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

U.S. DEPARTMENT OF ENERGY

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Kansas Geological Survey
Lawrence, KS 66047

EPA Region 7 Spring UIC
State Representatives Meeting

KANSAS GEOLOGICAL SURVEY
The University of Kansas

Outline

We don't know all the answers - Project Start Date (Dec 09)

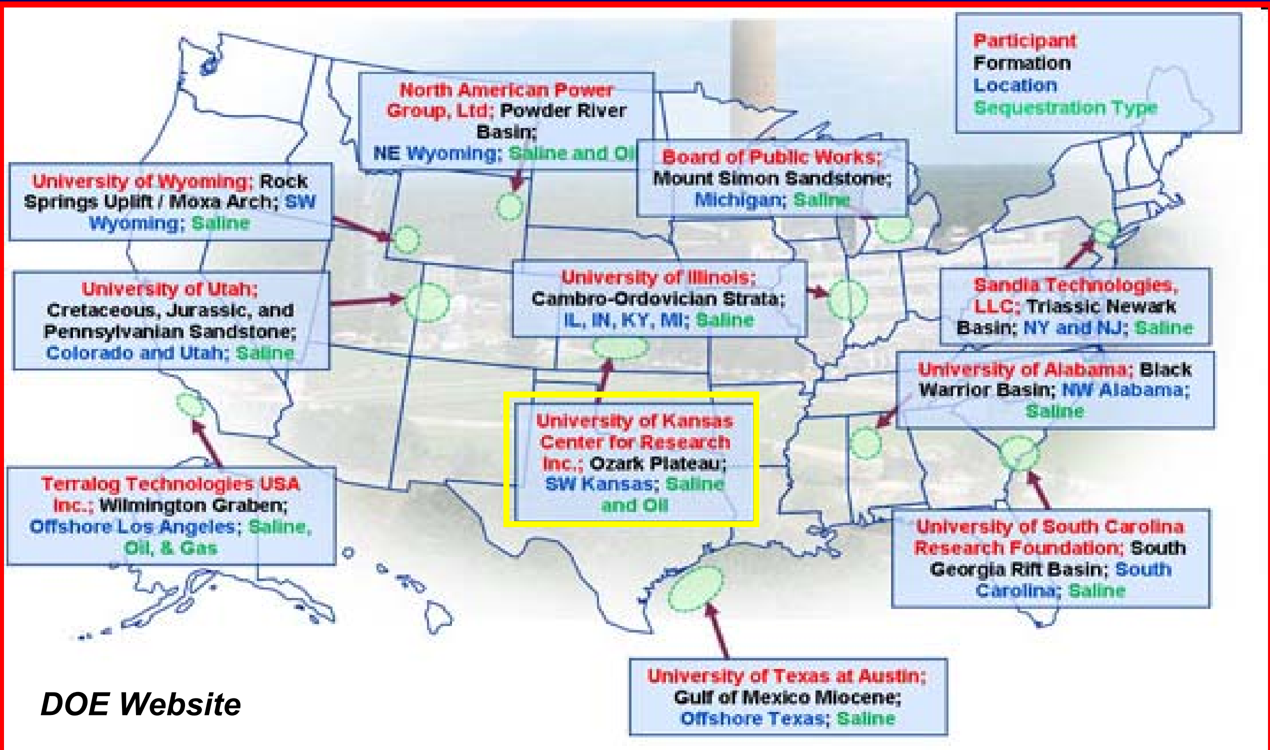
No CO_2 will be injected in this project.

Study Goal – Evaluate CO_2 Sequestration Potential in KS (deep saline)

- Overview - DOE-funded Project
- Relevance of CO_2 sequestration in Kansas
- Key Issues - Related to Geologic Sequestration of CO_2
  - Storage systems, Supercritical CO_2 injection, Fate of injected CO_2
    - Site selection for CO_2 sequestration
  - Ongoing Injection Projects
  - Leakage Pathways
  - Plume modeling
- Yaggy Gas Leakage/Explosion - Hutchinson
- Status of DOE-funded project
  - Data gathering – seismic, gravity-magnetics, well data
  - Geomodel development for 17+ county area
  - Geomodel development in Wellington Field in Sumner County

"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

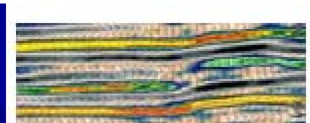
fairfieldnodal

LOCKHART GEOPHYSICAL

ECHO GEOPHYSICAL CORPORATION
INTEGRITY-STABILITY-INNOVATION

HALLIBURTON

HEDKE-SAENGER GEOSCIENCE, LTD



Bittersweet Energy Inc.

Charter Consulting
Integrated Geology & Geophysics

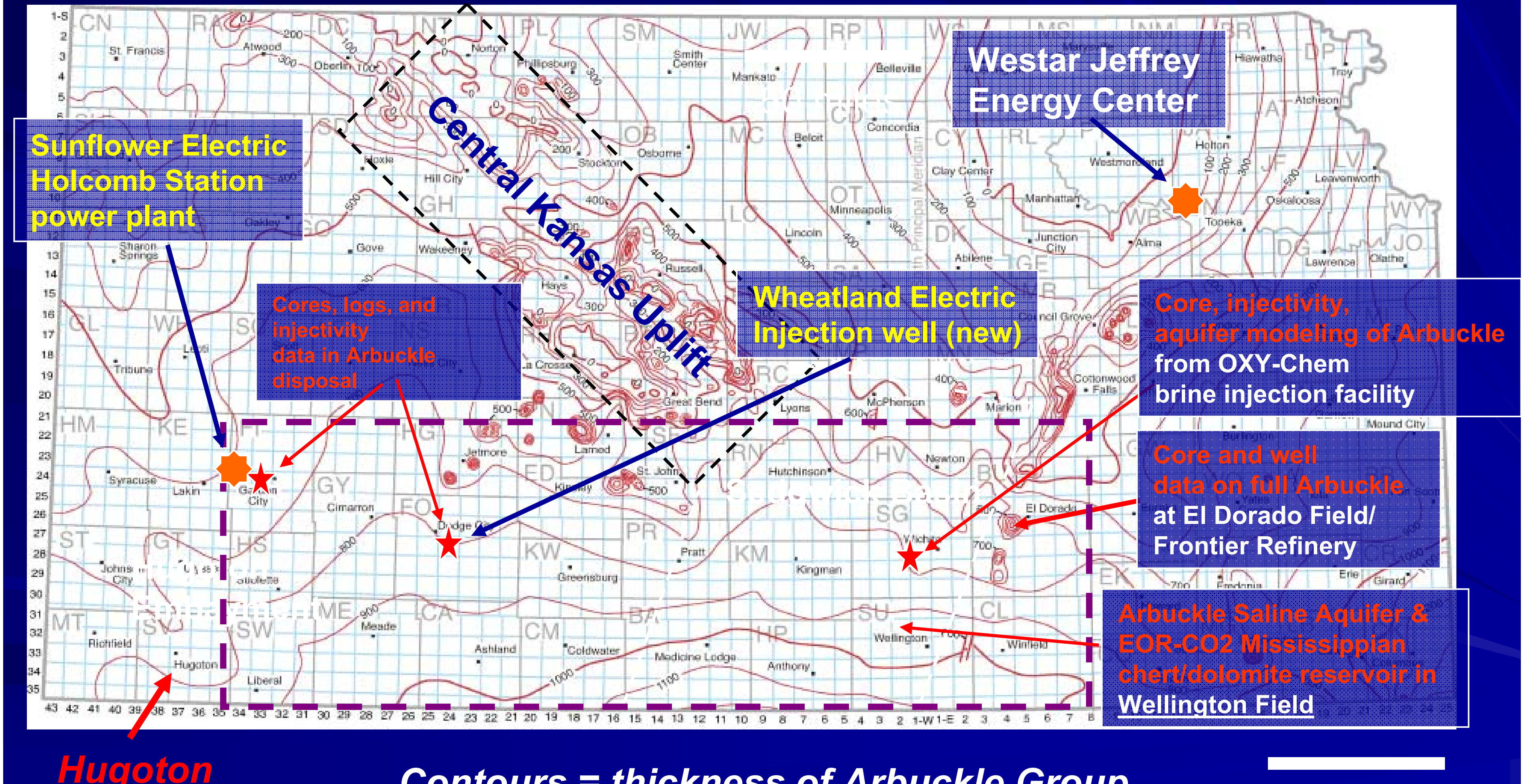
Petrotek

KOGER REMOTE SENSING

LOGDIGI
A LEADING CONSULTING COMPANY

DOE-CO2 Project Study Area

Wellington Field (Sumner County) + 17+ Counties

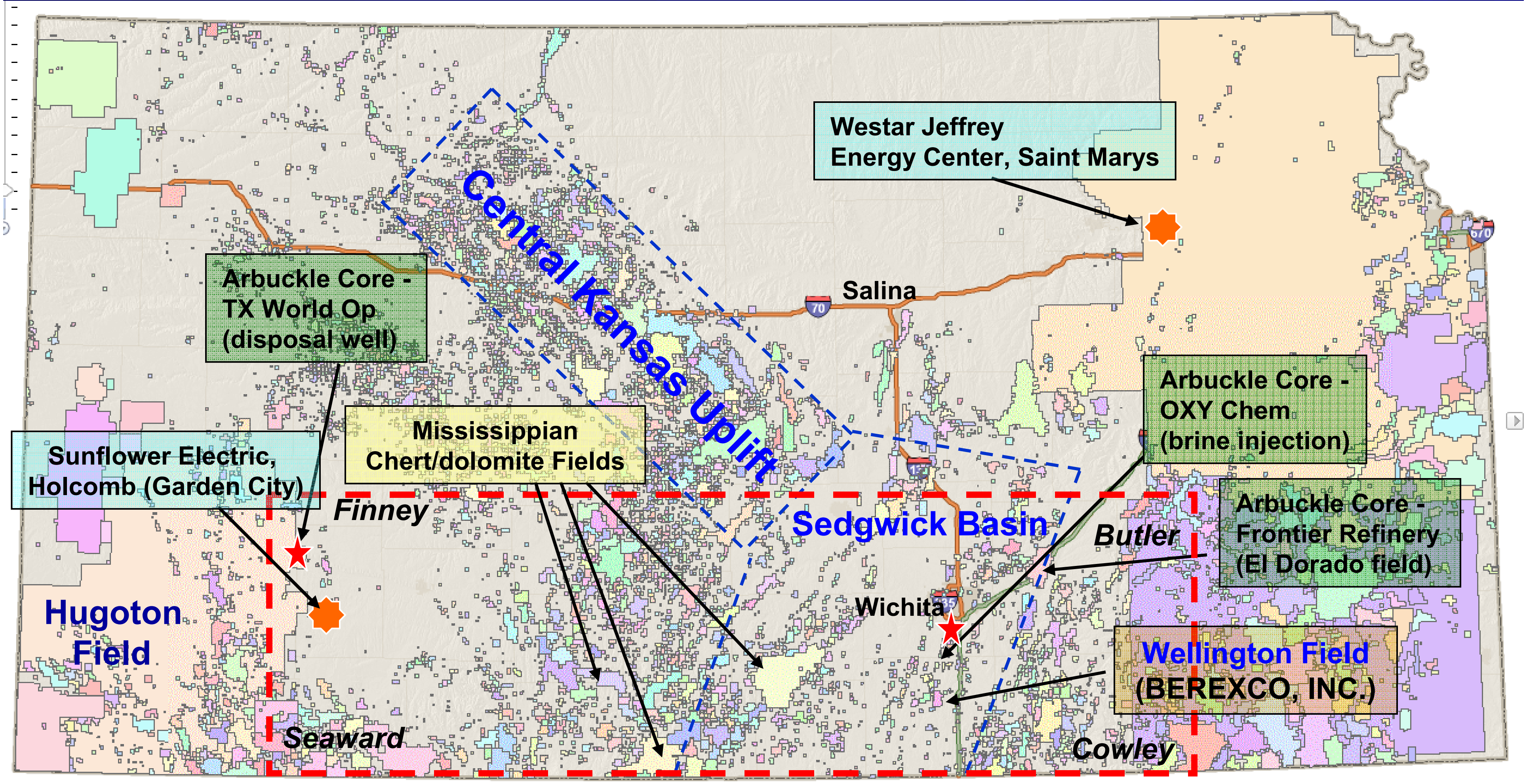


Contours = thickness of Arbuckle Group …thickest in southern Kansas

50 miles

Project Study Area with Oil and Gas Fields

Wellington Field (Sumner County) + 17 Counties

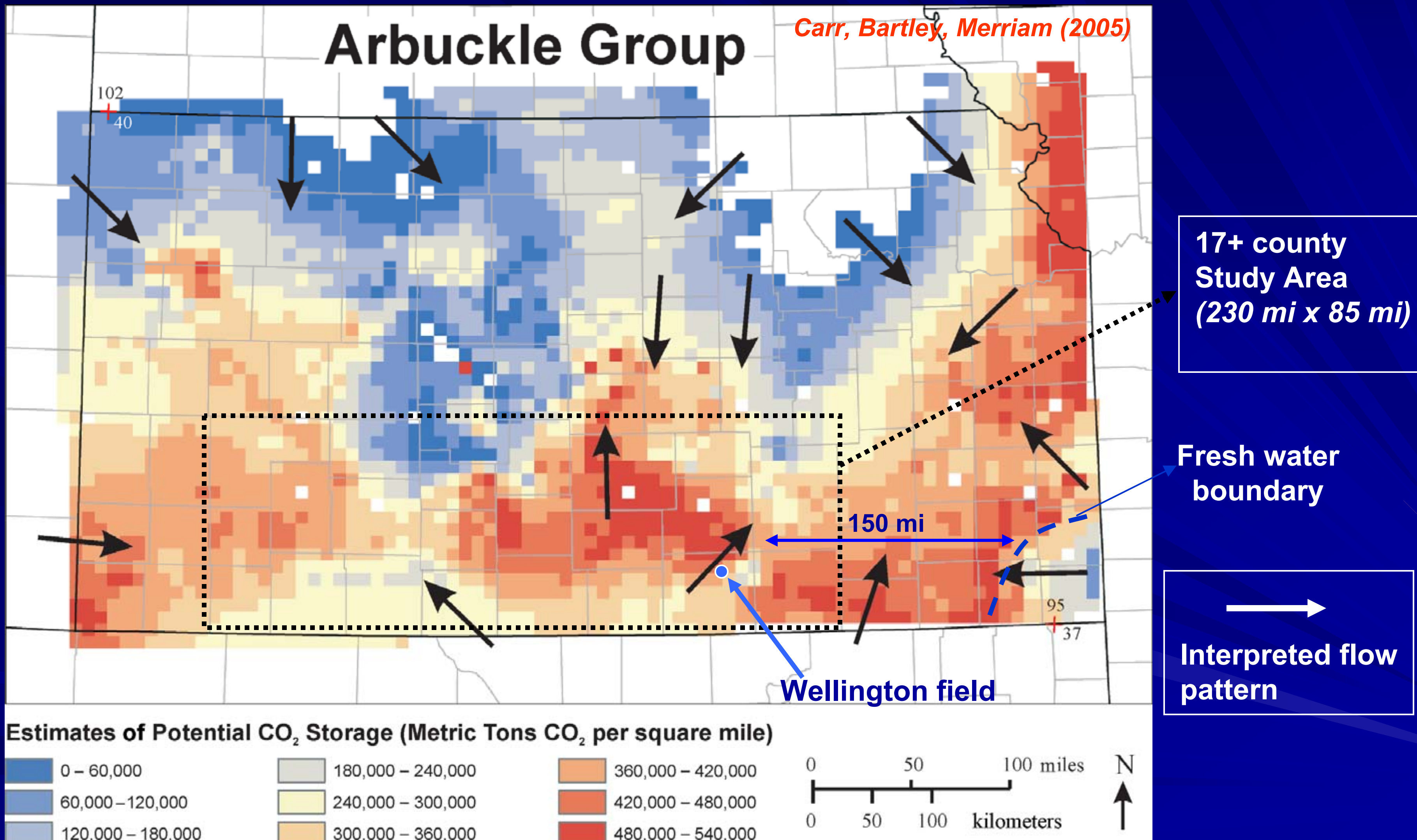


Regional study → ~20,000 sq. miles

50 miles

CO_2 Sequestration Target

Arbuckle Saline Aquifer



Red Areas – Sequestration capacity - at least 480,000 metric tons/mi^2

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

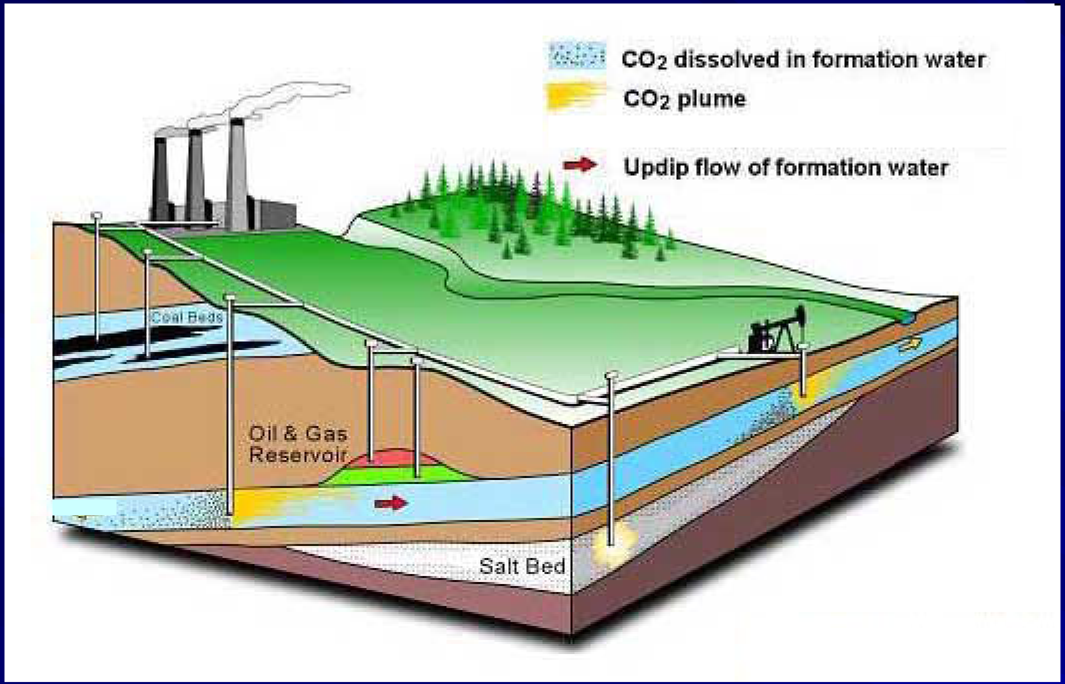
CO_2-Seq Potential - Wellington

CO_2 Seq Potential - Arbuckle 17+ Counties

Relevance of CO_2 Sequestration in KS

- 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



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

Global annual CO_2 emissions ≈ 8 * 10^9 tons

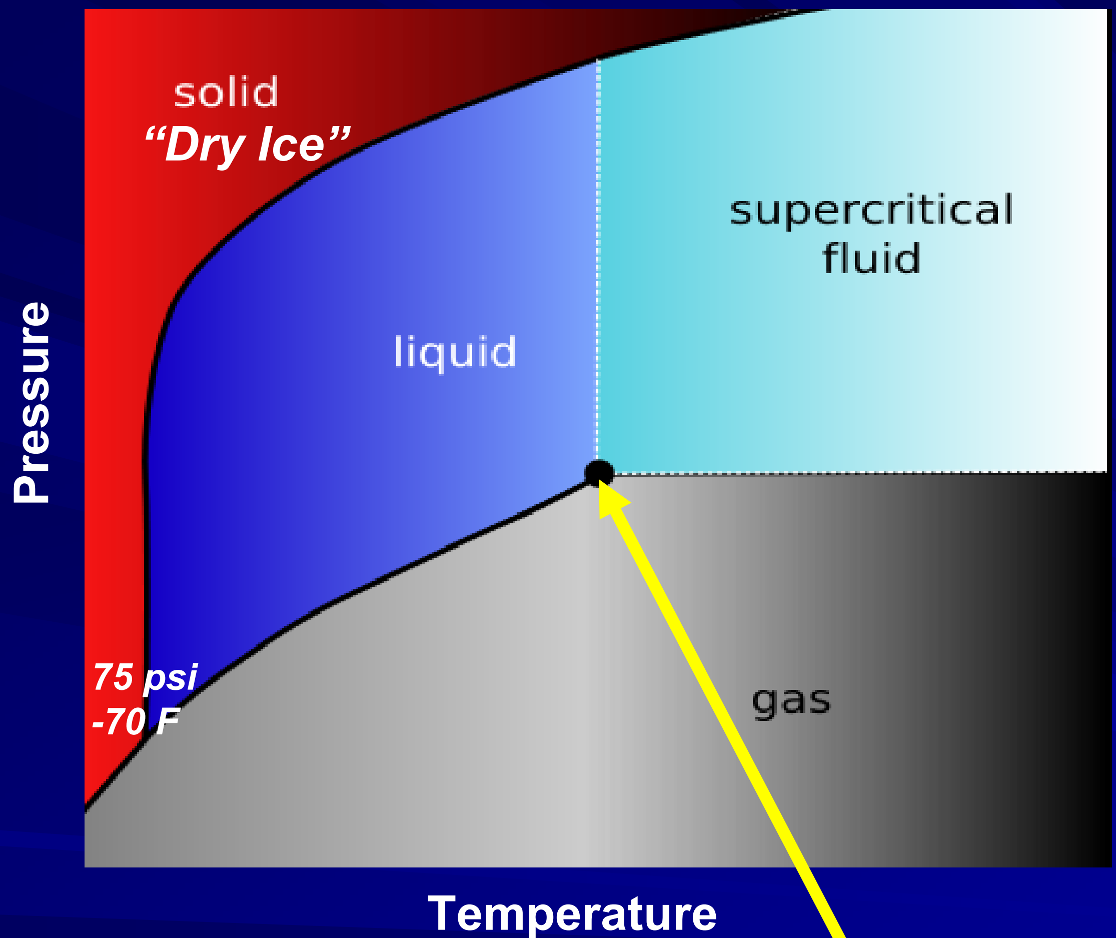
Earth Policy Institute

>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 - properties midway between gas and liquid

