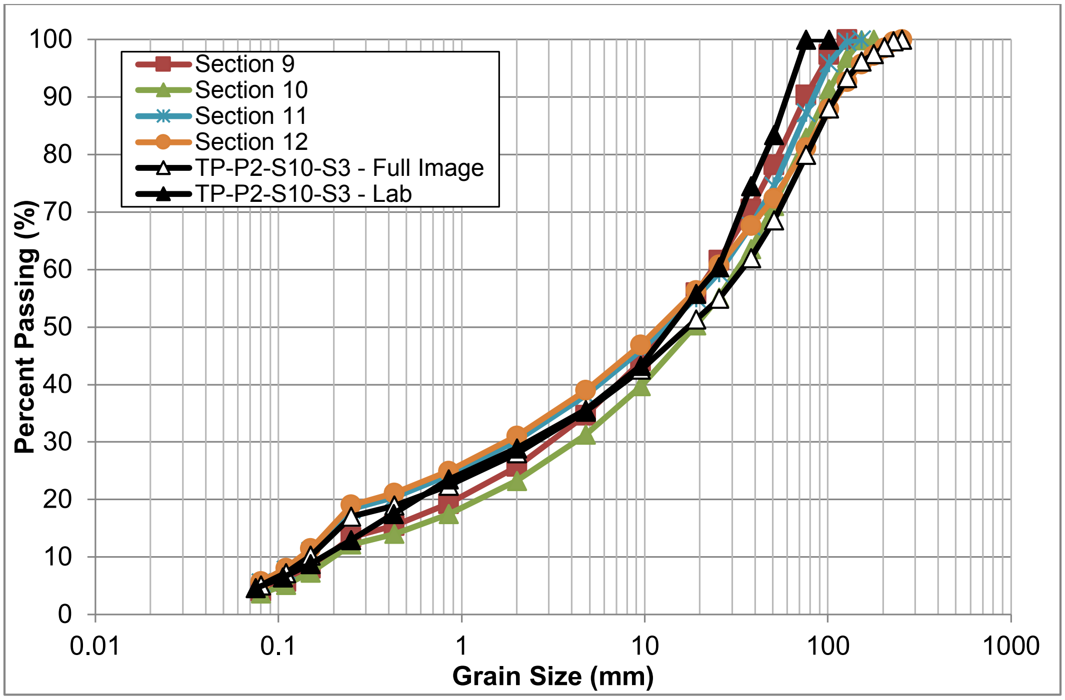


Figure 5.20 - Digital image processing grain size curves for TP-P2-S10-S3 Sections 9 through 12 with laboratory data and full image results.

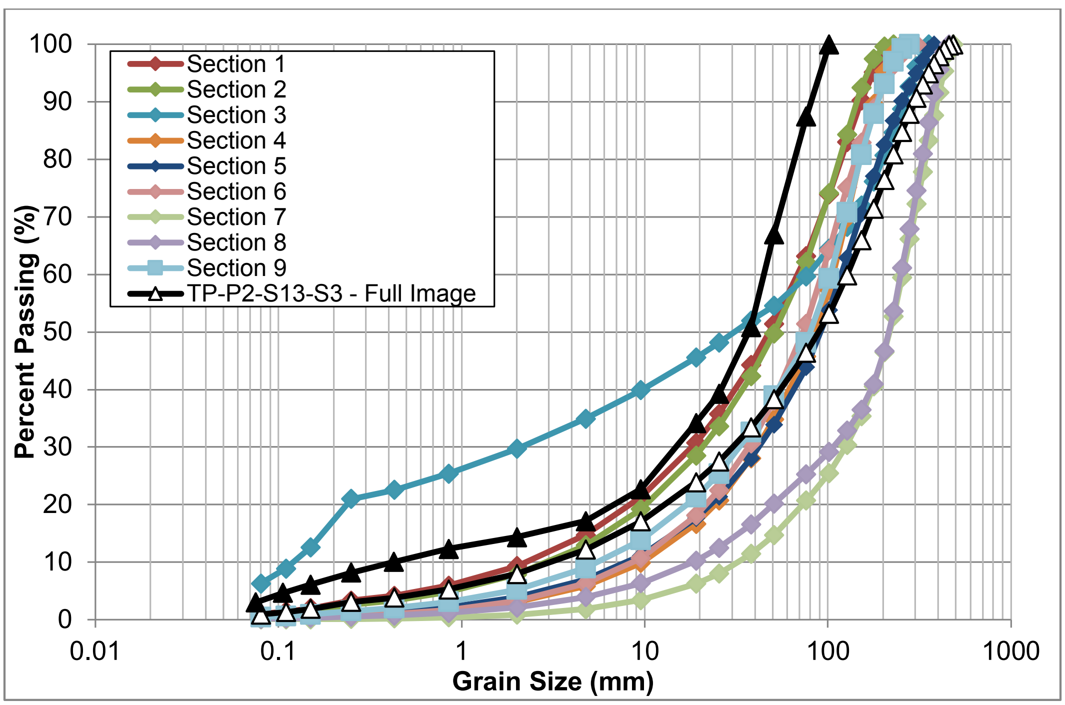


Figure 5.21 - Digital image processing grain size curves for TP-P2-S13-S3 Sections 1 through 9 with laboratory data and full image results.

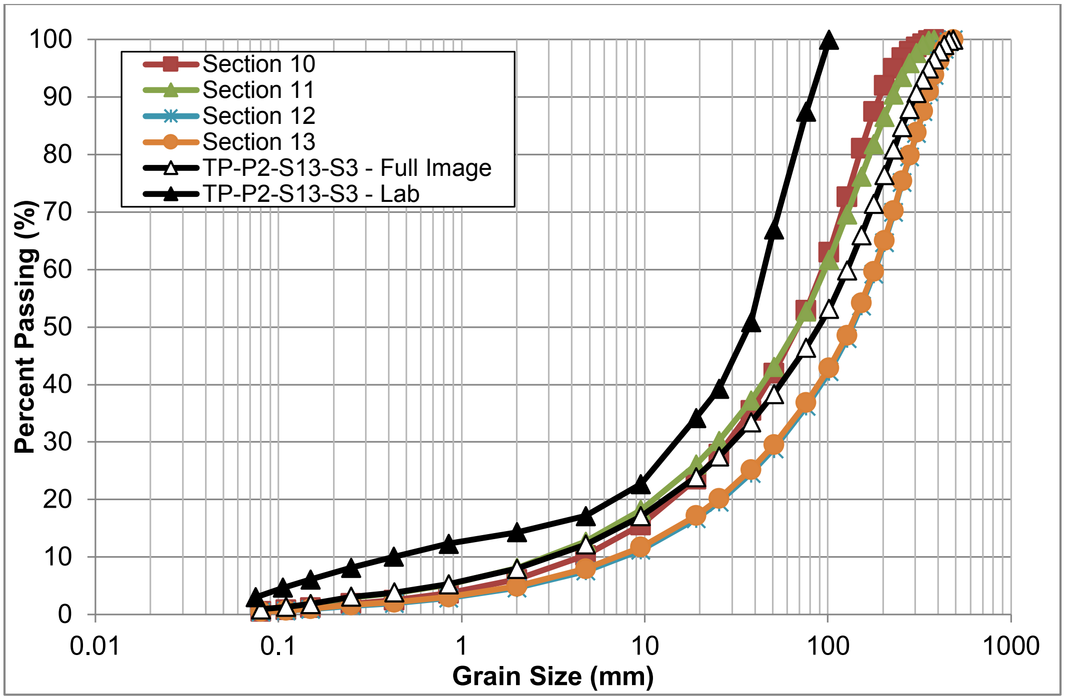


Figure 5.22 - Digital image processing grain size curves for TP-P2-S13-S3 Sections 10 through 13 with laboratory data and full image results.

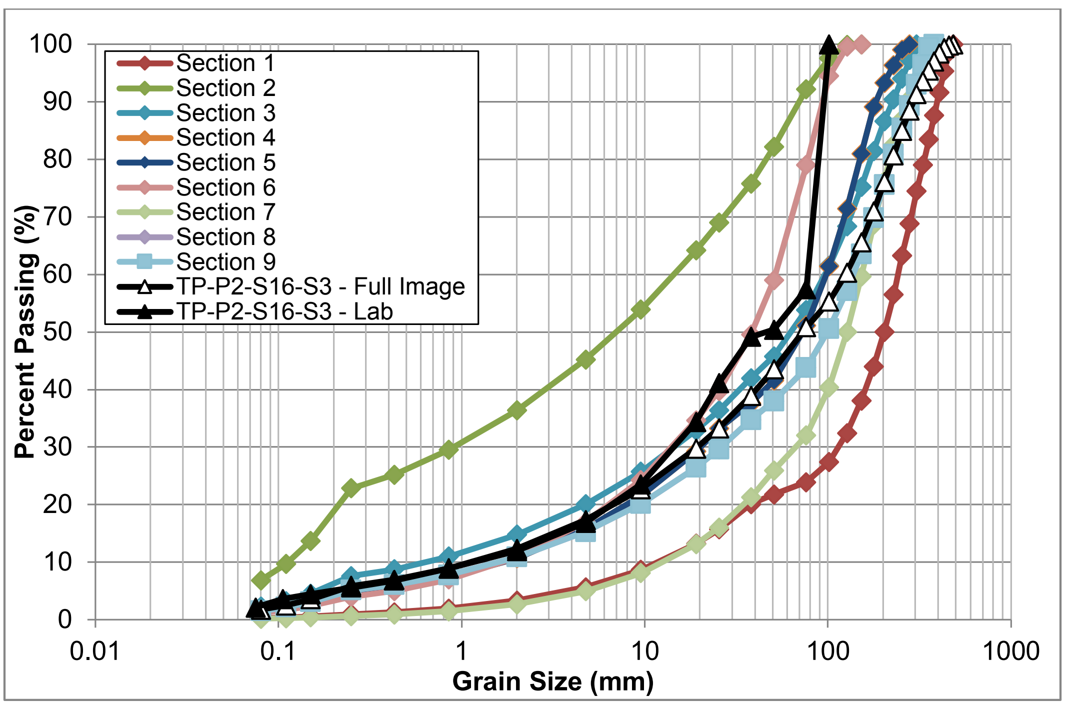


Figure 5.23 - Digital image processing grain size curves for TP-P2-S16-S3 Sections 1 through 9 with laboratory data and full image results.

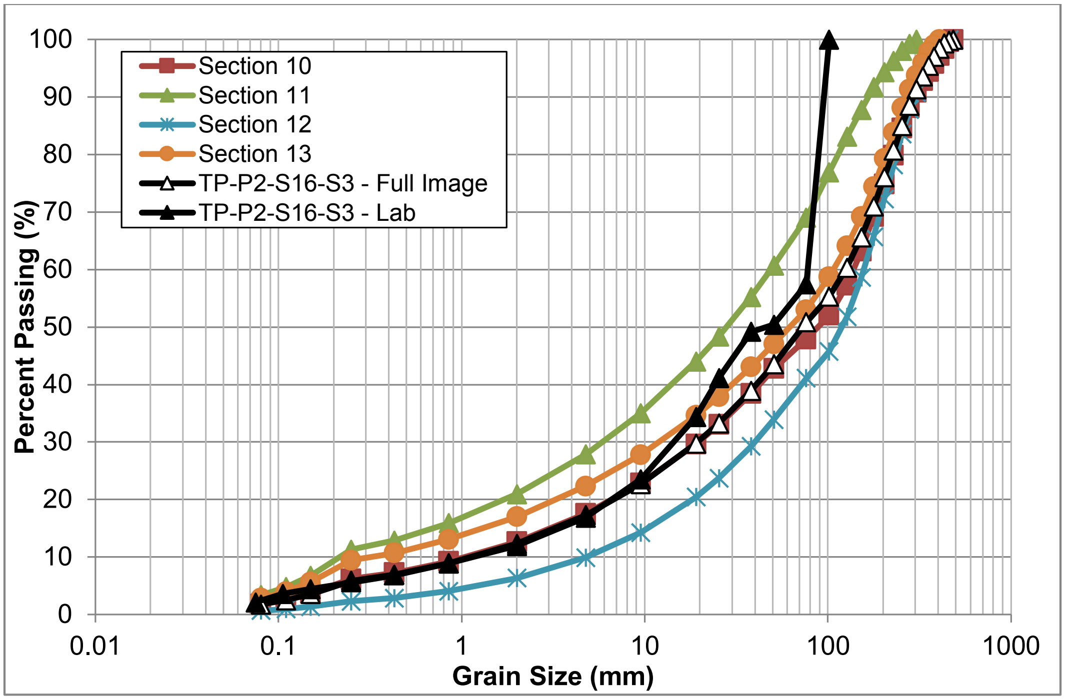


Figure 5.24 - Digital image processing grain size curves for TP-P2-S16-S3 Sections 10 through 13 with laboratory data and full image results.

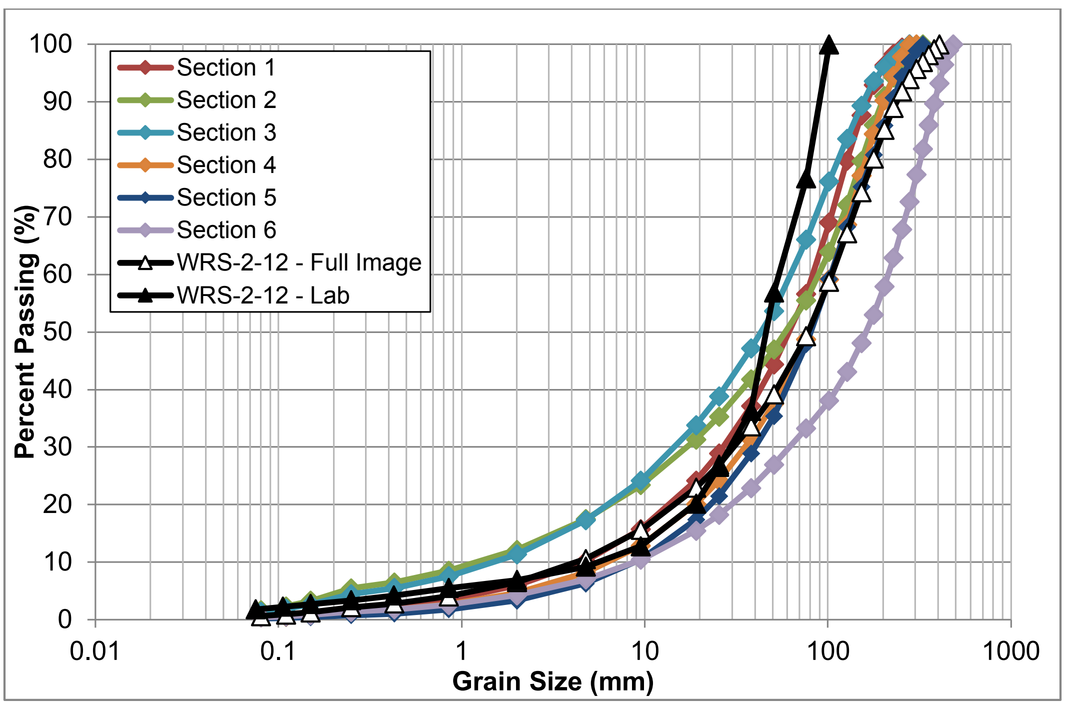


Figure 5.25 - Digital image processing grain size curves for WRS-2-12 Sections 1 through 6 with laboratory data and full image results.

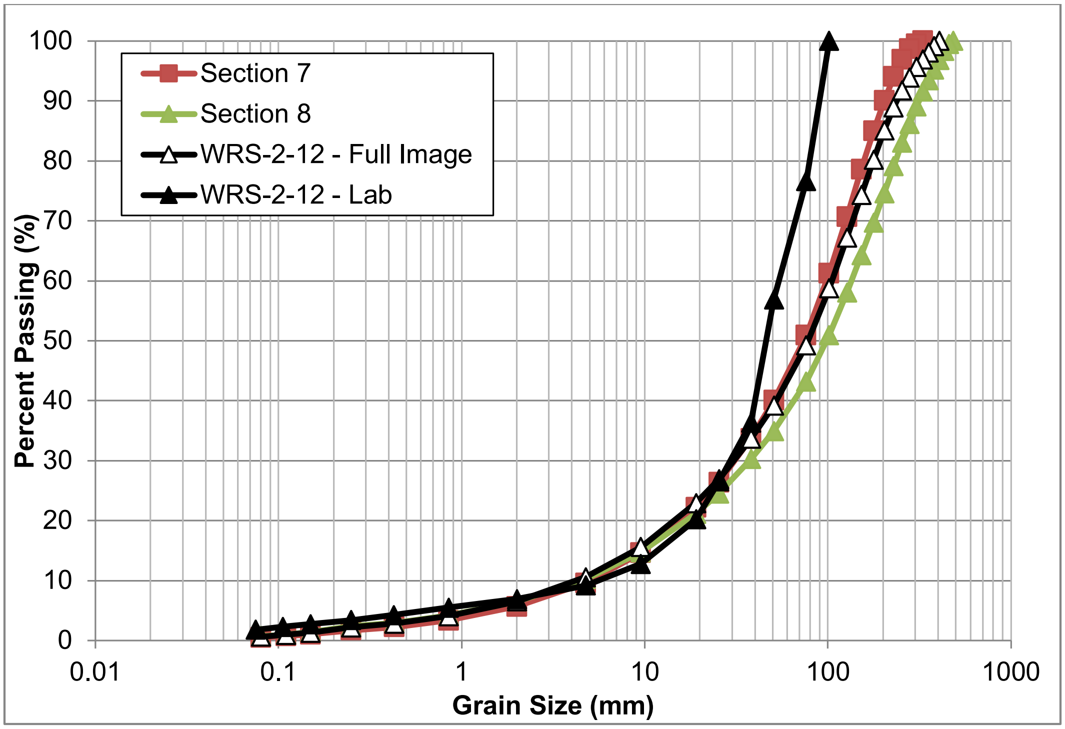


Figure 5.26 - Digital image processing grain size curves for WRS-2-12 Sections 7 and 8 with laboratory data and full image results.

The section analyses were able to illustrate differences in particle gradation within a single image. The group of curves presented in each set of plotted curves defines an envelope for the sample area. For sampling locations TP-P1-S5-S3, TP-P1-S6-S3, TP-P1-S9-S1, P1-P3-S2, TP-P2-S10-S3, and WRS-2-12, the grain size curves from the section analyses formed an envelope centered about the distribution for the full image. The percent passing values at a given grain size were within ±10% of the value generated using the entire image area. For these images, the grain sizes found in each of the sections were more homogeneous and were largely representative of the overall image area.

In contrast, the envelopes generated from locations TP-P1-S9-S1, TP-P1-S11-S2, P1-P6-S1, TP-P2-S13-S3, and TP-P2-S16-S3 had grain size curves with a difference of more than ±10% from the distribution of the full image area. The envelope was largest for TP-P1-S11-S2 with areas of visible segregation of material. Sample location TP-P1-S11-S2 also indicated the difficulty of delineating areas with high fines content. In the curves generated for Sections 3, 5, 6, and 7 of this image, a break in the curve is visible at the 0.25 mm (No. 60) sieve. The reason for this change in slope is unknown and may be a product of the computer software.

As described in Section 4.3.1.2, grain size distribution for samples with greater than 40% passing the No. 4 sieve behave as a soil-like material due to a high proportion of matrix material. The DIP results support the laboratory sieve results that the samples have less than 40% passing the 4.75 mm (No. 4) sieve, and that the stockpiles will behave as a rock-like material as they are clast supported. The rectangular section grain size analyses revealed only three images with sections with greater than 40% passing the No.4 sieve (Table 5.3). These areas are dominated by fines and would be expected to transmit the most water. The average percent passing the No. 4 sieve for the ten images was 17%, or approximately 17% of the waste rock material is 'matric material'.

Table 5.3 – Percent passing the No. 4 sieve and Sections with greater than 40% passing the No. 4 sieve

Sample Number	Percent passing No. 4 (4.75 mm) sieve for entire image (%)	Number of Image Sections with >40% passing No. 4 (4.75 mm) sieve
TP-P1-S5-S3	1.71	0 of 9
TP-P1-S6-S3	19.41	0 of 9
TP-P1-S9-S1	22.56	0 of 9
TP-P1-S11-S2	30.82	4 of 9
P1-P3-S2	11.87	0 of 9
P1-P6-S1	8.64	0 of 9
TP-P2-S10-S3	35.31	2 of 8
TP-P2-S13-S3	12.16	0 of 9
TP-P2-S16-S3	17.30	1 of 9
WRS-2-12	10.58	0 of 6

5.4 Solids and Void Volume

The Split Desktop software was also utilized to estimate the volume of waste rock material in each photograph. A best fit ellipse was generated for each delineated particle in the image and the dimensions of each ellipse were outputted and a total particle volume was calculated. The volume of an ellipsoid is given by the following relationship (Equation 5.1):

$$V = \frac{4}{3}\pi \mathrm{abc} \tag{5.1}$$

where a, b, and c are the elliptical radii, and a>b>c. The outputted data from the DIP analysis only provides the major and minor axes of the best fit ellipse, a and b. Axis c was assumed to be equal to axis b, such that a prolate ellipsoid is the best fit shape, where a>b=c (Figure 5.27).

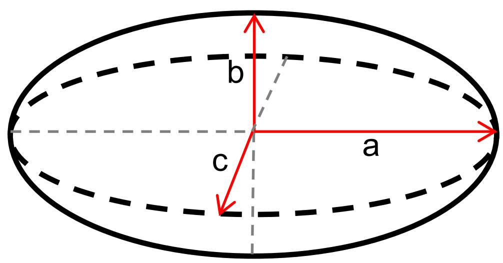


Figure 5.27 - Prolate ellipsoid with radii a>b=c

In addition to total particle volume, the open or coarse void space was mapped using the Split Desktop software (Split Engineering LLC, 2011a). The best fit ellipses for the void spaces were used to calculate volume using the same methodology as particle volumes. Coarse void space was visible only in *in situ* images, and was not visible in P1-P3-S2 and P1-P6-S1 as images were taken of the material after excavation from the stockpile face. Due to resolution in WRS-2-12, no open void space was visible and was assumed to be zero.

The total solids volume (V_S) and total coarse void volume (V_{CV}) were used to determine total volume (V_T), as well as the volume of material less than 4.75 mm (V_{MS}). The volume of matric solids, V_{MS}, was determined as a percentage of the total solids volume utilizing the percent passing the 4.75 mm sieve determined from the previous DIP grain size analyses. Table 5.4 provides a summary of the volume parameters and their method of calculation.

Table 5.4 - Volume relationships for determining proportions of coarse and fine waste rock

Variable	Relationship	Description
V_S	-	Volume of Solids (m^3) – Volume of all detected particles from the DIP image analysis
V_{CV}	-	Volume of Coarse Voids (m^3) – The open void space or air filled void volume determined from the DIP image analysis
V_{MS}	$V_{MS} = V_S \cdot (\%\, Pass\ 4.75\ mm)$	Volume of Matric Solids (m^3) – Volume of waste rock material with size less than the No. 4 sieve (4.75 mm),
V_{CS}	$V_{CS} = V_S - V_{MS}$	Volume of Coarse Solids (m^3) – Volume of waste rock greater than 4.75 mm
V_{MV}	$V_{MV} = V_{MS} \cdot n_m$	Volume of Matric Voids (m^3) – The volume of void space in the waste rock material of with size less than the No. 4 sieve (4.75 mm)
V_T	$V_T = V_S + V_{CV}$	Total Volume (m^3) – the volume of coarse and fine matric material, matric and coarse void space.

Table 5.5 provides a summary of the volume data from the DIP analyses for the ten images analyzed. The total volume calculated for each image has a wide range as a result of the scale of the photograph. Coarse void volumes were higher in areas with limited fines and large clasts, such as TP-P1-S5-S3 and TP-P2-S13-S3.

Table 5.5 - Volume of particles and coarse voids determined from DIP analysis output

Sample Number	Volume of Solids from DIP Output (V_s, m^3)	Volume of Coarse Voids from DIP Output (V_{CV}, m^3)	Percent Passing No. 4 (4.75mm) Sieve (%)	Volume of Matric Solids (<4.75mm) (V_{MS}, m^3)	Total Volume (V_t, m^3)
TP-P1-S5-S3	875.43	17.14	1.71	14.97	892.57
TP-P1-S6-S3	672.36	4.87	19.41	130.50	677.23
TP-P1-S9-S1	160.27	0.09	22.56	36.16	160.36
TP-P1-S11-S2	237.15	1.52	30.82	73.09	238.67
P1-P3-S2	151.78	-	11.87	18.02	151.78
P1-P6-S1	92.87	-	8.64	8.02	92.87
TP-P2-S10-S3	288.98	0.13	35.31	102.04	289.11
TP-P2-S13-S3	4868.12	25.50	12.16	591.96	4893.62
TP-P2-S16-S3	2447.54	0.51	17.3	423.42	2448.05
WRS-2-12	3270.51	0.00	10.58	346.02	3270.51

The object of obtaining volume data was to determine porosity values of the coarse solids and matric solids. These data assisted in the evaluation of a ‘macroporosity’ through voids mapping and ‘microporosity’ within the matric material. Through understanding the porosity and volume of fines, a preliminary evaluation of water flux through the waste rock pile can be determined. The following section provides an evaluation of waste rock porosity.

5.5 Porosity, Moisture Content and Flux Estimation in Waste Rock

Porosity is the ratio of the volume of void space to the total volume, where total volume includes volume of solids air and pore fluid (Equation 5.2):

$$n = \frac{V_v}{V_T} \tag{5.2}$$

Porosity was evaluated separately for the coarse and fine material (<4.75 mm) to determine the open void or macroporosity as well as microporosity in the fines. The relationships and variables utilized are presented in Table 5.6.

Table 5.6 - Porosity relationships for determining proportions of coarse and fine waste rock

Variable	Relationship	Description
n_m	-	Porosity of Matric Fines (m^3/m^3) – Porosity of matric material determined from soil-water characteristic curve Tempe cell tests
n_{cv}	$n_{cv} = \frac{V_{CV}}{V_T}$	Porosity of Coarse Voids (m^3/m^3) – Air filled porosity, or porosity of the open void space V_{CV}/V_T, this represents the porosity available for advective air flow and assumes no water flow will occur in these voids
n_{me}	$n_{me} = \frac{V_{MV}}{V_T}$	Effective Porosity of Matric Material (m^3/m^3) – Ratio of the volume of matric voids and total volume, this represents the porosity available for water flow in unsaturated conditions

Variable	Relationship	Description
n_t	$n_t = \frac{V_{CV} + V_{MV}}{V_T}$	Total Porosity (m^3/m^3) – Ratio of the sum of the volume of matric and coarse voids and total volume

The porosity calculations for each of the ten DIP images are presented in Table 5.7. The effective porosity of matric material represents the porosity available for water flow within the waste rock.

Table 5.7 - Porosity of matric and coarse waste rock material

Sample Number	Porosity of Matric Fines	Porosity of Coarse Voids	Effective Porosity of Matric Material	Total Porosity
	n_m	n_{cv}	n_{me}	n_t
TP-P1-S5-S3	0.417	0.0192	0.007	0.026
TP-P1-S6-S3	0.343	0.0072	0.066	0.073
TP-P1-S9-S1	0.464	0.0006	0.105	0.105
TP-P1-S11-S2	0.333	0.0064	0.102	0.108
P1-P3-S2	0.384	N/A	0.046	N/A
P1-P6-S1	0.473	N/A	0.041	N/A
TP-P2-S10-S3	0.363	0.0004	0.128	0.128
TP-P2-S13-S3	0.427	0.0052	0.052	0.057
TP-P2-S16-S3	0.312	0.0002	0.054	0.054
WRS-2-12	0.631	0.0000	0.067	0.067

The porosity of the matric material was typically within the range of 0.3 and 0.5 (30% to 50%), however due to the small proportion of fine material within the pile, the contribution to the overall porosity is low with a resulting overall porosity in the range of 0.05 to 0.12 (5% to 12%). The total porosity represents the available volume for water and air flow within the waste rock. However, the fines within the waste rock are unsaturated and only a portion of the total porosity is fluid filled, and the coarse void space is air filled. Utilizing the volumetric SWCC data, the volumetric water content of the fines can be estimated using the range of matric suctions measured during the field study, described in Section 4.4.2.

To understand water flow through the waste rock, a conceptual model was developed utilizing a unit volume of waste rock, or representative elemental volume (REV), corresponding to the proportions of fine and coarse waste rock determined using the DIP data. The REV is composed of clasts that support the structure, matric material where fluid flow occurs, and open air-filled void space (Figure 5.28). The proportion of matric material corresponds to the percent passing the 4.75 mm sieve, and therefore the REV has differing composition for each of the ten samples. Utilizing this conceptual model of a REV, the volume of water within the REV was estimated to assist in evaluating the residence time of pore fluid in one-dimensional flow.

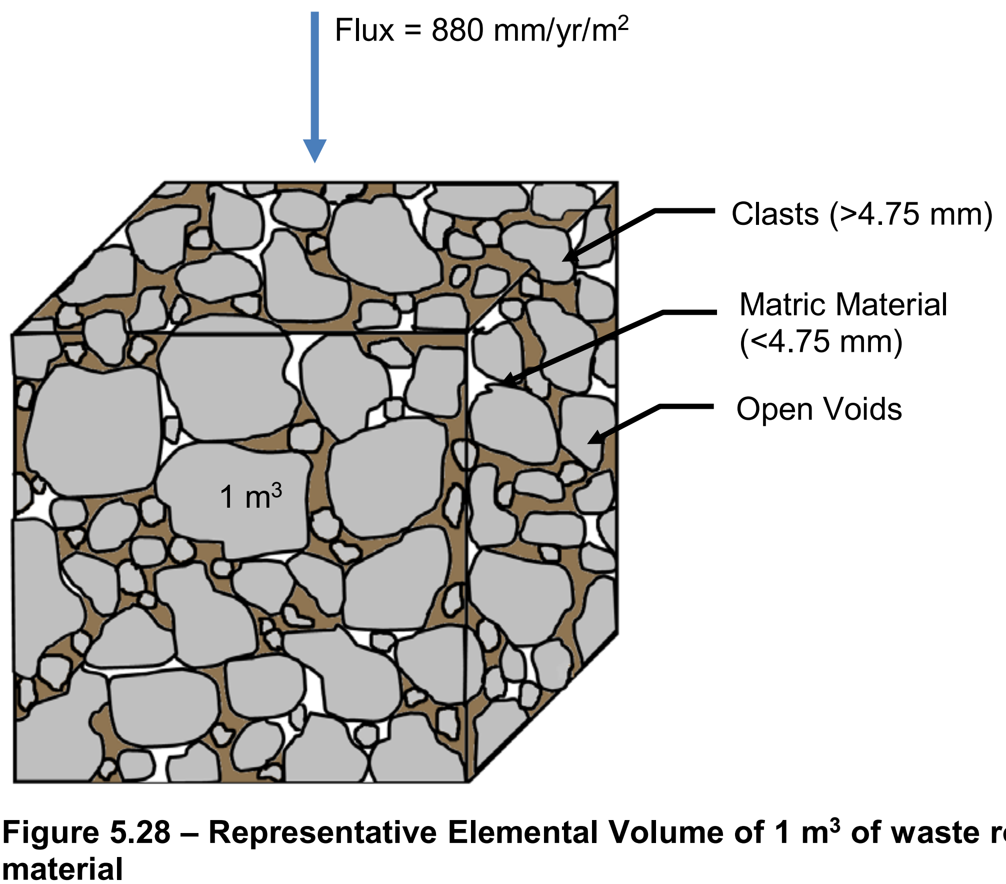


Figure 5.28 – Representative Elemental Volume of 1 m^3 of waste rock material

The volume of water within the REV was estimated using the SWCCs from the laboratory analysis as well as matric suction data from the test pit field campaign. Measured matric suction values on WRS 1 and WRS 2 fell between 1 kPa to 30 kPa. The volumetric water content at 1 kPa and 30 kPa were determined for each sample using SWCC results. The volumetric water content values provide the range of volumetric water contents that would be expected within the waste rock material *in situ*. The upper and lower bound volumetric moisture contents for each sample are provided in Table 5.8. Therefore, the volume of water within the REV is a function of the volumetric water content as well as the proportion of matric material within the REV. The proportion of matric material is given by the percent passing the No.4 (4.75 mm) sieve determined by the DIP analyses. It was assumed that the larger material would not contribute to the overall transmittable water within the REV. The total volume of water contained in the fine fraction was determined and expressed as a height of water or head (h_w) within the REV. The range of h_w for the matric suction range of 1 kPa to 30 kPa for each sample are detailed in Table 5.8.

Residence time is a valuable concept to understand loadings to the environment when hydrology data is coupled with geochemical data to understand mass transport. Due to the age of the waste rock piles, and the moisture observed throughout the waste rock pile, it was assumed the pile has wet-up and flux entering the pile would be equal to flux exiting, or a plug flow. Plug flow is a flow model where all water within the REV is travelling at the same velocity, or the velocity profile throughout is uniform perpendicular to the flow direction. Utilizing the assumption of plug flow and that the change in storage within the pile is negligible, residence time can be estimated for the samples.

Flux entering the pile was adopted from average annual precipitation data from Cochrane, Ontario, of 880 mm/year (2.4 mm/day) and assumed to be at a constant rate (Environment Canada, 2013).

Table 5.8 – Volumetric moisture contents from SWCC testing and corresponding maximum and minimum height of water within the REV

Sample Number	Volumetric Moisture Content at 1 kPa from SWCC (θ_w, dec.)	Volumetric Moisture Content at 30 kPa from SWCC (θ_w, dec.)	Percent Passing No. 4 (4.75mm) Sieve (%)	Min. Height of Water in 1 m^3 Waste Rock ($h_{w(min)}$, mm)	Max. Height of Water in 1 m^3 Waste Rock ($h_{w(max)}$, mm)
TP-P1-S5-S3	0.32	0.20	1.71	5.5	3.4
TP-P1-S6-S3	0.22	0.09	19.41	42.7	17.5
TP-P1-S9-S1	0.30	0.19	22.56	67.7	42.9
TP-P1-S11-S2	0.30	0.16	30.82	92.5	49.3
P1-P3-S2	0.33	0.18	11.87	39.2	21.4
P1-P6-S1	0.38	0.18	8.64	32.8	15.6
TP-P2-S10-S3	0.23	0.11	35.31	81.2	38.8
TP-P2-S13-S3	0.38	0.18	12.16	46.2	21.9
TP-P2-S16-S3	0.18	0.08	17.3	31.1	13.8
WRS-2-12	0.34	0.15	10.58	36.0	15.9

Residence time or flushing time was used to determine the time for water flow through the REV. Residence time for steady state conditions is defined as:

$$t_r = \frac{h_w}{P_A} \tag{5.3}$$

where t_r is the residence time, h_w is the height of water or total head within the REV, and P_A is the average annual precipitation. The retention times corresponding to the maximum and minimum heights of water are presented in Table 5.9.

Table 5.9 – Water content and residence time for a 1 m^3 REV

Sample Number	Residence Time for 1D flow of 1 m in REV (time in days)	
	Minimum	Maximum
TP-P1-S5-S3	1.4	2.3
TP-P1-S6-S3	7.2	17.7
TP-P1-S9-S1	17.8	28.1
TP-P1-S11-S2	20.5	38.3
P1-P3-S2	8.9	16.2
P1-P6-S1	6.5	13.6
TP-P2-S10-S3	16.1	33.7
TP-P2-S13-S3	9.1	19.2
TP-P2-S16-S3	5.7	12.9
WRS-2-12	6.6	14.9
Average Time	**10.0**	**19.7**

The residence times ranged from 1.4 days to 38.3 days for a wetting front to pass through the REV of 1 m^3 size. The average time for flow to pass through the REV for the ten tested samples was estimated to require 10 days to 20 days. The flow in the REV assumed that the fluid travels uninhibited through the fines in one dimension. The conceptual model also assumes that the fines are hydraulically connected and are not separated by clasts or open void space. It is important to note that REVs with small proportions of fines such as TP-P1-S5-S3 and TP-P2-S16-S3 have short residence times, as the time required to flush the total pore fluid volume is low. In the *in situ* waste rock with very little matric material, the fines may be located in discontinuous zones and the residence time may in reality be greater as the fines may not be hydraulically connected.

The average height of WRS 1 and WRS 2 prior to deconstruction was 20 m above the surrounding terrain. Consequently, the resulting estimate of residence time for a wetting front to travel from the surface of the pile to the base is 200 days to 1.1 years. Research by Nichol et al. (2003) estimated residence times of 4.4 years for a constructed waste rock pile 5 m in height, under natural rainfall conditions (303 mm/yr). The yearly net infiltration during the study from natural rainfall was 55%. The residence time estimated for the DLM waste rock assumes that the net infiltration is equal to the average annual precipitation of 880 mm/yr, and 100% infiltration occurs. The net percolation into the waste rock would likely be reduced as a result of the cover. The residence time for varying infiltration rates is provided in Table 5.10 utilizing the maximum residence time values in Table 5.9 to provide a conservative estimate. Infiltration rates of 50% correspond to similar conditions found by Nichol (2002), 25% infiltration would be an estimate of the approximate infiltration for the current cover system. Finally, 10% infiltration is provided as a lower limit. The infiltration rates provide an estimate of field conditions as the effects of evapotranspiration, runoff, change in storage, or actual evaporation from the surface of the stockpiles have not been investigated.

Table 5.10 – Residence time for varying degrees of infiltration

Sample Number	Residence Time for 1D flow in REV (days) for Varying Percent of Total Infiltration (880 mm/yr)			
	100%	50%	25%	10%
TP-P1-S5-S3	1.4	2.8	5.7	14.2
TP-P1-S6-S3	7.2	14.5	29.0	72.5
TP-P1-S9-S1	17.8	35.6	71.1	177.8
TP-P1-S11-S2	20.5	40.9	81.8	204.5

Sample Number	Residence Time for 1D flow in REV (days) for Varying Percent of Total Infiltration (880 mm/yr)			
	100%	**50%**	**25%**	**10%**
P1-P3-S2	8.9	17.7	35.4	88.6
P1-P6-S1	6.5	12.9	25.8	64.5
TP-P2-S10-S3	16.1	32.2	64.4	161.1
TP-P2-S13-S3	9.1	18.2	36.3	90.8
TP-P2-S16-S3	5.7	11.5	23.0	57.4
WRS-2-12	6.6	13.2	26.3	65.8
Average	**10.0**	**19.9**	**39.9**	**99.7**

For a 20 m pile, the corresponding residence times for 50%, 25%, and 10% infiltration are 1.1 years, 2.2 years, and 5.5 years, respectively. These data could be utilized in future analyses to compare with SoilCover (Geo-Analysis 2000 Ltd, 1998) surface flux boundary modelling to understand surface infiltration into the stockpiles.

The conceptual model provided above provides a method to estimate the residence time for matric flow within the waste rock. This method provides a first approximation of residence time as the water flow in the waste rock at the DLM is expected to primarily occur in the fine fraction due to the presence of a cover. The method does not take into consideration lateral flow, which may increase the residence time, nor the effect of wetting and drying. Consequently, the results presented in this thesis should be used primarily as a means to correlate with more complex numerical models. Other considerations include macropore or fast-pathway flow that would occur under higher infiltration rates. Transient infiltration conditions from variations in the climate cycle cause multiple arrival or residence times and have not been addressed in the present model. Porosity values and water storage capacity presented in the above sections can form the basis for further hydraulic modelling. Further assessment of the waste rock hydrology could provide validation of residence times evaluated using the conceptual model above, and be expanded for two dimensional seepage modelling. Flow data from further modelling can be coupled with mass transport data for assessment of mass loadings. The results are valuable for estimation prediction of ARD and quantifying seepage rates, which may assist DLM in future closure and rehabilitation for on-site structures.

Chapter 6.0 Summary and Conclusions

6.1 Summary

Mine waste management and the control of sulfide mineral oxidation is a major concern for the design and management of mine structures. Correct prevention, mitigation, and management of ARD production can decrease long term mining closure costs. Through a review of other mine waste literature, limited attention has been focused on the long term behaviour of waste rock under field conditions. In this thesis, the primary goal was to evaluate the geotechnical and hydrologic properties of two historic waste rock piles over the long-term and provide a basis to understand water flow through the waste rock. The objectives of the research program were, first, to evaluate the internal structure and properties of two waste rock stockpiles. Second, a sufficient sample inventory was collected for laboratory assessment of physical properties, and unsaturated soil properties were determined to assess water storage. Finally, digital image processing techniques were used to characterize large scale grain size and assess porosity and available water for matric flow.

Through multiple field campaigns, a large inventory of 100 samples was collected and processed to determine physical and hydrological properties. The test pit excavation program observed pile structure, weathering and oxidation, pore water parameters, and temperature. Examination of the internal pile structure was conducted during the profile sampling campaign. Post-processing of the samples included grain size distribution, paste pH, moisture content, Munsell soil colour, and detailed testing to determine hydraulic conductivity and soil water characteristic curves. Soil water characteristic curve data and grain size data from subsequent digital image processing were utilized to support preliminary flow modelling and residence times were estimated for matric flow. The conclusions of the study are presented below.

6.2 Conclusions

The objectives of the research program were achieved through completion of two phases. The first phase involved the design and execution of a field investigation to obtain *in situ* measurements and collect representative samples. The second phase involved two tasks; first, the evaluation of geotechnical and saturated-unsaturated properties of the representative samples. In addition, a detailed evaluation was conducted into the grain size distribution data using digital imaging techniques to evaluate hydraulic flow properties of the waste rock. The specific conclusions of the research program are:

1. Observations during the field program indicated that WRS 1 and WRS 2 showed evidence of construction as a push or paddock style dump, with some end-tipped deposition. Segregation of the material within the dump was evident, with coarse material at the base and dipping beds at the angle of repose; however structural elements are not well defined due to the coarse nature of the waste rock. The dump was constructed in 10 m to 15 m lifts separated by compacted traffic surfaces.

2. The stockpiles were clast rich, and had a clast supported structure with voids infilled with fine matric material or open void space. The dominant rock types were footwall mafic volcanics, intrusive lithologies and talc chlorite/chloritic greenstone. Evidence of oxidation and weathering was evident throughout the stockpiles and was varied by degree. Typically, oxidation was found on the surface of particles or the matric fines were oxidized.

3. *In situ* measurements of matric suction ranged from 1 kPa to 53 kPa for the waste rock material, and moisture content values for 20-L pail samples ranged from 0.3 wt% to 12.5 wt%. No significant

trend was observed with depth for these parameters, indicating a heterogeneous structural profile.

4. Field observations indicated the waste rock grain size ranged from clay sized material up to boulders of 2 m. The sampling program was limited to particles up to 75 mm, and the samples were effective in generating an envelope defining the fine grained endpoint of particle sizes. All waste rock samples tested were classified as rock-like, with less than 40% passing the 4.75 mm sieve. The research program determined that the waste rock piles behave as rock-like materials and have a clast supported structure. Grain size had no significant relation to the observed oxidation or other tested parameters.

5. Paste pH results were bimodal with the majority of samples tested within the neutral range of pH 6 to 8. Examination with Munsell soil colour indicated the greater the redness of a hue, paste pH values were typically more acidic.

6. Soil water characteristic curves for the waste rock had large transition zones and low air entry values with near immediate drainage occurred under small applied matric suctions. The cover material had greater storage capacity and underwent greater volume change. The *in situ* matric suction values were within the transition zone or desaturation zone of the waste rock SWCCs, indicating the fine fraction controls the water flow as it can retain water under these conditions.

7. Digital image processing was an effective method to characterize the larger grain size fraction within the waste rock pile, and data from the image analysis correlated well with measured grain-size data. Larger photographs may be required to fully characterize the

coarse grained endpoint of the full grain size distribution in WRS 1 and WRS 2.

8. Water flow will primarily occur in the <4.75 mm fraction of material, which on average accounts for 17% of the total waste rock mass.

9. Porosity relationships indicated that the effective porosity of the matric material (where water flow occurs) is low (0.5 to 0.12), due to the limited volume of fines within the pile.

10. A conceptual model was used to evaluate residence time for a stockpile of 20 m. Residence time was estimated to range from 200 days to 1.1 years with flow occurring in the matric material assuming 100% infiltration. Caution is recommended in adopting this residence time as the infiltration data does not account for runoff, evapotranspiration or effects of the cover material. For infiltration rates of 55%, 25%, and 10%, residence times for a 20 m pile were 1.1 years, 2.2 years, and 5.5 years. Studies of the influence of the cover system are necessary to better define the hydraulic behaviour and net percolation into the waste rock.

6.3 Recommendations for Future Research

The objectives of this research program involved the characterization of the geotechnical properties of waste rock at the DLM as well as preliminary evaluation of hydraulic flow through waste rock. These objectives were achieved, however additional research and interpretation in conjunction with additional research partners at DLM and the University of Waterloo is needed. The following are recommendations for further investigation to improve predictions for transport and release of dissolved constituents from the stockpiles:

1. The observations compiled in this research program provide an extensive data set to describe the physical and hydrologic

characteristics of the DLM waste rock. The observations can form the basis for continued development of models to understand fluid flow and reactive transport concepts. The knowledge can be directly applied at the DLM to assist in future waste rock structures and for ongoing mitigation and prediction of ARD.

2. Investigation into the required spatial area needed for accurate characterization of the full coarse grained endpoint for digital image processing is needed. The images used in this research program were focused on a small spatial area corresponding to a specific sampling location. Larger particles up to 2 m in size were observed during the field program however were not characterized in the study. DIP techniques may reduce future sampling requirements as large scale excavation programs have high costs and present logistical challenges. Additional photographs of the waste rock material may be sufficient for any additional characterization of the waste rock.

3. Correlations should be made between Munsell soil colour, paste pH and mineralogy via X-ray fluorescence (XRF) or X-ray diffraction (XRD). Whole rock elemental composition determined by these methods may be useful in determining which lithologies have greater potential for ARD generation. Munsell soil colour may be useful as a screening method for determining reactivity of the waste rock as specific hues may be associated with greater potential for ARD generation. Utilizing mineralogy and soil colour data may assist mine staff in determining material within the waste dumps acceptable for alternative uses (i.e. road building or borrow material) and what material must be placed in a facility for potentially acid generating (PAG) waste (i.e. PAG dump or segregated dump).

4. The concept of a rock-corrected SWCC should be examined to assess effects on porosity utilizing the method proposed by Yazdani et al (2000). The porosities for the SWCC containing coarse material should be compared to the porosities generated by the digital image processing portion of this research program.

5. Validation of the proposed conceptual model for matric water flow and residence time should be evaluated. A laboratory column test or small scale field test, such as a barrel test, may be an effective method to assess outflow volumes utilizing known proportions of fine and coarse material.

6. The conceptual model presented for matric flow provides a preliminary basis for understanding water storage and residence time. Expansion of the conceptual model to a numerical analysis using commercial seepage analysis software should be examined. It is recommended that SoilCover modelling could be couple with saturated-unsaturated numerical seepage modelling with measured SWCCs, saturated hydraulic conductivity functions and estimates of fines contents. Incorporation of these data would provide more accurate measurements for residence time as well as water flow behaviour within the pile.

7. The cover material was characterized during the field investigation and laboratory program with respect to geotechnical and hydrologic properties. Preliminary estimates of the net infiltration were explored in Section 5.5, however, further investigation into the surface flux boundary relationships for the cover material and vegetation should be pursued. SoilCover modelling could be utilized to accurately determine net percolation into the waste rock. Further investigation into the cover material to characterize infiltration, evapotranspiration, storage and runoff is recommended.

8. Open void volume or air filled porosity was quantified during the DIP analysis. These data should be examined in conjunction with air permeability measurements from the research program at the University of Waterloo to assess the validity of using DIP techniques to assess open void volume.

References

AMEC Earth & Environmental. (2009). *Detour Lake Project Hydrogeology Baseline Report* (Prepared for Detour Gold Corporation). Mississauga: AMEC Americas Ltd.

AMEC Earth & Environmental. (2010a). *Detour Lake Project Class Environmental Assessment for MNR Resource Stewardship and Facility Development Projects - Environmental Study Report*. Mississauga: AMEC Americas Ltd.

AMEC Earth & Environmental. (2010b). *Detour Lake Project Metal Leaching and Acid Rock Drainage Characterization Report* (Prepared for Detour Gold Corporation). Mississauga: AMEC Americas Ltd.

Andrina, J. (2009). *Physical and Geochemical Behaviour of Mine Rock Stockpiles in High Rainfall Environments* (Doctoral dissertation, University of British Columbia). Retrieved from https://circle.ubc.ca/bitstream/handle/2429/24652/ubc_2009_fall_andrina_judy.pdf?sequence=1

Andrina, J., Miller, S., & Neale, A. (2003, July). The Design, Construction, Instrumentation, and Performance of a Full-Scale Overburden Stockpile Trial for Mitigation of Acid Rock Drainage, Grasberg Mine, Papua Province, Indonesia. In *Application and Sustainability of Technologies*. Paper presented at 6th International Conference on Acid Rock Drainage (ICARD), Cairns, QLD, 14-17 July (pp. 123-132). Carlton South: The Australasian Institute of Mining and Metallurgy.

Andrina, J., Wilson, G.W., & Miller, S. (2009, June). Behaviour of Water Flow and Geochemical Mixing in Layered Waste Rock Stockpiles: A Meso-scale Experiment. Paper presented at 8th International Conference on Acid Rock Drainage (ICARD), Skellefteå, Sweden, 22-26 June. Stockholm, Sweden: Swedish Association of Mines, Mineral and Metal Producers.

Andrina, J., Wilson, G. W., & Miller, S. (2012, May). Waste Rock Kinetic Testing Program: Assessment of the Scale Up Factor for Sulphate and Metal Release Rates. Paper presented at 9th International Conference on Acid Rock Drainage (ICARD), Ottawa, Ontario, 20-26 May. Ottawa, Ontario: Mine Environment Neutral Drainage (MEND).

Andrina, J., Wilson, G.W., Miller, S., & Neale, A. (2006, March). Performance of the Acid Rock Drainage Mitigation Waste Rock Trial Dump at Grasberg Mine. Paper presented at 7th International Conference on Acid Rock Drainage (ICARD), St. Louis, Missouri, 26-30 March (pp. 30-44). St. Louis MO: American Society of Mining and Reclamation (ASMR).

ASTM Standard D2216 (2010). Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. West Conshohocken, PA: ASTM International.

ASTM Standard D2434 (2006). Standard Test Methods for Permeability of Granular Soils (Constant Head). West Conshohocken, PA: ASTM International.

ASTM Standard D4972 (2001, Reapproved 2007). Standard Test Methods for pH of Soils. West Conshohocken, PA: ASTM International.

ASTM Standard D6836 (2010). Standard Test Methods for Determination of the Soil Water Characteristic Curve for Desorption Using Hanging Column, Pressure Extractor, Chilled Mirror Hygrometer, or Centrifuge. West Conshohocken, PA: ASTM International.

ASTM Standard D6913 (2004, Reapproved 2009). Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis. West Conshohocken, PA: ASTM International.

Aubertin, M. (2013, August). Waste Rock Disposal to Improve the Geotechnical and Geochemical Stability of Piles. Paper presented at 23rd World Mining Congress, Montreal, Quebec, 11-15 August. Montreal, Quebec: Canadian Institute of Mining, Metallurgy and Petroleum.

Blackmore, S., Speidel, B., Critchley, A., Beckie, R. D., Mayer, K. U., & Smith, L. (2012, May). The Influence of Spatial Heterogeneity and Material Characteristics on Fluid Flow Patterns Through Two Unsaturated, Mixed Waste-rock Piles. Paper presented at 9th International Conference on Acid Rock Drainage (ICARD), Ottawa, Ontario, 20-26 May. Ottawa, Ontario: Mine Environment Neutral Drainage (MEND).

Blowes, D., & Ptacek, C. (1994). Acid-neutralization Mechanisms in Inactive Mine Tailings. In J. Jambor, & D. Blowes (Eds.), Environmental Geochemistry of Sulfide Mine-Wastes (pp. 271-292). Waterloo, Ontario: Mineralogical Association of Canada.

BoBo, T. (2001). What's new with the digital image analysis software Split-Desktop? Paper presented at 2001 High Tech Seminar - Blasting Technology, Instrumentation and Explosive Applications, Nashville, TN, 22-26 July (pp. 1-9). Nashville, TN.

Chi, X. (2010). *Characterizing low-sulfide instrumented waste-rock piles: image grain-size analysis and wind-induced gas transport* (Master's thesis, University of Waterloo). Retrieved from https://uwspace.uwaterloo.ca/handle/10012/5728

Detour Gold Corporation. (2012a). Projects - At a Glance. Retrieved January 7, 2014, from Detour Gold: http://www.detourgold.com/projects/at-a-glance/default.aspx

Detour Gold Corporation. (2012b). Projects - Detour Lake Mine. Retrieved from http://www.detourgold.com/projects/detour-lake-mine/default.aspx

Detour Gold Corporation. (2013). Company Snapshot. Retrieved from Detour Gold: http://www.detourgold.com/files/doc_downloads/Detour%20Gold%20Story%20-%20to%20Q3%202013_v001_t104iw.pdf

Environment Canada (2013). Canadian Climate Normals 1971-2000 Station Data: Cochrane. Retrieved from http://climate.weather.gc.ca/climate_normals/results_e.html?stnID=4142&lang=e&dCode=1&province=ONT&provBut=Go&month1=0&month2=12

Fala, O., Aubertin, M., Molson, J., Bussiere, B., Wilson, G. W., Chapuis, R., Martin, V. (2003, July). Numerical Modelling of Unsaturated Flow in Uniform and Heterogeneous Waste Rock Piles. Paper presented at 6th International Conference on Acid Rock Drainage (ICARD), Cairns, QLD, 14-17 July (pp. 895-902). Carlton South: The Australasian Institute of Mining and Metallurgy.

Fala, O., Molson, J., Aubertin, M., Bussiere, B., & Chapuis, R. P. (2006). Numerical Simulations of Long Term Unsaturated Flow and Acid Mine Drainage at Waste Rock Piles. Paper presented at 7th International Conference on Acid Rock Drainage (ICARD), St. Louis, Missouri, 26-30 March (pp. 582-597). St. Louis MO: American Society of Mining and Reclamation (ASMR).

Fines, P. (2006). Hydrologic Characterization of Two Full-Scale Waste Rock Piles (Master's thesis, University of British Columbia). Retrieved from https://circle.ubc.ca/handle/2429/17836

Fines, P., Wilson, G., Williams, D., Tran, A., & Miller, S. (2003, July). Field Characterisation of Two Full-Scale Waste Rock Piles. Paper presented at 6th International Conference on Acid Rock Drainage (ICARD), Cairns, QLD, 14-17 July (pp. 903-909). Carlton South: The Australasian Institute of Mining and Metallurgy.

Fredlund, D., & Xing, A. (1994). Equations for the soil-water characteristic curve. *Canadian Geotechnical Journal*, 31, 521-532.

Fredlund, D., Rahardjo, H., & Fredlund, M. D. (2012). *Unsaturated Soil Mechanics in Engineering Practice*. Hoboken, New Jersey: John Wiley & Sons.

Geo-Analysis 2000 Ltd. (1998). SoilCover (Version 4.01) [Project Workbook and Computer Software]. Saskatoon, Saskatchewan, Canada: University of Saskatchewan.

Harrison, B., Aranda, C., Sanchez, M., & Vizconde, J. (2012). Waste Rock Management at the Antamina Mine: Overall Strategy and Data Application in the Face of Continued Expansion. Paper presented at 9th International Conference on Acid Rock Drainage (ICARD), Ottawa, Ontario, 20-26 May. Ottawa, Ontario: Mine Environment Neutral Drainage (MEND).

Herasymuik, G. (1996). Hydrogeology of a sulfide waste rock dump (Doctoral dissertation, University of Saskatchewan). Retrieved from http://ecommons.usask.ca/handle/10388/etd-11132012-133516

Hunter, G., McDermott, C., Miles, N., Singh, A., & Scoble, M. (1990). A review of image analysis techniques for measuring blast fragmentation. *Mining Science and Technology*, *11*, 19-36.

Industry Canada. (2012, July 11). Canadian Industry Statistics (CIS): Gross Domestic Product (GDP) Mining, Quarrying, and Oil and Gas Extraction (NAICS 21). Retrieved from https://www.ic.gc.ca/app/scr/sbms/sbb/cis/gdp.html?code=21&lang=eng

Jambor, J. (1994). Mineralogy of Sufide-rich Tailings and Their Oxidation Products. In J. Jambor, & D. Blowes (Eds.), Environmental Geochemistry of Sulfide Mine-Wastes (pp. 59-102). Waterloo, Ontario.

Janzen, M. P., Nicholson, R. V., & Scharer, J. M. (2000). Pyrrhotite reaction kinetics: Reaction rates for oxidation by oxygen, ferric iron and for nonoxidative dissolution. *Geochimica et Cosmochimica Acta*, *64*(9), 1511-1522.

Javadi, M., Peterson, H.E., Blackmore, S.R., Mayer, K.U., Beckie, R.D., & Smith, L. (2012). Evaluating preferential flow in an experimental waste rock pile using unsaturated flow and solute transport modeling. Paper presented at 9th International Conference on Acid Rock Drainage (ICARD), Ottawa, Ontario, 20-26 May. Ottawa, Ontario: Mine Environment Neutral Drainage (MEND).

Kemeny, J. M. (1994). A practical technique for determining the size distribution of blasted benches, waste dumps, and heap-leach sites. *Mining Engineering*, *46*(11), 1281-1284.

Kemeny, J. M., Devgan, A., Hagaman, R. M., & Wu, X. (1993). Analysis of Rock Fragmentation Using Digital Image Processing. *Journal of Geotechnical Engineering*, *119*(7), 1144-1160.

Kemeny, J., Girdner, K., BoBo, T., & Norton, B. (1999). Improvements for Fragmentation measurement by Digital Imaging: Accurate Estimation of Fines. Paper presented at Sixth International Symposium for Rock Fragmentation by Blasting, Johannesburg, South Africa (pp. 103-110). Johannesburg, South Africa: The South African Institute of Mining and Metallurgy.

Kong, L. (2013). Compare DIP Method Analyzing Particle Size Distribution of Waste Rock (Bachelor’s thesis, University of Waterloo) Waterloo: University of Waterloo.

Lambe, T. W., & Whitman, R. V. (2008). *Soil mechanics, SI version*. New York: John Wiley & Sons.

Lottermoser, B. (2010). *Mine Wastes: Characterization, Treatment and Environmental Impacts* (3rd ed.). New York: Springer.

Maerz, N., Palangio, T., & Franklin, J. (1996, August). WipFrag Image Based Granulometry System. In Proceedings of the FRAGBLAST 5 Workshop on Measurement of Blast Fragmentation, Montreal, Canada, 23-24 August (pp. 91-99). Montreal: Taylor & Francis Group.

Marcoline, J., Beckie, R., Smith, L., & Nichol, C. (2003, July). Mine Waste Rock Hydrogeology - The Effect of Surface Configuration on Internal Water Flow. Paper presented at 6th International Conference on Acid Rock Drainage (ICARD), Cairns, QLD, 14-17 July (pp. 911-918). Carlton South: The Australasian Institute of Mining and Metallurgy.

McKeown, R., Barbour, L., Rowlett, D., & Herasymuik, G. (2000, June). Characterization of the grain-size distribution for waste rock from metal mines – A review of existing grain size data and an evaluation of the implications for hydrogeologic behaviour. Paper presented at CSCE Annual Conference, London, Ontario (pp. 203-209). London, Ontario: Canadian Society of Civil Engineers.

Mine Environment Neutral Drainage (MEND) (2001). In G. Tremblay & C. Hogan (Eds.), *MEND Manual: Volume 1 – Summary* (MEND Report 5.4.2a). Retrieved from http://mend-nedem.org/wp-content/uploads/2013/01/5.4.2a.pdf

Neuner, M., Gupton, M., Smith, L., Pham, N., Smith, L., Blowes, D., & Sego, D. (2009, June). Diavik Waste Rock Project: Unsaturated Water Flow. Paper presented at 8th International Conference on Acid Rock Drainage (ICARD), Skellefteå, Sweden, 22-26 June.

Stockholm, Sweden: Swedish Association of Mines, Mineral and Metal Producers.

Newman, L. (1999). Preferential Flow in Vertically Oriented Unsaturated Soil Layers (Master's thesis, University of Saskatchewan). Retrieved from http://ecommons.usask.ca/handle/10388/etd-12022008-140427

Nichol, C. (2002). Transient Flow and Transport in Unsaturated Heterogeneous Media: Field Experiments in Mine Waste Rock (Doctoral dissertation, University of British Columbia). Retrieved from http://circle.ubc.ca/handle/2429/13207

Nichol, C., Smith, L., & Beckie, R. (2003, July). Water Flow in Uncovered Waste Rock - A Multi-Year Large Lysimeter Study. Paper presented at 6th International Conference on Acid Rock Drainage (ICARD), Cairns, QLD, 14-17 July (pp. 919-926). Carlton South: The Australasian Institute of Mining and Metallurgy.

Nichol, C., Smith, L., & Beckie, R. (2005). Field-scale experiments of unsaturated flow and solute transport in a heterogeneous porous medium. *Water Resources Research*, *41*(W05018), 11p.

Nicholson, R. V., & Scharer, J. M. (1994). Laboratory Studies of Pyrrhotite Oxidation Kinetics. In C. Alpers, & D. Blowes (Eds.), Environmental Geochemistry of Sulfide Oxidation (pp. 14-30). Washington, DC: American Chemical Society.

O'Kane, M., Stoicescu, J., Januszewski, S., Mchaina, D. M., & Haug, M. D. (1998). Design of field test plots for a sloped waste rock surface. Paper presented at 15th National Meeting of the American Society for Surface Mining and Reclamation, St. Louis, MO, 16-21 May (pp. 368-378). St. Louis: ASSMR.

Pham, N., Sego, D.C., Blowes, D.W., Smith, L., & Amos, R.T. (2012). Heat Transport and the Effects of Climate Change in a Large-scale

Waste Rock Pile Located in a Continuous Permafrost Region at Diavik Diamond Mine. Paper presented at 9th International Conference on Acid Rock Drainage (ICARD), Ottawa, Ontario, 20-26 May. Ottawa, Ontario: Mine Environment Neutral Drainage (MEND).

Ritchie, A. (1994). The Waste-rock Environment. In J. Jambor, & D. Blowes (Eds.), The Environmental Geochemistry of Sulfide Mine-Wastes (pp. 133-161). Waterloo, Ontario: Mineralogical Association of Canada.

Robertson, J., Barazzuol, L., & Day, S. (2012, May). Extraction of ARD/ML Information from a Brownfield Site for Development of an ARD/ML Plan at the Detour Gold Mine, Ontario, Canada. Paper presented at 9th International Conference on Acid Rock Drainage (ICARD), Ottawa, Ontario, 20-26 May. Ottawa, Ontario: Mine Environment Neutral Drainage (MEND).

Smith, L. J., Macdonald, G., Blowes, D. W., Smith, L., Sego, D. C., & Amos, R. T. (2012). Diavik Waste Rock Project: Objectives, Construction, Current Conclusions and Implications. Paper presented at 9th International Conference on Acid Rock Drainage (ICARD), Ottawa, Ontario, 20-26 May. Ottawa, Ontario: Mine Environment Neutral Drainage (MEND).

Smith, L., & Beckie, R. (2003). Hydrologic and Geochemical Transport Processes in Mine Waste Rock. In J.L. Jambor, D.W. Blowes & A.I.M Ritchie (Eds.), Environmental Aspects of Mine Waste (pp. 51-72). Vancouver, BC: Mineralogical Association of Canada.

Smith, L., Amos, R., Chi, X., Blowes, D., Stastna, M., & Sego, D. C. (2011). Diavik Waste Rock Project: Characterization of Particle Size, Sulfur Content and Acid Generating Potential. Paper presented at Tailings and Mine Waste 2011, Vancouver, British

Columbia, 6-9 November. Vancouver: University of British Columbia.

Smith, L., Lopez, D., Beckie, R., Morin, K., Dawson, R., & Price, W. (1995). *Hydrogeology of Waste Rock Dumps* (MEND Associate Project PA-1). Retrieved from Mine Environment Neutral Drainage website: http://mend-nedem.org/wp-content/uploads/2013/01/1.Associate-Project-PA-1.pdf

Soil Survey Staff Division. (1993). *Soil Survey Manual* (Vol. United States Department of Agriculture Handbook No. 18). Washington, D.C.: United States Department of Agriculture.

SoilVision Systems Ltd. (2012). SVFLUX (Version 2.3.49) [Computer Software]. Retrieved from http://www.soilvision.com/downloads.shtml

Split Engineering LLC (2011a). Split-Desktop (Version 3.1.0.79) [Computer Software]. Tucson, AZ: Split Engineering LLC.

Split Engineering LLC. (2011b). Split-Desktop Version 3.1 Help Manual. Tucson: Split Engineering.

Stockwell, J., Beckie, R., & Smith, L. (2003, July). The Hydrogeochemical Characterisation of an Unsaturated Waste Rock Pile, Key Lake, Saskatchewan, Canada. Paper presented at 6th International Conference on Acid Rock Drainage (ICARD), Cairns, QLD, 14-17 July (pp. 927-937). Carlton South: The Australasian Institute of Mining and Metallurgy.

Stockwell, J., Smith, L., Jambor, J. L., & Beckie, R. (2006). The relationship between fluid flow and mienral weathering in heterogeneous unsaturated porous media: A physical and geochemical characterization of a waste-rock pile. *Applied Geochemistry, 21*, 1347-1361.

Sudhakar, J., Adhikari, G., & Gupta, R. (2006). Comparison of Fragmentation Measurements by Photographic and Image Analysis Techniques [Technical Note]. *Rock Mechanics and Rock Engineering*, *39*(2), 159-168.

Taylor, M., & Greenwood, R. (1985). Classification and surface water control. In M. Carter (Ed.), *Design of non-impounding mine waste dumps* (pp. 1-13). New York: American Institute of Mining Metallurgical and Petroleum Engineers Inc.

Terzaghi, K., Peck, R. B., & Mesri, G. (1996). *Soil mechanics in engineering practice*. New York: Wiley.

The International Network for Acid Prevention (INAP) (2009a). Global Acid Rock Drainage (GARD) Guide: 4.2.2.3 Waste Rock Storage Facilities. Retrieved from http://www.gardguide.com/index.php/Image:ARDNMDandSDinaWasteRockPile.jpg

The International Network for Acid Prevention (INAP) (2009b). Global Acid Rock Drainage Guide (GARD Guide) [Industry Wiki page]. Retrieved from http://www.gardguide.com/

Wickland, B., & Wilson, G. (2005). Self-weight consolidation of mixtures of mine waste rock and tailings. *Canadian Geotechnical Journal, 42*, 327-339.

Wilson, G. W. (2011). Rock Dump Hydrology: An Overview of Full-Scale Excavations and Scale-up Experiments Conducted During the Last Two Decades. Paper presented in 7th Australian Workshop on Acid and Metalliferous Drainage, Darwin, Australia, 20-24 June (pp. 1-16). Darwin, Australia: SMI Technology Transfer.

Wilson, J. (2000). Numerical Modelling of Unsaturated Flow in Vertical and Inclined Waste Rock Layers Using the SEEP/W Model (Master's thesis, University of Saskatchewan). Retrieved from http://ecommons.usask.ca/handle/10388/etd-06192003-213211

Yazdani, A., Barbour, L., & Wilson, G. (2000). Soil Water Characteristic Curve for mine waste rock containing coarse material. Paper presented at CSCE Annual Conference, London, Ontario (pp. 203-209). London, Ontario: Canadian Society of Civil Engineers.

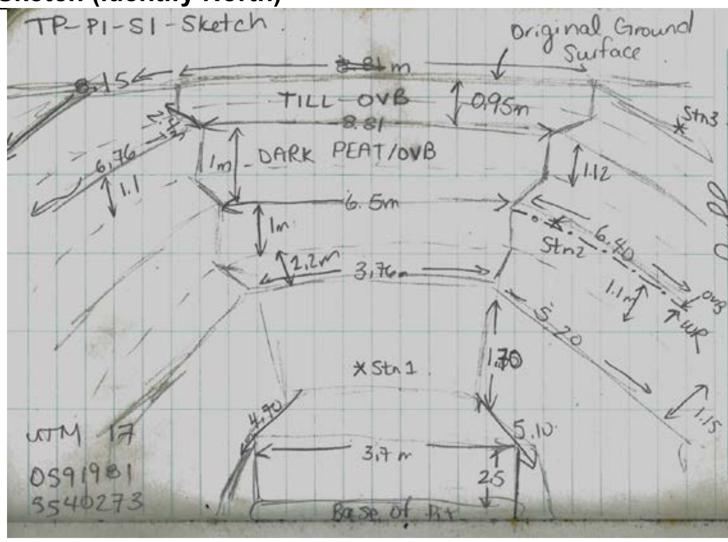
Appendix A – Field Program Logs and Photographs

Appendix A provides the field logging data collected during the test pit and profile grab sample field campaigns on WRS 1 and WRS 2. A total of 46 field logs are presented, 23 from the test pit campaign and 23 from the profile grab sample campaign. Each field log contains:

- Logging Location Identifier;
- Sampling Date and Time;
- GPS Coordinates;
- Sketch of the sampling area;
- Descriptions of material properties for each sampling location/unit; and;
- Photographs of the location indicating major features.

