



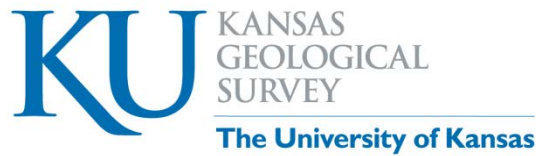
Pilot Scale CO₂ EOR in Mississippian Carbonate Reservoir at Wellington Field in South-Central Kansas

Yevhen Holubnyak, Willard Watney, Jason Rush, Mina Fazelalavi, and Dana Wreath

13th International Conference on
Greenhouse Gas Control Technologies
Lausanne, Switzerland

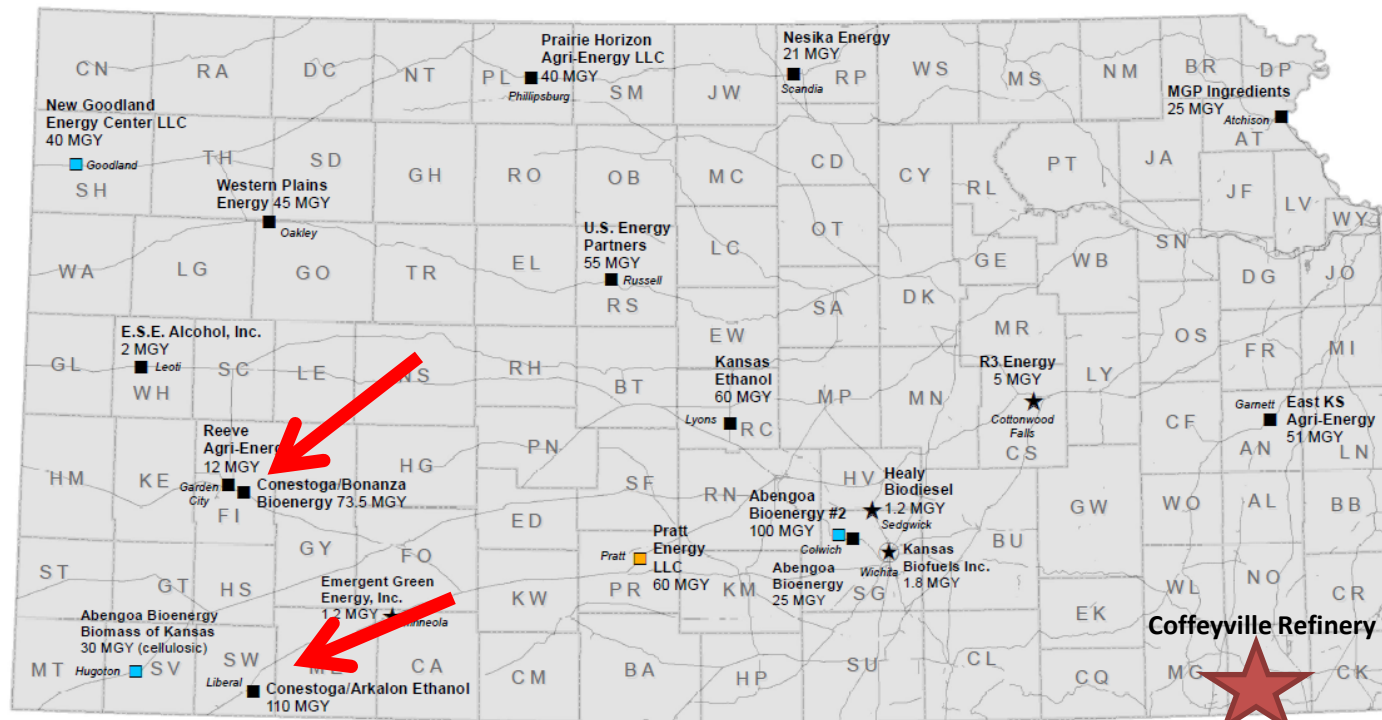
November 16, 2016

Participants



CO₂ Sources Suitable for EOR

Ethanol and Biodiesel Plant Activity in Kansas
September 2012



MGY = Millions of gallons per year of permitted capacity.
Capacities courtesy of Kansas Department of Health and Environment and the Kansas Department of Revenue.

* Permitted and Permit Pending codes refer to KDHE Bureau of Air and Radiation - Air Construction permits.

Ethanol Plants

- Existing: 12 plants, 519.5 MGY
- Under Construction: 3 plants, 170 MGY
- Permitted*: 0 plants, 0 MGY
- Permit Pending*: 1 plants, 60 MGY
- Idle: 0 plants, 0 MGY

Biodiesel Plants

- ★ Existing: 3 plants, 7.4 MGY
- ★ Under Construction: 0 plants, 0 MGY
- ★ Permitted*: 0 plants, 0 MGY
- ★ Permit Pending*: 0 plants, 0 MGY
- ★ Idle: 1 plant, 1.8 MGY

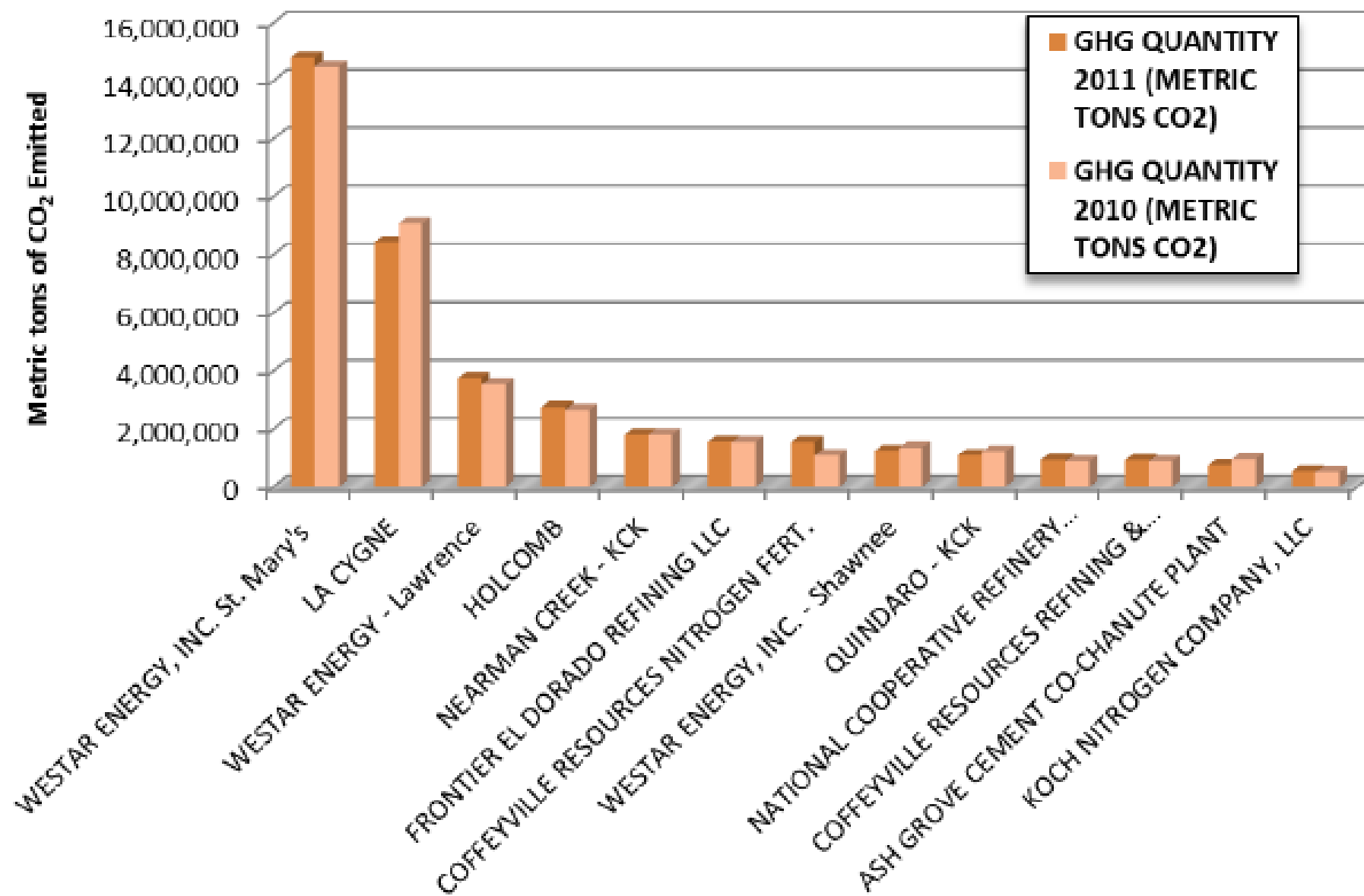
Kansas Department of Agriculture
Administrative Services, GIS
September 12, 2012



- Kansas holds more than **750 million barrels** of technical CO₂-EOR potential and **~240-370M** metric tons of CO₂ is required for recovery
- Economic results based on Hall Gurney field suggest an after-tax project IRR of about 20%
- Access to the significant volumes of ethanol-based CO₂ in Nebraska

Kansas CO₂ Emissions

(From sources greater than 500,000 metric tons annually)

