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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 CO2 Sequestration in Saline Aquifer and Depleted Oil Reservoir To Evaluate Regional CO2 Sequestration Potential of Ozark Plateau Aquifer System, South-Central Kansas"

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

**Fifteenth Quarter Progress Report**

**Date of Report: 8-6-13**

**Period Covered by the Report: April 1, 2013 through June 30, 2013**

**Contributors to this Report: John Doveton, Mina Fazelalavi, Paul Gerlach, Tom Hansen, Robert Goldstein, Dennis Hedke, Eugene Holubnayak, Jason Rush, Bradley King, Larry Nicholson, Jennifer Raney, Ray Sorenson, John Victorine, Lynn Watney, John Youle, Dana Wreath**

## EXECUTIVE SUMMARY

The project “Modeling CO2 Sequestration in Saline Aquifer and Depleted Oil Reservoir to Evaluate Regional CO2 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 CO2-EOR potential in the Mississippian tripolitic chert reservoir and CO2 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 CO2 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 mi2 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

| 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 | 2/7/2014 | | 70% |
| 2.0 Characterize the OPAS (Ozark Plateau Aquifer System) | 1/1/2010 | 01/01/10 | 9/30/2013 | | 85% |
| 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 | 10/31/12 | 100% |
| 7.0 Evaluate CO2 Sequestration Potential in Arbuckle Group Saline Aquifer | 8/1/2011 | 08/01/11 | 12/31/2011 | 10/31/12 | 100% |
| 8.0 Evaluate CO2 Sequestration Potential in Depleted Wellington field | 10/15/2011 | 10/15/11 | 7/30/2013 | +++ | 87% |
| 9.0 Characterize leakage pathways - risk assessment area | 1/1/2010 | 01/01/10 | 6/30/2012 | 10/31/12 | 100% |
| 10.0 Risk Assessment related to CO2-EOR and CO2 Sequestration in saline aquifer | 6/1/2012 | 06/01/12 | 9/30/2013 | ** | 90% |
| 11.0 Produced water and wellbore management plans - Risk assessment area | 1/1/2012 | 01/01/12 | 7/30/2013 | | 95% |
| 12.0 Regional CO2 sequestration potential in OPAS | 8/1/2012 | | 9/30/2013 | | 70% |
| 13.0 Regional source sink relationship | 1/1/2010 | 1/1//2010 | 9/30/2013 | | 85% |
| 14.0 Technology Transfer | 1/1/2010 | 01/01/10 | 2/7/1014 | | 85% |

| Milestone | Planned Completion Date | Actual Completion Date | Validation |
|---|---|---|---|
| HQ Milestone: Kick-off Meeting Held | 3/31/2010 | 03/31/10 | Completed |
| 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 |
| HQ Milestone: Establish database links to NATCARB and Regional Partnerships | 12/31/2010 | 12/31/10 | Completed |
| HQ Milestone: Annual Review Meeting attended | 3/31/2011 | 10/05/10 | Completed |
| HQ Milestone: 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 | 09/30/11 | Completed |
| HQ Milestone: Yearly Review Meeting of all recipients; opportunities for information exchange and collaboration | 12/31/2011 | 11/15/11 | Attended meeting |
| HQ Milestone: Complete at least one major field activity such as well drilling, 2-D or 3-D seismic survey, or well logging | 3/31/2012 | 08/15/12 | Completed 3D seismic Cutter compete |
| HQ Milestone: Complete at least one major field activity such as well drilling, 2-D or 3-D seismic survey, or well logging | 6/30/2012 | 10/09/12 | Completed cutter well reach TD |
| HQ Milestone: Semi-annual report (i.e. Quarterly Report ending June 30, 2012) on project activities summarizing major milestones and costs for the project 9/30/2012 | 9/30/2012 | 09/30/12 | Completed |
| FOA Milestone: Updated Project Management Plan | 3/31/2010 | 03/31/10 | |
| FOA Milestone: Submit Site Characterization Plan | 5/28/2010 | | Completed |
| 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 |
| FOA Milestone: Notification to Project Manager that actvities on the lessons learned document on site characterization have been initiated | 7/15/2012 | | 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, email summary |
| KGS Milestone 1.1: Hire geology consultants for OPAS modeling | 3/31/2010 | 03/31/10 | 92% Completed* |
| KGS Milestone 1.2: Acquire/analyze seismic, geologic and engineering data - Wellington field | 6/30/2010 | 06/30/10 | Completed, quarterly rpt |
| KGS Milestone 1.3: Develop initial geomodel for Wellington field | 9/30/2010 | 09/30/10 | Completed, email summary |
| 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 | 10/31/12 | completed |
| KGS Milestone 2.4: Evaluate CO2 Sequestration Potential of Arbuckle Group Saline Aquifer - Wellington field | 12/31/2011 | 10/31/12 | Completed |
| KGS Milestone 3.1: CO2 sequestration & EOR potential - Wellington field | 3/31/2012 | | 85% complete'++ |
| KGS Milestone 3.2: Characterize leakage pathways - Risk assessment area | 6/30/2012 | 10/31/12 | Completed |
| KGS Milestone 3.3: Risk assessment related to CO2-EOR and CO2-sequestration | 9/30/2012 | | 90% complete++++ |
| KGS Milestone 3.4: Regional CO2 Sequestration Potential in OPAS - 17 Counties | 12/7/2012 | | 75% complete+++++ |

## COMPLETED ACTIVITIES

**Task 7.0 Evaluate CO2 Sequestration Potential in Arbuckle Group Saline Aquifer in Wellington Field.**

**Task 9.0 Characterize leakage pathways - risk assessment area.**

## ONGOING ACTIVITIES - REGIONAL STUDY INCLUDING SOUTHWEST KANSAS

**Subtask 4.14. Examine diagenetic history of fracture fill**

Results are coming available regarding the diagenetic history of the Arbuckle Group based on petrographic and fluid inclusion analysis of the Wellington KGS #1-32 and a core from the uppermost Arbuckle at the OxyChem disposal facility located approximately 20 miles north of Wellington Field (Figure 1). As noted in the statement of work, fractures, where present, shall be analyzed for oil staining and cementation. Isotope analyses shall be carried out on cap rocks and compared with that from Mississippian and Arbuckle Group aquifers to understand if seals had exposure to post-depositional fluids and if the cementation can prevent CO2 leakage. Petrographic and fluid-inclusion studies shall determine whether diagenetic minerals predate oil migration to evaluate seal competency.

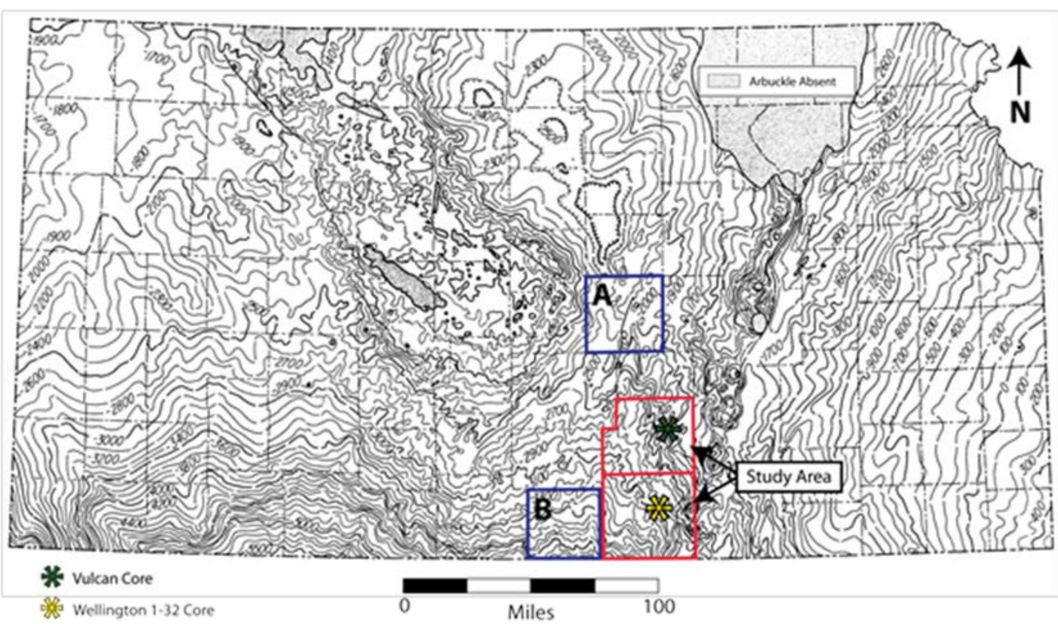



**Figure 1. Location of Vulcan and Wellington KGS #1-32 cores used in this diagenetic study by B. King. Map is the top of the Arbuckle Grop from Merriam (1963).**

The study of the diagenesis is the focus of the M.S. Thesis by Bradley King, who is completing his study at the Department of Geology at Kansas University. His work is in final review and the results described here are a portion of that work that will be defended later in the summer 2013.

The paragenetic chart defining the relative timing of the diagenetic event (Figure 2) is separated into an early and a late stage. Shortly after deposition, the Arbuckle carbonate was dolomitized, occurring on a regional scale in the northern Midcontinent. Early anhydrite cement is noted and may be related to the observation of beds of breccias are interpreted as the evaporate dissolution. These breccia beds cap some of the peritidal successions that are particularly abundant in the lower half the Arbuckle (lower Jefferson City-Cotter and Gasconade formations). Their dissolution could be the source of an early release of calcium sulfate released during breccia development.

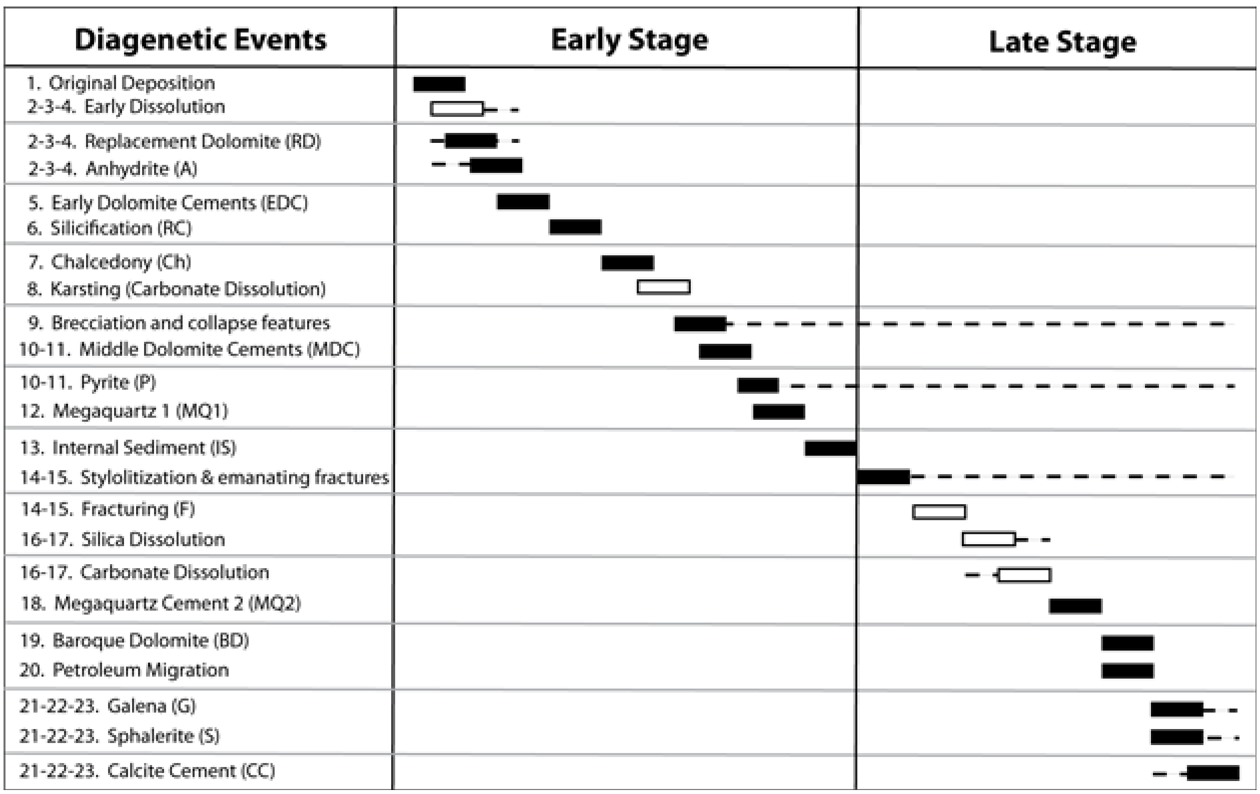



**Figure 2. Paragenesis of the Arbuckle Group with events separated into early and late stages. Porosity evolution is illustrated with solid boxes indicating a decrease in porosity and empty boxes indicating an increase in porosity. Dashed lines indicate a level of uncertainty regarding the duration of some events.**

Karst resulting from carbonate dissolution is a later event that is still considered early and prior to the main event of fracturing and dissolution that immediately preceded an event of silica and carbonate dissolution. The fracturing and dissolution are considered an early Late Stage development (Figure 2). Higher temperature baroque dolomite and petroleum migration followed fracturing in conjunction with basinal fluids moving out of the deeper Anadarko Basin lying to the south. The latest cement is calcite that may be as young as Laramide (early Tertiary) and may reflect the pulse of tectonism that corresponded with mountain building to the west (personal comm. Brad King). The calcite cement occurs in both the lower and upper Arbuckle and has also been found in the overlying Mississippian strata. Suggesting that fluid was migrating across the strata in contrast to other evidence that the current hydrostratigraphic units in the lower and upper Arbuckle are not involved in cross flow. Lateral stresses associated with distant tectonic events produce both compressional and extensional structures that could lead to opening of fractures during these tectonic episodes. The stratigraphically extended cementation event during the Laramide was not associated with notable fracturing at the microscopic scale, but it is inferred by King that vertical communication was at least established for a time during the Laramide leading to the vertical distribution of the late calcite cement. It is possible that the net effect of the extensive calcite cementation was to seal vertical pathways, an inference based on current evidence for a highly stratified system of brines in the Arbuckle and overlying Mississippian.

Figures 3 through 8 illustrate additional aspect of the M.S. thesis research being completed by Brad King.

