# Evaluation of Carbon Sequestration in Kansas -- Update on DOE-Funded Project

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Kansas Water Office

***Kansas Water Authority –Committee of the Whole***
***Wichita, May 14, 2010***

KANSAS GEOLOGICAL SURVEY
The University of Kansas

U.S. DEPARTMENT OF ENERGY

# Outline

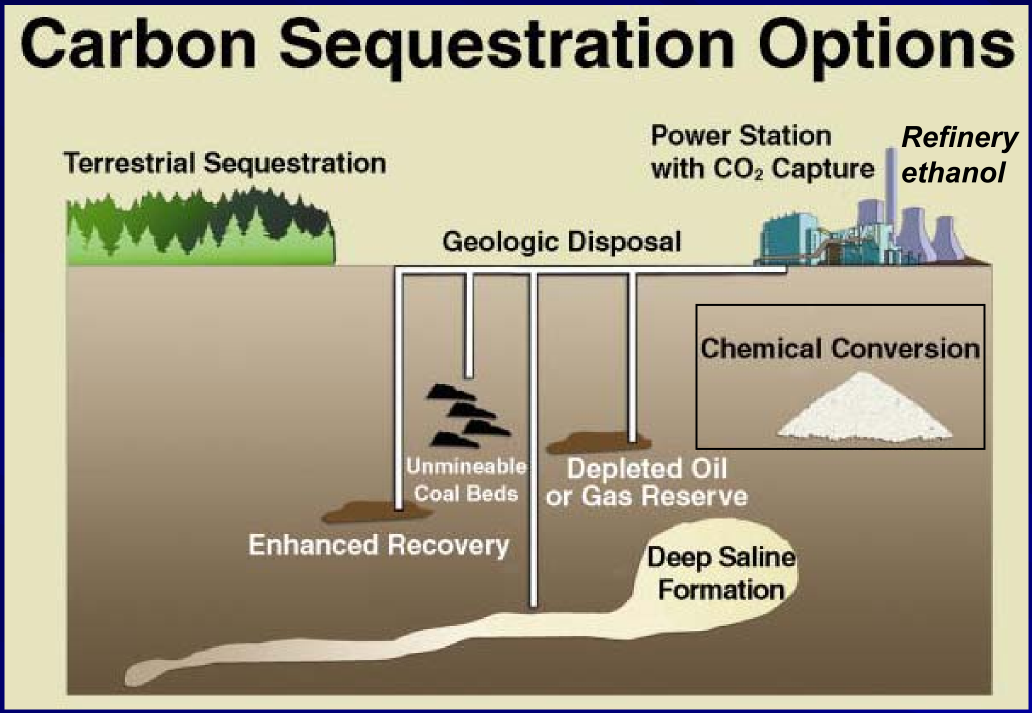
- Why consider carbon sequestration in Kansas?
- What are key components in geologic carbon sequestration?
  - Deep saline aquifers and Enhanced Oil Recovery (EOR)
  - Supercritical $CO_2$ injection
  - Dynamic processes that sequester $CO_2$ (flow and storage)
    - Geomodel development -- Quantitative aquifer/reservoir (EOR) characterization
  - Simulation of $CO_2$ sequestration at target sites
    - Estimate capacities and fate of $CO_2$
  - Risk Analysis - best practices
    - Evaluating well status
- Status of 3-year DOE-funded project (startup – Dec. 8, 2009)
  - Data gathering – seismic, gravity-magnetics, well data
  - Geomodel development for 17+ county area
  - Geomodel development in Wellington Field in Sumner County

Creation of KWA (Legislative Act of 1981) – Duties include "*Reviewing plans of any state or local agency related to the water resources of the state*"

# Relevance of $CO_2$ Sequestration in Kansas

- **Coal-fired power plants to produce for years in Kansas**
  - **Need to address problem of $CO_2$ emissions**
- **DOE efforts to develop carbon capture and storage (CCS) infrastructure**
  - **Kansas participating in that effort**
- **Initiatives of the *Midwestern Governors Association***
- **$CO_2$-EOR – proven & reliable technology**
  - **Potential applications in many depleted KS fields**
- **Deep saline aquifers – have potential to sequester large volumes of $CO_2$**
  - **Arbuckle saline aquifer in KS**
    - **Is deep and thick - suitable for *supercritical* $CO_2$ injection**
    - **Underlies a large area in south-central KS**
- **Kansas centrally located to major $CO_2$ emitting states and cities**
- **$CO_2$ sequestration has the potential of becoming a major industry in KS**
  - **Government incentives**
  - **Value of $CO_2$ as commodity**
  - **Infrastructure**
  - **Maturation of technology and regulations**

# Preeminence of Deep Saline Aquifer Sequestration of $CO_2$




**Industry participation in infrastructure development possible if $CO_2$-EOR is viable**

***Global annual $CO_2$ emissions ≈ 8 * $10^9$ tons***

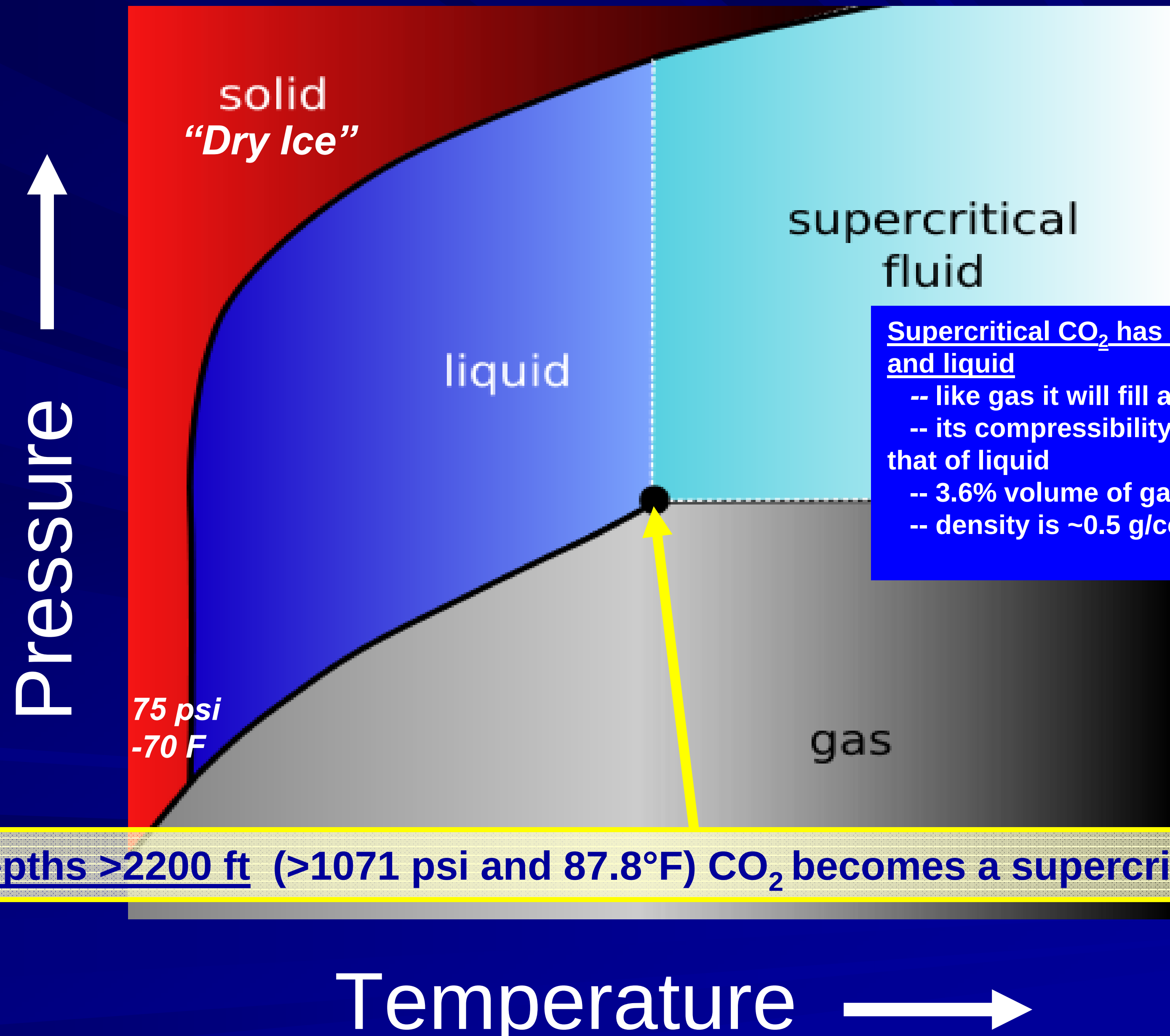
***Earth Policy Institute***

***>400 yrs Current Global emissions*** →

| Formation Type | $10^9$ Metric Tons | % |
|---|---|---|
| Saline Aquifers | 3,297 – 12,618 | 91.8 – 97.5 |
| Unmineable Coal Seams | 157 – 178 | 4.4 – 1.4 |
| Mature Oil & Gas Reservoirs | 138 | 3.8 – 1.1 |
| Total Capacity | 3,592 – 12,934 | 100.0 |

*DOE & NETL, "Carbon Sequestration Atlas of the US and Canada", 2008*

# Supercritical $CO_2$




**Supercritical $CO_2$ has properties of both gas and liquid**

-- like gas it will fill any given volume

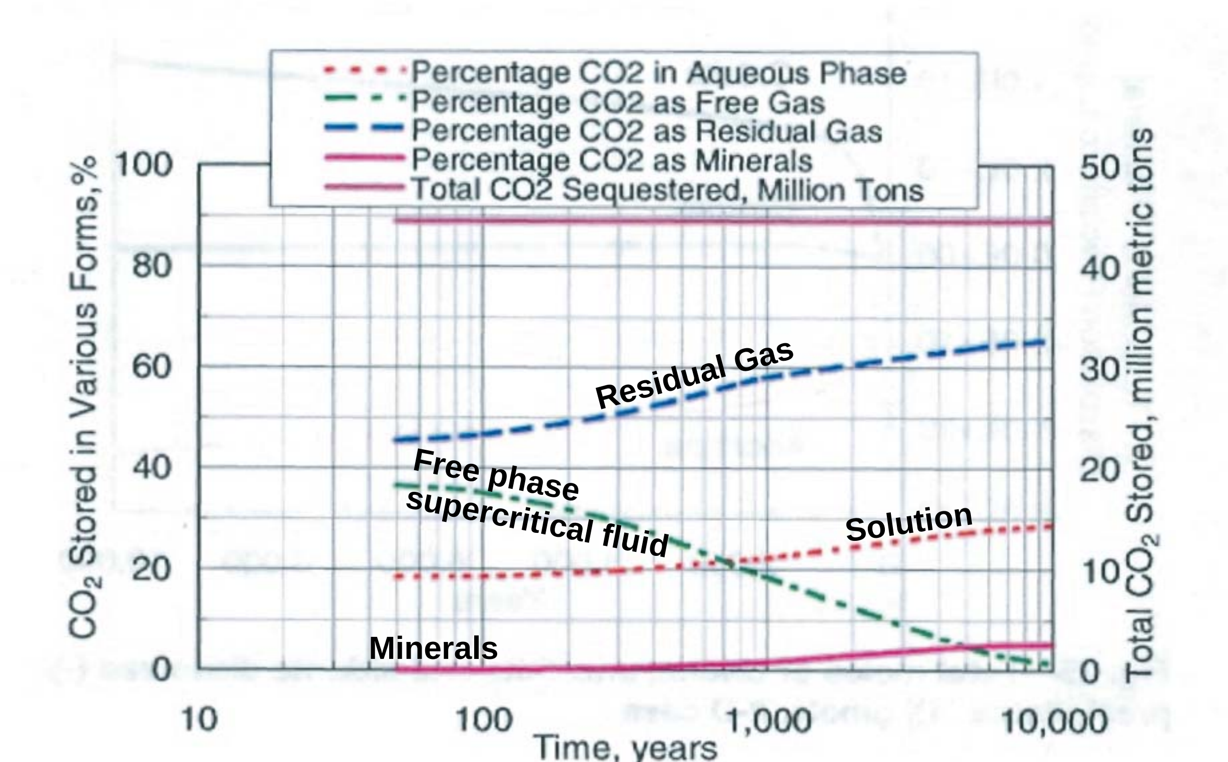
-- its compressibility properties resemble that of liquid

-- 3.6% volume of gas phase

-- density is ~0.5 g/cc (brine >1 g/cc)

**@ depths >2200 ft (>1071 psi and 87.8°F) $CO_2$ becomes a supercritical fluid**

# *In situ* entrapment of injected $CO_2$ -- simulation in a homogeneous aquifer




*Ozah, 2005 – In situ $CO_2$ distribution after 50 years of injection*

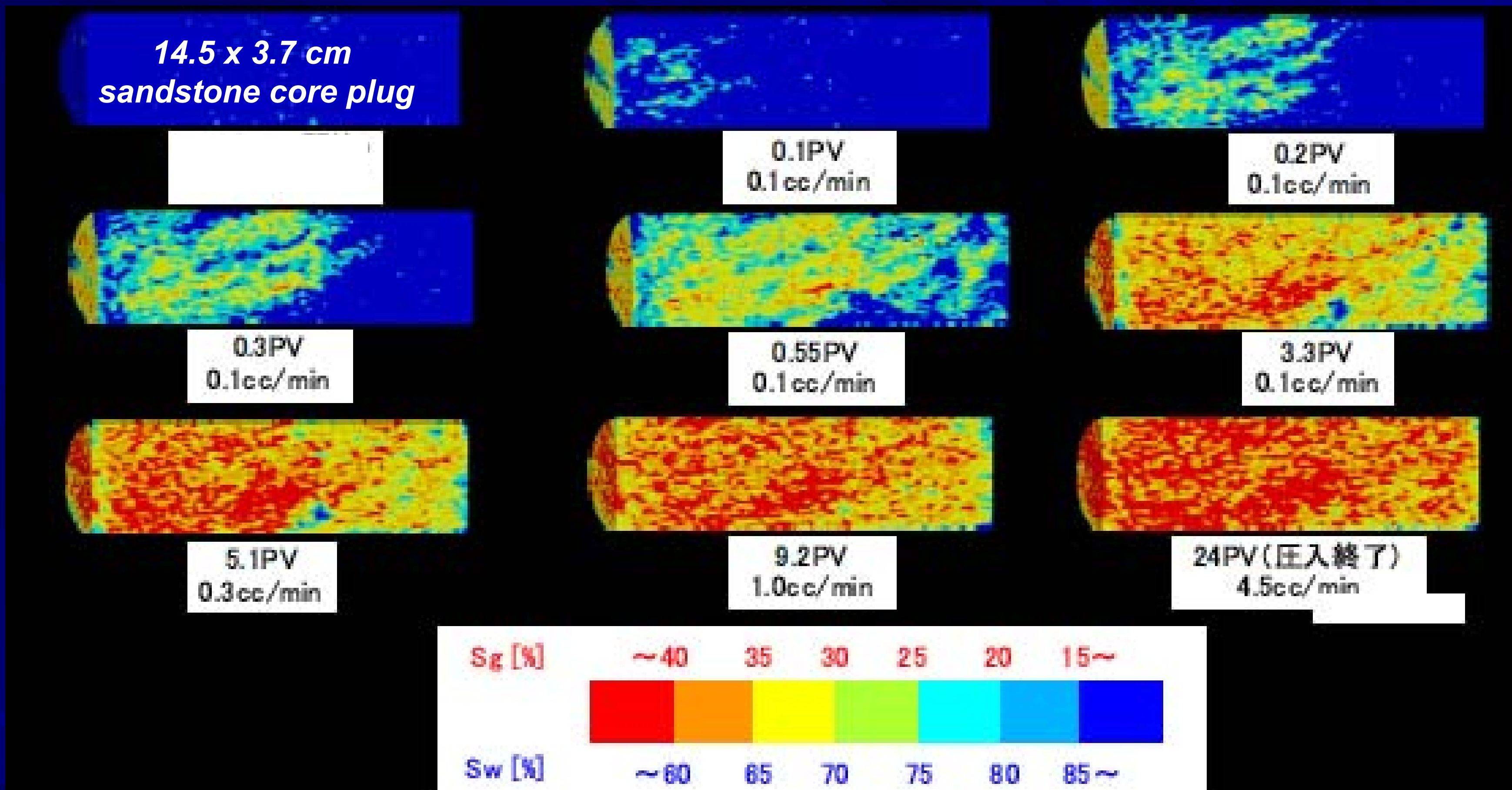
**Our study will estimate the amount of $CO_2$ (tons) that will sequestered in various states using site-specific geology, rock, and water properties**

**Majority of injected $CO_2$ gets trapped as residual gas saturation followed by $CO_2$ dissolved in brine solution.**

**$CO_2$ mineralization is a slow process.**

***DOE definition → "Commercial-scale" sequestration over project life* – *>30 million tons $CO_2$, (~510 million MCF)***

# CT images of supercritical $CO_2$ phase saturation distribution in a sandstone core



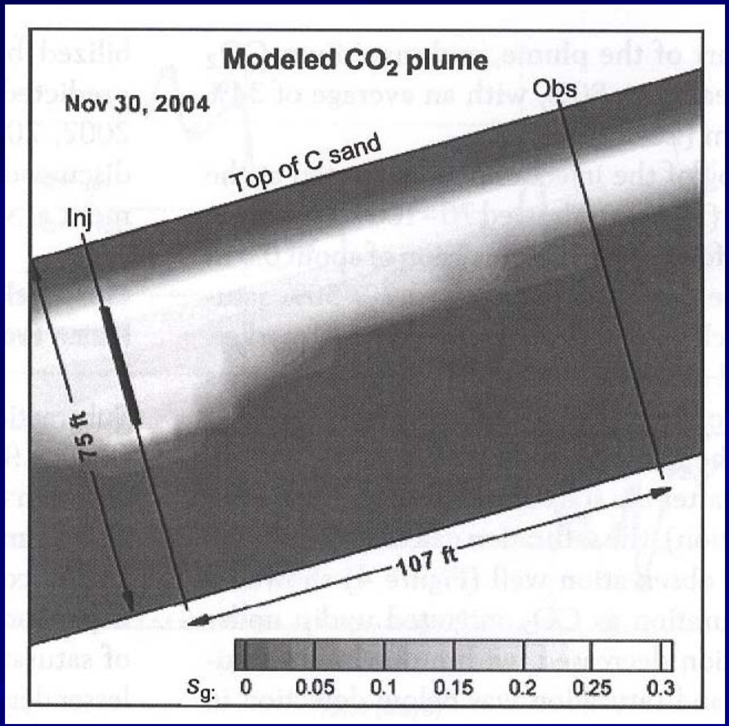

***Migration of supercritical $CO_2$ at different stages of $CO_2$ flooding compared to cumulative injected $CO_2$ volume (Ueda et al., 2007)***

