Geochemistry of an experimental waste rock pile, Cluff Lake, Saskatchewan

Roger Beckie, Leslie Smith, Karin Wagner

Earth and Ocean Sciences at UBC

Frederic Guerin

Areva Mining – Cogema Resources Inc.

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Outline

1. Overview of experiment
2. Primary mineralogy
3. Aqueous phase
4. Secondary mineralogy
5. Loading estimates

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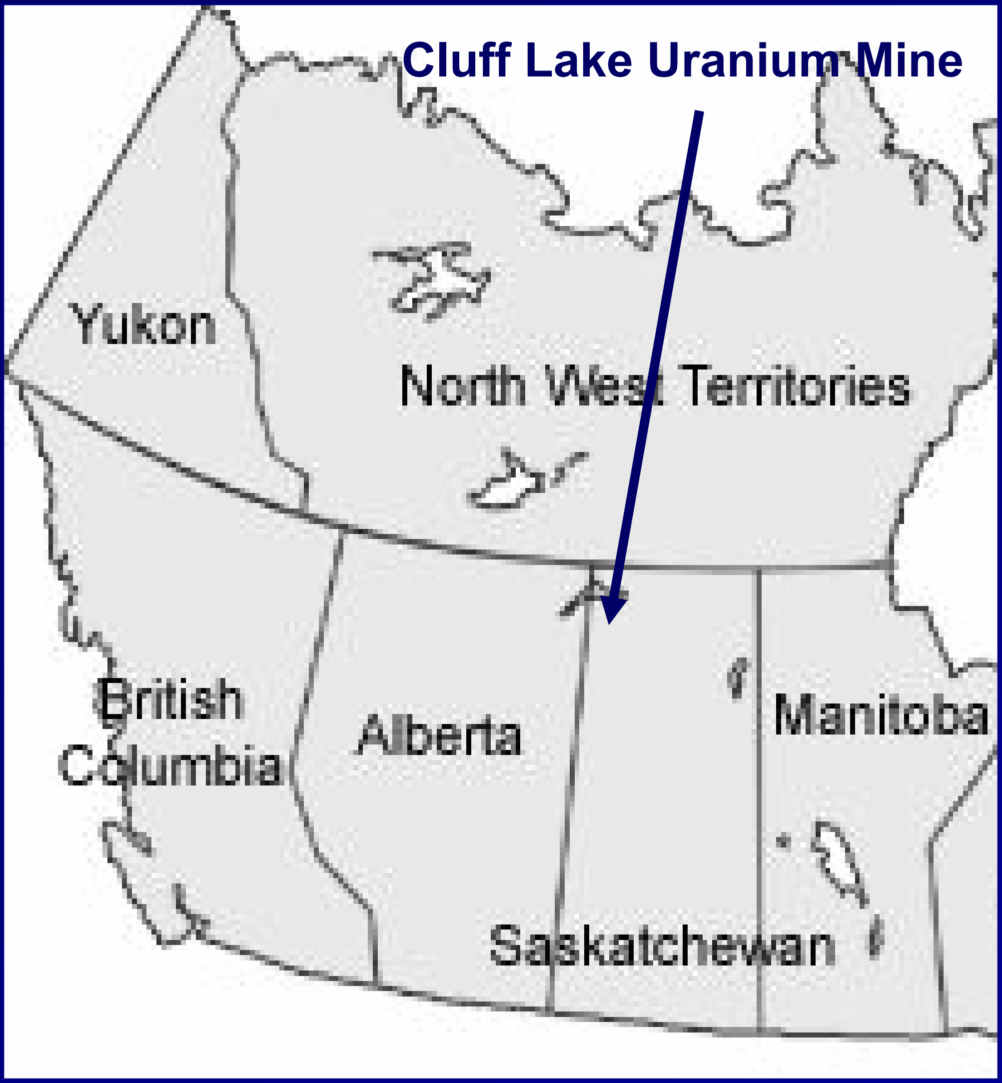
Field Site Description



- Multi-ring Carswell meteorite impact structure

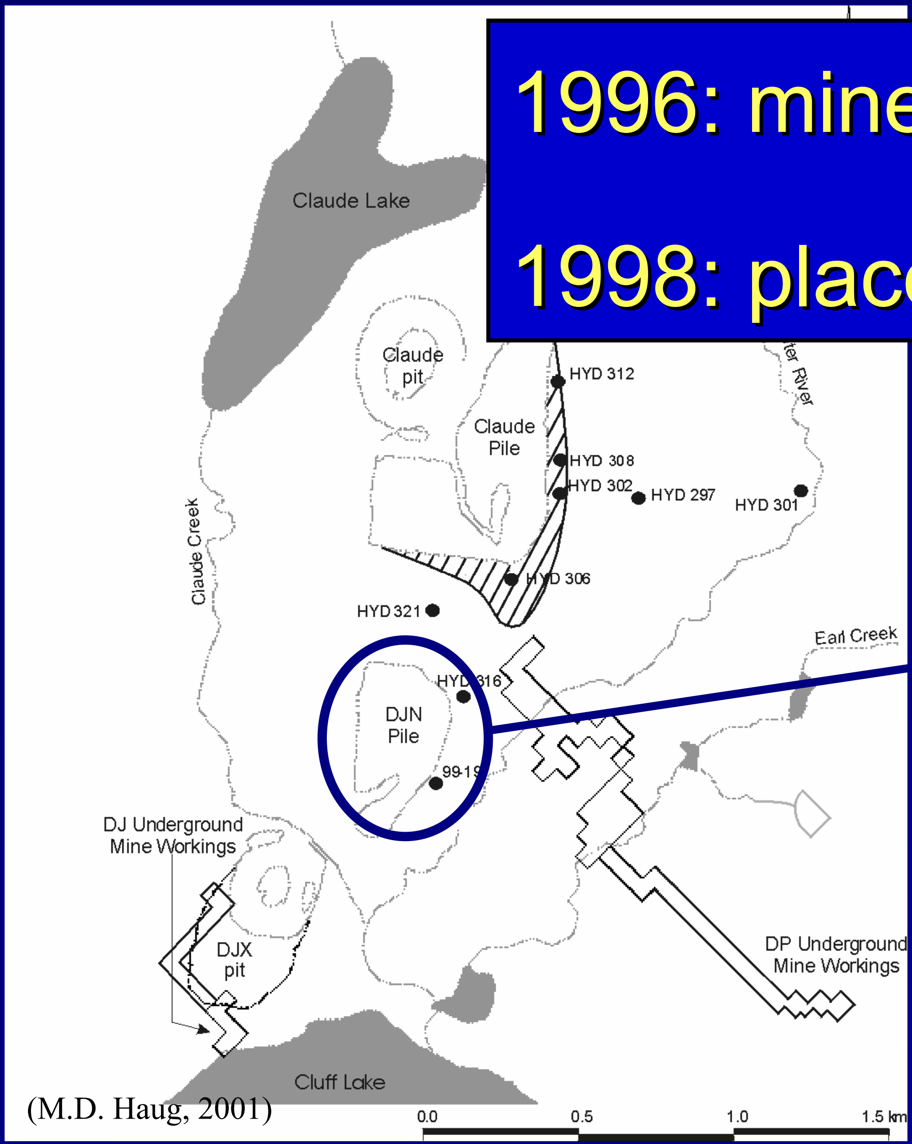
Waste rock:

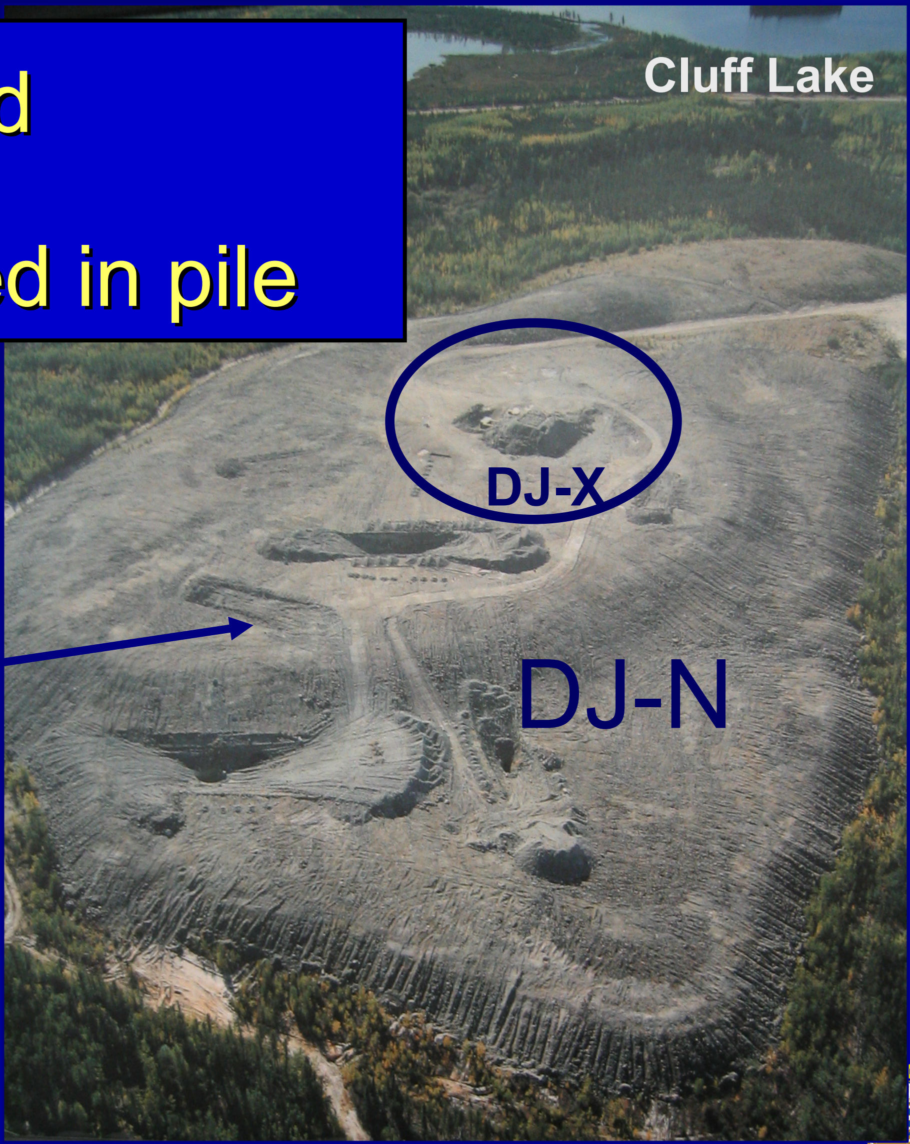
- –Peter-River aluminous gneiss
- –Earl River feldspathic gneiss
- –Small amounts of Athabasca sandstone

