Dry Stack Tailings Disposal at the Greens Creek Mine Admiralty Island, Alaska

Pete Condon

Petros GeoConsulting Inc.

Fairbanks, Alaska

19th MEND ML/ARD Workshop

November 28-29, 2012

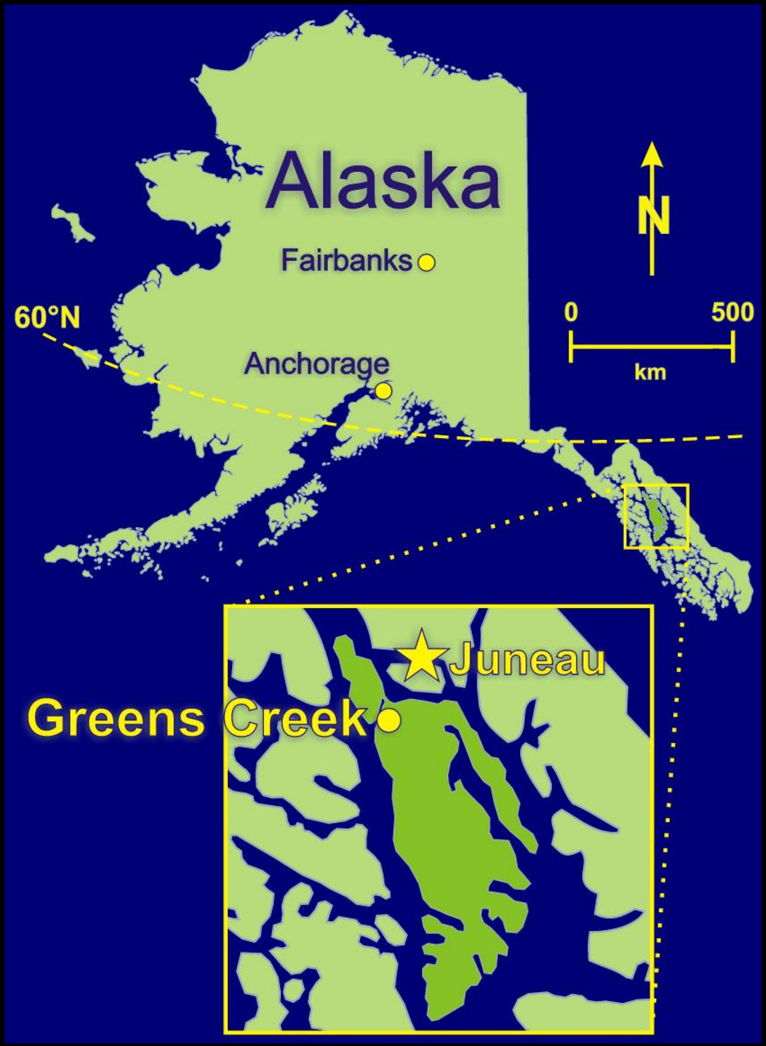
Vancouver, BC, Canada


(Greens Creek file)

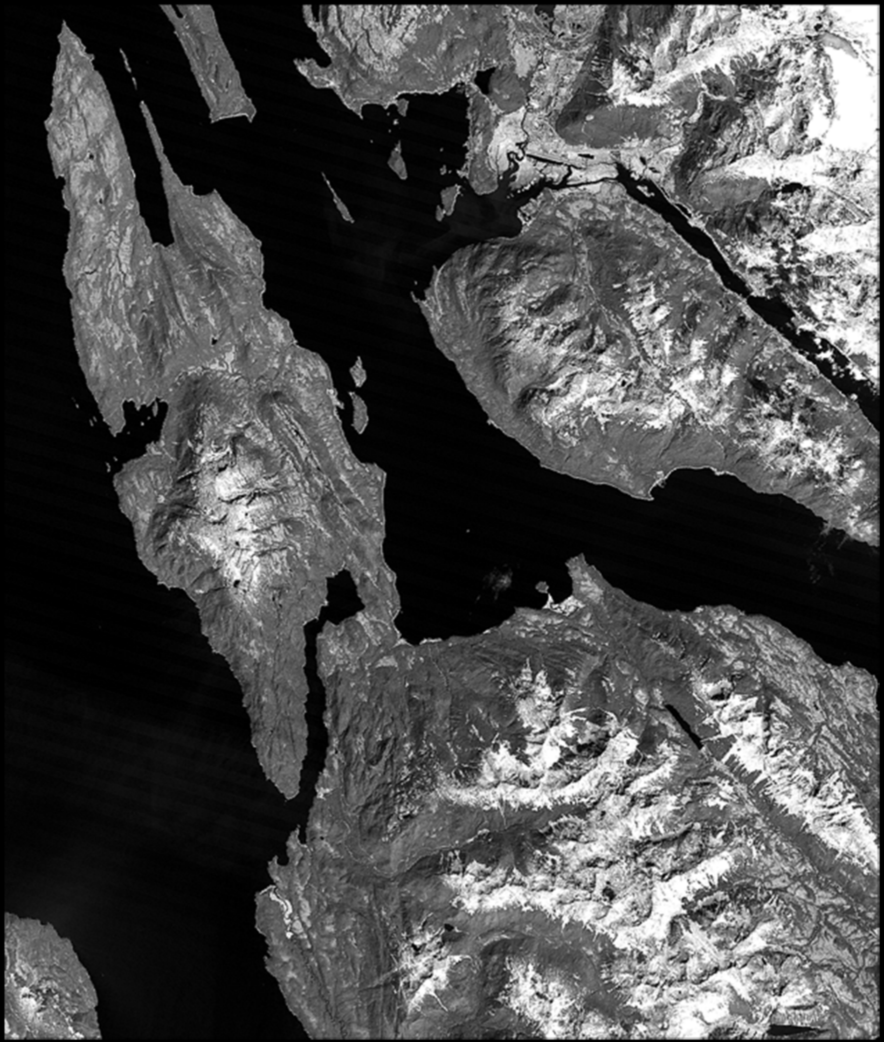
Acknowledgements:
Hecla Greens Creek Mining Company
Matt Lindsay (University of Saskatchewan)
Dave Blowes, Corina McDonald (University of Waterloo)
Luisa Hopp, Jeff McDonnell, Tom Giesen (Oregon State University)
M. Raudsepp & E. Pani, UBC; J. Jambor
O'Kane Consultants Inc.
Ward Wilson (University of Alberta)
Klohn Crippen Berger Ltd.
SRK, SGS/CEMI, USFS, ADEC, ADNR, Kennecott Minerals, Rio Tinto

