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.

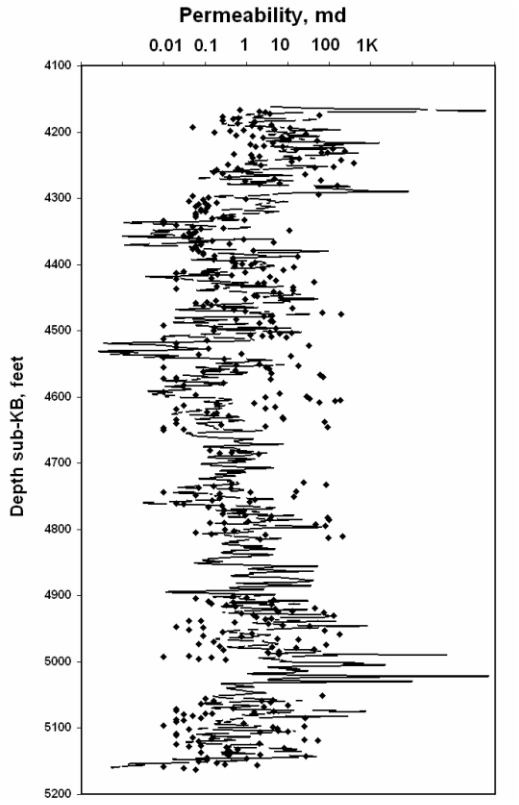


Figure 9. Wellington KGS #1-32 Arbuckle interval showing the permeability predicted by the MRI Coates equation calibrated to the core permeabilities. Prepared by J. Doveton.

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.

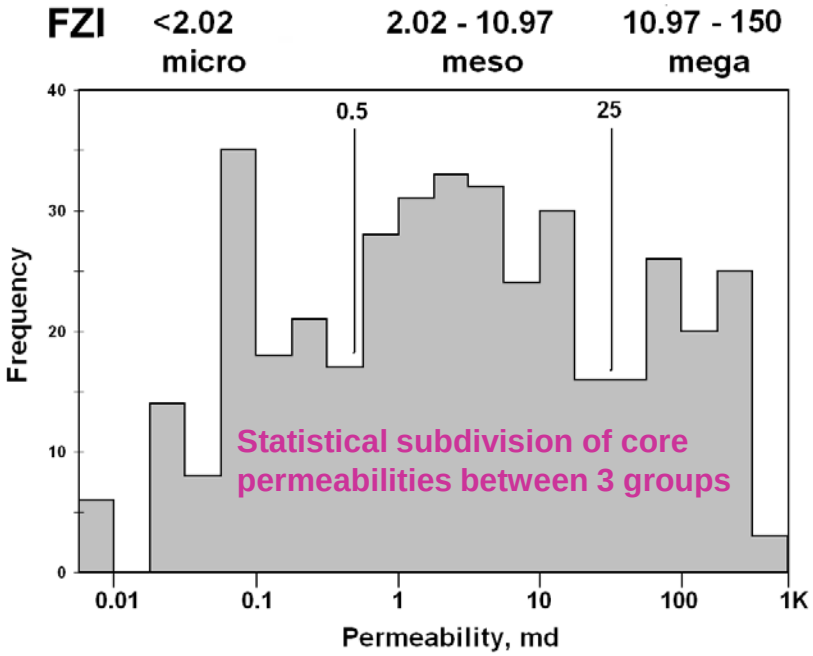


Figure 10. Statistical subdivision of core permeabilities comparing frequency of permeability by flow zone indicator (FZI). Prepared by J. Doveton.

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.

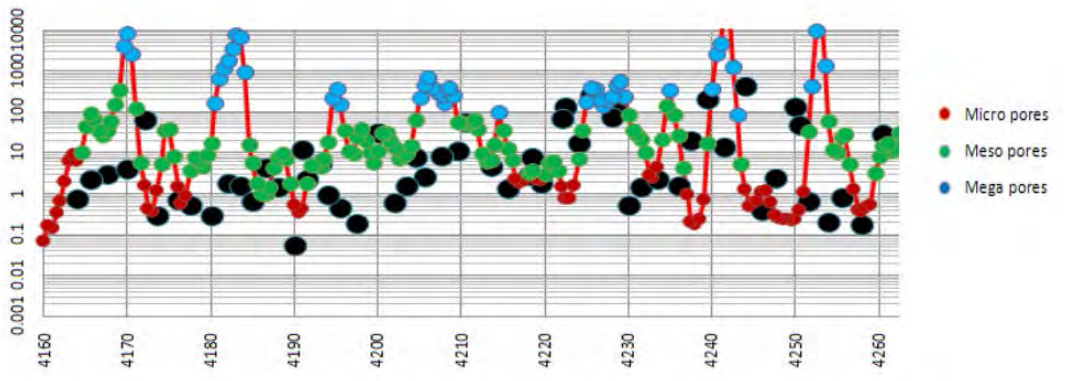


Figure 11. The computed permeability by the Fazelalavi method with micro, meso, and mega pores, is compared with the core analysis, shown as black dots. Prepared by J. Doveton.

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.

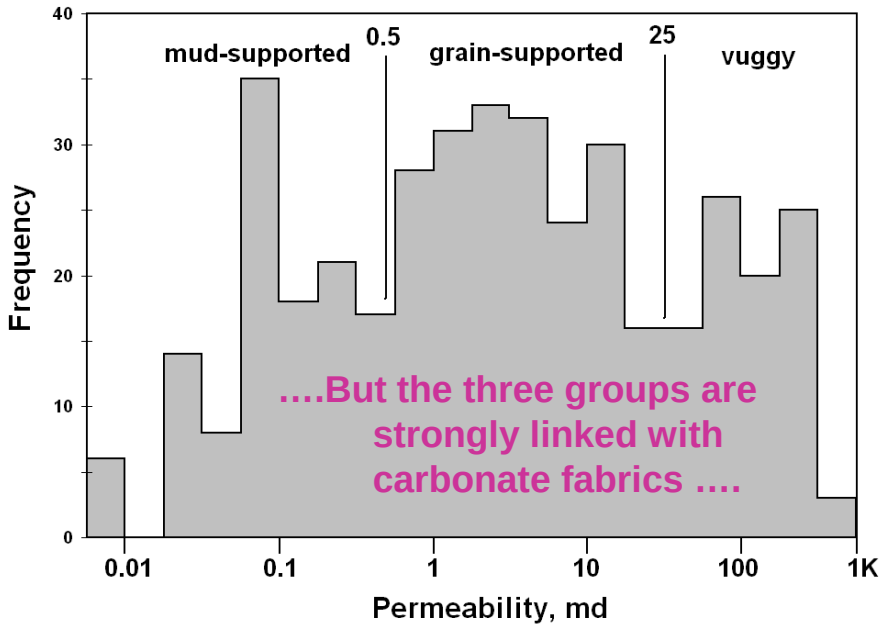


Figure 12. Distribution of permeability is closely related to carbonate fabrics. Prepared by J. Doveton.

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.

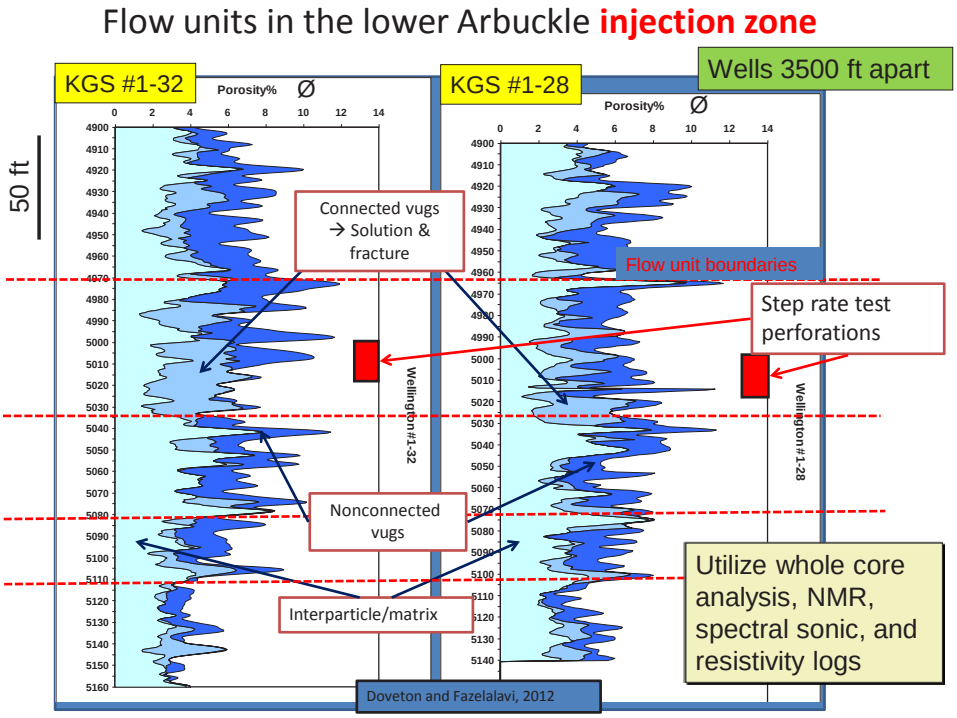


Figure 13. Flow units assigned based simply on stratigraphic patterns of pore type and porosity abundance that can be correlated between wells. This approach to pore classification and assigning properties that relate to the flow and storage of CO2 is what is sought through the use of fuzzy logic algorithms.

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*

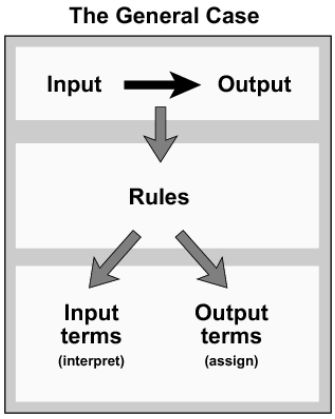


Figure 13. General description of a fuzzy system.

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.

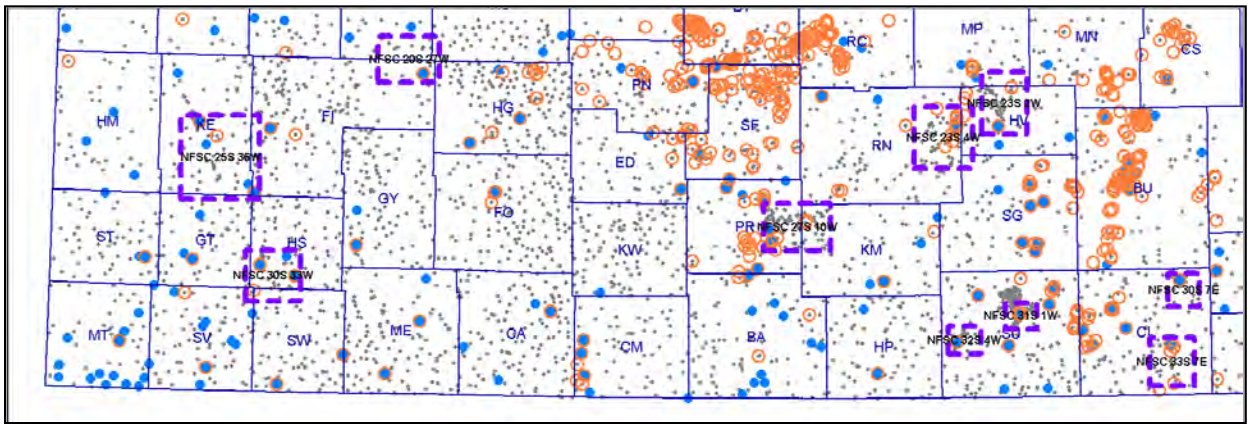


Figure 14. Ten modeling sites in south-central Kansas.

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.

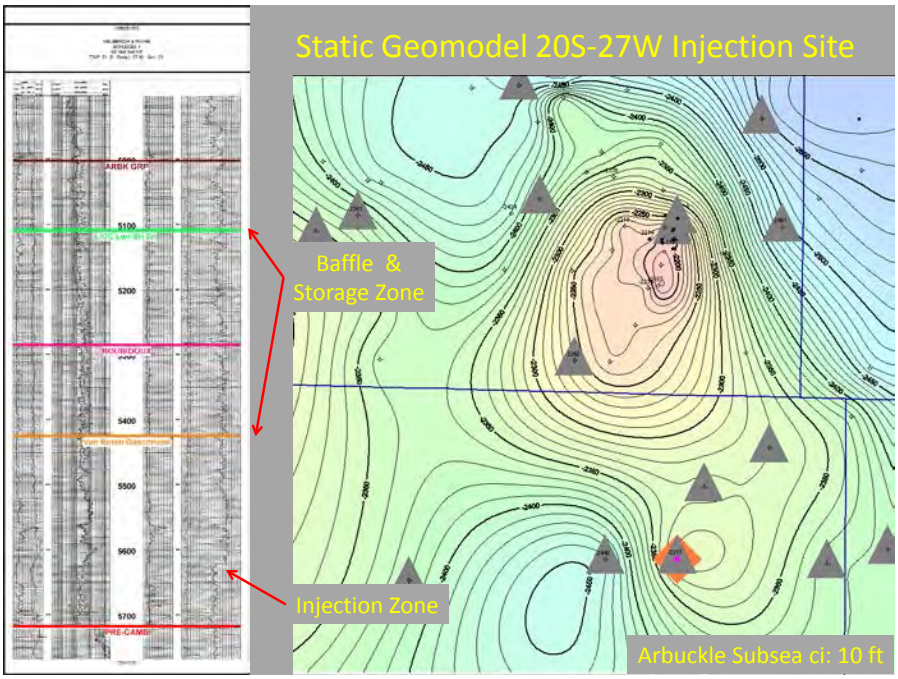


Figure 15. Arbuckle at this site is 800 ft thick on a structure that has approximately 150 ft of structural closure. Structure is also the site of Witt oil field that produces from the Mississippian from this structural closure.

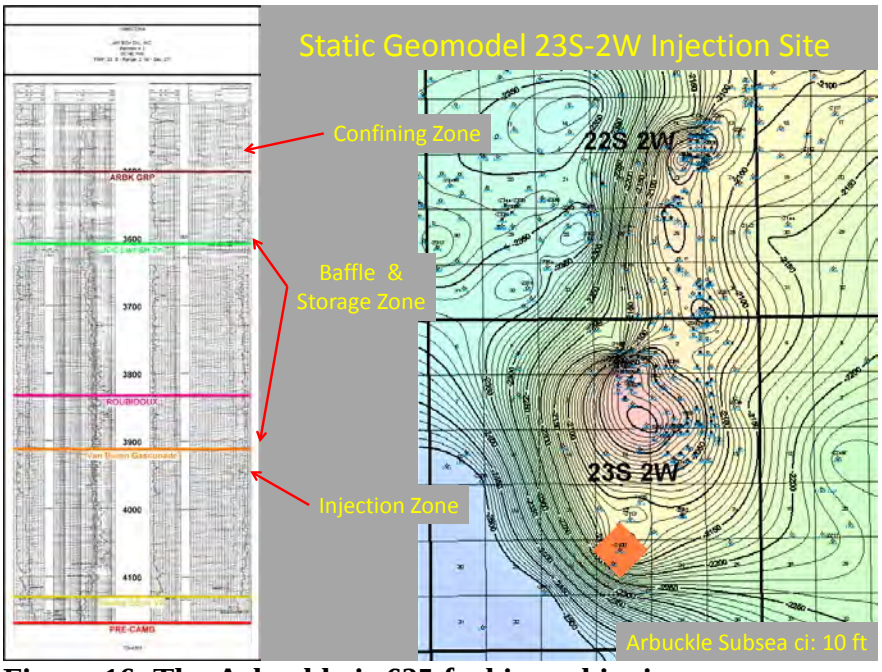


Figure 16. The Arbuckle is 625 ft this at this site over a structure that has 150 ft of relief. The structure also is the site of an oil field, Halstead. The pay zones in the field include Lansing-Kansas City, Mississippian, and Simpson Group.

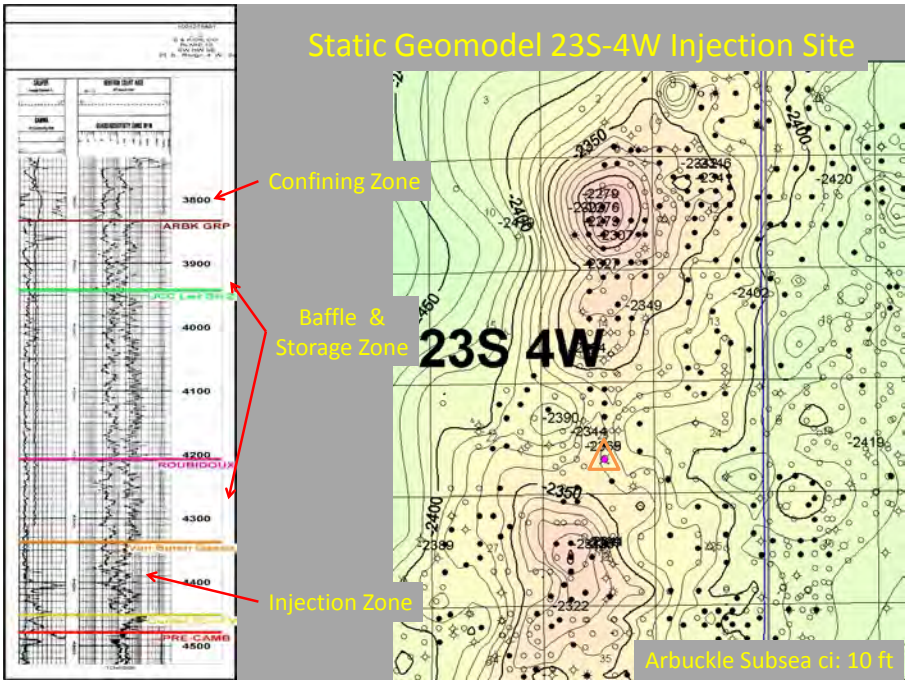


Figure 17. The Arbuckle is 700 ft thick on a structure with over 150 ft of closure. The site is the location of Burrton Field, a multipay field with a cumulative production of 87 million barrels of oil.

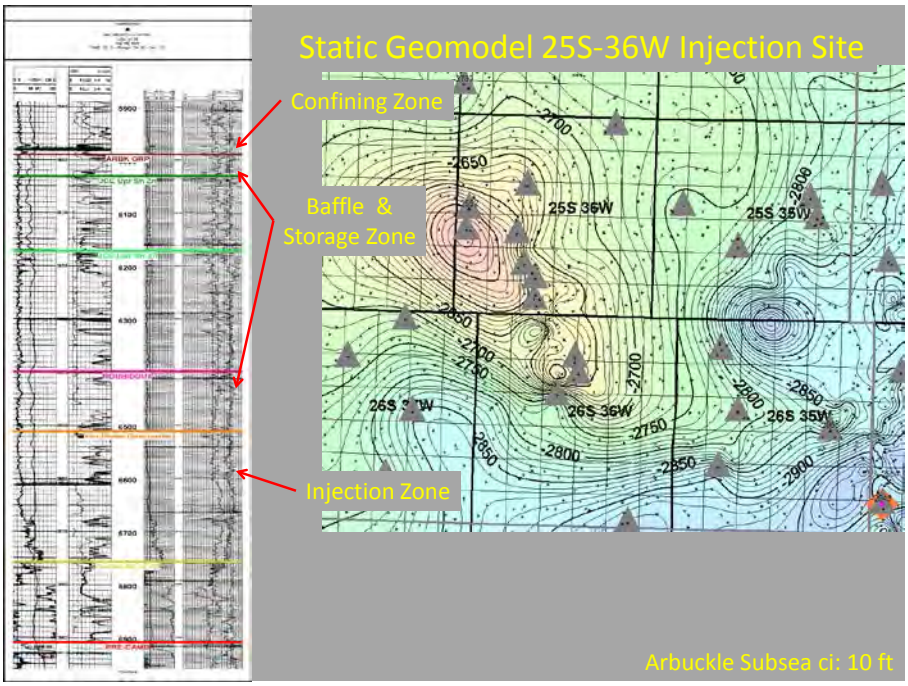


Figure 18. The site has 900 ft of Arbuckle and is located on a structure with 200 ft of closure. The site is the location of Lakin Field in Kearney County.

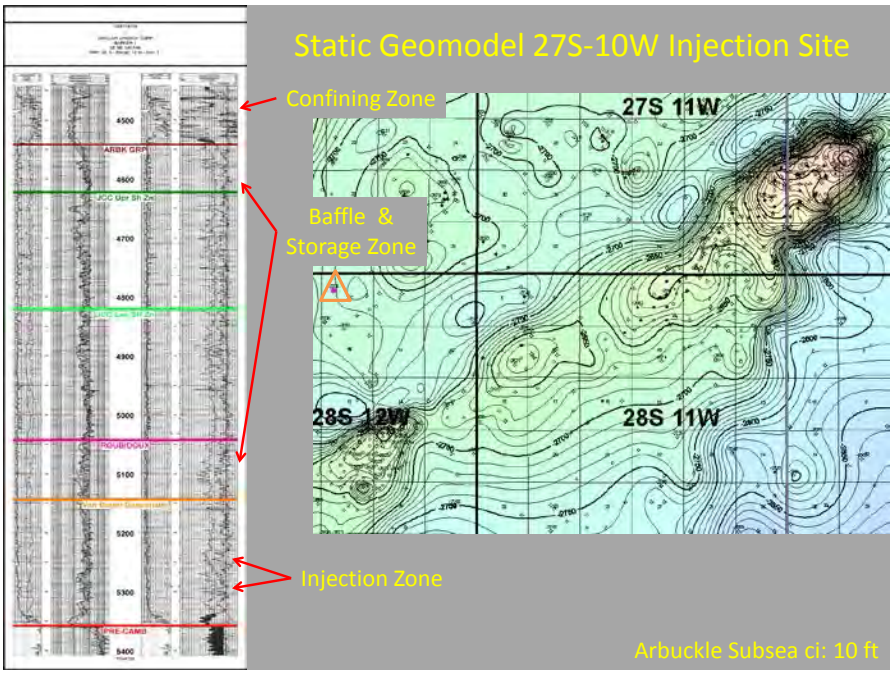


Figure 19. The site has 800 ft of Arbuckle and over 200 ft of structural closure. The site is the location of the multi-pay Cunningham oil field in Kingman County.

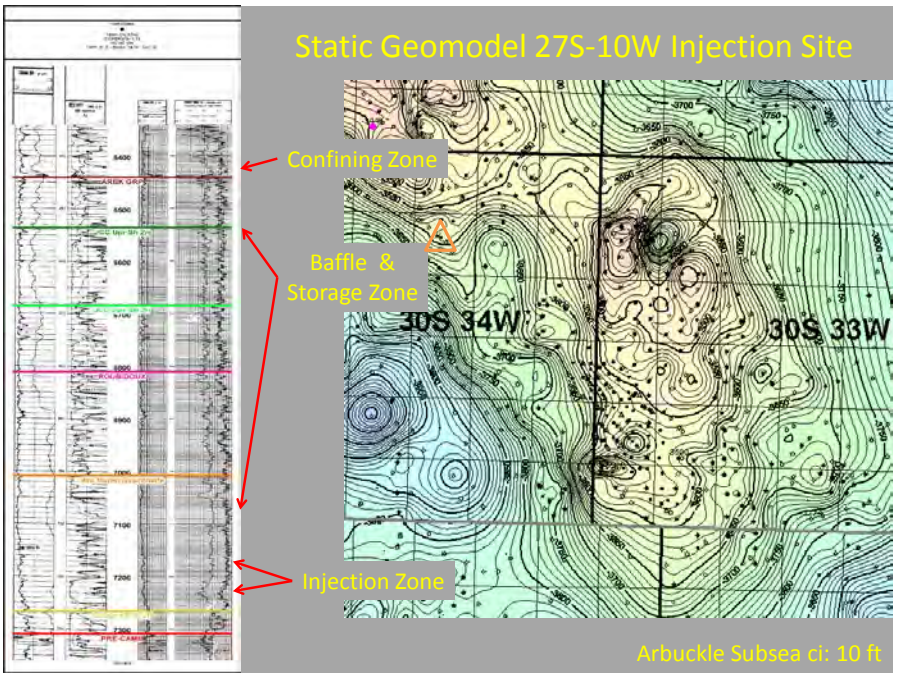


Figure 20. The location has 850 ft of Arbuckle with over 250 ft of relief on the structure. The site is also the location of Victory Field that has produced over 15.5 million BO from multiple producing horizons.

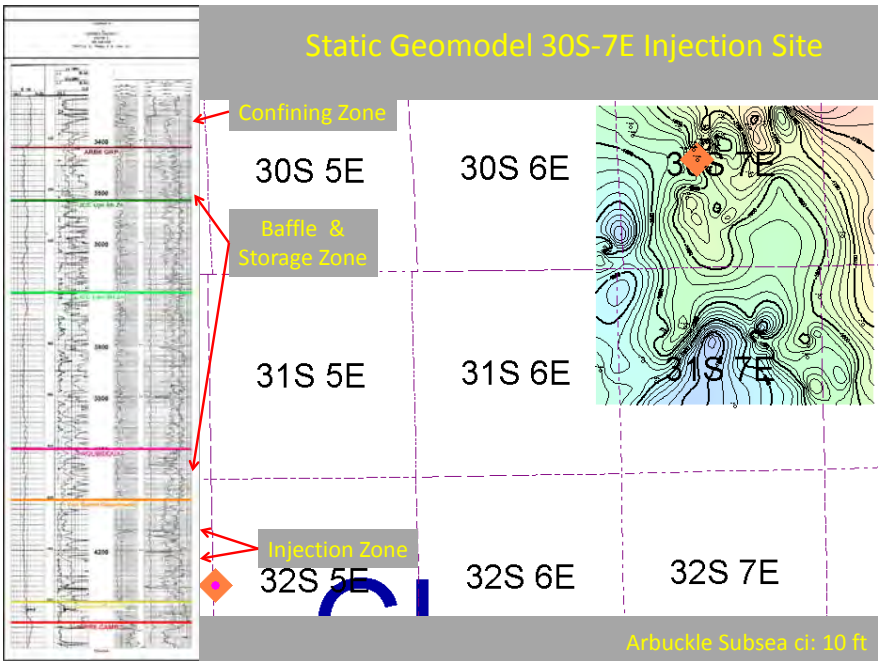


Figure 21. The site has 950 ft of Arbuckle and is the site of Box Field. The structure has in excess of 150 ft of relief.

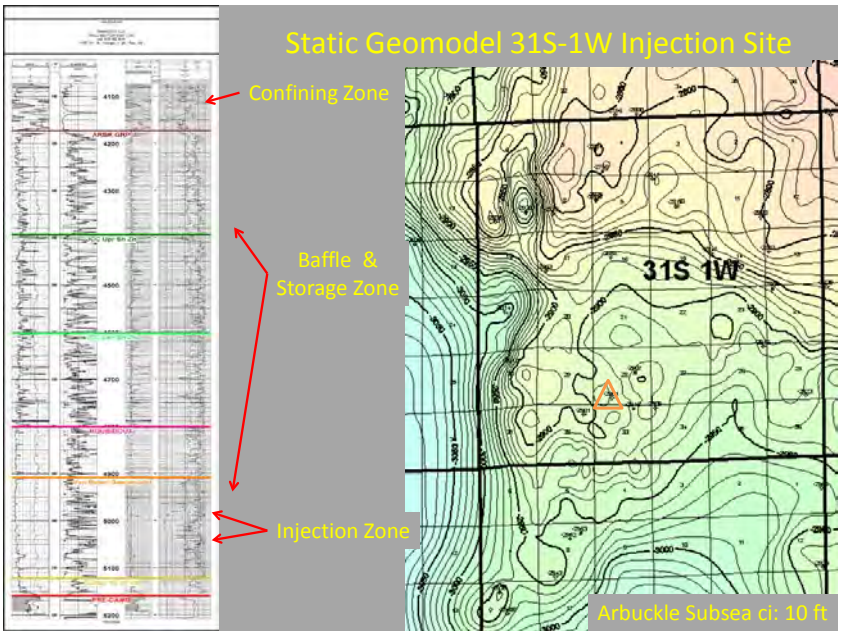


Figure 22. This location is Wellington Field, with its Mississippian oil pay zone. The structure has 100+ ft of relief and contains 1000 ft of Arbuckle.

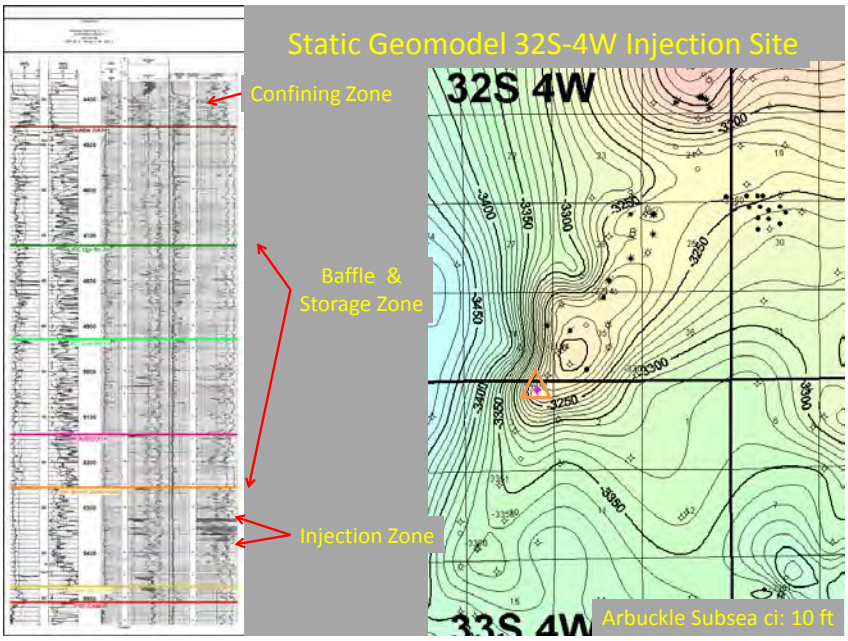


Figure 23. The location is another oil field, Yarnell that produces from the Mississippian. The Arbuckle is 1000 ft thick and the structural relief is around 100 ft.

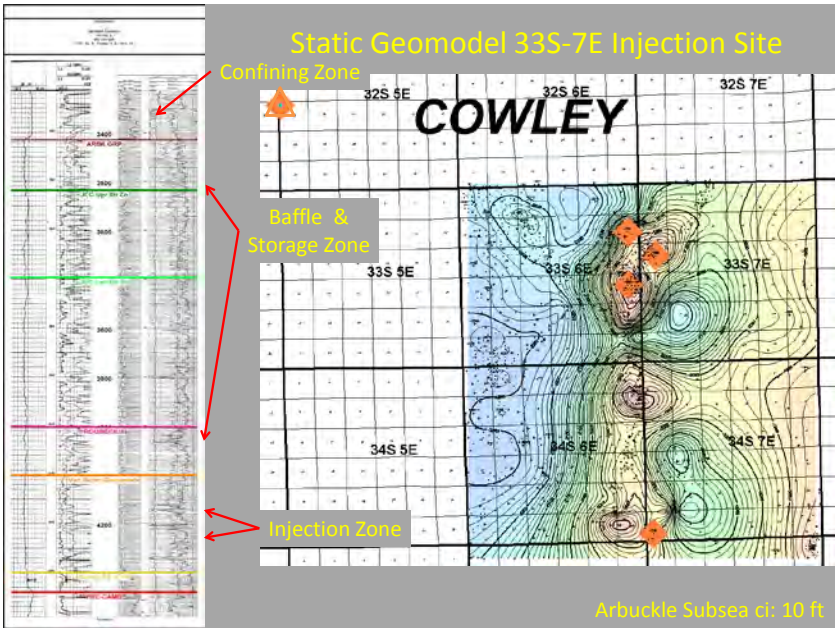


Figure 24. This location has 950 ft of Arbuckle with over 200 ft of relief. The site is also the location of Dexter Field with primary production from the Mississippian reservoir.

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.

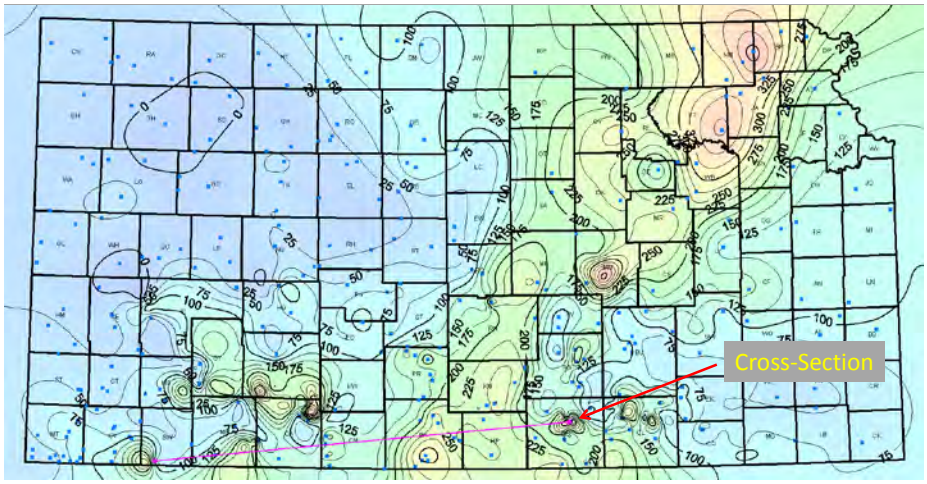


Figure 25. Combined isopach of the lower Mississippian, Chattanooga Shale, and Simpson Group in Kansas. West to east cross section index line is shown by the pink colored line.

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.

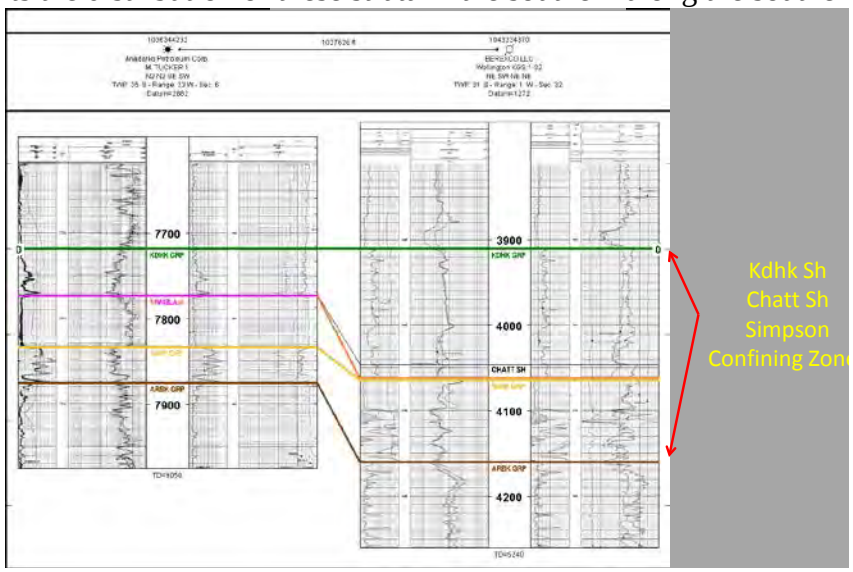
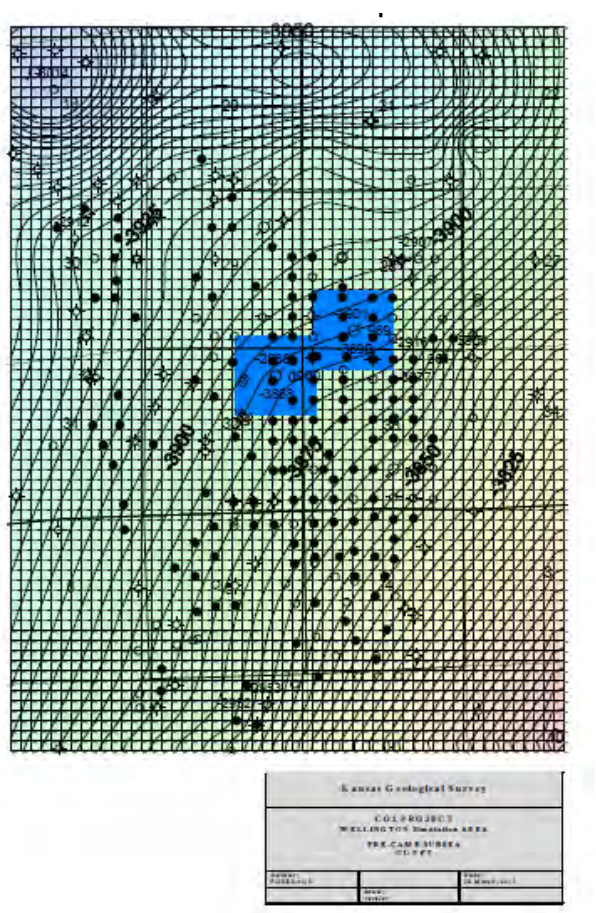


Figure 26. West to east cross section with a datum on the top of the "Kinderhook" limestone. Shales in general area thicker in the east along the axis of the underlying Proterozoic Midcontinent Rift System.

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).

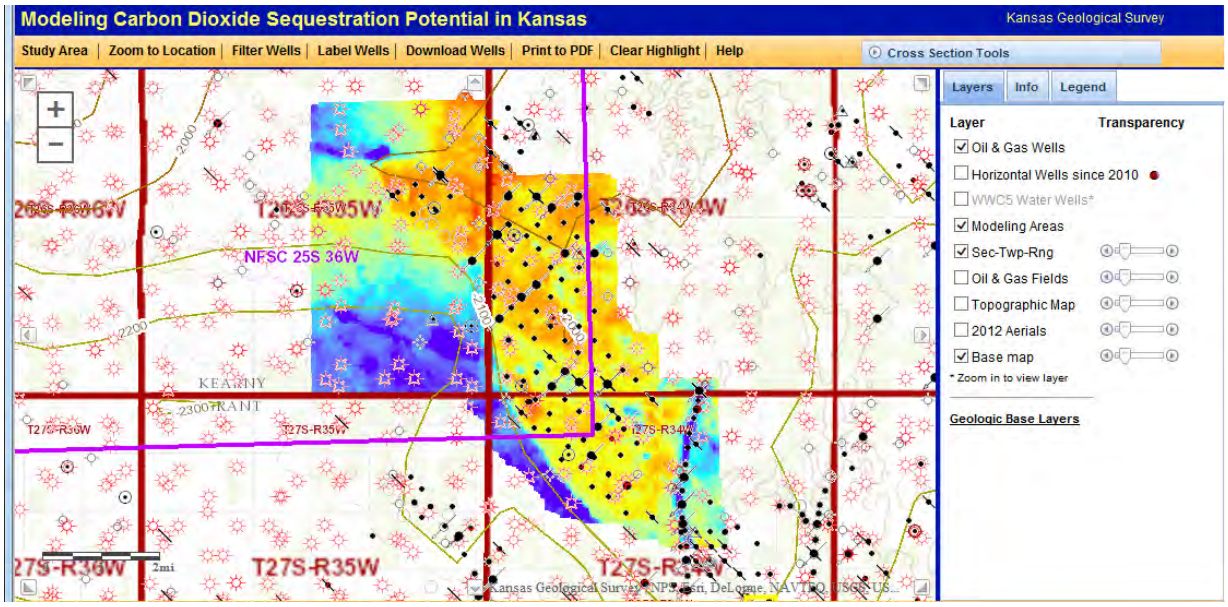
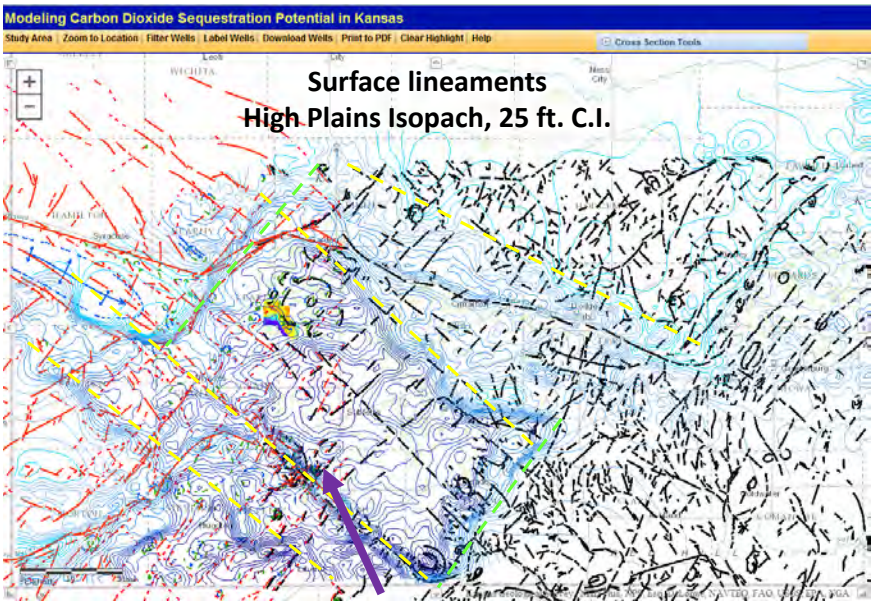


Figure 28. Project's interactive mapper at Pleasant Prairie Field shown time structure of top of Meramec from 3D seismic along with well information and regional contours of the Mississippian surface.

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).

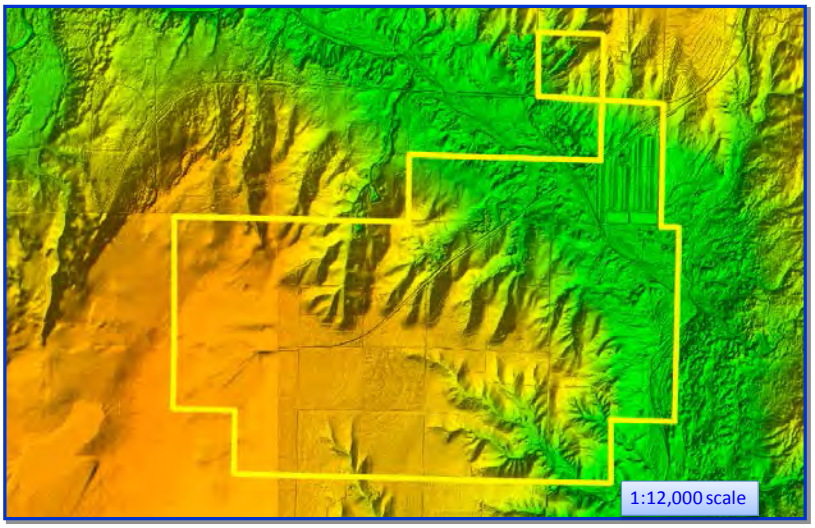


Figure 30. LiDAR image of the Cutter oil field in NE Stevens County, the site of new well and multicomponent seismic data. The area shown is highlighted with purple arrow on Figure 29.

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.

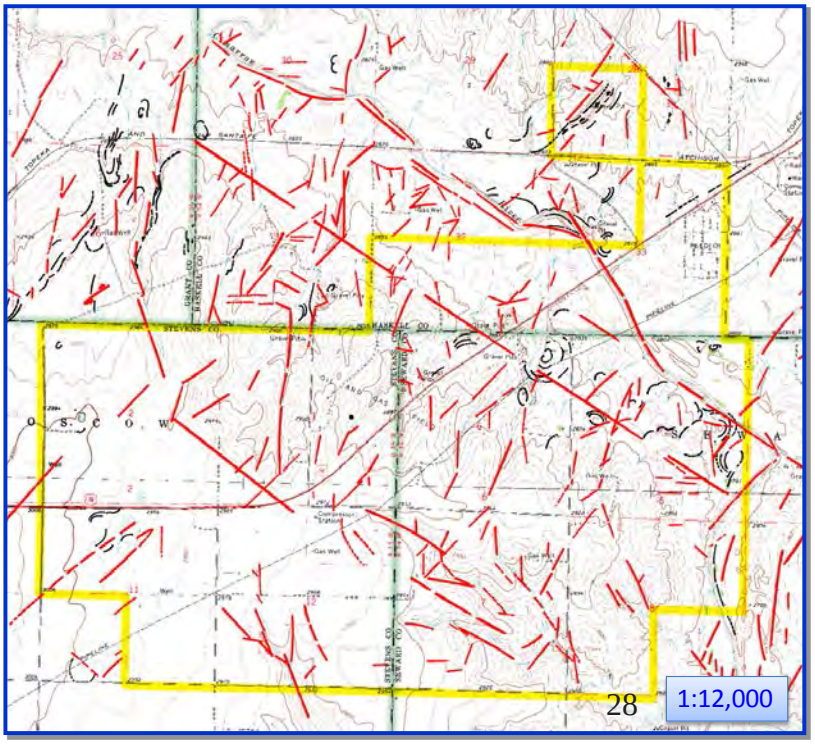


Figure 31. Lineaments derived from the LiDAR imagery over Cutter Field. LiDAR image is shown in Figure 30.

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).

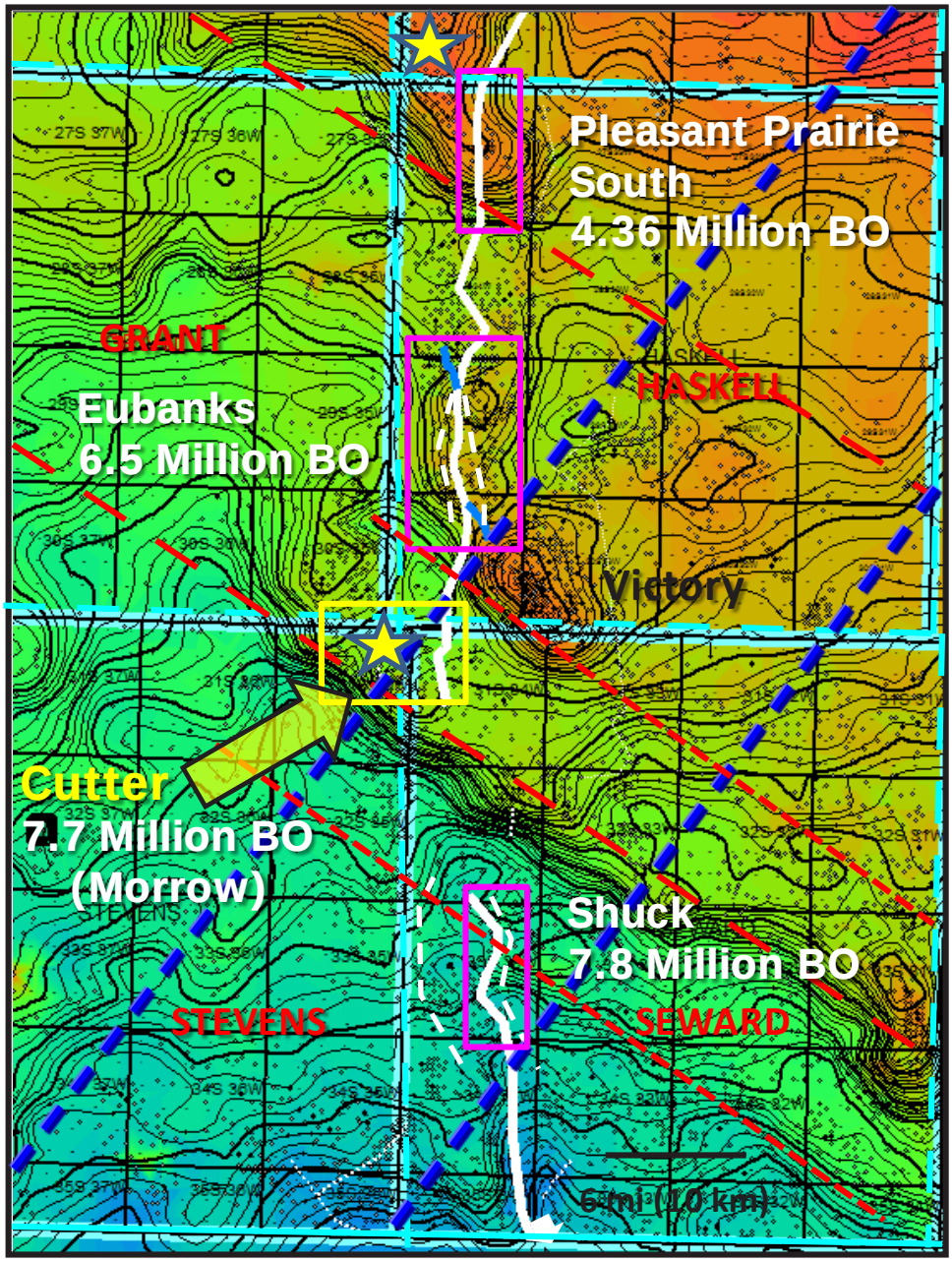


Figure 32. Structure top of Meramec Mississippian in the area of the set of field studies in southwest Kansas. The Cutter Field is highlighted in yellow. Red and blue dashed lines highlight the regional structural trends. Two of these structural trends intersect at Cutter Field. These structural trends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

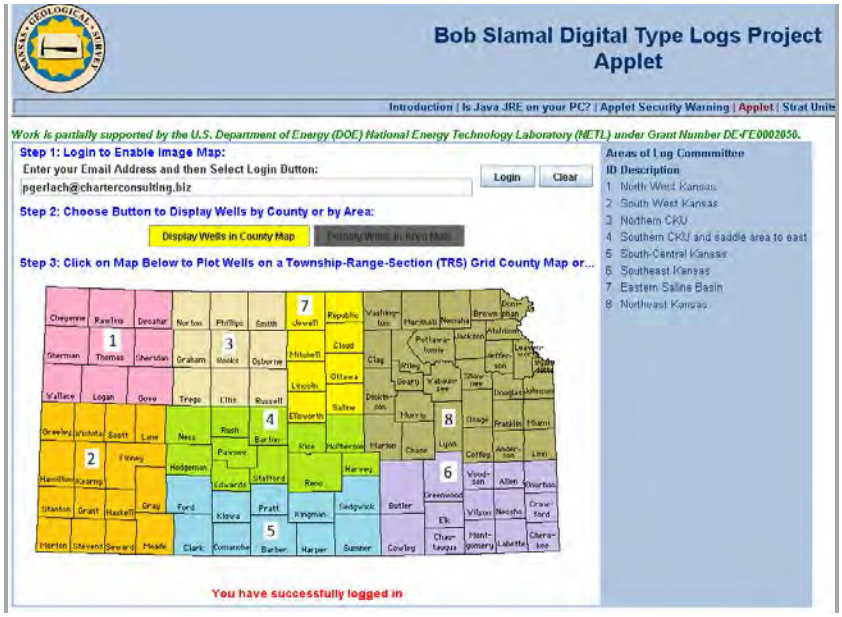


Figure 33. Type log interface showing areas assigned to team to correlate.

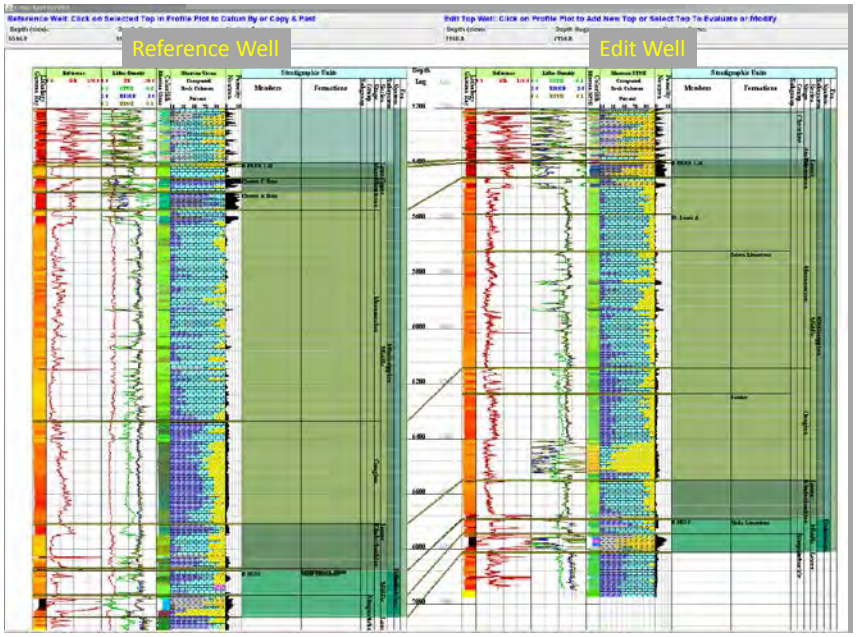


Figure 34. Comparison is preformed between a reference and edit well.

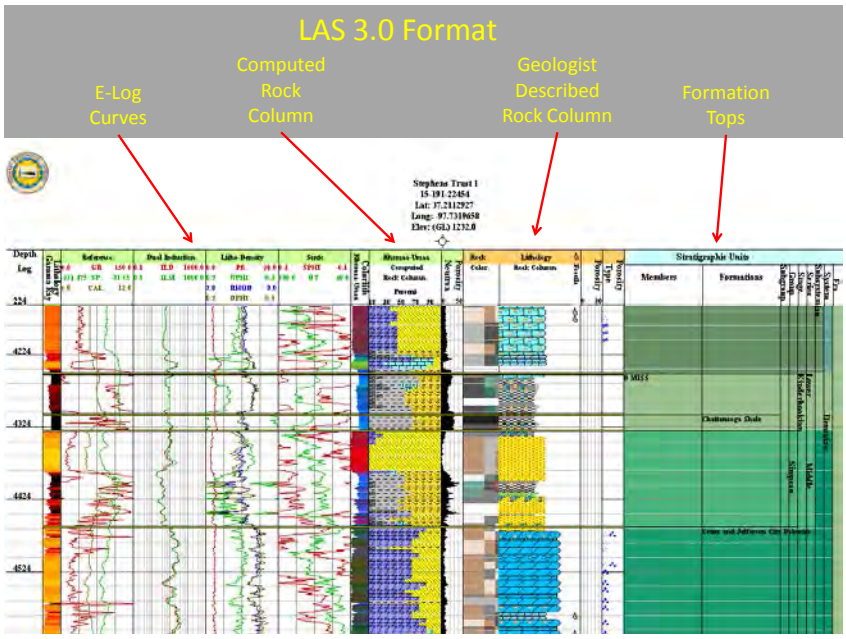


Figure 35. Information included in a LAS 3.O digital log file.

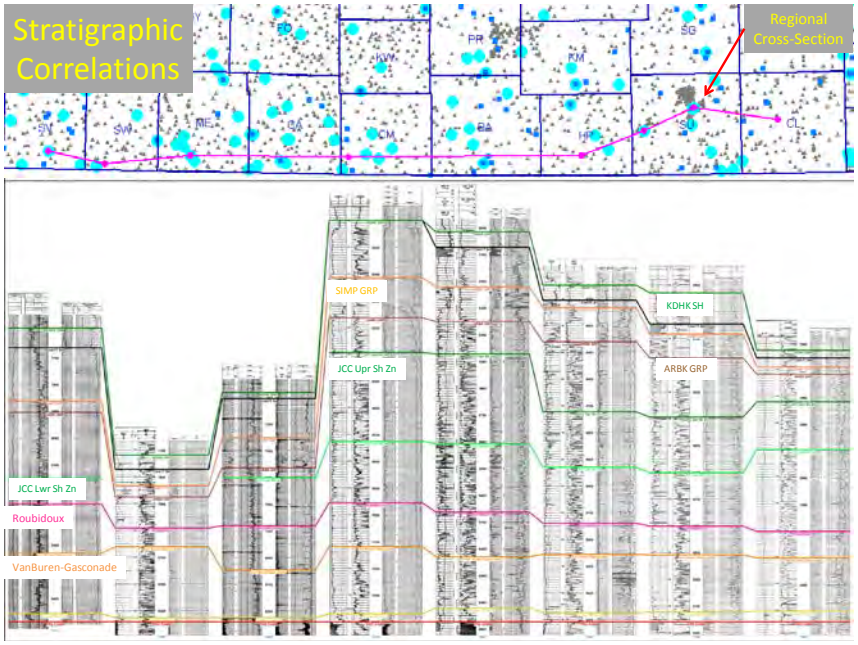


Figure 36. Regional west to east cross section across the southern portion of the study area in southern Kansas along the Oklahoma border.

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 4th, 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.

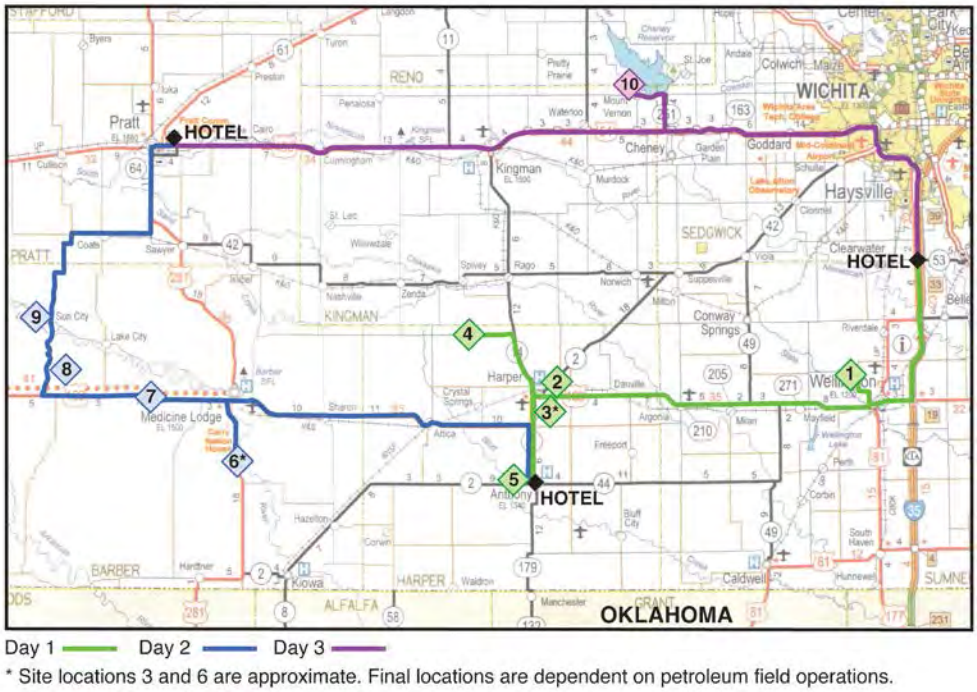


Figure 37. Route and stops in south-central Kansas for the 2013 Annual Field Conference.

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.

APPENDIX I

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

SIXTEENTH QUARTER PROGRESS REPORT

DOE F 4600.2
(5/09)
(All Other Editions are Obsolete)

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			
☒ Other (see special instructions) Topical — DOE F 241.3	A		http://www.osti.gov/estsc/241-4pre.jsp
** 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**

Sixteenth Quarter Progress Report

Date of Report: 10-31-13

Period Covered by the Report: July 1, 2013 to September 30, 2013

**Contributors to this Report: Brent Campbell, John Doveton,
Mina Fazelalavi, Paul Gerlach, Tom Hansen, Dennis Hedke,
Eugene Holubnayak, Larry Nicholson, Jennifer Raney, Jason Rush, 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		80%
2.0 Characterize the OPAS (Ozark Plateau Aquifer System)	1/1/2010	01/01/10	9/30/2013		90%
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	+++	90%
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		80%
13.0 Regional source sink relationship	1/1/2010	1/1//2010	9/30/2013		95%
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	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		90% 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		80% 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

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

1) Analysis of Cutter Field data including well logs, core, and seismic data

Weatherford Labs has completed 190 of the 307 whole core analyses and 42 of the 55 plug analyses of the 1024 ft of core acquired in the Berexco Cutter KGS #1. Whole core analysis include Kmax, K90, and Kvert, porosity, grain density, and fluorescence. Plug samples included analysis for air and klinkenberg permeability, porosity, grain density, and fluid saturations. The phi & k plotted versus depth (**Figure 1**) shows preliminary, incomplete analytical results for the core interval extending from the Morrow sandstone to the lower portion of the Arbuckle Group, the Gasconade Dolomite.

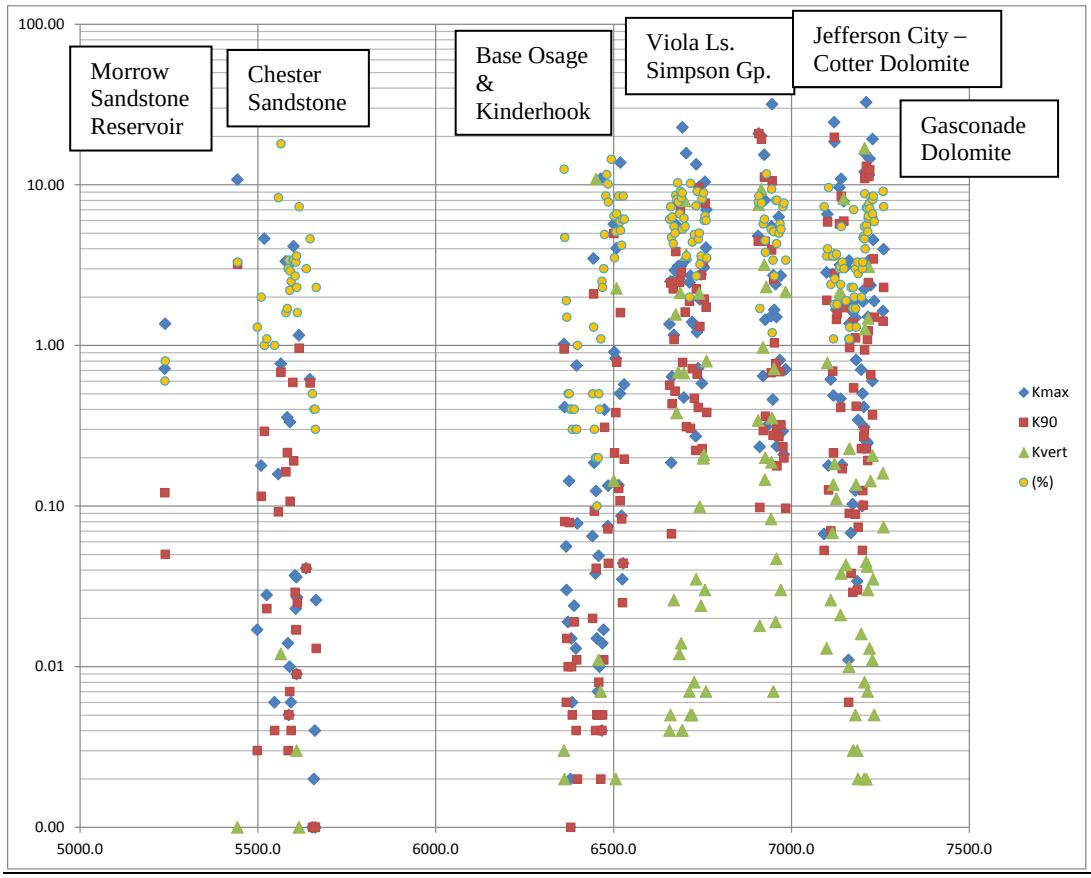


Figure 1. Porosity (%) and permeability (millidarcies) from full diameter core analysis including maximum (Kmax), 90 degrees to maximum (K90), and vertical (Kvert) vs. depth in feet below the surface.

Kmax ranges up to 10 md in the Chester to over 30 md for the portions of the Arbuckle strata. K90 and Kmax are similar in value while the Kvertical is less by up to several orders of magnitude than the other two measures of permeability. The latter suggests that fracture permeability is not significant in those intervals, at least as captured in the whole core samples. Porosity typically ranges between 1 and 10 percent, decidedly low, but in the range of the core from Wellington Field (KGS #1-32). A permeability-porosity crossplot indicates that for a single porosity value that the permeability varies by 4.5 orders of magnitude (**Figure 2**).

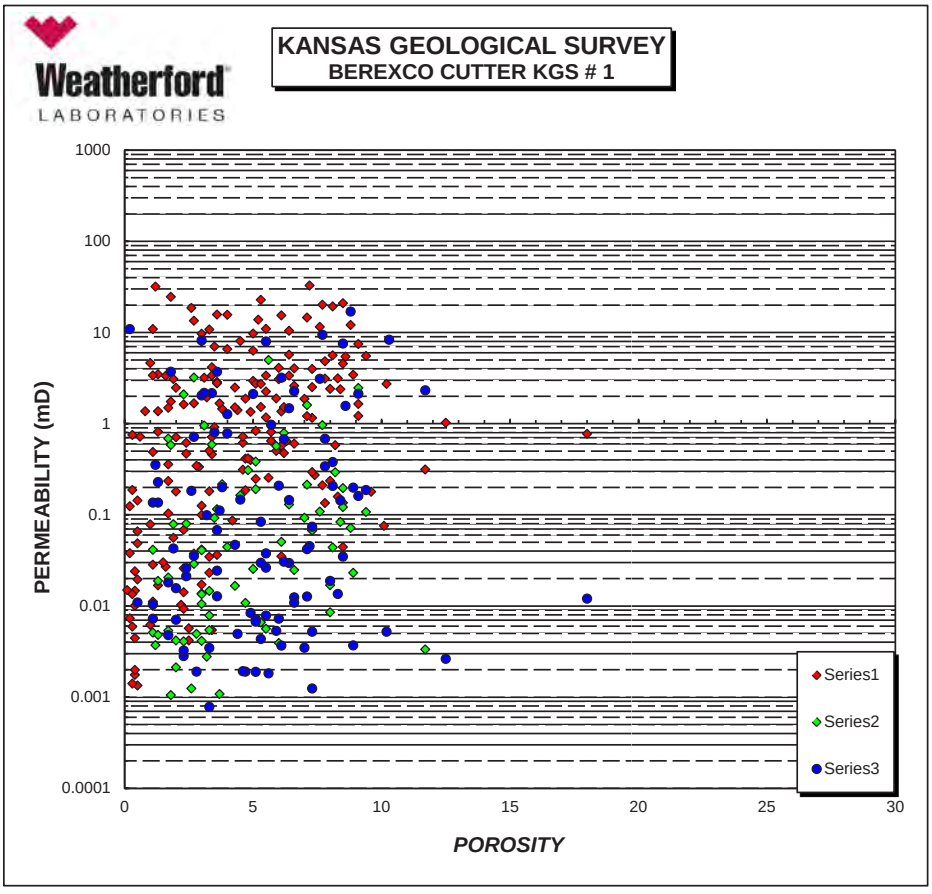


Figure 2. Permeability vs. porosity.

A crossplot of Klinkenberg permeability, ambient porosity, and water and oil saturations obtained from core plugs indicate Darcy-scale permeability, higher porosity, and oil saturation are present in the Lower Pennsylvanian Morrow oil reservoir sandstone while marginal permeability and slightly less oil saturations

are noted in core plugs from the Chester (Upper Mississippian) sandstone. Core plugs from the lower Arbuckle indicate low permeability and porosity below 10% while samples selected to analyze hydrocarbon shows (flurescence) also contain residual oil saturation at levels similar to the Morrow and Chester intervals (**Figure 3**).

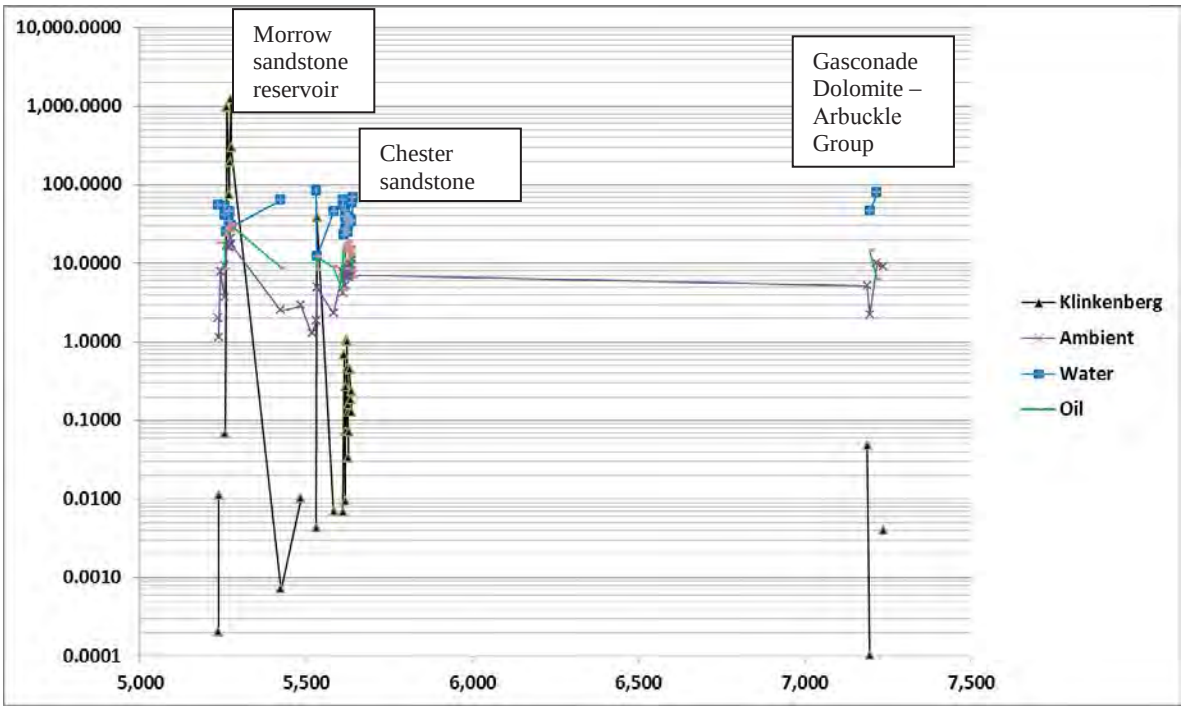


Figure. 3. Crossplot of permeability, ambient porosity, and water and oil saturations versus depth obtained from saturation analysis of core plugs selected from the Berexco Cutter KGS #1 core.

Also, 2 inch diameter horizontal plugs were sent to KSU for flow studies. End trimmings to make a right cylinder are being sent to Spectrum Petrographics Inc for thin section preparation. End samples of the core will also being used to obtain X-ray diffraction mineral composition.

2) Well testing and pressure buildup tests in lower Paleozoic strata at Cutter Field

Following drilling of the well, it was cased and cemented top to bottom. Eleven zones were selected to obtain connate fluids for geochemical analysis by perforating and swabbing the major hydrostratigraphic units that lie between the basal Pennsylvanian strata to the Proterozoic basement. Teams from Kansas University and Kansas State University joined in the sampling that will lead to analyses of cation and anions in solution, microbial content, and crude oil, the latter analysis following up on a series of oil shows.

The perforating and swabbing were started in June 2013 and extended through July 2013. Lower zones of the tests in the Arbuckle were also subjected to pressure buildup test to estimate permeability.

Eleven intervals were tested after casing was set and two DSTs were acquired during drilling (**Figures 4 and 5**). The protocol for acquiring fluid samples follows.

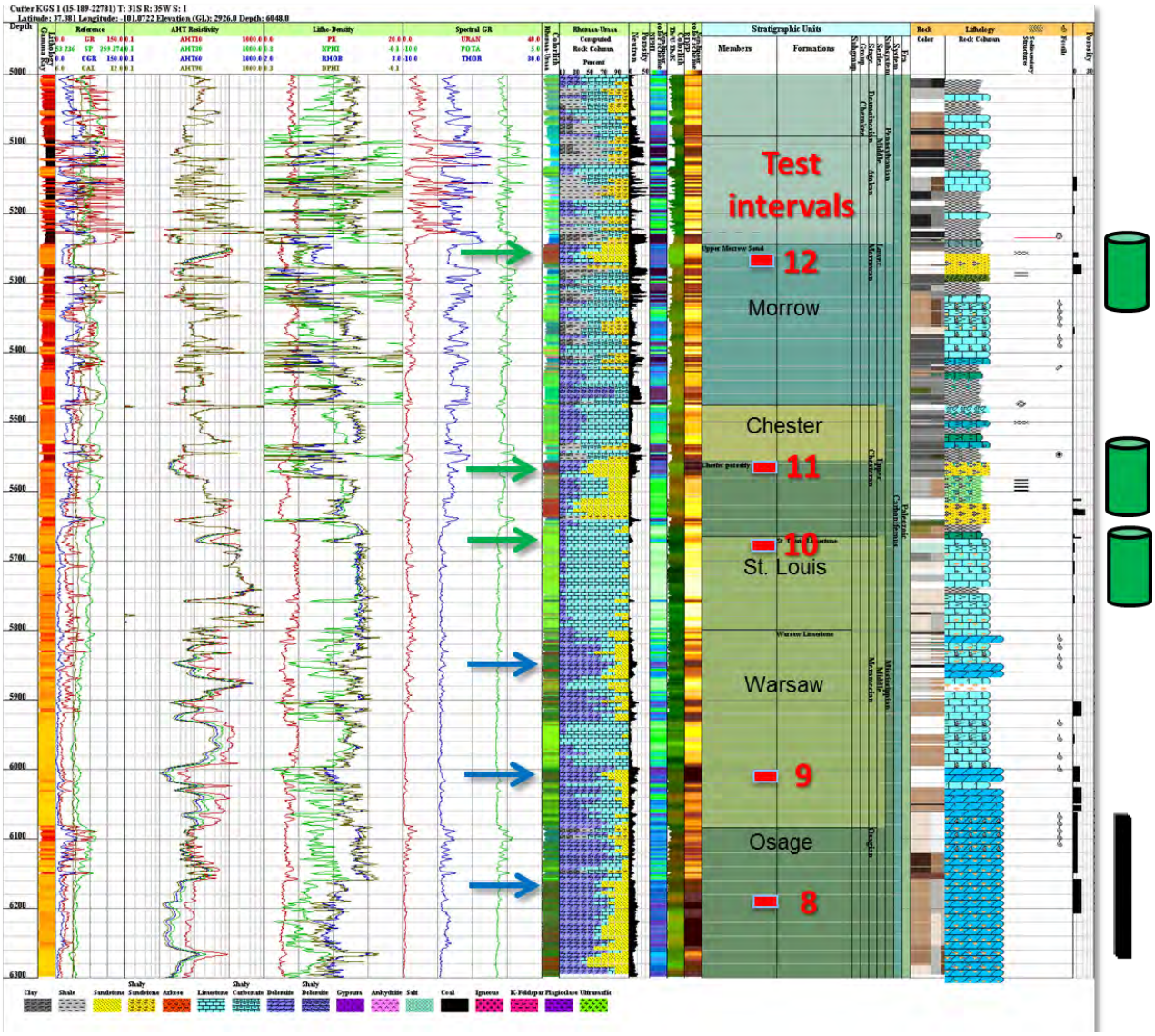


Figure 4. Upper portion of the cored interval in the Cutter KGS #1 well showing zones 8-11 that were tested.

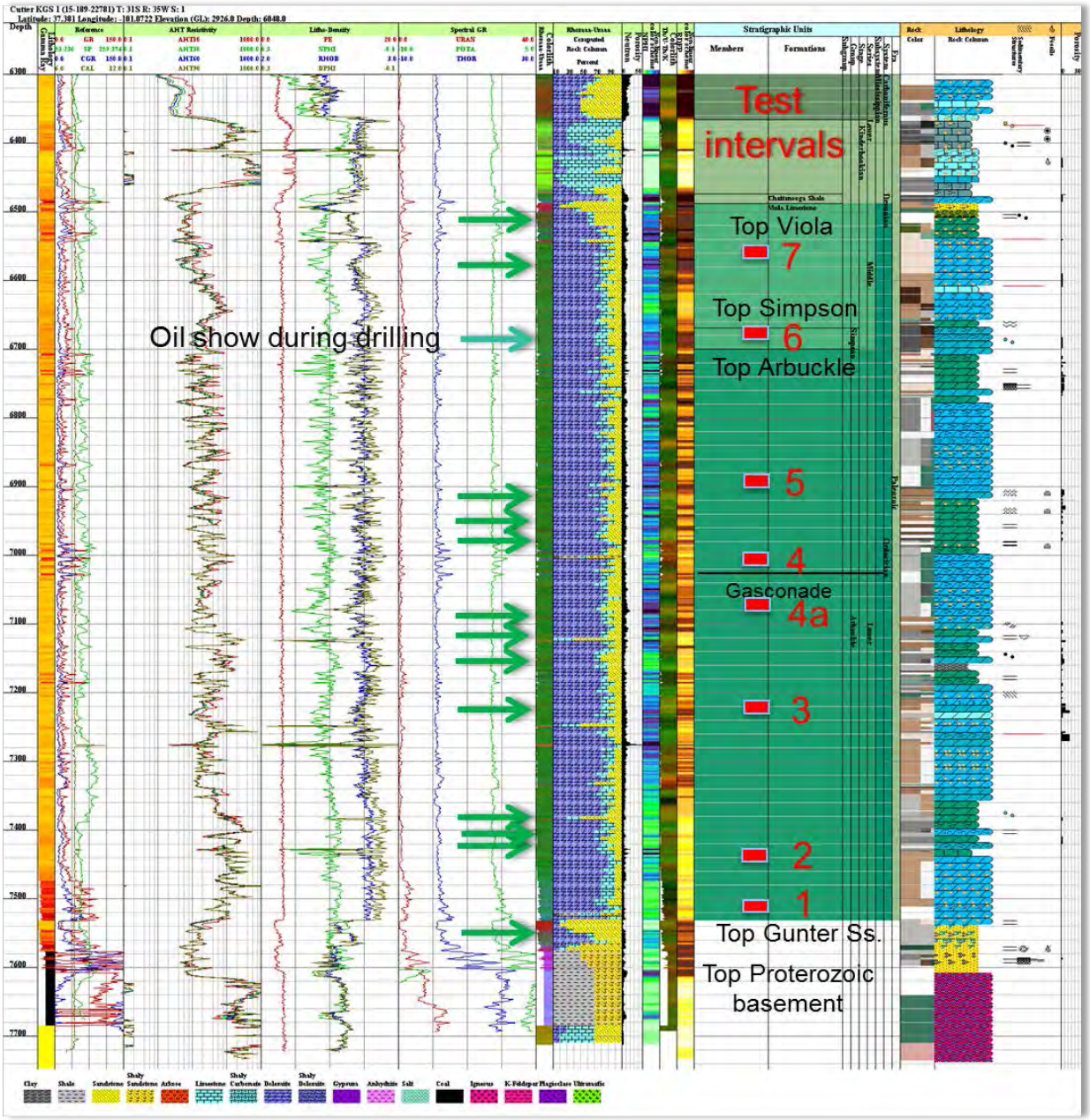


Figure 5. Lower portion of the cored interval in the Cutter showing test intervals 1 through 7.

Water sampling summary --

June-July, 2013 -- 11 perforating and swabbing, and 2 DST depth water samples were taken.
August, 2013 -- core plugs were sent off to Spectrum Petrographics Inc for thin section, 17 + 9 slides were returned.
September, 2013 -- water samples were analysed for ICP-OES for cation analysis, anion analyses are in progress.

Protocol and observations -- fluid sampling from swab tests during June-July, 2013

Water retrieved from interval was sampled inside a 5 gal jug for analysis, and two 2 gal. HDPE jugs which were filled to the top and sealed immediately upon retrieval.

As most of the water was very turbid and required filtering of most intervals before analysis could occur. Formation water in the upper intervals did allow for analysis without filtration. During filtering water was simultaneously collected in our sample packs. All containers were rinsed 3 times with formation water before taking final sample. All bottles were sealed with black electrical tape.

Sample packs included:

- 2-500ml clear HDPE bottles, Unacidified and Unfiltered
- 2-250 amber glass bottles (C^{14} dating), Unacidified and Unfiltered
- 2-125ml amber HDPE bottles, 1 Acidified and Filtered, 1 Unacidified and Unfiltered
- 2-125ml amber glass bottles, Acidified and Filtered
- 2-60ml clear glass bottles (Stable Isotopes), Unacidified and Unfiltered
- 2-50ml centrifuge tubes, 1 Unacidified and Unfiltered, 1 Acidified and Filtered
- 1-60ml clear class bottle (Oil sheen), underside of lid added aluminum foil
- 1-Vial clear glass (DIC)

Water was analyzed using the Hach Hydrolab MS5 with Hach Recon PDA, Mettler Toledo SevenGo Pro Dissolved Oxygen meter, Mettler Toledo SevenGo Conductivity meter, and Hach HQ40d Multi meter. As equalization was occurring, water was tested for Fe^{2+}, Total Fe, Alkalinity, and Sulfate using a UV-VIS spectrophotometer. Later, Nitrate, Ammonia, and an additional Total Fe test were added.Two water samples were measured to ensure accuracy and if the two results were in disagreement a third test was run.

Once equalization occurred measurements were made with the HACH Hydrolab, and 3 probes.

The 3 different probes and their tests:

- 1-Mettler Toledo SevenGo Pro meter-Dissolved Oxygen
- 2-Hach HQ40d Multi meter-pH, ORP, and Temperature
- 3-Mettler Toledo SevenGo meter-Conductivity, Resistivity, Salinity, and TDS

The Hach Hydrolab MS5 measured:

- Conductivity
- LDO
- ORP
- pH
- Resistivity
- Salinity
- Temperature
- TDS
- Turbidity

We waited for equilibration with the instruments, and then recorded measurements. Once we felt comfortable with the results we moved on to further analysis with testing kits. All testing kits were ran twice to ensure accuracy, if differed we again took a 3rd test.

Testing kits included:

- Alkalinity
- Chloride
- Do
- Nitrate
- Nitrite
- Phosphate
- Silica
- Sulfate

All 11 swab intervals and the two DST's were analysed in September 2013 for cation analysis via ICP-OES. Data received back October 1st. Information will shared in a subsequent quarterly report.

Pressure buildup test

Permeablity was measured in both core plugs and in full diameter core for the Cutter KGS #1 as noted above. Three pressure buildups were obtained following perforating and swabbing. The results are essentially parallel to a drill stem test but the packer is set above the perforation in casing and a value is opening below the tubing to allow fluid to enter the inner tubing. Pressure is recorded during the open flow period as it would during a normal DST.

Analyiss of the the pressure buildup in Test #2 (7218-7234 ft, upper Gasconade Dolomite) was analyzed using Fekete well test analysis software. Permeability and skin are calculated near the wellbore. Permeability is around 350 md and skin is 73. This

results assume a thickness of 16ft, which is the perforation interval. Permeability will be changed if the thickness is larger than 16ft. This perforated interval might be connected to lower and upper layers hence, the thickness might be thicker. Computed permeability of ~200 md was obtained using nuclear magnetic resonance log for this interval, indicating close agreement (**Figure 6**).

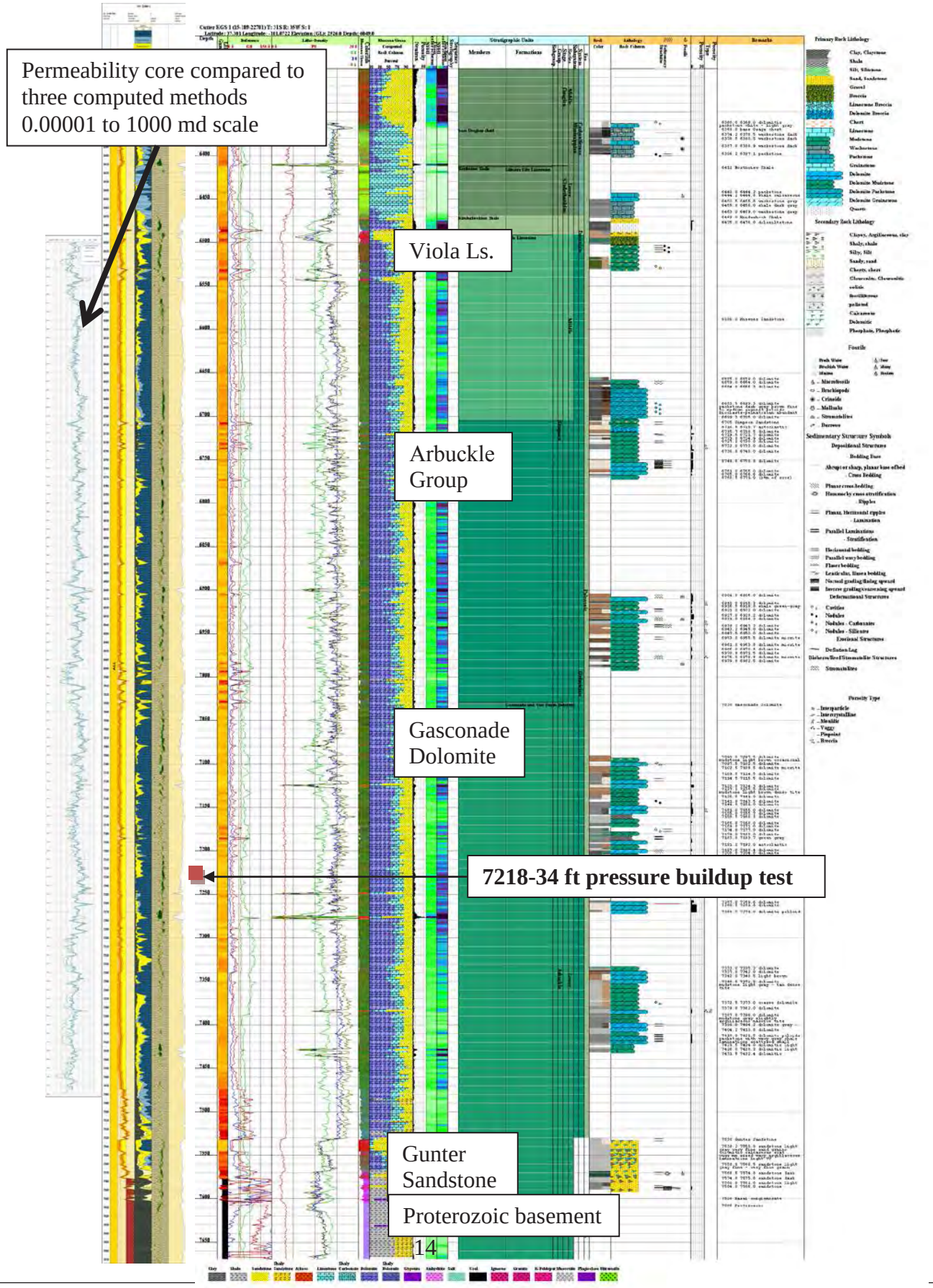
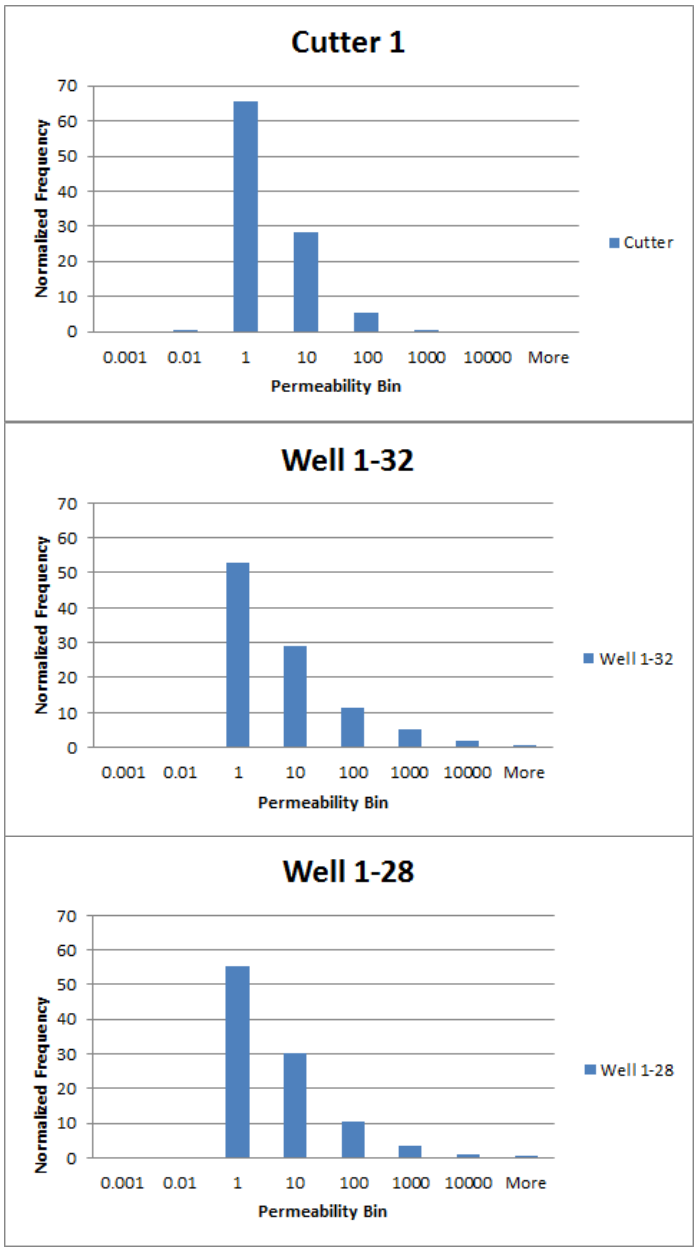

Permeability core compared to three computed methods 0.00001 to 1000 md scale
Viola Ls.
Arbuckle Group
Gasconade Dolomite
7218-34 ft pressure buildup test
Gunter Sandstone
Proterozoic basement

Figure 6. Cored interval with the addition of the computed permeability curve on left side. Interval in the upper Gasconade Dolomite is highlight that we perforated and subjected to a pressure buildup #2 test. Computed and permeability measured from this test are comparable with the test indicating approximately 350 md.

A preliminary comparison of permeability distribution in the Arbuckle Group for the Cutter KGS #1 and the two wells in Wellington Field, indicate that the permeability in the Cutter well is less than the #1-32 and #1-28 at Wellington Field (**Figure 7**). The frequency of the low permeability, 1-10 millidarcies, is higher in Cutter while the permeability over 1 Darcy, while small in wells at Wellington Field, is also lower.



The differences in permeability may require that the petrophysical models will differ between their use between these calibration sites. While lithofacies are similar,corelations with log properties may vary. This will be the next step in the analysis. The explanation may lie in the depositional fabric, diagenesis, or structure.

Figure 7. Permeability histograms for each of the new wells drilled in this study, Cutter 1 in Cutter Field, Well #1-32 and #1-28 from Wellington Field.

Task 18. Update Geomodels and Conduct Simulation Studies

1) Static and dynamic modeling of Eubank, Shuck, and Cutter fields

The characterization of the Morrow sandstone reservoir at Cutter Field has begun and simulation continues for the Chester sandstone reservoir at Eubank Field. Similation of the Chester reservoir at Pleasant Prairie South has been completed with results indicating that CO2-EOR will result in 1.95 million barrels of additional oil with a net utilization of CO2 of 5 mcf/bbl of oil (**Figure 8**). The oil recovered using CO2 represents nearly what was recovered in each phase of primary and secondary production attesting to the effectiveness of the CO2.

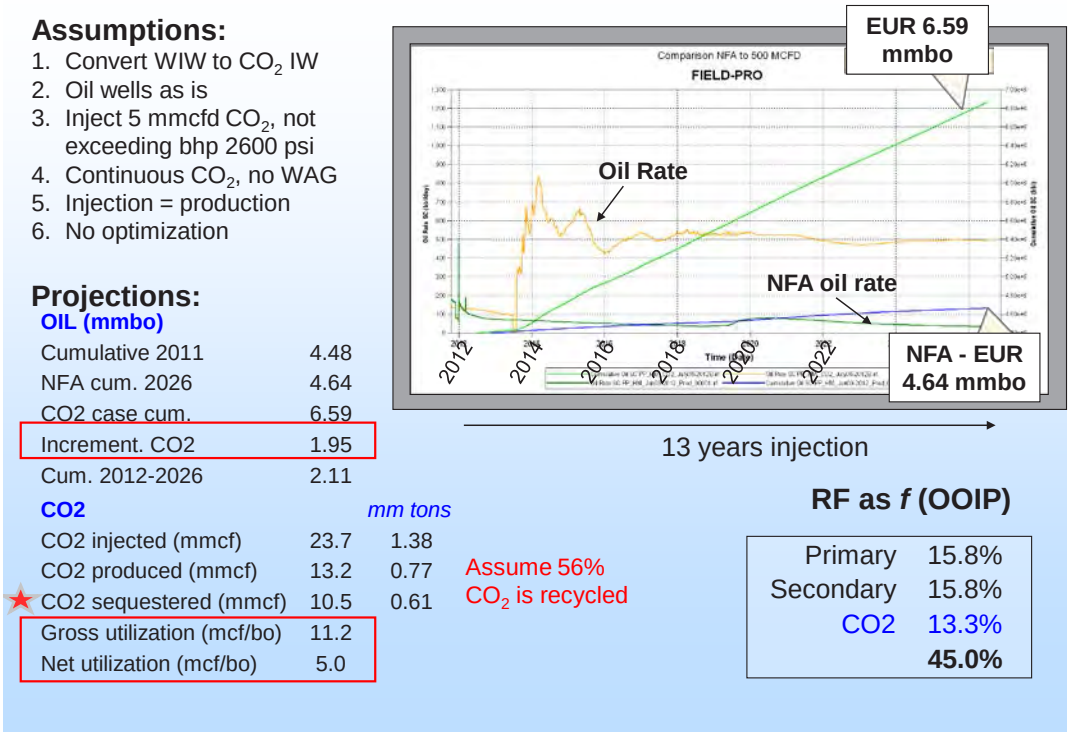


Figure 8. CO2-EOR projections for simulation from Pleasant Prairie South Field that is part of the SW CO2-EOR Initiative.

The basis for the geomodel development in the Chester and Morrow sandstone reservoirs are lithofacies defined from core but are distinguishable on well logs. Lithofacies are predicted using a neural network (**Figures 9 and 10**).

Simulation of the Chester sandstone reservoir is being completed at Eubank and when competed Schuck and Cutter will be modeled.

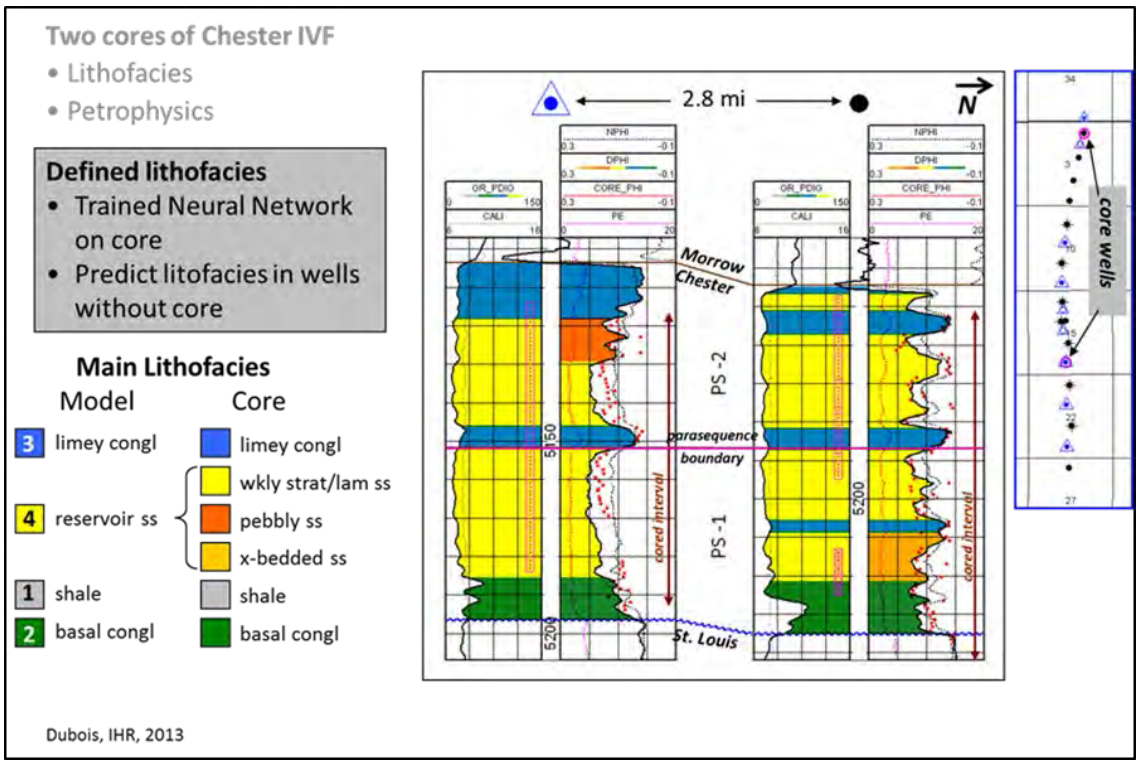
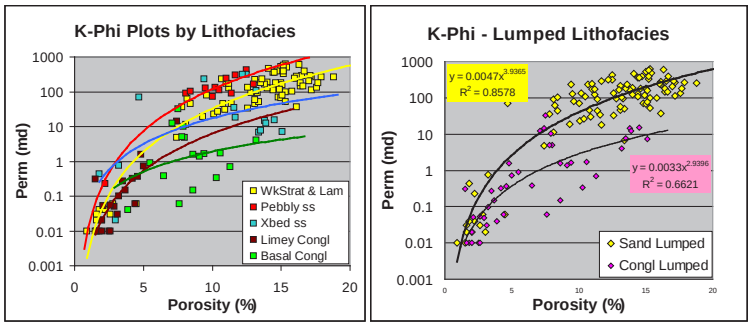


Figure 9. Illusration of two cored wells illustrating the correlation of lithofacies and well log properties.

Pleasant Prairie

- Five core lithofacies have somewhat distinctive K-Phi trends (left), but are not all distinguishable on logs
- Lumped into two lithofacies, Sandstone and Conglomerate (right)

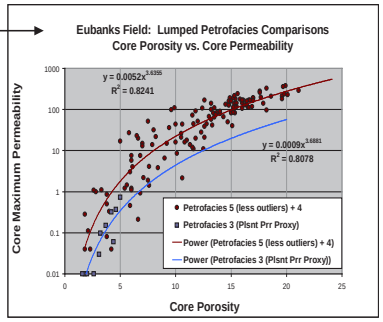
Pleasant Prairie South



Pore throats, hence permeability and capillary pressure (and Sw) are a function of lithofacies. Thus it is important to distinguish lithofacies in the characterization and modeling process

Eubank

- Lumped lithofacies in Eubank have very similar K-Phi relationships as Pleasant Prairie
- Eubank sandstone has very slightly lower permeability for a given porosity



Dubois, IHR, 2013

KGS, Wichita KS

2

Figure 10. Illustration showing relationships between pore throats, permeability, and water saturation and lithofacies.

Task 12. Regional CO2 Sequestration Potential in OPAS - 17 Counties

1) Calibration of Arbuckle rock properties with well logs and large scale, coarse grid static and dynamic modeling of regional sites to refine estimates of carbon storage potential

The core analysis for the Cutter KGS #1 continues to be made available as it has been analyzed by Weatherford over the past months. The Cutter well is the western calibration point for the regional assessment and is one of the 9 sites that will be simulated using a coarse grid model each covering multiple townships (Figure 11).

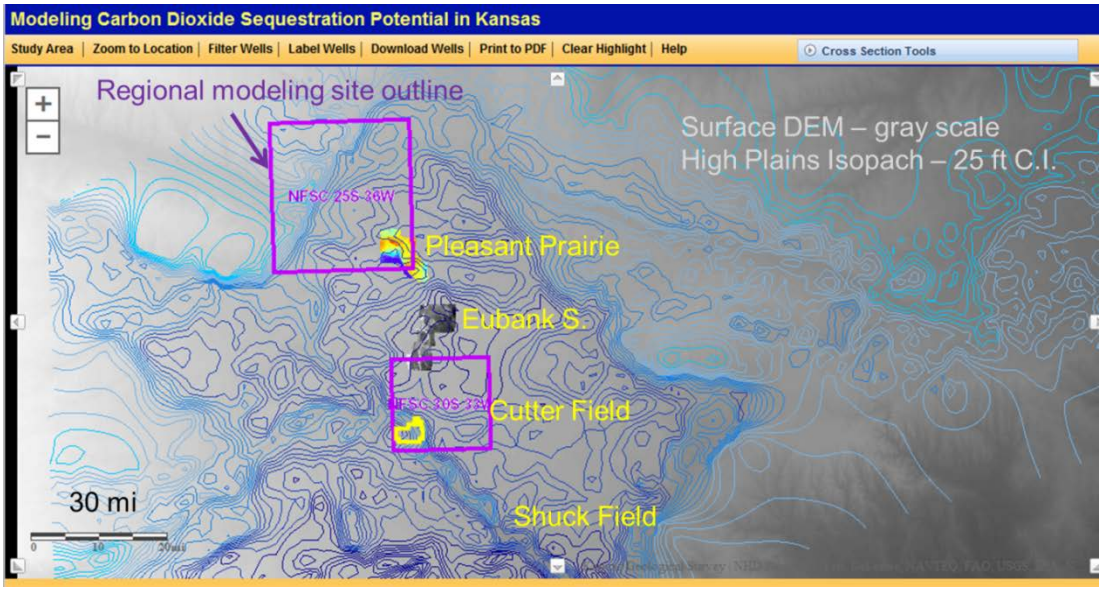


Figure 12. Isopach of the High Plains Aquifer in southwest Kansas with the location of two of the modeling sites for coarse grid simulation of CO2 injection of the Arbuckle. One includes Cutter field and the other Pleasant Prairie Field.

The coarse grid models such as that illustrated in **Fugure 13** will be constructed in 10 sites. A methodology called fuzzy logic was chosen to estimate permeability and other petrophysical properties of the rock using modern log suites (GR, N-D porosity, resistivity, photoelectric curve) and lithologic information based on sample descriptions obtained in georeports (**Figure 14**). Cored wells at Cutter and Wellington fields that were logged with an extensive set of tools provide the basis to develop correlations to permeability.

The basis of the petrophysical correlations has been previously described, quantifying the reservoir quality by pore type and lithofacies. Moreover, this classification has been

related to the stratigraphic intervals of the Arbuckle where certain lithofacies appear to dominate. The influence imposed by stratigraphy is being evaluated using the new data obtained from the Cutter well. The constraint of stratigraphy will be factored into the fuzzy logic approach.

Methodology for fuzzy logic prediction of permeability and related reservoir properties --

1.Classify zones in Arbuckle wells as to whether they belong to :

- Low permeability (<0.5 md), micropore, mud-supported petrofacies
- Intermediate permeability (0.5 – 25 md), mesopore, grain-supported petrofacies
- High permeability (>25 md), megapore, vuggy petrofacies

2. Following classification, assign a numerical value of permeability

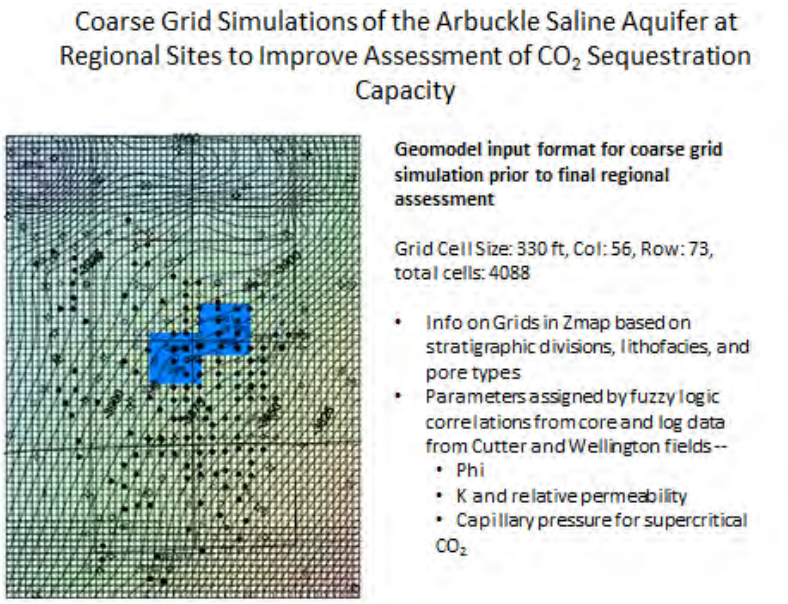


Figure 13. Coarse grid simulation framework to be used at 10 regional sites.

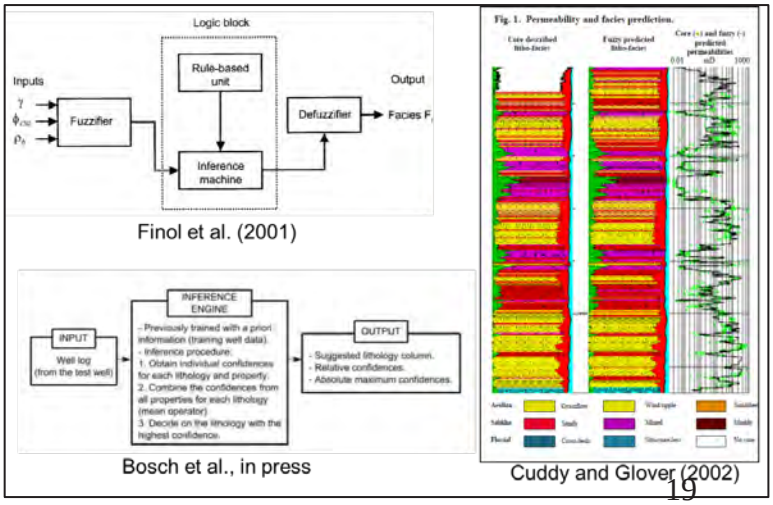


Figure 14. Fuzzy logic approach to permeability prediction.

2) Vetting of type logs and finalizing project interactive mapper

The type log web application was introduced to the community in a presentation at the Mid-Continent AAPG Meeting by Paul Gerlach. Next step is a webinar to engage the committee to review and offer refinements in the stratigraphic correlations.

The interactive mapper and carbon storage assessment will be finalized for the NATCARB and Carbon Storage Atlas by end of calendar year 2013 to meet deadlines on those activities.

