Biogeochemical Extraction for Rare Earth Elements and Uranium with Minimal Mine Legacy

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Overview

- Elliot Lake, Ontario
  - Uranium Mining History
  - Mineralogy and redevelopment opportunities

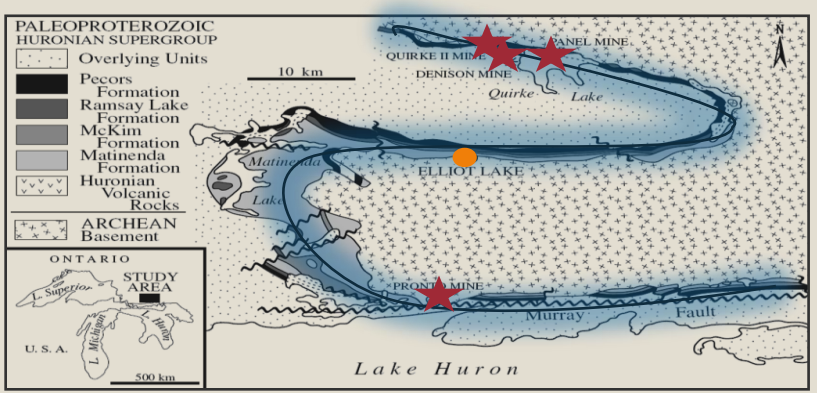
- Biogeochemical Extraction Study
  - Biogeochemical dissolution of minerals
  - Microcosm and column studies
  - Results and implementations

Perth, Australia → Elliot Lake, Canada

Elliot Lake & The Quirke Syncline

- Pre-1950
  - Uranium containing ore bodies discovered
- Mid-1950s to Mid-1990s
  - 12 active uranium mines
- Mid-2000s
  - Renewed interest in Uranium
- Present
  - **Redevelopment plans**

- Uranium-bearing conglomerate associated with thicker sections of the Matinenda Formation
  - "The Big Z"



Geology of the Elliot Lake area, northern Ontario

J.P. Burton & P. Fralick, Economic Geology. *Vol. 98, 2003, pp. 985-1001.*

Mineralogy of Conglomerate Beds

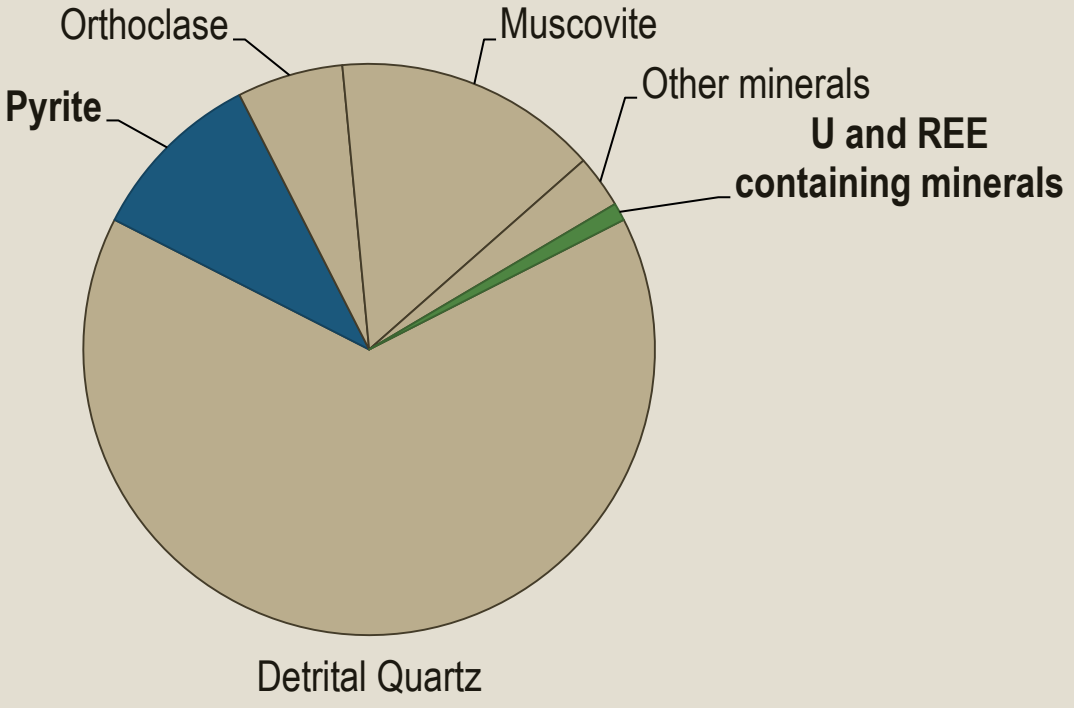
$$FeS_2 + \tfrac{7}{2}O_2 + H_2O$$

Sulphur oxidation

$$\rightarrow$$

$$Fe^{2+} + 2SO_4^{2-} + 2H^+$$

formation of ARD/AMD



Economic Interest in Redevelopment

- Minerals associated with the conglomerate beds of the Quirke Syncline contain elements of interest
  - Scandium, Yttrium, REEs, Thoriuim, Uranium

Row 4	Sc 21													
Row 5	Y 39													
Lanthanoids	La 57	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71
Actinides	Ac 89	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	By 97	Cf 98	Es 99	Fm 100	Nd 101	No 102	Lr 103

Minerals	Applications
Allanite, Brannerite, Coffinite, Florencite, Monazite, Mz-Silicate, Pitchblend, Thorite, Th-uraninite, Xenotime, UO_2-Rutile, UO_2-Pyrite, UO_2-Pyr-AlSi-mix	Magnets, NiMH batteries, Auto Catalysis, Fluid Cracking, Catalysis, Phosphors, Optic Polishing, Glass Additives