Test Pit Number :	TP-P1-S1	Sampling Date/Time:	July 30th 2011 11:50 am
Location :	Surface of Pile 1, top of main pile, near standpipe/casing		
GPS Coordinates: (UTM 17, NAD 83)		E: 591995	N: 5540199
Weather conditions :	Sunny, warm	Sampled by :	Aileen Cash/Ward Wilson

Location Sketch (identify North)



Soil Unit and Depth (From Surface)	Description of Units
Unit: Waste rock pile cover **Depth:** 0.0-0.5 m (Some areas up to 2.05 m due to slope)	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand with rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** No oxidation in cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Silty sand with clasts/cobbles up to 15-20 cm *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Some dark peat overburden also present on top of oxidized rock (0.95-2.05 m) **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended **Angularity of Rocks:** Fine grained matrix with rounded glacial cobbles **Moisture:** Moist, dry at surface **Tensiometer Reading:** 42 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S1-S3
Unit: Waste rock	**Material Type:** Waste Rock

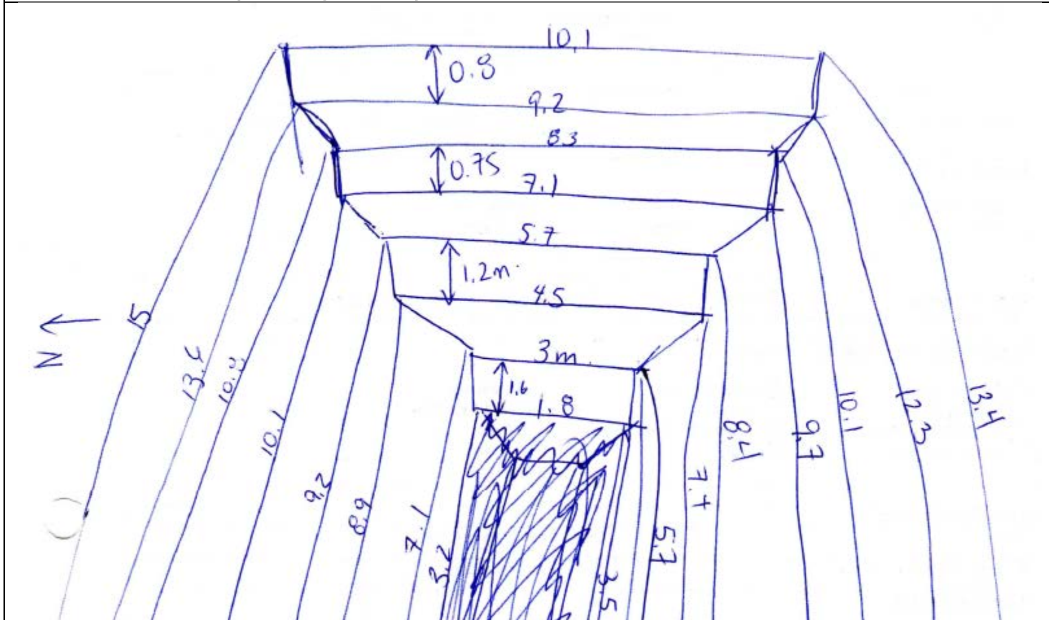
Depth: 0.95-2.05 m	**Rock Type:** Talc Chloride/Chloritic Greenstone **Colour:** Grey to black fresh surfaces, orange oxidized fines and surfaces **Presence of Oxidation:** Surface and matrix oxidation of waste rock **Percentage of Material Oxidized (%):** 60-70% surface oxidation **Sulphide Minerals Present:** Pyrite *Crystal Habit (Clusters, cubic):* Unknown Distribution (disseminated, veining, fracture fill): Unknown **Texture:** *Gradation:* Well graded, with material from 1m to fine silt/clay sized *Matrix or Clast supported:* Mix of intact rock and fine matrix material **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist, dry at surface **Tensiometer Reading:** 3 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S1-S2
Unit: Waste rock **Depth:** 2.05-5.20 m	**Material Type:** Waste Rock **Rock Type:** Talc Chloride/Chloritic Greenstone **Colour:** Orange with surface oxidation and oxidized fines, some grey fresh surfaces **Presence of Oxidation:** Surface and matrix oxidation of waste rock **Percentage of Material Oxidized (%):** 80-95% of material has presence of oxidation **Sulphide Minerals Present:** Pyrite *Crystal Habit (Clusters, cubic):* Unknown Distribution (disseminated, veining, fracture fill): Unknown **Texture:** *Gradation:* Well graded, with material from 1m to fine silt/clay sized *Matrix or Clast supported:* Mix of intact rock and fine matrix material **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Tensiometer Reading:** 8 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S1-S1
Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant Water sample collected : ☐ Yes ☒ No Sample ID: ______________________	
Observations / Other work performed : None	
Photos of Completed Test Pit:	

Photo 1 – TP-P1-S1 test pit profile looking north

Photo 2 - TP-P1-S1 test pit profile looking south

Photo 3: Tensiometer installation in base of test pit

Test Pit Number :	TP-P1-S2	**Sampling Date/Time:**	July 30th 2011 3:00 pm
Location :	Surface of Pile 1, north side of main pile, on slope		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 591915	**N:** 5540539
Weather conditions :	Sunny, warm	**Sampled by :**	Aileen Cash/Ward Wilson
Location Sketch (identify North)			



Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock pile cover **Depth:** 0.0-0.5 m	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand, rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** Little to no oxidation in cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* *Distribution (disseminated, veining, fracture fill):* N/A **Texture:** *Gradation:* Silty sand with clasts/cobbles up to 15-20 cm *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Roots and vegetation present in upper profile. **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended **Angularity of Rocks:** Fine grained matrix with rounded glacial cobbles **Moisture:** Moist, dry at surface **Tensiometer Reading:** 3 kPa **Sample Taken:** No **Sample Number:** N/A
Unit: Waste rock **Depth:** 0.50-0.80 m	**Material Type:** Waste Rock **Rock Type:** Talc Chloride/Chloritic Greenstone **Colour:** Orange oxidized fines and surfaces, with oxidized

	fines **Presence of Oxidation:** Surface and matrix oxidation of waste rock **Percentage of Material Oxidized (%):** 70-80% has surface oxidation **Sulphide Minerals Present:** Pyrite *Crystal Habit (Clusters, cubic):* Unknown/not observed *Distribution (disseminated, veining, fracture fill):* Unknown/not observed **Texture:** *Gradation:* Well graded, with material from 10-30 cm to fine silt/clay sized *Matrix or Clast supported:* Mix of intact rock and fine weathered matrix material **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended, possible oxidation front from surface **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Tensiometer Reading:** 14 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S2-S3
Unit: Waste rock **Depth:** 0.80-4.40 m	**Material Type:** Waste Rock **Rock Type:** Talc Chloride/Chloritic Greenstone **Colour:** Grey to black surfaces with some areas of orange surface oxidation **Presence of Oxidation:** Surface and matrix oxidation of waste rock **Percentage of Material Oxidized (%):** 10-20% has presence of oxidation **Sulphide Minerals Present:** Pyrite *Crystal Habit (Clusters, cubic):* Unknown/not observed Distribution (disseminated, veining, fracture fill): Unknown/not observed **Texture:** *Gradation:* Well graded, with material from 10-30 cm to fine silt/clay sized *Matrix or Clast supported:* Mix of intact rock and fine weathered matrix material **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist to very moist **Tensiometer Reading:** S1- 3 kPa; S2- 11 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S2-S1 and TP-P2-S2-S2
Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant Water sample collected : ☐ Yes ☒ No Sample ID: ______________	
Observations / Other work performed : None	

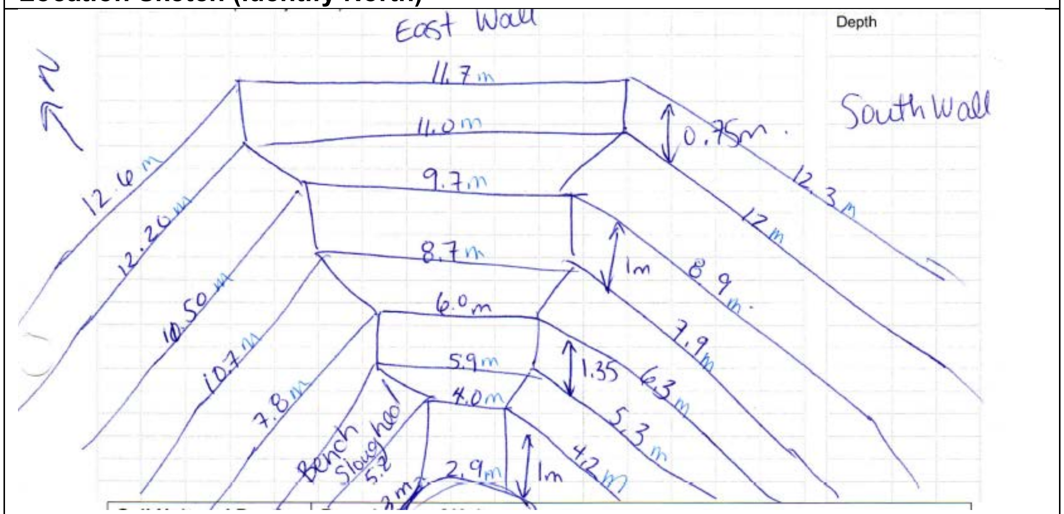
Photos of Completed Test Pit:
Photo 1 – TP-P1-S2 test pit profile looking south east

Photo 2 - TP-P1-S2 test pit profile looking south


Photo 3 – Tensiometer installation in base of test pit

Test Pit Number :	TP-P1-S3	**Sampling Date/Time:**	July 30th 2011 3:00 am
Location :	Surface of Pile 1, on flat inner area of pile		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 591833	**N:** 5540581
Weather conditions :	Sunny, warm	**Sampled by :**	Aileen Cash/Ward Wilson

Location Sketch (identify North)



Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock pile cover **Depth:** 0.0-0.3 m	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand with rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** Little to no oxidation in cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Silty sand with clasts/cobbles up to 15-20 cm *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Roots and vegetation present in upper profile. **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended **Angularity of Rocks:** Fine grained matrix with rounded glacial cobbles **Moisture:** Moist to dry, dry at surface **Tensiometer Reading:** N/A **Sample Taken:** No **Sample Number:** N/A
Unit: Waste rock **Depth:** 0.30-4.1 m	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow with some Talc

	Chloride/Chloritic Greenstone **Colour:** Orange oxidized fines and surfaces, some unoxidized surfaces **Presence of Oxidation:** Surface oxidation of waste rock, matrix does not have significant oxidation **Percentage of Material Oxidized (%):** 30% surface oxidation **Sulphide Minerals Present:** Pyrite *Crystal Habit (Clusters, cubic):* Unknown/not observed Distribution (disseminated, veining, fracture fill): Unknown/not observed **Texture:** *Gradation:* Well graded, with material from 10-50 cm, cobbles 1-10 cm and fine silt/clay sized matrix *Matrix or Clast supported:* Mix of intact rock and fine weathered matrix material **Structure:** (ordering/layering/unstructured/blended) – Possible traffic surface at overburden/waste rock interface (appears compacted) **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Tensiometer Reading:** S1- 6 kPa; S2- 11 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S3-S1; TP-P1-S3-S2

Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ____________

Observations / Other work performed :
None

Photos of Completed Test Pit:
Photo 1 – TP-P1-S3 test pit profile looking east

Photo 2 - TP-P1-S3 test pit profile looking north east

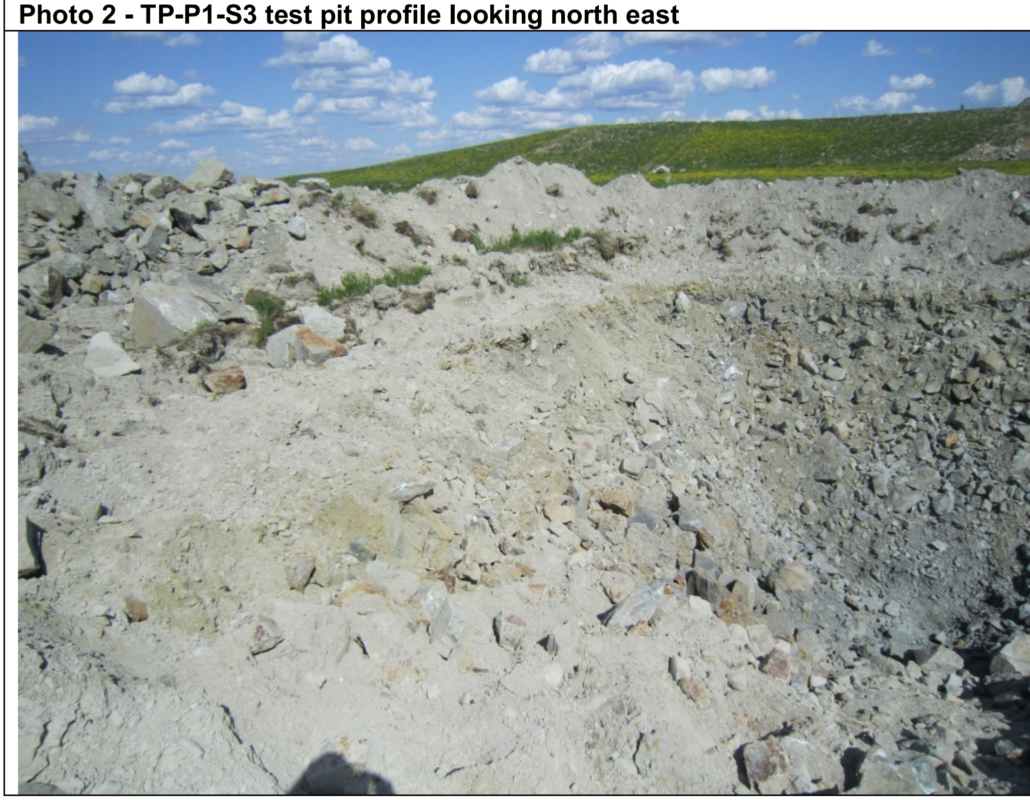
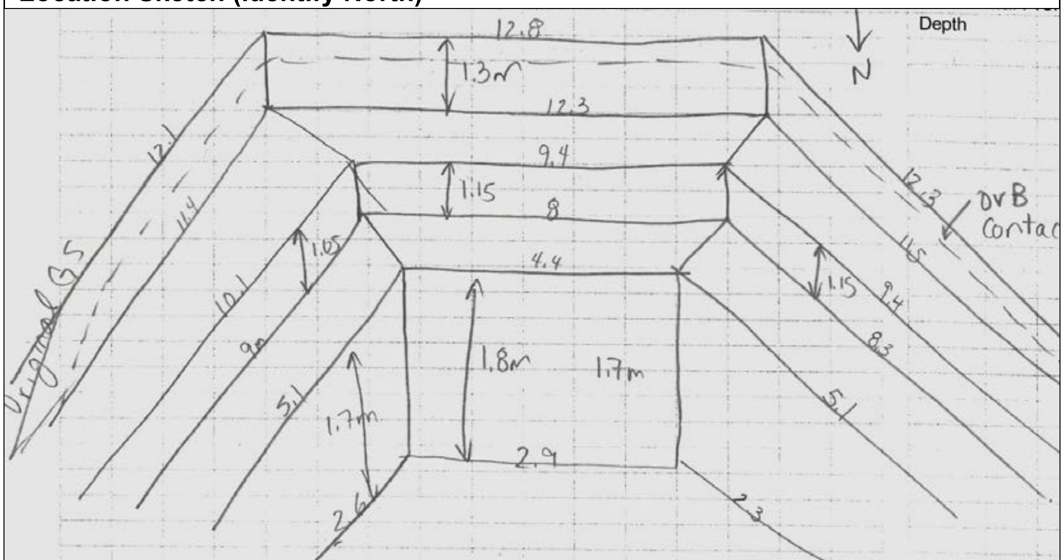


Photo 3 – TP-P1-S3 test pit profile looking south east

Test Pit Number :	TP-P1-S4	**Sampling Date/Time:**	Aug 16th 2011 9:00 am
Location :	Surface of Pile 1, on flat inner area of pile, near northwest corner		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 591829	**N:** 5540710
Weather conditions :	Overcast, cool, windy	**Sampled by :**	Aileen Cash/Pablo Urrutia

Location Sketch (identify North)



Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock pile cover **Depth:** 0.0-0.35 m (Some areas up to 0.55 m due to slope)	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand with rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** No oxidation in cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Silty sand with clasts/cobbles up to 15-20 cm, trace boulders up to 40 cm *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till).). Roots and vegetation present in upper 10-15 cm of profile. **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended, placed on a possible traffic surface **Angularity of Rocks:** Fine grained matrix with rounded glacial cobbles **Moisture:** Moist, dry at surface **Tensiometer Reading:** 30 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S4-S1

Unit: Waste rock **Depth:** 0.55-2.45 m	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow with some phenocrysts, trace Talc Chloride/Chloritic Greenstone **Colour:** Orange oxidized fines and surfaces, some unoxidized surfaces **Presence of Oxidation:** Trace surface oxidation on waste rock, matrix does not have significant oxidation **Percentage of Material Oxidized (%):** 10% surface oxidation **Sulphide Minerals Present:** Pyrite and pyrrhotite *Crystal Habit (Clusters, cubic):* Not Observed Distribution (disseminated, fracture fill): Not Observed **Texture:** *Gradation:* Well graded, with material from 70-80 cm to fine silt/clay sized *Matrix or Clast supported:* Mix of intact rock and fine matrix material, however clast supported **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended some coarser material with depth **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist to very moist **Tensiometer Reading:** 8.5 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S4-S2
Unit: Waste rock **Depth:** 2.45-4.25 m	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow with some veining, trace Talc Chloride/Chloritic Greenstone **Colour:** Grey to grey-black, trace orange oxidized surfaces **Presence of Oxidation:** Little visible surface oxidation, some small areas of oxidation present **Percentage of Material Oxidized (%):** <10% of material has presence of oxidation **Sulphide Minerals Present:** Pyrite and pyrrhotite *Crystal Habit (Clusters, cubic):* Not observed Distribution (disseminated, veining, fracture fill): Not observed **Texture:** *Gradation:* Fines in upper benches, average grain size of 5 cm, few large boulder sized particles *Matrix or Clast supported:* Mix of intact rock and fine matrix material **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended, sloughing in test pit **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Very moist **Tensiometer Reading:** 2 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S4-S3
Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant Water sample collected : ☐ Yes ☒ No Sample ID: ____________	
Observations / Other work performed : None	

Photos of Completed Test Pit:
Photo 1 – TP-P1-S4 test pit profile looking south

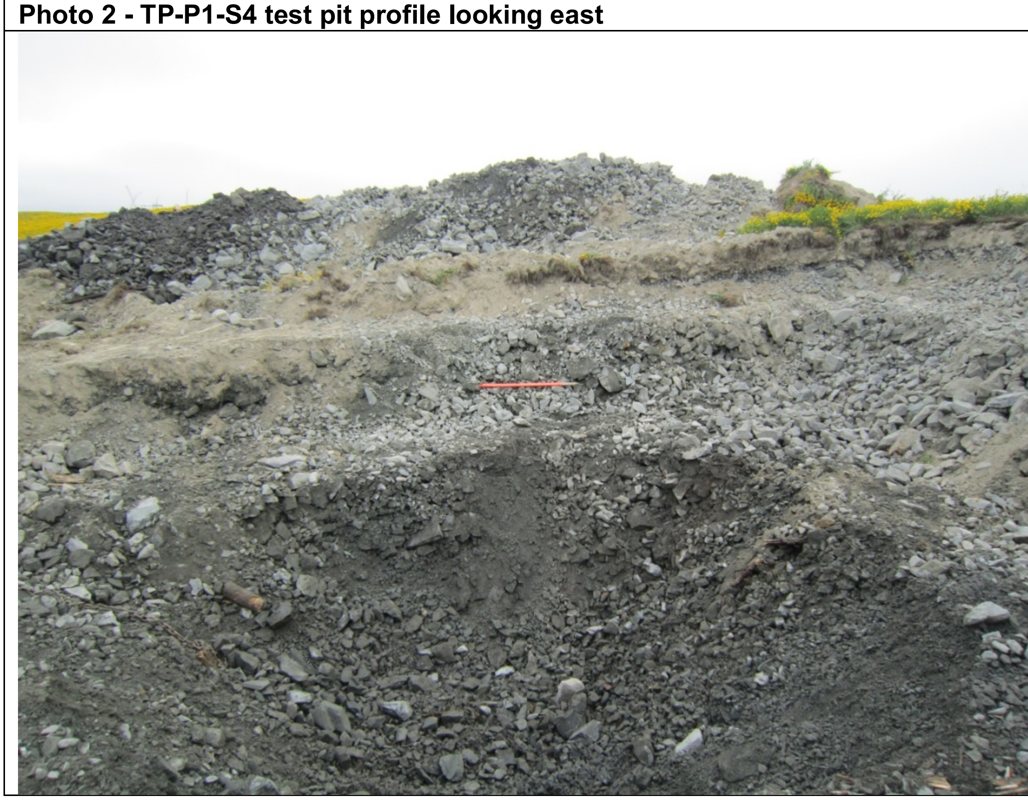
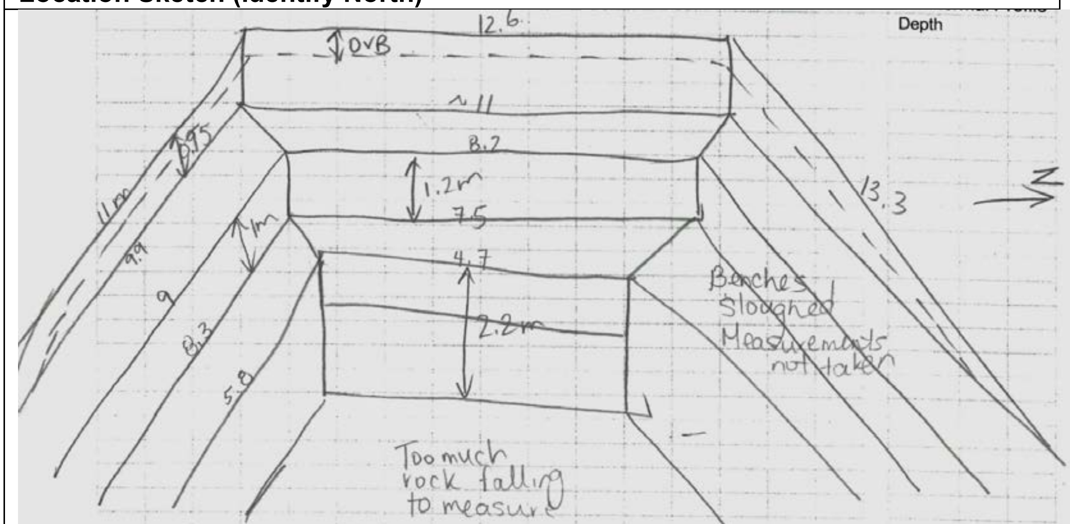
Photo 2 - TP-P1-S4 test pit profile looking east


Photo 3: TP-P1-S4 tensiometer installation on upper bench

Test Pit Number :	TP-P1-S5	**Sampling Date/Time:**	August 16th 2011 11:30 am
Location :	Northeast corner of Pile 1 on slope, near pile access road (near to open pit)		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 591929	**N:** 5540710
Weather conditions :	Sun and cloud, cool	**Sampled by :**	Aileen Cash/Pablo Urrutia

Location Sketch (identify North)



Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock pile cover **Depth:** 0.0-0.3 m (Some areas up to 0.65 m due to slope)	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand with rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** No oxidation in cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Silty sand with clasts/cobbles up to 15-20 cm *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Some dark peat overburden also present on top of oxidized rock (0.95-2.05 m) **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended **Angularity of Rocks:** Fine grained matrix with rounded glacial cobbles **Moisture:** Moist, dry at surface **Tensiometer Reading:** 50.4 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S5-S1
Unit: Waste rock	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow and Intermediate Intrusive,

Depth: 0.5-2.05 m	some Talc Chloride/Chloritic Greenstone **Colour:** Grey to black, some orange surface oxidation **Presence of Oxidation:** Trace surface oxidation on waste rock **Percentage of Material Oxidized (%):**<5% surface oxidation **Sulphide Minerals Present:** Pyrite and pyrrhotite *Crystal Habit (Clusters, cubic):* Not observed Distribution (disseminated, veining, fracture fill): Not observed **Texture:** *Gradation:* Blocky with large boulders up to one metre, matrix/fine grained material infilling between larger particles *Matrix or Clast supported:* Clast, mix of intact rock and fine weathered matrix material, some open voids are visible **Structure:** (ordering/layering/unstructured/blended) – Grain size increases with depth, material has open voids, is loose and settles easily **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Tensiometer Reading:** 21 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S5-S2
Unit: Waste rock **Depth:** 2.05-4.20 m	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow and Intermediate Intrusive, some Talc Chloride/Chloritic Greenstone **Colour:** Grey to grey-black, trace orange oxidized surfaces **Presence of Oxidation:** Little visible surface oxidation, some small areas of oxidation present on fracture surfaces **Percentage of Material Oxidized (%):**<5% **Sulphide Minerals Present:** Pyrite/pyrrhotite *Crystal Habit (Clusters, cubic):* Not observed Distribution (disseminated, veining, fracture fill): Disseminated **Texture:** *Gradation:* Very blocky, cobble sized particles 5-10 cm up to boulders 70-80 cm in width. Mean grain size approximately 10-15 cm. Fine material is sand sized and coarse. *Matrix or Clast supported:* Clast supported structure with less matrix material and open voids. **Structure:** (ordering/layering/unstructured/blended) – Coarsening downward, but material was loose and prone to sloughing **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Tensiometer Reading:** N/A – Too blocky and loose **Sample Taken:** Yes **Sample Number:** TP-P1-S5-S3

Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ______________________

Observations / Other work performed :
This test pit had large boulders and loose benches, making some measurements difficult. As a result, actual test pit depth is estimated.

Photos of Completed Test Pit:
Photo 1 – TP-P1-S5 test pit profile looking south

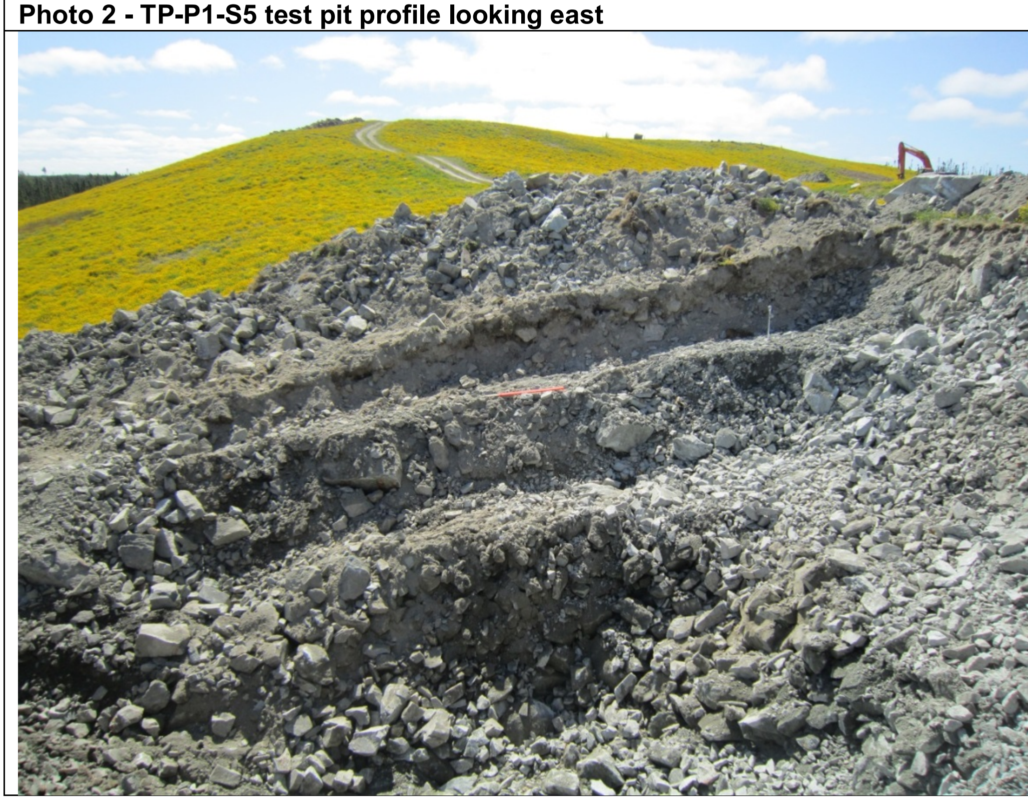
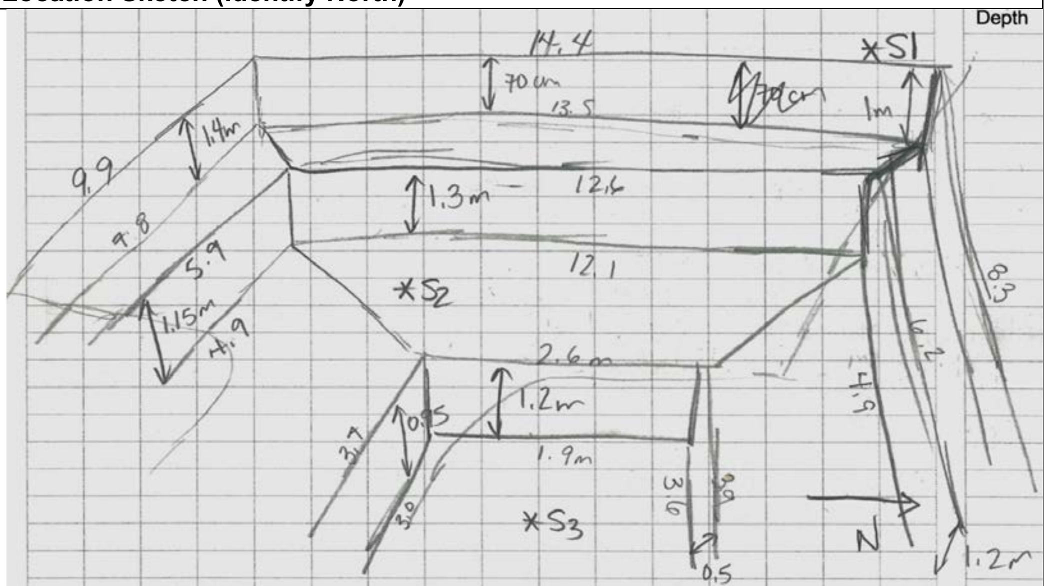
Photo 2 - TP-P1-S5 test pit profile looking east


Photo 3 – TP-P1-S5 tensiometer installation on upper bench

Photo 4 – TP-P1-S5 test pit wall looking west

Test Pit Number :	TP-P1-S6	**Sampling Date/Time:**	Aug 14th 2011 11:30 am
Location :	Northwest corner of Pile 1 on large flat lower dump area		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 591729	**N:** 5540610
Weather conditions :	Sunny, 25 C	**Sampled by :**	Aileen Cash/Pablo Urrutia
Location Sketch (identify North)			



Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock pile cover **Depth:** 0.0-0.3 m, some areas up to 0.5m	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand with rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** No oxidation in cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Silty sand with clasts/cobbles up to 15-20 cm *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Some dark peat overburden also present on top of oxidized rock (0.95-2.05 m) **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended **Angularity of Rocks:** Fine grained matrix with rounded glacial cobbles **Moisture:** Moist, dry at surface **Tensiometer Reading:** 17 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S6-S1
Unit: Waste rock	**Material Type:** Waste Rock **Rock Type:** Primarily Mafic Volcanic Flow

<table>
<tr><td>Depth: 0.50-3.5 m</td><td>Colour: Grey to black, some orange surface oxidation
Presence of Oxidation: Oxidation on surfaces and fractures – some areas with significant oxidation
Percentage of Material Oxidized (%): 50% surface oxidation
Sulphide Minerals Present: Pyrite
Crystal Habit (Clusters, cubic): Unknown
Distribution (disseminated, veining, fracture fill): Disseminated and fracture fill
Texture:
Gradation: Blocky with large boulders up to 2-3 m, average grain size is approximately 30 cm, with voids between boulders
Matrix or Clast supported: Mix of intact rock and fine matrix material, mainly clasts infilled with fines
Structure: (ordering/layering/unstructured/blended) – Grain size increases with depth, possible traffic surface at the base of the pit
Angularity of Rocks: Fine grained matrix with angular to very angular waste rock
Moisture: Moist fines, boulders are dry
Tensiometer Reading: 10 kPa
Sample Taken: Yes Sample Number: TP-P1-S6-S2</td></tr>
<tr><td>Unit: Waste rock

Depth: 3.5 m to End of Pit</td><td>Material Type: Waste Rock
Rock Type: Mafic Volcanic Flow (basalt)
Colour: Grey to grey-black
Presence of Oxidation: Little visible surface oxidation
Percentage of Material Oxidized (%): <5% of material has presence of oxidation
Sulphide Minerals Present: Pyrite
Crystal Habit (Clusters, cubic): Unknown
Distribution (disseminated, veining, fracture fill): Unknown
Texture:
Gradation: Base of the test pit gradation was much less than the upper benches with sand sized to 50 cm particles
Matrix or Clast supported: Dominated by matrix material – less large boulders
Structure: (ordering/layering/unstructured/blended) – Coarsening downward, but material was loose and prone to sloughing
Angularity of Rocks: Fine grained matrix with angular to very angular waste rock
Moisture: Moist
Tensiometer Reading: N/A – Too blocky and compacted
Sample Taken: Yes Sample Number: TP-P1-S6-S3</td></tr>
<tr><td colspan="2">Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ____________________</td></tr>
<tr><td colspan="2">Observations / Other work performed :
Operator had a difficult time creating benches due to the size of the waste rock – the test pit is dominated by large boulders and some boulders were too difficult to remove, resulting in sloughing in the pit</td></tr>
</table>

Photos of Completed Test Pit:

Photo 1 – TP-P1-S6 test pit profile looking west

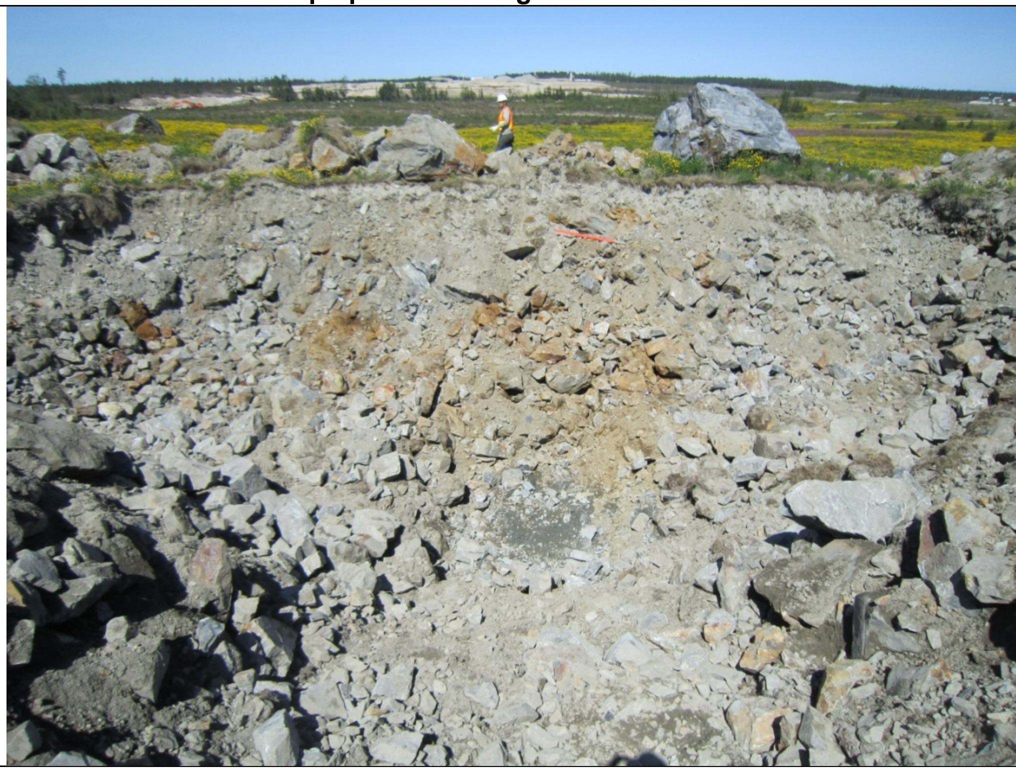


Photo 2 - TP-P1-S6 test pit profile looking east

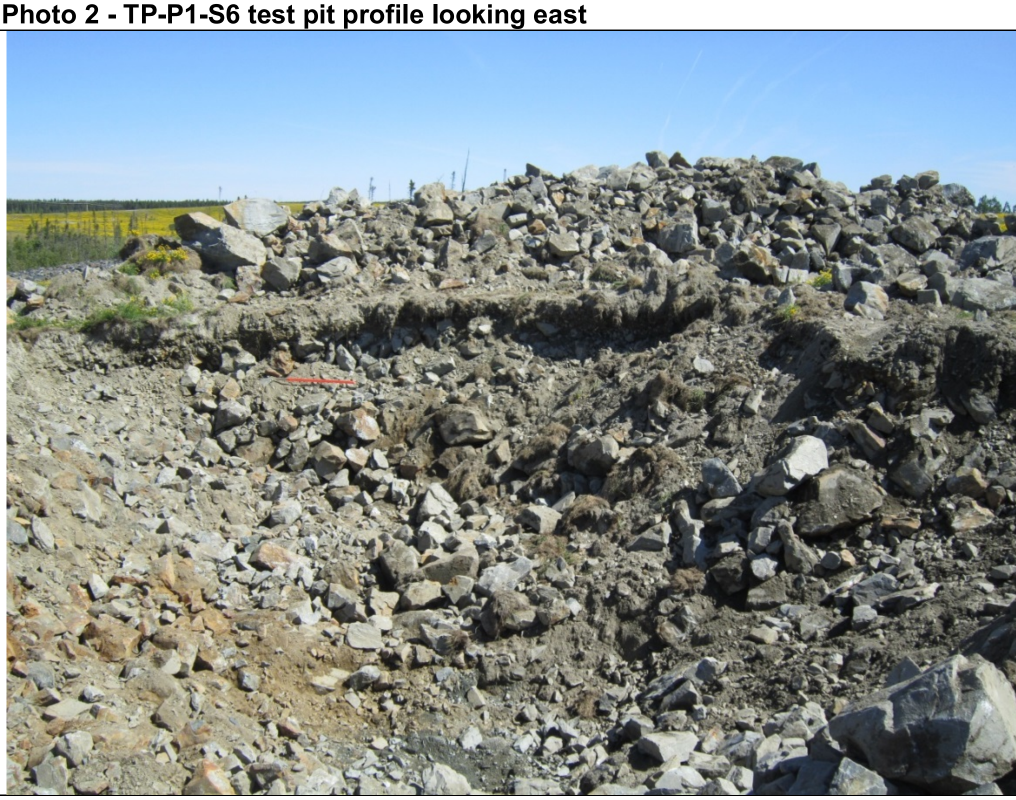


Photo 3: TP-P1-S6 tensiometer installation on upper bench in overburden material

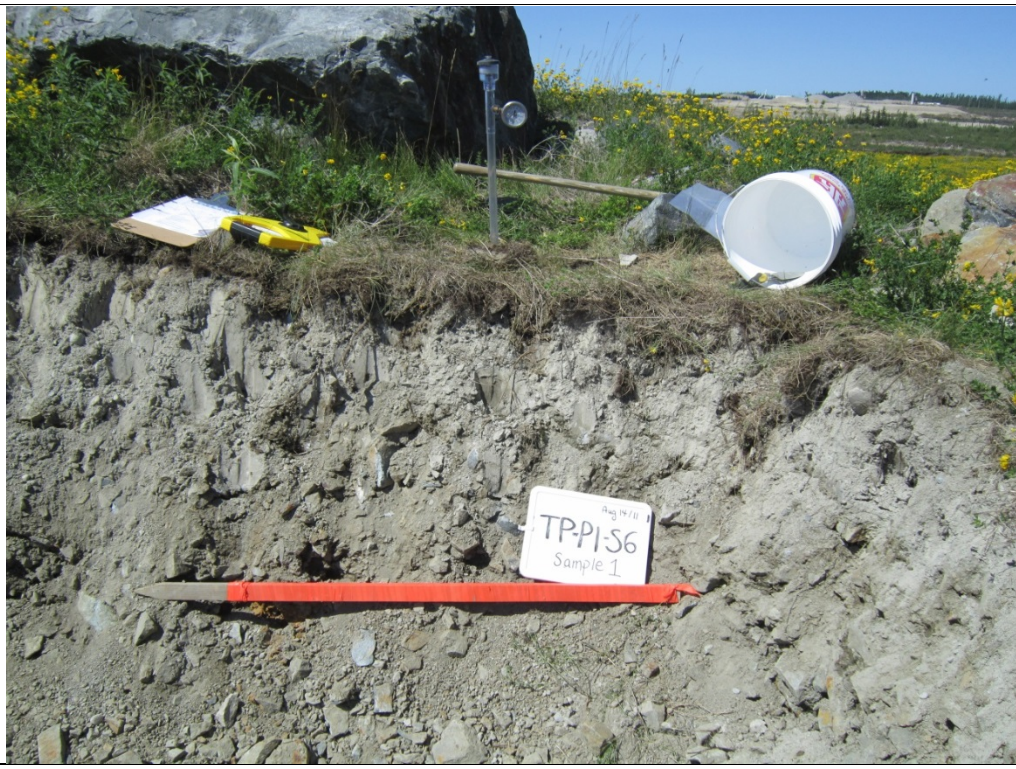
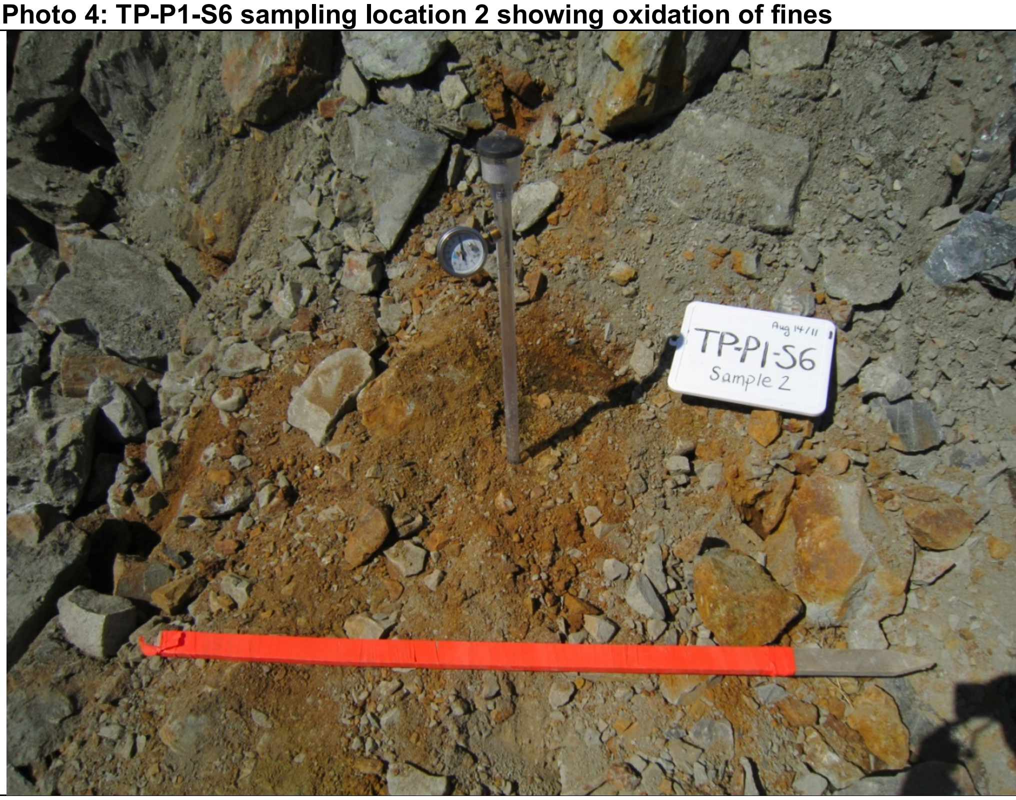
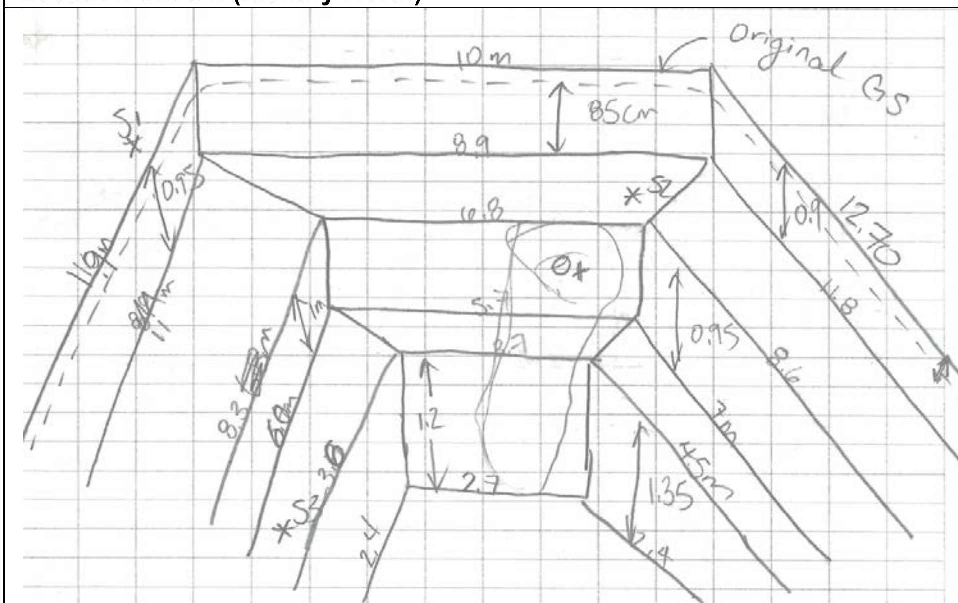


Photo 4: TP-P1-S6 sampling location 2 showing oxidation of fines



Test Pit Number :	TP-P1-S8	**Sampling Date/Time:**	Aug 15th 2011 9:00 am
Location :	Northwest corner of Pile 1 on large flat lower dump area		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 591929	**N:** 5540610
Weather conditions :	Sun, light wind	**Sampled by :**	Aileen Cash/Pablo Urrutia

Location Sketch (identify North)



Soil Unit and Depth (From Surface)	Description of Units
Unit: Waste rock pile cover **Depth:** 0.0-0.55 m	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand with rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** No oxidation in cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Silty sand with clasts/cobbles up to 15-20 cm *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Some dark peat overburden also present on top of cover, roots in upper profile **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended **Angularity of Rocks:** Fine grained matrix with rounded glacial cobbles **Moisture:** Moist, dry at surface **Tensiometer Reading:** 27 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S8-S1
Unit: Waste rock	**Material Type:** Waste Rock

Depth: 0.55-1.15 m	**Rock Type:** Mafic Volcanic Flow and Talc Chloride, some/trace Intermediate Intrusive **Colour:** Dark grey, some orange surface oxidation **Presence of Oxidation:** Oxidation on surfaces and fractures **Percentage of Material Oxidized (%):** 20% surface oxidation **Sulphide Minerals Present:** Pyrite, pyrrhotite, potassic alteration *Crystal Habit (Clusters, cubic):* Clusters Distribution (disseminated, veining, fracture fill): Disseminated **Texture:** *Gradation:* Sand and silt sized matrix with bolder and cobble sized partivles ranging from 1 cm to 100 cm. Average grain size is approximately 15 cm *Matrix or Clast supported:* Clast supported with matrix infill **Structure:** (ordering/layering/unstructured/blended) – Grain size increases with depth, possible traffic surface at the contact with the overburden **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist, dry at surface **Tensiometer Reading:** 15 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S8-S2
Unit: Waste rock **Depth:** 2.15-3.40 m	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow and Talc Chloride/Chloritic Greenstone (more TC than upper bench) **Colour:** Grey to grey-black with some oxidation on fracture surfaces **Presence of Oxidation:** Visible on fracture and joint surfaces of Mafic Volcanic Flow rock **Percentage of Material Oxidized (%):** 30% **Sulphide Minerals Present:** Pyrite/pyrrhotite *Crystal Habit (Clusters, cubic):* Not observed Distribution (disseminated, veining, fracture fill): Disseminated **Texture:** *Gradation:* Coarser particles near the middle to base of the excavation, boulders are up to 1-1.5 m with less fines *Matrix or Clast supported:* Dominated by clasts material – less fines **Structure:** (ordering/layering/unstructured/blended) – Coarsening downward, otherwise unstructured **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Tensiometer Reading:** 16 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S8-S3

Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ________________________

Observations / Other work performed :
Sloughing in of test pit occurred in some areas due to the large sized boulders – pit was difficult to excavate.

Photos of Completed Test Pit:
Photo 1 – TP-P1-S8 test pit profile looking south east

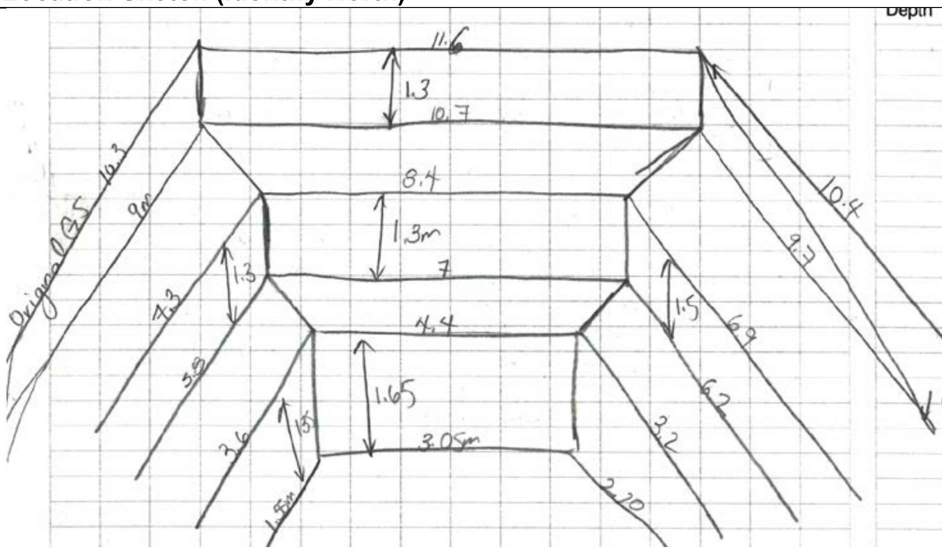
Photo 2 - TP-P1-S8 test pit profile looking east


Photo 3: TP-P1-S8 tensiometer installation on lower bench (Sample 3)

Photo 4: TP-P1-S8 waste rock excavated from test pit showing grain size range

Test Pit Number :	TP-P1-S9	**Sampling Date/Time:**	Aug 15th 2011 12:30 pm
Location :	East slope of main berm, adjacent to access road		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 592027	**N:** 5540612
Weather conditions :	Sun, light wind	**Sampled by :**	Aileen Cash/Pablo Urrutia

Location Sketch (identify North)



Soil Unit and Depth (From Surface)	Description of Units
Unit: Waste rock pile cover **Depth:** 0.0-0.4 m (Some areas up to 0.60 m due to slope)	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand with rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** No oxidation in cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Sand and silt with clasts/cobbles from 1 cm up to 40 cm, trace boulders up to 50 cm *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Roots and vegetation present in upper profile. **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended **Angularity of Rocks:** Fine grained matrix with rounded glacial cobbles **Moisture:** Moist, dry at surface **Tensiometer Reading:** 42 kPa **Sample Taken:** No **Sample Number:** N/A
Unit: Waste rock	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow with veining, Talc Chloride

Depth: 0.4-2.30 m	with potassic alteration, some/trace Intermediate Intrusive **Colour:** Orange and oxidized (surfaces of particles and fine fraction) **Presence of Oxidation:** Significant oxidation on surfaces and fractures **Percentage of Material Oxidized (%):** 90% surface oxidation **Sulphide Minerals Present:** Pyrrhotite, pyrite *Crystal Habit (Clusters, cubic):* Clusters and associated fractures and veins *Distribution (disseminated, veining, fracture fill):* Disseminated and fracture fill/veinlets **Texture:** *Gradation:* Fine to coarse sand fine fraction with gravel to boulder sized particles 5-10 cm, with larger boulders, greater fine fraction in upper bench in comparison to lower bench *Matrix or Clast supported:* Mix of intact rock and fine matrix **Structure:** (ordering/layering/unstructured/blended) – Grain size increases with depth, possible traffic surface at the contact with the overburden **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Tensiometer Reading:** S1 – 39.5 kPa, S2 – 16-18 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S9-S1 and TP-P1-S9-S2
Unit: Waste rock **Depth:** 2.3-3.40 m	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow with veining, Talc Chloride with potassic alteration, some/trace Intermediate Intrusive **Colour:** Orange oxidiation **Presence of Oxidation:** Significant oxidation - surfaces and fractures **Percentage of Material Oxidized (%):** 95% oxidation **Sulphide Minerals Present:** Pyrrhotite/pyrite *Crystal Habit (Clusters, cubic):* In MF and II rocks, crystal habit not observed *Distribution (disseminated, veining, fracture fill):* Disseminated, some fracture fill and in veins **Texture:** *Gradation:* Coarser particles near the middle to base of the excavation, with boulders up to 0.5 m. Fines are highly oxidized *Matrix or Clast supported:* Less fines present in lower bench, more large clasts. **Structure:** (ordering/layering/unstructured/blended) – Coarsening downward, but otherwise unstructured, however it is likely this is an area where tipping occurred **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Tensiometer Reading:** 8 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S9-S3

Reason for ending Test Pit	☐ Limits of excavator	☒ Target depth	☐ Other					
Presence of water:	☐ Yes	☒ No	If Yes :	☐ Flowing	☐ Stagnant			
Water sample collected :	☐ Yes	☒ No	Sample ID: ______________________					

Observations / Other work performed : None

Photos of Completed Test Pit:

Photo 1 – TP-P1-S9 test pit profile looking west

Photo 2 - TP-P1-S9 test pit profile looking east

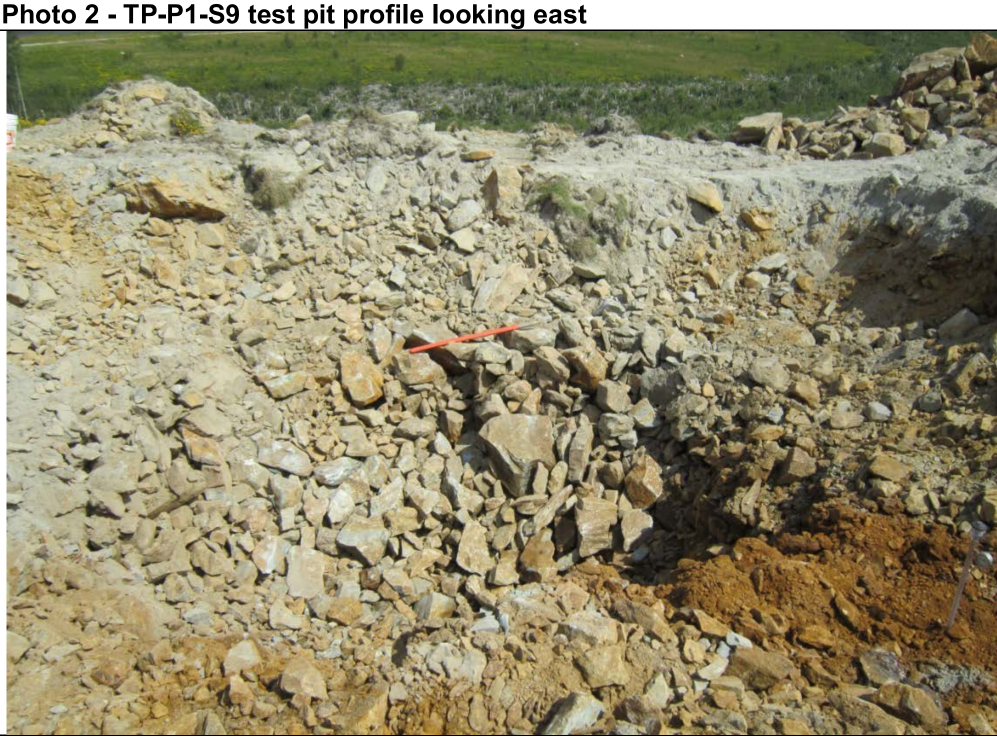
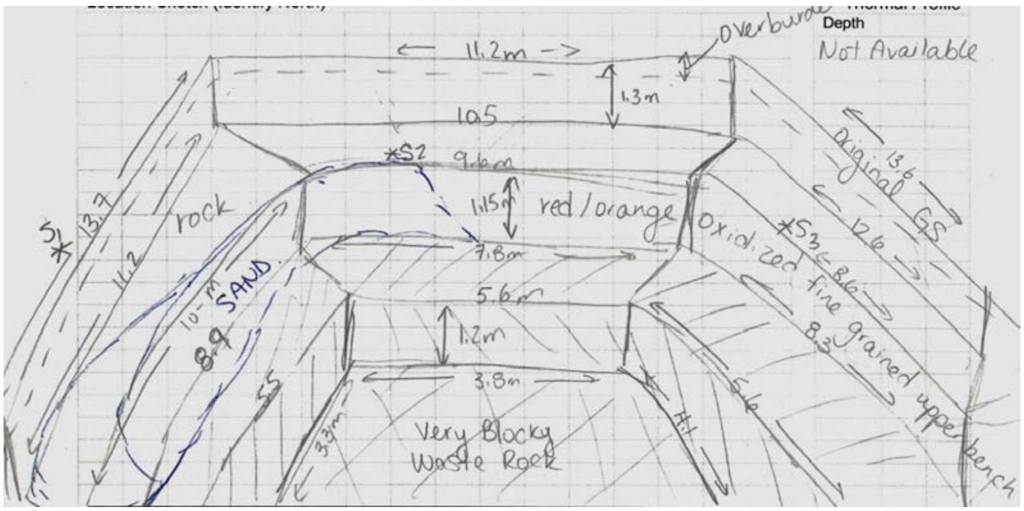


Photo 3 – TP-P1-S9 tensiometer installation on lower bench (Sample 3)

Photo 4 – TP-P1-S9 waste rock excavated from test pit showing potassic alteration

Test Pit Number :	TP-P1-S10	**Sampling Date/Time:**	Aug 13th 2011 9:00 am
Location :	South west berm of Pile 1, at toe of small berm		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 591729	**N:** 5540510
Weather conditions :	Cloudy and overcast, light rain during logging	**Sampled by :**	Aileen Cash/Pablo Urrutia

Location Sketch (identify North)



Soil Unit and Depth (From Surface)	Description of Units
Unit: Waste rock pile cover **Depth:** 0.0-0.3 m, , some areas up to 0.4 m	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand with rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** No oxidation in cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Silty sand with clasts/cobbles up to 15-20 cm *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Roots and vegetation present in upper profile. **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended. placed on a possible traffic surface **Angularity of Rocks:** Fine grained matrix with rounded glacial cobbles **Moisture:** **Tensiometer Reading:** 10 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S10-S1
Unit: sAND **Depth:** 1.3-1.55 m	**Material Type:** Sand **Rock Type:** N/A

	Colour: White to light brown **Presence of Oxidation:** No oxidation in sand, some waste rock mixed into sand with oxidized surfaces **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None (<0.01%) *Crystal Habit (Clusters, cubic):* N/A Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Fine to medium sand sized particles, some waste rock boulders in sand 10-50 cm *Matrix or Clast supported:* Horizon of sand in waste rock **Structure:** (ordering/layering/unstructured/blended) – No visible structure, sand is placed on very large waste rock boulders, and is located only on the east side of the pit **Angularity of Rocks:** N/A – Waste rock is angular **Moisture:** Moist to wet **Tensiometer Reading:** 5 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S10-S2
Unit: Waste rock, upper bench **Depth:** 0.4-1.55 m	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow, Intermediate Intrusive, some/trace Talc Chloride with potassic alteration **Colour:** Red/orange and oxidized surfaces, some grey-black waste rock **Presence of Oxidation:** Significant oxidation on surfaces of large boulders **Percentage of Material Oxidized (%):**80-90% surface oxidation, fine fraction is oxidized **Sulphide Minerals Present:** Pyrite, some potassic alteration *Crystal Habit (Clusters, cubic):* Not observed Distribution (disseminated, veining, fracture fill): Disseminated and fracture fill/joint surfaces **Texture:** *Gradation:* Very fine matrix (silt and sand sized) with gravel to cobble sized waste rock particles from 2 cm -150 cm *Matrix or Clast supported:* Both clasts and matrix dominate this bench **Structure:** (ordering/layering/unstructured/blended) – Grain size increases with depth, possible traffic surface at the contact with the overburden **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist to wet **Tensiometer Reading:** 6 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S10-S3
Unit: Waste rock, upper bench **Depth:** 1.15 m to 3.40 m	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow with some potassic alterartion and veining, minor Talc Chloride and Intermediate Intrusive **Colour:** Grey with surface oxidation, less oxidation than upper bench **Presence of Oxidation:** Some surface oxidation on boulders **Percentage of Material Oxidized (%):**25-40%

	Sulphide Minerals Present: Pyrrhotite/pyrite, <1% in the rocks *Crystal Habit (Clusters, cubic):* Not observed Distribution (disseminated, veining, fracture fill): Disseminated, some fracture fill and in veins **Texture:** *Gradation:* Large boulders ranging from 0.5 m to 2 m, with less fine material and some open voids *Matrix or Clast supported:* Bouldery – clast supported with little matrix **Structure:** (ordering/layering/unstructured/blended) – Coarsening downward, but otherwise unstructured **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** N/A **Tensiometer Reading:** N/A **Sample Taken:** No **Sample Number:** N/A

Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ______________________

Observations / Other work performed :
Very large boulders at the bottom of the test pit, overlain with finer waste rock and sand. The presence of sand was not seen in any other test pits and is not related to the waste rock material – could be overburden.

Photos of Completed Test Pit:

Photo 1 – TP-P1-S10 test pit profile looking south

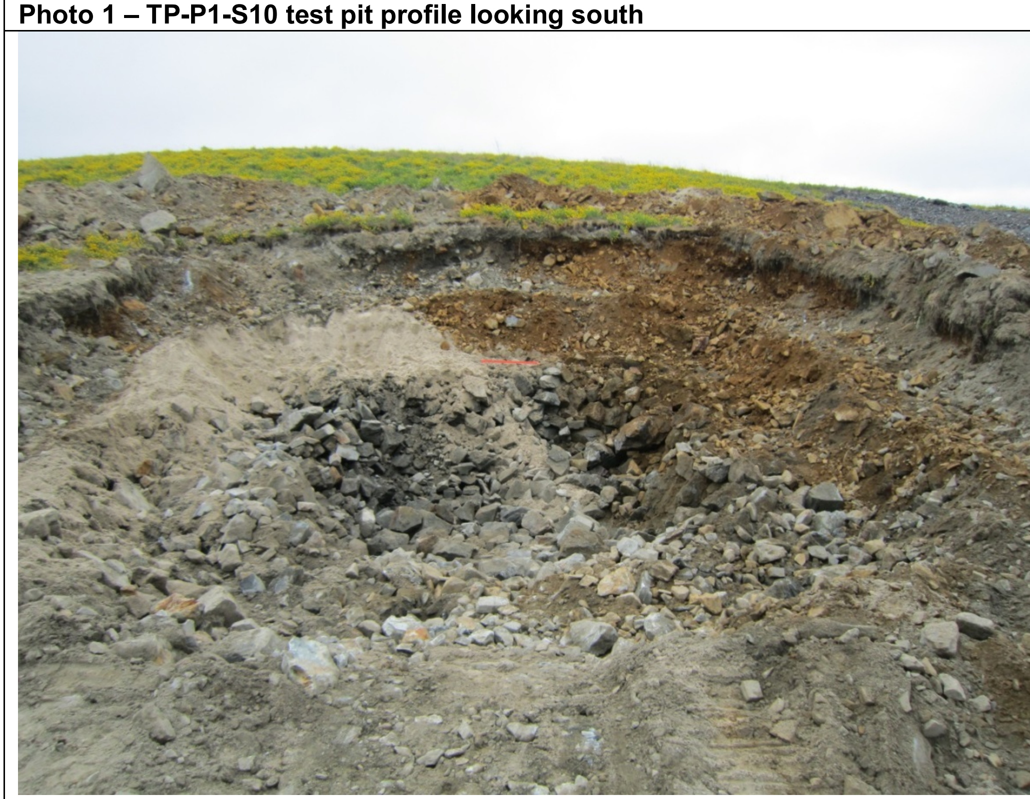


Photo 2 - TP-P1-S10 test pit profile looking east showing sand lens in test pit

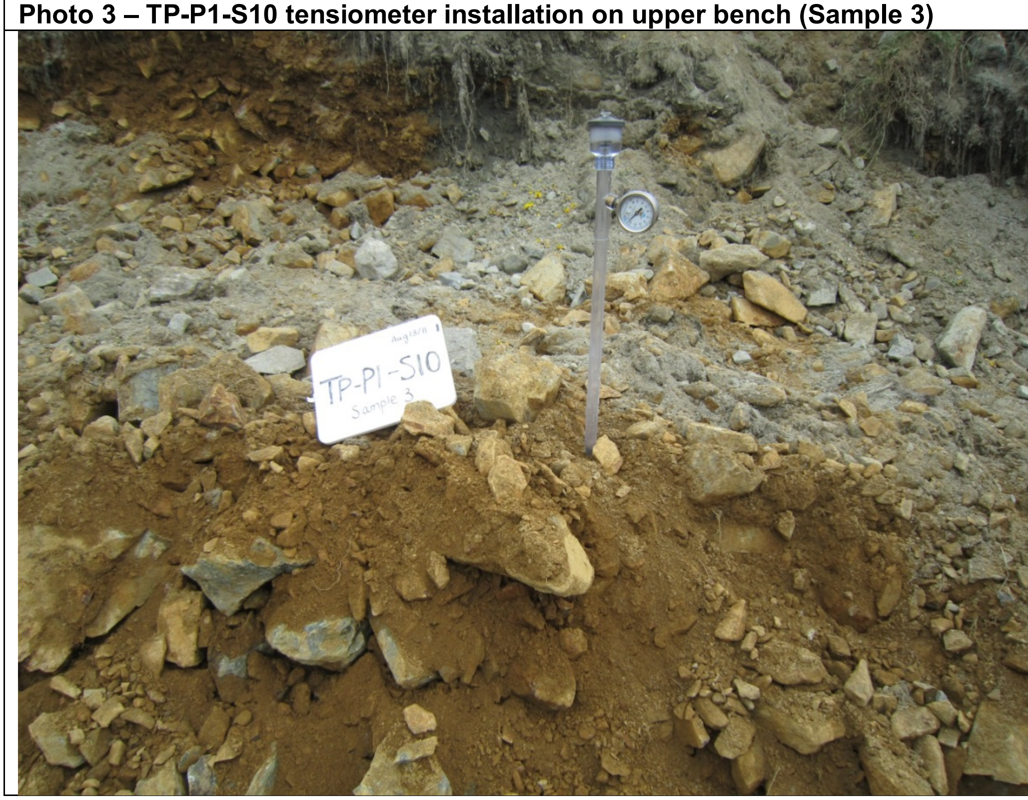
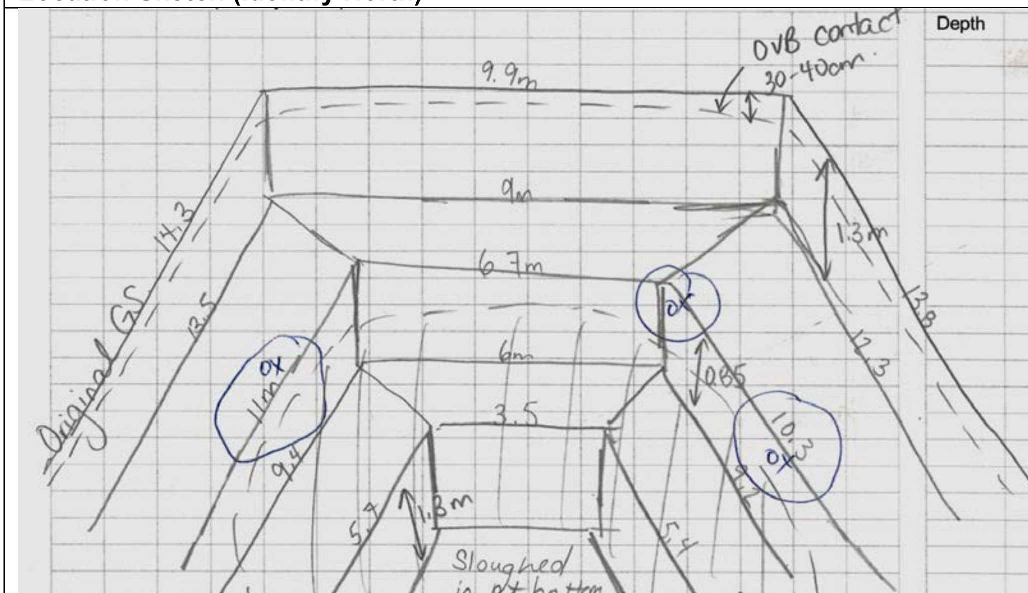
Photo 3 – TP-P1-S10 tensiometer installation on upper bench (Sample 3)


Photo 4 – TP-P1-S10 waste rock excavated from test pit showing potassic alteration

Test Pit Number :	TP-P1-S11	**Sampling Date/Time:**	August 13th 2011 12:00 am
Location :	Pile 1, lower bench is centre of waste rock pile		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 591829	**N:** 5540510
Weather conditions :	Overcast, cool	**Sampled by :**	Aileen Cash/Pablo Urrutia
Location Sketch (identify North)			



Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock pile cover **Depth:** 0.0-0.3 m, , some areas up to 0.4 m	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand with rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** No oxidation in cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Silty sand with clasts/cobbles up to 15-20 cm *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Roots and vegetation present in upper profile. **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended **Angularity of Rocks:** Fine grained matrix with rounded glacial cobbles **Moisture:** Moist to wet **Tensiometer Reading:** 11 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S11-S1
Unit: Waste rock	**Material Type:** Waste Rock

Depth: 0.4-2.0 m	**Rock Type:** Chert Zone (CH), Mafic Volcanic Flow, some Intermediate Intrusive **Colour:** Red/purple chert. Black-grey with orange oxidized surfaces **Presence of Oxidation:** Surface oxidation and potassic alteration and oxidation in fractures and joints **Percentage of Material Oxidized (%):**70% surface oxidation, fine fraction has some oxidation **Sulphide Minerals Present:** Pyrite/pyrrhotite, potassic alteration *Crystal Habit (Clusters, cubic):* Clusters Distribution (disseminated, veining, fracture fill): Disseminated **Texture:** *Gradation:* Fine sand sized matrix with gravel sized particles up to boulders of 0.7 m *Matrix or Clast supported:* Both clasts and matrix dominate this bench **Structure:** (ordering/layering/unstructured/blended) – Possible traffic surface at the contact with the overburden **Angularity of Rocks:** Fine to coarse grained matrix, angular to sub angular waste rock **Moisture:** Moist, dry at surface **Tensiometer Reading:** 3 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S11-S2, TP-P1-S11-S3
Unit: Waste rock **Depth:** 2.0 m to 3.45m	**Material Type:** Waste Rock **Rock Type:** Intermediate Intrusive, Mafic Volcanic Flow with some Chert/Mineralization Zone **Colour:** Grey with orange surface oxidation, Some purple potassic alteration **Presence of Oxidation:** Surface oxidation and potassic alteration and oxidation in fractures and joints **Percentage of Material Oxidized (%):**15-20% **Sulphide Minerals Present:** Pyrrhotite/pyrite, <1% in the rocks, some in chert *Crystal Habit (Clusters, cubic):* Not observed Distribution (disseminated, veining, fracture fill): Disseminated **Texture:** *Gradation:* Very blocky lower bench with particles ranging from gravel sized to large boulders up to 1 m *Matrix or Clast supported:* Bouldery – clast supported with little matrix **Structure:** (ordering/layering/unstructured/blended) – Coarsening downward, but otherwise unstructured **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Tensiometer Reading:** 5 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S11-S4

Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ______________________

Observations / Other work performed : Very large boulders at the bottom of the test pit resulted in difficult excavation of the test pit and sloughing
Photos of Completed Test Pit:
Photo 1 – TP-P1-S11 test pit profile looking north

Photo 2 - TP-P1-S11 tensiometer installation on upper bench (Sample 2)

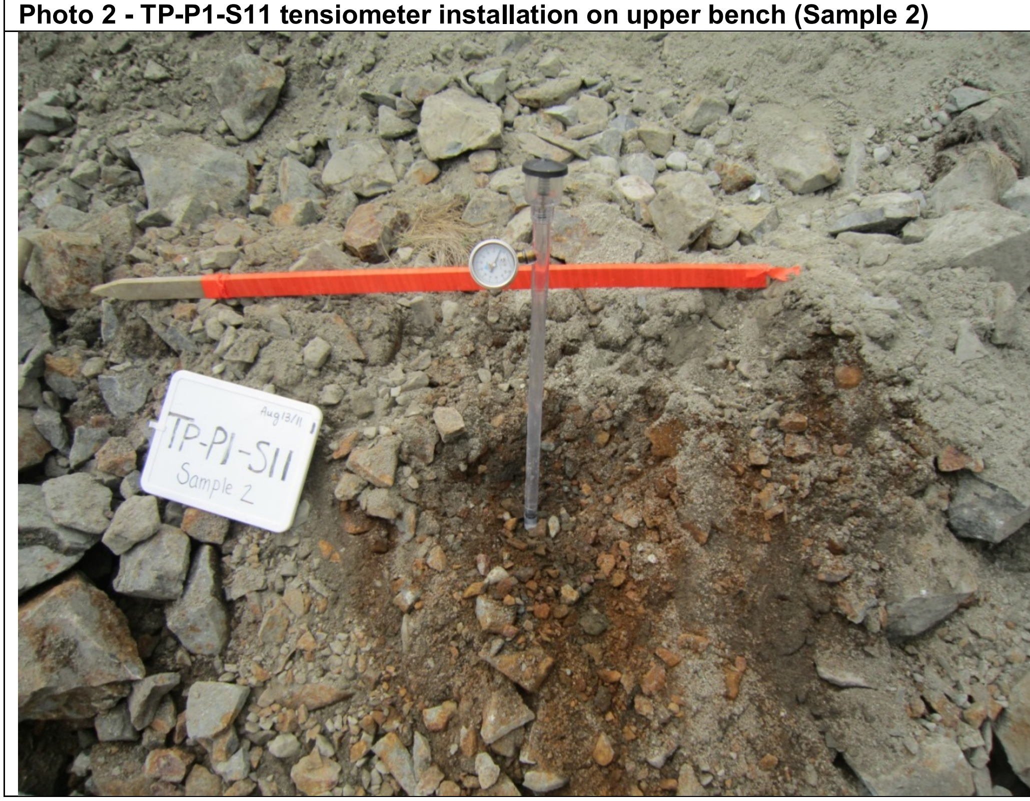
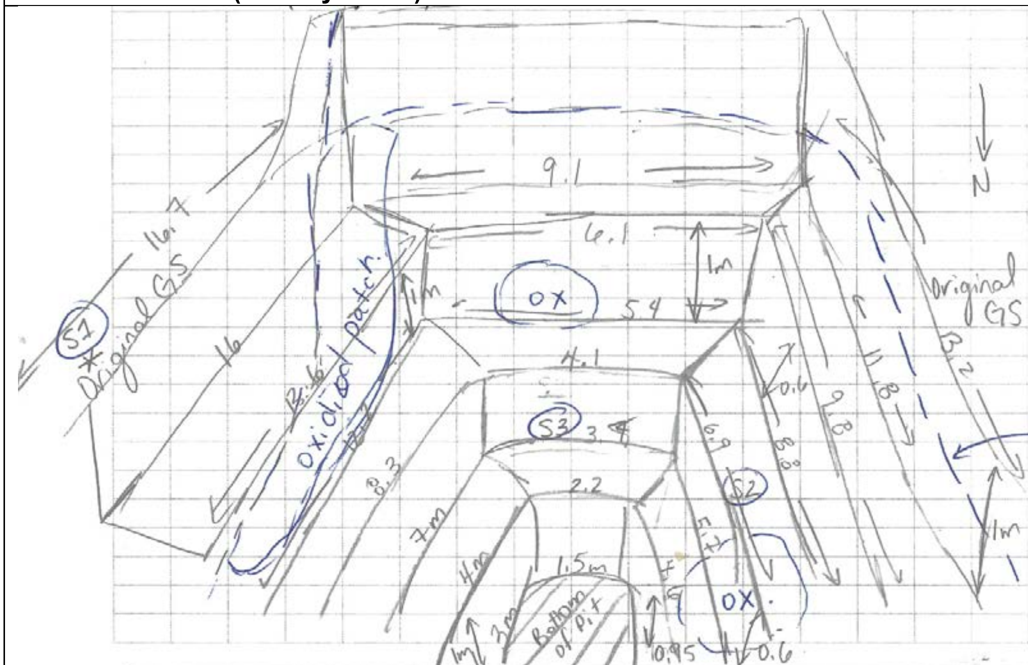


Photo 3 – TP-P1-S11 tensiometer installation on upper bench (Sample 3)

Photo 4 – TP-P1-S11 waste rock excavated from test pit showing grain size range

Test Pit Number :	TP-P1-S14	**Sampling Date/Time:**	August 12th 2011 10:30 am
Location :	Pile 1, lower bench is centre of waste rock pile		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 591829	**N:** 5540410
Weather conditions :	Sun and Cloud	**Sampled by :**	Aileen Cash/Pablo Urrutia
Location Sketch (identify North)			



Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock pile cover **Depth:** 0.0-0.5 m, , some areas up to 1.1 m	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand with rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** No oxidation in cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Sand and silt with clasts/cobbles from 1 cm up to 15 cm, trace boulders up to 50 cm *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Roots and vegetation present in upper profile. **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended, placed on a possible traffic surface **Angularity of Rocks:** Fine grained matrix with rounded glacial cobbles **Moisture:** Moist, dry at surface **Tensiometer Reading:** 16 kPa

	Sample Taken: Yes **Sample Number:** TP-P1-S14-S1
Unit: Waste rock **Depth:** 0.4-2.0 m	**Material Type:** Waste Rock **Rock Type:** Primarily Mafic Volcanic Flow and Talc Chloride/Chloritic Greenstone, some Intermediate Intrusive **Colour:** Grey rock with orange surface oxidation, and oxidized orange fines **Presence of Oxidation:** Surface oxidation and oxidized fine fraction **Percentage of Material Oxidized (%):**80% surface oxidation, fine fraction has some oxidation **Sulphide Minerals Present:** Pyrite/pyrrhotite, <1%, potassic alteration *Crystal Habit (Clusters, cubic):* Crystal habit not observed Distribution (disseminated, veining, fracture fill): Fracture fill **Texture:** *Gradation:* Fine sand sized matrix with gravel sized particles up to boulders of 1.0 m *Matrix or Clast supported:* Both clasts and matrix dominate this bench **Structure:** (ordering/layering/unstructured/blended) – Possible traffic surface at the contact with the overburden **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Tensiometer Reading:** 7 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S14-S2
Unit: Waste rock **Depth:** 2.0 m to 3.45 m	**Material Type:** Waste Rock **Rock Type:** Intermediate Intrusive, Mafic Volcanic Flow, Talc Chloride **Colour:** Grey with orange surface oxidation **Presence of Oxidation:** Surface oxidation on large size fraction, potassic alteration on surface of waste rock **Percentage of Material Oxidized (%):** 60% **Sulphide Minerals Present:** Pyrite/pyrrhotite *Crystal Habit (Clusters, cubic):* Cubic Distribution (disseminated, veining, fracture fill): Fracture fill **Texture:** *Gradation:* Ranges from fines to cobbles and boulders 10-40 cm and larger up to 1 to 2 m *Matrix or Clast supported:* Bouldery – clast supported with fine fraction filling in voids **Structure:** (ordering/layering/unstructured/blended) – Unstructured/blended, no visible layering, larger particle size with depth **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Tensiometer Reading:** N/A too blocky **Sample Taken:** Yes **Sample Number:** TP-P1-S14-S3
Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant	

Observations / Other work performed : Waste rock in test pit is relatively uniform

Photos of Completed Test Pit:

Photo 1 – TP-P1-S14 test pit profile looking south

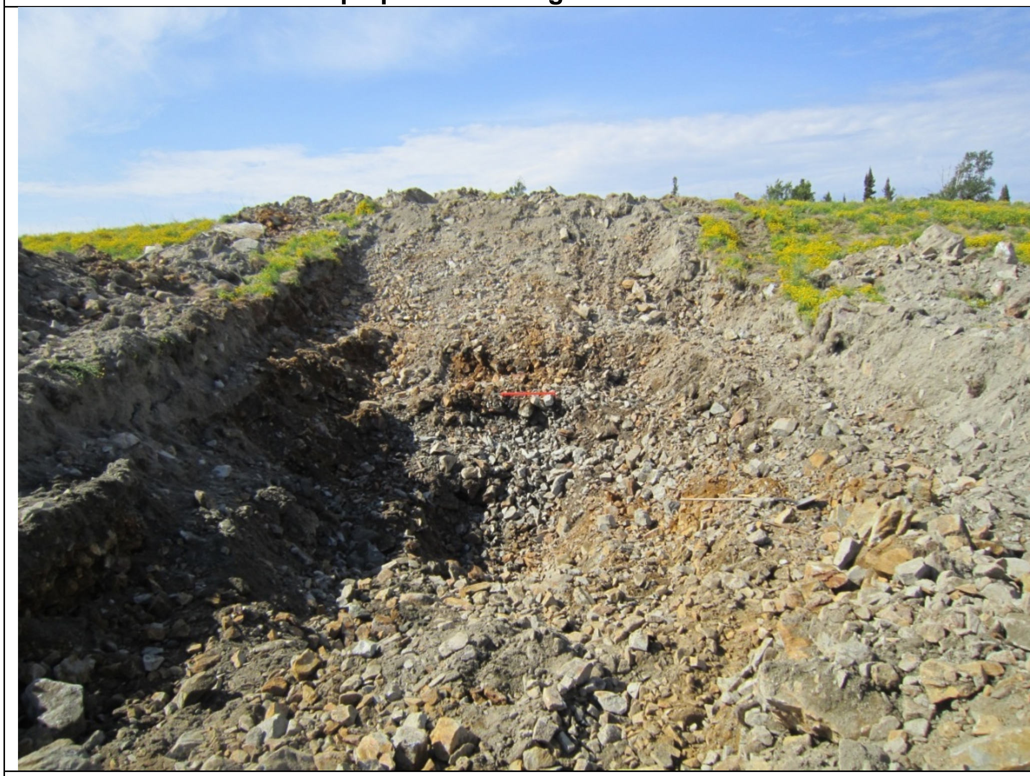


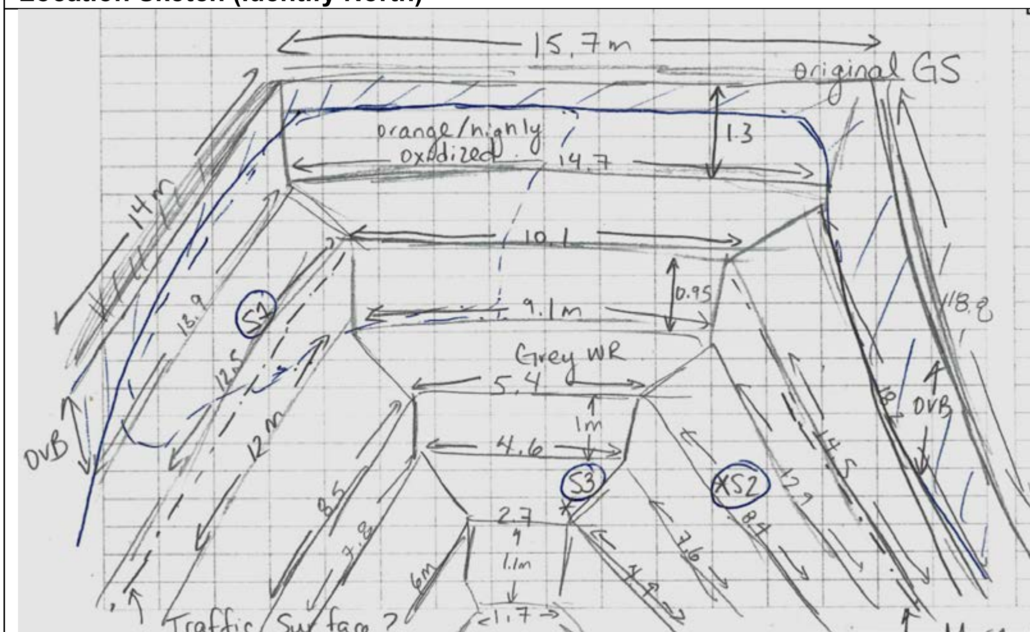
Photo 2 - TP-P1-S14 tensiometer installation on lower bench (Sample 3)

Photo 3 – TP-P1-S14 test pit profile looking south east

Photo 4 – TP-P1-S14 waste rock excavated from test pit showing grain size range

Test Pit Number :	TP-P1-S15	**Sampling Date/Time:**	August 12th 2011 2:00 pm
Location :	Pile 1, lower bench is centre of waste rock pile		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 591915	**N:** 5540412
Weather conditions :	Sun and Cloud	**Sampled by :**	Aileen Cash/Pablo Urrutia

Location Sketch (identify North)



Soil Unit and Depth (From Surface)	Description of Units
Unit: Waste rock pile cover **Depth:** 0.0-0.5 m, , some areas up to 0.7 m	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand with rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** No oxidation in cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Sand and silt with clasts/cobbles from 1 cm up to 15 cm, trace boulders up to 50 cm *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Roots and vegetation present in upper profile. **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended, placed on a possible traffic surface **Angularity of Rocks:** Fine grained matrix with rounded glacial cobbles **Moisture:** Moist, dry at surface **Tensiometer Reading:** 16 kPa **Sample Taken:** No **Sample Number:** N/A

Unit: Waste rock **Depth:** 0.5 m-2.25 m	**Material Type:** Waste Rock **Rock Type:** Talc Chloride/Chloritic Greenstone, Mafic Volcanic Flow/Volcanics, Intermediate Intrusive **Colour:** Grey rock with orange surface oxidation, and oxidized orange fines **Presence of Oxidation:** High amount of surface oxidation and oxidized fine fraction (primarily in sampling area) **Percentage of Material Oxidized (%):**80% surface oxidation, fine fraction is oxidized. Sample location is 100% oxidized, and some of the top bench is unoxidized **Sulphide Minerals Present:** Pyrite/pyrrhotite, <1%, potassic alteration *Crystal Habit (Clusters, cubic):* Crystal habit not observed Distribution (disseminated, veining, fracture fill): Fracture fill **Texture:** *Gradation:* Fine sand sized matrix with gravel sized particles up to boulders of 20-40 cm *Matrix or Clast supported:* Fine fraction is a large component in highly oxidized areas **Structure:** (ordering/layering/unstructured/blended) – Possible traffic surface at the contact with the overburden **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Wet **Tensiometer Reading:** 0 kPa - Rain **Sample Taken:** Yes **Sample Number:** TP-P1-S15-S1
Unit: Waste rock **Depth:** 2.25 m to 3.25 m	**Material Type:** Waste Rock **Rock Type:** Intermediate Intrusive, Mafic Volcanic Flow, some Talc Chloride **Colour:** Grey with orange surface oxidation **Presence of Oxidation:** Surface oxidation visible on particle surfaces **Percentage of Material Oxidized (%):**40% **Sulphide Minerals Present:** Pyrite/pyrrhotite *Crystal Habit (Clusters, cubic):* Not observed Distribution (disseminated, veining, fracture fill): Fracture/joint fill **Texture:** *Gradation:* Sand sized to 1-2 cm coarse sand matrix with 2-10 cm cobbles, some large boulders 40 cm to 1 m. *Matrix or Clast supported:* Both clasts and matrix dominate this bench **Structure:** (ordering/layering/unstructured/blended) – Unstructured/blended, no visible layering **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Wet **Tensiometer Reading:** 0 kPa - Rain **Sample Taken:** Yes **Sample Number:** TP-P1-S15-S2
Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant	
Observations / Other work performed : Coarser material at the base of the test pit, and oxidation is focused in the upper 2 m which is finer grained material.	