3) Timing structural activity encompassing southwest Kansas

The structural evolution of the southwestern Kansas and particularly the timing of the major tectonism in the Mid-continent is an important topic for understanding the development of primary structures as it affects the storage of CO2, namely closure and containment of the CO2, evaluating the integrity of seals and caprocks, providing context on the migration of fluids in the subsurface. This activity was pursued with the regional mapping team (Bittersweet), the team working on the SW CO2-EOR Initiative, and continued collaboration with the USGS and their activity – resource assessment of the Anadarko Basin. The work is described below in the regional mapping since the work has broader ramifications for the regional mapping.

Task 19. Integrate results with larger 17+ county OPAS project

1) Validate structural, stratigraphic, and well based analysis using regional 3D seismic, gravity-magnetics, and remote sensing

The description here focused on an analysis of the structural timing based on synthesis to date of geologic and geophysical information assembled for the regional study and the evaluation of seismic and well data from the study of Chester and Morrow fields in southwest Kansas.

Overview --

The Anadarko Basin the product of Proterozoic (Precambrian) extension that set up the lithologic and structural framework that we refer to as the basement. The structural extension was contininent wide leading to rifting events and basin creation including the the Oklahoma aulocogen and pull-apart basin (**Figure 15**). Concurent with the activity in Oklahoma, the Midcontinent Rift System was active that led to the development of a deep failed rift basin that bisects the state of Kansas from northeast to southwest.

Predominant orientation of the rifting events is northwest and northeasterly. The rifting occurred along existing crustal weaknesses but also cut across older basement trends recognized in the examination of gravity and magnetic maps coupled with age dating of basement rock obtained from drill cuttings and core. Phanerozoic (Cambrian to Recent)

deformation from dominated by compression, a distinct reversal in the stress field of the Proterozoic basement (**Figure 16).** This led to reactivation of older weak structures including the Oklahoma aulocogen forming the Amarillo-Wichita uplift and the Mid-Continent Rift System that led to formation of the Nemaha uplift in Kansas. The Hugoton Embayment was formed as a 10,000 km2 structural extension of the newly formed Anadarko Basin.

The primary tectonic stress originated from the convergence and collision of two tectonic plates forming a mountain chain that extended from the Appalachians, Ouchita, and the Marathon range that borders the southern portion of U.S. Tectonic forces noted as σ_1, major compressional stress vector, was believed to be oriented perpendicular to the axis of plate convergence, radiating away from the mountain front as it meandered through the southern part of the craton. The compressional stress extended northward large distances (100s of miles) leading to both uplift and subsidence (**Figure 16**).

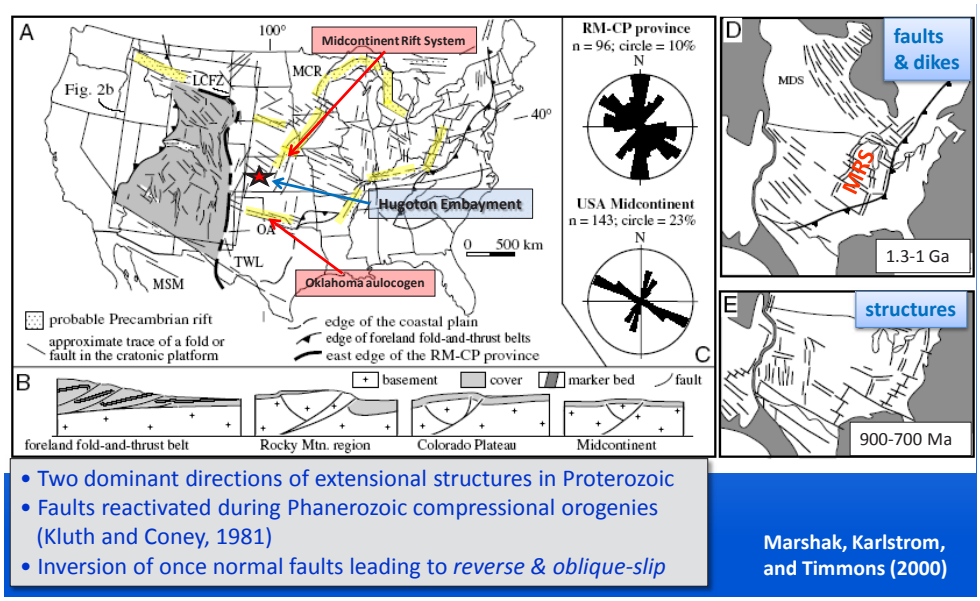


Figure 15. Extensional faults and folds dominate the late Precambrian (Proterozoic) basement of the U.S.

The peak tectonism in the southern Kansas and the Hugoton Embayment region occurred during the lower and middle Pennsylvanian (**Figures 17 and 18**). This is noted by the large sediment accommodation space and clastic sediment infilling of the Anadarko and adjoining Hugoton Embayment. The Atokan Thirteen Finger Limestone consists of a succession of thin dark carbonates and black to dark gray radioactive (elevated gamma ray) shales. This formation is limited to the lower reaches of the Hugoton Embayment and Anadarko Basin and is interpreted as a sediment starved, lower oxygen deposit resulting from a combination of sea level rise and subsidence in these area leading essentially to the drowning of the craton. Areas in the eastern Hugoton Embayment have normal shallow water carbonates, while immediately to the west, the strata are condensed (**Figure 19**). Sedimentary cycles that are deeper water deposits onlap onto the basal

Pennsylvanian unconformity along the higher reaches of the shelf along the western edge of the Central Kansas Uplift (**Figures 19 and 20**).

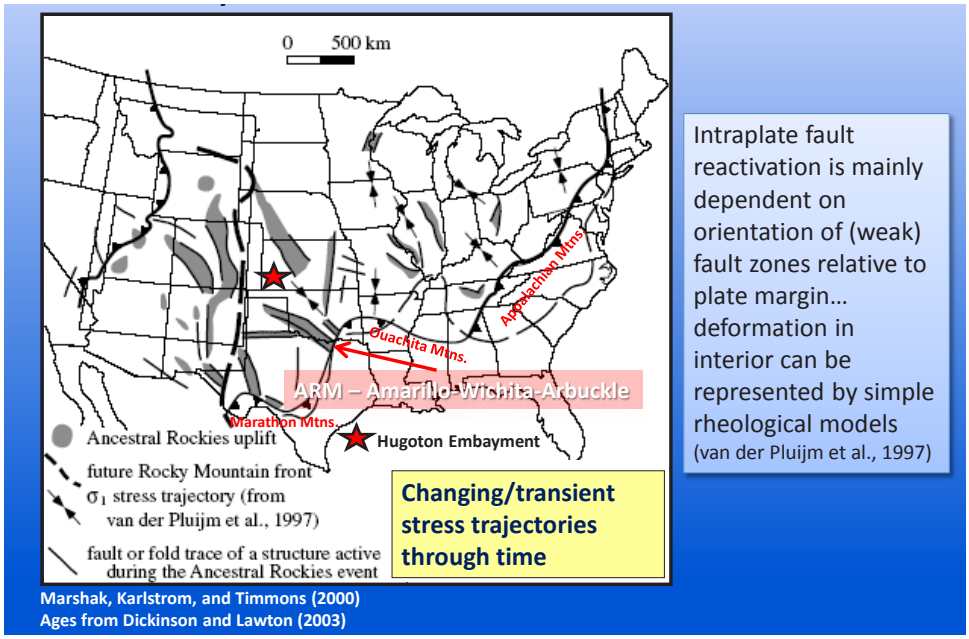


Figure 16. Late Paleozoic tectonism ranged in age from Chesterian to late Leonardian.

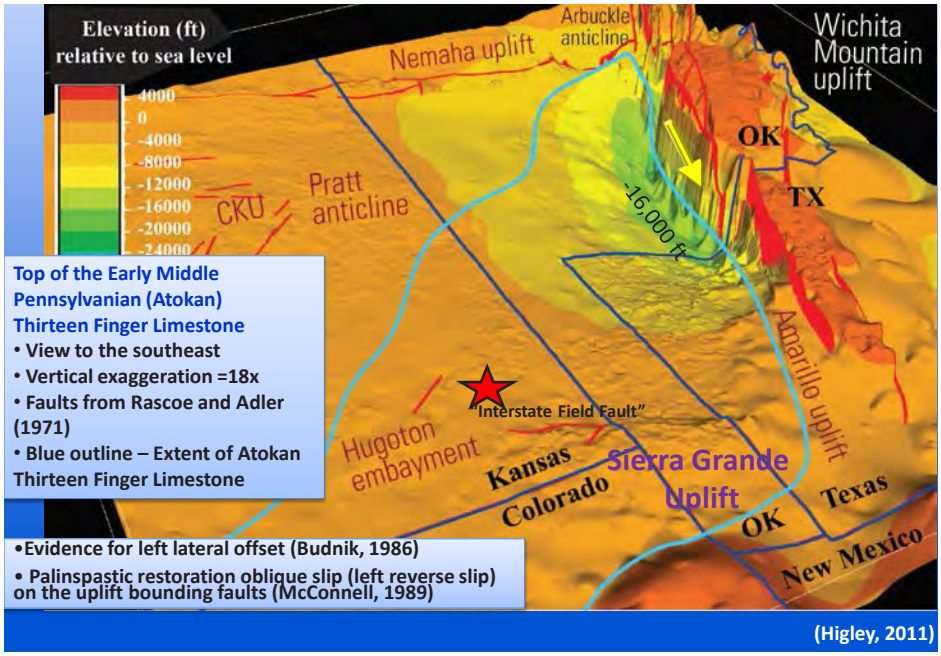


Figure 17. Three dimensional view of the surface on top of the Early Middle Pennsylvanian (Atokan) Thirteen Finger Limestone in southern Kansas and northern Oklahoma.

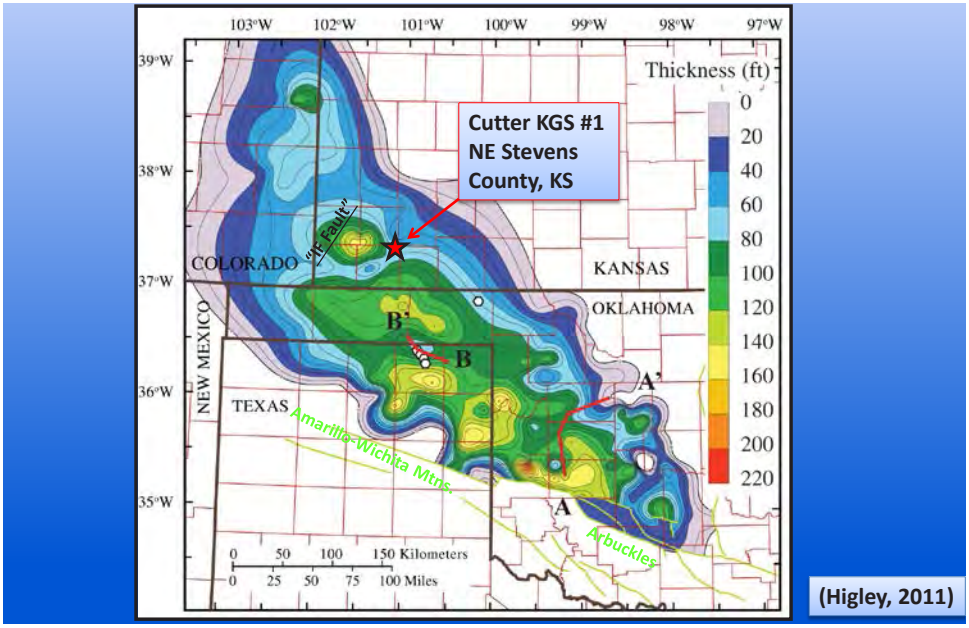


Figure 18. Isopachous map of the Thirteen Finger Limestone in southwest Kansas, Texas panhandle, and western Oklahoma.

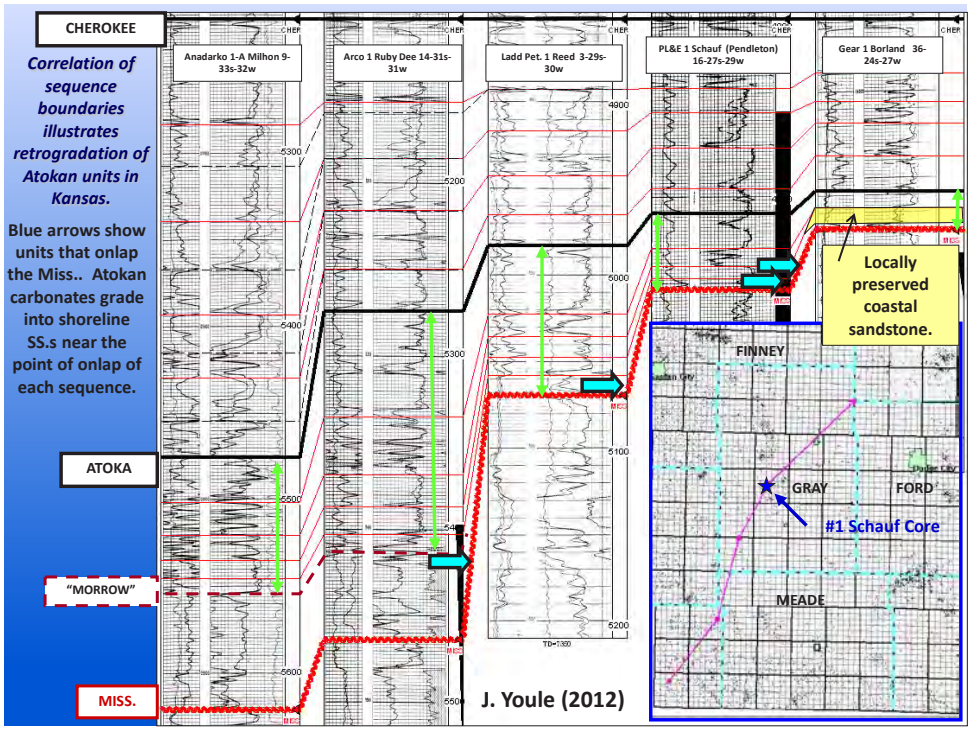


Figure 19. Stratigraphic cross section datum on the top of the middle Pennsylvanian Cherokee Group. Section extends from southwest corner of Kansas toward the northeast along the eastern margin of the Hugoton Embayment.

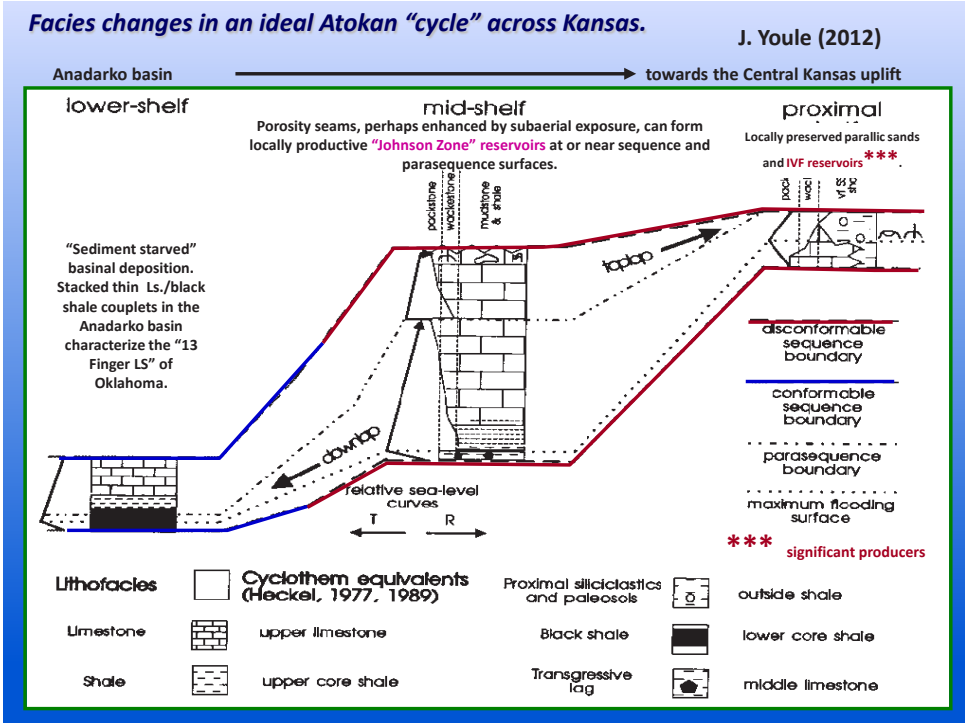


Figure 20. Cycle of sedimentation for the Atokan extending from SW to NE across the Hugton Embayment unto the west flank of the Central Kansas Uplift (Youle, 2012).

Additional work by the USGS Andarko Basin study identifies shale dominated intervals that have anomalously low resisitivity that together with burial history and depositional setting strongly suggest undercompaction and paleopressure extended into southwest Kansas in the Morrowan age strata (**Figure 21**, Nelson and Gianoutos, 2011). This is explained by rapid burial of shale rich strata that did not sufficiently dewater due the limited permeability.

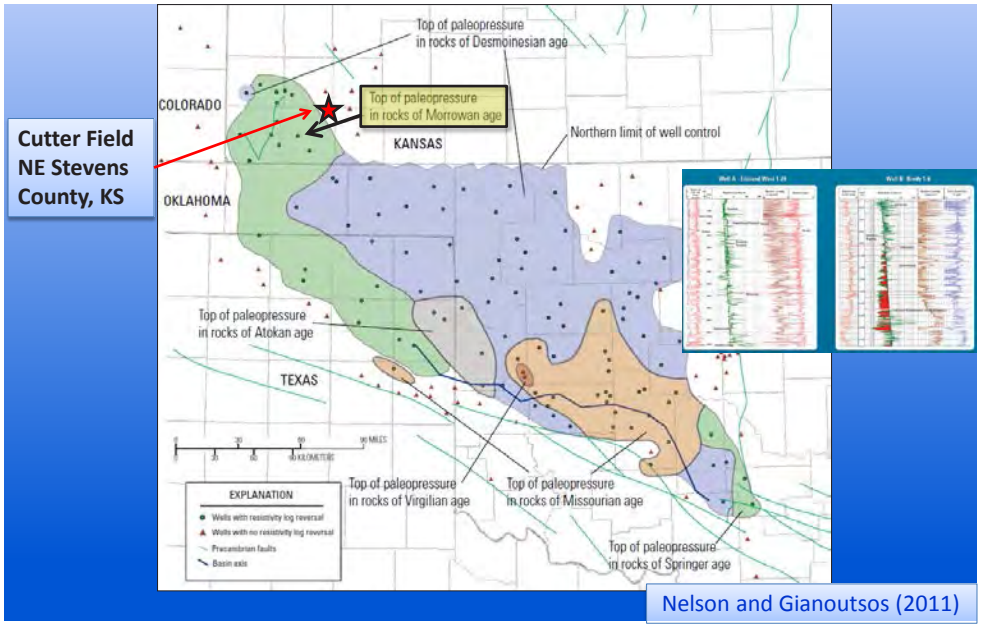


Figure 21. Map of paleopore pressure in the Anadarko basin and southern reaches of the Hugoton Embayment.

The Hugoton Embayment was clearly structurally active during the Morrow and Atokan time and the strata distribution and composition reflect the rapid subsidence of this area. The series of oil fields being examined in southwest Kansas are located in the south-central part of the Hugoton Embayment with reservoirs including the Chester age incised valley fill sandstone in Pleasant Prairie, Eubank, and Shuck fields, and the Upper Morrow fluvial-dominated channel sandstone at Cutter Field. The location of the fields in a map of the magnetic field intensity and the contours of the top of the Precambrian shows the relationship of the fields in relationship to large magnetic lineaments, several delimited in the map (**Figure 22**). The primary trend of the lineaments is northeast and northwest trending. However, it is not clear at this scale and of map what controls the location of the fields other than the location of the incised valley system of the Chester.

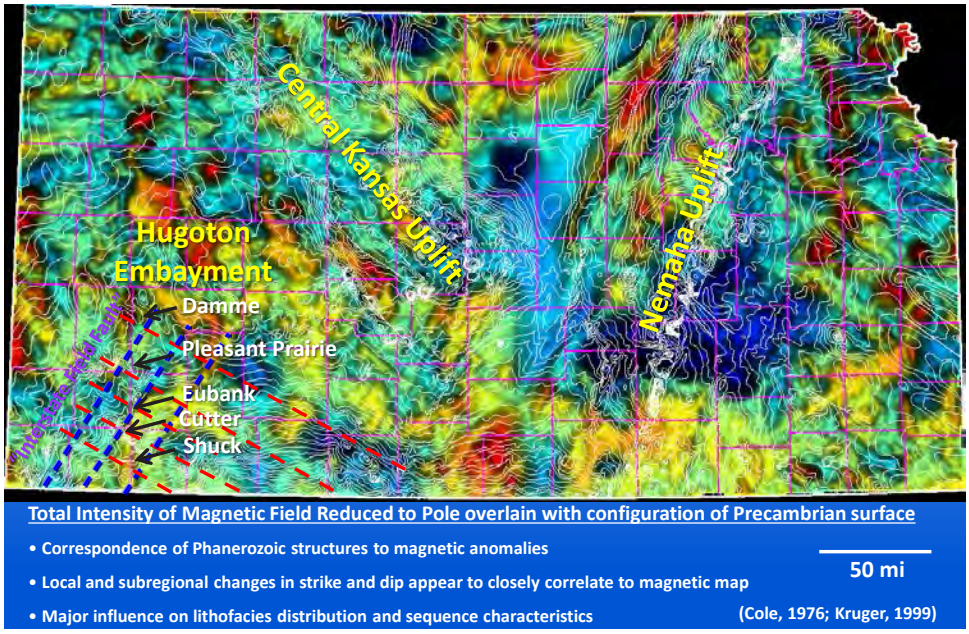


Figure 22. Total magnetic field reduced to pole overlain by the configuration of the Precambrian surface.

The geophysical limits of the Proterozoic Mid-continent Rift System were interpreted by Kruger (1997) who noted that the western boundary extended into the Hugoton Embayment and eastward to encompass the entire DOE study area in southern Kansas (**Figure 23**). The key deep well control used in the mapping of the Arbuckle used in the carbon storage assessment penetrated 600 ft of coarse grained arkosic strata in Seward County, the location of Shuck Field. This could be an isolated outlier, but in general the rift south of the terrane boundary that it crosses in central Kansas is only locally distinguished with arkosic sediment and is primarily represented by structural lineaments or more deep seated material such as magnetic bearing granite and basic igneous intrusives.

Further indications of the northeast and northwest trending lineaments is demonstrated again with a magnetic map, but this time total magnetic reduced to pole with a 2-10 mile

filter to emphasize higher frequency events. This map is overlain with a tilt angle processed magnetics emphasizing local contrasts in magnetic intensity (**Figure 24**).

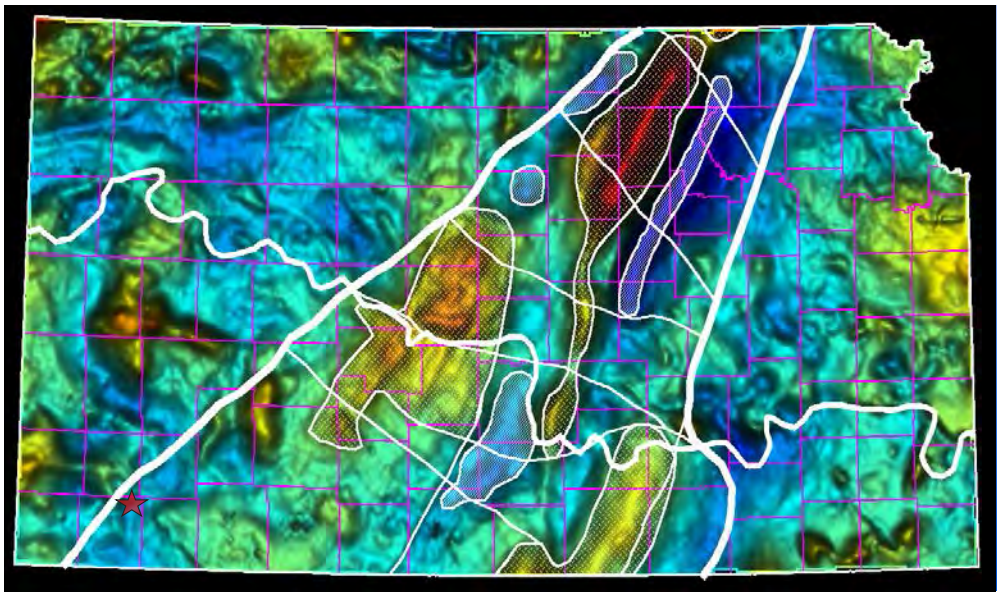


Figure 23. Gravity map of Kansas overlain with outlines of the Mid-continent rift system (northeast trending), which cross cuts the older Proterozoic accretionary terrane that trends northwesterly, cutting diagonally through the state.

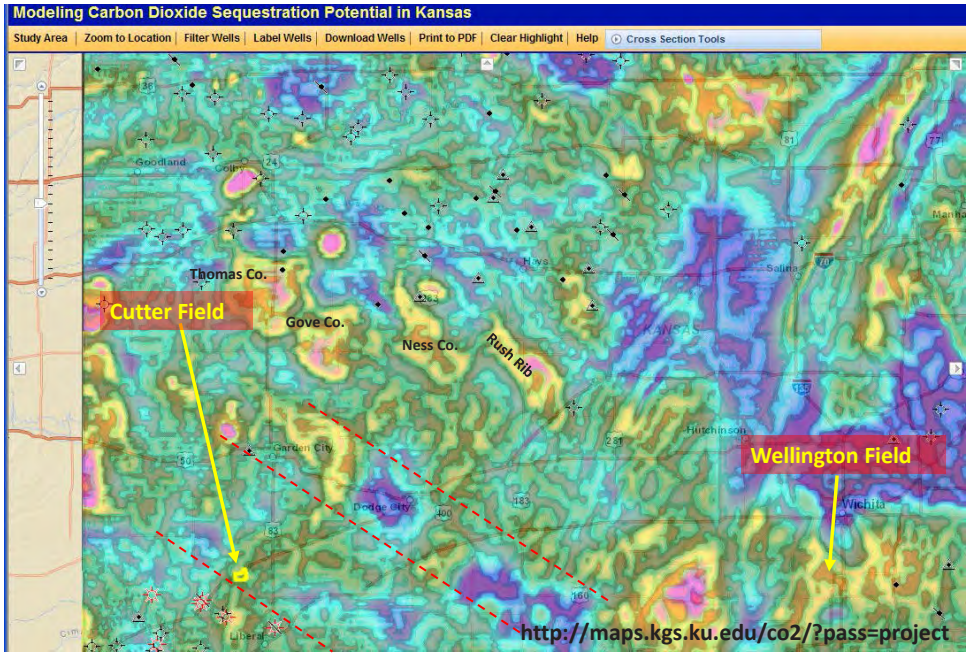


Figure 24.Total magnetic field intensity, reduced to pole (910 m) with 2-10 mile filter overlain with tilt angle emphasizing contrasts in the magnetic intensity. Area is western 2/3rd of Kansas.

The top of Chester Isopach map in southwestern Kansas provides a set of lineaments that are used in subsequent maps, used to outline the major structural fabric. In the case of the Chester Isopach, the south sides of the lineaments abruptly thicken compared to the north sides (**Figure 25**). The Chester is thickest in the southeast edge of the map along the Kansas-Oklahoma border.

The fields being studies with the exception of Damme are identified. The each field is associated with a structural high located near the junction of one or more of the lineaments. The Chester incised valley system trends more than 100 miles from north to south and is incised along the east side of each of these structures. Yet, the incised valley cuts through significant portions of the uplift suggesting that the valley formed prior to the uplift. Also, the Chester valley is incised at an angle to the lineaments but drains down the axis of the thickest Chester, which thickens abruptly across the lineaments. This suggests that the structure responsible for the thickening pattern of the Chester and the initial incision of the valley were subtle compared to the main tectonic activity that was to follow.

The current day structure on the top of the Mermec Mississippian is the erosional surface into which the Chester valley is incised (**Figure 26**). The northeast and northwest lineaments carried over from the Chester Isopach in **Figure 25** are included. Interestingly, the locations of abrupt changes in the structure map correspond to segments of the previously defined lineaments and are similarly oriented both northeasterly and northwesterly. Each of the oil fields corresponds with a domal uplift with a structurally steep or faulted west-southwest flank and a more gentle downwarped on the east side. Seismic evidence shown later confirms the faulting and the dome being a horst feature.

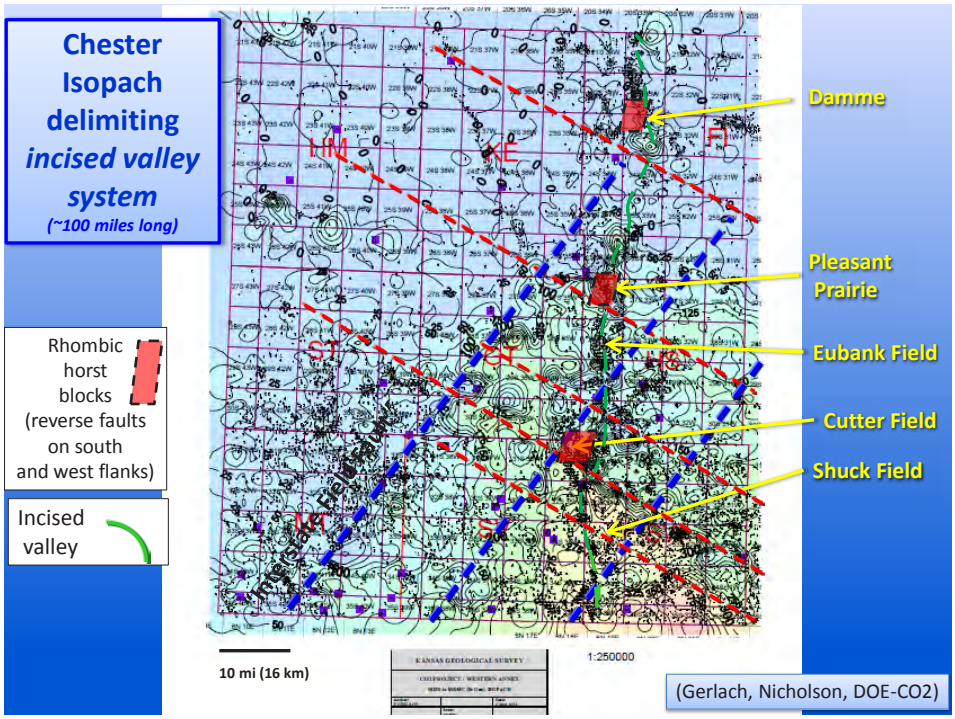


Figure 25. Isopachous map of the Chester strata.

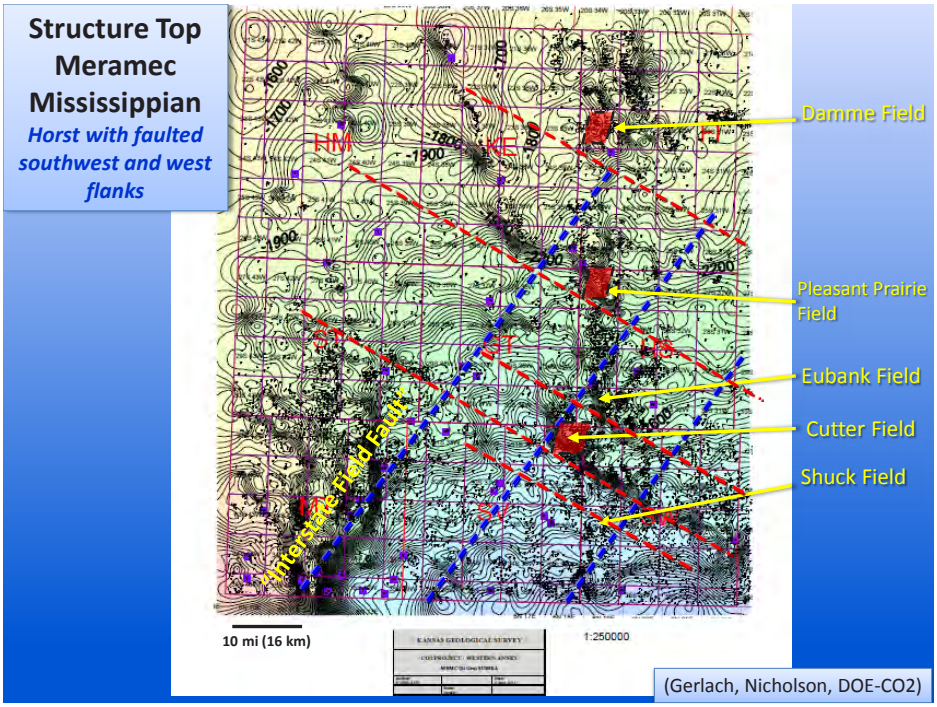


Figure 26. Stucture map, Top Meramec Mississippian.

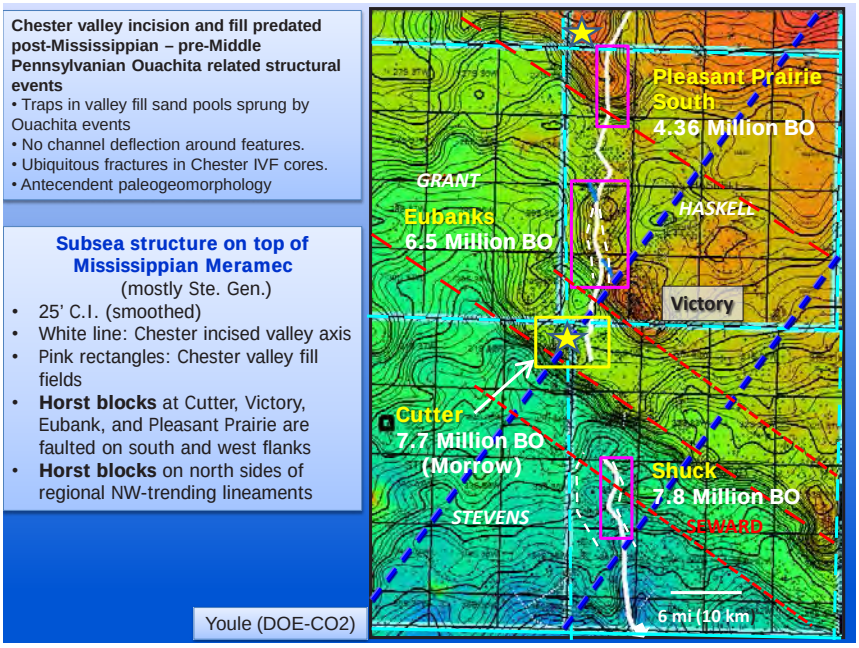


Figure 27. Structure map top of the Meramec Mississippian with Chester and Morrow producing fields that are being studied. Cutter Field with new well and core is highlighted.

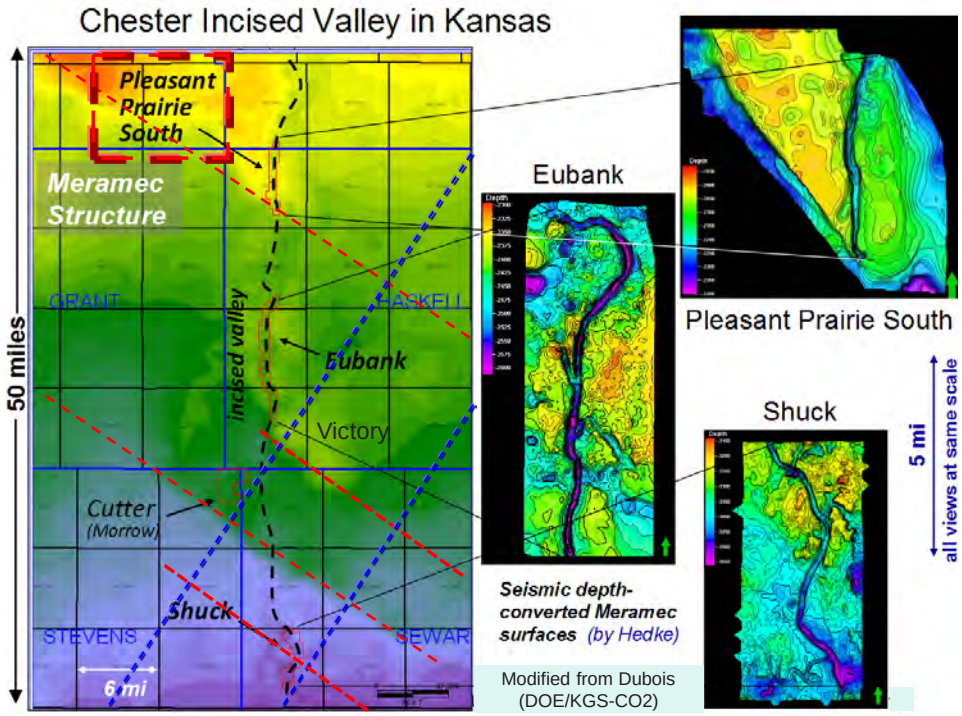


Figure 28. Stucture top of Meramec (left) with regional lineaments and location of Chester and Morrow fields being studied. Seismic time sufaces on the top of Meramec horizon at each field on the right reveal that the incised valley cross cuts the local domal/horst structures.

The importance of the regional lineaments in defining structure and location of these major oil fields is further exemplified in **Figures 27 and 28**. Victory Field of to the east of the Chester incised valley is a nother major oil field in a domal structure that is clearly influenced by the location of the regional lineaments. Multiple stacked oil pays characterize this field on one of the more prominent structures in the area. Figure 28 also provides seismic evidence that the incised valley cuts across the series of domal/horst blocks that define these fields indicating the timing of the major deformation occurred post Chester.

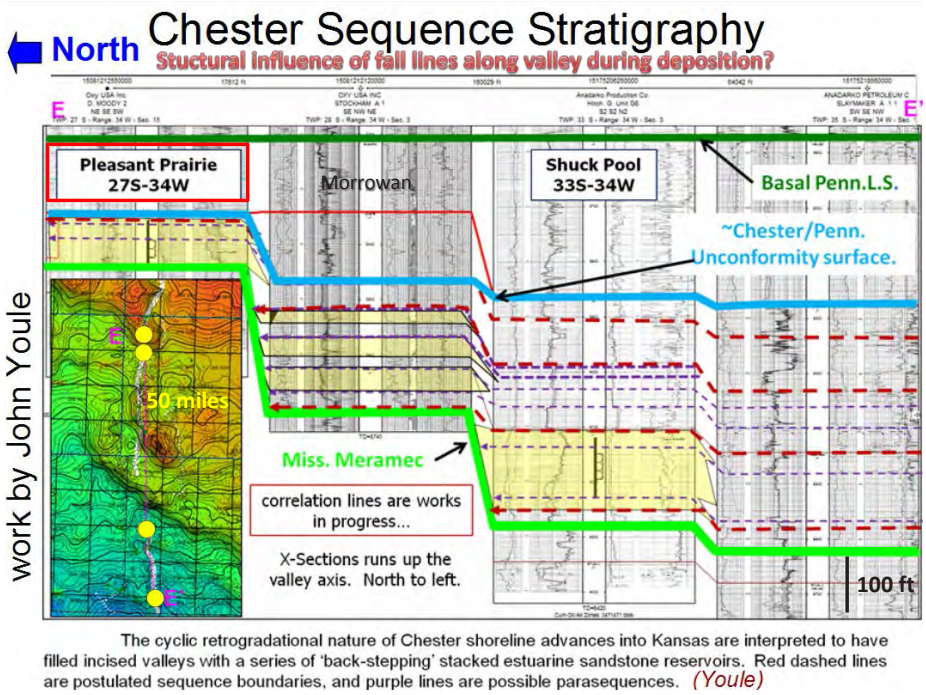


Figure 29. Regional north to south stratigraphic cross section in the Chester incised valley hung on a datum at the base of Atokan. Cross section illustrating step-wise stratigraphic thickening and addition of temporally distinct stratal packages that J. Youle refers to as parasequences.

The isopach of the Chester age strata showed the abrupt changes in thickness across each of the regional lineaments (**Figure 25)**. **Figure 29** documents the nature of the internal changes that correspond to the abrupt southward thickening that include 1) progressive, step-wise onlap and thinning of parasequences to the north and 2) varied sandstone stacking patterns that comprise the temporally distinct and time-transgressive nature of a relative sea level rise. The latter inferred rise in sea level led to progressive filling of the incised valley. The link to the regional lineaments indicates that differential subsidence occurred across them that contributed an important part to the increase in sediment accommodation through the Chester succession that filled the incised valley. Also of note is the stepwise increase in the thickness of the Morrow strata to the south paralleling the thickness increases of the Chester (**Figure 29**).

A seismic 3D volume donated for Pleasant Prairie Field provides detail of the domal structure (**Figure 30**). The field located on the map in **Figure 28** is a domal feature that with the 3D seismic reveals complex en echelon faulting, down to the west. Several of the faults are high angle reverse. Accompanying the faulting is apparent thickening of the lower Paleozoic strata on the downthrown side. This is not simple truncation of the strata at the base of the Pennsylvanian since the thickening is progressive in the Arbuckle stratat and post-Arbuckle, pre-Pennsylvanian intervals. This suggests that the structure had a extended history of development during the pre-Pennsylvanian.

The east side of the structure is bounded by a more gentle eastward dip, but the seismic reveals a deep-seated high angle fracture set that lies beneath the location of the Chester incised valley (**Figure 30**). Thus, the fractures may dicate the location of the valley and its linear tract across the structural uplift at Pleasant Prairie Field

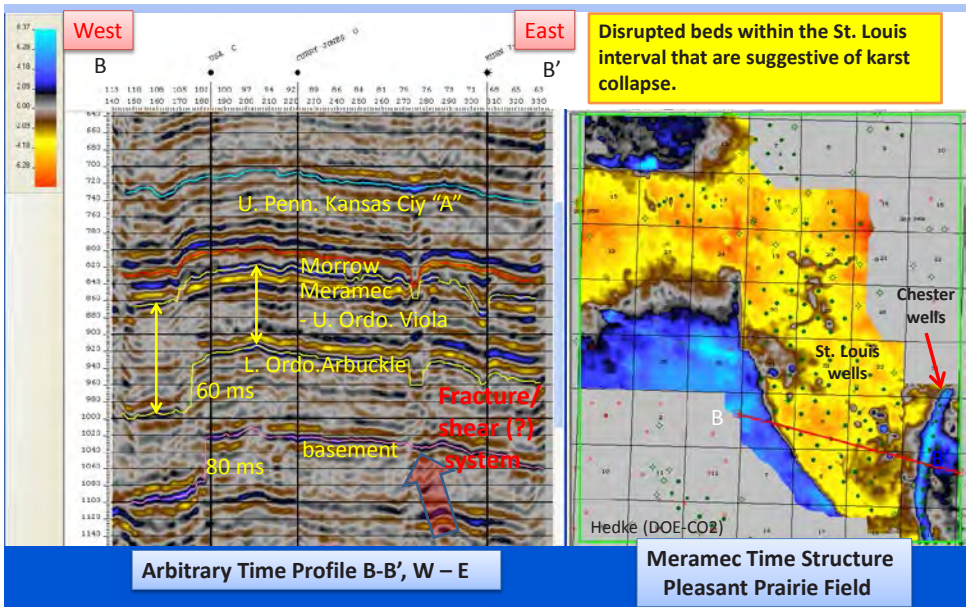


Figure 30. Arbitrary time section and Meramec time structure at Pleasant Prairie Field.

Another seismic profile, this time oriented southwest to northeast crosses the western flank of Pleasant Praire Field, reveals radiating high angle, down to the west-oriented faults (**Figure 32**). The faults are interpreted as a flower structure that is diagnostic of strike-slip faulting (**Figure 33**). While the lateral offset has not been documented, a right-lateral strain is strongly suggested. Accompanying the shear at this location is the shift in the spatial trend of the fault system, making a leftward jog general northward trend of the fault where it crosses the regional northwest trending lineament (**Figure 26**). This offset has the structure form of what is called a restaining bend (**Figure 33**), suggesting translation of the fault along a preexisting weakness (the lineament) leading to localized strain buildup. A horst uplift is a result along with tensional forces along the east side of the block that may be responsible for the fracture set along which the course of the incised valley developed.

The seismic isochron of the interval Morrow to the Proterzoic basement indicates a west-northwest trending lineament is the site of faulting on the west side of Pleasant Prairie while possible karst features extend eastward suggesting that the trend continues as fractures without offsest (**Figure 32**).

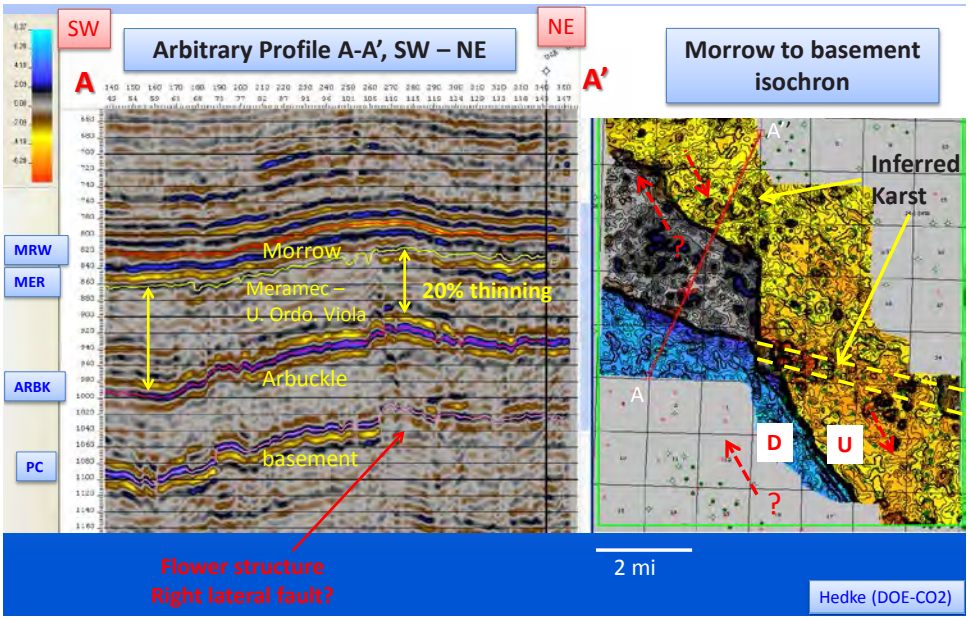


Figure 32. SW to NE arbitrary seismic profile and isochron of the interval from top of Morrow to the Proterozoic basement at Pleasant Prairie Field.

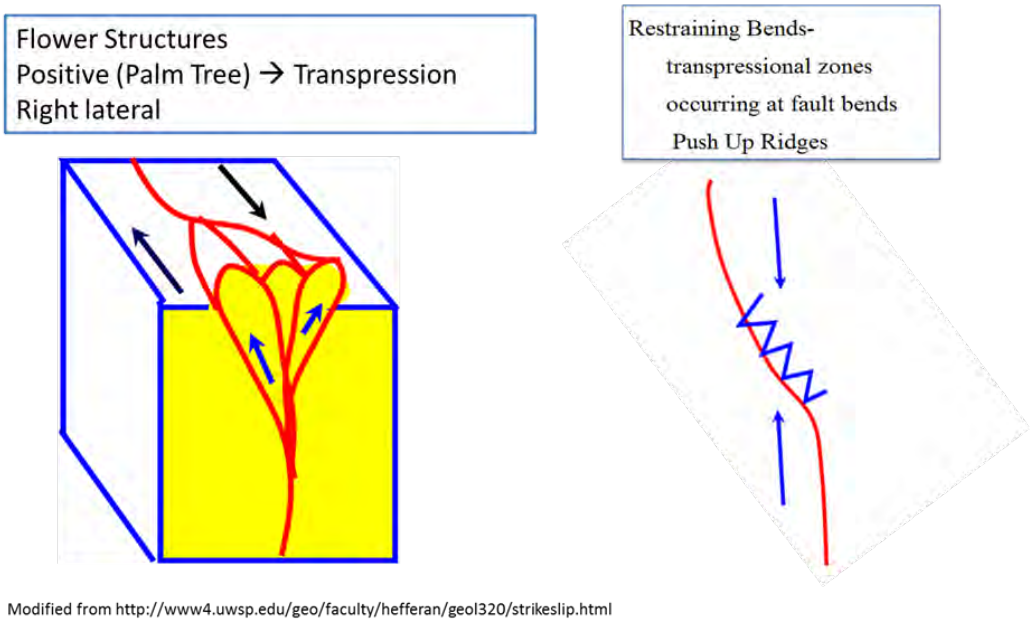


Figure 33. Flower structures and restraining bend are believe key structural components at Pleasant Prairie Field.

The time structure of the Arbuckle on the Pleasant Praire Field indicates that west-northwest trending lineament extends eastward from a fault to a linear trend of karst features developed on the Arbuckle unconformity surface (**Figure 34**). The recognition of apparent structurally influenced karst in the potential carbon storage site is important to

understand – 1) is the karsting limited to the Arbuckle or could the karst have extended to shallower horizons if the timing of the collapse is post-Arbuckle?

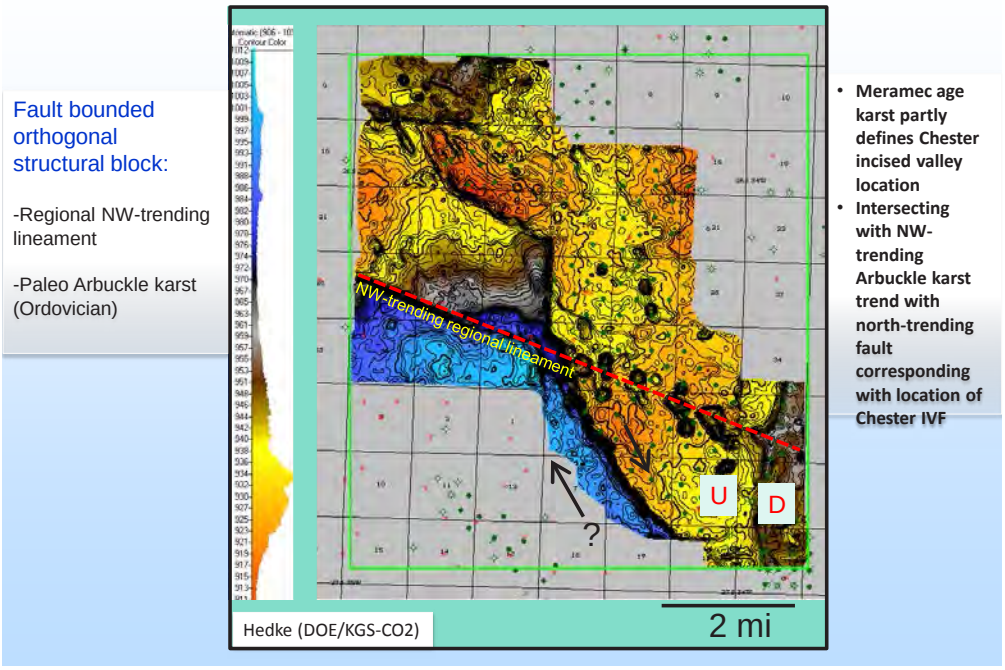


Figure 34. Time structure top of Arbuckle Pleasant Prairie Field.

Moving to Cutter Field, a cross section illustrates the subtle changes across a major bounding fault on the southwest side of the structure (**Figure 35**). The active faulting is post Chester and including contemporaneous movement with the deposition of the Morrow strata. The comparison of the wells in the cross section with a datum of the base of the Permian upper Wellington Formation and the structure cross sections indicates that the large down to the south structure was reactivated during the post-Permian to reverse the sense of this fault. The event may well be the Laramide tectonism of the early Tertiary. The major compressional tectonic event several hundreds of miles to the west apparently led to the reactivatiton of this northwest trending lineament and fault.

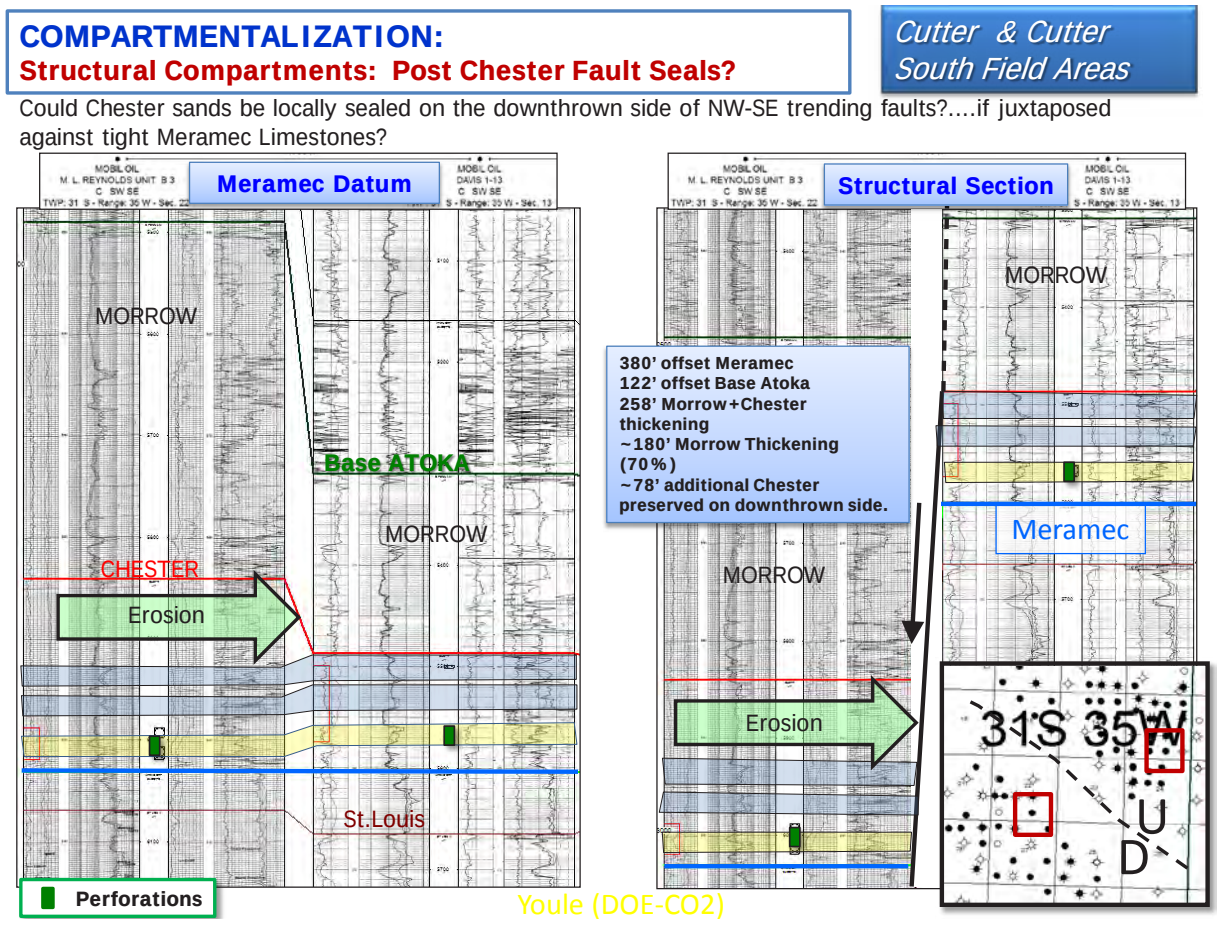


Figure 35. A pair of cross sections with a pair of wells crossing the southeast bounding down to the southwest fault at Cutter Field (Left) Meramec datum showing minor change in sand content and thickness of the Chester, while Morrow has thickness dramatically increases across the fault. (Right) Structural cross section showing offset across the fault with expanded thickness of the Morrow and other changes.

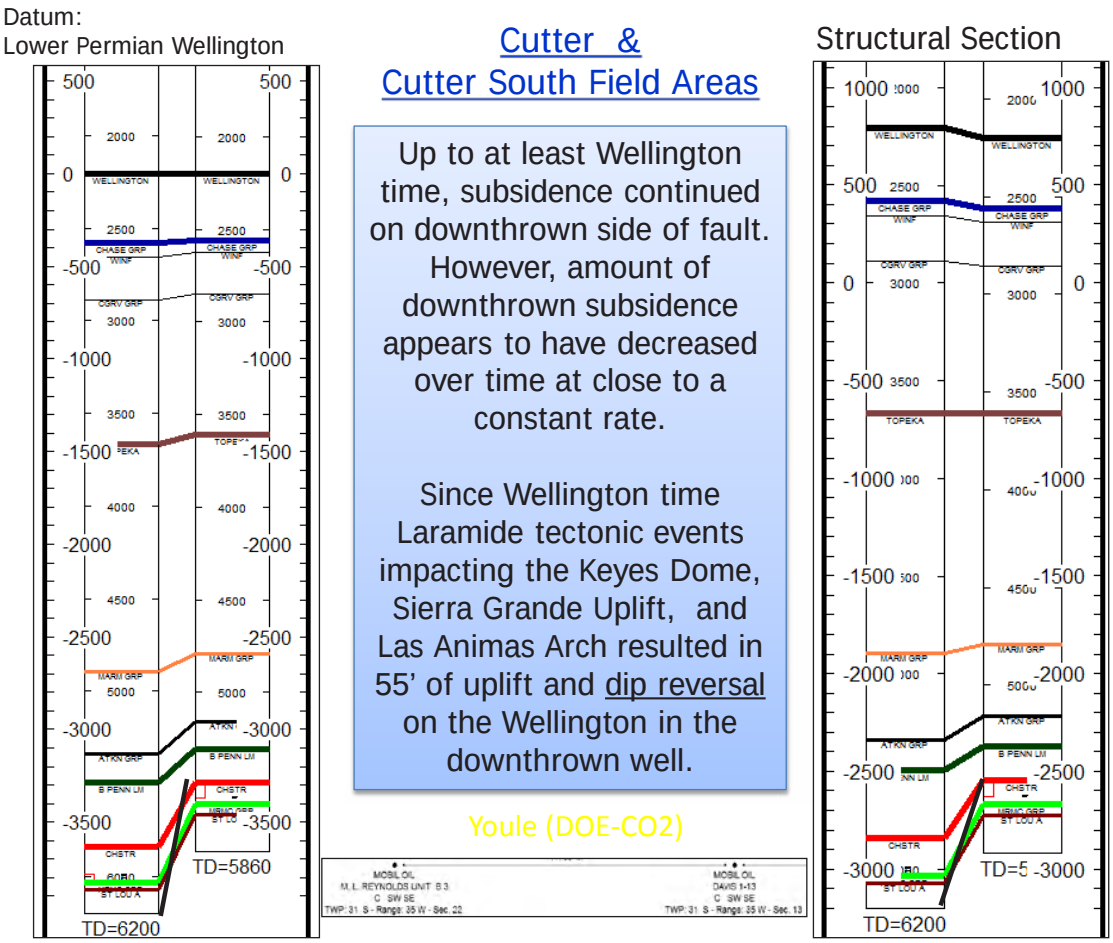


Figure 36. Stratigraphic (datum base of the lower Permian Wellington Fm.) and structural cross sections compared side by side to show the timing of the structure. The wells are the same as those shown in Figure 35.

Shuck Field is the southern most field of this study with a Chester incised valley reservoir that crosses another structural dome formed post Chester time (**Figure 36 and 37**). Shuck Field crosses another northwest trending lineament that affects both the isopach of the Chester and the current structure on top of the Meramec surface into which the Chester valley was incised. The Meramec surface drops abruptly south of dome and the narrow incised valley opens up to become a large estuary bay inferred from the estuarine sediments that fill the valley as described by J. Youle in core (**Figure 38**).

The northwest trending lineament on the south side of Shuck Field corresponds with a fault that is illustrated in **Figure 39**. The stratigraphic datum is the correlable shale called the Notch Flooding Shale that overlies the sandstone reservoir. Note that the sandstone thickens south of the fault by ~30%. This also corresponds with the southward thickening of the Morrow by ~100%. The fault apparently underwent initial movement in the Chester prior to the main tectonic in the Morrow and Atokan. This is supported by previous discussion above.

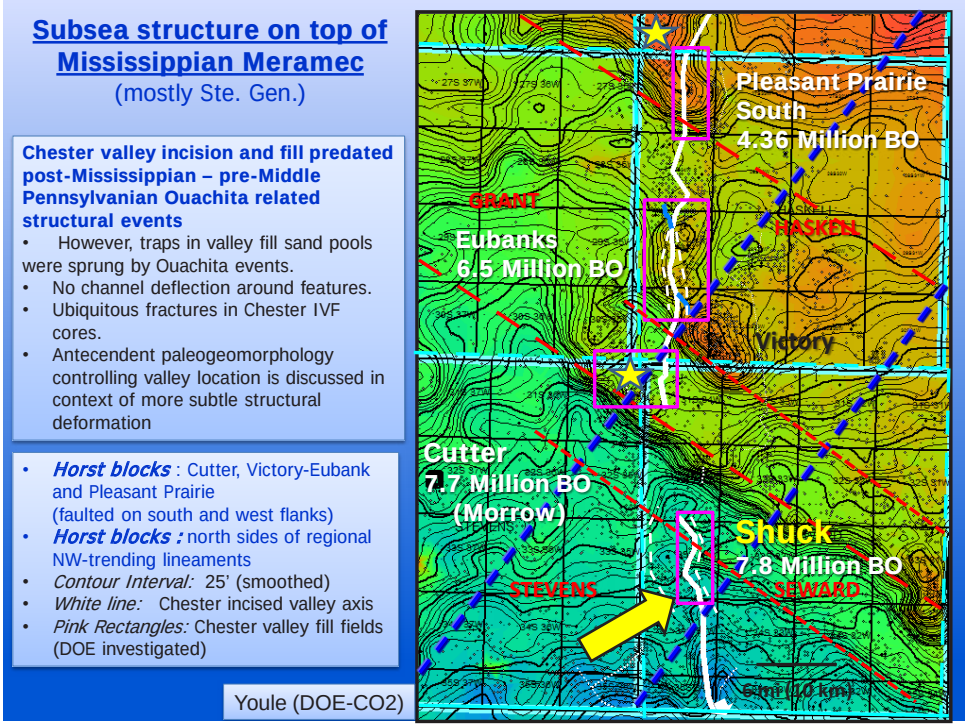


Figure 36. Meramec structure with location of the Shuck Field highlighted.

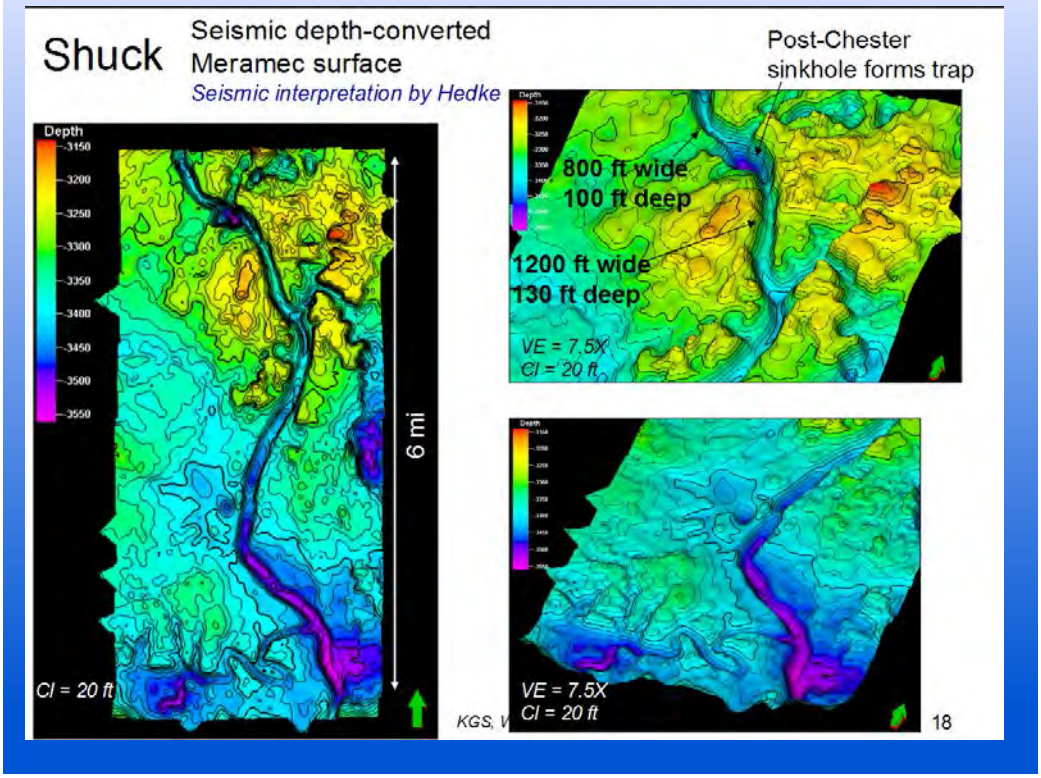


Figure 37. Chester incised valley crossing structure dome of Shuck field. Area south of the dome is structurally quiet on the south side of the regional northwest trending lineament.

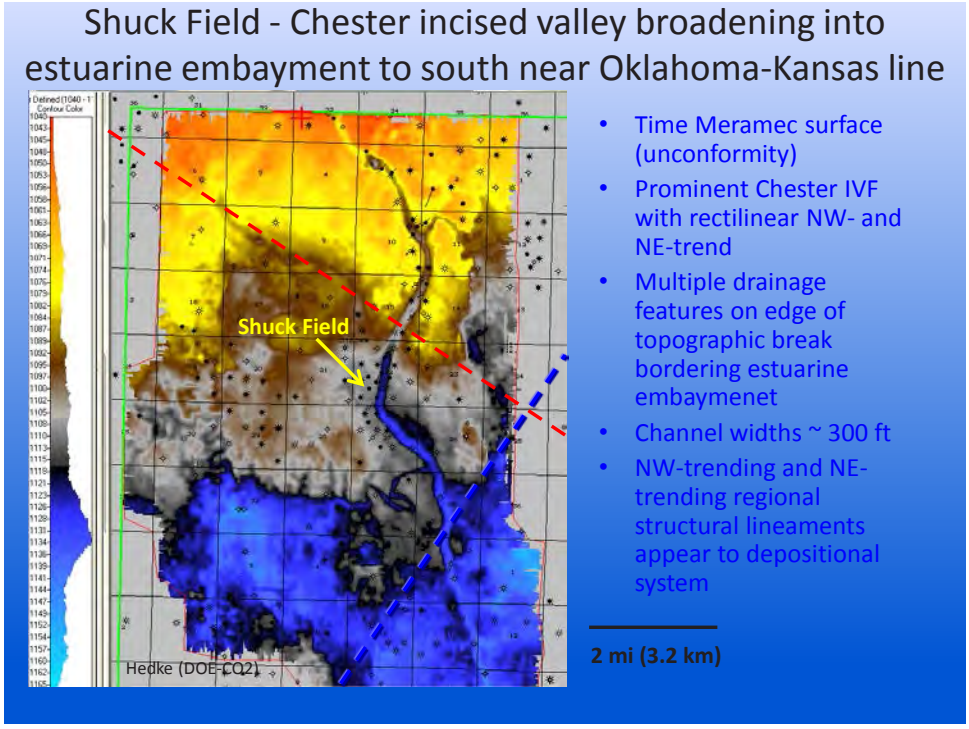


Figure 38. The incised valley opens up to become a large estuary with several drainage systems involved besides the main valley system.

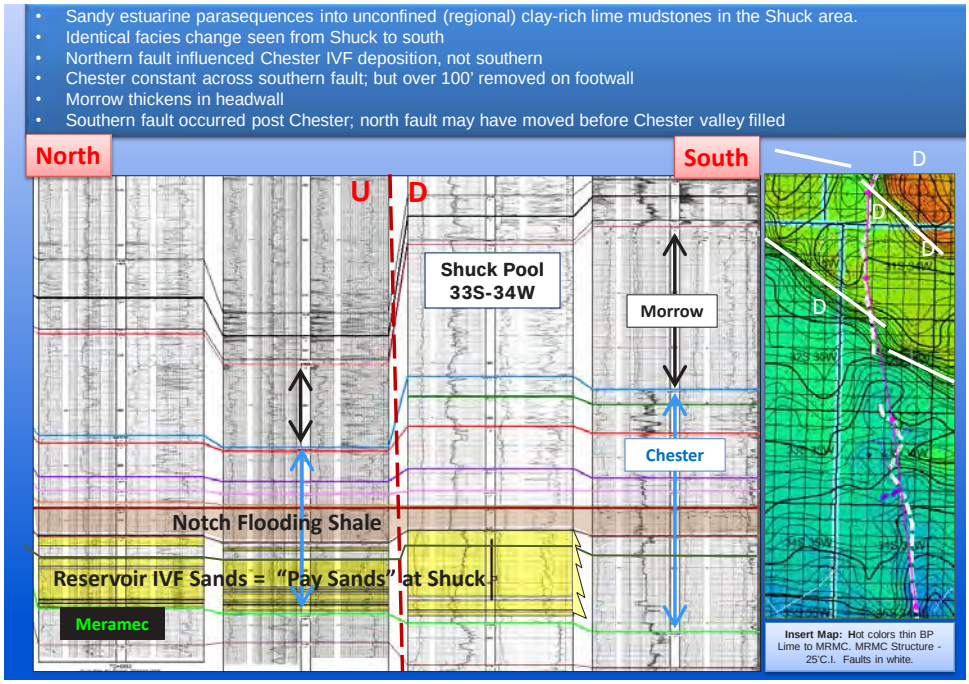


Figure 39. North-south stratigraphic cross section crossing northwest trending down to the south fault at Shuck Field. Datum it top of the Chester age Notch Shale.

The northwest trending fault at Shuck Field is further analyzed in **Figure 40**. As noted previously, the deformation across the fault is minor but does affect the character and thickness of the Chester sandstone reservoir. **Figure 40** (a) also indicates that the incised valley fill estuarine sandstone pinches out south of the fault as it reaches the wide estuarine bay. **Figure 40** (b) datumed on the Atokan shows the notable thickening in the Morrow and Atokan across the fault further supporting the major tectonism during these intervals. **Figure 40** (c) shows 300 ft of offset of the Atokan datum indicated notable post Atokan tectonic movement.

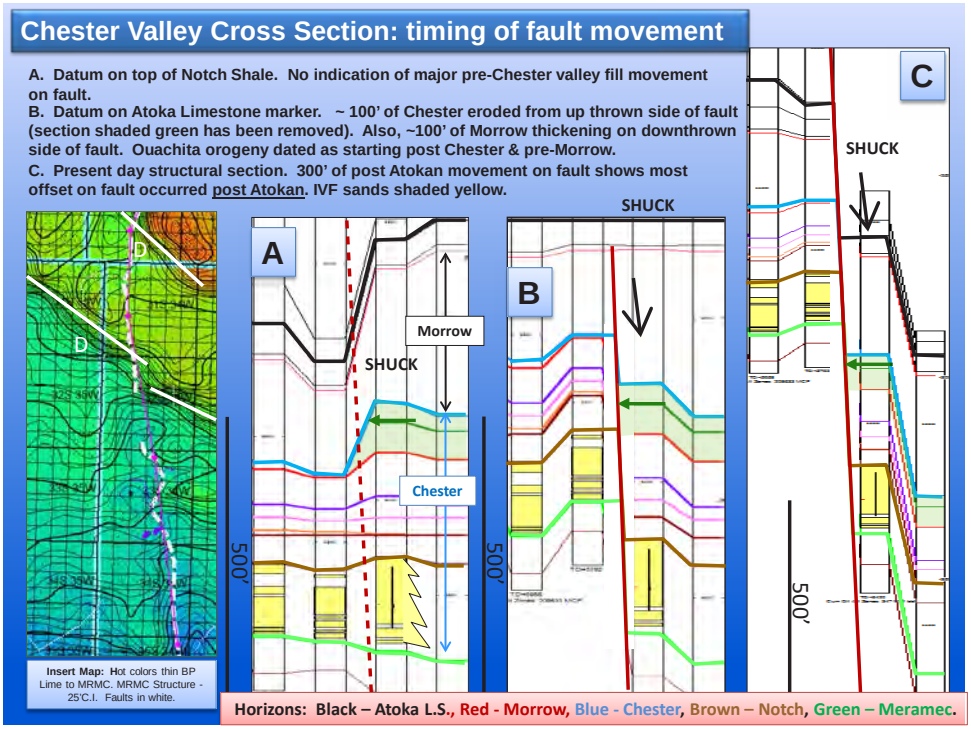


Figure 40. Three north-south cross sections at Shuck Field crossing notable northwest trending fault, (a) datum on the Notch Shale as in Figure 39, (b) datum on the Atokan Limestone, and (c) current day structure.

Seismic that has been examined in this area indicates that the overall deformation above the Atokan diminishing greatly, but is still a factor in the structural configuration and its affect on deoposition. **Figure 41** solidifies this point, showing the Isopach of the lower Permian from the top of the Hutchinson Salt Member to the Neva Limestone in the Council Grove Group. The regional lineaments are again shown and it is clear that the influence on deposition of this much younger interval is sill apparent with stepwise thickening to the southeast. The patterns of thickening have changed, probably as a result of the changing stress field as the Ouachita based tectonism migrated to the Marathon orogeny in south Texas.

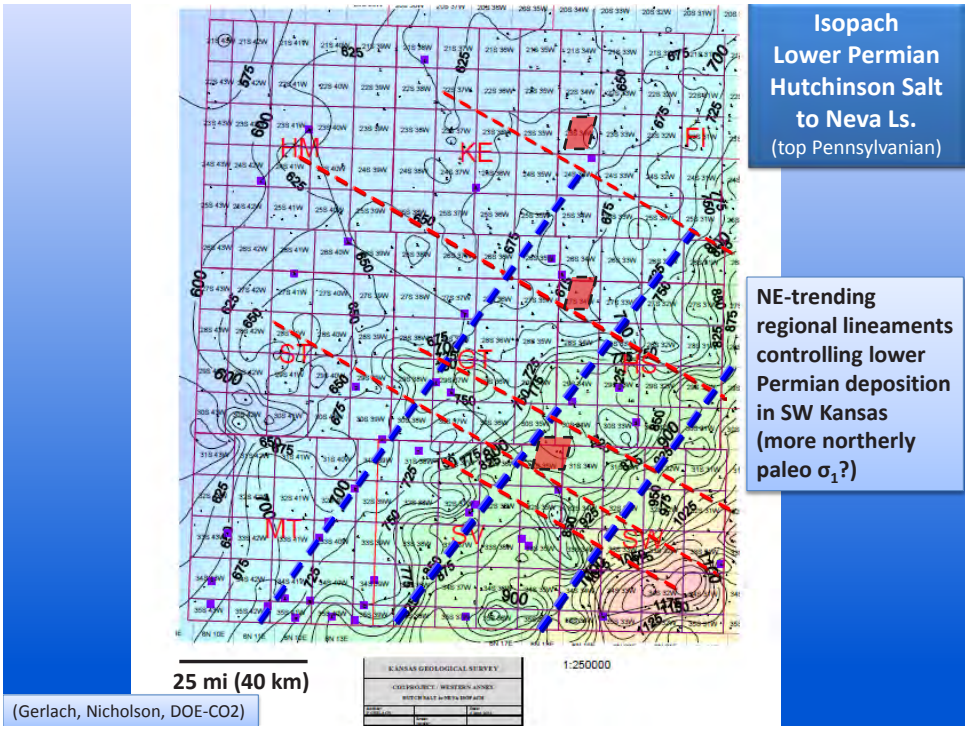


Figure 41. Isopach of the lower Permian Hutchinson salt to Neva Limestone.

The influence of lineaments in much younger deformation is also apparent in the examination of the trends of evaporite dissolution in western Kansas in the area discussed above.The isopach of the halite bearing Blaine Formation reveals a dissolution zone that forms a clear linear northeastern trend (**Figure 42**).The dissolution front also corresponds closely to the location of the western edge of the regionally thick High Plains Aquifer. The edge of the salt dissolution is also is expressed at the surface by a topographic escarpment. The coincidence strongly suggests cause and effect. The dissolution front is also the location of recent sinkholes.

The saturated thickness of the High Plains Aquifer and the thickness of the Blaine Formation closely correspond suggesting that the sediment accommodation for the aquifer originated with the dissolution of the halite (**Figure 43**). The rectilinear distribution on both maps also suggest that structural lineaments influence the processes leading to this development.

Importantly, their have been no indications of contamination of water in the High Plains Aquifer from the communication with brines from the pre-Permian. Rather these is local saltwater intrusion from the dissolution of Permian halite. This suggests that the structural control may be represented from preferred joint patterns that may be opened when stress from such features as post-Laramide uplift in the Rockies were active.

A more detailed view of the Blaine Formation structure shows the linear trends of highly gradient slopes that correspond to underlying salt dissolution.

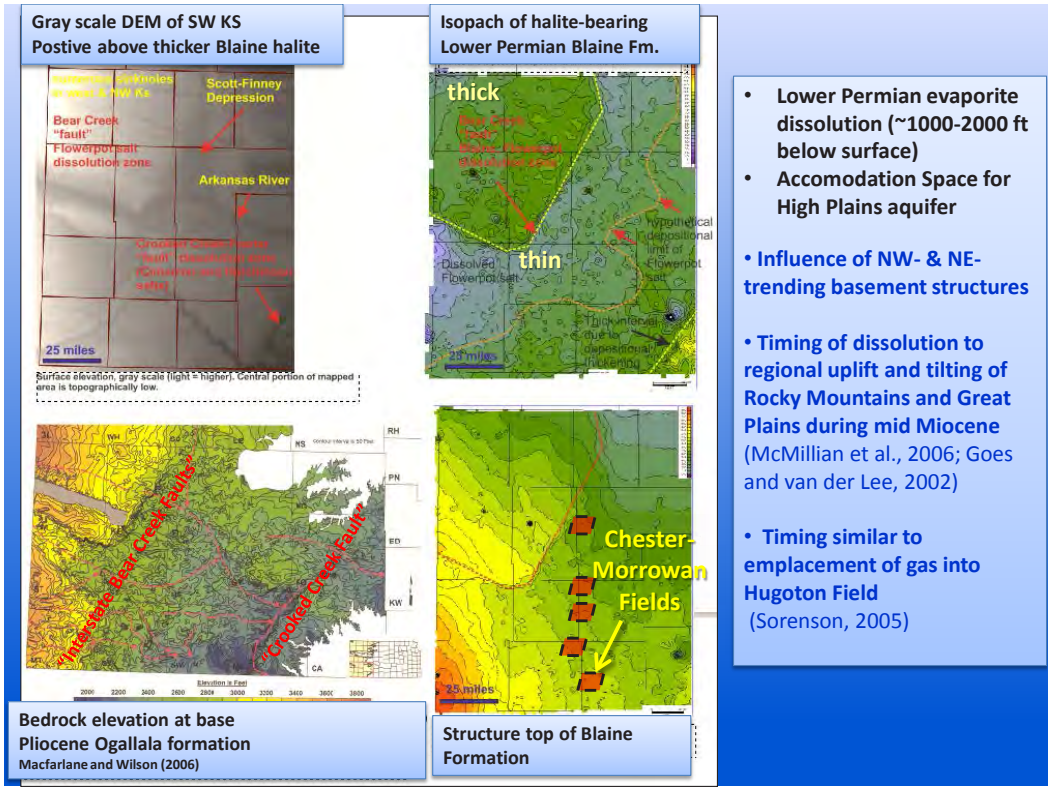


Figure 42. Surface topography (upper left), Isopach of the halite-bearing Blaine Formation (upper right), Bedrock elevation of the High Plains Aquifer (lower left), and structure top of the Blaine Formation (lower right).

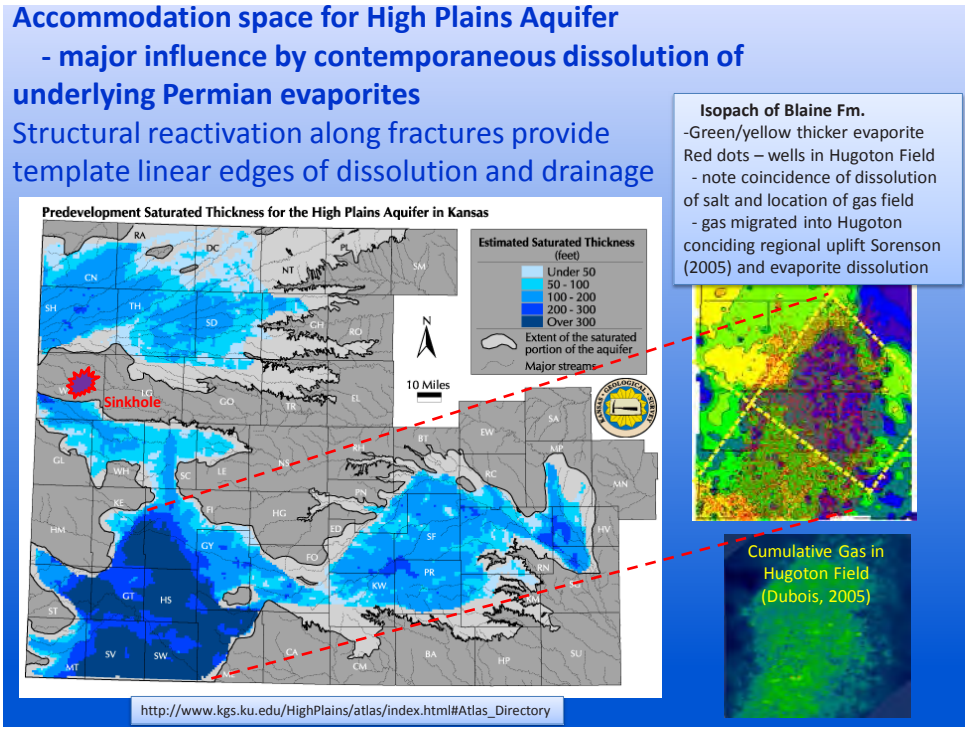


Figure 43. Saturated thickness of the High Plains Aquifer (left) compared to the Isopach of the Blaine Foration (upper right) shows similarity in shape. Lower right is the depiction of the Hugoton Gas Field as cumulative gas production corresponding to the shape and size of the previous maps.

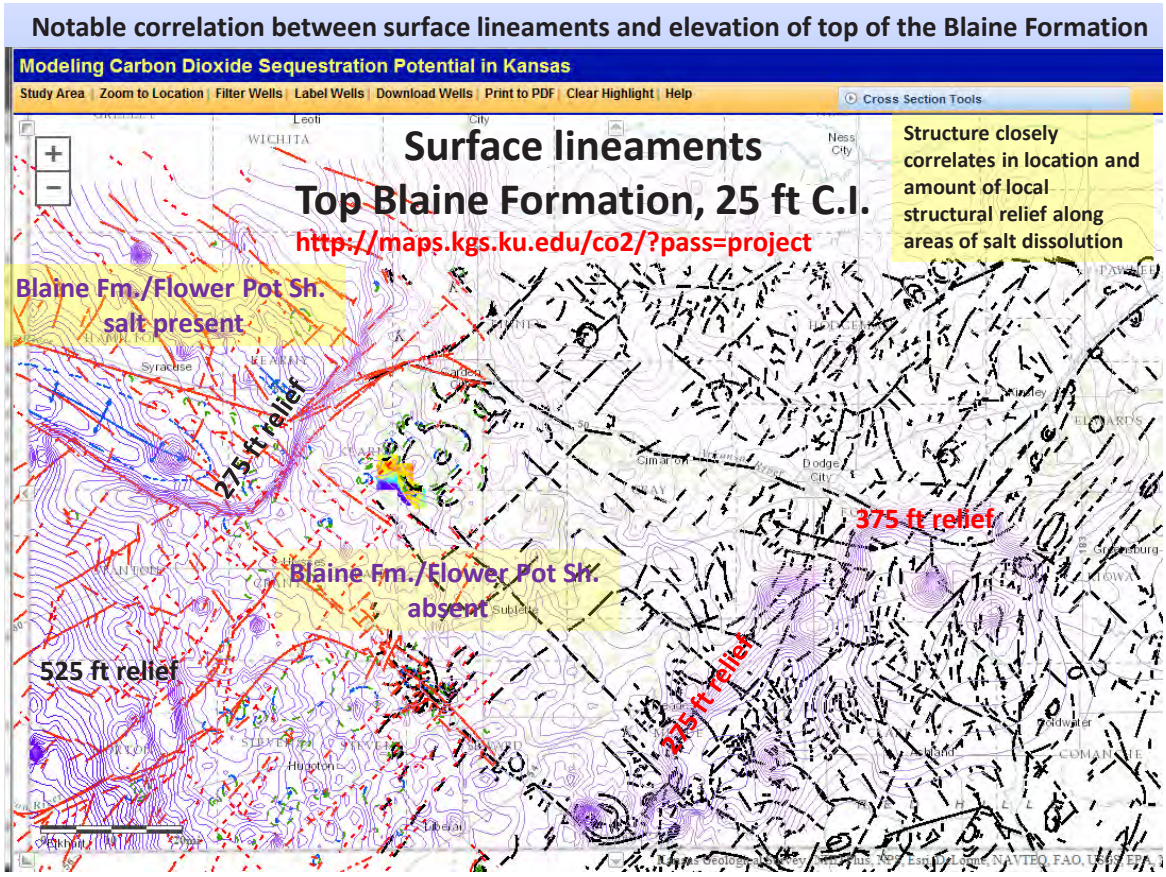


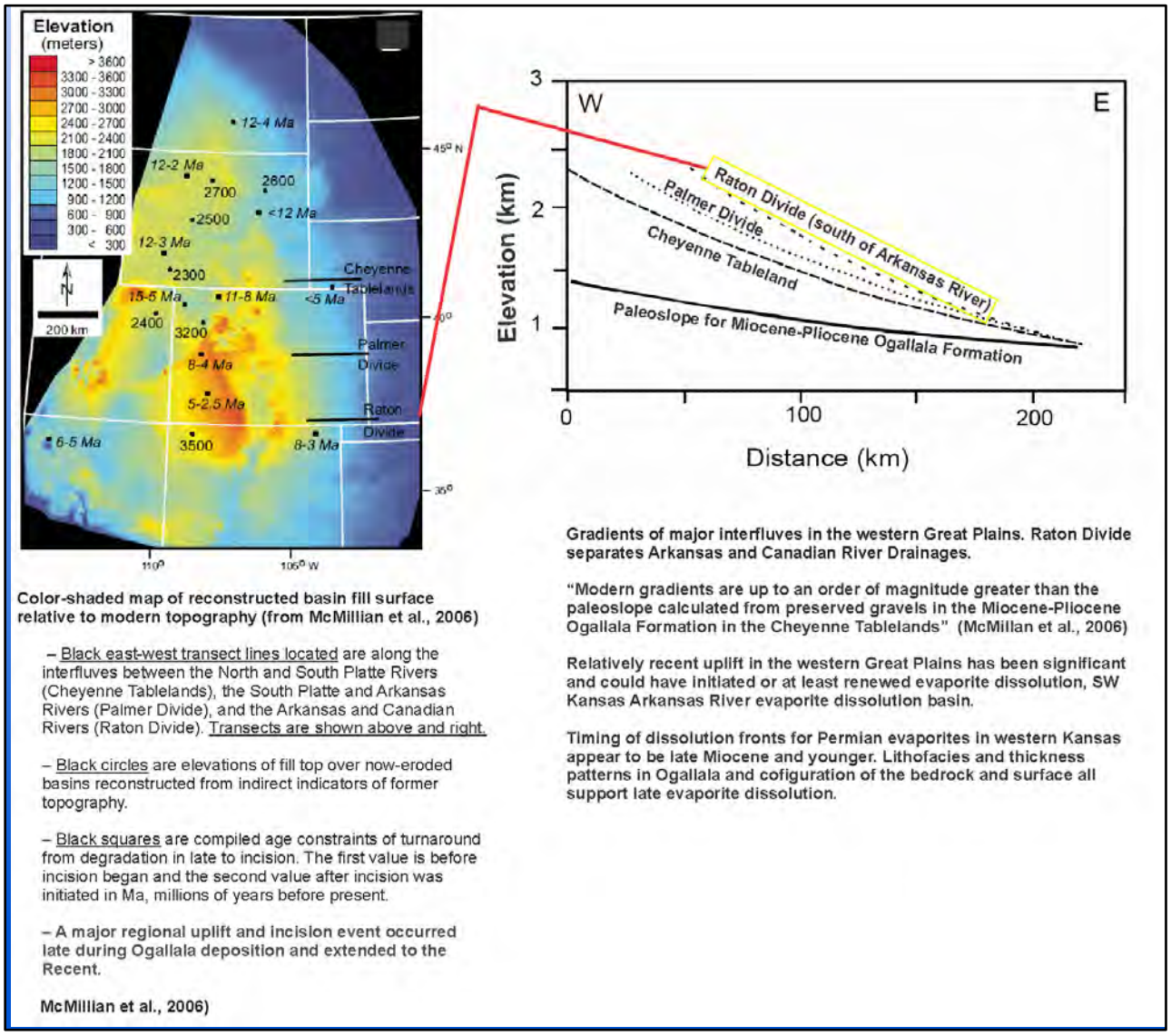
Figure 44. Elevaton on top of the Blaine Formation and identification of the locations of steeper gradients inferred to result from salt dissolution. Area missing salt corresponds to thick High Plains Aquifer. Surface lineaments are also overlain on this map.

Summary

The literature contains considerable evidence for post Laramide structural uplift that affects western Kansas and stream drainages on the high plains (**Figure 45**). Resulting extensional forces related to the uplift may have allowed joints to open and allow percolation of surface waters and contact the halite.

The degree of uplift of the High Plains Aquifer is seen when the attitude (dip azimuth and rate) is compared with the underlying Permian strata. The west to east lithofacies cross section of the High Plains Aquifer along the course of the Cimarron River shows essentially the same dip as the underlying Permian strata including the salt bearing intervals (**Figure 46**). Changes in lithofacies occur in High Plains Aquifer where the underlying underlying Permian section is either faulted or underwent sharp flexture (down to the east along a northeast trending structure). Lithofacies change abruptly from fine grained and clay to more sand rich (upper left of **Figure 46**). This suggests renewed activity along the structural line during deposition of the High Plains Aquifer, but without vertical offset on the deeper seated feature. Finally, similar dip rates of the late Tertiary

and Permian suggests that the aquifer is not at depositional dip, but is oversteepened as suggested by some workers (**Figure 45**). The abundance of clay near the western edge of the thick aquifer proximal to the salt dissolution front suggests a local reduction in the depositional gradient at locations where underlying salt underwent dissolution prior to and concurrent with sedimentation.



Color-shaded map of reconstructed basin fill surface relative to modern topography (from McMillian et al., 2006)

– Black east-west transect lines located are along the interfluves between the North and South Platte Rivers (Cheyenne Tablelands), the South Platte and Arkansas Rivers (Palmer Divide), and the Arkansas and Canadian Rivers (Raton Divide). Transects are shown above and right.

– Black circles are elevations of fill top over now-eroded basins reconstructed from indirect indicators of former topography.

– Black squares are compiled age constraints of turnaround from degradation in late to incision. The first value is before incision began and the second value after incision was initiated in Ma, millions of years before present.

– A major regional uplift and incision event occurred late during Ogallala deposition and extended to the Recent.

McMillian et al., 2006)

Gradients of major interfluves in the western Great Plains. Raton Divide separates Arkansas and Canadian River Drainages.

"Modern gradients are up to an order of magnitude greater than the paleoslope calculated from preserved gravels in the Miocene-Pliocene Ogallala Formation in the Cheyenne Tablelands" (McMillan et al., 2006)

Relatively recent uplift in the western Great Plains has been significant and could have initiated or at least renewed evaporite dissolution, SW Kansas Arkansas River evaporite dissolution basin.

Timing of dissolution fronts for Permian evaporites in western Kansas appear to be late Miocene and younger. Lithofacies and thickness patterns in Ogallala and cofiguration of the bedrock and surface all support late evaporite dissolution.

Figure 45. Post Laramide uplift of the central Rocky Mountains has been documented.

A recent sinkhole formed in early August 2013 (**Figure 47**) rekindled interest in this subsidence in this area that has occurred episodically in the historical past. Vestiges of previous sinkholes are clustered in the vicinity of this recent sink (**Figure 48**). It has been surmised by some that that the source of the subsidence is shallow such as karst in the immediately underlying Niobrara Chalk. But, the area is also the site of salt dissolution based on these observations – 1) the immediate area underlain by halite in the Flower Pot Shale where ~220 ft of salt is locally missing (**Figures 50 and 51**); 2) the potentiometric

surface of the formation water in the Permian is ~1650 ft below ground level (**Figure 49**) suggesting the potential for meteoroic water to perculate to depths of the salt-bearing strata, and 3) the recent sinkhole and the earlier sinkholes occur along an area of mapped northwesterly thinning of the halite that might be related to a regional lineament system as previously discussed.

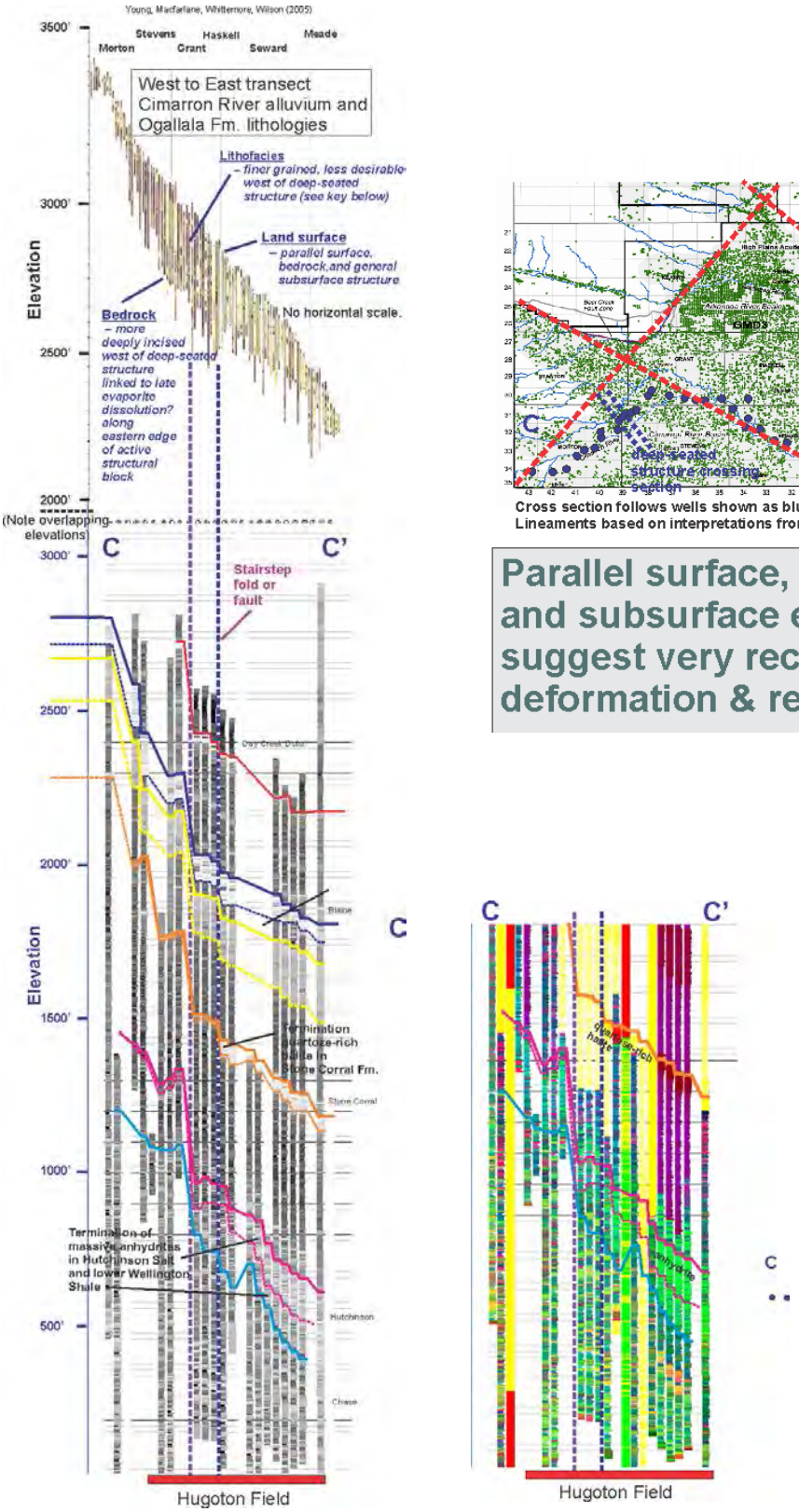


Figure 46. West to east structural cross section from ground surface into the lower Permian strata along a transect following the Cimarron River in the SW corner of Kasnas

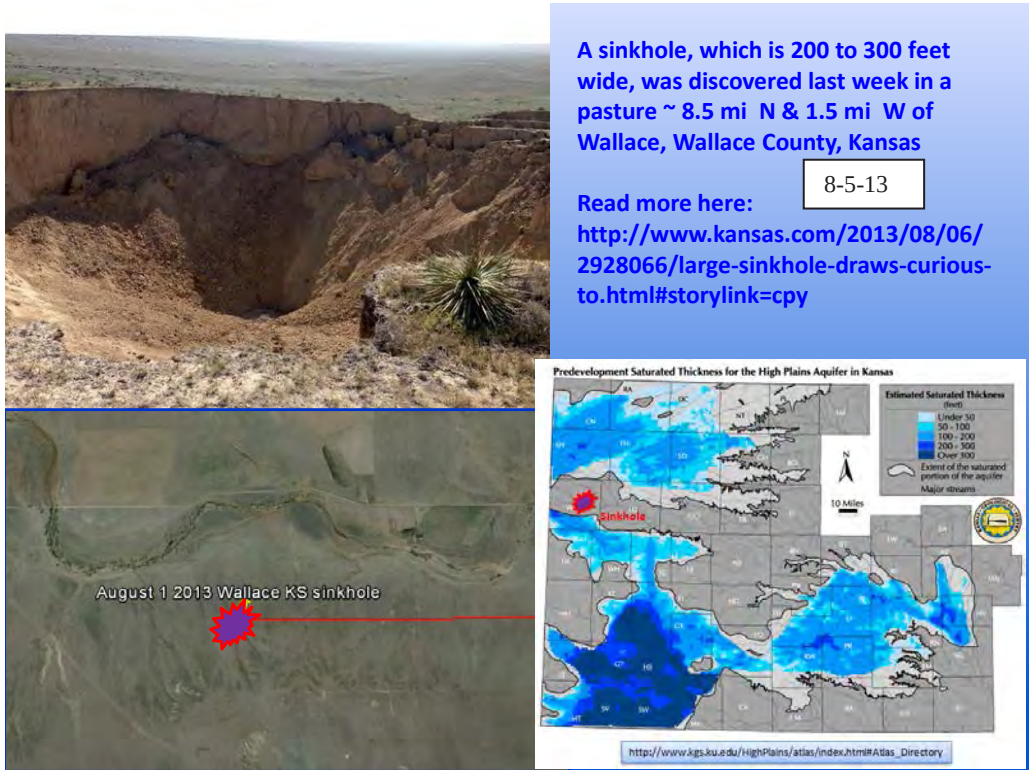


Figure 47. Recent sinkhole developed in western Kansas in area with the Blaine Formation halite is or has recently undergone dissolution.

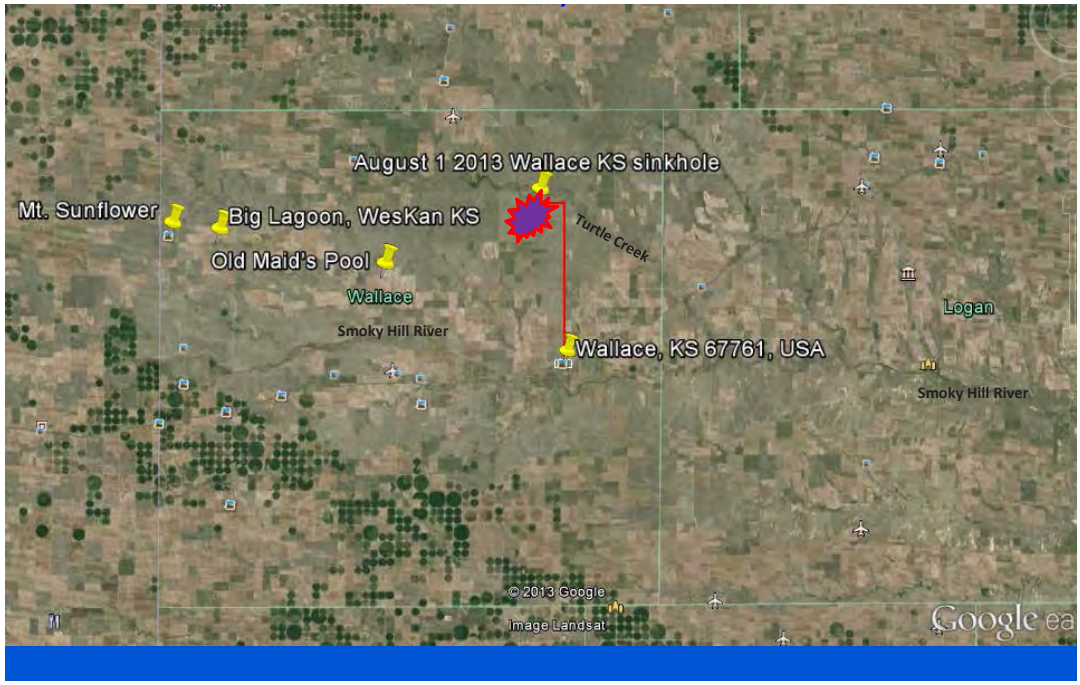


Figure 48. Recent sinkhole and those nearby along the headwaters of the Smokey Hill River.

The potentiometric surface is near the elevation of the salt (~1500 ft above sea level) so gravity flow of meteroric water could theoretically intercept the salt bed (**Figures 49, 50, and 51**).

Large cavities could develop in the salt and then eventually collapse, which could extend toward the ground surface via stopping. The process may be delayed over millennia as roof rock stabilizes the upward stopping and allows the cavern to widen.

In all of this discussion of possible structural controls and reactivation of basement lineaments, the salt dissolution appears to be driven my meteoroic water coming from above, not below. One of the largest gas fields in North America, Hugoton-Panoma Gas Area, accumulated below the salt beds and other less soluble evaporites beneath them. Natural gas has not leaked to the surface, nor is there any recorded leakage of formation brines from below the evaporite interval into the High Plains Aquifer. The potentiometric surface of the Permian has also remained considerably below that of a hydrostatic water column attesting in general to the general isolation of surface and deeper subsurface aquifer systems.

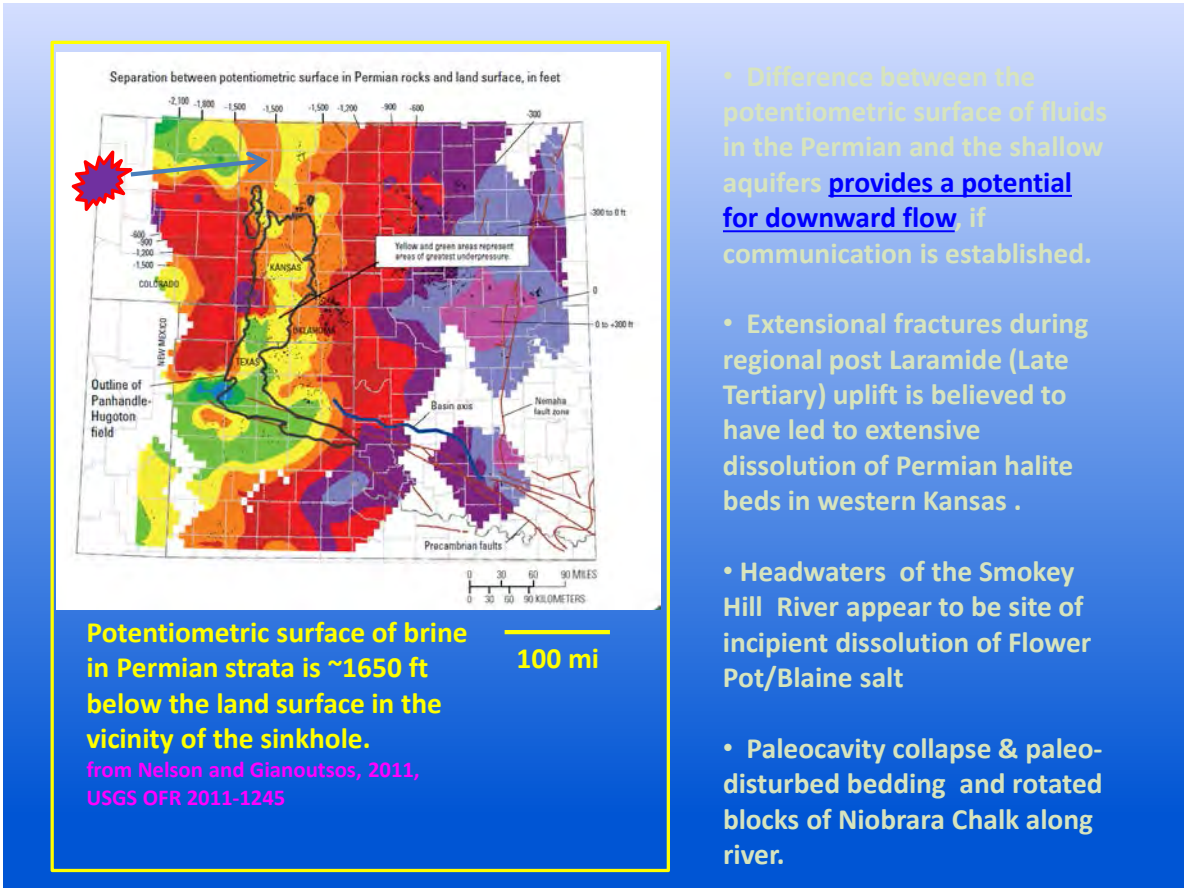


Figure 49. The potentiometric surface of the formation water in the Permian strata is approximately 1650 ft below the land surface at the location of the sinkholes noted in Figure 48.