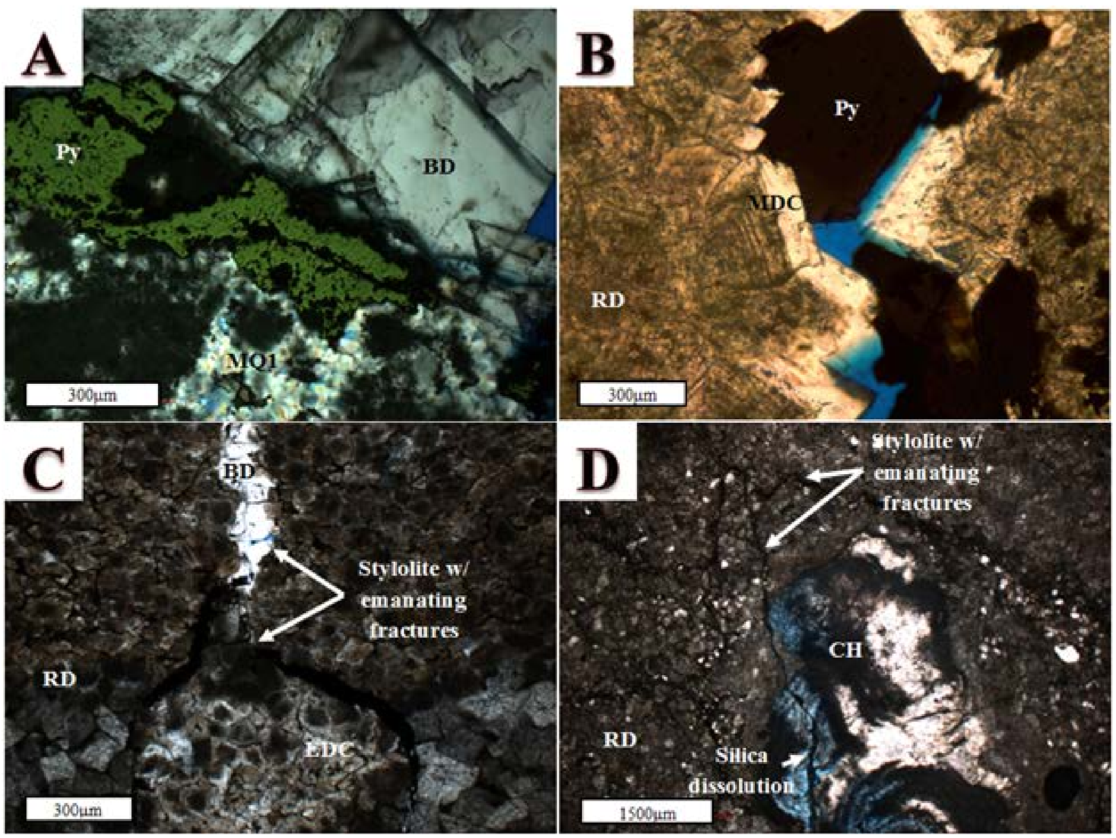



**Figure 3. (A) Combination of bright-field and crossed-polarized light photomicrograph of pyrite (Py) after megaquartz 1 (MQ1), followed by precipitation of baroque dolomite (BD) (sample 4977.7 from Wellington 1-32); (B) Transmitted light photomicrograph of vug likely associated with event 8 dissolution, lined with middle dolomite cements (MDC) and then**

**pyrite (Py) (sample 5070.6 from Wellington 1-32); (C) Transmitted light photomicrograph of replacement dolomite (RD) and early dolomite cements (EDC) truncated by stylolite and emanating fractures (event 14-15), fractures are subsequently filled with baroque dolomite (BD) (sample 4460.7 from Wellington 1-32); (D) Transmitted light photomicrograph of stylolite cross-cutting dolomitized (RD) material, emanating fracture cross-cuts chalcedony (Ch) with silica dissolution (event 16-17) occurring along fracture (sample 5070.6 from Wellington 1-32) (from King, M.S. Thesis).**

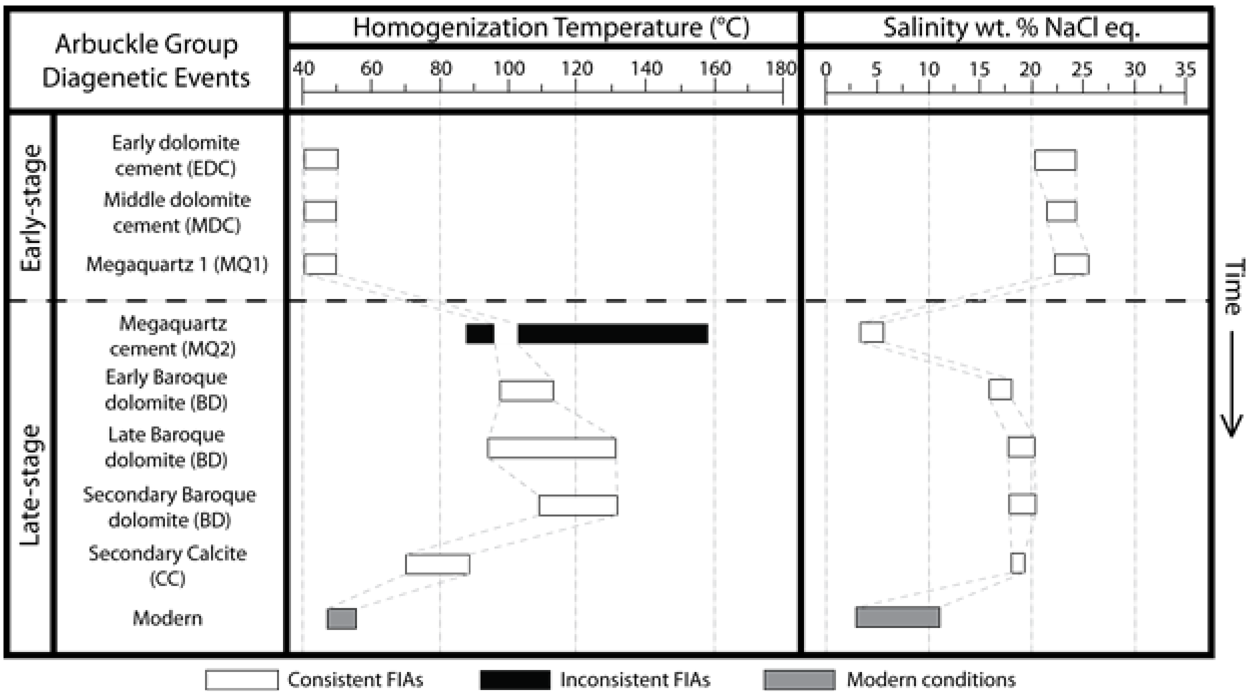



**Figure 4. Fluid evolution illustration that uses fluid inclusion data (Th and Tmice) to display changes in reservoir fluid temperature and salinity from early stage cements, to late stage cements, to modern time. Values are fairly consistent during early-stage diagenesis, with temperatures likely representing reservoir temperature due to burial, geothermal gradient, and Ordovician surface temperature. The precipitation of megaquartz cement 2 (MQ2) signifies a drastic decrease in salinity and increase in temperature, possibly linked to migration of high-temperature connate fluids from the Anadarko Basin. During baroque dolomite (BD) precipitation, salinity increases while temperatures continue to climb; this is thought to represent continued sourcing of hydrothermal fluids from the Anadarko Basin after Permian reflux. Secondary fluid inclusions in calcite cement (CC) record a decline in temperature and salinity at some point after precipitation of calcite. Modern values yield temperatures that are significantly lower than what was seen by the reservoir during late-stage diagenesis, but still slightly higher than early-stage temperatures, likely due to increased burial since the time of early-stage diagenesis. Modern salinity values fall between the range observed in megaquartz cement 2 and baroque dolomite, suggesting a continued influence of evaporites along the current fluid migration pathway (from King, M.S. Thesis).**

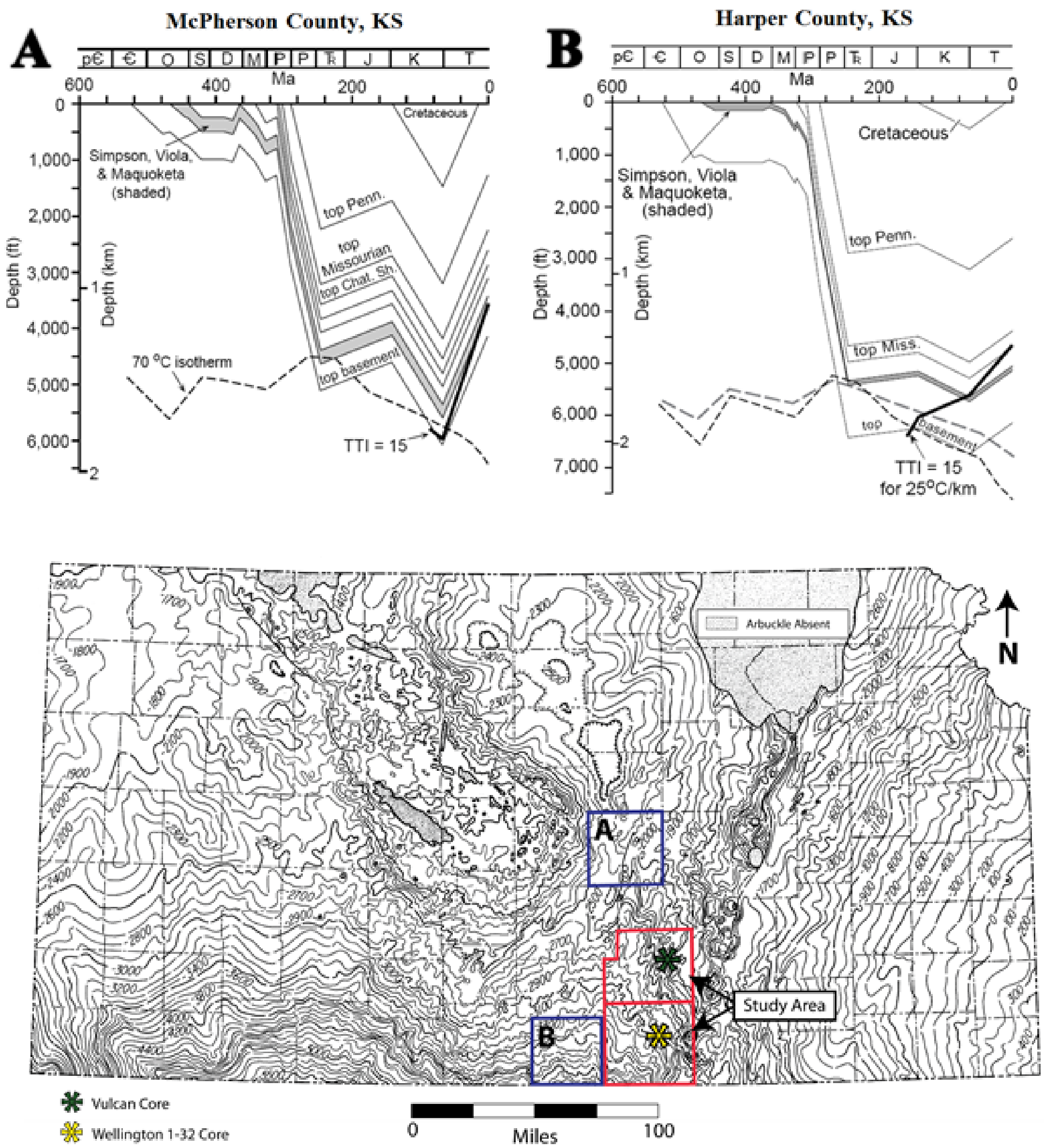



**Figure 5. Burial history models for Phanerozoic strata in McPherson and Harper Counties in Kansas (north and west of study area). Assuming the thickness of Cretaceous strata and geothermal gradients to be 1500ft (460m) and 30°C/km for McPherson County and 500ft (150m) and 25°C/km for Harper County, a 70°C geotherm was also calculated for both models (modified from Newell 1997). When considering Cambrian-Ordovician strata, the McPherson County model suggests a maximum temperature of approximately 74°C and the Harper County suggests a maximum temperature of approximately 73°C, both achieved early in Permian time. The bottom image is a structural map of the Arbuckle Group with county and study area locations; contour interval is 100ft (modified from Franseen et al. 1994) (from King, M.S. Thesis).**

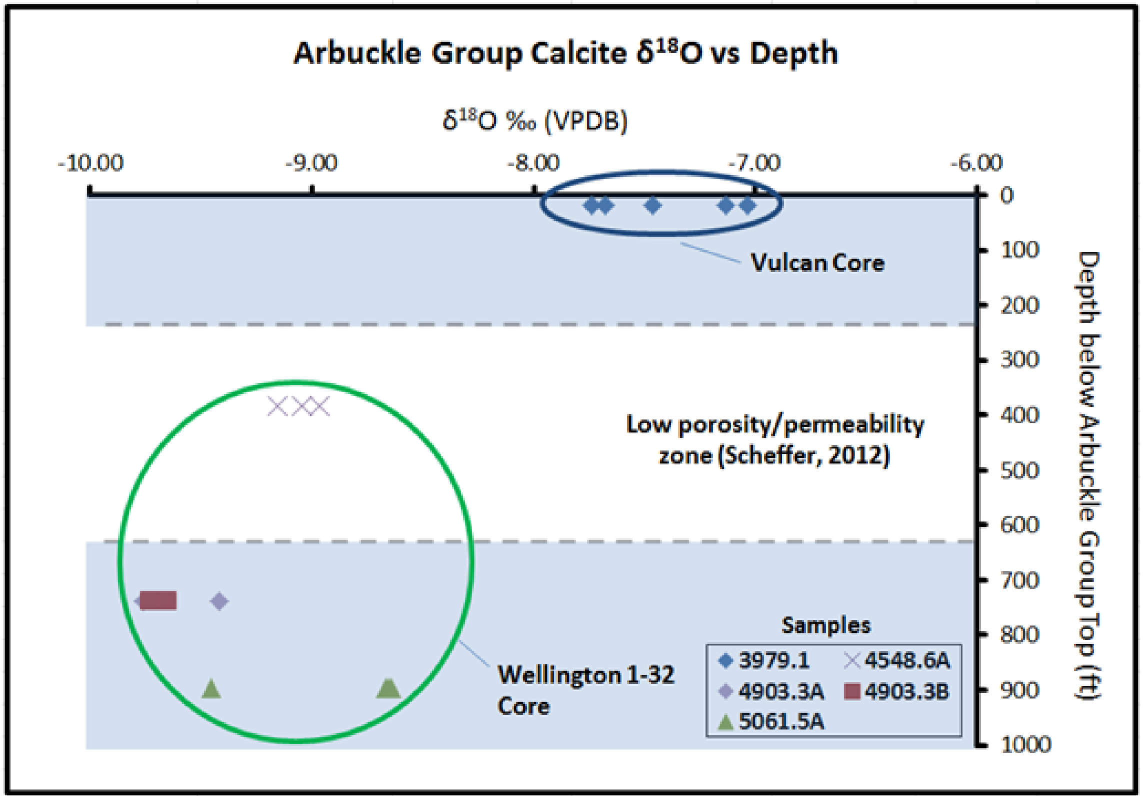



**Figure 6. Cross-plot of δ18O values and depth of samples. The only noticeable trend remains the more depleted nature of the Wellington core. Also, the δ18O values do not appear to be influenced by preferential fluid flow or a density gradient, as appeared to be the case with baroque dolomite; this may provide support for the influence of a fracture-controlled fluid flow system affecting the unit at the time of calcite precipitation. Scheffer's (2012) low porosity/permeability zone does not appear to affect the isotopic values of calcite throughout the Arbuckle Group. Blue boxes represent zone of higher porosity/permeability in the upper and lower Arbuckle Group (Scheffer, 2012) (from King, M.S. Thesis).**

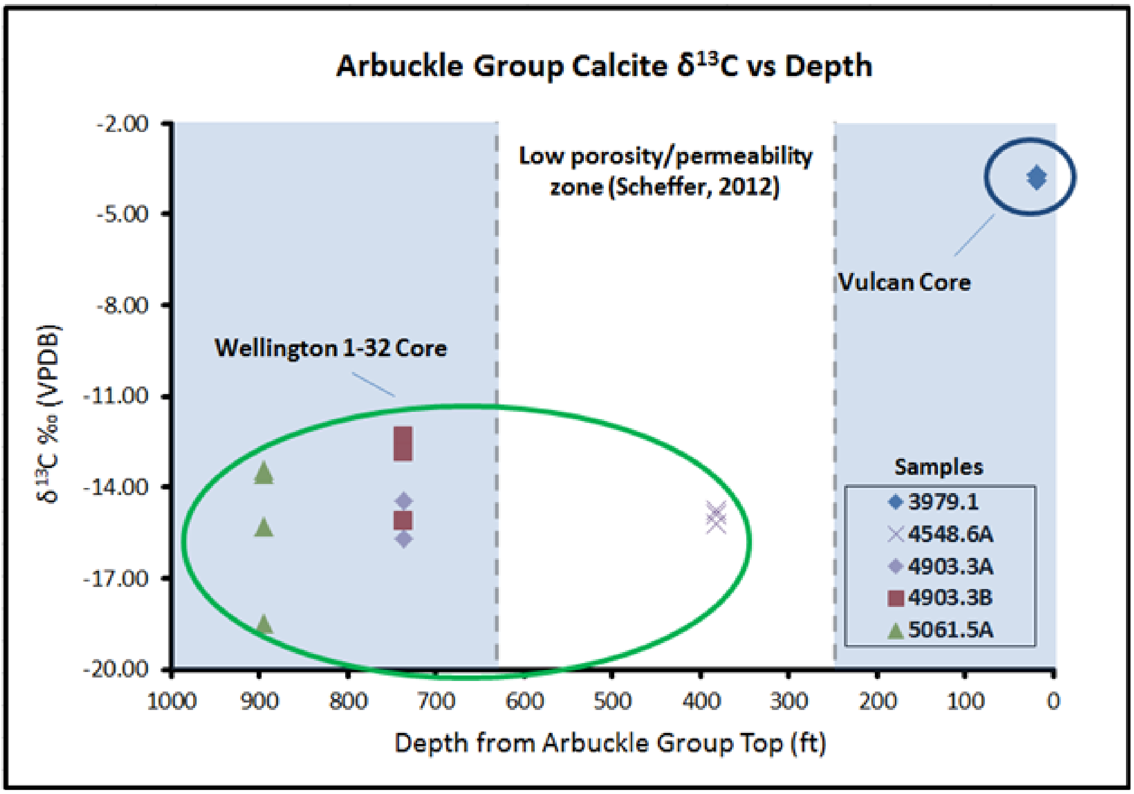



**Figure 7. Cross-plot of δ13C values and depth of samples. The only noticeable trend is the more depleted nature of the Wellington core samples. As with δ18O data, δ13C data does not appear to correlate with the modern zone of low porosity/permeability proposed by Scheffer (2012). Blue boxes represent zones of higher porosity/permeability in the upper and lower Arbuckle Group (Scheffer, 2012) (from King, M.S. Thesis).**

