Managing groundwater contaminants in the resource development industry

Global Water Institute: Water Conversations

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Canada's Capital University


Research Overview
Carleton
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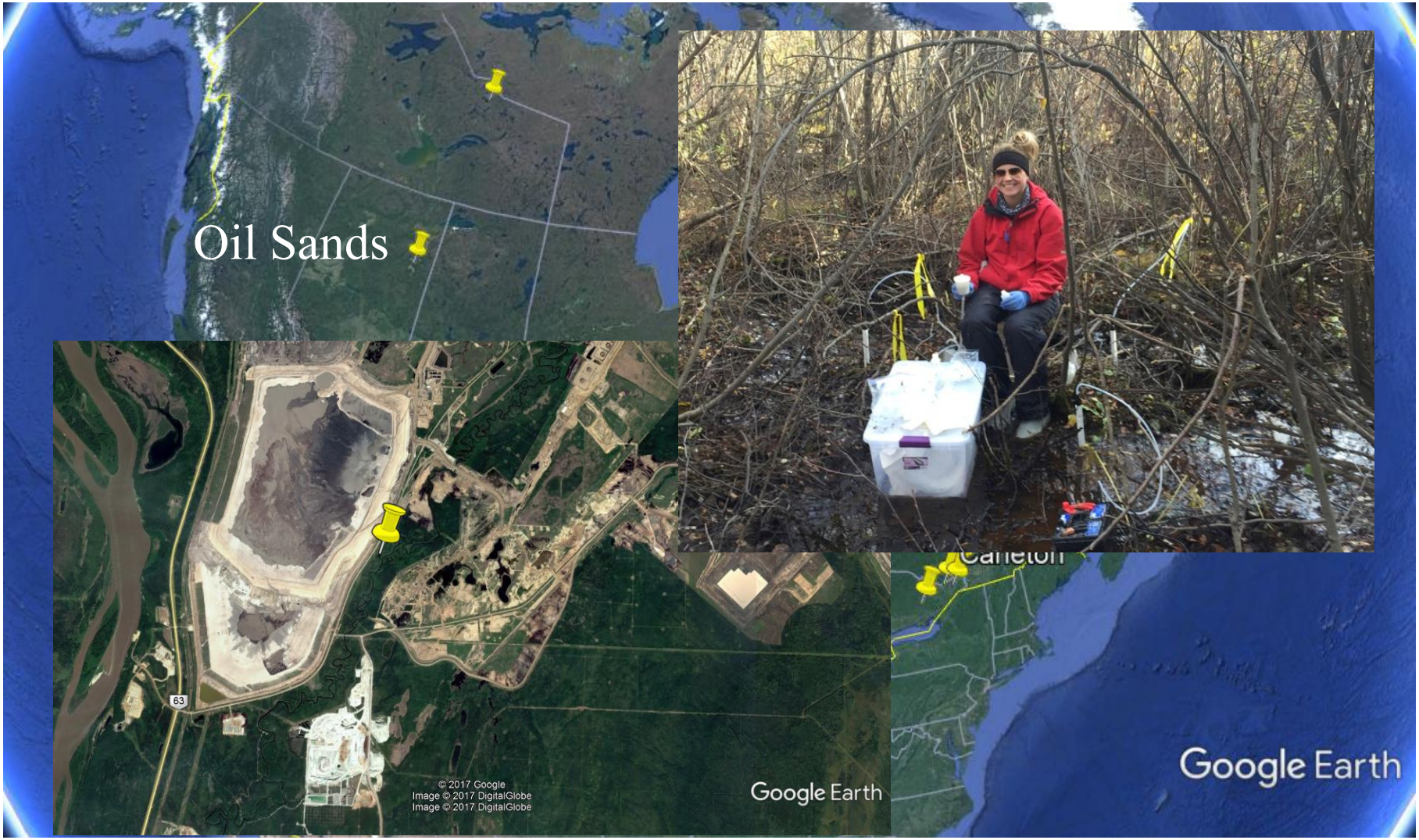
Oil Sands
63
