DOE F 4600.2
(5/09)
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ATTACHMENT 3
U.S. Department of Energy
FEDERAL ASSISTANCE REPORTING CHECKLIST AND INSTRUCTIONS

1. Identification Number: **DE-FE0002056**	2. Program/Project Title: **Modeling CO2 Sequestration in Saline Aquifer and Depleted Oil Reservoir to Evaluate Regional CO2 Sequestration Potential of Ozark Plateau Aquifer System, South-Central Kansas**		
3. Recipient: University of Kansas Center for Research			
4. Reporting Requirements:	Frequency	No. of Copies	Addresses
A. MANAGEMENT REPORTING			
☒ Progress Report	Q	Electronic Version to NETL>	FITS@NETL.DOE.GOV
☒ Special Status Report	A		
B. SCIENTIFIC/TECHNICAL REPORTING * (Reports/Products must be submitted with appropriate DOE F 241. The 241 forms are available at https://www.osti.gov/elink)			
Report/Product — Form			
☒ Final Scientific/Technical Report — DOE F 241.3	FG	Electronic Version to E-link>	http://www.osti.gov/elink-2413
☒ Conference papers/proceedings/etc.* — DOE F 241.3	A		http://www.osti.gov/elink-2413
☐ Software/Manual — DOE F 241.4			http://www.osti.gov/estsc/241-4pre.jsp
☒ Other (see special instructions) Topical — DOE F 241.3	A		
* *Scientific/technical conferences only*			
C. FINANCIAL REPORTING			
☒ SF-425, Federal Financial Report	Q, FG	Electronic Version To NETL>	FITS@NETL.DOE.GOV
D. CLOSEOUT REPORTING			
☐ Patent Certification	FC	Electronic Version To NETL>	FITS@NETL.DOE.GOV
☐ Property Certificate	FC		
☐ Other			
E. OTHER REPORTING			
☒ Annual Indirect Cost Proposal	A	Electronic Version To NETL>	FITS@NETL.DOE.GOV
☒ Annual Inventory Report of Federally Owned Property, if any	A		
☐ Other			
F. AMERICAN RECOVERY AND REINVESTMENT ACT REPORTING			
☐ Reporting and Registration Requirements			http://www.federalreporting.gov

FREQUENCY CODES AND DUE DATES:

A - As required; see attached text for applicability.
FG - Final; within ninety (90) calendar days after the project period ends.
FC - Final - End of Effort.
Q - Quarterly; within thirty (30) calendar days after end of the calendar quarter or portion thereof.
S - Semiannually; within thirty (30) calendar days after end of project year and project half-year.
YF - Yearly; 90 calendar days after the end of project year.
YP - Yearly Property - due 15 days after period ending 9/30.

QUARTERY PROGRESS REPORT

Award Number: DE-FE0002056

Recipient: University of Kansas Center for Research &
Kansas Geological Survey
1930 Constant Avenue
Lawrence, KS 66047

“Modeling CO_2 Sequestration in Saline Aquifer and Depleted Oil Reservoir to Evaluate Regional CO_2 Sequestration Potential of Ozark Plateau Aquifer System, South-Central Kansas”

Project Director/Principal Investigator: W. Lynn Watney
Principal Investigator: Jason Rush

Ninth Quarter Progress Report

Date of Report: January 31, 2011

Period Covered by the Report: October 1, 2011 through December 31, 2011

Contributors to this Report: Robin Barker, Saugata Datta, John Doveton, Mina Fazelalavi, David Fowle, Martin Dubois, Paul Gerlach, Dennis Hedke, Tom Hansen, Larry Nicholson, Jennifer Roberts, Jason Rush, Aimee Scheffer, Ray Sorenson, John Victorine, Lynn Watney, John Youle, Dana Wreath

EXECUTIVE SUMMARY

The project "Modeling CO_2 Sequestration in Saline Aquifer and Depleted Oil Reservoir to Evaluate Regional CO_2 Sequestration Potential of Ozark Plateau Aquifer System, South-Central Kansas" is focused on the Paleozoic-age Ozark Plateau Aquifer System (OPAS) in southern Kansas. OPAS is comprised of the thick and deeply buried Arbuckle Group saline aquifer and the overlying Mississippian carbonates that contain large oil and gas reservoirs. The study is collaboration between the KGS, Geology Departments at Kansas State University and The University of Kansas, BEREXCO, INC., Bittersweet Energy, Inc. Hedke-Saenger Geoscience, Ltd., Improved Hydrocarbon Recovery (IHR), Anadarko, Cimarex, Merit Energy, GloriOil, and Cisco.

The project has three areas of focus, 1) a field-scale study at Wellington Field, Sumner County, Kansas, 2) 25,000 square mile regional study of a 33-county area in southern Kansas, and 3) selection and modeling of a depleting oil field in the Chester/Morrow sandstone play in southwest Kansas to evaluate feasibility for CO2-EOR and sequestration capacity in the underlying Arbuckle saline aquifer. Activities at Wellington Field are carried out through BEREXCO, a subcontractor on the project who is assisting in acquiring seismic, geologic, and engineering data for analysis. Evaluation of Wellington Field will assess miscible CO_2-EOR potential in the Mississippian tripolitic chert reservoir and CO_2 sequestration potential in the underlying Arbuckle Group saline aquifer. Activities in the regional study are carried out through Bittersweet Energy. They are characterizing the Arbuckle Group (saline) aquifer in southern Kansas to estimate regional CO_2 sequestration capacity. Supplemental funding has expanded the project area to all of southwest Kansas referred to as the Western Annex. IHR is managing the Chester/Morrow play for CO2-EOR in the western Annex while Bittersweet will use new core and log data from basement test and over 200 mi^2 of donated 3D seismic. IHR is managing the industrial partnership including Anadarko Petroleum Corporation, Cimarex Energy Company, Cisco Energy LLC, Glori Oil Ltd., and Merit Energy Company. Project is also supported by Sunflower Electric Power Corporation.

Project Status: Subtasks completed within current quarter: Completed Subtasks 2.5 and 2.6 and 16.2 and 16.3 - Gathering and interpret gravity/magnetic data and remote sensing analysis for lineaments; Subtask 4.10 PVT analysis Subtasks completed till date include: 1) 3D seismic survey at Wellington field (Sumner County, KS) processed and p-wave interpreted, 2) Wellington field seismic data merged with donated 3D seismic data from the adjacent Anson and Bates fields, 3) Wellington 3D seismic interpretation includes structure, time slices, volumetric coherency, curvature, and fault/flexure mapping, 4) two test boreholes drilled in Wellington Field, 5) gravity and magnetic surveys over 17+ county regional study area have been reprocessed and suggested basement faults/fracture trends mapped for validation, 6) remote sensing data over 17+ county regional study area analyzed and surface lineaments mapped, 7) multiple stratigraphic horizons have been mapped over regional study area, 8) multi-township areas selected within regional study area for detailed characterization and simulation studies to evaluate CO_2 sequestration potential in Arbuckle Group saline aquifer, 9) depth-constrained cluster analysis conducted on petrophysical properties to identify Arbuckle flow-units and analysis tool incorporated into Java petrophysical application, 10) initial simulation studies of Arbuckle conducted at Oxy-Chem #10 well to north of Wellington Field in Sedgwick County and at Wellington Field in Sumner County to make preliminary estimates of CO_2 sequestration potential, 11) available Arbuckle DST data collected, analyzed, and mapped showing hydraulic communication with northwestern Ozark uplift outcrop in Missouri, 12) website has been updated to include maps of latest subsurface geology, remote sensing analysis, and reprocessed gravity and magnetic information, 13) initial core description made, 14) release new log analysis Java web tool, 15) updated interactive mapper with new legend and map section window.

Subtasks in progress: 1) nearly complete (85%) processing of converted (shear) wave and depth migrated seismic data at Wellington Field, 2) nearly completed with swab testing of #1-32 well to proceed when refined list of intervals is determined, 3) initial geochemical and microbiological analyses and results available from DSTs and existing swab tests from #-1-28 and #1-32, 4) special and routine core analysis from #1-32 is over 95% completed, core Slabbed and photographed, 5) establishing consistent regional internal stratigraphy of the Arbuckle with maps uploaded to online project mapper, 6) defining process to evaluate and establish regional faults and evaluate as potential leakage pathways, 7) re-evaluate selection of sites for more detailed mapping and later simulation using regional mapping, 8) decision made on reprocessing of regional seismic donated by industry from southwestern Kansas, 9) collection and evaluation of geologic and engineering data from four Chester/Morrow sandstone producing fields in southwestern Kansas over 50% complete and using information to evaluate drilling locations and input for simulation, 10) seismic data, regional mapping, and field studies in SW Kansas being to finalize location of basement test, 11) conducting intensive effort to evaluate quality control, normalize log response, and calibrate old log data, and 12) information on field size and depth made on large oil fields and inventory of sources of CO2 updated with new EPA information.

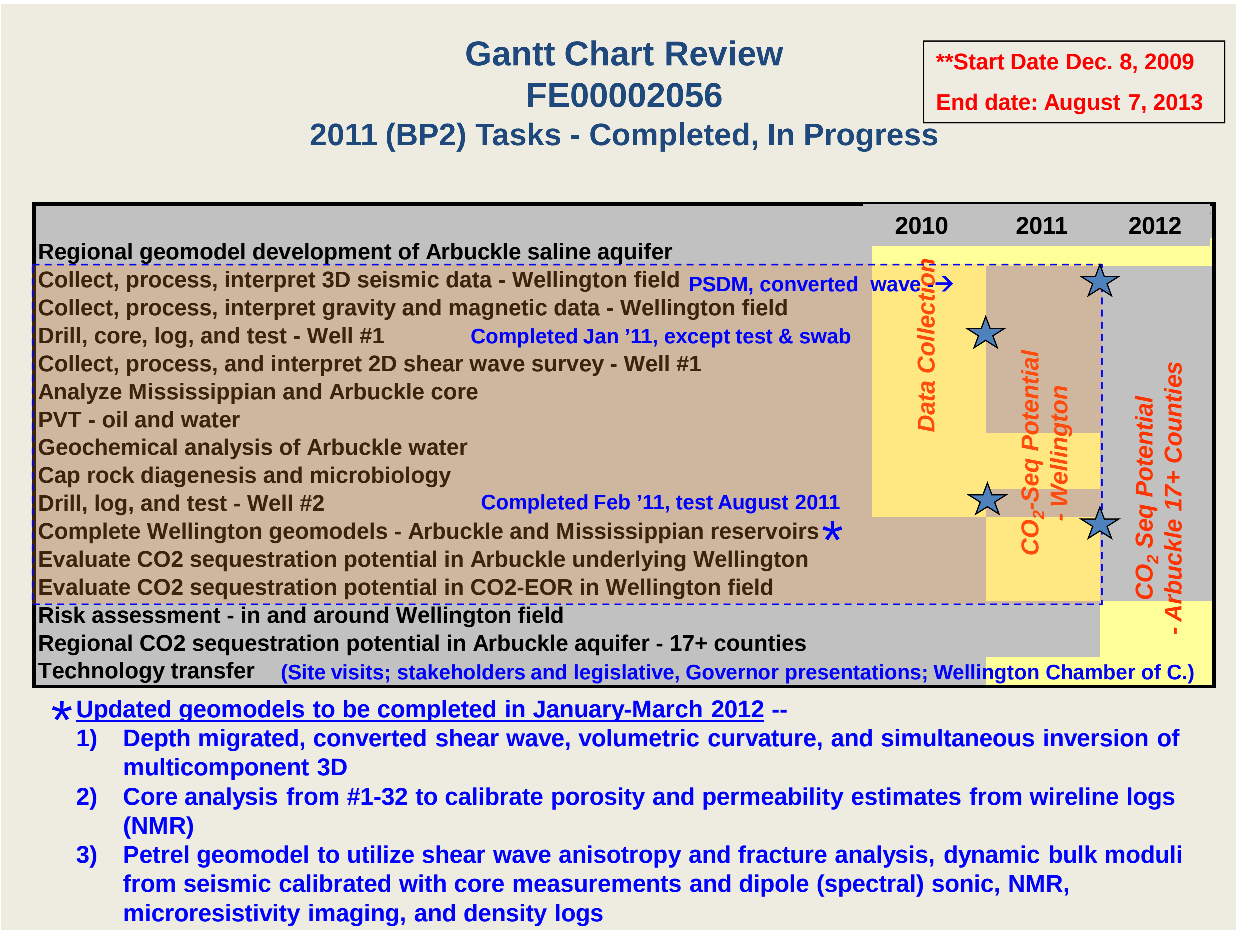
Task Name	Planned Start Date	Actual Start Date	Planned Finish Date	Actual Finish Date	% Complete
1.0 Project Management & Planning	12/8/2009	12/08/09	12/7/2012		55%
2.0 Characterize the OPAS (Ozark Plateau Aquifer System)	1/1/2010	01/01/10	6/30/2012		50%
3.0 Initial geomodel of Mississippian Chat & Arbuckle Group - Wellington field	1/1/2010	01/01/10	9/30/2010	09/30/10	100%
4.0 Preparation, Drilling, Data Collection, and Analysis - Well #1	9/15/2010	12/15/10	3/31/2011	08/30/11	100%
5.0 Preparation, Drilling, Data Collection and Analysis - Well #2	1/1/2011	02/20/11	6/30/2011	08/30/11	100%
6.0 Update Geomodels	5/1/2011	05/01/11	9/30/2011		90%
7.0 Evaluate CO2 Sequestration Potential in Arbuckle Group Saline Aquifer	8/1/2011	08/01/11	12/31/2011		60%
8.0 Evaluate CO2 Sequestration Potential in Depleted Wellington field	10/15/2011		3/31/2012		40%
9.0 Characterize leakage pathways - risk assessment area	1/1/2010	01/01/10	6/30/2012		30%
10.0 Risk Assessment related to CO2-EOR and CO2 Sequestration in saline aquifer	6/1/2012		9/30/2012		20%
11.0 Produced water and wellbore management plans - Risk assessment area	1/1/2012		10/31/2012		40%
12.0 Regional CO2 sequestration potential in OPAS	8/1/2012		12/7/2012		30%
13.0 Regional source sink relationship	1/1/2010		12/7/2012		40%
14.0 Technology Transfer	1/1/2010		12/7/2012		

Milestone	Planned Completion Date	Actual Completion Date	Validation
FOA Milestone: Updated Project Management Plan	3/31/2010	03/31/10	Completed
HQ Milestone: Kick-off Meeting Held	3/31/2010	03/31/10	Completed
FOA Milestone: Submit Site Characterization Plan	5/28/2010		
HQ Milestone: Begin collection of formation information from geologic surveys and private vendors	6/30/2010	01/01/10	Completed
HQ Milestone: Semi-Annual Progress Report on data availability and field contractors	9/30/2010	07/30/10	Submitted to Project manager
Milestone: Annual Review Meeting attended	3/30/2012		
FOA Milestone: Notification to Project Manager that reservoir data collection has been initiated	9/15/2010	01/01/10	Completed
FOA Milestone: Notification to Project Manager that subcontractors have been identified for drilling/field service operations	7/30/2010	01/01/10	Completed
FOA Milestone: Notification to Project Manager that field service operations have begun at the project site	7/1/2010	01/01/10	Completed
FOA Milestone: Notification to Project Manager that characterization wells have been drilled	6/3/2011	03/09/11	Completed
FOA Milestone: Notification to Project Manager that well logging has been completed	6/3/2011	03/09/11	Completed
HQ Milestone: Establish database links to NATCARB and Regional Partnerships	12/31/2010	12/31/10	Completed
FOA Milestone: Notification to Project Manager that activities to populate database with geologic characterization data has begun	12/31/2010	12/31/10	Completed
HQ Milestone: Annual Review Meeting attended	3/31/2011	10/05/10	Completed
Complete major field activities, such as drilling or seismic surveys at several characterization sites	6/30/2011	Note: This milestone was met collectively by all projects. No one project was held accountable to the milestone.	Completed
HQ Milestone: Semi-Annual Progress Report (i.e. Quarterly Report ending June 30, 2011)	9/30/2011		In progress
FOA Milestone: Notification to Project Manager that actvities on the lessons learned document on site characterization have been initiated	7/15/2012		
KGS Milestone 1.1: Hire geology consultants for OPAS modeling	3/31/2010	03/31/10	Completed, email summary
KGS Milestone 1.2: Acquire/analyze seismic, geologic and engineering data - Wellington field	6/30/2010	06/30/10	92% Completed*
KGS Milestone 1.3: Develop initial geomodel for Wellington field	9/30/2010	09/30/10	Completed, quarterly rpt
KGS Milestone 1.4: Locate and initiate drilling of Well #1 at Wellington field	12/31/2010	12/25/10	Completed, email summary
KGS Milestone 2.1: Complete Well#1 at Wellington - DST, core, log, case, perforate, test zones	3/31/2011	08/30/11	Completed, email summary
KGS Milestone 2.2: Complete Well#2 at Wellington - Drill, DST, log, case, perforate, test zones	6/30/2011	08/30/11	Completed, email summary
KGS Milestone 2.3: Update Wellington geomodels - Arbuckle & Mississippian	9/30/2011		75% complete***
KGS Milestone 2.4: Evaluate CO2 Sequestration Potential of Arbuckle Group Saline Aquifer - Wellington field	12/31/2011		80% complete****
KGS Milestone 3.1: CO2 sequestration & EOR potential - Wellington field	3/31/2012		40% complete+
KGS Milestone 3.2: Characterize leakage pathways - Risk assessment area	6/30/2012		30% complete
KGS Milestone 3.3: Risk assessment related to CO2-EOR and CO2-sequestration	9/30/2012		30% complete
KGS Milestone 3.4: Regional CO2 Sequestration Potential in OPAS - 17 Counties	12/7/2012		30% complete

Notes below from previous table.

* Geologic data acquired. Seismic data acquired and analysis in progress. Newly discovered production/injection data being assimulated.
**Workover rig moved into location 7-8-11
*** New geomodels for Arbuckle and Mississippian will use depth and shear wave seismic undergoing final interpreation
****Simulation will be completed on updated geomodel
+full field simulation for EOR will be performed on Mississippian reservoir on geomodel using new seismic data and calibrated log data from older wells

Summary version of Gantt Chart showing progress. Note end date of August 7, 2013



ACCOMPLISHMENTS

REGIONAL STUDY - INCLUDING SOUTHWEST KANSAS

ONGOING AND COMPLETED ACTIVITIES –

Subtask 2.3. Develop regional correlation framework and integrated geomodel.

Subtask 4.13. Correlate log & core - extend to OPAS.

Work continues on Subtasks 2.3 and 4.13 where logs on regional scale are being digitized to LAS files. LAS files are undergoing quality control and some are being redigitizing. Type wells and supertype logs will generally not need to be calibrated, but will be normalized as necessary. Scanned version of logs have been correlated in Geographix, but LAS files are in the process of being imported into Petrel to process the petrophysical data as 3D grid in the context of the stratigraphic correlations.

A set of logs called Strat Master is being correlated statewide (Figure 1). These wells span the deep and shallow strata and are the most modern of the logs available. Stratigraphic tops will undergo peer review and will be published.

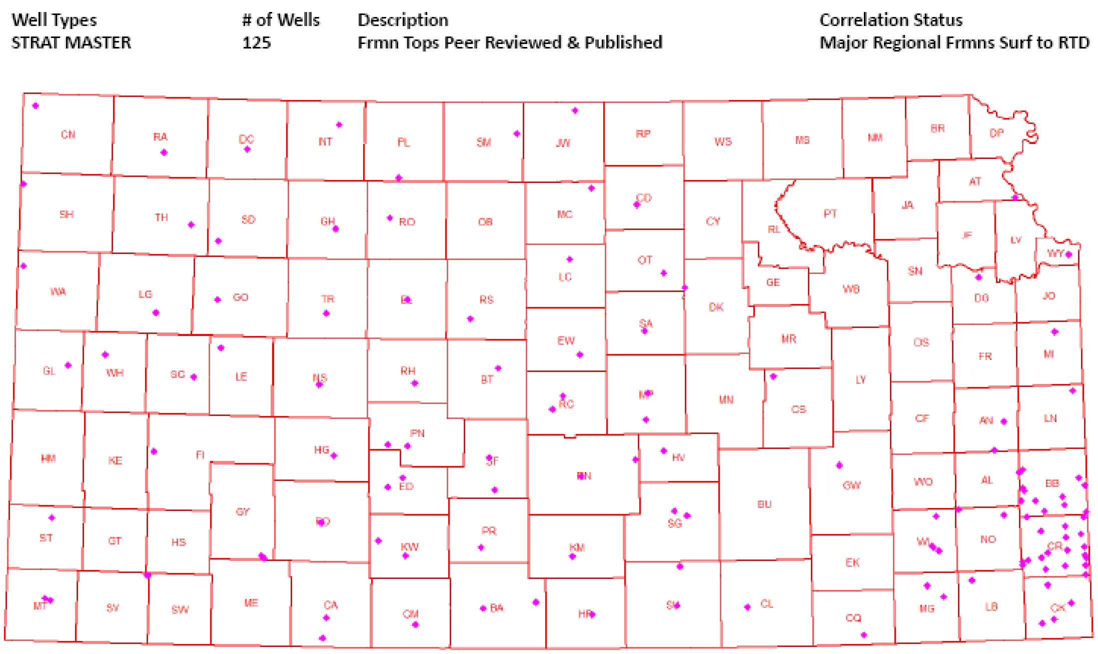


Figure 1. Key wells in Strat Master set. Each county has at least one well.

A set of wells previously correlated by members of the Kansas Geological Society in the 1960's comprise a set of "type well" (Figure 2). These wells provide a baseline to compare with Stat Master logs. Major formations in the type wells were correlated from surface to TD.

Well Types	# of Wells	Description	Correlation Status
STRAT TYPE	199	KG Soc Type Logs plus wells correlated	Major Regional Frmns Surf to RTD

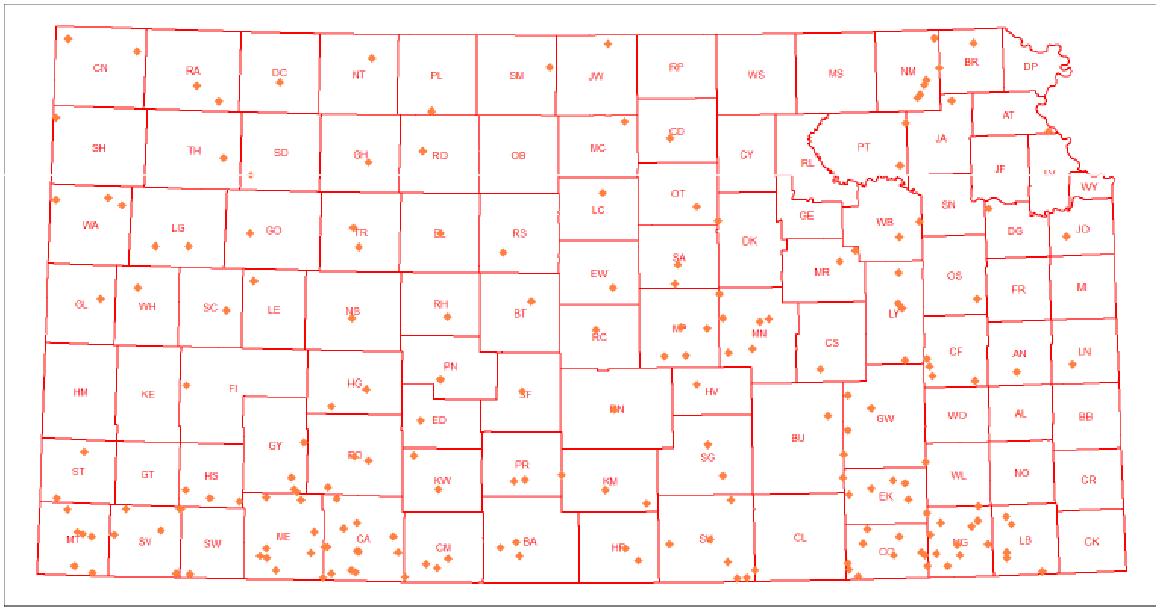


Figure 2. Strat Type wells are predominately the set of correlations published by the Kansas Geological Society in the 1960's.

Supertype wells have modern log suites and penetrate over 400 feet into the Arbuckle (Figure 3). Wells have been digitized and LAS files are undergoing quality control. Supertype wells have also been extended statewide due to considerations for evaluating hydraulic continuity of the Arbuckle toward surface exposures in Missouri to the east.

Well Types	# of Wells	Description	Correlation Status
SUPER TYPE	263	ARBK Penetration (>400 ft) Good Log Suite	Major Regional Frmns Surf to RTD

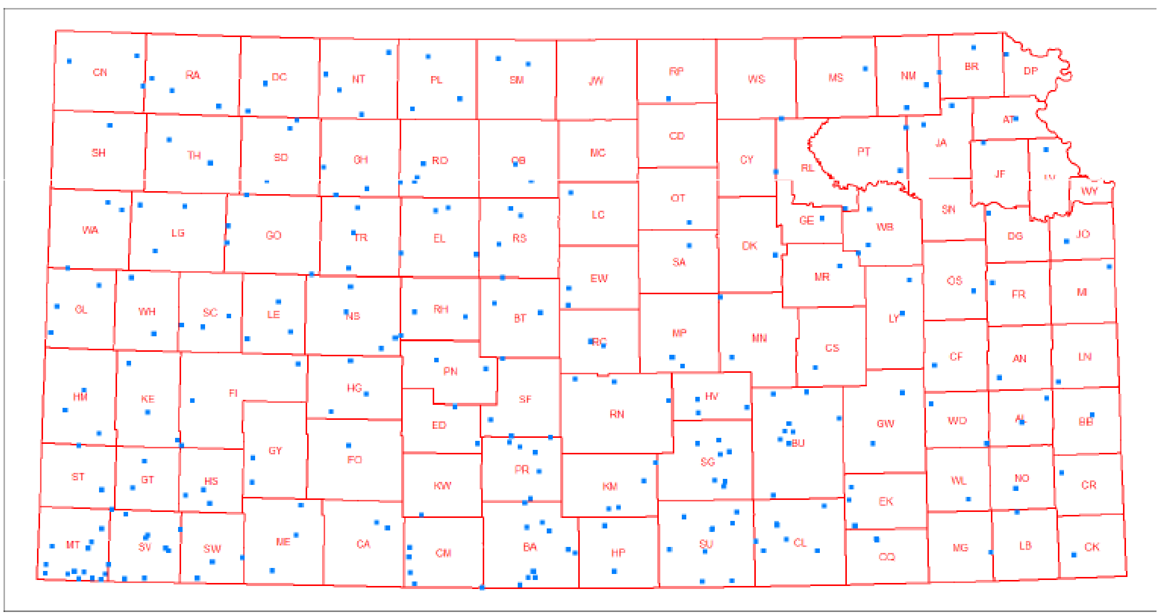


Figure 3. Distribution of supertype wells.

Status of correlations is illustrated by two regional stratigraphic log cross sections (Figure 4-7). First section runs from NW corner of Kansas to south-central Kansas just east of Wellington Field in Sumner County (Figure 5). Bottom layer is the Arbuckle, which is thin over the northern half of the cross section compared to southern Kansas, the location of the regional assessment for CO2 storage capacity (outlined in blue dashed line in Figure 4).

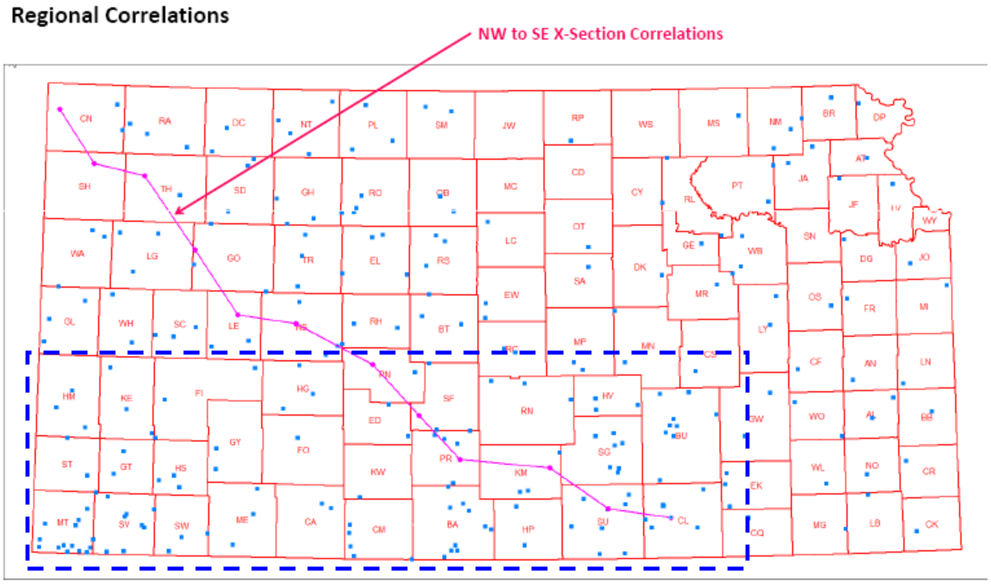


Figure 4. Index map for regional cross section from NW Kansas to South-Central Kansas.

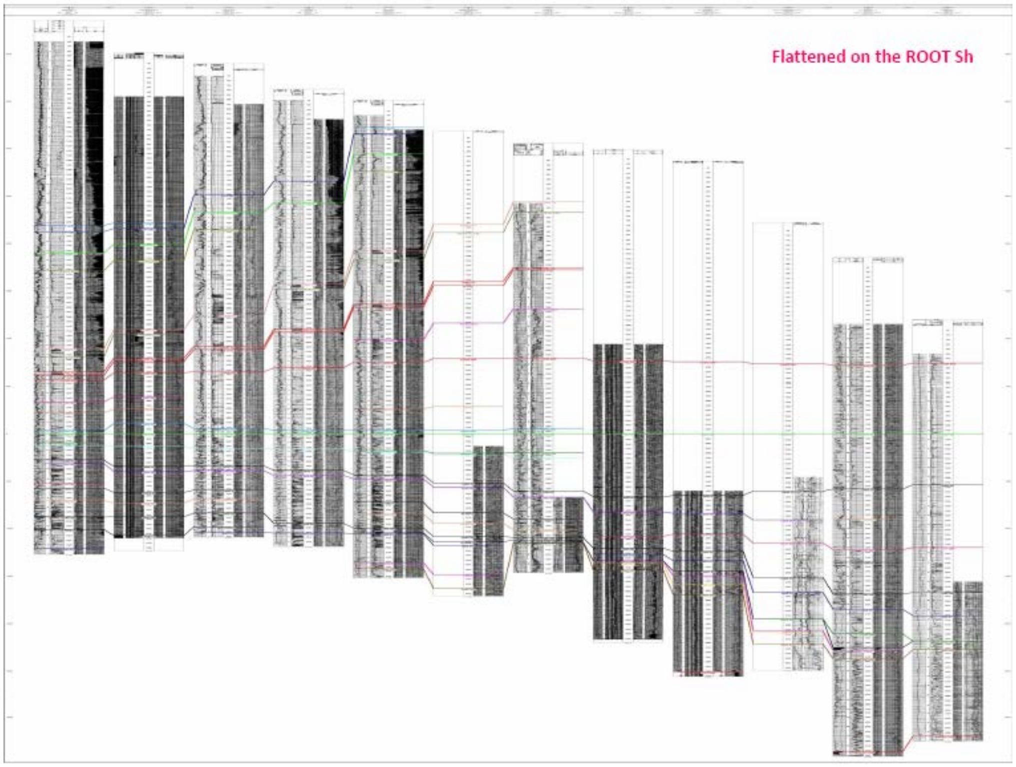


Figure 5. Stratigraphic NW-SE cross section indexed in map in Figure 5. Upper Virgilian Root Shale is datum.

A SW-NE stratigraphic log cross section extends across Kansas (Figure 7) showing thinning of the lower Paleozoic including the Arbuckle from the Hugoton Embayment on the SW Kansas, over the Nemaha Uplift, and into the Forest City Basin in NE Kansas. Thickest Arbuckle is in SW Kansas, area of study for the CO2 storage assessment.

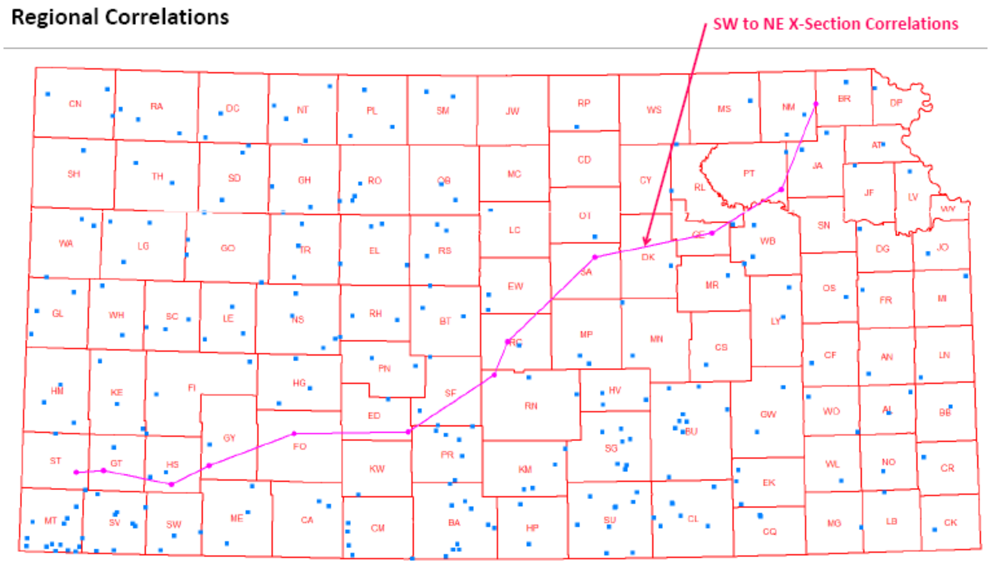
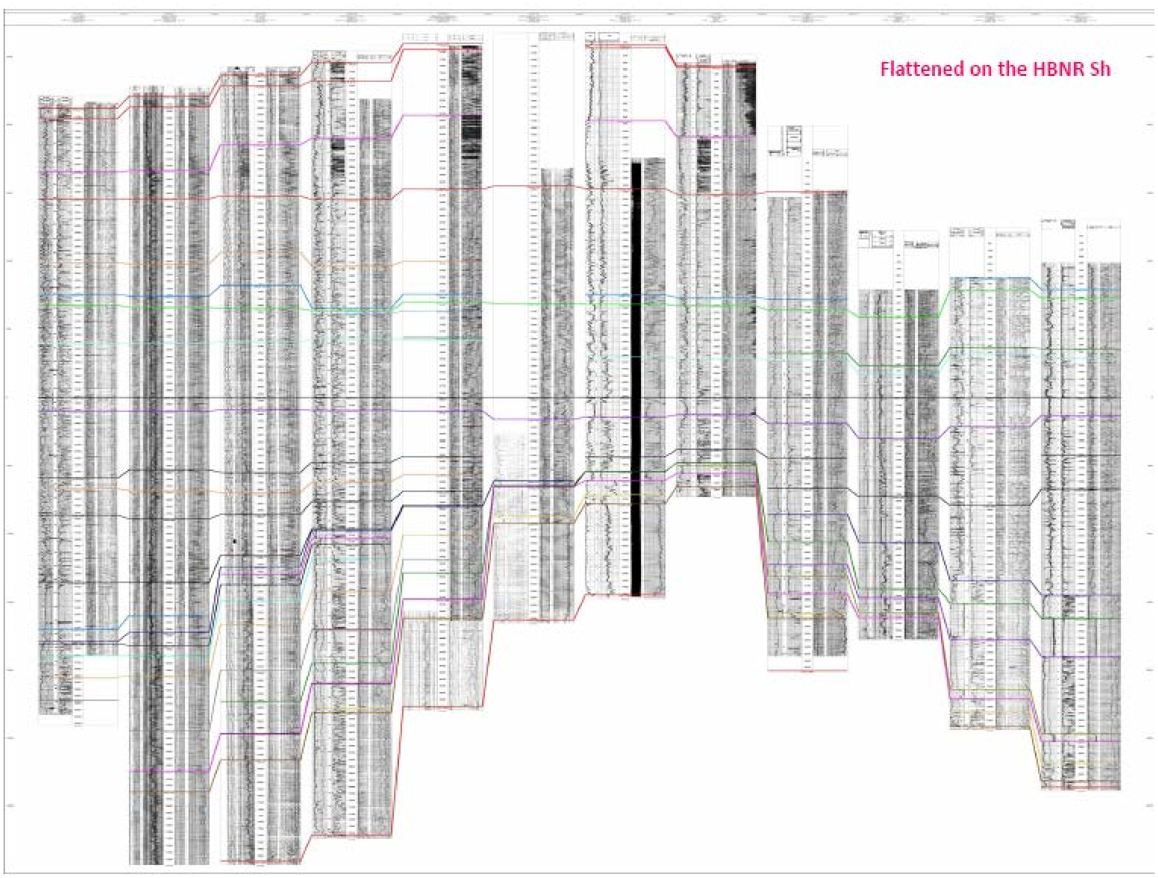


Figure 6. Index map for SW-NE stratigraphic log cross section shown in Figure 7 (below).



A relatively dense set of well log comprising type wells have been scanned in the area for estimating CO2 storage capacity (Figure 8). Well logs from this type well set are being digitized in eight areas selected for more detailed quantitative analysis in Petrel where conditions look favorable for local storage and containment of CO2.

Well Types	# of Wells	Description	Correlation Status
TYPE	1623	ARBK Penetration (<200 ft) Good Log Suite	Major Regional Frmns HBNR to RTD plus uphole tops*

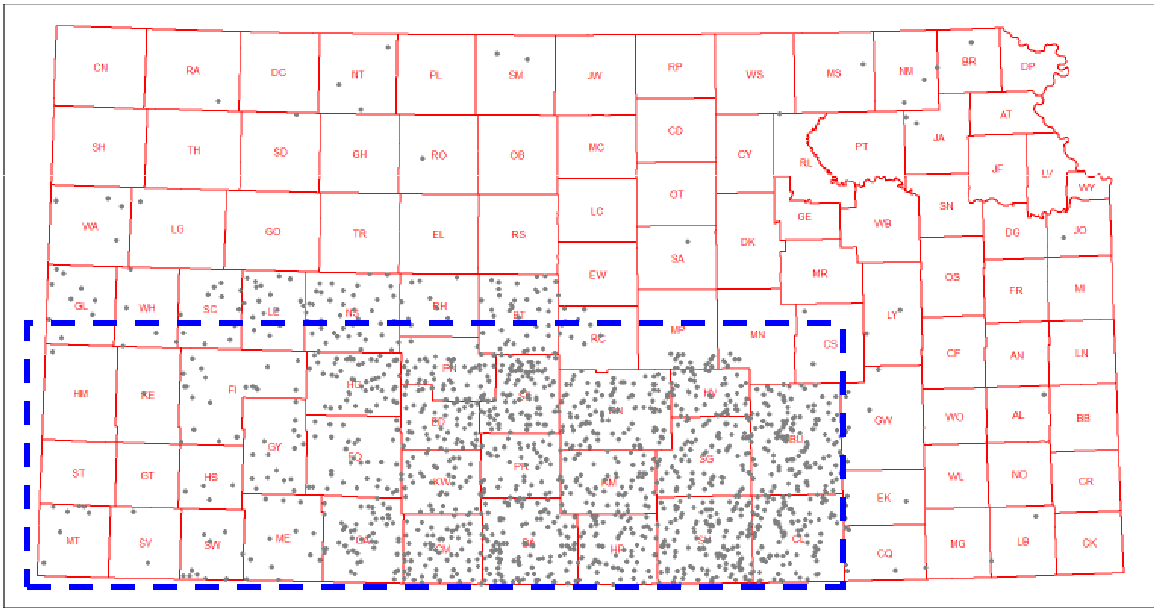


Figure 8. Type wells in study area. Arbuckle penetrations are less than 200 feet, but have a good well log suite – usually gamma ray, neutron or density porosity, resistivity.

All wells that are either scanned as rasters or are in LAS format compiled in this study are shown in Figure 9. Greatest density is in southern region where focus is on the characterization of the capacity of CO2 storage.

Well Types	# of Wells	Description	Correlation Status
Wells with Las or Raster	4439	Wells with Good Log Suite to Surf or Casing	Major Regional Frmns HBNR to RTD plus uphole tops*

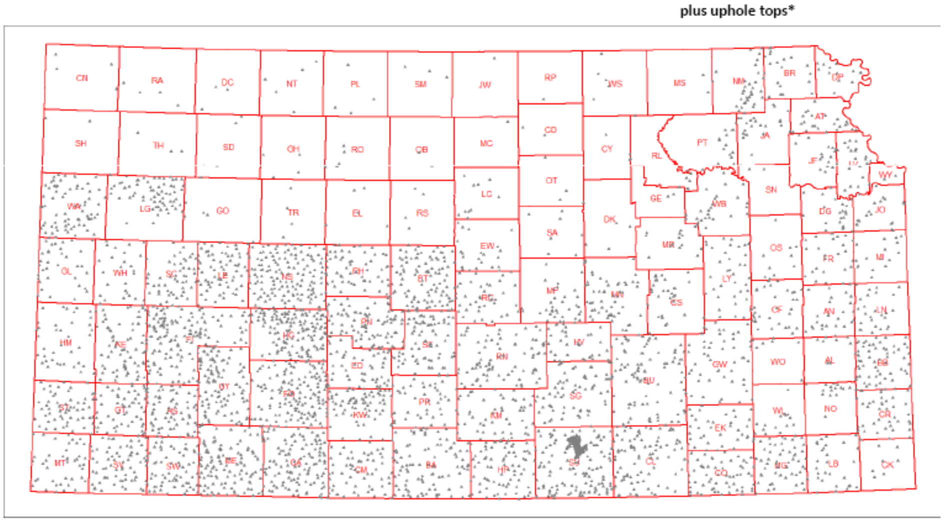


Figure 9. All LAS and raster images of well logs with good log suite to surface casing or surface.

The major stratigraphic units that have been correlated in Strat Master, Type, and Super Type wells are listed in Figure 10.

FORMATION	# of PICKS	ACO-1	KGS_CO2
LANS GRP	55147	6696	48450
HBNR SH	46732	5763	40969
MISS SYS	45446	3171	42273
KCTY GRP	29757	4089	25667
ARBK GRP	25655	4076	21579
CHRK GRP	24152	2473	21678
CHASE GRP	19393	47	19346
VIOLA	17857	570	17287
WINF	16946	205	16741
STNC Top	16623	4946	11677
MARM GRP	16437	20	16417
B STNC	15858	1112	14746
SIMP GRP	15682	0	15682
STNC	12692	0	12692
HUTCH SALT	12078	0	12078
KDHK GRP	11789	102	11687
TOPEKA	11222	2848	8374
B PENN LM	10457	3	10454
STARK SH	9580	652	8928
HERRINGTON	8758	0	8758
GAGE SH	8687	0	8687
KRIDER	8566	0	8566
WBNS GRP	8478	102	8376
MRMC GRP	7669	0	7669
CGRV GRP	7135	0	7135
WREFORD	6828	0	6828
Producing Zone	6202	0	0
M MRW LM	5818	0	5818
ST LOU A	5547	0	5547
BLAINE Top	5505	30	5475
NEVA	5341	0	5341
CEDAR HILLS SD	5337	0	5337
B KCTY GRP	5280	1240	4040
ROOT SH	4965	18	4947
CHST A ZN	3678	0	3678
SWOPE	3331	0	3331
PRE-CAMB	3137	2612	525

Subcontractor
Bittersweet Energy
Current Status
Of
1) Key Well Correlations, Tops Inventory & E-log Inventory

Formations with Most Frequent Picks

*plus uphole tops
NBRR
FT HAYS
GREENHORN
DAKOTA SD
BLAINE
CDR HILLS
STNC
HUTCH SALT
CHASE
CGRV
NEVA
WBNS
ROOT
TPKA

Figure 10. List of major stratigraphic tops correlated in wells used in this study.