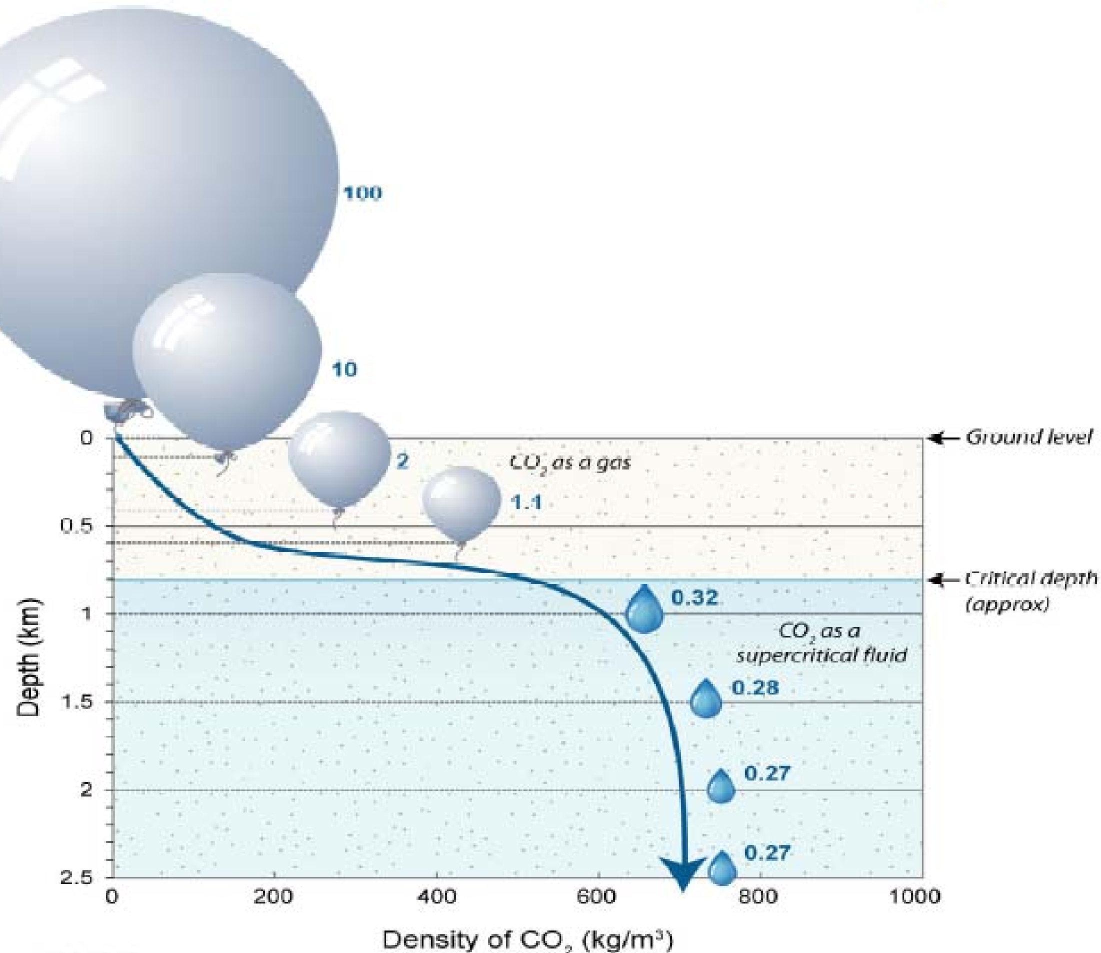
- Expands to fill a container like gas
- Has density like liquid
  - ρ ~ 0.5 g/cc
  - brine ρ >1 g/cc
- Viscosity order of magnitude less than oil and water

CO_2 becomes a supercritical fluid - > 1071 psi, 87.8F

Wikipedia

Effectiveness of Injecting Supercritical CO_2

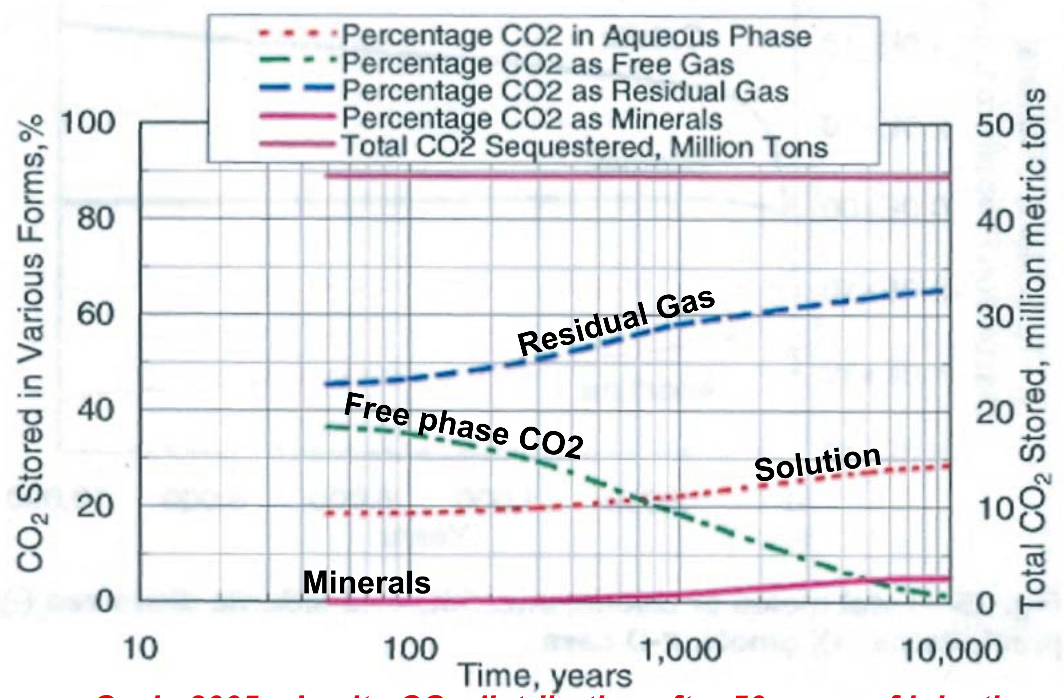
CO2 storage effectiveness increases with depth



In situ fate & entrapment of CO_2

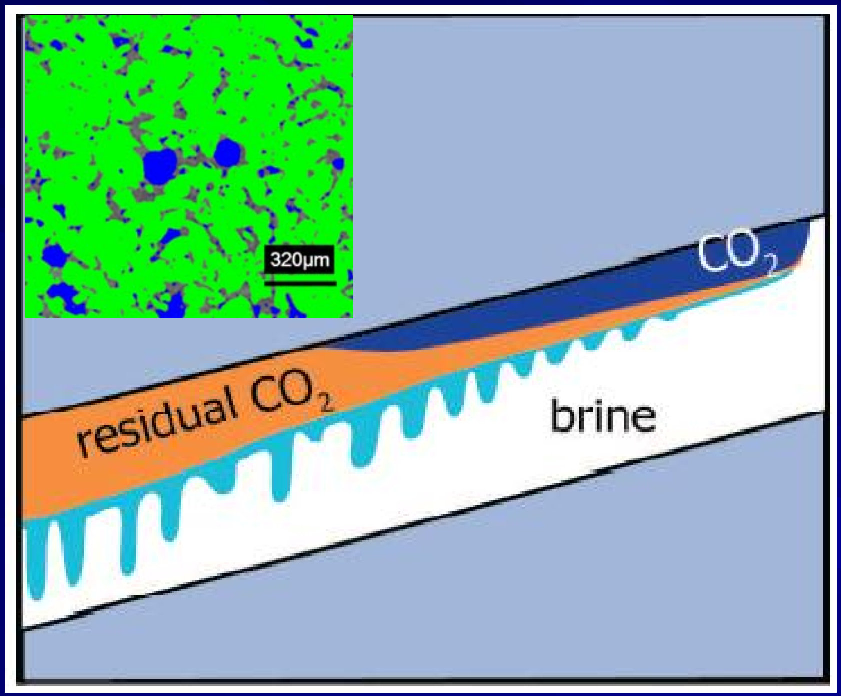
Injected CO_2 entrapped in 4 different ways

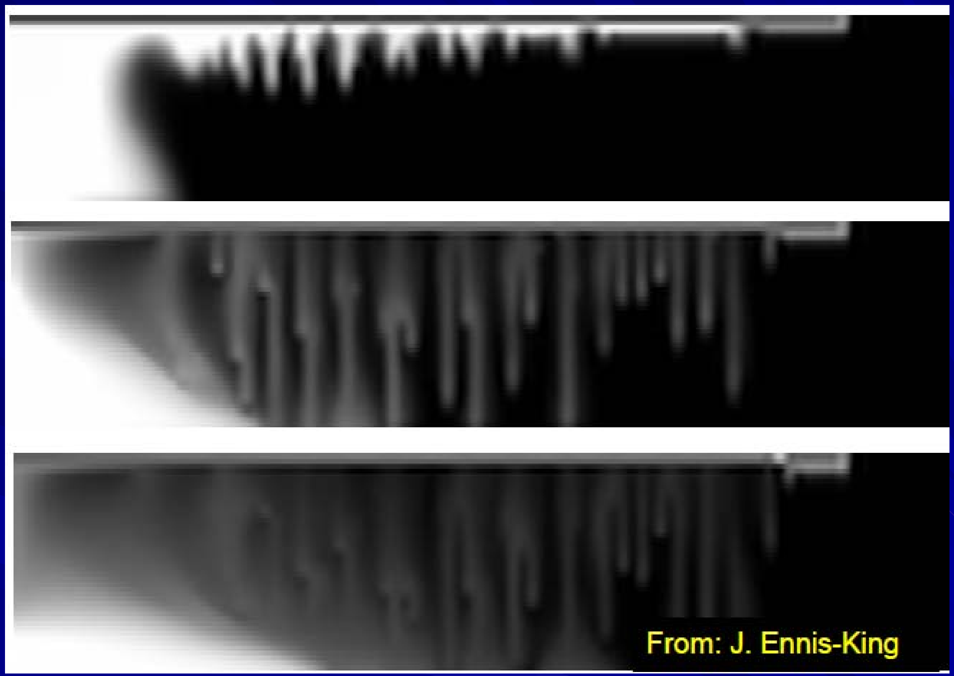
- **some dissolves in brine**
- **some gets locked as residual gas (saturation)**
- **some trapped as minerals**
- **Remaining CO_2 – resides as free phase**
  - **Sub- or super-critical as per *in situ* conditions (depth/pressure and temperature)**



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

Dissolution of CO_2 in Brine
Convection Cycle

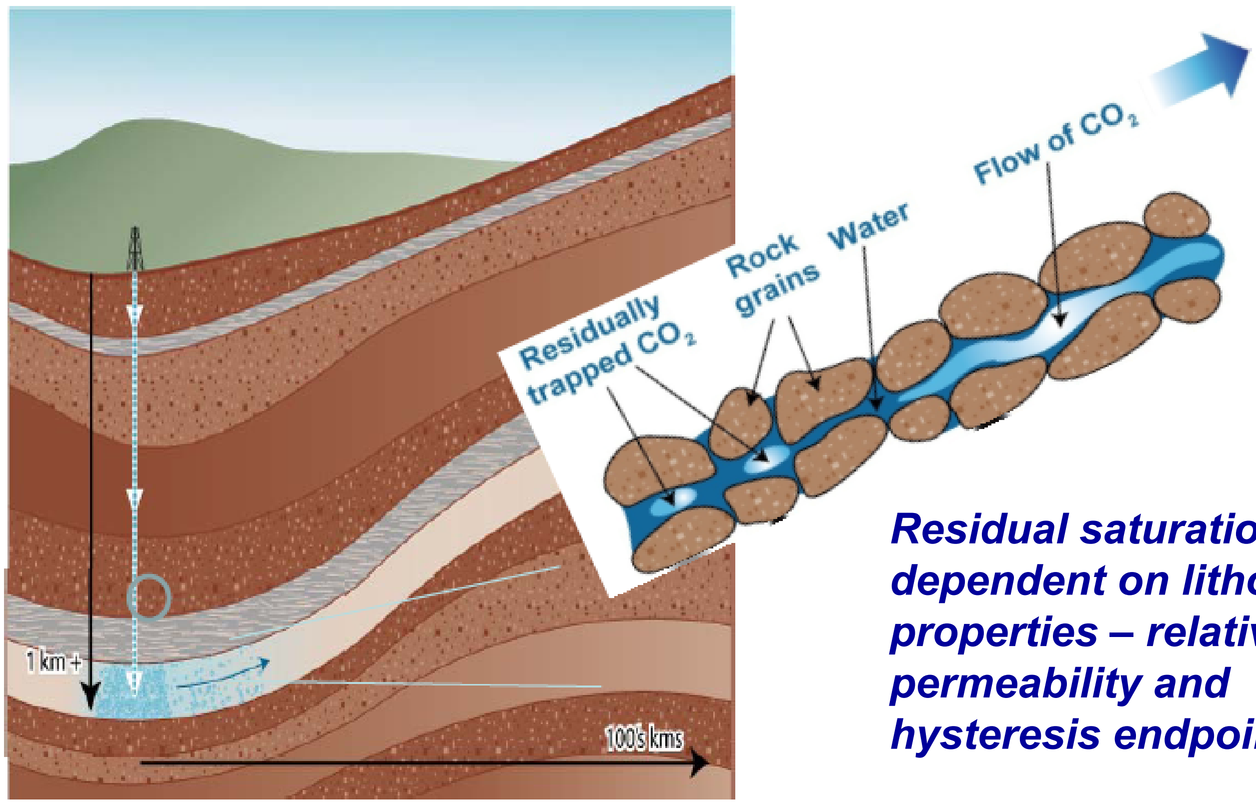




CO_2 Entrapment as Residual Gas

IEA Greenhouse Gas R&D Programme

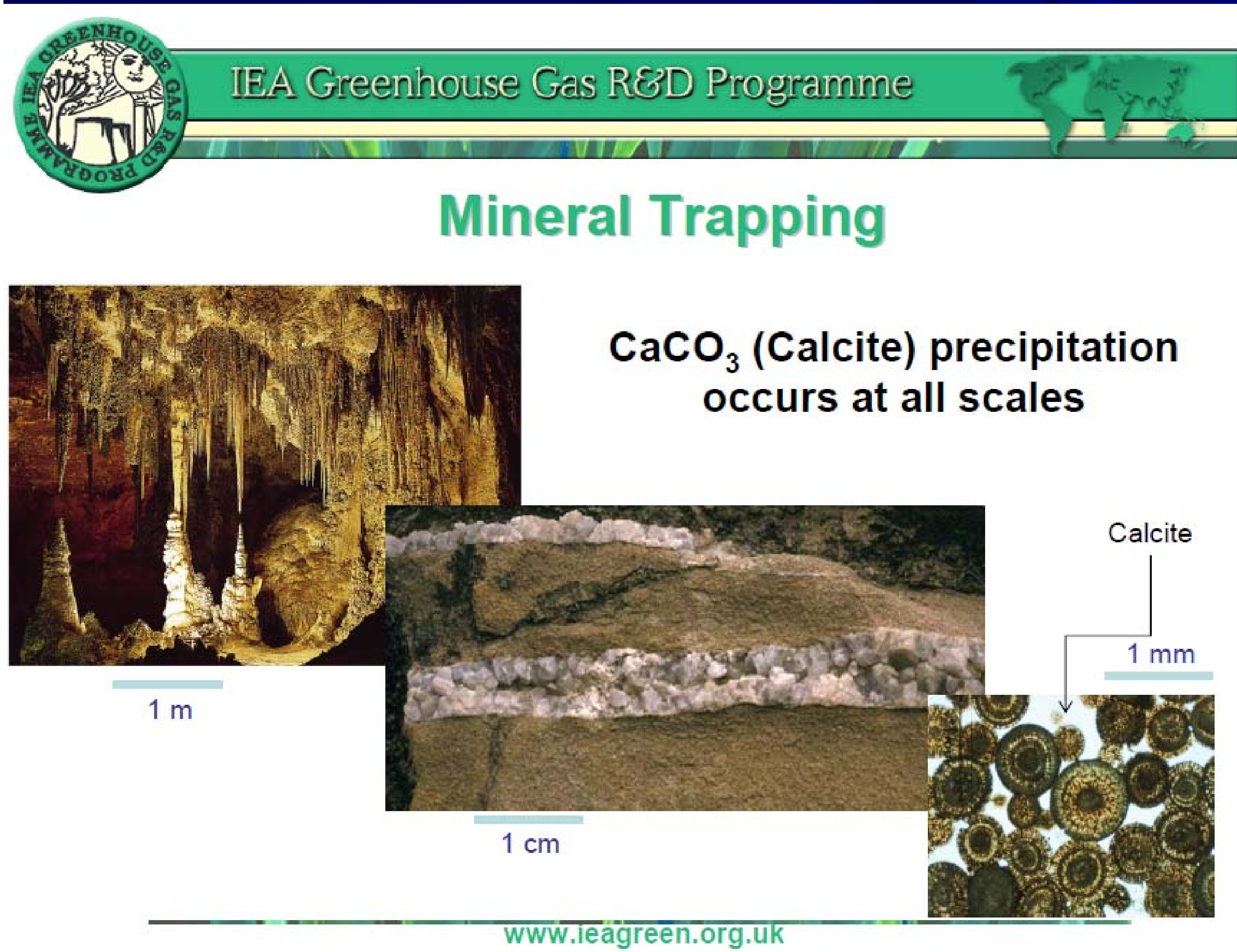
Residual Trapping



Residual saturation dependent on lithofacies properties – relative permeability and hysteresis endpoints

www.ieagreen.org.uk

CO_2 Entrapment as Minerals



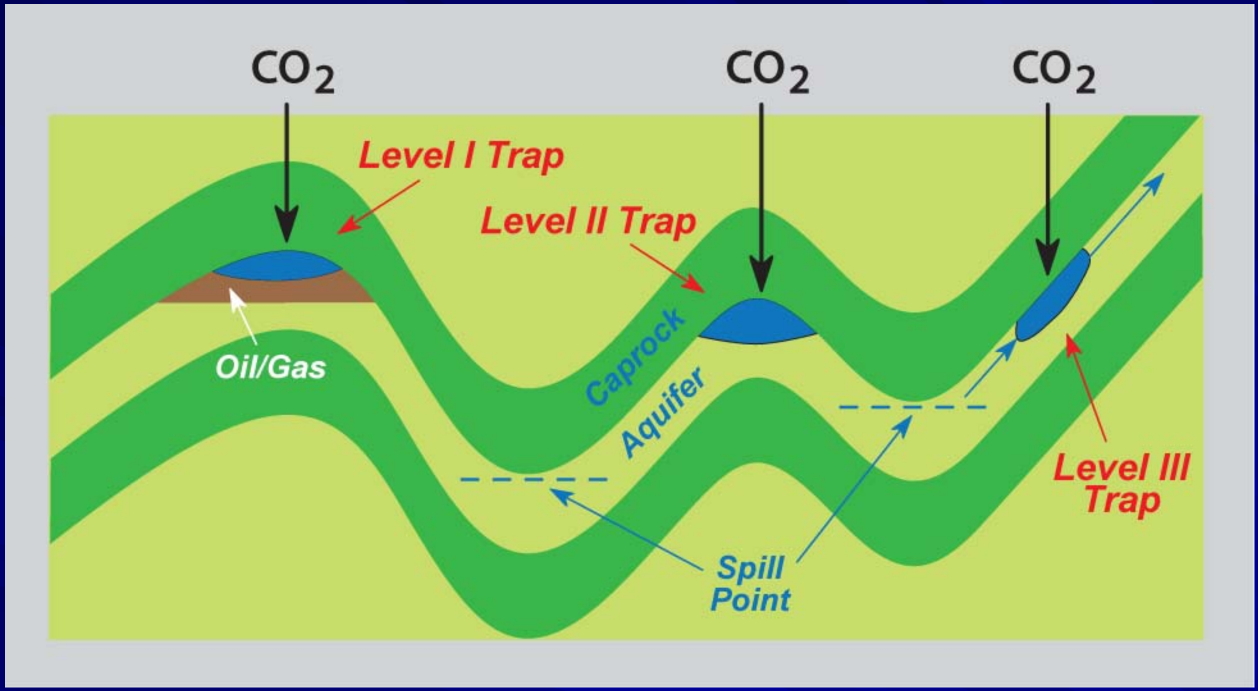
Very slow process.