Outline

- Overview
- Benefits and drawbacks
- Characterization and monitoring
- Minimizing environmental impacts (present and future)
- Conclusions



(M. Lindsay)



(Greens Creek file)

View of northern Admiralty Island and Juneau (upper right)

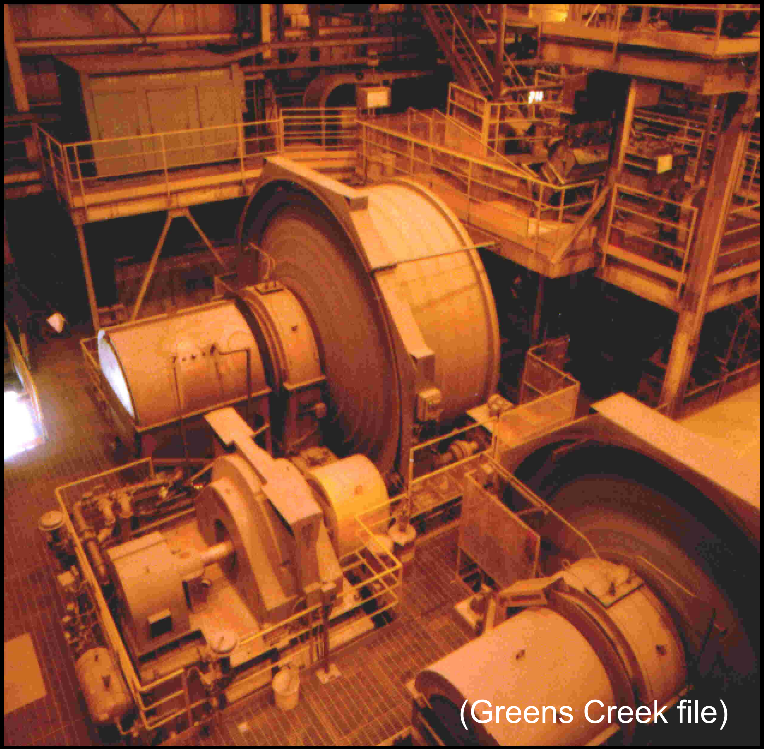
View of Greens Creek tailings pile (~60 acres)

Overview

- Underground Ag, Zn, Au, Pb mine
- Massive sulfide ore; argillite and phyllite host rock
- Production since 1989
- 7+ years remaining (exploration continues)
- ~2100 tons per day throughput (1600 TPD tails)
- 6.3 million tons of surface tailings
- High precipitation (~1400 mm as rain and snow)
- Seismically active area

View of Greens Creek portal (upper left) and mill/shop (right)

Hand sample of deformed Greens Creek massive sulfide



Ball and SAG mills (left) and froth flotation cells (right)

One of three 32-plate Sala filter presses (left). Tailings drop from the presses into load-out bays prior to being loaded into haul trucks or the backfill batch plant.

Views of tailings placement on the Greens Creek dry stack tailings pile. Filter-pressed tailings are spread with a bulldozer and compacted to > 90% standard Proctor density with a vibratory roller.

Views of tailings surface during ‘dry’ (left) and very wet (right) weather conditions

View of Greens Creek tailings pile (2011)

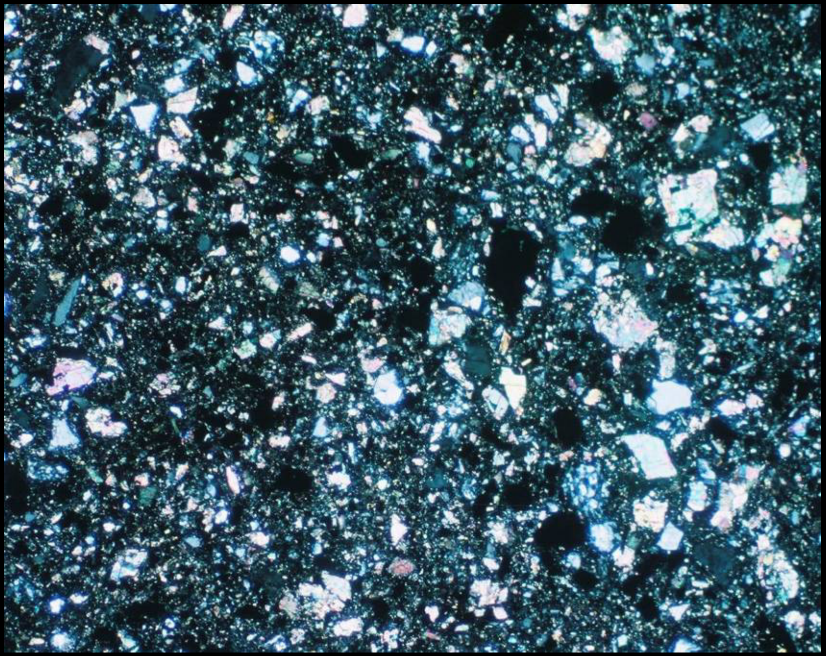
Physical Characteristics

Grain size	Silt, 80% -200 mesh
Limits	LL 19% PL 16% PI 3
In-situ moisture	16%
Opt. moisture	13%
Porosity	40%
Ksat	$2x10^{-6}$ cm/s
Friction Angle	39°
Standard Proctor	2.2 g/cm^3

