D.6 Solubility Controls on Metal Concentrations in Base and Precious Metal Mine Tailings

David W. Blowes, John L. Jambor,
K. Ulrich Mayer and Tom A. Al

Universities of Waterloo, British Columbia
and New Brunswick

Solubility Controls on Metal Concentrations in Base and Precious Metal Mine Tailings

D.W. Blowes[1], J.L. Jambor[1,2]
K.Ulrich Mayer[2], and T.A. Al[3]
[1]University of Waterloo
[2]University of British Columbia
[3]University of New Brunswick

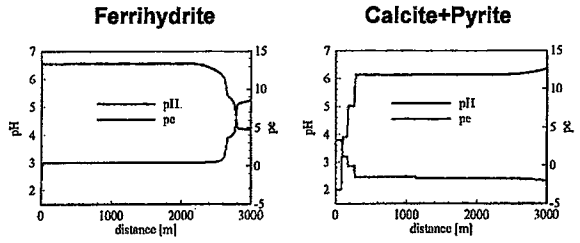
Solubility Controls on Metal Concentrations

- Limit metal concentrations in discharge water
- Result in accumulation of secondary phases
- Potential sources of dissolved metals if geochemical conditions change

Solubility Controls

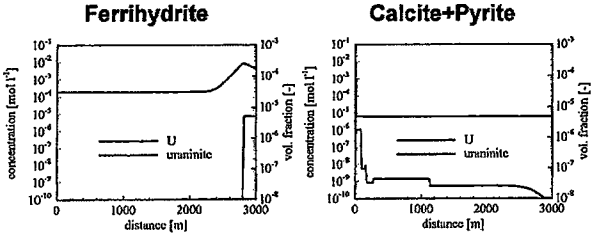
- Site specific
  - Dependent on:
    - Geochemical conditions
    - Mineralogy
- Small mineral masses may control water chemistry

pH and pe

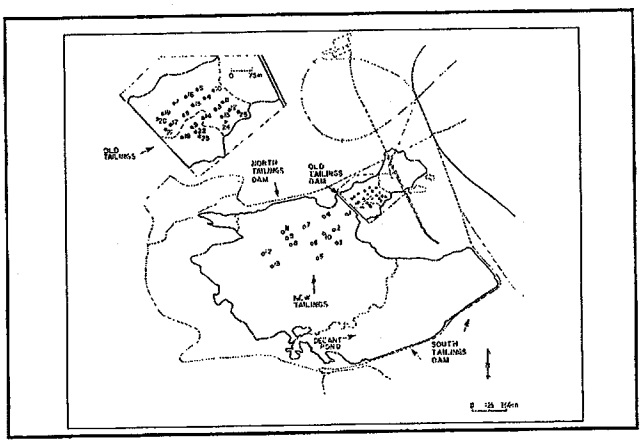


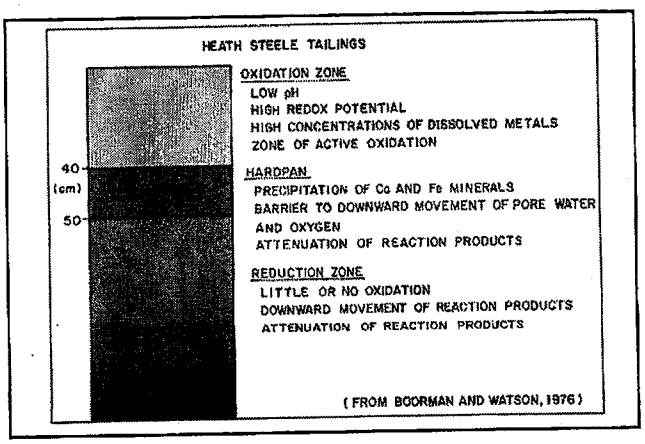
After Bain et al. (in press)