***-- Note upward trajectory of $CO_2$ fluid and dispersion of "plume"***

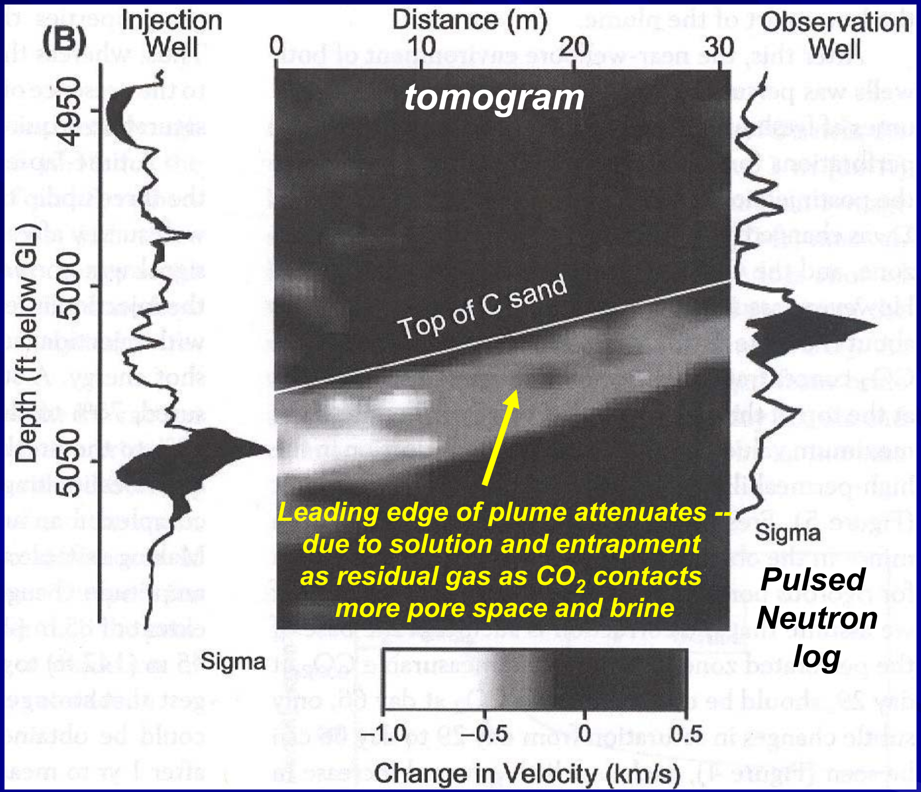
***even after several pore volumes***

# Frio Pilot Injection (Texas)
# -- free phase supercritical $CO_2$ plume

**Plume from Simulation**



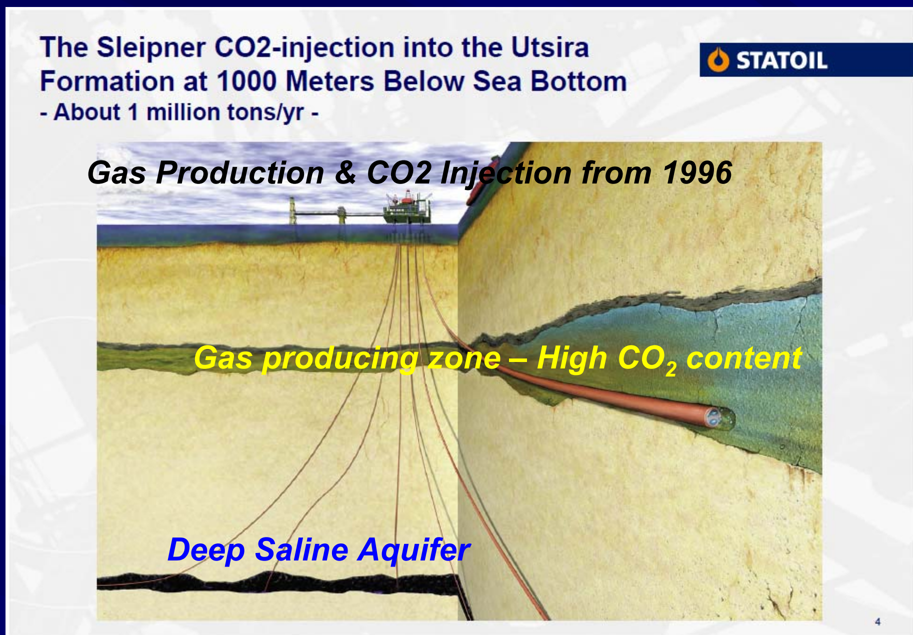

**Plume from cross-well seismic tomogram**

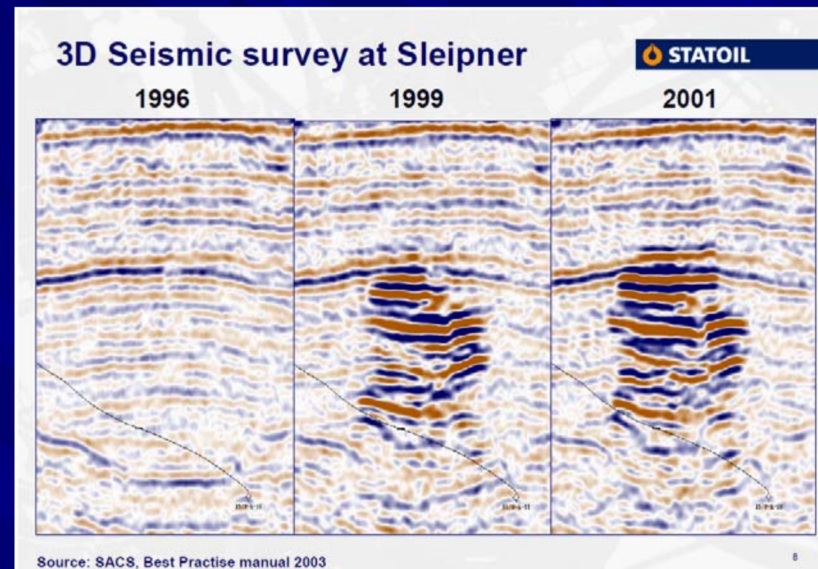



**Current tools (geologic modeling, reservoir simulation, wireline logging, 3D seismic) are capable of tracking subsurface $CO_2$ migration.**

*Hovorka et al., 2006*

# $CO_2$ Sequestration in Heterogeneous Aquifer
## Seismic Monitoring Results - Sleipner field (North Sea)



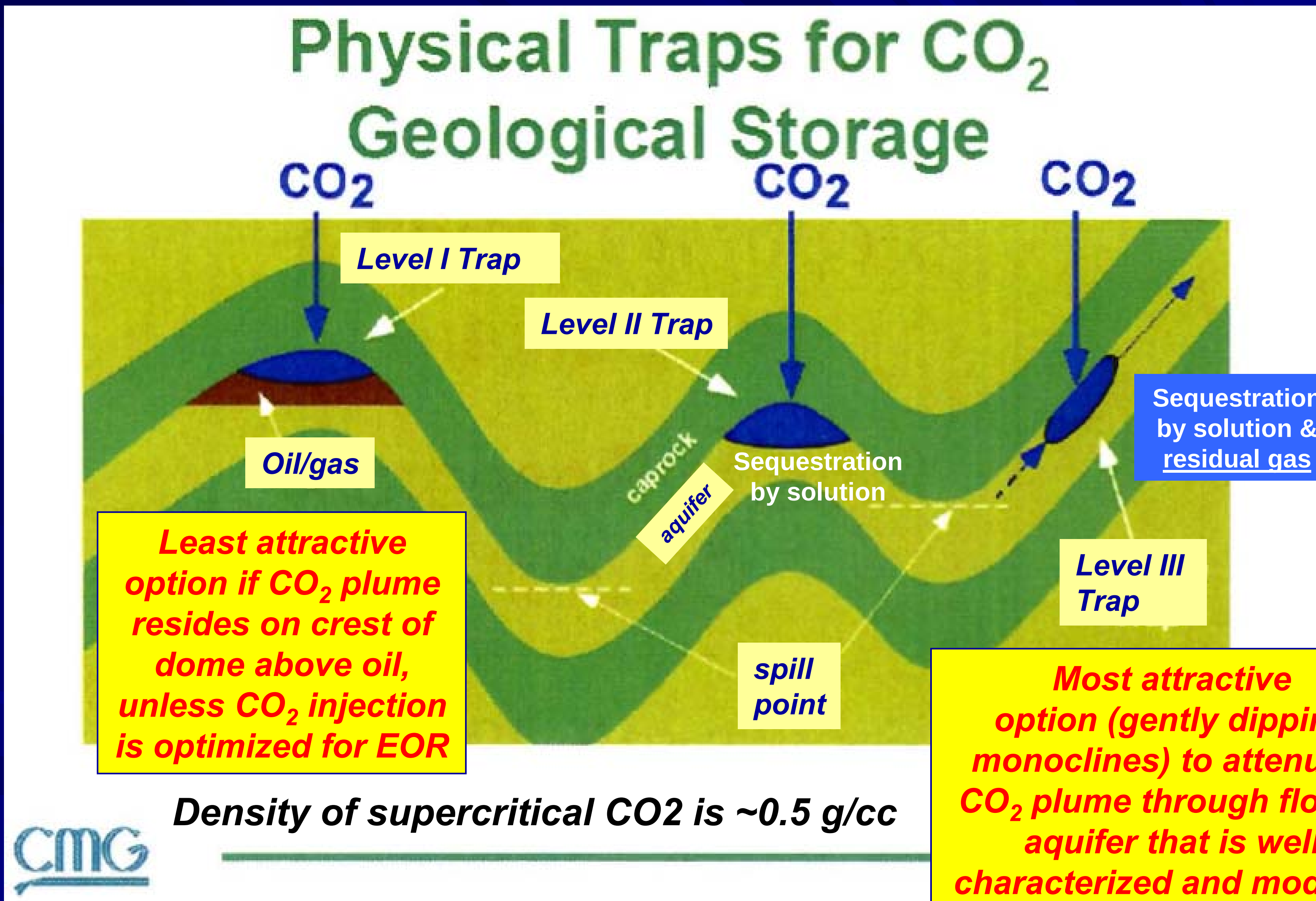





**Every time the $CO_2$ plume meets a thin shale layer, it spread out laterally. This lateral dispersion results in additional sequestration and plume degradation - $CO_2$ dissolving into fresh brine and getting trapped in fine pores of the rock.** *Torp & Gale, 2003*

**Shale layers (stratification) and aquitards – are present in the Arbuckle aquifer system.**

# Locating sites for $CO_2$ sequestration

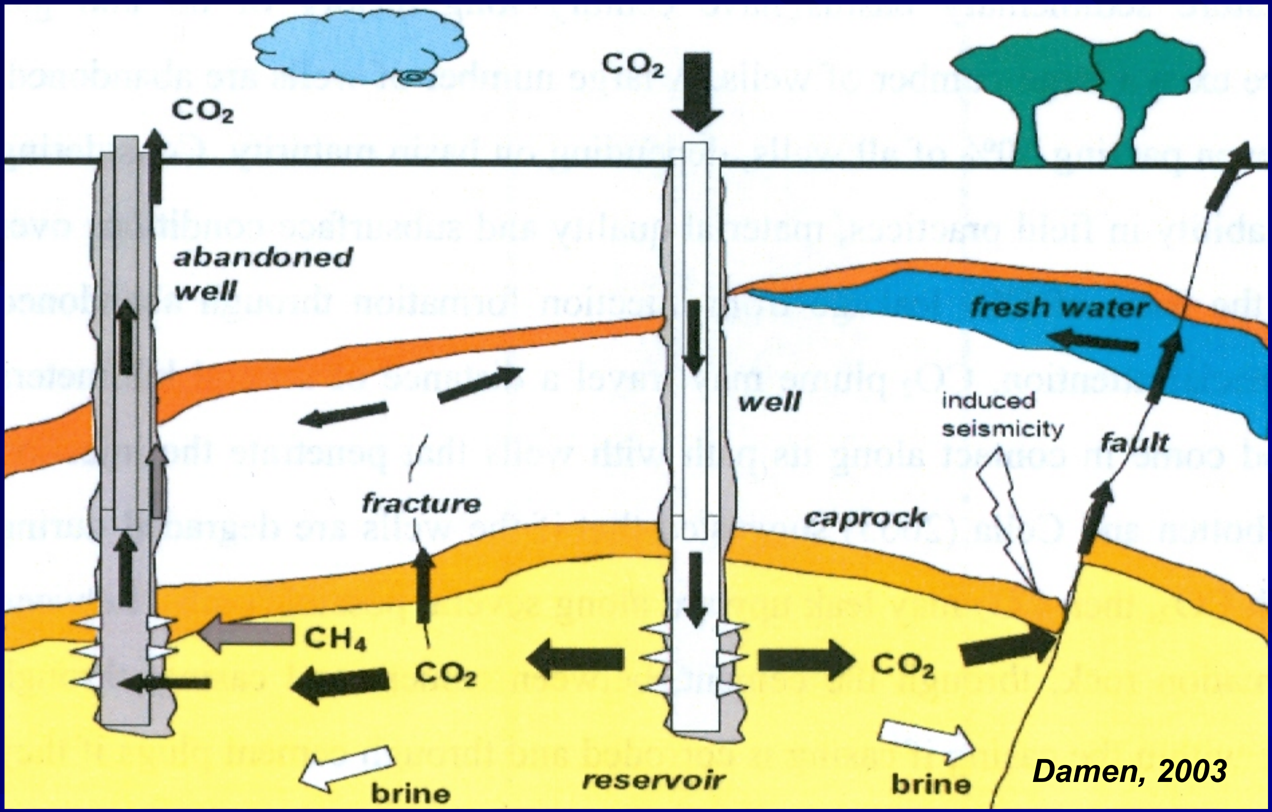



*Least attractive option if $CO_2$ plume resides on crest of dome above oil, unless $CO_2$ injection is optimized for EOR*

*Density of supercritical CO2 is ~0.5 g/cc*

*Most attractive option (gently dipping monoclines) to attenuate $CO_2$ plume through flow in aquifer that is well characterized and modeled*

# Risk Analysis – Conduit to the Surface



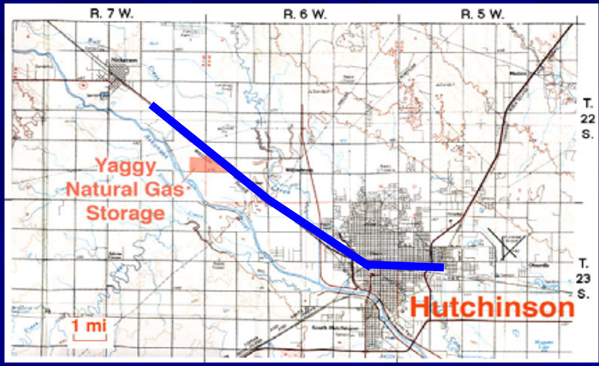

**Faults and fractures will be mapped in the 17+ county study area:**

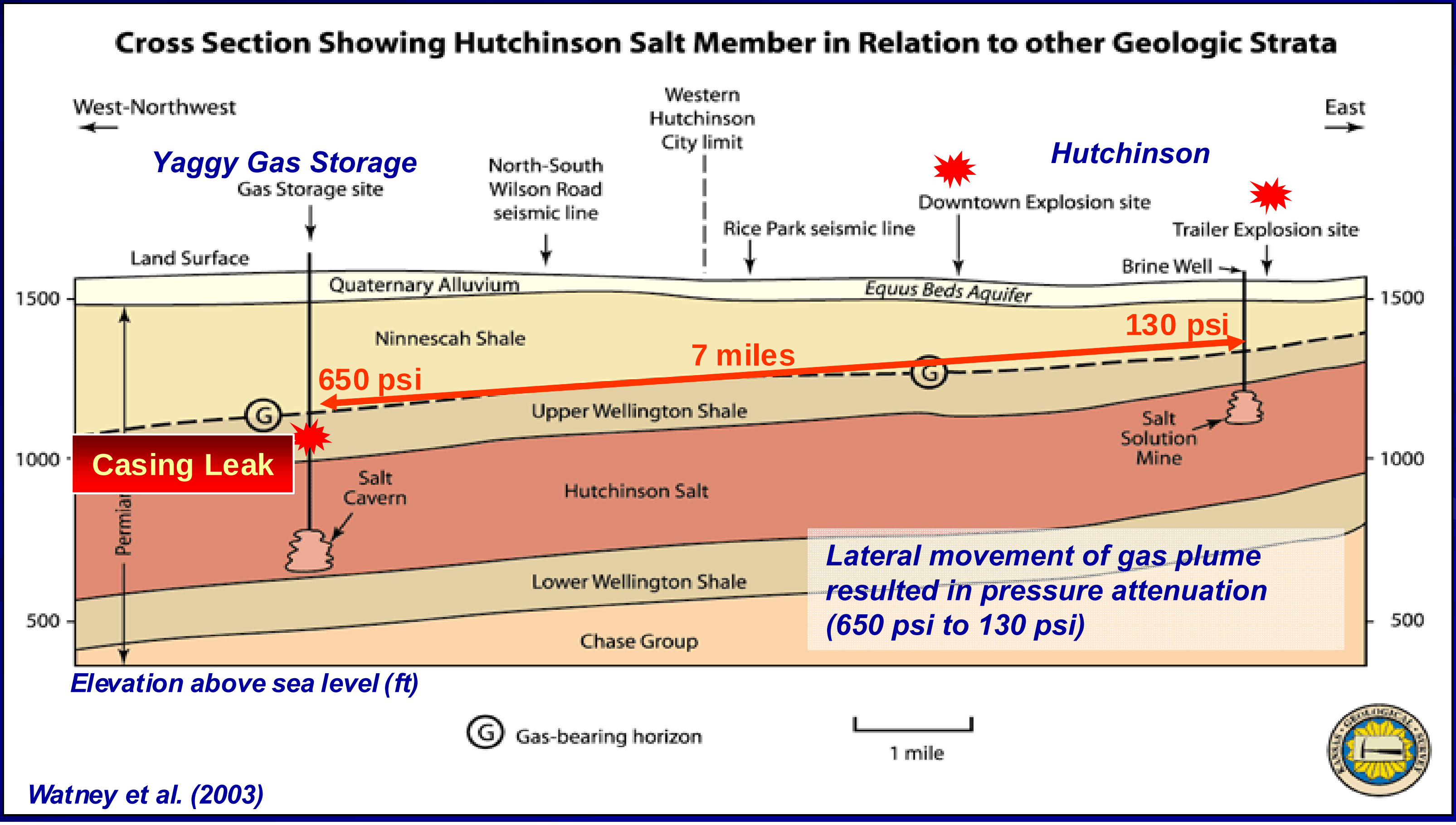
1. **Satellite imagery**
2. **Gravity/magnetic**
3. **Structure, isopach, and petrophysical maps**

