Saturations of Migrating Buoyant Fluids from Invasion Percolation Flow Simulation Using Small-Scale, High-Resolution Geologic Models With Realistic Heterogeneity*

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Search and Discovery Article #51409 (2017)**
Posted August 7, 2017

*Adapted from oral presentation given at AAPG 2017 Annual Convention and Exhibition, Houston, Texas, April 2-5, 2017

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Abstract

This study addresses the influence of lithologic heterogeneity at the sub-meter scale on the flow of buoyant fluids for different types of clastic sedimentary architectures from representative depositional environments. To adequately represent 3D heterogeneity, we present innovative techniques for generating digital models that combine a well-documented deterministic and descriptive bedform architecture component mimicking realistic crossbedding geometries with stochastic variability of petrophysical properties. One advantage of this approach is that it allows consideration of domain sizes larger than whole core and core plugs typically used for laboratory flow experiments, where small sizes may not fully capture depositional architecture. The main contribution of this study is the development of a predictive model for saturation estimation based on a comprehensive, yet simplified, set of geological models resembling a range of well-characterized and documented fluvial clastic facies. Basic geological features such as grain size distribution and sedimentary bedform architecture can be used to predict the fluid saturation during capillary/buoyancy-dominated flow conditions. These models are unique in regard to their geological realism and permit evaluation of the impact of sub-meter scale capillary heterogeneity on buoyant fluid flow scenarios that are relevant to petroleum migration, residual saturations (ROZ), and CO_2 flow. The digital models themselves expand characterization opportunities using a number of methods, including upscaling, connectivity, and bulk property anisotropy. Saturation results from simulations of small-scale domains can be used to benchmark expected values in larger reservoir scale domains.

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Trevisan, L., R. Pini, A. Cihan, J.T. Birkholzer, Q. Zhou, A. González-Nicolás, and T.H. Illangasekare, 2017, Imaging and Quantification of Spreading and Trapping of Carbon Dioxide in Saline Aquifers Using Meter-Scale Laboratory Experiments: Water Resources Research, v. 53/1, p. 485-502.

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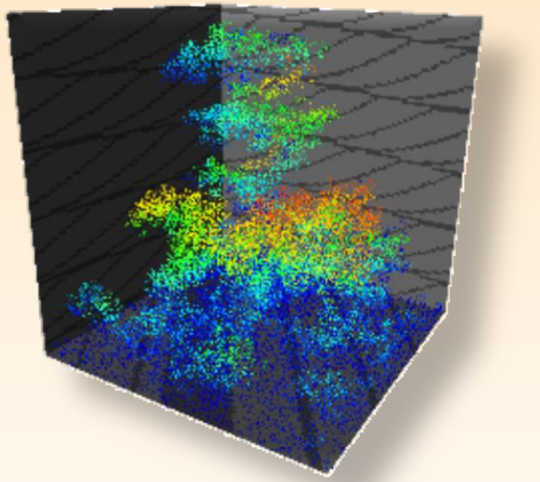

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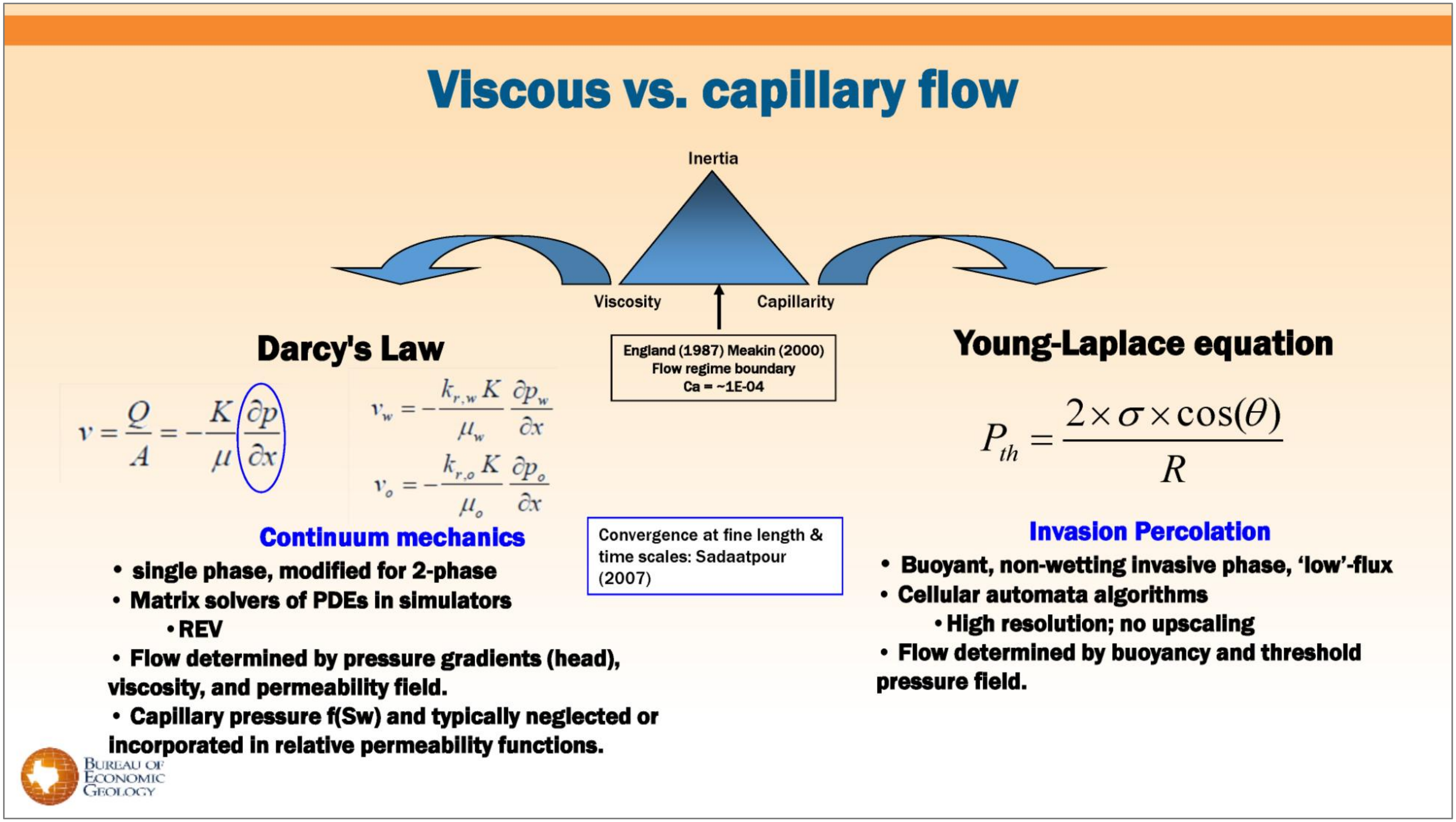
Acknowledgement is made to Landmark Software and Services, a Halliburton Company, for access to Permedia software.

