Hydrologic and Geochemical Characterization of Two Full – Scale Waste Rock Piles

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THE JOINT UNIVERSITY/INAP WASTE ROCK DUMP CHARACTERISATION PROJECT

Project Sponsors and Participants

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Project Background

- Two waste rock dumps excavated and placed in pits for permanent disposal.
- Two components to project:

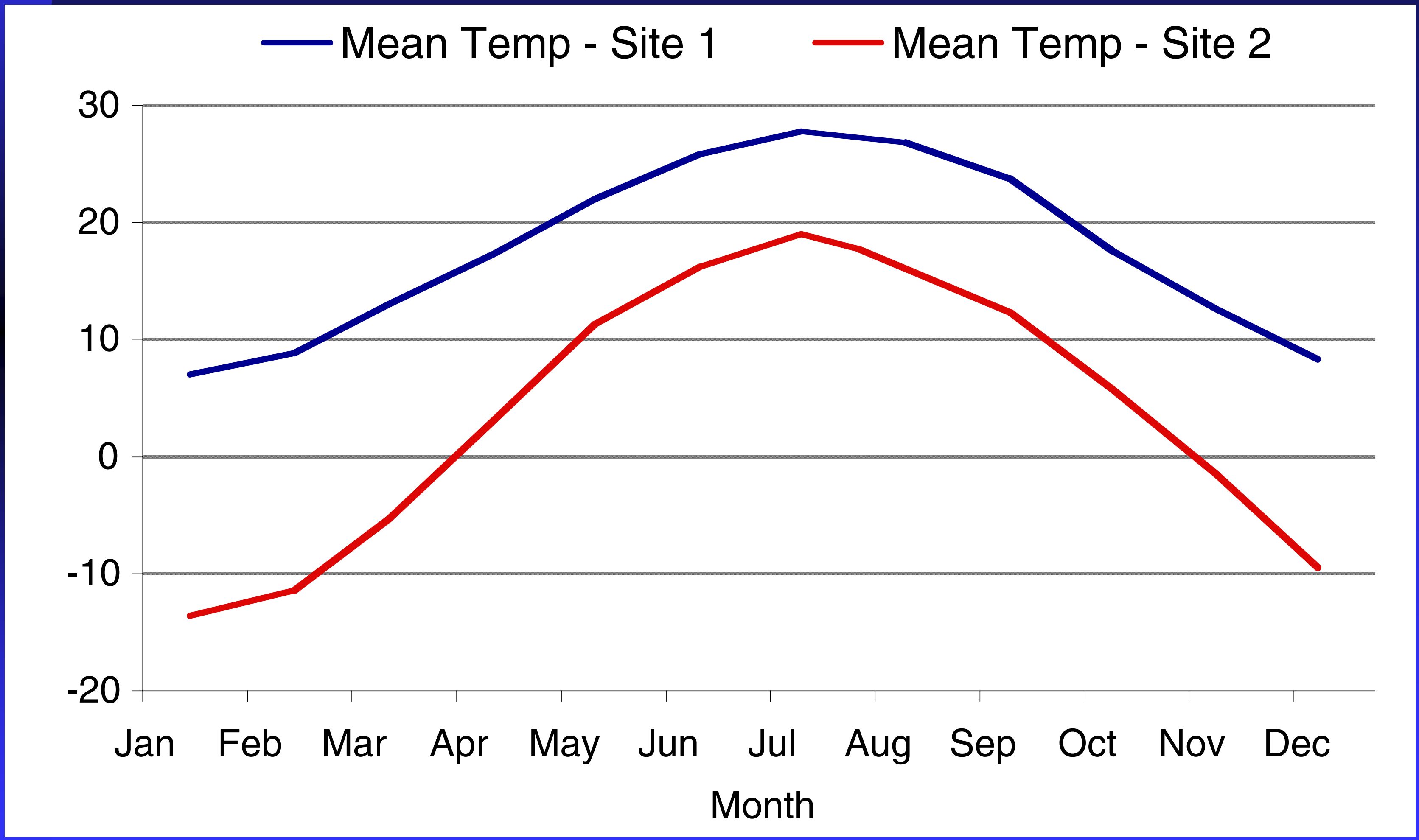
1. Physical and hydrological characterisation of waste rock dumps - Pamela Fines, UBC.
2. Geochemical and mineralogical characterisation of waste rock materials - Ai Binh Tran, EGi/ UQ.

Site Locations

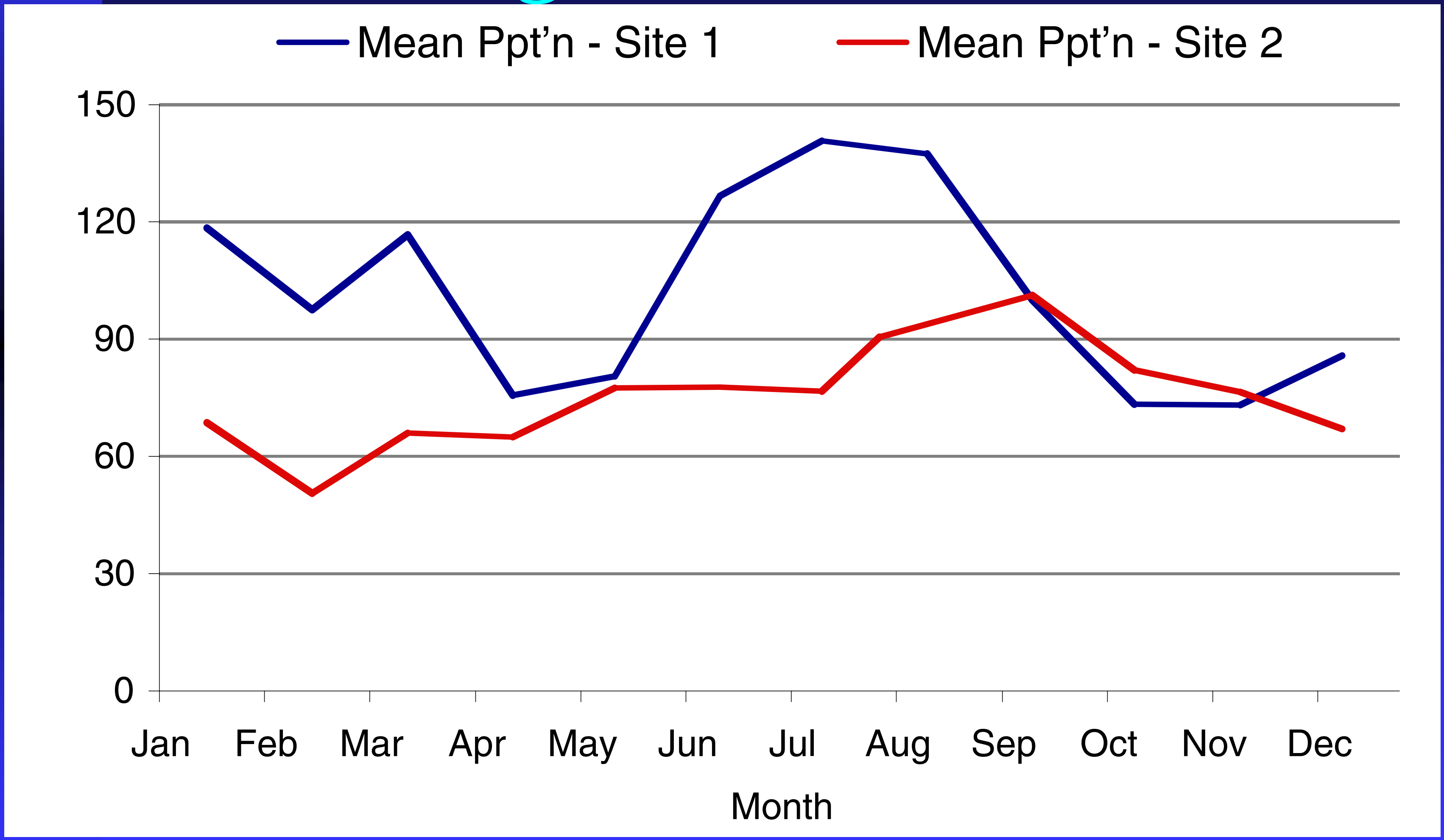
Site Background

- Site 1 ⇒ South Carolina, USA.
  - Warm, temperate climate.
  - Average rainfall 1200 mm/yr.
  - Average evaporation 1150 mm/yr.
- Site 2 ⇒ Sudbury, Canada.
  - Cold, continental climate.
  - Average precipitation 860 mm/yr.
  - Average evaporation 900 mm/yr.

Site Background



Site Background



Site Background

- Site 1:
  - Gold Mine with a 2 million tonne waste rock dump.
  - Pit lakes for permanent disposal of waste rock.
  - Geology:
    - Interbedded shales and siltstones. (i.e. Saprolite)
    - Seams of quartz and volcanic intrusions and metamorphic alteration.
- Site 2:
  - Nickel Mine with a 7.5 million tonne waste rock dump.
  - Cover system to be installed over relocated waste rock.
  - Geology:
    - located in the Sudbury geologic basin.
    - Composed of granite host rock and mineralized volcanic intrusions.
    - There is a thin mantle of surficial till over competent bedrock.

