The Influence of Geochemical Processes on Mine Waste Material Structure and Physical Stability

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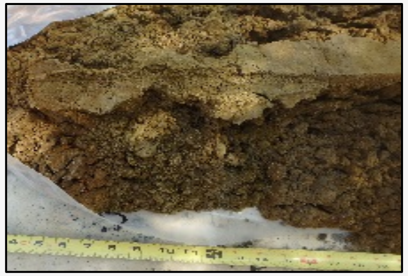
Presentation Outline



- Geochemical Processes or Mechanisms that Affect Large Scale Structures of Mine Waste Facilities
- Physical Implications from these Processes, Materials and Systems:
  - Changes in porosity and permeability (increase or decrease) resulting in a change in design parameters
  - Changes in strength and structure resulting in a change in physical stability
- Case Examples
- Summary






Introduction

Geochemical processes change the structure, strength and chemical stability of geologic materials (minerals) and by extension affect the stability large scale mine waste engineered structures :

- Metallurgical Waste Disposal (slag and other process waste)
- Waste Rock and Heap Leach Piles
- Tailings Storage Facilities
- Earthen and Tailings Dams

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Two main geochemical processes or mechanisms effect the physical and hydrologic properties of mine waste materials:

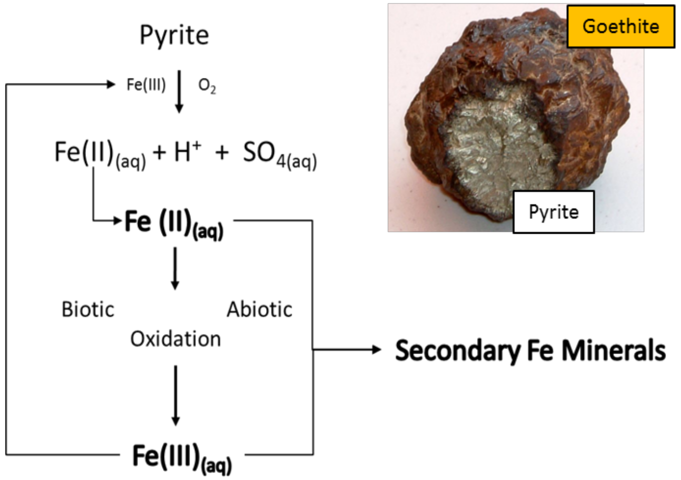
1. Primary Mineral Alteration (weathering): hydrolysis and dissolution of minerals within waste materials; and/or,
2. Secondary Mineral Formation: secondary precipitates form within the pore spaces of waste materials.

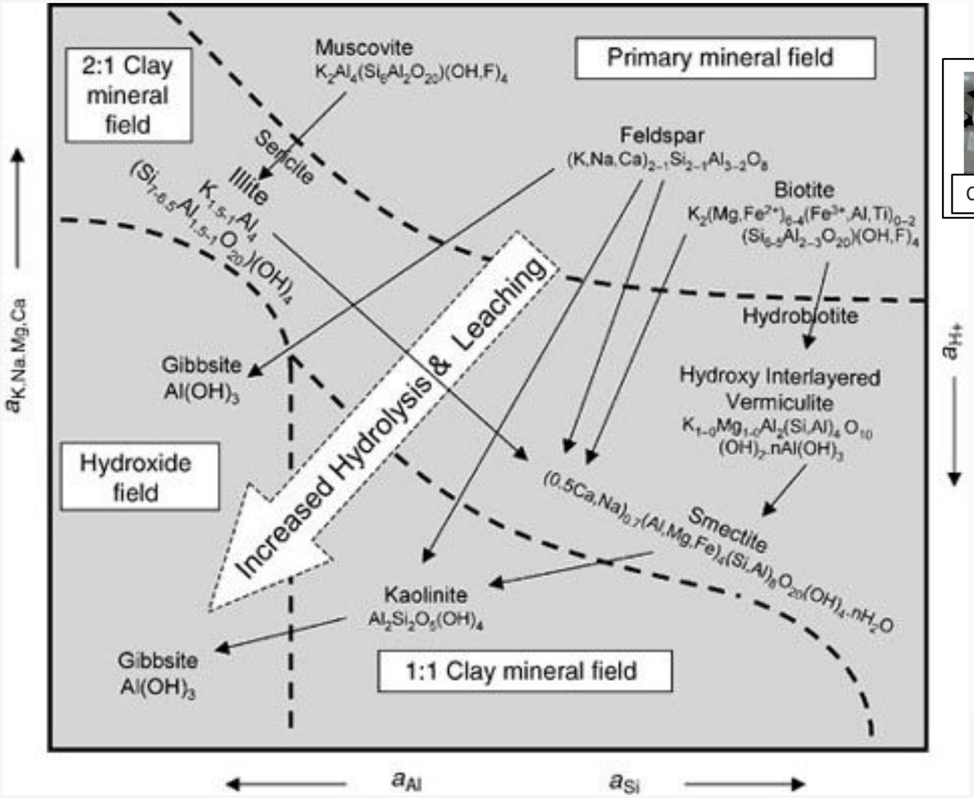
Weathering Affects Physical Properties of Mine Waste

- Weathering is the breakdown of rocks and minerals, by physical, chemical or biological processes.

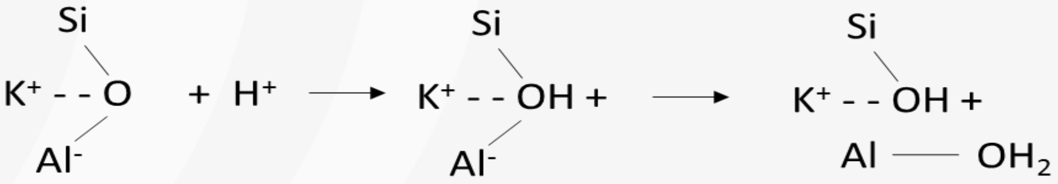
- Chemical weathering = mineralogical alteration.
  - Hydrolysis, Dissolution / Desorption
  - Oxidation and Neutralization

$$FeS_{2\,(s)} + 3.5\,O_{2\,(g)} + H_2O_{(l)} \leftrightarrow Fe^{2+}_{(aq)} + 2SO_4^{2-}{}_{(aq)} + 2H^+_{(aq)}$$





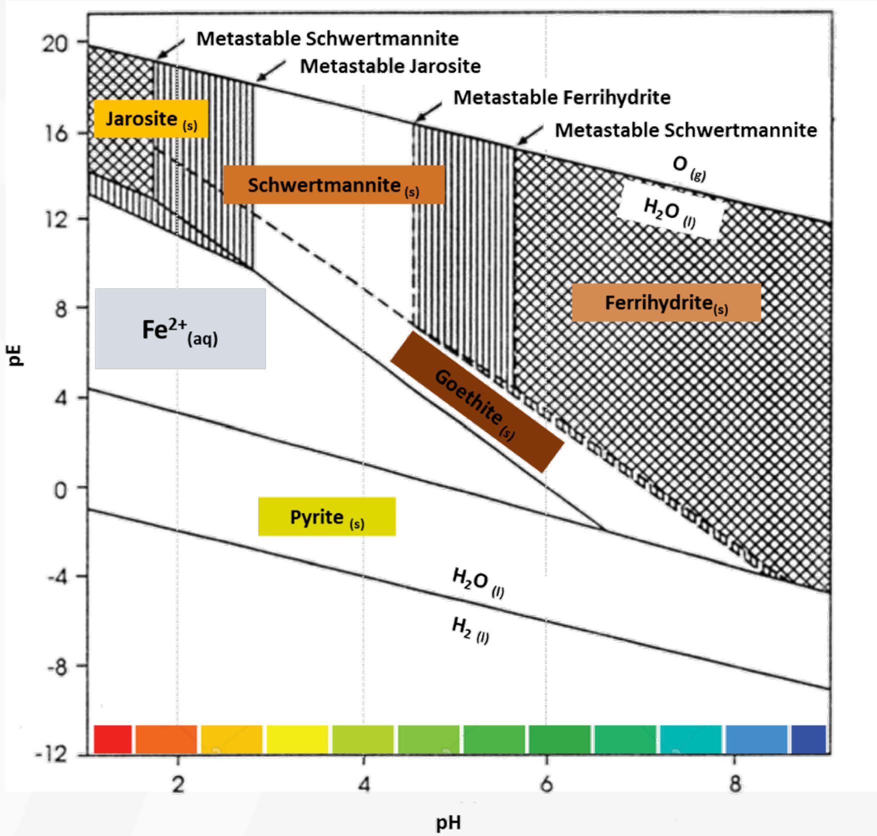
$$CaCO_{3\,(s)} + H^+_{(aq)} \rightarrow Ca^{2+}_{(aq)} + HCO_3^-{}_{(aq)}$$

