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

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AGNICO EAGLE

STORY environmental & geomatics

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# Presentation Overview:

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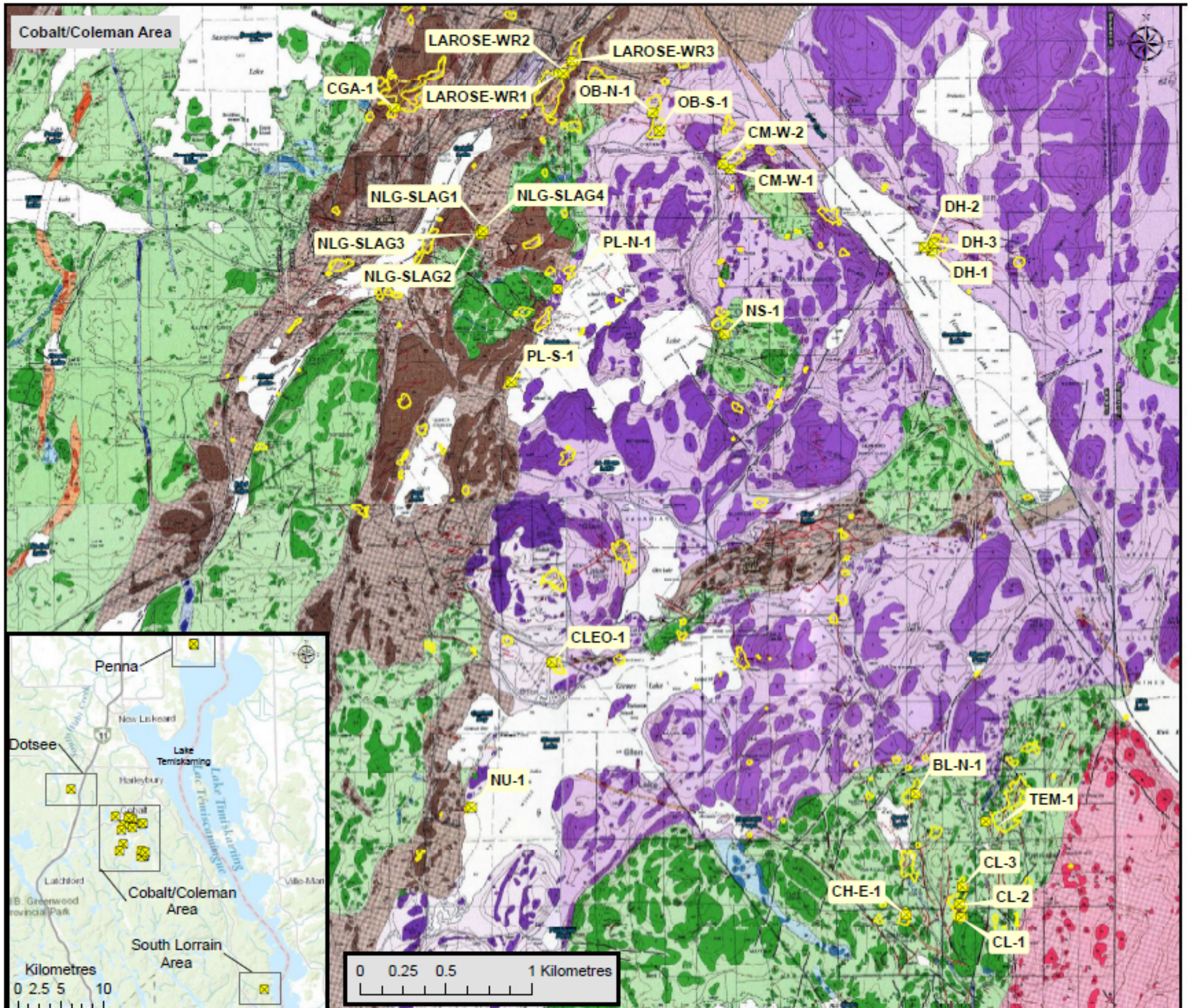
- General background – geology, mine design, ore processing
  - *see Charles Dumaresq talk for camp history*
- Agnico Eagle and the Cobalt Camp
- Geochemical characterization – how is it leaching?
- Hydrogeology challenges – how is it being transported?
- Next steps

# Background

# Geological Setting




- 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' ($Co_3(AsO_4)_2 \bullet 8H_2O$)
  - Annabergite ($Ni_3(AsO_4)_2 \bullet 8H_2O$)
- 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

# Mine Design

- 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!

