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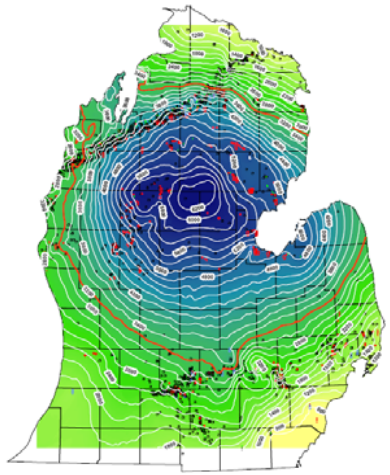

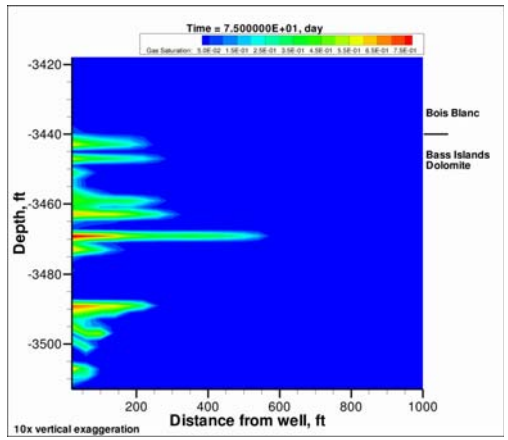


# *Michigan Basin, MRCSP State-Charlton 30/31 Field Test Site*

***Presented By: Neeraj Gupta, Battelle***

***Regional Carbon Sequestration Partnerships Initiative Review Meeting***
***October 6-8, 2008, Pittsburgh, PA***

NETL
U.S. Department of Energy/NETL

MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

# MRCSP Membership

# Michigan Basin- Otsego County Test Site Project Team

DTE Energy

***Abed Houssari, Becky Cook, Steve Rawlings, and others***

Michigan Basin Core Research Laboratory
Western Michigan University 1903 · 2003

***Dave Barnes, Bill Harrison, Sue Grammer***

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***Dave Ball, Neeraj Gupta, Phil Jagucki, Joel Sminchak, Jackie Gerst, Matt Place, Diana Bacon, Danielle Meggyesy, Judith Bradbury, and others***

NETL
U.S. Department of Energy/NETL

***Lynn Brickett, Charlie Byrer, Art Wells, Dave Wildman***

CORE ENERGY, LLC

***Robert Mannes, Joe Herpst, and Jane DeVeaux***

Leland Stanford Junior University
Die Luft der Freiheit weht
1891

***Mark Zoback and Laura Chiaramonte***

Schlumberger

***Dwight Peters***

***Additional Contributions by Numerous Other MRCSP Team Members***
***Outreach support by Sarah Wade, AJW Inc.***

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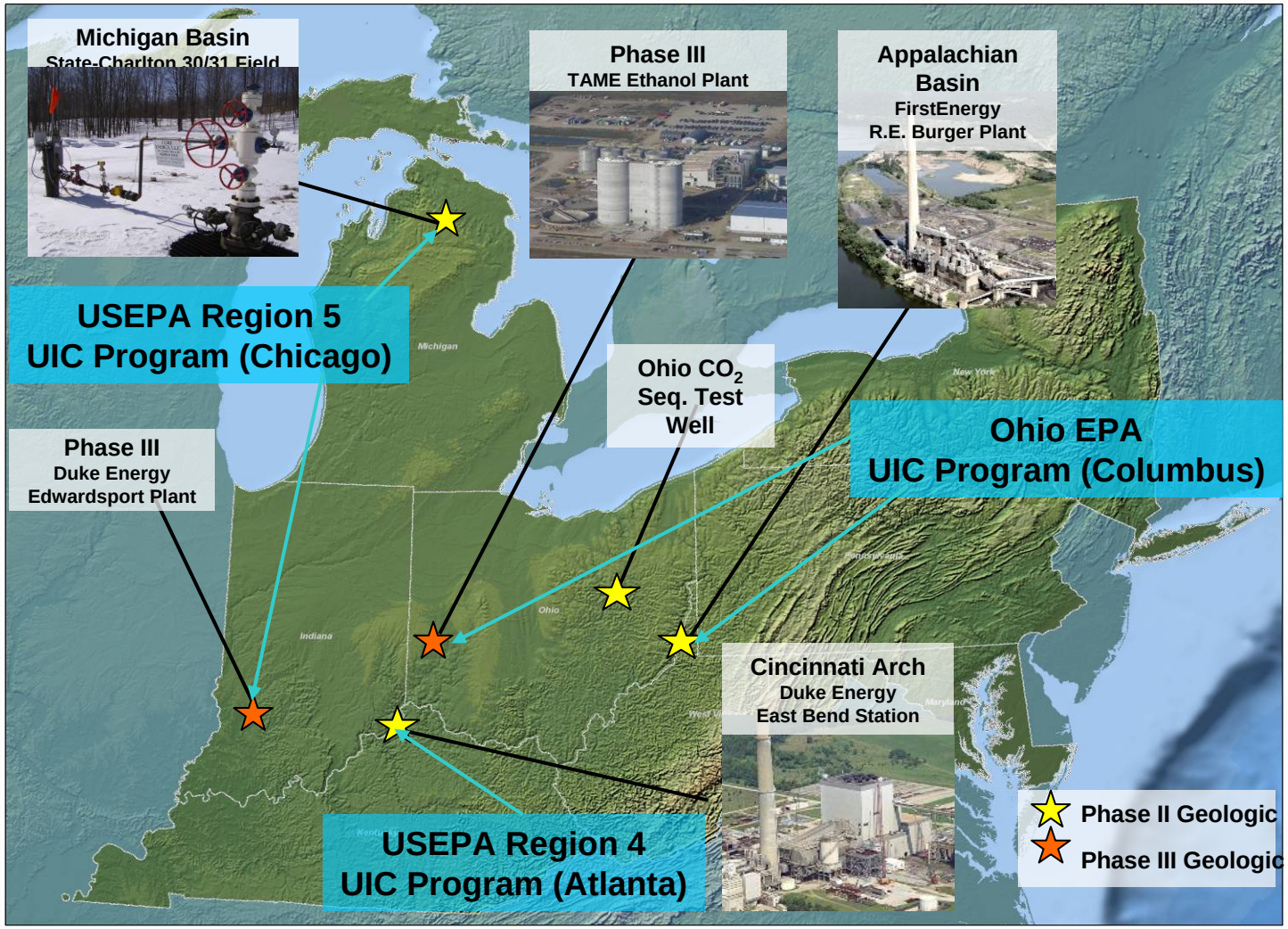
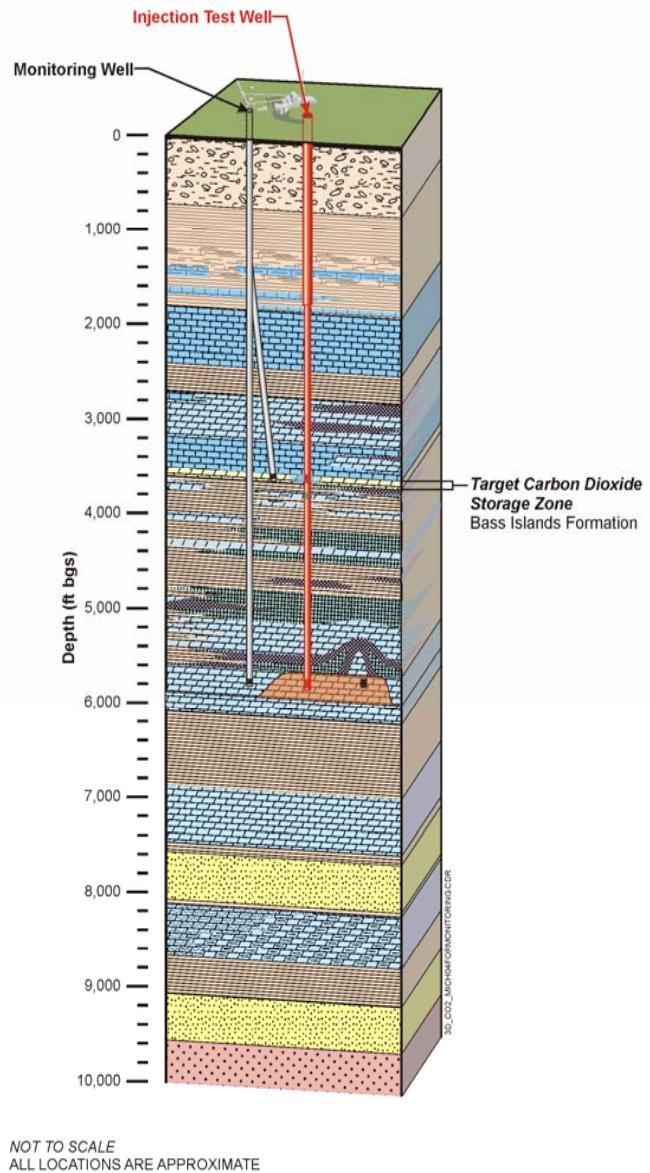
# MRCSP Field Test Sites



