Conceptual Overview of Mechanistic Scale-up in Waste Rock:
Lessons Learned from Diavik and Potential for Application to Other Mine Sites

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Scale-up

- Laboratory Data
  - Humidity cell leach rates
  - Acid base accounting
  - Mineralogy
  - Particle Size

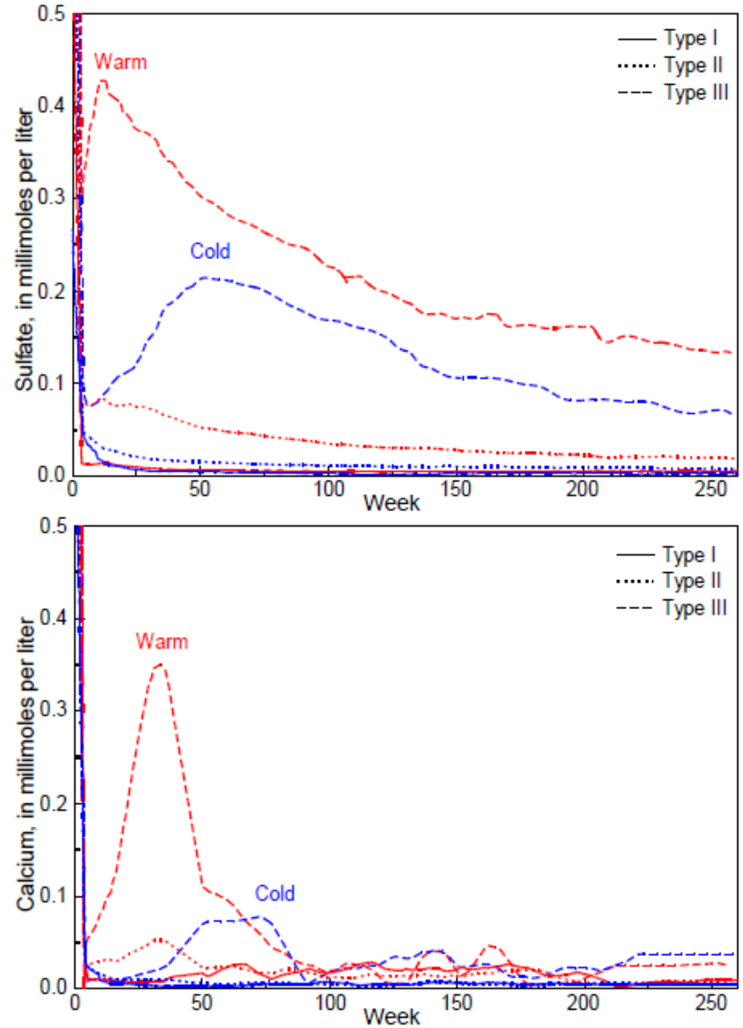
- Factors Affecting Leach Rates
  - pH
  - Moisture content
  - Particle size
  - Surface area
  - Temperature
  - Water–rock contact,
  - Oxygen concentration
  - Mineral content

General Scale-up Approach

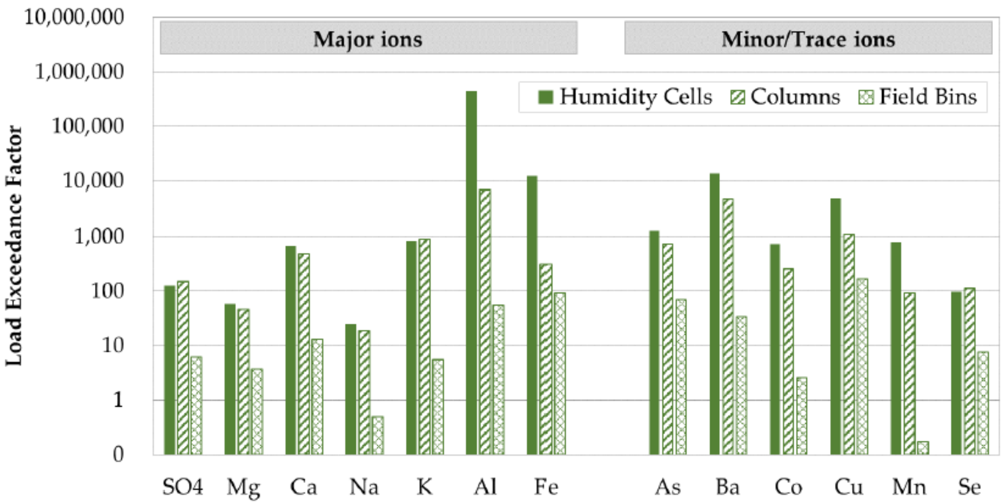
- Derive leach rates from humidity cell experiments
- Apply scaling factors
  - pH, moisture content, fragment size, temperature, water–rock contact, oxygen concentration, surface area, and mineral content
- Apply thermodynamic model to account for solubility constraints

