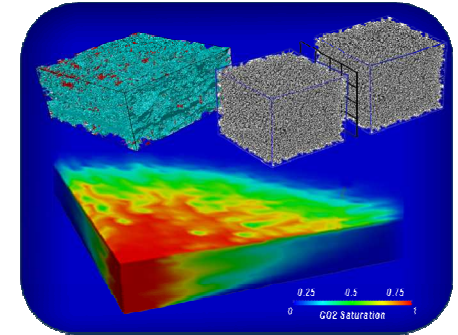
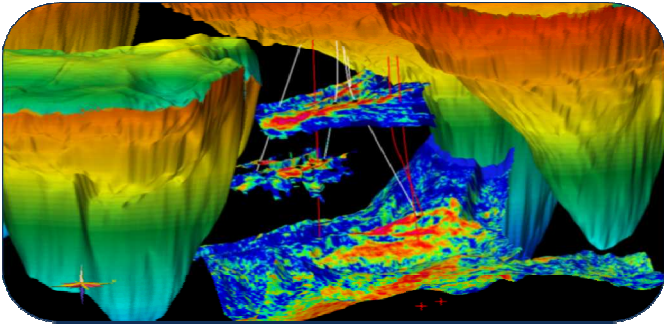


*Exceptional service in the national interest*

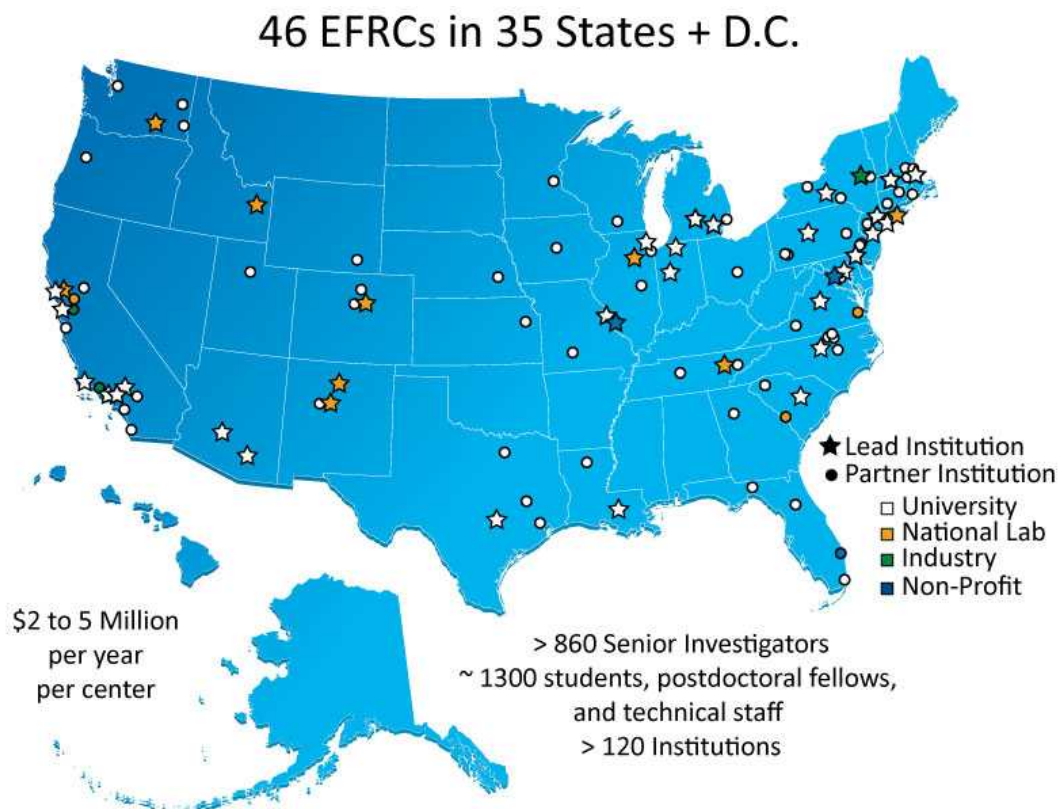


# Center for Frontiers of Subsurface Energy Storage (CFSES)

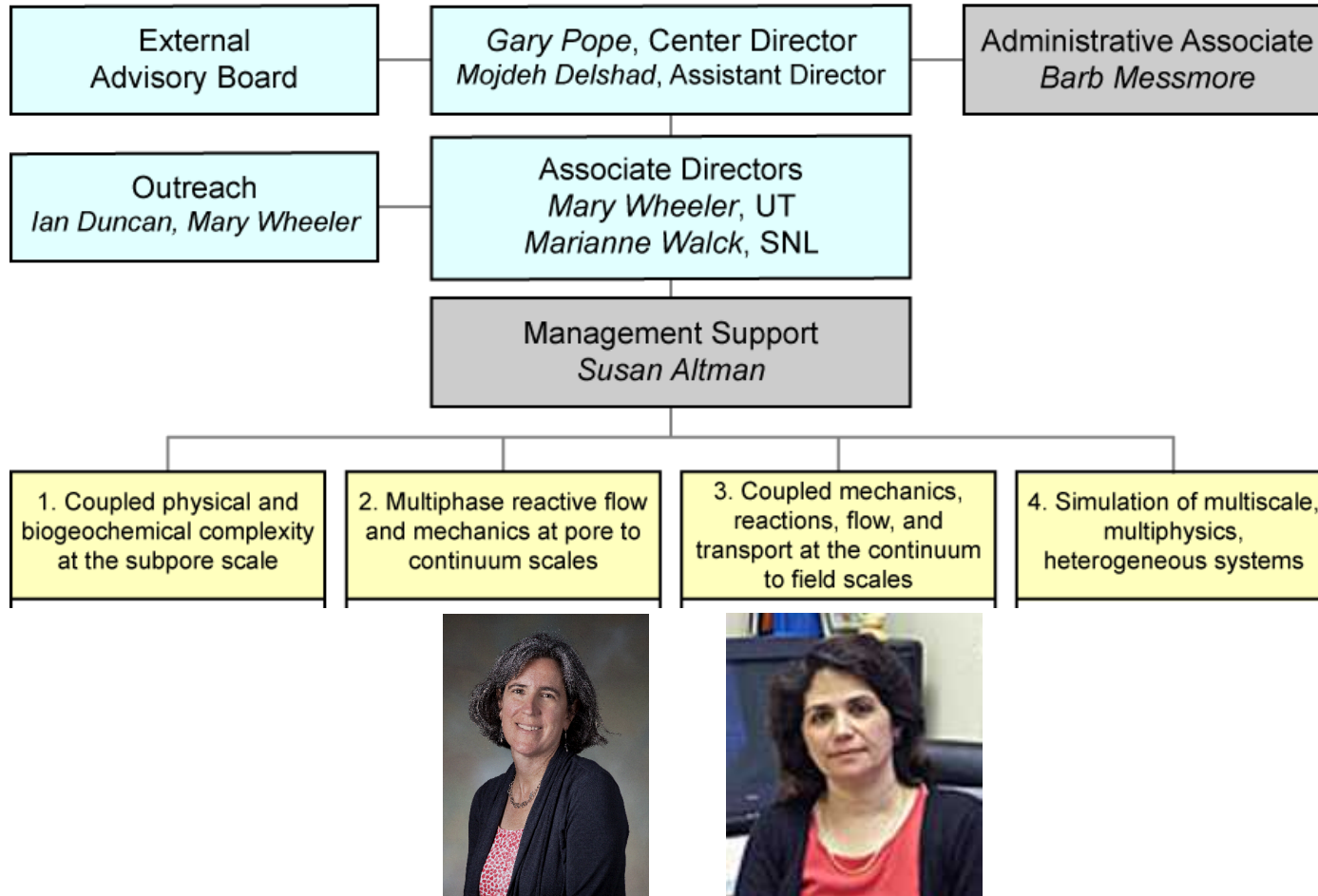
Susan J. Altman  
January 16, 2013

# The Energy Frontier Research Centers Aim to Accelerate Discovery Science for Energy Technologies

- Center started August 2009
- 5 year program with renewals
- \$15M (\$7M to SNL)
- **CFSES is one of 2 geosciences related EFRC**



