Control of sulphide oxidation in the pyrrhotite-rich tailings from the Cantung Mine, NWT.

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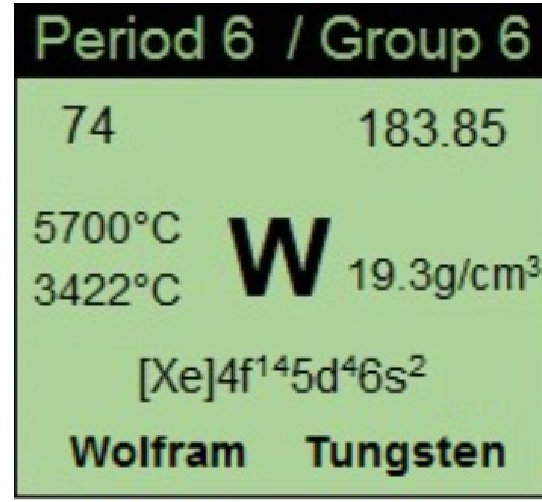
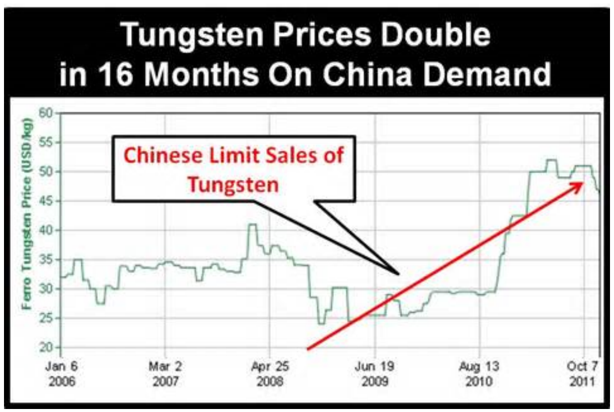
Location and Background

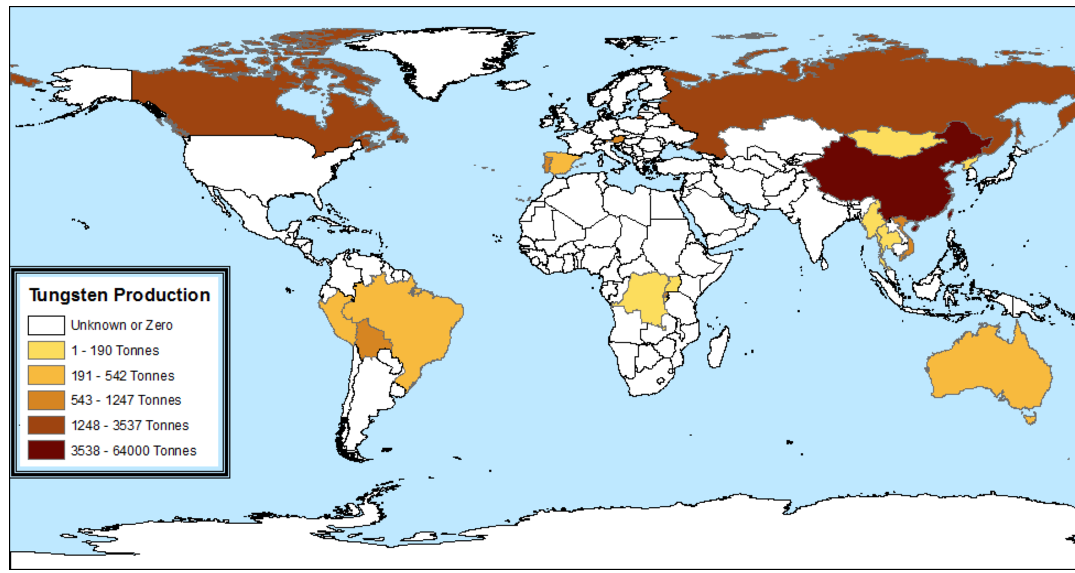
1954	deposit discovered
1956	
1960	
1962	Open pit production commenced
1963	Operations temporary suspended due to low tungsten prices
1964	
1966	Mill destroyed by fire
1967	A new 350 stpd mill was completed
1968	
1969	Capacity increased to 450 stpd
1970	
1971	Discovery of the "E Zone"
1973	
1974	Ore from underground added to mill
1975	Capacity increased to 500 stpd
1976	
1978	
1979	Capacity increased to 1000 stpd
1980	
1982	
1984	
1986	Site on Care and Maintenance
1988	
1990	
1992	
1994	
1996	
1997	NATCL purchased the Cantung mine
1998	
2000	Tungsten prices improve
2001	Mine reopens in December with underground operation
2002	
2003	NATCL was placed under CCAA, and the mine was closed
2004	NATCL successfully completed a plan of arrangement to deal with creditors
2005	Production resumed in September
2006	
2008	
2009	Operations suspended
2010	Operations resumed
2011	
2013	
2015	As of end of Nov, site on care and maintenance

Tungsten



- Tungsten (or Wolfram) is a heavy element with highest melting point and used in many alloys
- Most of the global supply comes from China, followed by Canada and Russia
- Prices are very susceptible production in China