# Agnico Eagle in Cobalt

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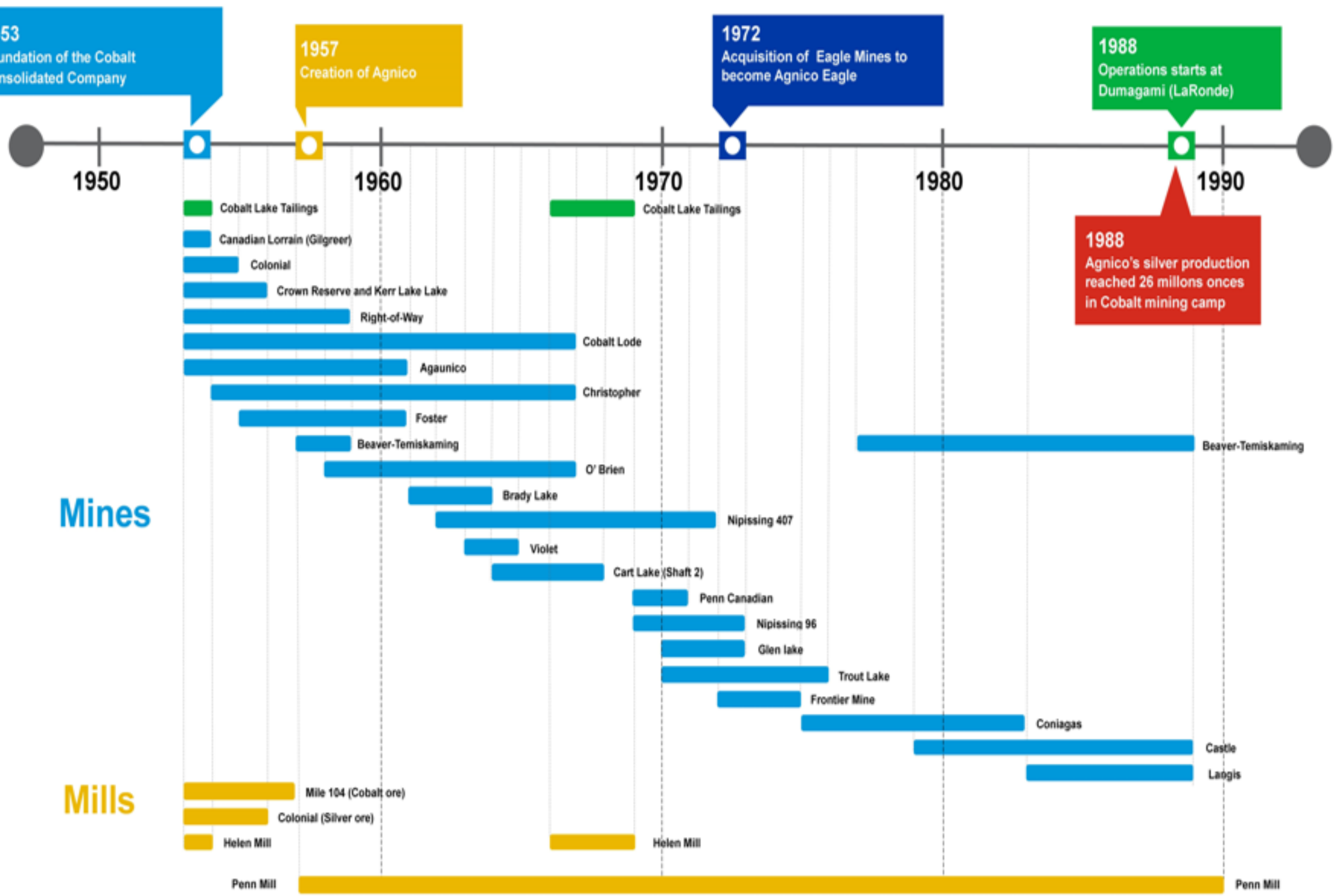
# Agnico Eagle at Cobalt – Road Map to Present Day

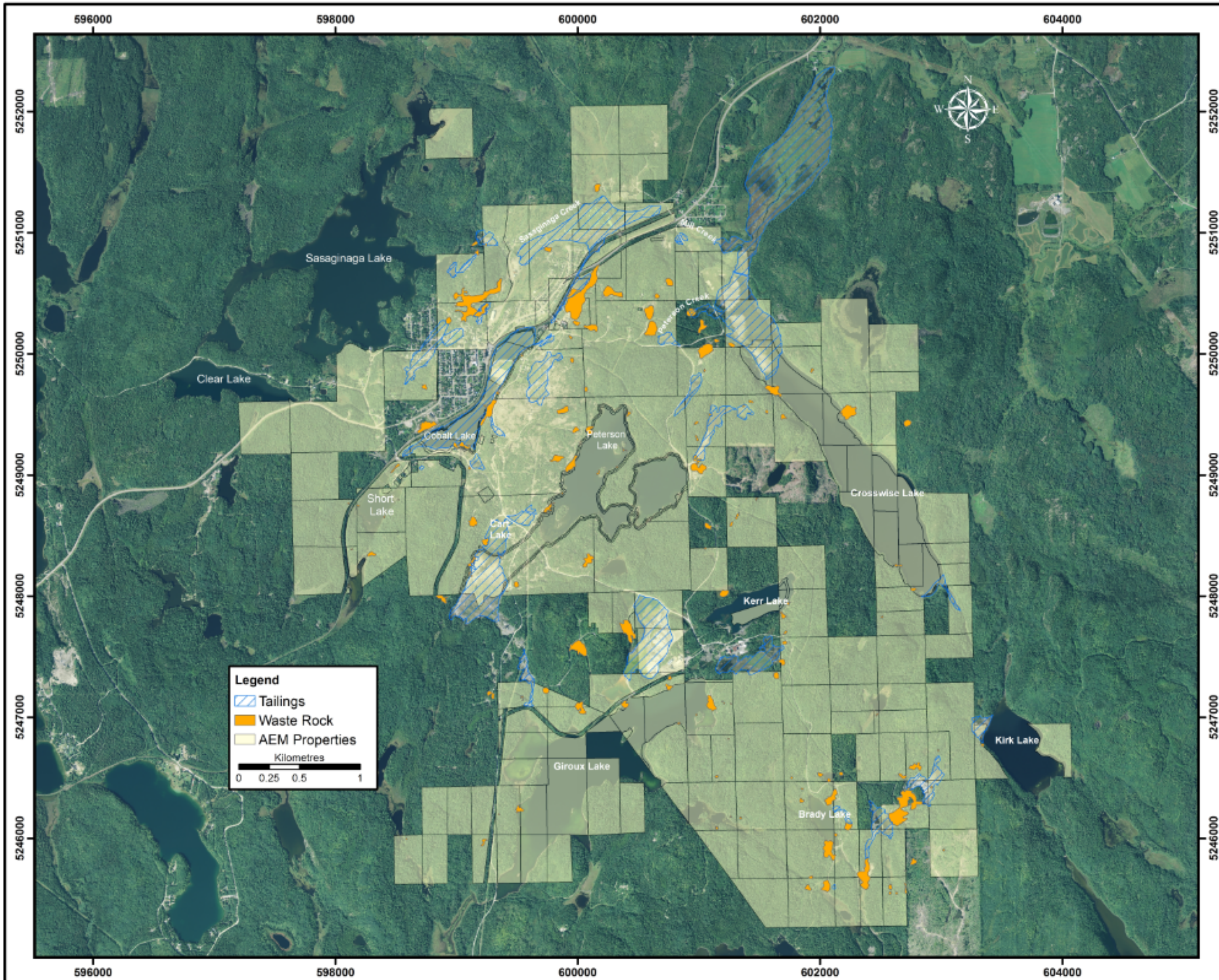
- 1957 to 1989 operations (not present in the first boom)
  - 25 mines and 4 mills, but over 200 properties due to opportunistic purchases for the return of the silver price
- 1992 to 2005 post closure works and monitoring
- 2006 – sold properties, but they were returned in 2010
- In 2012 the MNDM requested 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