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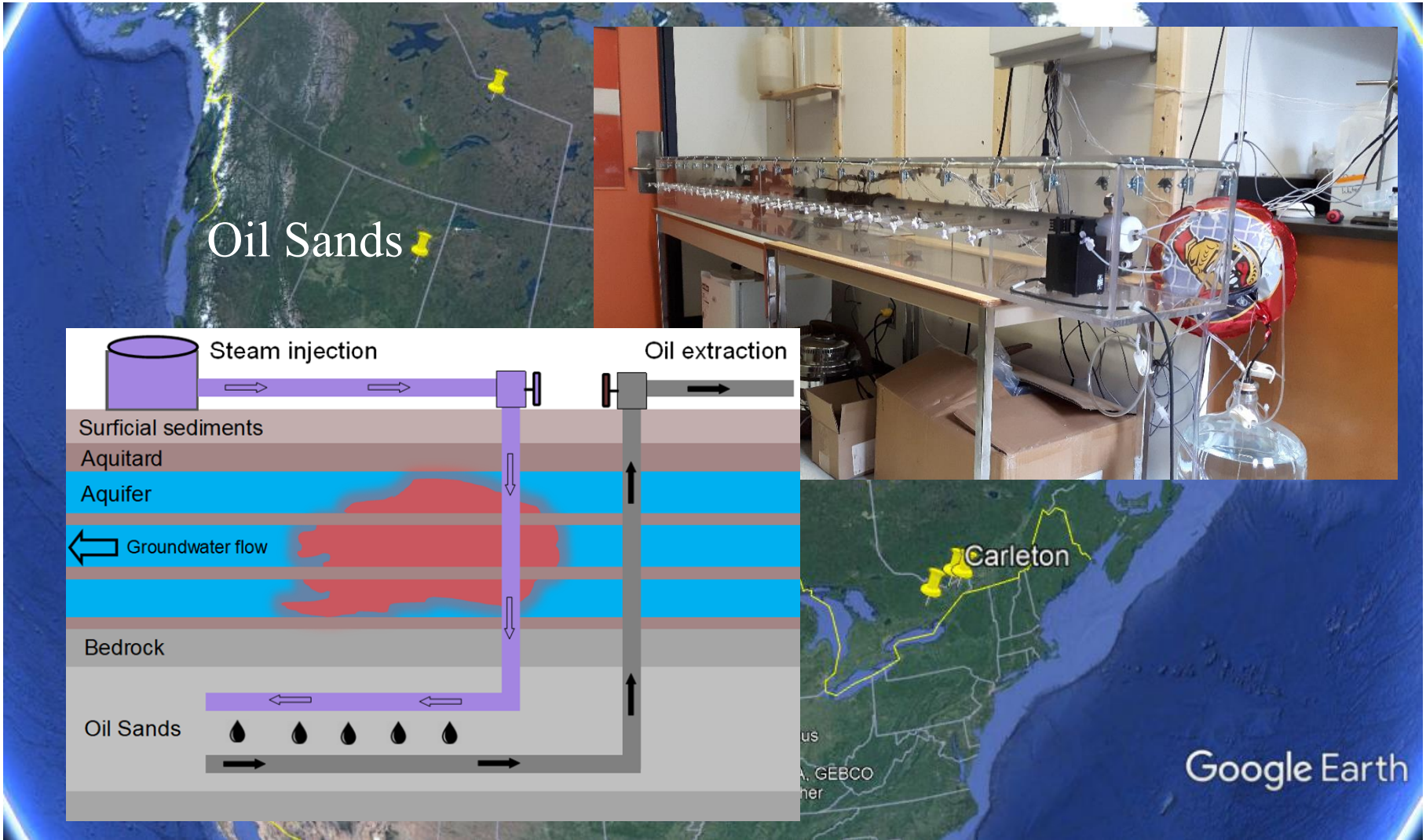
Oil Sands
Steam injection
Oil extraction
Surficial sediments
Aquitard
Aquifer
Groundwater flow
Bedrock
Oil Sands
Carleton
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WEBS Watershed
41
60
17
417
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34
640
40
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15
2
49