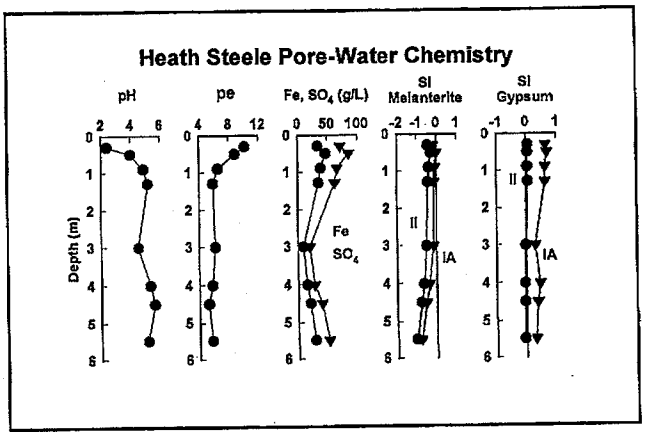
U and Uraninite

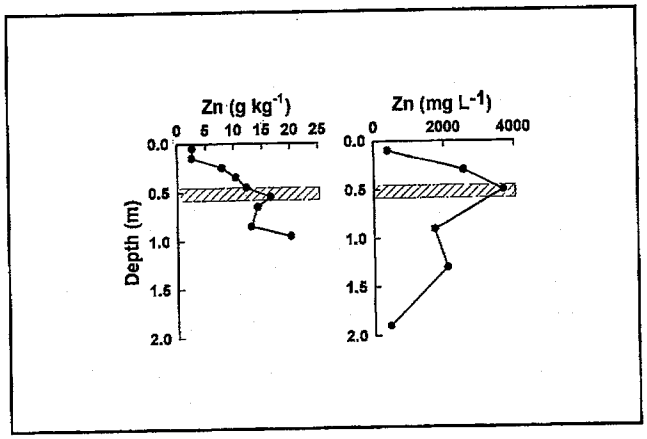


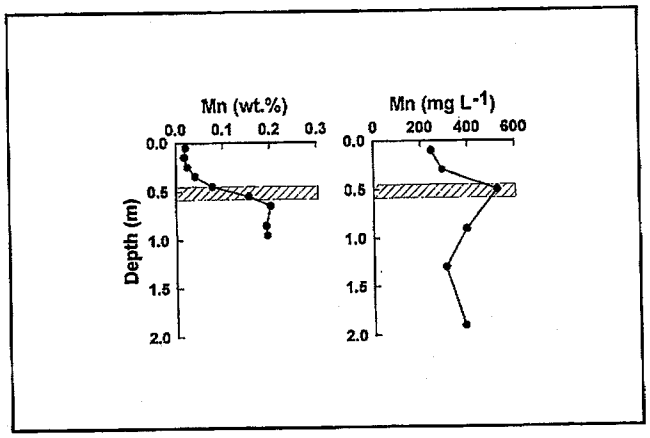
After Bain et al. (in press)

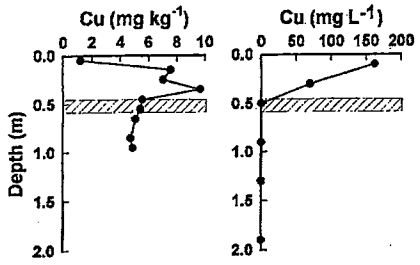

OLD TAILINGS
NORTH TAILINGS DAM
OLD TAILINGS DAM
NEW TAILINGS
DECANT POND
SOUTH TAILINGS DAM

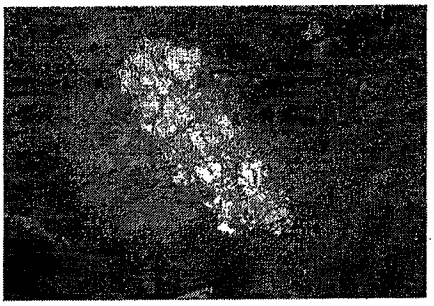

HEATH STEELE TAILINGS
OXIDATION ZONE
LOW pH
HIGH REDOX POTENTIAL
HIGH CONCENTRATIONS OF DISSOLVED METALS
ZONE OF ACTIVE OXIDATION
40
(cm)
50
HARDPAN
PRECIPITATION OF Co AND Fe MINERALS
BARRIER TO DOWNWARD MOVEMENT OF PORE WATER AND OXYGEN
ATTENUATION OF REACTION PRODUCTS
REDUCTION ZONE
LITTLE OR NO OXIDATION
DOWNWARD MOVEMENT OF REACTION PRODUCTS
ATTENUATION OF REACTION PRODUCTS
(FROM BOORMAN AND WATSON, 1976)