Ag + Ni + Co = Agnico

# Agnico Eagle at Cobalt – Present Day



# Technical Studies: Geochemistry

# Technical Studies – Geochemistry

- Waste rock and tailings geochemical characterization studies to confirm or revise leaching basis
  - Focus is on arsenic, but other elements also included such as cobalt, nickel, etc

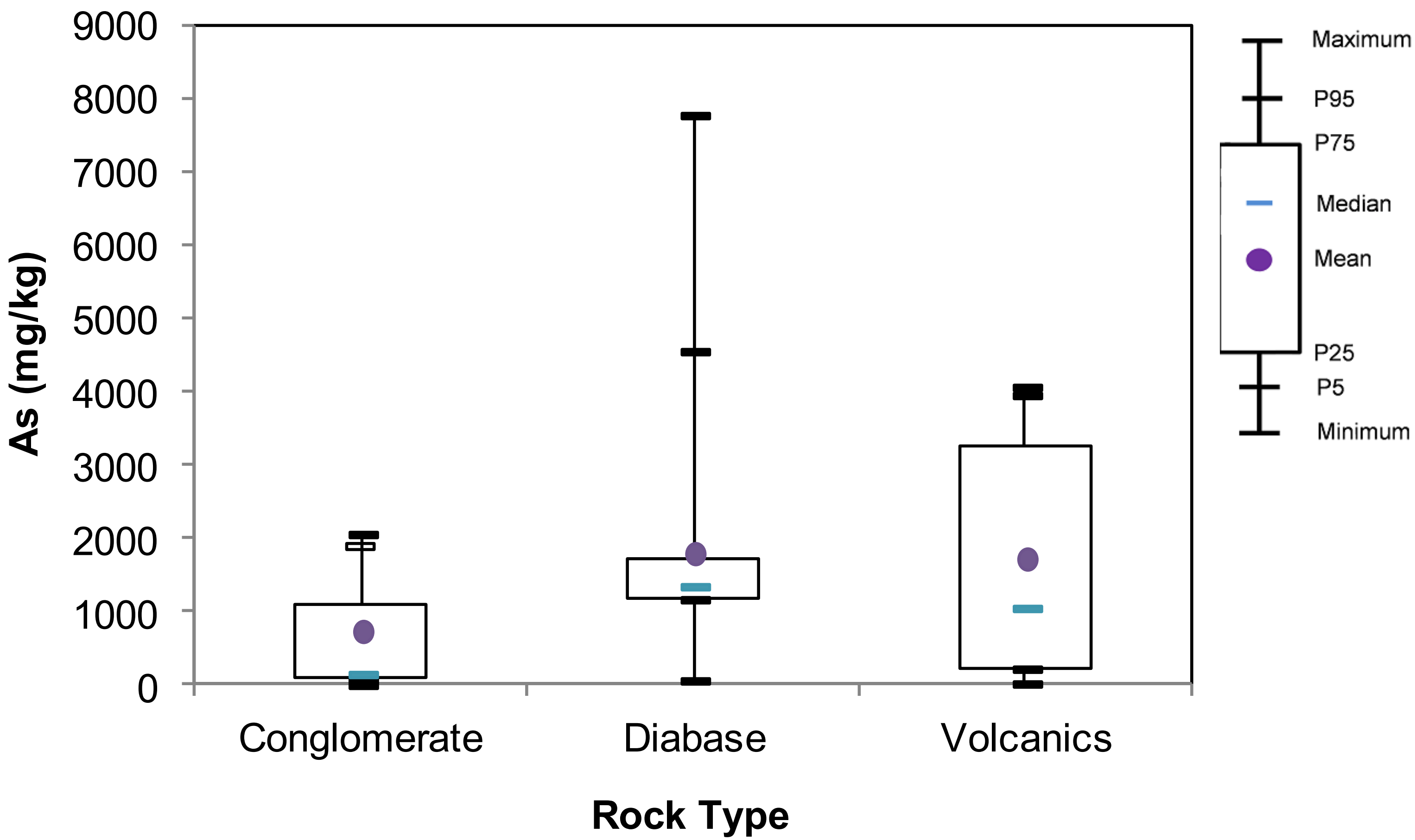
- General program
  - Geological setting and mineralogy review
  - Field tour with MNDM regional geologist Gary Gabrowski*
  - Review of previous work (e.g. Dumaresq 1993, MOE 2011)
  - Field sampling
  - Laboratory testing
  - Geochemical conceptual model development

