



EERC

EERC Technology... Putting Research into Practice

Phase II Williston Basin Northwest McGregor Oil Field Huff 'n' Puff Test

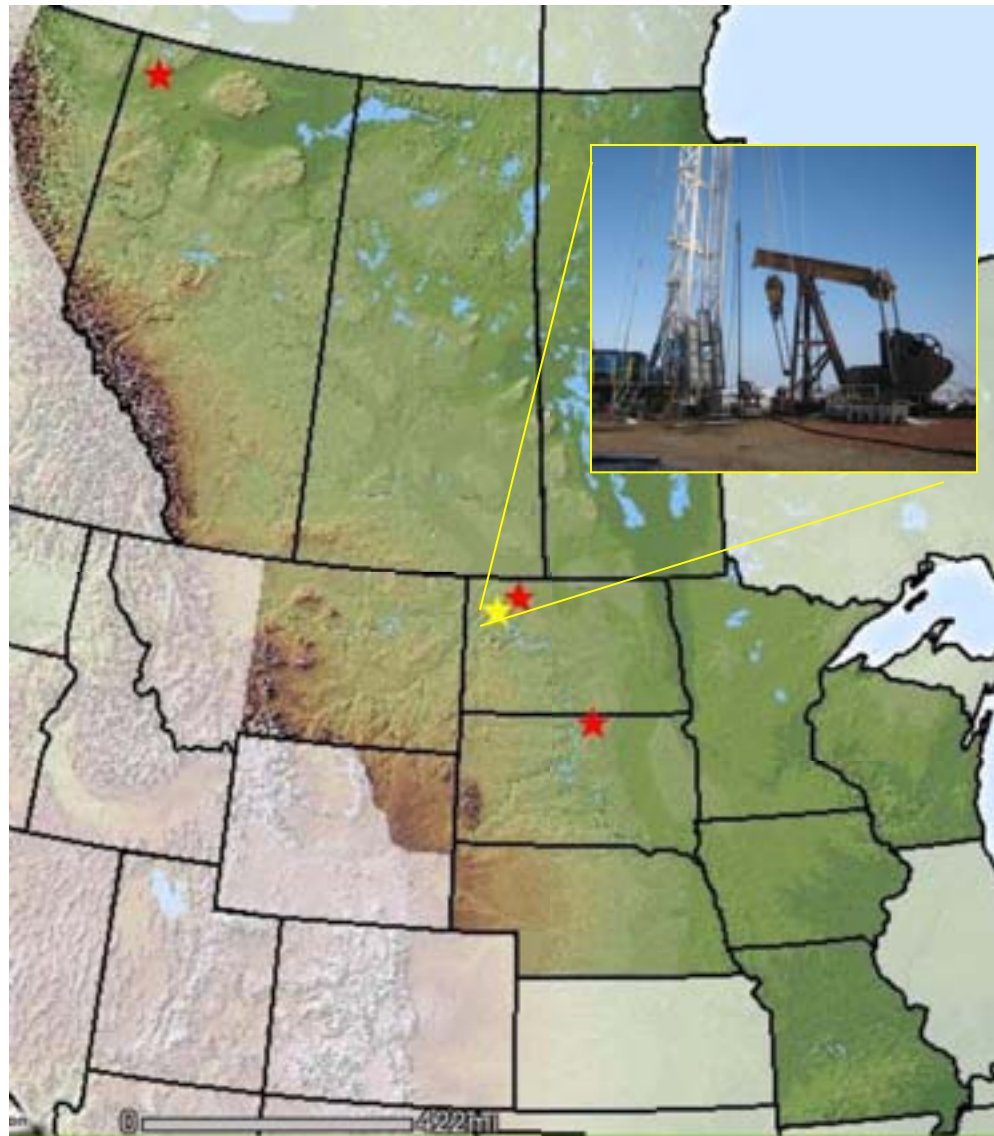
**Plains CO₂ Reduction (PCOR) Partnership
RCSP Annual Meeting
Pittsburgh, Pennsylvania**

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Energy & Environmental Research Center



Williston Basin CO₂ Huff 'n' Puff Test Williams County, North Dakota

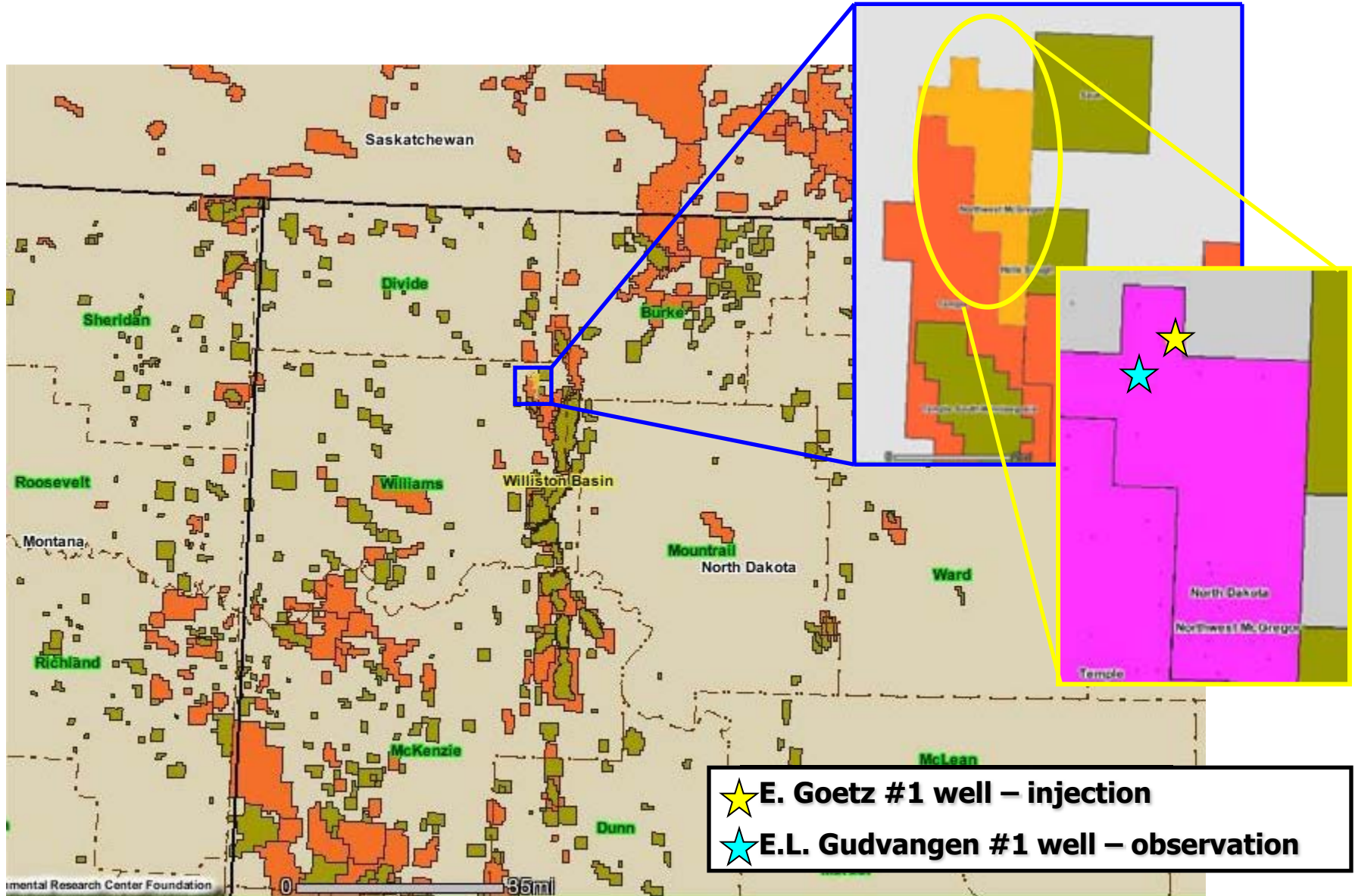


Located in the Northwest McGregor oil field in the northwestern corner of North Dakota.

Technical Goals:

- Evaluate the feasibility of simultaneous carbon dioxide (CO₂) sequestration and enhanced oil recovery (EOR) in a deep (>8000 ft) carbonate oil reservoir.
- Determine the effectiveness of the CO₂ huff 'n' puff (H&P) approach to stimulate oil recovery in the Williston Basin.
- Test the ability of two geophysical tools to monitor CO₂ in the reservoir under deep reservoir conditions.

H&P Location: E. Goetz Well in Northwest McGregor Field



Why the Northwest McGregor Field?

- The oil-producing formation is the Mission Canyon Fm, a carbonate reservoir that lies at a depth ranging from 8000 to 8500 ft.
- Key PCOR Partner, Eagle Operating, owns and operates the E. Goetz #1 well and the nearest other well, the E.L. Gudvangen #1 well, which is producing from the same reservoir.
- The Gudvangen well served as a limited observation well.
- Characteristics of the E. Goetz well are consistent with the project goals.
- The E. Goetz well is representative of many Williston Basin wells with respect to geology, engineering, and operational history.
- Results from the Northwest McGregor H&P can be applied to many wells in the Williston Basin and throughout the PCOR Partnership region.