Scale-up Complexity

- Temporal variability
  - Mineral weathering rate
  - Geochemical processes
  - Temperature
  - Moisture
- Variability by element



Langman et al., 2014. *Minerals*



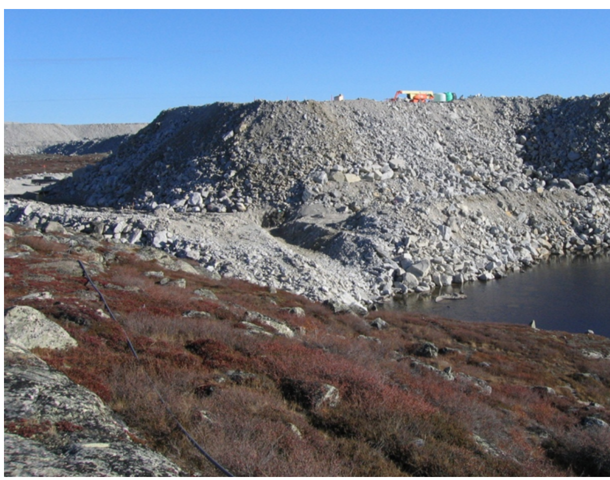
Kirchner and Mattson, 2015. *10th ICARD*

The Diavik Waste Rock Research Project

Humidity Cells and Static Tests

Active Zone Lysimeters

Test Piles



Diavik Waste Rock Characteristics

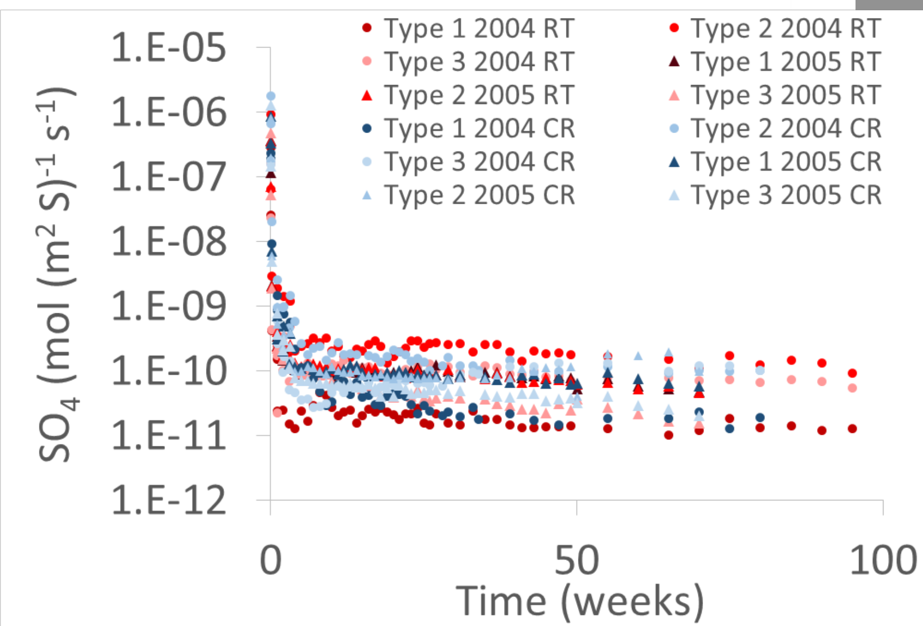
- Relatively homogeneous/ low sulphur
  - Granite with varying amounts of biotite schist
    - Type I: < 0.04 wt. % S
    - Type II: 0.04 – 0.08 wt. % S
    - Type III: >0.08 wt. % S
- Aerobic
  - O_2 = 21% throughout the pile – all the time
  - No reduction in oxidation rate due to lack of O_2
- Arid environment
  - mean annual precipitation 280 mm
  - 40% is rainfall
  - Water flow is primarily through fine-grained material
    - Limited macro-pore flow
- Permafrost
  - Field experiments freeze throughout in the winter