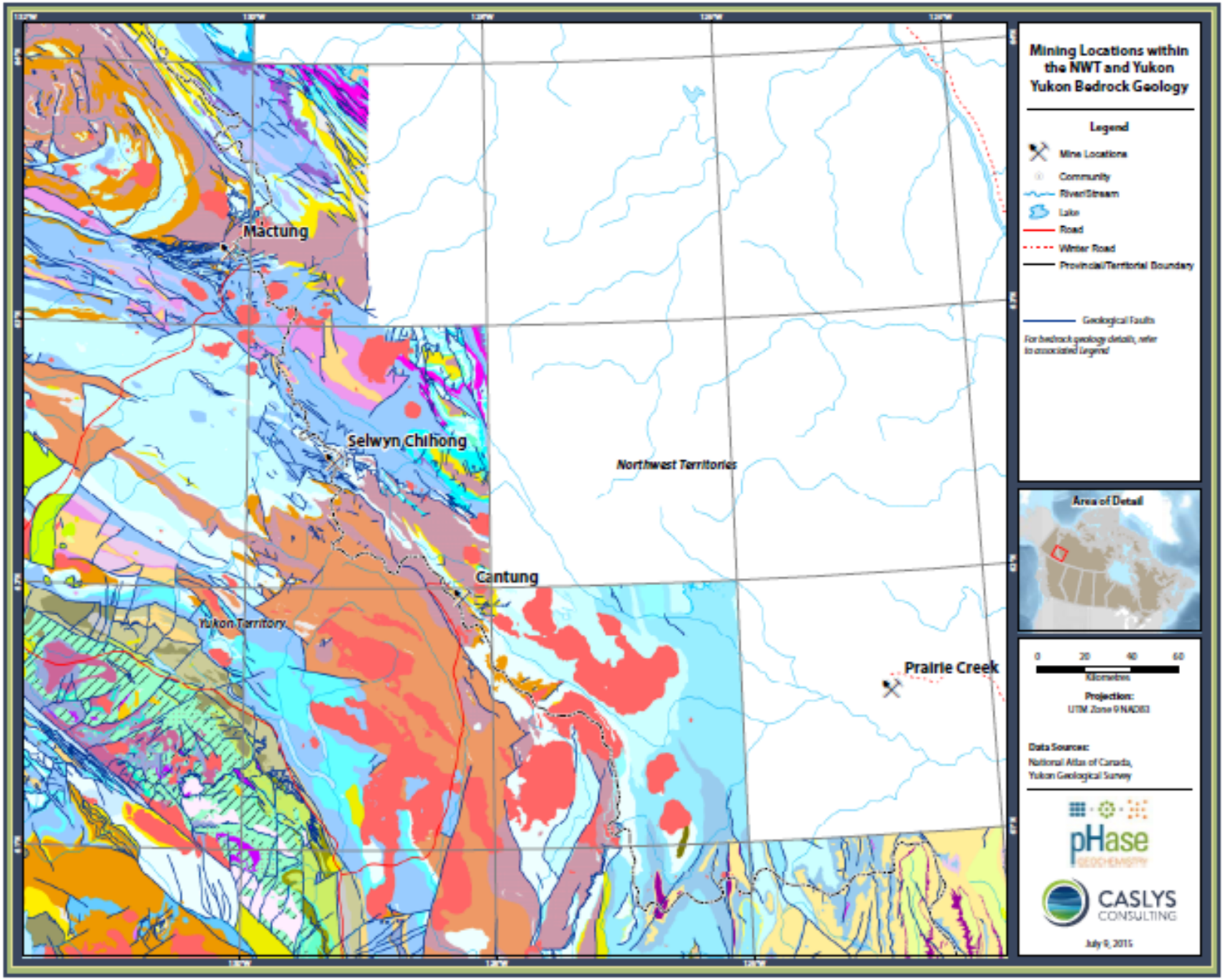




"Tungsten mined in 2013" by Dunhamspatial - Own work. Licensed under CC BY-SA 4.0 via Commons - https://commons.wikimedia.org/wiki/File:Tungsten_mined_in_2013.png#/media/File:Tungsten_mined_in_2013.png

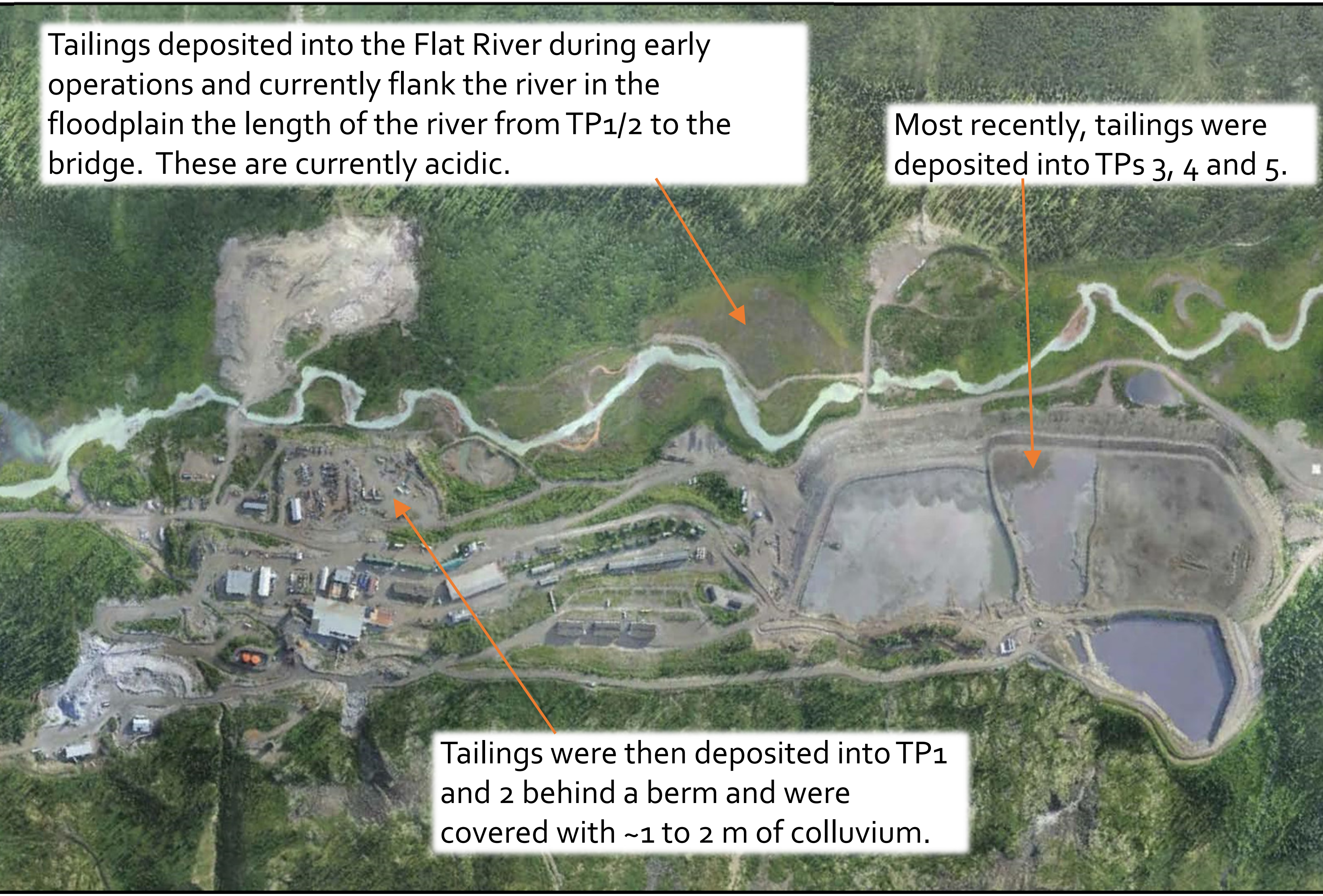
Geological Setting

- Cantung Mine is located within the Selwyn Tungsten Belt.
- This belt hosts a number of tungsten skarn deposits and is considered one of the world's largest tungsten districts.
- It is situated on the eastern margin of the Selwyn Basin, a subaqueous depositional basin that in the mine area comprises a thick sequence of Cambrian to Ordovician sedimentary strata including argillites, shales, dolomites and limestones.
- The Cantung deposits are scheelite [$Ca(WO_4)$] – chalcopyrite [$CuFeS_2$] bearing skarns developed in the Cambrian limestones near contacts with the Cretaceous granitic stocks



Mining Locations within the NWT and Yukon
Yukon Bedrock Geology
Legend
Mine Locations
Community
River/Stream
Lake
Road
Winter Road
Provincial/Territorial Boundary
Geological Faults
Mactung
Selwyn Chihong
Cantung
Prairie Creek
Northwest Territories
Yukon Territory
Area of Detail
Kilometres
Projection:
Data Sources:
National Atlas of Canada,
Yukon Geological Survey
pHase
CASLYS CONSULTING


Ski Hill Access Rd.
Old Landfill
Active Landfill
Tailings Pond 1 (Reclaimed)
Tailings Pond 2 (Reclaimed)
Flat River
Airstrip
Nahanni Range Rd.
Tailings Pond 3
Mine Site
Tailings Pond 5
Tailings Pond 4
Open Pit


Tailings deposited into the Flat River during early operations and currently flank the river in the floodplain the length of the river from TP1/2 to the bridge. These are currently acidic.
Most recently, tailings were deposited into TPs 3, 4 and 5.
Tailings were then deposited into TP1 and 2 behind a berm and were covered with ~1 to 2 m of colluvium.

