Geochemistry and Microbiology of Historic Waste Rock Piles at the Detour Lake Gold Mine, Ontario

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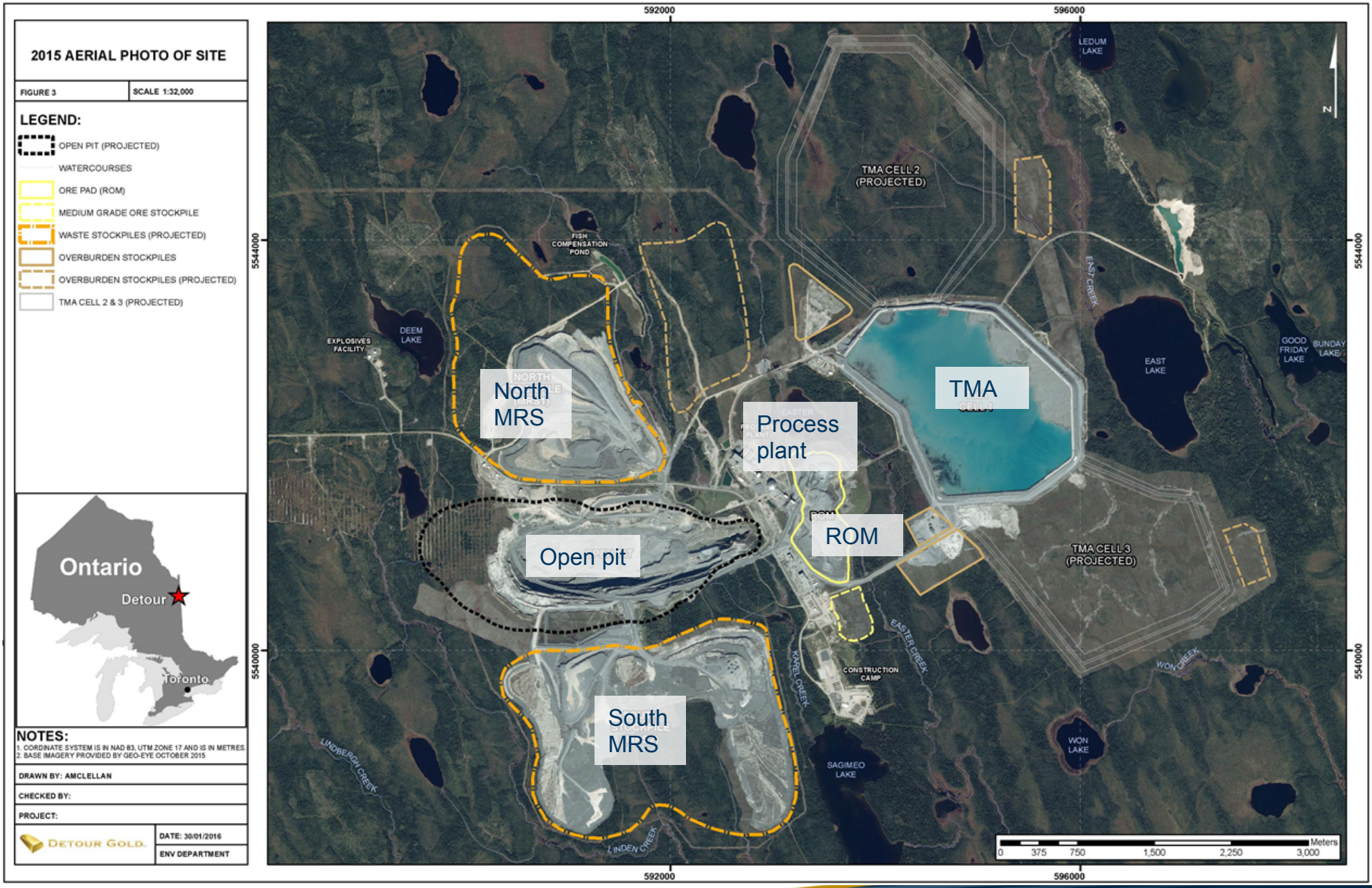
BACKGROUND
information

- Located in Northern Ontario
- Mine site built 2010 to 2012
- Open pit
- In 4th year of production
- Mine life of 22+ years
- Mill process rate ~60,000 tonnes per day (tpd)
- Mine rate ~250,000 tpd
- Projected to manage 1.6 BT of waste rock


2015 AERIAL PHOTO OF SITE
FIGURE 3
SCALE 1:32,000
LEGEND:
OPEN PIT (PROJECTED)
WATERCOURSES
ORE PAD (ROM)
MEDIUM GRADE ORE STOCKPILE
WASTE STOCKPILES (PROJECTED)
OVERBURDEN STOCKPILES
OVERBURDEN STOCKPILES (PROJECTED)
TMA CELL 2 & 3 (PROJECTED)
Ontario
Detour
Toronto
NOTES:
1. CORDINATE SYSTEM IS IN NAD 83, UTM ZONE 17 AND IS IN METRES.
2. BASE IMAGERY PROVIDED BY GEO-EYE OCTOBER 2015
DRAWN BY: AMCLELLAN
CHECKED BY:
PROJECT:
DETOUR GOLD
DATE: 30/01/2016
ENV DEPARTMENT
592000
596000
5544000
5540000
LEDUM LAKE
TMA CELL 2 (PROJECTED)
FISH COMPENSATION POND
EAST CREEK
EXPLOSIVES FACILITY
DEEM LAKE
EAST LAKE
GOOD FRIDAY LAKE
SUNDAY LAKE
North MRS
Process plant
TMA
ROM
Open pit
TMA CELL 3 (PROJECTED)
CONSTRUCTION CAMP
EASTER CREEK
KAREL CREEK
WON CREEK
South MRS
WON LAKE
SAGIMEO LAKE
LINDBERGH CREEK
LINDEN CREEK
N
Meters
0
375
750
1,500
2,250
3,000