Subtask 9.2. Map fracture-fault network.

Mapping and analysis of regional faults continues with task focused on verifying the faults using well cross sections, 3D seismic, gravity and magnetic data, and surface lineaments. In addition the amount of flexure and faulting is being compared using five structural surfaces of major stratigraphic units mapped across southern Kansas. The lower most horizon is the top Arbuckle (Figure 11) and the shallowest horizon is the Lower Permian Chase Group (Figure 15). The time span represented by these maps spans much of the Paleozoic with shallower horizons showing increasingly simplified structure. Verified faults have been noted in pink lineaments on these series of maps.

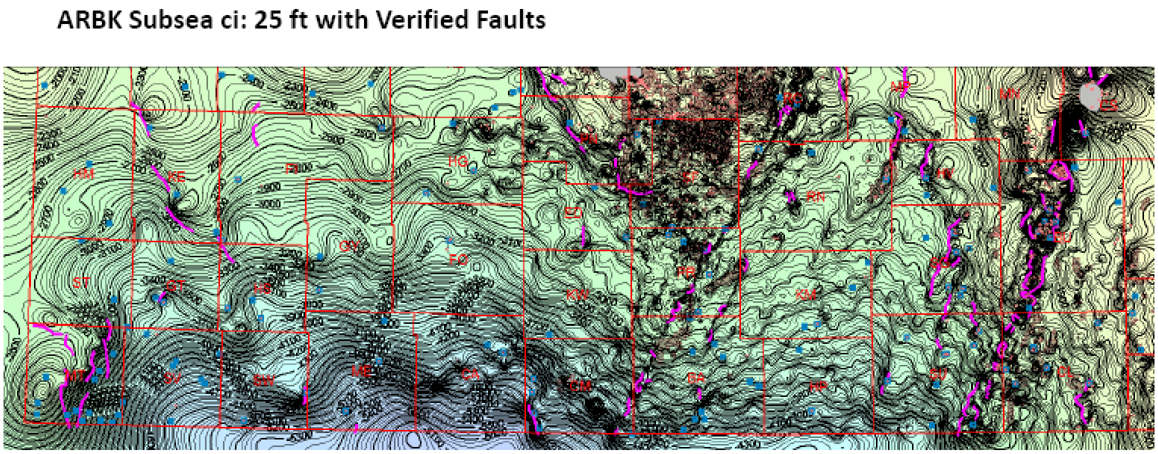


Figure 11. Structure top Arbuckle in southern Kansas study area with verified faults in pink lines.

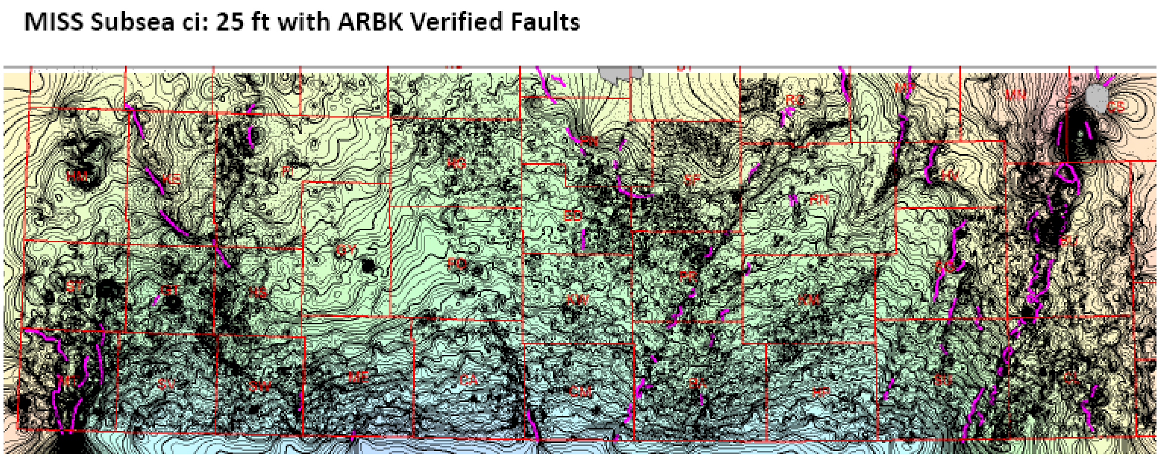


Figure 12. Structure map top Mississippian in southern Kansas study area with verified faults noted as pink lines.

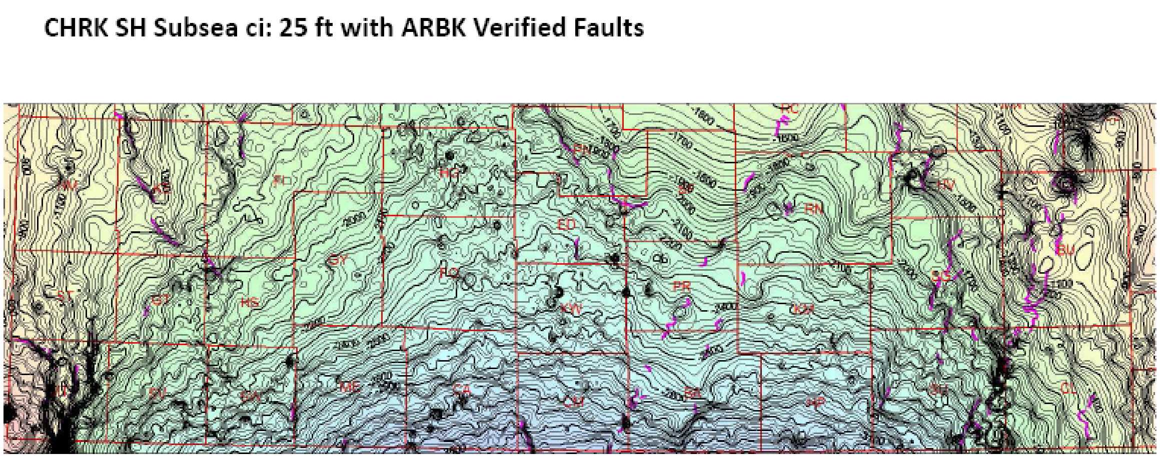


Figure 13. Structure map top of the Middle Pennsylvanian Cherokee Group in southern Kansas study area with verified faults noted as pink lines. Faults much diminished compared to the lower strata in Figures 11 and 12.

LANS Subsea ci: 10 ft with ARBK Verified Faults

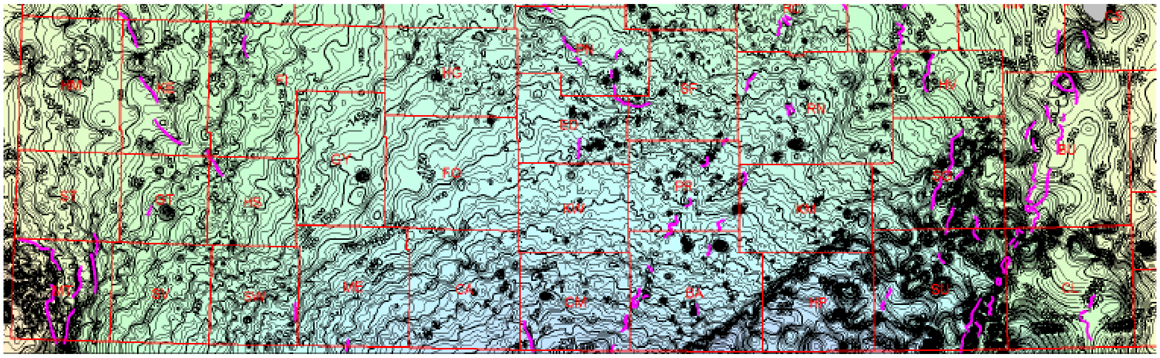


Figure 14. Structure map top of the Upper Pennsylvanian Lansing Group in southern Kansas study area with verified faults noted as pink lines. Much fewer verified faults overall in the Pennsylvanian compared to the lower Paleozoic. Complex contours in southeast Kansas are in an area where the Lansing Group carbonates downlap along a shelf margin bordering the Anadarko Basin to the south. Stratigraphic correlations have moved down to the equivalent section strata in lower shelf shales and thin carbonates. Area of Lansing downlap includes Sumner County and Wellington Field.

CHASE Subsea ci: 10 ft with ARBK Verified Faults

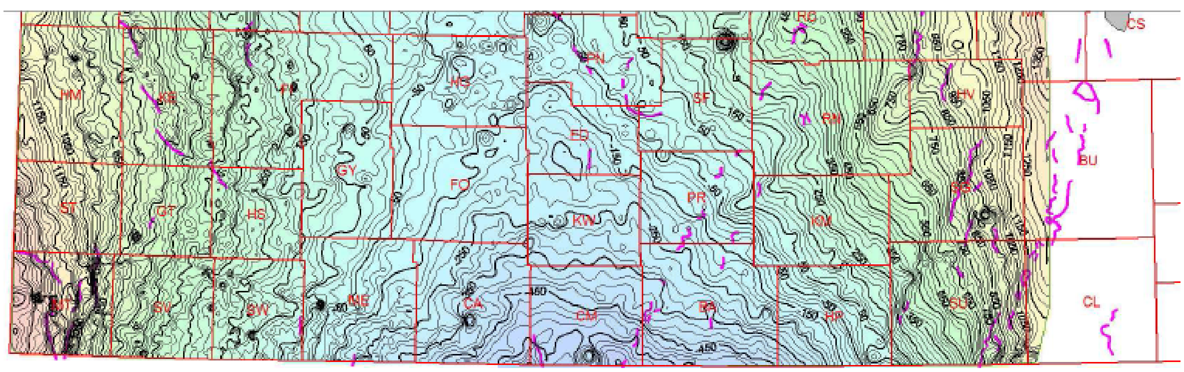


Figure 15. Structure map top of the Lower Permian Chase Group in the southern Kansas study area with verified faults noted as pink lines. The Permian strata have significantly fewer faults including Sumner County and Wellington Field area. Still, regional deformation has continued since the Permian expressed by broad embayment in central area cut by narrower flexures and anticlines trending NW and NE.

Subtask 12.1. Map Arbuckle reservoir compartments.

Additional well logs are being digitized to provide more detailed quantitative measurement of rock properties and Petrel modeling in ten prospective CO2 sequestration sites in southern Kansas illustrated on the map shown in Figure 16. Figures following through Figure 36 visit these 10 sites showing composite structure maps and supertype wells in successive pairs of figures.

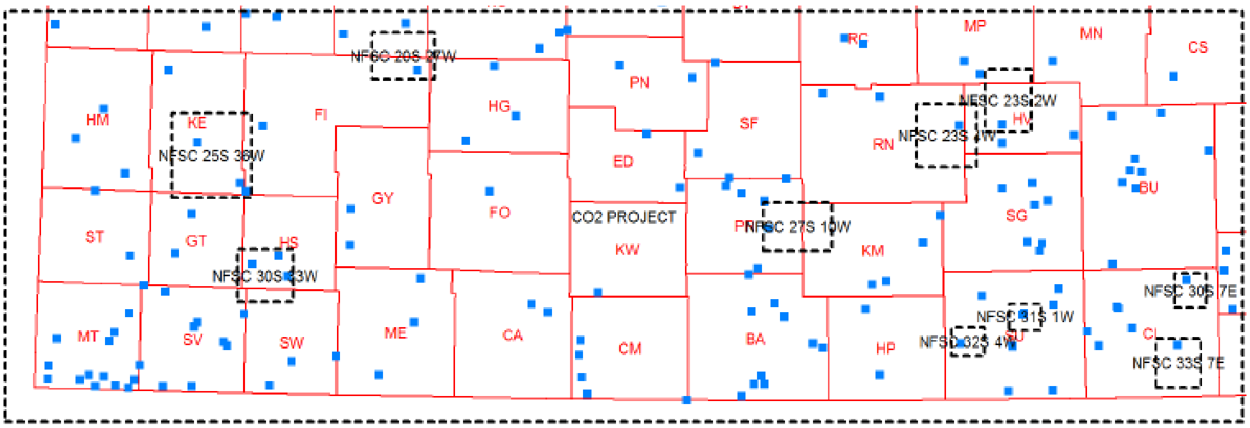


Figure 16. Map outlining prospective sequestration sites in southern Kansas reviewed in subsequent figures

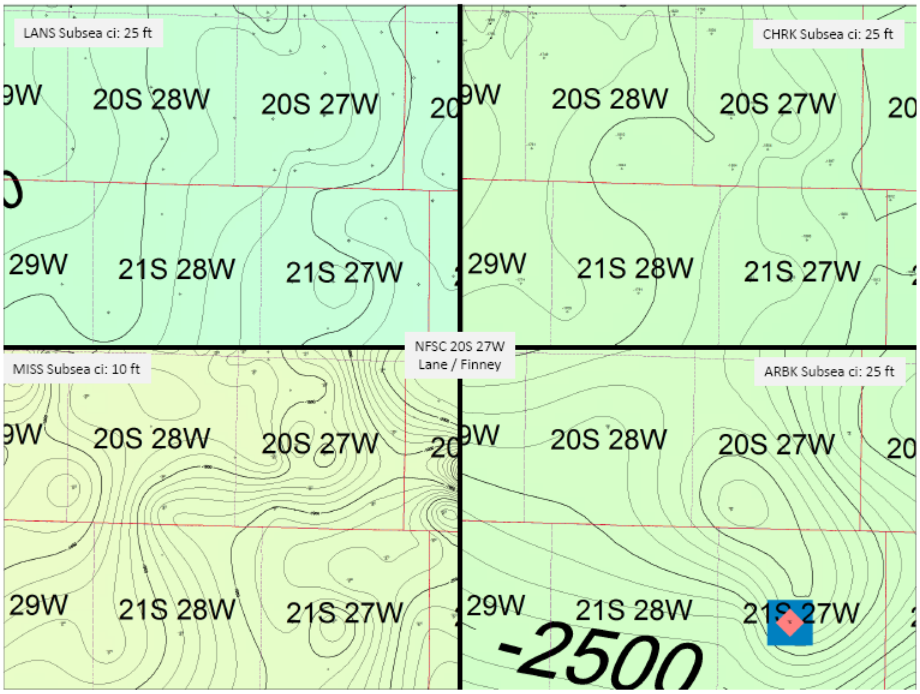


Figure 17. Structure map on top of Upper Pennsylvanian Lansing Group in Lane/Finney County NFSC 20 South-27 West prospective site for carbon sequestration. Structural closure is noted in southeast along with a supertype well (Figure 18) to provide understanding of the internal stratigraphy of the Arbuckle Group (deep saline aquifer).

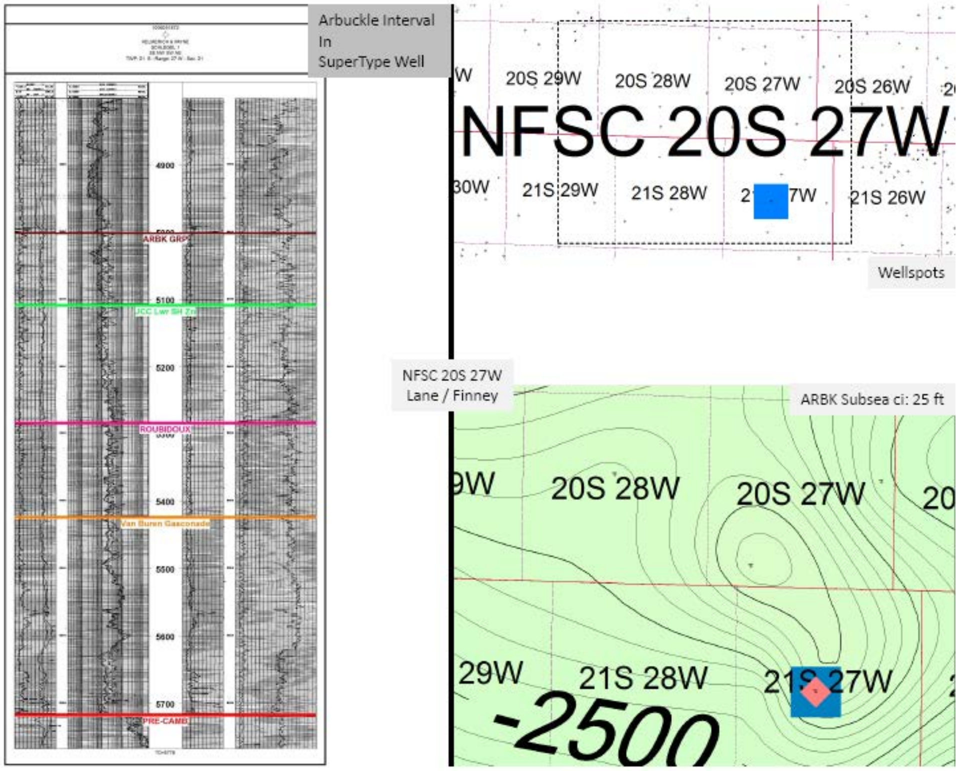


Figure 18. Supertype well in Lane-Finney County 20 South-27 West showing thick Arbuckle and its internal stratigraphic units that have correlated.

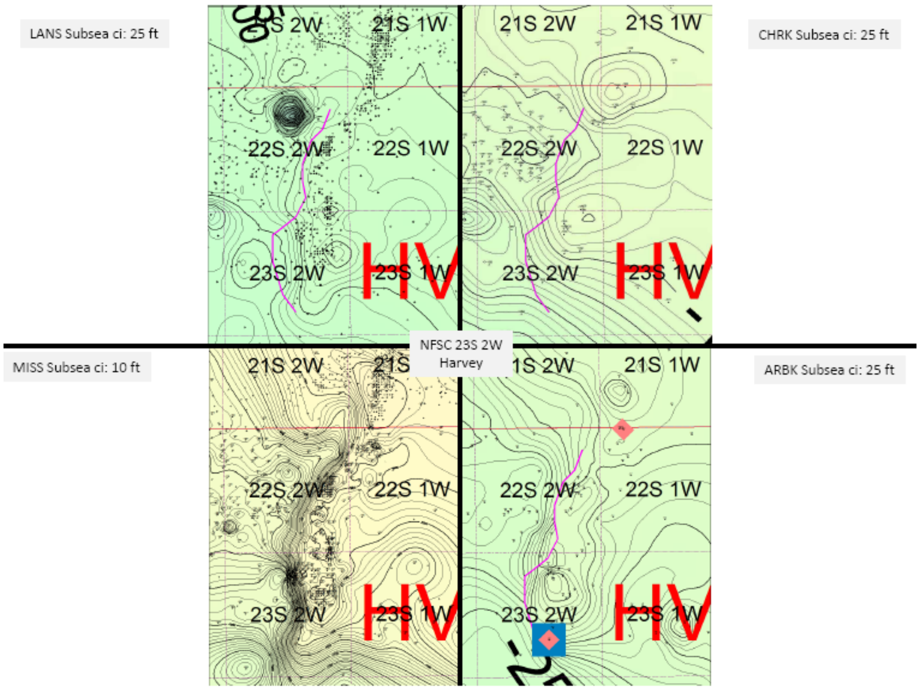


Figure 19. Structure map composite of four stratigraphic horizons including top Arbuckle, top Mississippian, top Cherokee, and top of Lansing Group in Harvey County NFSC 23 South-2 West prospective site for carbon sequestration. Faulting is indicated on west flank of a north-south trending anticline exhibiting structural closure up through these strata.

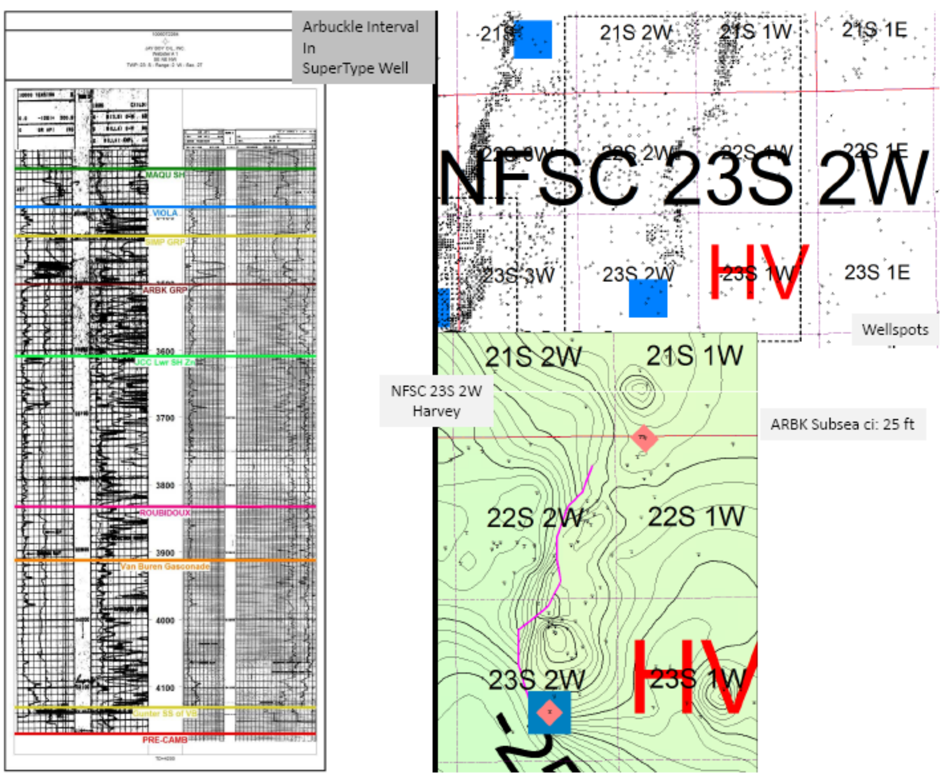


Figure 20. Supertype well in Harvey County NFCS 23 South-2 West prospective carbon sequestration site alongside top Arbuckle structure map and map showing oil fields that produce from the Mississippian strata. Site is analogous to Wellington Field. Very few wells penetrate the Arbuckle compared to the Mississippian and shallower strata. Arbuckle shows variable porosity.

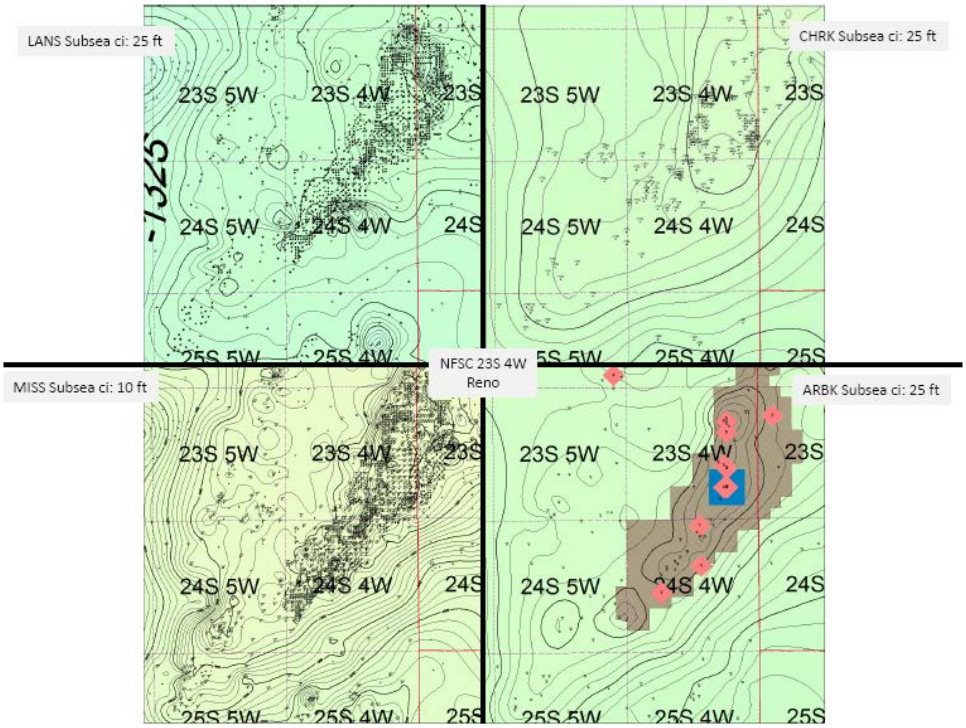


Figure 21. Composite structure maps for prospective carbon sequestration site in Reno County with notable structural closure in the Mississippian and Arbuckle. Oil production from Mississippian, again analogous to Wellington Field.

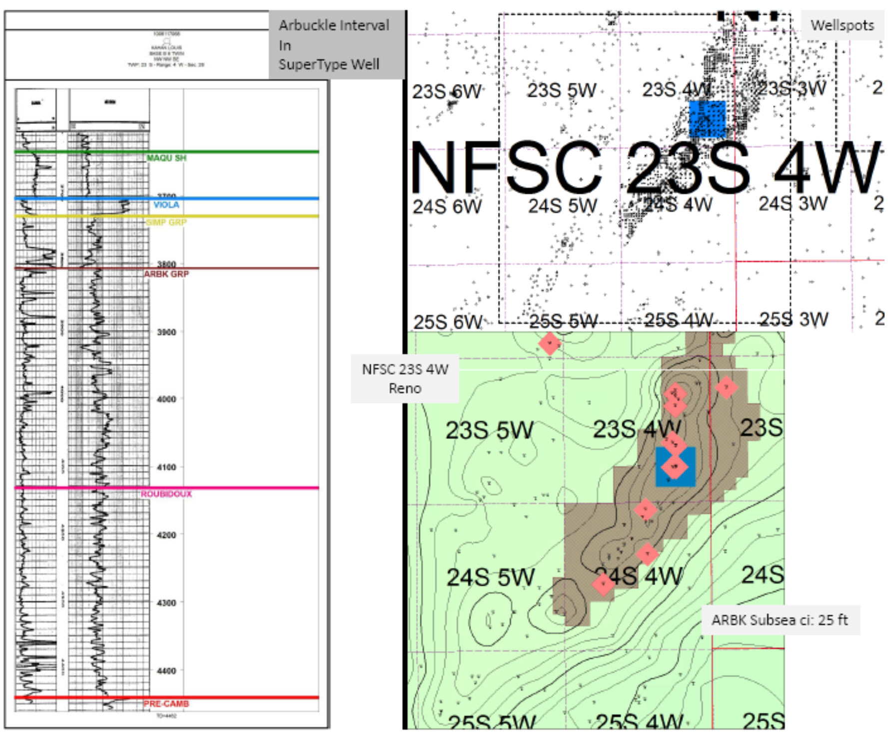


Figure 22. Supertype well for Reno County site and location maps to right showing location of supertype well.

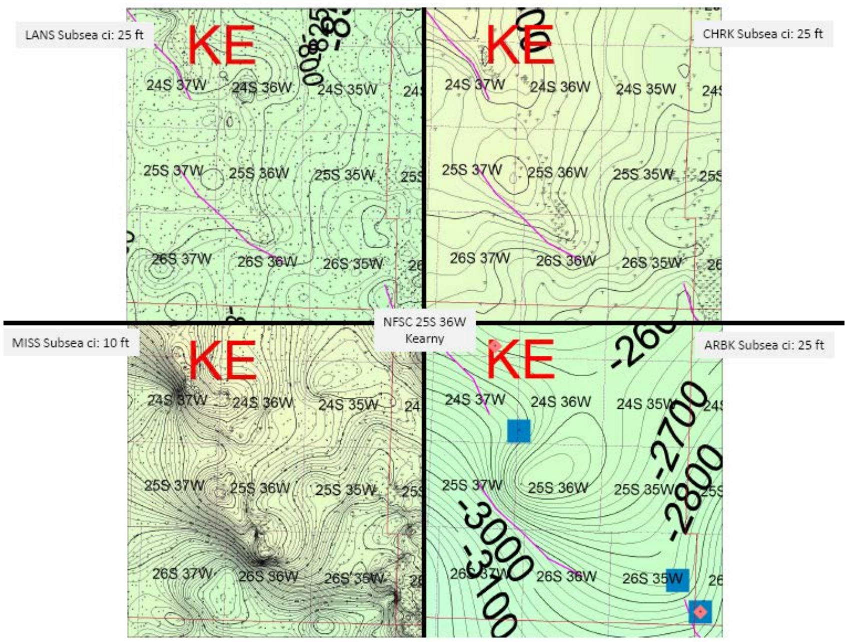


Figure 23. Composite set of structure maps for Kearny County NFSC 25 South-36 West prospective site for carbon sequestration to be modeled to refine estimates of regional carbon storage. Type (blue squares) and supertype wells shown (blue square with pink dot). Structure closure noted even at shallower structure at top of Lansing Group. Faulting in west flank noted in Arbuckle and at Mississippian levels, but Pennsylvanian strata with sealing shales appears to be unfaulted.

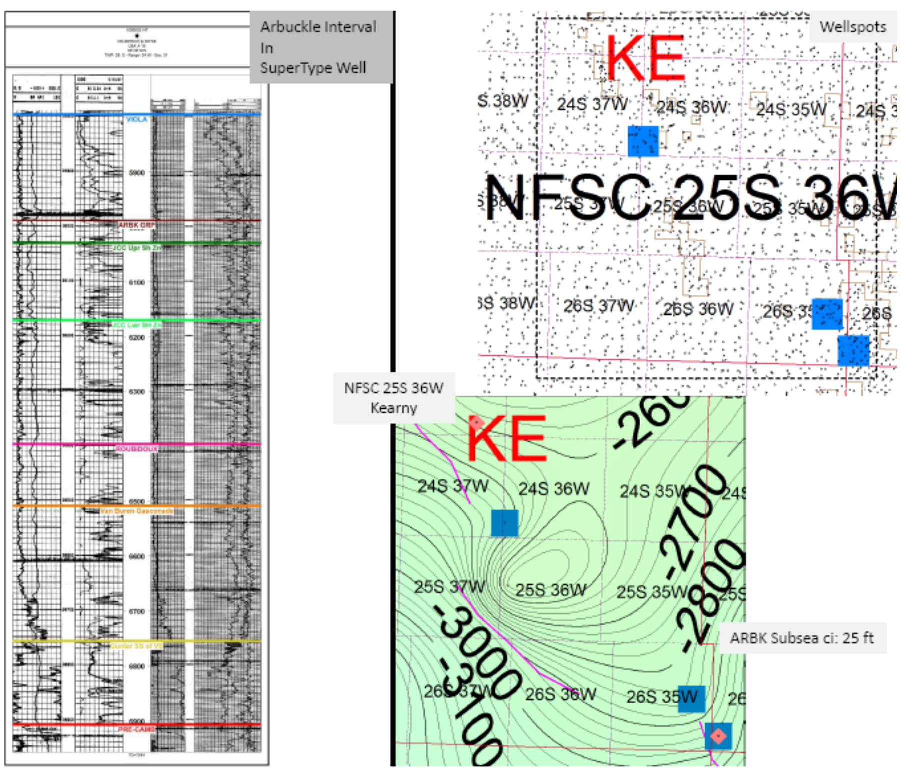


Figure 24. Supertype well showing Arbuckle Group saline aquifer at Kearney County NFSC 25 South-36 West site. Maps show Arbuckle structure and locations of type and supertype wells. Arbuckle is thick and has numerous porous and apparently tight intervals alternating through the interval.

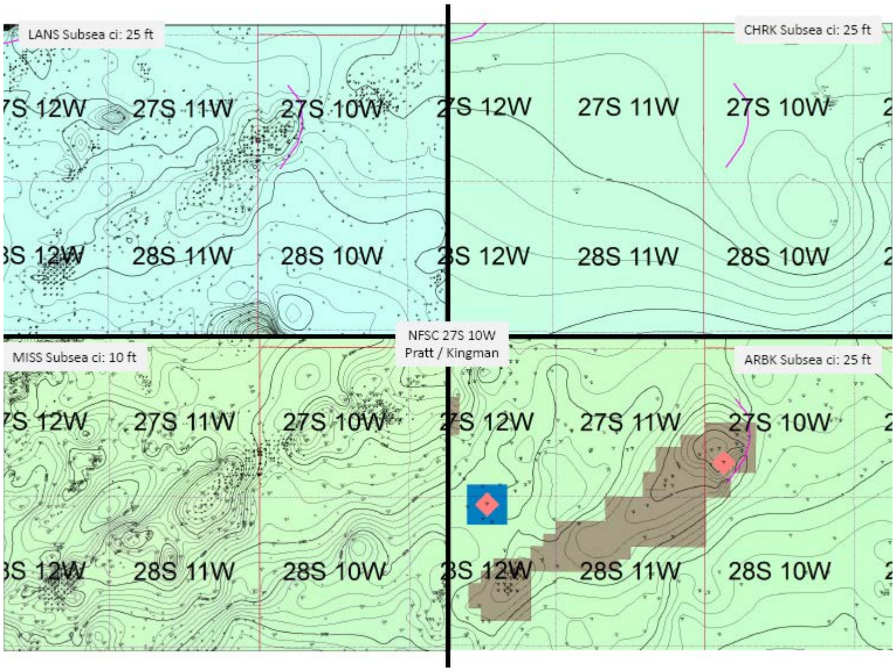


Figure 25. Structural composite maps for potential CO2 site in Pratt/Kingman County, NFSC 27 South-20 West. Area of possible containment with structural closure is highlight in gray. Type and super type wells are also shown.

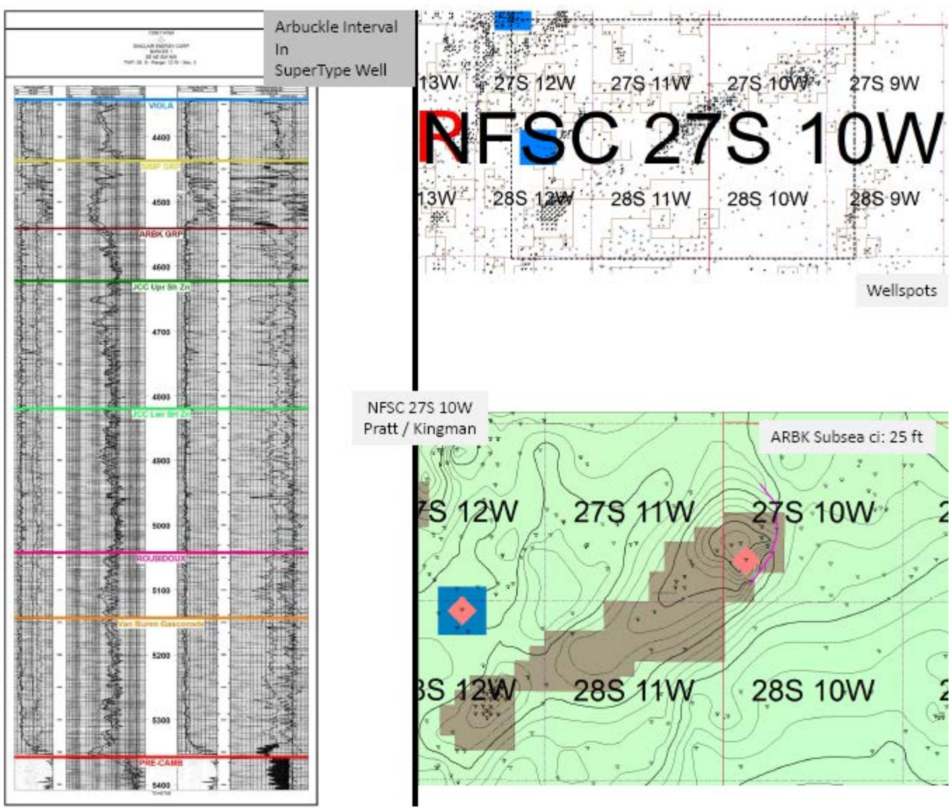


Figure 26. Supertype well in NFSC 27 South and 10 West. Site is overlain by oil field, analogous to Wellington Field.

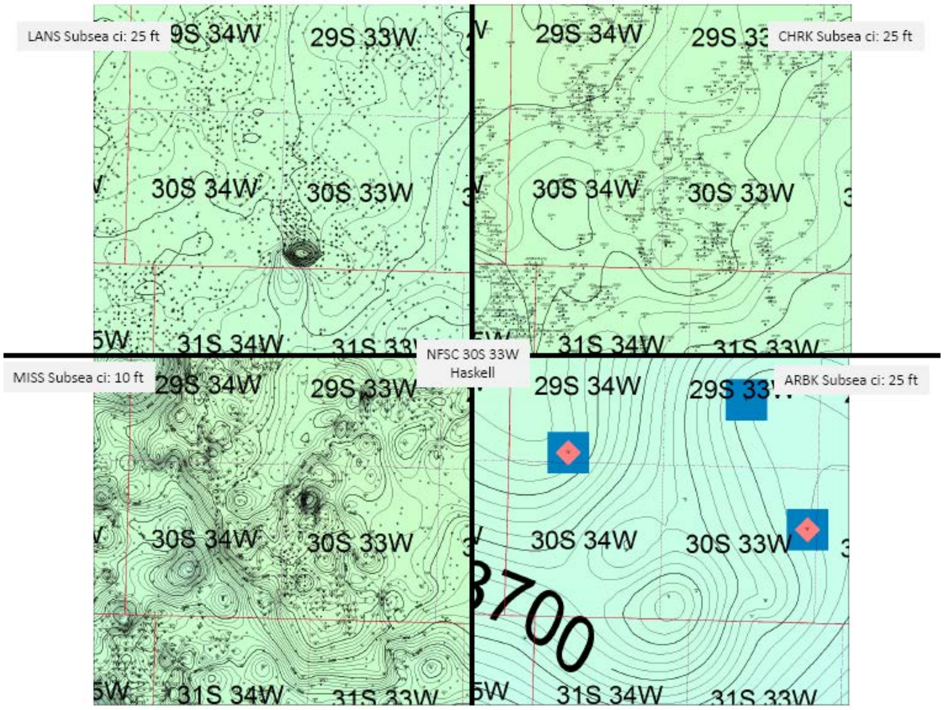


Figure 27. Composite structure map of potential Haskell County NFSC 30 South-33 West carbon sequestration site outlining areas of structural closure. Location has two supertype wells and one type well highlighted as blue squares.

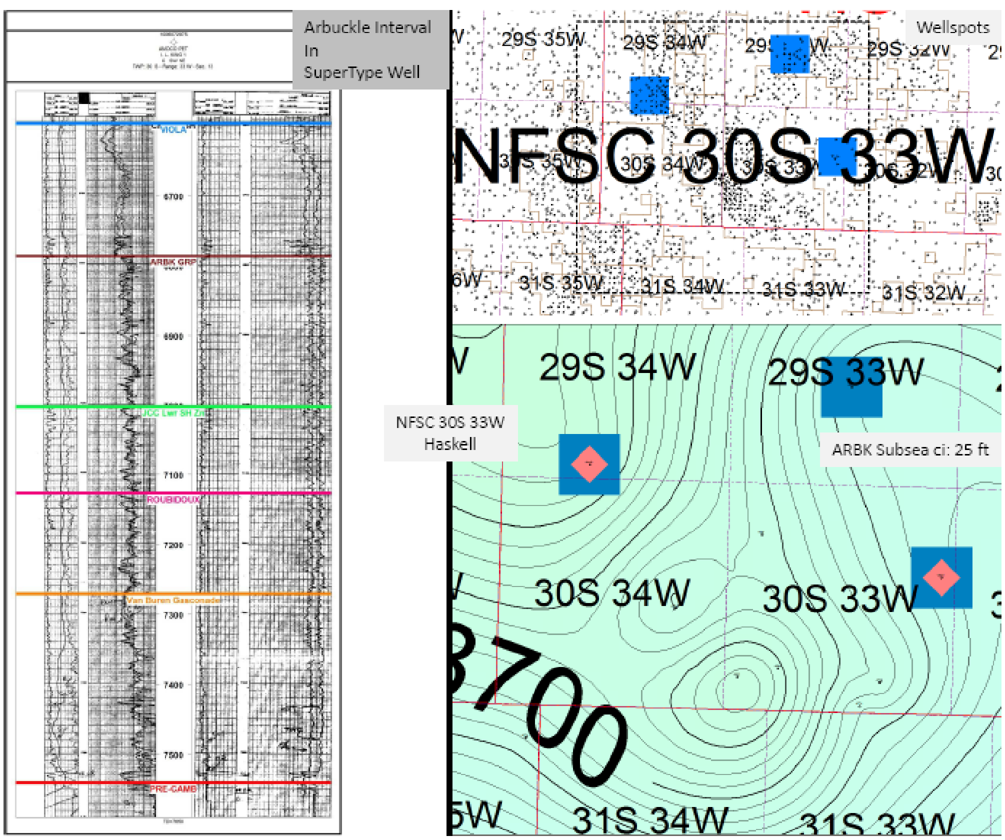


Figure 28. Supertype well in Haskell County, NFSC 30 South-33 West site for potential carbon sequestration. Arbuckle is thick with porous and less porous intervals.

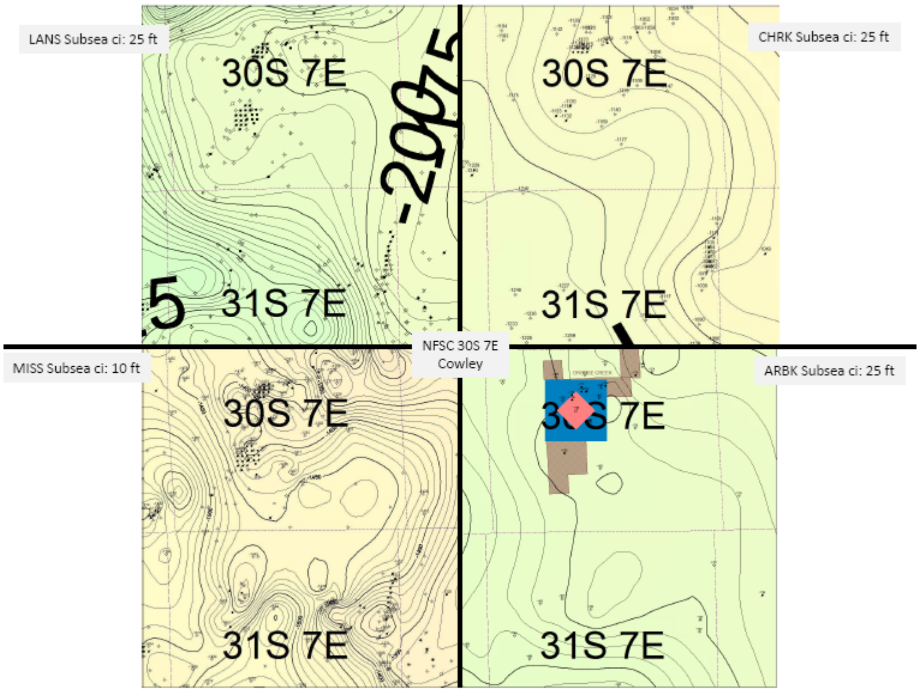


Figure 29. Composite structure maps for Cowley County, NFSC 30 South-7 East potential site for carbon sequestration. Local structural closure is indicated. Site has one supertype well and the location is also the site of a shallower oil field.