Photos of Completed Test Pit:
Photo 1 – TP-P1-S15 test pit profile looking south

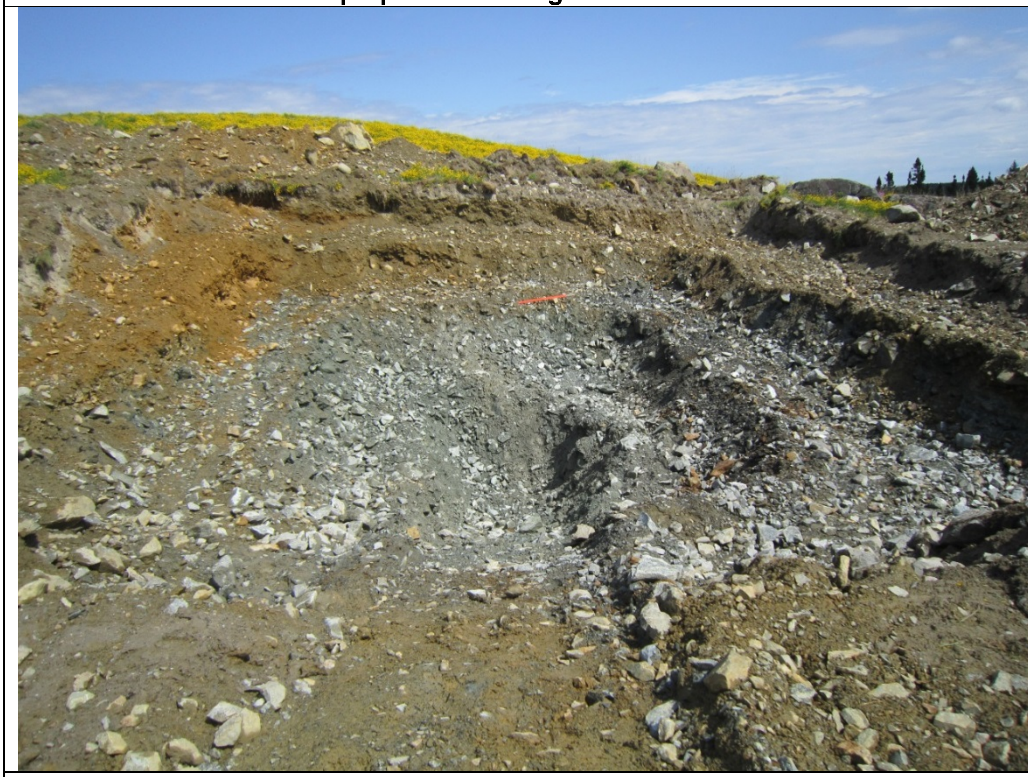


Photo 2 - TP-P1-S15 tensiometer installation on upper bench (Sample 1)

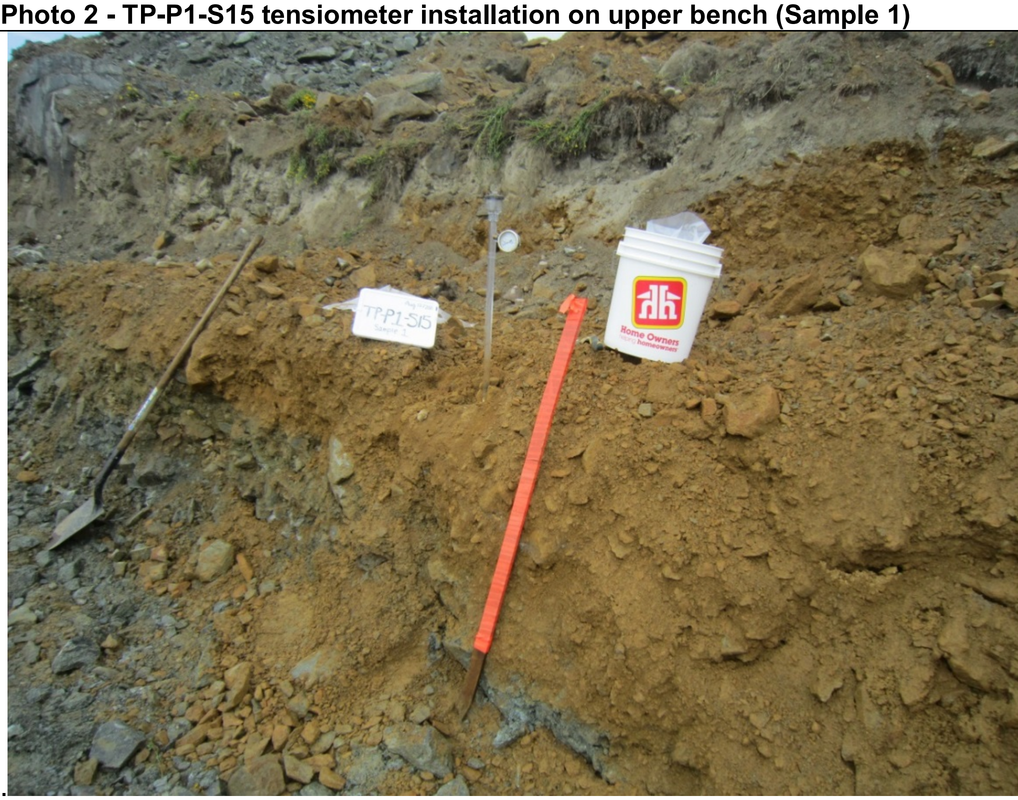


Photo 3 – TP-P1-S15 test pit profile looking east

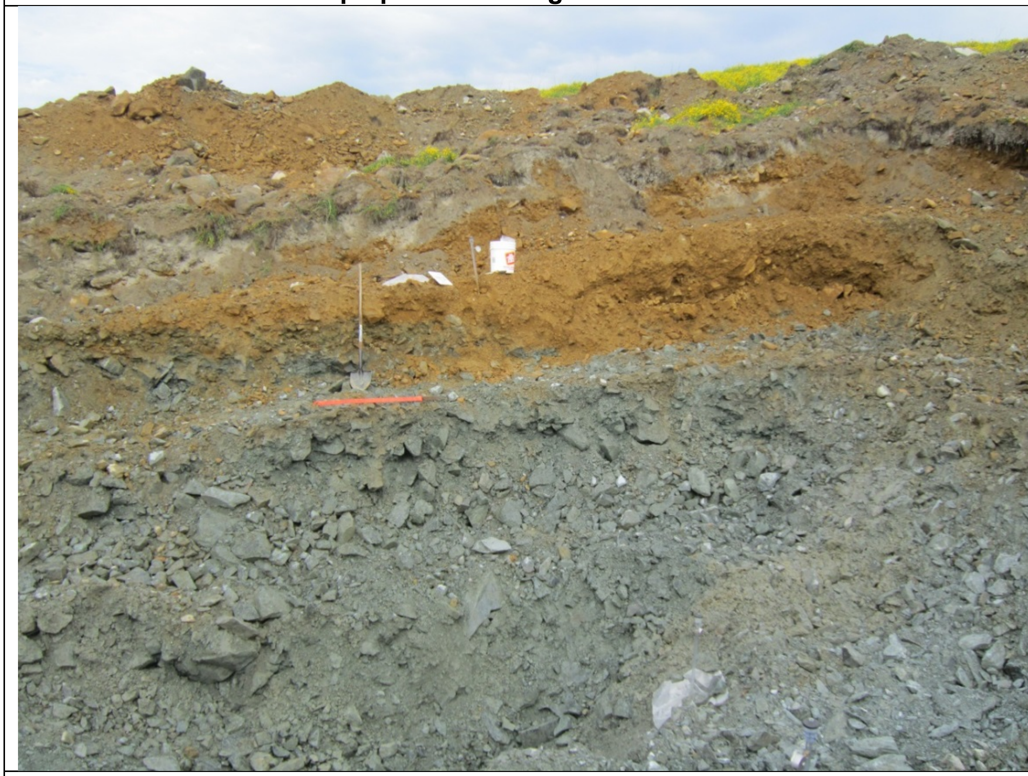
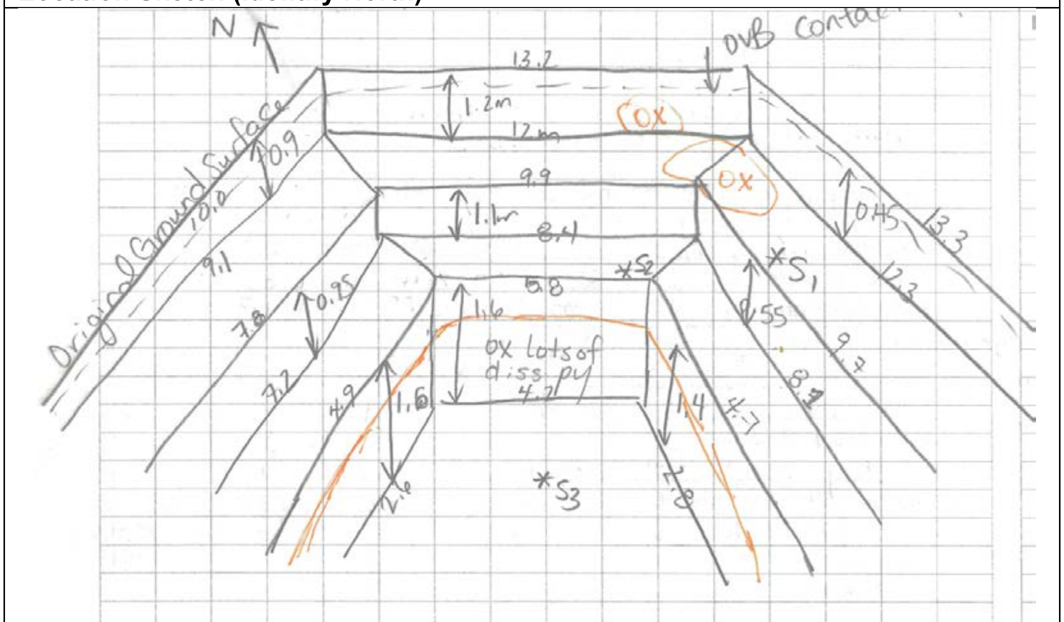


Photo 4 – TP-P1-S15 test pit profile looking south west

Test Pit Number :	TP-P1-S17	**Sampling Date/Time:**	August 14th 2011 10:30 am
Location :	South west corner of Pile 1, on top of south west berm		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 591686	**N:** 5540480
Weather conditions :	Sun, warm	**Sampled by :**	Aileen Cash/Pablo Urrutia

Location Sketch (identify North)



Soil Unit and Depth (From Surface)	Description of Units
Unit: Waste rock pile cover **Depth:** 0.0-0.3 m, , some areas up to 0.4 m	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand with rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** Little to no oxidation in cover material, some waste rock mixed into cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Sand and silt with clasts/cobbles from 1 cm up to 15 cm, trace boulders up to 50 cm *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Roots and vegetation present in upper profile. **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended, placed on a possible traffic surface **Angularity of Rocks:** Fine grained matrix with rounded glacial cobbles **Moisture:** Moist to dry **Tensiometer Reading:** N/A – Sun dried out the layer

	Sample Taken: No **Sample Number:** N/A
Unit: Waste rock **Depth:** 0.4-2.9 m	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow/Volcanics with calcite/white veining **Colour:** Grey rock with orange surface oxidation, and red/purple potassic alteration **Presence of Oxidation:** Some surface oxidation on some rock and two areas with significant oxidation **Percentage of Material Oxidized (%):**10-15% **Sulphide Minerals Present:** Pyrite/pyrrhotite, <1%, potassic alteration *Crystal Habit (Clusters, cubic):* Clusters along fractures Distribution (disseminated, veining, fracture fill): Fracture fill **Texture:** *Gradation:* Cobble sized, with sand and silt sized matrix, large boulders up to 1 m, average size is 10-15 cm *Matrix or Clast supported:* Clasts, little matrix material, and less decomposition and weathering of rock, material is quite angular **Structure:** (ordering/layering/unstructured/blended) – Very loose structure, coarsening downward, but blended/not significant structure **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist to dry **Tensiometer Reading:** Not taken **Sample Taken:** Yes **Sample Number:** TP-P1-S17-S1 & TP-P1-S17-S2
Unit: Waste rock **Depth:** 2.9 m to 3.90 m	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow, some Intermediate Intrusive **Colour:** Orange surface oxidation, black and grey fresh surfaces **Presence of Oxidation:** Surface oxidation and fully oxidized matrix **Percentage of Material Oxidized (%):** 60% **Sulphide Minerals Present:** Pyrite/pyrrhotite in highly oxidized areas and grey areas *Crystal Habit (Clusters, cubic):* Crystal habit not observed Distribution (disseminated, veining, fracture fill): Disseminated **Texture:** *Gradation:* Ranges from fines to cobbles and boulders 10-40 cm and larger up to 1 to 2 m *Matrix or Clast supported:* Mixed clasts with infilled matrix **Structure:** (ordering/layering/unstructured/blended) – Unstructured/blended, no visible layering **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist to wet **Tensiometer Reading:** 5 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S17-S3
Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant	

Observations / Other work performed : Very hot and dry, test pit dried out quite quickly.
Photos of Completed Test Pit:
Photo 1 – TP-P1-S17 test pit profile looking north

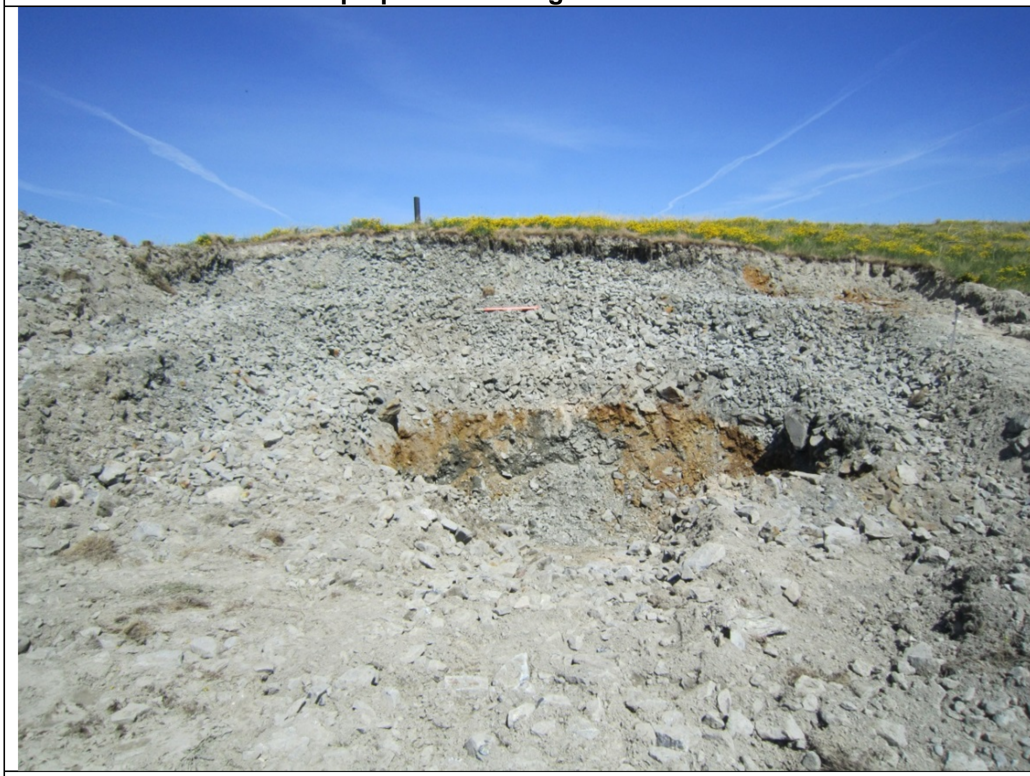



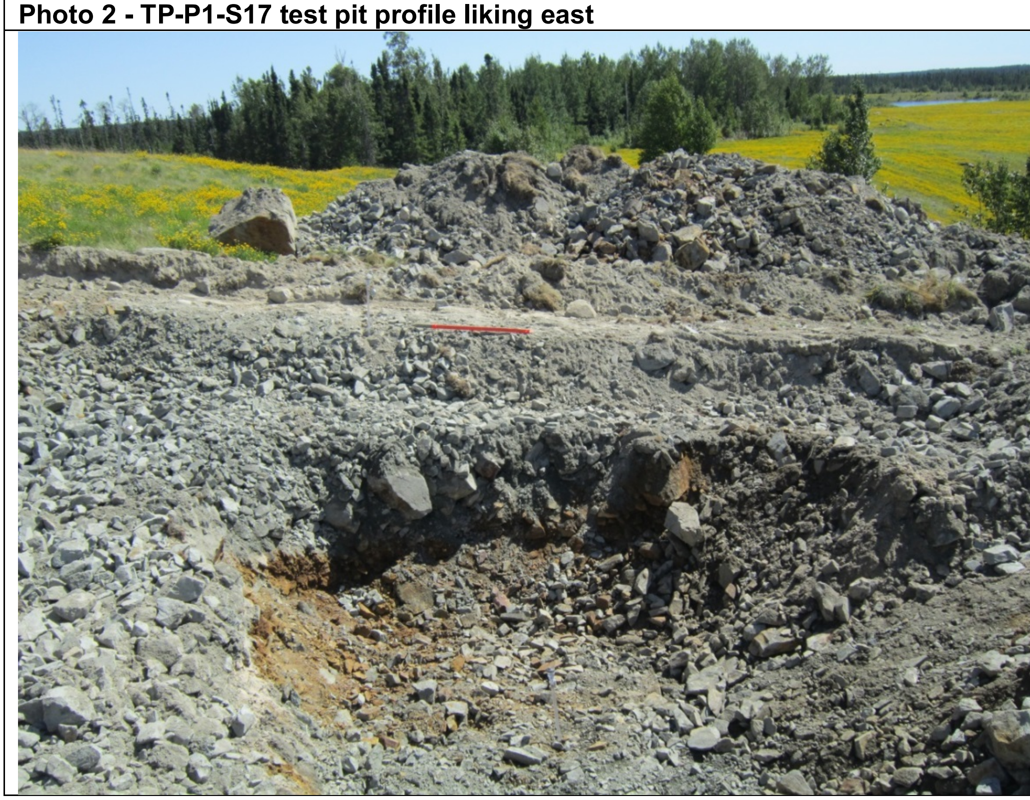
Photo 2 - TP-P1-S17 test pit profile liking east


Photo 3 – TP-P1-S17 tensiometer installation on lower bench (Sample 3)


Test Pit Number :	TP-P2-S1, TP-P2-S2, TP-P2-S3, TP-P2-S4, TP-P2-S5, TP-P2-S6		
Sampling Date/Time:	July 31st 2011		
Location :	Pile 1, lower bench is centre of waste rock pile		
Weather conditions :	Sunny, warm	**Sampled by :**	Aileen Cash/Pablo Urrutia

Test Pit and Depth (From Surface)	**Description of Units**
TP-P2-S1 and TP-P2-S2 **Unit:** Waste rock with overburden pile cover	**GPS Coordinates: (UTM 17, NAD 83) E:** 592199 **N:** 5541130 **Material Type:** Waste rock overlain with till overburden cover material **Rock Type:** Intermediate Intrusive, Mafic Volcanic Flow, some Talc Chloride **Colour:** Grey with orange surface oxidation **Presence of Oxidation:** Moderately reactive, surface oxidation with iron staining on joints and fractures **Sulphide Minerals Present:** Pyrite, <1% **Texture:** *Gradation:* Blocky with little to no fines, appears to be a rubble zone, with cobble sized material from 5 cm to 30 cm. *Matrix or Clast supported:* Open pored, clast supported **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended, could be the rubble zone at the base of a tipping layer. Test pit located on angle of repose slope **Moisture:** Moist **Tensiometer Reading:** N/A **Angularity of Rocks:** Blocky, angular waste rock **Sample Taken:** Yes – Composite sample from TP-P2-S1 and TP-P2-S2 **Sample Number:** TP-P2-S1&S2
TP-P2-S3 **Unit:** Waste rock with overburden pile cover (30 cm till cover)	**GPS Coordinates: (UTM 17, NAD 83) E:** 592167 **N:** 5541150 **Material Type:** Waste rock overlain with till overburden cover material **Rock Type:** Mafic Volcanic Flow, Talc Chloride **Colour:** Grey/black with orange surface oxidation **Presence of Oxidation:** Moderate to significant surface oxidation **Sulphide Minerals Present:** Pyrite/pyrrhotite, <1% **Texture:** *Gradation:* Much finer material in the pore spaces, particle size ranges from 2.5 cm to 20 cm *Matrix or Clast supported:* Mix of matrix and clasts **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended, could be an upper section of the rubble zone. Test pit located on angle of repose slope **Moisture:** Very Moist **Tensiometer Reading:** N/A **Angularity of Rocks:** Blocky, angular waste rock **Sample Taken:** Yes **Sample Number:** TP-P2-S3
TP-P2-S4	**GPS Coordinates: (UTM 17, NAD 83) E:** 592176 **N:** 5541159

Unit: Waste rock with overburden pile cover	**Material Type:** Waste rock overlain with till overburden cover material **Rock Type:** Mafic Volcanic Flow, Talc Chloride **Colour:** Grey with orange surface oxidation **Presence of Oxidation:** Some evidence of surface oxidation **Sulphide Minerals Present:** Pyrite, <1% **Texture:** *Gradation:* Blocky with little to no fines, appears to be a rubble zone, with cobble sized material from 40 cm to 1 cm. Coarse. *Matrix or Clast supported:* Open pored, clast supported **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended, could be the rubble zone at the base of a tipping layer. Test pit located on angle of repose slope **Moisture:** Moist **Tensiometer Reading:** N/A **Angularity of Rocks:** Blocky, angular waste rock **Sample Taken:** Yes **Sample Number:** TP-P2-S4
TP-P2-S5 **Unit:** Waste rock with overburden pile cover	**GPS Coordinates: (UTM 17, NAD 83) E:** 592139 **N:** 5541165 **Material Type:** Waste rock overlain with till overburden cover material **Rock Type:** Primarily Mafic Volcanic Flow, some Talc Chloride **Colour:** Grey with some orange surface oxidation **Presence of Oxidation:** Light surface oxidation with iron staining on joints and fractures **Sulphide Minerals Present:** Pyrite, <1% **Texture:** *Gradation:* Finer fraction is more evident, particles up to 300 mm with a fine clay-sand fraction. *Matrix or Clast supported:* Mix of matrix and clasts **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended, could be the rubble zone at the base of a tipping layer. Test pit located on angle of repose slope **Moisture:** Very Moist **Tensiometer Reading:** N/A **Angularity of Rocks:** Well graded matrix, blocky, angular waste rock **Sample Taken:** Yes **Sample Number:** TP-P2-S5
TP-P2-S6 **Unit:** Waste rock with overburden pile cover	**GPS Coordinates: (UTM 17, NAD 83) E:** 592143 **N:** 5541170 **Material Type:** Waste rock overlain with till overburden cover material **Rock Type:** Mafic Volcanic Flow and Talc Chloride **Colour:** Grey with some orange surface oxidation **Presence of Oxidation:** Light surface oxidation with iron staining on joints and fractures **Sulphide Minerals Present:** Pyrite, <1% **Texture:** *Gradation:* Finer fraction is more evident, particles up to 300 mm with a fine clay-sand fraction. *Matrix or Clast supported:* Mix of matrix and clasts

	Structure: (ordering/layering/unstructured/blended) – No visible structure, blended, could be the rubble zone at the base of a tipping layer. Test pit located on angle of repose slope **Moisture:** Very Moist **Tensiometer Reading:** N/A **Angularity of Rocks:** Well graded matrix, blocky, angular waste rock **Sample Taken:** No **Sample Number:** N/A

Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ____________________

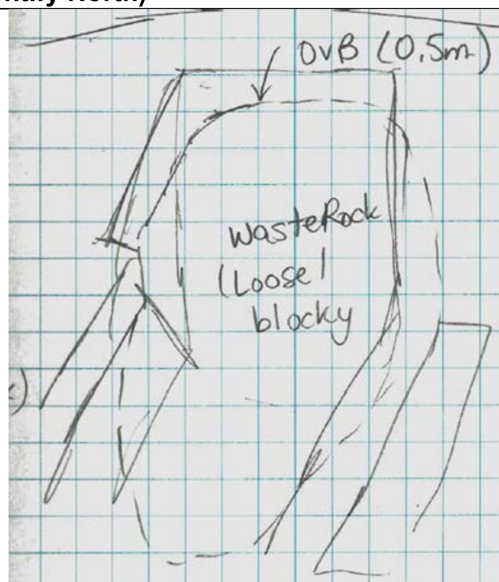
Observations / Other work performed : Test pits were quite small in comparison to those constructed on Pile 1 and remainder on Pile 2. Pits were filled in and capped with sand to prevent contamination with the nearby creek.

Photos of Completed Test Pit:

Photo 1 – Small test pit constructed on WRS 2 (TP-P2-S1)

Photo 2 – Photograph showing the presence of oxidation in the test pit

Test Pit Number :	TP-P2-S7	**Sampling Date/Time:**	July 31st 2011
Location :	West slope of Pile 2		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 592022	**N:** 5541090
Weather conditions :	Warm, sunny	**Sampled by :**	Aileen Cash/Ward Wilson
Location Sketch (identify North)			



Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock **Depth:** Not recorded – approximately 3 m	**Material Type:** Waste rock overlain with till overburden cover material **Rock Type:** Primarily Mafic Volcanic Flow, minor Talc Chloride **Colour:** Grey with orange surface oxidation **Presence of Oxidation:** Some to complete surface oxidation on blocky waste rock **Percentage of Material Oxidized (%):**30% surface oxidation **Sulphide Minerals Present:** Pyrite, <1%, pyrrhotite *Crystal Habit (Clusters, cubic):* Not observed Distribution (disseminated, veining, fracture fill): Not observed **Texture:** *Gradation:* Blocky with particles from 5 cm to 30 cm, but average grain size is 10 cm rock with some finer grained matrix. *Matrix or Clast supported:* Open pored, clast supported **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended, loose and blocky, likely an end or push dump **Angularity of Rocks:** Blocky, angular waste rock with fine grained matrix **Moisture:** Moist **Tensiometer Reading:** 16 kPa **Sample Taken:** Yes **Sample Number:** TP-P2-S7

Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ______________________

Observations / Other work performed : None

Photos of Profile Sampling Location:

Photo 1 – Sample TP-P2-S7

Photo 2 – Test Pit TP-P2-S7 looking east

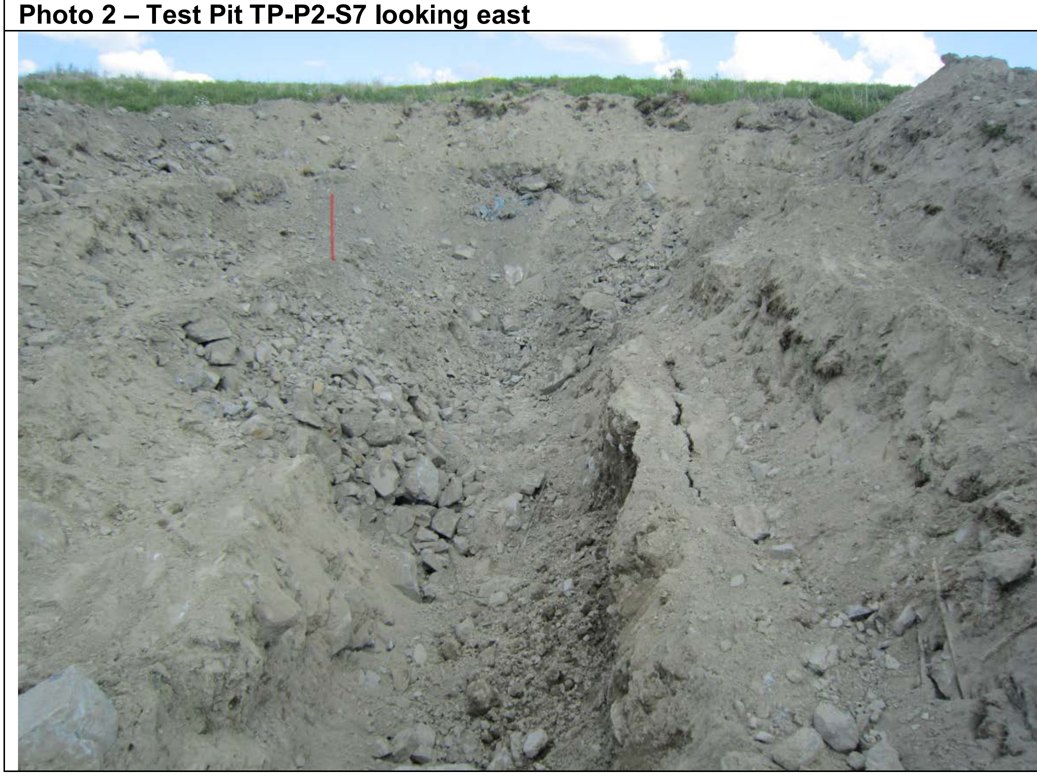
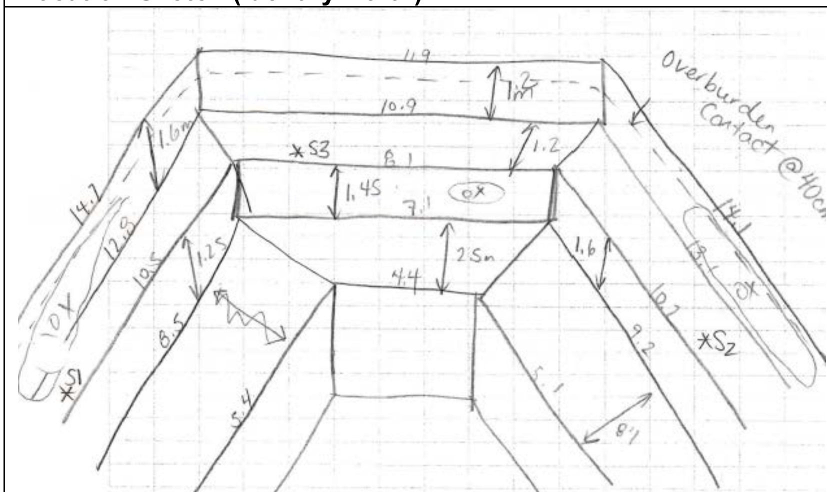


Photo 3 – Sampling of waste rock in TP-P2-S7

Photo 4 – Grain size range found in test pit, some orange oxidation on particles surfaces

Test Pit Number :	TP-P2-S10	**Sampling Date/Time:**	August 18th 2011 4:30 pm
Location :	Top of Pile 2 on NW corner of North lobe		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 592106	**N:** 5541299
Weather conditions :	Cloudy and windy	**Sampled by :**	Aileen Cash/Pablo Urrutia

Location Sketch (identify North)



Thermal Profile	
Depth	°C
0 cm	20.8
10 cm	20.8
20 cm	21.0
40 cm	19.0
80 cm	18.1
170 cm	16.2
200 cm	15.5
230 cm	15.3
320 cm	12.5
375 cm	10.2

Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock pile cover **Depth:** 0.0-0.4 m, some areas up to 0.6 m	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand with rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** No oxidation in cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Sand and silt with clasts/cobbles from 1 cm up to 15 cm, trace boulders up to 50 cm *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Roots and vegetation present in upper profile. **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended, placed on a possible traffic surface **Angularity of Rocks:** Fine grained matrix with rounded glacial cobbles **Moisture:** Moist, dry at surface **Tensiometer Reading:** N/A **Sample Taken:** No **Sample Number:** N/A
Unit: Waste rock **Depth:** 0.4-2.0 m	**Material Type:** Waste Rock **Rock Type:** Talc Chloride, Mafic Volcanic Flow/Volcanics with veining, some Intermediate Intrusive **Colour:** Grey/black rock with orange/red surface oxidation, and

<table>
<tr><td></td><td>oxidized orange fines
Presence of Oxidation: High amount of surface oxidation and oxidized fine fraction (primarily in sampling area
Percentage of Material Oxidized (%):80% surface oxidation, fine fraction is oxidized. Sample location is 100% oxidized, and some of the top bench is unoxidized.
Sulphide Minerals Present: Pyrite/pyrrhotite, <1%, potassic alteration
Crystal Habit (Clusters, cubic): Crystal habit not observed
Distribution (disseminated, veining, fracture fill): Fracture fill
Texture:
Gradation: Fine sand sized matrix with gravel/boulder and cobble sized particles from 10 - 50cm
Matrix or Clast supported: Both clasts and matrix dominate the upper bench
Structure: (ordering/layering/unstructured/blended) – Traffic surface at the contact with the overburden, no other structure visible
Angularity of Rocks: Fine to coarse grained matrix, angular to sub angular waste rock
Moisture: Moist
Tensiometer Reading: S1- 17 kPa, S2- 13 kPa
Sample Taken: Yes Sample Number: TP-P2-S10-S1 and TP-P2-S10-S2</td></tr>
<tr><td>Unit: Waste rock (Lower Bench)

Depth: 2.25 m to 3.25 m</td><td>Material Type: Waste Rock
Rock Type: Mafic Volcanic Flow, Talc Chloride/Chloritic Greenstone
Colour: Grey/Black with some orange surface oxidation
Presence of Oxidation: Some to little surface oxidation on material
Percentage of Material Oxidized (%):15-20%
Sulphide Minerals Present: Pyrite/pyrrhotite
Crystal Habit (Clusters, cubic): Clusters
Distribution (disseminated, veining, fracture fill): Disseminated
Texture:
Gradation: Larger grain size with boulders up to 1m, average grain size 10-20 cm
Matrix or Clast supported: Clasts supported with matrix infilling voids
Structure: (ordering/layering/unstructured/blended) – Unstructured/blended, no visible layering
Angularity of Rocks: Fine grained matrix with angular to very angular waste rock
Moisture: Moist Tensiometer Reading: N/A too blocky
Sample Taken: No Sample Number: N/A</td></tr>
<tr><td colspan="2">Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ______________________</td></tr>
<tr><td colspan="2">Observations / Other work performed : Ramp near pit entrance has highly oxidized material, however the rest of the pit appears unoxidized. Sample 1 was taken in the oxidized area for comparison</td></tr>
</table>

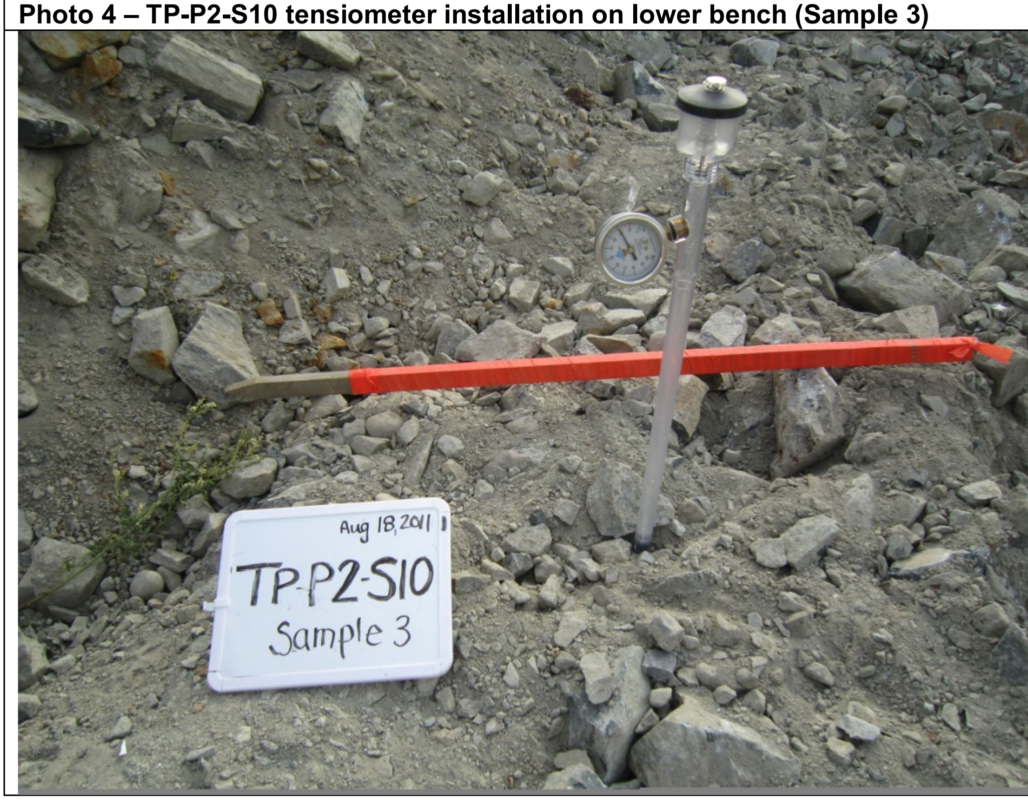
Photos of Completed Test Pit:

Photo 1 – TP-P2-S10 test pit profile looking south

Photo 2 - TP-P2-S10 tensiometer installation on upper bench (Sample 2)

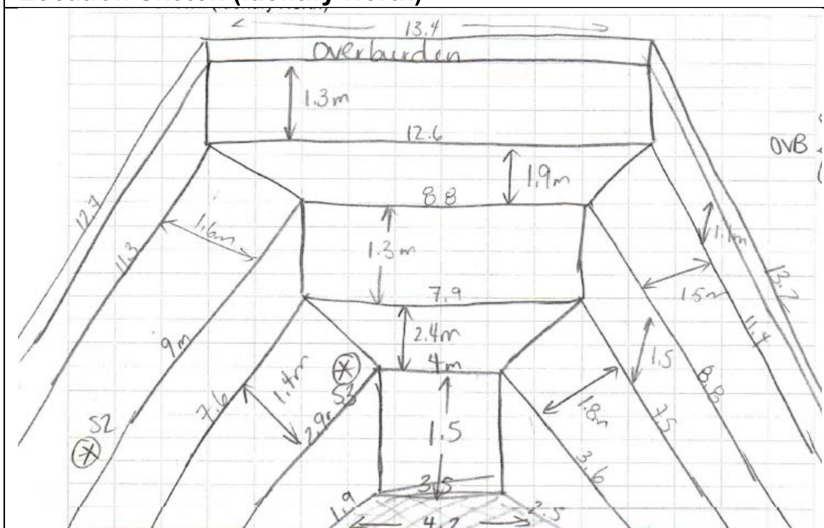
Photo 3 – TP-P2-S10 test pit profile looking east

Photo 4 – TP-P2-S10 tensiometer installation on lower bench (Sample 3)



Test Pit Number :	TP-P2-S11	**Sampling Date/Time:**	August 18th 2011 1:45 pm
Location :	Pile 1, lower bench is centre of waste rock pile		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 592181	**N:** 5541299
Weather conditions :	Cloudy and windy	**Sampled by :**	Aileen Cash/Pablo Urrutia

Location Sketch (identify North)



Thermal Profile

Depth	°C
Air Temp	26.3
10 cm	15.5
20 cm	15.1
40 cm	15
70 cm	15.6
145 cm	14.1
235 cm	13.5
310 cm	11.2
355 cm	9.1
Bottom of Pit	8.6

Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock pile cover **Depth:** 0.0-0.5 m	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand with rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** No oxidation in cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Sand and silt with clasts/cobbles from 1 cm up to 15 cm, trace boulders up to 50 cm, finer than material on Pile 1 *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Roots and vegetation present in upper profile. **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended, placed on a possible traffic surface **Angularity of Rocks:** Fine grained matrix with rounded glacial cobbles **Moisture:** Moist, dry at surface **Tensiometer Reading:** 20 kPa **Sample Taken:** Yes **Sample Number:** TP-P2-S11-S1
Unit: Waste rock (Upper Bench)	**Material Type:** Waste Rock **Rock Type:** Talc Chloride, Mafic Volcanic Flow/Volcanics, some Intermediate Intrusive

Depth: 0.4-2.7 m	**Colour:** Grey/black rock with orange/red surface oxidation **Presence of Oxidation:** Oxidation on the surfaces of rocks and in fine fraction **Percentage of Material Oxidized (%):**40% surface oxidation, fine fraction has some oxidation. Sample location has higher level of oxidation. **Sulphide Minerals Present:** Pyrite, pyrrhotite, potassic alteration *Crystal Habit (Clusters, cubic):* Crystal habit not observed Distribution (disseminated, veining, fracture fill): Not observed **Texture:** *Gradation:* Upper bench just below overburden has very large blocks up to 1 m or greater, voids are filled with finer material with smaller 15-20 cm particles *Matrix or Clast supported:* Predominantly larger material, clast supported **Structure:** (ordering/layering/unstructured/blended) – Upper bench is mainly boulders, with a possible traffic surface below the boulders, little other structure visible **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Tensiometer Reading:** 22 kPa **Sample Taken:** Yes **Sample Number:** TP-P2-S11-S1
Unit: Waste rock (Lower Bench) **Depth:** 2.25 m to 3.25 m	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow, Talc Chloride/Chloritic Greenstone, Intermediate Intrusive **Colour:** Grey/Black with some orange surface oxidation **Presence of Oxidation:** Some surface oxidation on material, matrix not highly oxidized **Percentage of Material Oxidized (%):**10-15% **Sulphide Minerals Present:** Pyrite/pyrrhotite *Crystal Habit (Clusters, cubic):* Cubic Distribution (disseminated, veining, fracture fill): Fracture fill **Texture:** *Gradation:* Fine sand to silt sized fine fraction with gravel, cobbles and boulders up to 70 cm. Average grain size 10 cm *Matrix or Clast supported:* Both clasts and matrix/fine fraction dominate this bench **Structure:** (ordering/layering/unstructured/blended) – Unstructured/blended, no visible layering **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Tensiometer Reading:** 10.5 kPa **Sample Taken:** Yes **Sample Number:** TP-P2-S11-S3
Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant Water sample collected : ☐ Yes ☒ No Sample ID: ______________________	
Observations / Other work performed :	

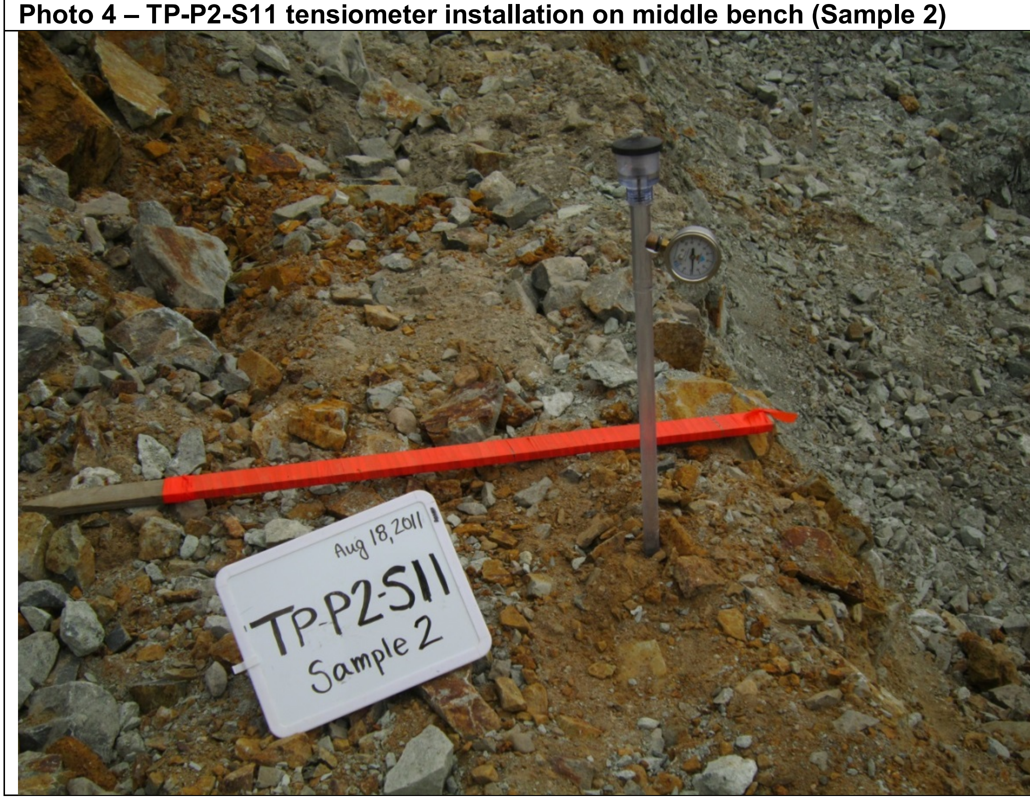
Photos of Completed Test Pit:

Photo 1 – TP-P2-S11 test pit profile looking south

Photo 2 - TP-P2-S11 tensiometer installation in overburden/cover (Sample 1)

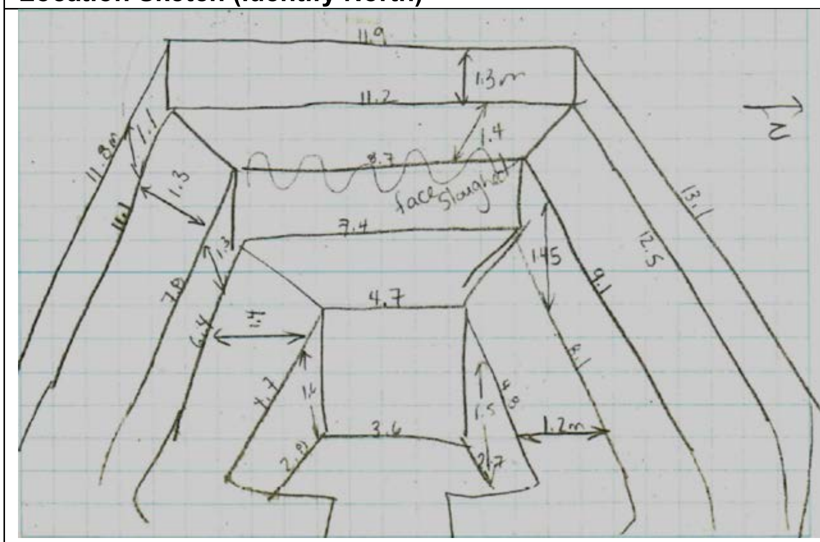
Photo 3 – TP-P2-S11 test pit profile looking east

Photo 4 – TP-P2-S11 tensiometer installation on middle bench (Sample 2)



Test Pit Number :	TP-P2-S12	**Sampling Date/Time:**	August 21, 2011 11:00 am
Location :	Near toe of North lobe, close to open pit and Kerrel Creek		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 592185	**N:** 5541307
Weather conditions :	-	**Sampled by :**	Aileen Cash/Pablo Urrutia

Location Sketch (identify North)



Thermal Profile

Depth	°C
Air Temp	27.0
10 cm	17.0
20 cm	16.9
45 cm	15.8
70 cm	15.9
130 cm	15.6
210 cm	12.7
245 cm	12.4
265 cm	10.8
310 cm	7.8
375 cm	7.1

Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock pile cover **Depth:** 0.0-0.4 m	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand with rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** No oxidation in cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Sand and silt with clasts/cobbles from 1 cm up to 15 cm, trace boulders up to 50 cm *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Roots and vegetation present in upper profile. **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended, placed on a possible traffic surface **Angularity of Rocks:** Fine grained matrix with rounded glacial cobbles **Moisture:** Moist, dry at surface **Tensiometer Reading:** 18 kPa **Sample Taken:** Yes **Sample Number:** TP-P2-S12-S1
Unit: Waste rock **Depth:** 0.4-2.0 m	**Material Type:** Waste Rock **Rock Type:** Talc Chloride, Mafic Volcanic Flow/Volcanics, with calcite veining

<table>
<tr><td></td><td>Colour: Grey/black rock with orange/red surface oxidation
Presence of Oxidation: Oxidation on the surfaces of rocks, however fine matrix is mostly unoxidized
Percentage of Material Oxidized (%):10-15% surface oxidation
Sulphide Minerals Present: Pyrite/pyrrhotite, potassic alteration
Crystal Habit (Clusters, cubic): Crystal habit not observed
Distribution (disseminated, veining, fracture fill): Pyrite in fractures, some dissemination
Texture:
Gradation: Coarsening downward with silt and sand sized matrix with gravel 1-2 cm up to 1 m boulders. Average grain size is 7-10 cm
Matrix or Clast supported: Predominantly clast supported with some areas of matrix supported rock
Structure: (ordering/layering/unstructured/blended) – Upper bench is mainly boulders, with a possible traffic surface below the boulders, little other structure visible
Angularity of Rocks: Fine to coarse grained matrix, angular to sub angular waste rock
Moisture: Moist Tensiometer Reading: 34 kPa
Sample Taken: Yes Sample Number: TP-P2-S12-S1</td></tr>
<tr><td>Unit: Waste rock

Depth: 2.0 m to 3.45 m</td><td>Material Type: Waste Rock
Rock Type: Mafic Volcanic Flow, Talc Chloride/Chloritic Greenstone
Colour: Grey/Black with orange to red-purple surface oxidation
Presence of Oxidation: Some surface oxidation on material, matrix not highly oxidized
Percentage of Material Oxidized (%):10-15%
Sulphide Minerals Present: Pyrite/pyrrhotite
Crystal Habit (Clusters, cubic): Crystal habit not observed
Distribution (disseminated, veining, fracture fill): Not observed
Texture:
Gradation: Coarsening downward with silt and sand sized matrix with gravel 1-2 cm up to 1 m boulders. Larger grain sizes predominate.
Matrix or Clast supported: Mainly clasts with open air pores
Structure: (ordering/layering/unstructured/blended) – Unstructured/blended, no visible layering
Angularity of Rocks: Fine grained matrix with angular to very angular waste rock
Moisture: Moist Tensiometer Reading: N/A too blocky
Sample Taken: Yes Sample Number: TP-P2-S12-S3</td></tr>
<tr><td colspan="2">Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ____________________</td></tr>
<tr><td colspan="2">Observations / Other work performed : None</td></tr>
</table>

Photos of Completed Test Pit:
Photo 1 – TP-P2-S12 test pit profile looking west

Photo 2 - TP-P2-S12 Test pit profile looking south

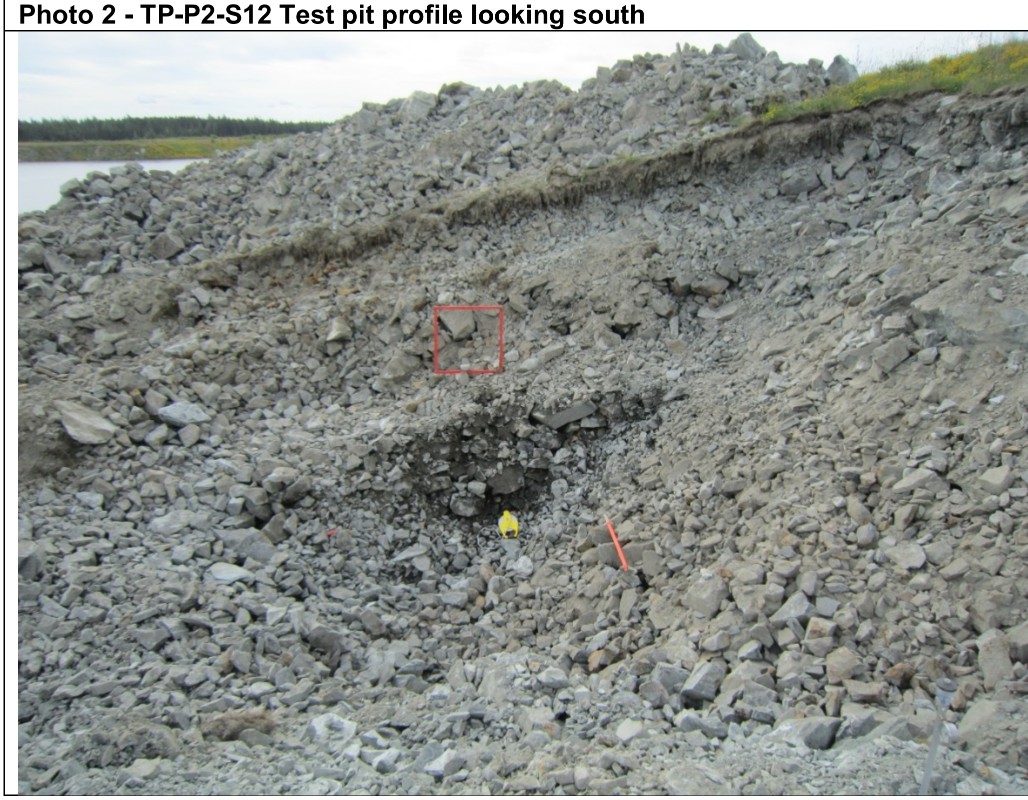
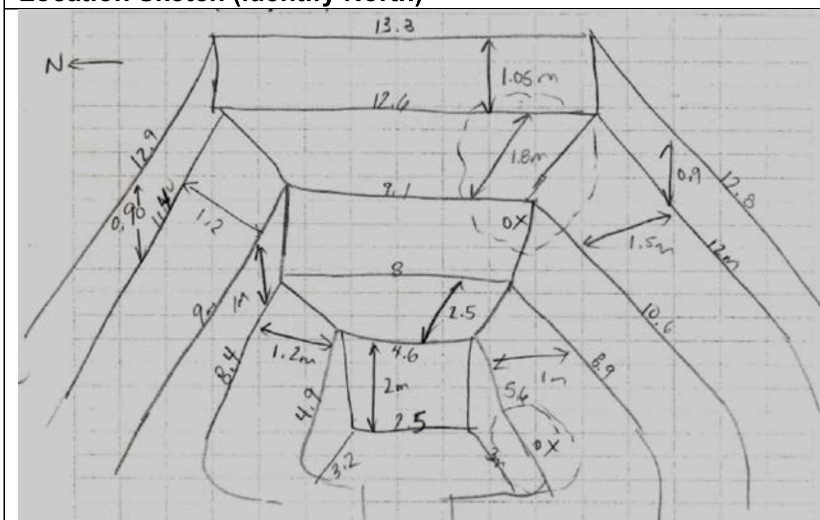


Photo 3 – TP-P2-S12 bottom of test pit showing blocky gradation

Photo 4 – TP-P2-S12 tensiometer installation on middle bench (Sample 2)

Test Pit Number :	TP-P2-S13	**Sampling Date/Time:**	August 20th 2011 9:45 am
Location :	South side of Pile 2 near access road, west of Campbell Pit		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 592027	**N:** 5541227
Weather conditions :	Sun and light wind	**Sampled by :**	Aileen Cash/Pablo Urrutia

Location Sketch (identify North)



Thermal Profile

Depth	°C
Air Temp	19.5
10 cm	17.3
20 cm	17.5
40 cm	17.7
80 cm	17.6
105 cm	16.4
125 cm	16.2
155 cm	15.0
200 cm	14.3
205 cm	13.9
305 cm	13.2
Bottom of Pit	9.9

Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock pile cover **Depth:** 0.0-0.4 to 0.8 m	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand with rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** No oxidation in cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Sand and silt with clasts/cobbles from 1 cm up to 30 cm, trace boulders up to 50 cm *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Roots and vegetation present in upper profile. **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended, placed on a possible traffic surface **Angularity of Rocks:** Fine grained matrix with rounded glacial cobbles **Moisture:** Moist, dry at surface **Tensiometer Reading:** 22 kPa **Sample Taken:** Yes **Sample Number:** TP-P2-S13-S1
Unit: Waste rock (Upper Bench) **Depth:** 0.4-2.10 m	**Material Type:** Waste Rock **Rock Type:** Talc Chloride, Mafic Volcanic Flow/Volcanics, Chloritic Greenstone **Colour:** Grey/black rock with orange-red/brown surface

<table>
<tr><td></td><td>oxidation
Presence of Oxidation: Oxidation on the surfaces of rocks and in fine fraction
Percentage of Material Oxidized (%):15% surface oxidation, fine fraction has some oxidation
Sulphide Minerals Present: Pyrite/pyrrhotite
Crystal Habit (Clusters, cubic): Crystal habit not observed
Distribution (disseminated, veining, fracture fill): Some dissemination, however most sulphides in veins
Texture:
Gradation: Finer matric of coarse sand/gravel to silt sized with gravel to boulder sized clasts up to Upper bench just below overburden has very large blocks up to 1 m or greater, voids are filled with finer material with smaller 15-20 cm particles
Matrix or Clast supported: Predominantly larger material, clast supported
Structure: (ordering/layering/unstructured/blended) – Coarsening downward, little other structure visible, possible traffic surface along interface with cover
Angularity of Rocks: Fine grained matrix with angular to very angular waste rock
Moisture: Moist
Tensiometer Reading: 14 kPa
Sample Taken: Yes Sample Number: TP-P2-S13-S2</td></tr>
<tr><td>Unit: Waste rock (Lower Bench)

Depth: 2.1 m to 4.0 m</td><td>Material Type: Waste Rock
Rock Type: Talc Chloride/Chloritic Greenstone, Mafic Volcanic Flow
Colour: Grey/Black with some orange surface oxidation
Presence of Oxidation: Surface oxidation dispersed within the lower bench, with one area of more intense oxidation
Percentage of Material Oxidized (%):10-15%
Sulphide Minerals Present: Pyrite/pyrrhotite
Crystal Habit (Clusters, cubic): Crystal habit not observed
Distribution (disseminated, veining, fracture fill): Disseminated
Texture:
Gradation: Large boulders (up to 1 m) in-filled with matrix, cobble and gravel sized particles
Matrix or Clast supported: Clast supported with matrix/fine fraction infilling the clasts
Structure: (ordering/layering/unstructured/blended) – Unstructured/blended, no visible layering, largest material at the bottom of the pit
Angularity of Rocks: Fine grained matrix with angular to very angular waste rock
Moisture: Very Wet Tensiometer Reading: 2 kPa
Sample Taken: Yes Sample Number: TP-P2-S13-S3</td></tr>
<tr><td colspan="2">Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ____________________</td></tr>
<tr><td colspan="2">Observations / Other work performed : Two casing pipes were uncovered in the test pit, but do not appear to be in use. Good temperature profile conducted.</td></tr>
</table>

Photos of Completed Test Pit:

Photo 1 – TP-P2-S13 test pit profile looking east

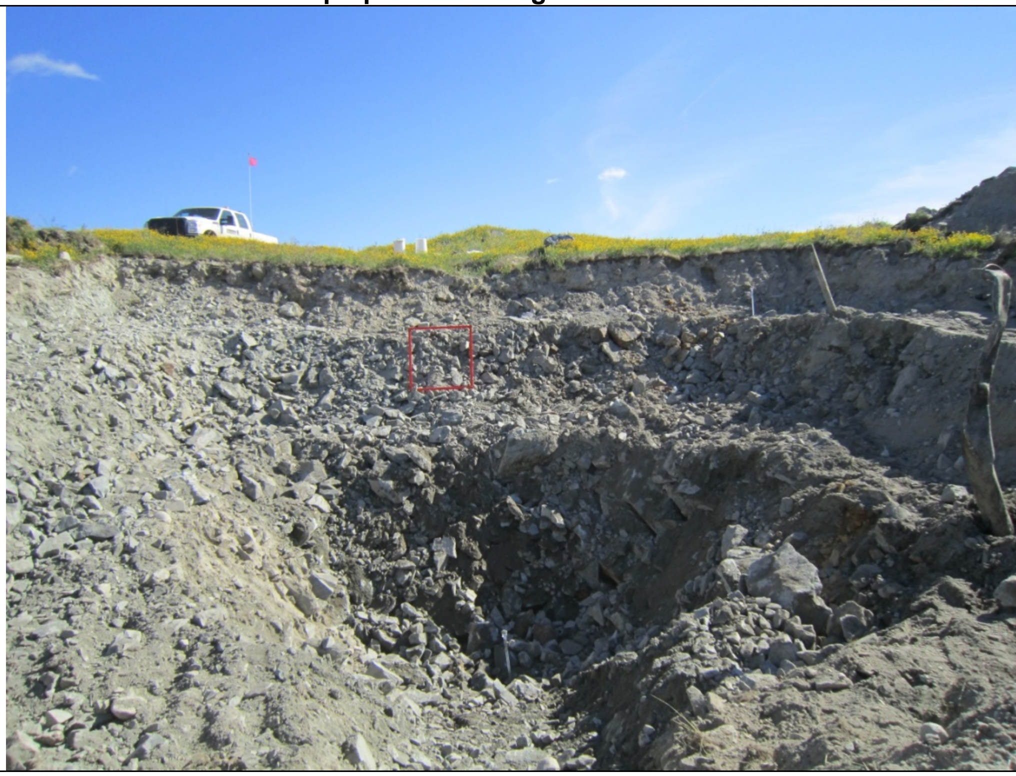


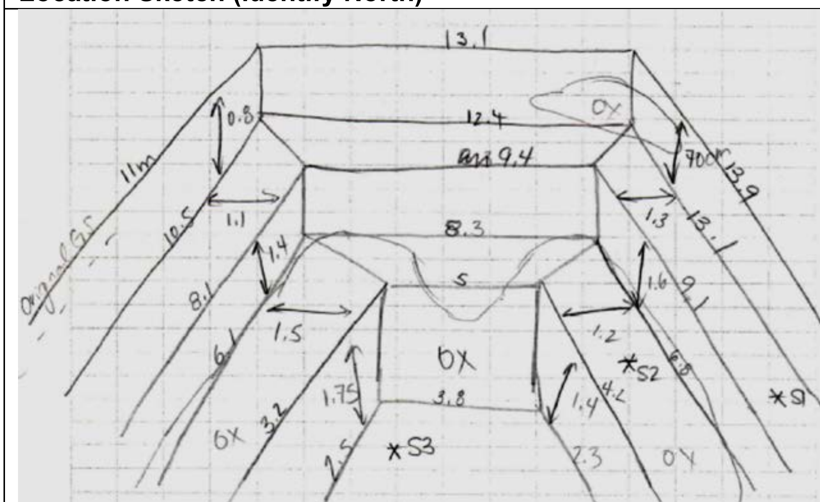
Photo 2 - TP-P2-S13 tensiometer installation in overburden/cover (Sample 1)

Photo 3 – TP-P2-S13 test pit profile looking south showing tensiometer installations

Photo 4 – TP-P2-S13 tensiometer installation in pit bottom (Sample 3)

Test Pit Number :	TP-P2-S14	**Sampling Date/Time:**	August 19th 2011 11:30 am
Location :	Southern lobe of Pile 2, close to Pile1 and access road		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 592094	**N:** 5541224
Weather conditions :		**Sampled by :**	Aileen Cash/Pablo Urrutia

Location Sketch (identify North)



Thermal Profile

Depth	°C
Air Temp	22.2
10 cm	15.2
20 cm	15.5
100 cm	14.8
140 cm	14.9
295 cm	10.9
340 cm	10.4

Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock pile cover **Depth:** 0.0-0.5 m	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand with rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** No oxidation in cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Sand and silt with clasts/cobbles from 1 cm up to 20-25 cm *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Roots and vegetation present in upper profile. *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Roots and vegetation present in upper profile. **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended, placed on a possible traffic re-graded surface **Angularity of Rocks:** Fine grained matrix with sub rounded glacial cobbles **Moisture:** Moist, dry at surface **Tensiometer Reading:** 30 kPa **Sample Taken:** Yes **Sample Number:** TP-P2-S14-S1

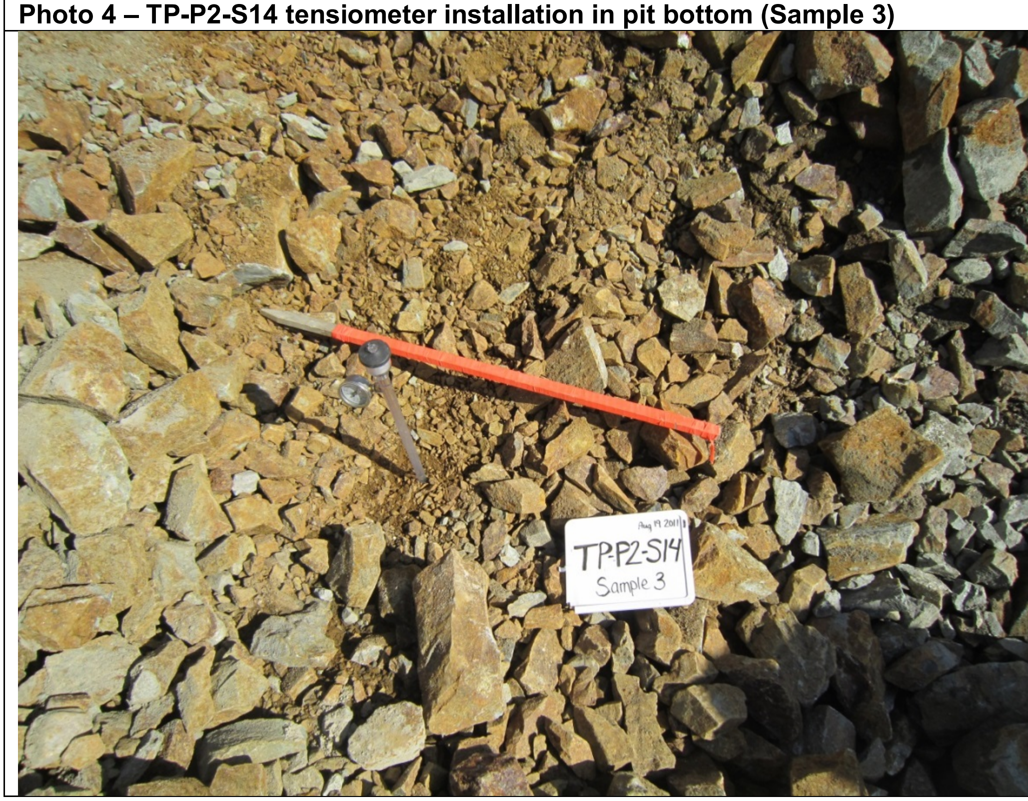
Unit: Waste rock (Upper Bench) **Depth:** 0.4-2.7 m	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow with veining **Colour:** Grey/black rock with orange-red/brown surface oxidation **Presence of Oxidation:** Oxidation on the surfaces of rocks in upper bench in east corner **Percentage of Material Oxidized (%):** 30-40% surface oxidation, fine fraction has some oxidation **Sulphide Minerals Present:** Pyrite/pyrrhotite *Crystal Habit (Clusters, cubic):* Clusters Distribution (disseminated, veining, fracture fill): Some veining **Texture:** *Gradation:* Finer sand sized matric material with gravel to boulder sized clasts *Matrix or Clast supported:* Predominantly larger material, clast supported **Structure:** (ordering/layering/unstructured/blended) – Distinct traffic surface on the NW pit wall, with very compacted material below the overburden **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Wet **Tensiometer Reading:** 4 kPa **Sample Taken:** Yes **Sample Number:** TP-P2-S14-S2
Unit: Waste rock (Lower Bench) **Depth:** 2.25 m to 3.25 m	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow, some Talc Chloride/Chloritic Greenstone **Colour:** Grey/Black to orange (high surface oxidation) **Presence of Oxidation:** Surface oxidation highest within the lower bench **Percentage of Material Oxidized (%):**80% surface oxidation **Sulphide Minerals Present:** Pyrite/pyrrhotite *Crystal Habit (Clusters, cubic):* Clusters Distribution (disseminated, veining, fracture fill): Veinlets **Texture:** *Gradation:* Large boulders (up to 0.6 m) in-filled with matrix, cobble and gravel sized particles *Matrix or Clast supported:* Clast supported (70%) with matrix/fine fraction infilling the clasts **Structure:** (ordering/layering/unstructured/blended) – Unstructured/blended, no visible layering, coarsening downward **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Very wet **Tensiometer Reading:** 1 kPa **Sample Taken:** Yes **Sample Number:** TP-P2-S14-S3
Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant Water sample collected : ☐ Yes ☒ No Sample ID: ______________________	
Observations / Other work performed : Temperature profile was difficult to measure due to highly blocky nature of the rock. Pit is located near a pre-existing drill hole	