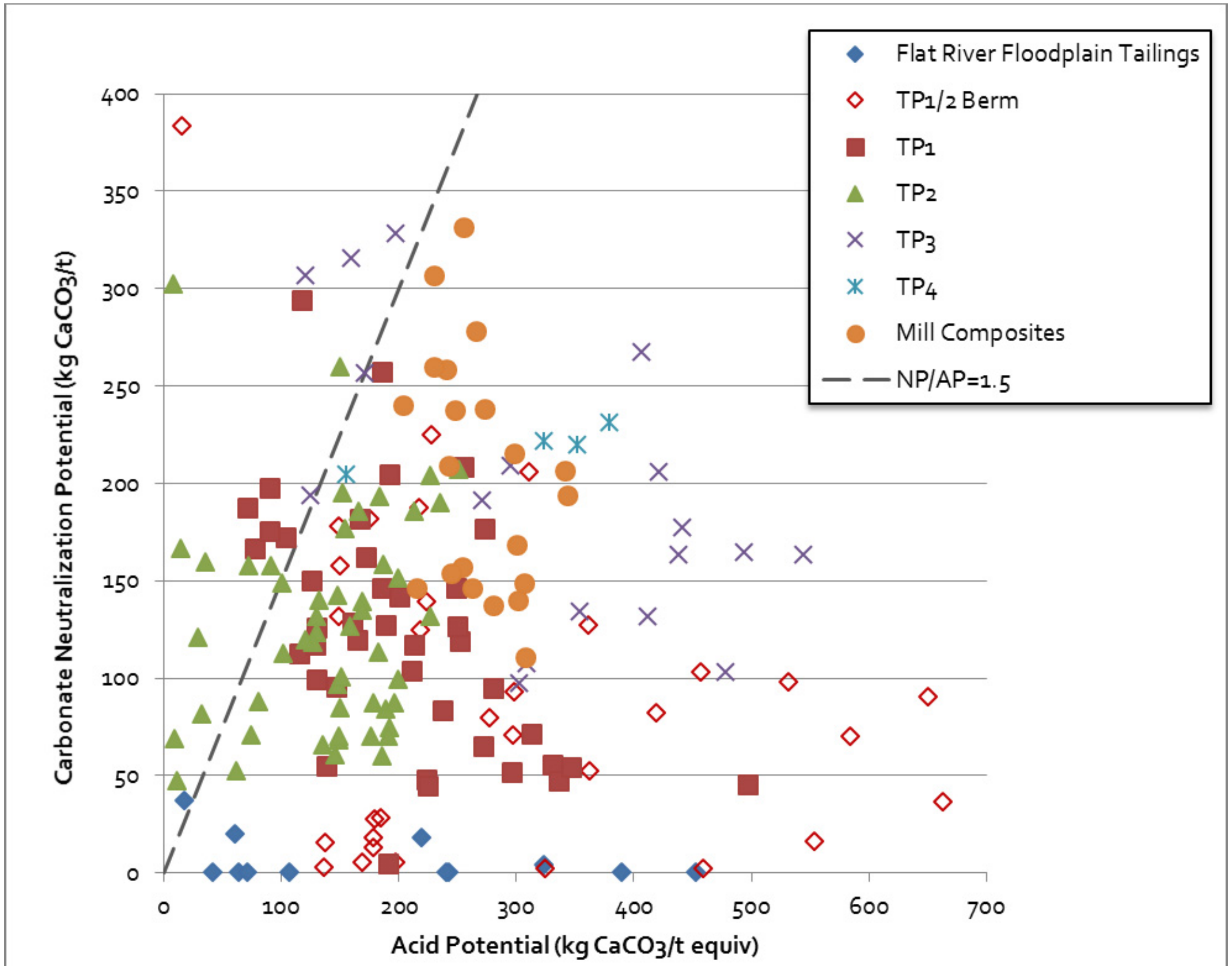
Climate

- Continental subarctic, humid climate regime
- ~620 mm mean annual total precipitation (50/50 rain/snow)
- ~320 mm mean annual potential evaporation
- Majority of net infiltration/ groundwater recharge occurs as a result of spring snowmelt

Tailings Properties

- Physical properties:
  - ~39% sand, ~56% silt, ~5% clay-size
  - Estimated porosity of 34%
  - ksat of 1 x 10-5 cm/sec
  - Relatively high ability to retain water under drainage or evaporative conditions
- ABA properties:
  - Total sulphur ranges from 0.5 to 18%, median of 7.5%
  - Carbonate NP ranges from nil to 332 kg $CaCO_3$/t, median of 160 kg $CaCO_3$/t
  - Majority of samples classify as PAG

ABA Results

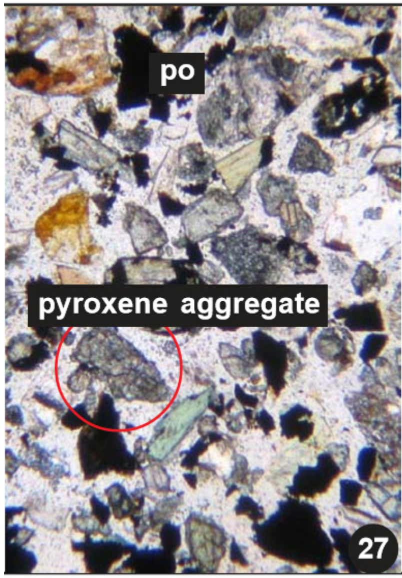


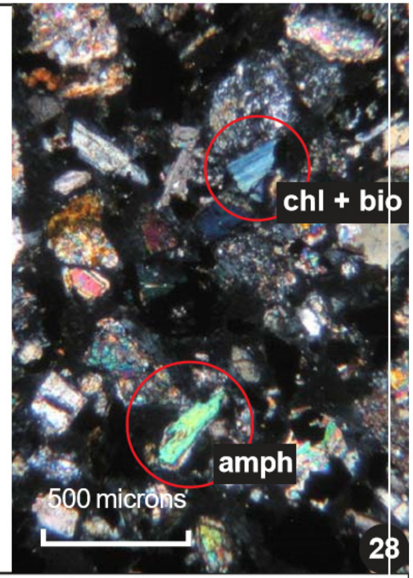
Flat River Floodplain Tailings
TP1/2 Berm
TP1
TP2
TP3
TP4
Mill Composites
NP/AP=1.5
Carbonate Neutralization Potential (kg CaCO3/t)
Acid Potential (kg CaCO3/t equiv)
400
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700