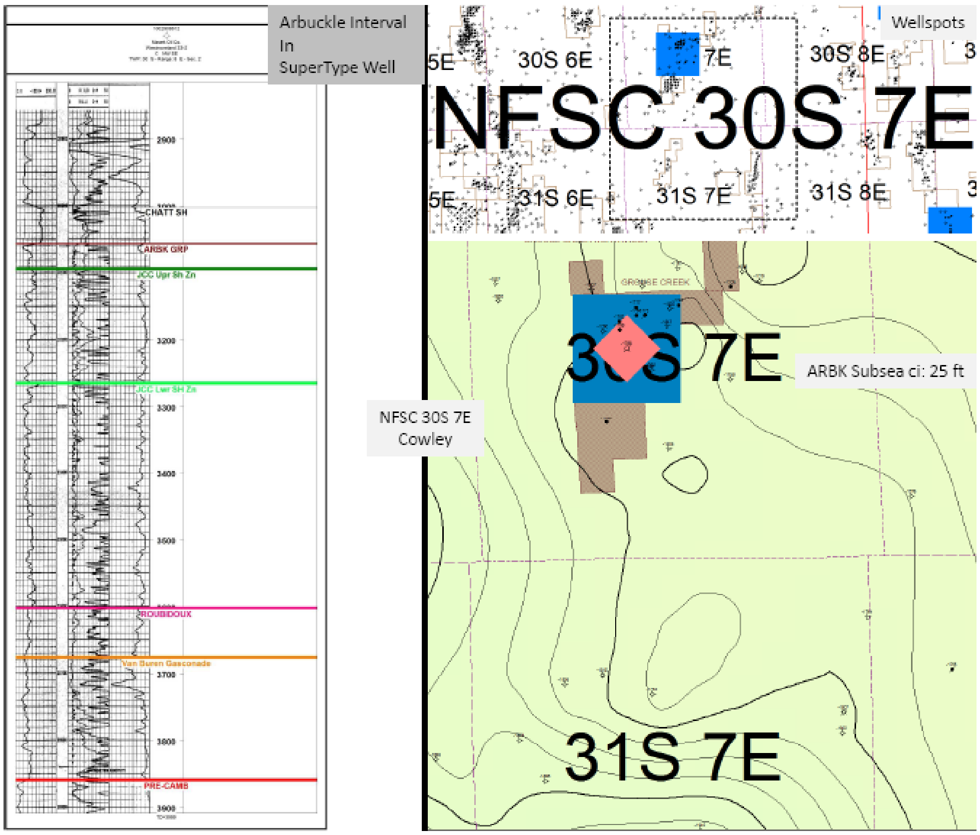


Figure 30. Supertype well in Cowley County, NFSC 30 South-7 East site for potential carbon sequestration. Arbuckle is thick with numerous more porous intervals suggested by the well log.

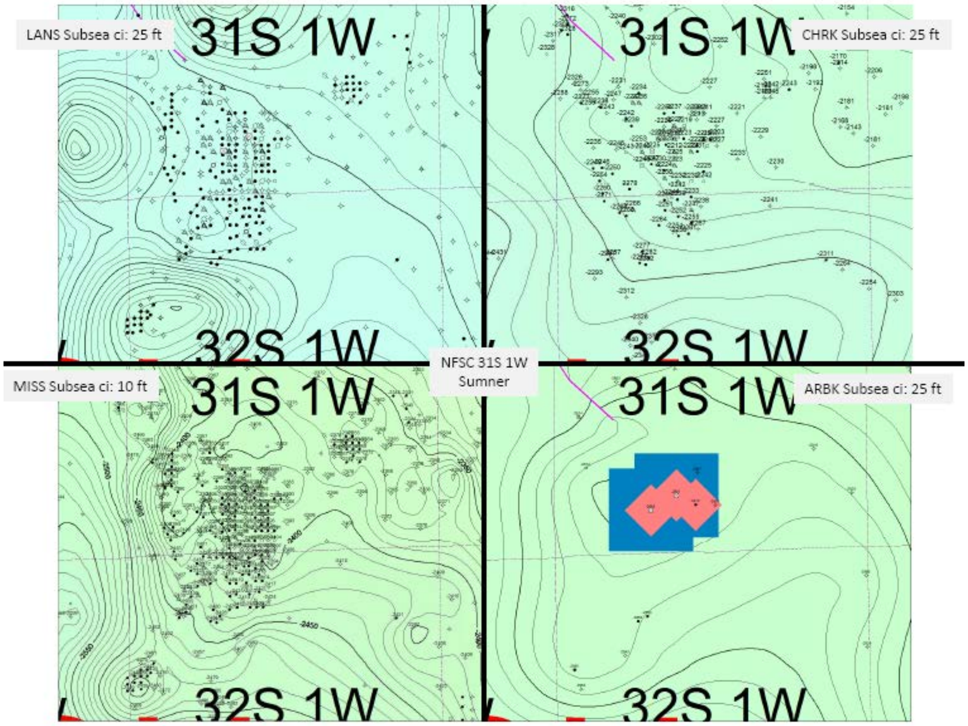


Figure 31. Composite structure maps for Sumner County, NFSC 31 South-1 West. This is Wellington Field, the site of detailed characterization and modeling and calibration point for the regional study.

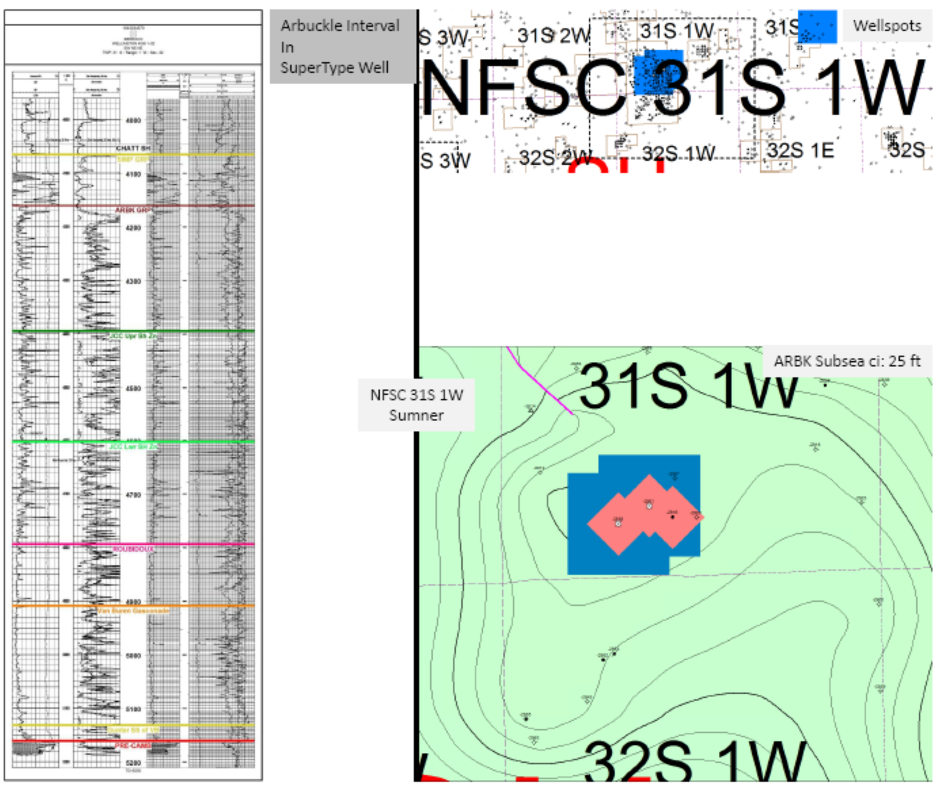


Figure 32. One of three supertype wells in Wellington Field, KGS Wellington #1-32. Structural close at level of Arbuckle supported by current seismic interpretation.

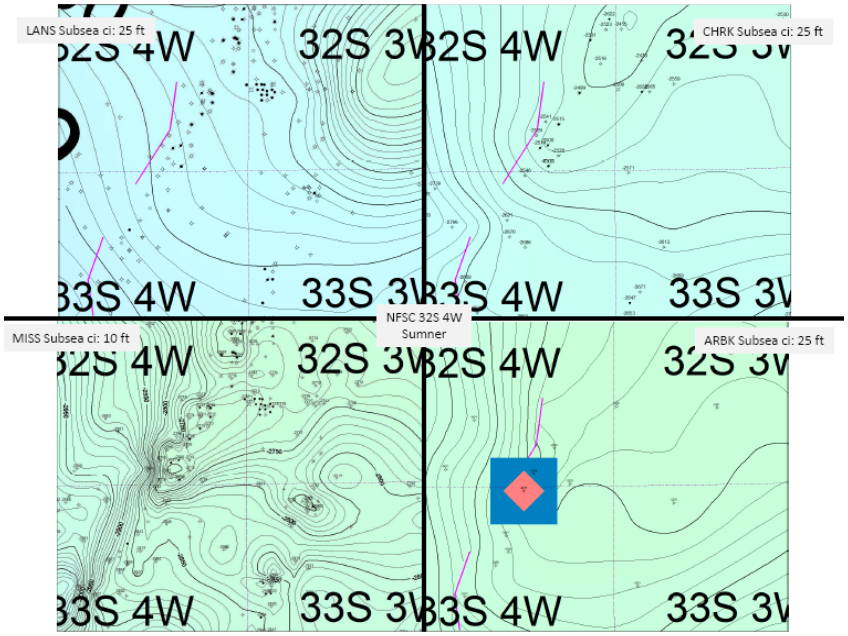


Figure 33. Composite structure maps in potential carbon sequestration site in western Sumner County, NFSC 32 South-4 West. Well control at Mississippian level notes structural closure. Possible faulting at depths of Arbuckle and Mississippian, but shallow Pennsylvanian horizons appear to be free of faulting.

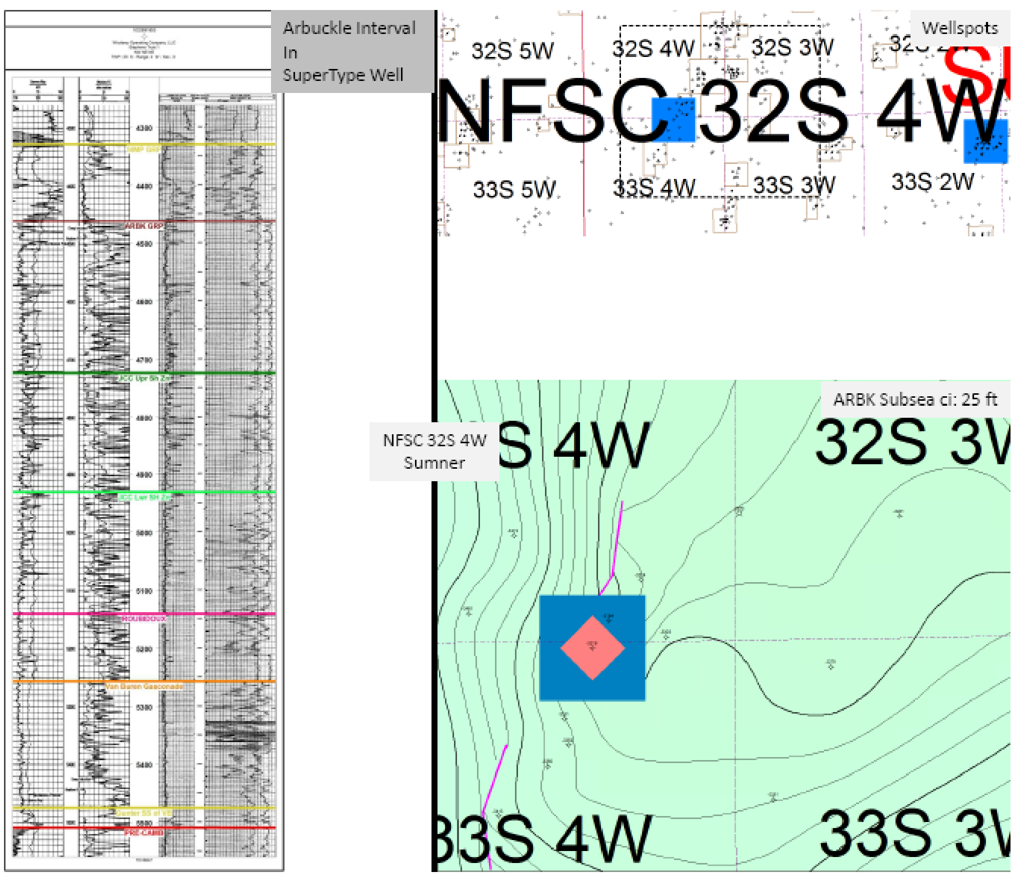


Figure 34. Supertype well in western Sumner County, NFSC 32 South-4 West site for potential carbon sequestration. Arbuckle is thick with variable porosity. Possible fault is indicated (pink line on adjoining map) on steeply dipping west flank of the structure.

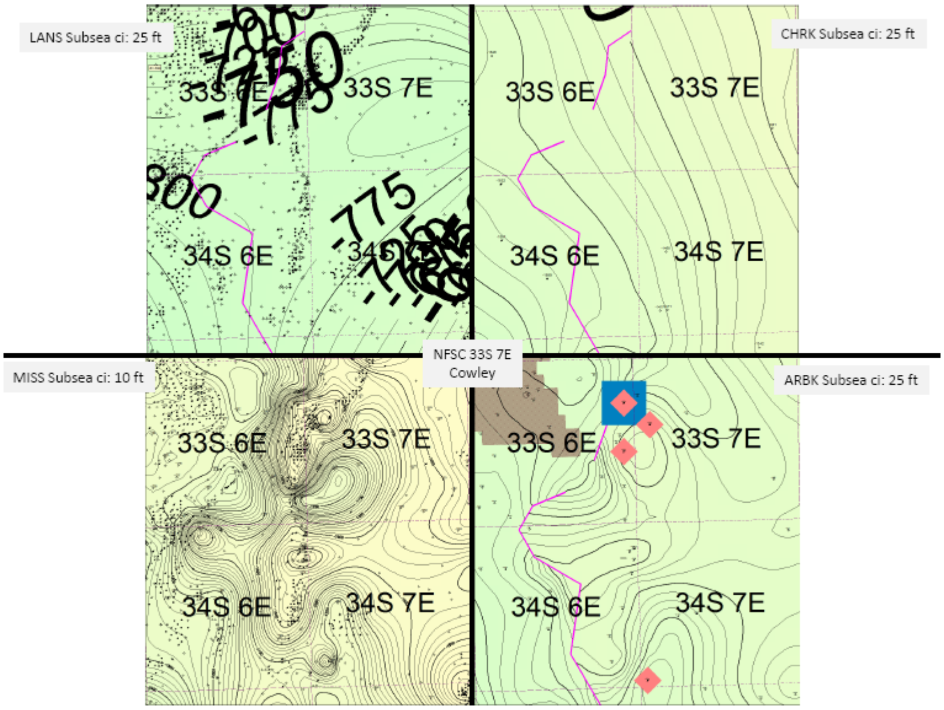


Figure 35. Composite structure map in Cowley County, NFSC 33 South-7 East showing structural closure at Mississippian and Arbuckle horizons. These zones appear to be faulted on west flank of this closure. Site coincides with an oil field.

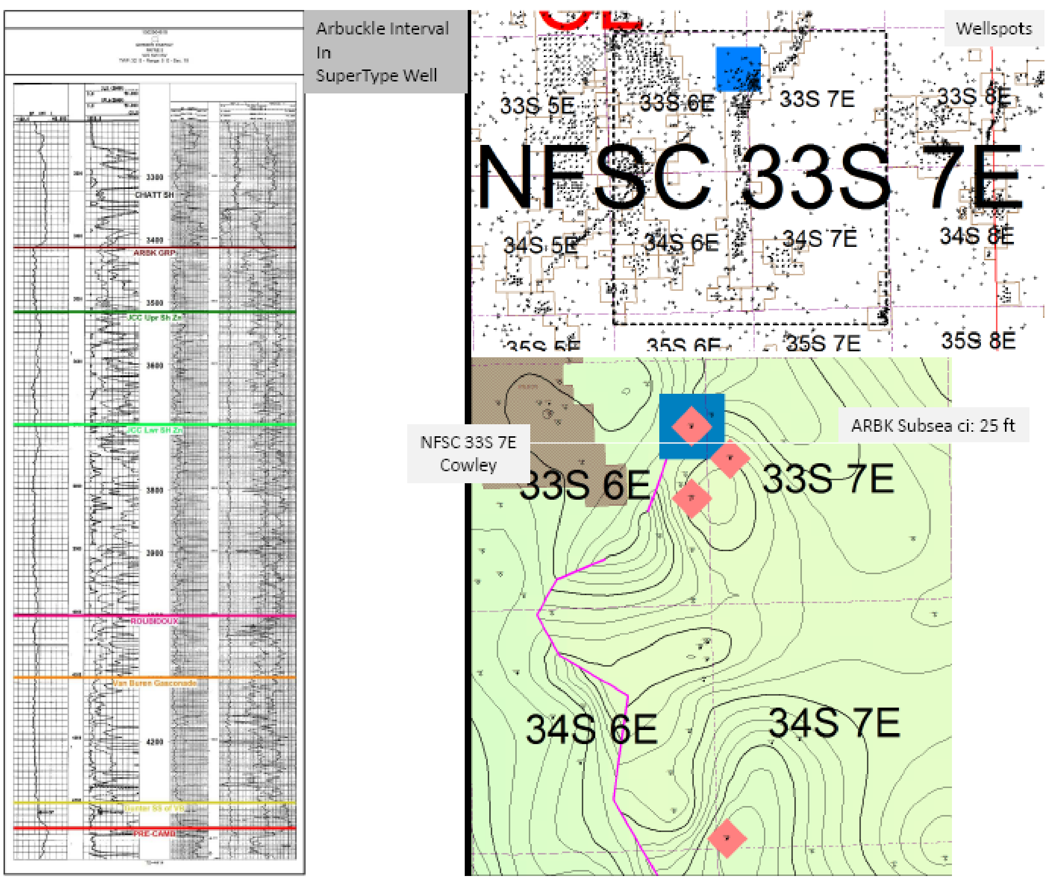


Figure 36. Supertype well at Cowley County site shows thick Arbuckle with variable porosity development.

Subtask 15.1. Extend regional study by evaluating CO2 sequestration potential.

Bittersweet team expanded the regional study to include SW Kansas. Latest efforts were focused on the characterization of the structure and stratigraphy in the area of the four Chester and Morrow oil fields being modeled to evaluate CO2-EOR in their sandstone reservoirs. The fields, Pleasant Prairie, Eubank, Cutter, and Shuck essentially run north to south across Finney, Haskell, and Seward counties. A regional structure of the top of the Arbuckle Group (Figure 36) shows southern dipping surface with smaller southerly plunging anticlines that trend N-S or N-NW and S-SE. Figure 37 is the structure map on top of the Meramec-age Mississippian, the solid widespread surface into which the Chester and Morrow incised valleys were cut.

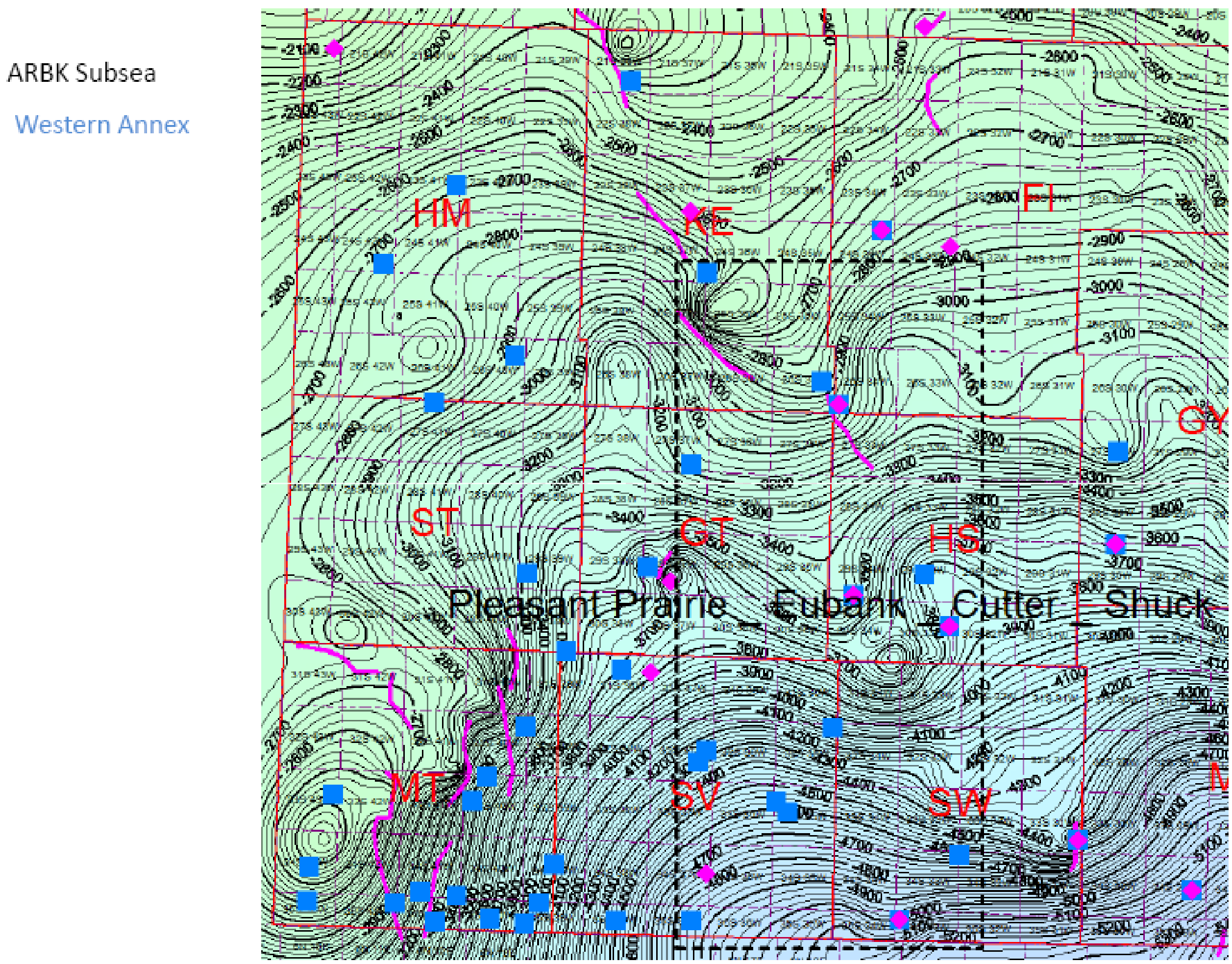


Figure 36. Structural configuration on top of the Arbuckle Group in southwestern Kansas. Small grids are townships, 6 miles on a side.

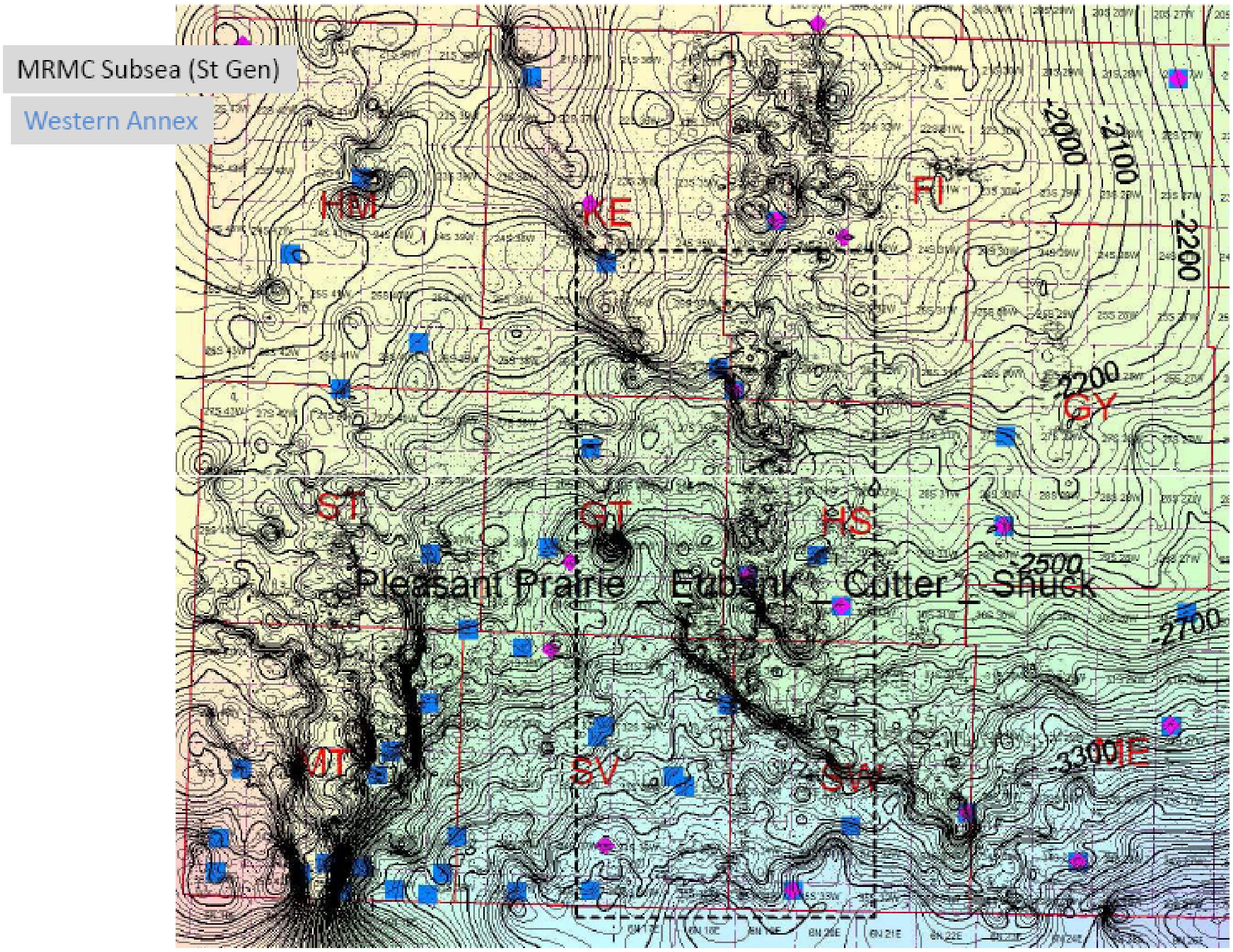
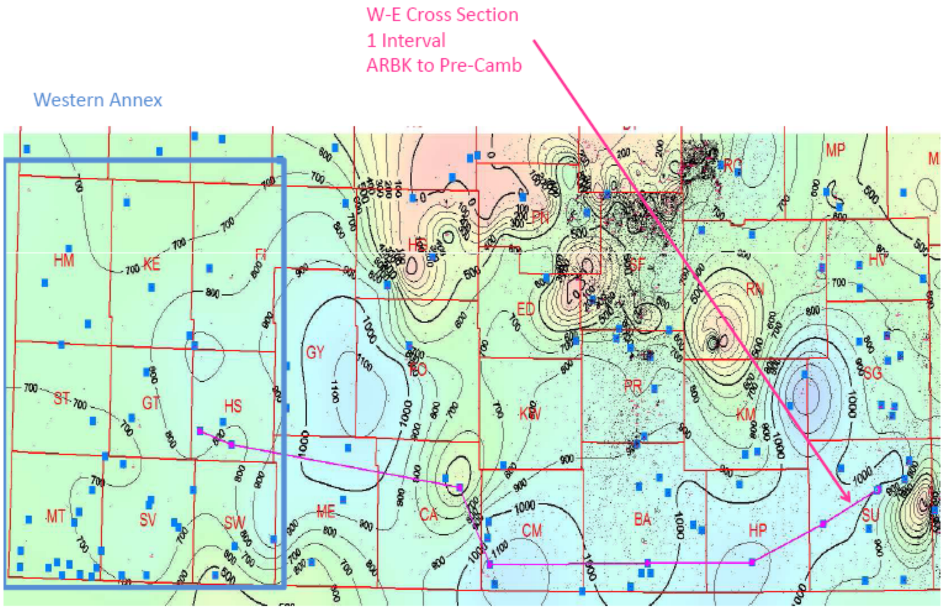


Figure 37. Structure contour map to Meramec Mississippian in area of four Chester and Morrow fields being evaluated for CO2-EOR. Southerly dipping strata interrupted by sharper breaks in slope along southern plunging anticlines in center of the map. Central anticlines are gradually dipping east flank and sharply dipping west flank. Structural high in the SW corner of Kansas corresponds to the east side of the larger Sierra Grande Uplift. In contract to the anticlines to the east, this structure dips eastward along three distinct N-S trending benches that border the Hugoton Embayment.

A cross section along the southern border of the study area of southern Kansas is shown in Figure 38. The section extends from Haskell County near the Chester-Morrow Fields to Wellington Field on the east. The distance of the cross section is ~200 miles. The cross section is a stratigraphic section hung on the top of the Arbuckle and illustrates rather consistent thickness of the Arbuckle across the southern portion of the study area with the exception the thinning over the Pratt anticline. The index map for the cross section, also in Figure 38, is an Isopach of the Arbuckle.



W-E X-Section
ARBK to Pre Camb Interval

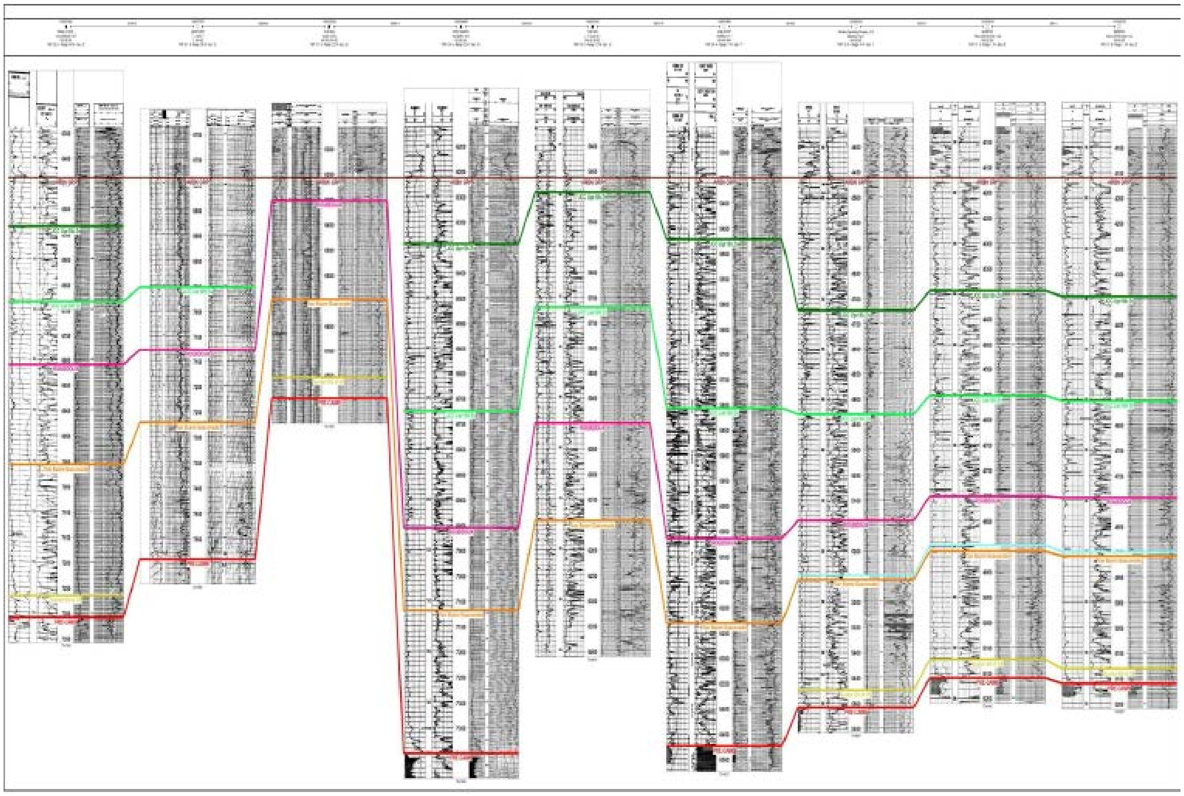


Figure 38 includes an index map above a stratigraphic well log cross section beneath the map. The map is an Isopach of the Arbuckle Group and the cross section shows that interval. Datum of the cross section is top Arbuckle.

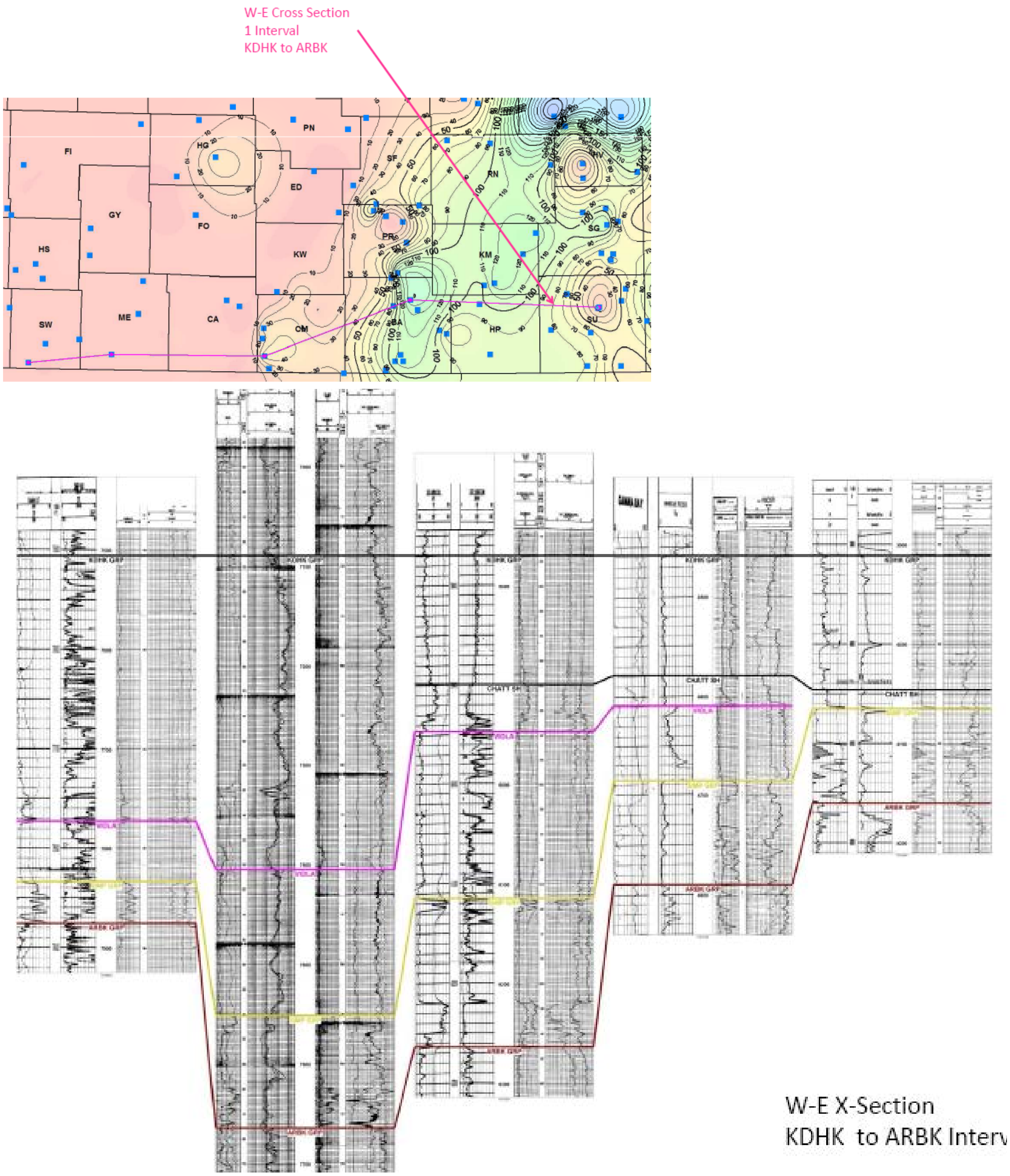
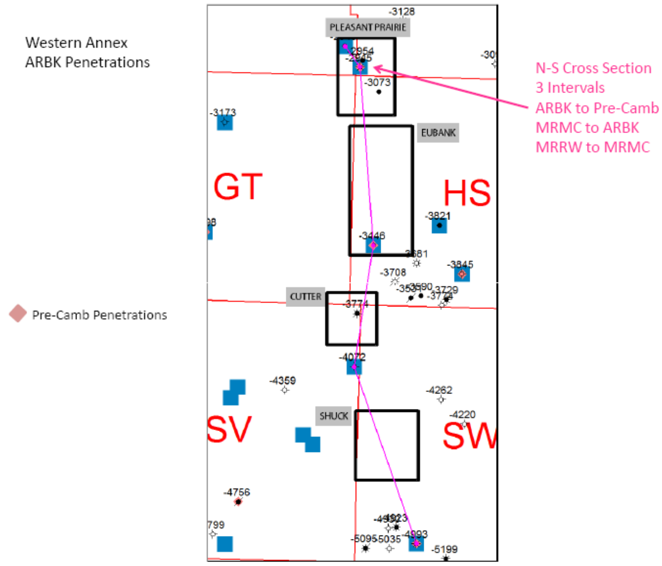


Figure 39. Cross section index map (top) that is an isopach of the Upper Devonian-Lower Mississippian Chattanooga Shale shows pinchout in the western portion of the study area including locations of the Chester and Morrow fields being studied. Shale overlies the Arbuckle and provides a caprock to the east while lower Mississippian strata above it will need to be evaluated for caprock suitability. Cross section is a stratigraphic well log section datumed at the top on the Mississippian. Lower correlation is the top of Arbuckle. The Chattanooga Shale found midway down the section (above the purple correlation line on the top of the Viola Limestone). The yellow correlation line is the top of Simpson Group that thins eastward.



N-S X-Section
ARBK to Pre Camb Interval

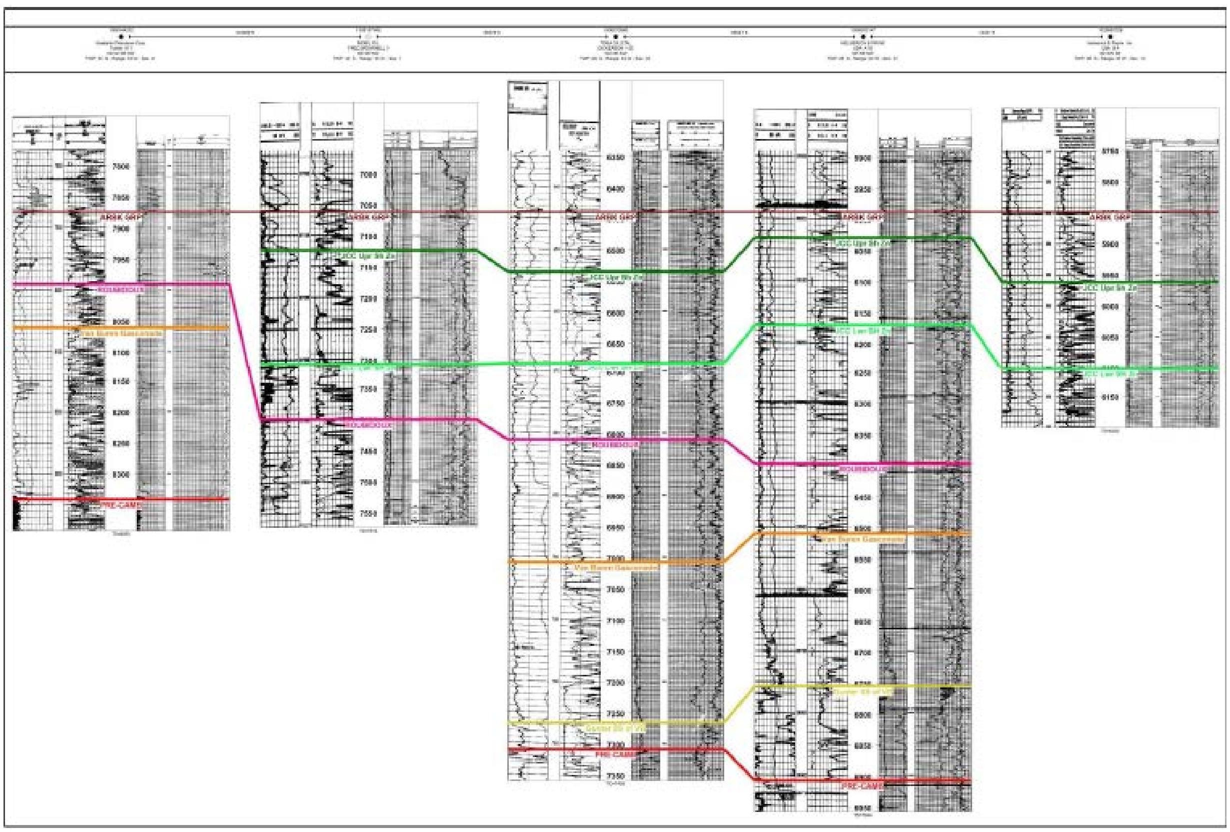


Figure 40. A north (left)-south (right) stratigraphic well log cross section connects each of the Chester-Morrow oil fields being evaluated for CO2-EOR. The index map is shown at the top of the figure. The cross section is datumed at the top of the Arbuckle and section

extends to the base the top of the Precambrian. The intervening correlations within the Arbuckle indicate general thinning of the Arbuckle toward the north.

The next set of map and cross section in Figures 40-47 were developed in Bittersweet subcontractor's review of the deep structure in the vicinity of the Chester-Morrow fields in southwestern Kansas. Besides the field investigations the seismic and regional data are being used to aid in the selection of where the new basement test will be drilled in early summer 2012. Figure 40 above set the stage for the following detail.

