CO_2 Injection Performance in the Fruitland Coal Fairway, San Juan Basin: Results of a Field Pilot

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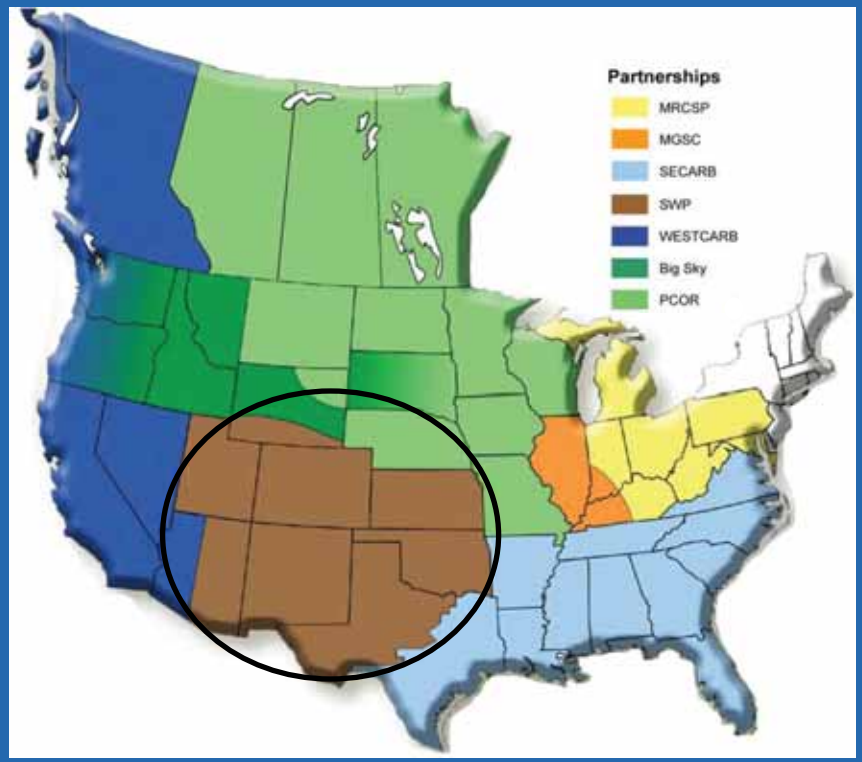
Outline

- Introduction
- Permitting and Regulatory
- Field Operations
- Measurement, Verification and Accounting
- Reservoir Characterization
- Reservoir Modeling
- Conclusions

Project Background

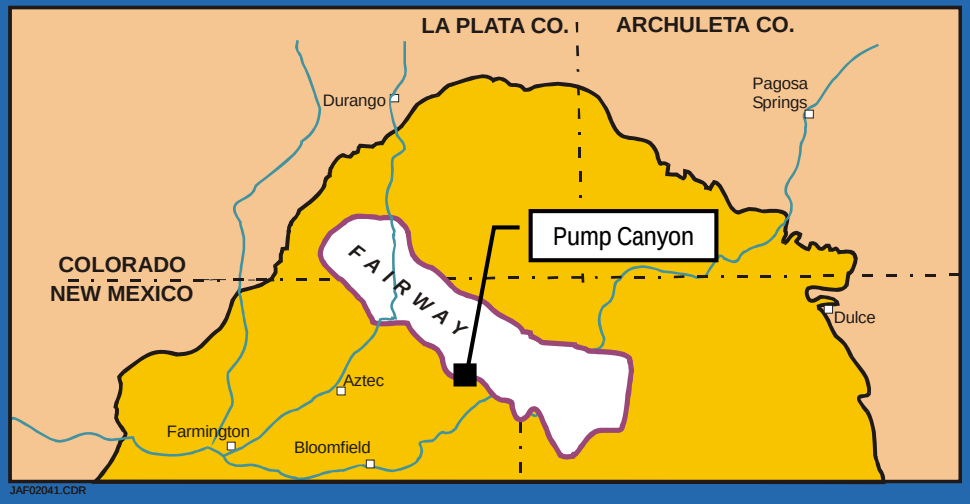
- **The Southwestern Partnership (SWP) is one of seven regional partnerships sponsored by the U.S. Department of Energy (DOE)**

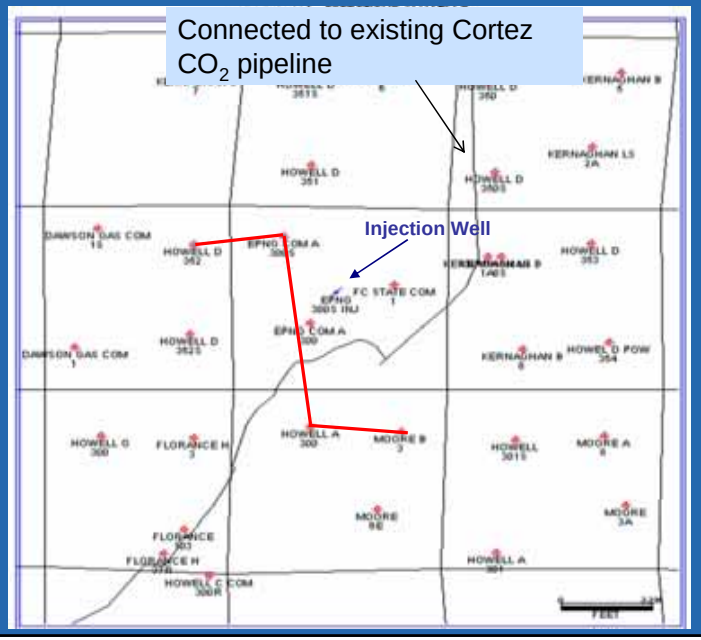


- **Phase I - Characterization**
- **Phase II – Validation**
  - **the SACROC Unit**
  - **the Aneth oil field**
  - **the Pump Canyon site : unmineable coalbed methane**
- **Phase III – Deployment**

Demonstration Site Selection

- **Key considerations:**
  - **Within the high-permeability fairway to maintain high CO_2 injection rates**
  - **Nearby source of CO_2 : Kinder-Morgan pipeline**
  - **Amongst ConocoPhillips-operated production wells**





Permitting and Regulatory

- Injector Well
  - Application for Permit to Drill and for Authorization to Inject
- Pipeline
  - Right of way must be obtained
    - Archeological survey
    - Environmental assessment (EA) study
- Site Access
  - Work Authorization Agreement (WAA) between the individual SWP contractors and ConocoPhillips
- National Environmental Policy Act (NEPA)
  - Environmental questionnaire must be completed
- National Historic Preservation Act (Section 106)
  - Any proposed surface disturbances must be reviewed by the State Historic Preservation Office (SHPO) and any Native American tribes
  - After being delayed, Section 106 was approved in April 2008, which allowed field operations to start.