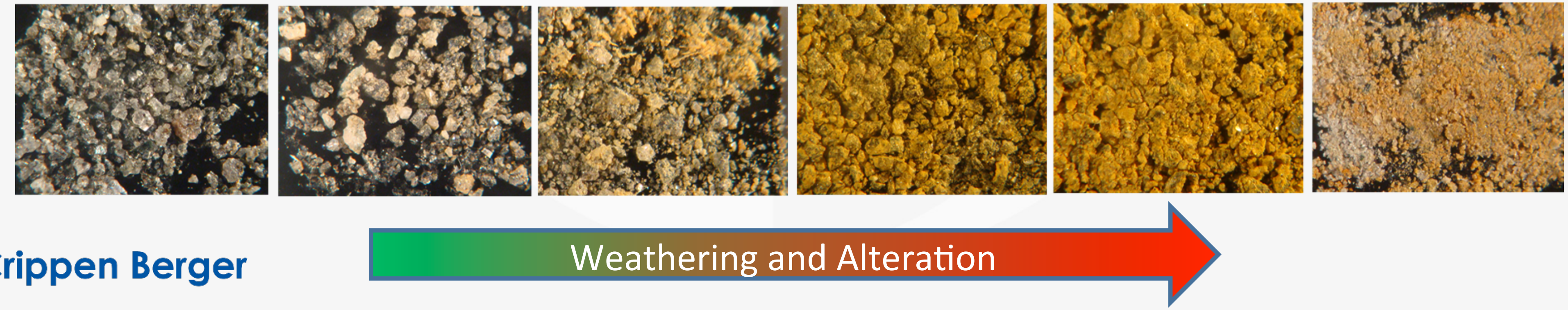


Sulphide dissolution and oxidation + carbonate and silicate dissolution and neutralization → mineralogical changes over time in Mine Waste Facilities

Mineral Alteration Changes Physical Properties

Primary Mineral	Sym	Chemical Formula	Molecular Weight (g/mol)	Specific Gravity	Hardness
Pyrrhotite	Po	$Fe_{(1-x)}S$	85.12	4.61 (avg)	3.5-4.5
Pyrite	Py	FeS_2	119.98	5.01	6.5
Galena	Gl	PbS	239.27	7.4	2.5
Chalcopyrite	Cpy	$CuFeS_2$	183.53	4.1-4.3	3.5-4.5
Alkali Feldspar	Fp	$(K,Na)[Ali_3O_8]$	278.33	2.55-2.63	6
Plagioclase	Pg	$Na[AlSi_3O_8]$-$Ca[Al_2Si_2O_8]$	270.77	2.62-2.76	6-6.5
Muscovite	Mv	$K_2Al_4[Si_6Al_2O_{20}](OH,F)_4$	398.71	2.77-2.88	2-2.5
Secondary Mineral	**Sym**	**Chemical Formula**	**Molecular Weight (g/mol)**	**Specific Gravity**	**Hardness**
Jarosite	Jar	$KFe_3(SO_4)_2(OH)_6$	500.81	2.9-3.3	2.5-3.5
Schwertmannite	Sch	$Fe_{16}O_{16}(OH)_{12}(SO_4)_2$	1545.76	3.77-3.99	2.5-3.5
Ferrihydrite	Fhy	Fe_2O_3•$0.5(H_2O)$	168.70	3.8	
Melaterite	Mel	$Fe^{2+}(SO_4)$•$7(H_2O)$	278.02	1.89-1.9	2
Rozenite	Roz	$Fe^{2+}(SO_4)$•$4(H_2O)$	223.97	2.2	2.3
Copiapite	Cop	$Fe^{2+}Fe^{3+}{}_4(SO_4)_6(OH)_2$•$20(H_2O)$	1249.94	2.1	2.5
Halotrichite	Hal	$Fe^{2+}Al_2(SO_4)_4$•$22(H_2O)$	890.40	1.78-1.9	1.5-2
Goethite	Gt	FeOOH	88.85	4.3	5-5.5
Anhydrite	Ah	CaSO4	136.1	2.97	3.5
Gypsum	Gp	$Ca(SO_4)_2$2H2O	172.2	2.3	2
Cerrusite	Cer	$PbSO_4$	267.21	6.58	3-3.5
Kaolinite	Kln	$Al_4[Si_4O_{10}](OH)_8$	258.16	2.61-2.68	2-2.5
Smectite	Smc	$(1/2Ca,Na)_{0.7}(Al,Mg,Fe)_4\,[(Si,Al)_8O_{20}](OH)_4 \cdot nH_2O$		2-2.7	1.5-2
Illite	Il	$K_{1.5-1.0}AL_4[Si_{6.5-7.0}Al_{1.5-1.0}O_{20}]\,(OH)_4$	389.34	2.6-2.9	1-2





