BC MEND ML/ARD ANNUAL WORKSHOP

MINE CLOSURE MANAGEMENT
GREENROAD GROUP

A Holistic Closure Strategy that Integrates the Cover System within the Context of the Surrounding Physical Environment

Greg Meiers, Mark Pernito, & Carlos Hillman

Dec 3, 2025
9:30 – 10:00 am

Lets control some oxygen ingress

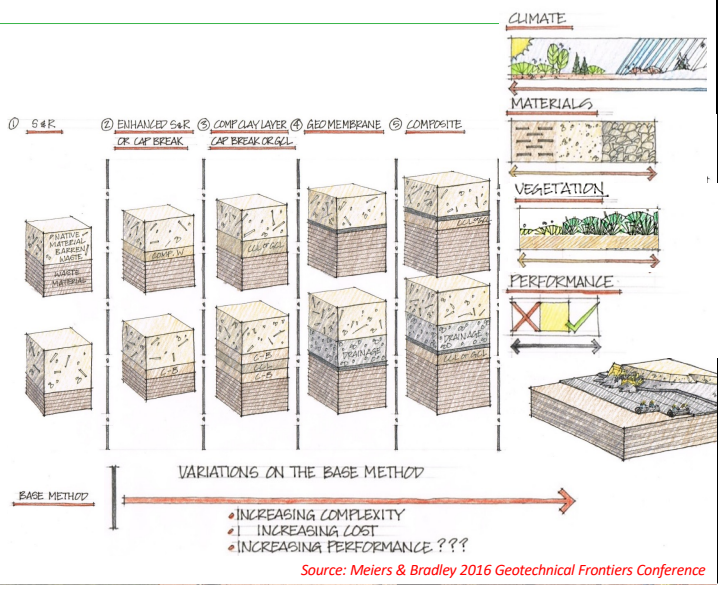
Presentation Outline

- Cover System Types
- Tailings Storage Facility (TSF) Cover System Criteria/Objectives
- TSF Cover Blind Case Study
  - Conceptual Model
- Test Cover
- Concluding Comments

Cover System Types

Complexity, Cost, and Performance

- In general, if there is an increase in cost and complexity there will be a reduction in net percolation and oxygen ingress
- However, other factors can influence performance, landscape, landform, foundation/subgrade, and hydrogeology



Source: Meiers & Bradley 2016 Geotechnical Frontiers Conference

Is it working after 20 years

Cover System Types – Objectives

Geosynthetic Barrier Layers

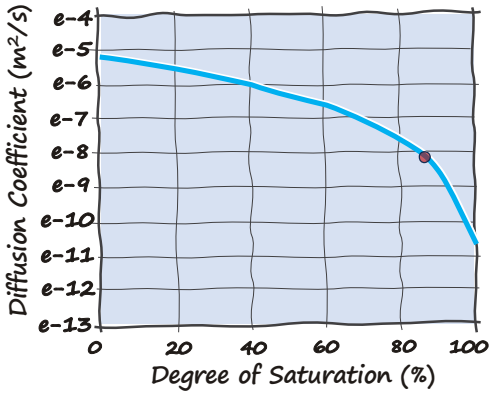
- There are different approaches to waste management
  - Containment - Primarily related to, for example, municipal landfills and contaminated sites.
  - Integration – Focus on mine waste cover systems for tailings storage facilities and waste rock dumps
- Given the recent introduction of geosynthetic barrier layers into the mining industry there is still an association with containment

Source: Meiers et al., 2016 GeoAmericas Conference

Cover System Types

Common Design Criteria for Geochemical Stability

- Limit water ingress and mobilisation of oxidation products
- Limit oxygen ingress and the oxidation of sulfide minerals



