

*Southwest Regional Partnership
on Carbon Sequestration*

Aneth EOR Project

In collaboration with
Resolute Natural Resources Company

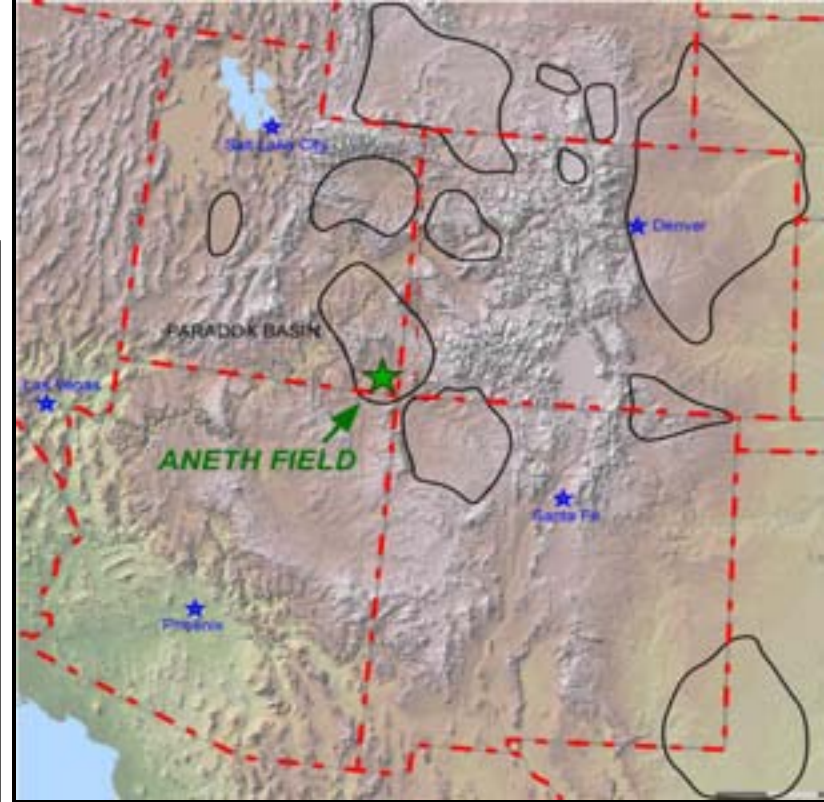
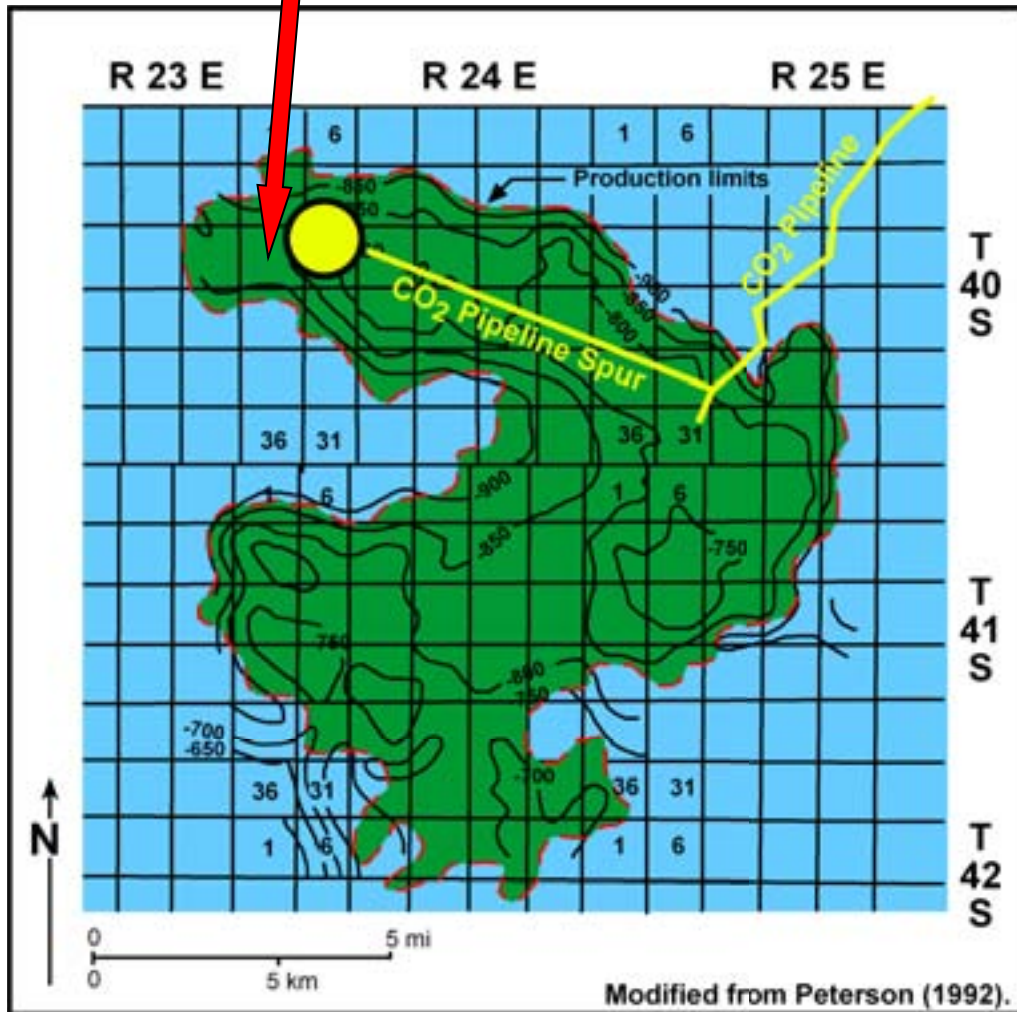
Jim Rutledge
Los Alamos National Laboratory



Outline of Presentations

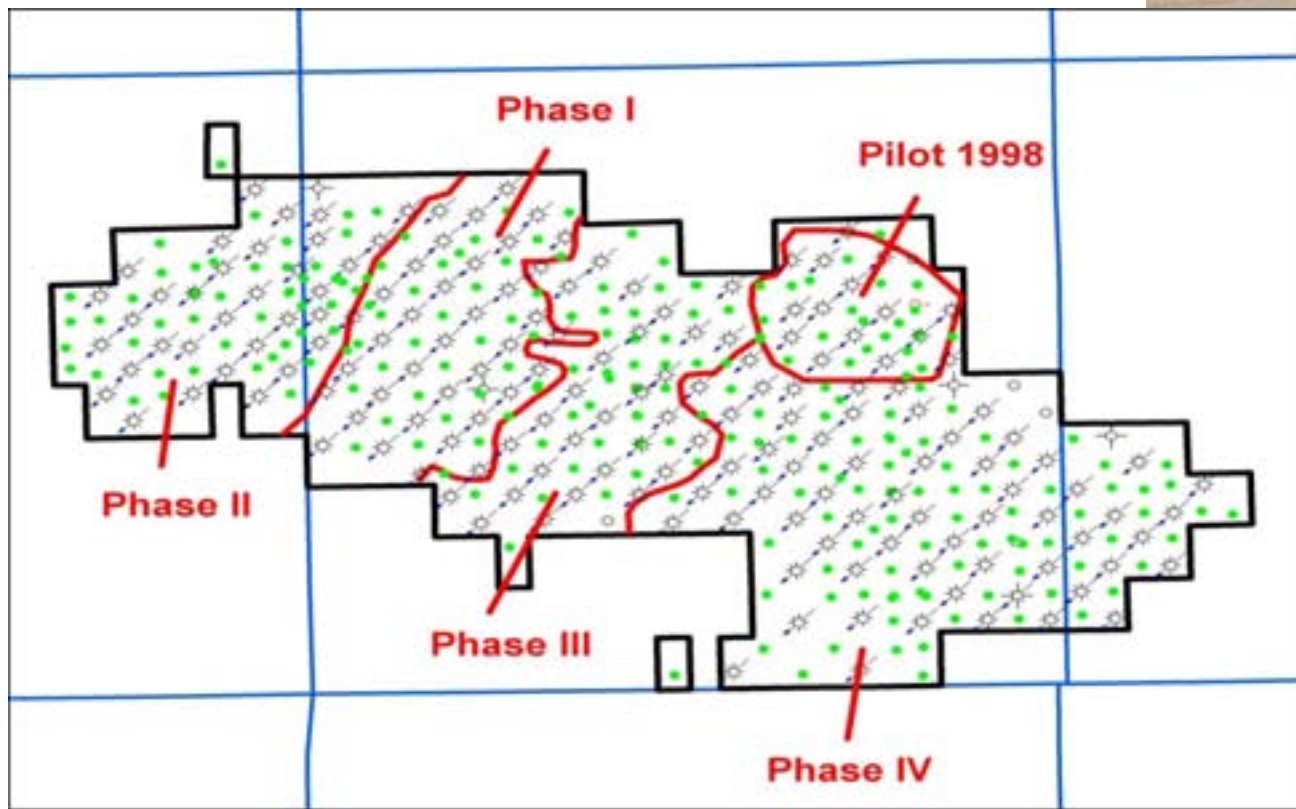
- **Introduction**
- **Time-lapse VSP and Microseismicity**
- **Tracer Study**
 - EGI at University of Utah
- **Reservoir Flow Modeling**
 - EGI at University of Utah
- **Gothic Shale Reservoir Seal**
 - Utah Geological Survey

Project CO₂ Monitoring Area



- Stratigraphic trap
- Discovered in 1956
- Waterflood initiated in 1961
- CO₂ initiated in 1985
- Current gross production rates
 - Aneth - 3,500 BOPD
 - McElmo Creek - 3,400 BOPD
 - Ratherford - 2,600 BOPD

