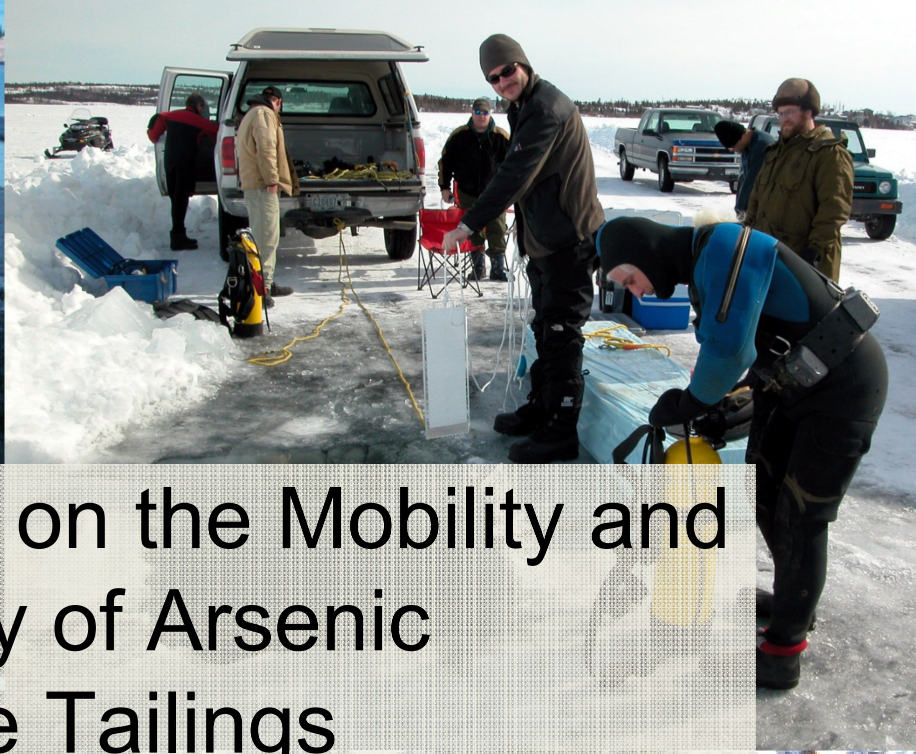
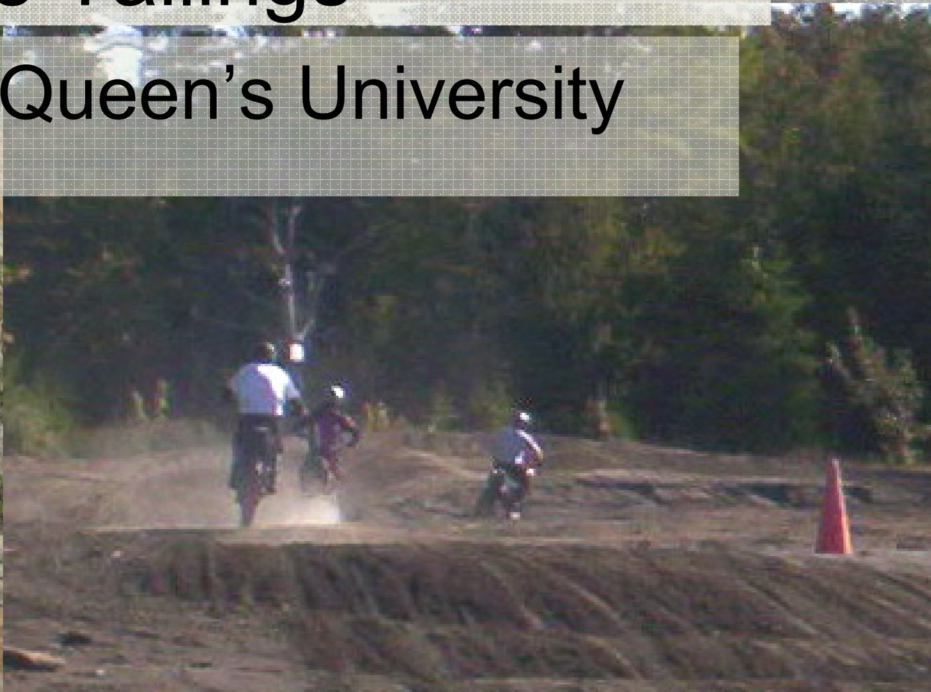



Mineralogical Controls on the Mobility and Bioaccessibility of Arsenic in Gold Mine Tailings

Heather Jamieson, Queen's University

Four examples from recent research at Queen's University

1. Giant Mine Tailings, Yellowknife

   S.R. Walker, H.E. Jamieson, A. Lanzirotti, C.F. Andrade, 2005. Canadian Mineralogist 43, 1205-1224.

2. Lake sediments, Yellowknife Bay

   C.F. Andrade, H.E. Jamieson, T.K. Kyser, T. Praharaj, D. Fortin, Applied Geochemistry (accepted 2008)

3. Roaster-impacted soils, Yellowknife area

   L. Wrye, H.E. Jamieson, Environmental Science & Technology (submitted)

4. Abandoned gold mines, Nova Scotia

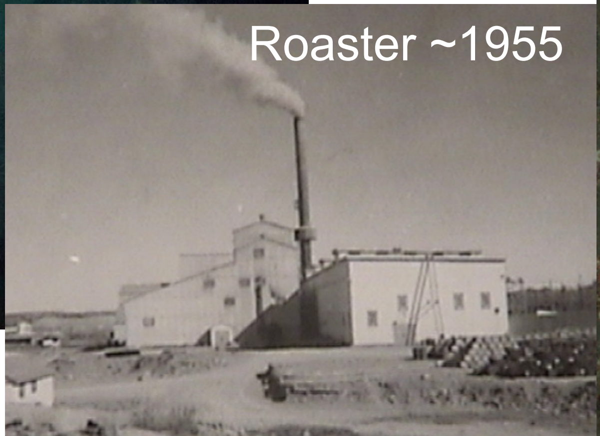
   S.R. Walker, M.B. Parsons, H.E. Jamieson, Canadian Mineralogist (submitted)

1. In what mineral form is As hosted in gold mine tailings that include roaster waste?

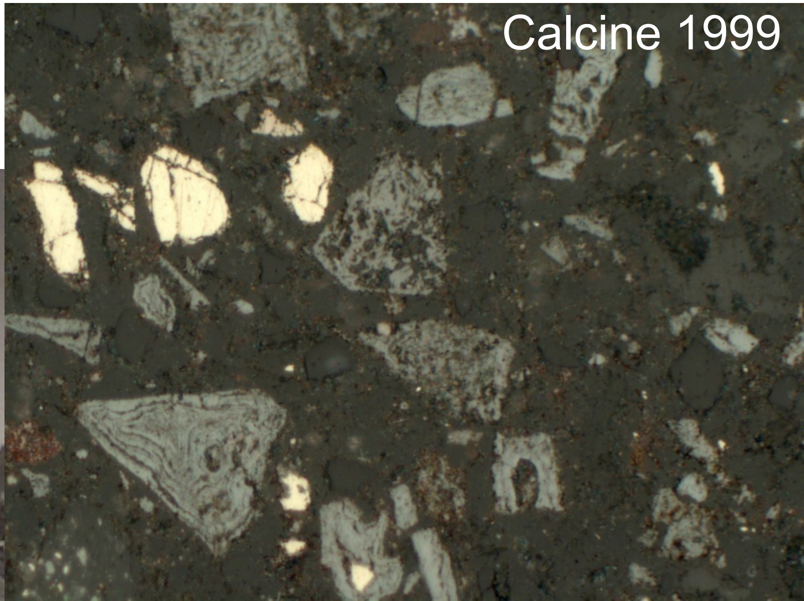
60 yr-old site managed by INAC with controlled public accessibility

