# Center for Frontiers of Subsurface Energy Security

SAND2013-7501C

# Research Theme I: Fluid-Driven Geomechanics

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# Objectives: Basic Research Needs

Injection of waste fluids such as $CO_2$ into the subsurface modifies the local state of stress in saline formations and in overlying caprock. We need to understand the range and scope of potential geomechanical responses to GCS to 1. minimize subsurface (and surface) damage to formations and infrastructure and 2. control such damage and associated leakage before and while/when it occurs.

- **Reservoir and caprock mechanical integrity** both pre- and post-injection require an assessment of geologic heterogeneity and the attendant ranges in geomechanical response
- **Fracture propagation** both at and below the fracture gradient and including geochemical influences and pore pressure effects is a major response to fluid injection
- **Early detection of damage and potential seismicity** is a main concern for subsurface engineering
- **Solutions to mitigate/avoid consequence**

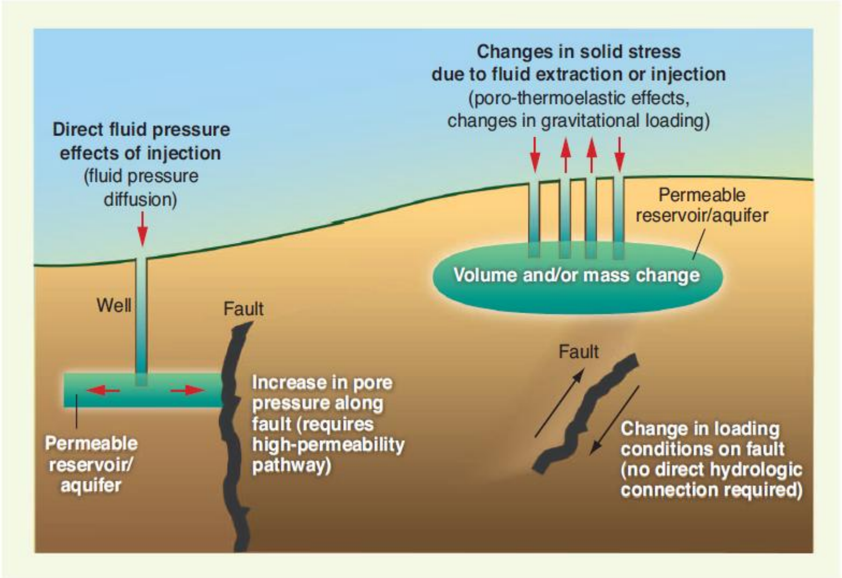



**Fig. 3. Schematic diagram of mechanisms for inducing earthquakes.** Earthquakes may be induced by increasing the pore pressure acting on a fault (**left**) or by changing the shear and normal stress acting on the fault (**right**). See (4).

Figure from Ellsworth, 2013

# Motivation

- Zoback and Gorelick, Ellsworth articles have gotten wide congressional attention
- Recent comparison of geomechanical response (In Salah, Weyburn, Sleipner) shows wide range of behavior
- NAS report lists GCS as major potential source of induced/triggered earthquakes