Is it working after 20 years

Cover System Criteria/Objectives

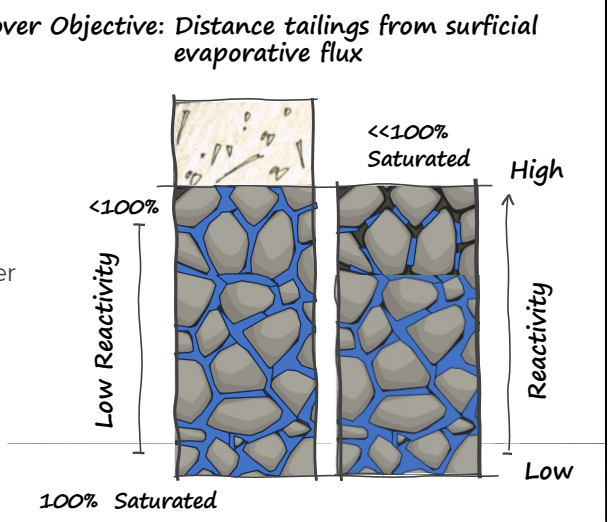
Less Common Criteria/Objectives for Geochemical Stability

Reducer Sulfide reactivity

- Reactivity is related to sulfides %, grain-size, and degree of saturation
- Maintain high degree of saturation and water film around sulfide minerals

$$k_r = k' \frac{6}{D_h}(1-n)C_p$$

D_h = equivalent particle diameter
n = total porosity
C_p=dry tailings sulfide concentration
k'= reactivity constant



Is it working after 20 years

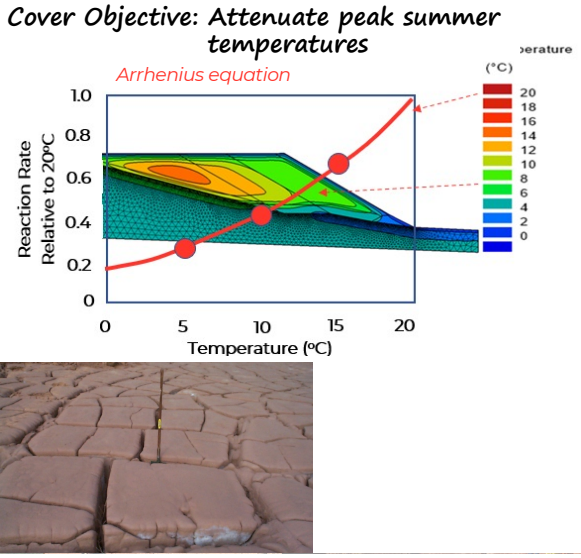
Cover System Criteria/Objectives

Less Common Design Criteria/Objectives

Geochemical Stability

Reduce sulfide reactivity

- Moderate peak summer surficial temperature, oxidation relative to Arrhenius equation
- Surficial tailings in summer exposed to solar radiation could be >30°C, but under a cover profile likely reach ~5°C



Is it working after 20 years

Cover System Criteria/Objectives

Less Common Design Criteria/Objectives

Geochemical Stability

Clean runoff

- Provide non-contact runoff mine water that can be discharged directly to the receiving environment or dilute mine water discharge point
- Cover does not need to be a barrier cover

Cover Objective: Provide non-contact runoff

Is it working after 20 years

Case Study - Closure Objectives

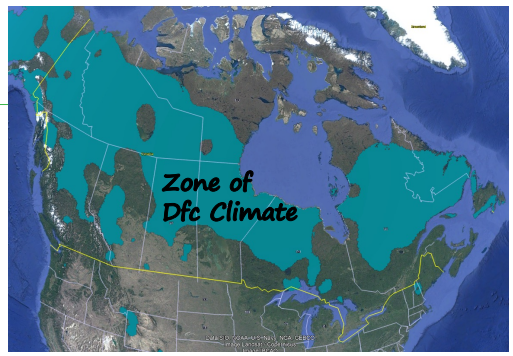
- Ten (10) closure objectives were established at the conceptual stage of the project
- While all closure objectives are important, two closure objectives guided the project and are as follows:
  1. To the extent possible reduce the number of dykes, minimize future dyke maintenance, raises, and future construction
  2. The cover system, landform, and foundation clay will attenuate ML/ARD to limit environmental loadings that will not exceed downstream long-term water quality criteria

