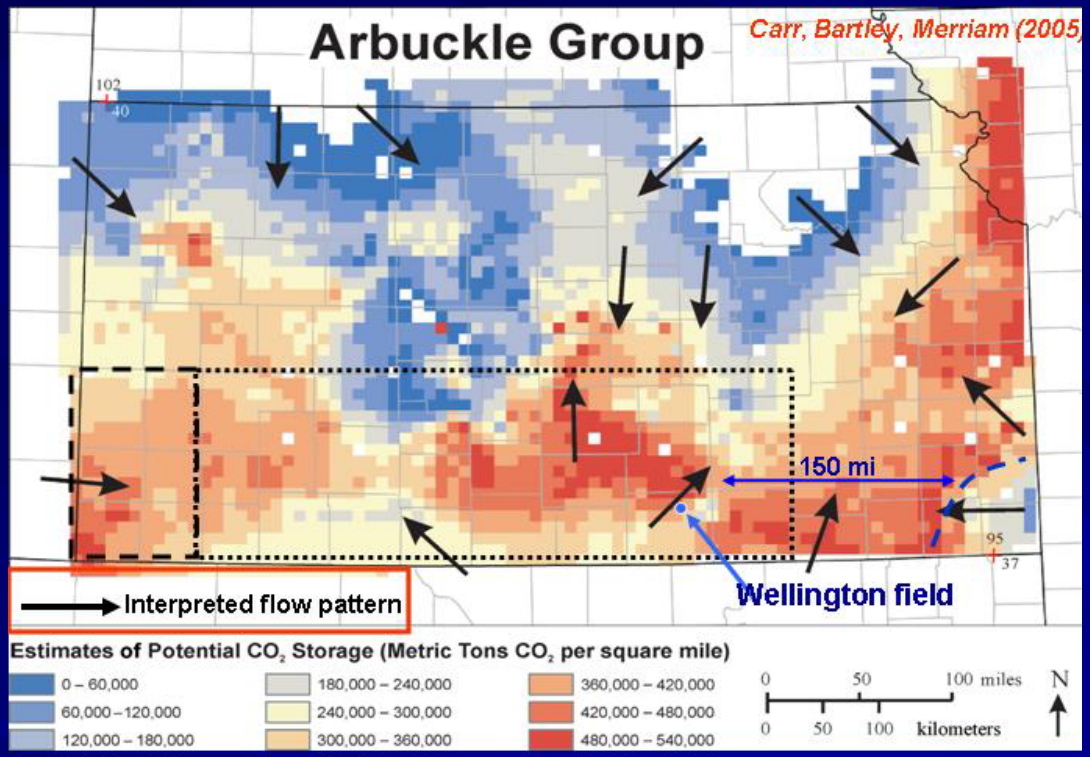
Evaluate CO_2 Sequestration Potential of Arbuckle Group Saline Aquifer and CO_2-EOR in select Mississippian and Chester-Morrow fields in southern Kansas



Total Budget = $12.6 million

DOE Funding = $9.9 million

W. Lynn Watney and Saibal Bhattacharya

GSAC Meeting, KGS

Dec 2, 2010

KANSAS GEOLOGICAL SURVEY
The University of Kansas

Outline

Study Goal

Evaluate CO_2 Sequestration Potential in KS

- Deep Saline Arbuckle Aquifer in southern KS
- Select depleted mature oil fields (Mississippian & Chester/Morrow)

Start Date - Dec 2009

No CO_2 will be injected in this 3-year project

- Overview - DOE-funded Project - ***Watney***
- Subsurface fate of injected CO_2 - ***Saibal***
- Update Geomodeling Studies – ***Watney***
- Update Reservoir Simulation Studies – ***Saibal***
- Upcoming Schedule - ***Saibal***

http://www.kgs.ku.edu/PRS/Ozark/index.html

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

***Newly funded DOE Project at KGS** – "Prototyping and testing a new volumetric curvature tool for modeling reservoir compartments and leakage compartments in the Arbuckle saline aquifer: Reducing uncertainty in CO_2 storage and permanence"*

***PIs**: Jason Rush & Saibal Bhattacharya*

***Industry Partners**: Murfin Drilling Co. and Vess Oil Corporation*

*Total Budget = $1.9 million, **DOE Funding = $1.5 million***

Southwest Regional Partnership on Carbon Sequestration

SWP

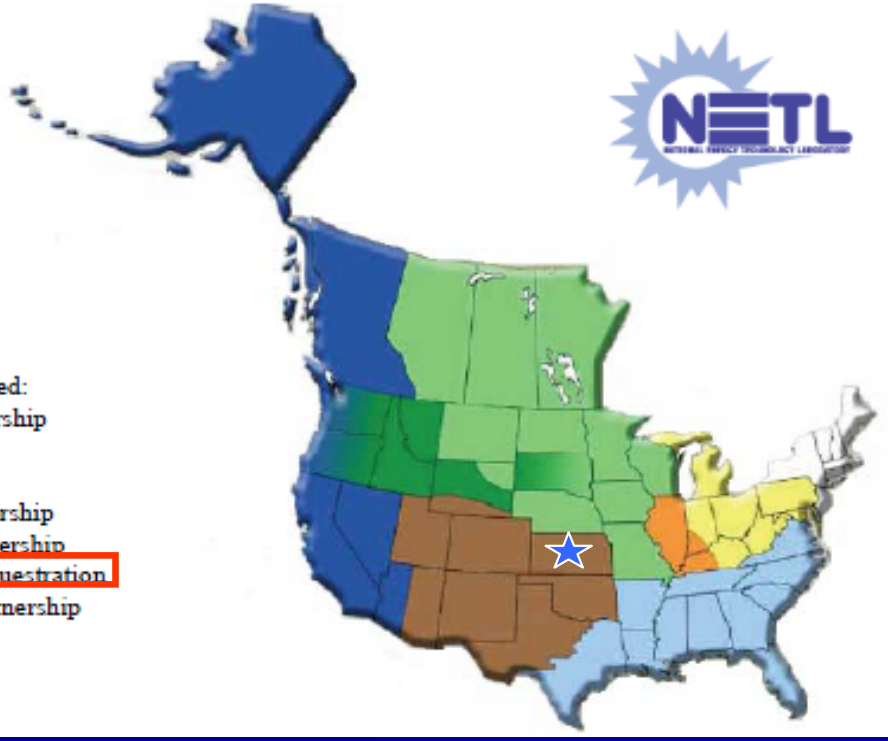
Carbon Sequestration Initiative

On November 21, 2002 Spencer Abraham, former Secretary of Energy, announced to the National Coal Council in Washington, DC a global climate change initiative involving "joint government-industry partnerships working together to find sensible, low cost solutions" for reducing GHG emissions.

These partnerships . . . each made up of private industry, universities, and state and local governments will become the centerpiece of our sequestration program. They will help us determine the technologies, regulations, and infrastructure that are best suited for specific regions of the country.

As a result, seven regional partnerships were formed:

- Big Sky Regional Carbon Sequestration Partnership
- Plains CO_2 Reduction Partnership
- Midwest Geological Sequestration Consortium
- Midwest Regional Carbon Sequestration Partnership
- Southeast Regional Carbon Sequestration Partnership
- Southwest Regional Partnership on Carbon Sequestration
- West Coast Regional Carbon Sequestration Partnership



NETL

8

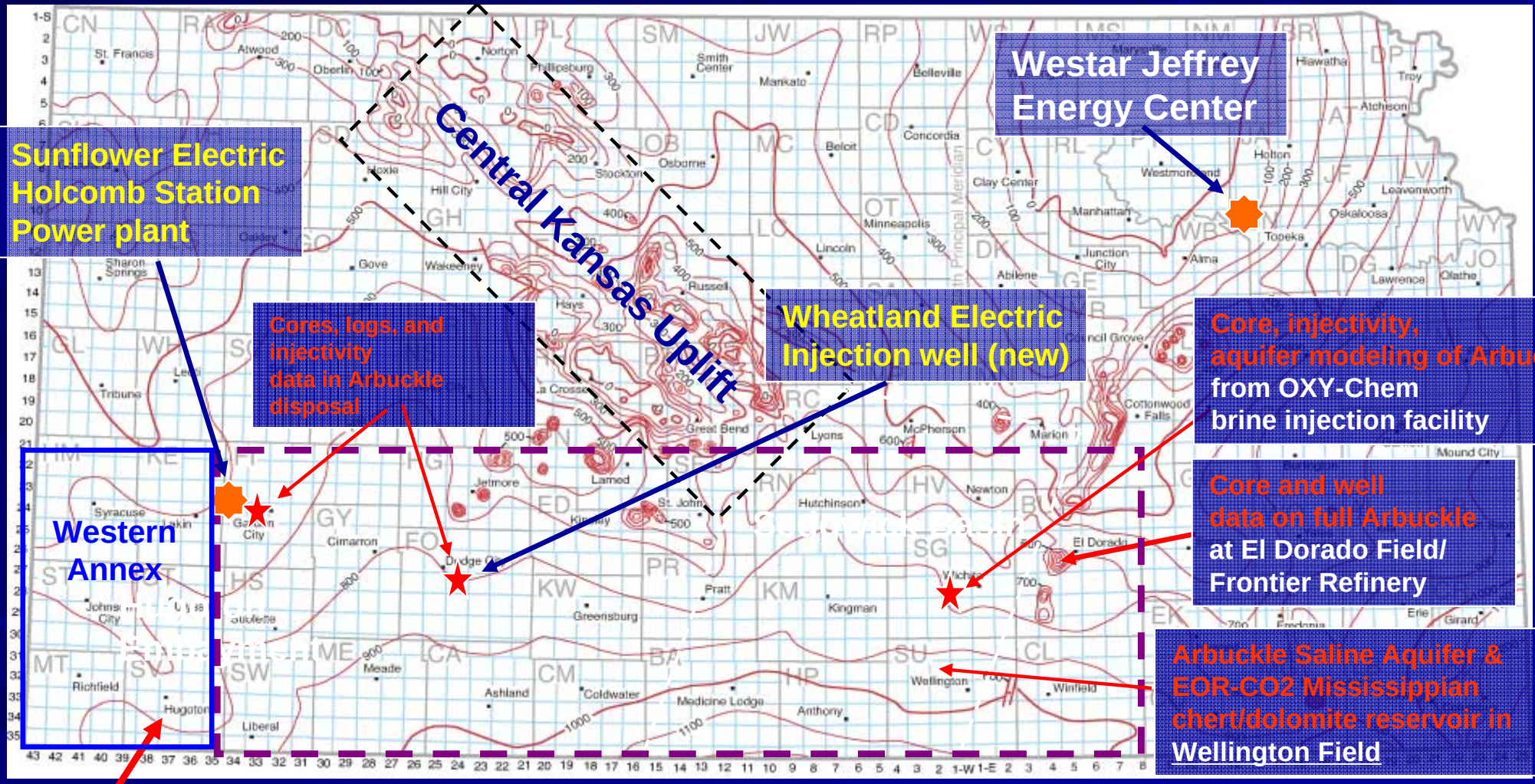
NATCARB (*National Carbon Sequestration Database and GIS*) is hosted at KGS and funded NETL

Relevance of CO_2 Sequestration in KS

- Coal-fired power plants to produce for years in Kansas
- DOE efforts to develop carbon capture and storage (CCS) infrastructure
- Initiatives of the ***Midwestern Governors Association***
- CO_2-EOR – proven technology for EOR- select depleted oilfields
- Deep saline aquifers – potential to sequester large volumes of CO_2
  - Arbuckle deep saline aquifer underlies large areas in southern KS
- KS centrally located to major CO_2 emitting states and cities
- CO_2 sequestration - potential to become a major industry in KS
  - Government incentives
  - Value of CO_2 as commodity
  - Infrastructure
  - Maturation of technology and regulations