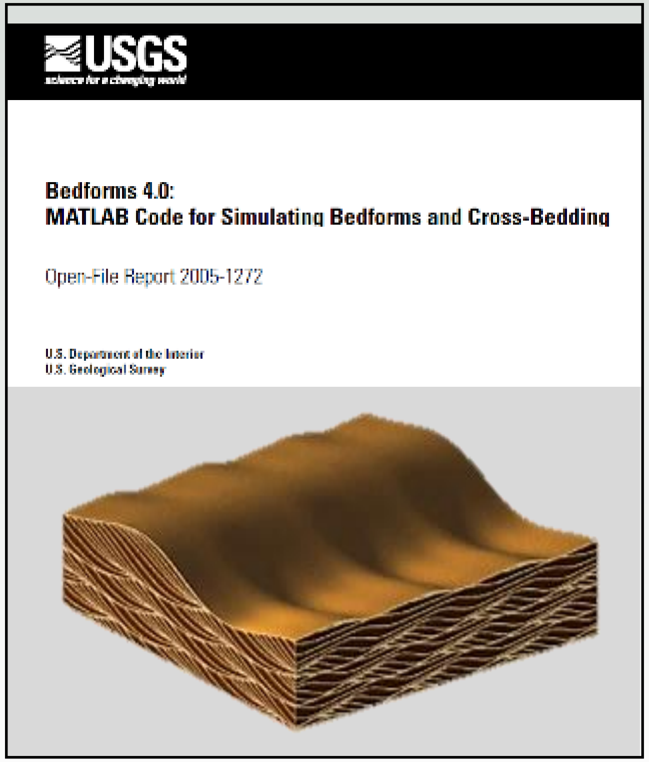
OBJECTIVES

- **Understand** the processes of capillary/buoyancy-dominated flow.
  - Hydrocarbon secondary migration; CO_2 injection; ROZ.
- **Quantify** the influence of meso-scale clastic heterogeneity on saturation.
- **Predict** saturations based on fundamental properties of geology and fluids.
  - Grain size distribution, sedimentary architecture, fluid density contrast

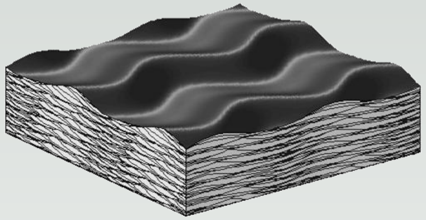


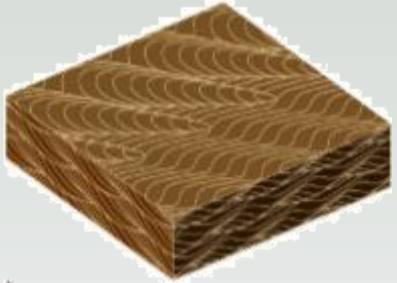
Presenter's notes: Forces controlling flow – triangle
High inertia = high reynold's number, non-laminar flow, Navier-Stokes approximations.
Bottom of triangle represents tow end members of viscosity and capillary dominated flow.
Transition from capillary to viscous around Ca ~ E-04 (England, 1987) – have more to say about Ca in next slide.
Go through two formalisms: different conceptualizations of important factors controlling flow at different scales – differ in importance put on capillary forces.
England cutoff: At E-04, capillary forces to viscous forces are 10,000:1; what is behind this cutoff??
For this reason, IP thought of as only representing 'slow' (i.e. migration) behavior.
Realistically, this flow can take place quite quickly as has been demonstrated in lab experiments.

Geologic Models with Realistic Heterogeneity

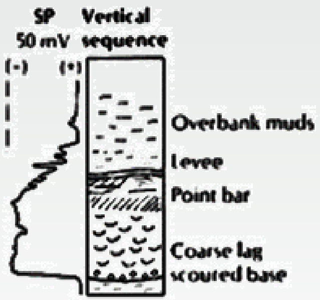


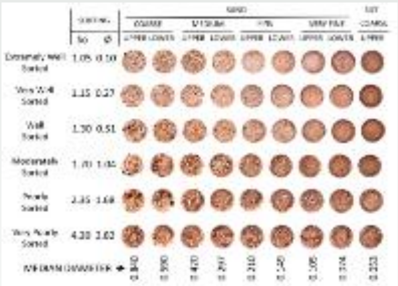
1) Generate 3D fabrics & Convert to 3D cellular cubes (binary).



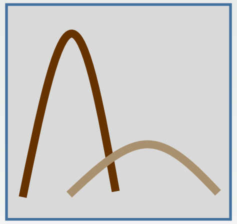


2) Assign facies: Pth distributions from facies 'library'





Pth Distributions



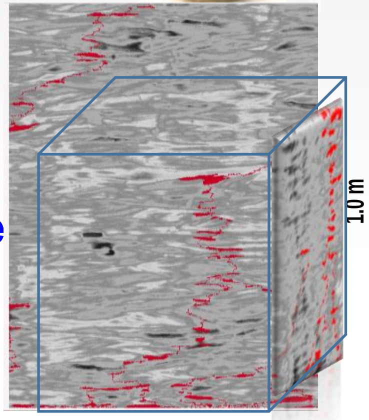
3) 3D IP flow simulation:

Threshold pressure range

Thousands of models simulate efficiently to define range of characteristic saturations.

