Transport of *Cryptosporidium parvum* Oocysts in Saturated Porous Media

Joseph Ryan, Yumiko Abe, and Rula Abu-Dalo

University of Colorado at Boulder

Ronald Harvey and David Metge

U.S. Geological Survey

Menachem Elimelech, Garrett Miller, and Zachary Kuznar

Yale University

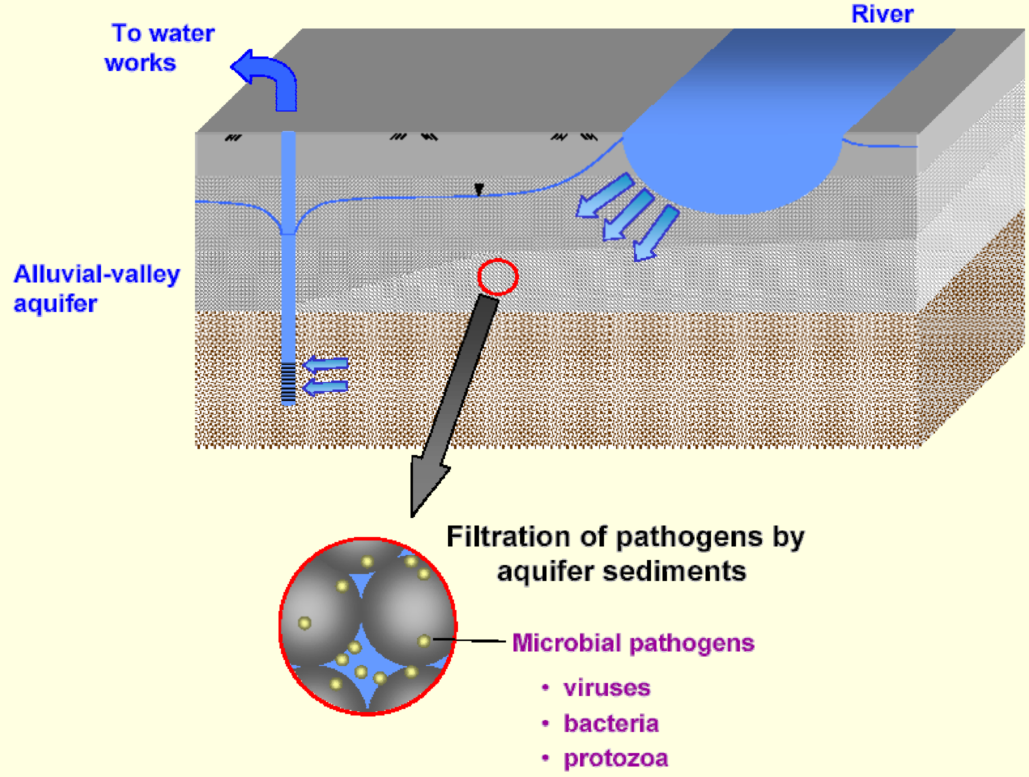
Outline

- Motivation for this research
- Characterization of *Cryptosporidium parvum* oocysts
- Effect of heterogeneity on oocyst transport in an intermediate-scale aquifer tank
- Effect of ionic strength and secondary minimum on oocyst deposition
- Comparison of oocyst and microsphere transport
- Importance of straining on oocyst transport

Riverbank Filtration

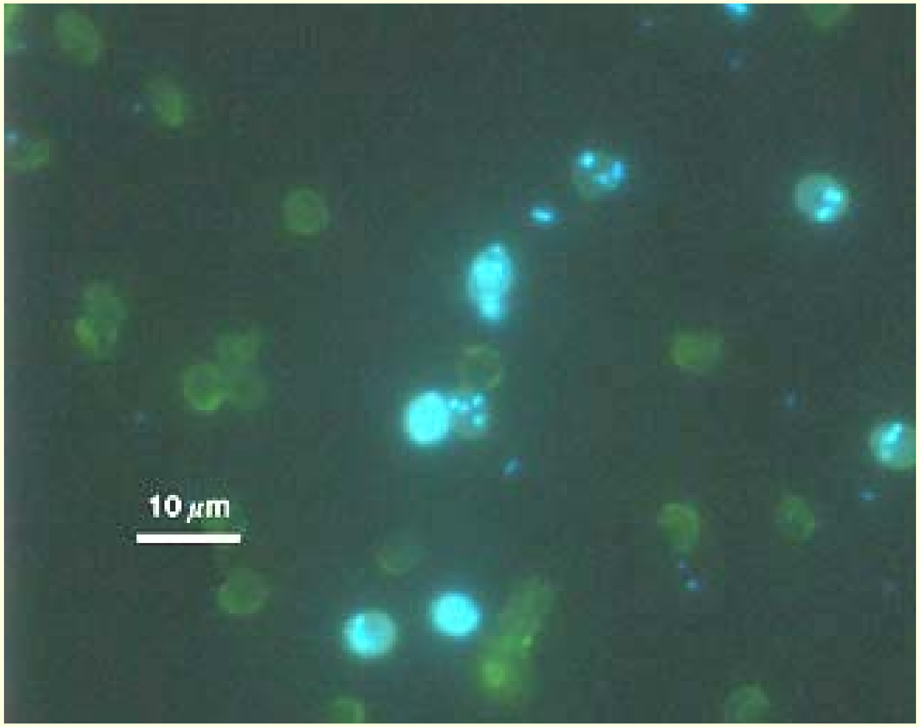
- Motivation
  - alluvial sediments
    - grain size variability
    - surface charge variability
    - solution chemistry variability

Tufenkji et al., ES&T, 2002



Cryptosporidium parvum Oocysts

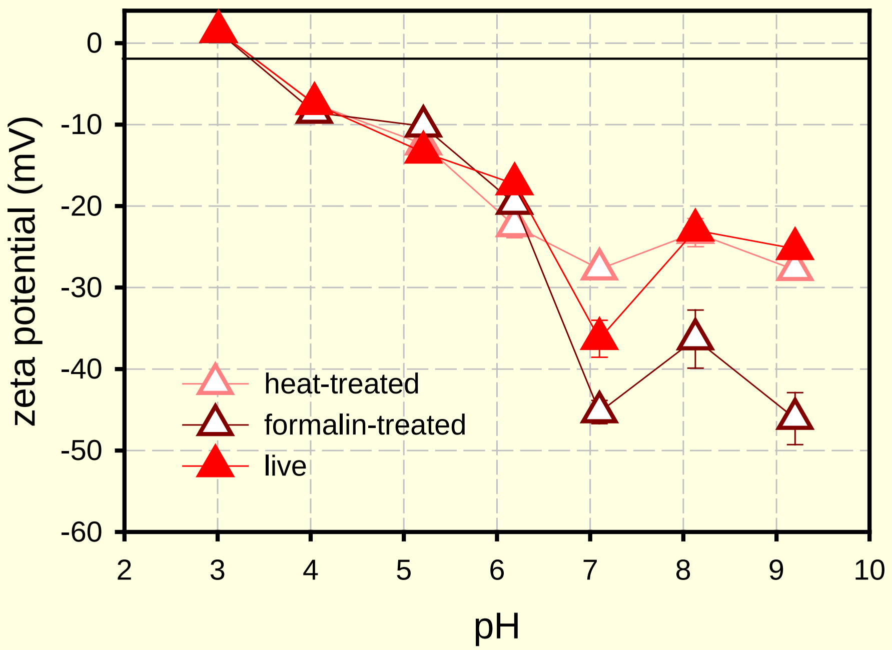
- Source
  - University of Arizona, Sterling Parasitology Laboratory
- Preparation
  - live, heat-treated, and formalin-inactivated
- Detection
  - DAPI stain
    - epifluoresence microscopy
    - flow cytometry