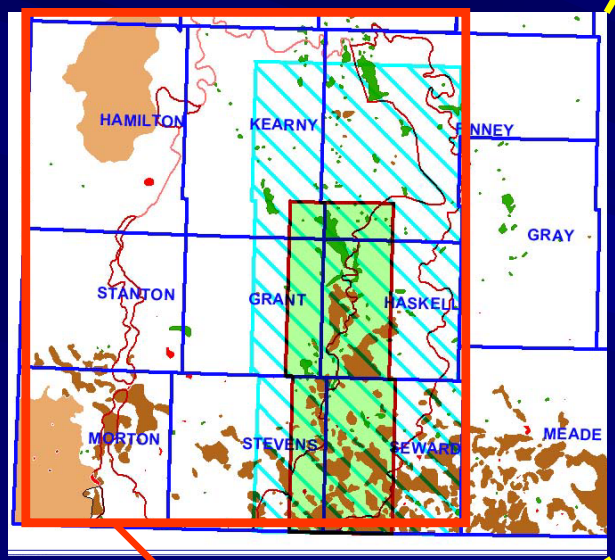
Original Project Study Area

Wellington Field (Sumner County) + 17+ Counties

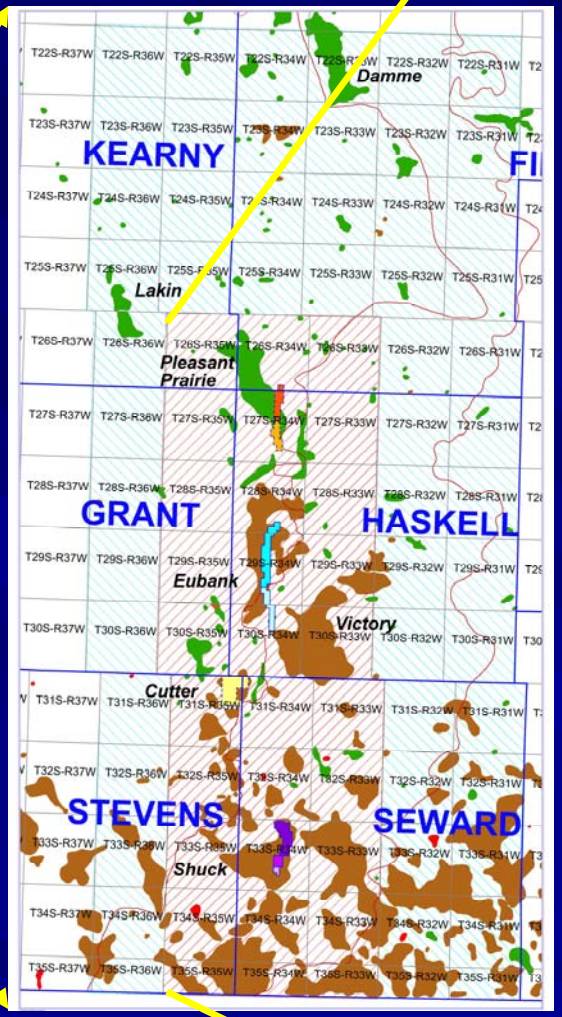


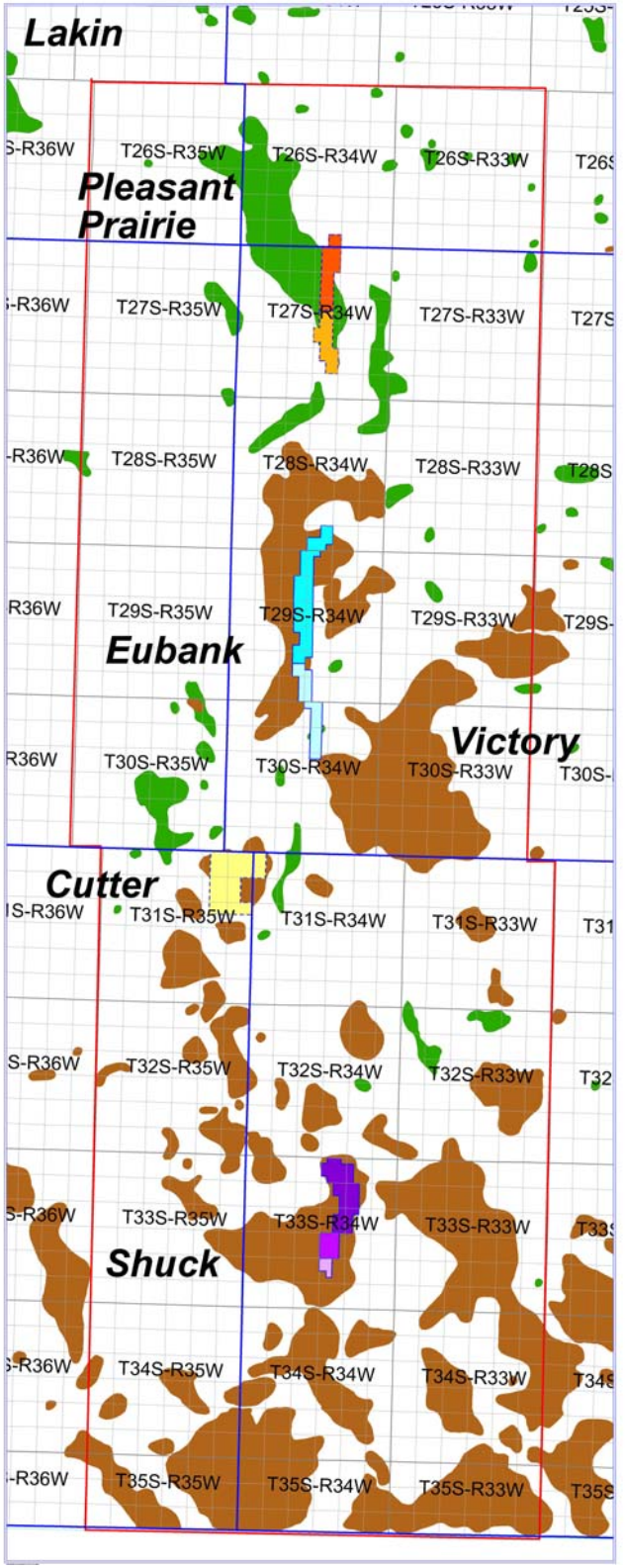
Project Extension Study Area

Western Annex



Western Annex Area



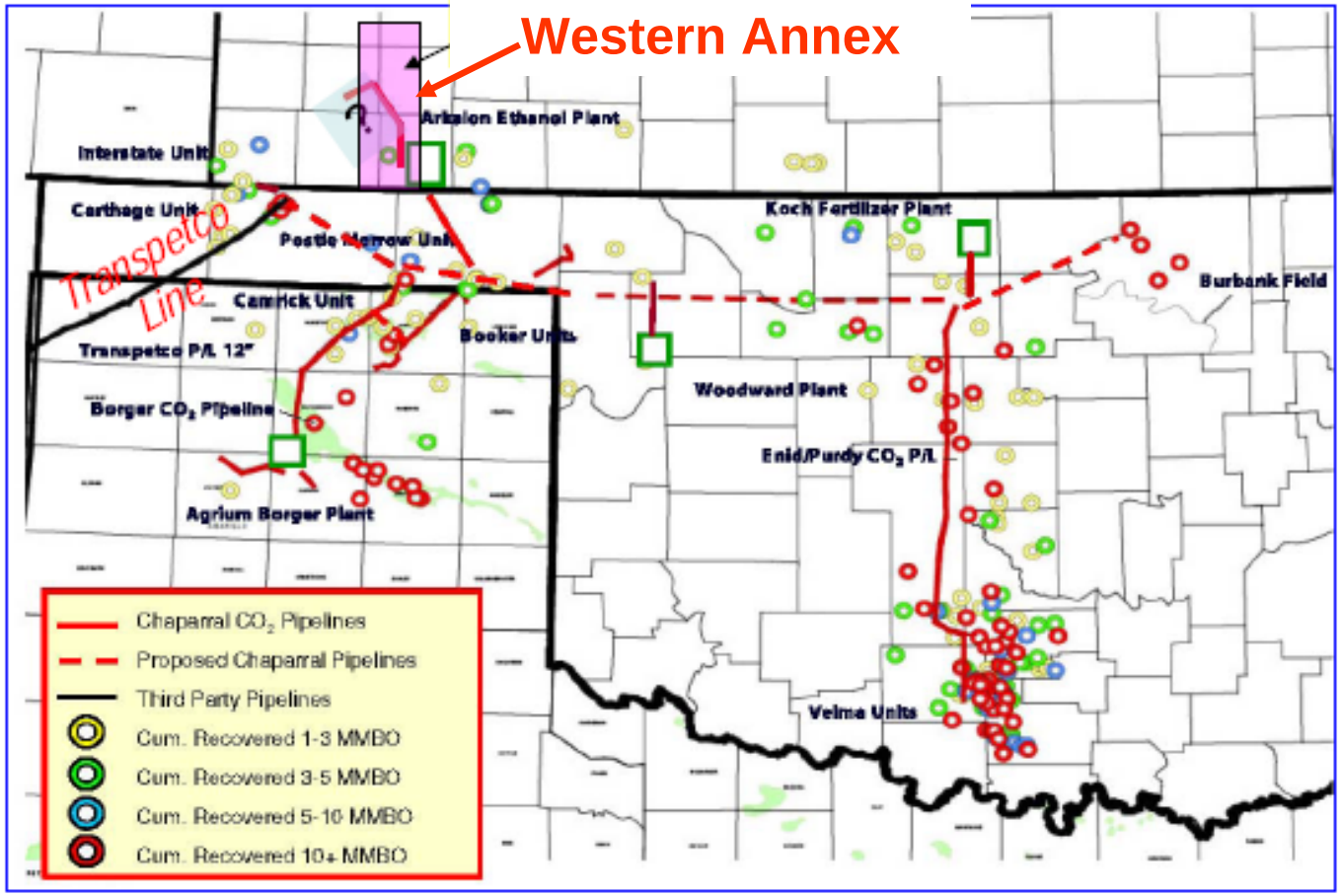


Project Objectives

- **Build Geomodels**
  - Field Scale
    - Wellington field (Sumner County)
    - Chester/Morrow fields (Western Annex)
  - Regional Scale – Integrated Model
    - Arbuckle saline aquifer - 17+ counties (south-central KS)
    - Arbuckle Saline Aquifer - Western Annex
- **Simulate CO_2 sequestration potential – Arbuckle Saline Aquifer**
  - 17+ county area & Western Annex
    - Identify and model potential sequestration sites
    - Estimate sequestration capacity of Arbuckle saline aquifer in KS
- **Simulate sequestration potential – CO_2-EOR in depleted fields**
  - Wellington field (Sumner County)
  - Several Chester/Morrow fields – Western Annex
- **Risk analysis related to CO_2 sequestration**
- **Technology transfer**

Existing CO_2 Pipeline Infrastructure
Vicinity of *Western Annex*

Infrastructure is gradually building:
Oklahoma CO2 Infrastructure



From: Chaparral Energy presentation at JP Morgan conference (March 2010)
http://www.chaparralenergy.com/pressreleases/JP%20Morgan%20HY%20Conf%20March%202010.pdf

Industry Partners

KU KANSAS GEOLOGICAL SURVEY
The University of Kansas

U.S. DEPARTMENT OF ENERGY

DEPARTMENT OF GEOLOGY
KANSAS STATE UNIVERSITY

KU THE UNIVERSITY OF KANSAS
Department of Geology

BEREXCO

PARAGON
GEOPHYSICAL SERVICES, INC

fairfieldnodal

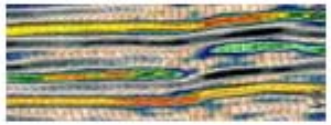
noble energy

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

Industry Partners – Western Annex

SW Kansas CO_2 Sequestration Consortium

Anadarko Petroleum Corporation

BEREXCO

CIMAREX

CISCO ENERGY

GloriOil

CELEBRATING 20 YEARS

MERIT ENERGY COMPANY

Industrial and Electrical Power Sources of CO_2

Project Team Members

Principal Investigators
Saibal Bhattacharya -- Lead Engineer
W. Lynn Watney - Lead Geologist

UNIVERSITY OF KANSAS

Kansas Geological Survey
Co-Principal Investigators
Kerry D. Newell, Co-PI -- stucture and diagenesis
Jason Rush, Co-PI -- Petrel geomodeling and data integration
Richard Miller, Co-PI -- seismic interpretation, shearwave analysis
John Doveton, Co-PI -- log petrophysics and core-log modeling
Jianghai Xia, Co-PI -- gravity-magnetics modeling & interpretation
Marios Sophocleous, Co-PI -- aquifer modeling & well testing

Key Personnel
John Victorine -- Java web app development
David Laflen -- manage core & curation
Mike Killion -- modify ESRI map service for project
Kurt Look, Glen Gagnon, manage and integrate data
Deb Stewart, Dan Suchy, LeaAnn Davidson,
Patrick Totaro, Matt Kuntzsch, Matt Kuntzsch, Jennifer DiDonato
Dana Heljeson - website
Valerie Moreau - accounting and reporting

KU Department of Geology
Evan Franseen, Co-PI -- stratigraphy and diagenesis of OPAS
Robert Goldstein, Co-PI -- diagenesis, fluid inclusion
Bradley King, GRI, diagenesis
David Fowle, Co-PI -- reactive pathways, microbial catalysis
Jennifer Roberts, Co-PI -- reactive pathways, microbial catalysis
Geology Technician (TBD) - fluid/rock handling
Aimee Scheffer - Microbial studies
Breanna Huff - Microbial studies

Services
LOGDIGI, LLC, Katy, TX - wireline log digitizing
KOGER, Dallas, TX - remote sensing data and analysis

Noble Energy, Houston, TX; Denver, CO
- collaborating company, fields adjoining Wellington
David DesAutels

SUBCONTRACTS

Kansas State University - Seismic and Geochemical Services
PI- Saugata Datta -- reactive pathways and reaction constants
PI- Abdelmoneam Raef -- seismic analysis and modeling
GRA - Robinson Barker - aqueous geochemistry
GRA 2 - seismic analysis and modeling

Bittersweet Energy, Inc., Wichita, KS
Tom Hansen, Principal, Wichita, Geological Supervision - regional data, hydrogeology of Arbuckle
Paul Gerlach -- regional data acquisition
Larry Nicholson -- regional data acquisition
Anna Smith -- regional data acquisition
Ken Cooper, Petrotek Engineering, Littleton, CO- engineer, well injection, hydrogeology
John Lorenz, FractureStudies, Edgewood, NM -- structural analysis

CMG - Simulation Services, Calgary, Alberta
simulation software and Greenhouse Gas Simulation Consultancy

Weatherford Laboratories, Houston, TX
core analyses

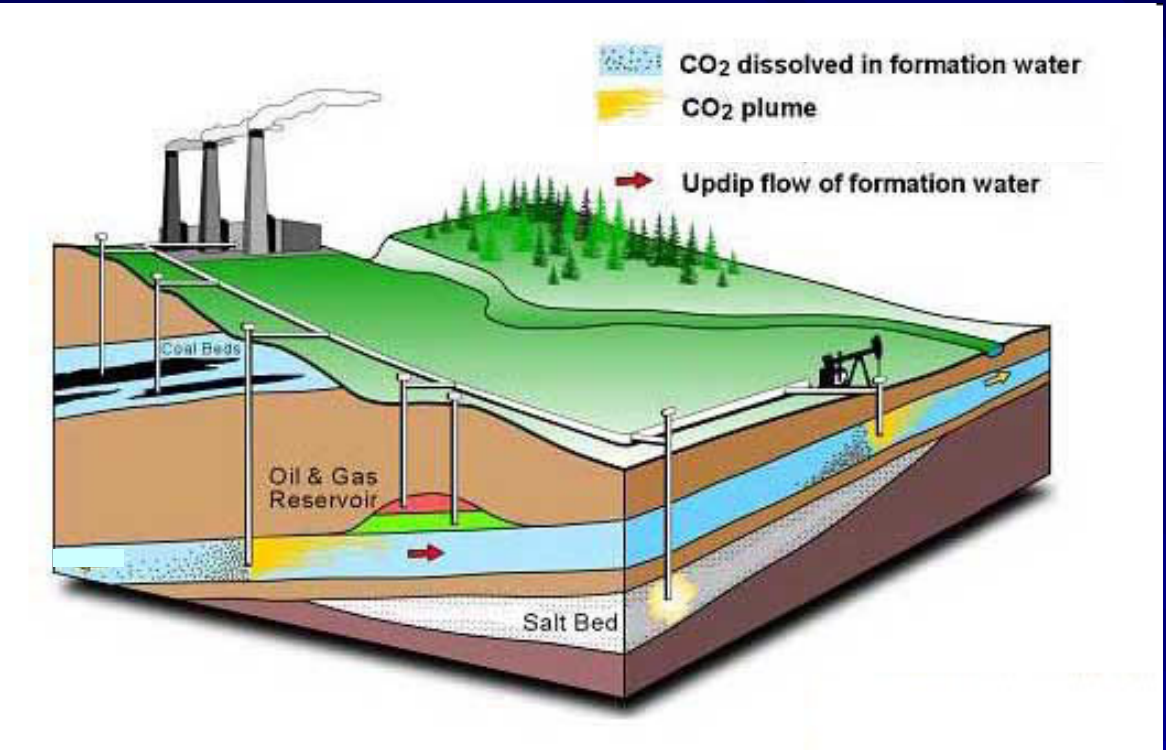
Berexco, Beredco Drilling -- Wichita, KS
access to Wellington Field; drilling, coring, completion and testing; modeling and simulation
Key Berexco staff
Dana Wreath - manager, reservoir and production engineer
Randy Koudele - reservoir engineer
Bill Lamb - reservoir engineer
Halliburton, Liberal, KS -- wireline logging services
Hedke-Saenger Geoscience, LTD., Wichita, KS - geophysical interpretation
Susan E. Nissen, McLouth, KS -- Geophysical Consultant - volumetic curvature
Russ Opfer, Lockhart Geophysical, Denver, CO -- gravity & mag
Bruce Karr, Fairfield Industries, Inc., Denver, CO -- 2D, 3D processing
Paragon Geophysical Services, Wichita, KS -- 3D seismic acquisition
Echo Geophysical, Denver, CO -- 3D p-wave seismic processing
Converging Point - QC seismic acquisition

Project Enhancement - Western Annex
Enhanced Oil Recovery - Chester/Morrow Fields
Martin Dubois -- geologist, project manager
John Youle -- geologist, geomodel development
Ray Sorenson -- geologist, geomodle development
Paul Gerlach -- geologist, geomodel development
petroleum engineer (TBN) -- reservoir simulation
Dennis Hedke, Susan Nissen - seismic interpretation
Paragon - seismic acquisition

Technical Outreach
Presentations to date

- Jan 2010 - Kansas House Energy and Utilities Committee, Topeka
- Feb. 2010 - DOE National Energy Technology Lab (NETL), Pittsburg, PA
- Apr 2010 - Southwest Kansas Royalty Owners Association, Hugoton
- Apr 2010 - Kansas Independent Oil and Gas Association, Great Bend
- May 2010 - Kansas Water Authority, Wichita
- May 2010 - EPA Region 7 UIC Meeting, Kansas City
- Aug 2010 - Kansas Next Step Oil and Gas Seminar, Hays
- Sep 2010 - Kansas Department of Health and Environment, Geology Fall Seminar, Wichita
- Oct 2010 – DOE-NETL Annual Review Meeting, Pittsburgh
- Nov 2010 - Kansas Geophysical Symposium
- Nov 2010 - Briefing to Kansas Corporation Commission officials on drilling at Wellington Field
- Nov 2010 – GSA Annual Meeting, Denver
- May 2011 – Abstract accepted for AAPG 2011 Annual Meeting, Houston