6.1 kPa

8.9 kPa



Compare to Physical model results

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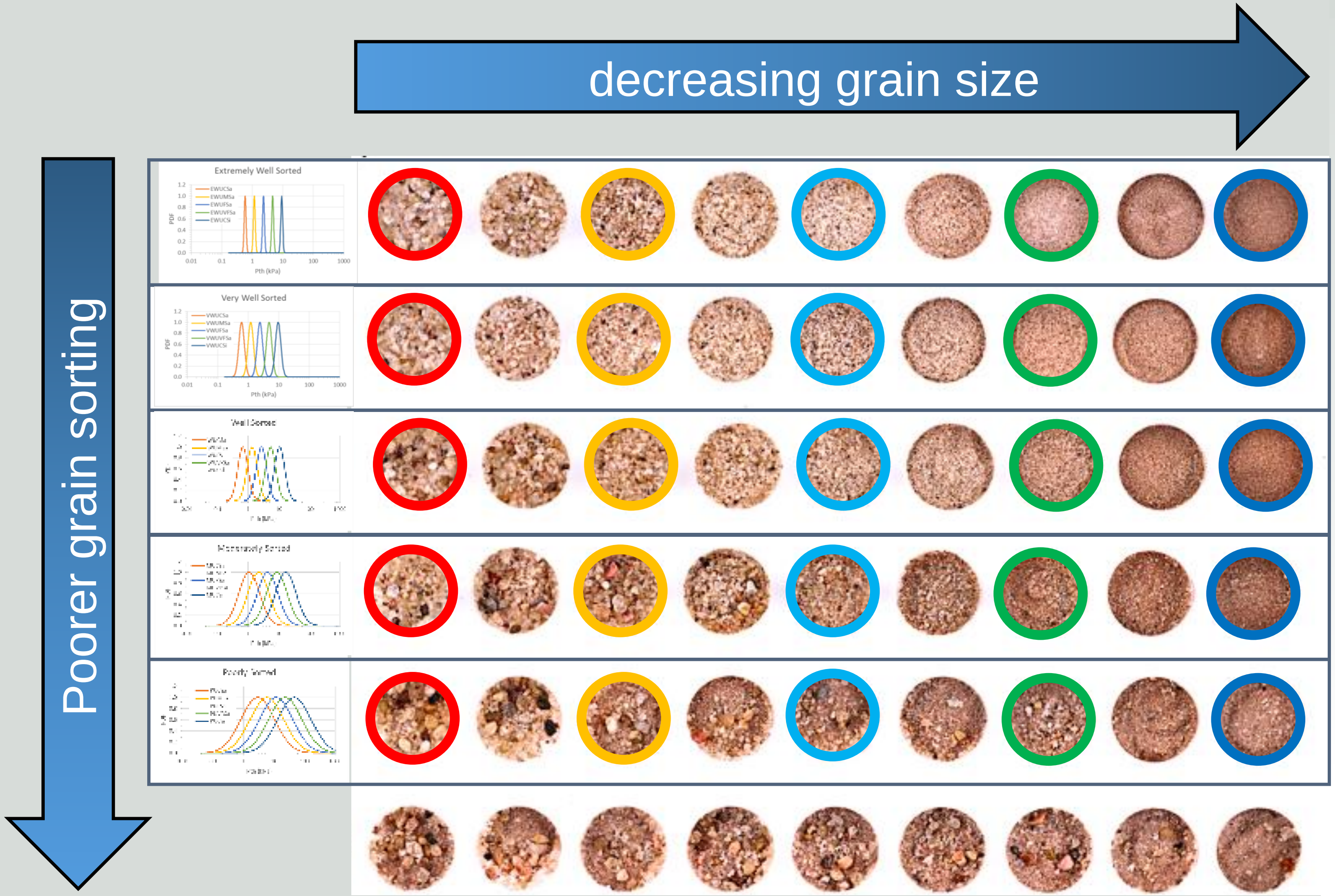
54 textural classes - 25 facies combinations



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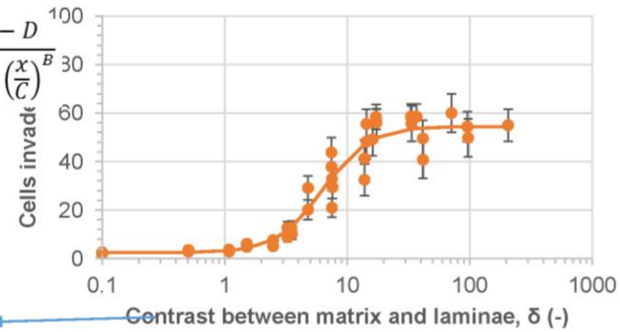
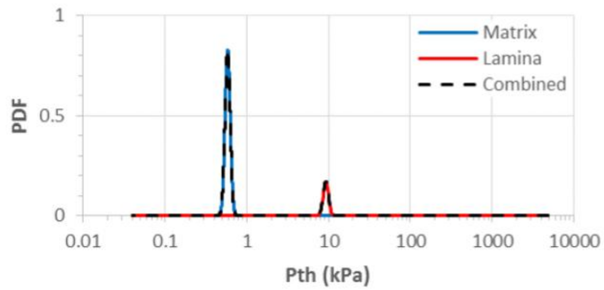
Impact of capillary heterogeneity and bedform architecture on fluid saturation

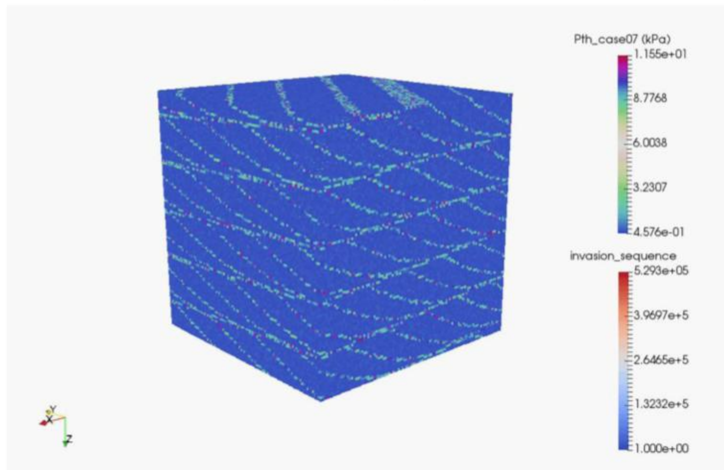
$$y = D + \frac{A - D}{1 + \left(\frac{x}{C}\right)^B}$$



$$\delta = \frac{|\mu_1 - \mu_2|}{\sigma}$$



Invasion Percolation (IP) simulations



Presenter's notes: Now I'm going to show simulation results of 7 cases with different textural contrasts for the same sedimentary model

Impact of 3D capillary heterogeneity and bedform architecture at the sub-meter scale on CO_2 saturation for buoyant flow in clastic aquifers