Tailings Mineralogy

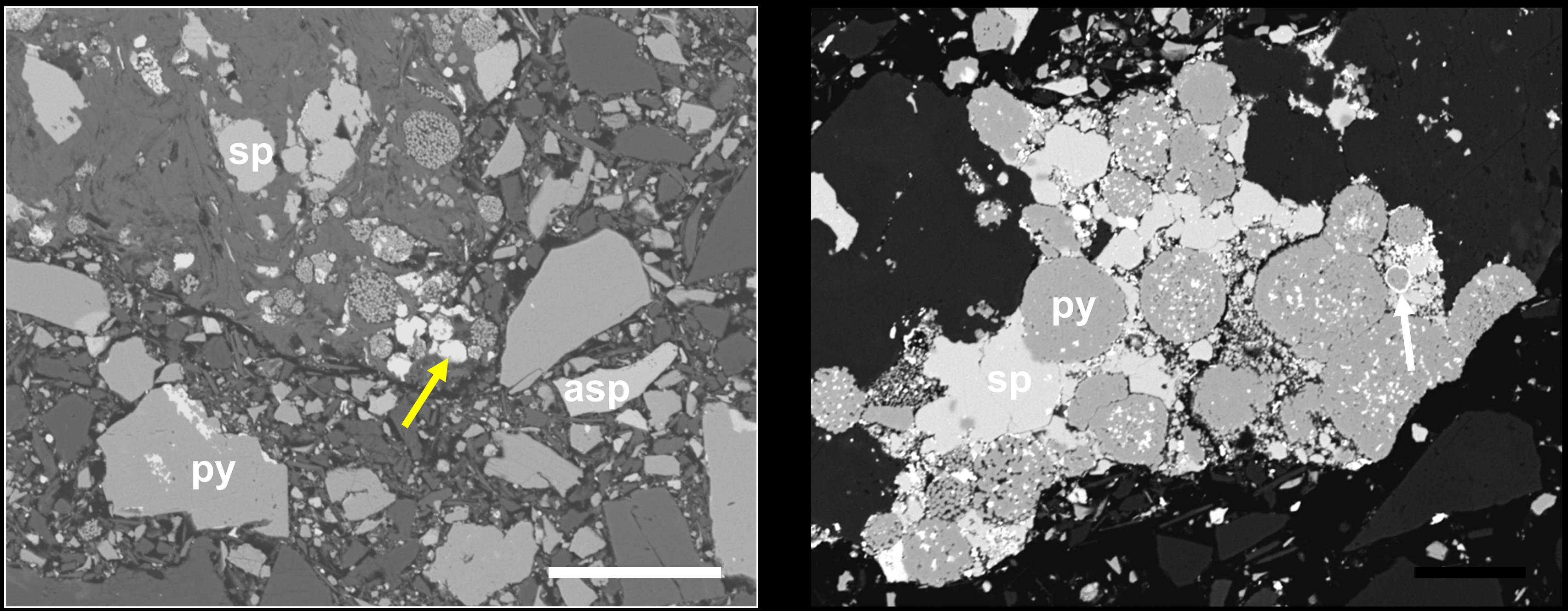
phase	ideal formula	wt. %
pyrite	FeS_2	34.3 ± 4.3
dolomite	$CaMg(CO_3)_2$	27.2 ± 3.0
quartz	SiO_2	12.1 ± 3.6
barite	$BaSO_4$	12.0 ± 3.8
muscovite	$KAl_2AlSi_3O_{10}(OH)_2$	3.8 ± 2.5
calcite	$CaCO_3$	3.4 ± 0.8
sphalerite	$(Zn,Fe)S$	2.5 ± 1.0
cymrite	$BaAl_2Si_2(O,OH)_8 \cdot H_2O$	2.1 ± 0.6
K-feldspar	$KAlSi_3O_8$	1.5 ± 0.6
chlinochlore	$(Mg,Fe)_5Al(Si_3Al)O_{10}(OH)_8$	1.5 ± 0.4
hydroxylapatite	$Ca_5(PO_4)_3(OH)$	1.2 ± 0.3
galena	PbS	0.7 ± 0.2

Results of quantitative XRD by Rietveld refinement (n=12). Arsenopyrite, tetrahedrite and chalcopyrite observed in optical examination.
(from Lindsay 2009)



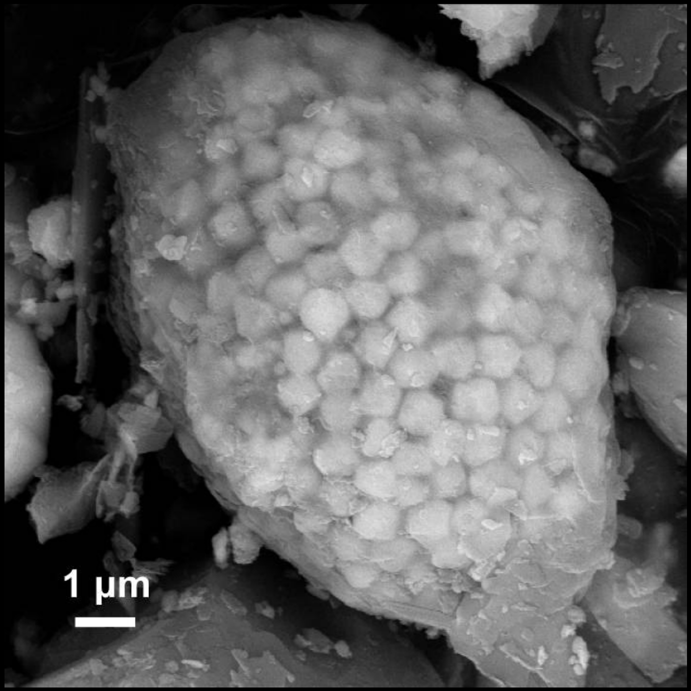
(J. Jambor)