Important effects –

1) *Precipitation leading to injectivity changes.*

2) *Dissolution and creation of cavities*
   -- Adversely affect integrity of the caprock.

CO_2 Injection Strategies

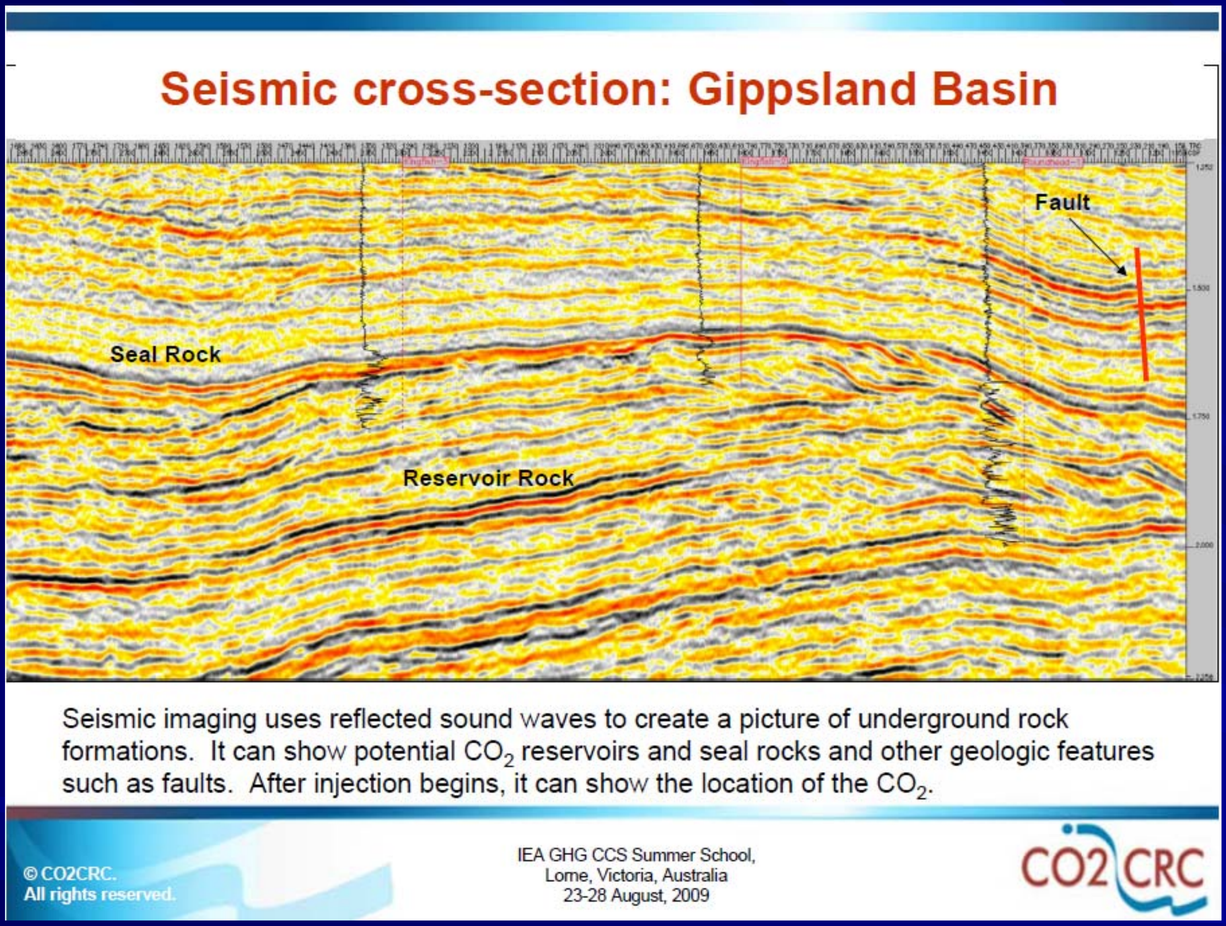


Level I Trap – solubility in oil and water, CO_2 pressure under cap rock, plume contained, CO_2 breakthrough at producing wells

Level II Trap – solubility in brine (convection), CO_2 pressure under cap, plume contained – HIGH RISK

Level III Trap – solubility in brine (convection), entrapment as residual gas, upward migration and attenuation of plume – LOWER RISK (in absence of conduits to surface)

Potential Sites for CO_2 Sequestration



- Gently dipping synclines

-Laterally continuous and competent seal

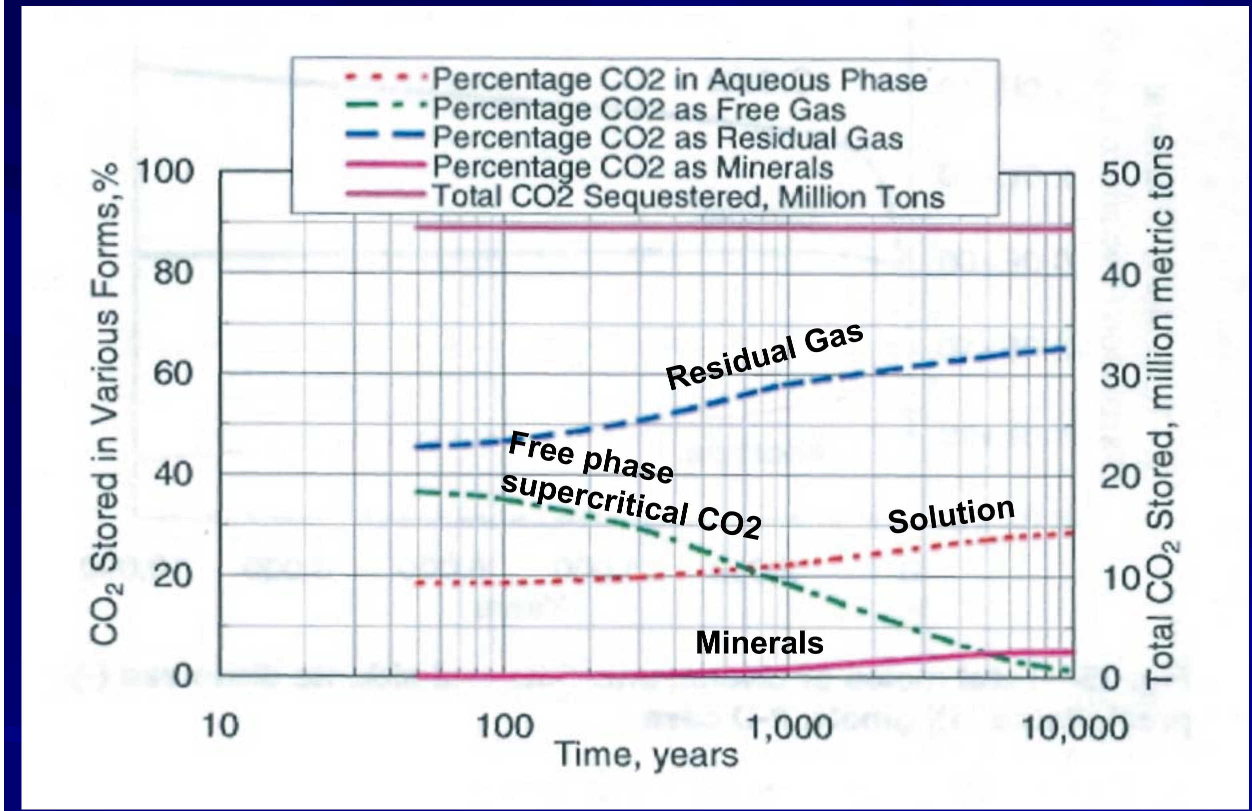
-Possible conduits to surface identified and remedial action taken

  - Avoid Faults/fractures,

  - Plug improperly abandoned wells

In Situ Fate & Entrapment of Injected CO_2
During monitoring phase

Homogeneous Reservoir Model



<u>CO_2 Entrapment Audit:</u>

1. Residual gas

- Start 45% to End 65%

2. Solution

- Start 18% to End 28%

3. Minerals

- Start negligible to End 5%

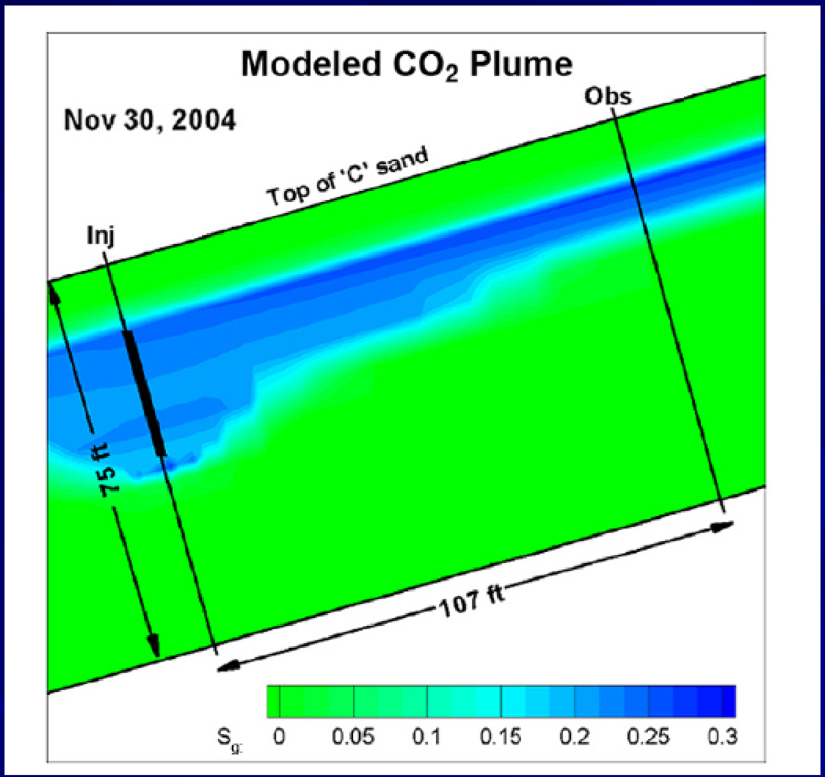
4. Free Phase

- Start 37% to End 2%

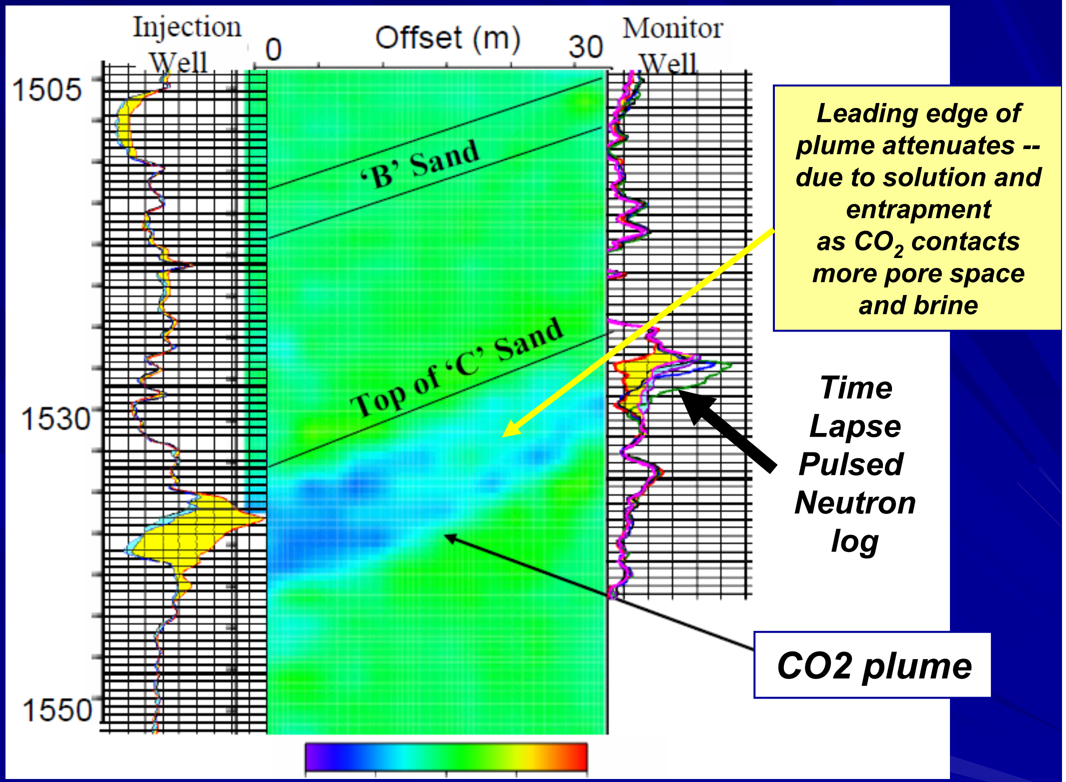
Ozah, 2005 – In situ CO_2 distribution after 50 years of injection

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

Plume from Simulation



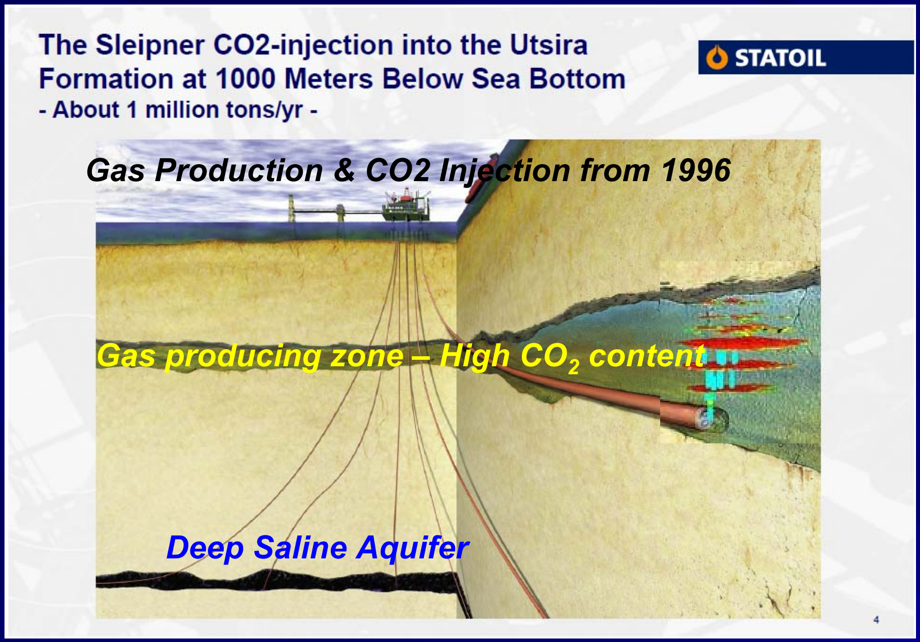
Plume from cross-well seismic tomogram

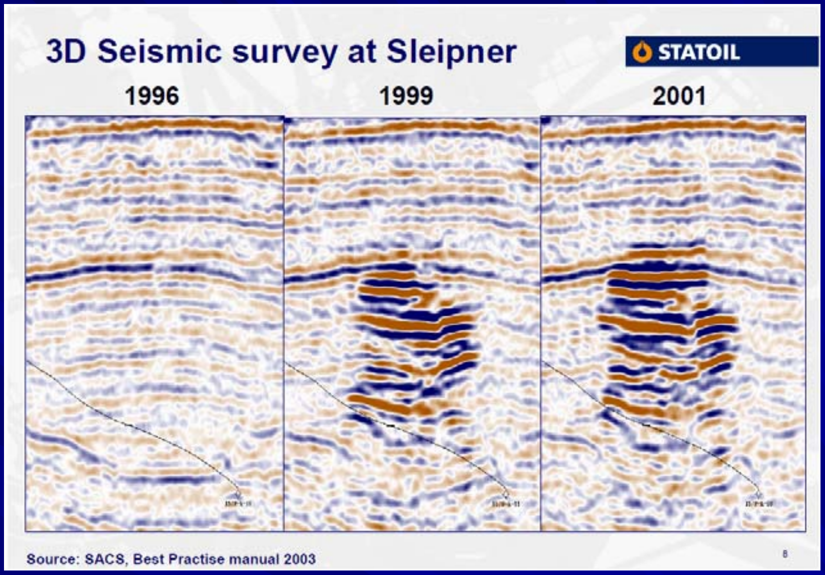


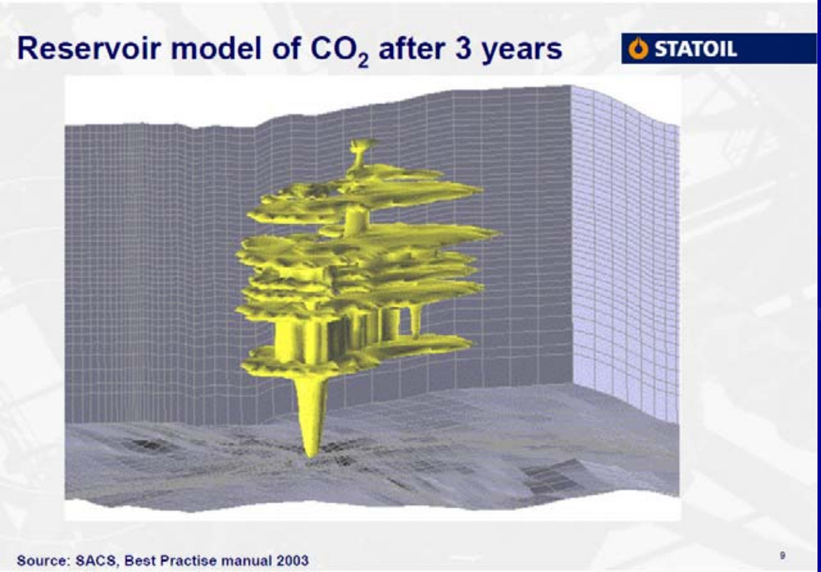
Current tools (geologic modeling, reservoir simulation, wireline logging, 3D seismic) are capable of tracking subsurface CO_2 migration.