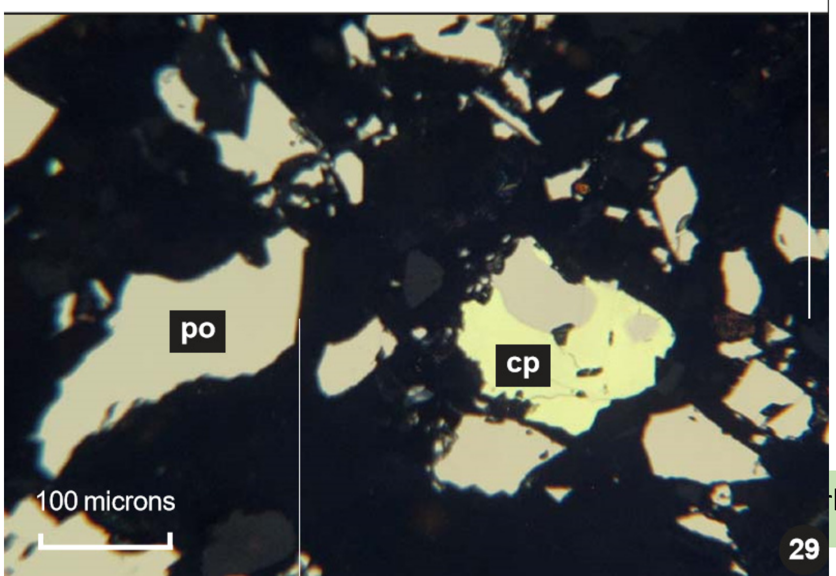
Tailings Properties

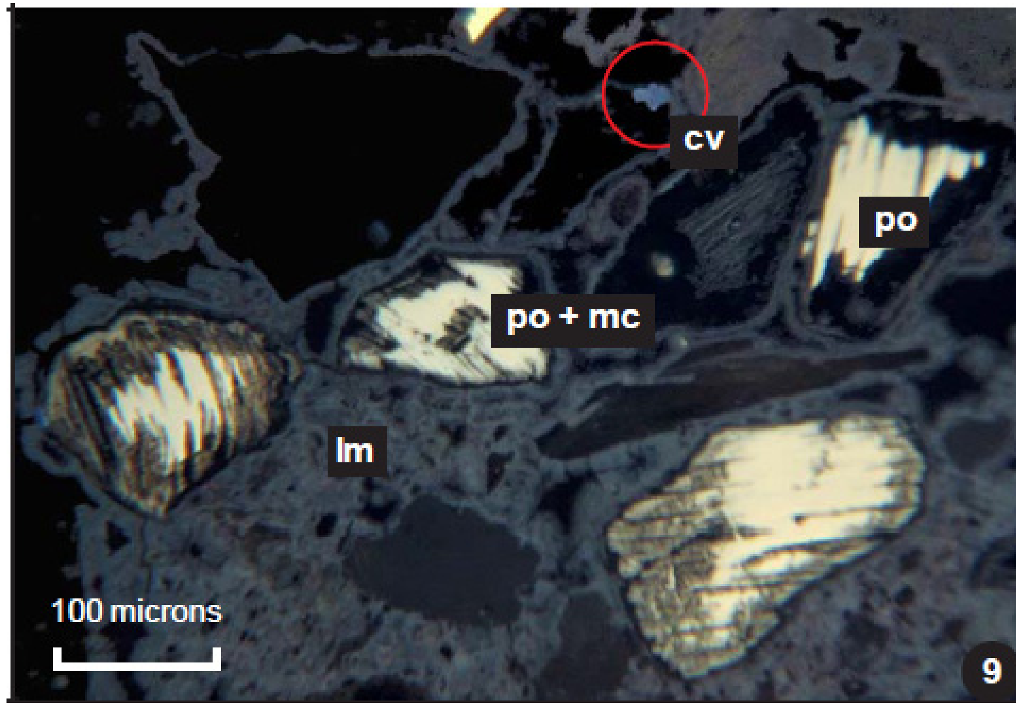
- Mineralization as scheelite [$CaWO_4$] occurs with massive replacement-style pyrrhotite in calc-silicate gangue within limestone.
- Key minerals include:
  - pyrrhotite [$Fe_{1-x}S$], with lesser chalcopyrite [$CuFeS_2$], sphalerite [ZnS] and minor amounts of bismuth
  - dolomite [$(Ca,Mg)CO_3$] and accessory calcite [$CaCO_3$],
- Other gangue minerals include quartz, microcline, biotite, actinolite, garnet, pyroxene, epidote, tourmaline and apatite.
- Oxidation products such as iron oxides-hydroxides (limonite, goethite, lepidocrocite), sulphates (jarosite, gypsum) and native sulphur are prevalent.

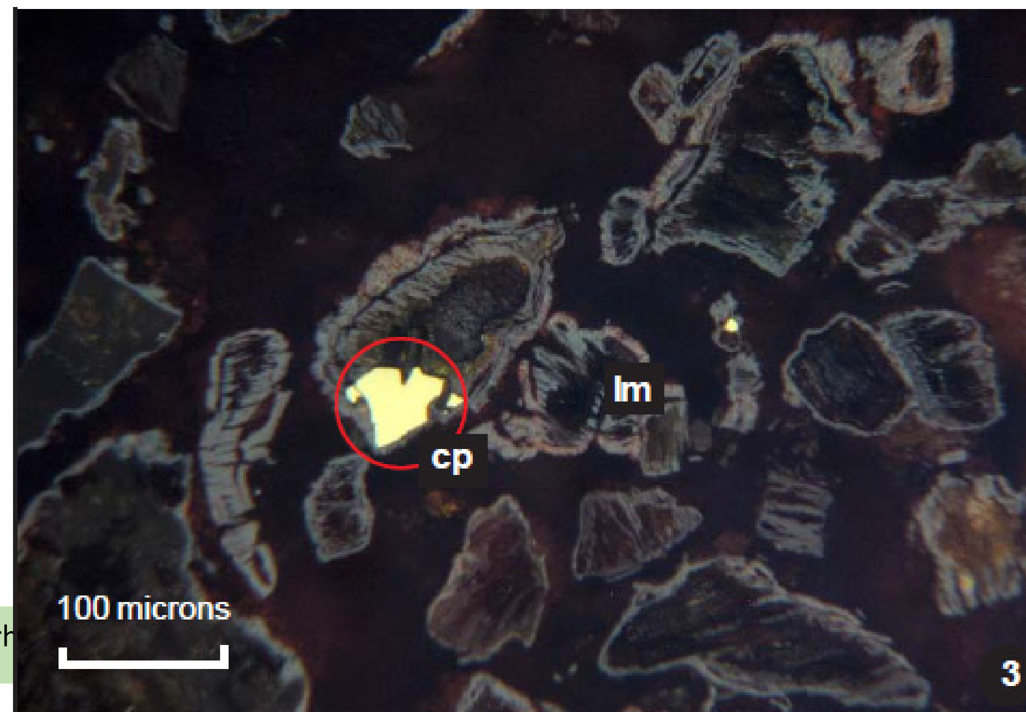
Po oxidation







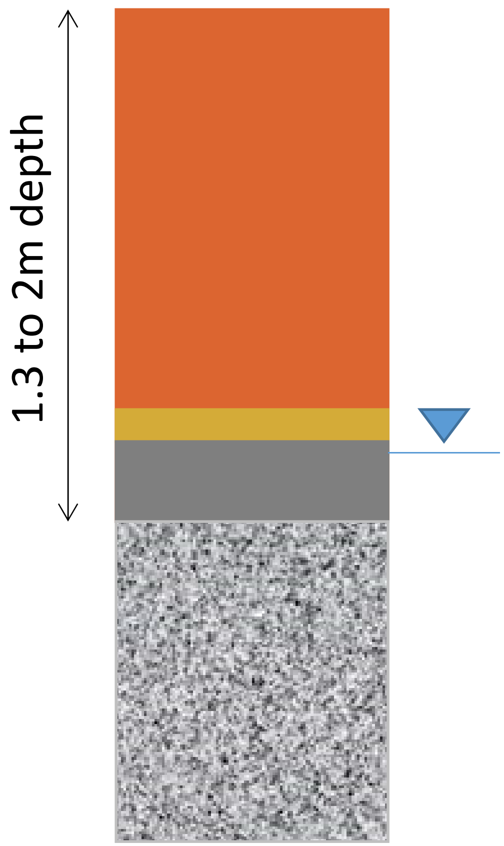




Geochemistry Overview: Flat River Floodplain Tailings

- Tailings deposited into the Flat River from 1962 to 1965 and currently flank the river in the floodplain the length of the river from TP1/2 to the bridge.