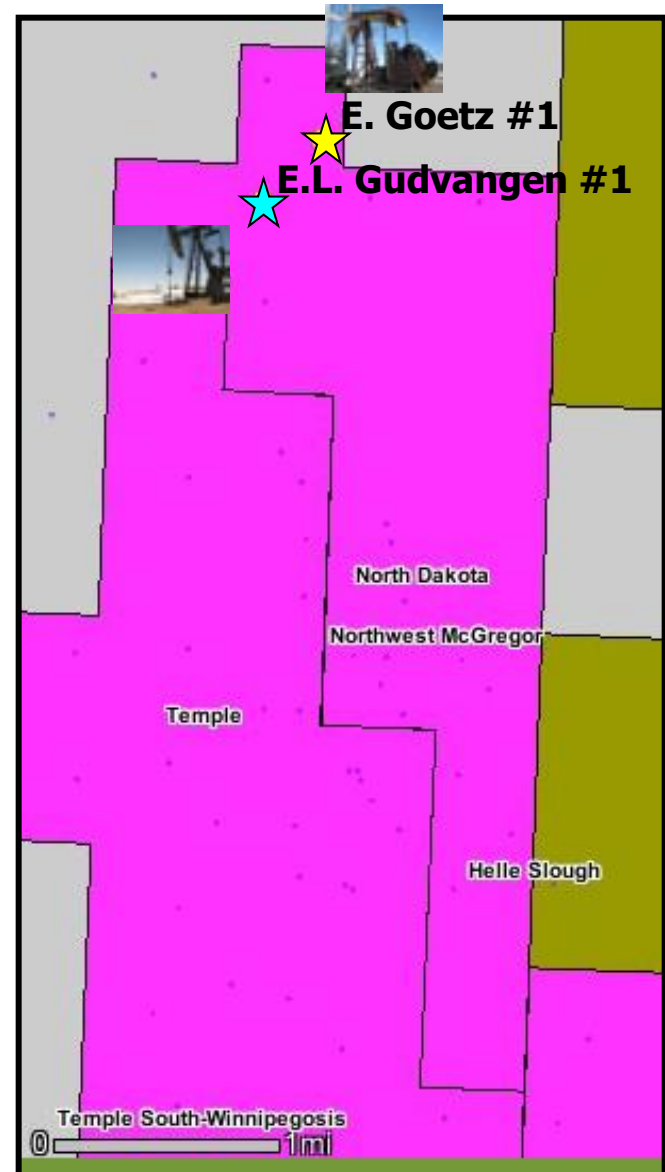
What Makes the Northwest McGregor H&P Unique?

- Few CO₂-based EOR projects have been in **carbonate reservoirs**.
- Those that have (e.g., Weyburn, Midale, Zama) have been significantly shallower (generally 5500 ft or less). At a **depth of 8050 ft**, Northwest McGregor is one of the deepest.
- **Pressure (3000 psig) and temperature (200 F)** is among the highest for a H&P operation.
- Provides opportunity to test H&P concept and the use of **state-of-the-art downhole logging and seismic techniques** (Reservoir Saturation Tool [RST] and Vertical Seismic Profile [VSP]) in a high-pressure and temperature environment and in an older existing well.



H&P Test Configuration

- E. Goetz #1 well serves as:
 - Injector
 - Producer
 - Monitor
- Inject a small volume of CO₂ over a short period of time and monitor for changes in reservoir and shallow subsurface conditions.
- Activities conducted over six phases:
 - Preinjection phase
 - Injection phase
 - Postinjection phase
 - Soak phase
 - Production phase
 - Postproduction phase
- E.L. Gudvangen #1 well serves as an observation well, meaning formation fluid samples (oil, gas, water) from it are collected at the surface and analyzed.



Key Elements of H&P Plan

1. Preinjection site characterization.
 - Baseline logging, fluid analyses, pressure and temperature.
2. Inject 440 tons of CO₂ into the E. Goetz #1.
3. Shut in E. Goetz #1 well.
 - Allows CO₂ to “soak” into the oil.
 - Soak period will last minimum 2 weeks.
 - Conduct second round of logging.
4. Bring E. Goetz #1 well back onto production.
5. Rate of oil production should start out higher than preinjection rate and decrease over time.
6. Close monitoring of oil production and fluid analysis over the postinjection period is conducted until oil production rate has returned to “normal.”
7. Conduct final round of logging to determine effects and fate of injected CO₂.

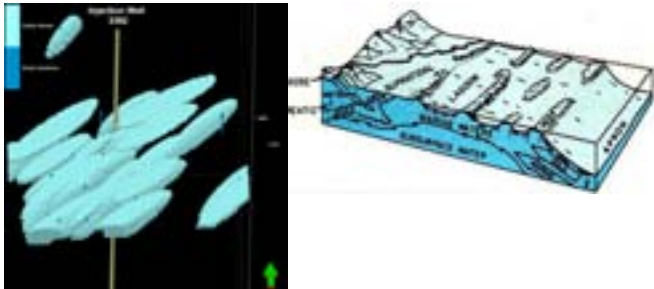
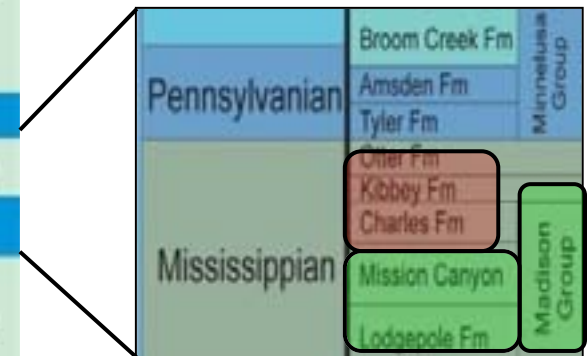
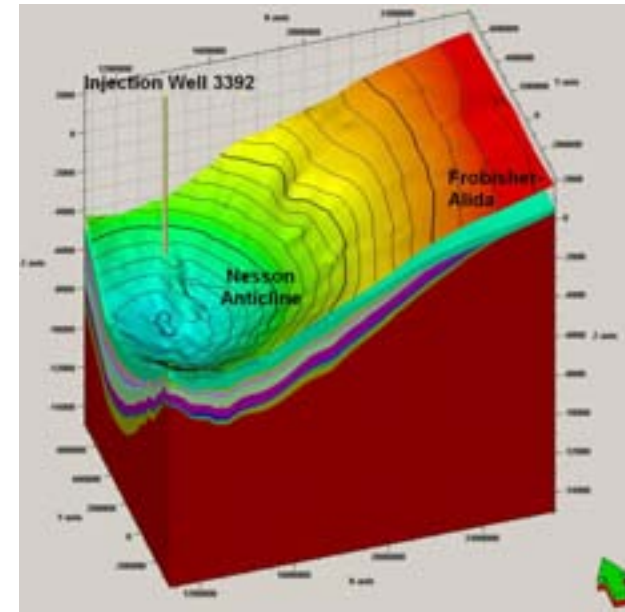


Geological Setting

Northwest McGregor Oil Field

- Located on the northern tip of the Nesson Anticline, which is near the depocenter of the Williston Basin.
- Primary production is from Mississippian Mission Canyon Formation.
- The Mission Canyon Fm is a carbonate-dominated formation that includes interbeds of anhydrite and salt. It was deposited in a mid energy depositional setting ending with a sabkha environment and represents a major regressive sequence.
- Oil production is interpreted to occur largely from shoals.

Age Units	Rock Units	Hydrogeologic Systems
Cenozoic	Quaternary	AQ5 Aquifer
	Tertiary	
Mesozoic	White River Grp Golden Valley Fm	TK4 Aquitard
	Fort Union Grp	
	Hell Creek Fm Fox Hills Fm	
	Pierre Fm Judith River Fm	
	Eggs Fm	
	Wobesa Fm	
	Carlisle Fm	
	Greenhorn Fm	
	Wade Fourche Fm	
	Mowry Fm	
Newcastle Fm Scul Creek Fm Inyan Kara Fm	AQ4 or Dakota Aquifer	
Jurassic	Swift Fm	TK3 Aquitard
	Rierson Fm Piper Fm	
Triassic	Spearfish Fm	
Permian	Minnekahta Fm Opache Fm	
	Broom Creek Fm	
Pennsylvanian	Amsden Fm Tyler Fm	AQ3 Aquifer
	Kibbey Fm Charles Fm	TK2 Aquitard
Mississippian	Mission Canyon Lodgepole Fm	AQ2 or Madison Aquifer
	Bakken Fm Three Forks Wahkiakum Cannonball Cannonball Cannonball Cannonball Cannonball	TK1 Aquitard
Devonian	Interlake Fm	
Silurian	Stromwell Fm Stony Mountain Fm	
Ordovician	Red River Fm	AQ1 Aquifer
	Winnipeg Grp Winnipeg Fm Black River Fm	
Cambrian	Deadwood Fm	