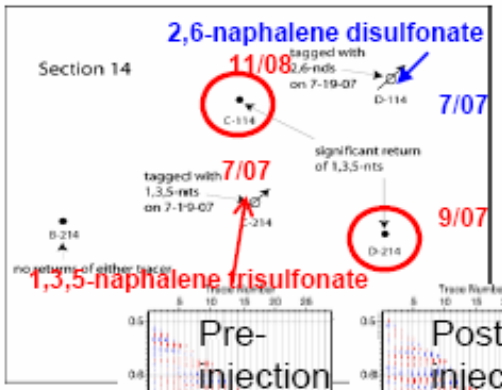
Field Operations
Injection Well Construction

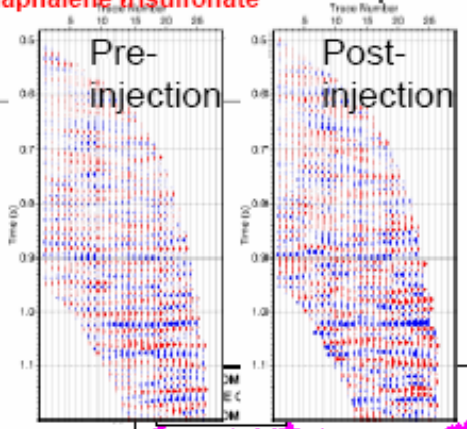
- Well drilled just above the upper coal to casing point at about 3,000 ft
- Kirtland shale (overlies the Fruitland coal) was cored
- First logging suite was conducted
- Casing was set
- Well drilled through Fruitland coal with air mist
- Hole under-reamed to 9 ½ "
- Coal cuttings collected through each coal
- Second logging suite and pre-injection VSP were run
- Well couldn’t be stimulated due to low pressure

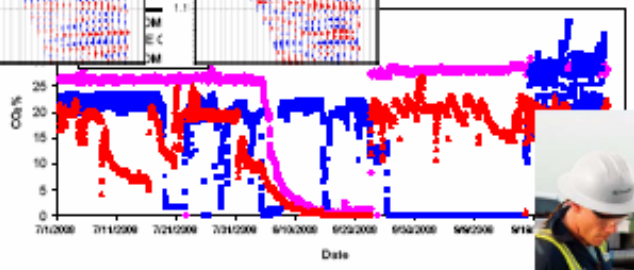
Field Operations
Pipeline Construction

- 4-inch diameter, 2.6-mile pipeline tied to the Kinder-Morgan operated Cortez pipeline
- Trenching started in January 2008 but was halted over State lands while waiting for the Section 106 consultation process to be completed
- Line is being turned over to move produced water from the site

Monitoring, Verification and Accounting







Distribution/Movement of CO2 **in** Reservoir

Tracers (Perflorocarbons-gas, naphalene sulfonates – H2O)

Time lapse VSP (Vertical Seismic Profiling)

Produced Fluids (fluid chemistry and [CO2])

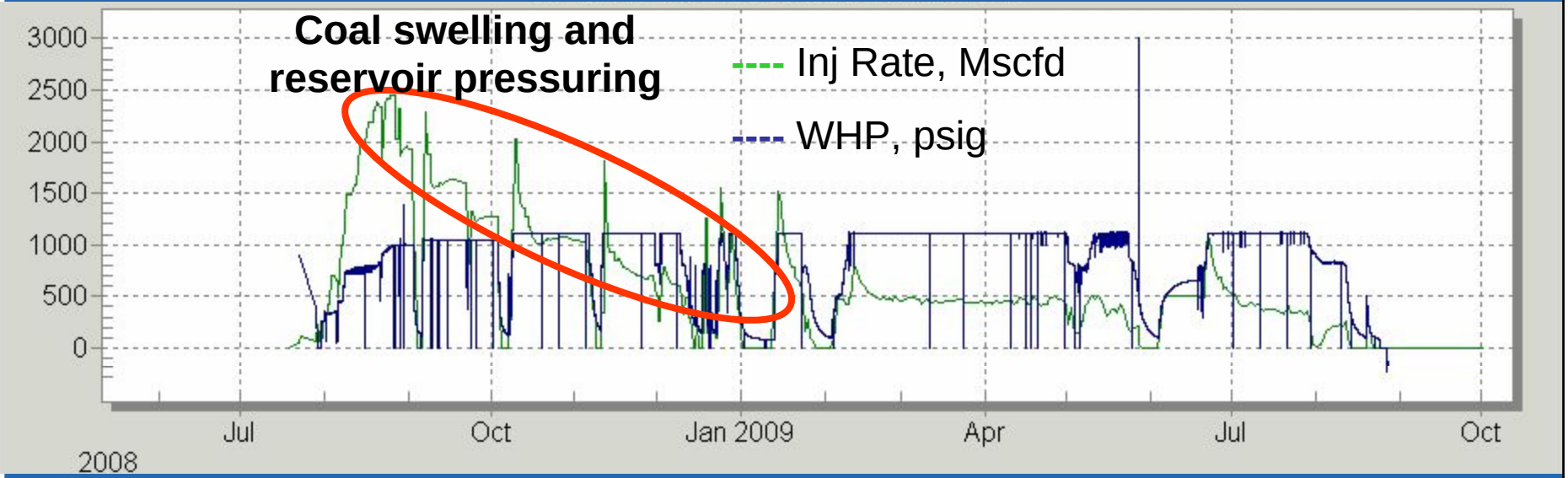
Tiltmeters + InSAR (Ground swell)

Injection Well

- Continuous surface measurements of CO_2 injection volumes, pressures and temperatures
- Downhole measurements of injection pressure and temperature
- Injection started on July 30th, 2008 and ended on July 29th, 2009
- Injection rate maximized at 1,100 psig