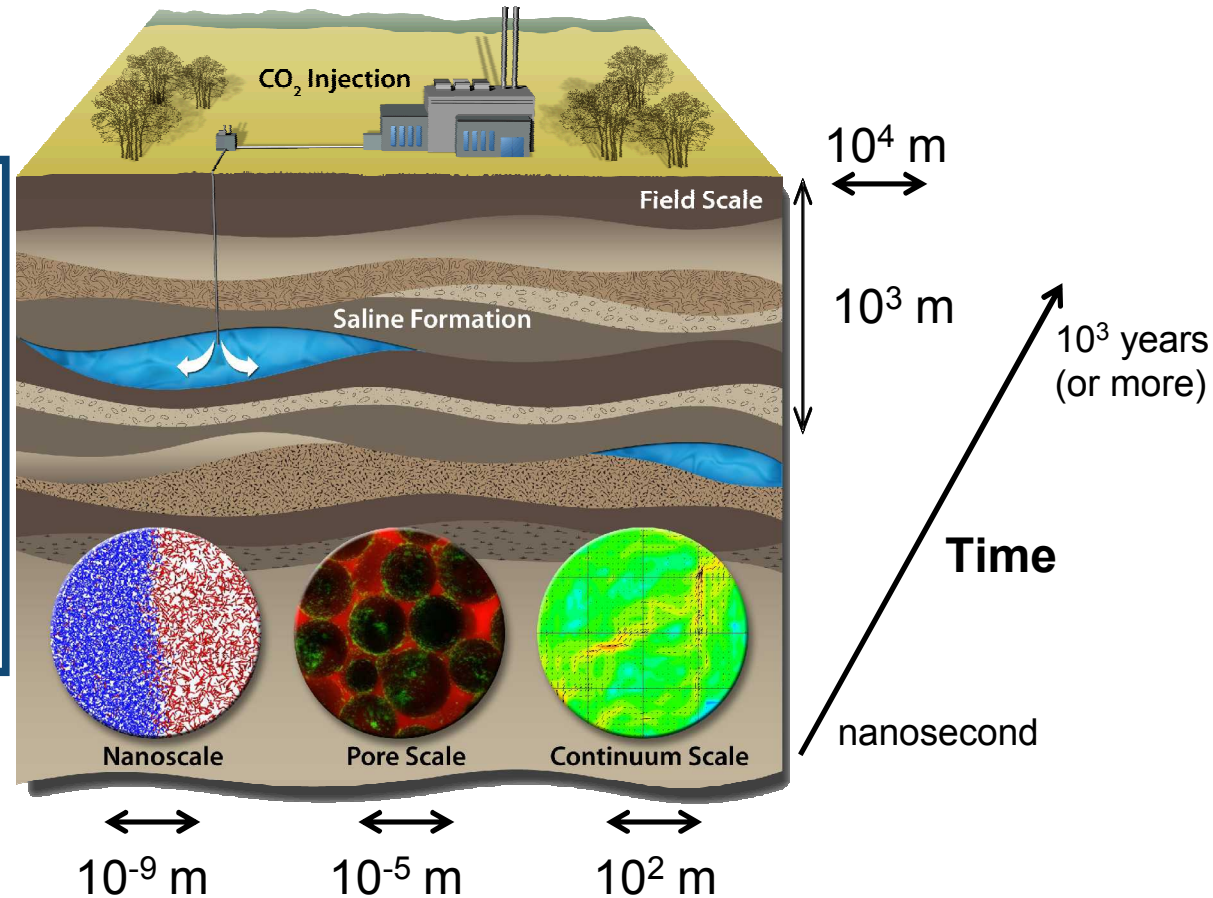
# Management Structure



# A Multi-scale, Multi-physics Approach is Needed to Study Underground CO<sub>2</sub> Storage

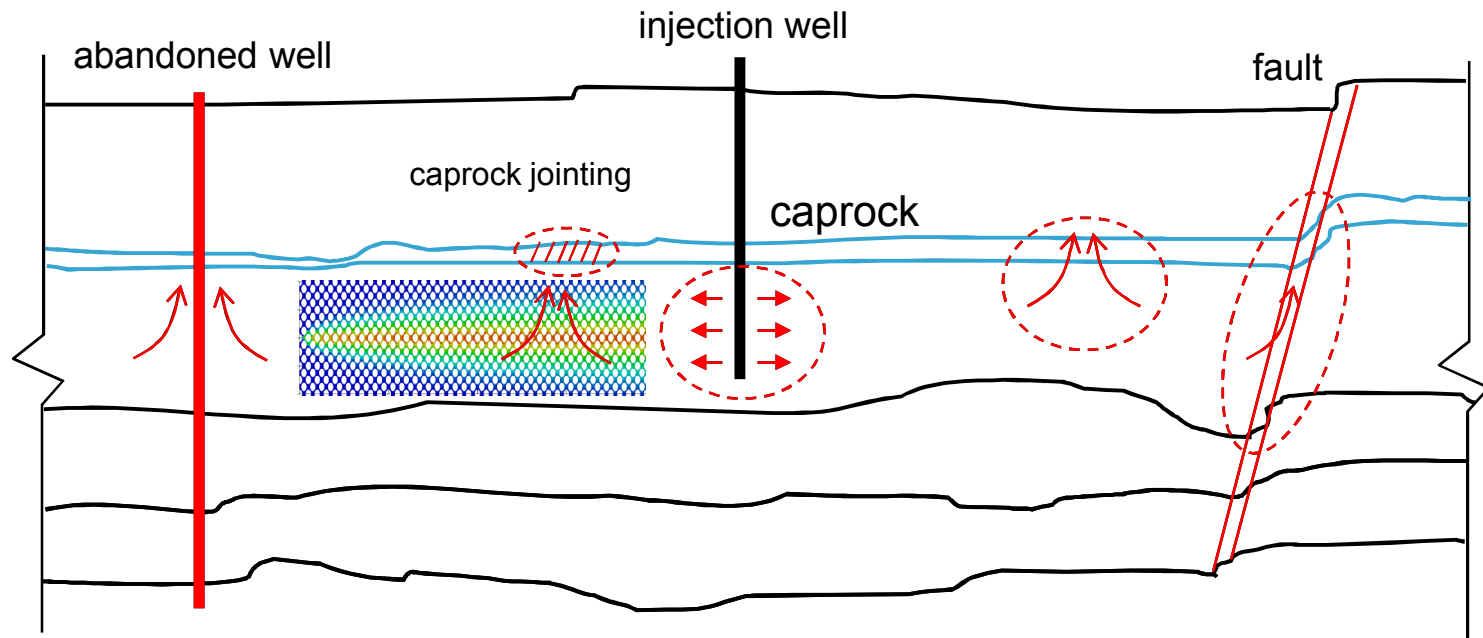
## Goal

Advance scientific understanding of subsurface biological, chemical and physical phenomena related to the storage of energy byproducts using an integrated experimental and modeling approach



# Ensure Safe Storage of CO<sub>2</sub>

- Leakage
  - Wellbores
  - Faults
- Injection induced damage
- Brine migration to overlying aquifers
- Induced seismicity