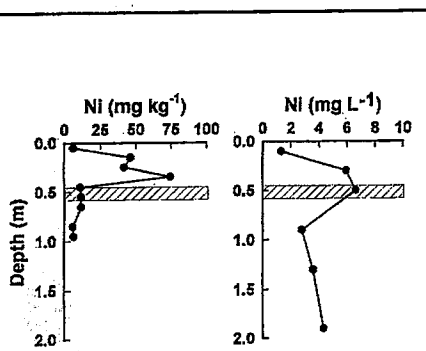

Heath Steele Pore-Water Chemistry
pH
pe
Fe, SO4 (g/L)
SI Melanterite
SI Gypsum
Depth (m)
Fe
SO4
II
IA

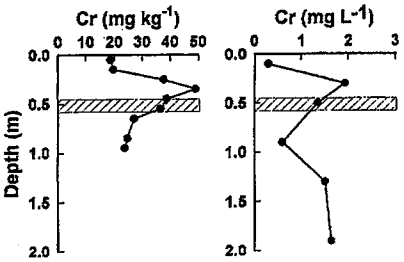

Zn (g kg-1)
Zn (mg L-1)
Depth (m)

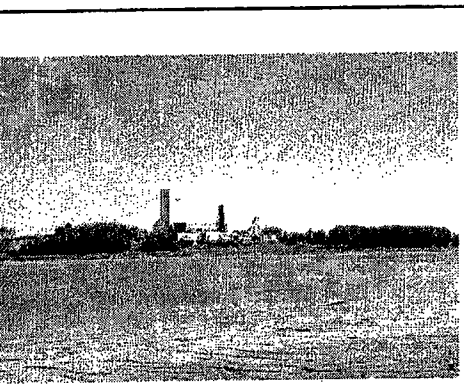

Mn (wt.%)
Mn (mg L-1)
Depth (m)

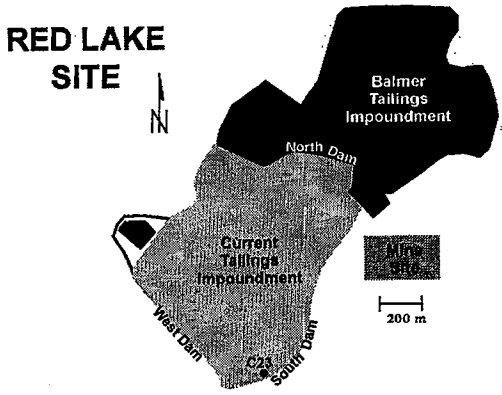

Cu (mg kg-1)
0 2 4 6 8 10
Cu (mg L-1)
0 50 100 150 200
Depth (m)
0.0
0.5
1.0
1.5
2.0




Ni (mg kg-1)
0 25 50 75 100
Ni (mg L-1)
0 2 4 6 8 10
Depth (m)
0.0
0.5
1.0
1.5
2.0


Cr (mg kg-1)
0 10 20 30 40 50
Cr (mg L-1)
0 1 2 3
Depth (m)
0.0
0.5
1.0
1.5
2.0



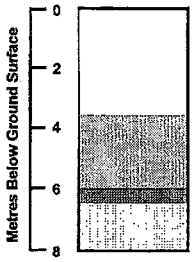

RED LAKE
SITE
N
Balmer
Tailings
Impoundment
North Dam
Current
Tailings
Impoundment
West Dam
C23
South Dam
200 m

Tailings Types

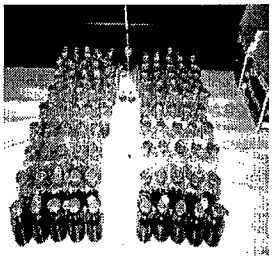
- **Flotation Tailings**
  - **Arsenopyrite (FeAsS), Gersdorffite (NiAsS)**
- **Roaster Tailings**
  - **As-bearing hematite (Fe_2O_3) and maghemite (Fe_2O_3)**
- **Autoclave Tailings**
  - **Ferric sulfarsenate $FeCa(SO_4)(AsO_4)(OH)$**
  - **H-K jarosite $(H_3O, K)Fe_3(SO_4)(OH)_6$**

Current Impoundment Tailings

- Flotation Tailings + Autoclave Tailings
- Flotation Tailings + Roaster Tailings
  - Peat
  - Clay