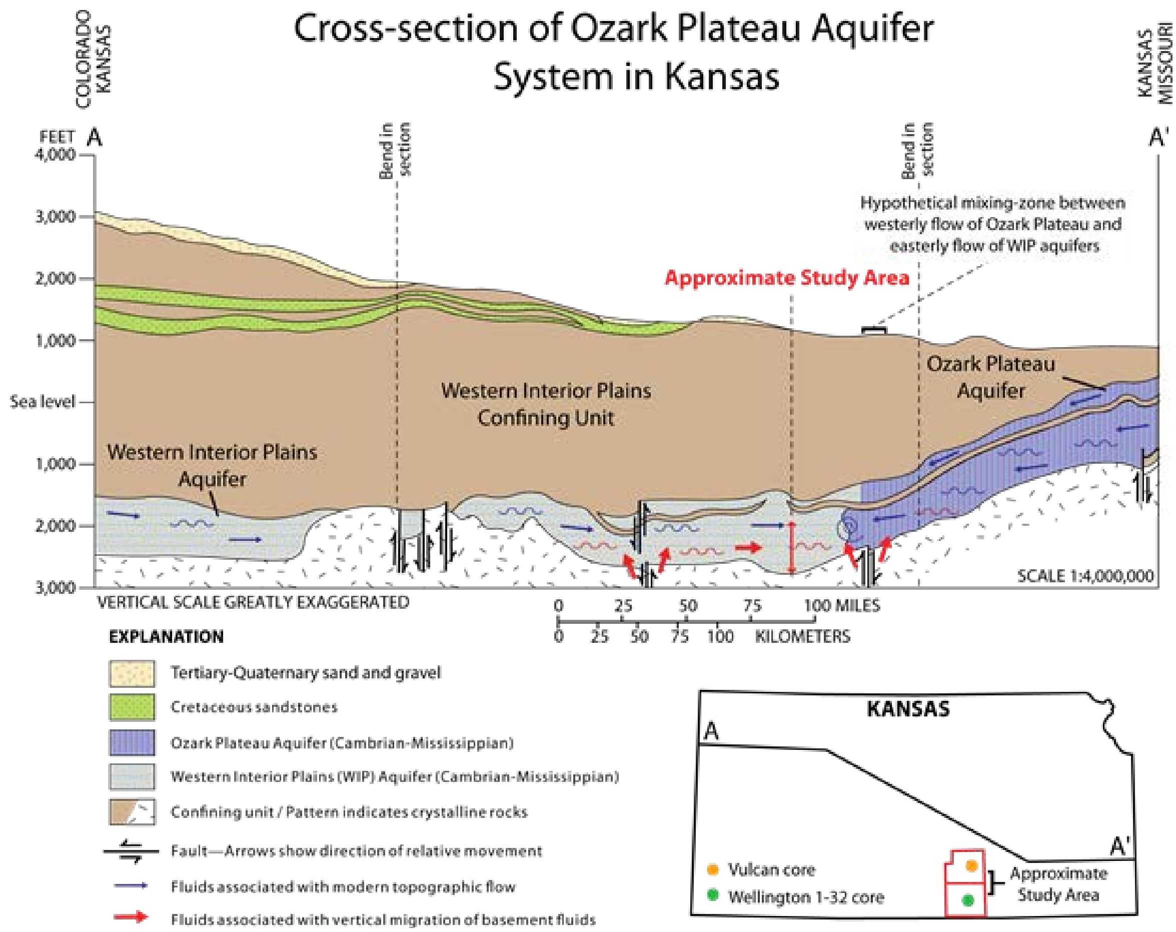



**Figure 8. Cross-section of the Ozark Plateau aquifer system (OPAS), the Cambrian-Ordovician Arbuckle Group is the basal component of this system (Carr et al., 2005). Illustration depicts easterly flow associated with the OPAS throughout the majority of Kansas, as well as the potential mixing-zone between the WIP aquifer and westerly flow from the Ozark Plateau aquifer in the eastern part of the state (Carr et al., 2005). Following strike-slip faulting (hypothesized as occurring during Ouachita or Laramide tectonic activity), and extension of faults into overlying strata, high-temperature, highly radiogenic Reagan sandstone or basement fluids migrate along fractures into overlying strata (illustrated by red symbols). The proximity of specific areas to fractures may have resulted in enhanced fluid flow in areas directly affected by fracturing (Wellington 1-32 core in the case of this study), while areas located further from fractures would display lower temperatures and more rock-dominated isotopic values (Vulcan core in the case of this study). The injected fluids precipitated high-temperature, highly radiogenic calcite cement (CC) in the Arbuckle Group. Fluid flow associated with tectonic activity could mark the transition of an advective system with fluids sourced from the Anadarko Basin, to a fracture-controlled fluid flow system with fluids sourced from the Reagan sandstone or basement rock. Image is modified from Miller and Appel (1997) (from King, M.S. Thesis).**

## Task 12.0 Regional CO2 sequestration potential in OPAS

As noted in the statement of project objectives the Recipient shall integrate geologic, seismic, gravity/magnetic, and remote sensing analyses to develop a regional geomodel for the Arbuckle Group saline aquifer including major faults/fracture zones, stratigraphically correlated horizons, and flow-units.

Revisions and refinements of the project's interactive mapper have been continued by the efforts of the DOE-CO2 project team. The mapper incorporates the entire set of structure and isopach maps and permits access to well data and cross section of the well log and georeports.

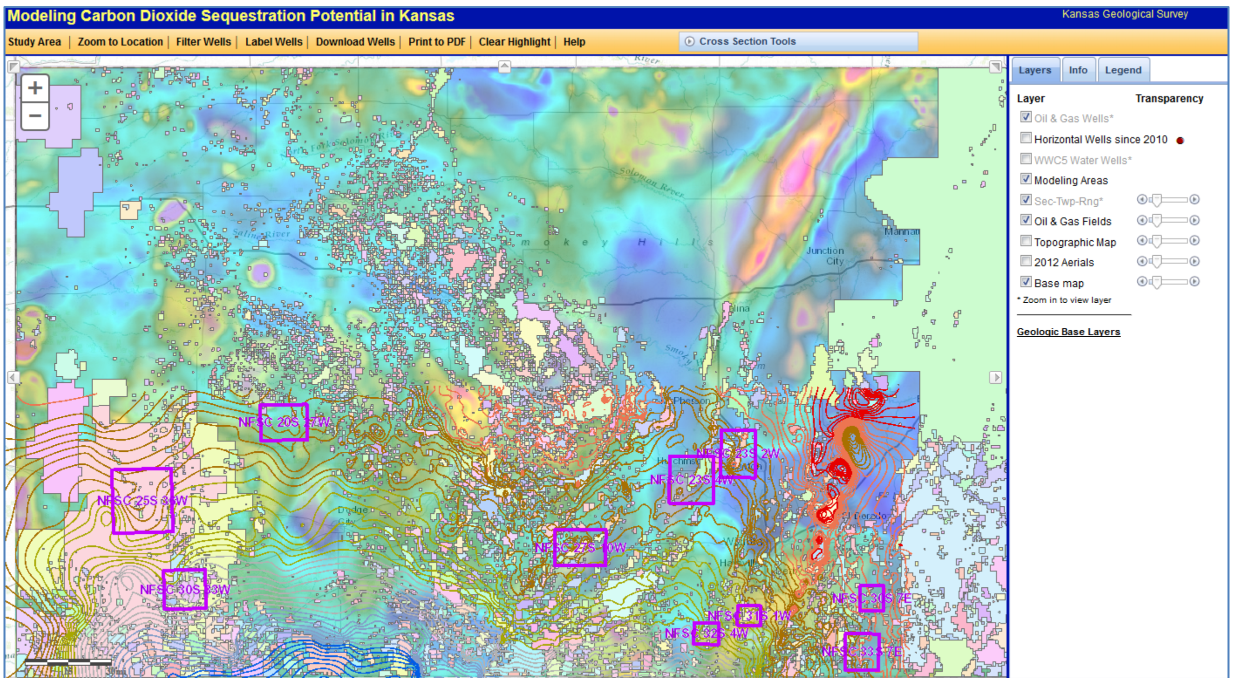



**Figure 8. Combined total magnetic field reduced to pole (910 meters) and residual Bouguer gravity data with the structure on top of the Arbuckle Group in study area in southern Kansas. Oil and gas fields are also shown and rectangles outlining the compartments that are the current focus of geomodeling and coarse grid simulation being used to estimate regional CO2 sequestration potential.**

### Subtask 12.2. Coarse grid simulation over select OPAS areas to estimate regional CO2 sequestration potential.

The statement of work notes that coarse-grid reservoir simulation studies with CMG-GEM will be conducted on select major Arbuckle compartments, where commercial volumes of CO2 may be sequestered without the free phase CO2 extending beyond the confines of the structure. The CO2 storage will be accomplished by using lithofacies-based petrophysical properties. Important considerations include prevention of the CO2 plume from breaching cap rock and reaching nearby fault and fracture networks. Simultaneous brine injection from upper zones shall be simulated to test for maximum CO2 sequestration potential.

An extensive effort has gone into calibration of the modern logs obtained by the recent drilling and coring in Wellington Field this work is extending to the new well that was also cored and logged at Cutter field. Critical parameters needed to evaluate CO2 storage include porosity, permeability, and capillary pressure and relative permeability for supercritical CO2, water, and rock. The results of the calibration sites are to be extended to regionally mapped area and specifically to the 10 modeling sites so that the geomodel can accurately represent the flow and storage of the injected CO2.

As has been previously shown that the relationship between porosity and permeability in the Arbuckle is not well defined on a large scale, but within the constraints of stratigraphy and lithofacies, patterns emerge that has shown considerable promise in being able to sufficiently populate the geomodels used to access CO2 storage so that accurate estimations of CO2 capacity can be accomplished.

The permeability predicted by the MRI Coates equation was calibrated to the core permeabilities (Figure 9). By and large, the general correlation is good. The MRI log also provides data where core was missing such as the high permeability intervals that could not be cored to jamming of the core barrel.

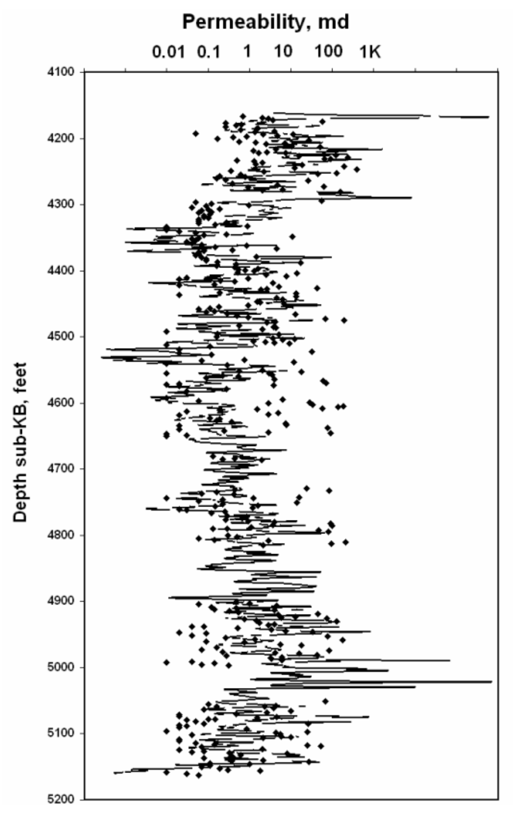



**Figure 9. Wellington KGS #1-32 Arbuckle interval showing the permeability predicted by the MRI Coates equation calibrated to the core permeabilities. Prepared by J. Doveton.**

A new method being developed by Fazelalavi et al. (in press) uses core analyses to define a flow zone indicator (FZI). The FZI was grouped into micro, meso, and mega pores ranging from <2.02 for micro, between 2.02 and 10.97 for meso, and from 10.97 to 150 for mega pores (Figure 10). There appear to be three distinct divisions plotting frequency versus permeability arranged by FZI.

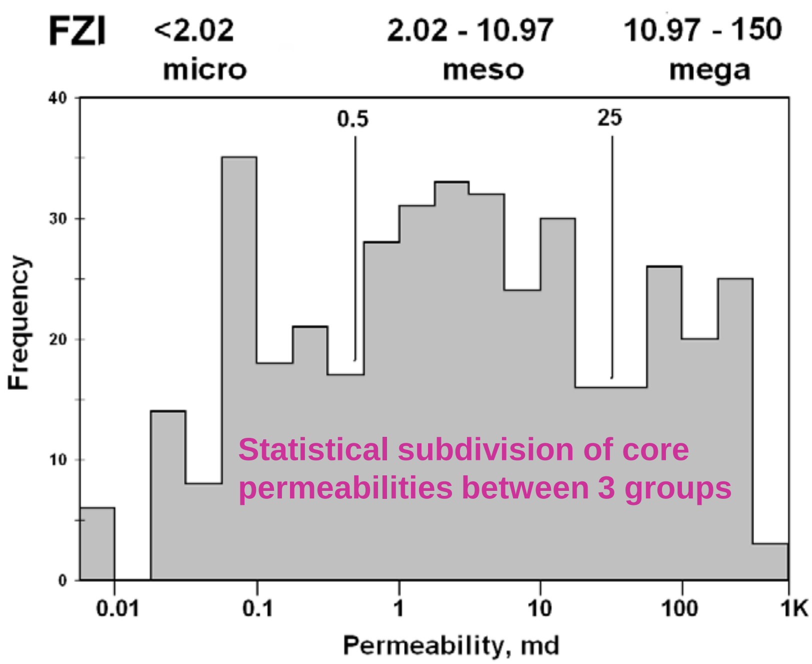



**Figure 10. Statistical subdivision of core permeabilities comparing frequency of permeability by flow zone indicator (FZI). Prepared by J. Doveton.**

The improved estimation of permeability by subdividing between micro, meso, and mega groups was accomplished by Fazelalavi et al. (in press) using core FZI and irreducible water saturation obtained from the MRI log. A depth plot of the permeability comparing computed to core measurements is shown in Figure 11. The correlation between the computed and measured permeability is closer than using the MRI Coates equation. The FZI-$Sw_{irr}$ method also provides estimates of the high end permeability that cannot be captured by the core along incomplete sampling because pores are too large or core could not be obtained in the field.