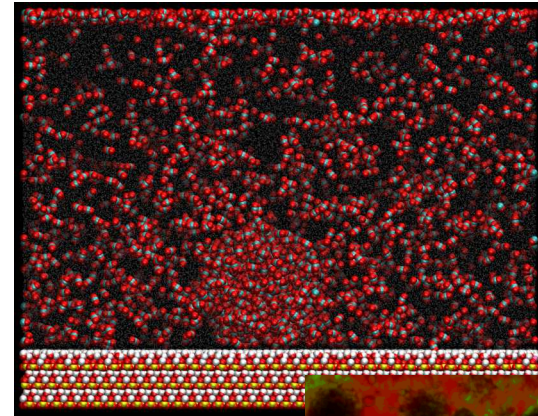


# CFSES Benefiting from Sandia's Geoscience Capabilities

## ■ Molecular dynamics simulation

Cygan, R.T., Romanov, V.N., and Myshakin, E.M. (2012) Molecular simulation of carbon dioxide capture by montmorillonite using an accurate and flexible force field. *Journal of Physical Chemistry C*, 116(24), 13079-13091.

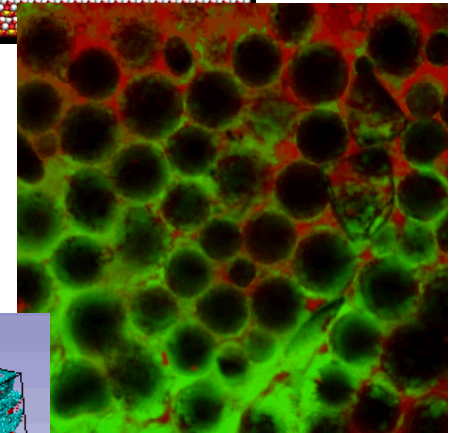
Criscenti, L. J., and R. T. Cygan (2013), Molecular Simulations of Carbon Dioxide and Water: Cation Solvation, *Environmental Science & Technology*, 47, 87-94.