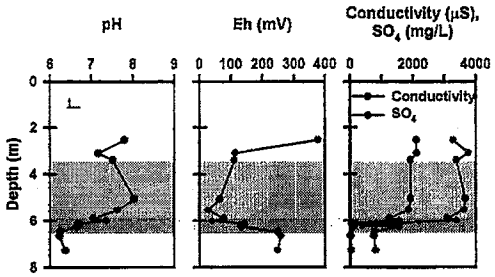


Methods

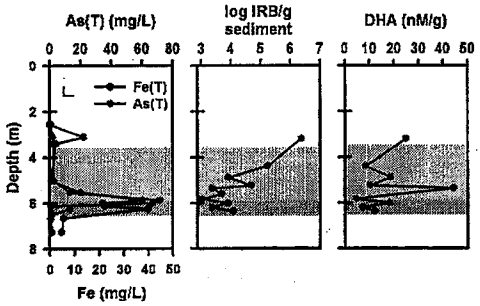


- Bacterial enumerations (MPN)
- Geochemical modelling (MINTEQA2)
- Near surface mineral analyses (XPS)

Water Chemistry



Iron Reduction

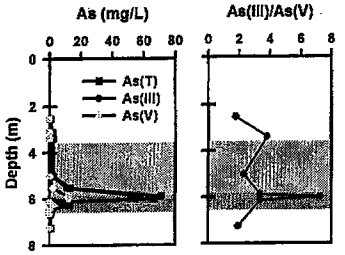


Dissolution Reactions

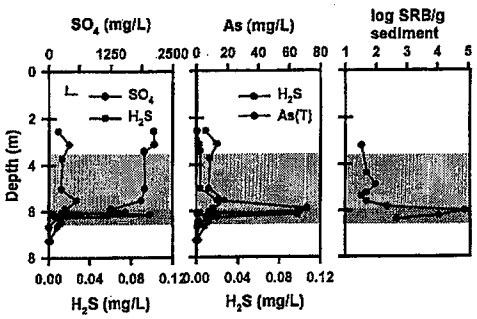
- Reduction of As-adsorbed hematite and/or maghemite:

$$2Fe_2O_3{\cdot}xHAsO_4^{2-} + CH_2O + 7H^+ \rightarrow 4Fe^{2+} + HCO_3^- + 4H_2O + 2xHAsO_4^{2-}$$

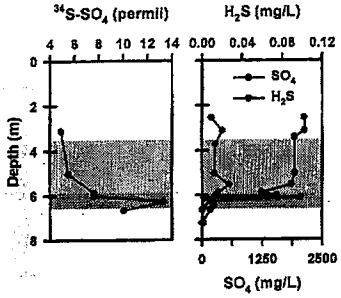
Arsenic Speciation



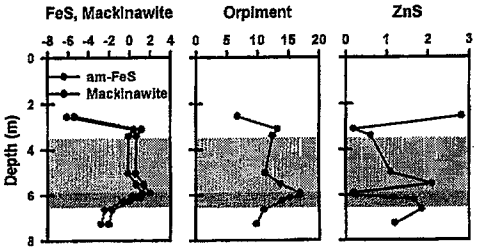
Sulfate Reduction



Sulfur Isotopes

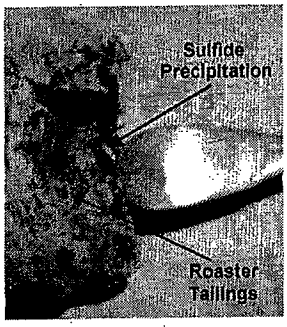


Saturation Indices

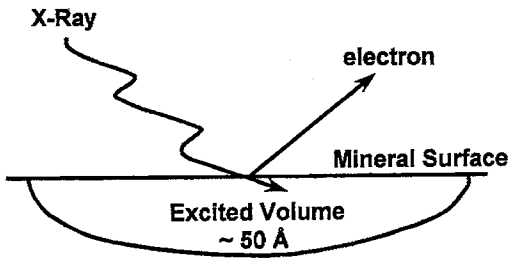


Sulfide Precipitation

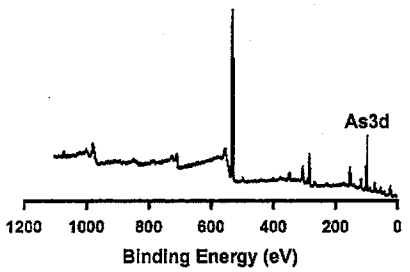
6 m depth at C23



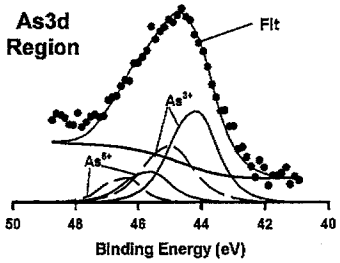
X-RAY Photoelectron Spectroscopy



XPS Analysis of Tailings



Narrow Scan - As3d Region



- As^{3+} Peak: B.E.= 43.9 eV
  - corresponds to As_2S_3
- As^{5+} Peak: B.E. = 45.9 eV
  - corresponds to As_2O_5