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

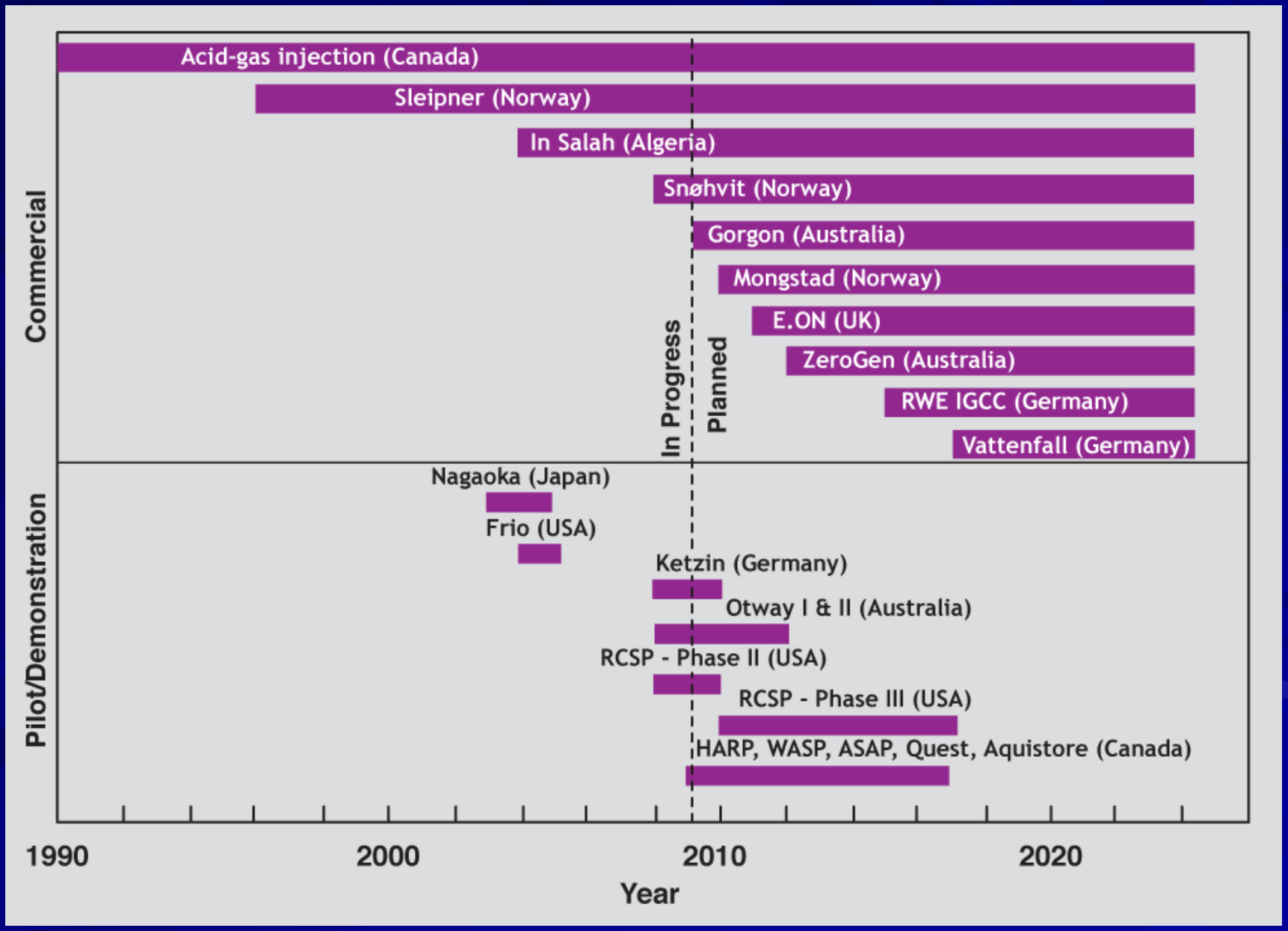
Formation Type	*10^9 Metric Tons*	*%*
Saline Aquifers	3,297 – 12,618	91.8 – 97.5
Unmineable Coal Seams	157 – 178	4.4 – 1.4
Mature Oil & Gas Reservoirs	138	3.8 – 1.1
Total Capacity	3,592 – 12,934	100.0

Dec 1, 2010 DOE Update:

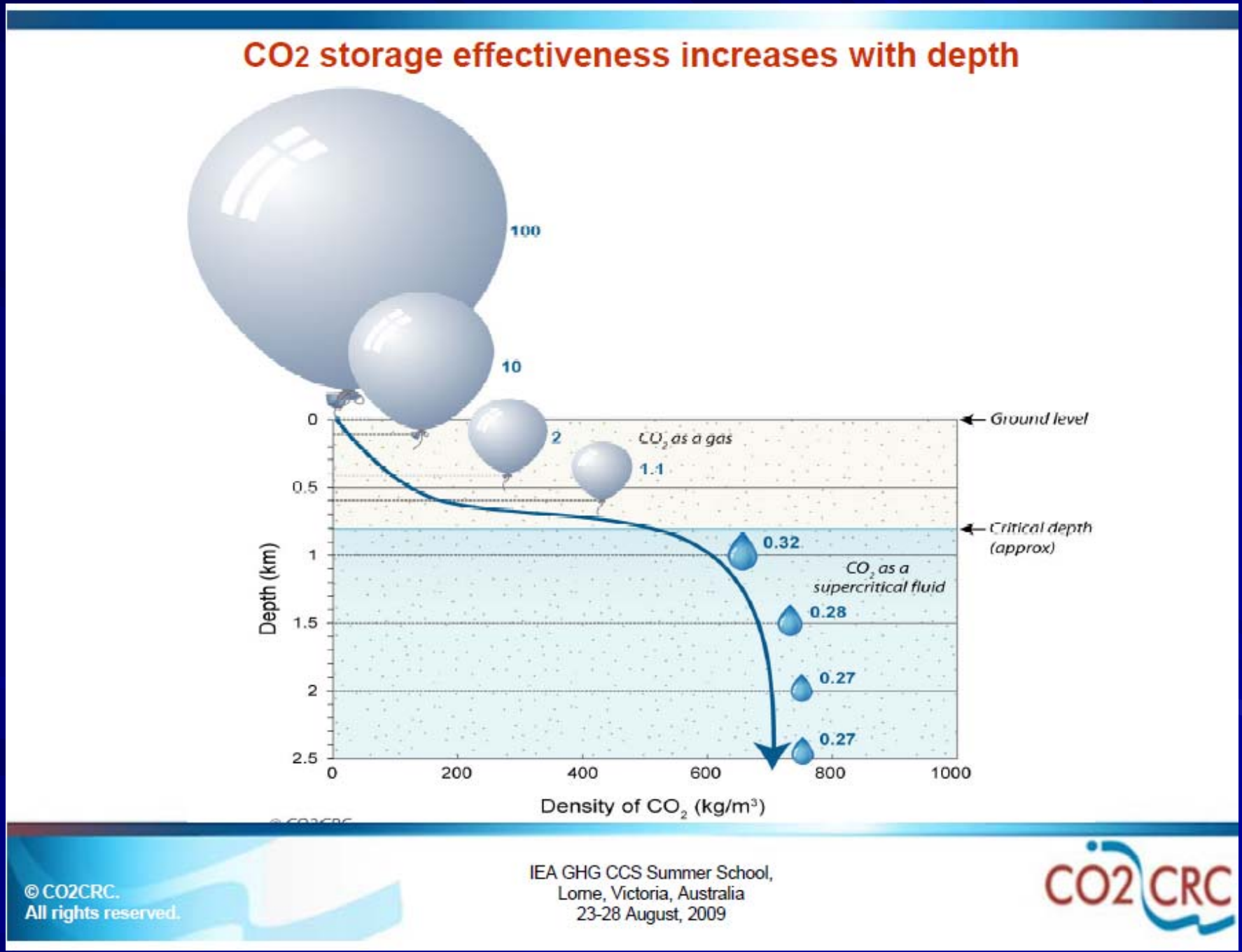
500 to 5700 yrs of storage capacity

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

CO_2 Sequestration Projects Worldwide
Deep Saline Aquifers



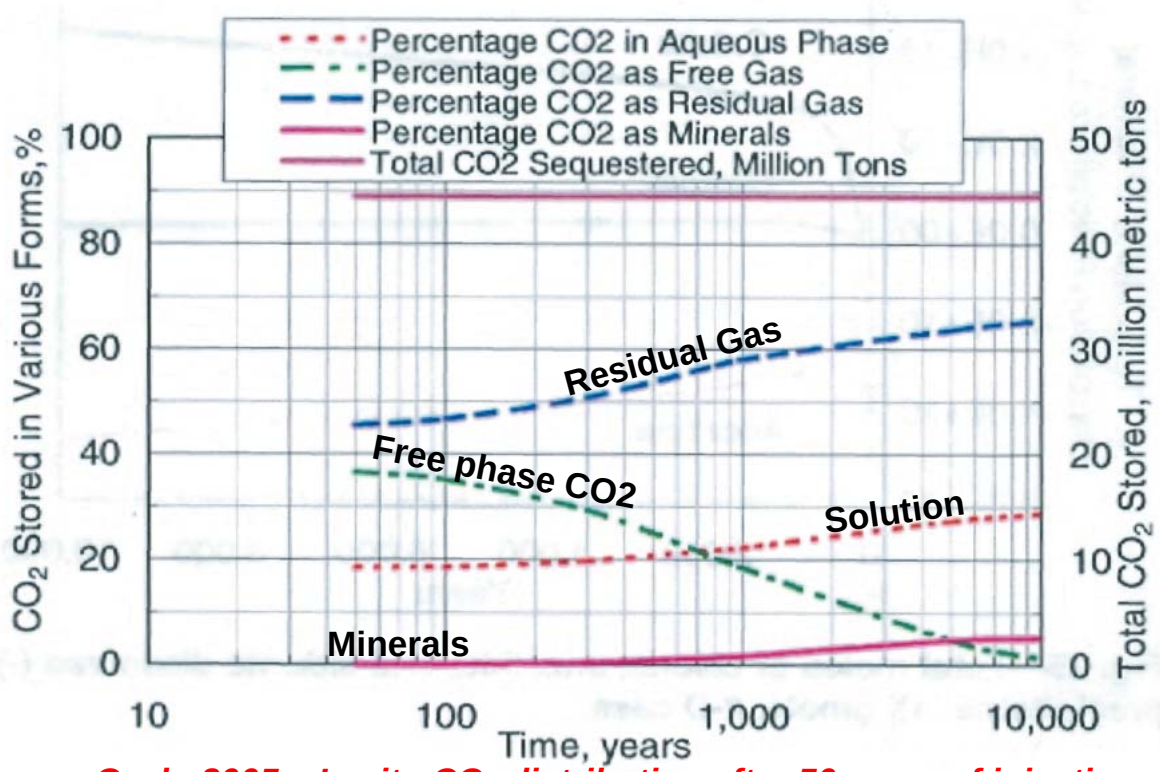
Effectiveness of Injecting Supercritical CO_2



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)**



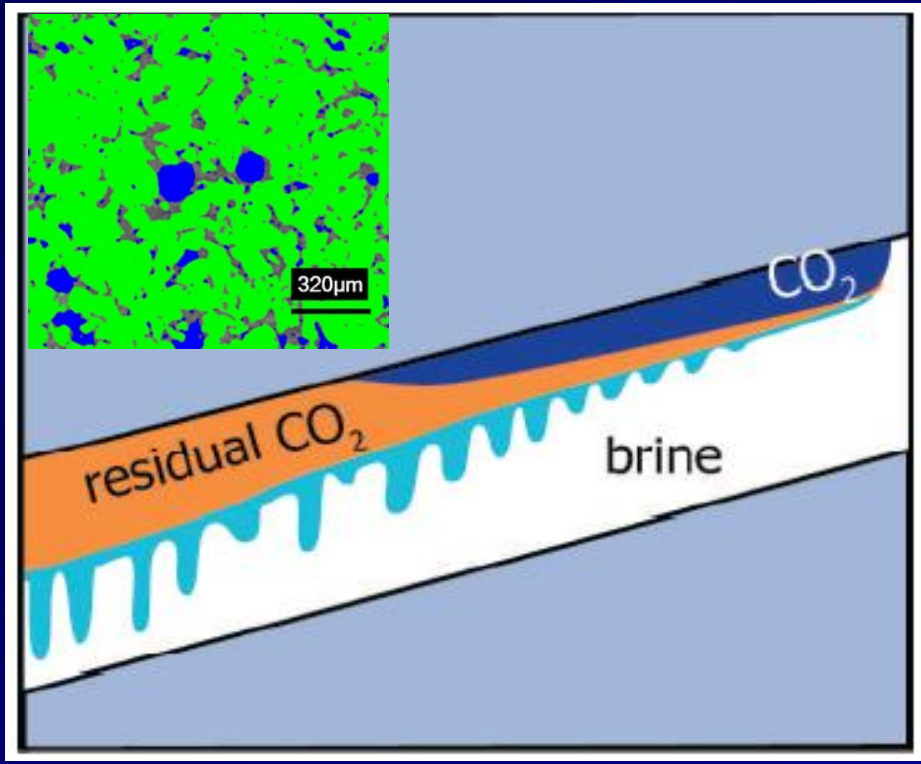
Ozah, 2005 – In situ CO_2 distribution after 50 years of injection

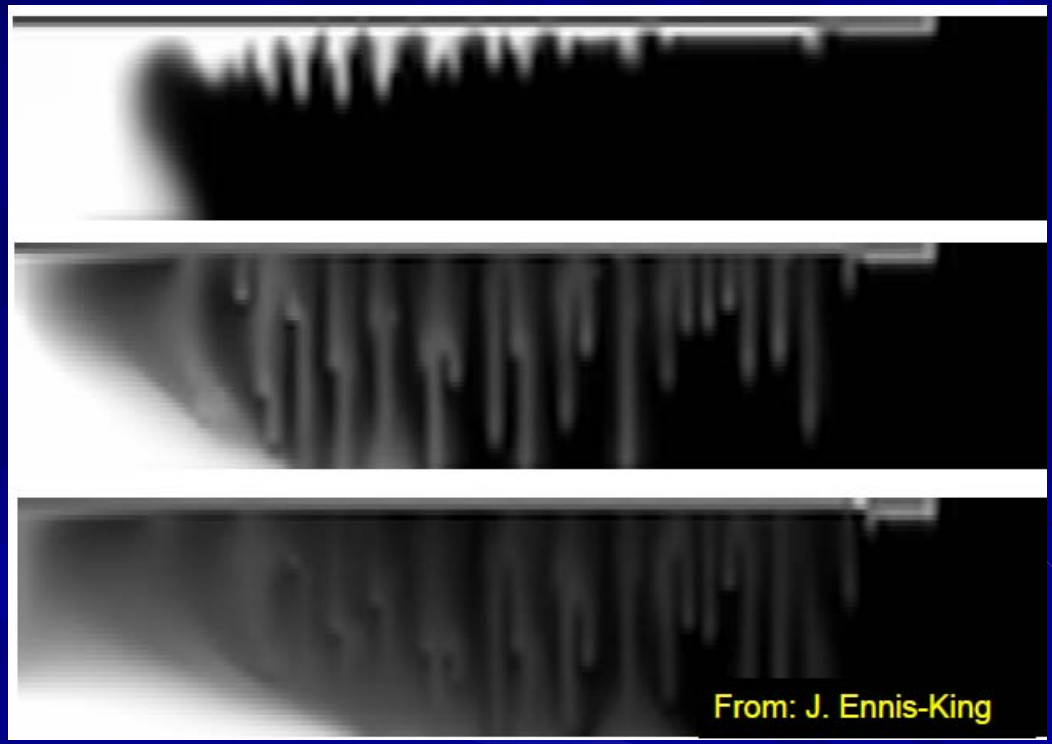
CO_2 Entrapment Audit:

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%***

Dissolution of CO_2 in Brine

Convection Cycle increases entrapment



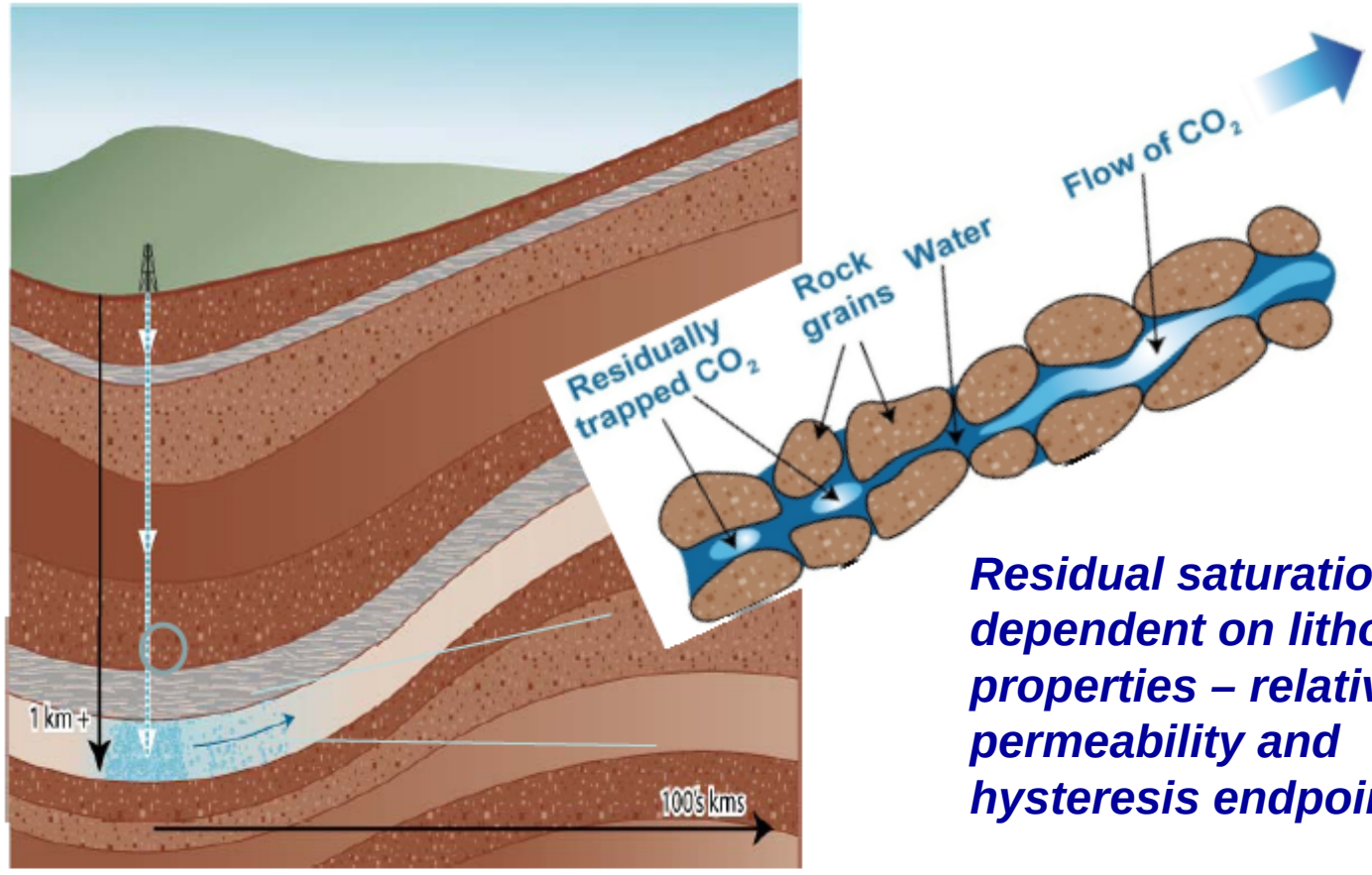


CO2CRC

CO_2 Entrapment as Residual Gas

IEA Greenhouse Gas R&D Programme

Residual Trapping



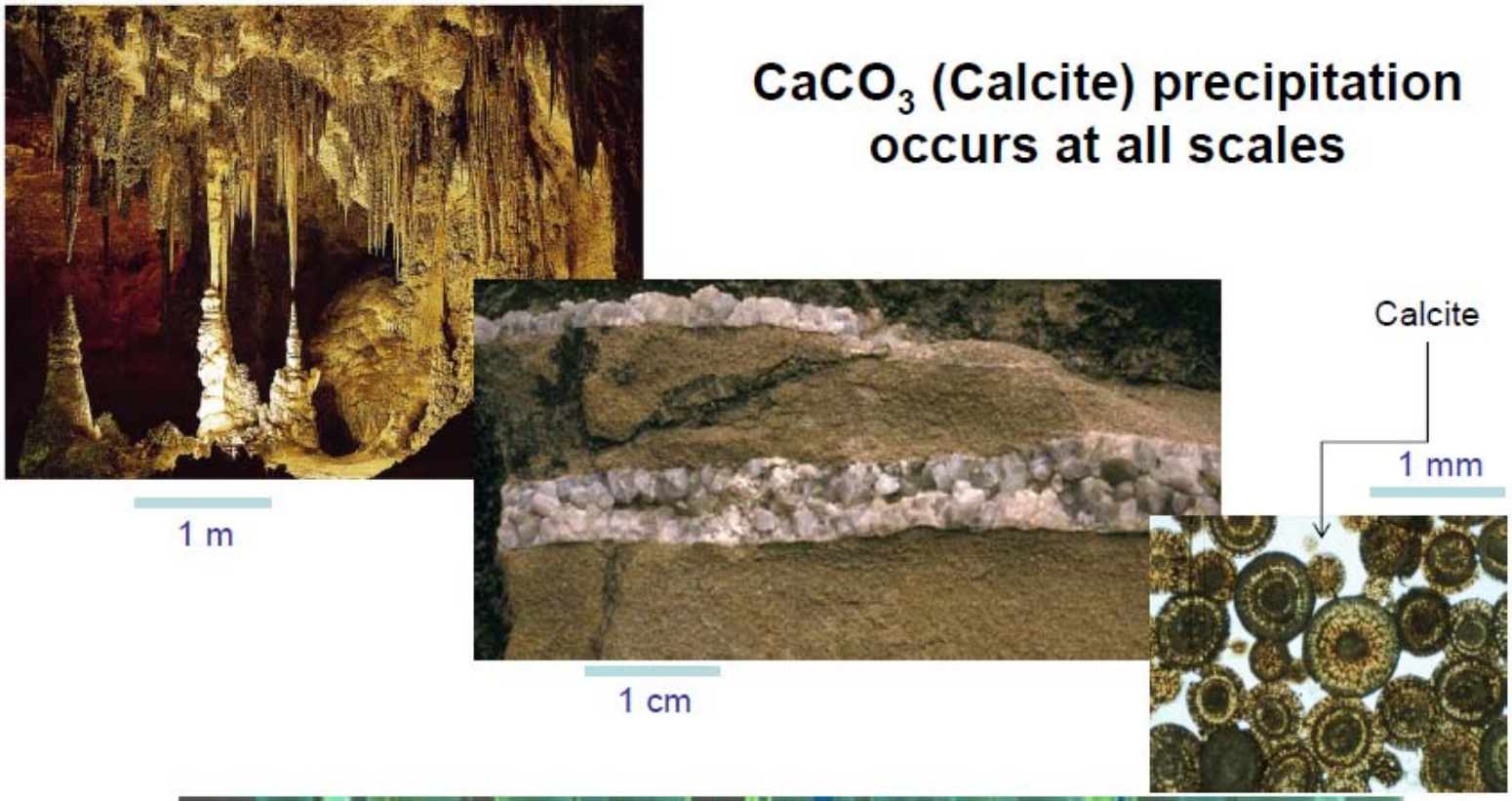
Residual saturation dependent on lithofacies properties – relative permeability and hysteresis endpoints

CO_2 Entrapment as Minerals

IEA Greenhouse Gas R&D Programme

Mineral Trapping

$CaCO_3$ (Calcite) precipitation occurs at all scales



www.ieagreen.org.uk

Very slow process.

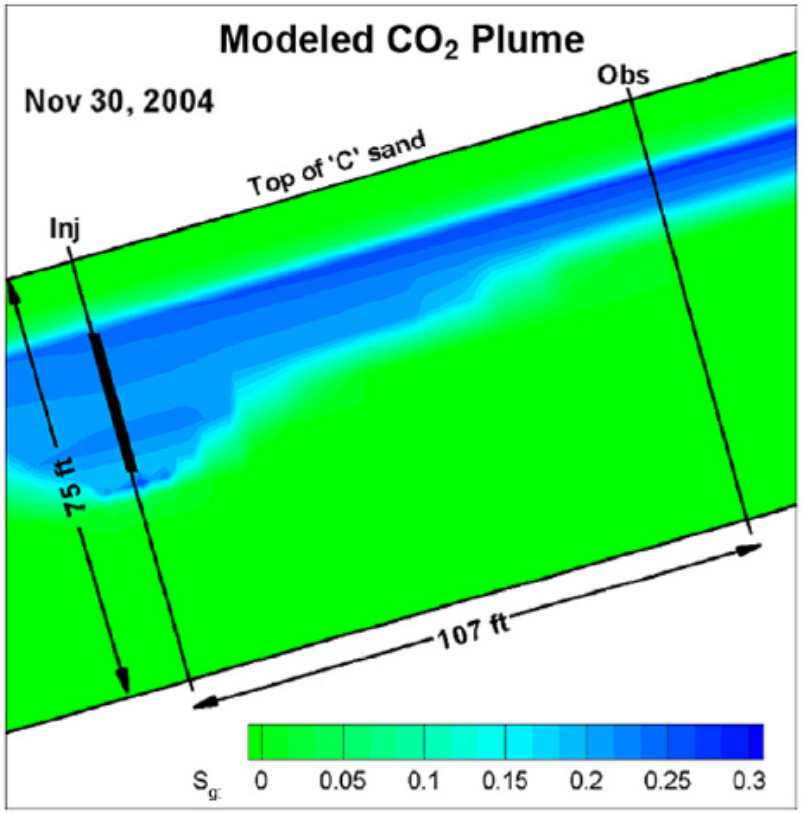
Important effects –

1) Precipitation leading to injectivity changes.

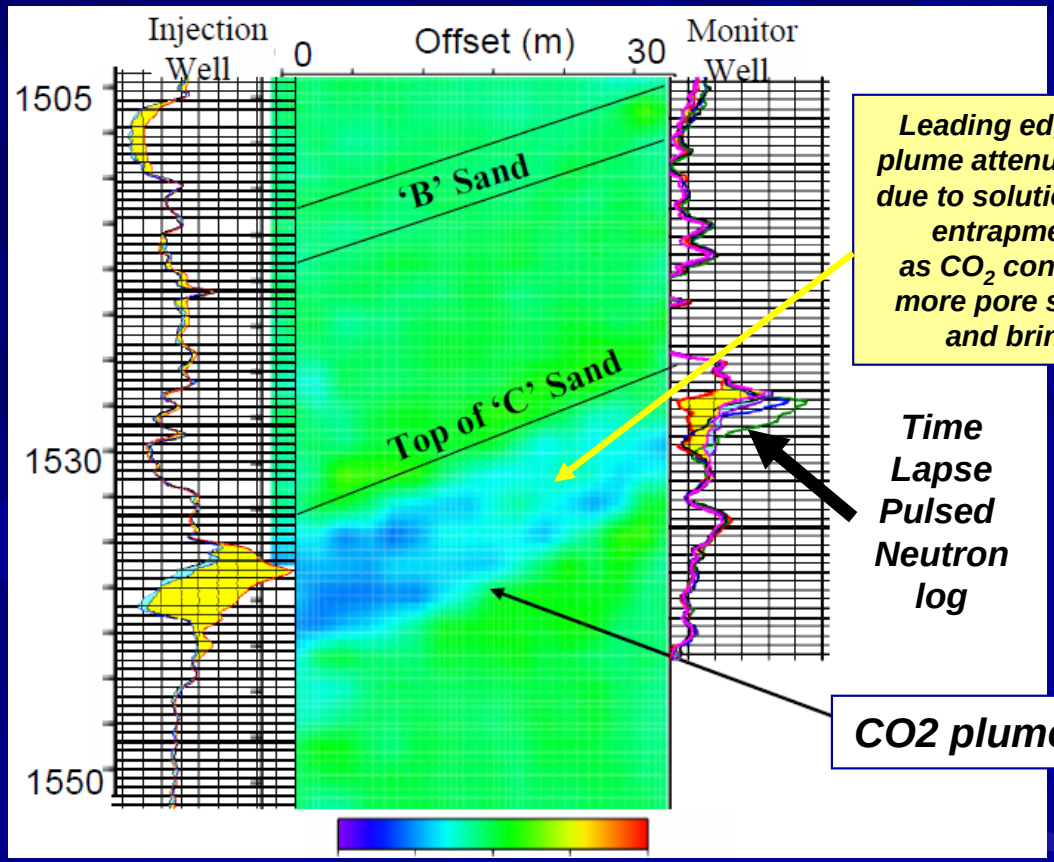
2) Dissolution and creation of cavities
-- Adversely affect integrity of the caprock.

Frio Pilot Injection (Texas)
- Free Phase Supercritical CO_2 Plume

Plume from Simulation



Plume from cross-well seismic tomogram

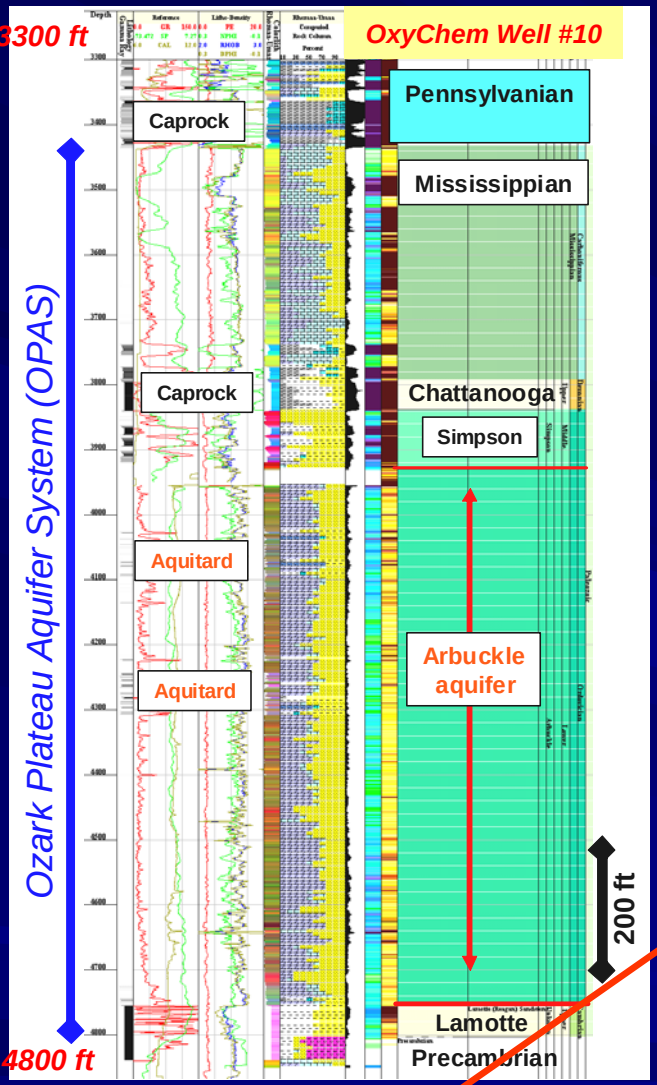


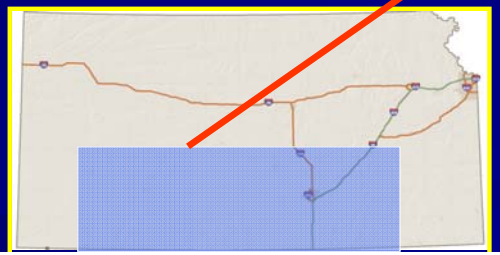
Current tools (geologic modeling, reservoir simulation, wireline logging, 3D seismic) are capable of tracking subsurface CO_2 migration.