Aneth Unit Injection Schedule

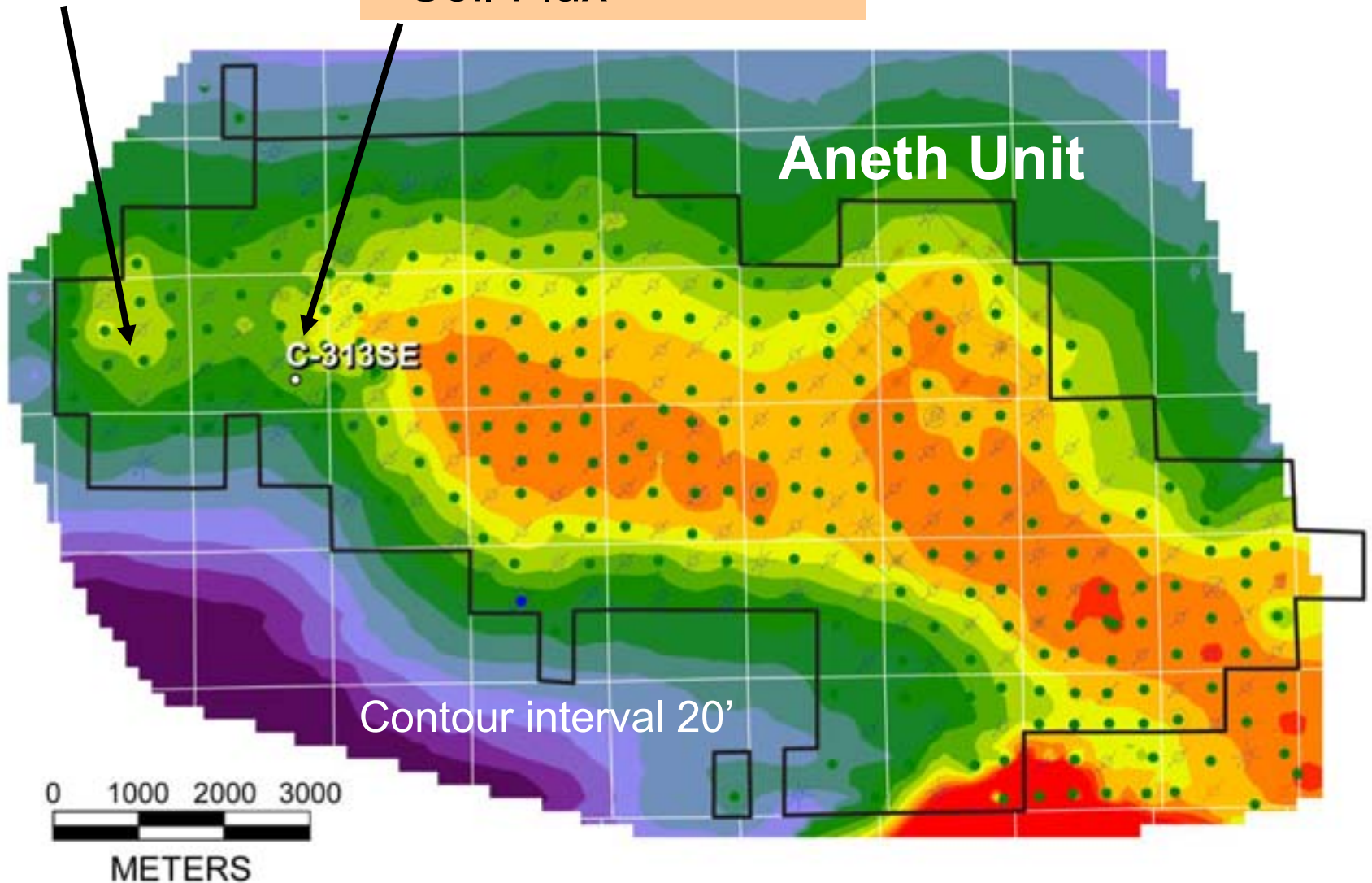


Phase I and II areas converted from water to CO₂ injection from Aug 2007 to April 2008

- Interwell Tracer Tests

- Time-Lapse VSP
- Microseismic
- Self-Potential
- Soil Flux

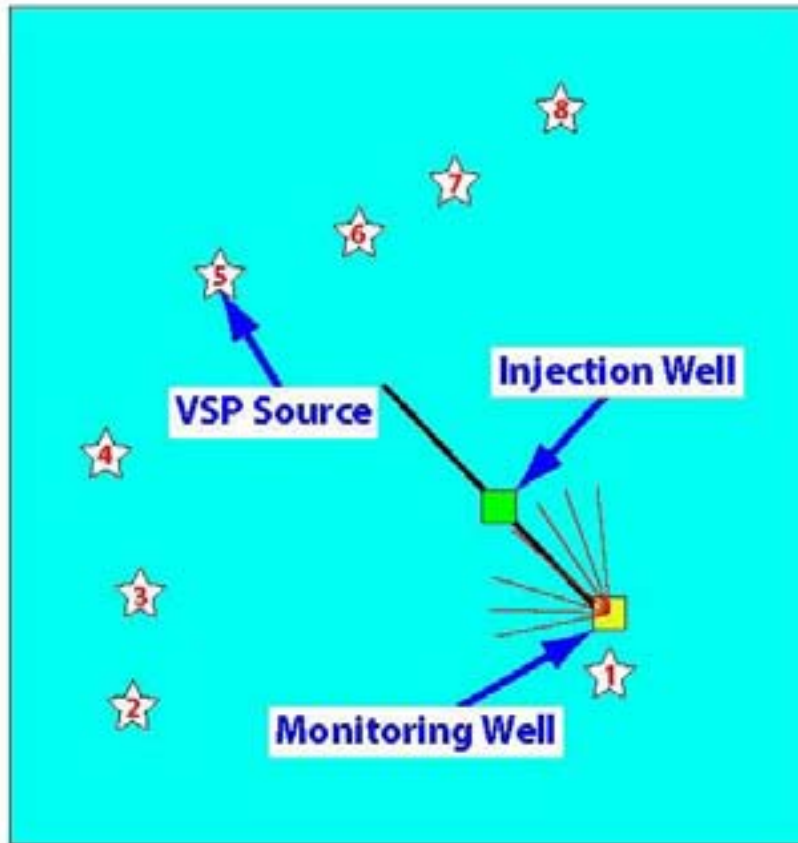
- Modeling and Simulation
- entire Aneth Unit



Geophone cable deployment – October, 2007



Time-Lapse VSP Surveys

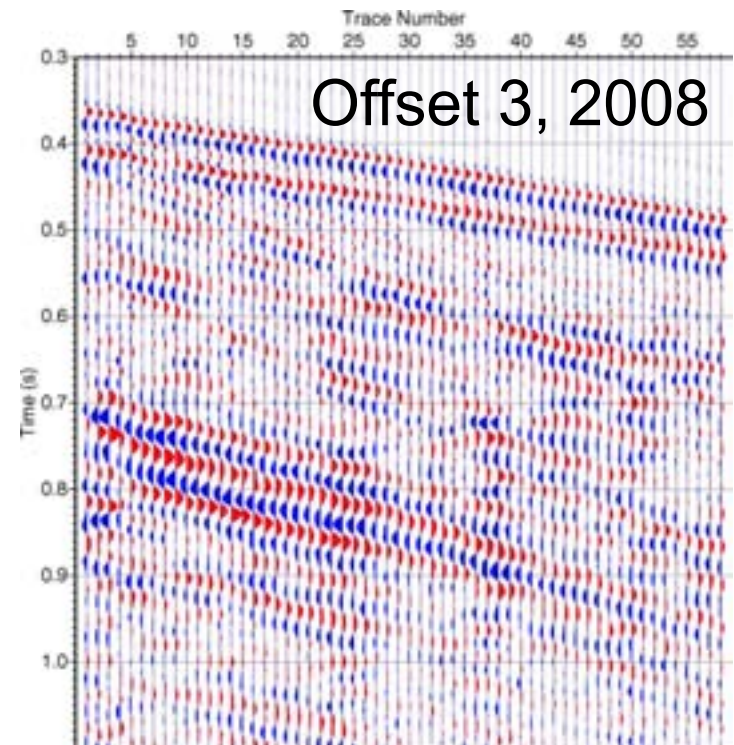
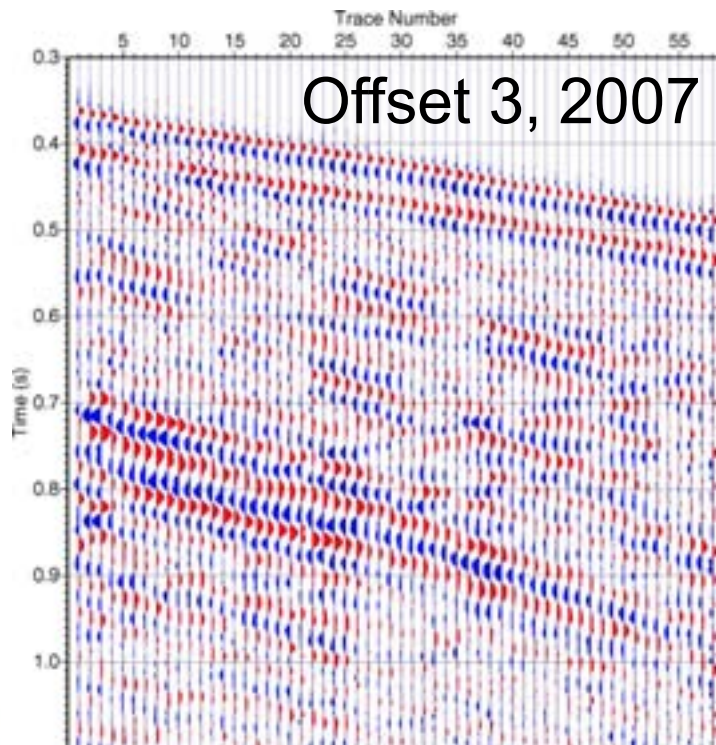


Section 13 – one square mile

- Horizontal well CO₂ injection:
Started in Feb. 2008
- Cemented geophone string:
60 levels: 805–1704 m
Reservoir: 1731–1786 m
- VSP sources:
One zero-offset, seven offsets
- Time-lapse VSP surveys:
 - Baseline: Oct. 2007
 - 1st repeat: Jul. 2008
 - 2nd repeat: Jan. 2009
- CO₂ injected:
~10,000 tones between VSPs

VSP Data Analysis

- Coda-wave interferometry
- Double-difference travelttime tomography
- Double-difference waveform tomography
- Elastic-wave reverse-time migration