Geochemistry Ranking of DGC site

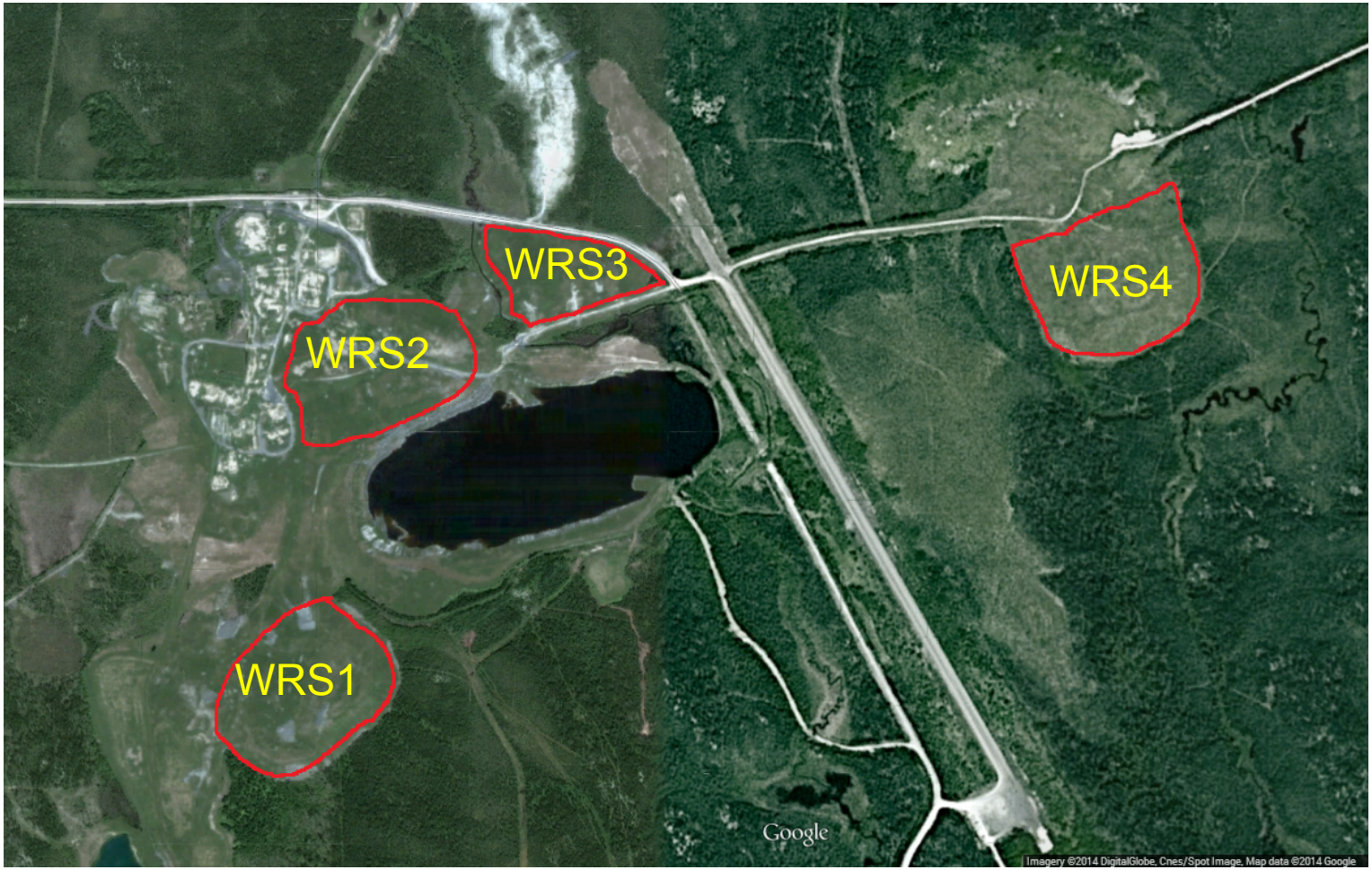
1. Site waste rock has median sulfur level of 0.2 wt.%, on the lower end of scale of ARD risk (range from 0.01 to 7 wt.%)
    - Primary minerals are pyrite, pyrrhotite, chalcopyrite
2. The neutralization minerals in the waste rock are primarily calcite, averaging 4 wt.%
3. Trace metals in the rock are below reference levels of concern (10x basalt reference) with exception sulfur, but are being monitored.
4. With the low sulfides, low trace metals, and available carbonates, the Detour site is in the lower area of ML-ARD risk when compared to global case histories.

Detour Lake Gold Mine - Site History

1. The site had 17 years of operation by Placer Dome (1983-1999) and 10 years of closure before Detour Gold commenced development

2. Five waste rock piles deposited by Placer Dome between 1983 and 1999 did not appear to be reactive
   - Soil cover was added to all waste rock piles at closure in 2000 to reduce future AMD
   - Monitoring showed only minor seasonal seepages
   - *No serious water quality detected during the 17 years of mine operation or in the 13 year post-closure period*

Detour Lake Mine at Closure



Focus of Current Research

- Many ARD research projects ask ‘How did ARD develop in waste rock piles and how can it be stopped?’

In support of their closure planning and risk management programs, Detour Gold reversed the question and asked:

- Why is ARD **NOT** occurring at this site?
- What conditions need to be created in the new waste rock piles to prevent ARD from developing?
- What can we learn from the historic waste rock piles to minimize ARD risk in the future?