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

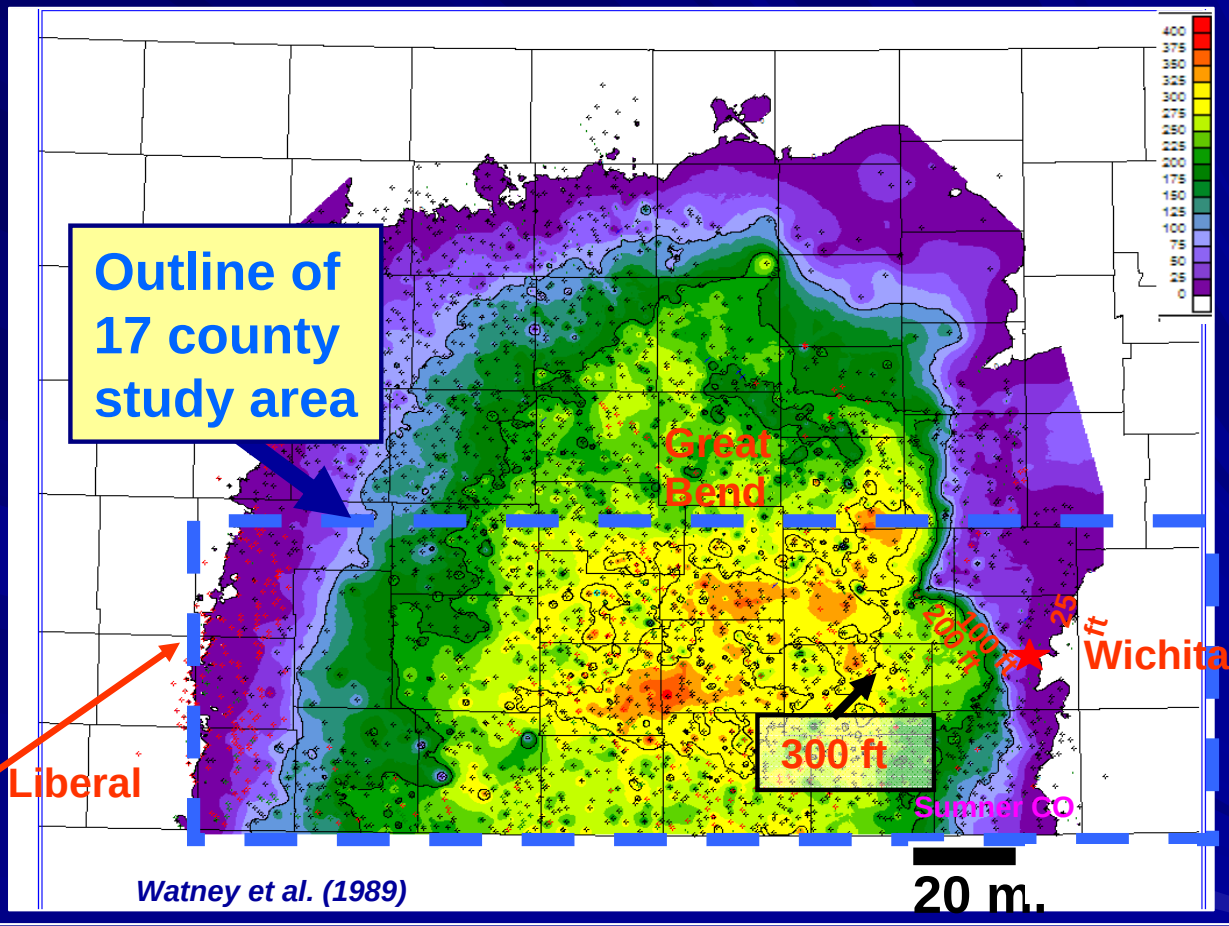
Ozark Plateau Aquifer System

Arbuckle Saline Aquifer with Primary, Secondary, and Tertiary Caprocks





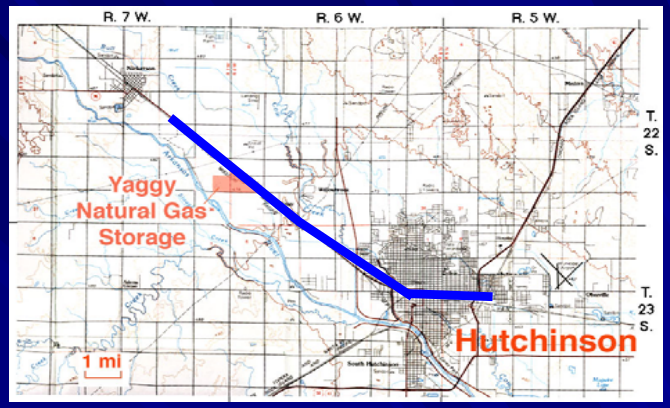
Net Halite (salt) Isopach (thickness), CI 100’



Total Permian evaporite thickness ranges from 400 to 2000’ in south-central KS. These evaporites serve as ideal cap rocks being located between shallow freshwater aquifers and hydrocarbon bearing strata and deeper Arbuckle saline aquifer.

Yaggy Gas Storage Leak - 2001

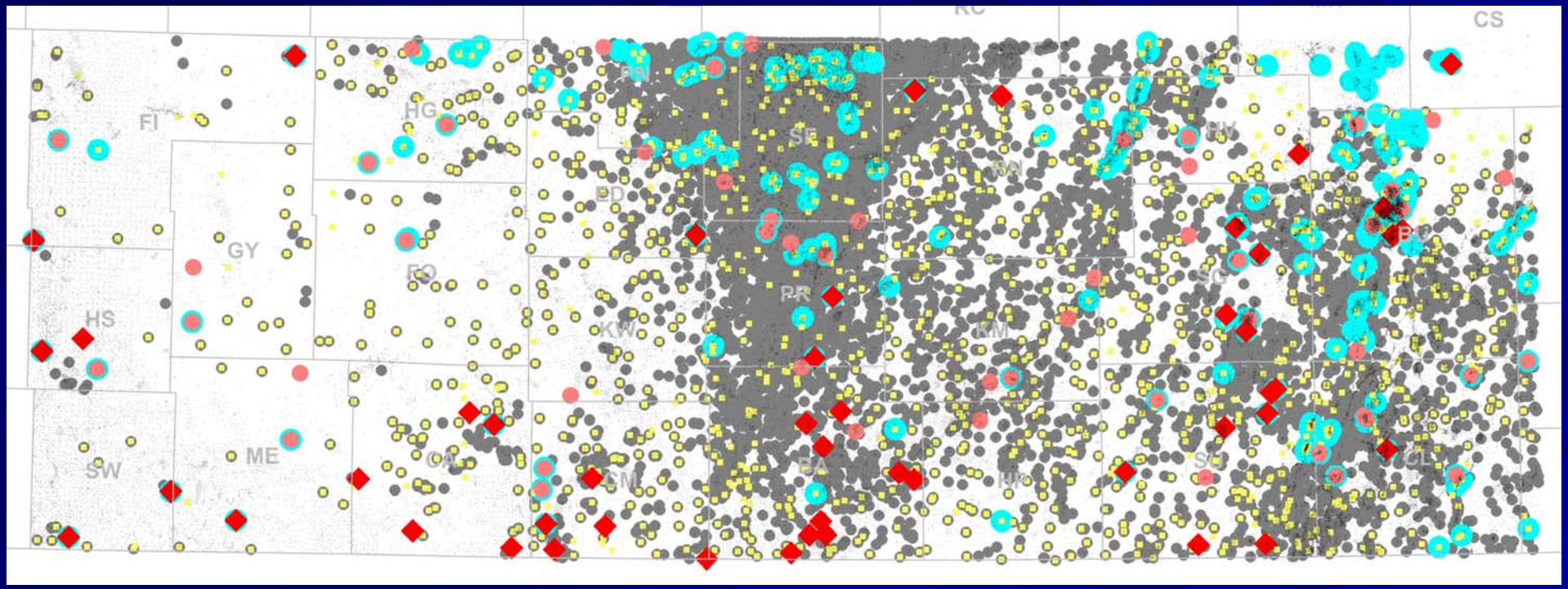
Site selection for CO_2 sequestration CRITICAL, because all wells drilled in the area have to be accounted for and properly completed before onset of CO_2 injection.



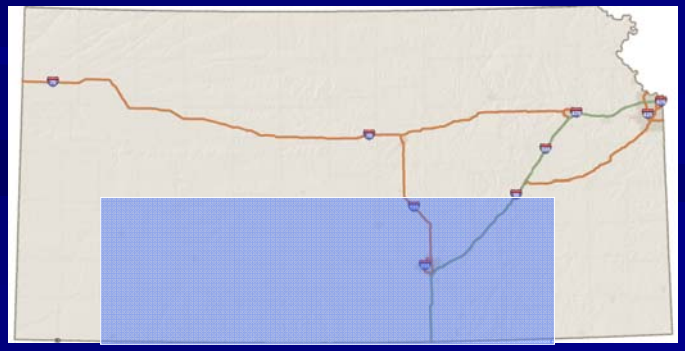
Cross Section Showing Hutchinson Salt Member in Relation to other Geologic Strata

Watney et al. (2003)

Wells Digitizing Inventory
Regional Mapping & Log Analysis



30 mi.

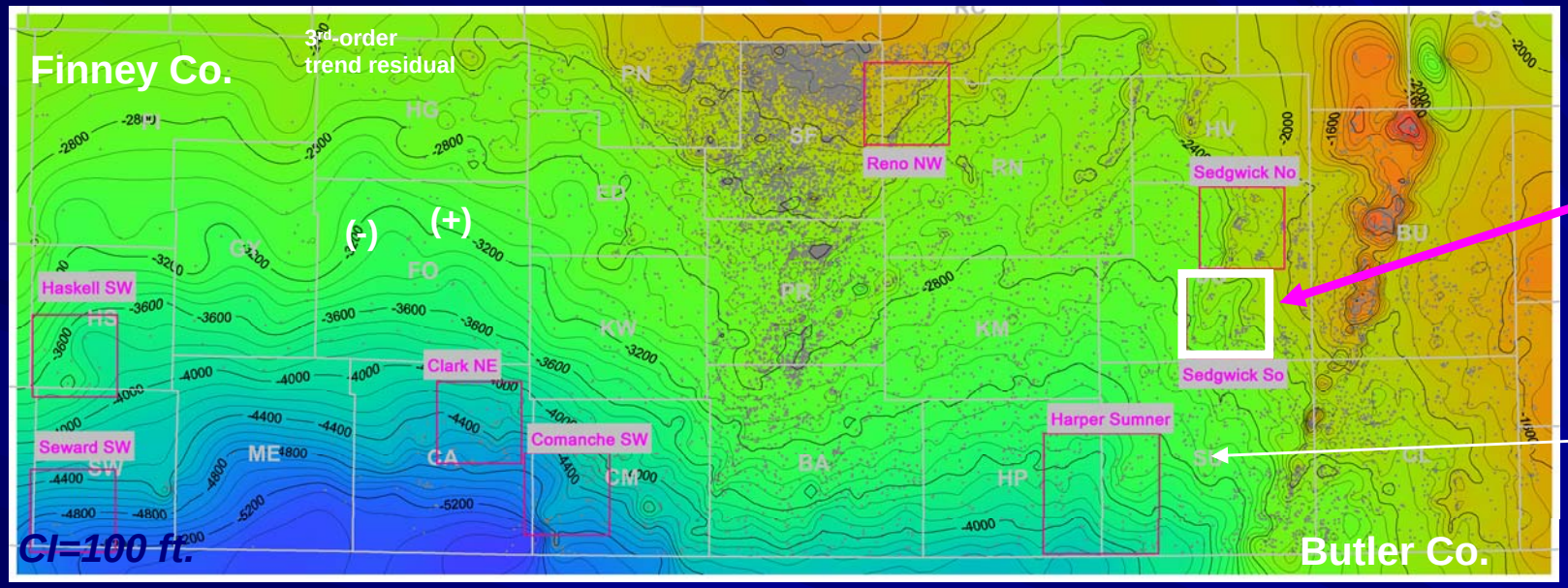


- LAS Files (300+ wells)
- Pre-Cambrian Wells = 292
- Arbuckle Wells = 14,105
- Type Wells (>200’ into Arbuckle) = 1,417
- Super Type Wells (>400’ into Arbuckle, 1980 or later) = 91

Regional Study – Tasks Completed and In Progress

Arbuckle Mapping and Areas of Interest

Structure top of Arbuckle Group, regional study area

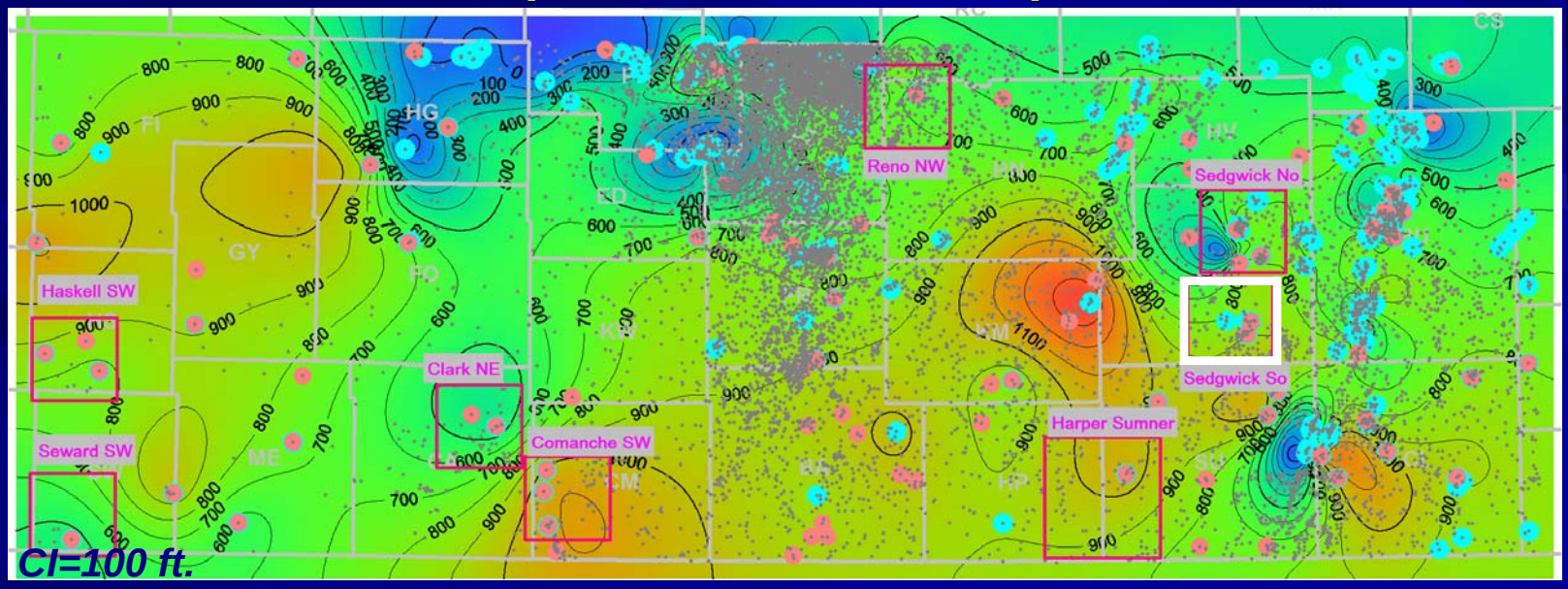


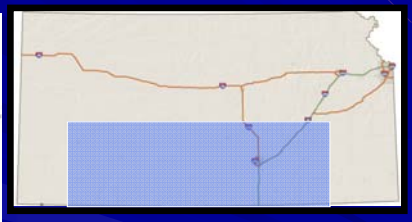
Initial Arbuckle modeling site southern Sedgwick County