Cluff Lake Mine & Waste Rock Pile

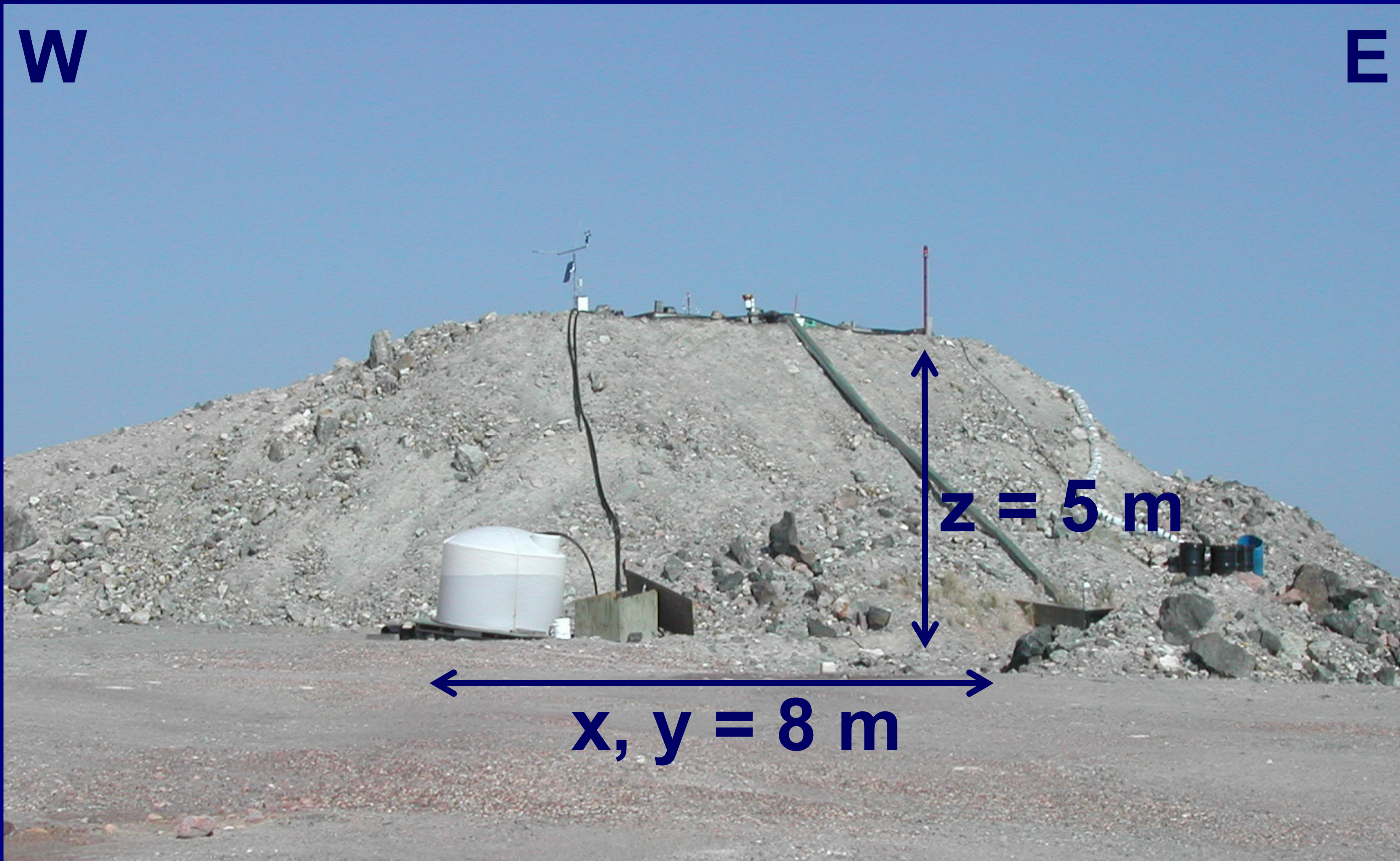
1996: mined

1998: placed in pile

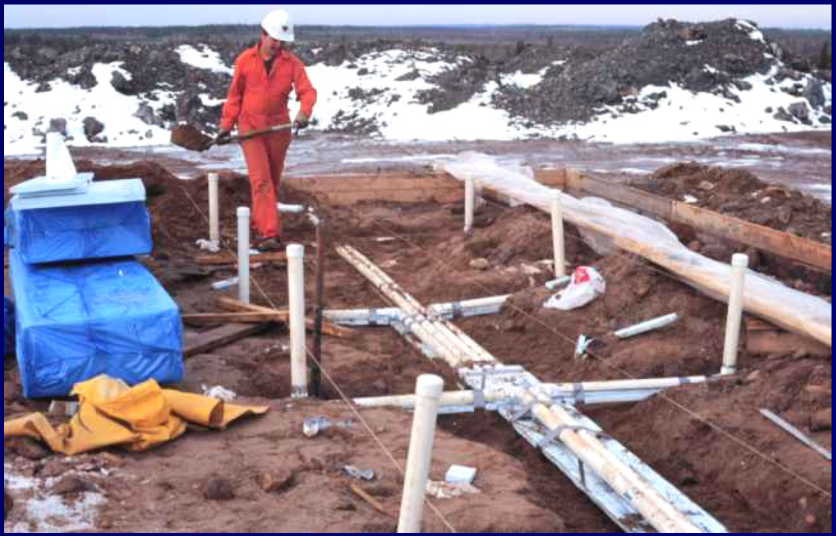




Constructed Waste Rock Pile Experiment



Pad and Piping

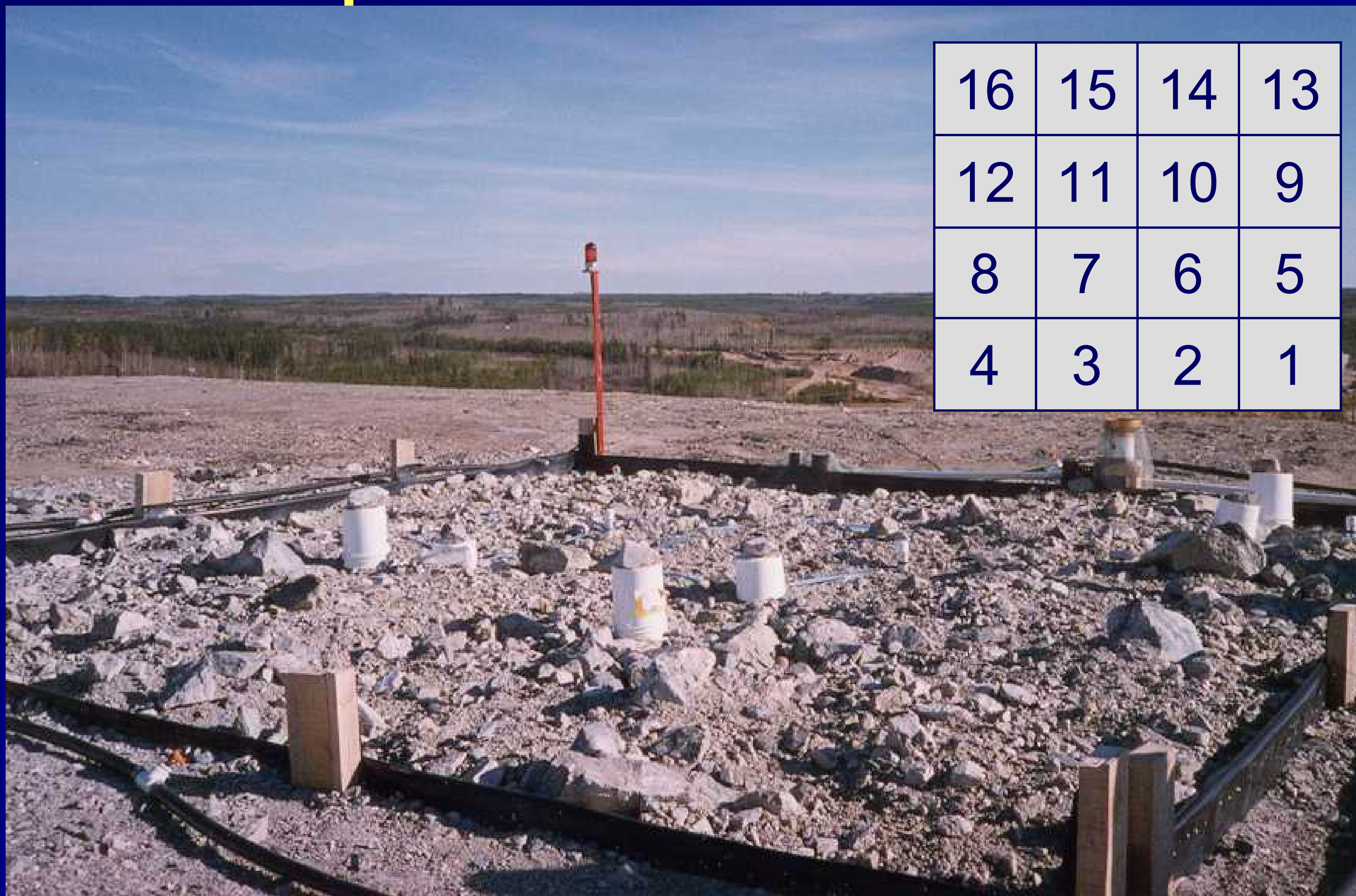


16 heat-traced outflow pipes

Lysimeter dividers

PVC and HDPE geomembrane

Top Surface of CPE



16	15	14	13
12	11	10	9
8	7	6	5
4	3	2	1

Instrumentation Hut & Outflow Sampling

Experimental Program

1997 – Sept. 1998	Construction of pile.
Sept. 1998 – Aug. 1999	Wetting up period.
Aug. 1999 – Aug. 2002	Natural and artificial rainfall, tracers.
Aug. 2002	Covered with compacted waste rock.
June 2004	Pile deconstruction.

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Hydrology

- Average Annual Air Temp: ~0°C (-45 to +35)
- Annual Rainfall: 305 mm
- Annual Precipitation: 455 mm