Hovorka et al., 2006, 4-20-06 NETL Fact Sheet & Daley et al., 2007

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



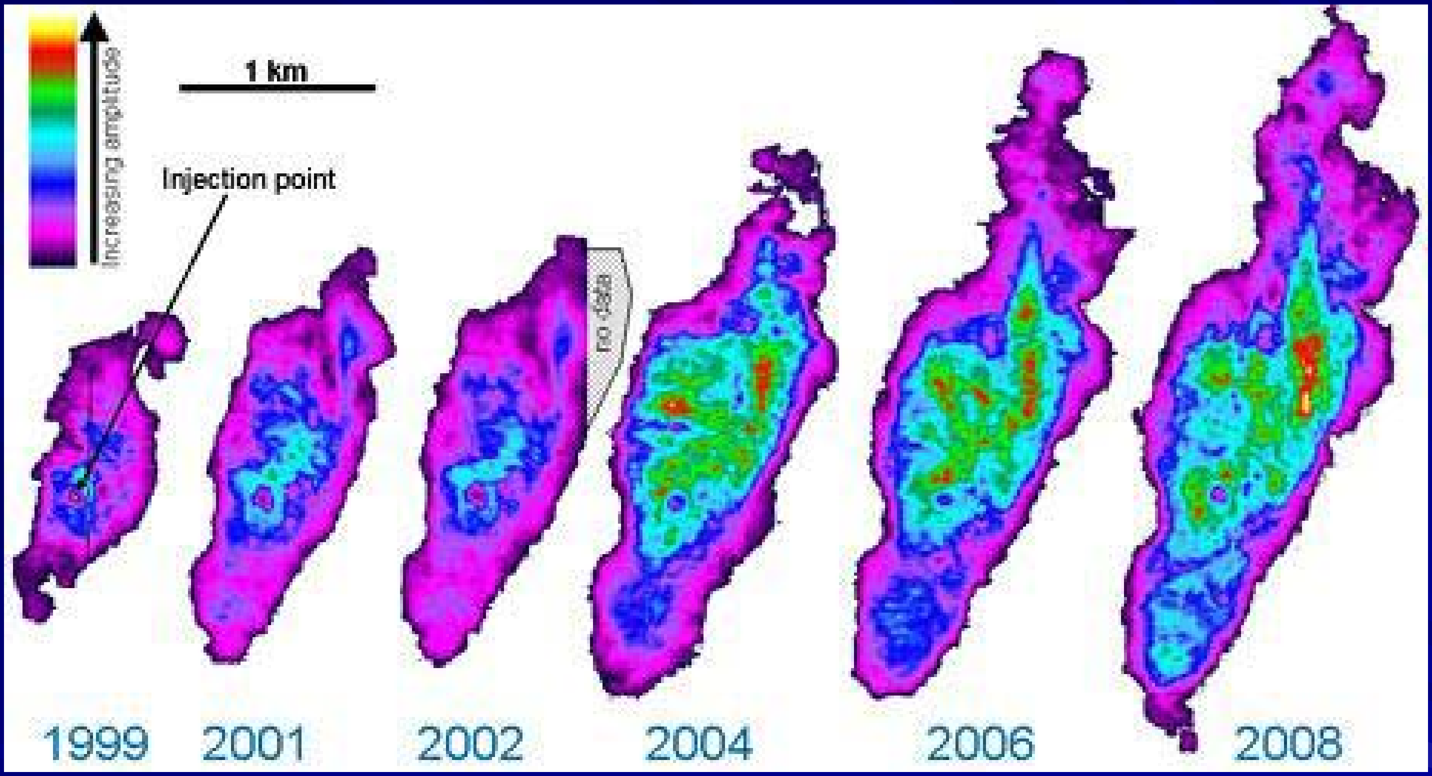




Every time the CO_2 plume meets a thin shale layer (< 5 m), it spread out laterally. This lateral dispersion results in additional sequestration and plume degradation - CO_2 dissolving into fresh brine and getting trapped in fine pores of the rock. *Torp & Gale, 2003*

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

Over 10 million metric tons of CO_2 have been stored in the Utsira formation since the project was started in 1996. Current area covers ~3 km^2 (1.2 mi^2) of roughly 26,000 km^2 (10,000 mi^2) available

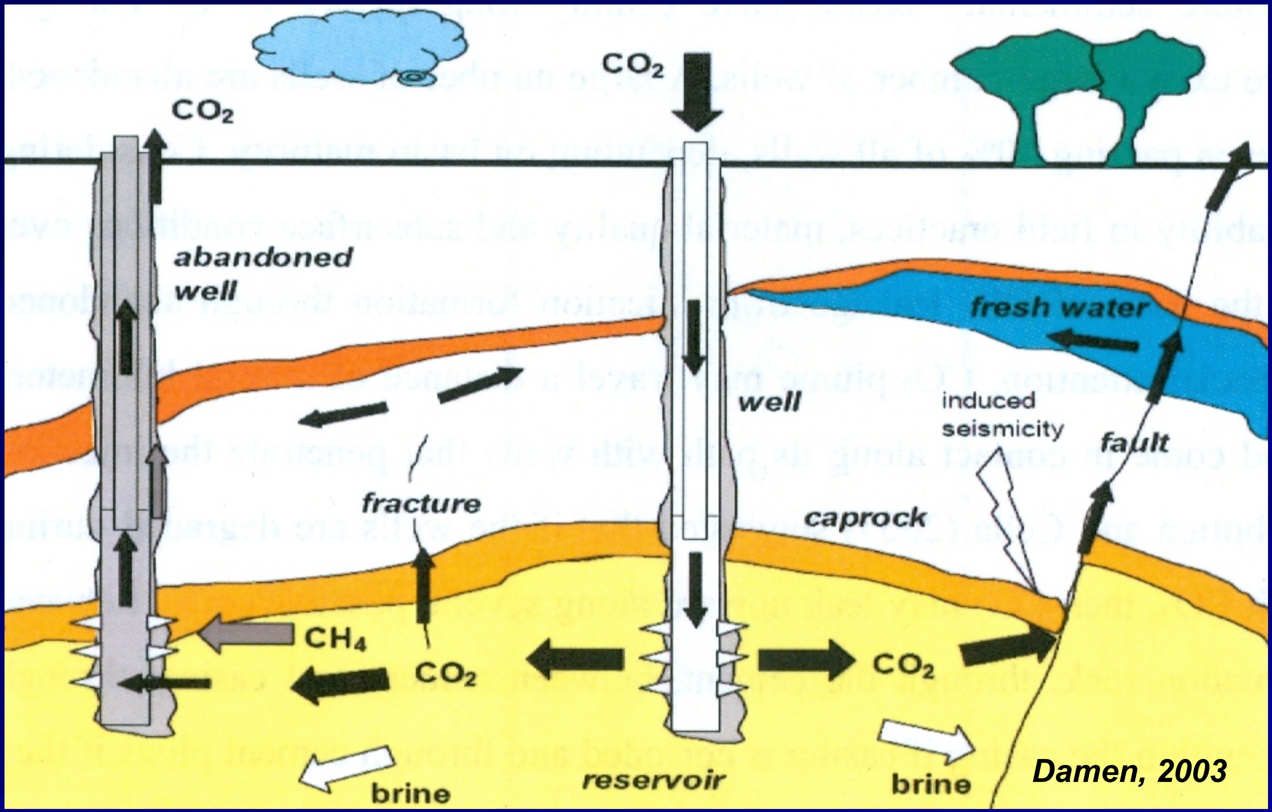


The Utsira Formation is a 200-250m thick massive sandstone formation located at a depth of 800-1000m beneath the seabed.

Color scale reflects increasing seismic amplitude ~vertical summed thickness of CO2 in sandstone

Leakage Pathways

Conduits 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

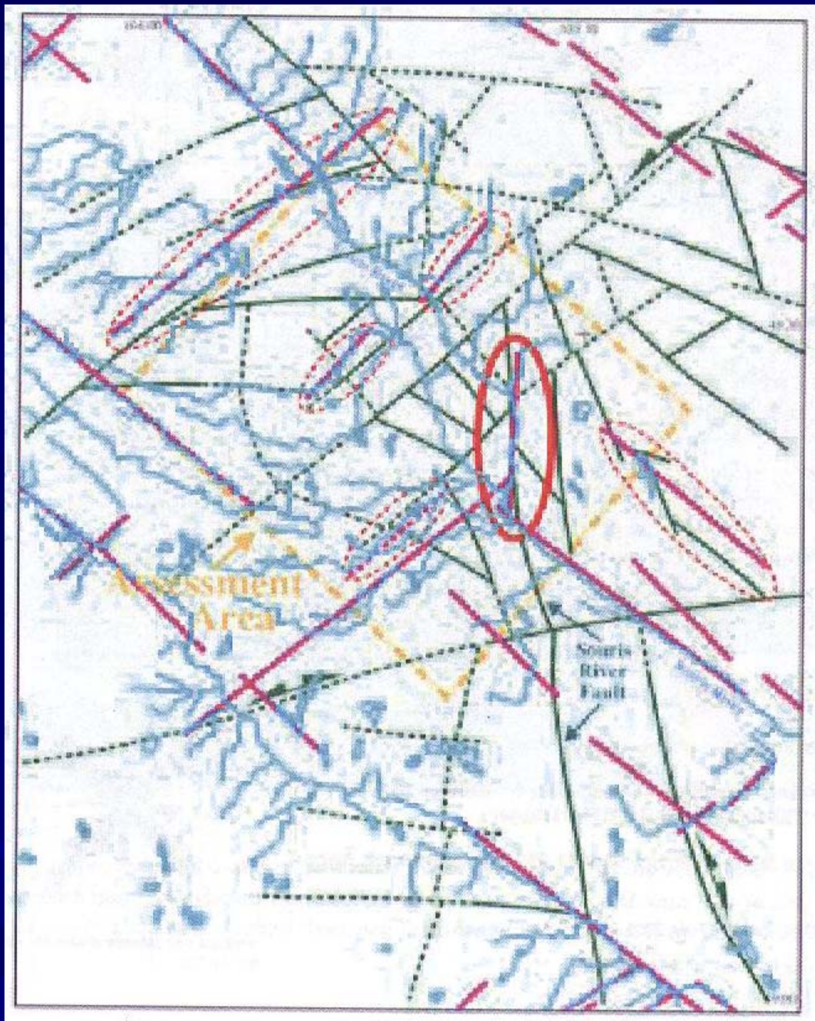
Site selection critical to minimize risks associated with CO_2 injection
Not all fractures/faults reach the surface – some do and need to be identified
Inventory of all plugged wells critical – REPLUG if needed.

Weyburn CO_2-EOR - Canada

- **Sep 2000** – CO_2 from gasification plant (N. Dakota) transported by 350 km pipeline & injected into Weyburn oilfield (Saskatchewan, Canada)
  - Weyburn – 50 yr depleted oil field
- Expected performance of CO_2-EOR **by 2035**
  - 155 million gross barrels of incremental oil recovery
  - Sequestration of 30 million tonnes of CO_2
- **Oct 2005** – CO_2 injection began at adjacent Midale oilfield
  - Expect 45-60 million barrels of incremental oil recovery

http://www.netl.doe.gov/publications/factsheets/project/Proj282.pdf

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

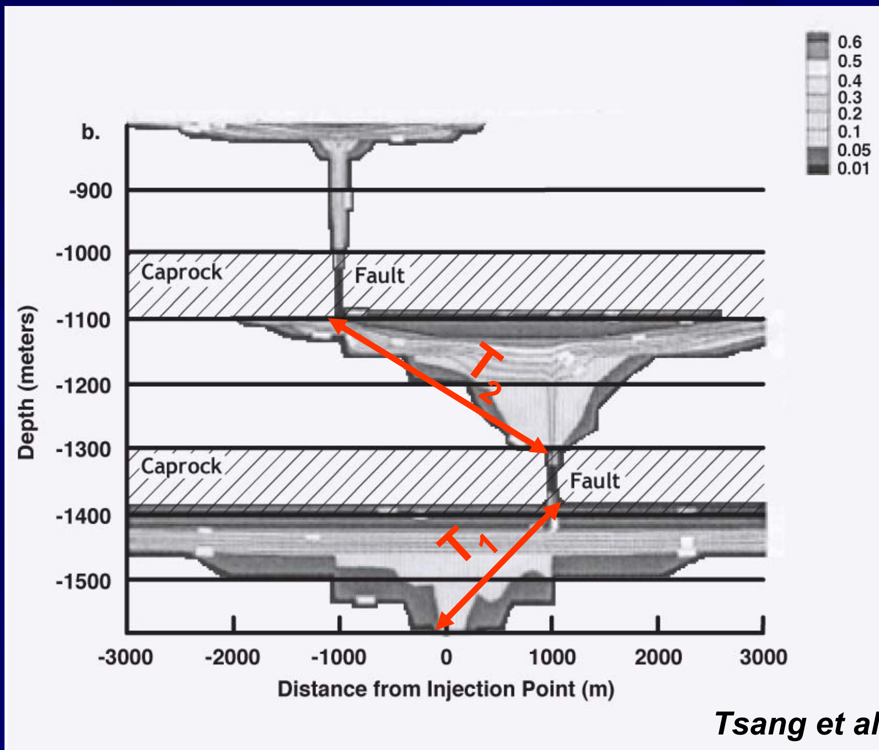
Purple* – *surface lineaments

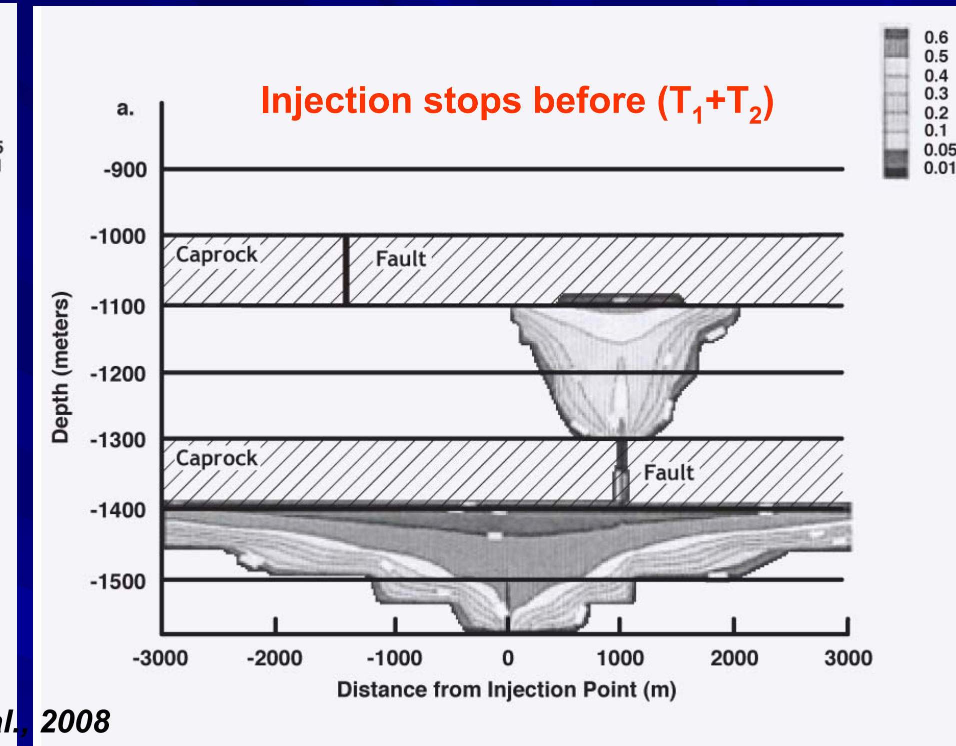
Red oval* – *Souris Valley fault (fault identified by seismic and HRAM coincide)

Broken Red* – *weak correlations between data sets

Not all sub-surface faults/fractures reach the surface

Plume Modeling
Plume Breaches Cap Rock via Fault/Weak zone





Tsang et al., 2008

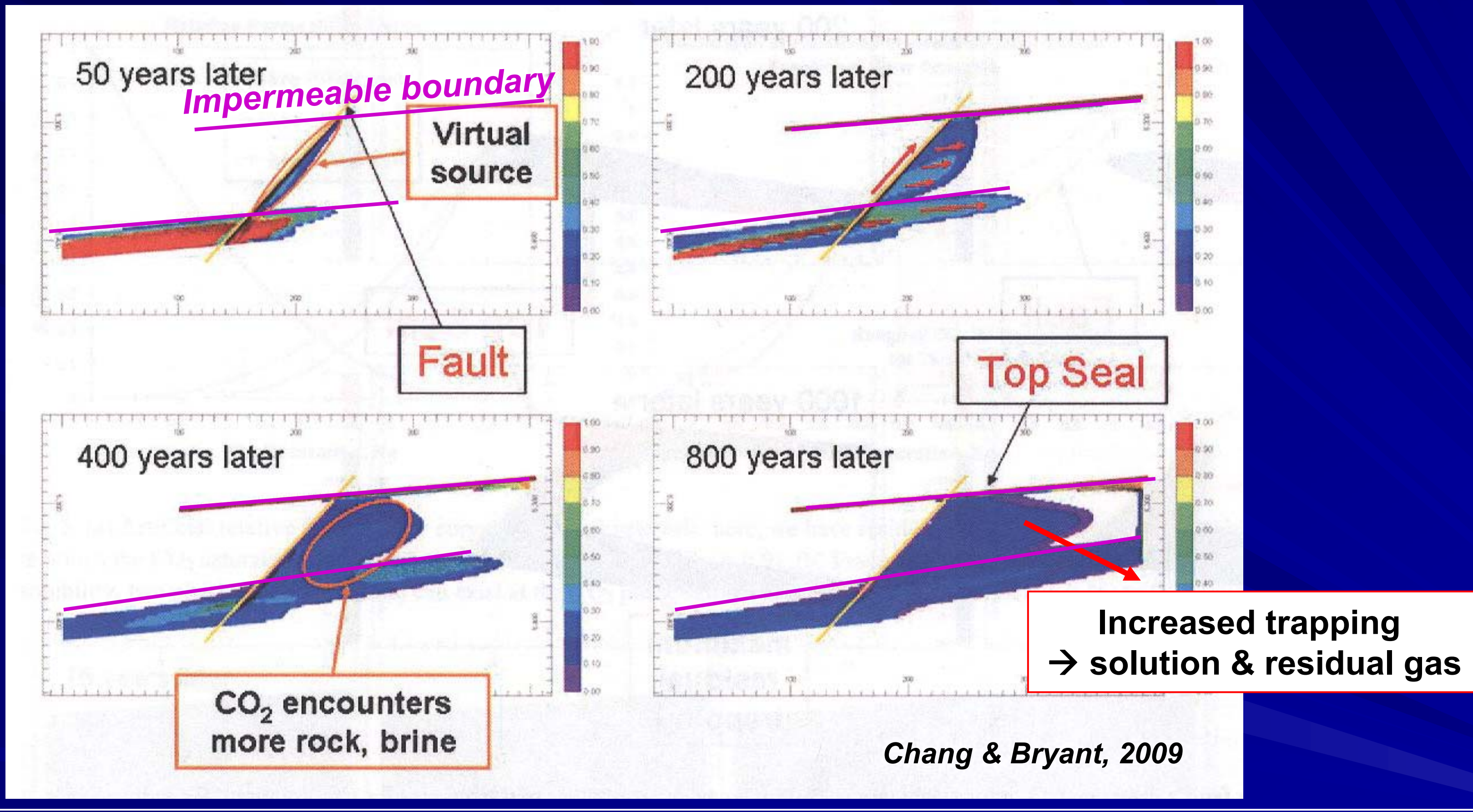
Simulated plume after breach → smaller and has lower pressure.

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?