# Injection System

- New well (State-Charlton 4-30) drilled for injection.
- Nearby well used for monitoring.
- Class V $CO_2$ Permit from EPA Region V
- Variety of other monitoring methods used

# Michigan Basin $CO_2$ Source

- $CO_2$ available from DTE gas processing plant
- Antrim Shale gas contains 15-30% $CO_2$ and is removed in amine based separation process
- Relatively pure $CO_2$ (99%) stream
- $CO_2$ periodically used for EOR floods in Niagaran Reef oil fields by Core Energy

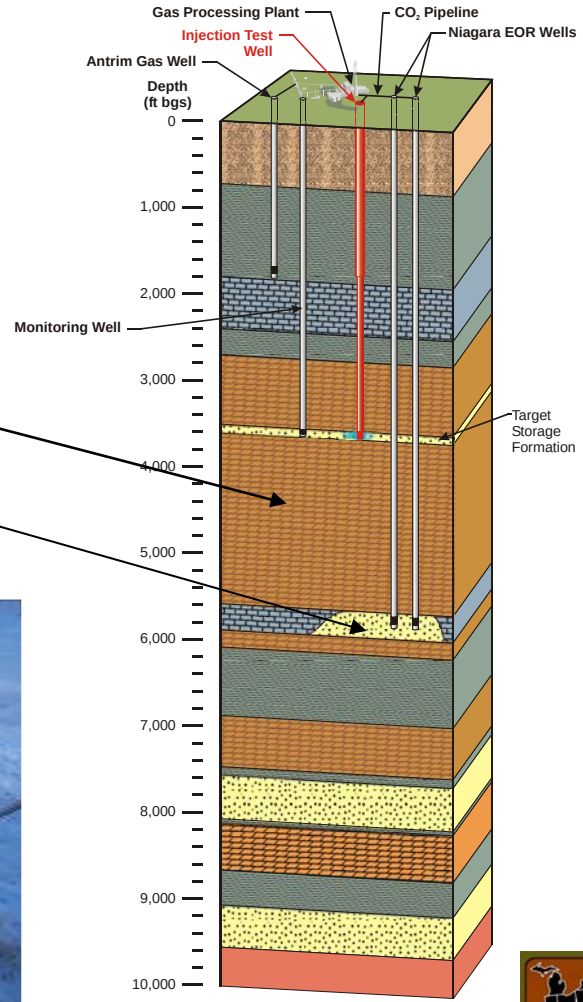
# Site Characterization, Injection Operations, and Monitoring

**~5000 Foot Deep Test Well Drilled in November 2006**

180 feet of core taken

## Injection Operations

**Starting Injection**




**Confining Layer: Amherstburg Limestone**

**Injection Target: Bass Islands Dolomite**

Well Column

# Testing Timeline

- Several test events were run over a period of several months in both monitoring well and the injection well.
- Tests provide information on hydraulic character of reservoir.

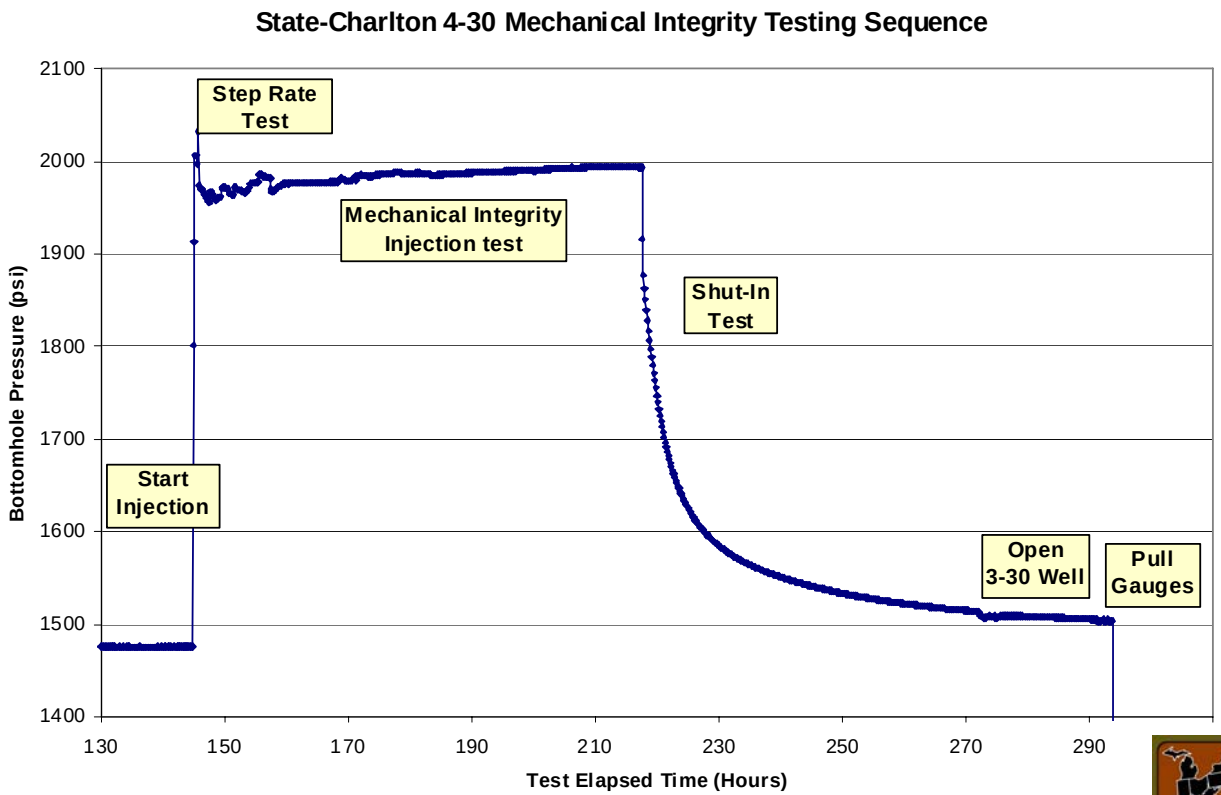
**Michigan Basin Test Schedule**

| 2007 | September | | | | October | | | | | November | | | | December | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3 | 10 | 17 | 24 | 1 | 8 | 15 | 22 | 29 | 5 | 12 | 19 | 26 | 3 | 10 | 17 | 24 | 31 |
| C3-30 Monitoring Well | | | | | | Swab Test | | Pressure-Temperature Monitoring | | | | | | | | | | |
| C4-30 Injection Well | | | | | | | | | | | | | | | | | | |

| 2008 | January | | | | February | | | | March | | | | | April | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7 | 14 | 21 | 28 | 4 | 11 | 18 | 25 | 3 | 10 | 17 | 24 | 31 | 7 | 14 | 21 | 28 |
| C3-30 Monitoring Well | Pressure-Temperature Monitoring | | | | | | | | | | | | | | | | |
| C4-30 Injection Well | | | | | Mech. Integrity Test | | Full Injection Test | | | | Post-Injection Recovery Monitoring | | | | | | |

