Nanoparticle transport in heterogeneous column experiments: the use of magnetic techniques

Michael Riley and John Tellam

Publication:

Riley, M. S., Suttie, N., Stevenson, C. T., Tellam, J. H. (2019) in *Colloids and Surfaces A*

Masters projects:

Finlay Campbell; Yifei Gu; Richard Parkinson; Clare Williams; David Burns; Graham Phillips

EPSRC
Engineering and Physical Sciences Research Council

THE UNIVERSITY OF BIRMINGHAM

GQ 19
Groundwater Quality 2019

Engineered nanoparticles (ENPs) in groundwater

- ENPs present in many everyday products
- certain to transfer to groundwater
- concerns over potential toxicity

The challenge

Identification and quantification of processes governing ENP migration

Engineered nanoparticle transport in rock

Processes might include:

- Advection
- Dispersion
- Physical Straining
- Attachment (irreversible)
- Attachment (reversible)

Potential model parameters:

- Effective porosity
- Dispersivity
- Straining coefficients
- Attachment rates
- Detachment rates
- Attachment capacities

Column experiments

Problems

- Non-unique parameter sets for a mathematical model (model equivalence)
- Many alternative mathematical models
- Heterogeneity of attachment processes

Magnetic Susceptibility Monitoring and Modelling (MSMM)

- Non-invasive system for monitoring and modelling column experiments

  → Multiple “breakthrough curves” within the column

- Magnetic particles

- A model fitting technique

- Imaging potential

Magnetic susceptibility

$$\text{Volume susceptibility } (\chi_v \text{ or } \kappa) = \frac{\text{Magnetisation}}{\text{Strength of applied field}} \quad \text{[Dimensionless]}$$

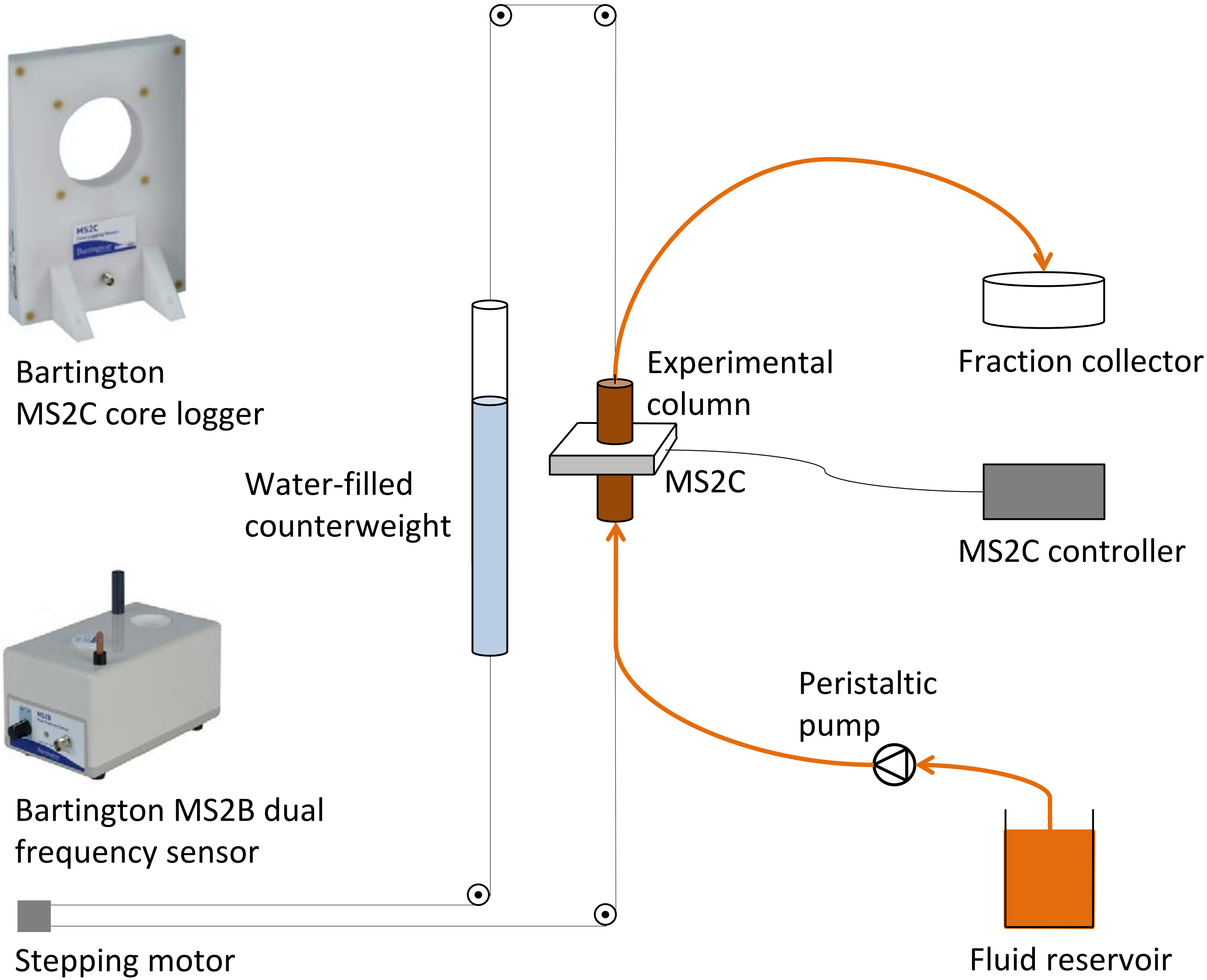
Sufficiently small magnetite NPs are *superparamagnetic*

