The Historic Cobalt Mining Camp: Evaluating Rehabilitation Options in a Hydro-Geochemically Challenged Environment

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Presentation Overview:

- General background – geology, mine design, ore processing
  - see Charles Dumaresq talk for camp history
- Agnico Eagle and the Cobalt Camp
- Geochemical characterization – how is it leaching?
- Hydrogeology challenges – how is it being transported?
- Next steps
Background


- Green = Archean metasediment & metavolcanics

- Brown = metasedimentary (mainly conglomerate)

- Purple = diabase sill and mineralization is generally within 200m of intrusion
Mineralogy

• Ore minerals
  - Native silver, gold, bismuth and arsenic
  - Arsenides, sulpharsenides, sulphides
  - Calcite, dolomite, quartz, and chlorite (gangue)

• Weathering minerals
  - Erythrite, or ‘cobalt bloom’ (Co$_3$(AsO$_4$)$_2$•8H$_2$O)
  - Annabergite (Ni$_3$(AsO$_4$)$_2$•8H$_2$O)

• Unique to the camp is a relative lack of iron minerals – poor capacity to retain arsenic at neutral pH

• No ARD – excess of carbonates, low sulphur
• Just like tailings management, in the early days there was none!

• Exploration was typically by hiring men from the pub and trenching – which was very similar to mining method

• Not unheard of to have up to 10 shafts on a property

• Stories of throwing a toque at a rock wall – if it stuck, mining went that way (silver ‘horns’)

• Shafts and workings often joined

• Drill holes often intersected other workings and in some cases tailings!

• More later on interconnections….
Ore Processing

• Processing of the ore consisted mainly of grinding, gravity concentration and cyanidation in the earlier years
• Flotation in later years, with mercury and pyrometallurgy used to recover silver from the highest grade ores
• Relatively crude processing methods resulted in re-working tailings in later years – but also tailings with high metal content
• Waste rock was effectively ore that did not pass the toque test!
• 1957 to 1989 operations (not present in the first boom)
  o 25 mines and 4 mills, but over 200 properties due to opportunistic purchases for the return of the silver price

• 1992 to 2005 post closure works and monitoring

• 2006 – sold properties, but they were returned in 2010

• In 2012 the MNDM requested an amendment to closure plans due to unfinished reclamation efforts – which resulted in new geochemical and hydrogeology studies
Agnico Eagle at Cobalt – Road Map to Present Day

1953
Foundation of the Cobalt Consolidated Company

1957
Creation of Agnico

1972
Acquisition of Eagle Mines to become Agnico Eagle

1988
Operations start at Dumagami (LaRonde)

1988
Agnico’s silver production reached 26 million ounces in Cobalt mining camp

Ag + Ni + Co = Agnico
Agnico Eagle at Cobalt – Present Day
Technical Studies: Geochemistry
• Waste rock and tailings geochemical characterization studies to confirm or revise leaching basis
  o Focus is on arsenic, but other elements also included such as cobalt, nickel, etc

• General program
  o Geological setting and mineralogy review
  o Field tour with MNDM regional geologist Gary Gabrowski*
  o Review of previous work (e.g. Dumaresq 1993, MOE 2011)
  o Field sampling
  o Laboratory testing
  o Geochemical conceptual model development
Technical Studies – Geochemistry

• Laboratory testing program included
  o Composition – aqua regia & ICP-MS
  o Acid-base accounting
  o Mineralogy
  o Water soluble leaching tests (i.e. SFEs)

• Material has been weathering for over 100 years in some cases – no real need for laboratory weathering tests
• Arsenic 10X basalt = 20 mg/kg
• Tailings up to 10,000 mg/kg
A diverse suite of arsenic hosting minerals based on deportment (normalized)

Mixture of primary (safflorite (CoAs$_2$)) and secondary phases (arsenates)

- **Nickeline**
- **Safflorite**
- **Zn As Oxide**
- **Ca-Fe-As Oxy/Hydroxide**
- **Ni Co Arsenate**
- **As Co Ni Sulphide**
- **Co-Fe-As Sulphide**
- **Other Cu Sulphides**
- **Arsenopyrite**
Mineral Solubility – As Leaching

Possible solubility limit from Co Arsenate (phreeqc)

2% As, from reprocessed tailings, pyrometallurgy and possibly contains arsenic oxide (2 g/L solubility)
Geochemistry: Leaching Conceptual Model
(Modified after S.Day, SRK)

- Accumulation in dry times (summer and winter)
- Flushing during freshet, high precip events
- Model is typical of sulphide reactivity

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\text{CoAs}_2
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- Oxidant \((O_2)\)
- H\(_2\)O (reactant)
- H\(_2\)O (transport mechanism)
- Arsenate(dissolved), cobalt precipitation
- e.g. erythrite

As, Co
Geochemistry: Challenges & Opportunities

• Challenges
  o long term reservoir creating soluble arsenic minerals
  o low immobilization potential (low iron environment)
  o Many sites and transport (hydro) – see next slides
  o Regulatory objectives and the geological setting

• Opportunities
  o solubility control (albeit high) and therefore water contact management as opposed to oxidation inhibition
  o Some sequestration noted
  o Metal leaching (Co, Ni) is relatively low due to alkaline conditions (as compared to ARD scenario)
Technical Studies: Hydrogeology
Hydrogeology Studies

• Some of the work completed to understand water movement
  o Monitoring wells in tailings and bedrock
  o Water level monitoring in shafts, raises, adits, open cuts, lakes and ponds
  o Instrumentation included survey-grade GPS and level loggers at key locations for extended periods
  o Digitized historic maps of underground workings, in both plan and section view
Hydrogeology Studies

• Work completed to understand water movement (continued)
  o Interviewed former miners and contractors who worked in the camp
  o Reviewed literature, including publications such as *Cobalt Mining Times Remembered* by William Sutton (2013 book by former miner)
  o Reviewed historical air photos of drained lakes
  o Conducted detailed bathymetric mapping of key surface water bodies (e.g., Cobalt Lake)
3D Video of underground workings
Plan view of workings (in lieu of animation)
Hydrogeology – Piping Connections
Valves present on both sides of bulkhead.
Glory Hole is 250 m north of lake
Hydrogeology: Challenges and Opportunities

• Challenges
  • Multiple owners (not only Agnico Eagle) and transport of loadings through connected networks
  • Mine hazards such as crown pillars and open stopes also are not only held by one owner

• Opportunities
  • Low permeability bedrock – therefore inhibition of mine water into groundwater
  • Preferential transport of water through the workings
Rehabilitation Next Steps
A risk based action plan has been developed with MNDM for the area to consider:

- Water quality
- Physical hazards
- Historical value

Working groups are being established to help establish water quality objectives and historical value.

In the meantime:

- Evaluate reclamation techniques on wholly owned sites
- Cobalt market – but caution needed with regards to closure obligations and the mandate of junior exploration companies
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