Net infiltration

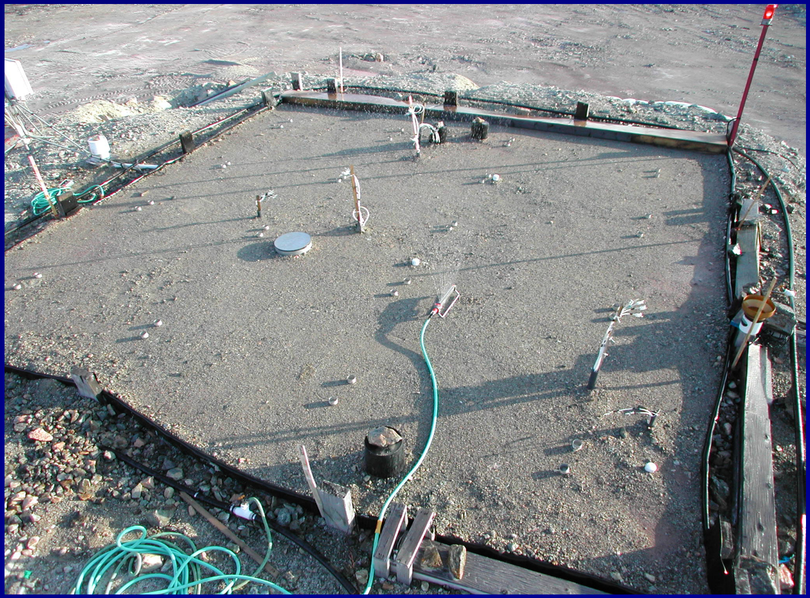
(% of precipitation)

Full pile:	56%
Individual lysimeters:	30% to 121%

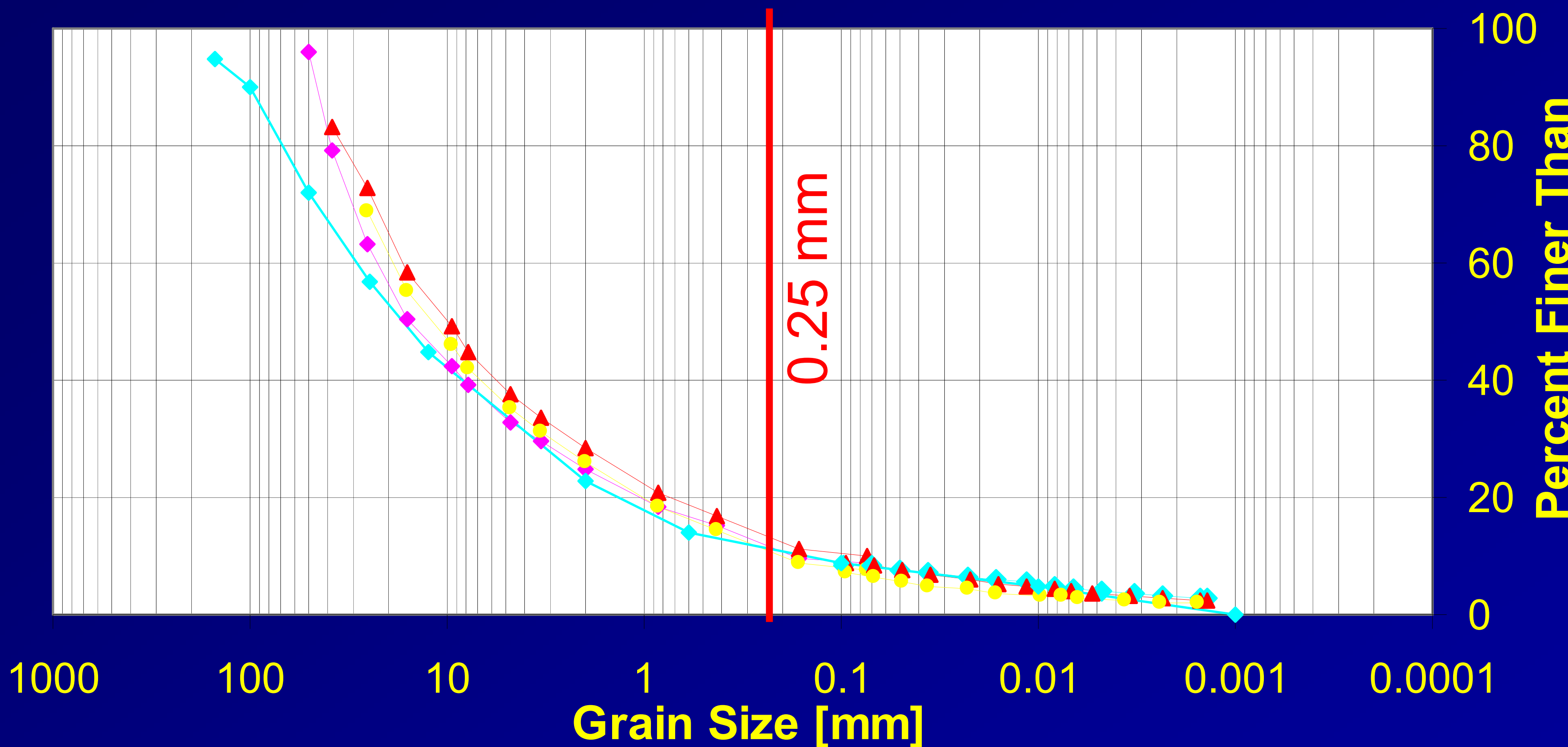
Mean water residence time: ~2.8 years

Low-Permeability Cover

- August 2002, waste rock with cobbles removed was added to surface of CPE and compacted to create a lower-permeability cover ($K \sim 10^{-7}$ m/s)
- Basal discharge reduced by factor ~2.5



DJX Waste Rock Grain Size Distribution



"soil-like" – matrix flow dominates

Geochemistry

- Mineralogy
  - Thin sections
  - Whole rock analysis
  - X-ray
  - SEM
  - Leco Furnace (total S)
- Water chemistry
  - Anions with IC ($n \approx 2500$)
  - Cations with ICP-OES ($n=272$) and ICP-MS ($n=165$)
  - Electrical conductivity
  - Standard water for calibrations (Jayne Simser, National Water Research Institute)