In randomly arranged groups of identical superparmagnetic NPs, the net susceptibility is proportional to the number of NPs present

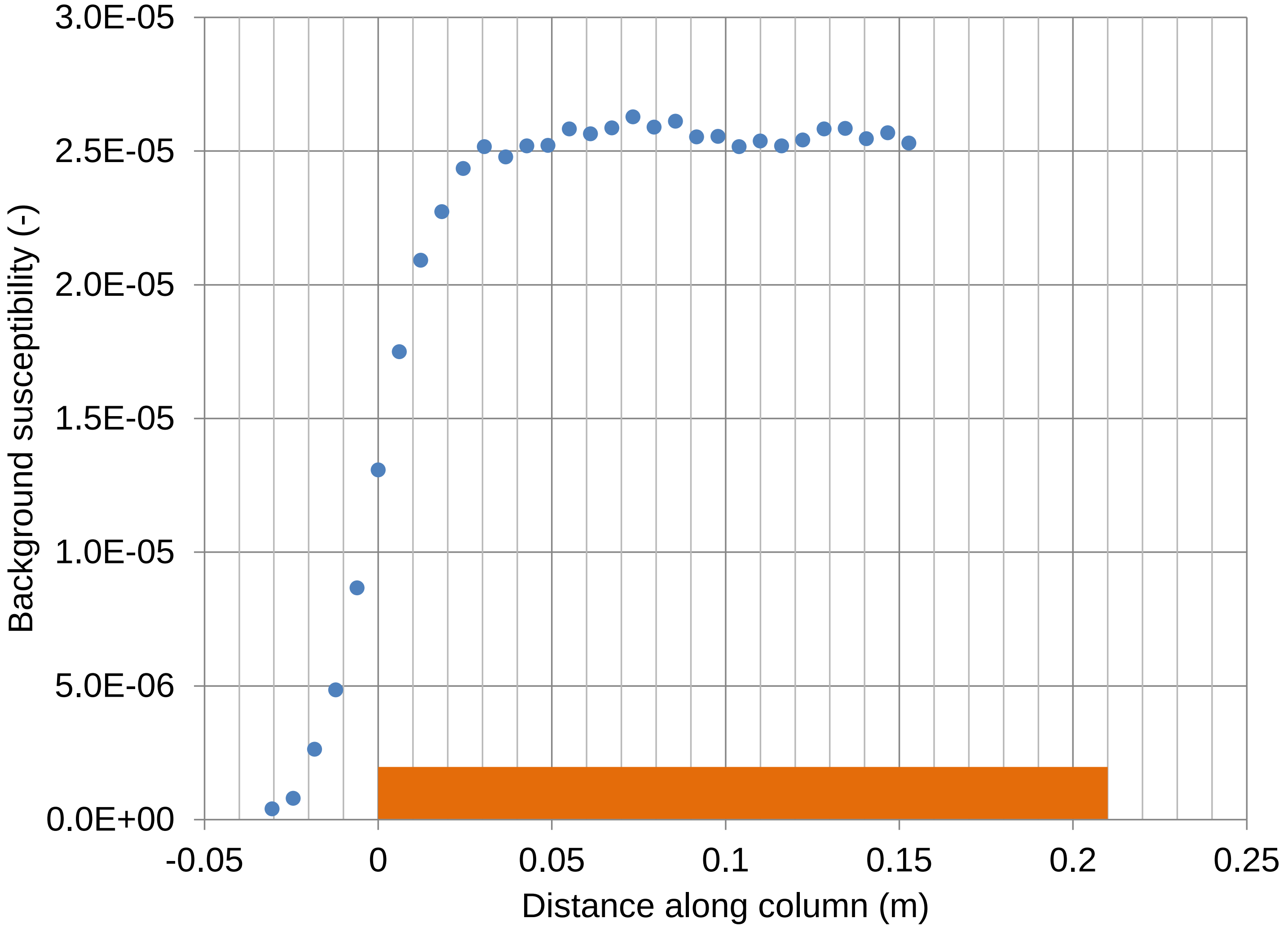
BUT

The susceptibility of NPs in suspension is greater than that of NPs that are not free to rotate

