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Center for Frontiers of Subsurface Energy Security: A DOE Energy Frontier Research Center

2015 Energy Frontier Research Center Principal Investigators' Meeting

October 26 - 27, 2015

U.S. DEPARTMENT OF ENERGY | Office of Science

TEXAS The University of Texas at Austin

Sandia National Laboratories

Introduction

Center Mission

To understand and control emergent behavior arising from coupled physics and chemistry associated with carbon sequestration in heterogeneous materials

Center Organization

EAB
Steve Bryant
Charles Christopher
Don DePaolo
Derek Elsworth
Scott Frailey
Kurt House
Jean Roberts

Management Team
Larry W. Lake – Director
Grant Heffelfinger – Associate Director
Susan Altman, Hilary Olson – Assistant Directors

Administrative Associate
Barb Messmore

THEME 1: FLUID-ASSISTED GEOMECHANICS
Theme Leads: Tom Dewers, Matt Balhoff
P. Eichhubl, N. Espinoza, N. Hayman, M. Hesse, A. Ilgen, M. Martinez, P. Newell, M. Wheeler, H. Yoon
C. Choens, K. Chojnicki, S. Lee, J. Major, Z. Sun

THEME 2: MULTIFLUID GEOCHEMISTRY
Theme Leads: Randall Cygan, Marc Hesse
P. Bennett, B. Cardenas, O. Ghattas, A. Ilgen, T. Larson, C. Tenney, C. Yang
K. Gilbert, E. Guiltinan, H. Christensen, T. Ho, C. McNeece, L. Wang, B. Wen

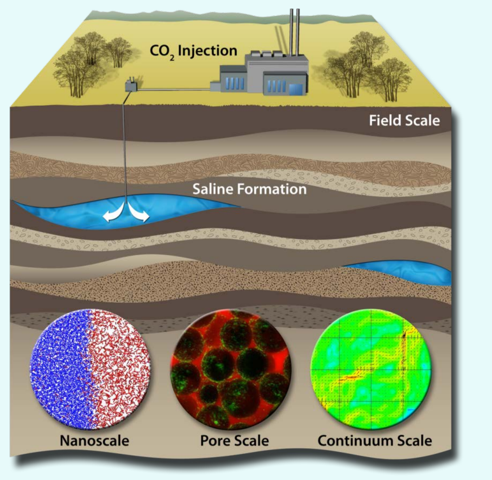
THEME 3: BUOYANCY-DRIVEN MULTIPHASE FLOW
Theme Leads: Tip Meckel, Mario Martinez
B. Cardenas, D. DiCarlo, S. Hovorka, K. Johnston, Y. Wang, H. Yoon, C. Huh
X. Chen, K. Chojnicki, P. Krishnamurthy, A. Kucala, L. Trevisan, A. Worthen, Z. Xue

Center Challenges

- Sustaining large storage rates, of order gigatons of CO_2 per year in the US, for decades without compromising other subsurface resources and without jeopardizing the security with which the CO_2 is stored;
- Using pore space with unprecedented efficiency, i.e., placing CO_2 so that it occupies half of the pore reservoir volume, rather than the typical current estimate of less than five percent;
- Controlling undesired or unexpected emergent behavior in the geostorage system, e.g. fracture propagation for unexpectedly long distances, or CO_2 plumes channeling through a much smaller volume of the storage reservoir.

	Challenge 1: Sustaining large storage rates	Challenge 2: Using pore space with unprecedented efficiency	Challenge 3: Controlling undesired or unexpected behavior
Theme 1: Fluid-Assisted Geomechanics	• Single fracture propagation and cohesive zone modeling • Phase-field modeling	• Single fracture propagation and cohesive zone modeling	• Bulk rock strengthening/weakening evaluation
Theme 2: Multifluid Geochemistry	• Caprock chemical and mechanical stability	• Bravo Dome brine-gas mass transfer • Chemistry at the fluid-fluid interface	• Caprock chemical and mechanical stability • Reactions of CO_2 with clay minerals
Theme 3: Buoyancy-Driven Multiphase Flow	• Meter-scale experiments • Core-scale X-ray CT experiments	• Meter-scale experiments • Core-scale X-ray CT experiments • Mesoscale modeling and invasion-percolation modeling • Ganglion dynamics modeling	• Nanoparticle experiments