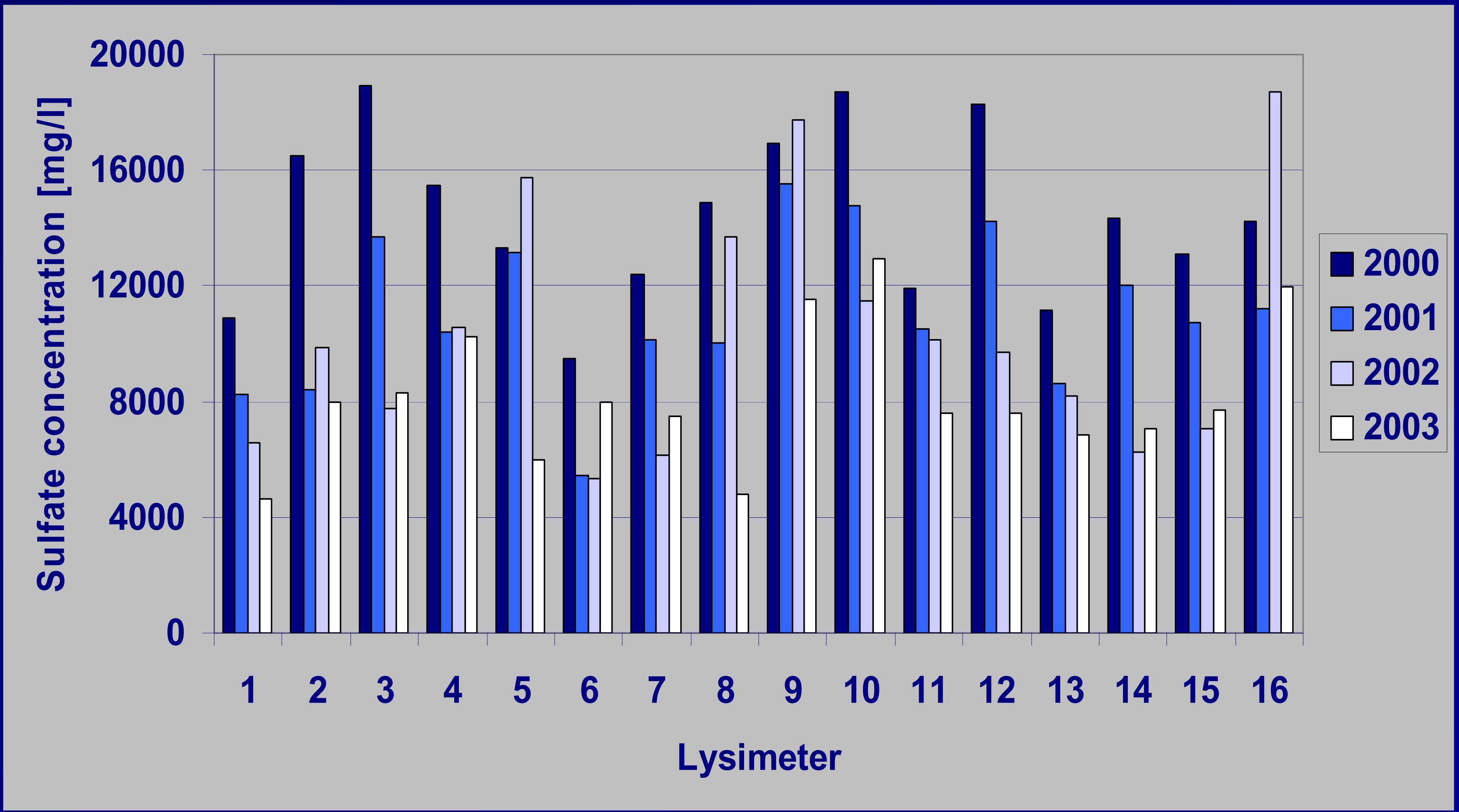
Primary Mineralogy

- quartz, k-feldspar, albite, chlorite, muscovite, kaolinite, smectite and amphibole
- Sulfide bearing minerals: pyrite and pyrrhotite
- Sulfide content: 0.45 wt % - 0.33 wt %
- Paste pH ~ 3.6
- NP/AP ratio ~0.3

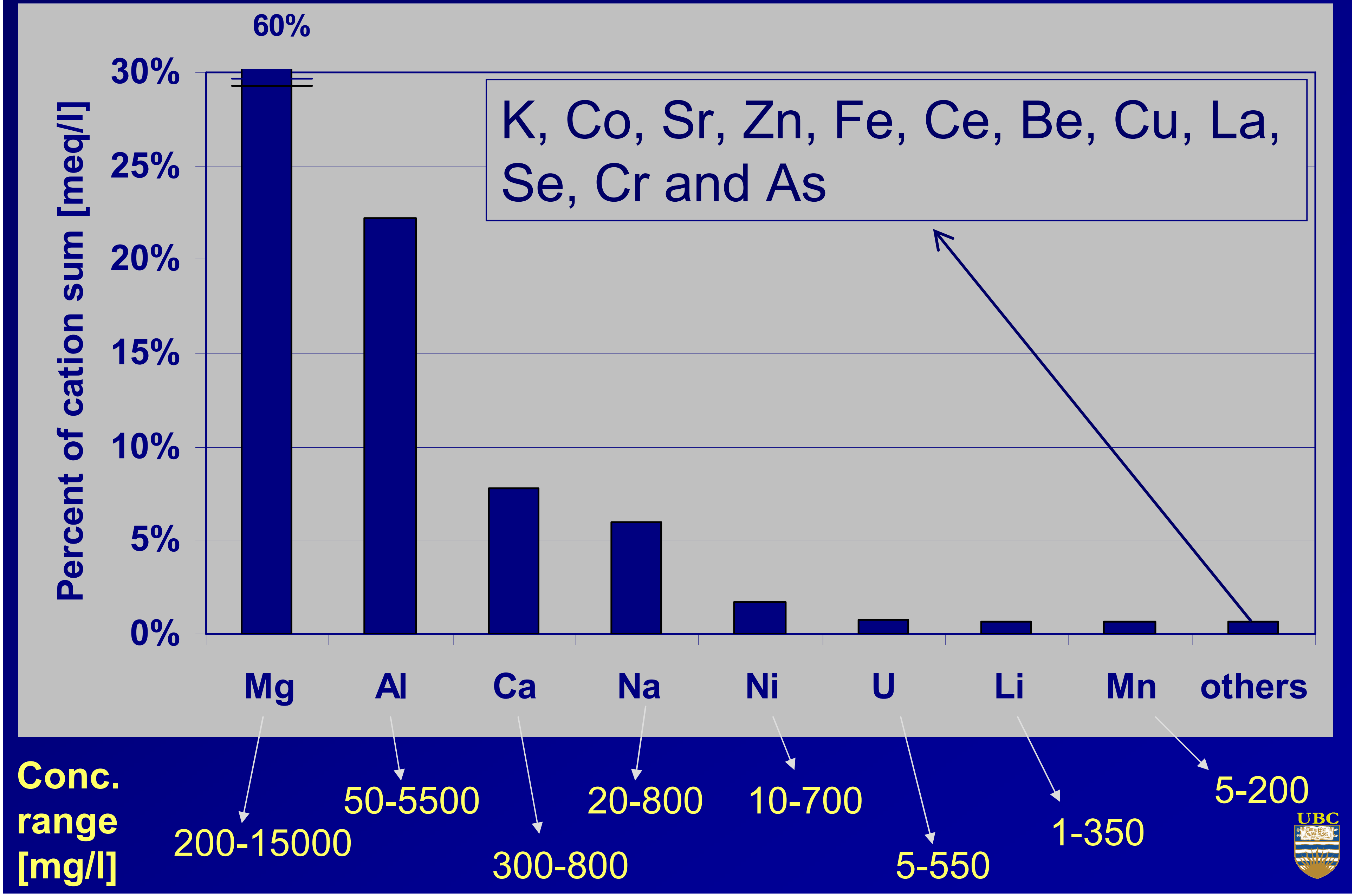
Aqueous Geochemistry

- Major anion: sulfate
- Concentration range: 600 – 35,000 mg/l
- Maximum: ~ 400,000 mg/l
- High spatial and temporal variability
- General decrease of sulfate concentration in the outflow water during the experiment
- pH 3.2 – 3.6, low variability