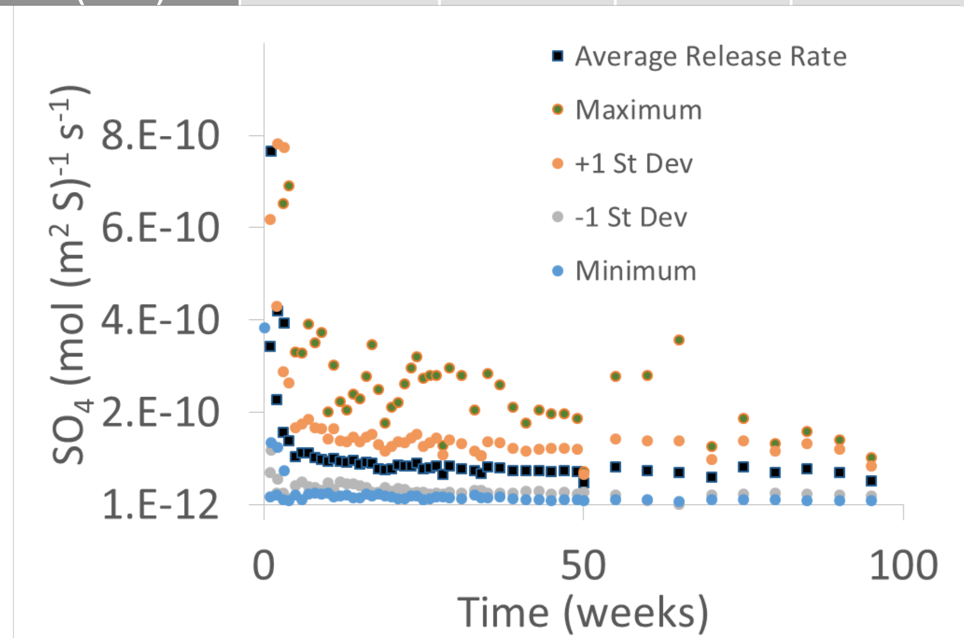
Humidity Cells – Intrinsic Sulfide Oxidation Rate

- 36 Humidity Cells
  - Type I, II and III
  - Cold room, room temperature
  - Samples of each collected in 2004 and 2005
  - Duplicates tests for all

- Rate dependent on:
  - Sulfide content
  - Surface area
  - Temperature

	Average	σ	min	max
mol (m^2 S)$^{-1}$ s^{-1}	8.8x10^{-11}	6.5x10^{-11}	6.5x10^{-12}	1.4x10^{-09}