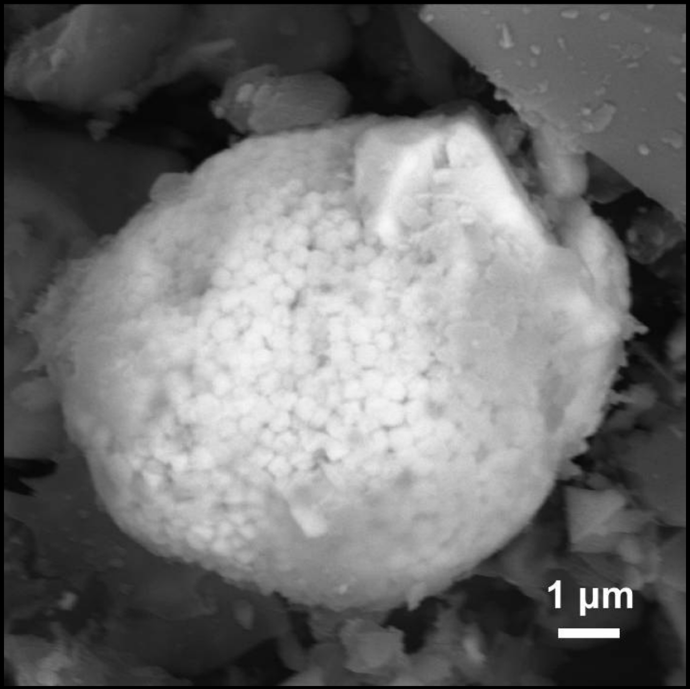
Thin section in plain reflected light (left) and transmitted light with polarizers crossed (right); width of field 2.2 mm.



(M. Lindsay)

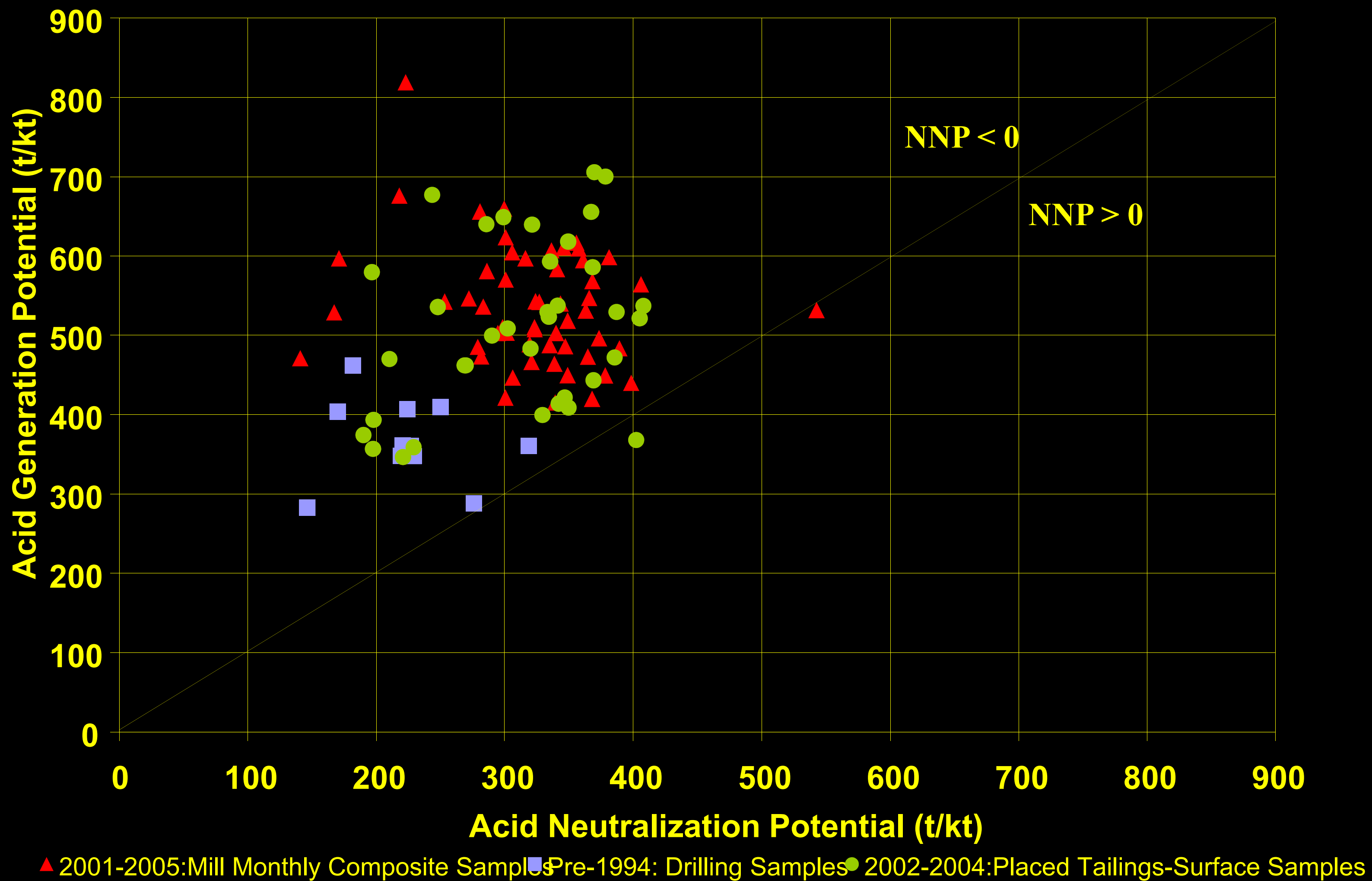
Backscatter electron micrographs of polished thin sections; scale bars indicate 20 μm. arrows point to galena.