***Site selection critical to minimize risks associated with $CO_2$ injection***
***Not all fractures/faults reach the surface – some do and need to be identified***
***Inventory of all plugged wells critical – REPLUG if needed.***

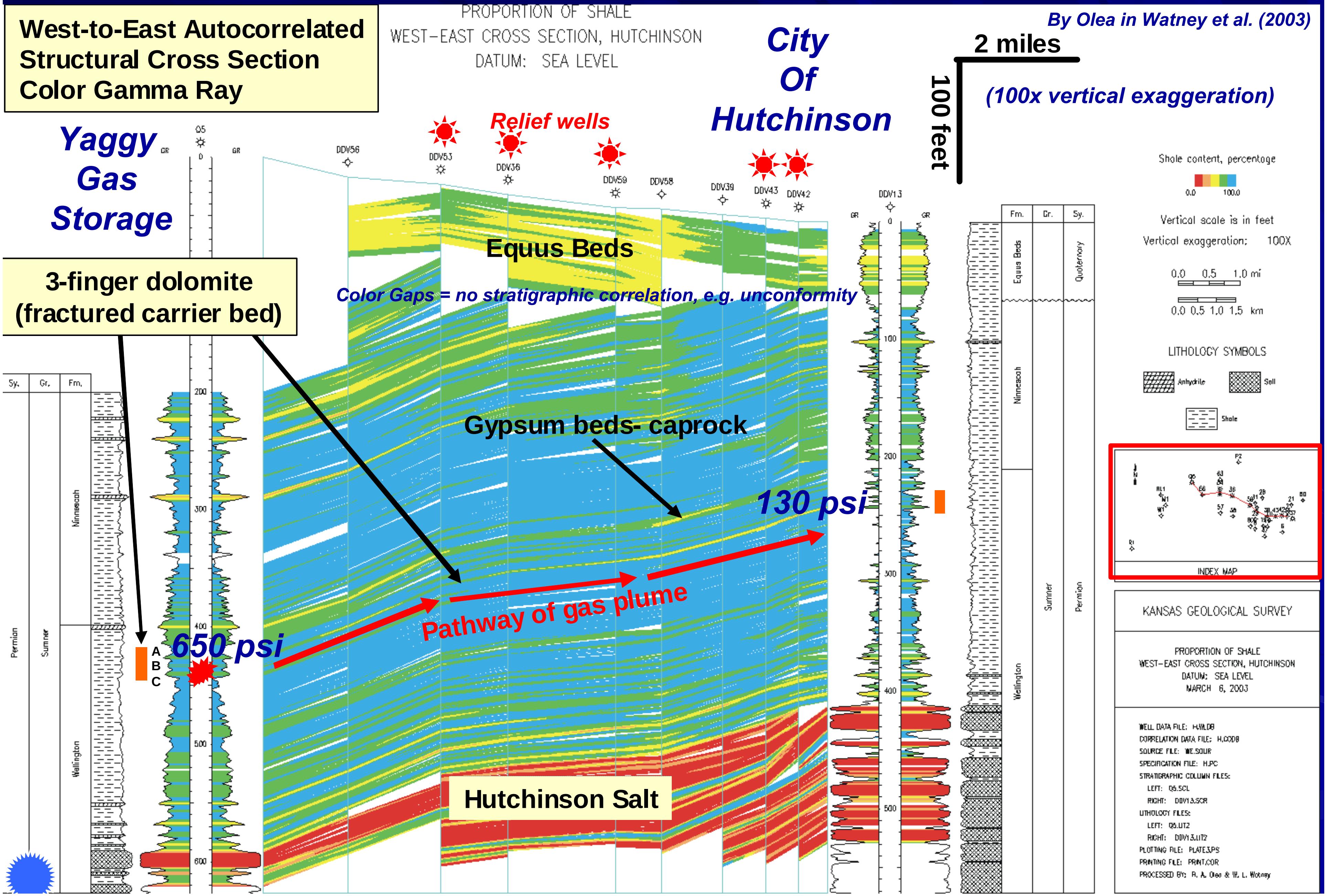
# Yaggy Gas Storage Leak - 2001

Site selection for $CO_2$ sequestration **CRITICAL,** because all wells drilled in the area <u>have</u> to be accounted for and properly completed before onset of $CO_2$ injection.



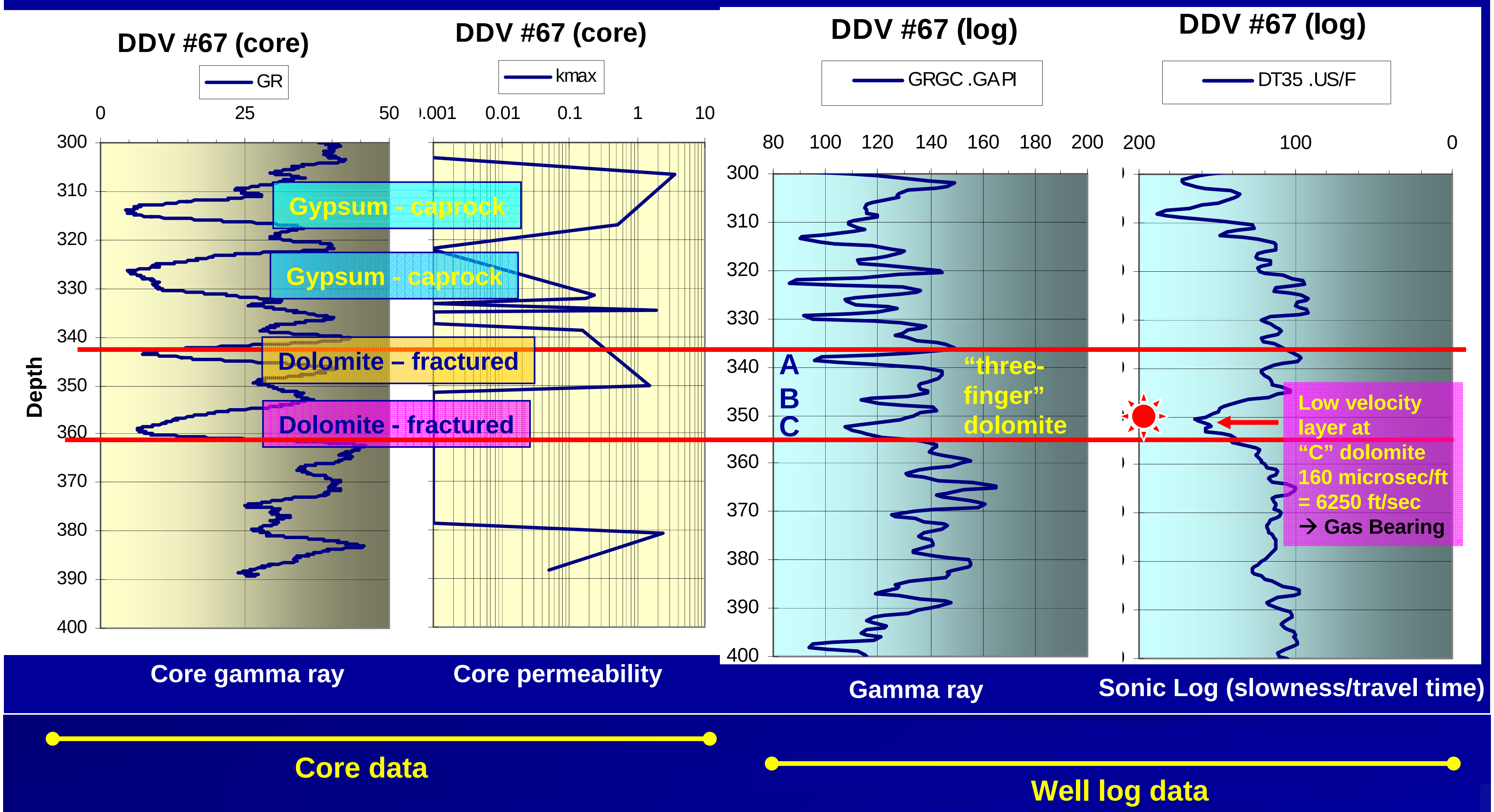



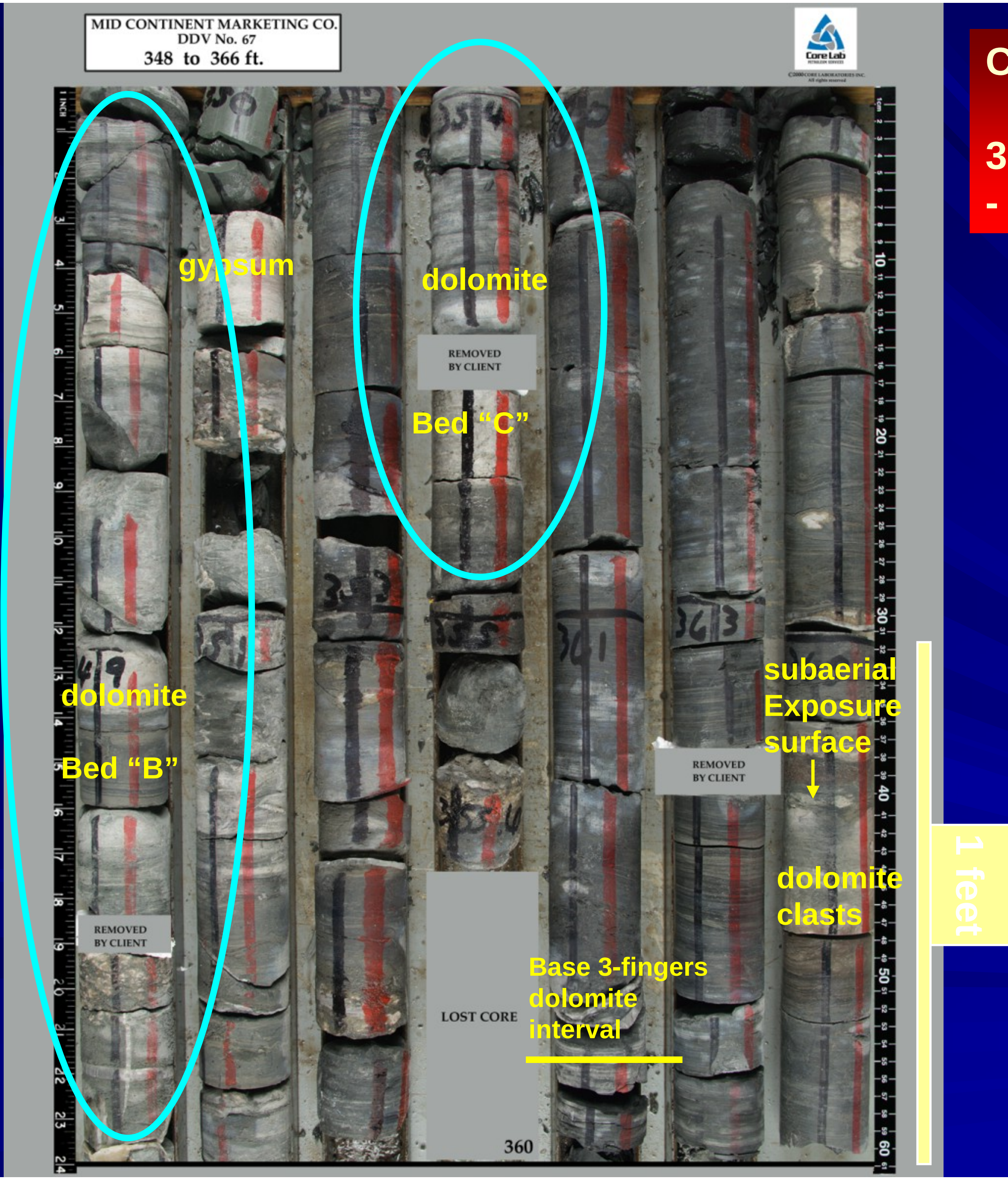
# Hutchinson Gas Leak – Slide 2



# Hutchinson Gas Leak – Slide 3 (extra)

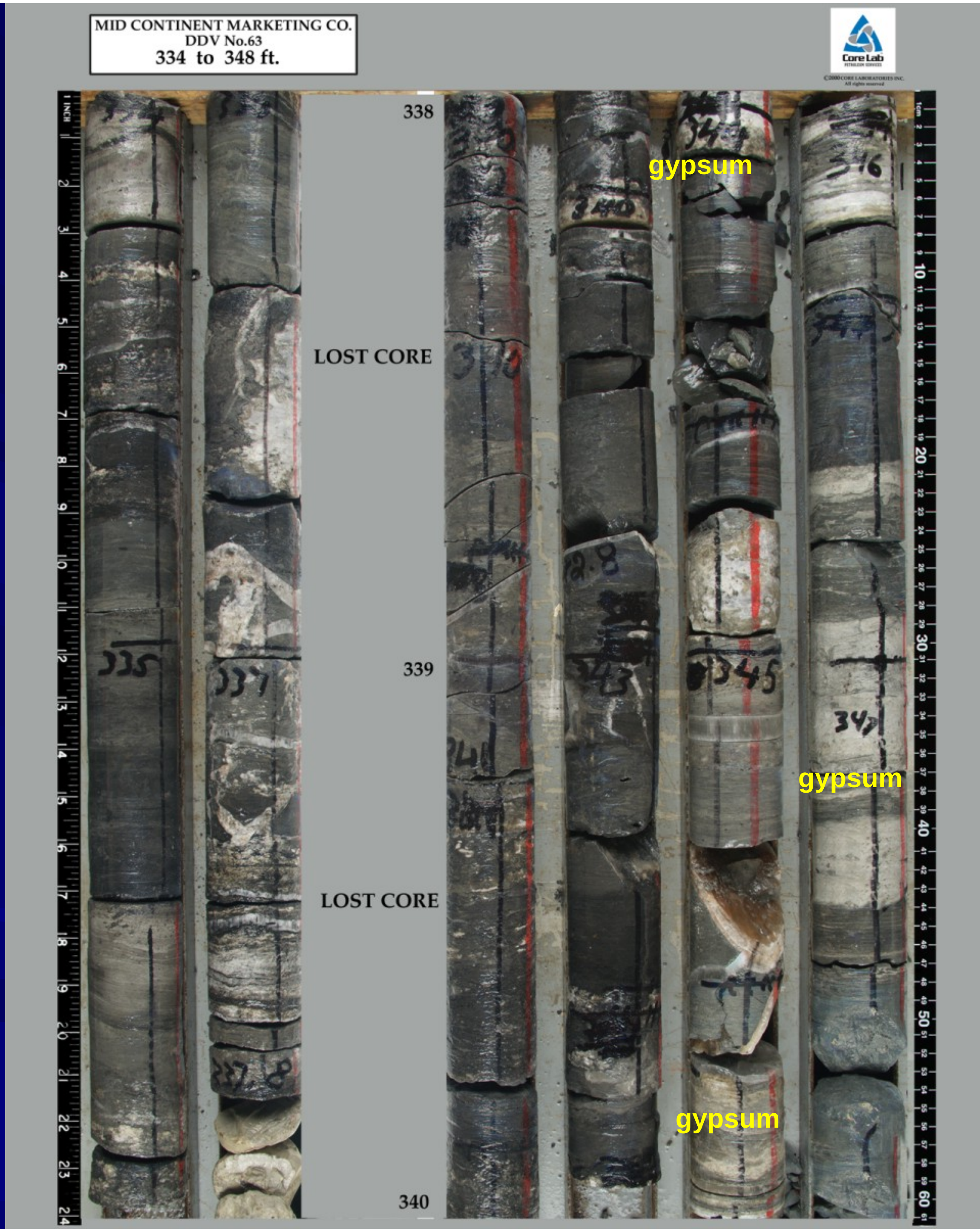
**Core and well log data**
**Gas-bearing well**
**DDV #67**
**Center of Wilson Road seismic line**