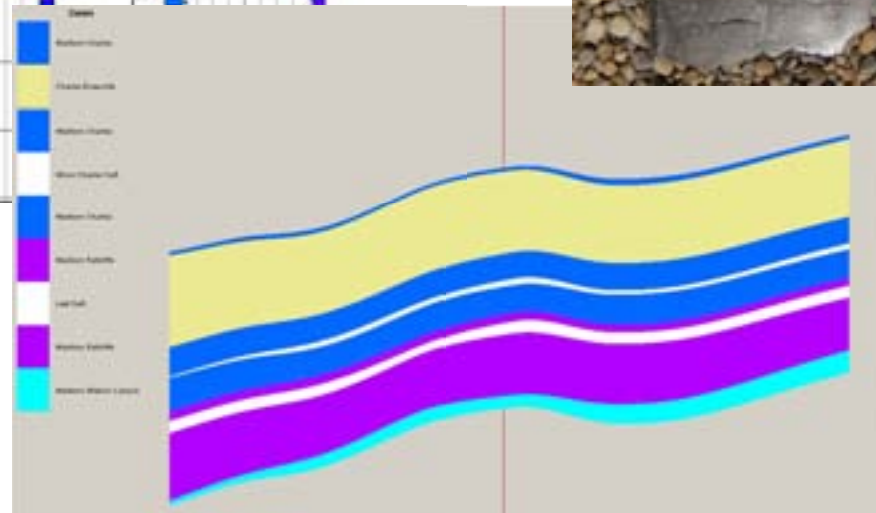
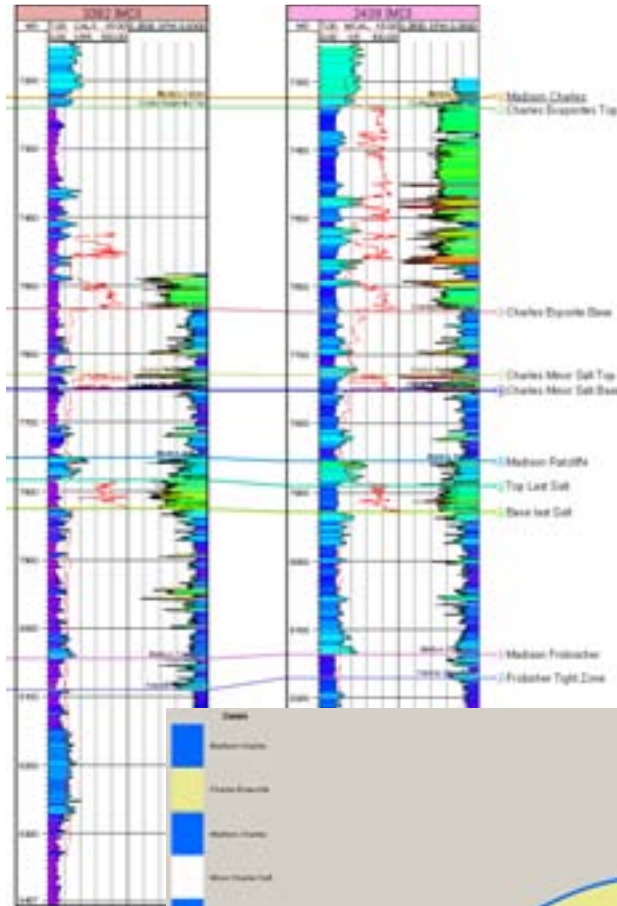
Reservoir and Well Characteristics

Reservoir

Lithology: primarily limestone
Average pay thickness: 14 ft
Porosity: 15%
Matrix permeability: 0.35 md
Secondary permeability: fractures
Depth (from surface) to pay: 8050 ft
Average temperature: 216 F
Initial reservoir pressure: 3127 psig
Oil gravity (API): 41.7
Cumulative oil production: 2.2 Mbo

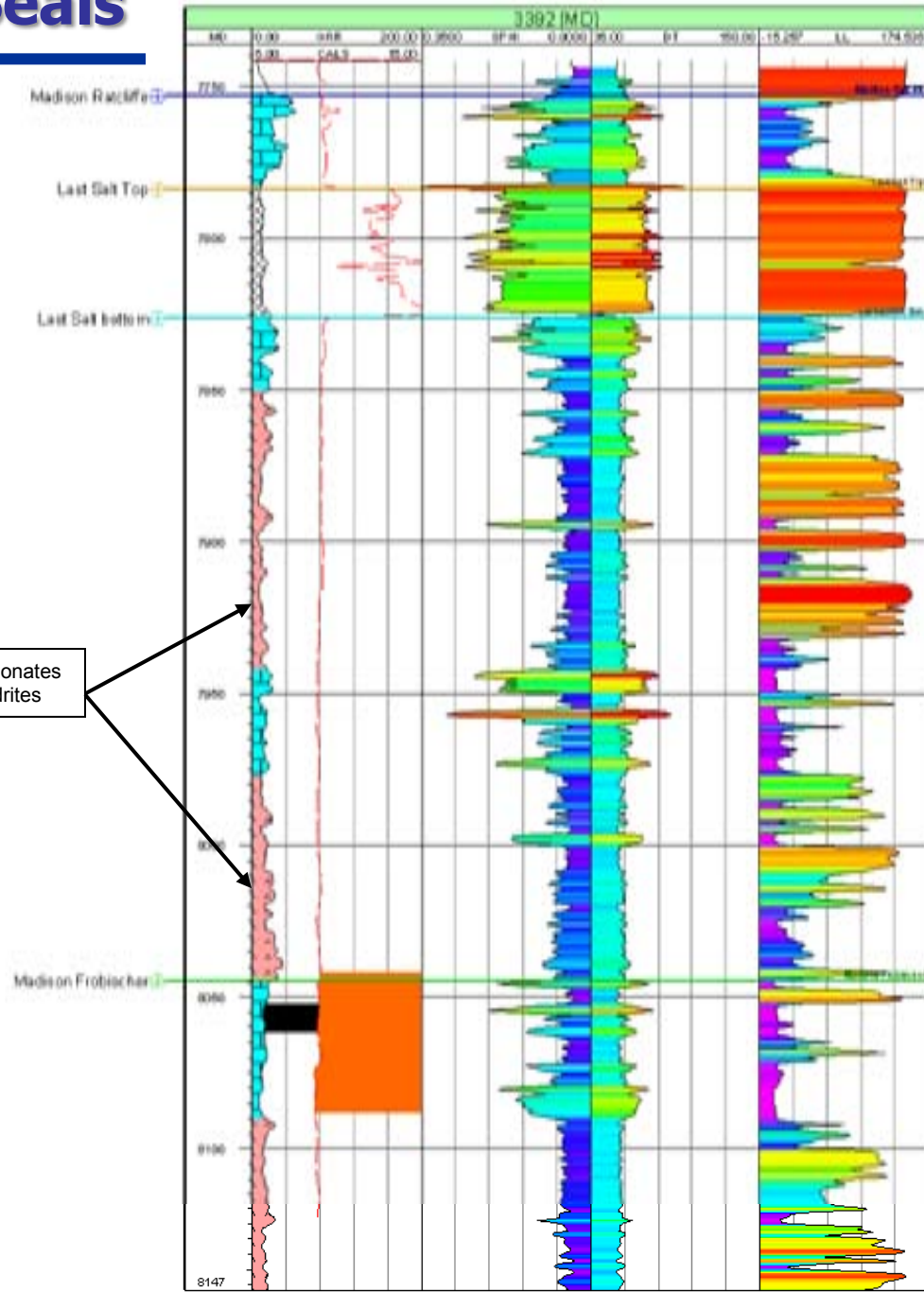
E. Goetz #1 Well

Location: Sec.12, T159N, R96W
NDIC well #: 3392
Date drilled: 7/31/1963
Perfs: 8052' to 8062 ft Madison
Casing inside diameter: 5½ in.
Tubing inside diameter: 2¾ in.
Packer set @: 7788 ft



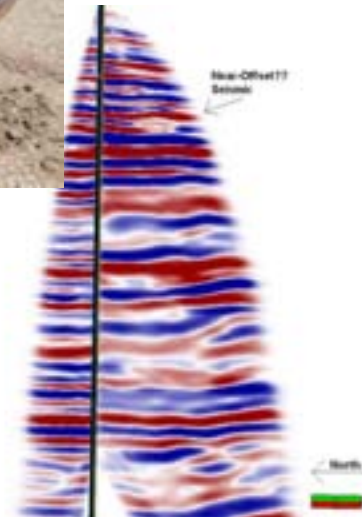
Target Injection Zone and Seals

- Log from E. Goetz #1.
- The black zone represents the perforated portion of the well, and the orange zone is the cored zone and represents the target injection zone.
- There are some vertical fractures present in the core; however, the overlying tight carbonates and anhydrites serve as a seal to prevent any vertical migration.
- Tight carbonates and anhydrites are represented by the peach zones.
- The Last Salt serves as an additional major seal, preventing any fluid from traveling vertically.
- There is also up to 300 ft of Upper Charles Fm salts that would act as a third sealing formation.