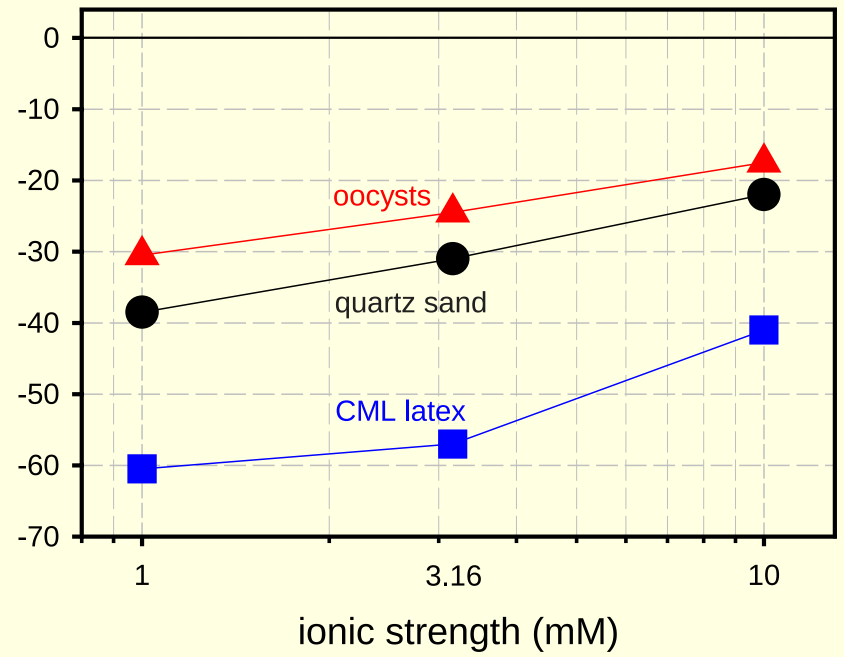
Cryptosporidium parvum Oocysts

- Zeta potential

Effect of Inactivation (I 0.1 mM)

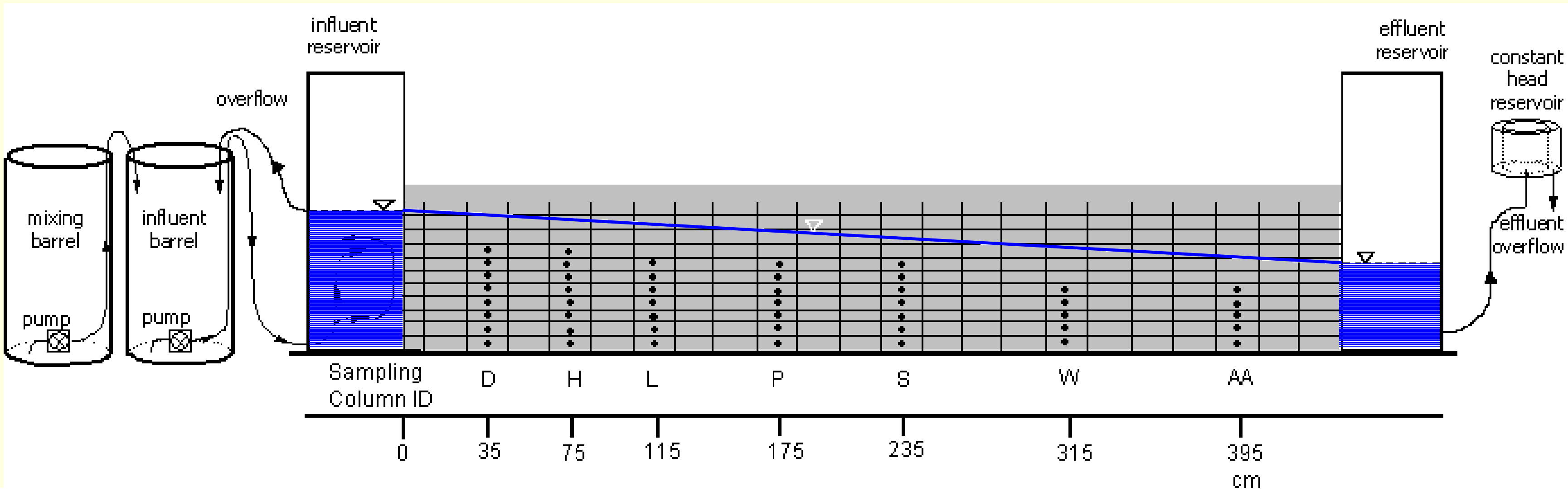


Effect of Ionic Strength (pH 5.6-5.8)



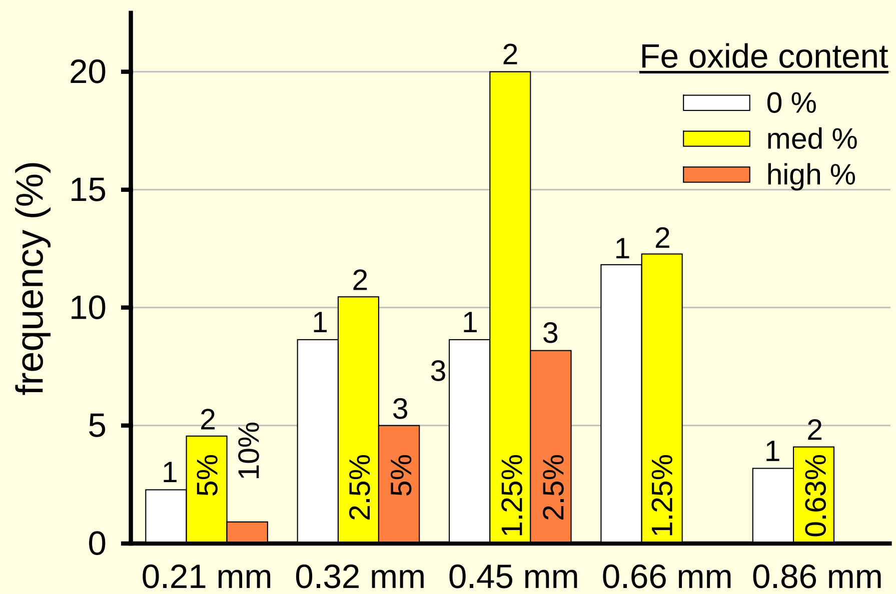
Aquifer Tank Experiment

- Tank Setup
  - 4.15 m length × (50-30) cm height × 10 cm width
  - head difference 20.0 cm, velocity: 10.0 m d^{-1}
  - injection
    - oocysts (formalin)
    - microspheres (4.6 µm, sulfate, fluorescent)
    - pH 5.8-6.0, 10^{-4} M NaCl
    - tracer (sodium nitrate, 10^{-4} M, UV detection)