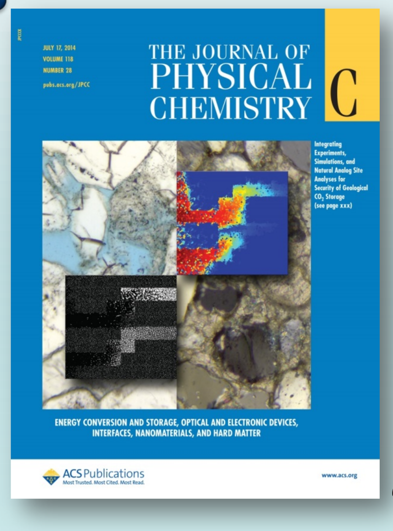
CFSES CENTER FOR FRONTIERS OF SUBSURFACE ENERGY SECURITY



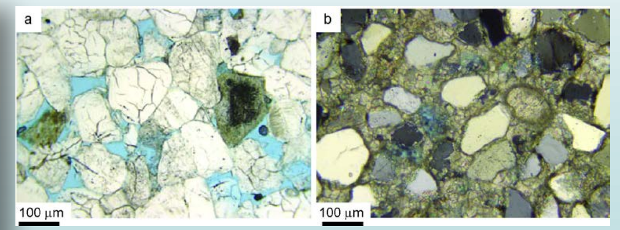
Accomplishments

Publications

- 103 publications
- 1041 citations
- Impact Factor as high as 9.8



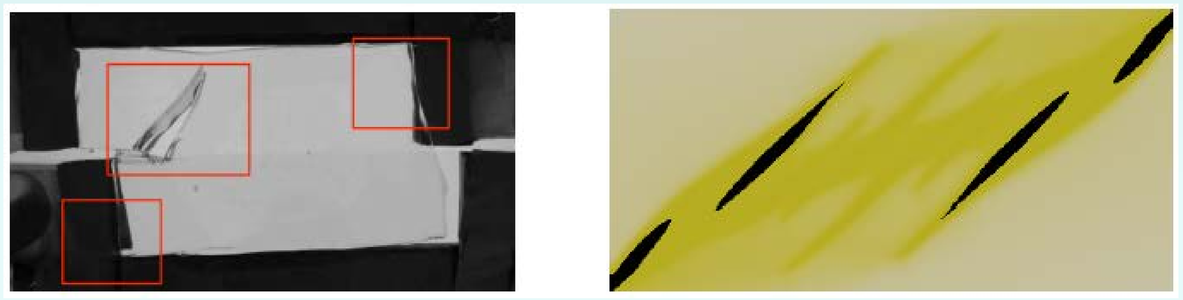
JPCC cover article: Altman, et al., 2014. Chemical and Hydrodynamic Mechanisms for Long-Term Geological Carbon Storage



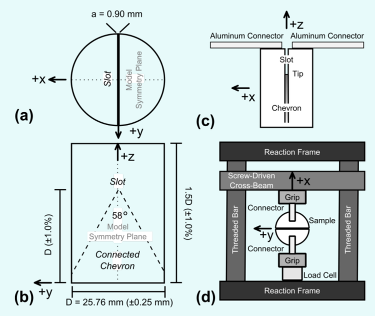
Photomicrographs of (a) unaltered and (b) altered sandstone in the vicinity of a natural CO_2 seepage conduit. Primary porosity, filled by blue epoxy in (a), has been completely occluded in altered sandstone [shown in (b)] by carbonate pore cement that precipitated from upward migrating CO_2-charged brine. Some secondary porosity resulted from grain dissolution. Little Grand Wash fault, Utah. (a) Plane-polarized light and (b) cross-polarized light.

Development and experimental validation of models for predicting fracture propagation

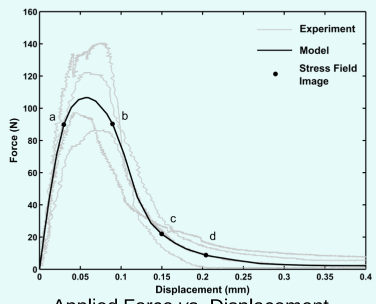
IMPACT: *These geomechanical models can be used to predict population distributions of emergent features (networks or cascades of fractures) with emphasis on quantifying connected fracture networks. They can also be used to help predict, and therefore prevent, undesired fracturing (Challenges 1 and 3).*