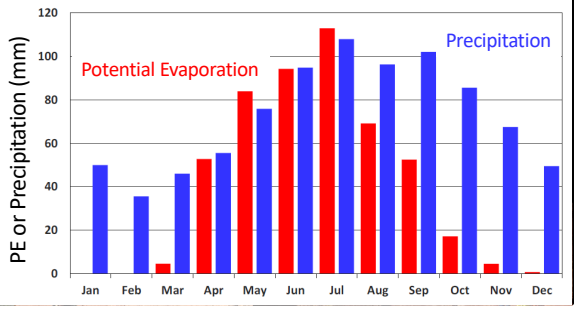
Is it working after 20 years

Background Information

Site Locations / Climate

- Canadian base metal mine that operated for over four decades
- Continental sub-arctic, Koppen-Geiger Climate:
  - Dfc, cold, without dry season, cold summer
- Rainfall ~900 mm/yr & potential evaporation is ~500 mm/yr





Background Information

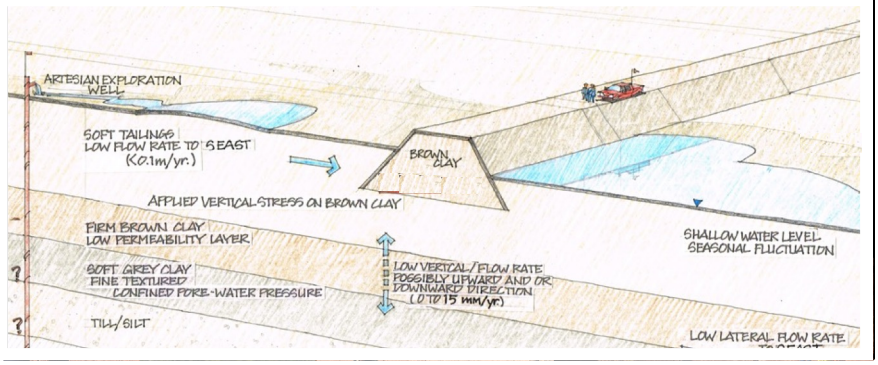
Landscape:

- Tailings are deposited in a topographic low, former lake, and primarily contained within the natural landscape
- Dykes are constructed primarily at the outflow and inflow to the former lake
- Tailings are fine textured (40 to 60% fines) and given the depositional environment have a low bearing capacity
- Challenge: Cover design must accommodate non-uniform settlement and low bearing capacity

Background Information

Lateral and vertical flow

- Thick subgrade clays have a low permeability, similar to a compacted clay liner (<1x10-7cm/s)
- Recharge to foundation clay ~20 mm/year
- Water level is shallow

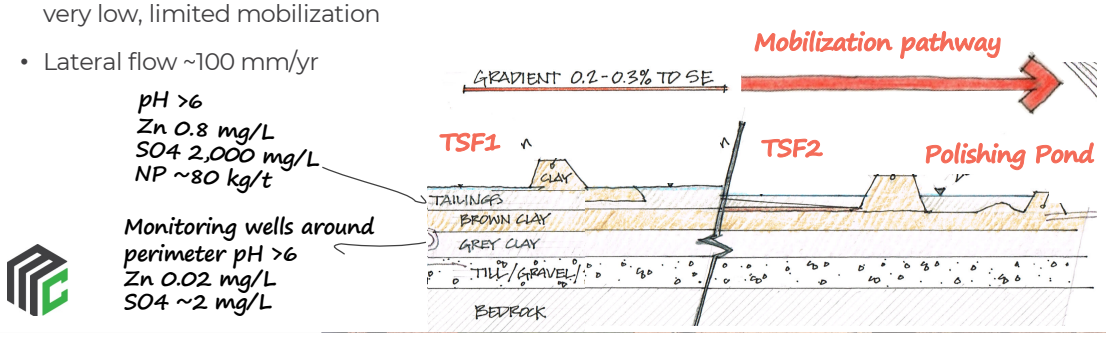


Background Information

Lateral and vertical groundwater / subsurface flow

Tailings are almost integrated into the environment

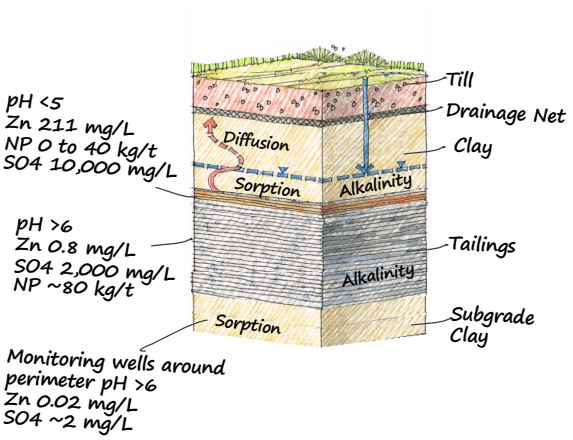
- Landform has an estimated 0.2% to 0.3% slope
- Lateral and vertical flow within the fine textured tailings and foundation clay is anticipated to be very low, limited mobilization
- Lateral flow ~100 mm/yr