Aquifer Tank Experiment

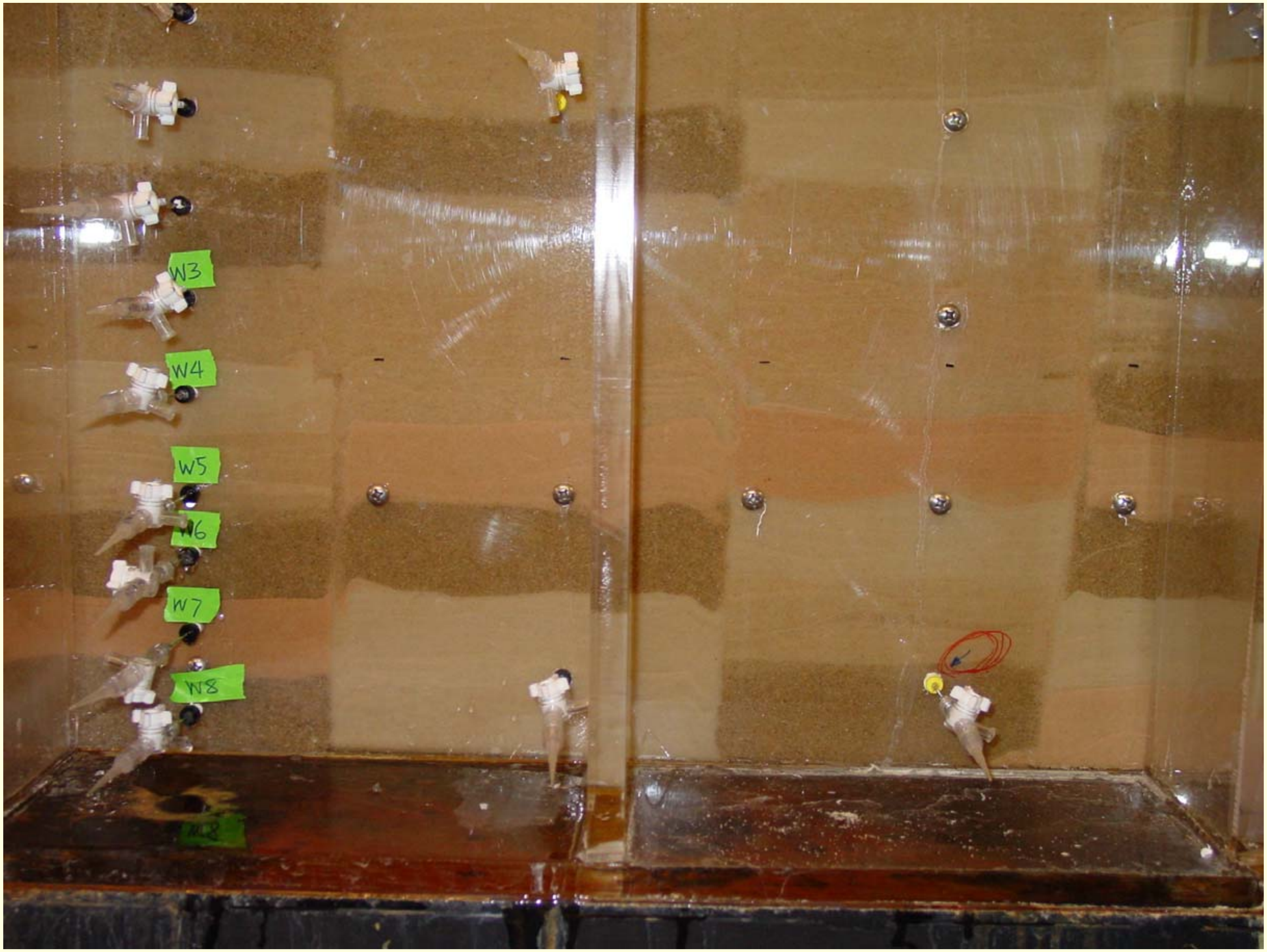
- Tank Packing
  - 5 × 20 cm blocks
  - grain size
  - ferric oxyhydroxide coating



		D		H		L			P			S				W				AA		
1	2	2	3	2	1	2	1	1	1	1	2	3	1	1	1	2	1	2	2	3	2	1
1	2	2	3	2	2	1	2	1	2	3	3	1	3	2	2	2	2	2	2	2	2	2
1	2	2	1	2	2	2	1	2	1	1	2	1	1	3	1	1	2	2	1	2	1	1
1	2	1	2	3	1	1	3	2	3	1	2	1	1	1	2	1	1	2	1	2	2	3
1	2	1	2	1	3	1	1	1	1	1	2	2	1	2	2	2	2	1	1	1	1	2
1	2	2	3	1	2	2	3	3	2	1	2	1	3	2	2	3	3	3	2	1	1	1
1	2	2	2	2	2	2	3	1	2	3	2	1	2	1	1	1	1	2	2	2	2	1
1	2	3	2	2	1	2	3	1	1	2	2	3	1	1	2	2	2	3	2	1	1	2
1	2	1	1	3	2	2	1	2	2	2	3	2	2	2	1	2	2	1	2	1	1	3
1	2	3	2	3	2	3	2	2	2	1	2	2	2	2	1	3	1	2	1	2	3	1
1	2	1	2	2	2	2	2	2	2	2	1	3	2	2	2	1	1	2	2	1	1	1

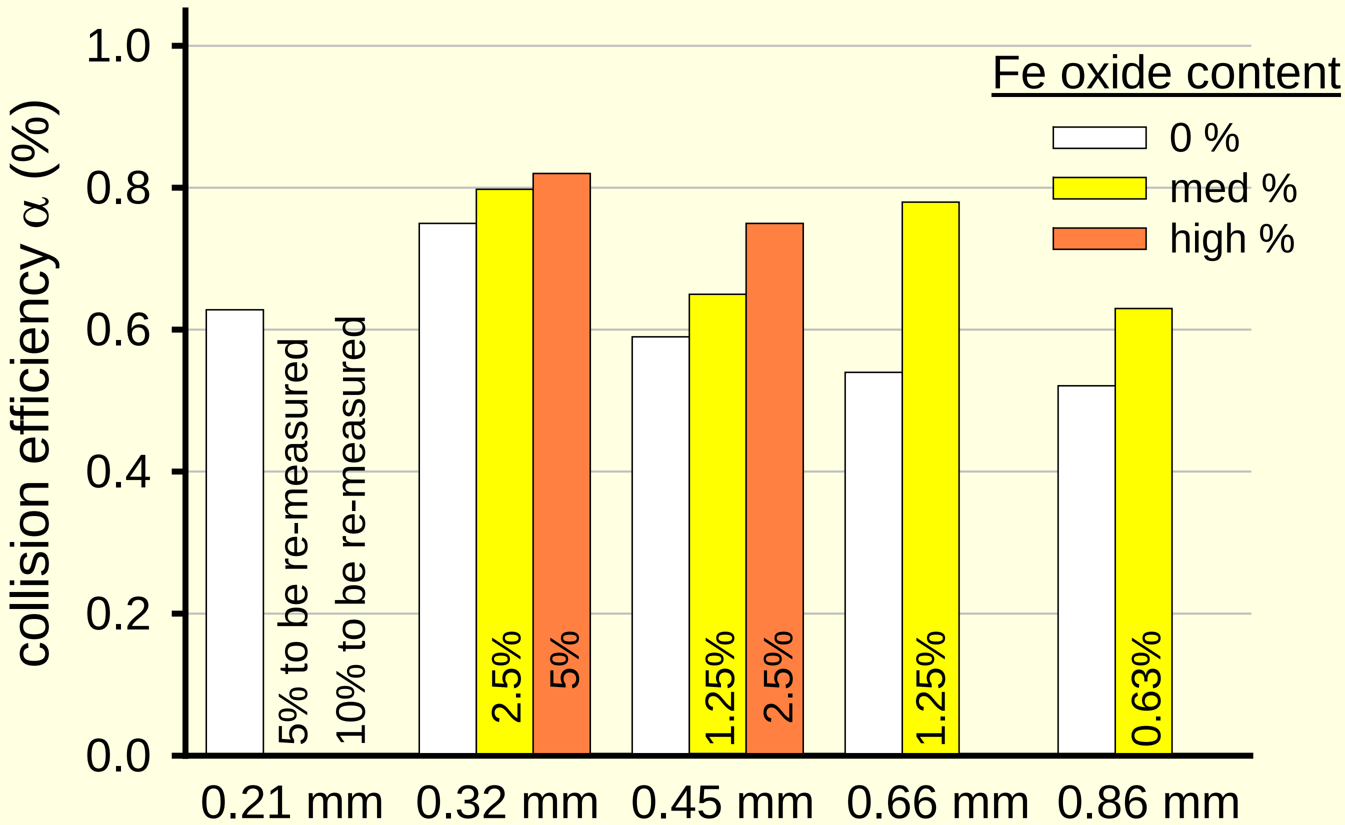
0.86 mm grain 0.66 mm grain 0.45 mm sand 0.32 mm sand 0.21 mm sand