Field Program

Test Pit Sampling Program

- Each test pit was photographed and visually logged.
- Material samples collected for
  - Water content
  - Bulk property testing
  - Geochemical analysis
- In-situ testing was conducted to measure soil suction and density.

Bulk Property Testing

- Samples were obtained for:
  - Particle size distribution
  - Paste pH
- Specific representative samples were selected for measurement of the soil water characteristic curves and saturated hydraulic conductivity.
- Particle size distributions were also used to predict the SWCC and Ksat functions for all materials and subsequent comparison with laboratory data.

Site 1, Southern USA

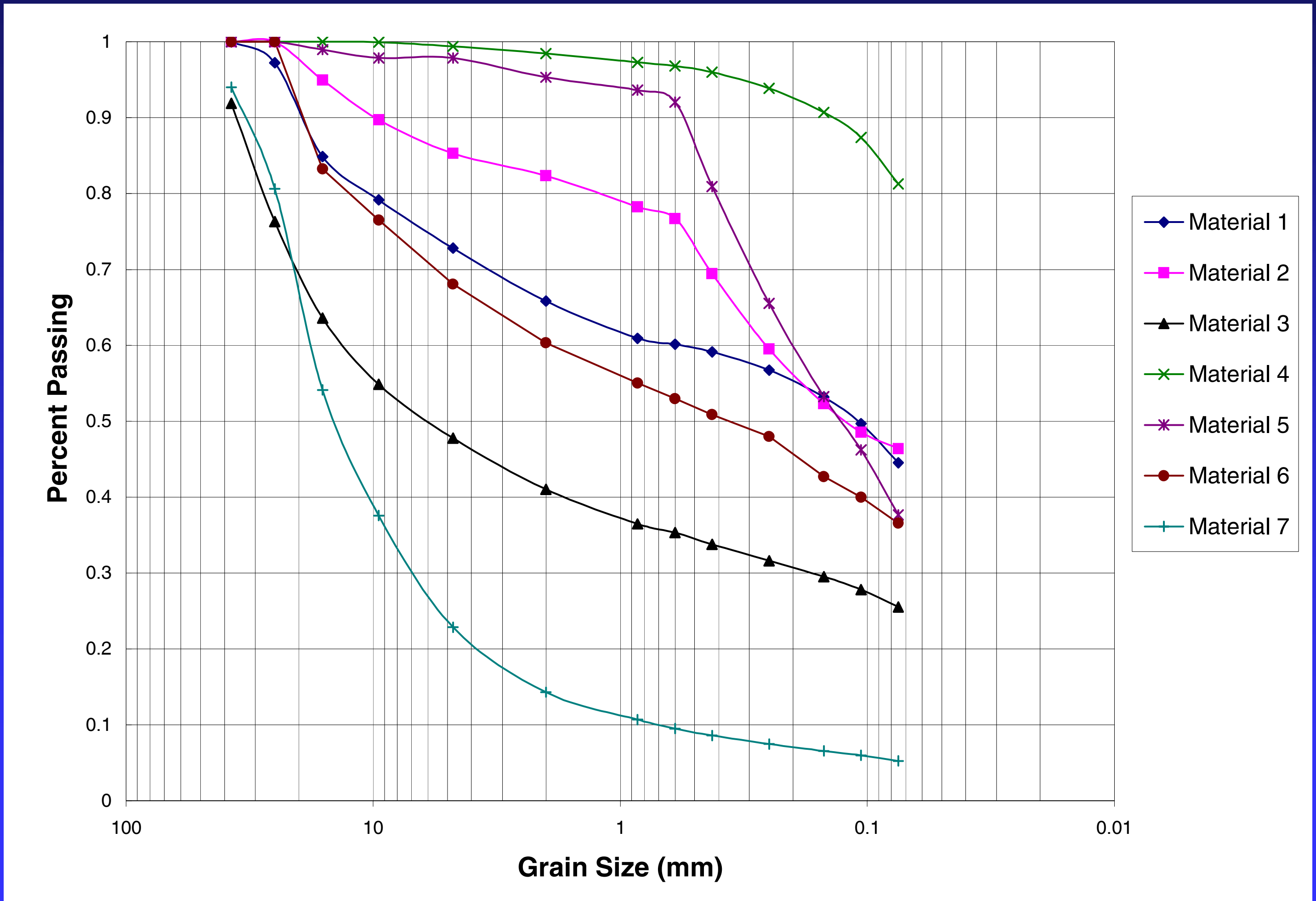
Field sampling Conducted between July and October 2000.

Site 1: Typical Materials

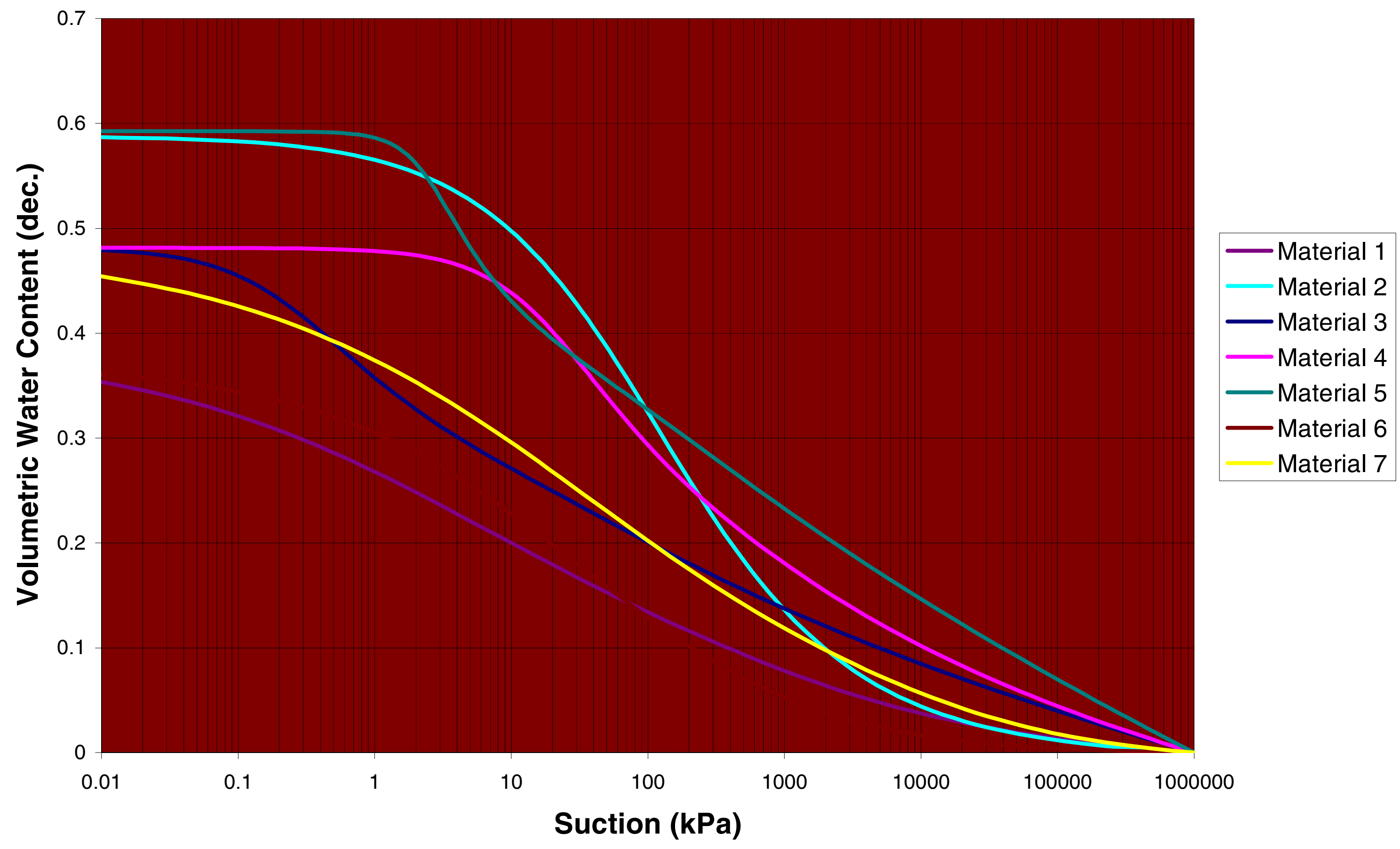
- Seven representative materials based on pH, grain size distribution, colour and texture.
- The materials in the dump were dense and highly compacted
- Material 1 and 4 represent the greatest weight fraction of material within the dump