Waste Rock Research

Diavik Diamond Mine

Detour Gold Mine

Carleton

Ore Chimney Gold Mine

Mining

Ore

Product

Waste Rock

Tailings

Oxidation of sulfide minerals

$$FeS_{2(s)} + \frac{7}{2}O_2 + H_2O \Rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$$

acidic conditions

$$FeS_{2(s)} + 14Fe^{3+} + 8H_2O \Rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+$$

M. Moncur

National Orphaned and Abandoned Mine Initiative (NOAMI)

Producing Mines in Canada

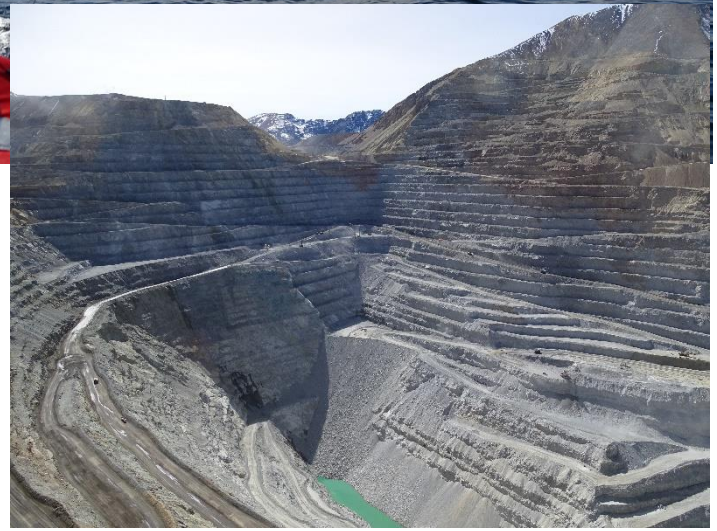
- Base metals
- Precious metals
- Base metals, Precious metals
- Iron ore
- Uranium
- Other metals
- Industrial minerals
- Diamonds
- Coal
- Bitumen
- Gas
- Oil
- Oil/Gas

http://atlas.gc.ca/

Closure Planning

- Humidity Cell Tests
  - Scale leaching rates from small 1 kg samples to large Mt waste-rock piles