The Hugoton Gas Area has also underwent fracture stimulation since the late 1950s when the technology was first deployed in the U.S. Besides the natural episodic structural movement, some quite recent, and the man-made fractures in the gas reservoir, the integrity of the Permian evaporites attests to the effectiveness as a caprock.

While the region has underwent a dynamic structural evolution, some subtle and episodic and others distinct and notable, the suitability of the area to commercial scale carbon storage in sites being studied appear to be favorable and continue to be evaluated relying on the wide range of observations from the microscopic scale to the regional level.

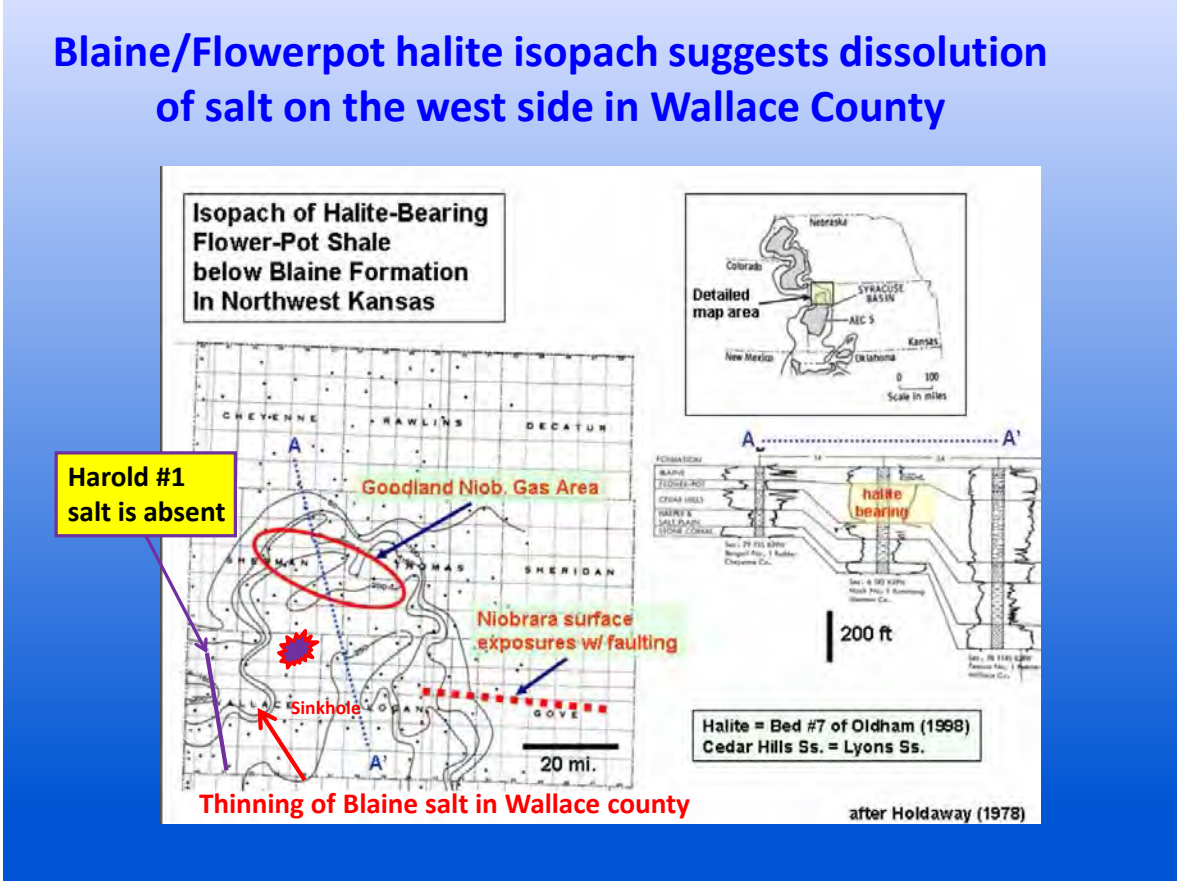


Figure 50. Isopach of halite bearing Flower Pot Shale showing location of the Harold #1 where the halite is absent (Figure 51).

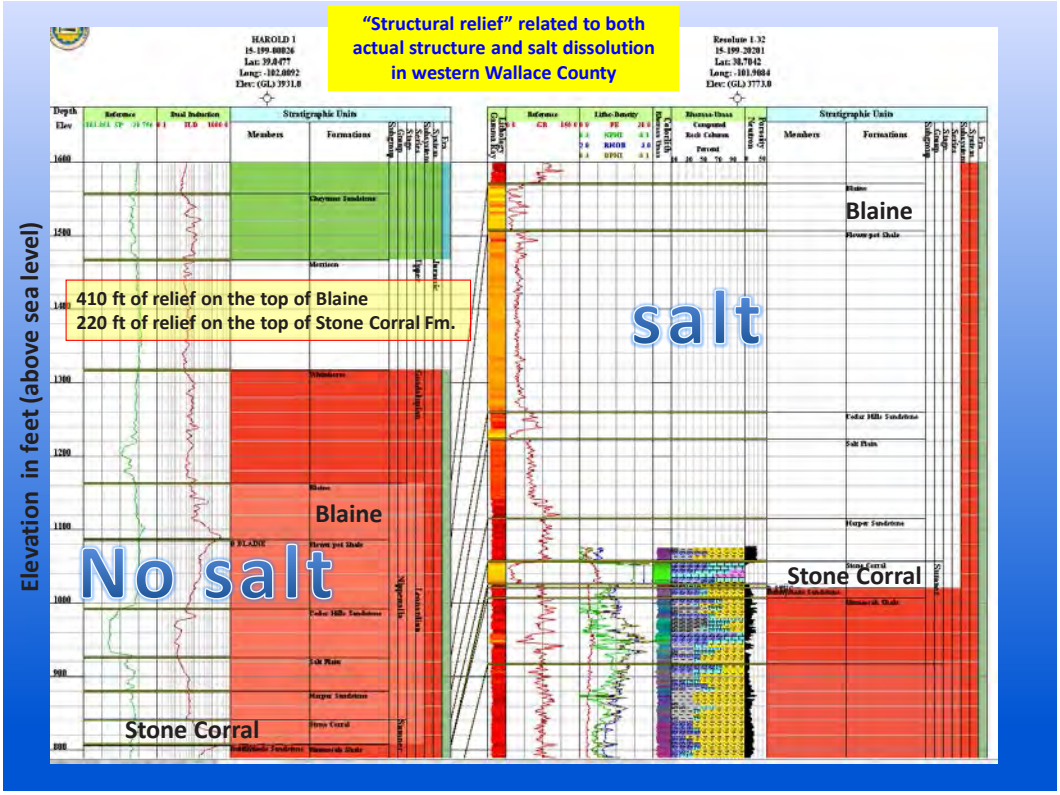


Figure 51. Structural cross section of the Blaine Foramtion to Stone Corral Formation showing two wells, one with halite/salt and one without, the Harold #1.

ONGOING ACTIVITIES - WELLINGTON FIELD –

Task 7. Evaluate CO2 Sequestration Potential in Arbuckle Group Saline Aquifer - Wellington field

New models have been completed for the Arbuckle saline aquifer and Mississippian oil reservoir at Wellington Field.

PRESENTATIONS AND PUBLICATIONS

Next Step Oil and Gas Seminar, Hays, KS

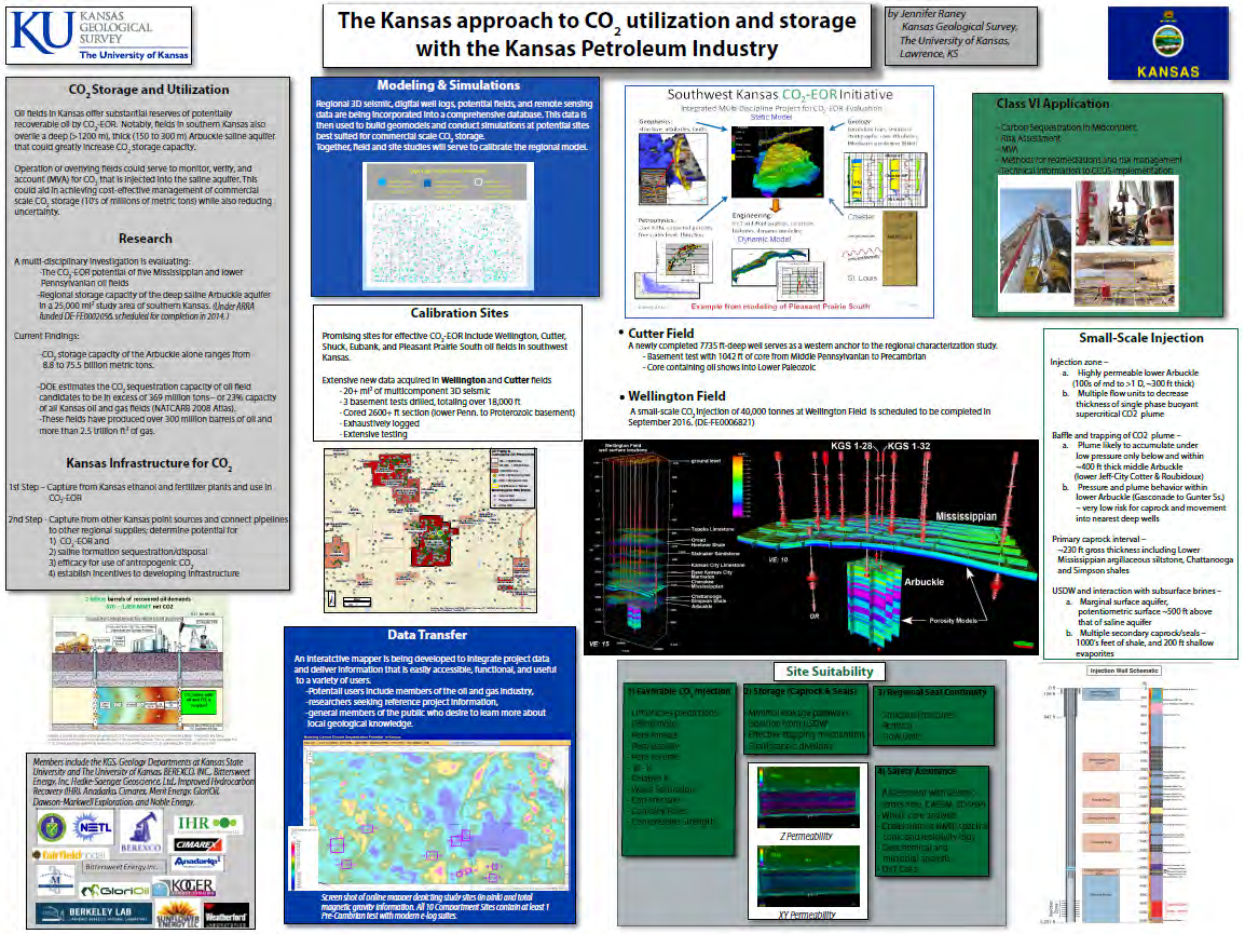
W. Lynn Watney, John Youle, Dennis Hedke, Paul Gerlach, Raymond Sorenson, Martin Dubois, Larry Nicholson, Thomas Hansen, David Koger, Ralph Baker, Jennifer Raney, 2013, *Sedimentologic and Stratigraphic Effects of Episodic Structural Activity During the Phanerozoic in the Hugoton Embayment*, Kansas USA.
http://www.kgs.ku.edu/PRS/Ozark/Reports/2013/Structural_analysis_Hugoton_Embayment.pdf

DOE Annual review meeting, August 20 & 21, 2013, Pittsburgh, PA

W. Lynn Watney and Jason Rush, Joint PIs, 2013, *Small scale field test demonstrating CO2 sequestration in Arbuckle saline aquifer and by CO2-EOR at Wellington field, Sumner County, Kansas DE-FE0006821*.
http://www.kgs.ku.edu/PRS/Ozark/Reports/2013/Watney_DE-FE0006821_FY13_Carbon_Storage_Review_v3.pdf

W. Lynn Watney and Jason Rush, Joint PIs, 2013, *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 Number (DE-FE0002056).*
http://www.kgs.ku.edu/PRS/Ozark/Reports/2013/DE-00002056_FY13_Carbon_Storage_Review.pdf

Jennifer Raney, 2013, *The Kansas approach to CO2 utilization and storage with the Kansas petroleum industry.* (see below)



Presentations, Midcontinent AAPG

Brent Campbell, 2013, Geochemical assessment of secondary oil recovery, and assessing potential quantification of CO2 sequestration in the underlying saline Arbuckle aquifer, AAPG Mid-Continent Section Meeting, Wichita.

John Doveton, 2013, Pore size and textural analysis of carbonates from nuclear magnetic resonance logging : an Arbuckle case study, AAPG Mid-Continent Section Meeting, Wichita.

Martin Dubois, 2013, CO2 Enhanced oil recovery and CO2 sequestration potential of the Mississippian Chester incised valley reservoir system, Haskell and Seward Counties, Kansas, AAPG Mid-Continent Section Meeting, Wichita.

Paul Gerlach, 2013, The Geologic History of Kansas, 2013 or Updating the Work of a Legend, AAPG Mid-Continent Section Meeting, Wichita.

Paul Gerlach, 2013, Online Development of New Kansas Type Logs, AAPG Mid-Continent Section Meeting, Wichita.

Yevhen Holubnyak, 2013, Reservoir Engineering Aspects of Pilot Scale CO2 EOR Project in Upper Mississippian Formation at Wellington Field in Southern Kansas, AAPG Mid-Continent Section Meeting, Wichita.

Yevhen Holubnyak, 2013, Dynamic Modeling of CO2 Geological Storage in the Arbuckle Saline Aquifer, AAPG Mid-Continent Section Meeting, Wichita.

John Youle, 2013, Depositional history and distribution of reservoir rocks in Chesterian incised valley fill pools: examples from Shuck and Eubank fields in southwestern Kansas, AAPG Mid-Continent Section Meeting, Wichita.

W. Lynn Watney, 2013, Seismic attribute analysis of the Mississippian chert at the Wellington Field, south-central Kansas, AAPG Mid-Continent Section Meeting, Wichita.

W. Lynn Watney, 2013, Systematic and episodic structural deformation in southern Kansas and implications for petroleum systems and CO2 storage, AAPG Mid-Continent Section Meeting, Wichita.

W. Lynn Watney, 2013, Evaluating CO2 Utilization and Storage in Kansas, AAPG Mid-Continent Section Meeting, Wichita.

W. Lynn Watney, 2013, Paleozoic Anchor Core in Southwest Kansas -- Berexco Cutter KGS #1 in Stevens County, AAPG Mid-Continent Section Meeting, Wichita.

W. Lynn Watney, 2013, Paleozoic Anchor Core in South-Central Kansas – Berexco Wellington KGS #1-32, Sumner County, AAPG Mid-Continent Section Meeting, Wichita.

KEY FINDINGS

1. Core analysis in the Cutter well is being used to predict permeability from the well logs. Core data indicates that the permeability ranges 4.5 orders of magnitude compared to porosity and is again closely related to the pore type and lithofacies. Pore space again is fabric selective.
2. Oil shows in the core analysis and shows of oil in the fluid sampling of the Arbuckle at Cutter Field substantiates the presence of oil in the lower Paleozoic strata, occurring in multiple horizons.
3. Preliminary results from the pressure buildup tests conducted during the perforating and swabbing in the Arbuckle of the Cutter well exhibit permeability in the 100s of millidarcies indicating zones are present with sufficient injectivity for CO2. However, these permeability measuremnts are quite a bit larger than measured in whole core analyses. More work needs to be done.
4. CO2-EOR simulation work at Pleasant Prairie oil field suggests a viable site for carbon storage. The analytical techniques are being refined and the results will be useful in building scoping models of CO2-EOR for analogous fields. Simulations from Eubank, Shuck, and Cutter will also be factored into the feasibility assessment and will result in refined scoping models for these types of reservoirs.
5. The fuzzy logic methodology is selected as the optimal method to interpolate properties in the regional assessment of the Arbuckle Group using modern suite of well logs and cuttings descriptions.
6. Anadarko Basin and Hugoton Embayment are structurally coupled system spanning Proterozoic extension to Phanerozoic compression.
7. Major structures in the Hugoton Embayment at serve as traps for the oil reservoirs being studied show prominent evidence of coupled and complex compressional events from far field stresses including diagnostic features such as flower structures and restraining bends developed along reactivated basement lineaments.
8. Episodic structural movement is the norm in the Midcontinent with post tectonic movement affecting sedimentation/stratigraphy throughout Phanerozoic including High Plains Aquifer.
9. Pattern of deformation suggests systematic controls affected by prominent basement weaknesses (the template) as revealed by potential fields and lineament analysis. Basement weaknesses interact with an evolving stress field leading to preferred patterns of deformation.
10. While southern Kansas has underwent a dynamic structural evolution, some subtle and episodic and others distinct and notable, the suitability of the area to commercial scale carbon storage in sites being studied appear to be favorable and continue to be evaluated relying on the wide range of observations from the microscopic scale to the regional level.

PLANS

1. Launch review of the stratigraphic correlations via the type log project and web application.
2. Complete carbon isotopic analysis of the Arbuckle Group at Wellington Field to aid in confirming physical stratigraphic correlations.
3. Complete assessment of the carbon storage volume in the Arbuckle for southern Kansas using new methodologies that have been established.
4. The interactive mapper and carbon storage assessment will be finalized for the NATCARB and Carbon Storage Atlas by end of calendar year 2013 to meet deadlines on those activities.
5. Continue to obtain core and fluid analyses from the Cutter well to understand communication between hydrostratigraphic units and relationship to the hydrocarbon shows.

APPENDIX I

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

SEVENTEENTH QUARTER PROGRESS REPORT

DOE F 4600.2
(5/09)
(All Other Editions are Obsolete)

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.

QUARTERLY 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**

Seventeenth Quarter Progress Report

Date of Report: 2-6-14

Period Covered by the Report: October 1, 2013 to December 30, 2013

**Contributors to this Report: Brent Campbell, Susan Carroll, Saugata Datta, John Doveton, Mina Fazelalavi, David Fowle, Dennis Hedke, Eugene Holubnayak, Christa Jackson, David Newell, Jennifer Raney, Jennifer Roberts, Megan Smith,
Michael Vega, John Victorine, Lynn Watney**

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		90%
2.0 Characterize the OPAS (Ozark Plateau Aquifer System)	1/1/2010	01/01/10	9/30/2013		95%
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	+++	90%
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	**	95%
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	02/01/12	9/30/2013	***	90%
13.0 Regional source sink relationship	1/1/2010	1/1//2010	9/30/2013	****	97%
14.0 Technology Transfer	1/1/2010	01/01/10	2/7/1014		90%

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 competed
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	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		90% 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		95% complete
KGS Milestone 3.4: Regional CO2 Sequestration Potential in OPAS - 17 Counties	12/7/2012		90% complete
HQ Milestone: Make data set from one site characterization project publicly available.	12/31/12	Note: This milestone was met collectively by all projects. No one project was held accountable to the milestone.	
HQ Milestone: Complete one major field activity to collect additional characterization data from well drilling, 2-D or 3-D seismic surveys, or well logging/testing.	03/31/13	Note: This milestone was met collectively by all projects. No one project was held accountable to the milestone.	
HQ Milestone: Complete, at a minimum, planning for one major field activity, such as well drilling, 2-D or 3-D seismic surveys, or well logging/testing.	06/30/13	Note: This milestone was met collectively by all projects. No one project was held accountable to the milestone.	
HQ Milestone: Yearly Review Meeting of active projects; opportunities for information exchange and collaboration	09/30/13	Attended Annual Review meeting in August	100% complete
HQ Milestone: Complete one field activity to collect characterization data from well drilling, 2-D or 3-D seismic surveys or well logging/testing.	12/31/13		
HQ Milestone: Complete analysis of field activity in project-related reservoirs to validate additional storage potential.	03/31/14		
HQ Milestone: Semi-annual progress reports for active projects (i.e. Quarterly Report ending March 31, 2014).	06/30/14		
HQ Milestone: Yearly Review Meeting of active projects; opportunities for information exchange and collaboration	09/30/14		

ONGOING ACTIVITIES - REGIONAL STUDY INCLUDING SOUTHWEST KANSAS

REGIONAL STUDY INCLUDING SOUTHWEST KANSAS) –

1) Refinement of type wells, interactive mapper, and GEMINI web applications

The interactive mapper has continued to undergo changes and improvements with plans to finalize for public release in first quarter 2014 (**Figure 1**).

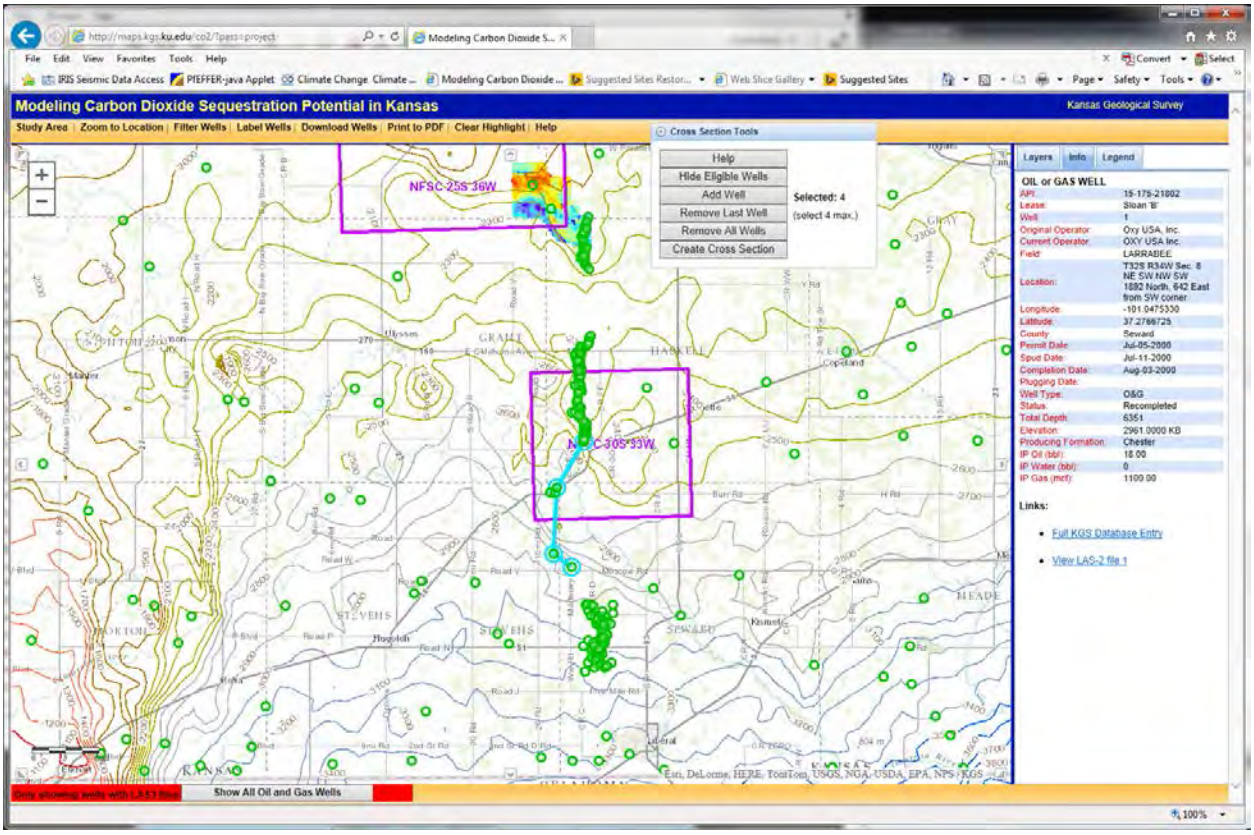


Figure 1. Interactive mapper showing distribution of the type wells in the western sector of the regional study area. Structure map on top of the Meramec Mississippian, field and type wells as green dots circles, and purple square in middle over Cutter and Victory fields corresponding to commercial scale CO2 injection modeling location.

Status of the GEMINI Web Application – modified from contributions by John Victorine

The Java-based GEMINI web application is nearing their final release in first quarter of 2014 and the status is described below. Functionality of these applications comprising GEMINI will closely be coordinated with the interactive mapper since many applications area launched via the map.

We have coined the term, "Subsurface Information Systems (SIS)" (Doveton, 2013) to capture the parallel to GIS in our efforts to provide imaging of the subsurface that is comparable to the functionality and expectations of GIS. This is the primary intent of the GEMINI application. Funding has allowed us to utilize our experience and observations to focus on creating a product that should become broadly applicable for use in other settings.

This new version of GEMINI supported in this project is the key means to access and interact with the project's type logs taking advantage of over 11 years of Java development experience at the Kansas Geological Survey (KGS) in developing the original web applications in the first release of GEMINI (*Geo-Engineering Modeling through INternet Informatics*) in 2003. The web application allows the geologist to seamlessly integrate databases and geological analytical tools across the web. Analytical tools were designed for use by the independent oil and gas operators, consultants, regulators, and other geoscientists promoting widely separated team members within and outside companies. The application is now extended to characterize the deep saline aquifers and caprocks to evaluate suitability for storing CO2.

Programming standards used to date include: 1) instituting policies and procedures of software development utilized in some sectors of the federal government, 2) Java Code Convention Document, 3) informal design and code review process, 4) Code Review Documentation, 5) periodic releases, and 6) Version Directories. The POC funding would bring the modules under a single application so that it can easily be certified under current self-regulating policies pertaining malware attacks.

The web application saves the data to the PC using the Log ASCII Standard (LAS) version 3.0 developed by the Canadian Well Logging Society. This version provides a means to collect all the geological data in one file. Although the *LAS 3.0 Format* has default data types, the user can add their own data types to the file provided they use the primary section types, i.e., Parameter, Definition and Data whenever possible, which are briefly paraphrased below -

- ~NewSection_Parameter contains a one dimensional data item consisting of (usually but not restricted to) one or two elements. Each line also contains a full description of that data.
- ~NewSection_Definition although structurally identical to a Parameter Data lines (see above), each Column Definition line is used to describe each matching (by order) channel contained in the matching Column Data section. The name, unit, log code, description and format (if used) contained in each Column Definition line fully describe the channel it refers to.
- ~NewSection_Data | NewSection_Definition
- Each line contains a series of delimited data values. The delimiting character is defined by the value of the DLM parameter in the ~Version section. Descriptions of each data are contained in the matching Column Definition section.

GEMINI Directory Structure

A major goal for this new release is to consolidate the source code for all the modules that have been created and revised. A centralized directory structure is being developed to access the different modules. The centralized directory structure allows for changes to a java file that is used by many web apps. With this structure type one change to a java file only requires recompiling all the affected web apps, where as with the old model the java file may or may not be modified, no consistency with the code.

The Log ASCII Standard (LAS) version 3.0 file IO Java classes are common to many web apps. The LAS 3.0 process will be modified to only retrieve the data that the web app needs without loading all the data in the LAS 3.0 file. When the user saves the data, the LAS 3.0 IO class will load & write any missing data from the original file as well as write changes from the web app to the LAS 3.0 file.

The new consolidated directory structure will also facilitate its use with well data in other locations. The growth and access to digital databases collected by state, federal, and international governments has opened vast amounts of subsurface borehole data inventories (**Figure 2**). Federal divisions such as Bureau of Ocean Energy Management
(BOEM), Bureau

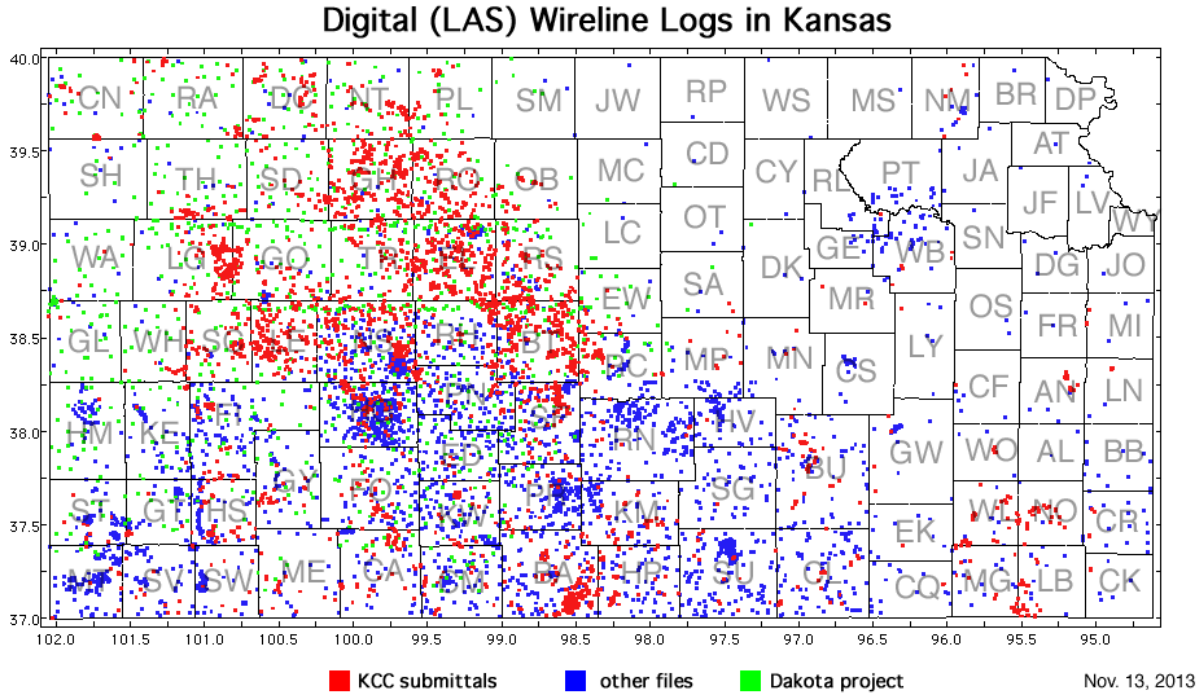


Figure 2. Current distribution of digital (LAS) log files in Kansas. Blue wells in southern Kansas are primarily from wells digitized in this project (DE-FE-0002056).

of Land Management, and US Geological Survey have vast amounts of digital borehole. NATCARB will also have access to a growing volume of digital well log data. GEMINI could allow user to "mine" the information.

Endorsements of GEMINI modules have been received internationally and modules have been used in our research (e.g., Doveton et al., 2004, Watney et al., 2004, Victorine et al., 2005, Bhattacharya et al. 2008, Watney et al. 2008, Doveton, 1994).

Update on Module Comprising GEMINI

Kansas Stratigraphic Units from KGS measured sections web site (http://www.kgs.ku.edu/PRS/Ozark/TYPE_LOG/Stratigraphic/)

This web site was created to illustrate the Kansas Stratigraphic Units for the TYPE LOG Project, the tasks to have the stratigraphic correlations established in this project verified by an external team of experts from the Kansas Geological Society. The web site displays the stratigraphic unit image web page from measured sections or core descriptions and is displayed as a profile plot with image tracks to illustrate the description. A link to a LAS 3.0 file is also available for the user to download the data used as well as a PDF document of the displayed image. A reference URL link is provided of the original source of the data. This site is rather unique in that it uses both outcrop measured sections, core and cuttings/sample descriptions, and lithologic solutions from well logs to understand the concepts of the stratigraphic units that are used as the basis for defining and correlating them.

The systemization of the stratigraphic nomenclature and classification is critical to correlate the strata critical characterization of oil reservoirs, reservoir seals, caprock, and saline aquifers used to store CO2. The tabular version of the Kansas stratigraphy is an interactive component of this website and the links for most of the stratigraphic units provide both important stratigraphic reference sections and type stratigraphic sections (**Figure 3, left**). The Mississippian System is used below to illustrate the classification/nomenclature and the specific link is made to the Pierson Formation of the Osagian as it has been described in a key surface exposure in Missouri (Thompson and Fellows, 1970) (**Figure 3, right**). This unit serves as an important confining layer at Wellington Field and has been extensively studied at this site. **Figure 3 (right)** illustrates measured section in the outcrop by Thompson and Fellows (1970) and the Pierson Formation, specifically.

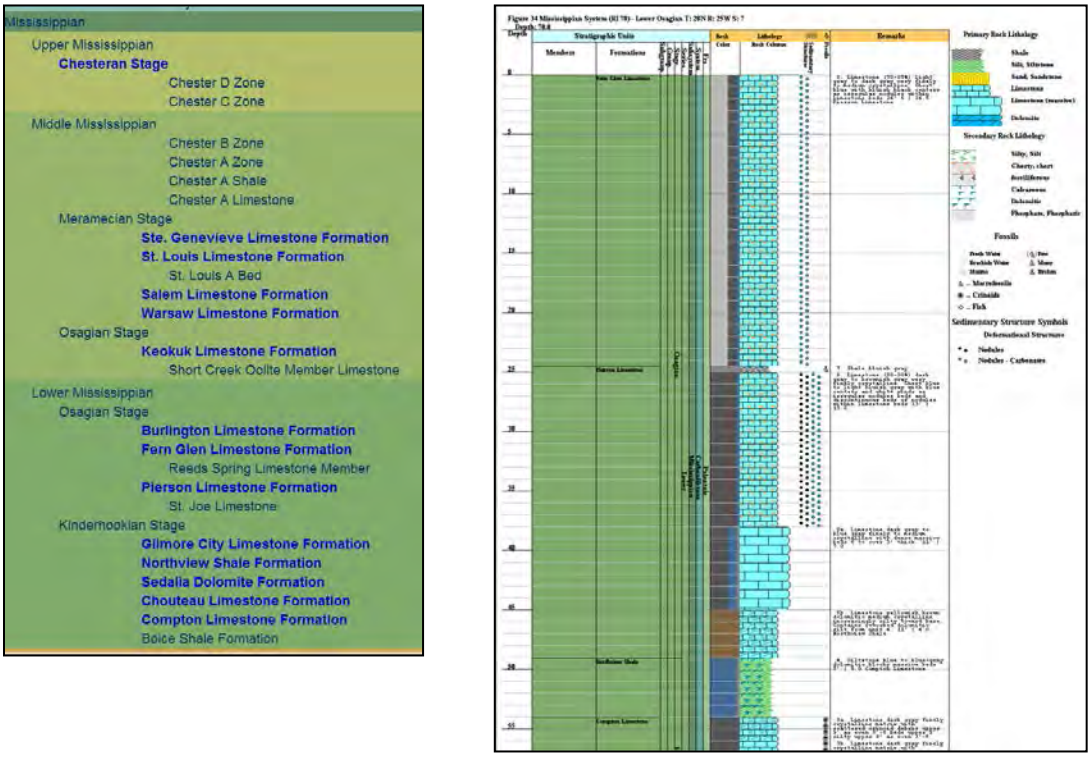


Figure 3. (left) Mississippian stratigraphic column. (right) Portion of reference section of the Mississippian on the right highlighting the Pierson Formation.

The graphical measured section is also available by another link to an LAS 3.0 formatted version of the measured section (**Figure 4**).

```
~Version
#MNEM .UNIT               VALUE  : DESCRIPTION
 VERS .                     3.0  : CWLS LOG ASCII STANDARD - VERSION 3.0
 WRAP .                      NO  : ONE LINE PER DEPTH STEP
 DLM  .                   COMMA  : DELIMITING CHARACTER (SPACE TAB OR COMMA)

~Well
#MNEM .UNIT                                                  VALUE  : DESCRIPTION                  (FORMAT) | ASSOC
 STRT  .F                                                      0.0  : START DEPTH                   {F}
 STOP  .F                                                     75.0  : END DEPTH                     {F}
 STEP  .F                                                      0.0  : STEP LENGTH                   {F}
 NULL  .                                                    -999.95 : NULL VALUE                    {F}
 COMP  .                                                            : Company                       {S}
 WELL  .          Figure 34 Mississippian System (RI 70) - Lower Osagian : Well Name                 {S}
 FLD   .                                                            : Field                         {S}
 SEC   .                                                           7 : Section                      {I}
 TOWN  .                                                         28N : Township (e.g. 42S)          {S}
 RANG  .                                                         25W : Range  (e.g. 25E)            {S}
 LOC   .       roadcut on the west bound lane of I-44 east of Mt. Vernon : Location (Sec Town Range) {S}
 LOC1  .                          NW 1/4 NE 1/4 SE 1/4 sec 7, T28N, R25W : Location 1 (quarter calls) {S}
 LOC2  .                                                            : Location 2 (footages)         {S}
 COUN  .                                                  Lawrence  : County                        {S}
 STAT  .                                                  Missouri  : State                         {S}
 CTRY  .                                                        US  : Country                       {S}
 PROV  .                                                            : Province                      {S}
 SRVC  .                                                            : Service Company               {S}
 LIC   .                                                            : License Number                {S}
 DATE  .                                                            : Completion Date               {D/M/YYY}
 API   .                                                            : API-Number                    {S}
 UWI   .                                                            : Unique Well ID Number         {S}
 LATI  .DEG                                                    0.0  : Latitude                      {F}
 LONG  .DEG                                                    0.0  : Longitude                     {F}
 GDAT  .                                                     NAD27  : Geodetic Datum                {S}
 X     .                                                       0.0  : X or East-West coordinate     {F}
 Y     .                                                       0.0  : Y or North South coordinate   {F}
 HZCS  .                                                            : Horizontal Co-ordinate System {S}
 UTM   .                                                       0.0  : UTM Location                  {F}
 STUS  .                                                   OUTCROP  : Well Status                   {S}
```

```
 ENG   .          Thompson & Fellows (1970, sec. J, p. 170-172  : Recording Engineer            {S}
 WIT   .                                                        : Witnessed By                 {S}

~Tops_Parameter
#MNEM .UNIT          VALUE  : DESCRIPTION                    {FORMAT} | ASSOCIATION
 IQKGS .                    : Profile Web App Saved Data Indicator {S}
 TOPS  .                    : Formation Source              {S}
 TOPDR .                    : Tops Depth Reference          {S}

~Tops_Definition
#MNEM .UNIT          VALUE  : DESCRIPTION                    {FORMAT} | ASSOCIATION
 TOPT  .F                   : Top Depth                     {F}
 TOPB  .F                   : Base Depth                    {F}
 RANK  .                    : Rank of Unit, i.e. (FORMATION, SYSTEM, etc) {S}
 LVL   .                    : Level of Confidence (GOLD, SILVER, COPPER...) {S}
 TOPN  .                    : Stratigraphic Unit Name       {S}
 TOPA  .                    : Alternate Name                {S}
 EON   .                    : EON Age                       {S}
 ERA   .                    : ERA Age                       {S}
 SYS   .                    : System                        {S}
 SER   .                    : Series                        {S}
 SSYS  .                    : Subsystem                     {S}
 SSER  .                    : Subseries                     {S}
 STG   .                    : Stage                         {S}
 GRP   .                    : Group                         {S}
 FORM  .                    : Formation                     {S}

~Tops_Data | Tops_Definition
# TOPT TOPB RANK LVL TOPN TOPA EON ERA SYS SER SSYS SSER STG GRP FORM
 0.0,24.5,"FORMATION","Poor","Fern Glen Limestone","-999.95","Phanerozoic","Paleozoic","Carboniferous","
 24.5,49.08,"FORMATION","Poor","Pierson Limestone","-999.95","Phanerozoic","Paleozoic","Carboniferous","
 49.08,0.0,"STAGE","Poor","Kinderhookian","-999.95","Phanerozoic","Paleozoic","Carboniferous","-999.95",
 49.08,54.08,"FORMATION","Poor","Northview Shale","-999.95","Phanerozoic","Paleozoic","Carboniferous","-
 54.08,68.58,"FORMATION","Poor","Compton Limestone","-999.95","Phanerozoic","Paleozoic","Carboniferous",
 68.58,69.08,"FORMATION","Poor","Cotter & Jefferson City Dolomite","Cotter & Jefferson City Dolomite","P

~IQ_Control_Parameter
#MNEM   .UNIT          VALUE  : DESCRIPTION                    {FORMAT} | ASSOCIATION
 IQKGS   .                     : Profile Web App Saved Data Indicator {S}
 IQSTRT  .F               0.0  : Starting Display Depth        {F}
 IQSTOP  .F              75.0  : Ending Display Depth          {F}
 IQSCLE  .FT/IN             5  : Plot Scale Feet/Inch         {F}
 IQGRP   .               ROCK  : LAS, ROCK or HORIZON         {S}
 IQORDR  .            DEFAULT  : DEFAULT or MODIFIED          {S}
 IQSHMIN .API             0.0  : Gamma Ray Minimum Value (Default) {F}
 IQSHLY  .API            60.0  : Gamma Ray Shaly Value (Default) {F}
 IQSH    .API            70.0  : Gamma Ray Shale Value (Default) {F}
 IQSHHOT .API           100.0  : Gamma Ray Hot Shale Value (Default) {F}
 IQSHMAX .API           150.0  : Gamma Ray Maximum Value (Default) {F}
 IQTHN   .                     : Thin Porosity Track Curve Mnemonic {S}
 IQOHM   .                     : Conductivity Image Track Curve Mnemonic {S}
 IQOHM_L .MMHO/M               : Conductivity Image Track Minimum Value {F}
 IQOHM_U .MMHO/M               : Conductivity Image Track Maximum Value {F}
 IQPHI   .                     : Porosity Image Track Curve Mnemonic {S}
```

Figure 4. Partial printout from the LAS 3.0 file based on the measured section of the Mississippian surface exposure illustrated in Figure 2 (right).

Reference: Thompson, T. L., and Fellows, L. D., 1970, Stratigraphy and conodont biostratigraphy of Kinderhookian and Osagean rocks of southwestern Missouri and adjacent areas: Missouri Geol. Survey and Water Resources, Rept. Inv. 45, 263 p.

Production Plot & Decline Curve Analysis Web Site (http://www.kgs.ku.edu/software/production/)



The new **production plot & decline curve analysis web application** allows the user to access production data from the Kansas Geological Survey (KGS) Database for Leases, Fields, Operators and Counties (**Figure 5**). The web application was designed to read & write production data from the user's PC as an ASCII Extensible Markup Language

(XML) file or as a comma-separated values (CSV) file. A "spread sheet" like table was provided to display the data retrieved, but editable to allow the user to add data to the existing list, i.e., download production data from the KGS Database and insert missing months or previous years that may not be recorded.

A decline curve analysis dialog was included to allow the user to predict the economic limit for a specific lease, field, operator and county. This analysis uses three methods for predicting the decline of a reservoir, exponential, harmonic and hyperbolic.

A previous Flash version runs on the KGS web site. The Flash version uses an action script that can only handle a finite size data set from the KGS database, from 1970 to the present. The Java version can handle a complete data set and it is designed to handle data from the user's PC.

The more complete and robust production plot will allow the users to extract details of the oil field database to facilitate analysis, e.g. obtaining data for evaluating CO2-EOR.

Reference: (1) SPE 83470: A Decline Curve Analysis Model Based on Fluid Flow Mechanisms by Kewen Li, SPE, and Roland N. Horne, SPE, Stanford University http://pangea.stanford.edu/~kewenli/spe83470.pdf

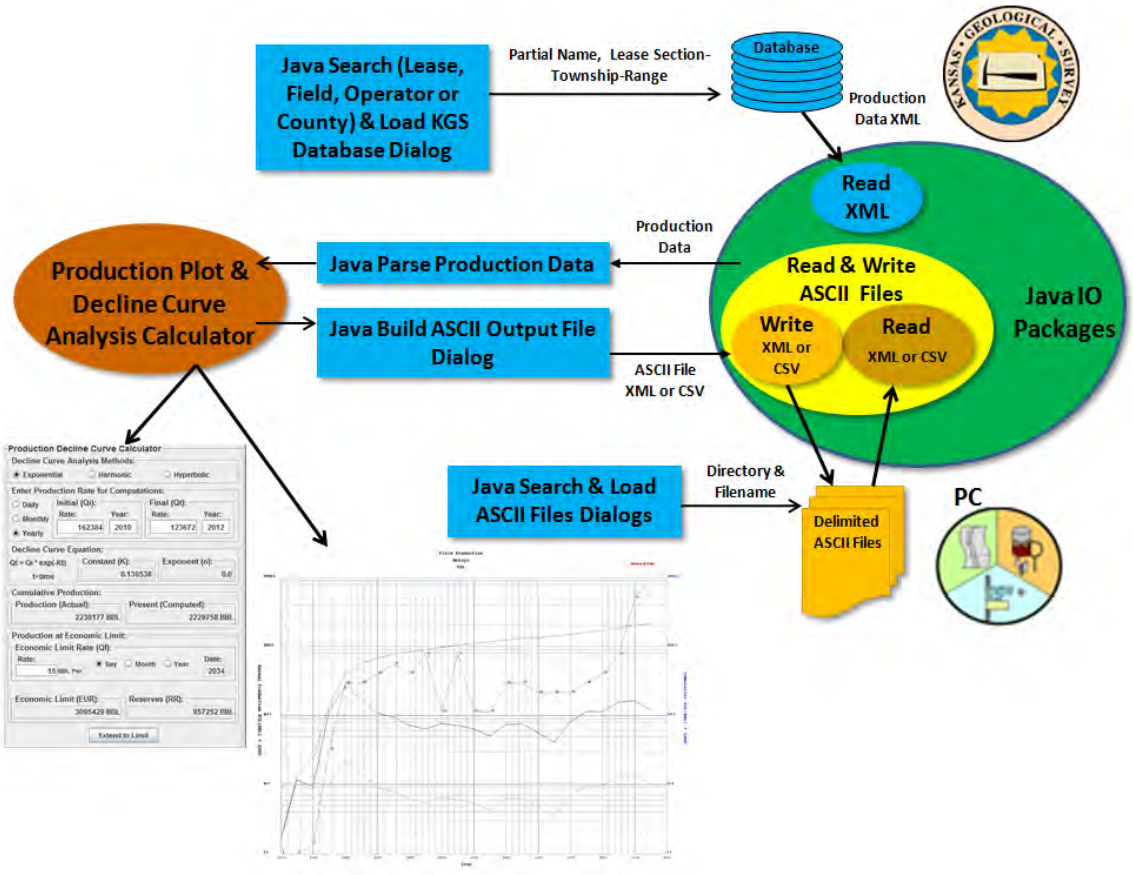


Figure 5. Flow chart showing the linkage of activities and flow of information used to access, manage, and analyze the oil and gas production information in the Production Plot App.

PfEFFER-java Web Site (http://www.kgs.ku.edu/software/PfEFFER-java/)



PfEFFER-java will replace PfEFFER Pro which is a practical tool for the real-time, interactive log analysis. The database and graphic features that were so useful in "Pro" are now implemented in the Java version to allow both rapid interaction and comparative evaluation of multiple interpretations or best case/worst case extremes. In addition, multiple zones are easily managed. This Applet is an interactive web application that allows the user to search & load data from the user's PC or from the Kansas Geological Survey (KGS) database & file server.

The previous version only allowed the user to add flow units one at a time. To add flow units more quickly and more accurately two methods were added, the Zonation ("Zone Kluster ("ZeKe") - A Depth Constrained Cluster Analysis") was used to predict flow units by log curves and from the formation tops list.

The previous version required for each flow unit that the user had to fill the spreadsheet manually. The code was modified so as a flow unit was created the spreadsheet would be automatically filled from default parameters.

The PfEFFER Excel version has the ability to colorize the spread sheet depending on the cut off values, which was added to this version.

This upgrade also created a new version for **Hingle & Pickett Plots** which will replace the GEMINI Pickett plot version. This version has a control dialog that is more dynamic, which will allow the user to modify plot lines on the plot to reflect changes without having to open an external dialog to create the lines. The user can also filter the data by data type of by depth; to add color automatically using colorlith RGB colors computed from the log data or color by depth from a set of 40 colors.

The capability has also been added to write the single flow unit spreadsheet as a comma spaced value (CSV) file. This will allow the user to import into an Excel spreadsheet to continue the analysis. The format of the spreadsheet is the same as the original PfEFFER spreadsheet. A diagram with the PfEFFER modeling is shown in **Figure 6**.

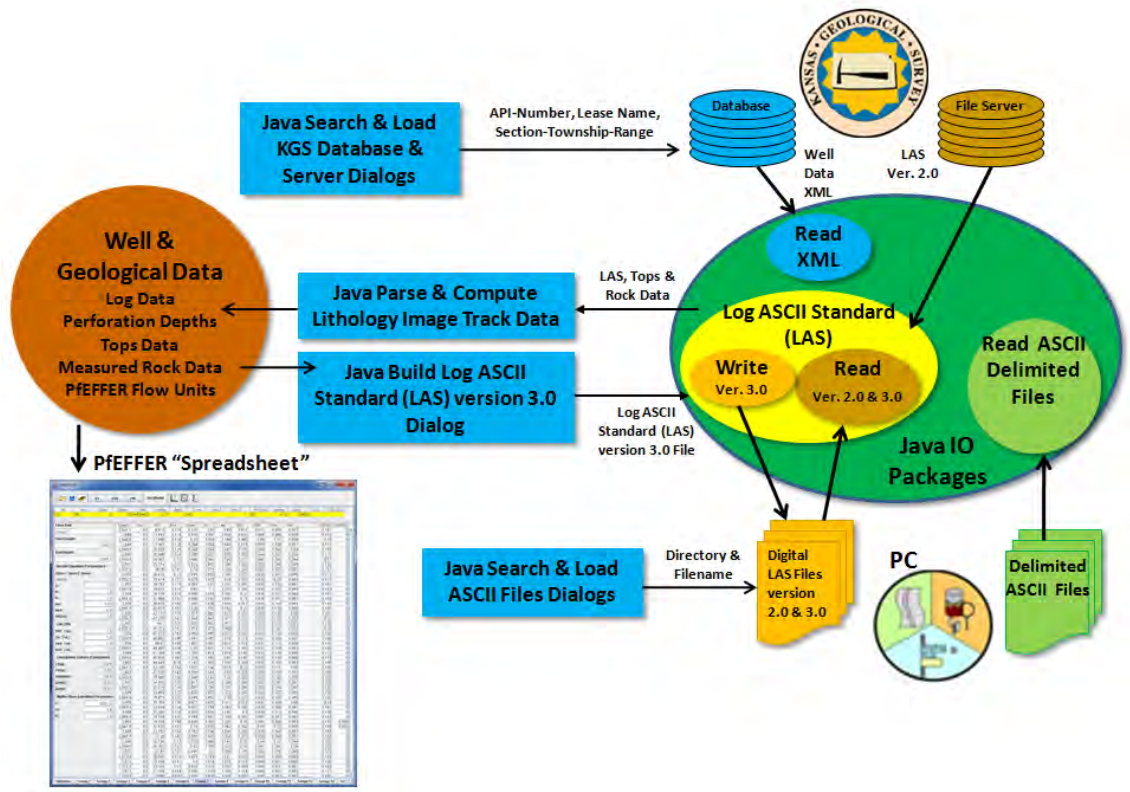


Figure 6. Information flow chart of the web application showing data exchange with PfEFFER-java App.

The PfEFFER-java basic functions are now include:

- Reading Log ASCII Standard (LAS) version 2.0 & 3.0
- Saving PfEFFER "Workbook" as Log ASCII Standard (LAS) version 3.0
- Calculation of porosity with option for shale correction and secondary porosity
- Shaly sand models for Sw calculation
- Pay-flag cutoffs
- Constructing a "Super Pickett" crossplot annotated with lines of water saturation, bulk volume water, and permeability

The Log Profile Plot can display the following:

- LAS Log Curves
- Gamma Ray Colorlith 3 Image Plot Track
- Lithology Rock Column (mineral composition) predicted from Gamma Ray, Bulk Density, Neutron Porosity and Photoelectric Factor Log Curves
- Colorlith 2 Plot Track

The PfEFFER Profile Plot can display:

- Reference Log Curves
- PfEFFER Computed Curves
- Gamma Ray Colorlith 3 Plot Track
- Lithology Rock Column
    - predicted from Gamma Ray, Bulk Density, Neutron Porosity and Photoelectric Factor Log Curves

Reference:
(1) PfEFFER pro http://www.kgs.ku.edu/PRS/software/pfeffer1.html
(2) Color Images of Kansas Subsurface Geology from Well Logs, D. R. Collins and J. H. Doveton, Computer & Geosciences, Vol. 12, No. 4B, pp.519-526 1986
(3) Visualization of Subsurface Geology from Wireline Logs, David R. Collins, Digital Mapping Techniques '98-Workshop Proceedings U. S. Geological Survey Open-File Report 98-487
(4) LAS 3.0 Log ASCII Standard Document #1 File Structures by Canadian Well Logging Society: http://www.cwls.org/las_info.php

PfEFFER Module Functionality

General
Resistivity
Porosity
Shale Volume

Archie Computational Equations
Evaluation of Water Saturation when either or both the Formation WaterResistivity and Constants of the Archie Equation are Known or Unknown
When both water resistivity and Archie equation constants are known
When water resistivity is unknown, but Archie constants are known
When water resistivity is known, but the Archie constants are unknown
When both water resistivity and the Archie constants are unknown

Pickett Plot
Fundamentals of the Pickett Plot
The Hough Transform Crossplot Method

Productivity
Productivity
Plotting Bulk Volume Water (BVW) lines on the Pickett plot

Pay
Pay Determination
Z-Plot: The Third Dimension

Permeability Prediction

Permeability Prediction from Wireline Logs

Addition of predicted permeability contours to the Pickett plot

Capillary Pressure

Capillary Pressure Applications

Mapping of capillary pressure contours onto the Pickett plot

Log Analysis Models for Shaly Sandstones

Movable Hydrocarbon Calculations

Hydraulic Flow

Hydraulic Flow Units in Oil and Gas Reservoirs

Definition of flow units in PFEFFER by depth-constrained cluster analysis

The new version of the Pickett plot and control dialog is shown below (**Figure 7**). The Hingle Plot is shown later. Save Plot action is still needed in order to create a Portable Network Graphic (PNG) of the Pickett Plot and the Hingle Plot. All the actions are visible and with the click of any buttons or modification of the text the change is automatically updated in the plot, i.e., the plot is now interactive, on-the-fly. One does not have to refresh the plot with a button. Filter buttons have been added to filter the data by a number of computed log curves as well as the standard Rt, PHIt, Vsh and Depth. One can color the data points using the colorlith colors. Color cutoffs will be added to the spreadsheet to show what variables pass the cutoff for gamma ray, porosity, water saturation, and bulk volume water.

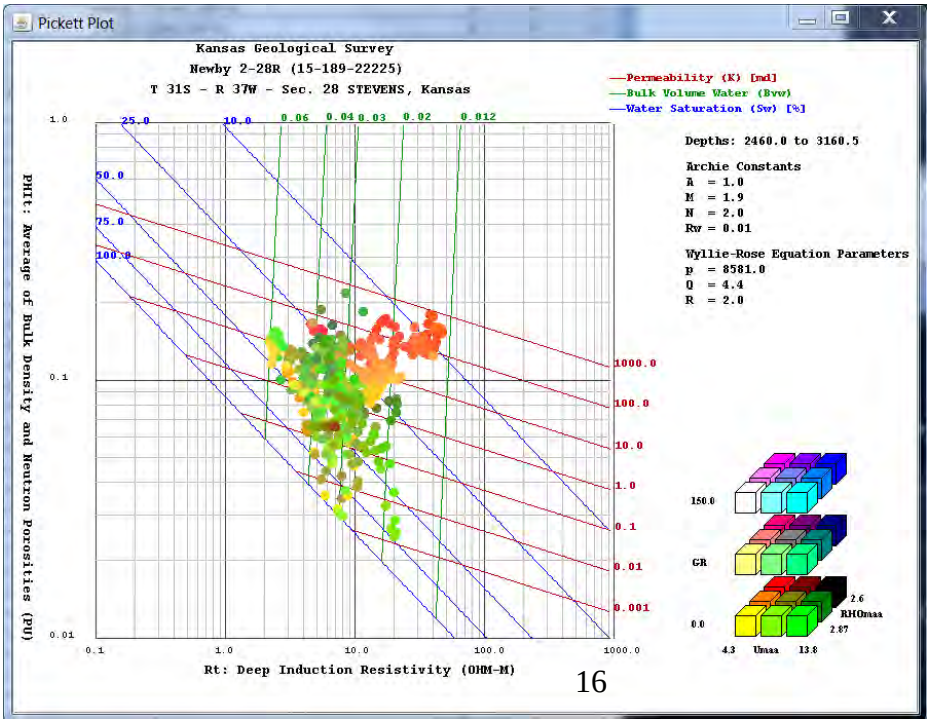


Figure 7. Example of the new version of the Pickett cross plot with rhoma-umma color plot (legend on lower right).

Computed values of Ro, BVW, apparent m, and Sw are shown on depth plot in **Figure 8**.

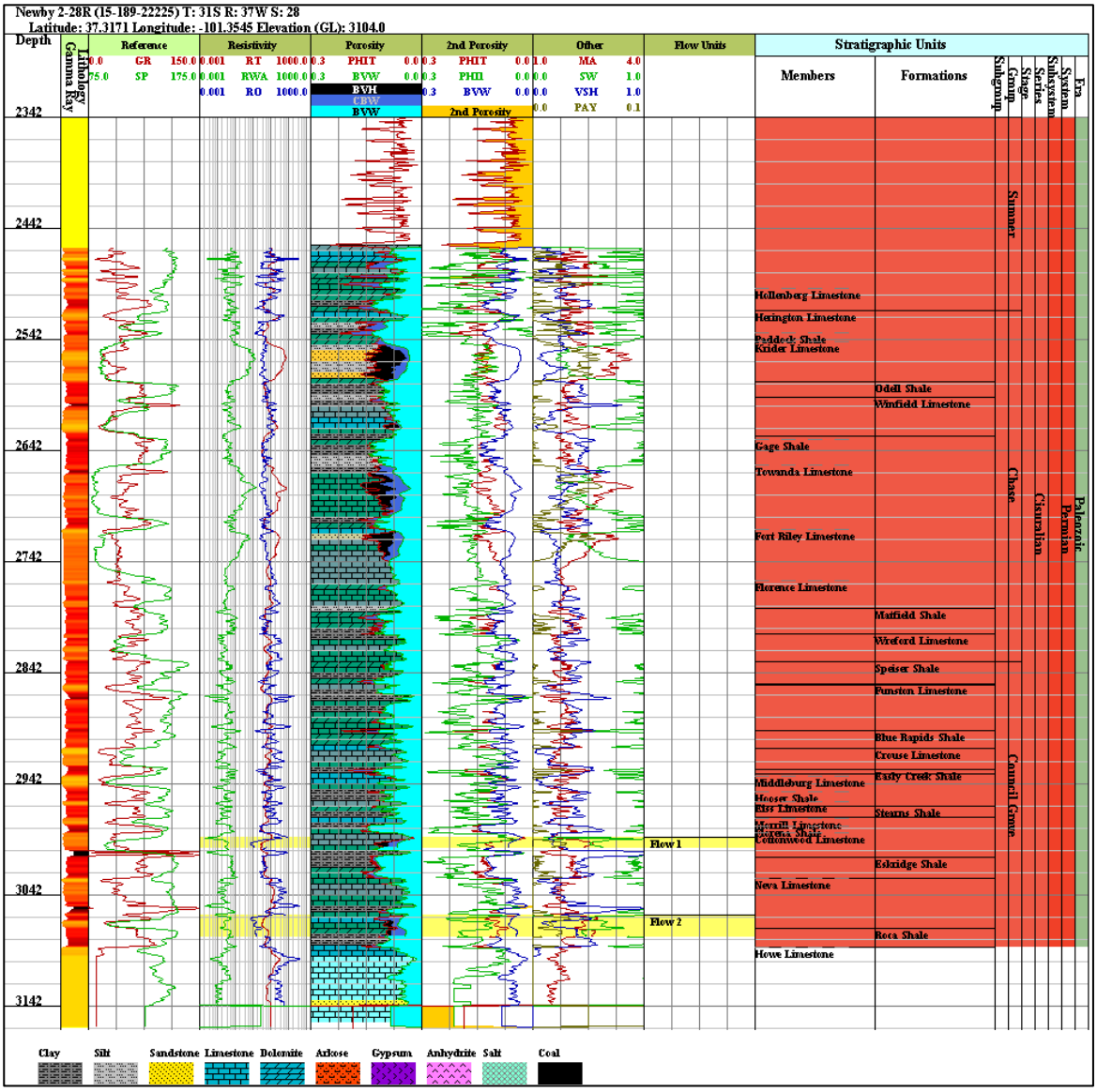
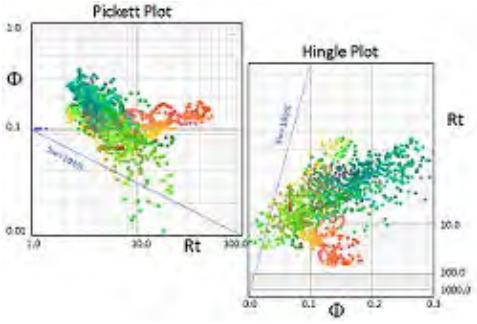


Figure 8. Depth plot showing results of PfEFFER analysis including derivation of Ro, Rwa, BVW, Sw, Ma, Vsh, and hydrocarbon pay/saturation.

Hingle & Pickett Plots Web Site (http://www.kgs.ku.edu/software/Pf/)



This web application was created to allow the user the ability to determine the Archie parameters though graphical means. The Hingle (1959) & Pickett (1973) plots provide graphical solutions to the Archie's equation, i.e., Water Saturation (Sw), Formation Water Resistivity (Rw), Archie Cementation factor (M), and Archie Saturation Exponent (N) from the log data without numerical calculations.

Pickett & Hingle Plots applet allows the user to add Water Saturation (Sw) Lines to the plot. Pickett Plot also allows the user to include Bulk Volume Water (BVW) and Permeability (K) Lines.

The web application was designed to help the user to create a best fit for the 100% Water Saturation Line by varying the product of Archie constant, Formation Water Resistivity (a*Rw) and varying the Archie Cementation factor (M).

The Hingle (1959) & Pickett (1973) Plots developed graphical solutions to Archie's equation, i.e., Water Saturation (Sw), Formation Water Resistivity (Rw), Archie Cementation factor (M), Archie Saturation Exponent (N) from the log data without numerical calculations.

Pickett & Hingle Plots allows the user to add Water Saturation (Sw) Lines to the plot. Pickett Plot also allows the user to include Bulk Volume Water (Bvw) and Permeability (K) Lines.

The web application was designed to help the user to create a best fit for the 100% Water Saturation Line by varying the product of Archie constant, Formation Water Resistivity (a*Rw) and varying the Archie Cementation factor (M).

Hingle Plot:

The y-axis is built from (1/Rt) 1/m but scaled in resistivity or conductivity (**Figure 10**). This allows the user to plot data directly to the plot. As m varies so does the grid lines and plotted log data. In the past Hingle Plots were plotted with a fixed grid lines as 1/M =

1/2, but with computers the axis can easily be changed to fit the data more clearly. The porosity (Φ) is plotted as a linear scale on the x-axis.

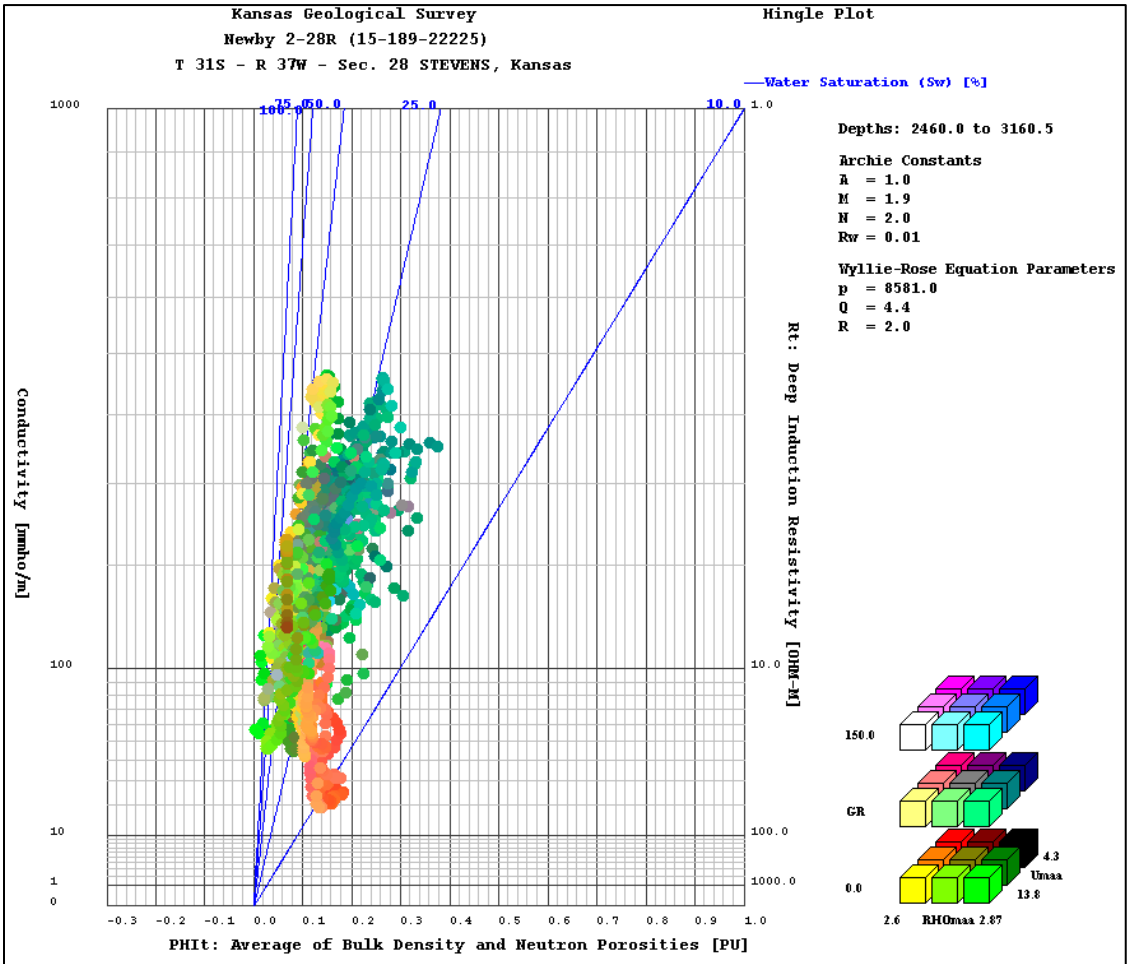


Figure 10. Hingle plot. Linear phi vs. log resistivity.

Pickett Plot:

A graphical solution to Archie's equation by plotting logarithmic scales of resistivity (Rt) versus porosity (Φ), allows linear representation of the data as y = m*x + b.

$$\log(\Phi) = (-1/M)*\log(Rt) + \log(a*Rw)/M - N*\log(Sw)/M$$

where log(Φ) is the y-axis and log(Rt) is the x-axis. log(a*Rw) is the y-intercept and (N*log(Sw)/M) is a family of lines.

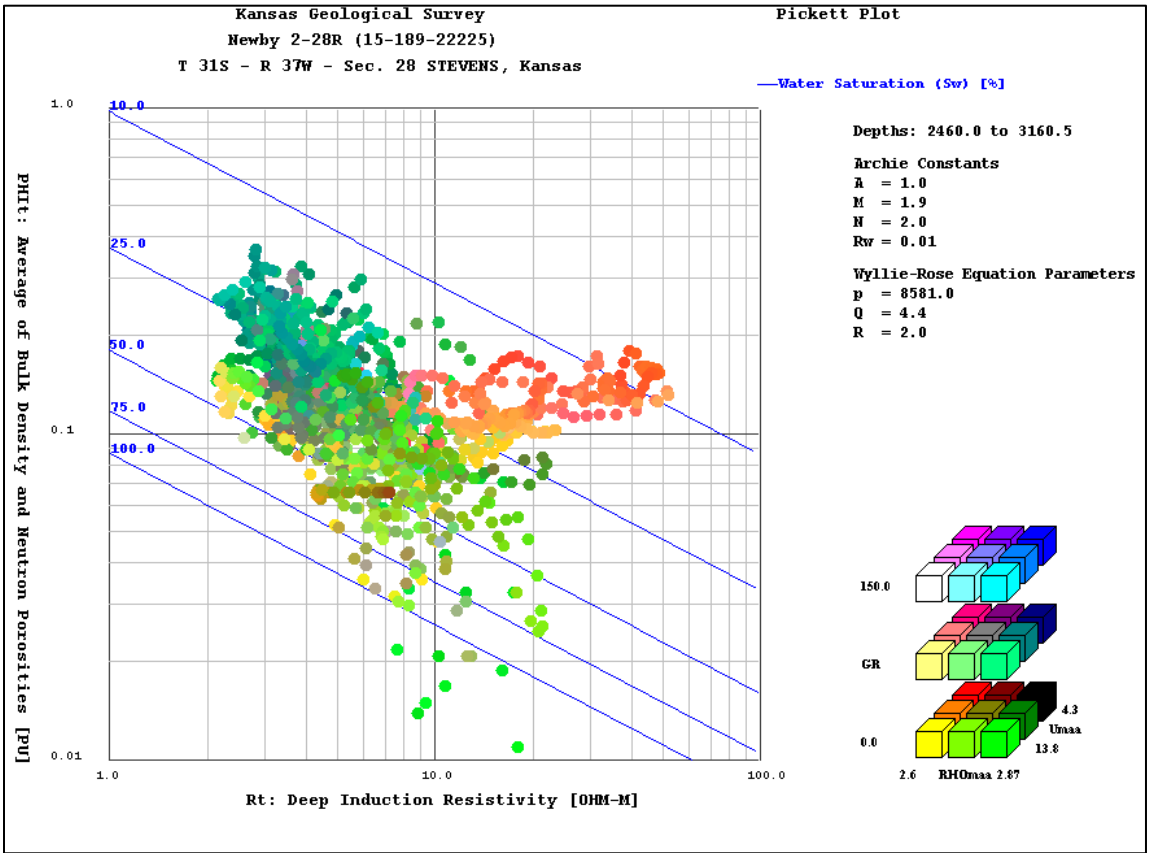


Figure 11. Newly revised Pickett cross plot displaying colors using RHOmaa-Umaa lithology determination.

Profile Plot Applet
(http://www.kgs.ku.edu/PRS/Ozark/TYPE_LOG/Profile_CO2.html)

Type Log Project (http://www.kgs.ku.edu/PRS/Ozark/TYPE_LOG/Profile.html)

The Profile Plot Applet is the same for both the DOE CO2 and Type Log projects; the only difference is the web page that launches the applet will place an identifier that will be used to load the well data from respective project database tables (**Figure 12**). The type interface has been described previously.

The Profile Plot Applet was created to load Log ASCII Standard (LAS) version 2.0 or 3.0 Files from the Kansas Geological Survey (KGS) Server, to retrieve the Type Log Tops Data and create a profile plot by depth. The user also has the ability to add an ASCII geologist report (measured section, core or cuttings descriptions) file. The user can verify that the data is complete before creating a LAS version 3.0 file of the selected well. The user can also create Portable Network Graphics (PNG) file of the profile image, which is automatically displayed in a HTML with the option to create a Portable Document File (PDF).

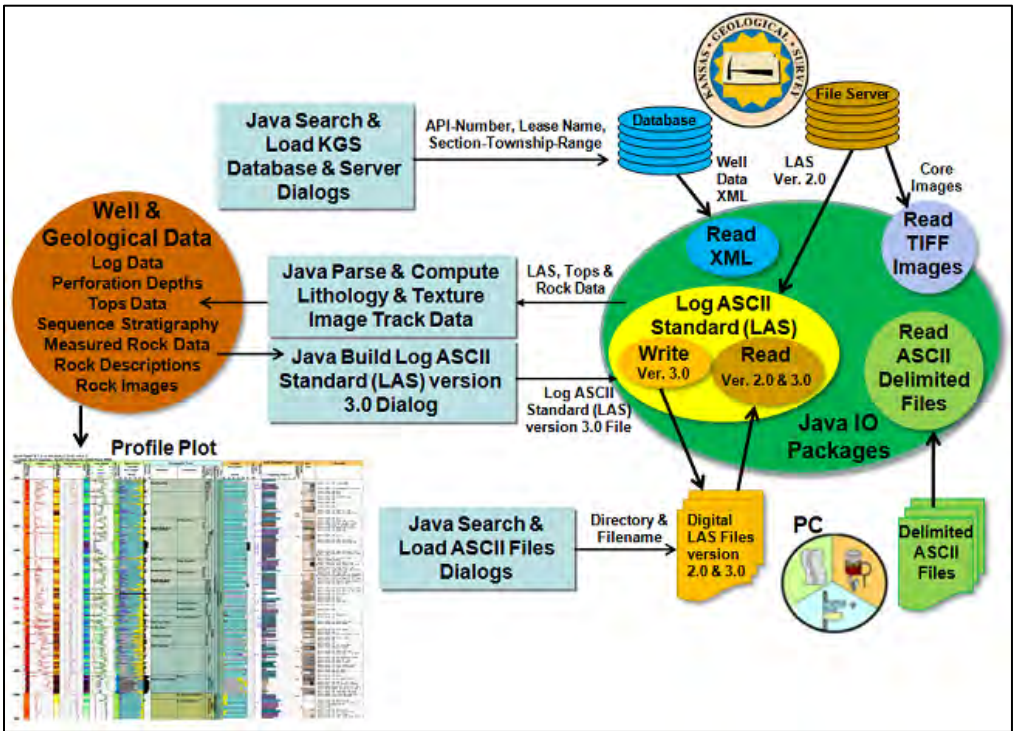
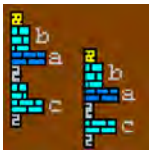


Figure 12. Information flow chart of the web application showing data exchange with the Well Profile.

General Cross Section Map Applet



- **DOE CO2 Project (http://www.kgs.ku.edu/PRS/Ozark/GXSection/GXSection_CO2_map.html)**

- **Type Log Project (http://www.kgs.ku.edu/PRS/Ozark/GXSection/GXSection_map.html)**

The General Cross Section Map Plot Applet is the same for both projects; the only difference is the web page that launches the applet will place an identifier that will be used to load the well data from respective project database tables.

The General Cross Section Map Plot Applet allows the user to place multiple well profiles on one plot (4 maximum) to view the wells with Log ASCII Standard (LAS) version 3.0 files.

Interactive Project Mapper (ESRI Map) Cross Section Applet
Example:
http://www.kgs.ku.edu/PRS/Ozark/GXSection/GXSection.html?sLIST=1043234370, 1043234355 Wellington KGS 1-32 and Wellington KGS 1-28 wells

This web applet is called from **ESRI Map Viewer** for the DOE CO2 Project or the General Cross Section Map Applet above. The user selects from a list of wells with Log ASCII Standard (LAS) version 3.0 files (4 maximum). The limit of 4 wells is based on concerns that video memory would be exceeded configurations if more wells are added based on typical PC hardware. The user selects the wells and the ESRI Map builds a comma delimited list of well KID's (*Kansas well ID*), which the cross section program parses the list and appends a ".las" to each KID and opens and parses each LAS3.0 file and creates the cross section image. This file can only access the LAS 3.0 file information from the DOE CO2 LAS3 Database Table when accessed from the **ESRI Map Viewer**.

Manually build Log ASCII Standard (LAS) version 3.0 Files for both the DOE CO2 Project Wells and for the Bob Slamal Digital Type Logs Project Wells

The **ESRI Map Cross Section Java Applet** was created to read and plot Log ASCII Standard (LAS) version 3.0 files. The LAS 3.0 files have to be created manually for the above cross section web applet. The DOE CO2 PROFILE Applet was used to create the LAS 3.0 Files as well as PROFILE Portable Network Graphic (PNG) and Portable Document Format (PDF) Files. *LAS 3.0 files and Image files were created for 1509 wells over a 4 ½ months period.* In many cases geologist reports were typed in for many wells to present a lithology column with the log plots. The profile plot web applet will automatically create a lithology rock column computed from the litho-density log data and presented to illustrate the lithology of well by depth if available (641 wells).
Note: Not all the wells have LAS 3.0 files for the 2000 wells of the DOE CO2 Project because there were no LAS 2.0 files in the KGS Server only 1500 wells have the LAS 3.0 file. Many of those wells have geologist reports that were typed in to represent the well lithology. The scanned logs of the remaining 500 wells are still accessible online and have been stratigraphically correlated.

The example below is from Cutter Field, a four well cross section running north to south with wells highlighted in blue circles and connected by a blue line (**Figure 13**).

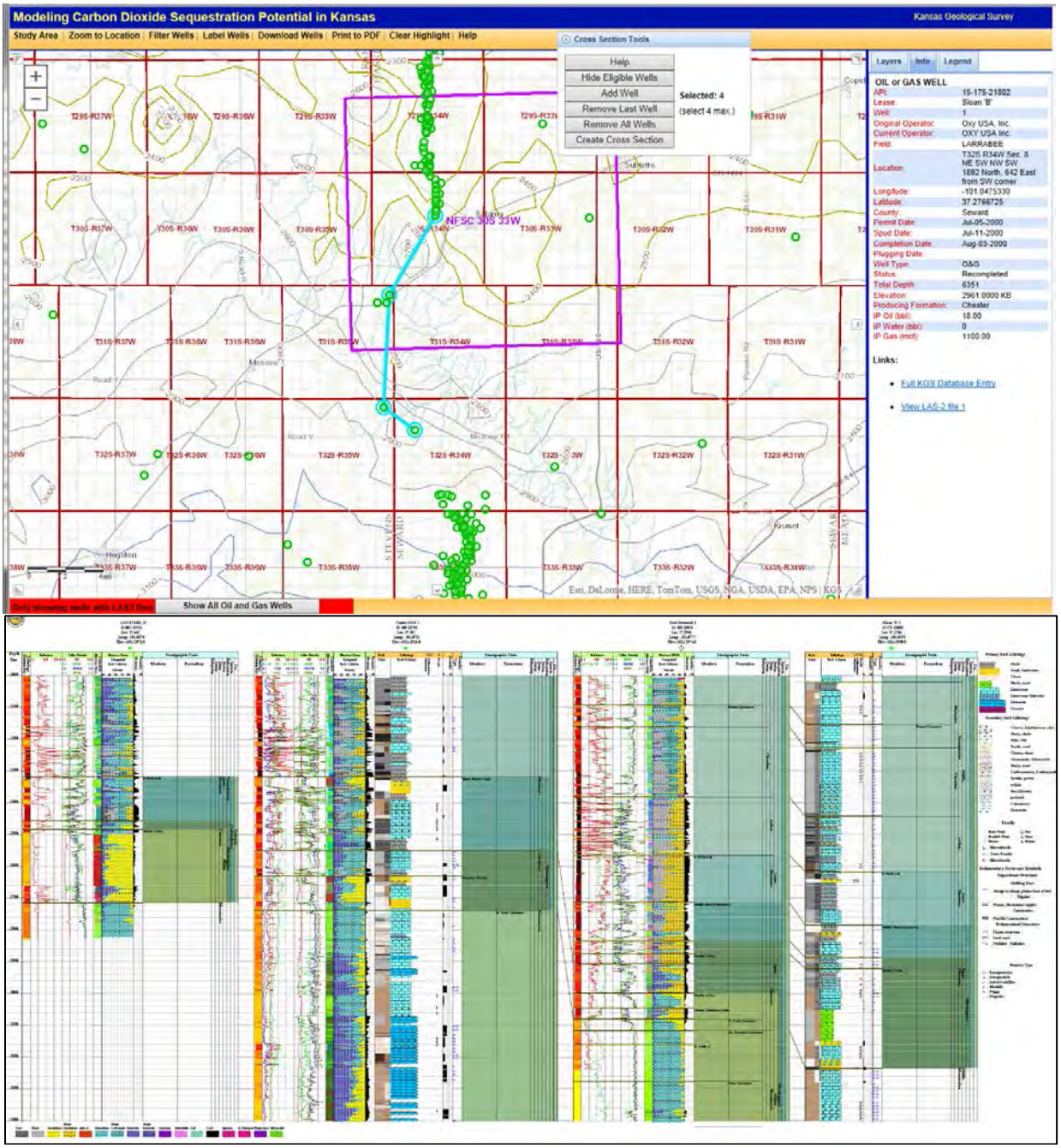


Figure 13. Current status of a the cross section app accessed via ESRI Map Cross Section Java Applet. Four wells shown from north (left) to south (right) using a structural datum.

South-central Kansas CO2 Project (*http://www.kgs.ku.edu/PRS/Ozark/Summary/)* & Bob Slamal Digital Type Logs Project (http://www.kgs.ku.edu/PRS/Ozark/TYPE_LOG/summary.html) Summary Web Pages

The summary web pages were created for each project to present the wells that are part of the project, i.e. Type Log Project's **500 wells** and DOE CO2 Project's **2000 wells** (**Figure 14**). The well table has links to well data web page for each well and links to display a profile plot portable network graphics (PNG) image of well data (log, tops and geologist cuttings report data). A link of the created Log ASCII Standard (LAS) version 3.0 file is generated to create the image files. Each summary web page also contains a list of web apps associated with the project. A number of web apps were created for each project to allow the user to build a profile plot or cross section plot for up to four wells at a time from the well list of each project.

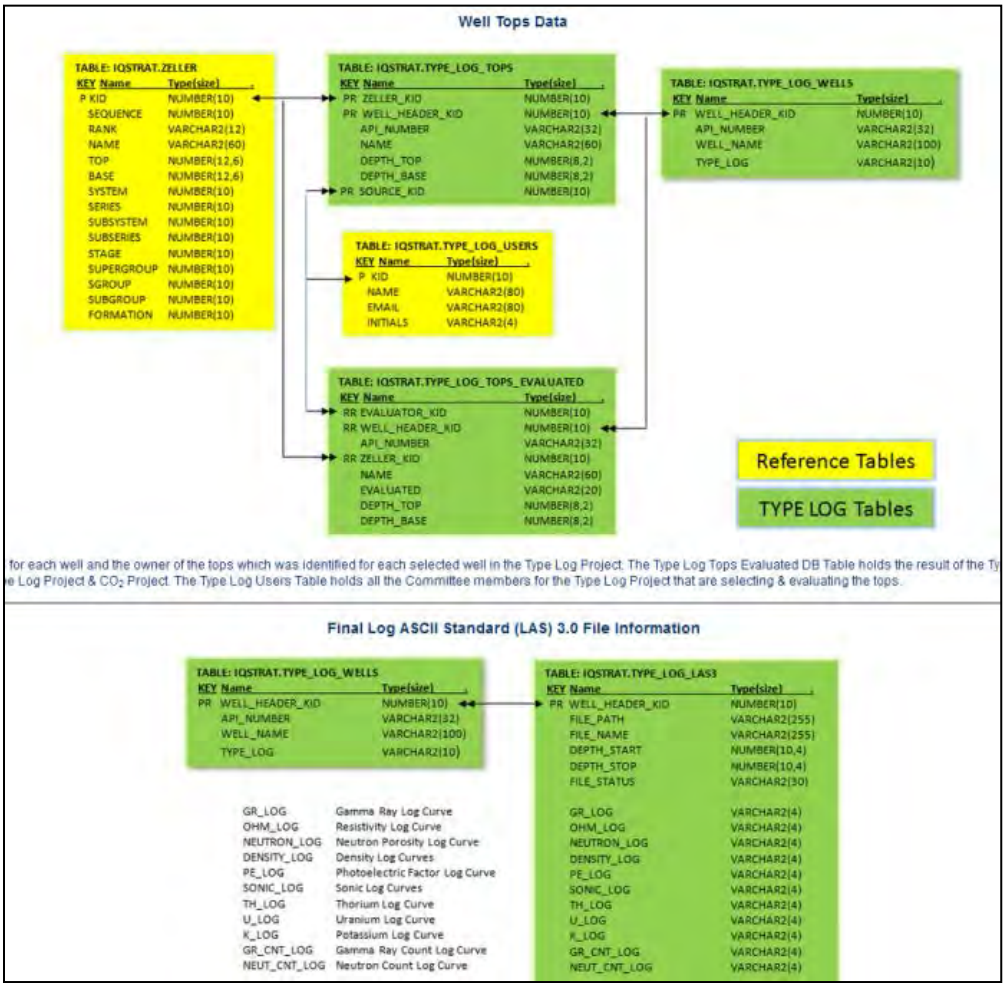


Figure 14. Stratigraphic well tops and LAS 3.0 data tables.

Status of Long-term goals of GEMINI

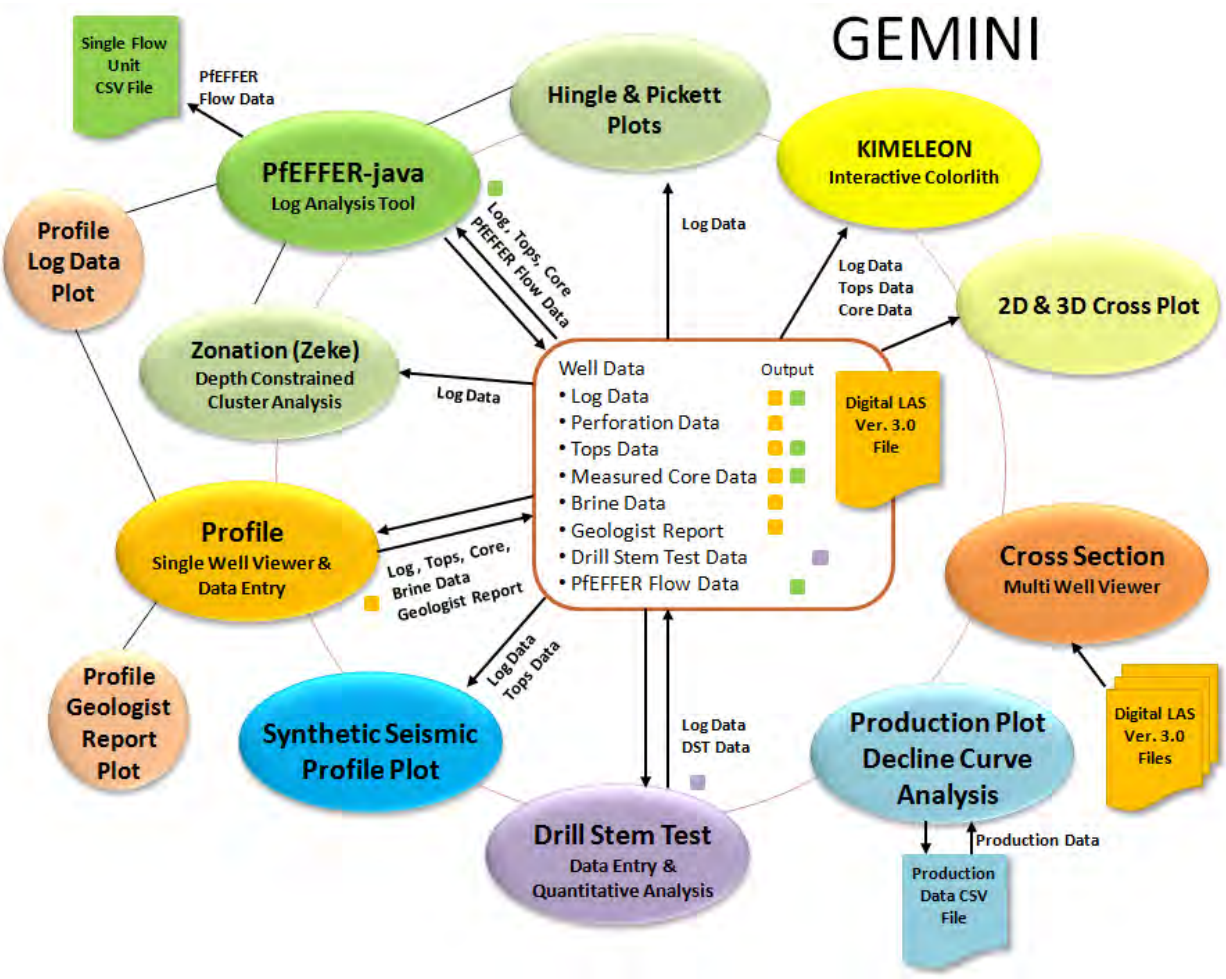


Figure 15. Complete layout of the Java web applications that comprise GEMINI.

Reorganize & Consolidate Java Source Code. There is a need to move beyond patching in new code and eliminate redundant code that consumes memory space needed to display the data. The remaining time of this contract will include review of the Java files and create more structured panels and frames that can be used by multiple data types, e.g., condense the 4 Data Dialog Java source files needed to import CSV Files to 1. This will help with development and make it easier to add other data types more efficiently. This task is 30% complete, starting with PfEFFER-java, Zonation and the Hingle & Pickett Plots web sites to be placed under a "GEMINI" source file data structure. When each module is compiled only the java files needed for the specific module is read and compiled.

XML Lookup Data Files. A number of Lookup Data XML Files have been create to make plots symbols or provide a way to parse the geologist reports into the plot tracks in the Profile web application. A couple of XML files, the stratigraphic units and the fossil genera list, are currently centered on Kansas and pertinent stratigraphic reference sections from nearby states. An objective is to incorporate other stratigraphic units of other states as well as fossil genera list from additional surface rock formations. The Profile could be established to allow the user to select the data by state.

The symbols for the lithology need to be modified in order to plot the lithology and textures with both base symbols and secondary, i.e. instead of creating a specific sandy limestone symbol, the limestone base symbol would include the addition of the sand symbol depending on the quantity referenced." Common fossil names are currently plotted, i.e. snails, clams, etc. Sedimentary structures are currently not parsed completely and triggers used to parse the types need to be refined. The Munsell Rock Color and Munsell Soil Colors have been updated and incorporated into the XML Files. The porosity type data files are parsing sufficiently, but terms like re-crystallined are not being found and there may be other terms that are not included. Symbols also need to e added for oil and gas shows, fluorescence, etc, found in cuttings descriptions.

Directory Locations need to be saved a new Saving Web Application Output to make this more convenient for the user. The "memory" of the location of saved directories is needed so eliminate the search for the same directory structure every time data or plots are saved. The program should remember the location of the last save at least or create a lookup xml that will be generated on the user's PC to remember the last save location so the program can go back to the last directory location as default.

Color image tracks for Core Data. There are a number of automatic tracks that are created with the LAS File data, i.e. colorlith, and color image tracks, that do not automatically appear or consistently appear when measured core data is present because the core data is not necessarily spaced at regular depths intervals that the program can detect.

Legends for Profile Output. Work is needed on the legends of the profile plot, the sedimentary structure, texture track do not plot correctly for long names. The ability is needed to add the legends to the bottom of the plot as part of the PDF document in a more organize manner, depending on the presentation of the data.

Creating a PDF document of Profile plot with paging. The present output creates one large image of the profile plot that really can only be printed to a large printer. If the user wishes to use a standard printer, the image is reduced to the size of the page. With paging the profile plot can be created as a PDF book with multiple pages easier to read with a standard printer.

Sequence Stratigraphy Track. Modify the sequence stratigraphy plot track to allow the user more flexibility, i.e. provide two areas with the one for surfaces and one for labels, etc.

Import rock image files into Profile. The user will be allowed to import user images to the Profile program and to provide a means to move the files with the LAS 3.0 file automatically so the user can share their well data and core images. A means is needed to upload the image files to the KGS Server and provide links within the LAS 3.0 file to plot the data or search for the files.

Icon image generator. Create a web application that will take text color mask and generate a png icon image. Text files are easier to modify than manipulating images.
90% COMPLETE - NOT Released and not fully tested

Rock Catalog Web Application. Redesign the rock catalog to a more general use along the lines of reading multiple LAS Files or multiple CSF Files or multiple data sets from the KGS database. To build a generic search engine that will allow filtering the data, present the data, and build a rock catalog output which the user can control, i.e. a poster or a book as a PDF document.

Brine Data Catalog Web Application. Create a web application like the rock catalog but centered on Brine data. This program will combine the KGS database data with either multiple CSV files or digital LAS files. The user will be able to decide the type of plots to create and the anions and cations to include in the plot.

Production Plot and Decline Curve Analysis. A general application is planned to allow the general user to import a CSV file and create a production plot of their data without having to depend on the KGS for their data.

2) Processing and analysis of 3D multicomponent seismic in Cutter field and the continued seismic interpretation at the other SW Kansas fields being studied for CO2-EOR

The prestack depth migration processing has been ongoing since December 2013 and that work continues. The quality of the multicomponent seismic acquisition at Cutter is such that is such that the success of the PSDM seems very likely (**Figure 16**). The latest interpretation activity at Cutter has been focused on the seismic pre-stack and post-stack inversions and lithological classification of the Morrowan strata using Hampson-Russell software.

The seismic profile in **Figure 16** shows the sag of the time section beneath the location of the Chester incised valley, the location of the secondary oil reservoir on the east side of the Cutter structural high on which the primary oil reservoir, the Morrow sandstone, is present. The time sag extends into the mid lower Mississippian, but the reflectors are flat in the lowermost Mississippian and Viola suggesting an origin to the sag related to dissolution in the Mississippian. This dissolution is further discussed below. A key point is that the horizontal

bedded lower Mississippian and Viola comprise the tightest rocks above the Arbuckle and necessarily is the most likely interval for caprock that would be required to store CO2 in the underlying Arbuckle. This will also be discussed in the section below, which examines the latest examination of the core.

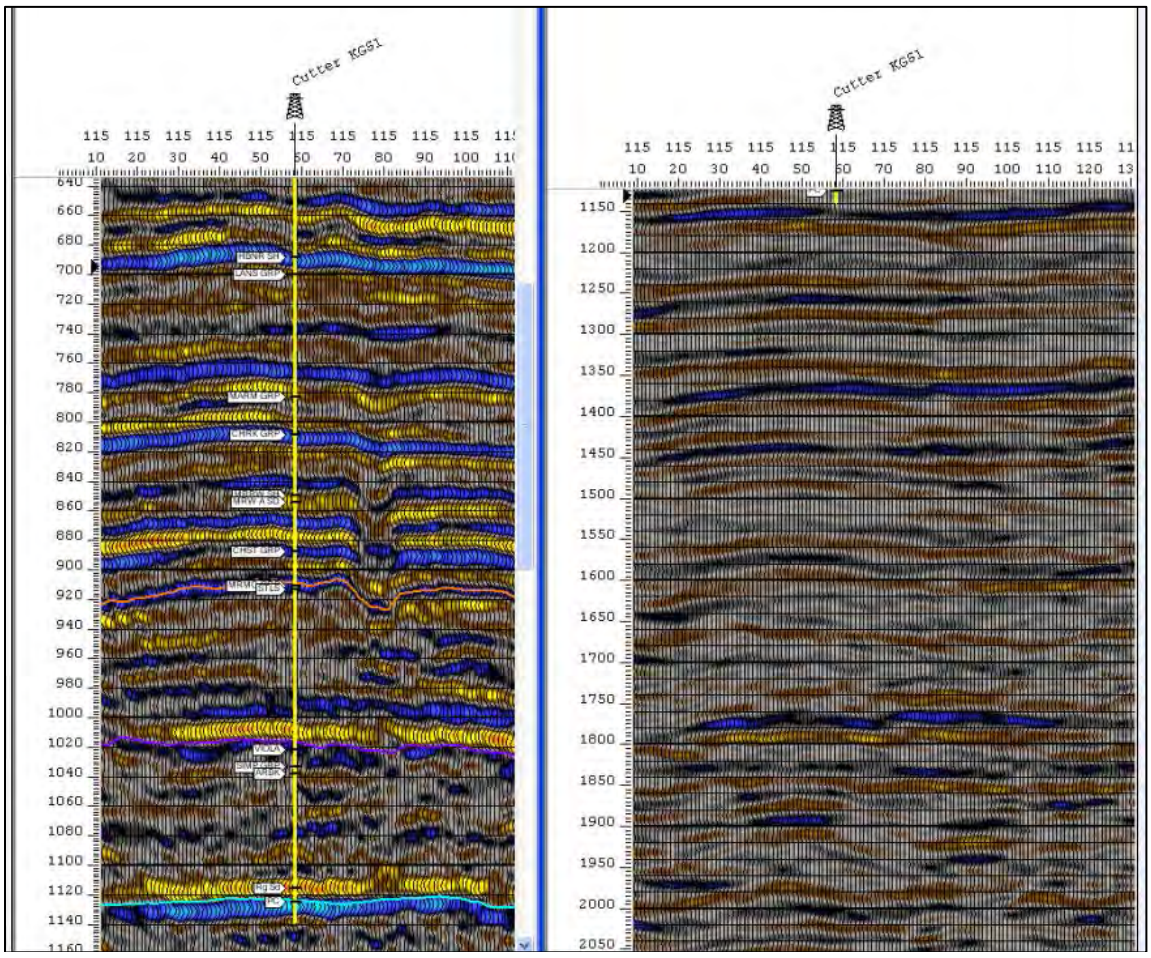


Figure 16. Arbitrary section in Cutter Field including the Cutter KGS #1 well and log ties to the seismic profile. Data quality is very good.

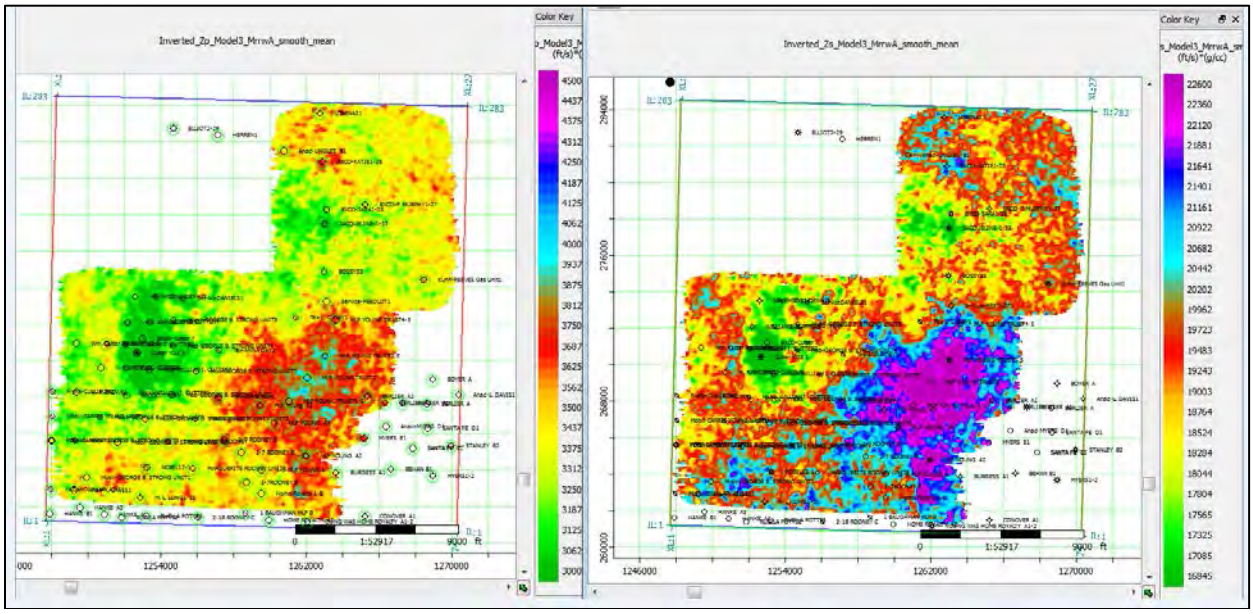


Figure 17. Preliminary prestack impedance models (p-wave on <u>left</u> and shear-impedance on <u>right</u>) of the Morrowan interval containing the lenticular sandstone oil reservoir generally in the northwestern corner of Cutter Field. This work continues toward resolving the lithological changes (sandstone, shale, and carbonate) and the results are encouraging, e.g., sandstone is in the region shown in green and carbonate in the red, blue and purple colors with highest impedance.

Work continues on Shuck Field southwest of Cutter to characterize and model the Chester valley fill sandstone reservoir. An example of some recent activity is recognition of karst development along the valley. A seismic time section tracks along the upper reaches of the Chester valley as shown in **Figure 18**. The valley is enlarged in width and depth at the location of what is likely a karst feature. The dissolution that led to the karst appears to have occurred in Mississippian-aged strata, as opposed to Arbuckle. The sagging interval between the Meramec and Arbuckle surfaces support this interpretation. This deformation present in this karst feature does not extend down to the basement.

This occurrence of karst from the dissolution of probable pre-existing evaporites in the Mississippian was previously noted in Pleasant Prairie, Eubanks, and Cutter fields, the latter discussed above. Karst development at these sites also appears to have influenced the location of the valley system. Structurally, the Chester valley is incised along the east side of the uplifted structural blocks that appeared to have exhibited subtle topographic relief during valley formation. The developing structures were previously described as linked to the compressional tectonics along the Amarillo-Wichita wrench fault system. Based on the seismic available for these fields, the east sides of these structures were under tension with well developed fracture system, while the west side was a site of compression exemplified by high-angle reverse and strike slip faults. The tensional side may have led to open fractures during subaerial exposure at the end of Meramec time when the Chester incised valley were cut. Meteoric water could have percolated down into the lower Meramec bedded evaporites leading to their dissolution and

eventual collapse forming karst features. Location of the channels also might be linked to the more prominent fracture sets.

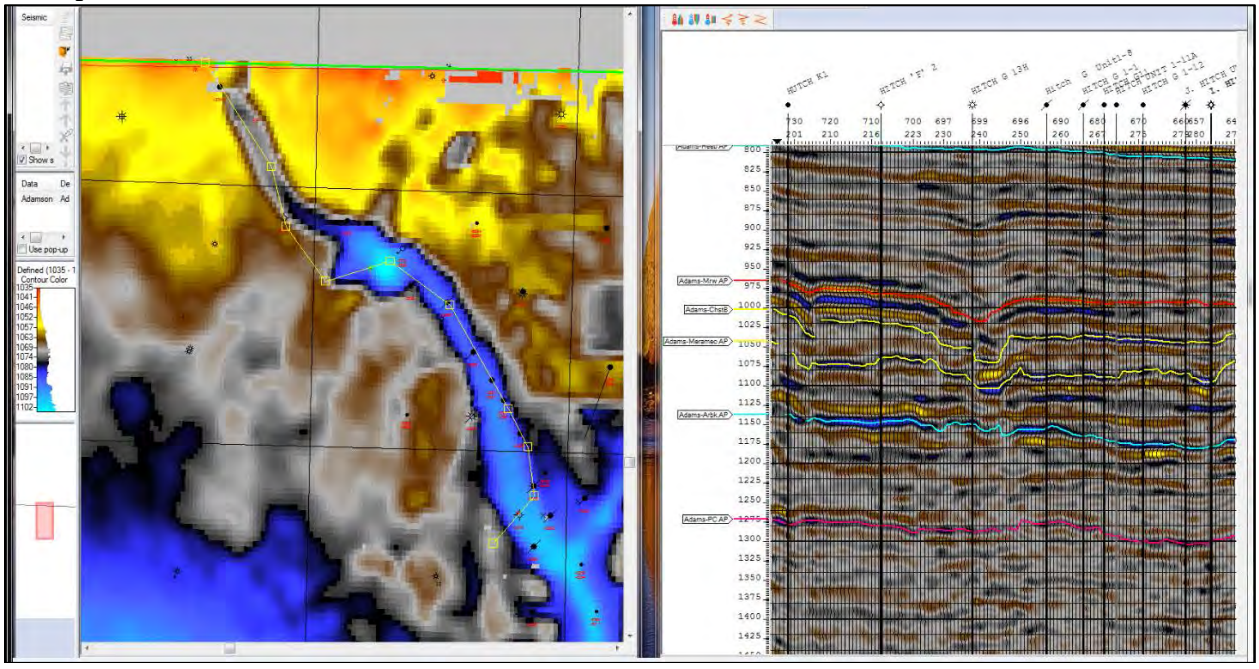


Figure 18. Meramec amplitude slice at Shuck Field showing seismic line along the axis of the Chester age incised valley, the location of the sandstone oil reservoir.

2) Ongoing hydrogeochemistry and petrophysical analyses at Cutter Field based on brines collection, tests, thin sections, and core analysis

Overview -- The Berexco Cutter KGS #1 well is located in Cutter Field the northeast corner of Stevens County reached basement at 7742 ft on September 28, 2012. One thousand and forty two feet of core were cut from near the base of the Middle Atokan Stage to the base of the lower Ordovician Gunter Sandstone. Cored intervals include the upper Morrow sandstone (main reservoir), Chester Sandstone, portions of the Ste. Genevieve, St. Louis, Warsaw, Osage, Kinderhook, Chattanooga Shale equivalent, Viola, Simpson, and Arbuckle Group. Oil shows were encountered in the Morrow, Chester, and Simpson sandstones during drilling. Additional oil shows observed under UV light were seen in core of the top of the Viola and in the Arbuckle.

An extensive suite of well logs were acquired including triple combo, microlog, elemental analysis, dipole sonic, magnetic resonance imaging, and microresistivity imaging tool. A 3D multicomponent seismic survey was also acquired over the Cutter Field to provide a comprehensive characterization to evaluate the CO2-EOR potential of the upper Morrow sandstone reservoir and the CO2 storage capacity of the deep Arbuckle saline aquifer.

The well serves as the western calibration site for the regional evaluation of the carbon storage in southern Kansas, an effort funded by DOE and cost sharing partners including Berexco, LLC, the operator of Cutter Field.

Cutter Field is also one of four fields with Chester and Morrow sandstone oil reservoirs being described and modeled to evaluate efficacy of CO2-EOR. This latter activity is part of the SW Kansas CO2-EOR Initiative.

This section focuses on lower Mississippian to top of Arbuckle interval in what is being evaluated as the caprock for CO2 injection into the Arbuckle. **Figure 19** shows well logs and computed lithology of the Osagean Mississippian to the top of the Upper Ordovician Viola Limestone. The Osage is a very porous cherty dolomitic limestone that is common too much of southern Kansas. The lowermost Osage is tight limestone in part argillaceous overlying the Kinderhook age limestone and thin dark shale interval above the Viola Limestone.