Site 1: Typical Structure

Typical Grain Size Distributions



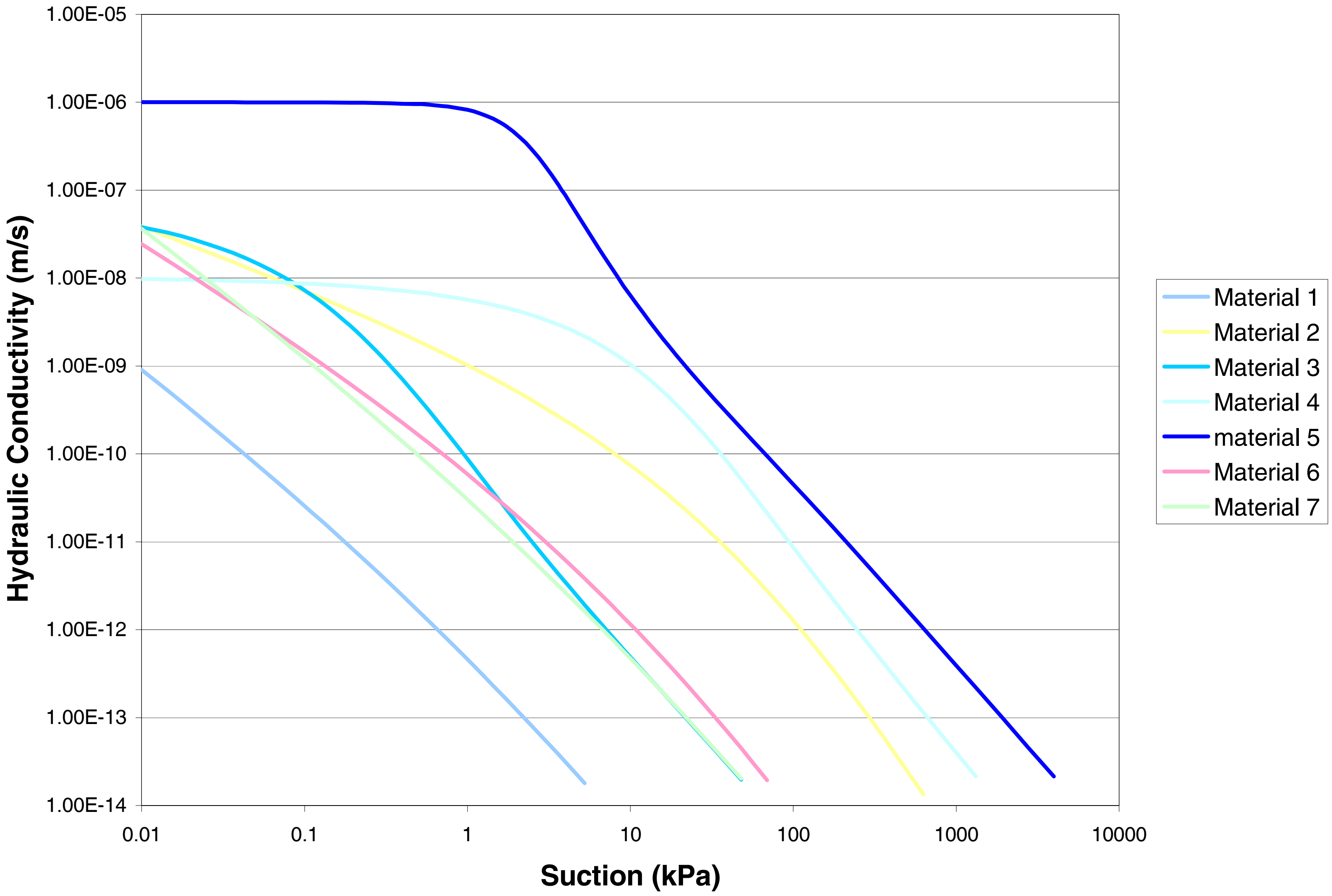
Soil Water Characteristic Curves



Saturated Hydraulic Conductivity

- Ksat values were evaluated by falling head testing in a permeameter
- Values were also back calculated from a consolidation test to estimate Ksat at higher stress levels similar to in situ conditions.
- Ksat values were typically 10^{-6} to 10^{-9} m/s