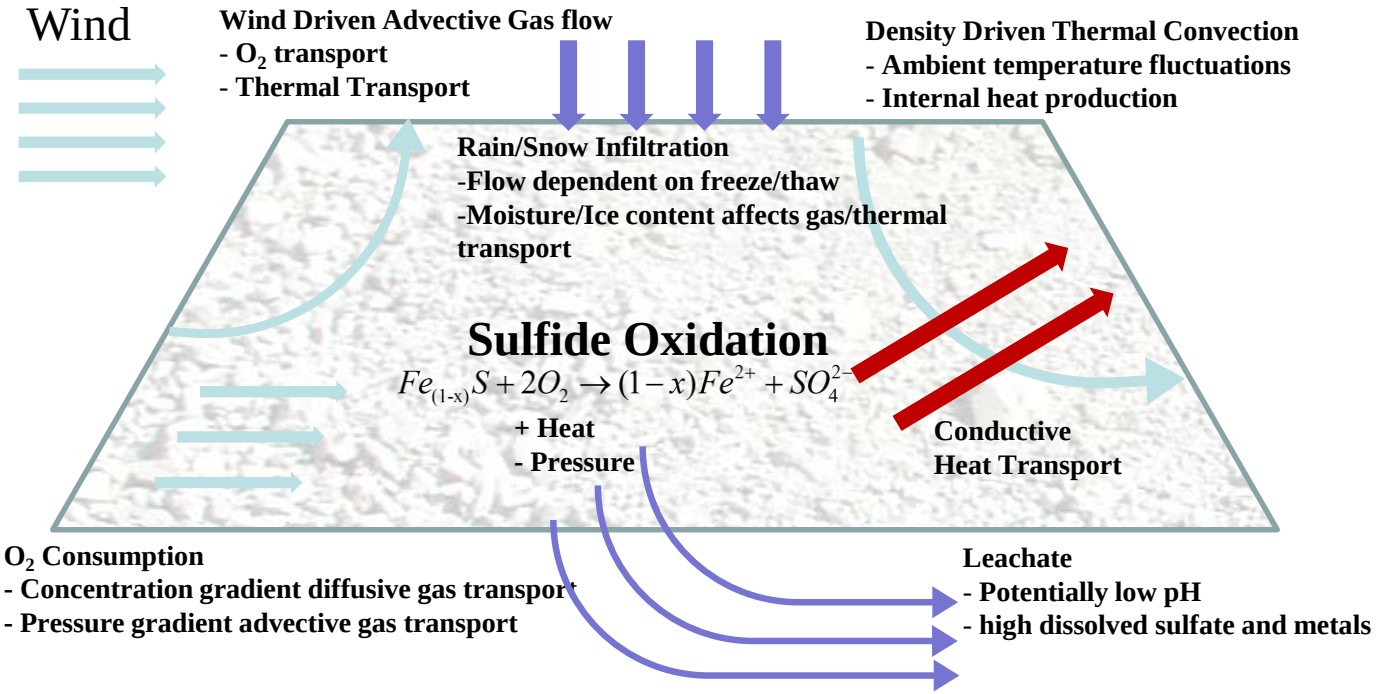
Scale!



Waste Rock Characteristics

- Large volume
- Trace sulfide content
- Very heterogeneous
- Unsaturated

Coupled Processes

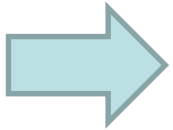


Diavik Waste-Rock Research Project

Diavik Waste-Rock Research Project

Diavik Waste-Rock Research Project

- Research Goal: Micro- to Macro-Scale
  - Scaling the temporal evolution of sulfide mineral weathering from laboratory to field systems



Diavik Waste-Rock Research Project

- Research Goal – Sulfide Oxidation in a Permafrost Region
  - Understand the geochemical, hydrological, and thermal conditions controlling the generation of acidic leachate from waste rock stockpiles in a permafrost environment

Diavik Waste-Rock Research Project

- Humidity Cell Experiments
  - Static tests
    - Paste pH, total S, sulfate S, sulfide S, NP, total C, NAG, ABA, particle size, mean surface area
  - Kinetic tests: 36 humidity cells initiated in 2005
    - 18 cells at 22 °C
    - 18 cells at 4 °C
    - Effluent analysed for pH, Eh, EC, alkalinity, anions, cations, nutrients

	2004	2005	2005i
Type I	2	2	2
Type II	2	2	2
Type III	2	2	2

Diavik Waste-Rock Research Project

- Active Zone Lysimeter Experiments
  - 2-m scale field experiments
  - Characterize leaching in the active freeze-thaw zone

Diavik Waste-Rock Research Project

- Test Piles Experiments
  - 15-m scale field experiments
  - approaching a realistic size

Operational-Scale Instrumentation

- Instrumented full-scale waste rock dump
- The real deal, but instrumentation is limited

Scale-up at Diavik

Full Scale Pile

80 m (1.2 x 10^{11} kg)

Test Piles

Active Zone Lysimeters

15 m (8.2 x 10^{7} kg)