# Technical Studies – Geochemistry

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

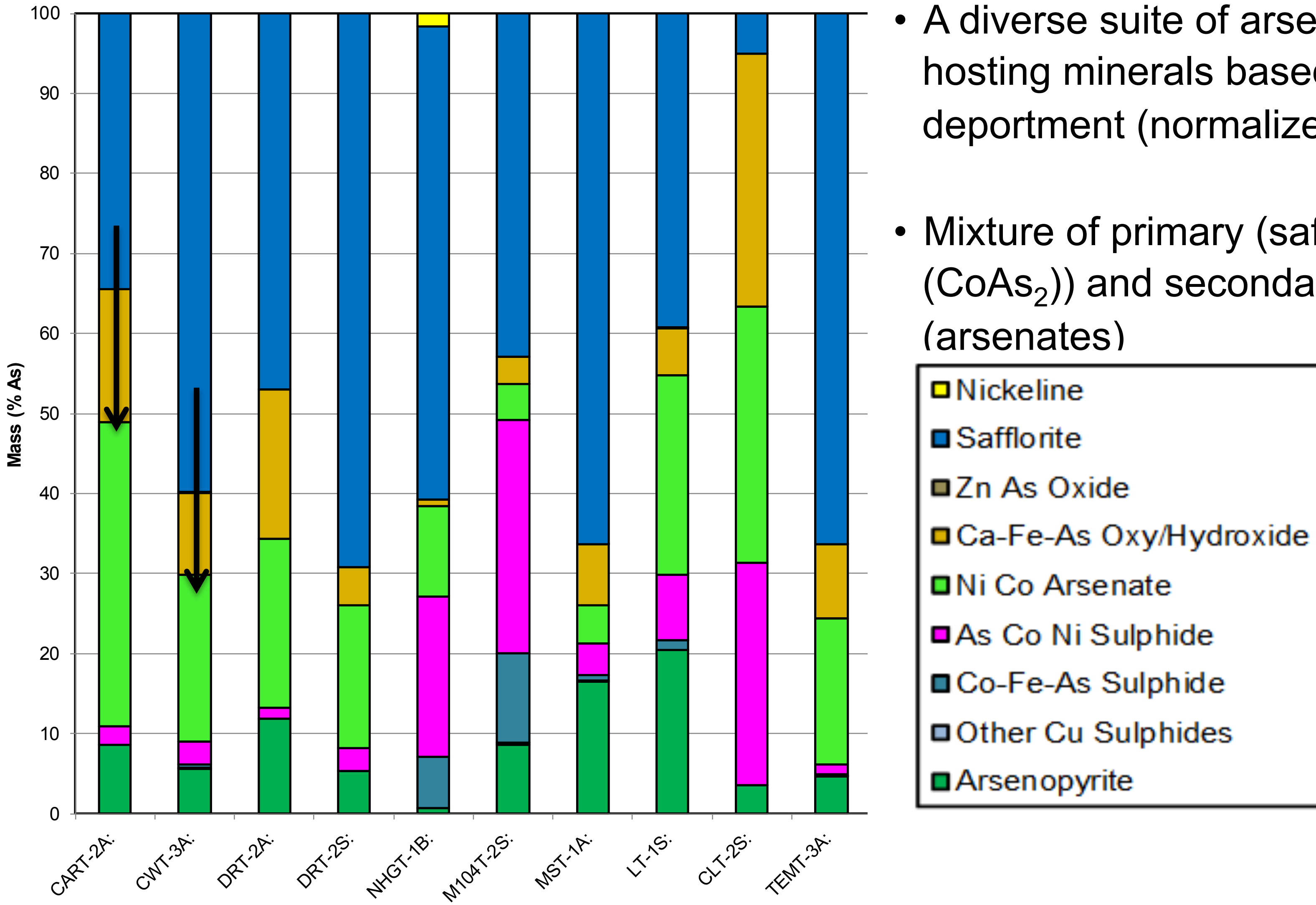
- Material has been weathering for over 100 years in some cases – no real need for laboratory weathering tests