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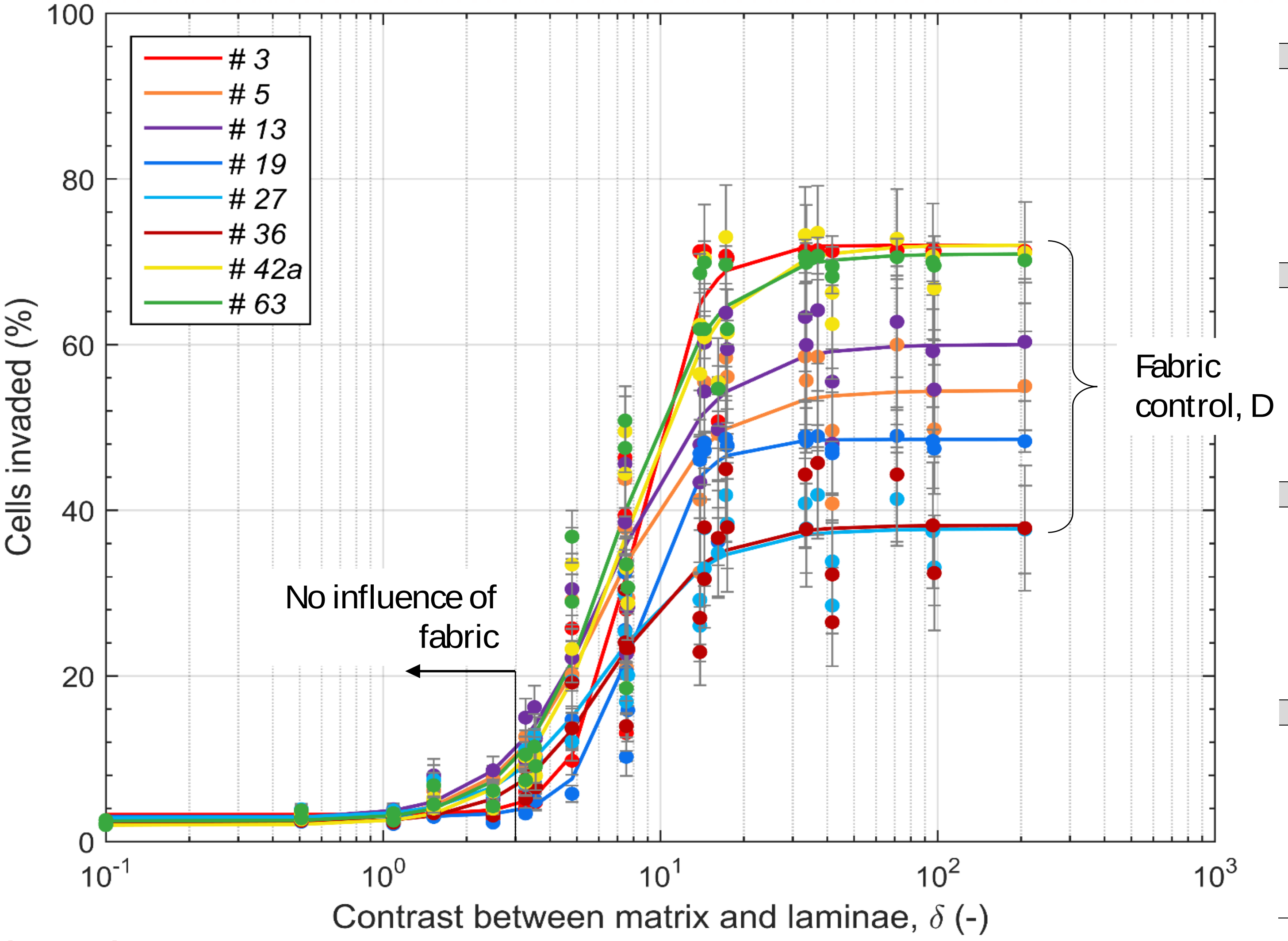
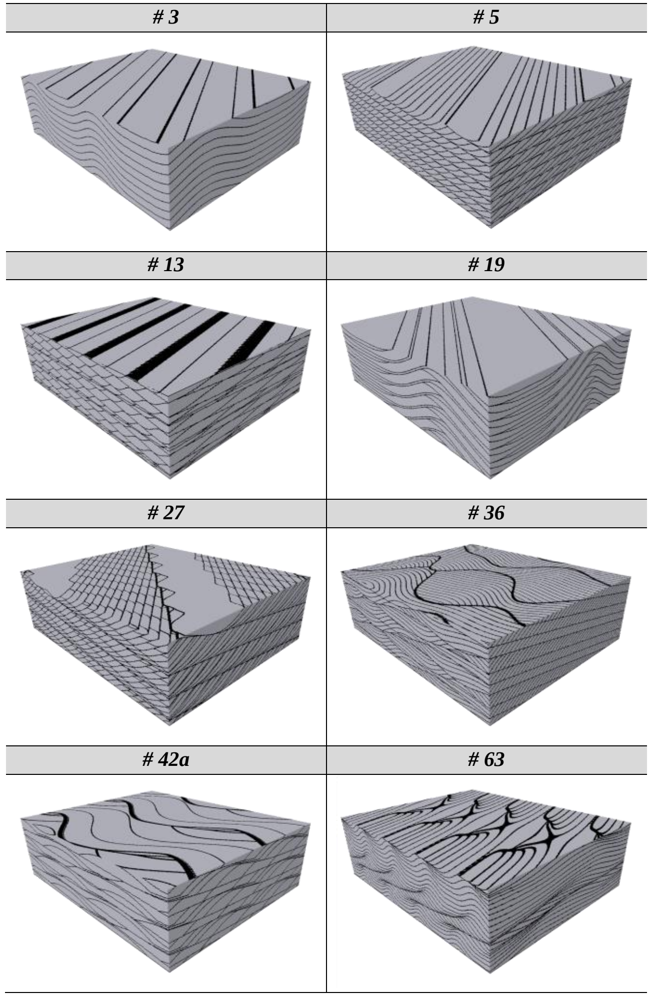
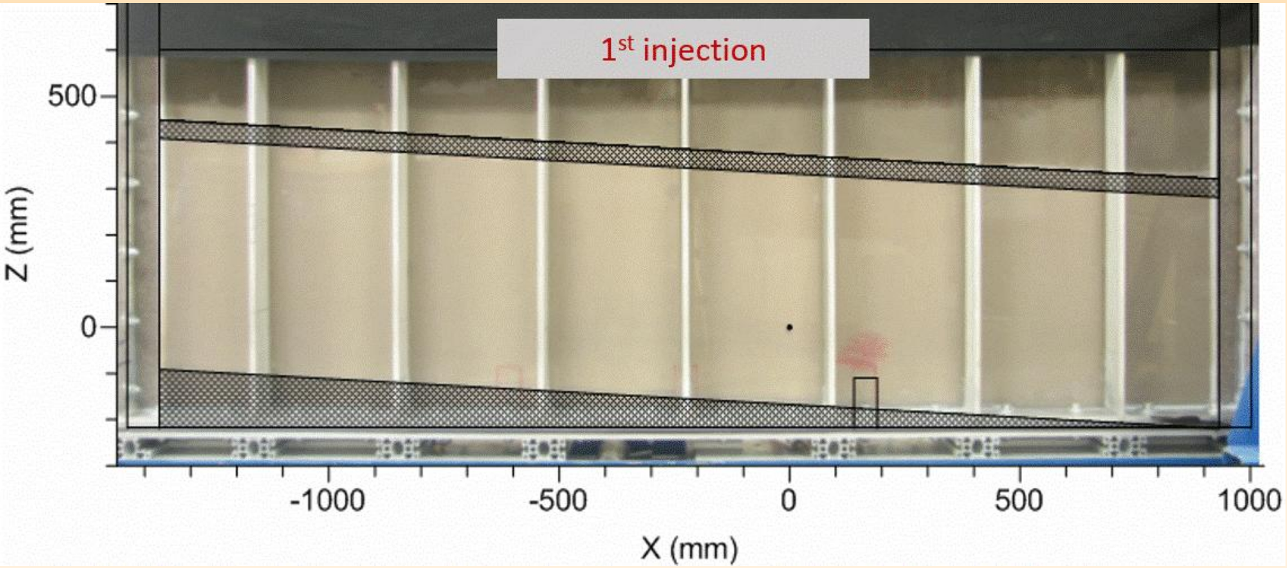