DGC Waste Rock Research Program

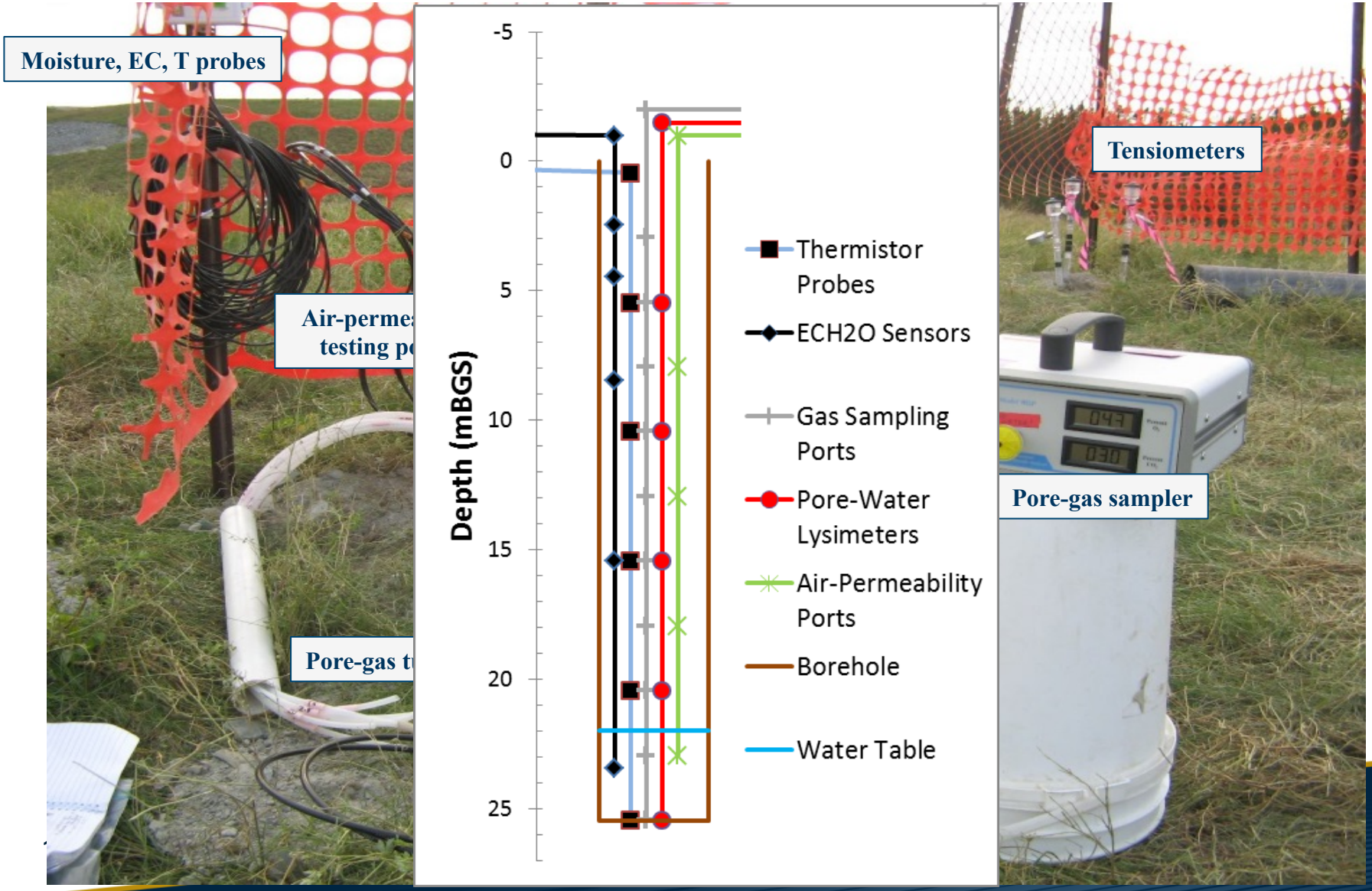
- Phase 1: In 2011, DGC started waste rock studies with University of Waterloo (UW). The project received a NSERC CRD grant to match DGC funds.
  - Coapplicants University of Alberta and Carleton U
  - 2 MSc students have graduated, 1 MSc near completion
- Phase 2: In 2015, UW with DGC support received a new NSERC CRD grant for five more years
  - 4 more graduate students and some coop students
- These research studies are based on 30+ years of waste rock history and will have 20 years going forward, which is unusual for closure planning

Historic Waste Rock Investigation

1. Two original rock piles needed to be moved:
   - Examined the interior while relocating the rock to new locations
   - Waste rock sampling and analysis

2. Two original rock piles were not moved:
   - Instrumented for long term internal observations
   - Borehole instrumentsBorehole instruments