Key Elements of Monitoring, Verification, and Accounting (MVA)

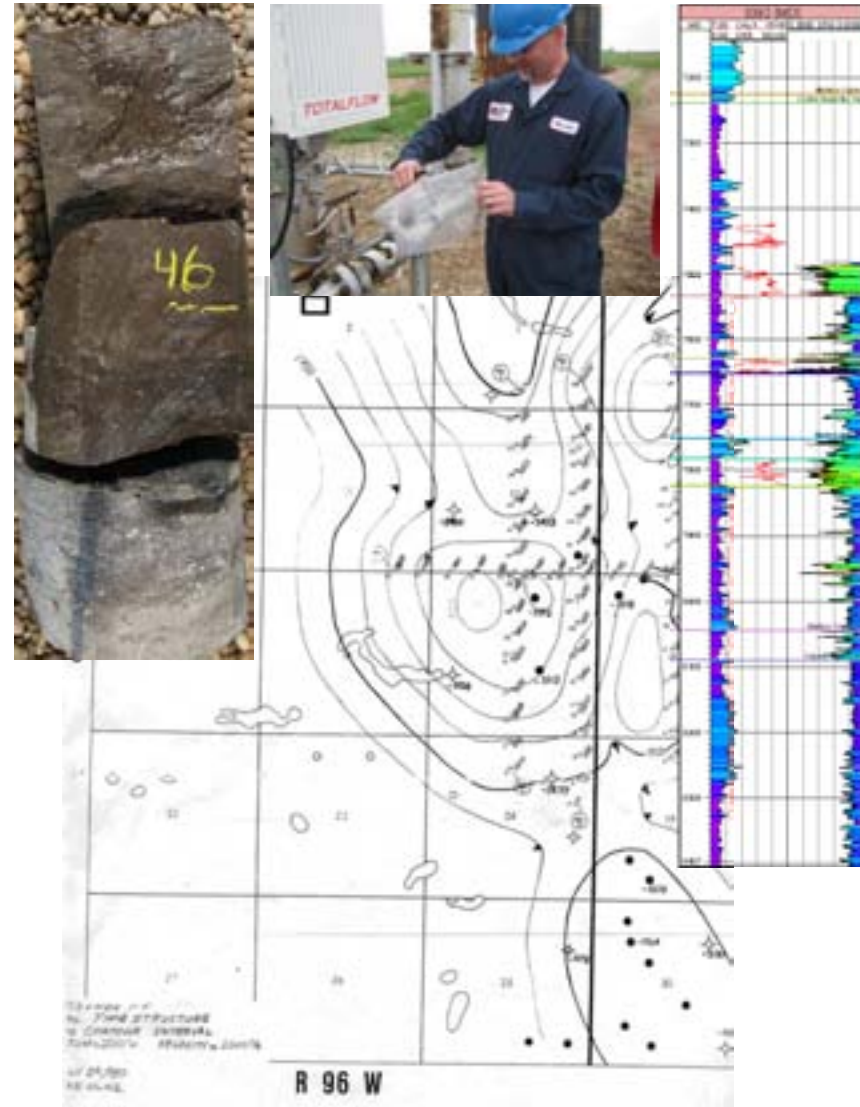
- Site characterization.
 - Establish baseline geological, geochemical, and geomechanical conditions.
- Estimate CO₂ fate through mass balance.
 - Surface flows, samples and analyses.
- Effects on formation properties.
 - Pressure buildup test before and after (formation pressure, permeability, skin factor).
- Movement of CO₂.
 - RST logs and VSP before and after injection.
- Out-of-zone migration.
 - Observation and shallow water well samples, perfluorocarbon tracer.



Site Characterization Activities

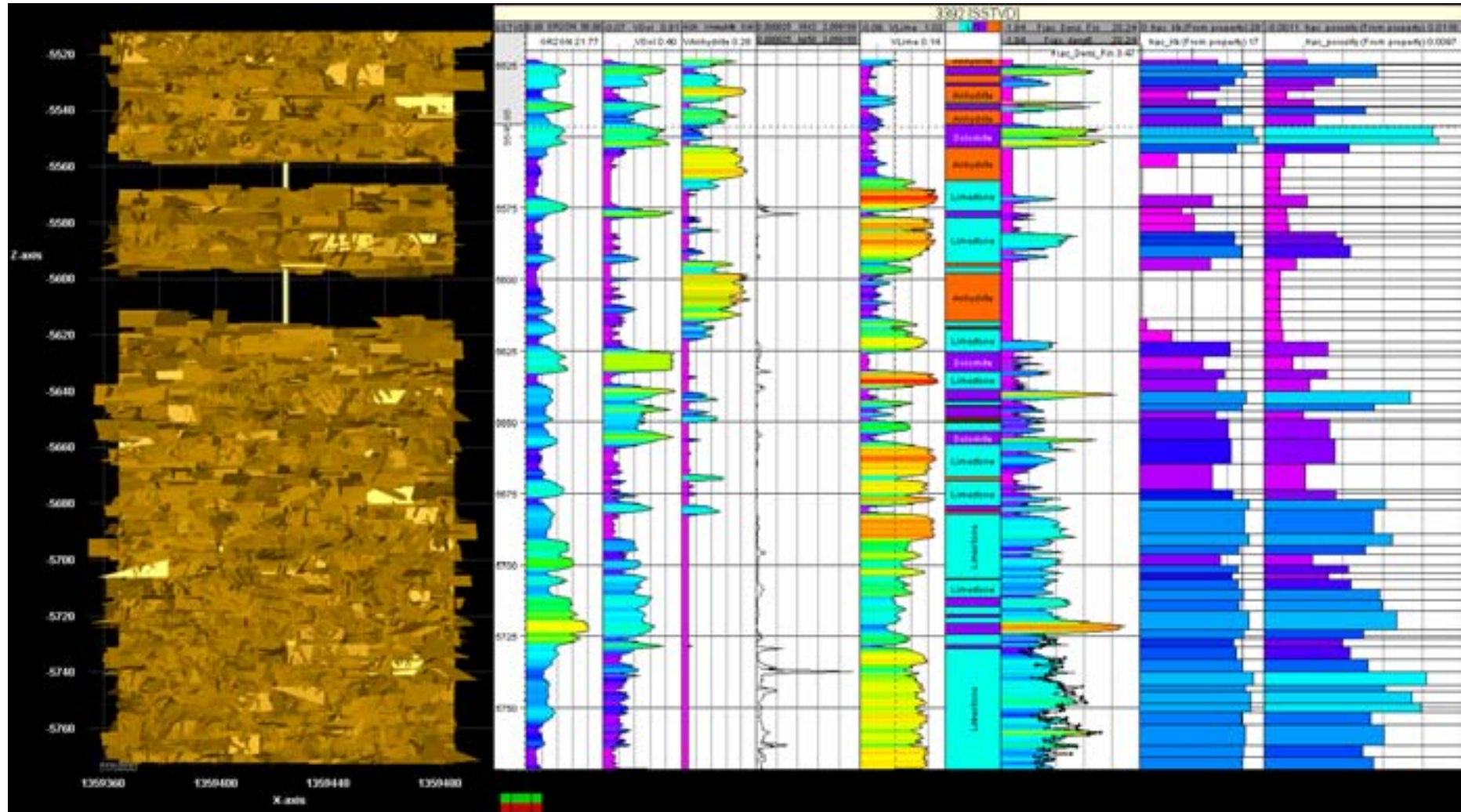
Conducted Before Injection

- Core of injection zone from E. Goetz #1 kept at North Dakota Geological Survey (NDGS) core library has been described and photographed.
- Historical well logs, seismic surveys, production, and drill stem test (DST) data collected for E. Goetz, Gudvangen, and 30 other wells in the area.
- Fluid samples (oil, water, gas) collected at the surface from the E. Goetz and Gudvangen wells, and shallow groundwater wells in area.
 - All fluids analyzed for CO₂, methane content, and tracer.
 - Water analyzed for key geochemical parameters, including pH, major anions and cations, and metals.



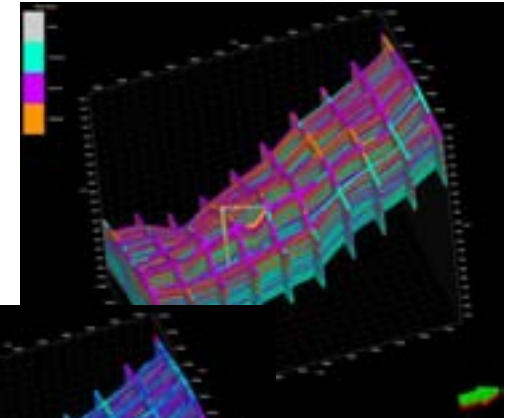
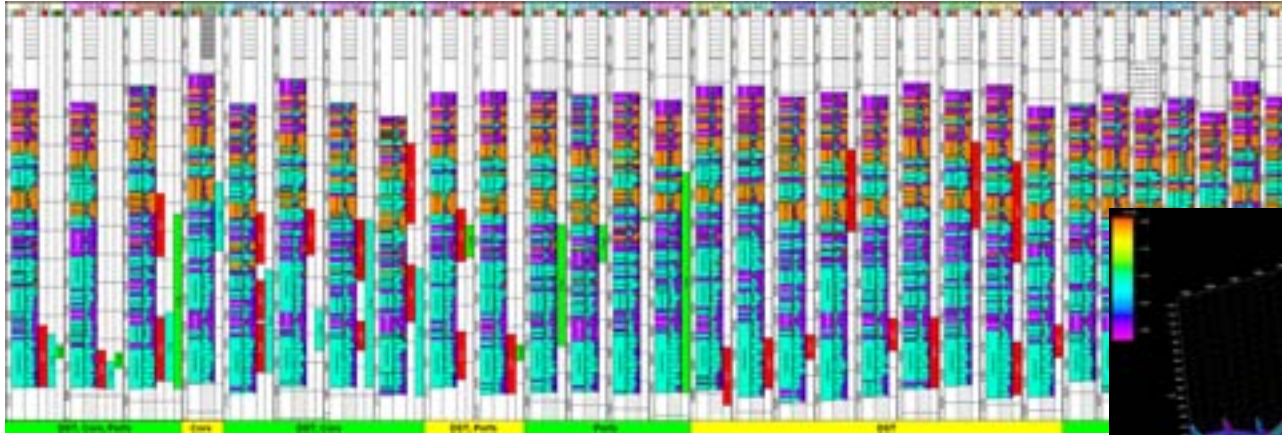
Site Characterization Activities (cont.)