Wellington Field

50 mi

Isopach Arbuckle Group





AREAS OF INTEREST

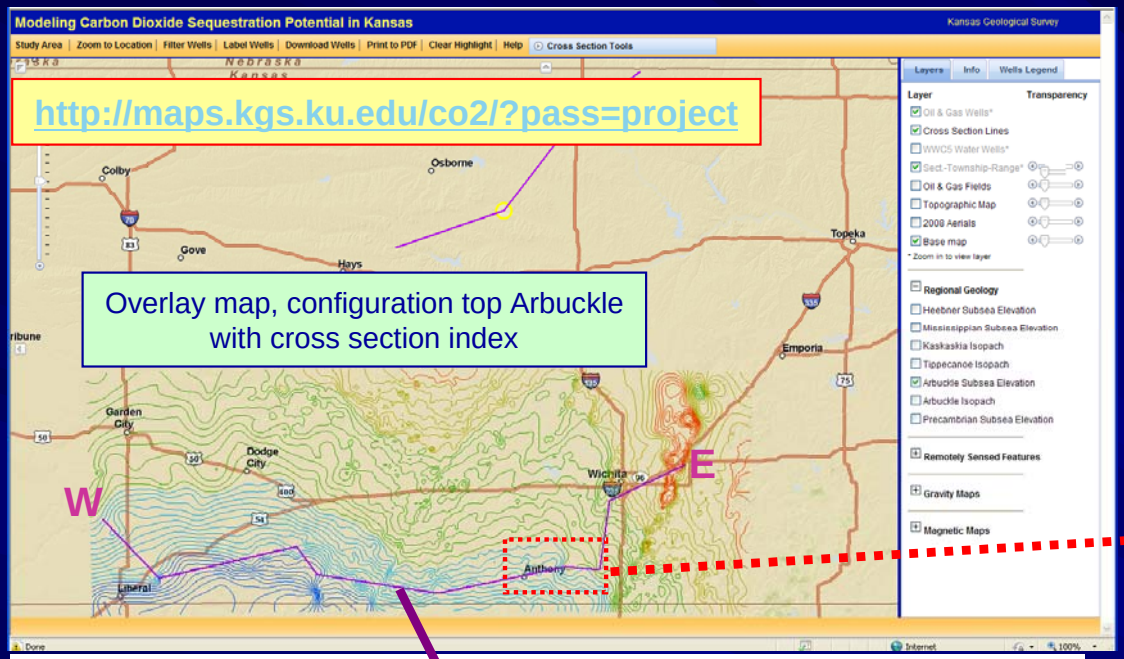
ARBK Penetrations

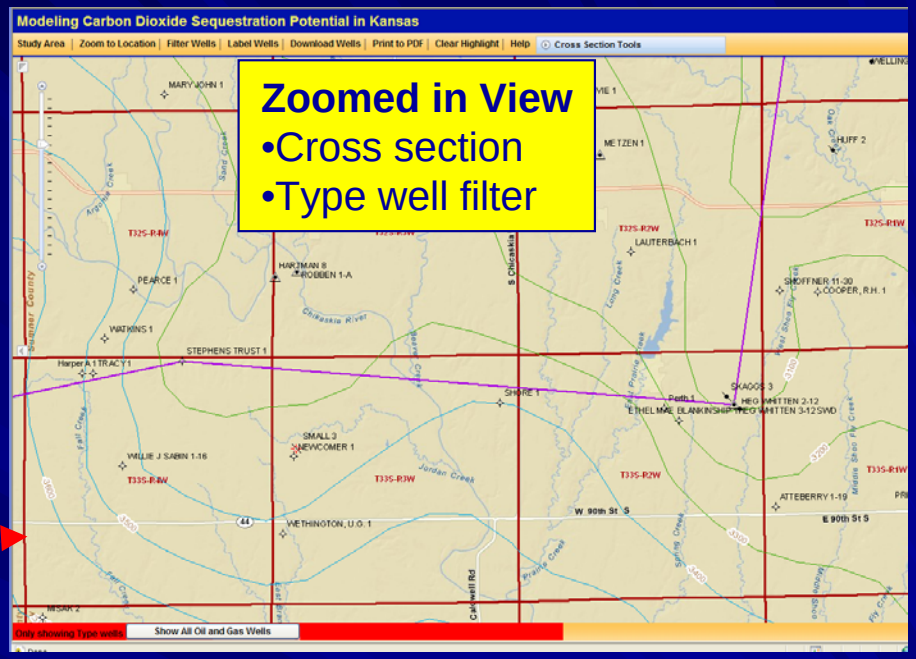
Super Type Well (91 wells)

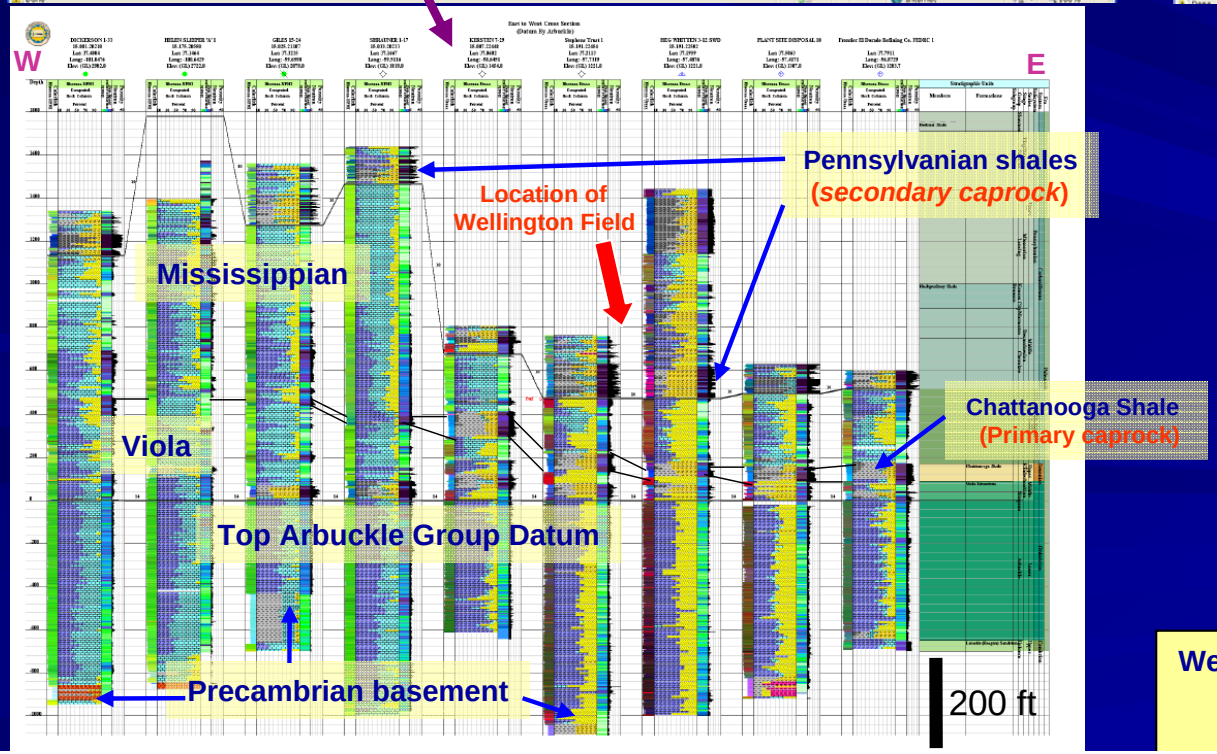
P-C Tests (292 wells)

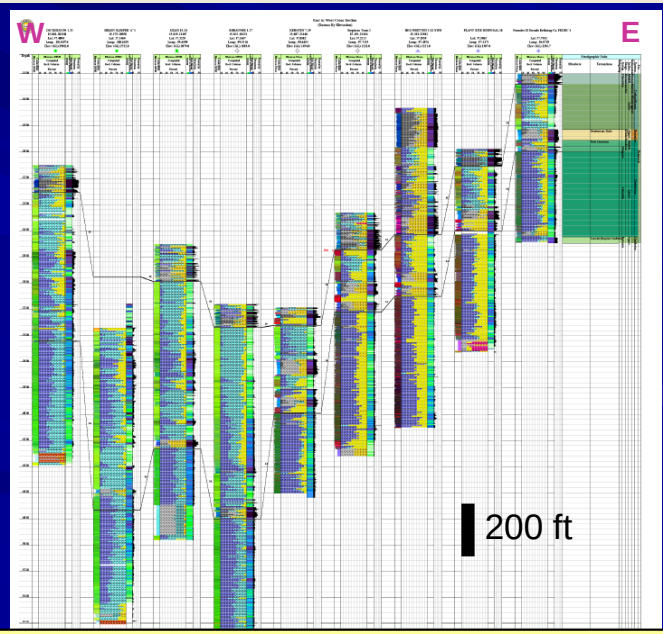
Regional Study – Tasks Completed and In Progress

Interactive Web-based Project Mapper and Well Data Analysis Tools





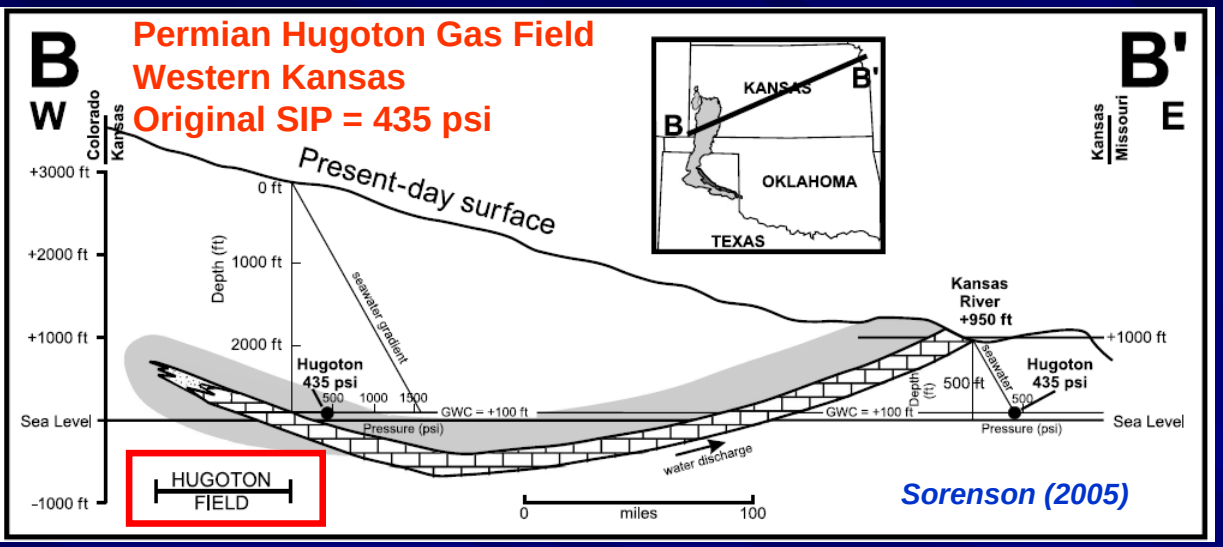




West-East Stratigraphic (left) & Structural (right) Cross Sections
Log-derived lithology and porosity
Mississippian to Precambrian interval

Regional Study – Tasks Completed and In Progress

Arbuckle Saline Aquifer Connected to Outcrop – Open System

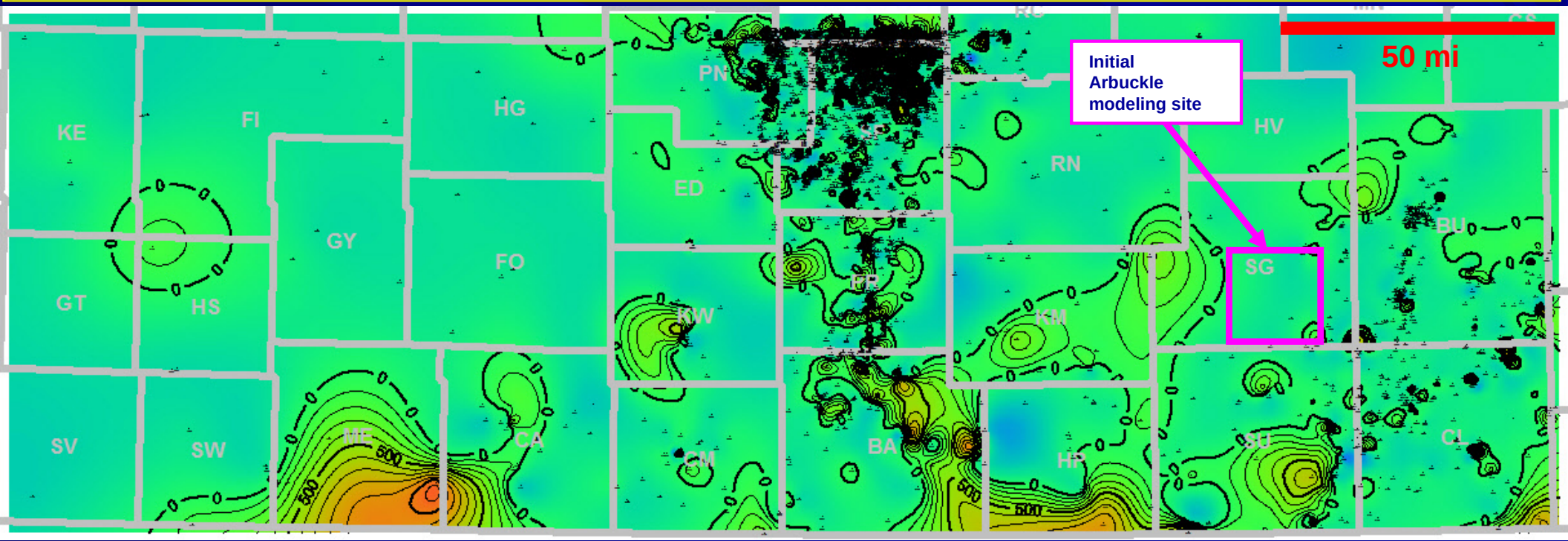


Arbuckle exposure at base of Missouri River, north-central Missouri – Elevation 450 ft