Borehole Instrumentation

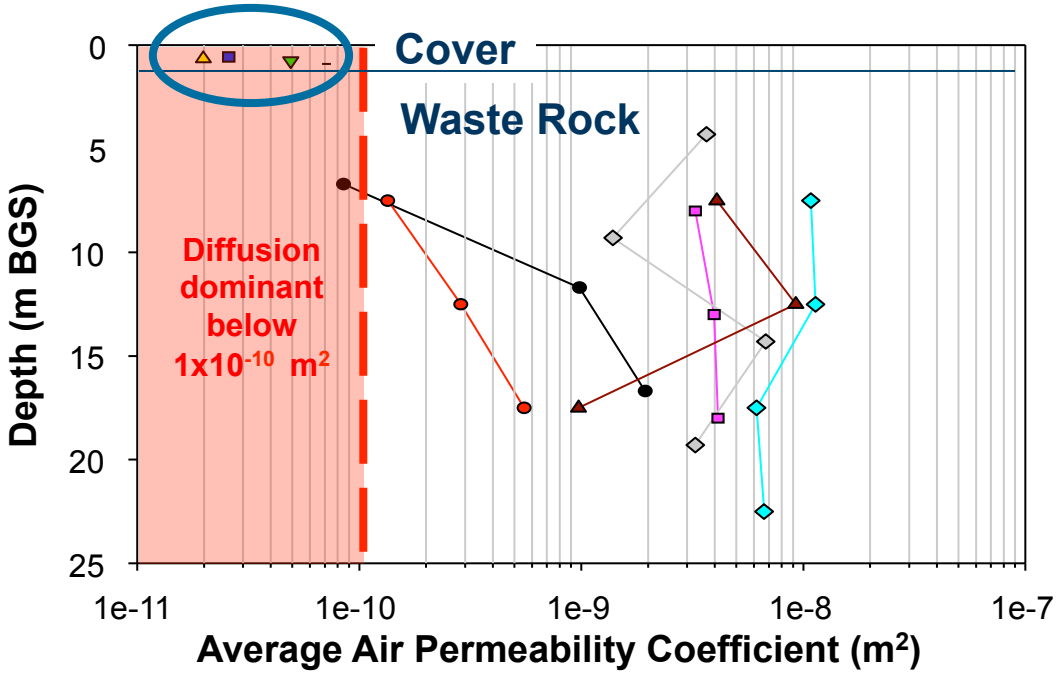


Summary of Investigation

- Summary of Key Findings

Soil Cover Characteristics

- The cover is a 0.3-1 m thick mix of overburden silt, sand and boulders
- Air permeability measurements:
  - gas permeability of the waste rock is high
  - cover is much less permeable and restricts advective gas transport
  - cover should reduce the rate of sulfide oxidation

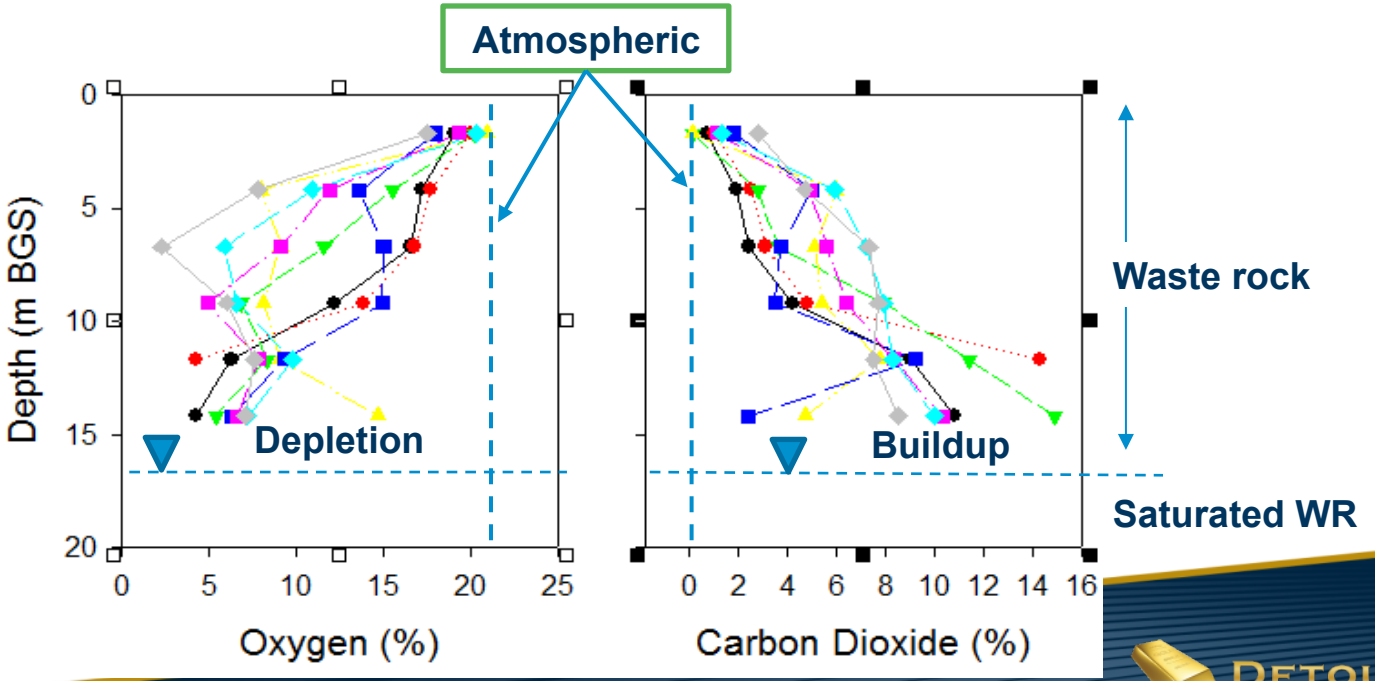


Waste Rock Pore Gas

- Soil gas measurements confirm that sulfide oxidation and pH neutralization by carbonate dissolution are occurring in the waste rock piles
- Sulfide oxidation consumes O_2
  - O_2 depletion at depth indicates that the cover restricts replenishment of atmospheric O_2
- Carbonate mineral dissolution releases CO_2 to the pore gas
  - CO_2 increase at depth indicates that the cover traps CO_2