Injection Profile

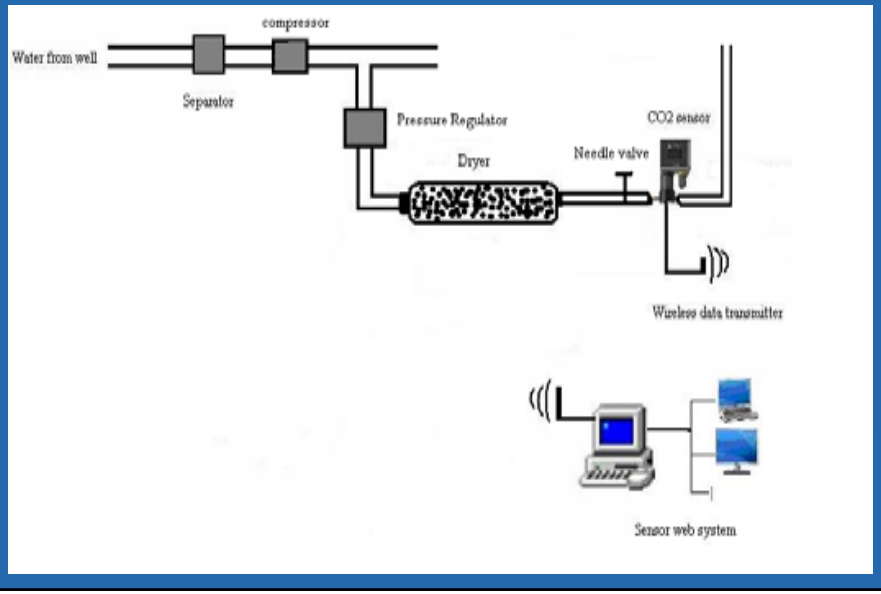
- Planning was to inject CO_2 in stages from bottom to top to minimize breakthrough
- Due to delays in permitting, CO_2 was injected simultaneously in the three layers



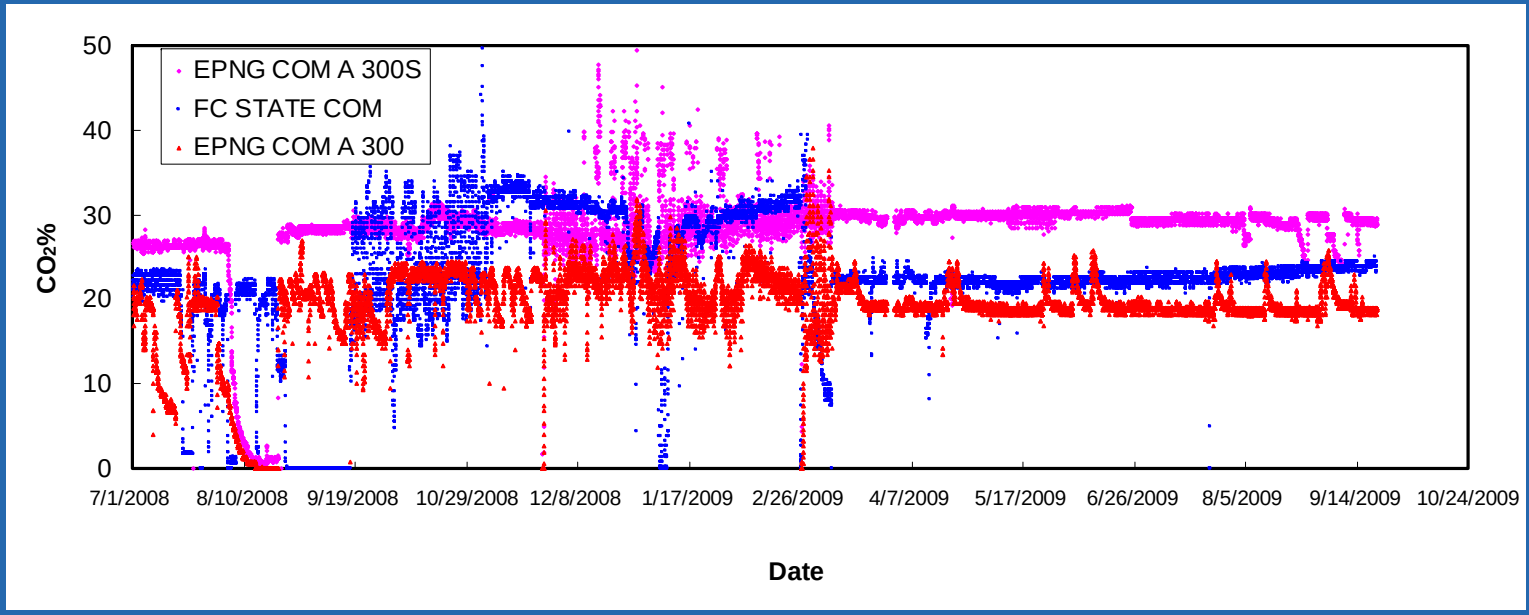
A total volume of 18,400 tons of CO_2 was injected

Offset Producer Wells

- CO_2 concentration change in the produced gas stream is an important tracking mechanism
- Used to determine the subsurface CO_2 movement and the CO_2 breakthrough point
- Sensors deployed for the 3 immediate offset wells