Aquifer Tank Experiment



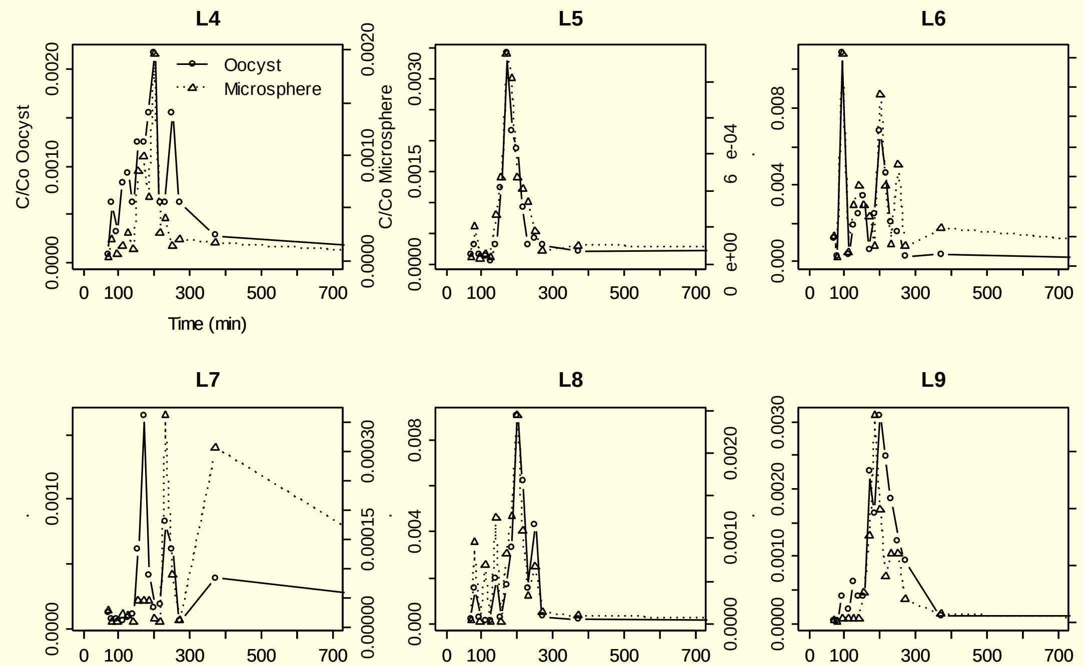
Aquifer Tank Experiment

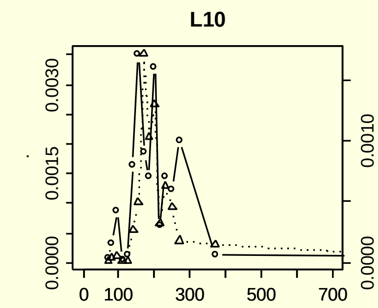
- Deposition in column experiments
  - oocysts, formalin inactivated



Aquifer Tank Experiment

- Breakthroughs in Tank
  - oocysts
    - flow cytometry
    - epifluorescence microscopy
  - microspheres
    - fluorimetry