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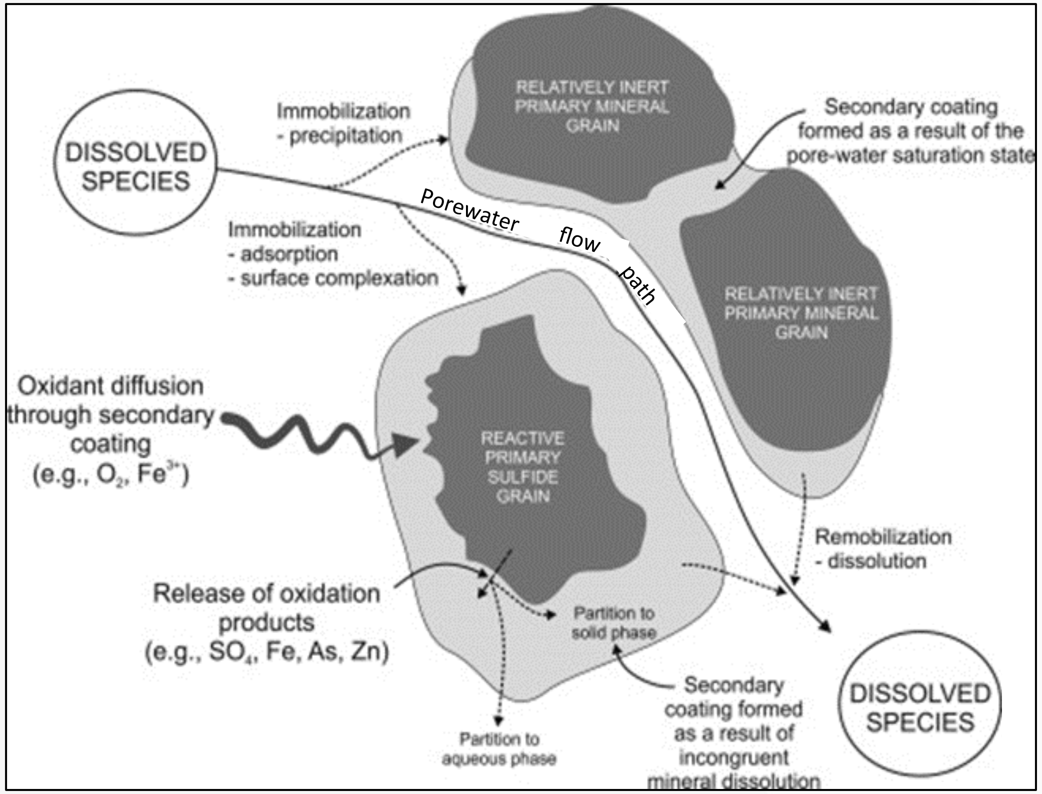
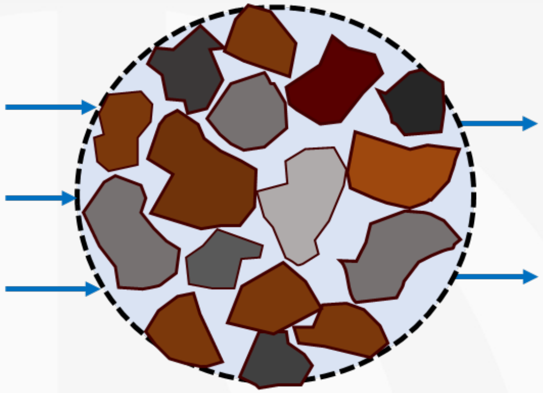
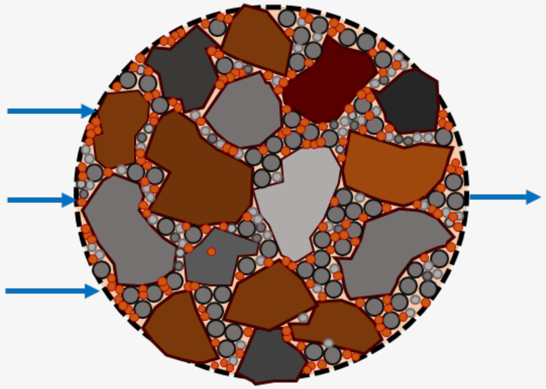
Mineral Alteration Affects Porosity and Permeability

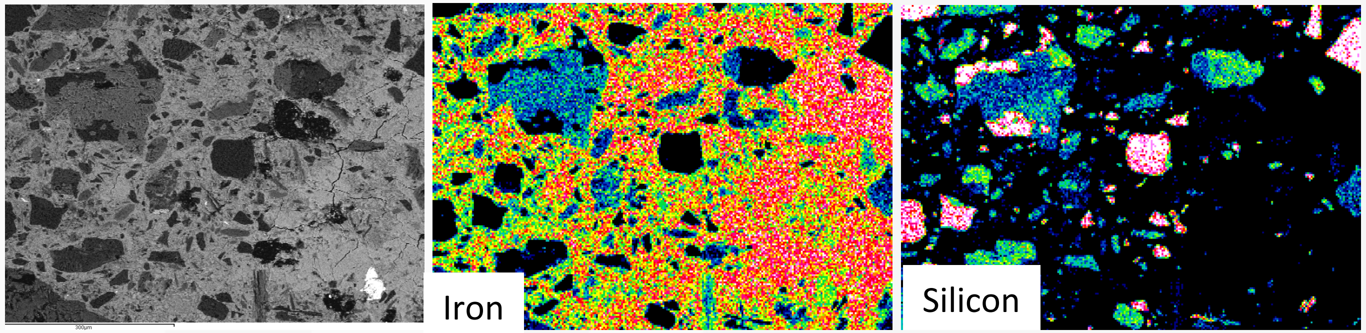




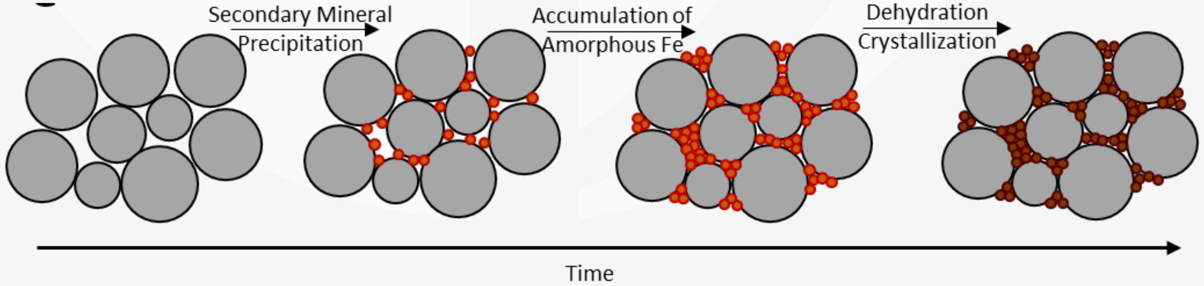
Higher Hydraulic conductivity



Lower Hydraulic conductivity



Weathered silicate primary minerals and secondary Fe products can reduce porosity and permeability



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Changes in Physical Properties Changes Structure and Strength

Key issues for consideration in geotechnical stability from geochemical changes include:

1. Degradation of structural fill resulting in a loss of physical stability;
2. Degradation of fill and filter materials resulting in a change in material permeability (increase or decrease) altering the original design parameters;
3. Accumulation of secondary mineral precipitates resulting in a change in material properties (i.e. permeability or strength).

Particle changes leading to changes in:

- Compressibility,
- Consolidation,
- Cohesion (increase or decrease)
- Porosity (increase or decrease)
- Permeability (increase or decrease)

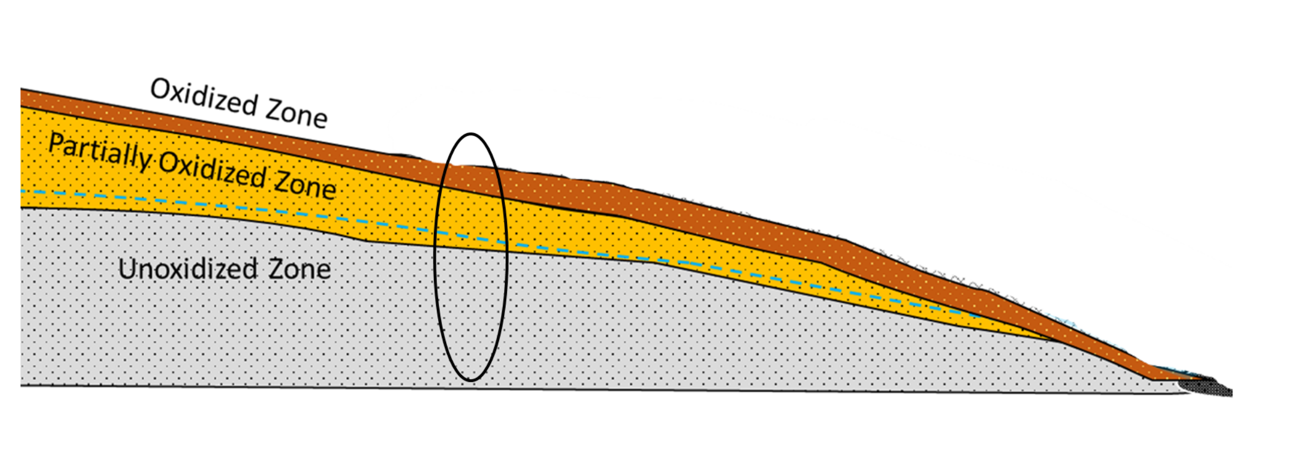
In some cases, the development of amorphous secondary minerals could lead to changes in key material behaviours (i.e. change from a frictional material where strength comes from grain to grain contact or to a frictionless material where the contact between grains is reduced).