Plume Modeling
Fault does not extend to surface



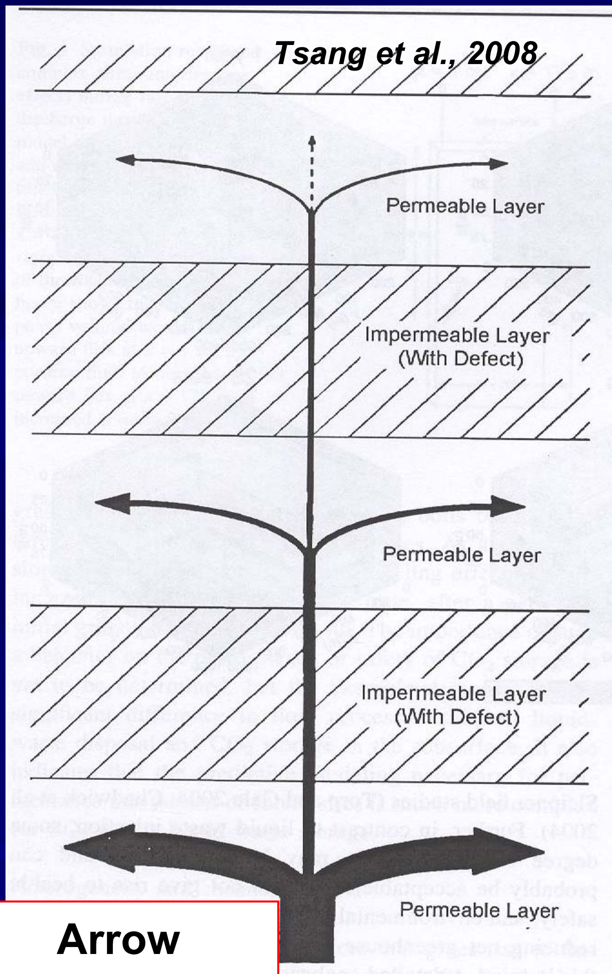
CO_2 leaks into fault and creates a "virtual CO_2 source".

CO_2 migrates updip and gets attenuated –

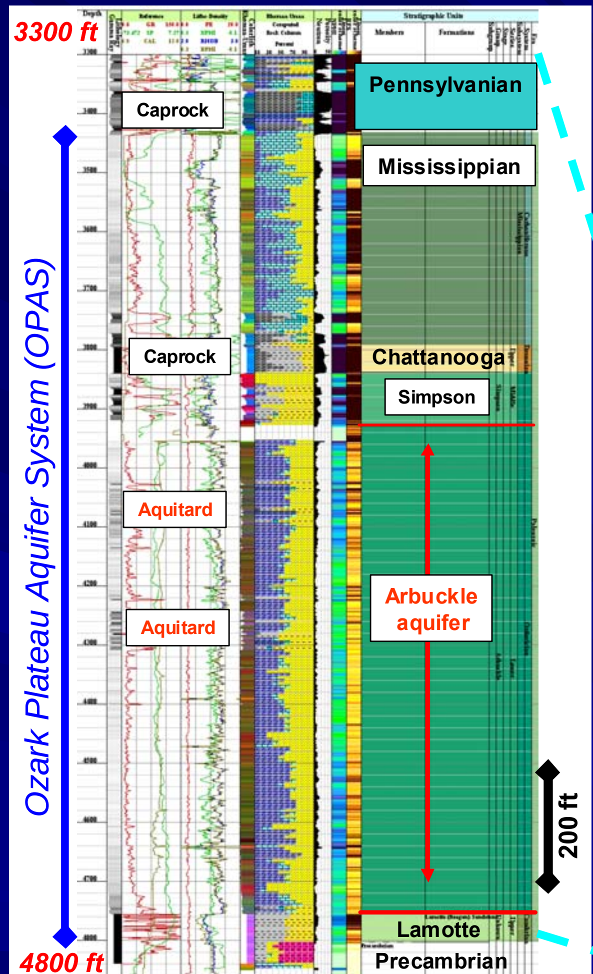
additional trapping in solution and as residual gas

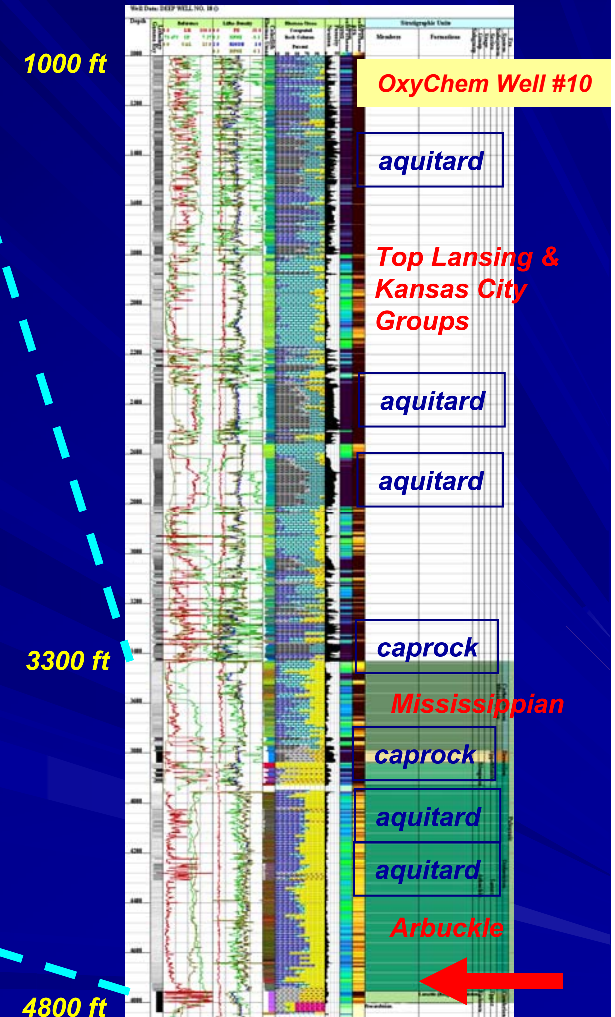
Hydrostratigraphy – Project Study Area

Multiple Caprocks & Aquitards - Leakage Attenuation



Arrow thickness = Relative amount of flow

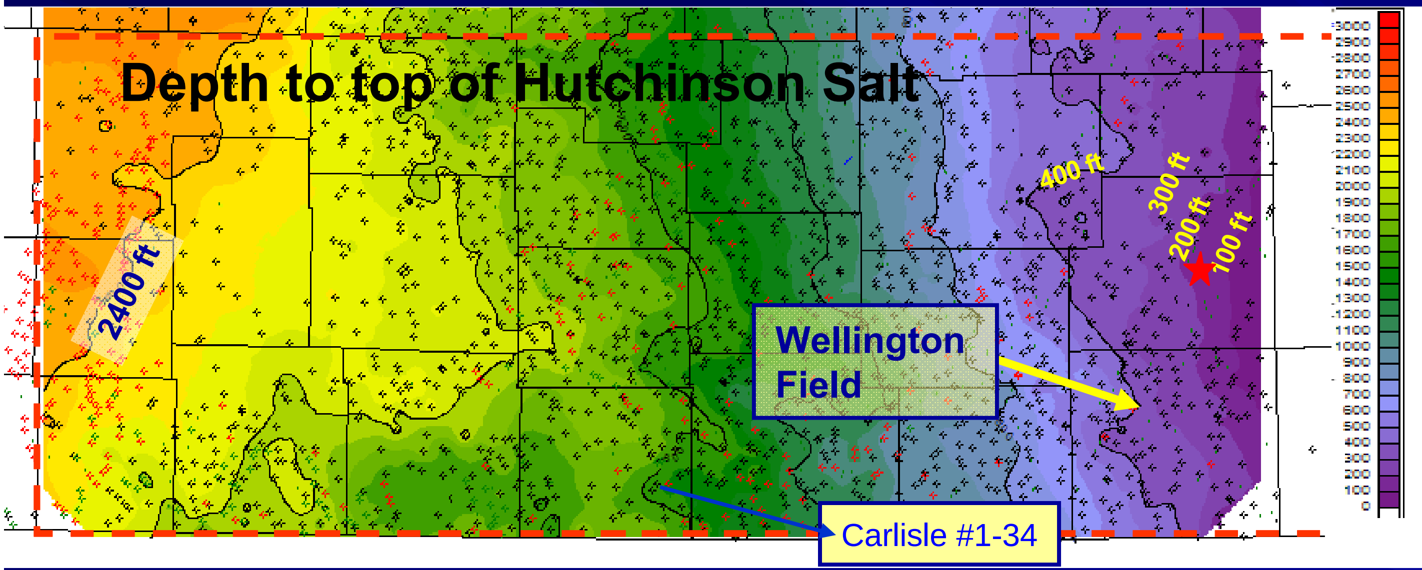




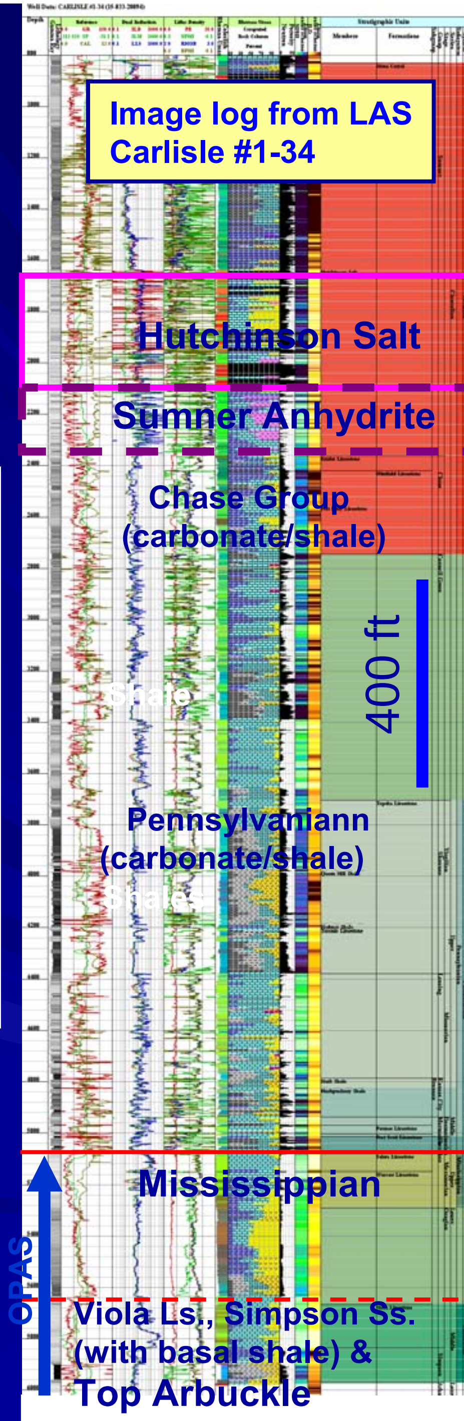
CO_2 plume undergoes pressure reduction upon breaching cap rock. Also additional CO_2 gets trapped in the fine pores of aquitards.

Suitability of Project

Evaporite seal overlying Arbuckle Saline Aquifer

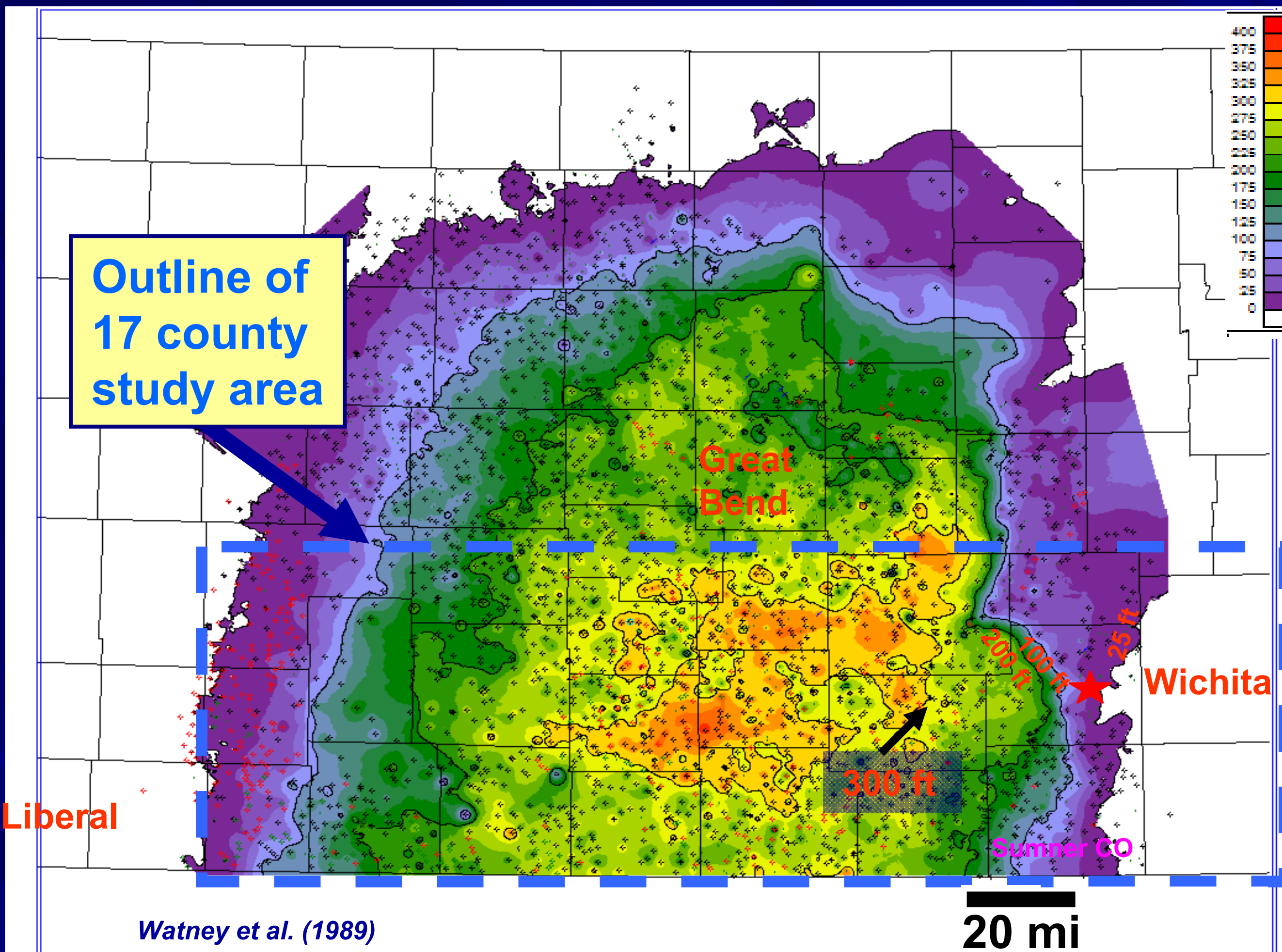


Regional study area: 230 mi x 85 mi



Total Permian evaporite thickness ranges from 400 to 2000 ft in south-central KS.

Extensive Regional Seal –
Lower Permian Hutchinson Salt



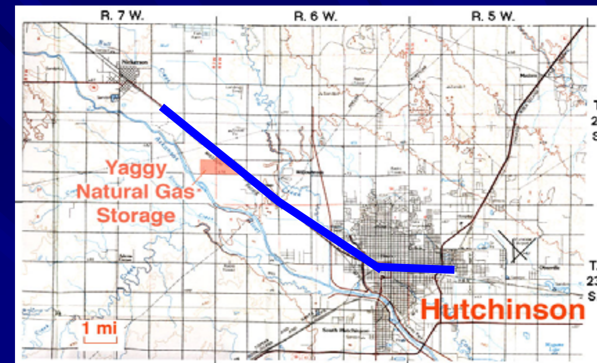
KGS maps show that total Permian evaporite thickness ranges from 400 to 2000 ft in south-central KS. These evaporites serve as ideal cap rocks. Located between shallow freshwater aquifers and hydrocarbon bearing strata and possible intervals of CO_2 sequestration.

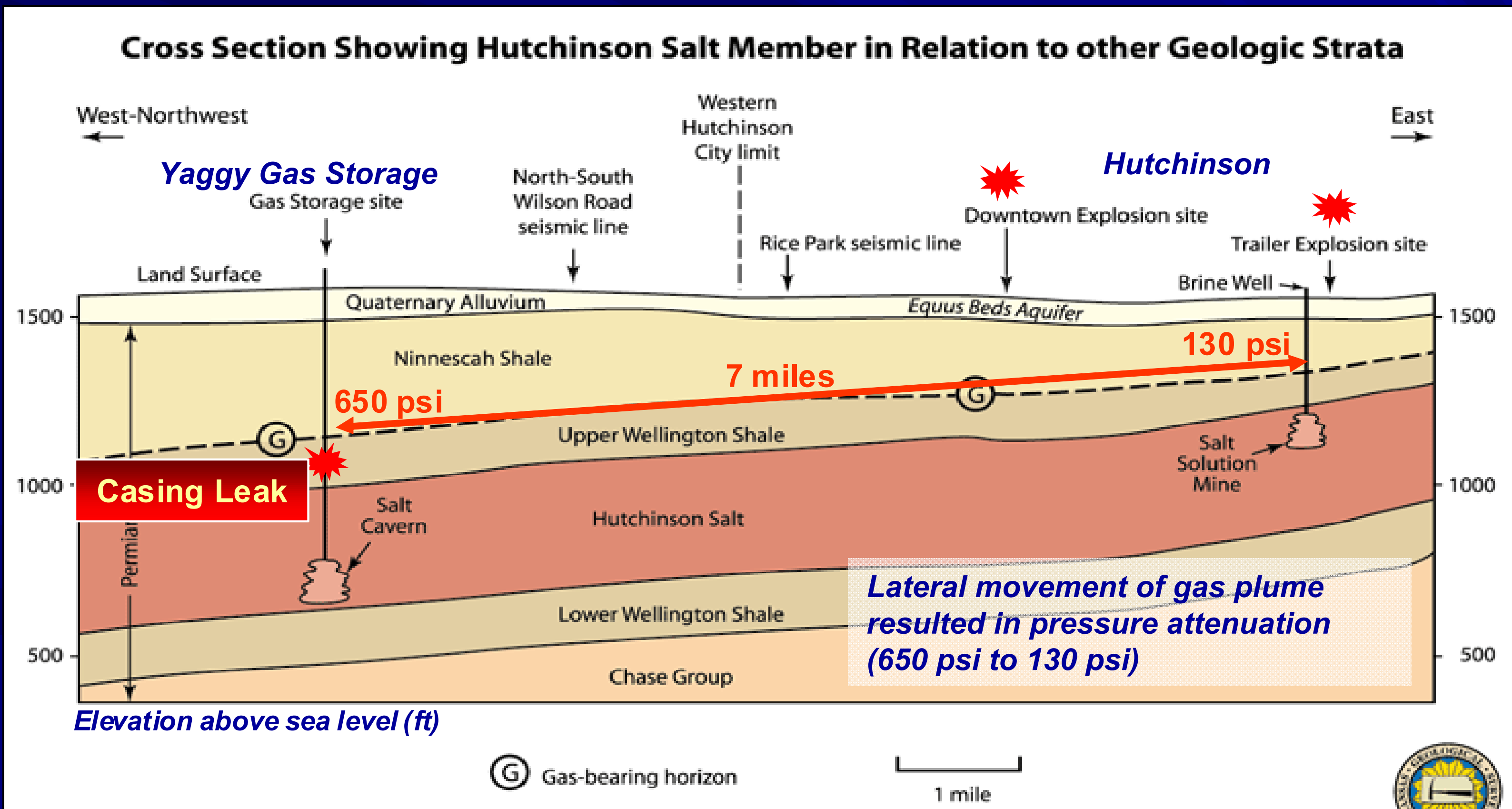
Net Halite (salt) Isopach (thickness)