Observed Depth of Oxidation: Flat River Floodplain Tailings



Typically upper 0.3 to 2m highly oxidized, sulphides predominantly depleted, pore water acidic with elevated metals — pH ~2 to 4

Hard pan (discontinuous) - iron oxides and sulphates

Unoxidized tailings (often saturated) — pH ~7 to 8

Sediment

Increasing NP and Sulphide

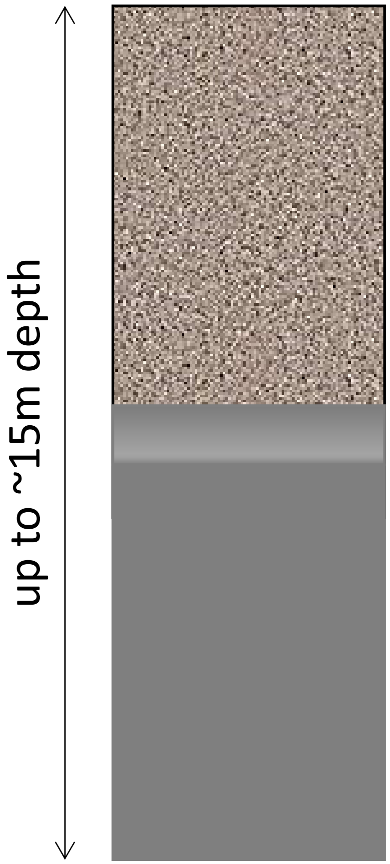
Geochemistry Overview: TP1 & 2

- TP1&2 were used for tailings deposition from 1965 to 1973.
- Tailings were covered with ~1m of till/colluvium
- Test pitting and drilling showed:
  - unoxidized, sandy / silty to clayey, dark greenish-grey to dark grey, considerably less oxidized and generally finer than Floodplain Tailings.
  - No evidence of oxidation is seen in the facility except for;

    (1) variably oxidized tailings sometimes observed at the cover-tailings interface, typically within 0.3 to 0.4 m immediately below the till cover,

    (2) orange/red oxidized tailings encountered in the berm which may have been excavated from the historic Floodplain Tailings when the berms were constructed.

Observed Depth of Oxidation: TP1 & 2 Tailings



Cover - typically upper **1 to 2m**	pH ~7 to 8
Minor evidence of oxidation (a few 10s of cm)	pH ~ 6 to 8
Unoxidized tailings (often saturated)	pH ~7 to 8

Geochemistry Overview: TP3, 4 & 5

- Deposition started in TP3 in ~1973 through 2007 and continued into TP4 and most recently in TP5.
- Tailings were observed to be fairly fresh, homogenous, unoxidized, sandy to silty with no definitive weathering profiles
- Most samples were greenish-gray to gray in colour with high sulphide content.

Geochemistry Overview: Tailings Porewater Quality

- Tailings were excavated from the Flat River Floodplain, TP1/2 and TP3 for inclusion in the field barrel program (initiated in 2010)
- Trends have been steady, median concentrations are provided below

	pH	SO_4	Al	Cd	Cu	Fe	Mn	Se	Zn
Tailings FR Floodplain	2.5	22,150	500	0.02	50	9,480	28	0.04	3
Tailings TP1/2	7.6	3,120	0.004	0.0002	0.002	0.6	12	0.001	0.03
Tailings TP3	7.9	1,630	0.008	0.0001	0.003	0.2	3	0.008	0.02

Depth of Oxidation

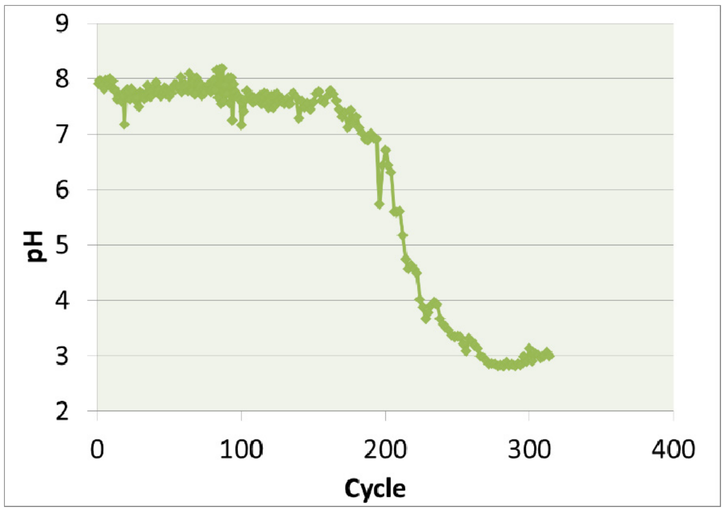
- There are two dominant processes that influence the depth to which oxygen can ingress into tailings.
  1. The rate at which **oxygen consumption** occurs (sulphides oxidize consuming oxygen in air)
     - Quantified by humidity cell testwork
  2. The rate of **oxygen diffusion** into the tailings mass

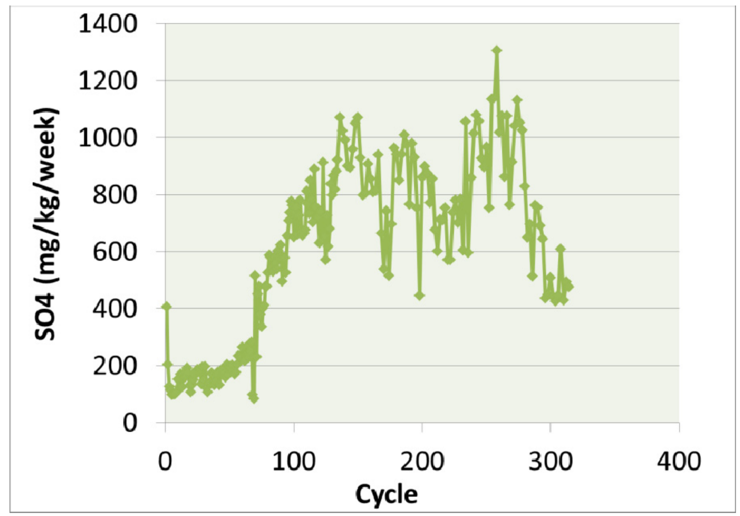
- 1-Dimensional Simplified Model* – pairing oxygen consumption and oxygen diffusion

* Model derived from: Nicholson, R.V., 1984. Pyrite Oxidation in Carbonate Buffered Systems: Experimental Kinetics and Control by Oxygen Diffusion, Ph.D. Thesis, Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, Canada.

Oxidation Rate

- Humidity cell testing was completed for +300 cycles.
- Sample collected from mill, sulphide content ~ 9%





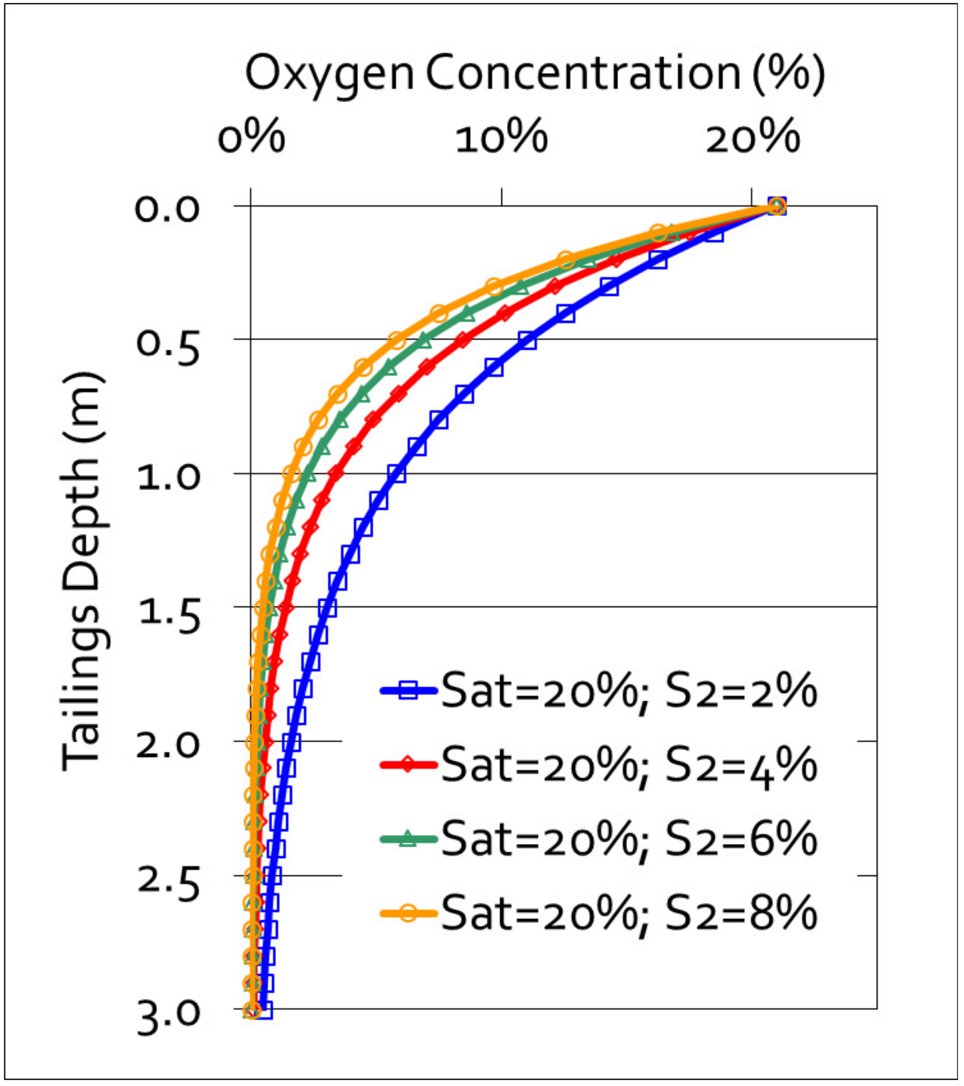
$$FeS + 2.25O_2 + 2.5H_2o \Rightarrow Fe(OH)_3 + SO_4^{2-} + 2H^+$$