Analysis of Fracture Data to Predict Fracture Distribution and the Effect of Fracture Networks on Injection and Fate of CO₂

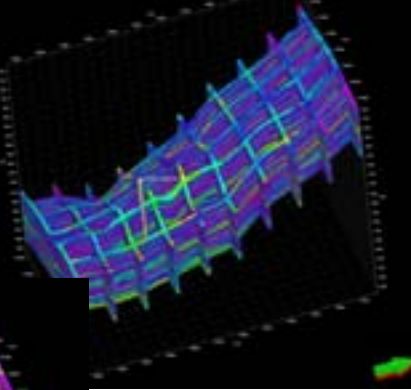


Site Characterization Activities (cont.)

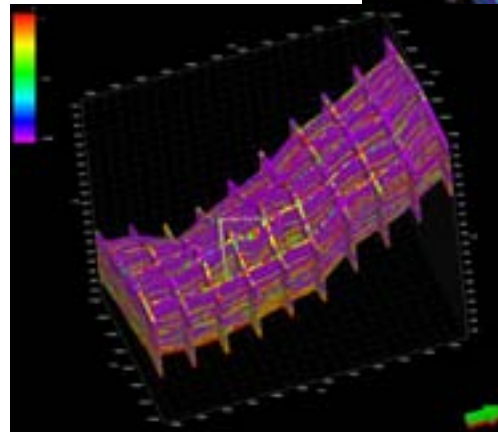
Static Petrophysical Modeling



Facies



Total Porosity



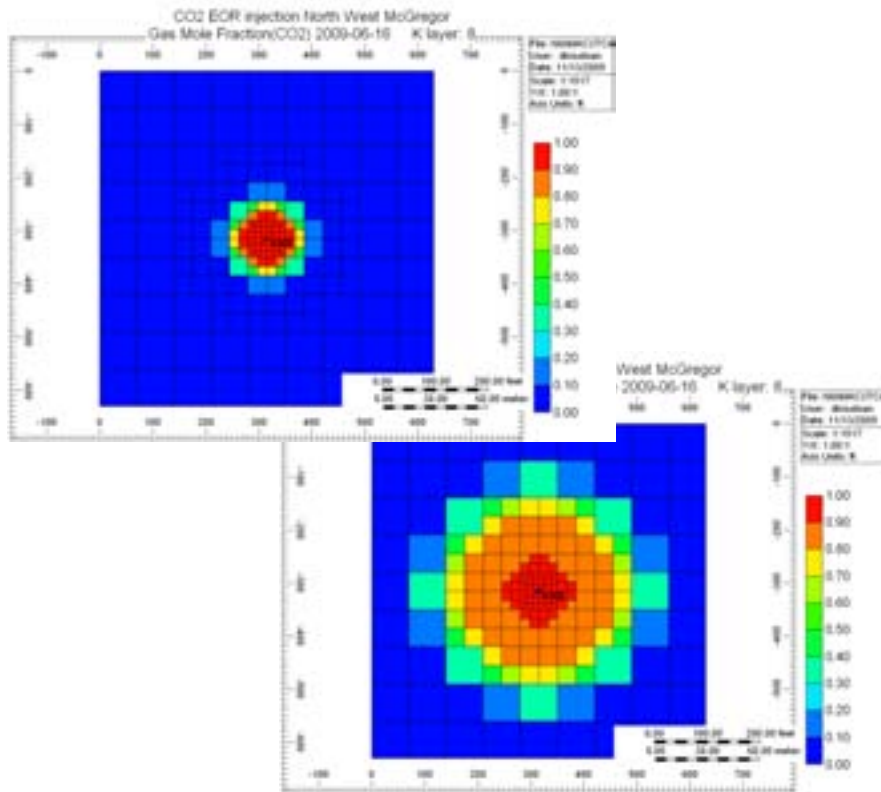
Permeability

Based on data from 30 wells in the Northwest McGregor Field and other surrounding fields.

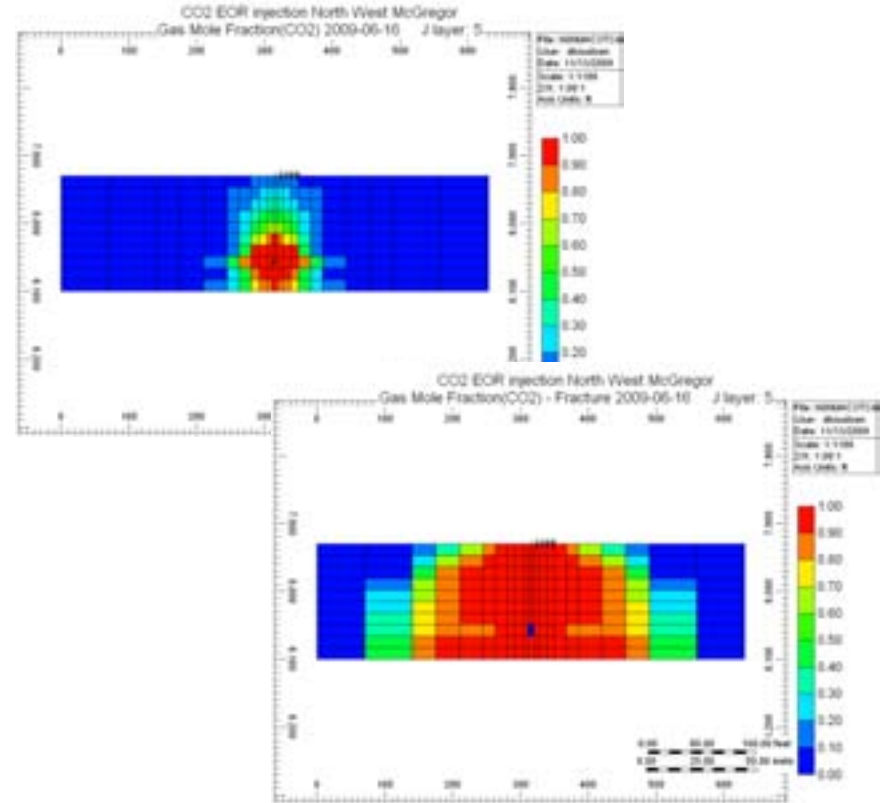
Served as the basis for dynamic modeling of the H&P operation.

Site Characterization Activities (cont.)

Dynamic Injection Modeling



Map View

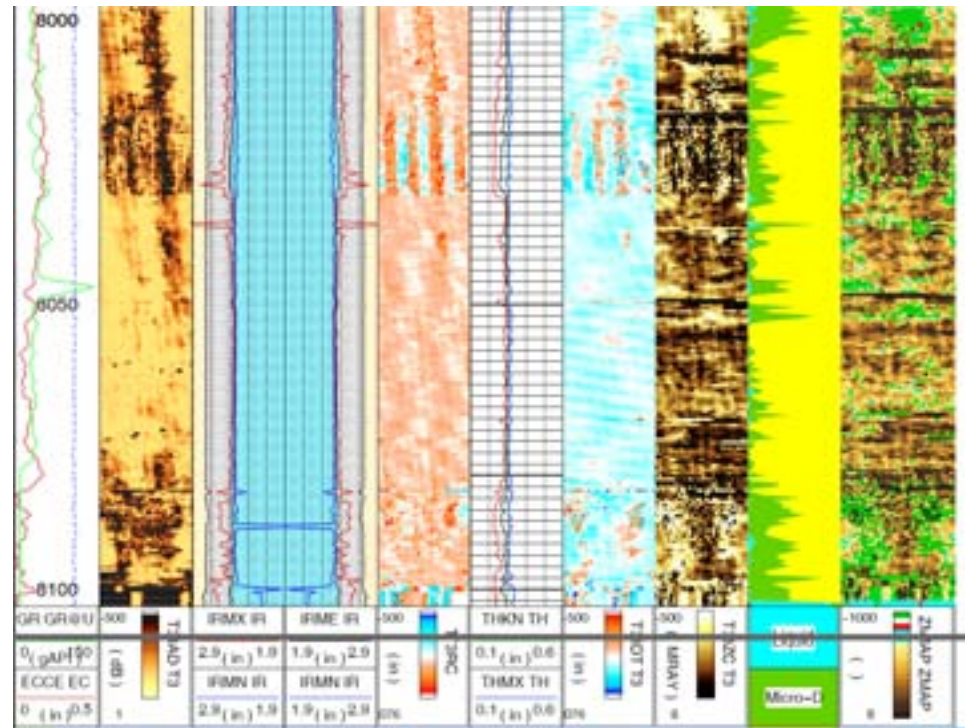


Cross Section

Field-Based Characterization and Set-Up Activities

Conducted on E. Goetz #1 Before Injection

- Goetz well taken off production.
- Pull tubing and pump, clean scale.
- **Run casing and cement well logging tool (Ultrasonic Imaging [USI] Tool).**
- Reinstall tubing in Goetz well.
- Set new CO₂ – rated packer.
- Pressure test tubing.
- Swab in well to clean workover fluid from perfs.