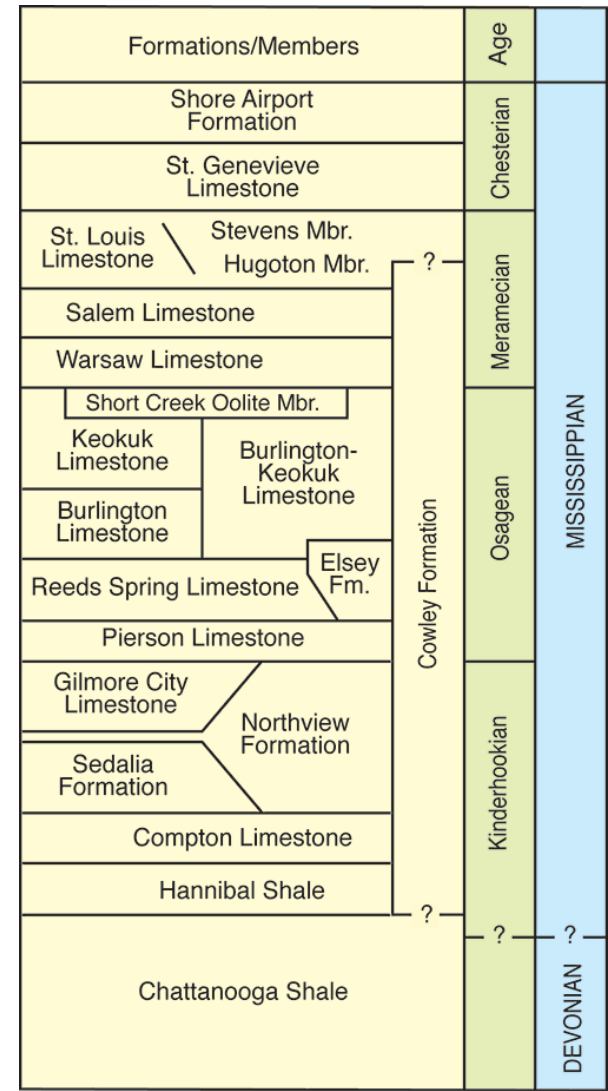
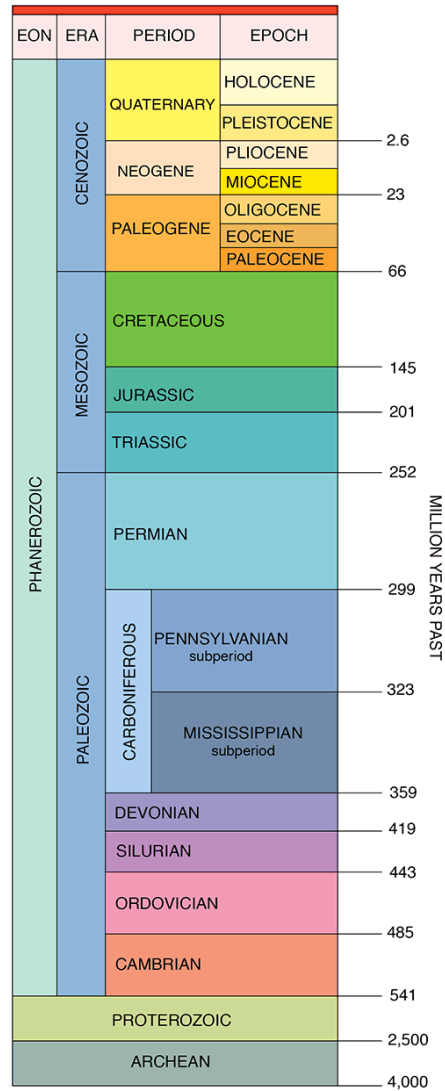
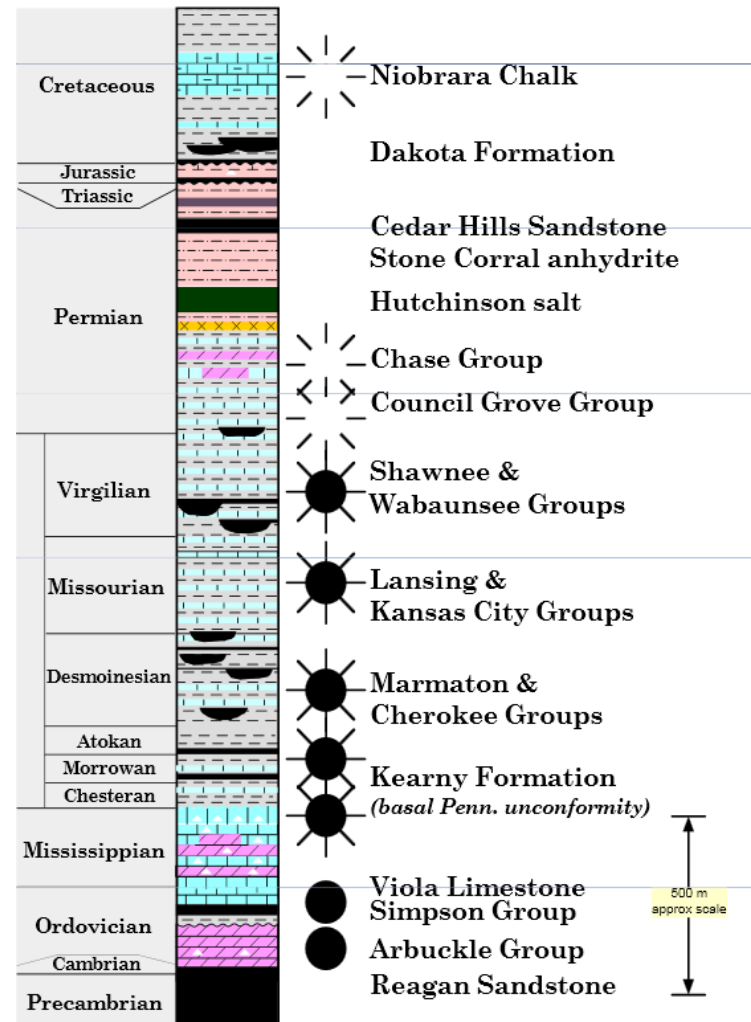


Potential Recoverable Resources:

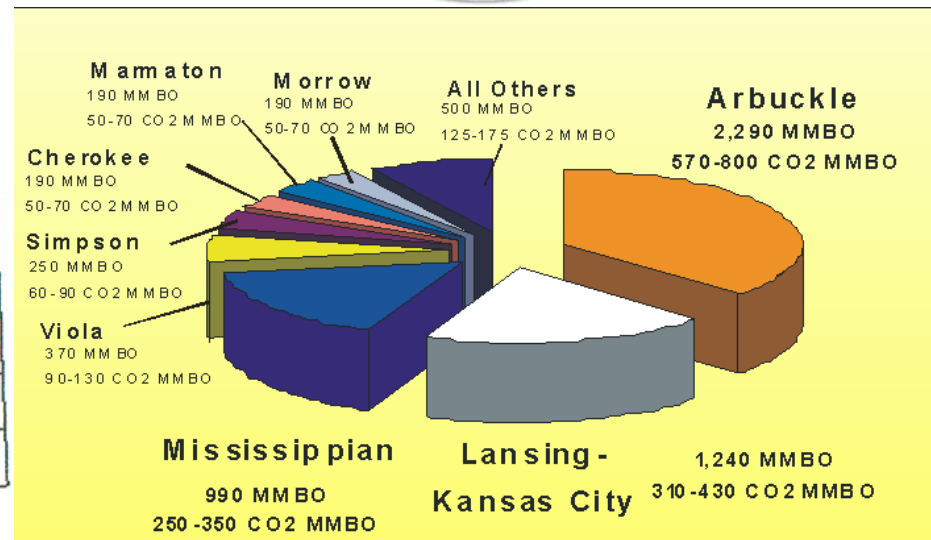
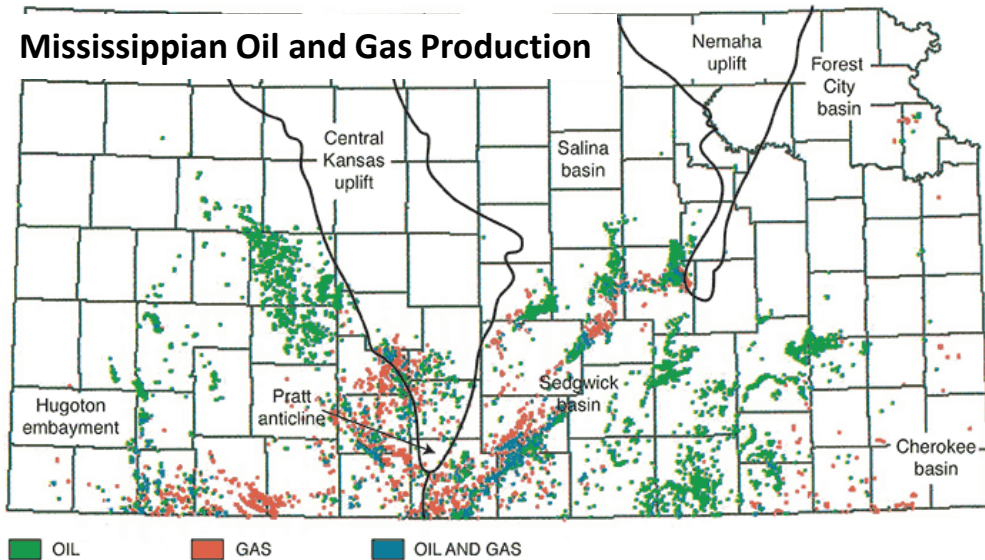
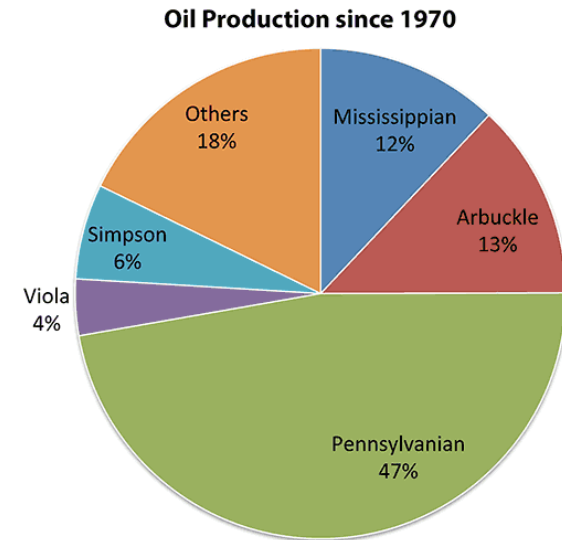
Formations of Interest