CO_2 Concentration Change Three Monitoring Wells



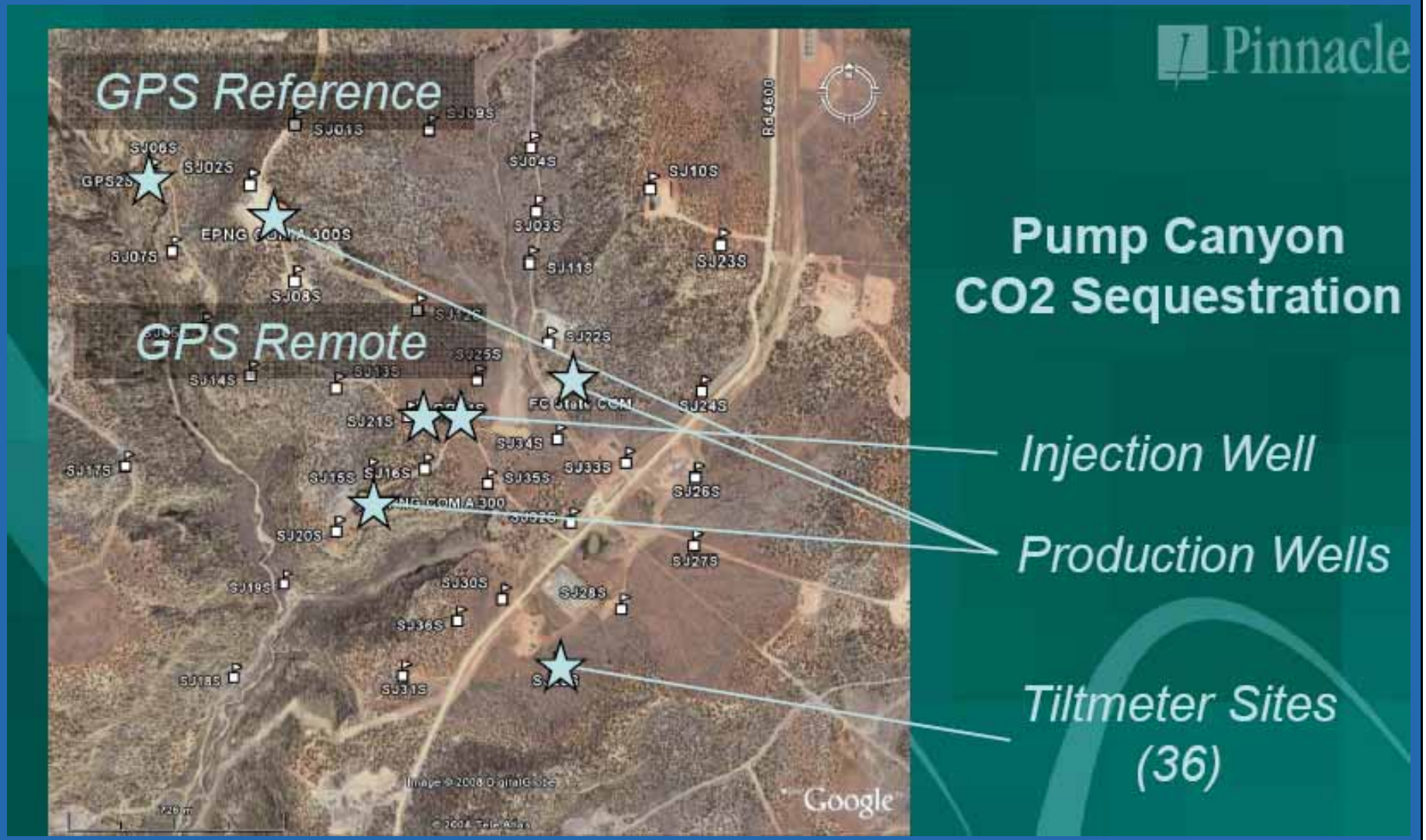
Gas samplings were performed regularly in surrounding wells. Increase in N_2 concentration was noticed in two wells.

	10/24/07	01/04/08	04/30/08	07/28/08	09/11/08	11/13/08	02/25/09	05/20/09
N_2%	0.051	0.039	0.147	0.078	0.448	**2.020**	**1.724**	**1.512**
CO_2%	19.8	19.4	19.7	20.6	19.4	23.7	21.4	20.0
CH_4%	75.9	78.9	76.3	78.0	76.7	72.1	73.7	74.8

Tiltmeters

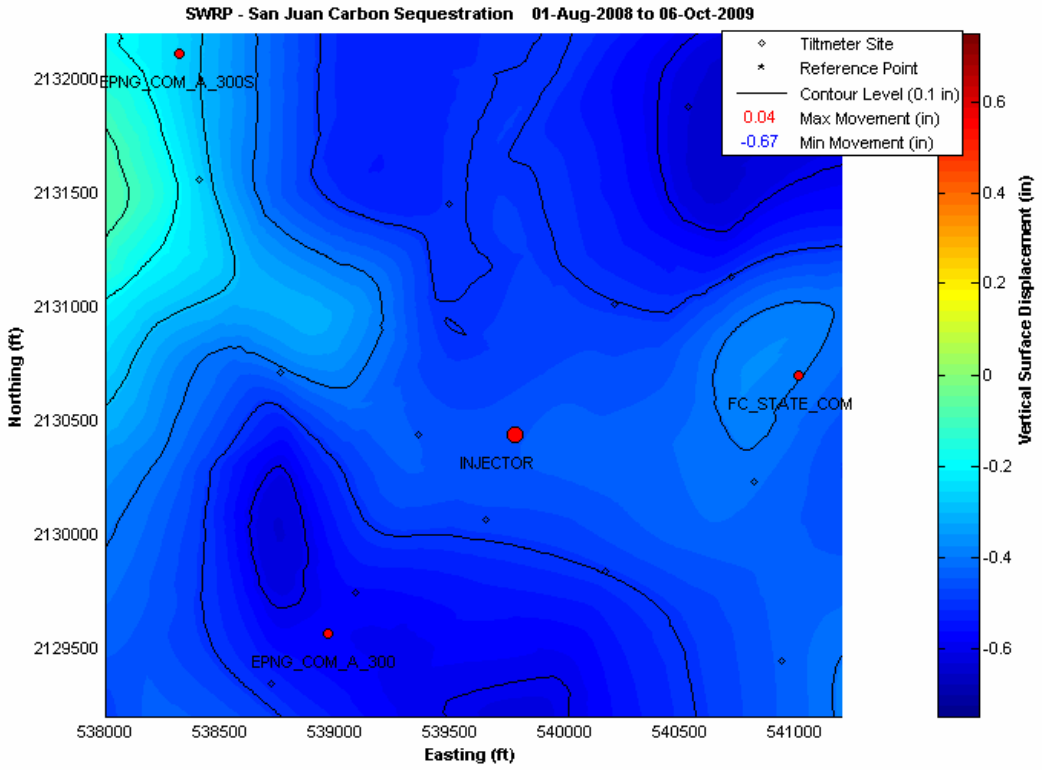
- Designed to measure very small changes (*relative* deformation) from the horizontal level
- A total of 36 surface Tiltmeters were installed in shallow 40ft deep boreholes
- Tiltmeters go through a settling process, which lasts approximately 2 weeks
  - 2 months settling for Pump Canyon due to permitting delays
- To determine the *absolute* changes in elevation, two differential GPS stations were integrated into the above Surface Tiltmeter Monitoring (STM) array