# Core from DDV #67

## 3-finger dolomite interval - gas conduit - fractured



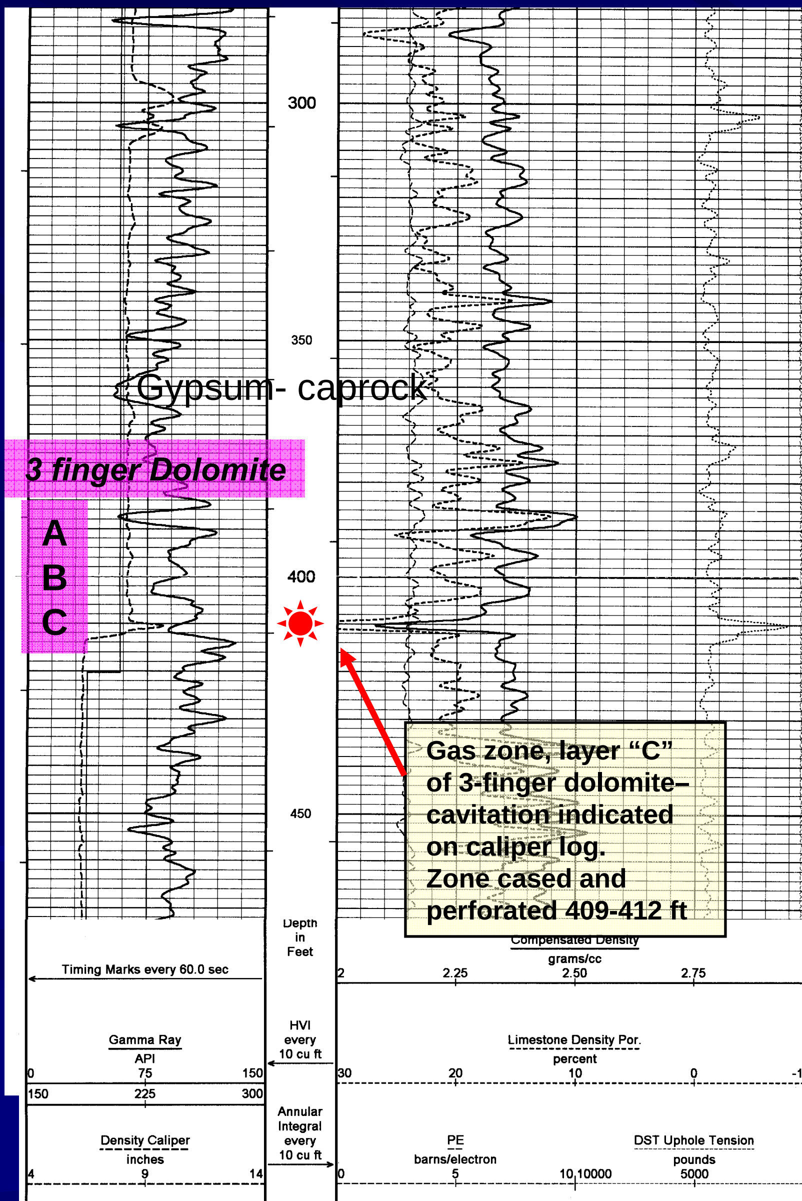

**Gypsum-rich interval "CAPROCK"**

**immediately above 3-finger dolomite**

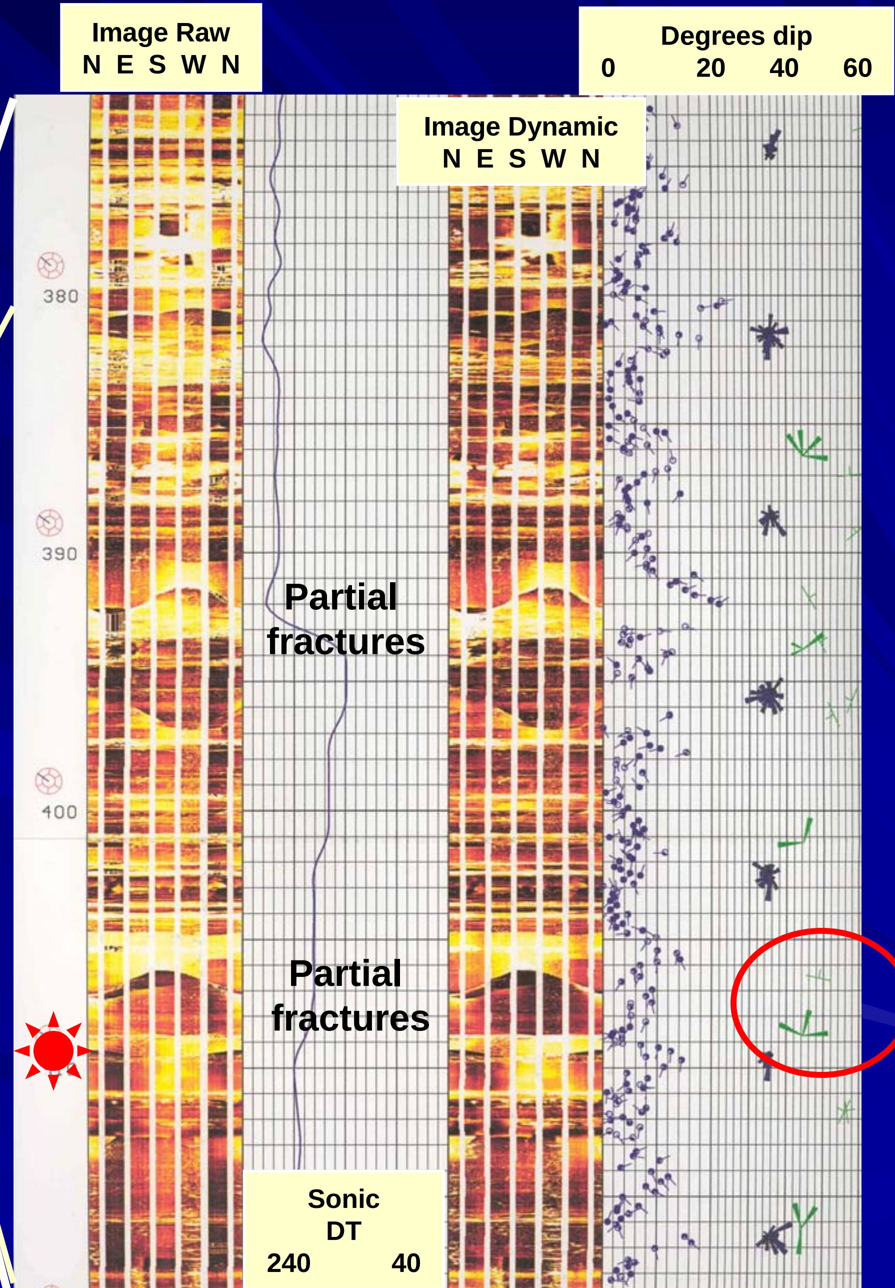
**DDV #63**

**Observation Well OB #2**

- Highest recorded pressure, 250 psi, during monitoring stage
- Adjacent to Yaggy Gas Storage Facility

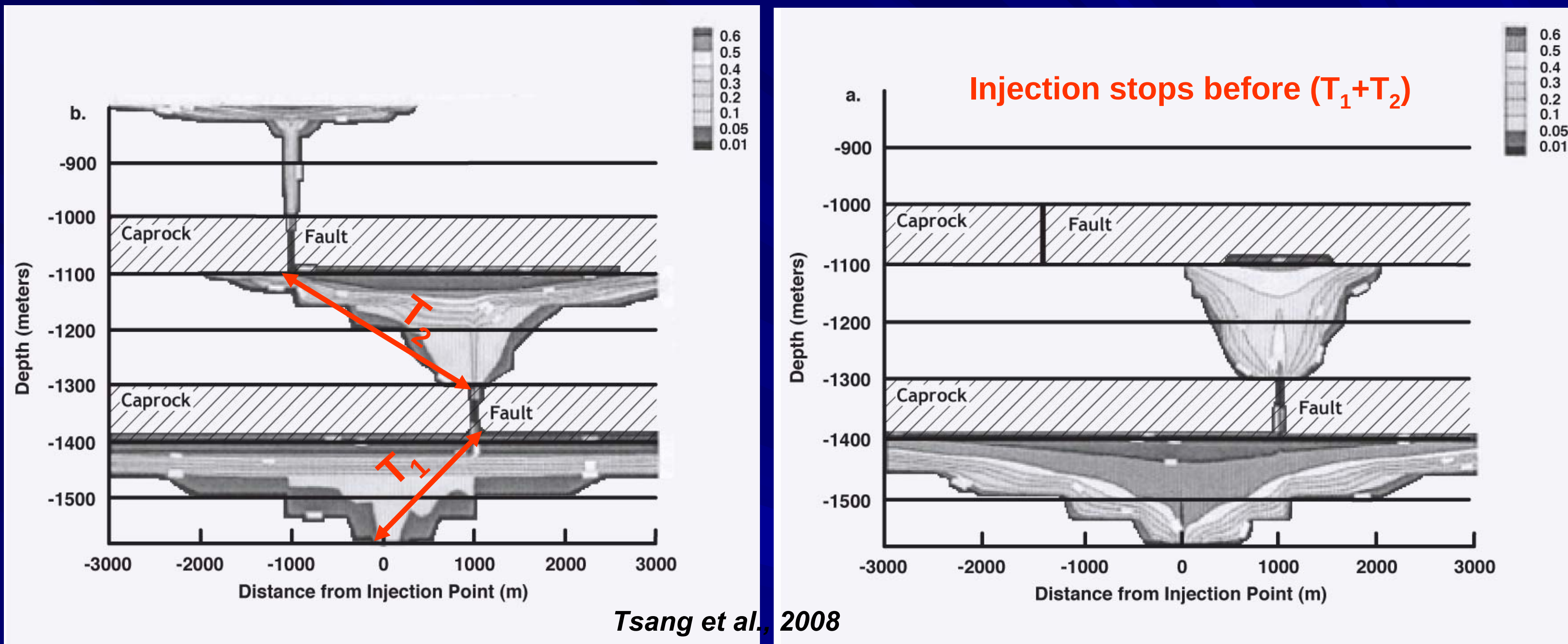



## Halliburton's Electro Micro Imager w/Sonic



# Risk Analysis – Faults

## Plume Breaches Cap Rock via Fault/Weak zone




*Tsang et al., 2008*

**Simulated plume after breach → smaller and has lower pressure.**

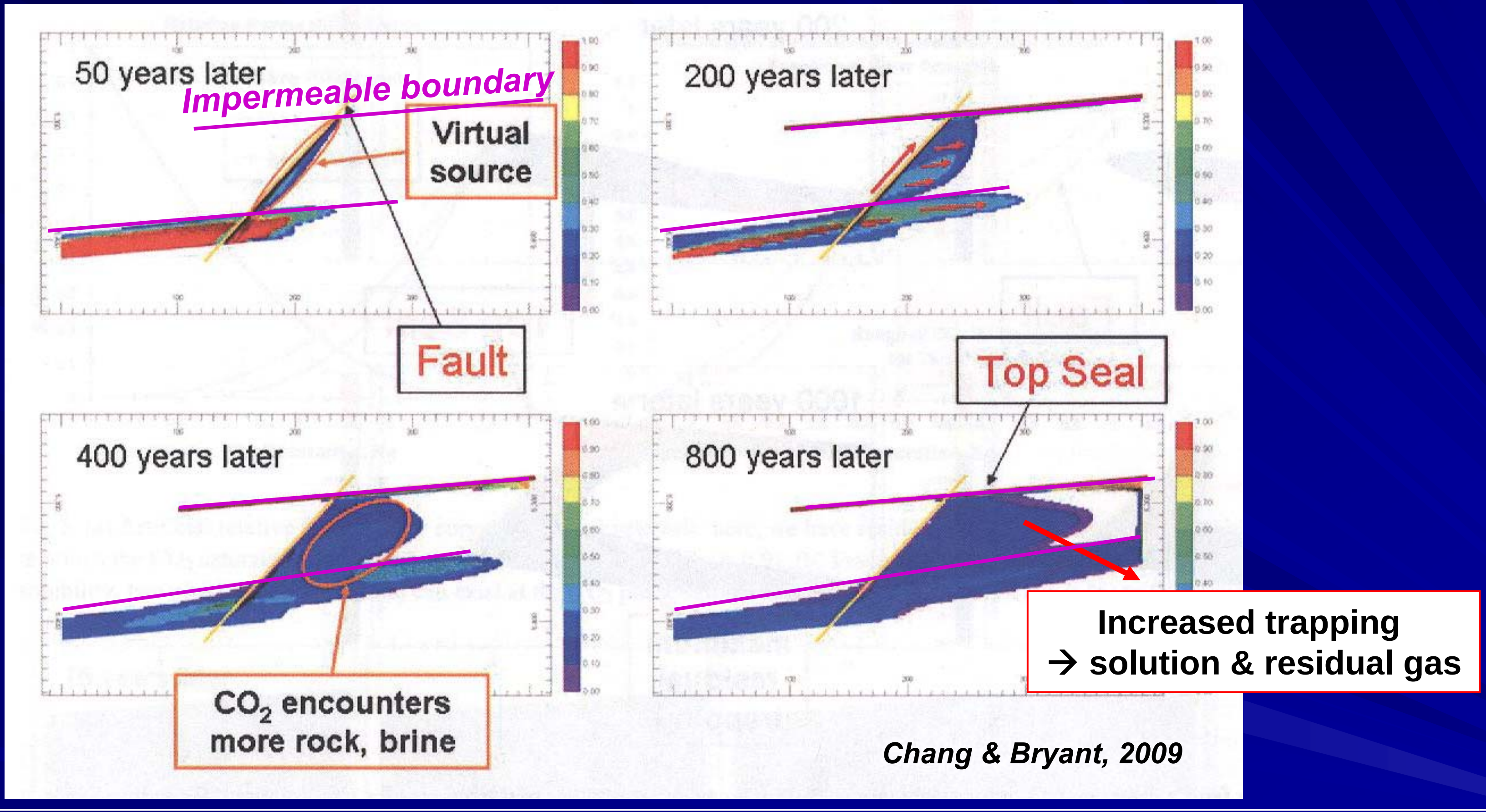
**If injection stops before plume reaches fault → then no leakage occurs.**

***What are the chances that the plume will breach successive cap rocks?***

***Is $CO_2$ sequestration tonnage economic before plume reaches fault?***

# Risk Analysis - Simulation

## Plume Intersects Inclined Fault and Caprock – Fault does not extend to surface

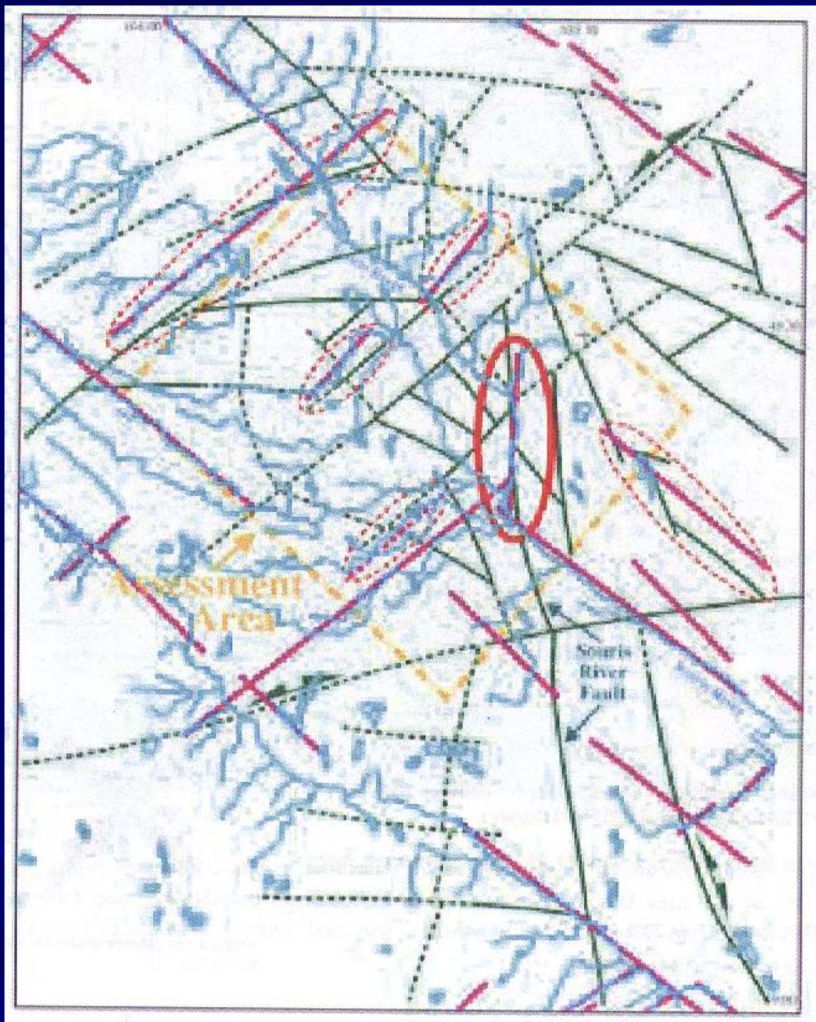



**$CO_2$ leaks into fault and creates a "virtual $CO_2$ source".**

**<u>$CO_2$ migrates updip and gets attenuated</u> –**

**additional trapping in solution and as residual gas**

# Weyburn $CO_2$-EOR - Canada




*IEA GHG Weyburn Summary Report 2000-04*
*~20 miles across base of map*

**Analysis of Natural Faults and Fractures**

***Solid Green* – *fault trends from seismic & HRAM (high resolution aeromagnetic)***

***Broken Green* – *trends from HRAM***

***Purple* – *surface lineaments***

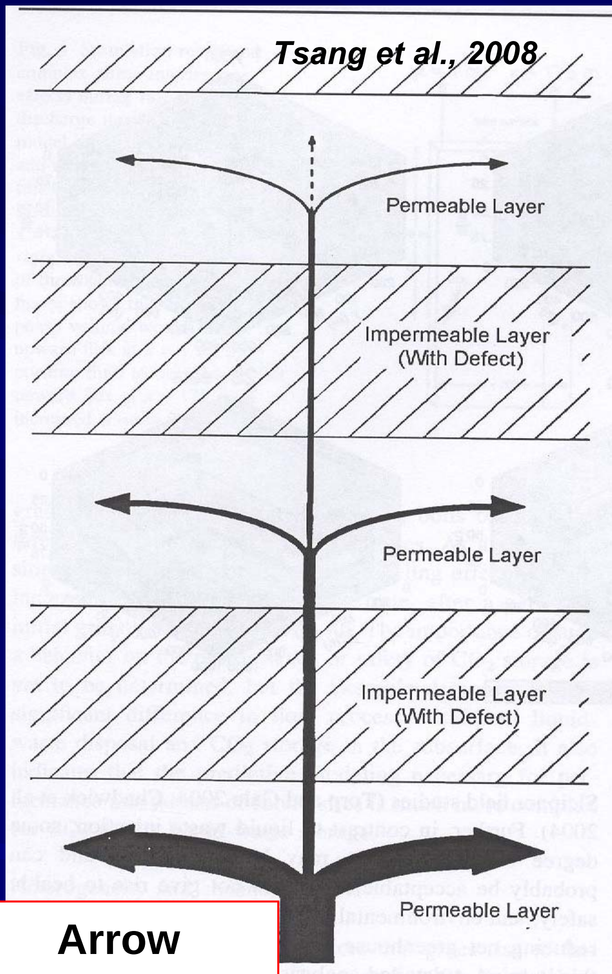
***Red oval* – *Souris Valley fault (fault identified by seismic and HRAM coincide)***