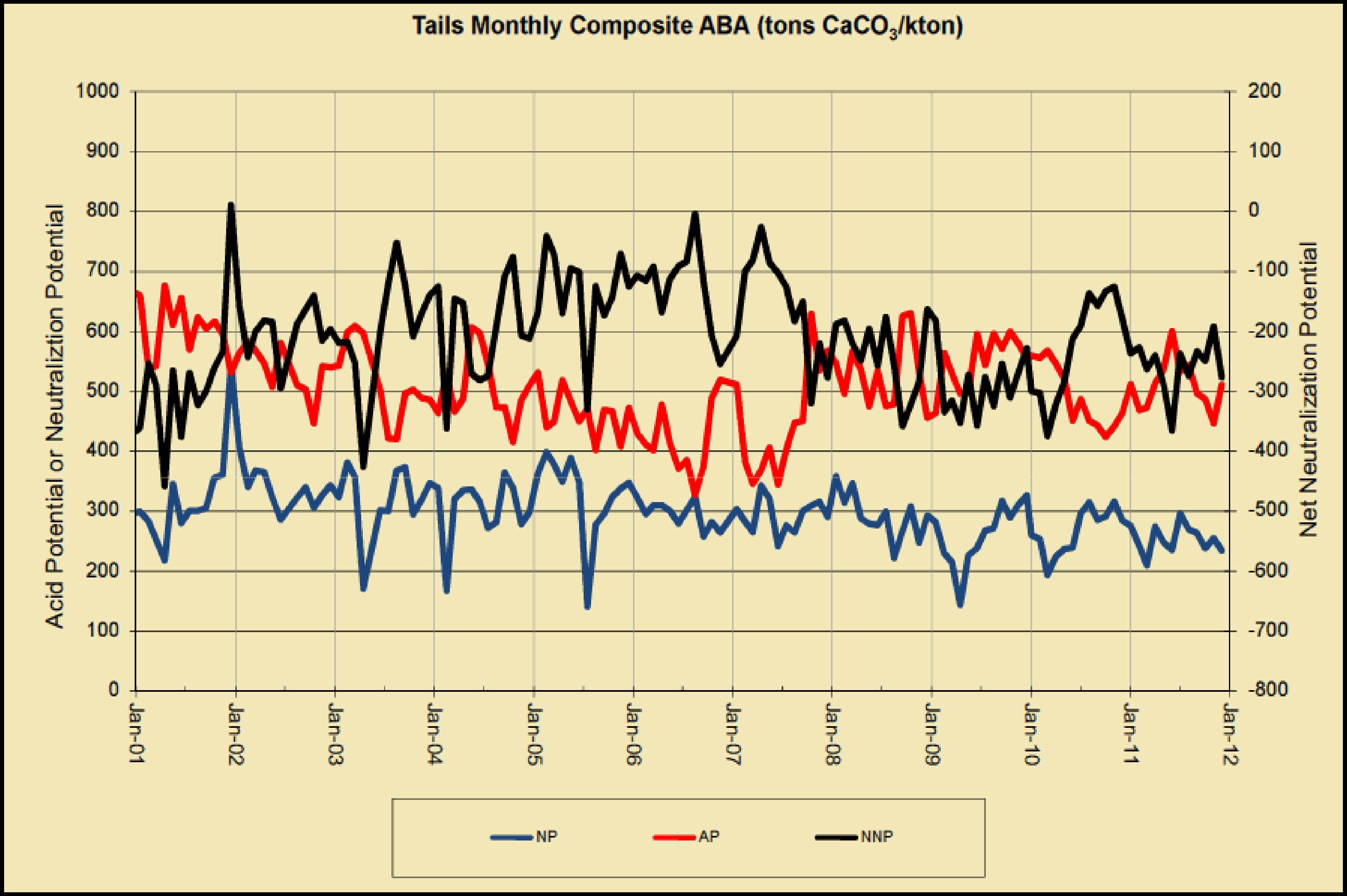


(M. Lindsay)