AGE LITHOLOGY

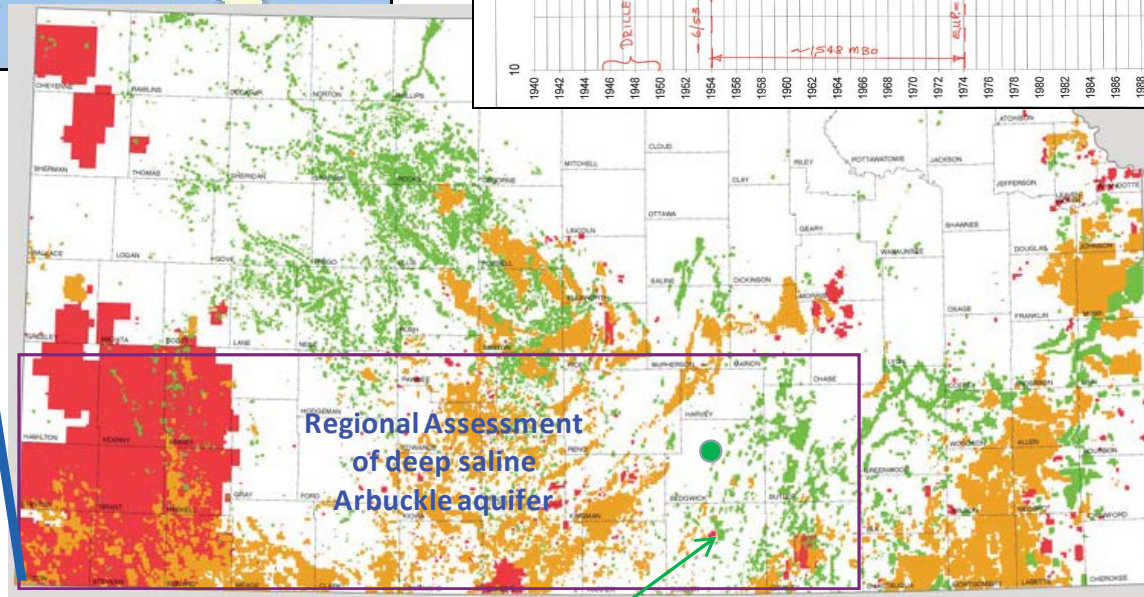
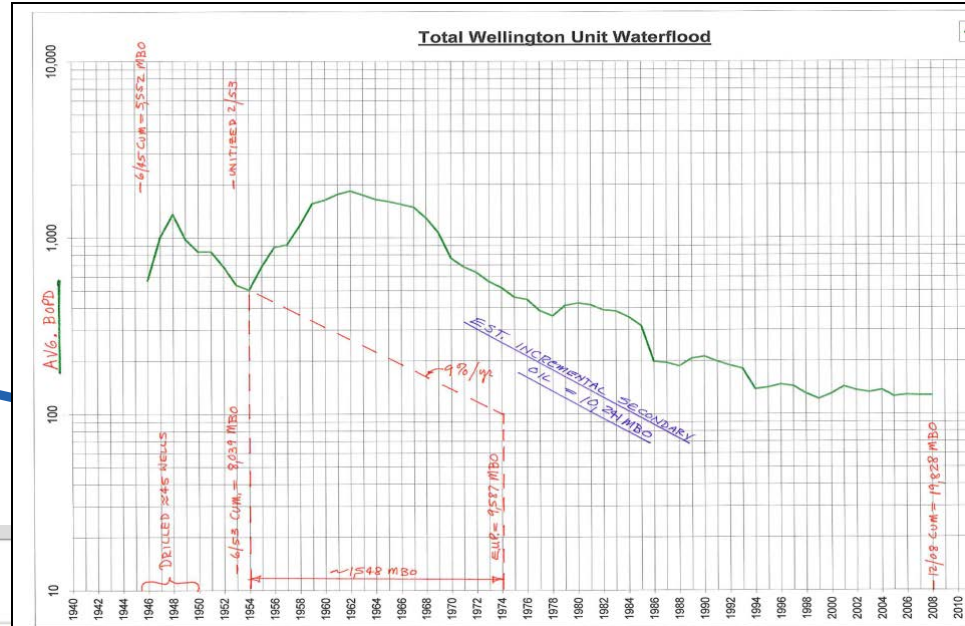
UNITS




Potential Recoverable Resources: Mississippian Group



Wellington Field, South KS

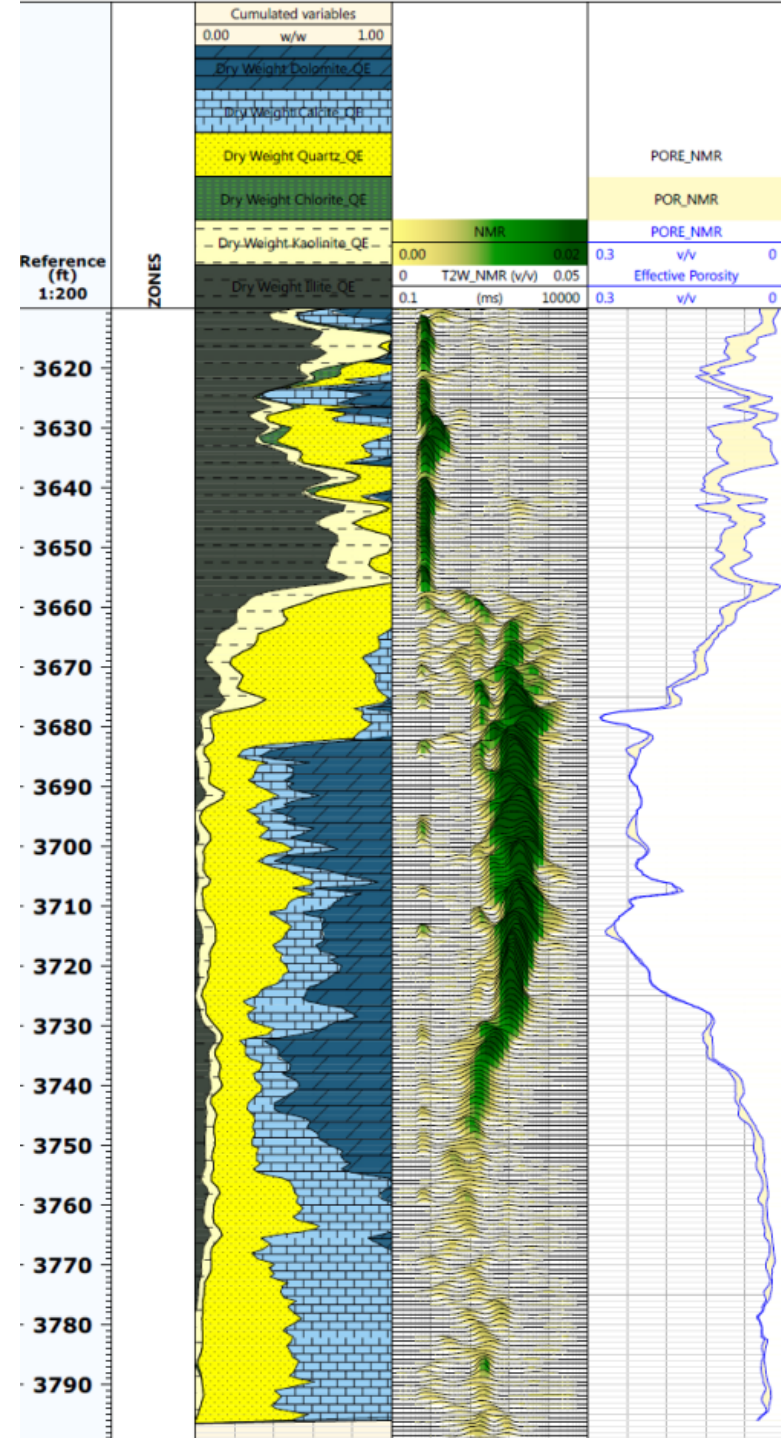


Plan for CO₂ EOR Pilot

- Find, characterize, and prepare oil field
- Find CO₂ source
 - Initially, ethanol plant  multiple sources
- Develop strategy for resource recovery through reservoir modeling
 - Several revisions
- Obtain a permit and drill a new injection well
- Organize surface infrastructure and deliver CO₂
 - Truck delivery
- Inject ~~~26,000~~ ~20,000 tones of CO₂ at 100-150 tones/day
- Monitor and manage CO₂ plume
- Vent produced CO₂

Reservoir Characterization

- Very old Neutron logs with or without resistivity logs for all wells
- 16 wells with complete suites of resistivity and porosity logs
- New wells drilled by KGS have a full set of modern logs
- Core is available from KGS #1-32
 - Porosity/permeability
 - Geochemistry
 - Geomechanical data
- 3D Seismic
- Formation fluids analysis