***Broken Red* – *weak correlations between data sets***

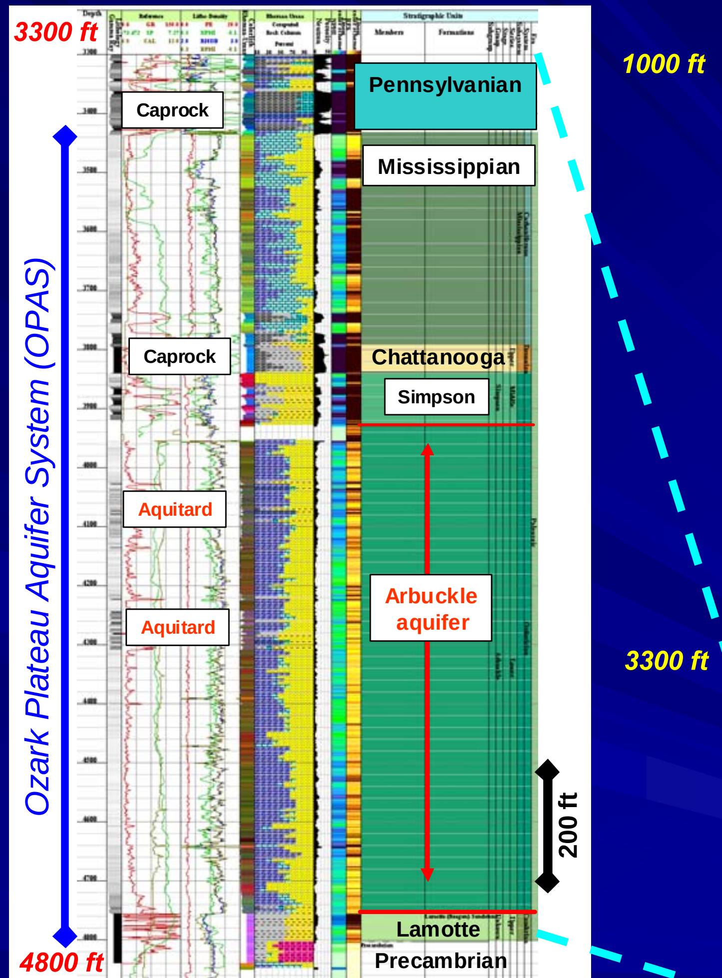
**Not all sub-surface faults/fractures reach the surface**

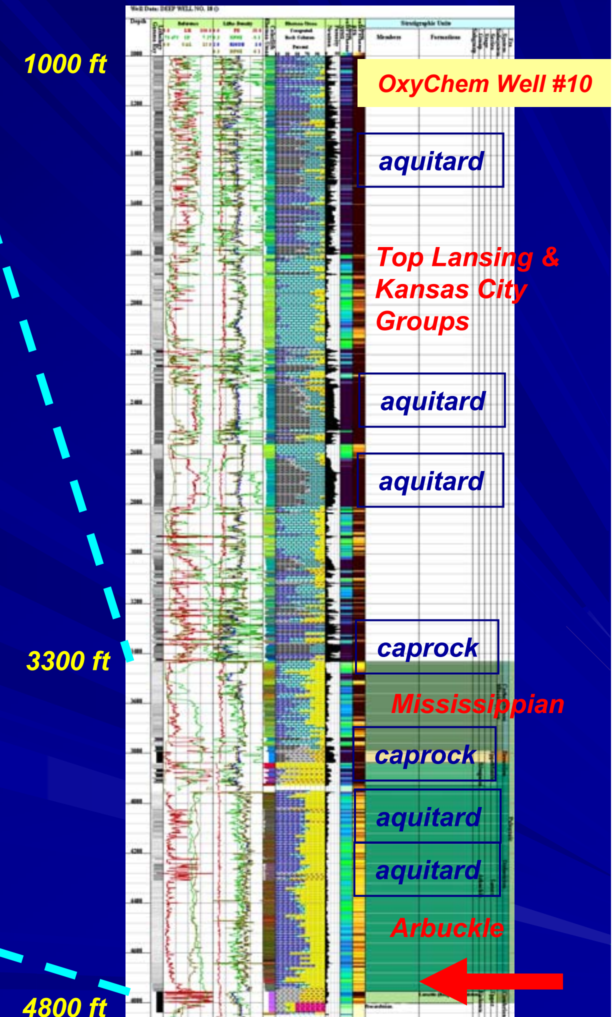
# Hydrostratigraphy in Kansas DOE-CO2 Study Area

## Multiple Caprocks & Aquitards → Leakage Attenuation



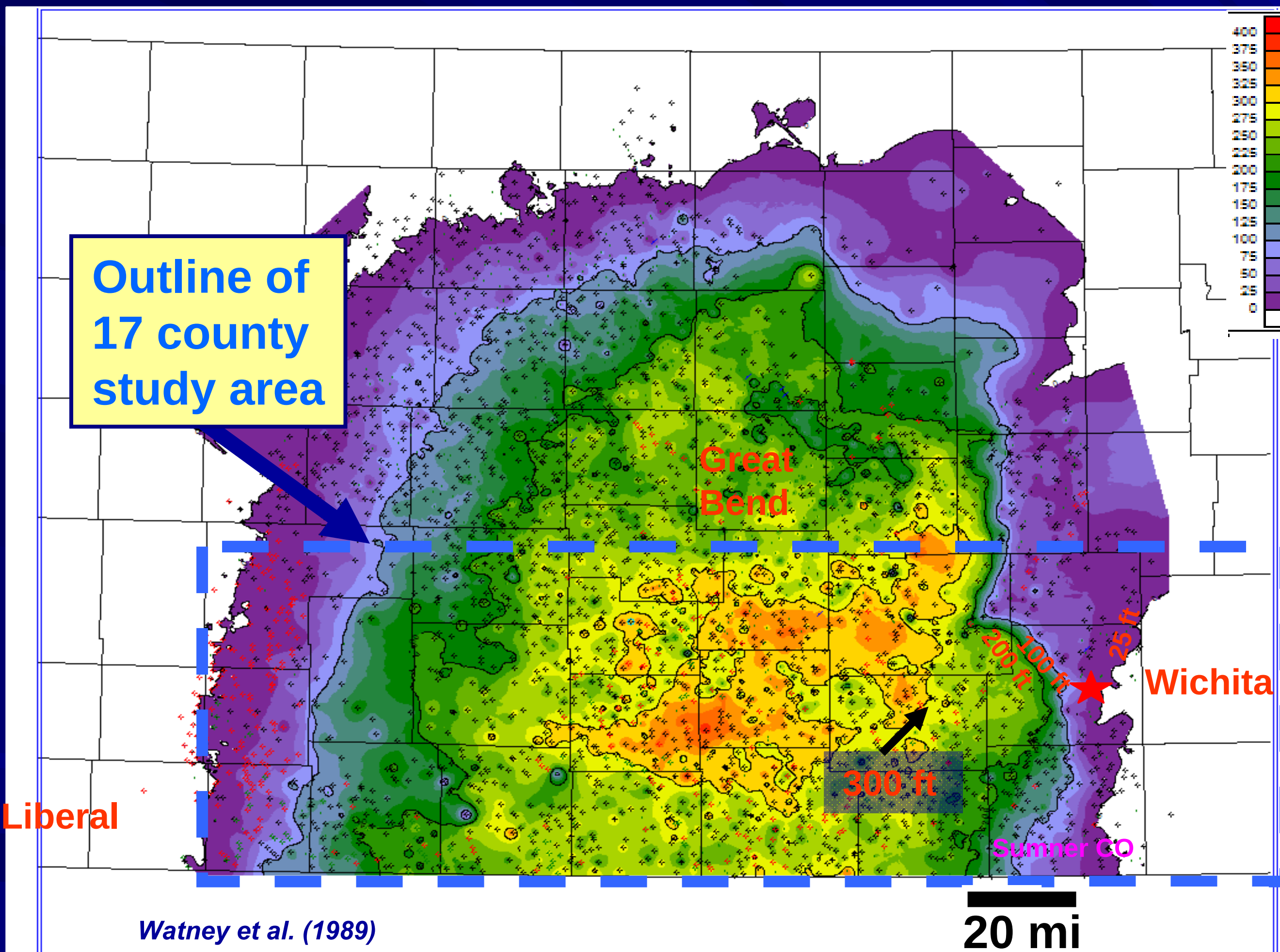

**Arrow thickness = Relative amount of flow**




$CO_2$ plume undergoes pressure reduction upon breaching cap rock. Also additional $CO_2$ gets trapped in the fine pores of aquitards.

# Regionally Extensive Caprock --
## *Lower Permian Hutchinson Salt Member*



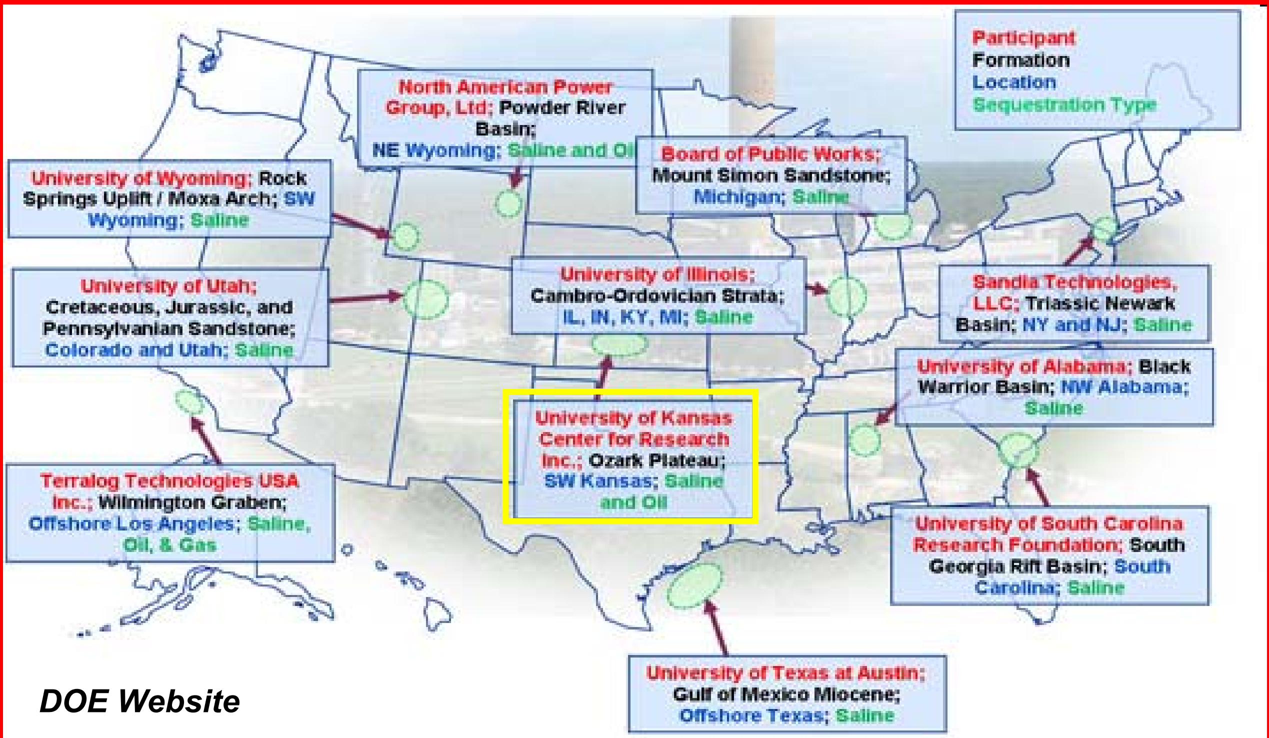

Additionally, KGS maps show that <u>total</u> Permian evaporite thickness ranges from 400 to 2000 ft in south-central KS. These evaporites serve as ideal cap rocks. Located between shallow freshwater aquifers and hydrocarbon bearing strata and possible intervals of $CO_2$ sequestration.

Net Halite (salt) Isopach (thickness)

Contour interval 100 ft

## "Evaluation of $CO_2$ sequestration potential in deep saline Ozark Plateau Aquifer System (OPAS) in south-central KS - *depleted oil fields and the deep saline Arbuckle aquifer*"

## -- American Recovery & Reinvestment Act



*DOE Website*

**DOE share:**
**$4,974,352**
**Match by KGS and partners:**
**$1,251,422**

**Principal Investigators:**
**Lynn Watney &**
**Saibal Bhattacharya**

**Duration:**
**December 8, 2009 to December 7, 2012**

# Project Objectives

- **Build 3 geomodels -**
  - *Mississippian oil reservoir at Wellington field (Sumner County) - depleted*
  - *Arbuckle saline aquifer underlying Wellington field*
  - *Regional Arbuckle saline aquifer system over 17+ counties*
- **Conduct simulation studies to estimate $CO_2$ sequestration potential -**
  - *Arbuckle saline aquifer underlying Wellington field*
  - *Miscible $CO_2$ flood in Wellington field (along with incremental oil recovery)*
- **Identify potential sites for $CO_2$ sequestration in Arbuckle saline aquifer - 17+ county area**
- **Estimated $CO_2$ sequestration potential of Arbuckle saline aquifer – 17+ county area**
- **Risk analysis related to $CO_2$ sequestration**
- **Technology transfer**

***No $CO_2$ will be injected in this project***

# Subjects Outside the Purview of this Project

- $CO_2$ capture from point sources
- $CO_2$ transmission – from source to injection sites
- Who owns the pore space?
- $CO_2$ injection regulations
- Leakage monitoring
- Liability

*Other DOE projects, ongoing and future, relate to $CO_2$ capture and transportation.*

*KS companies are working on proposals including demonstration projects related to $CO_2$ sequestration by $CO_2$-EOR and injection into underlying saline aquifers.*

# Participants in DOE-CO2 project

KU KANSAS GEOLOGICAL SURVEY
The University of Kansas

U.S. DEPARTMENT OF ENERGY

PARAGON GEOPHYSICAL SERVICES, INC

BEREXCO

noble energy

DEPARTMENT OF GEOLOGY
KANSAS STATE UNIVERSITY

KU THE UNIVERSITY OF KANSAS Department of Geology

fairfieldnodal

LOCKHART GEOPHYSICAL

ECHO GEOPHYSICAL CORPORATION
INTEGRITY-STABILITY-INNOVATION

HALLIBURTON

HEDKE-SAENGER GEOSCIENCE, LTD

Bittersweet Energy Inc.

Petrotek

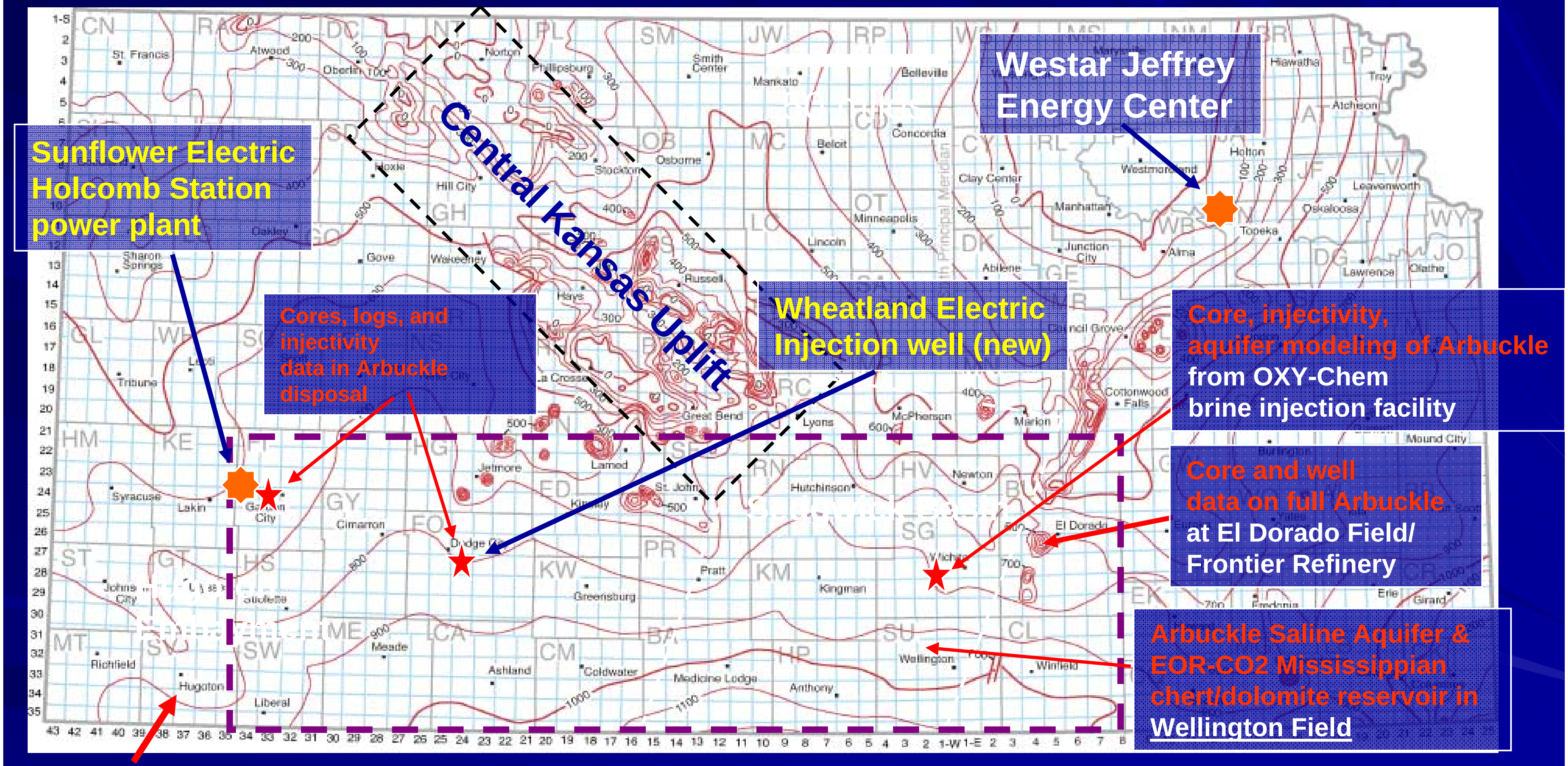
Charter Consulting
Integrated Geology & Geophysics