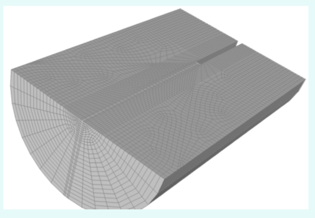
Comparison between experimental (left) and phase-field modeling results (right). The top, left, red rectangle in the left figure shows an experimentally induced fracture. The dark region in the right image indicates the fracture zone. Similar fracture initiation and propagation patterns are observed for both the experiments and the models.



fractured short-rod specimens



Applied Force vs. Displacement



finite-element model of short-rod specimen

References

Bishop, J.E., 2014. A Displacement-Based Finite-Element Formulation for General Polyhedra using Harmonic Shape Functions. International Journal for Numerical Methods in Engineering 97, 1-31.

Dewers, T.A., Newell, P., Broome, S., Heath, J., Bauer, S., 2014. Geomechanical behavior of Cambrian Mount Simon Sandstone reservoir lithofacies, Iowa Shelf, USA. International Journal of Greenhouse Gas Control 21, 33–48.

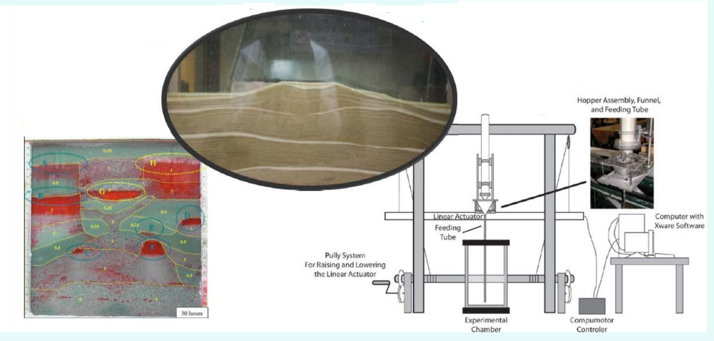
Rinehart, A.J., Bishop, J.E., Dewers, T., 2015. Fracture propagation in Indiana Limestone interpreted via linear softening cohesive fracture model. Journal of Geophysical Research-Solid Earth 120, 2292-2308.

Rinehart, A.J., Dewers, T., Broome, S.T., Eichhubl, P., In Review. Effects of CO_2 on mechanical variability and constitutive behavior of the Lower Tuscaloosa Formation, Cranfield Injection Site, USA. . International Journal of Greenhouse Gas Control.

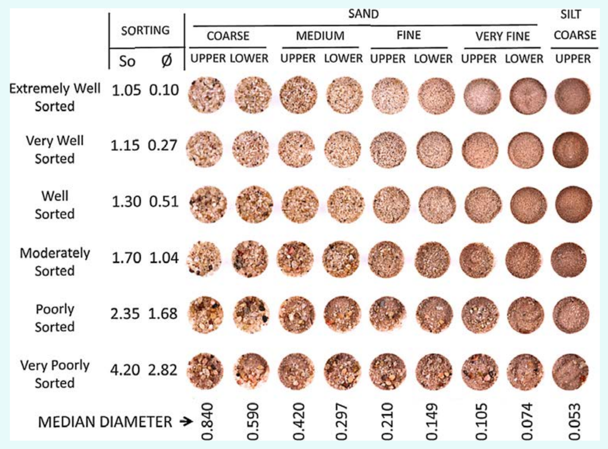
Martinez, M.J., Newell, P., Bishop, J.E., Turner, D.Z., 2013. Coupled multiphase flow and geomechanics model for analysis of joint reactivation during CO_2 sequestration operations. International Journal of Greenhouse Gas Control 17, 148-160.

Advancing fundamental understanding of capillary- and buoyancy-driven CO_2 flow and development of predictive models

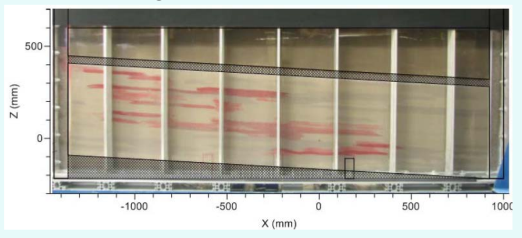
IMPACT: *Work provides new methods for predicting saturations in large rock volumes. Accounting for mesoscale heterogeneity and buoyancy-dominated flow deepens our understanding of subsurface CO_2 storage and migration. This understanding will help to develop an engineering approach to maximizing storage efficiency. (Challenge 2)*



Experimental setup being developed for imaging capillary/buoyancy driven CO_2 migration in two-dimensional heterogeneous media.