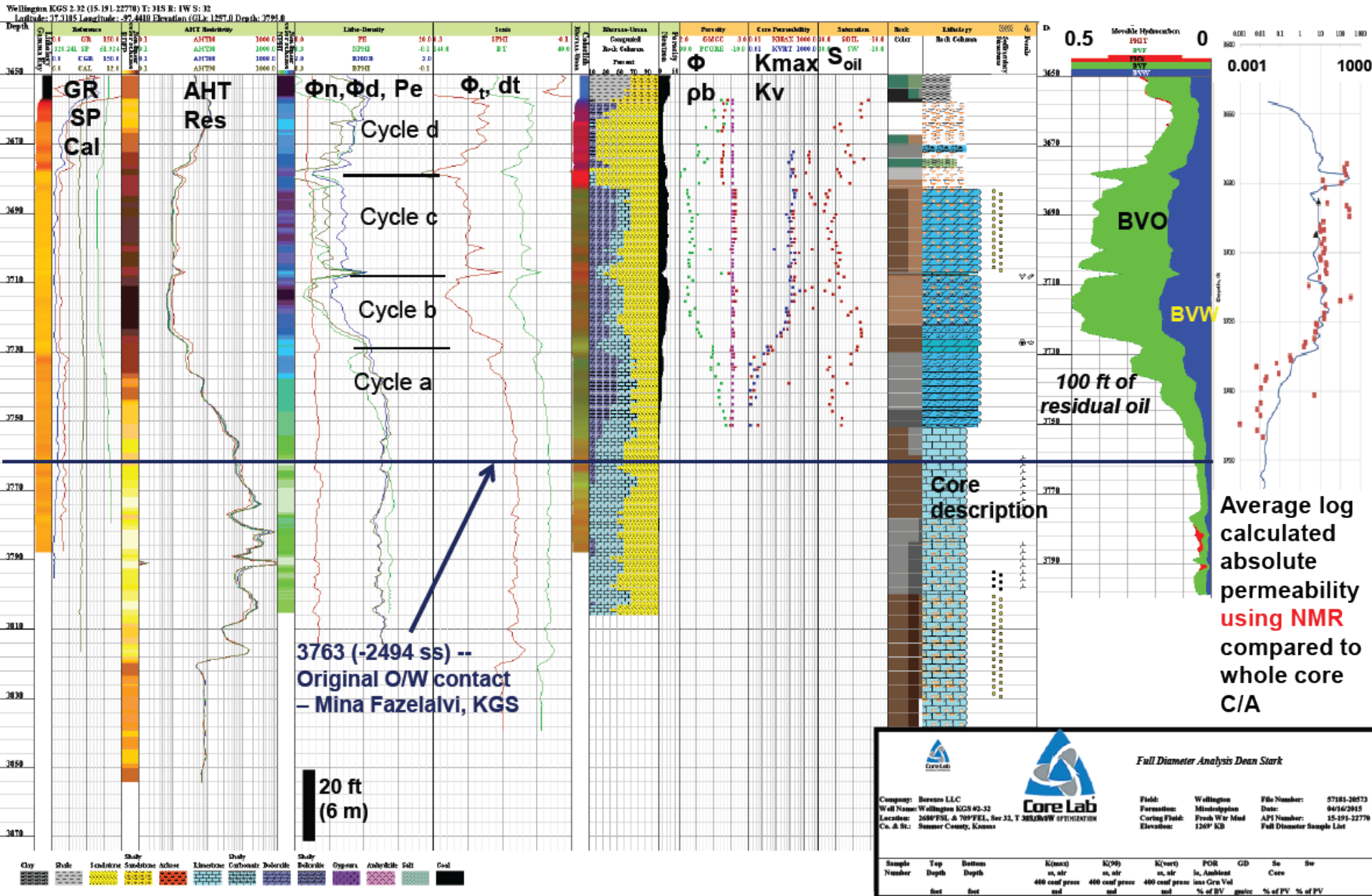




Injection Well Drilling and Coring

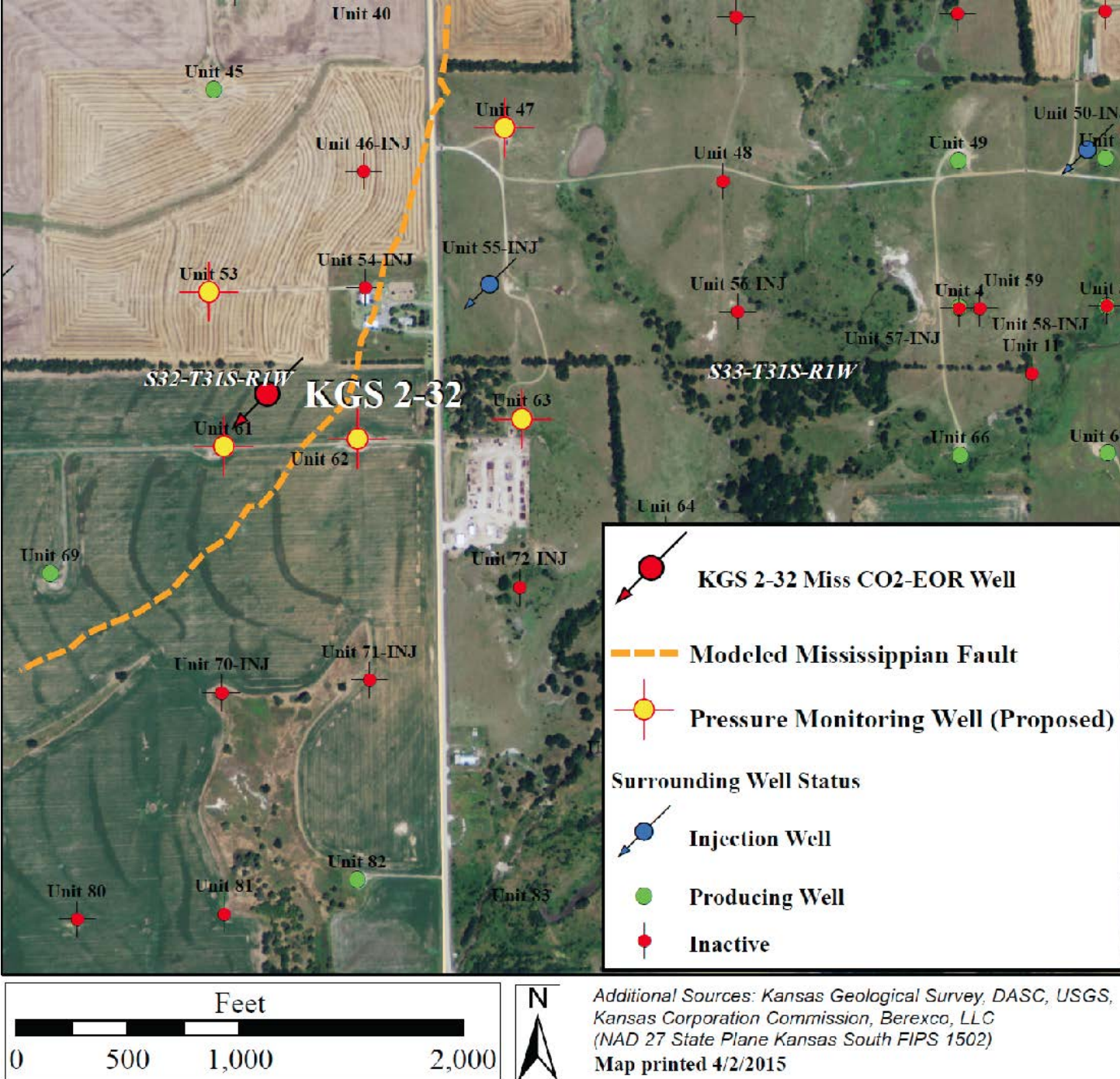
- Class II Well Permit
– 30 days process
- ~100 ft of new new core
- 70 ft of ~23% S_{or}
- 20% Phi
- 15-18 mD