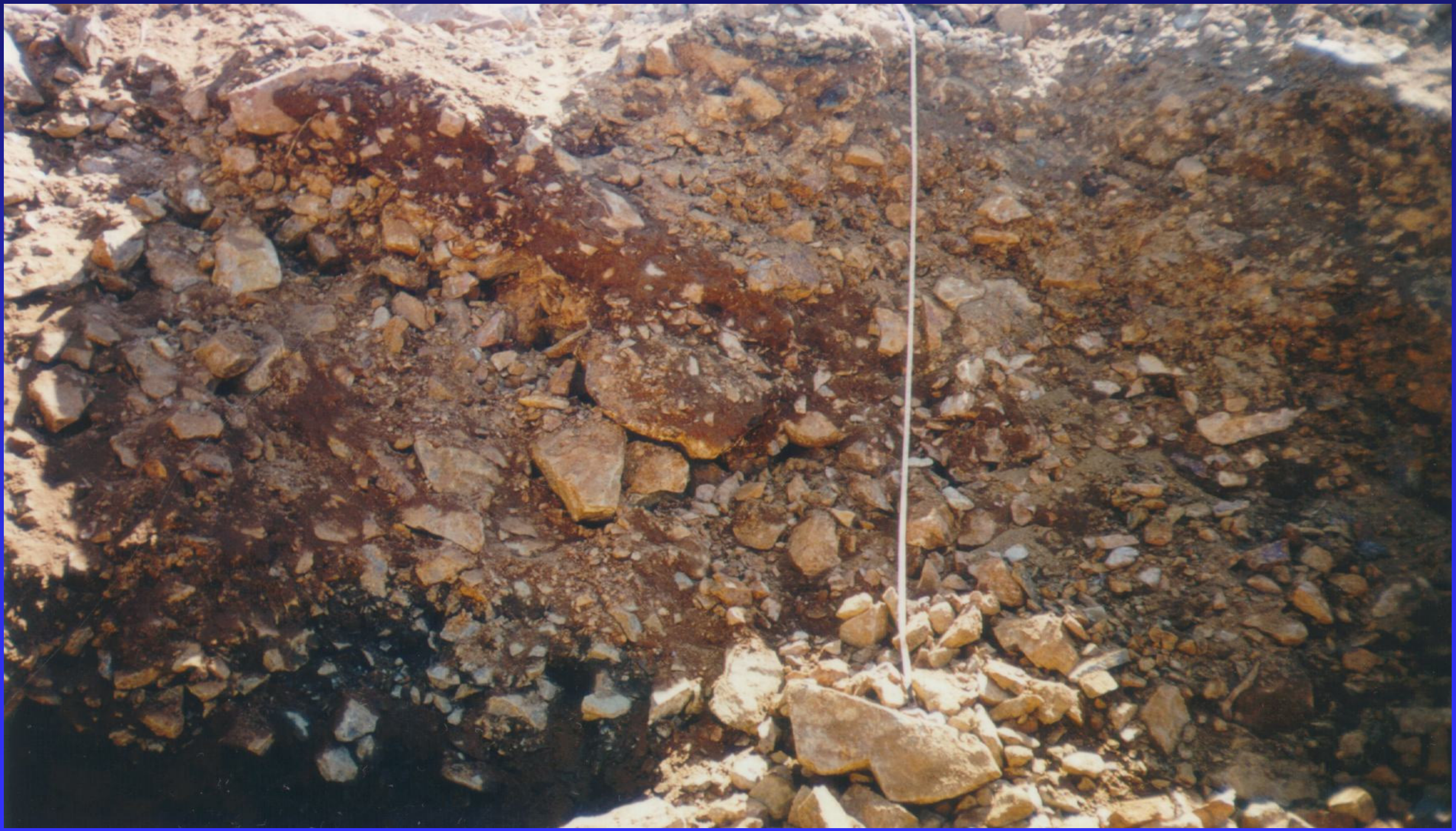
Hydraulic Conductivity



Site 2, Ontario Canada

Sampled between November, 2000 and September 2001

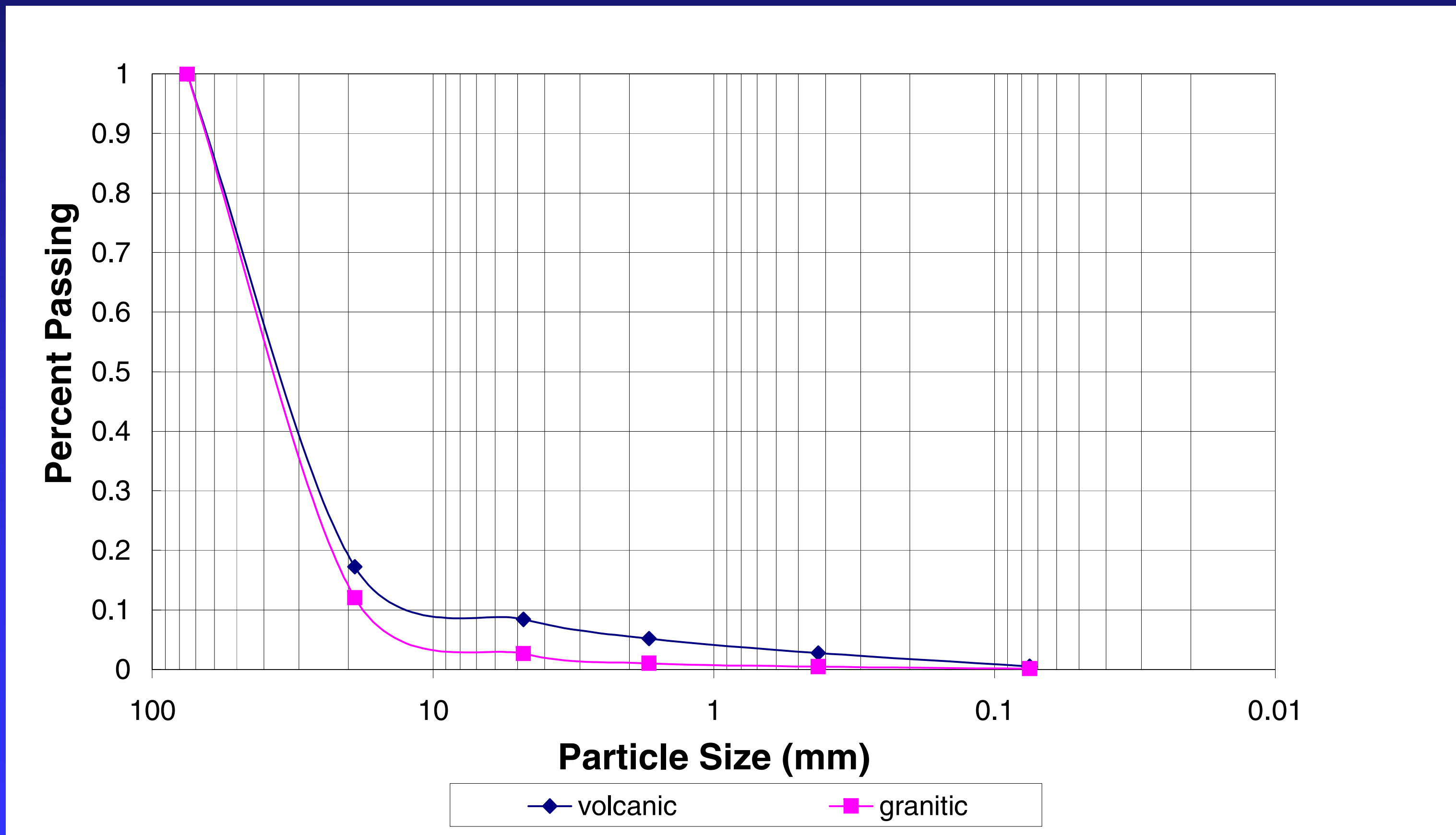
Site 2: Typical Structure



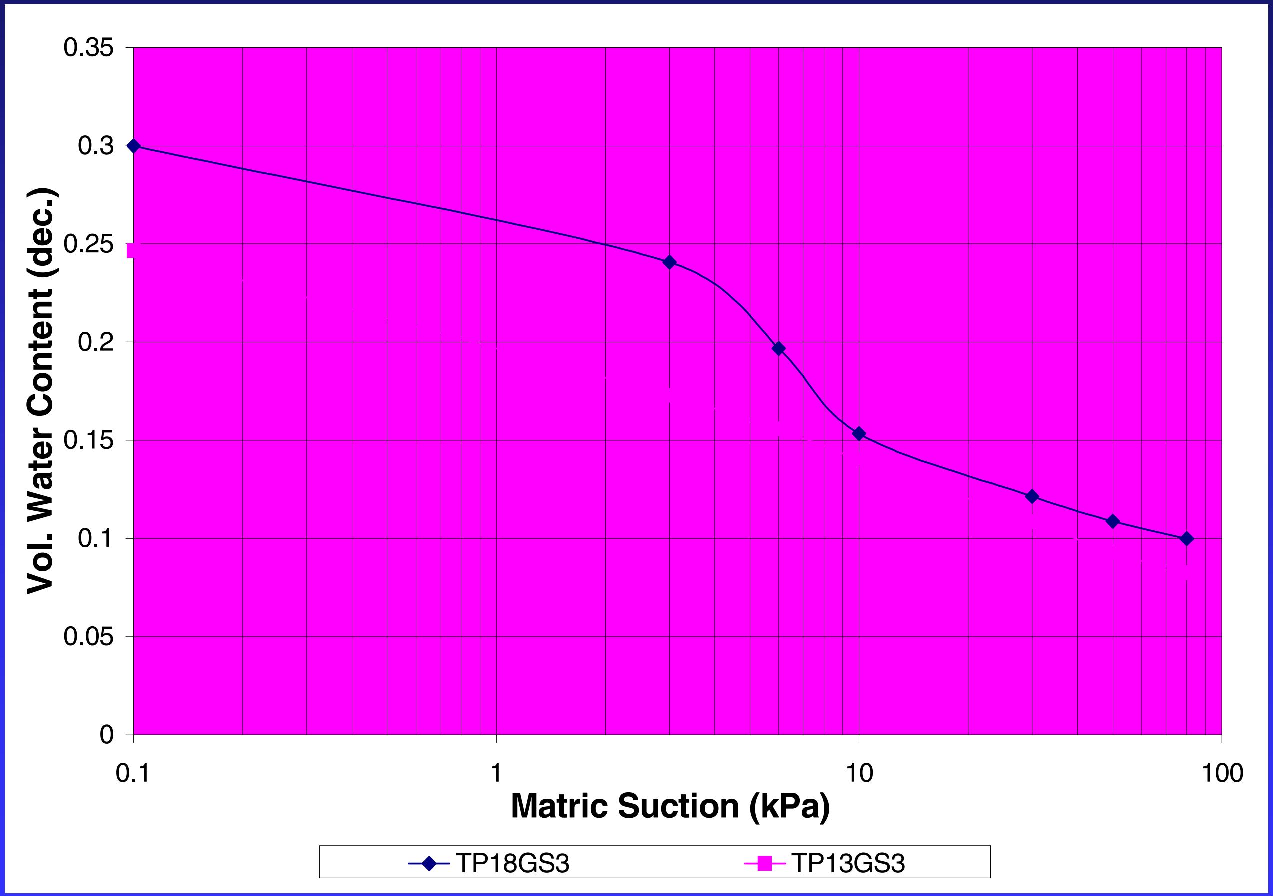
Field Observations

- The water content measured for each sample was typically less than 5%.
- In general, it appears that all layers encountered within the waste rock pile have a low water retention capacity.
- Preferential gravity dominated conduits allow infiltrating water to drain to the base of the pile.
- Field Observations suggest a partitioning of water
  - Water infiltrated and froze at the base of the dump
  - Toe seeps have pH less than 3 and contain high levels of sulfate and metals.

Typical Grain Size Distributions



Soil Water Characteristic Curves



Points to Note:

- Site 1
  - The geology is composed mainly of soft rock which has an average of 0.41% sulfur
  - The rock has weathered significantly over the past 10 years.
  - The bulk of the waste rock sampled in the dump could be considered fine grained with water contents greater than 15%.
- Site 2
  - Significant flushing is expected during the spring melt
  - The geology is mostly granitic, hard rock with about 2% sulfur
  - There has been little physical alteration of the rock since placement in the dump.
  - The bulk of the waste rock sampled in the dump is coarse grained with a water content of less than 5%.

Points to Note:

- Site 1
  - Structure and fine grained texture is controlling the migration of both water and oxygen within the dump.
- Site 2
  - The coarse grained nature of the materials results in an unrestricted supply of oxygen.
  - Fluid flow pathways are not well defined but are believed to occur within a very limited area of the waste rock cross section

Geochemical and Mineralogical Characterization

Mineralogy

Site 1 - Mineralogy	Site 2 - Mineralogy
Little identifiable sulphides	Pyrrhotite & chalcopyrite
Extensively reacted surfaces, reaction pitting	Some samples with extensively reacted surfaces
Gangue minerals predominantly clay, mica and quartz minerals	Gangue minerals predominantly clay, mica and quartz minerals

Mineralogy

Site 1 - Mineralogy	Site 2 - Mineralogy
Secondary Kaolinite in 5 of 6 samples analysed	Limonite/ goethite coatings on sulfides in 5 of 6 samples
Secondary jarosite detected in only 1 sample	Gypsum in 5 samples, jarosite in 1 sample
Iron hydroxides/ oxides detected in 1 sample	Iron hydroxide coatings on all samples (4 samples heavily coated)