The 54 geological facies used in the 2D stochastic invastion percolation simulations.

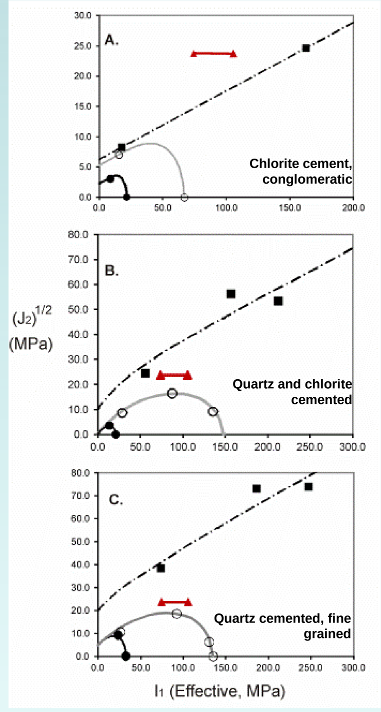


References

Meckel, T. A., S. L. Bryant, and P. R. Ganesh (2015), Characterization and prediction of CO2 saturation resulting from modeling buoyant fluid migration in 2D heterogeneous geologic fabrics, *International Journal of Greenhouse Gas Control*, *34*, 85-96.

Improved understanding of the impact of CO_2 exposure to potential geologic CO_2 storage reservoir rock types

IMPACT: *Increased understanding in how rock type and cement chemistry will impact fracturing during injection. Experimental evidence supports the possibility that injectate fluid chemistry could be engineered in such a way to improve injection sustainability and overall storage efficiency (Challenges 1 and 3).*



Experimental results of subjecting Cranfield rock types to CO_2-bearing brines. The red lines show the in-situ stress estimates. The dashed lines are estimates of the failure envelope and the solid gray lines are the yield surfaces. The failure envelope for testing shown in the top plot falls below the estimate for in-situ stress indicating that the chemical perturbations imposed by injecting CO_2 has abetted mechanical failure.

Geomechanical testing for acoustic and ultrasonic imaging of rock deformation

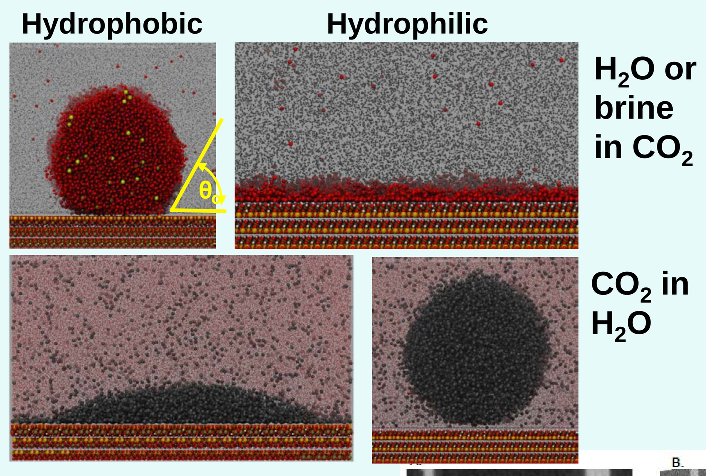
References

Major, J.R., Eichhubl, P., Dewers, T.A., Urquhart, A.S., Olson, J.E., Holder, J., 2014. The effect of CO_2-related diagenesis on geomechanical failure parameters: fracture testing of CO_2-altered reservoir and seal rocks from a natural analog at Crystal Geyser, Utah, 48th Mechanics / Geomechanics Symposium: Minneapolis, American Rock Mechanics Association, Minneapolis, MN, p. 5.

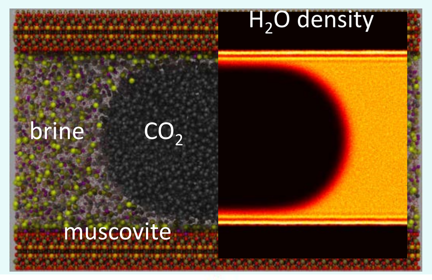
Rinehart, A.J., Dewers, T., Broome, S.T., Eichhubl, P., In Review. Effects of CO_2 on mechanical variability and constitutive behavior of the Lower Tuscaloosa Formation, Cranfield Injection Site, USA. . International Journal of Greenhouse Gas Control.