Humidity Cells

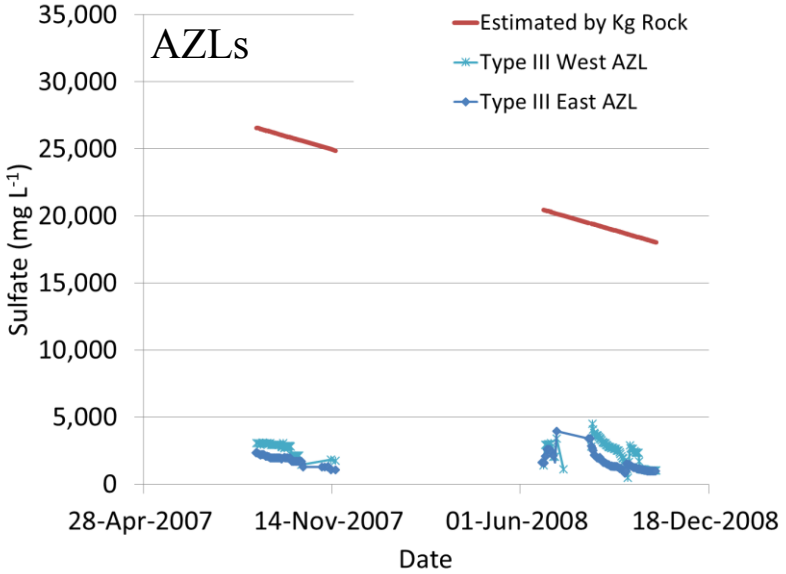
2 m (9,300 kg)

0.1 m (1 kg)

Scale-up Estimates – Back of Envelope Approach

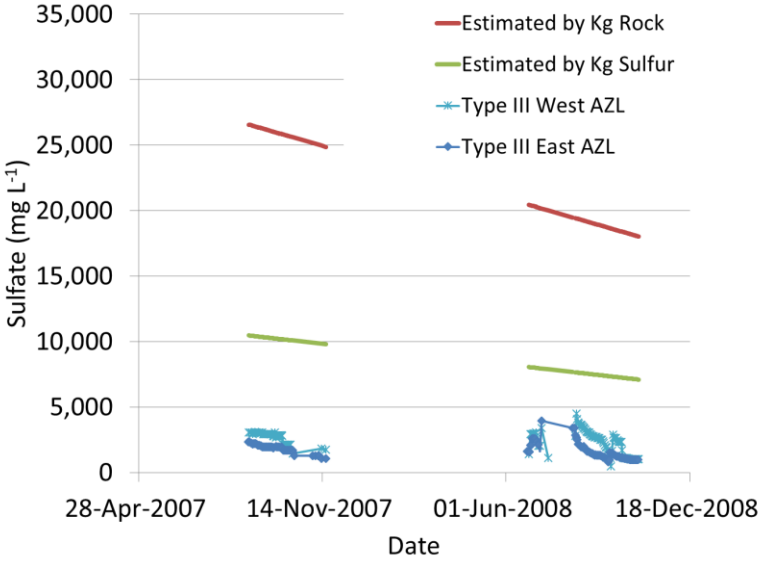
- Concentration calculations based on;
  - Reaction rates from humidity cell experiments
  - Rates scaled to weathering age of rock
  - Estimated residence time

- First (and simplest) estimate;
  - Scale to Mass of rock
    - 1 kg to 9,300 kg



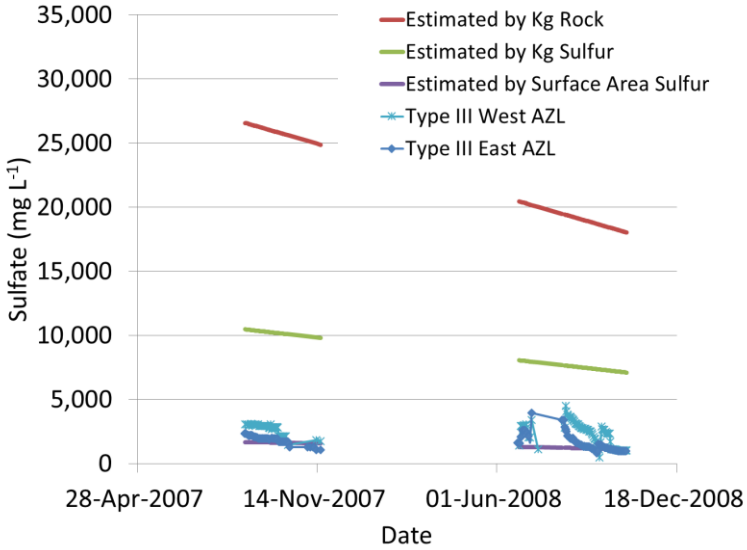
Scale-up Estimates – Back of Envelope Approach