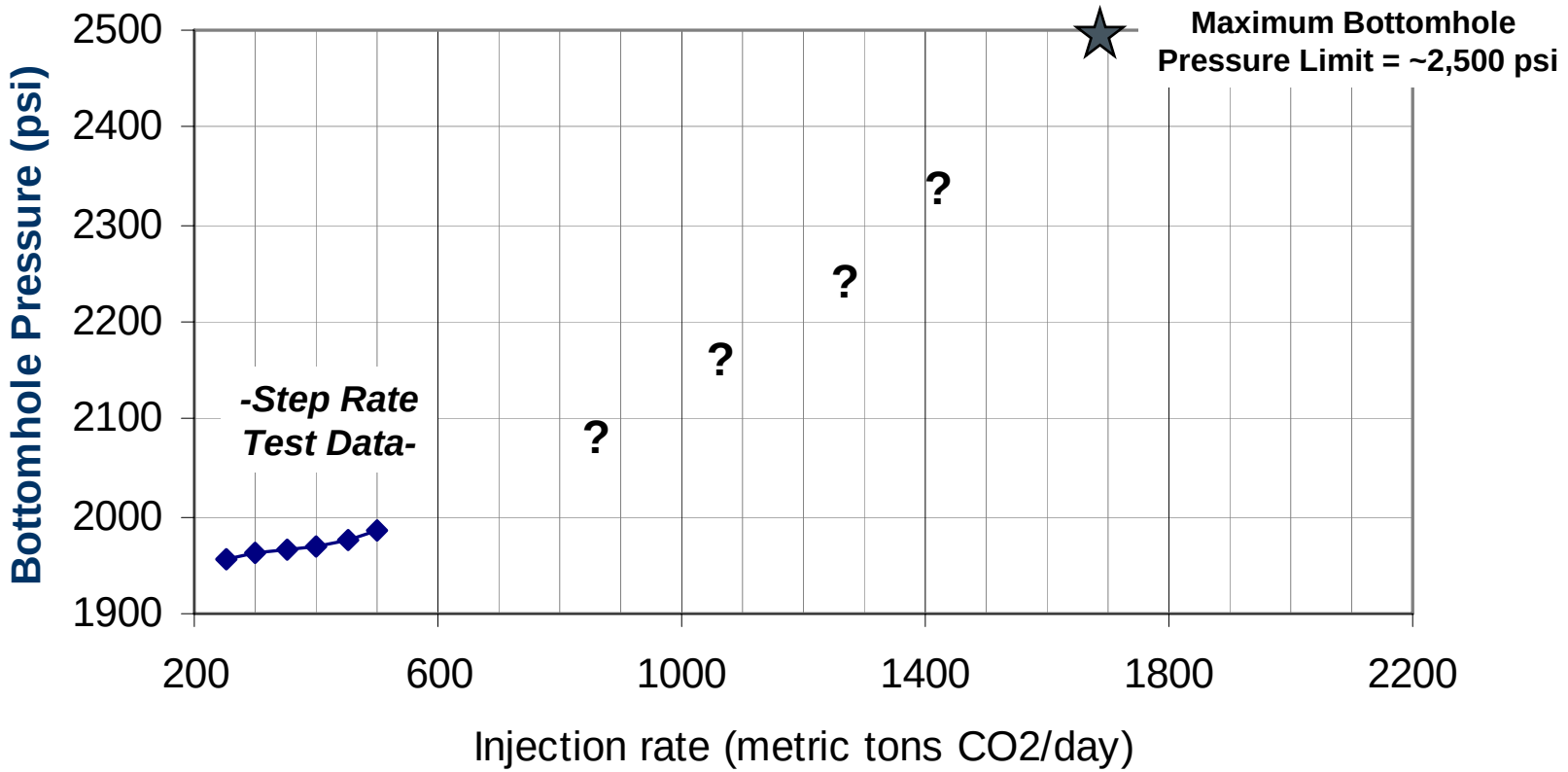
# $CO_2$ Injectivity Testing

- Initial step-rate test and shut-in test was completed with $CO_2$ prior to sustained injection as part of UIC mechanical integrity testing February 7-13, 2008.
- Testing provides data on hydraulic behavior of the reservoir system.



# $CO_2$ Step-Rate Injection Testing

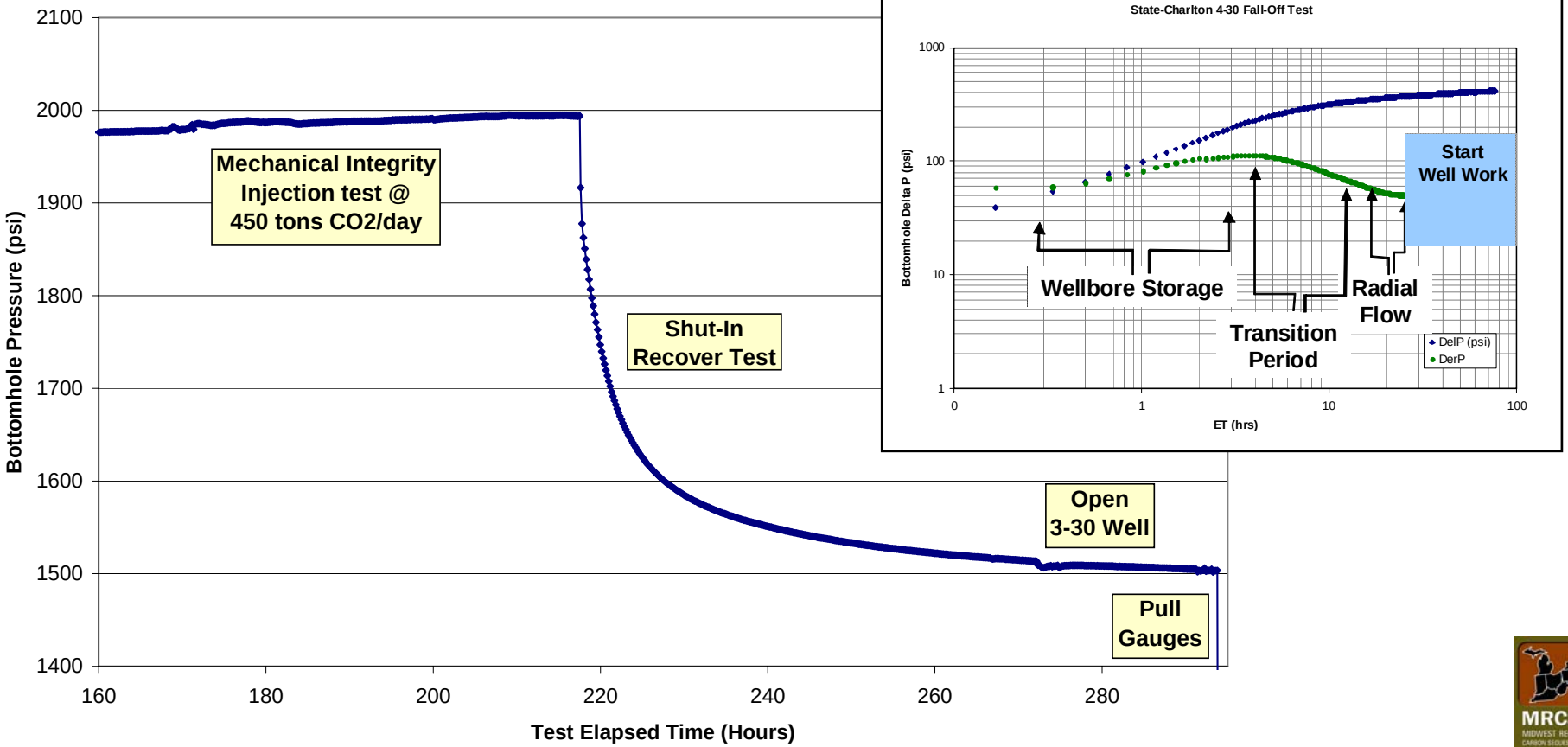
- Difficult to interpret pressure increase. Example, overall pressure increase only ~30 psi from 250-500 tpd injection rate.
- General trends suggest injection rates of over 1,500+ metric tons per day may be possible (>500,000 metric tons per year).



# $CO_2$ Pressure Shut-In Analysis

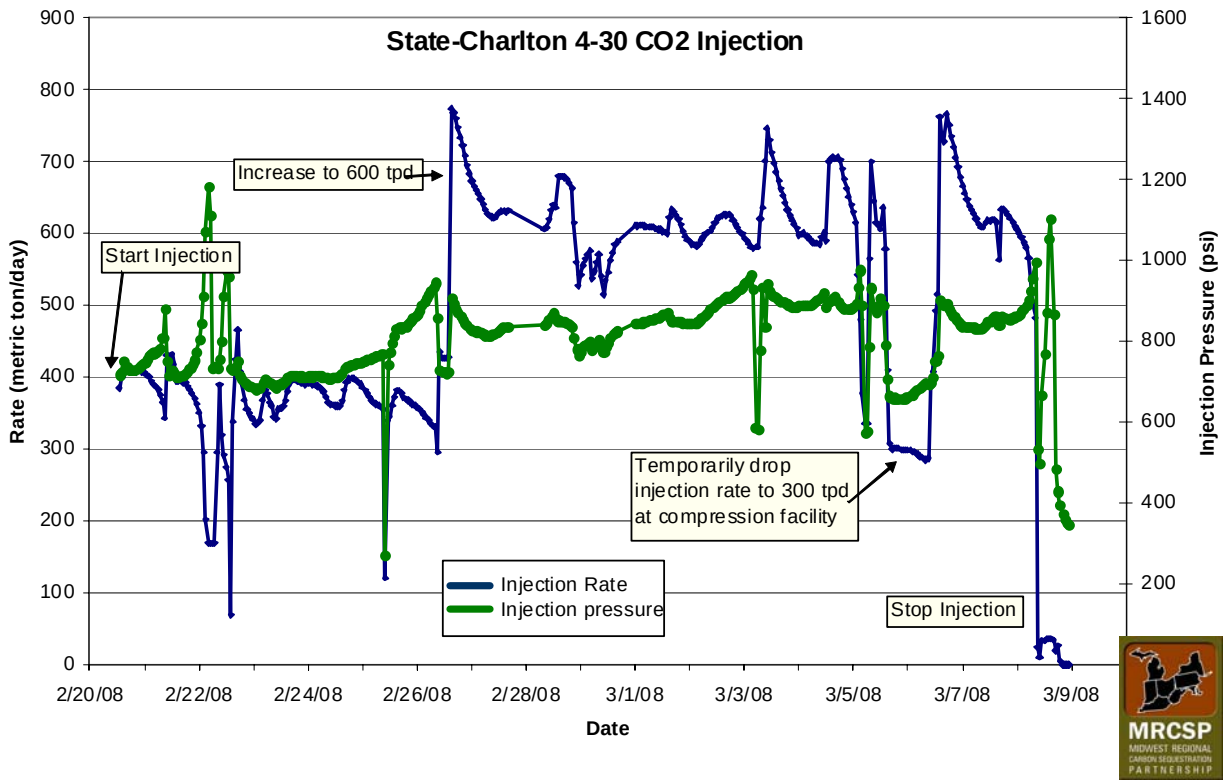
- Well shut-in after 60 hours of injection at 450 metric tons per day, injection stopped, and well shut-in for ~72 hrs.
- Response curve indicates well with wellbore storage and skin effects in a homogeneous reservoir. Assume fluid properties of formation brine for initial testing since injection volume is relatively small.