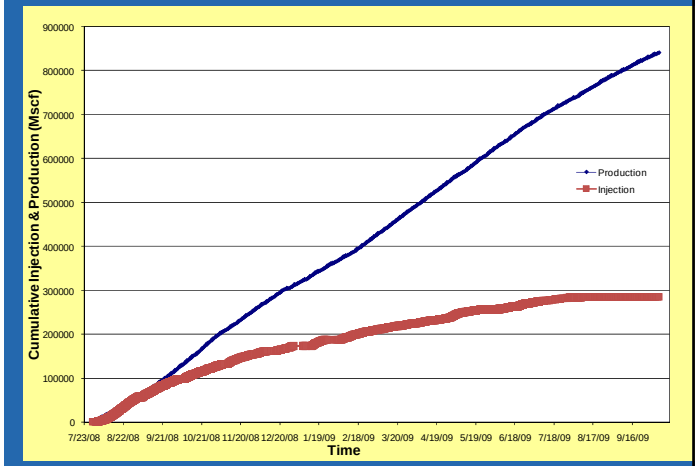
Tiltmeters Location



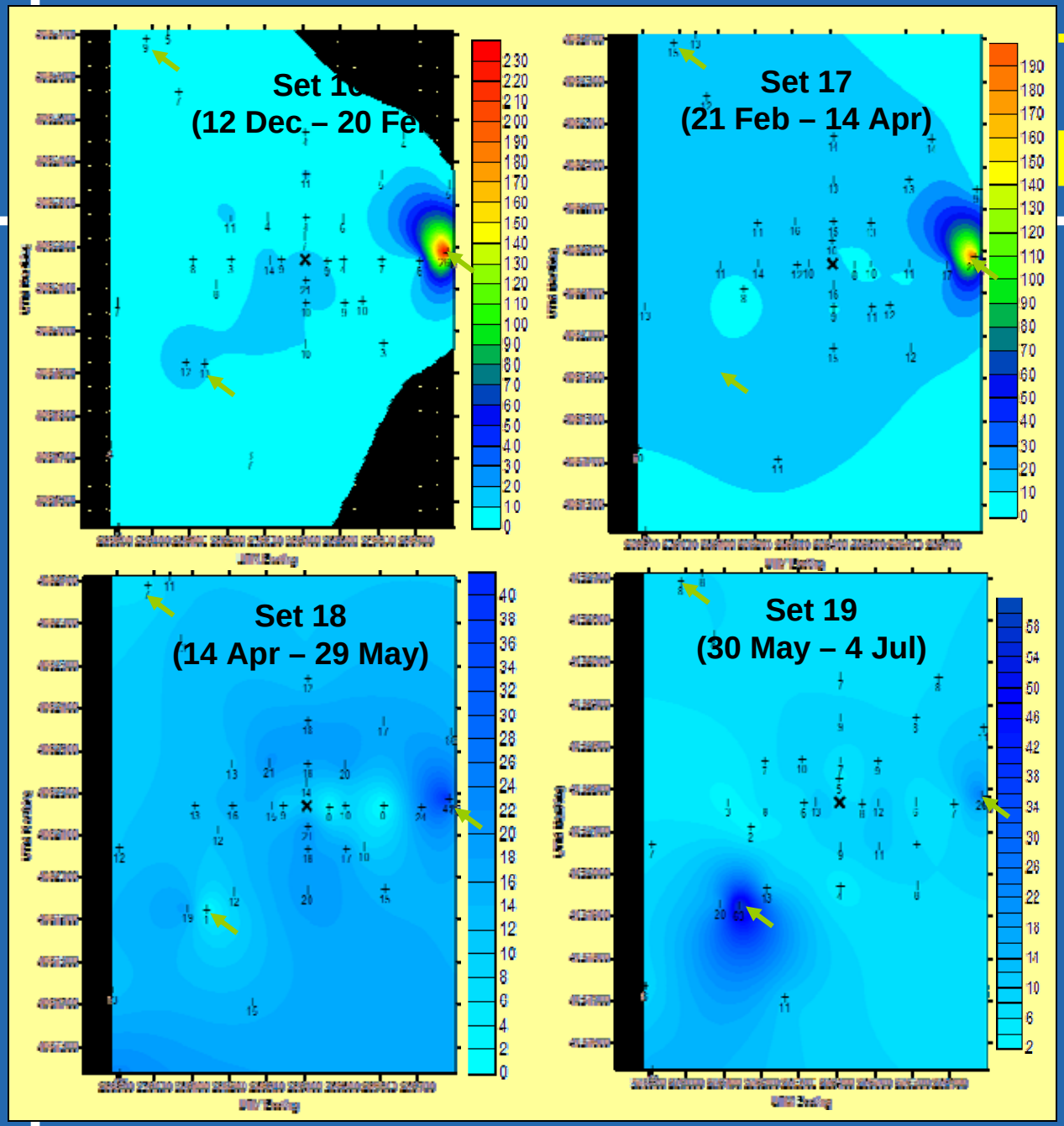
Tiltmeters Results

- No significant deformation in the area, verified by GPS





Tracer-Plume Breakthrough



- NETL simulations predict breakthrough of CO_2 at E offset well by December 2008 and at SW offset well by June 2009
- Conservative tracer breakthrough expected to precede CO_2 breakthrough.
- Consistent with gas sampling data