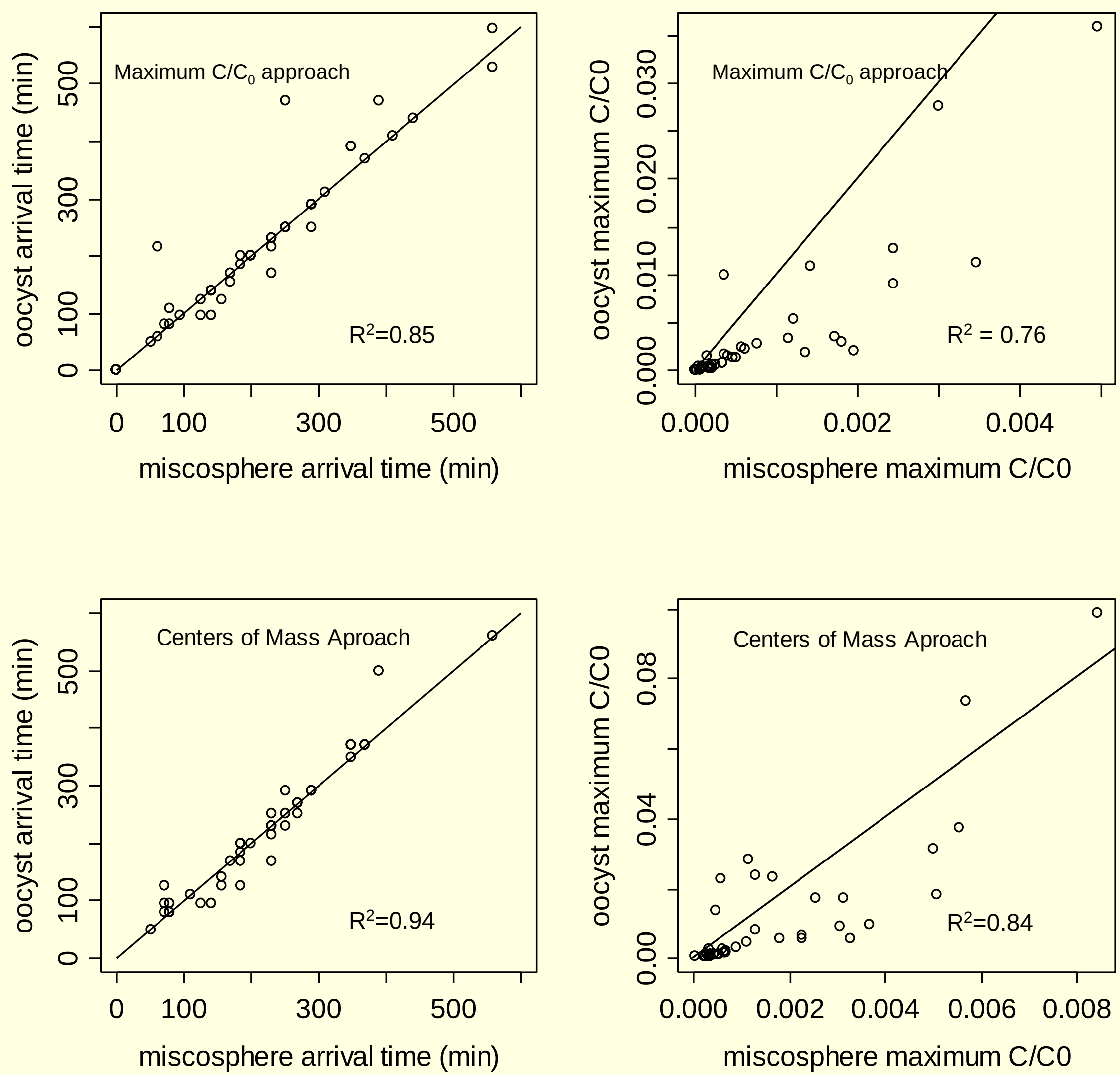


$C/C_0 \propto$ grain size

$C/C_0 \not\propto$ Fe oxide %

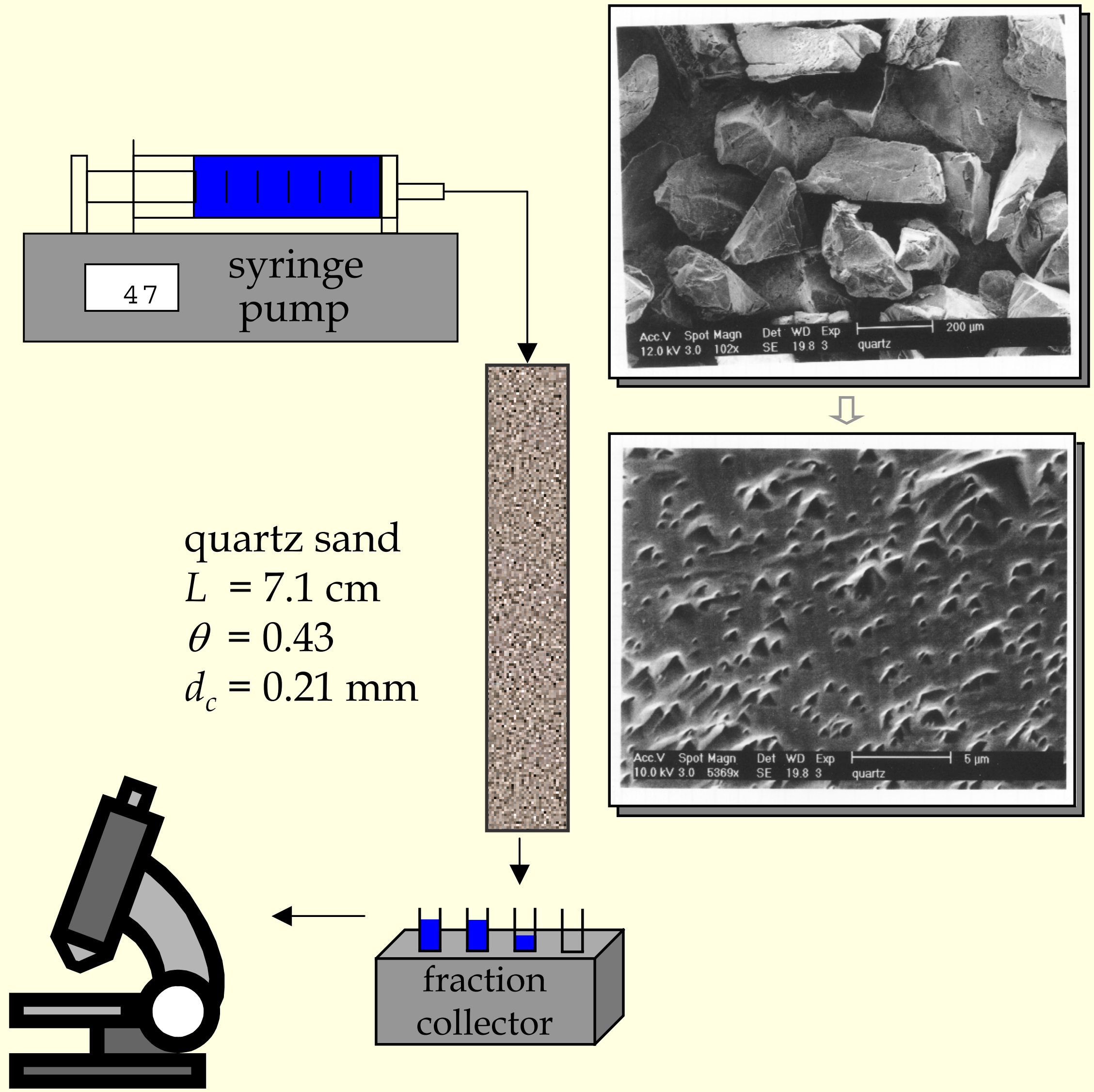
Aquifer Tank Experiment

- Surrogate?
  - microspheres arrive at same time
  - microspheres attenuated more rapidly
  - confirming results in columns



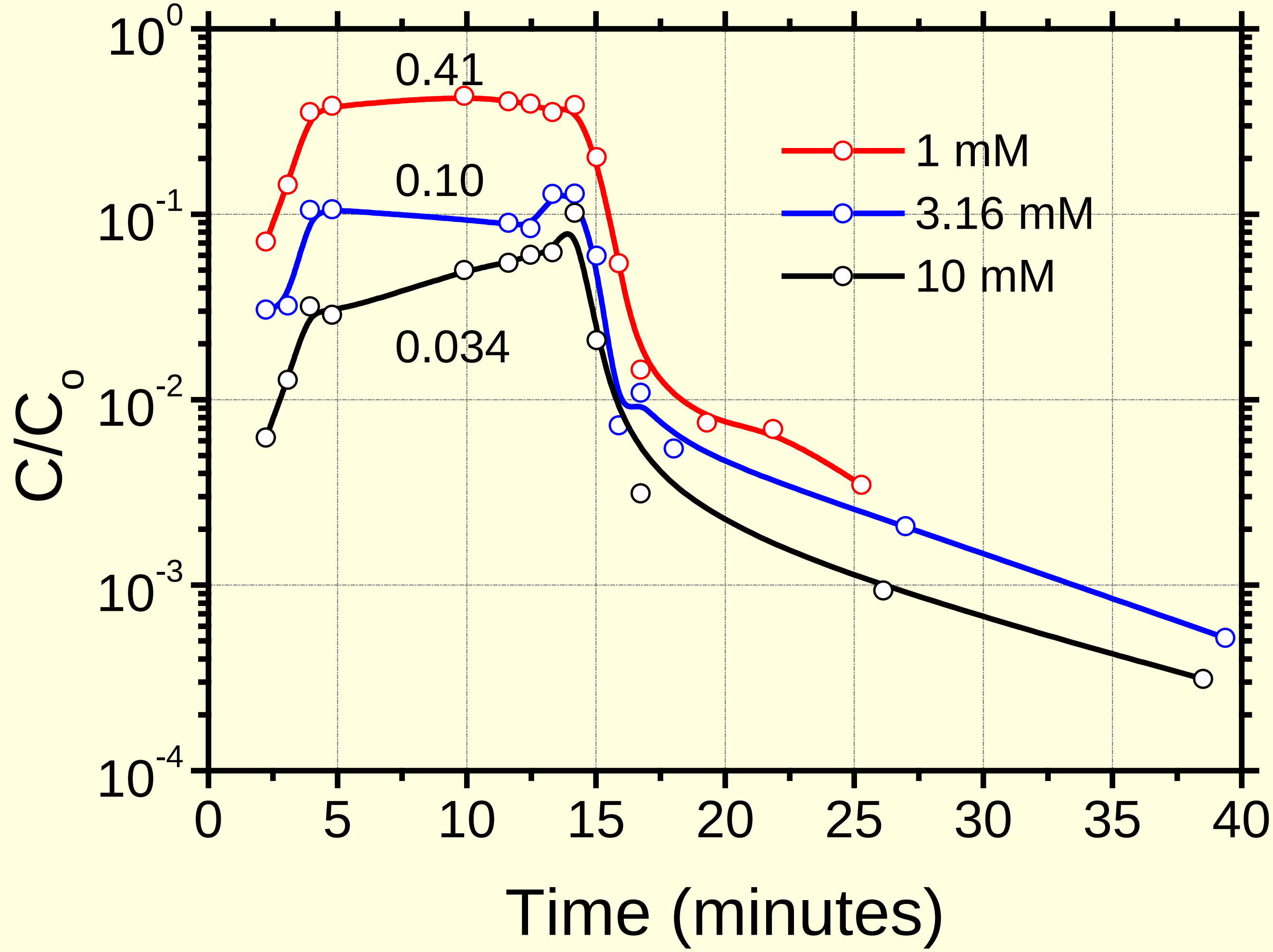
Column Experiments

- Injection
  - oocysts
    - heat-treated
  - microspheres
    - 4.1 µm
    - carboxyl-modified
    - fluorescent
  - solution
    - pH 5.6-5.8
    - I varied
  - flow rate
    - 2 mL min^{-1}