**State-Charlton 4-30 Mechanical Integrity Testing Sequence**



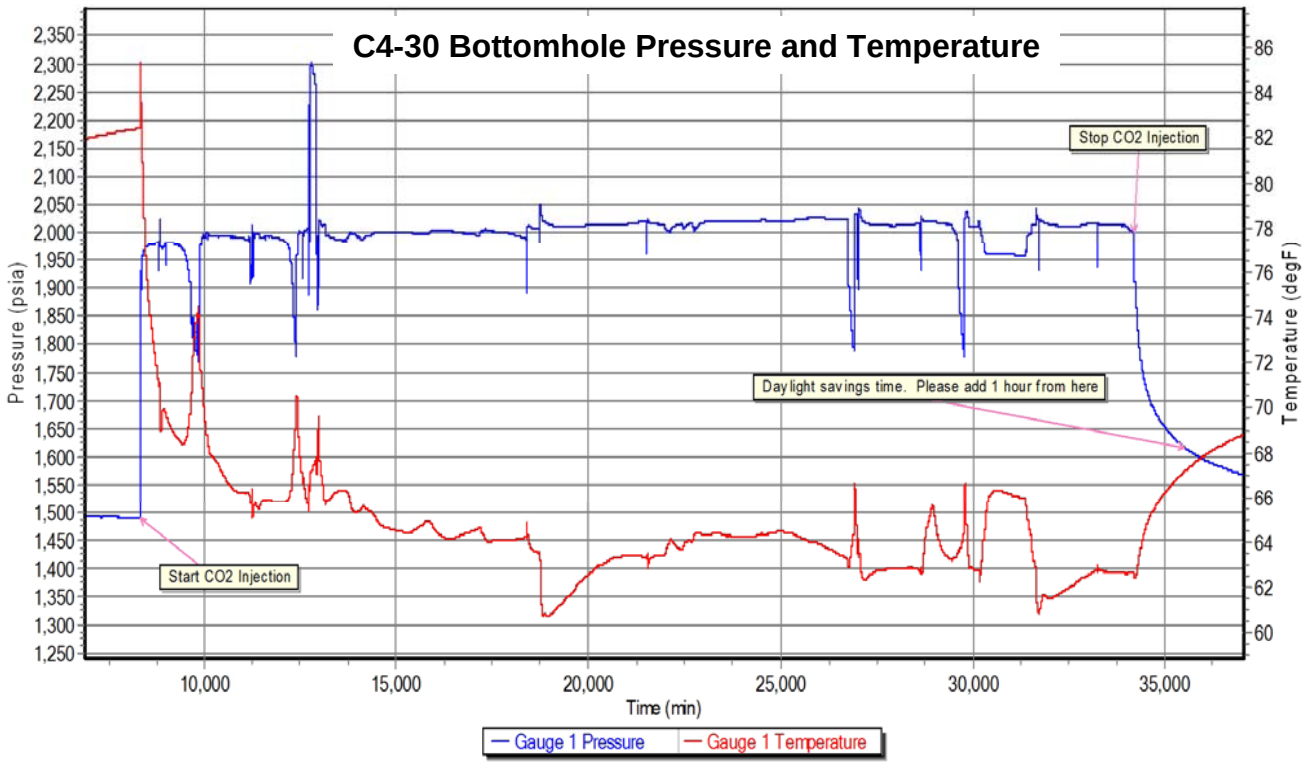
# $CO_2$ Injection Testing

- 10,241 metric tons $CO_2$ was injected from February 18-March 8, 2008 (including initial mechanical integrity test volume).
- Injection Rate increased from 400 to 600 metric tons/day after 1 week (some fluctuations in injection rate due to compression facility).
- Injection well was shut-in for 1 month after injection to track reservoir pressures decline and allow stabilization.

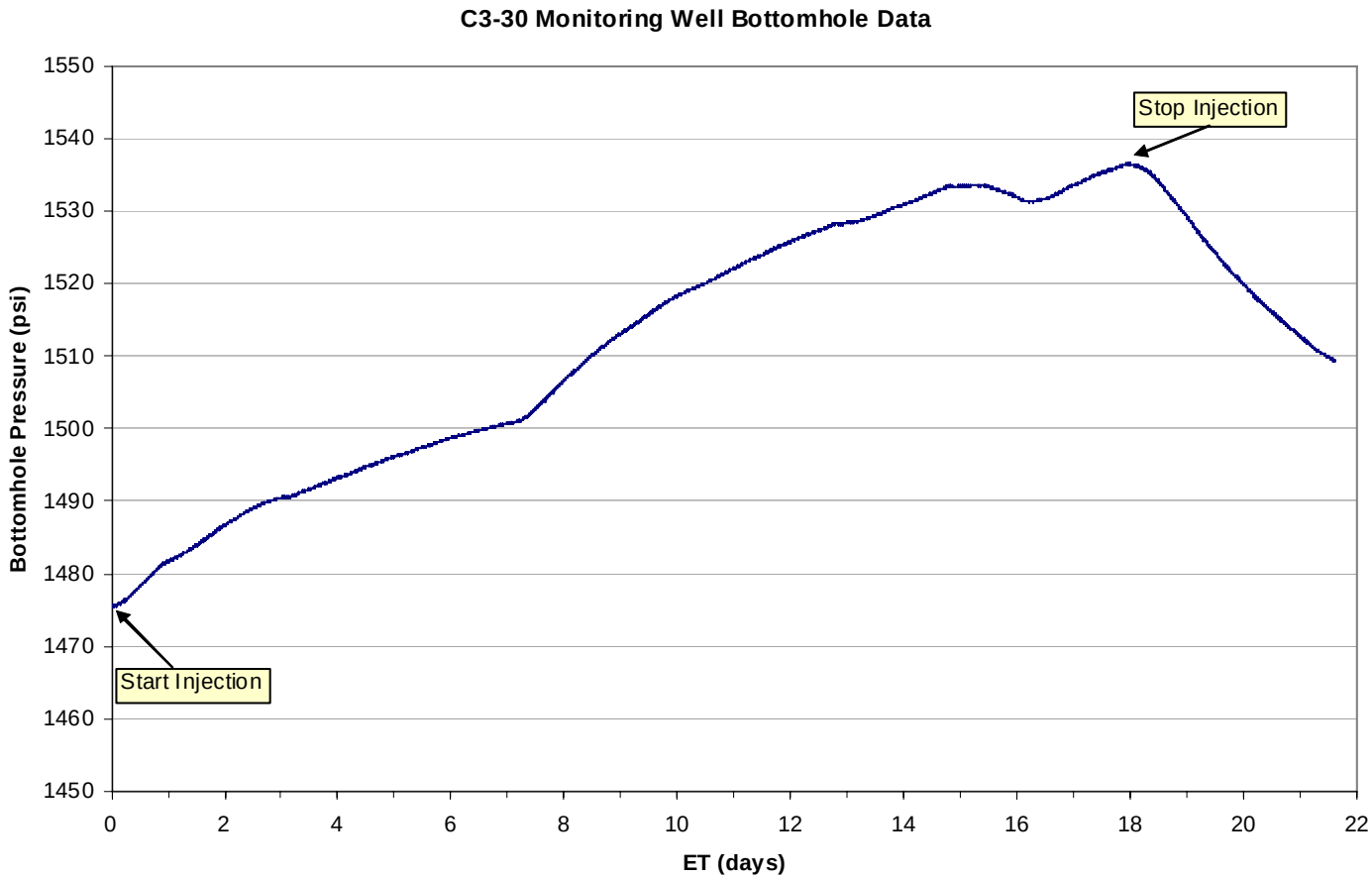
# $CO_2$ Injection Testing

- Bottomhole pressures were 2,000-2,020 psi during injection and generally stable throughout the 18 days of injection. Some fluctuations present due to supply variations at compression station.
- Overall, testing indicates rates of 600 metric tons/day or higher may be sustained in the Bass Islands Dolomite.