Soon to be remediated

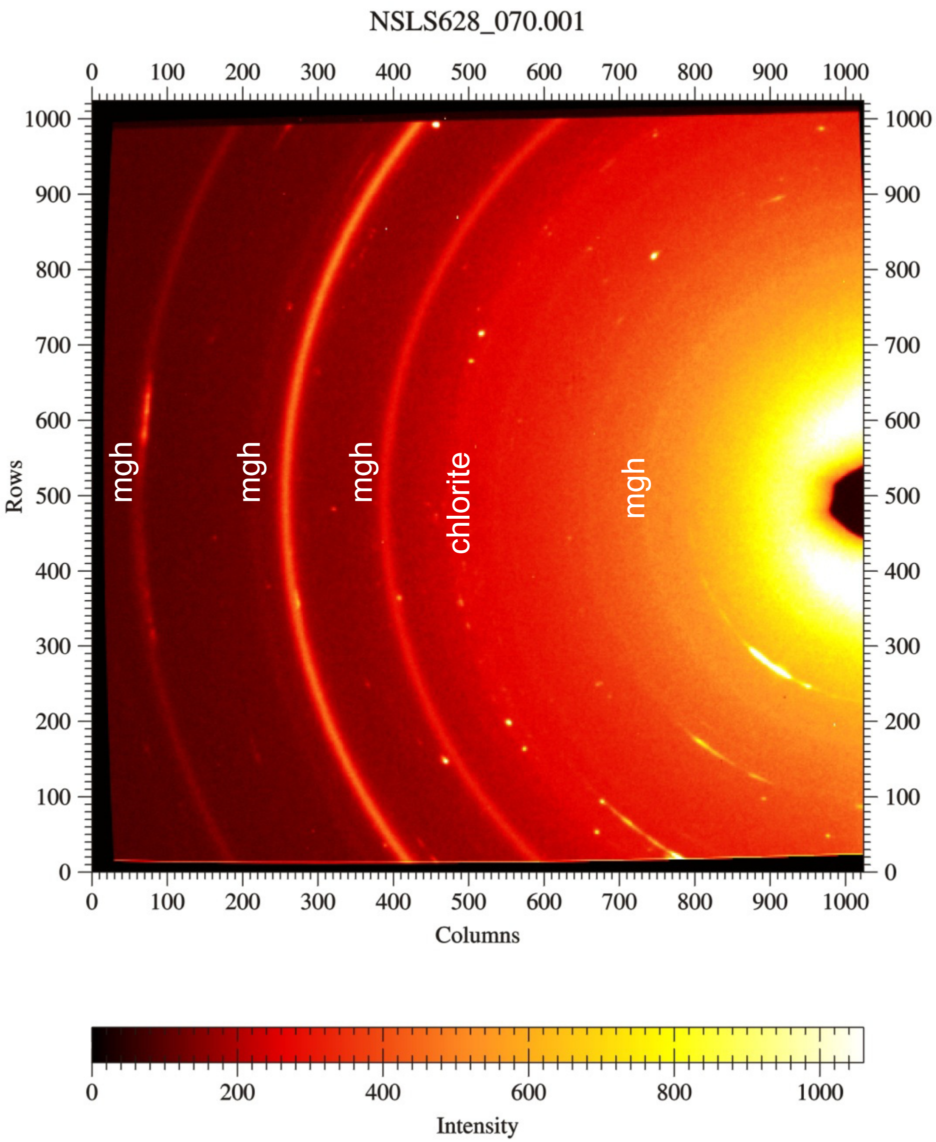
Mixture of flotation tailings & roaster waste (75% of arsenic in tailings from calcine)

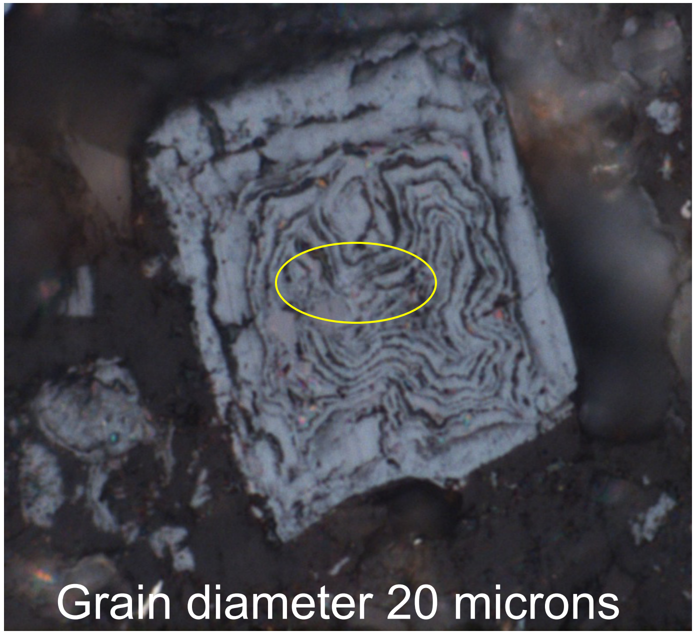


Field of view 0.160 mm x 0.120 mm



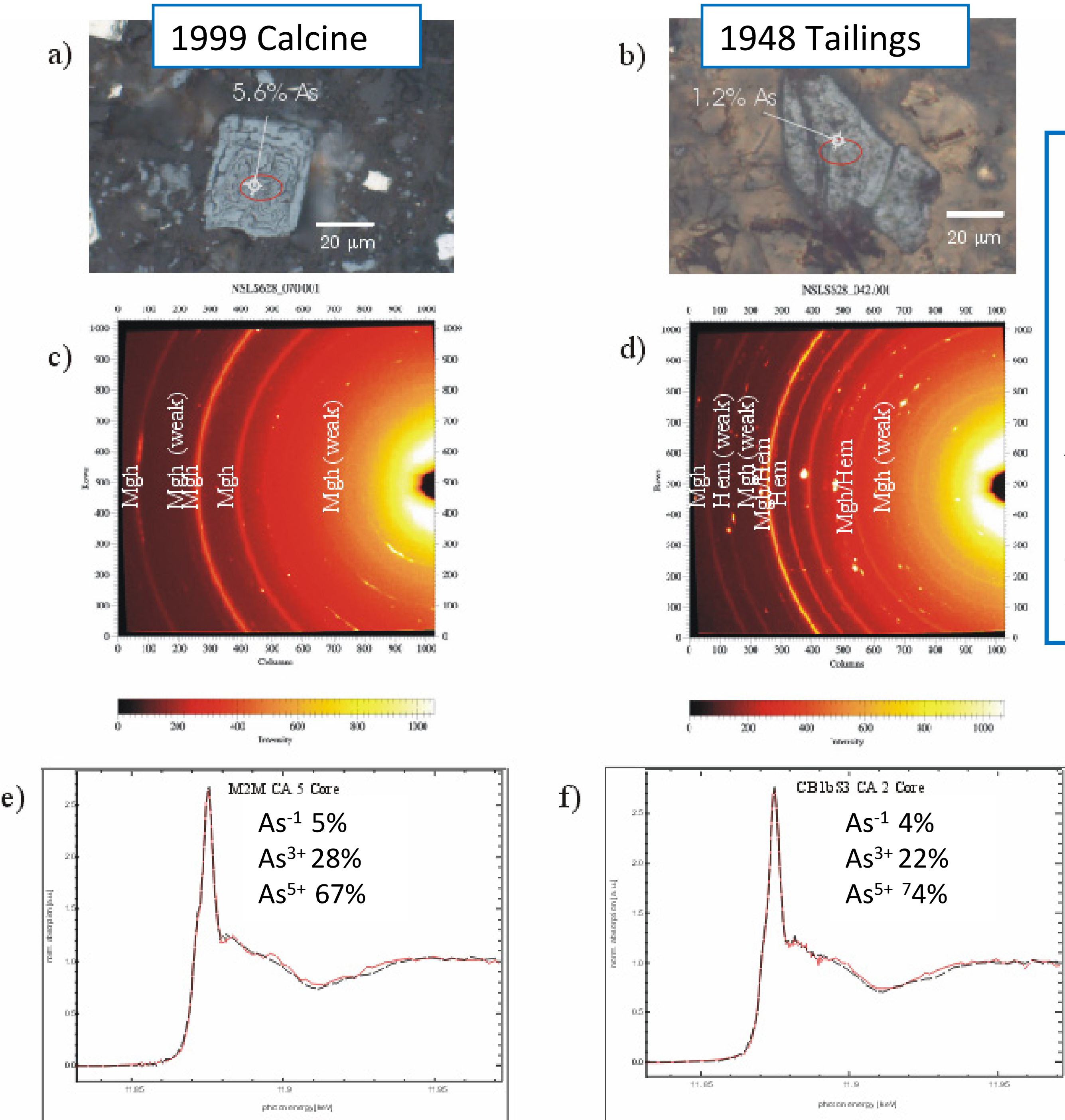
Synchrotron-based microXRD





Roaster oxides behave as powders and produce Debye rings

Centre of grain is nanocrystalline maghemite (γ-Fe_2O_3)