Injection Well Logging

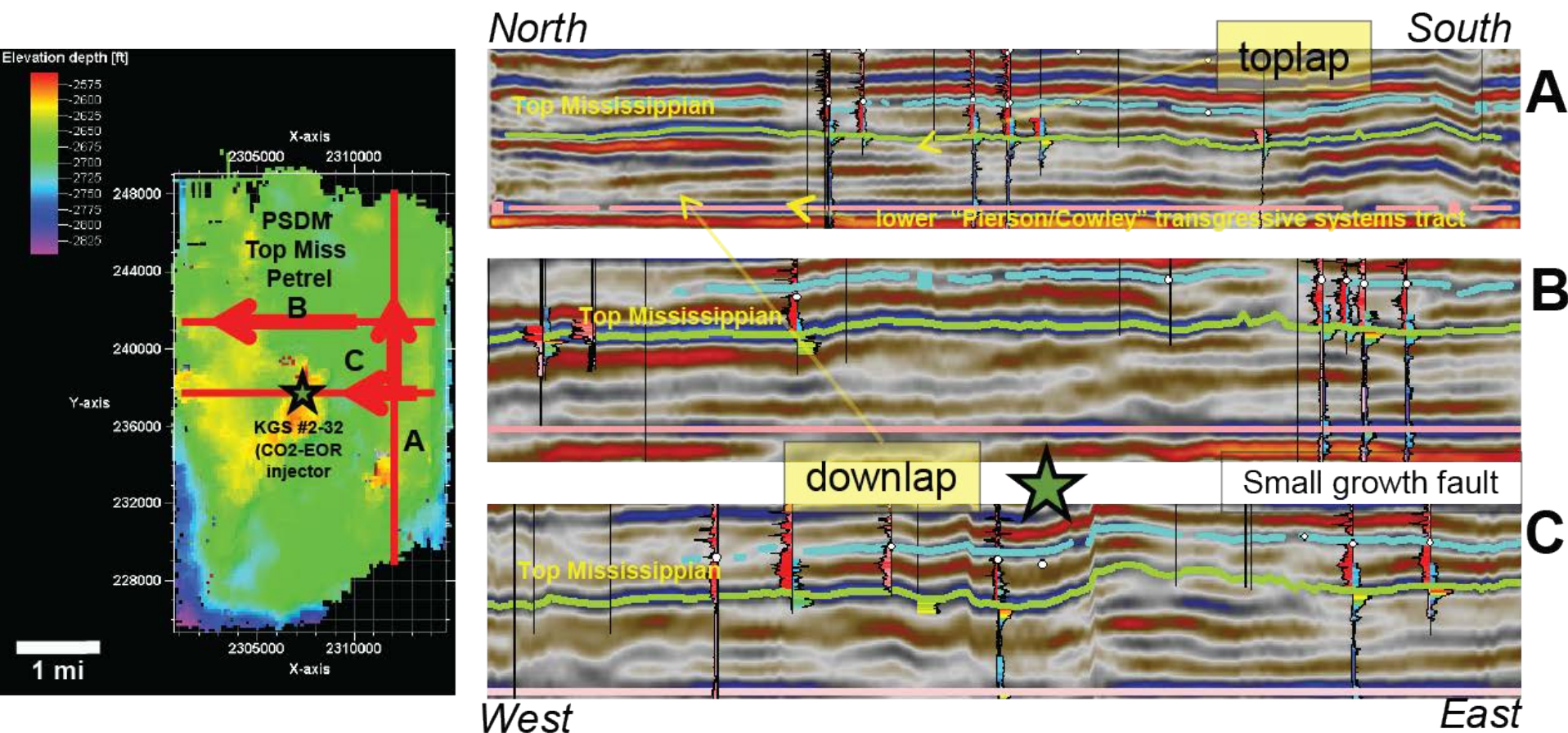


Well Tests

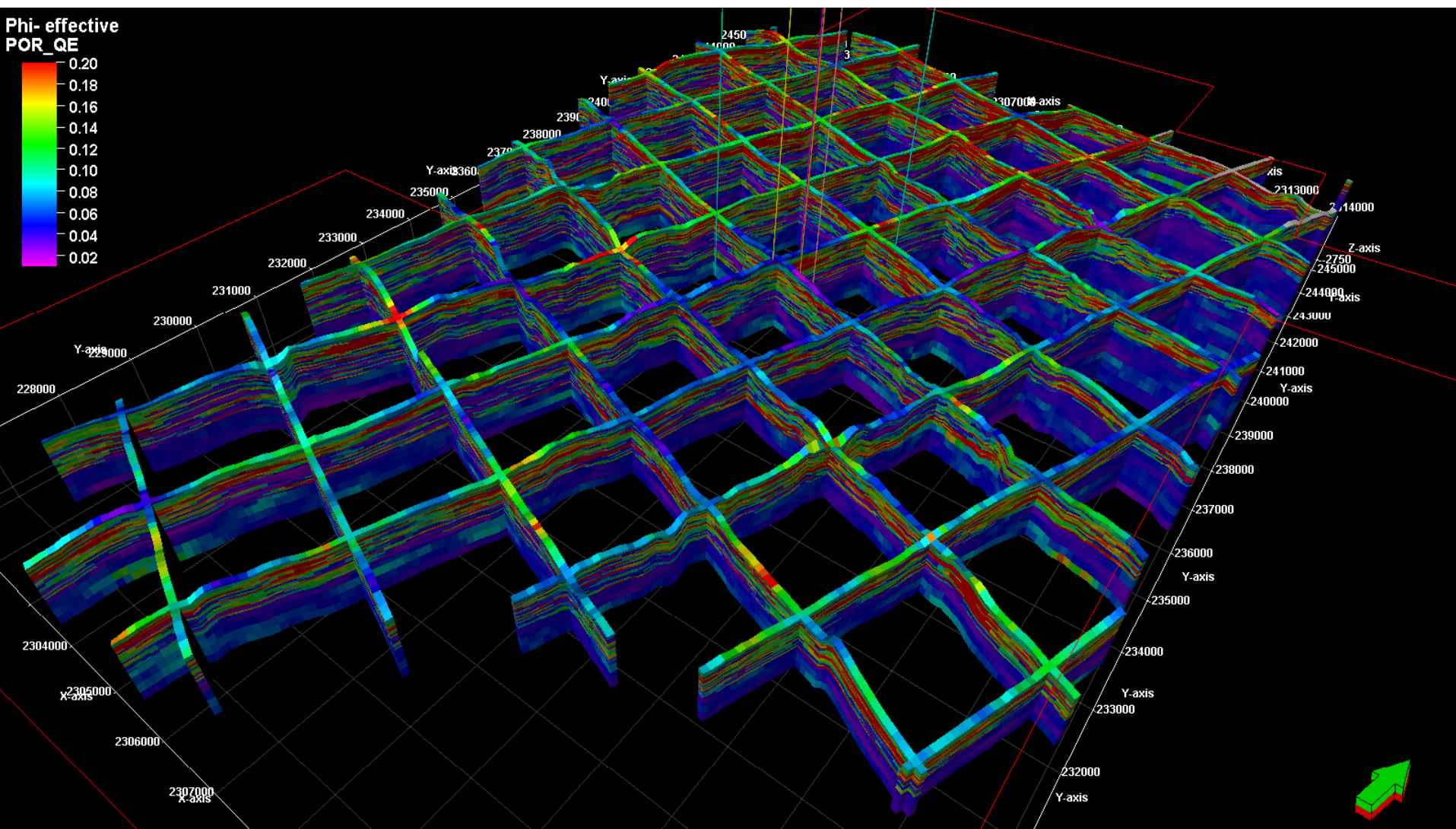
- Drill stem test
- Step rate test
- Interference test



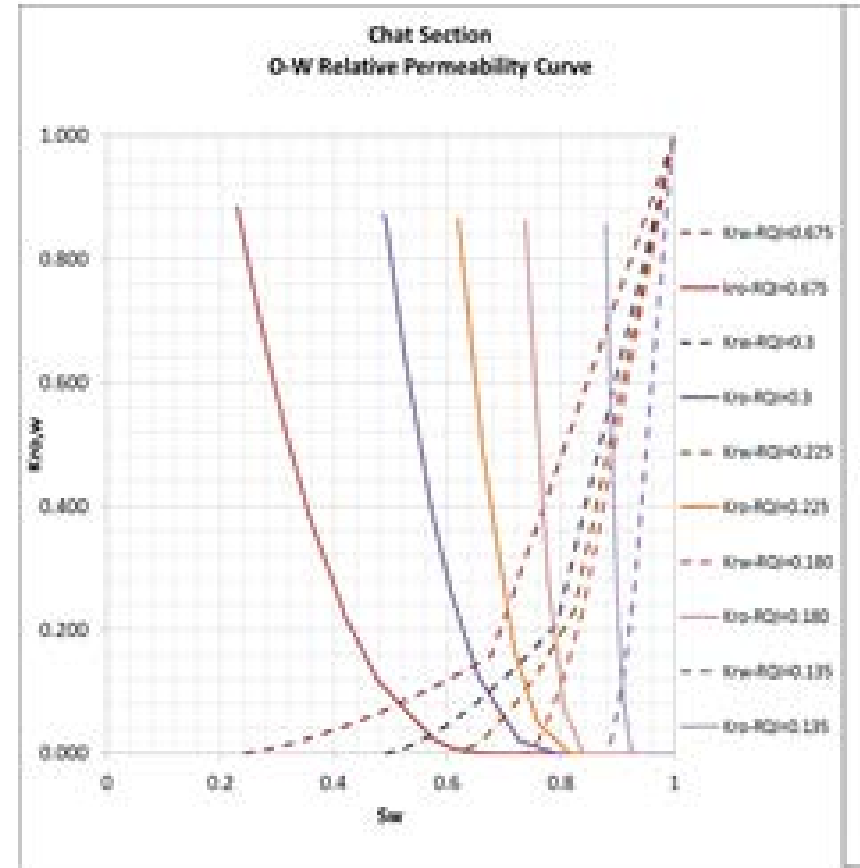
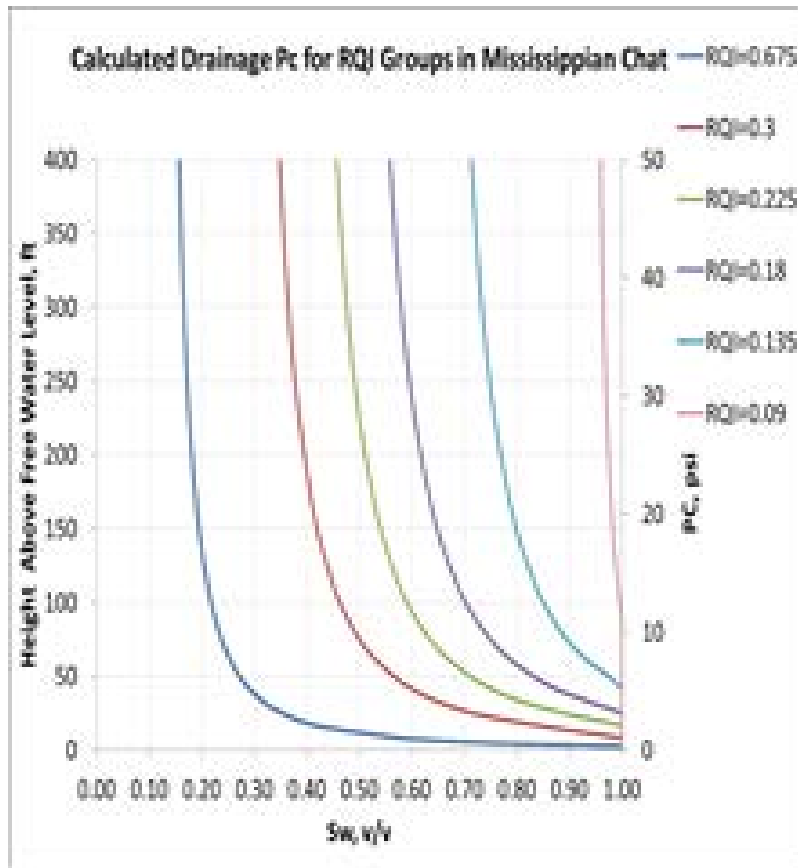
Seismic Stratigraphy Using PSDM



Improved Geologic Model

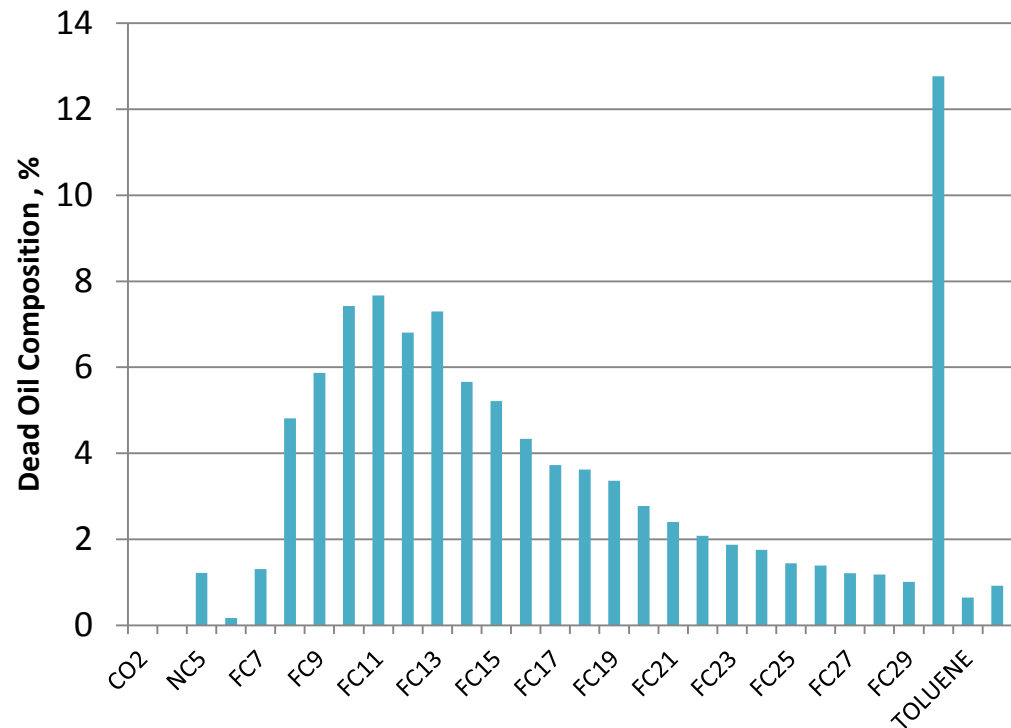


Capillary Pressure and Relative Permeability



Fluid Properties

- CO₂ Miscibility pressure is ~1650 psi
- Oil API gravity is 30°
- Oil composition
- Water composition
- PVT