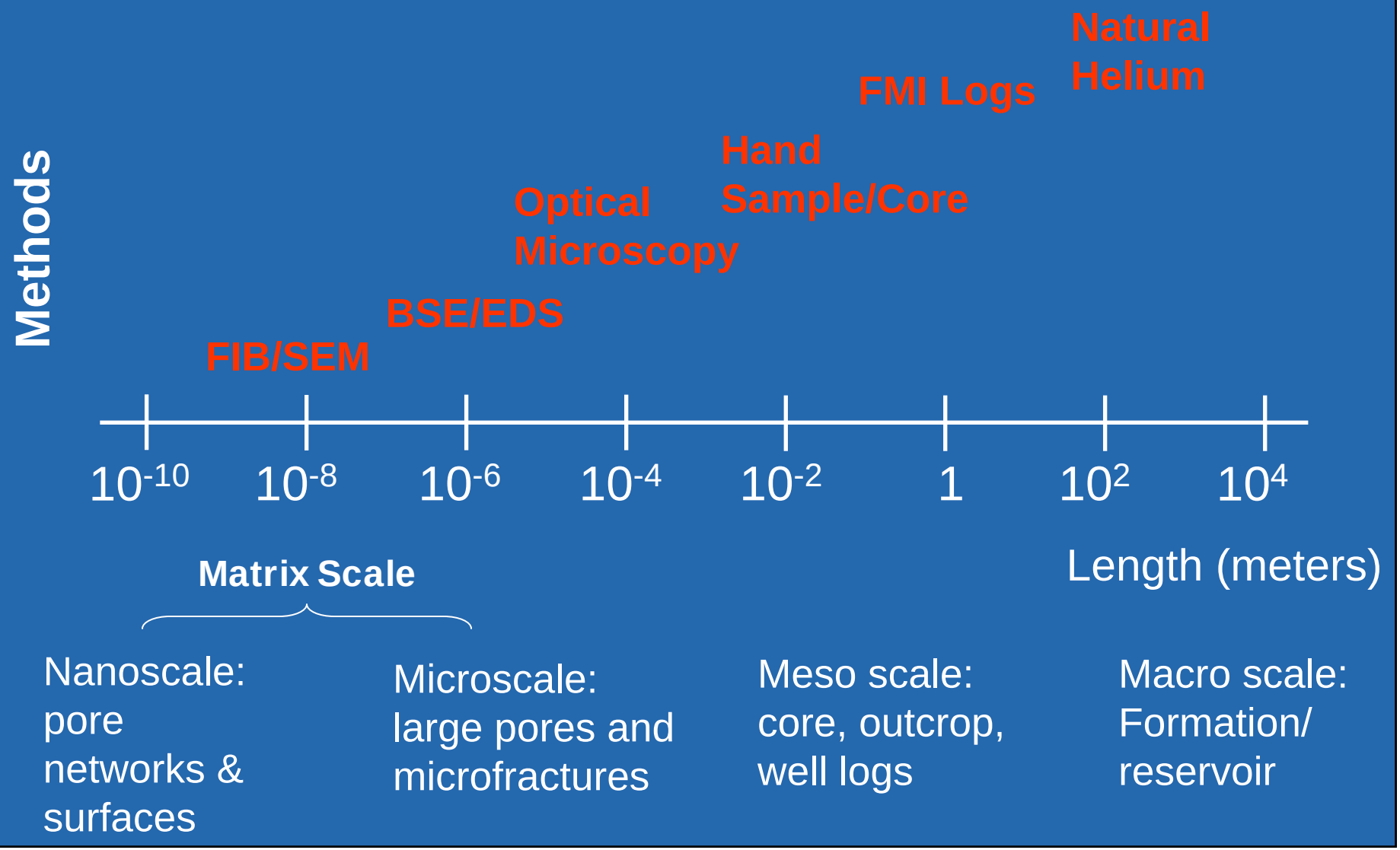
Passive Atmospheric Concentrations of PMCH

Investigation of Caprock Seal Integrity

Research focus:

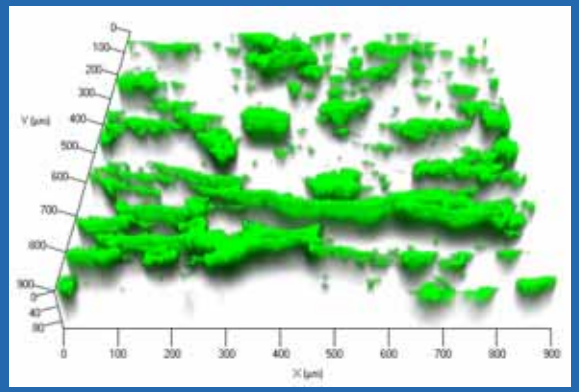
1. How do caprock matrix properties contribute to sealing capacity?
2. What are possible leakage pathways and how are they best characterized?
3. Natural helium offers a temporal and spatially integrated assessment of flow conditions and exists everywhere – can we take advantage of this to characterize large scale seal integrity before injection begins?