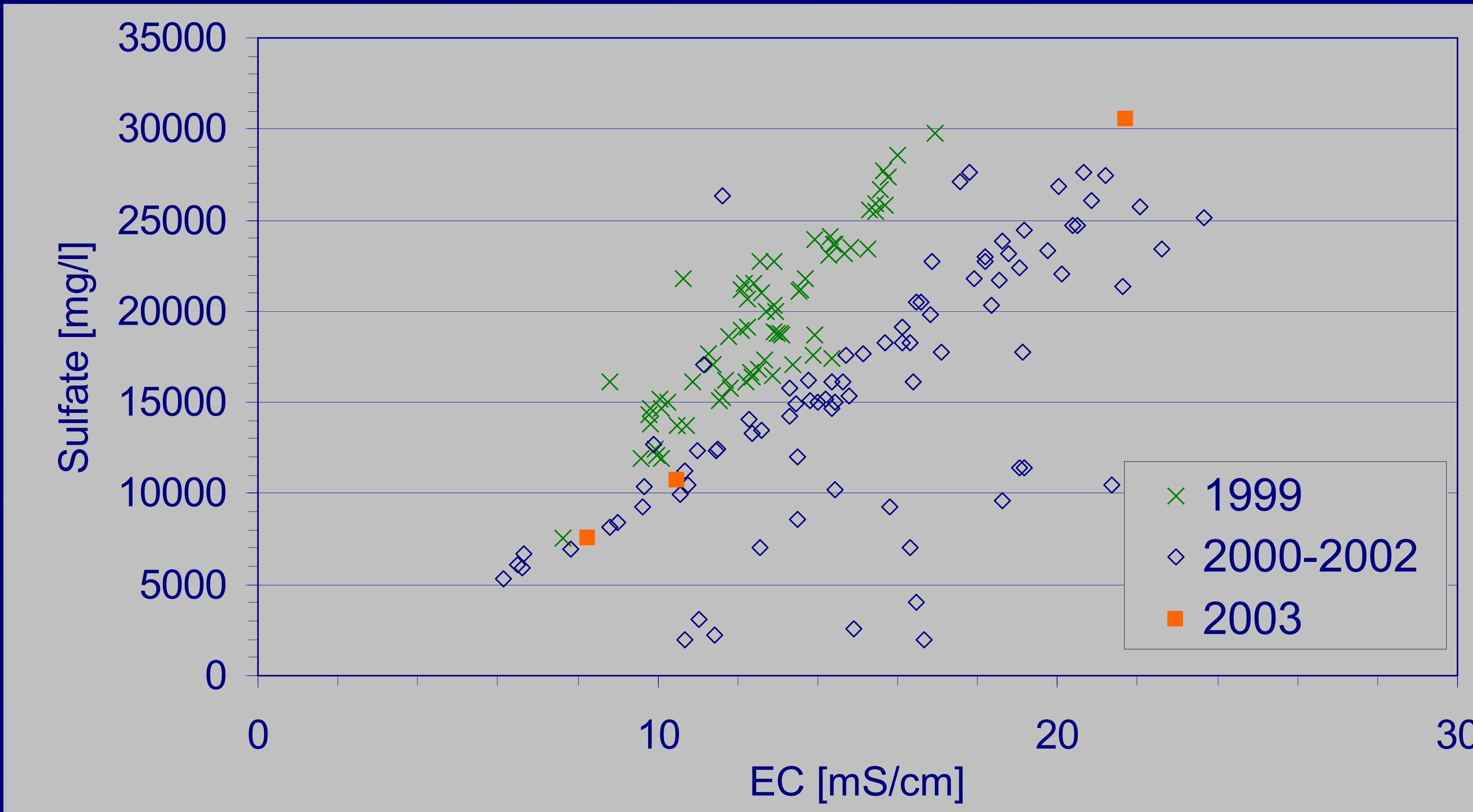
Outflow – Sulfate Concentrations



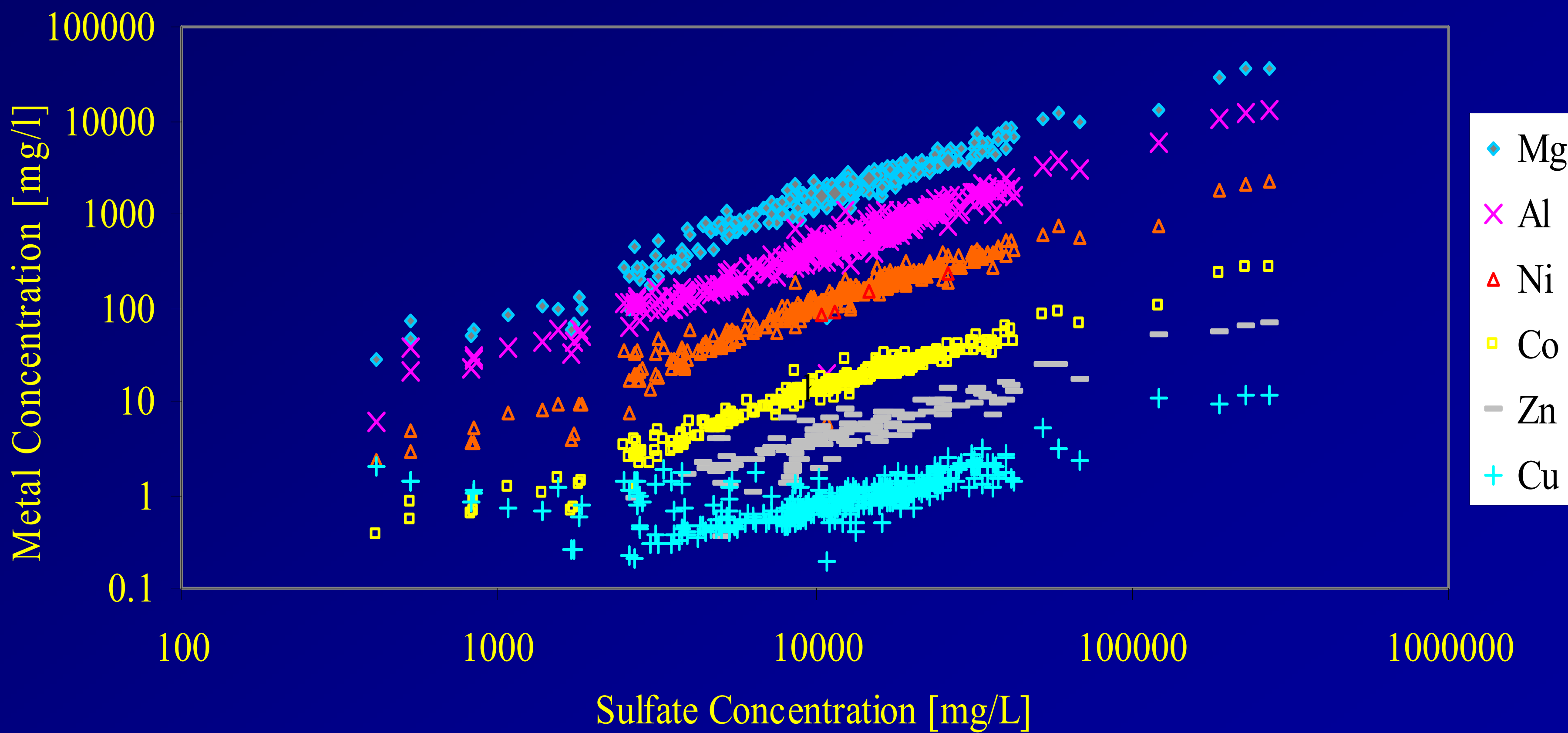
Outflow – Major Cations



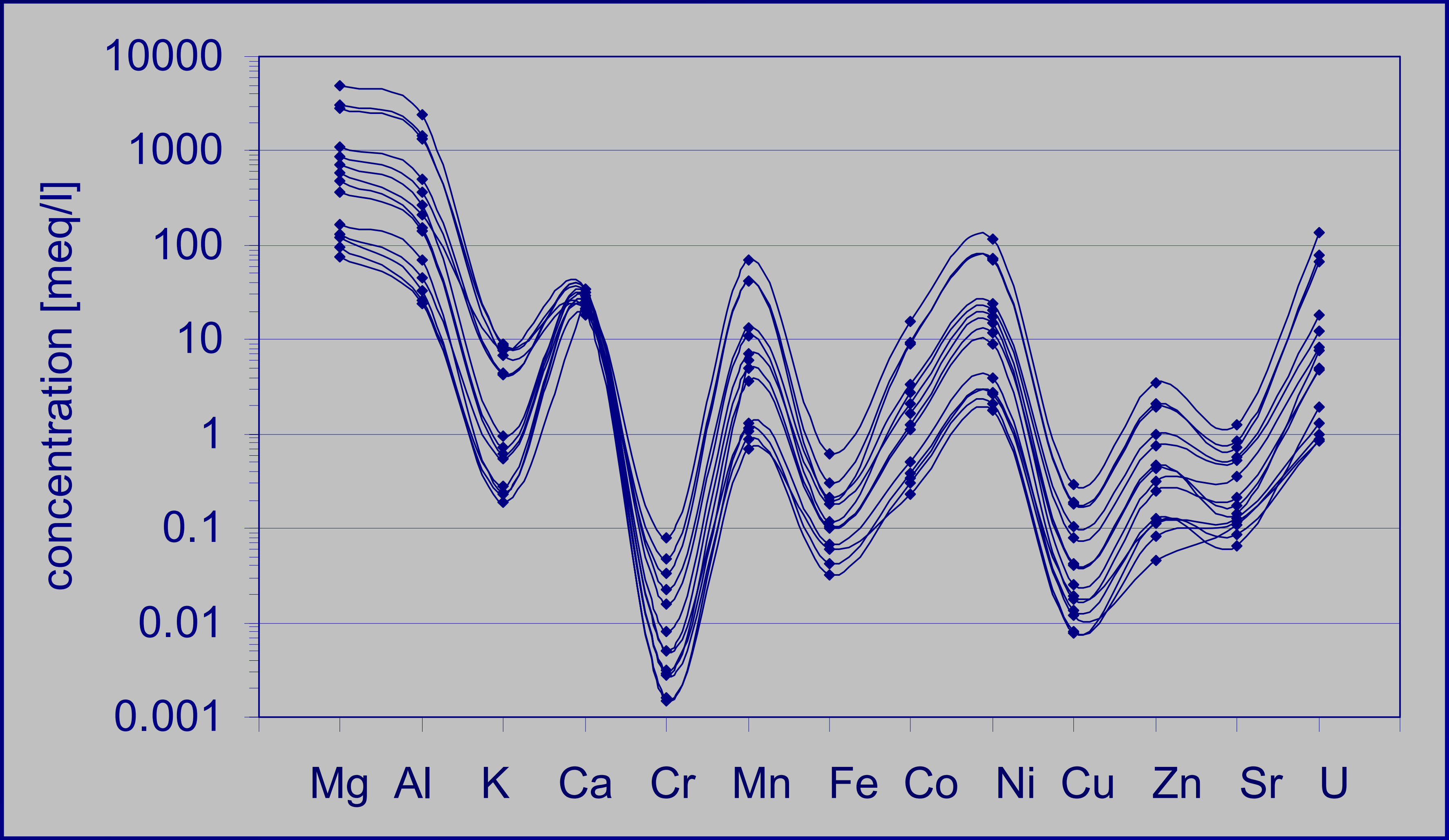
Results – E.C. vs. Sulfate Concentration



Sulfate correlation



Dilution



concentration [meq/l]
10000
1000
100
10
1
0.1
0.01
0.001
Mg Al K Ca Cr Mn Fe Co Ni Cu Zn Sr U

Brown coating: goethite and ferryhydrite ($FeO(OH)$, Fe_2O_3-$0.5H_2O$)

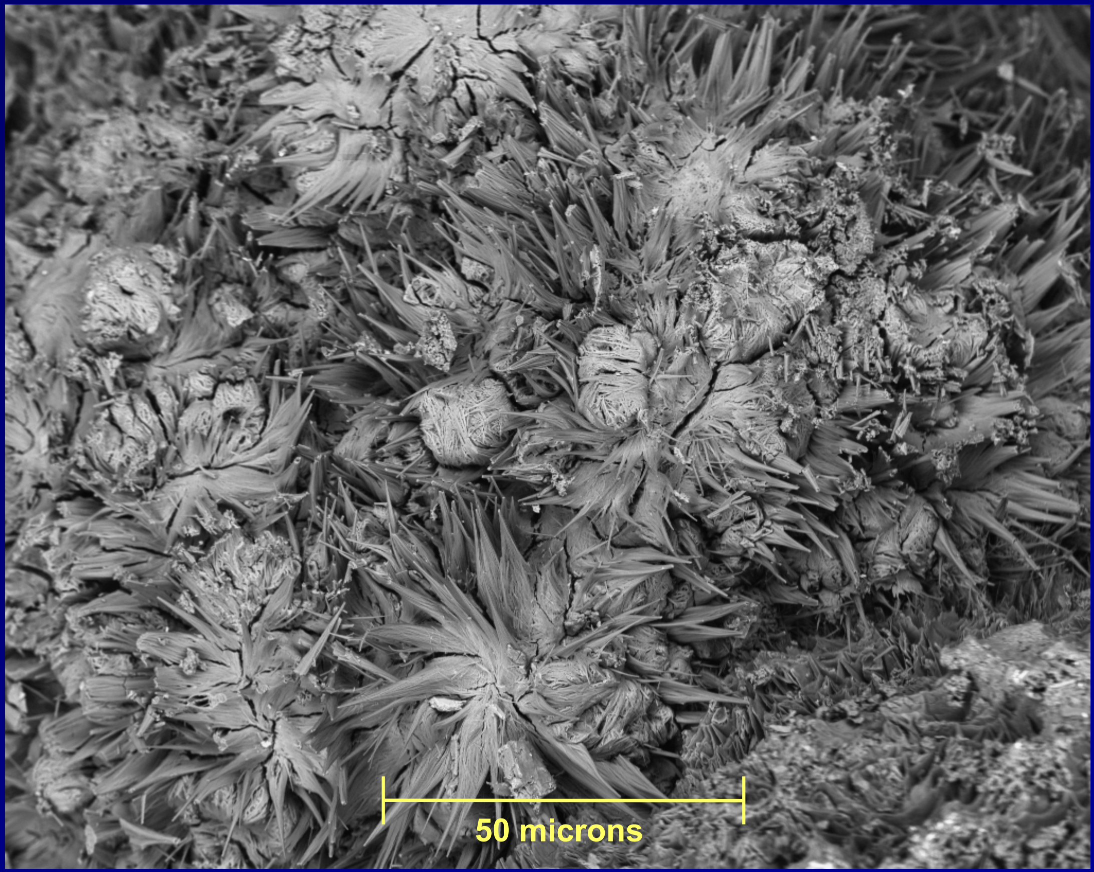
Yellow coating: jarosite $KFe_3(SO_4)_2(OH)_6$