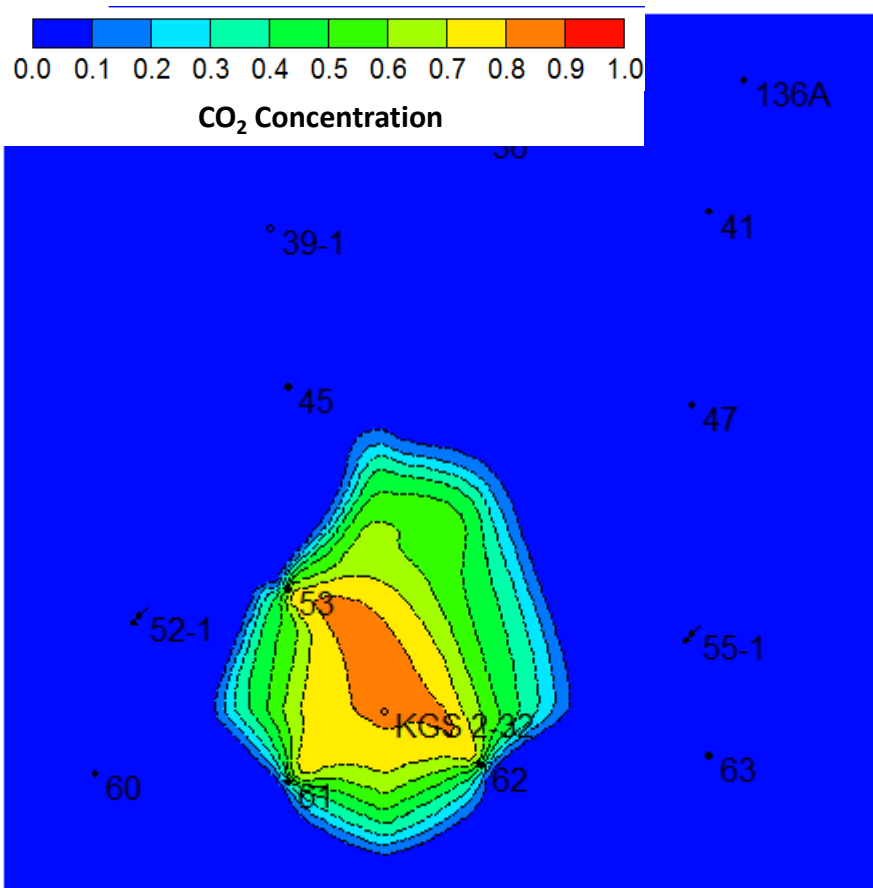


Reservoir Modeling

- Strategy for a flood
 - Monitoring optimization
 - Re-pressurization strategy for miscibility
 - CO₂ movement
- Economic forecast
 - Sweep efficiency
 - Oil production
 - CO₂ production

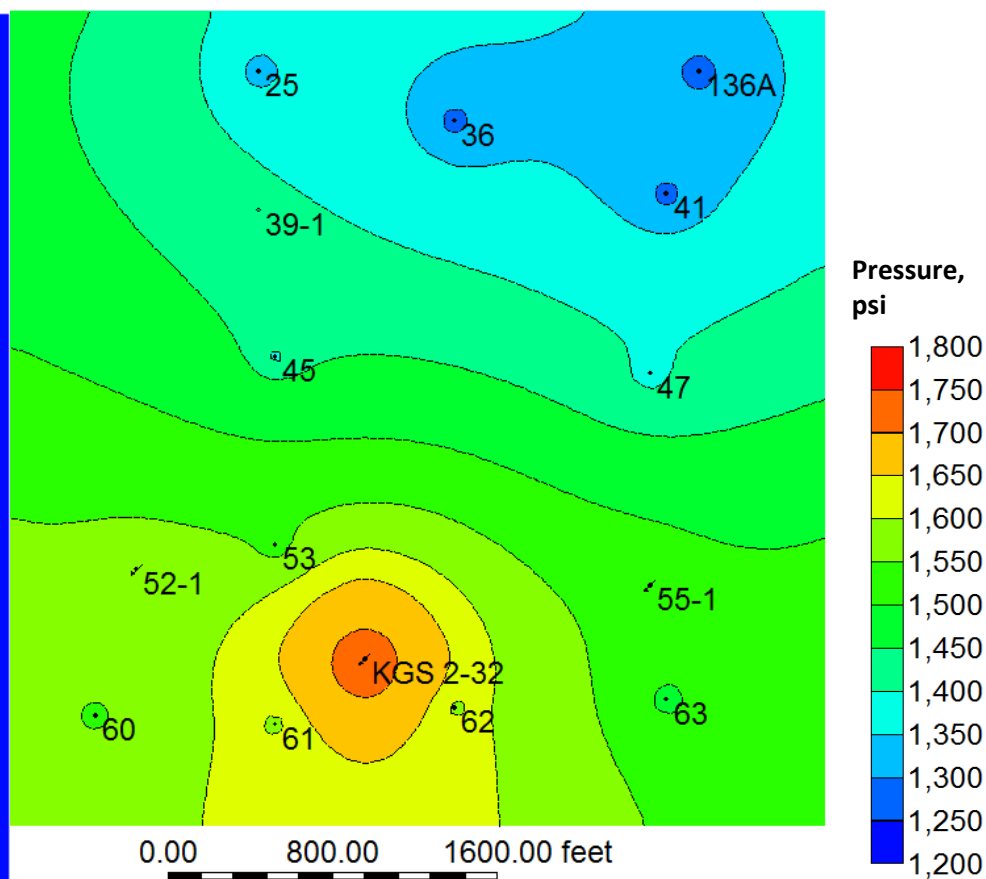


Forecasted CO₂ Movement in Reservoir

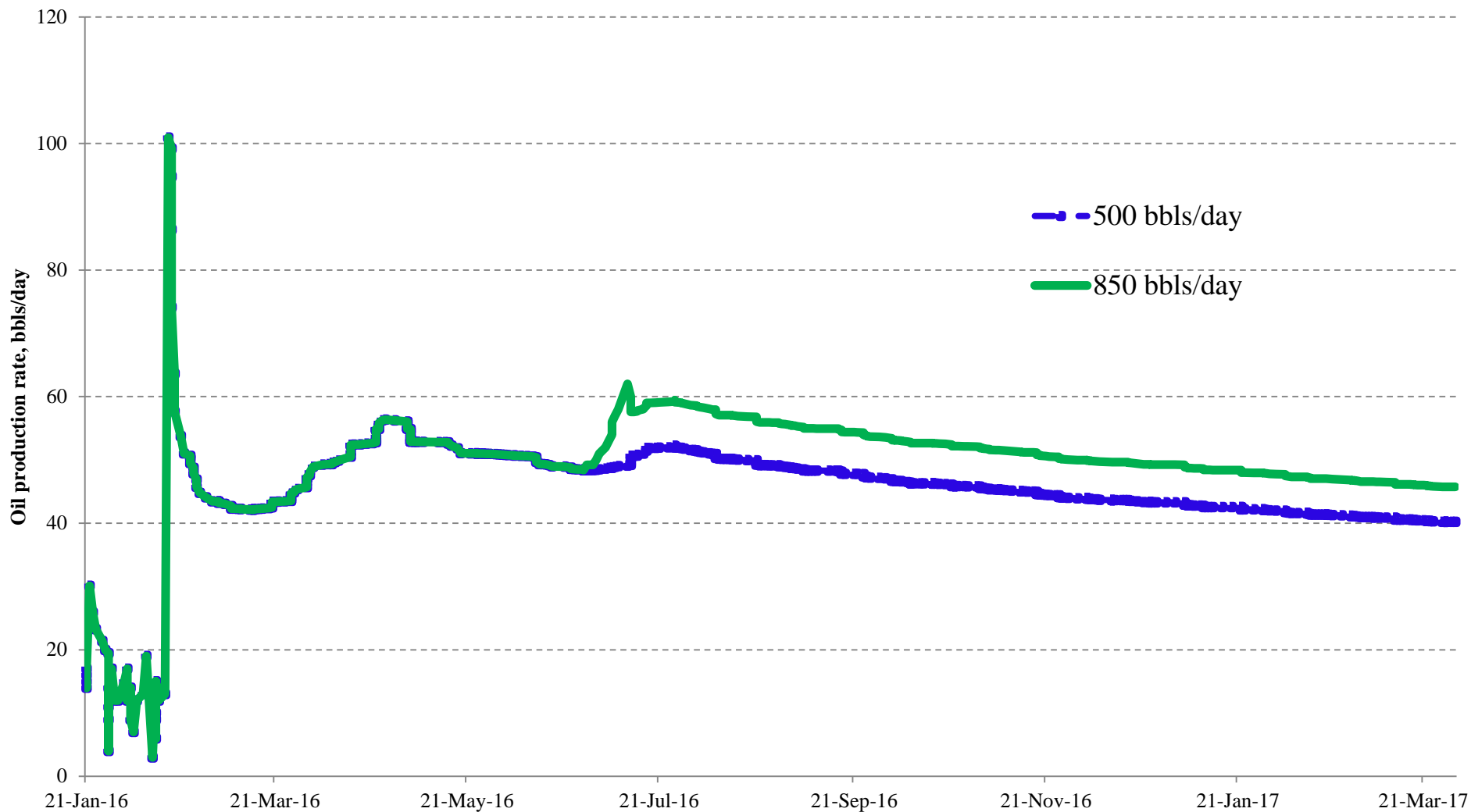


Forecasted Pore-Pressure Distribution at the Start of CO₂ Injection

Required miscibility pressure is ~1650



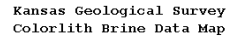
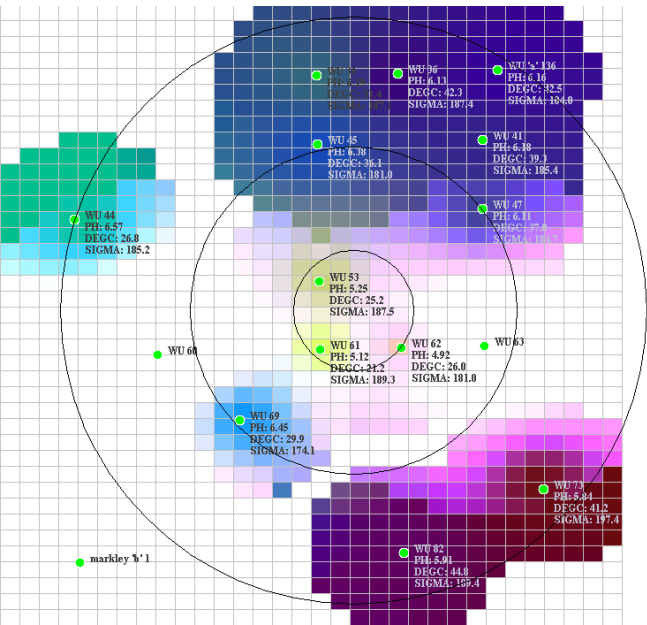
Waterflood Strategy after CO₂ Injection