Microseismic Monitoring

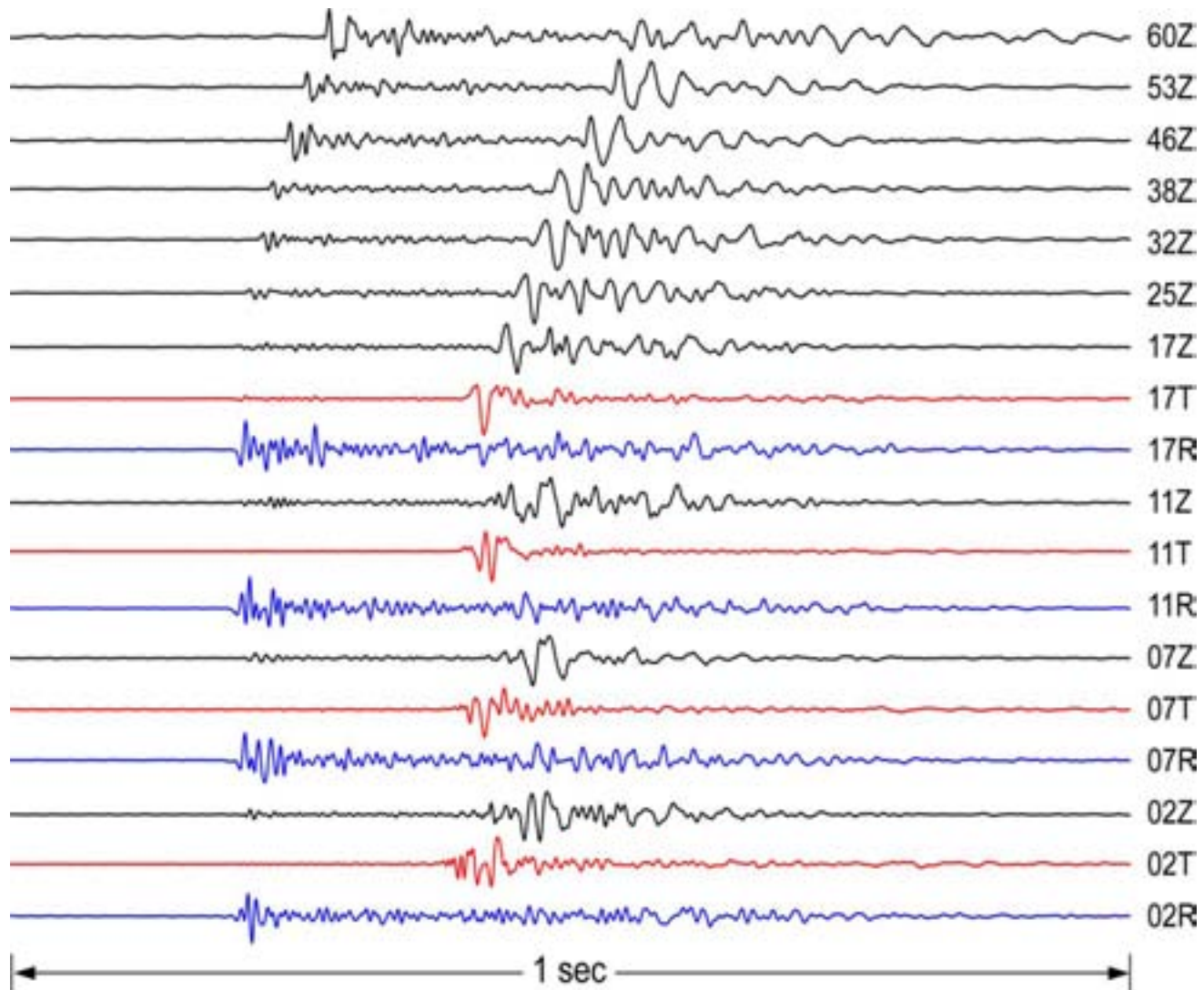


Monitoring 24 levels over 900 m length of the geophone array.

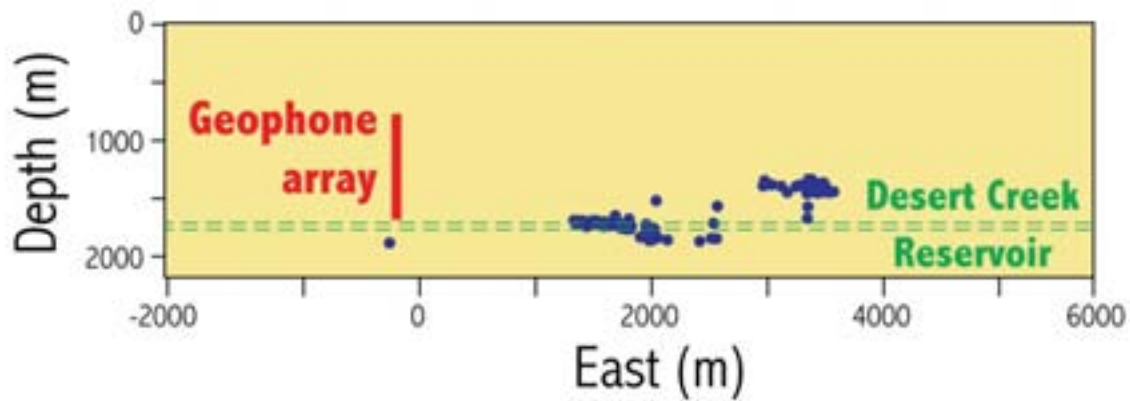
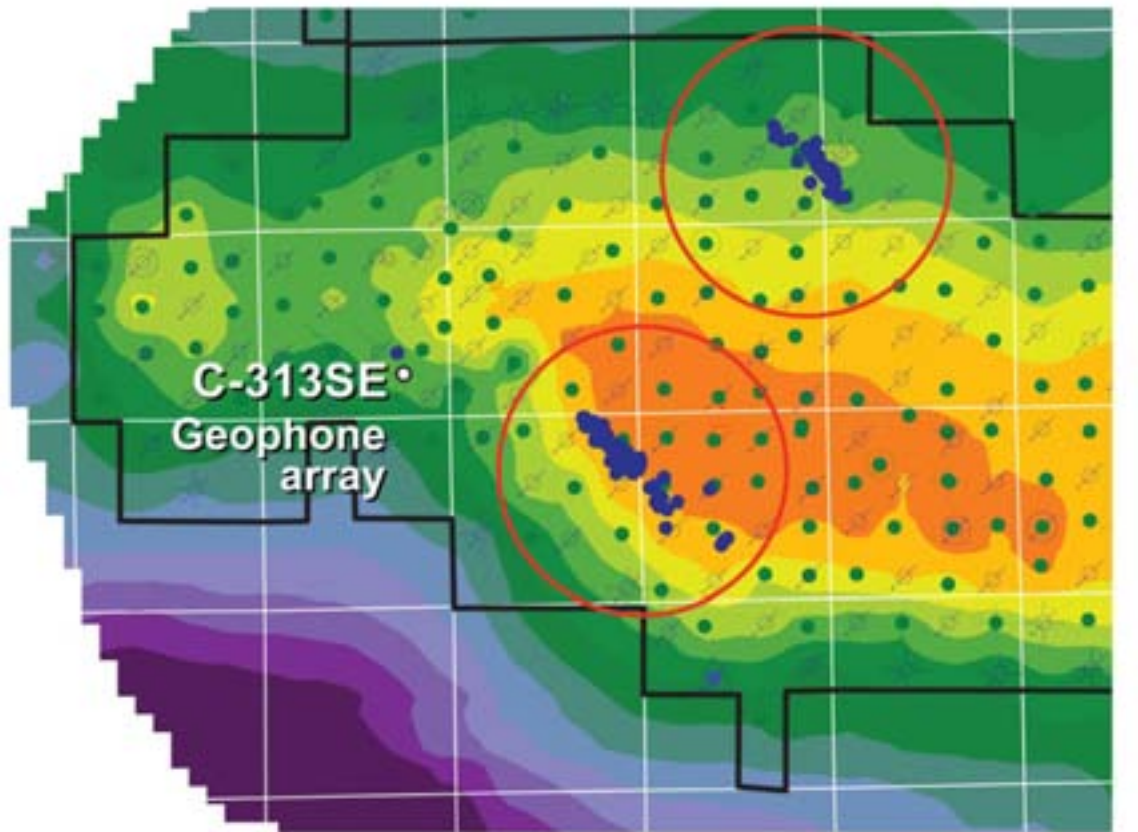
Satellite uplink back to Los Alamos.

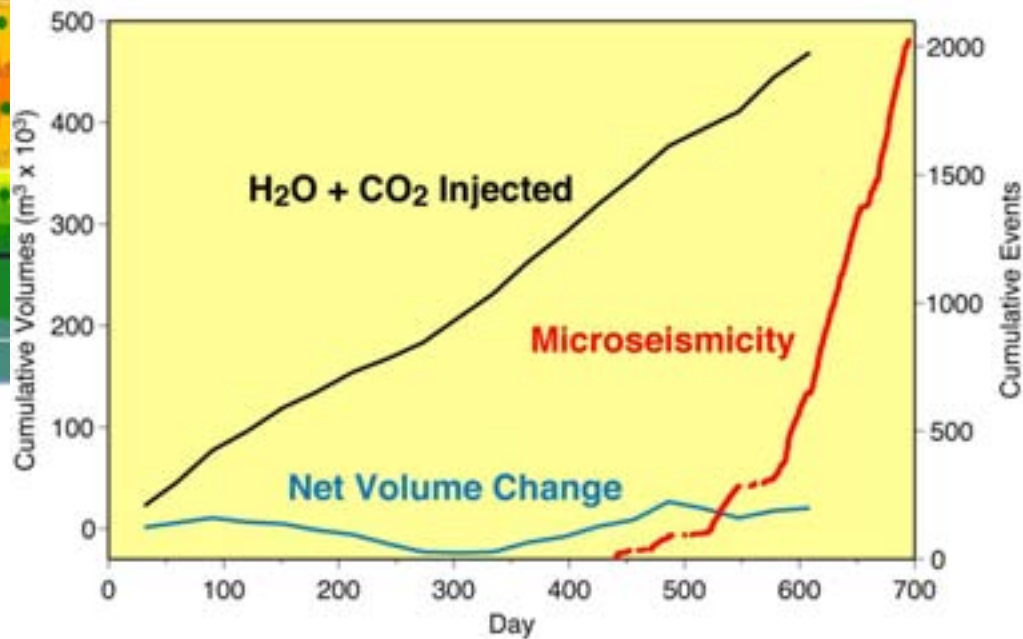
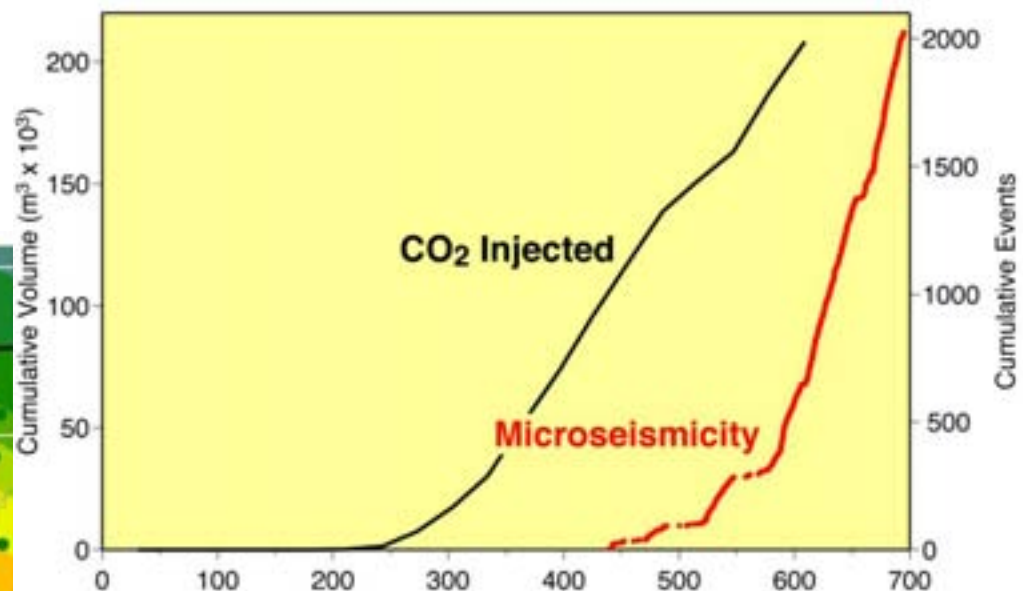
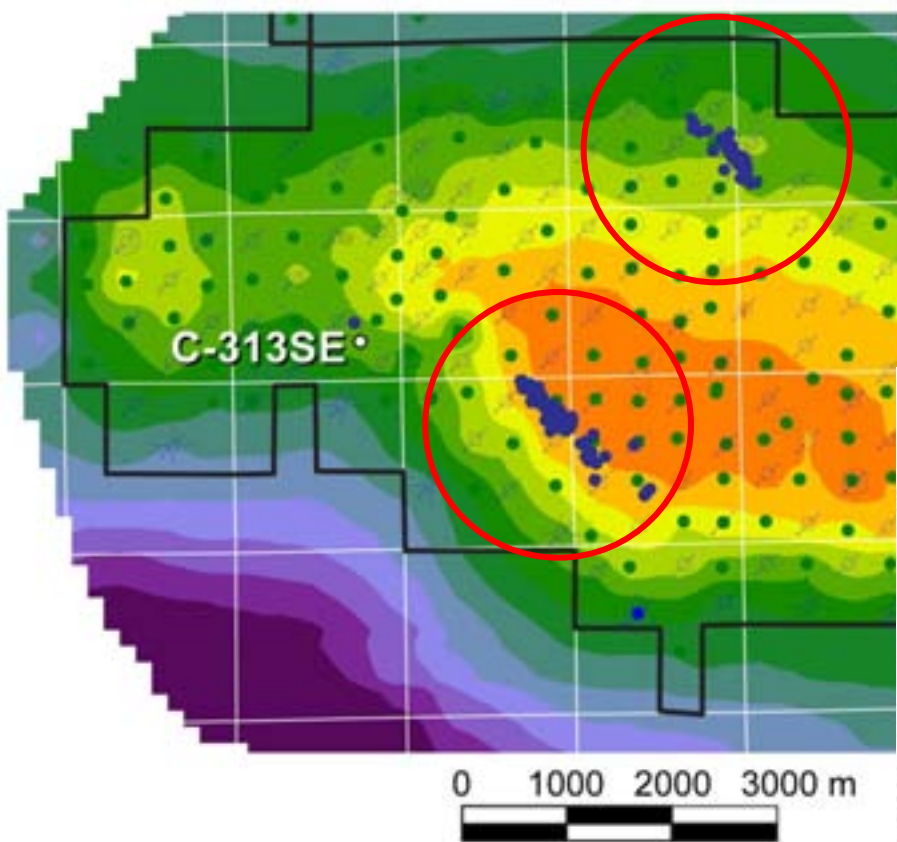