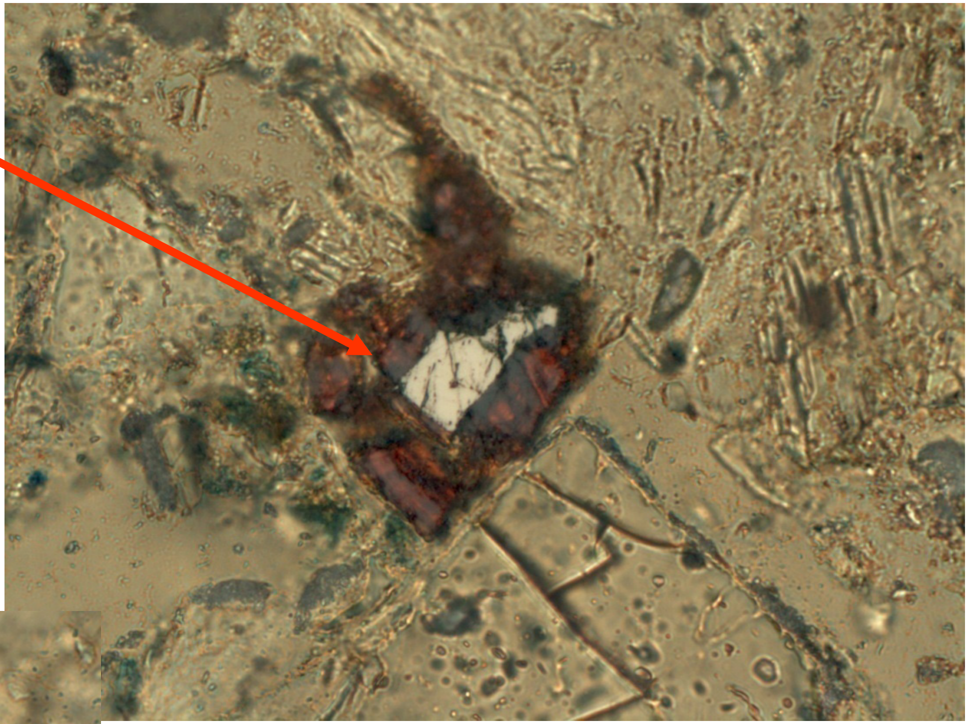
Roaster-generated Fe oxides (maghemite and hematite) contain 0.5 to 7% As

This is a mixture of As^{5+} and As^{3+}

Roaster oxides exposed to atmosphere for 60 years still contain As^{3+}

Oxidizing sulfides

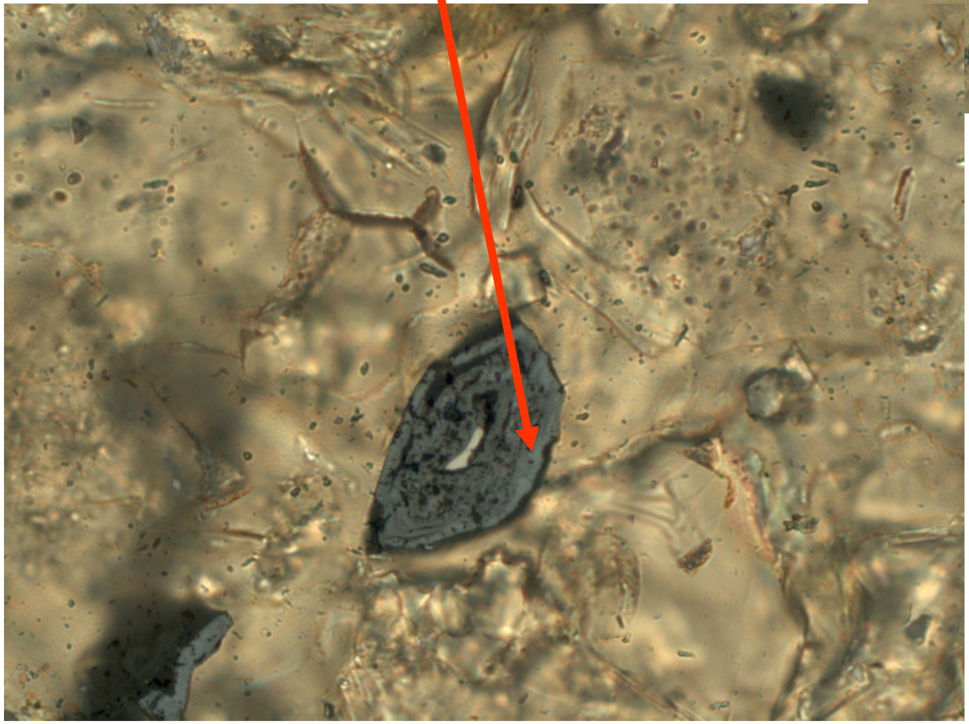
Arsenopyrite and pyrite with AsV-bearing iron oxyhydroxide rim