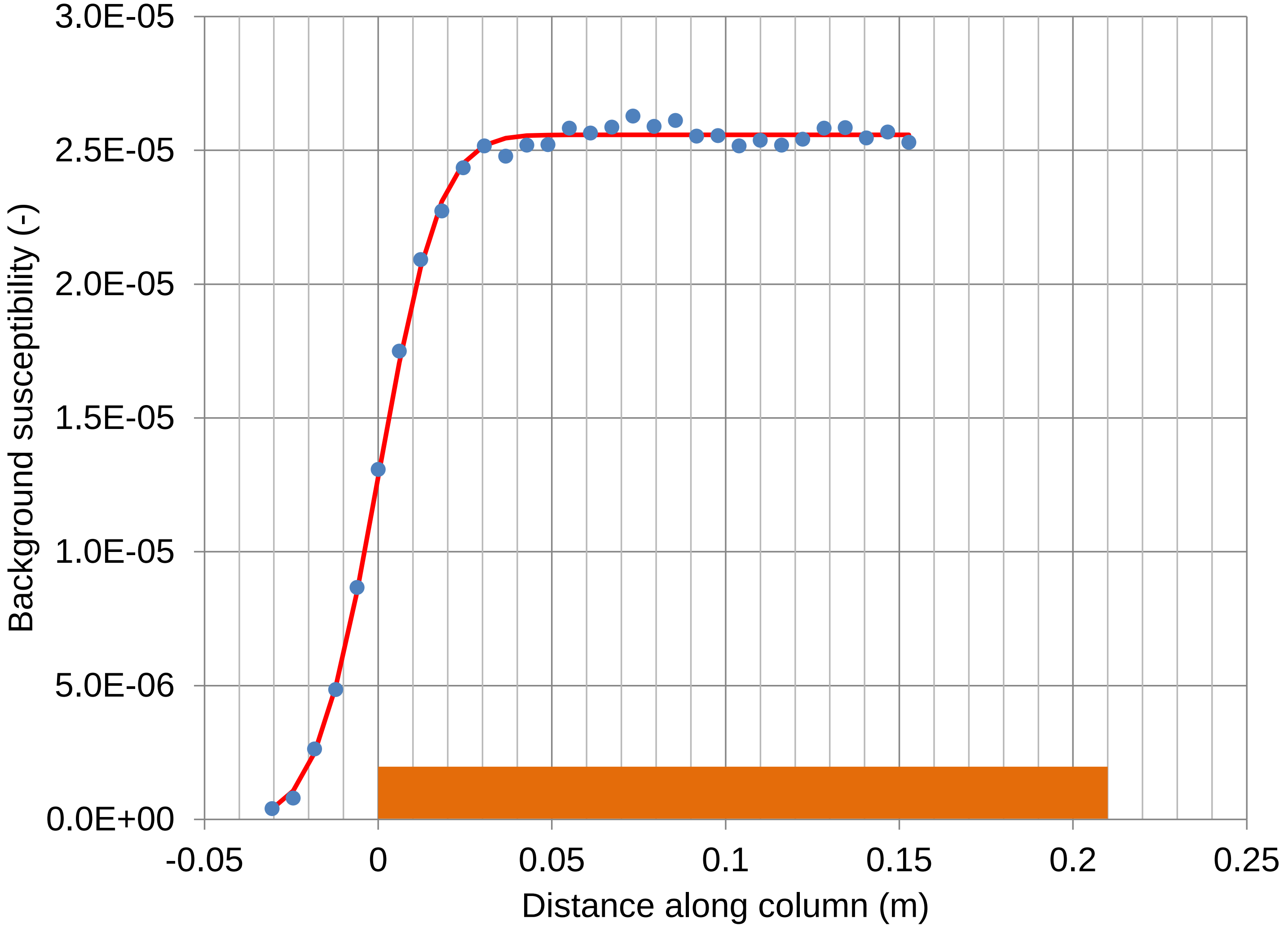
Experimental Rig



Instrument Response Function



Instrument Response Function

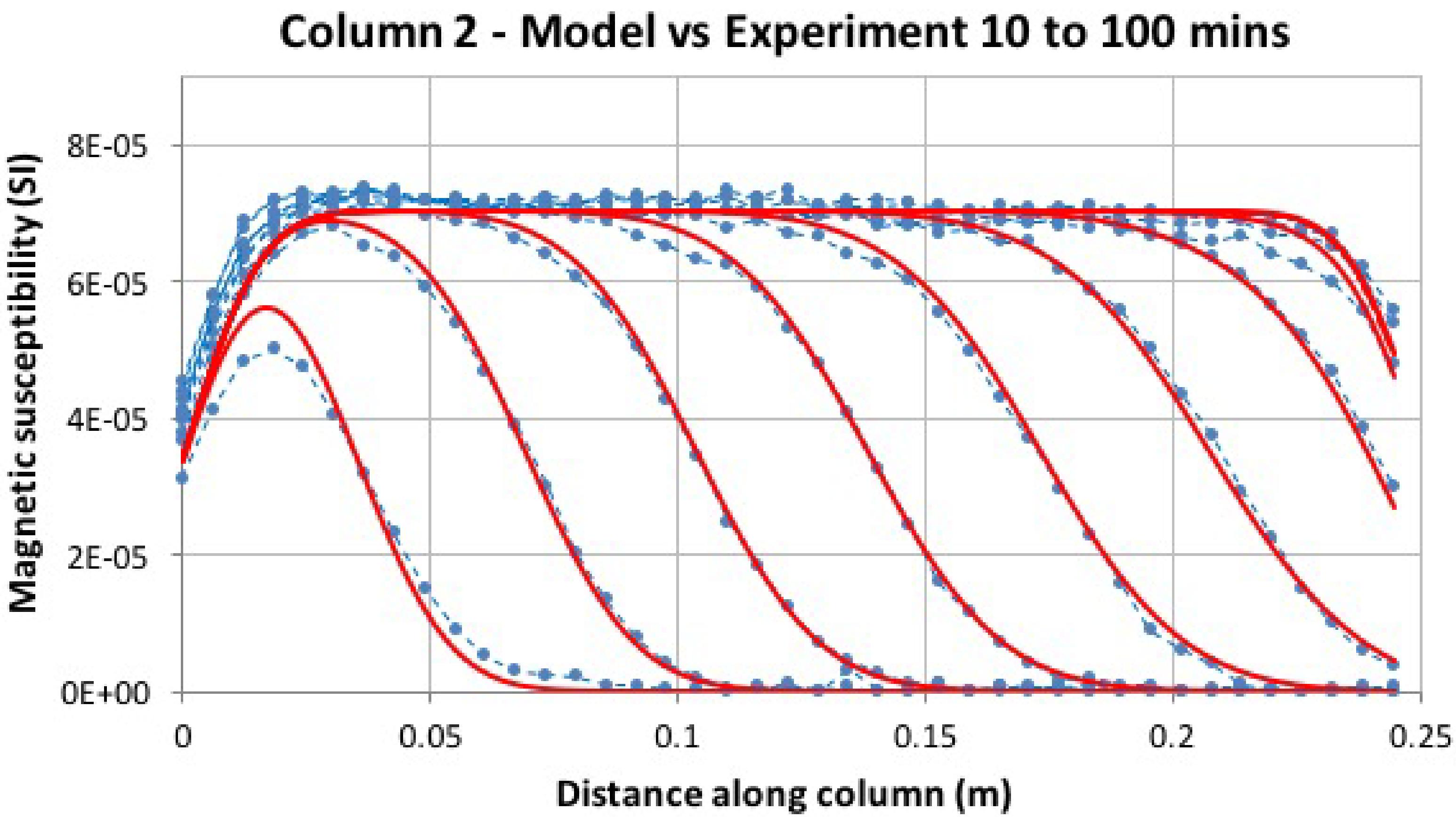


Modelling Strategy

- Select the mathematical model to be tested
- Simulate the transport experiment using the model
- Simulate the measurement process based upon the modelled concentrations
- Compare the results with the experimental data