Examples

Case 1: Sulphidic Base Metal TSF

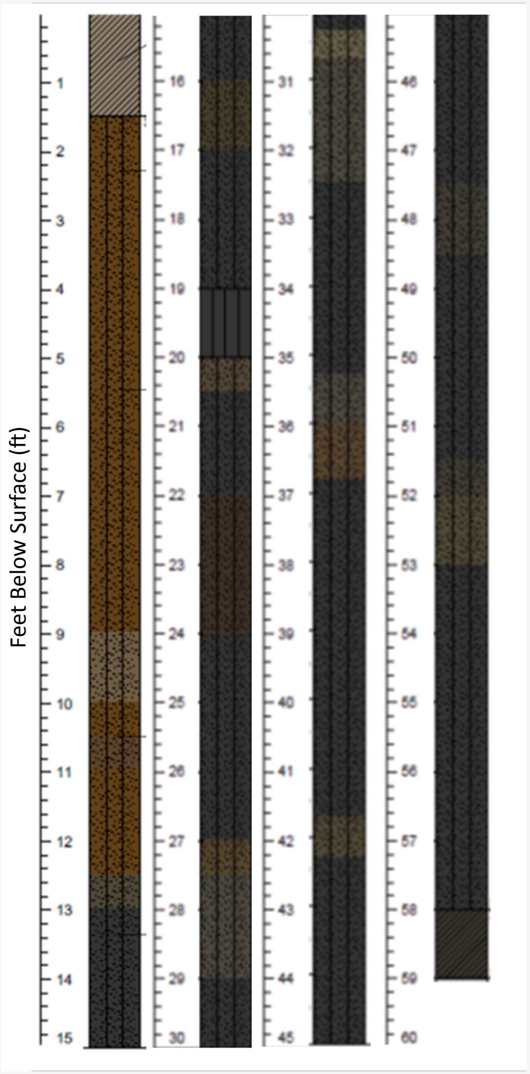
- Flooded base-metal TSF:
  - >100 km^2;
  - Deposition >50 yrs in several individual areas.
  - Geochemical assessments predicted PAG tailings.
  - Impacted surface and pore water quality:
    - Seepage from older areas well exceeded regulatory guidelines prior to treatment.
    - Seepage from younger areas was getting worse.

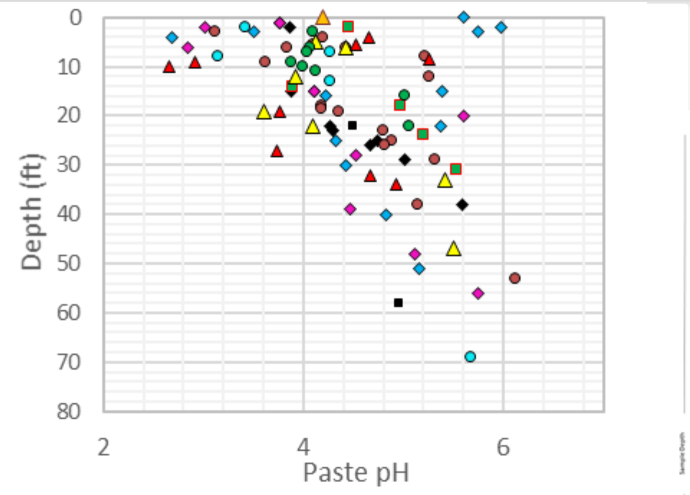
- Secondary minerals were observed as a product of changing geochemical conditions.
- **Evolution of tailings mineralogy as it relates to physical stability in the ageing TSF was largely unknown/unrecognized.**

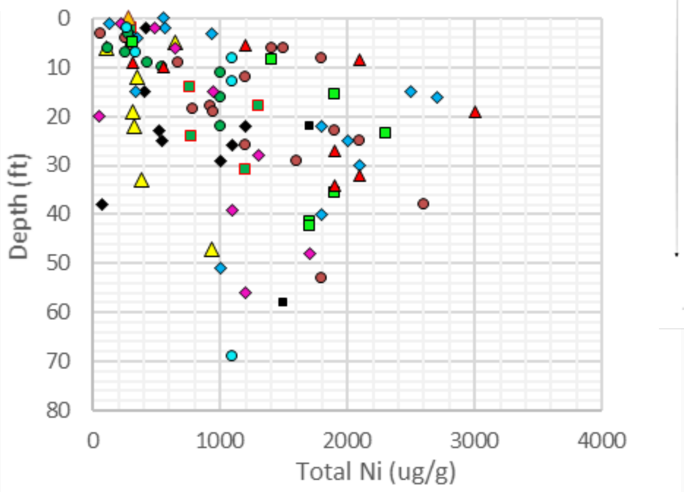


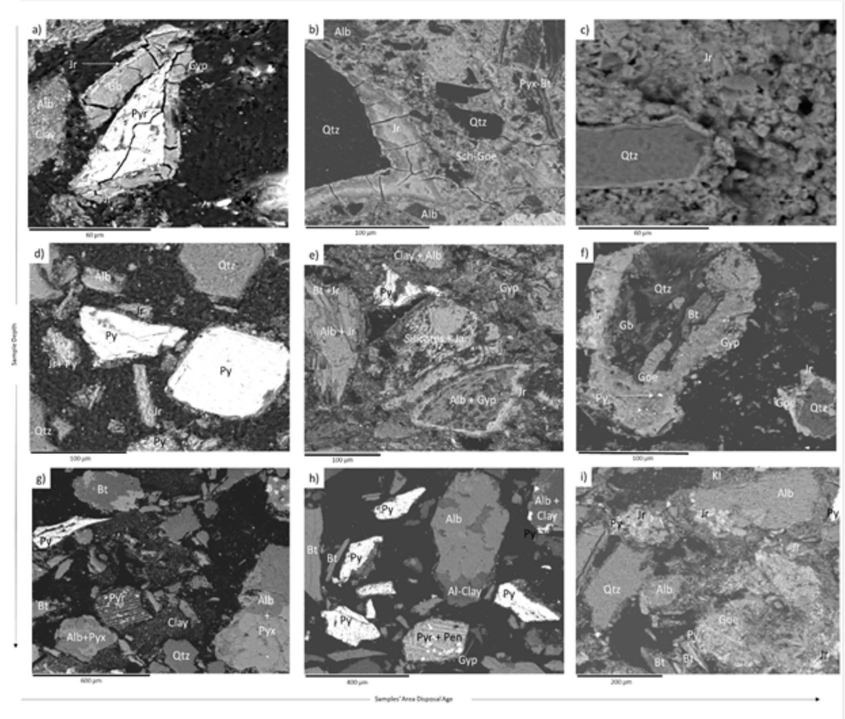
Case 1: Mineral Alteration Changes Physical Properties