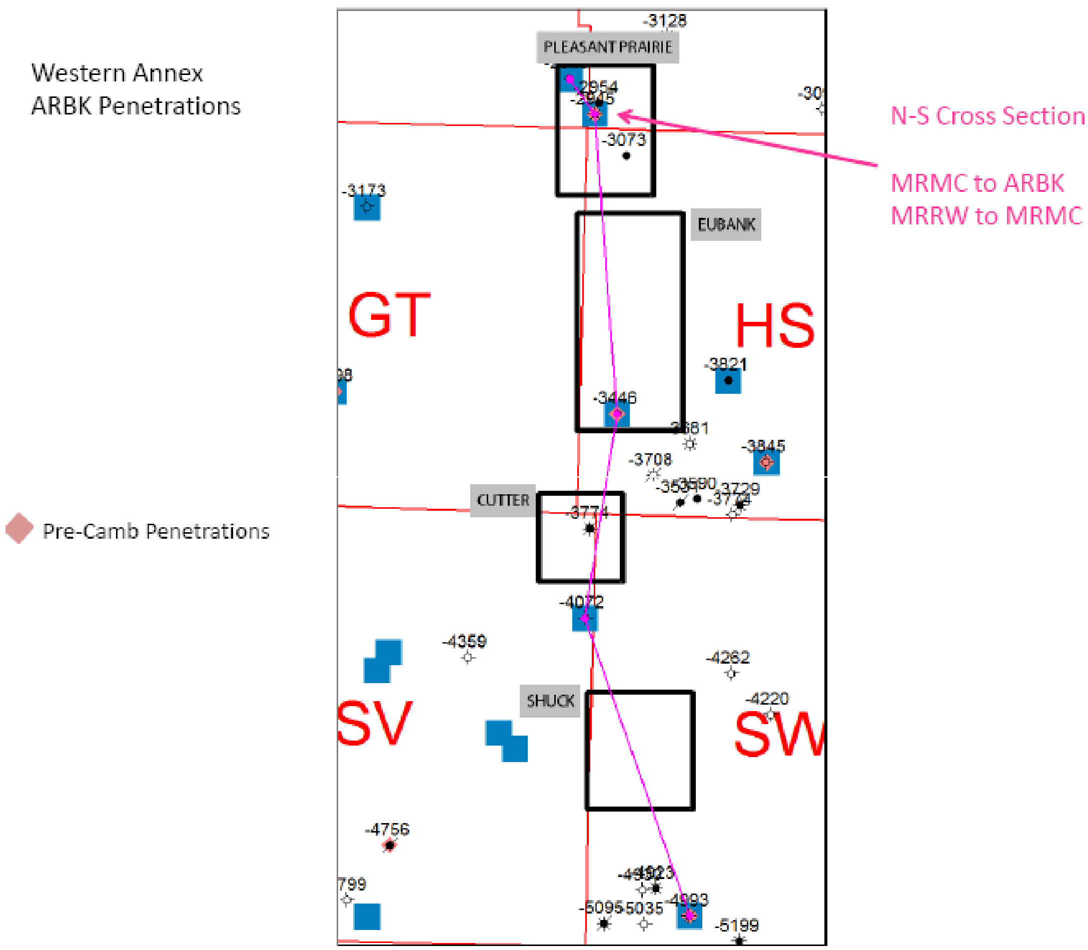


Figure 40. Base map showing the outline of donated seismic around the four Chester-Morrow fields in southwestern Kansas. Map also serves as an index for the following stratigraphic well log cross sections that run south to north through the mapped area.

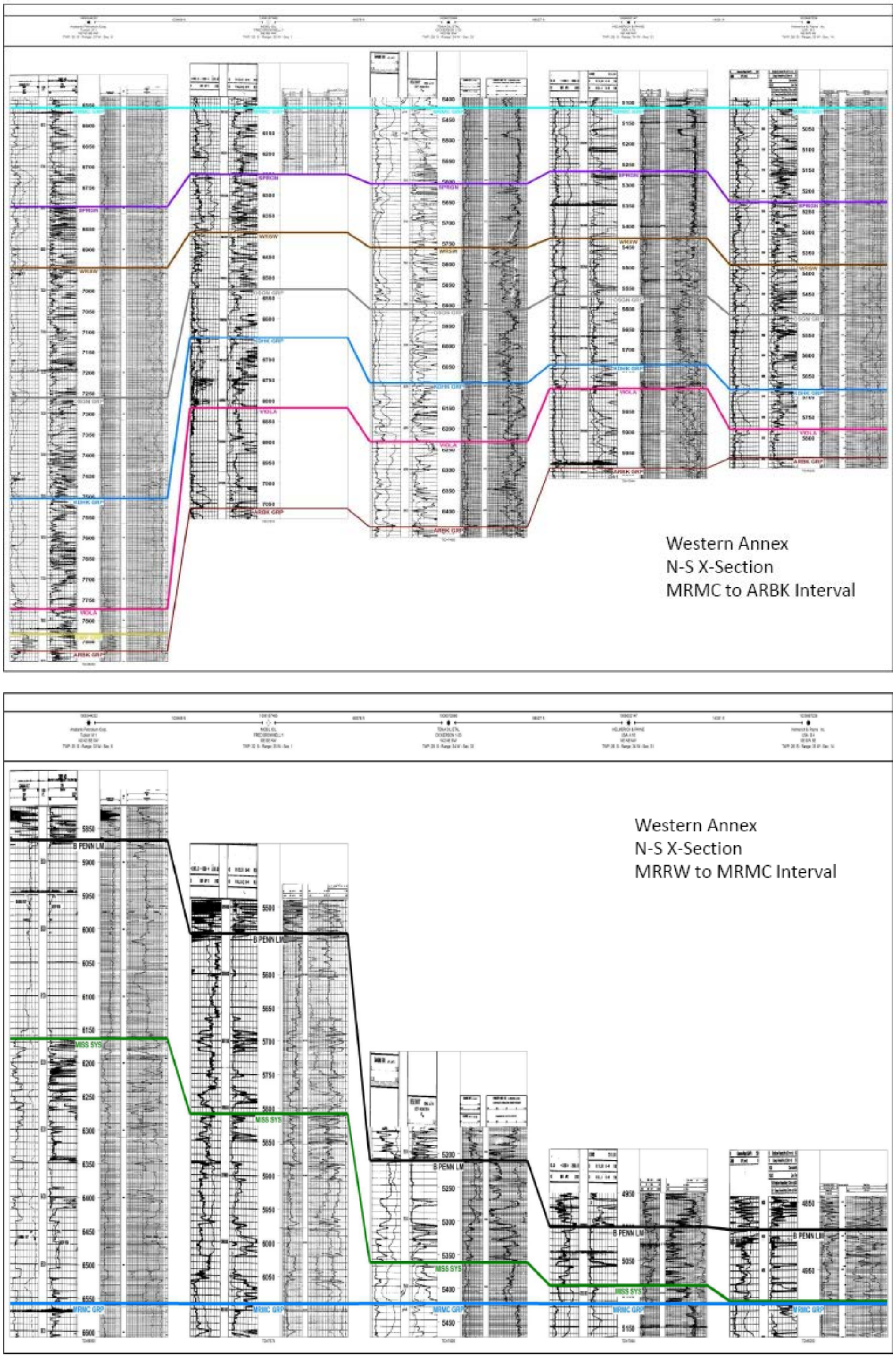
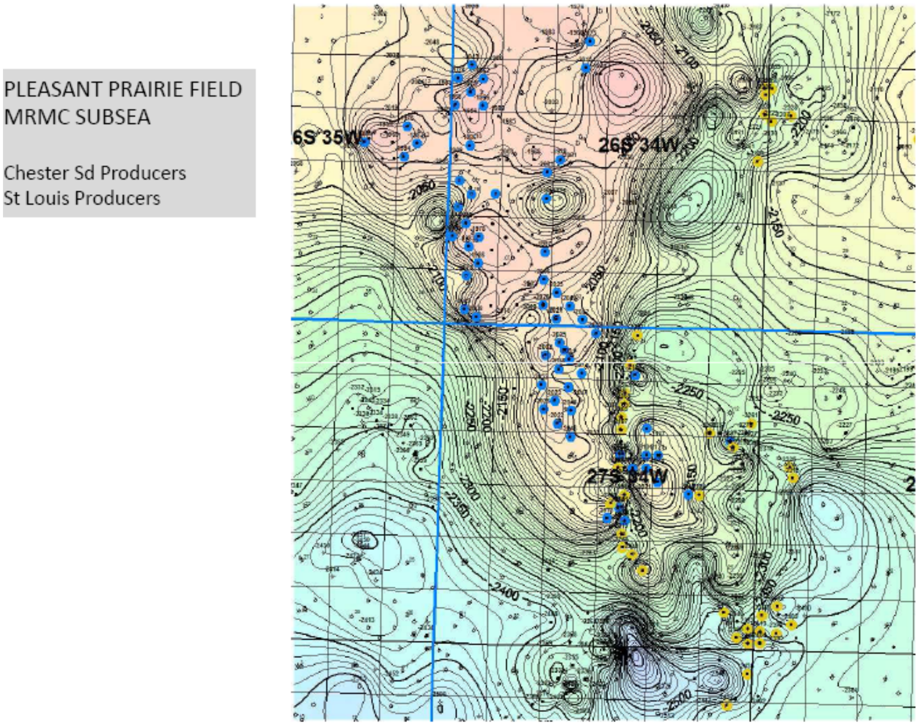


Figure 41. Same wells are shown in a two stratigraphic cross sections, top – Meramec Mississippian to Arbuckle and lower – Morrow to top of Meramec Mississippian. Strata all thicken southward (left) with thickening of Pennsylvanian strata more uniform than older strata.



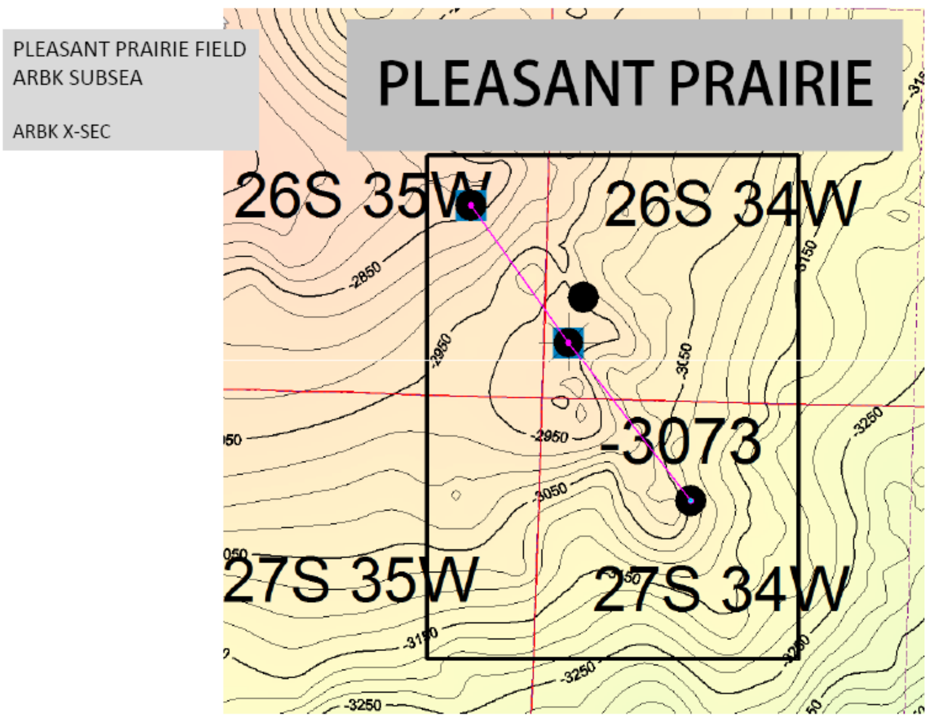


Figure 42 (a). Structure maps on top Meramec Mississippian (top) and top Arbuckle (lower) showing southern plunging anticline with local closure. Type wells are highlighted in lower map and index for cross section shown in Figure 42 (b).

PLEASANT PRAIRIE FIELD

ARBK X-SEC

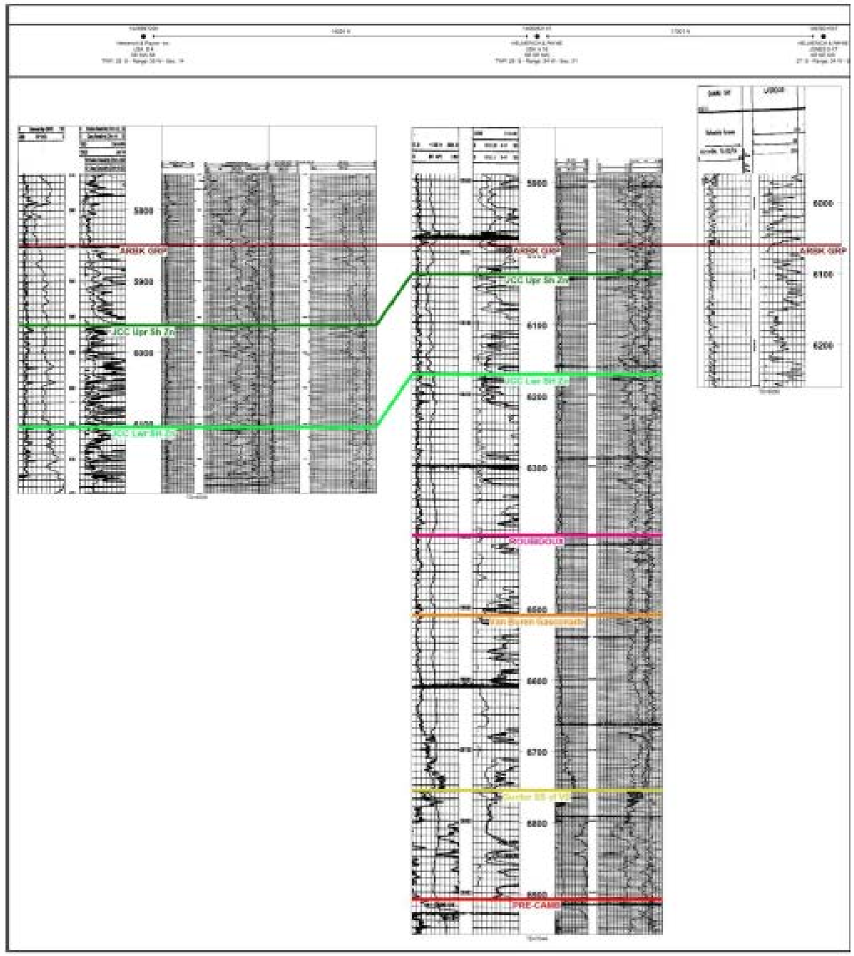


Figure 42 (b). South-to-north stratigraphic cross section with Arbuckle datum showing internal strata in the Arbuckle along the axis of Pleasant Prairie Field. Cross section index is in lower map of Figure 42 (a).

EUBANK FIELD
ARBK SUBSEA

ARBK X-SEC

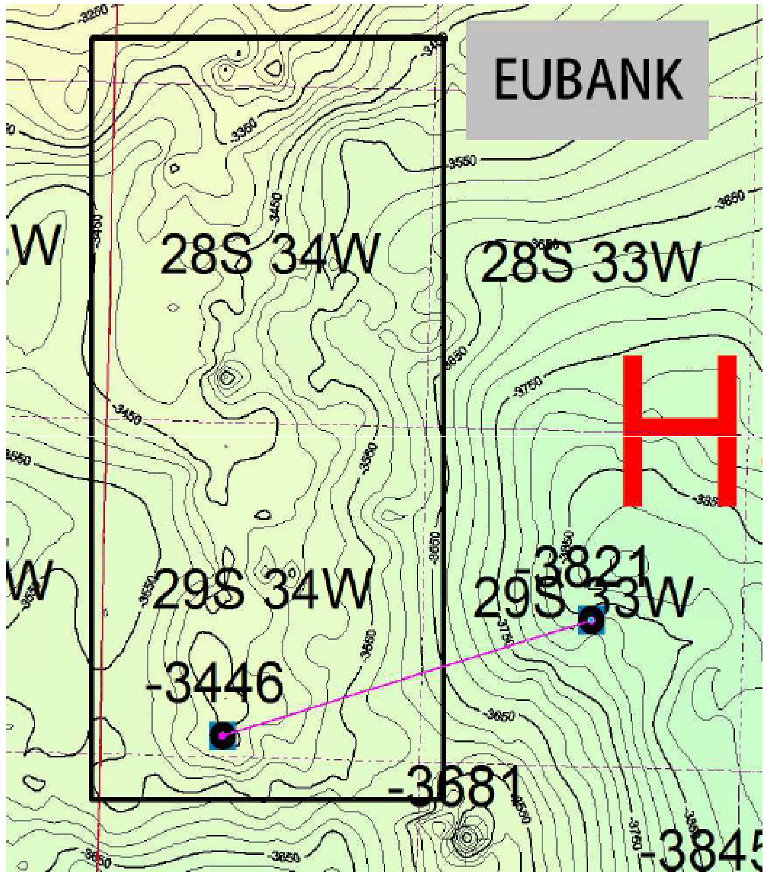


Figure 43. Eubank Field lies south of Pleasant Prairie Field (Figure 40) and the maps above show the structural details at the Meramec Mississippian (top) and the Arbuckle (bottom). Structure is a southerly plunging anticline with closure and looks well suited for potential Arbuckle carbon sequestration as well as serving as a site for CO2-EOR in the Chester Sandstone. Wells producing from the Chester highlighted in yellow in upper map. Lower map also serves as an index for west-east stratigraphic cross section in Figure 44 that follows.

EUBANK FIELD

ARBK X-SEC

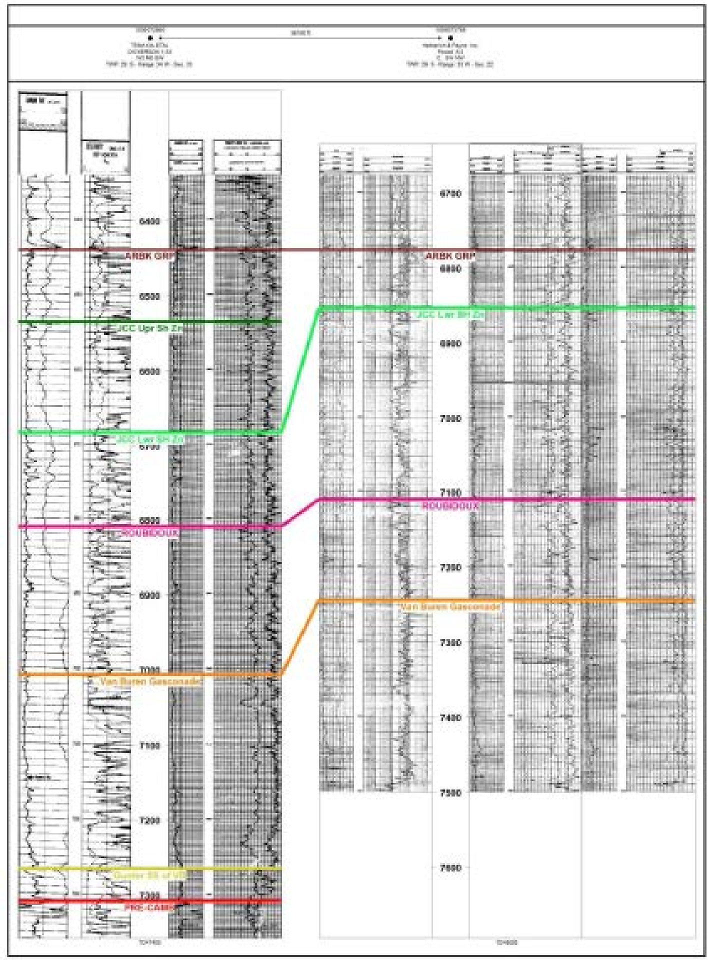


Figure 44. West-to-east stratigraphic cross section datumed on the top of the Arbuckle showing abrupt thickening of Arbuckle at its top to the west in area that is currently structurally higher, suggesting a structural reversal Top of Arbuckle appears to be truncated on east side.

Cutter Field lies southeast of Eubanks Field (Figure 40) and produces from more widespread sandstones of the Chester than those confined to the incised valley (Figure 45). The field lies on a local structural platform bounded by northwest trending flexural bends. Structural closure at Cutter Field consists of small amplitude local features compared to Pleasant Prairie and Eubanks fields. Lower map in Figure 45 serves as a cross section index for the cross section in Figure 46. Cross section indicates an Arbuckle that is similar to that to the north in Pleasant Prairie and Eubank fields.

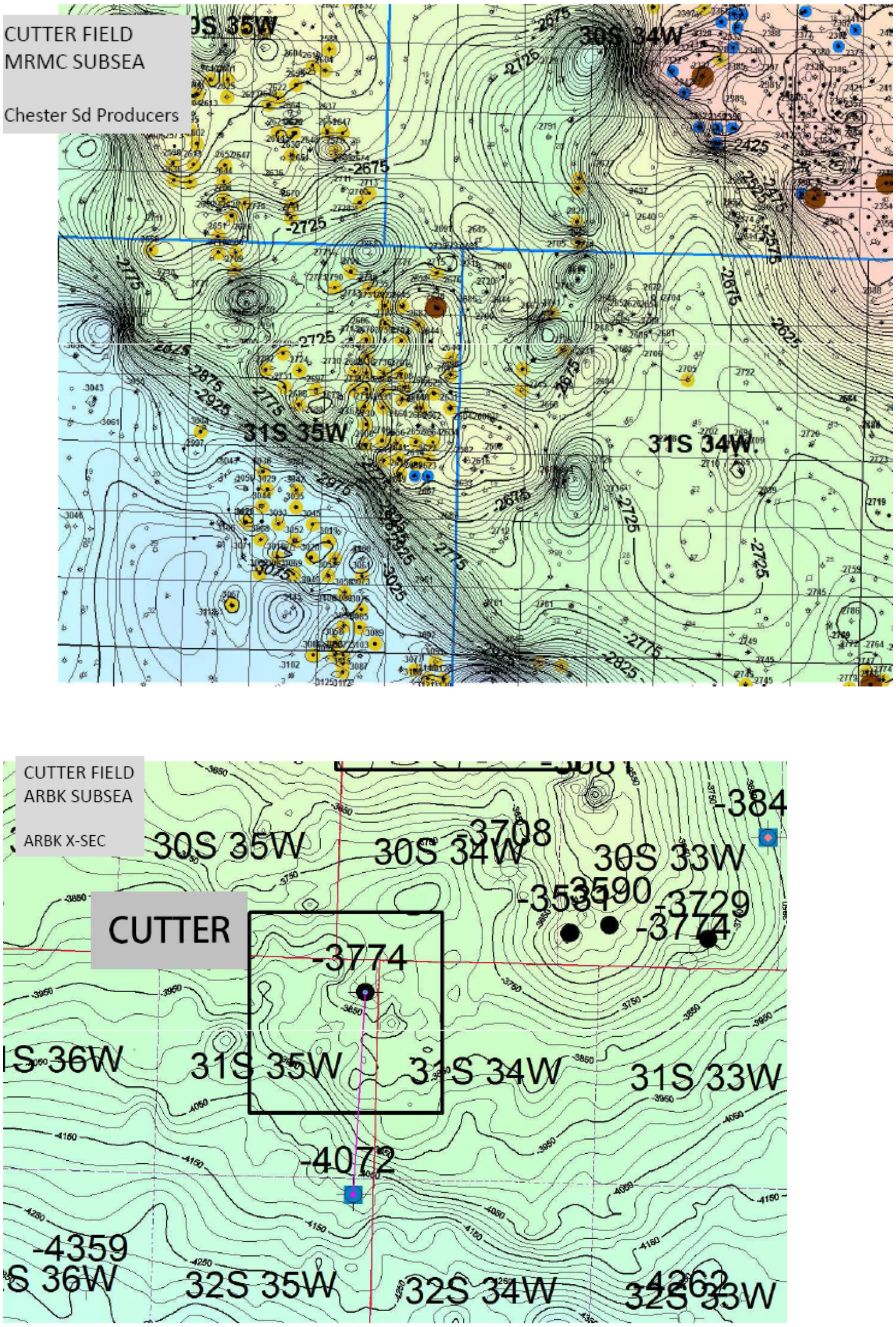


Figure 45. Structural contour maps of the top Meramec Mississippian (top) and the top Arbuckle (bottom map) at Cutter Field.

CUTTER FIELD

ARBK X-SEC

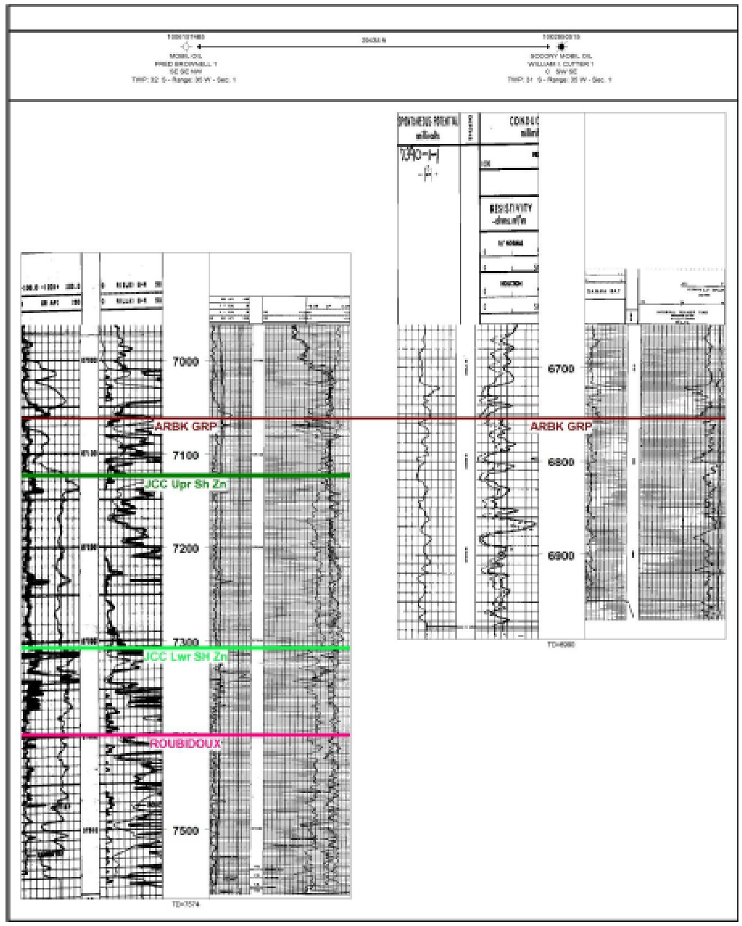


Figure 46. South-to-north stratigraphic cross section of the Arbuckle in and near Cutter Field. Note shaly tight areas in lower JCC lower shale zone that is correlated regionally from the east. Notable changes also occur in the internal character of the logs suggesting variations in porosity.

Shuck Field is the southernmost field producing from the Chester and located closest to the Oklahoma border. Arbuckle section is thicker in this area, but its internal properties are similar to the northern fields with more shale similar to that noted at Cutter Field (Figure 47). The field lies on west side of a small low amplitude north-south oriented anticline.

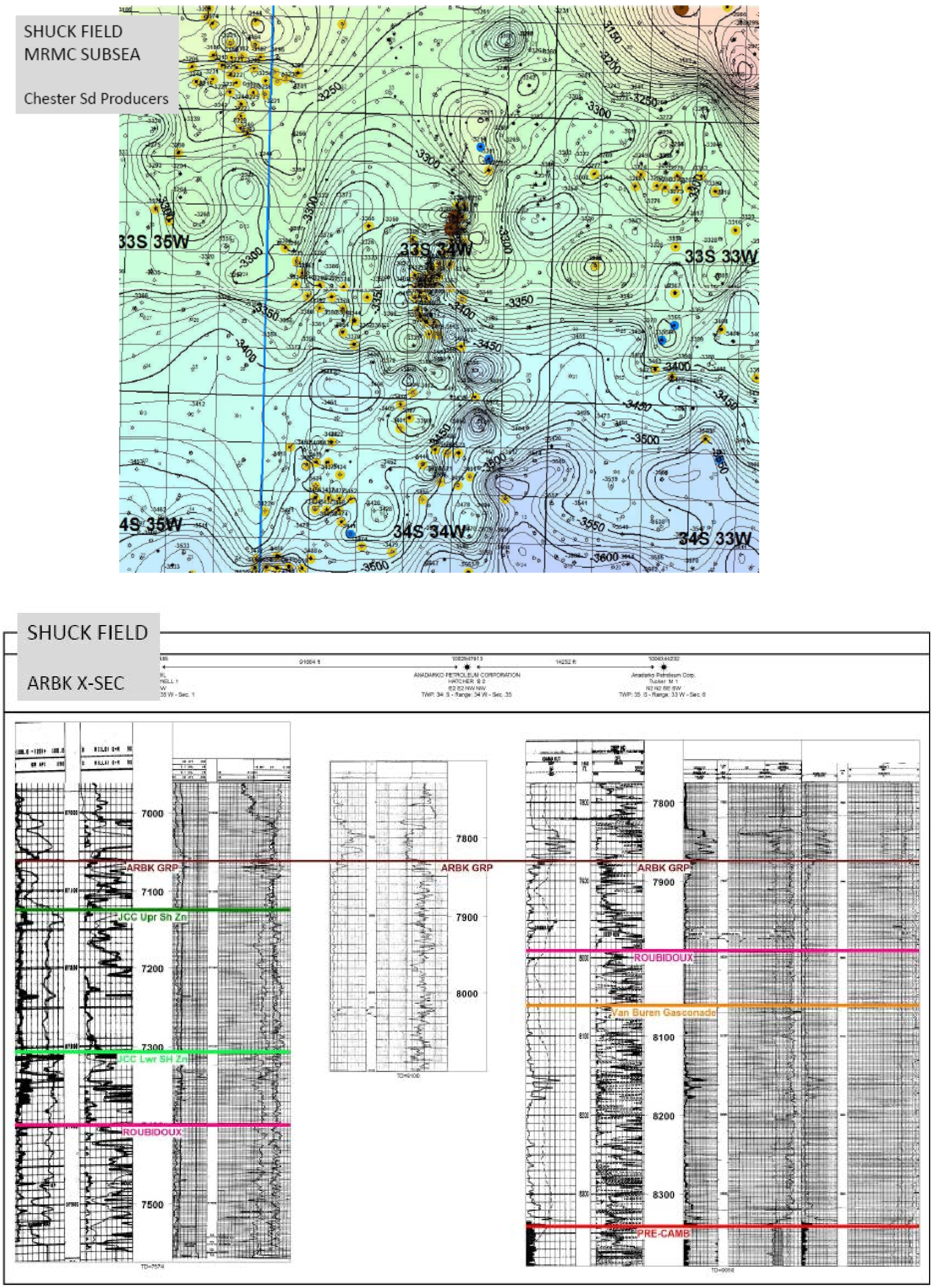


Figure 47. Structure top Meramec Mississippian (top map) and west-east stratigraphic well log cross section (bottom). Shaly Arbuckle intervals noted that are similar to as at Shuck.

Subtask 16.1. Assemble, reprocess, and interpret existing 3D seismic and other data.

SW Kansas CO2 Initiative group is finalizing data collection, describing cores, and making and refining maps, and processing and interpreting 3D seismic in the area of the four southwestern Kansas fields to prepare them for reservoir simulation. At the same time the relatively large volumes of seismic are being used to understand the deep structure and stratigraphic events near the fields. Seismic images over Pleasant Prairie Field were the first to be used to evaluate the deep structure and propagation of the deep structure to shallower depths. In addition, evidence of evaporites in the Spergen Mississippian and evidence for their local dissolution was established in this initial review. These data will be useful in field characterization, but also in choosing location for drilling of the basement test. This is the initial review with more interpretations to come.

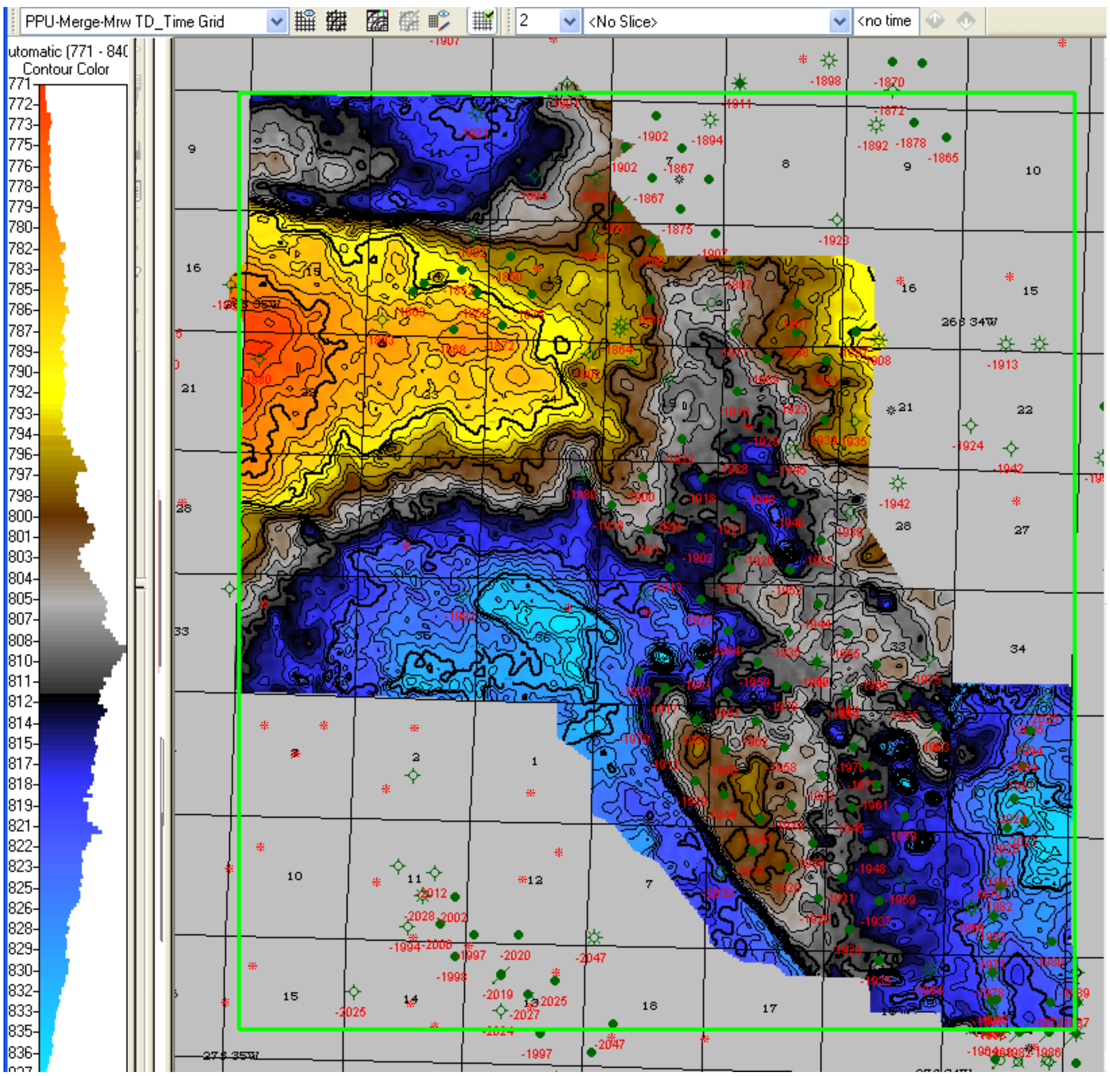


Figure 48. Morrow time structure, 2 ms contours, Pleasant Prairie Field. Structurally highest area (in time) is to the northwest with faults bounding the north, south and the west side of the southeast high.

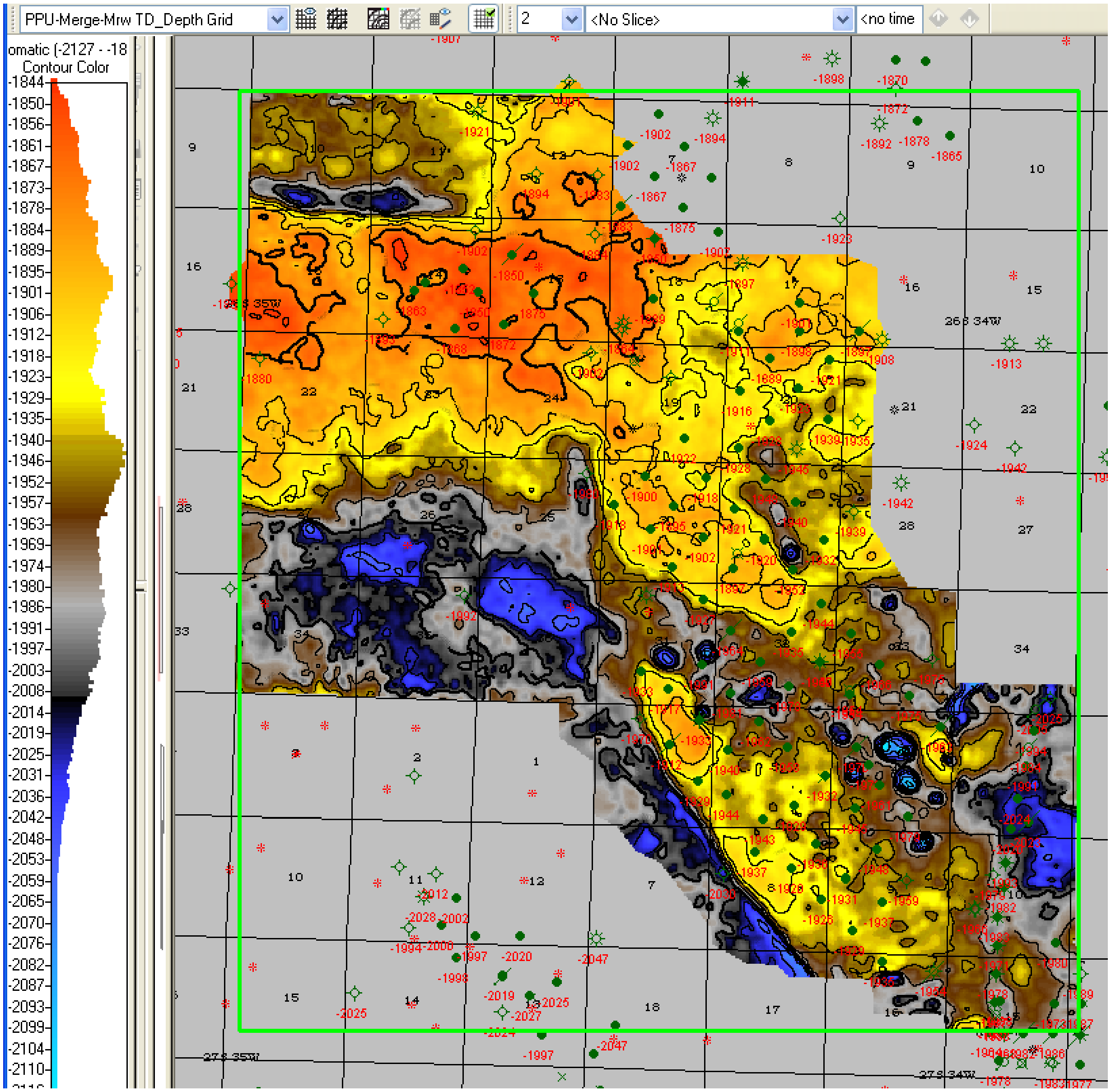


Figure 49. Morrow depth converted structure, 25 ft contours. Both Morrow time and depth structure provide indications of faulting on west flank, SW flank, NW flank of structure at Pleasant Prairie Field. Morrow depth converted structure accentuates WNW – SSE graben-like feature that crosses through the center of imaged area. Sharpest offset is on west flank of the southern structure high that parallels Damme Field. The graben-like feature is comprised of a series of karst-like closed lows suggesting dissolution. Since Morrow is primarily clastics, the closed lows we reflect passive collapse into underlying karst.

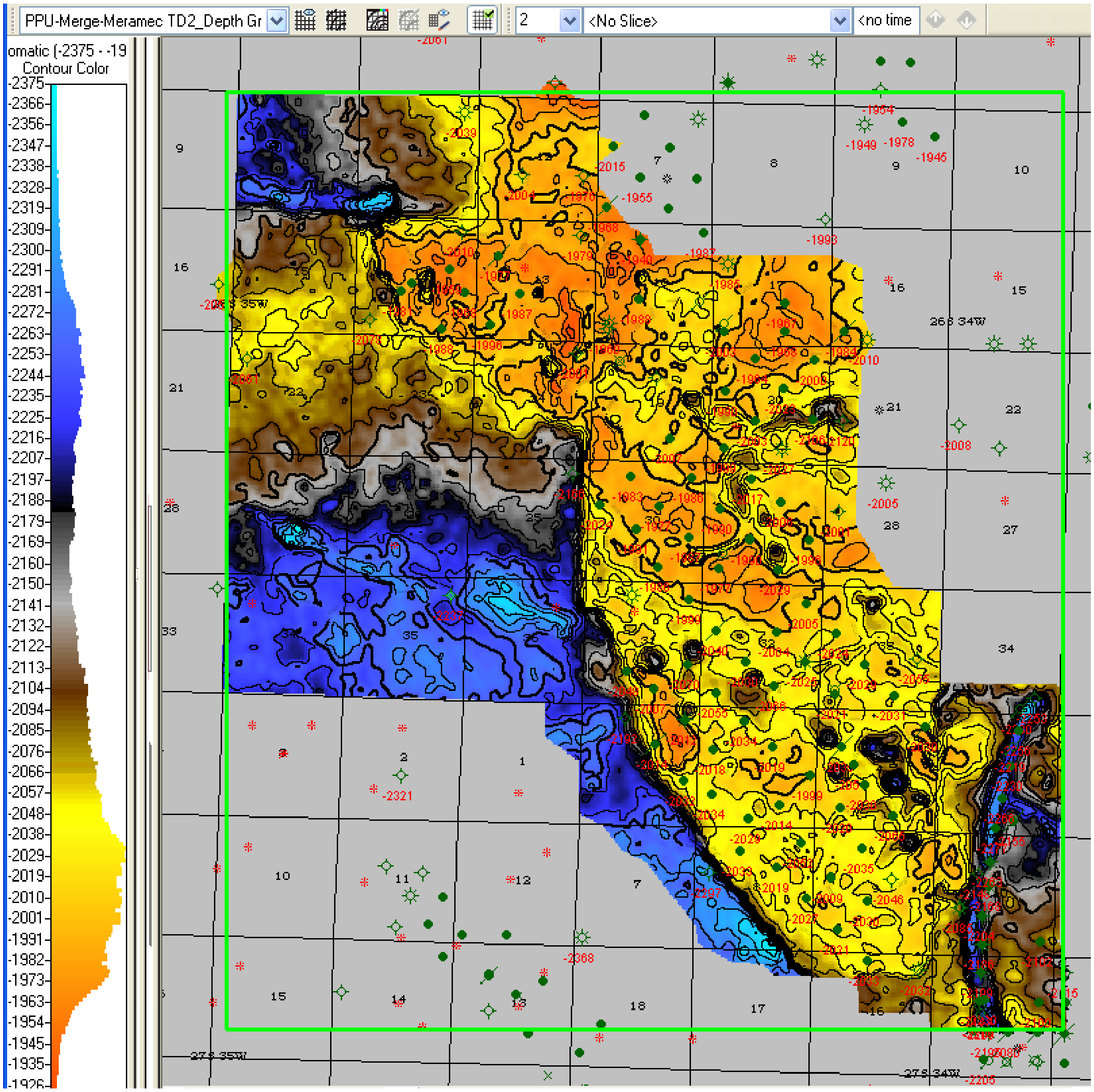


Figure 50. Meramec depth converted structure, 25 ft contour. Meramec time is similar to Morrow, except a deeply incised valley is accentuated on east flank of the structure. This is the location of the Chester-age incised valley fill sandstone reservoir. Meramec Time similar to Morrow, except deeply incised valley is accentuated on east flank. Meramec depth conversion shows fading of graben-like feature WNW – SSE, with karst-like features remaining as residual structures that extend across the larger high.

