Mechanisms of Arsenic Attenuation in a Gold Mill Tailings Impoundment

1 Alan Martin, 1Jonathan Mackin, 2Trevor Crozier, 2Stephen Hedberg, 2Dawn Paszkowski, 3John Jambor, 4Shawn Hiller and 4David Gelderland

1 Lorax Environmental Services Ltd., Vancouver, B.C., Canada
2 BGC Engineering Inc., Vancouver, B.C., Canada
3 Leslie Research and Consulting, Tsawwassen, B.C., Canada (Deceased)
4 Goldcorp Inc., Red Lake Gold Mines, Balmertown, Ontario, Canada
Overview

• Background and Site Setting
• Objectives
• Arsenic Attenuation Mechanisms
  ➢ Diffusive pathway
  ➢ Advective pathway
• Implications for tailings/water management
Site Setting – Cochenour, ON

Cochenour Wilanour Mine (Goldcorp)
Cochenour Wilanour Mine - Site History

- The milling of gold ores was conducted continuously at the site between 1939 and 1975, and for a brief period in 1982.
- Approximately 2.3 million tonnes of tailings were generated, with ores subjected to roasting and cyanidation.
- Site employs a ferric sulphate treatment system to reduce soluble arsenic in surface waters prior to discharge (Red Lake).
- Project re-activated in 2009, with production scheduled to commence in 2014 (20 year mine life). To supply ore to Campbell Mine.
Historic Tailings Deposition

Historic Mill Site

TMA Pond

Tailings Management Area
Water covered tailings
Study Objectives

- Quantify the various sources of arsenic to the Pond Area (arsenic mass balance); and
- Define the controls governing the remobilization and attenuation of arsenic and other tailings-related parameters.

Water/waste management strategies to:
- Reduce arsenic loadings to Pond Area
- Reduce volume/loading to treatment plant
Study Components

Water Balance
• Climate
• Hydrology
• Water management

Hydrogeology
• Hydrostratigraphy
• Water levels
• Hydraulic conductivity
• Water and As Flux
• 2-D Modelling (Seep/W)

Geochemistry
• Surface water quality
• Porewater chemistry
• Mineralogy (Petrography, XRD, SEM, XAS)
Arsenic Source – reductive dissolution of roaster products

Roaster Fe oxides (porous texture hematite)
Arsenic Attenuation Mechanism #1

Diffusive pathway: removal of dissolved As within porewaters of submerged tailings in Pond Area (natural bioremediation).
Pond Area

- Submerged tailings deposits
- Passive reclamation since 1975 (35 plus years)
- Cattail, horsetail, sedge
- Extensive benthic macrophytes
Pond Area – abundant benthic flora
Pond Area - Tailings

- quartz, plagioclase, muscovite, chlorite, and dolomite
- Sulfides: arsenopyrite, pyrrhotite
- Arsenic rich: 1,000-11,000 mg/kg

Split core showing pervasive root masses in tailings
Porewater - Methods

• Dialysis Arrays (peepers)
• 7 mm resolution profiling of dissolved species

• Parameters:
  ➢ Metals/metalloids
  ➢ pH, alkalinity
  ➢ Redox sensitive species (Fe, Mn, nitrate, H2S)

• Data used to define biogeochemical mechanisms and flux
Pond Area – As Porewater Profiles

- Elevated concentration of dissolved As in tailings porewaters (100-300 mg/L)
- Concentration gradient drives large upward diffusive flux towards benthic boundary.
Three principal mechanisms controlling the mobility of As:

1. Remobilization via reductive dissolution of Fe-oxides at or near the sediment-water interface

2. Removal from pore solution via *in situ* precipitation.

3. Re-supply of dissolved arsenic from deeper tailings horizons.
Pond Area – As Porewater Profiles
Spatial homogeneity

**Station 1**
- Interfacial release
- Removal
- Re-supply
- Porewater max = 210 mg/L

**Station 2**
- Porewater max = 350 mg/L
Pond Area – Diffusive Sink Mechanism: Precipitation of secondary sulfides

- Secondary phase could not be identified.

Possibilities:
- Discrete As sulfides
- Co-precip with Fe-sulfides.
Pond Area – Diffusive Sink

- Bi-directional diffusion of dissolved As to localized zone of removal.
- Diffusive sink acts to chemically isolate deeper As-rich porewater (200-300 mg/L) from the water column.
Pond Area – As Removal Rate

• Per unit area = 13 mg/m²/day (based on mean of 4 profiles)
• Area of Pond = 150,000 m²
• Annual removal rate = ~700 kg/year

• Current treatment system (ferric salt precipitation):
  - ~800,000 m³/year (~25 L/s)
  - Mean [As] feed = 0.7 mg/L
  - Mean [As] effluent = 0.03 mg/L
  - Annual removal rate = ~540 kg/year

Passive removal comparable to active treatment
Arsenic Attenuation Mechanism #2

Advective pathway: removal of dissolved As along groundwater flow paths at exit points from the facility (adsorption/precipitation)
Groundwater Exit Points

- Western Exit Point
- TMA Pond
- Southern Exit Point
Groundwater Elevations and Flux

Western Exit Point
~9 m$^3$/day

Southern Exit Point
~11 m$^3$/day
Exit of tailings-related groundwater based on:
- Hydraulic gradients, permeability and hydrostratigraphy
- 2-D seepage analysis
- Major ion signatures (TDS, Cl, SO₄)

Evidence for attenuation of several parameters along flow path:
- Arsenic
- Ammonia
- Other trace elements

All MOE compliance criteria are being met
Attenuation along Groundwater Flow Paths - Arsenic

Exit wells (0.01 to 0.04 mg/L)

Background
Attenuation along Groundwater Flow Paths – Arsenic Removal

Based on:

- Total groundwater flow of 20 m³/day
- Average [As] in tailings porewater = 50 mg/L
- Average [As] in tailings-influenced flow path downgradient of facility = 0.03 mg/L

Annual removal rate = ~370 kg/year
Groundwater Attenuation Mechanism? Clues from Hydrostratigraphy

Strong likelihood attenuation is associated with either Peat and/or Clay+Silt Unit.

Mechanism not known:
• Adsorption of As(III)?
• Sulfide mineral precipitation?
Attenuation along Groundwater Flow Paths - Ammonia

NH₄⁺ is strongly adsorbed by clay minerals through cation exchange. Suggests adsorption is important.
Summary & Implications for Tailings Management

Three forms of treatment at Cochenour Wilanour Mine:
1. Active treatment (~540 kg As/year)
2. Passive bioremediation - diffusive pathway (~700 kg As/year)
3. Passive removal - groundwater pathway (~370 kg As/year)

• Passive removal mechanisms contribute significantly to reducing loadings to surface water receptors, and contribute to lower active treatment costs.
Implications for Tailings Management: Bioengineering for As Stability

- Arsenic mobility is limited under strongly oxidizing and strongly reducing conditions.
- Mobility strongly enhanced under suboxic conditions.
- Practitioners must carefully consider risks associated with bioremediation efforts.
Thank you!

Questions?