# Geochemistry: Composition



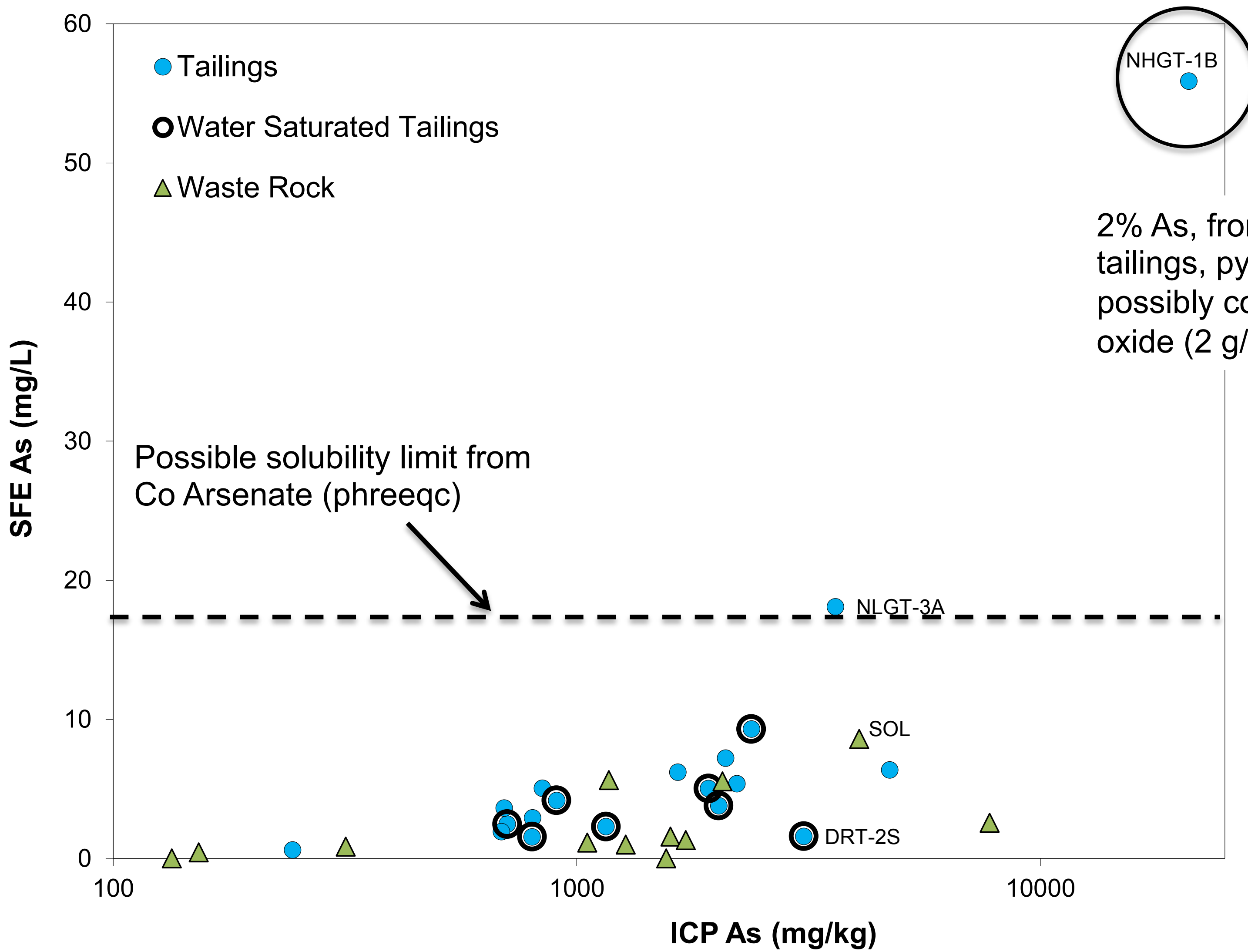

- Arsenic 10X basalt = 20 mg/kg
- Tailings up to 10,000 mg/kg

# Geochemistry: Waste Rock and Tailings Mineralogy




- A diverse suite of arsenic hosting minerals based on deportment (normalized)
- Mixture of primary (safflorite ($CoAs_2$)) and secondary phases (arsenates)

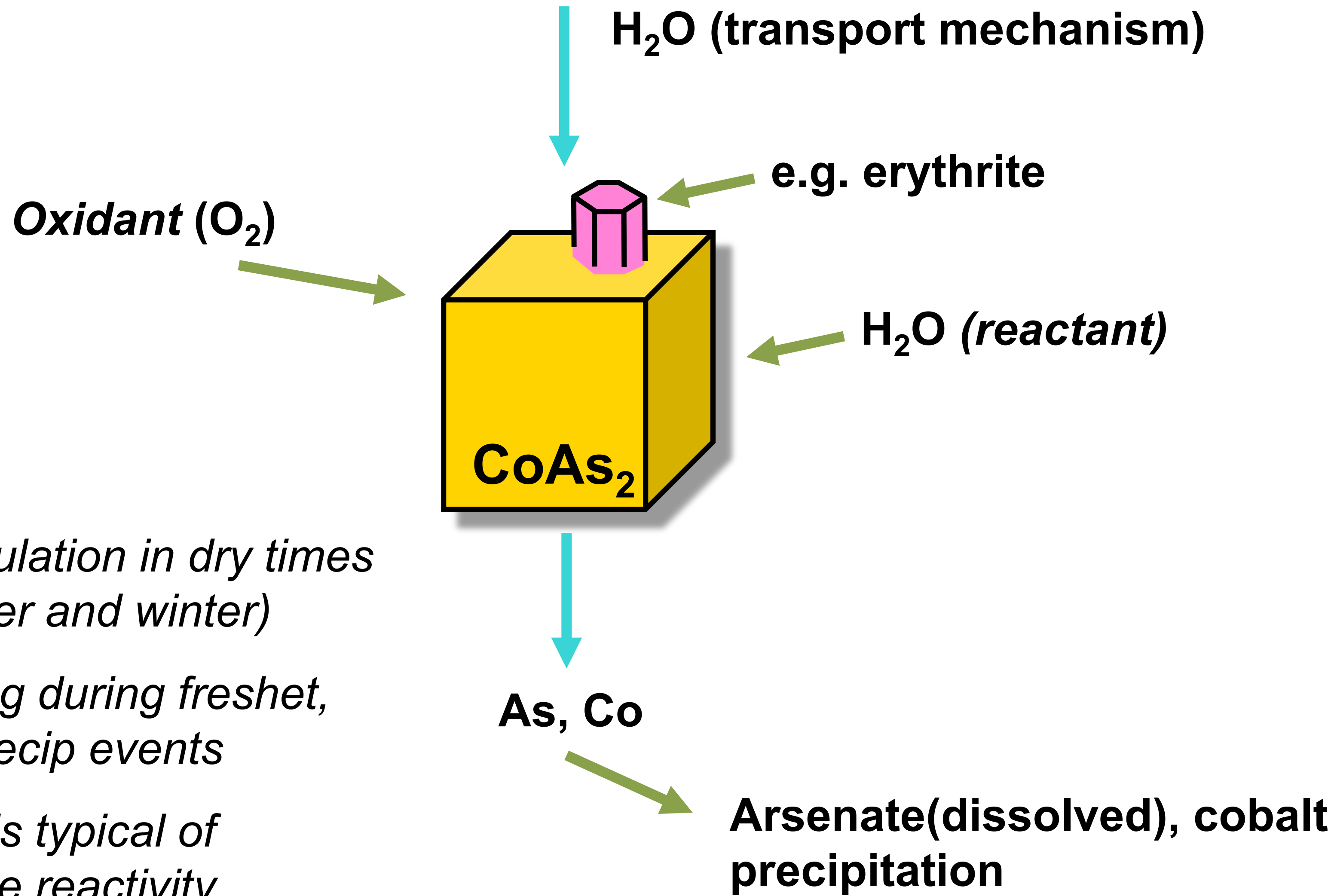
# Mineral Solubility – As Leaching




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*

# Geochemistry: Challenges & Opportunities

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

- Opportunities
  - solubility control (albeit high) and therefore water contact management as opposed to oxidation inhibition
  - Some sequestration noted
  - 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
  - Monitoring wells in tailings and bedrock
  - Water level monitoring in shafts, raises, adits, open cuts, lakes and ponds
  - Instrumentation included survey-grade GPS and level loggers at key locations for extended periods
  - Digitized historic maps of underground workings, in both plan and section view

# Hydrogeology Studies

- Work completed to understand water movement (continued)
  - Interviewed former miners and contractors who worked in the camp
  - Reviewed literature, including publications such as *Cobalt Mining Times Remembered* by William Sutton (2013 book by former miner)
  - Reviewed historical air photos of drained lakes
  - Conducted detailed bathymetric mapping of key surface water bodies (e.g., Cobalt Lake)