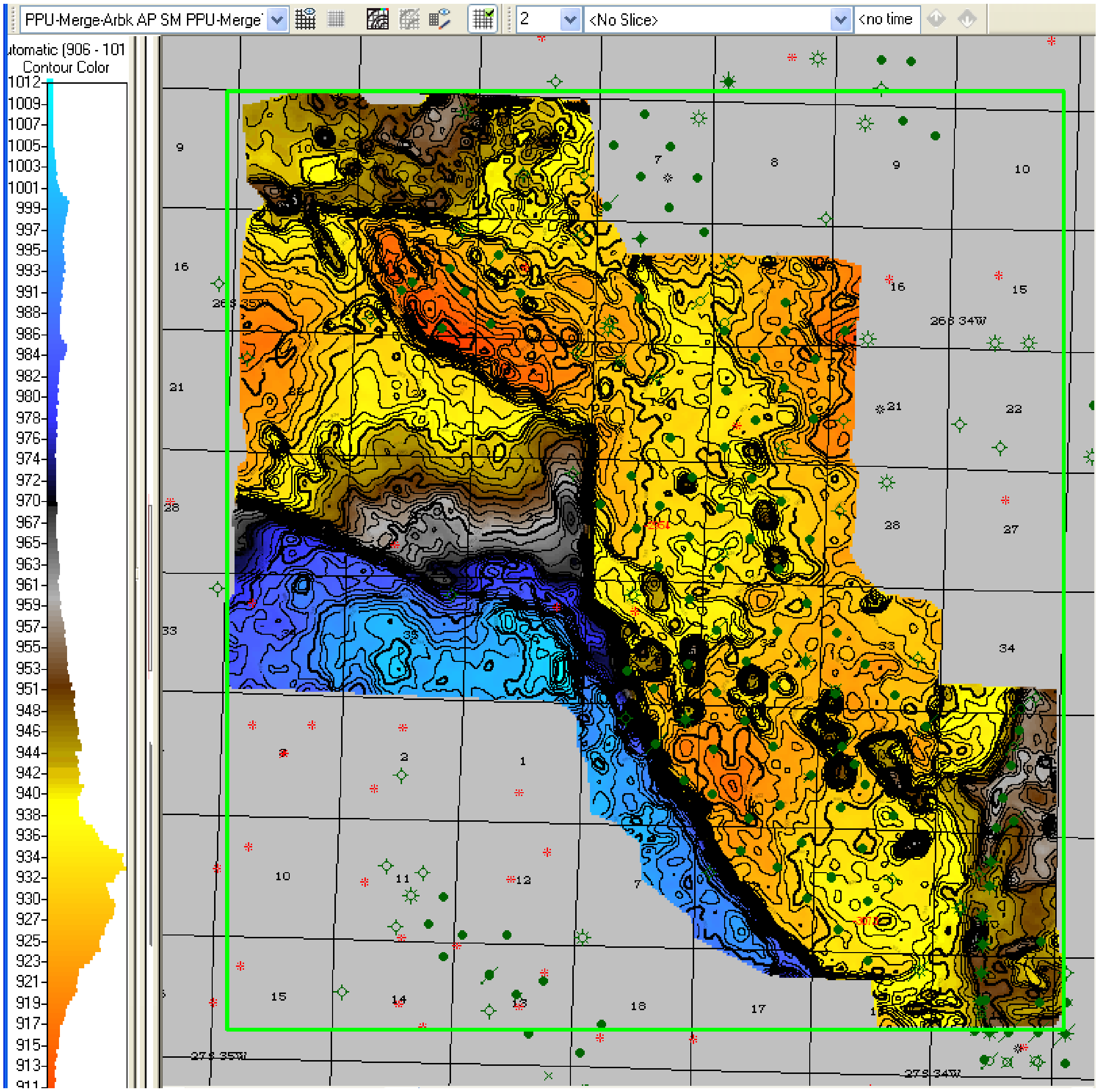


Figure 51. Arbuckle Time Structure. Arbuckle time shows sharply defined faults that bound this structure on south and cross the structure in the northwest and along the southeastern edge. The southeastern fault is also the site of the Chester incised valley (Figure 50).

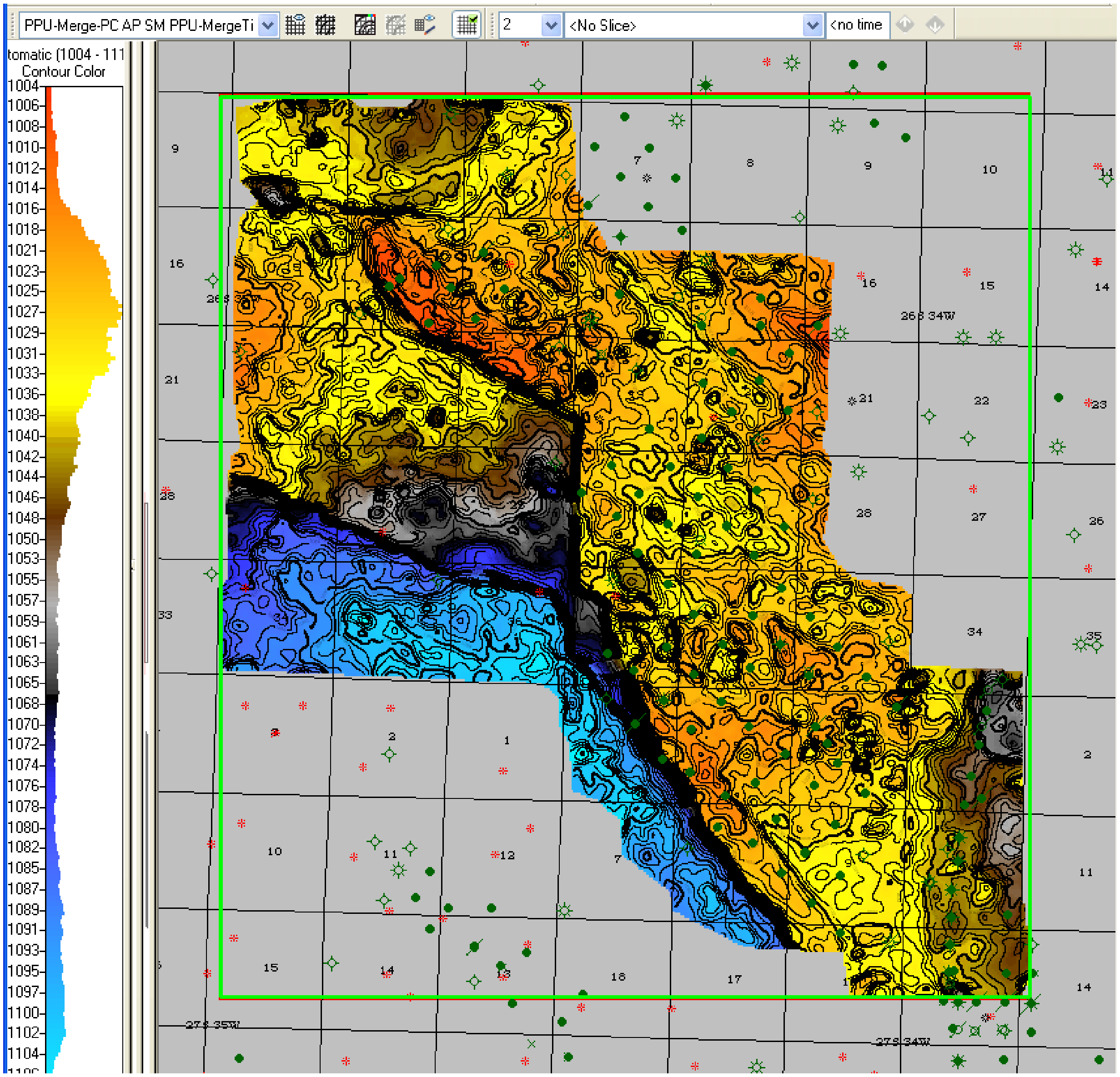


Figure 52. Precambrian time structure, 2 ms contours. Pre-Cambrian time is very similar to Arbuckle, although feature on NW flank fading in relief. The lack of vertical movement in the basement suggest that the shallower karst accentuated lineament (Figure 49-50) that crosses NW-SE in SE Pleasant Prairie may be an indication of slight structural movement that could cause zones of fracturing and possibly the karst and erosion in more easily dissolved strata such as evaporites and carbonates along unconformities (Dubois).

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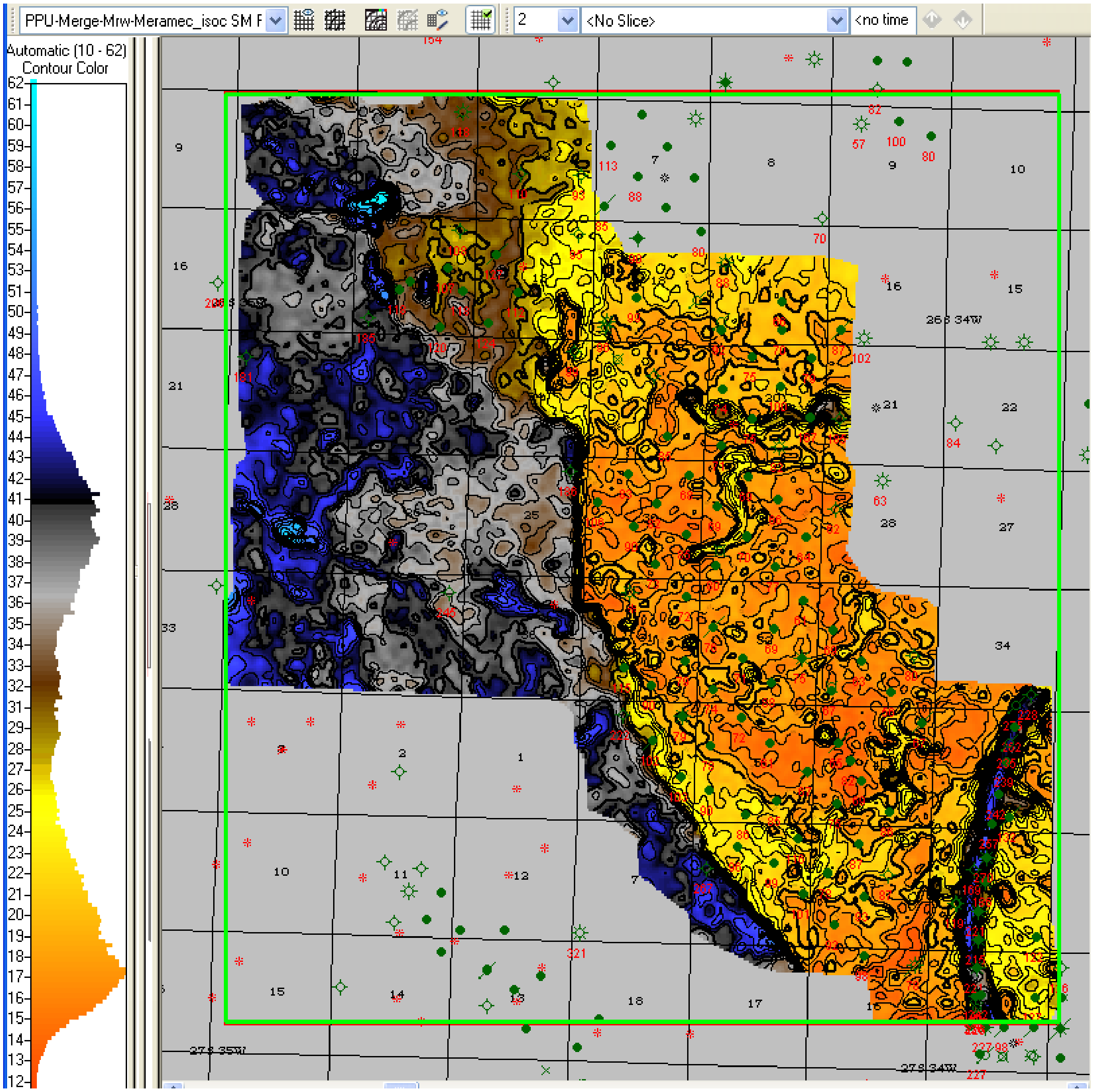


Figure 53. Morrow-Meramec isochron, 2 ms contours. Morrow – Meramec isochron is strongly influenced by basement structure (compare to Figure 52), incised valley is well-defined.

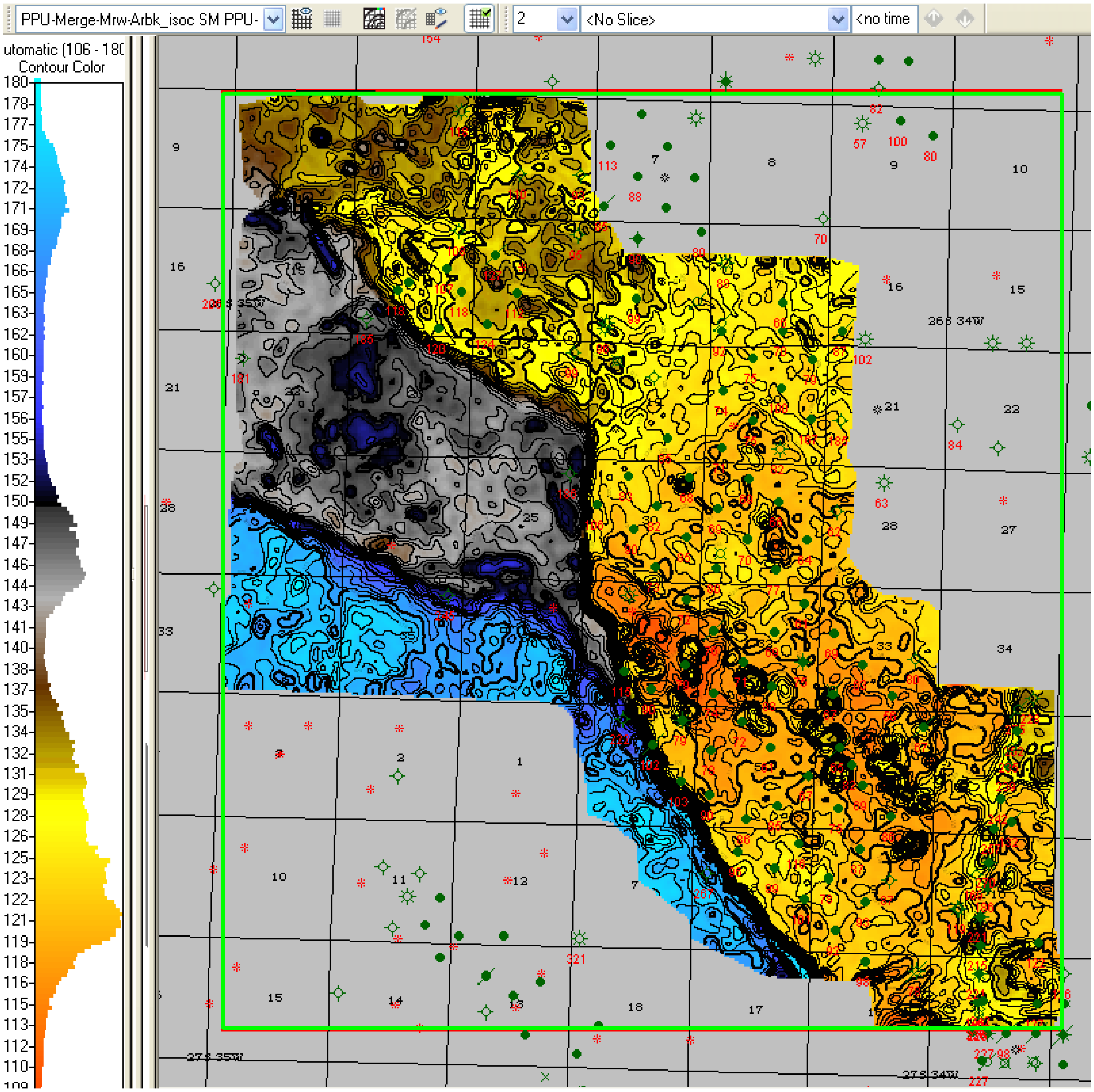


Figure 54. Morrow-Arbuckle isochron, 2 ms contours. Morrow-Arbuckle isochron shows abrupt azimuth change, sharpening the trend expressed at Morrow-Meramec isochron. The NW-SE karsted area is also visible.

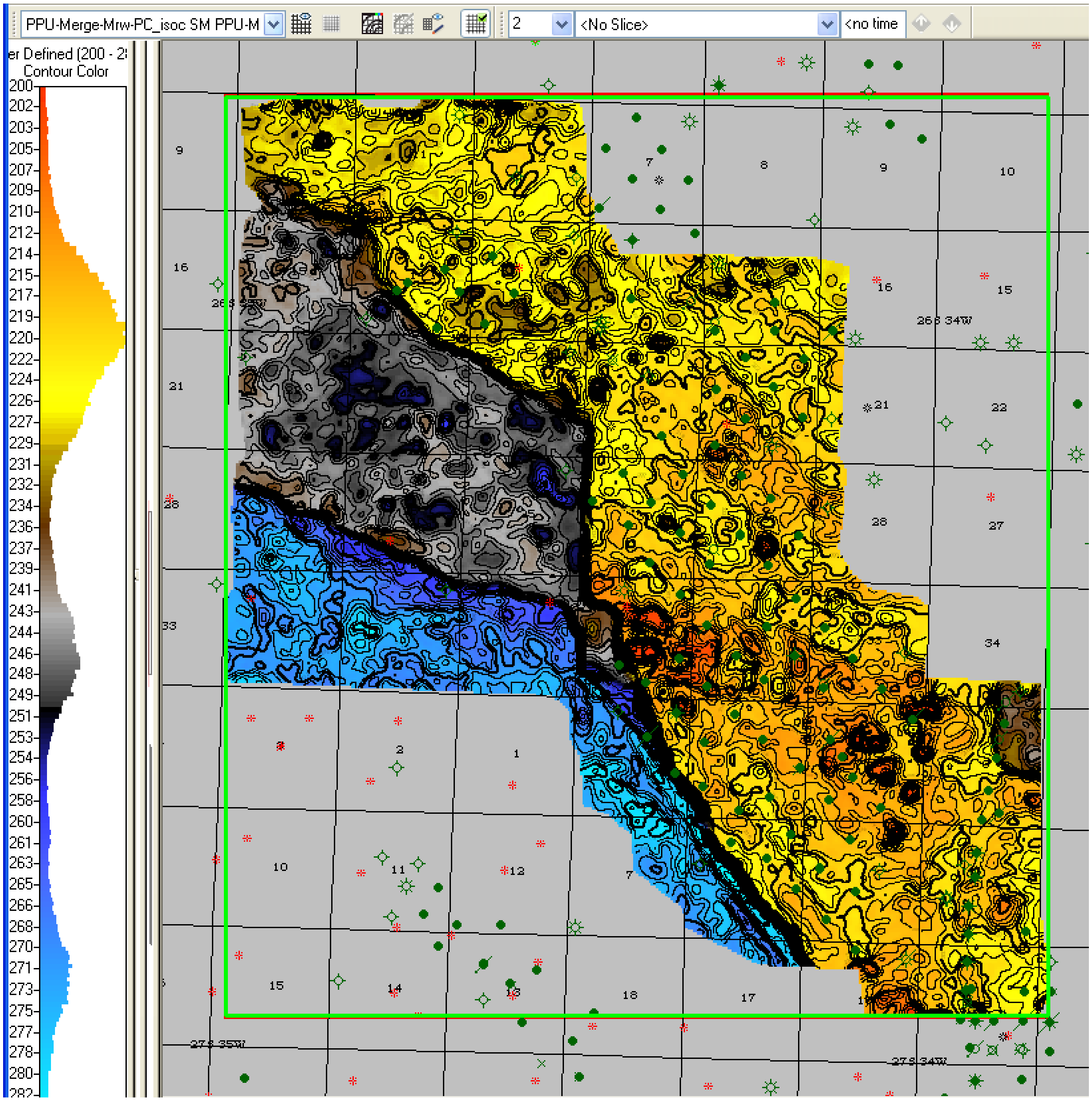


Figure 55. Morrow-Precambrian isochron, 2 ms contours. Morrow–basement parallels Morrow-Arbuckle, incised valley weakly expressed.

Velocities increase with depth, and so time ‘offsets’ become less striking. While there is some average velocity decrease northward off of the structure, the raw seismic data strongly supports faulting as seen in arbitrary seismic profiles in Figures 56 and 57.

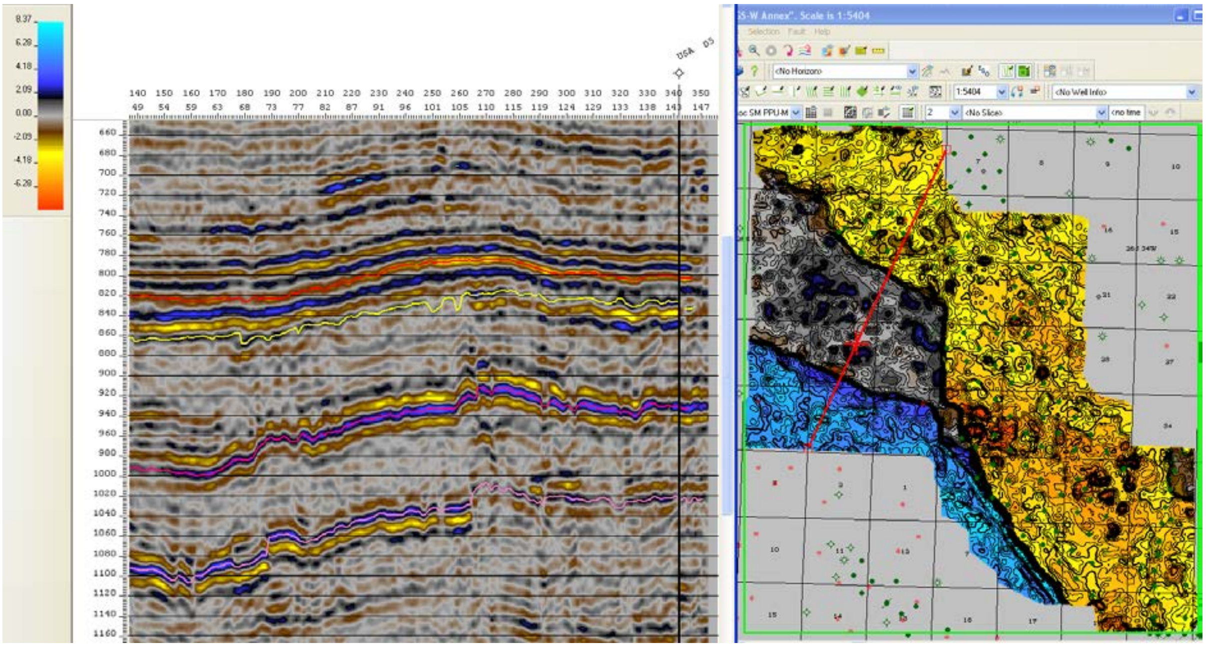


Figure 56. Arbitrary seismic profile A-A' running SW-NE across the Pleasant Prairie structure with Morrow to PC isochron shown on map. Markers are color coded: Morrowan = orange marker, Meramec = yellow marker, Arbuckle = cyan marker, Precambrian basement = red marker. Notice thickening of Arbuckle across apparent fault and lack of distinct faulting above the Mississippian.

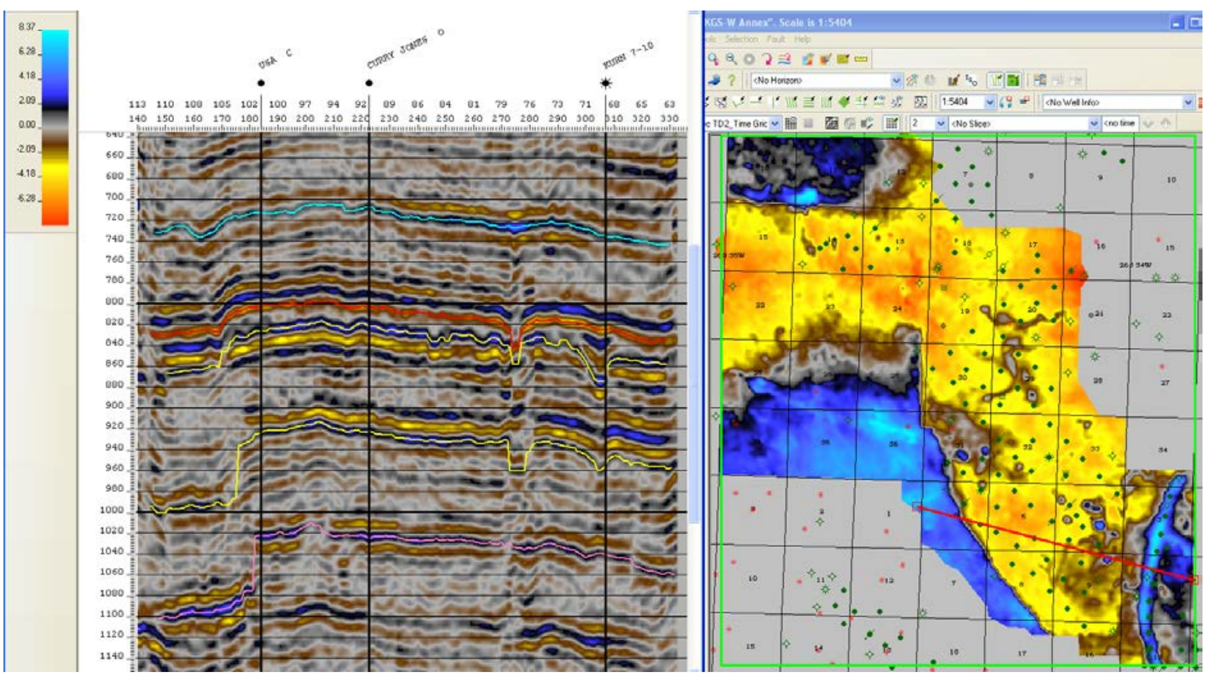


Figure 57. Arbitrary seismic profile B-B', W-E with Meramec time structure. Color coding of horizons same as in Figure 56. Large fault and offset on west flank. Possible faulting beneath the incised valley on far SE side of map.

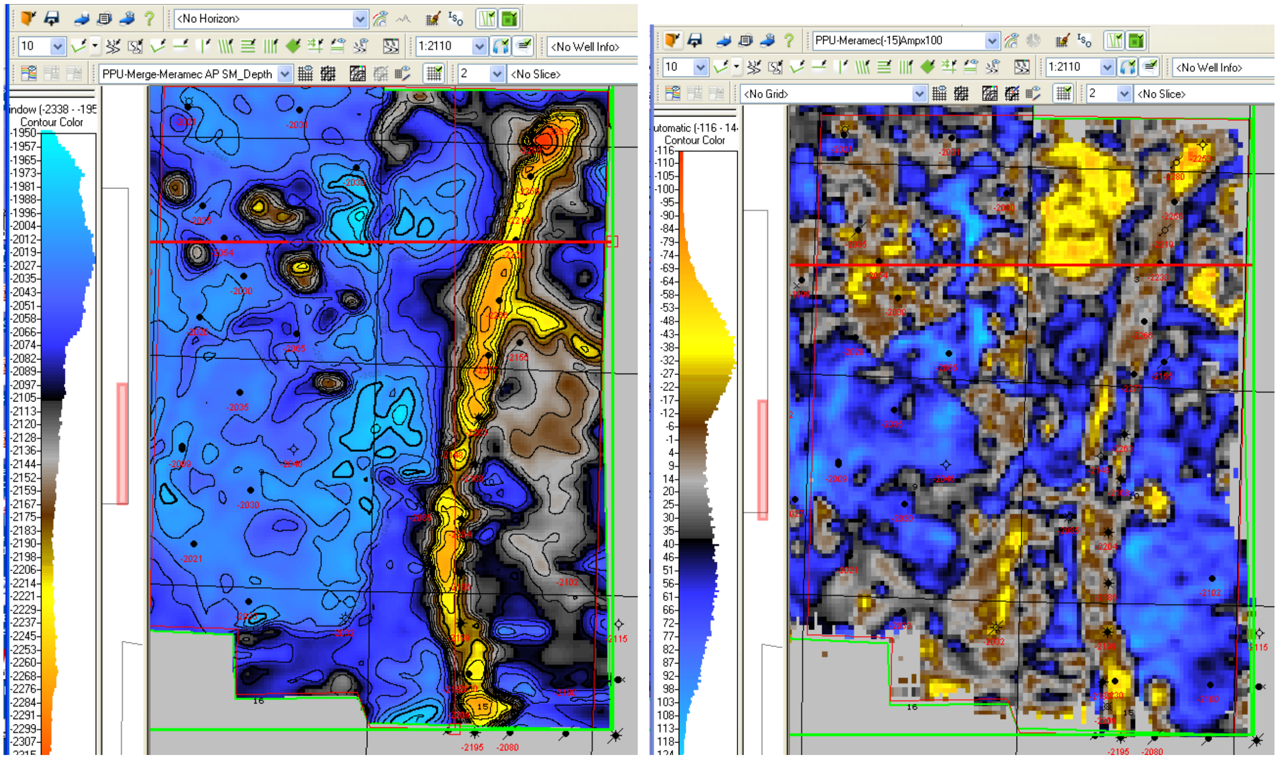


Figure 58. Meramec depth (left) compared to Meramec amplitude (right) in vicinity of the incised valley in southeasternmost Pleasant Prairie Field. Incised valley is clearly visible.

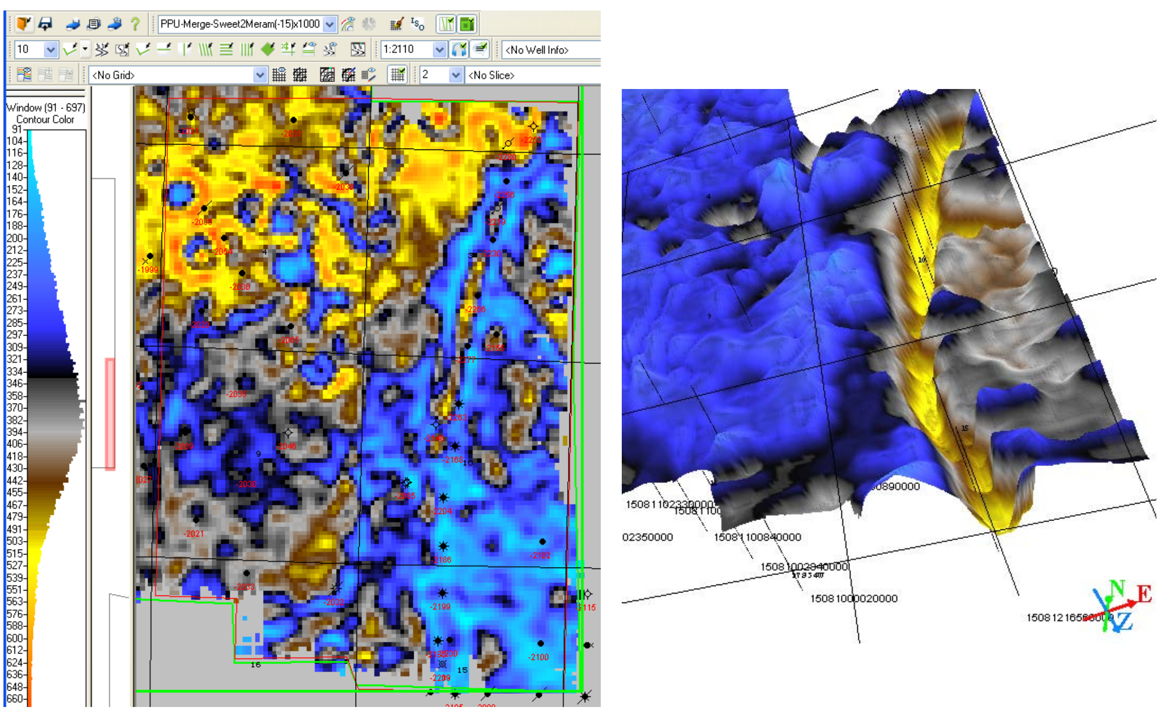


Figure 59. Meramec amplitude (left) and depth structure (right) clearly defining valley incised into the top of the Meramec carbonates.

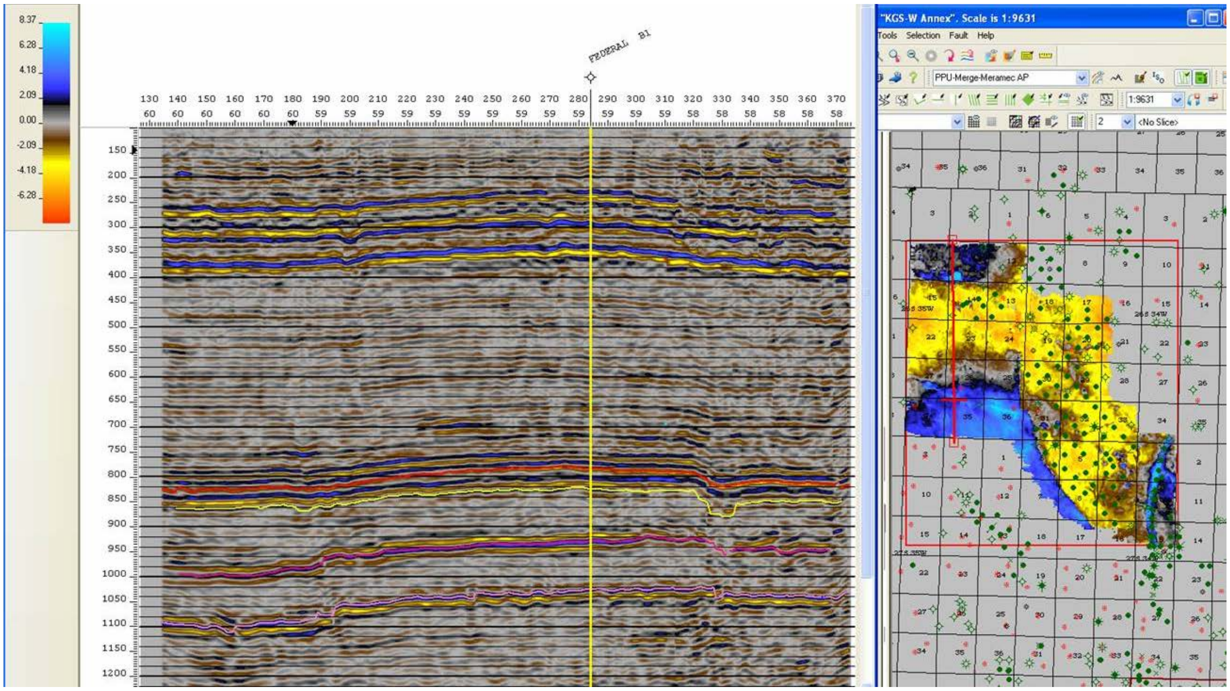


Figure 60. Arbitrary N-S seismic section showing very shallow events of lower Permian evaporites at top and Morrow, top Mississippian, and Viola seismic horizons below. Minor deformation is noted in shallow Permian horizons above Pleasant Prairie Field.

The strong indications of karst development along localized narrow lineament at Pleasant Prairie Field (Figures 54 and 55) led regional team to establish that anhydrite beds are developed at the Lower Meramec Spergen Limestone level in the Mississippian. These evaporites are depicted on regional map in Figure 61 and cross section in Figure 62.

Evaporites can form an excellent seal/caprock, but dissolution and karst can lead to pathways for fluid migration. Thus, the karst combined with evaporites needs to be further investigated. The seismic was instrumental in defining evidence for the local karst.

Sorenson notes that work by Abegg (1992) identified in core and log work over a hundred feet of ‘solution-collapse breccia’ in the Spergen/lower St.Louis in the Flynn #1 Shaw 31-31s-34 (Seward County), and in the Amoco #3 Wilson A core in 30-30s-33w (Haskell County). Abegg shows that log responses through intervals of ‘solution collapse breccia’ look nothing like log responses in the bedded Anhydrite intervals and consequently are more difficult to discern from logs alone. Abegg suggests that north and east of where the bedded anhydrites can be mapped from logs, lies a sizeable area where ‘solution-collapse breccias’ are preserved in the Mississippian section. Abegg’s maps are probably poorly constrained, but he shows his ‘solution-collapse breccia’ area to extend far enough north and east to include most of the Chester IVF fairway.

At least 120’ of Meramec rocks were removed by erosion in the solution karst lineament at Eubanks giving an absolute minimum estimate of the amount Chesterian sea level fall at

Eubanks. Logs correlations also show that the Chester valley extended at least as far as the KS-OK border. If we assume a 1 degree surface dip at the time of incision, and that sea level fell to only the OK-KS line during the Chester, then the MRMC surface at Eubanks would be sitting at an elevation of around 300' above sea level. Given these minimums, at Eubanks and points farther north, it seems plausible that the Spergen/St.Louis section could have been in contact with fresh water during Chesterian time.

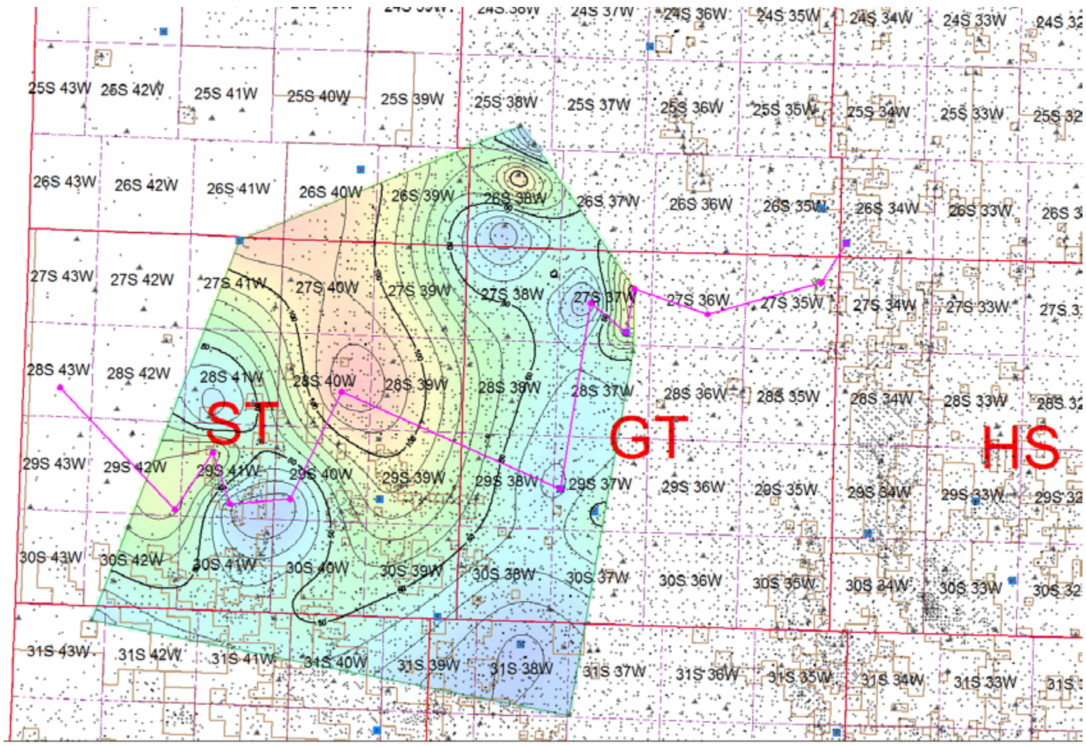


Figure 61. Spergen anhydrite isopach in southwestern Kansas (Gerlach and Nicholson). Maximum thickness of the evaporite exceeds 100 ft. Index for west to east stratigraphic well log cross section in Figure 62. Karsting is also noted by team member (Sorensen) to extend to east and north of this mapped area, but the exact nature of that karsting is problematic.

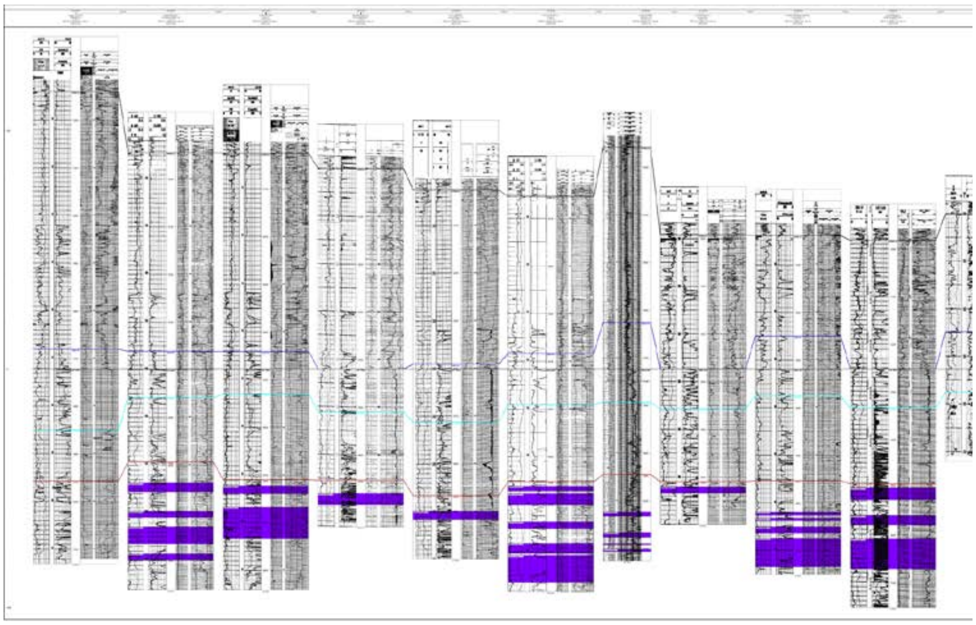


Figure 62. Lower Meramec Spergen anhydrite is highlighted on the west-to-east stratigraphic cross section. Section is indexed on map in Figure 61.

Youle suggests that at Shuck pool (33s-34w) in Seward Co., Cirilo (2001) points out that 3D seismic shows the trapping mechanism for the north end of the field was created by collapse into a karst located somewhere below the Chester. Cirilo speculates the karst may have originated in rocks as old as the Cambrian, something that Dennis's seismic work seems to suggest is plausible (or Ordovician at least). Shuck pool also lies within Abegg's Spergen/St.Louis 'solution-collapse breccia' fairway. It is also interesting to note that the karst collapse at Shuck occurred post Morrow. Sorensen noted that the sinkhole that forms the trap at the north end of the Hitch Unit (Shuck) collapsed after Chester deposition, probably in the Atoka. The key well within the sinkhole has a normal looking Chester channel section but is structurally low. This was originally interpreted as a down-to-the-west fault, until 3D seismic revealed that the downthrown block was circular. This dissolution of lower Ordovician strata is another alterative that needs to be evaluated in this area as part of the field investigations.

Montgomery and Morrison (1998) noted the presence of extreme pits/holes (up to 100' deep) along the floor of the incised valley at Eubanks, and also use 3D seismic to point out karsts adjacent to the valley. Unfortunately they made no mention of where these karst features were rooted, or the timing of their collapse. The pits/holes on the floor of the karst lineament at Eubanks did impact valley fill sedimentation. The question is whether the karst is tied to fractures system that allow fresh water to reach the zones of dissolution at depth.

Sorenson points out that there are at least 3 wells within the Pleasant Prairie area that exhibit disrupted beds within the St. Louis interval that are suggestive of karst collapse.

1) One well is located within the cluster of oil wells approximately 2 miles SW of the Pleasant Prairie bounding fault (in section 13?), outside the 3D survey. If you examine

the section below the base of the Pennsylvanian, the well I am referring to will be obvious.
2) One of the original 1950s Mississippian tests in Pleasant Prairie (S/2 section 31) was junked and abandoned due to lost circulation and related mechanical issues after reaching the Mississippian, and was replaced by a successful well only a short distance away.
3) One other St. Louis producing well in PPU (S/2 section 29?) has a distorted section which makes it difficult to correlate the various St. Louis porosity zones.

Volumetric curvature attribute was run by Hedke demonstrating the utility of the methodology to highly resolve small scale fracture systems. Two preliminary runs were made at Pleasant Prairie Field on the Meramec depth converted surface in Figure 63, Arbuckle surface in Figure 64, and Precambrian surface in Figure 65.