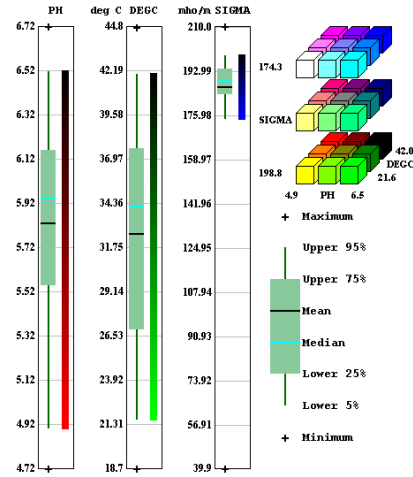
Operations: CO₂ Delivery and Surface Facilities



Fluid Monitoring

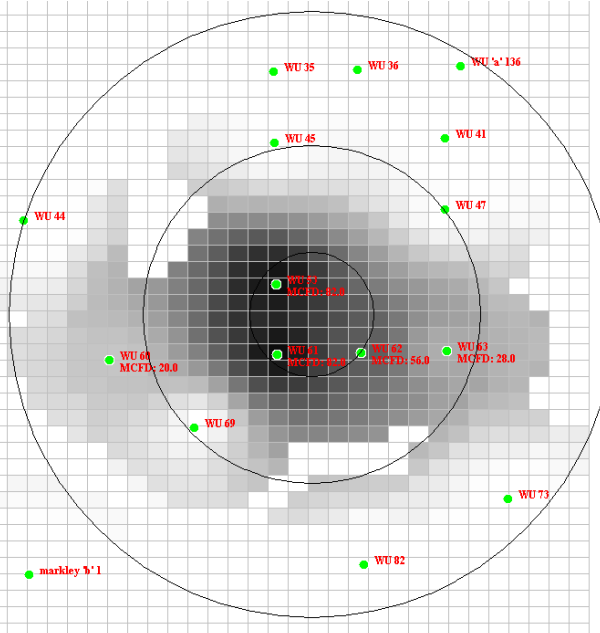


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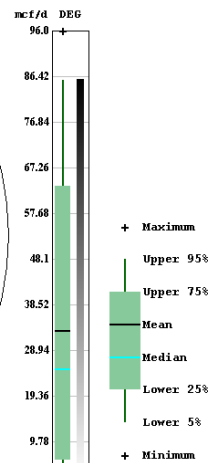
- Water chemistry
 - Alkalinity
 - pH
 - Cations/anions
 - Microbial