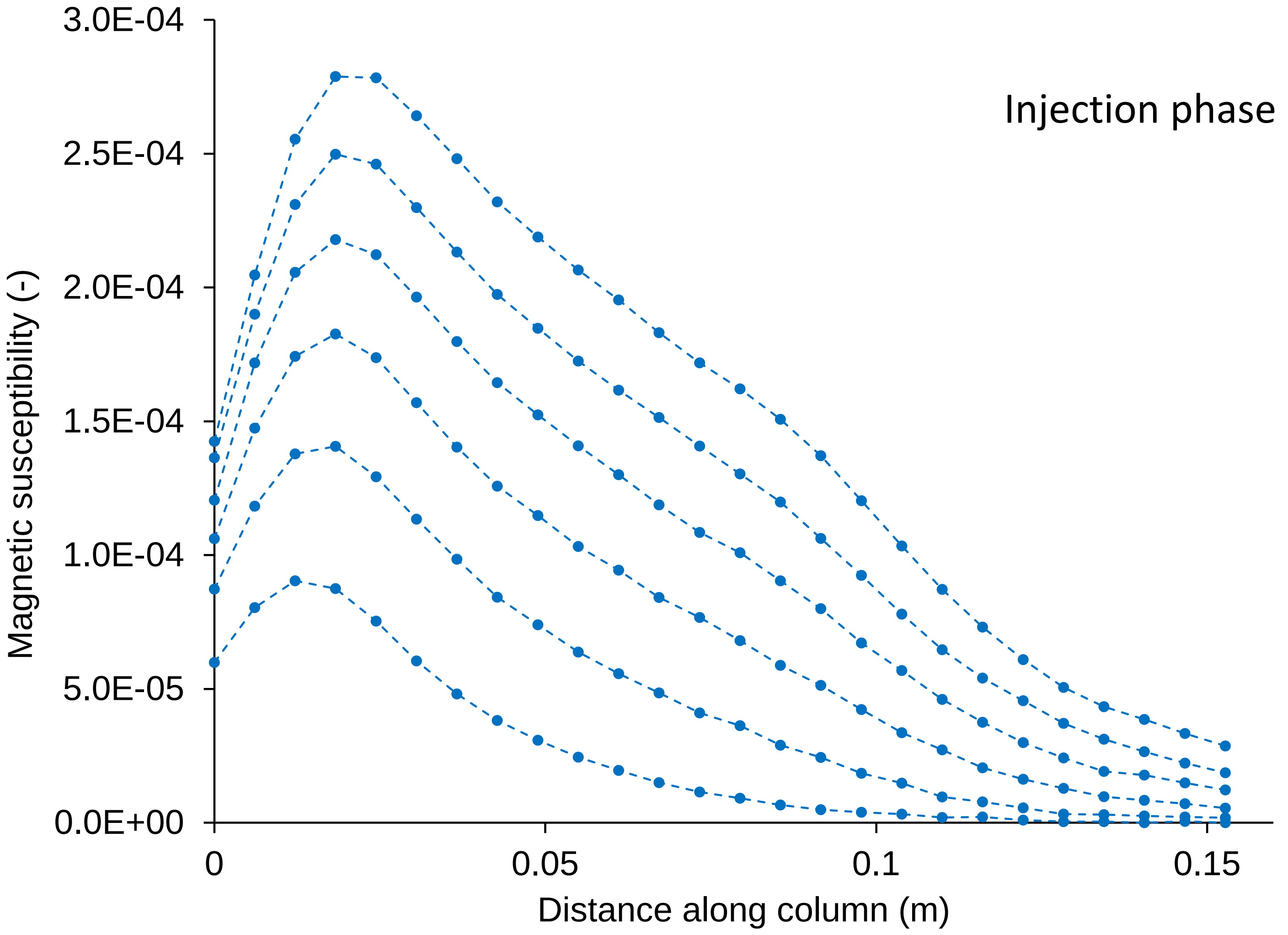
Homogeneous column – no particle retention

Injection phase (10 nm diameter magnetite ENPs)