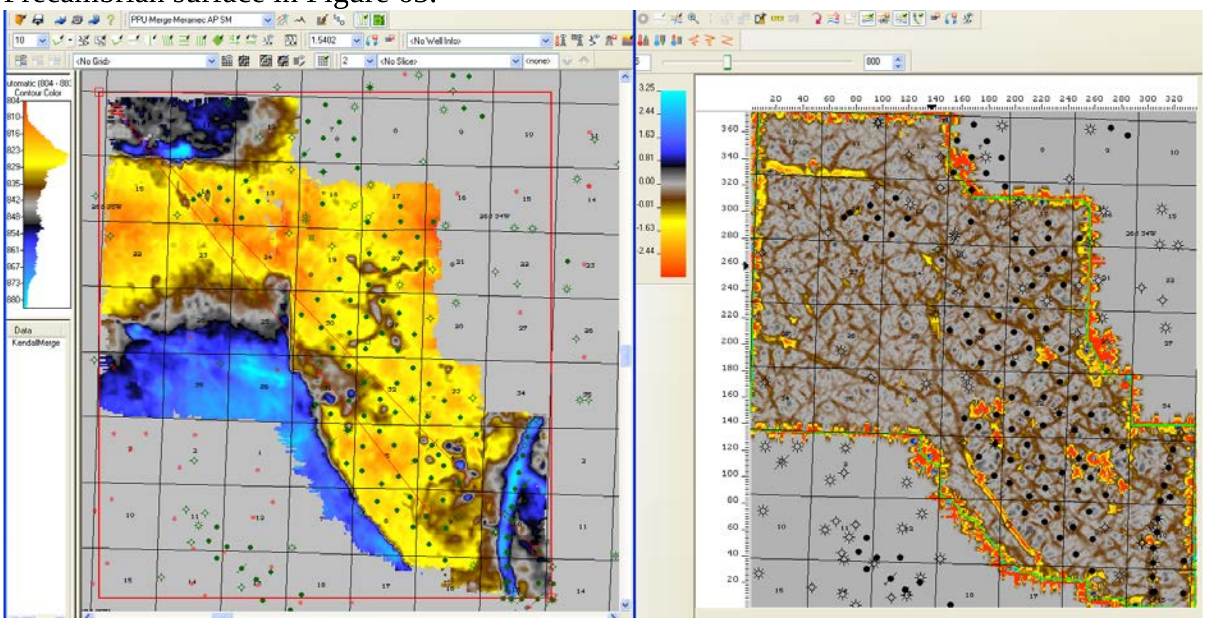


Figure 63. Volumetric curvature of the Meramec structure at Pleasant Prairie Field.

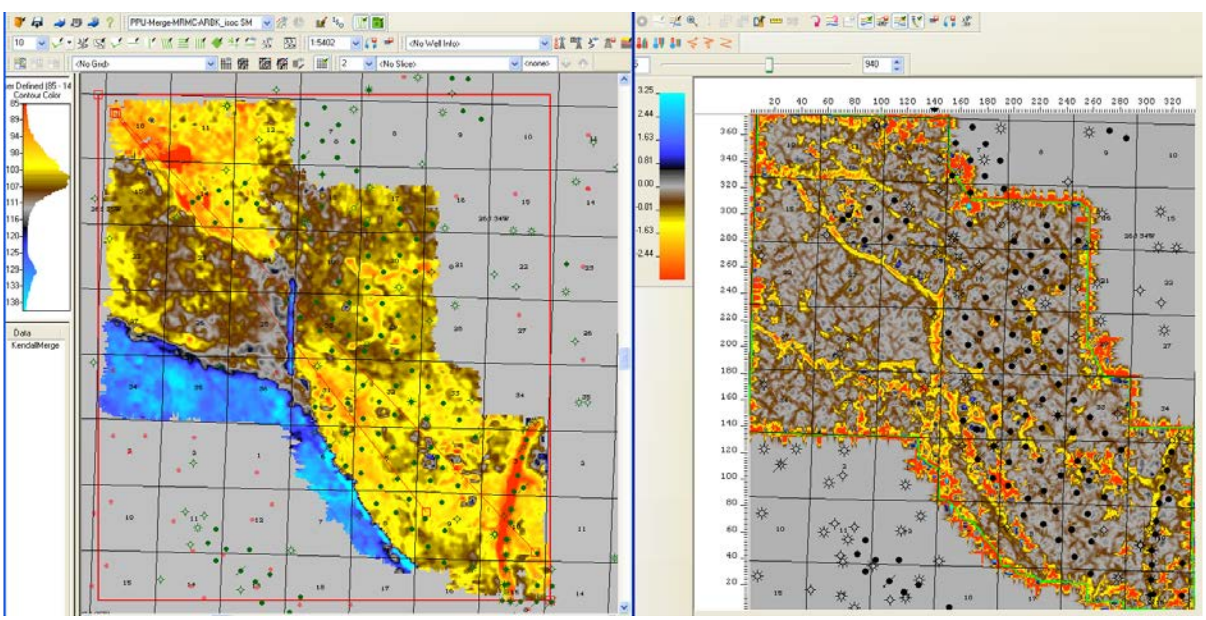


Figure 64. (previous page) Volumetric curvature of the Arbuckle structural surface at Pleasant Prairie Field. Note the curvature elements trending W-NW to E-SE in southeastern mapped area corresponding to what is previously noted at shallower horizons as a structural sag with multiple karst features connecting to the west with a fault.

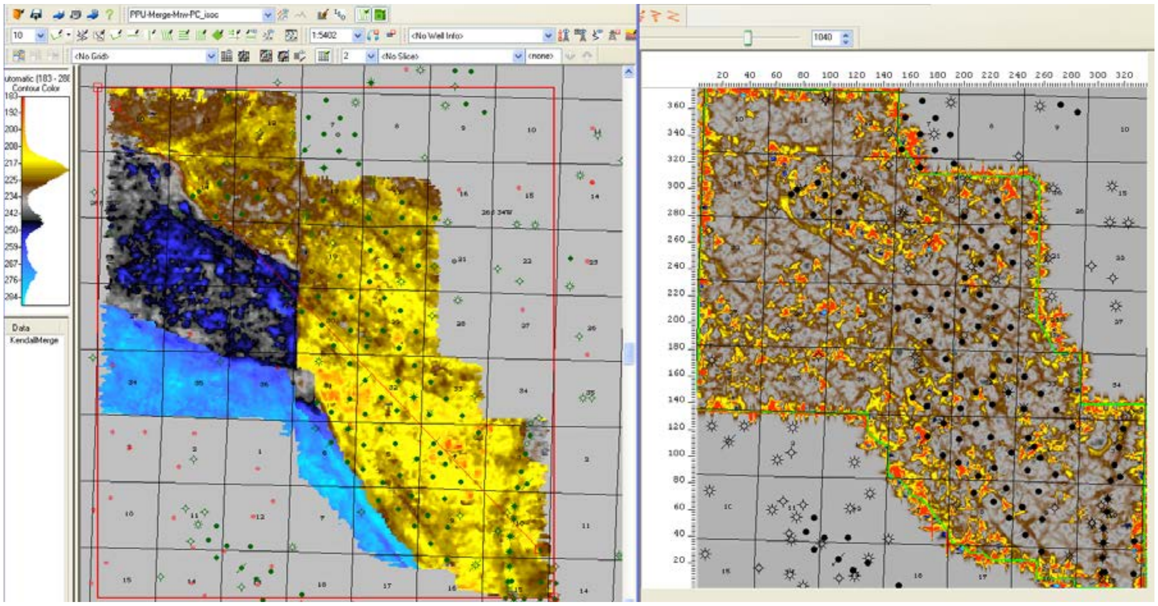


Figure 65. Volumetric curvature, Precambian at Pleasant Prairie Field.

Seismic data at Pleasant Prairie Field was compared with the regional structure mapping done by Bittersweet team using overly function of the interactive project mapper (Figure 66). Map and seismic image closely agree.

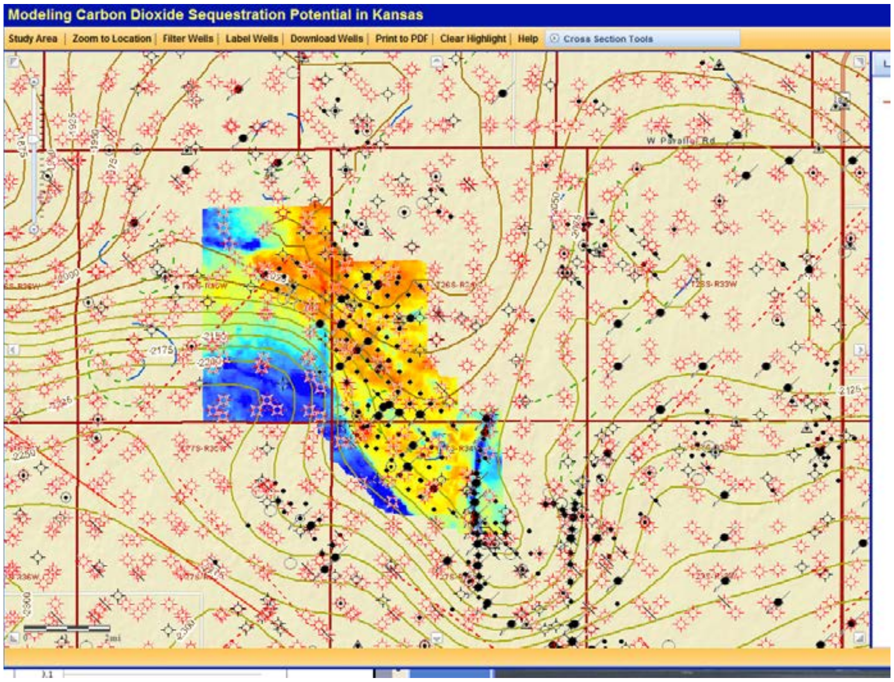


Figure 66. Meramec depth converted structure seismic compared with regional Mississippian structure.

Tilt angle of gravity map (tilt angle described in previous report) showing edges of deep seated gravity features was compared with an overlay of the Meramec structure from the seismic at Pleasant Prairie Field (Figure 67). Pleasant Prairie Field structure in the Mississippian falls on west side of circular tilt angle anomaly along black outline the represents maximum contrast in gravity, possible fault based or a basement intrusive. Similarly northwest bend corresponds to bend in black outline that extends northwestward beyond the field. Partial control of the shallower structure by basement heterogeneity is suggested.

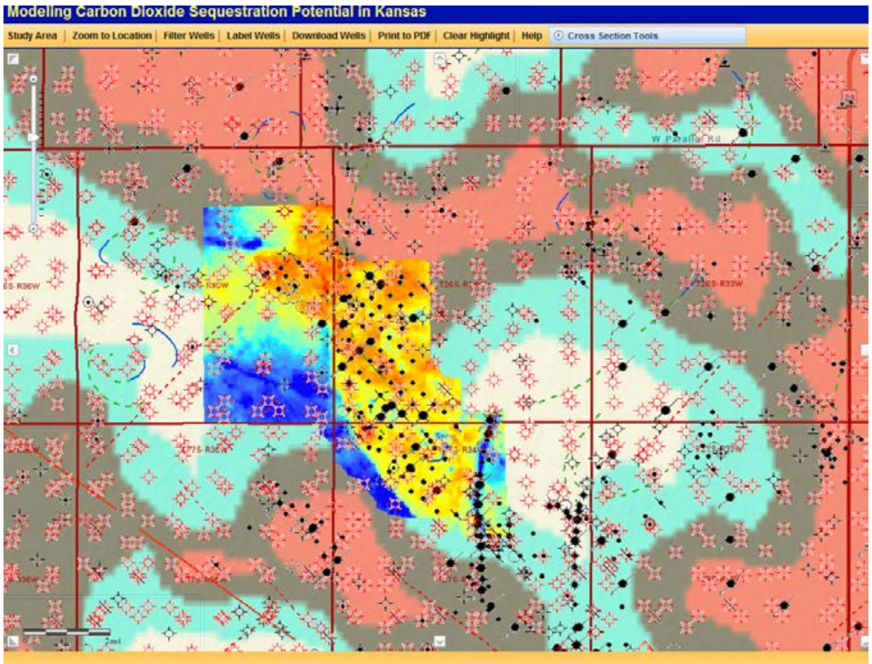


Figure 67. Map of the 2-10 mi tilt angle gravity anomaly compared with Meramec depth converted structure and surface lineaments (a few fine lines).

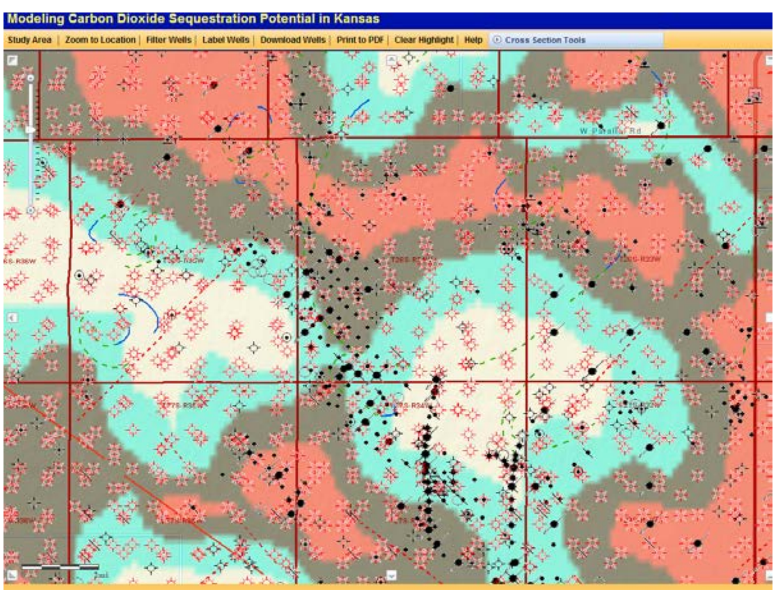


Figure 68. Same as Figure 67 without the seismic overlay.

Similarly, the seismic structure is compared with the magnetic tilt angle map (Figures 69 and 70).

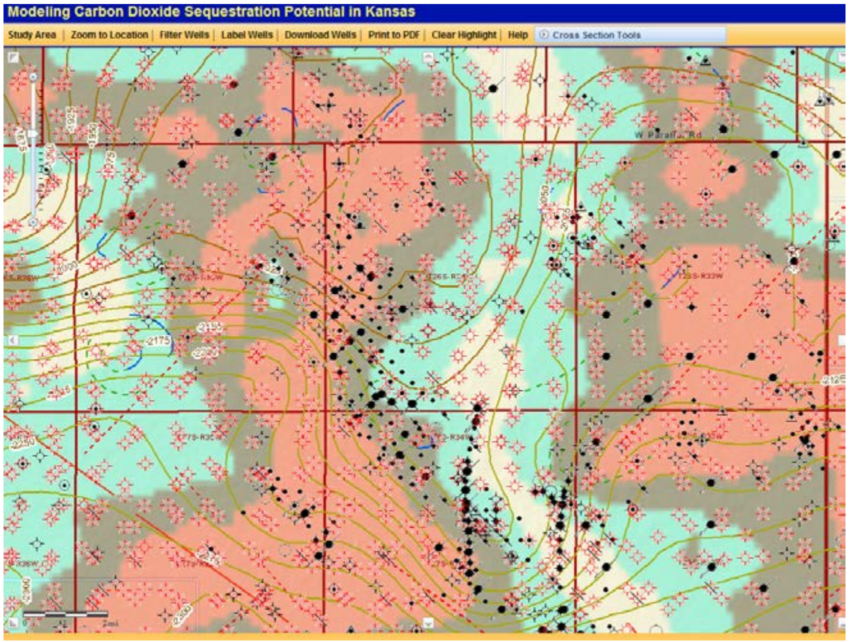


Figure 69. 2-10 mile tilt angle total magnetic field with regional Mississippian structure with contour overlay of regional map of Meramec structure by Bittersweet team. Note correspondence of northwest trend of field wells and west edge of regional structure and black outline of tilt angle map.

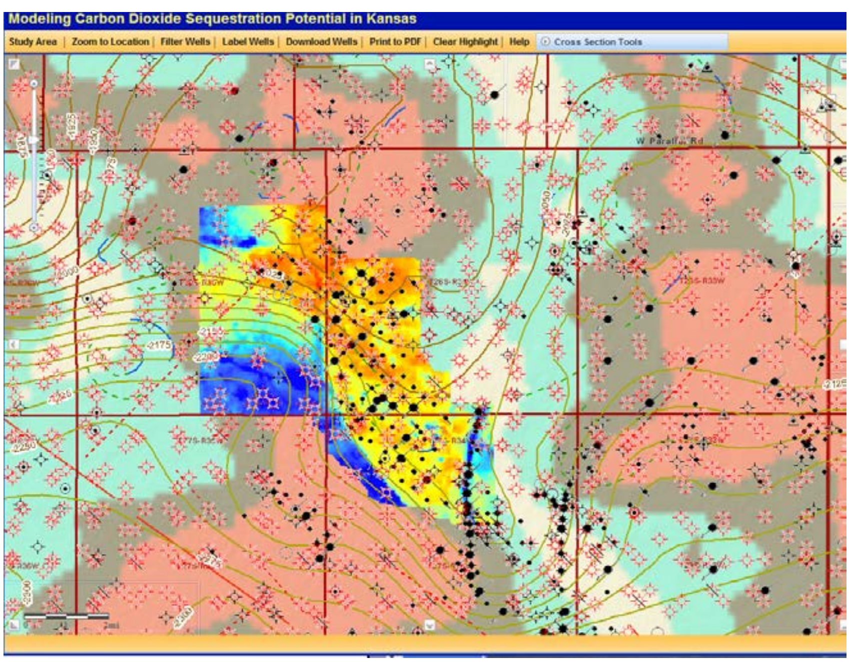


Figure 70. 2-10 mile tilt angle total magnetic field intensity with regional Mississippian structure and Meramec seismic structure. Comparison similar to Figure 69, suggesting basement heterogeneity affecting shallower structure.

The comparison with the tilt angle magnetic map concludes with an overlay of the Morrow depth converted seismic in Figure 71 and Precambrian time structure in Figure 72. The narrow blue colored NW-SE trending low or trough in Figure 71lies along edges of both anomaly boundaries of the magnetics (Figure 69) and the gravity (Figure 68). Similarly, Precambrian time structure is similar to a combination of the gravity and magnetic anomalies suggesting influence of deep seated basement heterogeneity.

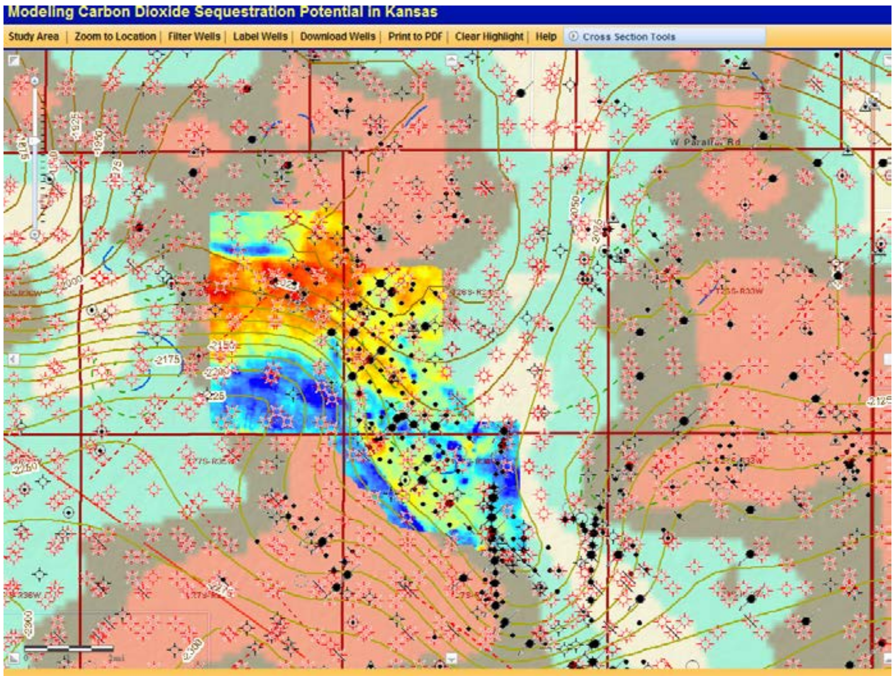


Figure 71. Morrow depth converted structure on 2-10 mile total magnetic field intensity with regional Mississippian structure.

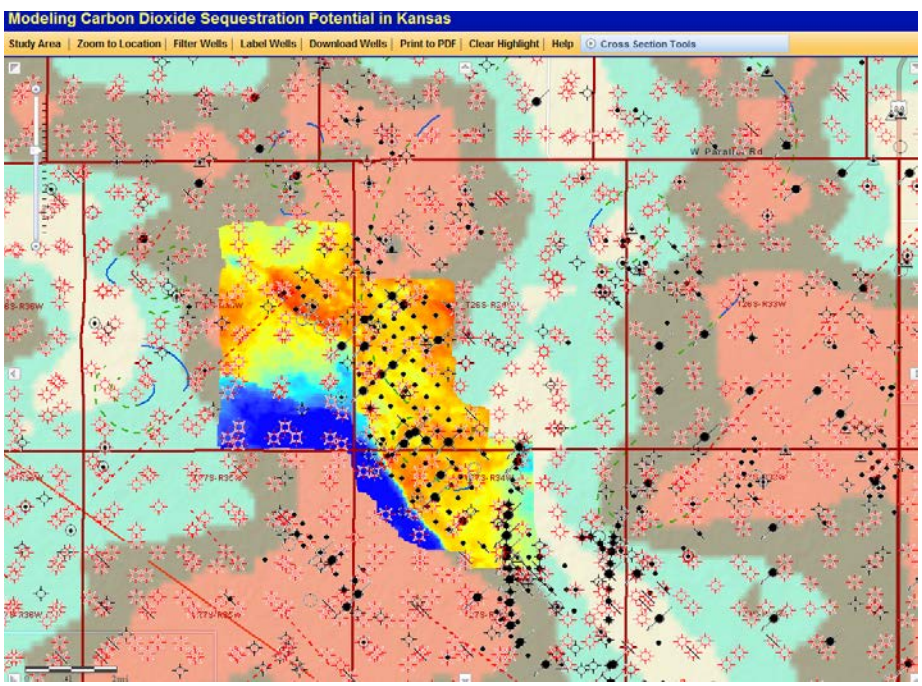


Figure 72. Precambrian time structure on magnetic tilt angle.

Subtask 17.2. Select Chester/Morrow field to acquire new data.

Geomodels are being developed in the four Chester/Morrow Fields and sites are being simultaneously evaluated sites for the basement well. Summary of the data collection in fields being studied as of December 21st are reviewed in Figure 73.

Summary table: data in four study fields

X - complete *O - gap*

Data Types		Shuck (Hitch & Elzold)	Eubanks	Pleasant Prairie	Cutter
Well data	LAS	done by KGS	Operator & KGS	Operator & KGS	Operator & KGS
	Rasters	done by KGS	Operator & KGS	Operator & KGS	Operator & KGS
	Tops set	done by KGS	X	X	X
Core Data	Conventional analysis	Only from two thesis - tables	X	X	X
	SCAL	None located yet	X	X	X
	Cores located	~10 Anadarko cores not found	X	X	X
PVT	Oil and gas composition	No PVT data	X	Limited PVT data	Limited PVT data
	Insitu Fluid properties	O	X		
	GOR & FVF	O	X	X	X
	Viscosity, density and other	O	X		
	MMP	O	O	O	O
Fluid histories	Daily oil production by well	Public data only	X	X	Partial by well
	Daily water production by well	O	X	X	Partial by well
	Daily gas production by well	O	X	X	Partial by well
	Daily water injection	O	X	X	Partial by well
Engineering	Injection profiles (logs)	O	X	X	X
	BHP- measured	O	X	X	X
	Static fluid levels	O	X	X	X
Reports	CO2 EOR feasibility study	Rumored to have been done	O	O	O
	Waterflood feasibility	O	X	O	X
	Technical Untitization report	O	agreement	agreement	NA
	Periodic waterflood reports	O	X	X	X
	Geologic studies	O	X	O	X
	Enginnering studies	O	X	O	O

Figure 73. Data summary for fields being studied in SW Kansas.

Basic workflow and timeline

Data - gather, process, organize

Seismic – reprocess (Eubanks), reinterpret, extract attributes

Reservoir characterization
- Core sedimentology and lithofacies
- Tie lithofacies to log attributes
- Estimate lithofacies in wells without core
- Lithofacies petrophysical classes
- Develop log phi correction algorithms

3D reservoir model (Petrel)
- Structural framework and wireframe (55ft cells)
- Integrate 3D seismic structure and attributes
- Populate with lithofacies (SIS)
- Property model (phi and K)
- Develop J function and populate SW

Fluid characterization – engineering and PVT

Simulation (CMG)
- History-matched primary and secondary (black oil)
- Forecast CO2 EOR response and CO2 storage

Simulations by field (appx.)	
Jan 2012	Pleasant Prairie
Apr 2012	Eubanks
Jul 2012	Shuck
Oct 2012	Cutter

Anadarko, December 14, 2011

Figure 74. Workflow and timeline as summarized by Dubois.

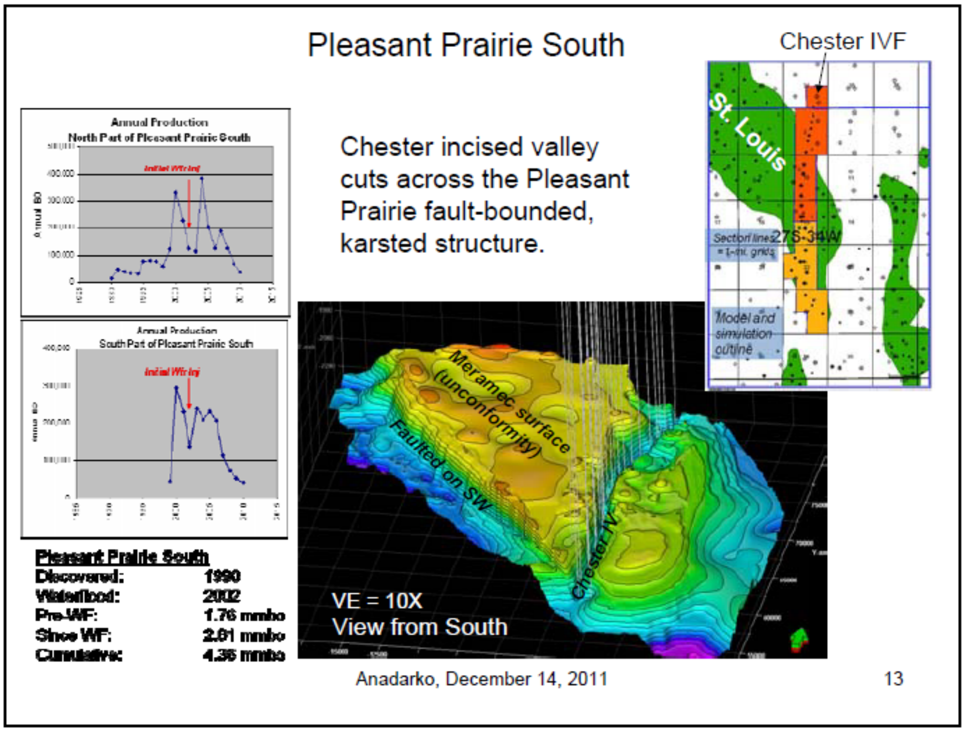


Figure 75. Summary of Pleasant Prairie Field reservoir geology. Note highest elevation on east flank of incised valley is lower than the west side and may represent contribution of faulting to define location of valley (see Figures 50, 51, 52, and 57).

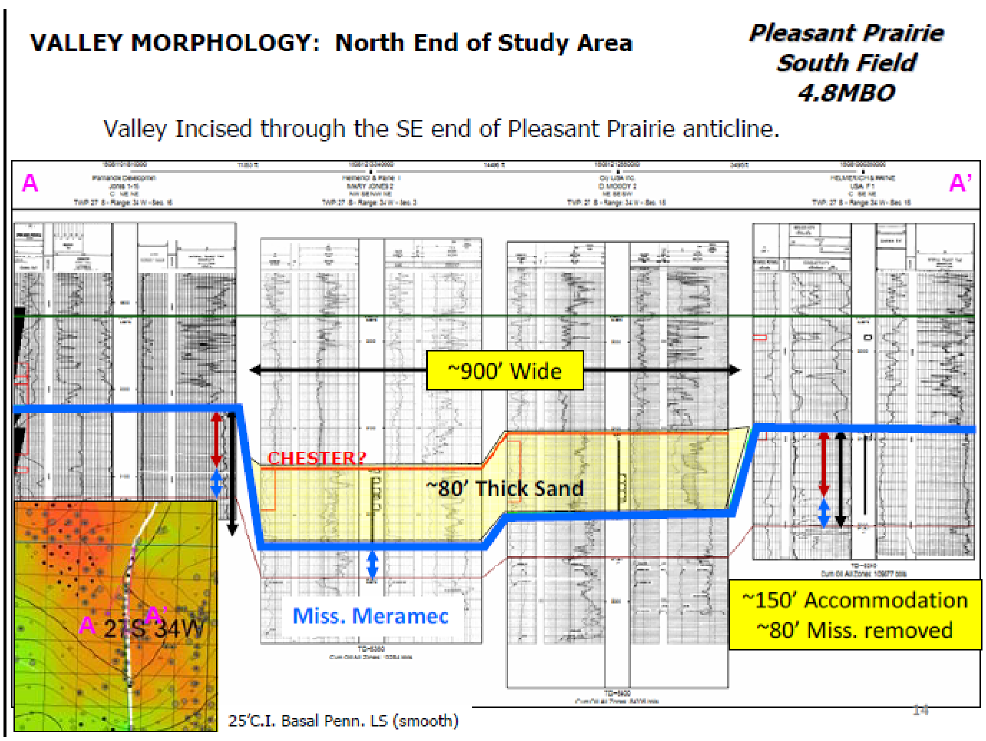


Figure 76. West to east cross section through SE end of Pleasant Prairie Field.

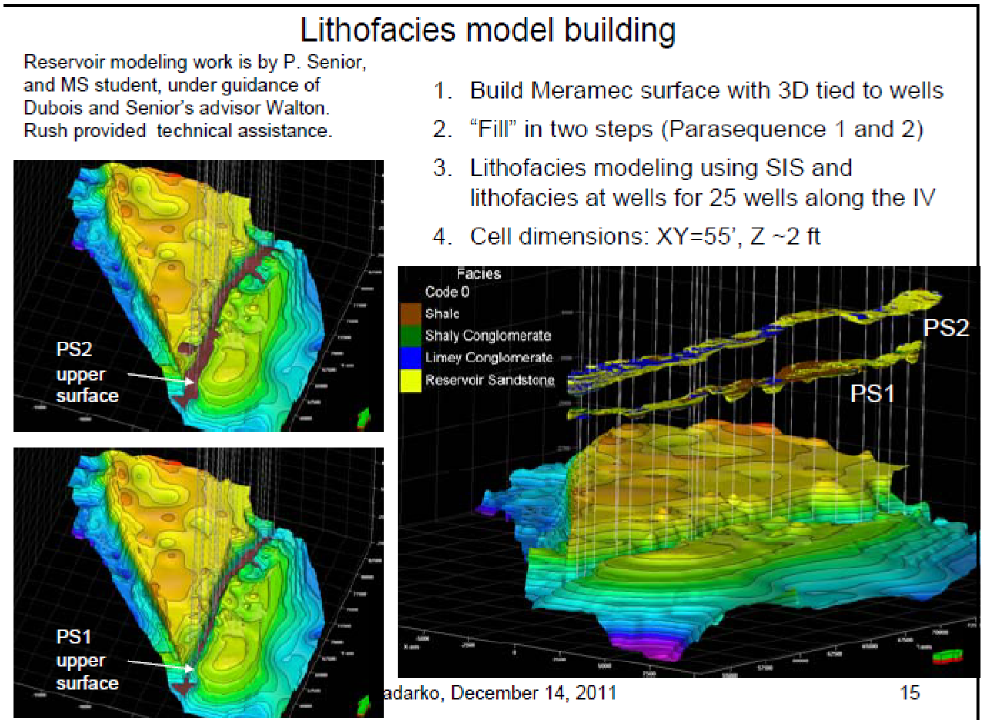


Figure 75. Lithofacies model building at Pleasant Prairie Field.

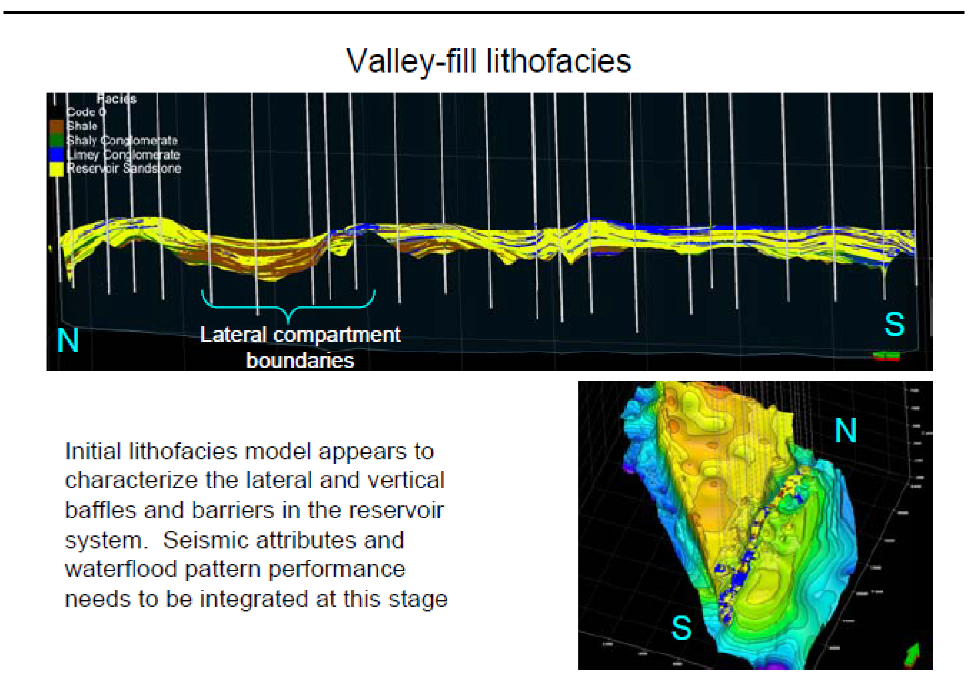


Figure 76. Valley fill lithofacies along the Chester incised valley at Pleasant Prairie Field.

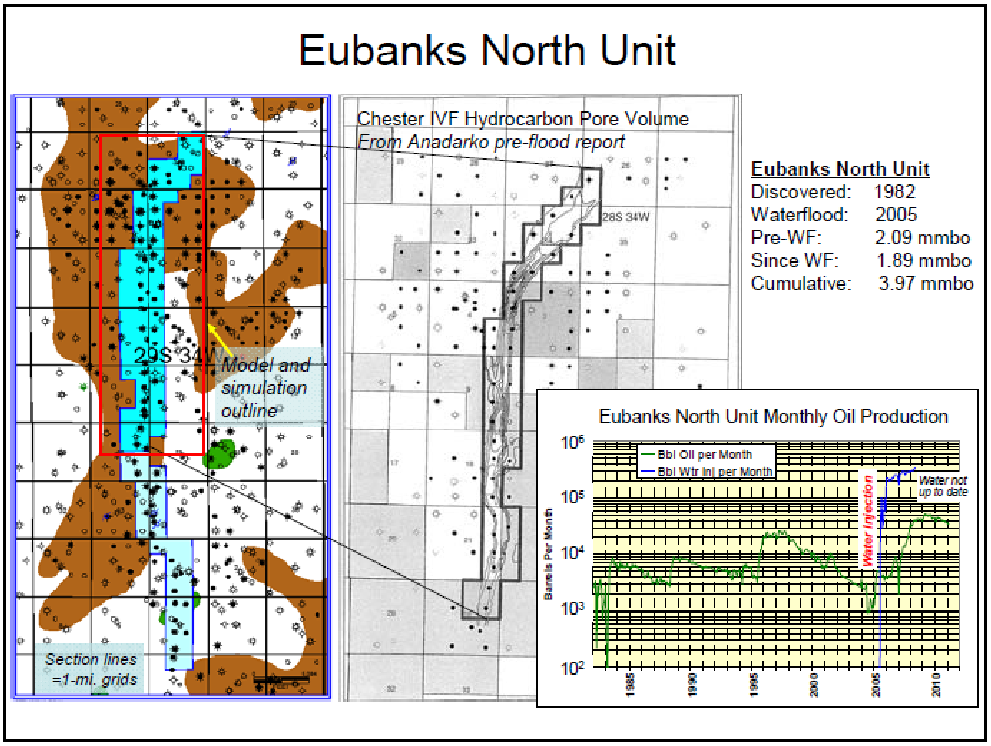


Figure 77. Well locations, hydrocarbon pore volume, and monthly production at Eubanks Field, incised Chester valley fill sandstone reservoir.

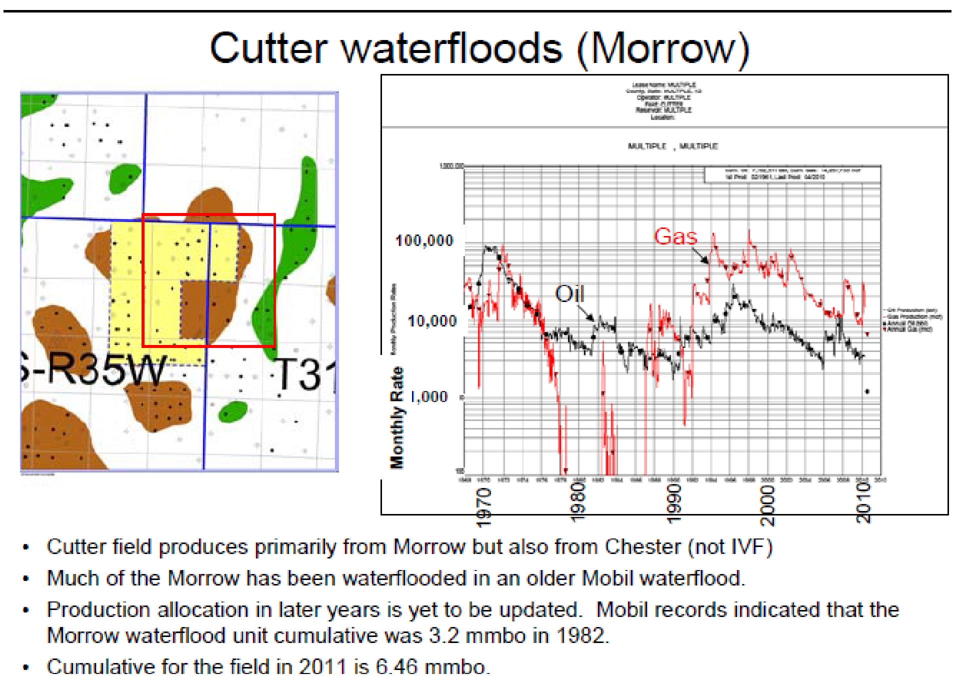


Figure 78. Cutter Field unit production area considered for modeling and response of field to waterflooding.

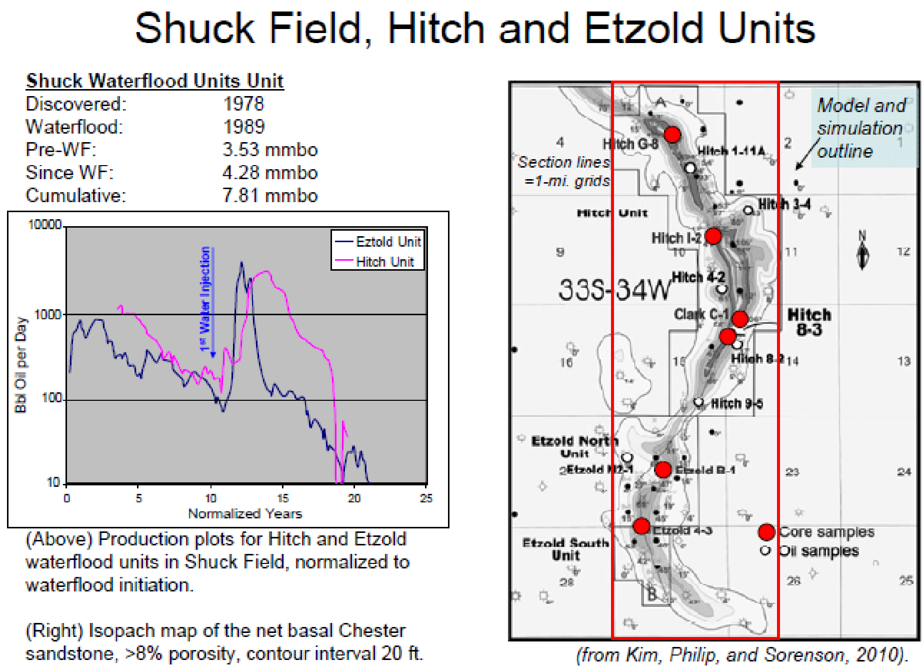


Figure 79. Shuck Field production and well location map.

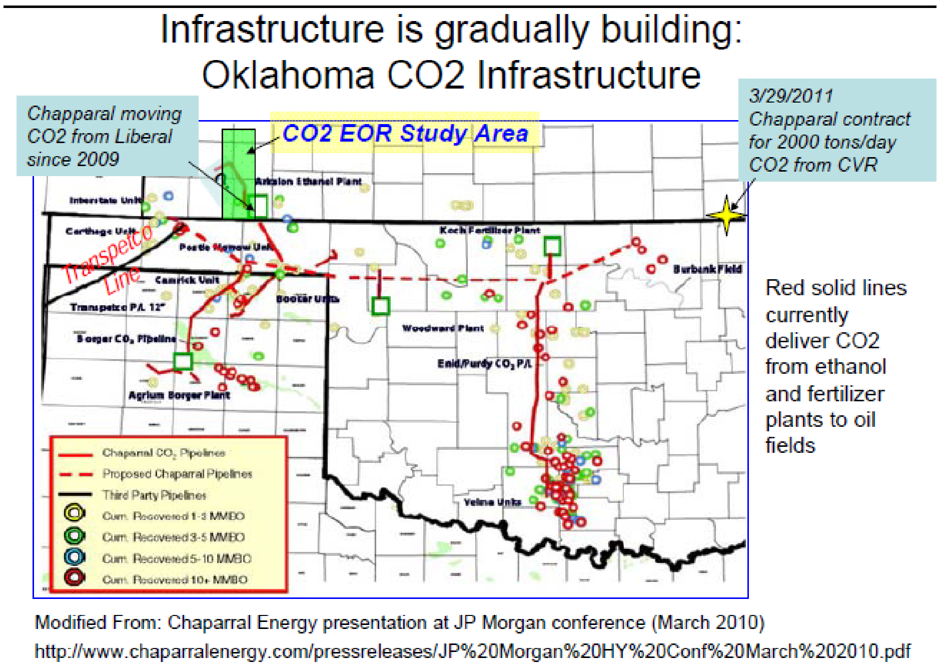


Figure 90. CO2 EOR study in southwestern Kansas in the context of proposed and operating CO2 pipelines in Oklahoma and Texas Panhandle. Outside of the Transpetco pipeline, sources of CO2 are anthropogenic.

Subbtask 13.1. Map major CO2 point sources in KS.