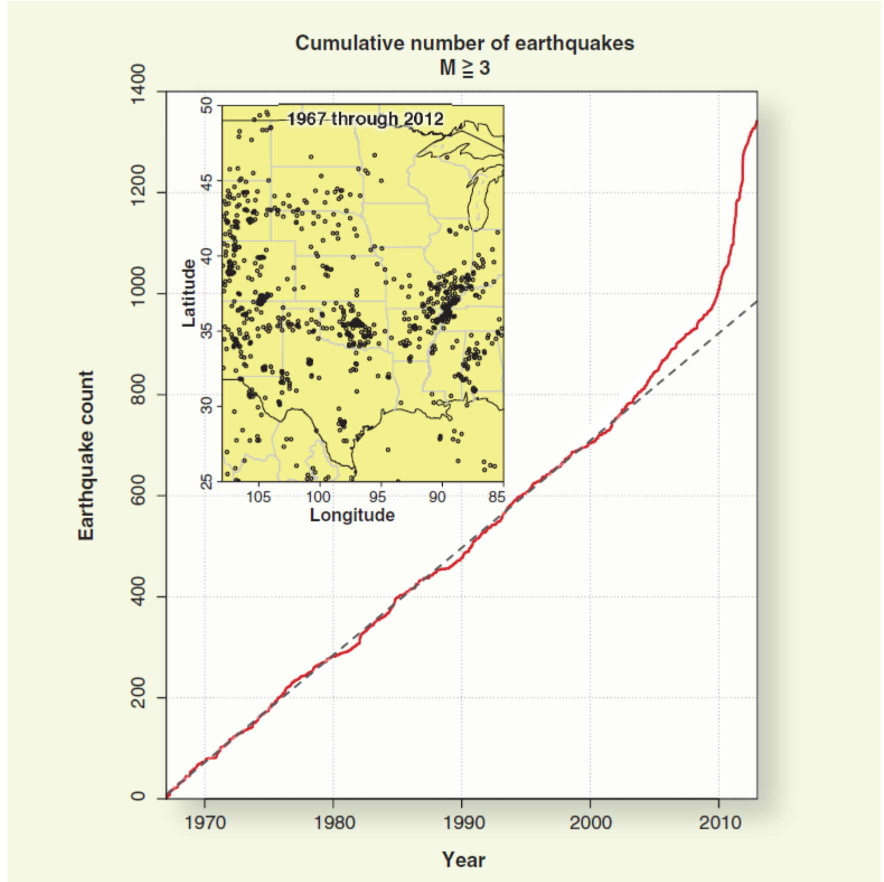



**Fig. 2. Cumulative count of earthquakes with $M \geq 3$ in the central and eastern United States, 1967–2012.** The dashed line corresponds to the long-term rate of 21.2 earthquakes/year. (**Inset**) Distribution of epicenters in the region considered here.

Figure from Ellsworth, 2013

# Sub-Themes/Research Plan

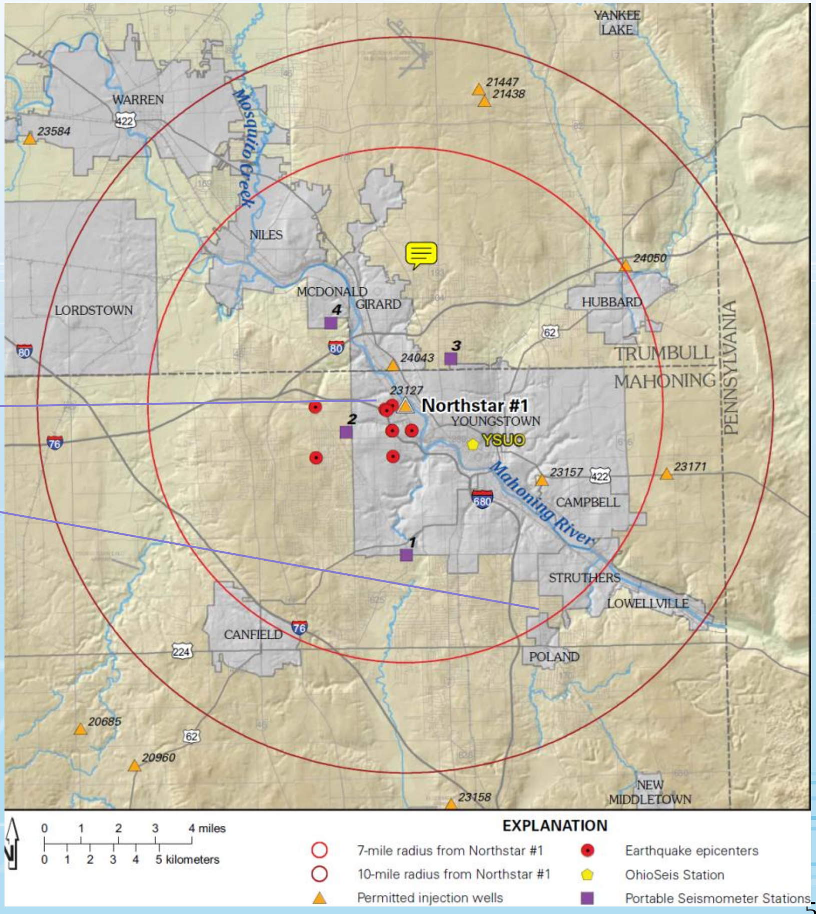
- Develop a comprehensive understanding of the mechanism of reservoir damage and fracture initiation and propagation in the subsurface through experiment and constitutive modeling
- Translate that understanding into numerical models for fracture growth and related damage in heterogeneous geomaterials
- Develop a model for diffraction and scattering of acoustic waves due to the propagation of fractures
- Use mathematical models and realistic representations of location uncertainties together with observed data from field sites in order to make quantitative predictions of the location and extent of reservoir damage, leakage pathways, and potential for induced seismicity during $CO_2$ sequestration.
- Develop monitoring and mitigation strategies (pore pressure plume guidance, brine withdrawal, nanoparticle injection, water curtains????)