8 fluvial sedimentary models

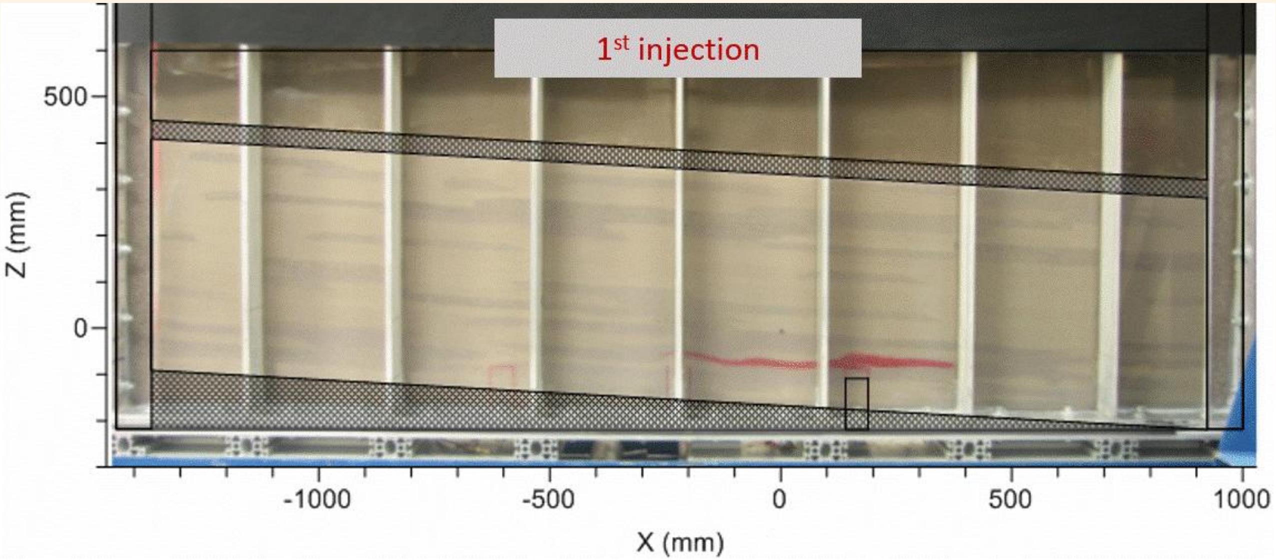


8 × 40 × 200 = 64,000 simulations

Meter-scale sand tank visualizations



homogeneous



heterogeneous

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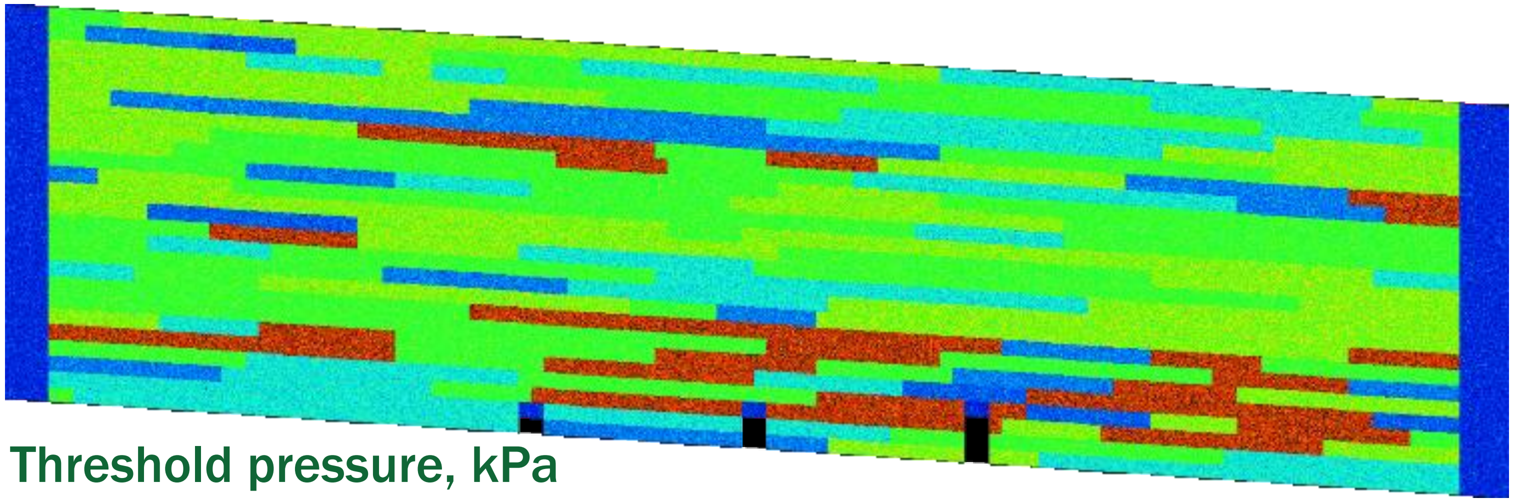
IP model of large heterogeneous sand tank

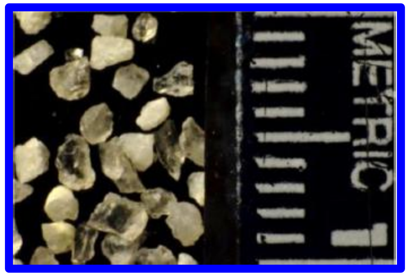


Hydrophilic silica sand: Granusil (angular)