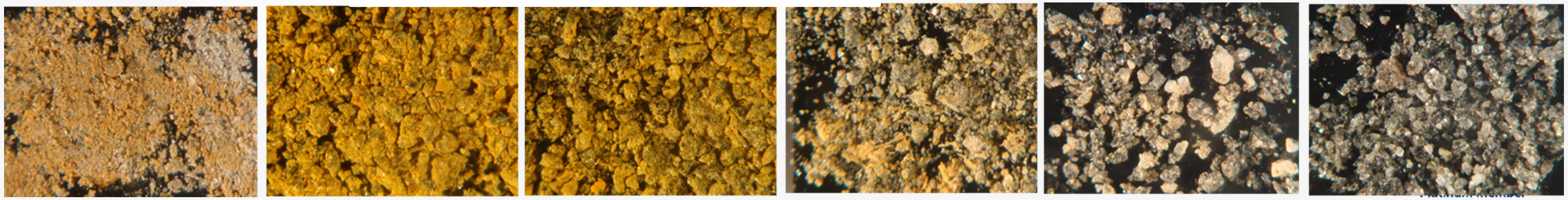
TSF Stratigraphy











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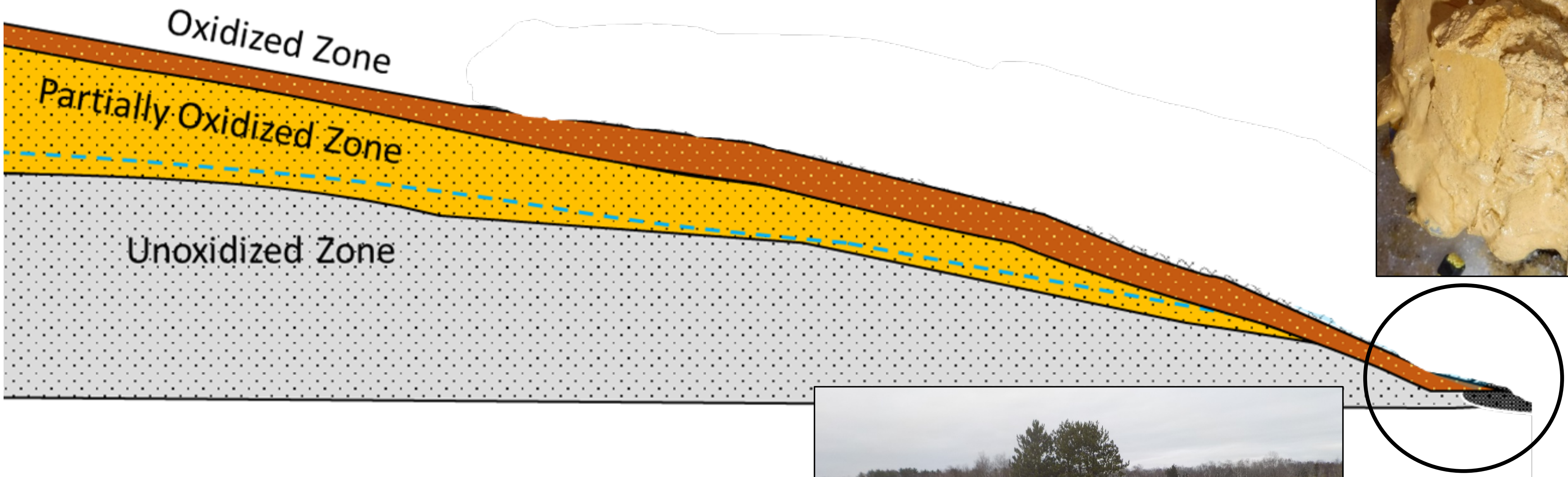
Case 1: TSF Mineral Alteration Changes Physical Properties