- Production history
 - Oil/water
 - CO₂ account

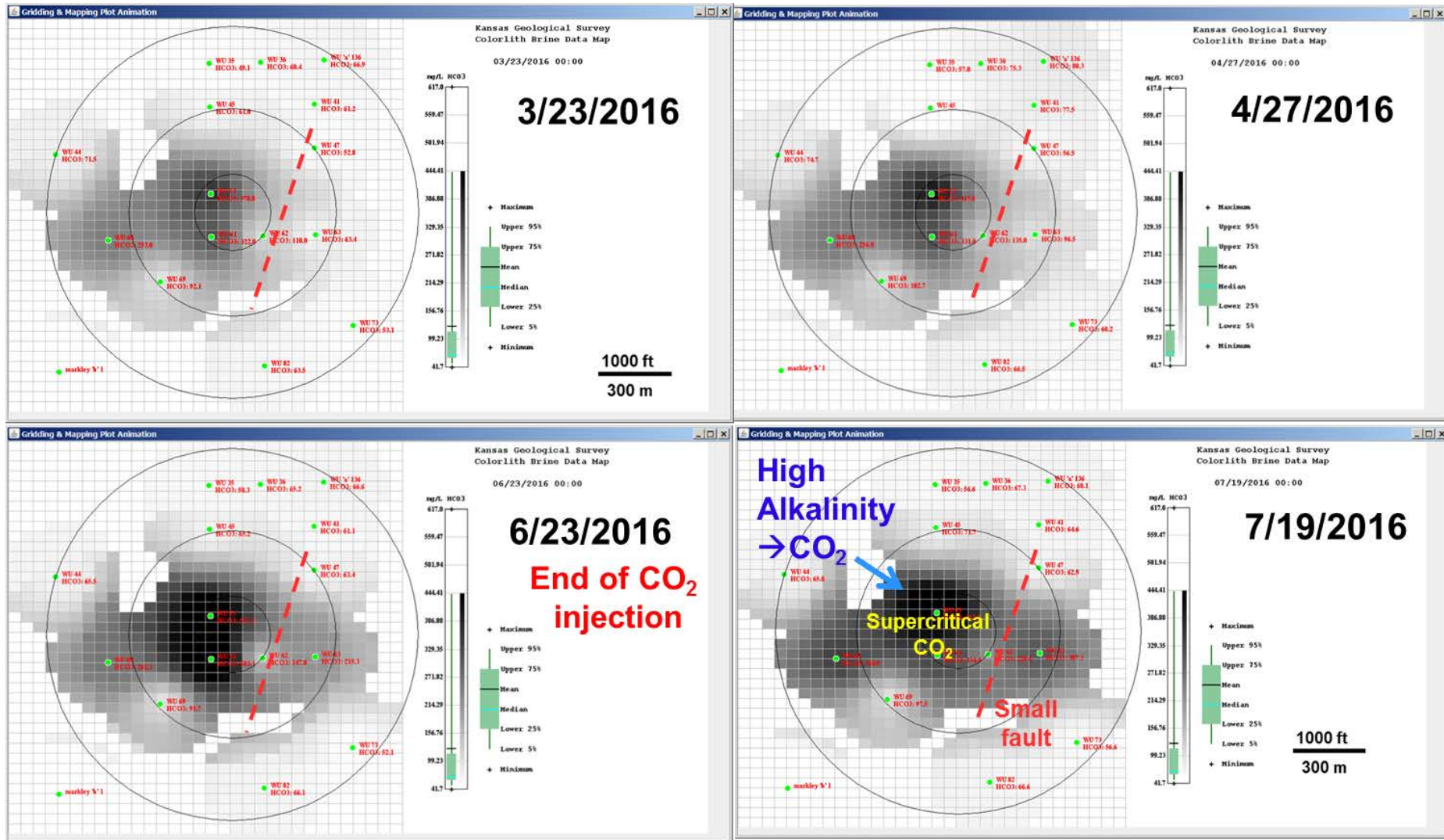


Kansas Geological Survey
Colorlith Brine Data Map

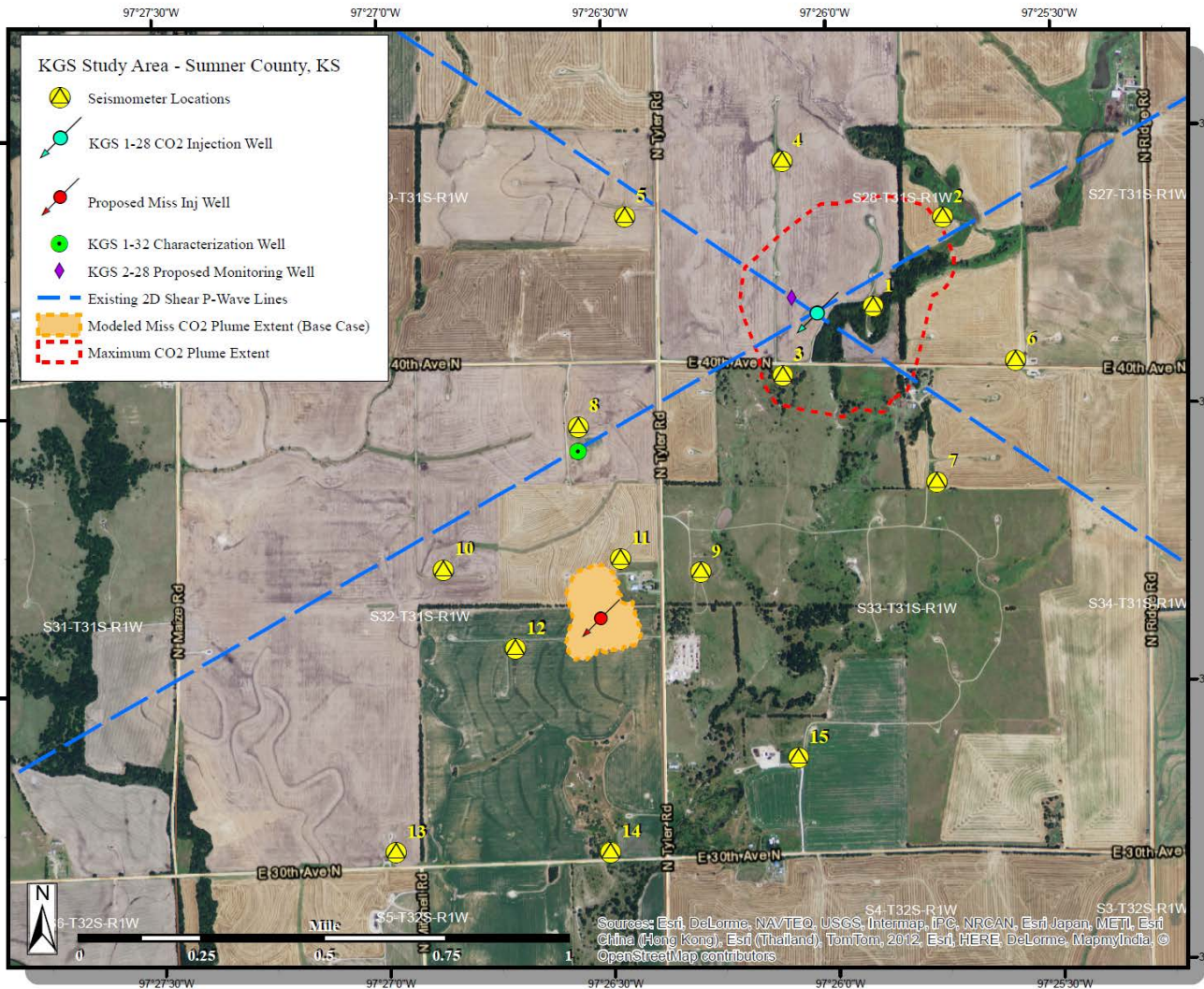
05/13/2016



Geochemical Monitoring: Field Alkalinity Progression

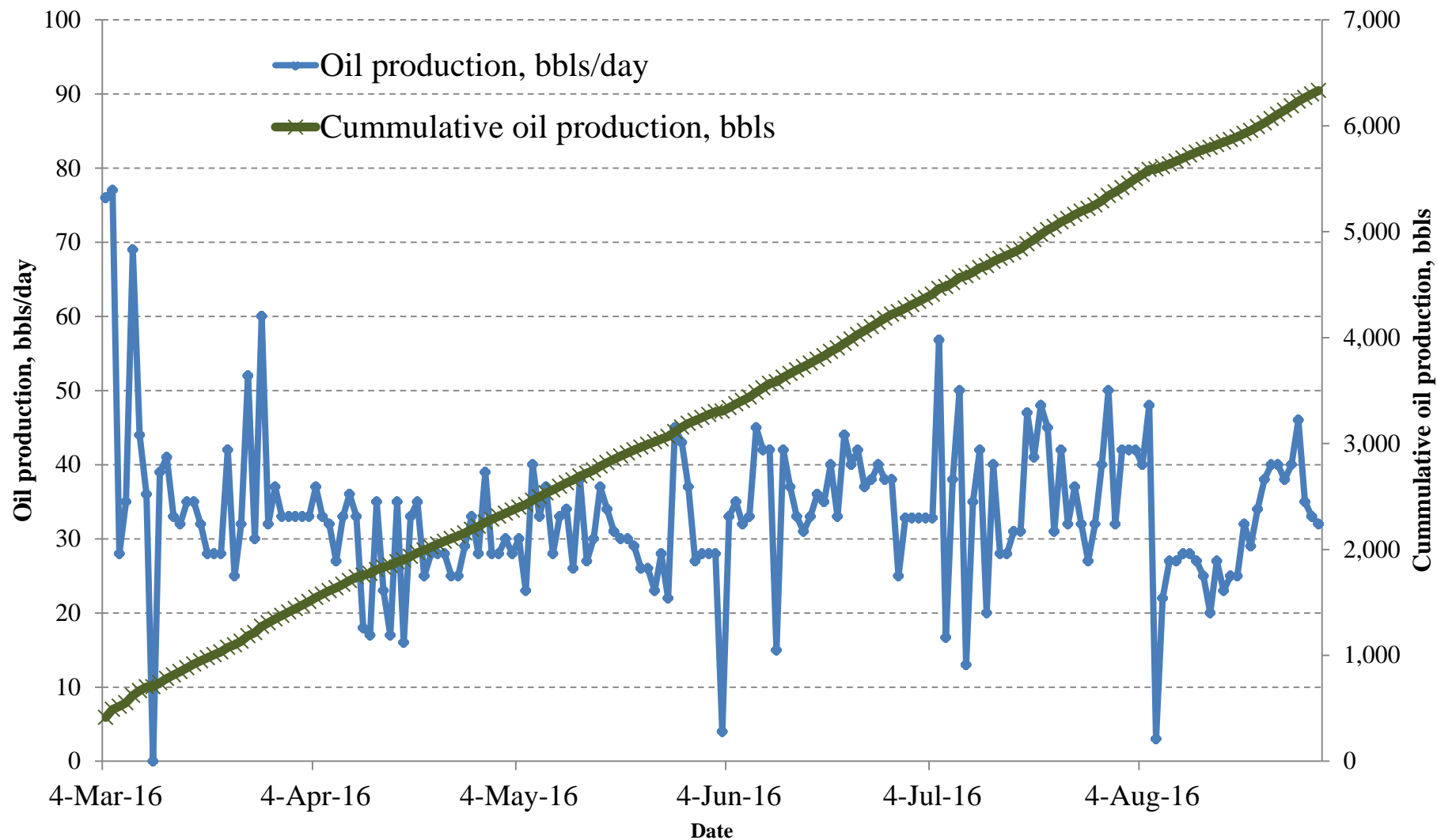


Seismic Monitoring

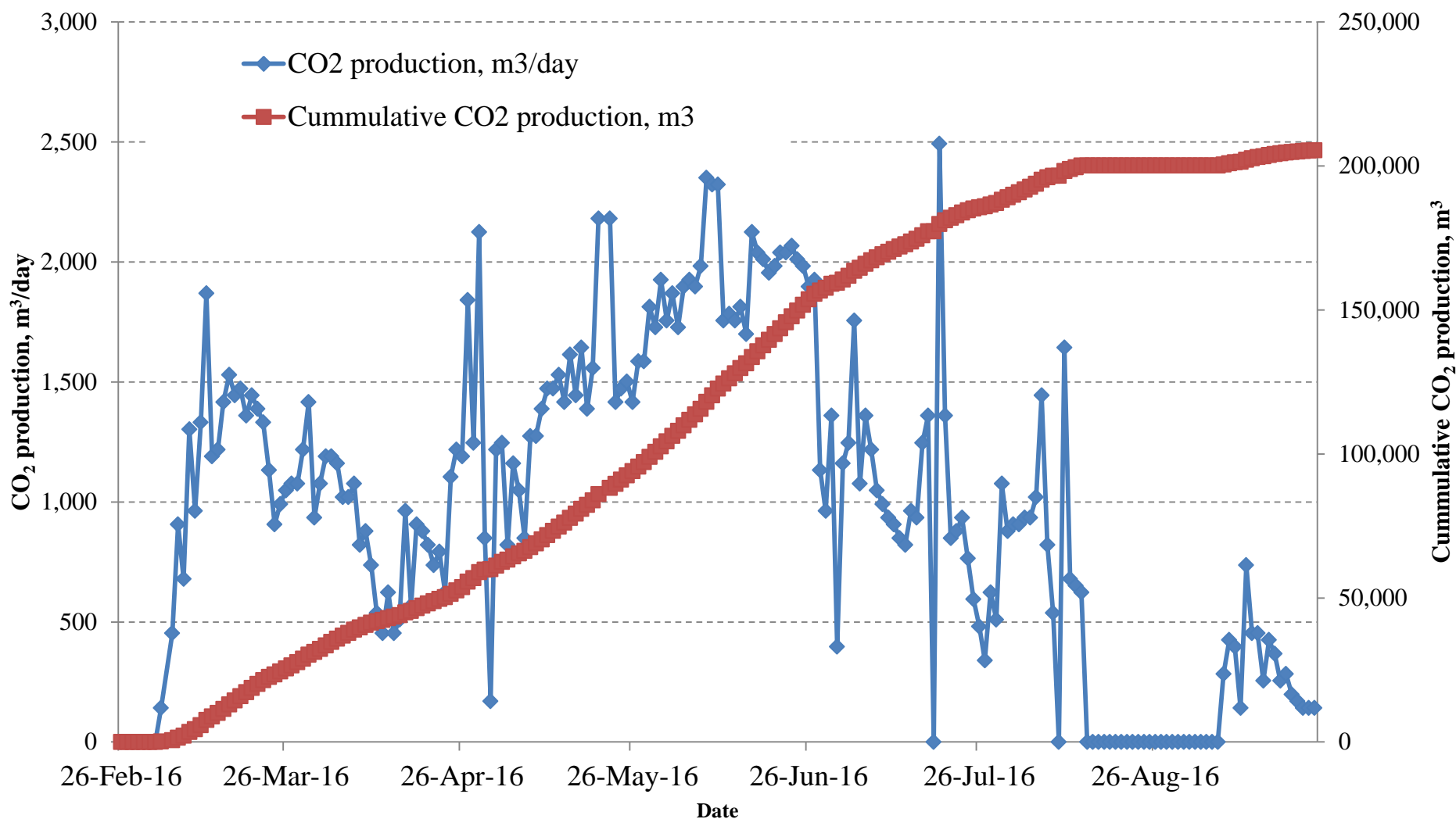


Housing setup for Sercel
(Mark Products) L-22D-
3D sensors, ~5 ft below
surface to minimize
surface noise; installed
below frost line in
bedrock

Incremental oil production (subtracted 9 bbls/day) recorded at a pilot area filed battery



CO₂ production from all installed separators at producing wells and pilot area field battery. At the end of September, 2016, 3 months since CO₂ injection cessation, only ~12% of injected CO₂ was produced



Summary

- Safe and efficient injection
 - No substantial deviations due to unforeseen circumstances (carbonate reservoir fracturing, temperature, pressure, etc.)
- Successful oil recovery
- Low CO₂ production/recovery
 - 13% of total injected CO₂ was lost to atmosphere since start of injection
- Manageable and conformable CO₂ plume

Acknowledgements & Disclaimer

Acknowledgements

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