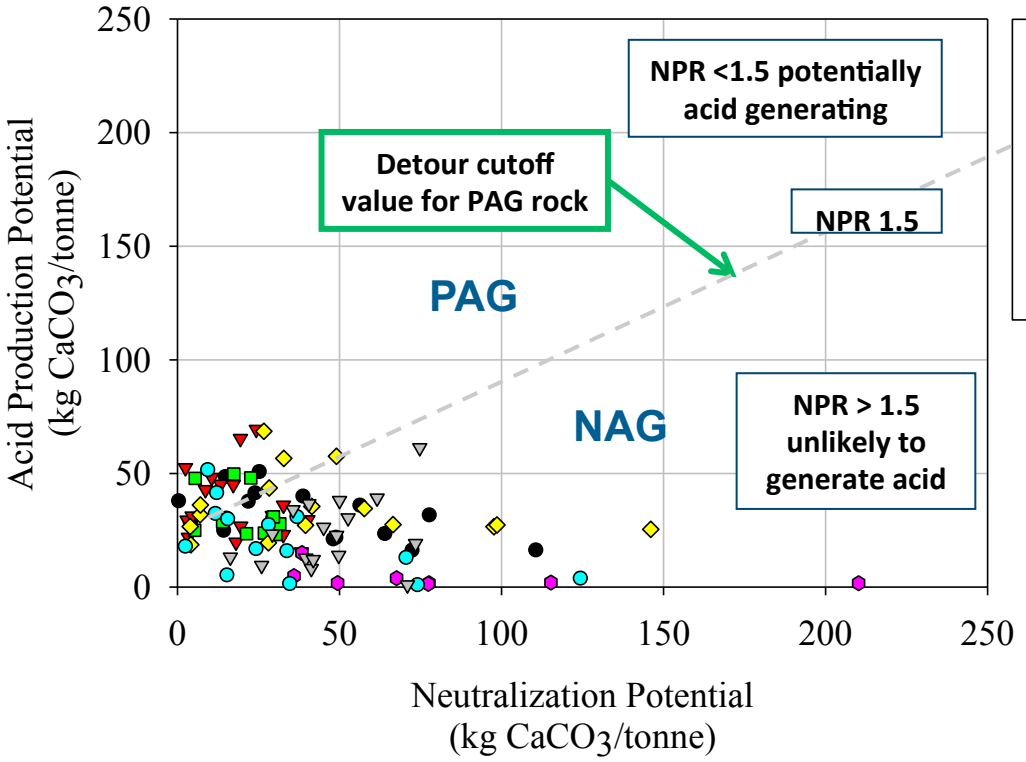
$$CaCO_3 + 2H^+ \rightarrow Ca^{2+} + CO_2 + H_2O$$

- Cover restricts (but does not stop) gas transport, limits rate of oxidation



Waste Rock Acid-Base Analysis

- ABA measurements indicate that historic WRS 1, 2 and 4 are unsegregated mixtures of PAG and NAG rock
  - Have higher PAG content than new waste rock (see table)
  - This historic waste rock is similar to the new PAG piles
- WRS 3 has lower S content, mostly NAG; similar to new NAG piles