Roaster iron oxide

AsIII and As V-bearing iron oxide around sulfide core

Field of view 0.16 x 0.12 mm

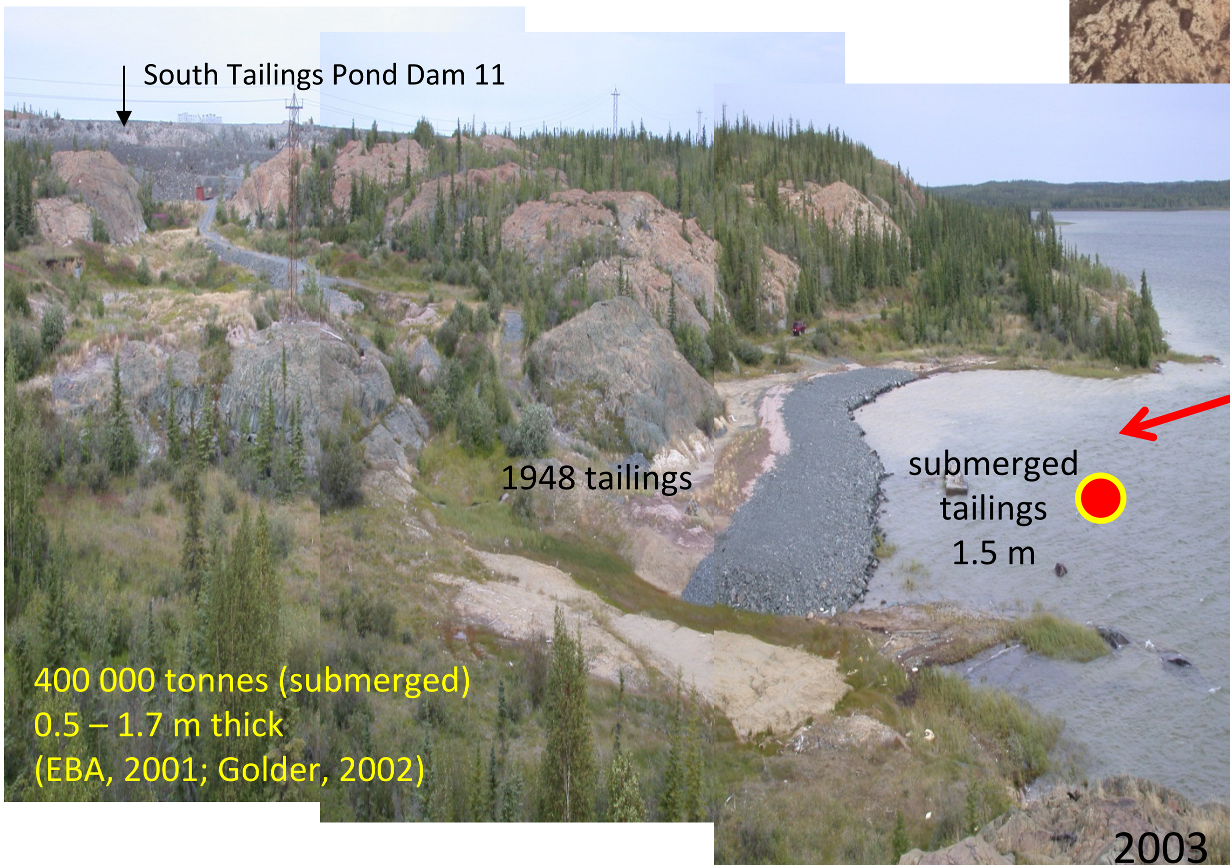


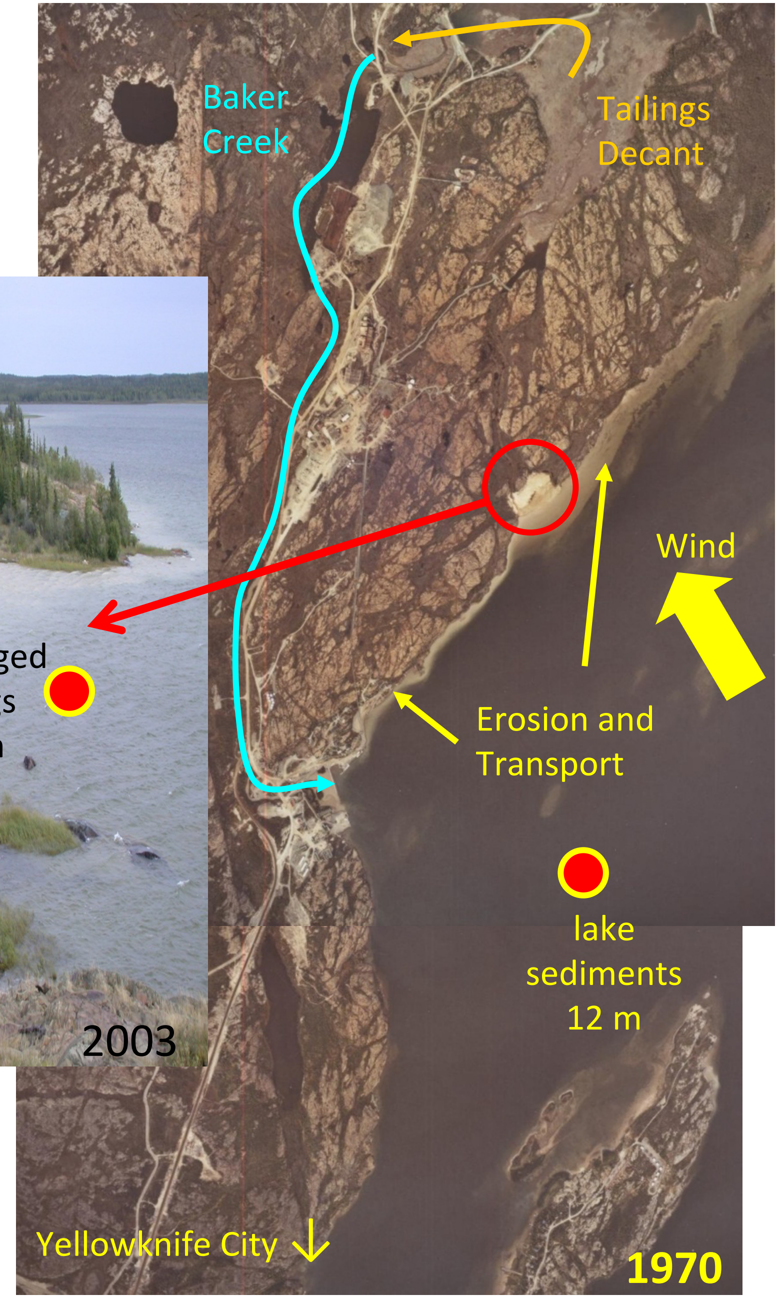
Conclusions

1. Tailings remediation plan designed for a mixture of oxide and sulfide-hosted As: composite cover

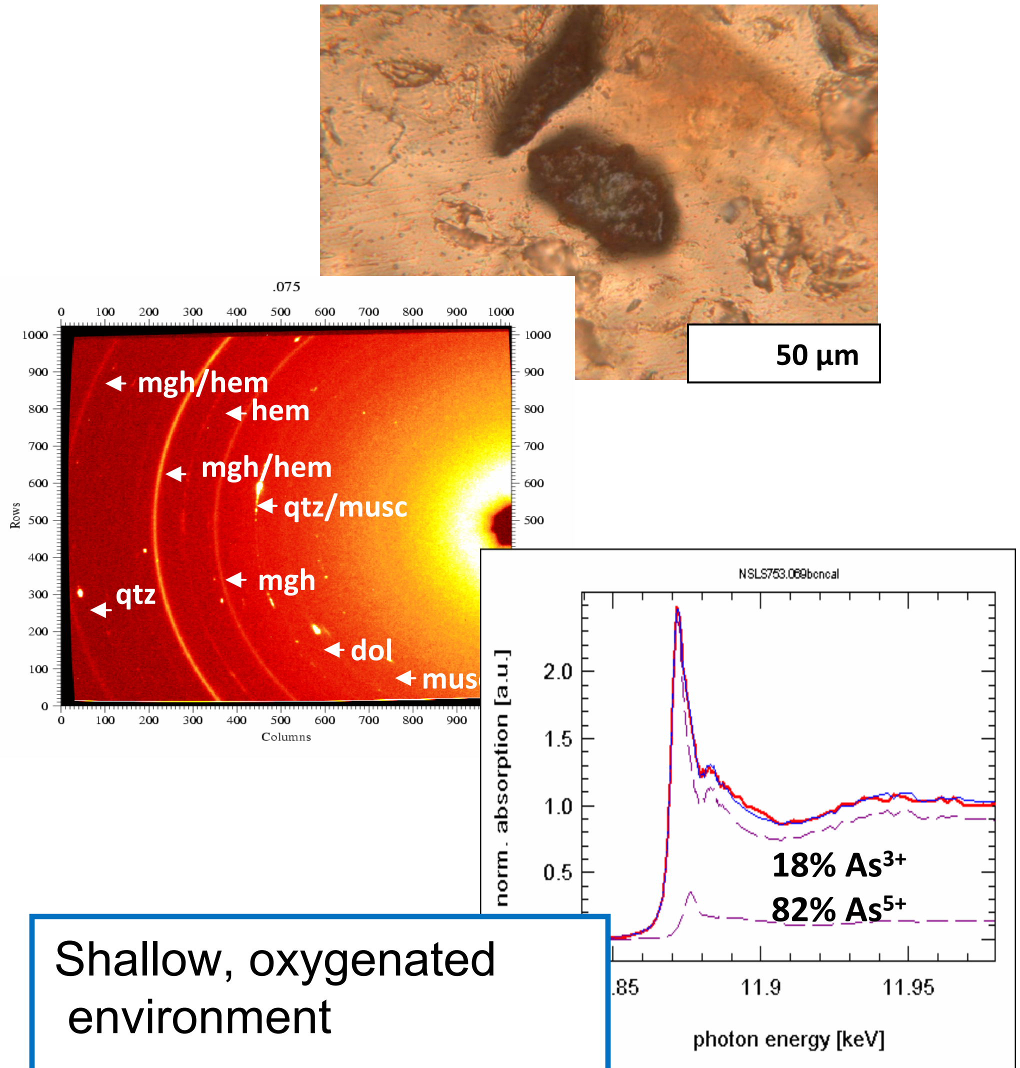
2. Understanding processing history is important to predict As mobility

2. Are As-bearing roaster oxides stable in Yellowknife Bay?





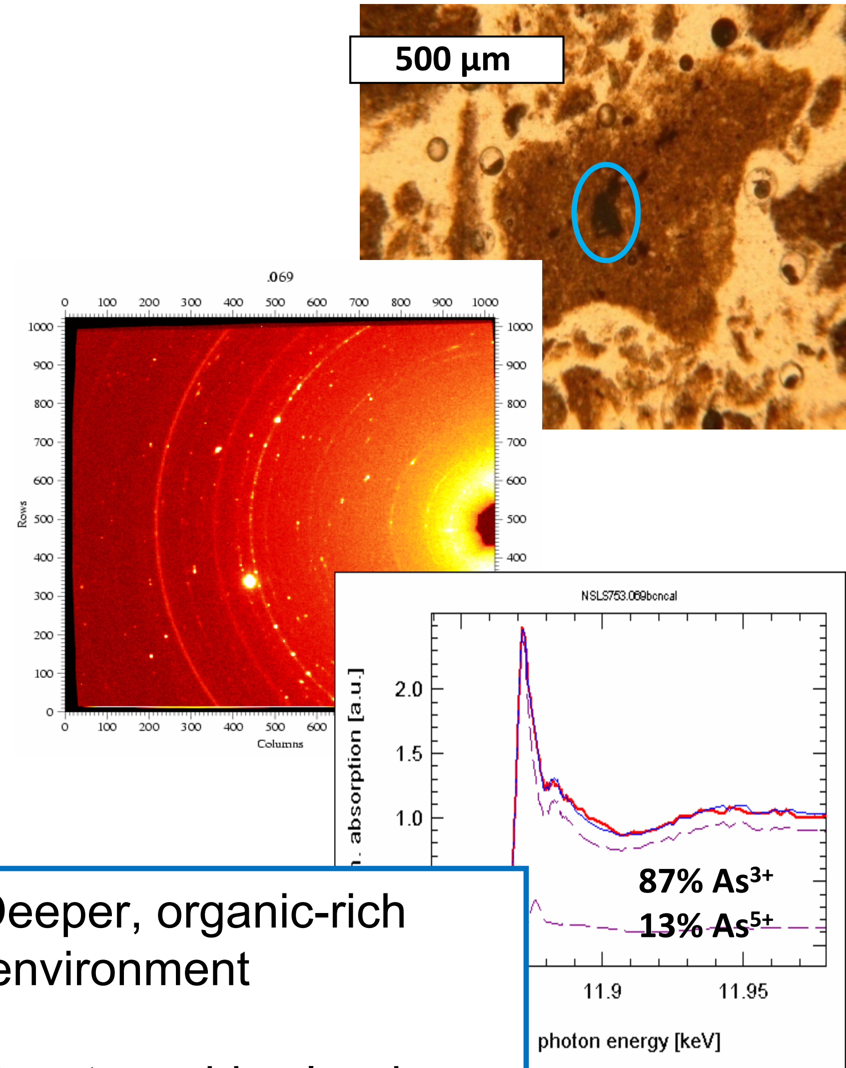
Submerged Tailings (1.5 m)



