The Geochemical and Biological Recovery of a Gold Mine Polishing Pond (Balmer Lake, Ontario)

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20th Annual British Columbia – MEND ML/ARD Workshop, December 4th to 5th, 2013
Balmer Lake, March 1993
Presentation Overview

- Background and site setting
- History of mine-related inputs
- Pathway to Recovery
  - Mine water/tailings management
  - Passive/active treatment
  - Natural processes
- Recovery Indicators
  - Water quality
  - Sediment quality
  - Aquatic biota
Study Location

- Goldcorp’s Red Lake Gold Mines.
- Balmertown (Ontario) 7 km northeast of the town of Red Lake.
Mine History

- Continuous gold mining since 1948.
- Originally two separate mines (Campbell and Dickenson Mines).
- In 2006, Goldcorp Inc. acquired the Canadian assets of Placer Dome Ltd. In the amalgamation, Red Lake Gold Mines was expanded to include the neighbouring Campbell Mine.
- Mines now referred to as “Campbell Complex” and “Red Lake Complex” of Goldcorp’s Red Lake Gold Mines.
Site Setting

Balmer Lake

Current Discharge Locations

Lake Features:
- Area = 260 ha
- Max depth = 4 m
- Organic rich sediments
- High DOC system

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Balmertown

Campbell Complex

Red Lake Complex

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History of Mine-Related Inputs

- Balmer Lake was originally designated as a “Tertiary Polishing Pond” to allow for:
  - Natural degradation of cyanide and ammonia
  - Particle settling
- Direct deposition of tailings to Balmer Lake prior to 1980 (predominantly roaster tailings).
- Discharge of untreated tailings pond overflow (1959 to 1992).
- Discharge of treated effluent (2004 to present).
Contaminant Sources

- **External loadings**
  - Discharge of mine-related effluents (1959 to present).
  - Historically elevated levels of cyanide, ammonia, arsenic, and heavy metals.

- **Internal loadings**
  - Post-depositional remobilization of arsenic from tailings/sediments in Balmer Lake.
Pathway to Recovery: Water/Tailings Management

- Increase in tailings/water storage:
  - Dam raises
  - Construction of addition settling/polish ponds
  - Construction of internal dykes to maximize tailings/water retention
- Implementation of clean water diversions (ditches circumventing tailings management areas)
- Construction of flow control weirs
- Dam upgrades to low permeability structures
Pathway to Recovery: Passive/Active Treatment

- 1992: Replacement of roaster with pressure oxidation (Campbell).
- 2000: Pressure oxidation (Red Lake Complex)
- 2000: SO$_2$-Air cyanide treatment (Red Lake Complex).
- 2003-2007: batch ferric salt addition to tailings pond (Red Lake Complex)
- 2007: Arsenic treatment system (Red Lake Complex).
Pathway to Recovery: Wetland Treatment

- Campbell Complex Wetland Area: 16 ha
- Capacity: 30,000 m³/day.
- Parameters: Ammonia, phosphorus, trace elements, toxicity.
Pathway to Recovery: Natural Processes in Balmer Lake

- Natural degradation of ammonia and cyanide.
- Biogenic scavenging: Metal assimilation/binding to organics followed by particle settling.
- Precipitation of secondary sulfides in reducing lake sediments (As, Cu, Ni, Zn, Co)
- Precipitation of secondary metal-bearing cyanide phases in reducing lake sediments (Cu, Ni, Zn)
- Natural sedimentation (dilution of mine-impacted sediments)
- Release of arsenic and heavy metals from sediments to the water column and export from Balmer Lake.
Lake Recovery:

Water Quality
Balmer Lake Water Quality: 1993-2012
Total Cyanide

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Cyanide (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>0.0</td>
</tr>
<tr>
<td>1996</td>
<td>0.2</td>
</tr>
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<td>2010</td>
<td>1.6</td>
</tr>
<tr>
<td>2012</td>
<td>1.4</td>
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</tbody>
</table>
Balmer Lake Water Quality: 1993-2012
Ammonia

Year

Ammonia-N (mg/L)
0 2 4 6 8 10

AMMONIA

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Balmer Lake Water Quality: 1993-2012
Total Copper

Year

Total Copper (mg/L)
0.0 0.2 0.4 0.6 0.8 1.0
COPPER

Year
Total Copper (mg/L)
Balmer Lake Water Quality: 1993-2012
Total Arsenic

Year


Total Arsenic (mg/L)

0.0 0.2 0.4 0.6 0.8 1.0

ARSENIC

Year


Total Arsenic (mg/L)
Arsenic Remobilization from Sediments: Reductive Dissolution of Fe oxides
Arsenic Remobilization from Sediments: Reductive Dissolution of Fe oxides

Reductive dissolution of As-bearing Fe oxides

Removal from porewaters via precipitation of secondary sulfide minerals
Source of Arsenic: Fe oxides

BSE Image of roaster Fe oxides: Sponge-texture hematite, hosting between 0.6 to 6.4 wt.% arsenic.