Plans for Development

- Plans for development of in situ above and below ground bioleaching pads
  - Uranium
  - REE
- *Acidithiobacillus ferrooxidans*
  - Promotes oxidation of iron containing sulphide mineral
- Requires closure planning methods to minimize
  - Acid drainage production
  - Radionuclide release
- Can be developed following detailed mineralogical and chemical analysis of residues of laboratory-scale bioleaching trials

Biogeochemical Dissolution of Sulphide Minerals

Microbial accelerated mineral dilution - releases Fe , S, protons

$$FeS_2 + \tfrac{7}{2}O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$$

$$\tfrac{1}{4}O_2 + H^+ + Fe^{2+} \xrightarrow{A.ferrooxidans} Fe^{3+} + \tfrac{1}{2}H_2O$$

Drives further mineral dissolution – releasing Fe, S, protons, **U**, **REEs**

$$FeS_2 + 8H_2O + 14Fe^{3+} \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+$$

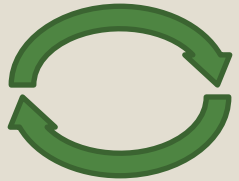
$$UO_2 + 2Fe^{3+} \rightarrow 2Fe^{2+} + UO_2^{2+}$$

Biogeochemical Dissolution of Sulphide Minerals

- The driving force: Fe^{2+}/Fe^{3+} redox couple

$$FeS_2 + \tfrac{7}{2}O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$$

$$\tfrac{1}{4}O_2 + H^+ + Fe^{2+} \xrightarrow{A.ferrooxidans} Fe^{3+} + \tfrac{1}{2}H_2O$$



$$16H^+ + 2SO_4^{2-} + 15Fe^{2+} \leftarrow 14Fe^{3+} + 8H_2O + FeS_2$$

$$UO_2^{2+} + 2Fe^{2+} \leftarrow 2Fe^{3+} + UO_2$$

Biogeochemical Mineral Dissolution Study

- Define and compare **laboratory experiment** and **industry application** conditions to optimize parameters promoting biogeochemical mineral dissolution of the pyrite-containing uranium ore of the Quirke Syncline.

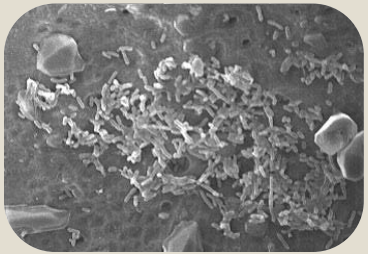
Objective 1: Determine biogeochemical mineral dissolution **capabilities of indigenous bacterium.**

Objective 2: Assess waste materials from ore in closure condition to provide insight to **closure options**.

Biogeochemical Mineral Dissolution Study

- Ore Material:
  - Drill core provided by Pele Mountain Resources collected from EcoRidge Uranium Project, Elliot Lake
  - Homogenized and crushed to size

- Microbes:
  - Laboratory Purified *A. ferrooxidans:* provided by Dr. Leduc, Dept. of Biology, Laurentian University
  - Environmental Consortium: cultivated from water samples collected from the former tailings storage area of Stanrock Mine



Biogeochemical Mineral Dissolution Study

	Microcosm	Column
Material	7.5 grams, <200 mesh	90 grams, 1-2 mm
Inoculum	1. water 2. *A. ferrooxidans* 3. environmental consortium	1. water 2. *A. ferrooxidans* 3. environmental consortium
Duration	80 days	7 months
Details	• nutrient solution or water as liquid media • solid-to-liquid ratio, 1:20 • 240 rpm on bench top shaker • Controlled temperature, 30°C	• water as liquid media • 0.5 L per hour supplied by peristaltic pump • Drip irrigation, recycled solution • Ambient room temperature, 21-26°C

Evidence for Biogeochemical Mineral Dissolution

- Microbial oxidation
  - Increasing oxidation-reduction potential
- Proton release
  - Decreasing pH