Case 1: TSF Mineral Alteration Changes Physical Properties

Deposited 1940's

Deposited 1960's

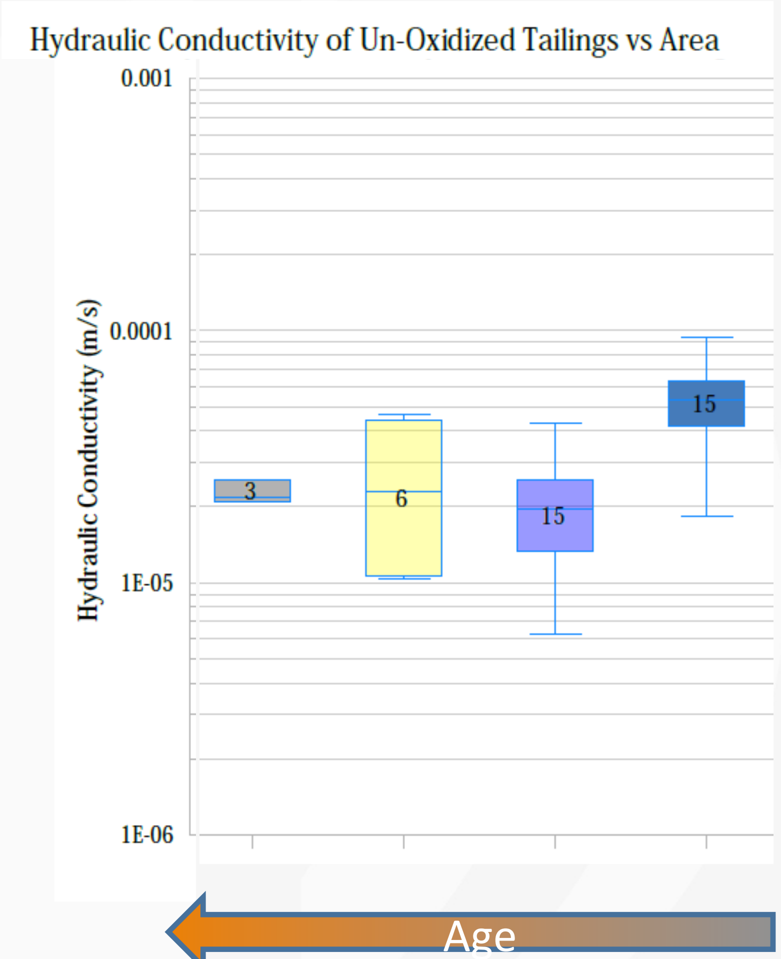
Deposited 1980's

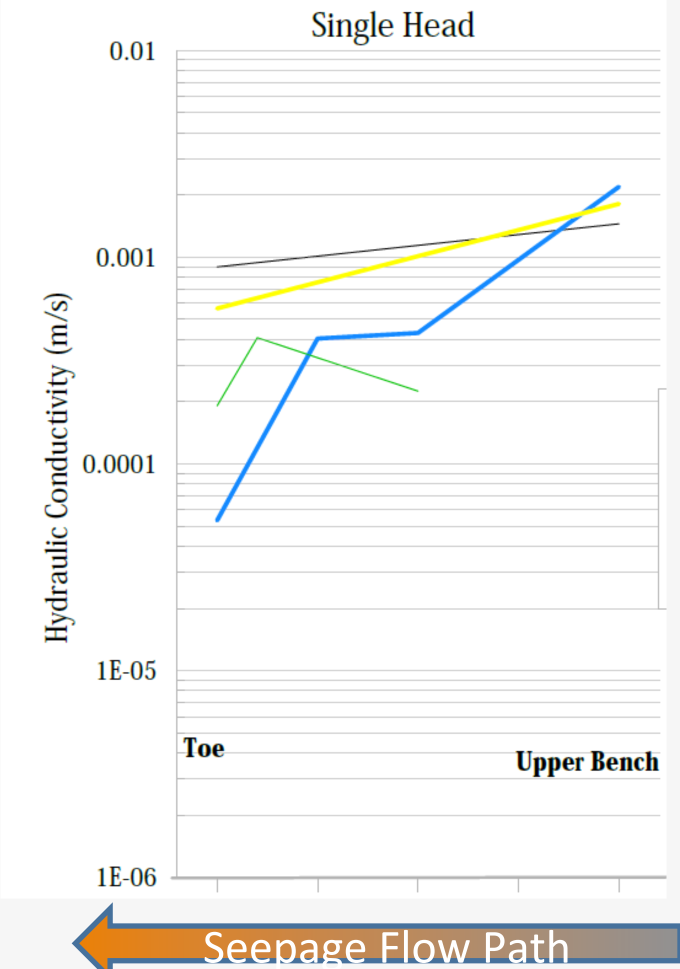
Deposited 1990's

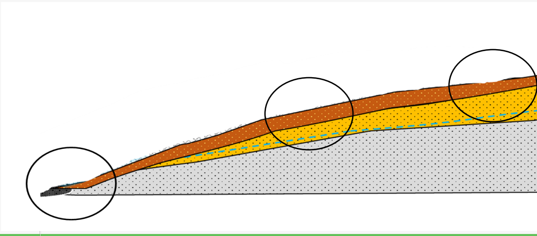
ML/ARD Progression

Weathering and Alteration

Case 1: TSF Mineral Alteration and Permeability Changes







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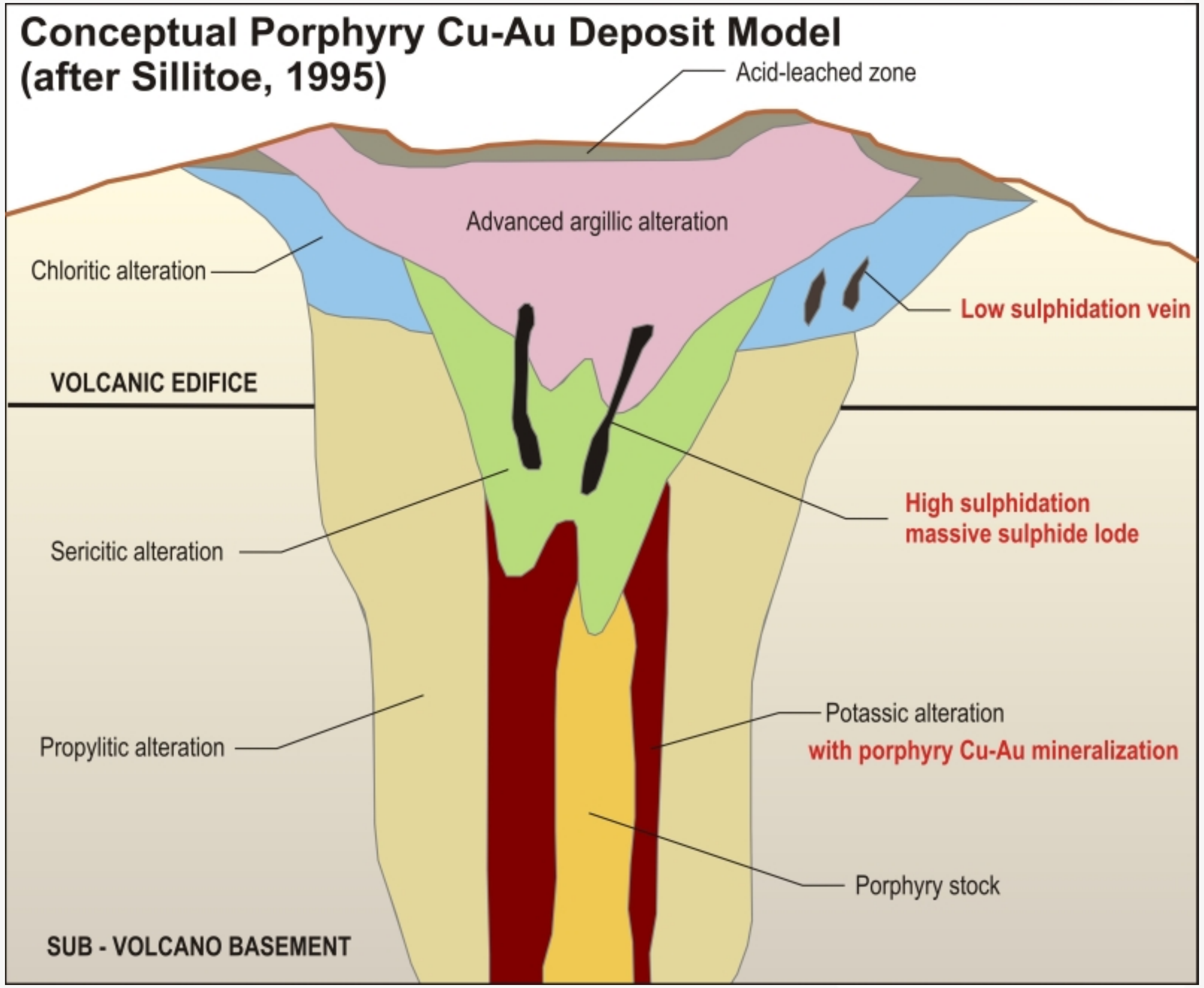
Case 2: Saline Seepage Water and Construction Fill Degradation

Au TSF:

- Slurry deposited tailings,
- Net Negative water balance,
- Reclaimed water – progressively more saline,
- Geochemical assessments predicted NPAG tailings
- No problem-right?

- Waste rock used to construct dams
  - Weathered and non-weathered BIF
  - Geotechnical testing used DI water showed competent material properties

Case 3: Highly Altered WR + Sulphide Oxidation

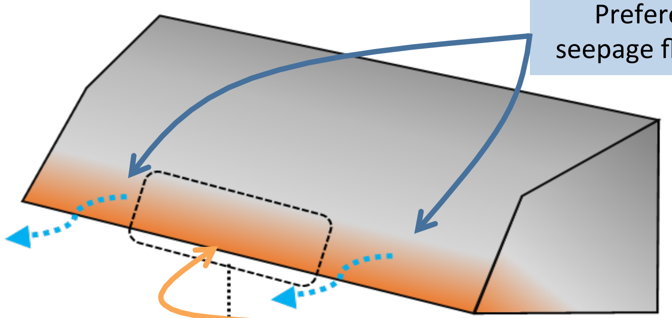


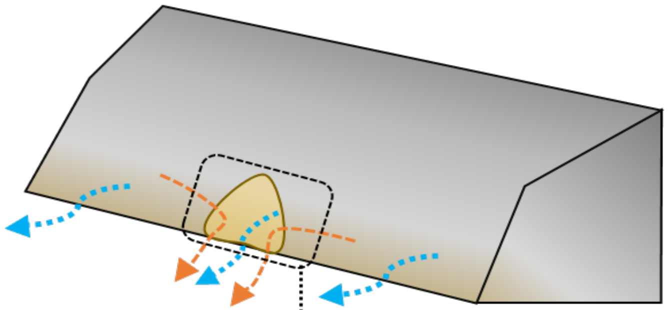
- Porphyry Cu-Au Mine:
  - Highly altered deposit type,
  - Carbonates present but high sulphide content,
  - PAG tailings and PAG + NPAG waste rock.

- Sulphide oxidation produced acidity,
- Acidity neutralized by available carbonates. Decades later, acidity is promoting silicate mineral alteration and neutralization by the dissolution of alteration products (clays).