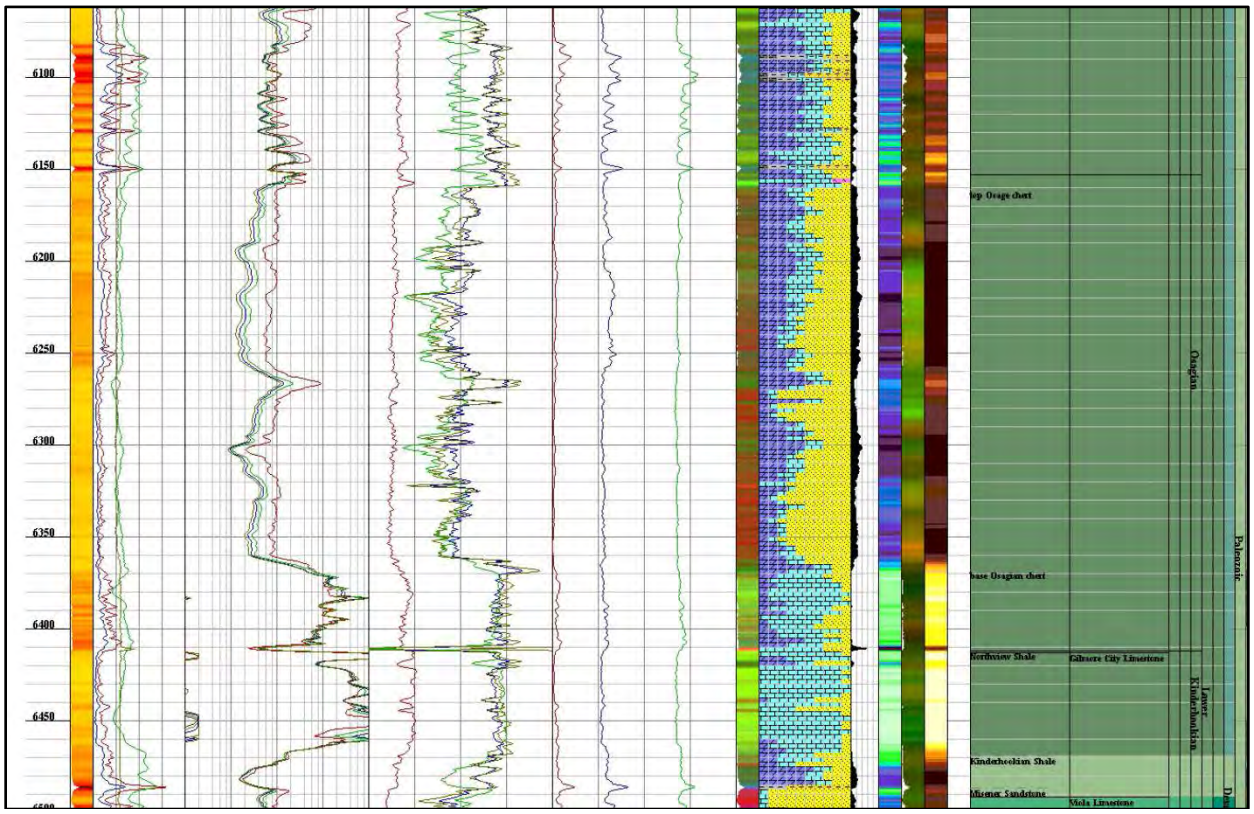


Figure 19. Mississippian Osage to top to Viola in the Cutter KGS #1 well.

The porous Osage Mississippian was not cored, but coring commenced in the first tight section to avoid possible lost circulation (**Figure 20**). The core gamma, nuclear magnetic resonance, and resistivity log combination in **Figure 20** illustrates the petrophysical characteristics of the 130 ft thick section that could serve as a potential caprock for CO2 injection in the underlying Arbuckle. The

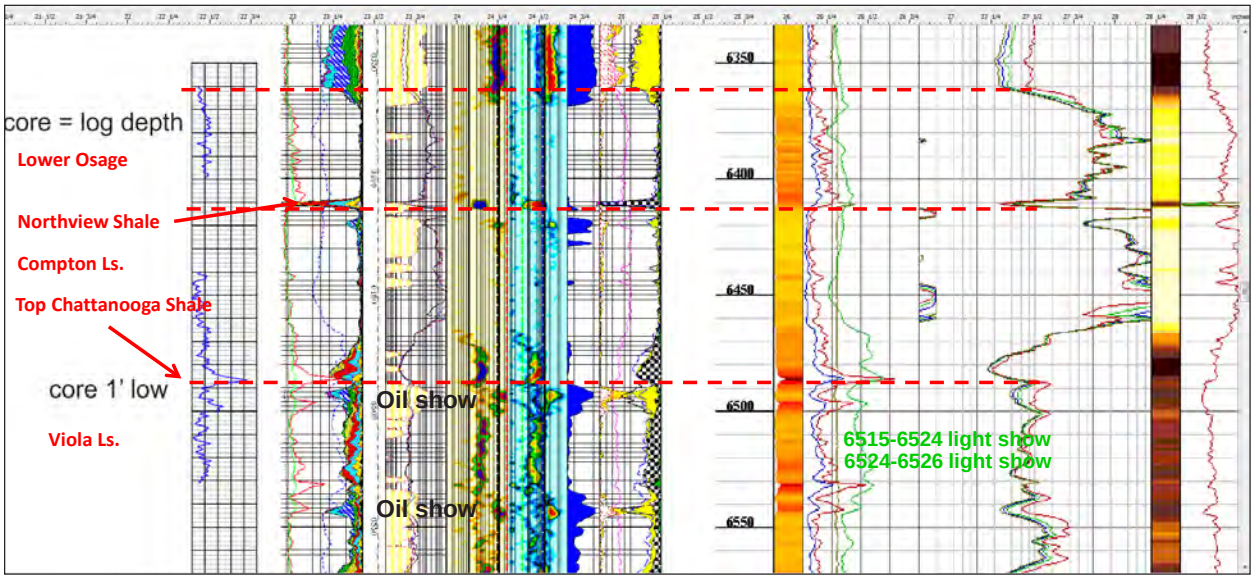
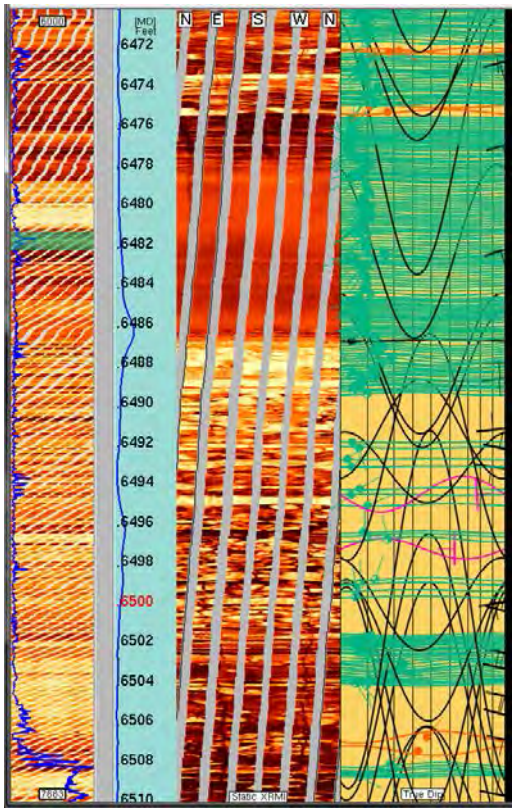


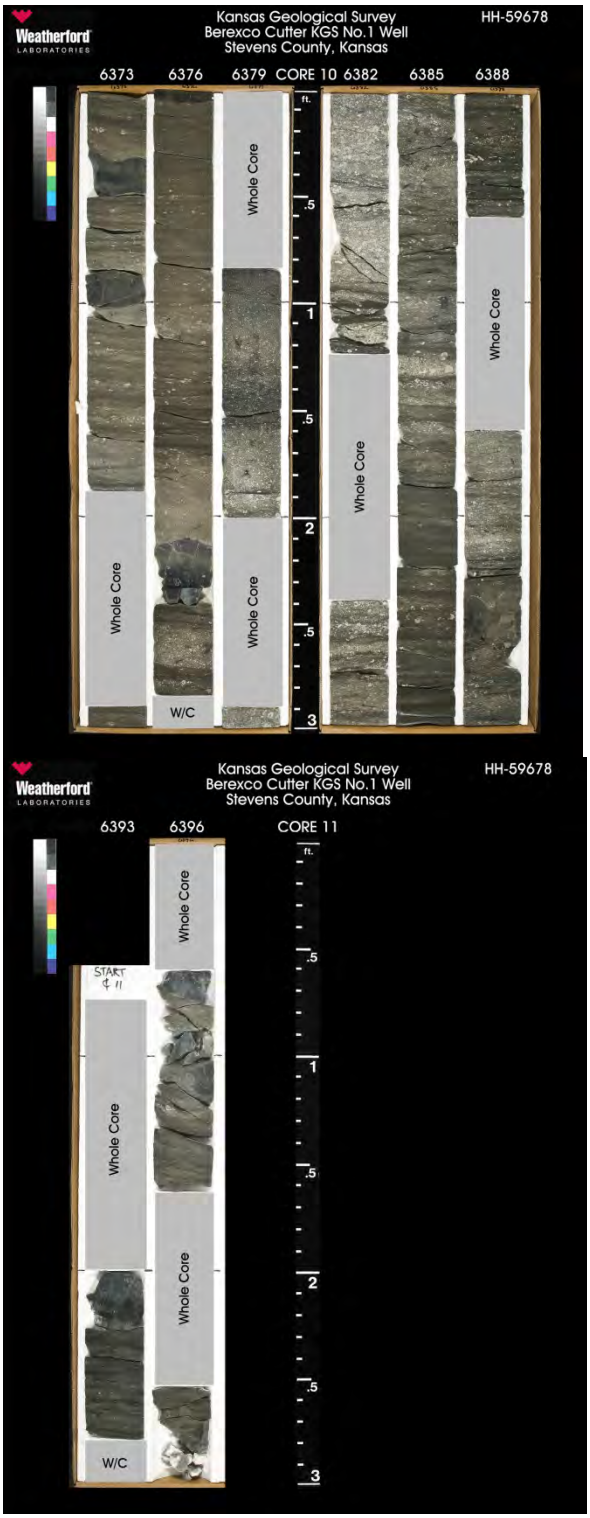
Figure 20. Tight rock is present above the Viola and oil shows are noted in the uppermost Viola Limestone, presumably contained by the overlying seal. Other oil shows were described in previous quarterly reports. The logs shown include nuclear magnetic resonance (NMR) on the left the gamma ray–resistivity curves on the right. The oil shows are denoted by the higher T1 values curve on the NMR log that exceeds the threshold for the presence of hydrocarbon.



The microresistivity image in **Figure 21** extends from the Chattanooga/Kinderhook Shale at the top into the uppermost Viola containing the oil show. Dense laminated nature of the shale is apparent. The uppermost Viola is a chert breccia. Both intervals show considerable induced fracturing (black wavy "smiles" on the image log).

Figures 22 and 23 include slab photos of these intervals ranging from lowermost Osage to the top of the Viola Limestone. The shaly carbonate and shale in this tight interval is the subject of continued investigation.

Figure 21. Microresistivity imaging of the Chattanooga Shale to top of the Viola Limestone.



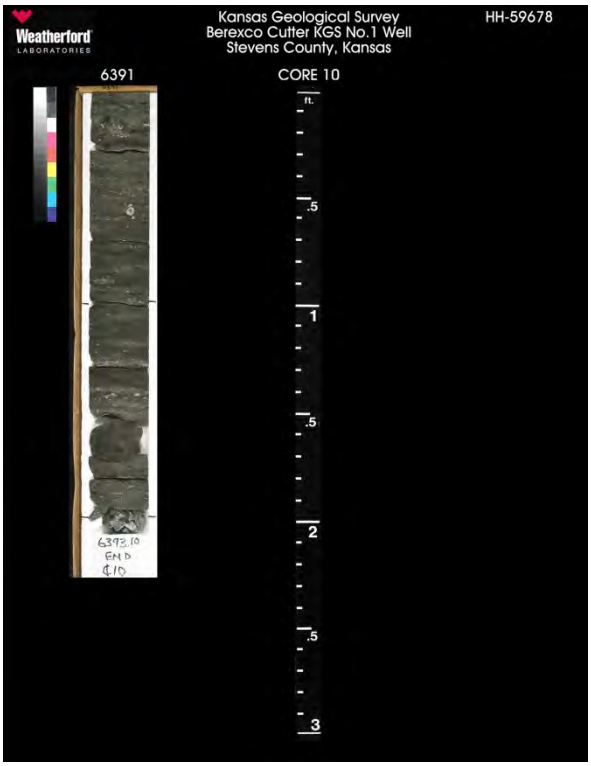


Figure 22. Lower most Osage Mississippian limestone. Very shaly and tight.

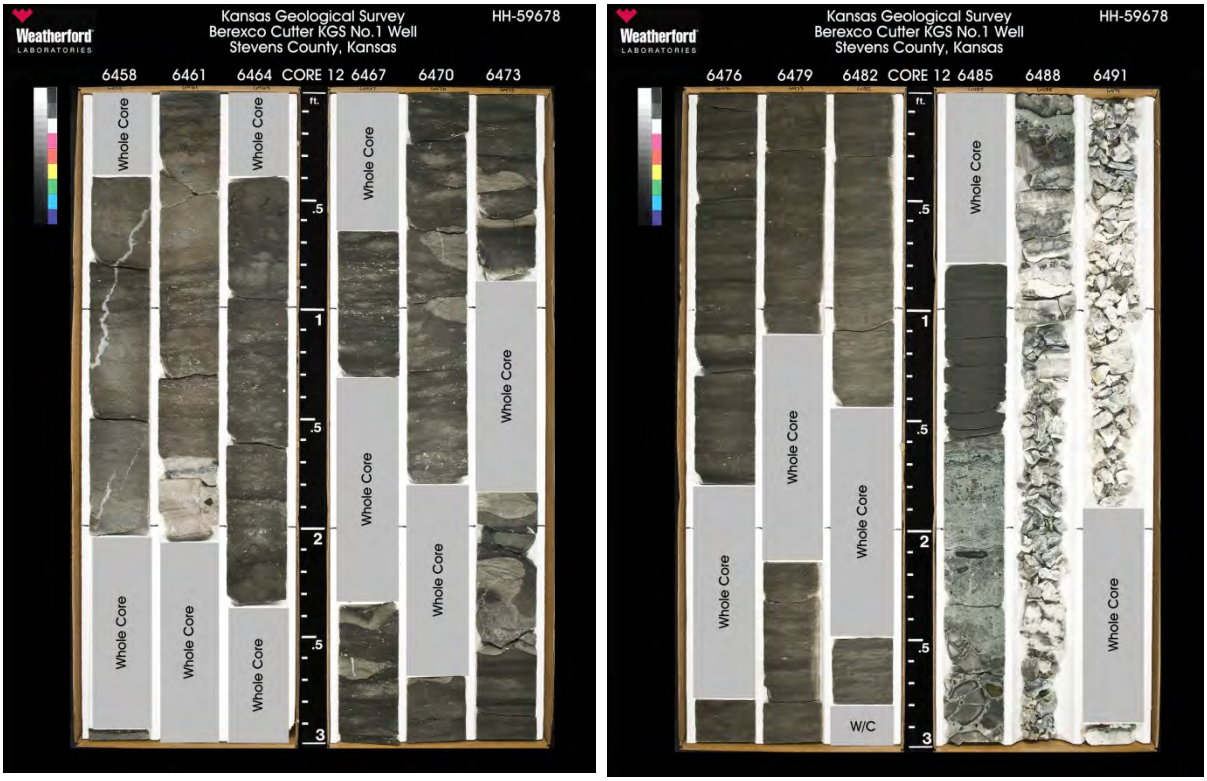


Figure 23. Lower Kinderhook Mississippian Limestone and shale resting on the top of the porous cherty Viola Limestone.

The initial core description of the lowermost Osage to top of the Viola Limestone follows.

6160; Top Osage chert

Core depth = log depth

6360.0; 6368.0; dolomitic packstone, white - light gray, siliceous fine grain peloid, large multi - cm sized light gray chert nodules, dense tite while logs suggest porosity, but depth are same **(transgression)**

6368.0; base Osage chert

(parasequence boundary)

6368.0; 6374.2; wackestone, gray, argillaceous, tite, scattered black chert nodules

6374.2; 6378.5; wackestone, dark gray, nodular black chert bed

6378.5; 6380.5; wackestone, dark gray, tite, scattered large crinoids, scattered chert

6380.5; 6381.0; shale **(transgressive)**

6381.0; 6387.0; packstone, increasing packstone beds to top w/ few wackestone, dark gray to light gray, tite, scattered large crinoids

6387.0; 6388.9; wackestone, dark gray, tite

6388.9; 6390.5; wackestone, gray, tite

6390.5; 6396.2; wackestone, dark gray, argillaceous, scattered large crinoids

6396.2; 6397.1; packstone, bioclasts, gray, crinoids

6397.1; 6399.0; wackestone - mudstone, dark gray, scattered nodular to bedded black chert, horizontal black ... sized burrows, crinoids, tite, argillaceous

6412; Northview Shale

6413; Gilmore City Limestone (Compton Limestone) (Kinderhook)

Core 1 ft low to log

6440.0; 6444.2; packstone, bioclastic debris, coarse, tite

6444.2; 6444.8; shale, calcareous, fossiliferous, hard

6444.8; 6450.5; packstone, bioclastic debris, coarse, tite

6450.5; 6455.8; wackestone, gray, silty, argillaceous, bioclasts, tite

6455.8; 6456.0; shale, dark gray, interbedded with carbonate, tite

6456.0; 6463.0; wackestone, gray, silty, argillaceous, tite

6463.0; 6469.0; wackestone, gray, argillaceous, silty, bioclasts, tite

6469.0; Kinderhook/Chattanooga Shale

6469.0; 6472.0; siltstone, gray, dolomitic, bioclasts, clasts of carbonate, tite

6472.0; 6475.0; sandstone, chert and sand, argillaceous / silt matrix, tite

6475.0; 6476.0; dolosiltstone, breccia, with argillaceous sand fill, fair porosity

6476.0; 6486.8; dolosiltite, dark gray, with quartz silt, poor porosity, argillaceous

6486.8; Misener Sandstone

6486.8; 6491.5; sandstone with abundant chert clasts, tan to gray, hard, clay, cement, tite

(**Transgressive**)

Kaskaskia-Tippecanoe Cratonic Sequence Boundary

6491.5; Viola Limestone

Ingrain digital rock physics lab donated multispectral scanning of key intervals of core from the Cutter KGS #1 for the interval from 6440.00’ – 7237.00’. The material was analyzed in their Houston facility to provide proof-of-concept of their capabilities. Portions of their analysis remain confidential, but material that can be shared with be included with the database on the well.

The following the public side of the data collected with the CoreHD® Continuous Core Viewer. A 4.0” diameter core was delivered to Ingrain’s lab in Houston, Texas sectioned into lengths of 1.10’ – 3.05’, preserved in plastic bags, and placed within cardboard boxes. Results include Ingrain’s CoreHD® Whole Core High Definition CT Scanning and Logging service. Each section of core was fully imaged in 3D at a resolution of 670 microns per vertical slice. Depth references from 6440.00’ – 7237.00’ were provided along with red and black orientation lines along the length of the core. The orientation markings were used to orient the Continuous Core Viewer movie clips for reference purposes. Bulk Density (RHOB) and Photoelectric Factor (PEF) were computed for each slice of the imaged core. The data is presented at multiple scales in log form. The overall CoreHD® log shows the entire core and is color coded to highlight different rock types within the core. The same data is also presented in log form in 25’ – 51’intervals. At the individual section scale, the log data is shown opposite the digital XCT images of the core.

Example of the Bulk Density (RHOB) and Photoelectric Factor (PEF) derived from Ingrain's analysis are included in **Figures 24 and 25** for the lower Osage to top of Viola Limestone in **Figure 24** and the Viola Limestone to the Simpson Sandstone in **Figure 25**.

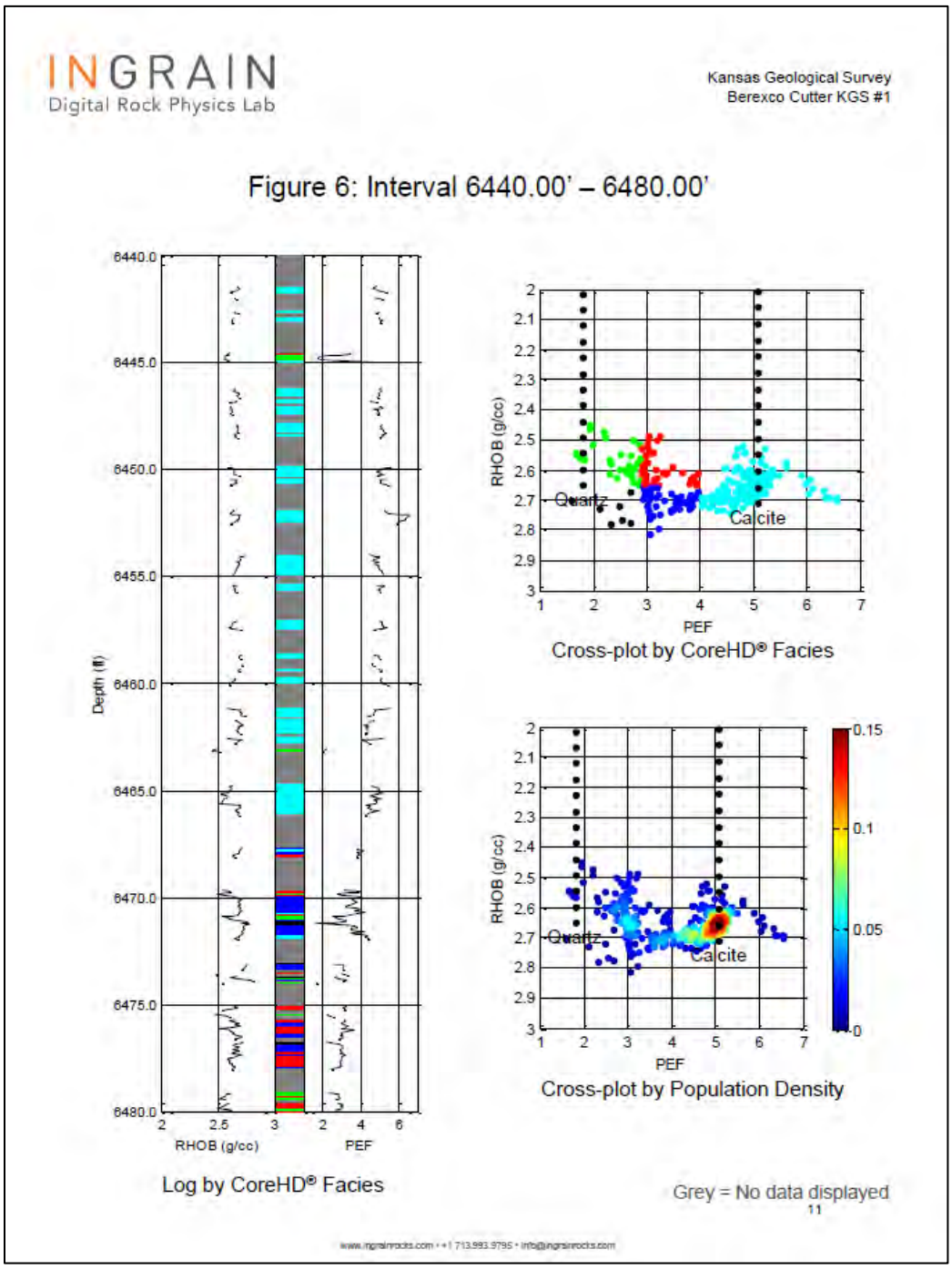


Figure 24. Bulk density and PEF measured by Ingrain for the Kinderhook limestone (light blue) and the shale below (dark blue and red). Misener sandstone at base is green colored interval.

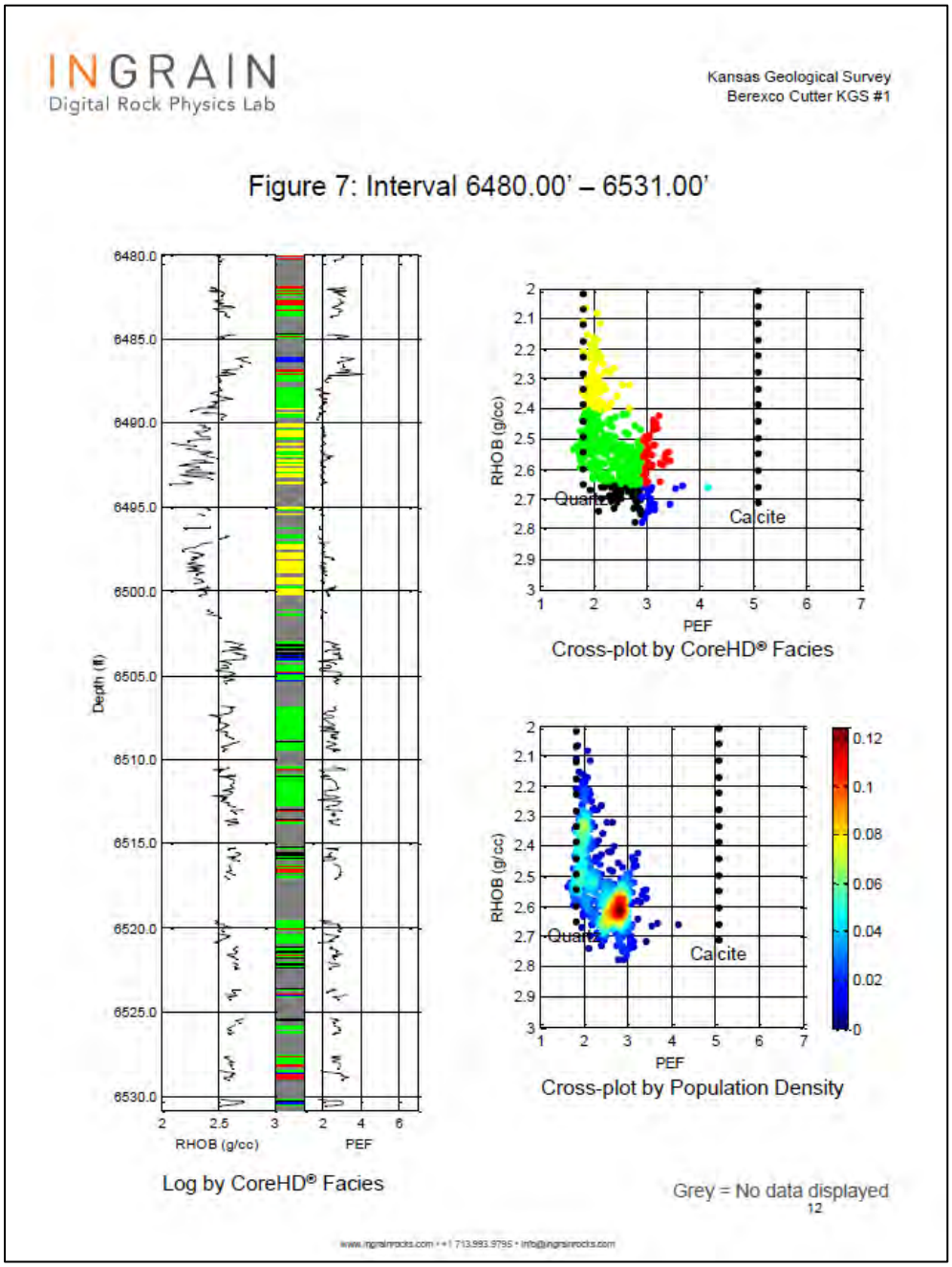


Figure 25. Ingrain's bulk density and PEF for the Viola Limestone (upper yellow-green) and the sandier interval at the base believed to be the Lower Ordovician Simpson Sandstone based on regional correlations.

2) Lithologic study of core plugs in preparation for further testing –

Core plugs were described by Michael Vega at Kansas State U. for use in selecting priorities for further analyses. The descriptions span the entire length of the core as noted below.

Cutter KGS#1 Depthwise Petrographic Summary

Morrow Formation

The Pennsylvanian aged Morrow Formation is a ~200' thick tan to gray sandstone to mudstone that extends from 5250' to 5450' (roughly), with shaly mudstone to wackestone facies persisting within the latter 150'.

- Sands are poorly to moderately sorted (just a few times seen) with a prominence of fine to very fine grained sediments, however the variation in grain size approached very coarse grained in some samples (~5261.1', 5260.6'). Good intergranular porosity is exhibited throughout the upper half with the lower mudstone to wackestone portion being tight. Subrounded to subangular grains dominate the sandy portion of the formation. The Morrow shows quartz dominance in the upper sands and shaly argillaceous materials through the lower mostly micrite cemented mudstones, hinting at the possibility of carbonate cement in the sands.
- Wackestone to packstone facies in lower portion exhibit broken bioclasts, mostly in the form of crinoid stems and bivalves, at mostly <10% total surface area with ~30% at 5403'.
- Heavy oil show and odor is noticeable throughout the formation, as this represents the pay zone for Cutter field.

Chester Formation

The Mississippian Chester Formation is a ~180' thick gray/light gray to tan sandstone to siltstone to mudstone that extends from 5480'-5660', with gray to olive shaly mudstone to wackestone facies persisting in the first ~70', followed by ~10' of low porosity fine to very fine grained gray sandstone, then ~40' of gray/dark gray tight siltstone, ~30' of low to tight porosity of light gray to tan sandstone, with the final ~15' returning to tight gray mudstone to wackestone facies. Oil shows were present throughout the formation.

- The upper shaly mudstone to wackestone region (~5480'-5550) is tight with an abundance (~10-30%) of bioclasts (mostly crinoids) in the wackestone facies, although the overall zone is predominantly mudstone with wavy nonparallel shaly laminations (~50%).
- The upper sandstone (~5558'-5570') exhibits low porosity, is quartz dominated, and is fine to very fine grained. Wavy shaly lamination and small (mm wide) black shaly fragments are present throughout.
- The siltstone zone (~5571.6'-5610.4') shows to be very tight with mm scale pyrite grains present in almost half of the samples, sometimes as cherty replacement textures (low chert content overall i.e. <10% of samples). Dark wavy shaly laminae persist through a majority of samples and ~28% of samples exhibit bioturbation structures typically in the form of burrows. Quartz dominance and predominantly micrite cement make up the lithologic components in addition to scattered pyrite as described above.
- The lower sandy portion of the Chester (~5611.4-5643.9') is tan to light gray and fine grained. Slightly fractured regions exhibit low to moderate porosity (~50%) while the rest remains tight. This zone is again quartz dominated with mostly micrite cement, with one spotted pyrite occurrence and a possible glauconite nodule.

- The lower mudstone to wackestone zone (~5645.45'-5662.45') is similar to the upper facies of similar lithology, except the former is more mineralogically diverse. Pyrite was found in up to multi-cm scale nodules and as fracture infillings and distinct blue elongated chert nodules were observed towards the base.
- Only one sample (5664.8') was provided for the upper St. Louis lime, and it showed a tight white chalky fine grained limestone packstone supported by broken bioclasts that were too small to discern.

Osagean Stage

The lower Mississippian aged Osage lime (~6361'-6370') is a white to light gray fine grained dolomite wackestone with an abundance of cm to multi-cm scale blue chert nodules. The zone exhibits an overall tight porosity with a slight vuggy region (~6363.7') bringing low to possibly moderate porosity. Vugs range from mm to cm scale and one larger vug (1/2 cm wide) showed secondary crystalline dolomite infillings. Predominantly micrite cement supports broken mm scale bioclasts in the form of crinoids. 6368' shows shaly argillaceous banding along with mm scale pyrite grains.

Upper Kinderhookian Stage

Upper Kinderhookian Stage rocks (~6373'-6650') show four distinct zones: gray/light gray fine grained dolomite wackestone to packstone (6370'-6470'), gray very fine grained sandstone to siltstone (~6473'-6484'), autoclastic cherty-dolomite brecciated zone (~6487'-6500'), and light gray/gray very fine grained dolomite mudstone (~6500'-6650').

- The uppermost wackestone to packstone facies is tight with an abundance of broken bioclasts (mostly crinoids (up to ~40%)) held intact by micritic cement. Cherty bedding is common in addition to shaly lamination and mineralogically it is relatively homogeneous with only dolomite, chert and argillaceous materials being observed.
- The very fine grained sandstone to siltstone zone is dominated by wavy argillaceous lamination, silty matrices and tight porosity, with observed minerals being dolomite, quartz, clays, and possibly chalcopyrite at ~6485'.
- The brecciated zone is composed of multi-cm scale angular chert clasts within a shaly mudstone (~30-40% shale) matrix and exhibits a significant amount of white powdery clay material (~30%). Low to moderate intergranular and fracture porosity was observed. Brecciated region provides increased heterogeneity.
- The final mudstone zone throughout the lower half is characterized by light gray very fine grained dolomitic mudstones with tight porosity and a few notable accessory minerals (i.e. pyrite, chalcopyrite, clays) as well as the expected array of chert nodules (up to cm scale) and argillaceous fracture infillings. Micrite cement was dominant however a few sparry regions were noted, and a silty texture was observed throughout the zone.

Simpson Group

The Simpson group is lithologically represented by gray to light gray dolomite mudstone to packstone facies and extends from ~6668' to 6986'. The upper half is packstone (fine to medium grained) dominated with the lower half being mostly mudstone (fine to very fine grained). The packstone zones typically exhibit low to moderate vuggy/intergranular porosity with vugs ranging from pinpoint to cm scale and often infilled with secondary crystalline dolomite. Mudstone zones are more commonly tight, however low vuggy and fracture porosity becomes prevalent towards the base.

- The uppermost ~20' of packstone (6668'-6696') contains mm scale skeletal fragments/bioclasts, mostly in the form of crinoids, as well as pelloids, within micrite cement. Large cm scale chert nodules are not uncommon and in fact approach ~30-40% with depth (down to 6700'). Wavy argillaceous lamination and visible crystalline dolomite within matrix is also prevalent in this ~30' interval.
- A tight mudstone zone exists between 6702' and 6718', with visible mm scale pyrite grains at ~6705' and dark shaly banding throughout.
- A highly porous zone exists at ~6740' with brecciated dolomite mudstone lithology and vuggy pores visibly distributed within the entirety of the sample. Angular clasts contribute good intergranular porosity.
- Between 6900' and 6980' the lithology is predominantly mudstone with scattered packstone zones. A slight increase in fracture pathways and vuggy pores promotes relative heterogeneity and pore diversity, however overall porosity is still moderate to low. A slightly brecciated zone (autoclastic) at ~6940' provides enhanced zonal heterogeneity. White clayey infillings are common in this 90' zone, especially in fracture regimes. The cement type is mostly micrite with scattered regions of sparite, in particular around 6930'. Mineralogically this lower region of the Simpson group hosts dolomite (both in matrix and in secondary vitreous infillings), silica (in the form of chert nodules), and various clay minerals. A relative absence of observable sulfides in this lower depth was noted.
- The final 20' above the base is relatively homogeneous and increasingly tight in comparison to the pore types that precede it.

Gasconade Dolomite

The Ordovician Gasconade dolomite is a fine to very fine grained gray/light gray dolomite mudstone to packstone that extends from ~7100'-7430'. A noticeable increase in vugs and fracture pathways in the middle of the formation (7191'-7339') promotes good vuggy and fracture porosity and therefore heterogeneity. A similar change is noted nearing the base (~7425'). Lithologically the Gasconade is dolomitic with large cm to multi cm scale chert nodules, scattered sulfide minerals (mostly pyrite, some chalcopyrite ~7350') and clay minerals as fracture infillings that are likely Fe-rich (?). Some zones exhibited green claystone facies indicating the possibility of glauconite (7210', 7235'). Vugs are often infilled with vitreous crystalline dolomite rhombs, and such textures can often be seen in matrices. The cement type is mostly micrite with scattered regions of sparite (~7340', 7400'). Wavy laminae are present, but not common, throughout the formation. An autoclastic brecciated zone exists at ~7191' with angular cherty clasts providing increased intergranular porosity and overall heterogeneity.

Gunter Sand

The Gunter sand is a fine to very fine grained light gray sandstone that extends from ~7530' to 7590'. Overall pore distribution is tight with a few zones showing low pinpoint and fracture porosity. Wavy nonparallel clayey/shaly lamination (gray to blue-green in color) persists through a majority of samples, with the green layers possibly indicative of glauconite and the gray layers demonstrating interbedded dolomite mudstone.

- A large cm scale chalcopyrite nodule was noted at ~7566' with a smaller mm scale nodule at ~7582'. Mm scale sub to euhedral glauconite crystals were spotted within the matrix of ~7558'.
- The upper region of this zone is moderately to well sorted with well-rounded grains with poorly sorted subrounded grains showing dominance nearing the base.
- Mineralogically the Gunter is composed of mostly quartz with scattered carbonate regions and a diverse array of accessory minerals (i.e. chalcopyrite, pyrite, glauconite and other clays, etc).

4) Calibration of Arbuckle rock properties with well logs and core for field use and for calibration of logs used in coarse-grid static and dynamic modeling at 10 regional sites to refine estimates of carbon storage potential –with contributions by David Newell, John Doveton, Mina Fazelalavi

The cored intervals of the lower Paleozoic in the Berexco Cutter KGS #1 well are illustrated in **Figure 26**. This is the latest core to be analyzed and routine porosity and permeability are described below.

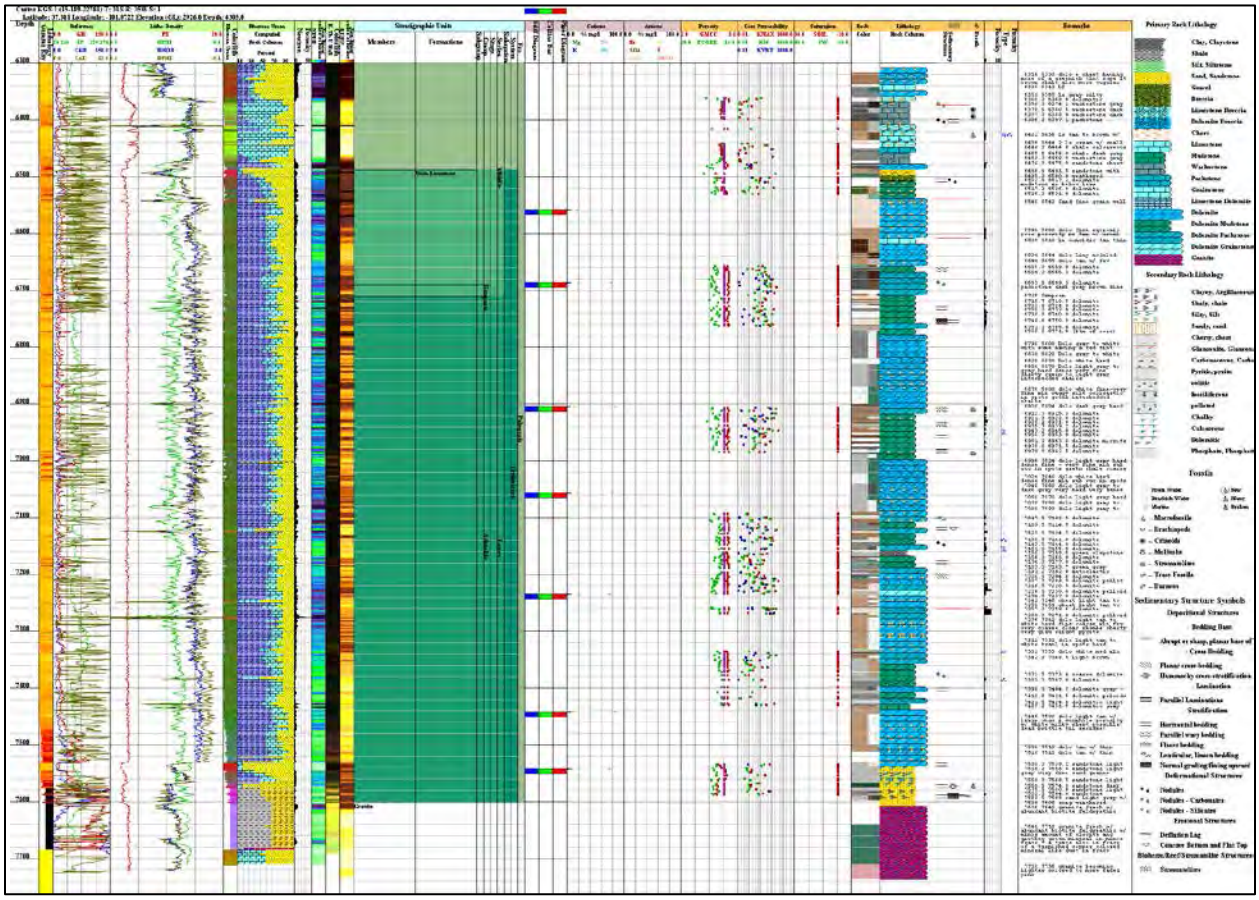


Figure 26. Lower Paleozoic portion of the Cutter KGS #1 cored interval, showing the porosity and permeability analysis alongside with well logs curves and lithology solution on the left and the core description on the right.

Whole core analysis of Cutter KGS #1 is briefly summarized with a scatter plot of the phi-k data. Kmax, K90, and Kvertical as well as some fluid saturation work was done on the Arbuckle interval (**Figure 27**). The latter was done to follow up on a series of oil shows (fluorescence) noted throughout many intervals of the Arbuckle whole core.

FULL DIAMETER CORE ANALYSIS

Weatherford LABORATORIES

KANSAS GEOLOGICAL SURVEY
BEREXCO CUTTER KGS # 1
STEVENS COUNTY, KANSAS

A.P.I. NUMBER : 15-189-22781
FIELD : Cutter
LOCATION :

FILE NO. : HH-59678
DATE : September 19, 2013
ANALYSTS : WH, SB, JR

MODIFIED DEAN STARK EXTRACTION

SMPL NO.	DEPTH (ft)	PERMEABILITY Kmax	K90	Kvert	G DEN (G/CC)	POR (%)	Sw (%)	So (%)	FLUORESCENCE %

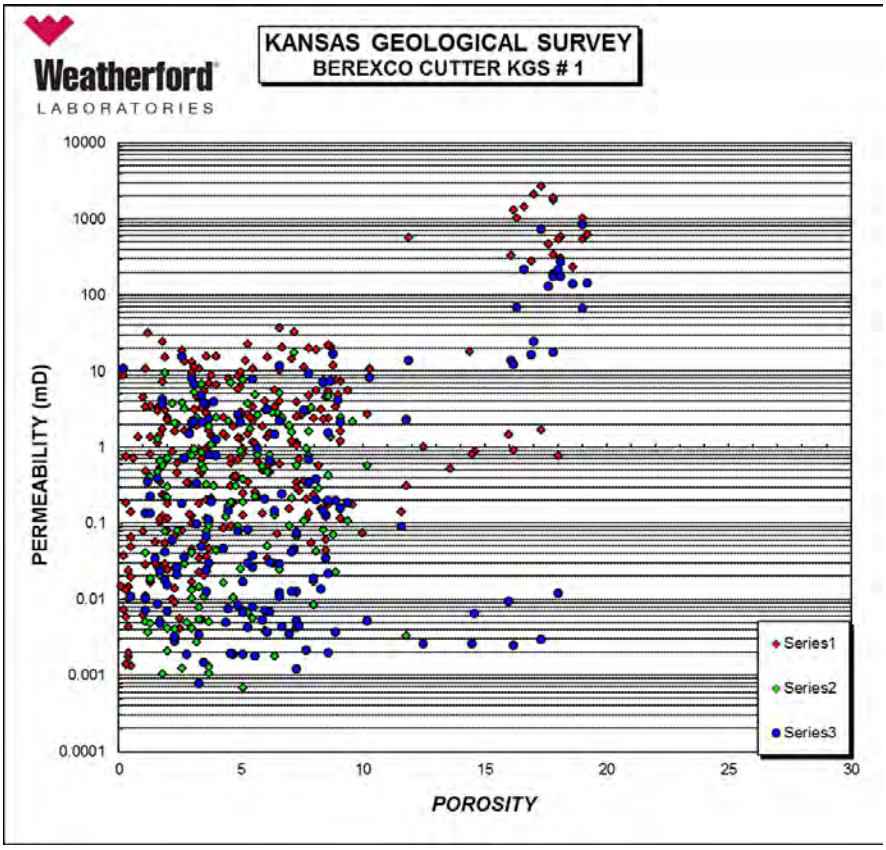


Figure 27. Routine porosity and permeability plot for the Cutter KGS #1 core.

In addition, the organic-rich portions of the Atokan-age mixed black shale-tight carbonate caprock above the Morrow sandstone reservoir and the Morrow shales were analyzed for total organic carbon and thermal maturity. The results indicate the Atokan shale ("Thirteen Finger Limestone") is thermally mature in early stages of oil generation. The organic matter is sufficiently rich and is oil prone. This is in contrast with the Morrow shales that are not oil prone and organic content is minor (**Figures 28-30**).

Weatherford LABORATORIES

TOTAL ORGANIC CARBON, PROGRAMMED PYROLYSIS DATA

KANSAS GEOLOGICAL SURVEY

Well Name : BEREXCO CUTTER KGS NO. 1 **Operator :** **API # :** 15-189-22781 **State :** KANSAS **County :** STEVENS **Weatherford Labs Project** HH-59678 /

Client ID	Depth (ft) Top	Sample Type	Sample Prep	*	Leco TOC	SRA S1	SRA S2	SRA S3	Tmax (°C)	**	Meas. % Ro	HI	OI	S2/S3	S1/TOC* 100	PI	Notes Checks	Notes Pyrogram	Lab ID
1-1TOC	5233.5	Chunk	NOPR		3.77	0.80	12.68	0.41	443			337	11	31	21	0.06	SRA TOC	n	101065946
1-1-1TOC	5233.7	Chunk	NOPR		1.83	0.20	0.80	0.22	445			44	12	4	11	0.20	TOC	n:lts2sh:hts2sh	101065948
1-5TOC	5237.4	Chunk	NOPR		0.24	0.07	0.30	0.22	440	**		127	93	1	30	0.19	TOC	n	101065950
1-8TOC	5240.5	Chunk	NOPR		1.55	0.32	1.20	0.34	445			77	22	4	21	0.21	SRA TOC	n:hts2sh	101065952
1-12TOC	5244.1	Chunk	NOPR		0.48	0.08	0.17	0.37	443	**		35	76	0	17	0.32	TOC	n:lts2sh:hts2sh	101065954
2-38TOC	5289.5	Chunk	NOPR		0.56	0.07	0.19	0.55	445	**		34	99	0	13	0.27	TOC	n:lts2sh:hts2sh	101065956
3-15TOC	5414.6	Chunk	NOPR		0.90	0.11	0.59	0.41	445			66	46	1	12	0.16	SRA TOC	n:lts2sh:hts2sh	101065958
5-53TOC	5535.5	Chunk	NOPR		0.16	0.04	0.07	0.42	440	**		45	256	0	27	0.37	TOC	n:lts2sh:hts2sh	101065960
6-47TOC	5589.15	Chunk	NOPR		0.53	0.11	0.46	0.36	442	**		86	68	1	21	0.19	TOC	n	101065962
12-47TOC	6486.2	Chunk	NOPR		0.18	0.03	0.12	0.41	442	**		68	233	0	17	0.20	SRA TOC	n:lts2sh	101065964
12-47-1TOC	6486.4	Chunk	NOPR		0.22	0.03	0.29	0.29	441	**		131	131	1	14	0.09	TOC	n:lts2sh	101065966

Notes:

"-1" – not measured or invalid value
TOC - Total Organic Carbon, wt. %
S1 - volatile hydrocarbon (HC) content, mg HC / g rock
S2 - remaining HC generative potential, mg HC / g rock
S3 - carbon dioxide content, mg CO_2 / g rock

* - Sample contaminated
** - low S2, Tmax is unreliable
Meas. %Ro - measured vitrinite reflectance
HI - Hydrogen Index = S2 x 100 / TOC, mg HC / g TOC
OI - Oxygen Index = S3 x 100 / TOC, mg CO_2 / g TOC
PI - Production Index = S1 / (S1+S2)

Pyrogram:
f - flat S2 peak
n - normal
ltS2sh - low temperature S2 shoulder
ltS2p - low temperature S2 peak
htS2p - high temperature S2 peak

LECO - TOC on LECO Instrument
SRA - Programmed Pyrolysis on SRA instrument
RE - Programmed Pyrolysis on Rock-Eval instrument
EXT - Extracted Rock
NOPR - Normal Preparation

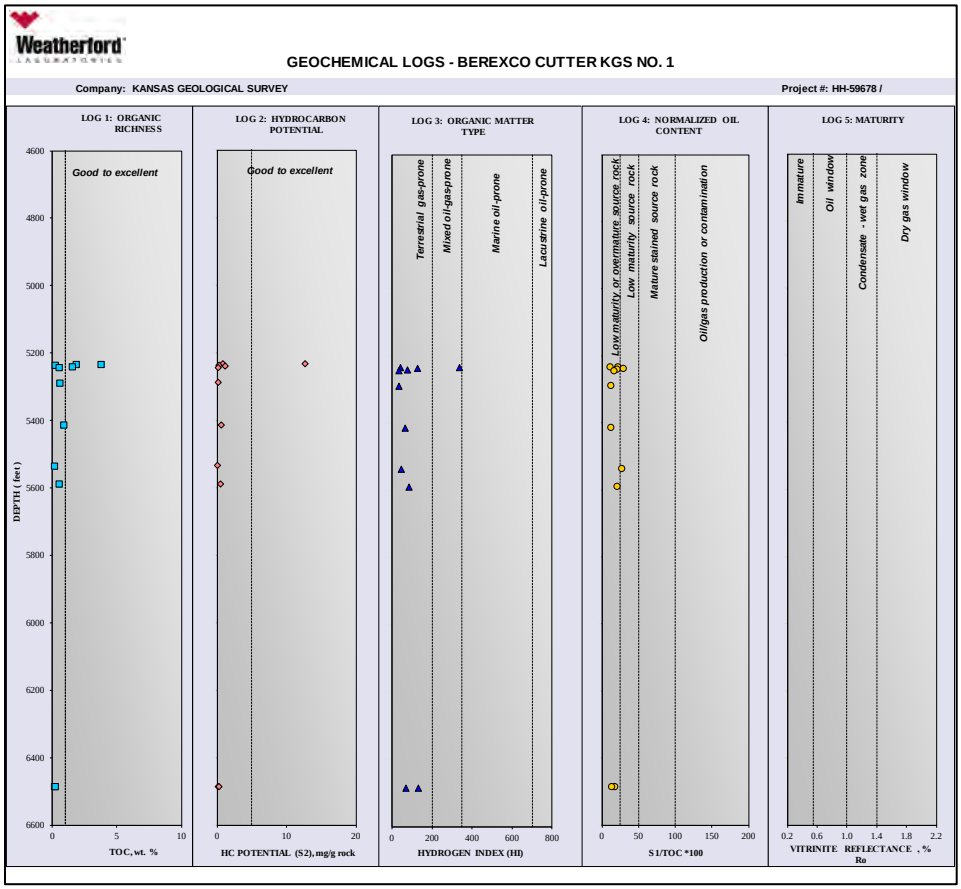
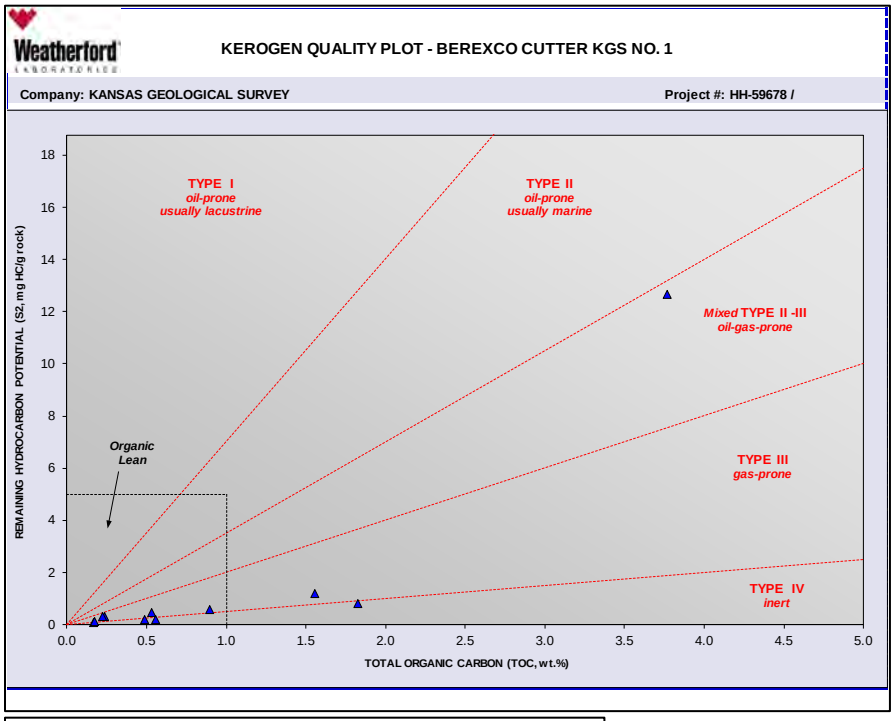


Figure 28. (upper) Total organic carbon (TOC) and organic richness and thermal maturity of the Atokan and Morrow shales from the Berexco Cutter KGS #1 core.



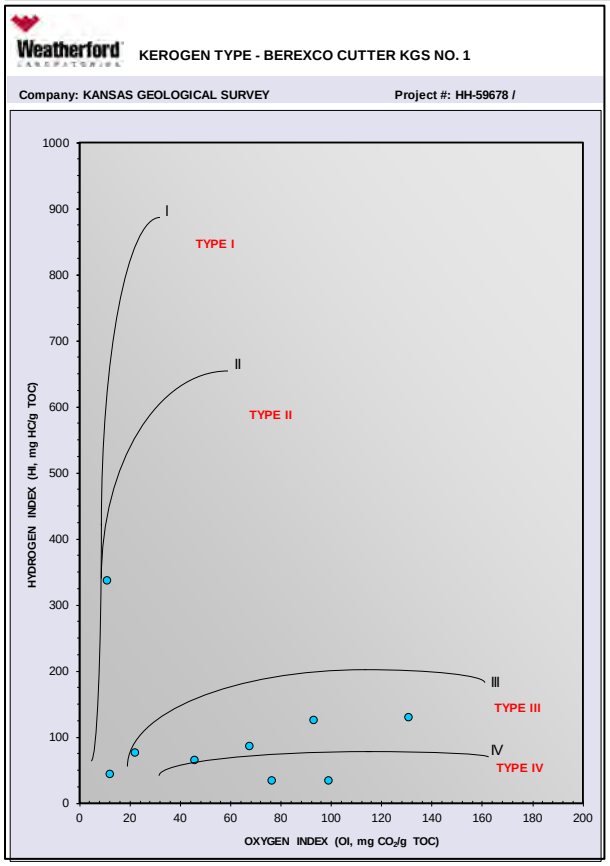
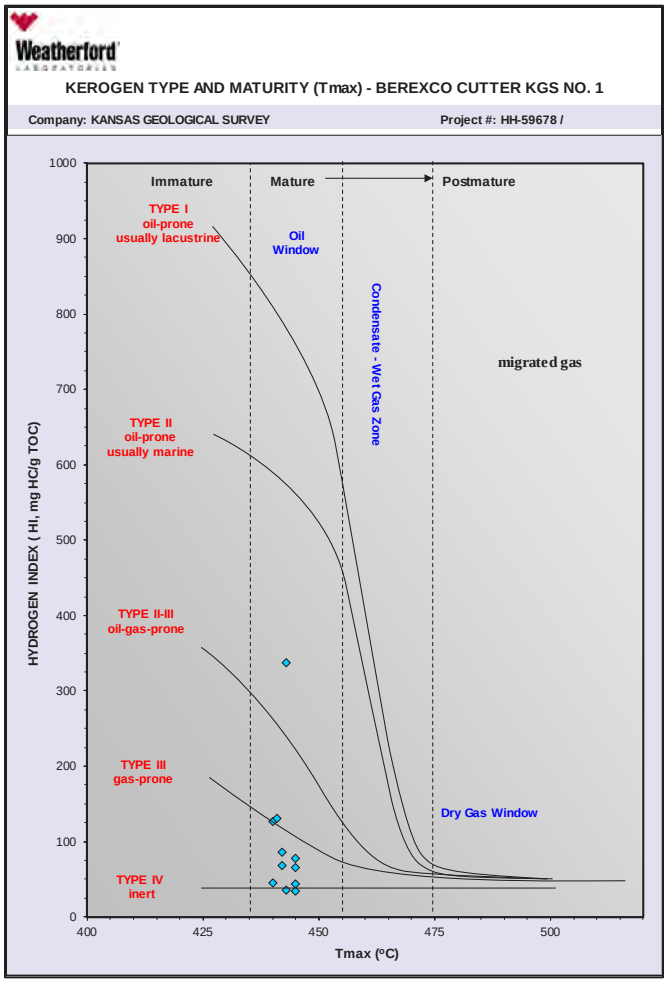


Figure 29. Plots of kerogen type and quality for Atokan and Morrow shales from the Cutter KGS #1.



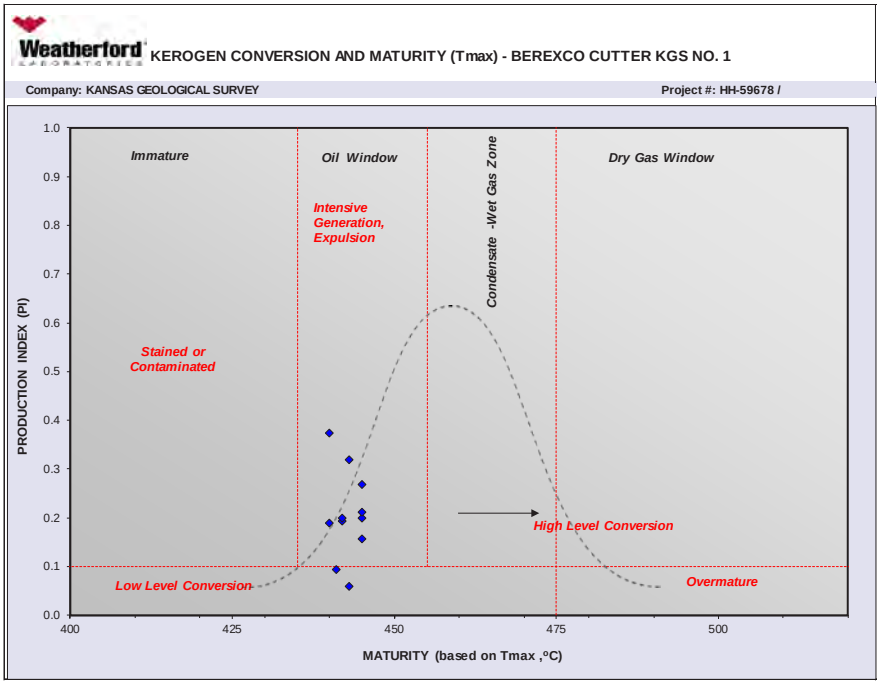


Figure 30. Organic type and maturity (Tmax) and kerogen conversion and maturity for Atokan and Morrow shales from the Cutter KGS #1.

5) Analysis of brine obtained from swab sampling at Cutter Field – contributions my Brent Campbell, Michael Vega, and Saugata Datta

Initial reports on the analysis of brines from the Cutter KGS #1 were measured by Kansas State University as listed below in a series of tables (Figure 31-35).

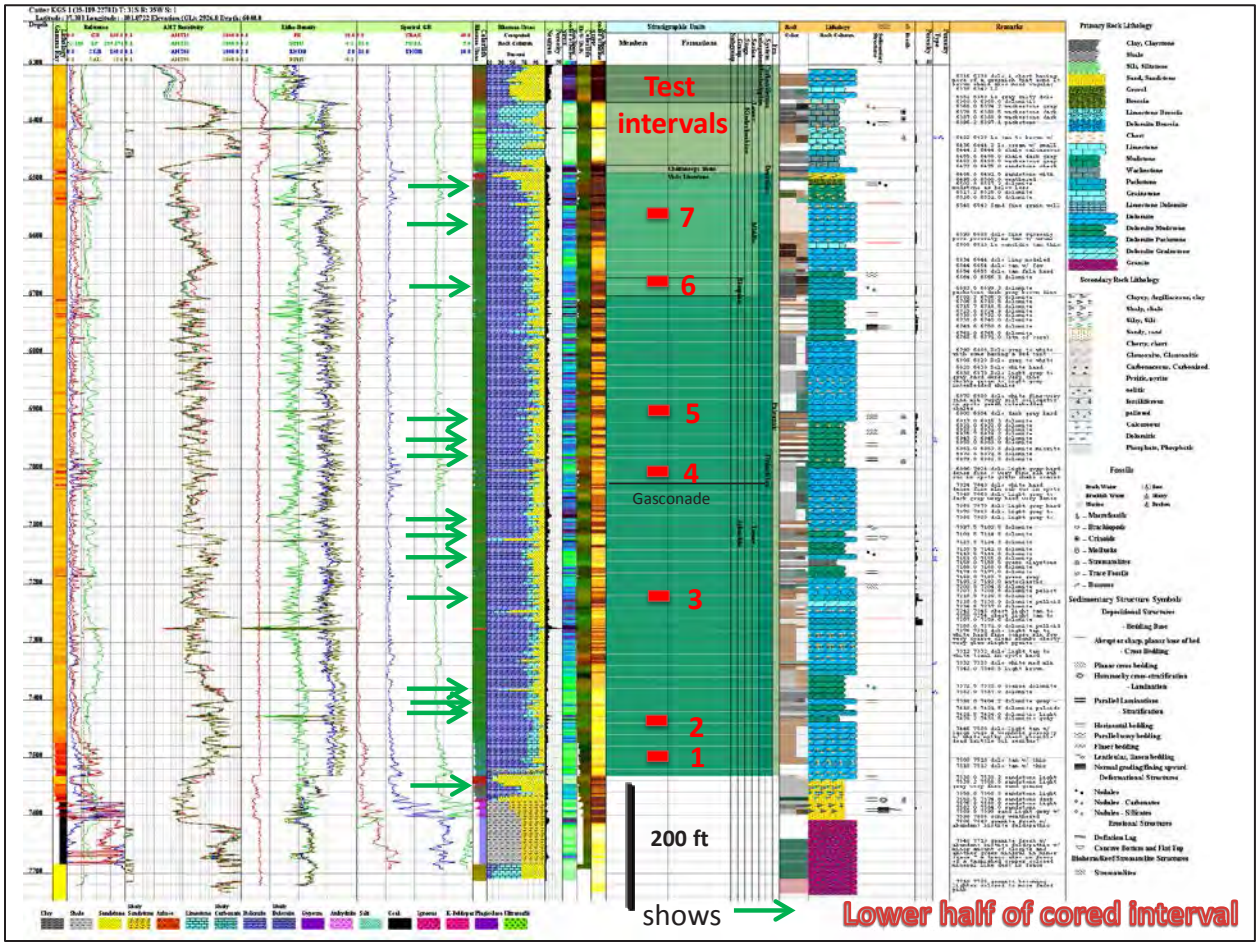


Figure 31. Lower Paleozoic profile log and core profile of the Cutter KGS #1 showing locations of the brine samples (red) and oil shows, mainly from core fluorescence (green arrows).

Field Data														
Name	Units	**Swab 1**	**Swab 2**	**Swab 3**	**Swab 4**	**Swab 5**	**Swab 6**	**Swab 7**	**Swab 8**	**Swab 9**	**Swab 10**	**Swab 11**	**DST 1**	**DST 2**
Date		6/25/2013	6/26/2013	7/1/2013	7/9/2013	7/10/2013	7/16/2013	7/22/2013	7/22/2013	7/23/2013	7/25/2013	7/26/2013	6/28/2013	7/3/2013
Depth	ft	7,543-7,532	7,442-7,430	7,234-7,218	7,056-7,046	6,904-6,880	6,686-6,676	6,558-6,543	6,204-6,194	6,010-6,000	5,680-5,670	5,622-5,545	7,442-7,430	7,100-6,300
Notes		45um filtered	45um filtered	45um filtered	45um filtered	45um filtered	unfiltered	unfiltered	10um filtered	10um filtered	10um filtered	10um filtered		
LDO	mg/L	-	-	2.04	2.15	2.2	5.05	5.78	2.9	1.87	15.7	33.7	-	-
Salinity	ppt	-	-	-	-	-	>70.74	64.56	>70.74	>70.74	47.7	>70.74	-	-
Conductivity	mS/cm	-	683	-	-	-	29.3	90.2	52.1	6.49	67.7	57.3	-	-
ORP	mV	-293.1	-	240	-38.7	-128.4	-97	59.9	-64.1	-110.4	-84.7	-167.3	-	-
pH		7.19	6.71	6.79	6.52	6.71	6.9	8.07	6.6	6.77	6.87	6.74	-	-
Resistivity	MΩ-cm	6.61	-	3.1	2.42	2.01	3.44	1.11	2.08	1.14	1.47	1.73	-	-
Temp.	°C	34.4	38.6	-	30.4	34.7	21.3	25.8	36.7	37.6	22.7	32.1	-	-
TDS	mg/LΩ	7.8	-	-	-	-	14.87	44.8	25.1	3.25	33.6	28.7	-	-

Figure 32. Identification of the swab and DST intervals and initial measurements of the brine samples collected from the swabbing and DST.

Cutter Major Ion Data						
Analyte Symbol	**K**	**Mg**	**Ca**	**Na**	**Cl**	**SO4**
Unit Symbol	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Detection Limit	0.1	0.1	0.1	0.1	0.03	0.03
Analysis Method	ICP-OES	ICP-OES	ICP-OES	ICP-OES	IC	IC
SWAB 1	1460	1190	9010	52600	67800	294
SWAB 2	1360	1140	8400	49700	41700	241
SWAB 3	987	896	6090	35600	106000	882
SWAB 4-Bad Run	23.6	14.1	104	648		
SWAB 4-Good Run	1100	898	6510	34700	43000	443
SWAB 5	1410	1470	9100	47600	76000	417
SWAB 6	1250	1300	8810	40000	29200	268
SWAB 7	1060	247	2430	19800	143000	4730
SWAB 8	814	865	5410	28700	53100	375
SWAB 9	803	1020	5420	23700	115000	1620
SWAB 10	830	363	1650	15900	20900	1790
SWAB 11	930	1290	6950	29700	11500	202
DST 1	1280	1070	7820	46600	68400	295
DST 2	963	858	5640	34300	12200	228

Figure 33. Cutter major cation data.

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Cutter Cation Data																
Analyte Symbol	**Ba**	**Al**	**K**	**Mg**	**Mn**	**Si**	**Ag**	**As**	**Be**	**Bi**	**Ca**	**Cd**	**Ce**	**Co**		
Unit Symbol	µg/L	mg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L		
Detection Limit	20	0.1	0.1	0.1	0.01	0.1	5	30	2	20	0.1	2	30	2		
Analysis Method	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES		
SWAB 1	1860	< 5	1460	1190	4.4	< 5	< 300	< 2000	< 100	< 1000	9010	< 100	< 2000	< 100		
SWAB 2	1690	< 5	1360	1140	2.85	8.2	< 300	< 2000	< 100	< 1000	8400	< 100	< 2000	< 100		
SWAB 3	1310	< 5	987	896	2.01	20.2	< 300	< 2000	< 100	< 1000	6090	< 100	< 2000	< 100		
SWAB 4-Reran, see below	30	< 0.1	23.6	14.1	0.1	0.1	< 5	< 30	< 2	< 20	104	< 2	< 30	< 2		
SWAB 5	1790	< 5	1410	1470	1.41	< 5	< 300	< 2000	< 100	< 1000	9100	< 100	< 2000	< 100		
SWAB 6	1750	< 5	1250	1300	1.58	6.2	< 300	< 2000	< 100	< 1000	8810	< 100	< 2000	< 100		
SWAB 7	< 1000	< 5	1060	247	5.29	< 5	< 300	< 2000	< 100	< 1000	2430	< 100	< 2000	< 100		
SWAB 8	< 1000	< 5	814	865	0.93	16.9	< 300	< 2000	< 100	< 1000	5410	< 100	< 2000	< 100		
SWAB 9	< 1000	< 5	803	1020	0.7	16.8	< 300	< 2000	< 100	< 1000	5420	< 100	< 2000	< 100		
SWAB 10	< 1000	< 5	830	363	2.33	28.9	< 300	< 2000	< 100	< 1000	1650	< 100	< 2000	< 100		
SWAB 11	< 1000	< 5	930	1290	0.63	9.6	< 300	< 2000	< 100	< 1000	6950	< 100	< 2000	< 100		
DST 1	1610	< 5	1280	1070	4.12	< 5	< 300	< 2000	< 100	< 1000	7820	< 100	< 2000	< 100		
DST 2	1460	< 5	963	858	3.37	11.6	< 300	< 2000	< 100	< 1000	5640	< 100	< 2000	< 100		

Cr	Fe	Cu	Li	Mo	Na	Ni	P	Pb	Sb	S	Se	Sn	Sr	Te	Ti	Tl	U	V	W	Y	Zn
µg/L	mg/L	µg/L	mg/L	µg/L	mg/L	µg/L	mg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L	µg/L
20	0.01	2	0.05	5	0.1	5	0.02	10	10	1	20	10	10	10	10	10	0.05	10	10	10	5
ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES	ICP-OES
< 1000	< 0.5	455	24.3	< 300	52600	< 300	< 1	< 500	< 500	203	< 1000	< 500	223000	< 500	< 500	< 500	< 3	< 500	< 500	< 500	23700
< 1000	< 0.5	130	23	< 300	49700	< 300	< 1	< 500	< 500	206	< 1000	< 500	213000	< 500	< 500	< 500	< 3	< 500	< 500	< 500	34700
< 1000	2.85	< 100	19.6	< 300	35600	< 300	< 1	< 500	< 500	192	< 1000	< 500	155000	< 500	< 500	< 500	< 3	< 500	< 500	< 500	13200
< 20	0.23	7	0.32	< 5	648	12	< 0.02	< 10	< 10	6	< 20	< 10	2700	< 10	< 10	< 10	< 0.05	< 10	< 10	< 10	68
< 1000	4.43	< 100	23.8	< 300	47600	< 300	< 1	< 500	< 500	178	< 1000	< 500	229000	< 500	< 500	< 500	< 3	< 500	< 500	< 500	22700
< 1000	7.85	< 100	16.7	< 300	40000	< 300	< 1	< 500	< 500	194	< 1000	< 500	232000	< 500	< 500	< 500	< 3	< 500	< 500	< 500	13800
< 1000	1.2	156	7.23	< 300	19800	< 300	1.37	< 500	< 500	446	< 1000	< 500	73400	< 500	< 500	< 500	< 3	< 500	< 500	< 500	< 300
< 1000	8.82	< 100	21.5	< 300	28700	< 300	< 1	< 500	< 500	196	< 1000	< 500	140000	< 500	< 500	< 500	< 3	< 500	< 500	< 500	11000
< 1000	7.34	< 100	30	< 300	23700	< 300	< 1	< 500	< 500	277	< 1000	< 500	146000	1100	< 500	< 500	< 3	< 500	< 500	< 500	5210
< 1000	4.13	134	12	284	15900	< 300	< 1	< 500	< 500	731	< 1000	< 500	51400	< 500	< 500	< 500	< 3	< 500	< 500	< 500	1000
< 1000	1.05	< 100	36.6	< 300	29700	< 300	< 1	< 500	< 500	268	< 1000	< 500	189000	< 500	< 500	< 500	< 3	< 500	< 500	< 500	< 300
< 1000	44.3	< 100	21.7	< 300	46600	< 300	< 1	< 500	< 500	189	< 1000	< 500	200000	< 500	< 500	< 500	< 3	< 500	< 500	< 500	3880
< 1000	53	< 100	17.8	< 300	34300	< 300	< 1	< 500	< 500	201	< 1000	< 500	145000	< 500	< 500	< 500	< 3	< 500	< 500	< 500	2290

Figure 34. Cutter minor cation Data.

Cutter Anion Data and Swab 4 Rerun

Analyte Symbol	Ba	Al	F	Cl	NO2 (as N)	Br	NO3 (as N)	PO4 (as P)	SO4
Unit Symbol	µg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Detection Limit	20	0.1	0.01	0.03	0.01	0.03	0.01	0.02	0.03
Analysis Method	ICP-OES	ICP-OES	IC	IC	IC	IC	IC	IC	IC
SWAB 1			< 20	67800	< 20	90.7	< 20	< 40	294
SWAB 2			< 20	41700	< 20	< 60	< 20	< 40	241
SWAB 3			30.6	106000	< 20	139	< 20	< 40	882
SWAB 4			< 20	43000	< 20	< 60	< 20	< 40	443
SWAB 5			< 20	76000	< 20	11	< 20	< 40	417
SWAB 6			24.6	29200	< 20	< 60	< 20	< 40	268
SWAB 7			149	143000	< 20	183	< 20	< 40	4730
SWAB 8			< 20	53100	< 20	< 60	< 20	< 40	375
SWAB 9			< 20	115000	< 20	191	< 20	< 40	1620
SWAB 10			< 20	20900	< 20	< 60	< 20	< 40	1790
SWAB 11			45.3	1150	< 20	< 60	< 20	< 40	202
DST 1			< 20	68400	< 20	< 60	< 20	< 40	295
DST 2			< 20	12200	< 20	< 60	< 20	< 40	228
SWAB 4 FA	< 2000	< 10							

Figure 35. Cutter anion data.

ONGOING ACTIVITIES - WELLINGTON FIELD – contributions by Jennifer Raney

1) Evaluate CO2 Sequestration Potential in Arbuckle Group Saline Aquifer at Wellington Field (Task 7).

The analysis of the Geomodel and simulation of the Arbuckle saline aquifer at Wellington Field focused on understanding the fate of CO2 for a 40,000 metric ton test injection (DE-FE0006821) (Figure 37). Wellington Field is also one of the sites to model commercial scale injection. Wellington and Cutter field studies are being used to calibrate the other eight sites for key parameters used in the geomodel including estimating permeability, capillary pressure and relative permeabilities for supercritical CO2, and reaction kinetics.

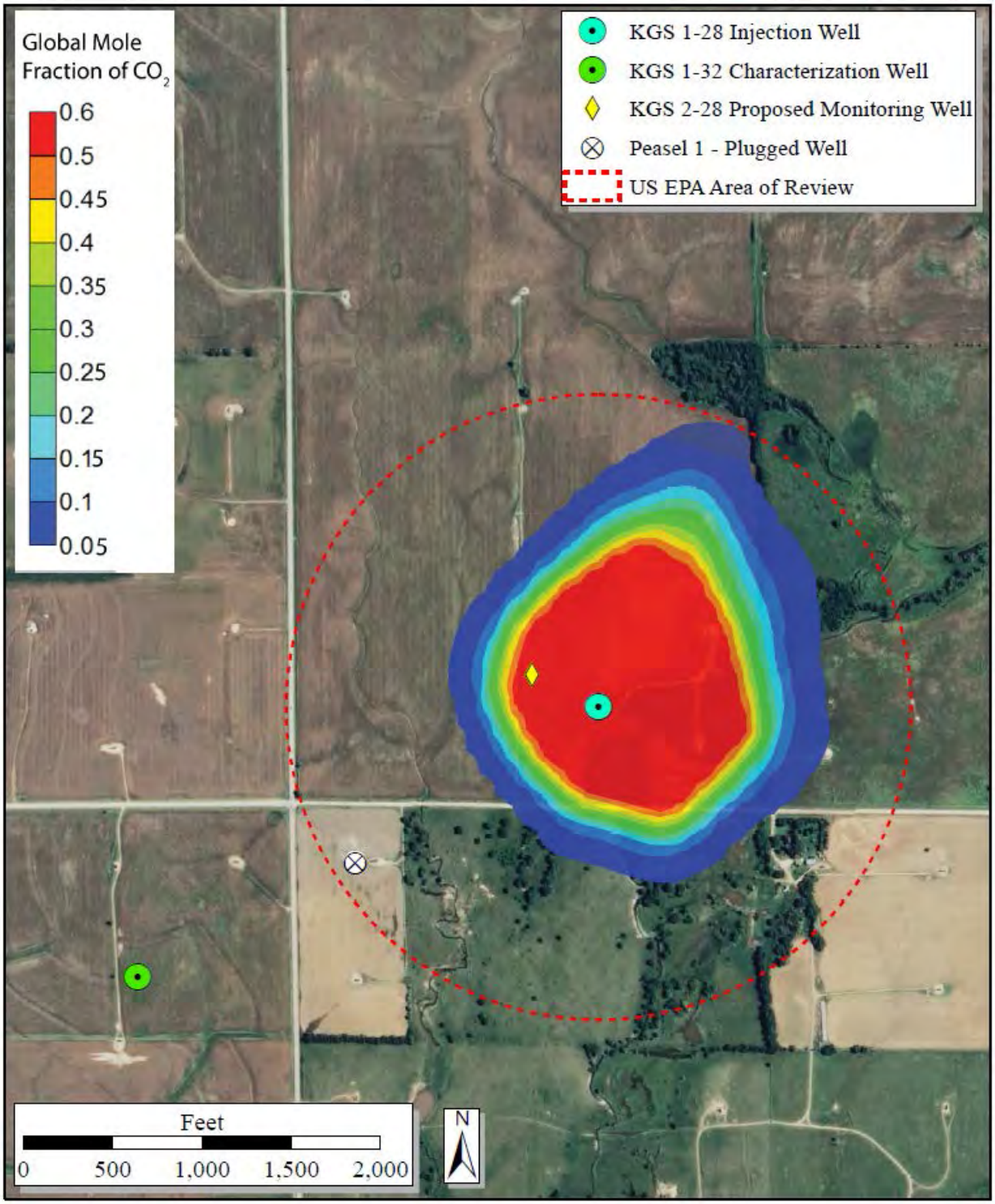


Figure 36. Footprint of a 40,000 metric ton CO2 plume limited to the lower Arbuckle saline aquifer.

The injection zone is limited to a 150 ft thick interval in the lower Arbuckle (Gasconade Dolomite), an interval that higher permeability and a confining layer above the injection zone (**Figure 37**).

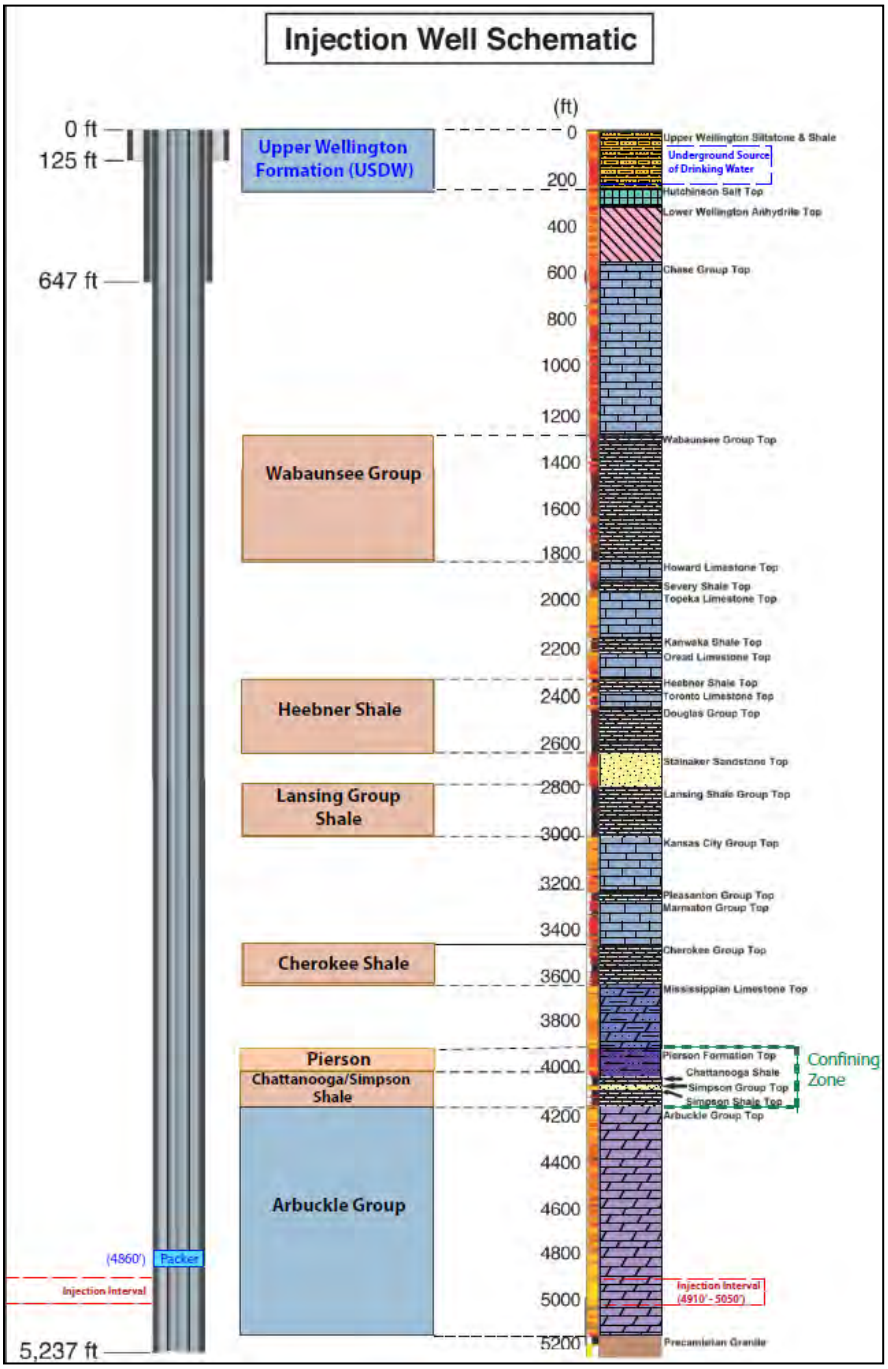


Figure 37. Well bore schematic for the injection well with the location of the injection zone shown in the lowermost Arbuckle saline aquifer.

2) **Microbiological studies on produced water (Subtask 4.12) and studies of in situ CO2 injection in Mississippian caprock and Arbuckle samples (both baffles and injection zone)** – contributions by Christa Jackson, David Fowle, Jennifer Roberts, Susan Carroll (LLNL), Megan Smith (LLNL)

In situ CO2 studies with rock (Mississippian caprock, the Pierson Formation and Arbuckle baffle material) and brine samples from Wellington were carried out at DOE-NETL labs in Pittsburgh (Jen Roberts, David Fowle, and Christa Jackson). Christa Jackson is studying the effect of CO2 on microbial populations in rock samples. Analysis continues with completion of Ms. Jackson's M.S. thesis this summer. This work is supported by a PRF grant to Jen Roberts.

Core plugs are being analyzed at the Lawrence Livermore National Lab by Susan Carroll, Megan Smith, and Harris Mason, all staff of LLNL. Brent Campbell at KSU will visit Susan's lab in spring 2014 to run additional samples from Wellington and Cutter fields.

Susan Carroll and her team are operating under a separate contract with DOE-NETL titled "*Enhanced porosity and permeability within carbonate CO2 storage reservoirs: An experimental and modeling study*" They are using 1.5 in diameter plugs from the Wellington KGS #1-32 (Carroll, et al., 2014). Current sampling has focused on the baffle interval, the initial sample from the mid Arbuckle with 0.016 md permeability. Preliminary findings include increased in permeability to 1.8 md, more than noted in any previous experiments as a consequence of reaction with the CO2-rich brine. Increased permeability is related to small increases in porosity or connectivity occurring at certain critical "pinch" locations. Experiments will continue with a sample displaying the highest permeability we have yet measured in a carbonate core (~600mD). Additional carbonate sample cores will be provided from Wellington and Cutter fields.

These initial tests of the baffle zone are most important for our Wellington Field modelling effort and reactive transport models and reaction kinetics will factor importantly into the refinement of our models.

The baffle zone is considered to be a fluid flow barrier in the current models based on extensive Kv-Kh modeling, 3D seismic integration with well data, and stable isotopic composition of brines that support isolation of hydrostatic units above and below the baffle. The CO2 flow experiments suggest that there is a potential for entry of CO2 into the baffle zone and contact with the finer pores. While this may comprise the baffle this reactive rock may also extend the storage, but also leading further reaction and capillary entrapment/imbibition of the CO2 into the fine pores.

3) Continued petrophysical analysis of the Arbuckle to improve estimates of permeability – contributions by Mina Fazelalavi and John Doveton

Calibration of logs for improved estimation of permeability has extended to use of Wellington KGS #1-32 as the standard and predicting permeability in Wellington KGS #1-28, the well that will serve as the injection well in the small scale CO2 test in (DE-FE0006821) (**Figure 38**). The

test to predict permeability is also being extended to the western calibration site in the Cutter KGS #1 where core analysis and the same suite of well logs are available.

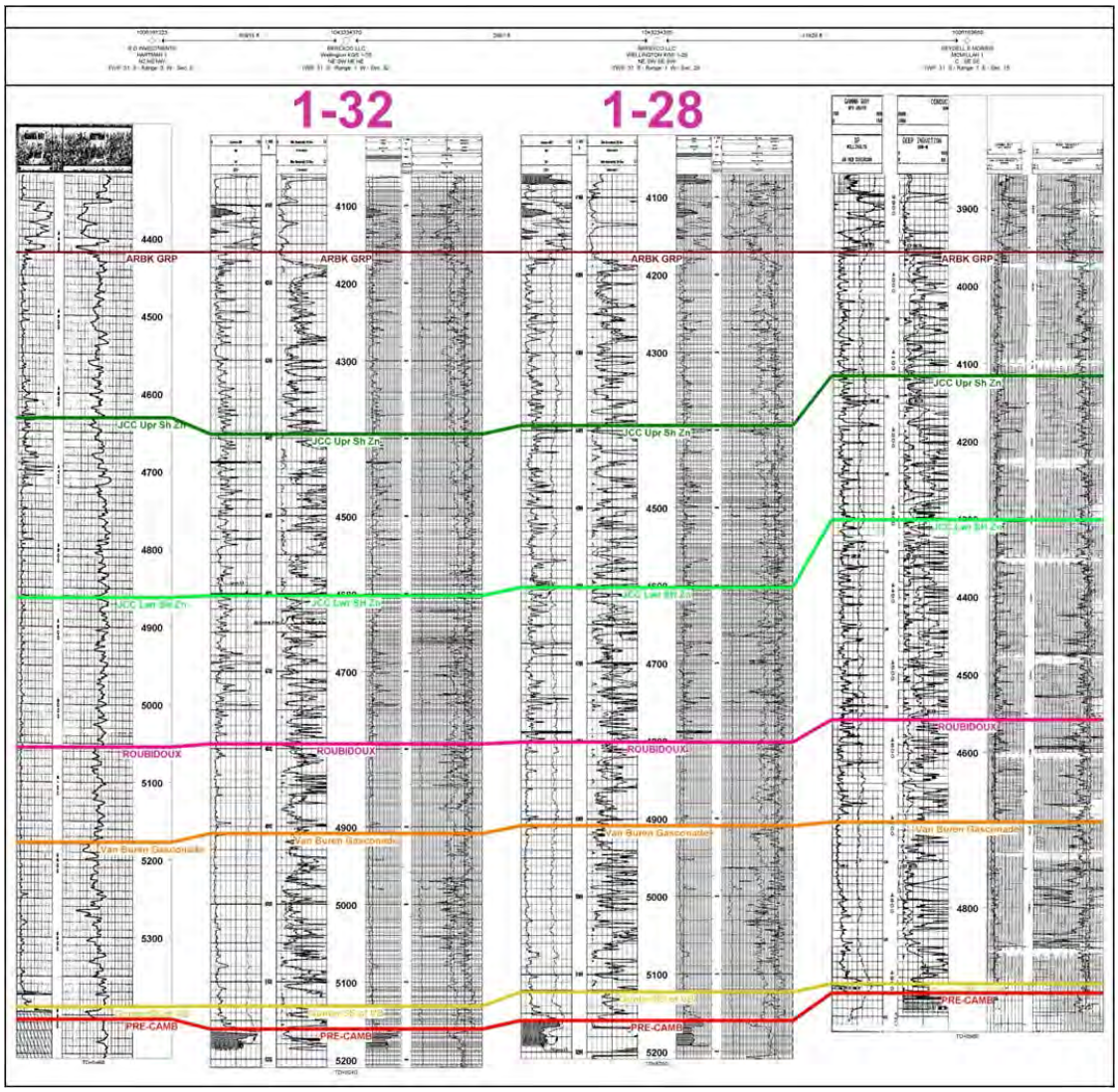


Figure 38. Well log cross section with the datum at the top of the Arbuckle showing the major correlations in Wellington KGS #1-32 and #1-28.

The permeability prediction is based on three classes, micro, mezzo, and macro pores that coincide with mud-supported, grain-supported and vuggy porosity (**Figure 39**). Permeability is closely tied to deposition and the presence or absence of grain supported fabrics. Later diagenesis also leads to vugs and formation of megapores that are the source of the largest permeability values, e.g, the injection zone in the lower Arbuckle in Wellington Field.

The correlation of the most vuggy intervals in wells #1-32 and #1-28 based on the petrophysical (log based) classification of pores is excellent (**Figure 40**). The reason is that the major vuggy

intervals are stratiform crackle breccias developed in meter scaled peritidal cycles that are believed to be related to evaporite dissolution.

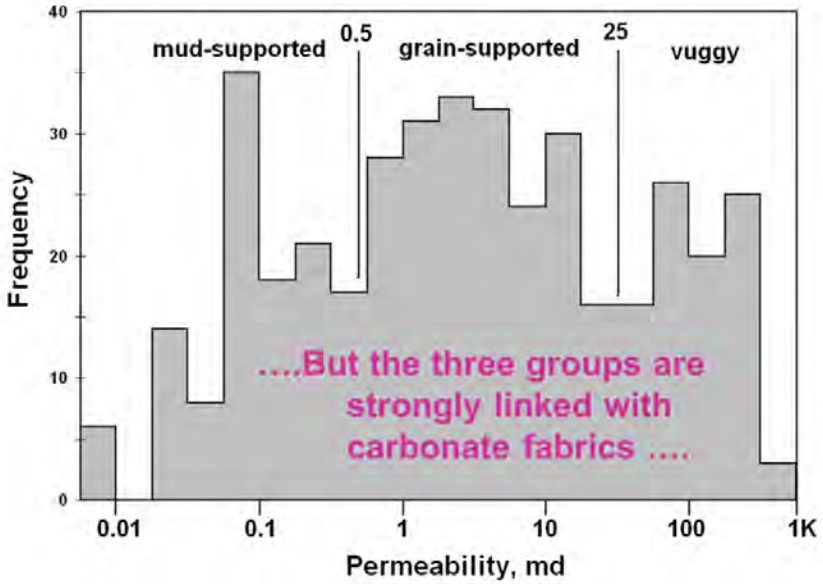


Figure 39. Classification of permeability from Wellington KGS #1-32.

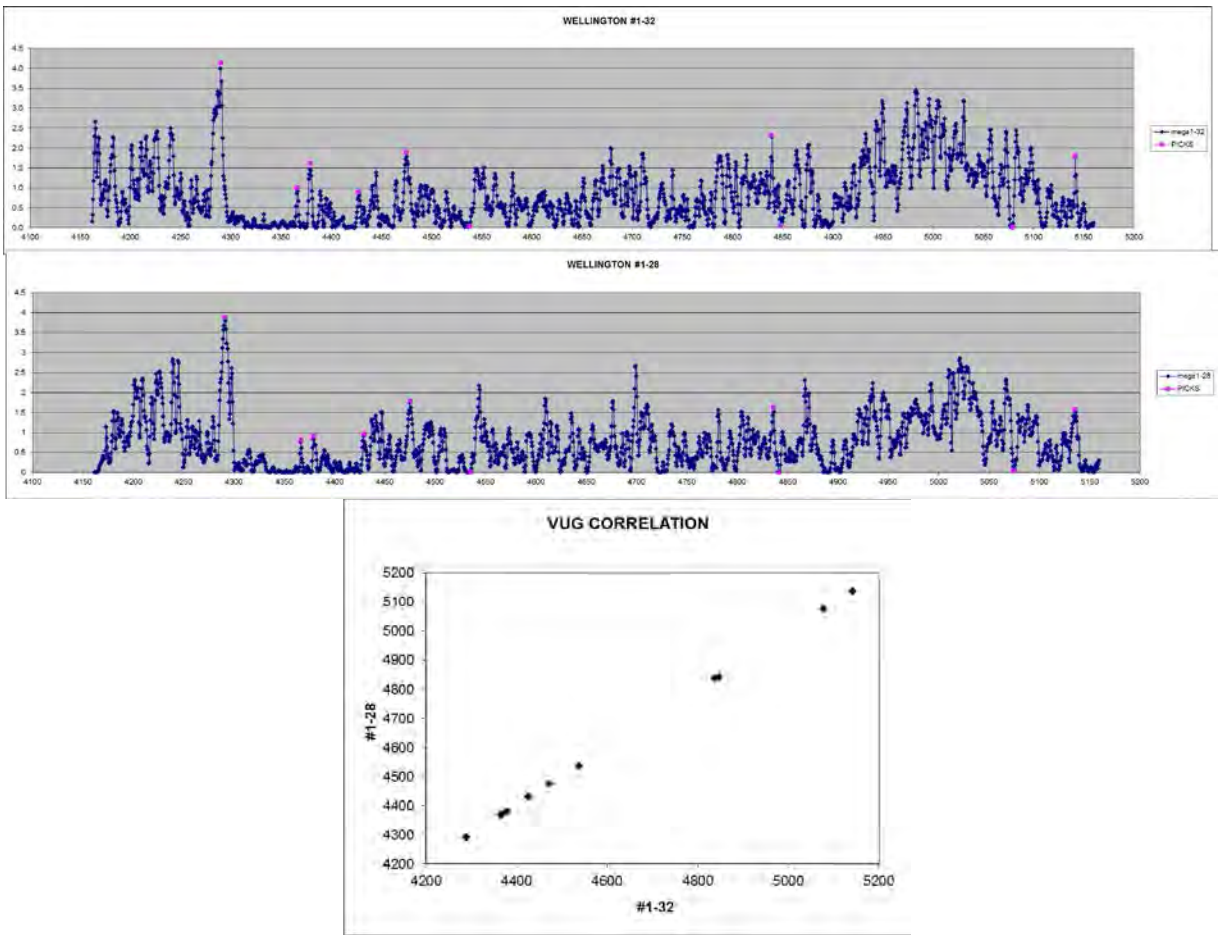
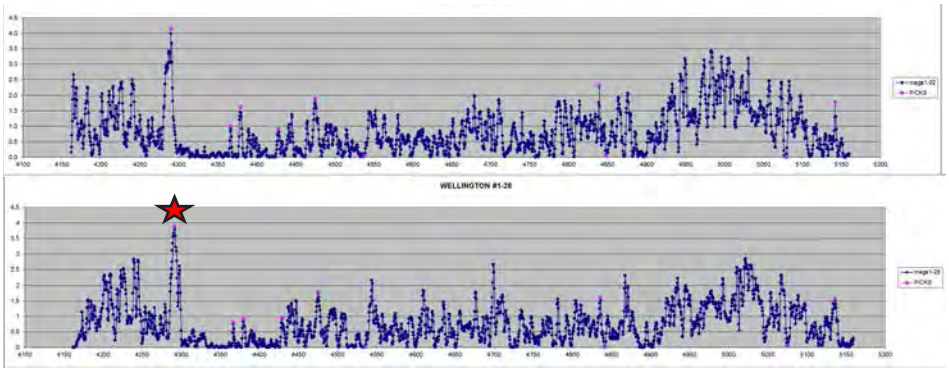
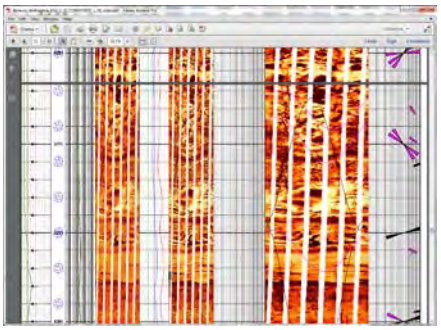


Figure 40. Correlation of vugs between Wellington KGS #1-32 and #1-28 is very high as noted in the plot or vugs and correlation of vugs by depth.

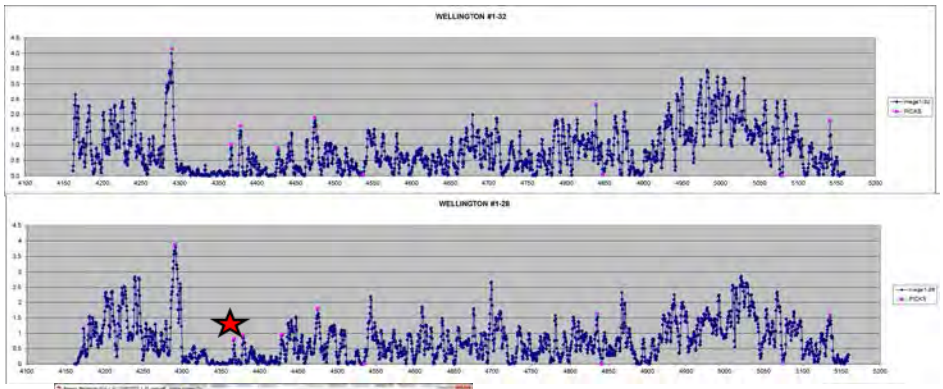
The major vuggy zones classified by modern triple combo log suites is confirmed through a series of figures that identify the vuggy zone and which are confirmed with the microresistivity imaging log **Figures 41-50**. Figures also compare non-vuggy zones for contrast, which are dominated instead by small pores in finer grained carbonate.

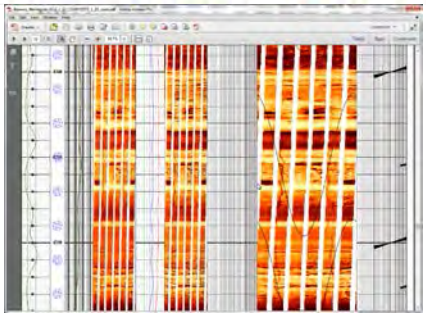




4291.5
NO RECOVERY BUT ADJOINING ROCK BETWEEN 4281 TO 4294 IS Dolo, lt brown, fxln, oolitic, vuggy and oomoldic poro, ns

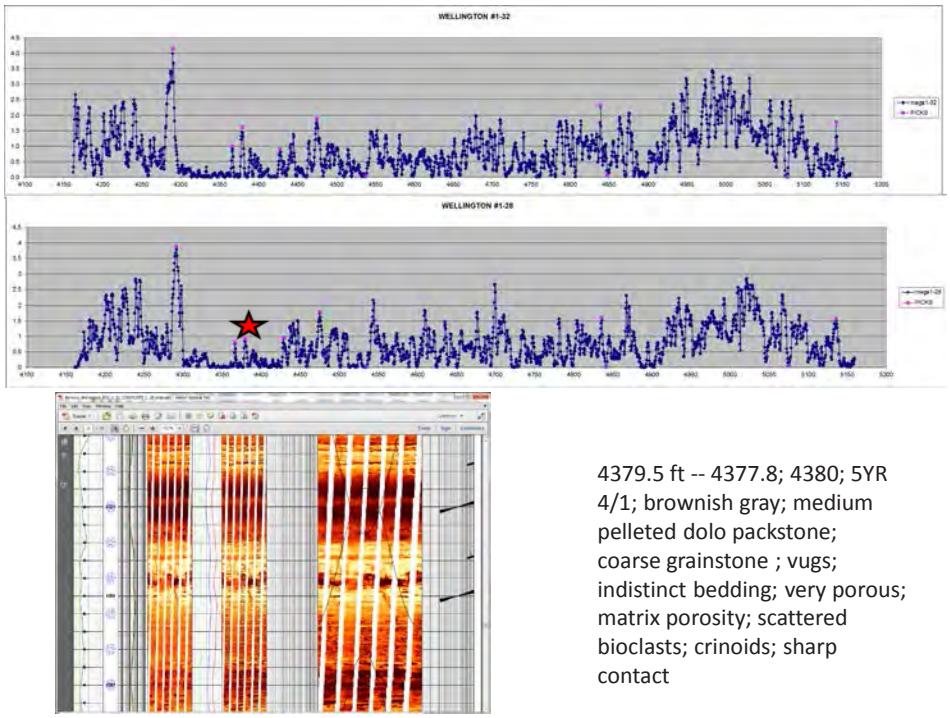
Figure 41. Very vuggy rock confirmed by MRI.





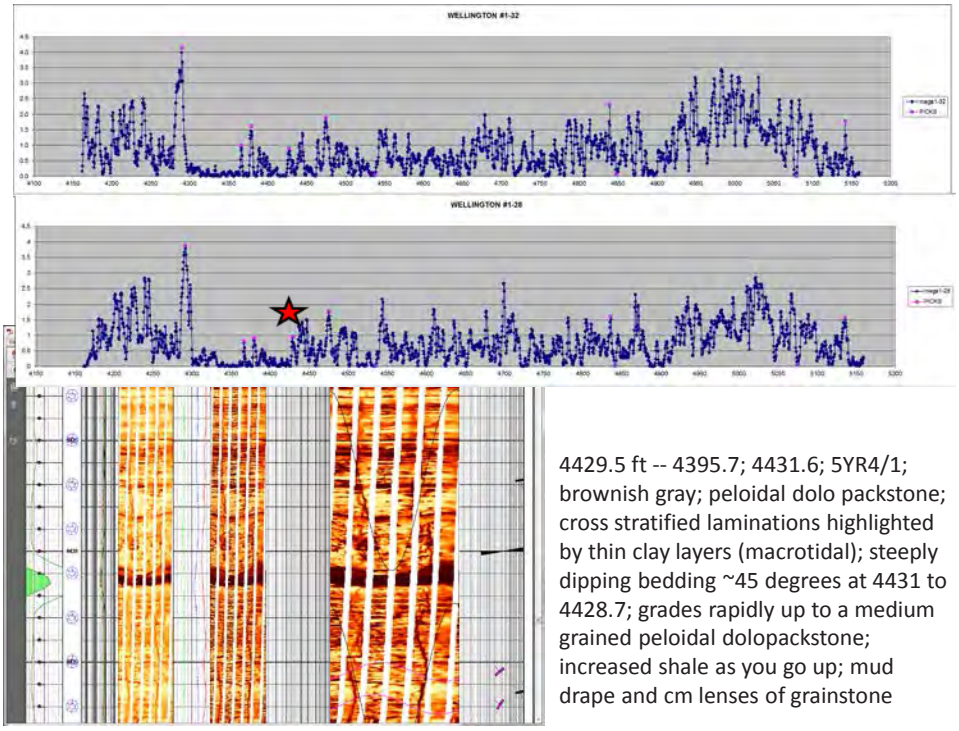
4366.5 FT -- 4365.5; 4367.2; 5Y6/1; light olive gray; dolo packstone; coarse; crinoid? coated grain; wavy bedded with mud chip conglomerate at base from reworking of bottom lithology; occasional darkened lithoclast within the grainstone; pinpoint interparticle porosity abundant; coated grains; small vug sub-cm to cm-scale; no fractures; good porosity; sharp boundary

Figure 42. Interval dominated by finer pores as confirmed by MRI.



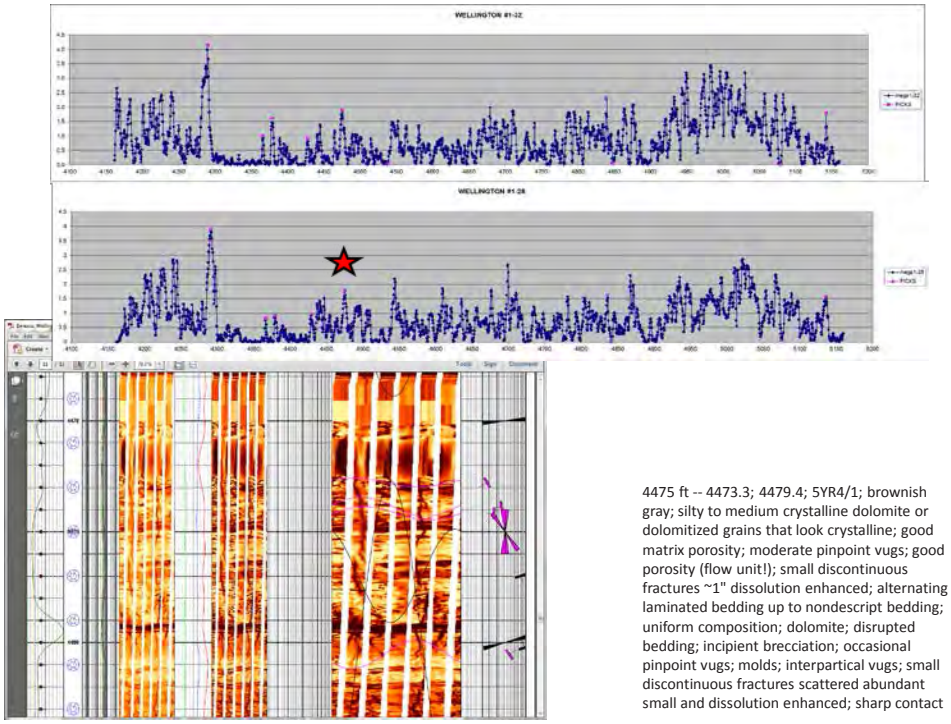
4379.5 ft -- 4377.8; 4380; 5YR 4/1; brownish gray; medium pelleted dolo packstone; coarse grainstone ; vugs; indistinct bedding; very porous; matrix porosity; scattered bioclasts; crinoids; sharp contact

Figure 43. Finer pore system with fewer vugs.