$$FeS_2 + \tfrac{7}{2}O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$$

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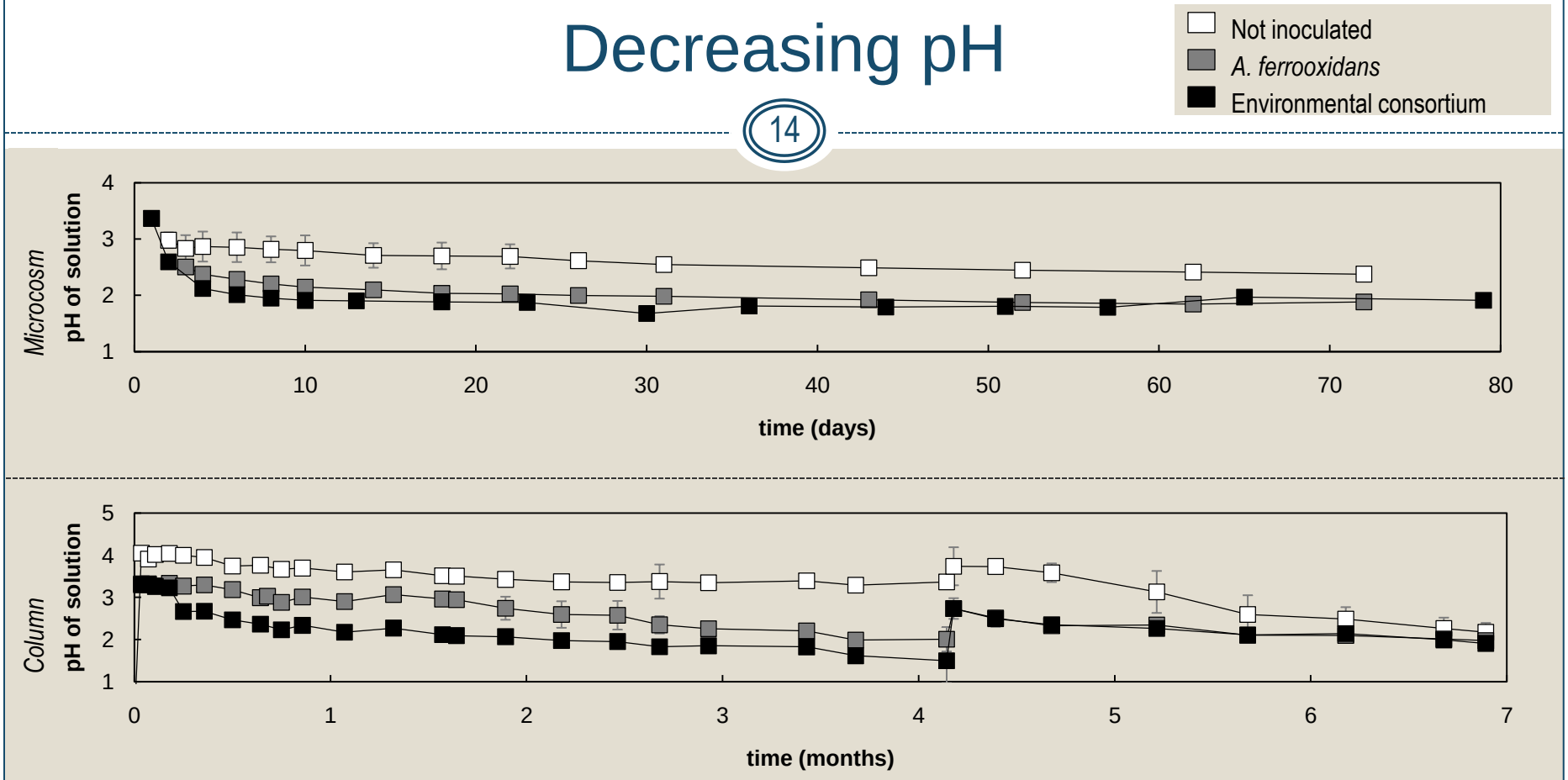
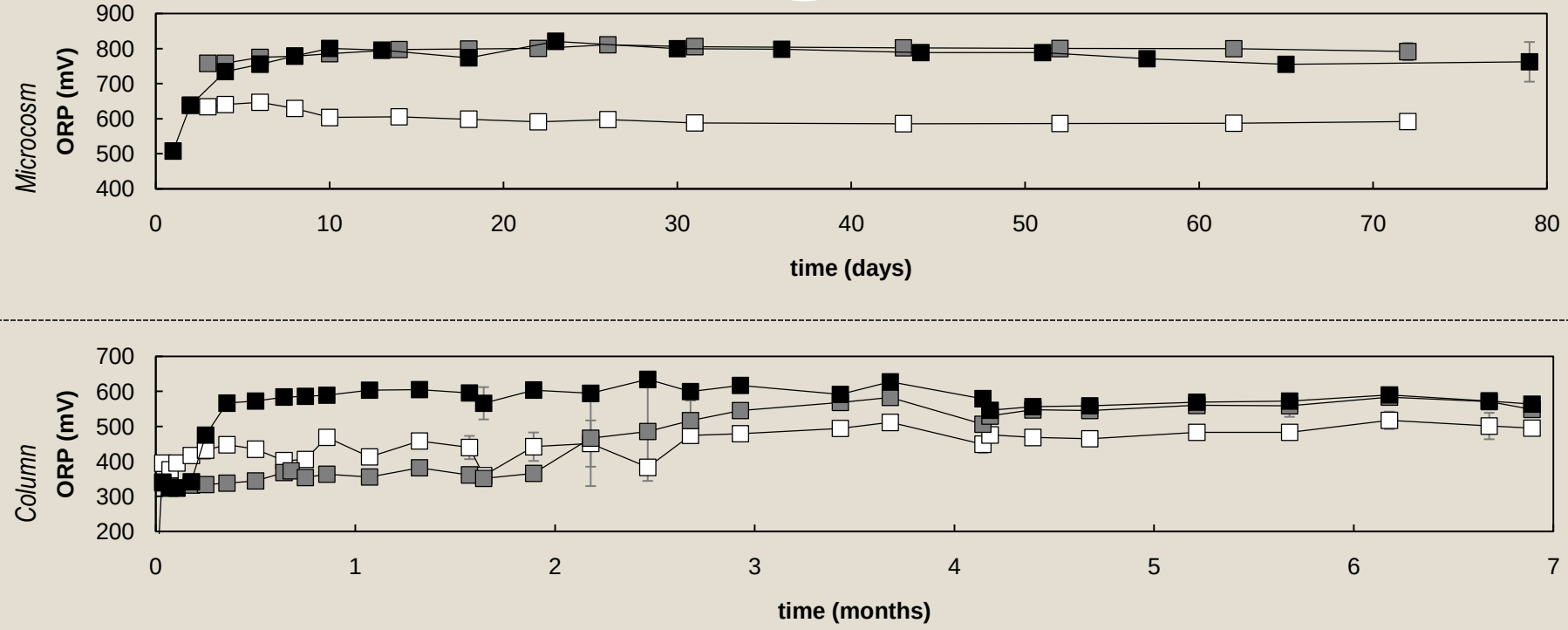
$$16H^+ + 2SO_4^{2-} + 15Fe^{2+} \leftarrow 14Fe^{3+} + 8H_2O + FeS_2$$