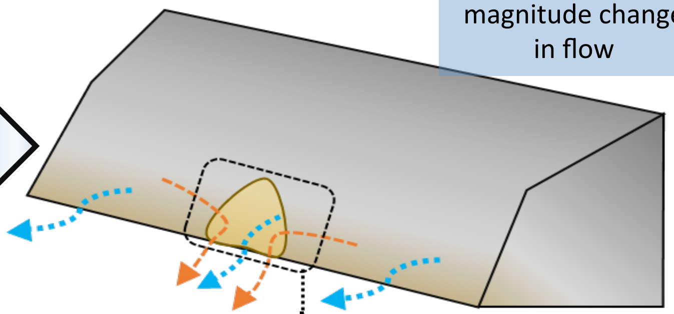
Case 4: Precipitates Reduce Seepage Flow in Waste Rock

Preferential seepage flow path





Order of magnitude change in flow



Flow ~0.1 L/sec

Low flow, saturated. Migrating seepage emergence (1m/4yrs), Porewater contains elevated Fe and fill materials filled with amorphous and crystalline precipitates

Fe-precipitates flushed, increased porosity, increased flow

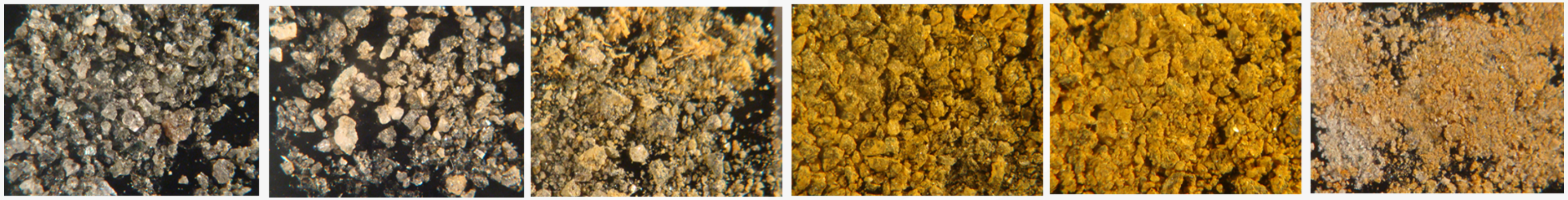
Flow ~1 L/sec

Case 5: Cements from Seepage through Slag

What Have We Learned from Case Examples?

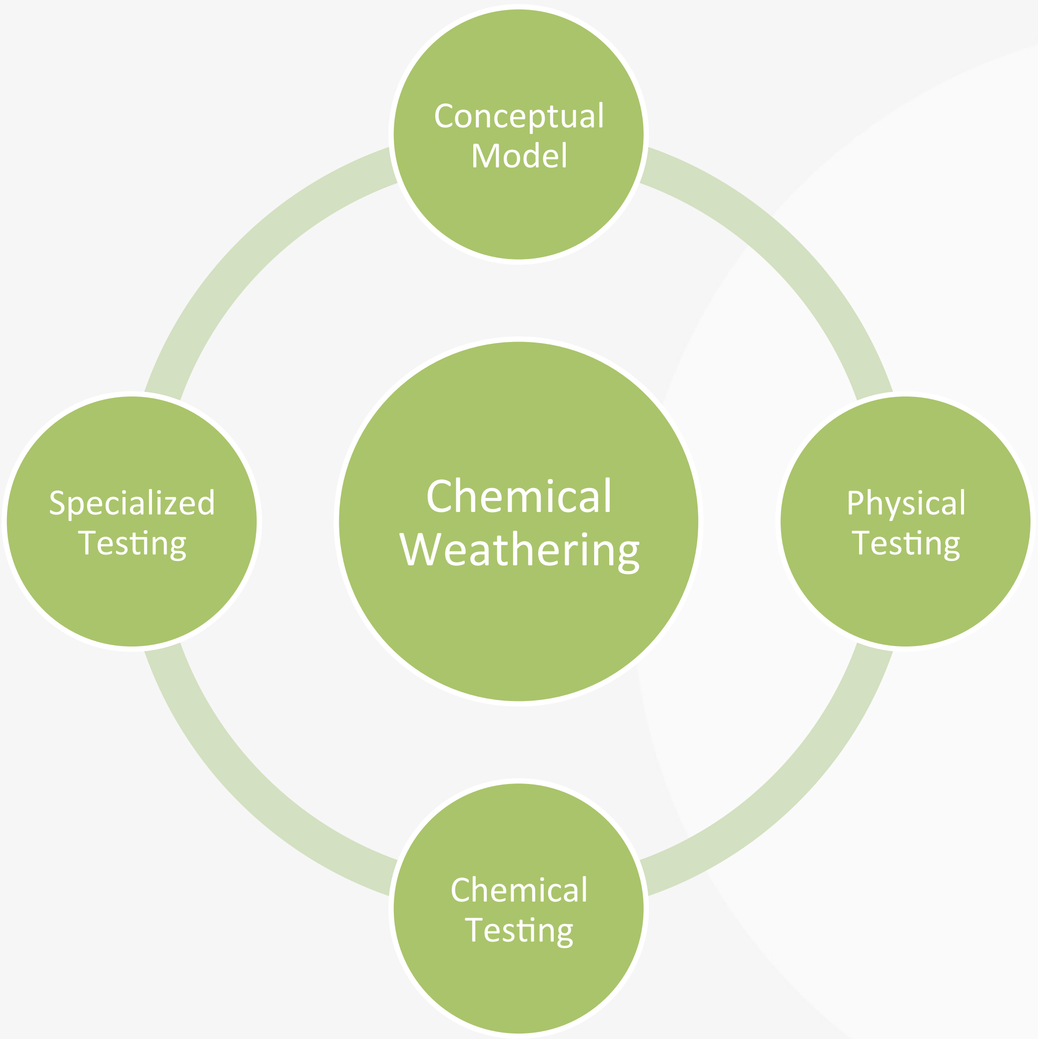
- Weathering primary minerals and the formation of secondary minerals is common in mine waste environments.
  - Can be accelerated in wet, saline, already highly altered deposits, high sulphide materials, acidic seepage, etc.);
  - Reactions are controlled by the surrounding physiochemical conditions and depend on the composition of the solids and liquids in the system
  - Results in physical and chemical changes to the materials