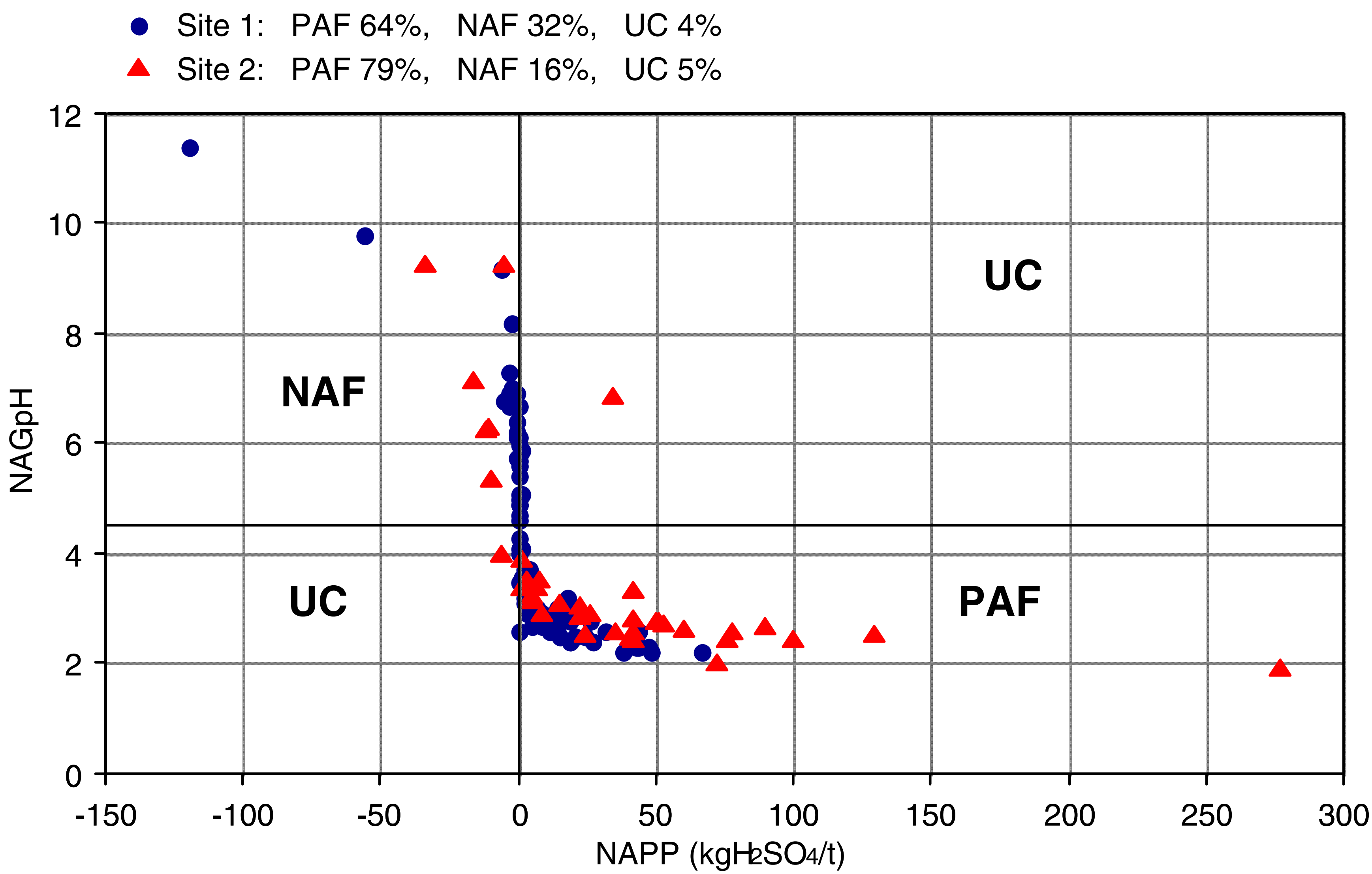
Geochemical Tests

- Testing Program (all samples):
  - $pH_{(1:5)}$ determination.
  - Acid -base analysis (total S & ANC).
  - Single addition net acid generation (NAG) testing.
- Testing Program (selected samples):
  - Acid buffering characteristic curves (ABCC).
  - Kinetic NAG tests.
  - Sequential NAG tests.
  - Multi-element scans on solids & water extracts.
  - Free draining leach column testing.
  - Surface chemistry and bulk mineralogical testing (EDTA & DW, SEM, XRD & Optical Microscopy)

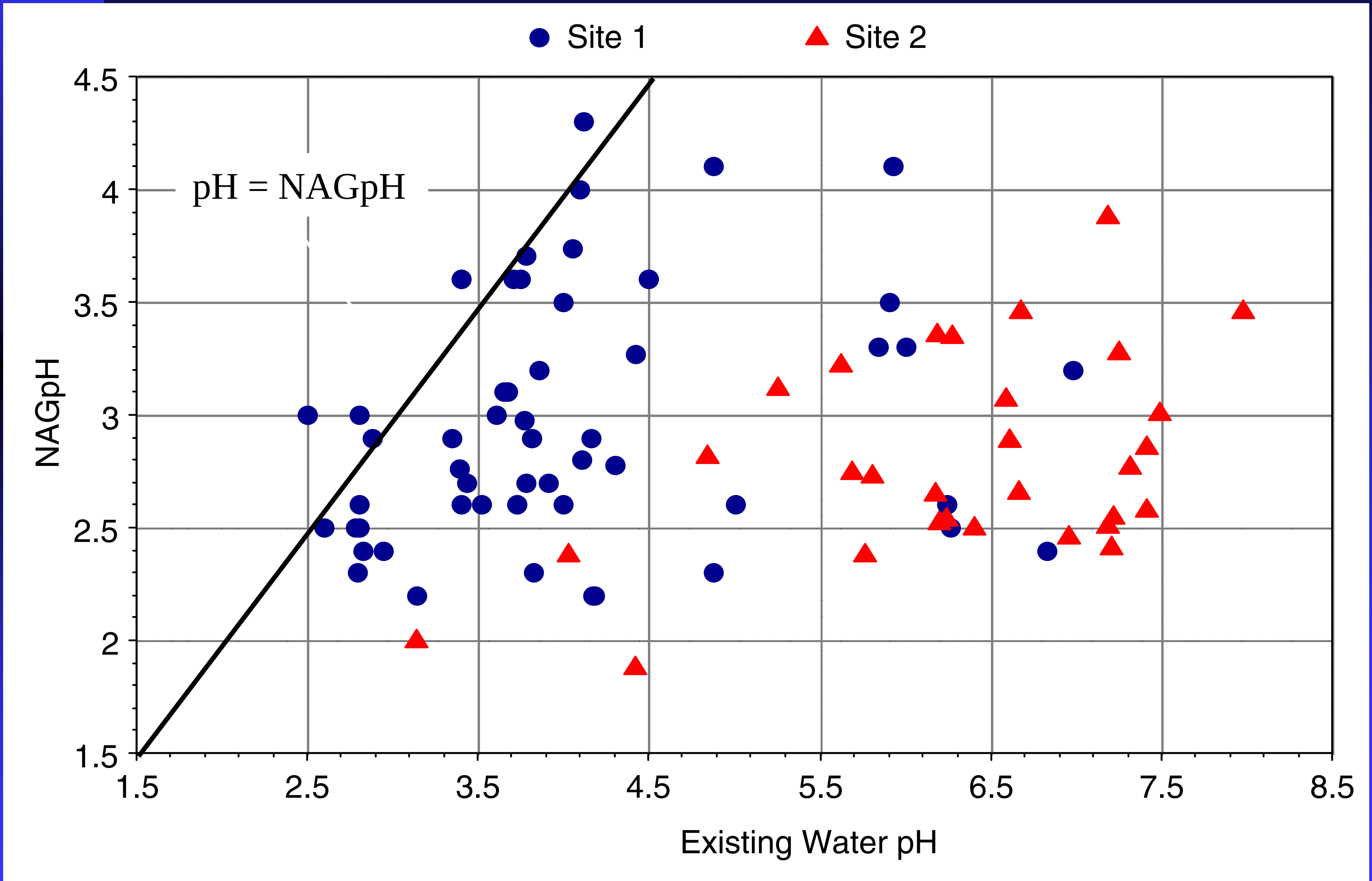
Summary of Geochemical Results

Parameters	Site 1 (90 Samples)	Site 2 (38 Samples)
Existing pH	48 samples had pH<4.5	3 samples had pH<4.5
Average Total S	0.4%	2%
Average ANC	3 kgH_2SO_4/t	20 kgH_2SO_4/t
Average NAPP	9 kgH_2SO_4/t	44 kgH_2SO_4/t
Elements enriched in solids	As, Mo & Se	Ag, Cu, Ni, S, & Sc
Elements enriched in water extracts	Al, Co, Mn & Ni	Al, Co, Cu, Fe, Ni, Sr, &Zn

Geochemical Classification



Comparison of pH & NAGpH



EDTA & DW Extracts

- Surface chemistry type test, ∴ only samples with high specific surface used in test, i.e. fine particles.
- Deionised water (DW) extraction needed.
- Because EDTA transfers both water soluble cations and those cations that are bound to the surface of particles and would not normally be leached if flushed in the environment.