& ~200 mi northeast

Assume hydrostatic gradient = 0.435 psi/ft

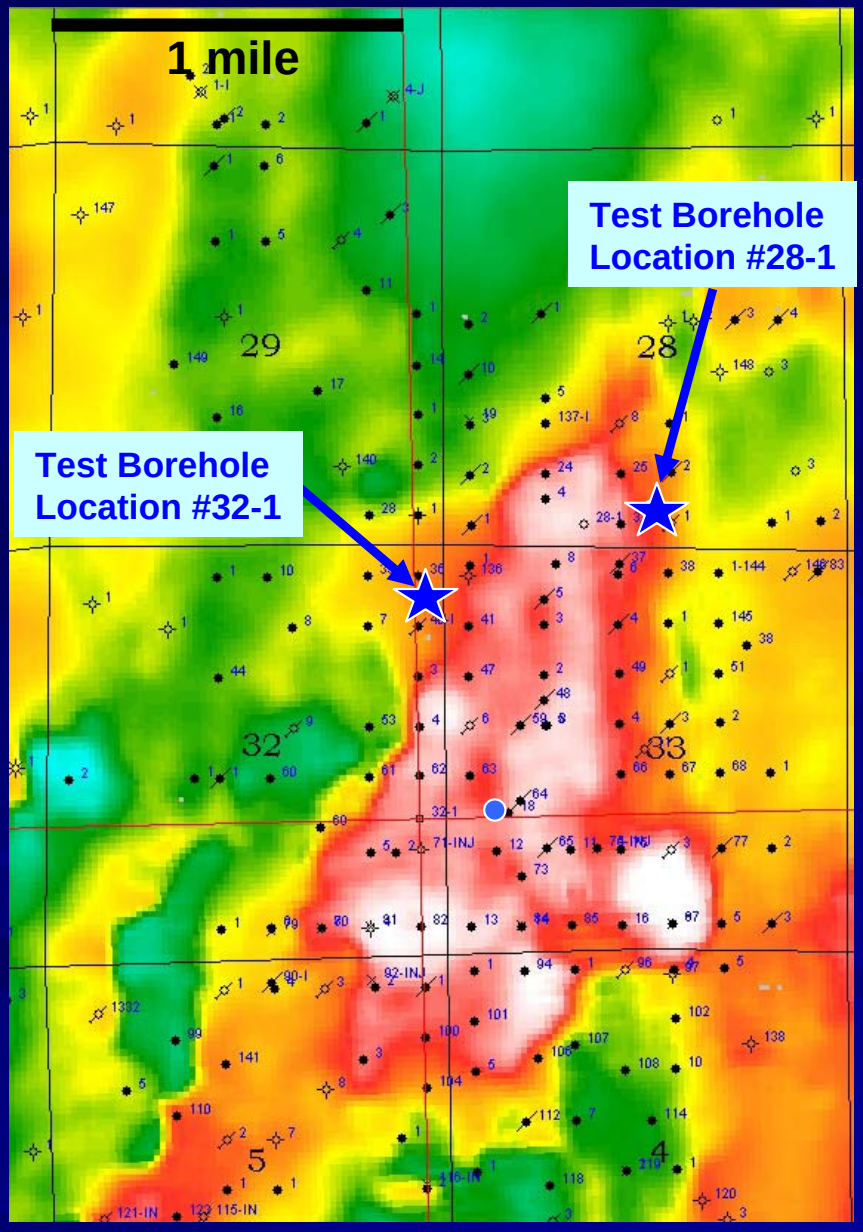
Map of the difference between estimated hydraulic head at base of Arbuckle test interval and measured shut-in pressure



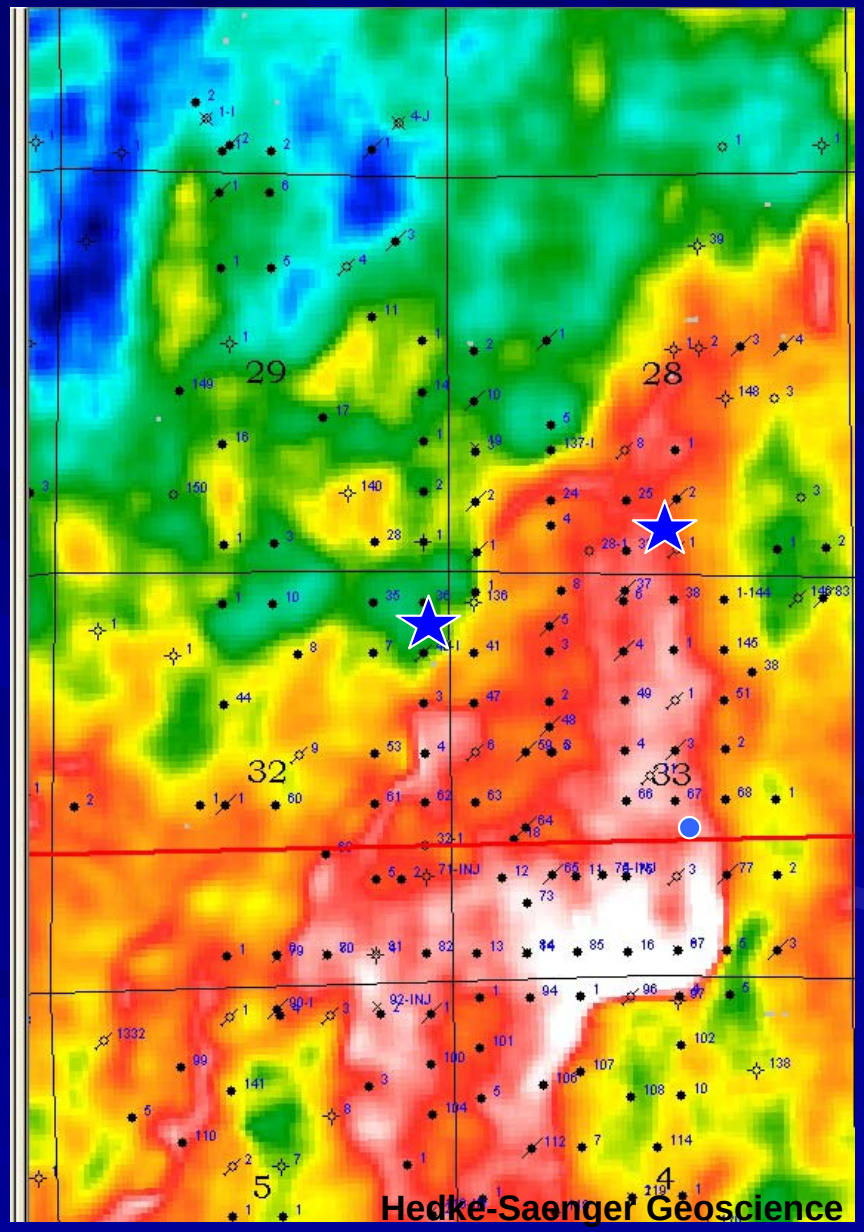
Wellington Field Study – Tasks Completed and In Progress

3D seismic P-Wave Processing, Initial Interpretations, & Borehole Site Selection

Mississippian Time Structure



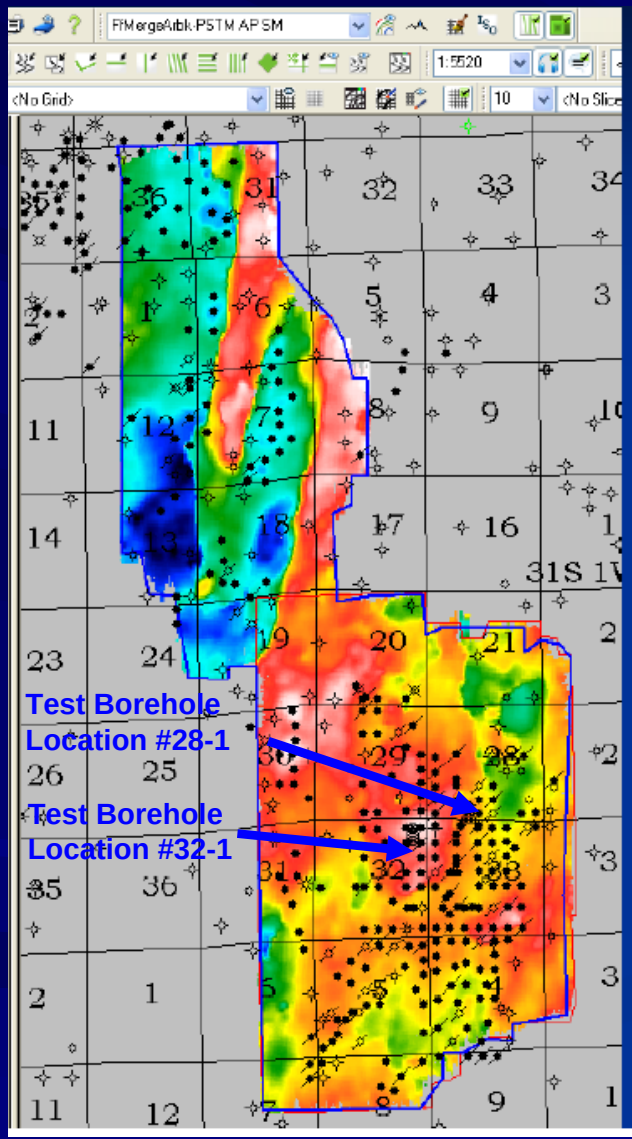
Mississippian Amplitude



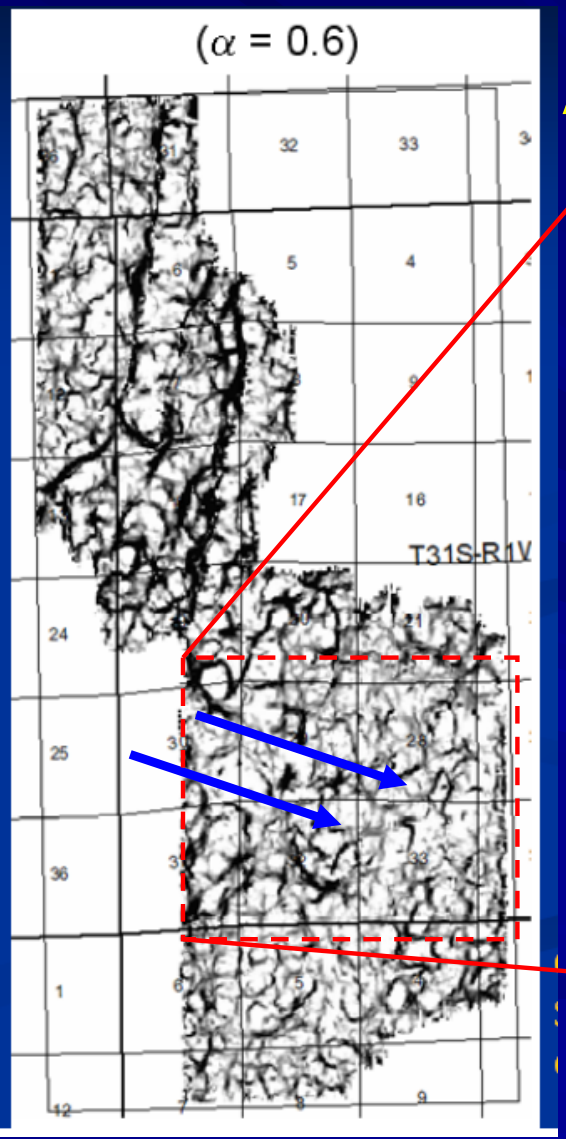
Wellington Field Study – Tasks Completed and In Progress