Microseismic Waveforms from Aneth

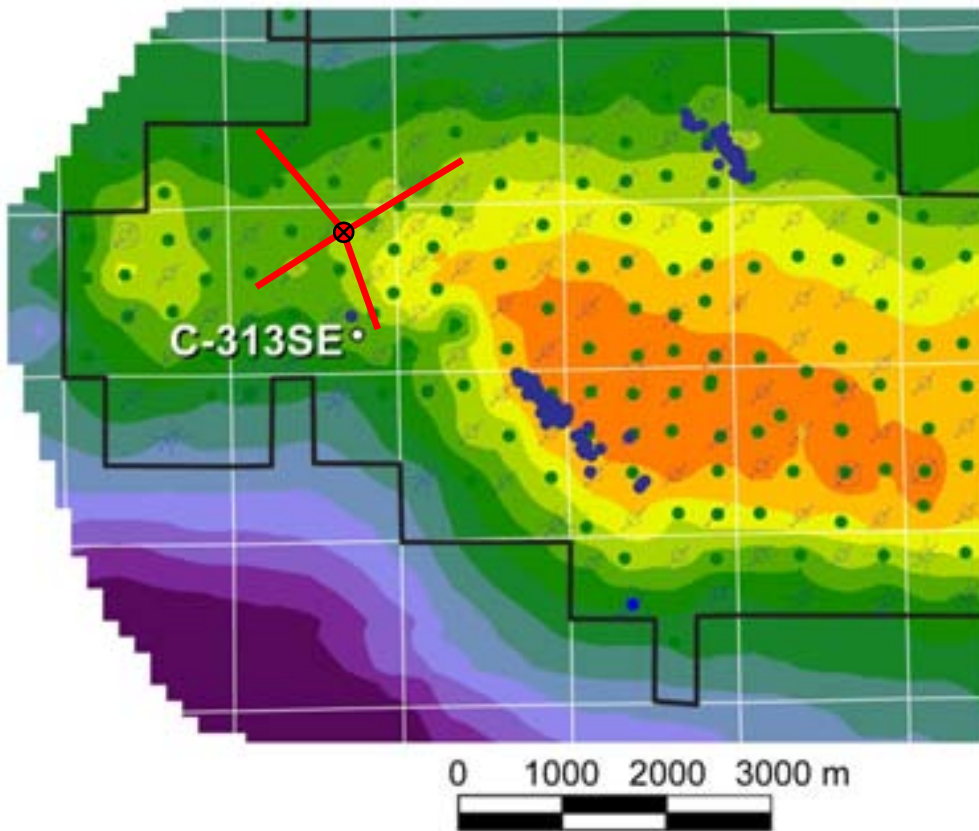


Microseismic Locations

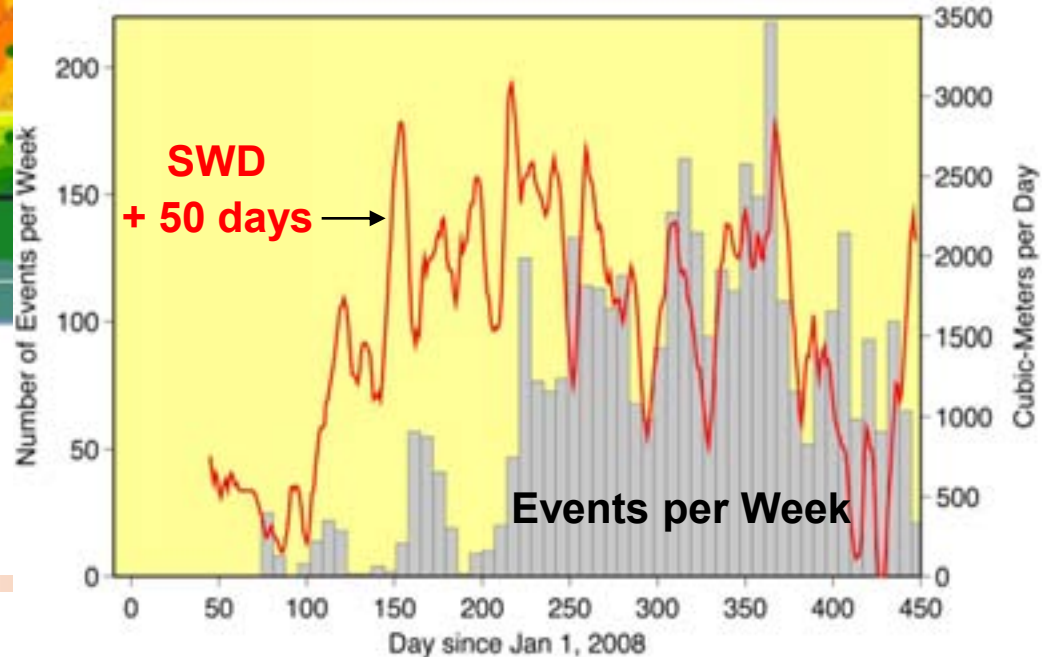
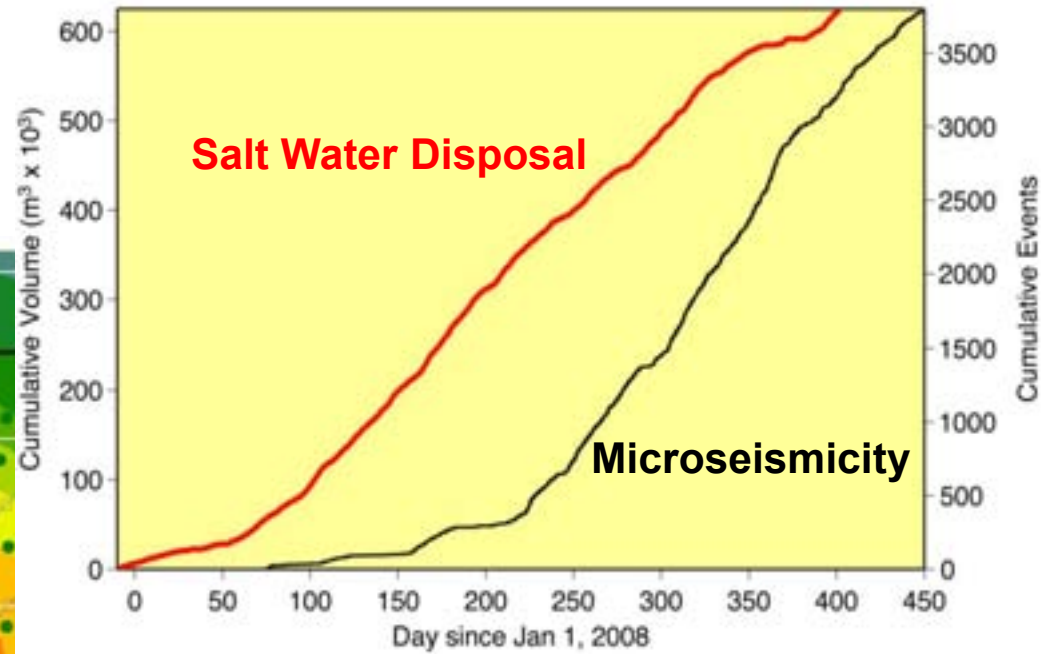
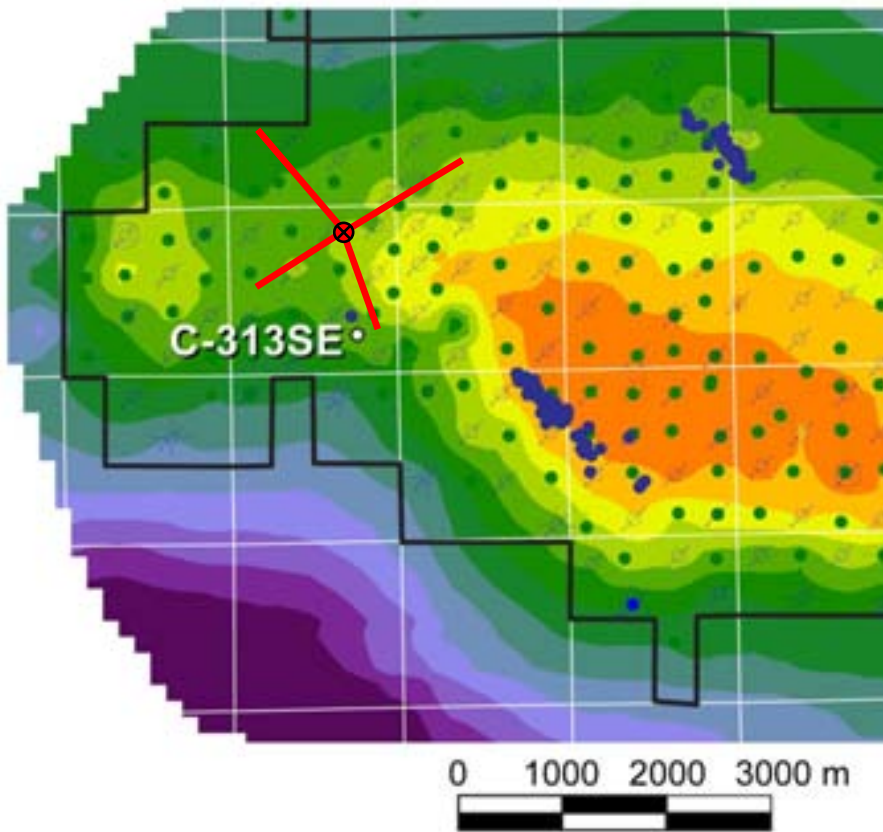