# Examples from Historical Fluid Injection Sites

Earthquake cluster associated with Northstar #1 waste water injection well into Mount Simon, Youngstown, Ohio

- Good quality data with nearby seismic station
- Relatively good knowledge of subsurface
- Likely seismicity associated with Precambrian basement fault??

Northstar #1 Injection well, Youngstown, OH

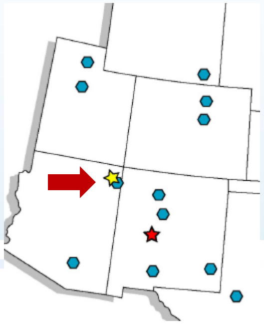

See: Person et al., 2013

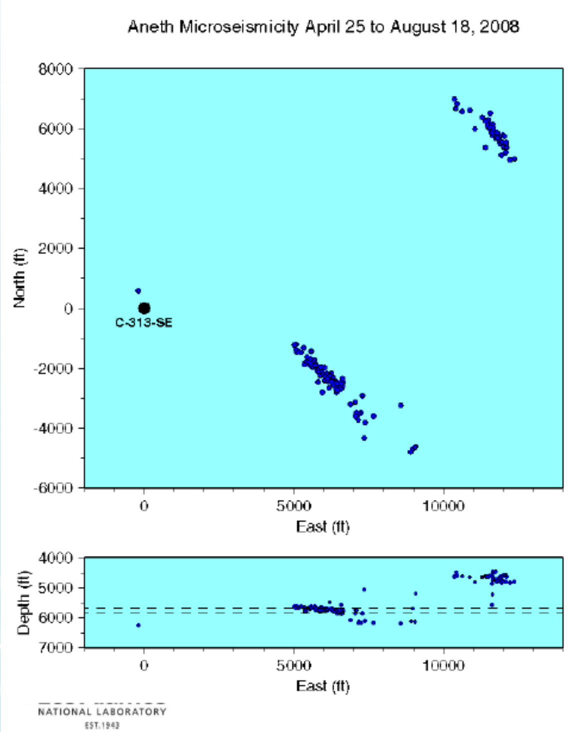
# Examples from NETL Partnership Activity

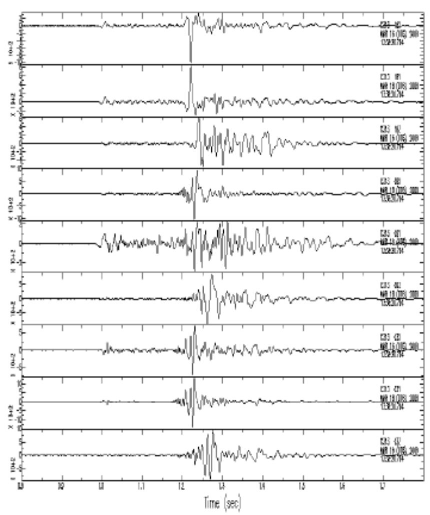
Microseismicity associated with $CO_2$ Injection, Aneth Field, Utah (Southwest Partnership)