Backscatter electron micrographs of pyrite framboids in tailings

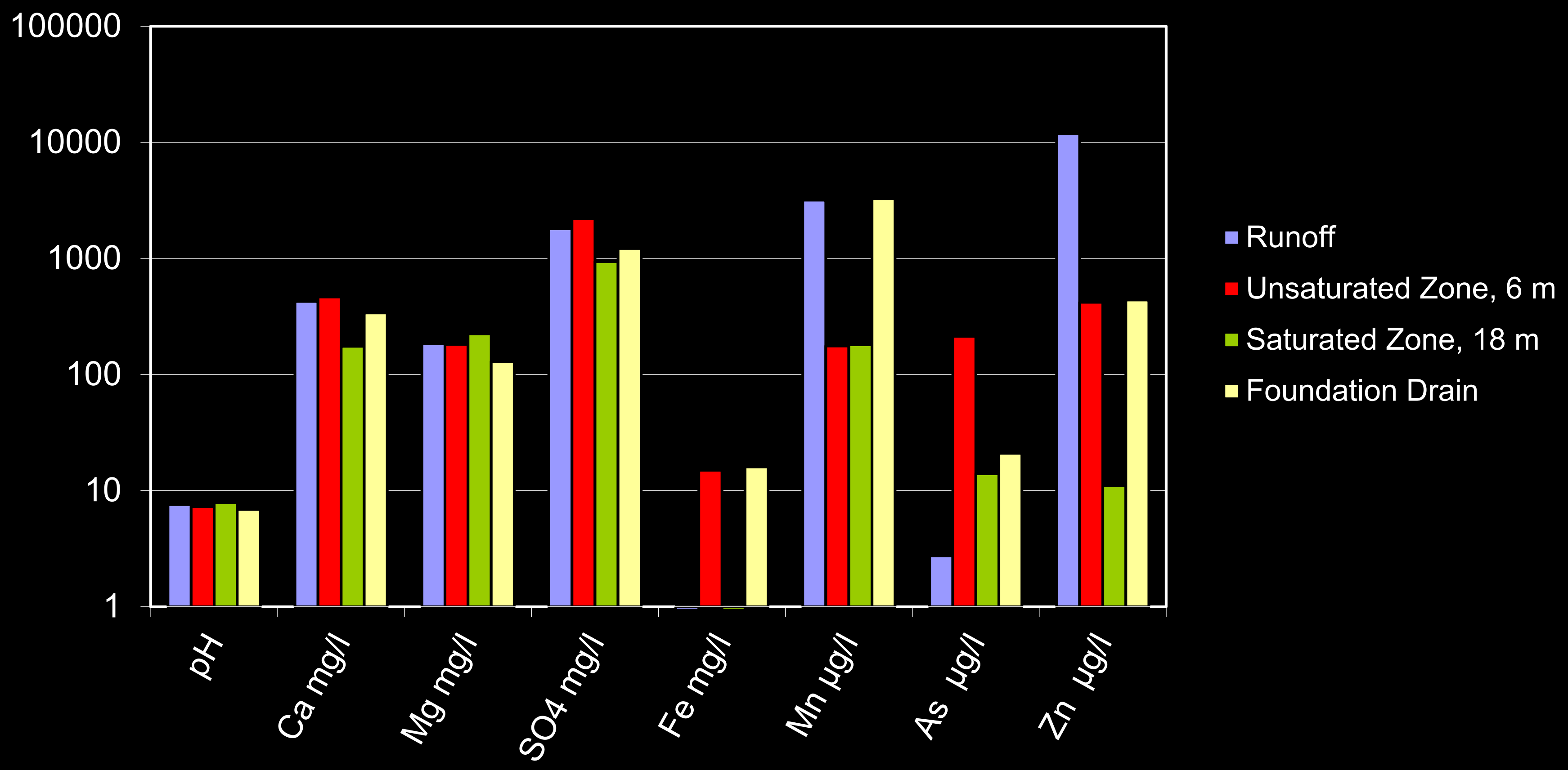


Acid Base Accounting Data



Acid Base Accounting Data (2001-2011)

Pore-water Compositions



Benefits and Drawbacks

Benefits

- Prevented a several year startup delay related to traditional dam foundation issues
- Lower capital costs
- Lower reclamation costs due to smaller footprint
- Lower water treatment costs
- Improved stability
- Allowed backfill of 50% of tailings

Drawbacks

- Higher operational costs
- Wet weather placement (access, erosion, compaction)
- Narrow margin for achieving target density
- Limited options for disposal of pond and ditch sediments
- Eliminated water cover options (oxygen, dust)

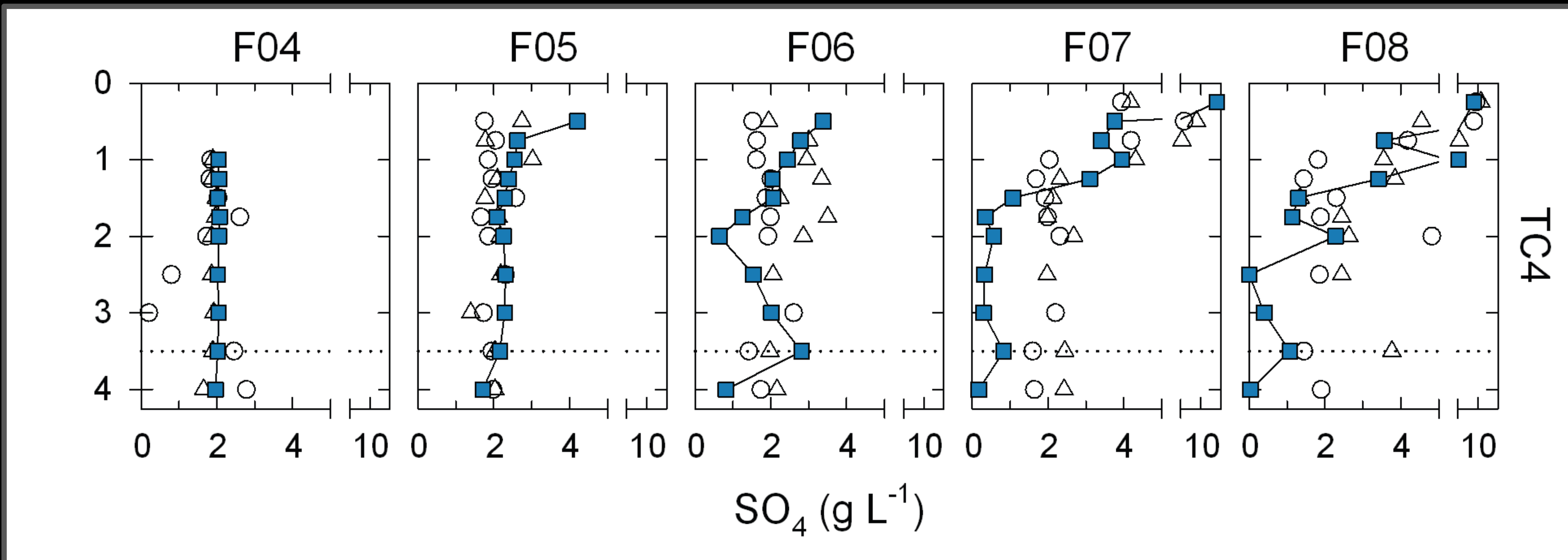
Characterization and Monitoring

- Mineralogy, geochem, ABA, kinetic testing
- Physical and hydrological characteristics
- Groundwater, pore water and surface water
- Air (dust)
- Density (in situ and Proctor)
- Pore pressure/tension
- Temperature
- Stability (inclinometer, survey hubs)
- Test cover performance
- Meteorological data
- Flow data