KOGER REMOTE SENSING

LOGDIGI
A LEADING CONSULTING COMPANY

# DOE-CO2 Project Study Area

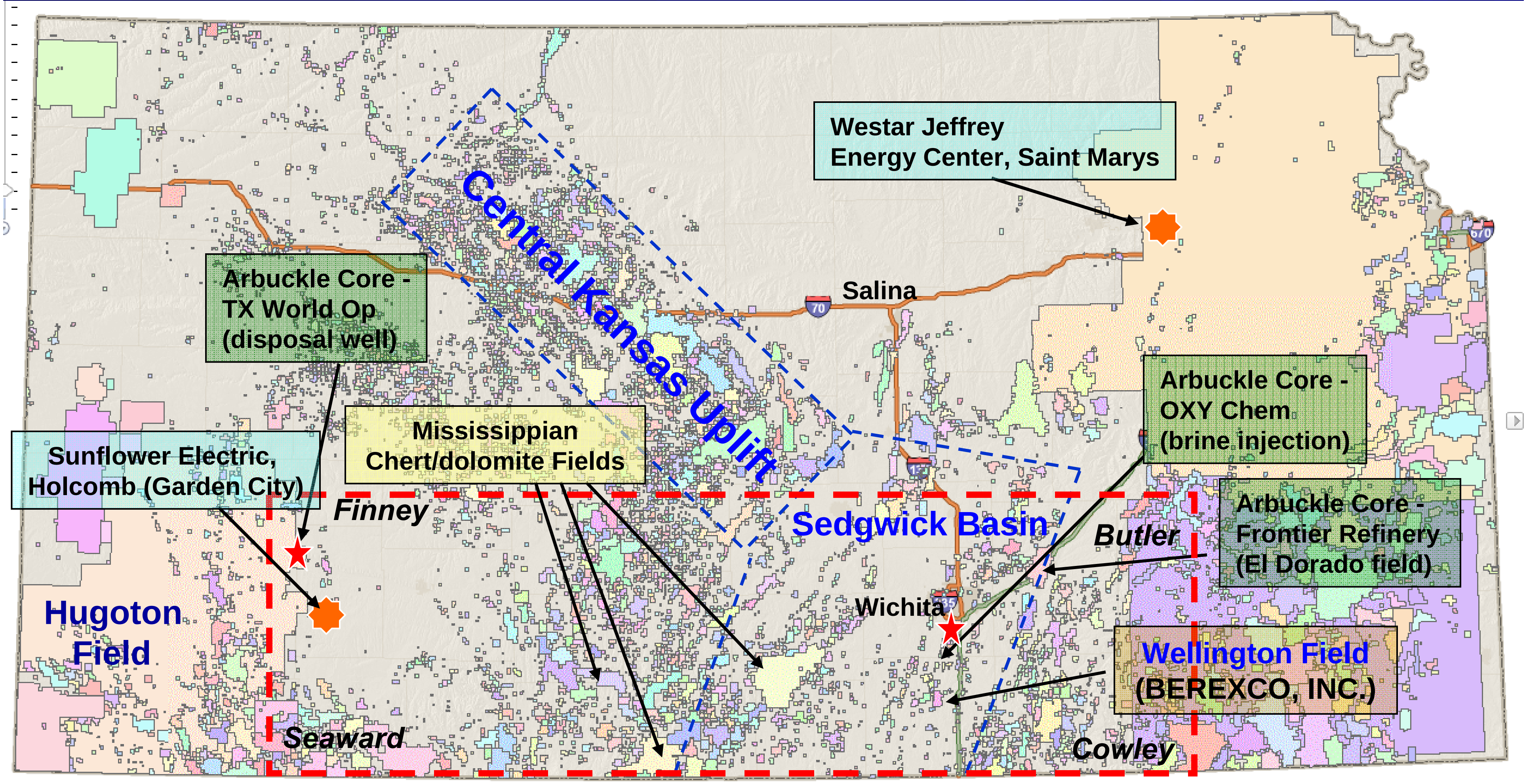
## Wellington Field (Sumner County) + 17+ Counties




*Contours = thickness of Arbuckle Group …thickest in southern Kansas*

# Project Study Area with Oil and Gas Fields

## Wellington Field (Sumner County) + 17 Counties




*Regional study → ~20,000 sq. miles*

50 miles

# Project Time Line

| | Year 1 | Year 2 | Year 3 |
|---|---|---|---|
| Regional geomodel development of Arbuckle saline aquifer | | | |
| Collect, process, interpret 3D seismic data - Wellington field | | | |
| Collect, process, interpret gravity and magnetic data - Wellington field | | | |
| Drill, core, log, and test - Well #1 | | | |
| Collect, process, and interpret 2D shear wave survey - Well #1 | | | |
| Analyze Mississippian and Arbuckle core | | | |
| PVT - oil and water | | | |
| Geochemical analysis of Arbuckle water | | | |
| Cap rock diagenesis and microbiology | | | |
| Drill, log, and test - Well #2 | | | |
| Complete Wellington geomodels - Arbuckle and Mississippian reservoirs | | | |
| Evaluate CO2 sequestration potential in Arbuckle underlying Wellington | | | |
| Evaluate CO2 sequestration potential in CO2-EOR in Wellington field | | | |
| Risk assessment - in and around Wellington field | | | |
| Regional CO2 sequestration potential in Arbuckle aquifer - 17+ counties | | | |
| Technology transfer | | | |

*Data Collection*

*$CO_2$-Seq Potential - Wellington*

*$CO_2$ Seq Potential - Arbuckle 17+ Counties*

**No $CO_2$ injection will take place in this project**

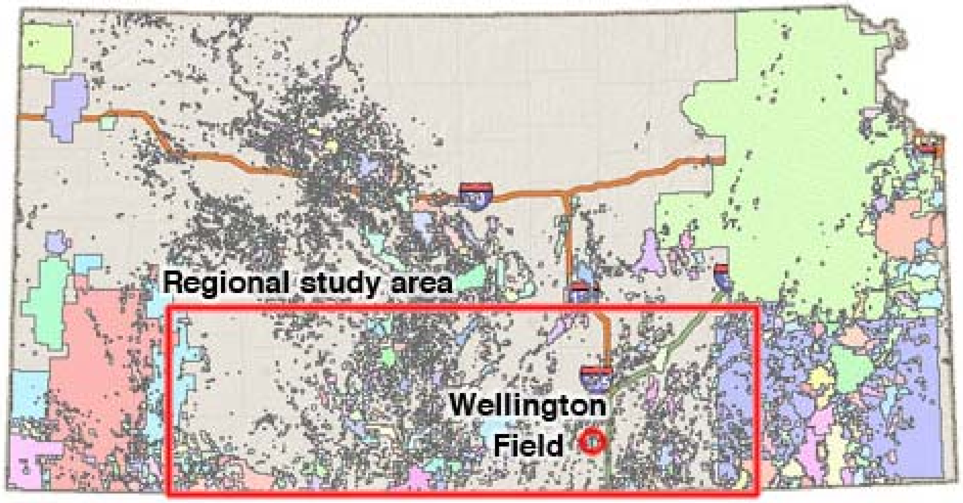
## South-central Kansas $CO_2$ Project
Kansas Geological Survey

### Project Overview
March 2010

**Abstract**

The proposed study will focus on the Wellington Field, with evaluation of the $CO_2$-EOR potential of its Mississippian chert ("chat") reservoir and the sequestration potential in the underlying Cambro-Ordovician Arbuckle Group saline aquifer. A larger geomodel study of the Arbuckle Group saline aquifer will then be undertaken for a 17+-county area in south-central Kansas to evaluate regional $CO_2$ sequestration. This study will demonstrate the integration of seismic, geologic, and engineering approaches to evaluate $CO_2$ sequestration potential.

### Project Area
March 2010




### About...

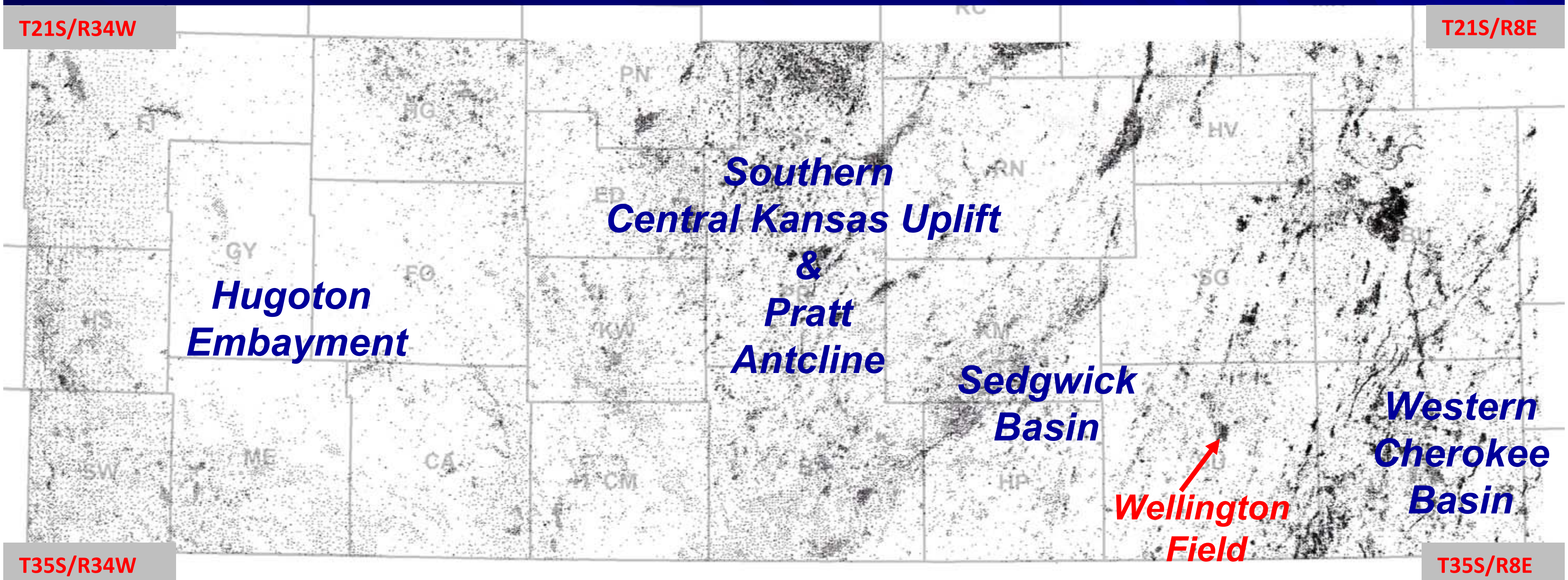
*South-central Kansas $CO_2$ Project* is a DOE-funded project of the Kansas Geological Survey. More ...

### Topics...

- Home
- Publications
- People

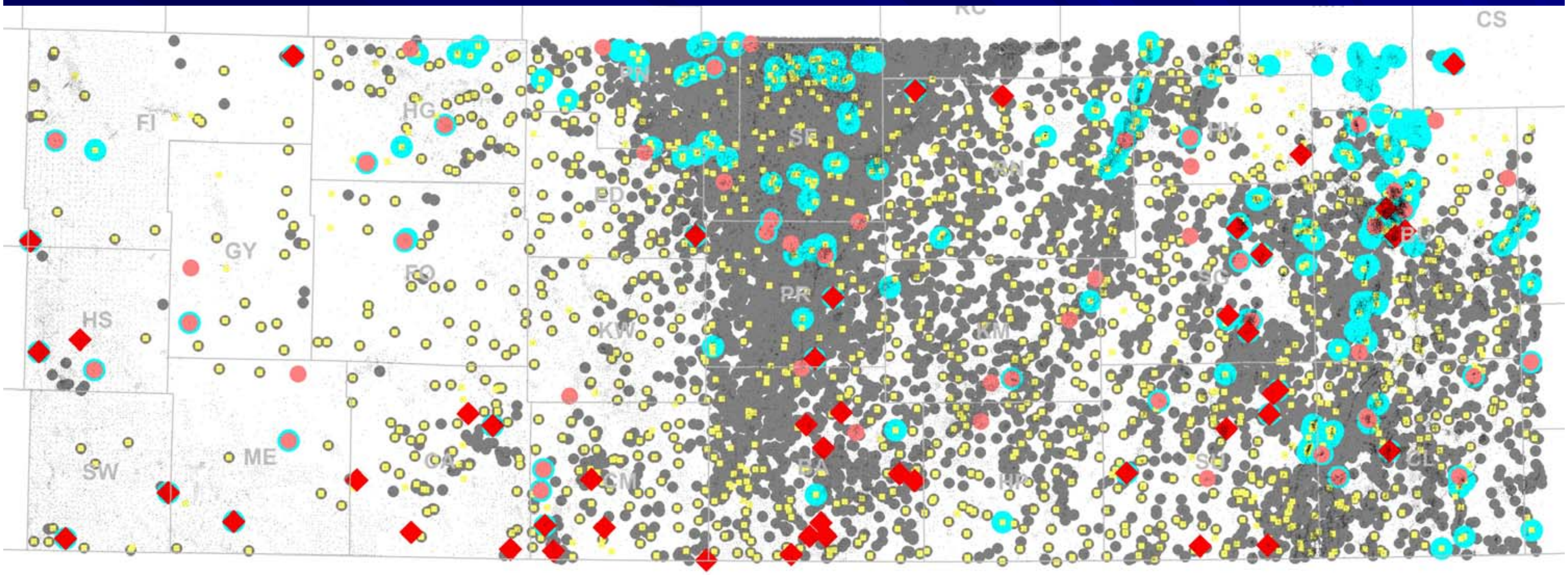
www.kgs.ku.edu/PRS/Ozark

# Well Count – Regional 17+ County Area




95,117 wells

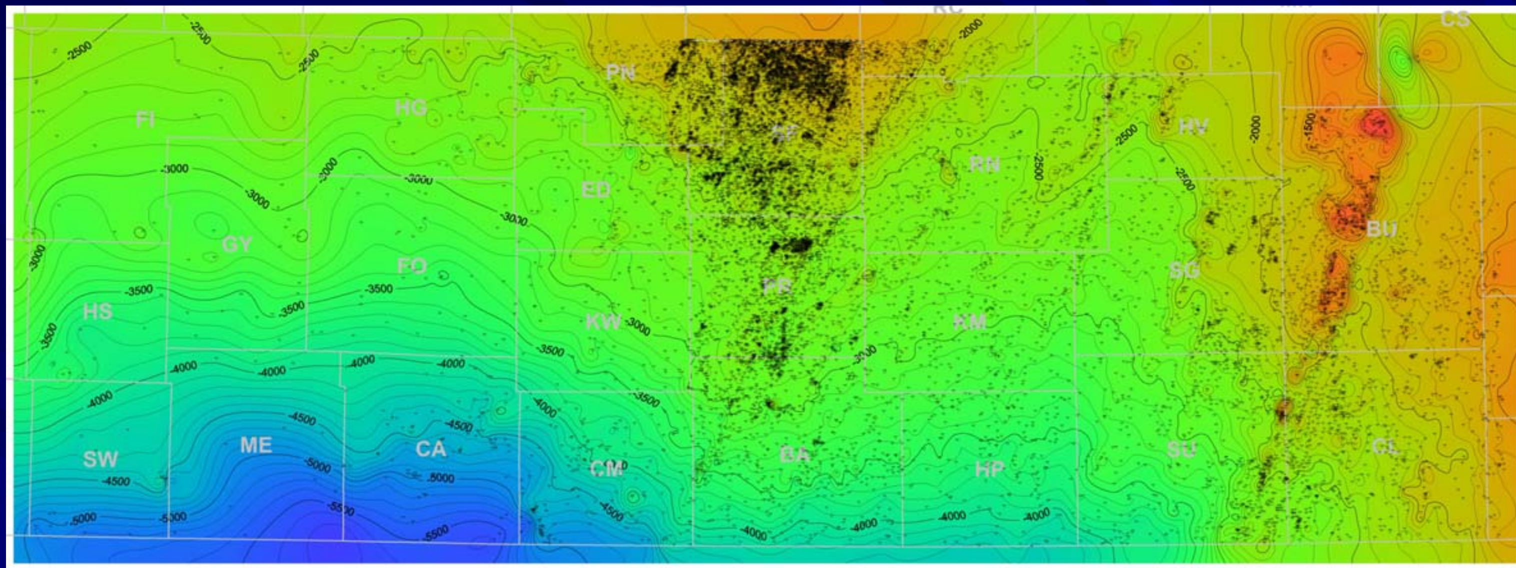
# Current Well Distribution
## Regional Mapping & Log Analysis




*30 mi.*

- LAS Files 48 wells (to date)
- Pre-Cambrian Wells = 292
- Arbuckle Wells = 14,105
- Type Wells (>200' into Arbuckle) = 1,417
- Super Type Wells (>400' into Arbuckle, 1980 or later) = 91