3D Seismic P-Wave Processing, Initial Interpretations, & Borehole Site Selection

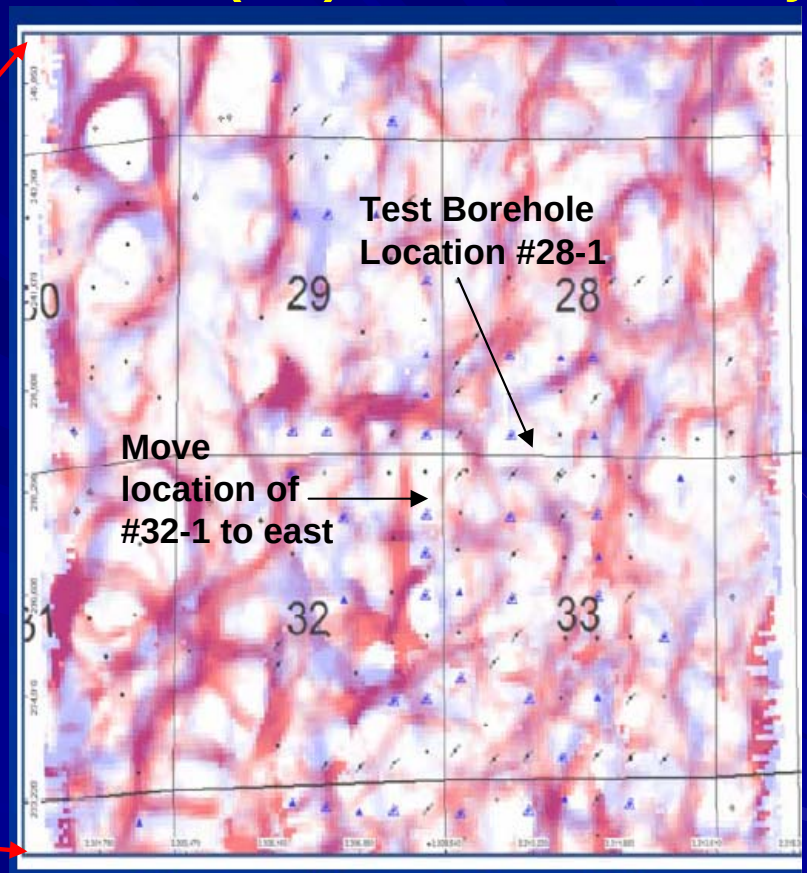
Arbuckle Time



Most Negative Curvature



Mississippian (*blue*)-Arbuckle (*red*) Curvature Overlay

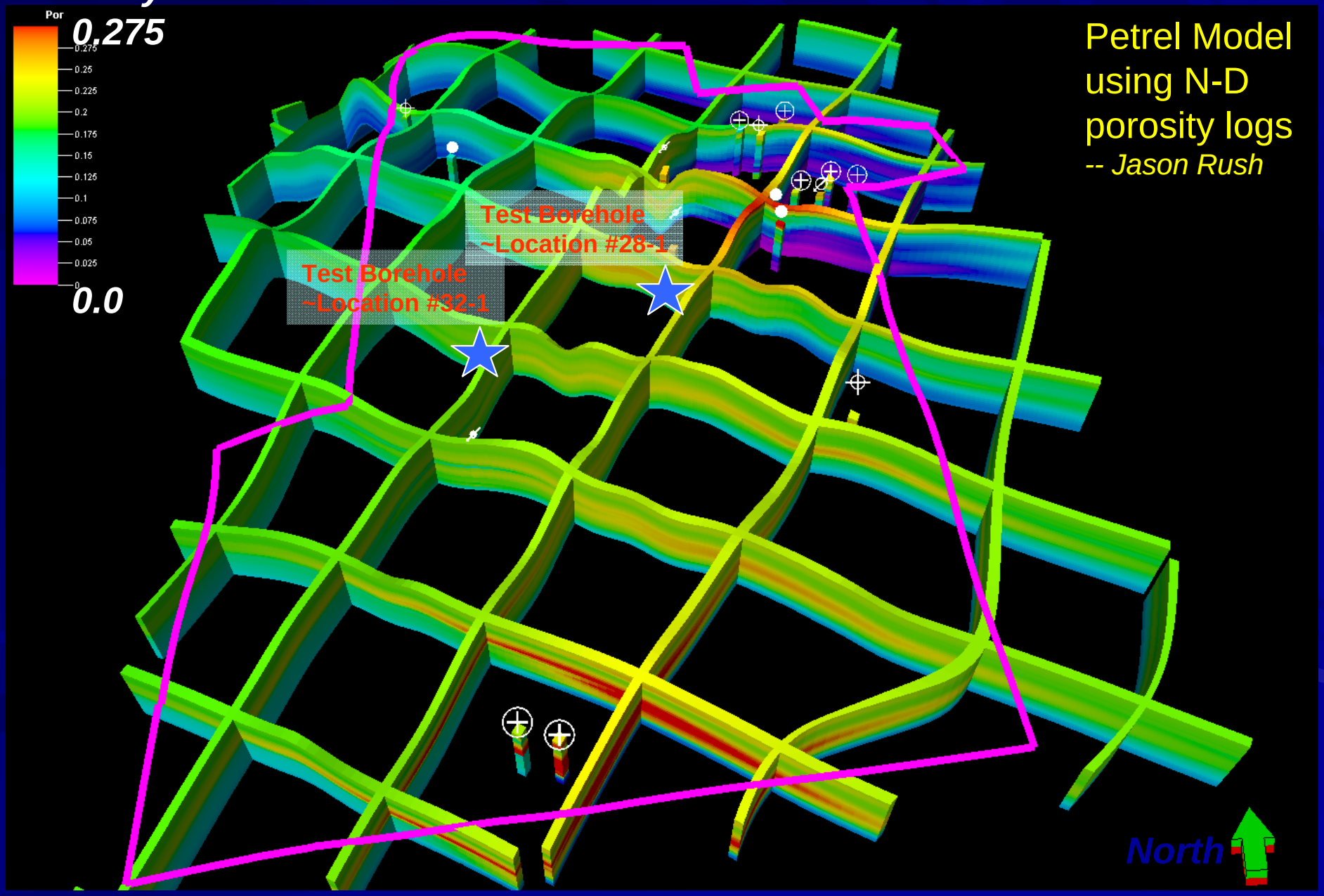


Courtesy of Susan Nissen / Geotexture

Wellington Field Study – Tasks Completed and In Progress

Geomodel Construction - Porosity Fence Diagram

Mississippian Oil Reservoir

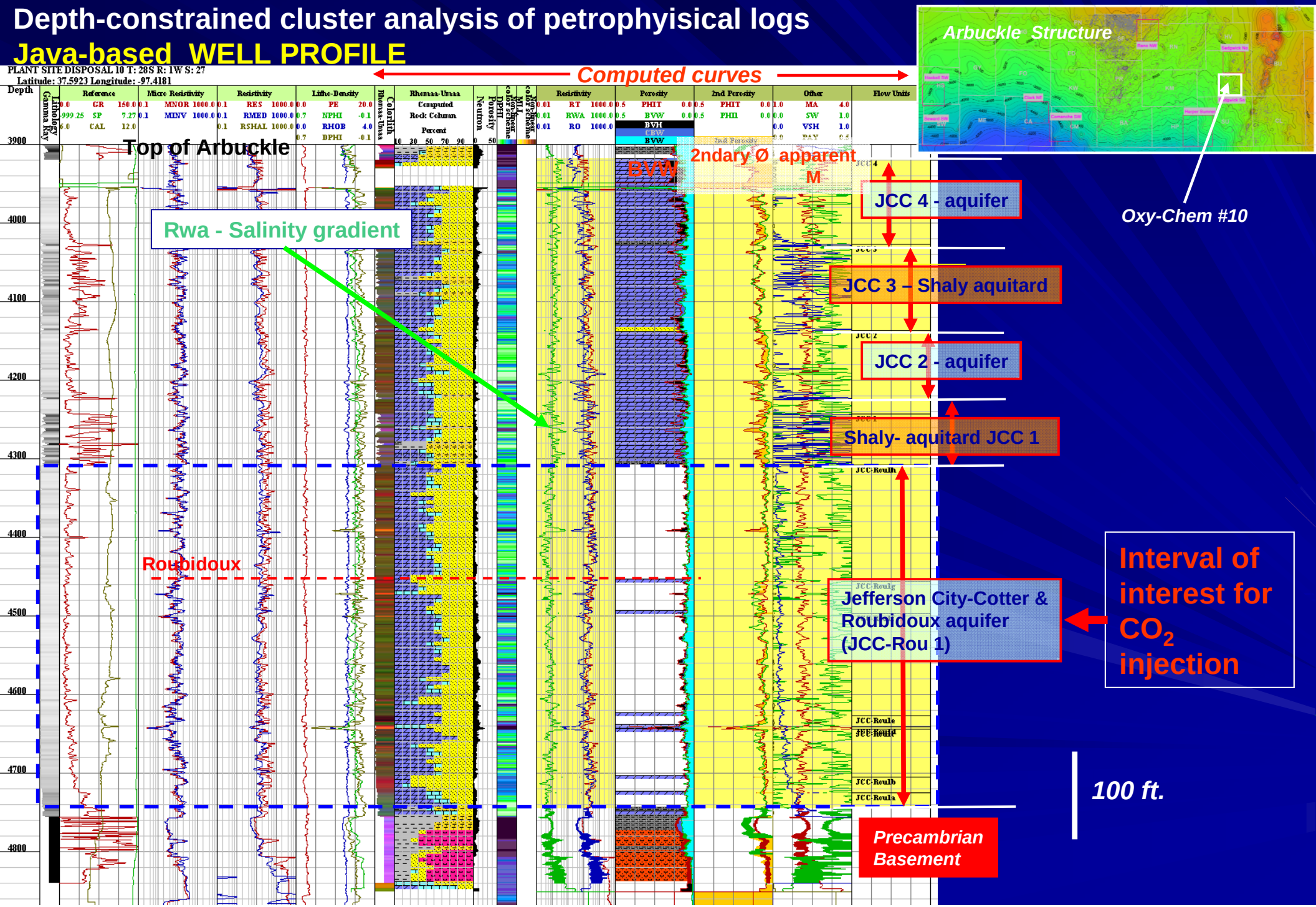


Initial Simulation Studies – Tasks Completed and In Progress

Arbuckle flow unit (*hydrostratigraphic unit*) characterization

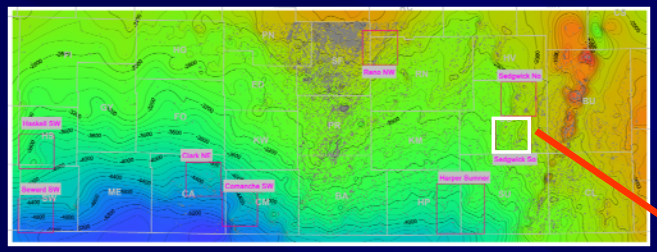
Depth-constrained cluster analysis of petrophyisical logs

Java-based WELL PROFILE



Initial Simulation Studies – Tasks Completed and In Progress

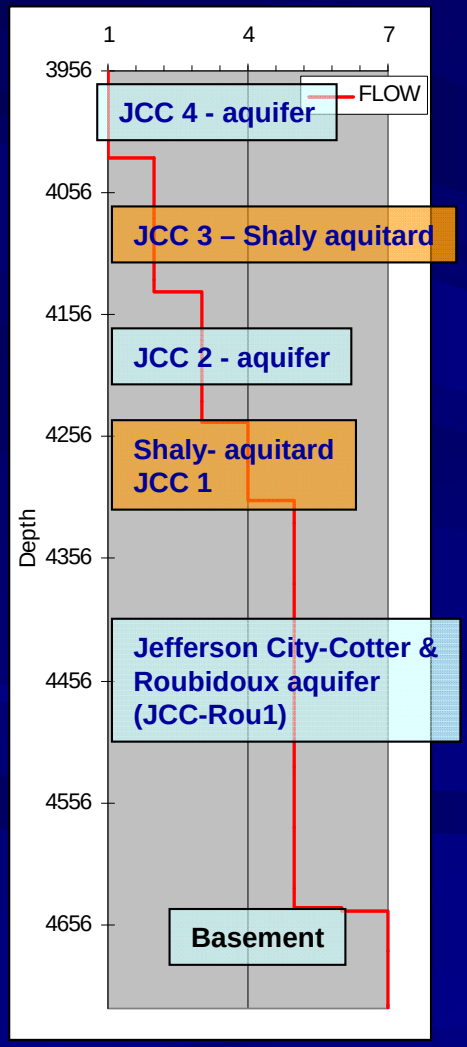
9 Township Model – centered around Oxy-Chem #10

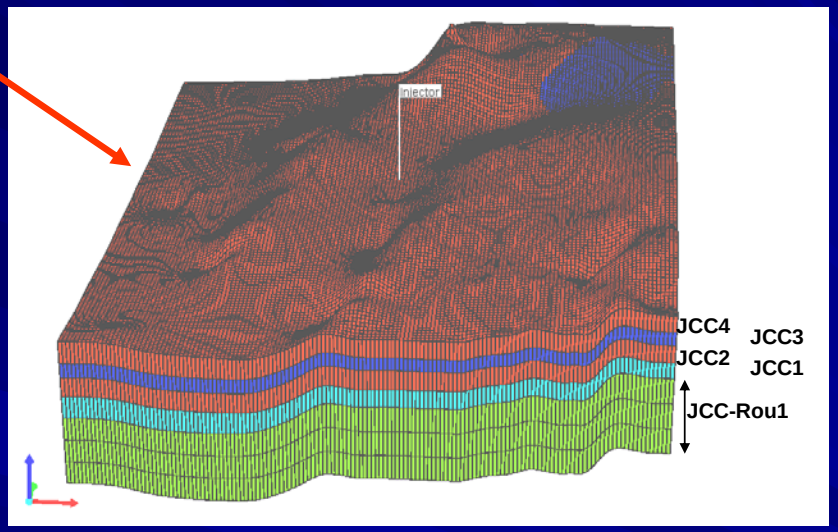


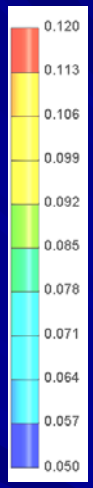
Grids: 330’ by 330’

Injection pressure < fracture pressure (3000 psi)

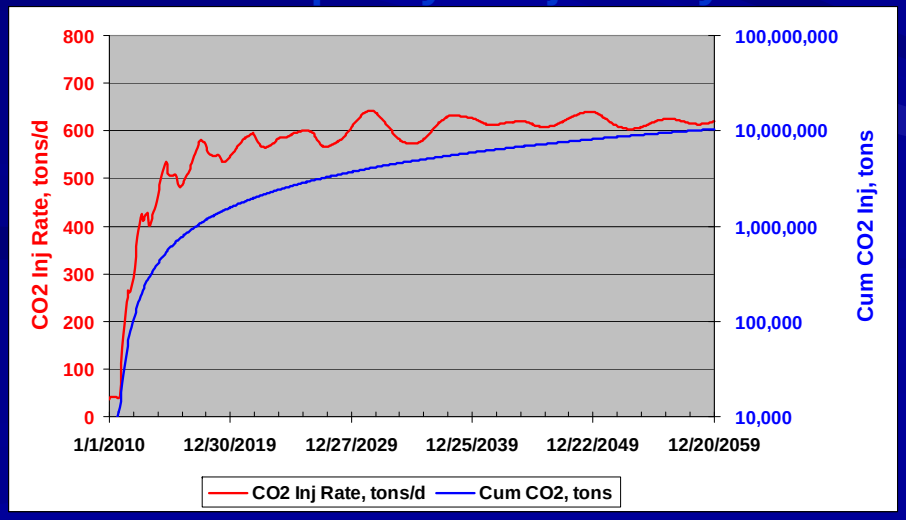
Injection from 2010 to 2060. Run till 2200.







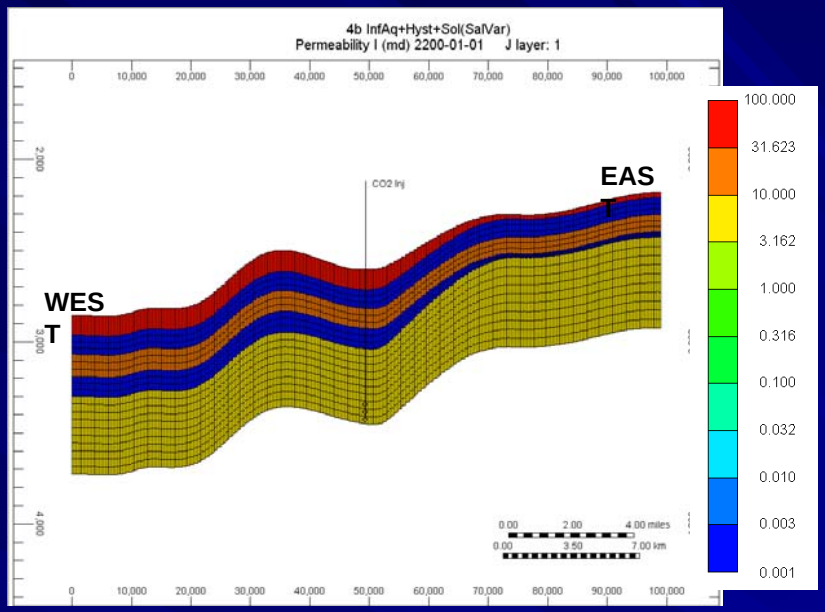
Capacity & Injectivity



Initial Simulation Studies – Tasks Completed and In Progress

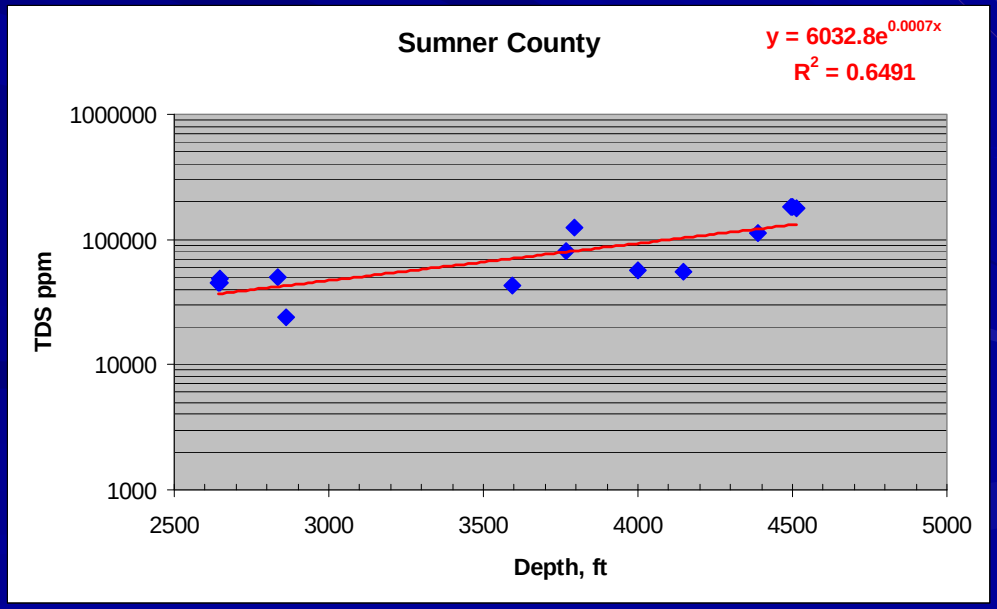
2D Model around Oxy-Chem #10 – 20 Layer Model Inputs

Approximately 300 core analysis archived from Arbuckle reservoirs – Byrnes et al 2003



		Oxy-Chem #10			Sumner CO		
Flow units	Layers	Avg Depth	Pr - Hyd Head	Frac Pr	ppm	Phi	K, md
1	1	2658.5	1245	3009	100079	0.12	100
2	2	2732	1277	3065	105363	0.05	0.001
2	3	2765.5	1292	3090	107863	0.05	0.001
2	4	2799	1307	3115	110422	0.05	0.001
3	5	2834.5	1322	3141	113201	0.12	20
3	6	2871	1338	3169	116130	0.12	20
3	7	2907.5	1354	3196	119135	0.12	20
4	8	2944.5	1370	3224	122261	0.06	0.001
4	9	2981.5	1386	3252	125469	0.06	0.001
4	10	3019	1402	3280	128806	0.06	0.001
5	11	3058.5	1419	3309	132418	0.09	10
5	12	3099.5	1437	3340	136273	0.09	10
5	13	3140.5	1455	3371	140241	0.09	10
5	14	3181.5	1473	3402	144324	0.09	10
5	15	3222.5	1491	3432	148526	0.09	10
5	16	3263.5	1509	3463	152851	0.09	10
5	17	3304	1526	3494	157246	0.09	10
5	18	3344.5	1544	3524	161768	0.09	10
5	19	3385.5	1562	3555	166478	0.09	10
5	20	3426.5	1580	3585	171325	0.09	10

Salinity vs. Depth



Upcoming Schedule

- Sites selected and permitted for test bore holes #1 & 2
- Industry partner (BEREXCO) completed land/lease legal work
- Rig to move to location for drilling test bore hole #1 on December 20th
- Rig reserved for 3 months
  - Will drill test bore hole #2 after completion of #1 – back to back, finish early February 2011
  - 1600 ft of core
  - Case well and test Arbuckle – pressure & water chemistry
- 2D shear wave survey shot after drilling test bore hole #1
  - Complete converted wave interpretation of multi-component 3D seismic survey
  - Model fractures & faults and refine geomodels of Mississippian oil reservoir and Arbuckle aquifer
- Core Analysis – mid-2011
- Geochemistry – mid-2011
- Revise Geomodel & Simulation – later half of 2011
- Western Annex – Parallel study starting from Feb 2011
- Project End Date – Dec 2012
- Planning to respond to anticipated new DOE solicitation for Small-scale pilot CO_2 injection in early 2011
  - < 500,000 tons of CO_2