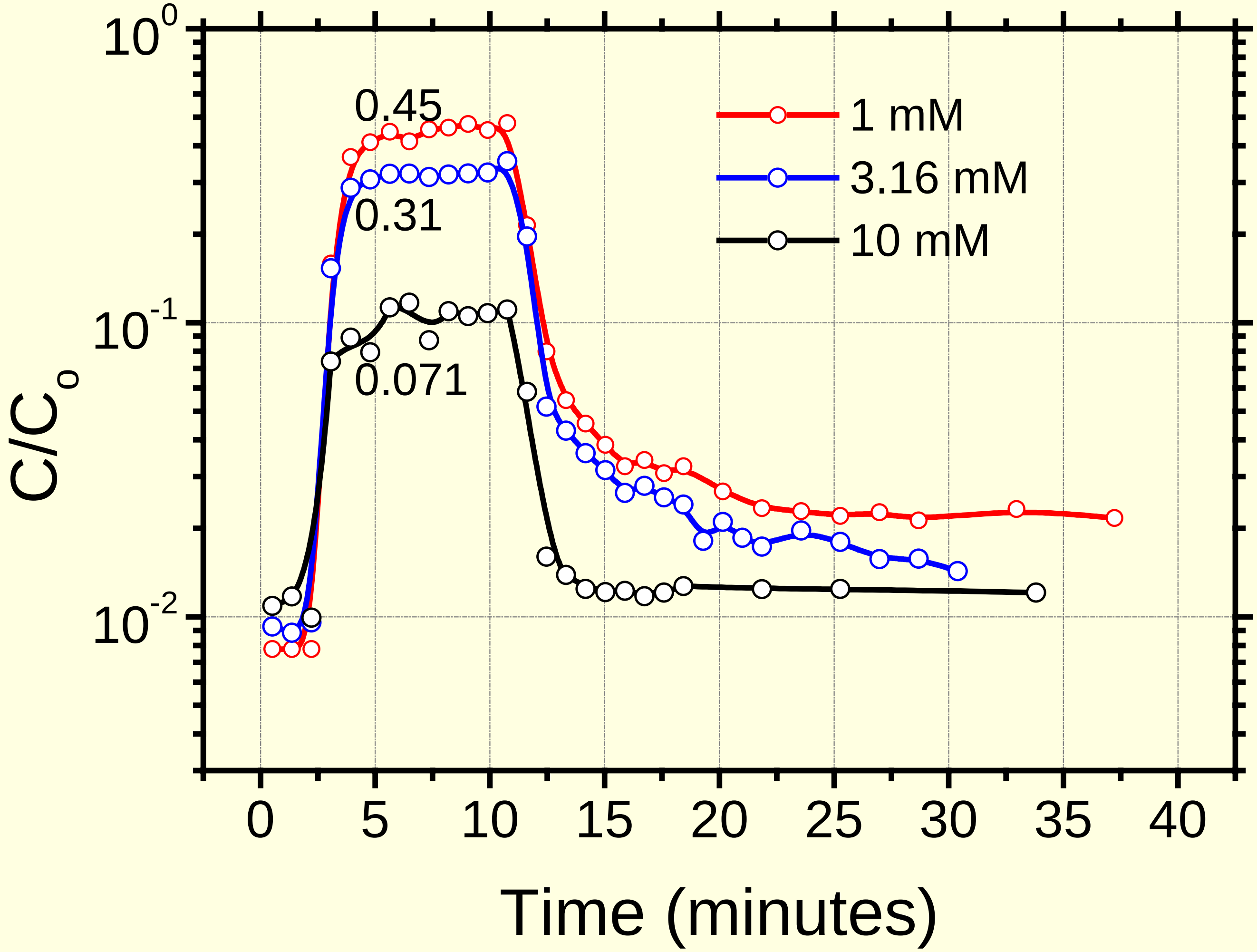
Column Experiments

- Oocysts



Column Experiments

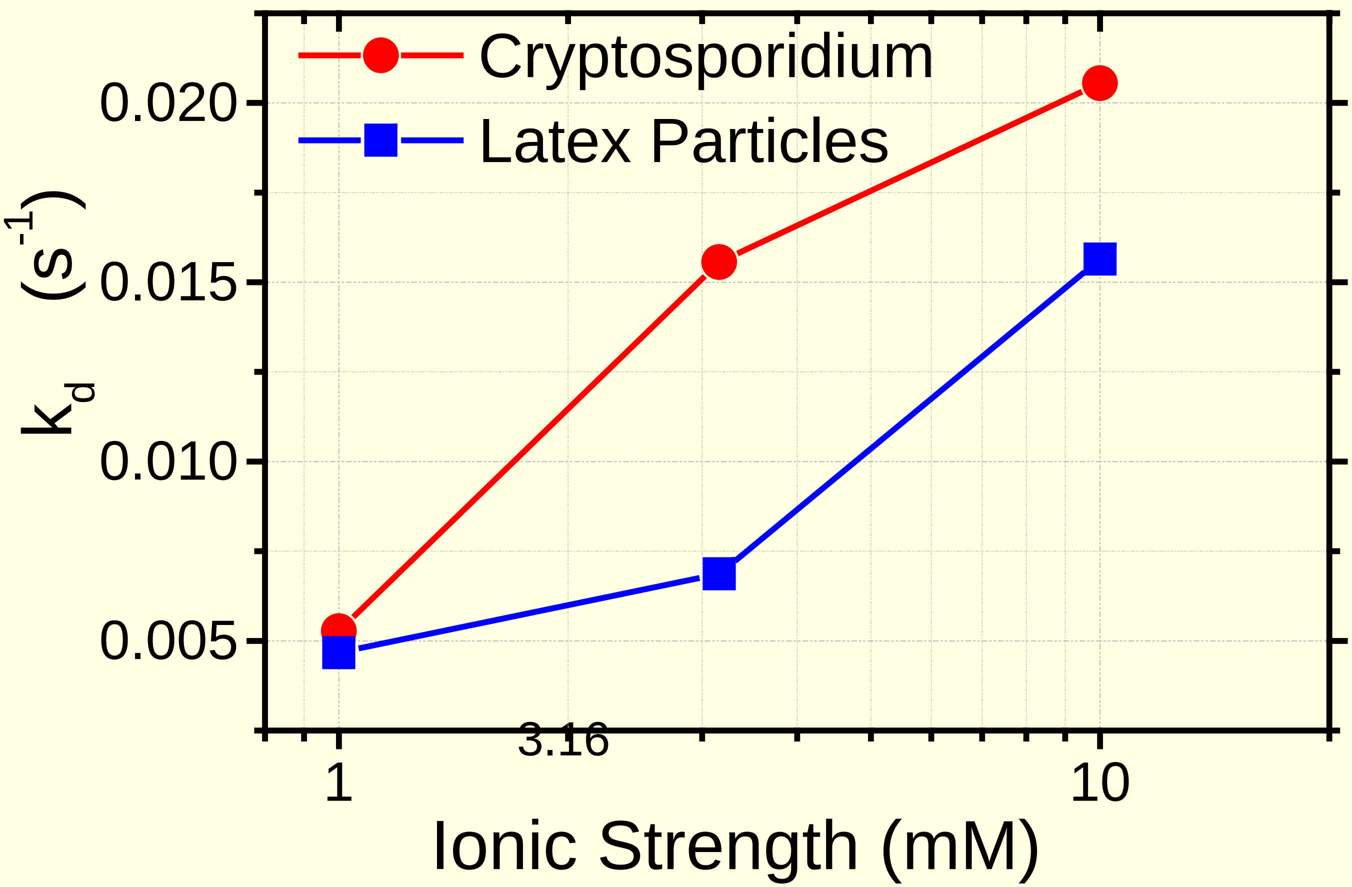
- Microspheres



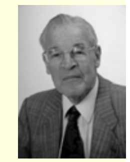
Column Experiments

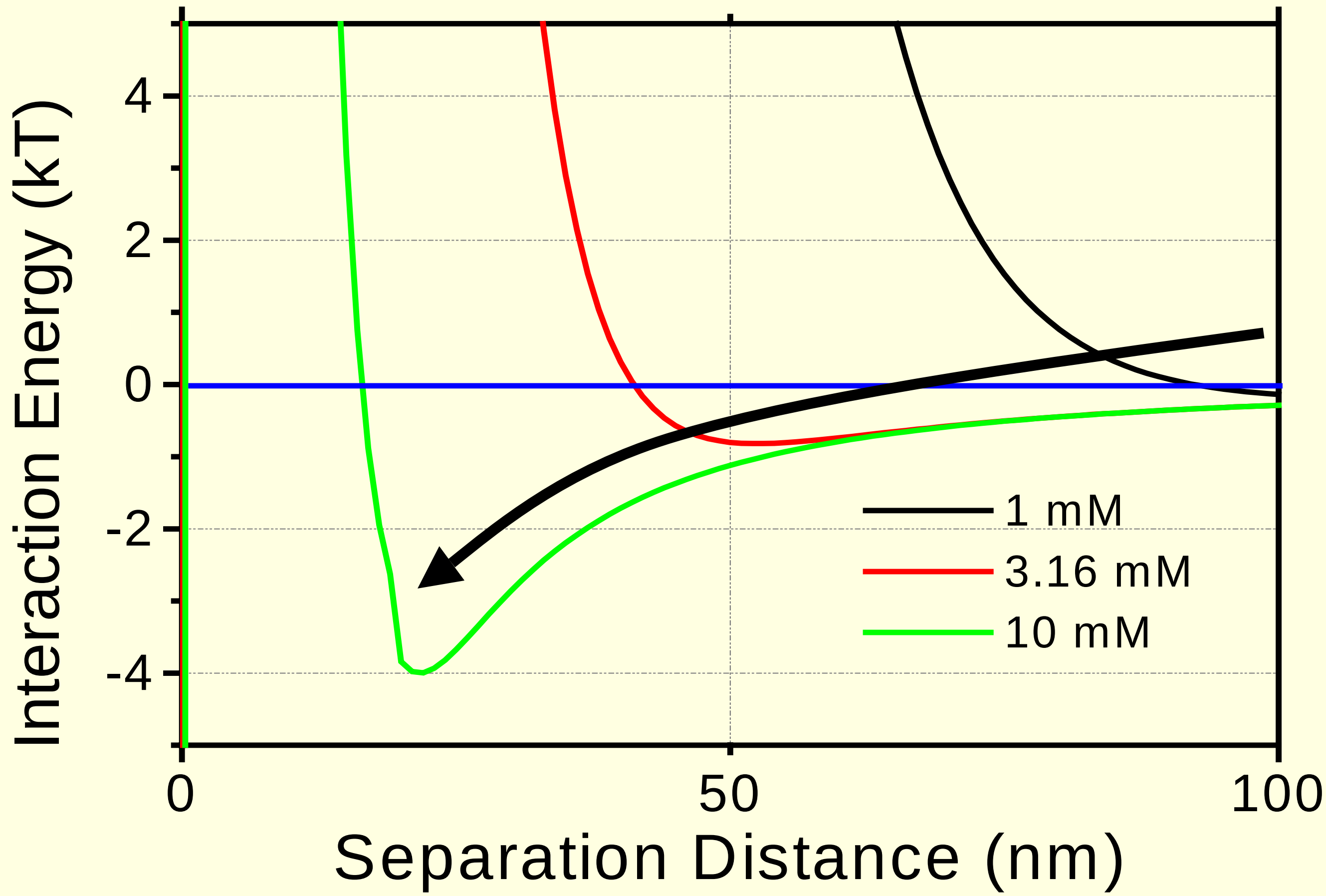
- Deposition rate coefficients

$$k_d = \ln\left(\frac{C}{C_0}\right)\frac{v}{\theta L}$$

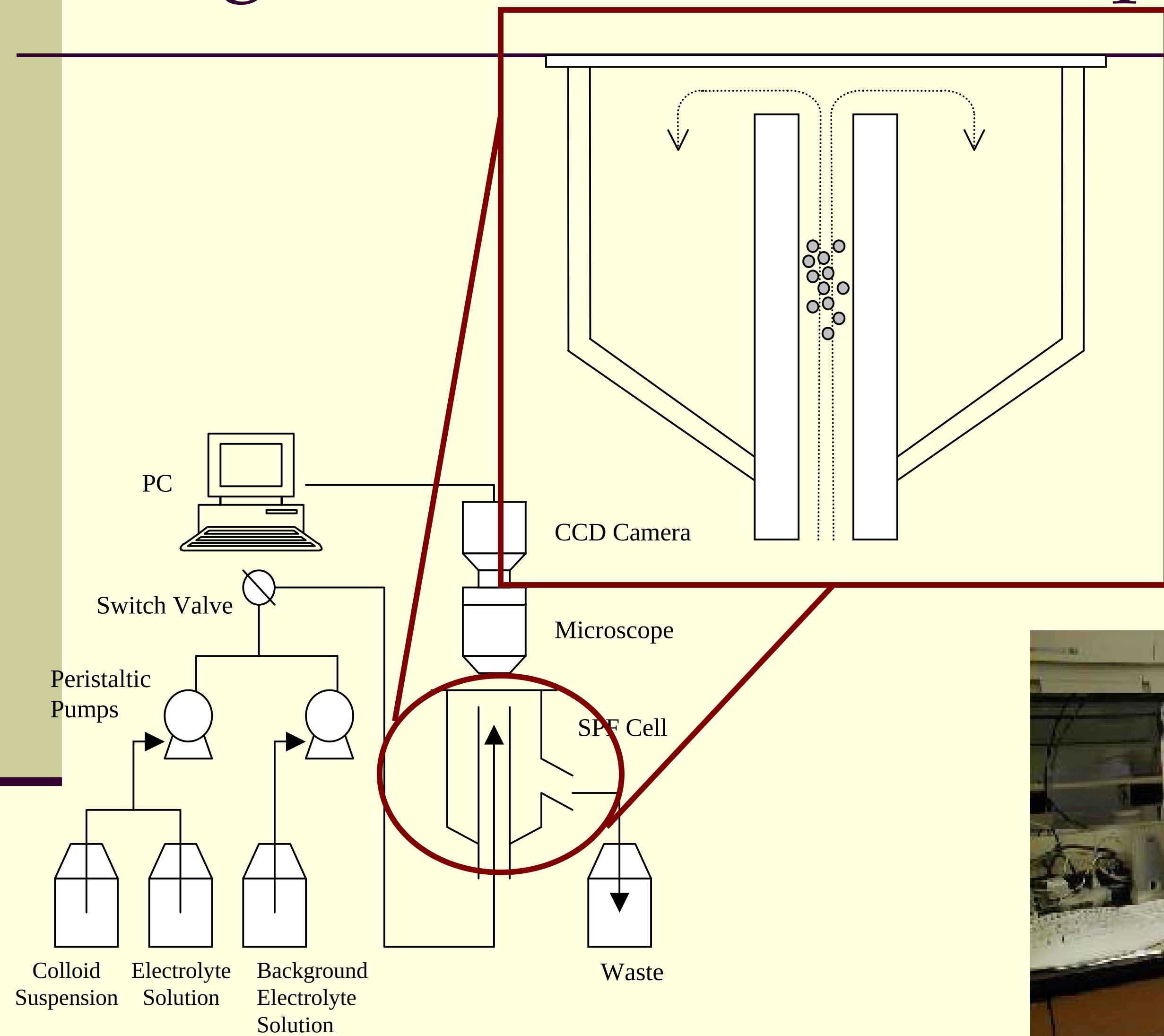


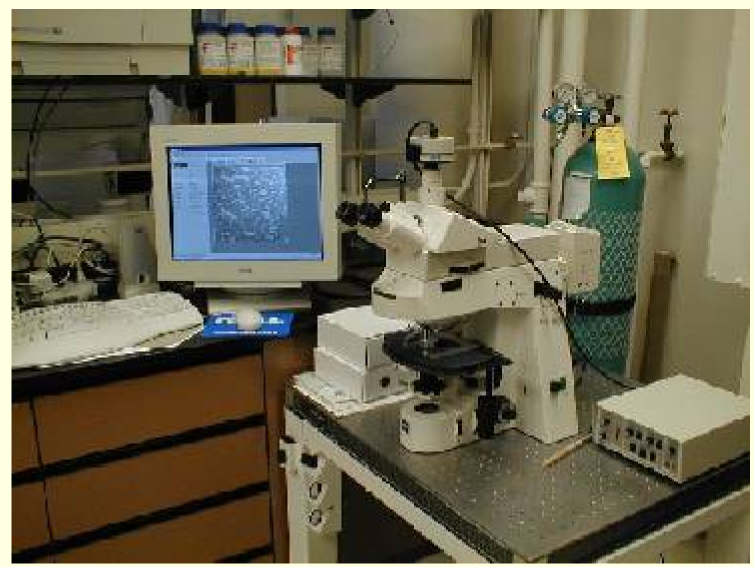
Column Experiments

- Effect of DLVO secondary minimum  V 