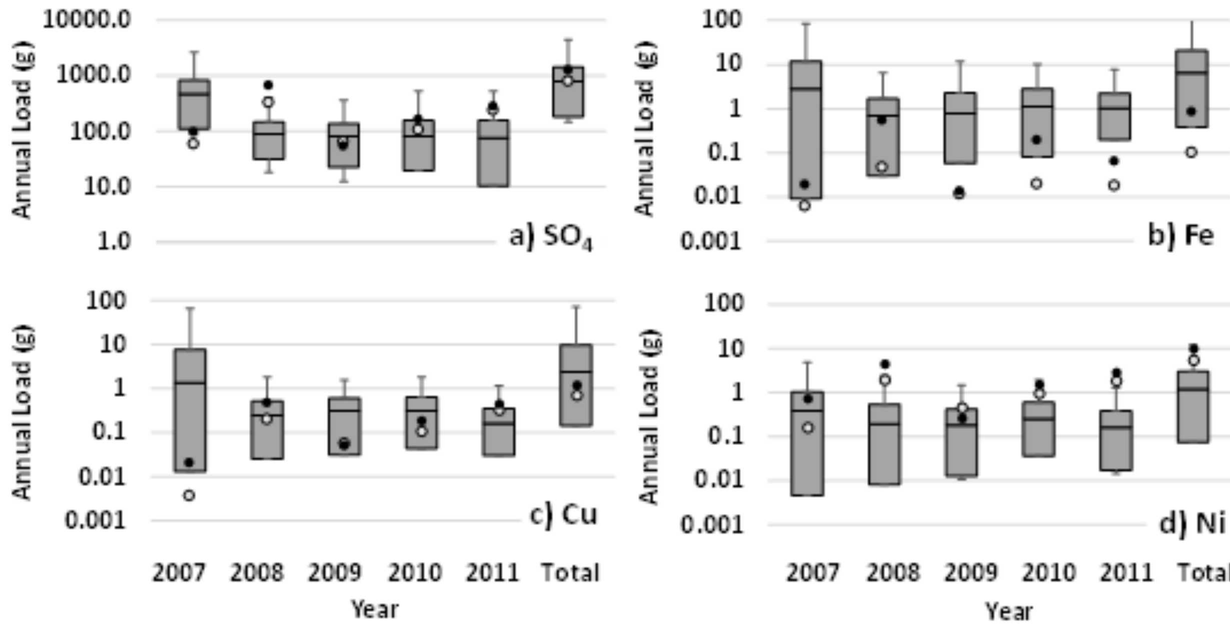




Bailey et al., *Submitted. Appl. Geochem.*

Scale to AZLs – Back of the Envelope Method

- Start with average humidity cell rate for each element
  - mol $(m^2\ S)^{-1}\ s^{-1}$
- Multiply by surface area of AZL experiments
- Multiply by sulfide content of AZL experiments
- Correct for temperature
  - AZL release rate in mol s^{-1} (i.e. mass per time)
- Calculate rate in mass per year – 22 weeks of weathering
- Assumptions/ Simplifications:
  - No oxidation in winter
  - No solubility controls
  - No oxygen depletion
  - All leachate flushed in year it is produced
  - Leach rate of all elements are a function of sulfide content



Bailey et al., *Submitted. Appl. Geochem.*

Particle Size

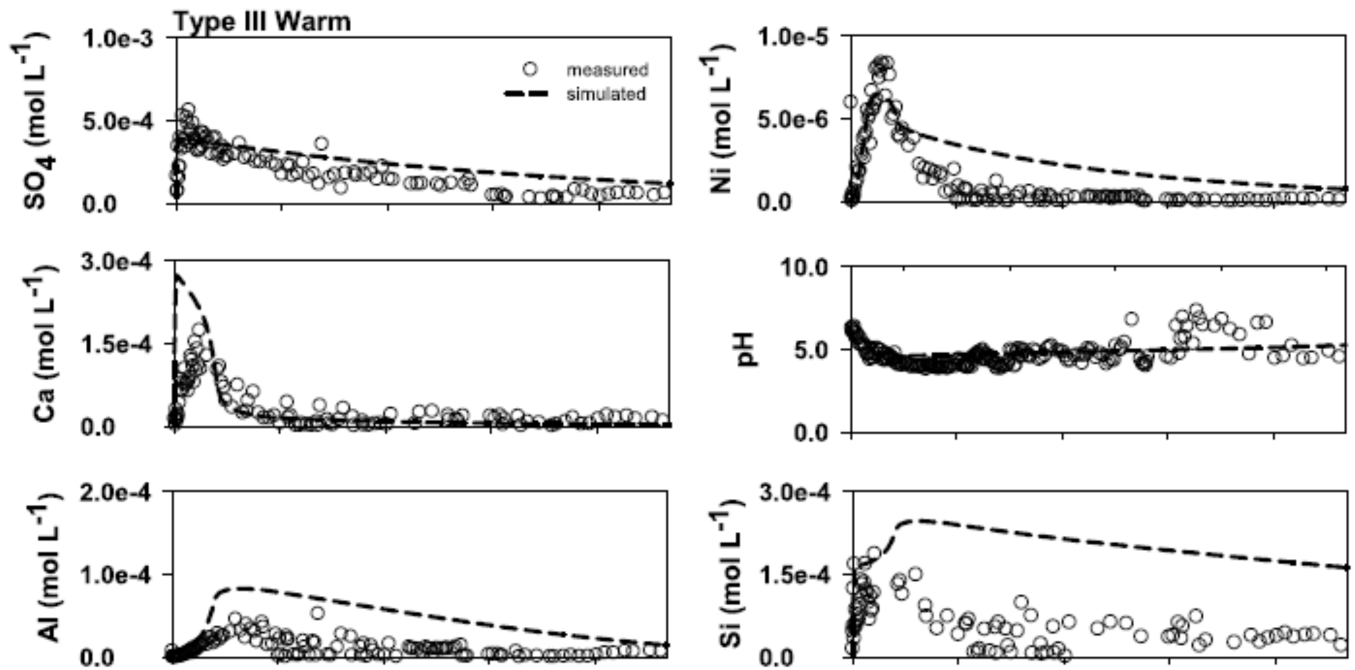
- Effects of particle size on scale-up
  - Reactive surface area
    - Based on geometric calculations, 98% of surface area is in <6.3 mm fraction
    - Fraction used in humidity cells
  - Water flow
    - Generally through fine material
    - Through coarse material in high flow periods

- The Diavik Research Project Approach
  - All oxidation occurs in <6.3 mm fraction
  - Water flow through fine fraction
    - 100% flushing of fine fraction
  - Humidity cells use blasted rock

Scale Surface Area to Field Scale:
AZL Surface Area = Humidity Cell Surface Area * Fraction of fines (<6.3mm) in AZLs