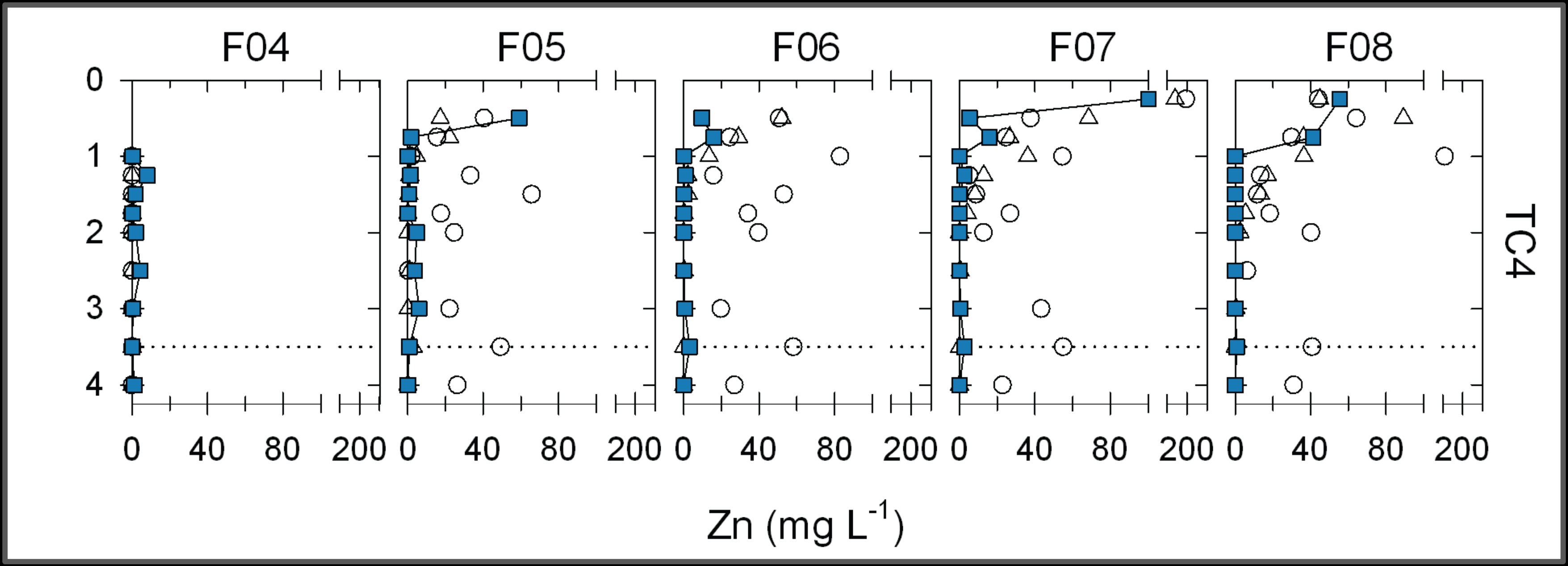
Minimizing environmental impacts (present and future)

- Water containment and diversion
- Water treatment (2500 GPM HDS WTP)
- Dust abatement
- Tracking abatement (wheel wash)
- Co-disposal of waste rock and tailings
- Water balance
- Chemical load balance
- Conceptual models
- Numerical models
- Test cover performance monitoring and modeling
- Carbon amendment testing

View of carbon amendment test cells and instrumentation on the Greens Creek tailings pile



Results of addition of 2.5 vol % peat and 2.5 vol % spent brewing grain (squares), non-amended control (triangles), non-excavated control (circles), dotted line indicates lower extent of treatment, depth in meters (from Lindsay and Blowes, 2011)



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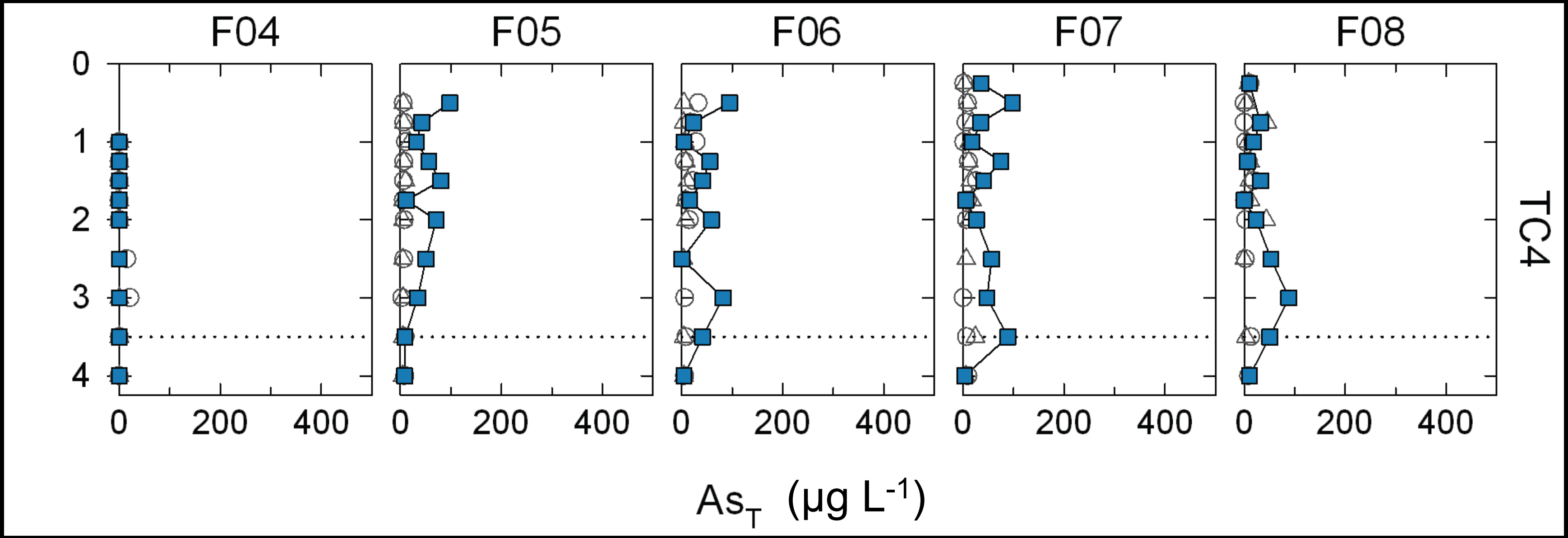