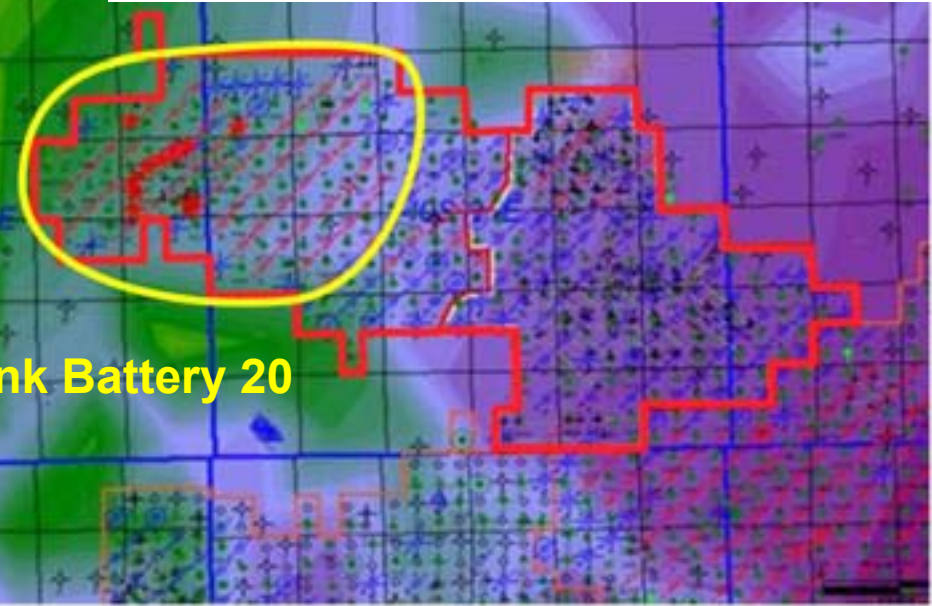
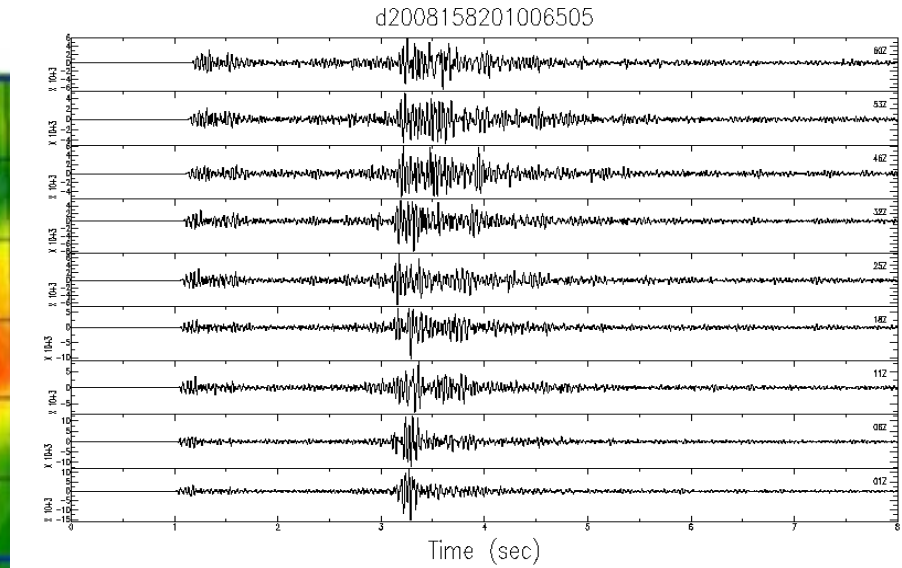
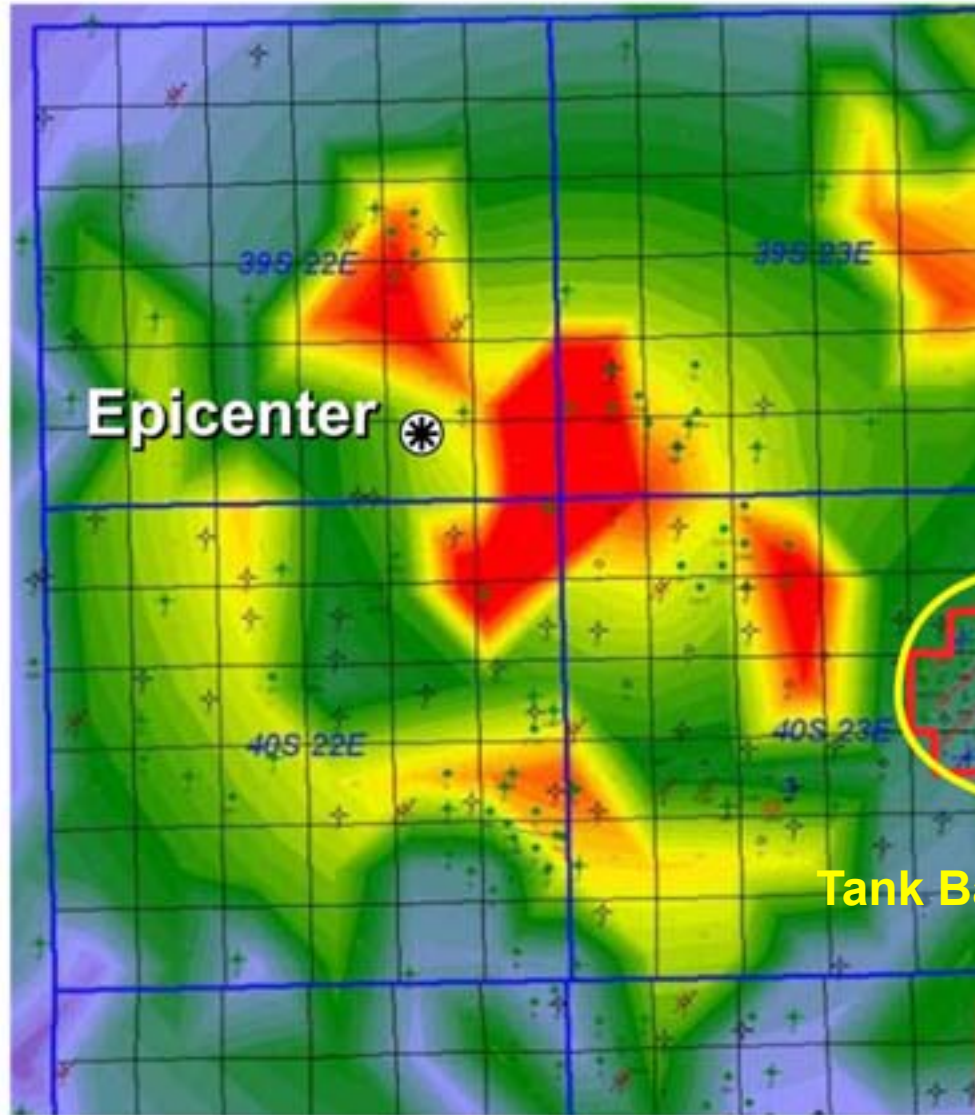
Salt Water Disposal and Seismicity