- Sandia worked on Aneth site geomechanics
- Excellent subsurface “earth model” available
- Detailed injection schedule
- 3D seismic data with downhole geophone array

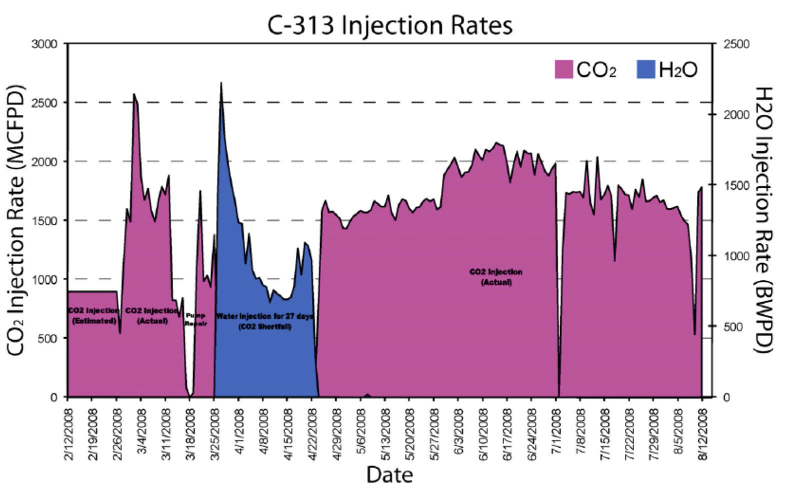
SWP Aneth Microseismicity, April – August, 2008






$CO_2$ and Water Injection Rates



# Addresses Key GCS Challenges

**The experiments, conceptual modeling and simulation capability developed in this theme will enable better assessment of risks associated with injection-induced fracturing at wells and in rock masses away from wells.**

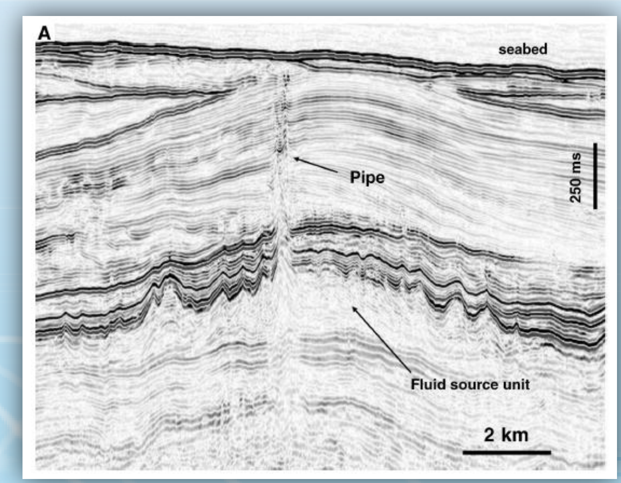
- **Maintaining large injection rates** (1 Mt/y/well) - for long times (several decades) raises likelihood of injection induced fractures in the storage formation even for injection below nominal frac pressure. Regulators need guidance as to whether these fractures increase risk of losing $CO_2$ containment.
- **Ensuring caprock integrity** - Fractures propagating from wells during the injection phase of GCS could be primary risk to caprock integrity, if conditions for "out of zone" propagation are met. Wide-scale perturbation of the stress state in and above the storage reservoir can cause caprock fracturing away from wells.
- **Minimizing Storage Footprint** - Injection-induced fractures from wells can alter the shape/nature of the $CO_2$ plume dramatically.
- **Reducing Risk of Induced Seismicity** – fluid injection is well known to trigger seismicity but apart from simple failure criteria, the causal aspects are not well understood

# Addresses Grand Challenge Science Questions

Injection-induced fracturing from wellbores is emergent phenomena with:

- Multiphase fluid flow;
- Far-from-equilibrium geo-mechano-chemical interactions at fracture tips;
- Heterogeneity in initial stress state and mechanical/petrophysical properties of storage formation and overlying/underlying formations;
- Heat transfer between injected fluid and formation;
- Mechanical and fluid boundary conditions.