Cover System Alternatives, #1

Cover Alternative #1 Diversion Cover

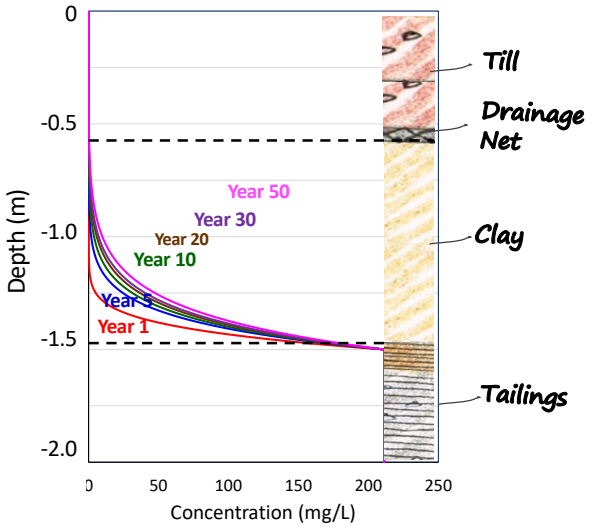
- Primary mobilization pathway for ML/ARD is diffusion up from tailing into the cover and discharged with runoff / lateral drainage
  - This is suppressed with a low net percolation rate, as little as 15 to 30 mm/yr
- The landform limits lateral flow / transport
- Alkaline tailings provide in-situ source control
- Subgrade clay provides low flow and sorption of metals



Simulated Results, #1

Cover Alternative #1, Diversion Cover

- Simulations were complete to assess the diffusive transport of metals from the tailings
- Low rates of net percolation ~15 to 30 mm/year were noted to supress metals transport
- Performance criteria was noted to be a low rate of net percolation by the subgrade clay