Shallow, oxygenated environment

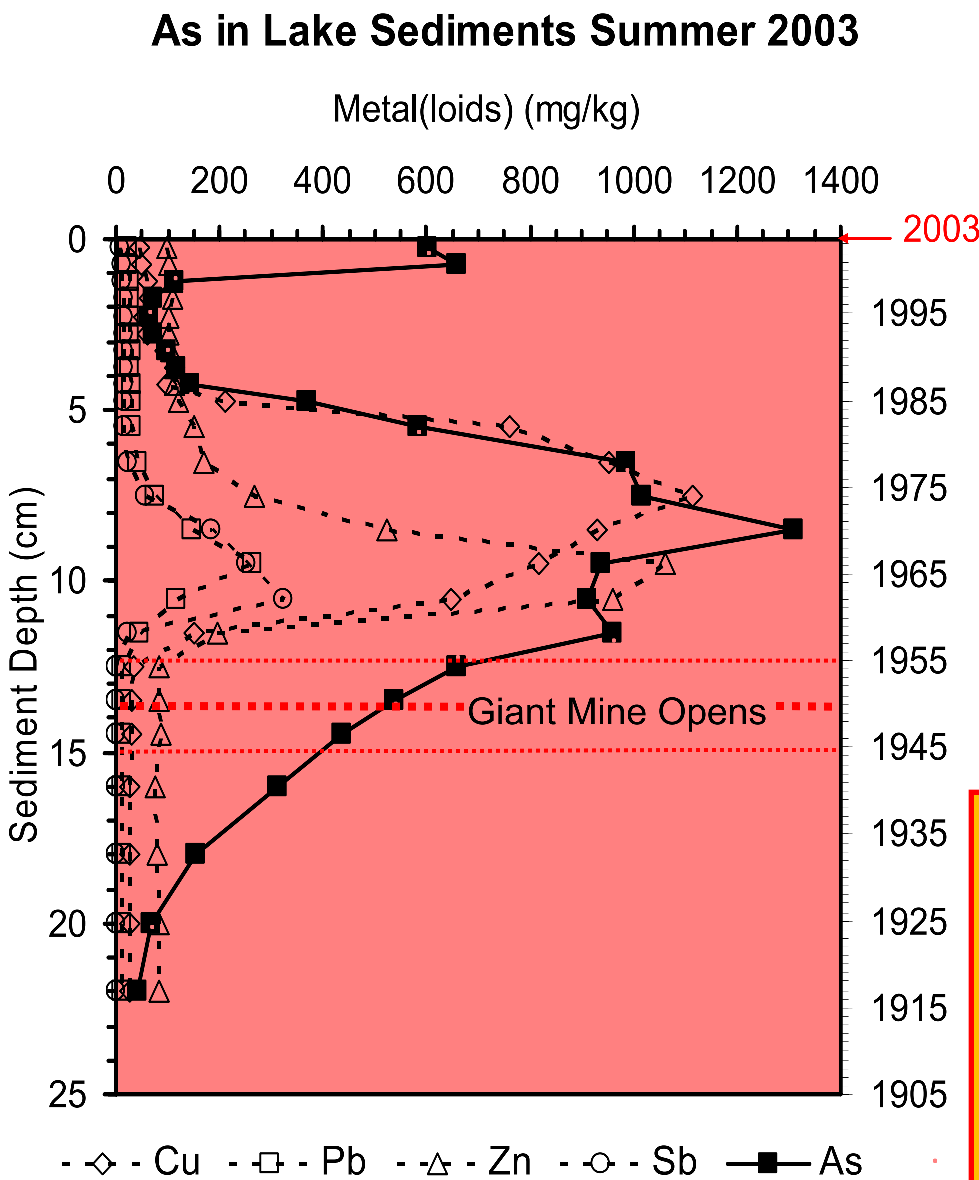
Roaster oxides similar to subaerial ones

Lake Sediment (12 m)



Deeper, organic-rich environment

Roaster oxides low in As^{5+} - preferentially leached or reduced



Sediment core records release of As and metals for ~25 years of mining

Emission controls limited metal release in later years

Pore water data (not shown) shows that As is migrating upwards from mid-core enrichment