- Concentration calculations based on;
  - Reaction rates from humidity cell experiments
  - Rates scaled to weathering age of rock
  - Estimated residence time
- Second estimate;
  - Scale to mass of sulphide minerals



Scale-up Estimates – Back of Envelope Approach

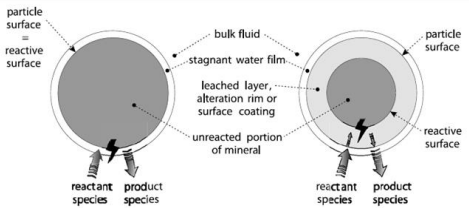
- Concentration calculations based on;
  - Reaction rates from humidity cell experiments
  - Rates scaled to weathering age of rock
  - Estimated residence time
- Try again;
  - Scale to estimated surface area of sulphide minerals



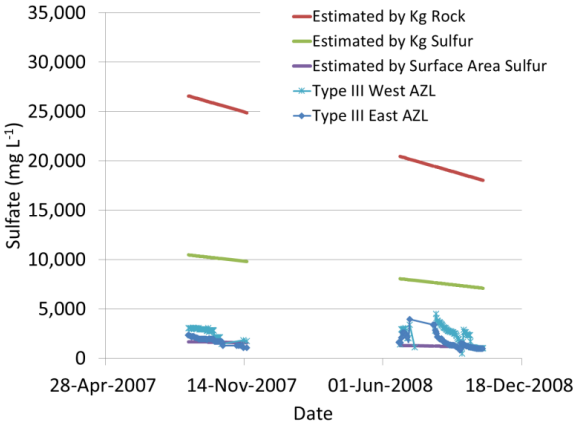
Scale-up Estimates – Back of Envelope Approach

- Scale to estimated surface area of sulphide minerals
  - **Sulphide oxidation is a surface controlled reaction**

Shrinking Core Model

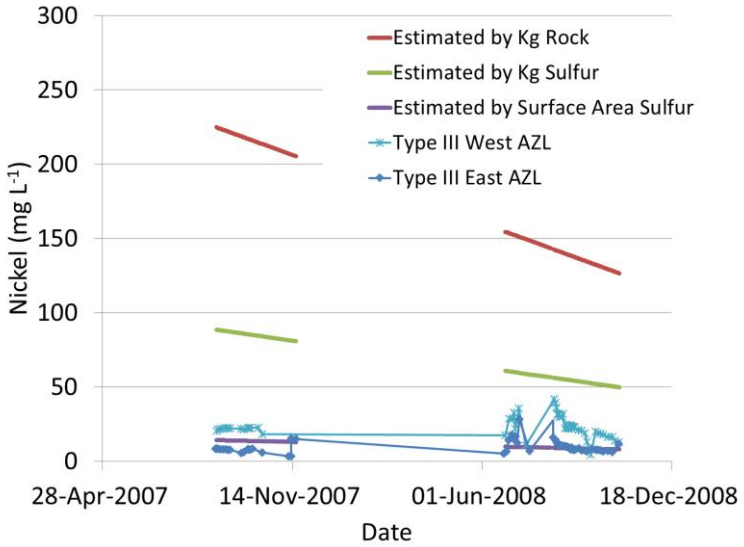


  - **Surface area per kg of rock decreases at larger scales**



Scale-up Estimates – Back of Envelope Approach

- Simple approach
  - No temperature correction
  - No secondary mineral precipitation/sorption
  - No pH/redox controls
  - Simple accounting of precipitation/infiltration
  - Works for conservative solutes