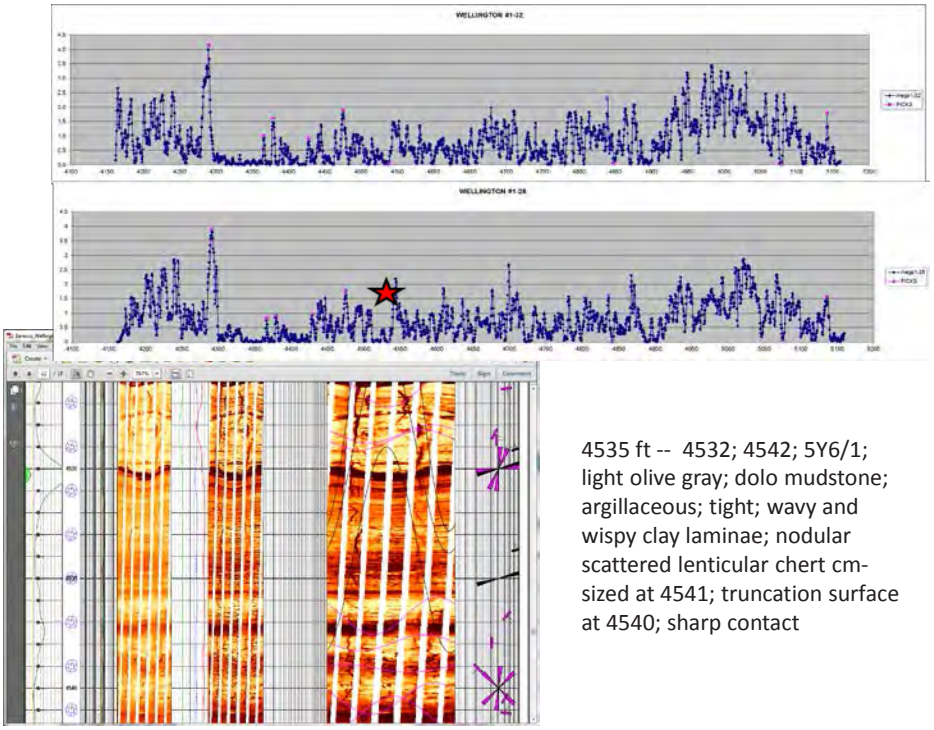
4429.5 ft -- 4395.7; 4431.6; 5YR4/1; brownish gray; peloidal dolo packstone; cross stratified laminations highlighted by thin clay layers (macrotidal); steeply dipping bedding ~45 degrees at 4431 to 4428.7; grades rapidly up to a medium grained peloidal dolopackstone; increased shale as you go up; mud drape and cm lenses of grainstone

Figure 44. Finer pores.



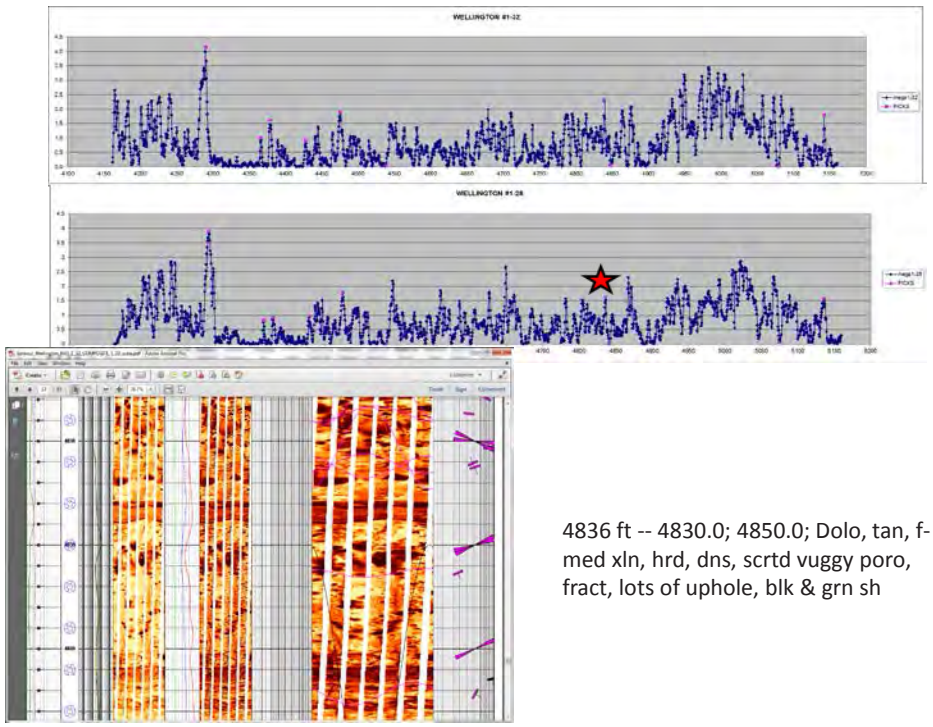
4475 ft -- 4473.3; 4479.4; 5YR4/1; brownish gray; silty to medium crystalline dolomite or dolomitized grains that look crystalline; good matrix porosity; moderate pinpoint vugs; good porosity (flow unit!); small discontinuous fractures ~1" dissolution enhanced; alternating laminated bedding up to nondescript bedding; uniform composition; dolomite; disrupted bedding; incipient brecciation; occasional pinpoint vugs; molds; interpartical vugs; small discontinuous fractures scattered abundant small and dissolution enhanced; sharp contact

Figure 45. Pinpoint vugs and dissolution enhanced fractures, i.e., moderate vugs.



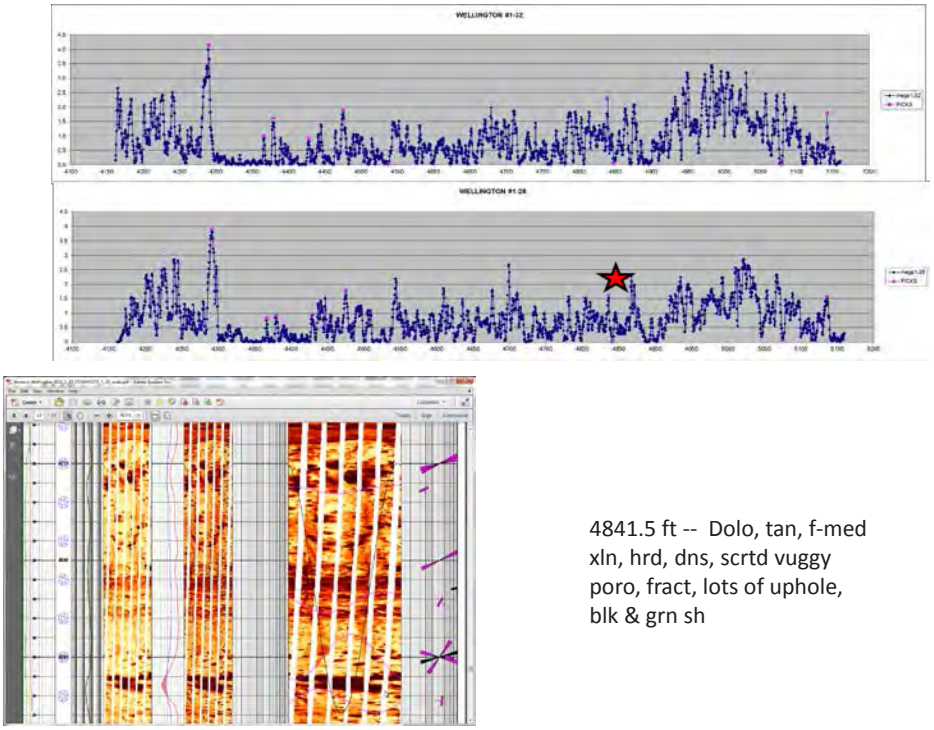
4535 ft -- 4532; 4542; 5Y6/1; light olive gray; dolo mudstone; argillaceous; tight; wavy and wispy clay laminae; nodular scattered lenticular chert cm-sized at 4541; truncation surface at 4540; sharp contact

Figure 46. No vugs in laminated sediment.



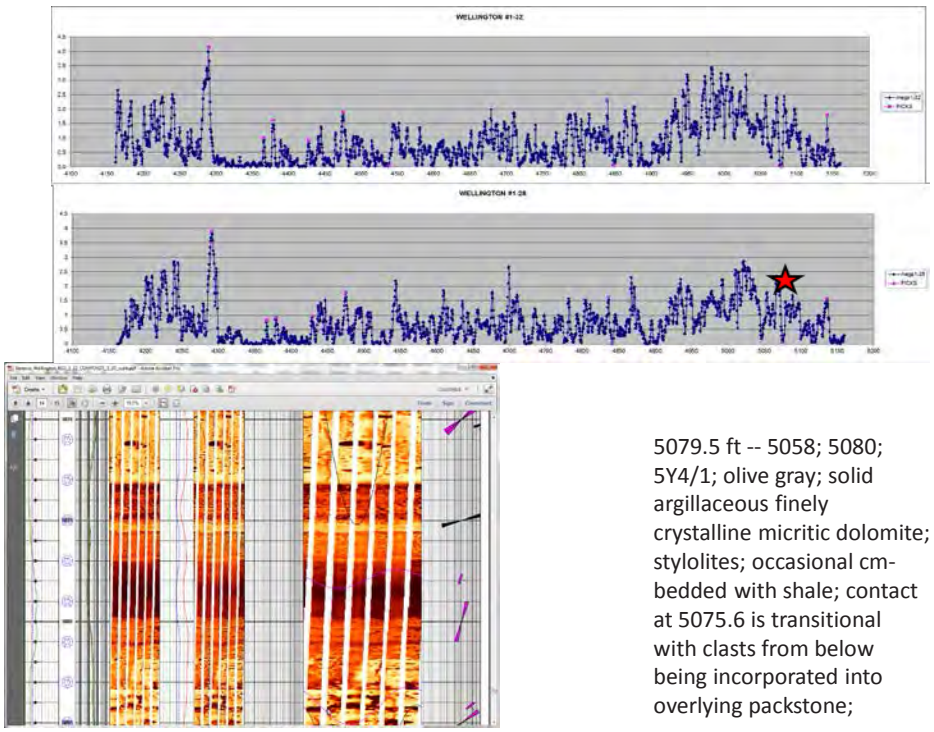
4836 ft -- 4830.0; 4850.0; Dolo, tan, f-med xln, hrd, dns, scrtd vuggy poro, fract, lots of uphole, blk & grn sh

Figure 47. Moderately vuggy.



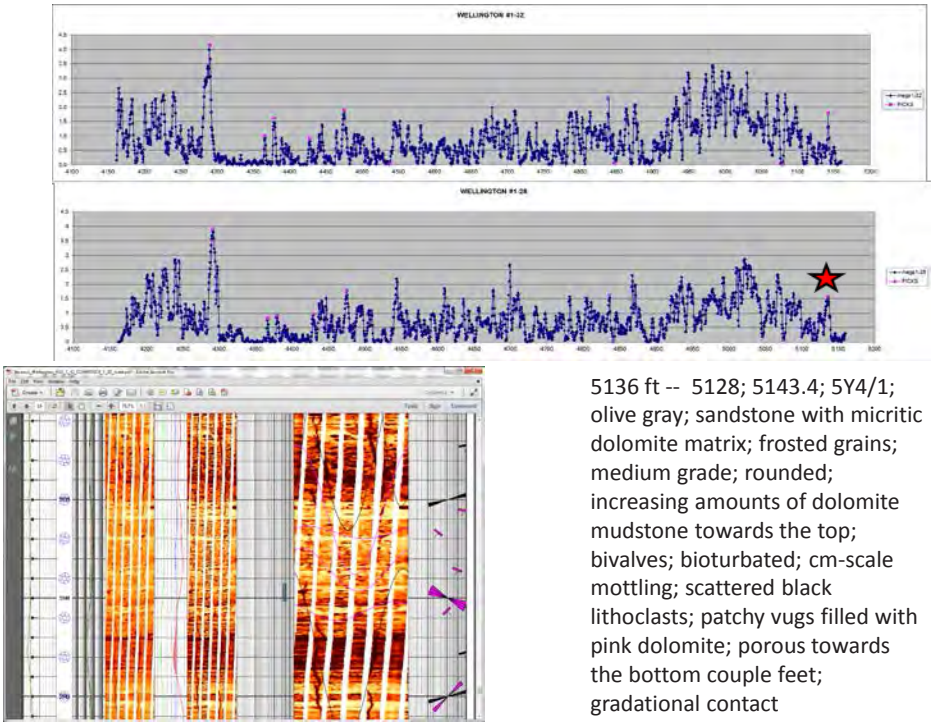
4841.5 ft -- Dolo, tan, f-med xln, hrd, dns, scrtd vuggy poro, fract, lots of uphole, blk & grn sh

Figure 48. Moderately vuggy pores with fractures.



5079.5 ft -- 5058; 5080; 5Y4/1; olive gray; solid argillaceous finely crystalline micritic dolomite; stylolites; occasional cm-bedded with shale; contact at 5075.6 is transitional with clasts from below being incorporated into overlying packstone;

Figure 49. Laminated non-vuggy strata bounded by moderately vuggy strata.



5136 ft -- 5128; 5143.4; 5Y4/1; olive gray; sandstone with micritic dolomite matrix; frosted grains; medium grade; rounded; increasing amounts of dolomite mudstone towards the top; bivalves; bioturbated; cm-scale mottling; scattered black lithoclasts; patchy vugs filled with pink dolomite; porous towards the bottom couple feet; gradational contact

Figure 50. Patchy vugs with lithoclasts.

Permeability Prediction using Fuzzy Logic – contributed by Mina Fazelalavi

Permeability was calculated by the Fuzzy logic method using bulk density, gamma ray, neutron porosity, resistivity, and NMR porosity (**Figure 51**). The Arbuckle was divided into size groups based on permeability range according to the table below:

Groups	Perm Range
Group 1	<0.1 -0.1
Group 2	0.1-1
Group 3	1-10
Group 4	10-100
Group 5	100-1000
Group 6	>1000

The standard deviation was calculated for each group and the mean and expected occurrence of each group :

GR	Average	St Dev
Group 1	95.76488	84.17437
Group 2	33.30036	27.12846
Group 3	29.14041	17.02753
Group 4	24.03175	9.575052
Group 5	22.60705	22.60705
Group 6	20.46637	20.46637

NPHI	Average	St Dev
Group 1	6.160036	2.967395
Group 2	6.522731	2.371281
Group 3	6.183291	2.417364
Group 4	6.19243	2.396884
Group 5	7.046955	7.046955
Group 6	7.802385	7.802385

RHOB	Average	St Dev
Group 1	2.714446	0.061818
Group 2	2.714708	0.081058
Group 3	2.71952	0.072948
Group 4	2.714091	0.062588
Group 5	2.700964	2.700964

Group 6	2.686561	2.686561

RT	Average	St Dev
Group 1	97.49969	230.2377
Group 2	26.81996	74.42095
Group 3	25.25195	50.49696
Group 4	22.19687	12.5079
Group 5	19.66179	19.66179
Group 6	21.76631	21.76631

The cf (combined Fuzzy possibility) was calculated for each group (group 1 through 6) for each depth and the maximum number for each group for each depth was determined.

There are few problems with the results: 1) Standard Deviation and mean from Neutron and Density log of all groups are close to each other therefore, Fuzzy logic may not predict the right group and 2) group 2 and 3 has the most expected occurrence therefore, possibility of group 2 and 3 increases.

Relation between Porosity and permeability (calculated Perm) was derived and graphed (**Figure 52**). Permeability doesn't change much with porosity within each group; therefore, the relations are not good. Predicted permeability from Fuzzy logic is compared to permeability that was calculated previously.

	Log Data							Predicted Perm using Fuzzy logic	Depth	Calculated Perm using FZI-Swphi
2	Depth	Calculated Perm	RHOB	GR	NPHI	RT	Por_NMR	0.06	4160	0.07
1642	4979.50	0.26	2.751	10.6269	5.5061	32.9736	0.08022	0.38	4980	0.26
1643	4980.00	0.26	2.7346	11.2318	4.633	30.555	0.0774	0.38	4980.5	0.33
1644	4980.50	0.33	2.6545	10.9802	4.5763	28.1949	0.07445	0.37	4981	0.77
1645	4981.00	0.77	2.5787	9.4599	5.163	20.6462	0.07338	0.38	4981.5	1.55
1646	4981.50	1.55	2.5807	8.4928	6.2768	12.9576	0.07464	0.38	4982	1.65
1647	4982.00	1.65	2.6412	9.1137	6.0905	9.5384	0.0773	0.38	4982.5	1.48
1648	4982.50	1.48	2.6575	10.7991	5.8882	7.2657	0.08118	0.38	4983	1.39
1649	4983.00	1.39	2.6129	11.5628	5.9121	6.0466	0.08288	0.38	4983.5	1.74
1650	4983.50	1.74	2.5964	10.7366	5.8522	6.1881	0.08427	0.38	4984	3.60
1651	4984.00	3.60	2.605	9.7989	5.9293	7.2456	0.08506	0.39	4984.5	54.48
1652	4984.50	54.48	2.5641	9.5473	6.6701	7.7275	0.08739	222.56	4985	174.74
1653	4985.00	174.74	2.5036	9.9551	8.1809	7.3442	0.09231	239.85	4985.5	739.85
1654	4985.50	739.85	2.5385	10.9267	8.523	7.1335	0.09232	0.39	4986	1287.58
1655	4986.00	1287.58	2.6613	11.1994	6.7623	7.9949	0.09162	0.38	4986.5	1151.45
1656	4986.50	1151.45	2.7439	10.9755	5.2616	9.9711	0.08596	0.38	4987	562.32
1657	4987.00	562.32	2.7628	11.3693	4.7985	12.1817	0.07928	0.37	4987.5	82.83
1658	4987.50	82.83	2.7494	11.7671	4.27	12.7163	0.06708	0.36	4988	41.73
1659	4988.00	41.73	2.6886	11.5093	3.8582	11.4686	0.06003	0.36	4988.5	25.49
1660	4988.50	25.49	2.6078	10.8044	3.8066	10.1246	0.05345	0.36	4989	38.98
1661	4989.00	38.98	2.5534	11.2229	4.3377	9.2695	0.05487	253.40	4989.5	336.02
1662	4989.50	336.02	2.5345	12.7021	4.8694	8.756	0.05783	0.36	4990	3975.49
1663	4990.00	3975.49	2.5604	13.7495	4.9385	9.054	0.06063	0.37	4990.5	18467.47
1664	4990.50	18467.47	2.6349	13.1304	4.8229	10.3497	0.06759	0.37	4991	23757.98
1665	4991.00	23757.98	2.6944	12.0633	4.9142	11.9155	0.06954	0.37	4991.5	12135.84
1666	4991.50	12135.84	2.6842	11.8652	5.5494	12.9807	0.06758	0.37	4992	1384.20
1667	4992.00	1384.20	2.6592	12.38	6.0485	14.5778	0.0649	0.36	4992.5	111.03
1668	4992.50	111.03	2.6608	12.7066	6.7636	16.8207	0.06173	0.36	4993	90.95
1669	4993.00	90.95	2.6664	12.0133	7.2228	17.0602	0.06084	0.36	4993.5	167.90
1670	4993.50	167.90	2.6887	10.7072	7.8062	15.8306	0.06144	0.37	4994	167.84
1671	4994.00	167.84	2.7213	10.9115	8.4076	15.9475	0.06322	0.37	4994.5	17.19
1672	4994.50	17.19	2.7022	11.7778	9.453	17.1363	0.06906	0.38	4995	1.58
1673	4995.00	1.58	2.6372	12.5049	10.0587	14.6037	0.08047	0.39	4995.5	0.81
1674	4995.50	0.81	2.6063	11.9821	10.5062	12.6479	0.0938	0.38	4996	0.50
1675	4996.00	0.50	2.628	10.6287	9.7665	14.0464	0.08552	0.39	4996.5	0.46
1676	4996.50	0.46	2.6455	10.7357	9.9245	18.6296	0.08907	244.92	4997	0.64
1677	4997.00	0.64	2.5889	11.5646	12.5826	22.1412	0.10606	239.58	4997.5	1.60
1678	4997.50	1.60	2.4863	12.7646	14.9365	22.3087	0.14323	234.43	4998	2.02
1679	4998.00	2.02	2.4805	13.299	16.7175	15.0487	0.15374	237.06	4998.5	0.78

Calculations | Std and mean of each 6 groups

Figure 51. Input parameters for estimating permeability. Computed permeability is also compared to actual permeability.

The computed permeabilities did not compare favorably with the actual permeability **(Figure 52)**

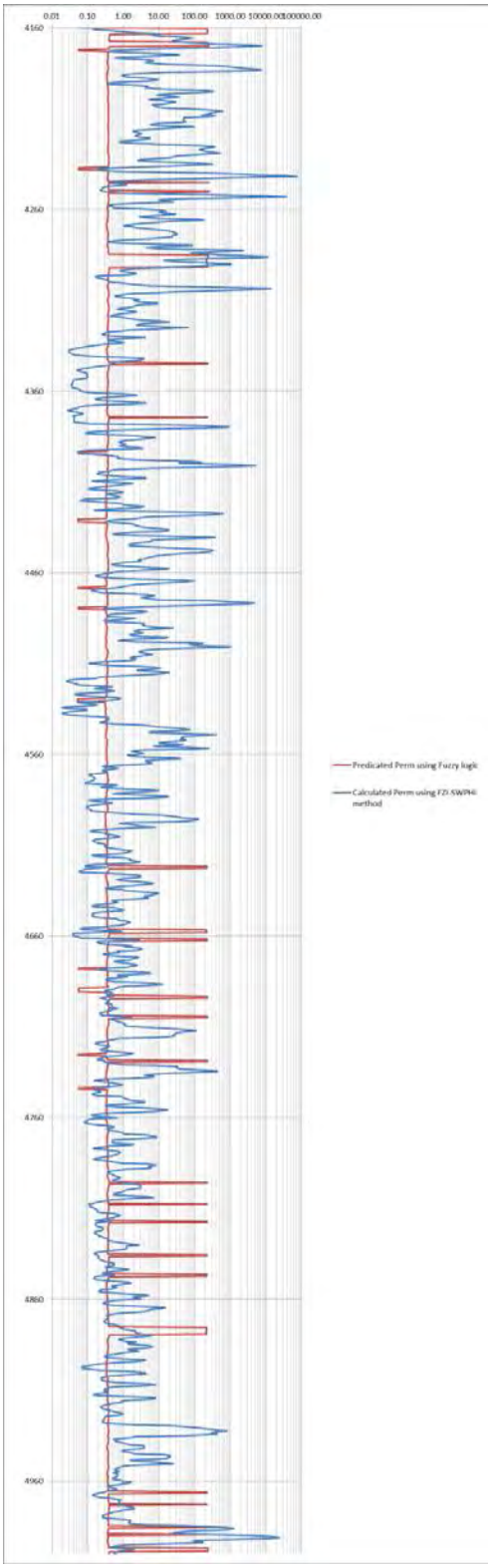


Figure 52. Computed permeability (red) vs. actual permeability (blue).

Permeability prediction equations were developed for each group and plotted, basically, delimiting permeability ranges by roughly horizontal lines on a phi-k plot (**Figure 53**).

Zone 1

GR	Average	St Dev
Group 1	101.895	83.55994
Group 2	45.71726	48.2402
Group 3	33.38468	28.51834
Group 4	30.11903	23.92971
Group 5	29.01567	23.27889
Group 6	27.22201	11.99986

Number of occurance	
Group 1	176
Group 2	931
Group 3	580
Group 4	223
Group 5	102
Group 6	41

NPHI	Average	St Dev
Group 1	6.064756	2.972793
Group 2	6.389757	2.498833
Group 3	6.57545	2.30765
Group 4	6.505085	2.300614
Group 5	6.946657	2.478907
Group 6	6.271548	2.683021

Group 1	$y = 0.0669x^{0.066}$
Group 2	$y = 0.5673x^{0.1587}$
Group 3	$y = 2.4294x^{-0.041}$
Group 4	$y = 30.535x^{0.0298}$
Group 5	$y = 453.91x^{0.2086}$
Group 6	$y = 7133.1x^{0.2368}$

RHOB	Average	St Dev
Group 1	2.71585	0.051983
Group 2	2.713963	0.079275
Group 3	2.717269	0.075916
Group 4	2.713674	0.081037
Group 5	2.707493	0.070457
Group 6	2.703121	0.154442

RT	Average	St Dev
Group 1	115.1965	259.4625
Group 2	42.08003	137.3583
Group 3	21.54381	11.88055
Group 4	22.39796	13.97829
Group 5	23.44688	15.14134
Group 6	22.83545	15.3912

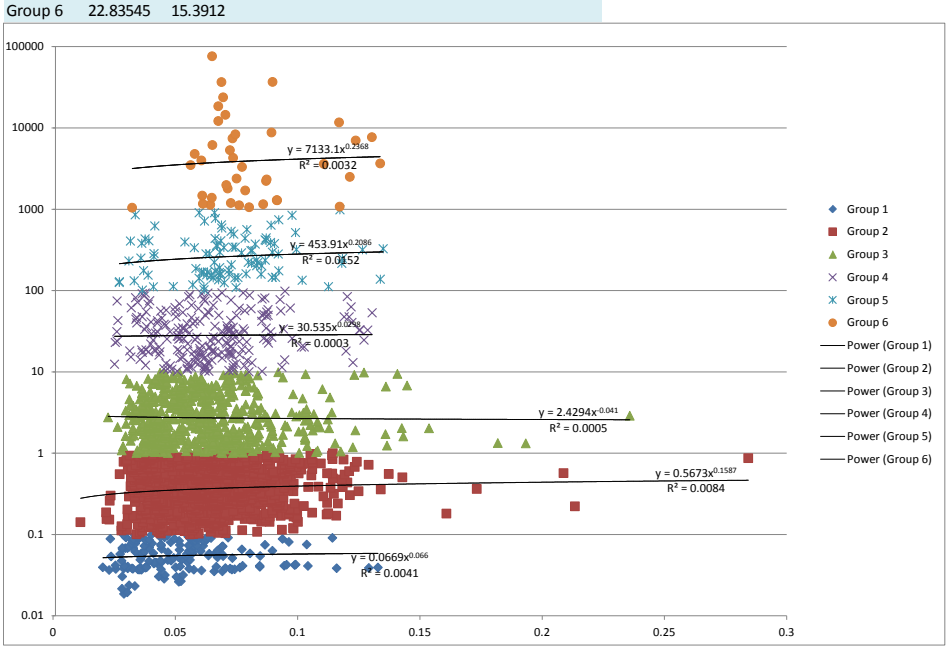


Figure 53. Plot of equations for six groups of permeability on a phi-k plot.

Drainage Capillary Pressure Curves in Arbuckle – contributed by Mina Fazealavi

The PC curves were derived based on a theoretical method (M.F.Alavi) that relates endpoints of capillary pressure curves to Reservoir Quality Index (RQI). Based on investigation, there are good correlations between endpoints of capillary pressure curves (entry pressure and Irreducible water saturation) and RQI.

Key well (well 1-32) was used to calculate Pc curves for Arbuckle. Generated PC curves from NMR log of well 1-32 were used to find correlations between endpoints and RQI for determination of PC curves. PC curves from NMR were in Mercury-air system which they were converted to CO2-brine system (**Figure 54**).

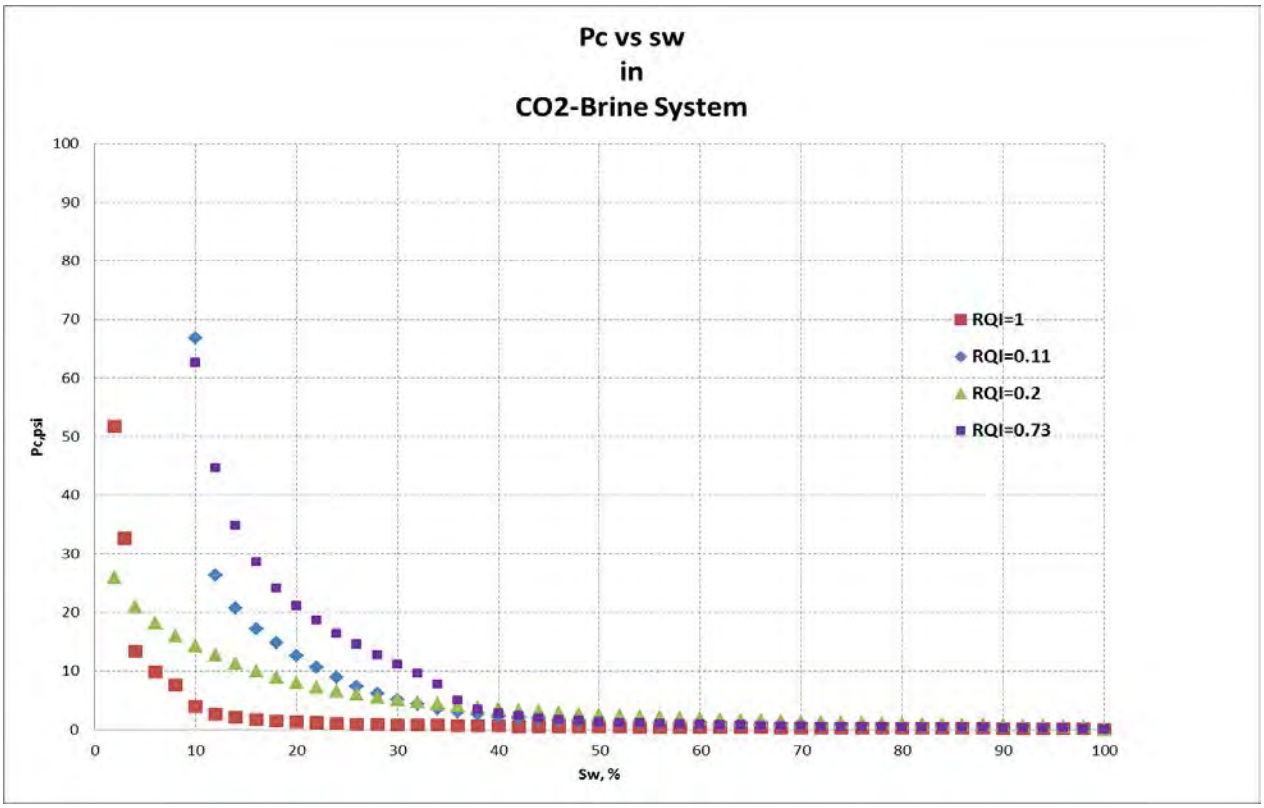


Figure 54: PC curves generated from NMR

a. Entry Pressure

Based on SCAL data of other fields, a good correlation can be found between capillary entry pressure and RQI. Pore throat at Entry pressure in well 1-32 was determined from Winland R35 and entry pressure was calculated from pore throat radius. Winland R35 was calculated using Eq. 1:

$$\log R35 = 0.732 + 0.588 \log K - 0.864 \log \varphi \qquad \text{Eq. 1}$$

Previously, permeability of Arbuckle in Well 1-32 was determined. Based on porosity and calculated permeability of Well 1-32, RQI in this well was obtained. R35 was plotted against RQI in **Figure 55** to find an equation in terms of RQI:

$$R35=12.885RQI^{-1.178} \quad \text{Eq. 2}$$

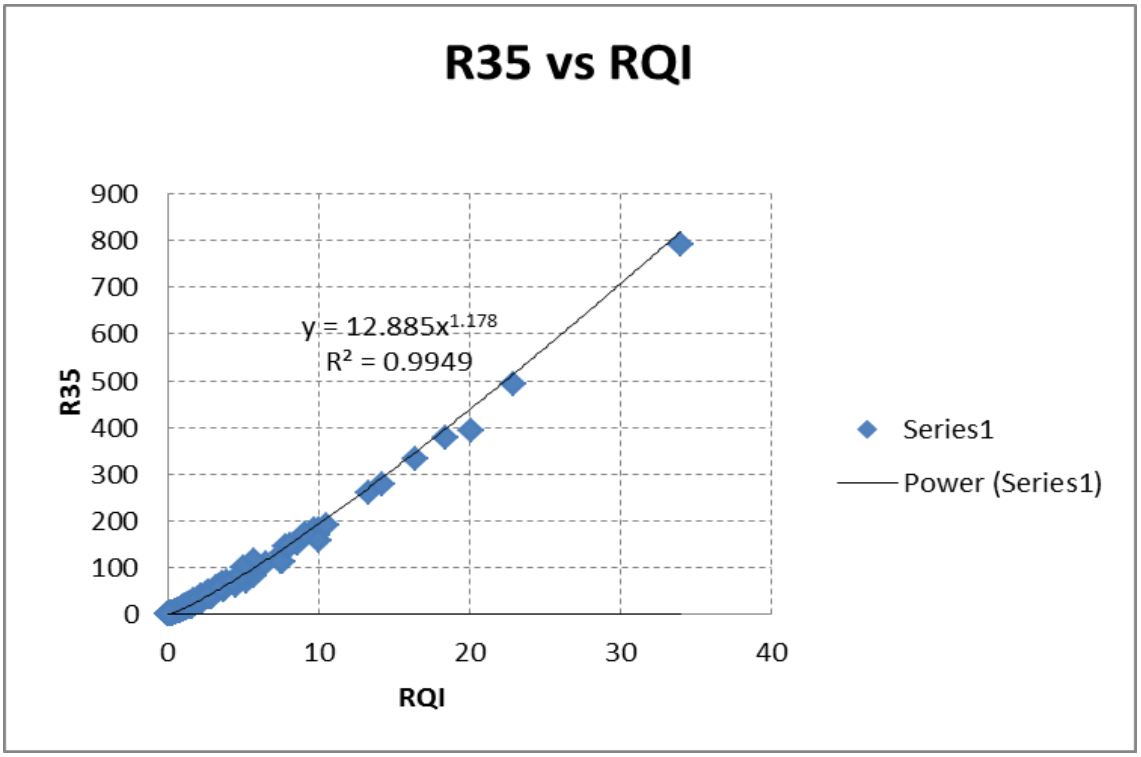


Figure 55: R35 versus RQI

Equation 2 was multiplied by a factor (1.35) to calculate pore throat radius (Eq. 3). The factor, 1.35, was determined based on studies of other carbonate reservoirs.

$$R_{entry}=1.35 * (a * RQI^b) \quad \text{Eq. 3}$$

Entry pressure was calculated using Eq. 3 and interfacial tension between CO2 and Brine, Eq. 4:

$$P_e=\frac{2*\sigma cos\theta*0.147}{1.35*(a*RQI^b)} \quad \text{Eq. 4}$$

A Function between Entry pressure and RQI was found by calculating Eq. 4 for P_{entry} in terms of RQI. Interfacial tension of 30 dyne/cm was calculated by an equation from an article "***Interfacial Tension Data and Correlations of Brine/CO_2 Systems under Reservoir Conditions, (Chalbaud et al. 2006)***". Contact angle of zero was used for CO2-Brine system. After simplifying, equation 4 becomes:

$$P_e=0.507*RQI^{-1.178} \quad \text{Eq.5}$$

b. Irreducible Water Saturation

Irreducible water saturation is needed to calculate normalized Non-Wetting phase saturation (SnWn). Based on Irreducible water saturation of SCAL data, mainly carbonate reservoirs,

irreducible water saturation at certain capillary pressure can be correlated, very well, to RQI of the rock. There is a good correlation between irreducible water saturation of reservoir rocks and RQI. NMR data of Well 1-32 was used to determine irreducible water saturation at a Pc of 20 Bars (290 psi). Also interfacial tension between CO2 and water was given to Tech-Log Module to find Swirr versus depth for this well. Irreducible water saturation in Well 1-32 in Arbuckle is plotted against RQI in **Figure 56**.

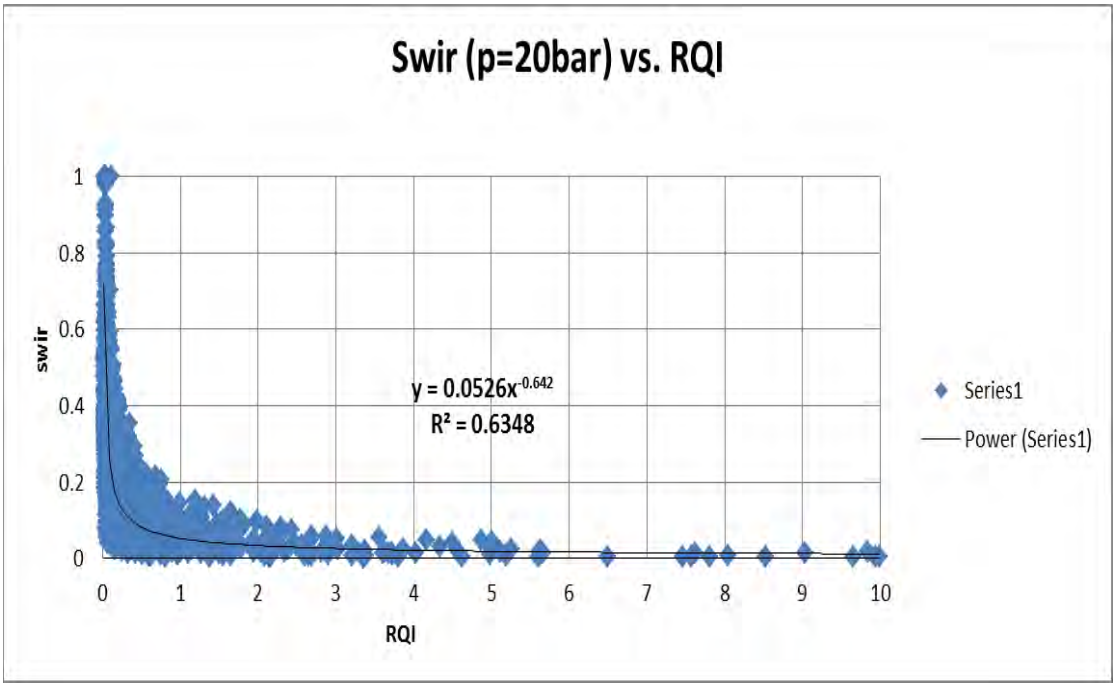


Figure 56: Irreducible water saturation vs. RQI

The relation in Eq. 6 was obtained between Swir and RQI:

$$Swir=0.0526*RQI^{-0.642} \quad \text{Eq. 6}$$

c. Shape of Normalized Pc curve

Pc curves which were obtained from NMR (**Figure 54**) were normalized by plotting SnWn (Normalized Non-Wetting Phase Saturation, Eq. 9) versus EQR (Equivalent Radius, Eq. 7). The Shape of Normalized PC curves appear in **Figure 57**. To find EQR at any Pc, entry pressure of the PC curve was used. A function in the form of Eq. 7 was fit though the normalized data points in Fig 4 and constants a and b of this equation were found.

$$S_{nwn} = (1 - aEQR)(1 - EQR^b) \quad \text{Eq. 7}$$

$$a = 1.07$$

$$b = 34.82$$

Equivalent Radius is a function of entry pressure and capillary pressure (Equation 8); where, entry pressure is a function of RQI, which is given by Eq. 5.

$$EQR = \frac{P_e}{P_c} \quad \text{Eq.8}$$

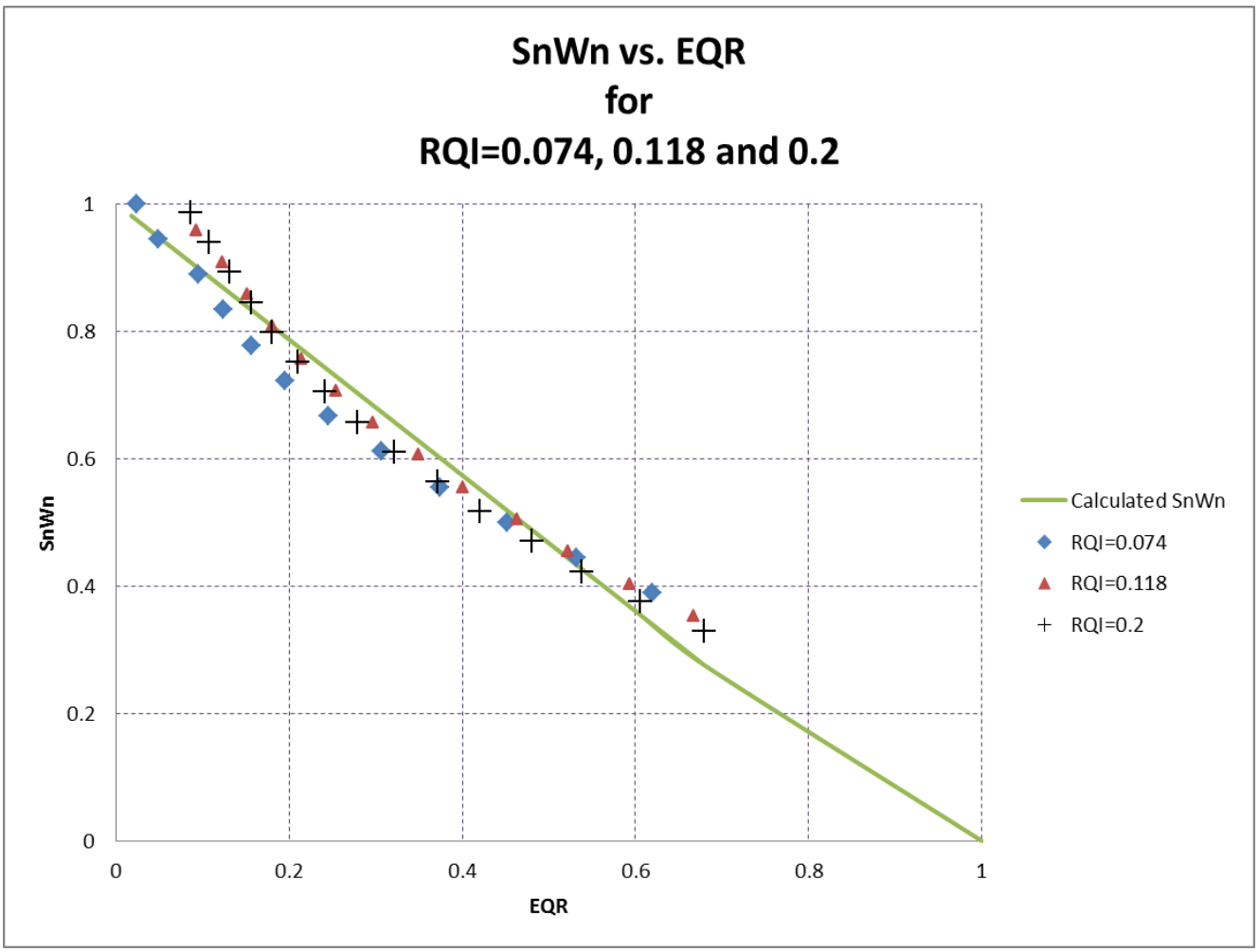


Figure 57: Snwn vs. EQI for RQI 1, 5.19 and 20

Snwn which is normalized non wetting phase saturation is defined by Eq. 9. Irreducible water saturation was calculated using equation 6 and initial water saturation is known at every Pc.

$$S_{nwn} = \frac{1-S_{wi}}{1-S_{wir}} \quad \text{Eq. 9}$$

Values of constants a and b of Equation 7 which were derived by regression before were replaced in Eq.7 to get Eq. 10. This equation will be used to calculate drainage capillary pressure curves.

$$S_{nwn} = (1 - 1.07\frac{P_e}{P_c})(1 - \frac{P_e}{P_c}^{34.82}) \quad \text{Eq. 10}$$

d. Calculation of Drainage Capillary Pressure Curves

Equation 11 is obtained from Eq.9 which will be used for calculating drainage water saturation:

$$S_{wi} = 1 - S_{nwn}(1 - S_{wir}) \quad \text{Eq. 11}$$

According to equation 11, initial water saturation (swi) is a function of snwn . It was shown that Snwn is a function of Pe and Pc (Eq. 10) where Pe is a function of RQI. Snwn in Equation 11 can be replaced by respective functions and an equation can be obtained which express swi in terms of RQI and PC:

$$S_{wi} = 1 - \left(1 - a\frac{0.507RQI^{-1.178}}{P_c}\right)\left(1 - \left(\frac{0.507RQI^{-1.178}}{P_c}\right)^{b}\right)(1 - 0.0526RQI^{-0.642})$$

Eq.12

Constants (a and b) were previously found (Eq. 7), they were incorporated into Eq. 12 which gives water saturation for every Pc and RQI. Nine Pc curves were calculated for 9 rock-types. RQI in Arbuckle changes from 0.017 to 34. This range was divided into 9 subdivisions, **table 1**:

Table 1: Subdivisions of RQI range

RT	RQI from	RQI To	Ave RQI
1	40	10	25
2	10	2.5	6.25
3	2.5	1	1.75
4	1	0.5	0.75
5	0.5	0.4	0.45
6	0.4	0.3	0.35
7	0.3	0.2	0.25
8	0.2	0.1	0.15
9	0.1	0.01	0.055

Mid-range of each subdivision was used to calculate 9 Pc curves using Eq.12, **Table 2.** The generated Pc curves are shown in **Figure 58**. These curves are in agreement with NMR Pc curves, when the right permeability and RQI are considered and compared (**Figure 59**).

Nomenclature

a= constant
b= constant
EQR = Equivalent Radius
NMR= Nuclear magnetic resonance
P_e = Entry Pressure
PC=capillary pressure
RQI= Reservoir Quality Index (μm)
R35= Winland R35
R_{entry}= pore throat radius at entry pressure
Snwn = Normalized non-wetting phase saturation
Swi =Initial water saturation
S_{wir}= Irreducible water saturation (fractional pore volume)

Table 2: Nine Pc curves for nine RQI

a	b	Drainage PcTable in Arbuckle							
1.07	34.82								
RQI	25	6.25	1.75	0.75	0.45	0.35	0.25	0.15	0.055
Pe	0.011435	0.058541	0.262246	0.711518	1.298744	1.746207	2.595581	4.737753	15.44758918
swir	0.006661	0.016219	0.036724	0.06327	0.087826	0.103203	0.128088	0.177801	0.338589041
Pc	swi								
0	1	1	1	1	1	1	1	1	1
0.1	0.128	0.632	1	1	1	1	1	1	1
0.2	0.067	0.324	1	1	1	1	1	1	1
0.3	0.047	0.222	0.938	1	1	1	1	1	1
0.4	0.037	0.170	0.712	1	1	1	1	1	1
0.5	0.031	0.139	0.577	1	1	1	1	1	1
0.6	0.027	0.119	0.487	1	1	1	1	1	1
0.7	0.024	0.104	0.423	1	1	1	1	1	1
0.8	0.022	0.093	0.375	0.955	1	1	1	1	1
0.9	0.020	0.085	0.337	0.856	1	1	1	1	1
1	0.019	0.078	0.307	0.776	1	1	1	1	1
2	0.013	0.047	0.172	0.420	0.722	0.942	1	1	1
3	0.011	0.037	0.127	0.301	0.510	0.662	0.936	1	1
4	0.010	0.032	0.104	0.242	0.405	0.522	0.733	1	1
5	0.009	0.029	0.091	0.206	0.341	0.438	0.612	1.010	1
6	0.009	0.026	0.082	0.182	0.299	0.382	0.532	0.873	1
7	0.008	0.025	0.075	0.165	0.269	0.343	0.474	0.773	1
8	0.008	0.024	0.071	0.152	0.246	0.313	0.431	0.699	1
9	0.008	0.023	0.067	0.143	0.229	0.289	0.397	0.641	1
10	0.008	0.022	0.064	0.135	0.215	0.271	0.370	0.595	1
12	0.008	0.021	0.059	0.123	0.193	0.243	0.330	0.525	1
14	0.008	0.021	0.056	0.114	0.178	0.223	0.301	0.476	1
20	0.007	0.019	0.050	0.099	0.151	0.187	0.249	0.386	0.885
30	0.007	0.018	0.046	0.087	0.130	0.159	0.209	0.317	0.703
40	0.007	0.018	0.043	0.081	0.120	0.145	0.189	0.282	0.612
50	0.007	0.017	0.042	0.078	0.113	0.137	0.177	0.261	0.557
60	0.007	0.017	0.041	0.075	0.109	0.131	0.168	0.247	0.521
70	0.007	0.017	0.041	0.073	0.106	0.127	0.163	0.237	0.495
80	0.007	0.017	0.040	0.072	0.104	0.124	0.158	0.230	0.475
90	0.007	0.017	0.040	0.071	0.102	0.122	0.155	0.224	0.460
100	0.007	0.017	0.039	0.070	0.101	0.120	0.152	0.219	0.448
150	0.007	0.017	0.039	0.068	0.096	0.114	0.144	0.206	0.411
200	0.007	0.017	0.038	0.067	0.094	0.112	0.140	0.199	0.393
300	0.007	0.016	0.038	0.066	0.092	0.109	0.136	0.192	0.375

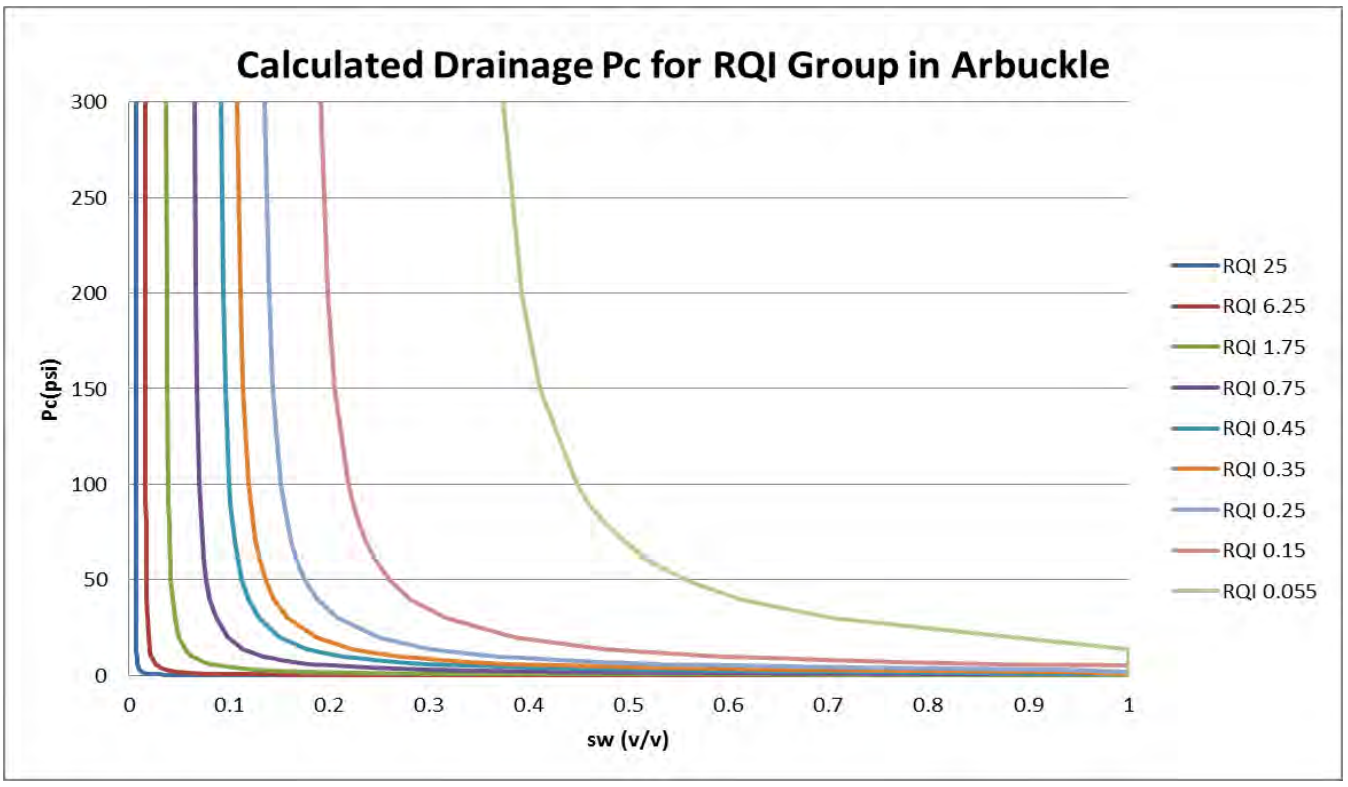


Figure 58: Nine Pc curves for 9 rock types for the specified RQI

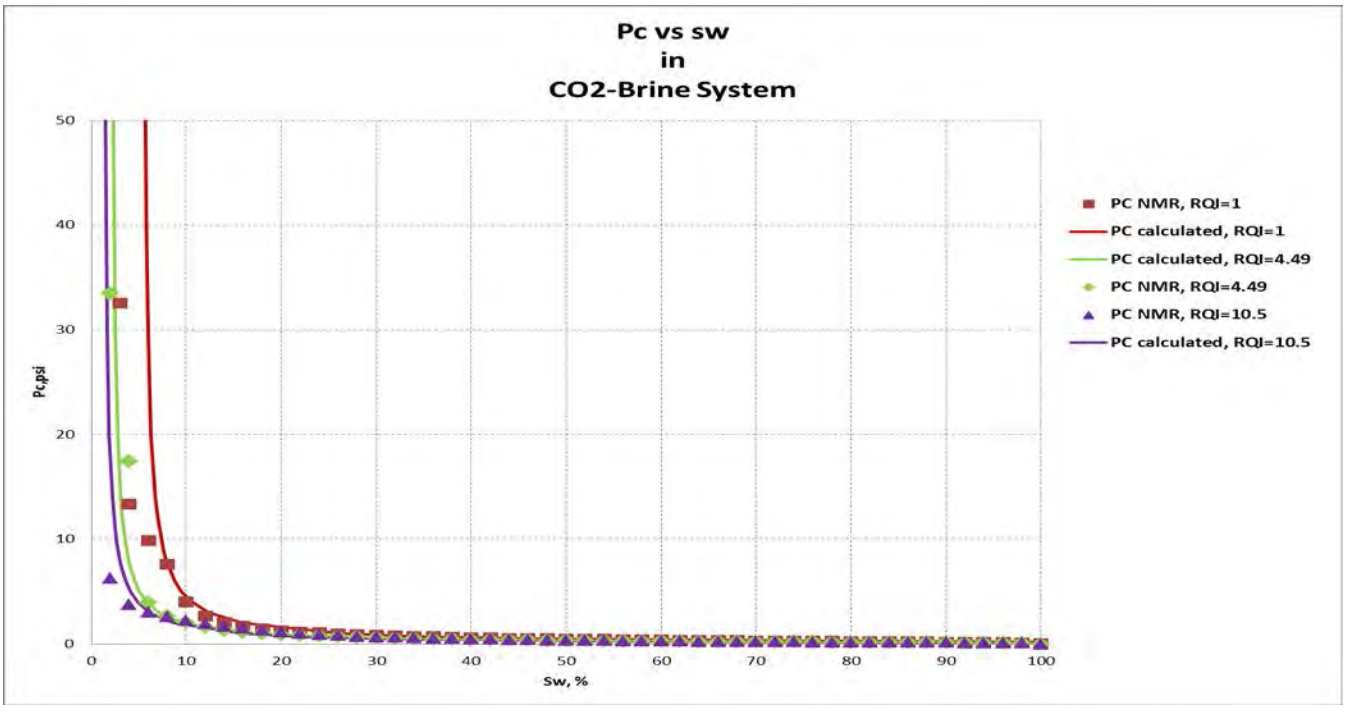


Figure 59: Calculated PC compared with generated PC from NMR

Capillary entry pressure with supercritical CO2 varies significantly with reservoir quality (**Figure 58**). The CO2 behaves in a similar way to nonwetting oil or gas and at reservoir pressure, water saturation varies with supercritical varies from near zero to just over 70% as illustrated in the upper half of the Arbuckle saline aquifer in Wellington KGS #1-32 (**Figure 60**).

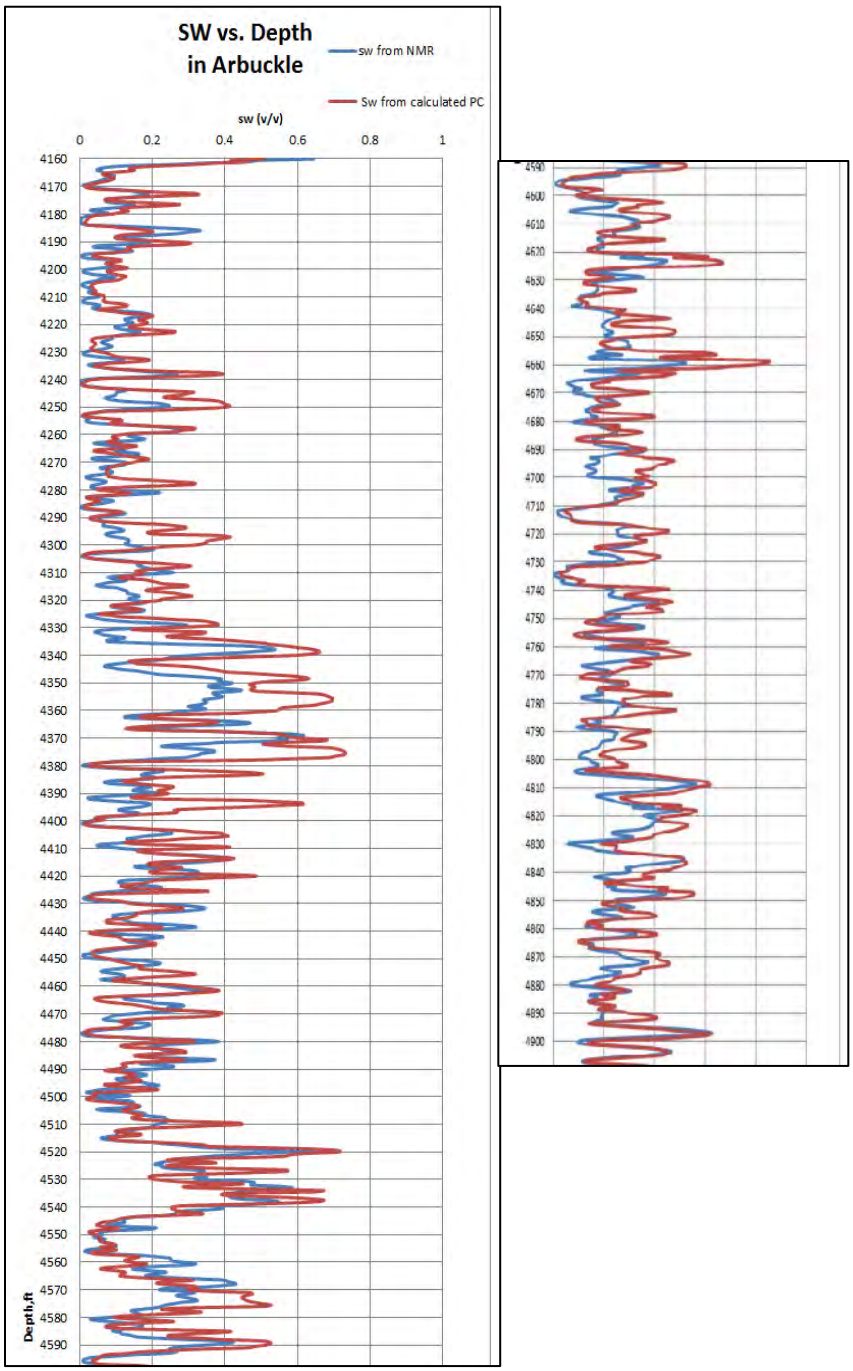


Figure 60. Computer water saturation in the upper Arbuckle with supercritical CO2.

4) Initiated approach to model effects of simultaneous regional CO2 injection

Once permeability prediction is further validated, the modeling of 10 commercial scale CO2 injection sites will begin. We are also collection Class I shut-in pressure and injection data in the regional study area to evaluate cumulative effects on pressure of long term injection. We will simulation via mapping the regional pressure field by the simultaneous injection of all 10 sites. The intent is to understand the interference and location of potential pressure build and fluid displacement. The assumption is that with a nearly flat potentiometric surface of the Arbuckle that the aquifer is an open communicating system. The issue is that in a short-term injection scheme that pressure buildup does not occur. This assessment can only be obtained via dynamic modeling.

5) Static and dynamic modeling of Eubank, Shuck, and Cutter fields

Modeling of Eubank Field continues and reservoir characterization at Cutter Field is underway. At Cutter, seismic processing interpretation continues in order to attempt to resolve the geometry of the Morrow sandstone reservoir. The sandstone is encased with shale with minor impedance contrast, so p-wave alone is insufficient to resolve the reservoir. Rather, the converted wave is being used with growing success to resolve the sandstone.

6) Vetting of type logs and finalizing project interactive mapper

This activity was delayed as work was performed on the information included in the LAS files. Data and software are ready to go to re-engage the type log committee in first quarter 2014 to verify the stratigraphic correlations. Similarly, the project mapper will be least in the same timeframe.

PRESENTATIONS AND PUBLICATIONS

AAPG Midcontinent Section Meeting as noted in earlier quarterly report.

KEY FINDINGS

1. Shear Impedance from 3D seismic at Cutter Field appears to be providing success in resolving the geometry of the sandstone reservoir.
2. Sealing strata are present above the Arbuckle at Cutter Field and analysis continues to understand their physical properties and suitability for containing CO2 injection in the Arbuckle.
3. The Arbuckle has similar composition, pore types, and petrophysical response as a Wellington Field, but the aquifer is less permeable.

4. The salinity from DST and swabbing in the Arbuckle in the Cutter KGS #1 ranges from 29,000 to 106,000 chlorides i.e. is highly variable. Analysis continues.
5. The Atokan shale that caps the Morrow oil reservoir is organic rich and in the oil generating thermal window and is generating oil.
6. In situ tests of CO2 and Arbuckle plugs continues and latest flow experiments by LLNL indicate low permeable zones (0.02 md) can have a 1000 fold increase in permeability (1.8 md) with dissolution of the dolomitic matrix along "pinch" points. This can increase access of CO2 to low permeability rocks to increase storage and to access finer pores that can also lead to trapping CO2.
7. Permeability prediction continues to be refined with additional work presented here to validate the three tiers of permeability – micro, meso, and macro vug scale pores. Fuzzy logic was used to predict permeability, but the success is limited. Instead, the approach is using variations of neutral networks.
8. Capillary pressure curves with supercritical CO2 and water were computed for the Arbuckle. The water saturations under inset conditions range from near zero to just over 70%, the latter associated with smaller pores. Irreducible water saturation increases with poorer reservoir quality.

PLANS

1. Complete the regional CO2 assessment.
2. Complete geomodeling and simulations of commercial scale CO2 injection at the 10 regional sites.
3. Complete the Wellington models for the Mississippian and the Arbuckle.
4. Complete the modeling of the SW Kansas fields.
5. Complete the type logs and release the interactive mapper.
6. Begin writing chapters of the final report.

REFERENCES

Carroll, S. Smith, M., Mason, H.E., 2014, Quarterly Report Q1FY14 to DOE/NETL, "Enhanced porosity and permeability within carbonate CO2 storage reservoirs: An experimental and modeling study, 8 pg.

APPENDIX I

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

EIGHTEENTH QUARTER PROGRESS REPORT

DOE F 4600.2
(5/09)
(All Other Editions are Obsolete)

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.

1

QUARTERLY 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

Eighteenth Quarter Progress Report

Date of Report: 5-8-14

Period Covered by the Report: January 1, 2014 to March 31, 2014

Contributors to this Report: Brent Campbell, Saugata Datta, John Doveton, Mina Fazelalavi, Yousuf Fadolalkarem, David Fowle, Dennis Hedke, Eugene Holubnayak, Christa Jackson, Jennifer Raney, Clyde Redger, Jennifer Roberts, Jason Rush, George Tsoflias Michael Vega, John Victorine, Lynn Watney

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		90%
2.0 Characterize the OPAS (Ozark Plateau Aquifer System)	1/1/2010	01/01/10	9/30/2013		95%
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	+++	90%
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	**	95%
11.0 Produced water and wellbore management plans - Risk assessment area	1/1/2012	01/01/12	7/30/2013		98%
12.0 Regional CO2 sequestration potential in OPAS	8/1/2012	02/01/12	9/30/2013	***	92%
13.0 Regional source sink relationship	1/1/2010	1/1//2010	9/30/2013	****	97%
14.0 Technology Transfer	1/1/2010	01/01/10	2/7/1014		90%

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 competed
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	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		90% 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		95% complete
KGS Milestone 3.4: Regional CO2 Sequestration Potential in OPAS - 17 Counties	12/7/2012		90% complete
HQ Milestone: Make data set from one site characterization project publicly available.	12/31/12	Note: This milestone was met collectively by all projects. No one project was held accountable to the milestone.	
HQ Milestone: Complete one major field activity to collect additional characterization data from well drilling, 2-D or 3-D seismic surveys, or well logging/testing.	03/31/13	Note: This milestone was met collectively by all projects. No one project was held accountable to the milestone.	
HQ Milestone: Complete, at a minimum, planning for one major field activity, such as well drilling, 2-D or 3-D seismic surveys, or well logging/testing.	06/30/13	Note: This milestone was met collectively by all projects. No one project was held accountable to the milestone.	
HQ Milestone: Yearly Review Meeting of active projects; opportunities for information exchange and collaboration	09/30/13	Attended Annual Review meeting in August	100% complete
HQ Milestone: Complete one field activity to collect characterization data from well drilling, 2-D or 3-D seismic surveys or well logging/testing.	12/31/13		
HQ Milestone: Complete analysis of field activity in project-related reservoirs to validate additional storage potential.	03/31/14		
HQ Milestone: Semi-annual progress reports for active projects (i.e. Quarterly Report ending March 31, 2014).	06/30/14		
HQ Milestone: Yearly Review Meeting of active projects; opportunities for information exchange and collaboration	09/30/14		

TASK SUMMARY IN PREPARATION FOR COMPLETION OF THE PROJECT

This quarterly report includes all of the tasks and subtasks with dialog pertaining to activities conducted in this quarter or comments related to the completion of the tasks by the end of the project.

Task 1: Program Management and Reporting (PMP)

Task 2. Characterize the OPAS

Subtask 2.1. Acquire geologic, seismic and engineering data
Subtask 2.2. Develop regional correlation framework and integrated geomodel
Subtask 2.3. Subsurface fluid chemistry and flow regime analysis
Subtask 2.4. Gather and interpret KGS's gravity and magnetic data
Subtask 2.5. Remote sensing analysis for lineaments

Data associated with Task 2 have been being compiled and are being using to establish the final regional storage assessment. Information will be uploaded to the interactive mapper and NATCARB. The latest versions of the structure, isopach, and fault maps are available, but have yet to be uploaded to the interactive mapper (**Figure 1**). The recent seismicity in southern Kansas and Oklahoma has led to a closer inspection of our assembled subsurface data, in particular, structural maps. We will confirm accuracy and consistency in mapping known and indicated faults from which will make our final interpretations.

A simpler web address for our interactive mapper is now being used -- **http://maps.kgs.ku.edu/co2**. The digital type logs in the project will be reviewed in the next quarter before the project is completed. Similarly, stratigraphic correlations will be reviewed. Additional digital deep wells will be inventoried in the study area due the recent increase in drilling in southern Kansas and operators increasing the submission rate for digital (LAS).

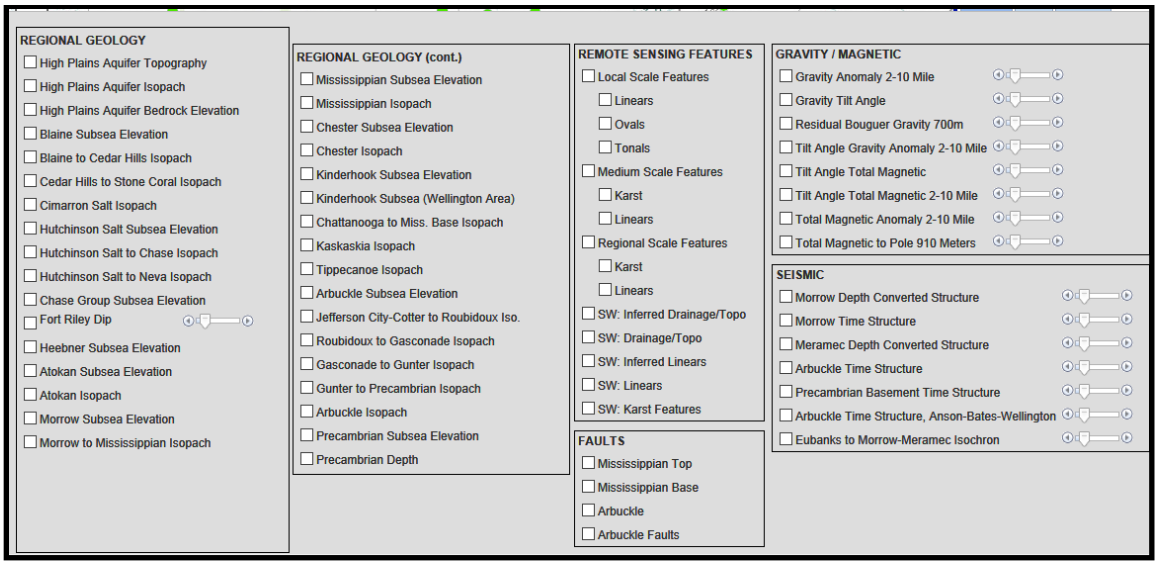


Figure 1. Latest version of the dropdown menu showing map layers currently present for the project interactive mapper -- http://maps.kgs.ku.edu/co2

Task 3. Geomodel of Mississippian Chat & Arbuckle Group - Wellington field.

Subtask 3.1. Collect geologic & engineering data
Subtask 3.2. Collect 3D seismic data
Subtask 3.3. Process 3D seismic data
Subtask 3.4. Collect gravity and magnetic data
Subtask 3.5. Interpret seismic, gravimetric, and magnetic data
Subtask 3.6. Initial geomodel - Wellington

A field-wide geomodel for the Mississippian oil reservoir will be completed in the final two quarters.

The Arbuckle geomodel has been completed and utilized in the Class VI application of DE-FE0006821. The seismic data needed for the model has been processed and interpreted, but student thesis work funded by other means continues to refine the interpretation including petrographic analysis of the Mississippian reservoir at Wellington Field by Montalvo summarized in **Appendix A -- Diagenesis and distribution of diagenetic facies in the Mississippian of south-central Kansas.**

Task 4: Preparation, Drilling, Data Collection and Analysis – Test Borehole #1

Subtask4.1. Locate Test Borehole #1
Subtask 4.2. Permitting for Test Borehole #1
Subtask 4.3. Drill, retrieve core, and run DST – Test Borehole #1
Subtask 4.4. Openhole Wireline Logging – Test Borehole #1

Subtask 4.5. Wellbore Completion – Test Borehole #1
Subtask 4.6. Analyze wireline log - Test Borehole #1
Subtask 4.7. Test and sample fluids (water) from select intervals – Test Borehole #1
Subtask 4.8. Analyze Arbuckle core from Test Borehole #1
Subtask 4.9. Analyze Mississippian core from Test Borehole #1
Subtask 4.10. PVT analysis of oil and water from Mississippian chat reservoir
Subtask 4.11. Analyze water samples from Test Borehole #1
Subtask 4.12. Microbiological studies on produced water
Subtask 4.13. Correlate log and core properties
Subtask 4.14. Examine diagenetic history of fracture fill

Subtasks 4.1 focused on the geochemical and microbiological aspects of CO2 interaction with the rock continues to be addressed. Work is summarized by Christa Jackson, M.S. candidate at KU in **Appendix B – "Geological and Microbiological Influences on Reservoir and Seal Material During Exposure to Supercritical CO_2, Arbuckle Group, Kansas"**. This work is supported by both DOE-NETL and The Petroleum Research Fund.

Task 5. Preparation, Drilling, Data Collection, and Analysis - Test Borehole #2

Subtask 5.1. Locate Test Borehole #2
SubTask 5.2. Permitting for Test Borehole #2
Subtask 5.3. Drill, and run DST – Test Borehole #2
Subtask 5.4. Openhole wireline logging - Test Borehole #2
Subtask 5.5. Complete well and perforate selectively to test and sample fluids – Test Borehole #2
Subtask 5.6. Analyze wireline log – Test Borehole #2

Task 6. Update Geomodels

Subtask 6.1. Hydrogeologic studies
Subtask 6.2. 2D shear wave survey
Subtask 6.3. Process & interpret 2D shear
Subtask 6.4. Revise 3D seismic interpretation
Subtask 6.5. Update geomodel - Arbuckle & Miss

Yousuf Fadolalkarem is working with the Wellington 2D and 3D seismic data in a thesis titled, "Pre-stack Seismic Attribute Analysis of the Mississippian Chert and the Arbuckle at the Wellington Field, South-central Kansas". This study is examining the pre-stack 3D seismic data attribute analysis and inversion to predict reservoir properties of the Mississippian cherty dolomite and the Arbuckle Group. Synthetic wedge modeling of pre-stack seismic is being used to examine relationships between reservoir thicknesses and AVO impedance inversion techniques that will be applied to 3D pre-stack field seismic data using the Hampson-Russell software. These techniques are P- and S-impedance inversion, Lambda-mu-rho inversion and Elastic Impedance inversion. Predictions from the pre-stack analysis will be compared to well data and post-stack analysis results.

This work will help define the relationships between seismic data attributes and properties of the Mississippian reservoir and Arbuckle aquifers at the Wellington and will help advance the understanding of capabilities and limitations of pre-stack seismic methods for predicting reliably reservoir thickness and porosity. The final full-field reservoir models of the Mississippian and Arbuckle will utilize these results as possible in the timeframe available before the final report is completed. This work is leveraging the DOE-NETL funding with support from the Kansas Interdisciplinary Carbonate Consortium (KICC).

An update of the Mississippian geomodel in Wellington Field was made by J. Rush. The focus of the latest work was directed to further resolve the stratigraphy and structure using the 3D seismic survey. The well log-based structure on the top of the Mississippian for the combined Anson-Bates and Wellington Fields show the broad structural high over the Wellington Field (Figure 2). This is compared to the area of higher relief in the Anson-Bates area to the northwest.

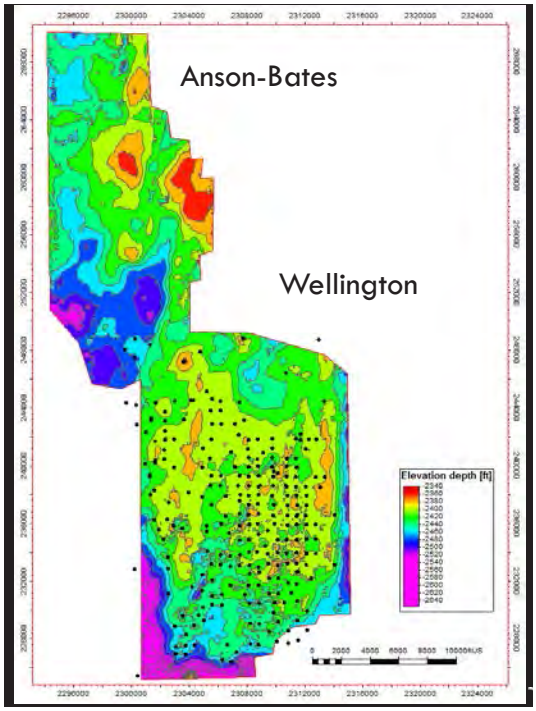


Figure 2. Structure top of Mississippian with elevations derived from well log data.

A west-to-east well log (gamma ray and porosity) cross section across the field delimits the higher porosity at the top of the Mississippian interval (**Figure 3**). These well data serve as the calibration for resolving the internal seismic stratigraphy shown in subsequent figures. A Petrel layering model of the Mississippian in **Figure 4** shows three major internal divisions of the Mississippian. The light blue colored basal Pierson (lower “Cowley facies”) is classified as a transgressive systems tract (TST). These layers thicken to the east (landward) and notably thin basinward to the west. The basal strata also onlap an underlying erosional surface.

The darker blue middle Mississippian strata step basinward, west of the location of toplap truncation (Figure 4). There also appears to be erosion of the topset strata that is interpreted to have occurred during a sea level lowstand. This internally consistent and correlatable layer model also suggests that the structural high is persistently positive during the Mississippian, supporting earlier work suggesting the same. The red colored thin upper Mississippian is the residual cherty interval that appears to be concentrated over the structural high, likely reflecting the more intense weathering on the crest (**Figure 4**).

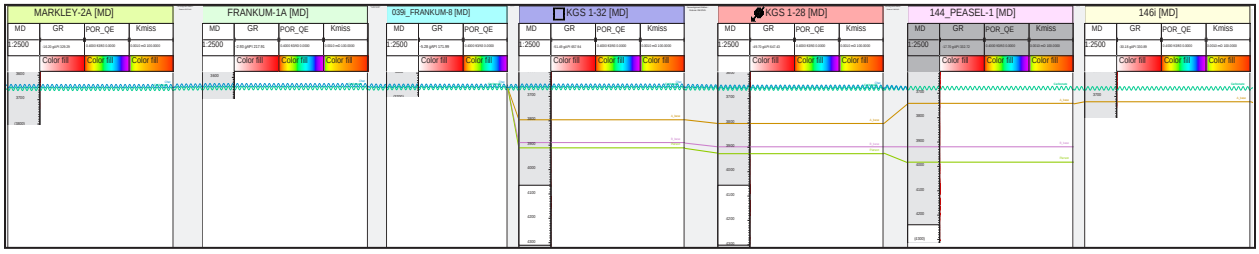


Figure 3. West-to-east cross section including #1-32 and #1-28. Higher porosity reservoir interval is located on top of the Mississippian. Internal stratal markers are shown by correlations lines.

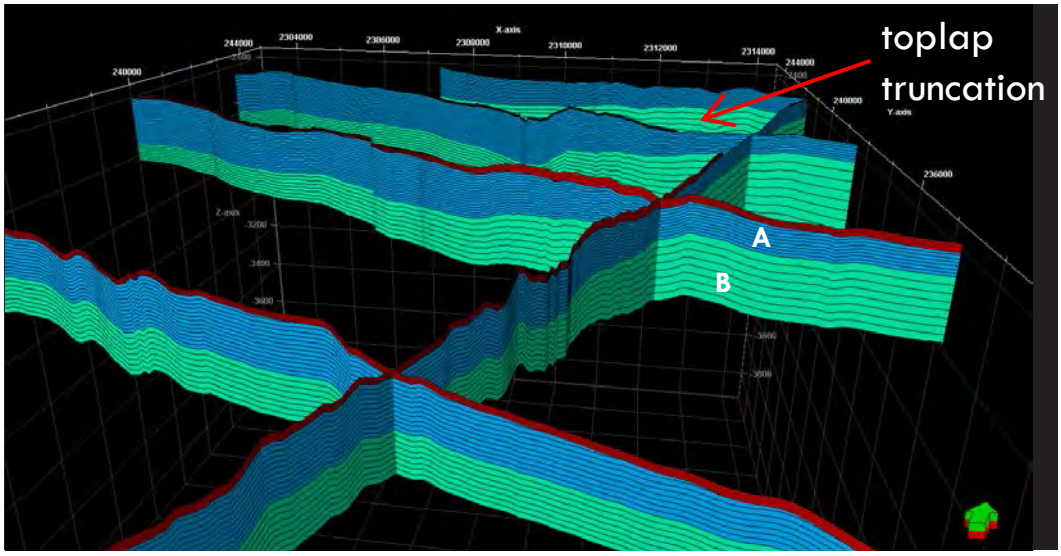


Figure 4. Petrel layering based on correlation of logs and seismic data.

Figure 5 illustrates the structural elements that have been clarified with the depth-converted systems. As indicated in **Figure 4**, the Mississippian reveals set patterns of internal strata geometries. These strata are slightly interrupted by local structure, but show the downlap and onlap quite clearly on the 3D seismic (**Figure 5**). The basal Mississippian is quite irregular (yellow line) overlapping a local structural high at #1-32 where the Chattanooga Shale has been previously eroded prior to the Mississippian transgression. Moreover, the seismic discontinuities

bounding it on west and east sides suggest faulting to form a horst that was present at least until the upper Mississippian.

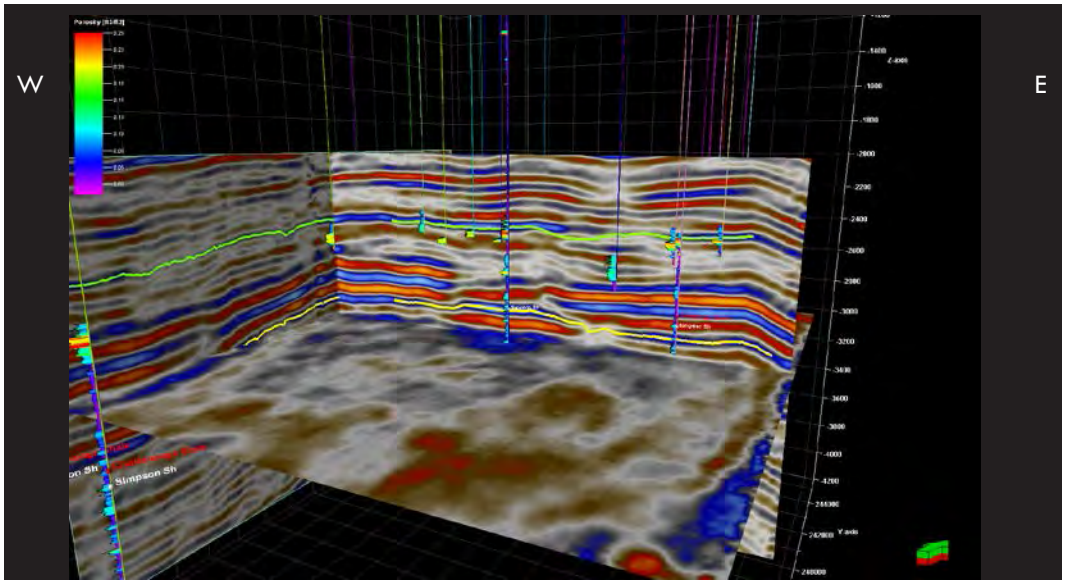


Figure 5. Faults, grabens, and Mississippian onlap are key structural and depositional features recognized on this inline-cross line extract of the 3D seismic volume at Wellington Field. The top of Mississippian is bright green line and the base of the Mississippian is the yellow line. This visualization is in depth. Deep wells #1-32 and #1-28 are shown along W-E crossline.

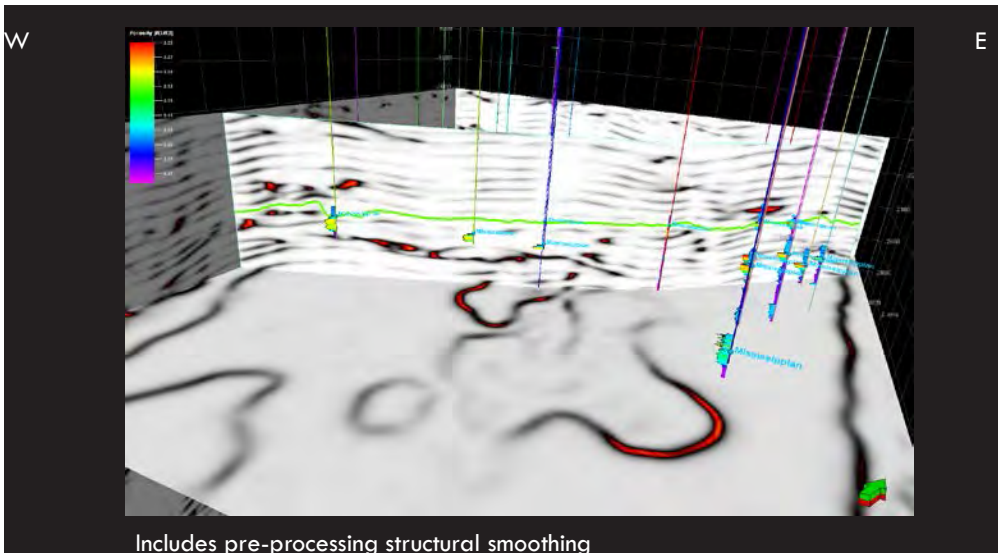


Figure 6. Wellington Field seismic showing variance attribute on PSDM.

The prestack depth migration was used to show a variance attribute that helped to further delimit the likely faults at the base of the Mississippian (**Figure 6**). The red wavy lines are the likely

faults developed near the crest of the structural high. Note their location and the configuration of the top for the Mississippian, again indicating the possible diminished offset on the faults the higher in the Mississippian. A key point is that the structure continues to be active current with deposition, preceding the major tectonic activity at the end of the Mississippian.

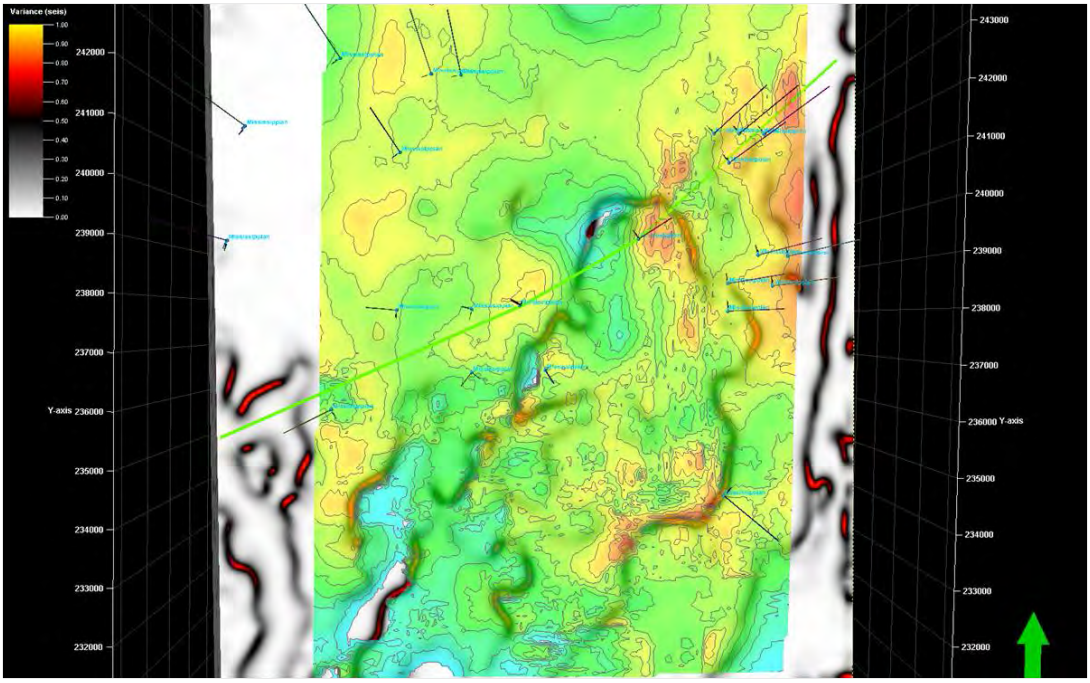


Figure 7. Wellington Field seismic structure co-rendered with Variance Attribute (PSDM).

The map view of the Variance Attribute shown in **Figure 7** at the base of the Mississippian indicates the southeast portion of Wellington Field is outlines by a fault that closely outlines the highest portion of the structure. Well #1-32 is on the west side, outside of the area within the faulted (horst) volume. The structural offset across the faults is relatively low, <50 ft, but is also accompanied by drape/flexure beyond the fault itself.

The structural activity that was concurrent with deposition persists to through the Upper Pennsylvanian where the thick (100 ft) Oread Limestone on the east side of Wellington Field thins dramatically to the west (**Figure 8**). The paleotopography is representative of a regional change from shelf to basin for the Oread Limestone, basin to the west-southwest and landward east and north.

Fault interpretation with the variance attribute is confirmed as illustrated by the anomaly intersecting with the cross line profile of the seismic amplitude (**Figure 9**).

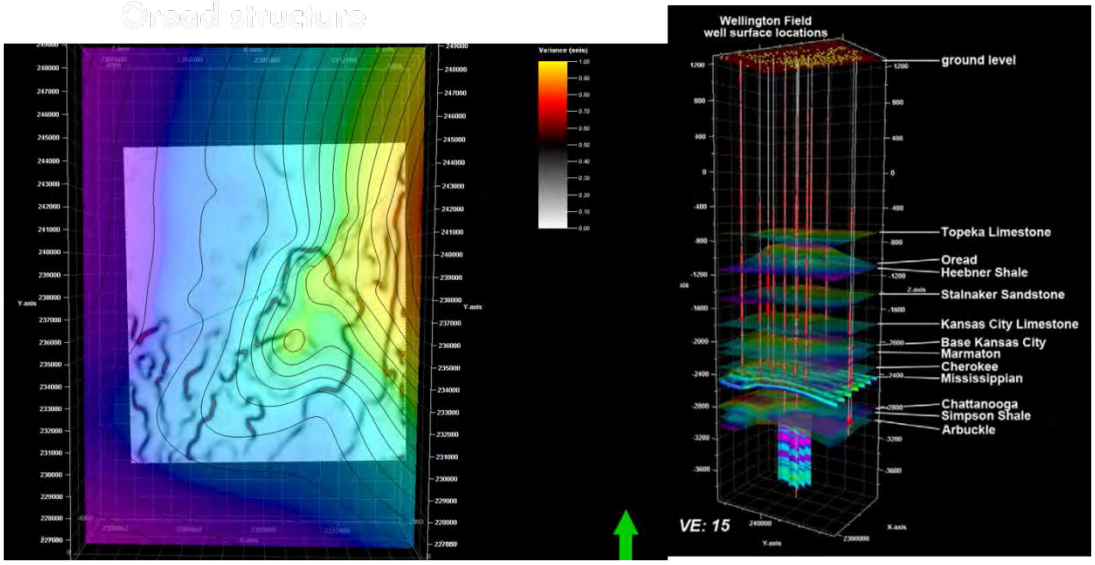


Figure 8. Oread shelf edge closely corresponds to the underlying NE-trending fault.

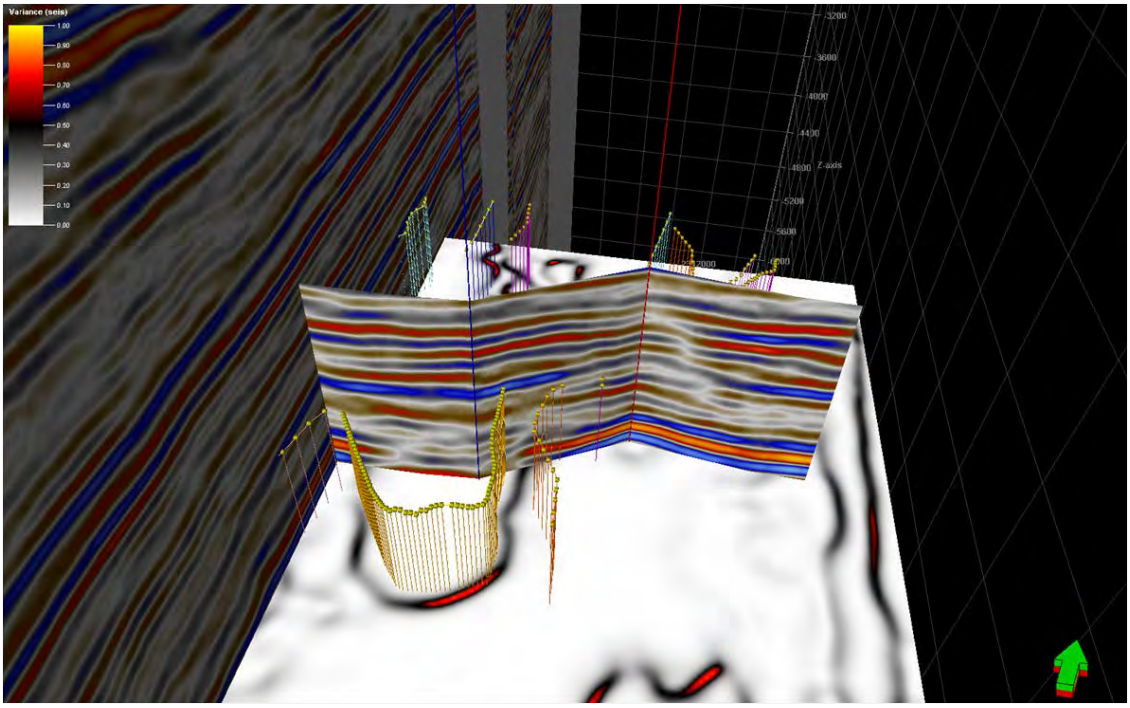


Figure 9. Wellington Field, fault model and variance.

The volumetric curvature (VC) was previously used to define discontinuities in the seismic until it was realized that the data seemed to be too noisy (**Figure 10**). The pattern of the VC at this stage of the processing also suggested an artifact from the acquisition "footprint". More work on the use of VC is needed, particularly; looking at different resolutions, before move convincing

results can be obtained as noted in another DOE supported study at Bemis-Shutts Field in Kansas.

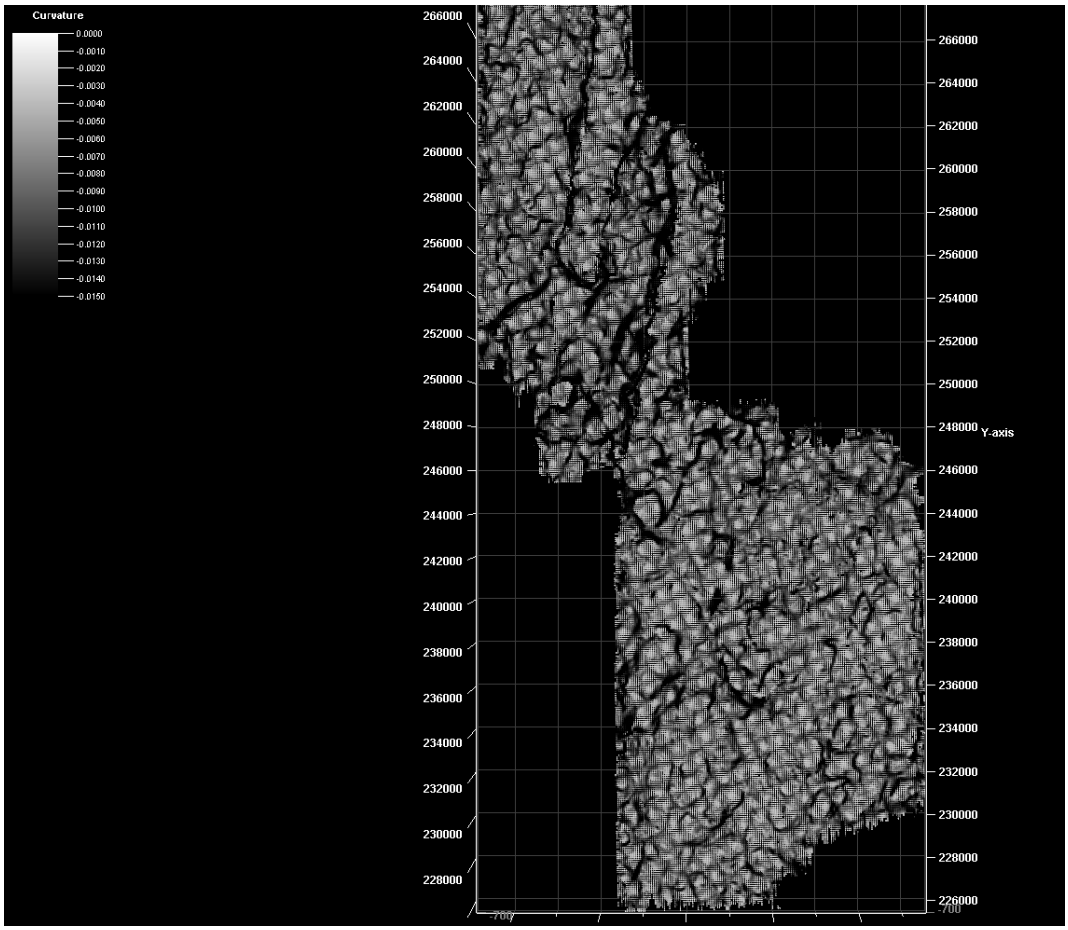


Figure 10. Volumetric Curvature -- Too noisy? Need to QC using different lateral resolutions. More convincing results were found for the Bemis-Shutts project.

The Petrel-based genetic inversion of the 3D volume to obtain the porosity for the layered Mississippian model is shown in **Figure 11**. The more continuous porosity is noted on the west side of the field corresponding the portion of the middle portion of the Mississippian before it toplaps to the east.

A detailed layer-based porosity model of the entire Mississippian in **Figure 12** further shows the toplap of the layers and porosity to the east and the downlap to the west. The layers clearly show the progradational packages, even at this reservoir scale.

The porosity log used in the gridding that is displayed in **Figure 12** was smoothed. This log porosity profile is compared with the seismically derived porosity from the genetic inversion in **Figure 13**. The resampling to the 3-D grid uses exact transform seismic porosity to log values

during SGS. The porosity model uses SGS & the seismic porosity attribute. There is an excellent correlation between the logs and the log-seismic integrated model.

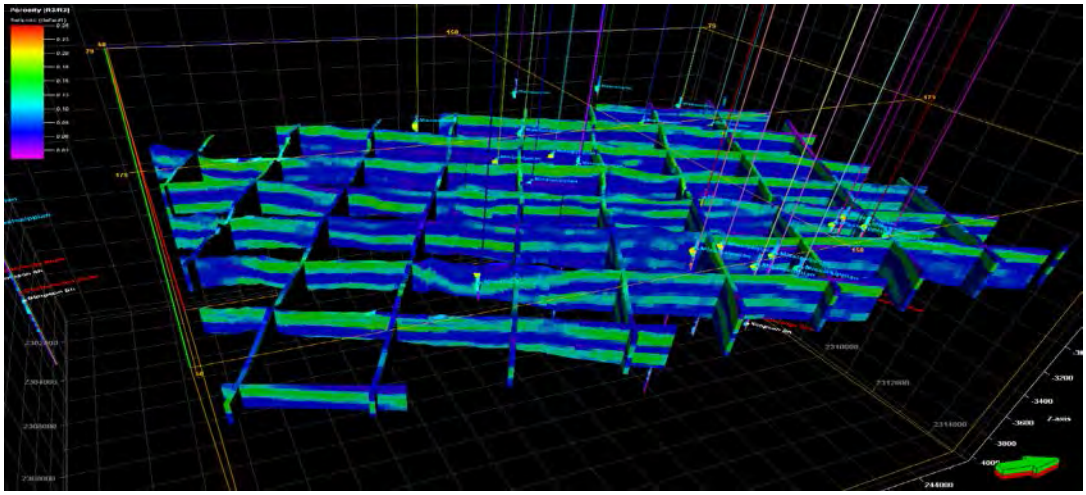


Figure 11. Genetic Inversion sampled to 3-D Grid for the Mississippian reservoir.

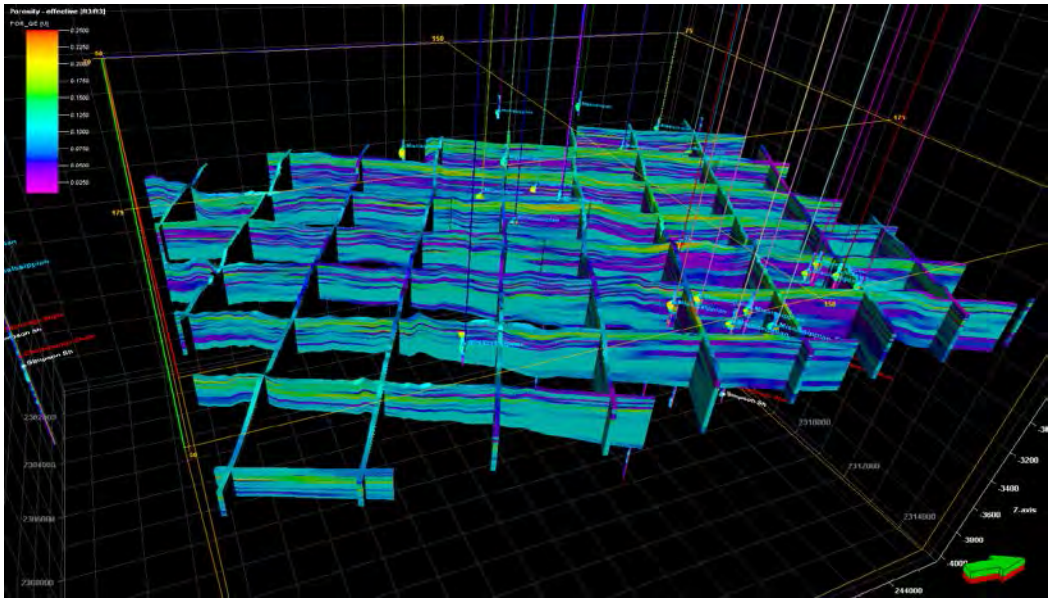


Figure 12. Porosity Model using SGS & Seismic Porosity Attribute. The seismic porosity attribute distribution is normalized to upscaled porosity values.

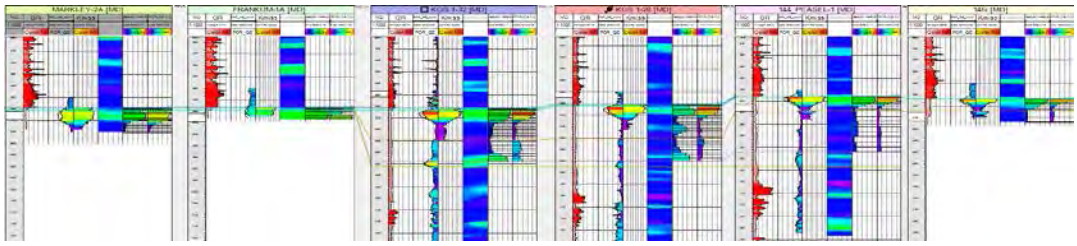


Figure 13. Seismic porosity attribute and upscaling results along west-east well cross section.

The interim conclusions from revisiting and updating the geomodel of the Mississippian reservoir at Wellington include:

1. Conductive fractures dominate fluid flow into wellbore (PLT) in low K reservoirs. The Mississippian has both high and low permeability facies, thus fracture modeling is very important. CO2 injection will likely be affected by the fractures presenting themselves as either conduits or barriers to the CO2.
2. Mississippian has similar tight basinal expressed as the “lower Cowley facies” that are part of the TST. These facies thicken unto the Wellington structure while the reservoir facies undergo toplap and truncation from west to east across the field.
3. Seismic attributes aid *comprehensive* characterization, particularly to delimit high angle fractures and faults that do not intersect the wellbores and have smaller offsets that are usually attributed to flexure.
4. Production decline can be overcome or injection of fluids like CO2 can be tailored when fractures and faults are considered in the geomodeling and simulation activities.

Task 7. Evaluate CO2 Sequestration Potential in Arbuckle Group Saline Aquifer - Wellington field

Subtask 7.1. CO2 sequestration potential
Subtask 7.2. Long-term effectiveness of cap rock
Subtask 7.3. CO2 sequestered in brine
Subtask 7.4. CO2 sequestered as residual gas
Subtask 7.5. CO2 sequestered by mineralization
Subtask 7.6. Field management - max CO_2 entrapment
Subtask 7.7. Monte Carlo - total CO_2 seq capacity

The geomodel and simulation studies used in the Class VI application for project DE-FE0006821 were completed in this quarter. The Wellington data in particular are being to calibrate the type logs for the regional study area using a neural network. The approach is described later under Task 12 -- **Regional CO2 Sequestration Potential in OPAS - 17 Counties.**

The Class VI application used a permeability model that is admittedly biased to the matrix pores with the whole core analyses and nuclear magnetic resonance tool. DST’s and variable rate pulse

test were used to scale the results to these measurements to adjust the permeability as used in the simulation for the Class VI permit application (**Figure 14**). The 50 ft flexure noted to the immediate west of #1-28 corresponds with the fault suggested in recent work described above (**Figures 7, 8, and 9**). The fault also cuts into the Mississippian and at least flexure continuing to affect the Upper Pennsylvanian Oread Limestone thickness shown in **Figure 8**.

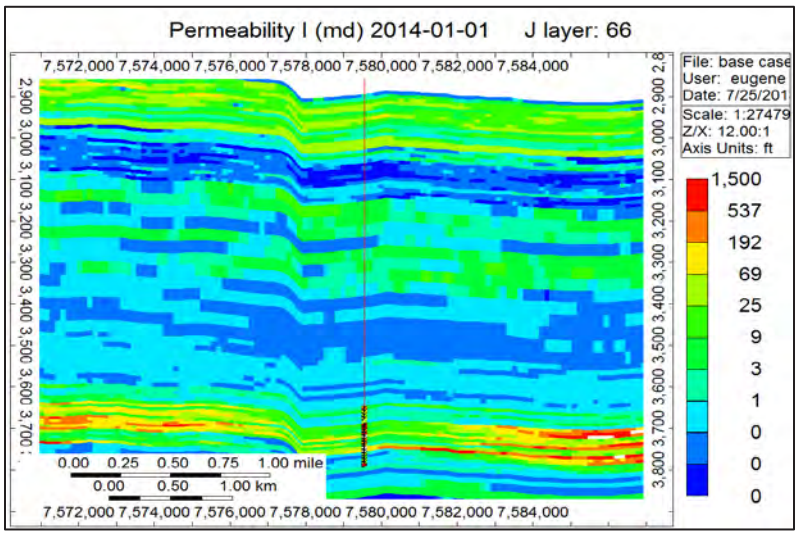


Figure 14. A west to east permeability profile of the Arbuckle crossing the location of the proposed injection well #1-28.