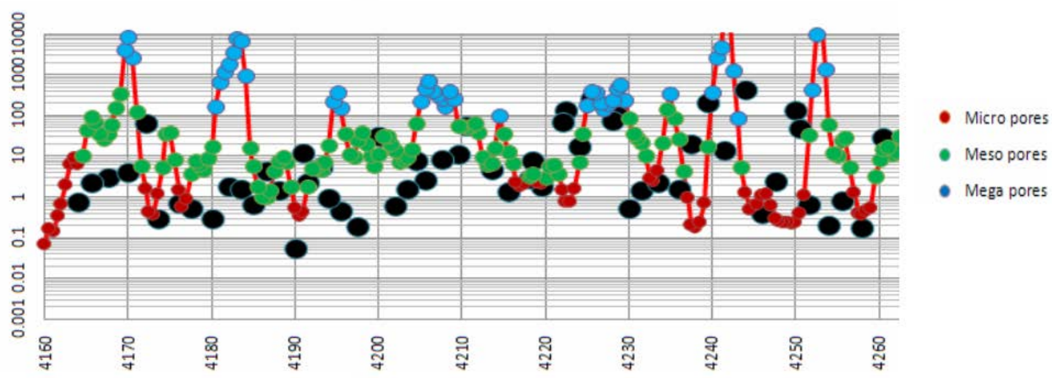



**Figure 11. The computed permeability by the Fazelalavi method with micro, meso, and mega pores, is compared with the core analysis, shown as black dots. Prepared by J. Doveton.**

The pore sizes are very closely linked to carbonate fabric (Figure 12) with a closely correspondence between mud-supported and micro, grain-supported and meso, and vuggy and mega pores. In addition, the vuggy pores are closely linked to breccias that are believed to be the result of the dissolution of pre-existing evaporates.

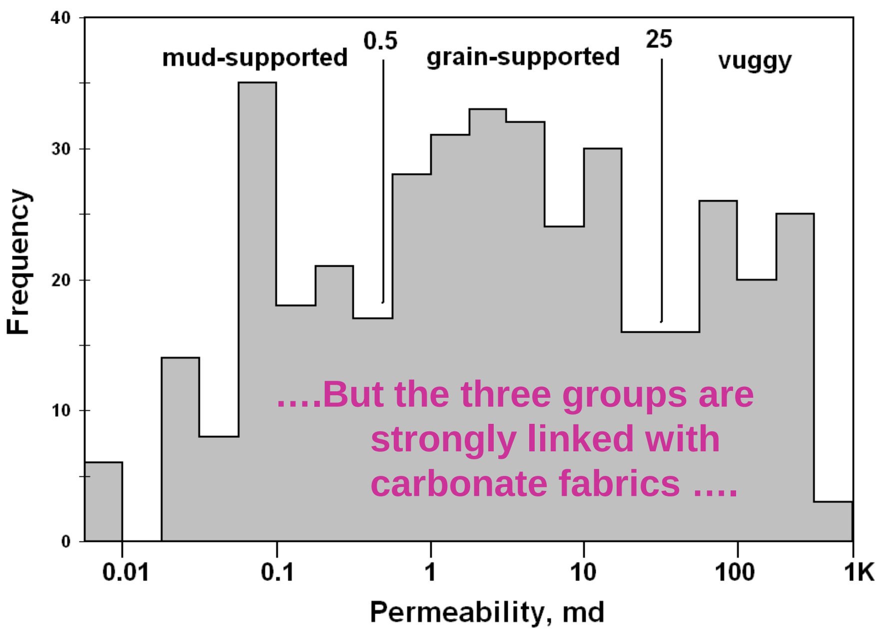



**Figure 12. Distribution of permeability is closely related to carbonate fabrics. Prepared by J. Doveton.**

The distribution of pores is also closely related to the stratigraphy and can be correlated between wells as noted in the correlation of porosity and pore types between wells Wellington #1-32 and #1-28 within the lower, more highly permeable interval of the Arbuckle (Figure 13). This further supports the concept that the pore distribution and related rock properties can be correlated to modern petrophysical logs. The challenge is to determine what log suites are needed to provide an accurate, quantitative estimate of rock properties to use as input into a reservoir simulator to obtain an accurate estimate of the storage capacity of CO2. This is being addressed via the use of fuzzy logic.

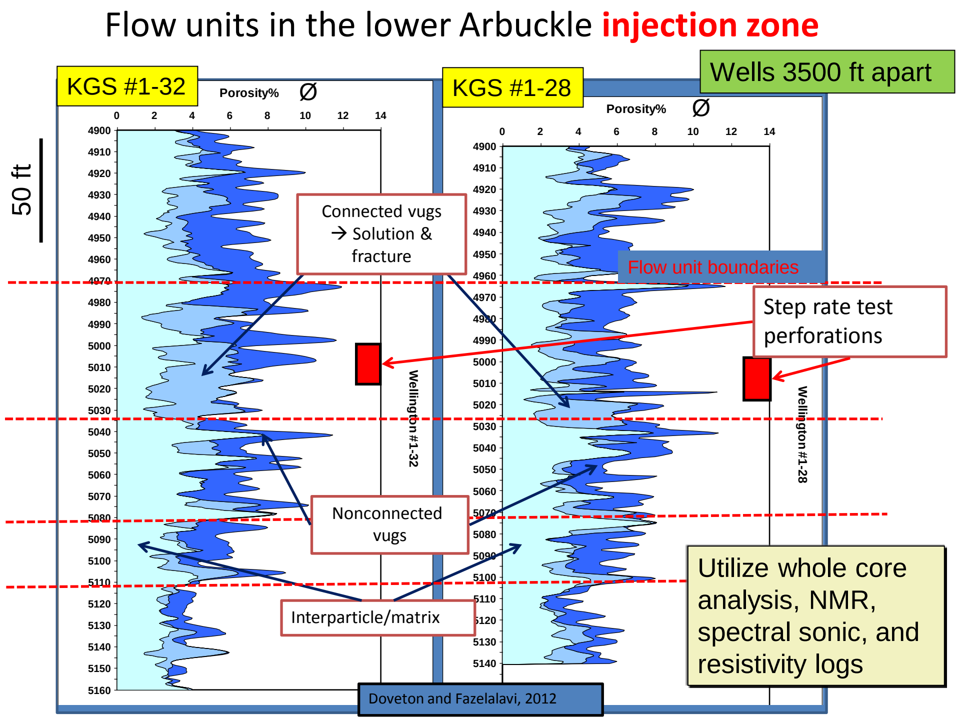



**Figure 13. Flow units assigned based simply on stratigraphic patterns of pore type and porosity abundance that can be correlated between wells. This approach to pore classification and assigning properties that relate to the flow and storage of CO2 is what is sought through the use of fuzzy logic algorithms.**

Fuzzy logic methodology was chosen because of its utility in use of many types of input variables and ability to specify their uncertainty. The results are repeatable and the analysis is quite transparent relative to other common statistical methods such as neural network.

Matlab will be used to perform the analysis. As summarized by Matlab,

> *"The point of fuzzy logic is to map an input space to an output space, and the primary mechanism for doing this is a list of if-then statements called rules. All rules are evaluated in parallel, and the order of the rules is unimportant. The rules themselves are useful because they refer to variables and the adjectives that describe those variables. Before you can build a system that interprets rules, you must define all the terms you plan on using and the adjectives that describe them. Figure 13 shows the general description of a fuzzy system. Fuzzy inference is a method that interprets the values in the input vector and, based on some set of rules, assigns values to the output vector." -- http://www.mathworks.com/help/fuzzy/foundations-of-fuzzy-logic.html?nocookie=true#FP59888*

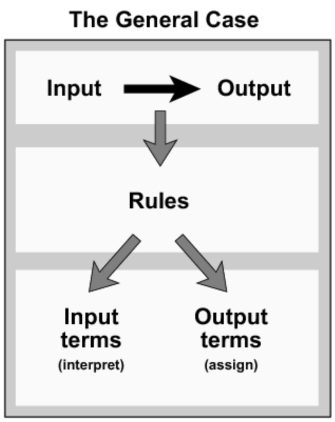



**Figure 13. General description of a fuzzy system.**

The objective will be to classify zones in Arbuckle wells as to whether they belong to 1) Low permeability (<0.5 md), micropore, mud-supported petrofacies; 2) Intermediate permeability (0.5 – 25 md), mesopore, grain-supported petrofacies; or 3) High permeability (>25 md), megapore, vuggy Petrofacies. Following this classification, a numerical value of permeability and other parameters will be assigned.

The sites of the coarse grid simulation have been previously as noted in Figure 14. All sites have a least one Precambrian test with modern well log suites.

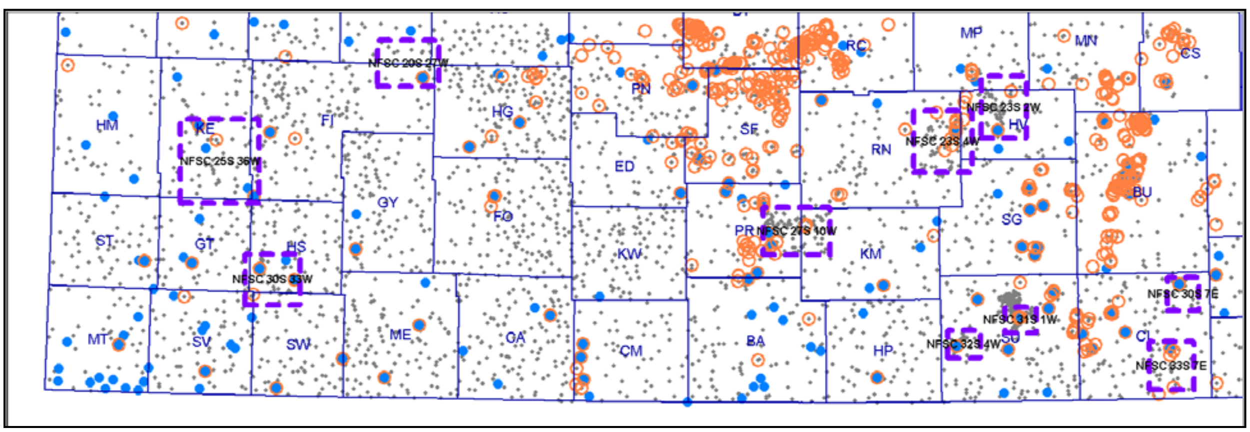


**Figure 14. Ten modeling sites in south-central Kansas.**

Each site is described below in Figures 15-24 including a type log of the Arbuckle at the site and a structure map on the top of the Arbuckle. The well control is also shown. Cover covered at each site is generally four townships or about 144 mi$^2$.

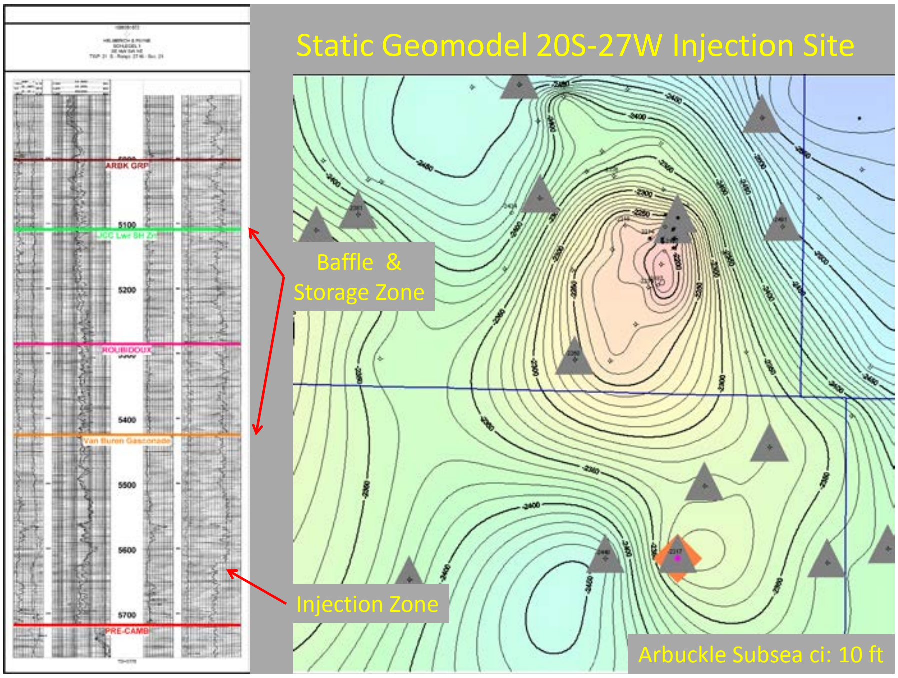



**Figure 15. Arbuckle at this site is 800 ft thick on a structure that has approximately 150 ft of structural closure. Structure is also the site of Witt oil field that produces from the Mississippian from this structural closure.**

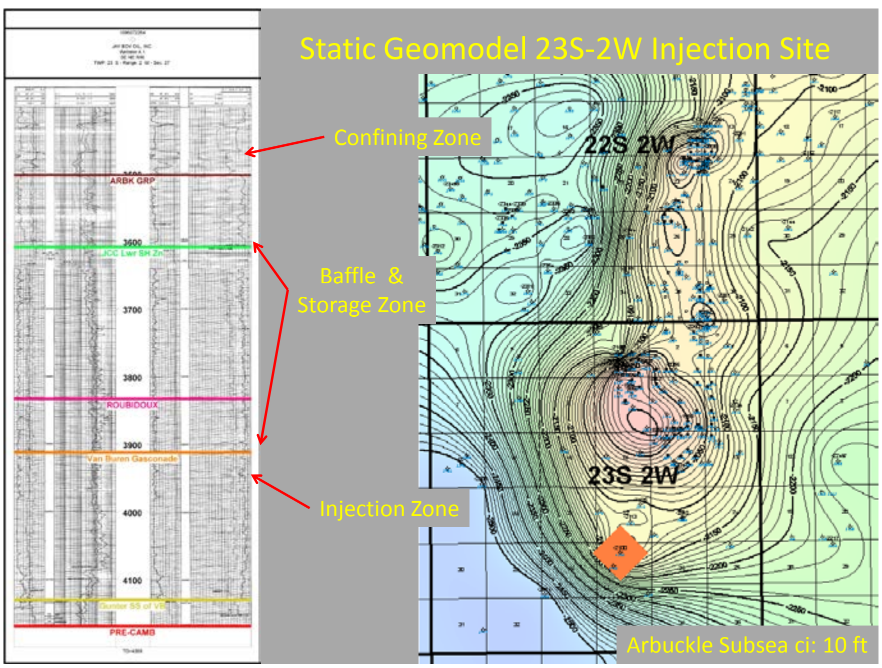



**Figure 16. The Arbuckle is 625 ft this at this site over a structure that has 150 ft of relief. The structure also is the site of an oil field, Halstead. The pay zones in the field include Lansing-Kansas City, Mississippian, and Simpson Group.**

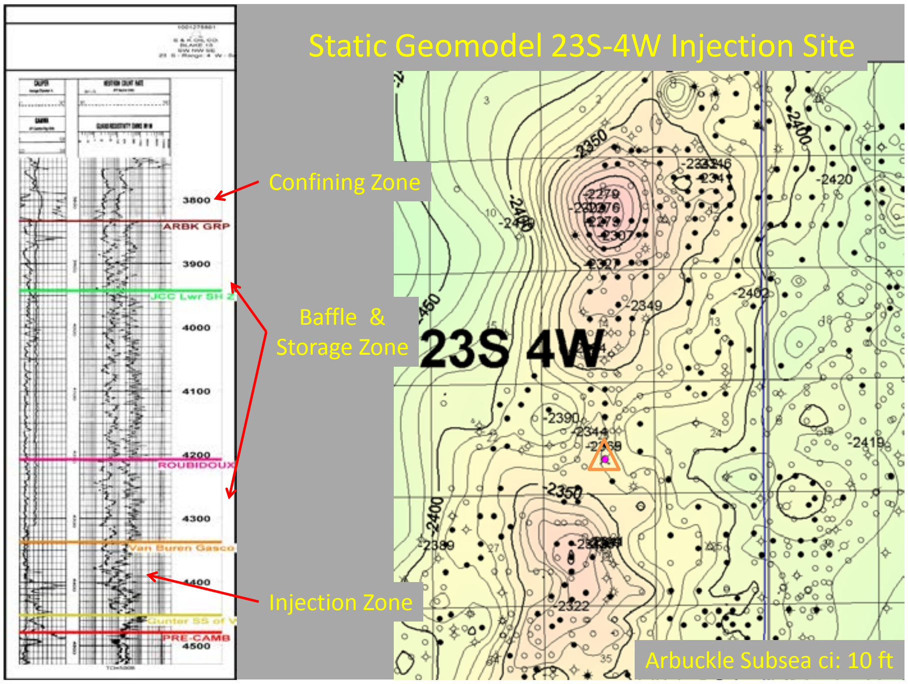



**Figure 17. The Arbuckle is 700 ft thick on a structure with over 150 ft of closure. The site is the location of Burrton Field, a multipay field with a cumulative production of 87 million barrels of oil.**