$$UO_2^{2+} + 2Fe^{2+} \leftarrow 2Fe^{3+} + UO_2$$

Decreasing pH



Increase of ORP



Release of Elements of Interest

- Biogeochemical mineral dissolution drives the dissolution other minerals
  - Economic interest: Uranium, Scandium, Yttrium, Rare Earth Elements

$$FeS_2 + \tfrac{7}{2}O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$$

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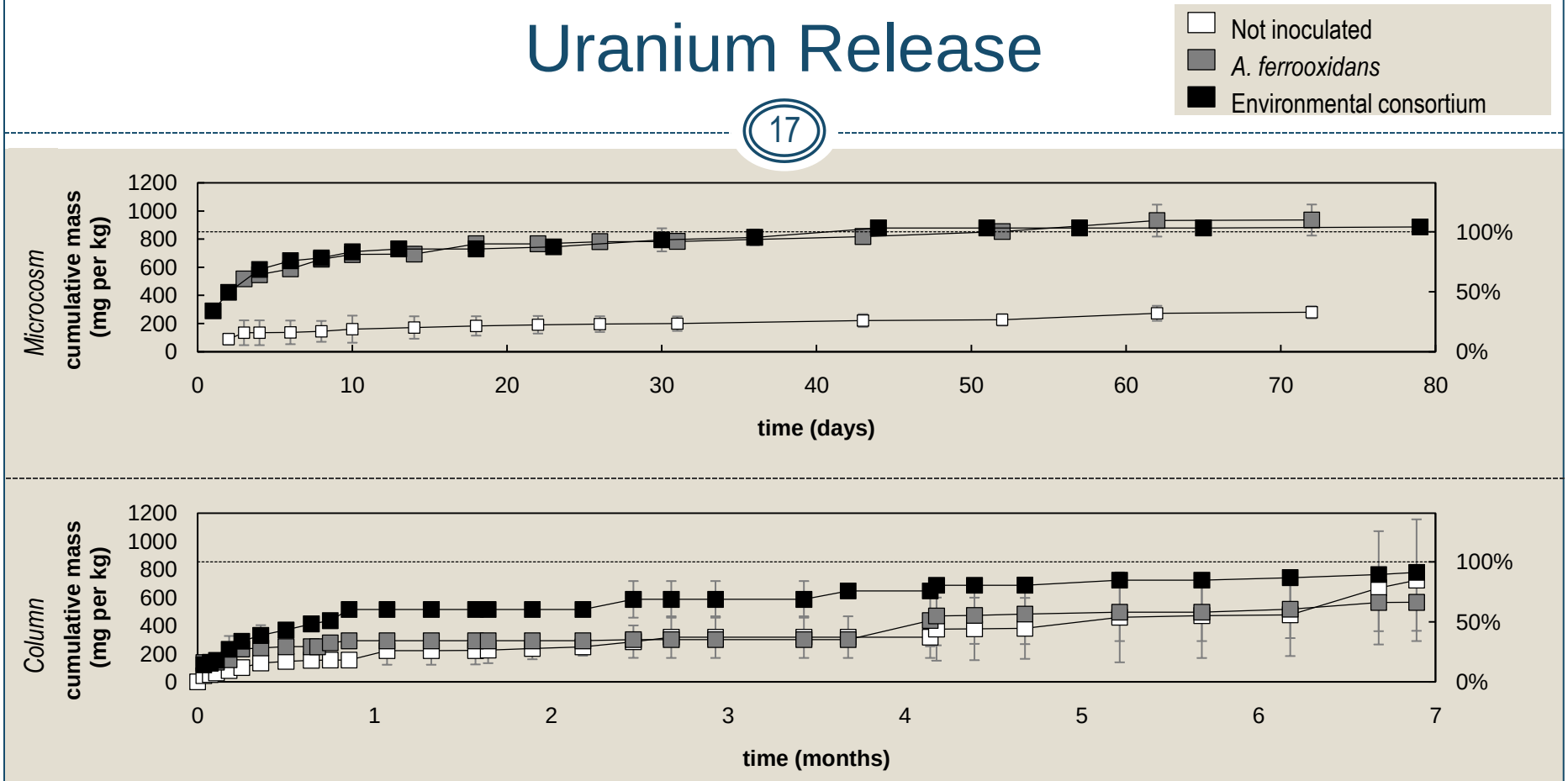
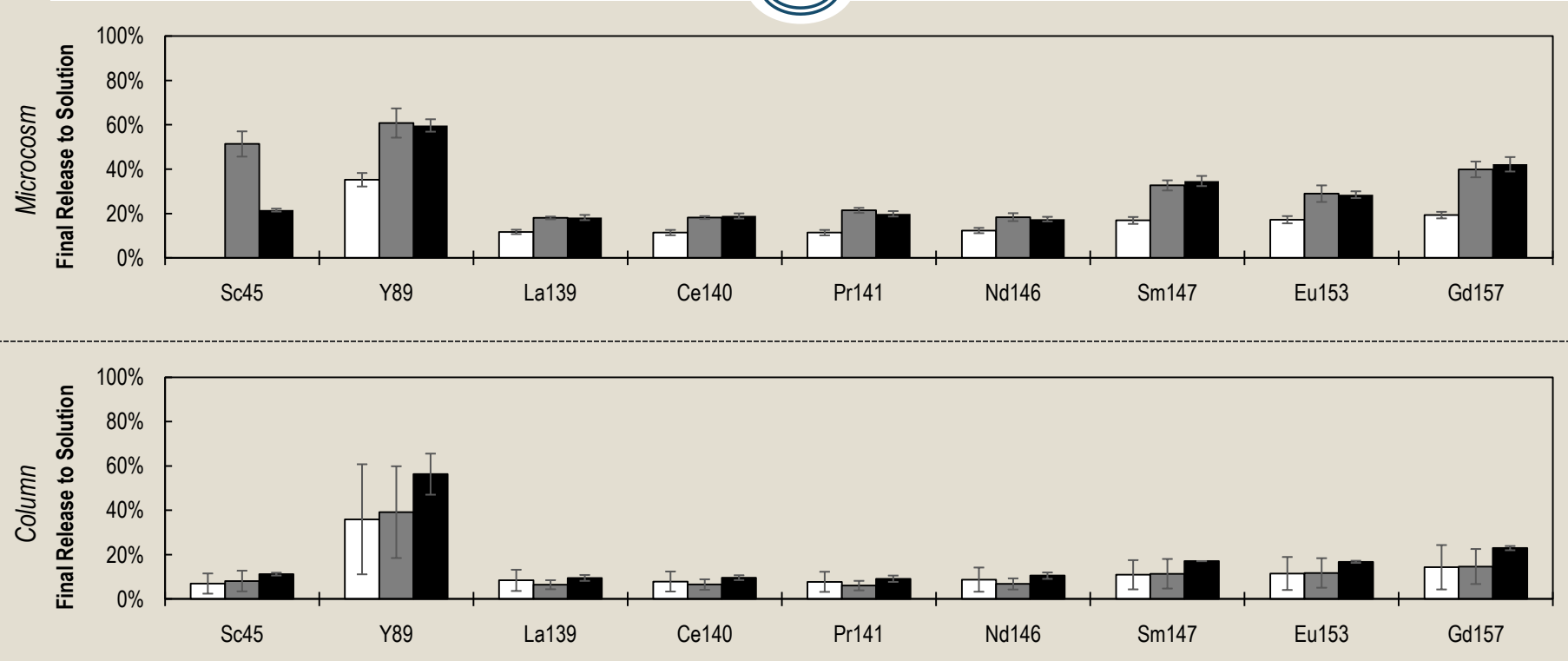
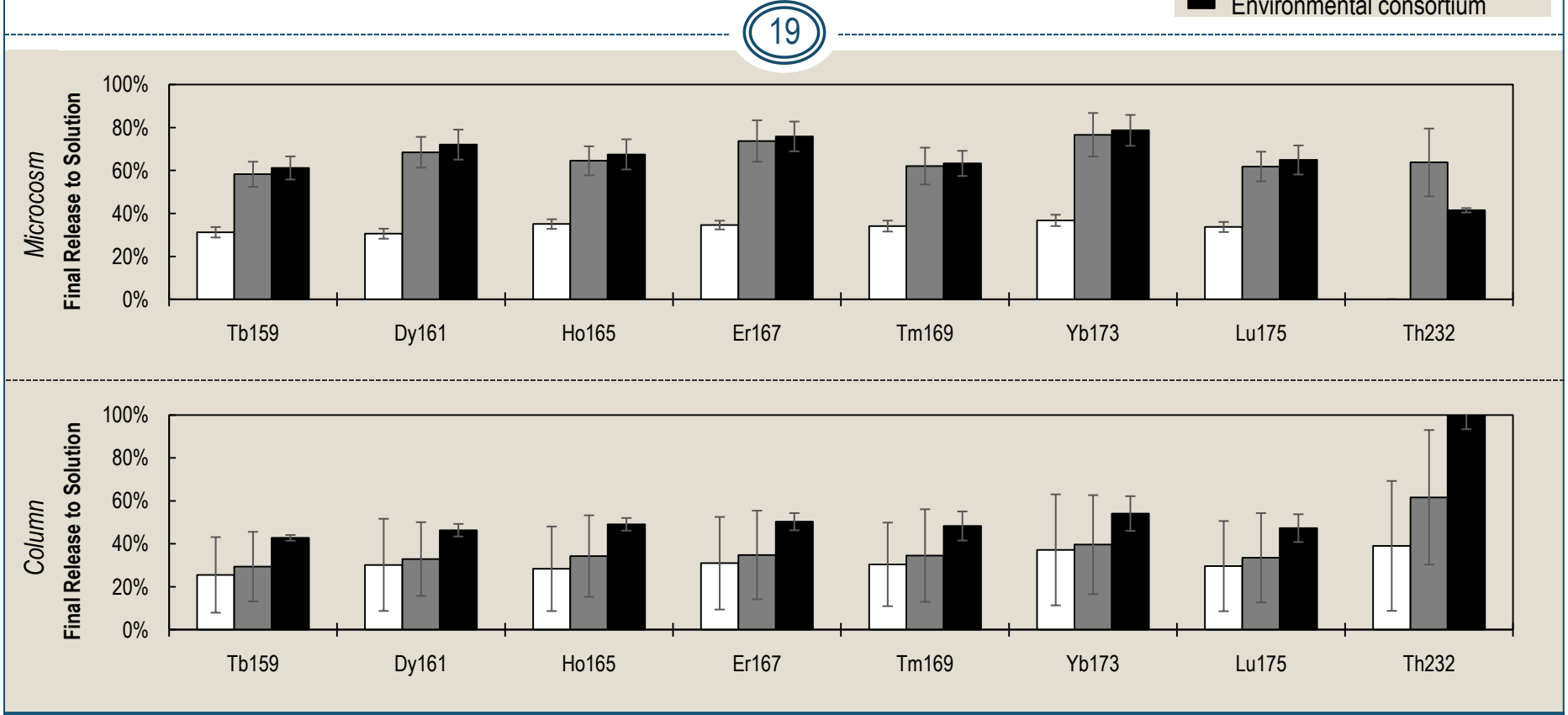
Uranium Release