Hydrated magnesium & aluminum sulfates

$MgSO_4$-nH_2O & $KAl_3(SO_4)_2(OH)_6$

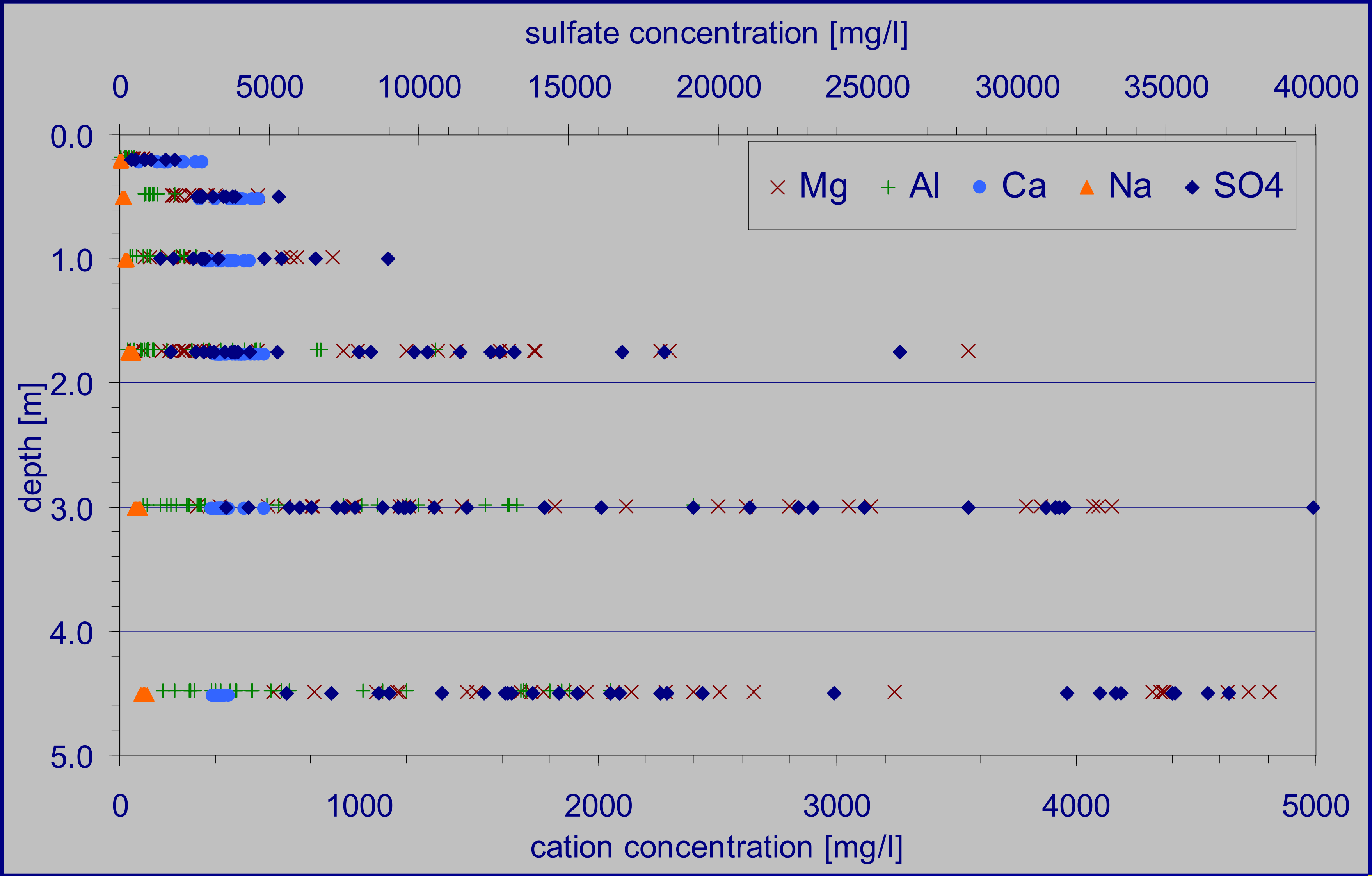
Annabergite $Ni_3(AsO_4)_2$-$8H_2O$

Scanning Electron Microscopy



Hydrated aluminum sulfates

Pore water chemistry



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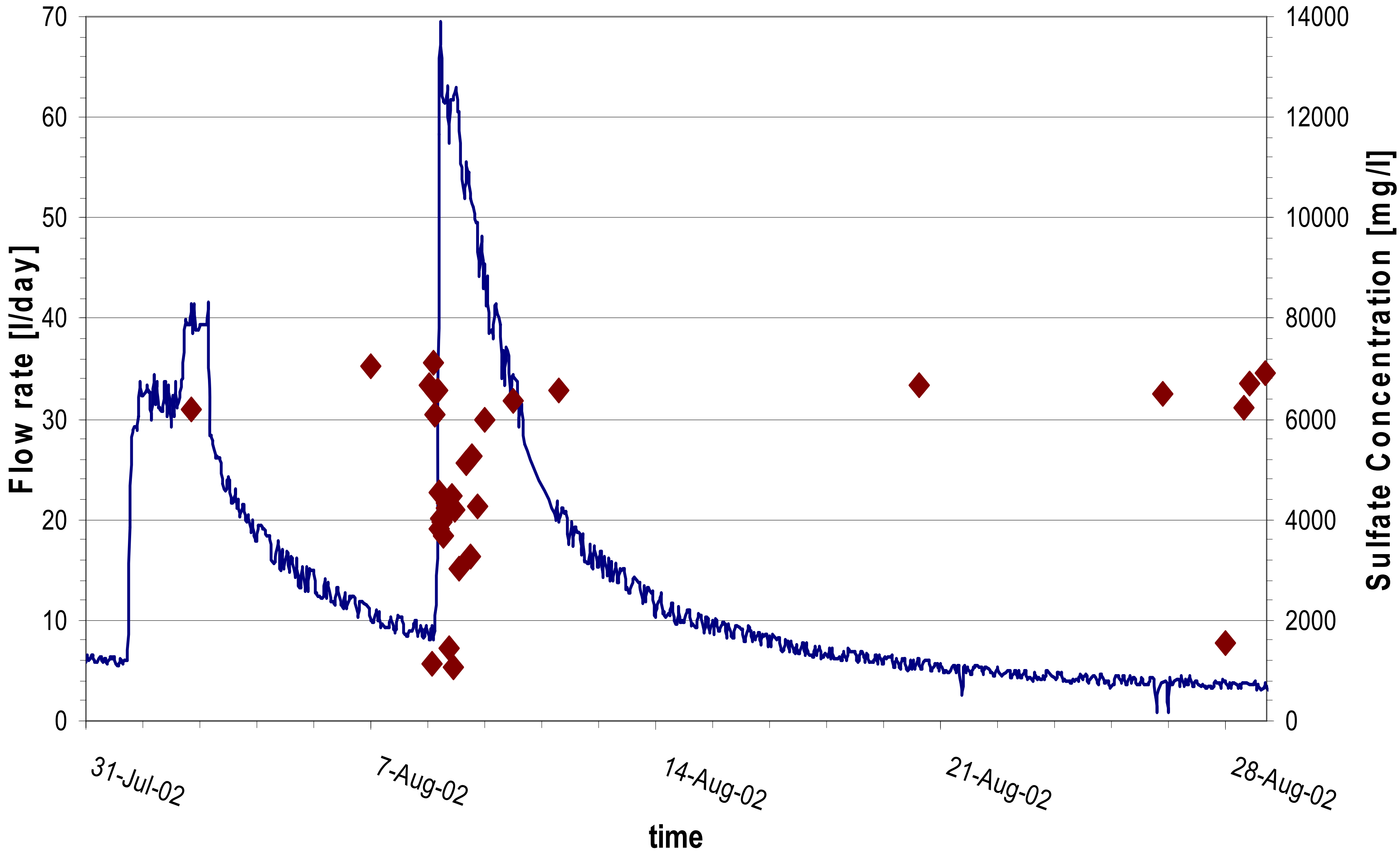
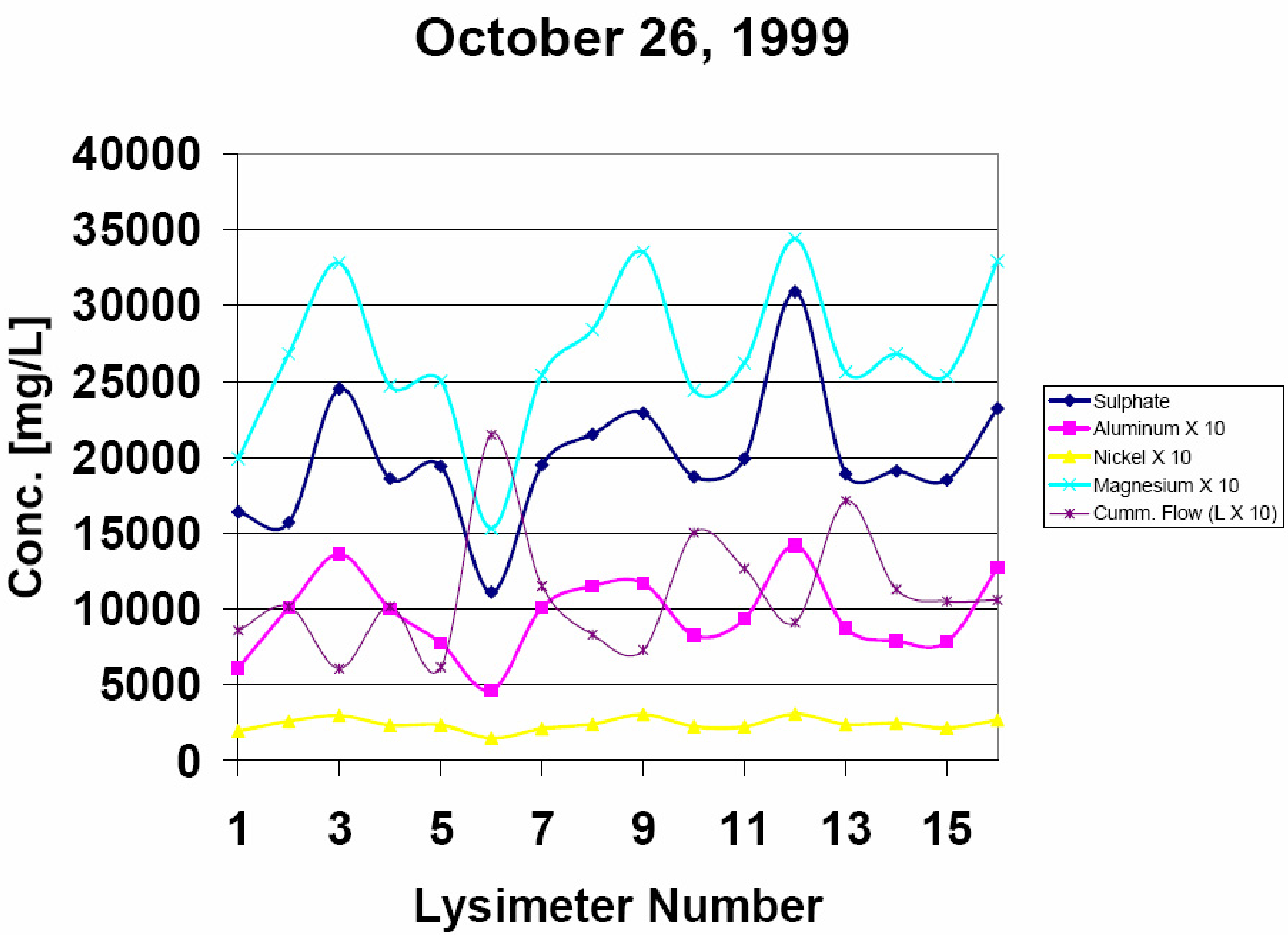
Flow Rates and Outflow Chemistry

Dry conditions	Wet conditions
↓	↓
Flow in fine-grained matrix	Flow in coarse grained material
↓	↓
Relatively slow	Relatively fast
↓	↓
Long time for water-rock interactions	Short time for water-rock interactions
↓	↓
Outflow water relatively concentrated	Outflow water relatively fresh