Threshold pressure, kPa

0.05 1.5 2.1

#16



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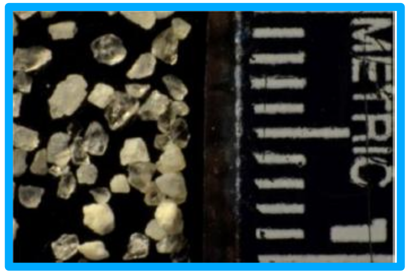

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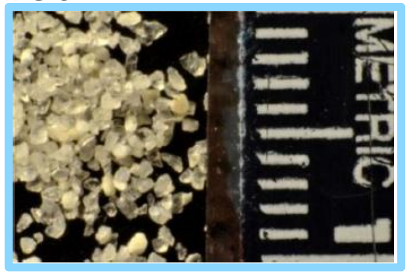

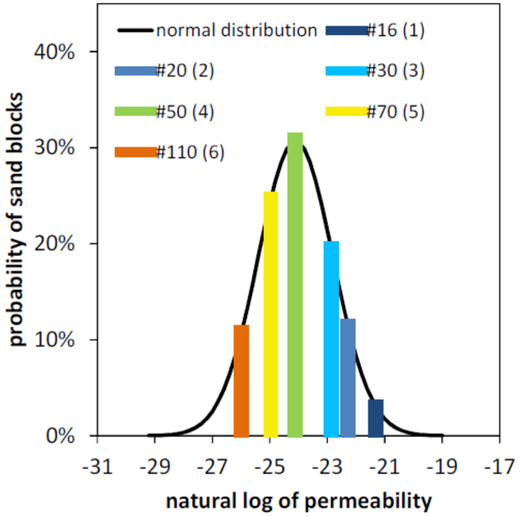

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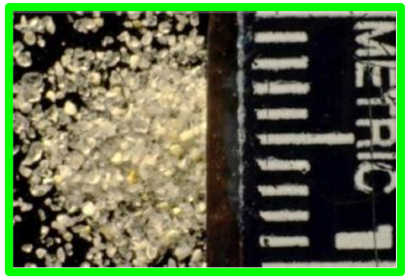

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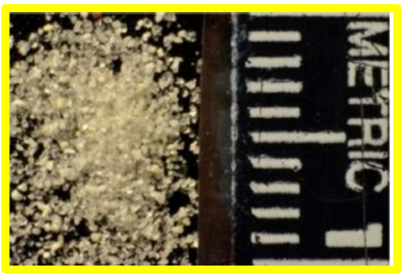