Sc, Y, Light REEs

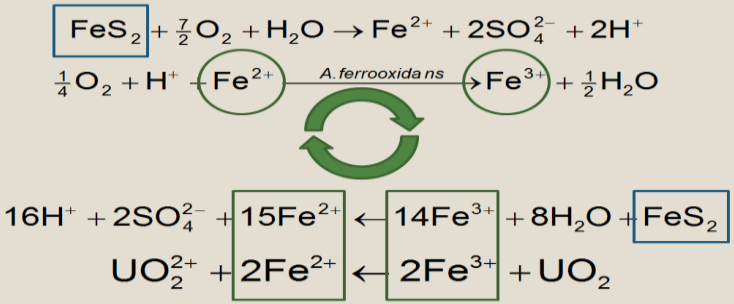


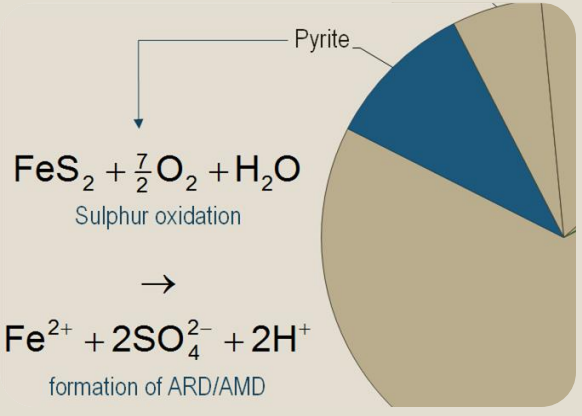
Heavy REE, Th


Not inoculated
A. ferrooxidans
Environmental consortium
Microcosm
Final Release to Solution
100%
80%
60%
40%
20%
0%
Tb159
Dy161
Ho165
Er167
Tm169
Yb173
Lu175
Th232
Column
Final Release to Solution
100%
80%
60%
40%
20%
0%
Tb159
Dy161
Ho165
Er167
Tm169
Yb173
Lu175
Th232

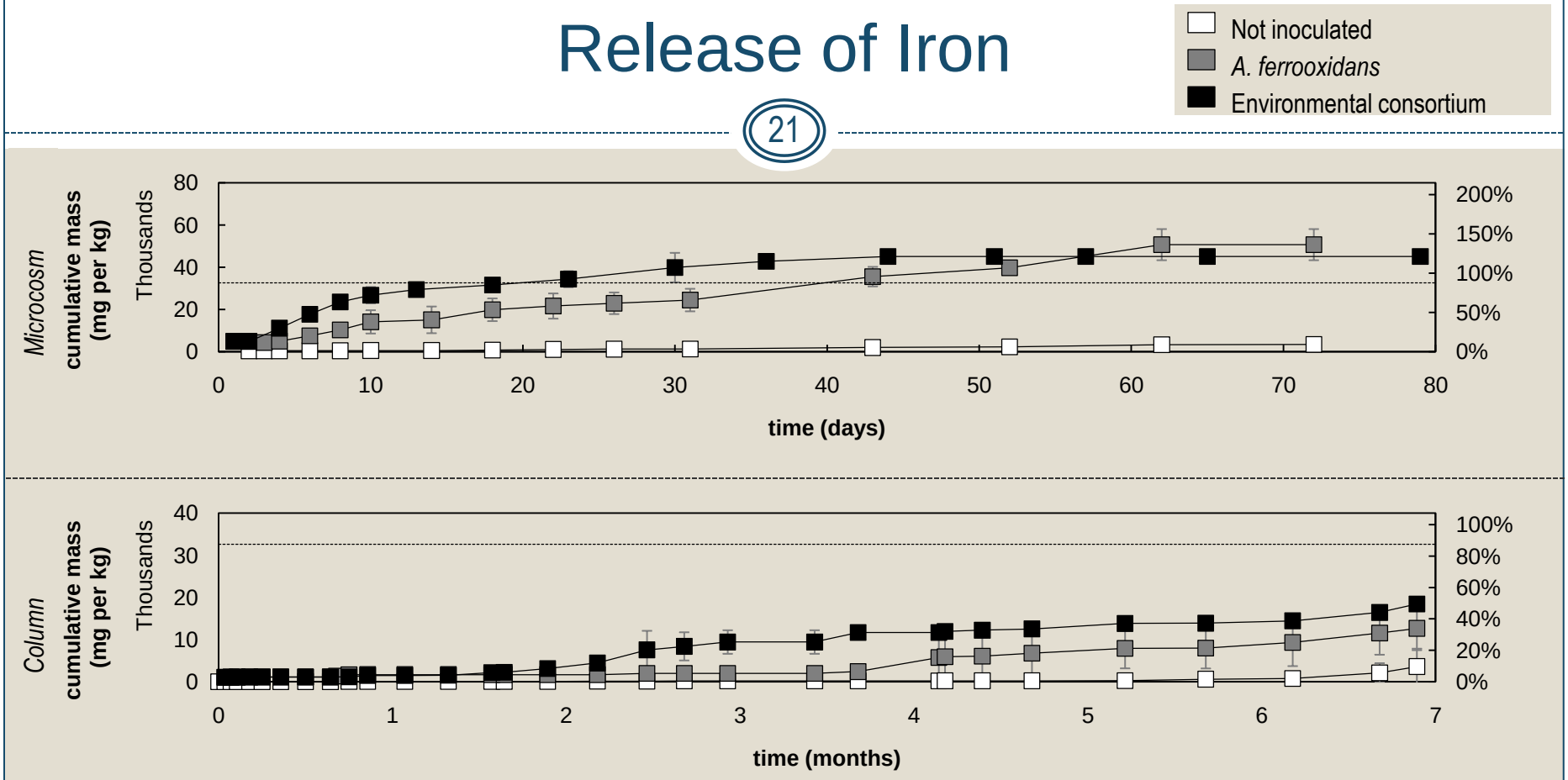
Insight to Material at Closure State

- Sulphur content of residue material has impact on plans for decommissioning and closure