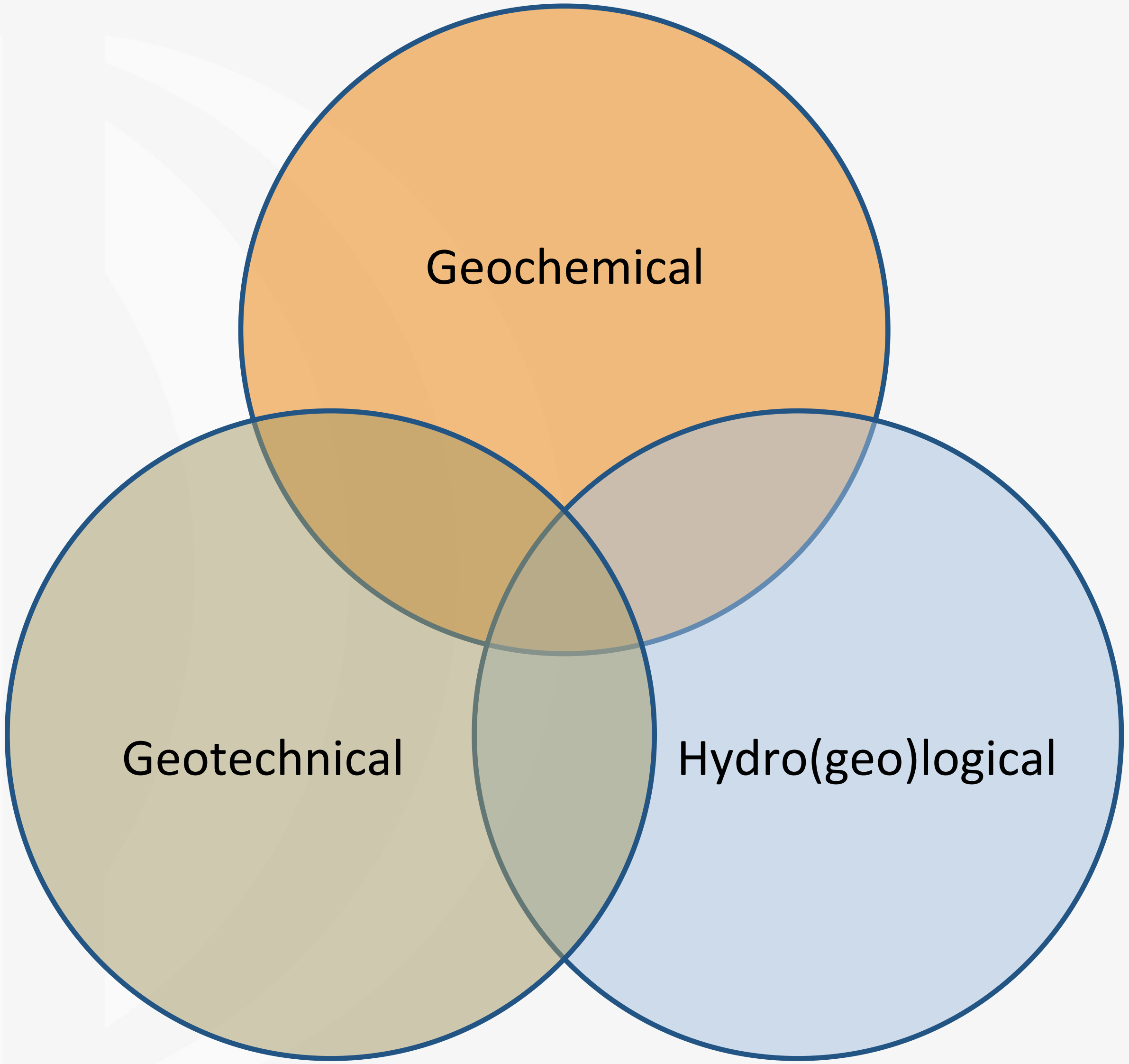
- However, the influence of geochemical change on physical material properties is not well understood in our current state of practice.



Increased Weathering and Alteration

How Do We Improve Our State of Practice?

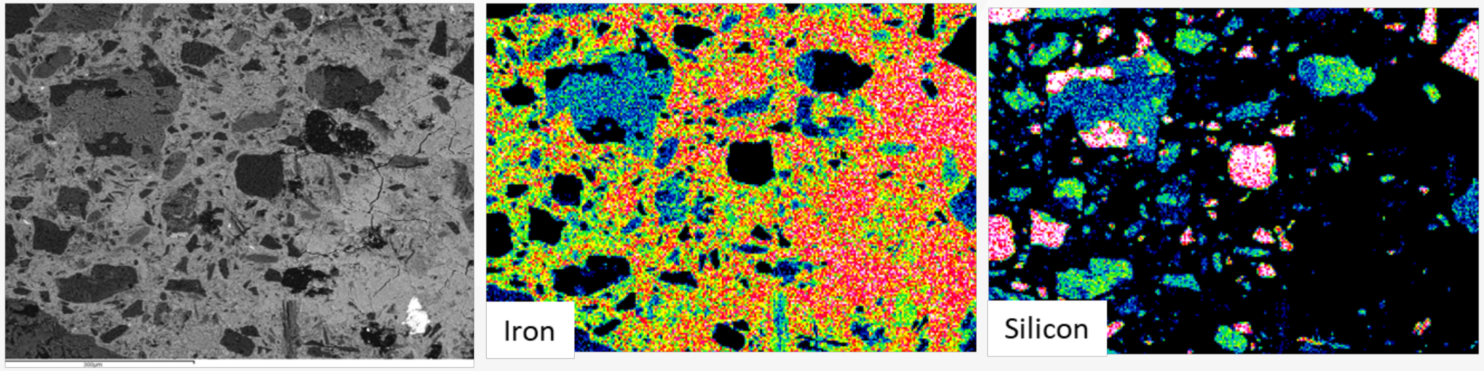




Summary

- Changes to the physical and chemical nature of tailings, dam fill, waste materials and process/pore and seepage waters are important factors that should be considered in mine waste management (environmental + geotechnical)
  - Regular physical monitoring will help identify problems associated mineral alteration and/or precipitate formation before physical changes are observed (e.g. rise in phreatic surface)
  - Specialized field monitoring and laboratory testing is often needed to determine site specific geochemical processes
  - Understanding reaction pathways can help predict outcomes and even mitigate issues early (and reduce risk)
- The importance of geochemical processes as a function of mineral alteration and understanding its relation to dam stability will likely become increasingly important as greater scrutiny is placed on waste management now and in the future.

Silicate primary minerals and secondary Fe products filling pore spaces



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Thank You!

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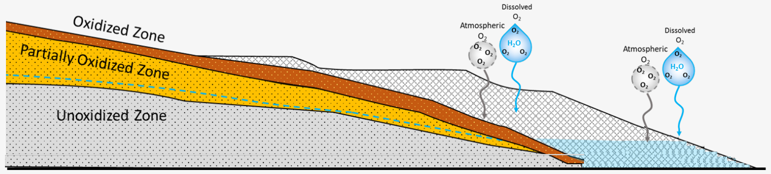
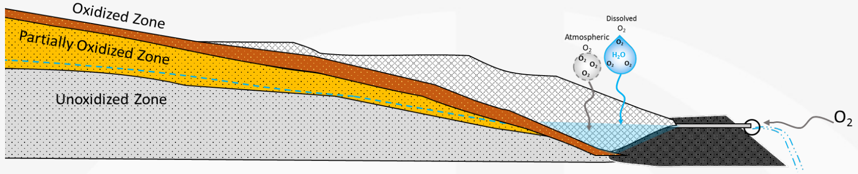
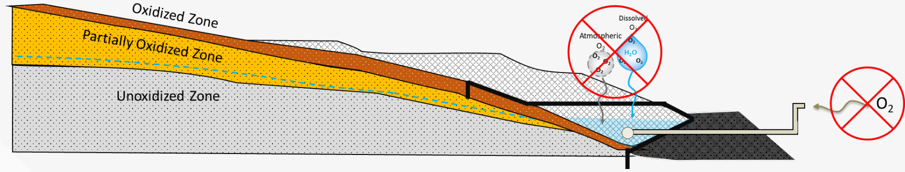
Up to the Challenge.

Engineering, Geoscience and Environmental Services

Precipitates in Seismic Stabilizing Buttresses







Free Flowing
Non-Flooded

Constructed 2014

Flooded
Non-Covered

Constructed 2010

Flooded
Covered

Constructed 1998

Precipitate Accumulation

Problem Investigation

Problem:
- Observed changes in facility performance (e.g. phreatic surface, seepage emergence, porosity and permeability, pore or seepage water quality)
- Observed physical changes in tailings, dam fills, or waste materials

Geochemical, hydro(geo)logical, and geotechnical review

Physical
- Subsurface investigations (test pitting, drilling, core extraction, geotechnical testing)
- Solid material characterization (rock, tailings)
- Chemical and mineralogical composition

Chemical
- Seepage and porewater quality
- Geochemical testing of solids + seepage or porewater
- Hydrological and hydrogeological modelling and prediction
- Geochemical modelling and prediction

Specialized
- Customized laboratory testing and field trials
- Risk reduction and remediation