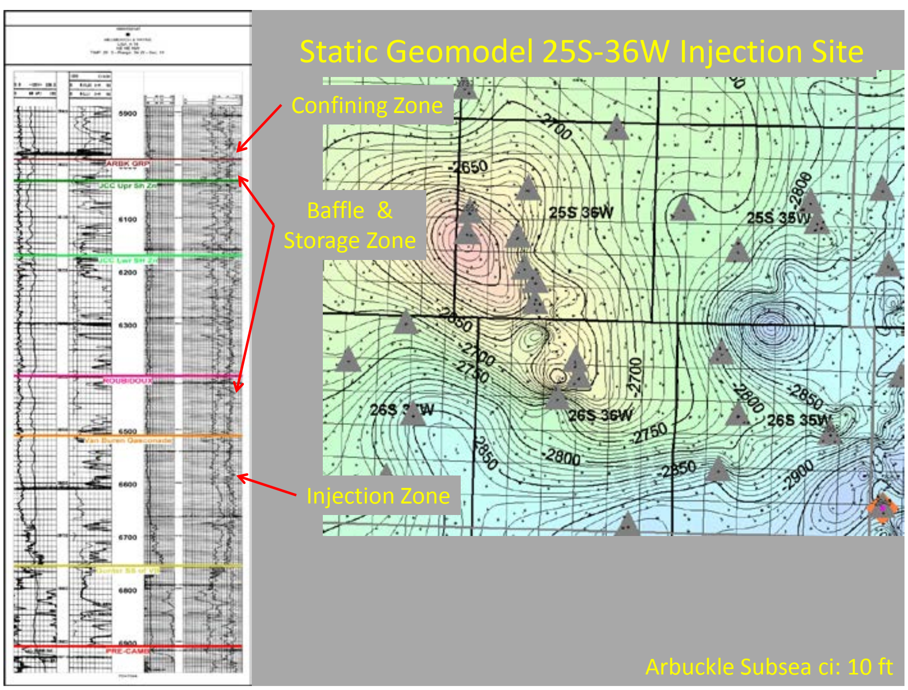



**Figure 18. The site has 900 ft of Arbuckle and is located on a structure with 200 ft of closure. The site is the location of Lakin Field in Kearney County.**

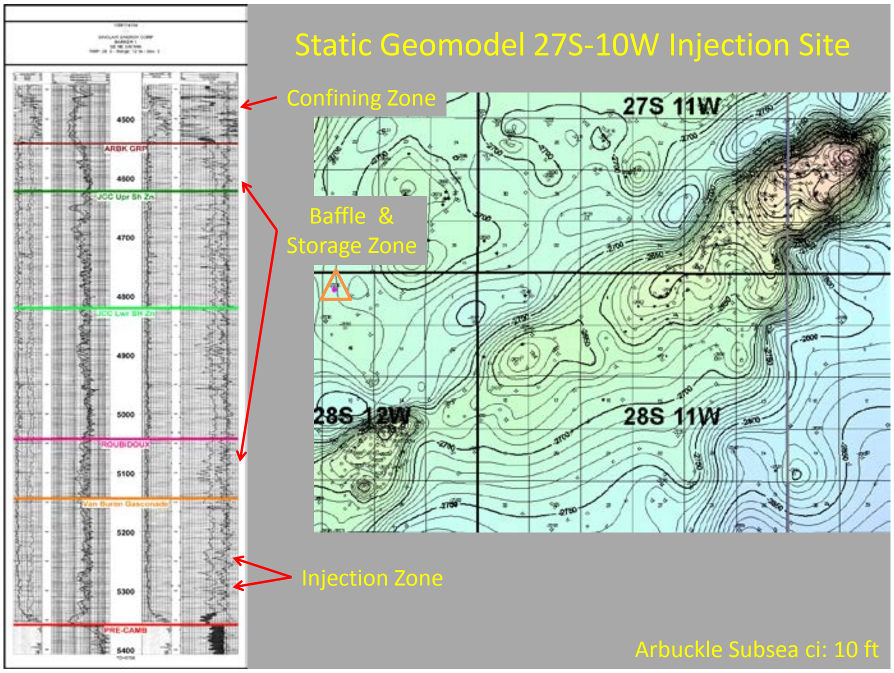



**Figure 19. The site has 800 ft of Arbuckle and over 200 ft of structural closure. The site is the location of the multi-pay Cunningham oil field in Kingman County.**

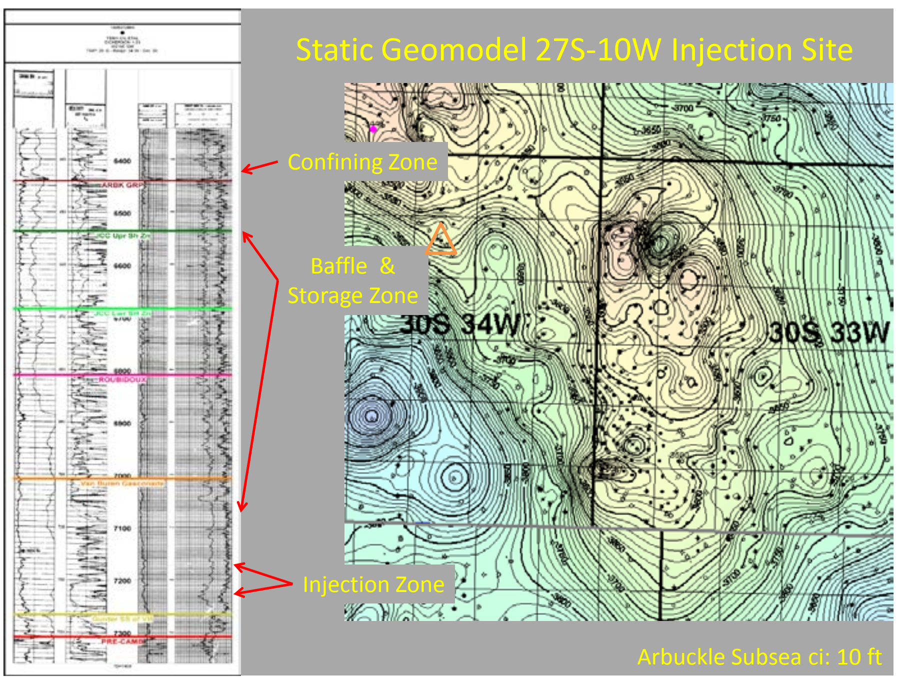



**Figure 20. The location has 850 ft of Arbuckle with over 250 ft of relief on the structure. The site is also the location of Victory Field that has produced over 15.5 million BO from multiple producing horizons.**

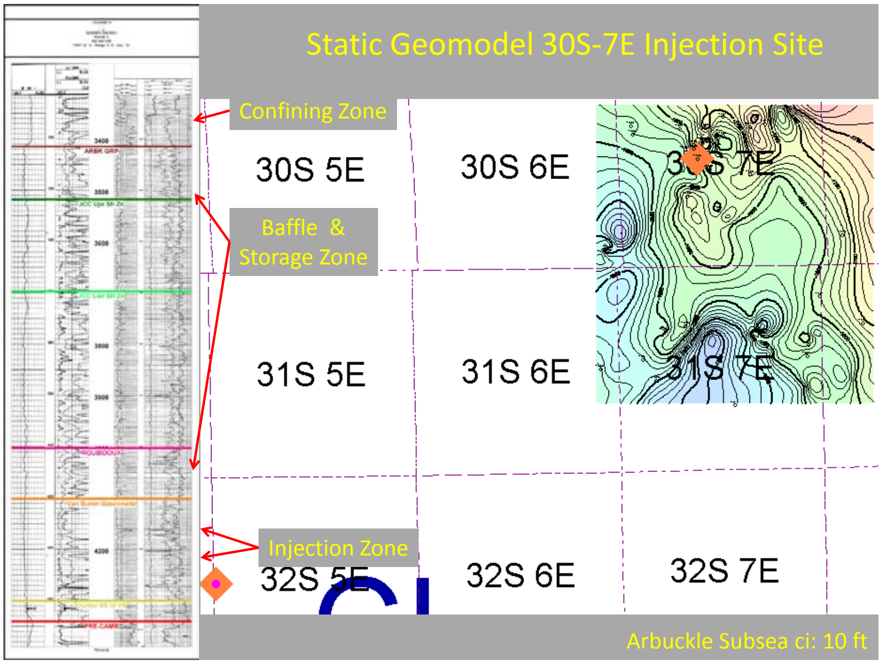



**Figure 21. The site has 950 ft of Arbuckle and is the site of Box Field. The structure has in excess of 150 ft of relief.**

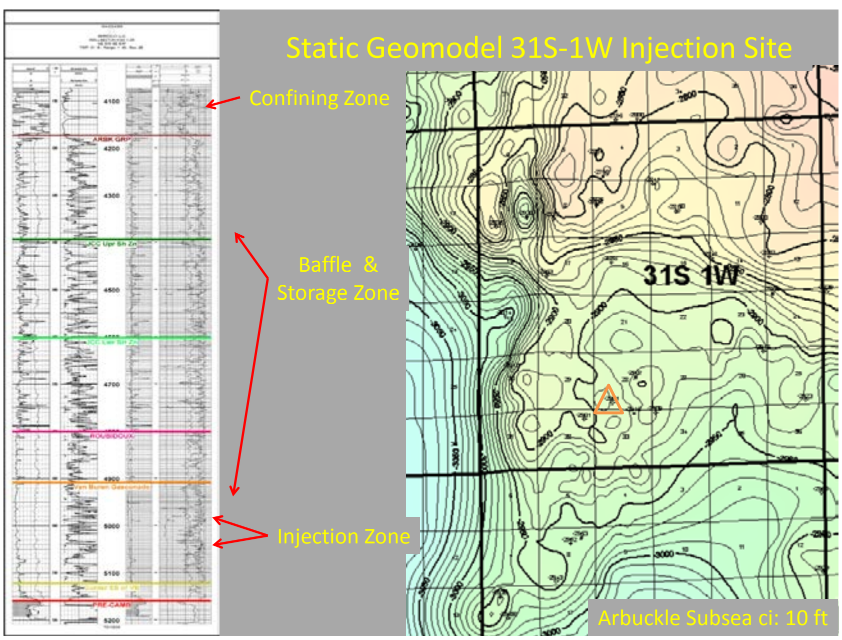



**Figure 22. This location is Wellington Field, with its Mississippian oil pay zone. The structure has 100+ ft of relief and contains 1000 ft of Arbuckle.**

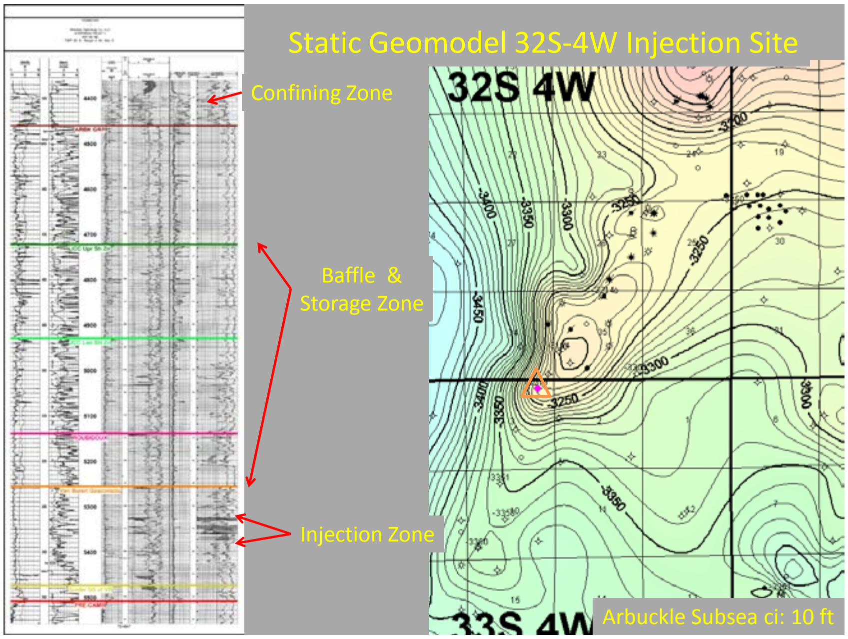



**Figure 23. The location is another oil field, Yarnell that produces from the Mississippian. The Arbuckle is 1000 ft thick and the structural relief is around 100 ft.**

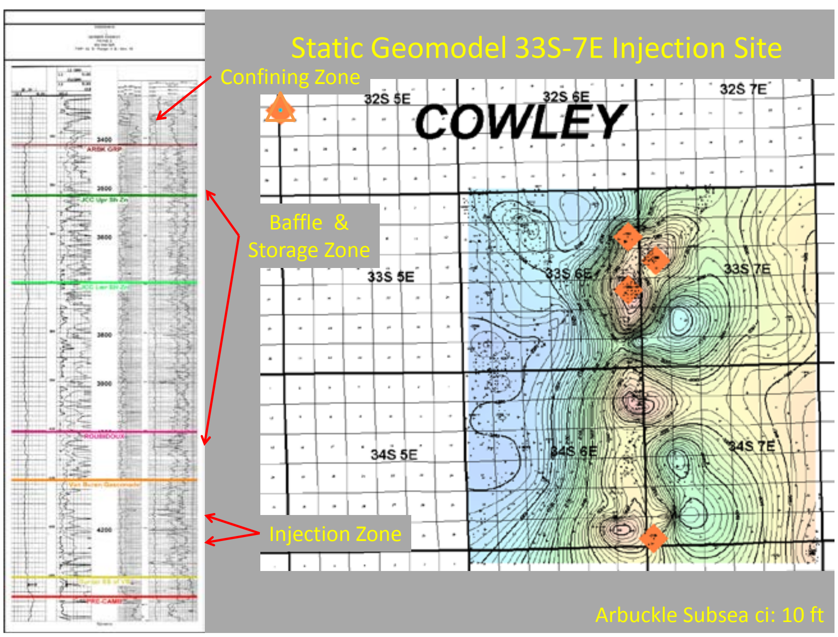



**Figure 24. This location has 950 ft of Arbuckle with over 200 ft of relief. The site is also the location of Dexter Field with primary production from the Mississippian reservoir.**

An important component of regional storage and site selection is the caprock. Originally, the Chattanooga Shale, and particularly, the black shale facies was considered the caprock. As discussed in previous reports, the confining layers have been extended to include the Simpson Group in its shalier lithofacies and the lower Mississippian that is shaly in widespread areas in southern Kansas. Drilling and coring at Wellington and Cutter fields have provided conclusive evidence that the thicker, uniform shalier carbonate lithofacies provide the likelihood of being a caprock. Additional study of local strata is necessary to confirm their integrity. A composite isopach of these strata is shown in Figure 25 and confirm their widespread distribution in southern Kansas.

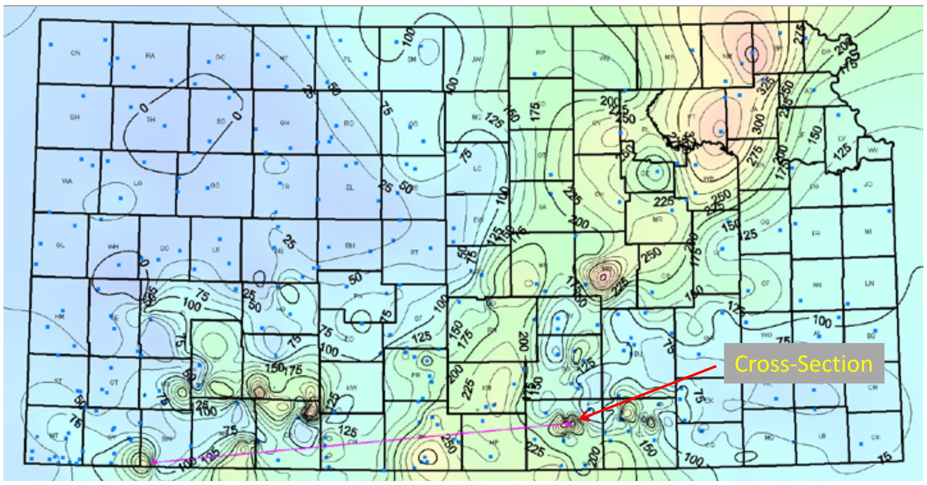



**Figure 25. Combined isopach of the lower Mississippian, Chattanooga Shale, and Simpson Group in Kansas. West to east cross section index line is shown by the pink colored line.**

The distribution of these strata reflects the subsidence during the early and mid-Paleozoic above the Proterozoic Midcontinent Rift System that transects Kansas. The cross section in Figure 26 highlights the distribution of these strata in the southern along the southern portion of the state.