As is recaptured near surface by Fe-Mn oxydroxide layer

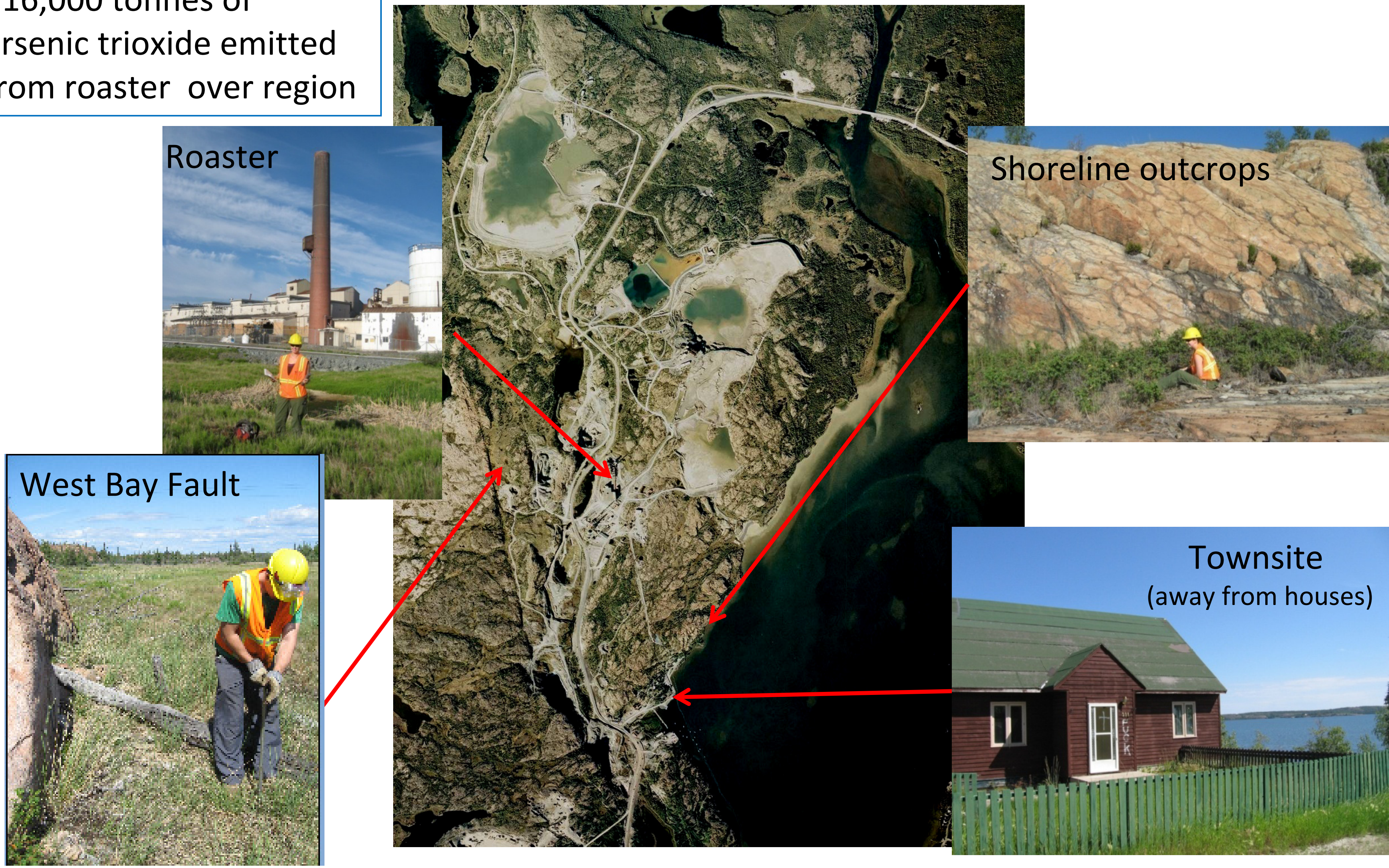
Conclusions

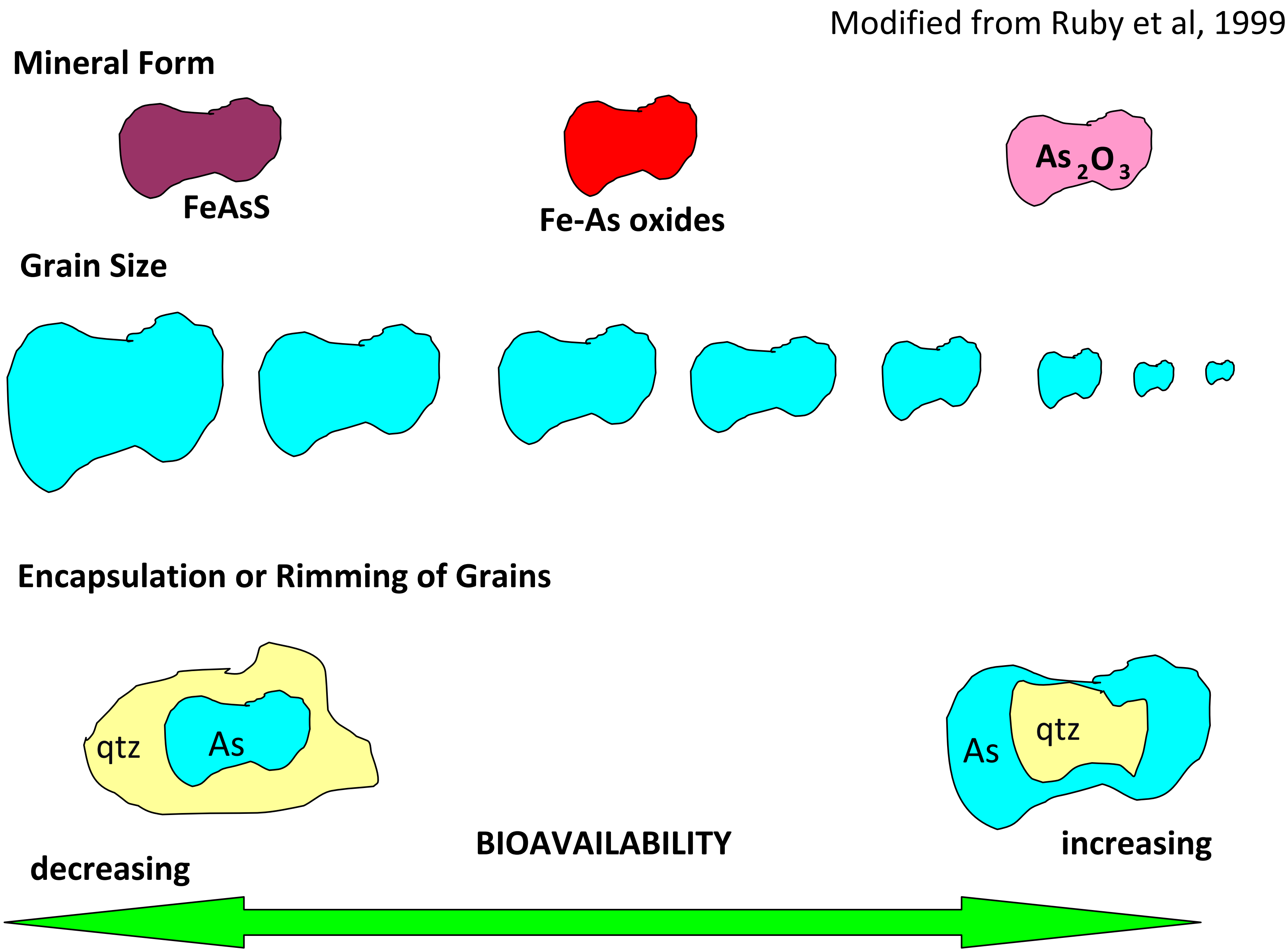
1. Cover not recommended for submerged tailings (As-hosting roaster oxides are stable)

2. Nutrient loading to Yellowknife Bay should be limited to preserve As-hosting Fe oxydroxides)

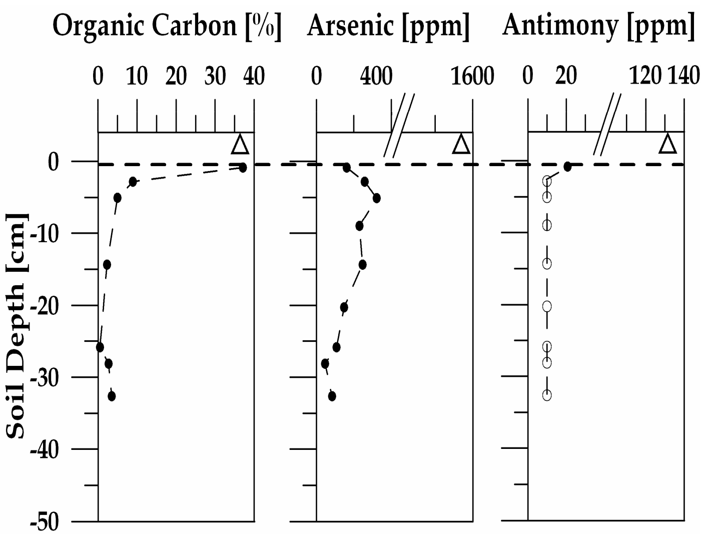
3.Can one distinguish between natural and anthropogenic arsenic in soils near Giant Mine?

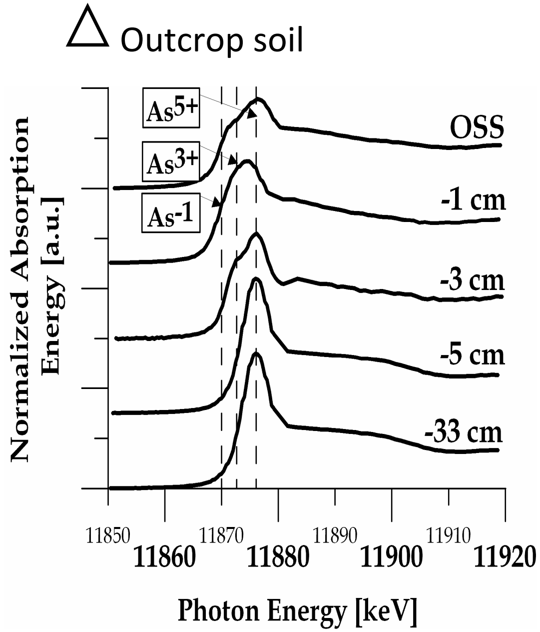
~16,000 tonnes of arsenic trioxide emitted from roaster over region