- Calculating O_2 consumption rate at pH near neutral:

$$1.2 \times 10^{-5} \text{ to } 3.5 \times 10^{-5} \text{ mol/m}^2\text{/s}$$

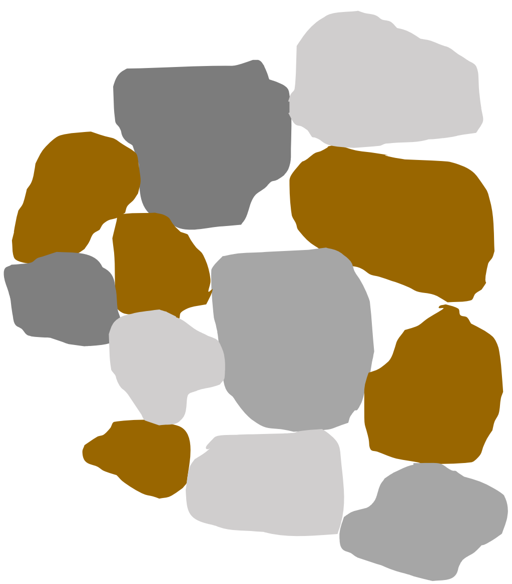
Depth of Oxidation – varying S content

- Assuming low saturation and varying S content
- Higher S content, the lower the depth of oxidation
- With low saturation, depth of oxidation could vary from ~1 to 2.5 m
    - e.g. floodplain tailings

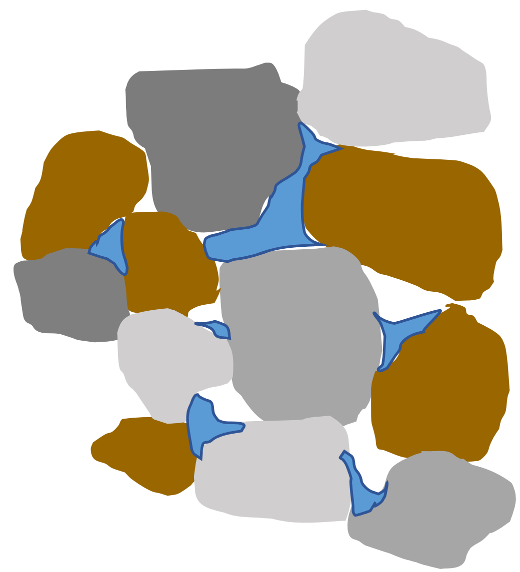


Depth of Oxidation

- This oxygen consumption rate measured in the humidity cell is not limited by the presence of oxygen – i.e. O_2 is fully available to all sulphide particles.
- In the field, O_2 is only available in pore spaces not filled with water.



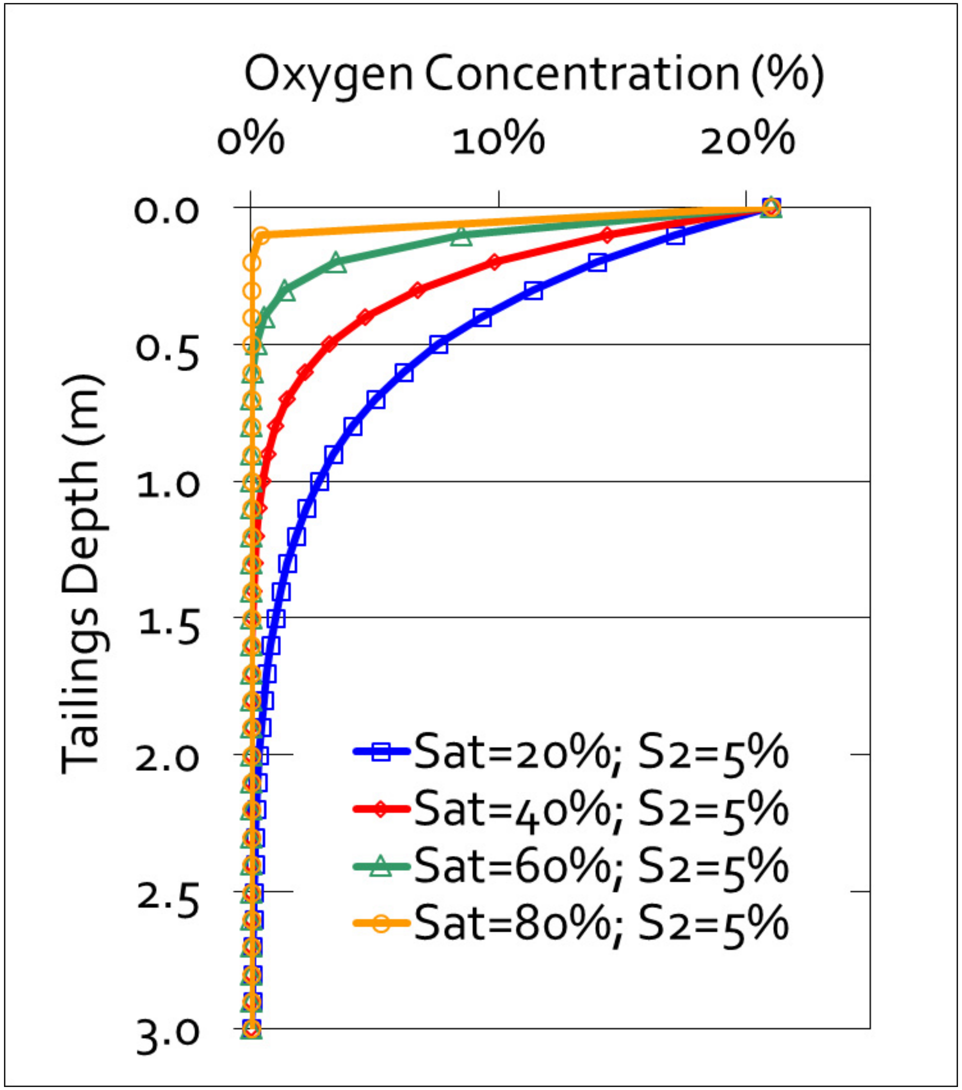
Unsaturated, particles exposed to O_2



Higher degree of saturation, fewer particles exposed to O_2

Depth of Oxidation – varying saturation

- Varying degree of saturation with a typical S content
- Higher degree of saturation, the lower the depth of oxidation
- Saturation has a greater influence than S content, with high saturation limiting O_2 to top ~10 cm or so