## ■ Subsurface microbial geochemistry

Kirk, M. F. (2011), Variation in Energy Available to Populations of Subsurface Anaerobes in Response to Geological Carbon Storage, *Environmental Science & Technology*, 45(15), 6676-6682.

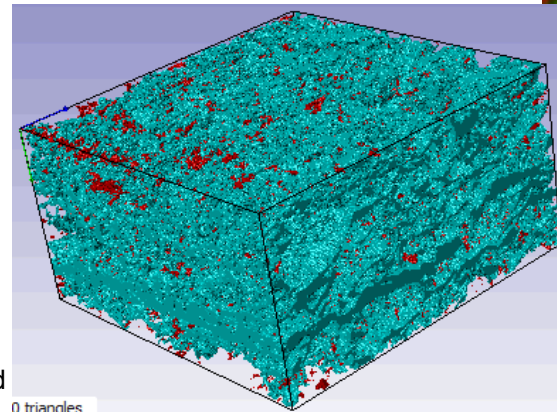
Kirk, M. F., E. F. Santillan, L. K. McGrath, and S. J. Altman (2012), Variation in Hydraulic Conductivity with Decreasing pH in a Biologically-Clogged Porous Medium, *International Journal of Greenhouse Gas Control*, 11, 133-140.



## ■ Nanometer scale research

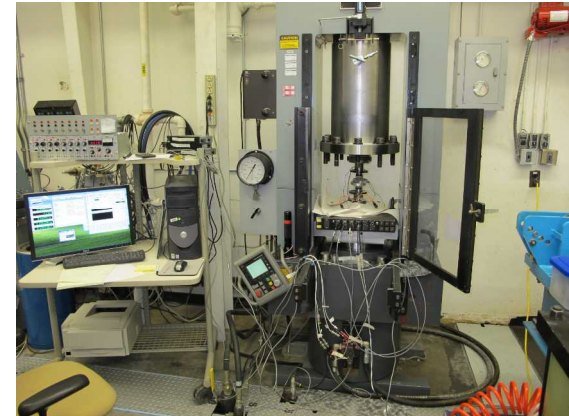
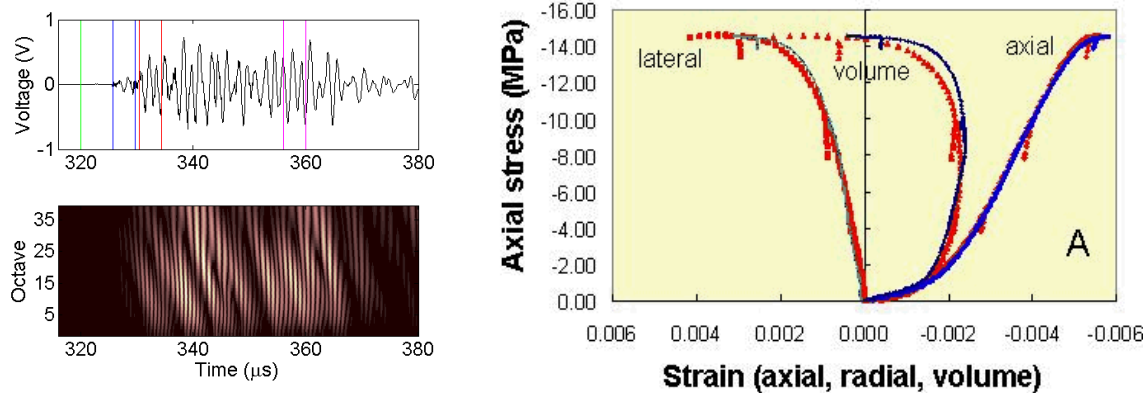
Dewers, T. A., J. Heath, R. Ewy, and L. Duranti (2012), Three-dimensional pore networks and transport properties of a shale gas formation determined from focused ion beam serial imaging, *International Journal of Oil Gas and Coal Technology*, 5(2-3), 229-248.