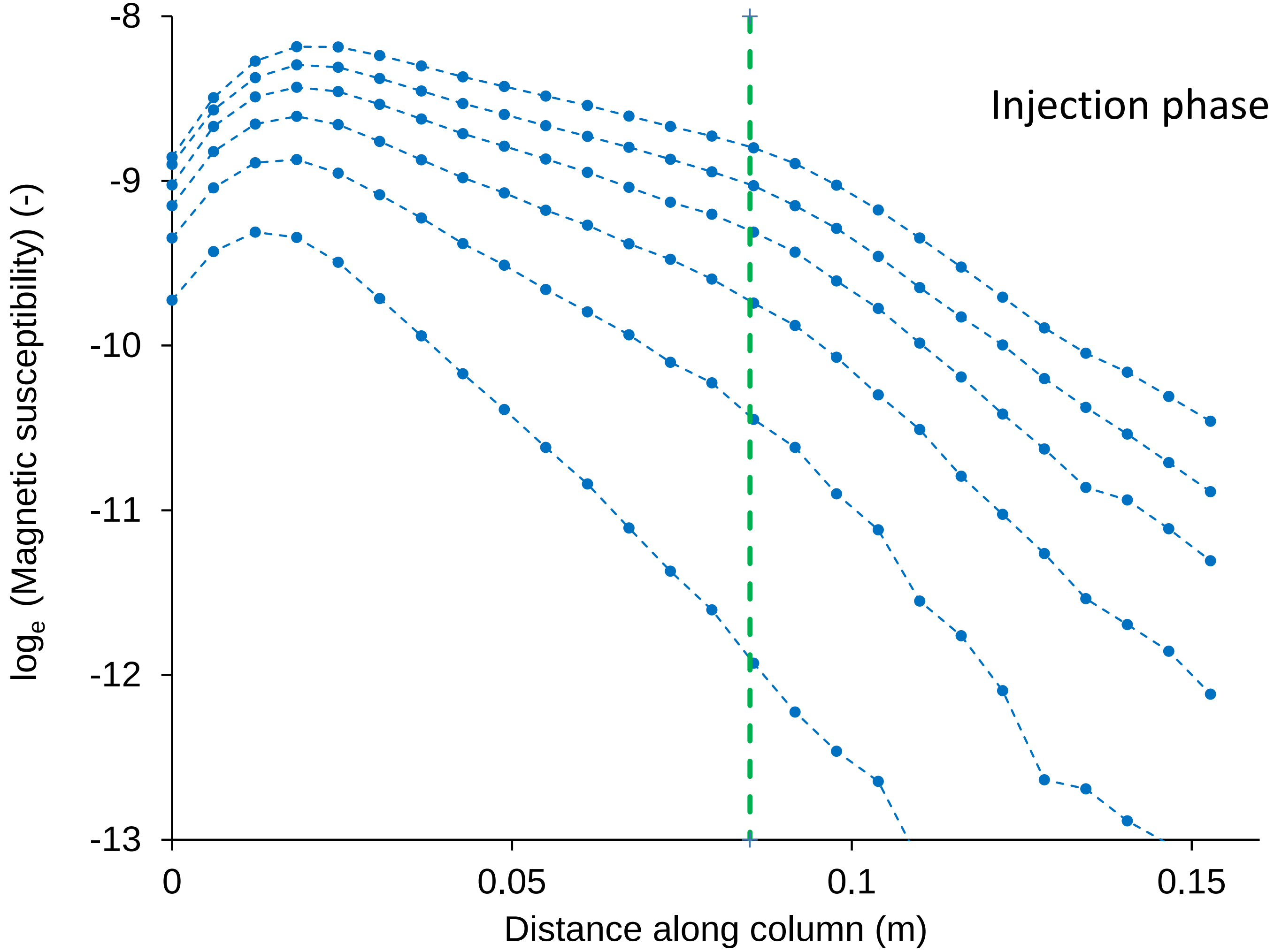


Measurements: Solid blue circles
Model: Red lines

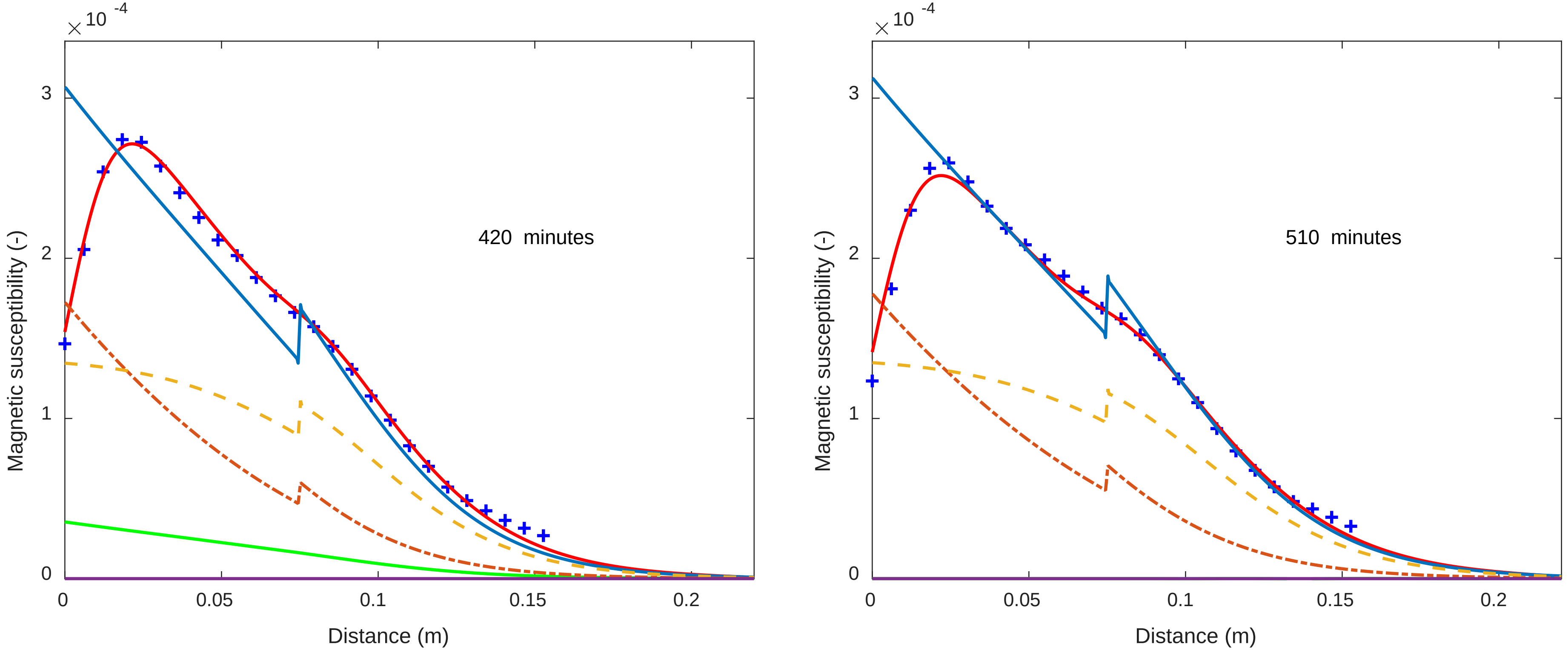
Complex column with strong particle retention