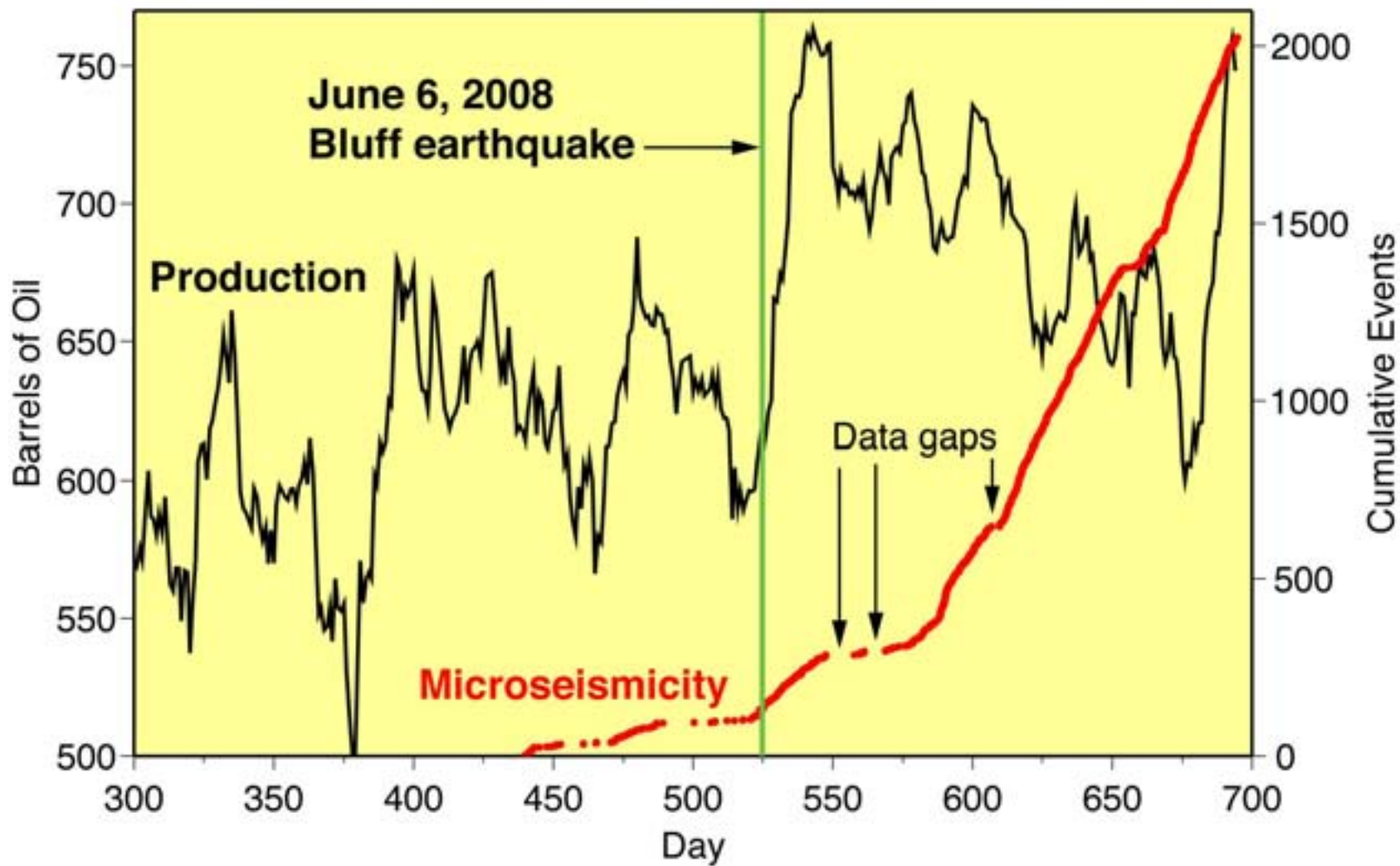


Salt Water Disposal and Seismicity



Shake Intensity – Bluff M3.6 Earthquake June 6, 2008





Microseismic Summary

- **Microseismic locations reveal NW-SE striking structures near the margins of the reservoir**
- **Microseismic activity does not correlate with current, “local” changes in injection activity**
- **Seismicity appears to lag deeper salt-water disposal, but is isolated from the injector.**
 - SWD a proxy for reservoir-wide production?
- **June 6 Bluff M3.6 earthquake may have affected production and reservoir seismicity**
 - Stress transfer driving pore pressure increase?

Tracer Testing at Aneth

Pete Rose and Kevin Leecaster,
Energy and Geoscience Institute at University of Utah

- **Method:**
 - Inject two distinct tracers into two injection wells
 - Perfluorohydrocarbons
 - Alcohols
- **Purpose:**
 - Evaluate, compare, & test potential tracers for CO₂ sequestration applications
 - Examine approaches for reducing the costs of such tests

Tracer Comparison

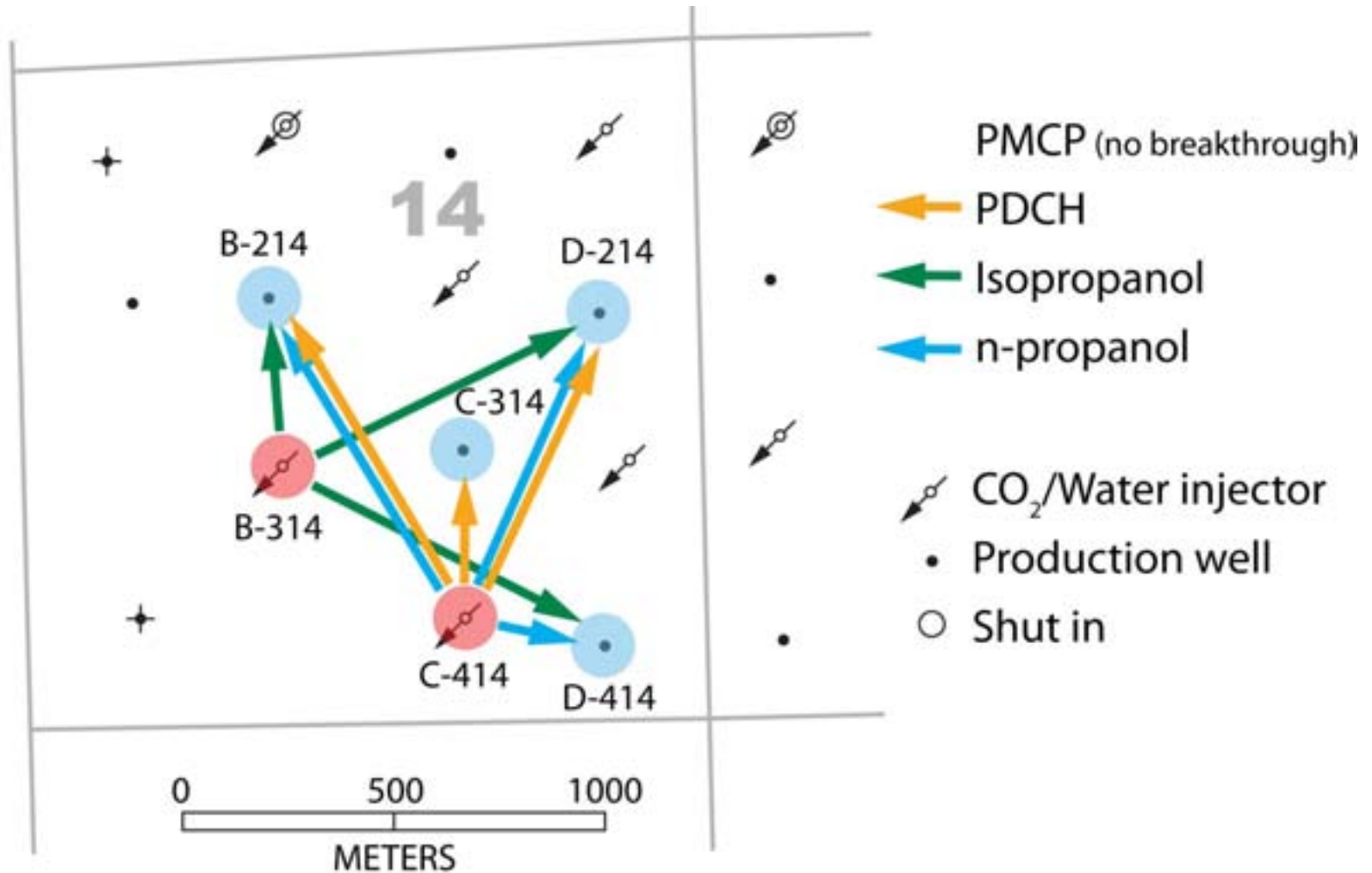
- **Perfluorocarbons**

- Highly detectable (parts per trillion)
- Insoluble in water
- Thermally & biologically stable
- Expensive

- **Low molecular weight alcohols**

- Detectable to parts per billion
- Miscible with water
- Thermally stable, but biologically unstable
- Inexpensive

CO₂-Flood (Vapor-Phase) Tracer Test (Initiated on 7/21/09)



Tracer Test Conclusions

- Breakthrough of both alcohol tracers & one perfluoro-hydrocarbon tracer to several of the surrounding wells
- The demonstration of the first reported use of alcohols as tracers in either oilfield CO₂ flooding or CO₂ sequestration
- Significant tracer cost savings in the use of alcohol tracers--greater than a 100-fold reduction in tracer costs alone