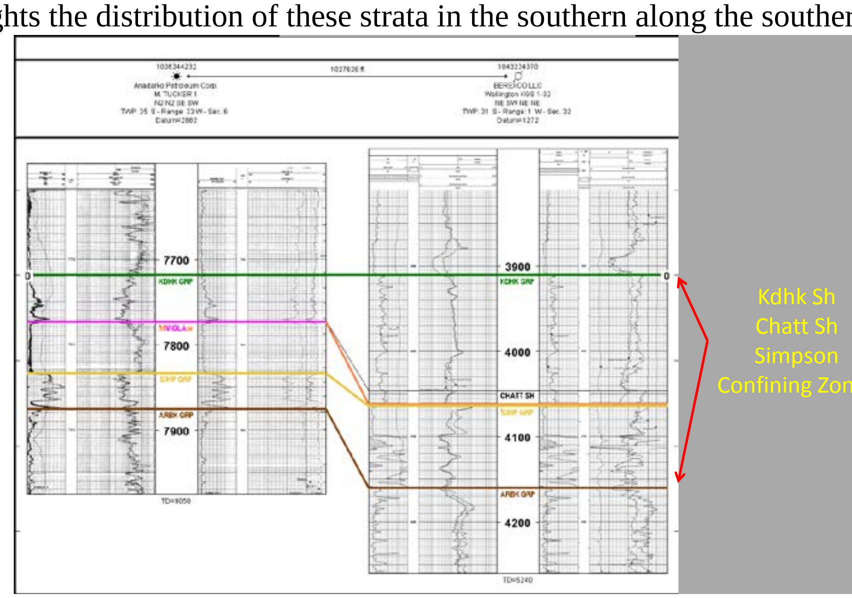
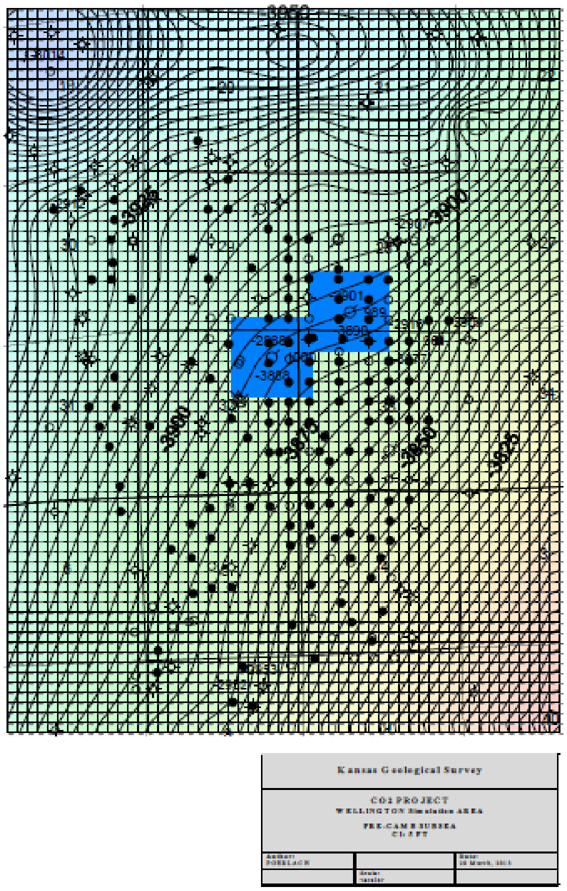



**Figure 26. West to east cross section with a datum on the top of the "Kinderhook" limestone. Shales in general area thicker in the east along the axis of the underlying Proterozoic Midcontinent Rift System.**

The coarse grid geomodels in each of the regional sites will have a sufficient number of cells to provide reliable models that will be used to develop correlations with petrophysical data that will provide the means to improve capacity estimates at a regional scale (Figure 27).




CI: 5 ft all maps
Grid Cell Size: 330 ft, Col: 56, Row: 73, total cells: 4088
If you zoom in close you can see the individual cell values.

**Info on Grids in Zmap (ascii multiple files zipped into one file)**

**Figure 27. Example of a coarse grid geomodel for Wellington Field that will be constructed for use in CMG simulations to estimate CO2 storage capacity.**

### Task 16: Collect and Analyze Existing Data for Developing Regional Geomodel for Arbuckle Group Saline Aquifer in Western Annex

Regional seismic data was assemble, reprocess, and is being interpreted to aid in reservoir characterization in selected fields including Pleasant Prairie, Eubanks, and Schuck fields.
The seismic data is being integrated with other data such as wireline logs, field production data, cores, etc. to develop a geomodel for the Arbuckle Group saline aquifer for evaluation of CO2 sequestration potential. An example of the integration is the time structure of the Meramec Mississippian in Pleasant Prairie in southwest Kansas that is now a layer on the project's interactive mapper (Figure 28).

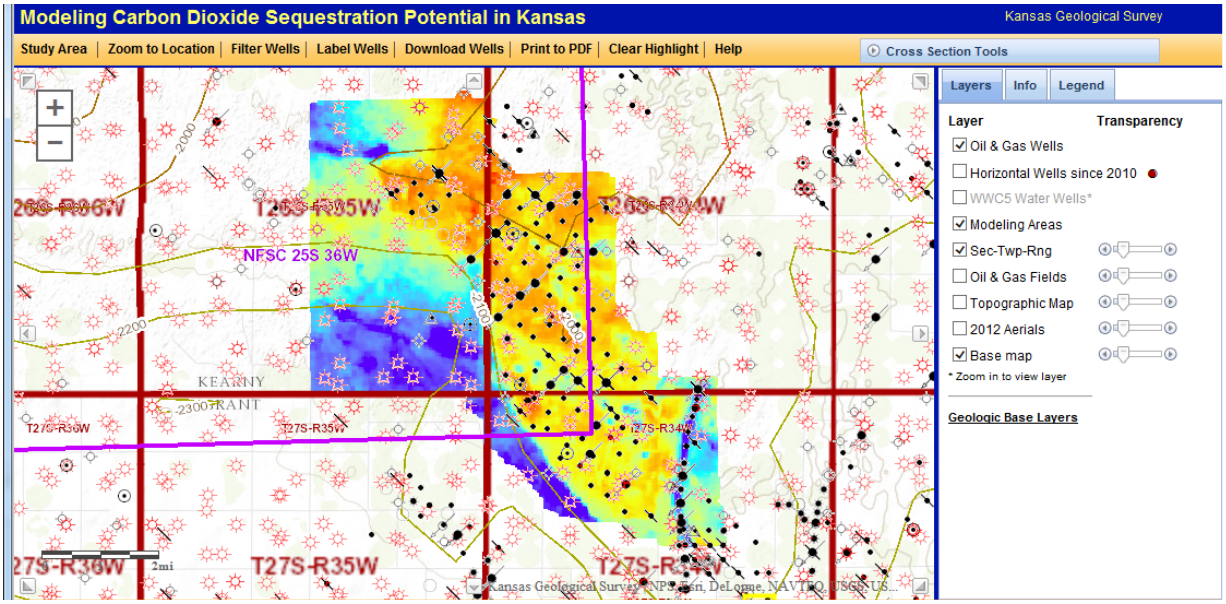
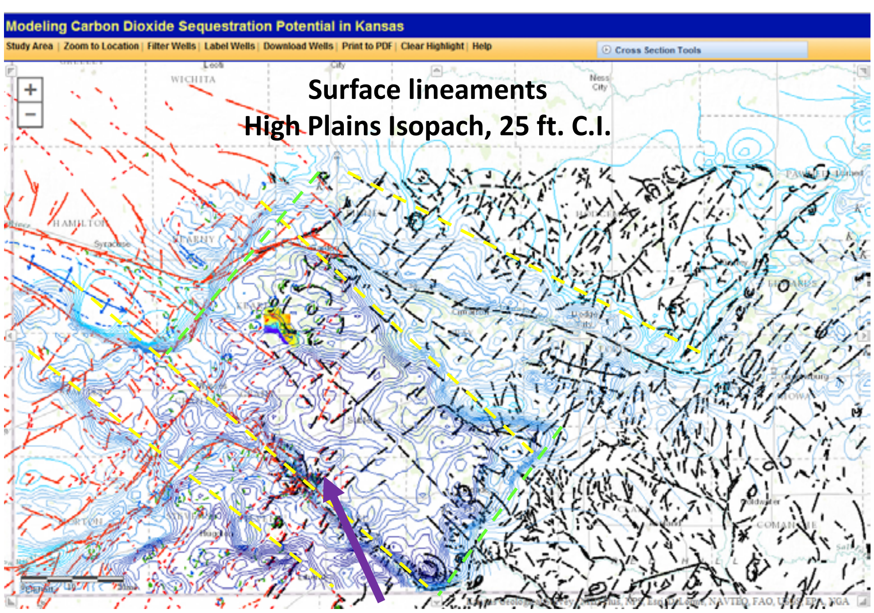



**Figure 28. Project's interactive mapper at Pleasant Prairie Field shown time structure of top of Meramec from 3D seismic along with well information and regional contours of the Mississippian surface.**

### Subtask 16.3. Remote sensing analysis

Remote sensing data has been mapped and interpretations have been made relating influence of bedrock features in the Western Annex (southwest Kansas). Surface lineaments for example tie very closely with an isopach of the shallow unconfined High Plains Aquifer. Deeper structure and its effect on evaporite dissolution are partly responsible for the distribution of the High Plains Aquifer. Surface lineaments reveal structural and depositional heterogeneities that are important to explaining latest events in the geologic history (Figure 29).




**= Figure 29. Surface lineaments overlain on an isopach of the High Plains Aquifer in southwest Kansas. The aquifer is most important to the Kansas economy. Its distribution is closely delineated by the surface lineaments, the red set recently added as part of the Western Annex funding and the black set that are part of the original funding.**

In addition to the satellite and airphoto data, airborne LiDAR (Light Detection and Ranging) data was used from Stevens County to develop a detailed set of surface lineaments overlying Cutter Field (Figure 30).

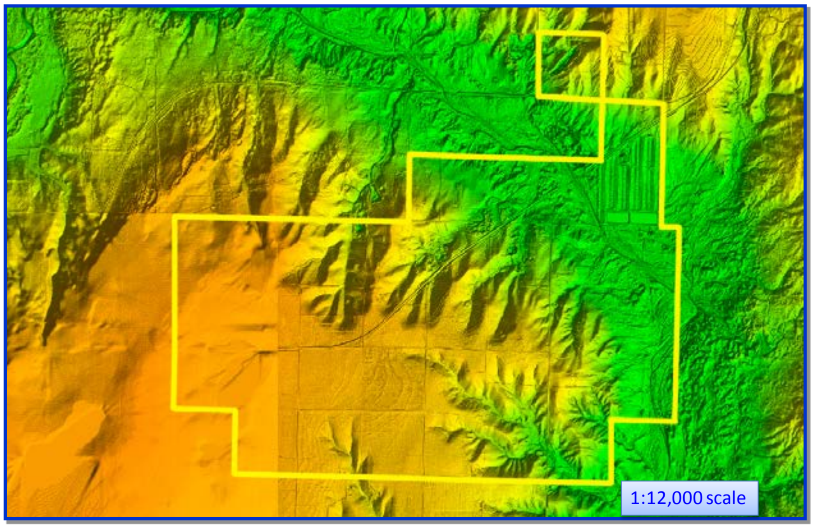



**Figure 30. LiDAR image of the Cutter oil field in NE Stevens County, the site of new well and multicomponent seismic data. The area shown is highlighted with purple arrow on Figure 29.**

The LiDAR data was interpreted to produce a set of lineaments, a dominant set of longer northwest trending and an abundant set of shorter northeast trending features (Figure 31). These trends correspond closely to the trends of lineaments at a regional scale. As the Cutter Field seismic and subsurface data are analyzed, these surface lineaments will be compared that that information.

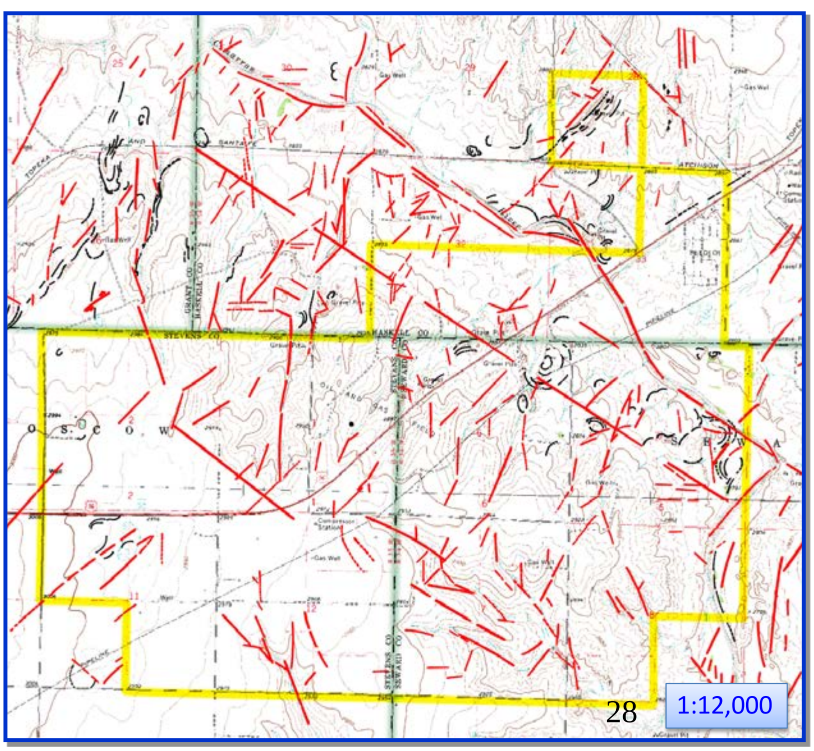



**Figure 31. Lineaments derived from the LiDAR imagery over Cutter Field. LiDAR image is shown in Figure 30.**

The lineaments derived from LiDAR data are put in perspective of the regional structural framework with a structural contour map on the top of the Meramec Mississippian (Figure 32).