Fracture control of (presumed) CO2 leakage at reservoir-caprock interface from Colorado Plateau (photos by Peter Mozley)




Leakage pathway imaged in seismic cross-section
From Cartwright et al., 2007

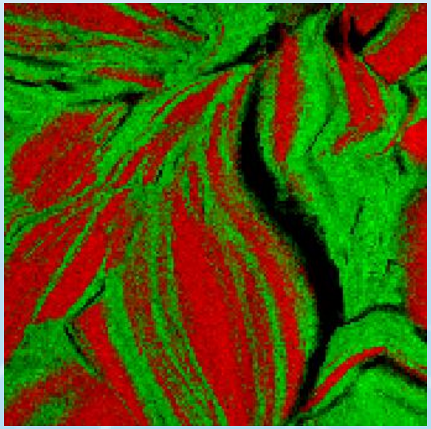
# Additional Impact

**Subsurface Energy Security:**

•Tools+understanding useful for wide scale, areally dense, short term fluid injection for hydraulic fracturing – what will subsurface look like (in terms of containment of fluids below USDW) after three decades of unconventional oil and gas development?

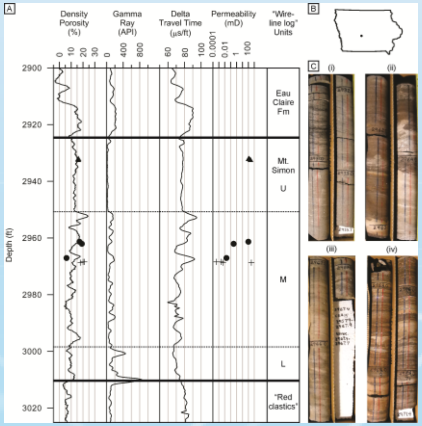
•Fluid pressure driven and chemistry driven fractures in nuclear waste repositories

•Fracture initiation/fault slip associated with large-scale geothermal development.



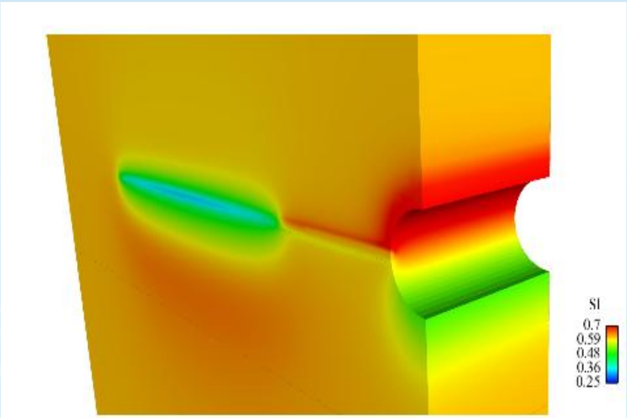
Pore scale constitutive models….