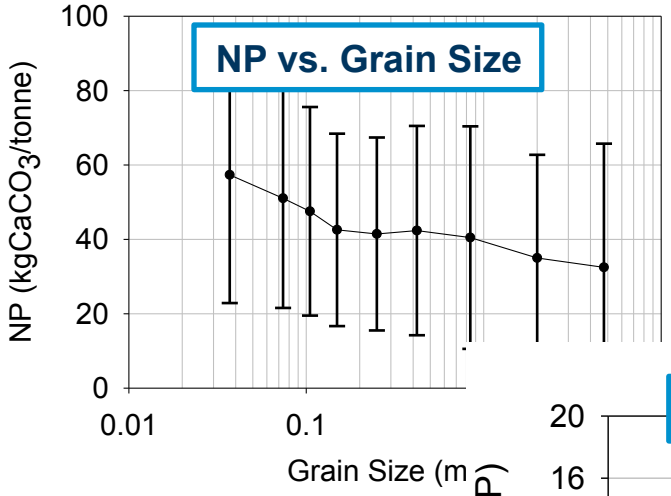


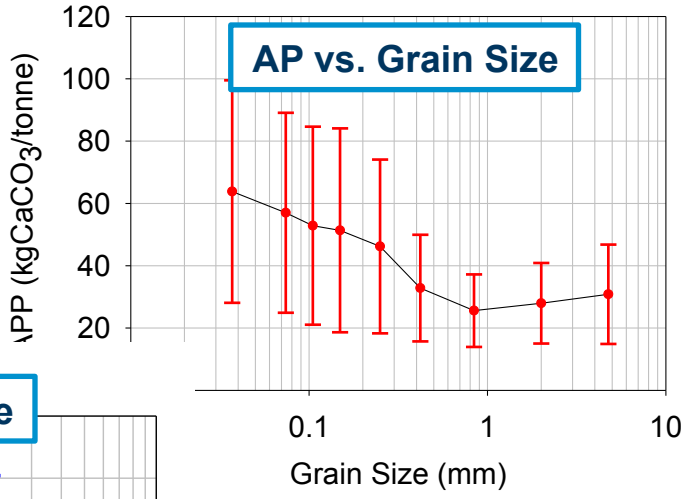
NPR = NP/AP
NPR < 1.5 = PAG

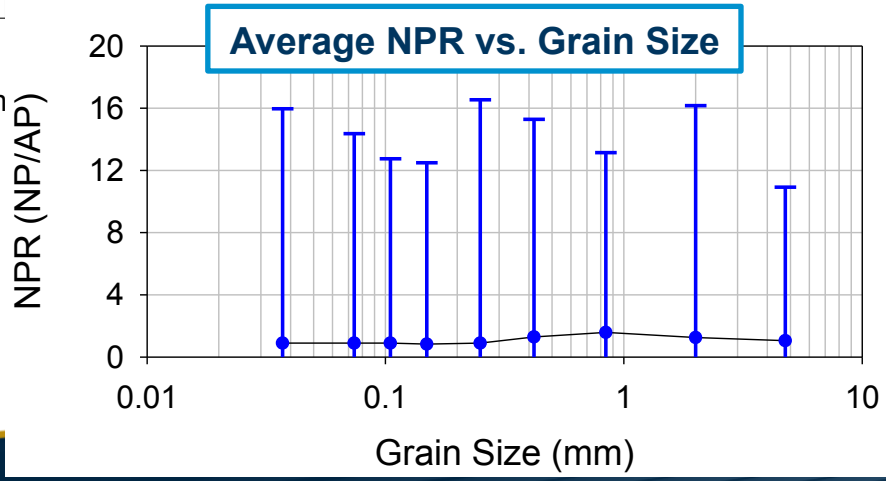
	# of Samples	% PAG (NPR < 1.5)
WRS1	42	62 %
WRS2	29	72 %
WRS3	16	0 %
WRS4	31	47 %
New rock		20 %

Potential Reactivity vs Grain Size

- Analysed carbon (NP) and sulfur (AP) content versus grain size to identify relationships between reactivity of the waste rock particles and grain size
- Fine fractions in the waste rock are enriched in both carbon and sulfur
- Resulting neutralization potential ratio (NPR) is consistent across the range of grain sizes, indicating no preferential reactivity vs grain size