Photos of Completed Test Pit:

Photo 1 – TP-P2-S14 test pit profile looking south showing tensiometer installations

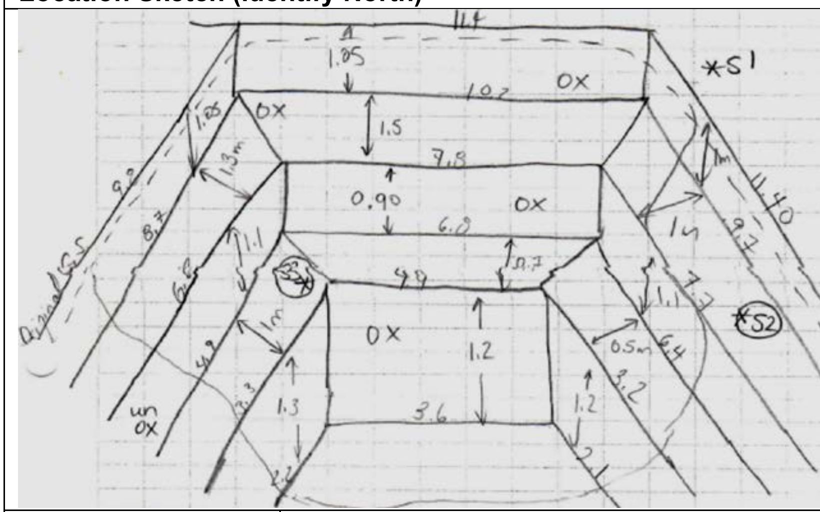
Photo 2 - TP-P2-S14 S14 test pit profile looking east

Photo 3 – TP-P2-S14 tensiometer installation in waste rock (Sample 2)

Photo 4 – TP-P2-S14 tensiometer installation in pit bottom (Sample 3)


Test Pit Number :	TP-P2-S15	**Sampling Date/Time:**	August 19th 2011 11:30 am
Location :	Top of southern lobe of Pile 2, close to open pit		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 592178	**N:** 5541223
Weather conditions :	Sun and light wind	**Sampled by :**	Aileen Cash/Pablo Urrutia

Location Sketch (identify North)



Thermal Profile	
Depth	°C
Air Temp	26.1
10 cm	17.9
20 cm	17.5
40 cm	18
80 cm	18.4
120 cm	16.9
190 cm	16.4

Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock pile cover **Depth:** 0.0-0.35 m	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand with rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** No oxidation in cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Sand and silt with clasts/cobbles from 1 cm up to 20-25 cm *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Roots and vegetation present in upper profile. **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended, placed on a possible traffic re-graded surface **Angularity of Rocks:** Fine grained matrix with rounded glacial cobbles **Moisture:** Moist, dry at surface **Tensiometer Reading:** 53 kPa **Sample Taken:** Yes **Sample Number:** TP-P1-S15-S1
Unit: Waste rock **Depth:** 0.4-2.0 m	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow and Talc Chloride/Chloritic Greenstone

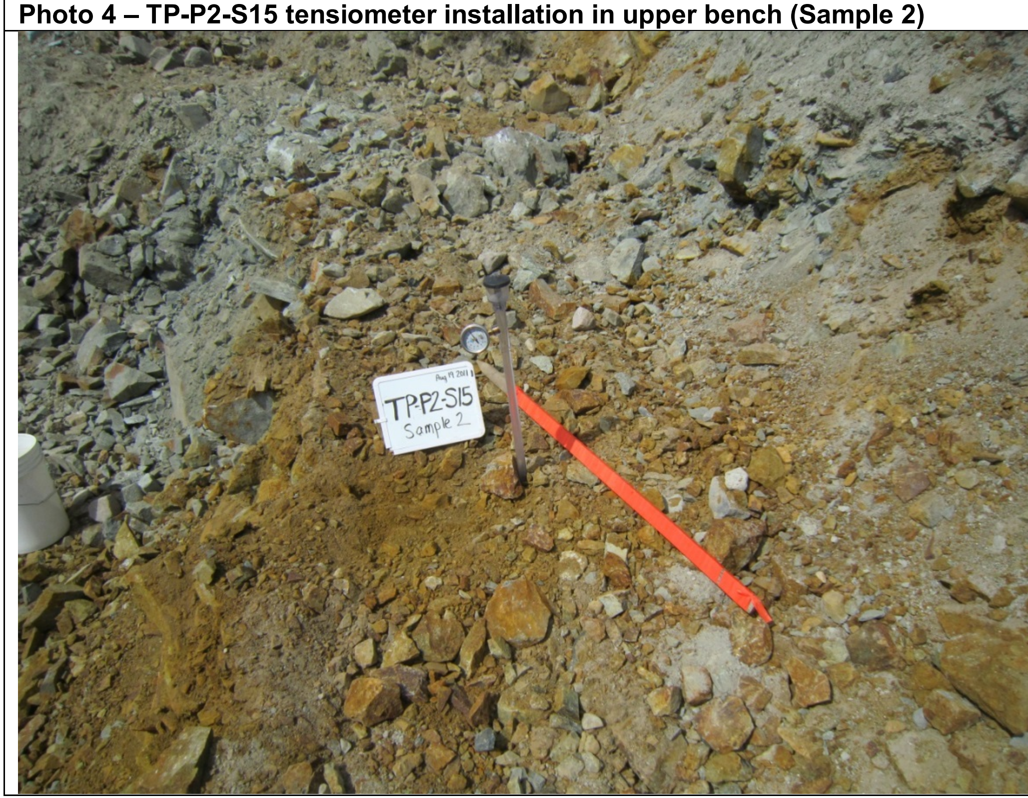
	Colour: Grey/black rock with orange-red/brown surface oxidation **Presence of Oxidation:** Surface oxidation and oxidized fine fraction **Percentage of Material Oxidized (%):**70-75% surface oxidation, fine fraction has some oxidation **Sulphide Minerals Present:** Pyrite/pyrrhotite in mafic rock, potassic alteration *Crystal Habit (Clusters, cubic):* Clusters Distribution (disseminated, veining, fracture fill): Veining, dissemination **Texture:** *Gradation:* Fine silt and sand sized matrix with gravel to boulder sized material. Average grain size is 100-200 mm. *Matrix or Clast supported:* 50% matrix and 50% clasts, clasts are packed and all voids are filled with matrix material **Structure:** (ordering/layering/unstructured/blended) – Coarsening downward, no evident structures, appears blended **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Tensiometer Reading:** 20 kPa **Sample Taken:** Yes **Sample Number:** TP-P2-S15-S2
Unit: Waste rock (Lower Bench) **Depth:** 2.0 m to 3.2 m (End of Pit)	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow, some Talc Chloride **Colour:** Grey/black rock with orange-red/brown surface oxidation **Presence of Oxidation:** Surface oxidation as well as oxidation in matrix **Percentage of Material Oxidized (%):**70-80% surface oxidation **Sulphide Minerals Present:** Pyrite/pyrrhotite *Crystal Habit (Clusters, cubic): Not observed* Distribution (disseminated, veining, fracture fill): Fracture fill **Texture:** *Gradation:* Very blocky cobbles and boulders with some sand sized matrix. Average grain size is 150 mm, some boulders up to 70-80 cm *Matrix or Clast supported:* Clast supported (70%) with matrix/fine fraction infilling the clasts **Structure:** (ordering/layering/unstructured/blended) – Unstructured/blended, no visible layering, coarsening downward **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Tensiometer Reading:** 15 kPa **Sample Taken:** Yes **Sample Number:** TP-P2-S15-S3
Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant Water sample collected : ☐ Yes ☒ No Sample ID: ____________________	

Observations / Other work performed : Test pit was in direct sunlight and cover material dried out quickly. Temperature profile was difficult to measure due to blocky nature of rock
Photos of Completed Test Pit:
Photo 1 – TP-P2-S15 test pit profile looking east

Photo 2 - TP-P2-S15 test pit looking south showing tensiometer installations

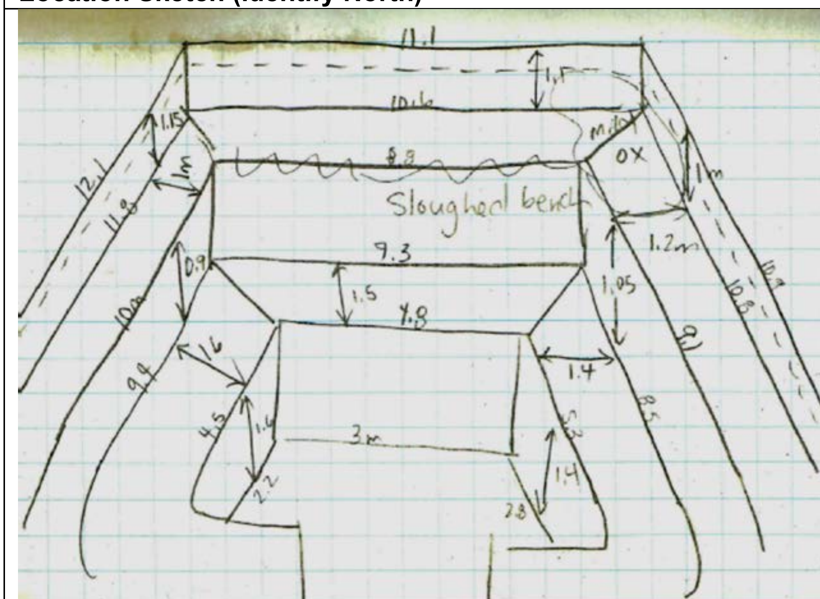

Photo 3 – TP-P2-S15 tensiometer installation in overburden (Sample 1)

Photo 4 – TP-P2-S15 tensiometer installation in upper bench (Sample 2)



Test Pit Number :	TP-P2-S16	**Sampling Date/Time:**	August 21th 2011 9:00 am
Location :	Toe of south lobe closest to the open pit		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 592178	**N:** 5541223
Weather conditions :	Sun and light wind	**Sampled by :**	Aileen Cash/Pablo Urrutia

Location Sketch (identify North)



Thermal Profile	
Depth	°C
Air Temp	27.0
10 cm	13.9
20 cm	14.1
60 cm	13.6
90 cm	11.7
110 cm	9.1
145 cm	7.6
180 cm	5.3
210 cm	5.6
280 cm	5.2
310 cm	3.4
360 cm	4.1

Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock pile cover **Depth:** 0.0-0.35 m	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand with rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** No oxidation in cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Sand and silt with clasts/cobbles from 1 cm up to 15 cm, trace boulders up to 50 cm *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Roots and vegetation present in upper profile. **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended, placed on a possible traffic surface **Angularity of Rocks:** Fine grained matrix with rounded glacial cobbles **Moisture:** Wet **Tensiometer Reading:** 1 kPa **Sample Taken:** Yes **Sample Number:** TP-P2-S16-S1
Unit: Waste rock (Upper Bench)	**Material Type:** Waste Rock

Depth: 0.4-2.0 m	**Rock Type:** Talc Chloride/Chloritic Greenstone with some Mafic Volcanic Flow, calcite veining with sulphide minerals **Colour:** Grey/black and green rock with trace orange-red/brown surface oxidation **Presence of Oxidation:** Some surface oxidation in NW corner of test pit **Percentage of Material Oxidized (%):**10-15% surface oxidation **Sulphide Minerals Present:** Pyrite/pyrrhotite in mafic rock *Crystal Habit (Clusters, cubic):* Clusters Distribution (disseminated, veining, fracture fill): Veining, little dissemination **Texture:** *Gradation:* Fine silt and sand sized matrix with gravel to boulder sized material. Average grain size is 100-200 mm *Matrix or Clast supported:* 50% matrix and 50% clasts, clasts are packed and all voids are filled with matrix material **Structure:** (ordering/layering/unstructured/blended) – Coarsening downward, no evident structures, appears blended **Angularity of Rocks:** Fine to coarse grained matrix, angular to sub angular waste rock **Moisture:** Moist **Tensiometer Reading:** 29.5 kPa **Sample Taken:** Yes **Sample Number:** TP-P2-S16-S2
Unit: Waste rock (Lower Bench) **Depth:** 2.0 m to 3.2 m (End of Pit)	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow, some Talc Chloride **Colour:** Grey/black rock with orange-red/brown surface oxidation **Presence of Oxidation:** Surface oxidation as well as oxidation in matrix **Percentage of Material Oxidized (%):**70-80% surface oxidation **Sulphide Minerals Present:** Pyrite/pyrrhotite *Crystal Habit (Clusters, cubic):* Not observed Distribution (disseminated, veining, fracture fill): Fracture fill **Texture:** *Gradation:* Very blocky cobbles and boulders with some sand sized matrix. Average grain size is 150 mm, some boulders up to 70-80 cm *Matrix or Clast supported:* Clast supported (70%) with matrix/fine fraction infilling the clasts **Structure:** (ordering/layering/unstructured/blended) – Unstructured/blended, no visible layering, coarsening downward **Angularity of Rocks:** Fine grained matrix with angular to subangular waste rock **Moisture:** Moist **Tensiometer Reading:** 24 kPa **Sample Taken:** Yes **Sample Number:** TP-P2-S16-S3
Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant	

Water sample collected : ☐ Yes ☒ No   Sample ID: ____________________
Observations / Other work performed :
Photos of Completed Test Pit:
Photo 1 – TP-P2-S16 test pit profile looking west

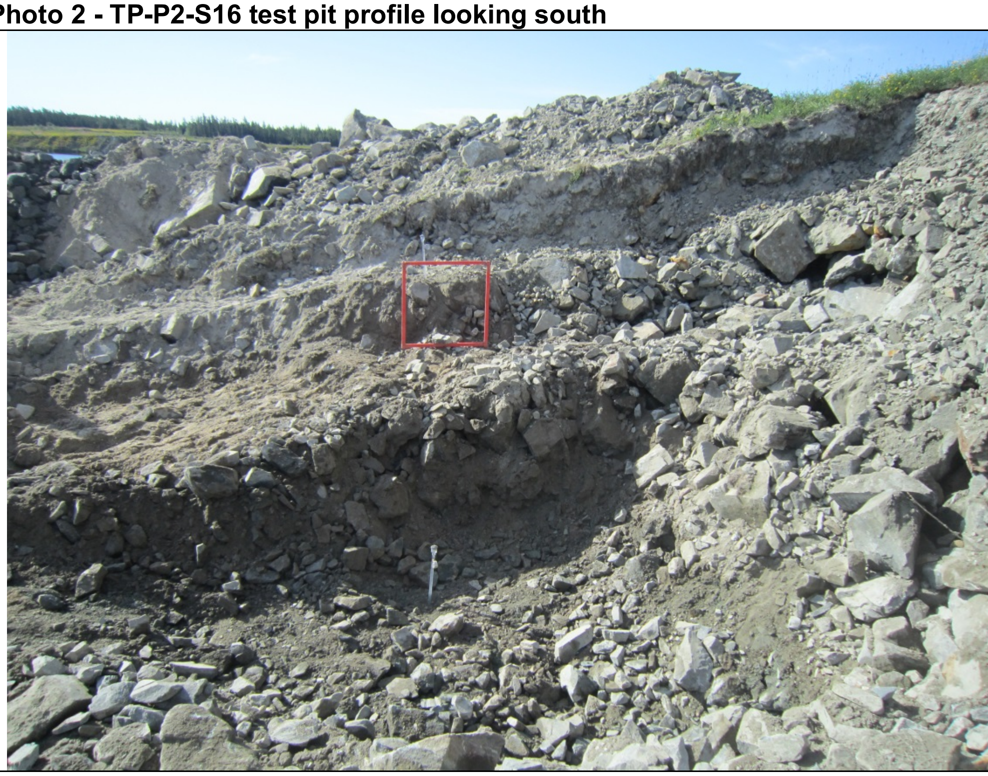
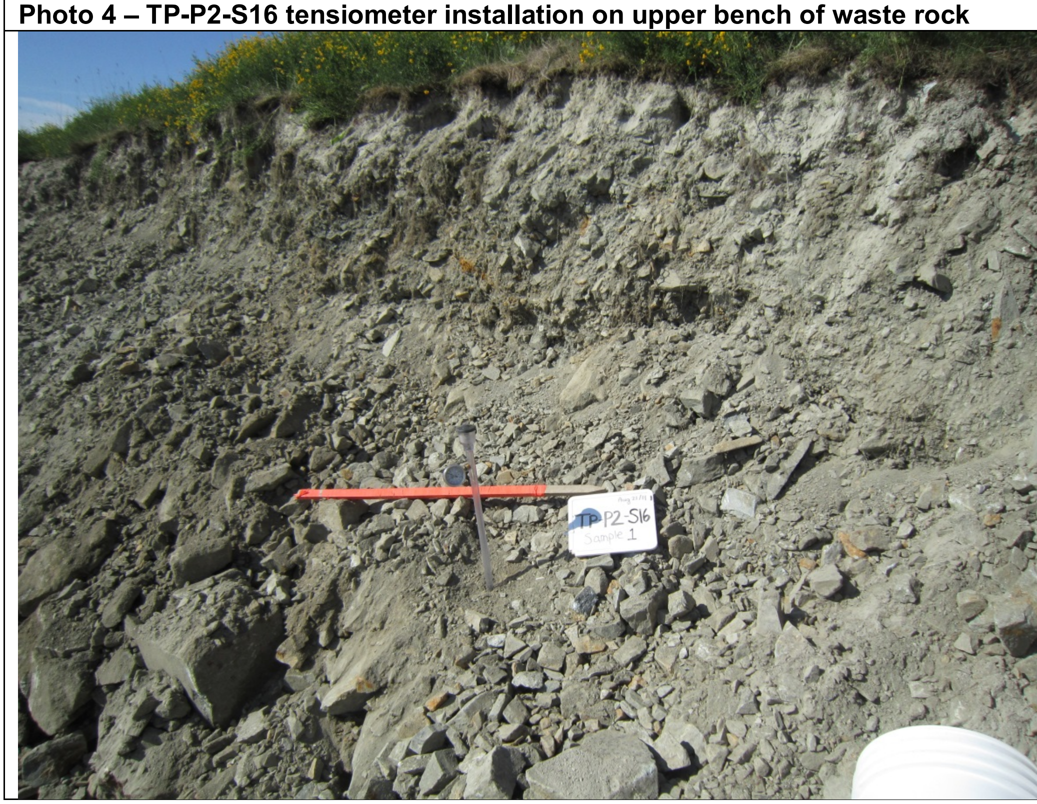
Photo 2 - TP-P2-S16 test pit profile looking south


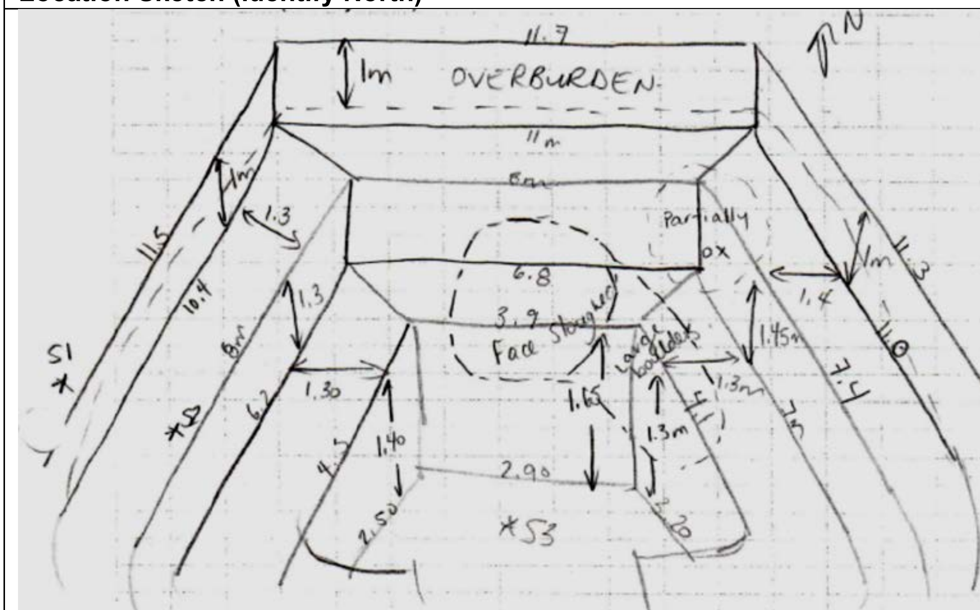
Photo 3 – TP-P2-S16 test pit profile looking east

Photo 4 – TP-P2-S16 tensiometer installation on upper bench of waste rock



Test Pit Number :	TP-P2-S17	**Sampling Date/Time:**	Aug 20th 2011 11:30 am
Location :	Toe of southern lobe of Pile 2, near west end of open pit		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 592104	**N:** 5541152
Weather conditions :	Sunny and cloud	**Sampled by :**	Aileen Cash/Pablo Urrutia

Location Sketch (identify North)



Soil Unit and Depth (From Surface)	Description of Units
Unit: Waste rock pile cover **Depth:** 0.0-0.4 m (Some areas up to 1.00 m)	**Material Type:** Till Overburden with organics (grass cover) **Rock Type:** Silty sand with rounded glacial boulders and cobbles **Colour:** Light brown-grey, some dark organics in root zone **Presence of Oxidation:** No oxidation in cover material **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** None *Crystal Habit (Clusters, cubic): N/A* Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Silty sand with clasts/cobbles up to 15-20 cm *Matrix or Clast supported:* Matrix supported – mainly fine grained material (i.e. fine grained sandy till). Some dark peat overburden also present on top of oxidized rock (0.95-2.05 m) **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended **Angularity of Rocks:** Fine grained matrix with rounded glacial cobbles **Moisture:** Moist in roots to dry at surface **Tensiometer Reading:** 32 kPa **Sample Taken:** Yes **Sample Number:** TP-P2-S17-S1

Unit: Waste rock **Depth:** 0.60-2.40 m	**Material Type:** Waste Rock **Rock Type:** Mainly Talc Chloride, some volcanics **Colour:** Grey to black, orange oxidized fines and surfaces **Presence of Oxidation:** Surface and matrix oxidation of waste rock **Percentage of Material Oxidized (%):** 60-70% surface oxidation **Sulphide Minerals Present:** Pyrite *Crystal Habit (Clusters, cubic):* Unknown Distribution (disseminated, fracture fill): Disseminated **Texture:** *Gradation:* Well graded, average grain size of 100 mm, silty to coarse sand matric – some boudlers up to 60-70 cm *Matrix or Clast supported:* Matrix with clasts, upper bench has higher proportion of fines **Structure:** (ordering/layering/unstructured/blended) – Coarsening downward **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist to wet **Tensiometer Reading:** 18 kPa **Sample Taken:** Yes **Sample Number:** TP-P2-S17-S2
Unit: Waste rock **Depth:** 2.05-5.20 m	**Material Type:** Waste Rock **Rock Type:** Talc Chloride with some volcanics **Colour:** Grey/black with orange with surface oxidation **Presence of Oxidation:** Orange to red-purple staining on the surface – few particles have completely oxidized surfaces **Percentage of Material Oxidized (%):** 15-20% of material has presence of oxidation on the surface **Sulphide Minerals Present:** Some Pyrrhotite/Pyrite *Crystal Habit (Clusters, cubic):* Unknown Distribution (disseminated, veining, fracture fill): Unknown **Texture:** *Gradation:* Large boulders infilled with small cobbles and some matrix, average particle size 300-400 mm *Matrix or Clast supported:* Clast supported, loose boulders **Structure:** (ordering/layering/unstructured/blended) – Coarsening downward structure **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist to dry **Tensiometer Reading:** N/A too blocky **Sample Taken:** Yes **Sample Number:** TP-P-S17-S3

Reason for ending Test Pit ☐ Limits of excavator ☒ Target depth ☐ Other
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID:

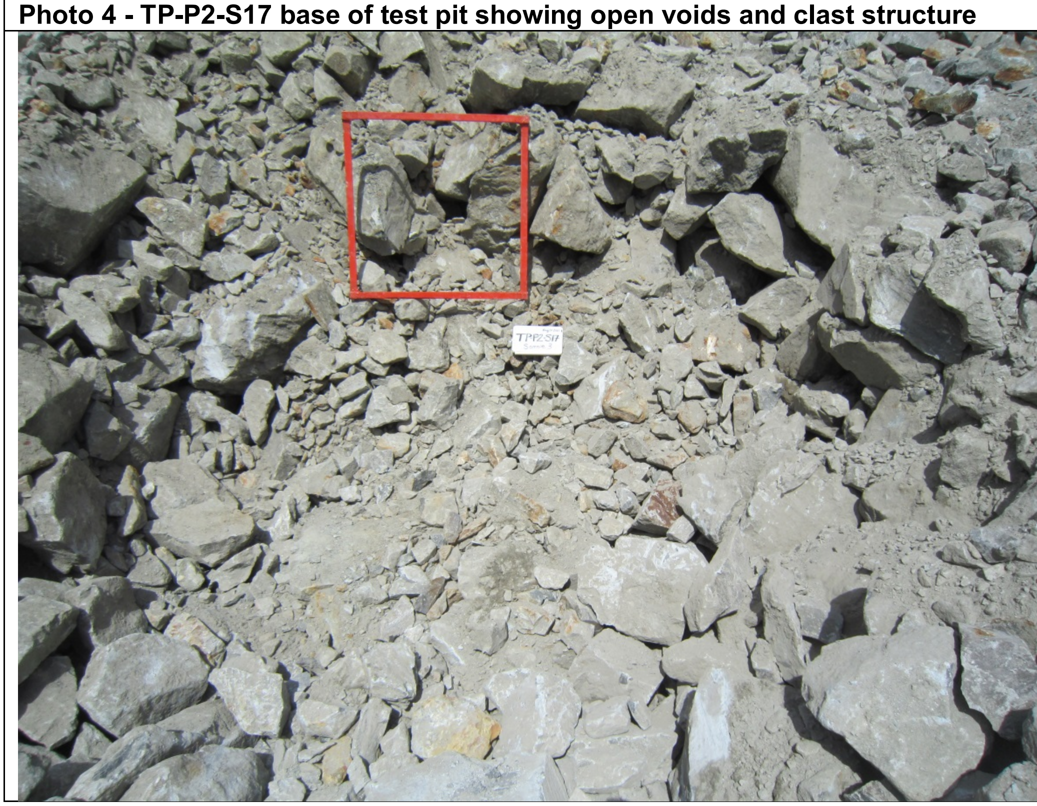
Observations / Other work performed :
None

Photos of Completed Test Pit:
Photo 1 – TP-P2-S17 test pit profile looking north-west

Photo 2 - TP-P2-S17 test pit profile looking east

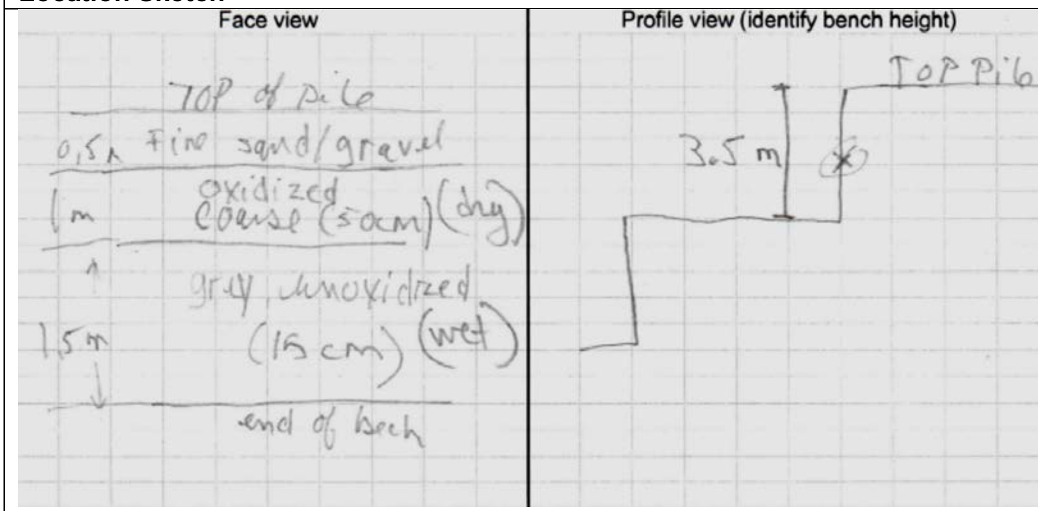

Photo 3 – TP-P2-S17 tensiometer installation at Sample 2 location

Photo 4 - TP-P2-S17 base of test pit showing open voids and clast structure



Profile Number :	WRS-2-1	**Sampling Date/Time:**	Oct 20th 2011 3:10 pm
Location :	Top bench of Stockpile 2		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 592138	**N:** 5541298
Weather conditions :	Cloudy, windy, 5°C	**Sampled by :**	Clarence Trapper

Location Sketch



Soil Unit and Depth (From Surface)	Description of Units
Unit: Waste rock **Location:** Excavated face of Stockpile 2	**Material Type:** Waste Rock **Rock Type:** Unknown **Colour:** Grey to black **Presence of Oxidation:** Surface and matrix oxidation of some waste rock, oxidation **Percentage of Material Oxidized (%):** N/A **Sulphide Minerals Present:** N/A – Not recorded *Crystal Habit (Clusters, cubic):* N/A Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Not recorded *Matrix or Clast supported:* Mix of intact rock and matrix **Structure:** (ordering/layering/unstructured/blended) – Oblique layering moving north, compact **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Wet **Sample Taken:** Yes **Sample Number:** WRS-2-1

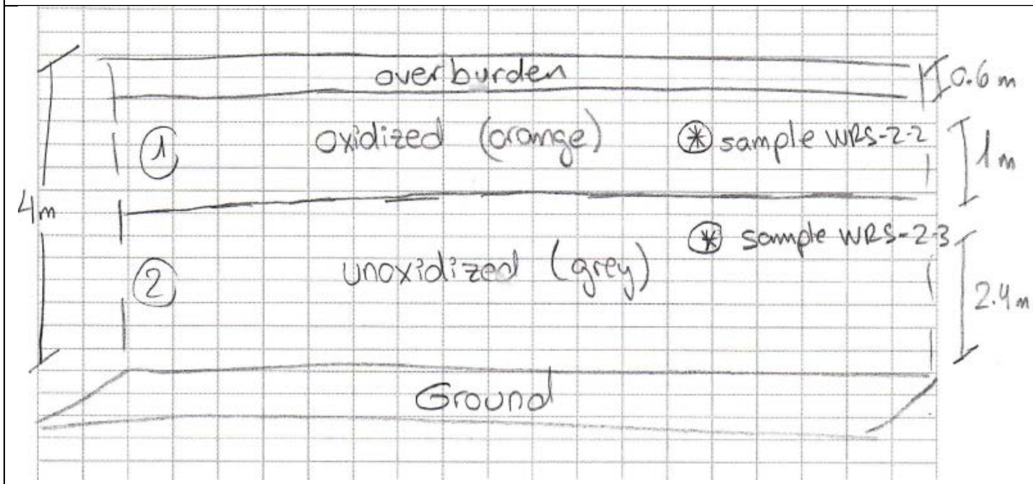
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ______________________

Observations / Other work performed :
None

Photos of Sampling Location: No photographs taken

Profile Number :	WRS-2-2 and WRS-2-3	**Sampling Date/Time:**	Oct 31st 2011 3:10 pm
Location :	Stockpile 2		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 592197	**N:** 5541310
Weather conditions :	Cloudy, light rain	**Sampled by :**	Pablo Urrutia

Location Sketch



Soil Unit and Depth (From Surface)	Description of Units
Unit: Waste rock **Location:** Excavated face of Stockpile 2	**Material Type:** Waste Rock **Rock Type:** Mafic flow/ volcanics **Colour:** Orange with some grey **Presence of Oxidation:** High surface and matrix oxidation **Percentage of Material Oxidized (%):** 95% **Sulphide Minerals Present:** Pyrite and Pyrrhotite *Crystal Habit (Clusters, cubic):* Not recorded Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Fine sandy matrix with gravel, cobbles and boulders up to 50 cm, average size 10-15 cm *Matrix or Clast supported:* Clast supported, 60% clasts **Structure:** (ordering/layering/unstructured/blended) – Blended, and compact (possible traffic surface) **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Sample Taken:** Yes **Sample Number:** WRS-2-2
Unit: Waste rock **Location:** Excavated face of Stockpile 2	**Material Type:** Waste Rock **Rock Type:** Volcanics (Mafic flow) **Colour:** Grey to black – little oxidation **Presence of Oxidation:** Some oxidation **Percentage of Material Oxidized (%):** 20% **Sulphide Minerals Present:** Pyrite and pyrrhotite

	Crystal Habit (Clusters, cubic): N/A Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Fine sandy matrix with gravel, cobbles and boulders up to 70 cm, average size 10-15 cm *Matrix or Clast supported:* Clast supported, 60% clasts **Structure:** (ordering/layering/unstructured/blended) – No visible structure **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Sample Taken:** Yes **Sample Number:** WRS-2-3

Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ______________________

Observations / Other work performed :
None

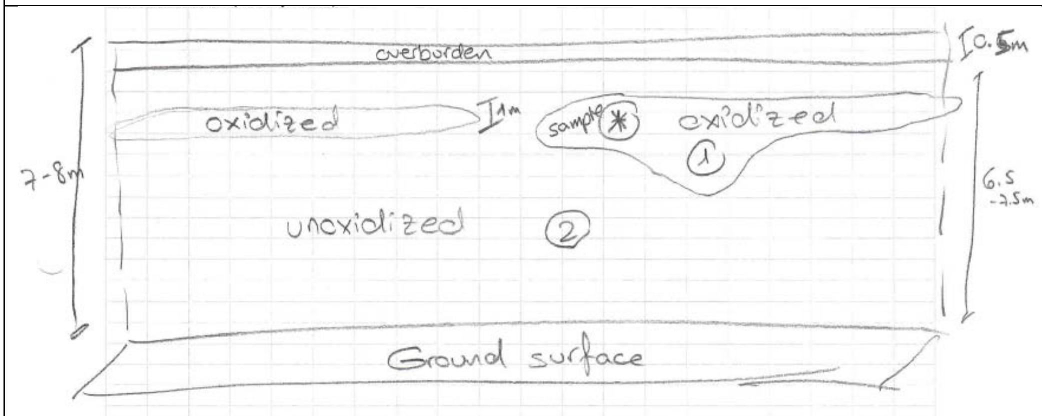
Photos of Sampling Location:

Photo 1 – Location of sampling for WRS-2-2 and WRS-2-3

Photo 2 - Location of sampling for WRS-2-2 and WRS-2-3 – close up

Profile Number :	WRS-2-4	Sampling Date/Time:	Nov 1st 2011 5:00 pm
Location :	Stockpile 2		
GPS Coordinates: (UTM 17, NAD 83)		E: 592093	N: 5541234
Weather conditions :	Cloudy	Sampled by :	Pablo Urrutia/Clarence Trapper

Location Sketch



Soil Unit and Depth (From Surface)	Description of Units
Unit: Waste rock **Location:** Excavated face of Stockpile 2 – Sample extracted by frontal loader from the slope. Sample contains sand from overburden.	**Material Type:** Waste Rock **Rock Type:** Mafic flow/ volcanics **Colour:** Orange oxidation with some grey **Presence of Oxidation:** High surface and matrix oxidation **Percentage of Material Oxidized (%):** 80% **Sulphide Minerals Present:** Pyrite and Pyrrhotite (2-5%) *Crystal Habit (Clusters, cubic):* Not recorded Distribution (disseminated, veining, fracture fill): Not recorded **Texture:** *Gradation:* Fine sandy matrix with gravel, cobbles and boulders up to 60 cm, average size 10-15 cm *Matrix or Clast supported:* Clast supported, 50% clasts **Structure:** (ordering/layering/unstructured/blended) – Blended, and compact (possible traffic surface) **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Sample Taken:** Yes **Sample Number:** WRS-2-4
Unit: Waste rock **Location:** Excavated face of Stockpile 2 – Sample not collected due to safety concerns	**Material Type:** Waste Rock **Rock Type:** Not observed **Colour:** Grey to black – little oxidation **Presence of Oxidation:** Little to no oxidation **Percentage of Material Oxidized (%):** 5%

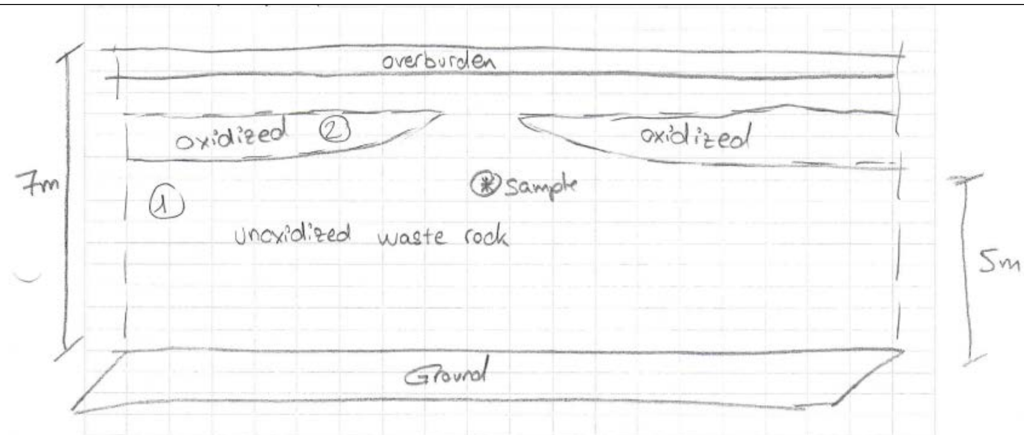
as slope looks unstable	**Sulphide Minerals Present:** Pyrite and pyrrhotite *Crystal Habit (Clusters, cubic):* N/A Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Matrix or Clast supported:* Clast supported **Structure:** (ordering/layering/unstructured/blended) – Coarsening downward, some blending **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Sample Taken:** No **Sample Number:** N/A
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant Water sample collected : ☐ Yes ☒ No Sample ID: ______________________	
Observations / Other work performed : None	

Photos of Sampling Location:

Photo 1 – Sample taken by front end loader from exposed slope

Profile Number :	WRS-2-5	**Sampling Date/Time:**	Nov 1st 2011 5:10 pm
Location :	Stockpile 2		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 592111	**N:** 5541212
Weather conditions :	Cloudy	**Sampled by :**	Pablo Urrutia/Clarence Trapper

Location Sketch



Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock **Location:** Excavated face of Stockpile 2 – Sample extracted by frontal loader from the slope.	**Material Type:** Waste Rock **Rock Type:** Mafic flow/ volcanics **Colour:** Grey with some orange oxidation **Presence of Oxidation:** Some surface oxidation **Percentage of Material Oxidized (%):** 30-40% **Sulphide Minerals Present:** Pyrite and Pyrrhotite (<2%) *Crystal Habit (Clusters, cubic):* Not recorded Distribution (disseminated, veining, fracture fill): Not recorded **Texture:** *Gradation:* Fine sandy matrix with gravel, cobbles and boulders up to 50 cm, average size 10 cm *Matrix or Clast supported:* Clast supported **Structure:** (ordering/layering/unstructured/blended) – Blended **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Sample Taken:** Yes **Sample Number:** WRS-2-5
Unit: Waste rock **Location:** Excavated face of Stockpile 2 – Sample not collected due to safety concerns	**Material Type:** Waste Rock **Rock Type:** Not observed **Colour:** Orange to red (due to oxidation) **Presence of Oxidation:** Highly oxidized **Percentage of Material Oxidized (%):** >90%

as slope looks unstable	**Sulphide Minerals Present:** Pyrite and pyrrhotite *Crystal Habit (Clusters, cubic):* N/A Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Matrix or Clast supported:* Clast supported **Structure:** (ordering/layering/unstructured/blended) – Compacted layer of approximately 1 m **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Sample Taken:** No **Sample Number:** N/A

Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ______________________

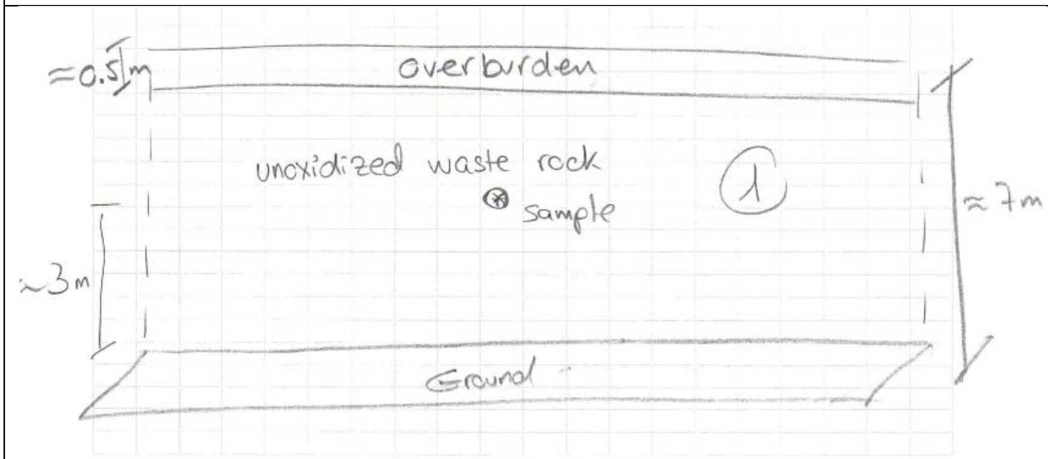
Observations / Other work performed :
None

Photos of Sampling Location:

Photo 1 – Sample taken by front end loader from exposed slope

Profile Number :	WRS-2-6	Sampling Date/Time:	Nov 1st 2011 5:20 pm
Location :	Stockpile 2		
GPS Coordinates: (UTM 17, NAD 83)		E: 592084	N: 5541194
Weather conditions :	Cloudy	Sampled by :	Pablo Urrutia/Clarence Trapper

Location Sketch



Soil Unit and Depth (From Surface)	Description of Units
Unit: Waste rock **Location:** Excavated face of Stockpile 2 – Sample extracted by frontal loader from the slope.	**Material Type:** Waste Rock **Rock Type:** Talc chloride **Colour:** Grey with some orange oxidation **Presence of Oxidation:** Some surface oxidation **Percentage of Material Oxidized (%):** 60% **Sulphide Minerals Present:** Pyrite and Pyrrhotite (<2%) *Crystal Habit (Clusters, cubic):* Not recorded Distribution (disseminated, veining, fracture fill): Not recorded **Texture:** *Gradation:* Fine sandy matrix with gravel, cobbles and boulders up to 40 cm, average size 5 cm *Matrix or Clast supported:* Clast supported **Structure:** (ordering/layering/unstructured/blended) – Blended, no visible structure **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Sample Taken:** Yes **Sample Number:** WRS-2-6

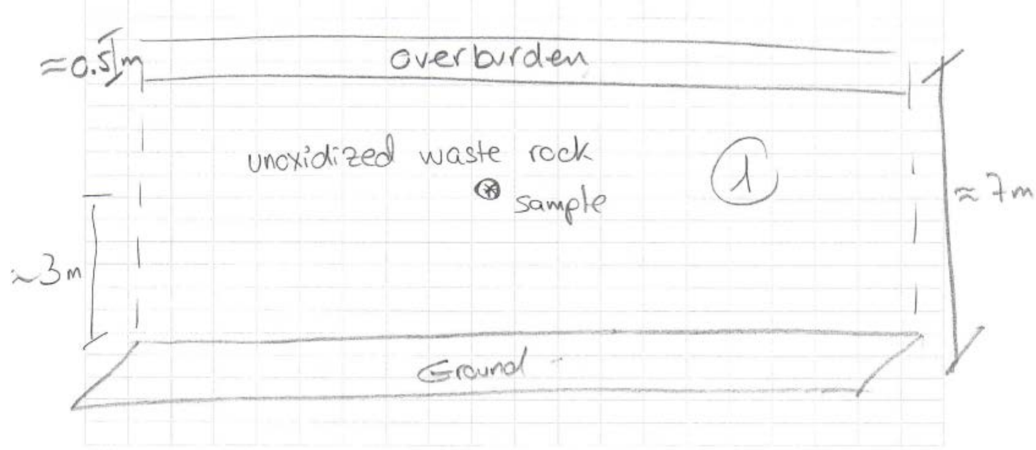
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ______________________

Observations / Other work performed :
None

Photos of Sampling Location:
Photo 1 – Sample taken by front end loader from exposed slope


Profile Number :	WRS-2-7	**Sampling Date/Time:**	Nov 1st 2011 5:30 pm
Location :	Stockpile 2		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 592084	**N:** 5541194
Weather conditions :	Cloudy	**Sampled by :**	Pablo Urrutia/Clarence Trapper

Location Sketch



Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock **Location:** Excavated face of Stockpile 2 – Sample extracted by frontal loader from the slope.	**Material Type:** Waste Rock **Rock Type:** Talc chloride **Colour:** Grey with some orange oxidation **Presence of Oxidation:** Some surface oxidation **Percentage of Material Oxidized (%):** 60% **Sulphide Minerals Present:** Pyrite and Pyrrhotite (<2%) *Crystal Habit (Clusters, cubic):* Not recorded Distribution (disseminated, veining, fracture fill): Not recorded **Texture:** *Gradation:* Fine sandy matrix with gravel, cobbles and boulders up to 40 cm, average size 5 cm *Matrix or Clast supported:* Clast supported **Structure:** (ordering/layering/unstructured/blended) – Blended, no visible structure **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Sample Taken:** Yes **Sample Number:** WRS-2-6

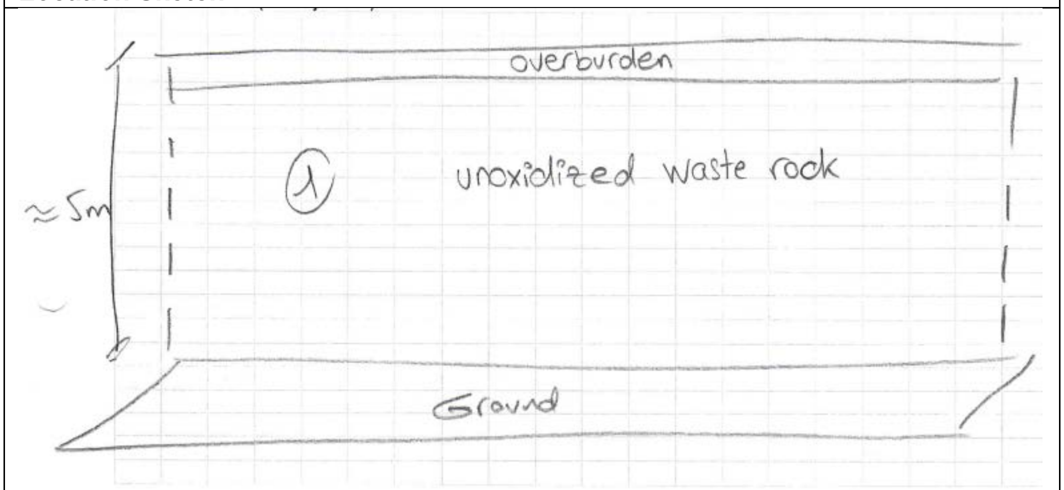
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ______________________

Observations / Other work performed :
None

Photos of Sampling Location:
Photo 1 – Sample taken by front end loader from exposed slope


Profile Number :	WRS-2-8	**Sampling Date/Time:**	Nov 1st 2011 5:40 pm
Location :	Stockpile 2		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 591978	**N:** 5541234
Weather conditions :	Cloudy, windy	**Sampled by :**	Pablo Urrutia/Clarence Trapper

Location Sketch



Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock (upper unit) **Location:** Excavated face of Stockpile 2 – Sample extracted by frontal loader from the slope and logged at 10 m from slope due to slope instability	**Material Type:** Waste Rock **Rock Type:** Mafic flow/volcanics **Colour:** Grey to dark grey, some brown **Presence of Oxidation:** Some oxidation – brown in colour **Percentage of Material Oxidized (%):** 50-60% **Sulphide Minerals Present:** Pyrite and Pyrrhotite (<2%) *Crystal Habit (Clusters, cubic):* N/A Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Fine sandy matrix with gravel, cobbles and boulders up to 1 m, average size 5 cm *Matrix or Clast supported:* Clast supported – 60% clasts **Structure:** (ordering/layering/unstructured/blended) – Blended, layer appears compacted and finer than above unit **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Sample Taken:** Yes **Sample Number:** WRS-2-8

Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ______________________

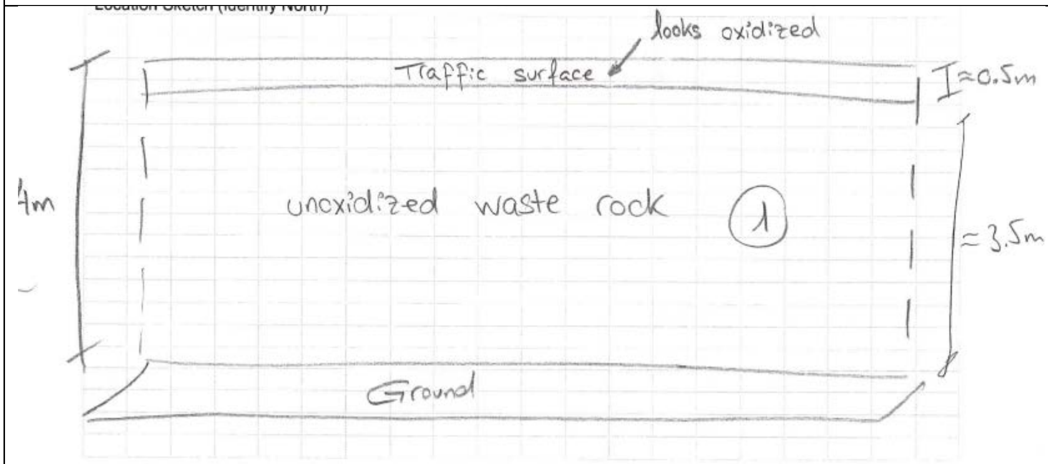
Observations / Other work performed :
None

Photos of Sampling Location:
Photo 1 – Sampling location on exposed face of Stockpile 2

Photo 2 – Sample after extraction by front end loader


Profile Number :	WRS-2-9	**Sampling Date/Time:**	Nov 2nd 2011 4:30 pm
Location :	Stockpile 2		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 592125	**N:** 5541136
Weather conditions :	Cloudy	**Sampled by :**	Pablo Urrutia/Clarence Trapper

Location Sketch



Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock **Location:** Excavated face of Stockpile 2 – Sample extracted by frontal loader from the slope.	**Material Type:** Waste Rock **Rock Type:** Mafic flow/volcanics **Colour:** Grey **Presence of Oxidation:** Some oxidation on particle surfaces – ranging from orange to red-purple **Percentage of Material Oxidized (%):** 50-60% **Sulphide Minerals Present:** Pyrite and Pyrrhotite (<2%) *Crystal Habit (Clusters, cubic):* N/A Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Fine sandy matrix with gravel, cobbles and boulders up to 50 cm, average size 15 cm *Matrix or Clast supported:* Clast supported **Structure:** (ordering/layering/unstructured/blended) – Blended, no significant visible structure **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Sample Taken:** Yes **Sample Number:** WRS-2-9

Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ____________________

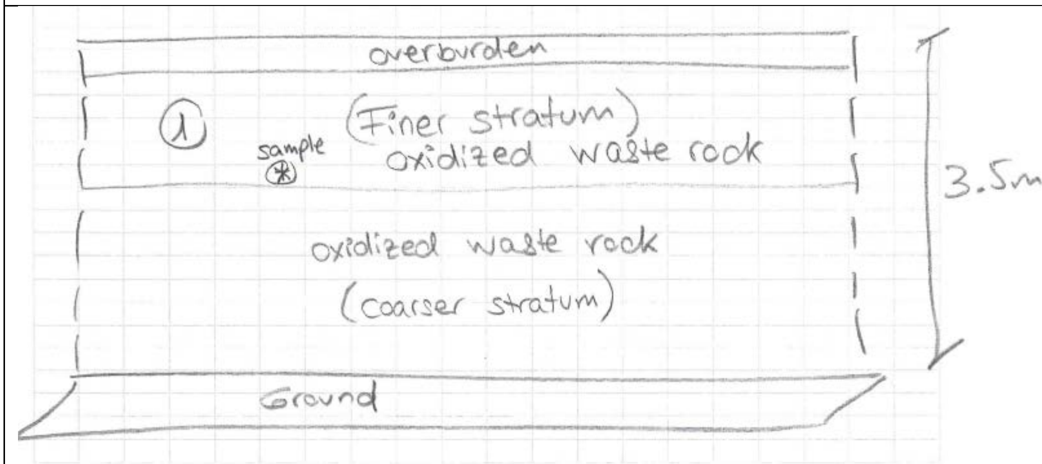
Observations / Other work performed :
None

Photos of Sampling Location:
Photo 1 – Sampling location on exposed face of Stockpile 2

Photo 2 – Sample after extraction by front end loader


Profile Number :	WRS-2-10	**Sampling Date/Time:**	Nov 2nd 2011 4:30 pm
Location :	Stockpile 2		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 592160	**N:** 5541232
Weather conditions :	Clear, 6°C	**Sampled by :**	Pablo Urrutia/Clarence Trapper

Location Sketch



Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock **Location:** Excavated face of Stockpile 2 – Sample extracted by shovel from slope.	**Material Type:** Waste Rock **Rock Type:** Talc chloride **Colour:** Orange to red – matrix and surface oxidation **Presence of Oxidation:** Highly oxidized – ranging from grey-orange to red **Percentage of Material Oxidized (%):** 80-95% **Sulphide Minerals Present:** Pyrite and Pyrrhotite (<5%) *Crystal Habit (Clusters, cubic):* N/A Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Fine sandy matrix with gravel, cobbles and boulders up to 40 cm, average size 5 cm *Matrix or Clast supported:* Clast supported **Structure:** (ordering/layering/unstructured/blended) – Coarsening downwards, fines are more compacted **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Sample Taken:** Yes **Sample Number:** WRS-2-10

Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ______________________

Observations / Other work performed :
None

Photos of Sampling Location:
Photo 1 – Sampling location on exposed face of Stockpile 2

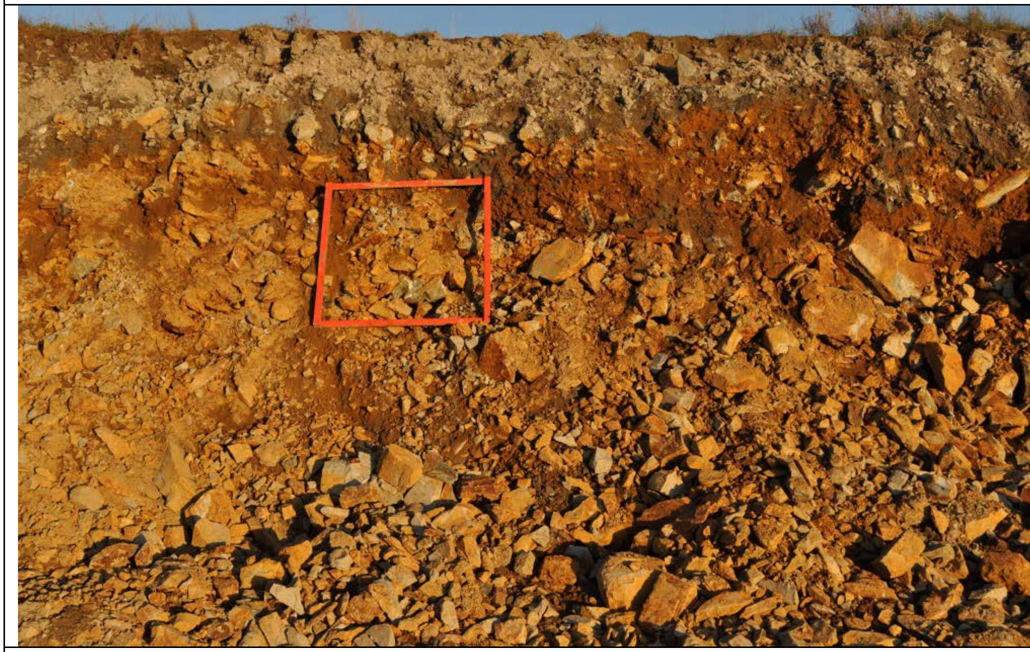
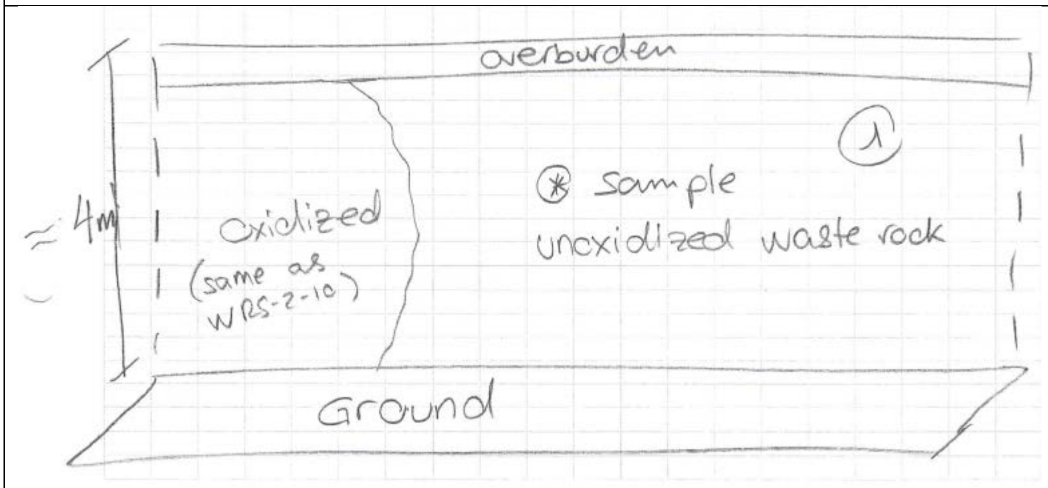



Photo 2 – Sample location after extraction by shovel


Profile Number :	WRS-2-11	**Sampling Date/Time:**	Nov 4th 2011 5:30 pm
Location :	Stockpile 2		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 592160	**N:** 5541232
Weather conditions :	Clear, 6°C	**Sampled by :**	Pablo Urrutia/Clarence Trapper

Location Sketch



Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock **Location:** Excavated face of Stockpile 2 – Sample extracted by shovel from slope.	**Material Type:** Waste Rock **Rock Type:** Talc chloride and mafic flow **Colour:** Grey with some orange surface oxidation **Presence of Oxidation:** Some oxidation **Percentage of Material Oxidized (%):** 40-50% **Sulphide Minerals Present:** Pyrite and Pyrrhotite (<2%) *Crystal Habit (Clusters, cubic):* N/A Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Fine sandy matrix with gravel, cobbles and boulders up to 50 cm, average size 10-15 cm *Matrix or Clast supported:* Clast supported **Structure:** (ordering/layering/unstructured/blended) – Compacted traffic surface below cover material – some angular sloped waste rock **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Sample Taken:** Yes **Sample Number:** WRS-2-11

Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ______________________

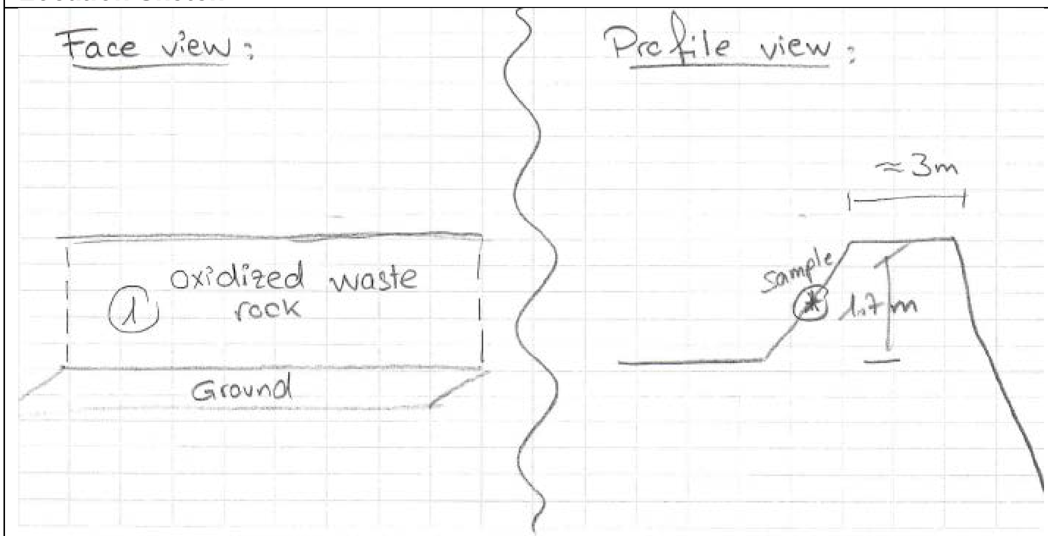
Observations / Other work performed :
None

Photos of Sampling Location:
Photo 1 – Sampling location on exposed face of Stockpile 2

Photo 2 – Sample location after extraction by shovel


Profile Number :	WRS-2-12	Sampling Date/Time:	Nov 4th 2011 5:50 pm
Location :	Stockpile 2		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 592160	**N:** 5541232
Weather conditions :	Clear, 6°C	**Sampled by :**	Pablo Urrutia/Clarence Trapper

Location Sketch



Soil Unit and Depth (From Surface)	Description of Units
Unit: Waste rock **Location:** Excavated face of Stockpile 2 – Sample extracted by shovel from slope.	**Material Type:** Waste Rock **Rock Type:** Talc chloride **Colour:** Grey with orange surface oxidation **Presence of Oxidation:** Yes, oxidation throughout **Percentage of Material Oxidized (%):** 80-95% **Sulphide Minerals Present:** Pyrite and Pyrrhotite (2-5%) *Crystal Habit (Clusters, cubic):* N/A Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Fine sandy matrix with gravel, cobbles and boulders up to 60 cm, average size 10-15 cm *Matrix or Clast supported:* Clast supported – 70% clasts **Structure:** (ordering/layering/unstructured/blended) – Blended – very blocky structure **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Sample Taken:** Yes **Sample Number:** WRS-2-12

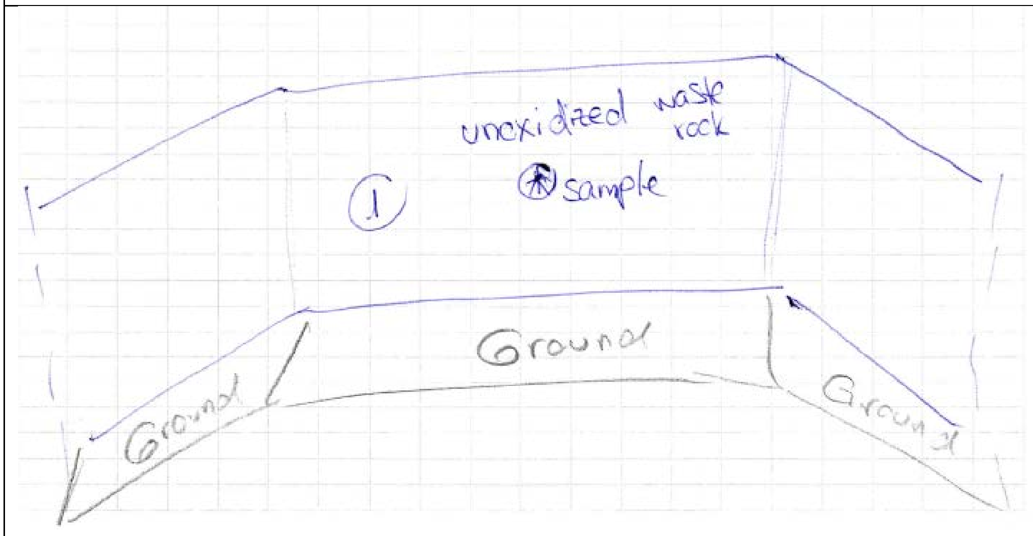
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ______________________

Observations / Other work performed :
None

Photos of Sampling Location:
Photo 1 – Sampling location on exposed face of Stockpile 2


Profile Number :	WRS-2-13	**Sampling Date/Time:**	Nov 8th 2011 1:40 pm
Location :	Stockpile 2		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 592070	**N:** 5541186
Weather conditions :	Overcast, 5°C	**Sampled by :**	Pablo Urrutia/Travis Desormeaux

Location Sketch



Soil Unit and Depth (From Surface)	**Description of Units**
Unit: Waste rock **Location:** Excavated face of Stockpile 2 – Sample extracted by shovel from slope.	**Material Type:** Waste Rock **Rock Type:** Talc chloride and mafic flow **Colour:** Grey to dark grey **Presence of Oxidation:** Some surface oxidation **Percentage of Material Oxidized (%):** 40% **Sulphide Minerals Present:** Pyrite and Pyrrhotite (<2%) *Crystal Habit (Clusters, cubic):* N/A Distribution (disseminated, veining, fracture fill): N/A **Texture:** *Gradation:* Fine sandy matrix with gravel, cobbles and boulders up to 1 m *Matrix or Clast supported:* Clast supported – 60% clasts **Structure:** (ordering/layering/unstructured/blended) – Coarsening downward, but blended **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Moisture:** Moist **Sample Taken:** Yes **Sample Number:** WRS-2-13

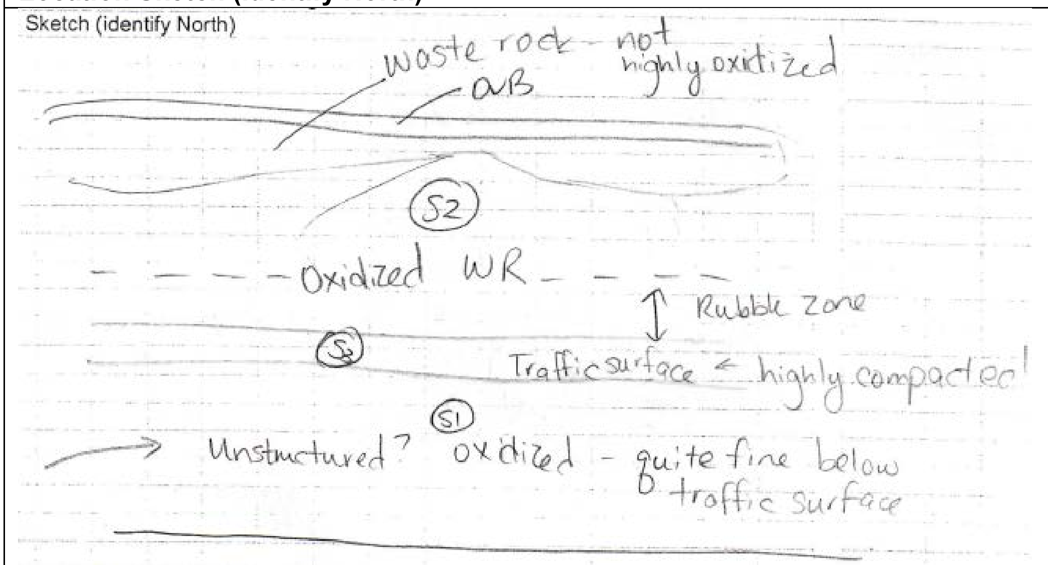
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ____________________

Observations / Other work performed :
None

Photos of Sampling Location:
Photo 1 – Sampling location on exposed face of Stockpile 2


Profile Number :	P1-P1	**Sampling Date/Time:**	June 20th 2012 7:45 am
Location :	Pile 1		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 591994	**N:** 5540447
Weather conditions :	Cloudy	**Sampled by :**	Aileen Cash/Jeff Bain/Adam Lentz

Location Sketch (identify North)



Soil Unit and Depth (From Surface)	**Description of Units**
Location on Face: Lower bench below traffic surface	**Material Type:** Waste Rock **Rock Type:** Mafic volcanics with disseminated sulphides, some Talc Chloride **Colour:** Brown/orange oxidation, grey fresh surfaces **Presence of Oxidation:** Highly weathered, surface oxidation, fine grained matrix is mostly oxidized **Percentage of Material Oxidized (%):** 90-100% **Sulphide Minerals Present:** Pyrrhotite/pyrite *Crystal Habit (Clusters, cubic): Not observed* Distribution (disseminated, veining, fracture fill): Disseminated **Texture:** *Gradation:* Coarse, maximum particle size of 40 cm with sand sized matrix *Matrix or Clast supported:* Clast supported structure **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended, placed on a possible traffic surface **Angularity of Rocks:** Fine grained matrix with angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P1-S1
Location on Face: Middle waste rock zone above rubble area	**Material Type:** Waste Rock **Rock Type:** Primarily Mafic Volcanic Flow, some Talc Chloride/Chloritic Greenstone and Intermediate Intrusive **Colour:** Orange/brown oxidized surfaces

	Presence of Oxidation: Surface oxidation and oxidized fine fraction, cementation **Percentage of Material Oxidized (%):**90% oxidation **Sulphide Minerals Present:** Pyrite/pyrrhotite, *Crystal Habit (Clusters, cubic):* Not observed Distribution (disseminated, veining, fracture fill): Fracture fill and disseminated **Texture:** *Gradation:* Fines are highly oxidized, large blocks have mainly surface oxidation *Matrix or Clast supported:* Clast supported with infilling of fines **Structure:** (ordering/layering/unstructured/blended) – Rubble zone above the traffic surface (coarsening downward), no evidence of angle of repose bedding **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P1-S2
Location on Face: Above traffic surface near rubble zone	**Material Type:** Waste Rock **Rock Type:** Mainly talc chloride/chloritic greenstone **Colour:** Orange/red-brown with red-purple staining **Presence of Oxidation:** Surface oxidation of larger blocks, fines highly oxidized, evidence of cementation/compaction **Percentage of Material Oxidized (%):** 80-90% **Sulphide Minerals Present:** Pyrite/pyrrhotite *Crystal Habit (Clusters, cubic):* Not observed Distribution (disseminated, veining, fracture fill): Disseminated **Texture:** *Gradation:* Course/poorly graded, large clasts up to 50 cm, fines are coarse sand and silt sized matrix *Matrix or Clast supported:* Clast supported with fine infilling **Structure:** (ordering/layering/unstructured/blended) – Traffic surface – sample taken near the compacted traffic surface **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P1-S3
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant Water sample collected : ☐ Yes ☒ No Sample ID: ______________________	
Observations / Other work performed : Traffic surface visible, upper and lower zones show rubble coarse material but no bed orientation	

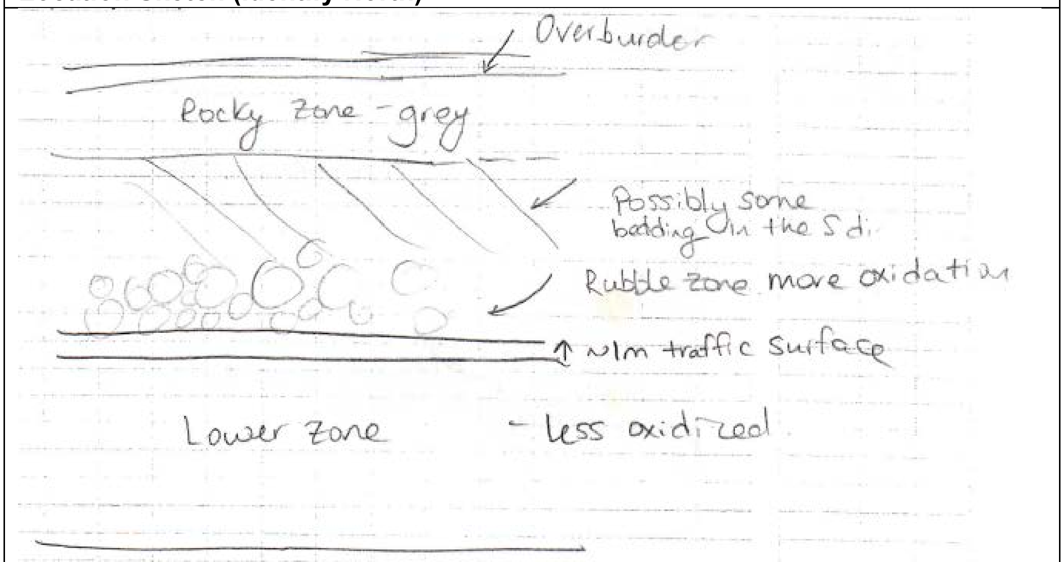
Photos of Profile Sampling Location:
Photo 1 – P1-P1-S1 Sample