# $CO_2$ Injection Monitoring

- Pressure response in C3-30 monitoring well located about 150 m (500 ft) from the injection well shows about a 60 psi increase within the Bass Islands Dolomite formation. No direct indication of $CO_2$ breakthrough was detected at this well.

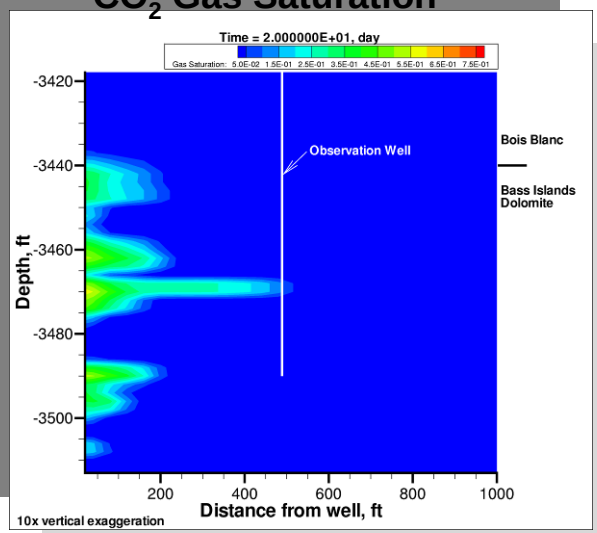


# Reservoir Simulations ($STOMPCO_2$)

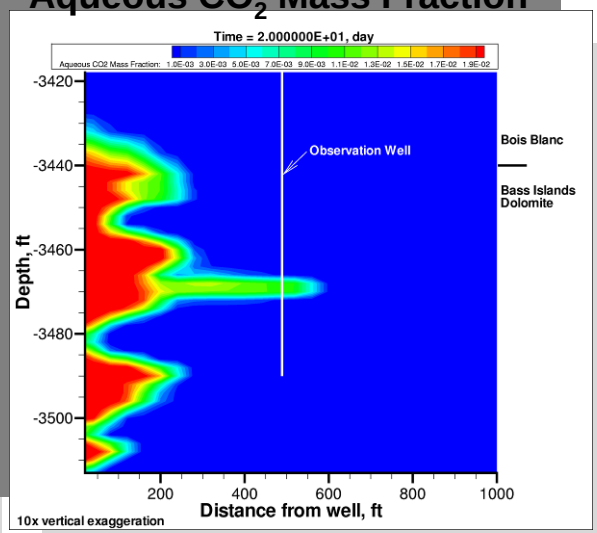
- Simulations indicate injection rates of 500 metric tons $CO_2$ per day are feasible in the Bass Islands Dolomite.
- In practice, injection rate was more variable during testing.
- 2D radial simulations show $CO_2$ moving about 152 m (500 ft) from injection well.

**STOMPCO2 Simulation Results at the End of Injection (500 tpd for 20 days)**

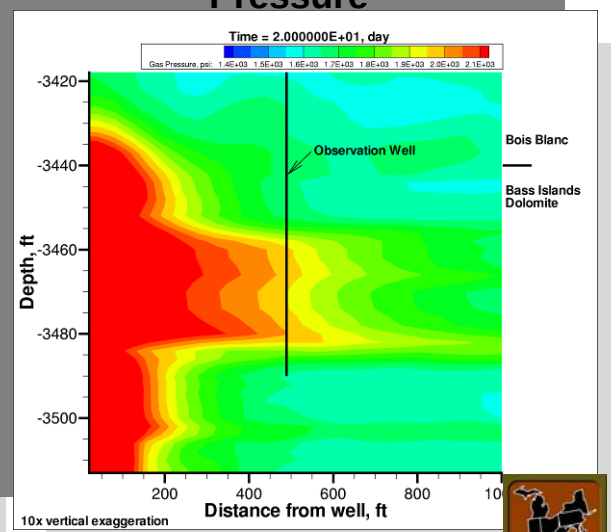
**$CO_2$ Gas Saturation**




**Aqueous $CO_2$ Mass Fraction**




**Pressure**



# Reservoir Simulation vs. Observations

- Pressure predictions from STOMPCO2 were fairly similar to those observed in the field.
- Injection rate was somewhat unpredictable and difficult to simulate.
- Model calibration to field data is currently underway using actual injection rates. However, this effort looks to be a minor refinement as the model was fairly accurate.

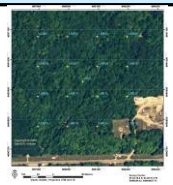
**Preliminary Modeled vs. Observed Pressures**

| Monitoring Point | Maximum Bottomhole Pressure (psi) | |
|---|---|---|
| | STOMPCO2 Simulated | Observed |
| **C4-30 Injection Well** | 2,100 | 2,020 |
| **C3-30 Monitoring Well** | 1,555* | 1,535 |