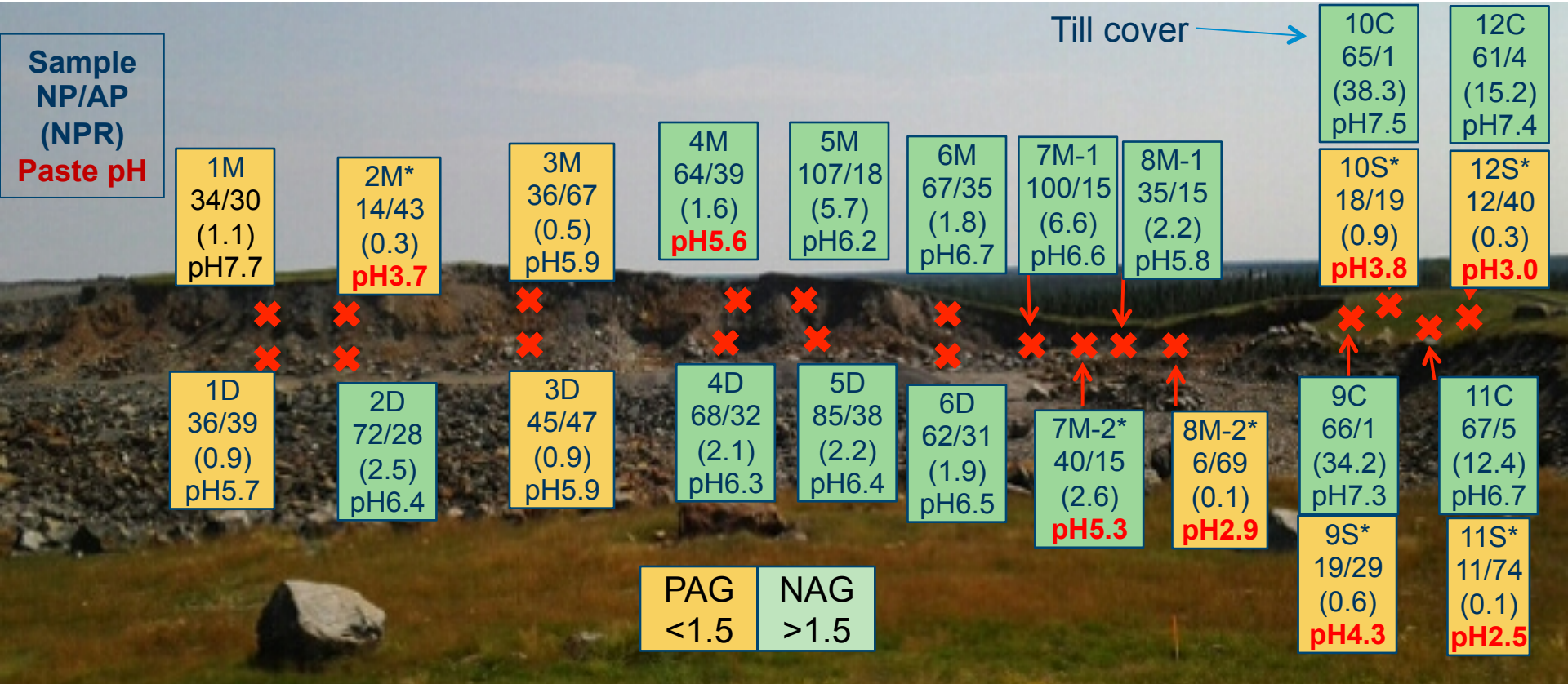




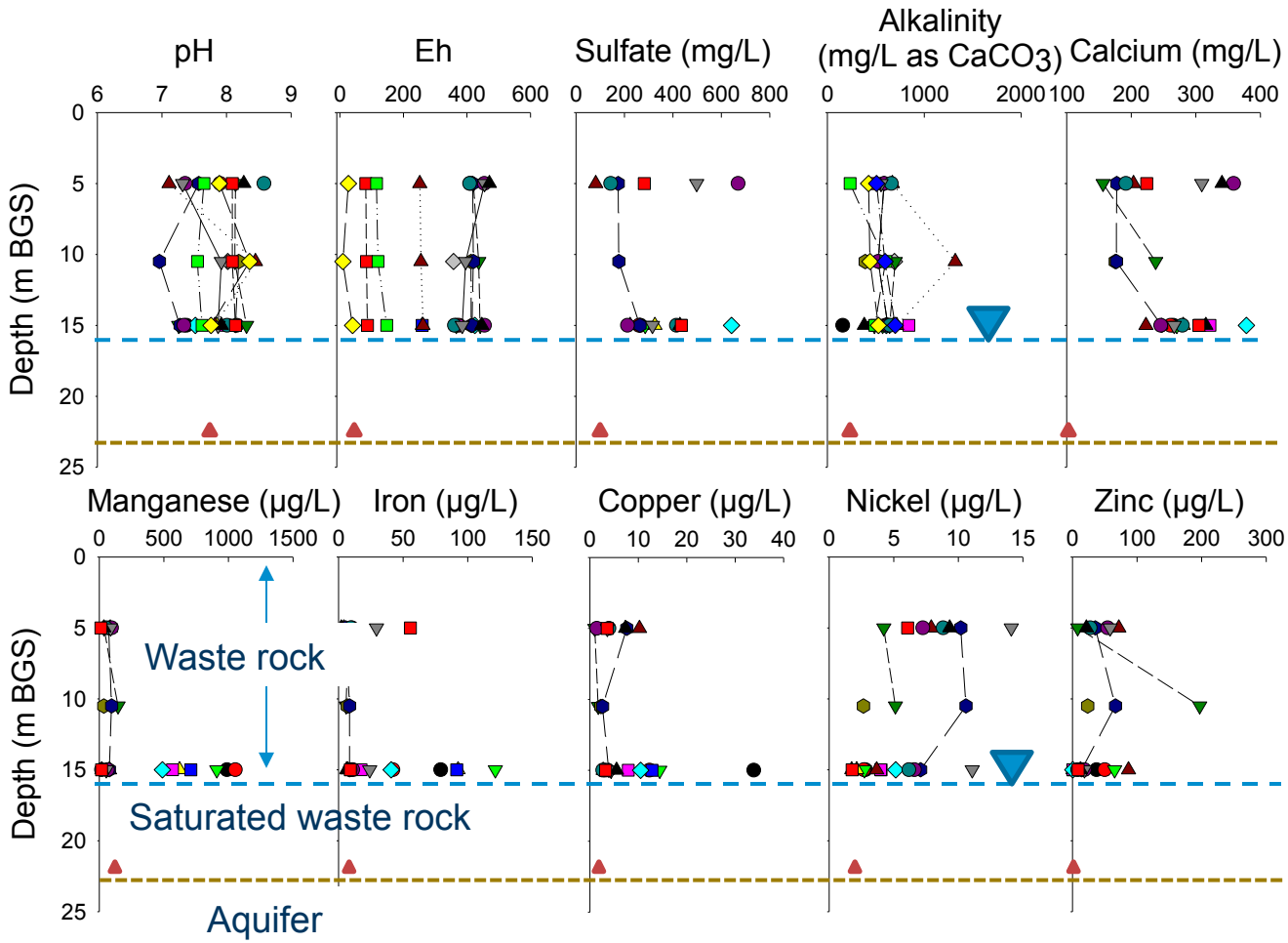
Showing average and 1 StdDev
NPR = NP/AP

Waste Rock Distribution and Paste pH

- Paste pH identifies
  - Localized PAG zones with reactive sulfide oxidation and acidic pH
  - Extensive zones of neutral pH, due to active carbonate mineral dissolution
- No pattern to these zones – the PAG and NAG rock are intermixed
- The high NP of the waste rock mixture has limited the development and extent of acidic conditions for more than 30 years