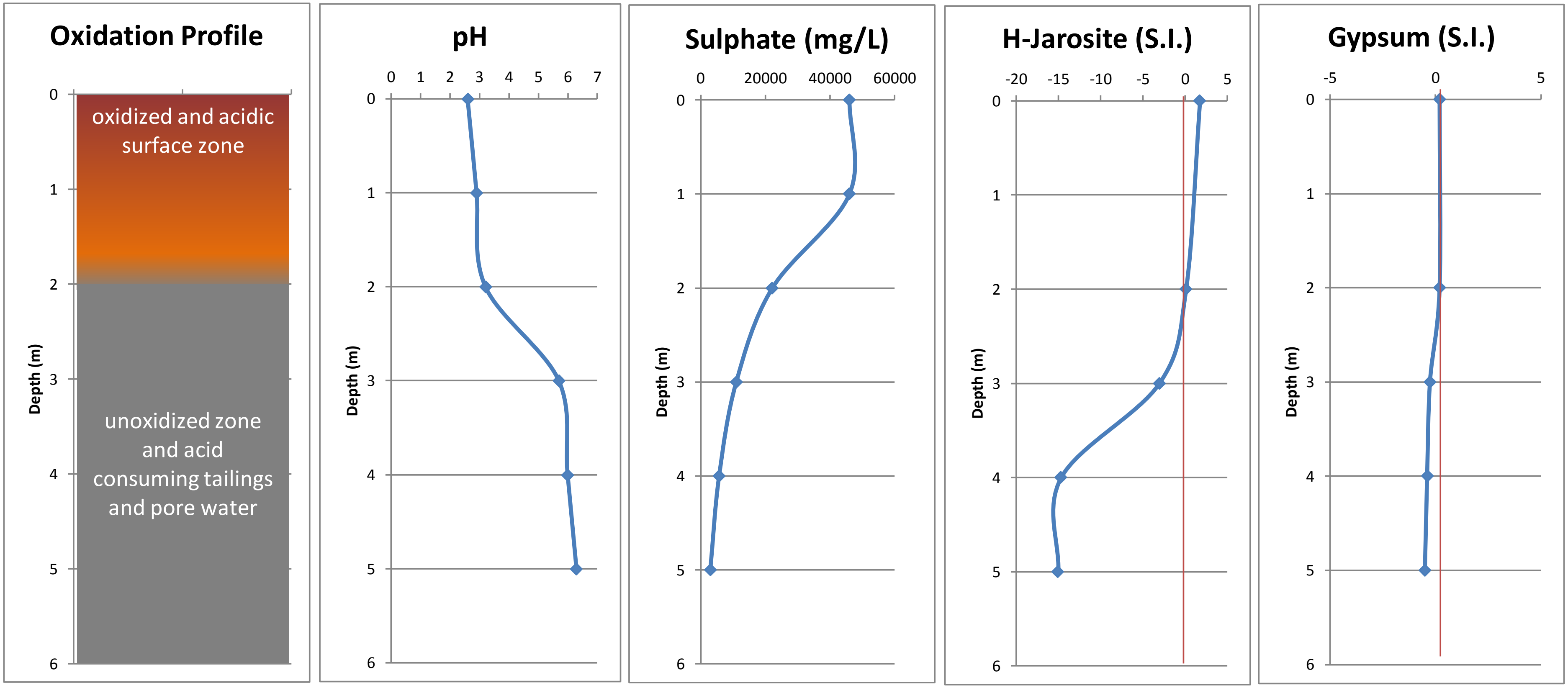


Depth of Oxidation

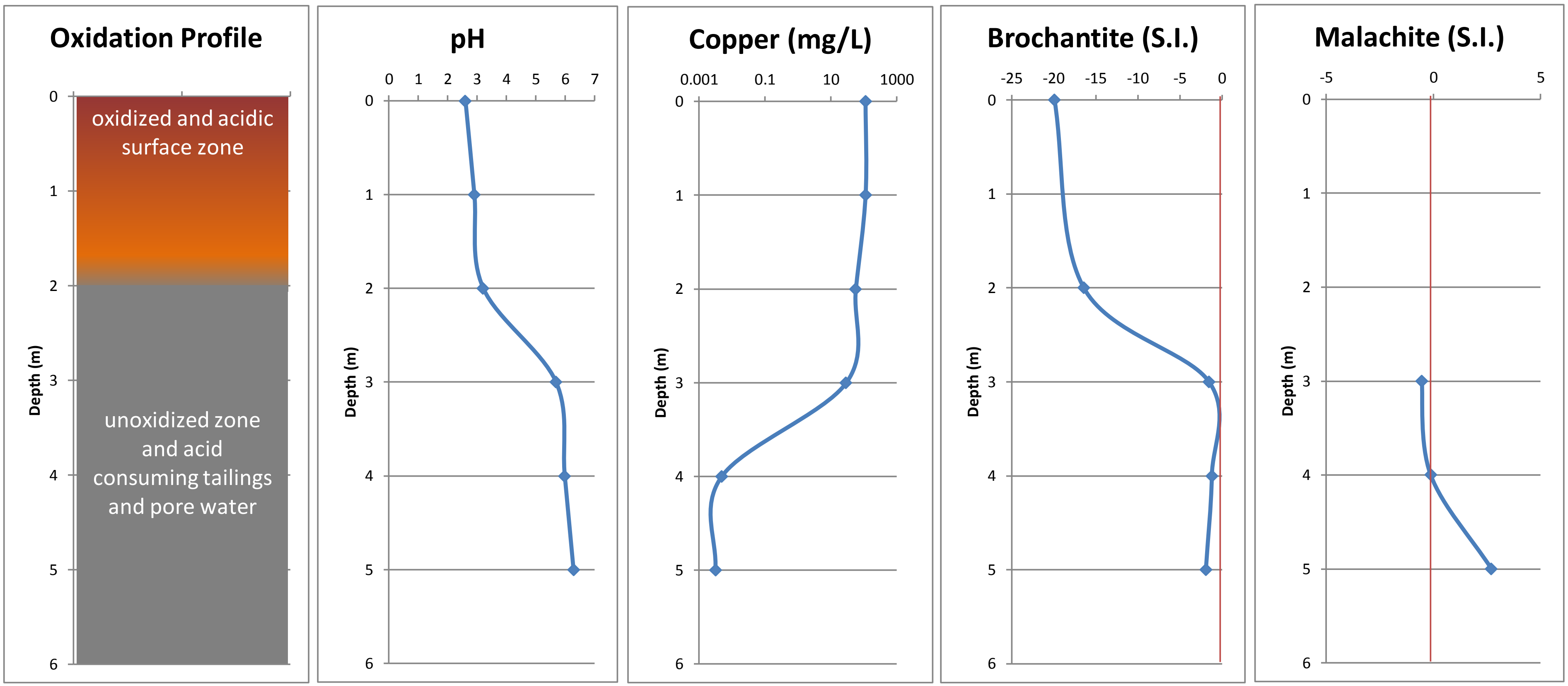
- Conceptual model agrees with observations in the Floodplain tailings and TP facilities
- Floodplain tailings are unsaturated and observations suggest the depth of oxidation is between 30 cm and 2m.
- TPs 1 and 2 have high degree of saturation and tailings have remained non-acidic, evidence of oxidation appears confined to within a few 10s of cm below the interface of the cover.