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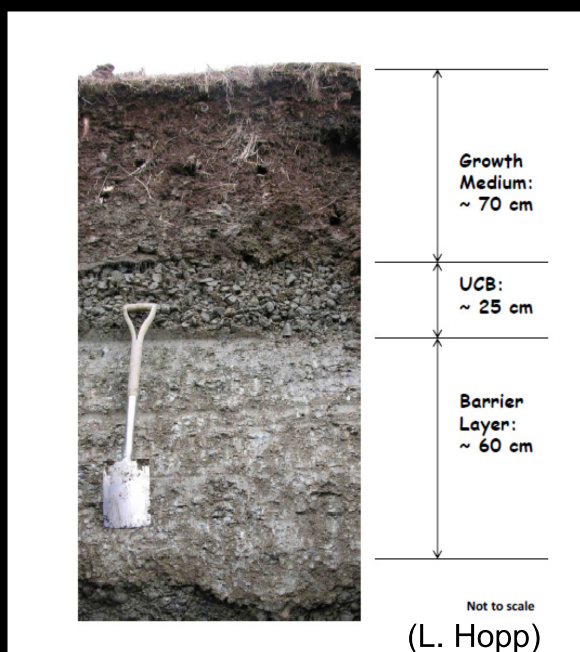
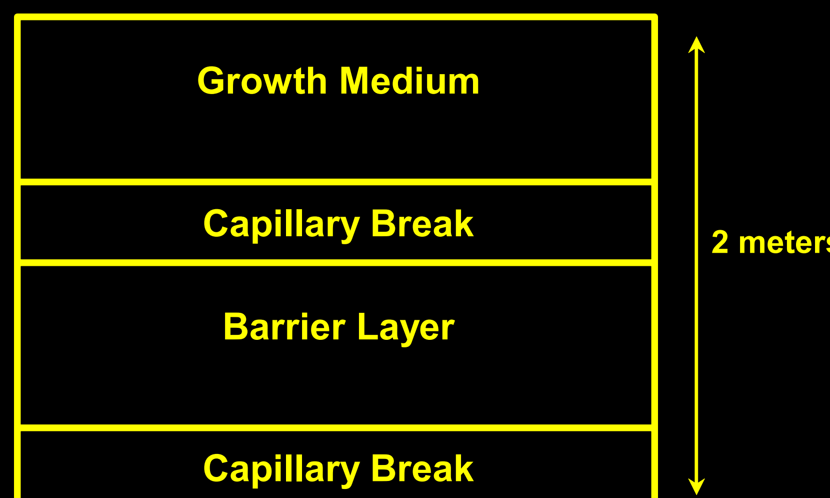
In situ treatment (sulfate reduction)(Lindsay and Blowes, 2011, McDonald et al., 2012)

- Tested addition of peat, spent brewing grain, municipal biosolids to tailings (5-10 vol %)
- Improved pore water quality; reduced sulfate, metals and trace element concentrations; increased alkalinity
- May reduce time required to meet water quality targets
- Not recommended for oxidized materials due to reductive mobilization of Fe, As and other elements (may be counter-productive with respect to co-disposal of weathered waste rock)
- Cellulose degrading enzyme assays contribute to the understanding of microbial processes in the test cells



Cover Design



Cover design

- Reduces advective and diffusive oxygen transport and subsequent sulfide oxidation
- Prevents contact of runoff with tailings and waste rock
- Allows for re-establishment of native spruce-hemlock forest
- Performance monitoring indicates design is effective
- Barrier layer remains saturated and does not freeze
- Investigating potential modifications to reduce costs without limiting effectiveness; landform/watershed size scale-up

Conclusions

- The decision to employ dry stack technology was based primarily on geotechnical constraints imposed by the foundation sediments
- Opting for dry stack avoided start-up delay, reduced capital costs, limited footprint, improved stability, lowered closure and water treatment costs and allowed for underground backfill
- Operational costs are higher and wet weather placement is challenging
- Characterization of the tailings and monitoring of the pile and surrounding area are robust
- Information from the site is used to develop good conceptual models for flow and geochemical conditions
- Numerical models are calibrated to existing conditions then used to provide an indication of long term performance
- Test cover performance monitoring and modeling are essential elements of the long term closure strategy for the tailings pile
- In situ carbon amendment show promise for porewater remediation, provided the tailings/waste rock is not oxidized

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Thanks for bearing with me