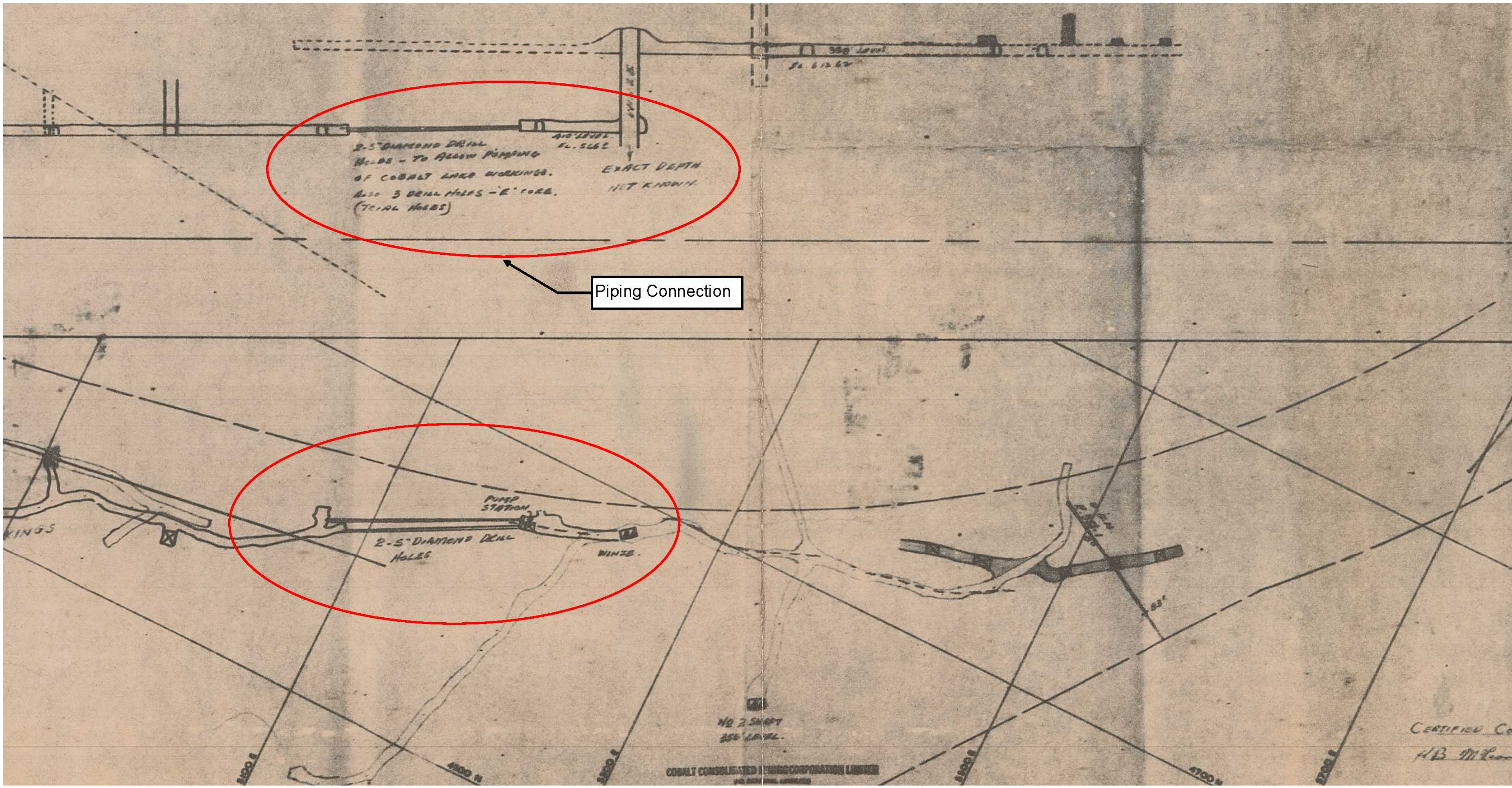
# Hydrogeology

3D Video of underground workings

# Hydrogeology

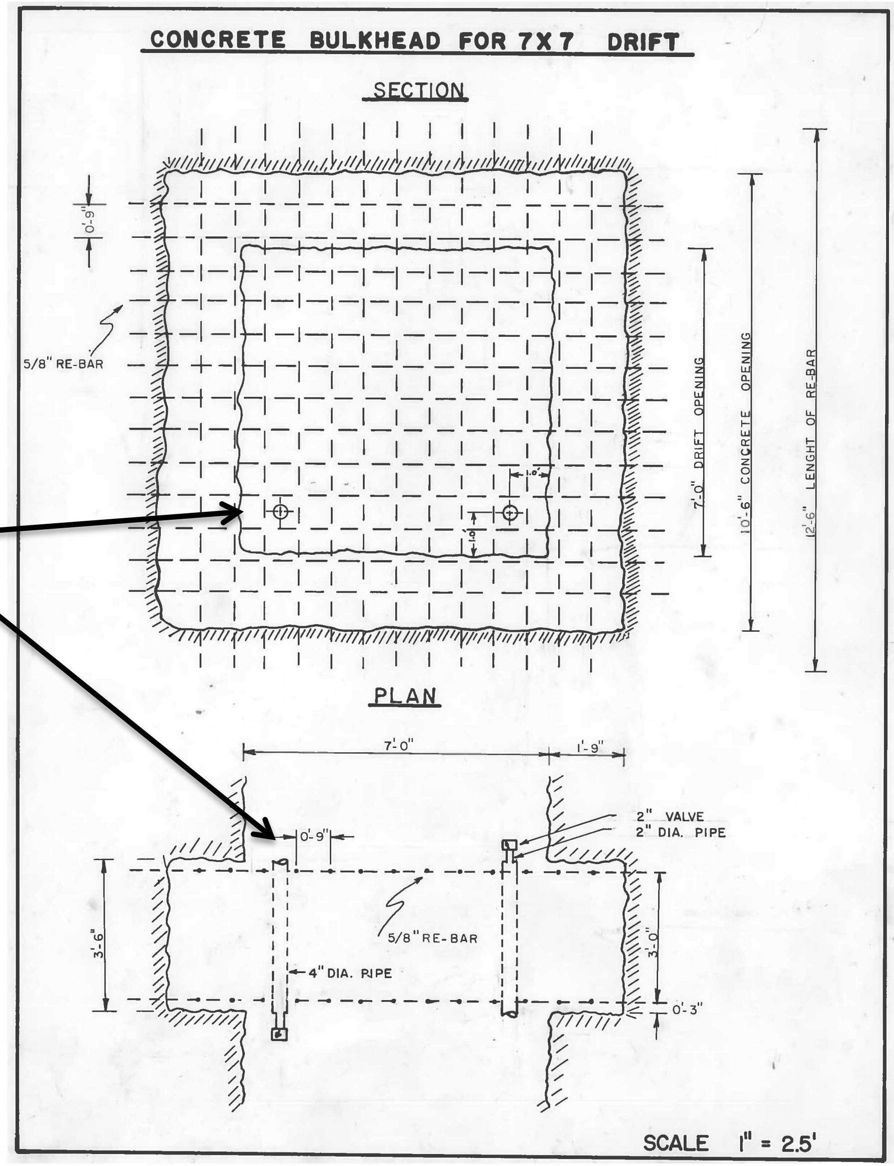
Plan view
of workings
(in lieu of
animation)