Photo 2 - P1-P1-S2 Sample


Photo 3 – P1-P1-S3 Sample

Photo 4 – Excavated face of Profile 1

Profile Number :	P1-P2	**Sampling Date/Time:**	June 2nd 2012 9:13 am
Location :	On excavation face of main section of pile		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 591951	**N:** 5540447
Weather conditions :	Cloudy, cool	**Sampled by :**	Aileen Cash/Jeff Bain/Adam Lentz
Location Sketch (identify North)			



Soil Unit and Depth (From Surface)	**Description of Units**
Location on Excavated Face: Below old traffic surface	**Material Type:** Waste Rock **Rock Type:** Mainly Talc Chloride with some mafic volcanics and intermediate **Colour:** Grey, some orange/red surface oxidation **Presence of Oxidation:** Mostly grey, some oxidized surfaces and fractures, fines not highly oxidized **Percentage of Material Oxidized (%):**10% **Sulphide Minerals Present:** Pyrrhotite/pyrite *Crystal Habit (Clusters, cubic): Not observed* Distribution (disseminated, veining, fracture fill): Disseminated, weakly **Texture:** *Gradation:* Clast supported, fines are clay sized, talcy, coarse, maximum particle size of 40 cm with sand sized matrix *Matrix or Clast supported:* Clast supported structure, with fines infilling **Structure:** (ordering/layering/unstructured/blended) – No visible structure, blended, below an old traffic surface **Angularity of Rocks:** Fine grained matrix with angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P2-S1
Location on Excavated Face:	**Material Type:** Waste Rock

Material from traffic surface	**Rock Type:** Talc Chloride/Chloritic Greenstone and Intermediate Intrusive **Colour:** Dark Grey **Presence of Oxidation:** Limited oxidation, fine grained traffic surface with little surface oxidation **Percentage of Material Oxidized (%):**5% oxidation **Sulphide Minerals Present:** Pyrite/pyrrhotite, *Crystal Habit (Clusters, cubic):* Not observed Distribution (disseminated, veining, fracture fill): Finely disseminated **Texture:** *Gradation:* Fine grained waste rock within traffic surface *Matrix or Clast supported:* Matrix supported, <1cm material dominates **Structure:** (ordering/layering/unstructured/blended) – Traffic surface, compacted zones up to 1 m **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P2-S2
Location on Excavated Face: Above road surface, above rubble zone	**Material Type:** Waste Rock **Rock Type:** Talc Chloride/Chloritic Greenstone, Intermediate Intrusive, Mafic volcanics **Colour:** Grey to orange **Presence of Oxidation:** Surface and fracture oxidation, mostl **Percentage of Material Oxidized (%):**5% oxidation **Sulphide Minerals Present:** Pyrite/pyrrhotite, *Crystal Habit (Clusters, cubic):* Not observed Distribution (disseminated, veining, fracture fill): Finely disseminated **Texture:** *Gradation:* Fine grained waste rock within traffic surface *Matrix or Clast supported:* Matrix supported, <1cm material dominates **Structure:** (ordering/layering/unstructured/blended) – Not cemented, possible layering in zone above the rubble area **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P2-S3

Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ______________________

Observations / Other work performed : None

Photos of Profile Sampling Location:
Photo 1 – Excavation to fresh material on exposed face of WRS 1

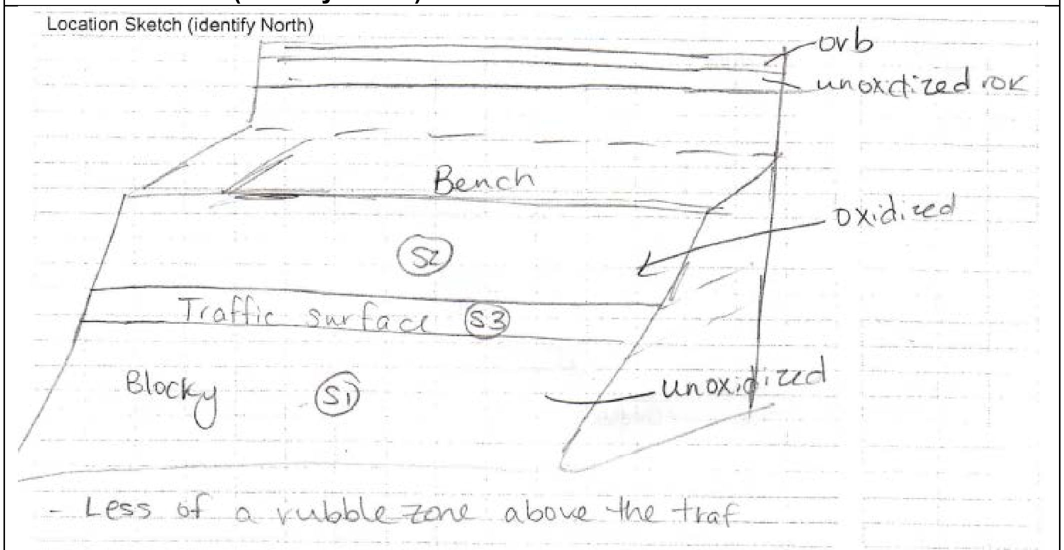
Photo 2 – Excavated face showing grey traffic surface with oxidixed waste rock above

Photo 3 – P1-P2-S2 Sample

Photo 4 – P1-P2-S3 Sample

Profile Number :	P1-P3	**Sampling Date/Time:**	June 20th 2012 9:37 am
Location :	WRS 1 main N-S excavated face		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 591966	**N:** 5540494
Weather conditions :	Overcast, 13°C	**Sampled by :**	Aileen Cash/Jeff Bain/Adam Lentz

Location Sketch (identify North)



Soil Unit and Depth (From Surface)	**Description of Units**
Location on Excavated Face: Below traffic surface	**Material Type:** Waste Rock **Rock Type:** Talc Chloride **Colour:** Grey fresh surfaces **Presence of Oxidation:** Limited oxidation, on surfaces of some rocks, not in fines **Percentage of Material Oxidized (%):** 5% **Sulphide Minerals Present:** Pyrrhotite/pyrite *Crystal Habit (Clusters, cubic): Not observed* Distribution (disseminated, veining, fracture fill): Disseminated, fracture fill **Texture:** *Gradation:* Very blocky, up to 50 cm, not much fine material *Matrix or Clast supported:* Clast supported structure **Structure:** (ordering/layering/unstructured/blended) – No significant visible structure **Angularity of Rocks:** Fine grained matrix with angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P3-S1
Location on Excavated Face: Above traffic surface	**Material Type:** Waste Rock **Rock Type:** Talc Chloride/Chloritic Greenstone, Intermediate Intrusive **Colour:** Orange/red surface oxidation, grey unoxidized **Presence of Oxidation:** Highly oxidized surfaces, fines are

	mostly oxidized **Percentage of Material Oxidized (%):**60% surface oxidation, fine fraction has some oxidation **Sulphide Minerals Present:** Pyrite/pyrrhotite *Crystal Habit (Clusters, cubic):* Crystal habit not observed Distribution (disseminated, veining, fracture fill): Weakly disseminated **Texture:** *Gradation:* Blocky *Matrix or Clast supported:* Clast supported (70% clasts) **Structure:** (ordering/layering/unstructured/blended) – No visible layering in the rubble zone, no visible layering **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P3-S2
Location on Excavated Face:	**Material Type:** Waste Rock **Rock Type:** Talc Chloride/Chloritic Greenstone, Intermediate Intrusive **Colour:** Grey, unoxidized **Presence of Oxidation:** Little surface oxidation, some fines are oxidized **Sulphide Minerals Present:** Pyrite/pyrrhotite *Crystal Habit (Clusters, cubic):* Crystal habit not observed Distribution (disseminated, veining, fracture fill): Weakly disseminated **Texture:** *Gradation:* Blocky structured infilled with silty sand sized fines *Matrix or Clast supported:* Clast supported (60% clasts), matrix infilling **Structure:** (ordering/layering/unstructured/blended) – Compacted traffic surface, which corresponds with a change in the degree of oxidation **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P3-S3
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant Water sample collected : ☐ Yes ☒ No Sample ID: ______________________	
Observations / Other work performed : None	

Photos of Profile Sampling Location:

Photo 1 – Exposed vertical profile of WRS 1 showing grey traffic surface contact

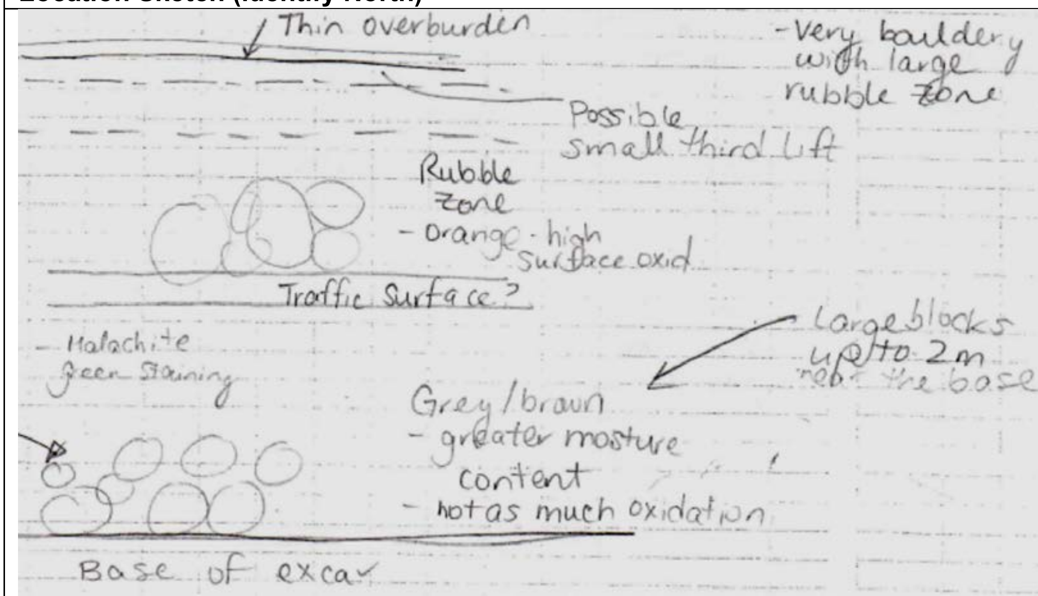
Photo 2 – 1 m reference square showing range of particle sizes

Photo 3 – Samples extracted from Profile 3

Photo 4 – Sample P1-P3-S2

Profile Number :	P1-P4	**Sampling Date/Time:**	June 20th 2012 9:50 am
Location :	Stockpile 1, on N-S excavated profile		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 591975	**N:** 5540538
Weather conditions :	Overcast	**Sampled by :**	Aileen Cash/Jeff Bain/Adam Lentz

Location Sketch (identify North)



Soil Unit and Depth (From Surface)	Description of Units
Location on Excavated Face: Below traffic surface	**Material Type:** Waste Rock **Rock Type:** Talc Chloride, some mafic volcanics **Colour:** Brown/orange oxidation, grey fresh surfaces **Presence of Oxidation:** Mainly surface oxidation with oxidation of matrix fines **Percentage of Material Oxidized (%):** 40-50% **Sulphide Minerals Present:** Pyrrhotite/pyrite *Crystal Habit (Clusters, cubic): Clusters* Distribution (disseminated, veining, fracture fill): Disseminated/veinlets **Texture:** *Gradation:* Mix of clast, cobble an boulder material with silty sand fines *Matrix or Clast supported:* Clast supported structure, equal proportion of clasts and matric material **Structure:** (ordering/layering/unstructured/blended) – No visible structure **Angularity of Rocks:** Fine grained matrix with angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P4-S1
Location on Excavated Face:	**Material Type:** Waste Rock **Rock Type:** Talc Chloride, some quart pieces, mafic volcanics

	Colour: Brown/orange oxidation, grey fresh surfaces **Presence of Oxidation:** Both surface oxidation and matric fines are oxidized **Percentage of Material Oxidized (%):** <20% **Sulphide Minerals Present:** Pyrrhotite/pyrite *Crystal Habit (Clusters, cubic): Not observed* Distribution (disseminated, veining, fracture fill): Disseminated **Texture:** *Gradation:* Matrix dominates and is coarse sand sized, large blocks up to 70 cm in sample – 2 -3 m boulders observed in the sample zone *Matrix or Clast supported:* Matrix supported zones with large clasts **Structure:** (ordering/layering/unstructured/blended) – Sample taken from above a very coarse rubble zone or likely end dumped area **Angularity of Rocks:** Fine grained matrix with angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P4-S2
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant Water sample collected : ☐ Yes ☒ No Sample ID: ____________	
Observations / Other work performed : Excavated face had very large boulders and the face sloughed in various locations	

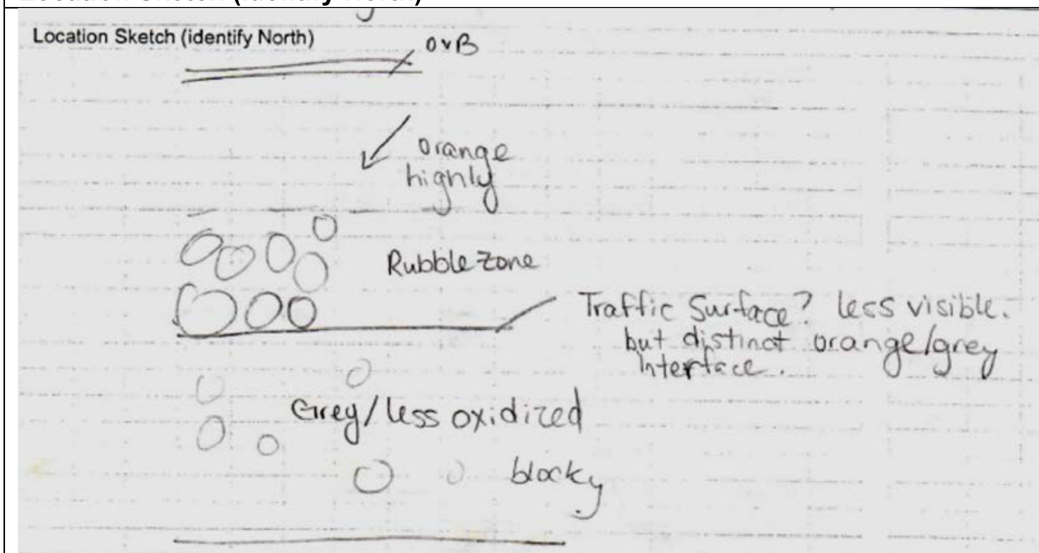
Photos of Profile Sampling Location:
Photo 1 – Excavation of Stockpile face showing blocky material

Photo 2 - Sample P1-P4-S1

Photo 3 – Sample P1-P4-S2

Profile Number :	P1-P5	**Sampling Date/Time:**	June 20th 2012 10:55 am
Location :	North corner of WRS 1		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 591989	**N:** 5540559
Weather conditions :	Overcast	**Sampled by :**	Aileen Cash/Jeff Bain/Adam Lentz

Location Sketch (identify North)



Soil Unit and Depth (From Surface)	**Description of Units**
Location on Excavated Face: Below traffic surface near middle of unoxidized zone	**Material Type:** Waste Rock **Rock Type:** Talc Chloride, some intermediate intrusive **Colour:** Grey/black with orange surface oxidation **Presence of Oxidation:** Areas of surface oxidation on larger boulders, matric material has some oxidation **Percentage of Material Oxidized (%):** 20-30% **Sulphide Minerals Present:** Pyrrhotite/pyrite *Crystal Habit (Clusters, cubic): Not observed* Distribution (disseminated, veining, fracture fill): Weakly disseminated, sulphides associated with quartz veins **Texture:** *Gradation:* Blocky – boulder and cobbles with silty and sand fines *Matrix or Clast supported:* Clast supported with matric fines infilling **Structure:** (ordering/layering/unstructured/blended) – No visible structure, except a possible traffic surfaces **Angularity of Rocks:** Fine grained matrix with angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P5-S1
Location on Excavated Face: Above traffic surface and rubble zone	**Material Type:** Waste Rock **Rock Type:** Talc Chloride, mafic volcanic flow **Colour:** Orange oxidation, some grey fresh surfaces **Presence of Oxidation:** Surfaces of almost all particles are

	completely oxidized, fine grained fraction is orange **Percentage of Material Oxidized (%):** 90-100% **Sulphide Minerals Present:** Pyrrhotite/pyrite *Crystal Habit (Clusters, cubic): Not observed* Distribution (disseminated, veining, fracture fill): Weakly disseminated **Texture:** *Gradation:* Clasts and cobbles with silt and sand sized matrix – surfaces of clasts covered in matrix fines/weathered material *Matrix or Clast supported:* Both clasts and matric material dominate the sample area **Structure:** (ordering/layering/unstructured/blended) – Blocky rubble zone at the base of the traffic surface with a fining upward gradation – bedding was not visible **Angularity of Rocks:** Fine grained matrix with angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P5-S2
Location on Excavated Face: Above rubble zone	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow, Talc Chloride **Colour:** Orange/red oxidation with some grey surfaces **Presence of Oxidation:** High level of surface oxidation, fines are oxidized **Percentage of Material Oxidized (%):** 80% **Sulphide Minerals Present:** Pyrite/pyrrhotite *Crystal Habit (Clusters, cubic):* Not observed Distribution (disseminated, veining, fracture fill): Weakly disseminated **Texture:** *Gradation:* Ranges from fines to cobbles and boulders 10-40 cm and silty and sand fines *Matrix or Clast supported:* 50% fines and clasts – as sample is taken from the top portion of the bench **Structure:** (ordering/layering/unstructured/blended) – No visible bedding, blocky rubble zone at the base, fining upward **Angularity of Rocks:** Fine grained matrix with angular to very angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P5-S3
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant Water sample collected : ☐ Yes ☒ No Sample ID: ______________________	
Observations / Other work performed : None	

Photos of Profile Sampling Location:
Photo 1 – Highly oxidized profile, large boulders and oxidized fines

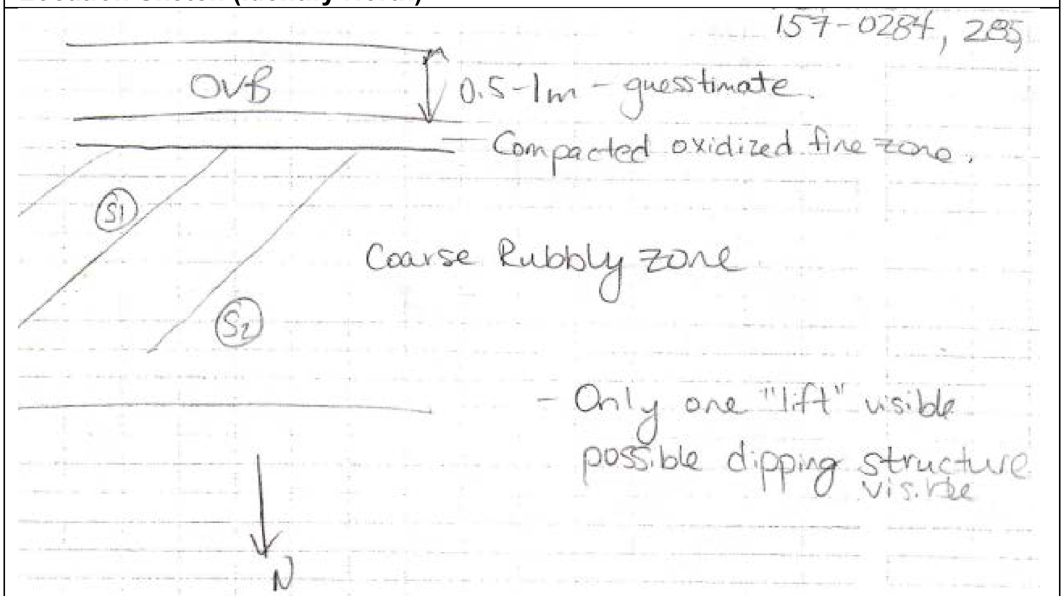
Photo 2 – Sample P1-P5-S1


Photo 3 – Sample P1-P5-S2

Photo 4 – Sample P1-P5-S3

Profile Number :	P1-P6	**Sampling Date/Time:**	June 20th 2012 12:40 am
Location :	Stockpile 1, on N-S excavated profile		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 591908	**N:** 5540414
Weather conditions :	Overcast, light rain	**Sampled by :**	Aileen Cash/Jeff Bain/Adam Lentz

Location Sketch (identify North)



Soil Unit and Depth (From Surface)	Description of Units
Location on Excavated Face: Near the base of the excavation	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow, Intermediate Intrusive, some Talc Chloride **Colour:** Grey fresh surfaces, with some clay on surfaces **Presence of Oxidation:** Some small areas of surface oxidation **Percentage of Material Oxidized (%):** 10-15% **Sulphide Minerals Present:** Pyrrhotite/pyrite *Crystal Habit (Clusters, cubic):* Clusters Distribution (disseminated, veining, fracture fill): Weakly disseminated, mainly in clusters **Texture:** *Gradation:* Coarse cobbles and boulders up to 40-60 cm, average material size is 10 cm, with a fine grained matrix *Matrix or Clast supported:* Clast with matric material infilling, matrix supported **Structure:** (ordering/layering/unstructured/blended) – Possible dipping beds, traffic surface above bedded structure **Angularity of Rocks:** Fine grained matrix with angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P6-S1
Location on Excavated Face:	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow, Talc Chloride, Intermediate

	Intrusive **Colour:** Orange surface oxidation, most surfaces are grey/fresh surfaces **Presence of Oxidation:** Red/orange surface oxidation precipitates on surface – some yellow sulphur coloured oxidation **Percentage of Material Oxidized (%):** Not observed **Sulphide Minerals Present:** Pyrrhotite/pyrite *Crystal Habit (Clusters, cubic): Not observed* Distribution (disseminated, veining, fracture fill): Disseminated **Texture:** *Gradation:* *Matrix or Clast supported:* Large clasts – clast supported structure, fewer fines **Structure:** (ordering/layering/unstructured/blended) – Sample taken from above a very coarse rubble zone or likely end dumped area **Angularity of Rocks:** Fine grained matrix with angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P6-S2
Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant Water sample collected : ☐ Yes ☒ No Sample ID: ________________________	
Observations / Other work performed : None	

Photos of Profile Sampling Location:

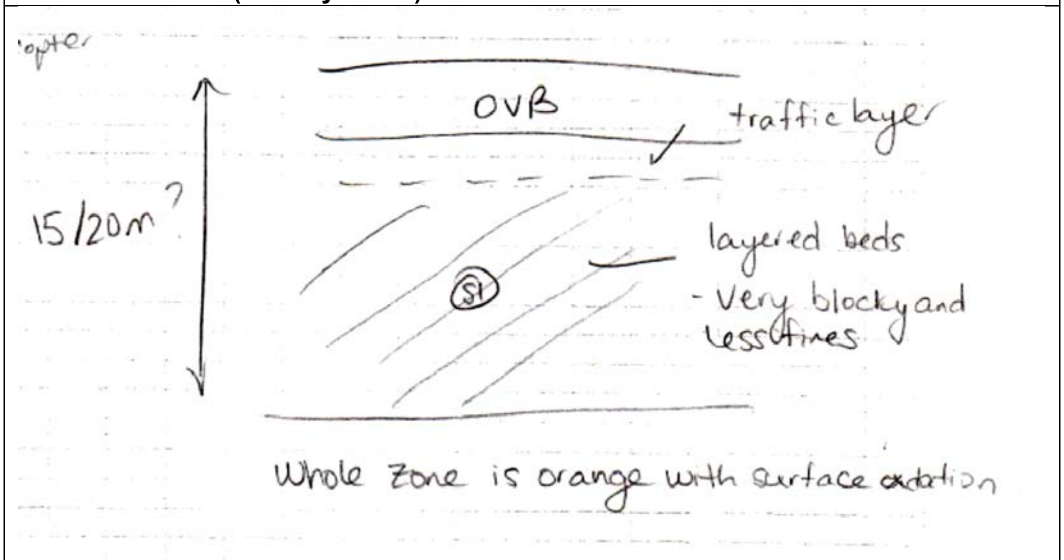
Photo 1 – Excavated face at Profile 6 with 1 m reference square

Photo 2 – Sample P1-P6-S1

Photo 3 – Sample P1-P6-S2

Profile Number :	P1-P7	Sampling Date/Time:	June 20th 2012 12:30 am
Location :	Stockpile 1, south end of excavated profile		
GPS Coordinates: (UTM 17, NAD 83)		E: 591895	N: 5540412
Weather conditions :	Overcast	Sampled by :	Aileen Cash/Jeff Bain/Adam Lentz

Location Sketch (identify North)



Soil Unit and Depth (From Surface)	Description of Units
Location on Excavated Face: Middle of face	**Material Type:** Waste Rock **Rock Type:** Talc Chloride, some intermediate intrusives **Colour:** Orange surface oxidation, grey to black fresh surfaces **Presence of Oxidation:** Most surfaces oxidized with some cementation of fines **Percentage of Material Oxidized (%):** 95% **Sulphide Minerals Present:** Pyrrhotite/pyrite *Crystal Habit (Clusters, cubic): Not observed* Distribution (disseminated, veining, fracture fill): Disseminated/veinlets **Texture:** *Gradation:* Cobbles and boulders, maximum of 40-60 cm, sand sized matrix *Matrix or Clast supported:* Clast supported structure, very blocky with little fine material – some infilling of voids **Structure:** (ordering/layering/unstructured/blended) – Some visible layering due to dumping, uniform material **Angularity of Rocks:** Fine grained matrix with angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P7-S1

Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ____________

Observations / Other work performed : None

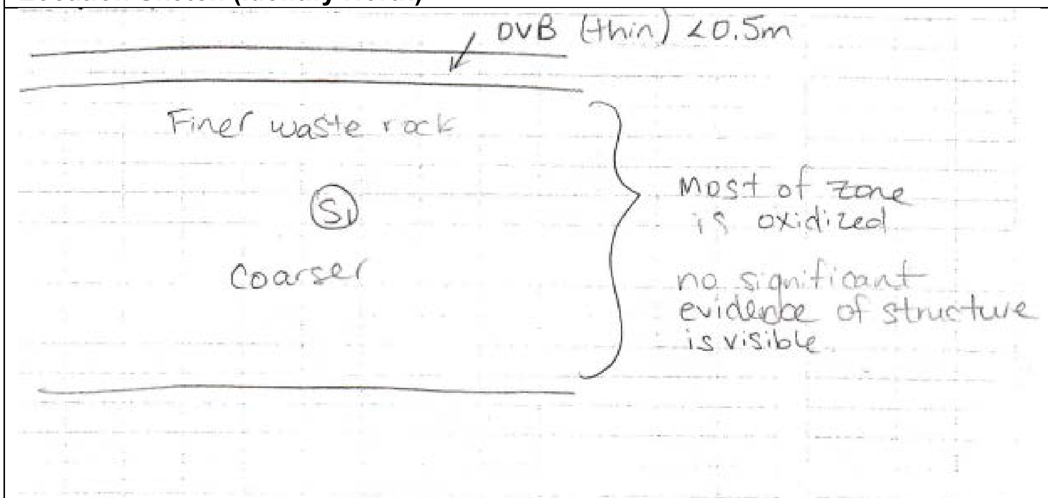
Photos of Profile Sampling Location:

Photo 1 – Excavated face of Profile 7 with 1 m reference square

Photo 2 – Sample P1-S7-S1

Profile Number :	P1-P8	**Sampling Date/Time:**	June 20th 2012 1:00 pm
Location :	South end of WRS 1, single bench of waste rock		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 591834	**N:** 5540412
Weather conditions :	Overcast, light rain	**Sampled by :**	Aileen Cash/Jeff Bain/Adam Lentz

Location Sketch (identify North)



Soil Unit and Depth (From Surface)	**Description of Units**
Location on Excavated Face: Middle of waste rock face	**Material Type:** Waste Rock **Rock Type:** Mafic flow, some quartz veining **Colour:** Orange surface oxidation, light grey fresh surfaces **Presence of Oxidation:** High surface oxidation and oxidation in fractures, precipitates on joints **Percentage of Material Oxidized (%):** 90% **Sulphide Minerals Present:** Pyrrhotite/pyrite *Crystal Habit (Clusters, cubic): Clusters* Distribution (disseminated, veining, fracture fill): Dissemination on fractures **Texture:** *Gradation:* Cobble sized material with some boulders, average particle size approximately 10 cm *Matrix or Clast supported:* Clast supported, however clasts are smaller, and fines infill the structure **Structure:** (ordering/layering/unstructured/blended) – No visible layering, however the material appears to get coarser with depth **Angularity of Rocks:** Fine grained matrix with angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P8-S1

Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ____________________

Observations / Other work performed : Waste rock in test pit is relatively uniform

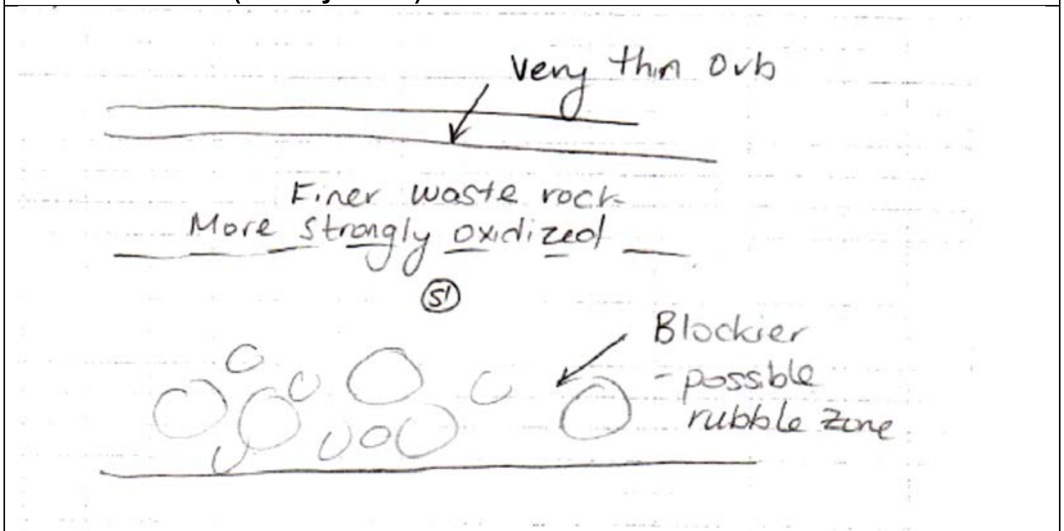
Photos of Profile Sampling Location:

Photo 1 – Excavated face of Profile 8 with 1 m reference square

Photo 2 – Sample P1-P8-S1

Profile Number :	P1-P9	Sampling Date/Time:	June 20th 2012 2:00 pm
Location :	Stockpile 1, south end of dump		
GPS Coordinates: (UTM 17, NAD 83)		E: -	N: -
Weather conditions :	Overcast, rain	Sampled by :	Aileen Cash/Jeff Bain/Adam Lentz

Location Sketch (identify North)



Soil Unit and Depth (From Surface)	Description of Units
Location on Excavated Face: Below traffic surface	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic Flow **Colour:** Grey with some orange and red surface oxidation and staining **Presence of Oxidation:** Mainly surface oxidation with oxidation of matrix fines **Percentage of Material Oxidized (%):** 20-30% **Sulphide Minerals Present:** Pyrrhotite/pyrite *Crystal Habit (Clusters, cubic):* Not observed Distribution (disseminated, veining, fracture fill): Weakly disseminated **Texture:** *Gradation:* Very coarse, cobbles and boulders, less matric material with infilling in the voids *Matrix or Clast supported:* Clast supported structure **Structure:** (ordering/layering/unstructured/blended) – Traffic surface at the overburden interface with finer, compact material. No significant structure or layering visible **Angularity of Rocks:** Fine grained matrix with angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P9-S1

Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ______________________

Observations / Other work performed : GPS location not recorded

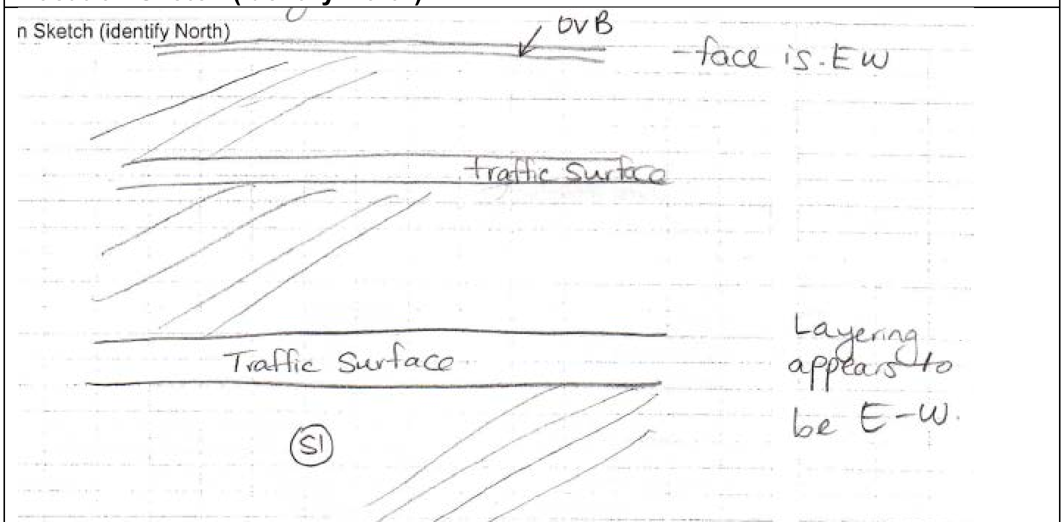
Photos of Profile Sampling Location:

Photo 1 – Excavated face of Profile 9 with 1 m reference square, very blocky

Photo 2 – Sample P1-P9-S1

Profile Number :	P1-P10	**Sampling Date/Time:**	June 20th 2012 2:15 pm
Location :	Stockpile 1, near crusher and haul road, sample from deepest bench		
GPS Coordinates: (UTM 17, NAD 83)		**E:** 592010	**N:** 5540591
Weather conditions :	Overcast, rain	**Sampled by :**	Aileen Cash/Jeff Bain/Adam Lentz

Location Sketch (identify North)



Soil Unit and Depth (From Surface)	**Description of Units**
Location on Excavated Face: Below lower traffic surface	**Material Type:** Waste Rock **Rock Type:** Mafic volcanic flow and Intermediate intrusive, some quartz veining **Colour:** Grey rock with some orange surface oxidation **Presence of Oxidation:** Mainly surface oxidation on large cobbles and boulders, fine fraction is not highly oxidized **Percentage of Material Oxidized (%):** 20-30% **Sulphide Minerals Present:** Pyrrhotite/pyrite *Crystal Habit (Clusters, cubic): Clusters* Distribution (disseminated, veining, fracture fill): Weakly disseminated **Texture:** *Gradation:* Mix of clast, cobble an boulder material with silty sand fines – coarse grained area with less matric material *Matrix or Clast supported:* Clast supported structure, very blocky with some matric material **Structure:** (ordering/layering/unstructured/blended) – Benches of waste rock separated by compacted layers (traffic surfaces). Sample taken from below a traffic surface in the lowest visible bench **Angularity of Rocks:** Fine grained matrix with angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P10-S1

Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ________________________

Observations / Other work performed : Sample contained large waste rock that could not be collected in the 20 L pail
Photos of Profile Sampling Location:
Photo 1 – Excavated profile with oxidized traffic surface and clast supported blocky grey waste rock

Photo 2 – Sample P1-S10-S1


Profile Number :	P1-P11	Sampling Date/Time:	June 20th 2012 9:50 am
Location :	Stockpile 1, near crusher on second WR bench (above P1-P10)		
GPS Coordinates: (UTM 17, NAD 83)		E: 592058	N: 5540598
Weather conditions :	Rain	Sampled by :	Aileen Cash/Jeff Bain/Adam Lentz

Location Sketch (identify North)
No Sketch available

Soil Unit and Depth (From Surface)	Description of Units
Location on Excavated Face: Below traffic surface	**Material Type:** Waste Rock **Rock Type:** Mafic Volcanic flow with some Talc Chloride/Chloritic Greenstone **Colour:** Grey with small areas of orange surface oxidation **Presence of Oxidation:** Little to no oxidation, some small spots on particle surfaces **Percentage of Material Oxidized (%):** 10% **Sulphide Minerals Present:** Pyrrhotite/pyrite *Crystal Habit (Clusters, cubic): Not observed* Distribution (disseminated, veining, fracture fill): Weakly disseminated **Texture:** *Gradation:* Mix of clast, cobble an boulder material with sand/silt and clayey fines – average particle size is 30-40cm with infilling of fine matrix *Matrix or Clast supported:* Clast supported structure, equal proportion of clasts and matric material **Structure:** (ordering/layering/unstructured/blended) – Traffic surfaces and benched construction evident in the area, sample taken below a traffic surface, some layering evident **Angularity of Rocks:** Fine grained matrix with angular waste rock **Sample Taken:** Yes **Sample Number:** P1-P11-S1

Presence of water: ☐ Yes ☒ No If Yes : ☐ Flowing ☐ Stagnant
Water sample collected : ☐ Yes ☒ No Sample ID: ________________________

Observations / Other work performed : None

Photos of Profile Sampling Location:
Photo 1 – Excavated face of Profile 11 showing angle of repose layering with 1 m reference square

Photo 2 – Sample P1-S1-S1

Appendix B – Summary of Sample Properties

Appendix B presents a summary of the field and laboratory testing data. The following data includes:

- Table B.1 - Sample Inventory - Sample Spatial Location and Material Type Data;
- Table B.2 - Sample Inventory - In Situ and Laboratory Data;
- Table B.3 to Table B.49 – Grain Size Distribution Data; and;
- Figure B.1 to B.13 – Soil Water Characteristic Curves for Gravimetric, Volumetric and Degree of Saturation Data.

Table B.1 **Sample Inventory - Sample Spatial Location and Material Type Data**

Identifier	Stockpile	Date/Time	Sample Taken	Sample Type		GPS Location		
				Material	Rock Types	Easting	Northing	Elevation
TP-P1-S1-S1	WRS 1	7/30/2011 12:00	Y	Waste Rock	TC/CG	591995	5540499	-
TP-P1-S1-S2	WRS 1	7/30/2011 12:00	Y	Waste Rock	TC/CG	591995	5540499	-
TP-P1-S1-S3	WRS 1	7/30/2011 12:00	Y	Cover	OVB	591995	5540499	-
TP-P1-S2-S1	WRS 1	7/30/2011 14:45	Y	Cover	OVB	591915	5540539	-
TP-P1-S2-S2	WRS 1	7/30/2011 14:45	Y	Waste Rock	TC/CG	591915	5540539	-
TP-P1-S2-S3	WRS 1	7/30/2011 14:45	Y	Waste Rock	TC/CG	591915	5540539	-
TP-P1-S3-S1	WRS 1	7/30/2011 16:30	Y	Waste Rock	MF, TC/CG	591833	5540581	-
TP-P1-S3-S2	WRS 1	7/30/2011 16:30	Y	Cover	OVB	591833	5540581	-
TP-P1-S4-S1	WRS 1	8/16/2011 9:00	Y	Cover	OVB	591837	5540712	-
TP-P1-S4-S2	WRS 1	8/16/2011 9:00	Y	Waste Rock	MF/TC	591837	5540712	-
TP-P1-S4-S3	WRS 1	8/16/2011 9:00	Y	Waste Rock	MF, some TC	591837	5540712	-
TP-P1-S5-S1	WRS 1	8/16/2011 11:30	Y	Cover	OVB	591933	5540734	-
TP-P1-S5-S2	WRS 1	8/16/2011 11:30	Y	Waste Rock	II,MF,TC	591933	5540734	-
TP-P1-S5-S3	WRS 1	8/16/2011 11:30	Y	Waste Rock	II,MF,TC	591933	5540734	-
TP-P1-S6-S1	WRS 1	8/14/2011 11:30	Y	Cover	OVB	591714	5540611	-
TP-P1-S6-S2	WRS 1	8/14/2011 11:30	Y	Waste Rock	MF	591714	5540611	-
TP-P1-S6-S3	WRS 1	8/14/2011 11:30	Y	Waste Rock	MF	591714	5540611	-
TP-P1-S8-S1	WRS 1	8/15/2011 9:00	Y	Cover	OVB	591929	5540614	-
TP-P1-S8-S2	WRS 1	8/15/2011 9:00	Y	Waste Rock	MF, TC, trace II	591929	5540614	-
TP-P1-S8-S3	WRS 1	8/15/2011 9:00	Y	Waste Rock	MF/TC	591929	5540614	-
TP-P1-S9-S1	WRS 1	8/15/2011 12:30	Y	Waste Rock	MF, TC, trace II	592032	5540613	-
TP-P1-S9-S2	WRS 1	8/15/2011 12:30	Y	Waste Rock	MF, TC, trace II	592032	5540613	-
TP-P1-S9-S3	WRS 1	8/15/2011 12:30	Y	Waste Rock	MF, TC, trace II	592032	5540613	-
TP-P1-S10-S1	WRS 1	8/13/2011 9:00	Y	Cover	OVB	591732	5540513	-
TP-P1-S10-S2	WRS 1	8/13/2011 9:00	Y	Sand	SAND	591732	5540513	-
TP-P1-S10-S3	WRS 1	8/13/2011 9:00	Y	Waste Rock	MF, TC, II	591732	5540513	-
TP-P1-S11-S1	WRS 1	8/13/2011 12:00	Y	Cover	OVB	591829	5540510	-
TP-P1-S11-S2	WRS 1	8/13/2011 12:00	Y	Waste Rock	MF, II	591829	5540510	-

Identifier	Stockpile	Date/Time	Sample Taken	Sample Type		GPS Location		
				Material	Rock Types	Easting	Northing	Elevation
TP-P1-S11-S3	WRS 1	8/13/2011 12:00	Y	Waste Rock	MF, II	591829	5540510	-
TP-P1-S11-S4	WRS 1	8/13/2011 12:00	Y	Waste Rock	II, CH	591829	5540510	-
TP-P1-S14-S1	WRS 1	8/12/2011 10:30	Y	Cover	OVB	591829	5540417	-
TP-P1-S14-S2	WRS 1	8/13/2011 10:30	Y	Waste Rock	MF, TC, trace II	591829	5540417	-
TP-P1-S14-S3	WRS 1	8/14/2011 10:30	Y	Waste Rock	MF, TC, some II	591829	5540417	-
TP-P1-S15-S1	WRS 1	8/12/2011 14:00	Y	Waste Rock	TC, MF, II	591921	5540415	-
TP-P1-S15-S2	WRS 1	8/12/2011 14:00	Y	Waste Rock	II, MF, some TC	591921	5540415	-
TP-P1-S15-S3	WRS 1	8/12/2011 14:00	Y	Waste Rock	TC	591921	5540415	-
TP-P1-S17-S1	WRS 1	8/14/2011 14:00	Y	Waste Rock	MF	591686	5540480	-
TP-P1-S17-S2	WRS 1	8/14/2011 14:00	Y	Waste Rock	MF	591686	5540480	-
TP-P1-S17-S3	WRS 1	8/14/2011 14:00	Y	Waste Rock	MF, II	591686	5540480	-
TP-P2-S1/TP-P2-S2	WRS 2	7/31/2011	Y	Waste Rock	MF, TC	592199	5541130	-
TP-P2-S3	WRS 2	7/31/2011	Y	Waste Rock	MF, TC	592167	5541150	-
TP-P2-S4	WRS 2	7/31/2011	N	-	TC, MF	592176	5541159	-
TP-P2-S5	WRS 2	7/31/2011	Y	Waste Rock	MF, some TC	592139	5541165	-
TP-P2-S6	WRS 2	7/31/2011	N	-	TC	592143	5541170	-
TP-P2-S7	WRS 2	7/31/2011	Y	Waste Rock	MF, some TC	592031	5541299	-
TP-P2-S10-S1	WRS 2	8/18/2011 16:30	Y	Waste Rock	TC, some MF	592106	5541321	-
TP-P2-S10-S2	WRS 2	8/18/2011 16:30	Y	Waste Rock	TC, some MF	592106	5541321	-
TP-P2-S10-S3	WRS 2	8/18/2011 16:30	Y	Waste Rock	MF, TC	592106	5541321	-
TP-P2-S11-S1	WRS 2	8/18/2011 13:45	Y	Cover	OVB	592185	5541307	-
TP-P2-S11-S2	WRS 2	8/18/2011 13:45	Y	Waste Rock	MF, II, TC	592185	5541307	-
TP-P2-S11-S3	WRS 2	8/18/2011 13:45	Y	Waste Rock	MF, II, TC	592185	5541307	-
TP-P2-S12-S1	WRS 2	8/21/2011 11:00	Y	Cover	OVB	592259	5541306	-
TP-P2-S12-S2	WRS 2	8/21/2011 11:00	Y	Waste Rock	TC, some MF	592259	5541306	-
TP-P2-S12-S3	WRS 2	8/21/2011 11:00	Y	Waste Rock	TC, some MF	592259	5541306	-
TP-P2-S13-S1	WRS 2	8/20/2011 9:45	Y	Cover	OVB	592027	5541227	-
TP-P2-S13-S2	WRS 2	8/20/2011 9:45	Y	Waste Rock	TC, MF	592027	5541227	-
TP-P2-S13-S3	WRS 2	8/20/2011 9:45	Y	Waste Rock	TC, MF	592027	5541227	-
TP-P2-S14-S1	WRS 2	8/19/2011 10:00	Y	Cover	OVB	592094	5541224	-

Identifier	Stockpile	Date/Time	Sample Taken	Sample Type		GPS Location		
				Material	Rock Types	Easting	Northing	Elevation
TP-P2-S14-S2	WRS 2	8/19/2011 10:00	Y	Waste Rock	MF	592094	5541224	-
TP-P2-S14-S3	WRS 2	8/19/2011 10:00	Y	Waste Rock	MF, some TC	592094	5541224	-
TP-P2-S15-S1	WRS 2	8/19/2011 11:30	Y	Cover	OVB	592178	5541223	-
TP-P2-S15-S2	WRS 2	8/19/2011 11:30	Y	Waste Rock	MF, TC	592178	5541223	-
TP-P2-S15-S3	WRS 2	8/19/2011 11:30	Y	Waste Rock	MF, some TC	592178	5541223	-
TP-P2-S16-S1	WRS 2	8/21/2011 9:00	Y	Waste Rock	TC, some MF	592257	5541222	-
TP-P2-S16-S2	WRS 2	8/21/2011 9:00	Y	Waste Rock	TC, some MF	592257	5541222	-
TP-P2-S16-S3	WRS 2	8/21/2011 9:00	Y	Waste Rock	TC, some MF	592257	5541222	-
TP-P2-S17-S1	WRS 2	8/20/2011 11:30	Y	Cover	OVB	592104	5541152	-
TP-P2-S17-S2	WRS 2	8/20/2011 11:30	Y	Waste Rock	TC, some MF	592104	5541152	-
TP-P2-S17-S3	WRS 2	8/20/2011 11:30	Y	Waste Rock	TC, some MF	592104	5541152	-
WRS-2-1	WRS 2	10/20/2011 15:10	N	-		592138	5541298	354
WRS-2-2	WRS 2	10/31/2011 15:10	Y	Waste Rock	MF	592197	5541319	287
WRS-2-3	WRS 2	10/31/2011 15:10	Y	Waste Rock	MF	592197	5541319	286
WRS-2-4	WRS 2	11/1/2011 17:00	Y	Waste Rock	MF	592093	5541234	288
WRS-2-5	WRS 2	11/1/2011 17:10	Y	Waste Rock	MF	592111	5541212	286
WRS-2-6	WRS 2	11/1/2011 17:20	Y	Waste Rock	TC	592084	5541194	287
WRS-2-7	WRS 2	11/1/2011 17:30	Y	Waste Rock	MF	591987	5541228	275
WRS-2-8	WRS 2	11/1/2011 17:40	Y	Waste Rock	MF	591978	5541234	277
WRS-2-9	WRS 2	11/2/2011 16:30	Y	Waste Rock	MF	592125	5541136	285
WRS-2-10	WRS 2	11/4/2011 17:15	Y	Waste Rock	TC	592160	5541232	286
WRS-2-11	WRS 2	11/4/2011 17:30	Y	Waste Rock	MF,TC	592157	5541197	286
WRS-2-12	WRS 2	11/4/2011 17:50	Y	Waste Rock	TC	592137	5541217	285
WRS-2-13	WRS 2	11/8/2011 13:40	Y	Waste Rock	MF,TC	592070	5541186	285
P1-P1-S1	WRS 1	6/20/2012 7:45	Y	Waste Rock	MF, some TC	591944	5540447	-
P1-P1-S2	WRS 1	6/20/2012 7:45	Y	Waste Rock	MF, some TC, II	591944	5540447	-
P1-P1-S3	WRS 1	6/20/2012 7:45	Y	Waste Rock	TC	591944	5540447	-
P1-P2-S1	WRS 1	6/20/2012 9:15	Y	Waste Rock	TC, some MF,II	591951	5540447	-
P1-P2-S2	WRS 1	6/20/2012 9:15	Y	Waste Rock	TC, II	591951	5540447	-
P1-P2-S3	WRS 1	6/20/2012 9:15	Y	Waste Rock	TC, MF,II	591951	5540447	-

Identifier	Stockpile	Date/Time	Sample Taken	Sample Type		GPS Location		
				Material	Rock Types	Easting	Northing	Elevation
P1-P3-S1	WRS 1	6/20/2012 9:37	Y	Waste Rock	TC	591966	5540494	-
P1-P3-S2	WRS 1	6/20/2012 9:37	Y	Waste Rock	TC, II	591966	5540494	-
P1-P3-S3	WRS 1	6/20/2012 9:37	Y	Waste Rock	TC, II	591966	5540494	-
P1-P4-S1	WRS 1	6/20/2012 9:50	Y	Waste Rock	TC, some MF	591975	5540538	-
P1-P4-S2	WRS 1	6/20/2012 9:50	Y	Waste Rock	TC, MF	591975	5540538	-
P1-P5-S1	WRS 1	6/20/2012 10:55	Y	Waste Rock	TC, II	591989	5540559	-
P1-P5-S2	WRS 1	6/20/2012 10:55	Y	Waste Rock	TC, MF	591989	5540559	-
P1-P5-S3	WRS 1	6/20/2012 10:55	Y	Waste Rock	TC, MF	591989	5540559	-
P1-P6-S1	WRS 1	6/20/2012 12:40	Y	Waste Rock	MF, II, some TC	591908	5540414	-
P1-P6-S2	WRS 1	6/20/2012 12:40	Y	Waste Rock	TC, II, some MF	591908	5540414	-
P1-P7-S1	WRS 1	6/20/2012 12:30	Y	Waste Rock	TC, some II	591895	5540412	-
P1-P8-S1	WRS 1	6/20/2012 13:00	Y	Waste Rock	MF	591834	5540412	-
P1-P9-S1	WRS 1	6/20/2012 14:00	Y	Waste Rock	MF	-	-	-
P1-P10-S1	WRS 1	6/20/2012 14:15	Y	Waste Rock	MF, II	592010	5540591	-
P1-P11-S1	WRS 1	6/20/2012 15:00	Y	Waste Rock	MF, TC	592058	5540598	-

Table B.2 **Sample Inventory - *In Situ* and Laboratory Data**

Identifier	Stockpile	Sample Taken	Matric Suction (kPa)	Gravimetric Moisture Content: Matric Sample (wt%)	Gravimetric Moisture Content: 20-L Pail Sample (wt%)	Paste pH (pH units)	Munsell Soil Colour (Dry Colour)
TP-P1-S1-S1	WRS 1	Y	8.0	-	N/A	2.8	10YR 6/8
TP-P1-S1-S2	WRS 1	Y	3.0	-	3.3%	2.7	10YR 5/6
TP-P1-S1-S3	WRS 1	Y	42.0	-	12.5%	7	10YR 4/1
TP-P1-S2-S1	WRS 1	Y	3.0	-	5.7%	7.5	5Y 7/1
TP-P1-S2-S2	WRS 1	Y	11.0	-	1.6%	6.8	10Y 6/1
TP-P1-S2-S3	WRS 1	Y	14.0	-	5.5%	2.5	10YR 5/8
TP-P1-S3-S1	WRS 1	Y	6.0	-	2.0%	6.8	10Y 5/1
TP-P1-S3-S2	WRS 1	Y	11.0	-	5.9%	7.8	2.5Y 7/2
TP-P1-S4-S1	WRS 1	Y	30.0	6.0%	3.5%	7.5	5Y 7/1
TP-P1-S4-S2	WRS 1	Y	8.5	3.5%	1.7%	7.1	5Y 5/1
TP-P1-S4-S3	WRS 1	Y	2.0	2.9%	2.2%	7.3	10Y 5/1
TP-P1-S5-S1	WRS 1	Y	50.5	-	2.4%	7.2	5Y 6/2
TP-P1-S5-S2	WRS 1	Y	21.0	3.1%	1.3%	6.5	10Y 6/1
TP-P1-S5-S3	WRS 1	Y	N/A - Blocky	-	0.9%	6.4	10Y 6/1
TP-P1-S6-S1	WRS 1	Y	17.0	6.0%	6.2%	7.5	5Y 7/1
TP-P1-S6-S2	WRS 1	Y	10.0	-	3.2%	3.5	10YR 5/4
TP-P1-S6-S3	WRS 1	Y	N/A - Blocky	-	1.5%	7.1	10Y 6/1
TP-P1-S8-S1	WRS 1	Y	22.0	5.8%	4.6%	7.7	2.5Y 6/1
TP-P1-S8-S2	WRS 1	Y	15.0	3.5%	2.1%	6.7	5Y 6/2
TP-P1-S8-S3	WRS 1	Y	16.0	4.2%	2.6%	6.8	5Y 5/2
TP-P1-S9-S1	WRS 1	Y	39.5	5.7%	2.8%	3.3	10YR 5/8
TP-P1-S9-S2	WRS 1	Y	17.0	4.1%	1.8%	4.4	10YR 5/6
TP-P1-S9-S3	WRS 1	Y	6.0	5.8%	3.1%	2.3	7.5YR 5/8
TP-P1-S10-S1	WRS 1	Y	10.0	6.1%	6.1%	7.5	2.5Y 6/2
TP-P1-S10-S2	WRS 1	Y	5.0	2.9%	2.5%	7	2.5Y 7/2
TP-P1-S10-S3	WRS 1	Y	6.0	3.7%	1.9%	3	10YR 5/6
TP-P1-S11-S1	WRS 1	Y	11.0	16.7%	4.9%	7.7	2.5Y 6/2

Identifier	Stockpile	Sample Taken	Matric Suction	Gravimetric Moisture Content		Paste pH	Munsell Soil Colour
			(kPa)	Matric Sample (wt%)	20-L Pail Sample (wt%)	(pH units)	(Dry Colour)
TP-P1-S11-S2	WRS 1	Y	3.0	5.1%	2.9%	4.4	10YR 4/3
TP-P1-S11-S3	WRS 1	Y	-	4.1%	2.8%	6	5Y 5/1
TP-P1-S11-S4	WRS 1	Y	5.0	-	0.3%	-	-
TP-P1-S14-S1	WRS 1	Y	16.0	-	5.0%	7.3	5Y 6/2
TP-P1-S14-S2	WRS 1	Y	7.0	5.0%	3.1%	2.9	10YR 5/6
TP-P1-S14-S3	WRS 1	Y	N/A - Blocky	4.8%		4	10YR 5/4
TP-P1-S15-S1	WRS 1	Y	Rain	6.0%	4.6%	2.9	10YR 5/6
TP-P1-S15-S2	WRS 1	Y	Rain	5.8%	3.6%	4.9	5Y 5/2
TP-P1-S15-S3	WRS 1	Y	Rain	7.5%	5.0%	6.8	5Y 7/1
TP-P1-S17-S1	WRS 1	Y	-	-	0.8%	7.2	5Y 6/2
TP-P1-S17-S2	WRS 1	Y	-	3.4%	1.7%	5.1	2.5Y 5/3
TP-P1-S17-S3	WRS 1	Y	5.0	2.3%	1.7%	6.5	5Y 5/2
TP-P2-S1/TP-P2-S2	WRS 2	Y	-	-	-	-	-
TP-P2-S3	WRS 2	Y	-	-	-	6.4	2.5Y 6/1
TP-P2-S4	WRS 2	N	-	-	-	-	-
TP-P2-S5	WRS 2	Y	-	-	-	7.2	10YR 6/1
TP-P2-S6	WRS 2	N	-	-	-	-	-
TP-P2-S7	WRS 2	Y	-	-	-	6.5	10YR 5/1
TP-P2-S10-S1	WRS 2	Y	17.0	17.0	4.3%	5.8	10YR 6/4
TP-P2-S10-S2	WRS 2	Y	13.0	13.0	4.3%	6.4	2.5Y 5/3
TP-P2-S10-S3	WRS 2	Y	N/A - Blocky	-	-	6.7	2.5Y 6/2
TP-P2-S11-S1	WRS 2	Y	20.0	20.0	2.6%	8	2.5Y 7/2
TP-P2-S11-S2	WRS 2	Y	22.0	22.0	4.7%	4.3	10YR 5/6
TP-P2-S11-S3	WRS 2	Y	10.5	10.5	4.1%	6.7	10Y 6/1
TP-P2-S12-S1	WRS 2	Y	34.0	34.0	-	7.4	2.5Y 7/1
TP-P2-S12-S2	WRS 2	Y	18.0	18.0	3.2%	6.7	10Y 6/1
TP-P2-S12-S3	WRS 2	Y	N/A - Blocky	-	-	6.9	2.5Y 6/1
TP-P2-S13-S1	WRS 2	Y	22.0	22.0	7.1%	8	2.5Y 7/1

Identifier	Stockpile	Sample Taken	Matric Suction	Gravimetric Moisture Content		Paste pH	Munsell Soil Colour
			(kPa)	Matric Sample (wt%)	20-L Pail Sample (wt%)	(pH units)	(Dry Colour)
TP-P2-S13-S2	WRS 2	Y	14.0	14.0	3.5%	5.6	2.5Y 5/2
TP-P2-S13-S3	WRS 2	Y	2.0	2.0	4.8%	6.7	2.5Y 6/1
TP-P2-S14-S1	WRS 2	Y	30.0	30.0	5.6%	7.8	2.5Y 7/2
TP-P2-S14-S2	WRS 2	Y	4.0	4.0	4.0%	3	10YR 5/4
TP-P2-S14-S3	WRS 2	Y	1.0	1.0	4.2%	2.9	10YR 5/6
TP-P2-S15-S1	WRS 2	Y	53.0	53.0	4.6%	7.5	5Y 7/1
TP-P2-S15-S2	WRS 2	Y	20.0	20.0	3.7%	3.6	10YR 5/6
TP-P2-S15-S3	WRS 2	Y	15.0	15.0	3.2%	3.9	10YR 5/4
TP-P2-S16-S1	WRS 2	Y	29.5	29.5	5.7%	5.2	5Y 6/2
TP-P2-S16-S2	WRS 2	Y	24.0	24.0	3.1%	6.2	2.5Y 6/1
TP-P2-S16-S3	WRS 2	Y	1.0	1.0	3.7%	6.9	5Y 6/1
TP-P2-S17-S1	WRS 2	Y	32.0	32.0	6.0%	7.4	2.5Y 6/2
TP-P2-S17-S2	WRS 2	Y	18.0	18.0	4.9%	6.3	5Y 7/1
TP-P2-S17-S3	WRS 2	Y	N/A too blocky	-	-	6.7	5Y 6/2
WRS-2-1	WRS 2	N	-	-	-	-	-
WRS-2-2	WRS 2	Y	-	-	-	3.3	7.5YR 4/6
WRS-2-3	WRS 2	Y	-	-	-	6.5	5Y 5/1
WRS-2-4	WRS 2	Y	-	-	-	6.3	10YR 6/3
WRS-2-5	WRS 2	Y	-	-	-	6.4	5Y 5/1
WRS-2-6	WRS 2	Y	-	-	-	6.4	5Y 2/6
WRS-2-7	WRS 2	Y	-	-	-	4.3	10YR 5/3
WRS-2-8	WRS 2	Y	-	-	-	6.6	5Y 6/1
WRS-2-9	WRS 2	Y	-	-	-	6.6	2.5Y 6/2
WRS-2-10	WRS 2	Y	-	-	-	3.2	10YR 5/6
WRS-2-11	WRS 2	Y	-	-	-	6.1	2.5Y 5/1
WRS-2-12	WRS 2	Y	-	-	-	4.1	10YR 5/6
WRS-2-13	WRS 2	Y	-	-	-	6.6	5Y 6/1
P1-P1-S1	WRS 1	Y	-	-	-	2.8	10YR 5/6

Identifier	Stockpile	Sample Taken	Matric Suction (kPa)	Gravimetric Moisture Content		Paste pH (pH units)	Munsell Soil Colour (Dry Colour)
				Matric Sample (wt%)	20-L Pail Sample (wt%)		
P1-P1-S2	WRS 1	Y	-	-	-	2.9	10YR 4/6
P1-P1-S3	WRS 1	Y	-	-	-	3.4	10YR 5/6
P1-P2-S1	WRS 1	Y	-	-	-	6.8	10Y 6/1
P1-P2-S2	WRS 1	Y	-	-	-	6	2.5Y 6/2
P1-P2-S3	WRS 1	Y	-	-	-	6.1	2.5Y 6/2
P1-P3-S1	WRS 1	Y	-	-	-	6.8	10Y 6/1
P1-P3-S2	WRS 1	Y	-	-	-	6.1	2.5Y 5/4
P1-P3-S3	WRS 1	Y	-	-	-	6.8	10Y 6/1
P1-P4-S1	WRS 1	Y	-	-	-	6.3	2.5Y 7/2
P1-P4-S2	WRS 1	Y	-	-	-	4.4	2.5Y 5/3
P1-P5-S1	WRS 1	Y	-	-	-	6.7	5Y 6/2
P1-P5-S2	WRS 1	Y	-	-	-	4.8	10YR 6/4
P1-P5-S3	WRS 1	Y	-	-	-	6.6	2.5Y 6/3
P1-P6-S1	WRS 1	Y	-	-	-	6.3	2.5Y 6/1
P1-P6-S2	WRS 1	Y	-	-	-	N/A	-
P1-P7-S1	WRS 1	Y	-	-	-	3.2	10YR 5/6
P1-P8-S1	WRS 1	Y	-	-	-	5.1	10YR 5/4
P1-P9-S1	WRS 1	Y	-	-	-	3.1	10YR 5/4
P1-P10-S1	WRS 1	Y	-	-	-	6.7	2.5Y 5/2
P1-P11-S1	WRS 1	Y	-	-	-	6.5	10Y 6/1

Table B.3: Grain Size Distributions (TP-P1-S1)			
Test Pit Number:	TP-P1-S1	Sample Numbers:	
Easting:	591995	TP-P1-S1-S1	Waste Rock
Northing:	5540499	TP-P1-S1-S2	Waste Rock
		TP-P1-S1-S3	Cover Material

20-L Pail Sample Particle Size Distribution:

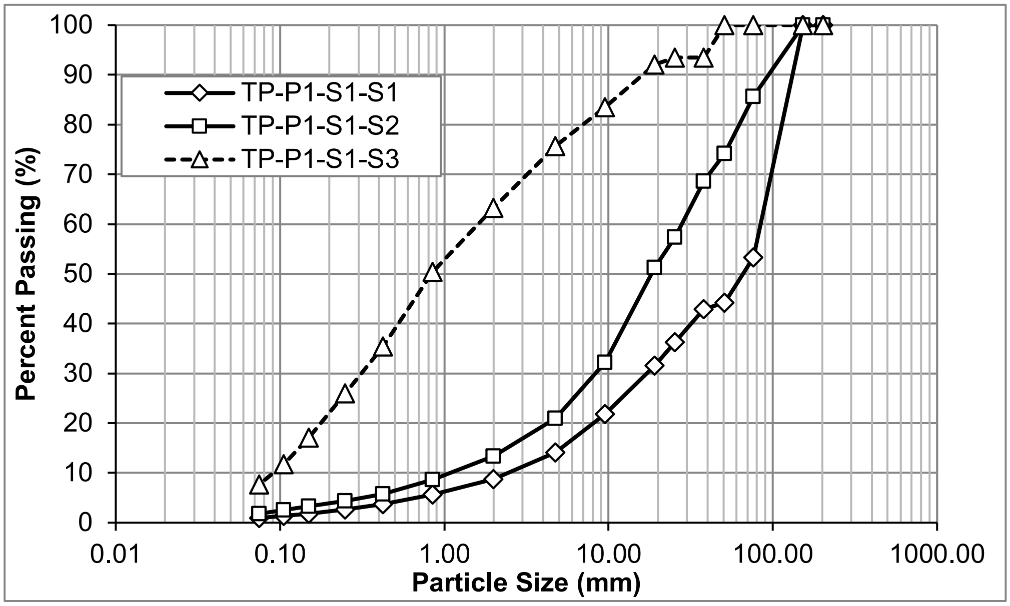


Table B.4: Grain Size Distributions (TP-P1-S2)			
Test Pit Number:	TP-P1-S2	Sample Numbers:	
Easting:	591915	TP-P1-S2-S1	Cover Material
Northing:	5540539	TP-P1-S2-S2	Waste Rock
		TP-P1-S2-S3	Waste Rock

20-L Pail Sample Particle Size Distribution:

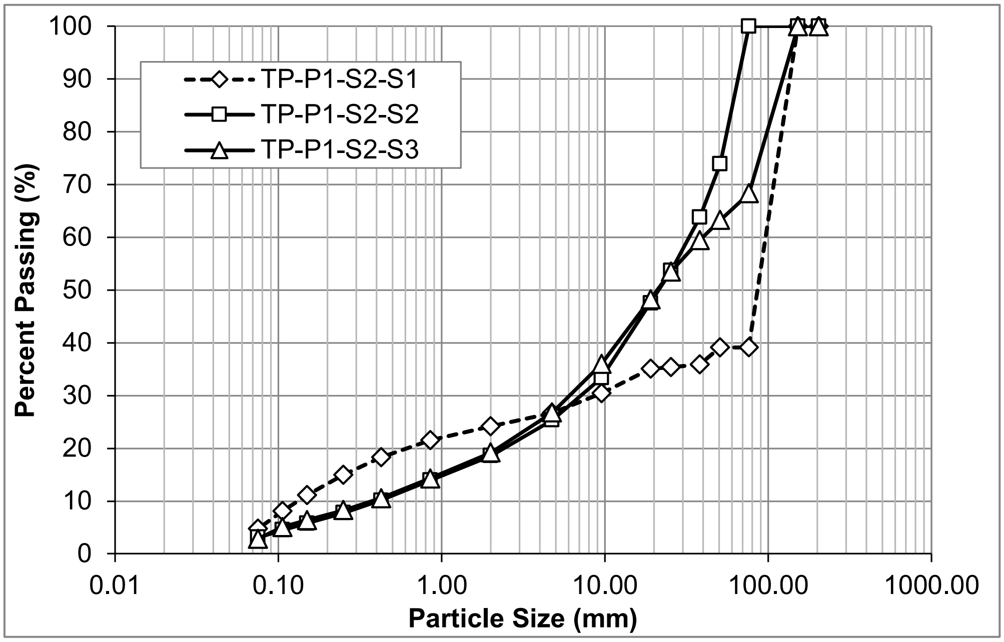


Table B.5: Grain Size Distributions (TP-P1-S3)			
Test Pit Number:	TP-P1-S3	Sample Numbers:	
Easting:	591833	TP-P1-S3-S1	Waste Rock
Northing:	5540581	TP-P1-S3-S2	Cover Material

20-L Pail Sample Particle Size Distribution:

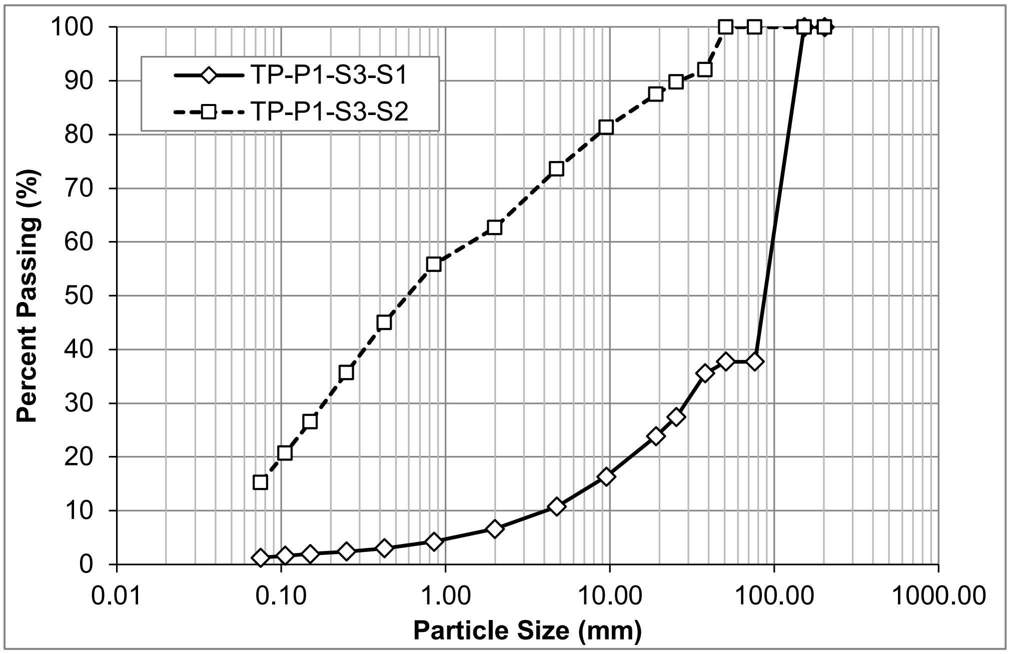
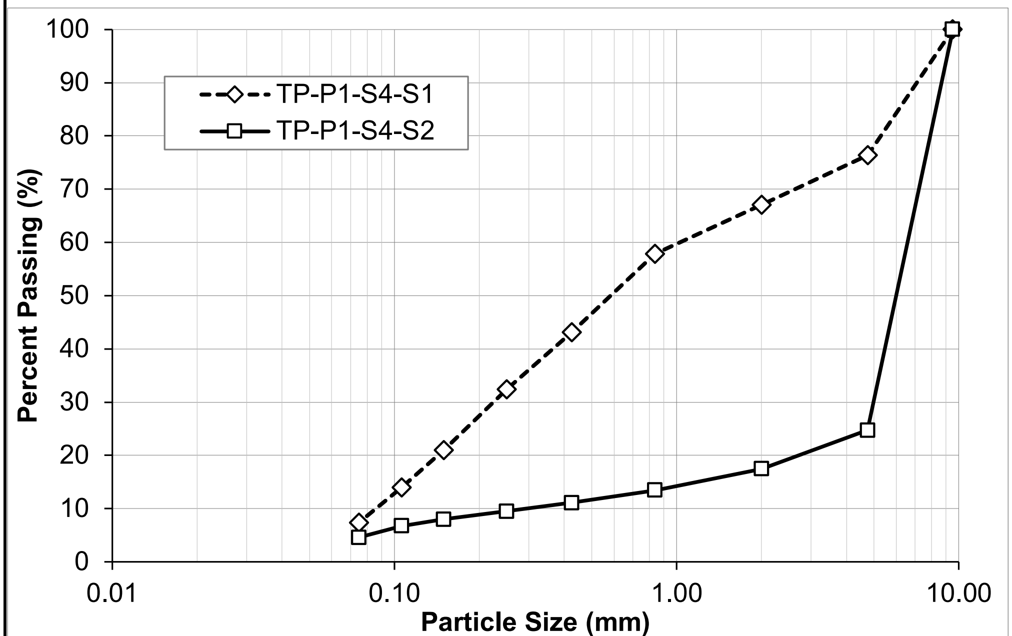


Table B.6: Grain Size Distributions (TP-P1-S4)

Test Pit Number:	TP-P1-S4	Sample Numbers:	
Easting:	591837	TP-P1-S4-S1	Cover Material
Northing:	5540712	TP-P1-S4-S2	Waste Rock
		TP-P1-S4-S3	Waste Rock

Matrix Bag Sample Particle Size Distribution:



20-L Pail Sample Particle Size Distribution:

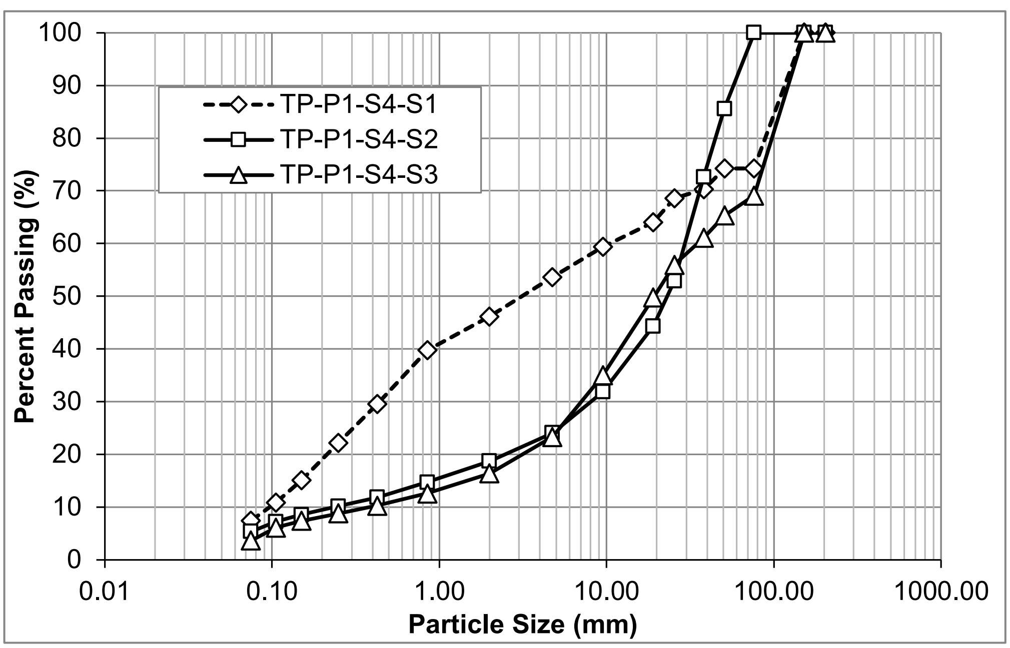
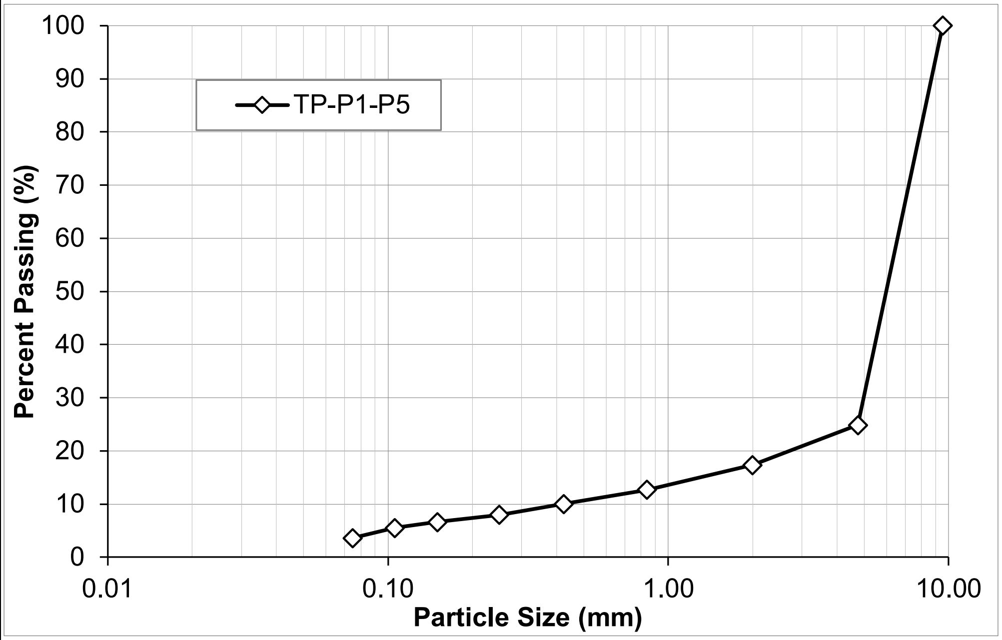