EDTA & DW Extracts

Total EDTA Cations =

Includes water soluble and EDTA extracted cations

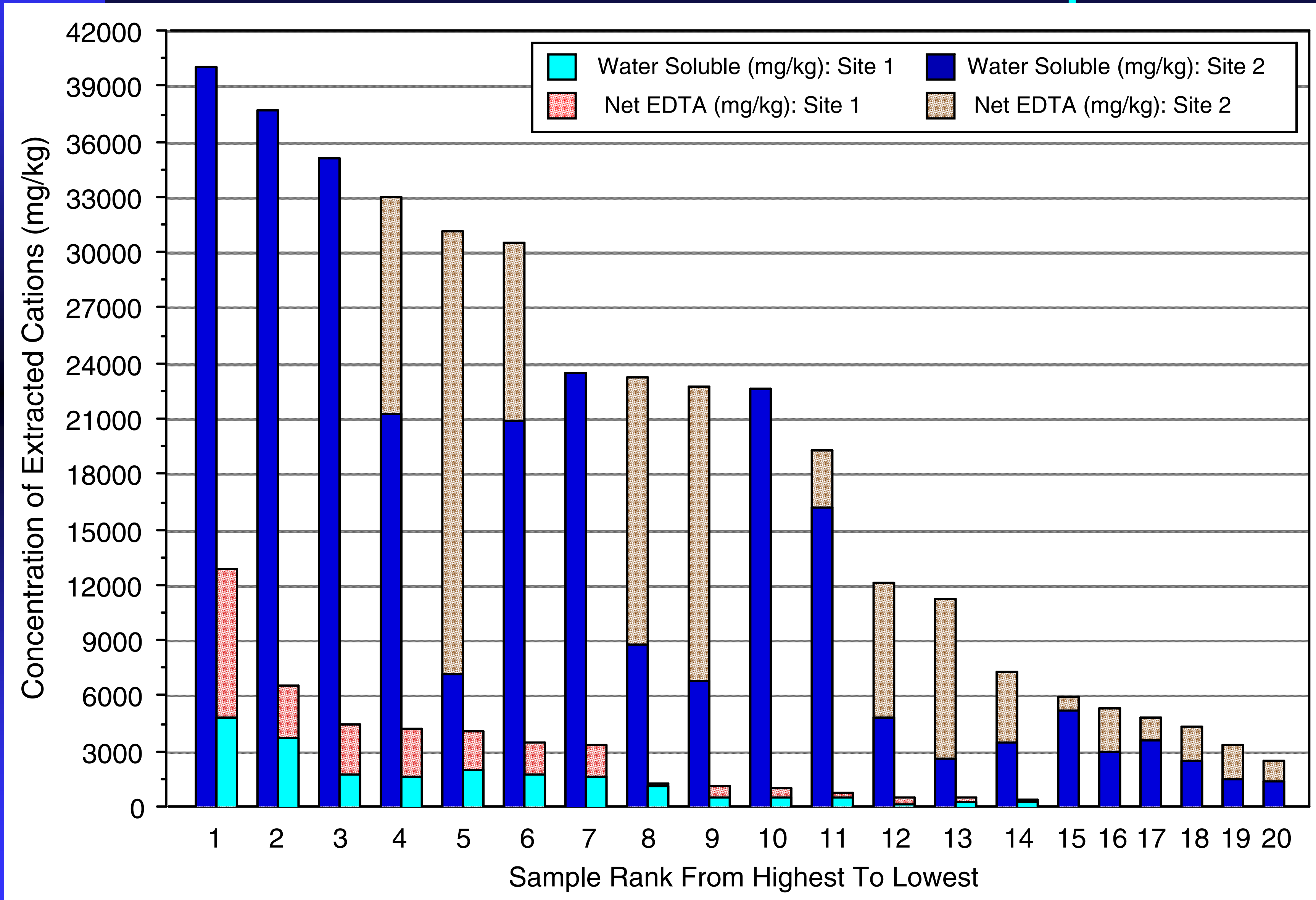
Net EDTA Cations =

Total EDTA - Water Soluble

Percentage of Water Soluble Cations =

$$\frac{\text{Water Soluble}}{\text{Total EDTA}} \times 100\%$$

EDTA Cations - Site Comparison

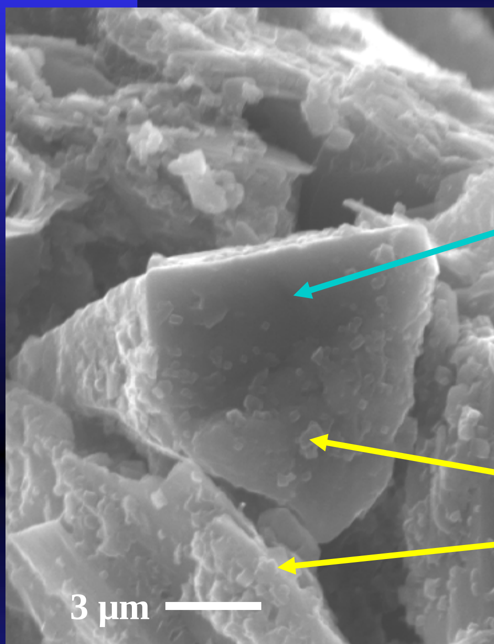


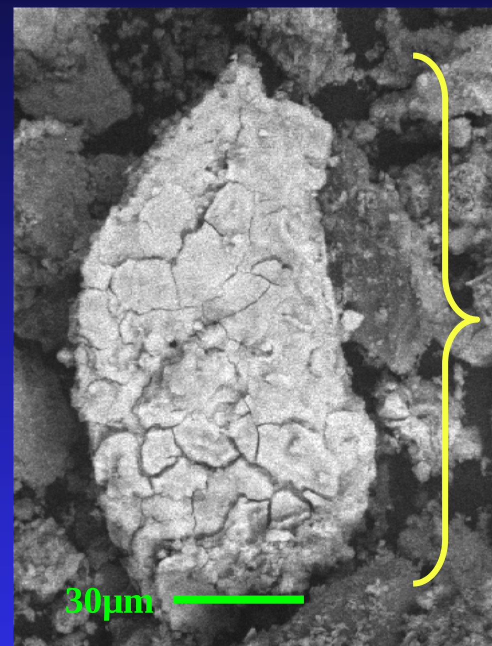
EDTA & DW Extracts

- Majority of oxidation products at Site 1 are not water soluble - **suggests that waste rock is more readily flushed.**

- Majority of oxidation products at the Site 2 are water soluble - **suggests that flushing at the site may have been limited.**

SEM Test Results





Site 1 - TP23GS5x

Some armouring of particles evident.

Site 2 - TP12GS2

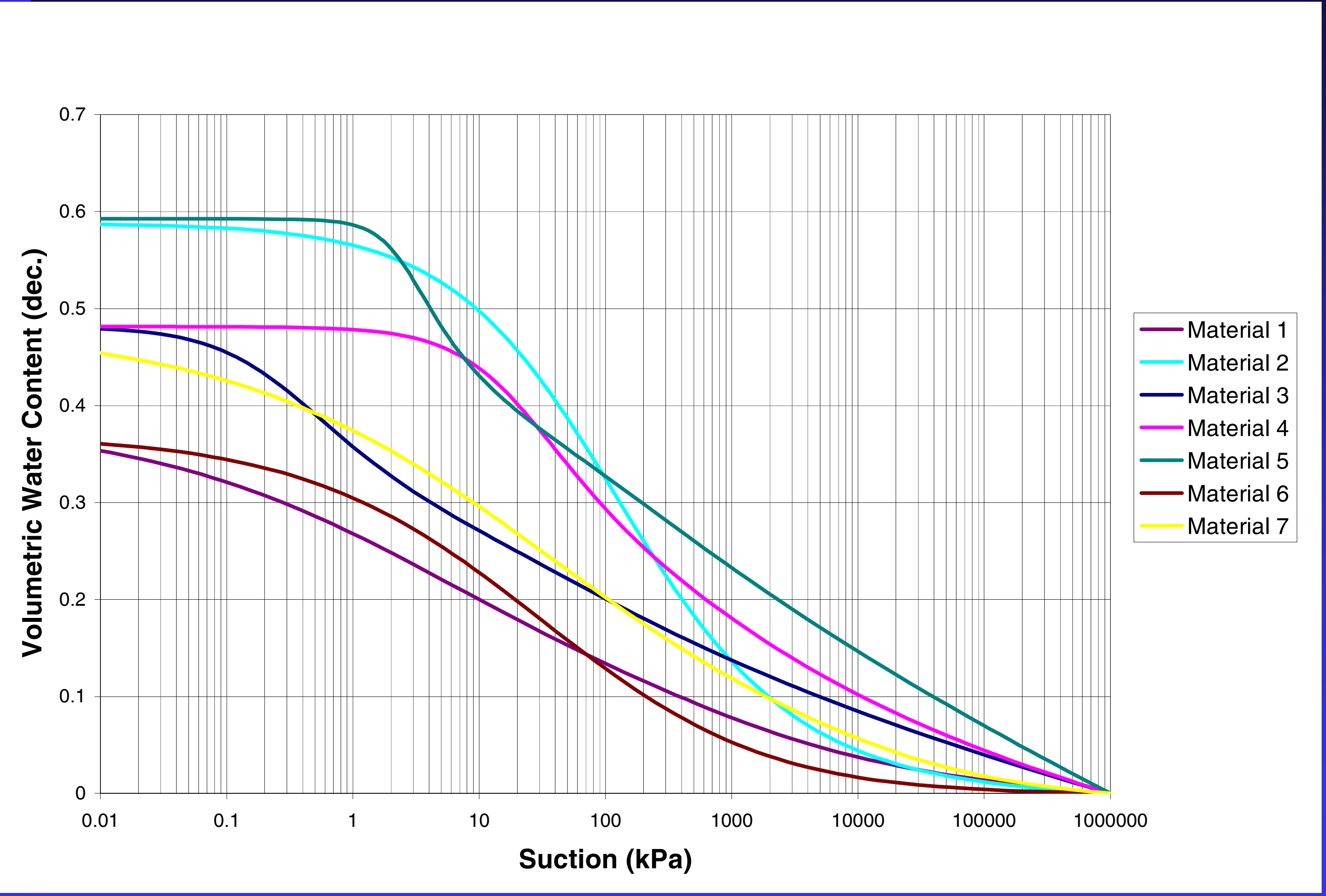
Large degree of armouring. Multiple layers of coatings in some samples.