Preinjection Characterization Activities

Provides Key Data on Baseline Conditions

- RST provides data on near-well bore gas/fluid saturation.
- VSP provides lithology and gas/fluid saturation away from the well bore, up to 1000 ft depending on conditions.
- Collect and analyze downhole fluid samples under reservoir conditions. Provides data on reservoir geochemistry.
- Set pressure “bombs” to collect reservoir temperature and pressure data as part of a 72-hour pressure buildup test. Provides data on effective permeability and injectivity of the well.



CO₂ Injection for H&P

- 440 tons injected over 36 hours in late June 2009.
- CO₂ was purchased from Praxair, shipped from a gas plant in Wyoming by rail to North Dakota, and delivered to the site by truck.



Soak Period Activities

Run Second RST

Tool is small enough to be run down the tubing and can be run in such a way so as not to lose any injected CO₂ or pressure in the well.

Allows us to compare near-well bore gas/fluid saturation immediately after injection to preinjection and later postinjection conditions.

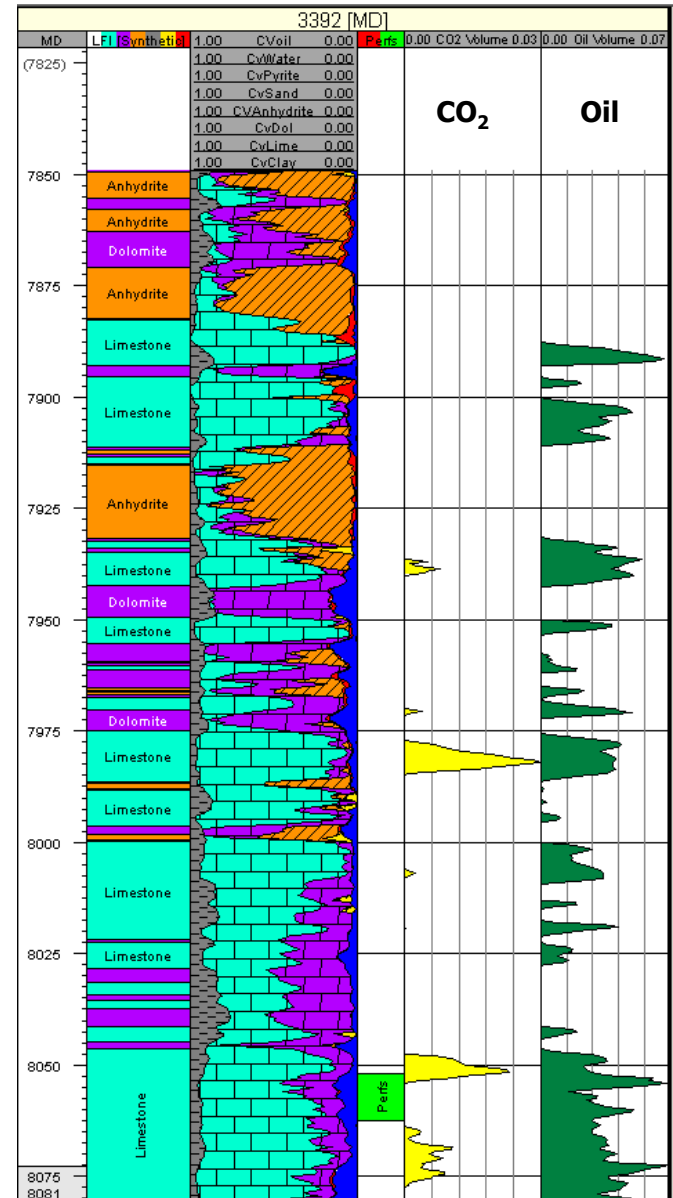
Results showed several zones within the E. Goetz #1 well with measurable CO₂.

Collect and analyze fluid samples and pressure data from **Gudvangen observation well**.

- **No statistically relevant changes observed.**

Collect and analyze fluid samples from **shallow groundwater wells**.

- **No statistically relevant changes observed.**



Post-Soak Period Activities

Conducted immediately after the soak phase.
Soak period lasted 2 weeks.

- Well was opened, CO₂ gas blow-off was measured, and downhole gauges were retrieved for data analysis.
- Oil flowed from the well within hours and the soak period was determined to be over.
- The pump was reinstalled, a P-gauge was set, and the production phase began.



Production Period

After 2-week soak period, E. Goetz #1 was put on production phase, the time during which the well produces oil at a rate greater than the pre-H&P production rate. Summer 2009 production data indicate this will last several months.

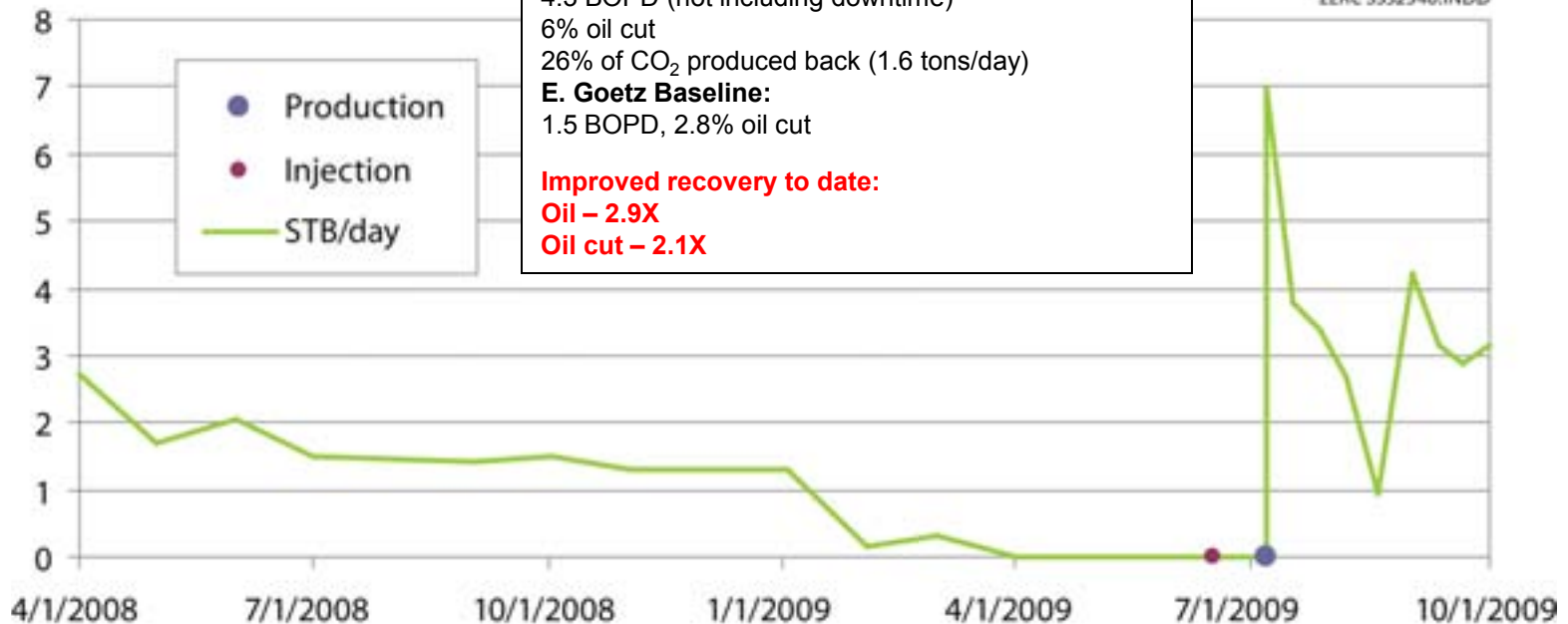
Production Totals (July 6 through September 17, 2009):

Days	Oil	Water	Gas
73	242 bbl	3782 bbl	1991 Mcf (116.5 tons)

Averages (July 6 through September 17, 2009):

4.3 BOPD (not including downtime)
 6% oil cut
 26% of CO₂ produced back (1.6 tons/day)
E. Goetz Baseline:
 1.5 BOPD, 2.8% oil cut