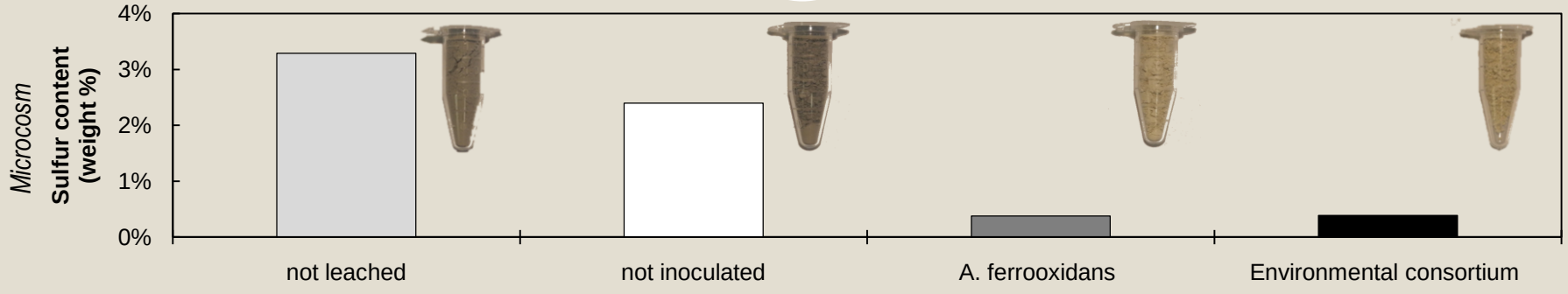
Release of Iron



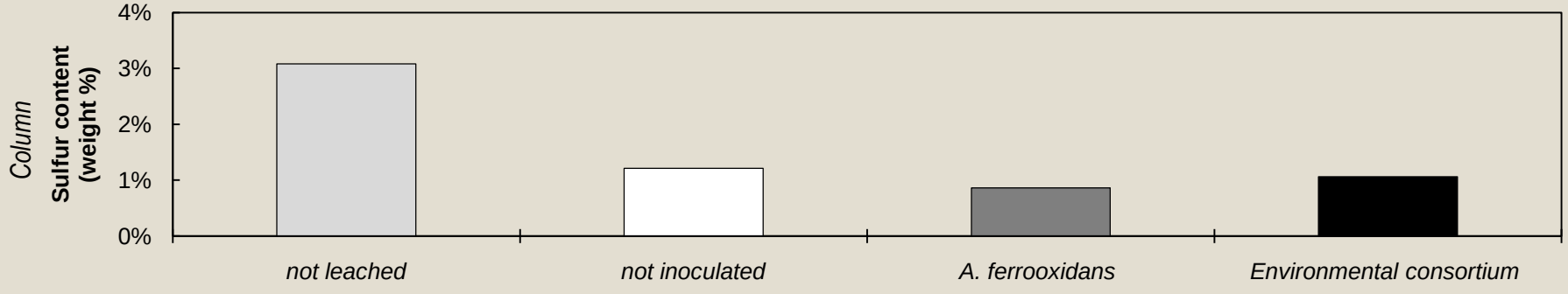
Removal of Sulfur

Not inoculated
A. ferrooxidans
Environmental consortium

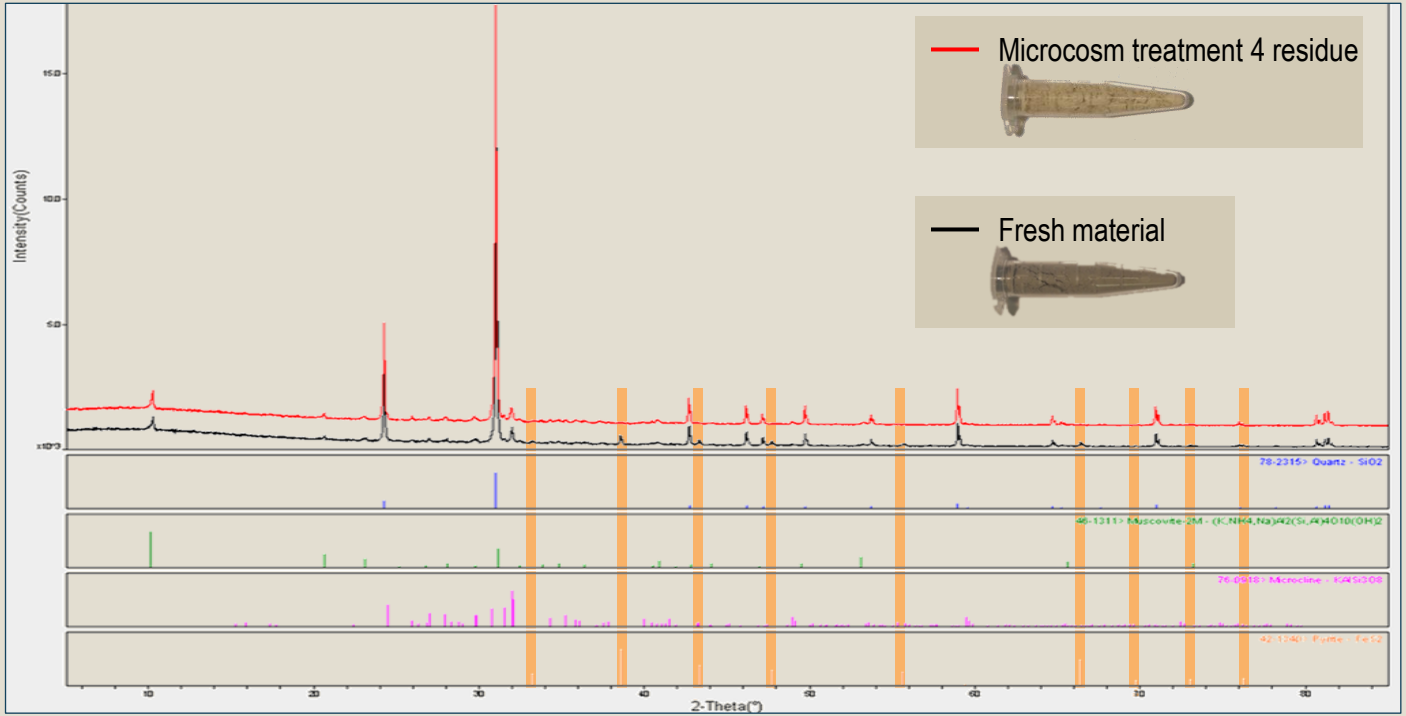
Microcosm



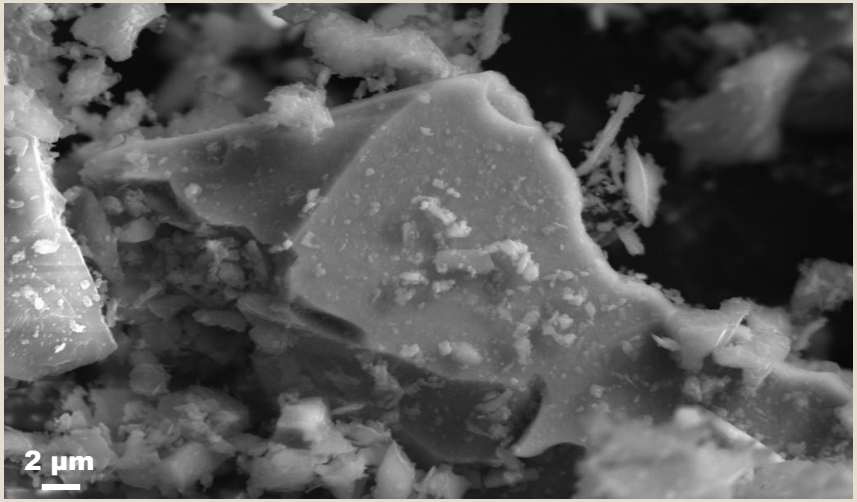
Column



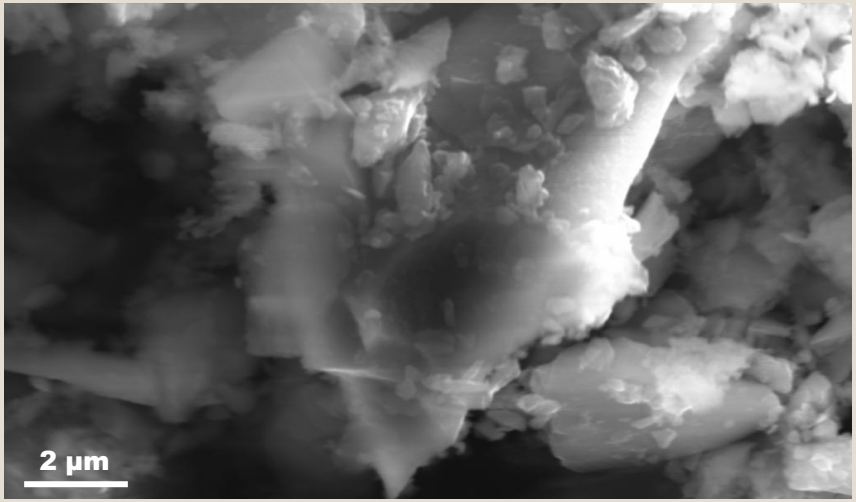
Dominant Mineral Phases



SEM Images – Pyrite Grains



Fresh material



Microcosm treatment 4 residue

Summary and Implications

Objective 1: Determine biogeochemical mineral dissolution **capabilities of indigenous bacterium.**

- Similar recovery of elements of economic interest from both pure and environmental inoculums.
- Close to complete recovery of uranium
- Considerable release for Sc, Y, heavy REEs and Th

- Indigenous bacterium consortium has ability to conditions to promote biogeochemical mineral dissolution

Summary and Implications

Objective 2: Assess waste materials from ore in closure condition to provide insight to **closure options**.

- Analytical analysis provide evidence for the complete dissolution of iron and almost complete remove of sulphur in the microcosms
- Pyrite is not evident as a dominate mineral phase of residue material from the microcosms treated with *A. ferrooxidans* after 80 days

- Results indicate complete geochemical mineral dissolution of pyrite, indicating the potential absence of minerals responsible for promoting AMD production

Moving Forward

- ‘Waste’ material
  - Total chemistry
  - Intense mineralogical investigation
- Simulated Leach Closure Strategies
  - Investigate at microcosm scale
  - Apply to large column scale

Acknowledgments

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Ontario
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