Contour interval 100 ft

Yaggy Gas Storage Leak - 2001

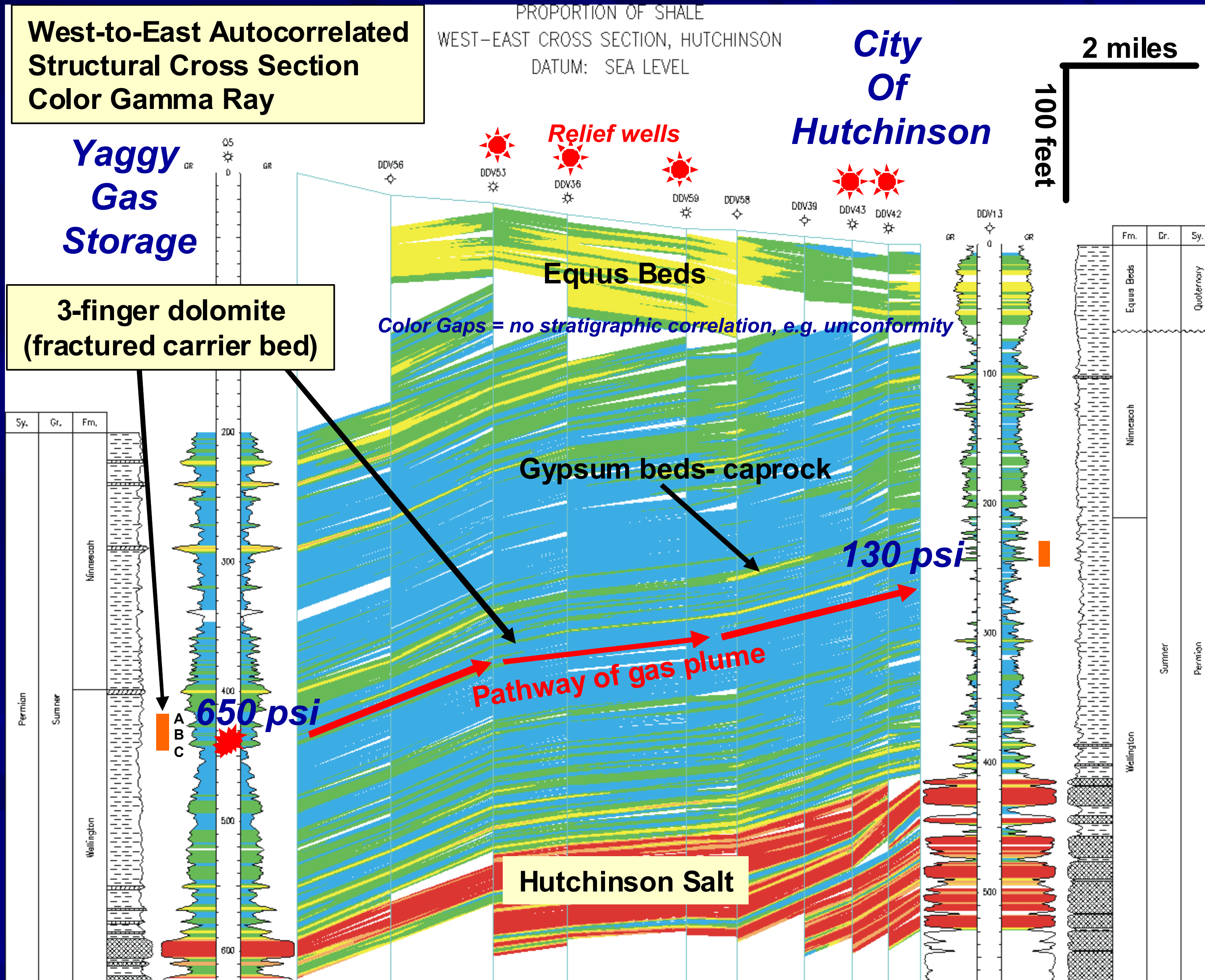
Site selection for CO_2 sequestration CRITICAL, because all wells drilled in the area have to be accounted for and properly completed before onset of CO_2 injection.





Watney et al. (2003)

Hutchinson Gas Leak – Slide 2



South-central Kansas CO_2 Project
Kansas Geological Survey

Project Overview

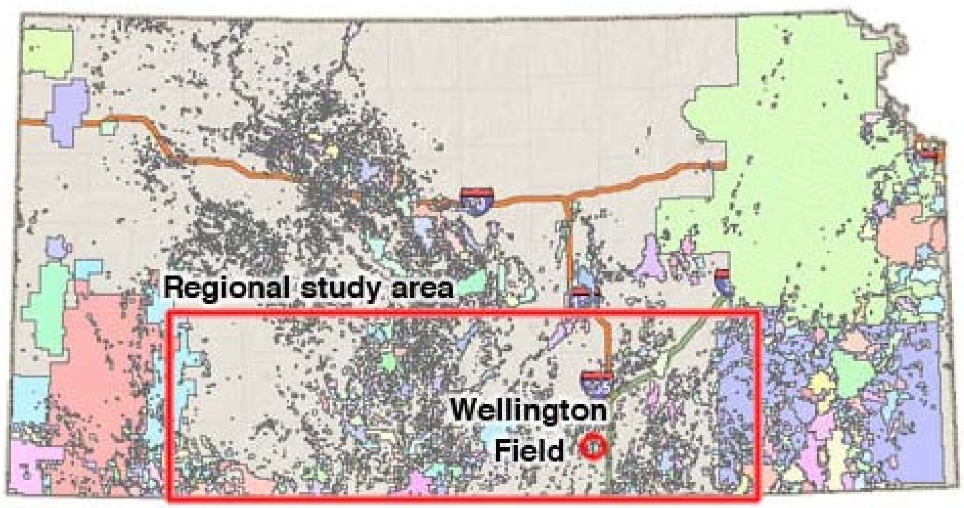
March 2010

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...

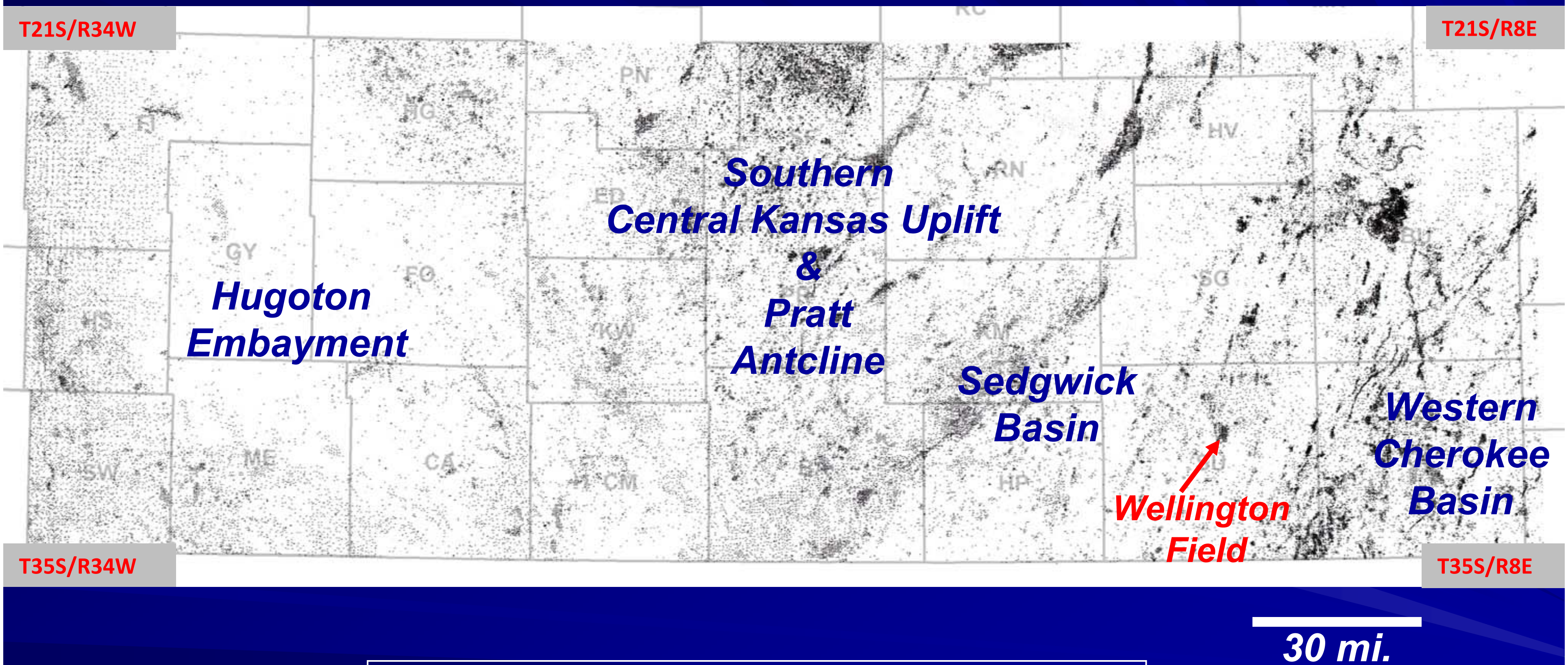
Home

Publications

People

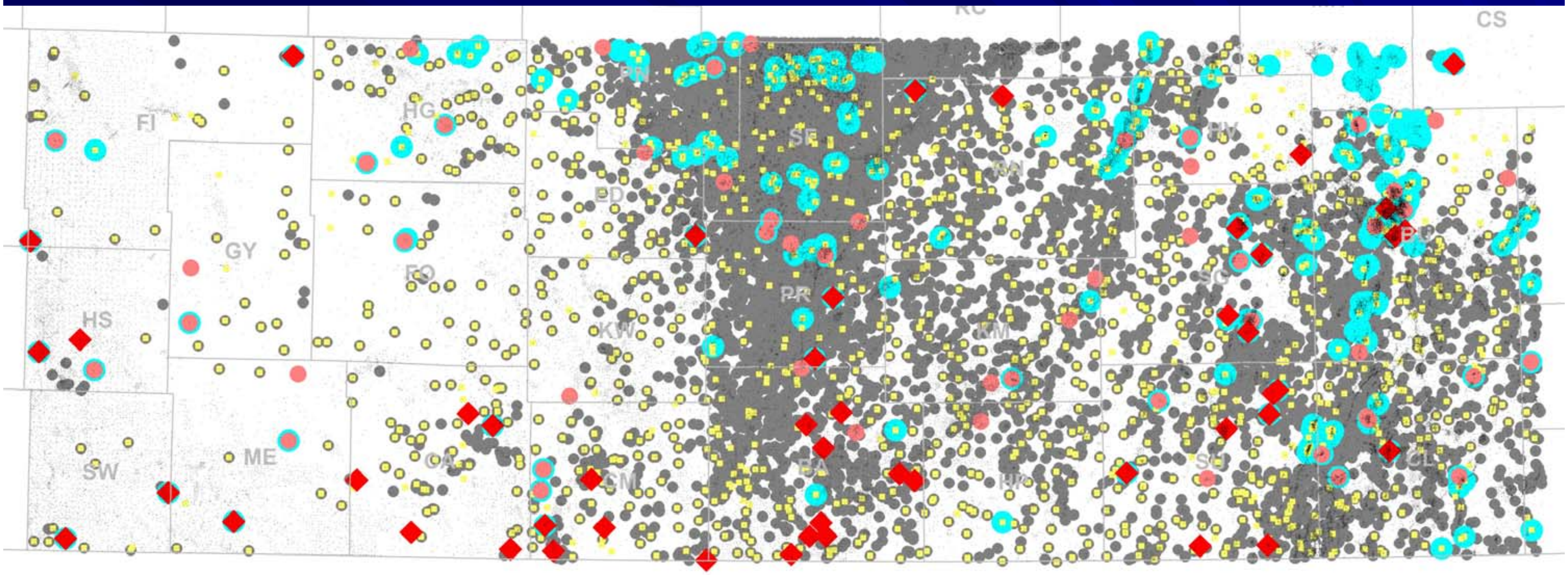
www.kgs.ku.edu/PRS/Ozark

Well Count – Regional 17+ County Area



Total well count in KGS database - 95,117

Identify Wells for Digitizing
-- Regional Mapping & Log Analysis



30 mi.

LAS Files 48 wells (to date)

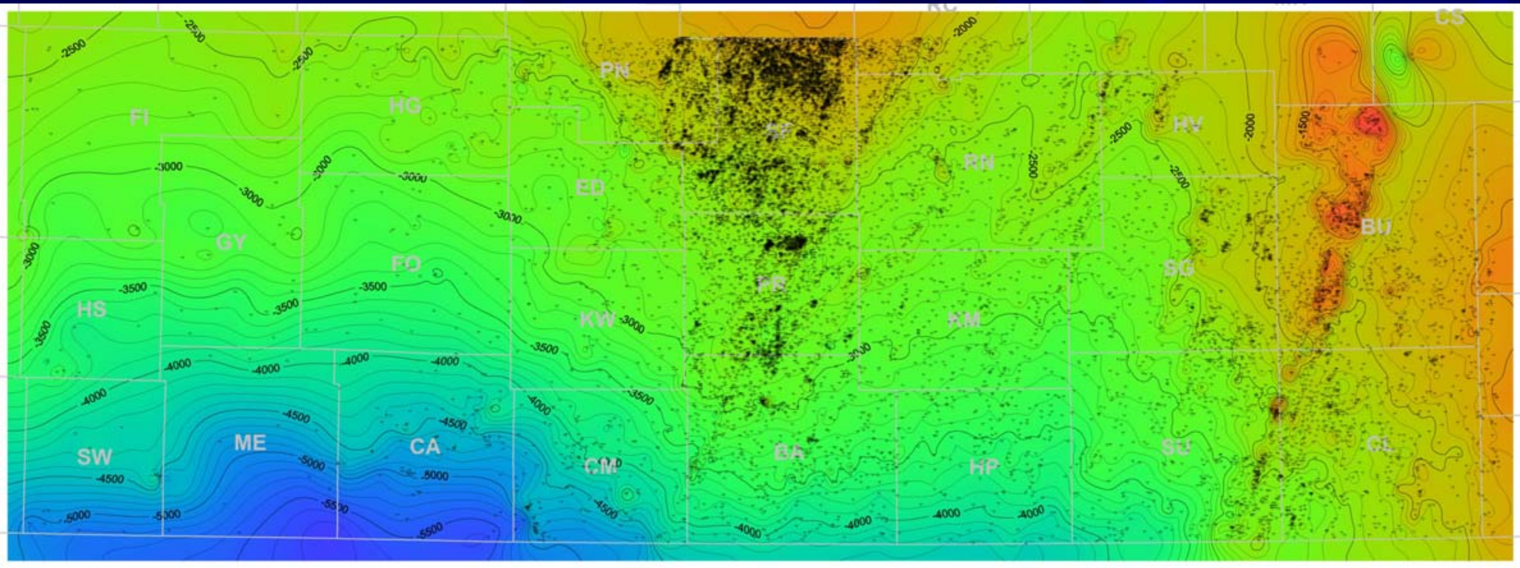
Pre-Cambrian Wells = 292

Arbuckle Wells = 14,105

Type Wells (>200’ into Arbuckle) = 1,417

Super Type Wells (>400’ into Arbuckle, 1980 or later) = 91

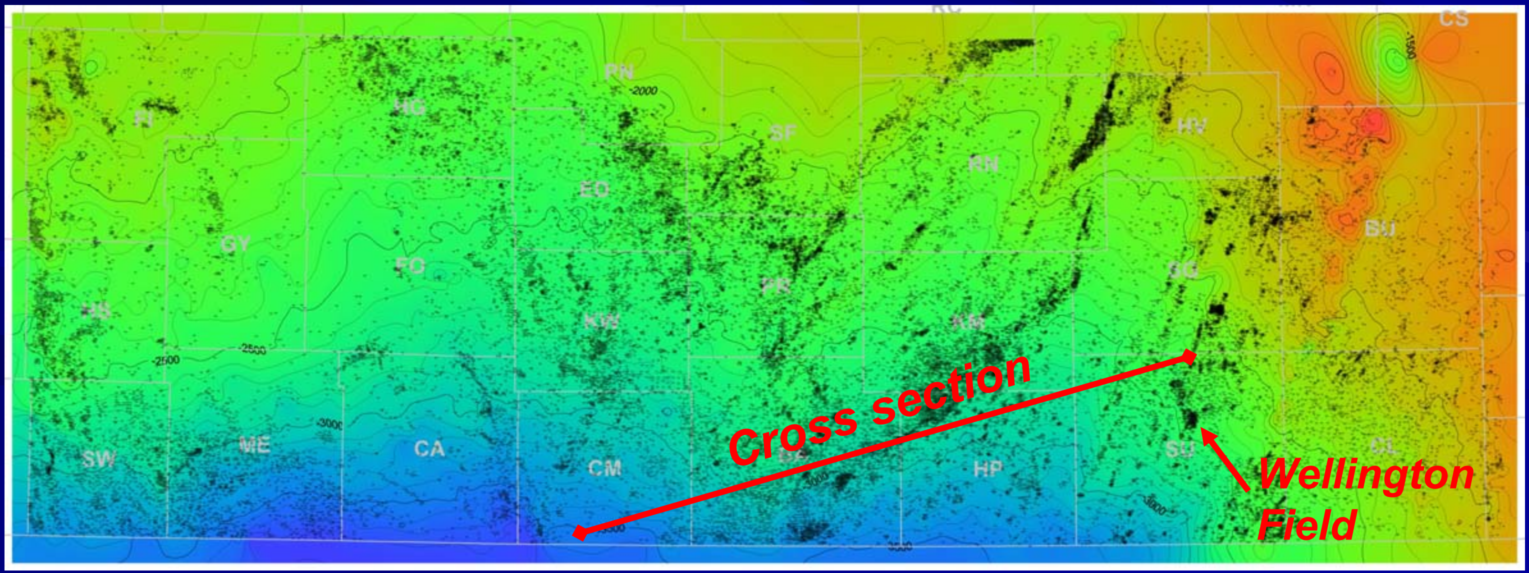
Top of Arbuckle Structure



14,105 wells

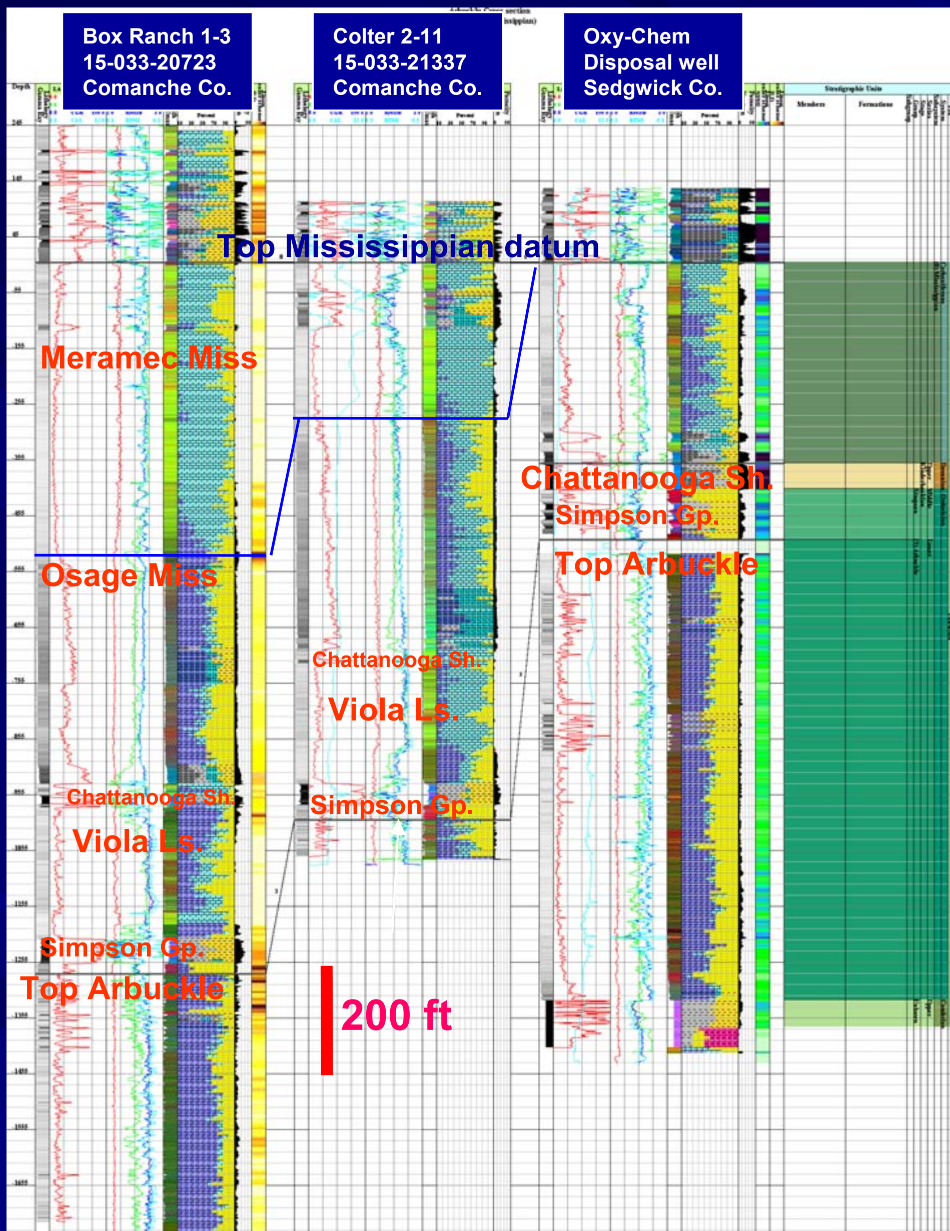
30 mi.