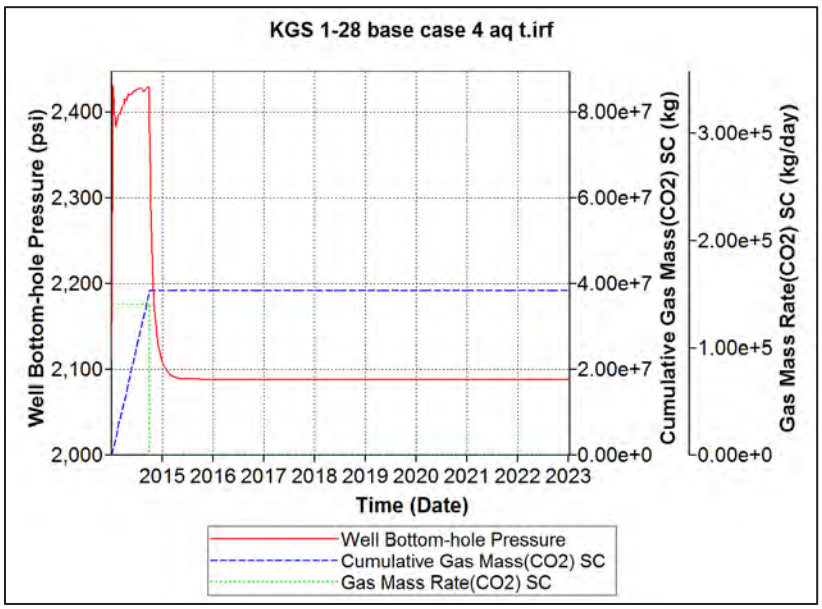


Figure 15. Simulated bottom hole pressure, 325 psi max. (0.485 psi/ft) 120 tonne/day, 40,000 tonne total CO_2.

The maximum simulated bottom hole pressure with this modeling used for the Class VI application is close to what the pressure would be under hydrostatic conditions (**Figure 15**). This conservative pressure would permit the injection of 40,000 tonnes of CO_2 over ~9 months.

The size of the resulting CO2 plume with free phase gas saturations varying from nearly zero to one spans a diameter of ~2000 ft (**Figure 16**). The nearly 100% free phase CO2 portion of the plume should intersect the observation well #2-28.

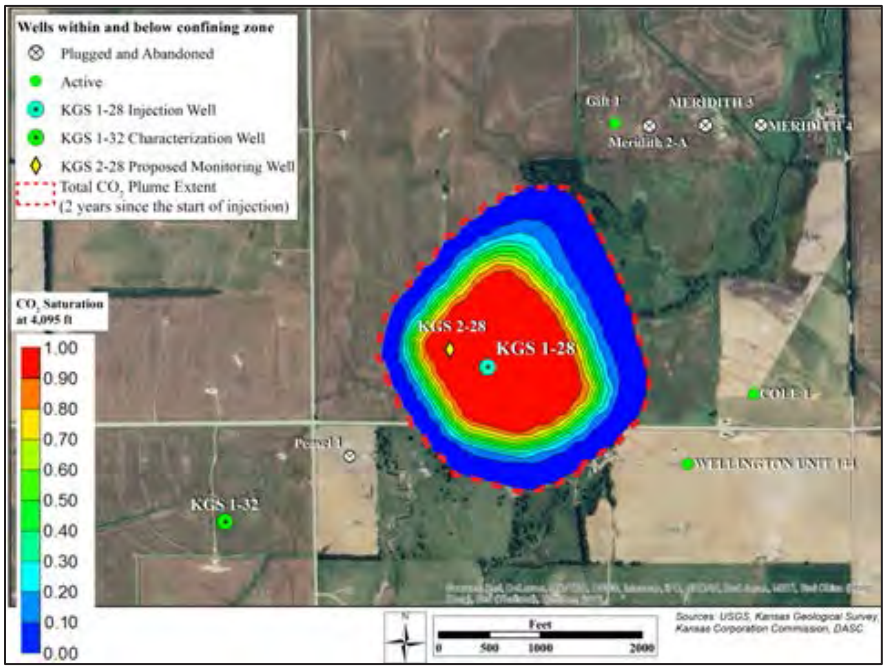


Figure 16. Simulated CO2 plume with pressure, volume, and time described in Figure 15.

Task 8. Evaluate CO2 Sequestration Potential by CO2-EOR in Depleted Wellington field

Subtask 8.1. CO2-EOR potential
Subtask 8.2. Long-term effectiveness of cap rock
Subtask 8.3. CO2 sequestered in brine and residual gas
Subtask 8.4. CO2 sequestered by mineralization
Subtask 8.5. Field management - optimize CO2-EOR
Subtask 8.6. Monte Carlo - total CO2 seq capacity

The full-field simulation has yet to be completed. As described above the field-wide geomodel for the Mississippian is underway.

Task 9. Characterize leakage pathways - Risk assessment area

Subtask 9.1. Collect reservoir characterization data - external sources
Subtask 9.2. Map fracture-fault network
Subtask 9.3. Verify seal continuity and integrity
Subtask 9.4. Inventory well status
Subtask 9.5. Gather expert advice on well integrity

Wells have been inventoried and well integrity has been defined. The newest geomodel will be used to further model the fractures and faults that are now being resolved as previously described above.

Task 10: Risk Assessment Related to CO_2-EOR in Mississippian Chat Reservoir and CO_2 Sequestration in Arbuckle Aquifers

Subtask 10.1. Model CO_2 plume for 100, 1000, and 5000 yrs after injection stops
Subtask 10.2. Model plume attenuation during and after injection
Subtask 10.3. Model effects of natural aquifer flow on CO_2 plume
Subtask 10.4. Estimate time frame for free phase CO_2 to become negligible
Subtask 10.5. Model effectiveness of cap rocks to contain leakage
Subtask 10.6. Leakage modeling through abandoned wells
Subtask 10.7. Model worst-case CO_2 leakage scenario
Subtask 10.8. Estimate surface environmental effects due to leakage

Simulations with leakage has been examined, but will be updated using the final geomodel.

Task 11: Produced Water and Wellbore Management Plans

Subtask 11.1. Identify at-risk wells in Wellington Field
Subtask 11.2. Outline Best Practices and well recompletion plans for at-risk wells
Subtask 11.3. Outline Best practices and well completion plans for new CO_2 injector wells
Subtask 11.4. Summarize practices in place for disposal of produced water

Wells have been examined for at-risk characteristics. Steps will be taken to plug a well in close proximity to the CO2 plume generated by the small scale injection test. Other wells lie significantly beyond this area that would need to be addressed if larger scale disposal would be considered. The criteria followed in this assessment will become the best practice. If there is any doubt, remedial action will be necessary.

Task 12. Regional CO2 Sequestration Potential in OPAS - 17 Counties

Subtask 12.1. Map reservoir compartments in Arbuckle aquifer in a regional context
Subtask 12.2. Coarse grid simulation over select OPAS areas to estimate regional CO_2 sequestration potential
Subtask 12.3. Generalized estimates of miscible CO_2-EOR in similar and larger oil fields in approximately 17 counties
Subtask 12.4. Estimate regional CO_2 sequestration potential of OPAS

The regional assessment of CO2 storage potential in southern Kansas has undergone a year long process of refining estimates of key variables that are essential in accurate reporting. It has been previously shown how the original estimates were made based on average properties and assumptions. The work progressed in this quarter set on a course of providing the best realization of permeability both Kv and Kh, capillary pressure, and estimates of reaction rates to provide

reliable storage numbers. The calibration wells #1-28 and #1-32 at Wellington and the Cutter KGS #1 were used in this analysis. The geomodels are being constructed for the 10 regional simulation sites that are analogous to the Wellington and Cutter fields with structural closure and overlying oil field (**Figure 17**).

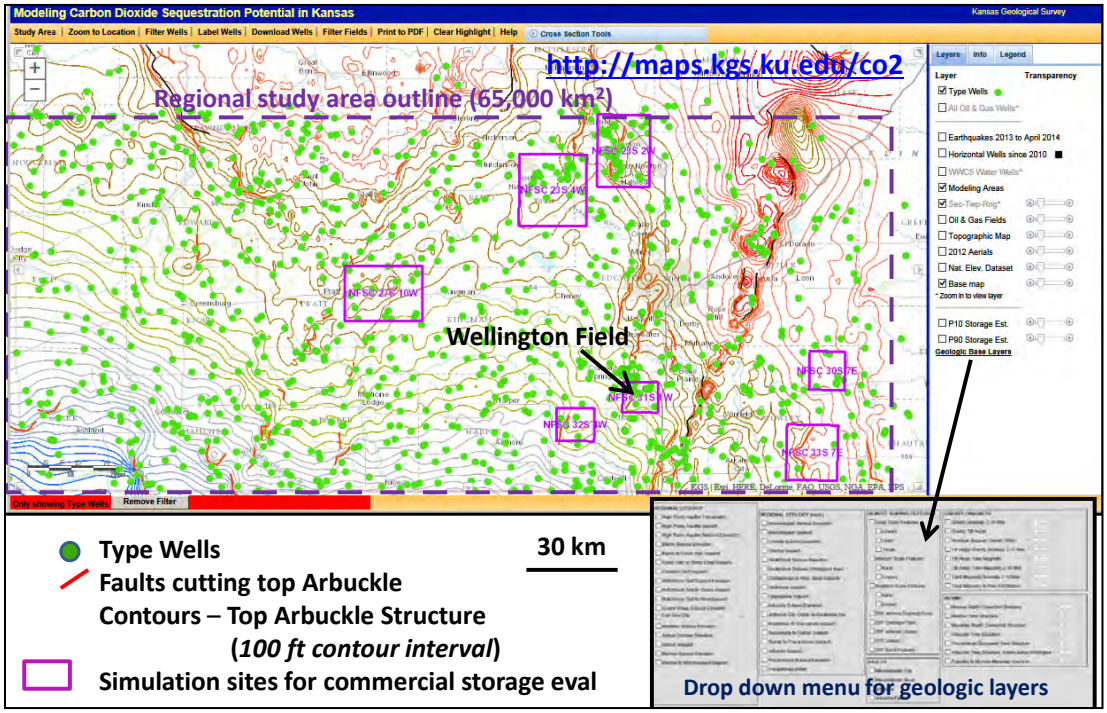


Figure 17. Interactive mapper showing the eastern 7 regional modeling sites, Wellington Field, and the type wells and faults on a structure map of the top of the Arbuckle.

The oil fields play an important role in making the economics of capturing the anthropogenic by utilizing for CO2-EOR (**Figure 18**). Screening of oil fields for suitability for CO2-EOR has been implemented on the interactive mapper including producing zone, depth, and cumulative production. API gravity will be used as a proxy for estimating minimum miscibility pressure.

The permeability prediction for use in the regional modeling and storage assessment has been a difficult exercise when we moved beyond the cored and fully logged calibration wells in Wellington and Cutter Fields. However, a consensus was reached on the realizations that are being generated to and complete the sequestration potential task.

The key decision was to move to a neural network solution after having examined many alternatives. That testing of the latter proved troublesome even though in concept, the originally looked quite promising, e.g., fuzzy logic. The neutral net is being validated with the calibration wells. The input variables include the well logs that have been digitized in the regional study

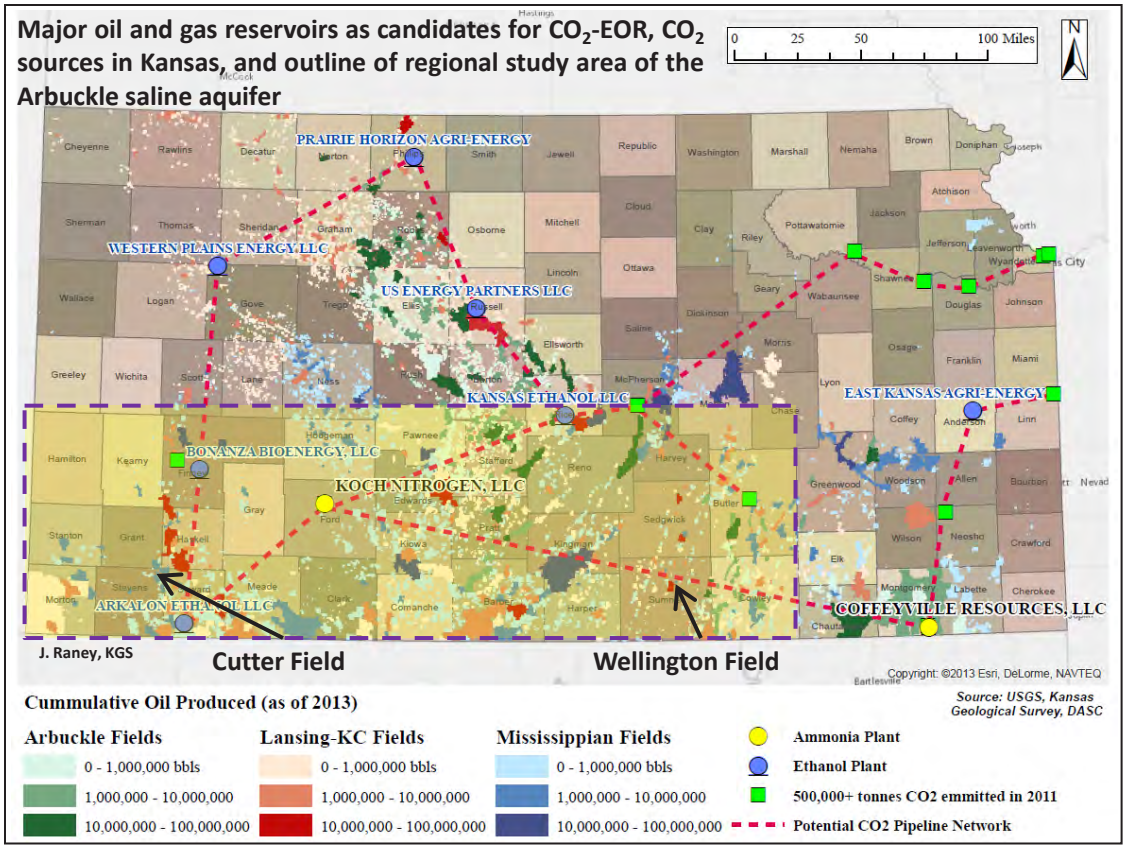


Figure 18. Key oil fields that are targeted for CO2-EOR and hypothetical pipeline framework to get CO2 to the oil fields.

area including gamma ray, porosity, and connected porosity computed by the Archie Equation when Rw is known (**Figure 19**). The CGR, corrected gamma ray, is preferred, but it is not available unless a spectral gamma ray was run (**Figure 20**). The cleaner, low GR intervals commonly contain the grain-supported rock often with matrix porosity. While not a rule, this is quite common in Paleozoic carbonates. The total gamma ray has to suffice, but dolomites like in the Arbuckle can have elevated gamma ray and would be possibly biased to lower permeability.

Porosity is correlated to permeability and is the primary variable that correlations are generally made. However, the permeability in the Arbuckle dolomites cannot be estimated from porosity alone unless the other important variables are considered (**Figure 21**).

Connected porosity is a useful indicator of higher permeability (**Figures 22 and 23**). Since hydrocarbon is not a factor in the saline aquifer, the electrical connectivity of the pores becomes a good indicator of the permeability.

The neural network utilizes these variables to provide a "realization" of the permeability (**Figure 24**). The use of realization is to indicate that is an approximation with an uncertainty that has yet

to be thoroughly established. The uncertainty will be introduced from studies of the outcomes when computed injectivity can be compared with observed results.

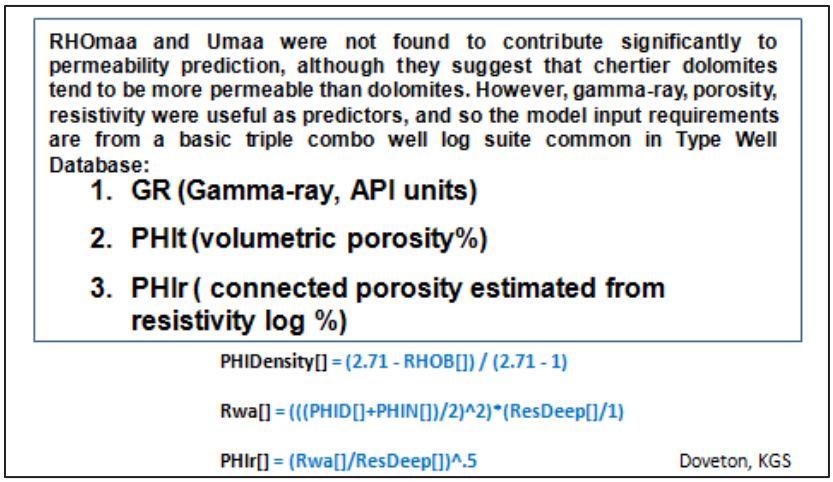


Figure 19. Input variables for the neutral network solution to estimate permeability.

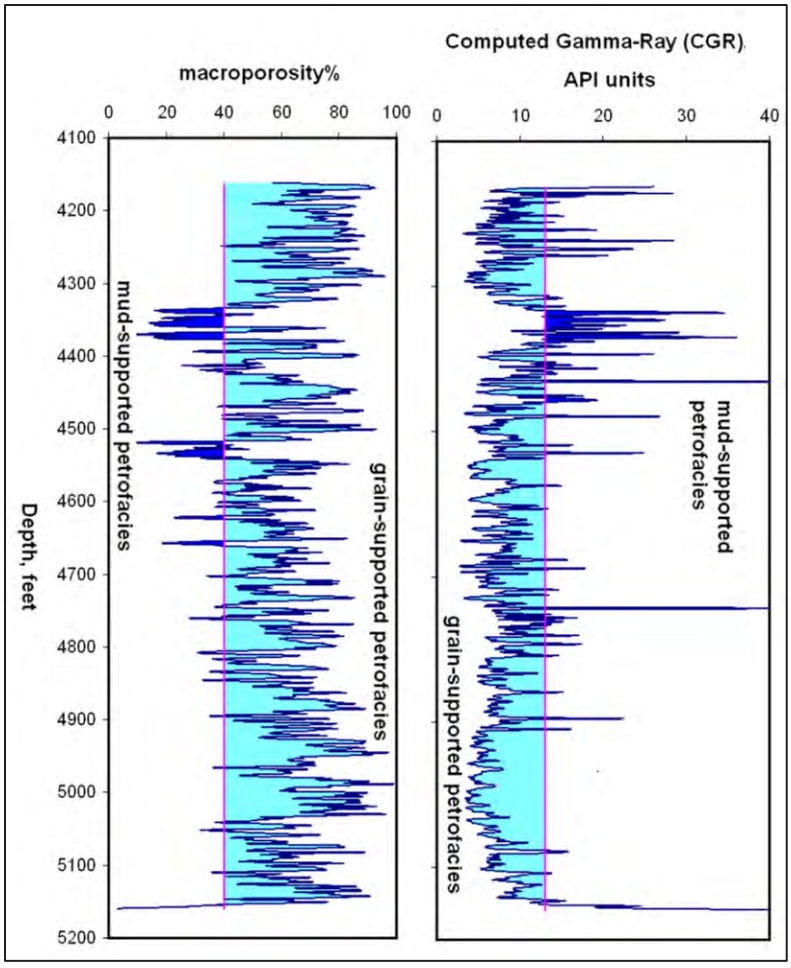


Figure 20. The CGR (K+Th) shows good distinction between more permeable grainstones and less permeable mudstones. Complication: Standard gamma-ray logs include uranium, which may bias grainstones towards mudstones

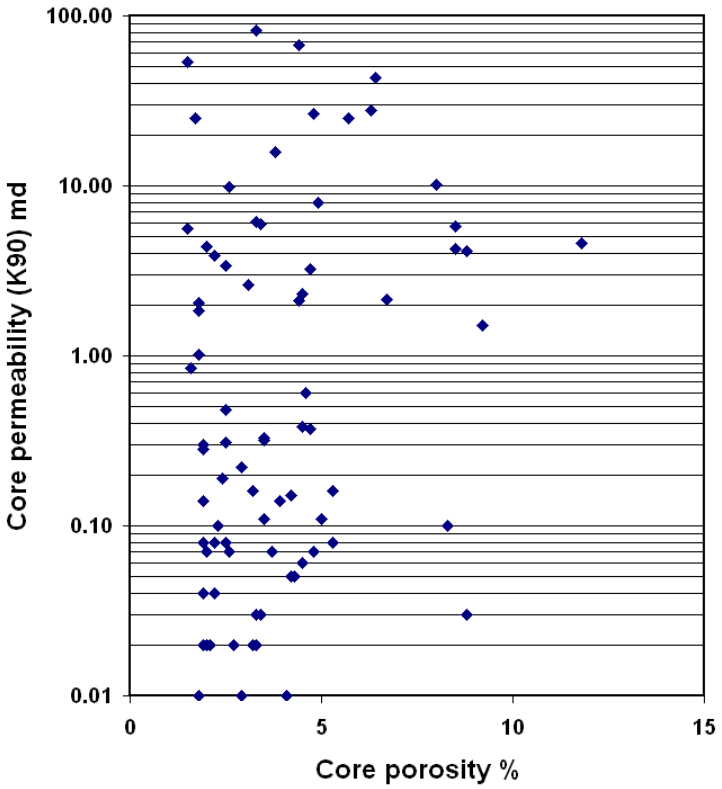


Figure 21. PHIt (volumetric porosity%). There must be some relationship between porosity and permeability.

From the first Archie equation for carbonates:

$$F = \frac{R_o}{R_w} = \frac{1}{\Phi_R^2}$$

where Φ_R is the electrically connected porosity.

So,

$$\Phi_R = \sqrt{\frac{R_w}{R_o}}$$

Complication: Rw is significantly higher in the top of the Arbuckle than in the middle and this variability needs to be accommodated in the calcuation of PHIr

Figure 22. Connected porosity is estimated from resistivity logs when Rw is known. (Hint: the connected porosity should not exceed the total porosity.)

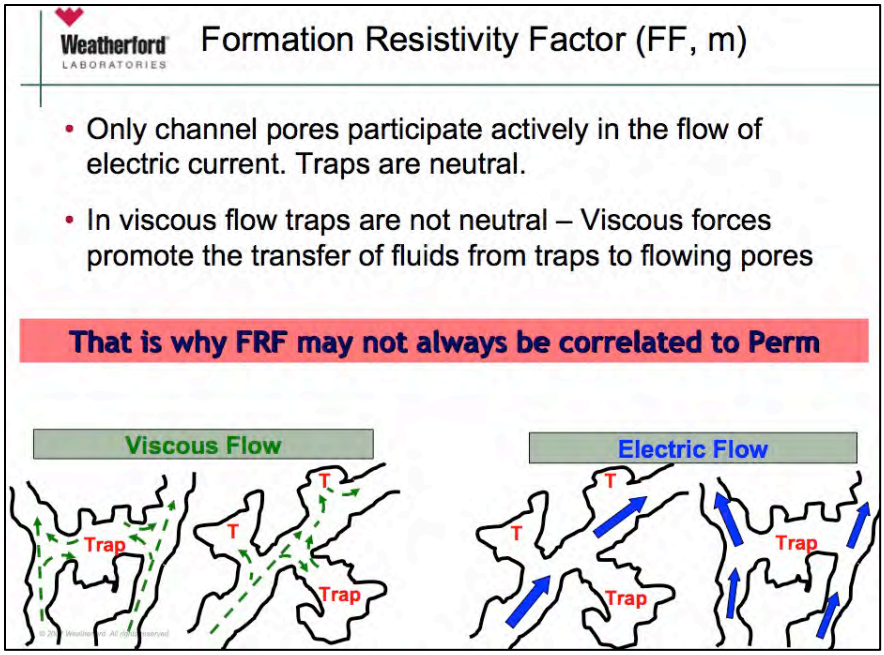


Figure 23. Weatherford warns that electrical connectivity does not necessarily mimic fluid connectivity, but they imply that it is worth trying.

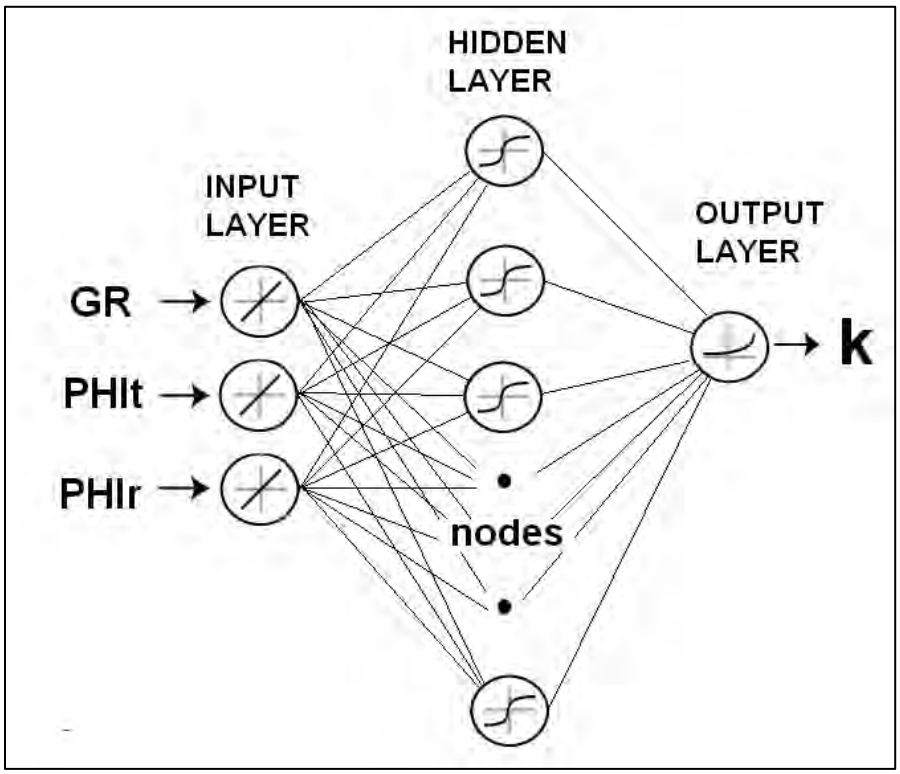


Figure 24. Neural network (NN) prediction of Arbuckle permeability from logs

Results of permeability estimated from the neural network compared with actual permeability indicate that the dynamic range is quite good compared to trials with other methods. The 40-node model was selected for use in creating the permeability realizations for the type wells (**Figure 25**). While the R-squared is below 21% for the 40-mode neural network, it is the best result in the trial and error process that was pursued over the past year (**Figure 26**).

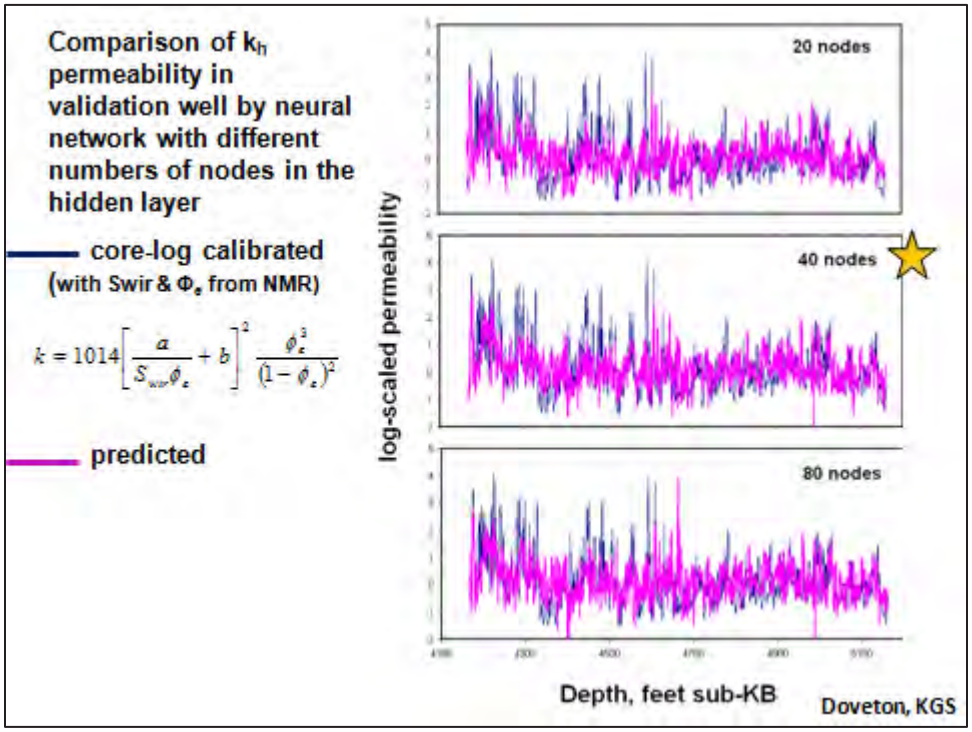


Figure 25. Prediction of permeability in the Arbuckle of the validation well Wellington #1-28 from regression analysis of calibration well #1-32 based on gamma-ray, porosity, and electrically connected porosity.

The need to establish an Rw to determine connected porosity is a matter of fitting a Ro line on a Pickett plot, iteratively fitting the Rt with the Ro line to solve for Rw, or plot a Rwa vs depth. The resulting Rw generally varies with depth in the Arbuckle and once that trend is established, the Rw can be extrapolated as is being done in this neural network methodology (**Figure 28**).

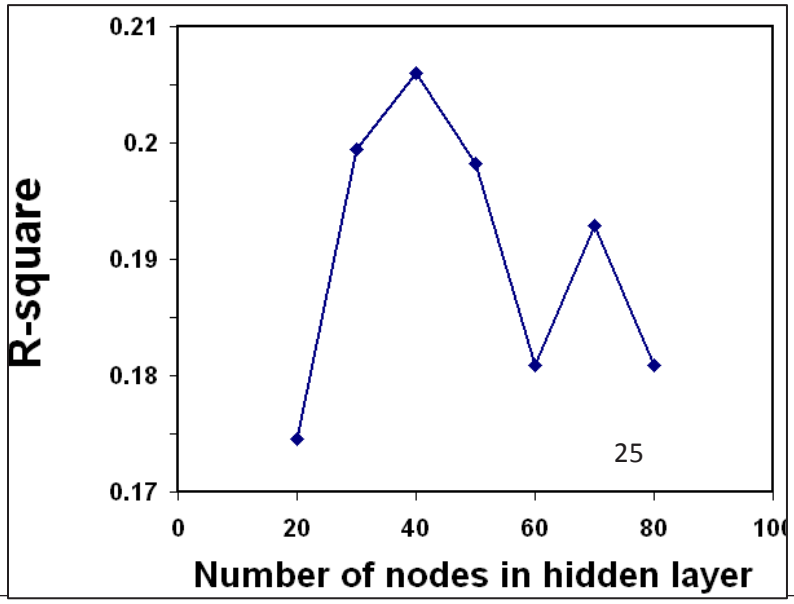


Figure 26. R-square of NN predictions of permeability with actual permeabilities in validation well #1-28 for different number of nodes in the hidden layer.

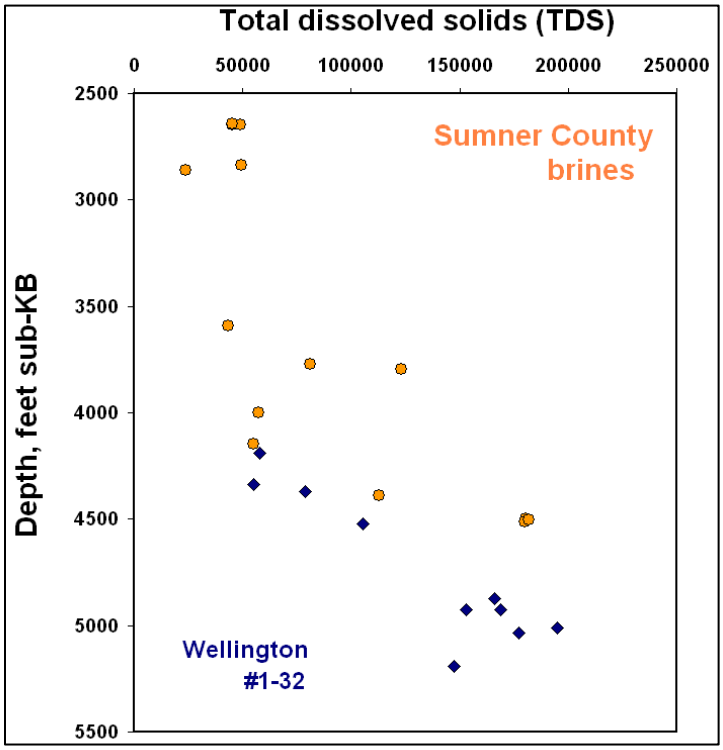


Figure 28. Use catalog salinities for validation purposes and estimate Rw from Pickett plot and/or Rwa versus depth.

Once the permeability is established and distributed to the wells, the next steps include estimating the vertical permeability and defining the flow units. Considerations were given to the use of "Fisher Plots" as shown in **Figure 29** for the wells #1-32 and #1-28. This methodology includes 1) use the log of Kh, 2) determine the mean – using only depths where Kh is provided, 3) at each depth calculate the deviation of the Log(Kh) at that depth from the mean Log(Kh), 4) plot the cumulative deviation vs depth where continual changes in direction indicate a zone of commonality (**Figure 29**). While this approach was considered, a visual correlation of flow units based on a combination of plots of Kh and Kv was defined to establish a reliable, regional correlation of flow units (**Figures 30 and 32**). Since the pore types and abundance are closely linked to lithofacies and stratigraphy, this is a satisfying outcome.

The flow units have been extended to all the wells that have penetrated the Arbuckle interval and structure and isopachous maps have been constructed for each flow unit (Figure 33). The flow units and their attributes will initially be used to simulate commercial scale CO2 injection at the

10 regional sites (Figure 33). Since the permeability (Kh and Kv) and porosity are reported for every half foot, the data will be upscaled to accommodate the large volume of the model.

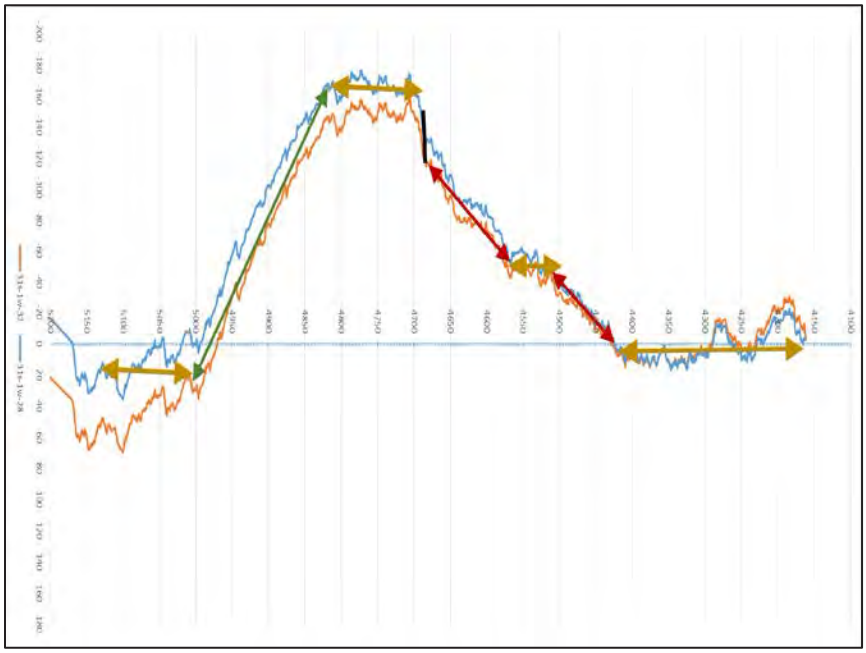


Figure 29. Flow unit Fisher Plot – Cumulative deviation of the log kh from the mean log Kh versus depth for Wellington KGS #1-28 and #1-32. Arrows indicate zones of commonality where cumulative permeability increases at various rates.

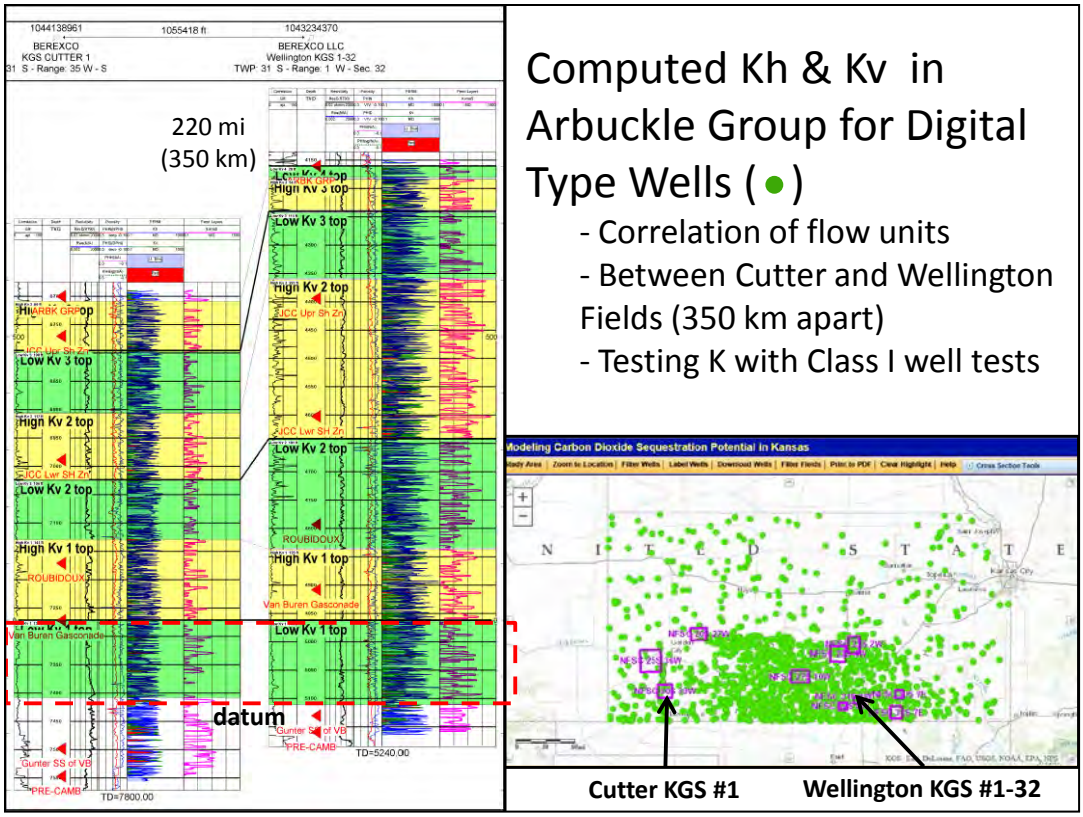


Figure 30. Cross section between Cutter KGS #1 and Wellington KGS #-32 Arbuckle flow units based on Kv and Kh closely tied to stratigraphic units.

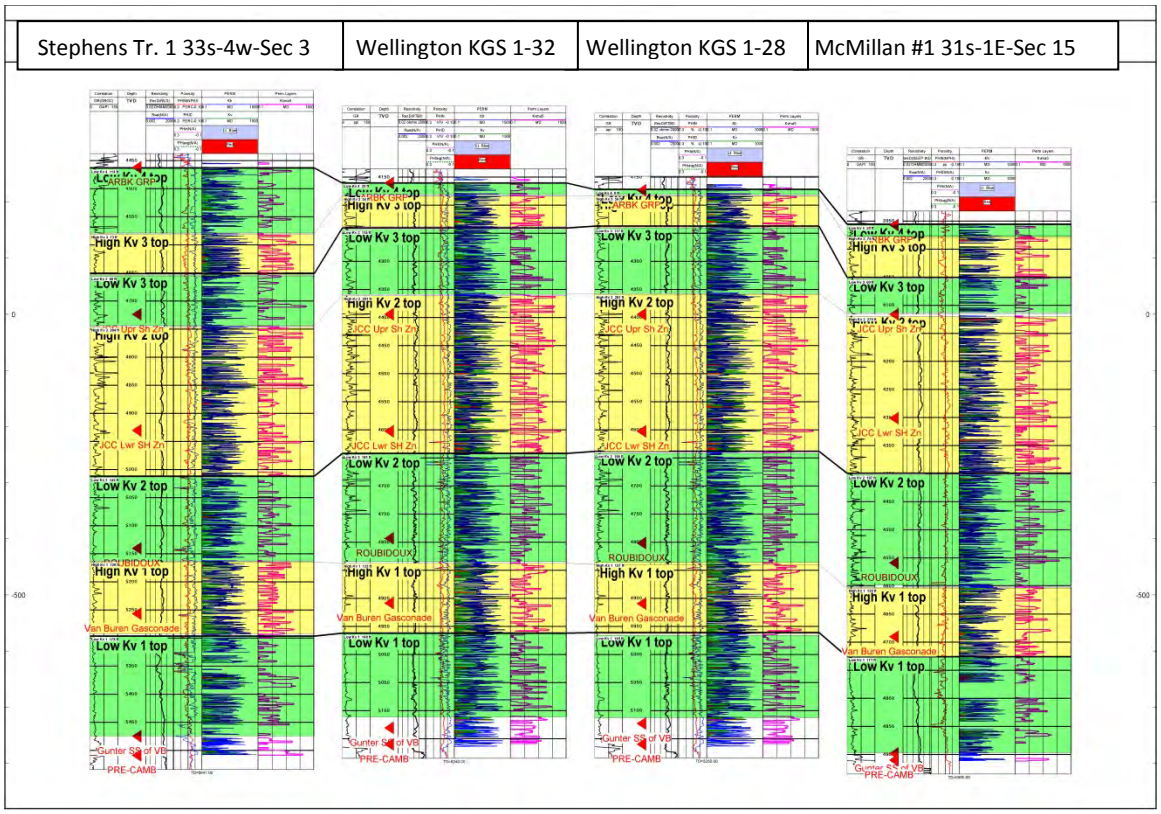


Figure 31. SW-NE cross section illustrating correlation of flow units in the Arbuckle in the vicinity of Wellington Field.

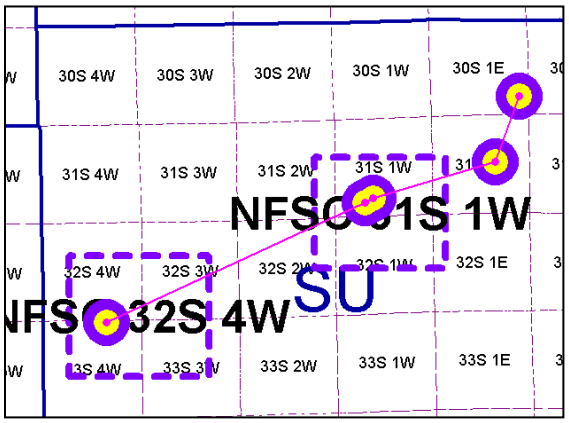


Figure 32. Cross section index for cross section shown in Figure 31.

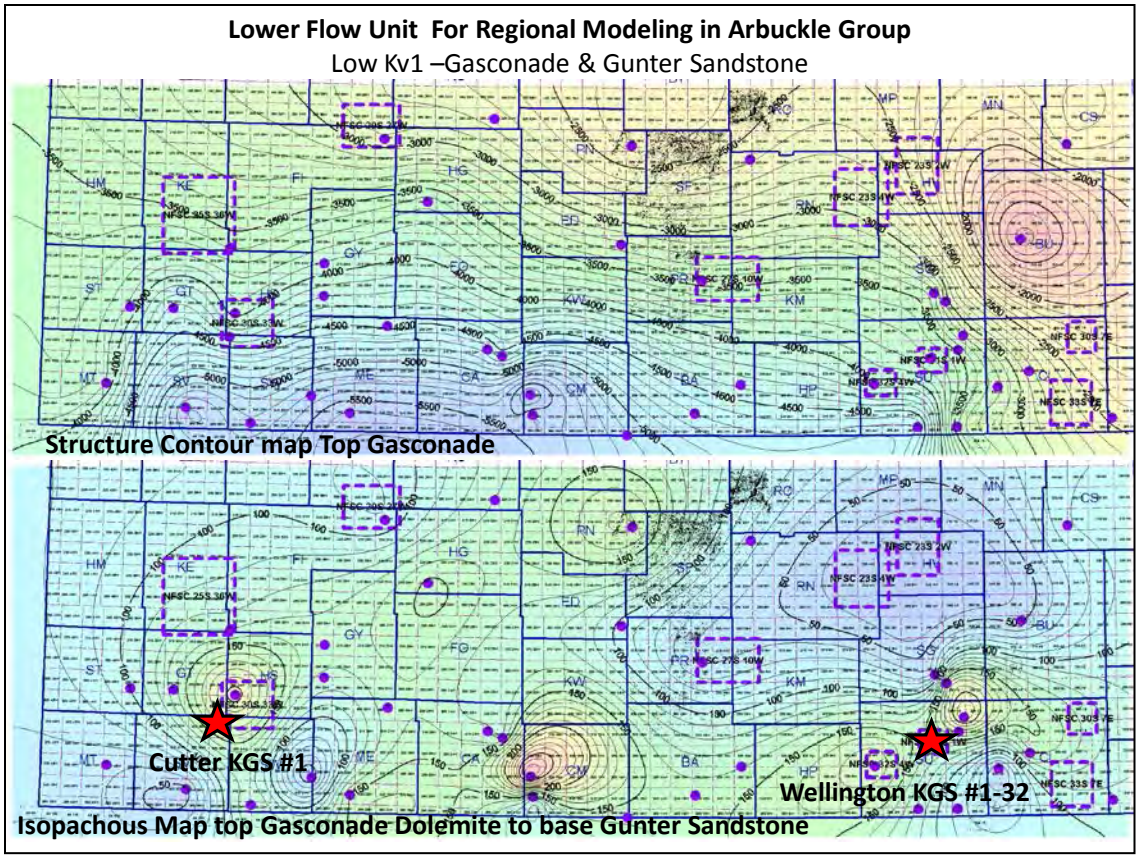


Figure 33. Structure and isopachous maps of the lower flow unit of the Arbuckle for the southern Kansas study area. Purple boxes identify the locations of regional simulations.

Simulations and estimates of CO2 storage capacity will also utilize the capillary pressure to account for an important trapping mechanism of CO2 (**Figure 34**). The standard capillary tables will be used as input into the simulations. It has been previously demonstrated that considerable amounts of microporosity exist in the Arbuckle, including the injection interval, that would contribute to trapping CO2 (**Figure 35**).

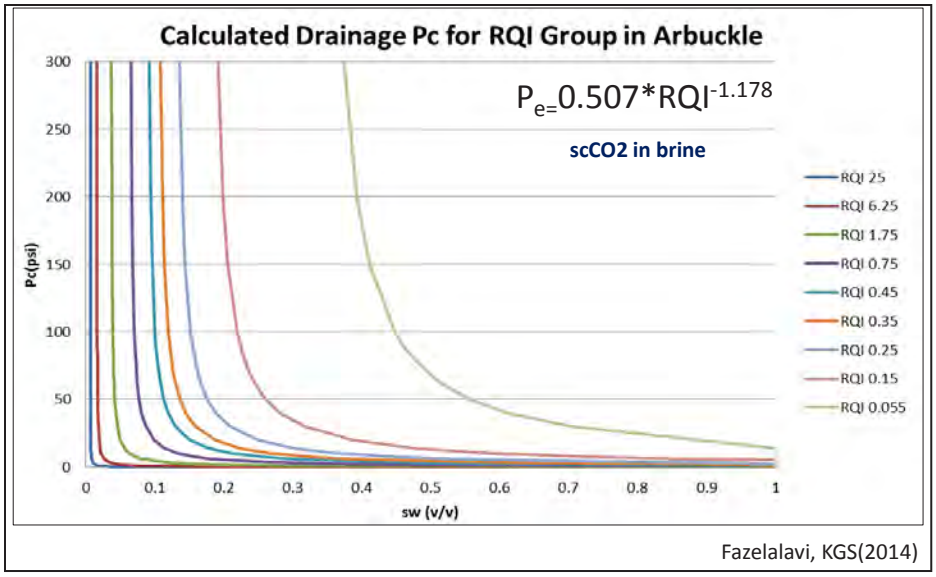


Figure 34. Range of pore types in Arbuckle Group quantified by reservoir quality index (RQI).

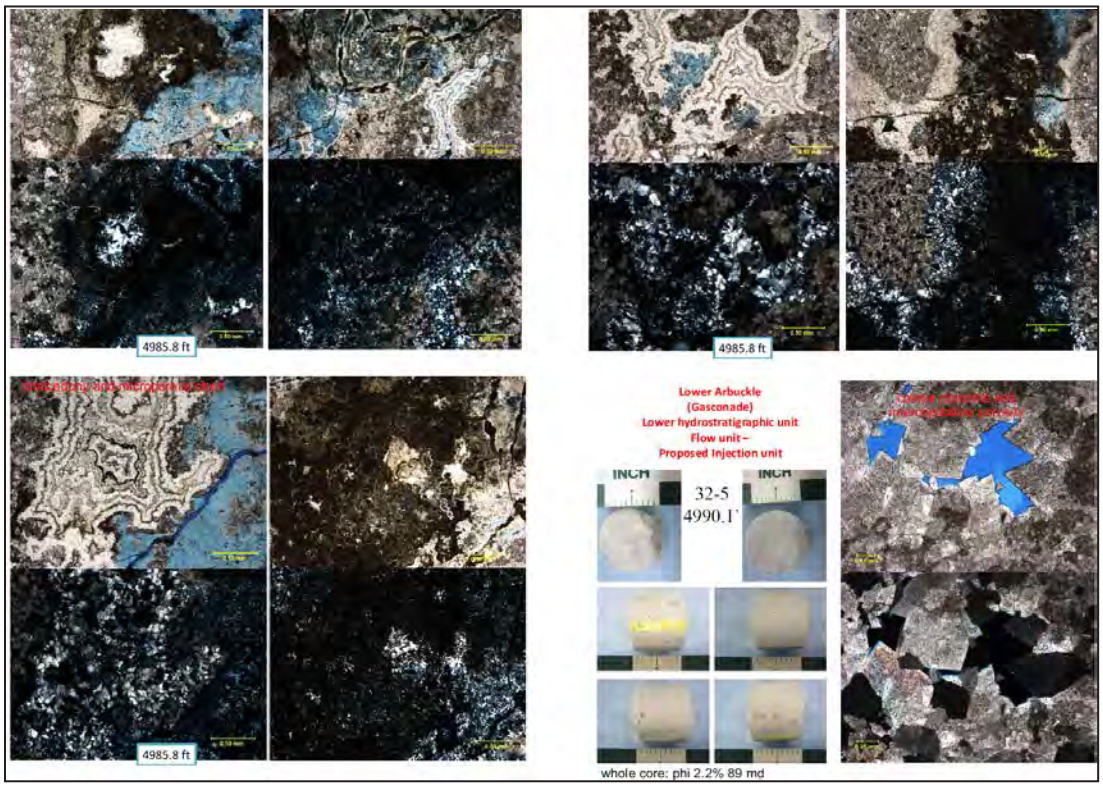


Figure 35. Microporosity is abundant, even in the lower Arbuckle injection zone that would be important for capillary trapping (imbibition) of CO2.

Java Web Application Update

The analysis and visualization of the petrophysical data used in the regional assessments and interpretations is facilitated by the Java web applications tools, available as standalone **http://www.kgs.ku.edu/Gemini/Tools/Tools.html** or accessible via the interactive mapper.

New Database Connection to Retrieve Data

A new database connection was developed to retrieve data that is now common to all of the web apps. Eventually, all GEMINI Tools will be combined into one directory structure to facilitate access and use of all (12 and counting) of the apps including passing information from one application to another. This integration will also facilitate updates to the software since one change can then be compiled for all 12 web apps instead of making 12 changes and recompiling, thus minimizing the chances for mistakes.

Type Log Applet Update

TYPE LOG APPLET is a vital means to keep the stratigraphic nomenclature and classification current and will be available to revise and refine the stratigraphic units (top picks) for the 502 type logs currently available for the state of Kansas. The application allows the user to add, modify, or verify existing stratigraphic units (tops). A stratigraphic committee will review the type logs and test the application before the completion of the project.

The procedure has been simplified with basic testing completed.

Step 1: Login to Enable Image Map:
Enter your email address into the text field and select the "Login" Button.
The "Display Wells in County Map" Button will turn Yellow, meaning it is selected.

Step 2: Choose Button to Display Wells by County or by Area:

Step 3: Click on Map to Plot Wells on a Township-Range-Section (TRS) Grid County Map or Area Map.

Step 4: User would review wells in assigned area containing “skeleton” stratigraphic units (top picks).

Step 5: User can agree with picks (top depths) or not. If you select one of the units, a dialog will appear identifying the owner of the top and asking you to "Agree" or "Disagree". If you do not agree with picks you need to enter a different depth, and then select the "Disagree" Button.

Step 6: If you enter a NEW Stratigraphic Unit (top pick) for a well, a top that is not already created, you become the owner for that top for that well. All other users can agree or disagree, if they disagree PLEASE put a depth you feel the top should be at.

- Only the owner of the top pick within a specific well will be allowed to change the depth. When you select the top a dialog will appear with the owner at the top of the dialog.

- For Each Top Pick within each well must have at least 3 people agreeing with the depth for the
  - top to be accepted as "GOLD". The goodness of a top pick has 4 levels as follows,
  - Lowest Level: "LEAD" The user creates a top within a well.
  - "COPPER" At least ONE Person agrees with your depth for the top pick.
  - "SILVER" At least TWO People agree with your depth for the top pick.
  - Highest Level: "GOLD" At least THREE People agree with your depth for the top pick.

  NOTE: you can have any number disagreeing with your pick, but you only need three to agree to make it "GOLD".

Step 7: The Well is considered "COMPLETE" when at least 95% to 100% (100% is better) of the top picks are "GOLD". Mission accomplished.

User will be able to examine correlations in cross sections at assist in making refinements (**Figure 36**).

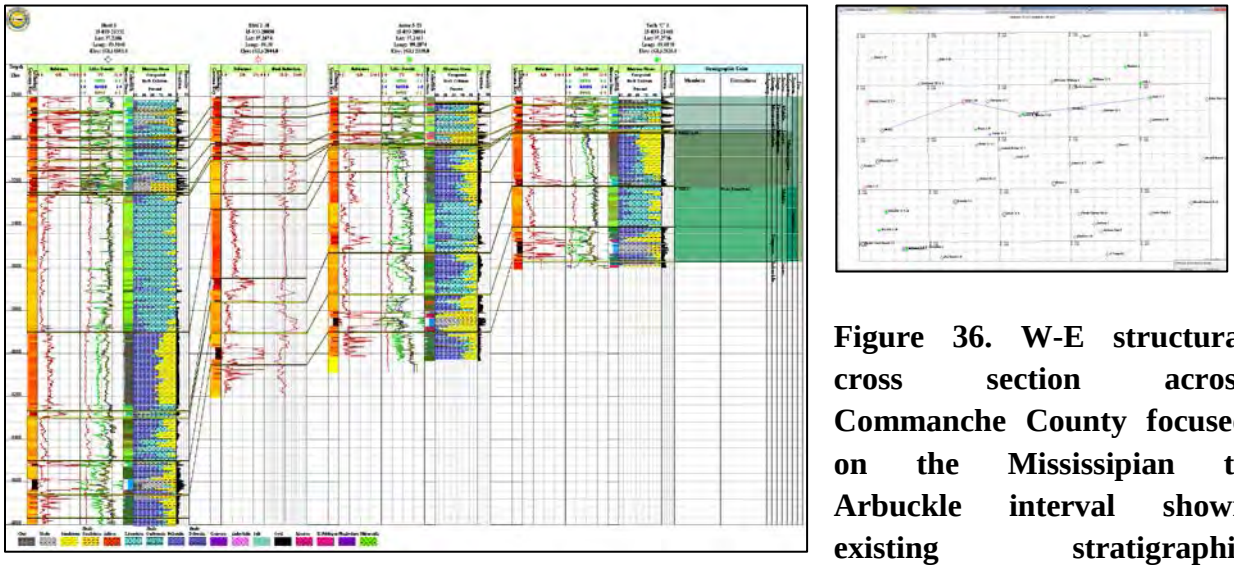


Figure 36. W-E structural cross section across Commanche County focused on the Mississipian to Arbuckle interval shown existing stratigraphic correlations and lithologic variability that will provide useful in establishing the correllations.

GEMINI Source Directory Update

All the web apps are now part of GEMINI after merging the Kimeleon Source Code. Presently the following web apps are part of the GEMINI Source Directory,

- Drill Stem Test (DST) Data Entry & Quantitative Analysis
- PfEFFER-java
- Hingle & Pickett Plots
- Kimeleon
- Zone Kluster (Zeke) - A Depth Constrained Cluster Analysis
- Profile (Expanded LAS File Viewer)

Specifically the primary source code that is common to all the above web apps are the Input-Output (I/O) Java Files. Read & Write Log ASCII Standard (LAS) files, Read Comma-separated values (CSV) files specifically for Tops, Core, although geologist report is included. Also the Kansas Geological Survey (KGS) well data download specifically LAS Files and Image Files and KGS Database downloads, i.e., Core Data, Tops Data, Perforation Data & DST Data. The following web apps still need to be added to the GEMINI Directory Structure,

- Synthetic Seismic Profile Plot
- 3D & 2D Cross Plots
- KGS Well Data Web Site - specifically the "Display Using Gemini" (LAS) Applet.

Production Plot & Decline Curve Analysis does not really have any common java source files so it will not be included in the GEMINI Java Source Directory. Cross Section may ultimately be separate from GEMINI because of the plot tracks and how they are handled, but the I/O is the same as above. There are a few of web apps that also need to be considered for inclusion in GEMNI,

- LAS File Viewer, which is really a subset of the Profile web app
- LAS File Viewer with Wavelet Analysis.
- Digitize Electric Well Log (E-Log) Images (Digitizer)

Finally, the LAS File Viewer may be replaced by using Profile and removing the input dialogs and allowing the user read in their data by the I/O Java classes. This decision will be made before the completion of the project. Current GEMINI app directory is shown in **Figure 37**.

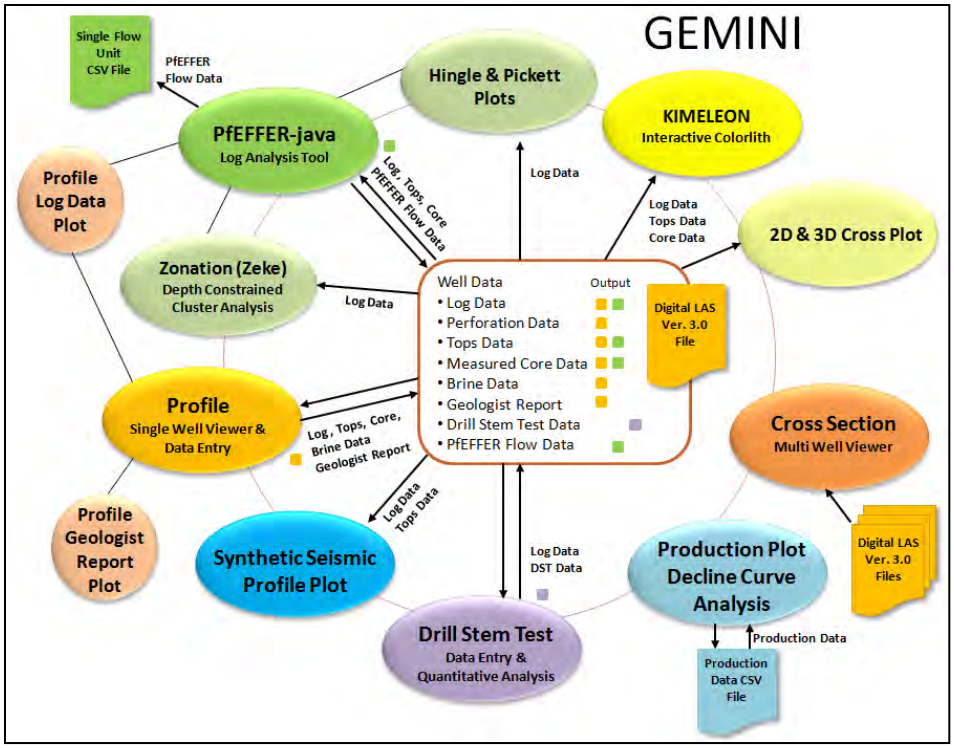


Figure 37. Gemini Directory of Java Apps

Java Commonality

The Gemini Java File Matrix provides commonality of the files with each web app. There is also an I/O web app that is on both files, which identifies the base Input-Output (I/O) Java files that are basically common to all the web apps. The I/O web app only reads in the well data and writes the data to a Log ASCII Standard (LAS) version 3.0 file.

The I/O Java Files composed of the following,

- Read Log ASCII Standard (LAS) version 2.0 & version 3.0 Files
- Write Log ASCII Standard (LAS) version 3.0 File
- Read Comma-separated Values (CSV) Files
- Read Extensible Markup Language (XML) generated in the Kansas Geological Survey (KGS) ORACLE PL/SQL Stored Procedures.

Improve Structure and Coding of Java-Applications Toward Commercialization

A proposal was prepare for an internal completion at KU to acquire funds that directed toward the commercialization of the Java web applications used to manage and view the data. The essence of this application is included in **Appendix F**.

Task 13: Regional Source-Sink Relationships in approximately 17 Counties in South-Central Kansas

Subtask 13.1. Map major point CO_2 sources in Kansas
Subtask 13.2. Map major CO_2 sinks in Kansas

The practical and economic linkage of the CO2 source and sinks has been taken up with the Kansas Governor's Office and the Department of Commerce. See **Appendix E**.

Task 14: Technology Transfer

Subtask 14.1. Build and maintain project website with interactive access to data and analyses via graphic display and analytical web tools
Subtask 14.2. Link project web-site to relevant DOE databases
Subtask 14.3 Submit project results to peer reviewed journals for publication

Task 15: Extend Regional Study of Ozark Plateau Aquifer System (OPAS) to the Western Border of Kansas – "Western Annex" and extend the type log database to include the whole state of Kansas to address fluid flow under commercial scale CO2 sequestration.

Subtask 15.1. Extend regional study by evaluating CO_2 sequestration potential in 5000 mi^2 area west of the existing 17+ county area and extend the type log database to the whole state of Kansas to address fluid flow under commercial scale CO_2 sequestration.

Subtask 15.2. Create consortium of companies

Subtask 15.3. Encourage development of business plan to sequester emitted CO_2

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

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

Subtask 16.2. Analysis of KGS's gravity and magnetic data
Subtask 16.3. Remote sensing analysis

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

Subtask 17.1. Collect existing seismic, geologic, and engineering data – Chester/Morrow fields
Subtask 17.2. Select Chester/Morrow field to acquire new data

Subtask 17.3. Collect new multicomponent 3D seismic survey
Subtask 17.4. Process multi-component 3D seismic survey

Subtask 17.5. Develop initial geomodel for the selected Chester/Morrow field

Cutter and Eubanks Seismic Processing and Interpretation

The focus for the seismic interpretation using the p- and s-wave Cutter and Eubanks fields has been the lithological classification of the oil reservoir is via Hampson-Russell software. Useful results appear to be coming from both post-stack and pre-stack inversion. The pre-stack inversion results are then theoretically useable for a further classification to discriminate sand/shale/carbonate, etc. This is also done inside Hampson-Russell. It is clear that inversion alone moves us to a significantly greater understanding of the broad lithological context.

green = mostly shale
yellow-orange = mostly sand
blue-magenta = mostly carbonate

Several preliminary examples are shown from Cutter (**Figure 38**) and Eubank

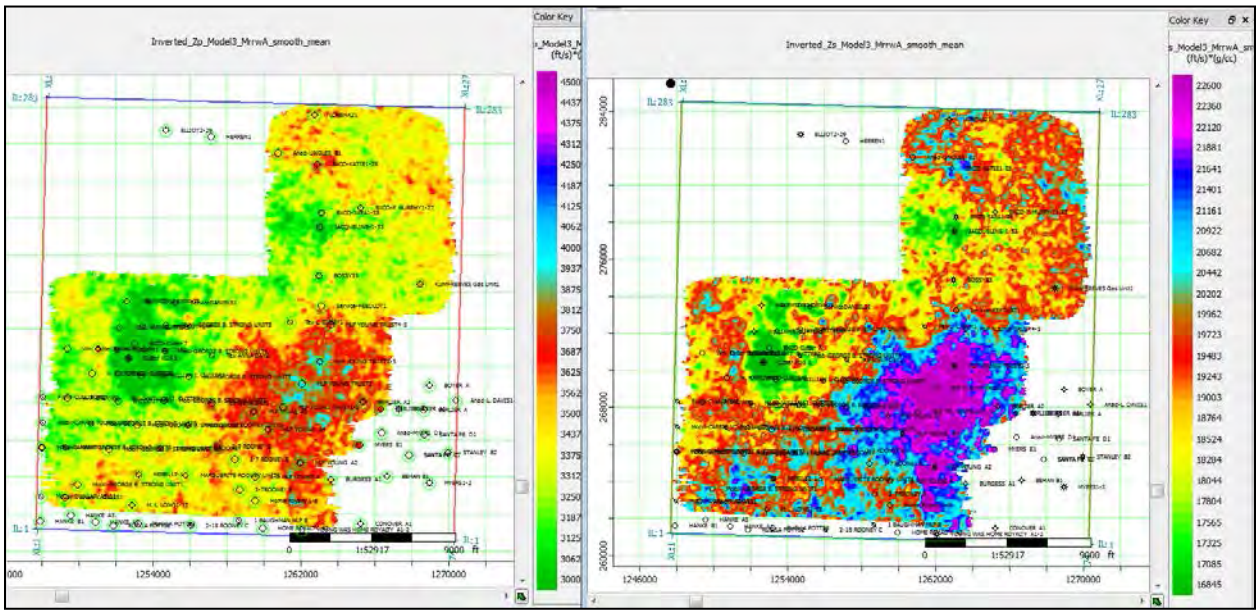


Figure 38. Preliminary velocity*density inversions in the Morrow Shale interval in Cutter Field.

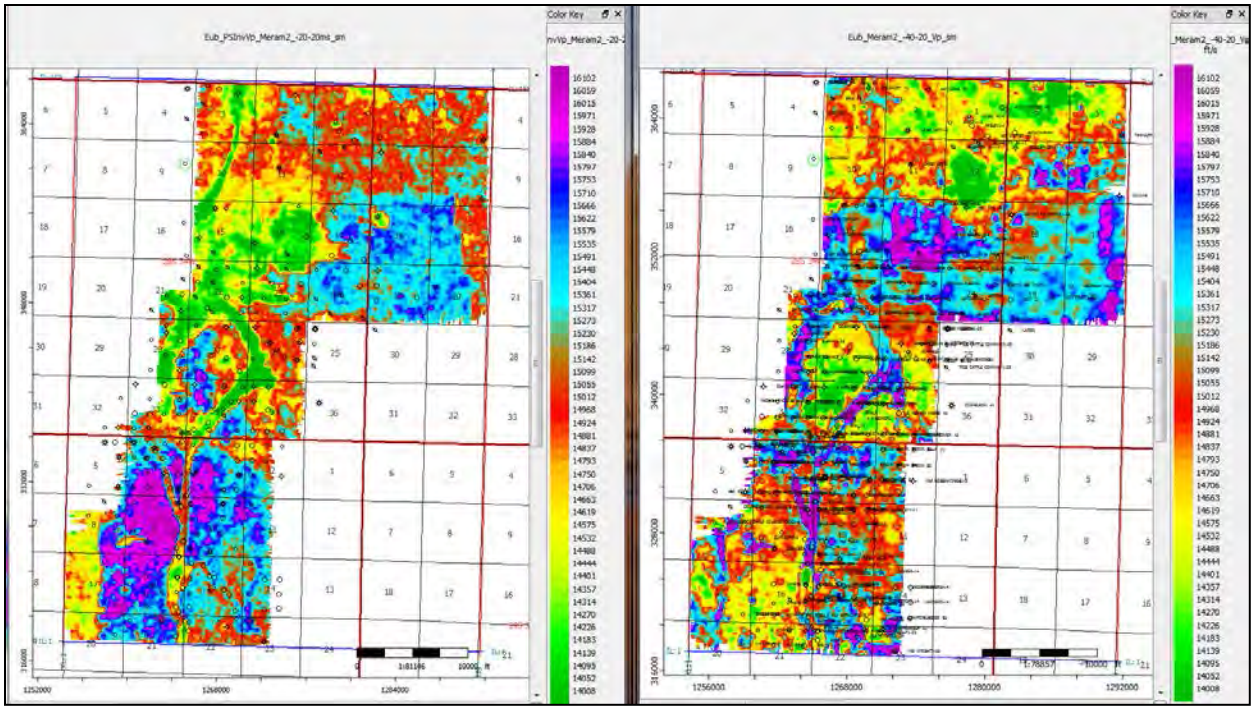


Figure 39. Preliminary post- or pre-stack inversions of the velocity extraction 20-20 (20 ms above Meramec, with a window extending upward 20 ms) in Eubank Field.

Seismic Interpretation of the Arbuckle at Cutter Field

Clyde Redger, a student at KU, is conducting his thesis work titled, "*Seismic Reservoir Characterization of the Arbuckle Group and the Upper Morrow Sandstone from 3D-3C Seismic Data at the Cutter Field, southwest Kansas*". This study will augment work by Hedke-Saenger and assess the capability of using multicomponent seismic methods to characterize Arbuckle and Upper Morrow sandstone reservoirs. Seismic attributes including acoustic impedance, shear impedance, and Vp/Vs ratios will be extracted from 3D P-wave and PS-wave volumes and will be used to generate reservoir property predictions. The accuracy of these predictions will be assessed with blind wells. This research is significant in that it will develop seismic methods for characterizing Arbuckle and Morrow reservoirs in the southwest Kansas region. Improved reservoir characterization in Arbuckle and Upper Morrow sandstone reservoirs could potentially benefit future enhanced oil recovery operations and CO2 sequestration projects.

Subtask 17.6. Select location for Test Borehole #3
Subtask 17.7. Complete permitting requirements for Test Borehole #3
Subtask 17.8. Drill, retrieve core, log, and run DST – Test Borehole #3
Subtask 17.9. Openhole Wireline Logging – Test Borehole #3
Subtask 17.10. Wellbore Completion – Test Borehole #3
Subtask 17.11. Analyze wireline log - Test Borehole #3

Subtask 17.12. Test and sample fluids (water) from select intervals – Test Borehole #3
Subtask 17.13. Analyze Arbuckle core from Test Borehole #3
Subtask 17.14. Analyze Chester/Morrow core from Test Borehole #3
Subtask 17.15. PVT analysis of oil and water from Chester/Morrow oil reservoir
Subtask 17.16. Analyze water samples from Test Borehole #3

Update Kansas State University by Saugata Datta, Brent Campbell, Michael Vega

Water Chemistry Analyses

The analyses performed were for cation concentration determination in this quarter for both the swabbed and DST depths. Mass balance between cation and anion data was determined and was within the 5% acceptable range. Reanalysis of the water samples will be determined to ensure accuracy for both cations and anions. Samples will be analyzed again for cations at KGS this week for confirmation.

LLNL

We will be working with Dr. Susan Carroll and Dr. Megan Smith from LLNL starting this summer. Our earliest projected start date, from Susan Carroll, is June 23rd. Our prediction that we will be able to analyze 1-2 cores this summer depending on the time it takes for each core plug. Core plugs have been sent to Dr. Jessie Maisano and Dr. Matthew Colbert of UT Austin's lab for our CT scans of the core plugs. We have sent 7 core plugs for pre-experimental flow through analysis and imaging. Michael Vega and Brent Campbell have been approved and received Academic Cooperation Participant status from LLNL.

Seven core plugs were chosen (five from Cutter, three from Wellington) to perform supercritical CO_2 flow through experiments at Lawrence Livermore National Laboratory. These designations were made based on mineralogical and petrophysical properties because these play a vital role in the overall water-rock geochemistry of CO2 induced mineralization and precipitation reactions.

Mineralogy Updates

Upon completion of the core plug analyses for Cutter KGS#1, further fine scale investigation was desired in order to supplement features observed in cores. Twenty-five new thin sections have thereby been processed where results will shared in a few weeks' time:

The goal is to have a complete document with photomicrographs from each section and detailed descriptions by Mid-May, 2014.

Cutter KGS #1 Brine Analyses

Field Data

Name	Units	Swab 1	Swab 2	Swab 3	Swab 4	Swab 5	Swab 6	Swab 7	Swab 8	Swab 9
Date		6/25/2013	6/26/2013	7/1/2013	7/9/2013	7/10/2013	7/16/2013	7/22/2013	7/22/2013	7/23/2013
Depth	ft	7,543-7,532	7,442-7,430	7,234-7,218	7,056-7,046	6,904-6,880	6,686-6,676	6,558-6,543	6,204-6,194	6,010-6,000
Notes		45um filtered	45um filtered	45um filtered	45um filtered	45um filtered	unfiltered	unfiltered	10um filtered	10um filtered
LDO	mg/L	-	-	2.04	2.15	2.2	5.05	5.78	2.9	1.87
Salinity	ppt	-	-	-	-	-	>70.74	64.56	>70.74	>70.74
Conductivity	mS/cm	-	683	-	-	-	29.3	90.2	52.1	6.49
ORP	mV	-293.1	-	240	-38.7	-128.4	-97	59.9	-64.1	-110.4
pH		7.19	6.71	6.79	6.52	6.71	6.9	8.07	6.6	6.77
Resistivity	MΩ-cm	6.61	-	3.1	2.42	2.01	3.44	1.11	2.08	1.14
Temp.	°C	34.4	38.6	-	30.4	34.7	21.3	25.8	36.7	37.6
TDS	mg/LΩ	7.8	-	-	-	-	14.87	44.8	25.1	3.25

Cutter Major Ion Data

Analyte Symbol	K	Mg	Ca	Na	Cl	SO4
Unit Symbol	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Detection Limit	0.1	0.1	0.1	0.1	0.03	0.03
Analysis Method	ICP-OES	ICP-OES	ICP-OES	ICP-OES	IC	IC
SWAB 1	1460	1190	9010	52600	67800	294
SWAB 2	1360	1140	8400	49700	41700	241
SWAB 3	987	896	6090	35600	106000	882
SWAB 4-Bad Run	23.6	14.1	104	648		
SWAB 4-Good Run	1100	898	6510	34700	43000	443
SWAB 5	1410	1470	9100	47600	76000	417
SWAB 6	1250	1300	8810	40000	29200	268
SWAB 7	1060	247	2430	19800	143000	4730
SWAB 8	814	865	5410	28700	53100	375
SWAB 9	803	1020	5420	23700	115000	1620
SWAB 10	830	363	1650	15900	20900	1790
SWAB 11	930	1290	6950	29700	11500	202
DST 1	1280	1070	7820	46600	68400	295
DST 2	963	858	5640	34300	12200	228

- **Note:** Swab 4 was reran due to inaccurate data return. 2nd test gave data in-line with other ion chemistry.

Cutter	Swab	Swab Depth	Sample #	Depth	Kmax	K90	Kvert	Por %	Reason
			2-30	5281.65	1025.558	Kh-plug	851.621	19.0	Upper Miss, very high perm and porosity.
Mississippian 5,480'	Swab 11	5,622-5,545	6-36	5578.70	3.340	0.163	<.001	1.6	Middle Miss, with thin and isotope data within 7 feet.
			9-1	6360.10	1.021	0.949	0.003	12.5	Thin section and isotope data available.
	Swab 6	6,686-6,676	15-25	6679.50	10.712	7.130	8.292	10.3	Thin section and isotope data available.
Arbuckle 6,700'			15-49	6703.90	15.724	0.312	3.688	3.6	High perm, low por
			16-1	6715.95	2.719	0.305	0.005	10.2	Lower perm, higher por.
			16-47	6761.40	7.002	0.383	0.798	3.7	Thin section and isotope data within 3 feet.
	Swab 5	6,904-6,880	18-42	6945.40	31.733	10.559	0.353	1.2	Within Injection, very high perm
	Swab 4	7,056-7,046	20-9	7098.50	2.849	1.908	0.013	3.6	Thin section and isotope data available.
			20-30	7120.25	24.516	19.733	3.685	1.8	Within Injection, very high perm
	Swab 3	7,234-7,218	22-45	7222.50	2.371	0.658	0.143	8.4	Thin section and isotope data available.
			23-10	7266.30	0.079	Kh-plug	15.809	2.6	Kvert much higher than Kmax, really low perm
?7,400'			24-29	7362.00	1.319	0.261	3.959	3.9	Kvert much higher than Kmax with low perm
Injection ?7,401'	Swab 2	7,442-7,430	26-3	7428.45	3.035	1.053	0.390	1.6	Thin section and isotope data within 1 feet.
	Swab 1	7,543-7,532	27-4	7533.00	5.785	1.798	0.077	4.9	Thin section and isotope data within 4 feet.
?7,500'	Swab 1	7,543-7,532	27-6	7535.60	1.114	1.106	<.001	5.6	Thin section and isotope data within 2 feet.
	Not Used								
	Swab 10	5,680-5,670							
	Swab 9	6,010-6,000							
	Swab 8	6,204-6,194							
	Swab 7	6,558-6,543							

Wellington	Swab/DST	Water Depth	Depth	Sample #	Reason
Mississippian 3,660'	DST 1	3,690-3,664	3684.20	3-25	Isotope data available, xrd and thin section within 7 feet
Arbuckle 4,160'	DST 4	4,190-4,175	4187.75	*12-47	Thin Section and Isotope data available
	DST 3	4,390-4,280	4342.50	16-49	Isotope data available, thin section within 23 ft.
	Swab 5	4,390-4,370	4379.10	*17-27	Isotope data, xrd and thin section available
4,900'	DST 2	4,575-4,465	4515.30	19-51	Thin Section available, Isotop within 4 ft.
Injection 4,901'	DST 7	4,937-4,917	4903.80	30-4	Isotope data, xrd and thin section available
	DST 7	4,937-4,917	4925.70	30-26	Isotope data, xrd and thin section available
	DST 7	4,937-4,917	4929.10	30-30	Isotope data availabe, thin section above and below
	Swab 1	5,015-4,995	4985.75	31-27	XRD and thin section available, isotope within 5 ft.
	Swab 1	5,015-4,995	4990.10	32-5	Isotope data and thin section available
5,130'	DST 6	5,047-5,026	5054.60	33-5	Isotope data and thin section available
			Robin Used		
			3678.90	3-19	Isotope data available, xrd and thin section within 7 feet
	Not Used				
	Swab 4	4,885-4,865			
	DST 8	4,885-4,866			
	Swab 3	4,938-4,918			
	Swab 2	5,020-5,000			
	DST 5	5,233-5,133			

March '14 Cutter KGS#1 Thin Section Order

Order No.	Sample No.	Formation Name	Depth
1	2-10	Morrow Sand	5261.1'
2	2-25	Morrow Sand	5276.5'
3	2-35	Morrow Sand	5286.25'
4	13-2	Kinderhookian	6501.3'
5	15-48	Simpson	6702.35'
6	16-27	Simpson	6741.45'
7	18-35	Simpson	6938.75'
8	19-9	Simpson	6972.8'
9	20-9	Gasconade	7098.85'
10	20-21	Gasconade	7110.35'
11	21-28	Gasconade	7177.25'
12	22-13	Gasconade	7190.7'
13	22-14	Gasconade	7191.4'
14	22-32	Gasconade	7209.9'
15	24-2	Gasconade	7235.25'
16	24-7-1	Gasconade	7340.55'
17	24-10	Gasconade	7343.2'
18	25-12	Gasconade	7405.3'
19	27-24	Gunter Sand	7553.65'
20	27-29	Gunter Sand	7558.7'
21	27-37	Gunter Sand	7566.2'
22	28-15	Gunter Sand	7582.1'

March '14 Wellington Thin Section Order

Order No.	Sample No.	Formation Name	Depth
23	13-41	Upper Arbuckle	4225.7'
24	13-46	Upper Arbuckle	4230.3'
25	14-4	Upper Arbuckle	4247'

Cutter KGS#1 Depthwise Petrographic Summary

Morrow Formation

The Pennsylvanian aged Morrow Formation is a ~200' thick tan to gray sandstone to mudstone that extends from 5250' to 5450' (roughly), with shaley mudstone to wackestone facies persisting within the latter 150'.

- Sands are poorly to moderately sorted (just a few times seen) with a prominence of fine to very fine grained sediments, however the variation in grain size approached very coarse grained in some samples (~5261.1', 5260.6'). Good intergranular porosity is exhibited throughout the upper half with the lower mudstone to wackestone portion being tight. Subrounded to subangular grains dominate the sandy portion of the formation. The Morrow shows quartz dominance in the upper sands and shaley argillaceous materials through the lower mostly micrite cemented mudstones, hinting at the possibility of carbonate cement in the sands.
- Wackestone to packstone facies in lower portion exhibit broken bioclasts, mostly in the form of crinoid stems and bivalves, at mostly <10% total surface area with ~30% at 5403'.
- Heavy oil show and odor is noticeable throughout the formation, as this represents the pay zone for Cutter field.

Chester Formation

The Mississippian Chester Formation is a ~180' thick gray/light gray to tan sandstone to siltstone to mudstone that extends from 5480'-5660', with gray to olive shaley mudstone to wackestone facies persisting in the first ~70', followed by ~10' of low porosity fine to very fine grained gray sandstone, then ~40' of gray/dark gray tight siltstone, ~30' of low to tight porosity of light gray to tan sandstone, with the final ~15' returning to tight gray mudstone to wackestone facies. Oil shows were present throughout the formation.

- The upper shaley mudstone to wackestone region (~5480'-5550) is tight with an abundance (~10-30%) of bioclasts (mostly crinoids) in the wackestone facies, although the overall zone is predominantly mudstone with wavy nonparallel shaley laminations (~50%).

- The upper sandstone (~5558'-5570') exhibits low porosity, is quartz dominated, and is fine to very fine grained. Wavy shaley lamination and small (mm wide) black shaley fragments are present throughout.
- The siltstone zone (~5571.6'-5610.4') shows to be very tight with mm scale pyrite grains present in almost half of the samples, sometimes as cherty replacement textures (low chert content overall i.e. <10% of samples). Dark wavy shaley laminae persist through a majority of samples and ~28% of samples exhibit bioturbation structures typically in the form of burrows. Quartz dominance and predominantly micrite cement make up the lithologic components in addition to scattered pyrite as described above.
- The lower sandy portion of the Chester (~5611.4-5643.9') is tan to light gray and fine grained. Slightly fractured regions exhibit low to moderate porosity (~50%) while the rest remains tight. This zone is again quartz dominated with mostly micrite cement, with one spotted pyrite occurrence and a possible glauconite nodule.
- The lower mudstone to wackestone zone (~5645.45'-5662.45') is similar to the upper facies of similar lithology, except the former is more mineralogically diverse. Pyrite was found in up to multi-cm scale nodules and as fracture infillings and distinct blue elongated chert nodules were observed towards the base.
- Only one sample (5664.8') was provided for the upper St. Louis lime, and it showed a tight white chalky fine grained limestone packstone supported by broken bioclasts that were too small to discern.

Osagean Stage

The lower Mississippian aged Osage lime (~6361'-6370') is a white to light gray fine grained dolomite wackestone with an abundance of cm to multi-cm scale blue chert nodules. The zone exhibits an overall tight porosity with a slight vuggy region (~6363.7') bringing low to possibly moderate porosity. Vugs range from mm to cm scale. Larger vug (1/2 cm wide) showed infillings of secondary crystalline dolomite. Predominantly micrite cement supports broken mm scale bioclasts in the form of crinoids. 6368' shows shaley argillaceous banding along with mm scale pyrite grains.

Upper Kinderhookian Stage

Upper Kinderhookian Stage rocks (~6373'-6650') show four distinct zones: gray/light gray fine grained dolomite wackestone to packstone (6370'-6470'), gray very fine grained sandstone to siltstone (~6473'-6484'), autoclastic cherty-dolomite brecciated zone (~6487'-6500'), and light gray/gray very fine grained dolomite mudstone (~6500'-6650').

- The uppermost wackestone to packstone facies is tight with an abundance of broken bioclasts (mostly crinoids (up to ~40%)) held intact by micritic cement. Cherty bedding is common in addition to shaley lamination and mineralogically it is relatively homogeneous with only dolomite, chert and argillaceous materials being observed.
- The very fine grained sandstone to siltstone zone is dominated by wavy argillaceous lamination, silty matrices and tight porosity, with observed minerals being dolomite, quartz, clays, and possibly chalcopyrite at ~6485'.
- The brecciated zone is composed of multi-cm scale angular chert clasts within a shaley mudstone (~30-40% shale) matrix and exhibits a significant amount of white powdery

clay material (~30%). Low to moderate intergranular and fracture porosity was observed. Brecciated region provides increased heterogeneity.

- The final mudstone zone throughout the lower half is characterized by light gray very fine grained dolomitic mudstones with tight porosity and a few notable accessory minerals (i.e. pyrite, chalcopyrite, clays) as well as the expected array of chert nodules (up to cm scale) and argillaceous fracture infillings. Micrite cement was dominant however a few sparry regions were noted, and a silty texture was observed throughout the zone.

Simpson Group

The Simpson group is lithologically represented by gray to light gray dolomite mudstone to packstone facies and extends from ~6668' to 6986'. The upper half is packstone (fine to medium grained) dominated with the lower half being mostly mudstone (fine to very fine grained). The packstone zones typically exhibit low to moderate vuggy/intergranular porosity with vugs ranging from pinpoint to cm scale and often infilled with secondary crystalline dolomite. Mudstone zones are more commonly tight, however low vuggy and fracture porosity becomes prevalent towards the base.

- The uppermost ~20' of packstone (6668'-6696') contains mm scale skeletal fragments/bioclasts, mostly in the form of crinoids, as well as pelloids, within micrite cement. Large cm scale chert nodules are not uncommon and in fact approach ~30-40% with depth (down to 6700'). Wavy argillaceous lamination and visible crystalline dolomite within matrix is also prevalent in this ~30' interval.
- A tight mudstone zone exists between 6702' and 6718', with visible mm scale pyrite grains at ~6705' and dark shaley banding throughout.
- A highly porous zone exists at ~6740' with brecciated dolomite mudstone lithology and vuggy pores visibly distributed within the entirety of the sample. Angular clasts contribute good intergranular porosity.
- Between 6900' and 6980' the lithology is predominantly mudstone with scattered packstone zones. A slight increase in fracture pathways and vuggy pores promotes relative heterogeneity and pore diversity, however overall porosity is still moderate to low. A slightly brecciated zone (autoclastic) at ~6940' provides enhanced zonal heterogeneity. White clayey infillings are common in this 90' zone, especially in fracture regimes. The cement type is mostly micrite with scattered regions of sparite, in particular around 6930'. Mineralogically this lower region of the Simpson group hosts dolomite (both in matrix and in secondary vitreous infillings), silica (in the form of chert nodules), and various clay minerals. A relative absence of observable sulfides in this lower depth was noted.
- The final 20' above the base is relatively homogeneous and increasingly tight in comparison to the pore types that precede it.

Gasconade Dolomite

The Ordovician Gasconade dolomite is a fine to very fine grained gray/light gray dolomite mudstone to packstone that extends from ~7100'-7430'. A noticeable increase in vugs and fracture pathways in the middle of the formation (7191'-7339') promotes good vuggy and fracture porosity and therefore heterogeneity. A similar change is noted nearing the base (~7425'). Lithologically the Gasconade is dolomitic with large cm to multi cm scale chert

nodules, scattered sulfide minerals (mostly pyrite, some chalcopyrite ~7350') and clay minerals as fracture infillings that are likely Fe-rich (?). Some zones exhibited green claystone facies indicating the possibility of glauconite (7210', 7235'). Vugs are often infilled with vitreous crystalline dolomite rhombs, and such textures can often be seen in matrices. The cement type is mostly micrite with scattered regions of sparite (~7340', 7400'). Wavy laminae are present, but not common, throughout the formation. An autoclastic brecciated zone exists at ~7191' with angular cherty clasts providing increased intergranular porosity and overall heterogeneity.

Gunter Sand

The Gunter sand is a fine to very fine grained light gray sandstone that extends from ~7530' to 7590'. Overall pore distribution is tight with a few zones showing low pinpoint and fracture porosity. Wavy nonparallel clayey/shaley lamination (gray to blue-green in color) persists through a majority of samples, with the green layers possibly indicative of glauconite and the gray layers demonstrating interbedded dolomite mudstone.

- A large cm scale chalcopyrite nodule was noted at ~7566' with a smaller mm scale nodule at ~7582'. Mm scale sub to euhedral glauconite crystals were spotted within the matrix of ~7558'.
- The upper region of this zone is moderately to well sorted with well-rounded grains with poorly sorted subrounded grains showing dominance nearing the base.
- Mineralogically the Gunter is composed of mostly quartz with scattered carbonate regions and a diverse array of accessory minerals (i.e. chalcopyrite, pyrite, glauconite and other clays, etc).

Task 18: Update Geomodels and Conduct Simulation Studies - Evaluate CO_2 Sequestration Potential in Arbuckle Group Saline Aquifer and by CO_2-EOR in Select Chester/Morrow Field in the Western Annex

Subtask 18.1. Update geomodels of the Chester/Morrow sands and Arbuckle Group saline aquifer in selected field
Subtask 18.2. Optimize geomodel for simulation - Flow-unit identification, fracture charaterization, and upscaling

Subtask 18.3. Simulate potential of CO_2 sequestration in Arbuckle Group saline aquifer

Subtask 18.4. Simulate of CO_2 sequestration potential by CO_2-EOR in the selected Chester/Morrow field

Simulation Studies of Chester/Morrow Oil Fields

Shuck Field model simulations will be finished in the next quarter, slowed by the lack of well-scale data and what is there is paper (or pdf) rather than tabular digital. Cutter geomodel and the simulation will also be completed in the next quarter.

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

Deliverables for the Final Report

1. Reservoir geomodel of Wellington Mississippian Chat reservoir and its CO_2-sequestration and CO_2-EOR potential.
2. Reservoir geomodel of Arbuckle Group saline aquifer underlying Wellington field and its CO_2-sequestration potential
3. Regional geomodel of OPAS covering 17+ counties in south central Kansas and its CO_2-sequestration potential
4. Risk assessment studies related to CO_2 sequestration including characterization of leakage pathways, vertical communication within the Arbuckle Group, and well abandonment histories in the 17+ county study area and the Western Annex.
5. Geomodel and simulations of CO_2 sequestration potential of the Arbuckle Group saline aquifer and of CO_2-EOR in a select Chester/Morrow incised valley sandstone oil reservoir in the Western Annex – a new addition of ~5,000 mi^2 to the regional study.
6. Results and interpretation of the seismic surveys, and interpretation of all laboratory analysis performed in the 17+ county study area and the Western Annex.

PRESENTATIONS AND PUBLICATIONS

Watney, W.L., 2014, Carbon Storage and Utilization in Kansas – Are We Ready?: KU Department of Geology Colloquium, January 23.

Watney, W.L., 2014, Fluid Migration and Accumulation within the Mississippian: Why 2% oil cut here, 15% oil cut one mile away: AAPG Mississippian Forum, Oklahoma City (also brought Wellington KGS #1-32 core to workshop).

KEY FINDINGS

1. Geomodels of Mississippian and Arbuckle being updated including a significant improvement in the resolution of the structural content in the seismic data.
2. The Mississippian reservoir geometry is closely tied to structural activity that was active at the time of deposition. The strata offlap to the west and toplap to the east. Overlying "chat" residual chert is thicker on the highest crestal, eastern portion of Wellington Field.
3. Conductive fractures dominate fluid flow into wellbore (PLT) in low K reservoirs. The Mississippian has both high and low permeability facies, thus fracture modeling is very important. CO2 injection will likely be affected by the fractures presenting themselves as either conduits or barriers to the CO2.

4. Mississippian has similar tight basinal expressed as the “lower Cowley facies” that are part of the TST. These facies thicken unto the Wellington structure while the reservoir facies undergo toplap and truncation from west to east across the field.
5. Seismic attributes aid *comprehensive* characterization, particularly to delimit high angle fractures and faults that do not intersect the wellbores and have smaller offsets that are usually attributed to flexure.
6. Production decline can be overcome or injection of fluids like CO2 can be tailored when fractures and faults are considered in the geomodeling and simulation activities.
7. Simulation of injecting 40,000 tonnes of CO2 into the Arbuckle at Wellington results in maximum pressure at approximately hydrostatic and size of plume within 2000 ft in diameter.
8. Interactive mapper includes known and inferred faults; tools to filter oil fields by cumulative production, depth, production bubble map to show time change and relative difference between leases useful in scoping heterogeneity in the process of targeting opportunities for CO2-EOR.
9. A methodology to estimate horizontal and vertical permeability in wells with typical modern well log suites has been developed using core, log, and well test data from Wellington and Cutter fields. A neural network using gamma ray, total porosity, and connected porosity [phir = (Rwa/ResDeep)^0.5] is used to extend permeability estimates to the key type wells in the region.
10. Regional flow units based on the permeability have been established for the type wells. The flow units conform to the conventional stratigraphic correlations. Local fracture and faulting or local cross flow dissolution will provide local variations. However, the controls of permeability are still tied closely to lithofacies and their pore type constrained by the strata architecture, namely a hierarchy of peritidal cycles. Larger scale cycles are widely correlatable.
11. Java Web Apps are undergoing revisions that will facilitate use, updating, and portability for use on other computer platforms. Moreover, the tools are being grouped to allow user to access software in a logical workflow. The archive data still remains the LAS 3.0 file that captures the resulting analyses.

PLANS

1. Complete geomodeling and simulations of commercial scale CO2 injection at the 10 regional sites and the regional CO2 assessment.
2. Complete the updates for the Wellington geomodels simulations.
3. Complete the modeling of the SW Kansas fields.
4. Gather results for write final report.

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SPENDING PLAN

Please see next page.

APPENDIX A.

Diagenesis and distribution of diagenetic facies in the Mississippian of south-central Kansas

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Key Findings

- Paragenesis from four Mississippian cores suggests that chertification and dolomititzation occurred early in the diagenesis.
- The majority of the porosity was developed during the onset of meteoric diagenesis with minor porosity developed during burial.
- Image analysis show that porosity is higher in dolomitized facies, and followed by sponge-spicule rich packestones and grainstones with high content of moldic and vuggy porosity.
- Calcite cementation plays an important role in porosity destruction after generation of porosity in meteoric settings.

Significance

The Mississippian system in south-central Kansas, a hydrocarbon prolific system of rocks, has very complex rock textures and petrophysical characteristics that resulted from passage trough different diagenetic environments (Montgomery et al., 1998, Watney et al, 2001, Mazullo et al., 2009). Understanding how these textures were formed is important because producing hydrocarbon units are tied to a specific set of diagenetic textures (e.g. intercrystalline porosity in dolomites, sponge-spicule moldic porosity, chert microporosity). Therefore, any reservoir quality evaluation needs a deliberate knowledge of diagenesis in the formation to understand the generation and occlusion of porosity, and maximize the production capacity of the reservoir. The objective of this research is to determine the origin and nature of the different diagenetic facies in the Mississippian system and understand their stratigraphic distribution in south-central Kansas. Four Mississippian cores in three different localities are used to cover a broad spectrum of diagenetic alterations in the Formation (Fig. 1). The contribution of this research will enhance interpretations of stratigraphy, reservoir characteristics and paleotopographic reconstructions implied from interpreted diagenetic environments in the Mississippian system.

Geologic Setting

The Mississippian System is found on cores in south central Kansas at more than 4,000 ft below the surface. It was deposited in shallow tropical seas of a gently southward dipping carbonate platform that covered most of Kansas. In the southern region of Kansas the shelf edge of this platform is found and it borders the Anadarko basin near the Kansas-Oklahoma state line. The stratigraphy is predominantly restricted to Kinderhokian, Osagean and Lower Meramecian stages and include from base to top: (1) dark siltstone and shale of the Kinderhookian shale, (2) dark, argillaceous, skeletal lime wackestone and packstone interbedded with calcareous shales comprising the Osagean limestone, (3) brown, argillaceous and dolomitic limestones containing

intervals of dark-colored, bedded chert, composing the Cowley facies, and (4) light-colored, spiculitic chert of the "chat" (Figure 1)(Montgomery et al., 1998).

The Mississippian is characterized by a regional unconformity found throughout most of the subsurface of Kansas separating Mississippian and Pennsylvanian strata (Merriam, 1963). This unconformity resulted from a regional uplift (Central Kansas uplift) and eustatic drop in sea level near the end of the Mississippian (Gutschick and Sandberg, 1983). The surface of this unconformity is preserved as a paleokarst deposit. In many oil fields, a chert breccia, informally called "the Mississippian chat", is the main reservoir rock that formed during karstification related to pre-Pennsylvanian unconformity. Recent interpretations by Mazullo et al. (2009) show that other minor unconformities can be found within the Mississippian strata. These minor unconformities resulted from fluctuations in sea level that intermittently exposed and submerged the shelf edge. Fluctuations in sea-level are important because they can change the diagenetic enviroment conditions trough time.

Methods

The petrography of four cores (Fig. 1) is interpreted to determine the properties and the origin of the different diagenetic facies and fit them into a paragenetic framework. Transmitted light microscopy, cathodoluminescence and scanning electron microscopy are used for thin section descriptions. In order to understand the relationship between diagenetic events and porosity, porosity calculations from point counting on photomicrographs is used. Diagenetic interpretations will be supported with geochemical analysis (stable isotopes; trace elemental concentrations of Ca, Mg, Sr, Fe and Mn from electron microprobe) to determine the environment at which minerals are precipitated and the source of the texture modifying fluids. X-ray diffraction analyses are performed to determine the mineral composition of complex facies. Petrophysical data is by far more abundant than core data and thus it will be used to determine the relationship between stratigraphy and paragenesis in each locality by building 3d static models using SIS Petrel software.

Preliminary Results

Rhodes Field (Cores: Harbaugh UB15 and George Michael 1-8)

The Mississippian section covered in two cores from the Rhodes field belongs to the Cowley facies. Chert breccia ("chat"), green shale interbedded with lenses of spiculite wackestone or packestone, discontinuous porcelaneous chert beds, and echinoderm rich packestone or grainstone are the major lithologies recognized in cores on the basis of texture, grain types and diagenetic alterations. Of all the lithologies the chert breccia ("chat") and spiculite wackestone or packestone contain the highest porosities, <8% and <13% respectively. The presence of microporosity in many chert fragments suggests that this numbers can be higher.

Paragenesis in the Cowley facies suggests at least nine events of porosity destructive cementation including: chertification, chalcedony cementation, clay cementation, calcite cementation, and baroque dolomite cementation. The relative time of their occurrence based on petrographic cross-cutting relationships is shown in a paragenesis diagram in figure 2. Porosity enhancing processes are less common and are particularly tied to dissolution of carbonate and silica during the onset of meteoric environment (karstification). A considerable amount of microporosity, vuggy porosity and siliceous sponge-spicule moldic porosity is found throughout the Formation. The monaxon sponge-spicules are made of amorphous Opal-A, a very metastable form of silica. In areas where the sponge-spicules are not preserved by early chertification (or by

other forms of silica) they dissolve out easily. This dissolution is interpreted to occur during meteoric alteration when the fluids where no longer supersaturated with respect to silica.

In particular facies, calcite cementation has occluded most of the sponge-spicule molds and fractures reducing porosity by <5%. Cross-cutting relationships and analysis of cathodoluminescence images suggest that calcite was precipitated during a meteoric environment and continued during the early burial conditions. Calcite fractures appeared compactionally deformed in core samples. A late void-filling calcite cement is also found after precipitation of baroque dolomite. Stable isotope data from these cements is been collected to support the diagenetic interpretations.

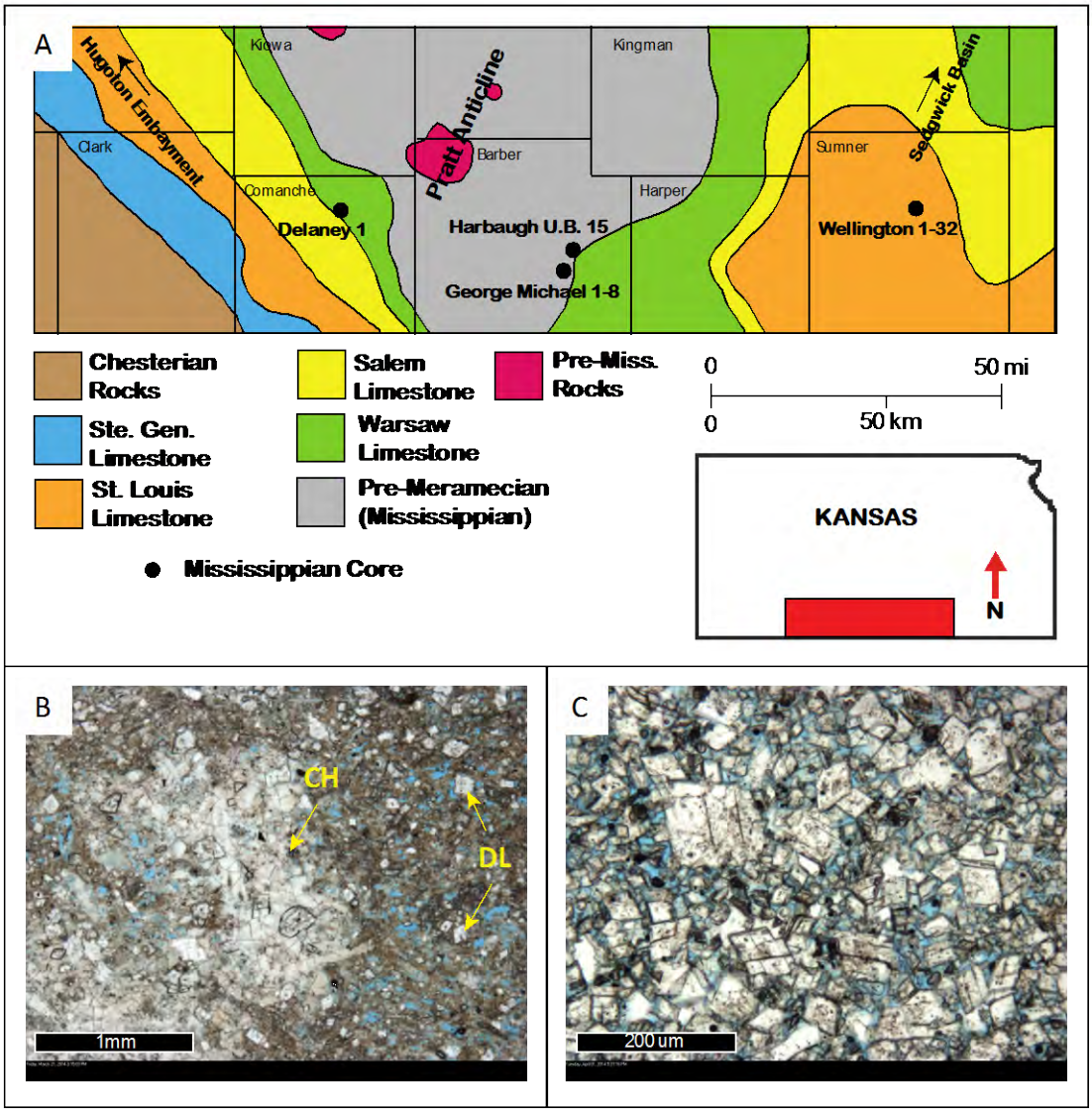


Figure 1. ***A)*** *Mississippian-Pennsylvanian Unconformity subcrop map for the study area. The location of four Mississippian cores used in this study is illustrated. (Modified from Franseen, 2006).* ***B)*** *Photomicrograph of a sponge-spicule rich cherty and dolomitic limestone. Nodular chert (CH) still preserves some of the sponge-spicule textures. Sponge-spicules outside chert nodules were dissolved leaving a mosaic of moldic porosity (blue epoxy). Photomicrograph was taken in plane-polarized light (George Michel 1-8, 4611 ft).* ***C)*** *Photomicrograph of a dolomite*

with a high content of intercrystalline porosity. Dolomite is characterized by finely to medium crystalline rhombs (20-180 μm) forming a planar-euhedral mosaic. Photomicrograph was taken in plane-polarized light (Wellington 1-32, 3892.25 ft).

Dolomite is locally found in both cores. It replaces the matrix of poorly silicified spiculites and inside chert nodules (Fig. 1). The exact timing and length of dolomitization with respect to chertification is still inconclusive but the occurrence of dolomite inclusions inside chert nodules and the absence of silica-replaced dolomites suggest that dolomitization occurred prior chertification. The variable range in dolomite crystal size and zonations seen in cathodoluminescence suggest that dolomitization occurred in various stages. Dolomite does not have a direct impact in the reservoir performance (Mazullo et al. 2009). This in part is explained by the relatively minor amounts of dolomite and the occurrence of dolomitization before secondary porosity was generated. Note from figure 1B that the dolomite is not found on the sponge-spicule molds, which suggest that dolomitization occurred before silica dissolution took place.