Aneth Geological Model Development

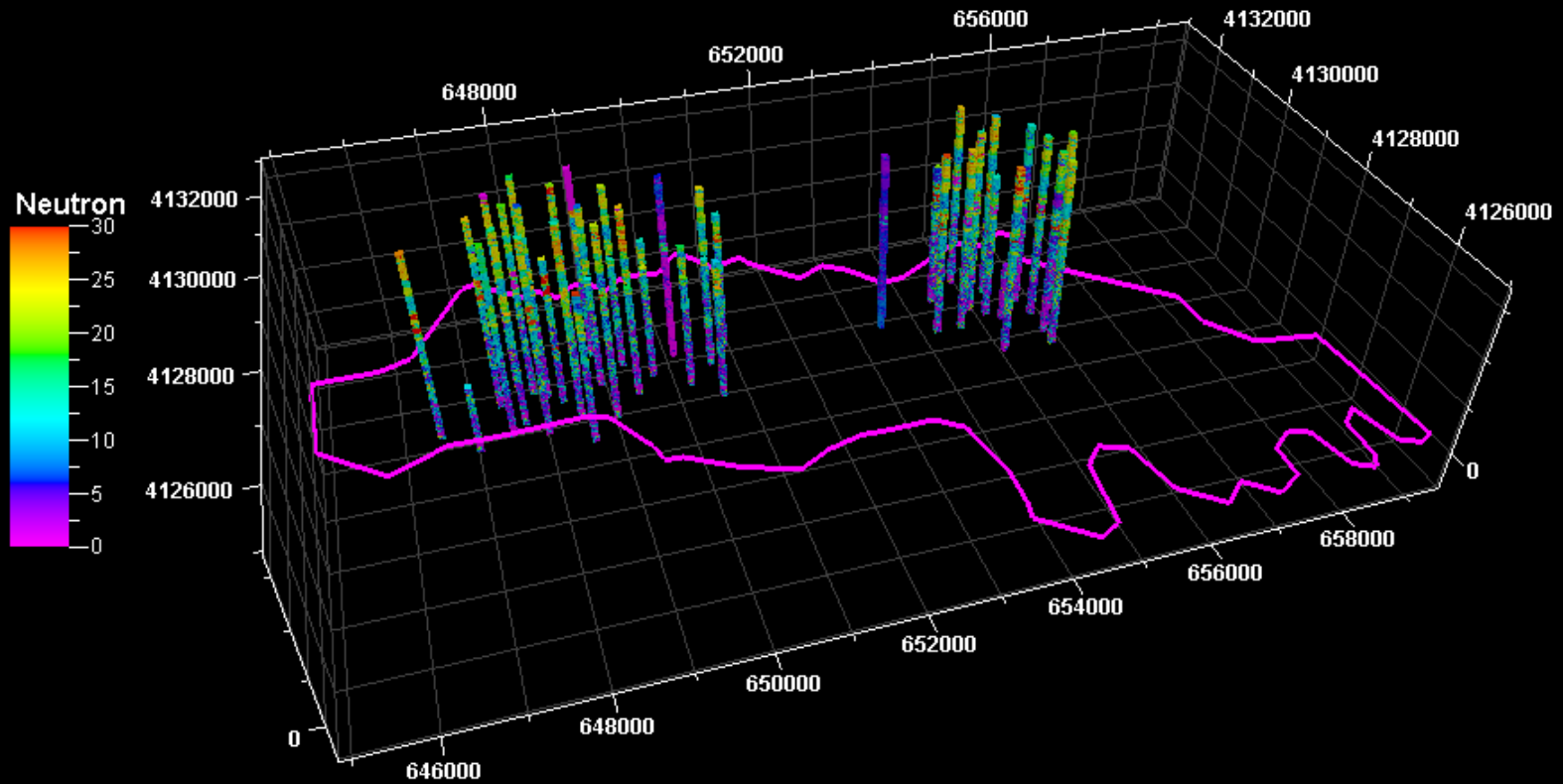
Si-Yong Lee and Chuan Lu

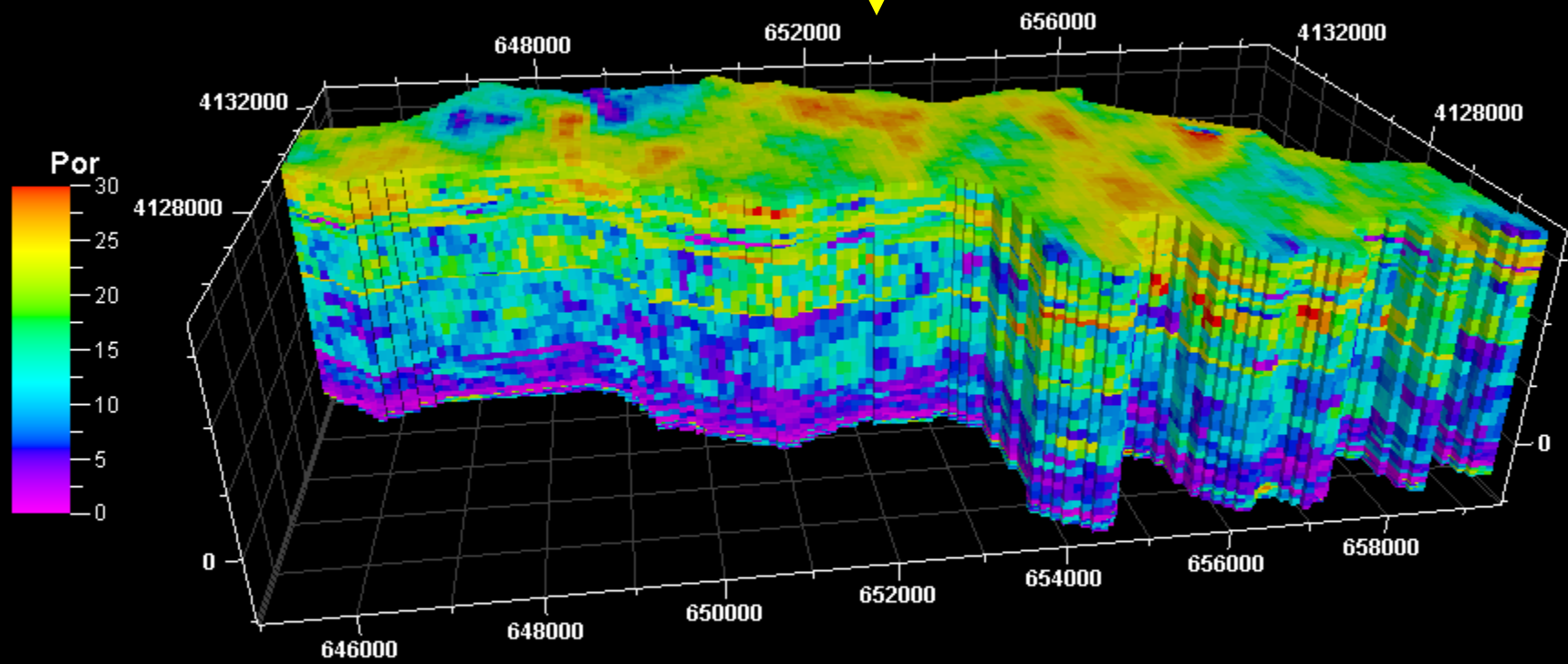
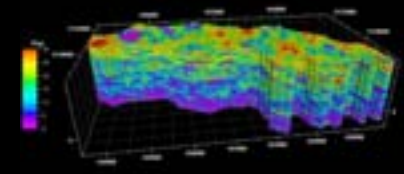
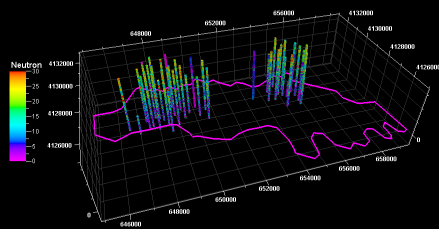
Energy & Geoscience Institute - University of Utah

Data Acquisition

- Geophysical well log images – *digitized by EGI*
- Core plug analyses – *Terra Tek/UGS*
(porosity, density, and permeability)
- Stratigraphic formation tops data - *UGS*
- Well information – completion zones - *Resolute*
- Injection/production history - *Resolute*