Complex column with strong particle retention

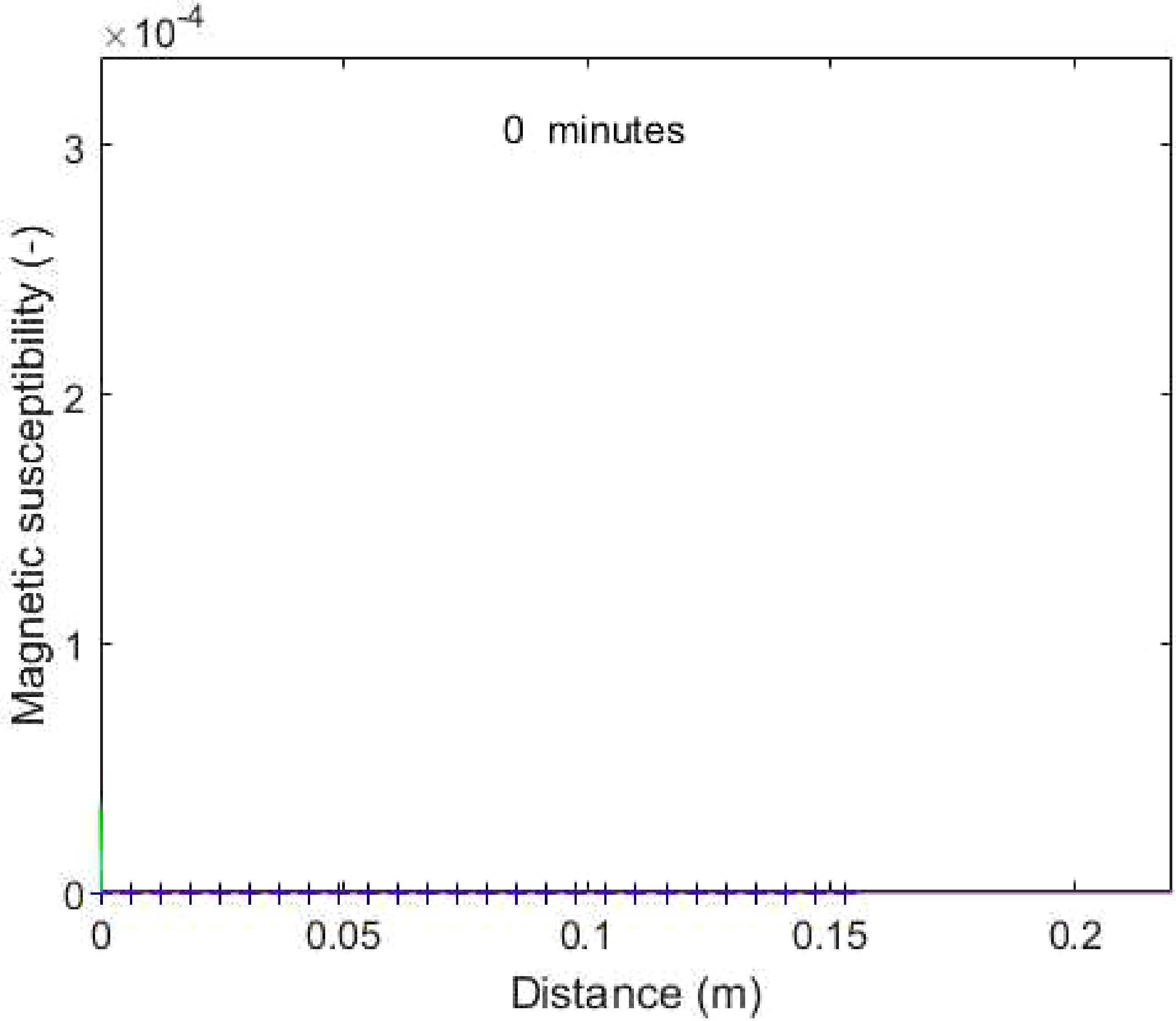


Complex column – strong particle retention



Measurements + + + + +
Modelled measurements
Fluid phase
Strained phase
Irreversibly attached phase
Total of retained phases