Geochemical and Physical Interactions

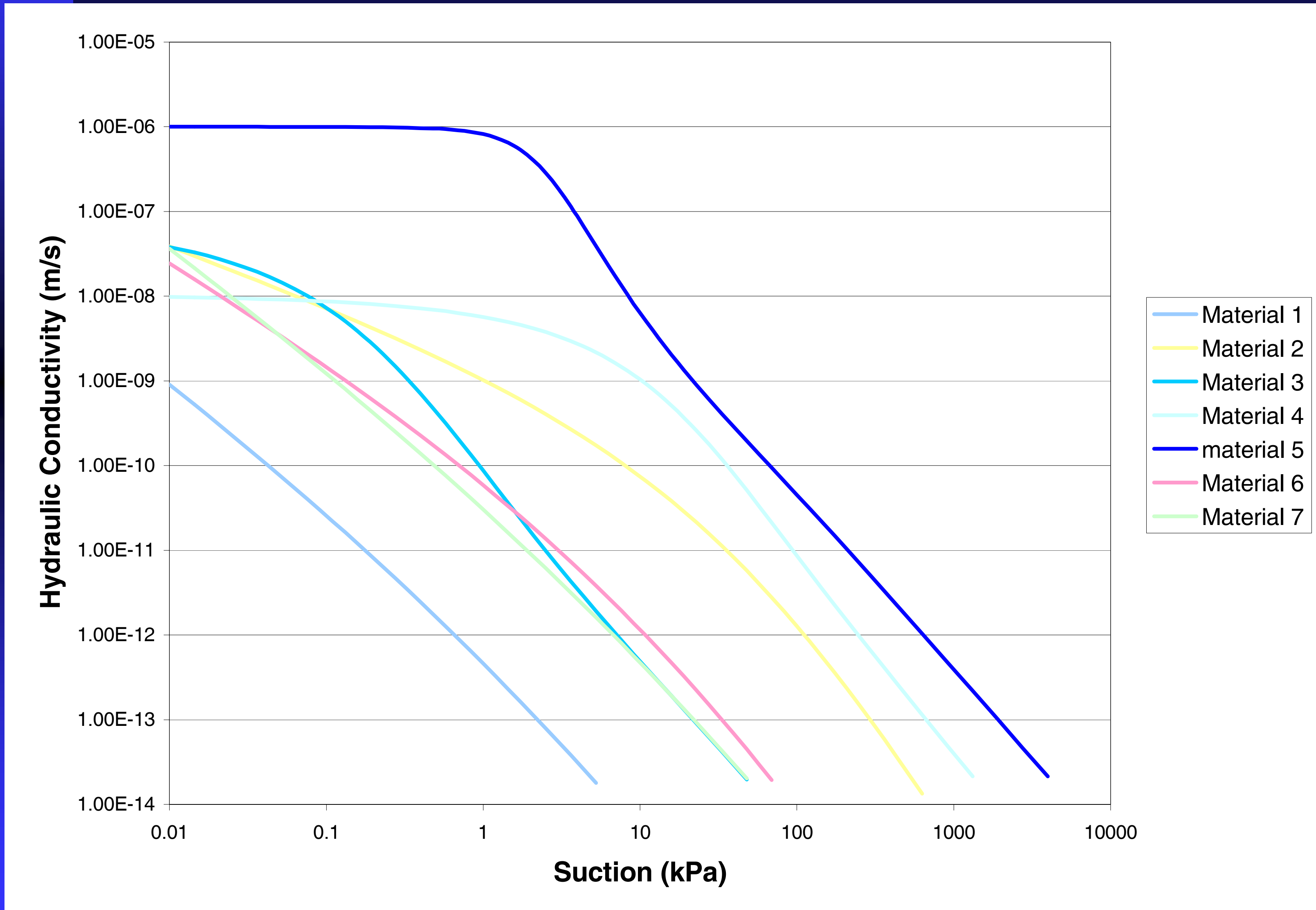
Numerical Simulation – SEEP/W

- Three representative sections were developed based on the total percentage of materials sampled in the waste rock pile
- Layers were constructed at 40^{o} – to simulate the structure observed
- Infiltration rates of ranging from 50 mm/year to 1000 mm/year were analysed to determine the impact on the development of seepage pathways