Bioaccessibility = Fraction soluble in relevant body fluids

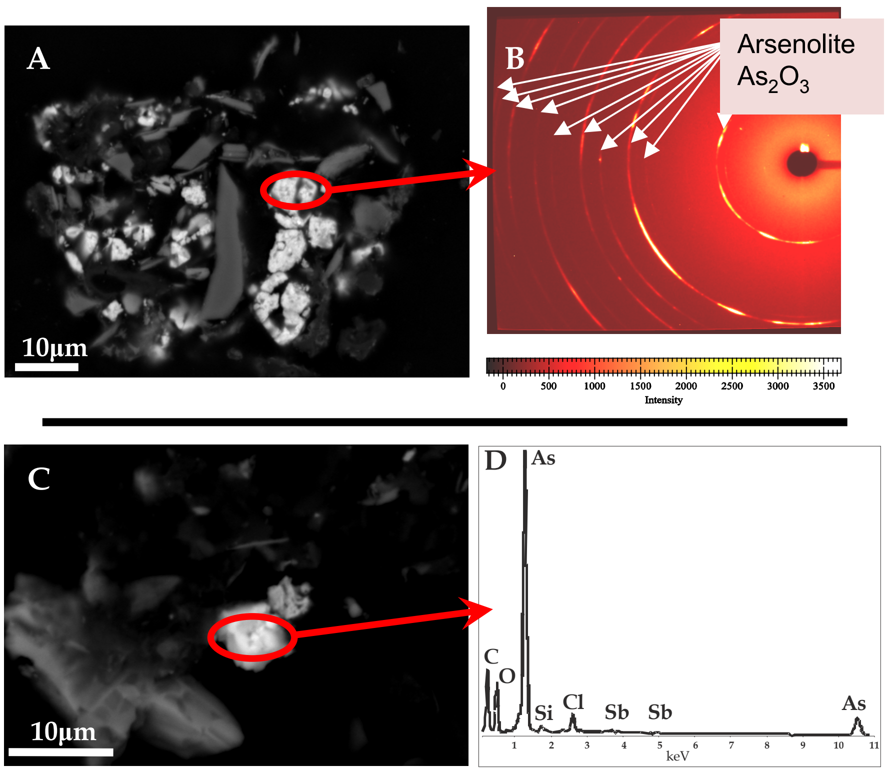


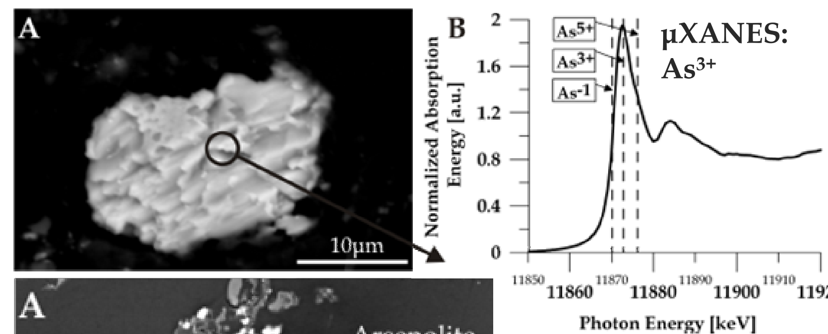


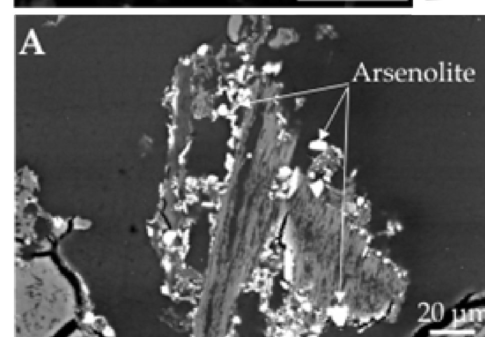
Near surface soils are enriched in:

- total As
- Antimony
- As^{3+}
- organic C

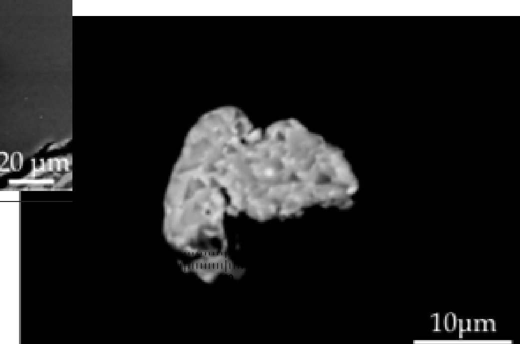
"Outcrop" soils are very high in As

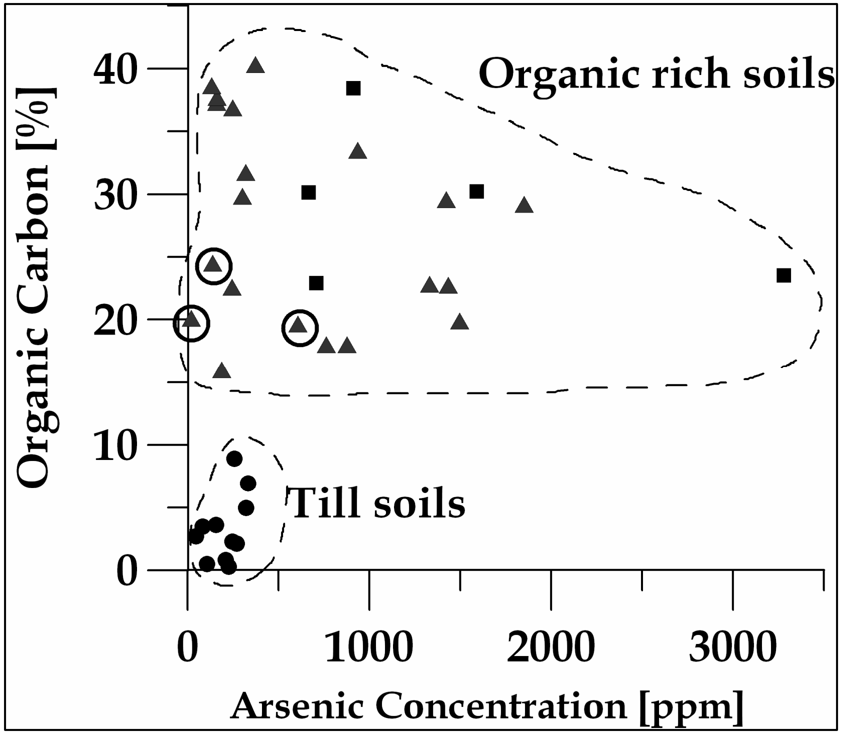






BSE images: As-rich particles appear bright





▲ soil core ■ soil from outcrop

All organic-rich soils contain arsenic trioxide particles except those circled

One thin section contained >145 particles of arsenic trioxide

Maghemite (roaster oxide) particles also found

Canadian Soil Quality Guideline 12 ppm total As
Yellowknife Area Soil Guideline 150 ppm total As

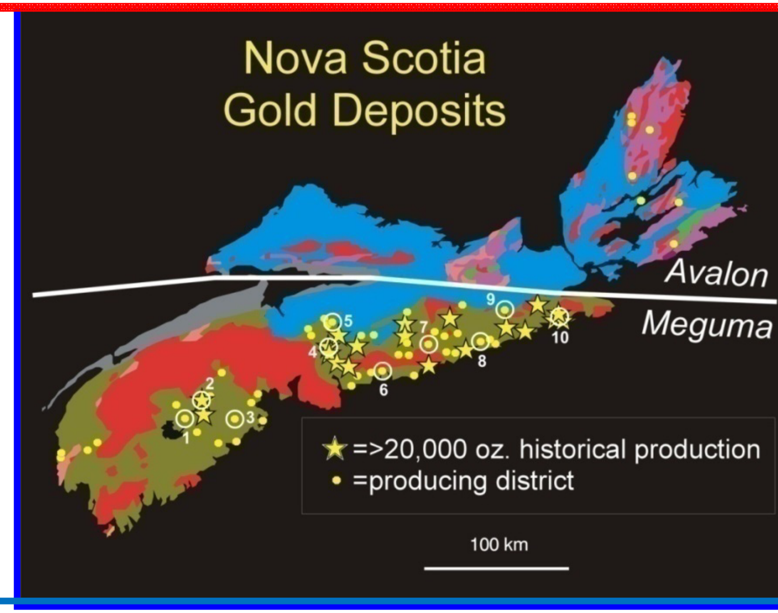
Conclusions

1. As from roaster fallout can be distinguished from natural As

2. Arsenic trioxide particles may be a source of soluble As for decades

3. May represent human health risk through ingestion or inhalation in publicly accessible areas

4. What is the relationship between As mineralogy and bioaccessibility in gold mine tailings in Nova Scotia?



Many historic mine sites are publicly accessible

Some are used for recreational purposes (dirtbikes, ATVs)

As concentrations in tailings
~350 times local soil background

1000's times Soil Quality Guideline

29 samples of near-surface tailings used for mineralogy (Queen's-GSC) and bioaccessibility tests (Royal Military College)

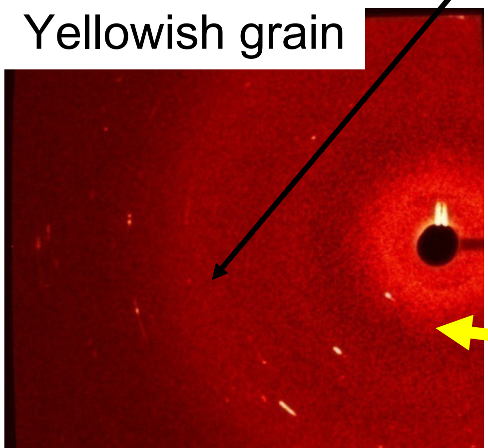
Based on detailed petrography, electron microprobe analysis, and synchrotron-based microanalysis (particularly microXRD), As-bearing grains include:

- Primary Sulfides (arsenopyrite and pyrite)
- Fe arsenates (scorodite, kankite, amorphous)
- As-bearing iron oxyhydroxides (goethite, akaganeite, lepidocrocite, amorphous)
- Ca-Fe arsenates (yukonite, amorphous)
- Tooeleite (ferric arsenite-sulfate)
- Pharmacosiderite (potassium iron arsenate)
- Realgar (secondary arsenic sulfide)
- Roaster-generated As-bearing oxides (maghemite, hematite)

Three different Fe-arsenates (As^{5+})