Reactive Transport Modelling

Conceptual model

Oxidation by $O_{2(aq)}$:

$$Fe_{0.852}Ni_{0.004}Co_{0.001}S + 1.9285O_{2(aq)} + 0.143H_2O \rightarrow 0.852Fe^{2+} + 0.004Ni^{2+} + 0.001Co^{2+} + SO_4^{2-} + 0.286H^+$$

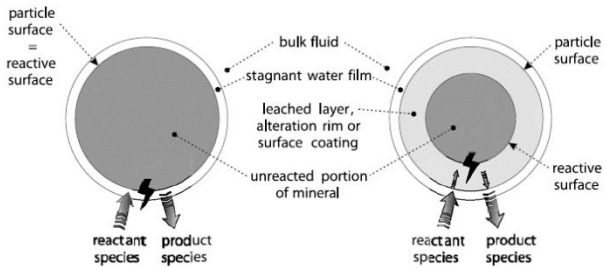
Oxidation by Fe^{3+}:

$$Fe^{2+} + 0.25O_{2(aq)} + H^+ \rightarrow Fe^{3+} + 0.5H_2O$$

$$Fe_{0.852}Ni_{0.004}Co_{0.001}S + 1.714Fe^{3+} \rightarrow 2.566Fe^{2+} + 0.004Ni^{2+} + 0.001Co^{2+} + S^0$$

$$S^0 + 1.5O_{2(aq)} + H_2O \rightarrow SO_4^{2-} + 2H^+$$

Sulfide oxidation simulated using shrinking core model.

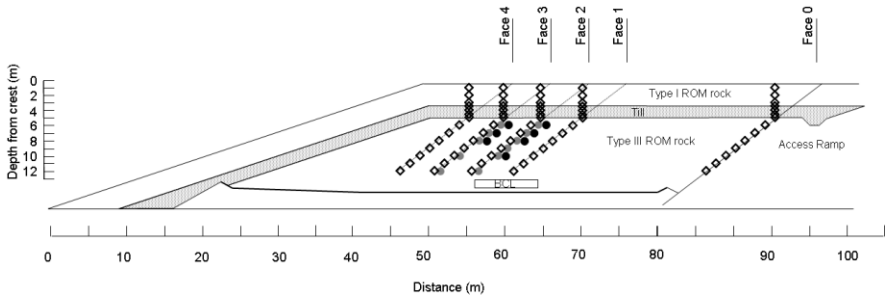


Mayer et al., 2002

- **Hydrology**
  - FAO P-M calculated infiltration
  - n, vG α, vG n, K_{sat} from site characterization
- **Geochemistry**
  - pO_2: 0.21; pCO_2: 0.000317
  - Sulfides: pyrrhotite, chalcopyrite, sphalerite, pentlandite
  - Host: calcite, dolomite, biotite, muscovite, albite
  - Secondary: jarosite, ferrihydrite, gibbsite, amorphous silica, gypsum, siderite
- **Temperature**
  - Average daily temperature 2007-2015

Scaling

- Future Work
  - Heterogeneity
  - Operational Scale
  - Covers



- Conclusions and Implications
  - Humidity cell tests can be used to reasonably predict solute concentrations/loadings at the field-scale
    - Mechanistic
      - Model calibrated for humidity cells
      - Scaled with only measurable parameters
    - Complex geochemistry
    - Complex hydrology
    - Complex temperature
  - Critical for long-term planning of mine closure
    - Allows appropriate plan to be developed at early in mine life
    - Cheaper and more effective
    - Regulatory and Social Licence

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Good Bye!