Multiscale Investigation of Sealing Behavior

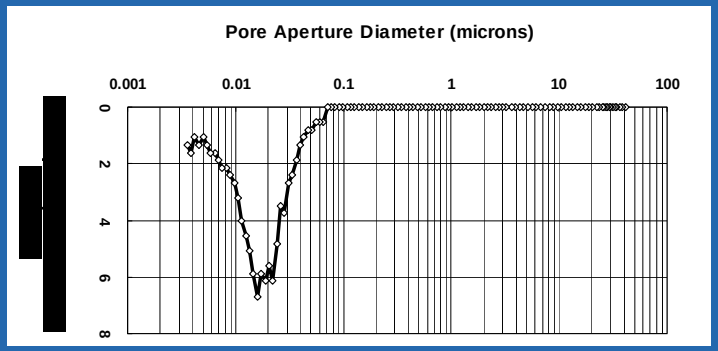


Matrix Scale: Nano to Micro

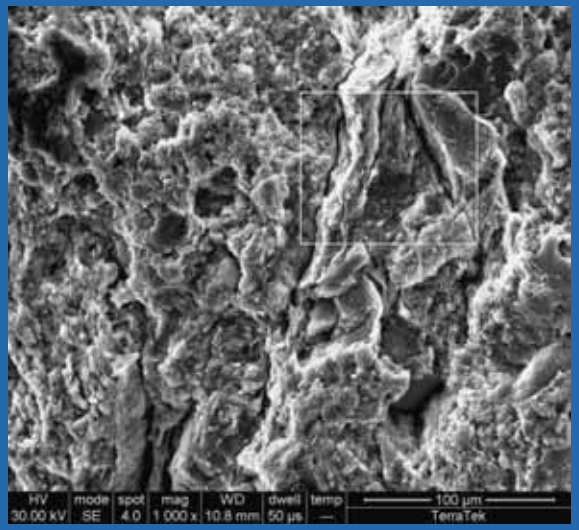
LSCM at 2062.10 ft



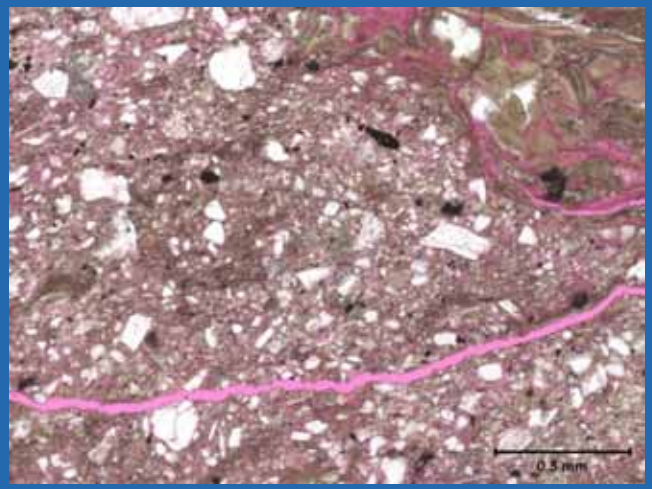
MICP at 2062.40 ft



SEM at 2062.30 ft



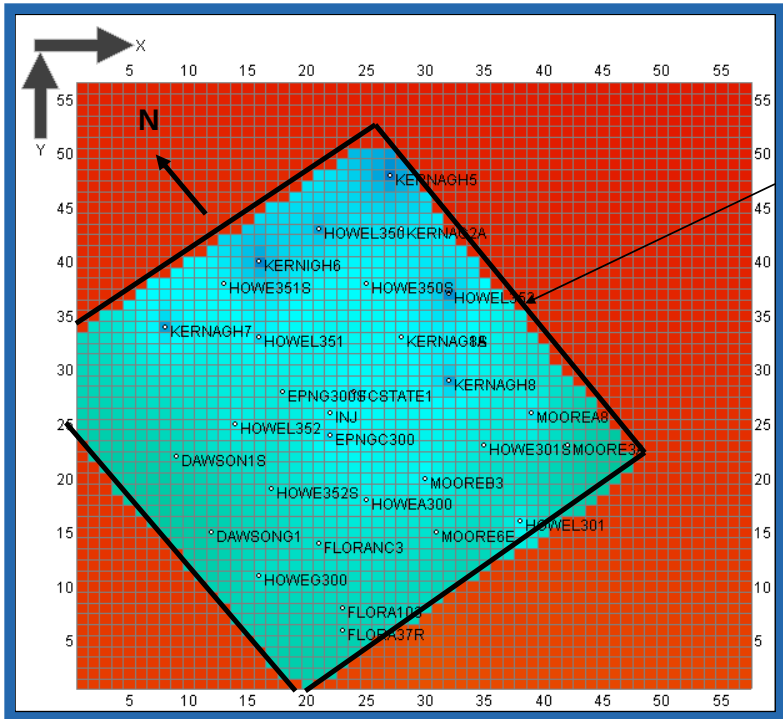
Thin section at 2062.30 ft



Major Findings

- Matrix seal quality is high
- Fractures are present, some of which are “open”
- Some forms of mineralization may be chemically sensitive to CO_2
- Helium and neon data lead to additional conceptual models

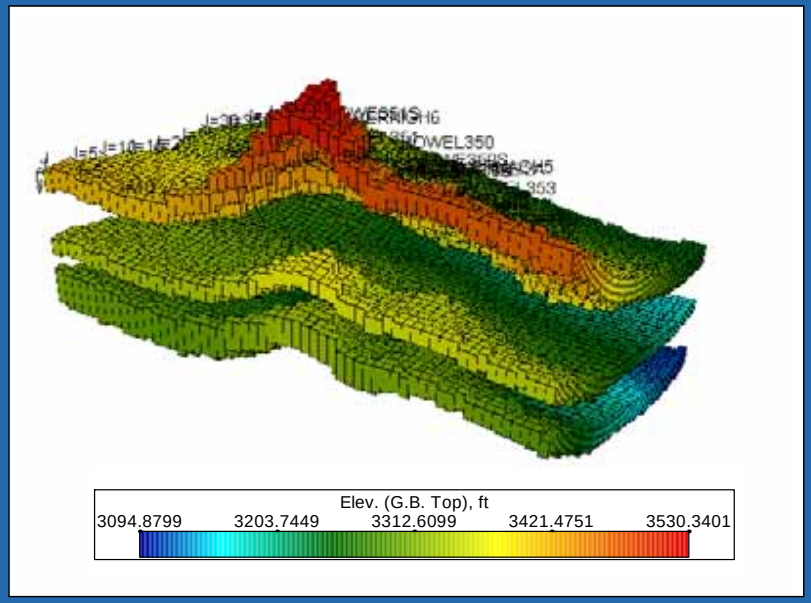
Reservoir Modeling



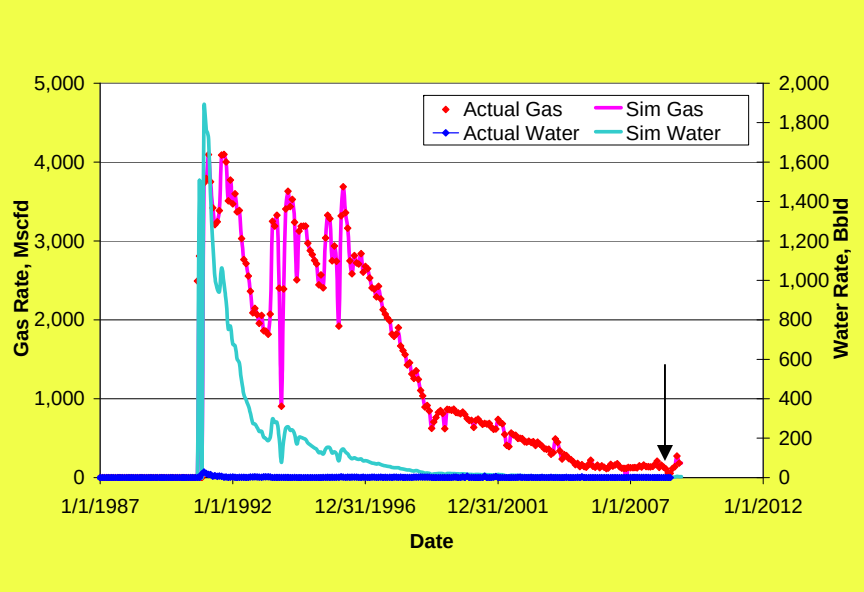
No Flow Boundary

- *COMET3* reservoir simulator model
- 3 layers, 9-section model
- 27 producing wells, 1 injection well
- Y axis of Comet grid aligned with face cleat orientation (N35E)