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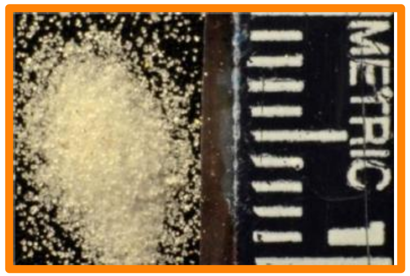
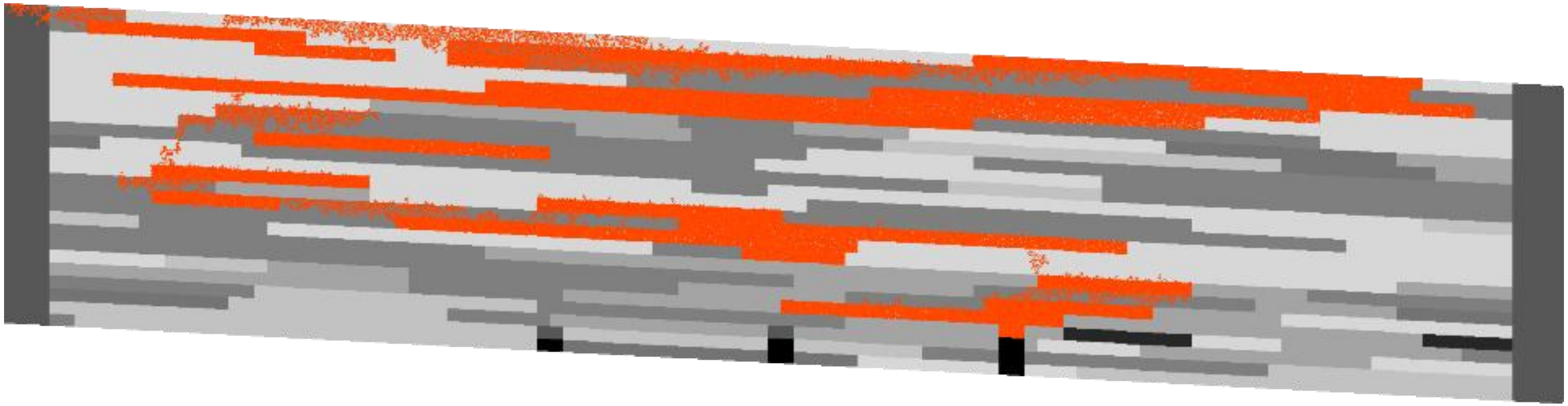
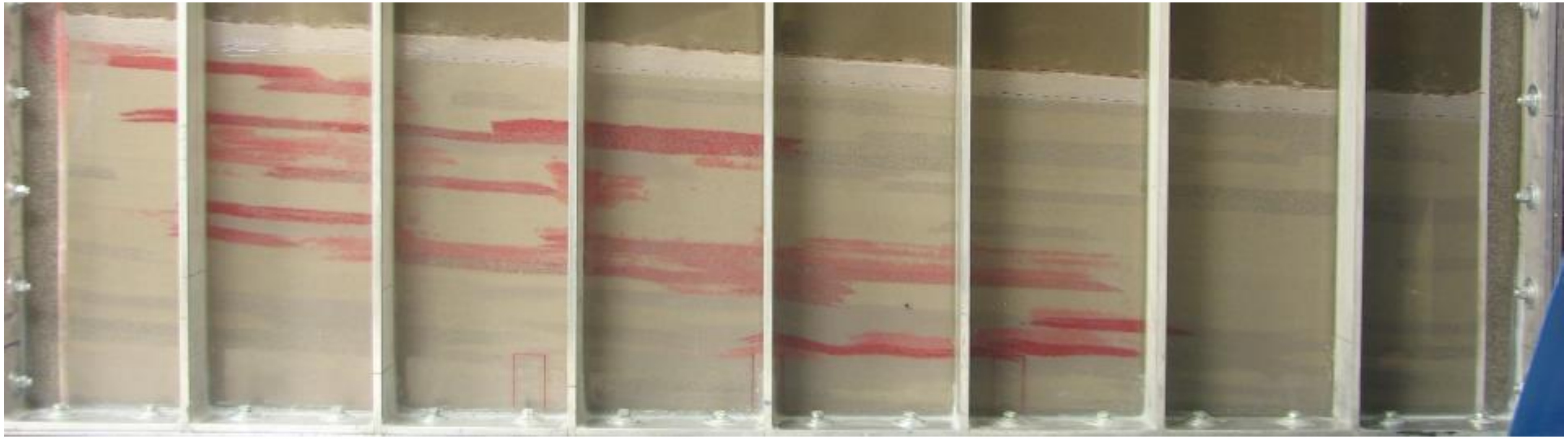
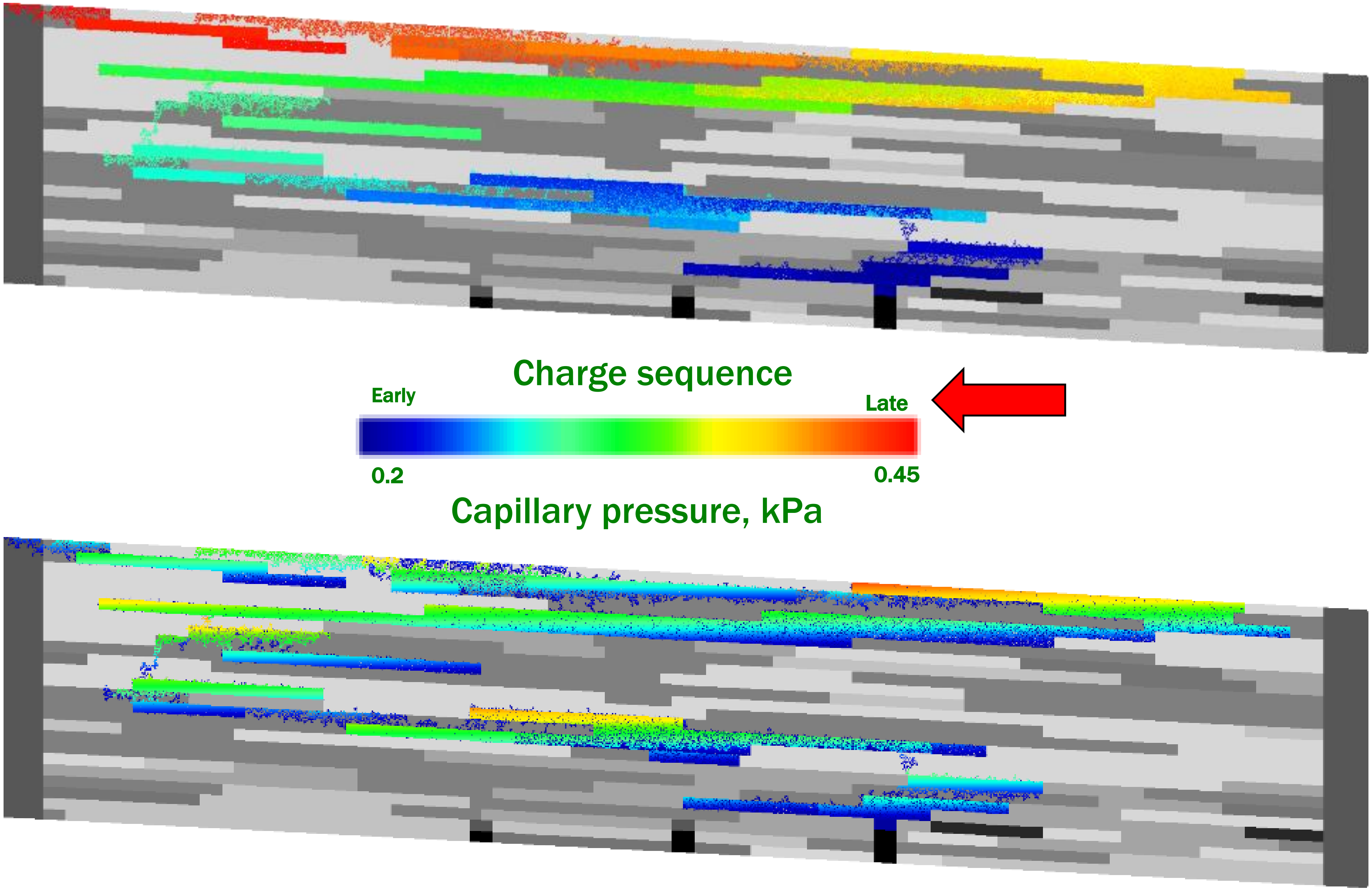


IP model of large heterogeneous sand tank



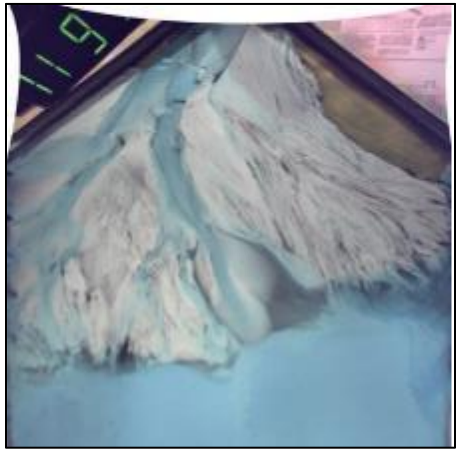


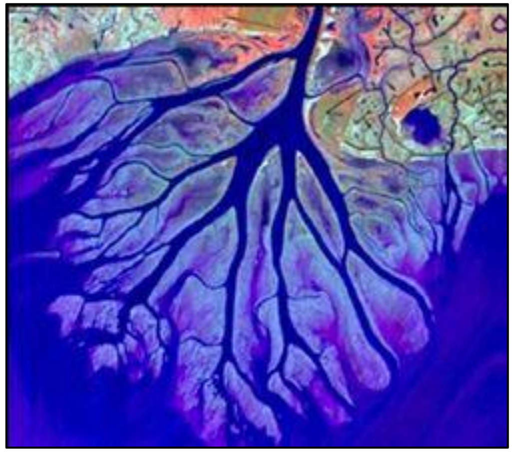
IP model of large heterogeneous sand tank