In relationship to the task of identifying major CO2 point sources and sinks for CO2, Bittersweet team has categorized fields by cumulative production in major reservoir units including Upper Pennsylvanian Lansing and Kansas City Groups, Mississippian, and Arbuckle (Figures 91-93). Also fields greater than 10 million barrels cumulative production have been identified (Figure 94). Inventory of sources of CO2 has been updated with new EPA information.

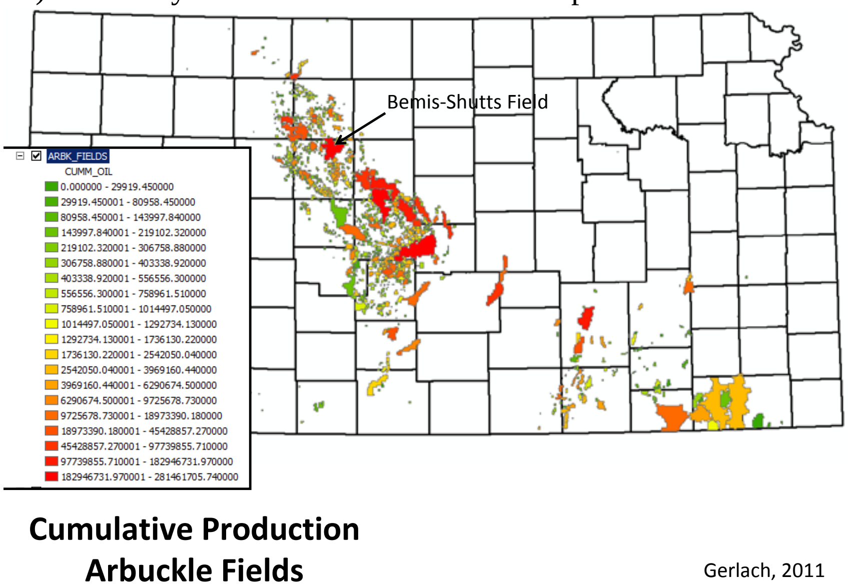


Figure 91. Cumulative production from fields producing from the Arbuckle.

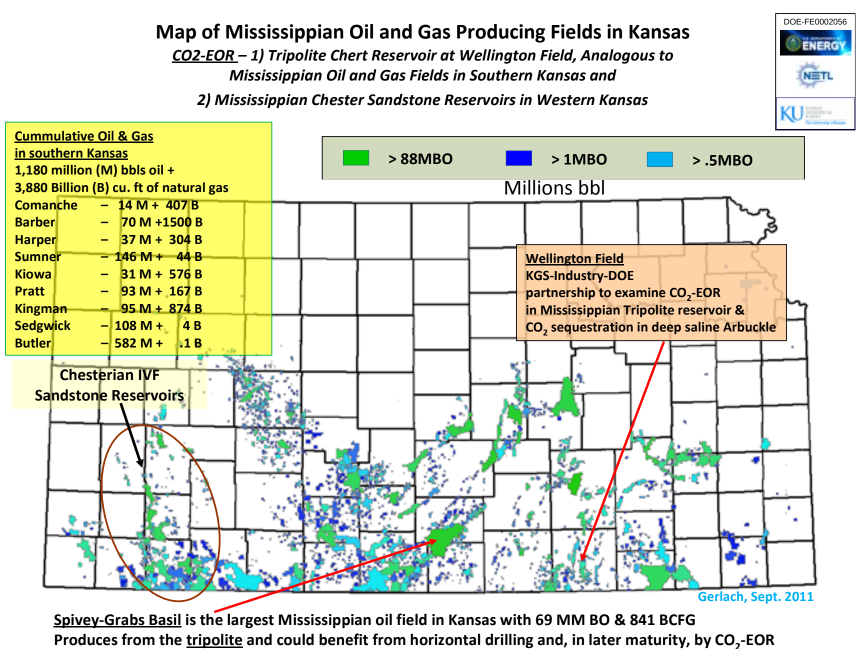


Figure 92. Cumulative production from fields producing from the Mississippian.

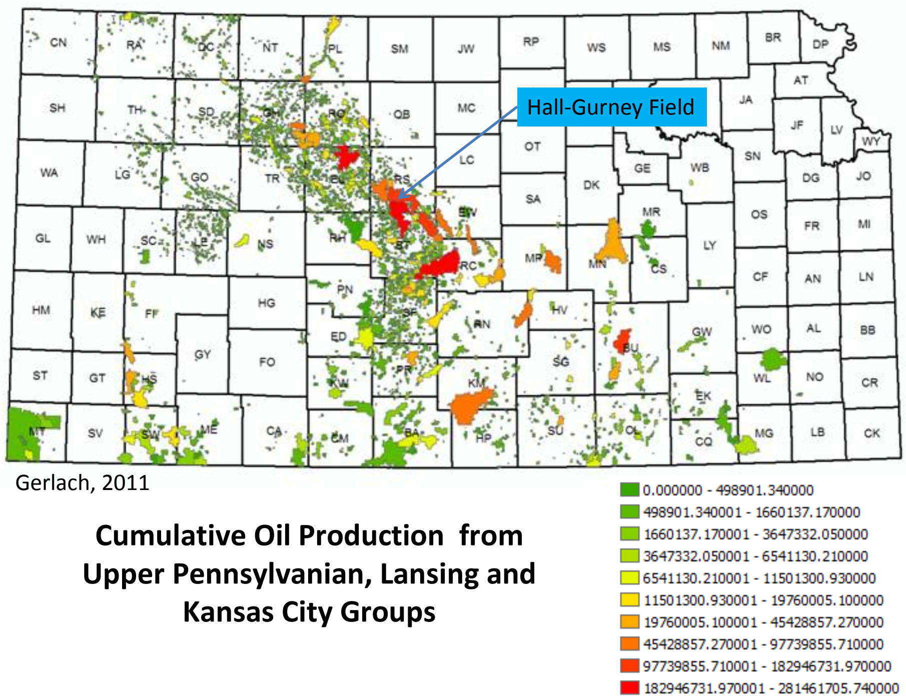


Figure 93. Cumulative production from fields producing from Lansing and Kansas City Groups.

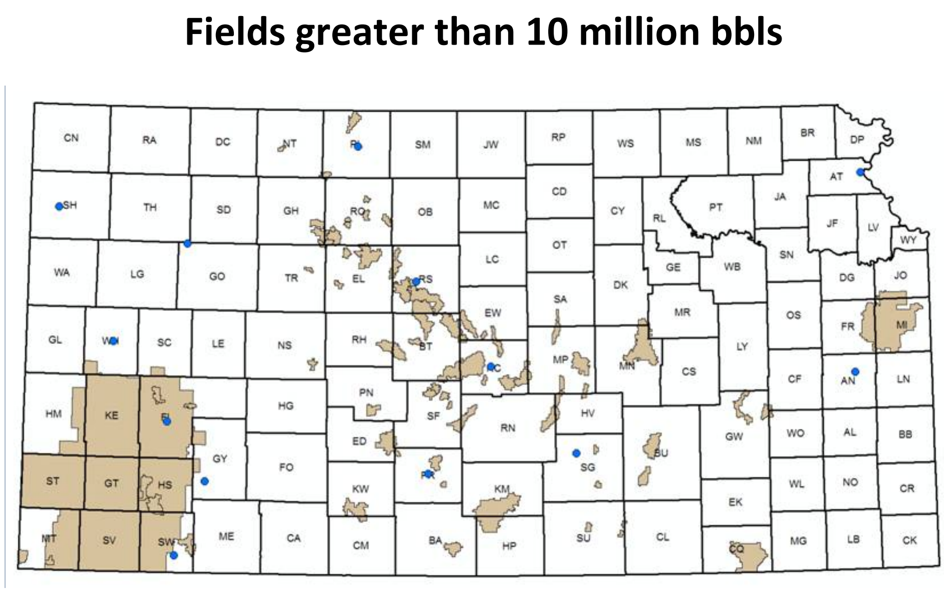


Figure 94. Fields that have produced over 10 millions barrels of cumulative oil.

WELLINGTON FIELD

ONGOING & COMPLETED ACTIVITIES –

Subtask 4.8. Analyze Arbuckle core
Subtask 4.9. Analyze Mississippian core

Whole core analyses have been completed for Berexco Wellington KGs #1-32. Core data will be used to calibrate the wireline logs to assist in build a new version of the geomodels for the Mississippian and Arbuckle as well as provide analytical data to evaluate the caprocks and barriers to vertical migration of CO2. Cross plot of porosity and permeability for the Cherokee through Arbuckle interval is shown in Figure 95. Additional illustrations show the variation of core analyses by depth (Figures 96-100).

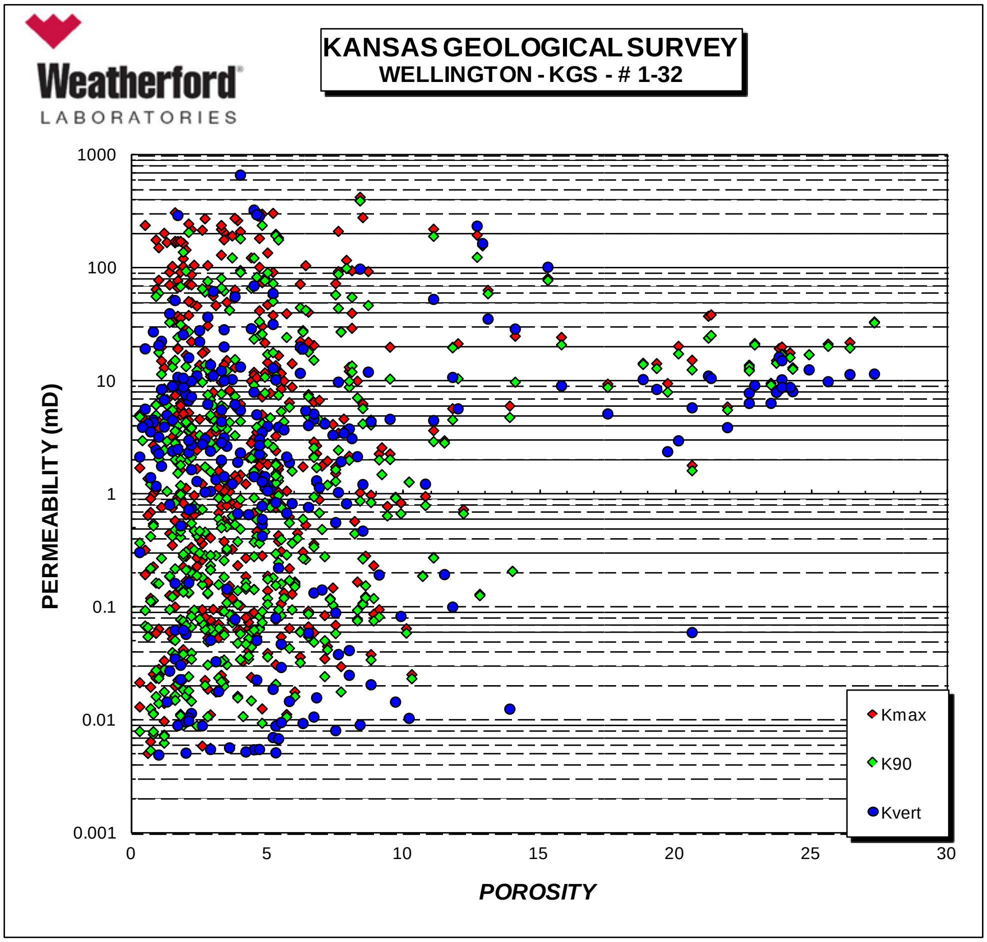


Figure 95. Permeability versus porosity for whole core in Wellington KGS #1-32 showing color coding for Kmax, maximum permeability, k90, permeability at 90 degrees to the maximum permeability, and kvert, permeability measured vertically in the whole core.

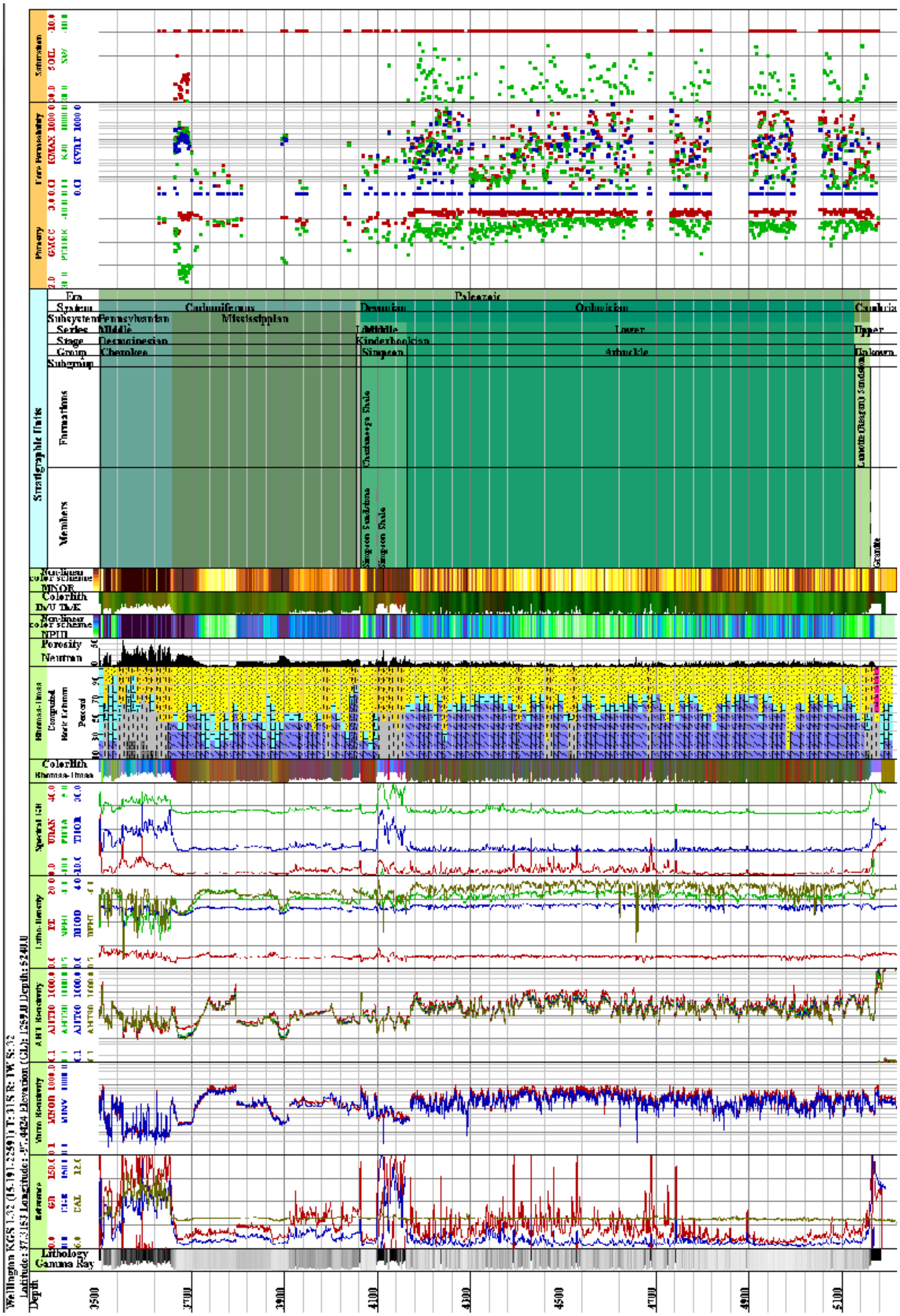


Figure 96. Well profile with geophysical logs, lithofacies solution from logs, stratigraphic tops, and core porosity, permeability, and water and oil saturation for the full cored interval from the top of the Cherokee to the base of Arbuckle.

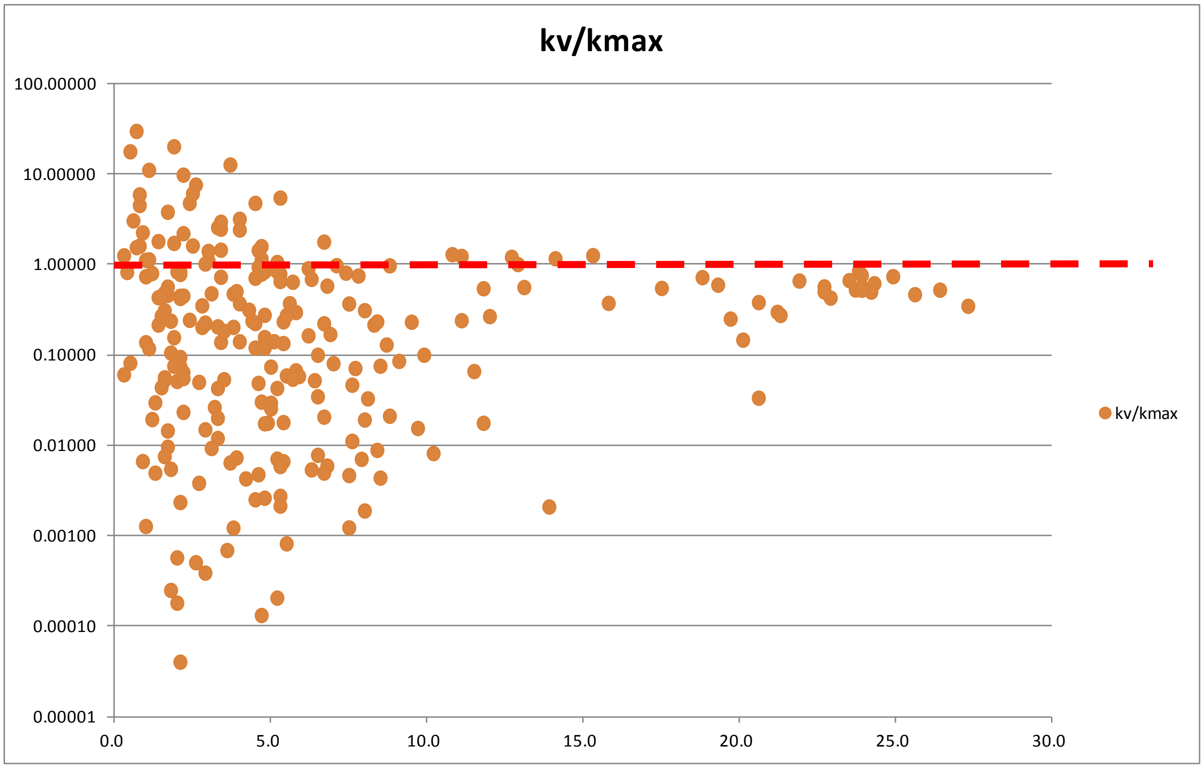


Figure 97. Vertical permeability divided by maximum permeability. Few samples have vertical permeability exceeding maximum horizontal permeability. High Kv generally indicates fractures.

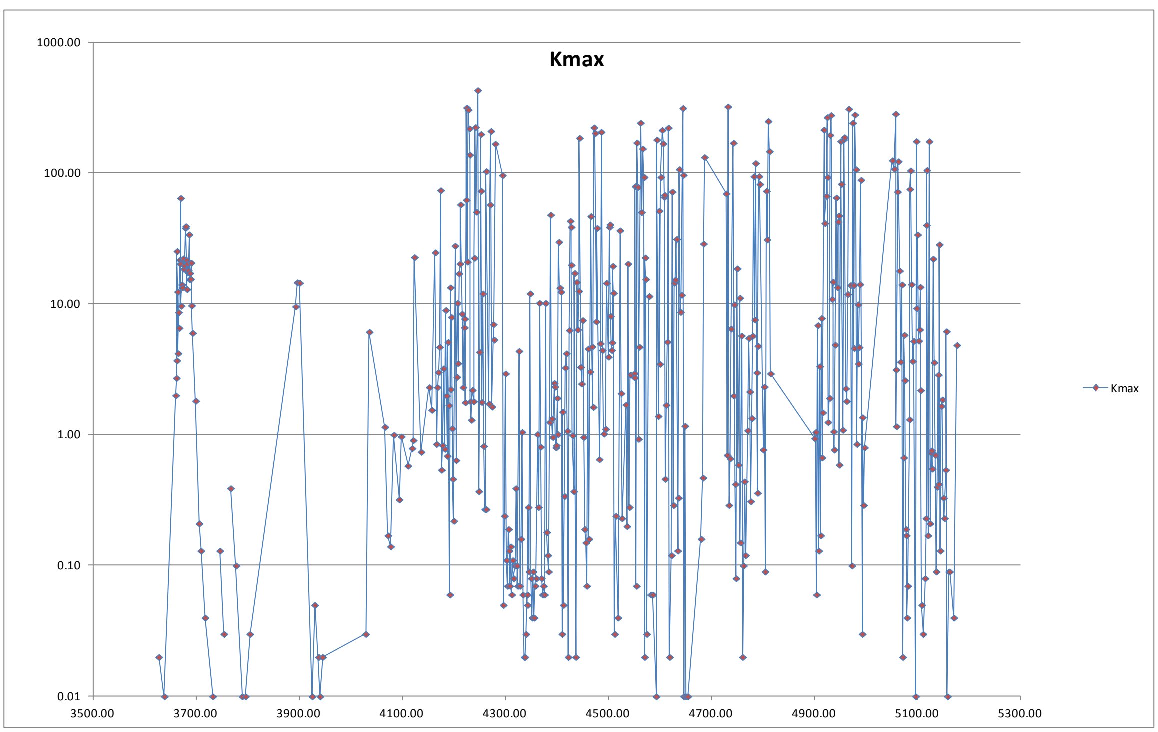


Figure 98. Maximum permeability versus depth from the shallow Cherokee Group shales on left to the base of the Arbuckle on the right.

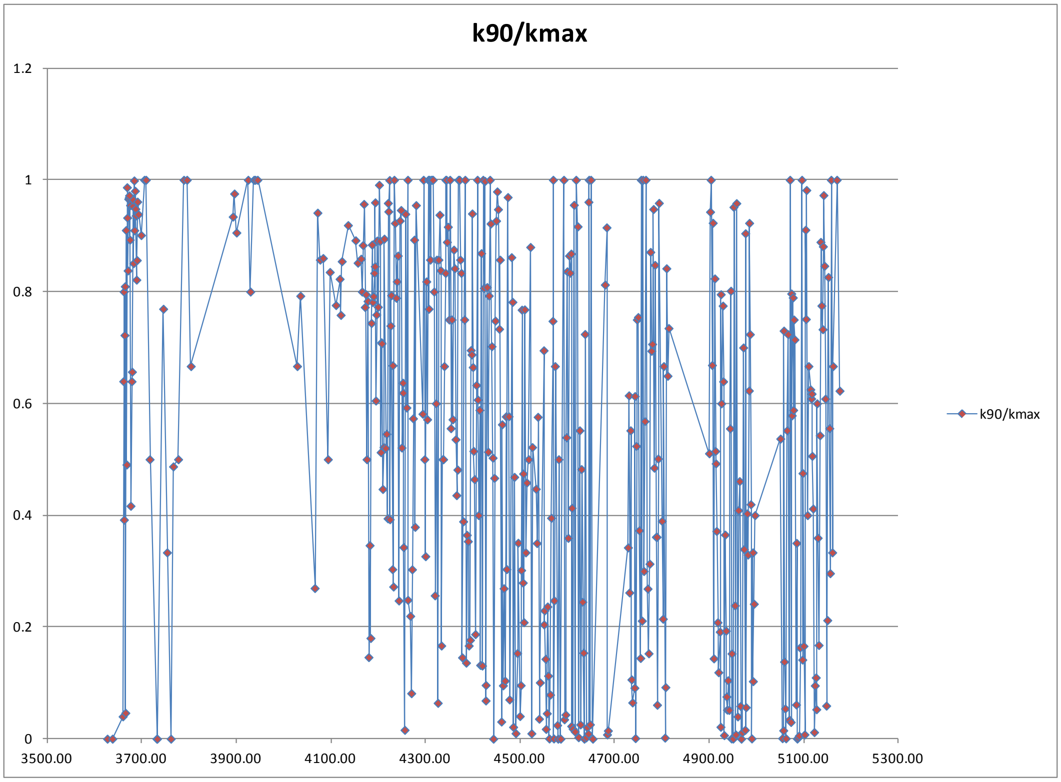


Figure 99. Ratio of permeability at 90 degrees to max. perm. Divided by kmax vs. depth. Some samples have a very low permeability at 90 degrees compared to kmax suggesting directionality to the permeability.

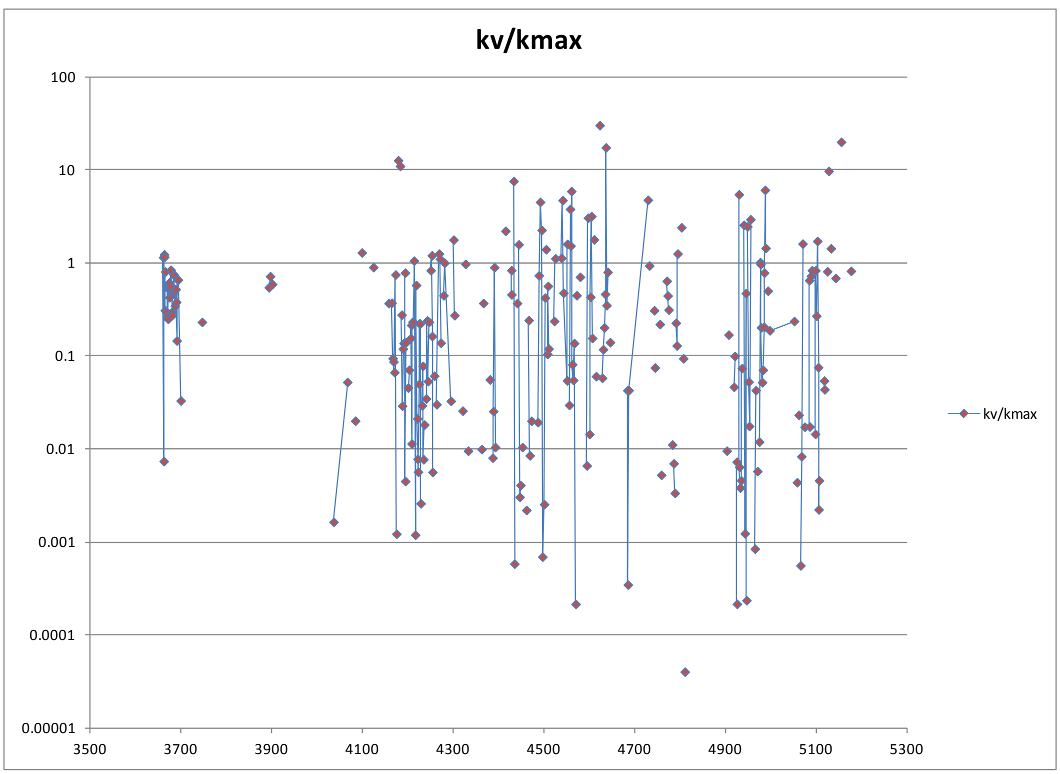


Figure 100. Kvertical divided by kmax versus depth.

Samples were analyzed by Scheffer and Igor Haljasmaa at NETL labs in Pittsburgh for her microbial studies. She also examined possible caprocks in the lower Mississippian darker argillaceous, dense organic-rich carbonates. Sample plugs selected at 4002 feet and 4029 feet were analyzed for porosity and permeability as tight rocks. These low permeability samples were not measured by Weatherford routine analysis based in visual inspection. Rather helical CT scans were made of these low permeability intervals. Figure 101 shows the core slabs from the depths above and Figures 101 to 103 show core and measurements that were made on the two samples.

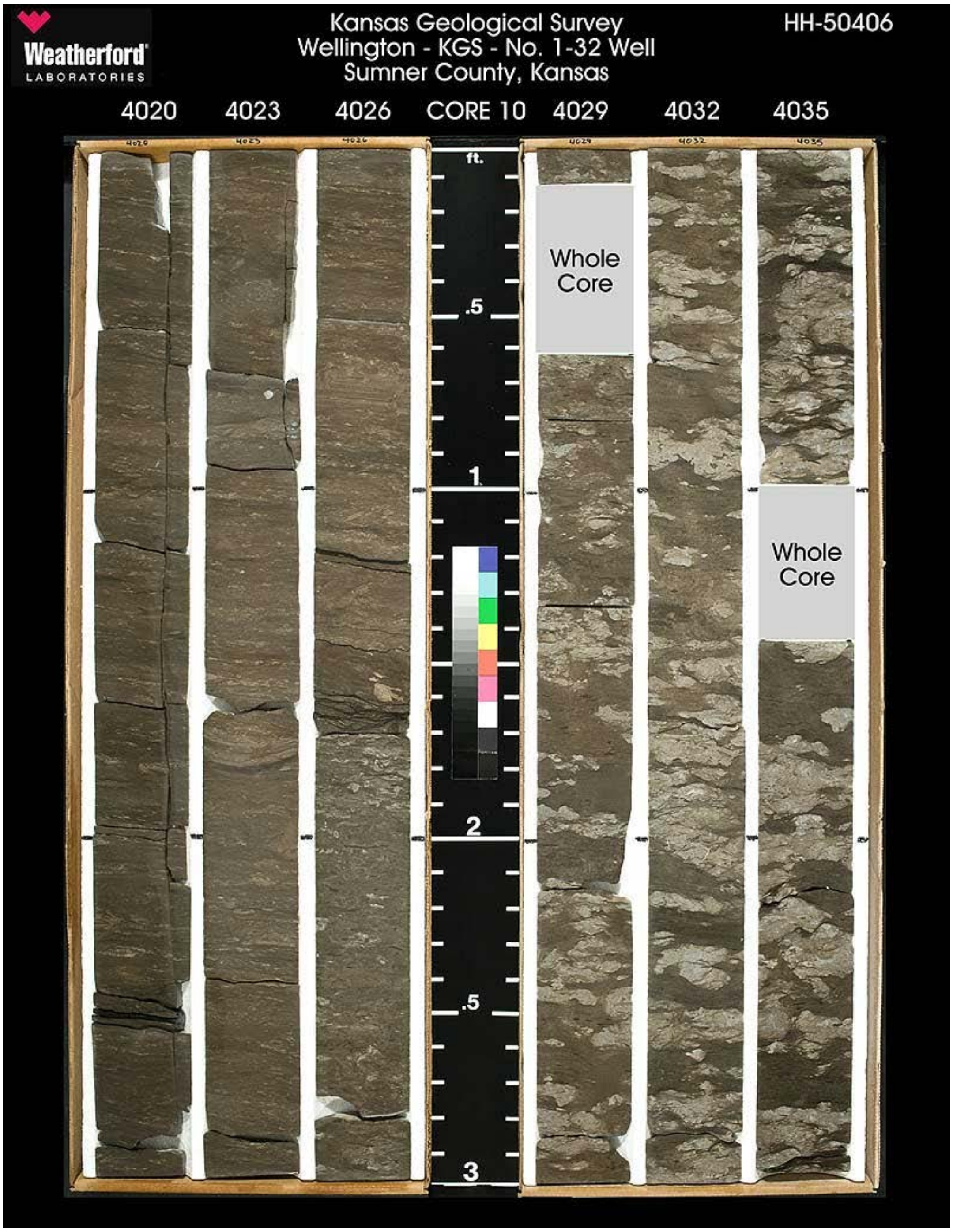
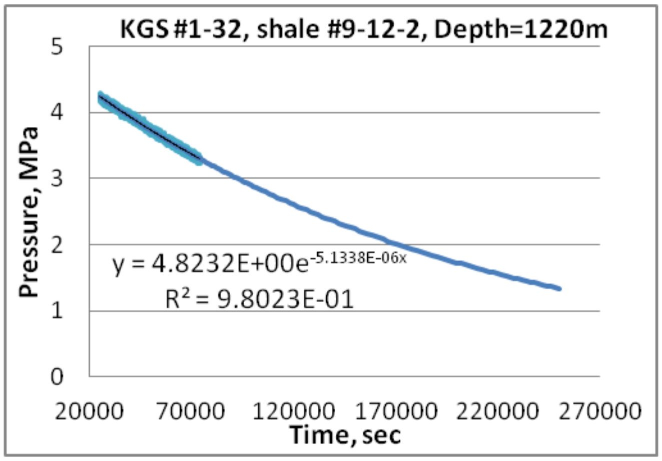


Figure 101. Dense argillaceous dark carbonates in lower Mississippian may serve as caprocks in Wellington Field. Sample intervals analysed as tight rocks include 4002 and 4029 ft.

Porosity was measured in this tight carbonate samples using a Helium porosimeter, HP-401 (TEMCO, Inc.). Porosity of 0.5% was obtained by averaging several sets of measurements. Permeability was measured by pulse decay method. Only a relatively small portion of decay curve was recorded since measurement was time as limited. Results are noted below.

1220 meters =4002.6 feet



$\tau = \dfrac{\beta_T \mu \phi L^2 s}{\theta_1^2}$ p_{conf} = 12MPa;

pp changes from 0 to 5MPa, hence p_{av}=2.5MPa

β_T = 4.06E-7 Pa^{-1}; μ = 2.28E-5 Pa-s; (@p_{av})

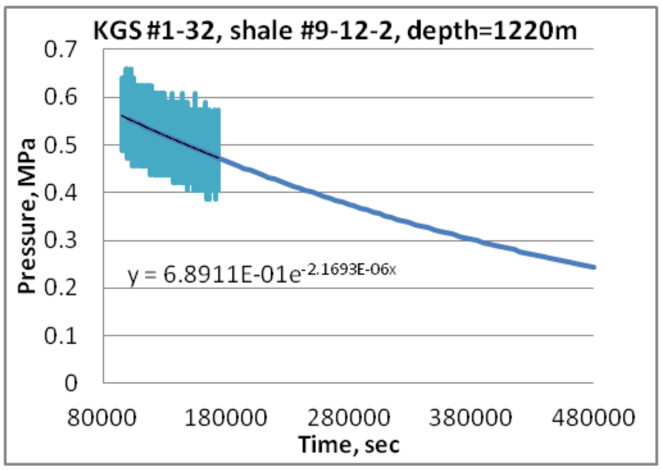
D = 3.796 cm; L = 7.316 cm; ϕ = 0.5%;

V_d = 0.8cc; V_{sam} = $\pi D^2 L/4$ = 82.8 cc;

V_{pore}= V_{sam} ϕ = 0.414cc; α_d = V_d / V_{pore}= 1.93;

$\tan\theta_1 = 1/(\alpha_d\, \theta_1)$ $\Rightarrow$ θ_1 = 0.664

s = 5.1338E-6 sec^{-1}; $\boxed{k \approx 2.9 \text{ nD}}$



p_{conf} = 5MPa;

pp changes from 1.6 to 2.2MPa $\Rightarrow$ p_{av}=1.9MPa

β_T = 5.33E-7 Pa^{-1}; μ = 2.26E-5 Pa-s; (@p_{av})

s = 2.1693E-6 sec^{-1}; $\boxed{k \approx 1.6 \text{ nD}}$

Figure 102. Permeability of the lower Mississippian tight carbonates was in the nanodarcy range as indicated in summary on the right margin of this figure.

Under the above experimental conditions, the assumptions of pulse decay method are satisfied rather poorly since only a small portion of the decay curve was acquired. Therefore, the obtained values of permeability are rather approximate. Nevertheless, we can state that the permeability of the sample is in the range of several nanoDarcies (definitely, below 10 nD).

Note that porosity was measured at "low pressure" conditions (p_{conf}=p_{pore}=0.7MPa). Under the experimental conditions (p_{conf}=12MPa or 5MPa), we would expect some reduction in porosity (say, by 10%), which should give even slightly lower value of permeability.

Additional measurements were made of the tight lower Mississippian carbonates including bulk modulus from ultrasonic measurements. A second sample of the Lower Mississippian had a higher permeability, 50 microD, compared to the single-nanoD sample noted above. I tried to pick samples that would represent an upper and lower range for the formation.

An ultrasonic analysis of two samples was made to determine bulk moduli as described in Figure 103.

Figure 103. -- Ultrasonic Velocity Measurement Report

Core Data Report

File Name	KGS-10-10-1	Well	KGS-No1-32
Location	Summer County	Latitude/Longitude	
Field	Wellington	Formation	
Company		Country	US
Lab	PITT	Client	AS
Operator	IH	Current Time	12/29/2011 4:41:25 PM

NO.	Sample ID	Depth (m)	Length (cm)	Diam. (cm)	Temp(C)	Baro Pres (PSI)	Conf Pres	Diff Pres (atm)	Visc (cP)	P1 (atm)	P2 (atm)	Flow Rate (cc/sec)	Perm (md)	Pmean (atm)
1	KGS-10-10-1	1228	8.208	3.8	21	14.5	1000	1.0941	0.017631	2.0808	0.9867	0.0071	0.053	1.5337
2	KGS-10-10-1	1228	8.208	3.8	21	14.5	1000	1.5193	0.017631	2.5059	0.9867	0.0113	0.053	1.7463
3	KGS-10-10-1	1228	8.208	3.8	21	14.5	1000	2.0117	0.017631	2.9983	0.9867	0.0164	0.051	1.9925
4	KGS-10-10-1	1228	8.208	3.8	21	14.5	1000	2.6231	0.017631	3.6098	0.9867	0.0234	0.049	2.2982
5	KGS-10-10-1	1228	8.208	3.8	21	14.5	1000	3.2468	0.017631	4.2335	0.9867	0.0318	0.047	2.6101

1228 m = 4029 ft. Grain density is 2.67 g/cc. Organic rich carbonate near base of Mississippian.

***** D A T A LO G ***********************													
Sample ID		KGS 10-10-1											
Ref. Temp		22° C											
Operator		IH											
Well		KGS #1-32											
sample		oilshale											
Porosity		UNKNOWN											
USER PARAMETERS													
Core Diameter		3.800 cm	3.8	cm									
Core Length		8.208 cm	8.208	cm	Dry mass		Bulk density		Grain density				
Bulk Volume		93.088 cc	93.088	cc	230.65	g	2.48	g/cc	2.67	g/cc			
Ref. Core Diameter		3.803 cm											
Ref. Core Length		3.809 cm											
Ref. Core Volume		43.267 cc											
Date	Time		Pressure	Pressure	Pressure	Pressure	Pressure	Pressure	Pressure	Pressure	Pressure	Grain	Calculated
			P1	P2	equil. 1	P1 ref	P2 ref	equil. 2	P1 sample	P2 sample	equil. 3	Volume	Porosity
			psia	psia	psia	psia	psia	psia	psia	psia	psia	cc	percent
12/28/2011	2:45:29 PM		14.179	96.075	57.655	14.182	96.097	65.315	14.187	96.108	76.124	86.17	7.432
12/28/2011	2:52:52 PM		14.195	96.11	57.815	14.197	96.116	65.374	14.202	96.116	76.119	86.617	6.952
12/28/2011	3:00:13 PM		14.202	96.116	57.839	14.205	96.118	65.406	14.205	96.116	76.124	86.476	7.103
											Average:	86.421	7.16

***** D A T A LO G ***********************													
Sample ID		KGS 10-10-2											
Ref. Temp		22° C											
Operator		IH											
Well		KGS #1-32											
sample		oilshale											
Porosity		UNKNOWN											
USER PARAMETERS													
Core Diameter		3.795 cm	3.795	cm									
Core Length		8.420 cm	8.42	cm	Dry mass		Bulk density		Grain density				
Bulk Volume		95.241 cc	95.241	cc	233.2	g	2.45	g/cc	2.67	g/cc			
Ref. Core Diameter		3.803 cm											
Ref. Core Length		3.809 cm											
Ref. Core Volume		43.267 cc											
Date	Time		Pressure	Pressure	Pressure	Pressure	Pressure	Pressure	Pressure	Pressure	Pressure	Grain	Calculated
			P1	P2	equil. 1	P1 ref	P2 ref	equil. 2	P1 sample	P2 sample	equil. 3	Volume	Porosity
			psia	psia	psia	psia	psia	psia	psia	psia	psia	cc	percent
12/27/2011	3:21:28 PM		13.903	96.506	57.836	13.903	96.513	65.568	13.908	96.502	76.687	86.856	8.805
12/27/2011	3:32:35 PM		13.906	96.449	57.936	13.917	96.44	65.553	13.917	96.411	76.654	87.579	8.046
12/27/2011	3:55:09 PM		13.917	96.389	57.909	13.924	96.378	65.506	13.927	96.37	76.594	87.587	8.037
											Average:	87.34	8.30

1220 meters = 4002.6 ft.