Table B.7: Grain Size Distributions (TP-P1-S5)	
Test Pit Number: TP-P1-S5 Easting: 591933 Northing: 5540734	Sample Numbers: TP-P1-S5-S1 Cover Material TP-P1-S5-S2 Waste Rock TP-P1-S5-S3 Waste Rock

Matrix Bag Sample Particle Size Distribution:



20-L Pail Sample Particle Size Distribution:

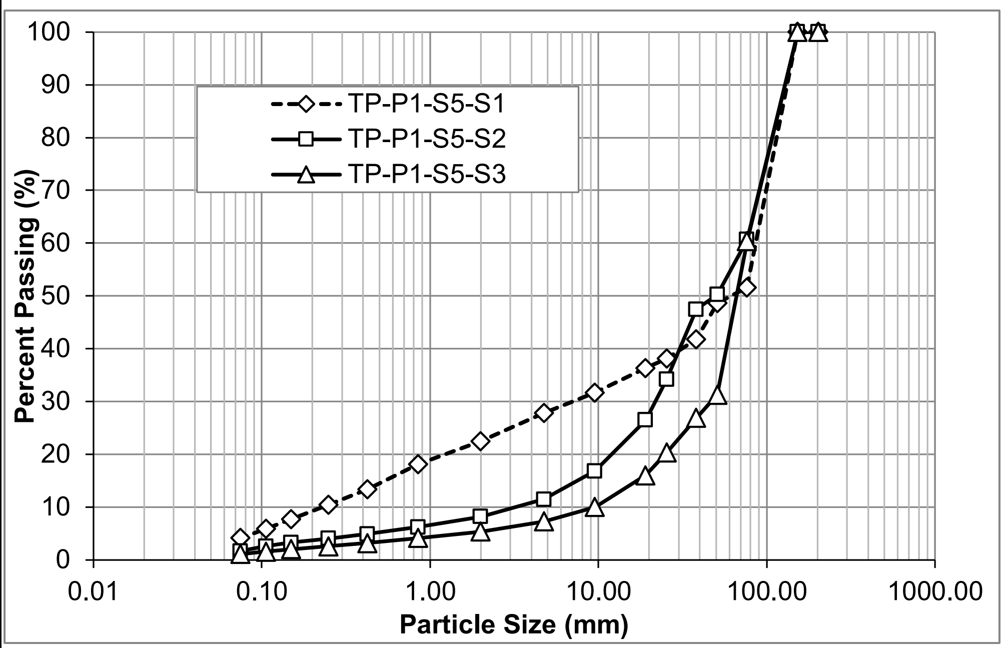
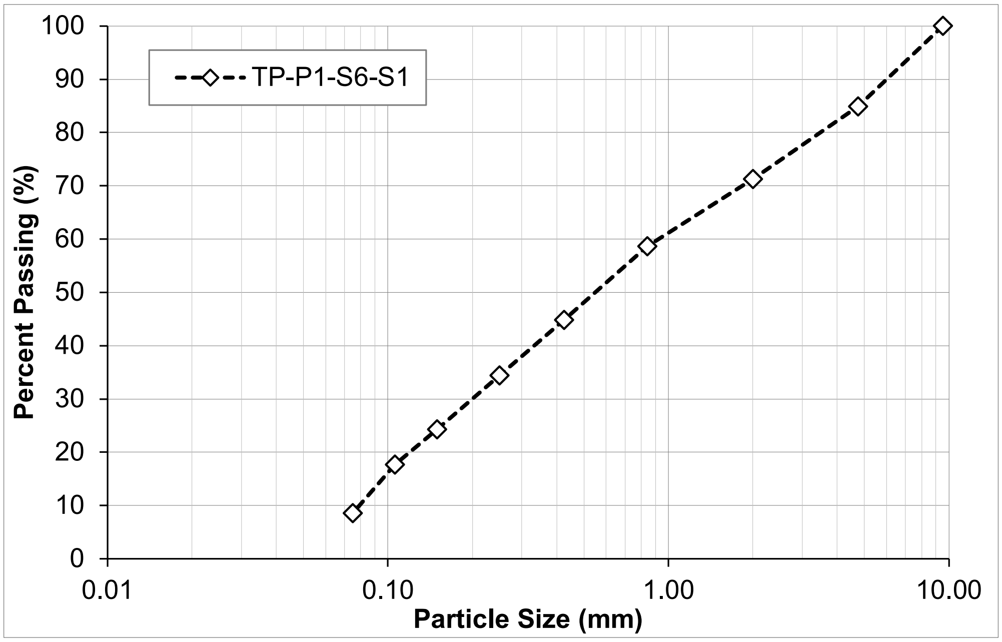


Table B.8: Grain Size Distributions (TP-P1-S6)			
Test Pit Number:	TP-P1-S6	Sample Numbers:	
Easting:	591714	TP-P1-S6-S1	Cover Material
Northing:	5540611	TP-P1-S6-S2	Waste Rock
		TP-P1-S6-S3	Waste Rock

Matrix Bag Sample Particle Size Distribution:



20-L Pail Sample Particle Size Distribution:

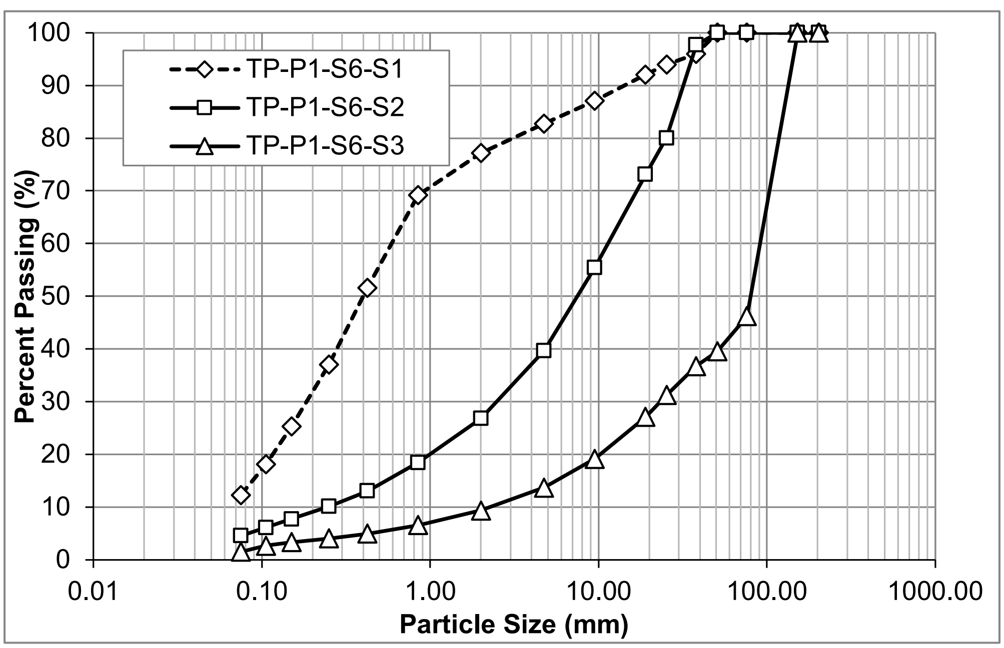
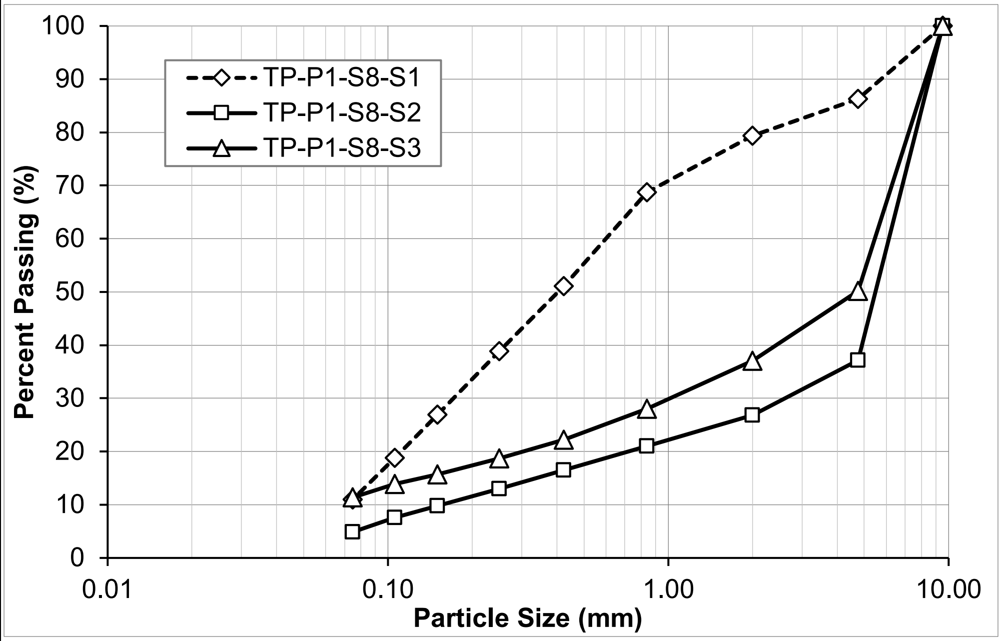


Table B.9: Grain Size Distributions (TP-P1-S8)	
Test Pit Number: TP-P1-S8 Easting: 591929 Northing: 5540614	Sample Numbers: TP-P1-S8-S1 Cover Material TP-P1-S8-S2 Waste Rock TP-P1-S8-S3 Waste Rock

Matrix Bag Sample Particle Size Distribution:



20-L Pail Sample Particle Size Distribution:

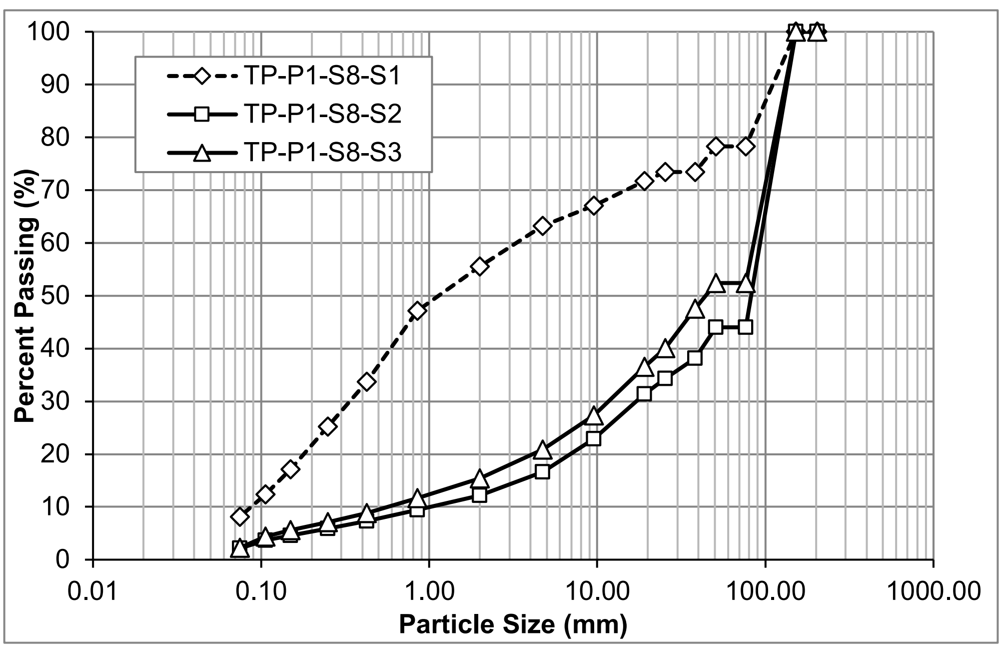
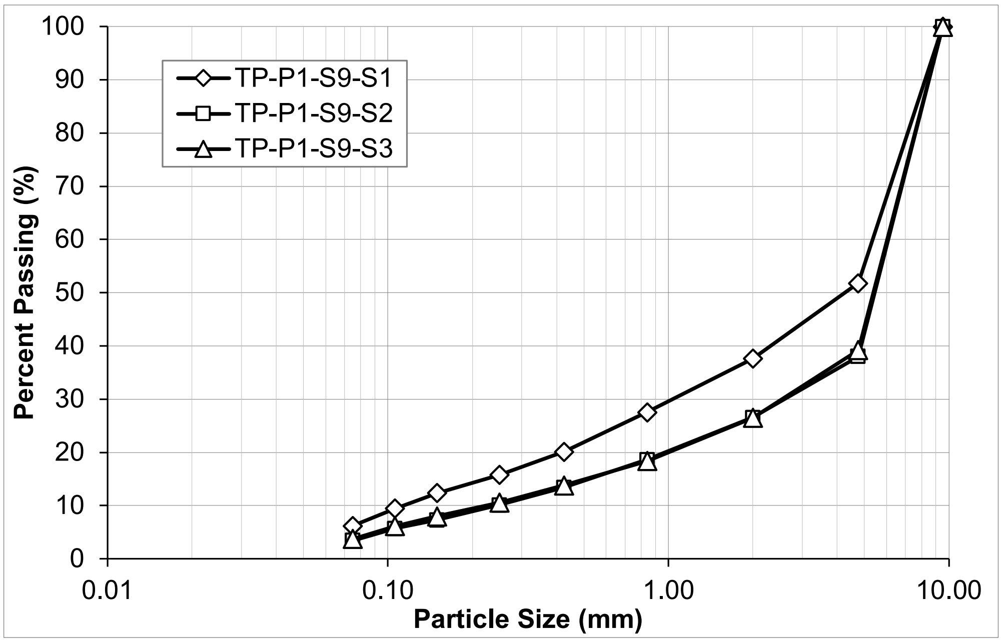


Table B.10: Grain Size Distributions (TP-P1-S9)

Test Pit Number:	TP-P1-S9	Sample Numbers:	
Easting:	592032	TP-P1-S9-S1	Waste Rock
Northing:	5540613	TP-P1-S9-S2	Waste Rock
		TP-P1-S9-S3	Waste Rock

Matrix Bag Sample Particle Size Distribution:



20-L Pail Sample Particle Size Distribution:

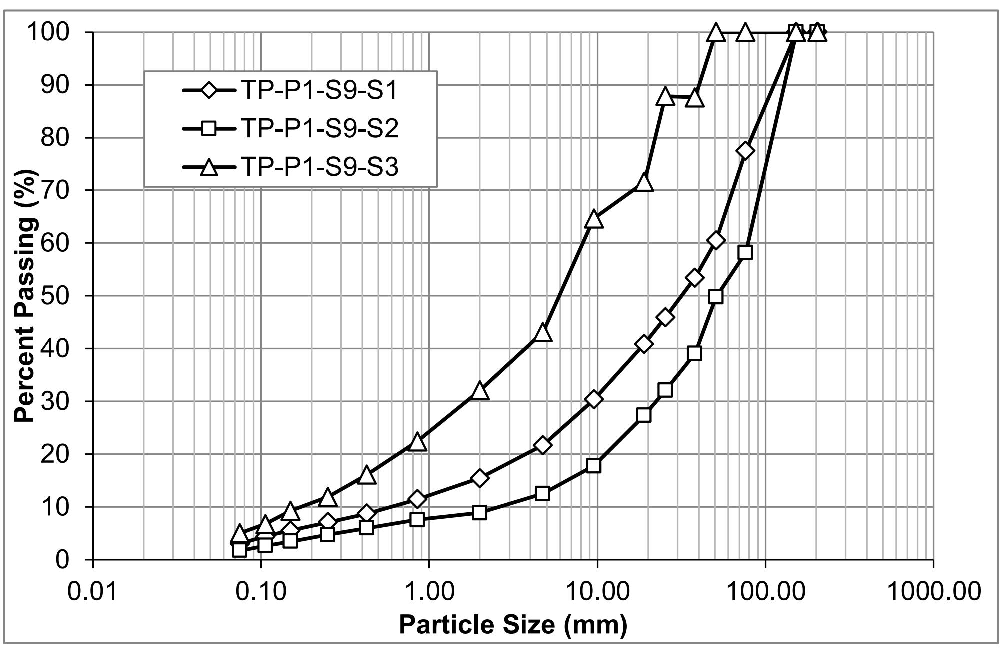
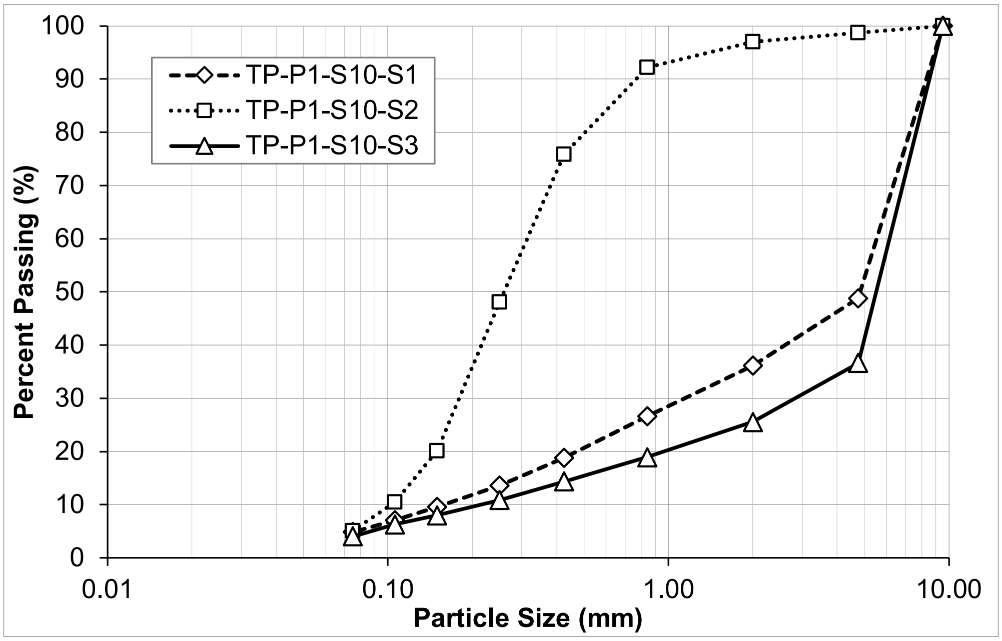


Table B.11: Grain Size Distributions (TP-P1-S10)

Test Pit Number:	TP-P1-S10	Sample Numbers:	
Easting:	591732	TP-P1-S10-S1	Cover Material
Northing:	5540513	TP-P1-S10-S2	Sand
		TP-P1-S10-S3	Waste Rock

Matrix Bag Sample Particle Size Distribution:



20-L Pail Sample Particle Size Distribution:

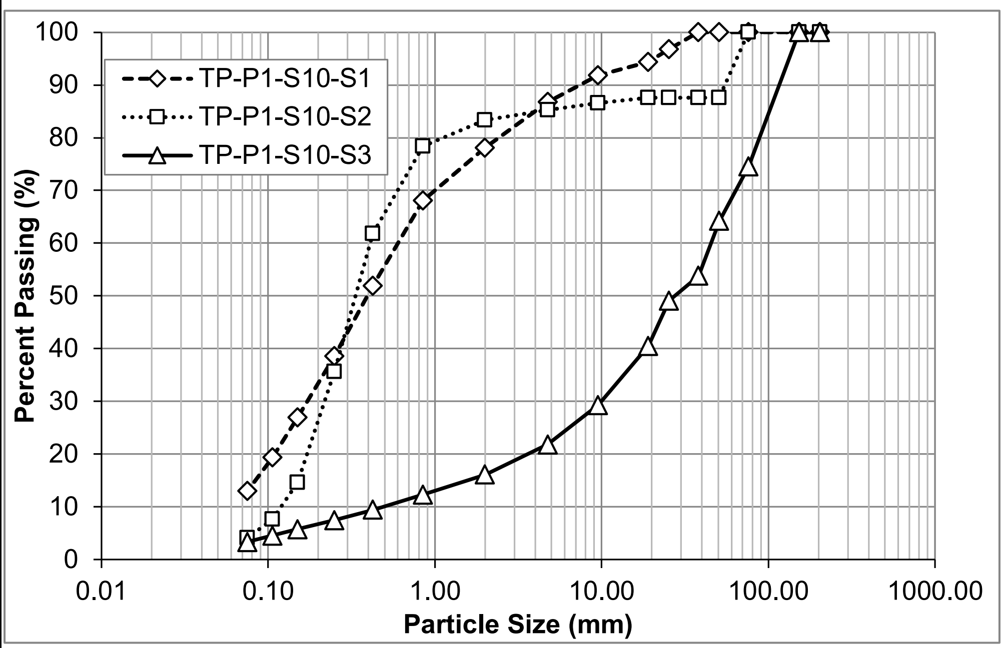
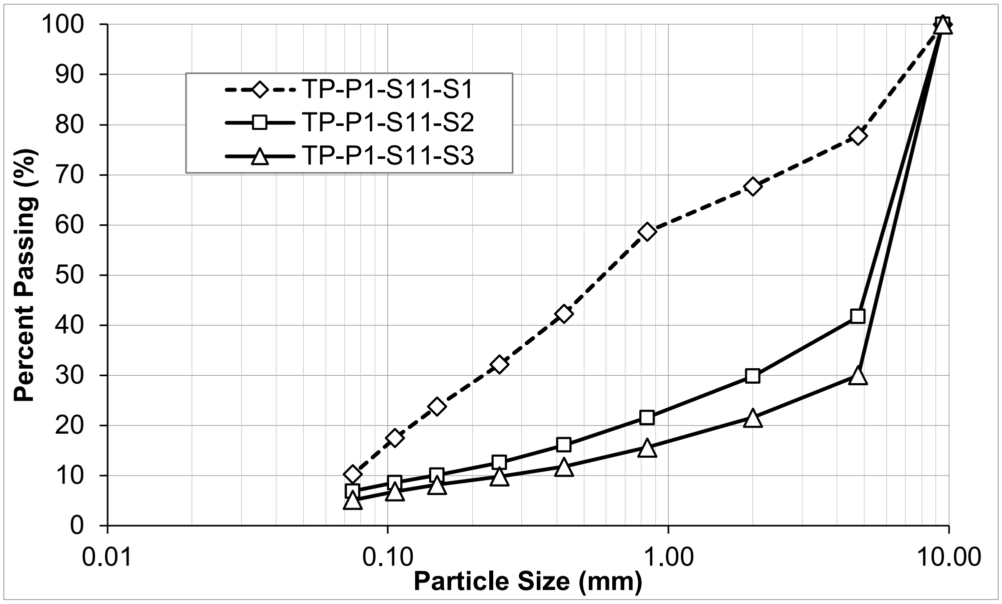


Table B.12: Grain Size Distributions (TP-P1-S11)			
Test Pit Number:	TP-P1-S11	Sample Numbers:	
Easting:	591829	TP-P1-S11-S1	Cover Material
Northing:	5540510	TP-P1-S11-S2	Waste Rock
		TP-P1-S11-S3	Waste Rock
		TP-P1-S11-S4	Waste Rock

Matrix Bag Sample Particle Size Distribution:



20-L Pail Sample Particle Size Distribution:

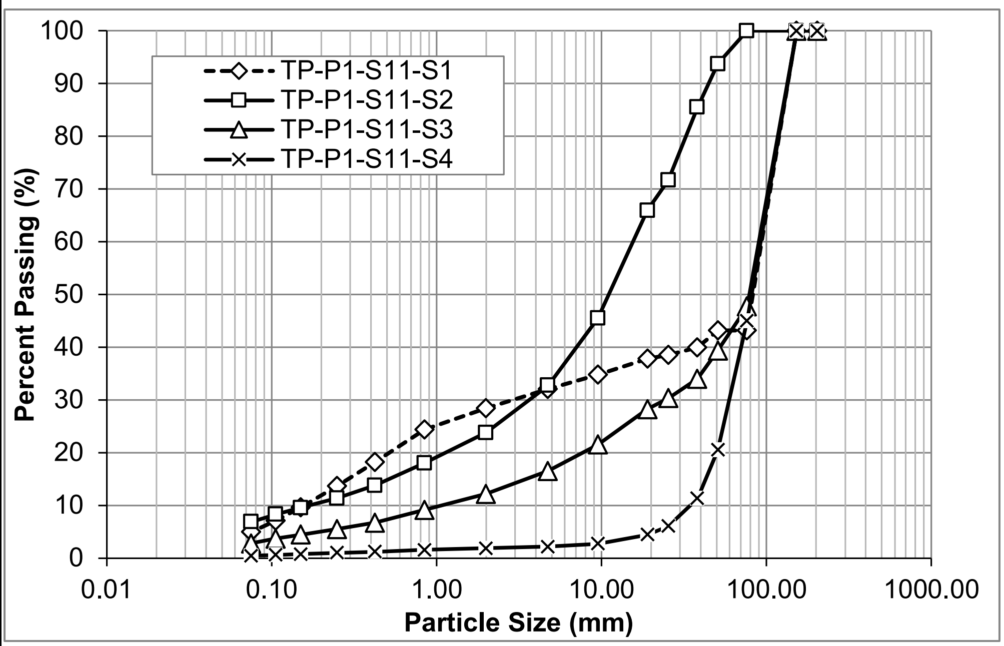
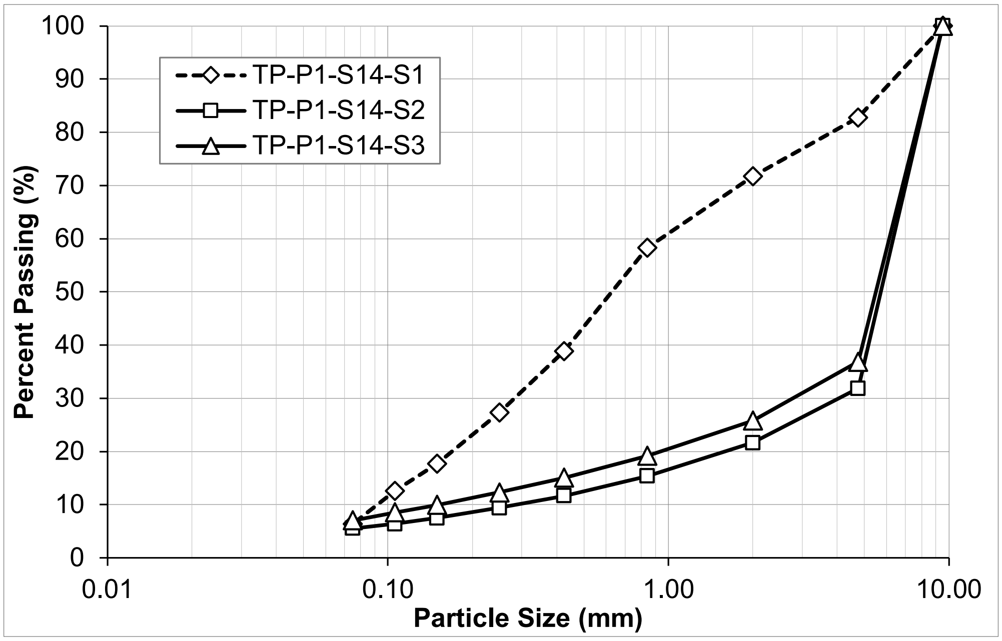


Table B.13: Grain Size Distributions (TP-P1-S14)

Test Pit Number:	TP-P1-S14	Sample Numbers:	
Easting:	591829	TP-P1-S14-S1	Cover Material
Northing:	5540417	TP-P1-S14-S2	Waste Rock
		TP-P1-S14-S3	Waste Rock

Matrix Bag Sample Particle Size Distribution:



20-L Pail Sample Particle Size Distribution:

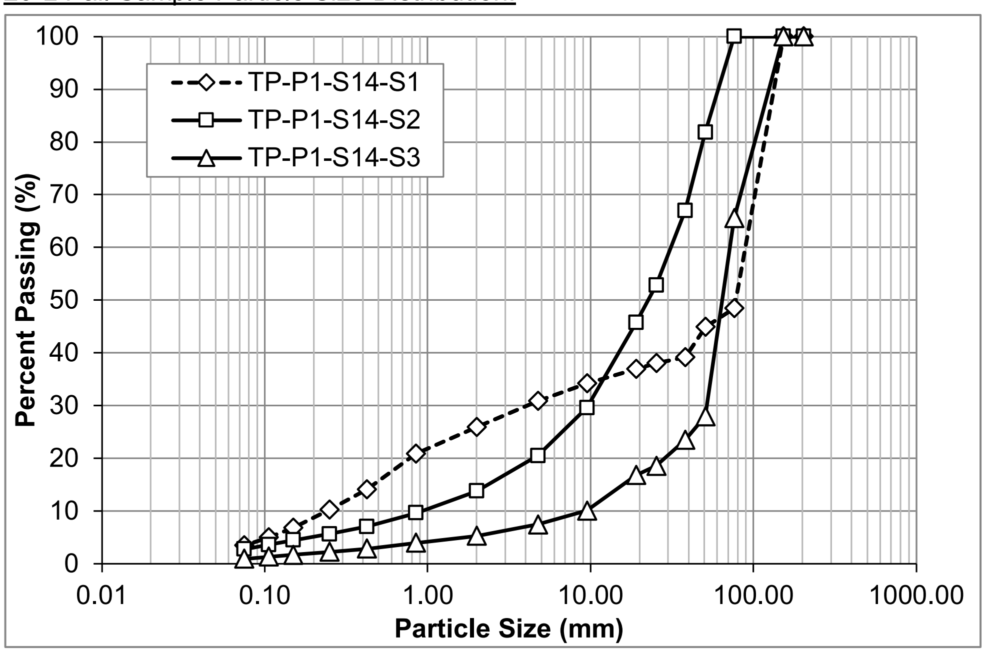
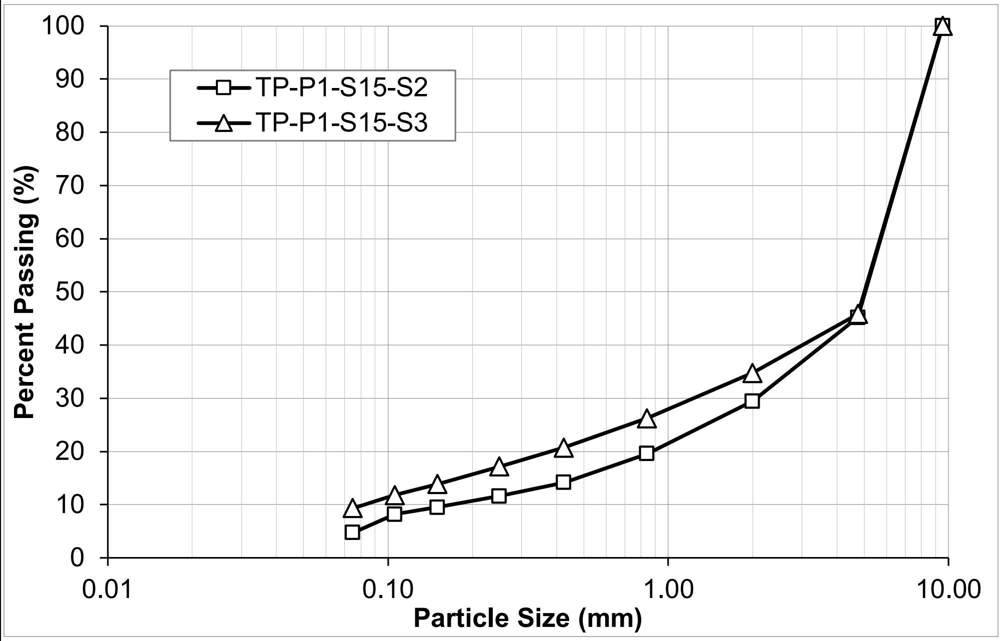


Table B.14: Grain Size Distributions (TP-P1-S15)			
Test Pit Number:	TP-P1-S15	Sample Numbers:	
Easting:	591921	TP-P1-S15-S1	Waste Rock
Northing:	5540415	TP-P1-S15-S2	Waste Rock
		TP-P1-S15-S3	Waste Rock

Matrix Bag Sample Particle Size Distribution:



20-L Pail Sample Particle Size Distribution:

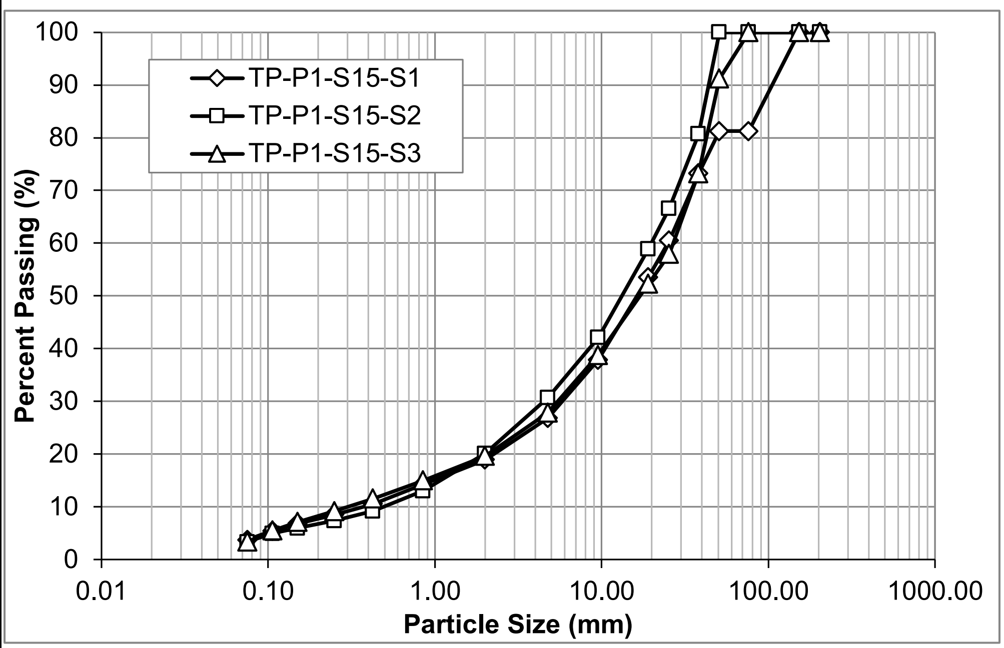
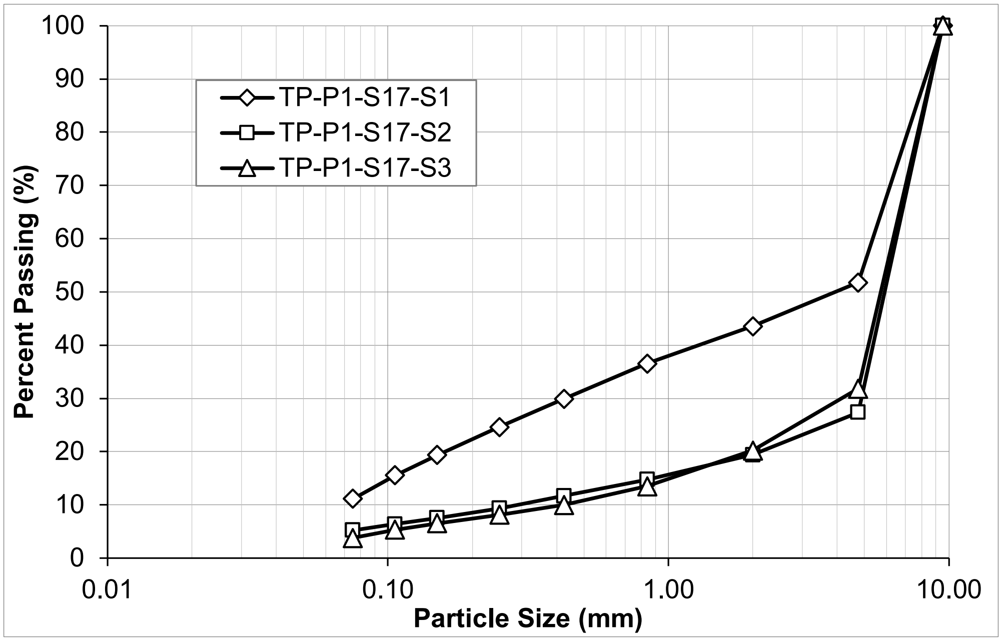


Table B.15: Grain Size Distributions (TP-P1-S17)

Test Pit Number:	TP-P1-S17	Sample Numbers:	
Easting:	591686	TP-P1-S17-S1	Waste Rock
Northing:	5540480	TP-P1-S17-S2	Waste Rock
		TP-P1-S17-S3	Waste Rock

Matrix Bag Sample Particle Size Distribution:



20-L Pail Sample Particle Size Distribution:

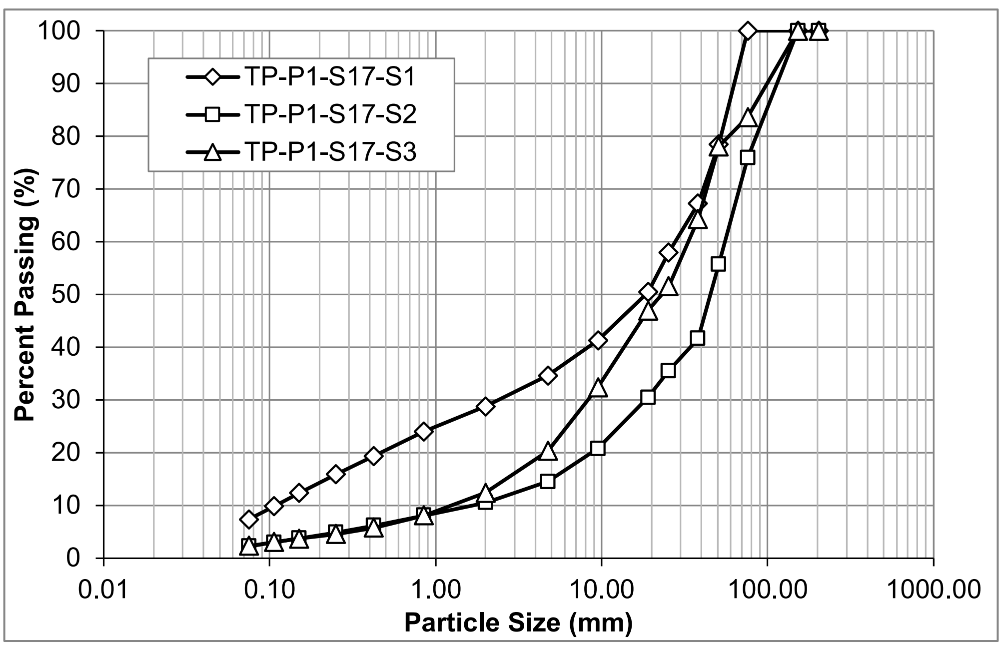


Table B.16: Grain Size Distributions (TP-P2-S3)			
Test Pit Number:	TP-P2-S3	Sample Numbers:	
Easting:	592167	TP-P1-S3	Waste Rock
Northing:	5541150		

20-L Pail Sample Particle Size Distribution:

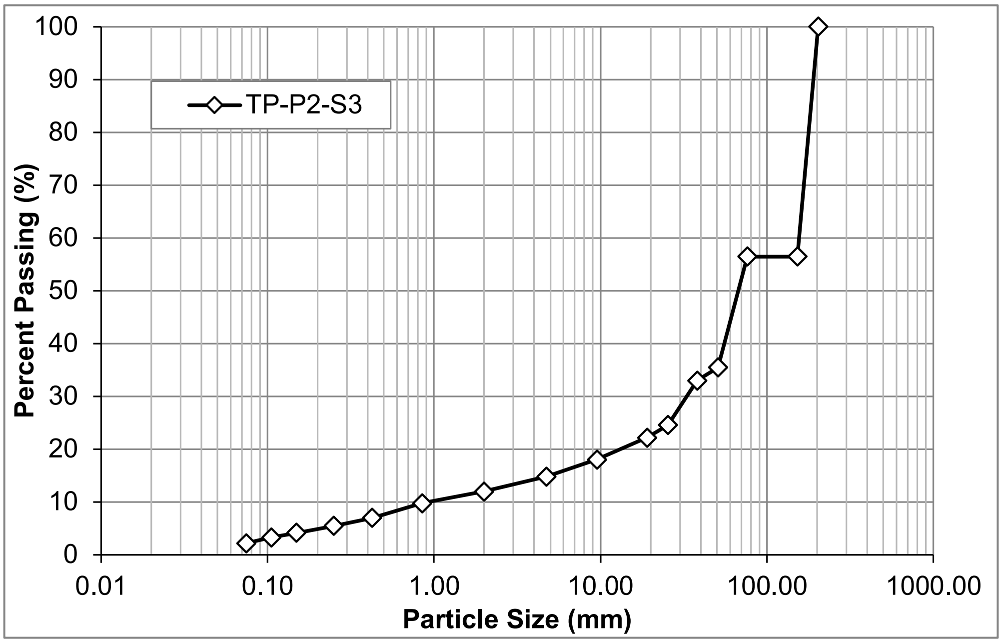


Table B.17: Grain Size Distributions (TP-P2-S5)			
Test Pit Number:	TP-P2-S5	Sample Numbers:	
Easting:	592139	TP-P1-S5	Waste Rock
Northing:	5541165		

20-L Pail Sample Particle Size Distribution:

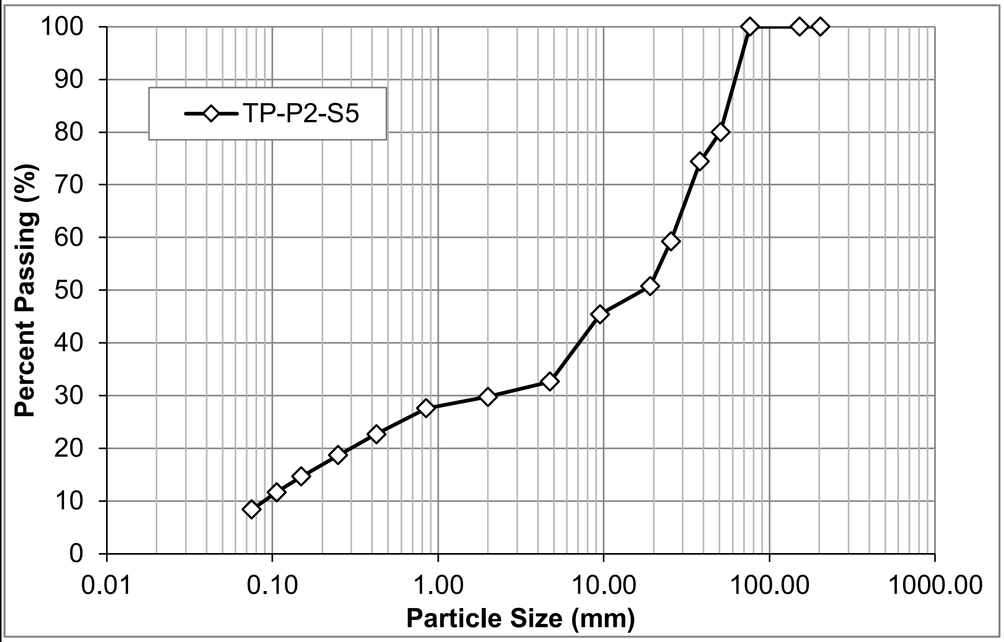


Table B.18: Grain Size Distributions (TP-P2-S7)	
Test Pit Number: TP-P2-S7 Easting: 592031 Northing: 5541299	Sample Numbers: TP-P1-S7 Waste Rock

20-L Pail Sample Particle Size Distribution:

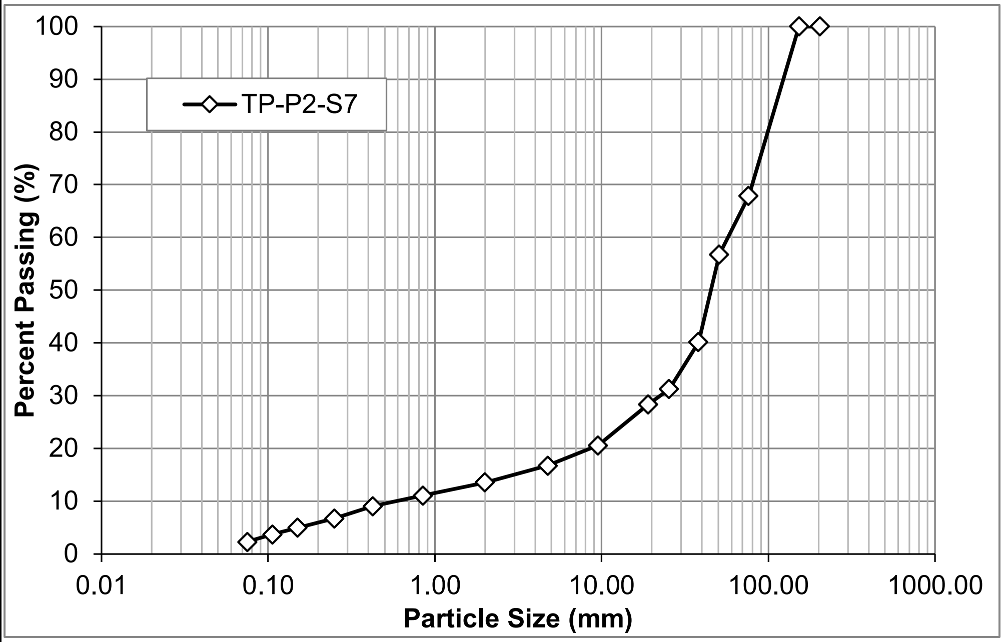
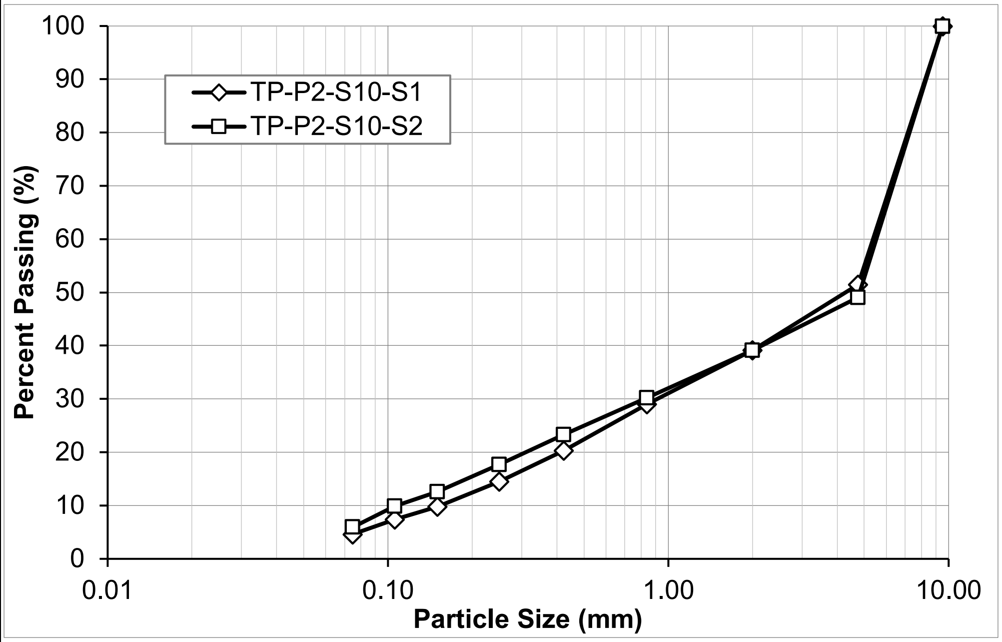


Table B.19: Grain Size Distributions (TP-P2-S10)	
Test Pit Number: TP-P2-S10 Easting: 592106 Northing: 5541321	Sample Numbers: TP-P2-S10-S1 Waste Rock TP-P2-S10-S2 Waste Rock TP-P2-S10-S3 Waste Rock

Matrix Bag Sample Particle Size Distribution:



20-L Pail Sample Particle Size Distribution:

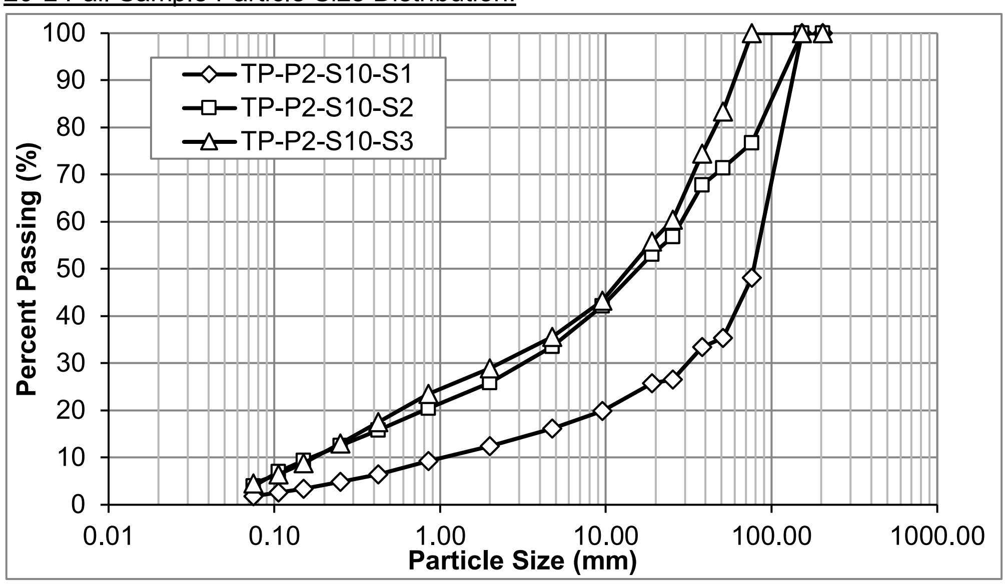
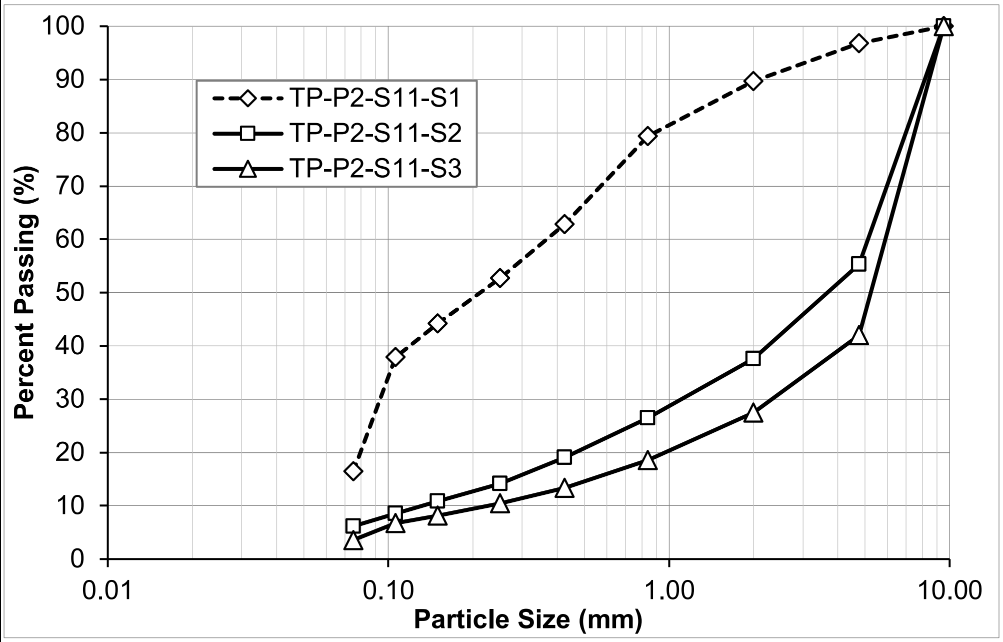


Table B.20: Grain Size Distributions (TP-P2-S11)	
Test Pit Number: TP-P2-S11 Easting: 592185 Northing: 5541307	Sample Numbers: TP-P2-S11-S1 Cover Material TP-P2-S11-S2 Waste Rock TP-P2-S11-S3 Waste Rock

Matrix Bag Sample Particle Size Distribution:



20-L Pail Sample Particle Size Distribution:

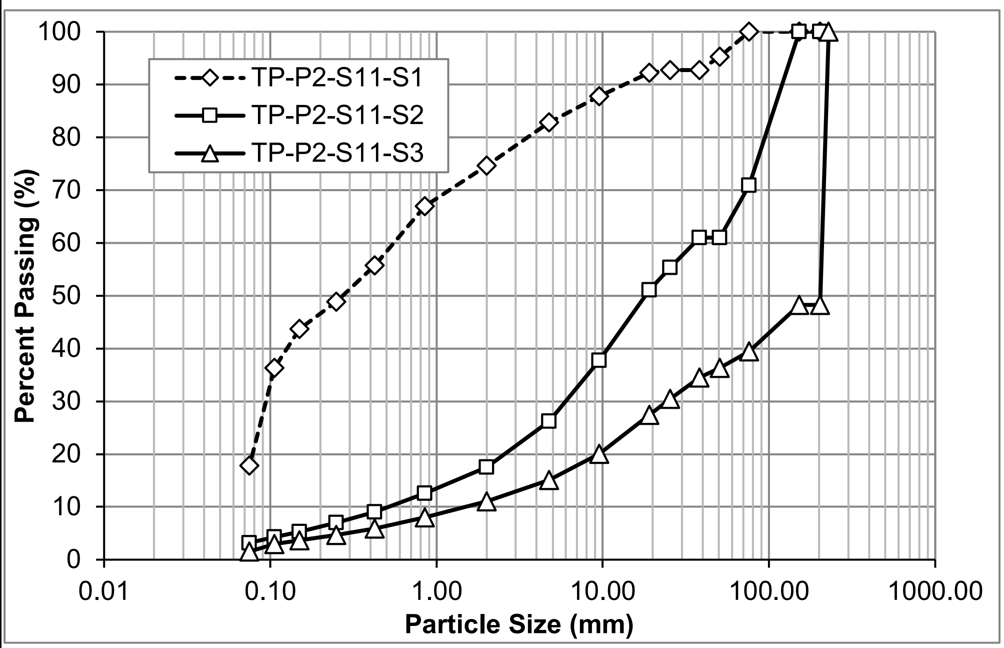
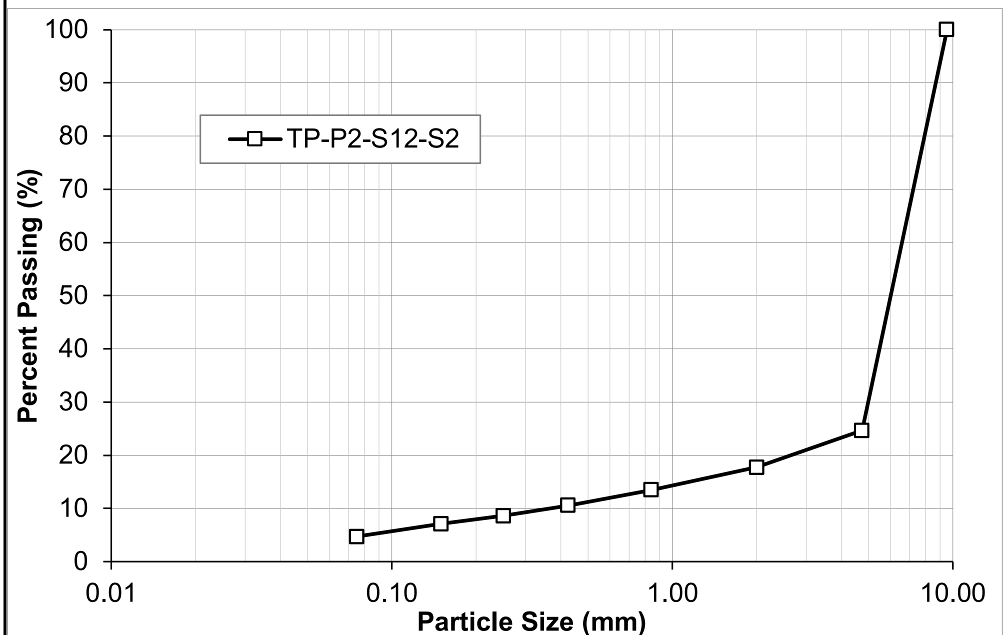


Table B.21: Grain Size Distributions (TP-P2-S12)

Test Pit Number:	TP-P2-S12	Sample Numbers:	
Easting:	592259	TP-P2-S12-S1	Cover Material
Northing:	5541306	TP-P2-S12-S2	Waste Rock
		TP-P2-S12-S3	Waste Rock

Matrix Bag Sample Particle Size Distribution:



20-L Pail Sample Particle Size Distribution:

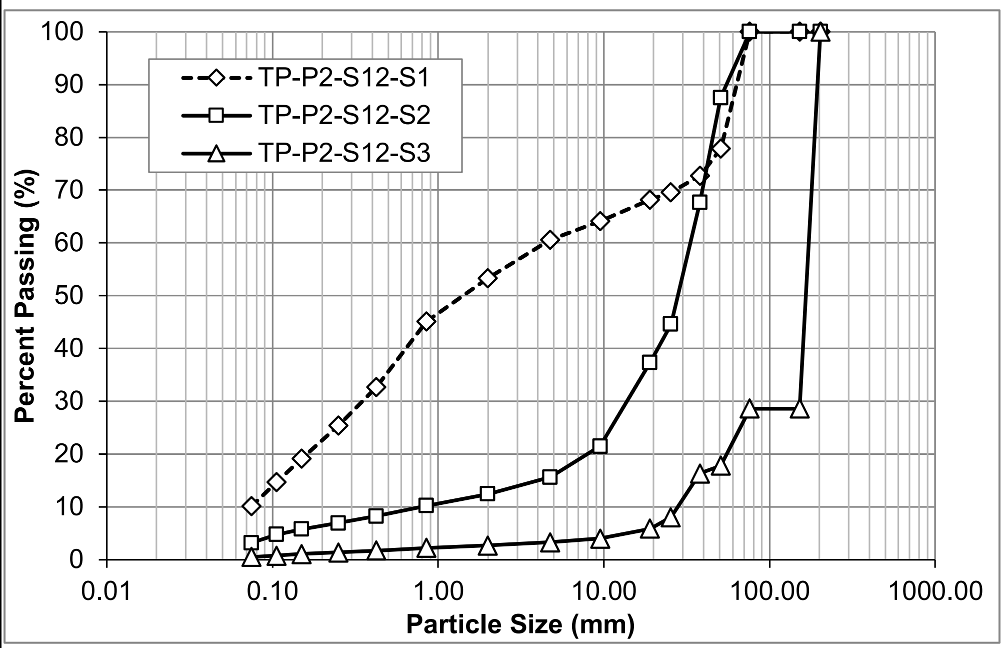
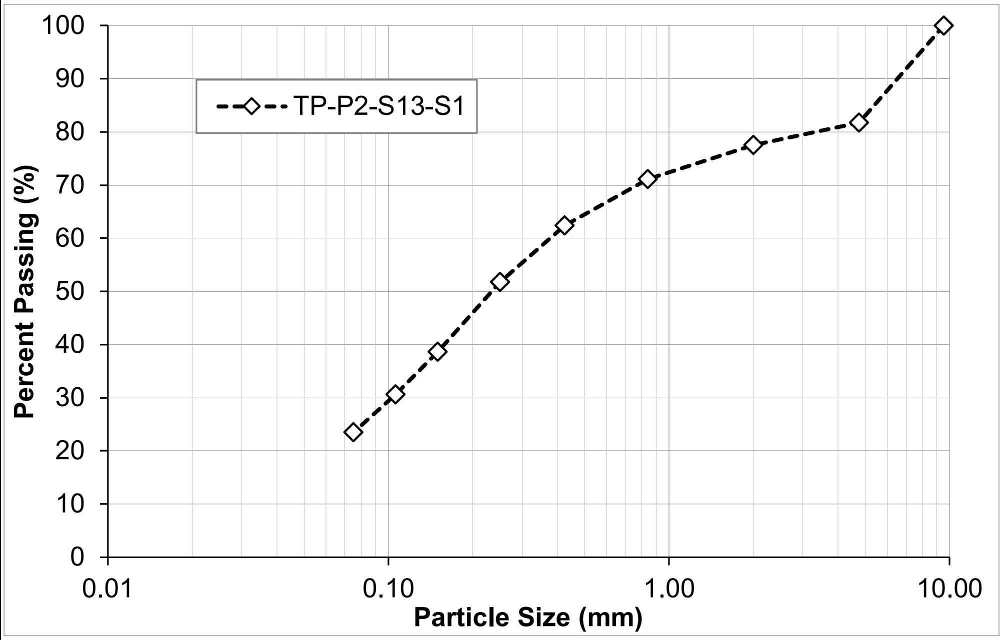


Table B.22: Grain Size Distributions (TP-P2-S13)			
Test Pit Number:	TP-P2-S13	Sample Numbers:	
Easting:	592027	TP-P2-S13-S1	Cover Material
Northing:	5541227	TP-P2-S13-S2	Waste Rock
		TP-P2-S13-S3	Waste Rock

Matrix Bag Sample Particle Size Distribution:



20-L Pail Sample Particle Size Distribution:

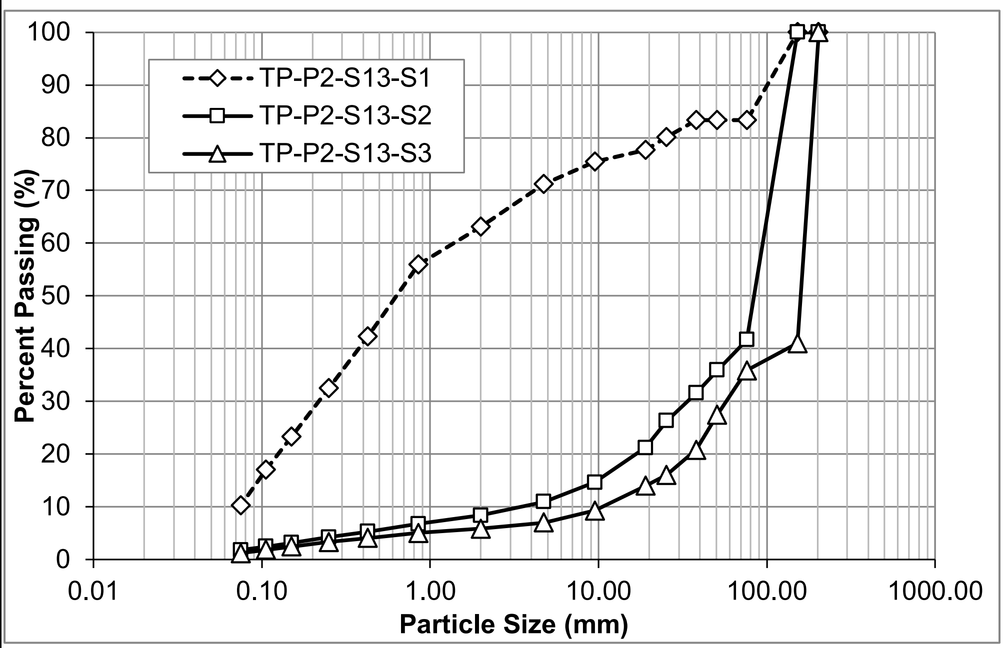
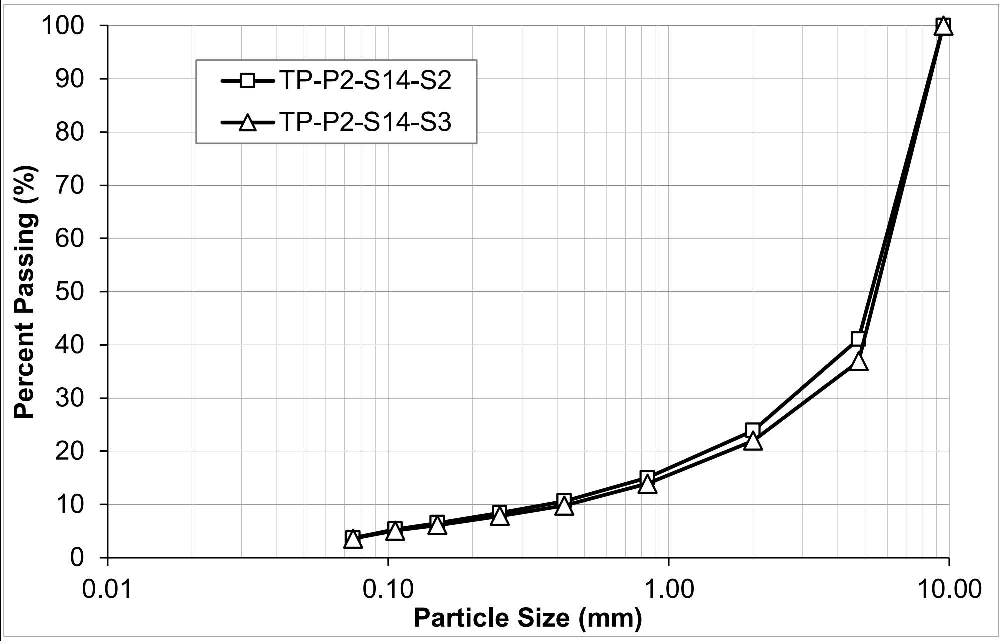


Table B.23 Grain Size Distributions (TP-P2-S14)

Test Pit Number:	TP-P2-S14	Sample Numbers:	
Easting:	592094	TP-P2-S14-S1	Cover Material
Northing:	5541224	TP-P2-S14-S2	Waste Rock
		TP-P2-S14-S3	Waste Rock

Matrix Bag Sample Particle Size Distribution:



20-L Pail Sample Particle Size Distribution:

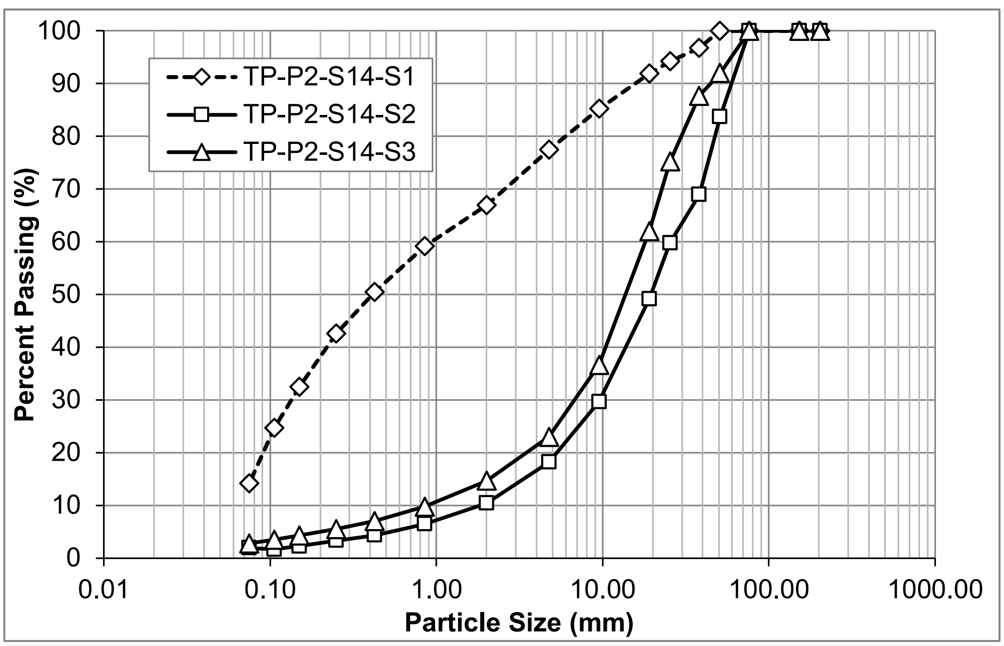
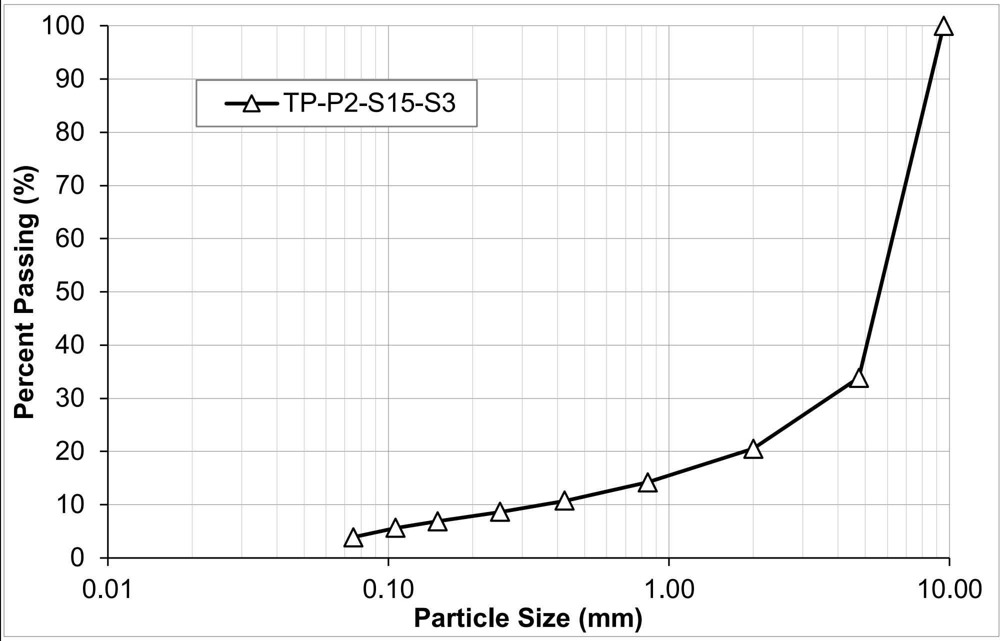


Table B.24: Grain Size Distributions (TP-P2-S15)

Test Pit Number:	TP-P2-S15	Sample Numbers:	
Easting:	592178	TP-P2-S15-S1	Cover Material
Northing:	5541223	TP-P2-S15-S2	Waste Rock
		TP-P2-S15-S3	Waste Rock

Matrix Bag Sample Particle Size Distribution:



20-L Pail Sample Particle Size Distribution:

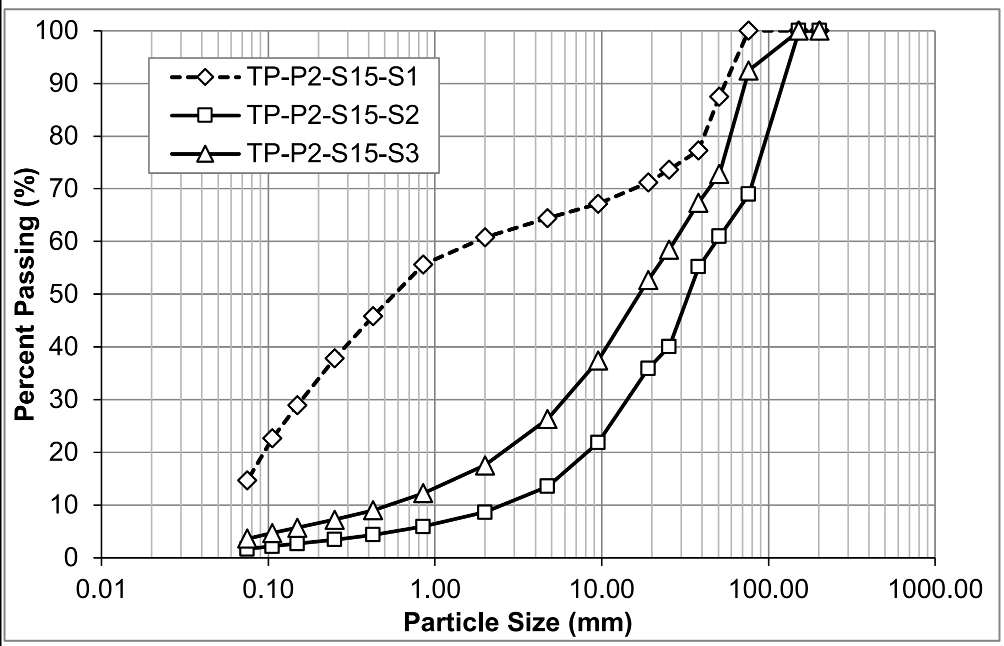
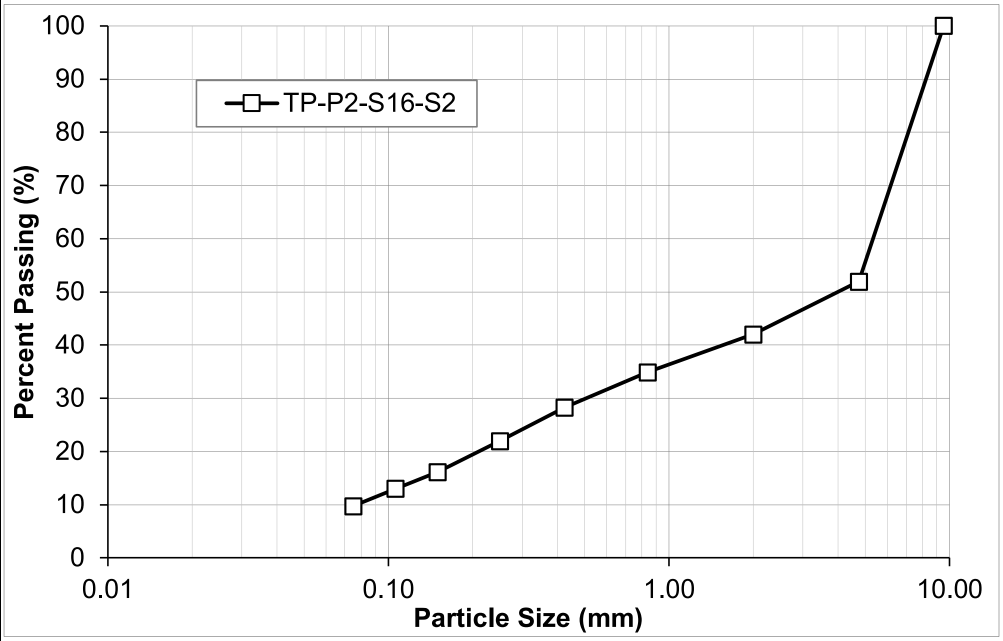