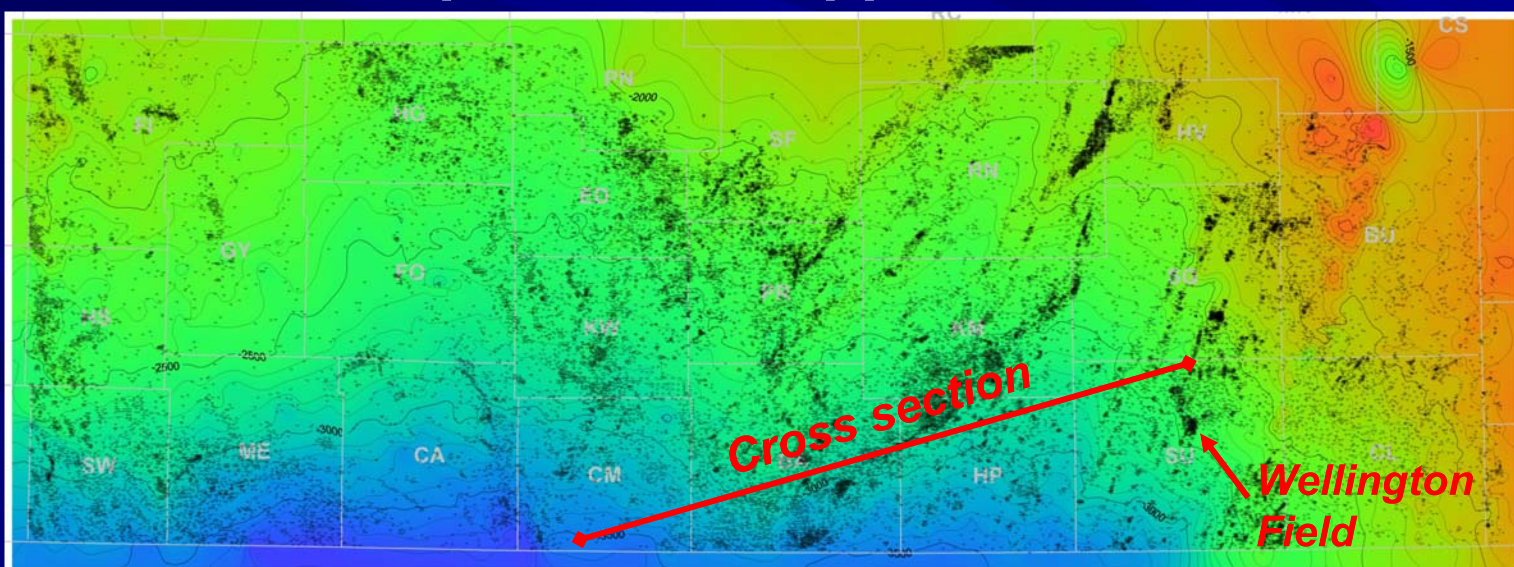
# Top of Arbuckle Structure




14,105 wells

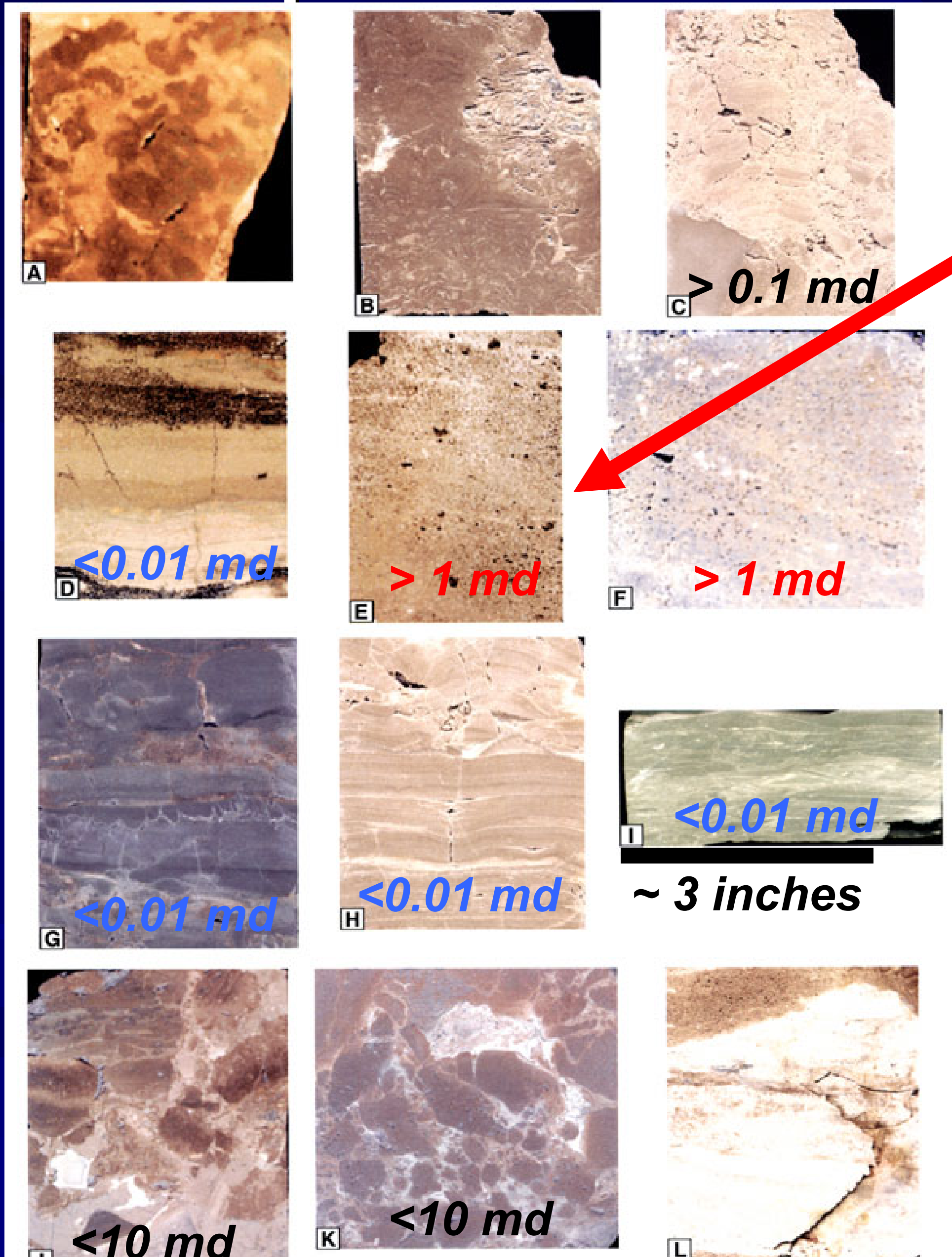
30 mi.

# Top of Mississippian Structure




35,415 wells

# Aquifer flow units and seals/caprock



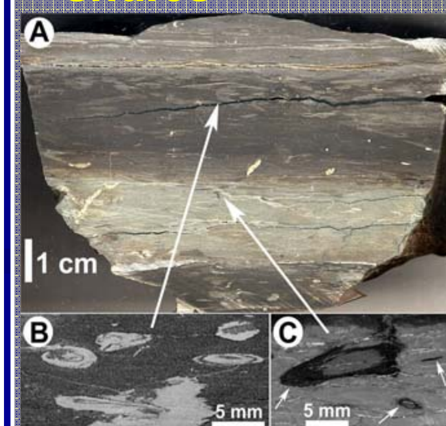

Franseen et al. (2004)

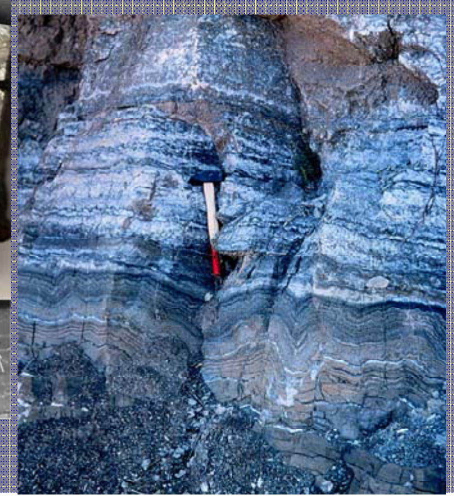
*Strata comprising **Arbuckle saline aquifer** vary from porous flow units/aquifers to aquitards and aquitards.*

***Caprocks** = thicker shales e.g., Chattanooga Shale, succession of Pennsylvanian and Permian shales and evaporites*

***Permo-Penn. shales***

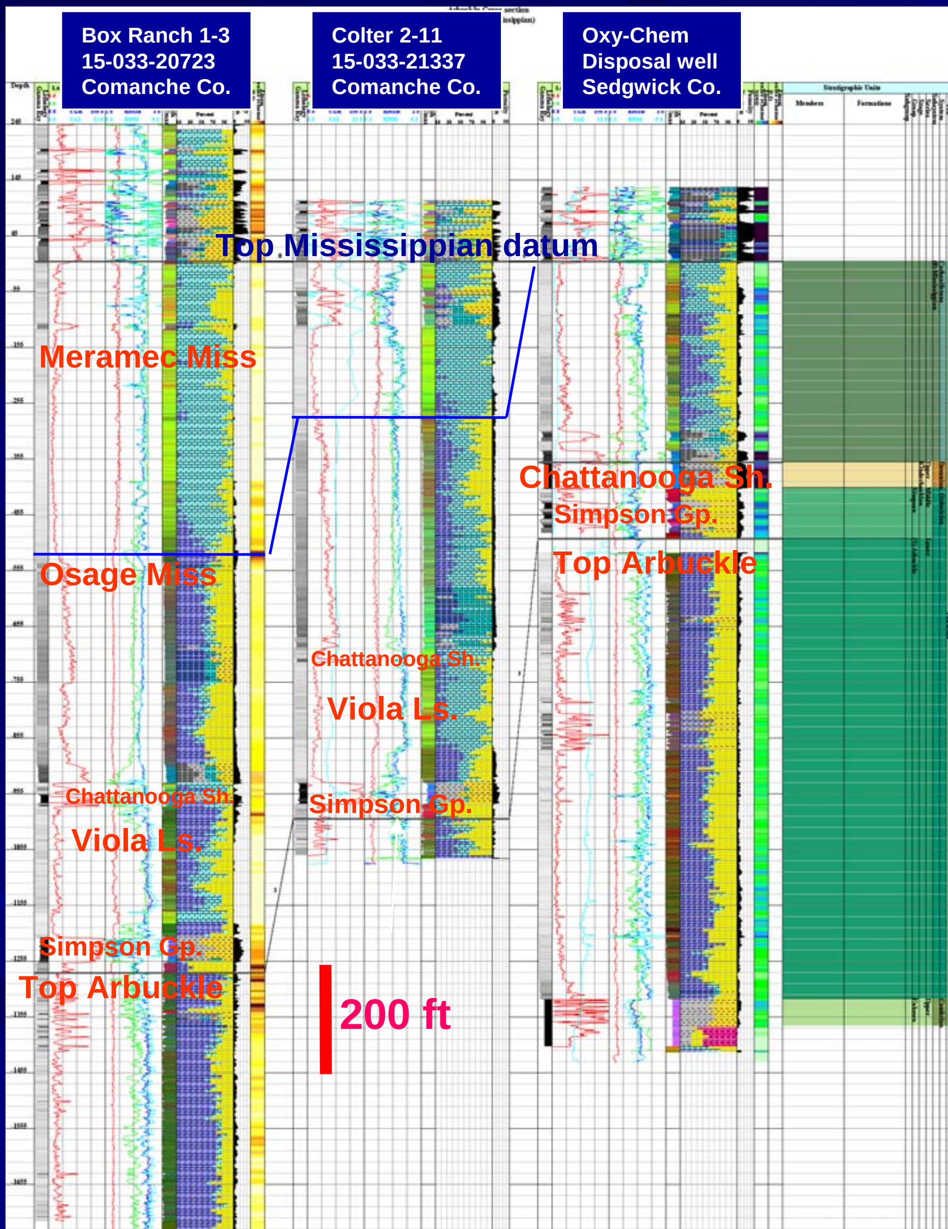
***Permian evaporite beds***



Lobza & Schieber (1999)

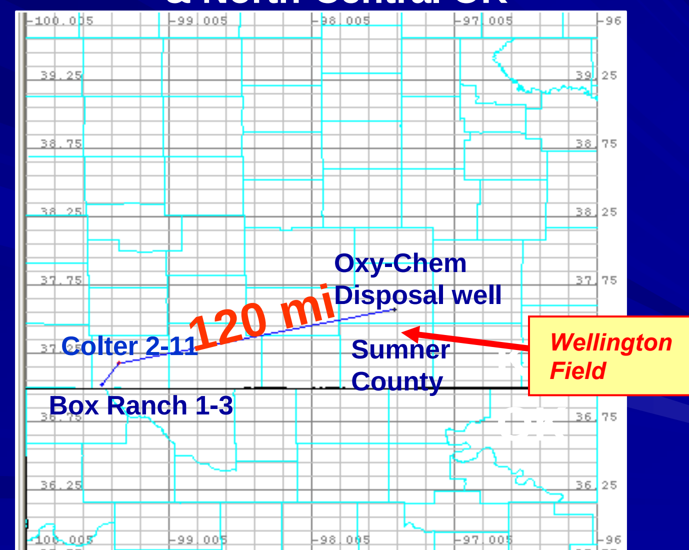
# KGS Web-Tool under development - Well Profile & Cross Section
# Interactive tool to convey hydrostratigraphy (aquifers/caprocks)




**<u>Three well stratigraphic cross section with datum on top of the Mississippian carbonates</u>** showing –

- gray scale gamma ray,
- lithology as multicolor image track,
- mineralogy percentage in color,
- porosity as variable thickness black profile.

**Index map, South-Central KS & North-Central OK**

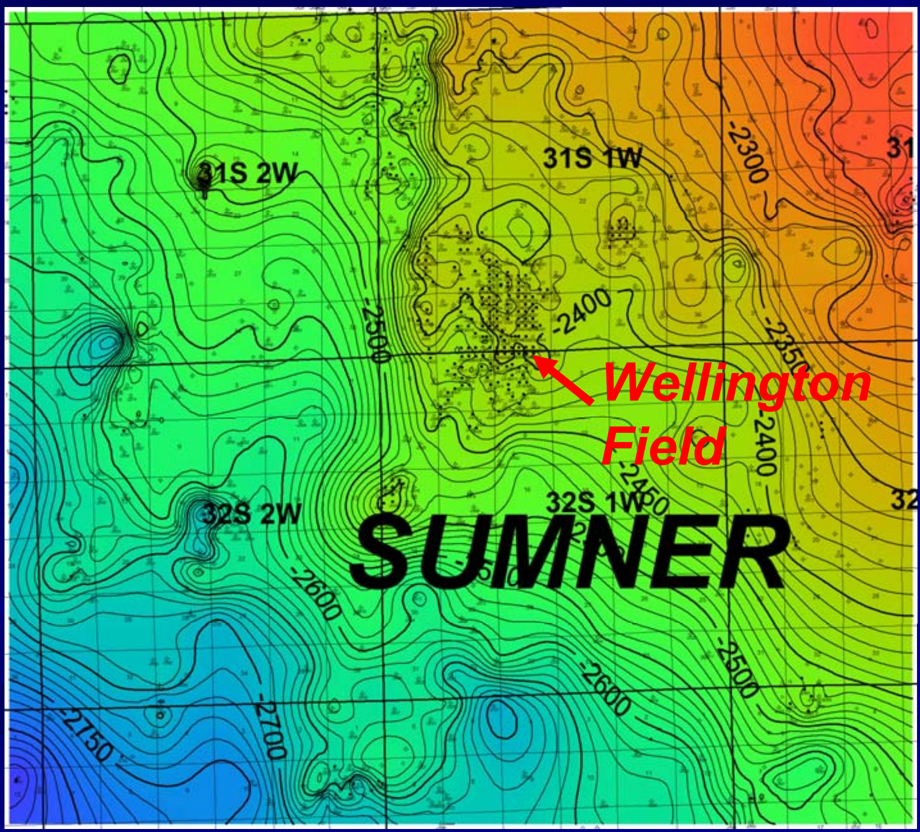


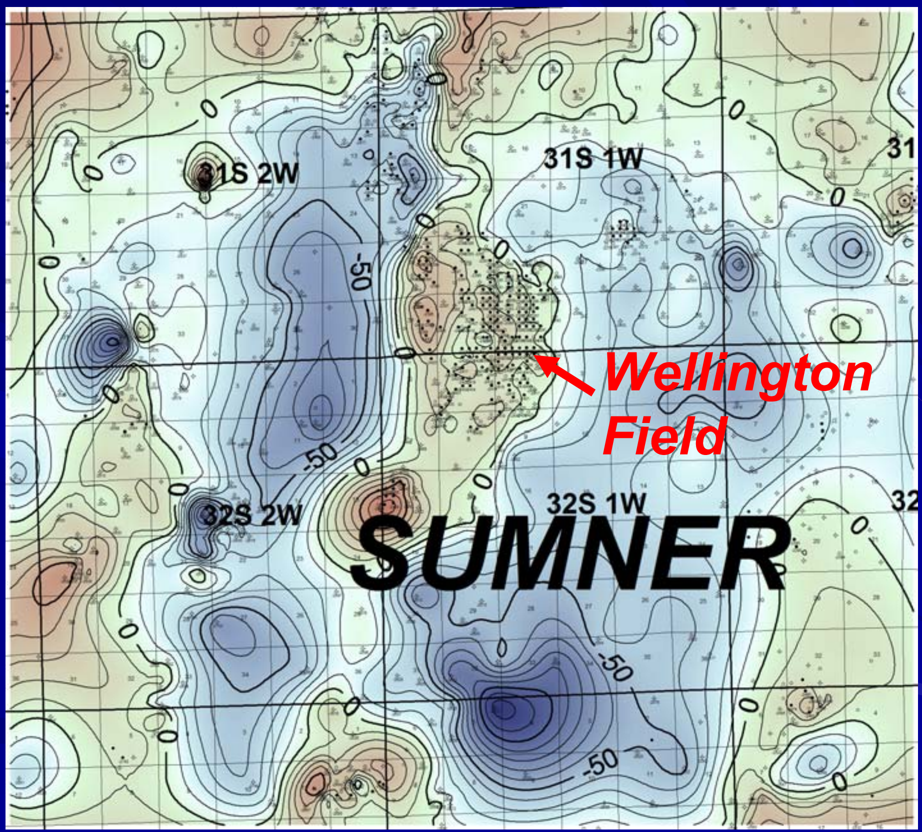

**All well data saved in <u>LAS 3.0 format</u>**

# Isolating sites for potential $CO_2$ sequestration through regional mapping

**Mississippian Subsea**
**25 ft C.I.**

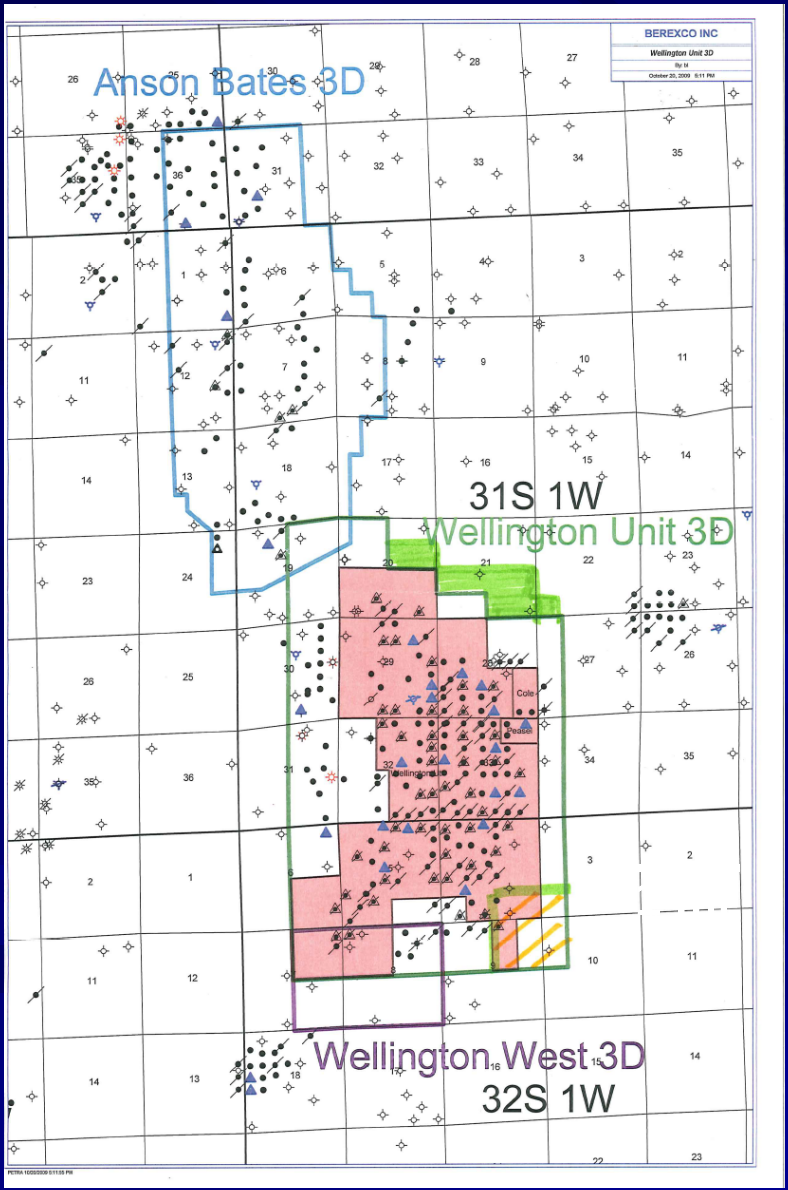
**3rd Order Residual of Mississippian Subsea**
**25 ft C.I.**