*corrected for observed in-situ pressure

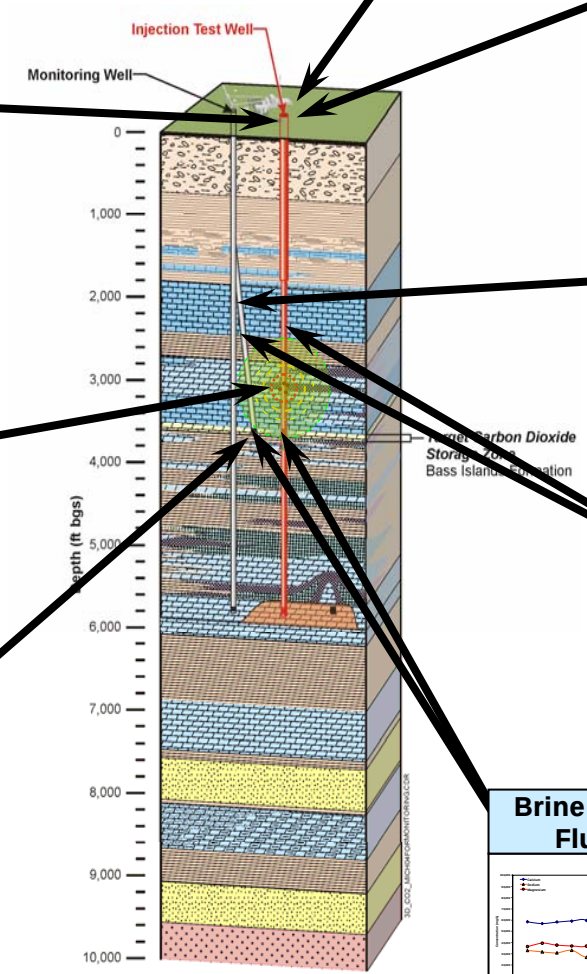
# MMV Program

**PFT Tracer Survey**

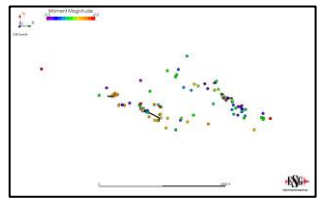


**Surface Gas Meters**

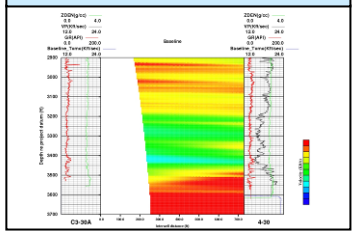
**System Monitoring**



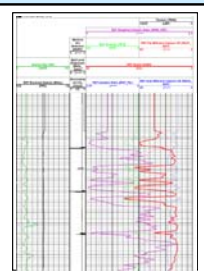

**Acoustic Emissions**



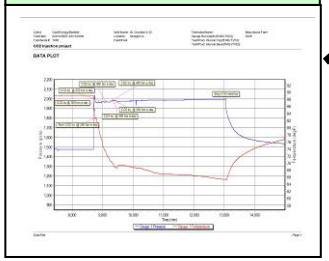
**Cross-Well Seismic**



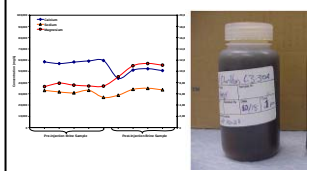
**Wireline Monitoring**



**Downhole Pressure**



**Brine Chemistry and Fluid Sampling**



# Monitoring technology is an important part of our testing

Acoustic Array

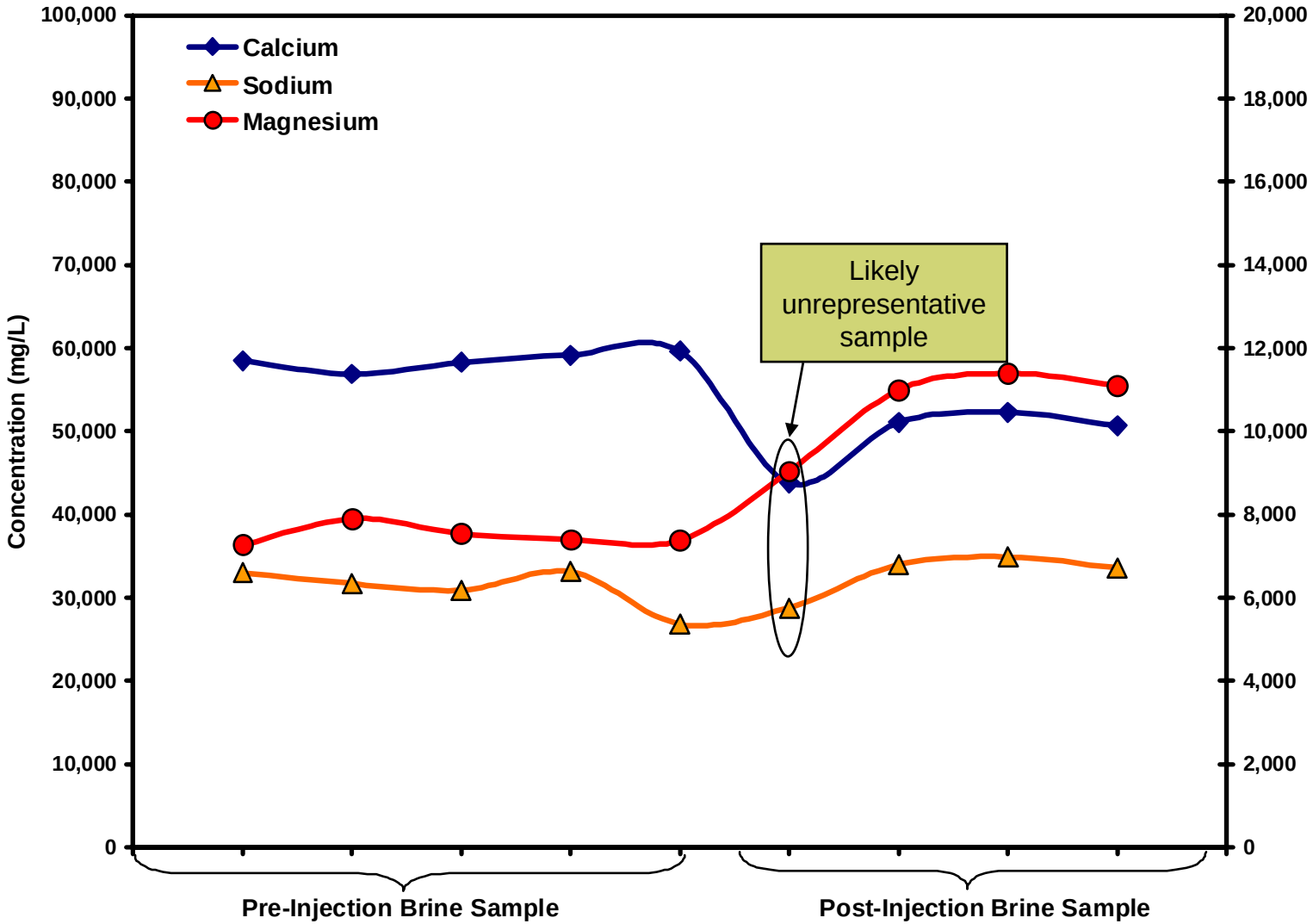
Monitoring Well
(about 500 feet from injection well)


Cross Well Seismic Analys

# Fluid Sampling

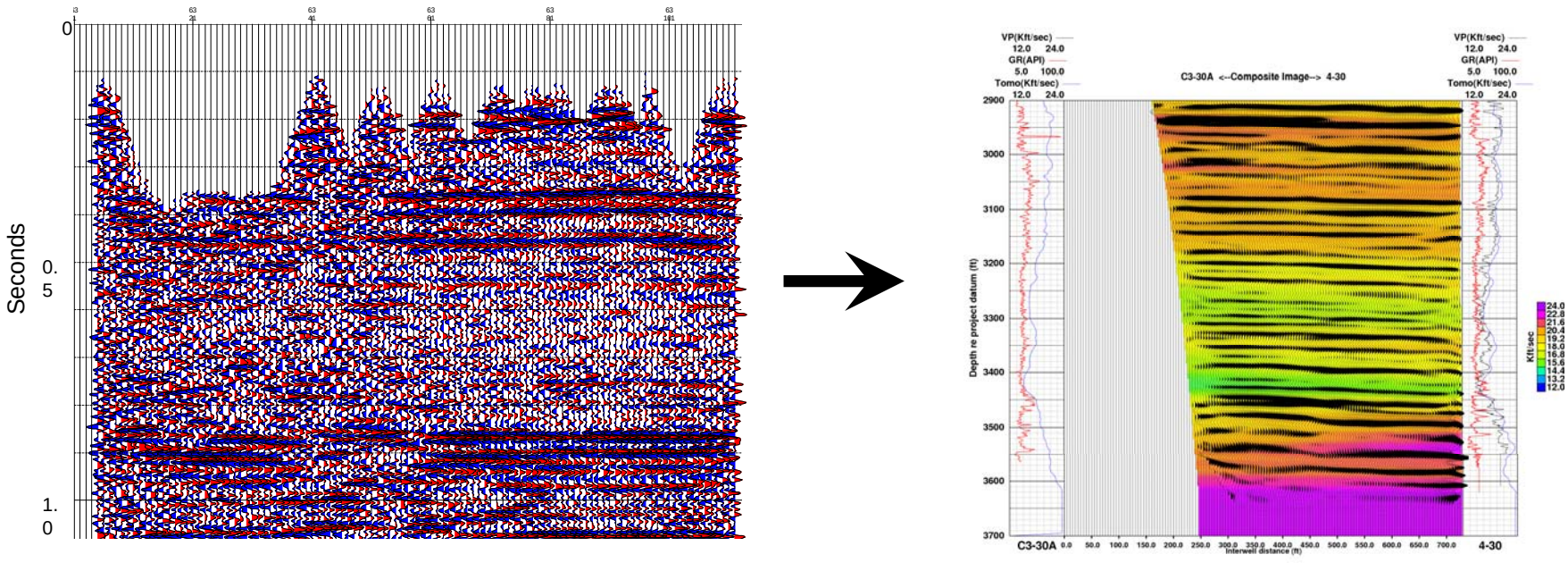
- Pre injection samples swabbed and analyzed for major cations and anions.
  - Formation brine contained high TDS (greater than 300,000 ppm)
- Post injection samples were taken more than a month after injection from the monitoring well
  - Multiple samples were taken over 18 hours to ensure formation brine was collected
  - No breakthrough detected
- More sampling events may be useful to confirm results

# Michigan Brine Sampling Analysis (pre and post injection)



# Crosswell Seismic

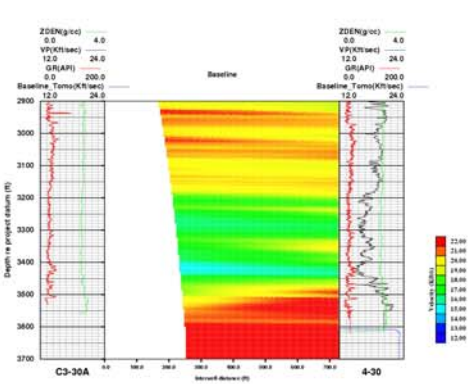
- Glacial till made 3D seismic difficult to use.
- Crosswell survey run between 4-30 and C3-30A
- Excellent signal to noise ratio and high energy source yield resolution of only a few meters
- Repeat survey completed on May 5, 2008



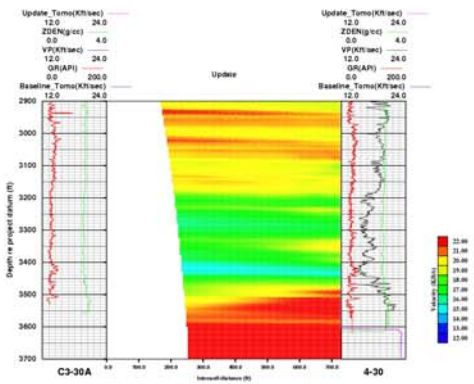
# Cross-Well Seismic Repeat Survey

- The difference between the two surveys shows a velocity decrease in the Amherstburg formation, approximately 300 ft above the perforated injection interval, with no apparent connection with the velocity change area at the injection interval.