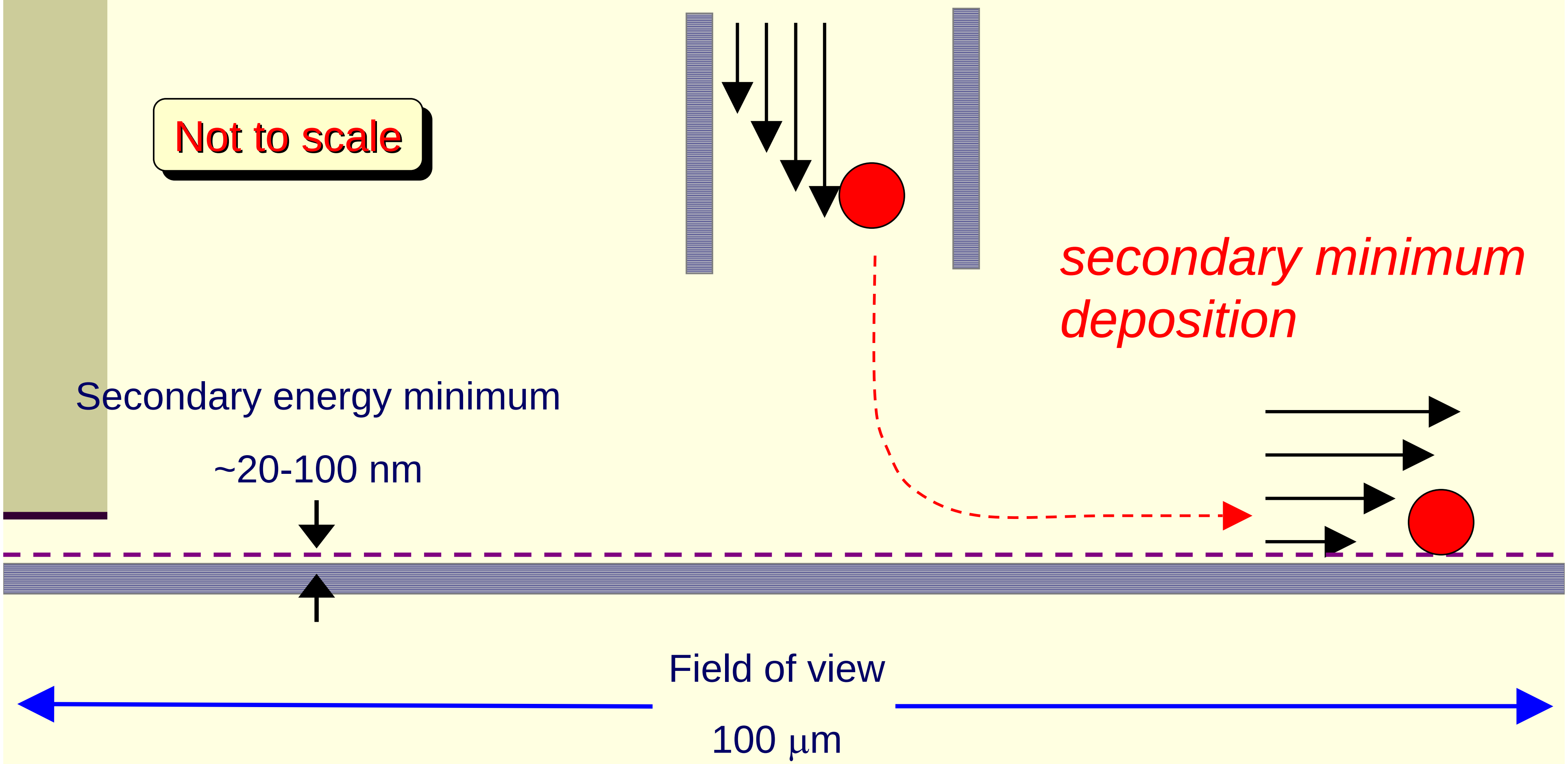


Stagnation Point Flow Experiments





Stagnation Point Flow Experiments



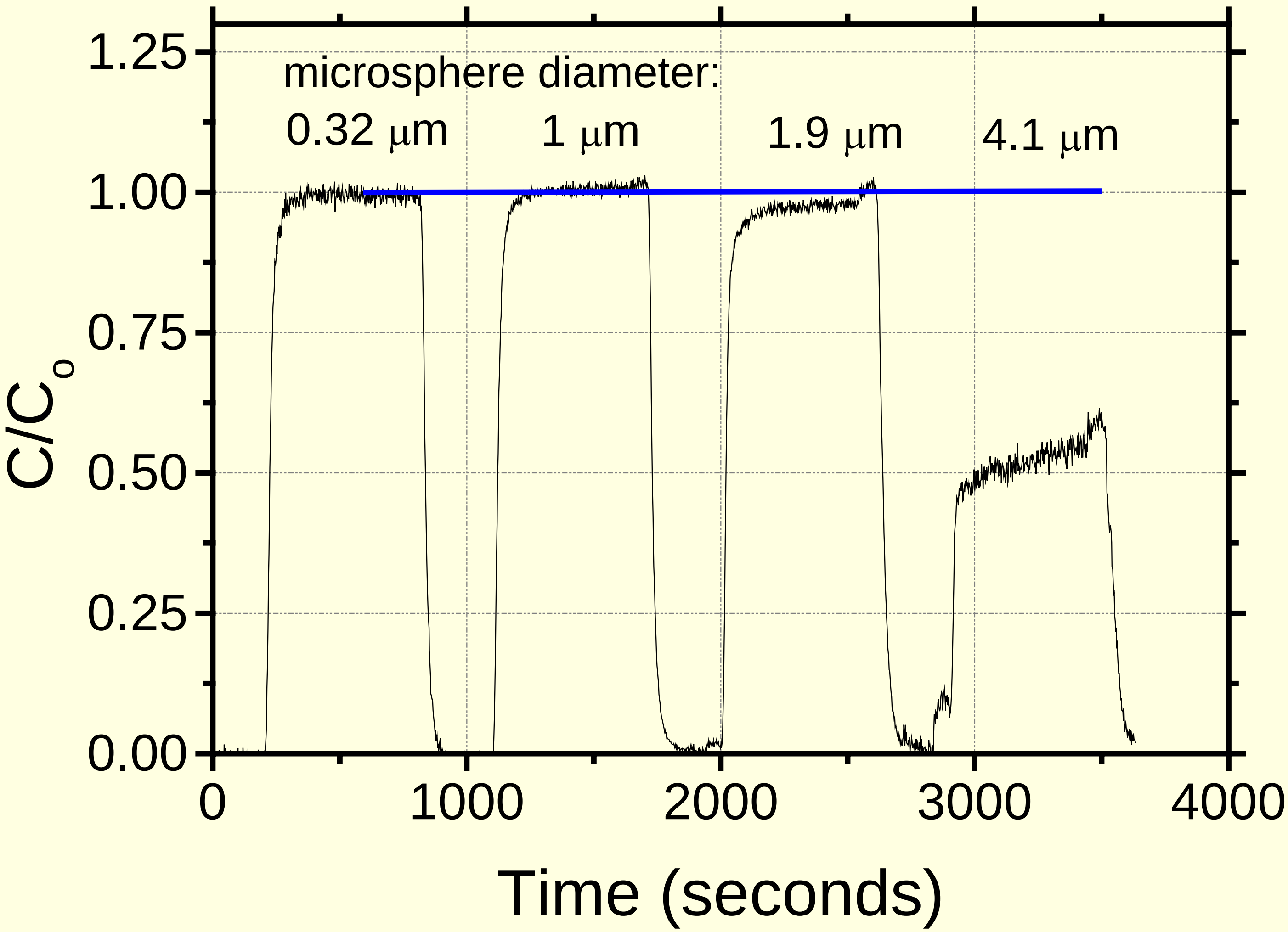
Stagnation Point Flow Experiments

- Oocyst deposition

ionic strength (mM)	measured deposition
1	0
3.16	0
10	0
100	0

Column Experiments

- Straining



Conclusions

- Heterogeneity
  - physical > geochemical
    (grain size) (surface charge)
- Ionic strength
  - oocyst deposition depends on ionic strength
- Secondary minimum
  - oocyst deposition occurring in secondary minimum
- Surrogate
  - microsphere transport similar to oocyst
- Straining
  - significant process for ~4 μm particles in 210 μm sand

Acknowledgements

- U.S. Environmental Protection Agency

  This research is funded by U.S. EPA - Science To Achieve Results (STAR) Program

  Grant # R-82901001-0

- U.S. Department of Agriculture

- Jeremy Redman (Yale University)
- Nicole DeNovio, Christina Osborn, Amanda Peirce, Sara Reinsel, Alice Wood (University of Colorado)