# Hydrogeology – Piping Connections

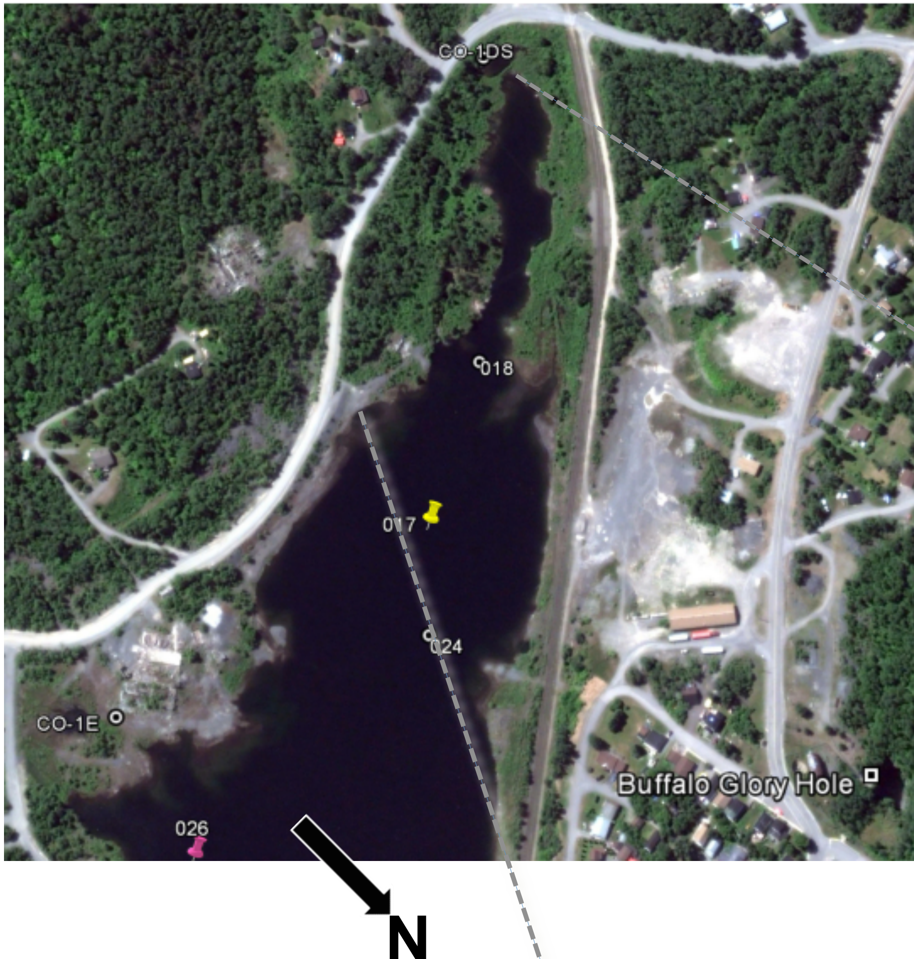


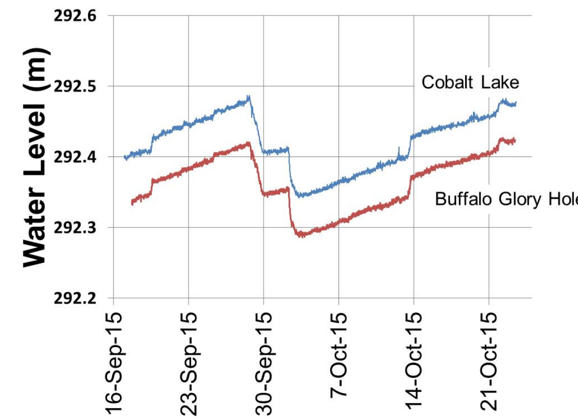
# Hydrogeology – Bulkhead Design

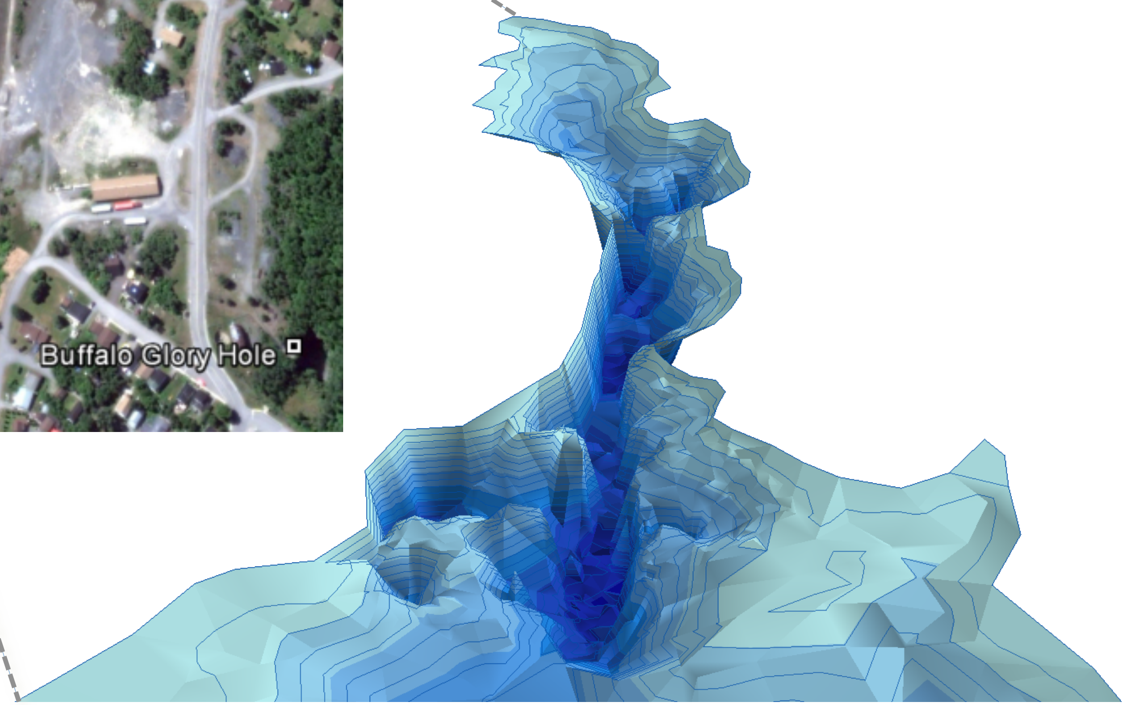
Valves present on both sides of bulkhead



# Hydrogeology – Cobalt Lake Connectivity

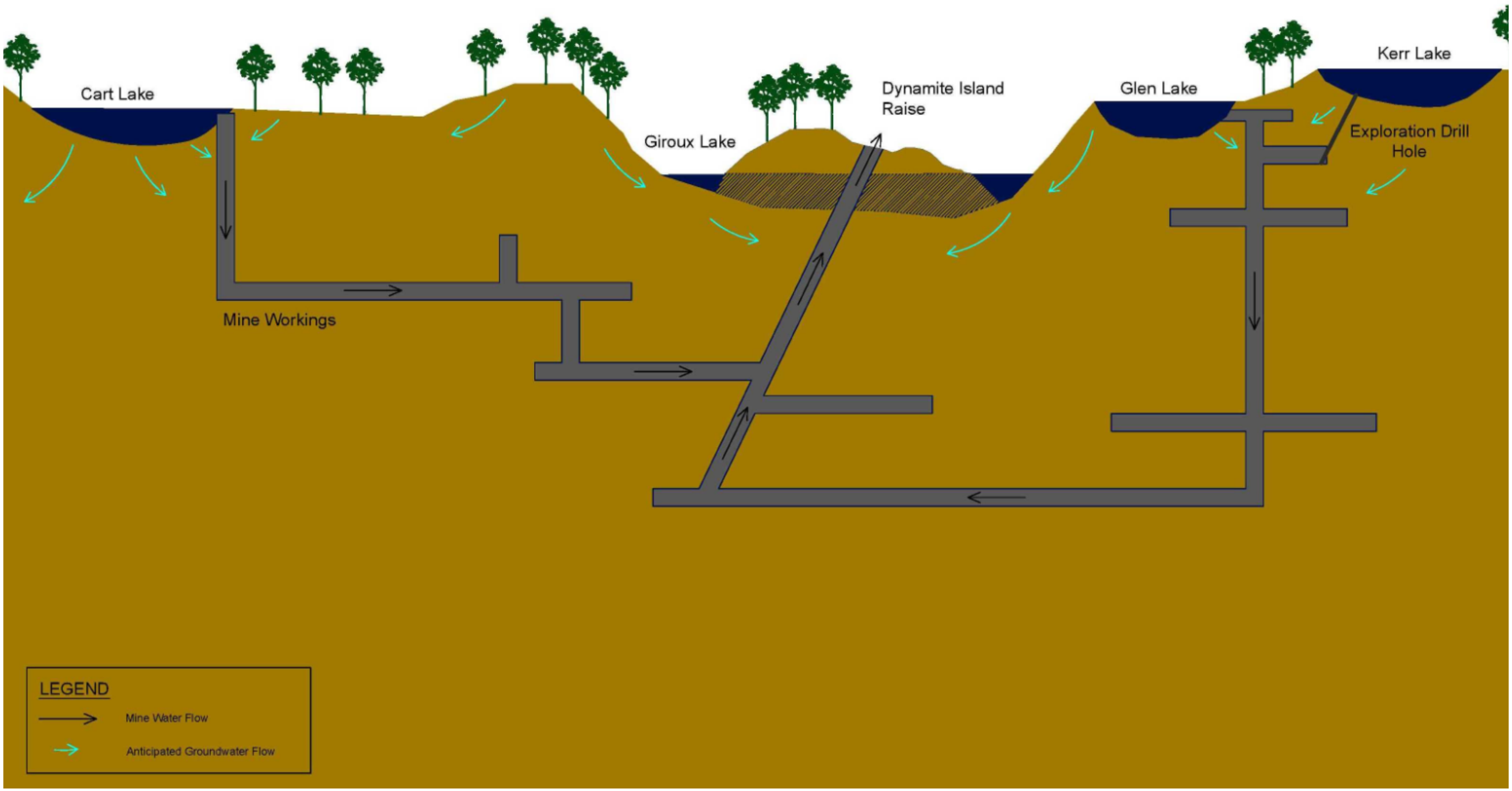


Glory Hole is 250 m north of lake

# Hydrogeology – Resulting Conceptual Model



# 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

# 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

# Acknowledgements and Thanks!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- Thanks for listening!