Improved recovery to date:
Oil – 2.9X
Oil cut – 2.1X



Post-Production Period Activities

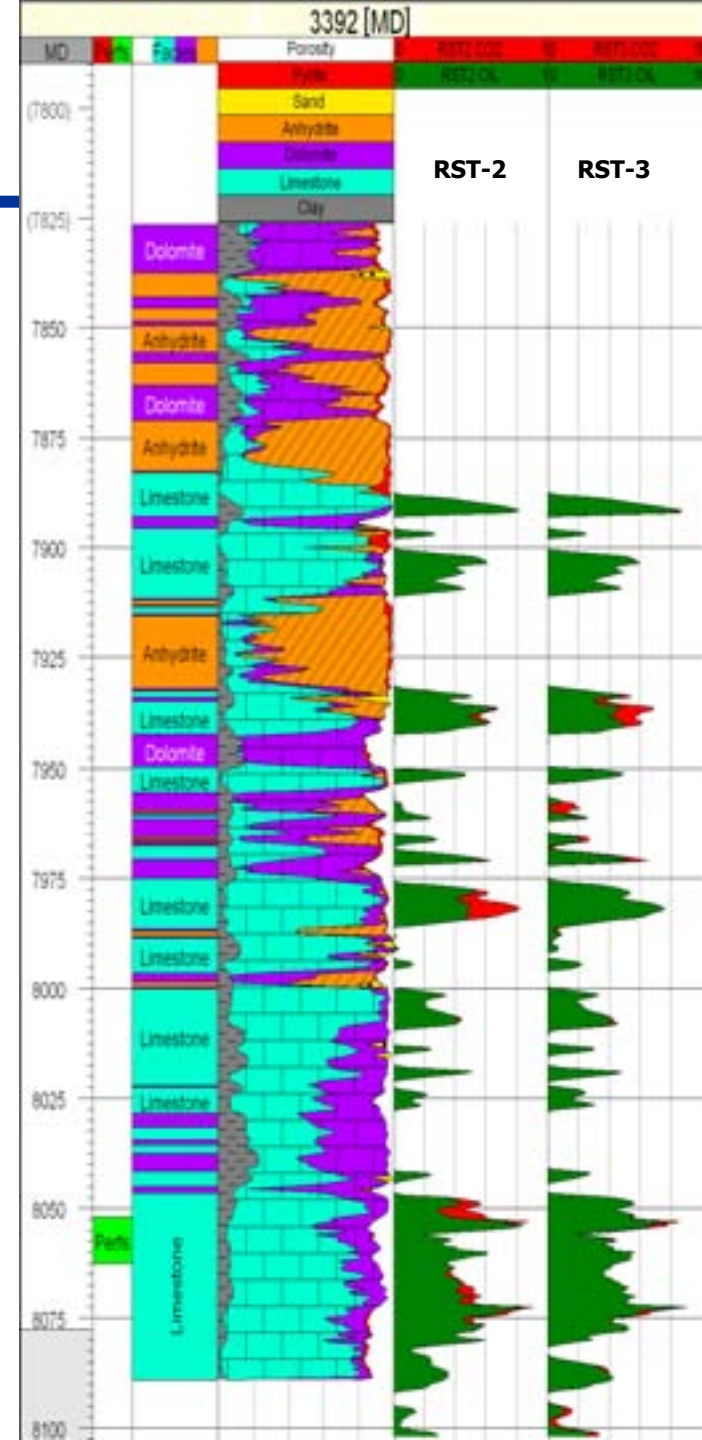
Conducted after approximately 3 months of production.

- Collected and analyzed another downhole fluid sample under reservoir pressure and temperature.
- Ran a third RST.
- Ran a second VSP survey.
- Collected surface fluid samples from the Gudsvangen and shallow groundwater wells.
 - No observable changes.
- Ran a second USI log and caliper log to determine effects on casing and the precise position of the perfs.

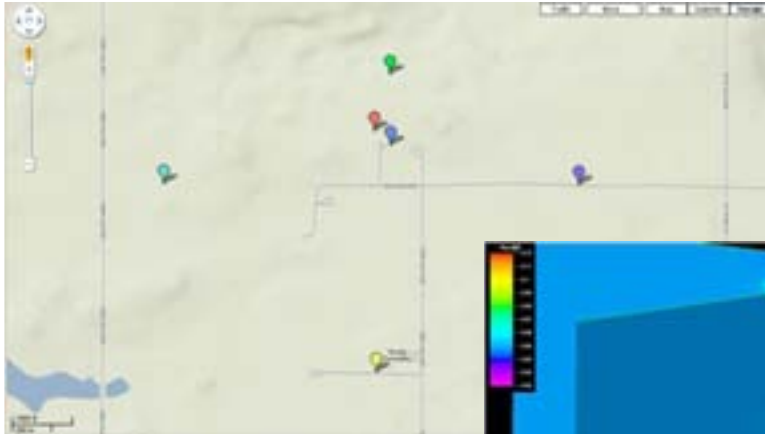


Compare RST Results

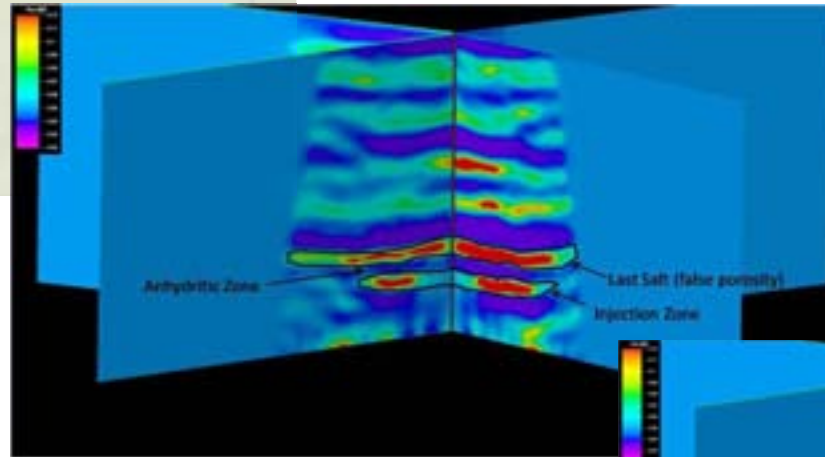
- Compare the RST results from the “soak period” (second run in early July 2009) to the RST results from after 3 months of the “production period” (third run in early October 2009).
- Time between the second and third RST runs is approximately 3 months:
 - CO₂ saturation in the vicinity of the perforations has significantly decreased.
 - CO₂ in some zones above the perforations appears to have increased.
 - Tells us CO₂ has not migrated above the first anhydrite seal.
 - Tells us the RST can provide meaningful data in a carbonate reservoir under relatively high-pressure and temperature conditions.



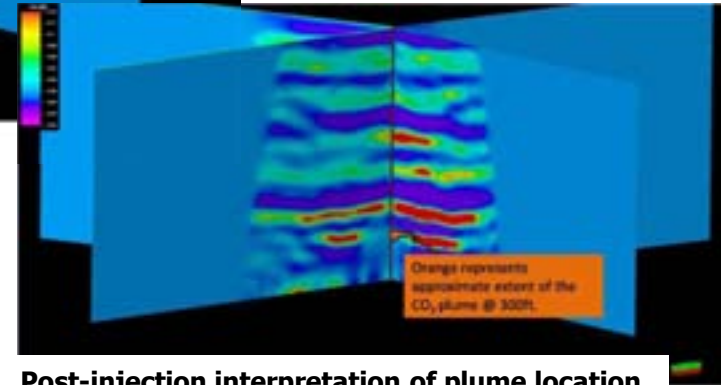
Preview of Latest VSP Results



Locations of vibro trucks

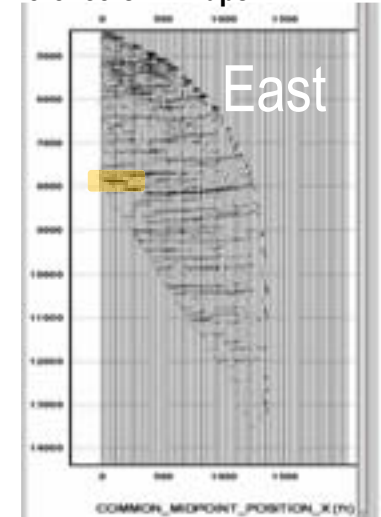


Pre-injection baseline results
(seismic inverted to effective porosity)