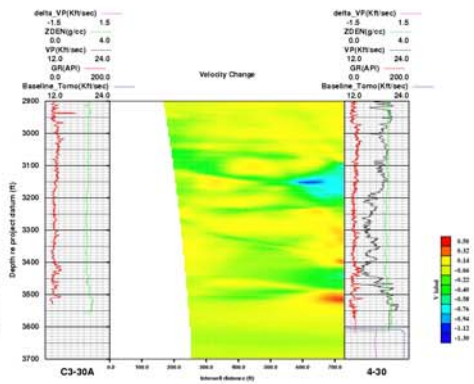
Baseline Survey



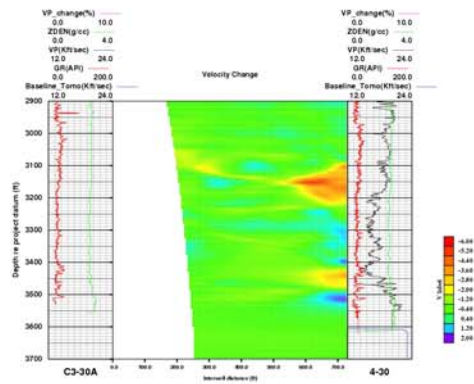

Repeat Survey




Straight Difference

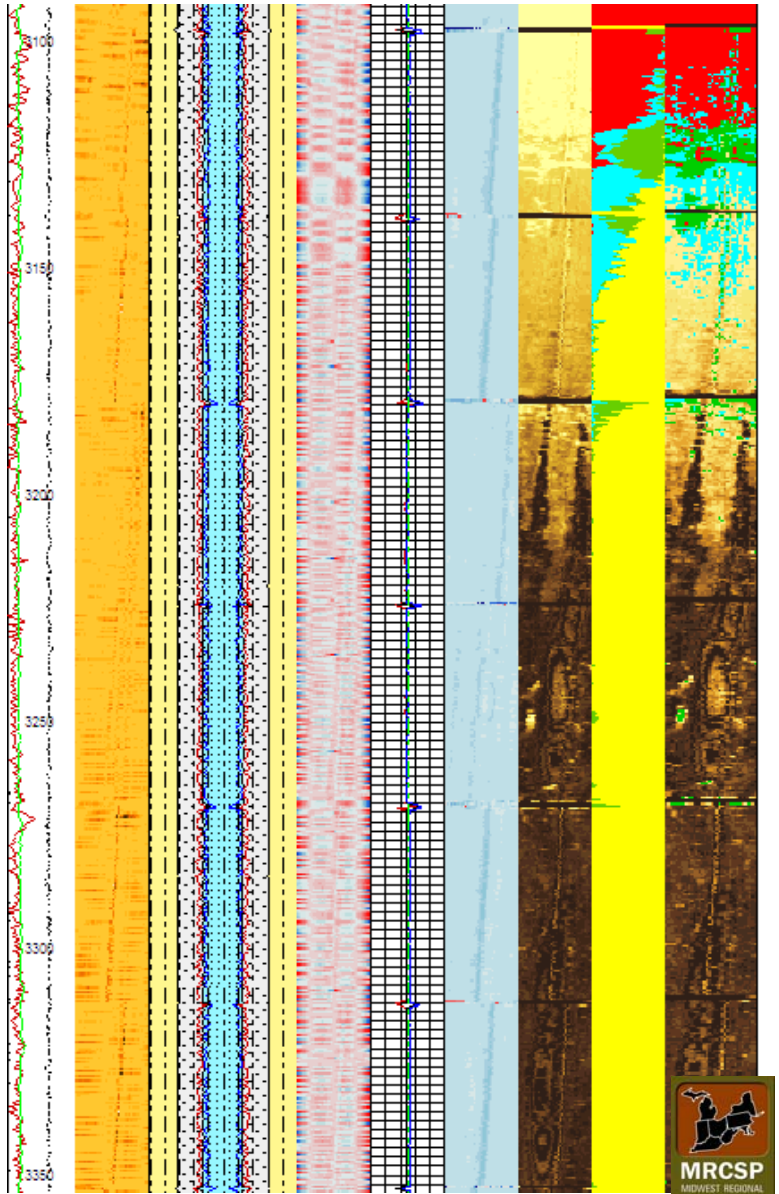



% change from baseline to repeat. Reds-yellows indicate decreases in velocity



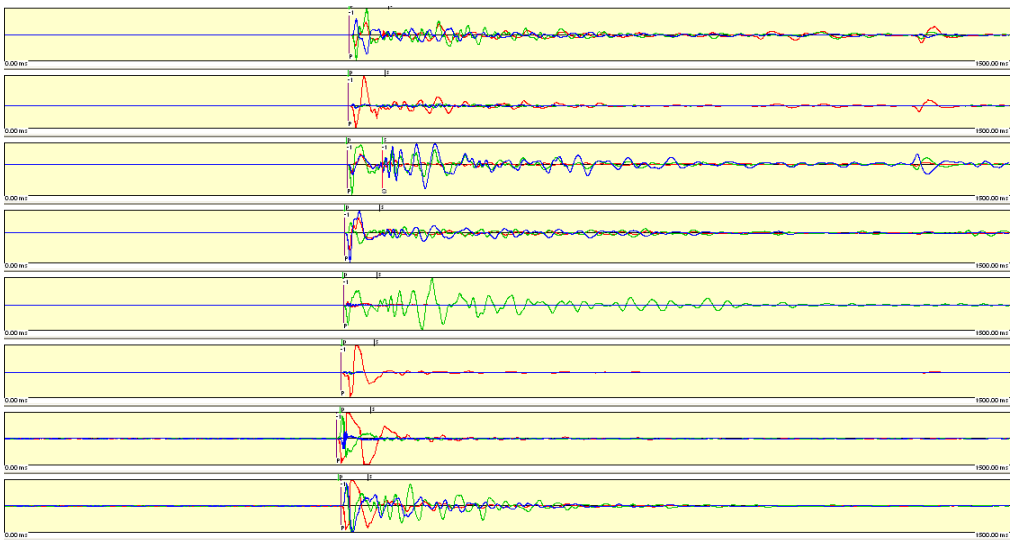
# Evaluating Migration Pathways

- Potential causes for seismic velocity change were evaluated
  - A more detailed cement bond log (Isolation Scanner) was run to examine the cement quality
  - No obvious migration pathways were found between the injection depth and the velocity anomaly
  - Gas appears to be potentially present behind the casing at the location of the anomaly, based on wireline data
  - It is unclear if this is $CO_2$ or methane (there was a gas show during drilling). The available methods do not distinguish between $CO_2$ and $CH_4$
  - ***So far there is not conclusive evidence that the velocity change is due to $CO_2$.***



# Acoustic Emissions (Micro-Seismic)

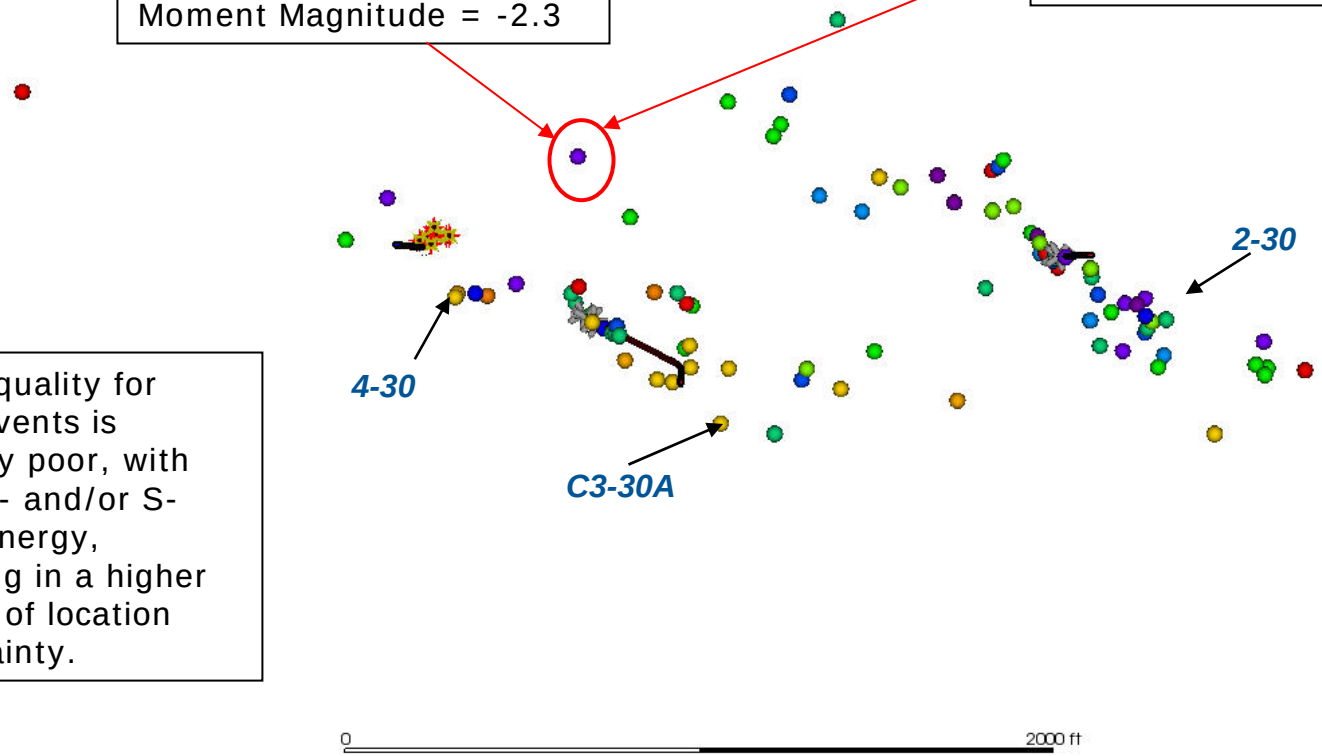
- Eight level arrays were installed in monitoring wells C3-30A and 2-30 during the entire injection
- Over 100 events were recorded
  - It is unlikely all of these are associated with injection
  - However, some events appear to be related to the EOR operations occurring in the deeper Niagaran Reefs