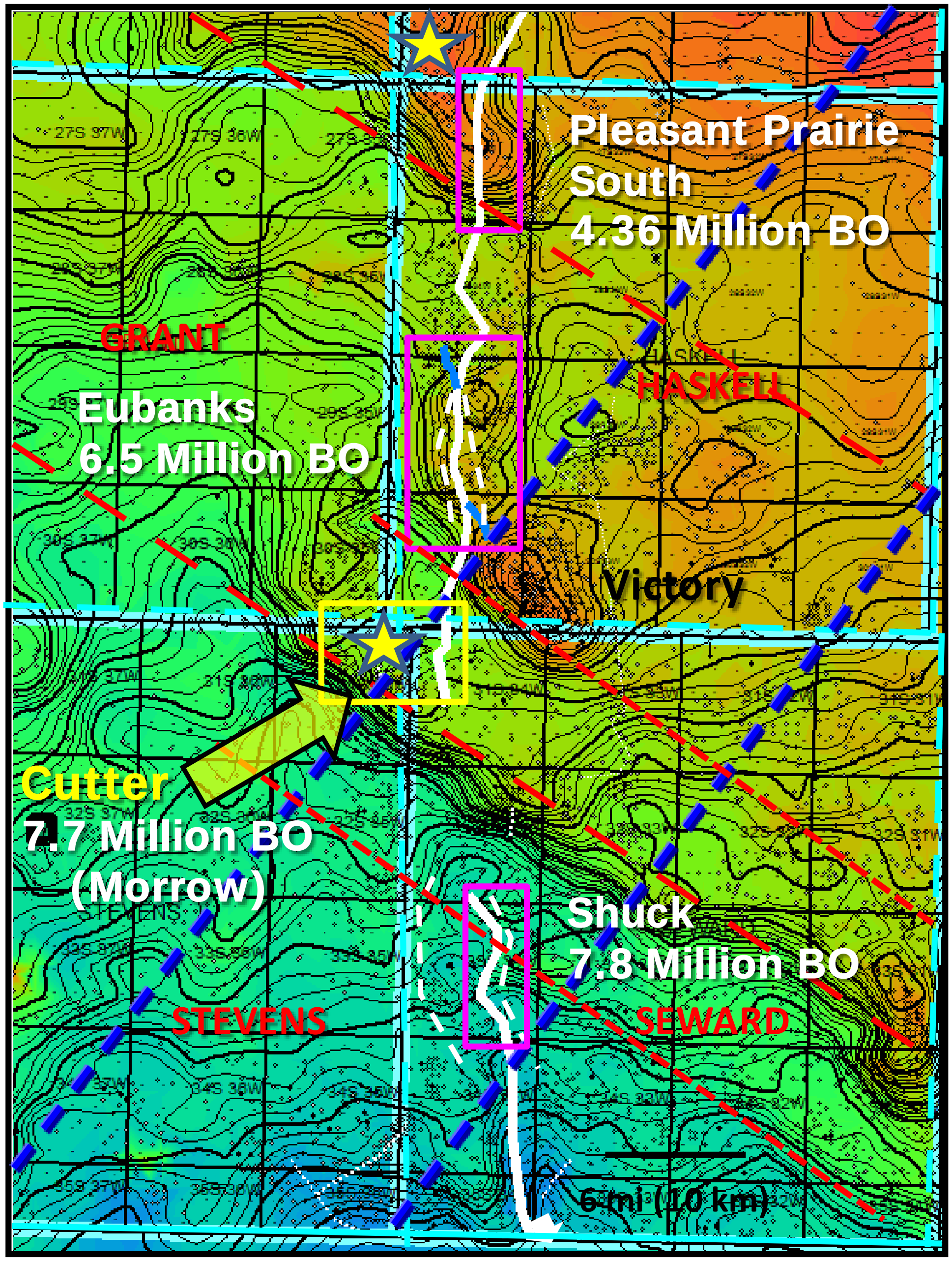



**Figure 32. Structure top of Meramec Mississippian in the area of the set of field studies in southwest Kansas. The Cutter Field is highlighted in yellow. Red and blue dashed lines highlight the regional structural trends. Two of these structural trends intersect at Cutter Field. These structural trends correspond closely to surface lineaments.**

**Task 17. Acquire (New) Data at a Select Chester/Morrow Field to Model CO2 sequestration Potential in the Western Annex.**

Core analysis of the Cutter Field well, the Cutter KGS #1 continues at the labs in Weatherford, Houston, TX.

The first processed volume of the multicomponent 3D seismic survey has been provided by Fairfield. Results will be used to develop a geomodel of the Morrowan oil reservoir and deep Arbuckle saline aquifer.

Testing of the Cutter KGS #1 well continued through June. Selected Arbuckle, Simpson, Chattanooga, and Mississippian intervals are being perforated. A wireline conveyed tool designed by Triolobite Testing to obtain buildup pressures from test intervals in the Arbuckle was successful. Geochemical analyses will be performed by Kansas State U. and Kansas U. to investigate the CO2-rock interaction.

**Task 19: Integrate Results with Larger 17+ County Regional Project in South-central Kansas**

The Recipient shall incorporate and merge results from the proposed project enhancement study, covering the Western Annex (a 5,000 mi2 extension), with those from the 17+ county regional study to evaluate CO2 sequestration capacity of the deep Arbuckle Group saline aquifer, currently underway in south central Kansas, thereby increasing the study area by ~25%.

**Type Logs**

The type logs have been extended to the entire state to allow regional characterization and evaluate continuity of the Arbuckle saline aquifer and adjoining strata beyond the study area in southern Kansas. The log database is extensive. Wells included in this database have been digitized and correlated and are now accessible on the interactive mapper. The following is the accounting of the wells.

- Total DOE CO2 Wells: 2003
- DOE CO2 Wells without LAS 2.0 Files: 516
- DOE CO2 Wells without LAS 2.0 Files with LAS 3.0 Files: 49 ( Geo-report & Tops only in LAS 3.0 File )
- DOE CO2 Wells with LAS 3.0 Files: 1159 (~75 % Complete)
- DOE CO2 Wells not Type Log Wells: 766
- Wells with Litho-density logs: 551
- Wells with litho-density logs with PE: 248
- DOE CO2 Wells with Geologist Reports: 314
- DOE CO2 Wells with Geologist Reports in LAS 3.0 Files: 303

While stratigraphic correlations have been completed, they will be verified by a team of experienced geologists in the Fall 2013. Individuals are volunteering their time. The interface to this task is online and will lead the team through their assigned areas (Figure 33). A reference well and well to be compared and correlations will be verified (Figures 34 and 35). A regional cross section illustrates current stratigraphic correlations (Figure 36).

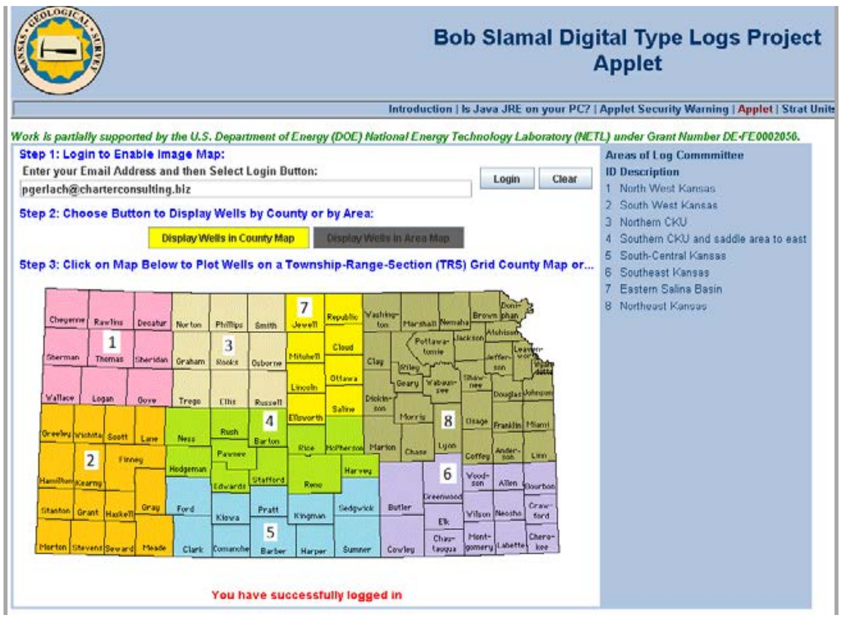



**Figure 33. Type log interface showing areas assigned to team to correlate.**

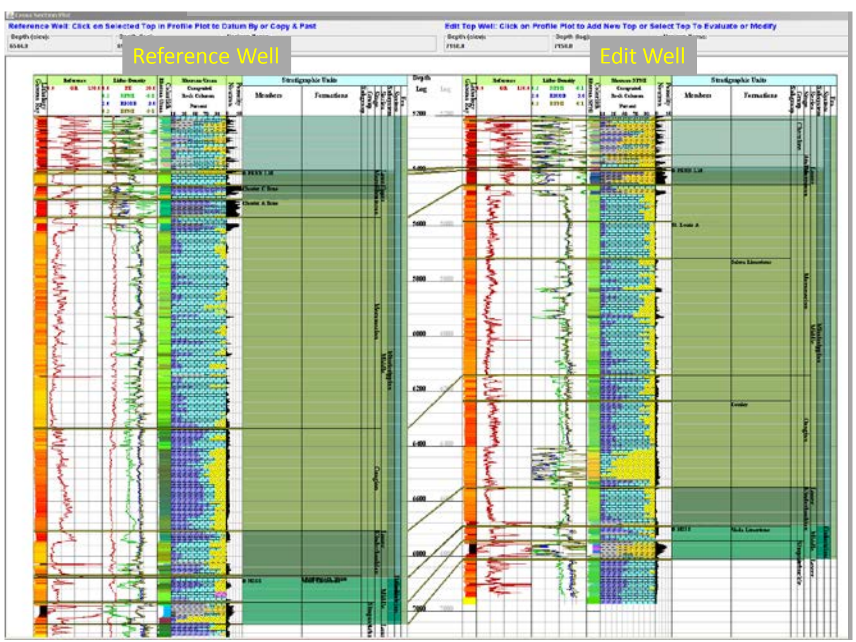



**Figure 34. Comparison is preformed between a reference and edit well.**

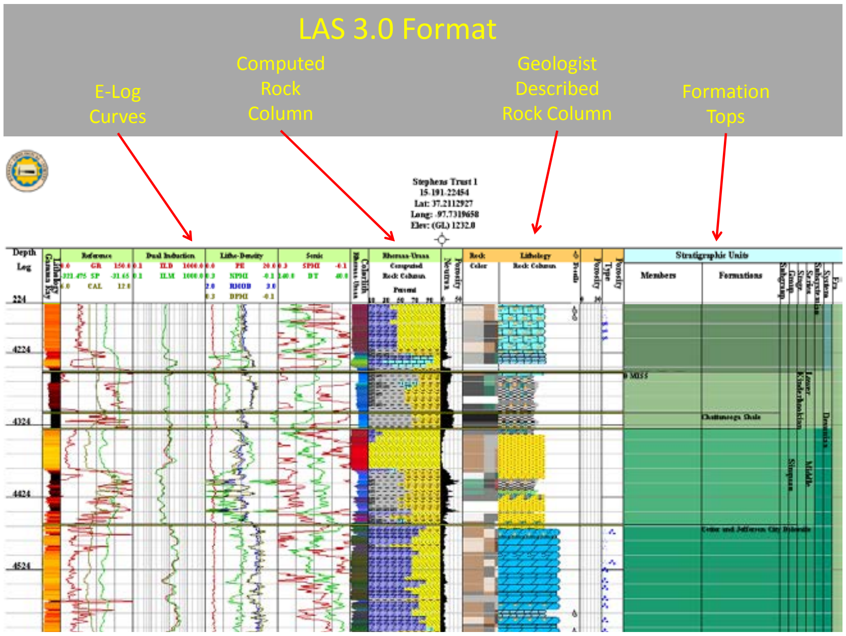



**Figure 35. Information included in a LAS 3.O digital log file.**

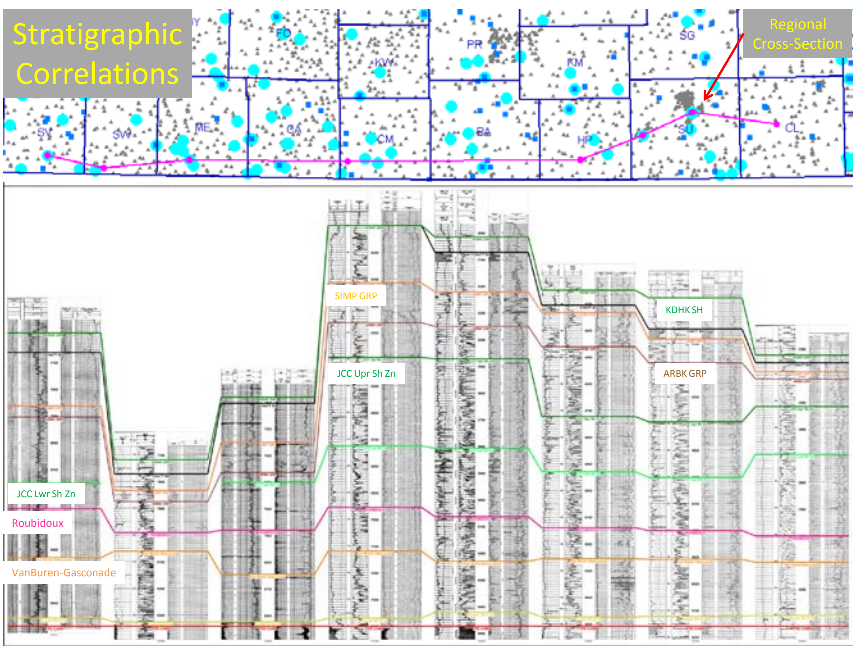



**Figure 36. Regional west to east cross section across the southern portion of the study area in southern Kansas along the Oklahoma border.**

## PRESENTATIONS AND PUBLICATIONS

Watney, W.L., Newell, K.D., Holubnyak, E., and Raney, J., 2013, "Oil and Gas in Central Kansas Potential for Enhanced Oil Recovery Using CO2", regarding use of petroleum coke in refinery that would include CO2 generation: to McPherson Kansas Development Corporation hosted meeting, April 3.

Watney, W.L., 2013, Analysis of the Late Devonian to Early Carboniferous (Fransnian-Tornaisian) Woodford (Chattanooga) Shale, presentation to AAPG Forum Woodford, Oklahoma City, April 11. This is an important caprock in Kansas and Oklahoma.

Watney, W.L., 2013, Petrophysical Analyses and Integrated Approaches, April 16-19, AAPG Short Course, Austin, TX. Centerpiece of the course material comes from the DOE-CO2 project

Watney, W.L., 2013, Mississippian Exploration: Stratigraphy, Petrology, and Reservoir Properties with an emphasis on Wellington Field, April 23, Denver, RMAG & PTTC Symposium titled, "Making Money with Science", April 23, Denver, Colorado.

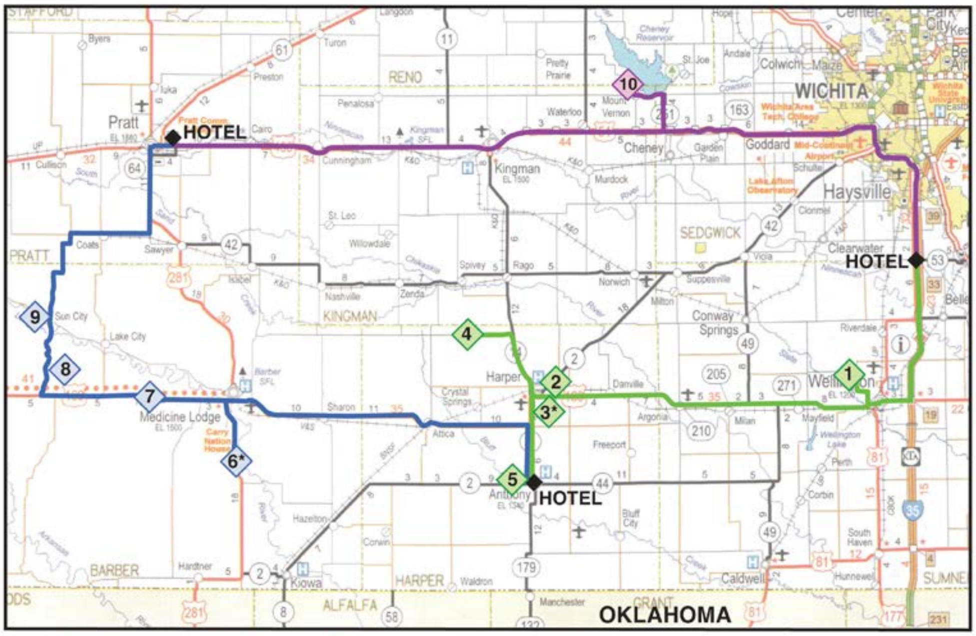
W. Lynn Watney, John Youle, Dennis Hedke, Paul Gerlach, Raymond Sorenson, Martin Dubois, Larry Nicholson, Thomas Hansen, David Koger, and Ralph Baker, 2013, Sedimentologic and Stratigraphic Effects of Episodic Structural Activity During the Phanerozoic in the Hugoton Embayment, Kansas USA: AAPG Annual Meeting, Oral presentation, Pittsburgh, PA, May 21

W. Lynn Watney, Jason Rush, Martin Dubois, Robinson Barker, Tiraz Birdie, Ken Cooper, Saugata Datta, John Doveton, Mina Fazelalavi, David Fowle, Paul Gerlach, Thomas Hansen, Dennis Hedke, Yevhen Holubnyak, Breanna Huff, K. David Newell, Larry Nicholson, Jennifer Roberts, Aimee Scheffer, Ayrat Sirazhiev, Raymond Sorenson, Georgios Tsoflias, Eugene Williams, Dana Wreath, John Youle, 2013, Evaluating Carbon Storage in Morrowan and Mississippian oil fields and Underlying Lower Ordovician Arbuckle Saline Aquifer in Southern Kansas: AAPG Annual Meeting, Poster, Pittsburgh, PA, May 20.