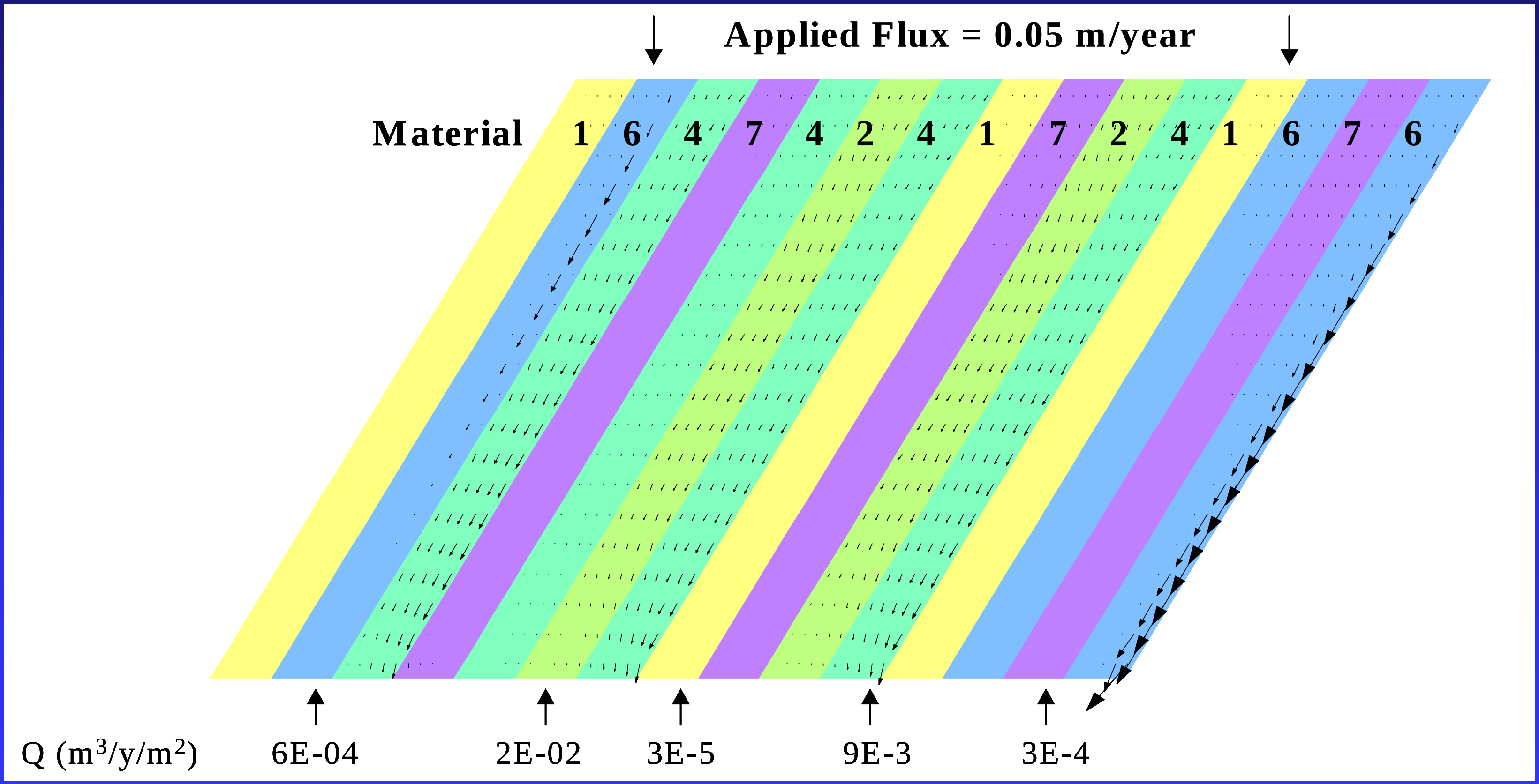
Soil Water Characteristic Curves

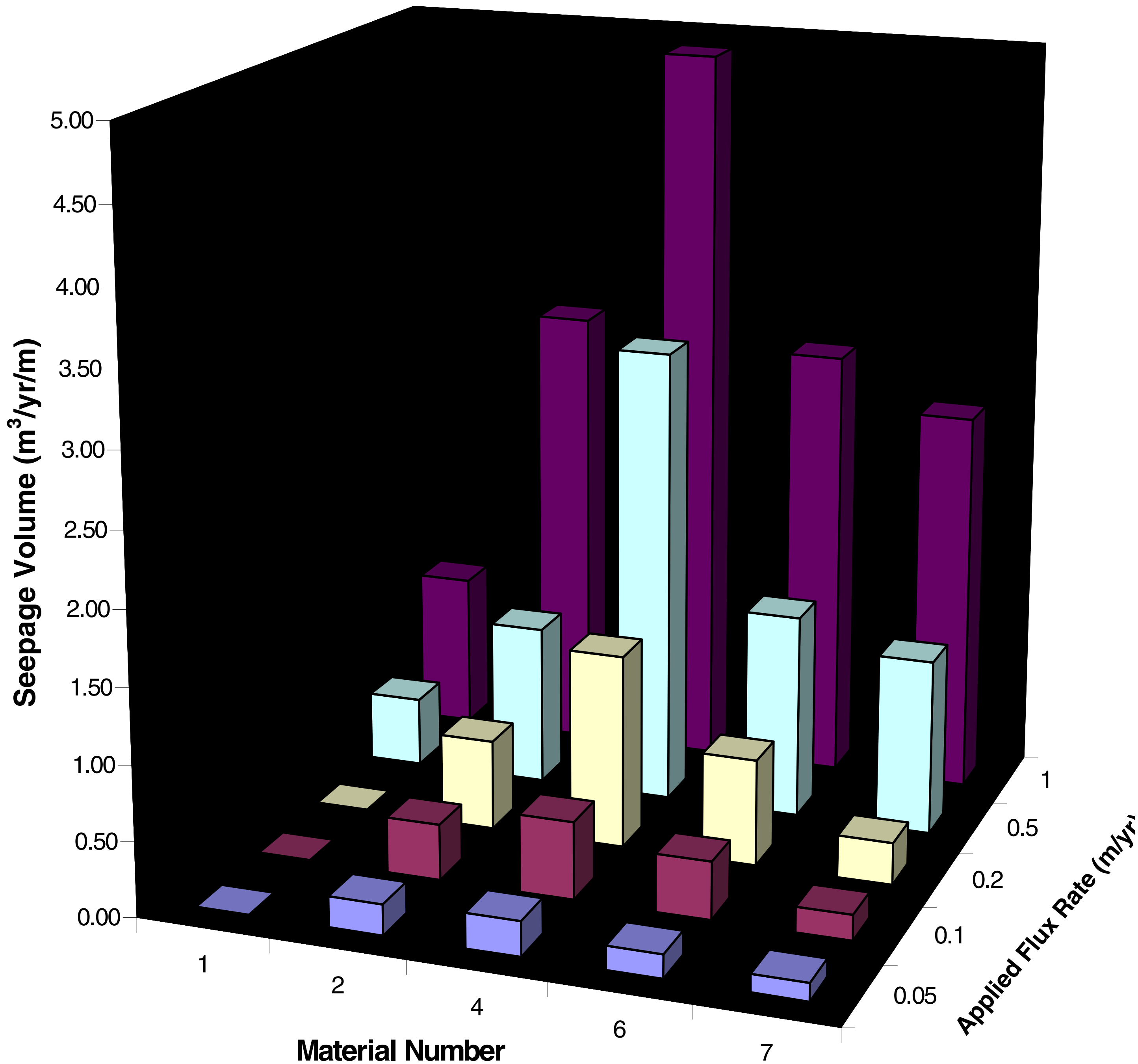


Hydraulic Conductivity



Seepage Section





Seepage Volume (m3/yr/m)
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1
2
4
6
7
Material Number
1
0.5
0.2
0.1
0.05
Applied Flux Rate (m/yr)

Seepage Modelling Results

- Silt rich layers become preferential pathways for flow.
- 80% of flow occurs through silt rich materials
- Only at highest infiltration rates (1000 mm/year) to coarse layers begin to transmit liquid water
- Clay layers have insufficient hydraulic conductivity to transmit large amounts of water and dissolved constituents

Particle Size - Site 1

Test pit 15 at Site 1

Dominance of clay to sand sized particles at this site

Particle Size - Site 2

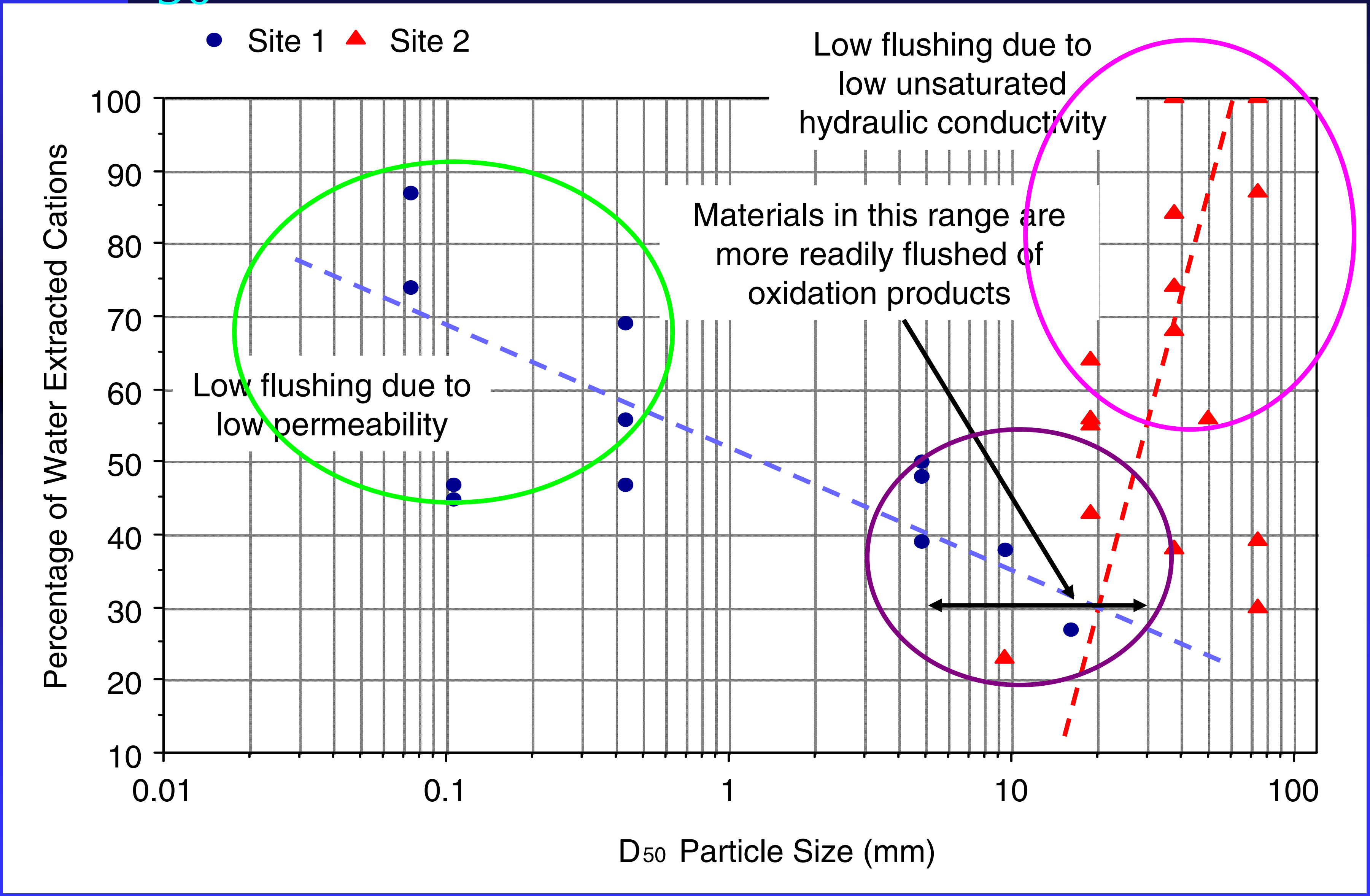
Dominance of cobble to boulder sized particles

Comparisons

- Geochemical/ mineralogical characteristics of the samples were not statistically influenced by the location of the samples from the edge of the dump or with depth.

- **HOWEVER, there was a trend when the D_{50} particle size was compared with the EDTA extractable cation concentrations.**

D_{50} size Vs Fraction Water Soluble



Conclusions

- Samples that had a $D_{50} < 1$ mm had a higher percentage of water soluble cations.
- Suggested that waste rock in this size range was not readily flushed.
- This could have possibly been due to the low saturated hydraulic conductivity of these materials.

Conclusions

- Samples that had a D_{50} > 30 mm also had a higher percentage of water soluble cations.
- Also suggested that these size ranges experienced limited flushing.
- This could have possibly been due to the unsaturated conditions within the dump and the low unsaturated hydraulic conductivity of the materials.

Conclusions

- Samples that had a D_{50} between 5 mm and 30 mm generally contained a lower percentage of water soluble cations.
- This suggested that materials in this size range were more readily flushed of oxidation products.

Conclusions

- The results suggest that waste rock dumps undergo preferential flushing/ storage of oxidation products; AND
- The dump internal structure strongly influences the geochemistry of the dump materials.

Questions?