Heath et al., 2013




…to continuum multiphysics…

Dewers et al., 2013

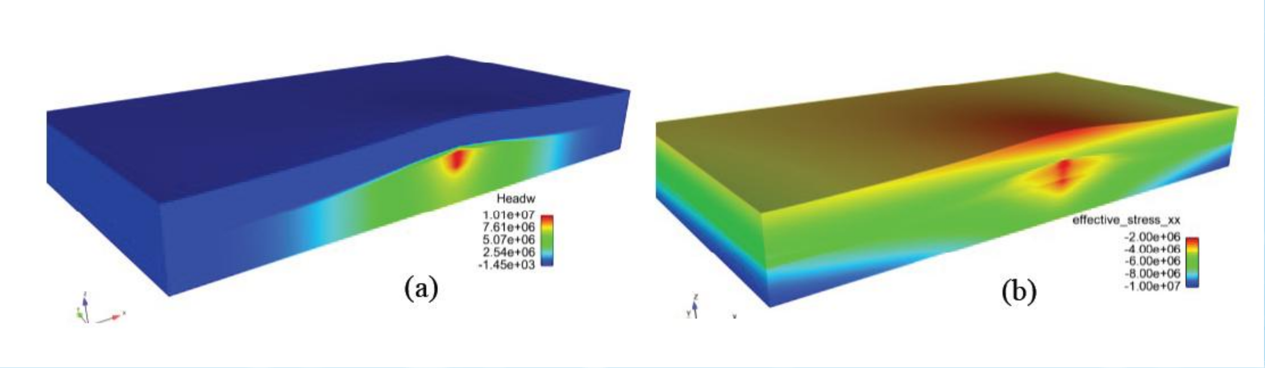



…to full scale simulation

Hansen et al., 2011

# Feeds From Previous CFSES Work

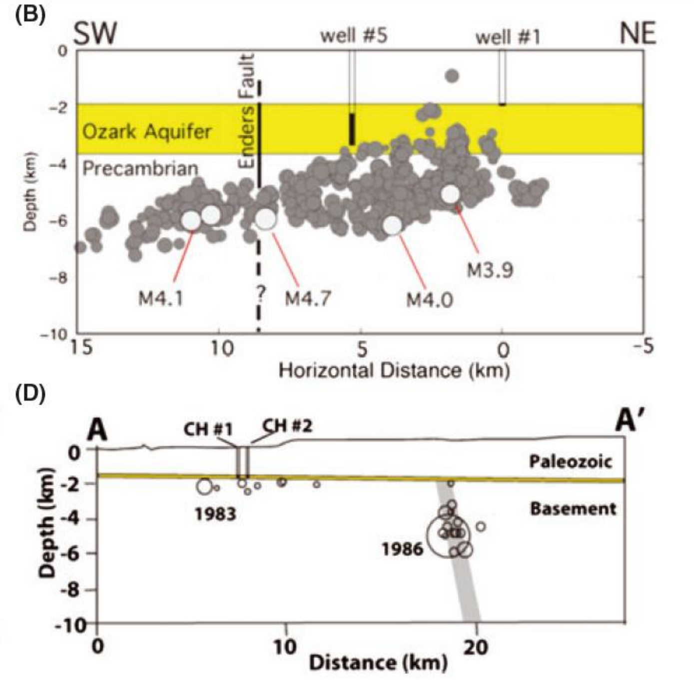
- Mt Simon geomechanics and Kayenta model validation (Dewers et al., 2013)
- Cranfield thermo-mechanical testing (Rinehart et al.)
- Shale lithofacies mechanics (Rinehart et al.)
- Fracture propagation experiments & modeling (Major et al., Rinehart and Bishop)
- In Salah modeling (Newell, Martinez, Bishop)
- New ultrasonics/AE, Multiphase, HPHT, and creep lab facilities (Rinehart, Dewers et al.)
- Seismic inversion methodology (Srinivasan et al.)




Martinez et al., IJGHGC, 2013

# Potential discussion talking points

- What are we overlooking?
- Too broad a focus?
- Budget limitations as guide to narrowing selection?
- Skill Sets for PIs & coPIs?
- Synergy – how to explain the synergy from doing this in context of EFRC, i.e. how is this not business as usual for each of the researchers involved?




Locations of earthquake epicenters (circles) and injection wells for Guy, Arkansas 2010-2011 and Lake, Ohio 1983-1986 earthquake swarms (Person et al., 2013)