Event Effects: Freshening of Outflow



Flow - chemistry



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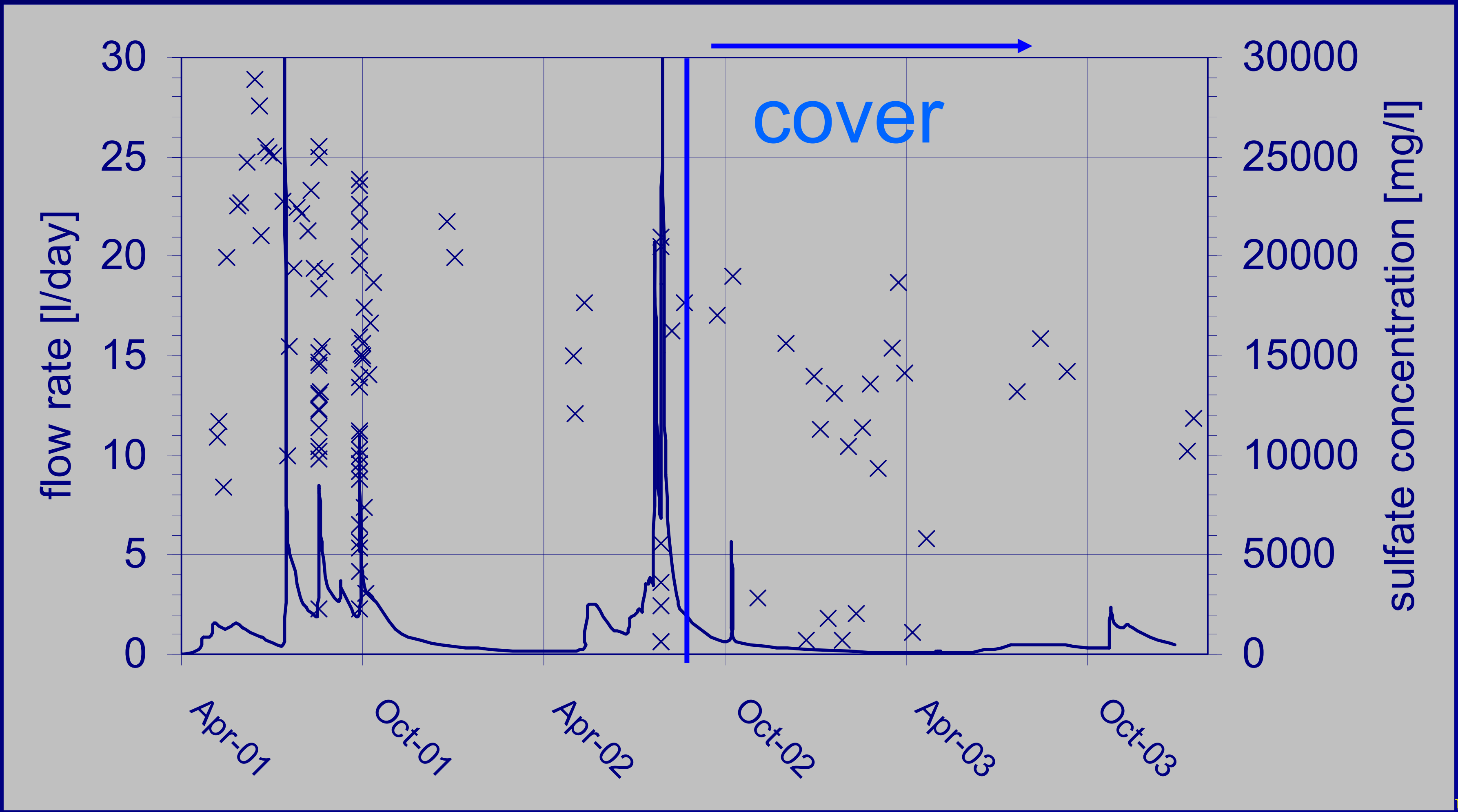

Loading at Base of CPE

(mg SO_4/kg/week)

Year	Mean	Summer High	Winter Low
2000	5.6	19	~0.1
2001	3.8	11	~0.1
2002	3.5	16	~0.1

Humidity Cells	
Fine 0.6 mm	66
Coarse 2 mm	27
Hollings et al (2001)	

Aerobic leach columns

35 – 40 kg, 3 L rinse per week

	Pore Volumes	Percent of initial leached		
		Ni	U	S
Pile Experiment	~1.25 (5.5 years)	11 %	37 %	5 %
Leach Columns	~1.25 (2 weeks)	17 %	50 %	N/A
	~10 (20 weeks)	34 %	79 %	N/A

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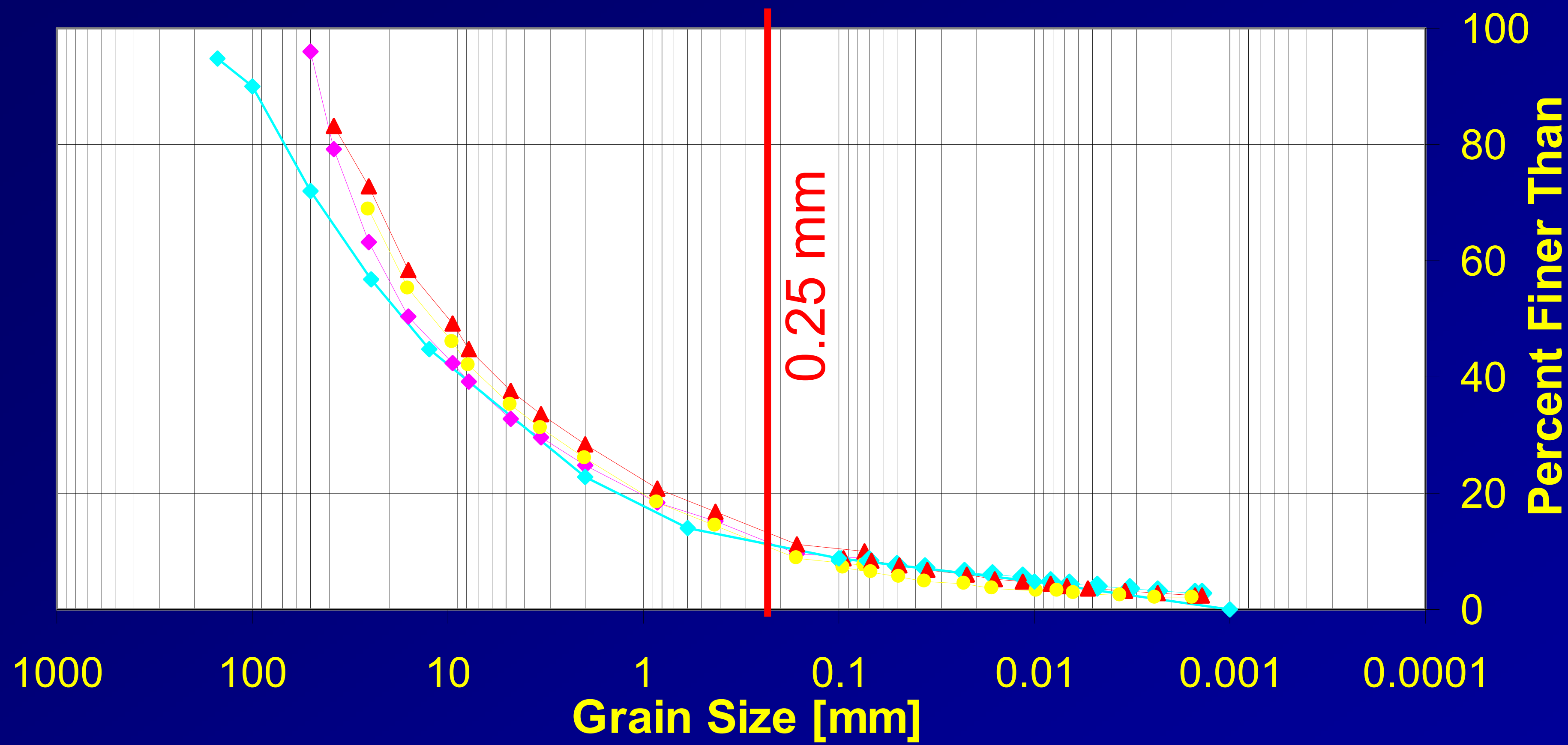

Reactive fraction?

Conclusions

- Principal buffer minerals: chlorite and muscovite.
- E.C. good predictor of chemistry.
- Dominant chemistry; relative proportions constant.
- Dilution highly variable in space and time.
- General inverse correlation between outflow chemistry and flow.
- Low permeability cover induced a decrease in flow rates and coincident reduction in outflow concentrations.
- During the 4 year experiment ~ 5 % or 150 kg of sulfur were released.
- U and Ni appear to be dominantly in finer, leachable fraction.

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Acknowledgments

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