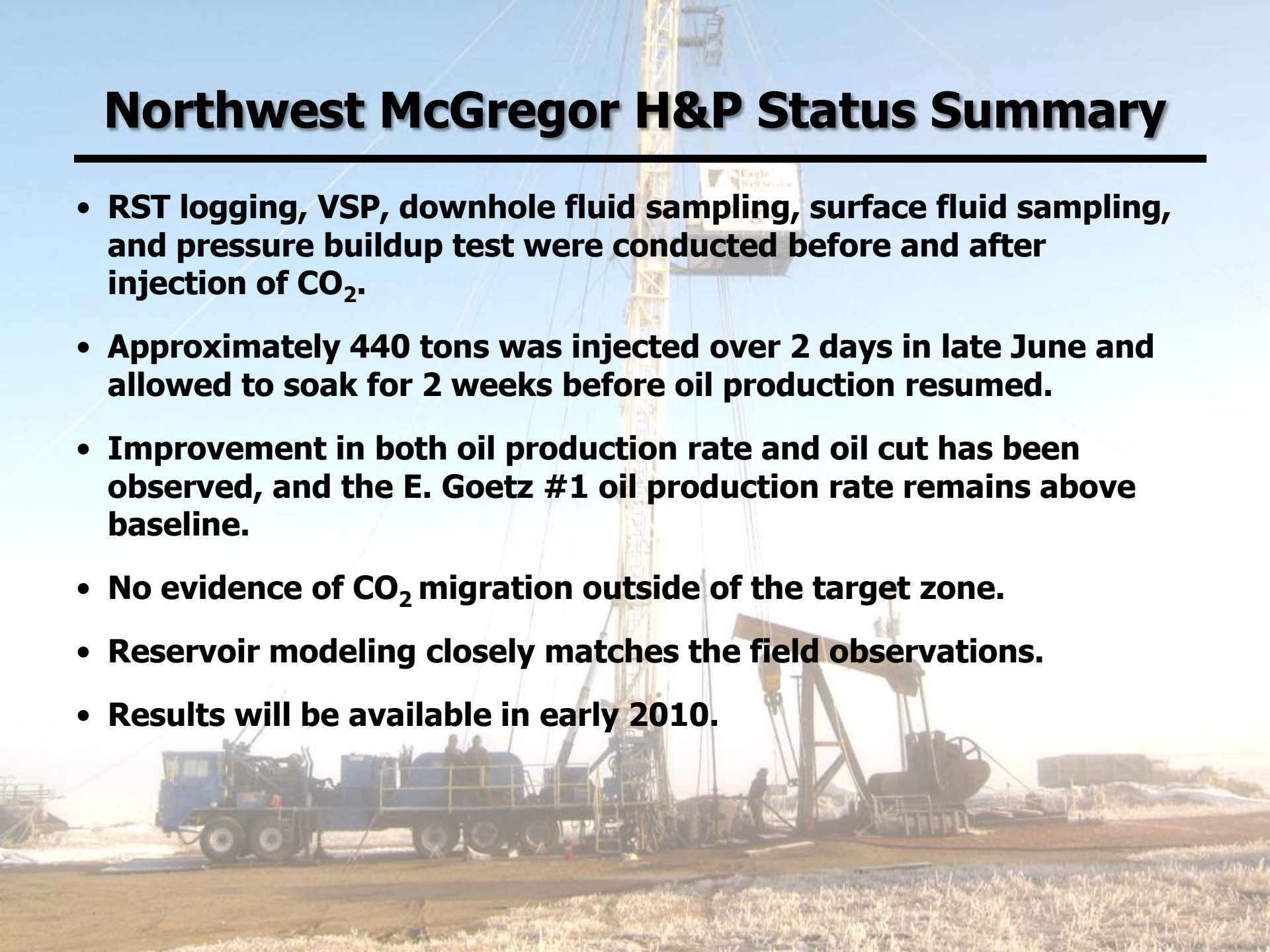
Post-injection interpretation of plume location
(seismic inverted to effective porosity)

Difference CDP maps:



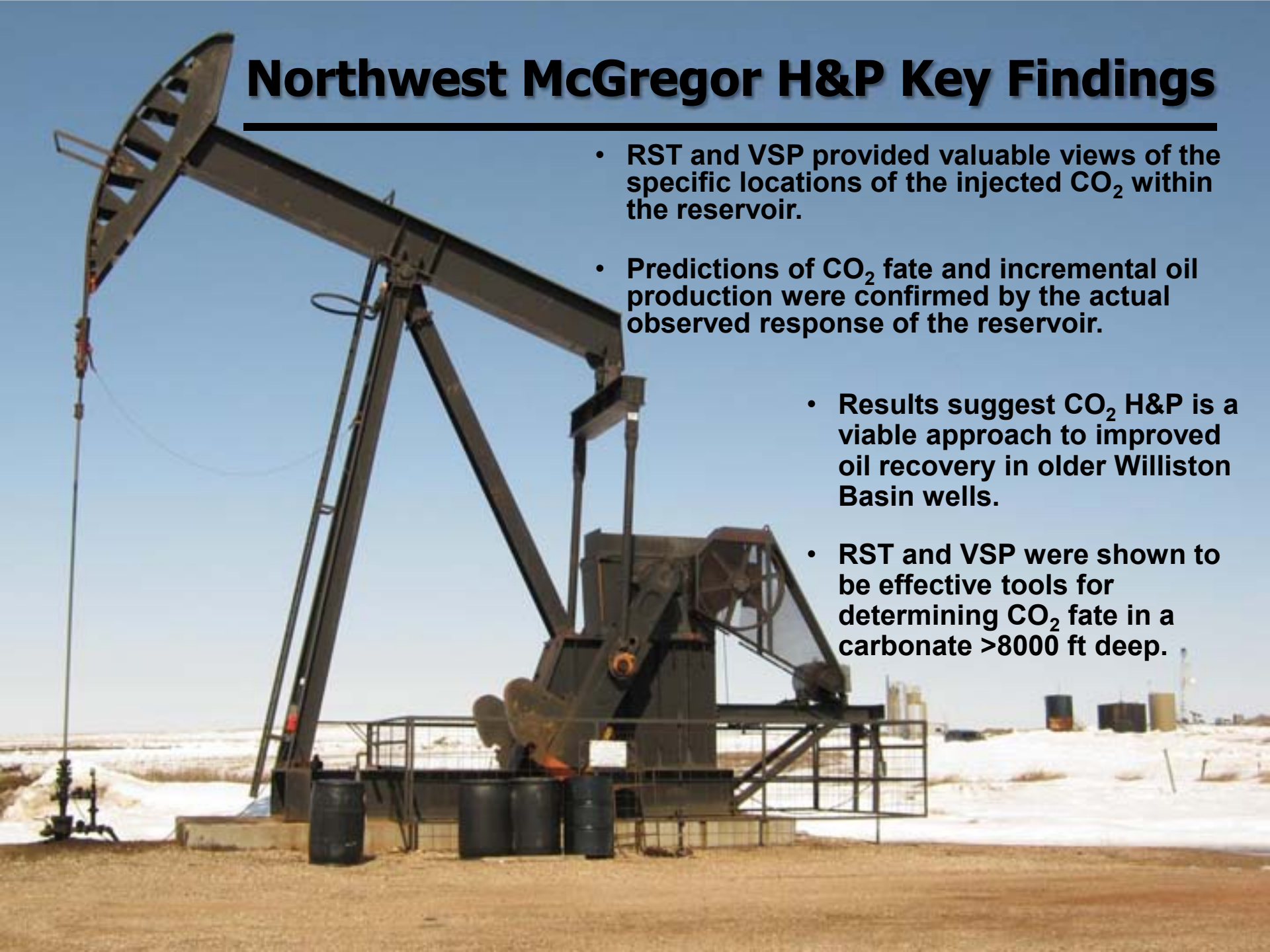
Northwest McGregor H&P Status Summary

- **RST logging, VSP, downhole fluid sampling, surface fluid sampling, and pressure buildup test were conducted before and after injection of CO₂.**
- **Approximately 440 tons was injected over 2 days in late June and allowed to soak for 2 weeks before oil production resumed.**
- **Improvement in both oil production rate and oil cut has been observed, and the E. Goetz #1 oil production rate remains above baseline.**
- **No evidence of CO₂ migration outside of the target zone.**
- **Reservoir modeling closely matches the field observations.**
- **Results will be available in early 2010.**



Northwest McGregor H&P Key Findings

- RST and VSP provided valuable views of the specific locations of the injected CO₂ within the reservoir.
- Predictions of CO₂ fate and incremental oil production were confirmed by the actual observed response of the reservoir.
- Results suggest CO₂ H&P is a viable approach to improved oil recovery in older Williston Basin wells.
- RST and VSP were shown to be effective tools for determining CO₂ fate in a carbonate >8000 ft deep.



Summary of Key Points Regarding CO₂ EOR in the PCOR Partnership Region

- There are many potential sources of large volumes of CO₂ in the PCOR Partnership region, but capture and compression face economic challenges.
- There are many oil fields throughout the PCOR Partnership region that may be suitable for the application of large-scale CO₂ injection for EOR operations.
- The size of the prize is over 3.4 billion barrels of oil worth over \$238 billion at \$70 per barrel.
- Large-scale commercial projects and research efforts show that large-scale CO₂ injection into deep formations can be safe and economical.



Summary of Key Points Regarding CO₂ EOR in the PCOR Partnership Region (cont.)

- The use of CO₂ for H&P on individual wells in the region may yield further economically attractive opportunities, making the prize even larger and providing additional incentive to the creation of a CO₂ distribution infrastructure.
- The development and expansion of carbon credit-trading markets for credits associated with geologic storage of CO₂ will bring additional value to EOR projects.
- The PCOR Partnership and the EERC are working to make these projects a reality.



Contact Information



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