Upscaled Porosity Logs

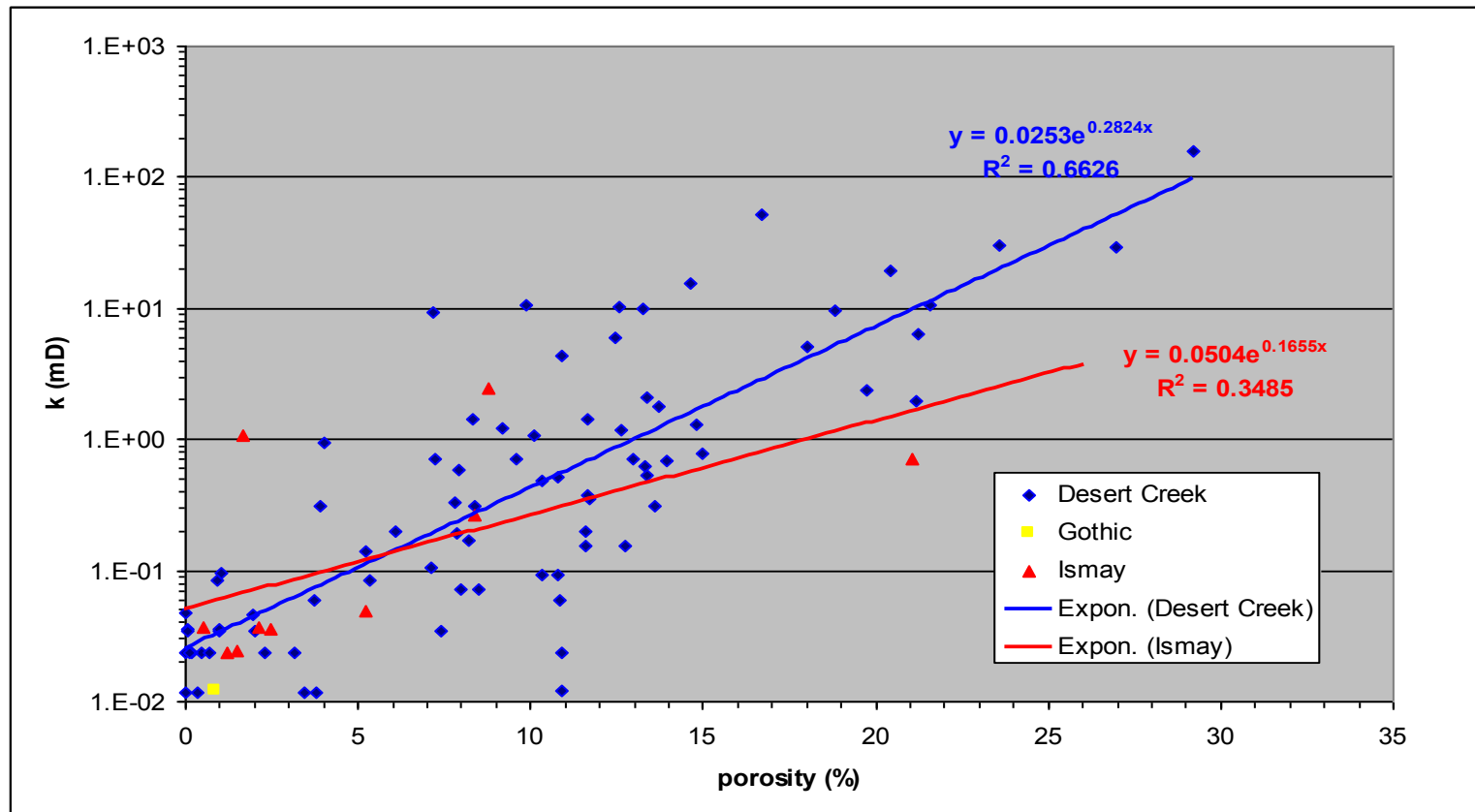


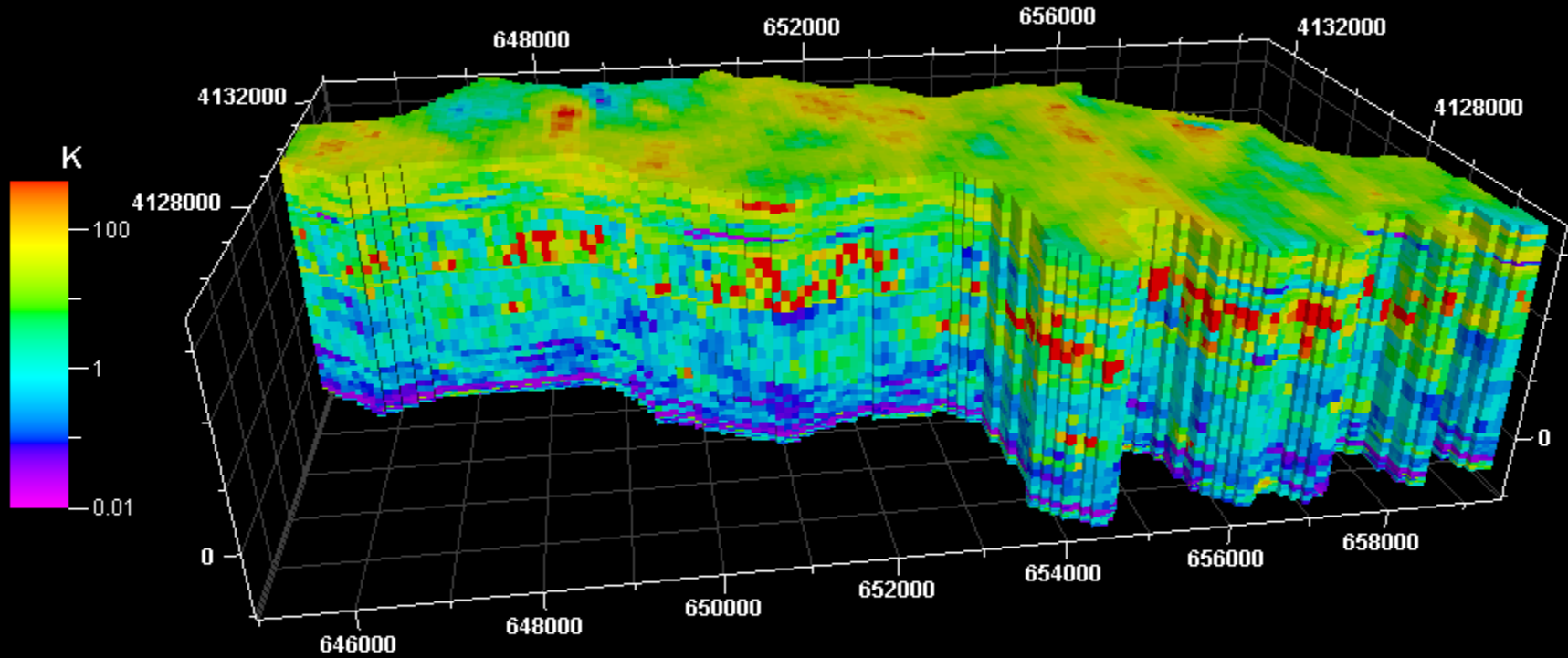
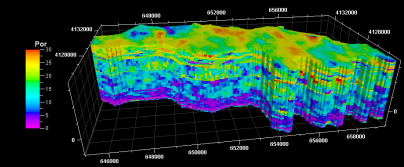
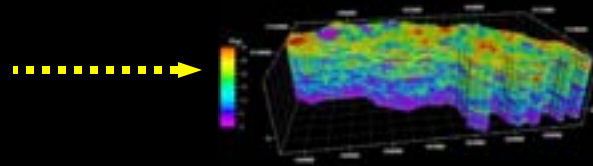
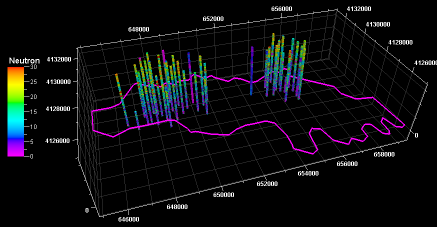


Upscaled Porosity Field
($n=227,950$; $dx=dy=100m$; $nz=41$)



Porosity vs. Permeability





Permeability Field
 (n=227,950; dx=dy=100m; nz=41)



On Going and Future Work

- **Grid conversion for PFloTran**
- **Examining grid effects with a series of different grid spacing or sizes**
- **Inter-code comparison with a commercial simulator**
- **Continue Digitizing well logs**
- **Stochastic simulation approach**
- **Simple history matching**
- **Simulation of a series of CO₂ / WAG EOR**

The Gothic Shale at the Aneth Unit: Seal for Hydrocarbons and Carbon Dioxide Geologic Sequestration

Thomas C. Chidsey, Jr., *Utah Geological Survey*

Jason Heath, *New Mexico Institute of Mining & Technology,*
and

Thomas Dewers, *Sandia National Laboratories*



Sealing Quality Assessment

Geochemical properties:

- TOC/Rock Eval.
- CO₂ adsorption isotherm
- XRD, XRF

Petrological description:

- Thin sections
- SEM, BSE, LSCM

Fracture analysis:

- Fracture type, orientation, dip, mineral fill, assessment of failure potential of natural fractures

Petrophysical properties:

- Tight rock analysis method
- Permeability, porosity

Geomechanical properties:

- Continuous strength profiling
- Multistage compression testing
- Multi-stress path testing



Conclusions (in part)

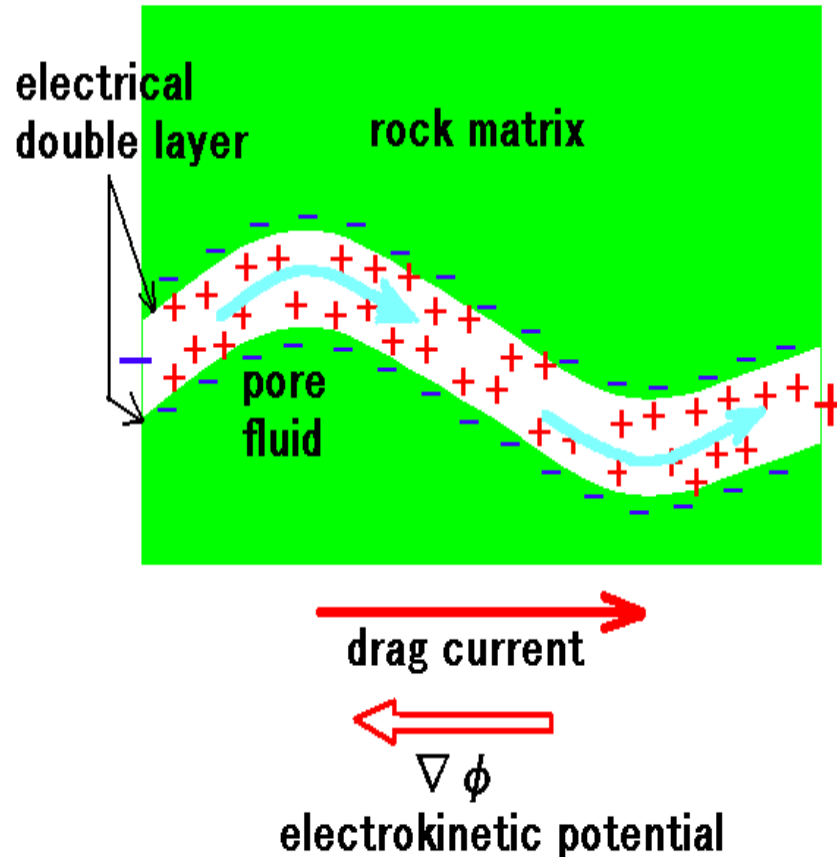
- The Gothic shale is an effective seal above the Desert Creek reservoir zone.
- The Gothic is remarkably uniform mudstone/shale.
- Continuous unconfined compressive strength profiles show a relatively uniform homogenous shale package.
- Should support very large CO₂ columns based on mercury injection capillary pressure and pore aperture distributions analysis.
- Compressional testing suggests some degree of hydraulic fracture containment.
- Near the base of the Gothic section vertical to subvertical extensional fractures are present.



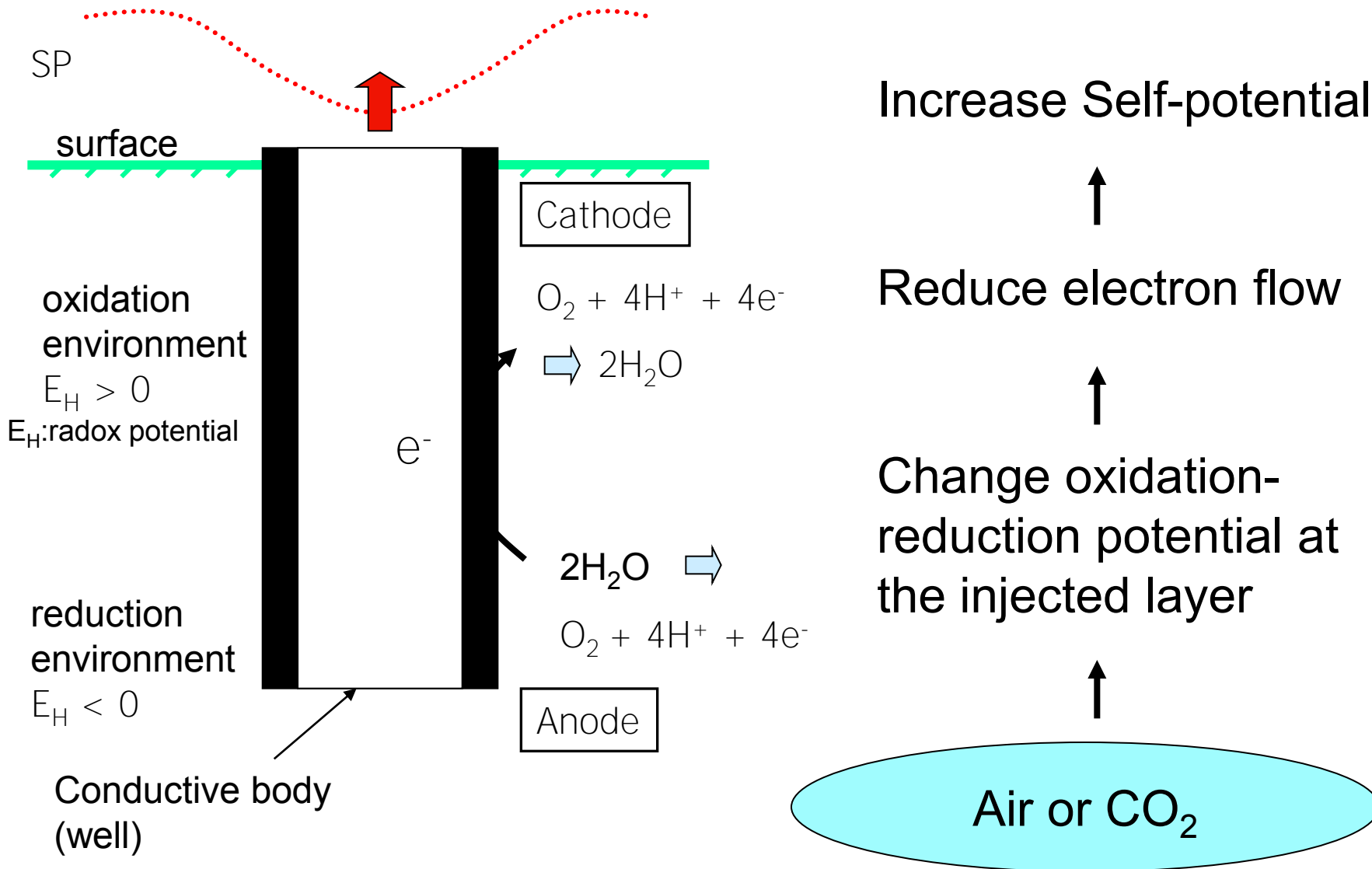
Self-potential monitoring in Aneth

Y. Nishi, T. Tosha, N. Tenma and T.Ishido
(AIST - Japan)

Electrokinetic potential



REDOX self-potential change expected for CO2 injection (Tosha et al., 2007)



Self-Potential data recorded in Aneth: C313 injection well