Ultrasonic Velocity Measurement Report

Sample and Experiment Information for File 1324068705			
Well:	KGS#1-32	Organization:	National Energy Technology Lab
Depth:	1220.0 m	Transducer:	NETL_1.5inch_1
Formation:	Wellington	Rock type:	shale #9-12-2
Dry bulk density:	2.600 gm/cm^3	Porosity:	
Sat. bulk density:		Pore fluids:	argon
Diameter:	37.97 mm	Entered Length:	73.16 mm

Comments: User: igor on al1500 at Thu Dec 8 13:41:33 EST 2011
Expt name: 1324068702
Expt date: Fri Dec 16 15:52:08 2011
Print date: Mon Dec 19 14:17:54 2011
A2D File:

Event Picks for File 1324068705							
Event	Conf	Pore	Diff	Temp	t_p	$t_s^{(1)}$	$t_s^{(2)}$
	MPa	MPa	MPa	°C	μsec	μsec	μsec
0	4.1	0.2	0.5	23.0	23.926	41.255	41.505
1	5.2	0.2	0.3	23.1	23.963	41.004	41.255
2	6.1	0.1	0.4	23.2	23.800	40.754	41.004
3	8.1	0.1	0.5	23.4	23.550	40.841	41.004
4	8.1	0.2	0.3	23.3	23.550	40.754	40.754
5	10.1	0.2	0.3	23.5	23.462	40.754	40.687
6	12.1	0.2	0.1	23.7	23.462	40.716	40.645
7	15.1	0.1	-0.1	23.8	23.462	40.653	40.645
8	20.1	0.2	-0.2	24.2	23.424	40.653	40.524
9	25.1	0.2	-0.3	24.6	23.424	40.528	40.524
10	25.1	0.2	-0.3	24.5	23.487	40.465	40.465
11	30.0	0.2	-0.5	24.7	23.212	40.465	40.399
12	35.1	0.2	-0.7	25.0	23.212	40.465	40.336
13	40.2	0.2	-0.9	25.3	23.174	40.340	40.273
14	35.1	0.2	-0.7	24.7	23.212	40.465	40.273
15	30.1	0.2	-0.6	24.0	23.212	40.465	40.353
16	25.1	0.1	-0.3	23.4	23.212	40.465	40.465
17	20.0	0.1	-0.2	22.7	23.462	40.503	40.562
18	15.1	0.2	0.1	22.0	23.462	40.653	40.716
19	12.1	0.1	0.1	21.7	23.613	40.653	40.754

Observed Velocities and Moduli for File 1325264321									
Event	Conf	Pore	Diff	Temp	V_p	$V_s^{(1)}$	$V_s^{(2)}$	Young's Modulus	Poisson's Ratio
	MPa	MPa	MPa	°C	m/s	m/s	m/s	GPa	
0	4.1	0.2	0.4	23.1	4382	2573	2573	43.73	0.237
1	6.1	0.2	0.5	23.1	4442	2614	2614	45.07	0.235
2	8.1	0.1	0.2	23.3	4503	2645	2625	45.96	0.240
3	10.1	0.2	0.1	23.4	4503	2678	2667	46.84	0.228
4	15.1	0.2	0.1	24.0	4598	2722	2723	48.69	0.230
5	20.0	0.2	-0.3	24.3	4630	2768	2769	50.00	0.222
6	25.0	0.2	-0.5	23.6	4731	2816	2817	51.91	0.226
7	29.9	0.1	-0.6	24.0	4731	2828	2841	52.34	0.220
8	34.9	0.2	-0.9	23.6	4800	2865	2866	53.63	0.223
9	39.8	0.2	-0.9	24.0	4800	2878	2866	53.79	0.221
10	34.9	0.1	-0.8	23.6	4835	2853	2853	53.59	0.233
11	30.0	0.1	-0.6	22.9	4800	2840	2841	53.02	0.231
12	25.0	0.2	-0.4	22.8	4731	2828	2829	52.20	0.222
13	20.0	0.2	-0.1	22.7	4731	2804	2805	51.62	0.229
14	15.1	0.2	-0.0	22.6	4598	2768	2757	49.62	0.218
15	10.1	0.2	0.2	22.5	4566	2700	2712	48.07	0.229
16	8.1	0.1	0.1	22.8	4503	2700	2667	47.09	0.225
17	6.1	0.2	0.3	22.7	4472	2624	2604	45.26	0.241
18	4.1	0.2	0.4	22.5	4412	2563	2563	43.68	0.245

Sample Lengths for File 1325264321	
Event	Sample Length
	mm
0	82.08
1	82.08
2	82.08
3	82.08
4	82.08
5	82.08
6	82.08
7	82.08
8	82.08
9	82.08
10	82.08
11	82.08

1228 meters = 4029 feet

Ultrasonic Velocity Measurement Report

Sample and Experiment Information for File 1325264321			
Well:	KGS#1-32	Organization:	National Energy Technology Lab
Depth:	1228.0 m	Transducer:	NETL_1.5inch_1
Formation:	Wellington	Rock type:	Oil-bearing carbonate #10-10-1
Dry bulk density:	2.670 gm/cm^3	Porosity:	7.2%
Sat. bulk density:		Pore fluids:	argon
Diameter:	38.00 mm	Entered Length:	82.08 mm

Comments: User: igor on al1500 at Thu Dec 8 13:41:33 EST 2011
Expt name: 1325264317
Expt date: Fri Dec 30 12:01:40 2011
Print date: Mon Jan 09 10:25:01 2012
A2D File:

Event Picks for File 1325264321							
Event	Conf	Pore	Diff	Temp	t_p	$t_s^{(1)}$	$t_s^{(2)}$
	MPa	MPa	MPa	°C	μsec	μsec	μsec
0	4.1	0.2	0.4	23.1	27.458	48.258	48.132
1	6.1	0.2	0.5	23.1	27.207	47.757	47.631
2	8.1	0.1	0.2	23.3	26.956	47.381	47.506
3	10.1	0.2	0.1	23.4	26.956	47.005	47.005
4	15.1	0.2	0.1	24.0	26.581	46.503	46.378
5	20.0	0.2	-0.3	24.3	26.455	46.002	45.877
6	25.0	0.2	-0.5	23.6	26.079	45.501	45.376
7	29.9	0.1	-0.6	24.0	26.079	45.376	45.125
8	34.9	0.2	-0.9	23.6	25.829	45.000	44.874
9	39.8	0.2	-0.9	24.0	25.829	44.874	44.874
10	34.9	0.1	-0.8	23.6	25.703	45.125	45.000
11	30.0	0.1	-0.6	22.9	25.829	45.250	45.125
12	25.0	0.2	-0.4	22.8	26.079	45.376	45.250
13	20.0	0.2	-0.1	22.7	26.079	45.626	45.501
14	15.1	0.2	-0.0	22.6	26.581	46.002	46.002
15	10.1	0.2	0.2	22.5	26.706	46.754	46.503
16	8.1	0.1	0.1	22.8	26.956	46.754	47.005
17	6.1	0.2	0.3	22.7	27.082	47.631	47.757
18	4.1	0.2	0.4	22.5	27.332	48.383	48.258

Observed Velocities and Moduli for File 1325264321									
Event	Conf	Pore	Diff	Temp	V_p	$V_s^{(1)}$	$V_s^{(2)}$	Young's Modulus	Poisson's Ratio
	MPa	MPa	MPa	°C	m/s	m/s	m/s	GPa	
0	4.1	0.2	0.4	23.1	4382	2573	2573	43.73	0.237
1	6.1	0.2	0.5	23.1	4442	2614	2614	45.07	0.235
2	8.1	0.1	0.2	23.3	4503	2645	2625	45.96	0.240
3	10.1	0.2	0.1	23.4	4503	2678	2667	46.84	0.228
4	15.1	0.2	0.1	24.0	4598	2722	2723	48.69	0.230
5	20.0	0.2	-0.3	24.3	4630	2768	2769	50.00	0.222
6	25.0	0.2	-0.5	23.6	4731	2816	2817	51.91	0.226
7	29.9	0.1	-0.6	24.0	4731	2828	2841	52.34	0.220
8	34.9	0.2	-0.9	23.6	4800	2865	2866	53.63	0.223
9	39.8	0.2	-0.9	24.0	4800	2878	2866	53.79	0.221
10	34.9	0.1	-0.8	23.6	4835	2853	2853	53.59	0.233
11	30.0	0.1	-0.6	22.9	4800	2840	2841	53.02	0.231
12	25.0	0.2	-0.4	22.8	4731	2828	2829	52.20	0.222
13	20.0	0.2	-0.1	22.7	4731	2804	2805	51.62	0.229
14	15.1	0.2	-0.0	22.6	4598	2768	2757	49.62	0.218
15	10.1	0.2	0.2	22.5	4566	2700	2712	48.07	0.229
16	8.1	0.1	0.1	22.8	4503	2700	2667	47.09	0.225
17	6.1	0.2	0.3	22.7	4472	2624	2604	45.26	0.241
18	4.1	0.2	0.4	22.5	4412	2563	2563	43.68	0.245

Sample Lengths for File 1325264321	
Event	Sample Length
	mm
0	82.08
1	82.08
2	82.08
3	82.08
4	82.08
5	82.08
6	82.08
7	82.08
8	82.08
9	82.08
10	82.08
11	82.08

Subtask 4.11. Geochemical analysis of water samples.
Subtask 4.12. Microbiological studies on produced water.

Work continues on the geochemical and microbial analyses of cores and fluids.

Abstract and poster were presented at the NETL annual review meeting held in November in Pittsburgh in additional to oral presentation on the project. The following is the abstract that was accepted and presented.

Laboratory CO2 flow experiments to model hydrochemical and mineralogical changes in the Arbuckle aquifer during CO2 Storage

BARKER, R.1*, WATNEY, L.2, BHATTACHARYA, S.4, STRAZISAR, B.3, KELLY, L.1, FORD, S.1, DATTA, S.1
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2 Kansas Geologic Survey, Lawrence, Kansas lwatney@kgsu.ku.edu
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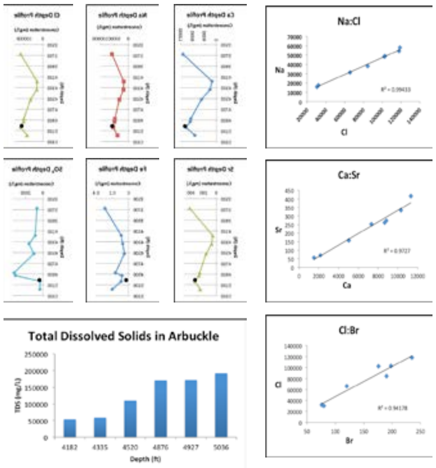
The saline Arbuckle aquifer in south-central Kansas has been proposed for a pilot scale injection of CO2 [1]. This paper presents characterization of Arbuckle mineralogy and hydrogeochemistry along with experimental flow cell data and geochemical modelling of CO2 injection. Two wells (KGS 1-32 and 1-28) have been drilled to the basement to provide rock core and brine data for a site specific determination of the storage potential of the Arbuckle. Thin section and XRD data reveal dominant mineralogy in the injection zone to be dolomite with sporadic cherty nodules. Chert appears to replace dolomicrite and euhedral dolomite as well as infilling porosity. Porosity values range between 1.2 and 11.8% within the injection zone. Drill stem test water samples were collected from 8 depths (3677, 4182, 4335, 4520, 4876, 4927, 5036, 5183 ft) to describe the changing brine chemistry with depth. Sulfate peaks at 4876' and 4927' may be indicative of microbial action at these depths. Chemical analysis show a hyper saline brine (~50,000 - 190,000 TDS) dominated by Cl, Na and Ca. Elemental ratios of Cl:Br, Na:Cl and Ca:Sr are what is expected of a typical saline aquifer system [2]. Major and trace elemental chemistry suggest the brine originated from evaporated seawater that has been affected by digenetic processes.

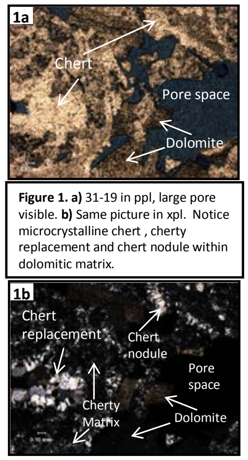
Laboratory flow experiments carried out at the National Energy Technology Laboratory show increases in Ca, Mg, Na and Cl while Fe, S, P and SO4 decrease within the first 15 hours while hours 15 through 24 show a reverse trend for these elements. Flow experiments at supercritical temperatures and pressures allow determination of the extent of mineral carbonation, mineral dissolution reactions and help constrain reaction rates determined through geochemical modelling [3].

[1] Carr et al. (2005) AAPG Bulletin. 89 1607-1627. [2] Barker et al. (2011) Abstract, American Geophysical Union. [3] Kharaka et al. (2006) J. Geochem. Explor. 89 183-183

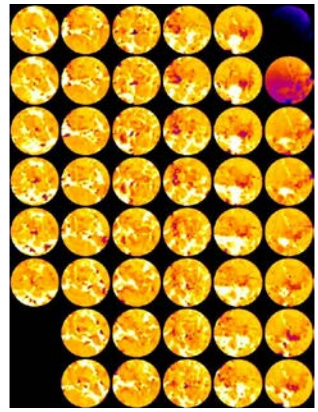
Paper summarized the work on water and rock characterization as illustrated in Figures ________



8 drill stem tests and 1 swab test have been analyzed to create depth profiles of major species



Thin section pictures of core plug used in supercritical flow experiment



Medical CT scan of core plug after 24 hour flow experiment at NETL

Figure 104. Water and rock characterization.

- National Energy Technology Laboratory, Pittsburgh, PA Core Flow Laboratory, Aug 15-30, 2011
- Core Flow System 839z instrument was used to flow brine and CO_2 through formation core
- Core from the injection zone was used (31-19, see the mineralogy section for XRD and thin section data)
- Confining pressure 2100 psi; Temperature 40°C
- Brine only was flowed at 0.2 mL/min for 13 hours to saturate core
- CO_2 was introduced with brine at 1 mL/min
- Effluent collected hourly for analyses (‘hour 14’ is an average of over night brine+CO_2 flow)

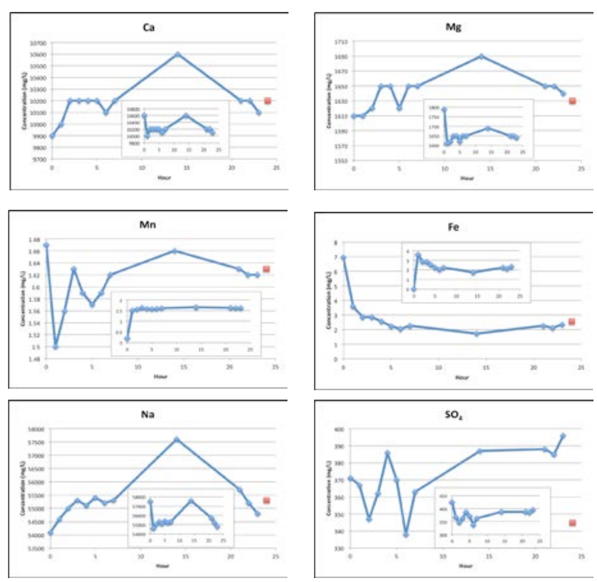


Figure 105. Supercritical flow experiments.

Introduction to the poster -

Arbuckle aquifer in SC Kansas has been targeted for this CO2 sequestration project as a way to mitigate future release of this green house gas. Deep saline aquifers are one of the most appealing geologic formations for sequestration because they are unfit for drinking and usually isolated from fresh water sources. Secure, long term storage involves mineralization reactions that require the presence of certain minerals and ionic species to facilitate precipitation reactions 1600 feet of core was taken from well KGS 1-32 for mineralogical description and formation core samples have been analyzed with X-ray diffraction, thin section and electron micrograph Water samples have been collected from 8 drill stem tests (DST) (3677', 4182', 4335', 4520', 4876', 4927', 5036') and 1 swab test (5010') in the Mississippi and Arbuckle aquifers and analyzed for detailed hydrogeochemistry and microbial geochemistry

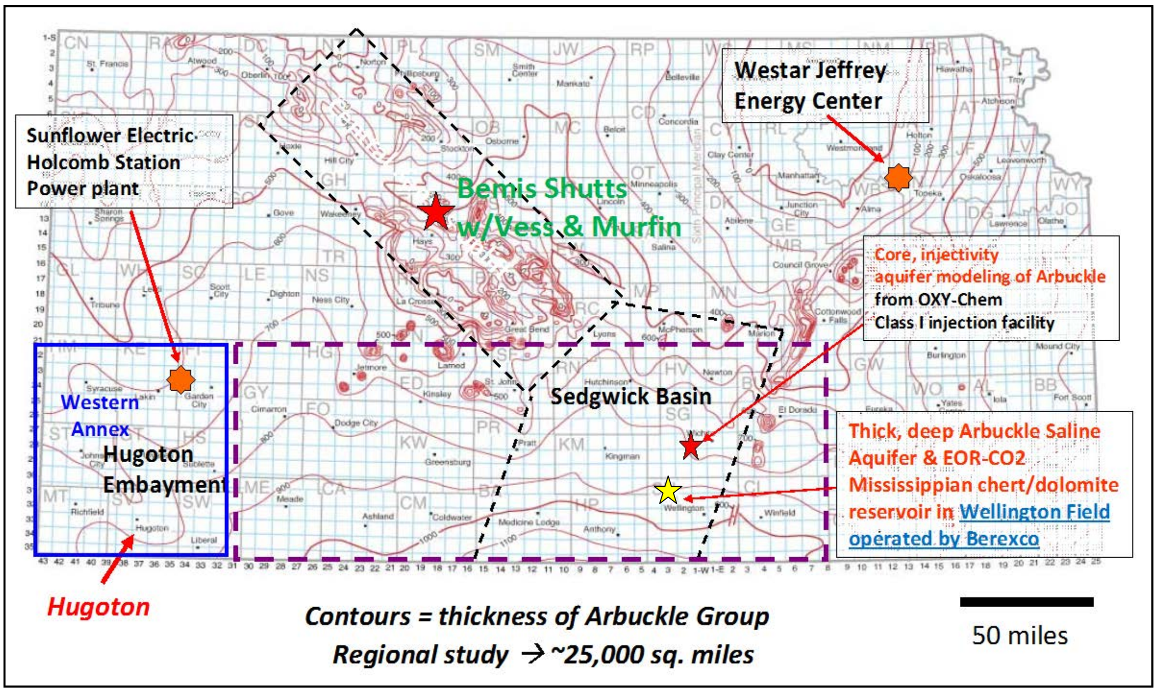


Figure 106: Contour map of the Arbuckle group in Kansas and regional study area (purple dashed polygon). Experimental wells KGS 1-32 and 1-28 located in the Sedgwick Basin are 4 miles north west of Wellington, KS (yellow star). Map courtesy of the Kansas Geologic Survey.

The Arbuckle is lower part of the Ozark Plateau Aquifer System which includes the freshwater Ogallala aquifer. Salinity values in the aquifer range from 30,000 to 120,000 ppm Arbuckle Group rocks are late Cambrian to early Ordovician in age consisting generally of porous dolomitic carbonates with interbedded shale-y aquitards. The Arbuckle is overlain by the Simpson sandstone and the Cherokee shale (absent in KGS 1-32, present in 1-28). Economically important Mississippian oil reservoir lies above them. Two wells (KGS 1-32 and 1-28) were drilled 3000 ft apart in the Wellington field, Sumner Co, SC Kansas (figure 1). The wells extend through the entire Arbuckle formation and into the Precambrian granite bedrock below (figure 2)

Hydrogeochemistry and Microbial Geochemistry

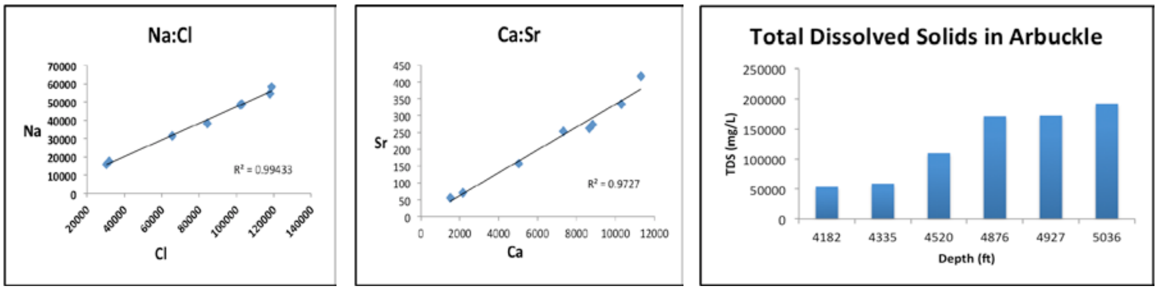
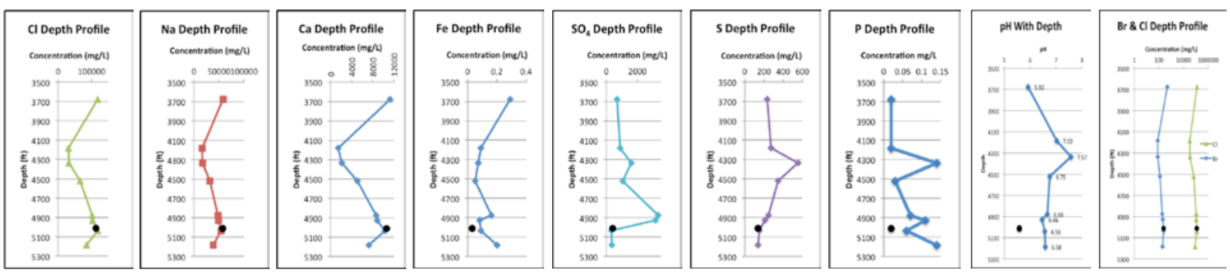


Figure 107: Elemental ratios of closely associated species. Correlation between these species is high, typical of a saline aquifer system. Linear correlation signifies Arbuckle is single, connected system. Figure 2: Total dissolved solids for the 6 DST samples within the Arbuckle increase with depth.

Figure 108: Depth profiles of major cations and anions from DST. Black dot represents swab test 1. Concentrations increase with depth throughout the Arbuckle. Peaks in SO4, P and S could be related to microbial action



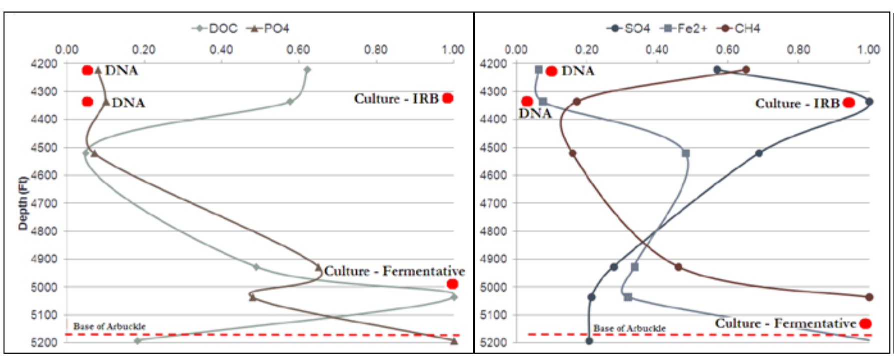


Figure 4: Evidence of microbial metabolism from aqueous geochemistry:

- DOC and PO_4 are at a minimum in profile @ 4520'
- Higher biomass may be expected at depth
- Dissimilatory iron reduction
- Sulfate reduction
- Methanogenesis (Likely CO_2 reduction)

Figure 109. See caption to right.

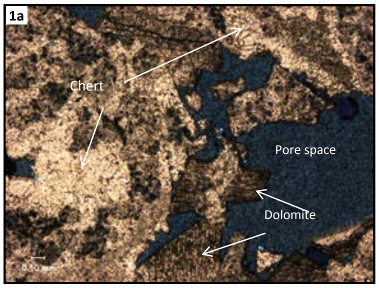
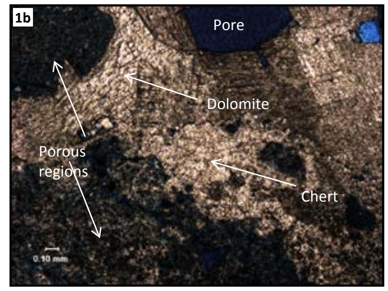


Figure 1: Thin sections of core plug 31-19 used in flow through experiment
a) 31-19 in ppl, large pore space visible surrounded by largely impermeable chert and dolomite.
b) 31-19 in ppl. Impermeable dolomite and chert next to porous cherty carbonate regions. Small scale heterogeneity is evident in this picture.



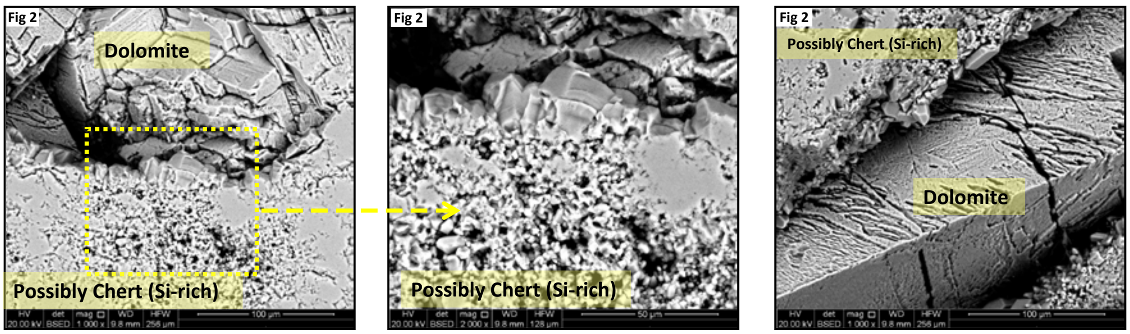


Figure 110. Formation caprock and mineralogy.

Figure 2. SEM images of Core plug 31-19 before CO2 flow. Chert/dolomite interface is important zone that could develop fractures and dissolution.

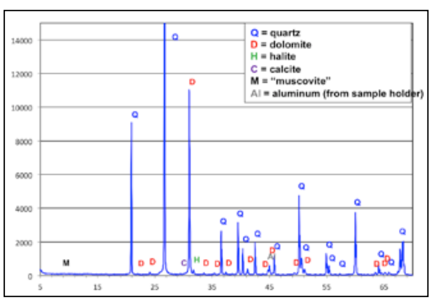


Figure 3. **Formation rock mineralogy:** XRD pattern of core plug 31-19 from the proposed injection showing a dominant mineralogy of quartz (chert) and dolomite. **Caprock mineralogy** includes quartz, dolomite, calcite, muscovite, gypsum, pyrite, ferroan clinochlore and palygorskite.

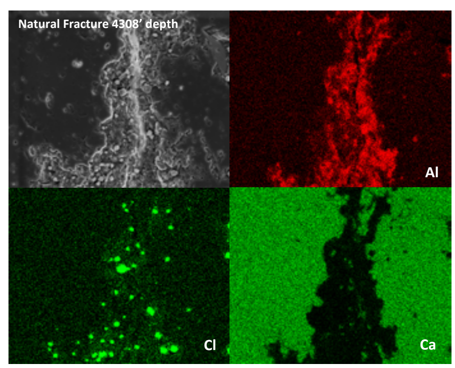
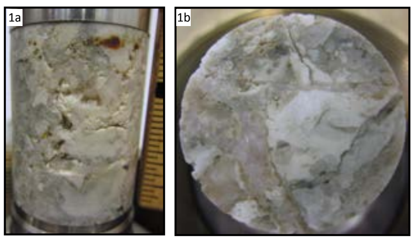
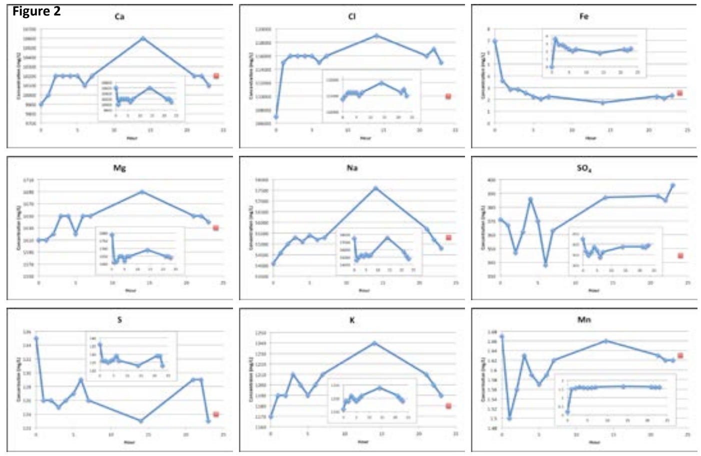


Figure 111. SEM imaging and analysis.

- National Energy Technology Laboratory, Pittsburgh, PA Core Flow Laboratory, Aug 15-30, 2011
- Core Flow System 839z instrument was used to flow brine and CO_2 through formation core
- Core from the injection zone was used (31-19, see the mineralogy section for XRD and thin section data)
- Confining pressure 2100 psi; Temperature 40°C
- Brine only was flowed at 0.2 mL/min for 13 hours to saturate core
- CO_2 was introduced with brine at 1 mL/min
- Effluent collected hourly for analyses ('hour 14' is an average of over night brine+CO_2 flow)

Figure 1: Core plug 31-19 (4977', Kmax 4.59) used in NETL flow through experiment. Core is autoclastic breccia, highly porous consisting mainly of dolomite and chert with possible secondary calcite. **a)** side view and **b)** top view of plug.





- **Figure 2:** Time series (24 hour) analysis for CO_2-brine flow-through experiment using water collected from swab test 1 from KGS 1-28 (5000-5020') and core plug number 31-19 (4977 ft).
- 'Hour zero' represents 13 hours flow of only brine at 0.2 mL/min
- CO_2 injection began at hour 1; flow rate of 1 mL/min for CO_2 and brine
- Pre-flow analysis of swab 1 show different brine composition. The inset graphs show the 'hour zero' data replaced with the pre flow swab 1 data
- The values for pre flow brine were either higher (SO_4, Mg, Ca, Na) or lower (Cl, Fe, Mn). The difference in brine compositions could be due to contamination or chemical changes prior to CO_2 introduction
- The red data point represents 'hour 24' and is separate due to an experimental uncertainty

Figure 112. Supercritcal flow experiments.

Figure 3. Medical CT scan (250um resolution) of core plug 31-19 used in supercritical flow experiment at NETL. White areas are dense material, orange is more porous and darker areas are open vugs. Apparent changes in the after image include an increase in dense material, potentially due to mineral precipitation. Supporting evidence can be found in flow effluent analyses where 15-24 hours showed decreases in Ca, Mg, Na and SO_4 which could be due to mineral precipitation.

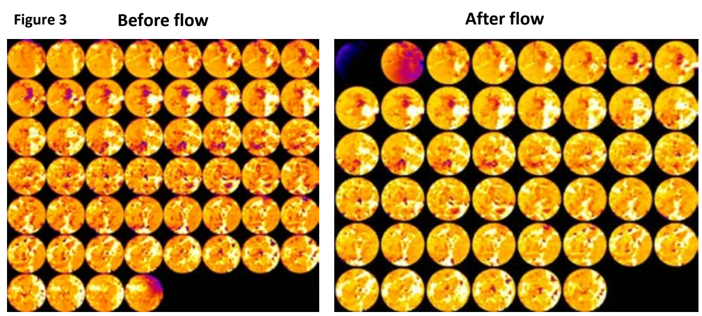


Figure 113. Medical CT scans of core plugs.

Conclusions and Future Work

The hydrogeochemical facies in the Arbuckle is majorly Na-Ca-Cl type with high salinity and showing an increasing trend with depth. Average salinity of the injection zone formation water is of the order of 116,000 ppm Cl

Major cations and anions show increasing concentrations with depth (eg. Na, Cl, SO4, Ca and Mg), indicating more dissolution of these ions

Robust microbial communities were found including methanogenic, iron reducing and sulfate reducing bacteria

High organic carbon at certain depths indicate high biomass that might affect geochemical reactions during CO_2 injection

Mineralogical description of core recovered from KGS 1-32 show extensive small and large scale heterogeneity with major mineralogy being dominated by dolomitic limestone with frequent cherty nodules and infillings. Microfractures and discontinuous argillaceous zones where marked all through the 1600 ft core. Caprock mineralogy included quartz, dolomite, pyrite, muscovite, palygorskite and gypsum

SEM images of the core plugs show clear interface between chert and dolomite where fractures could develop with dissolution reactions

Flow-through experiments of the core plug showed variable responses for major species involved over a 24 hour period. From 0-5 hours Ca, Cl, Mg, Na, SO_4 and K increased while Fe, S and K decreased. From 5-15 hours Ca, Cl, Mg, Na, SO_4, K and Mn increased while Fe and S decreased. From 15-23 hours SO_4, Fe and S increased while Ca, Cl, Na, Mg, K and Mn decreased. Further time series results might indicate effect of high SO_4 and Cl in the system make a difference in dissolution kinetics and extent of carbonate mineralization in the injection zone

Apparent increase in dense material in the core plugs after supercritical flow experiments seen in CT scans could imply mineral precipitation; This conclusion is also supported by decreases in Ca, Mg, Na, Cl, and SO_4 measured in the last 10 hours of the experiment

References:

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Lu, P., Fu, Q., Seyfried, W., Hereford, A., Zhu, C. 2010. Navajo Sandstone-brine-CO2 interaction: implications for geological carbon sequestration. Environmental Earth Science. 62:101-118.

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Subtask 6.3. Process & interpret 2D shear
Subtask 6.4. Revise 3D seimic interpretation
Subtask 6.5. Update geomodel - Arbuckle & Miss

This work is critical to building the new geomodel for the Mississippian oil reservoir and Arbuckle saline aquifer at Wellington Field. The 2-D shear wave seismic lines were acquired in August of 2011 and results have been integrated with the 3D multicomponent seismic survey at Wellington. The result of the processing and interpretation are expected in February 2012. The basemap of the 2D shear wave lines is shown in Figure 114. Prestack time and depth migrated sections are shown in Figures 115 and 116, coincident with the location of the 2D lines, but extracted from the 3D survey.

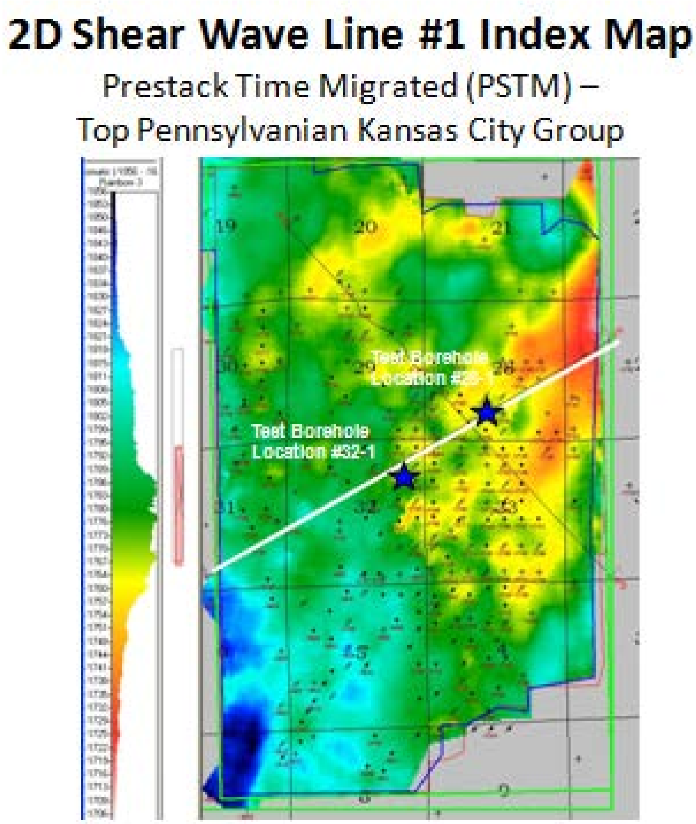

Figure 114. Two oblique 3D shear wave seismic surveys were acquired in August 2011 as shown on this map.

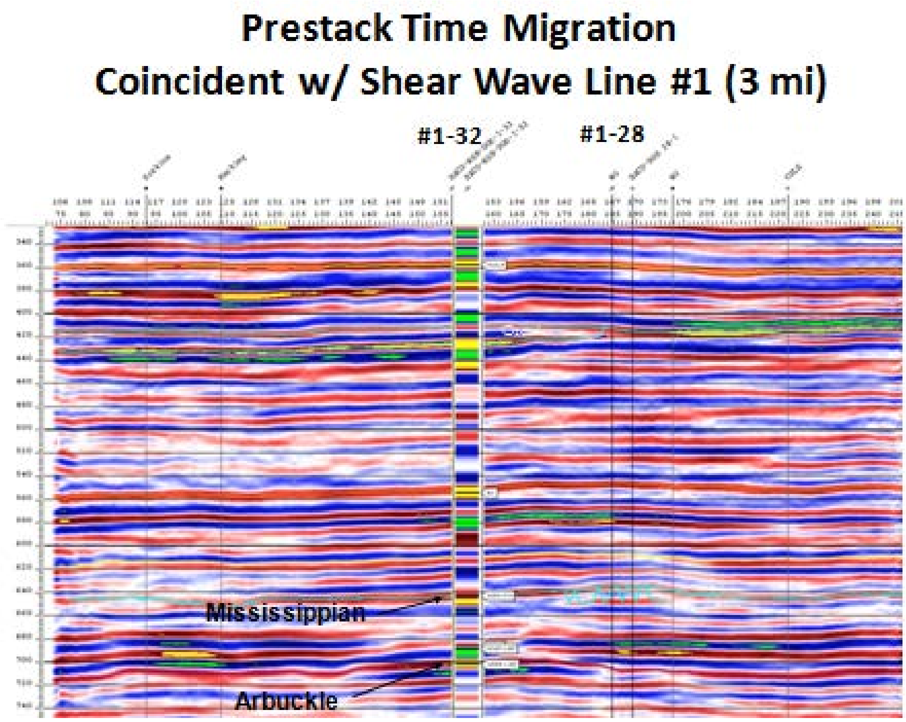

Figure 115. Prestack time section with locations of two wells drilled for this project. Synthetic from #1-32 is shown.

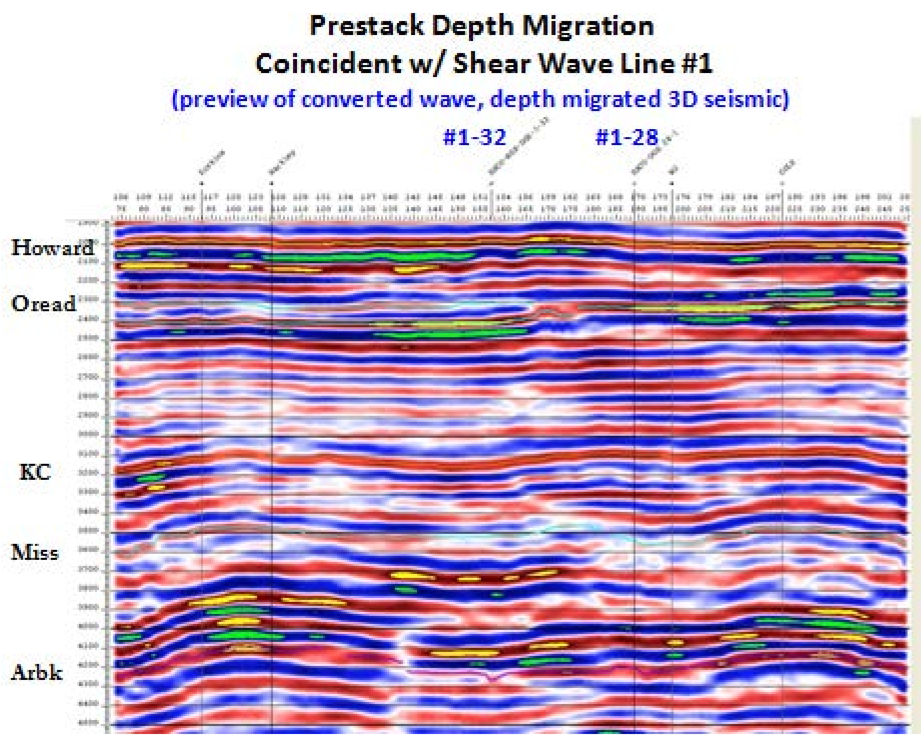

Figure 116. Prestack depth migrated section along shear wave line #1. Locations of #1-32 and #1-28 wells are shown. Record quality is excellent. Arbuckle shows discontinuity west of #1-32 while overlying units are laterally very continuous.

Remaining Seismic Work at Wellington Field

Activity-Entity / Timeline	Nov-11	Dec-11	Jan-12
Wellington Area			
PreStack Depth Migration (PSDM) -FarifieldNodal	X		
PSDM Volumetric Curvature Processing - Geo-Texture			
PSDM Volumetric Curvature Interpretation - Nissen			
PSDM Interpretation -HS Geo		X	
Impedance Inversion - PSDM input-HS Geo		X	
Elastic Inversion - Pre-stack Time Migration (PSTM) Input-HS Geo		X	
Spectral Decomposition (Frequency Domain Processing)-HS Geo			X
2D Shear Wave Processing-FairfieldNodal	X		
2D Shear Wave Interpretation-HS Geo		X	
Converted Wave Processing-FairfieldNodal	X	X	
Converted Wave Interpretation- HS Geo		X	

Figure 117 shows chart of remaining seismic work at Wellington Field.

Presentations

Several presentations made during the 9th quarter including testimony on project for CO2 injection at Wellington Field at hearing on pore space ownership at joint session on energy and the environment in Kansas legislature.

Presentation made at annual project review meeting in Pittsburgh in November and at American Geophysical Union Annual Fall Meeting in San Francisco in December 2011.

Key Findings

1. Faulting on regional scale can be delimited and validated with close subsurface control, 3D seismic, and analysis of potential fields data.
2. Ten areas in the regional study have been indentified for prospective carbon sequestration sites. They are based on finding closed structures with deep saline aquifer below and oil field overlying the thick saline aquifer.
3. Some of the selected sites are faulted, but faulting appears to be limited to the aquifer itself and does not extend to shallower Pennsylvanian and Permian strata.
4. Arbuckle stratigraphy at the regional sites selected in southern Kansas are quite similar – thick, variable porosity.
5. Deeper stratigraphy beneath the Chester and Morrow oil fields being studied in SW Kansas include thick Arbuckle with modest thinning to the north. Porous Arbuckle is

developed lower in the section while upper units of the Arbuckle can be shaly, particularly to the south in Cutter and Shuck fields

6. Deep seated faults are present in the SW Kansas area near and alongside fields that are being studies. It also appears karst is developed from dissolution of evaporites of the Spergen Mississippian and possibly carbonate dissolution in the upper Arbuckle. The karst is known to affect the locations of some of the incised valleys including Pleasant Prairie and Eubank and Shuck. No karst is noted at Cutter with the current data available. It is possible that faulting coincides with the incised valley in Pleasant Prairie using the new seismic interpretation.
7. Cutter field is located off to the side of the sharply incised valley system, but closure along the field at the Mississippian or Arbuckle is minor in contrast with Pleasant Prairie and Eubank fields.
8. Newly processed seismic and new interpretations of the Wellington seismic data should provide exemplary information for the geomodel.
9. Core data is being released and incorporated into calibrating the well logs.
10. Geochemical and sample analyses continues and should provide invaluable data for refining simulations of CO_2 injection.

Plans

1. Build new geomodels with latest data and work toward simulations in SW fields and Wellington.
2. Run another set of swab samples in Wellington #1-32.
3. Start quantitative analysis of LAS files on regional level and incorporate analysis into Petrel for geocellular geomodel development.

Cost Plan/Status

COST PLAN/STATUS

	Year 1 Starts: 12/8/09	Ends: 2/7/11				BP2 Starts 2/8/11	Ends 8/7/12	
Baseline Reporting Quarter	12/8/09-12/31/09 Q1	1/1/10-3/31/10 Q2	4/1/10-6/30/10 Q3	7/1/10-9/30/10 Q4	10/1 - 12/31/10 Q5	1/1/11 - 3/31/11 Q6	4/1/11 - 6/30/11 Q7	7/1/11-9/30/11 Q8
Baseline Cost Plan (from SF-424A)	(from 424A, Sec. D)							
Federal Share	$1,007,622.75	$1,007,622.75	$1,007,622.75	$1,007,622.75	$0.00	$0.00	$0.00	$1,169,543.00
Non-Federal Share	$277,260.75	$277,260.75	$277,260.75	$277,260.75	$0.00	$0.00	$0.00	$303,182.75
Total Planned (Federal and Non-Federal)	$1,284,883.50	$1,284,883.50	$1,284,883.50	$1,284,883.50	$0.00	$0.00	$0.00	$1,472,725.75
Cumulative Baseline Cost	$1,284,883.50	$2,569,767.00	$3,854,650.50	$5,139,534.00	$5,139,534.00	$5,139,534.00	$5,139,534.00	$6,612,259.75
Actual Incurred Costs								
Federal Share	$4,019.93	$84,603.97	$494,428.37	$111,405.52	$238,675.97	$1,902,936.55	$625,853.17	$275,754.50
Non-Federal Share	$0.00	$0.00	$0.00	$84,564.82	$251,354.30	$20,887.31	$6,043.03	$552.19
Total Incurred Costs-Quarterly (Federal and Non-Federal)	$4,019.93	$84,603.97	$494,428.37	$195,970.34	$490,030.27	$1,923,823.86	$631,896.20	$276,306.69
Cumulative Incurred Costs	$4,019.93	$88,623.90	$583,052.27	$779,022.61	$1,269,052.88	$3,192,876.74	$3,824,772.94	$4,101,079.63
Variance								
Federal Share	$1,003,602.82	$923,018.78	$513,194.38	$896,217.23	-$238,675.97	-$1,902,936.55	-$625,853.17	$893,788.50
Non-Federal Share	$277,260.75	$277,260.75	$277,260.75	$192,695.93	-$251,354.30	-$20,887.31	-$6,043.03	$302,630.56
Total Variance-Quarterly Federal and Non-Federal)	$1,280,863.57	$1,200,279.53	$790,455.13	$1,088,913.16	-$490,030.27	-$1,923,823.86	-$631,896.20	$1,196,419.06
Cumulative Variance	**$1,280,863.57**	**$2,481,143.10**	**$3,271,598.23**	**$4,360,511.39**	**$3,870,481.12**	**$1,946,657.26**	**$1,314,761.06**	**$2,511,180.12**