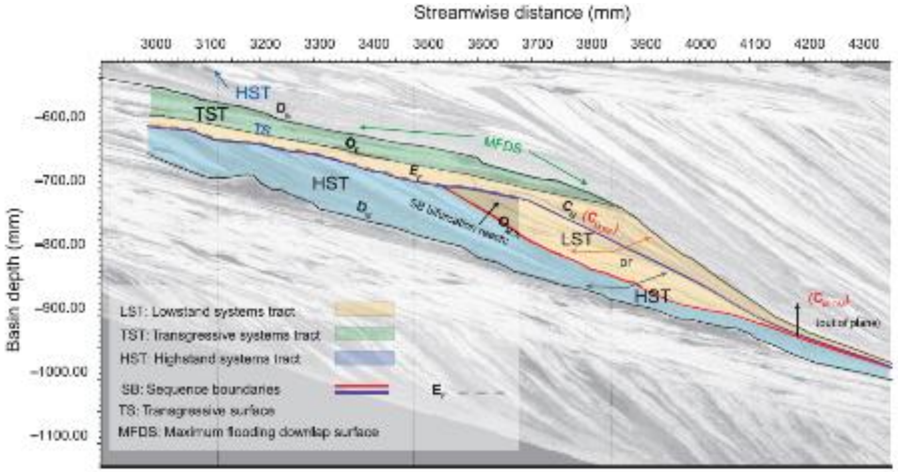


Ongoing work

Cantelli, A., Wonsuck, K., Martin, J., Mullin, J., Paoloa, C., Strong, N., XES Basin: NCED Data Repository.
https://repository.nced.umn.edu/browser.php?current=location&keyword=17&location=2&dataset_id=29







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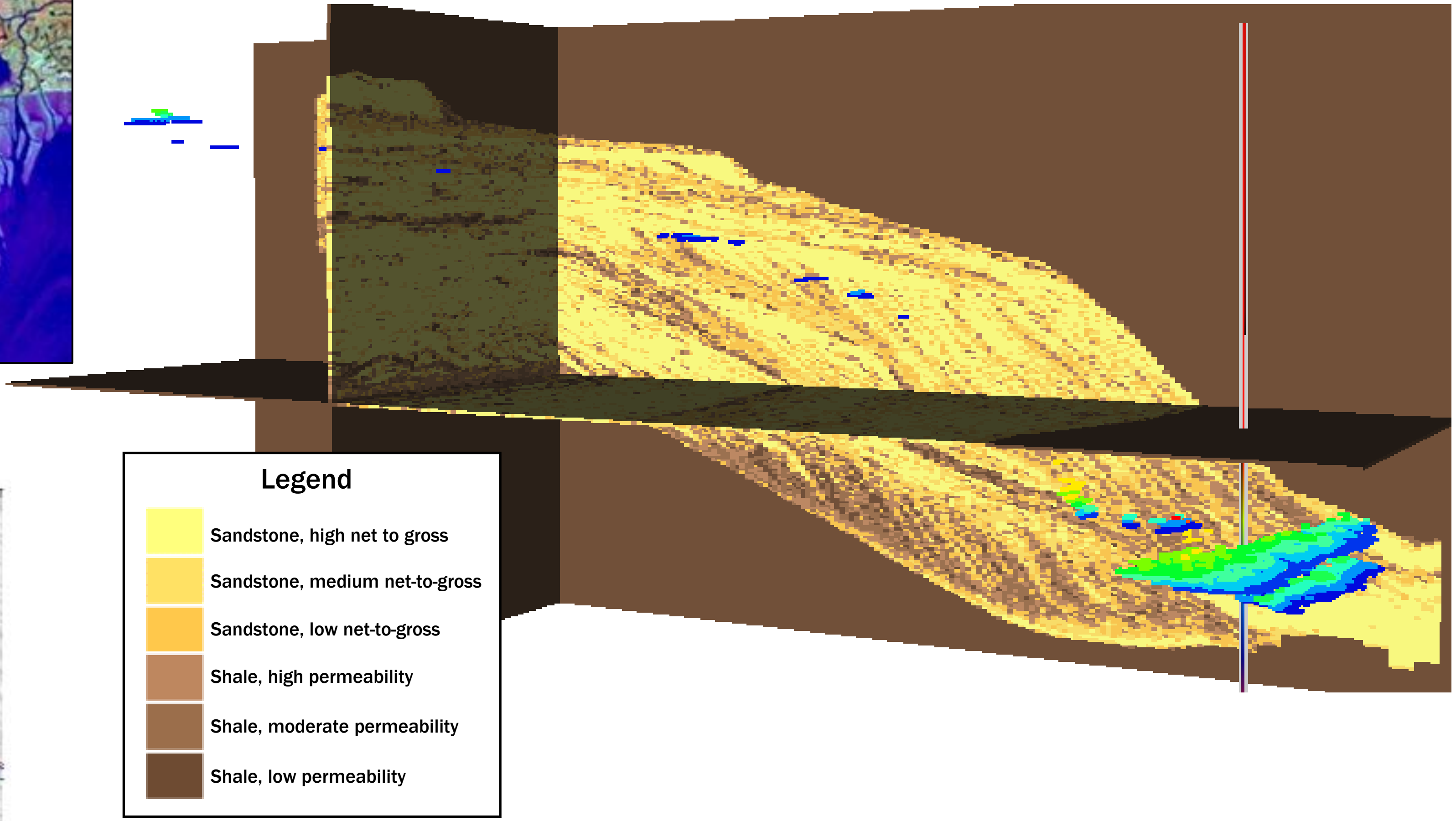

Related poster: Beckham et al., Theme 7, Tuesday Morning

RELATED PUBLICATIONS

- Trevisan, L., Krishnamurthy, P.G., Meckel, T.A. (2017). Impact of 3D capillary heterogeneity and bedform architecture at the sub-meter scale on CO_2 saturation for buoyant flow in clastic aquifers. *International Journal of Greenhouse Gas Control*, 56 (1), 237-249.
- Trevisan, L., Pini, R., Cihan, A., Birkholzer, J.T., Zhou, Q., González-Nicolás, A., Illangasekare, T.H. (2017). Imaging and quantification of spreading and trapping of carbon dioxide in saline aquifers using meter-scale laboratory experiments. *Water Resources Research*, 53 (1), 485-502.
- Trevisan, L., Illangasekare, T.H., Meckel, T.A. (2017) Modelling plume behavior through a heterogeneous sand pack using a commercial invasion percolation model, GGGG, 10.1007/s40948-017-0055-5.
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- Meckel, T.A., Krishnamurthy, P.G., Trevisan, L. A method to generate small scale, high-resolution 3D sedimentary bedform architecture models representing realistic geologic facies (under review).
- Meckel, T., Bryant, S. L., and Ravi Ganesh, P. (2015) Characterization and prediction of CO_2 saturation resulting from modeling buoyant fluid migration in 2D heterogeneous geologic fabrics: International Journal of Greenhouse Gas Control, v. 34, p. 85-96, http://doi.org/10.1016/j.ijggc.2014.12.010
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Questions?

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