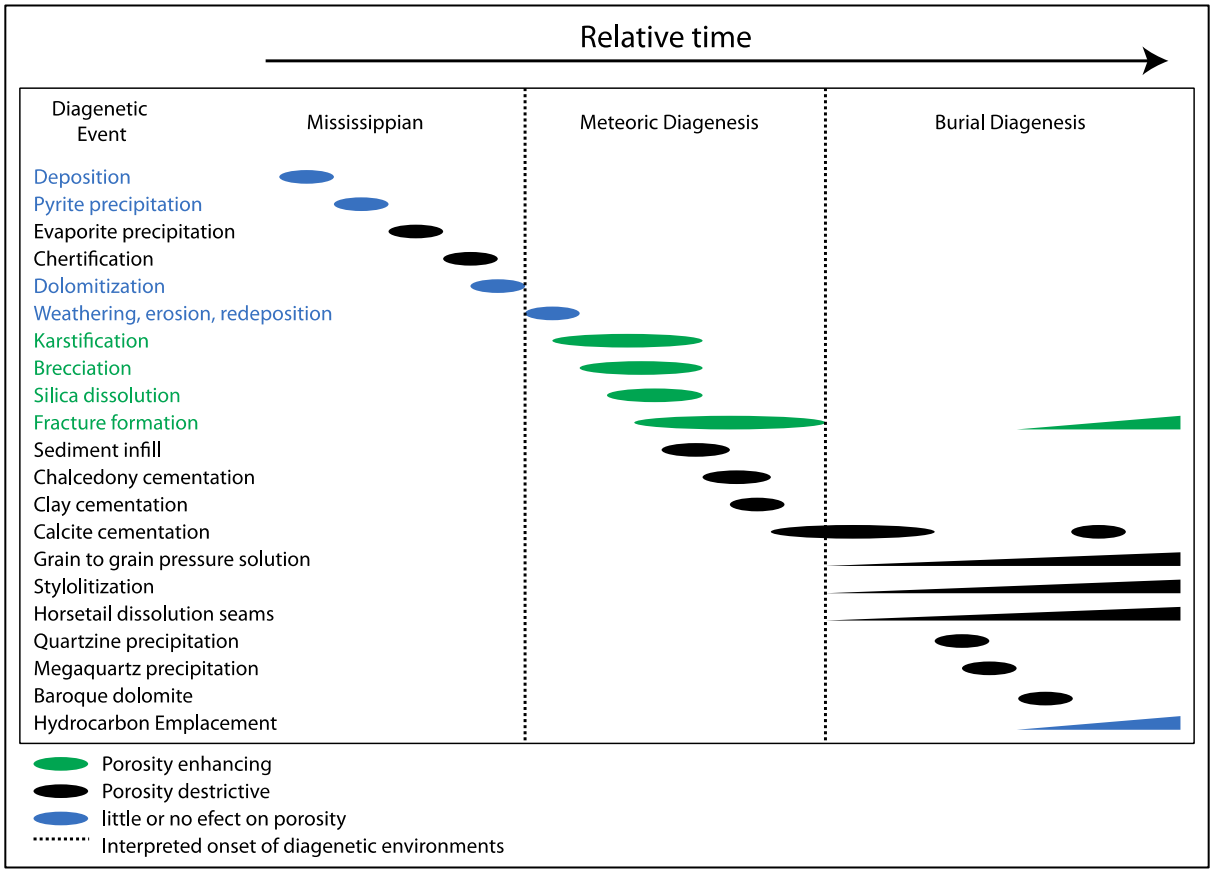


Figure 2. Paragenesis for the Cowley Formation from the wells Harbaugh UB 15 and George Michael 1-8 in Rhodes field, Barber county, south-central Kansas.

Wellington Field (Core: Wellington 1-32)

Mississippian time-equivalent strata are described from the Wellington 1-32 core. Lithologies recognized in core include: chert breccia and conglomerate ("chat"), chert nodule-rich dolomite, argillaceous dolosiltite, dolomitized bioclastic packestones and echinoderm-rich wackestones and packestones. The main reservoir in the field is 20 ft thick brown colored, finely

crystalline dolomite with scattered sponge-spicule-rich chert nodules, with up to 30% intercrystalline pores. The breccias and conglomerates are not good reservoir rocks in the Wellington field.

Stratigraphically, the Mississippian stratain the Wellington field are in a more distal and deeper locality than the Rhodes field with respect to the Mississippian carbonate shelf. Differences in the paragenesis are readily seen in the pervasive replacement with dolomite and the occurrence of calcite cements much later in the paragenesis (King, 2013). Dolomitization was early and pervasive, replacing almost the entire Mississippian section whereas in the Rhodes field dolomite is found locally. In addition the presence of silica-replaced evaporite nodules is far more abundant in the wellington field.

Chertification and Dolomitization

Our results show that chertification and dolomitization occurred at relatively close times in all cases. The change-over from dolomitization and silicification may occur several times in the diagenetic history of a sediment (Hess, 1990). Knauth's (1979) model for shallow-water early chert in limestone is coincived by analogy with the Dorag mixing-zone model for dolomitization (Badiozamani, 1973). A mixing zone of marine connate waters and meteoric waters represents a convenient geochemical environment for silica (opal-CT and quartz) or dolomite precipitation (Knauth 1979 and Badiozamani 1973). Although these models have been challenged before, it gives us an alternative to think about the environments in which both minerals can precipitate at relatively close times during the Mississippian. Selective replacement, mixing-water ratios and other kinetic parameters will play an important role in precipitating either dolomite or chert.

APPENDIX B.

Geological and Microbiological Influences on Reservoir and Seal Material During Exposure to Supercritical CO_2, Arbuckle Group, Kansas

Christa Jackson[1], David Fowle[1], Brian Strazisar[3], W. Lynn Watney[1,23], Aimee Scheffer[4], and Jennifer Roberts[1]

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2) *Kansas Geological Survey, Lawrence, KS*
3) *National Energy Technology Lab, Pittsburgh, PA*
4) *ConocoPhillips, Houston, TX*

Key Findings

- Dolomite dissolution occurs during exposure of reservoir (Arbuckle dolomite) and seal (dolomitic Lower Mississippian informal Pierson formation) materials to 100% $pCO_{2(SC)}$, as a result of a 0.5-1.0 unit drop in pH
- Pyrite dissolution occurs during exposure of Pierson formation (seal) to 100% $pCO_{2(SC)}$
- Secondary precipitation of iron oxides occurs during exposure of Pierson formation (seal) to 100% $pCO_{2(SC)}$, which could improve seal integrity by decreasing porosity and permeability

Significance

The Arbuckle Group (reservoir) and Lower Mississippian (informal) Pierson formation (seal) in southern Kansas are being investigated for storage of captured CO_2 emissions, a process referred to as Carbon dioxide Capture and Storage (CCS) (IPCC, 2005).

CO_2 exposure effects during and after subsurface injection vary depending on temperature, pressure, injection rate, formation geology, fluid geochemistry, and native microbial ecology. These effects must be explored to provide necessary data for optimization of injection and well-monitoring plans.

Injection of super critical CO_2 is targeted at the base of the Arbuckle Group (~1500 m depth). Here we investigate experimentally the geochemical and microbiological effects of supercritical CO_2 exposure on the Arbuckle Group cherty dolomite (reservoir) and Pierson formation dolomitic silty shale (seal). Changes in geochemistry and microbiology during CO_2 injection can affect porosity and permeability, which in turn, can affect seal integrity and the injectivity and storage capacity of the reservoir.

Research Summary

Background

The Cambro-Ordovician Arbuckle Group, a deep saline reservoir, in southern Kansas is being evaluated for CO_2 storage. The Arbuckle Group is generally composed of cherty dolomite, with some interbedded carbonate shales. CO_2 injection will occur at the base of the Arbuckle reservoir (~1500 m below land surface). The Arbuckle is ~305 m thick and average injection zone conditions are 50 °C and 172 bar, at which CO_2 will be in a supercritical state (Span and Wagner, 1996). Supercritical CO_2 ($CO_{2(SC)}$) behaves like a buoyant fluid, and will naturally

migrate towards shallower formations. Mechanisms of $CO_{2(SC)}$ sequestration include structural/stratigraphic trapping, residual trapping, mineral trapping, and solubility trapping (Han et al., 2010).

Arbuckle Group pore waters increase in salinity with depth, from 32-128 ppt, and range in pH from 6.32-7.08. Pore water geochemistry shows an increase in methane at the base of the Arbuckle, which indicates the presence of methanogenic microorganisms (Scheffer, 2012). Methanogens can sequester CO_2 by metabolically reducing it to CH_4 (e.g. Balch et al., 1979; Konhauser, 2007). Methanogens are also more resistant to the damaging effects of high pCO_2. The presence of these microorganisms in the injection zone may enhance CO_2 sequestration.

The Pierson formation is considered an alternate seal for the Arbuckle and overlying Simpson groups (Scheffer, 2012). At injection, the Pierson formation is approximately 1200 m deep, and 36 m thick. Due to the variable thickness of the primary seal (Chattanooga shale), this alternate seal is an important part of the CO_2 storage system. The Pierson formation is an organic rich, low permeability, dolomitic silty shale.

Experimental Design and Methodology

Powdered Arbuckle dolomite (core plugs from 1302 m and 1408 m) and Lower Mississippian dolomitic shale (core plugs from 1215 m and 1219 m) were reacted with artificial brine and 100% pCO_2 under reservoir temperature and pressure (50°C, 172 bar) for at least 30 days. A rock/brine ratio of 10 g/250 ml was used for all experiments. These experiments were conducted in duplicate using Teflon-lined static steel autoclaves at the National Energy Technology Lab in Pittsburgh, PA. The artificial brine was based on the chemistry of Arbuckle pore waters (based on analyses of drill stem tests from KGS well #1-32; e.g. Scheffer, 2012), and was deoxygenated by bubbling with N_2 (see figure 1). Experimental controls were conducted in parallel to the CO_2 experiments, and were exposed to 100% pN_2. 2 mg/l of peptidoglycan, purified from the cell walls of *Bacillus subtilis*, was added to a set of experiments as a proxy for microbial biomass.

	Cation and Anion Concentrations (mg/L)										
	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Fe^{2+}	Si	B	Cl^{-}	SO_4^{2-}	Br^{-}	HCO_3^{-}
DST 4	2546.82	565.20	259.14	19310.62	0.39	47.92	9.80	36000.00	910.00	180.00	375.30
Artificial Brine	2603.55	552.17	275.56	19824.91	BDL	BDL	11.49	35186.73	833.97	175.51	244.06
*BDL = below detection level											

Figure 1: Brine Chemistry. An artificial brine based on the chemistry of an Arbuckle drill stem test (DST 4 at 1279 m depth, from KGS Well # 1-32) was used in all experiments. The artificial brine was gassed with N_2 to remove dissolved O_2 prior to starting the experiments.

Brine samples were syringe-filtered (0.22-0.45 μm) and acidified with HNO_3 to preserve them at the end of each experiment. Brines were analyzed for major cations using ICP-OES, and major anions using IC. Bulk changes in mineralogy were determined via x-ray diffraction. Dissolution features, and evidence of secondary mineral precipitation were observed via SEM.

Results

Results from experimental vessels (biotic/sterile with CO_2) were compared to controls to assess changes in mineralogy and brine chemistry after CO_2 exposure. Changes in mineralogy and brine chemistry could impact seal integrity and reservoir storage capacity and injectivity.

Brine Chemistry

Exposure to 100% $pCO_{2(SC)}$ caused a 0.5 to >1 unit decrease in brine pH. An increase in Mg, Ca, and HCO_3 concentrations occurred in Arbuckle and Lower Mississippian experiments, which indicates dolomite ($CaMg(CO_3)_2$) dissolution. The dissolution of Lower Mississippian sulfur-bearing minerals, like pyrite, upon exposure to CO_2 is indicated by an increase in total S concentrations.

Mineralogy

No changes in bulk mineralogy were indicated for the Arbuckle dolomite experiments. Dissolution features were observed in dolomite crystals via SEM, which corroborates the brine chemistry results (see figure 2).

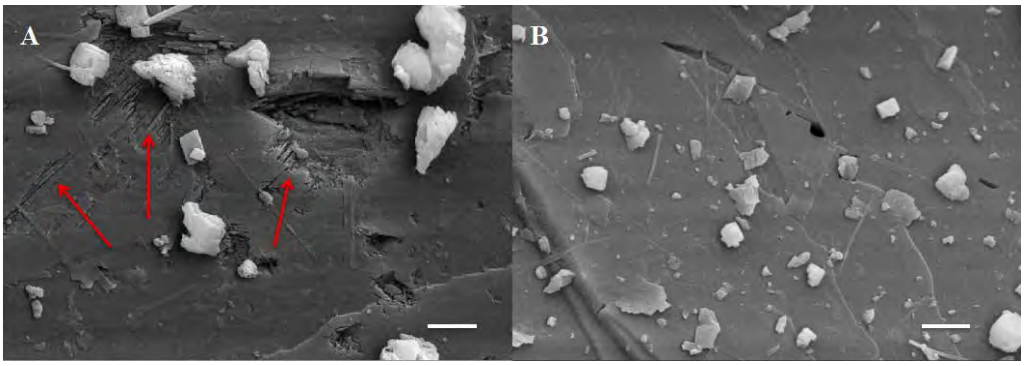


Figure 2: Dolomite Dissolution. Dissolution features, denoted by red arrows, can be seen on the surface of $CO_{2(SC)}$-reacted dolomite grains from the Arbuckle Group (A). These features are absent from the surface of unreacted Arbuckle dolomite (B). Images were taken using the secondary electron detector of a LEO field emission scanning electron microscope. Scale bars are 1μm in length.

Framboidal pyrite was observed in the unreacted Pierson formation, and secondary precipitation of iron oxides was observed in the $CO_{2(SC)}$-reacted Pierson formation experiments (see figure 3). These observations are consistent with the brine chemistry data, which shows an increase in total S concentrations for the $CO_{2(SC)}$-reacted experiments. While the dissolution of pyrite would release Fe and S into solution, we do not see an increase in Fe concentrations because it is conserved in the solid phase as an Fe-oxide.

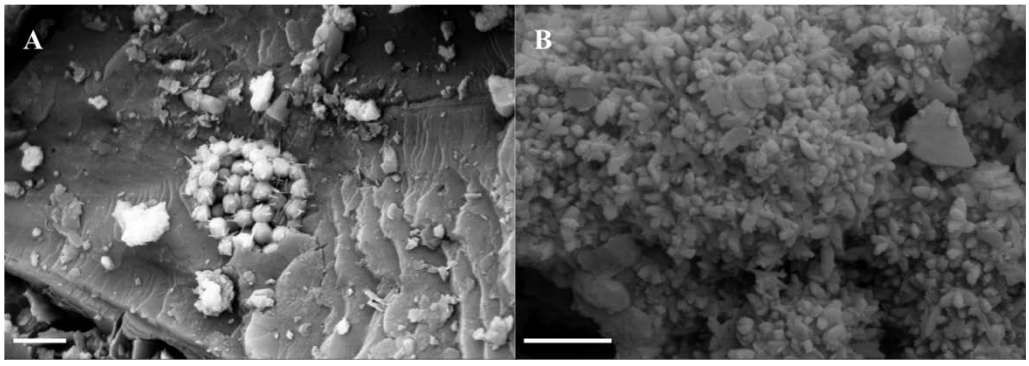


Figure 3: Framboidal Pyrite and Secondary Preciptitation of Iron Oxides. Framboidal pyrite crystals are present in unreacted Lower Mississippian material, and may be dissolved upon exposure to $CO_{2(SC)}$ (A, center). Pyrite dissolution would release Fe and S into the brine, where it

could react with other ions to form secondary minerals, or could remain in solution. Secondary precipitation of Fe-oxides can be seen in $CO_{2(SC)}$-reacted Lower Mississippian material (B). Images were taken using the secondary electron detector of a LEO field emission scanning electron microscope. Scale bars are 1μm in length.

Implications

The dissolution of dolomite due to pH decrease during CO_2 injection could enhance porosity and permeability in the Arbuckle reservoir. This may facilitate injectivity and enhance storage capacity. The dissolution of dolomite and pyrite within the Pierson formation, however, could negatively impact seal integrity, as enhanced permeability may allow the CO_2 to migrate into shallower formations. Dissolution of pyrite could also result in the mobilization of arsenic, as arsenic can be associated with iron and sulfur-bearing minerals. Toxic metal mobilization is of great environmental concern in CO_2 injection settings, because CO_2 migration into a shallow freshwater reservoir could result in toxic metal contamination of drinking water. The secondary precipitation of Fe-oxyhydroxides, however, may sequester toxic metals and clog pore space (Richmond et al., 2004). Trace metal analysis of the experiment brines is currently underway, which will assess the presence, and determine the fate of toxic metals such as As, Pb, Cr, and Cu.

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APPENDIX C.

Determination of Capillary Pressure Curves in the Mississippian Lime Play, Kansas, Based on the New Method Which Relates Pc Curves to RQI (Reservoir Quality Index)

Mina Fazelalavi[1], Lynn Watney[1], John Doveton[1], Jason Rush[1], Mohsen Fazelalavi[2], Maryam Fazelalavi[3], Minh C. Nguyen[4]

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2) Independent Consultant, Iran
3) Senergy, Stavanger, Norway
4) KICC, Dept. of Petroleum Engineering, University of Kansas, Lawrence, KS

Key Findings

- According to an investigation of SCAL data from several fields, there are strong correlations between endpoints of capillary pressure curves and RQI (Reservoir Quality Index).
- Both the entry pressure of the non-wetting phase and the irreducible saturation of the wetting phase of rocks with similar pore size distributions (unimodal, bimodal, or tri-modal) can be defined as functions of RQI.
- Pc curves are normalized to find a general equation. A single equation relating normalized non-wetting saturation to equivalent radius (EQR) is determined for all rock types with similar pore size distributions.
- The Mississippian reservoir consists of two main zones, Tripolitic chert (Chat) and Carbonate. The Chat zone overlies the Carbonate section in the Mississippian of the Wellington field.
- Pore size distributions are mainly bimodal in the Chat (tripolite) and unimodal in the carbonate. Therefore; two different sets of Pc curves were derived.

Significance

Capillary pressure curves are essential for accurate reservoir characterization and reservoir simulation to optimize oil recovery. On the other hand, accurate representation of capillary pressure curves is also crucial on modeling capillary trapping of CO2 during the post-injection period and saturation distribution.

Based on the oil migration path in the reservoir, drainage or imbibition capillary pressure can be used for the description of initial water saturation. When oil migrates from the side of the reservoir to the top of the structure and then downwards to the spill point, the initial water saturation is described by drainage capillary pressure curves. In some reservoirs, based on log data, it seems that oil migration has been from below the oil-water contact (OWC) to the top of the reservoir and all over the entire reservoir area. In these cases, there is residual oil saturation below the OWC, as indicated by log saturations. When oil has migrated from bellow the OWC to the top of the reservoir, imbibition Pc curves are more appropriate for the description of the initial water saturation.

Pc curves are often related to permeability of the rock or the Flow Zone Indicator (FZI) in studies reported in the literature. However, in rocks deposited in a variety of geological sedimentary environments, different Pc curves could exist for a single permeability or a specific FZI. In this method, based on our studies on SCAL data of several carbonate reservoirs, entry pressure, irreducible water saturation and therefore Pc curve of a rock are better related to its Reservoir Quality Index (RQI).

In this project, both drainage and imbibition capillary pressure curves were derived in the Mississippian reservoir. The Mississippian reservoir is comprised of two main zones: Tripolitic chert (Chat) and Carbonate. The two layers have different properties i.e different permeability, porosity and mainly different pore size distribution (bi-modal and unimodal). Due to this heterogeneity, the model was divided into two main zones or layers, Chat and Carbonate, and six capillary pressure curves were derived in each zone for different RQI ranges.

Methodology

Both drainage and imbibition Pc curves were calculated for each zone in the reservoir i.e. Chat and Carbonate. In this abstract, only drainage capillary pressure curves are discussed which were used in the model. Since permeability in all wells (Fazelalavi et al., 2013) as a function of depth was estimated prior for this project, the RQI at each depth could be determined. Therefore, Pc curves are defined for each RQI range in the Mississippian. The Grid of the dynamic or static model of the reservoir is divided into several Saturation Regions, each with a specific RQI range. For each region, a specific Pc curve is prepared.

Generalized Pc curves for the Mississippian formation of the Spivey-Grabs field (Watney et al., 2002; Bhattacharya et al., 2003) in addition to those based mainly on NMR data from well 1-32 and well 1-28 in the Wellington field were used to generate Pc curves for both Chat and Carbonate sequences of the Mississippian reservoir. The shape of the generalized Pc curves of Spivey-Grabs field were normalized and used in the process. Generated Pc curves from NMR log of well 1-32 were used to find correlations between endpoints and RQI for determination of Pc curves.

a. Entry Pressure

Based on SCAL data of other fields, a good correlation can be found between capillary entry pressure and RQI. The entry pressure in Well 1-32 was determined from NMR data using oil and water interfacial tension. In the Mississippian formation two correlations were obtained; one for the Chat conglomerate and another for the carbonate section of this formation.

b. Irreducible Water Saturation

Irreducible water saturation is needed to calculate normalized Non-Wetting phase saturation (Snwn). Based on Irreducible water saturation of SCAL data, mainly from carbonate reservoirs, irreducible water saturation at certain capillary pressure can be correlated, very well, to the RQI of the rock. There is a good correlation between irreducible water saturation of reservoir rocks and RQI. NMR data of Well 1-32 was used to determine irreducible water saturation at a Pc of

20 Bars (290 psi). Interfacial tension between Oil and water was given to the Tech-Log Module to find Swir versus depth for this well.

c. Shape of the Normalized Pc curve

Pc curves, which were obtained from NMR logs, were normalized by plotting Snwn (Normalized Non-Wetting Phase Saturation) versus EQR (Equivalent Radius). EQR is obtained from division of entry pressure over Pc. Therefore Equivalent Radius is a function of entry pressure and capillary pressure; where, entry pressure is a function of RQI. Therefore, the shape of normalized Pc curves can be expressed in terms of Pc and RQI.

$$S_{nwn} = (1 - a\frac{P_e}{P_c})(1 - \frac{P_e}{P_c}^b) \quad \text{Eq. 1}$$

d. Calculation of Drainage Capillary Pressure Curves

The following equation was used to calculate drainage water saturation in the Mississippian Chat and Carbonate:

$$S_{wi} = 1 - S_{nwn}(1 - S_{wir}) \quad \textit{Eq.2}$$

Initial water saturation (Swi) is a function of Snwn. It was shown in Eq. 1 that Snwn is a function of Pe and Pc where Pe is a function of RQI. Snwn in Equation 2 can be replaced by respective functions and an equation can be obtained which expresses Swi in terms of RQI and PC.

Results

Drainage capillary pressure curves were calculated for Mississippian Chat and Carbonate using Eq 2, Fig. 1 and 2:

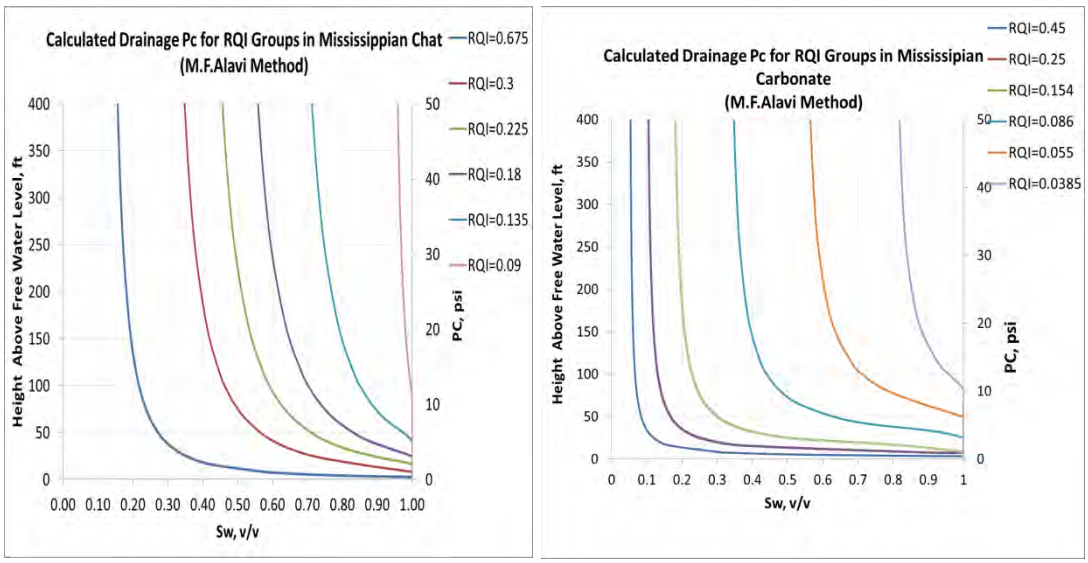


Figure 1: Drainage Pc curves for Chat

Drainage Capillary pressure curves for each saturation region for each RQI range were given to Petrel and Water saturation were modeled for both Mississippian Chat and Carbonate, Fig. 3 and 4:

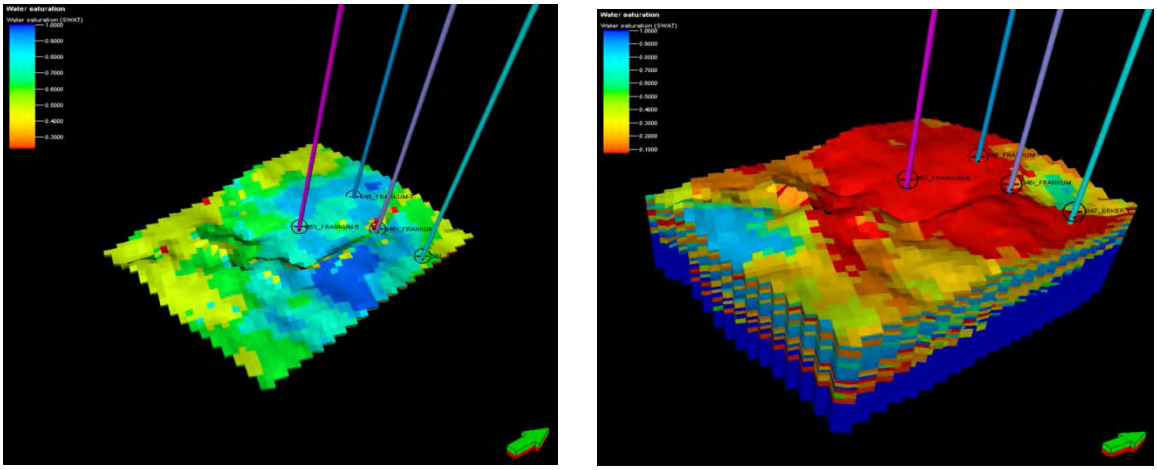


Figure 3: Water Saturation Distribution for Chat

Fig

APPENDIX E

January 21, 2014 Prospectus Governor's Conference Implementing CO2 Utilization and Storage (CCUS) in Kansas

To discuss the potential and challenges of large-scale carbon dioxide utilization and storage (CCUS) in Kansas, the Kansas Geological Survey proposes a one-day conference engaging industry, decision makers, and public.

CCUS offers significant potential for economic development for Kansas. A 2010 report for the Midwest Governor's Association indicated more than 750 million barrels of oil is potentially recoverable with enhanced recovery methods using carbon dioxide[1]. Oil prices and improved technology have rekindled interest by Kansas petroleum industry in the cost-effective application of CCUS to revive older fields. However, CO_2 will necessarily come from man-made sources such as ammonia, ethanol, refinery, and power plants requiring capital investments to capture the CO_2 and readiness of the oil fields to receive the CO_2. Stakeholders must understand the oil resource, infrastructure requirements, financial and human resource needs, and the environmental and regulatory environment to develop a unified vision of large-scale CCUS in Kansas. The Governor's Conference would be dedicated to strengthening understanding and establishing comprehensive goals.

Date: (TBD)

Location: Hyatt Regency in Wichita, KS

Target participants: 150 total from Governor's Office, KCC, KDHE, Kansas Dept. of Commerce, Kansas Dept. of Agriculture, KIOGA, Kansas Geol. Society, industry including petroleum and CO_2 sources (ethanol, ammonia, power plant, refinery; gas suppliers), legislators, informed public, environmental advocacy groups, academia, KGS, TORP, PTTC, Interstate Oil and Gas Compact Commission, Groundwater Protection Council, Kansas Water Office, DOE, RPSEA, AAPG, Permian CCUS Center, Midwest Governor's Association

Goals:

1. Convey benefits and potential challenges of large-scale deployment of CCUS in Kansas.
2. Introduce infrastructure and workforce needs for large-scale CCUS in Kansas.
3. Understand importance of man-made CO_2 for large-scale CCUS in Kansas.

Objectives:

[1] CCI for MGA, 2012, CO2-EOR Potential in the MGA Region, 16 p. -- http://www.midwesterngovernors.org/Publications/EOR2011.pdf

- Establish potential of CCUS as a major boost to rural economic development in Kansas.
- Address safety and environmental considerations based on implementation in other locations.
- Describe CO_2 behavior and its management when stored underground.
- Summarize beneficial use of CO_2 in an oil reservoir, reference to large-scale examples.
- Introduce management of CO_2 in oil fields for long-term storage.
- Review readiness of oil fields and petroleum industry to conduct large-scale CCUS in Kansas.
- Assess of size and locations of oil resource in Kansas for CCUS.
- Analyze current and potential delivery of CO_2 for use in CCUS.
- Describe investment requirements and economics of CO_2-EOR.
- Discuss steps toward large scale implementation of CO_2-EOR.

Format: One day with 1) plenary session with keynote speakers, 2) breakout, 3) plenary session #2 with a panel providing summaries of breakout meetings, 4) summary with keynote speakers.

Product: White paper with meeting summary, recommendations, and action items.

PROPOSED AGENDA FOR GOVERNORS CONFERENCE

"Implementing CO_2 Utilization and Storage (CCUS) in Kansas"

7:30-8:30 Registration, coffee, continental breakfast, posters, exhibits
8:30-9:00 Overview, concepts, and goals of the meeting (Governor/KGS)
9:00-10:30 Presentations from stakeholders in CO_2 supply and distribution, readiness and needs of Kansas petroleum industry for CO_2 utilization, regulations for CO_2 capture and utilization, economic impact assessment, viewpoint of state policy makers, KGS summary
10:30-11:00 Break (discussion, exhibits posters)
11:00-12:00 Continue presentations

12:00-1:30 Networking lunch with keynote presentation (Potentially – "challenges and opportunities for aggregation of CO_2 supply and distribution to Kansas oil fields")
1:30-3:00 Breakout sessions:

1. Steps toward implementing large-scale CCUS in Kansas
    i. CO_2 supply – sources and transportation
    ii. CO_2 utilization -- Readiness and needs
    iii. Aggregation of CO_2 supply and CO_2 utilization in Kansas oil fields
2. Economic incentives for CO_2 capture and CO_2 suppliers
3. Regulation
    i. Well and Field permitting
    ii. Primacy of Class VI Injection permitting and implications of using added storage for CO_2 beneath the oil reservoir in deep saline aquifers

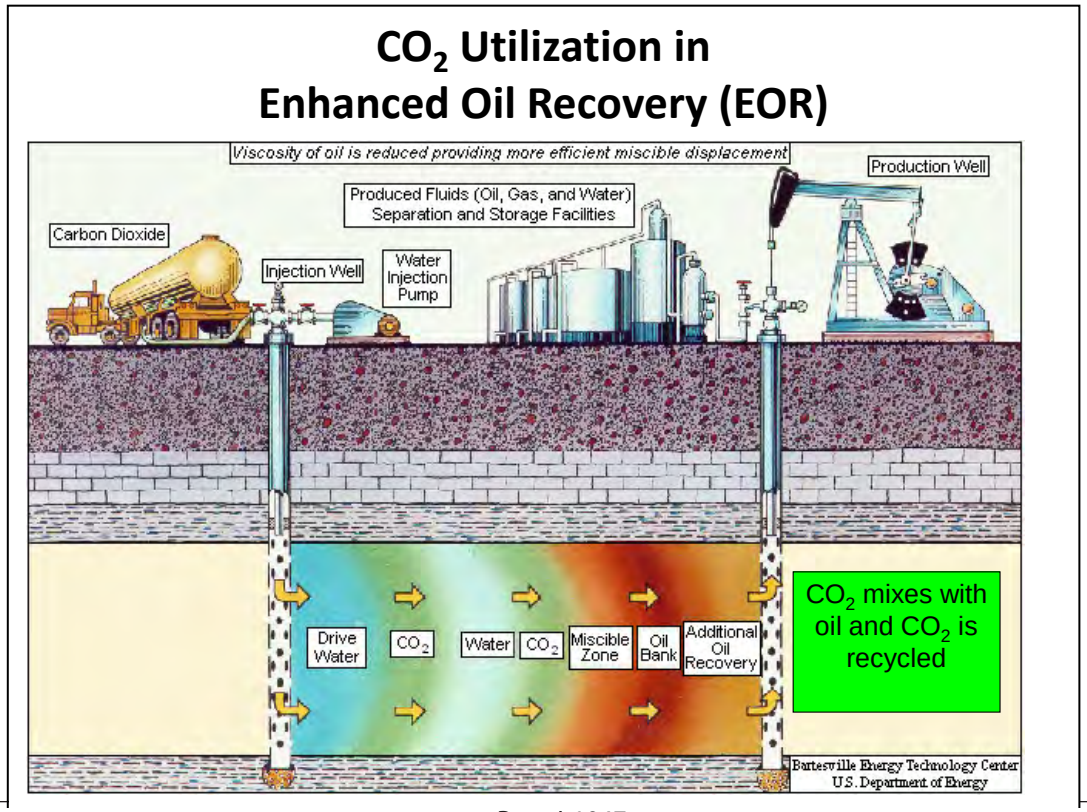
4. Environmental Concerns
    i. Secure CO_2 storage
    ii. Induced seismicity

3:00-4:30 Plenary session to discuss breakout sessions via panel with session chairs and wrap-up with key points, action items, and future plans

4:30-5:30 Discussion with posters and exhibits

Background

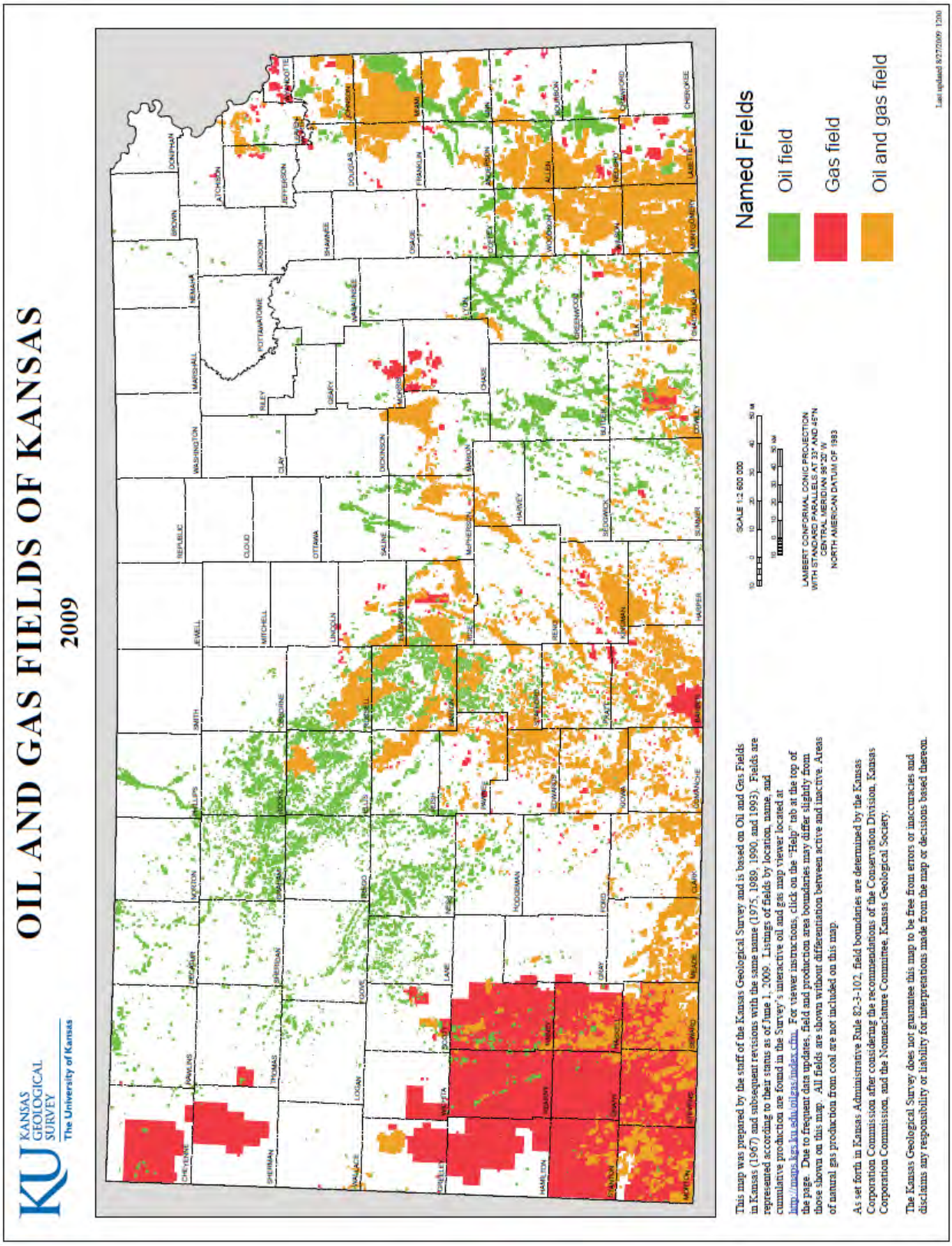
1. CO_2 supply, resource, projections
    a. CO_2 behavior in an oil reservoir and capability for incremental oil recovery
    b. Geologic (naturally occurring) CO_2, e.g., supplying west Texas, Wyoming, Montana
    c. Anthropogenic CO_2, e.g., industrial sources – fertilizer, cement, ammonia, and ethanol plants; power plants in Kansas and Midwest
    d. Readiness – factors influencing supply
        i. Regulation
        ii. Capture technology and economics
        iii. Distribution – rail and pipeline distribution system
2. Utilization of CO_2 in Kansas
    a. Establish demand for CO_2 in the oil field
    b. Future use – develop plans for implementation and infrastructure
    c. Technical timeframe
        i. Oil field and operator readiness
        ii. Field modeling and implementation plan to ensure success
        iii. Scenarios for aggregating CO_2 supply and distribution to the field
        iv. Economic incentives?



STEPS TOWARD CO_2 UTILIZATION AND STORAGE IN KANSAS

1. **Core Concepts and Goals –**
   a. Combine oil field and deeper saline aquifer storage to provide large capacity storage for long term,
   b. Regulatory primacy over EPA to manage CO_2 in Kansas,
   c. Public awareness and support for carbon management,
   d. Business opportunities and advocacy
   e. R&D support and integration with needs of Kansas – aquifer and public health, petroleum, transportation from CO_2 source to sink
2. **Increase capacity of storage with underlying saline aquifer storage**
   a. Insure injection rate with backup disposal
   b. Analogous to Wellington and southwestern fields modeled as part of SW KS CO_2-EOR Initiative
3. **Identify fields for miscible and immiscible CO_2 oil recovery**
4. **Refine KGS interactive CO_2 oil and gas mapper for access to key information**
   a. Highlight and extract cumulative oil; depth; temperature; oil gravity
      i. Screen and highlight candidate fields/plays for CO_2 miscibility, total field and lease performance, recoverable reserves and CO_2 requirements (volume and rates)
   b. Identify resources for CO_2-EOR via **interactive map of Kansas oil fields** utilizing web apps to analyze the data "*on the fly*"
   c. Develop scoping models of oil fields to forecast technical success and favorable economics currently
   d. Reply results of **CO_2 test injection at Wellington Field (DE-FE0006824)** and four fields (Shuck, Eubanks, Cutter, and Pleasant Prairie South) in as part of **SW Kansas CO_2-EOR Initiative (DE-FE0002056)**.
5. **Monitoring and compliance for carbon trading and effective and economic use to satisfy regulators**
   a. Continue dialog with our legislators to encourage support of carbon management in Kansas
6. **Establish interest and participation of field operators and CO_2 suppliers**
   a. Develop portfolio of prospective oil fields with operator interest
   b. Establish infrastructure scenarios (location and transportation options for CO_2)
7. **Engage stakeholders to develop, support and underwrite strategic initiative**
   a. Planning grant to administrate and develop components of a Kansas CO_2 initiative/Kansas Model for CO_2 Utilization and Storage
      i. Secure advisory group of operators, gas suppliers, officials with Department of Commerce and KU, lawmakers and regulators
      ii. Define needs to address uncertainties and concerns, weigh challenges and concerns against benefits to affect public perception, sequestration defined, state of readiness, engaging community, leveraging what has been learned, priorities, and opportunities via **Governor's Conference**
      iii. Timetable and costs for planning and development
      iv. Establish state of the technology in Kansas via research and workshop workshops and share resources and scoping models
8. **Encourage collaborative research in carbon management**

9. **KU Research Initiative -- Sustaining the Planet, Powering the World**
10. **Education and public acceptance with open dialog**


OIL AND GAS FIELDS OF KANSAS
2009
KU KANSAS GEOLOGICAL SURVEY
The University of Kansas
Named Fields
Oil field
Gas field
Oil and gas field
SCALE 1:2 500 000
LAMBERT CONFORMAL CONIC PROJECTION
WITH STANDARD PARALLELS AT 33° AND 45°N
CENTRAL MERIDIAN 98°20' W
NORTH AMERICAN DATUM OF 1983
This map was prepared by the staff of the Kansas Geological Survey and is based on Oil and Gas Fields in Kansas (1967) and subsequent revisions with the same name (1975, 1989, 1990, and 1993). Fields are represented according to their status as of June 1, 2009. Listings of fields by location, name, and cumulative production are found in the Survey's interactive oil and gas map viewer located at http://maps.kgs.ku.edu/oilgas/index.cfm. For viewer instructions, click on the "Help" tab at the top of the page. Due to frequent data updates, field and production area boundaries may differ slightly from those shown on this map. All fields are shown without differentiation between active and inactive. Areas of natural gas production from coal are not included on this map.
As set forth in Kansas Administrative Rule 82-3-102, field boundaries are determined by the Kansas Corporation Commission after considering the recommendations of the Conservation Division, Kansas Corporation Commission, and the Nomenclature Committee, Kansas Geological Society.
The Kansas Geological Survey does not guarantee this map to be free from errors or inaccuracies and disclaims any responsibility or liability for interpretations made from the map or decisions based thereon.
Last updated 8/27/2009 1200

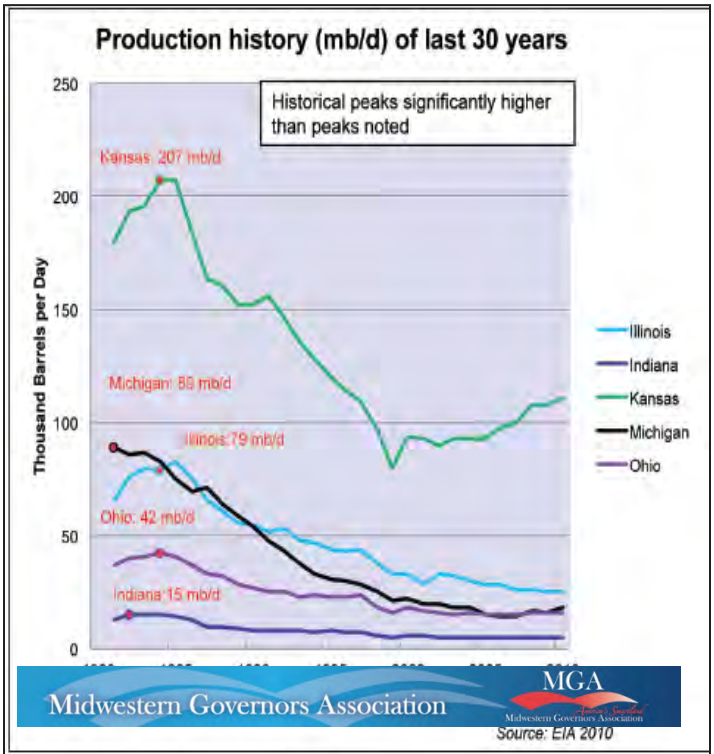
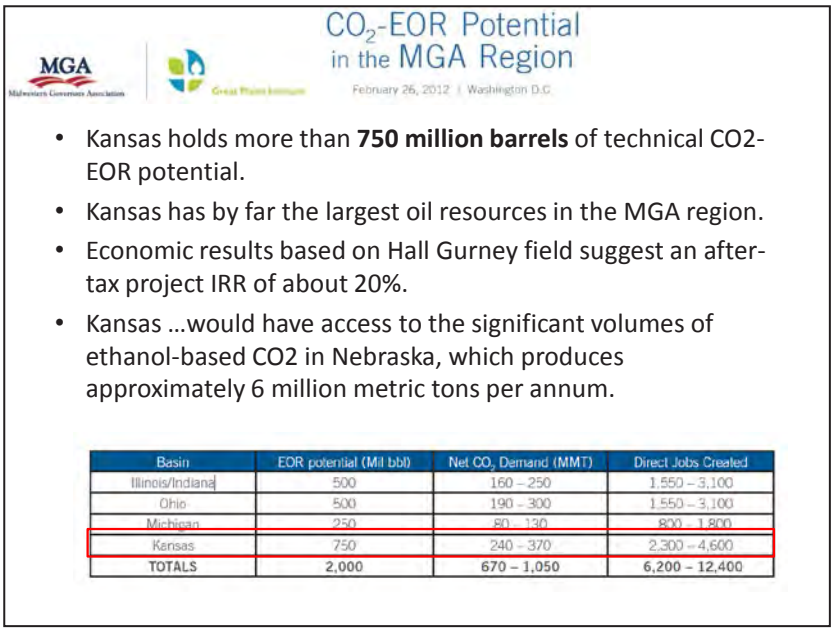


Figure 4: MGA 30 year production

Kansas is well positioned to receive CO_2 from neighboring anthropogenic sources to the north and east.

http://www.midwesterngovernors.org/Publications/EOR2011.pdf.

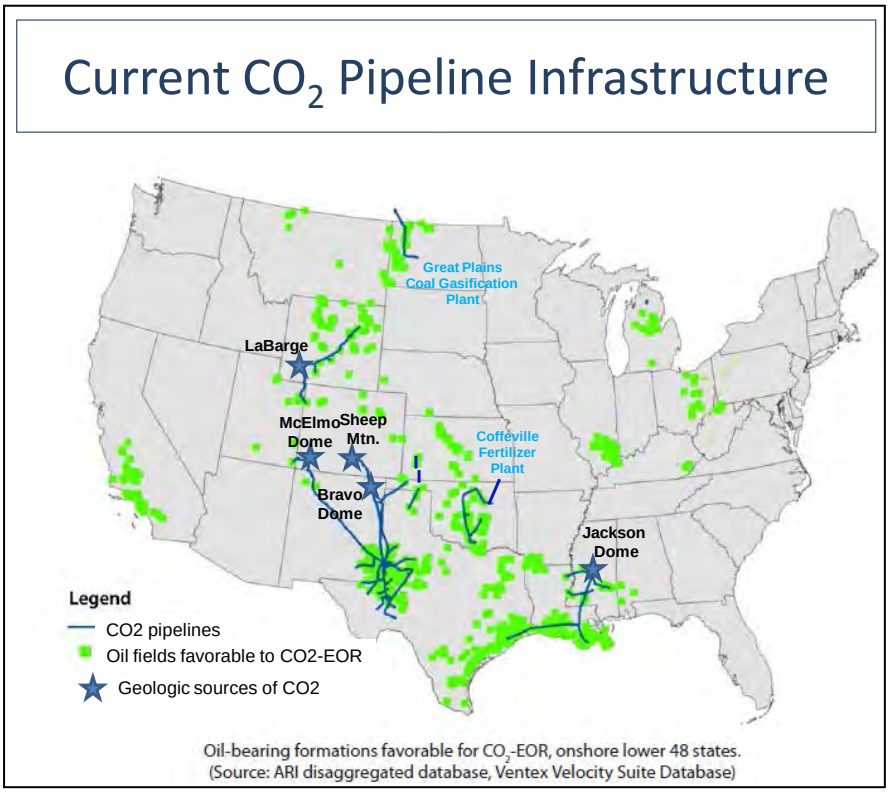


Study sponsored by MGA indicates Kansas has considerable CO_2-EOR potential. 750 million barrels would require an estimated 240-370 million metric tons of CO_2 (4.62-7.12 BCF CO_2).

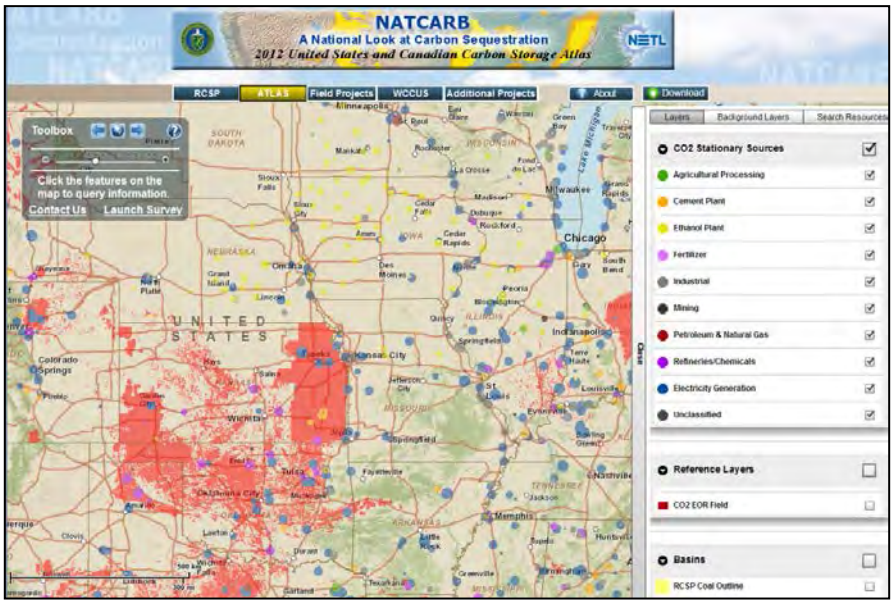
19.25	MCF/tonne

Current market value of compressed pipeline CO_2 is 2% price of oil.

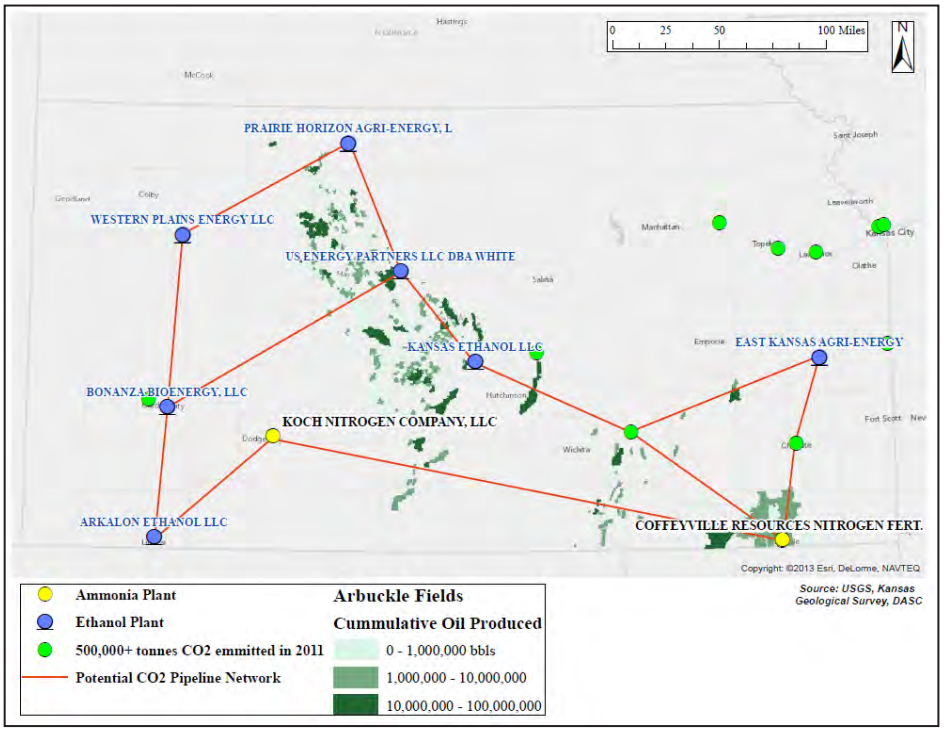
$2.00	cost per MCF
$38.50	**cost per tonne**



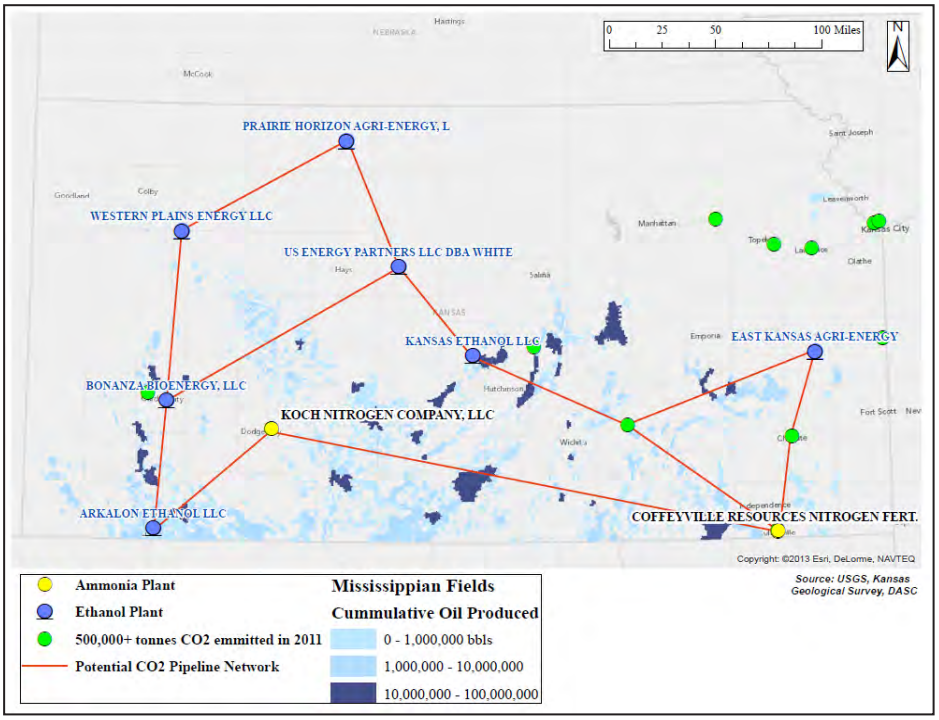
ɔil and gas
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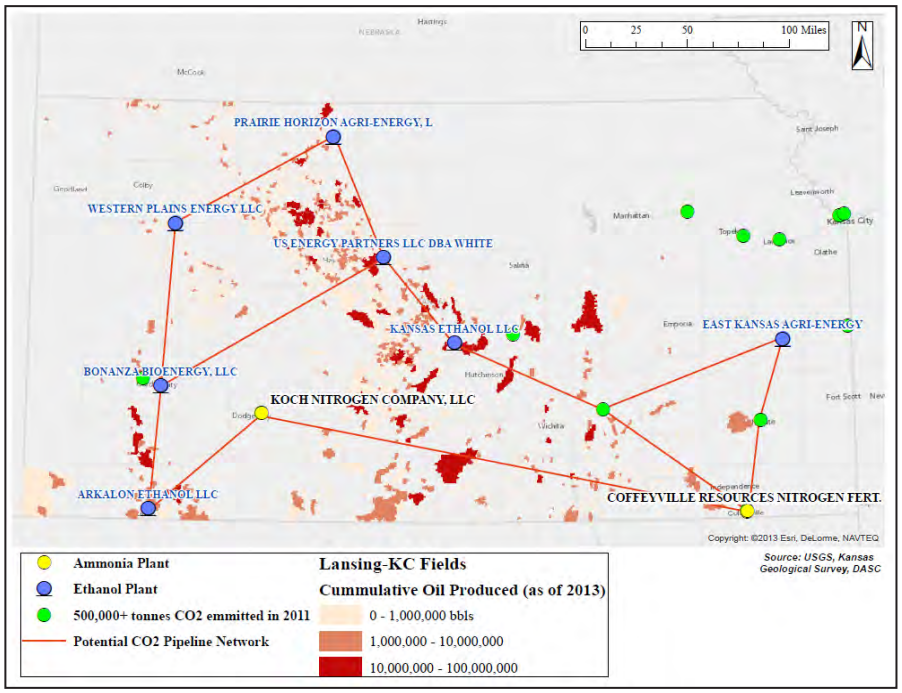
Kansas has it's own local sources of CO_2, but ethanol plants (yellow dots on map) are numerous in Nebraska, which has limited oil and gas resources. MGA suggests CO_2 could potentially be transported to Kansas.



Kansas oil fields producing from Arbuckle Group reservoirs. CO_2-EOR would vary from partial to fully miscible recovery, affecting efficiency of oil recovered. Ethanol (blue dots) and ammonia plants (yellow dots), and large stationary CO_2 including power plants and refineries (green dots) are down with potential pipeline system providing CO_2 to oil fields.



Kansas oil fields producing from Mississippian reservoirs. Most of these reservoirs would likely have miscible CO_2-EOR.



Kansas oil fields producing from Lansing-Kansas City reservoirs. Most of these reservoirs would likely have miscible CO_2-EOR.

Kansas Incentive for carbon capture and storage

Kansas H.B. 2419 creates tax incentives for carbon capture and storage, namely income tax deductions for the amortization of CCS equipment costs and property tax exemptions.



HOUSE BILL No. 2419

AN ACT enacting the carbon dioxide reduction act; providing for income tax reductions and property tax exemptions; providing for regulation of carbon dioxide injection wells; amending K.S.A. 2006 Supp. 79-32,117, 79-32,120 and 79-32,138 and repealing the existing sections; also repealing K.S.A. 2006 Supp. 79-32,117f.

Be it enacted by the Legislature of the State of Kansas:

New Section 1. Sections 1 through 7, and amendments thereto, may be cited as the carbon dioxide reduction act.

New Sec. 2. (a) As used in sections 2 through 5, and amendments thereto:

(1) "Carbon dioxide injection well" means any hole or penetration of the surface of the earth used to inject carbon dioxide for underground storage or for enhanced recovery of hydrocarbons and any associated machinery and equipment used for such injection of carbon dioxide. "Carbon dioxide injection well" does not include underground storage.

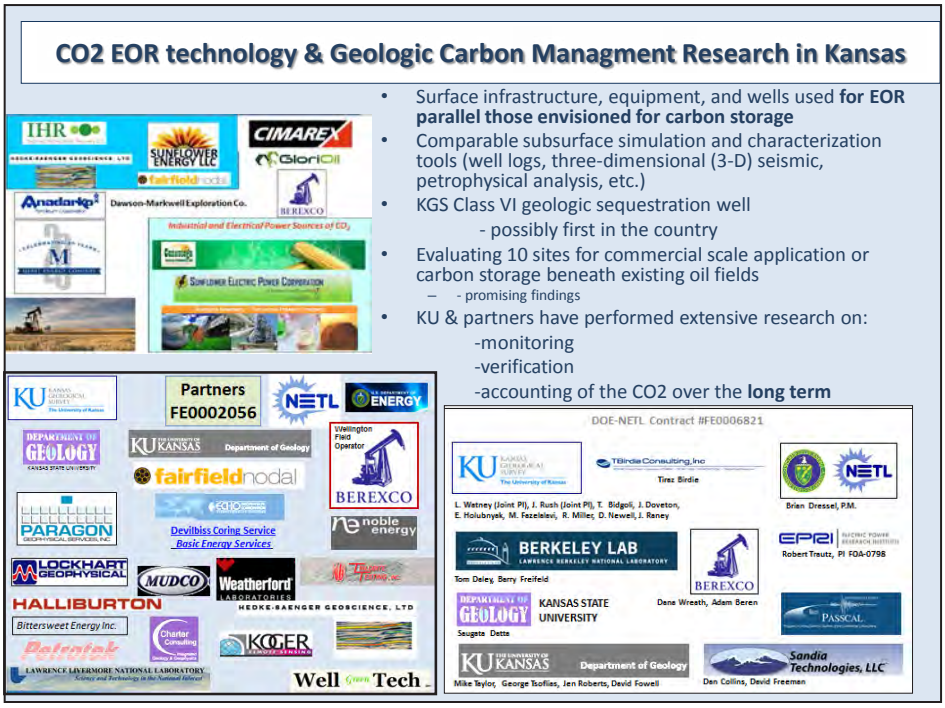
(2) "Commission" means the state corporation commission.

(3) "Underground storage" means any underground formation where carbon dioxide is injected for sequestration.

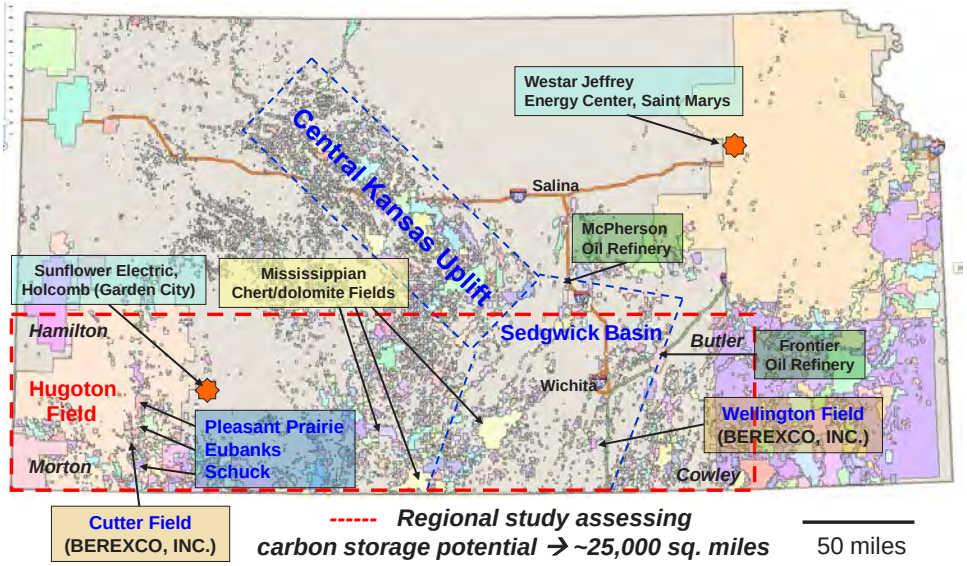
(b) For the purposes of protecting the health, safety and property of the people of the state, and preventing escape of carbon dioxide into the atmosphere and pollution of soil and surface and subsurface water detrimental to public health or to plant, animal and aquatic life, the commission, on or before July 1, 2008, shall adopt separate and specific rules and regulations establishing requirements, procedures and standards for the safe and secure injection of carbon dioxide and maintenance of underground storage of carbon dioxide. Such rules and regulations shall include, but not be limited to: (1) Site selection criteria; (2) design and development criteria; (3) operation criteria; (4) casing requirements; (5) monitoring and measurement requirements; (6) safety requirements, including public notification; (7) closure and abandonment requirements, including the financial requirements of subsection (e); and (8) long-term monitoring.

http://www.c2es.org/us-states-regions/policy-maps/ccs-financial-incentives

Tax deductions and property tax exemptions are in place.



Kansas has been conducting research in CO_2-EOR since the late 1990s and work continues today to facilitate this technology as it is applied to Kansas oil reservoirs.

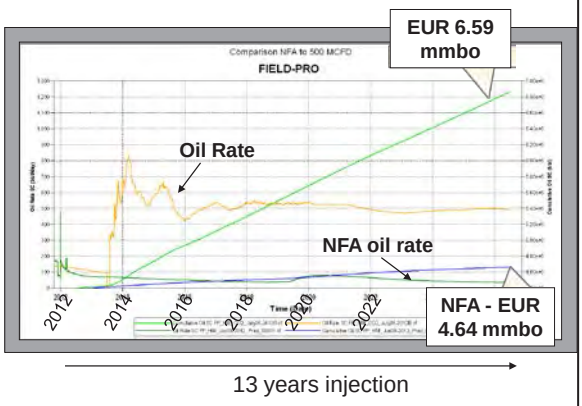


Current research conducted by KU and KGS are focused on field studies and main reservoir types to make them ready for CO_2-EOR.

CO2 EOR Projections – Pleasant Prairie South Field

Assumptions:

1. Convert WIW to CO2 IW
2. Oil wells as is
3. Inject 5 mmcfd CO2, not exceeding bhp 2600 psi
4. Continuous CO2, no WAG
5. Injection = production
6. No optimization



Projections:

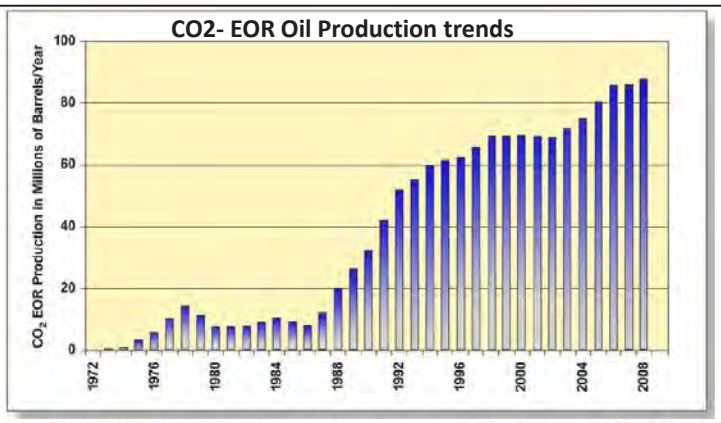
OIL (mmbo)		
Cumulative 2011	4.48	
NFA cum. 2026	4.64	
CO2 case cum.	6.59	
Increment. CO2	1.95	
Cum. 2012-2026	2.11	
CO2		*mm tons*
CO2 injected (mmcf)	23.7	1.38
CO2 produced (mmcf)	13.2	0.77
CO2 sequestered (mmcf)	10.5	0.61
Gross utilization (mcf/bo)	11.2	
Net utilization (mcf/bo)	5.0	

assume 56% CO2 is recycled

RF as *f* (OOIP)

Primary	15.8%
Secondary	15.8%
CO2	13.3%
	45.0%

Example of analysis of a Mississippian oil reservoir in southwest Kansas simulating recovery of oil using CO_2.



Major U.S. CO_2 Operators (OGJ Biennial EOR Survey 2008)

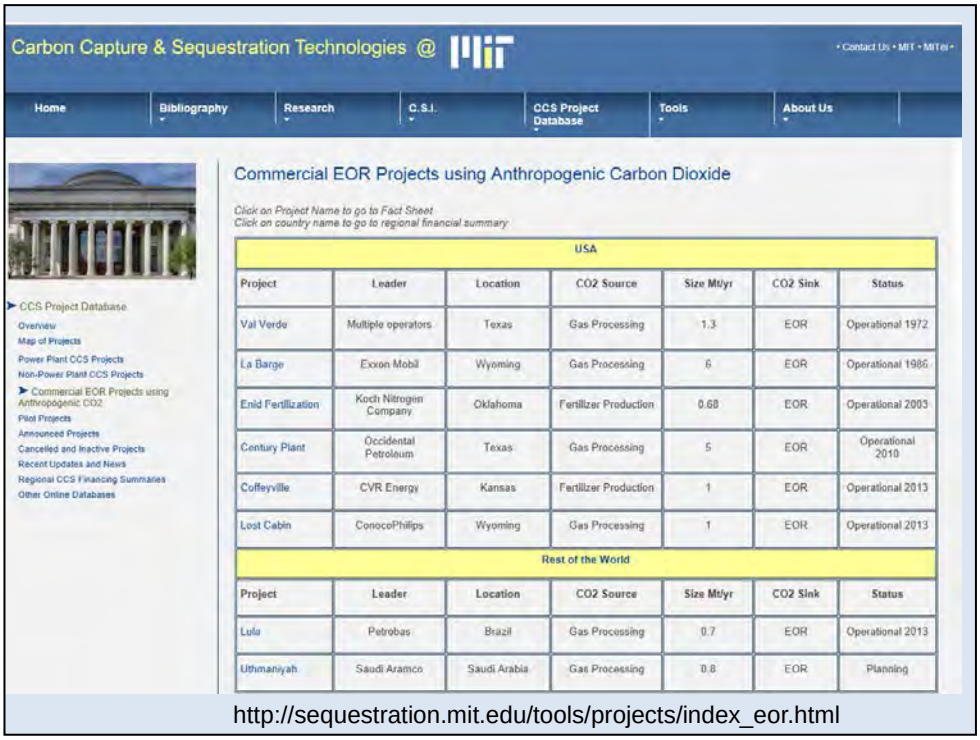
Company	Miscible Projects	Locations	Incremental Production (MBO/D*)
Occidental	29	TX, NM	90.2
Hess	6	TX	25.3
Kinder Morgan	1	TX	24.2
Chevron	4	CO, TX, NM	21.3
Denbury Resources	13	MS, LA	17.8
Merit Energy	7	WY, OK	13.6
ExxonMobil	2	TX, UT	11.7
Anadarko	4	WY	9.0
Whiting Petroleum	3	TX, OK	6.9
ConocoPhillips	2	TX, NM	5.5
12 other independents	28	TX, OK, UT, KS, MI	14.9
Total	99		240.4

* thousand barrels of oil per day

Illustrative Costs and Economics of a CO_2 EOR Project

Oil Price ($/Barrel)	**$70**
Gravity/Basis Differentials, Royalties and Production Taxes	($15)
Net Wellhead Revenues ($/Barrel)	**$55**
Capital Cost Amortization	($5 to $10)
CO_2 Costs (@ $2/Mcf for purchase; $0.70/Mcf for recycle)	($15)
Well/Lease Operations and Maintenance	($10 to $15)
Economic Margin, Pre-Tax ($/Barrel)	**$15 to $25**

http://www.netl.doe.gov/technologies/oil-gas/publications/EP/small_CO2_eor_primer.pdf



Carbon Capture & Sequestration Technologies @ MIT

Home | Bibliography | Research | C.S.I. | CCS Project Database | Tools | About Us

CCS Project Database
Overview
Map of Projects
Power Plant CCS Projects
Non-Power Plant CCS Projects
Commercial EOR Projects using Anthropogenic CO2
Pilot Projects
Announced Projects
Cancelled and Inactive Projects
Recent Updates and News
Regional CCS Financing Summaries
Other Online Databases

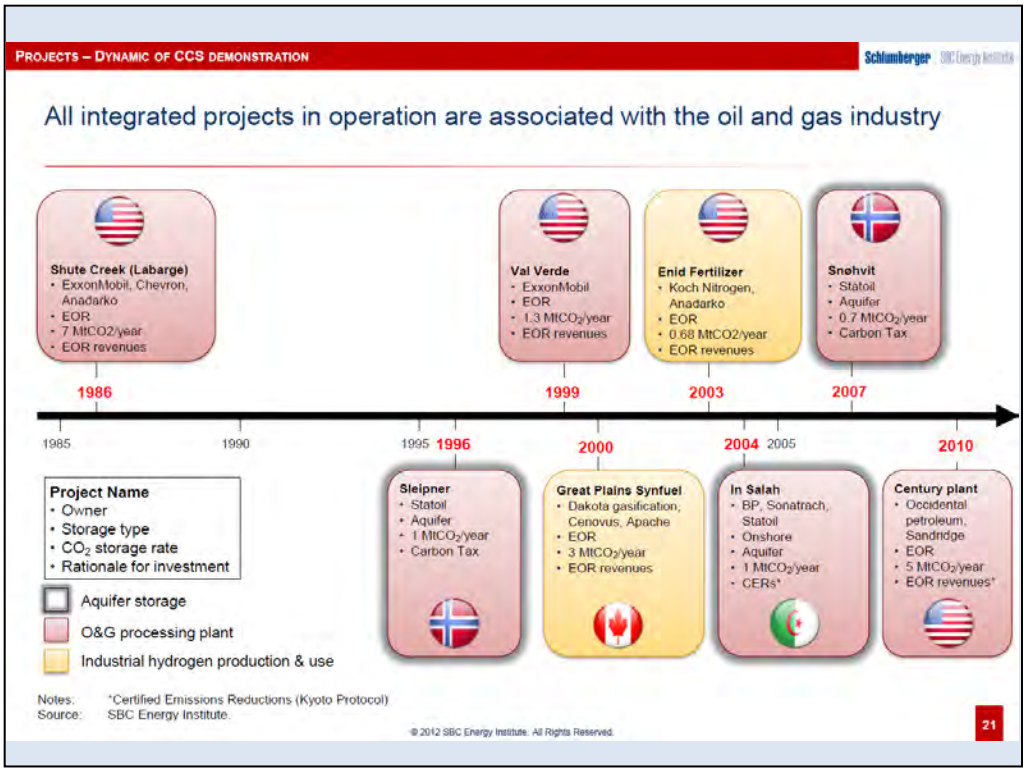
Commercial EOR Projects using Anthropogenic Carbon Dioxide

Click on Project Name to go to Fact Sheet
Click on country name to go to regional financial summary

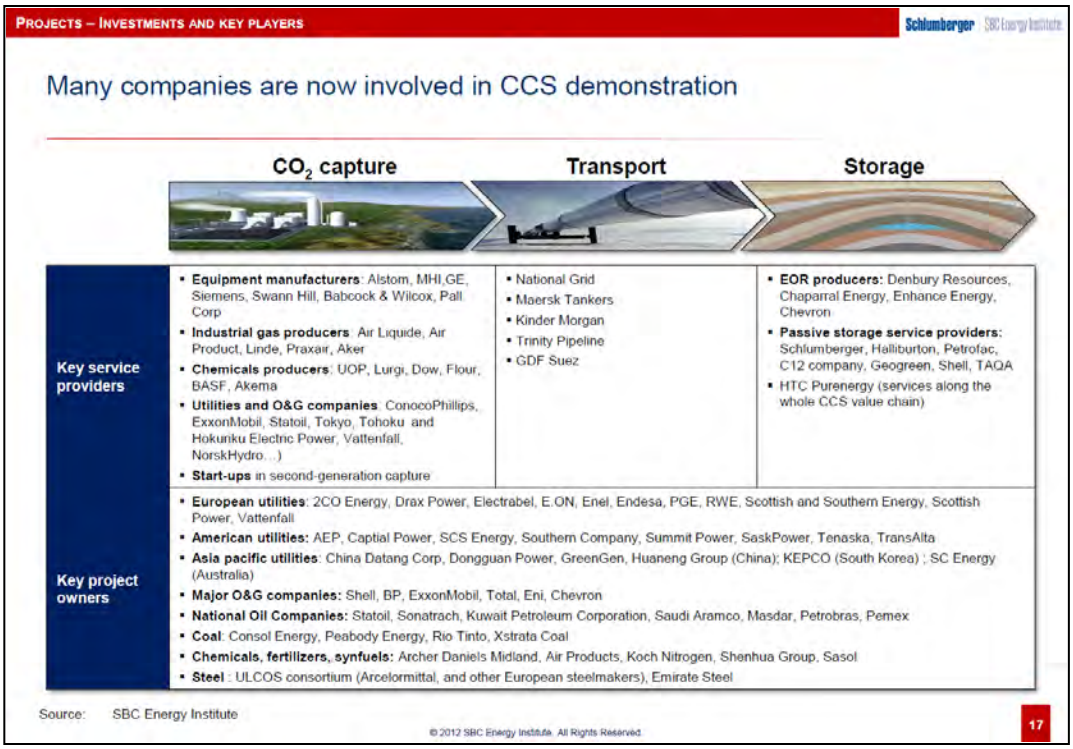
USA						
Project	Leader	Location	CO2 Source	Size Mt/yr	CO2 Sink	Status
Val Verde	Multiple operators	Texas	Gas Processing	1.3	EOR	Operational 1972
La Barge	Exxon Mobil	Wyoming	Gas Processing	6	EOR	Operational 1986
Enid Fertilization	Koch Nitrogen Company	Oklahoma	Fertilizer Production	0.68	EOR	Operational 2003
Century Plant	Occidental Petroleum	Texas	Gas Processing	5	EOR	Operational 2010
Coffeyville	CVR Energy	Kansas	Fertilizer Production	1	EOR	Operational 2013
Lost Cabin	ConocoPhillips	Wyoming	Gas Processing	1	EOR	Operational 2013
Rest of the World						
Project	Leader	Location	CO2 Source	Size Mt/yr	CO2 Sink	Status
Lula	Petrobas	Brazil	Gas Processing	0.7	EOR	Operational 2013
Uthmaniyah	Saudi Aramco	Saudi Arabia	Gas Processing	0.8	EOR	Planning

http://sequestration.mit.edu/tools/projects/index_eor.html

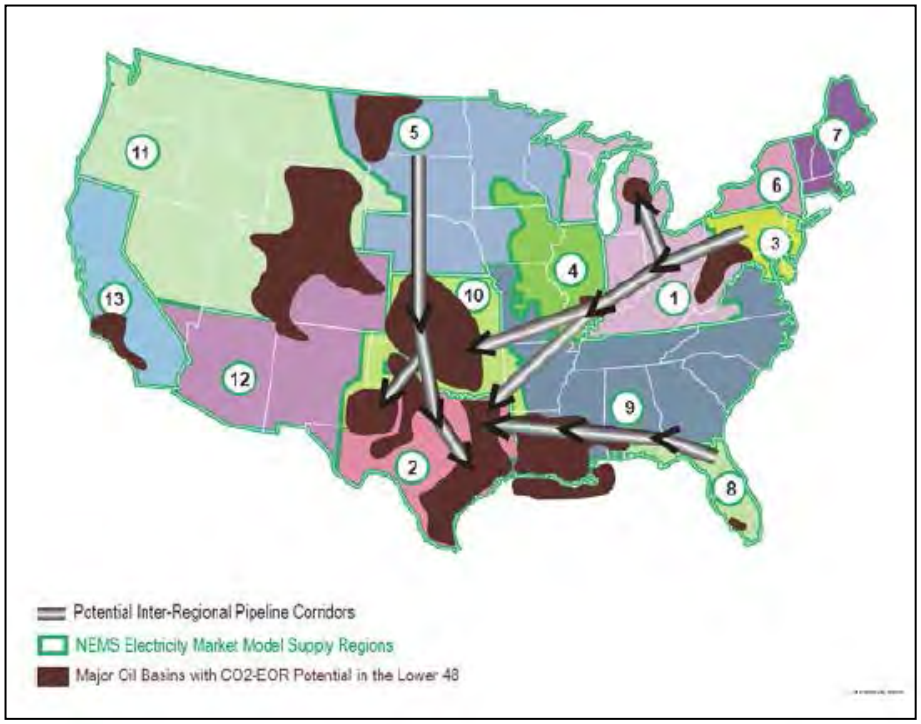
Gas Processing and fertilizer plants commercially capture CO_2 today including Koch Dodge City fertilizer plant. CO_2 is used primarily for beverages while their Enid plant is in part used for CO_2-EOR.



Large industrial gas suppliers are interested in the CO_2-EOR market in Kansas.



Study published by Schlumberger indicating that CO_2 abatement potential for power plants using carbon storage in oil and gas reservoirs is reasonable.







APPENDIX F.

Improving efficiency and user-friendliness of the Java Applications

Proposal submitted to KU --
Integrated Real-Time Subsurface Analysis Web Applications, W. Lynn Watney, P.I. , John Doveton, Co-I, John Victorine, Technician, Jennifer Raney, Technician, Budget Requested

Abstract (1/2 page)

Proof of concept (POC) funding is requested from KUIC to extend the utilization of the GEMINI (*Geo-Engineering through INternet Informatics*) computing platform to a unique and likely commercial application for personal computers, smartphones, and tablets that could be used by industry, government, education to access and query subsurface data in proximity to the user. Mobile GEMINI would access digital borehole data and provide analytical and imaging solutions based on location of user or locations of projects. The objectives of the POC activity includes reconfiguring multiple software modules for access through a single entry point, maximize features of the mobile devices to "mine" the digitial borehole data in real-time, and use standard LAS (log ascii standard) 3.0 format to easily to save, update, share, and archive data and results.

To establish proof of concept, Mobile GEMINI will be tested using digital borehole data that is publically available on the Kansas Geological Survey website. This will set the stage for future integration with proprietary industry databases and other public information, with the latter having grown markedly in the past decade.

Lay Description of Technology (1/2 page)

The technology behind Mobile GEMINI closely resembles the Geographic Information Systems (GIS) that is frequently used on most mobile GPS devices and smartphones, e.g., Google Earth. Much like popular street mapping programs, mobile GEMINI would provide GIS-like investigation of the Earth's subsurface using the primary and most abundant source of information available, borehole information records obtained in the search for water, oil, and gas or disposal and injection of material. Large and growing public data sites such as the Kansas Geological Survey have built large inventories of digital borehole data. The POC funding will tailor software to efficiently access, manage, and illustrate the subsurface information on the mobile devices giving the informed user the ability to view the subsurface using their location coordinates or these specified by the user. The information would be most useful to industry, regulators, educators, and others who wish to learn about the subsurface. The team has extensive experience in building Java web applications and interfacing with databases. A niche market for

this mobile software application is believed to be untapped and is an important next step for the development team.

John Victorine is the principal programmer who will build Mobile GEMINI. He will spend half his time in the coming year on this activity. Jennifer Raney will apply her expertise in GIS and database management and familiarity with the software and mobile computing technology to assist in the development, testing, and working with our industry partner with the goal to take the Mobile GEMINI to commercialization.

1) General Background

Novel web-based petrophysical software developed by the Kansas Geological Survey (KGS) over the past 13 years is poised for commercialization across a broad marketplace. Existing programs will be enhanced to enterprise computing levels for use as a mobile application and extending its use far beyond its current implementation at the KGS. Rapid, consistent, quantitative analytical and visualization software are essential to understand the earth's subsurface and resolve challenges currently faced in managing natural resources, environmental characterization, and remediation practices, e.g., enhanced targeting of unconventional oil and gas resources via horizontal drilling, managing groundwater extraction, and storing CO_2 in the subsurface. We have coined the term, "Subsurface Information Systems (SIS)" to capture the parallel to GIS in our efforts to provide imaging of the subsurface that is comparable to the functionality and expectations of GIS (Doveton, 1994). Over the past decade, our petrophysical research has demonstrated the growing demand for use of the in-house petrophysical software and the developers now wish to elevate the software to commercial status. The POC funding would allow us to utilize our experience and observations to focus on creating a product with the most viable commercial application. We believe that extending the application to mobile devices such as cell phones and tablets will fulfill the rapidly growing demand for intuitive, accessible, and informative means to independently investigate the subsurface.

The commercialization would proceed in parallel to research and development of new tools supported to date by federal agencies, industry partners, and the KGS. The existing petrophysical tools are freeware developed as part of the GEMINI (*Geo-Engineering through INternet Informatics*) project sponsored by the Department of Energy *(DE-FC26-00BC15310*) from 2000 to 2003. Of late, the programming effort has been reinforced with support from DE-FE0002056, "*Modeling CO2 Sequestration… in South-Central Kansas*" from 2009 to present. The software, written in Java and using XML tables referenced by the software features 13 separate modules released as applets as described at **http://www.kgs.ku.edu/Gemini/Tools/Tools.html**. The Java applets provide user-friendly access, analysis, and visualization of single and multiple borehole measurements, and analyses obtained from rocks recovered from the boreholes. The software modules read and write output into standard, simply formatted ascii files (LAS 3.0, Heslop et al., 1999) that permit ease of use, data sharing, adding new information, and archiving. Several of the Java applets are accessed through ESRI mapping software to provide a familiar interface to

locate the boreholes and initiate the software. The applets are used many times a day by the public without issue, so the software has clearly been tested and is deemed very reliable and stable. October 2013 web hits on GEMINI tools totaled 990. Oracle database access in same period was 56,000.

2) Commercial Application of Research (Market size, comparisons with currently available products, similar applications or use)

The technical capabilities of these unique subsurface analysis tools are diverse, and will therefore be applicable to multiple markets, both public and private. Generally, the tools are valuable to geologically-related industries interested in markets such as mining (e.g., oil & gas), geothermal, environmental, geotechnical, as well as for higher-level educational purposes. Due to the integrity and robustness of the database management system, the software sets an unprecedented standard for collecting and maintaining the geological and petrophysical data required to characterize and evaluate subsurface conditions. By integrating this information with highly intuitive, automated software, a broad spectrum of users will find value in the tools that were once constrained to only the highest level of industry.

Input parameters into the database will be maintained and updated using techniques exclusive the KGS combined with the former Log ASCII Standard (LAS) 2.0 format to achieve unparalleled dataset capabilities. The LAS 2.0 is rapidly becoming the industry standard to store and transmit digital geological information, but is only capable of storing a narrow spectrum of the types of subsurface data available today (Heslop, 1999; Qiang, 2005). The newly improved LAS 3.0 version incorporates an unforeseen amount of data into a single archive, which can analyzed to accomplish a wider set of goals. For example, the LAS 3.0 has already gained wide popularity in the Middle East, where the high functionality and detail of the data format enables its use in drilling horizontal wells (Naji, 2012). The KGS has a strong awareness of the burgeoning petroleum industry, and predicts that trend will continue to proliferate throughout the United States. By the end of last June, 247 active horizontal wells in Kansas were producing 260,000 barrels per month of oil (http://www.kansascommerce.com/index.aspx?NID=520**).** This recent surge of horizontal drilling pales in comparison to the more than 88,000 vertical oil and gas wells currently active or producing in Kansas, making it the 8th largest oil and natural gas producer in the United States. However, dispersed resources and high exploration costs have begun to make traditional drilling practices less viable for independent oil and gas operators in Kansas, which, according to the president of the Kansas Independent Oil & Gas Association, make up 92% of oil and 63% gas wells drilled in the state (www.kioga.org)

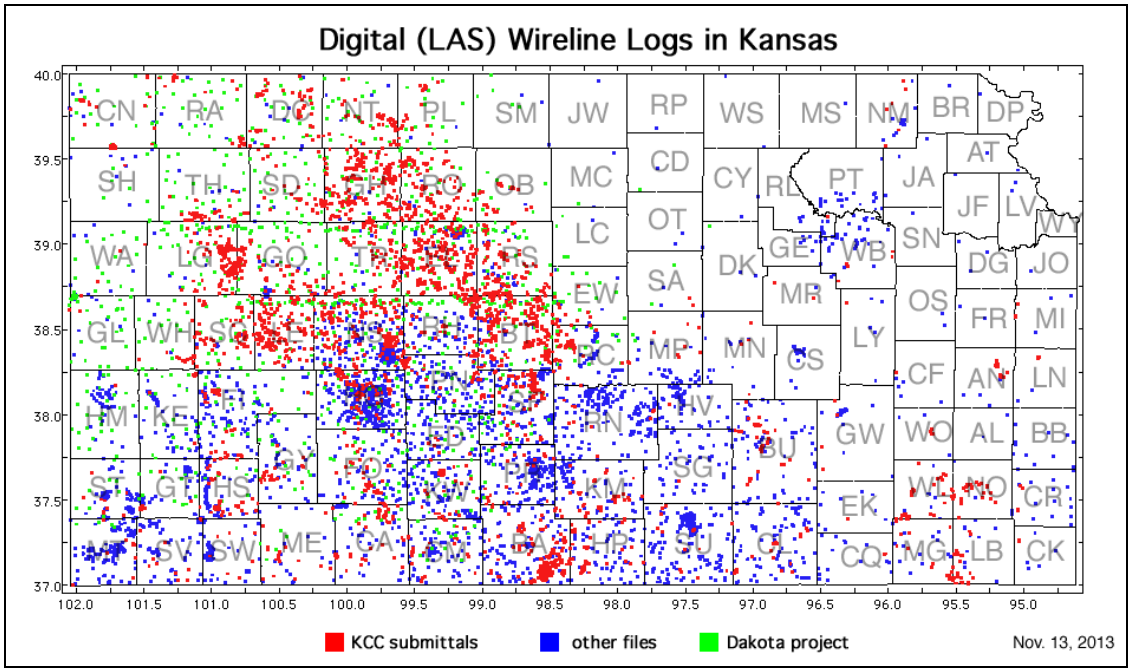
Advancements to the SIS developed by the KGS will provide smaller independents with proven, state-of-the-art technology necessary to carry out successful exploration activity, protect the environment, and continue to support local Kansas communities. While similar software tools are available, exorbitant licensing fees, expert-level training requirements, and immense computer processing capacity has made them practically unusable outside of the largest enterprises. For example, SubsurfaceViewer is a Java and XML based program from Germany

that can perform functions such as regional geospatial surveys, integrated well log analysis, and subsurface visualization that are analogous to the SIS tool being promoted by the KGS. However, commercial licenses to this software are expensive, and more importantly, are designed primarily for highly skilled professional geologists with strong backgrounds in computer modeling (http://subsurfaceviewer.com/ssv/index.php?id=1#thema02). Similar tools are offered by RockWare Inc. (http://www.rockware.com/), Paradigm Epos applications (http://www.pdgm.com/Products/Epos), and the industry-giant Schlumberger (http://www.software.slb.com). Performing even simple subsurface investigations with these tools is notoriously time and labor intensive and demands a high level of skill (Samberg, 2007). To move beyond this user base, the software must work intelligently with minimal complexity to extend its use to practicing geoscientists and technical teams, those who may have limited expertise in petrophysical analysis. The SIS tools will directly address these budgeting and operability issues to create something well suited to an untapped niche market, while simultaneously building a framework that optimizes interoperability to expand into larger industries in the future (Crangle, 2007).

Technology innovation

Industry demand and anticipated market -- The mobile version of GEMINI would provide targeted integrated analysis obtaining similar outcomes as 3D modeling including high-resolution stratigraphic correlation, characterize hydrocarbon pay zones and pore systems by employing predictive modeling techniques, and using automated, quantitative color imaging to enhance visual tracking and characterization.

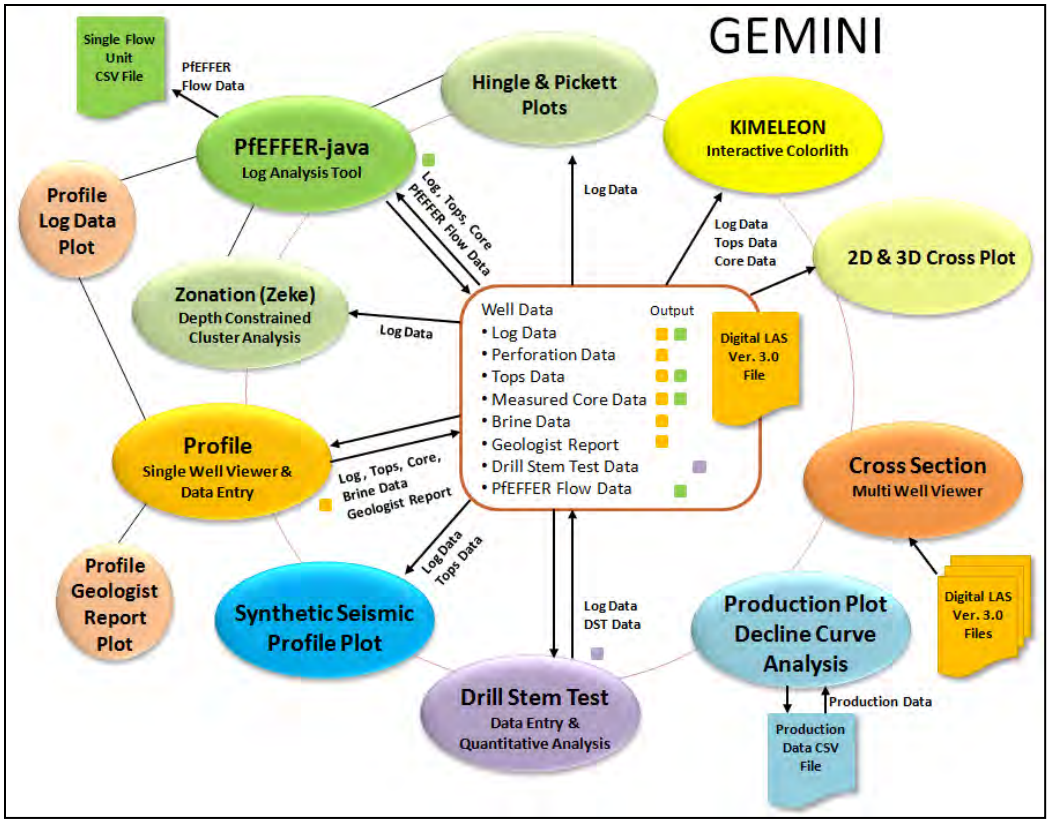
The growth and access to digital databases collected by state, federal, and international governments has opened vast amounts of subsurface borehole data inventories. Federal divisions such as Bureau of Ocean Energy Management (BOEM), Bureau of Land Management , and US Geological Survey have vast amounts of digital borehole. The POC grant will focus on the KGS borehole database. An intelligent mobile application such as Mobile GEMINI could allow user to “mine” the information (see map below).



The current generation of GEMINI software is solid working technology that works with the computing environment and data repository at the KGS. Funding has remained focused on tool refinement suited to meet obligations of our multi-million dollar external funding from DOE and serve users accessing the KGS website.

The total lines of GEMINI code, version 2.6, in October 2002 was 157,000 as part of 502 source files. Programming standards used to date include: 1) instituting policies and procedures of software development utilized in some sectors of the federal government, 2) Java Code Convention Document, 3) informal design and code review process, 4) Code Review Documentation, 5) periodic releases, and 6) Version Directories. The POC funding would bring the modules under a single application so that it can easily be certified under current self-regulating policies pertaining malware attacks.

Endorsements of GEMINI modules have been received internationally and modules have been used in our research (e.g., Doveton et al., 2004, Watney et al., 2004, Victorine et al., 2005, Bhattacharya et al. 2008, Watney et al. 2008, Doveton, 1994).



3) Specific goals, objectives, project milestones, and anticipate results

Goal of POC Funding -- The goal is to extend the interoperability of GEMINI to mobile computing devices to facilitate implementation in industry and government.

Objective -- The objective to aggregate individual software modules into a single entry point so that all the tools could be used and data could be saved to a common file that can be read by each software module. Tools would be accessed individually or as part of an explicitly defined, logical workflow to guide users through the application, an outcome that goes back to the original GEMINI. Use of the simple LAS 3.0 file data structure as common file is unique to this application.

Project Milestones – 1) Research topics in mobile computing platform (1 month), 2) Outline programming steps and modifications to existing software (1 month), 3) Integrate existing modules via a single entry point (2 months), 4) Modify software to adapt to mobile computing device (3 months), 5) Write new software to use features of mobile computing device, e.g., GPS, (3 months), 6) Testing with the KGS digital borehole database and release of prototype software (2 months).

Anticipated Results -- The anticipated "mobile GEMINI" would use enhanced versions of existing intelligent algorithms to maximize petrophysical interpretations to a particular device. As in the existing software, the measured data and computed results are displayed in standardized plots including images and curves that would be carried out in seconds. Results are

saved in standard ascii file structure (LAS 3.0), a simple output file that can be used in high-end 3-D modeling software or in Excel spreadsheets.

4) Description of project plan, including anticipate barriers and technical difficulties

The project plan is described above under Milestones that take the POC grant through the 1-year of support. John Victorine is the programmer/technician who has worked at the KGS on GEMINI and the 2nd generation software for the past 13 years. He is efficient, a dedicated hard worker, focused on excellence in programming. He is a physicist by education and a programmer in his distinguished career in federal and state institutions. John routinely accurately scopes out his work. During the original GEMINI 3-year build, he also commissioned portions of the programming to a three-person team. He managed the various skill sets and schedules, and successfully integrating their work to meet our lofty contract objectives. John is always aware of feature creep and stays focused on overall objectives. His goal is success, which is clearly where we have gone in our extended collaboration. Jenn Raney brings new perspectives with her background in GIS, database management, and skillset and interest in mobile computing.

John will continue to be the key player in the commercial release of this software and support would similarly be sought – including maintenance, coordinating with the licensing company on upgrades and improvements based on user feedback. The bottom line is that he really wants to do this and see commercialization. We as a team are similarly committed to continue to explore petrophysical applications that will continue to improve the software.

COMMERCIAL SUPPORT (1 PAGE)

According to recent updates, Kansas is the 8th largest oil and gas producer in the country, and the petroleum industry provides 67,000 jobs in the state. However, unlike other states, the oil and gas industry is largely dominated by independent operators that manage just a cluster of wells in localized areas. This framework called for the development of a unified state Geological Survey to provide widespread access to subsurface data, and also explains the close interaction between the KGS with independent operators throughout Kansas.

Alternatively, recent advancements in drilling technology have raised public awareness and environmental concerns. Often, environmental consulting agencies must evaluate subsurface conditions to verify the protection of drinking water sources, formulate decisions for corrective action when contaminants are involved, and investigate any potential hazards such as seismic events. With these issues receiving more attention in the press, questions are on the rise as to what is known about the subsurface, and how the information can be shared. The tools provided by the KGS can be equally useful to these individuals from an environmental protection vantage point, just as they are to the opposing industry.

These are reasons why the KGS is strongly relied upon as resource for environmental research, resource exploration, and drilling ventures, and how it continues to support the needs of both

independents and commercial industry members. The KGS GEMINI tools currently receive consistent use from visitors, with almost 1000 client requests hitting the GEMINI website in the month of October alone. Furthermore, the number of requests sent to the Oracle database that houses all borehole information was over 56,000 in the same month. Direct correspondence with operators has provided positive feedback of the GEMINI programs, and indicates the growing demand and continued use of the software.

Commercial support for the proposed SIS tools is inherently built into the relationship of the KGS with the petroleum industry, as well as the regulatory framework of the data sharing required by Kansas law. Essentially, all new digital borehole data is legally required to be submitted to state regulatory agencies, and is then made publicly available after a given time period. Ultimately, these records are released to the KGS and integrated with the same database that runs the SIS tools. By definition, the KGS database will steadily grow and improve as operators drill and log wells with higher quality tools, and then submit their digital information as required by law. As the commercial industry expands, so too will the dataset by which the SIS tools operate, leading to better coverage, software performance, and accuracy of the analysis.

APPENDIX I

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

NINETEENTH QUARTER PROGRESS REPORT

DOE F 4600.2
(5/09)
(All Other Editions are Obsolete)

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			
☒ Other (see special instructions) Topical — DOE F 241.3	A		http://www.osti.gov/estsc/241-4pre.jsp
** 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.

QUARTERLY 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

Eighteenth Quarter Progress Report

Date of Report: 8-5-14

Period Covered by the Report: April 1, 2014 to June 30, 2014

Contributors to this Report: Brent Campbell, Saugata Datta, John Doveton, Mina Fazelalavi, Eugene Holubnayak, Jennifer Raney, Jason Rush, Lynn Watney

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		90%
2.0 Characterize the OPAS (Ozark Plateau Aquifer System)	1/1/2010	01/01/10	9/30/2013		95%
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	+++	99%
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	**	99%
11.0 Produced water and wellbore management plans - Risk assessment area	1/1/2012	01/01/12	7/30/2013		99%
12.0 Regional CO2 sequestration potential in OPAS	8/1/2012	02/01/12	9/30/2013	***	99%
13.0 Regional source sink relationship	1/1/2010	1/1//2010	9/30/2013	****	98%
14.0 Technology Transfer	1/1/2010	01/01/10	2/7/1014		99%

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 competed
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	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		98% 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		Completed - **email summary to come**
KGS Milestone 3.4: Regional CO2 Sequestration Potential in OPAS - 17 Counties	12/7/2012		99% complete***
HQ Milestone: Make data set from one site characterization project publicly available.	12/31/12	Note: This milestone was met collectively by all projects. No one project was held accountable to the milestone.	
HQ Milestone: Complete one major field activity to collect additional characterization data from well drilling, 2-D or 3-D seismic surveys, or well logging/testing.	03/31/13	Note: This milestone was met collectively by all projects. No one project was held accountable to the milestone.	
HQ Milestone: Complete, at a minimum, planning for one major field activity, such as well drilling, 2-D or 3-D seismic surveys, or well logging/testing.	06/30/13	Note: This milestone was met collectively by all projects. No one project was held accountable to the milestone.	
HQ Milestone: Yearly Review Meeting of active projects; opportunities for information exchange and collaboration	09/30/13	Attended Annual Review meeting in August	100% complete
HQ Milestone: Complete one field activity to collect characterization data from well drilling, 2-D or 3-D seismic surveys or well logging/testing.	12/31/13	Note: This milestone was met collectively by all projects. No one project was held accountable to the milestone.	
HQ Milestone: Complete analysis of field activity in project-related reservoirs to validate additional storage potential.	03/31/14	Note: This milestone was met collectively by all projects. No one project was held accountable to the milestone.	
HQ Milestone: Semi-annual progress reports for active projects (i.e. Quarterly Report ending March 31, 2014).	06/30/14		
HQ Milestone: Yearly Review Meeting of active projects; opportunities for information exchange and collaboration	09/30/14		

TASK SUMMARY IN PREPARATION FOR COMPLETION OF THE PROJECT

This quarterly report is the last, prior to submitting the final report. All of the tasks and subtasks are listed herein with dialog pertaining to activities conducted in this last quarter.

Task 1: Program Management and Reporting (PMP)

Task 2. Characterize the OPAS

Subtask 2.1. Acquire geologic, seismic and engineering data

Type logs are being checked for completeness prior to final release.

Subtask 2.2. Develop regional correlation framework and integrated geomodel

Final review of framework correlations being completed using Java based correlation application (**Figure 1**).

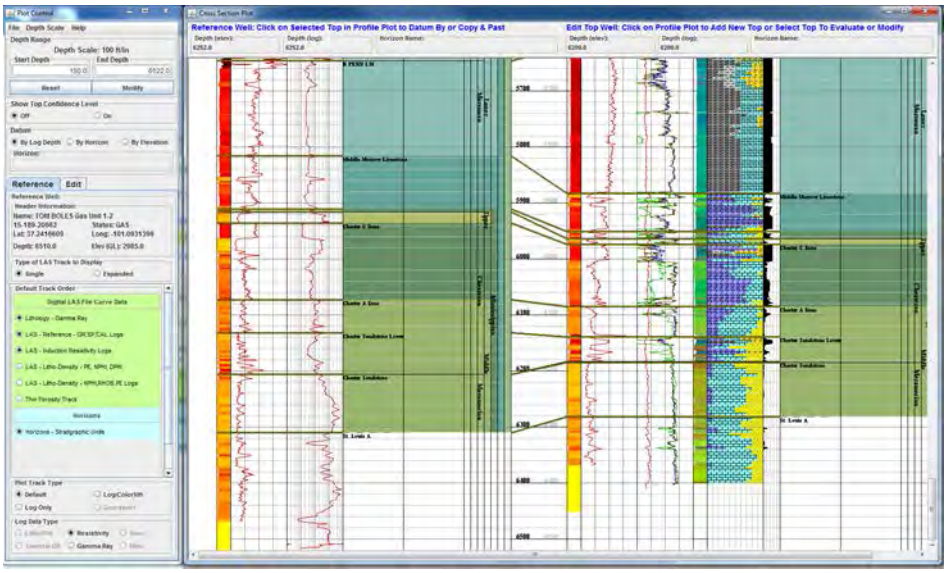


Figure 1. Correlations of type logs being checked.

Subtask 2.3. Subsurface fluid chemistry and flow regime analysis.

Evaluating flow units in 4-Township,
Commercial Scale Simulation of CO2 Storage, greater Wellington Field

Ten regional sites were selected in southern Kansas for large scale CO2 storage in the Arbuckle saline aquifer. Estimates of the permeability, vertical and horizontal, were used to establish flow units. The test case for the modeling using the flow units was the greater Wellington Field area. The flow units in Wellington KGS #1-32 were initially defined by Mina Fazelalavi (**Figure 2 left**). Fifteen layers were defined. These are compared with those derived by Paul Gerlach who used vertical permeability to define flow units for the same well (**Figure 2, right**).

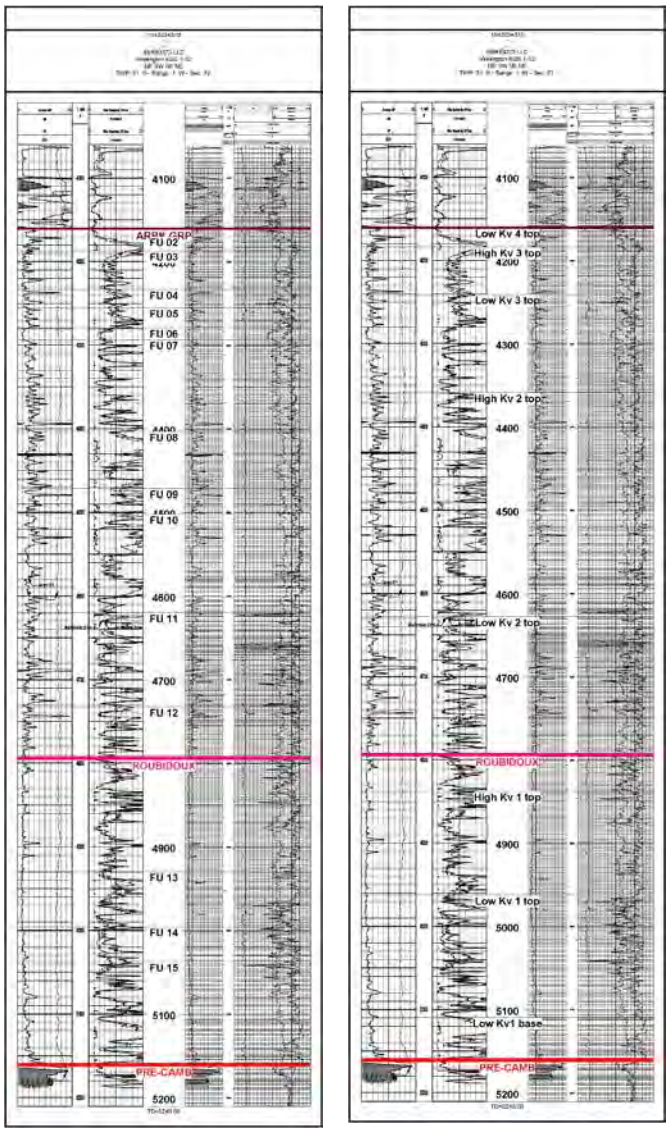


Figure 2. (left) flow units derived from horizontal permeability and (right) derived from vertical permeability for Wellington KGS #1-32.

Mina's approach, the Lorenz method, is often used by engineers. Mina compared this classification of the 15 flow units with a number of attributes as listed below, summarized in **Figure 3**, and illustrated in a depth plot in **Figure 4**.