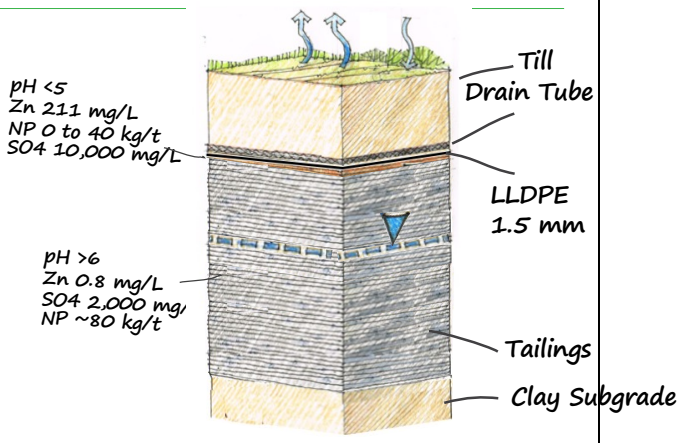


Cover System Alternatives, #2

Cover Alternative #2

Geomembrane Cover

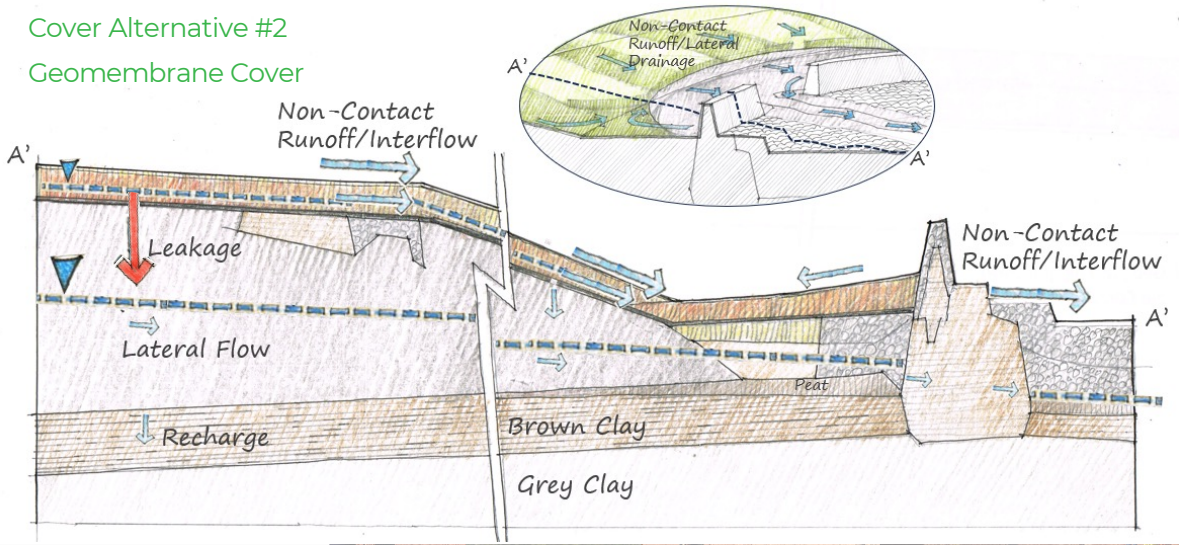
- Geomembrane provides a physical barrier
  - Design criteria to provide non-contact runoff
  - Provide / if required dilution in the polishing pond
  - What about net percolation / leakage
- Leakage may elevate the phreatic surface… But likely not influence discharge water quality
- Mobilization of ML/ARD would be controlled by water flow through the landform



Loading Model, #2

Cover Alternative #2

Geomembrane Cover

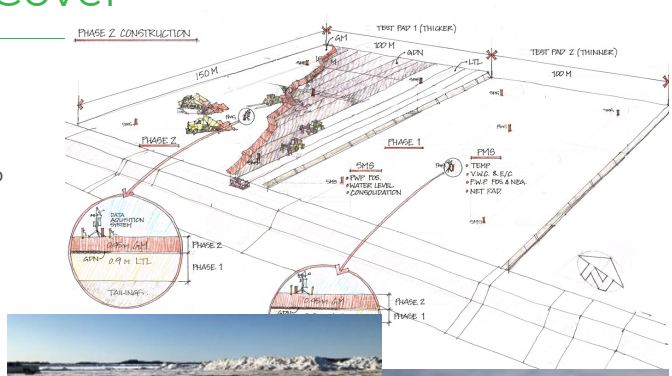


Constructability Test Cover

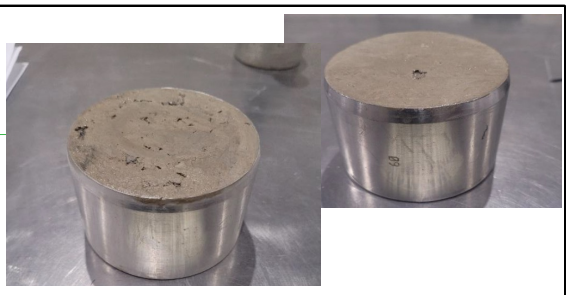
Cover Alternative #1
Diversion Cover

Objectives: Test cover was constructed over two years to:

- Assess constructability aspects over low load bearing capacity tailings and assess parameters that influence performance
- Demonstrate low net percolation rates to supress metals transport and meet discharge water quality criteria
- Gain context for other factors that may influence performance, cover thickness, drainage net, physical conditions