EDS spectra showing presence of sorbed As, Ni and Zn.
Balmer Lake Water Quality: 1993-2012
Total Arsenic

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<td>2008</td>
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<tr>
<td>2010</td>
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<td>2012</td>
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</tbody>
</table>
Arsenic Flux to Sediments

1993

290 kg/year

1999

4,700 kg/year

Thick oxic zone

Thin oxic zone
Arsenic versus Copper

Increase in As mobility coincident with a decrease in Cu and NH₃ levels.

Decrease in toxicity likely allowed for enhanced algal growth.
By 2000, eutrophic conditions had developed in Balmer Lake.

High algal productivity sustained by sewage inputs.
Lake Recovery:
Sediment Quality
Sediments – Metal Content

Trace Element Content (mean in uppermost 10 cm)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1994</th>
<th>2006</th>
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<tbody>
<tr>
<td>As (mg/kg)</td>
<td>4,817</td>
<td>2,012</td>
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<tr>
<td>Cu (mg/kg)</td>
<td>4,156</td>
<td>1,873</td>
</tr>
<tr>
<td>Ni (mg/kg)</td>
<td>3,320</td>
<td>3,241</td>
</tr>
<tr>
<td>Zn (mg/kg)</td>
<td>3,513</td>
<td>2,316</td>
</tr>
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</table>

- Concentrations of As, Cu, Ni and Zn strongly elevated in surface sediments (tailings-related signature).
- High metal content likely responsible for impairment of benthic invertebrate community.
- Rate of sediment recovery predicted to be low, in low sedimentation rate systems.
Sediments – Arsenic Content


Related to loss of arsenic via:
1. Dissolution of solids and release to water column.
2. Vertical mixing in the sediment column (likely owing to bioturbation).
Lake Recovery:
Fish Resources
Fisheries Resources

- 1978: No fish were caught, likely owing to the presence of elevated concentrations of cyanide, ammonia and trace elements (e.g., Cu).
- 1996: A number of small forage fish species including pearl dace, fathead minnows and ninespine stickleback caught for first time.
Fisheries Resources cont.

- In the spring of 1999, 19 adult walleye were released to Balmer Lake as part of a radio telemetry study. The majority of fish survived at least 12 months, at which time the tracking devices expired.
- 2000: three of the telemetry fish were captured and re-released.
- 2000: first capture of white suckers and large schools of forage fish evident.
- 2002: the federal government removed Balmer Lake from the tailings management system and now the *Fisheries Act* applies to the lake.
Fisheries Resources - 2005

- 2005: juvenile walleye were captured for the first time indicating recent reproductive success of the 1999 introduced population.
- 2008: documented northern pike for the first time.
Summary

- Overall, Balmer Lake has transitioned from a non-productive water body in the 1980’s to one containing a representative species assemblage for shallow lakes in northern Ontario.
- Fish community is relatively healthy despite continued impairment of benthic community assemblage.

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>1978</td>
<td>No Fish</td>
</tr>
<tr>
<td>1996</td>
<td>Forage Fish</td>
</tr>
<tr>
<td>1999</td>
<td>Walleye Introduced</td>
</tr>
<tr>
<td>2000</td>
<td>White Suckers</td>
</tr>
<tr>
<td>2005</td>
<td>Juvenile Walleye</td>
</tr>
<tr>
<td>2008</td>
<td>Northern Pike</td>
</tr>
</tbody>
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Summary cont.

• Rate of WQ recovery can be rapid for parameters governed by external loading mechanisms (e.g., CN, NH$_3$, Cu).

• Rate of WQ recovery can be slow for parameters governed by internal loading mechanisms (e.g., As). Relevant factors:
  – Type of mine waste generated (phase associations)
  – Conditions of depositional environment (Eh, pH)

• Sediment recovery is slow in systems characterized by low sedimentation rate and bioturbation.

• “Recovery” of the system can result in unexpected consequences.
Thank You!