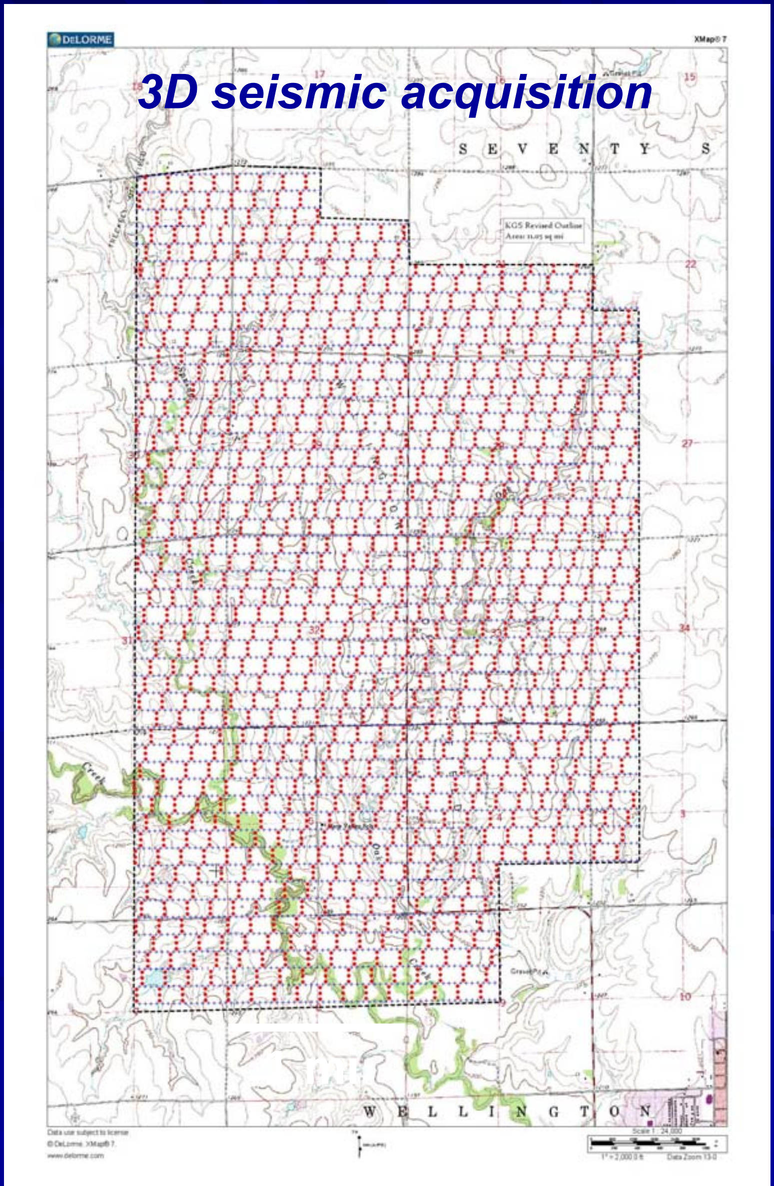


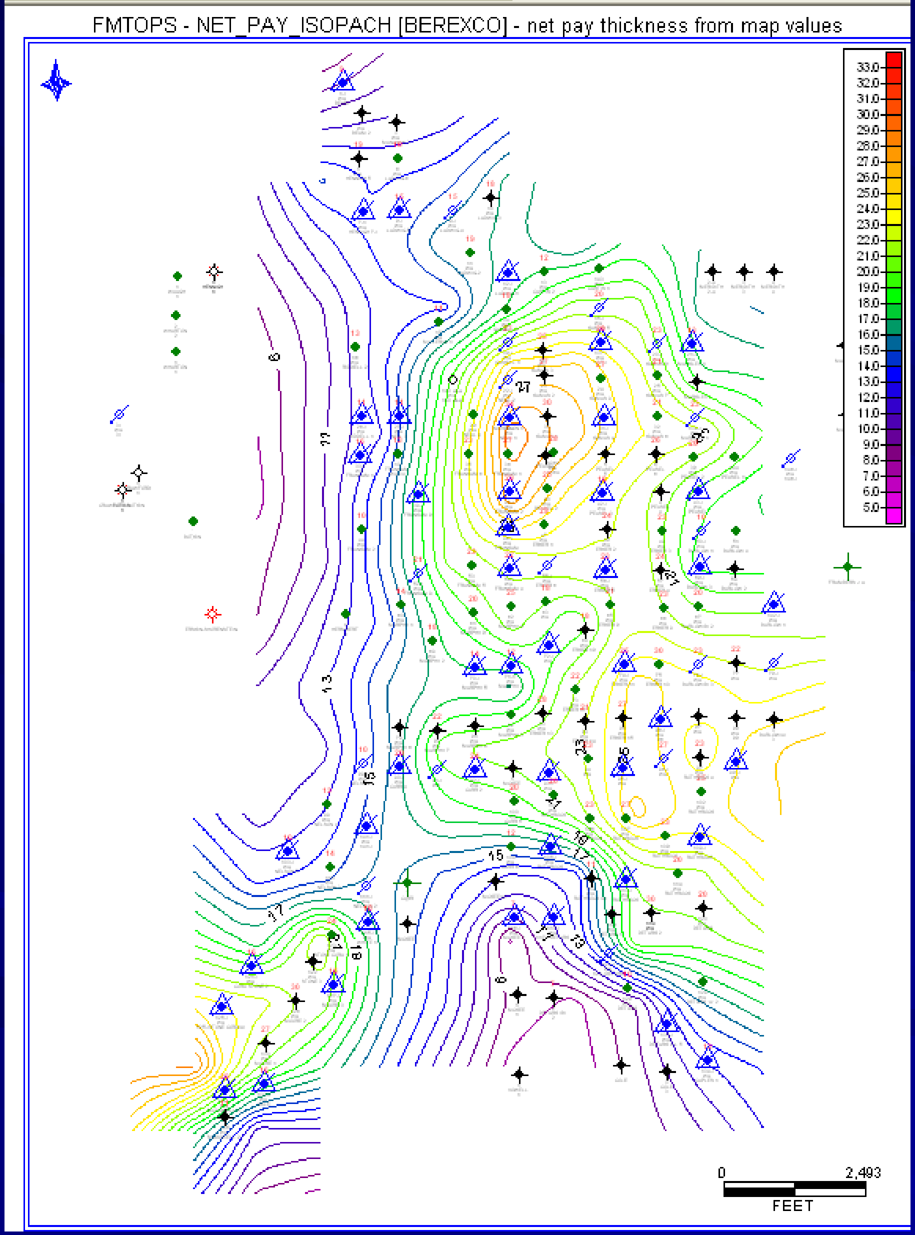

*3 mi.*

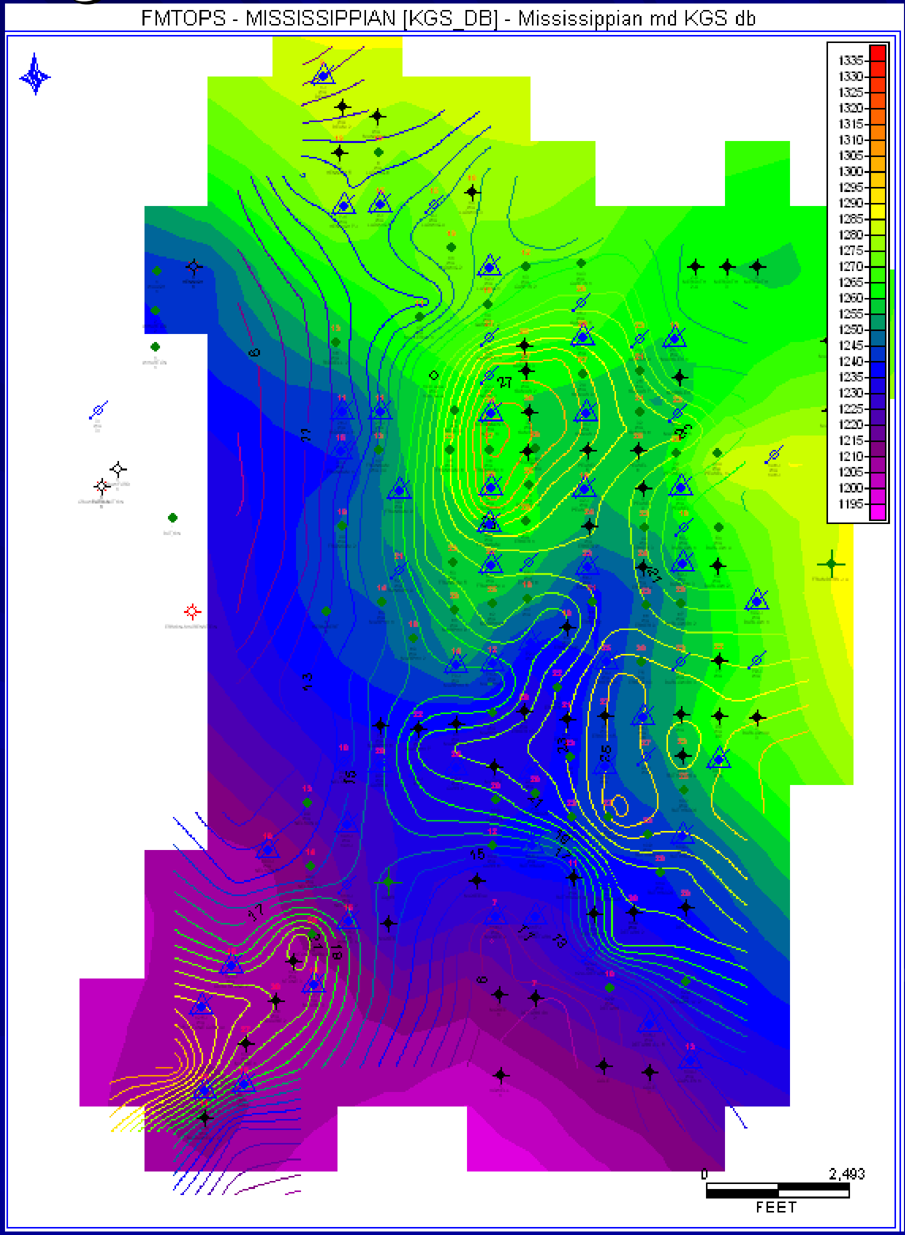
# 3D seismic completed (Paragon) – April 10, 2010
# High Resolution Gravity/Magnetic (Lockhart) - March & June, 2010
# 2D shear wave seismic (Lockhart) – June, 2010

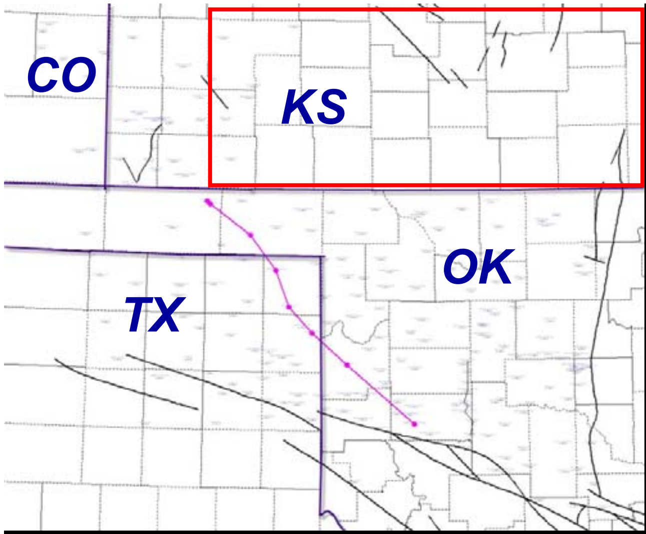


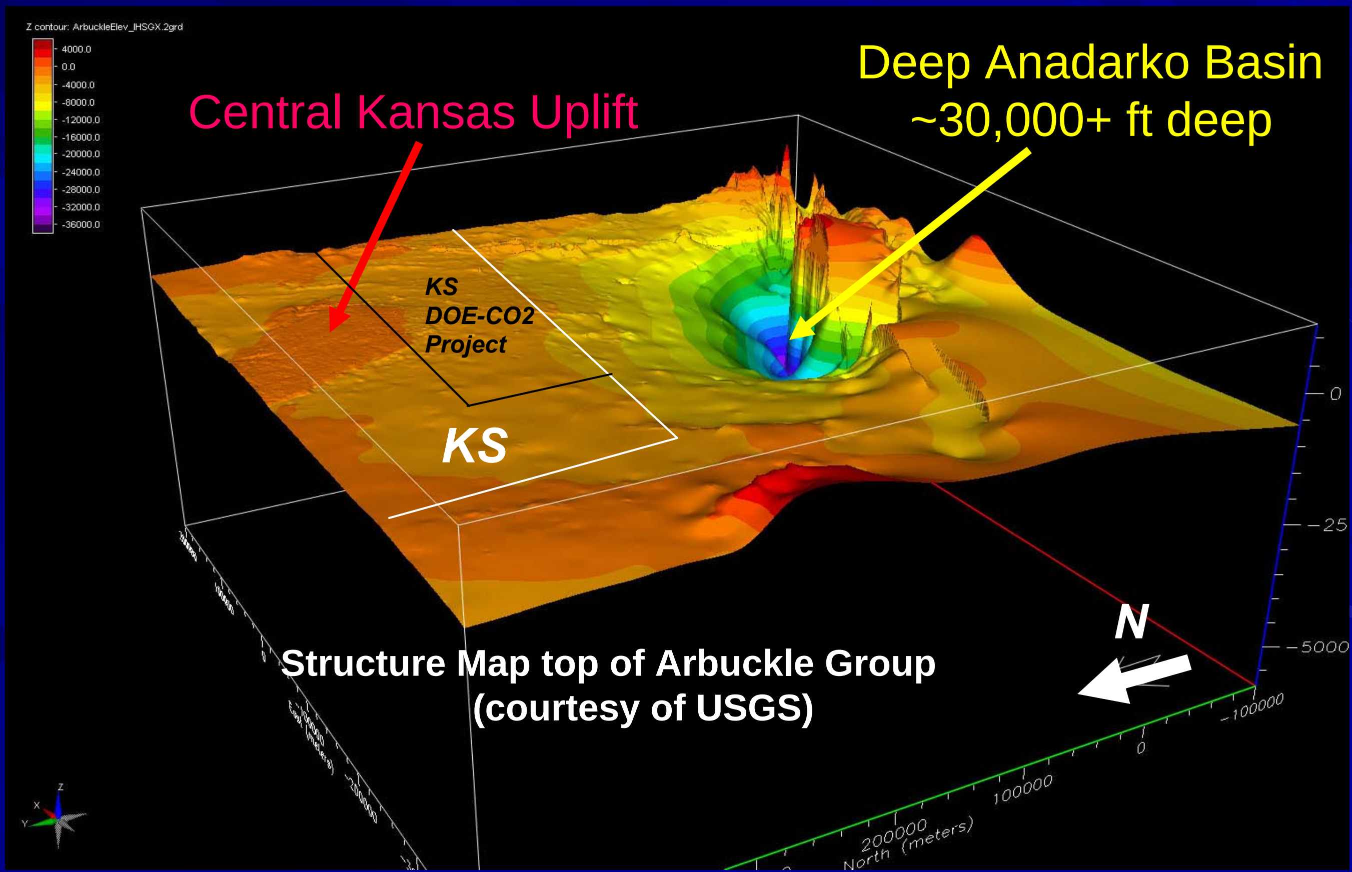
# Initial mapping of reservoir being studied for $CO_2$-EOR at Wellington Field






# Kansas’ DOE-CO2 project will utilize information from USGS’ Anadarko Basin Project, which has reached the first phase of completion




Structure Map top of Arbuckle Group (courtesy of USGS)

# Summary

- Evaluation of $CO_2$ sequestration potential requires an integrated, interdisciplinary effort.
- Estimating $CO_2$ capacity requires careful targeting of sites and quantitative characterization and dynamic modeling.
- Safety and risk analysis are vital components in sequestration projects to address environmental concerns.
- In Kansas, $CO_2$ sequestration may become a major activity offering economic benefits.