Top of Mississippian Structure



35,415 wells

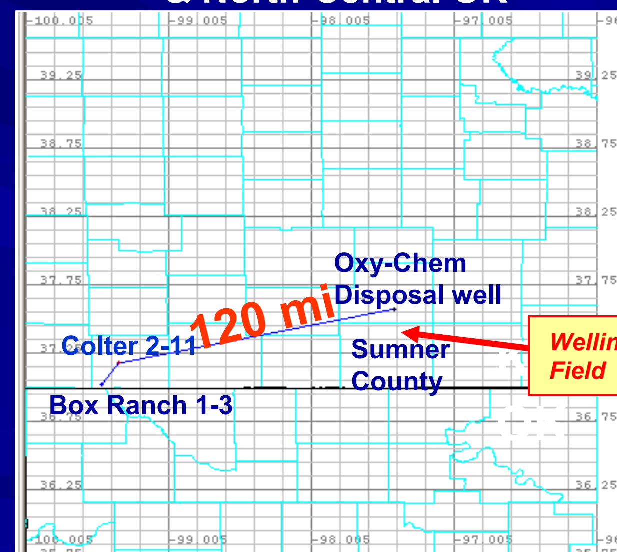
KGS Web-Tool under development - Well Profile & Cross Section
Interactive tool to convey hydrostratigraphy (aquifers/caprocks)



<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.

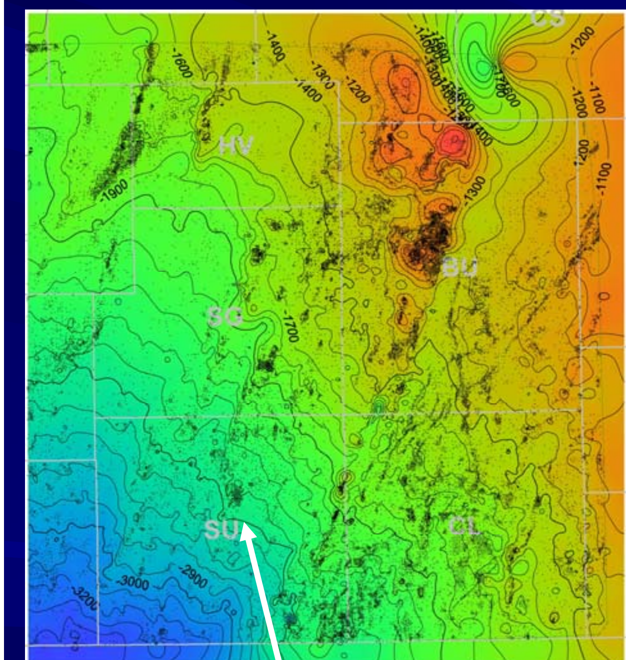
Index map, South-Central KS & North-Central OK



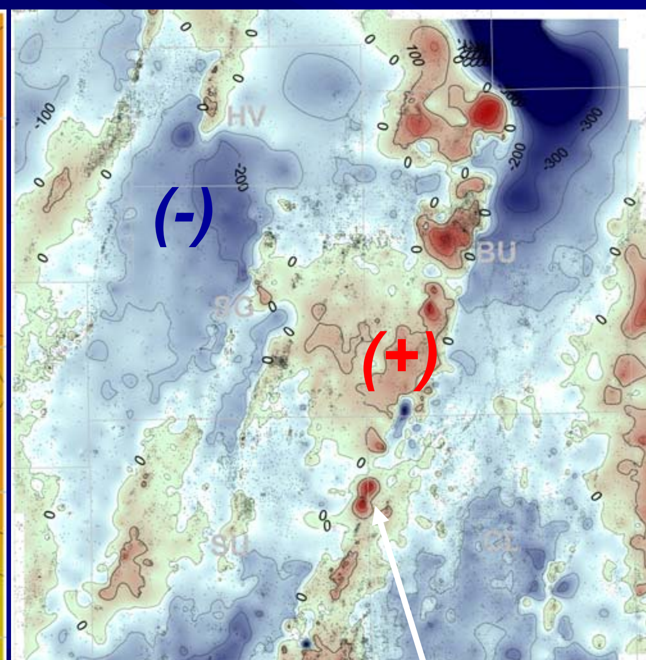
All well data saved in <u>LAS 3.0 format</u>

Eastern Portion of Regional Study Area
Preliminary Mapping

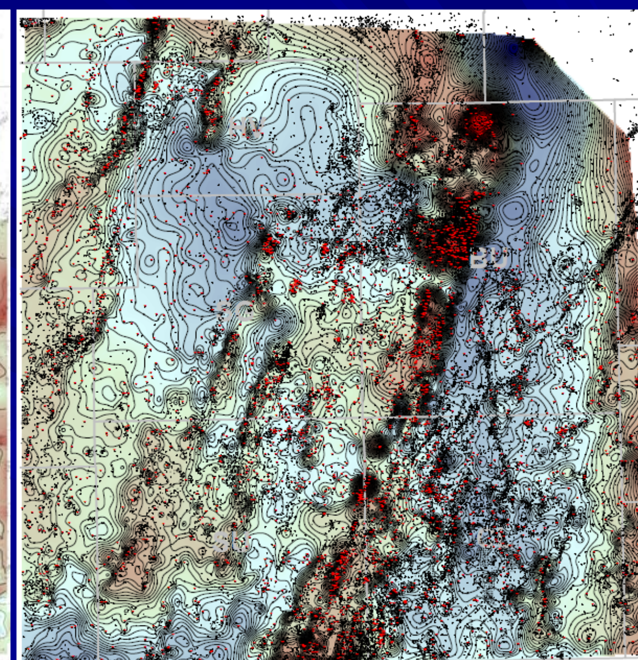
Mississippian Subsea
100 ft C.I.



3rd Order Residual of
Mississippian Subsea
100 ft C.I.



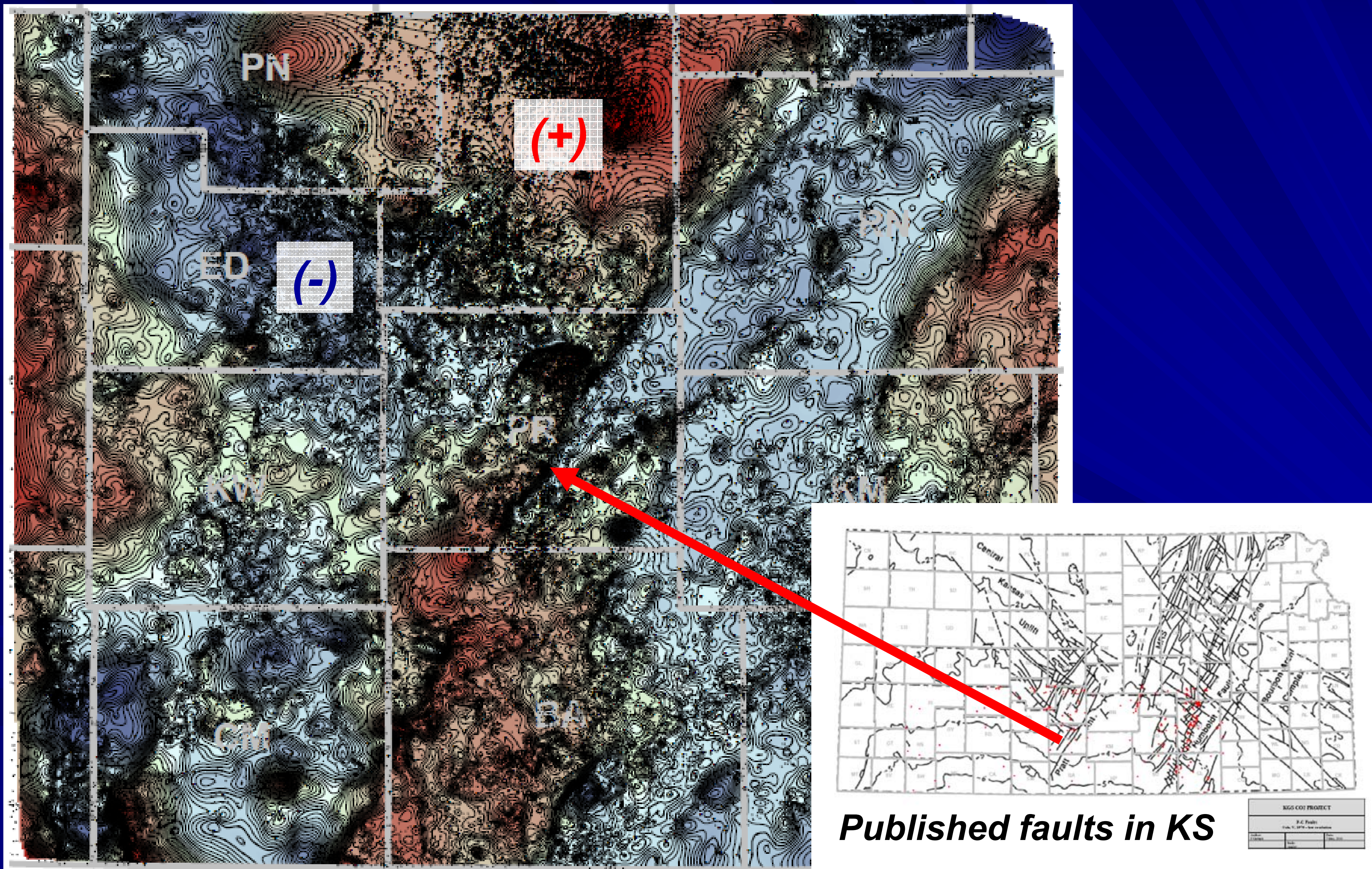
3rd Order Residual of
Arbuckle Subsea
25 ft C.I.



Wellington Field
Sumner County

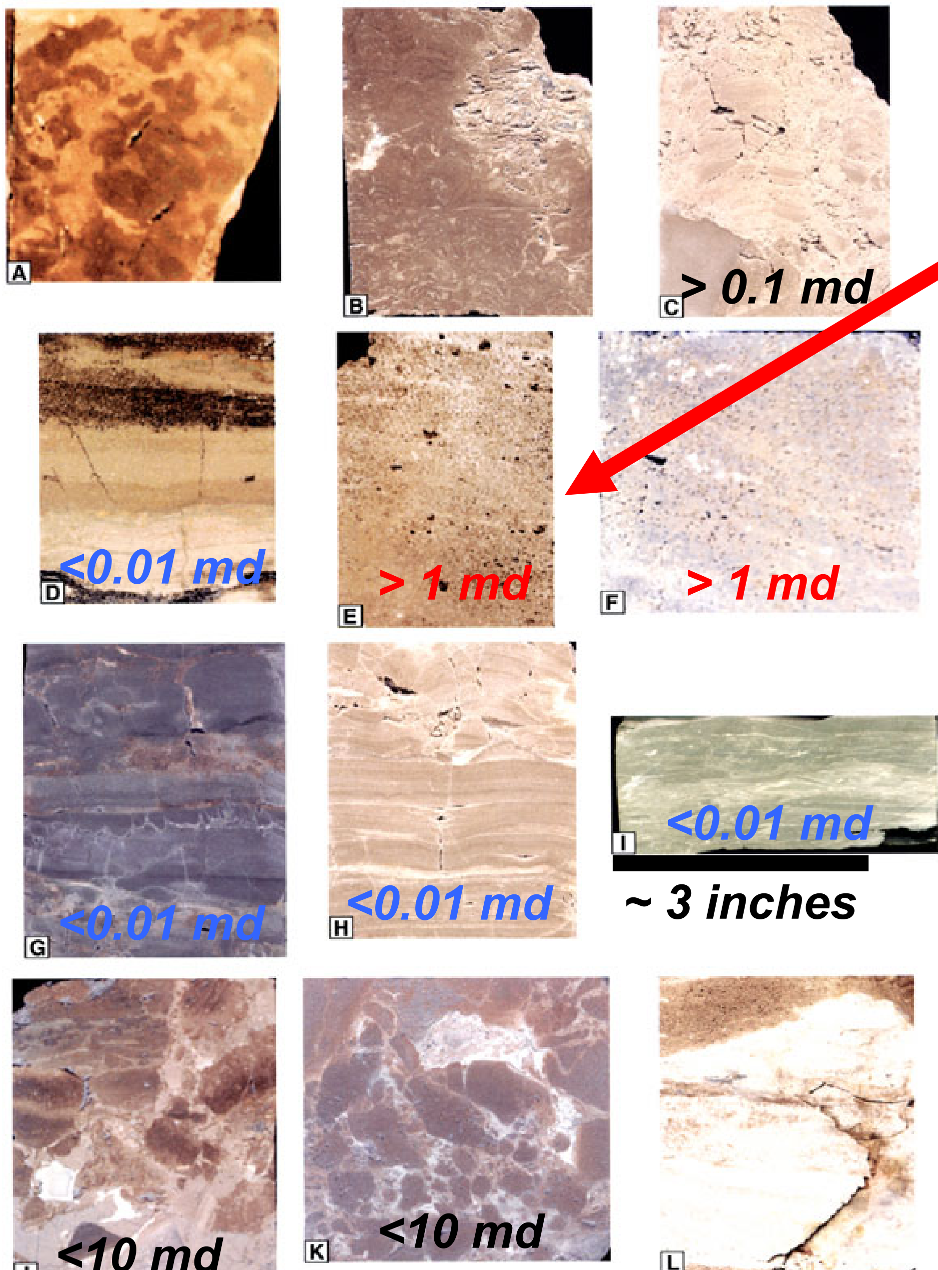
El Dorado Field
on Nemaha Uplift

3rd Order Residual -- Arbuckle Subsea
South-Central Kansas



Published faults in KS

Aquifer flow units and seals/caprock

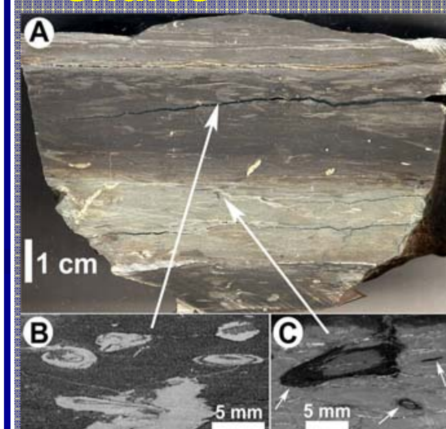


Franseen et al. (2004)

*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



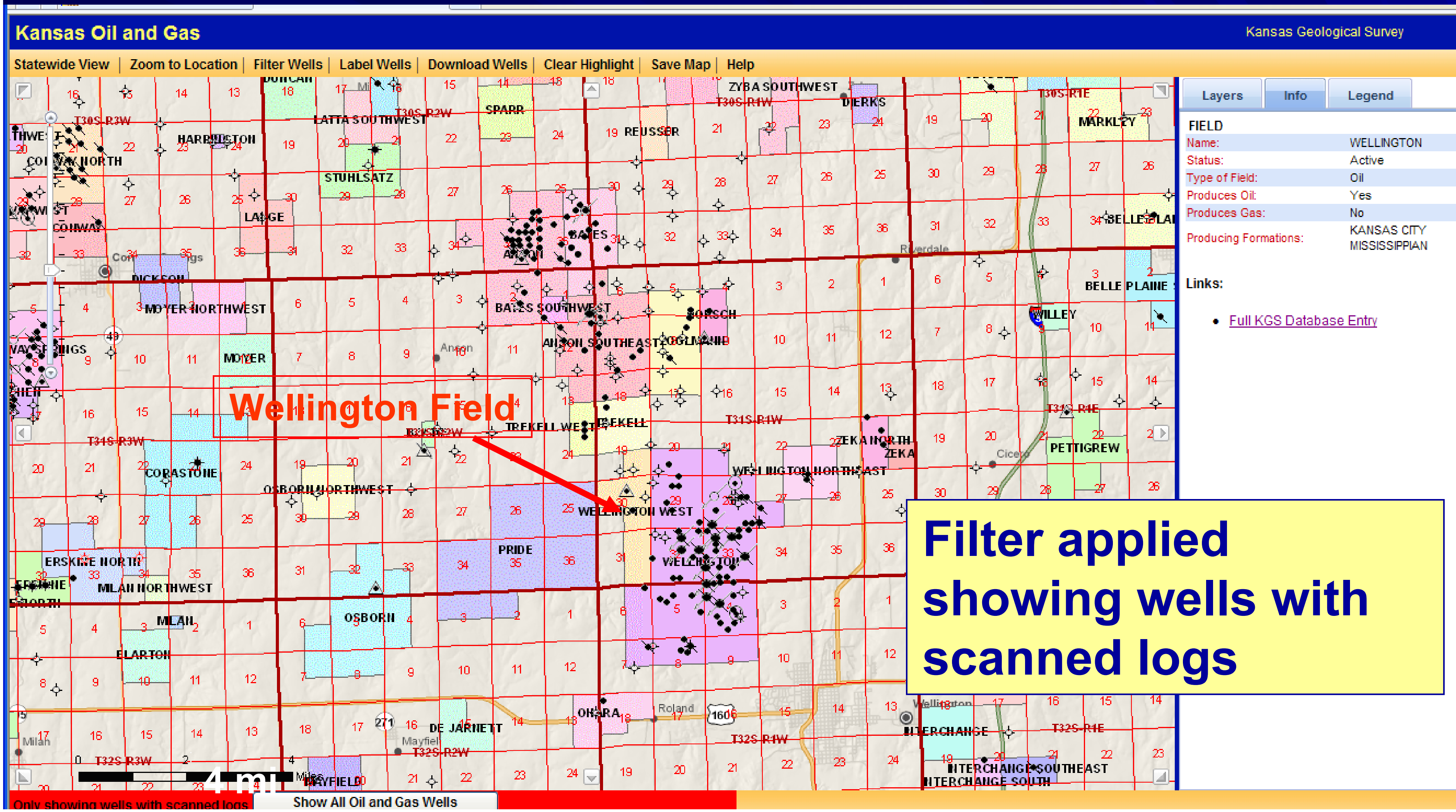
Lobza & Schieber (1999)