➢ Control of ARD is dependent on maintaining a high degree of saturation

Predictions of Basal Seepage Quality



Predictions of Basal Seepage Quality



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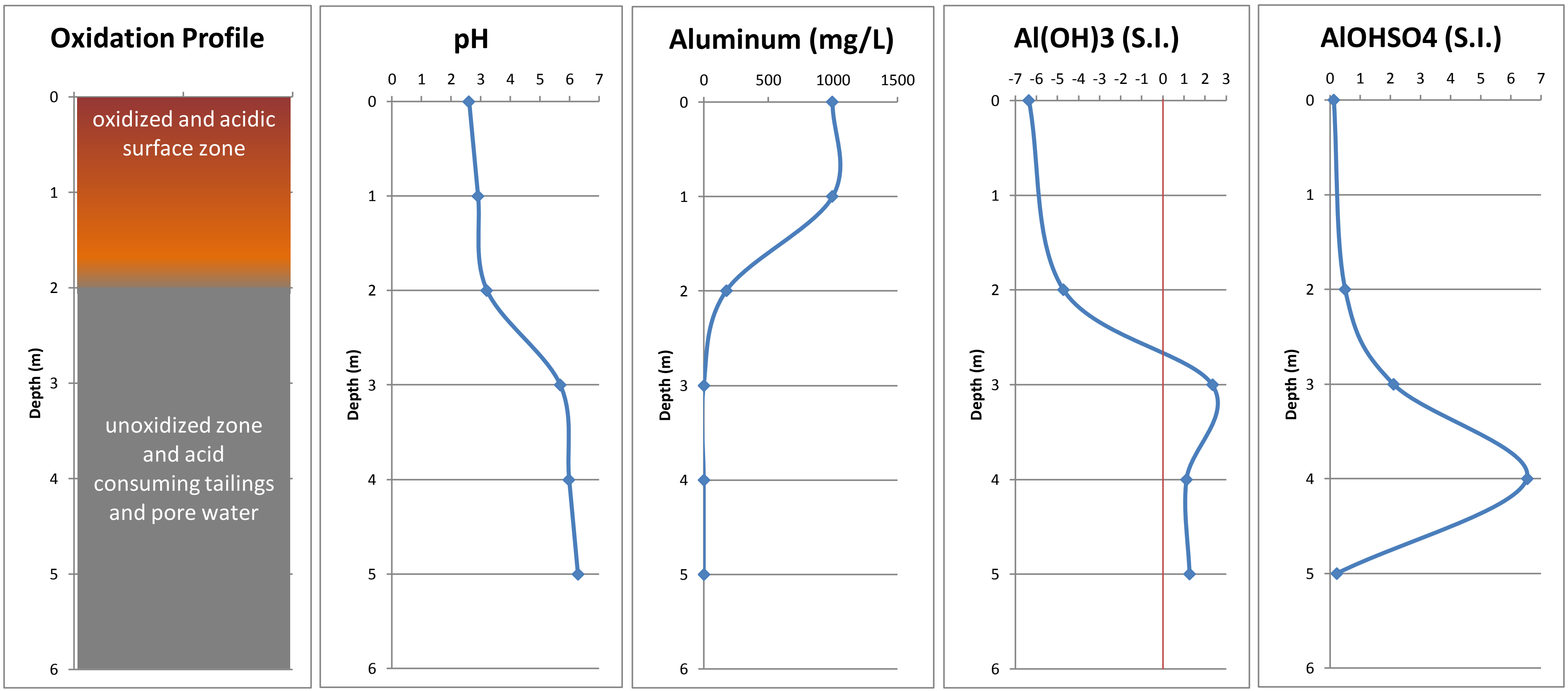
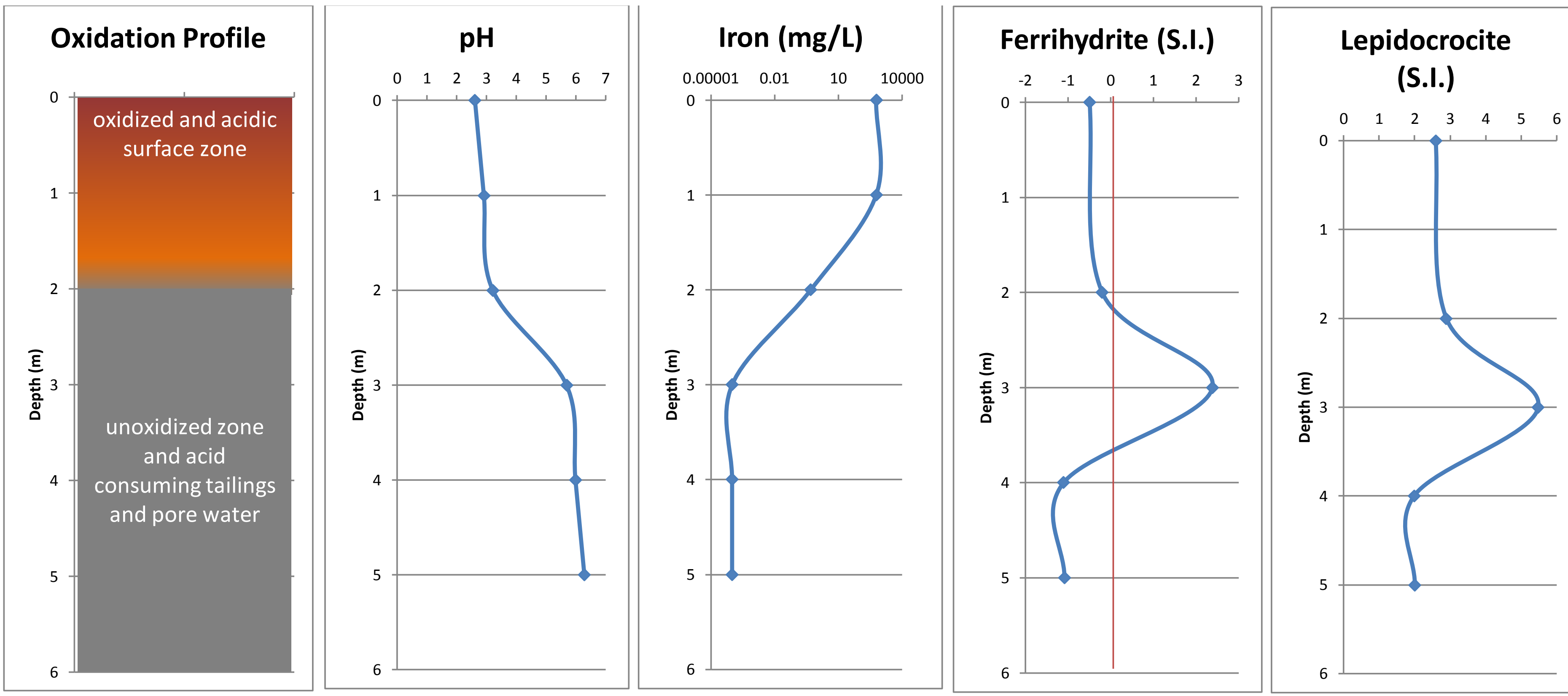


Predictions of Basal Seepage Quality



Closure Concept

- Contrary to objectives of the majority of covers which are intended to minimize infiltration, the closure concept for the Cantung tailings is to maximize the degree of saturation, i.e. promote infiltration.
- With the cover, it is expected that saturation will be higher, basal seepage will remain near neutral with low concentrations of key parameters, tailings will not oxidize to acidic conditions, surface run-off will remain unaffected.

Thank you

Thanks also to:

- North American Tungsten Corp.
- O'Kane Consultants Ltd.
- Ron Nicholson
- BC Ministry of Energy and Mines, Natural Resources Canada and the MEND Program