Heath, J.E., Dewers, T.A., McPherson, B.J., Petrusak, R., Chidsey, T.C., Jr., Rinehart, A.J., Mozley, P.S., Kotula, P.G., 2011, Pore networks in continental and marine mudstones: characteristics and controls on sealing behavior. *Geosphere* 7, 429-454.



# CFSES Benefiting from Sandia's Geoscience Capabilities

## ■ Geomechanical Testing and Modeling



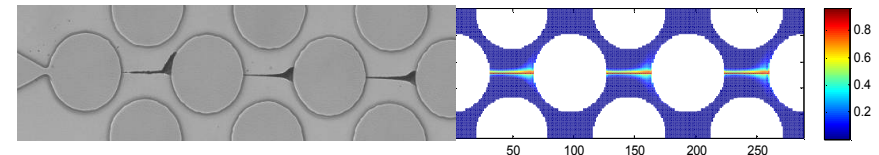
Dewers, T., P. Newell, S. Broome, J. Heath, and S. Bauer (In Review), Geomechanical Behavior of Cambrian Mount Simon 2 Sandstone Lithofacies, Iowa Shelf, USA, *Journal of Geophysical Research Solid Earth*.

Zhang, Y., et al. (In Review), Induced seismicity in crystalline basement rocks by fluid injection into basal aquifers, *Ground Water*.

## ■ Reactive Transport Modeling

Davison, S. M., H. Yoon, and M. J. Martinez (2012), Pore scale analysis of the impact of mixing-induced reaction on viscosity variations, *Advances in Water Resources*, 38, 70-80.

Yoon, H., A. J. Valocchi, C. J. Werth, and T. Dewers (2012), Pore-scale simulation of mixing-induced calcium carbonate precipitation and dissolution in a microfluidic pore network, *Water Resources Research*, 48.



# CFSES Benefiting from Sandia's Geoscience Capabilities

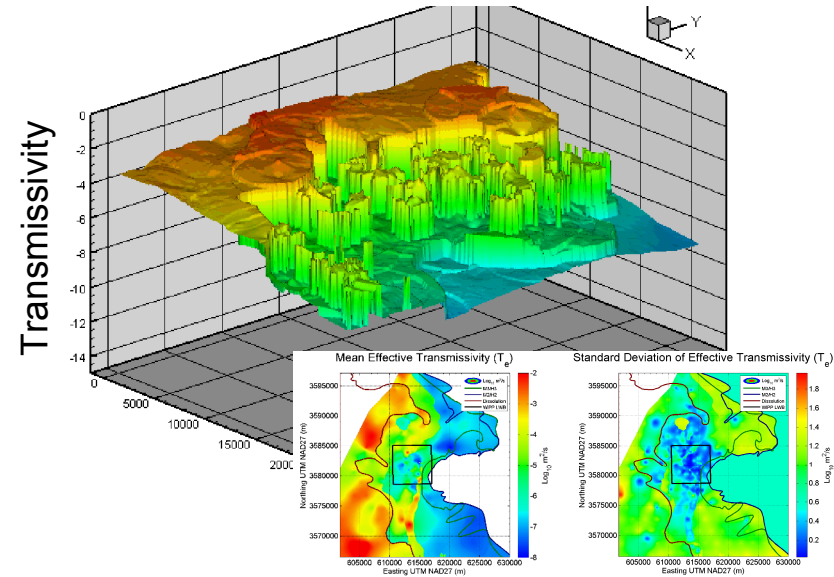


## ■ Probabilistic Inverse Modeling

Yoon, H., and S. A. McKenna (2012), Highly parameterized inverse estimation of hydraulic conductivity and porosity in a three-dimensional, heterogeneous transport experiment, *Water Resources Research* 48.

Yoon, H., D. B. Hart, and S. A. McKenna (In Press), Parameter estimation and predictive uncertainty in stochastic inverse modeling of groundwater flow: Comparing null-space Monte Carlo and multiple starting point methods, *Water Resources Research*.

Ray, J. S.A. McKenna, B. van Bloemen Waanders and Y. Marzouk, 2012, Bayesian reconstruction of binary media with unresolved fine-scale spatial structures, *Advances in Water Resources*, 44, pp. 1-19.