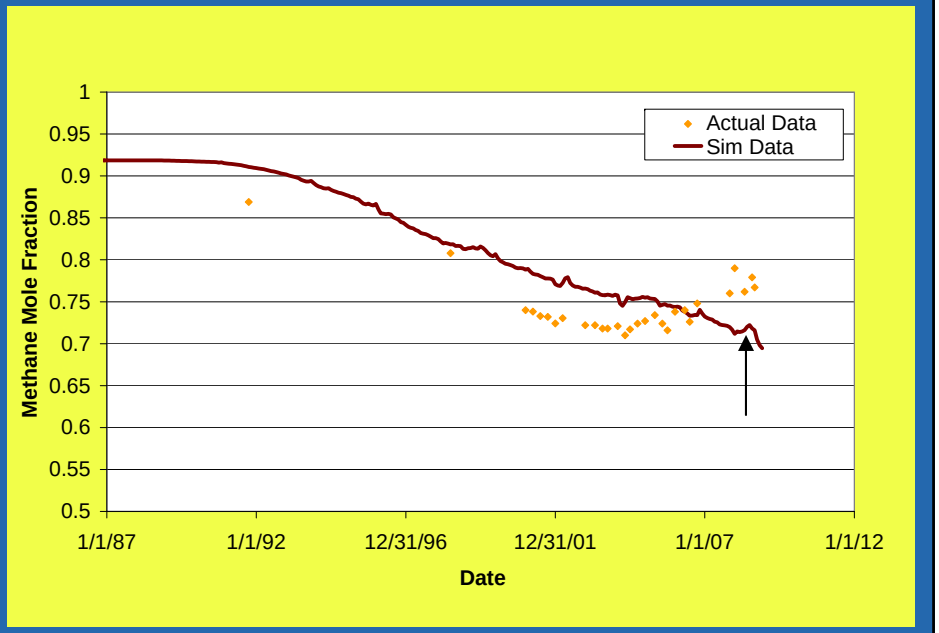
- Elevation and thickness maps generated in PETRA based on logs from 21 wells.
- Maps were included in reservoir model



History Match Results

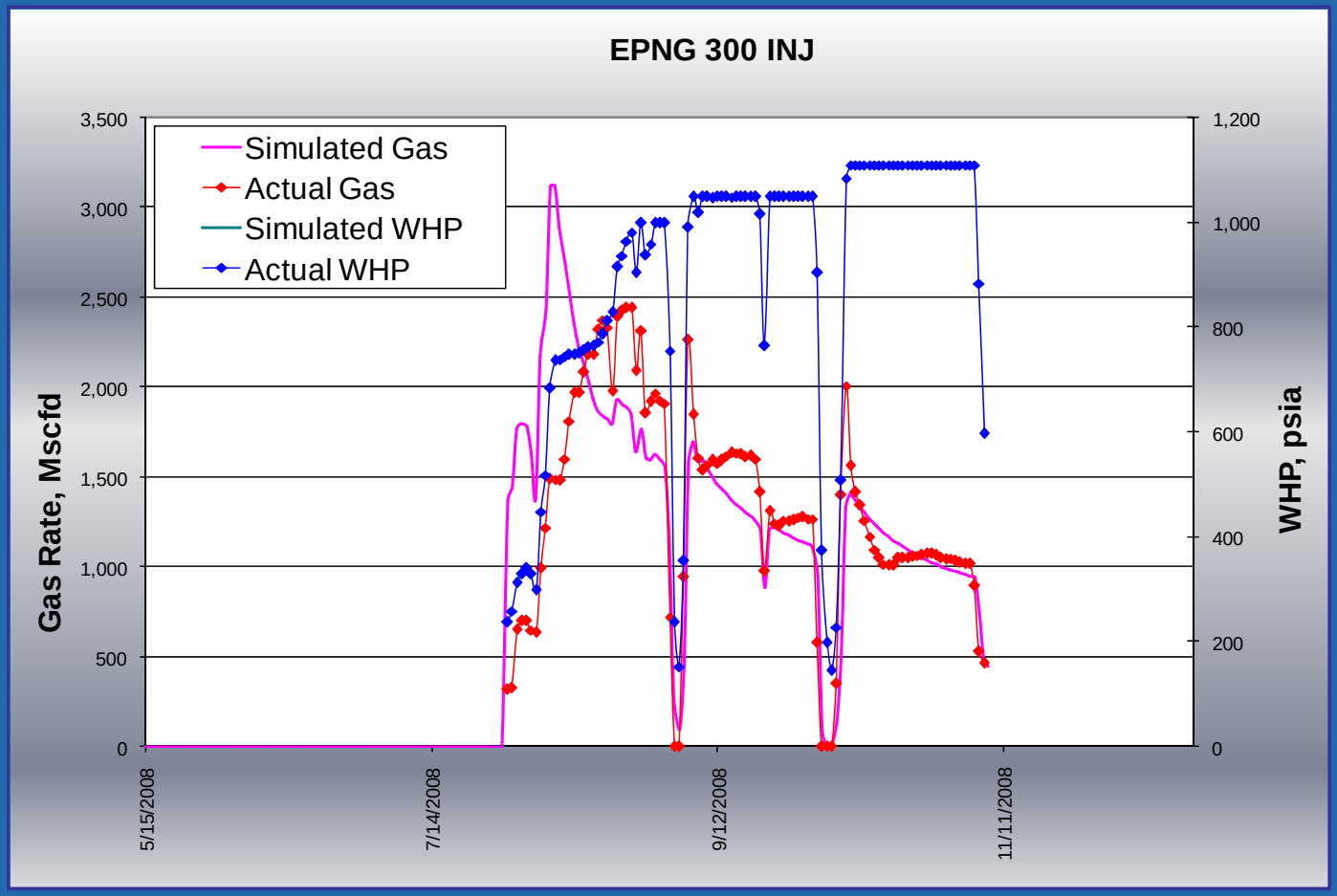


- Gas rate and methane mole fraction of produced gas matched
- Water data of poor quality: not matched



- **Permeability optimized at 550 mD**
- **Porosity at 1.6%**

History Match Results Injector



Peak too early probably due to overestimation of near-well permeability and/or underestimation of pressure but cumulative injected gas volume acceptable.

Model Update

- Permeability allowed to be higher in bottom coal
  - Injectivity profile test results show 83% of the CO_2 going into lowermost layer
  - Logs show coal of better quality
- Included produced nitrogen composition from gas samples
- Updated production/injection data until April 2009
- History match under way

Conclusions

- Injection is a success: 316 MMcf of CO_2 injected at injection rates up to 2,500 Mcfd (high permeability)
- However coal swelling and reservoir pressuring decreased injectivity: rates down to 500 Mcfd
- All ground deformation techniques converge to the same conclusion
  - Effectiveness was probably limited due to the small amount of CO_2 injected

Conclusions

- CO_2 sensors are an excellent means of monitoring breakthrough
  - Monitoring N_2 concentration might be as important
- Reservoir model adequately predicted production and injection performances
- Automated monitoring will end sometimes in the fall of 2009 and long-term (non-automated monitoring) should last another year