Permian evaporite beds

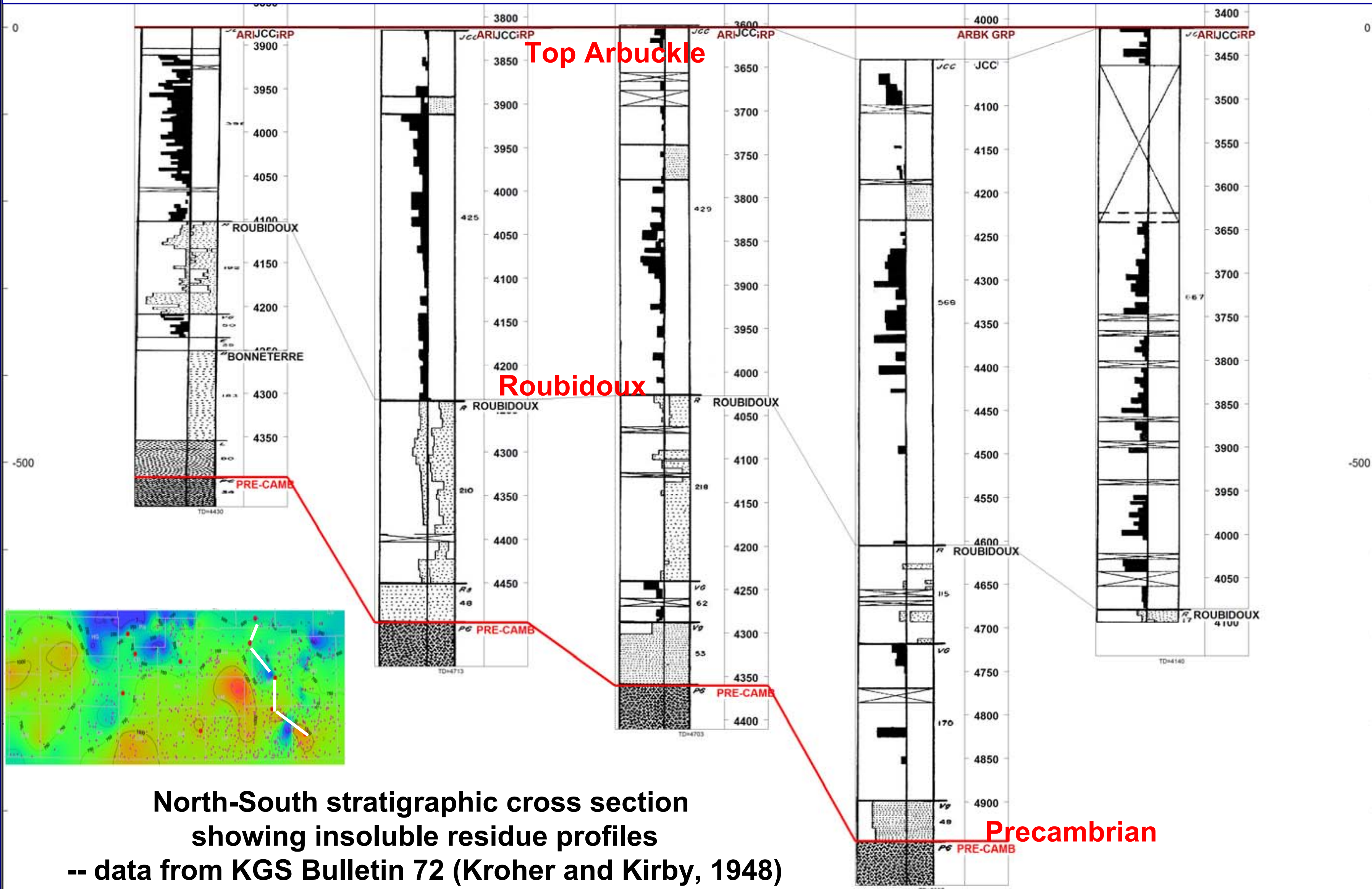
Work in Progress

Adapting Oil and Gas Map Viewer for Project

- Google-type map interface to pan and zoom
- *Display <u>ALL</u> wells, access well data, launch well profile and cross section web tools*
- *Display georeferenced maps and simulations*



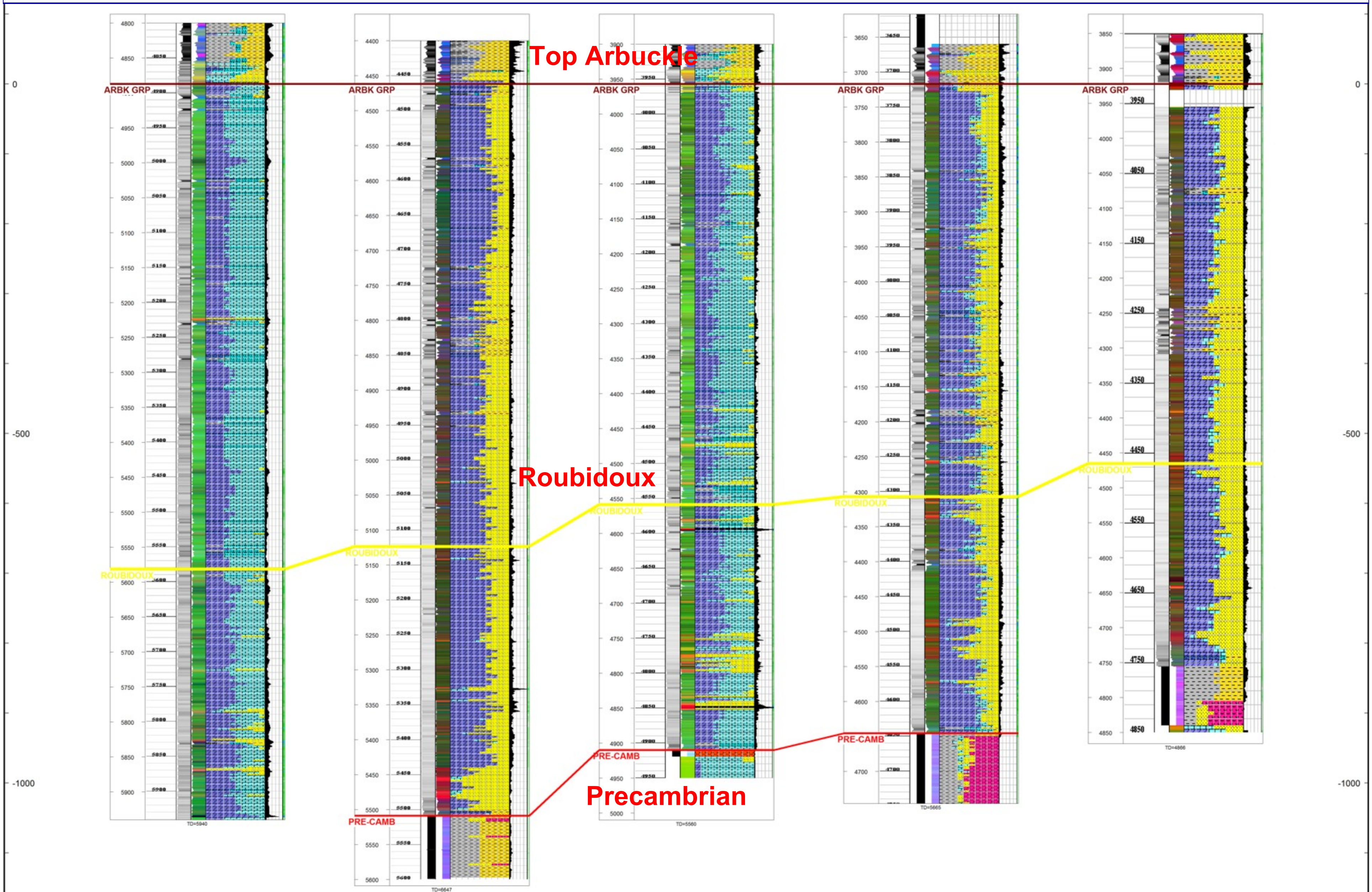
Establishing Internal Stratigraphy -- published insoluble residue logs



North-South stratigraphic cross section showing insoluble residue profiles -- data from KGS Bulletin 72 (Kroher and Kirby, 1948) index on previous map

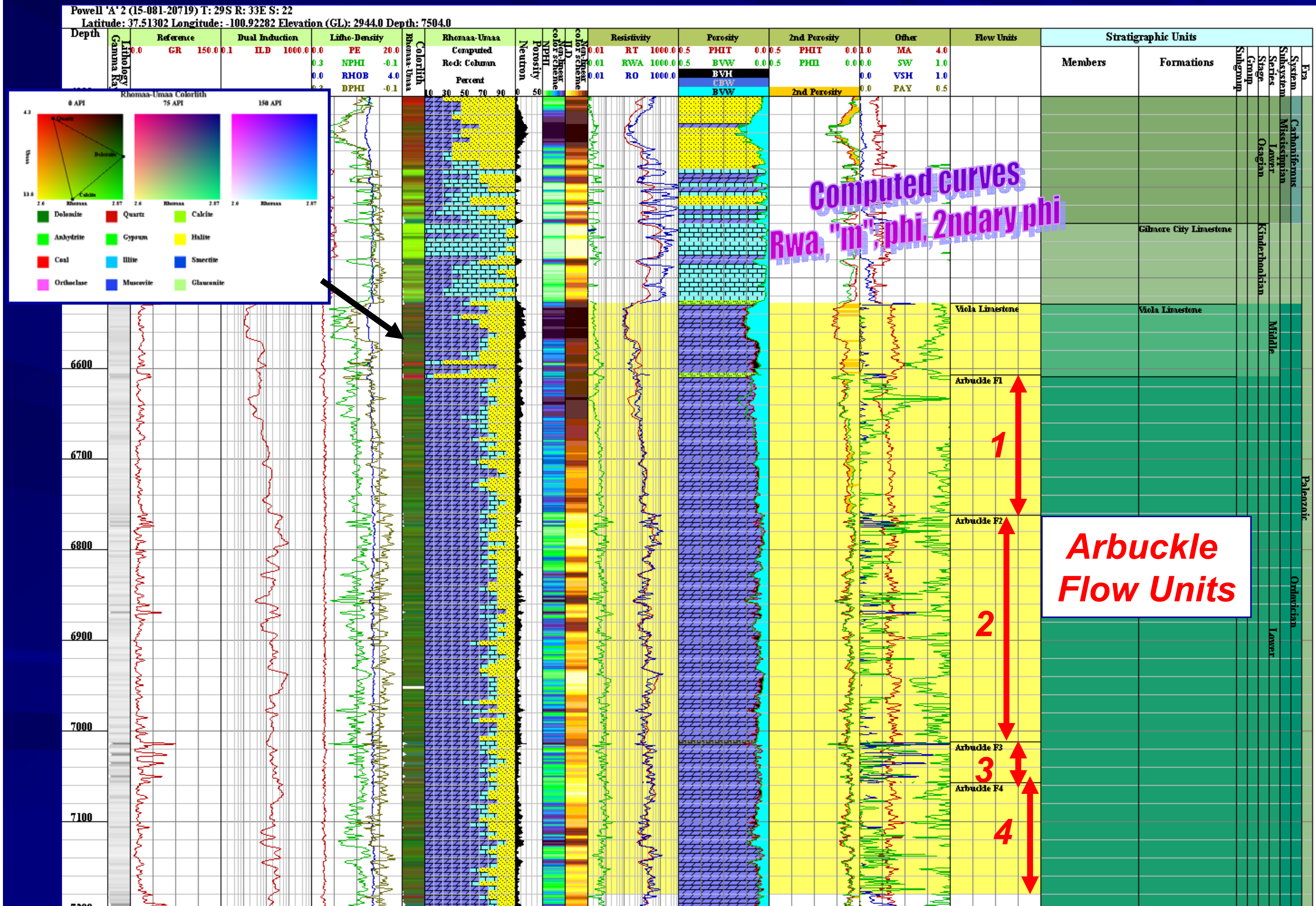
Lithology Computed from Well Logs

-- Verified with Sample logs – Stratigraphic Correlation and Flow Unit Definition

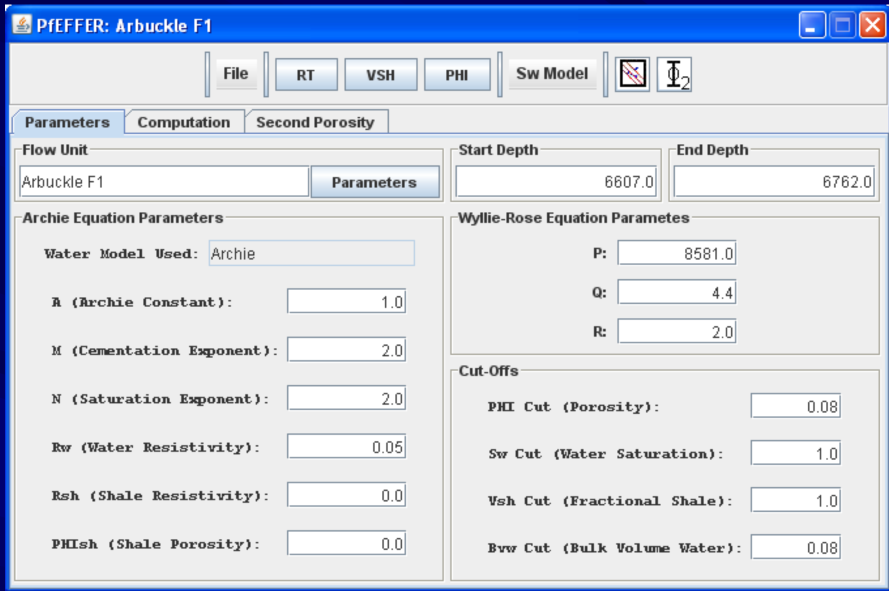


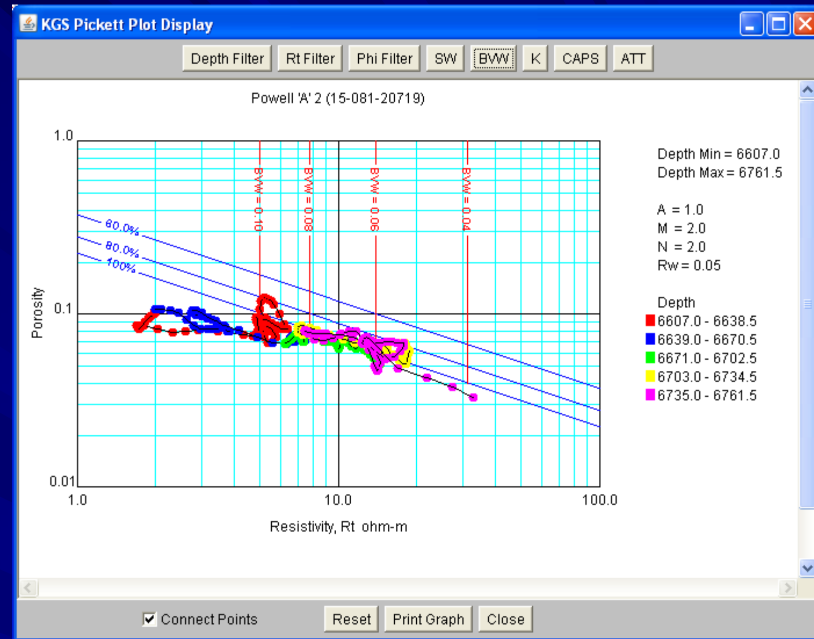
Web-Based Tools Used to Analyze Flow Units

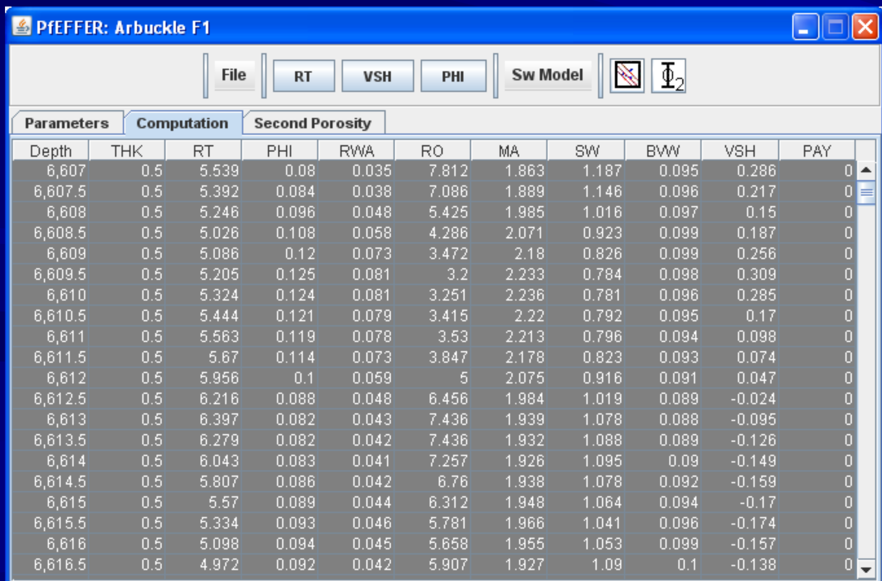
-- Digital Log from Haskell County, KS



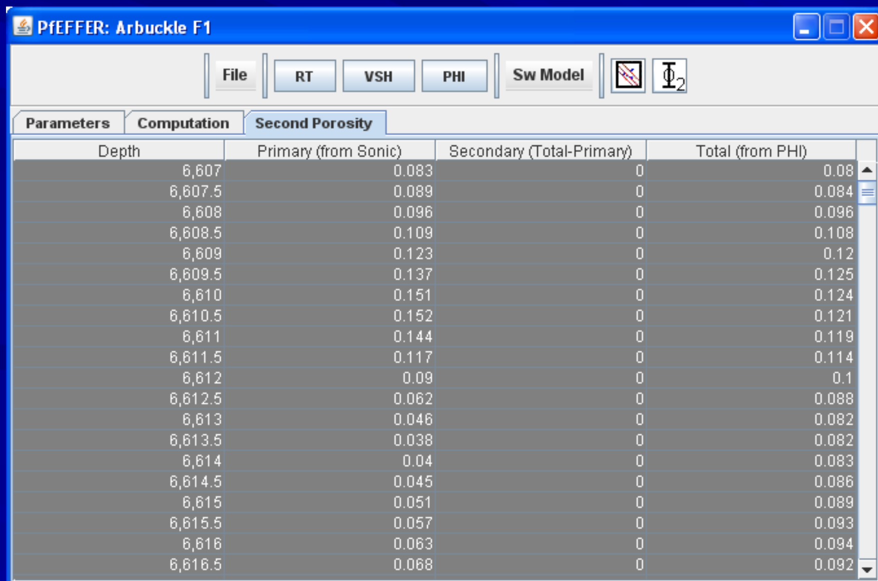
Web-based tool for Flow Unit Analysis







Depth	THK	RT	PHI	RWA	RO	MA	SW	BVW	VSH	PAY
6,607	0.5	5.539	0.08	0.035	7.812	1.863	1.187	0.095	0.286	0
6,607.5	0.5	5.392	0.084	0.038	7.086	1.889	1.146	0.096	0.217	0
6,608	0.5	5.246	0.096	0.048	5.425	1.985	1.016	0.097	0.15	0
6,608.5	0.5	5.026	0.108	0.058	4.286	2.071	0.923	0.099	0.187	0
6,609	0.5	5.086	0.12	0.073	3.472	2.18	0.826	0.099	0.256	0
6,609.5	0.5	5.205	0.125	0.081	3.2	2.233	0.784	0.098	0.309	0
6,610	0.5	5.324	0.124	0.081	3.251	2.236	0.781	0.096	0.285	0
6,610.5	0.5	5.444	0.121	0.079	3.415	2.22	0.792	0.095	0.17	0
6,611	0.5	5.563	0.119	0.078	3.53	2.213	0.796	0.094	0.098	0
6,611.5	0.5	5.67	0.114	0.073	3.847	2.178	0.823	0.093	0.074	0
6,612	0.5	5.956	0.1	0.059	5	2.075	0.916	0.091	0.047	0
6,612.5	0.5	6.216	0.088	0.048	6.456	1.984	1.019	0.089	-0.024	0
6,613	0.5	6.397	0.082	0.043	7.436	1.939	1.078	0.088	-0.095	0
6,613.5	0.5	6.279	0.082	0.042	7.436	1.932	1.088	0.089	-0.126	0
6,614	0.5	6.043	0.083	0.041	7.257	1.926	1.095	0.09	-0.149	0
6,614.5	0.5	5.807	0.086	0.042	6.76	1.938	1.078	0.092	-0.159	0
6,615	0.5	5.57	0.089	0.044	6.312	1.948	1.064	0.094	-0.17	0
6,615.5	0.5	5.334	0.093	0.046	5.781	1.966	1.041	0.096	-0.174	0
6,616	0.5	5.098	0.094	0.045	5.658	1.955	1.053	0.099	-0.157	0
6,616.5	0.5	4.972	0.092	0.042	5.907	1.927	1.09	0.1	-0.138	0



Depth	Primary (from Sonic)	Secondary (Total-Primary)	Total (from PHI)
6,607	0.083	0	0.08
6,607.5	0.089	0	0.084
6,608	0.096	0	0.096
6,608.5	0.109	0	0.108
6,609	0.123	0	0.12
6,609.5	0.137	0	0.125
6,610	0.151	0	0.124
6,610.5	0.152	0	0.121
6,611	0.144	0	0.119
6,611.5	0.117	0	0.114
6,612	0.09	0	0.1
6,612.5	0.062	0	0.088
6,613	0.046	0	0.082
6,613.5	0.038	0	0.082
6,614	0.04	0	0.083
6,614.5	0.045	0	0.086
6,615	0.051	0	0.089
6,615.5	0.057	0	0.093
6,616	0.063	0	0.094
6,616.5	0.068	0	0.092

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