# Microseismic Activity Map


This event was recorded on February 27, 2008 @ 17:51:38. It is of high signal quality and originates from a depth below the sensor arrays.

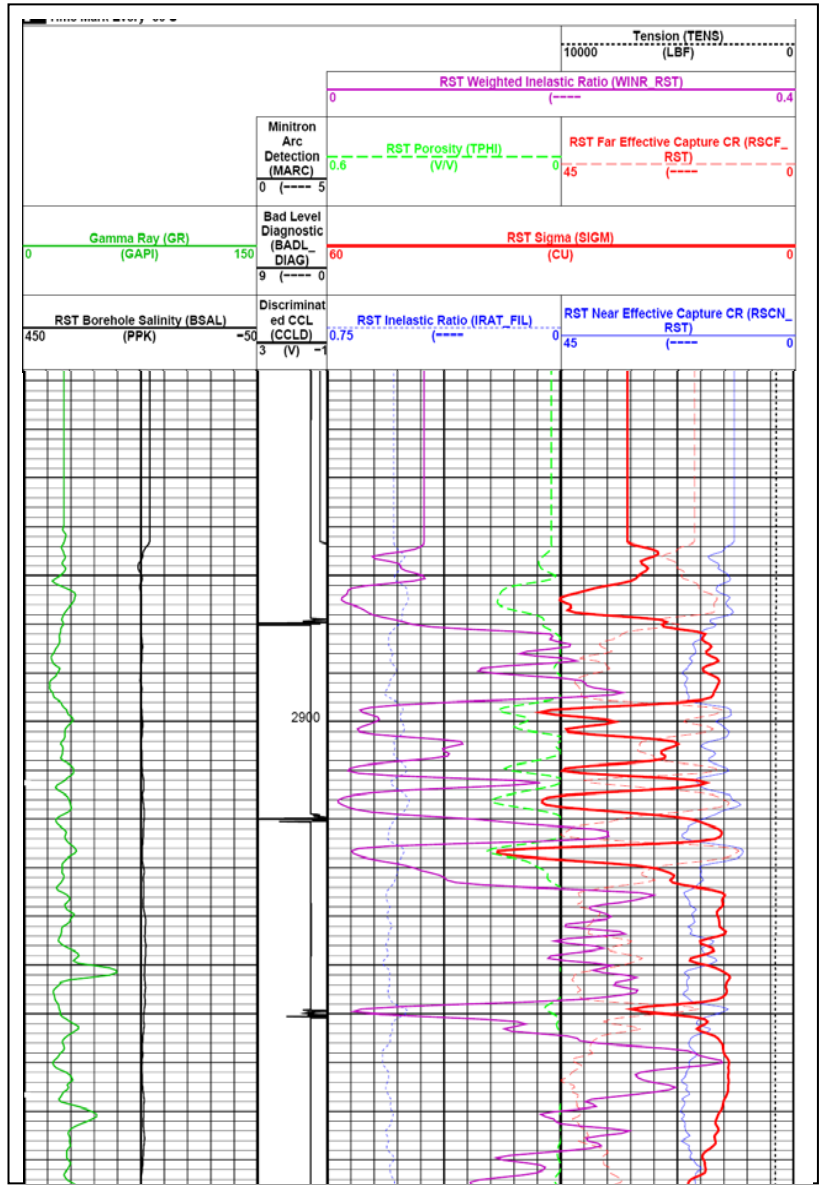
Moment Magnitude = -2.3




Signal quality for most events is typically poor, with weak P- and/or S-wave energy, resulting in a higher degree of location uncertainty.

# Pulsed Neutron (RST)

- Baseline and two repeat surveys performed in the C3-30A monitoring well
- No definitive indication of $CO_2$ at the monitoring well
- This matches the modeling results

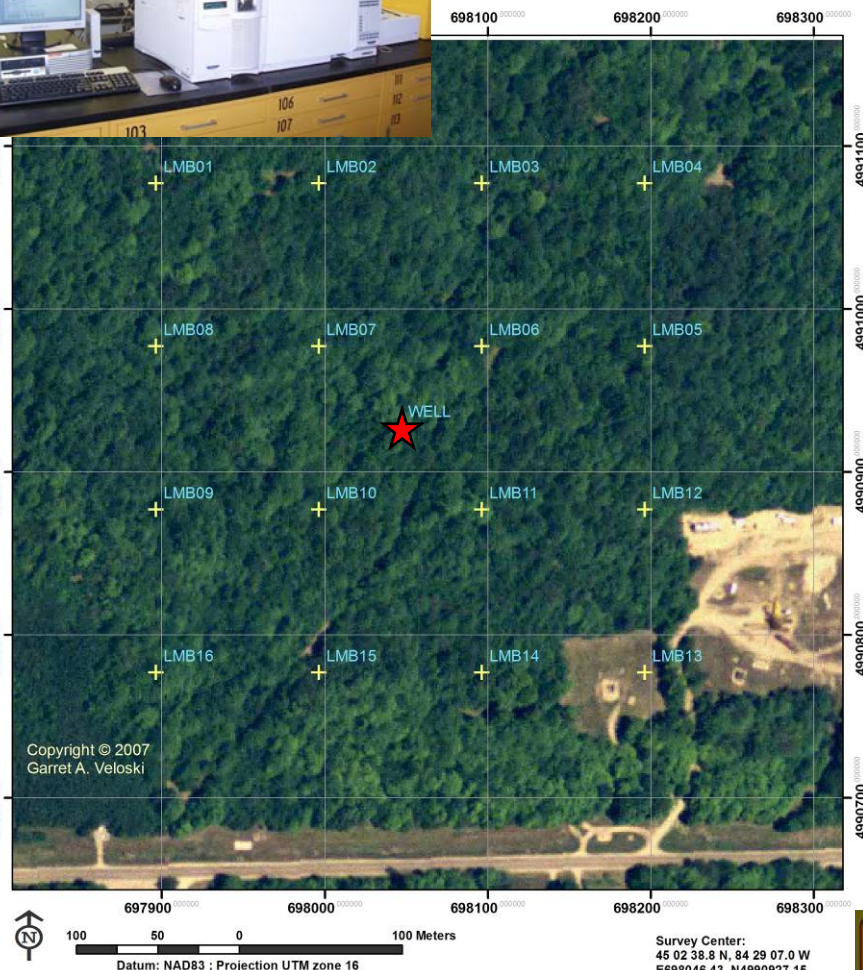


# Tracers

- The Michigan site has multiple sources of $CO_2$, which would make surface detection techniques very difficult
- NETL injected a PFT tracer into the injection stream and has been monitoring for leakage

# Tracers

- NETL injected a PFT tracer into the injection stream and has been monitoring for leakage
- Numerous soil gas and atmospheric samples were taken pre injection
- Post injection samples have not contained any of the tracers and do not indicated any leakage

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# Public outreach is a key component of our research


An informational meeting was held at the Johannesburg-Lewiston Area School, July 2007, to inform the local public about the project

# Conclusions

- Bass Islands Dolomite in northern Michigan Basin has suitable injectivity for $CO_2$ sequestration at an industrial scale, on the order of several hundred thousand metric tons per year in one well.
- Well tests proved useful in analyzing injection potential, even though we did not approach maximum injection rates.
- Injection test analysis was used to define the hydraulic behavior of the reservoir system in terms of flow behavior and leakage.
- Reservoir simulations provide fairly accurate predictions of hydraulic response to injection.
- It is not clear if the cross-well seismic based velocity anomaly ~300 ft about perforated interval is due to natural gas or $CO_2$. However, the potential upward migration pathways for $CO_2$ have been eliminated.
- All objectives of the initial injection phase have been successfully completed