Humidity Cells – Reactive Transport Model

- Geochemical understanding
- Quantification of;
  - Sulfide weathering
  - Buffering reactions
  - Temperature dependence
  - Changes in rates over time

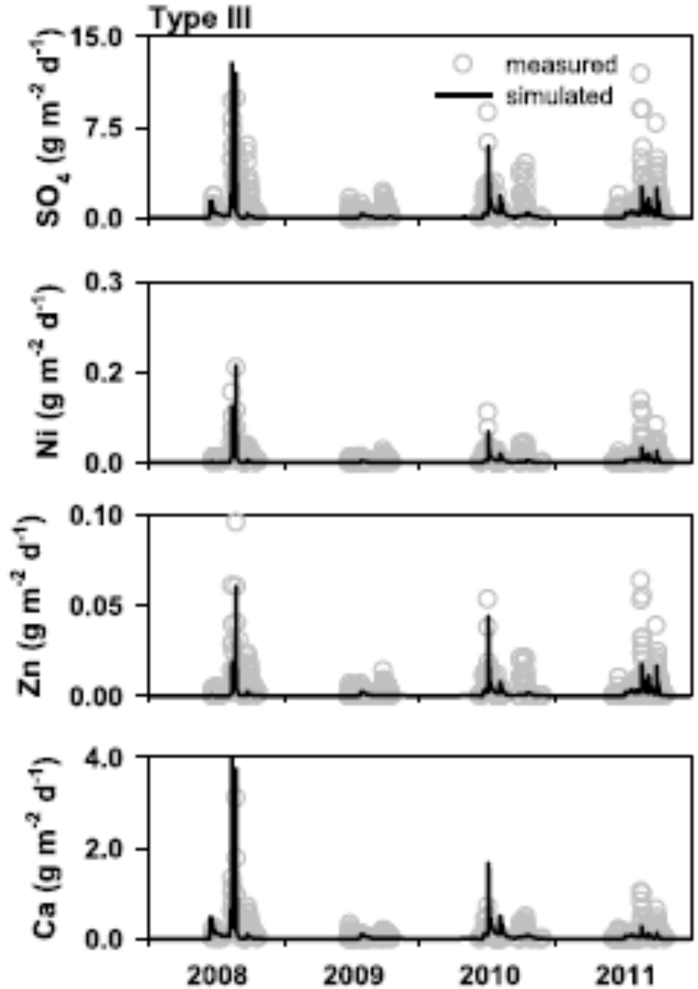


Wilson et al, 2018. *Appl. Geochem.*

Scale to AZLs – Reactive Transport Model

- Apply humidity cell simulations
  - Apply surface area and measured mineral content data
  - Compensate for temperature
  - Thermodynamic constraints on mineral solubility
  - No recalibration
- Apply estimate of field hydrology – precipitation and snow-melt
- Account for freeze/thaw dynamics

- Assumptions/Simplifications:
  - No oxidation in winter
  - ~~No solubility controls~~
  - No oxygen depletion
  - ~~All leachate flushed in year it is produced~~
  - ~~Leach rate of all elements are a function of sulfide content~~



Wilson et al, 2018. *Appl. Geochem.*

Characterization and Parameters

- Humidity Cells
  - Leach rates
  - Mineralogical characterization
    - C and S
    - Sulfides
    - Buffering minerals
  - Physical characteristics
    - Particle size
    - Surface area
  - Temperature dependence

- Field Scale
  - Mineralogical characterization
    - C and S
    - Sulfides
    - Buffering minerals
  - Physical characteristics
    - Particle size
    - Surface area
    - Porosity
    - Hydraulic Conductivity
  - Hydrology
    - Infiltration estimate

Additional Complexity

- O_2
  - Atmospheric at Diavik throughout pile
  - Coupling of transport processes and temperature
  - Can be incorporated into modelling if transport rates can be estimated
- Non-matrix flow
  - Dry conditions at Diavik minimize macro-pore flow
  - Batter flow
  - Can be estimated based on site hydrology but modeling more challenging
- Heterogeneity
  - Diavik relatively homogeneous
  - Simulations have been done to consider heterogeneity at field scale
  - Provide range of uncertainty associated with predictions
- Limited *a priori* information
  - E.g. Hydrology – infiltration estimates are good approximation
  - E.g. Particle size/surface area – analogous case studies/professional knowledge, refine models over time

Moving Forward

- Application of Diavik methodology and modelling to other sites

- Short Course:

  Scaling predictions of mine waste geochemistry with reactive transport modelling.

  GAC-MAC-IAH Conference | Quebec City, May 2019

Thank you!

Questions