Development of basic understanding of the effect of mineral types on supercritical CO_2 wettability

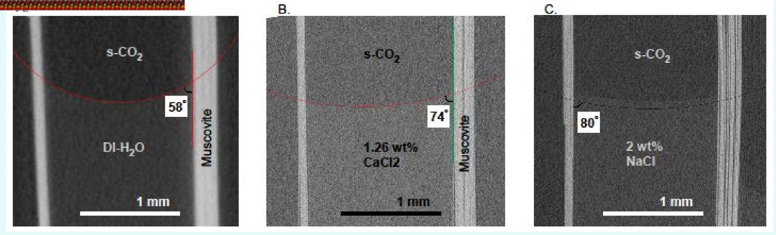
IMPACT: *Increased understanding of wetting angle allows for better prediction of dissolution trapping, CO_2 pore-space access, and, when also looking at brine chemistry, mineral dissolution and precipitation. (Challenge 2)*



Molecular dynamics simulation of brine/CO_2 wetting in the equivalent of a muscovite capillary tube being used in the mXRCT experiments.



Experiment: high-resolution micro X-ray CT scanning of CO_2/brine/mineral interface



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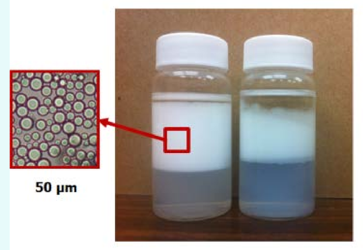
Chaudhary, K., Guiltinan, E.J., Cardenas, M.B., Maisano, J.A., Ketcham, R.A., Bennett, P.C., In Press. Wettability measurements under reservoir conditions using X-ray imaging with application to the brine-supercritical CO_2 system. *Geochem., Geophys., Geosyst.*

Deng, W., M. A. Balhoff, and M. B. Cardenas (Submitted), Effects of local capillary number on non-wetting fluid snap-off in pores, *Water Resources Research*.

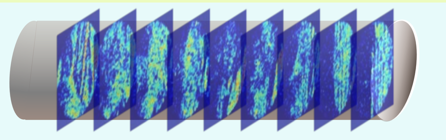
Tenney, C.M., Cygan, R.T., 2014. Molecular Simulation of Carbon Dioxide, Brine, and Clay Mineral Interactions and Determination of Contact Angles. *Environmental Science & Technology* 48, 2035-2042.

Development of engineered materials to control leakage and increase CO_2 emplacement volume

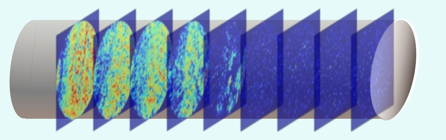
IMPACT: *Nanoparticle placement prior to CO_2 injection can lead to increased volume of CO_2 stored (Challenge 2) and control leakage (Challenge 3).*



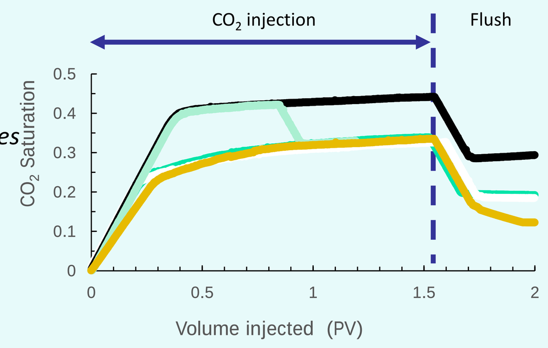
Vials showing nanoparticle emulsions. The expanded view shows nanoparticles (dark rings) around CO_2 bubbles.



Imaged CO_2 flow WITHOUT nanoparticles



Imaged CO_2 flow WITH nanoparticles



Effluent curves of CO_2 in column flow experiments with (black) and without (yellow, green) nanoparticles. Nanoparticles lead to more placement and retention of CO_2

References

Zhang, R., Ghosh, R., Sen, M.K., Srinivasan, S., 2013. Time-lapse surface seismic inversion with thin bed resolution for monitoring CO_2 sequestration: A case study from Cranfield, Mississippi. International Journal of Greenhouse Gas Control 18, 430-438.

Zhang, R., Sen, M.K., Phan, S., Srinivasan, S., 2012. Stochastic and deterministic seismic inversion methods for thin-bed resolution. Journal of Geophysics and Engineering 6, 611-618.

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