Table B.25: Grain Size Distributions (TP-P2-S16)			
Test Pit Number:	TP-P2-S16	Sample Numbers:	
Easting:	592257	TP-P2-S16-S1	Waste Rock
Northing:	5541222	TP-P2-S16-S2	Waste Rock
		TP-P2-S16-S3	Waste Rock

Matrix Bag Sample Particle Size Distribution:



20-L Pail Sample Particle Size Distribution:

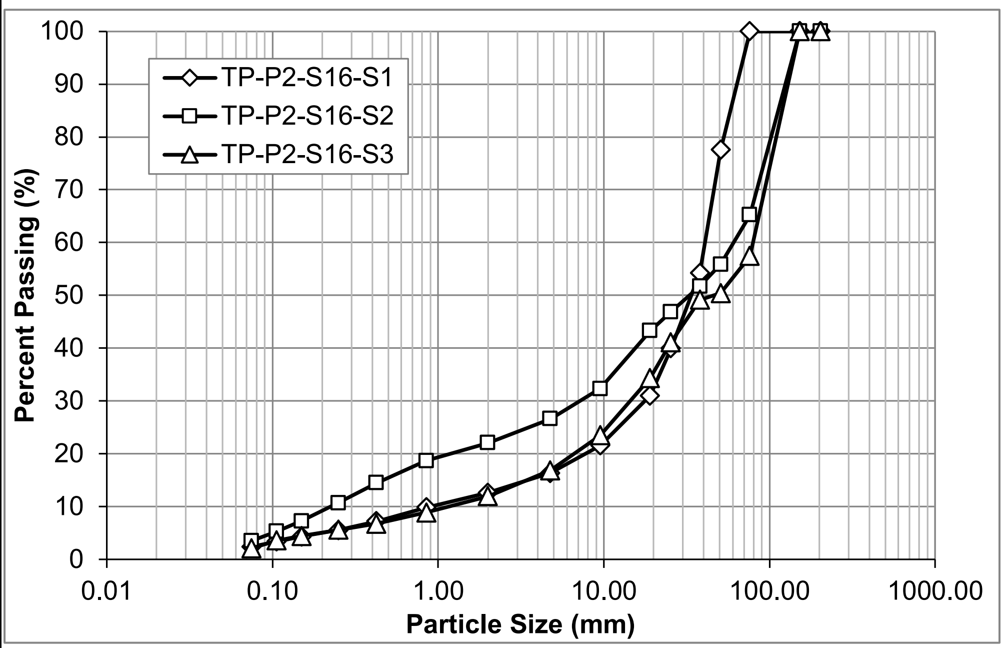
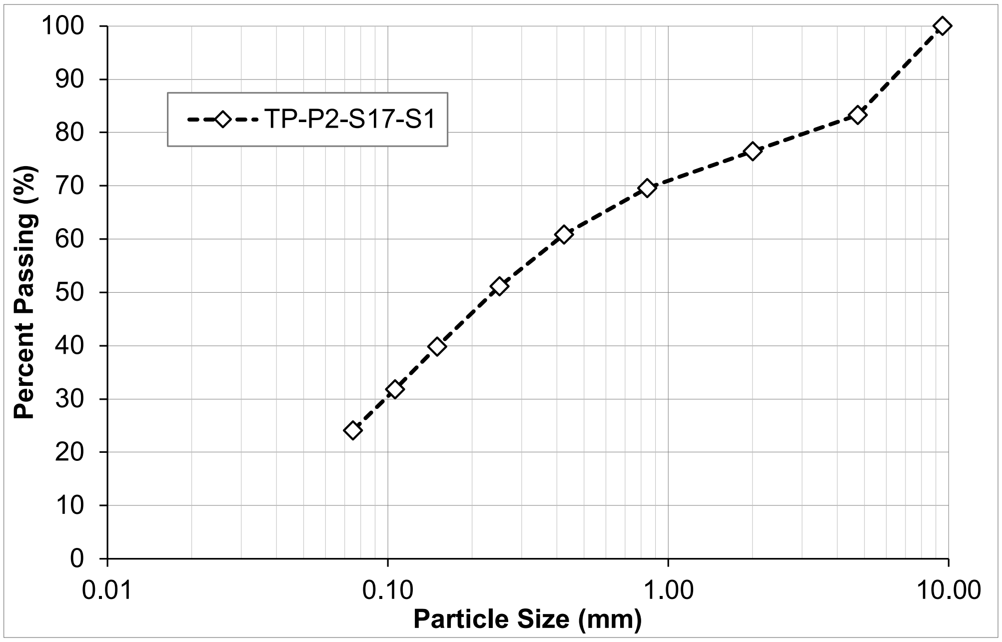


Table B.26: Grain Size Distributions (TP-P2-S17)

Test Pit Number:	TP-P2-S17	Sample Numbers:	
Easting:	592104	TP-P2-S17-S1	Cover Material
Northing:	5541152	TP-P2-S17-S2	Waste Rock
		TP-P2-S17-S3	Waste Rock

Matrix Bag Sample Particle Size Distribution:



20-L Pail Sample Particle Size Distribution:

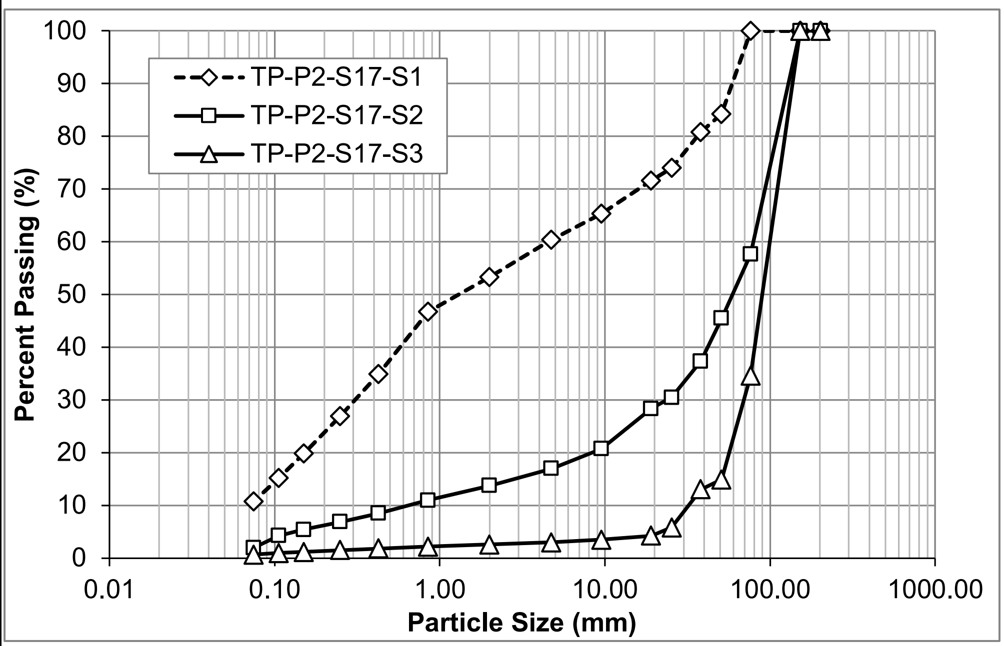


Table B.27: Grain Size Distributions (WRS-2-2)			
Profile Number:	WRS-2-2	Sample Numbers:	
Easting:	592197	WRS-2-2	Waste Rock
Northing:	5541319		

20-L Pail Sample Particle Size Distribution:

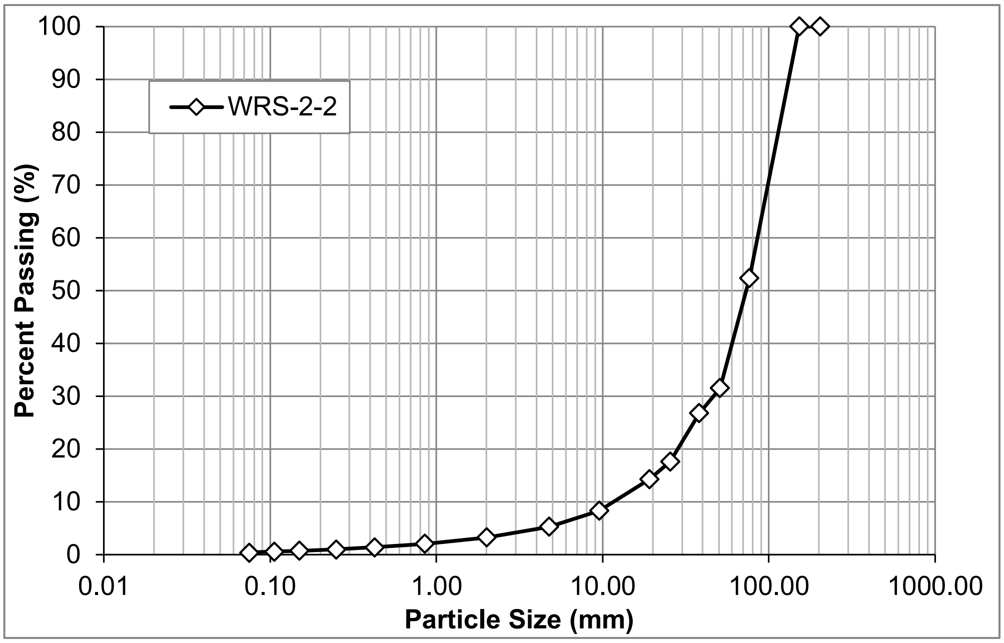


Table B.28: Grain Size Distributions (WRS-2-3)			
Profile Number:	WRS-2-3	Sample Numbers:	
Easting:	592197	WRS-2-3	Waste Rock
Northing:	5541319		

20-L Pail Sample Particle Size Distribution:

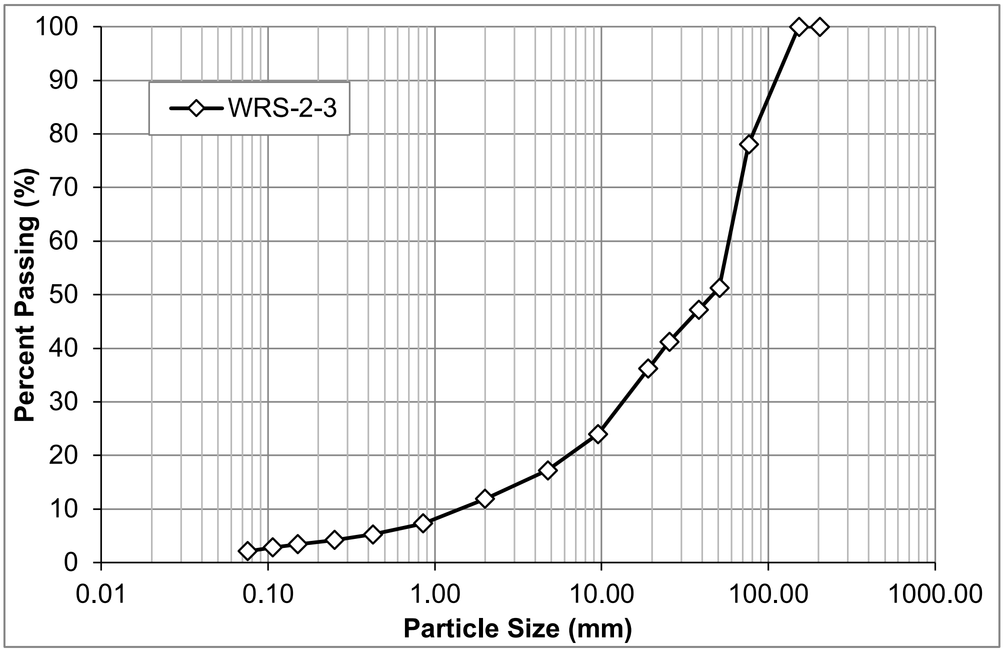


Table B.29: Grain Size Distributions (WRS-2-4)			
Profile Number:	WRS-2-4	Sample Numbers:	
Easting:	592111	WRS-2-4	Waste Rock
Northing:	5541212		

20-L Pail Sample Particle Size Distribution:

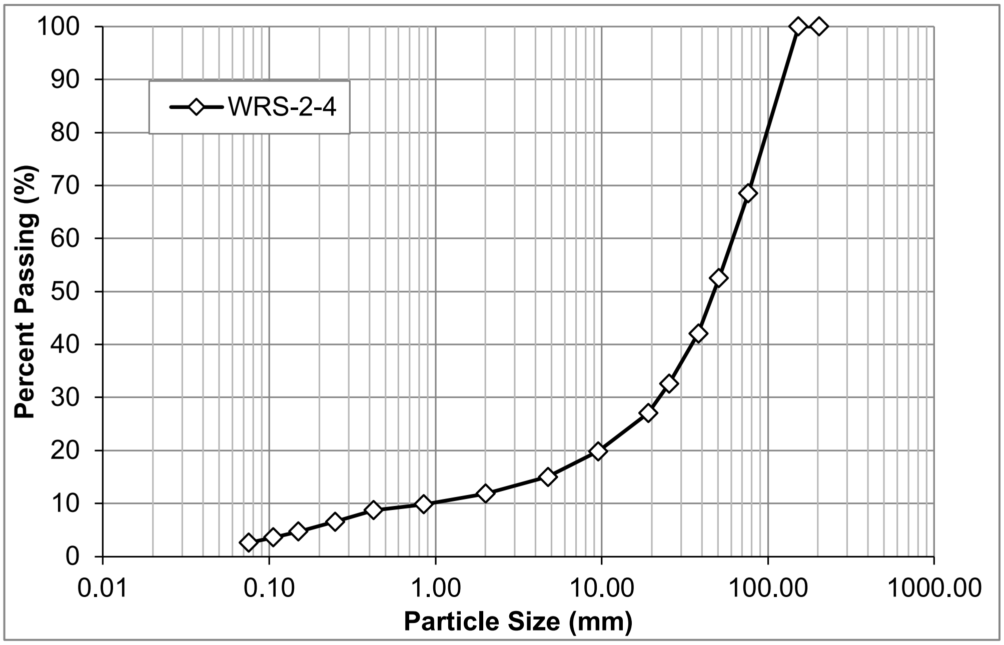


Table B.30: Grain Size Distributions (WRS-2-5)			
Profile Number:	WRS-2-5	Sample Numbers:	
Easting:	592111	WRS-2-5	Waste Rock
Northing:	5541212		

20-L Pail Sample Particle Size Distribution:

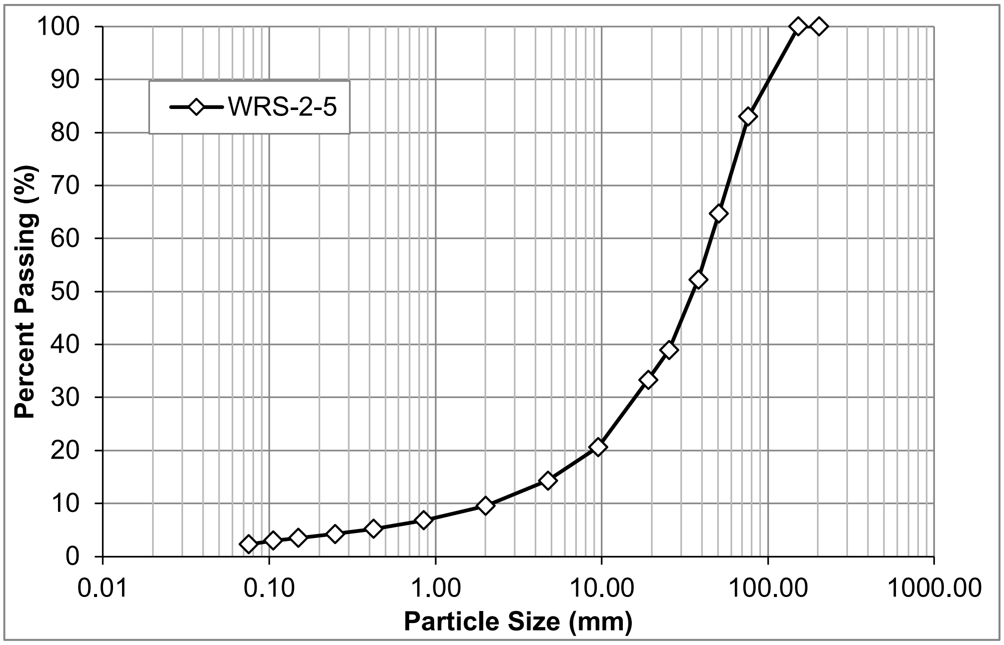


Table B.31: Grain Size Distributions (WRS-2-6)	
Profile Number: WRS-2-6 Easting: 592084 Northing: 5541194	Sample Numbers: WRS-2-6 Waste Rock

20-L Pail Sample Particle Size Distribution:

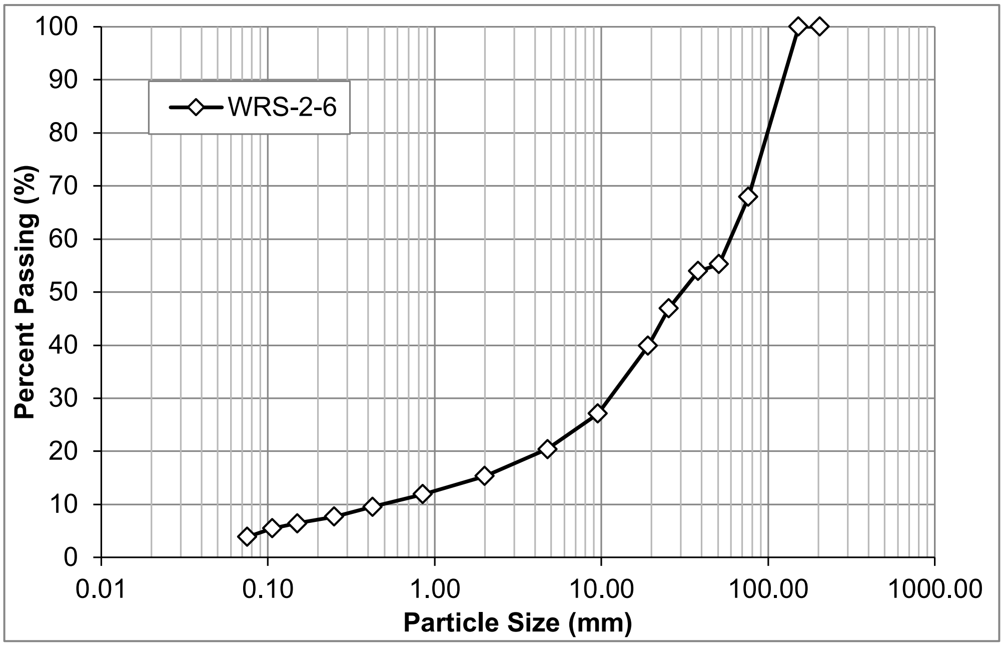


Table B.32: Grain Size Distributions (WRS-2-7)	
Profile Number: WRS-2-7 Easting: 591987 Northing: 5541228	Sample Numbers: WRS-2-7 Waste Rock

20-L Pail Sample Particle Size Distribution:

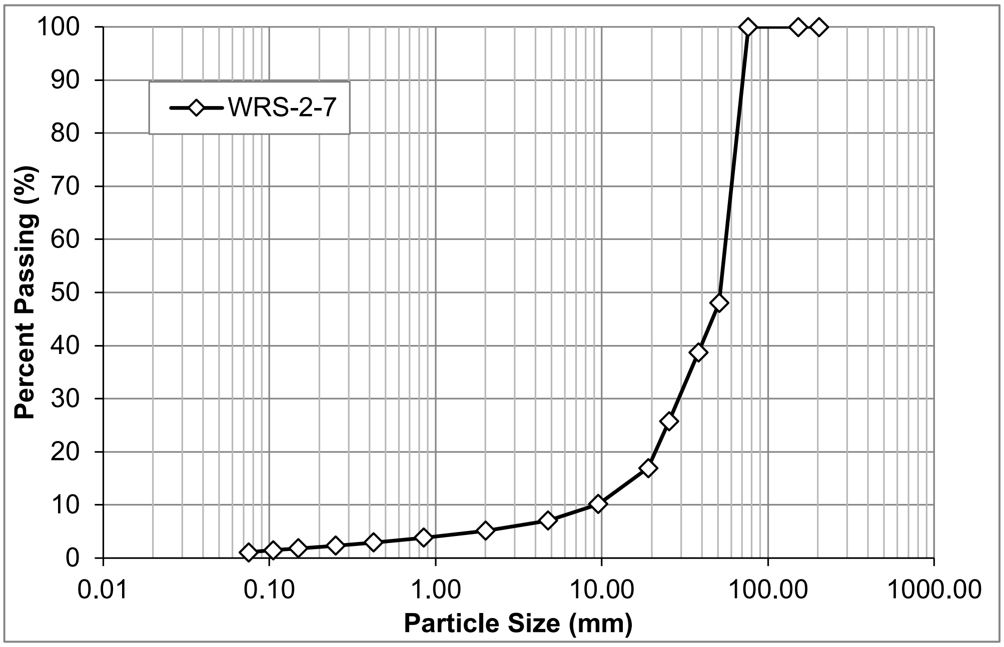


Table B.33: Grain Size Distributions (WRS-2-8)

Profile Number:	WRS-2-8	Sample Numbers:	
Easting:	591978	WRS-2-8	Waste Rock
Northing:	5541234		

20-L Pail Sample Particle Size Distribution:

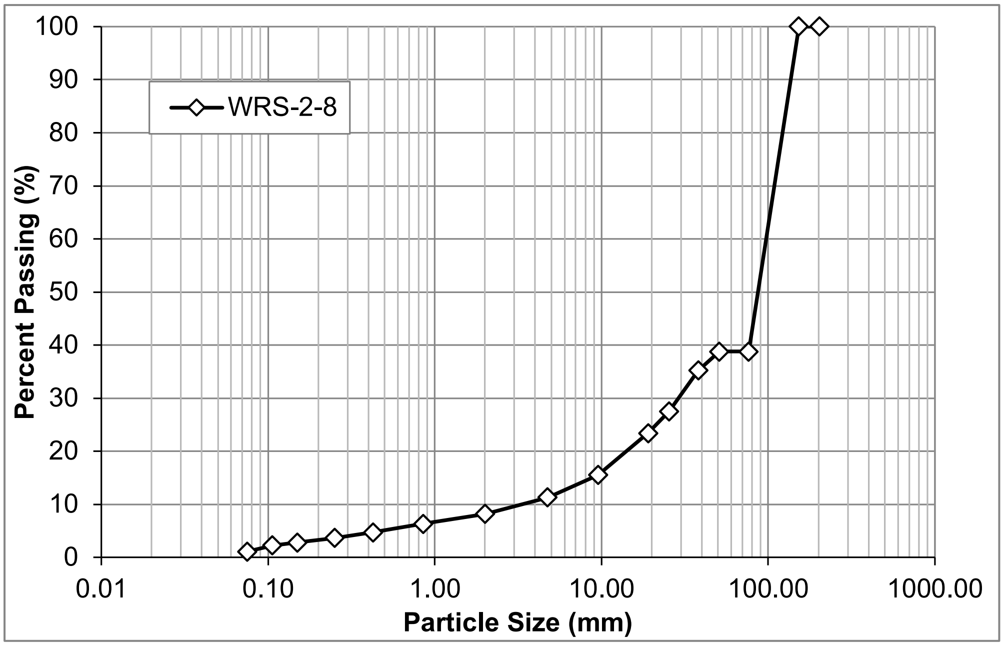


Table B.34: Grain Size Distributions (WRS-2-9)

Profile Number:	WRS-2-9	Sample Numbers:	
Easting:	592125	WRS-2-9	Waste Rock
Northing:	5541136		

20-L Pail Sample Particle Size Distribution:

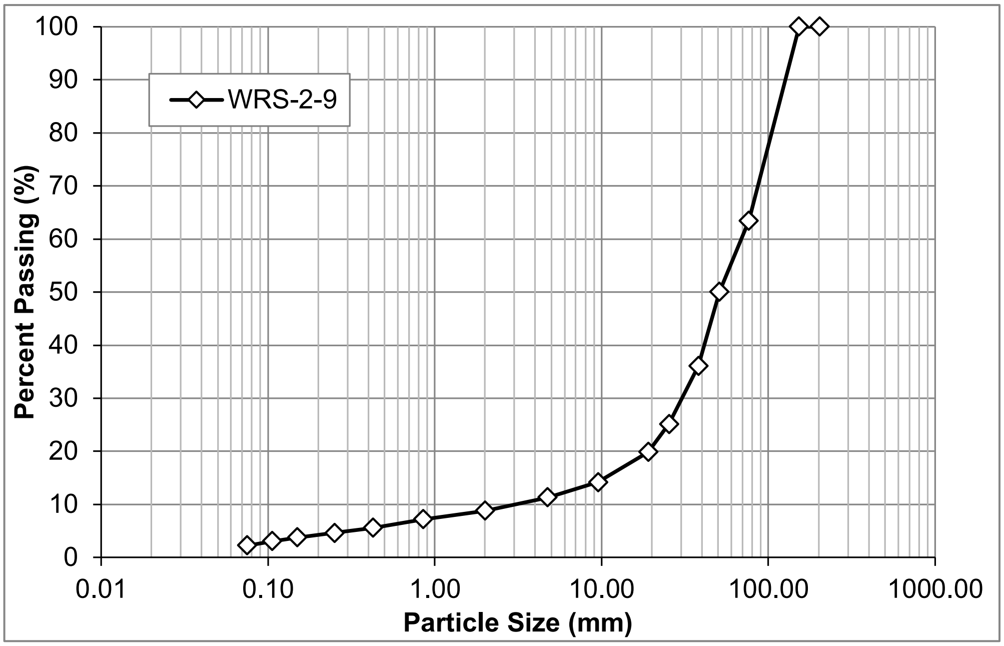


Table B.35: Grain Size Distributions (WRS-2-10)

Profile Number:	WRS-2-10	Sample Numbers:	
Easting:	592160	WRS-2-10	Waste Rock
Northing:	5541232		

20-L Pail Sample Particle Size Distribution:

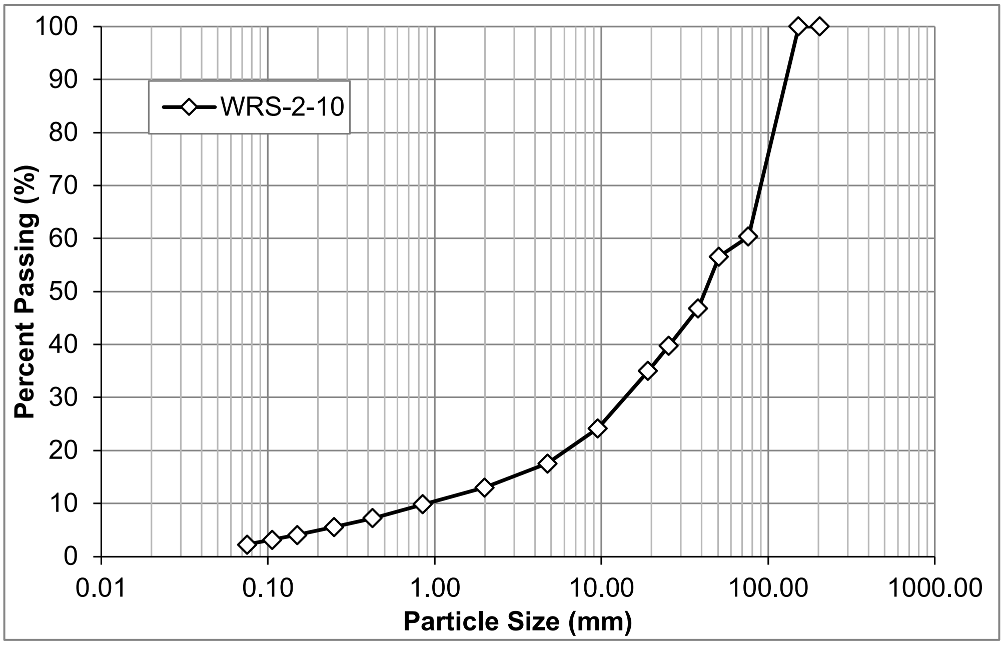


Table B.36: Grain Size Distributions (WRS-2-11)

Profile Number:	WRS-2-11	Sample Numbers:	
Easting:	592157	WRS-2-11	Waste Rock
Northing:	5541197		

20-L Pail Sample Particle Size Distribution:

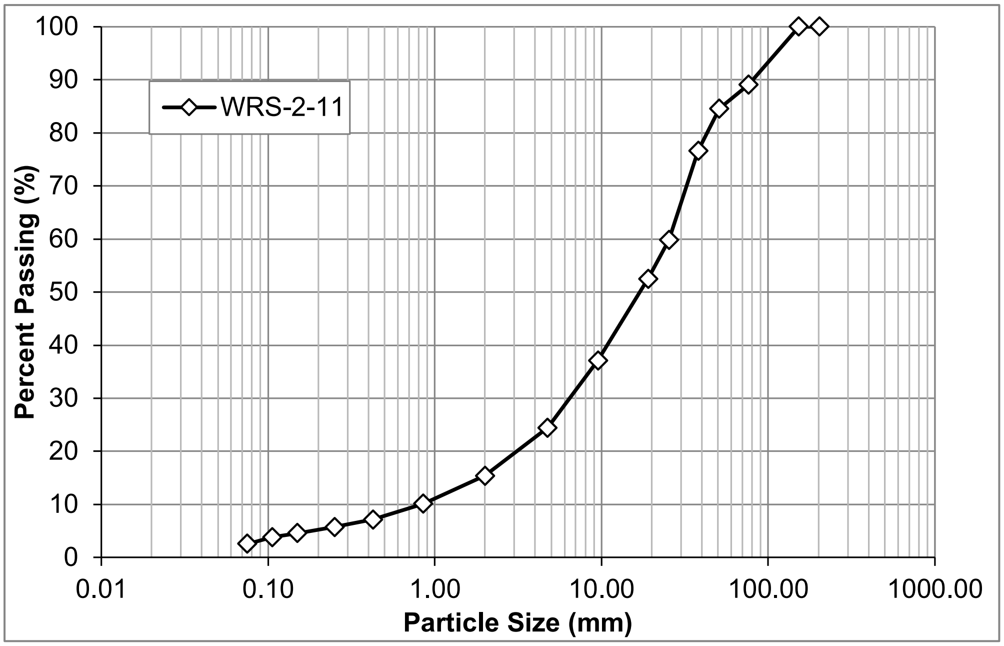


Table B.37: Grain Size Distributions (WRS-2-12)	
Profile Number: WRS-2-12 Easting: 592137 Northing: 5541217	Sample Numbers: WRS-2-12 Waste Rock

20-L Pail Sample Particle Size Distribution:

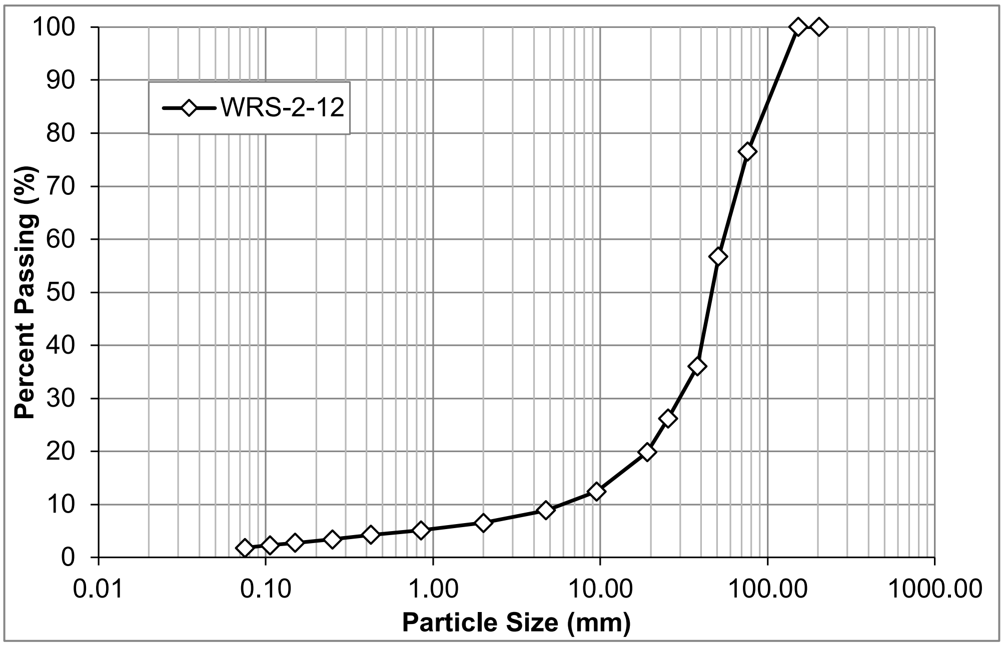


Table B.38: Grain Size Distributions (WRS-2-13)			
Profile Number:	WRS-2-13	Sample Numbers:	
Easting:	592070	WRS-2-13	Waste Rock
Northing:	5541186		

20-L Pail Sample Particle Size Distribution:

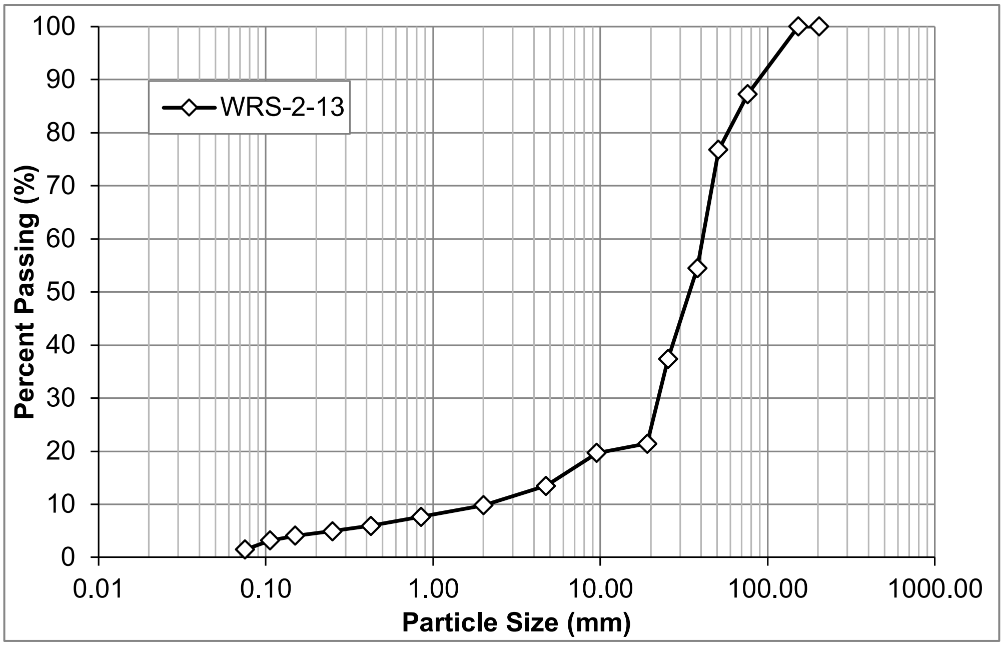


Table B.39: Grain Size Distributions (P1-P1)

Profile Number:	P1-P1	Sample Numbers:	
Easting:	591944	P1-P1-S1	Waste Rock
Northing:	5540447	P1-P1-S2	Waste Rock
		P1-P1-S3	Waste Rock

20-L Pail Sample Particle Size Distribution:

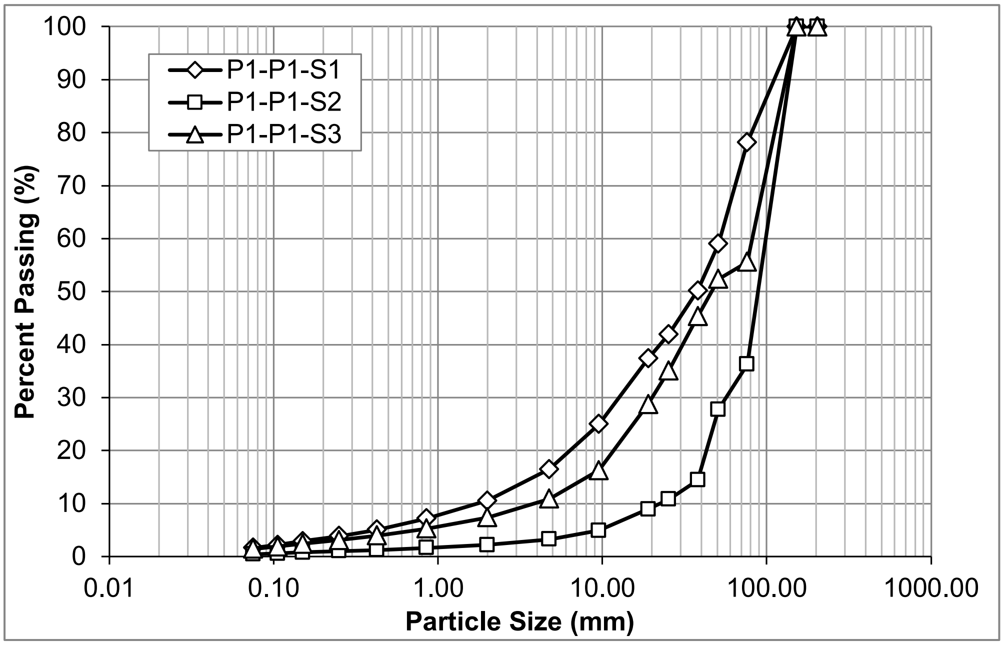


Table B.40: Grain Size Distributions (P1-P2)

Profile Number:	P1-P2	Sample Numbers:	
Easting:	591951	P1-P2-S1	Waste Rock
Northing:	5540447	P1-P2-S2	Waste Rock
		P1-P2-S3	Waste Rock

20-L Pail Sample Particle Size Distribution:

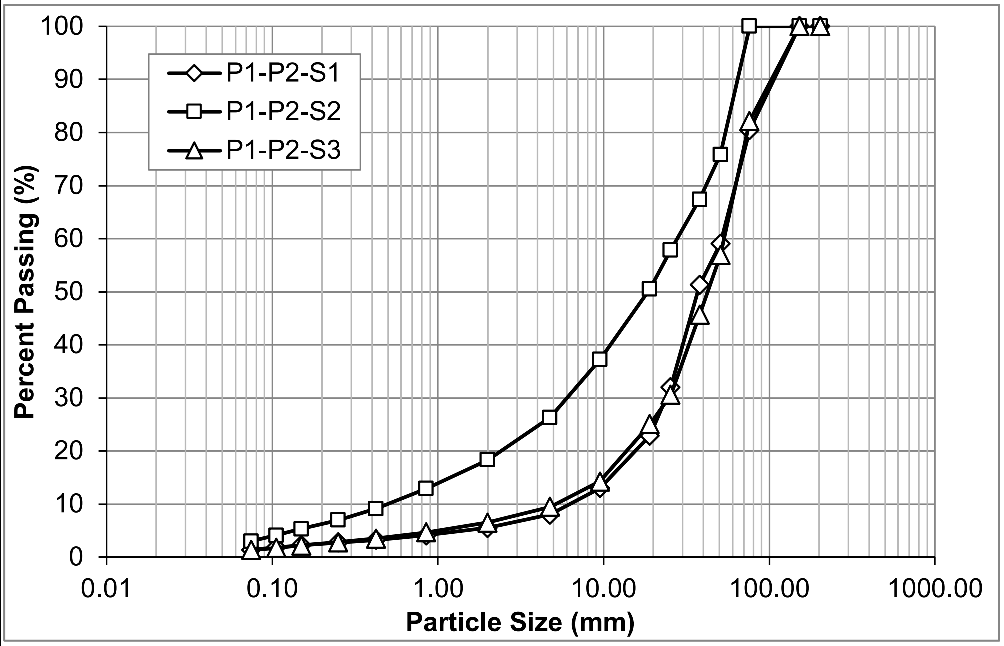


Table B.41: Grain Size Distributions (P1-P3)			
Profile Number:	P1-P3	Sample Numbers:	
Easting:	591966	P1-P3-S1	Waste Rock
Northing:	5540494	P1-P3-S2	Waste Rock
		P1-P3-S2	Waste Rock

20-L Pail Sample Particle Size Distribution:

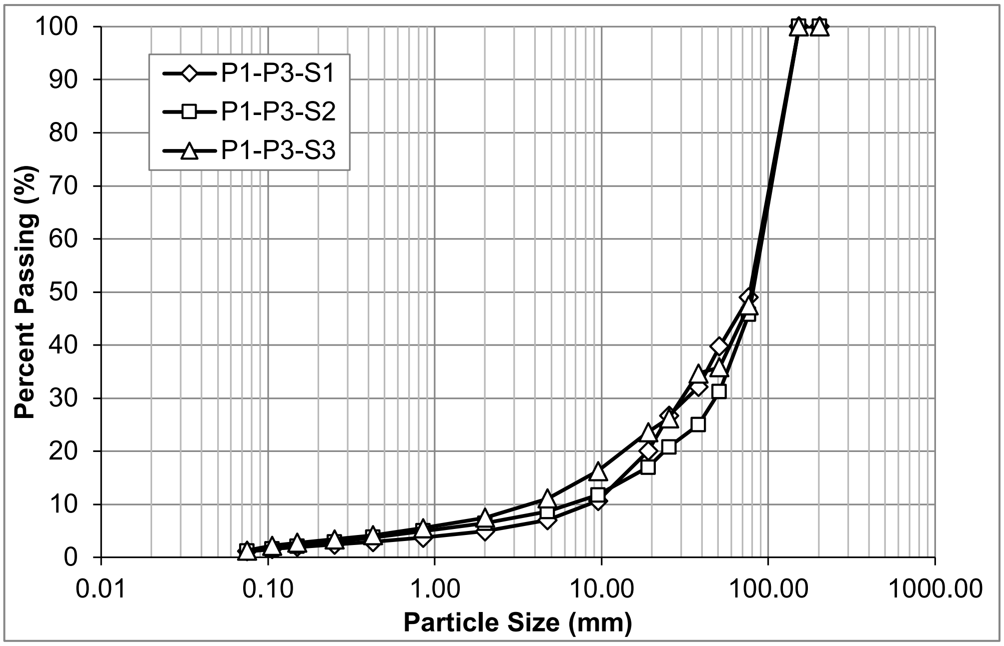


Table B.42: Grain Size Distributions (P1-P4)			
Profile Number:	P1-P4	Sample Numbers:	
Easting:	591975	P1-P4-S1	Waste Rock
Northing:	5540538	P1-P4-S2	Waste Rock

20-L Pail Sample Particle Size Distribution:

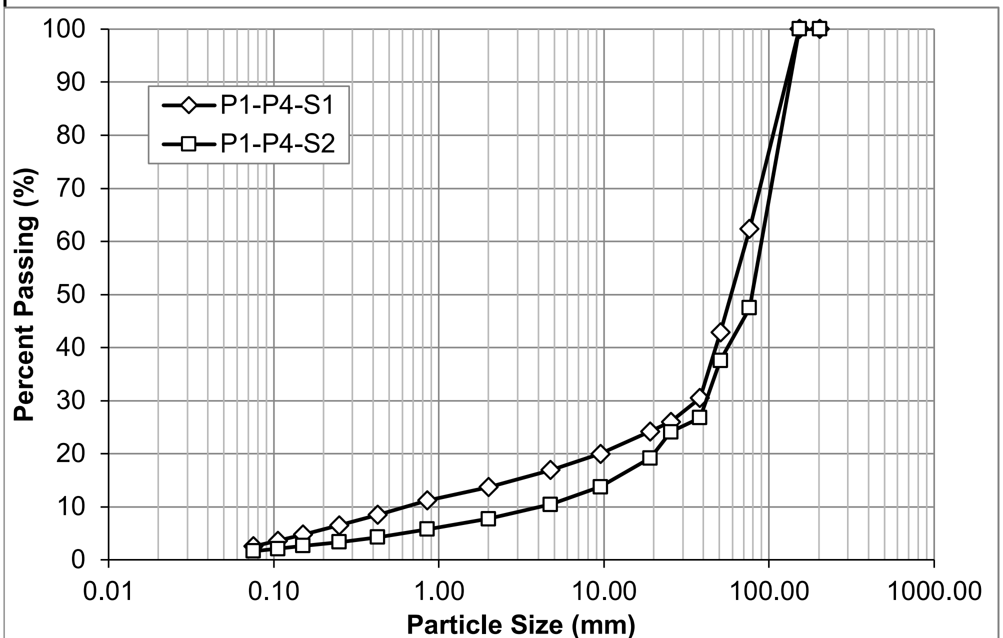


Table B.43: Grain Size Distributions (P1-P5)

Profile Number:	P1-P5	Sample Numbers:	
Easting:	591975	P1-P5-S1	Waste Rock
Northing:	5540538	P1-P5-S2	Waste Rock
		P1-P5-S3	Waste Rock

20-L Pail Sample Particle Size Distribution:

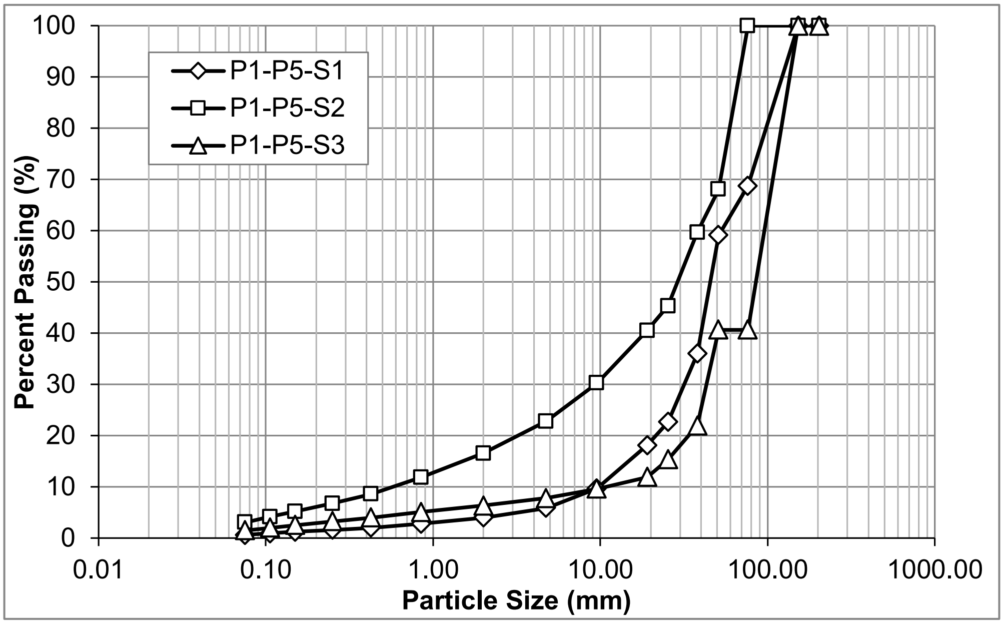


Table B.44: Grain Size Distributions (P1-P6)			
Profile Number:	P1-P6	Sample Numbers:	
Easting:	591908	P1-P6-S1	Waste Rock
Northing:	5540414	P1-P6-S2	Waste Rock

20-L Pail Sample Particle Size Distribution:

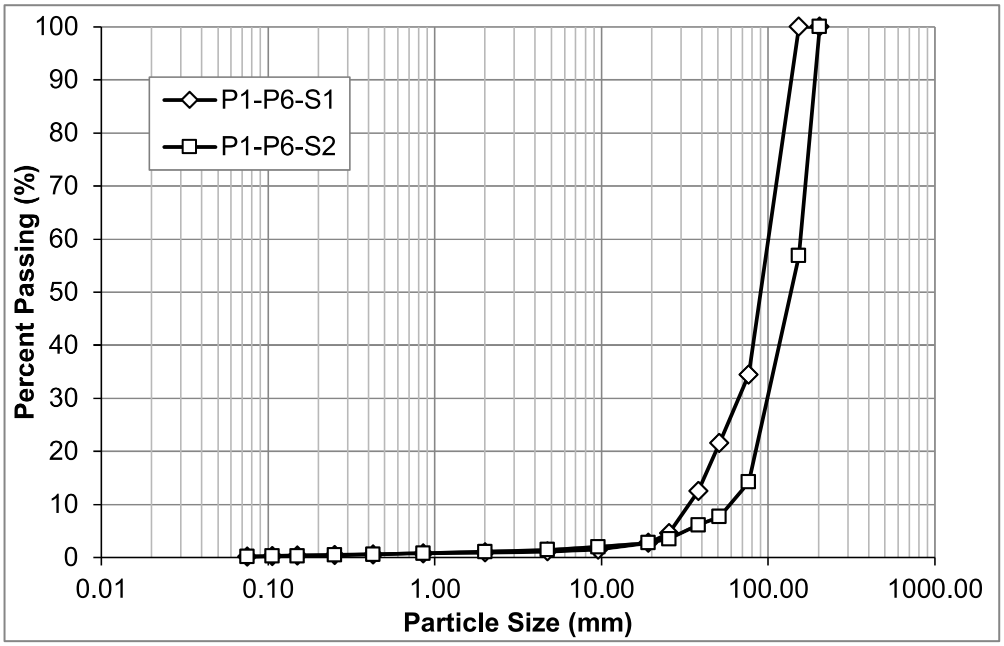


Table B.45: Grain Size Distributions (P1-P7)			
Profile Number:	P1-P7	Sample Numbers:	
Easting:	591895	P1-P7-S1	Waste Rock
Northing:	5540412		

20-L Pail Sample Particle Size Distribution:

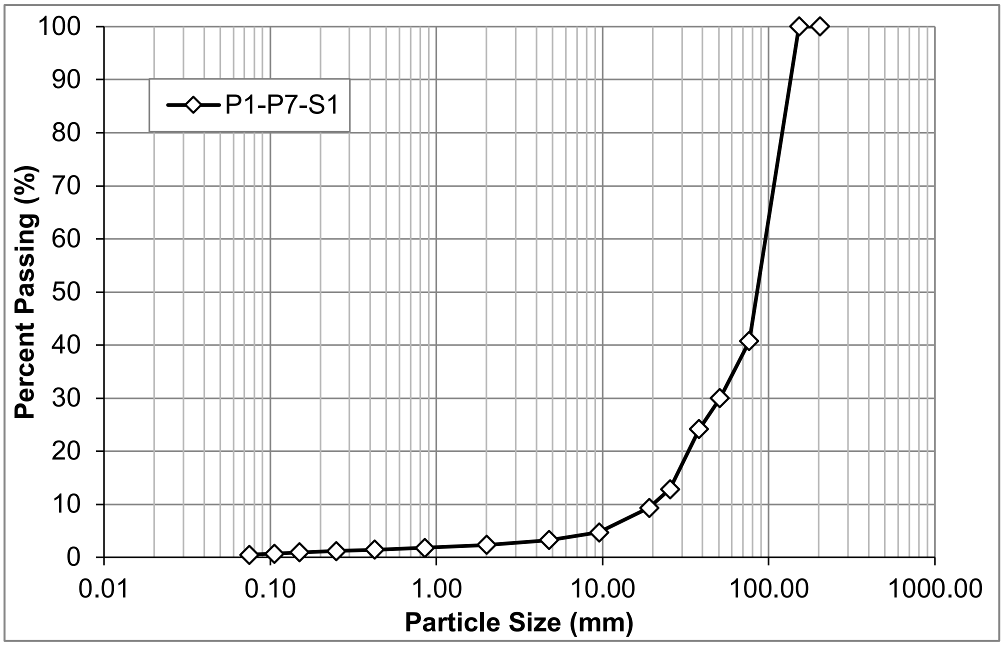


Table B.46: Grain Size Distributions (P1-P8)

Profile Number:	P1-P8	Sample Numbers:	
Easting:	591834	P1-P8-S1	Waste Rock
Northing:	5540412		

20-L Pail Sample Particle Size Distribution:

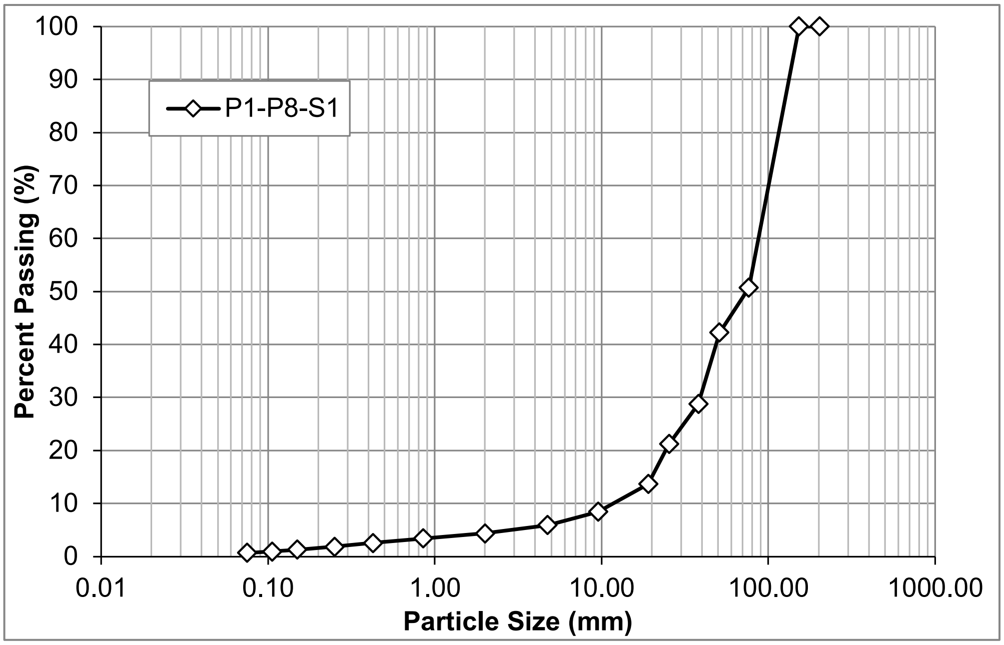


Table B.47: Grain Size Distributions (P1-P9)	
Profile Number: P1-P9 Easting: - Northing: -	Sample Numbers: P1-P9-S1 Waste Rock

20-L Pail Sample Particle Size Distribution:

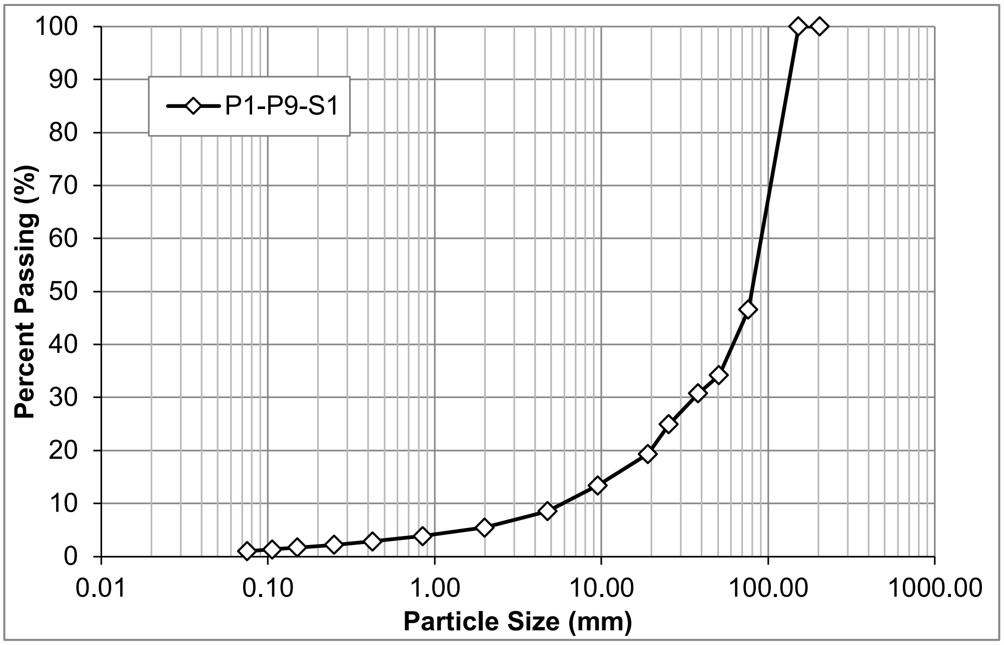


Table B.48: Grain Size Distributions (P1-P10)	
Profile Number: P1-P10 Easting: 592010 Northing: 5540591	Sample Numbers: P1-P10-S1 Waste Rock

20-L Pail Sample Particle Size Distribution:

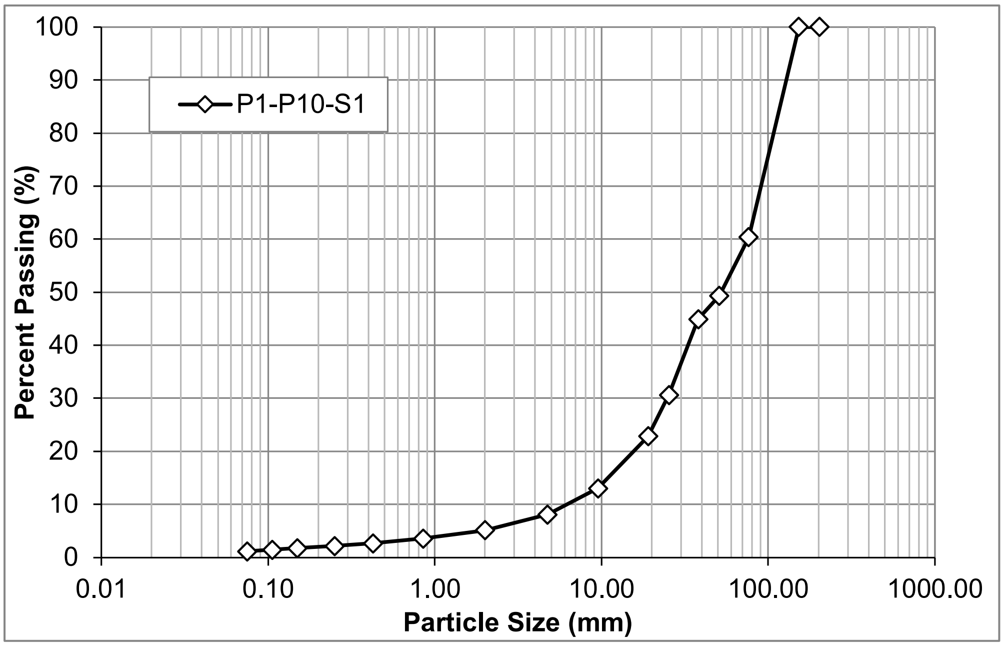
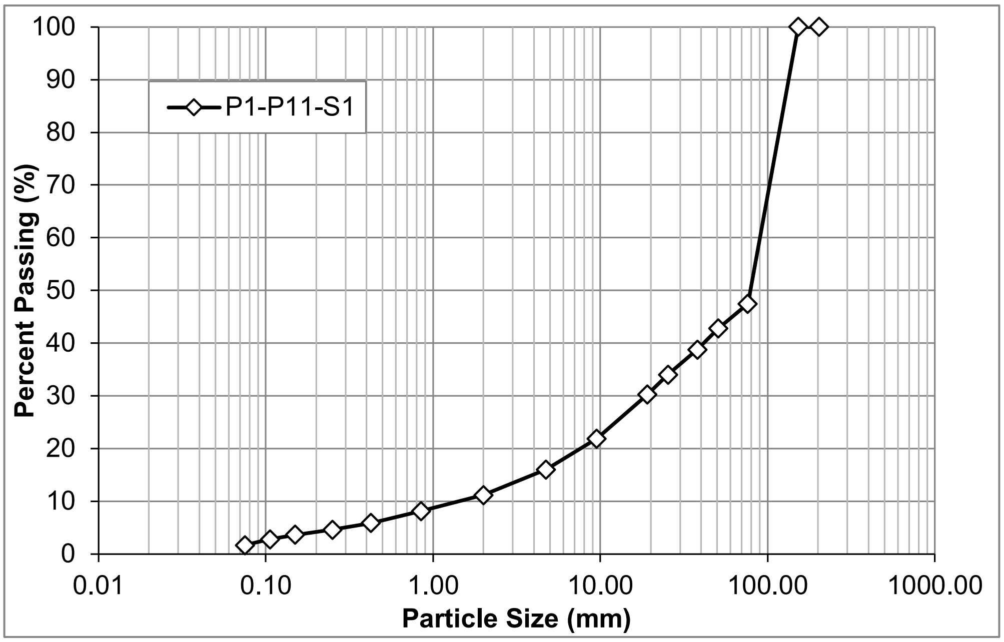


Table B.49: Grain Size Distributions (P1-P11)			
Profile Number:	P1-P11	Sample Numbers:	
Easting:	592058	P1-P11-S1	Waste Rock
Northing:	5540598		

20-L Pail Sample Particle Size Distribution:



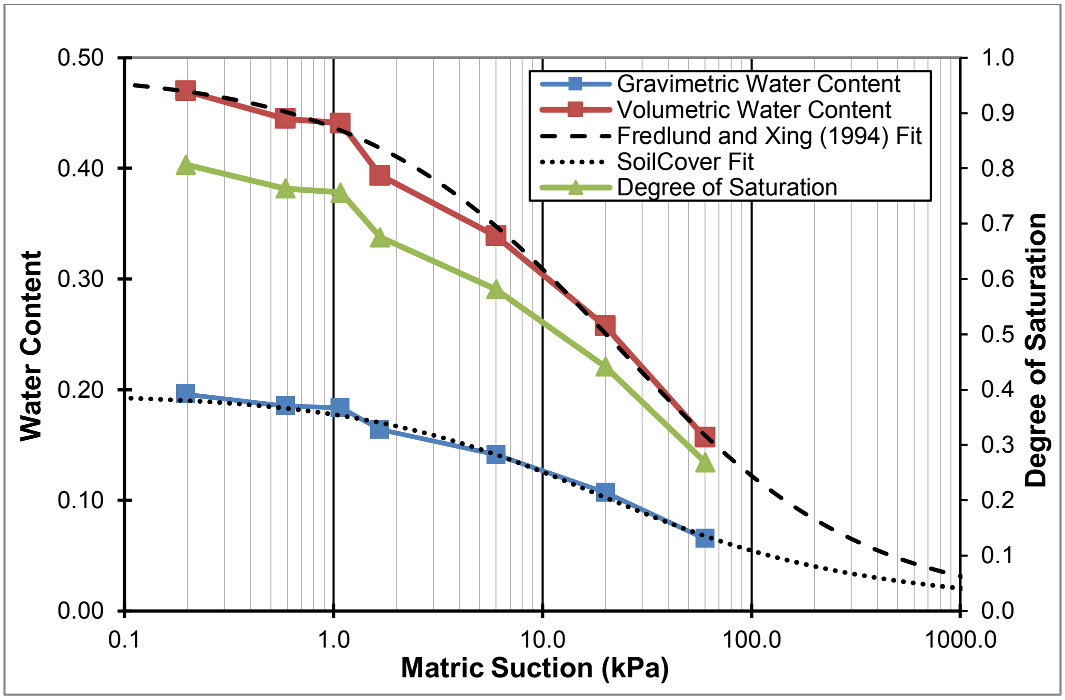


Figure B.1 – Soil-Water Characteristic Curves for TP-P1-S4-S1 cover sample, including gravimetric, volumetric, and degree of saturation data

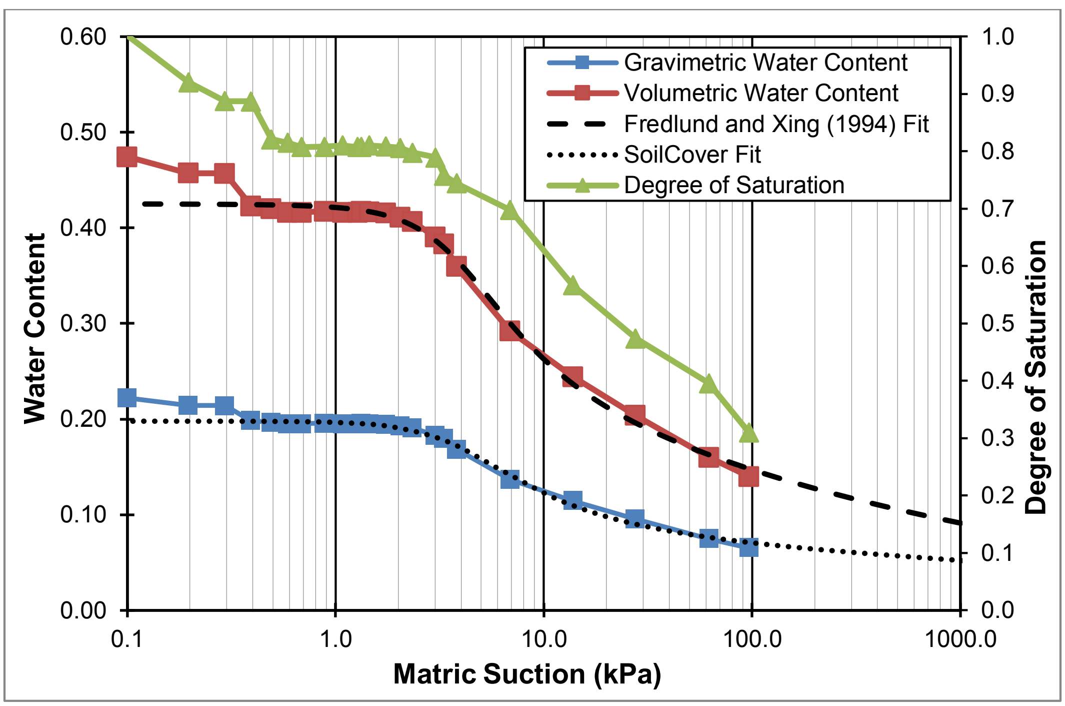


Figure B.2 – Soil-Water Characteristic Curves for TP-P1-S11-S1 cover sample, including gravimetric, volumetric, and degree of saturation data

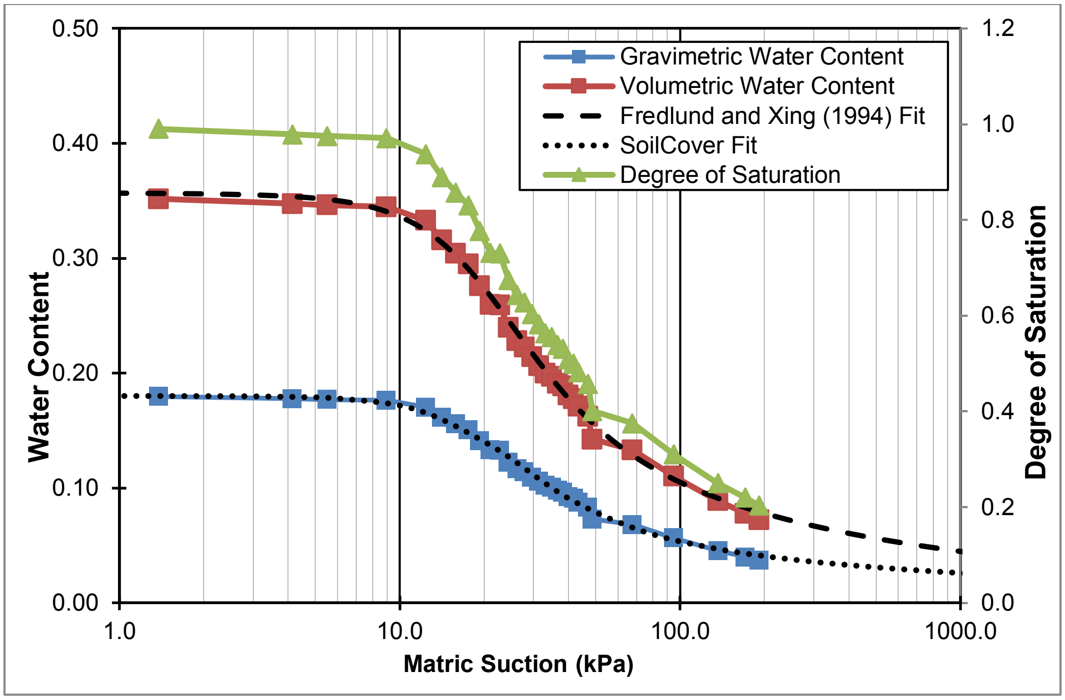


Figure B.3 – Soil-Water Characteristic Curves for TP-P1-S14-S1 cover sample, including gravimetric, volumetric, and degree of saturation data

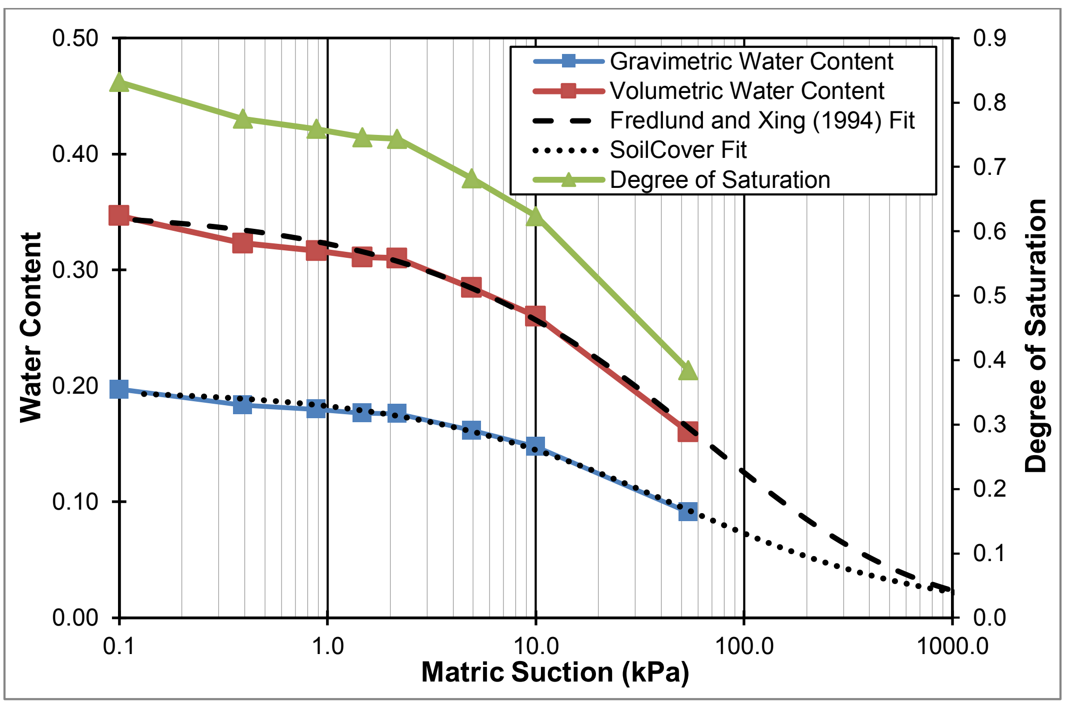


Figure B.4 – Soil-Water Characteristic Curves for TP-P1-S5-S3 waste rock sample, including gravimetric, volumetric, and degree of saturation data

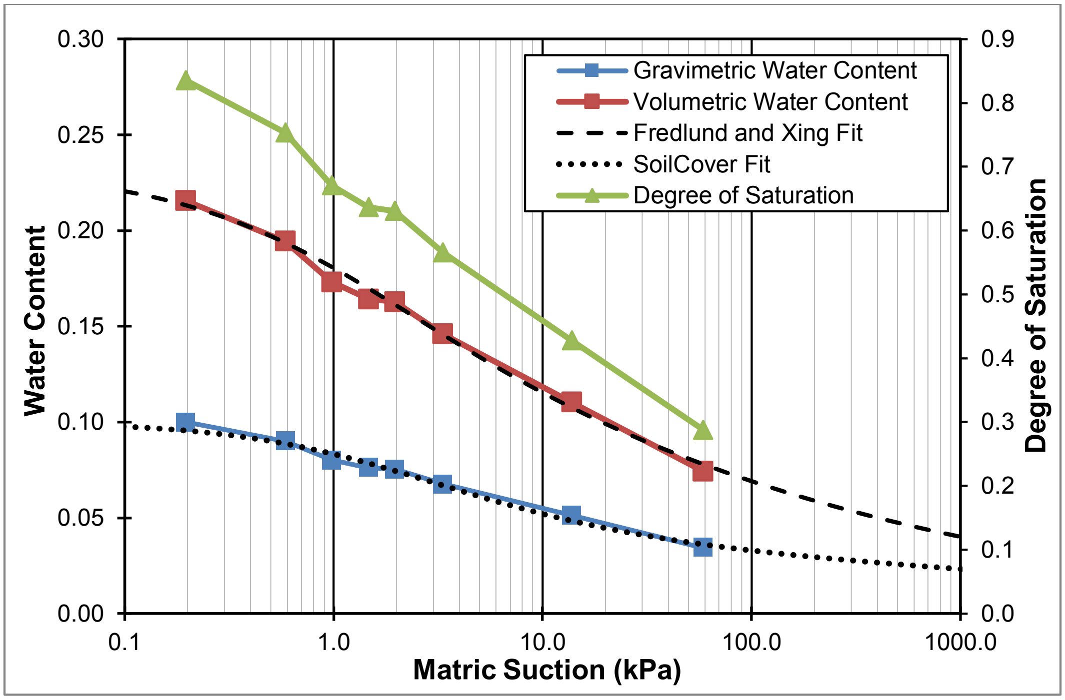


Figure B.5 – Soil-Water Characteristic Curves for TP-P1-S6-S3 waste rock sample, including gravimetric, volumetric, and degree of saturation data