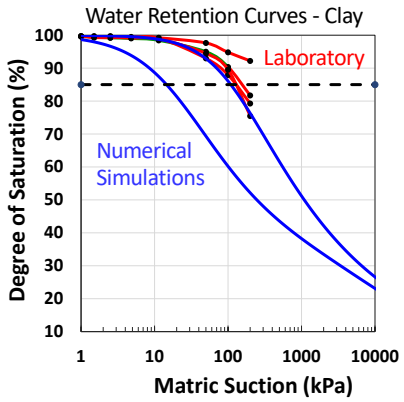
Constructability Test Cover



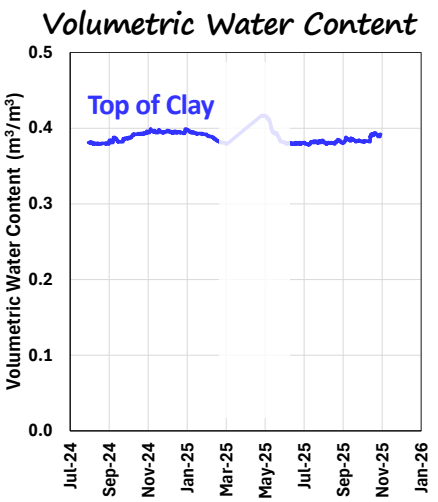
Cover Alternative #1 Diversion Cover

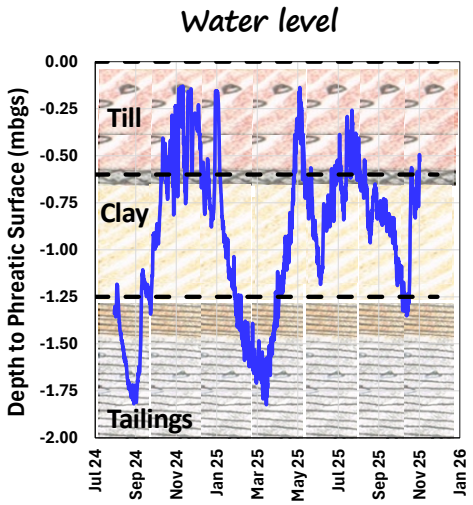
Characterisation

- Water Retention Curves
  - Undisturbed clay samples of the tailings and clay were collected
  - Clay appeared to be uniform albeit with some observed pocks / structure
  - The clay, with winter placement and nominal traffic compaction provided good water retention properties



Constructability Test Cover – Measured Performance

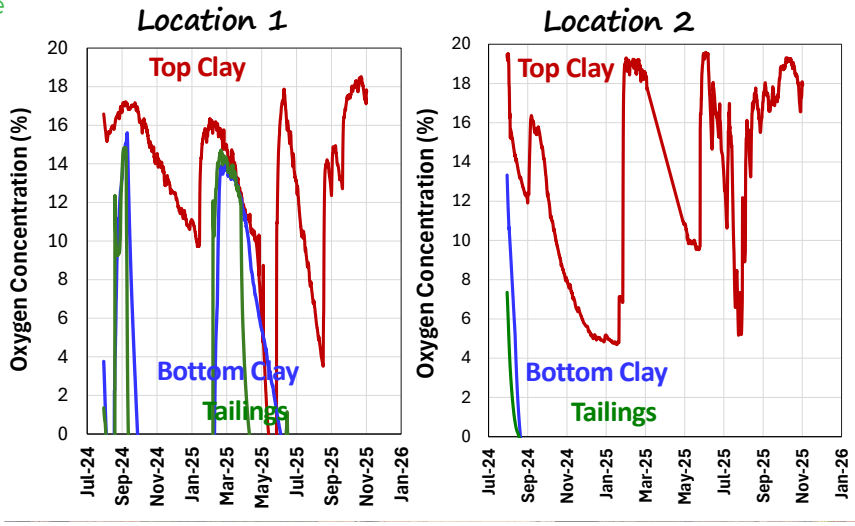




Constructability Test Cover

Measured Performance

- Oxygen is not a design criteria
- Winter / water level induced oxygen ingress at Location 1
- The depletion in oxygen is primarily due to water levels, not consumption
- Tailings have a low reactivity / oxidation rate



Presentation Summary Points

- Don't get caught up in explaining the process, explain the risk
- The cover systems are one component of the closure strategy, identify these opportunities within your mine site domain
- Covers can be constructed over low load bearing capacity systems / tailings
- Cover system design criteria / objectives may change over the design / assessment period


GREENROAD
MINE WASTE MANAGEMENT
HYDRO GEOCHEM GROUP
MINE CLOSURE MANAGEMENT
GEOCONTAM RISK MANAGEMENT
RESOURCESTACK