Summary

- As and Fe released by microbially-mediated reduction
- Sulfate reduction occurs below zone of Fe(III) reduction
- As and Fe reprecipitated as As_2S_3 and FeS

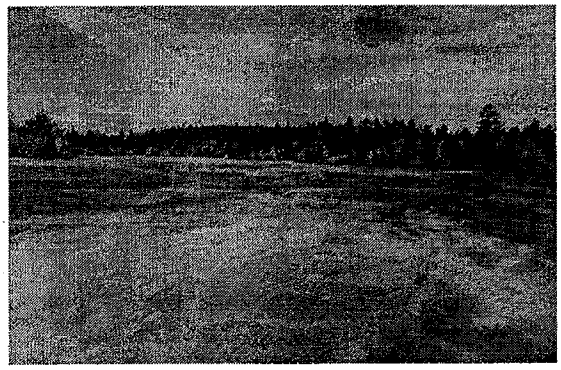
Reactive Transport in Mine Wastes

Model MIN3P:

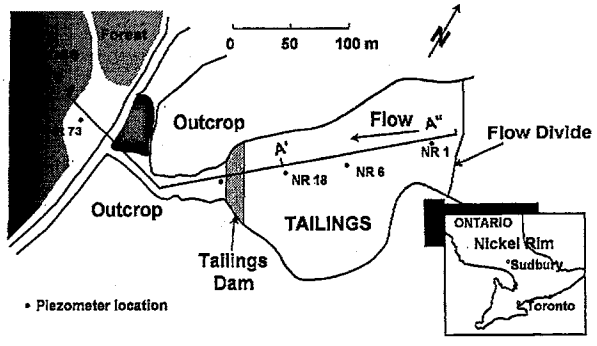
- Mayer, 1999
- Reactive transport in variably-saturated media
- Partial equilibrium formulation
- Global implicit approach (direct substitution)

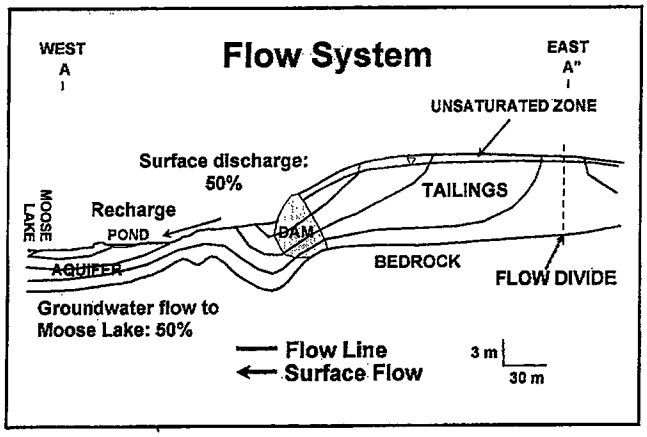
Geochemical system:

- Nickel Rim tailings impoundment
- Johnson et al., 2000, Bain et al., 2000



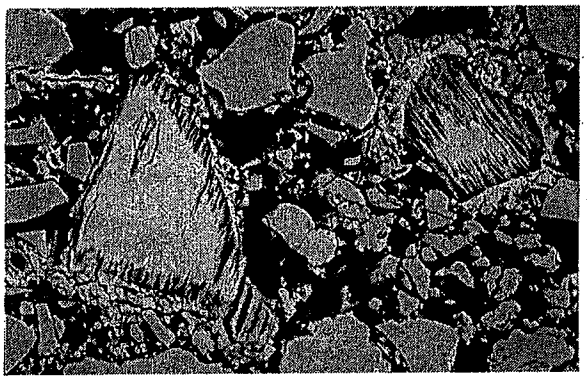
Nickel Rim Tailings Impoundment



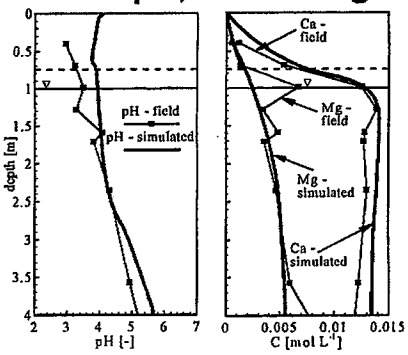


Tailings Mineralogy

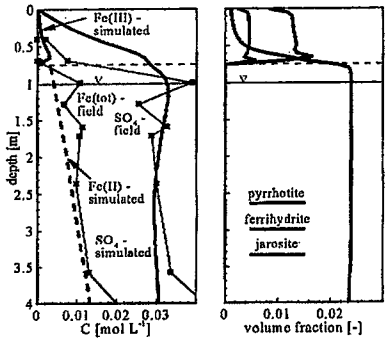
- Primary minerals:
  - pyrrhotite, chalcopyrite, pentlandite
  - calcite
  - anorthite, biotite
- Secondary minerals
  - covellite
  - jarosite, gypsum
  - $Fe(OH)_3$, $Al(OH)_3$
  - SiO_2



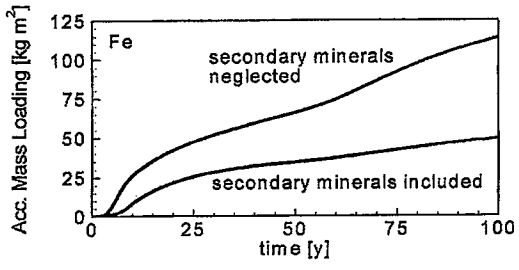
NR6 - pH, Ca and Mg



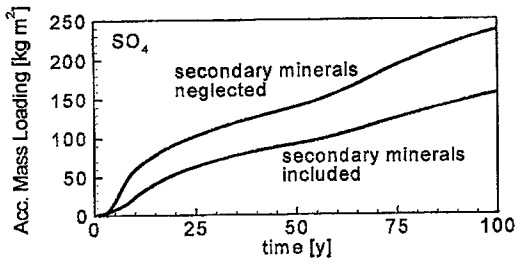
NR6 - Fe and SO_4



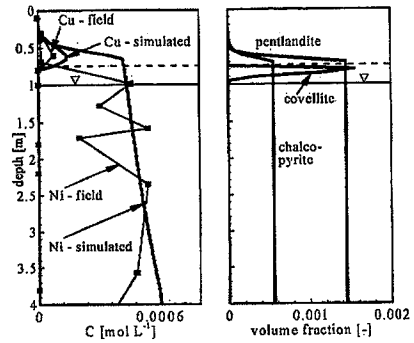
Fe - Loading

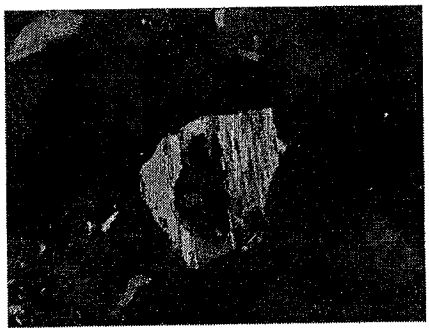


SO_4 - Loading

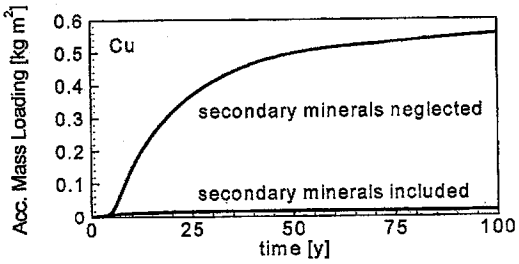


NR6 - Cu and Ni

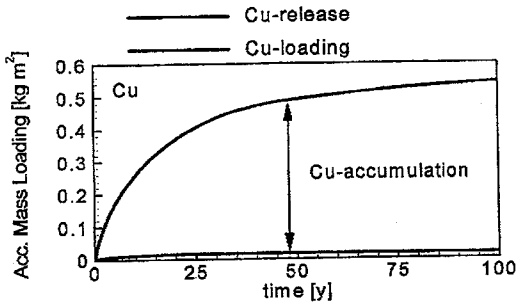




Cu - Loading



Cu – Release and Loading



Conclusions

- **Solubility controls are site specific**
- **Limit metal concentrations**
- **Dissolution may increase concentrations**

- **Combining site characterization and reactive transport modelling provides a powerful tool for decision making**