DOE Site visit and project review, June 3-5, 2013, Regional CO2 Storage, Wellington and Cutter field calibration sites, SW Kansas CO2-EOR Initiative, and Small Scale CO2 Test Injection at Wellington, Wichita, KS.

Watney, L., Rush, J., Raney J., and Brian Dressel, DOE Project Manager, 2013, Presentation to the 2013 KGS Annual Kansas Field Conference. Participants included Kansas legislators and state officials, morning of Tuesday, June 4$^{th}$, Meet bus at site of Wellington KGS #1-32. Brought core and posters in addition to describing DOE-CO2 project and answering questions pertaining economics, safety, and policy.

*The 2013 KGS Annual Field Conference was carried out by Shane A. Lyle, Catherine S. Evans, Rex C. Buchanan, and Robert S. Sawin and was focused on "South-Central Kansas Oil Exploration, Water Allocation, and Range Management". This project is operated by the Kansas Geological Survey and funded, in part, by the Kansas Water Office, the Kansas Department of Transportation, and the Kansas Department of Wildlife,* *Parks and Tourism. The Wellington Field was Stop #1 on the trip that traversed south-central Kansas (Figure 37). Members of the DOE-CO2 team met the bus at the site of Berexco Wellington KGS #1-32 in Wellington Field.*




Day 1 Day 2 Day 3

* Site locations 3 and 6 are approximate. Final locations are dependent on petroleum field operations.

**Figure 37. Route and stops in south-central Kansas for the 2013 Annual Field Conference.**

Participants of the field trip included:

Steve Abrams, Senator, Arkansas City
Steve Adams, Natural Resource Advisor, Kansas
Department of Wildlife, Parks and Tourism
Larry Biles, State Forester, Kansas Forest Service
Elaine Bowers, Senator, Concordia
Kim Christiansen, Assistant Secretary/Chief
Counsel, Kansas Department of Agriculture
Pete DeGraaf, Representative, Mulvane
Marci Francisco, Senator, Lawrence
Raney Gilliland, Director, Kansas Legislative
Research Department
Ramon Gonzalez, Jr, Representative, Perry
Bob Grant, Representative, Frontenac
Tom Hawk, Senator, Manhattan
Dave Heinemann, Chair, Kansas Geological Survey
Advisory Council (GSAC)
Bob Henthorne, Chief Geologist, Kansas

Department of Transportation
Kyle Hoffman, Representative, Coldwater
Robin Jennison, Secretary, Kansas Department of Wildlife, Parks and Tourism
Laura Kelly, Senator, Topeka
Dan Kerschen, Senator, Garden Plain
Mike King, Secretary, Kansas Department of Transportation
Annie Kuether, Representative, Topeka
Cindy Lash, Principal Analyst, Kansas Legislative Research Department
Wayne Lebsack, President, Lebsack Oil Production, Inc.
Lane Letourneau, Water Appropriation Program Manager, Division of Water Resources/KDA
Earl Lewis, Assistant Director, Kansas Water Office
Judy Loganbill, Educator, Wichita Public Schools
Brad Loveless, Director, Biology and Conservation Programs, Westar Energy
Rob Manes, State Director, The Nature Conservancy
Ed Martinko, Director, Kansas Biological Survey
Karma Mason, Member, Kansas Water Authority
Peggy Mast, Senator, Emporia
Carolyn McGinn, Senator, Sedgwick
John Mitchell, Director, Division of Environment/ Kansas Department of Health and Environment
M.S. Mitchell, Member, Kansas Water Authority
Tom Moxley, Representative, Council Grove
Ralph Ostmeyer, Senator, Grinnell
Larry Powell, Senator, Garden City
Tracy Streeter, Director, Kansas Water Office
John Strickler, Trustee, The Nature Conservancy, Kansas Chapter
Josh Svaty, Senior Advisor, US Environmental Protection Agency Region 7
Vern Swanson, Representative, Clay Center
Ed Trimmer, Representative, Winfield
Jim Ward, Representative, Wichita
Wade Wiebe, Director of Partner Relations, Kansas Department of Transportation

Information conveyed to the participants was focused on the role of Wellington Field in the evaluation of storage and utilization of CO2 in Kansas.

1) *Wellington serving as a calibrate site for the Mississippian reservoir the subject of intensive drilling in south-central Kansas; Summarized the information to describe*

*and model this reservoir at Wellington to use as context for subsequent stops by the field conference attendees -- display of core to illustrate the rock and the supporting posters to show complexity of the Mississippian interval in south-central Kansas*

2) *Collaborative research at Wellington to evaluate utilization for EOR in the Mississippian and storage of CO2 in underlying saline aquifer (showing core of injection zone and referring to posters);*
3) *Research and testing supported by DOE as part of large study directed toward CO2 use and storage in Kansas supported by Berexco and other industry and academic partners*
4) *Benefit to industry and state –*
    a) *as yet unrealized potential to use CO2 to tap an additional ~750 million bbls of oil from existing fields including Mississippian (stranded from CO2 pipeline system and lack of adequate geologic CO2);*
    b) *will need to obtain anthropogenic CO2 to attain this next step for Kansas;*
    c) *project is testing and establishing tailored methodologies to optimize CO2 injection, to monitor and verify the CO2 that is injected to do safely and comply with regulations and requirements for providers of CO2 who wish or need to sequester the CO2.*
5) *Shared results and information with the petroleum industry and public to develop and optimize for new CO2 projects.*

*Key talking points --*

*Wellington Field is a key test site that is part of an industry-government collaboration between KU/KGS, NETL/DOE, and Berexco, LLC that began in 2010 and will continue through 2016.*

*With the characterization phase being completed, project will run a pilot injection of CO2 to evaluate the efficacy of disposing of CO2 in a deep saline aquifer and secondly, to conduct a pilot test using CO2 to recover oil from the Mississippi Lime reservoir. If test is successful, and CO2 fully implemented, Wellington Field could realize a 15% additional oil recovery or roughly 3 million bbls.*

*Wellington Field has produced 20 million bbl field with successful history of oil production from the Mississippian oil reservoir Wellington Field since 1929… THAT'S 84 yrs ago. Waterflood or secondary recovery began ~1955 which have resulted in producing as much oil as during primary; 55 current producing wells, 139+ original oil wells. In 2012, Wellington Field produced 48,000 bbls annually, 2.3 BOPD per well.*

*Wellington Field is within the Mississippi Lime horizontal well play. The MLP began in January 2010 with the first horizontal well drilled by Sandridge. The Miss Lime play has expanded into western and central Kansas, now with over 150 wells drilled and nearly ½ million barrels of oil produced or roughly 6% of our oil production in Kansas in 2.5 years. That is a big deal to communities undergoing this development.*

*Importantly, Wellington Field serves as an excellent calibration site to further understand this complex oil reservoir system that we call the Miss Lime Play. And we have seen surprises because of the extensive data that is usually not obtained.*

*An extensive public data is being compiled and is accessible online at the KGS including 3D seismic, two wells drilled and logged to the Precambrian, nearly 1600 ft of core and related analyses. The project will include analyses, conclusions, and a synthesis of a large team, including students and faculty at KU and KSU. They have addressed important issues of the Mississippian reservoirs that will be part of the legacy of this project.*

*The project will soon file a Class VI application with EPA to inject CO2 into the saline aquifer. We hope to be the first in the country to receive such a permit. The monitoring techniques required by the Class VI permit will help the Kansas industry who is interested in utilization of CO2 to be able to certify its containment in a cost effective manner. This is precisely why we need collaboration with industry for such testing since this is NEW and needs to be practical and economic. Results from the evaluation will be important for the use of anthropogenic CO2 from industrial and electrical power sources, who will be the primary or only suppliers of CO2 in this part of the country. The combined storage capacity of CO2 in Wellington Field is currently estimated at roughly 30 million metric tons or 510 billion cu. ft of CO2.*

*Abengoa Colwich – 2000 tons/yr.; all ethanol 2.2 million/yr; large industrial 1 million; 500 Mw power plant ~12 million per year.*

*Berexco is a key local industry partner -- 1) cost share for the sponsored project, 2) access to the field, and 3) their extensive expertise. I TRUST that moving the project from the R&D phase to implementation should not be long in our case. In turn, the industry at large can then apply what we learn at Wellington to other fields. A recent study estimated that CO2 for EOR in Kansas oil fields could recover an estimated 370 million bbls of additional oil.*

*The $10 million characterization project, underwritten by NETL-DOE and cost share partners, is also being carried out regionally in southern Kansas with other industry and academic partners including modeling of four additional oil fields that lie between Garden City and Liberal, Kansas. This project ends February 2014.*

*The pilot project at Wellington Field is an $11 million project to inject 70,000 metric tons of CO2 from Abengoa's Colwich ethanol plant west of Wichita. Provided Class VI is approved quickly, we will start the injection mid-late 2014 and will wrap up in 2016.*

Rex Buchanan, KGS Director, addresses field trip participants at Wellington Field.

Participants examine core and posters related to the Wellington project.

Discussion followed the presentations.

**KEY FINDINGS**

1. Diagenesis of the Arbuckle indicates early dolomitization and associated dissolution. This dissolution is predominately fabric selective based on multiple lines of porosity characterization from the core to the suite of petrophysical logs.
2. The dissolution of preexisting thin bedded evaporates that cap peritidal cycles is common in the lower Arbuckle (Gasconade Dolomite). A crackle breccia resulted that is strataform in distribution. Pores can be cm-sized in breccia fabric forming distinct correlatable flow unit subdivisions in the lower Arbuckle.
3. Later fracturing and silica dissolution overprint this earlier diagenesis and contribute additional porosity and modifying and enhancing earlier pores. The timing appears to be deeper burial and precedes precipitation of higher temperature dolomite (baroque habit) and petroleum migration. This is the last notable fracturing and dissolution event.
4. Very late calcite cement is noted throughout the stratigraphic interval extending from the Mississippian to the Arbuckle. This event may be related to minor cratonwide deformation in corresponding with Laramide tectonism in the Early Tertiary. It is inferred that the calcite precipitated from water that communicated across the layers. However, current pressure and geochemical data indicate isolation of the hydrostratigraphic units.
5. Petrophysical modeling for the regional simulation sites has proceeded more slowly than anticipated due to complexity of the pores. We have a way forward incorporating rock property data into a fuzzy logic system to be able to confidently estimate rock properties from modern log suites and georeports that are part of our type log dataset.
6. The regional modeling sites are set for static and dynamic modeling that will be used to determine the CO2 storage capacity in the Arbuckle.

7. The project interactive mapper is nearly a final stage of completion allowing access to maps and well data for the project as well as providing web tools to work with the data. The last set of data to be added is maps of the shallow aquifer system.
8. The type log project is set for a team of experts to verify stratigraphic correlations of the Bittersweet team. Modern digital logs provide a view of the lithology and porosity and the cross section feature provides means of interpreting the geology.

## PLANS

1. The testing of the Cutter KGS #1 well will be completed with both pressure and fluid samples obtained from a dozen set of perforations.
2. A new version of the geomodel of the Mississippian will be completed in Petrel and initial runs of CO2-EOR will be simulated.
3. The penultimate regional CO2 storage estimates will be obtained based on the integration of the simulations of the regional sites extended to the stratigraphic and petrophysical information of the regional well dataset.

## SPENDING PLAN

See next page.

**COST PLAN/STATUS**

| | BP 1 Starts: 12/8/09 | Ends: 2/7/11 | | | | BP2 Starts 2/8/11 | Ends 8/7/12 | | | | | BP3 Starts 8/8/12 | Ends 2/7/14 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 12/8/09-12/31/09 | 1/1/10-3/31/10 | 4/1/10-6/30/10 | 7/1/10-9/30/10 | 10/1 - 12/31/10 | 1/1/11 - 3/31/11 | 4/1/11 - 6/30/11 | 7/1/11-9/30/11 | 10/1/11 - 12/31/11 | 1/1/12 - 3/31/12 | 4/1/12 - 6/30/12 | 7/1/12 - 9/30/12 | 10/1/12 - 12/31/12 | 1/1/13 - 3/31/13 | 4/1/13 - 6/30/13 |
| Baseline Reporting Quarter | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | Q11 | Q12 | Q13 | Q14 | Q15 |
| **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 | $1,169,543.00 | $1,169,543.00 | $1,169,543.00 | $316,409.00 | $316,409.00 | $316,409.00 | $316,409.00 |
| Non-Federal Share | $277,260.75 | $277,260.75 | $277,260.75 | $277,260.75 | $0.00 | $0.00 | $0.00 | $303,182.75 | $303,182.75 | $303,182.75 | $303,182.75 | $81,854.50 | $81,854.50 | $81,854.50 | $81,854.50 |
| 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 | $1,472,725.75 | $1,472,725.75 | $1,472,725.75 | $398,263.50 | $398,263.50 | $398,263.50 | $398,263.50 |
| 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 | $8,084,985.50 | $9,557,711.25 | $11,030,437.00 | $11,428,700.50 | $11,826,964.00 | $12,225,227.50 | $12,623,491.00 |
| **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 | $523,196.12 | $453,026.11 | $238,793.52 | $1,282,545.00 | $1,314,156.54 | $395,319.33 | $299,454.96 |
| Non-Federal Share | $0.00 | $43,980.04 | $40,584.78 | $13,195.88 | $526,210.30 | $35,887.34 | $414,511.02 | $20,247.24 | $16,687.00 | $61,683.20 | $150,646.51 | $221,053.41 | $121,637.40 | -$65,989.76 | $15,344.70 |
| Total Incurred Costs-Quarterly (Federal and Non-Federal) | $4,019.93 | $84,603.97 | $535,013.15 | $124,601.40 | $764,886.27 | $1,938,823.89 | $1,040,364.19 | $296,001.74 | $539,883.12 | $514,709.31 | $389,440.03 | $1,503,598.41 | $1,435,793.94 | $329,329.57 | $314,799.66 |
| Cumulative Incurred Costs | $4,019.93 | $88,623.90 | $623,637.05 | $748,238.45 | $1,513,124.72 | $3,451,948.61 | $4,492,312.80 | $4,788,314.54 | $5,328,197.66 | $5,842,906.97 | $6,232,347.00 | $7,735,945.41 | $9,171,739.35 | $9,501,068.92 | $9,815,868.58 |
| **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 | $646,346.88 | $716,516.89 | $930,749.48 | -$966,136.00 | -$997,747.54 | -$78,910.33 | $16,954.04 |
| Non-Federal Share | $277,260.75 | $233,280.71 | $236,675.97 | $264,064.87 | -$526,210.30 | -$35,887.34 | -$414,511.02 | $282,935.51 | $286,495.75 | $241,499.55 | $152,536.24 | -$139,198.91 | -$39,782.90 | $147,844.26 | $66,509.80 |
| Total Variance-Quarterly Federal and Non-Federal) | $1,280,863.57 | $1,156,299.49 | $749,870.35 | $1,160,282.10 | -$764,886.27 | -$1,938,823.89 | -$1,040,364.19 | $1,176,724.01 | $932,842.63 | $958,016.44 | $1,083,285.72 | -$1,105,334.91 | -$1,037,530.44 | $68,933.93 | $83,463.84 |
| Cumulative Variance | **$1,280,863.57** | **$2,437,163.06** | **$3,187,033.41** | **$4,347,315.51** | **$3,582,429.24** | **$1,643,605.35** | **$603,241.16** | **$1,779,965.17** | **$2,712,807.80** | **$3,670,824.24** | **$4,754,109.96** | **$3,648,775.05** | **$2,611,244.61** | **$2,680,178.54** | **$2,763,642.38** |