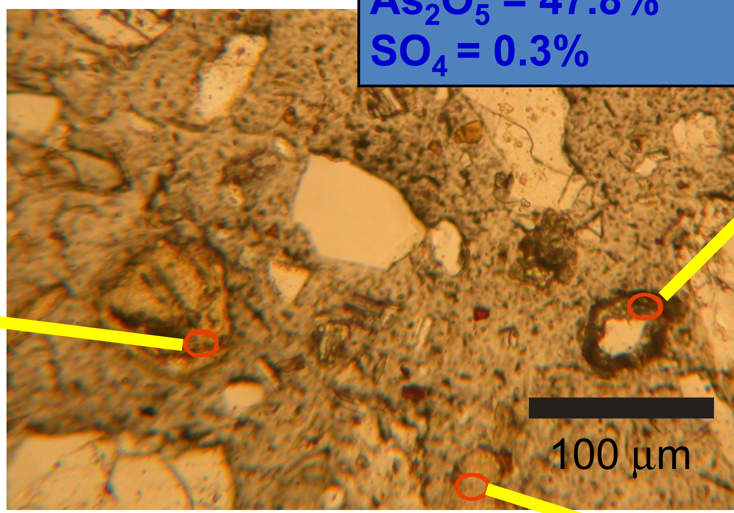
Broad ring at ~3 Å
- "amorphous" Fe-arsenate

Yellowish grain



Amorphous
- short-range ordered

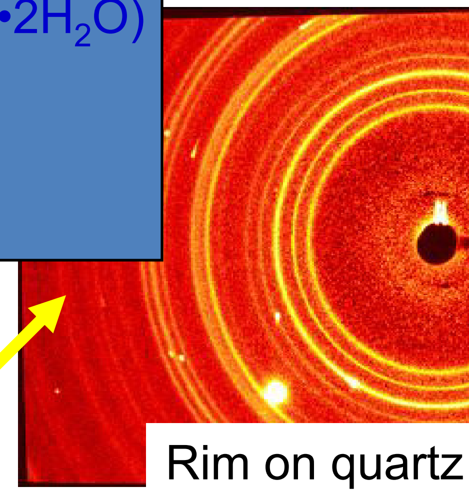
Fe_2O_3 = 24.0%
As_2O_5 = 27.9%
SO_4 = 2.4%



Transmitted Light

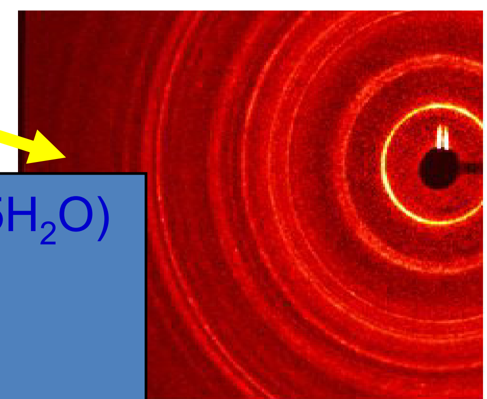
Scorodite ($FeAsO_4 \cdot 2H_2O$)

Fe_2O_3 = 27.5%
As_2O_5 = 47.8%
SO_4 = 0.3%



Rim on quartz

Faint yellowish grain

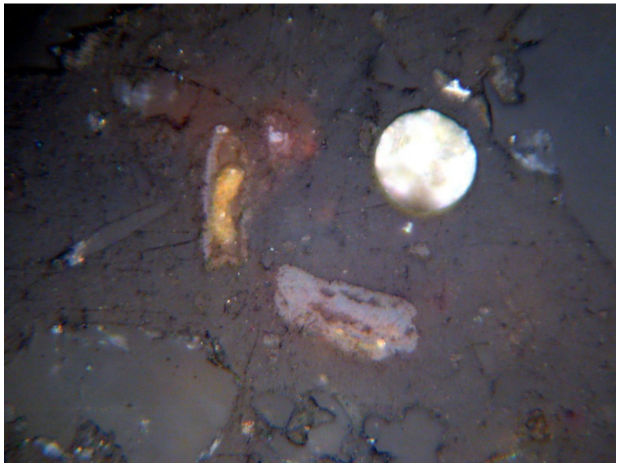


Kankite ($FeAsO_4 \cdot 3.5H_2O$)

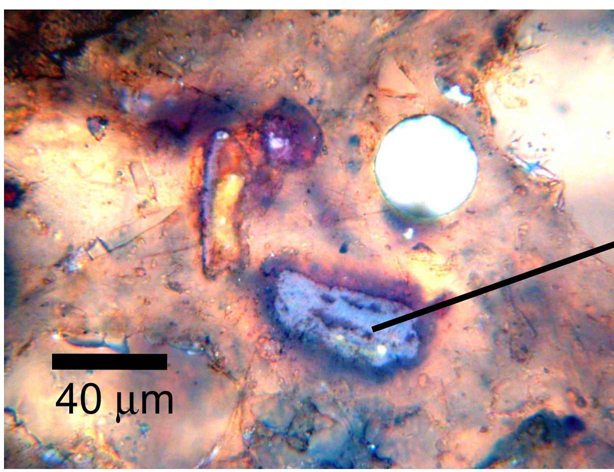
Fe_2O_3 = 30.6%
As_2O_5 = 45.5%
SO_4 = 0.3%

- **All concentrations by EPMA**

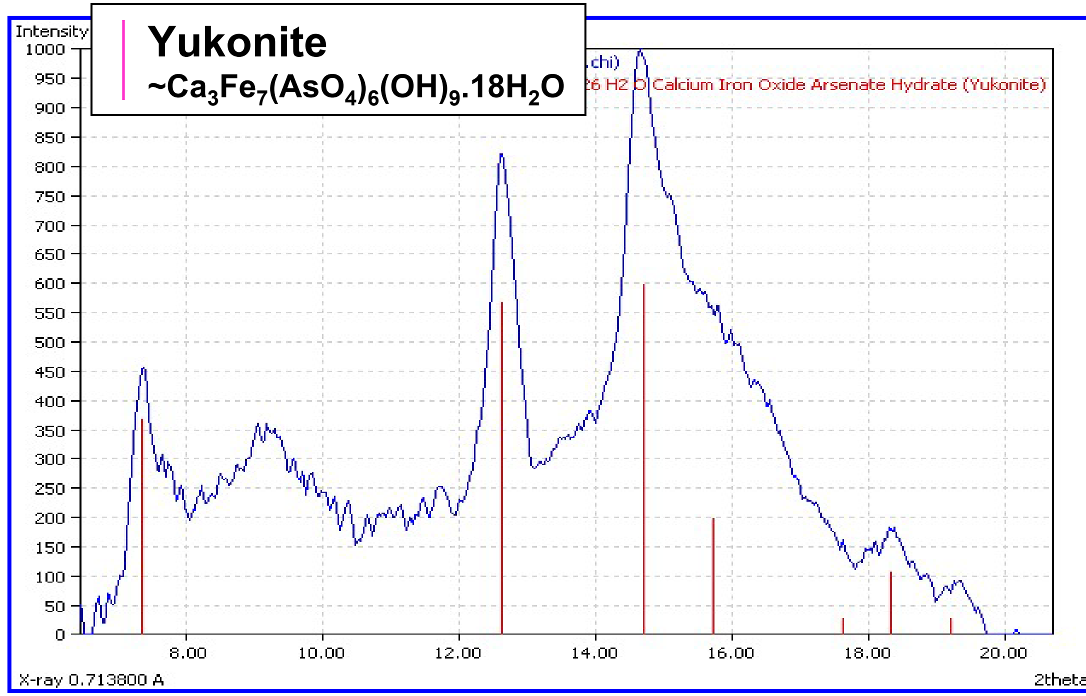
Yukonite



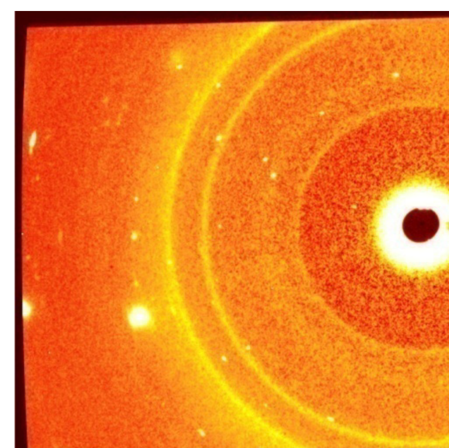
Reflected light



Transmitted and reflected light



Fe_2O_3 = 32.7%
As_2O_5 = 35.6%
SO_4 = 0.3%
CaO = 7.4%



Bioaccessibility tests at RMC:
Simulated gastric (pH= 1.5) and intestinal (pH=7) fluids
Overall , arsenic bioaccessibility is low (0.3 to 48%)

Correlation between As mineralogy and bioaccessibility:

Low bioaccessibility

Arsenopyrite and scorodite

- Coarsely crystalline arsenopyrite slow to react
- Scorodite known to be stable in acidic environments (pH ~2)

High bioaccessibility

Yukonite and amorphous Ca-Fe arsenates

- Ca-Fe arsenates stable in pH-neutral solution, soluble under acidic conditions

Conclusions

1. Arsenic bioaccessibility is strongly controlled by mineralogy

2. Ca-Fe arsenates are soluble in gastric fluid, scorodite is not.

3. Remediation needs to consider arsenic mineralogy

Acknowledgements

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