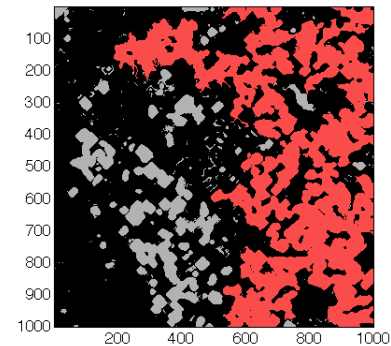
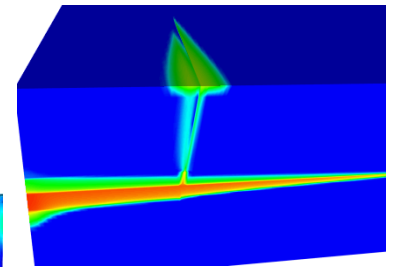
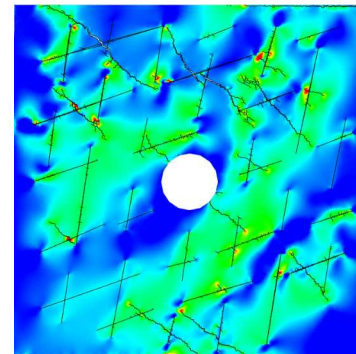


## ■ Coupled Hydro-Mechanical Modeling

Bishop, J.E. and O.E. Strack, 2011, A statistical method for verifying mesh convergence in Monte Carlo simulations with application to fragmentation, *Int. Journal for Numerical Methods in Engineering*, 88 (3)

McKenna, SA and DQ Pike (In Press), Fluid Pressure Redistribution Events within a Fault: Impact of Material Property Correlation, *Recent Advances in Hydrogeology*, Cambridge University Press (Mishra and Kuhlmann, editors).

Martinez, M. J., P. Newell, J. Bishop, and D. Turner (In Review), Coupled multiphase flow and geomechanics model for analysis of joint reactivation during CO<sub>2</sub> sequestration operations, *International Journal of Greenhouse Gas Control*.

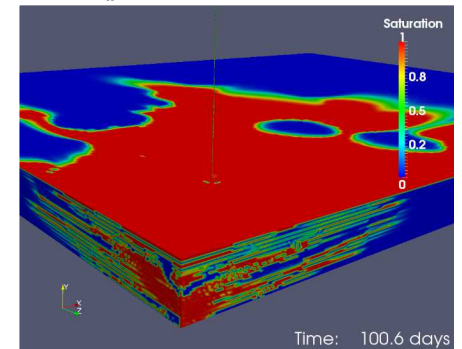
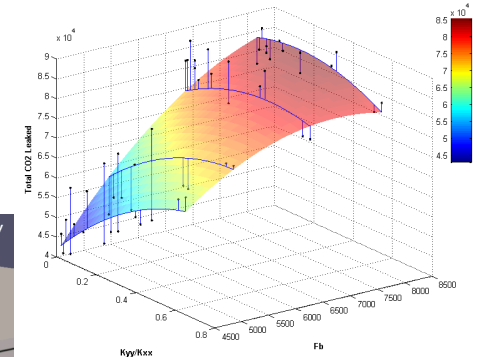
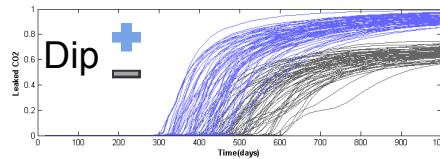
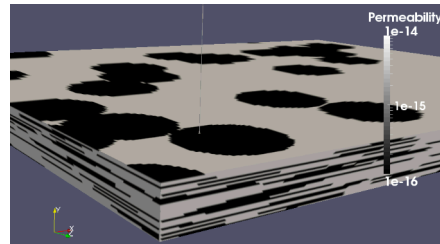




# Related Work in Carbon Sequestration

## ■ CO<sub>2</sub> Injection in Heterogeneous Media

Martinez, et al., 2011, Computational Thermal, Chemical, Fluid and Solid Mechanics for Geosystems, Sandia National Laboratories report, SAND2011-6643, 222 pp.



## ■ National Scale Sequestration Economics

Heath, J.E., P.H. Kobos, J.D. Roach, T.A. Dewers, S.A. McKenna, 2012, Geologic Heterogeneity and Economic Uncertainty of Subsurface Carbon Dioxide Storage, *SPE Economics & Management*,

Injection costs as a function of injection well permeabilities