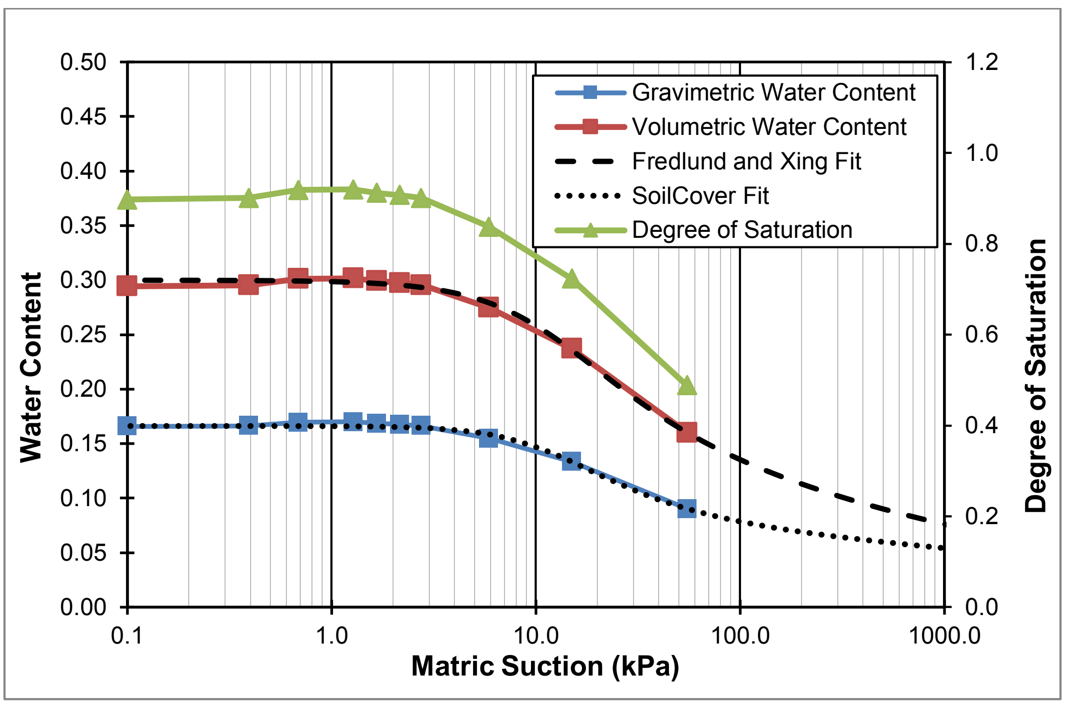


Figure B.6 – Soil-Water Characteristic Curves for TP-P1-S9-S1 waste rock sample, including gravimetric, volumetric, and degree of saturation data

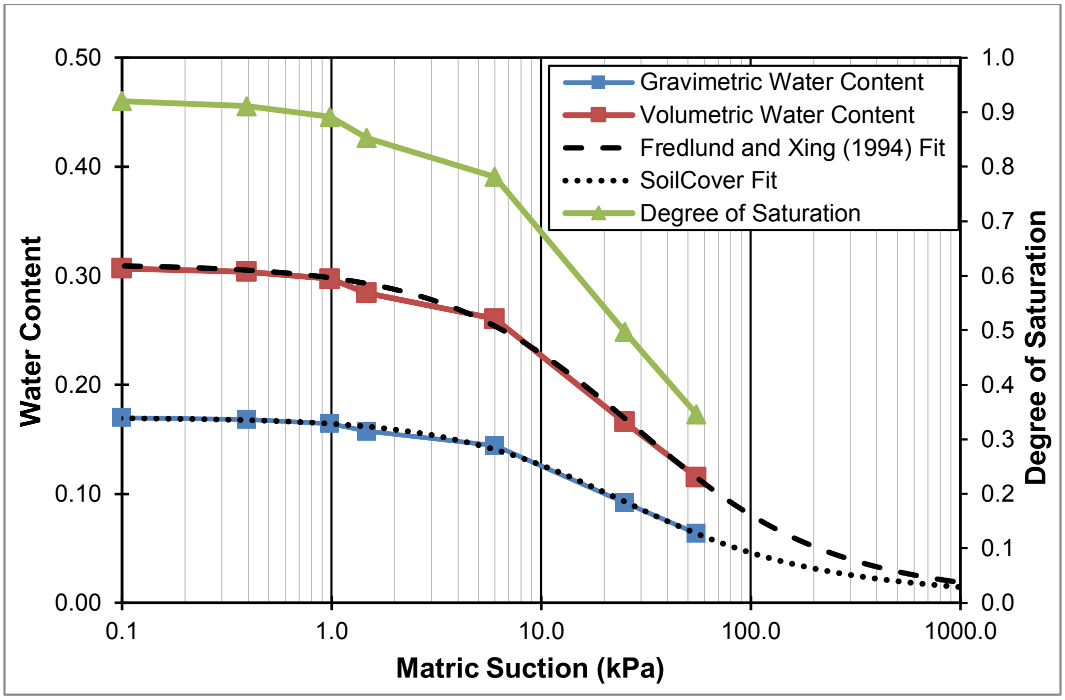


Figure B.7 – Soil-Water Characteristic Curves for TP-P1-S11-S2 waste rock sample, including gravimetric, volumetric, and degree of saturation data

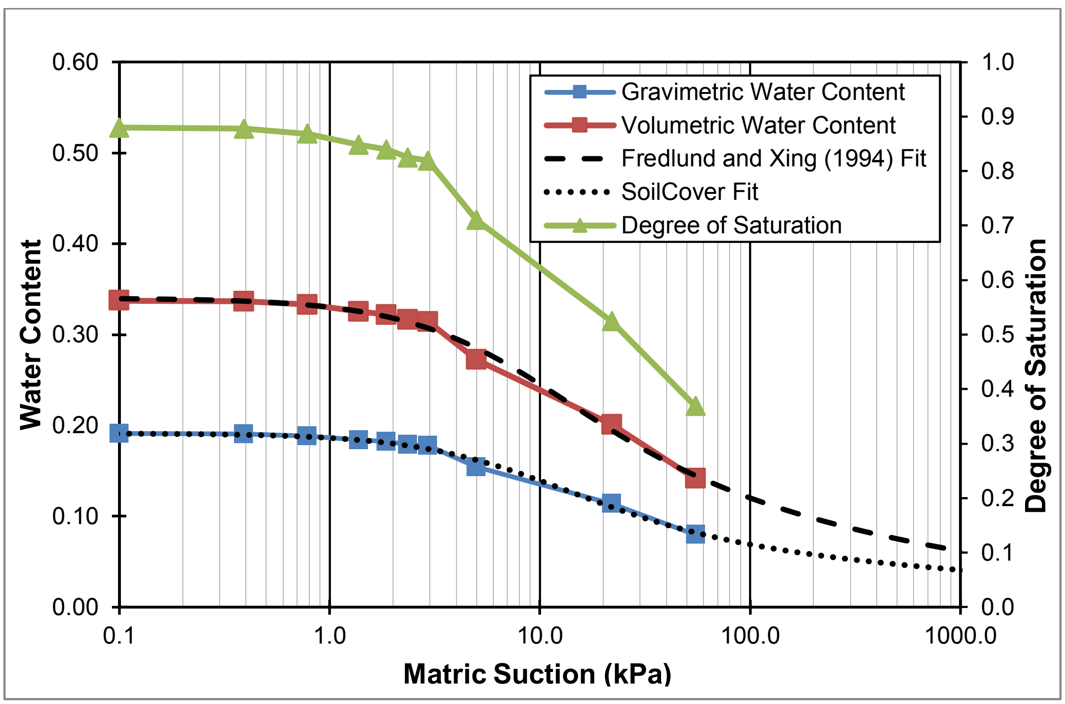


Figure B.8 – Soil-Water Characteristic Curves for P1-P3-S2 waste rock sample, including gravimetric, volumetric, and degree of saturation data

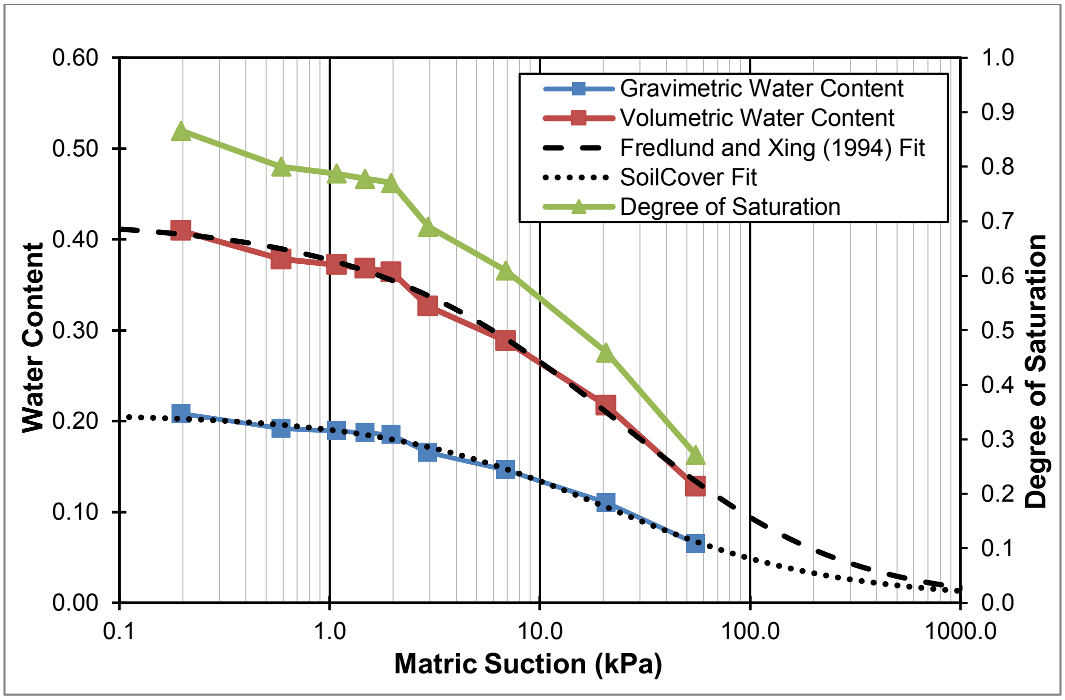


Figure B.9 – Soil-Water Characteristic Curves for P1-P6-S1 waste rock sample, including gravimetric, volumetric, and degree of saturation data

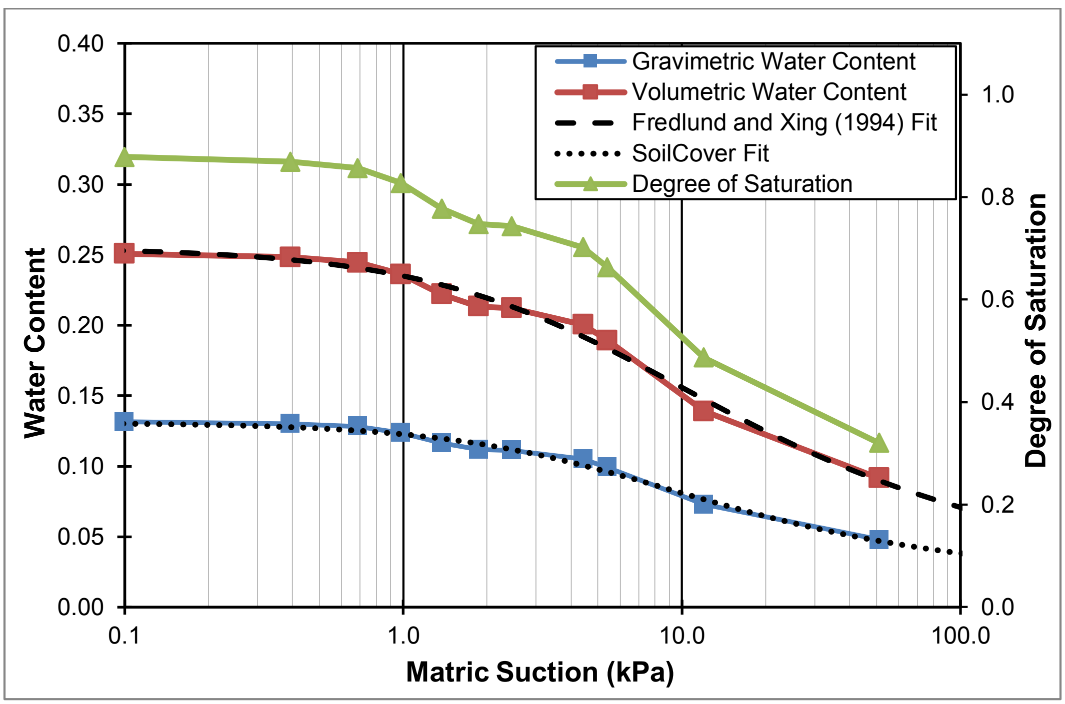


Figure B.10 – Soil-Water Characteristic Curves for TP-P2-S10-S3 waste rock sample, including gravimetric, volumetric, and degree of saturation data

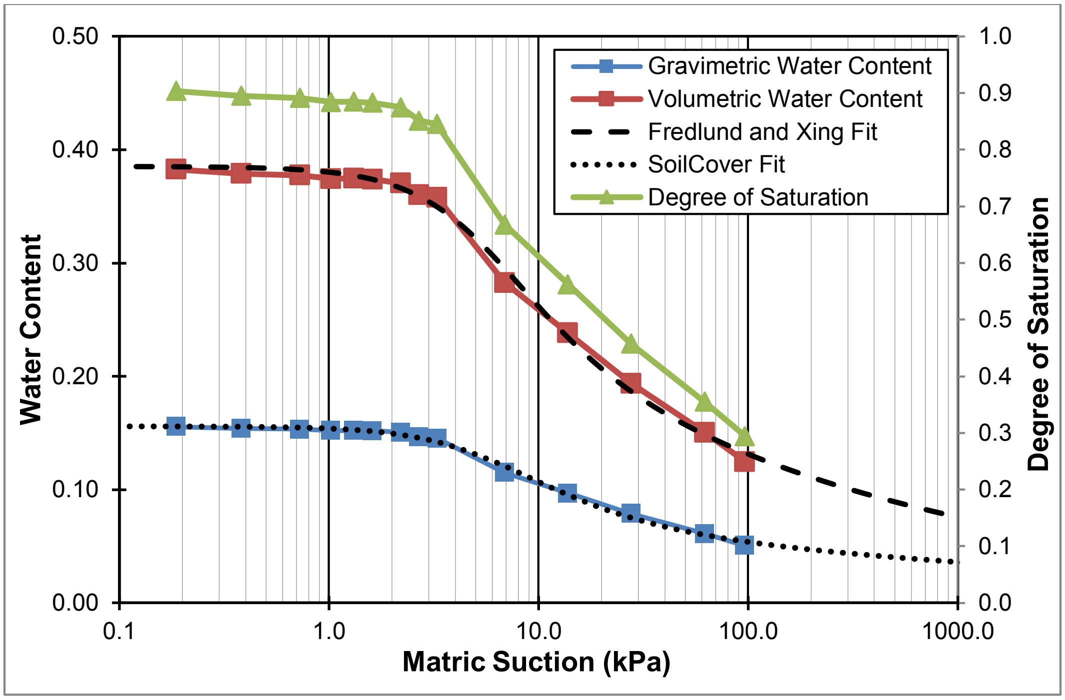


Figure B.11 – Soil-Water Characteristic Curves for TP-P2-S13-S3 waste rock sample, including gravimetric, volumetric, and degree of saturation data

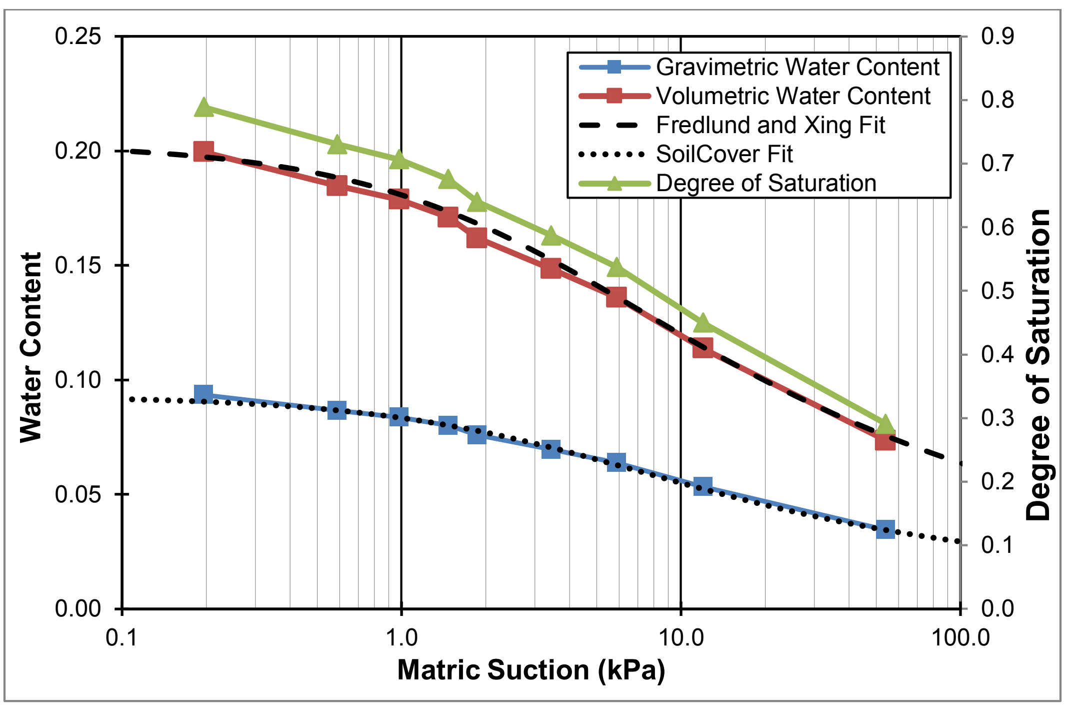


Figure B.12 – Soil-Water Characteristic Curves for TP-P2-S16-S3 waste rock sample, including gravimetric, volumetric, and degree of saturation data

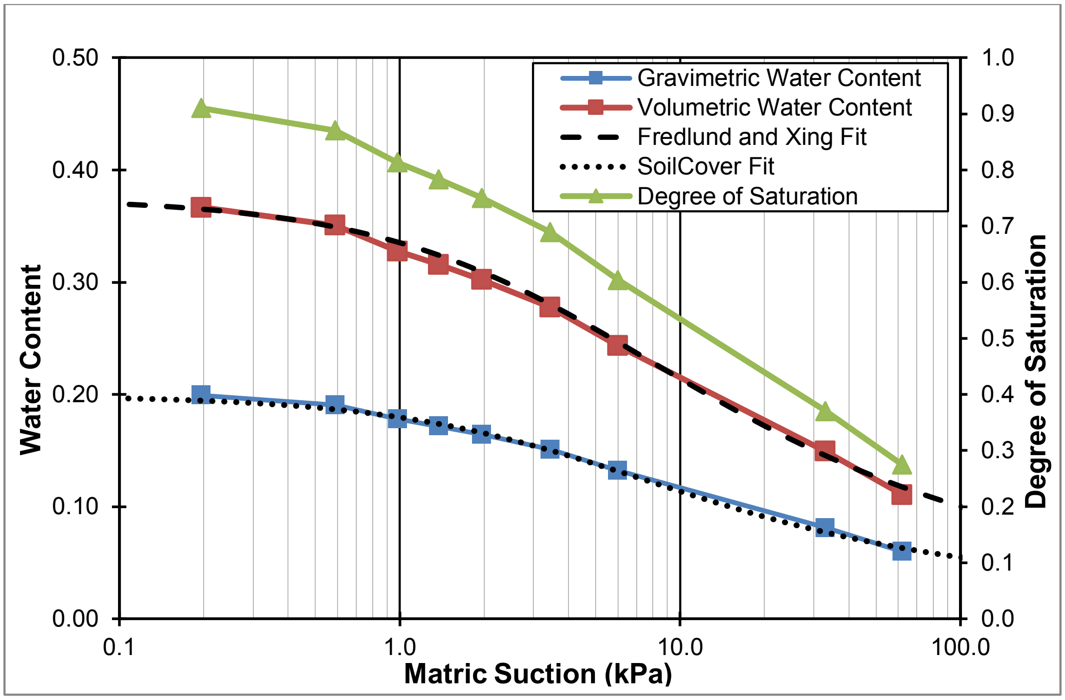


Figure B.13 – Soil-Water Characteristic Curves for WRS-2-12 waste rock sample, including gravimetric, volumetric, and degree of saturation data

Appendix C – Digital Image Processing Figures Distribution Plots

Appendix C presents the images utilized in Split Desktop for Digital Image Processing. For each of the ten images utilized in the study, three figures are provided in the following appendix.

- The original unaltered image of the sample location;
- The image after delineation using the Split Desktop Software;
- The image with numbered rectangular sections, which were used to analyze grain size in each quadrant of the image; and;
- Sample calculation for determining a composite grain size curve.

Figure C.1 - Photograph of sampling location TP-P1-S5-S3

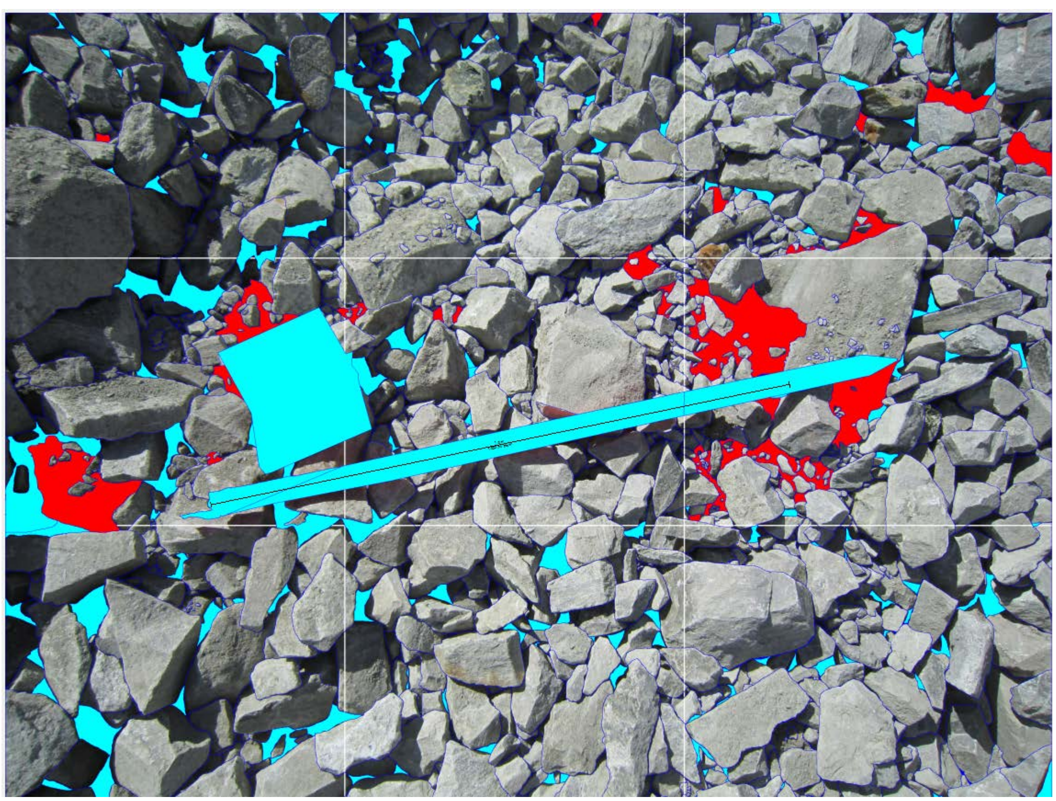


Figure C.2 - Sampling location TP-P1-S5-S3 with delineations from Split Desktop analysis

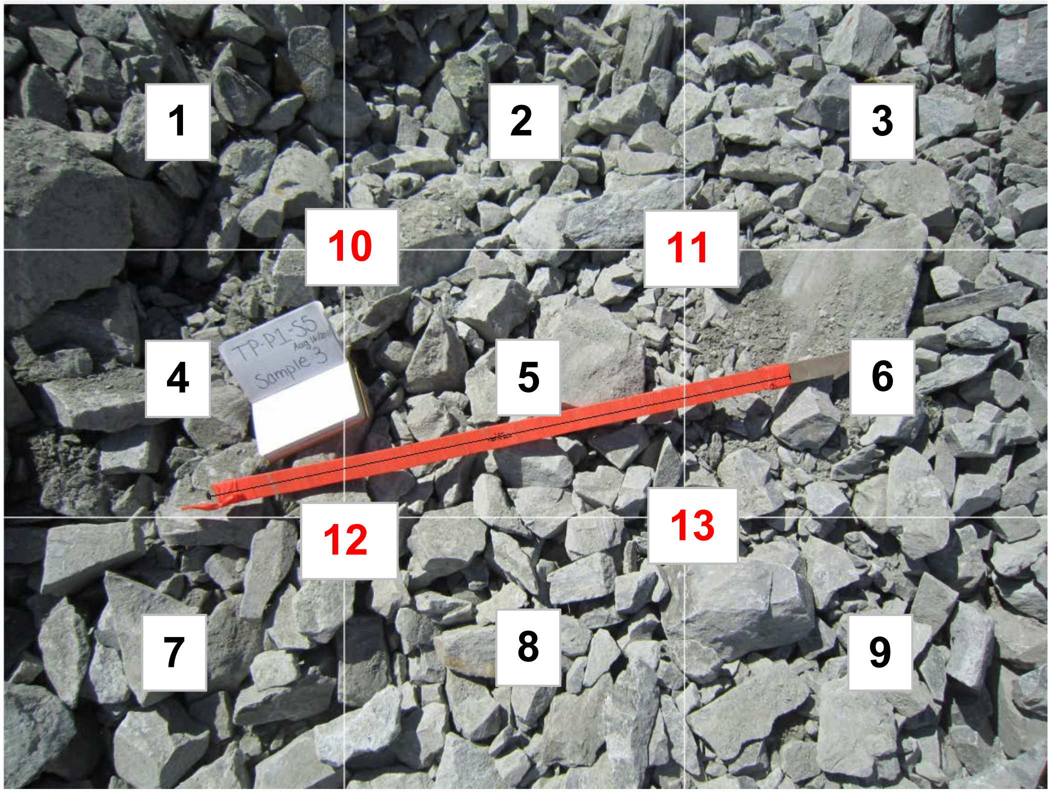


Figure C.3 - Sampling location TP-P1-S5-S3 with section numbers for the evaluation of the range of grain size using Split Desktop

Figure C.4 - Photograph of sampling location TP-P1-S6-S3

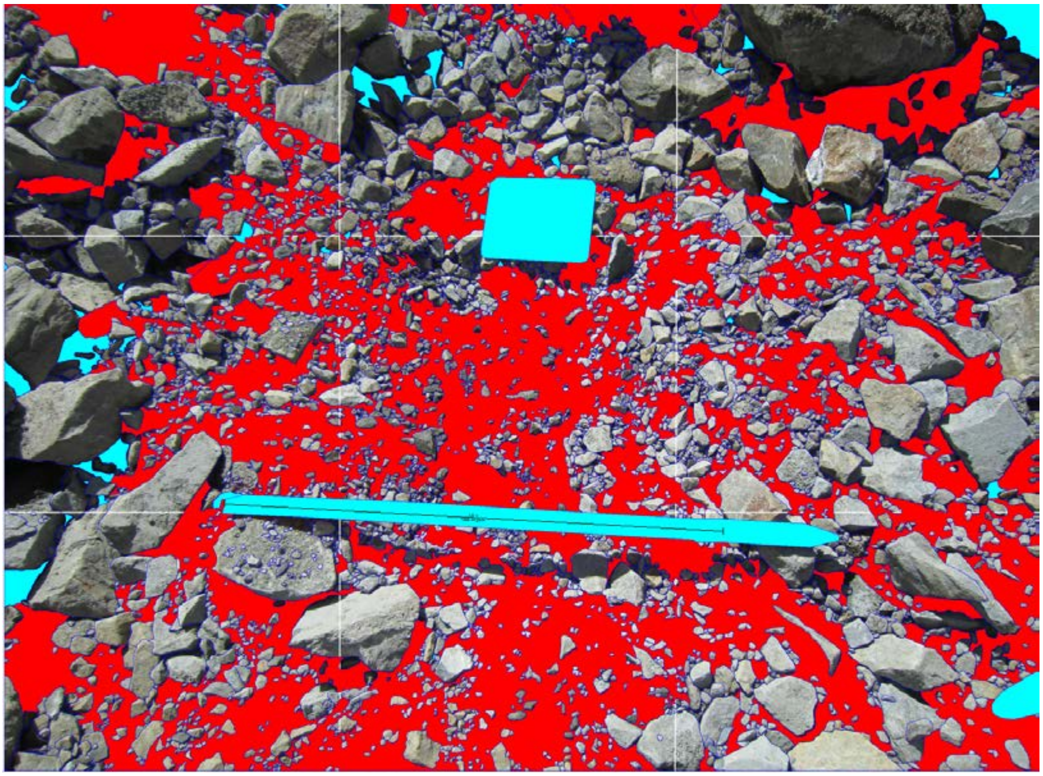


Figure C.5 - Sampling location TP-P1-S5-S3 with delineations from Split Desktop analysis

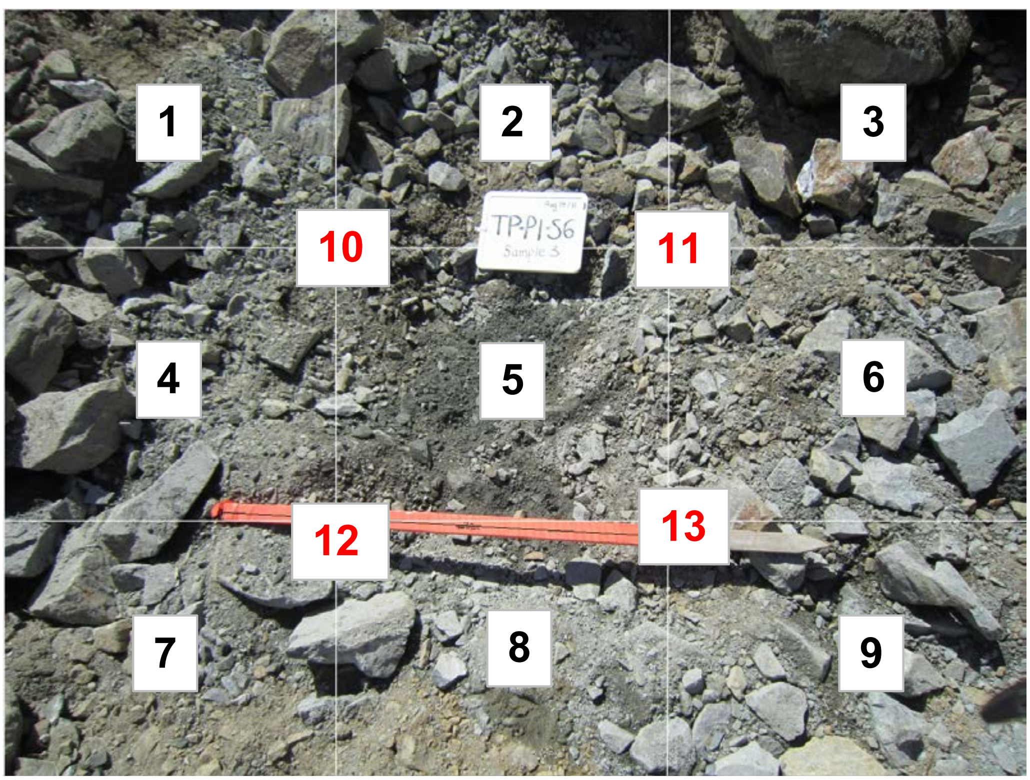


Figure C.6 - Sampling location TP-P1-S5-S3 with section numbers for the evaluation of the range of grain size using Split Desktop

Figure C.7 - Photograph of sampling location TP-P1-S6-S3

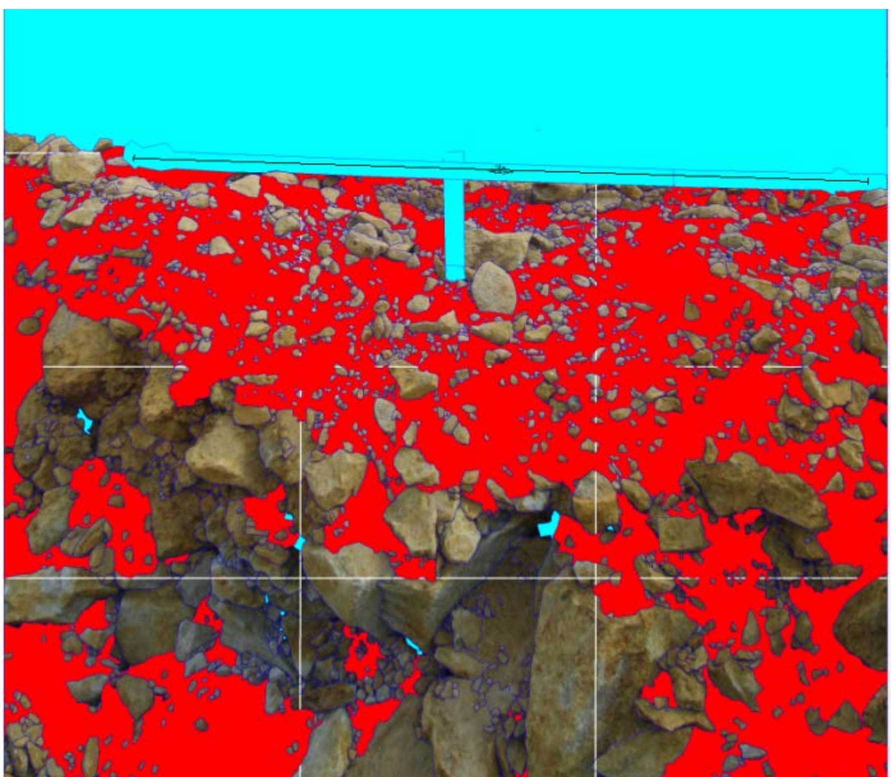


Figure C.8 - Sampling location TP-P1-S5-S3 with delineations from Split Desktop analysis

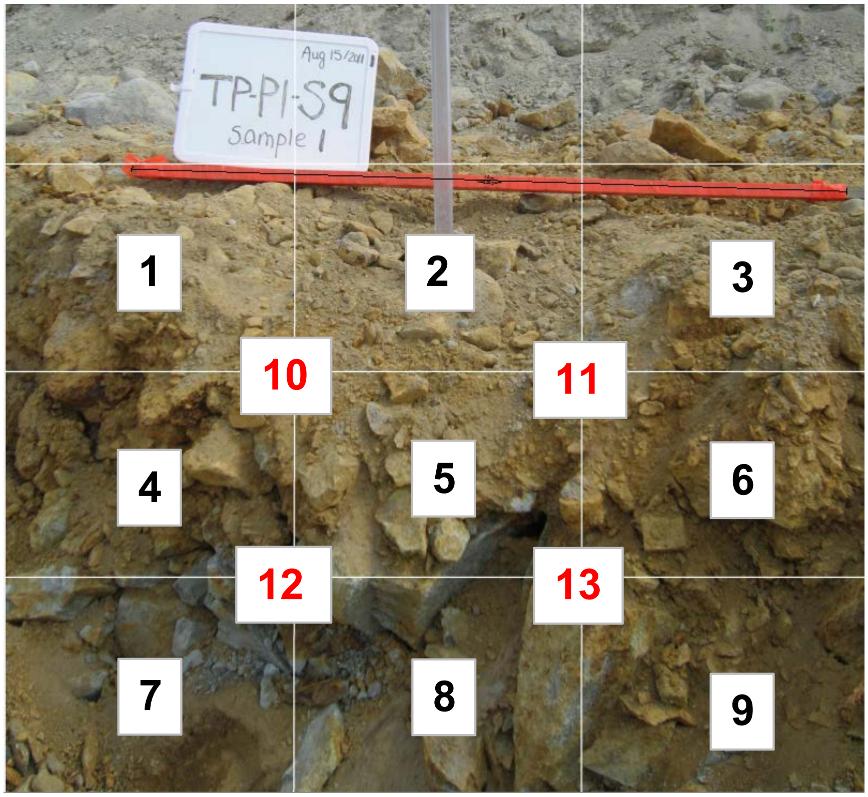


Figure C.9 - Sampling location TP-P1-S5-S3 with section numbers for the evaluation of the range of grain size using Split Desktop

Figure C.10 - Photograph of sampling location TP-P1-S11-S2

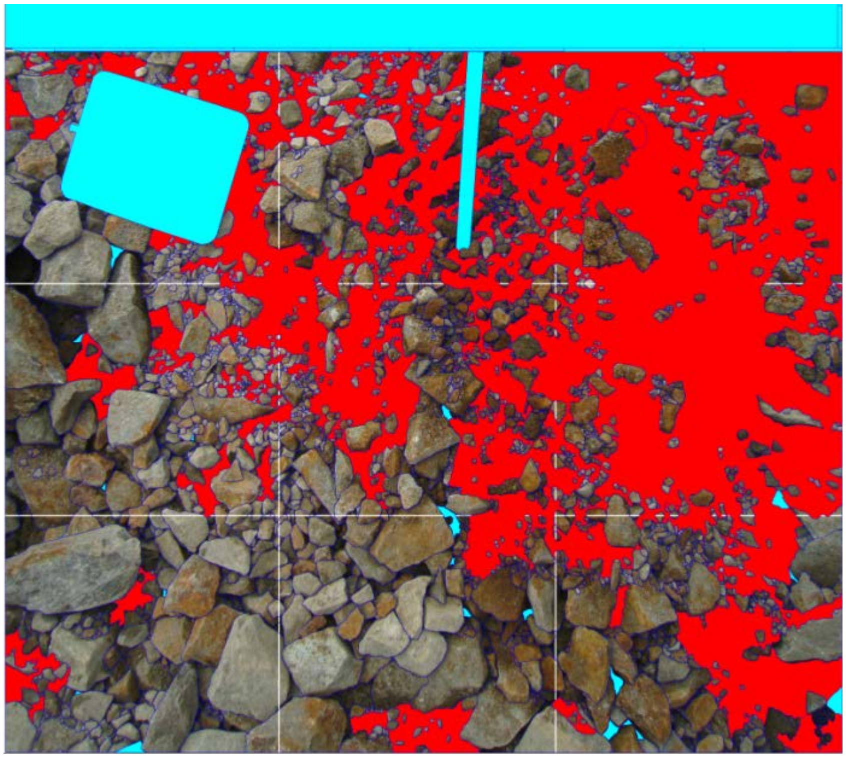


Figure C.11 - Sampling location TP-P1-S5-S3 with delineations from Split Desktop analysis

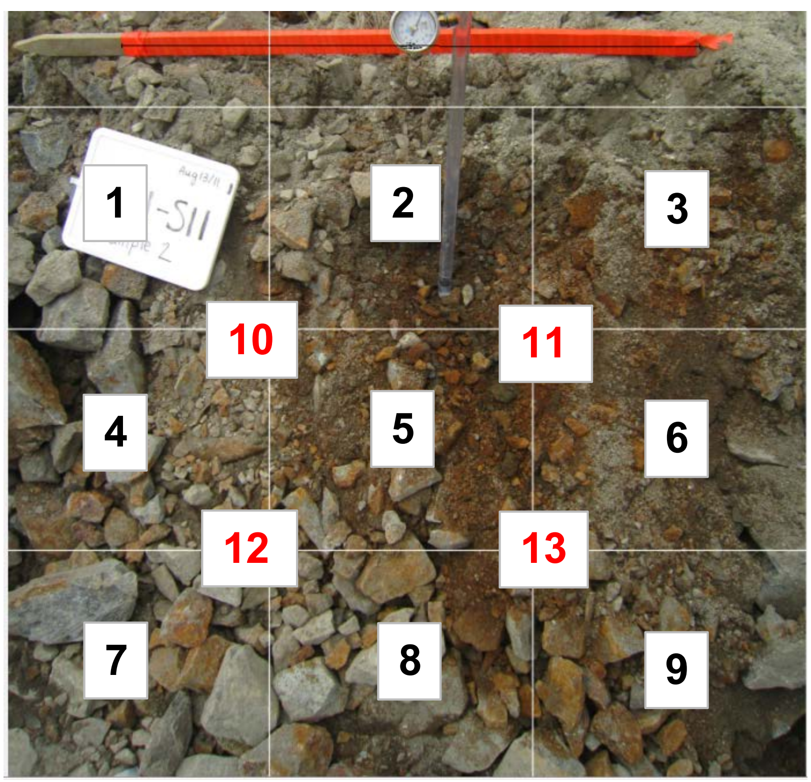


Figure C.12 - Sampling location TP-P1-S11-S2 with section numbers for the evaluation of the range of grain size using Split Desktop

Figure C.13 - Photograph of sampling location P1-P3-S2

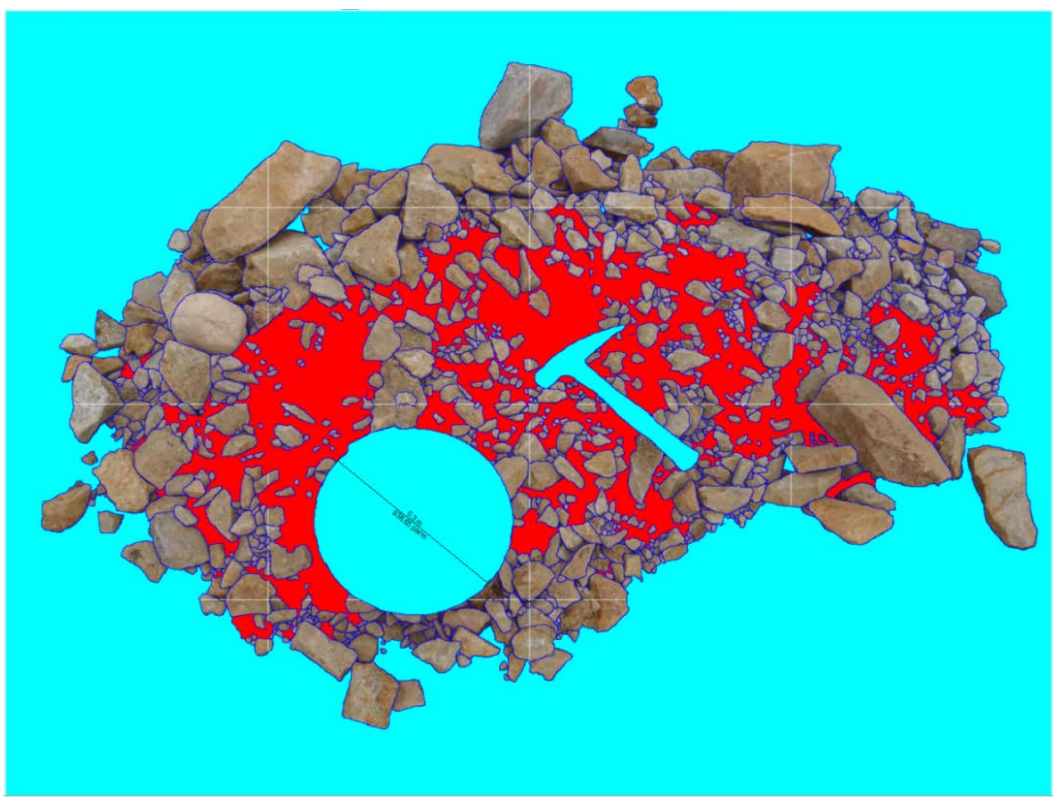


Figure C.14 - Sampling location P1-P3-S2 with delineations from Split Desktop analysis

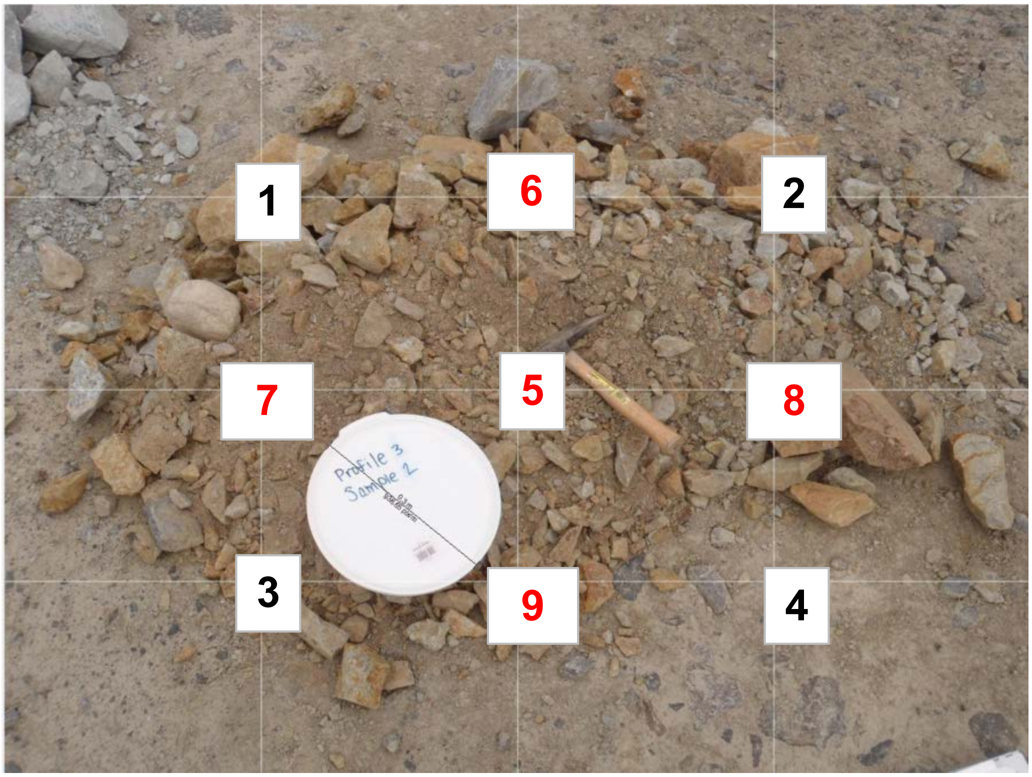


Figure C.15 - Sampling location P1-P3-S2 with section numbers for the evaluation of the range of grain size using Split Desktop

Figure C.16 - Photograph of sampling location P1-P6-S1

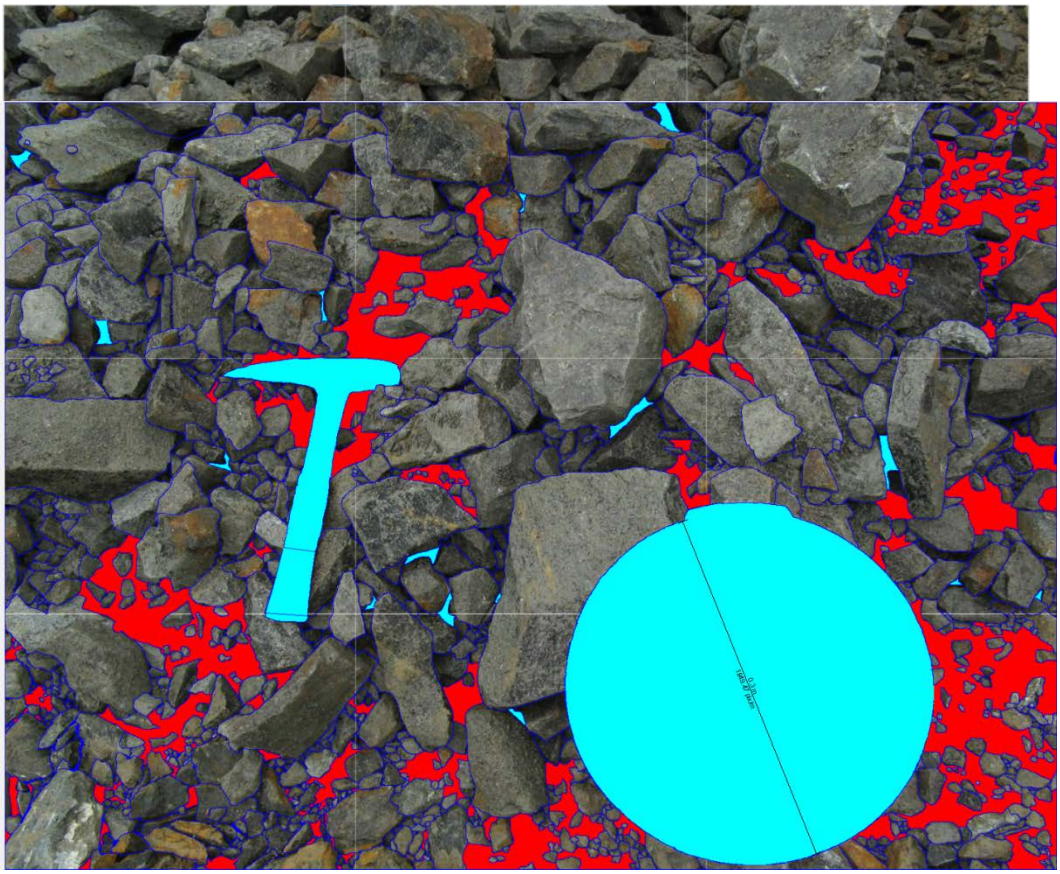


Figure C.17 - Sampling location P1-P6-S1 with delineations from Split Desktop analysis

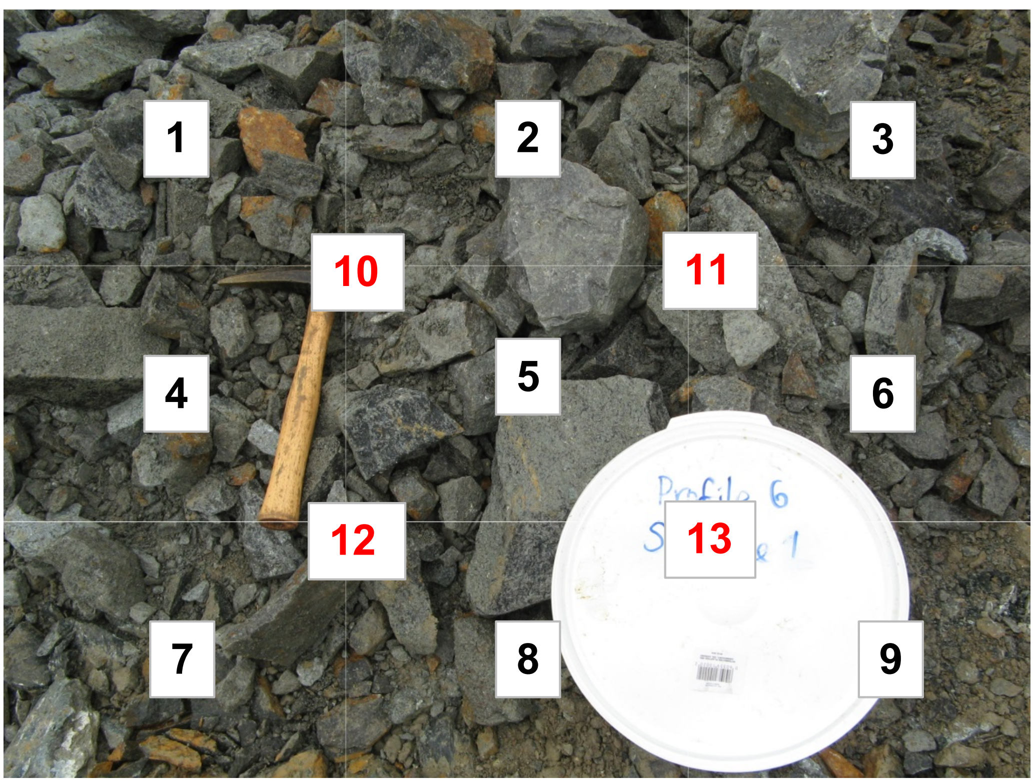


Figure C.18 - Sampling location P1-P6-S1 with section numbers for the evaluation of the range of grain size using Split Desktop

Figure C.19 - Photograph of sampling location TP-P2-S10-S3

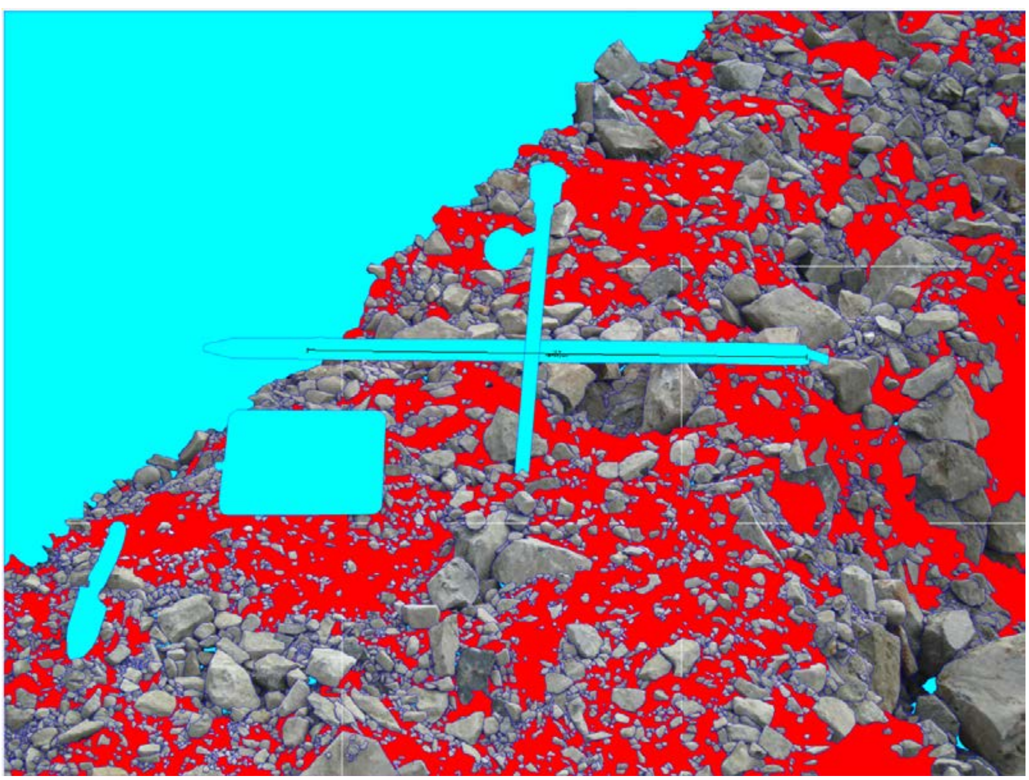


Figure C.20 - Sampling location TP-P2-S10-S3 with delineations from Split Desktop analysis

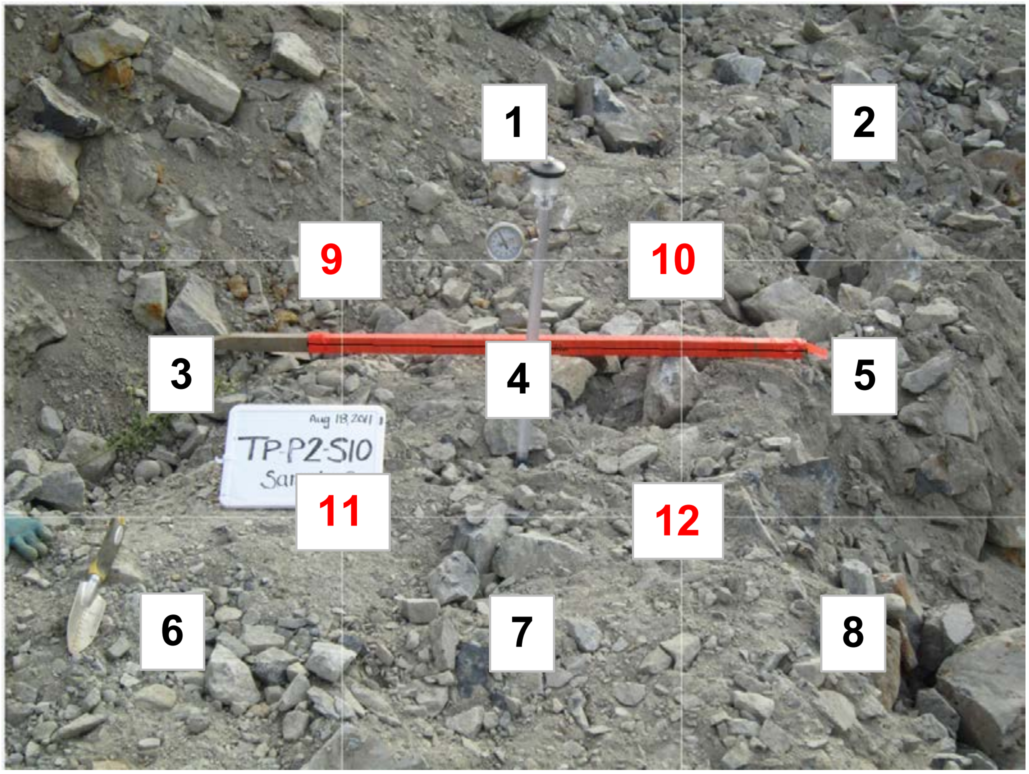


Figure C.21 - Sampling location TP-P2-S10-S3 with section numbers for the evaluation of the range of grain size using Split Desktop

Figure C.22 - Photograph of sampling location TP-P2-S13-S3

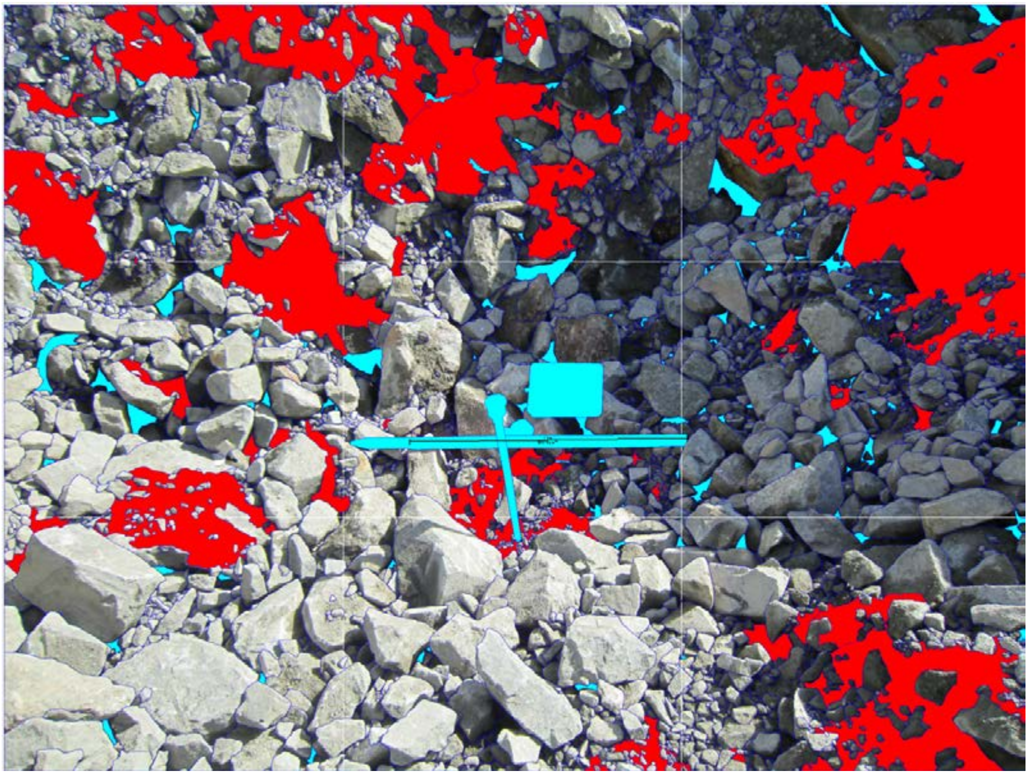


Figure C.23 - Sampling location TP-P2-S10-S3 with delineations from Split Desktop analysis

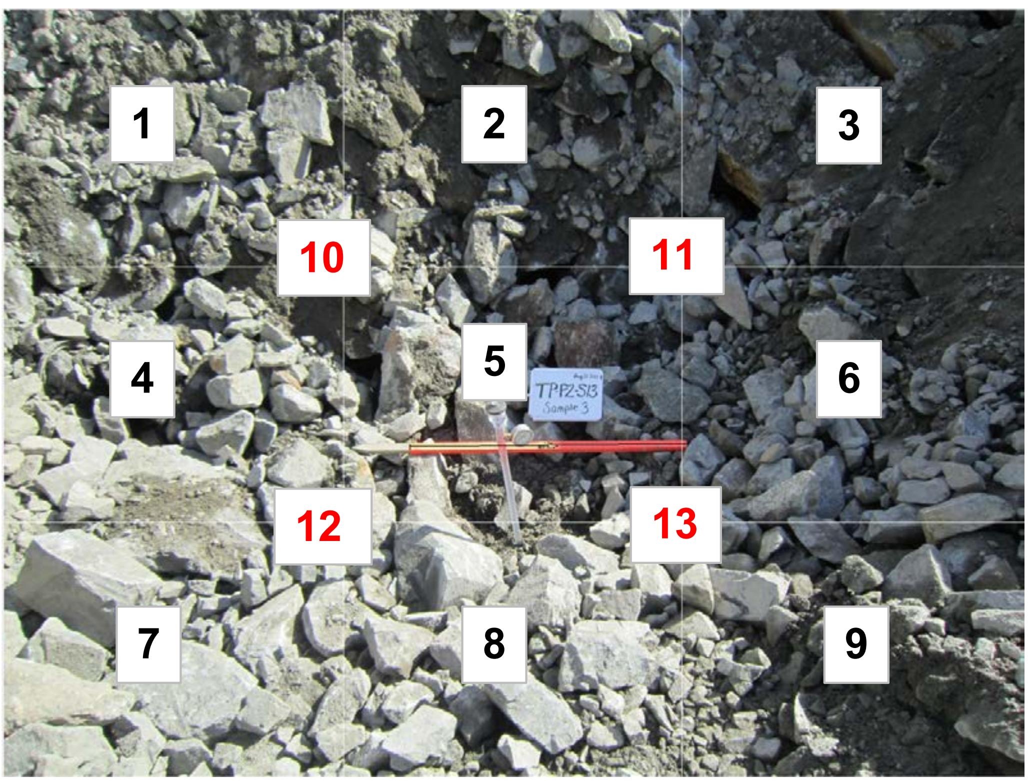


Figure C.24 - Sampling location TP-P2-S10-S3 with section numbers for the evaluation of the range of grain size using Split Desktop

Figure C.25 - Photograph of sampling location TP-P2-S16-S3

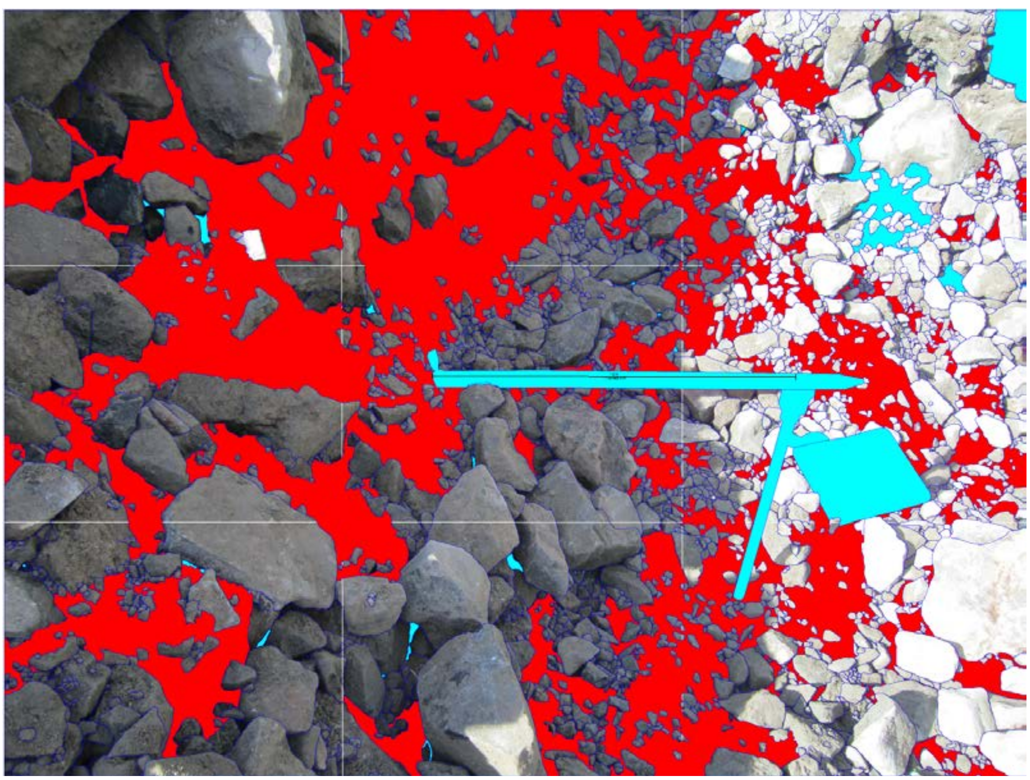


Figure C.26 - Sampling location TP-P2-S16-S3 with delineations from Split Desktop analysis

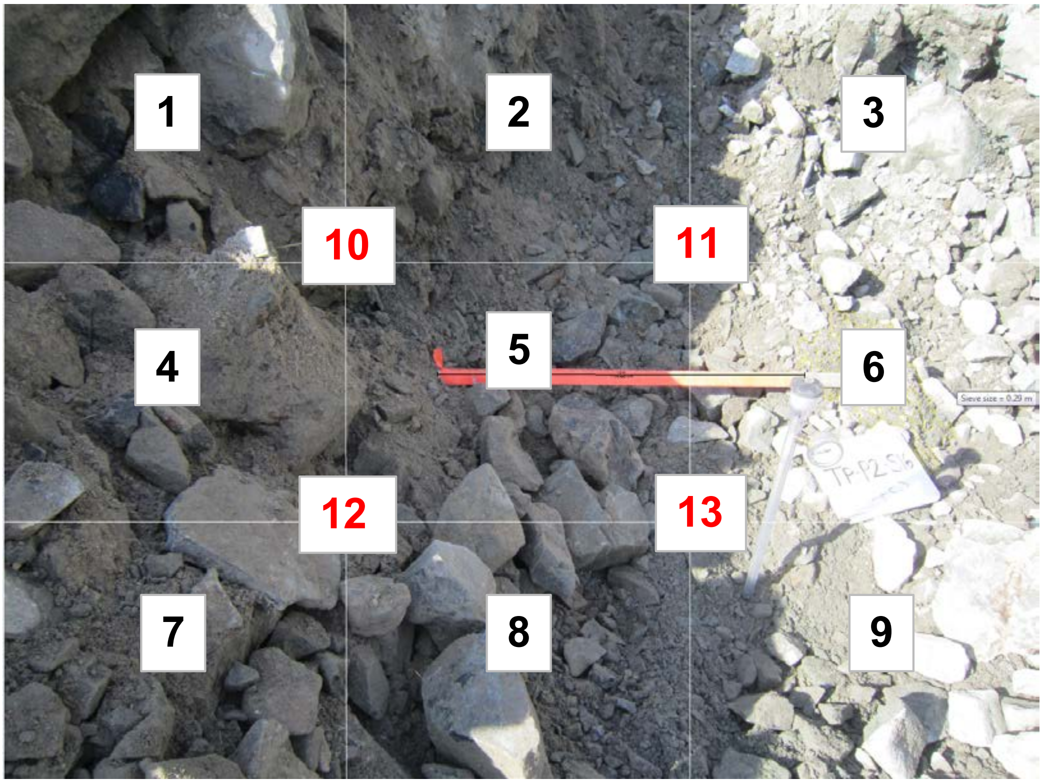


Figure C.27 - Sampling location TP-P2-S10-S3 with section numbers for the evaluation of the range of grain size using Split Desktop

Figure C.28 - Photograph of sampling location WRS-2-12

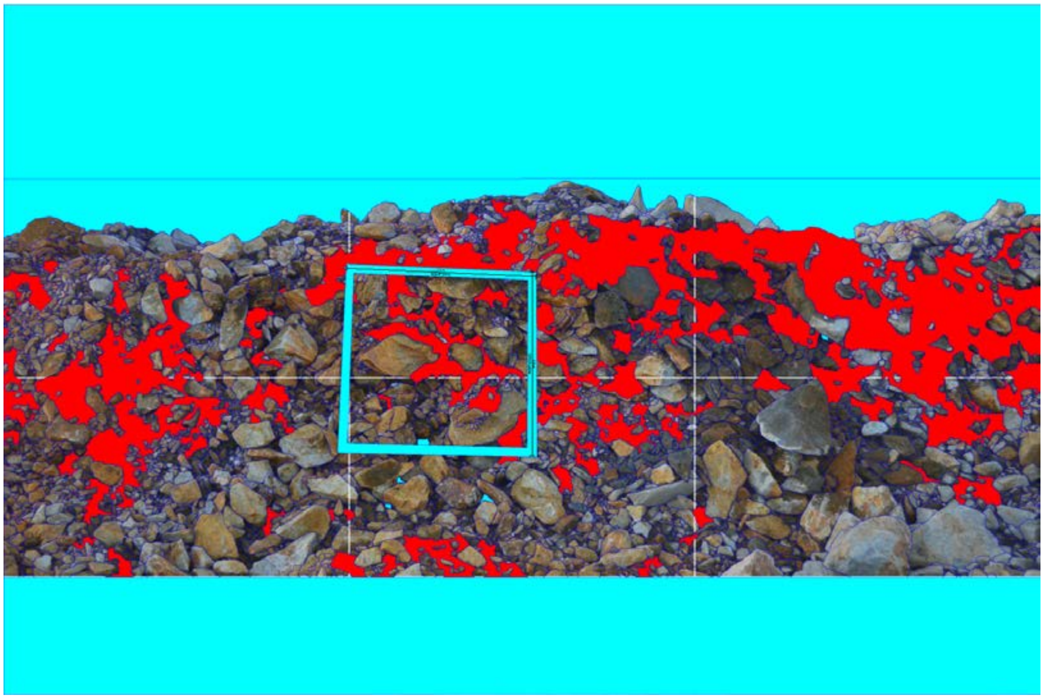


Figure C.29 - Sampling location WRS-2-12 with delineations from Split Desktop analysis

Figure C.30 - Sampling location WRS-2-12 with section numbers for the evaluation of the range of grain size using Split Desktop

The composite curve was determined utilizing both data from the DIP results (green) and the laboratory analysis (blue). The charts on the previous page provide an example of data from one analysis. The composite curve is determined through the following steps which are labelled on the charts below.

1. Material greater than 101.6 mm utilizes the data strictly from the DIP analysis as the laboratory analysis does not measure this material. These data are utilized for the upper portion of the curve, and no modification is made to the data.

2. To incorporate the measured laboratory data, a simulated total sample weight that would include the larger size particles must be determined. The simulated sample weight is given by:

$$Simulated\ Sample\ Weight = \frac{Dry\ Sample\ Wt\ (Lab)}{\%\ Passing\ 101.6\ mm\ Sieve/100}$$
$$= \frac{4.19}{\frac{60.27}{100}}$$
$$= 6.95\ kg$$

3. The Mass of Soil Retained (kg) from the laboratory analysis is provided, and is used to calculate a new Percent Retained (Dec.) for the measure grain size data, utilizing the Simulated Sample Weight (kg).

$$Percent\ Retained\ (Dec.) = \frac{Mass\ Retained\ on\ Sieve\ (kg)}{Simulated\ Sample\ Weight\ (kg)}$$
$$= \frac{1.66\ kg}{6.95\ kg}$$
$$= 0.2489$$

4. The new Percent Passing (%) is calculated utilizing the new Percent retained values for the Laboratory Measured data.

5. The composite curve is plotted with the combine data from Steps 1 and 4 (see following table).

Sample Calculation for Composite Grain Size Distribution Calculations

Digital Image Processing Results	
Grain Size (mm)	Percent Passing (%)
355.6	100
330.2	99.33
304.8	98.19
279.4	96.92
254	95.28
228.6	92.97
203.2	89.46
177.8	85
152.4	79.36
127	71.6
101.6	60.27
76.2	44.78
50.8	27.73
38.1	19.7
25.4	12.17
19.05	8.65
9.53	3.8
4.75	1.67
2	0.6
0.85	0.22
0.43	0.1
0.25	0.05
0.15	0.03
0.11	0.02
0.08	0.01

Laboratory Measured Results Dry Sample Wt. = 4.19 kg	
Grain Size (mm)	Percent Passing (%)
101.6	100.000
76.200	60.365
50.800	31.287
38.100	26.883
25.400	20.336
19.050	16.047
9.525	10.023
4.750	7.265
2.000	5.356
0.850	4.154
0.425	3.214
0.250	2.579
0.150	2.028
0.106	1.594
0.075	1.095
0	0

Composite Grain Size Curve Results Simulated Sample Weight = 6.95 kg [2]				
Grain Size (mm)	Mass of Soil Retained (kg)	Percent Retained (Dec.)	Percent Passing (Dec.)	Percent Passing (%)
355.6	0	0	1	100
330.2	0.0466	0.0067	0.9933	99.33
304.8	0.0793	0.0114	0.9819	98.19
279.4	0.0883	0.0127	0.9692	96.92
254	0.1141	0.0164	0.9528	95.28
228.6	0.1606	0.0231	0.9297	[1] 92.97
203.2	0.2441	0.0351	0.8946	89.46
177.8	0.3102	0.0446	0.85	85
152.4	0.3922	0.0564	0.7936	79.36
127	0.5397	0.0776	0.716	71.6
101.6	0.7879	0.1133	0.6027	60.27
76.200	1.6613	0.2389	0.3638	36.38
50.800	1.2188	0.1753	0.1886	18.86
38.100	0.1846	0.0265	0.1620	16.20
25.400	0.2744	0.0395	0.1226	12.26
19.050	0.1798	0.0259	0.0967	9.67
9.525	0.2525	0.0363	0.0604	6.04
4.750	0.1156	0.0166	0.0438	4.38
2.000	[3] 0.08	0.0115	0.0323	[4] 3.23
0.850	0.0504	0.0072	0.0250	2.50
0.425	0.0394	0.0057	0.0194	1.94
0.250	0.0266	0.0038	0.0155	1.55
0.150	0.0231	0.0033	0.0122	1.22
0.106	0.0182	0.0026	0.0096	0.96
0.075	0.0209	0.0030	0.0066	0.66
pan	0.0459	0.0066	0.0000	0.00