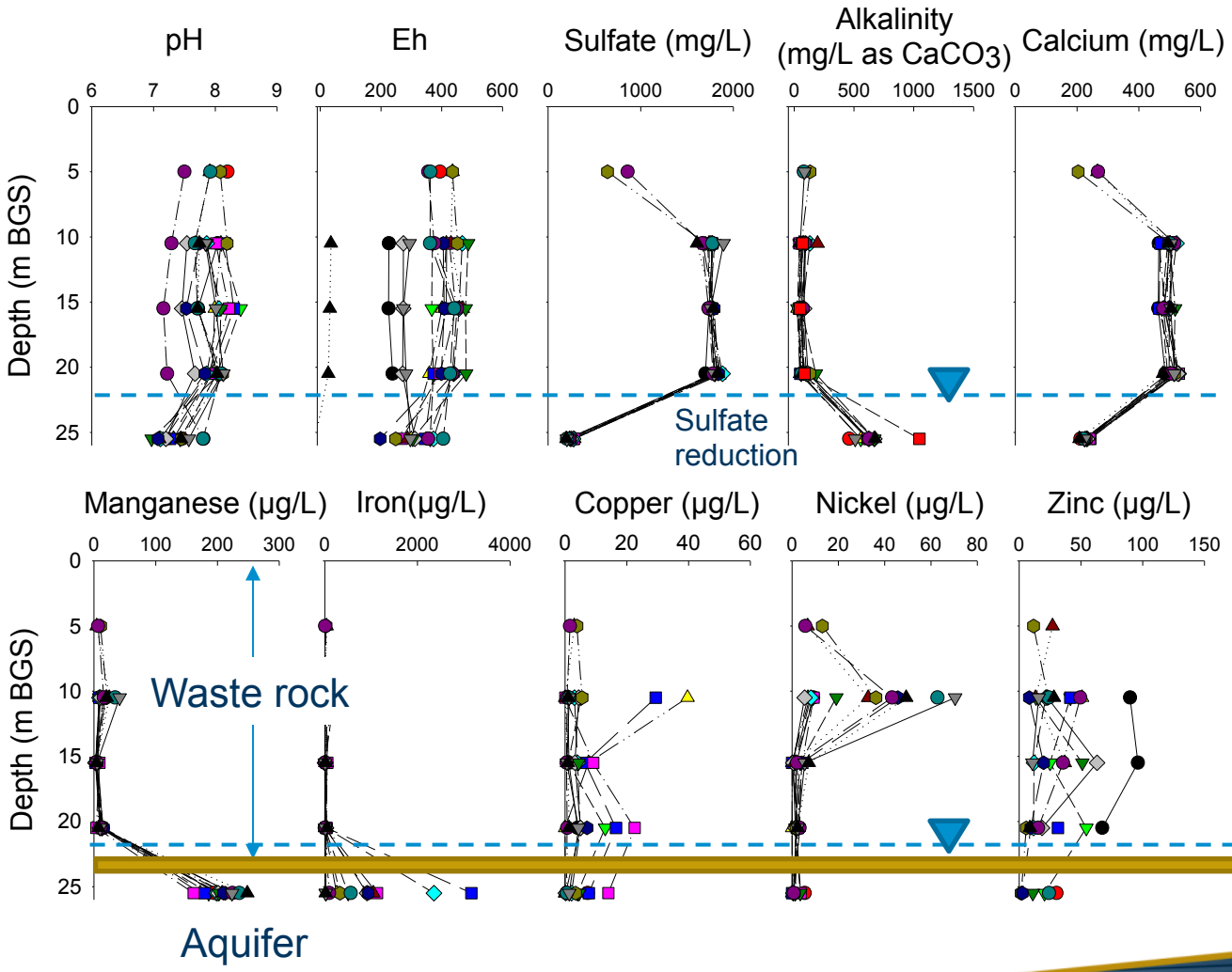
Porewater Chemistry - Waste Rock Matrix



WRS 3

- Mostly NAG rock, little PAG
- Gases show that sulfide oxidation is occurring
- Low PAG content = Neutral pH, attenuation leading to low concentrations of metals & SO_4
- Cover contributes to low rate of oxidation & low release of metals
- Composition of WRS 3 is similar to new NAG dumps at the mine
- New NAG dumps may have similar chemical behaviour

Porewater Composition - Waste Rock Matrix

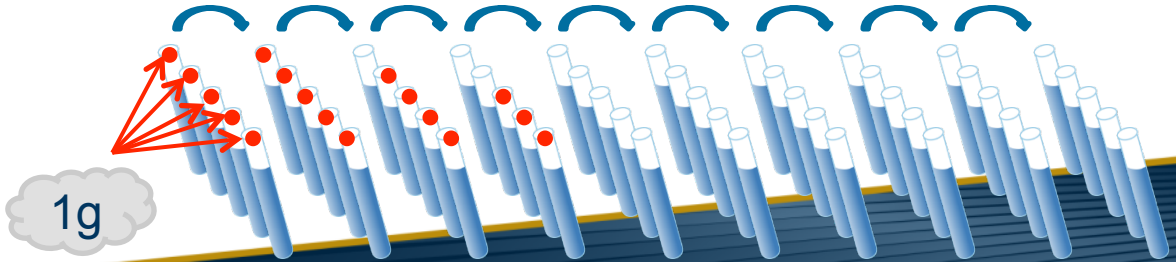


WRS 4

- Mostly NAG, some PAG
- Elevated SO_4 (=oxidation)
- Abundant NP leads to neutral pH and metal removal reactions within the stockpile
- Limited evidence of ML-ARD release to aquifer
- Composition of WRS 4 is similar to new PAG rock
- New PAG dumps may have similar chemical behaviour

Microbial Characterization

- Several techniques were used to identify the role of microbial activity in the waste rock
  - DNA analysis of bacteria and fungus at genus level
  - Enumerations of iron and sulfur oxidizing bacteria (SOB)
    - SOBn; neutrophilic sulfur oxidizers
    - SOBa; acidophilic sulfur oxidizers
    - FeO; acidophilic iron oxidizers
- Summary:
- Common AMD-related iron and sulfur oxidizing bacteria are present throughout the waste rock piles
- Acidic conditions promote the dominance of AMD-generating populations
  - SOBn major population at WRS#1
  - FeO also numerous in acidic microenvironments
  - SOBa at low numbers throughout
  - Enrichment of iron and sulfur oxidizing bacteria DNA at low paste pH



Summary

- Our soil gas, porewater chemistry and microbial characterization measurements in the historic waste rock piles indicate
  - Common AMD-related iron and sulfur oxidizing bacteria are present throughout the waste rock piles
  - Sulfide oxidation is occurring
  - The cover and heterogeneous structure of the historic waste rock piles restrict gas transport and sulfide oxidation
  - Metal attenuation reactions are occurring in the waste rock piles
  - The high NP of the historic waste rock mixtures has limited the development and extent of acidic conditions and metal leaching for more than 30 years

Phase 1 Outcomes

- New NAG waste rock is similar to historic WRS 3
- New PAG waste rock piles appear to be similar to WRS1, 2 and 4
    - Expect the new NAG and PAG dumps to behave similar to the old dumps
- In support of their risk management and closure planning, this research indicates that careful management of the new waste rock will help Detour to limit or prevent future ML-ARD releases from their waste rock dumps, for example,
    - by using dump construction methods to disrupt gas transport in the waste rock piles
    - through use of covers that have lower permeability, to limit advective gas transport and downward migration of sulfide oxidation products
- Phase 2 research is moving forward, *e.g.*
    - Grain-scale understanding of the sulfide oxidation and neutralization pathways and rates, to improve predictability of ML-ARD
    - The role of soil covers on water balance, gas transport and ML-ARD

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