Complex column – strong particle retention



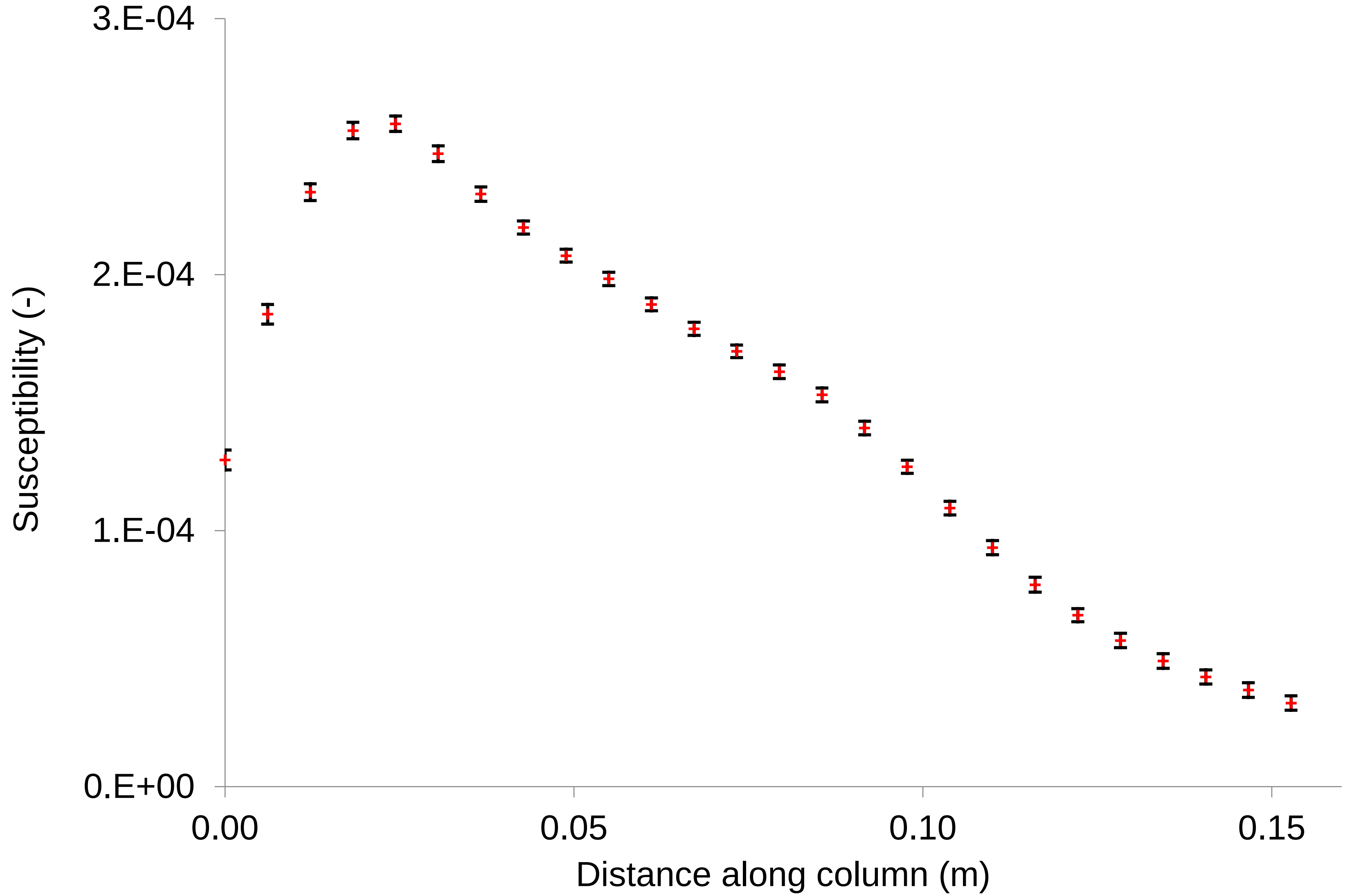
Summary

Magnetic susceptibility monitoring and modelling allows us to “look inside” an experimental column, which

- produces exceptionally large data sets

and has the potential to:

- reduce the problem of model equivalence
- identify column heterogeneity
- quantify processes in heterogeneous columns



3.E-04
2.E-04
1.E-04
0.E+00
Susceptibility (-)
0.00
0.05
0.10
0.15
Distance along column (m)