1) flow units derived from Lorenz plot (SLMP)
2) GR
3) lithology
4) T2 distribution which shows pore size
5) K90
6) Kv
7) Arithmetic average of Kh
8) Arithmetic average of Kv
9) Harmonic average of Kv
10) flow capacity %
11) storage capacity %

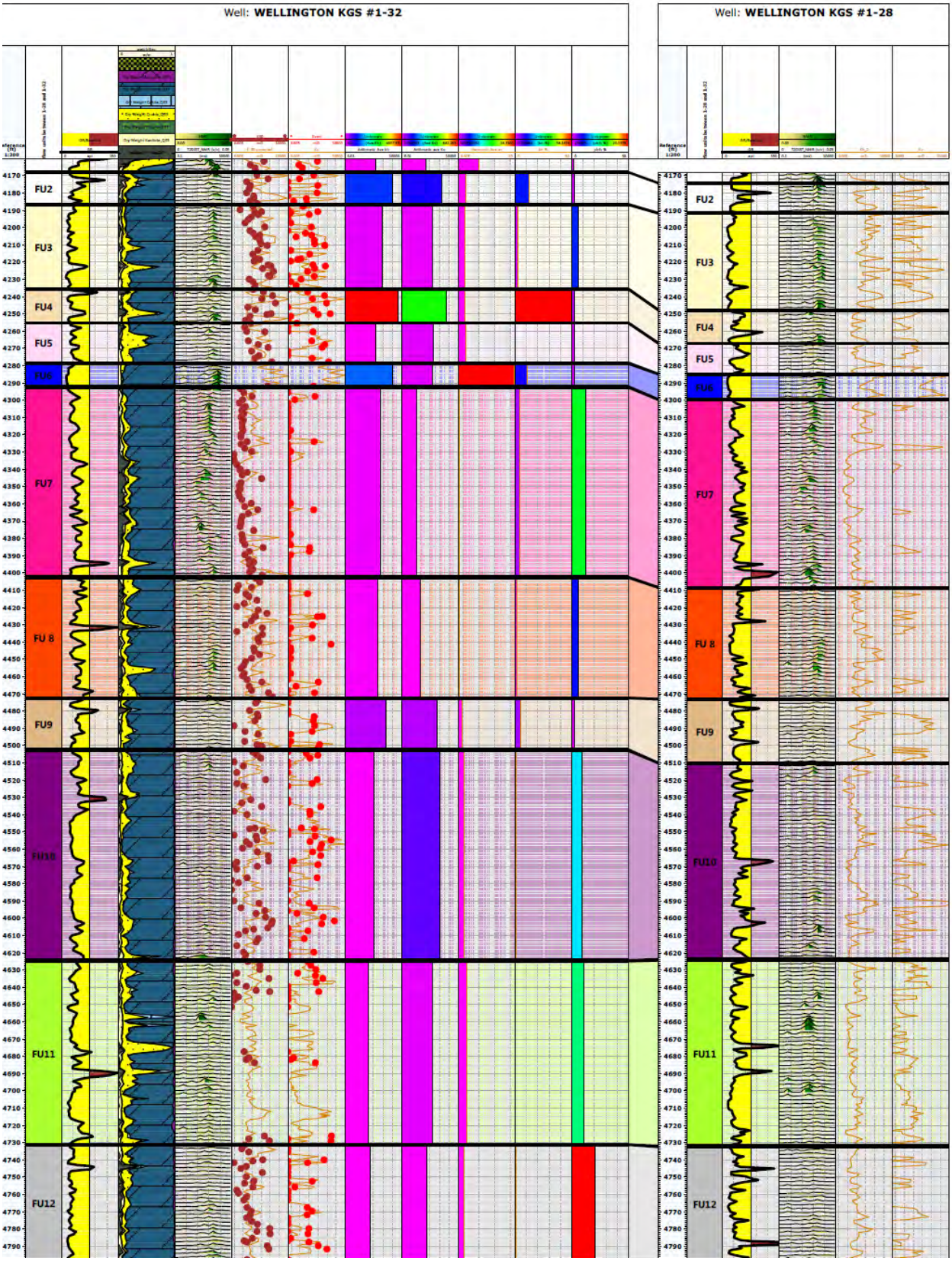
Each flow unit has a distinct permeability (Kv and Kh), flow capacity, and storage capacity. Even pore size distribution, GR, and lithology are indicatives of differences of each layer. However, correlating these detailed flow units beyond the heavily calibrated Wellington Field presents challenges – to do so expeditiously with more limited information.

	Depth						
Flow Unit Number	from	to	ΣKh %	Σ ϕh %	Ave K	Σ Kh/Σ ϕh	flow unit type
FU01	4160	4168	0.096785	1.511252	21.55	0.064042934	baffle
FU02	4168	4186.5	9.490357	2.142572	946.94	4.429422306	Permeable
FU03	4186.5	4235.5	2.129447	5.73142	82.27	0.371539118	fair to low capacity
FU04	4235.5	4256	44.43726	2.514279	4007.55	17.67395686	Very Permeable
FU05	4256	4278	0.199295	2.101346	16.96	0.094841469	baffle
FU06	4278	4292	8.232712	2.002677	1113.22	4.110853325	Permeable
FU07	4292	4300.5	0.004002	1.127471	0.89	0.003549412	baffel
FU08	4300.5	4305.5	6.696173	0.540471	2304.80	12.38952248	Permeable
FU09	4305.5	4397.5	0.560327	9.548474	11.61	0.05868241	baffle
FU10	4397.5	4402	2.566065	0.500545	1078.75	5.126542716	Permeable
FU11	4402	4472	0.975126	5.127107	26.42	0.190190219	Permeable
FU12	4472	4502.5	3.463398	1.953841	211.56	1.772610543	Permeable
FU13	4502.5	4986.5	3.160263	44.88617	9.10	0.070406158	baffle
FU14	4986.5	4996	16.20864	0.95441	3677.33439	16.98289076	Very Permeable
FU15	4996	5034.5	1.465964	4.500618	72.0576278	0.325725091	fair to low capacity
FU16	5034.5	5200	0.314184	14.85735	3.59366448	0.021146683	baffle

Layer Top	Model	Mina Flow Unit
4,160	Layer 01	FU01
4,184	Layer 02	FU02
4,241	Layer 03	FU04
4,359	Layer 04	FU09
4,429	Layer 05	FU11
4,500	Layer 06	FU12
4,571	Layer 07	FU13
4,642	Layer 08	FU13
4,837	Layer 09	FU13
4,879	Layer 10	FU13
4,928	Layer 11	FU13
4,962	Layer 12	FU13
5,109	Base Model	FU16

Figure 3. Wellington KGS #1-32, properties of flow units define by Mina.

Paul's flow units (**Figure 2, right**) are upscaled and the focus on differentiation of vertical permeability. The upscaling has led to some changes in boundaries, but the basic framework of Mina's flow units is still present (**Figures 5-76**). The Lorenz Plot shown in **Figure 6** and are compared in the depth plot of Wellington KGS #1-32 in **Figure 7**.


Well: WELLINGTON KGS #1-32
Well: WELLINGTON KGS #1-28
FU2
FU3
FU4
FU5
FU6
FU7
FU 8
FU9
FU10
FU11
FU12

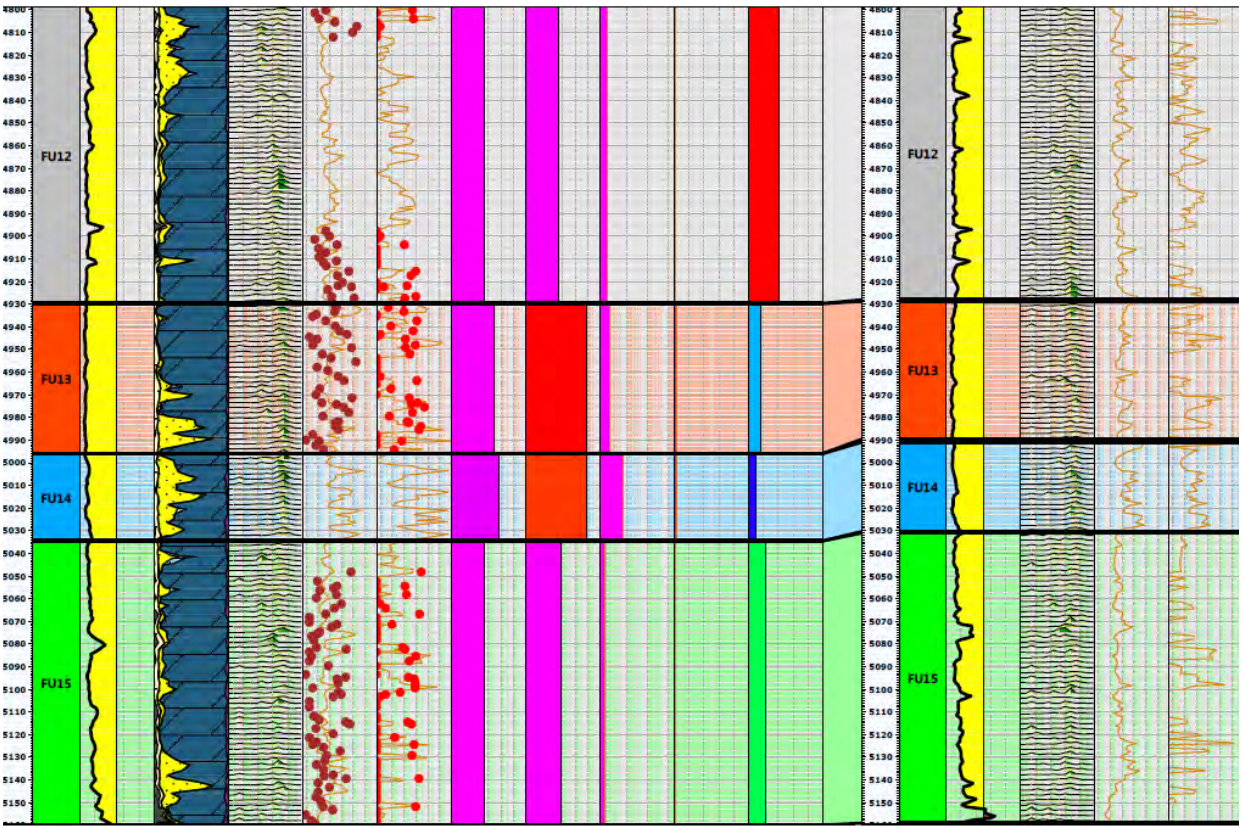


Figure 4. Comparison of Mina's 15 flow units between wells #1-32 and #1-28.

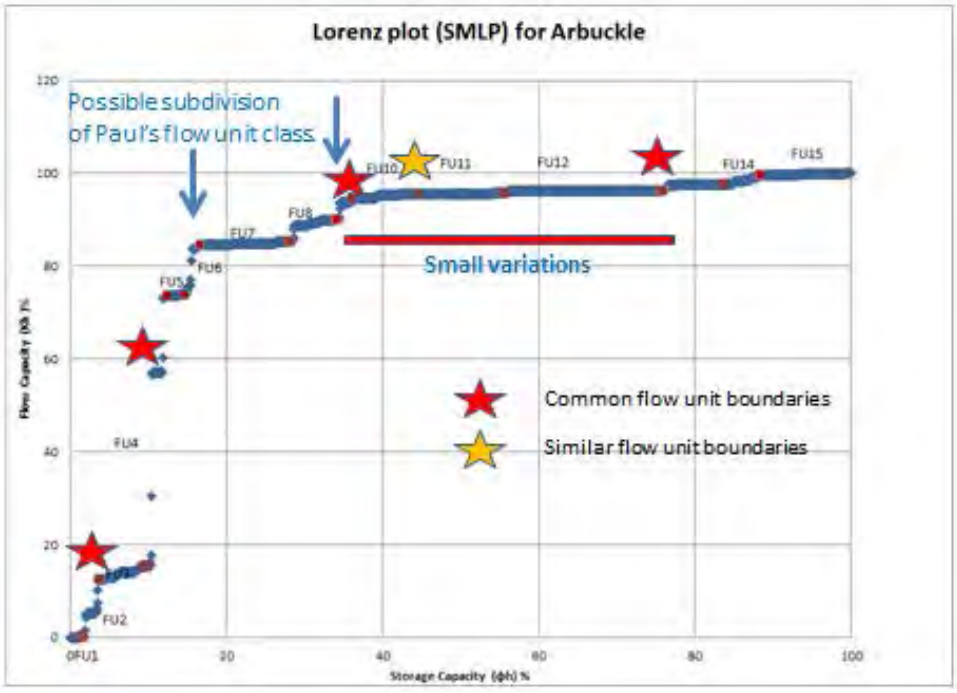


Figure 5. I have labeled the common flow unit boundaries. These units capture a lot of the variability. Mina's flow unit is based on Kh and Paul includes use of Kv to distinguish the layers. It is my understanding that Kv is very important so it needs to be factored into the flow unit classification.

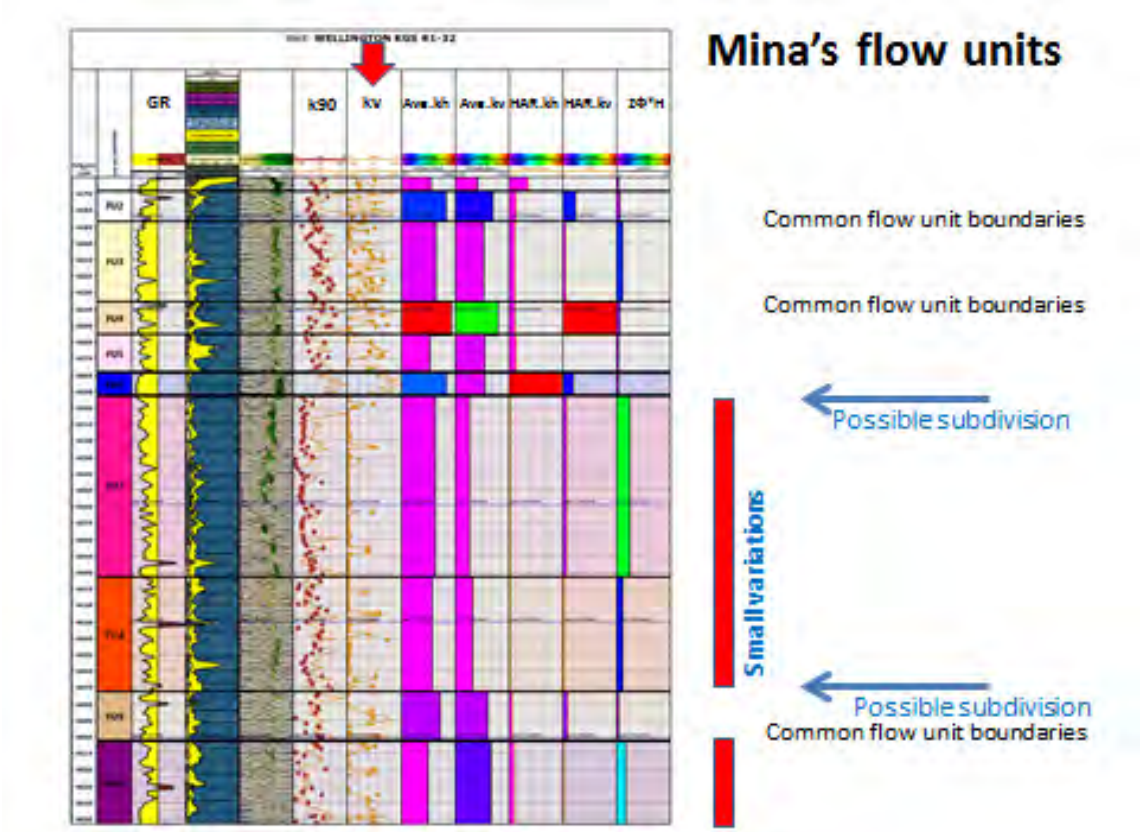


Figure 6. Comparison of Mina's and Paul's (faint blue dashed line) flow units indicate potential to add flow unit boundaries in the latter. Two of Paul's boundaries are included in Mina's FU7 and FU8. The boundary between FU7 and FU8 is very minor as also seen in Figure 6 and noted by the red bar (small variations).

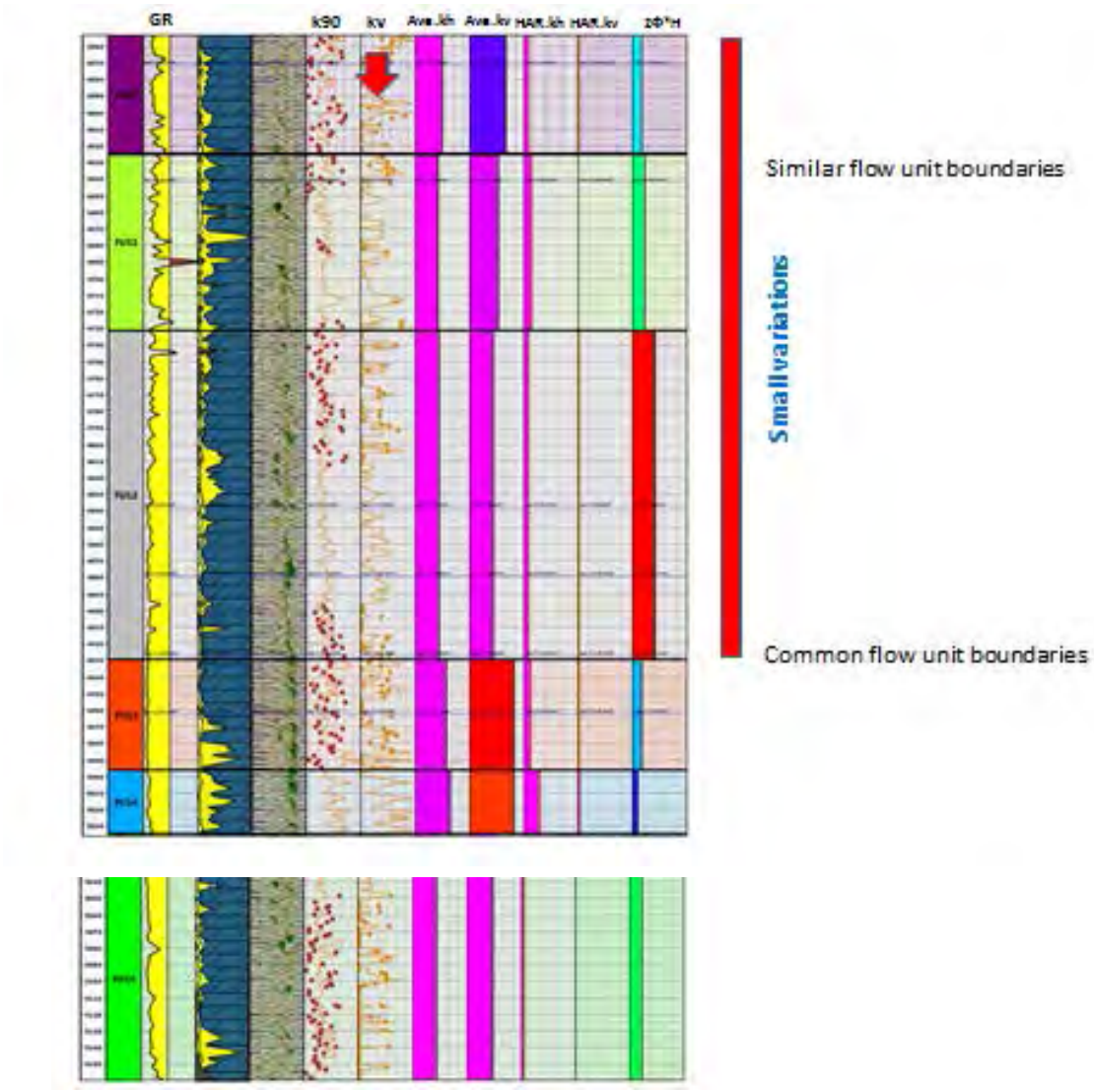


Figure 7. Mina's and Paul's flow units (faint blue dashed lines) have subdivided Arbuckle into multiple flow units in the interval noted as "small variations".

The flow unit delineation was investigated early on using depth-constrained cluster analysis (*http://www.kgs.ku.edu/stratigraphic/ZONATION/*), comparing results with Wellington KGS #1-32 and #1-28 (**Figure 8 and 9**). Technique does not examine interwell correlation so flow unit designation varies between wells and becomes problematic.

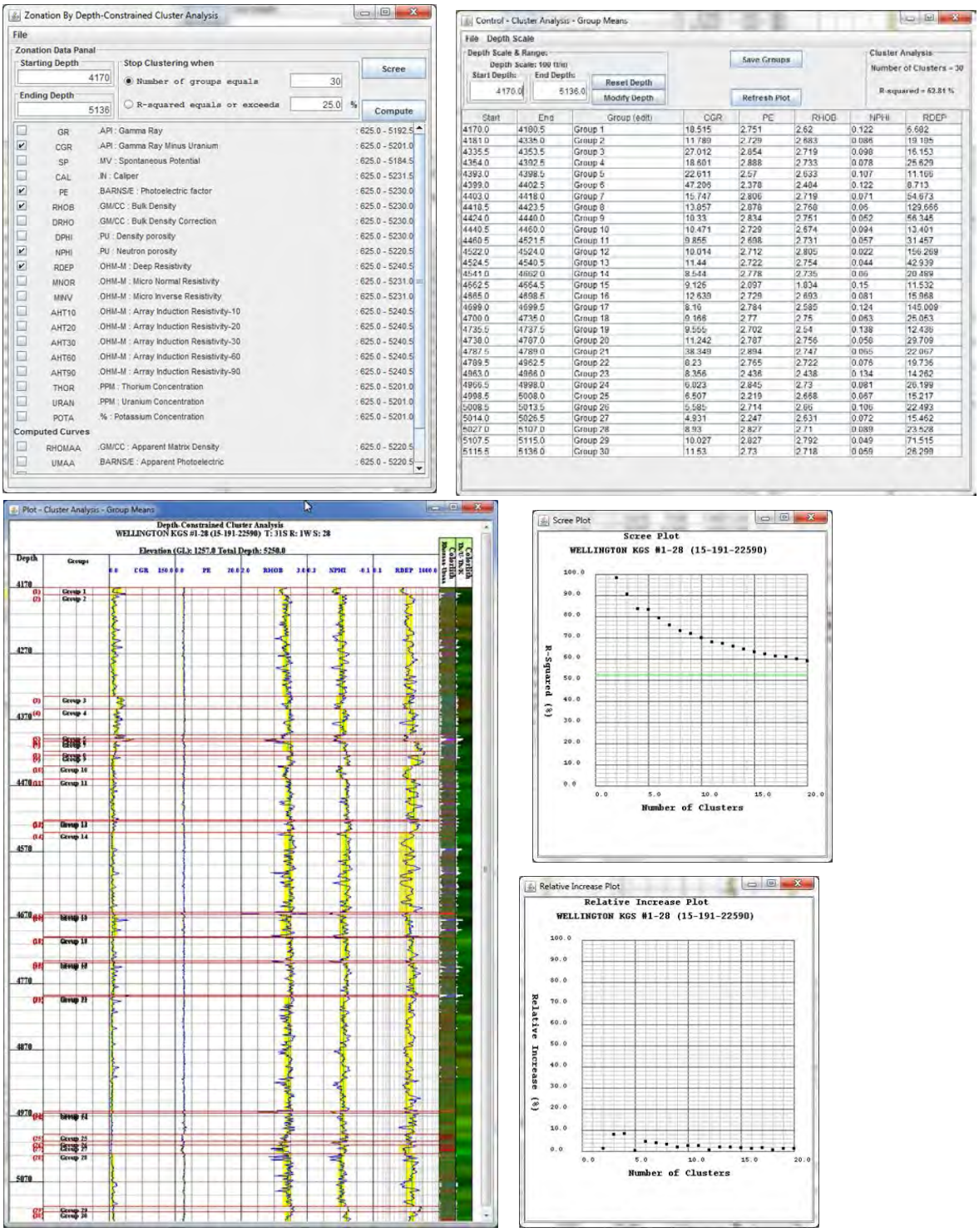


Figure 8. Computation of zonation by depth-constrained clustering for Wellington KGS #1-28.

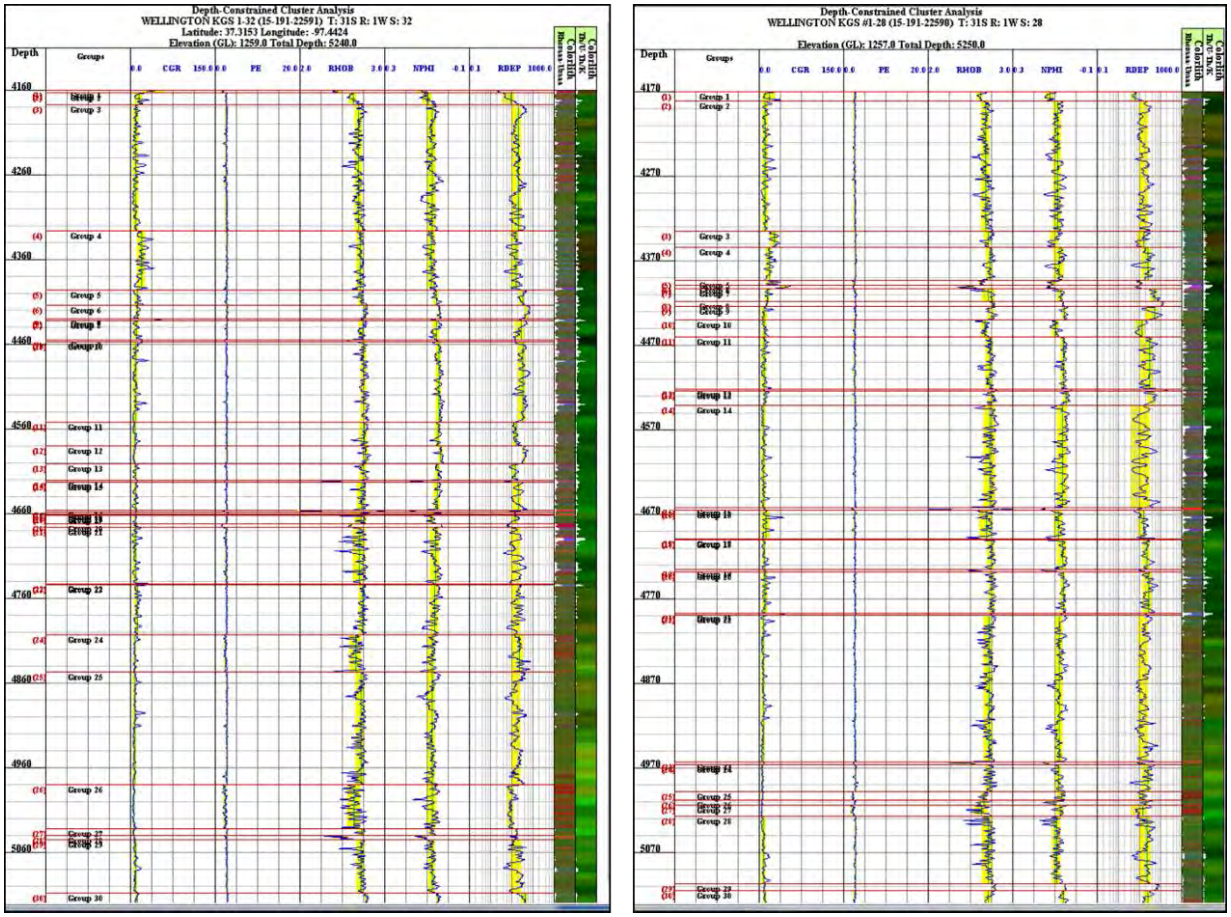


Figure 9. Zonation by depth-constrained clustering for #1-32 (left) and #1-28 (right).

Subtask 2.4. Gather and interpret KGS's gravity and magnetic data

Subtask 2.5. Remote sensing analysis for lineaments

Task 3. Geomodel of Mississippian Chat & Arbuckle Group - Wellington field.

Subtask 3.1. Collect geologic & engineering data
Subtask 3.2. Collect 3D seismic data
Subtask 3.3. Process 3D seismic data
Subtask 3.4. Collect gravity and magnetic data
Subtask 3.5. Interpret seismic, gravimetric, and magnetic data
Subtask 3.6. Initial geomodel - Wellington

Task 4: Preparation, Drilling, Data Collection and Analysis – Test Borehole #1

Subtask4.1. Locate Test Borehole #1
Subtask 4.2. Permitting for Test Borehole #1
Subtask 4.3. Drill, retrieve core, and run DST – Test Borehole #1
Subtask 4.4. Openhole Wireline Logging – Test Borehole #1
Subtask 4.5. Wellbore Completion – Test Borehole #1
Subtask 4.6. Analyze wireline log - Test Borehole #1
Subtask 4.7. Test and sample fluids (water) from select intervals – Test Borehole #1
Subtask 4.8. Analyze Arbuckle core from Test Borehole #1
Subtask 4.9. Analyze Mississippian core from Test Borehole #1
Subtask 4.10. PVT analysis of oil and water from Mississippian chat reservoir
Subtask 4.11. Analyze water samples from Test Borehole #1
Subtask 4.12. Microbiological studies on produced water
Subtask 4.13. Correlate log and core properties
Subtask 4.14. Examine diagenetic history of fracture fill

Task 5. Preparation, Drilling, Data Collection, and Analysis - Test Borehole #2

Subtask 5.1. Locate Test Borehole #2
SubTask 5.2. Permitting for Test Borehole #2
Subtask 5.3. Drill, and run DST – Test Borehole #2
Subtask 5.4. Openhole wireline logging - Test Borehole #2
Subtask 5.5. Complete well and perforate selectively to test and sample fluids – Test Borehole #2
Subtask 5.6. Analyze wireline log – Test Borehole #2

Task 6. Update Geomodels

Subtask 6.1. Hydrogeologic studies
Subtask 6.2. 2D shear wave survey
Subtask 6.3. Process & interpret 2D shear
Subtask 6.4. Revise 3D seismic interpretation
Subtask 6.5. Update geomodel - Arbuckle & Miss

Update in Step Rate Test - Mina Fazelalavi

Step-rate test and interference tests were re-analyzed and better results are obtained. Results of the recent well test analysis discussed below. Calculated permeability from step-rate test and interference tests are almost in agreement with log derived permeability. Skin is negative due to either fracture around the wellbore caused by injection or acidizing before the injection. The former statement seems to be more valid.

Step-rate test was modeled with FEKETE software and permeability and skin were calculated. Interference test was also modeled with FEKETE. A composite model was considered for this test due to change in permeability and flow capacity at some distance from the wellbore. Two permeabilities were calculated for two radii (regions) from Wellington KGS 1-32.

The calculated permeability from step-rate test is 113 mD for 30 ft interval that has vertical communication based on Lorenz plot that was used to designate flow units (as previously discussed). There are vertical barriers above and below this interval. 25 ft of this interval is perforated. This permeability is close to log derived average permeability (74mD) for the same interval. Results are described in **Figure 10**.

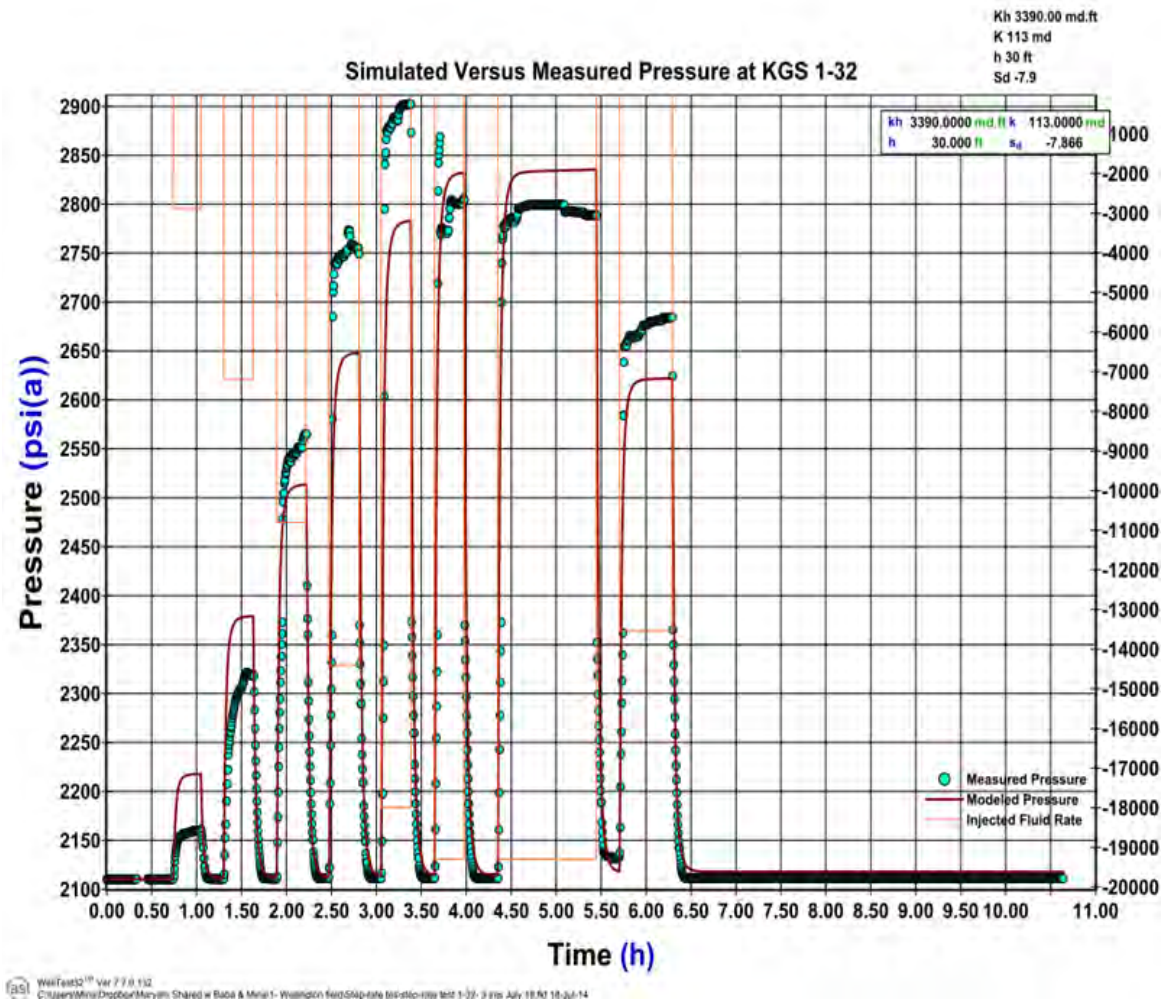


Figure 10. Step-rate test analysis revised, simulated vs. matched.

Well 1-32 was the injection well and 1-28 was the observation well. Distance between 1-32 and 1-28 is 3500ft (**Figure 11**). Better results were obtained when composite model with dual porosity-permeability was considered. Based on this model, permeability around well 1-32 to a radius of 2493 ft (region 1) has a lower value (100 mD) for 30 ft interval that is in vertical communication.

Permeability is 124 D from radius of 2493ft to the vicinity of 1-28. Permeability derived from the interference test is close to log derived average permeability (74mD). Bigger permeability for the farther radius can be associated with fracture or fault between two wells.

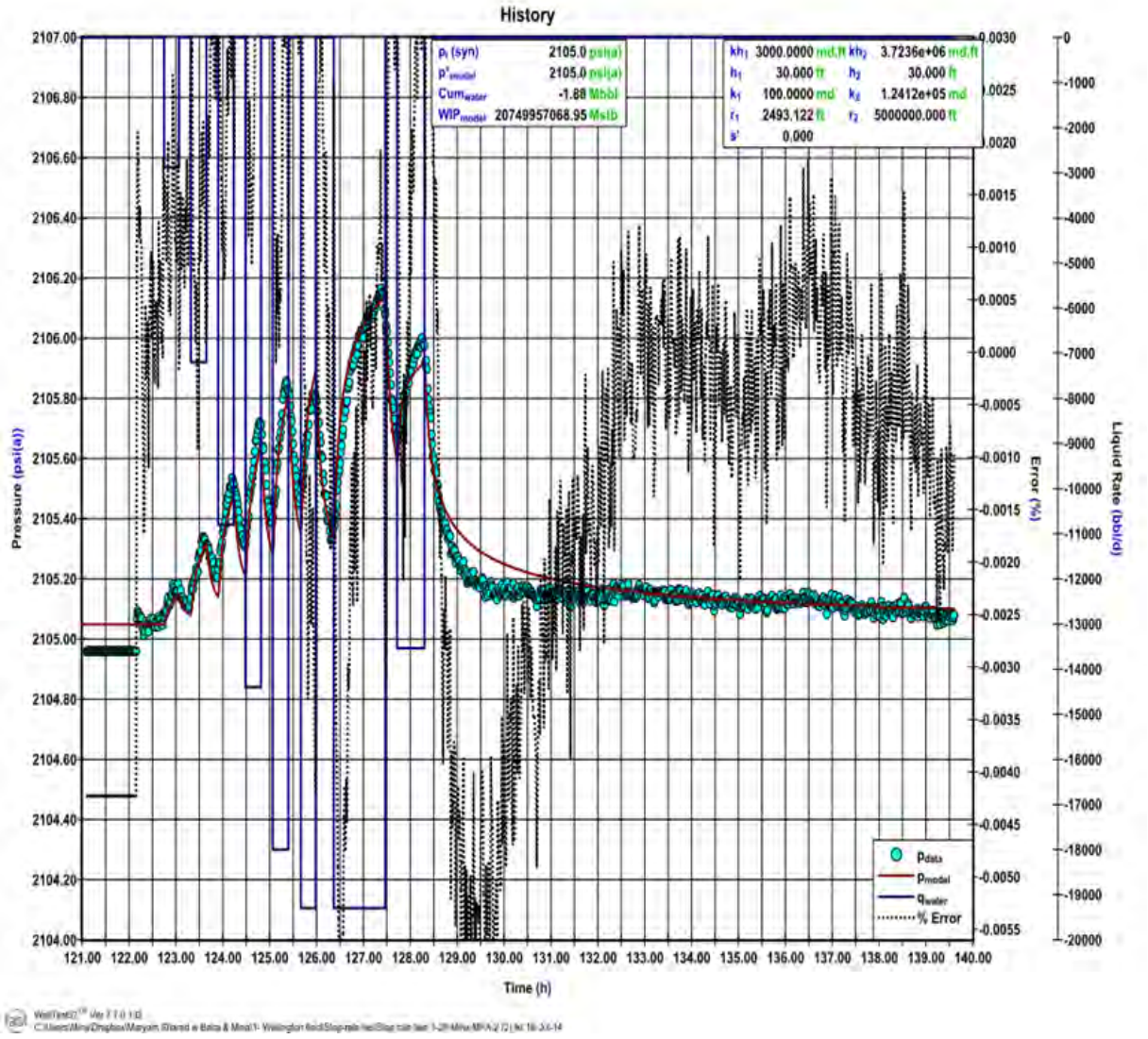


Figure 11. Interference test results in 1-32 and choosing 1-28 as an observation well.

This model shows the two zones with different radius and permeabilities. Zone 1 is from well 1-32 to a radius of 2493ft and zone 2 is from 2493ft to well 1-28 (**Figure 12**).

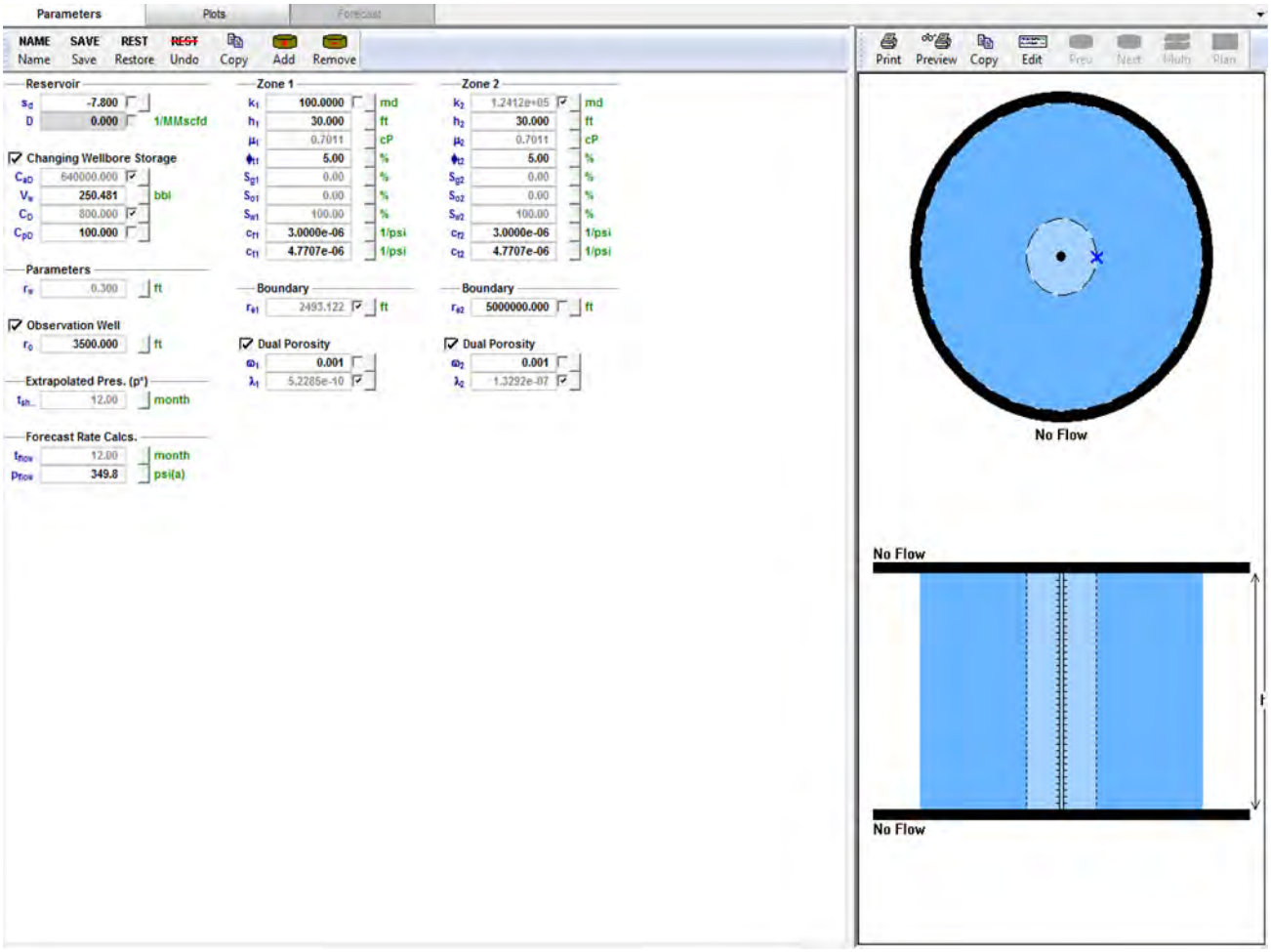


Figure 12. Composite model diagram and parameters.

Comparison of Step Rate Test analysis with DST results

DST 1 and 4 are only suitable for analysis. The Horner Plot is shown in **Figure 13**. DST 2 and 3 are not suitable for analysis. In DST 2, the flowing pressure is equal to shut-in pressure therefore; there is no build-up to analyze. Just temperature and pressure are useful. For DST 3, flowing pressure is equal to shut-in pressure therefore, there is no build up to analyze.

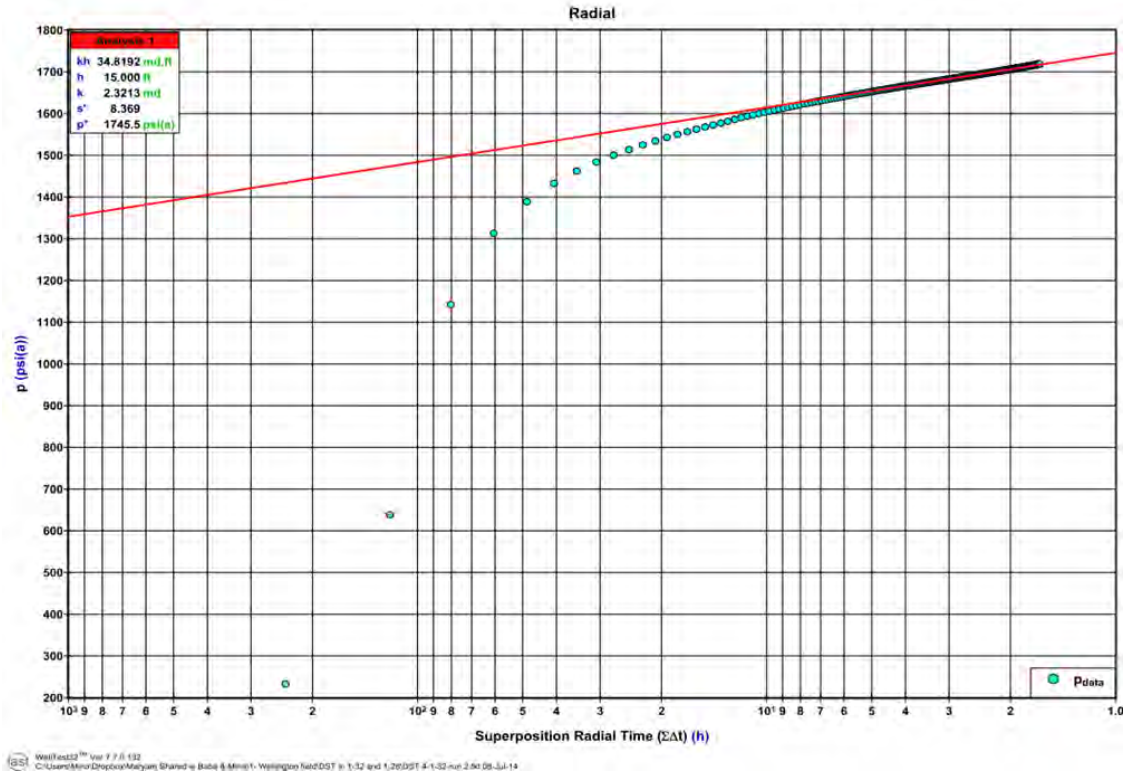


Figure 13. Horner plot for DST 4 in Wellington KGS #1-32, interval 4175 to 4190 ft.

Of the DSTs in Wellington KGS #1-28, only DST 1 is suitable for analysis **(Figure 14)**.

DSTs 2, 3 and 4 are not suitable for analysis. DST 2 has a short flow transient period. Pressure from this test is useful. -DST 3: Like DST 2 has a short transient time. Pressure from this test is useful. DST 4 is not suitable for the same reasons as 2 and 3.

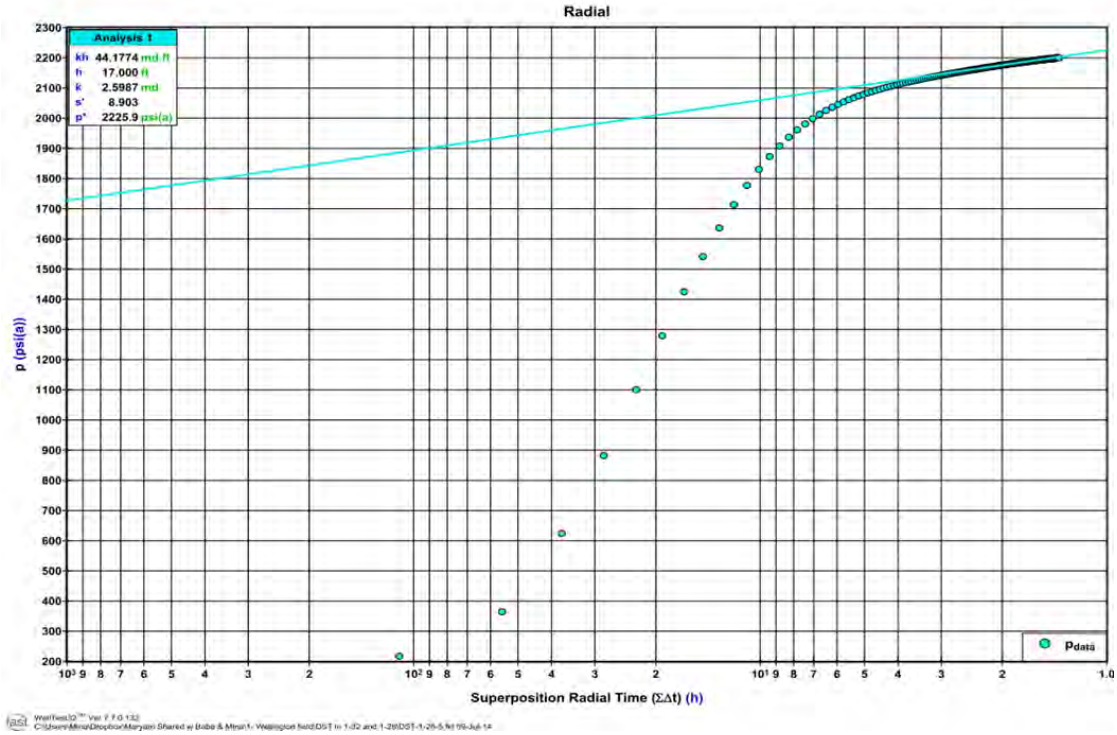


Figure 14. DST 1 in Wellington KGS #1-28, interval: 5133-5250ft.

The results of the step rate and drill stem tests are summarized in **Figure 15**.

Well 1-32				
DST Interval	K from DST	Log connectivity	Average Log derived K90	Average Core K90
ft	mD	ft	mD	mD
4175-4190	2.32	4175-4090	4.61	4.59

Well 1-28				
DST Interval	K from DST	Log cennectivity	Average Log derived K90	Average Core K90
ft	mD	ft	mD	mD
5133-5250	2.60 mD	5133-5160	2.17 (5133-5160)	NA

Step-Rate Test results				
Interval	Gauge depth@	K from Step-rate test	Average log derived K90	Average Core K90
ft	ft	mD	mD	mD
30	4869	113	74	NA

Interference test result				
Interval	K for zone 1	K for zone 2	Ave K90 from log for zone1	Average Core K90
ft	mD	D	mD	mD
30	100	124	74	NA

Figure 15. Results of step rate and drill stem tests.

Summary of updated step rate test --

- Permeability calculated from Step-rate test and interference test are almost in agreement with log derived permeability.
- Permeability calculated from DST tests in 1-32 and 1-28 are in agreements with core data.
- Permeability of 124D from the interference test is associated with a radius farther away from 1-32 to the vicinity of well 1-28 which can be related to fault or fracture.
- Appropriate model and correct thickness were not selected in the former analysis. Skin was large and therefore, calculated permeability was affected by the large skin.
- Results can be improved if correct model and thickness selected.

Comments Regarding the Previous Step Rate Test analysis

- Thickness of injection zone was assumed 200 feet which is not right. Perforated interval is 25 feet and it is in the middle of FU 14 according to Lorenz plot. Thickness of this unit is only about 30 ft and it is bounded by almost impermeable layers which are above and below the unit.
- Calculated skin factor (s) is 200. This high s is very abnormal in carbonate reservoirs.
- Since the skin is very high, to obtain pressure match, calculated permeability times thickness (kh) had been increased to 4.24E+5 which is not correct.

Comments Regarding the Previous Interference Test analysis

- Thickness of injection interval was assumed 200 ft which is not correct. Actual thickness of affected interval by injection is 30 ft or less as was discussed.
- Volume of reservoir affected by injection had been increased by a factor of 6.66. Therefore, pressure signal at well 28 is reduced by a factor of 6.66. To compensate for this reduction, higher permeability had been calculated.

Please refer to additional discussion in Key Findings near the end of this report.

Task 7. Evaluate CO2 Sequestration Potential in Arbuckle Group Saline Aquifer - Wellington field

Subtask 7.1. CO2 sequestration potential
Subtask 7.2. Long-term effectiveness of cap rock
Subtask 7.3. CO2 sequestered in brine
Subtask 7.4. CO2 sequestered as residual gas
Subtask 7.5. CO2 sequestered by mineralization
Subtask 7.6. Field management - max CO_2 entrapment
Subtask 7.7. Monte Carlo - total CO_2 seq capacity

Task 8. Evaluate CO2 Sequestration Potential by CO2-EOR in Depleted Wellington field

Subtask 8.1. CO2-EOR potential
Subtask 8.2. Long-term effectiveness of cap rock
Subtask 8.3. CO2 sequestered in brine and residual gas
Subtask 8.4. CO2 sequestered by mineralization
Subtask 8.5. Field management - optimize CO2-EOR
Subtask 8.6. Monte Carlo - total CO2 seq capacity

The full-field simulation has yet to be completed. As described above the field-wide geomodel for the Mississippian is underway.

Task 9. Characterize leakage pathways - Risk assessment area

Subtask 9.1. Collect reservoir characterization data - external sources
Subtask 9.2. Map fracture-fault network
Subtask 9.3. Verify seal continuity and integrity
Subtask 9.4. Inventory well status
Subtask 9.5. Gather expert advice on well integrity

Wells have been inventoried and well integrity has been defined. The newest geomodel will be used to further model the fractures and faults that are now being resolved as previously described above.

Task 10: Risk Assessment Related to CO_2-EOR in Mississippian Chat Reservoir and CO_2 Sequestration in Arbuckle Aquifers

Subtask 10.1. Model CO_2 plume for 100, 1000, and 5000 yrs after injection stops
Subtask 10.2. Model plume attenuation during and after injection
Subtask 10.3. Model effects of natural aquifer flow on CO_2 plume
Subtask 10.4. Estimate time frame for free phase CO_2 to become negligible
Subtask 10.5. Model effectiveness of cap rocks to contain leakage
Subtask 10.6. Leakage modeling through abandoned wells
Subtask 10.7. Model worst-case CO_2 leakage scenario
Subtask 10.8. Estimate surface environmental effects due to leakage

Simulations with leakage has been examined, but will be updated using the final geomodel.

Task 11: Produced Water and Wellbore Management Plans

Subtask 11.1. Identify at-risk wells in Wellington Field
Subtask 11.2. Outline Best Practices and well recompletion plans for at-risk wells
Subtask 11.3. Outline Best practices and well completion plans for new CO_2 injector wells
Subtask 11.4. Summarize practices in place for disposal of produced water

Wells have been examined for at-risk characteristics. Steps will be taken to plug a well in close proximity to the CO2 plume generated by the small scale injection test. Other wells lie

significantly beyond this area that would need to be addressed if larger scale disposal would be considered. The criteria followed in this assessment will become the best practice. If there is any doubt, remedial action will be necessary.

Task 12. Regional CO2 Sequestration Potential in OPAS - 17 Counties

Subtask 12.1. Map reservoir compartments in Arbuckle aquifer in a regional context

The development of flow units was previously discussed. Establishing flow units for the regional type logs was accomplished and tie well with the regional stratigraphic subdivisions and correlations previously established (e.g., **Figures 16 and 17**).

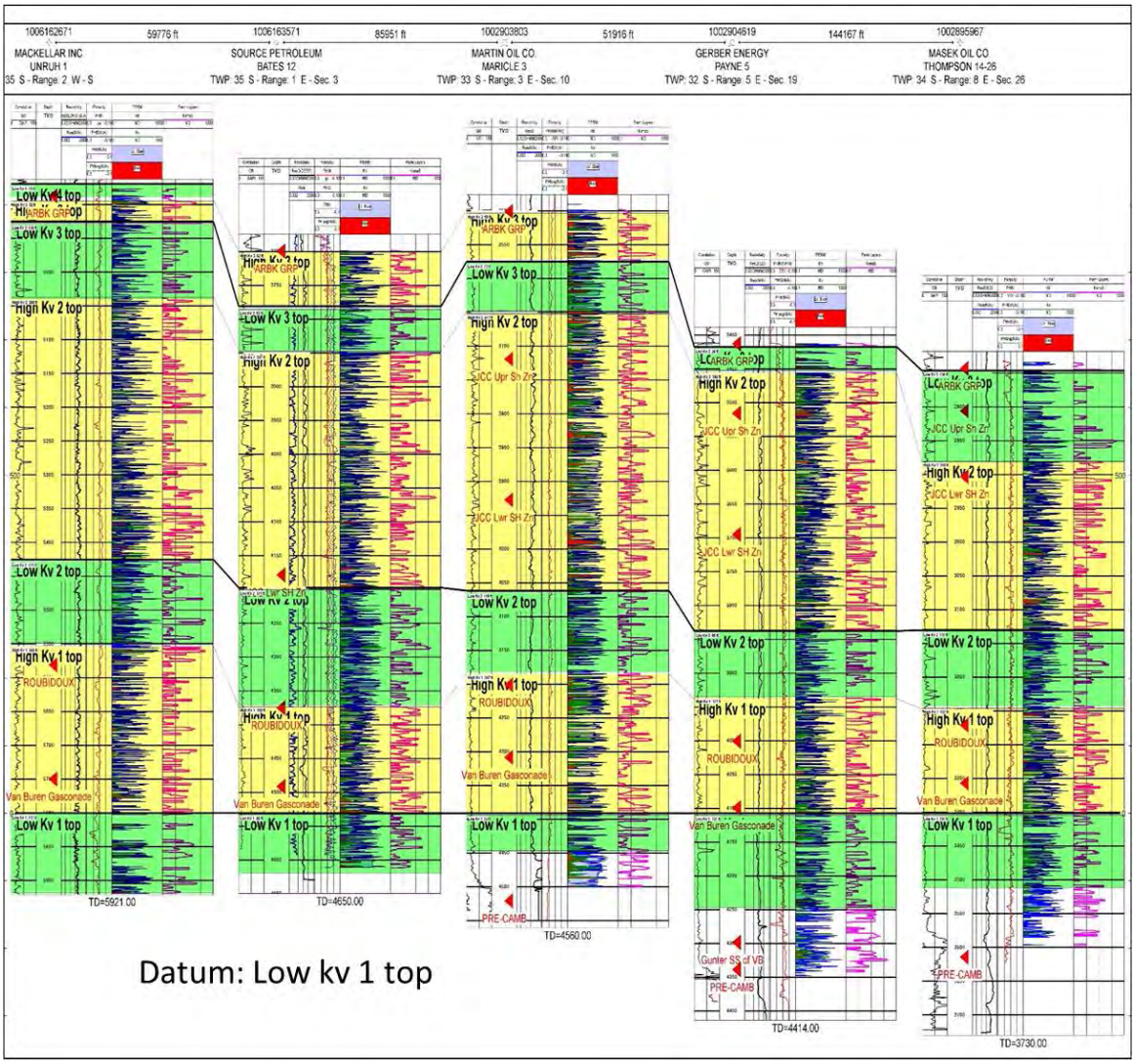


Figure 16. Example of correlation of major regional correlatable flow units in the Arbuckle in area 5 including Wellington Field.

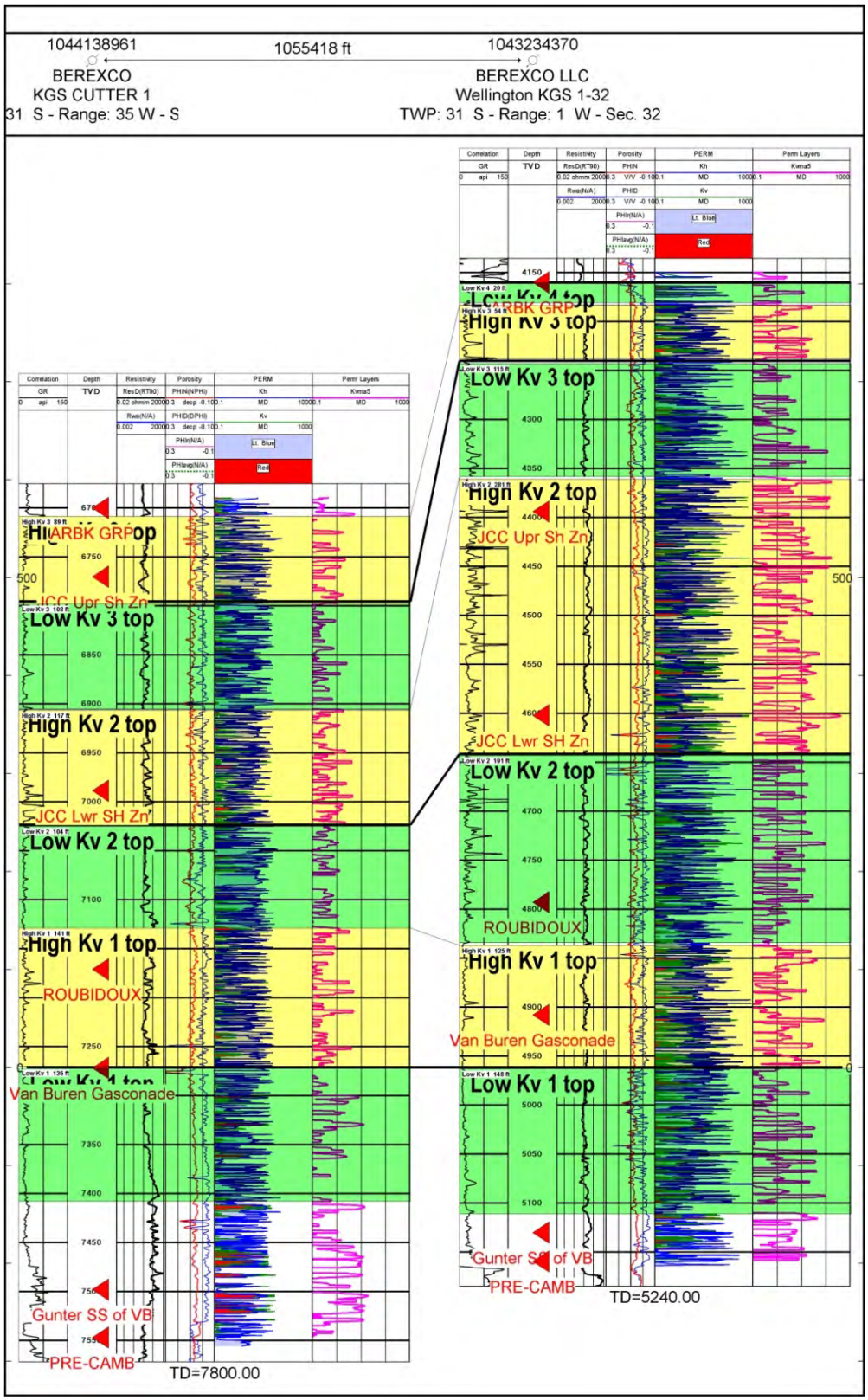


Figure 17. Correlation of flow units between Cutter KGS #1 and Wellington KGS #1-32. Distance of correlation is 200 miles, but does not imply continuous continuity. Several of units are truncated or pinch out between these anchor wells.

Regional flow units are being used to simulate commercial scale injection in 10 sites in southern Kansas and eventually the entire region of southern Kanas. An example of the input grids for the 4-township simulation is illustrated in **Figure (18)**.

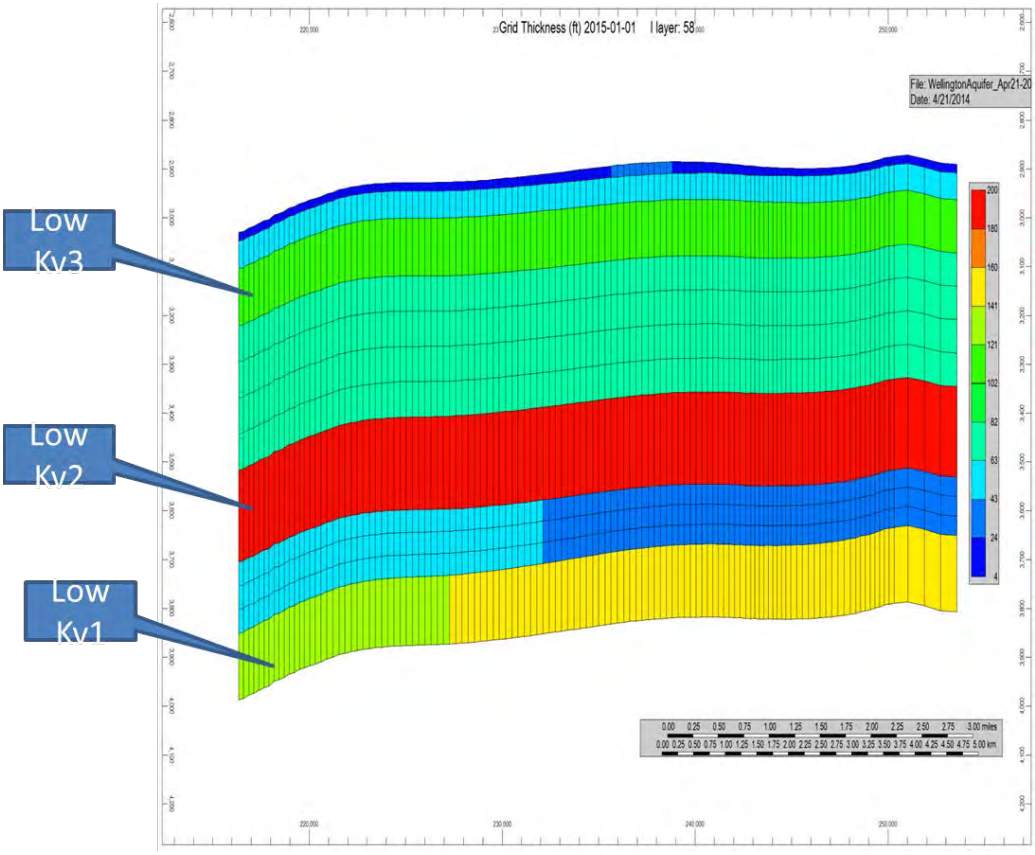


Figure 18. Initial simulation layers for the Arbuckle in the regional 4-township scale simulation of commercial scale CO_2 storage in the four-township area including Wellington.

Distribution of the 14 high and low kv layers created by P. Gerlach in southern Kansas are illustrated as a series of isopachs, first the high Kv (**Figures 19-24)**, followed by the low kv layers (**Figures 25-32)**. These large regional layers were exported as grids to CMG-GEM compositional simulator and will be used to compute the CO_2 storage capacity in southern Kansas.

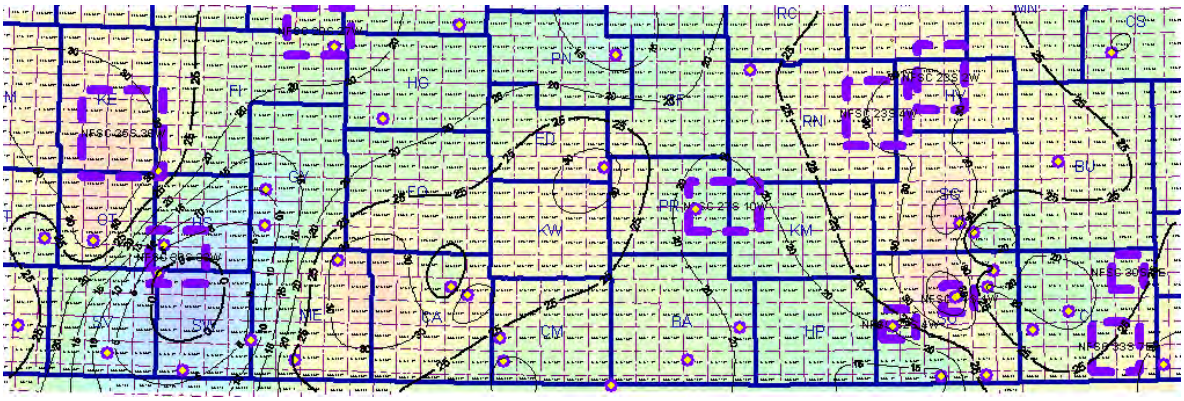


Figure 19. High Kv1 layer kh

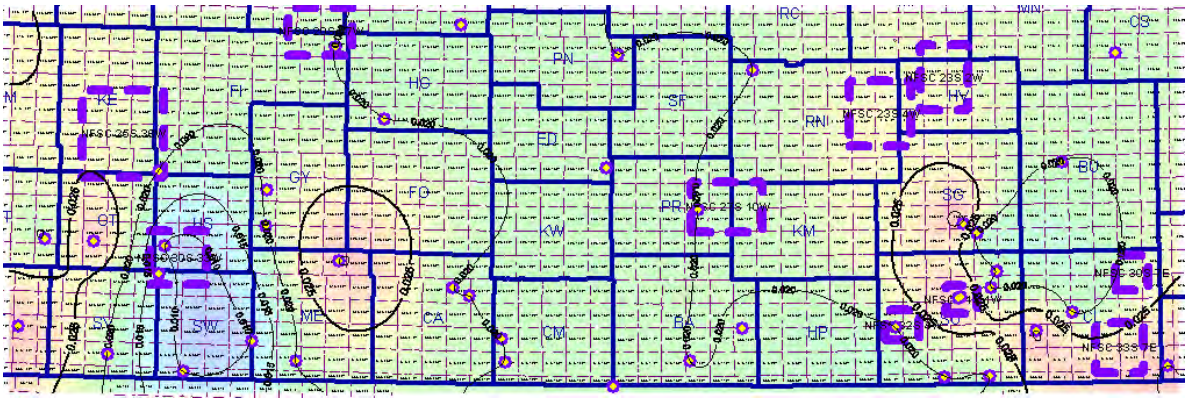


Figure 20. High Kv1 layer kv

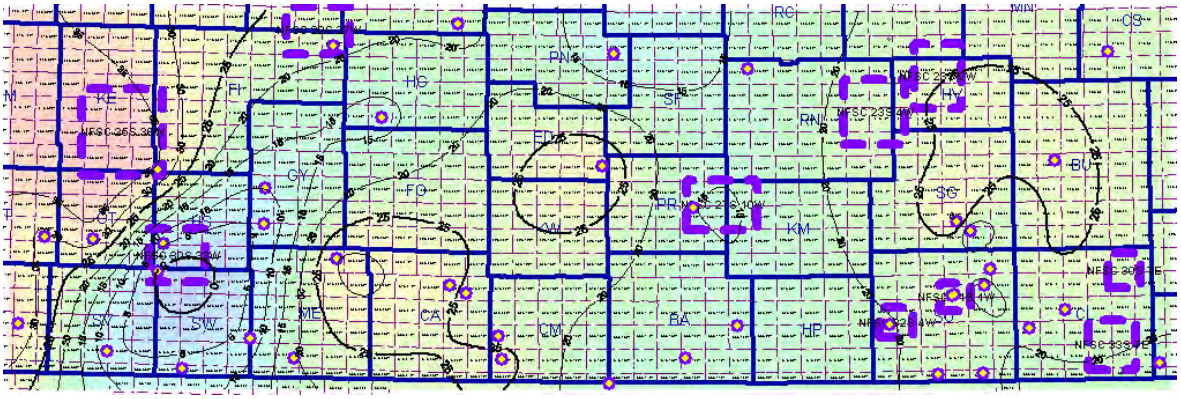


Figure 21. High Kv2 layer kh

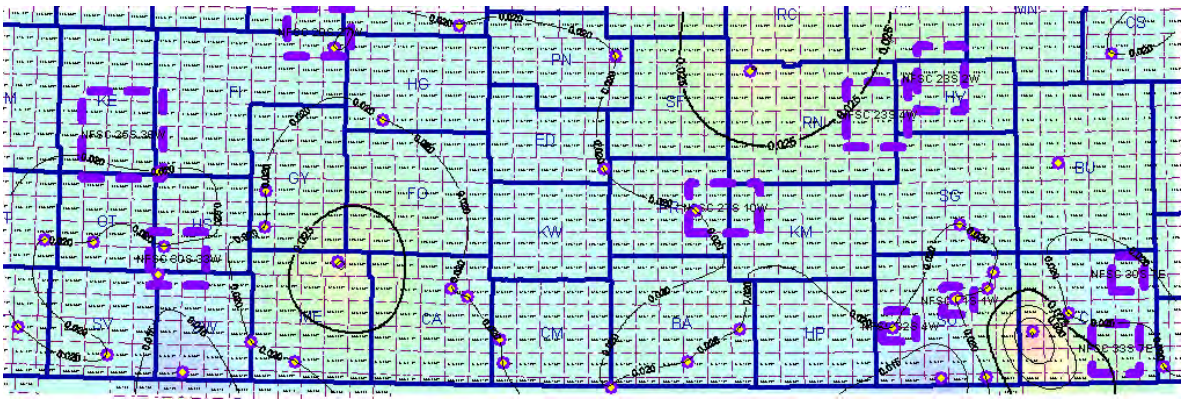


Figure 22. High kv2 layer kv

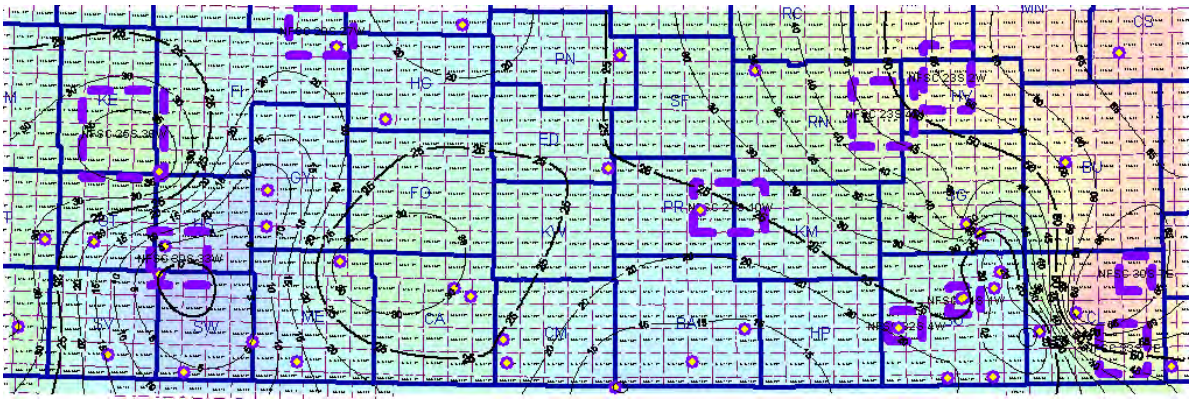


Figure 23. High kv3 layer kh

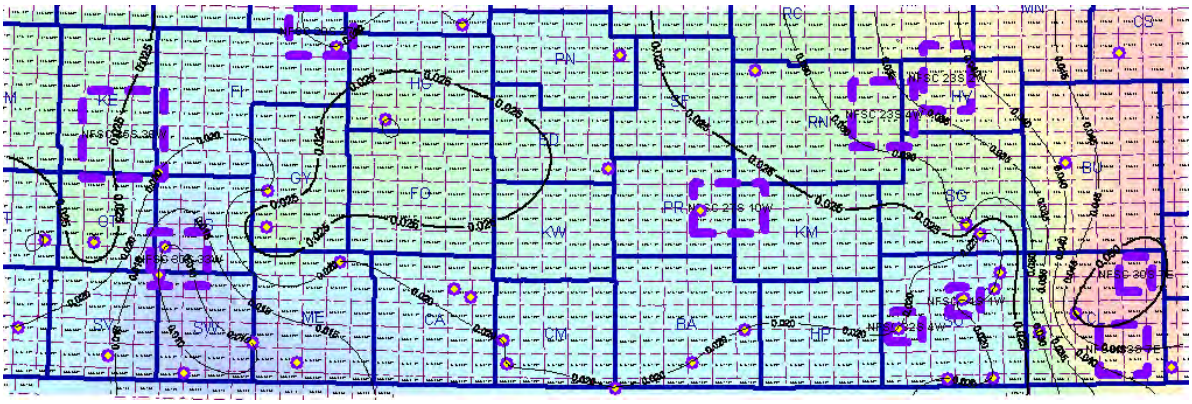


Figure 24. High kv3 layer kv

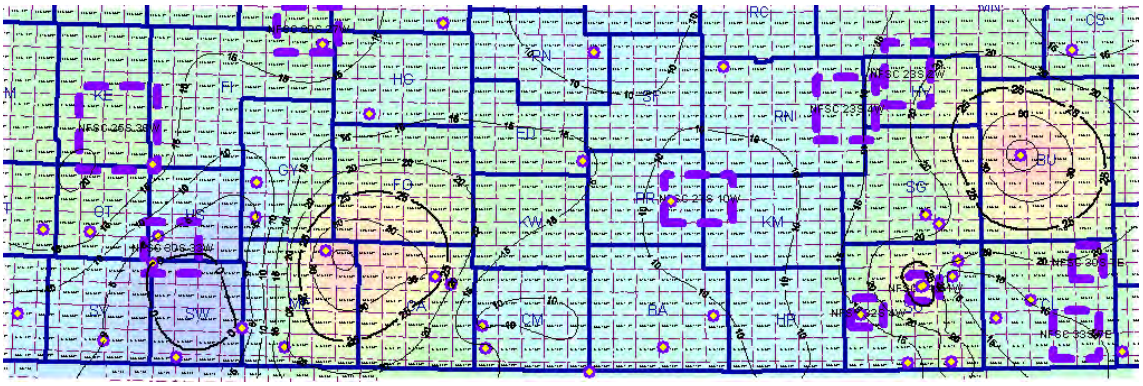


Figure 25. Low kv1 layer kh

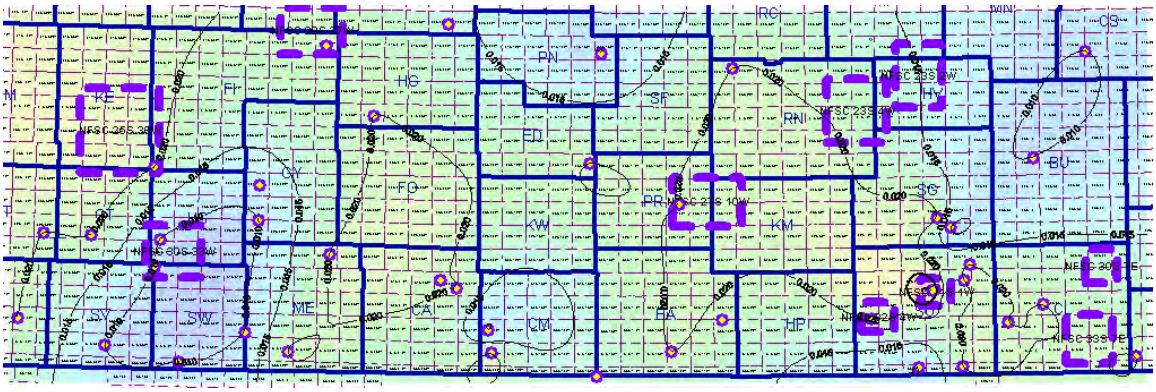


Figure 26. Low kv1 layer kv

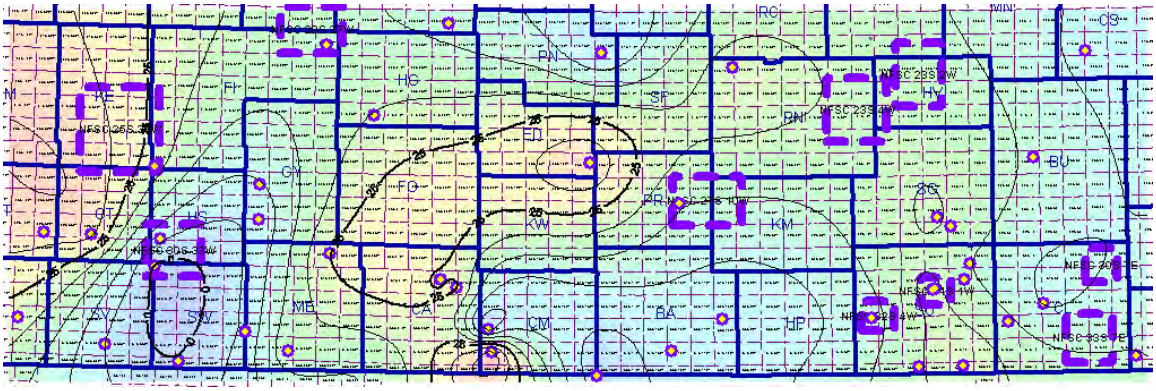


Figure 27. Low kv2 layer kh

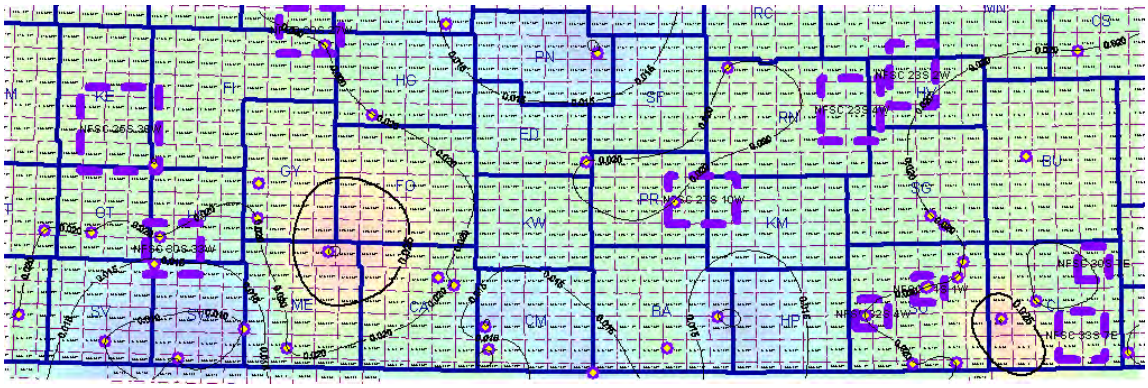


Figure 28. Low kv2 layer kv

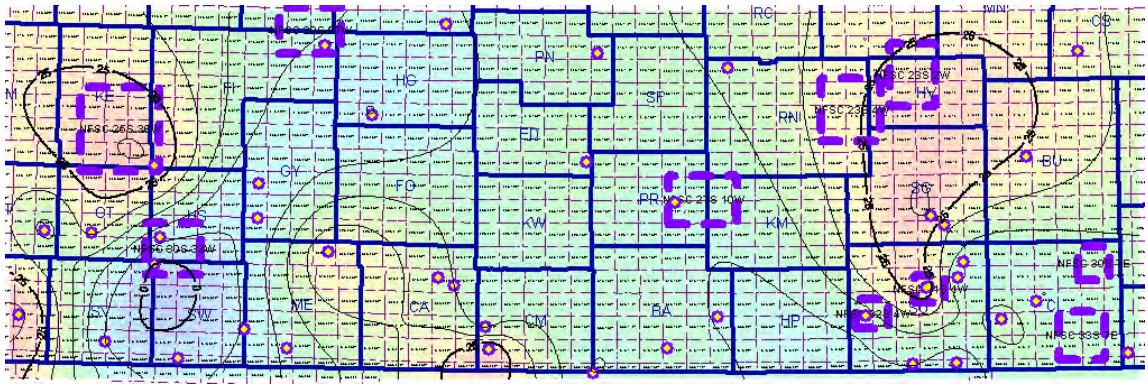


Figure 29. Low kv3 layer kh

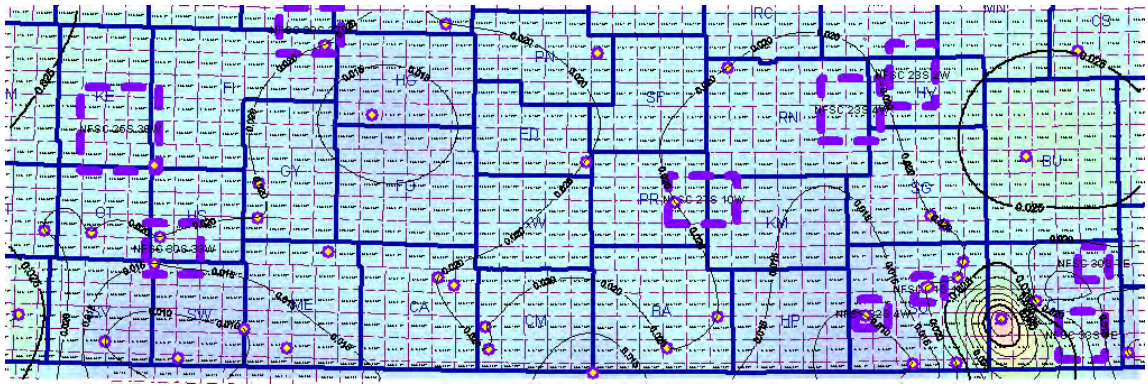


Figure 30. Low kv3 layer kv

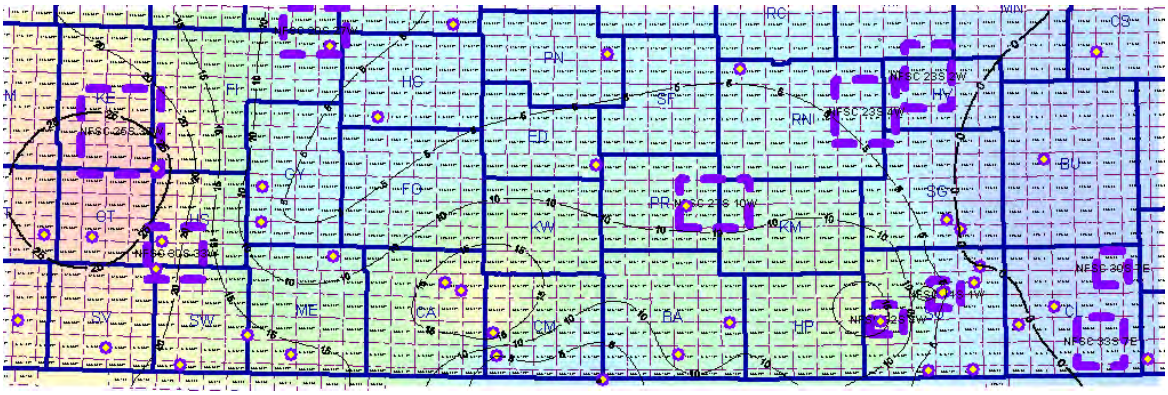


Figure 31. Low kv4 layer kh

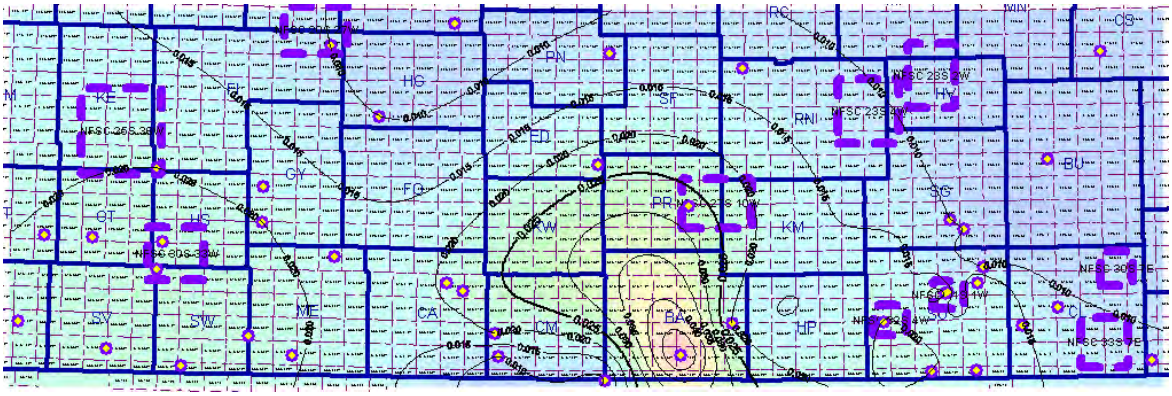


Figure 32. Low kv4 layer kv

Subtask 12.2. Coarse grid simulation over select OPAS areas to estimate regional CO_2 sequestration potential

The regional grid to be used over southern Kansas is 2500x2500 ft and 12 layers, thus there will be 1.64 MM coarse grid cells in the model. It is anticipated that at least 100K cells will be added for local grid refinement at each injection area (highlighted in yellow in **Figure 33**) this would add another million cells. Initial estimate is that the model should be roughly 2.6 MM cells. The structural configuration and a 3D view of the model grids for the CMG simulator are shown in **Figures 33-35**. Finer gridding was carried out at each of the 10 regional modeling sites as illustrated in **Figure 36**. This finer gridding reflects the greater level of detail in these regions and the individual models that were separately run in each of these injection sites.

A west-to-east structural cross section (**Figure 37)** shows the vertical distribution of the grid layers with color depicting thickness of each layer.

These regional views the Arbuckle saline aquifer will be extended to include the many other stratigraphic layers and their attributes, gravity and magnetic and remote sensing to bring together the full geologic perspective.

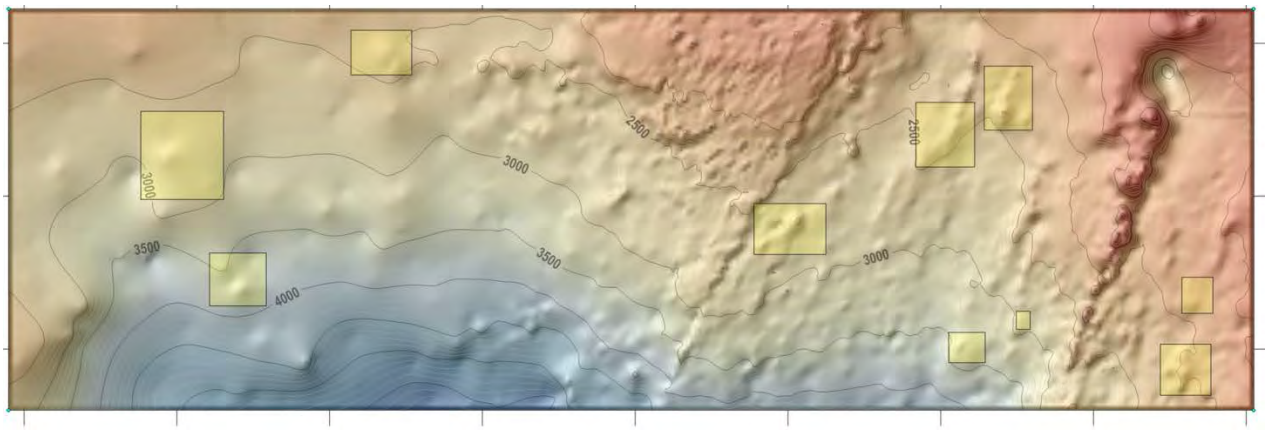


Figure 33. Structure map top of Arbuckle showing Study areas

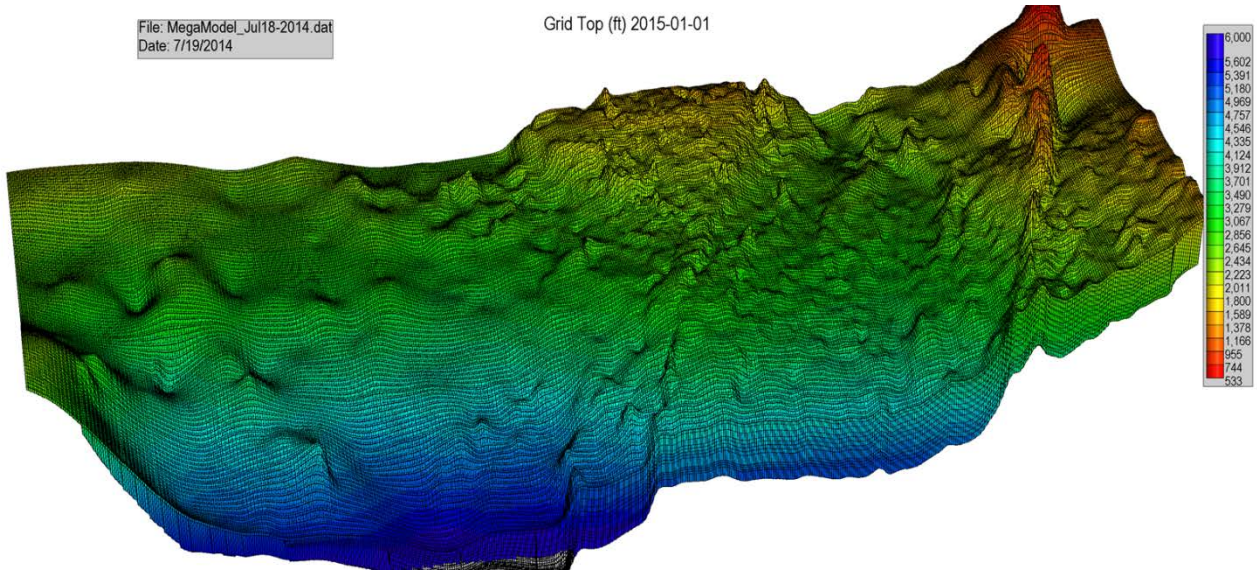


Figure 34. Initial coarse grid of Arbuckle and flow units, 7/18/2014.

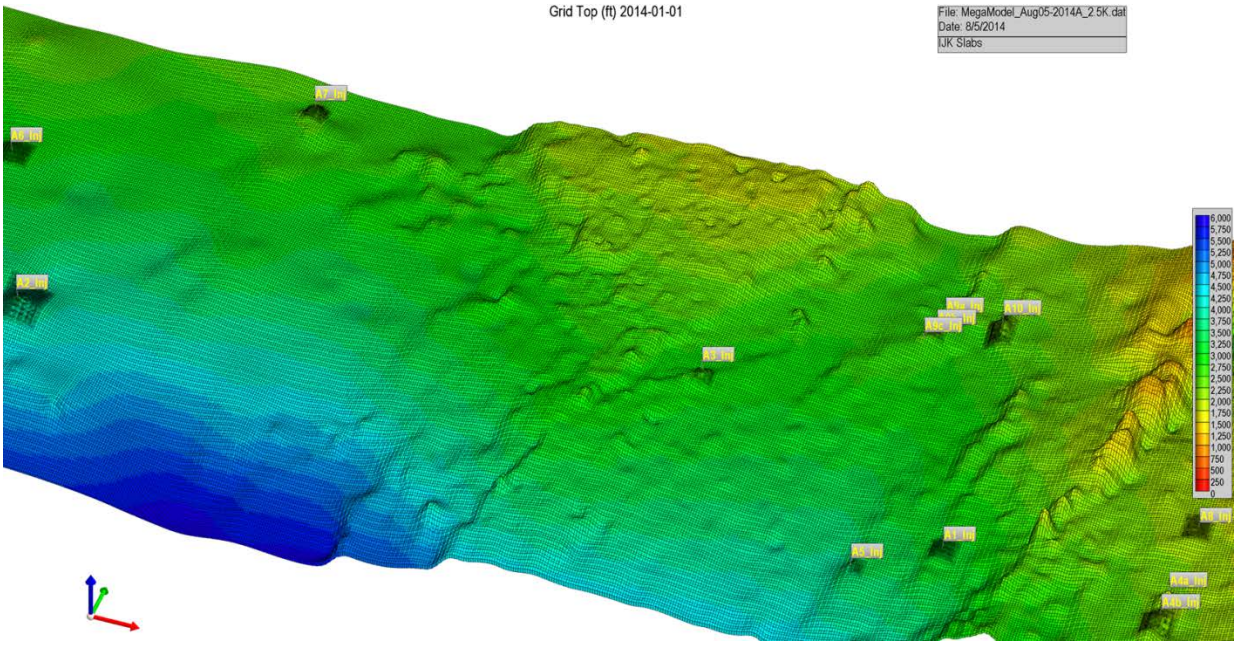


Figure 35. Megagrid (2500 x2500) showing local refinement at 10 sites with commercial sized CO2 injection simulations.

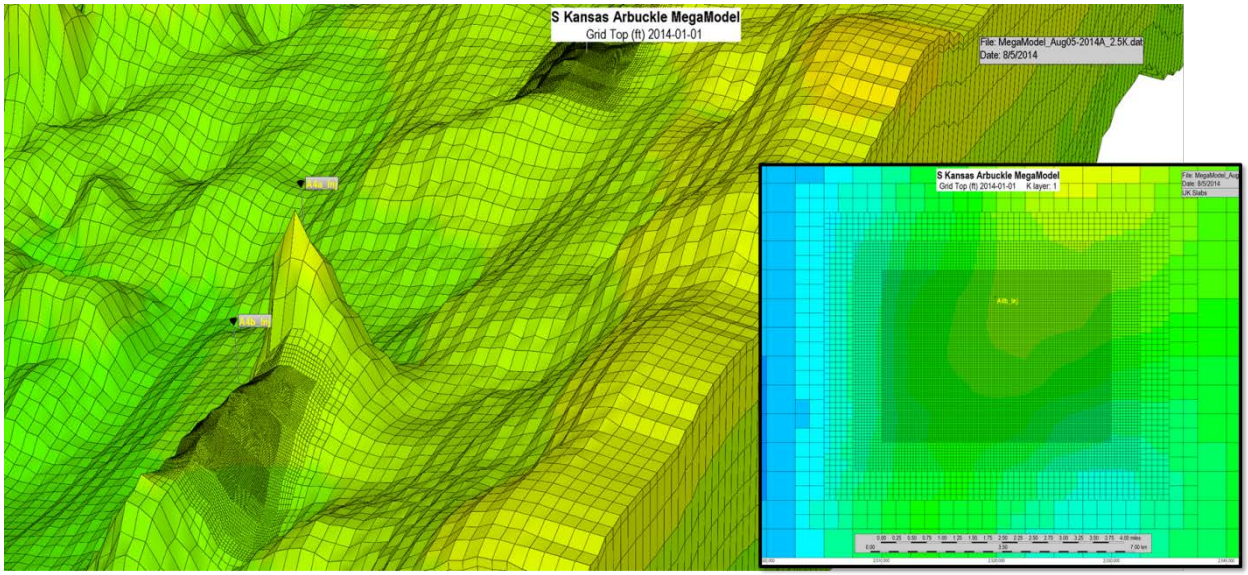


Figure 36. Illustration of local grid refinement. Injection site is A4a and A4b in extreme southeastern portion of the study area in the Cherokee Basin, located east of the Nemaha Uplift.

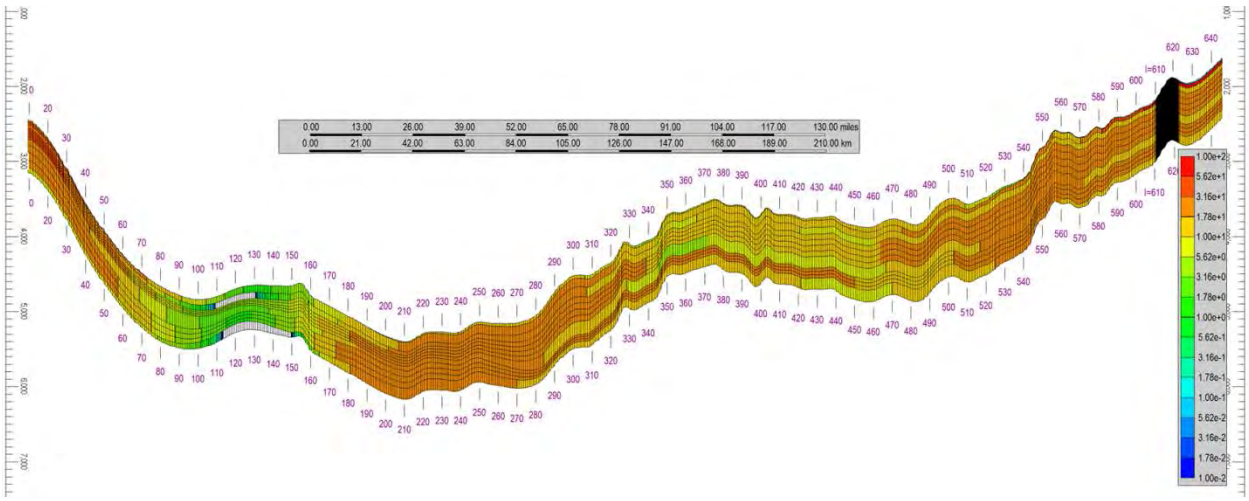


Figure 37. Cross section showing layers with layer thickness highlighted in color. Layers proportional with surface truncation.

Besides flow units and their properties, input parameters for the compositional simulations have been addressed with the information acquired from the core and fluid analyses, petrophysical data, and tests. An important parameter is mineral composition utilized by the CMG simulator to estimate the interaction for the CO_2. The geochemical logs run in Wellington KGS #1-28 and #1-32 were calibrated with core analysis to provide a continuous profile of major and minor minerals (**Figure 38**). These abundances are to be used in ongoing simulations to approximate the reaction kinetics at in situ conditions as summarized in **Figure 39**.

Another important variable in the simulation is to address the imbibition of the CO_2 in the finer pore space based on capillary entry pressure of supercritical CO_2. Analyses of core and petrophysical data, in particular, nuclear magnetic resonance (NMR) were used to derive an imbibition Pc table for the Arbuckle (**Figure 40**). Calculated imbibition Pc is plotted versus reservoir quality index (**Figure 41**).



Figure 38. Wellington #1-32, Major mineral phases of the flow units in the Arbuckle based on geochemical log backed by XRD. Major dolomite, followed by quartz, calcite, kaolinite, illite, anhydrite, chlorite, siderite, and pyrite.

Mineral	Average In Permeable Flow Units
Avg Siderite	0.004%
Avg Pyrite	0.007%
Avg Chlorite	0.021%
Avg Anhydrite	1.708%
Avg Illite	1.850%
Avg Kaolinite	4.956%
Avg Calcite	5.839%
Avg Quartz	15.315%
Avg Dolomite	70.300%

Reactions
$Dolomite + 2H^+ = Ca^{2+} + Mg^{2+} + 2\ HCO_3^-$
$CO_2(aq) + H_2O = H^+ + HCO_3^-$
$MgHCO_3^+ = Mg^{2+} + HCO_3^-$
$CaCO_3(aq) + H^+ = Ca^{2+} + HCO_3^-$
$CaHCO_3^+ = Ca^{2+} + HCO_3^-$

Figure 39. Major and minor chemical reactions with CO_2 considered for the simulations.

a	b	Imbibition PcTable in Arbuckle							
1.00E-06	0.898								
RQI	25	6.25	1.75	0.75	0.45	0.35	0.25	0.15	0.055
Pe	0.011	0.057	0.255	0.691	1.261	1.696	2.521	4.602	15.005
CO2r	0.314	0.275	0.231	0.198	0.175	0.164	0.148	0.122	0.065
swir	0.007	0.016	0.037	0.063	0.088	0.103	0.128	0.178	0.339
Pc	swi								
0	0.685741	0.725	0.769	0.802	0.825	0.836	0.852	0.878	0.935
0.1	0.092574	0.301	0.581	0.718	0.776	0.799	0.827	0.865	0.931
0.2	0.054945	0.199	0.472	0.652	0.733	0.766	0.804	0.852	0.928
0.3	0.04075	0.153	0.401	0.598	0.696	0.736	0.783	0.840	0.924
0.4	0.033204	0.125	0.350	0.554	0.663	0.709	0.763	0.828	0.921
0.5	0.028492	0.108	0.313	0.517	0.634	0.684	0.744	0.816	0.918
0.6	0.025256	0.095	0.284	0.485	0.607	0.662	0.726	0.805	0.914
0.7	0.022891	0.086	0.260	0.458	0.584	0.641	0.709	0.795	0.911
0.8	0.021082	0.078	0.241	0.434	0.562	0.621	0.694	0.784	0.908
0.9	0.019653	0.072	0.225	0.413	0.542	0.603	0.679	0.774	0.904
1	0.018493	0.068	0.212	0.394	0.524	0.587	0.665	0.765	0.901
2	0.013043	0.045	0.140	0.281	0.402	0.467	0.557	0.684	0.871
3	0.011103	0.036	0.111	0.228	0.335	0.397	0.486	0.624	0.845
4	0.010095	0.032	0.095	0.196	0.292	0.350	0.437	0.577	0.821
5	0.009473	0.029	0.085	0.175	0.263	0.317	0.400	0.540	0.799
6	0.009049	0.027	0.078	0.160	0.241	0.292	0.371	0.509	0.779
7	0.008741	0.026	0.073	0.148	0.224	0.272	0.348	0.483	0.761
8	0.008506	0.025	0.069	0.139	0.211	0.256	0.329	0.461	0.745
9	0.008321	0.024	0.066	0.132	0.200	0.244	0.313	0.443	0.730
10	0.008171	0.023	0.063	0.126	0.191	0.233	0.300	0.426	0.716
12	0.007944	0.022	0.059	0.117	0.177	0.216	0.278	0.399	0.690
14	0.007778	0.021	0.056	0.111	0.166	0.203	0.262	0.378	0.669
20	0.007472	0.020	0.051	0.098	0.146	0.178	0.230	0.333	0.617
30	0.007224	0.019	0.047	0.088	0.129	0.156	0.201	0.292	0.561
40	0.007096	0.018	0.044	0.082	0.120	0.145	0.185	0.269	0.524
50	0.007017	0.018	0.043	0.079	0.114	0.137	0.176	0.254	0.498
60	0.006963	0.018	0.042	0.077	0.110	0.132	0.169	0.243	0.479
70	0.006924	0.017	0.041	0.075	0.108	0.129	0.164	0.235	0.464
80	0.006894	0.017	0.041	0.074	0.105	0.126	0.160	0.229	0.452
90	0.006871	0.017	0.040	0.073	0.104	0.124	0.157	0.224	0.443
100	0.006852	0.017	0.040	0.072	0.102	0.122	0.154	0.220	0.434
150	0.006794	0.017	0.039	0.069	0.098	0.116	0.146	0.208	0.408
200	0.006763	0.017	0.039	0.068	0.096	0.113	0.142	0.201	0.393
300	0.006732	0.017	0.038	0.066	0.093	0.110	0.138	0.194	0.377

	RQI		
RT	**from RQI**	**To RQI**	**Ave RQI**
1	40	10	25
2	10	2.5	6.25
3	2.5	1	1.75
4	1	0.5	0.75
5	0.5	0.4	0.45
6	0.4	0.3	0.35
7	0.3	0.2	0.25
8	0.2	0.1	0.15
9	0.1	0.01	0.055

Figure 40. (upper table) - Irreducible water saturation vs. capillary pressure for individual reservoir quality indices (RQI). (lower table) – RQI, reservoir quality index classes 1-9.

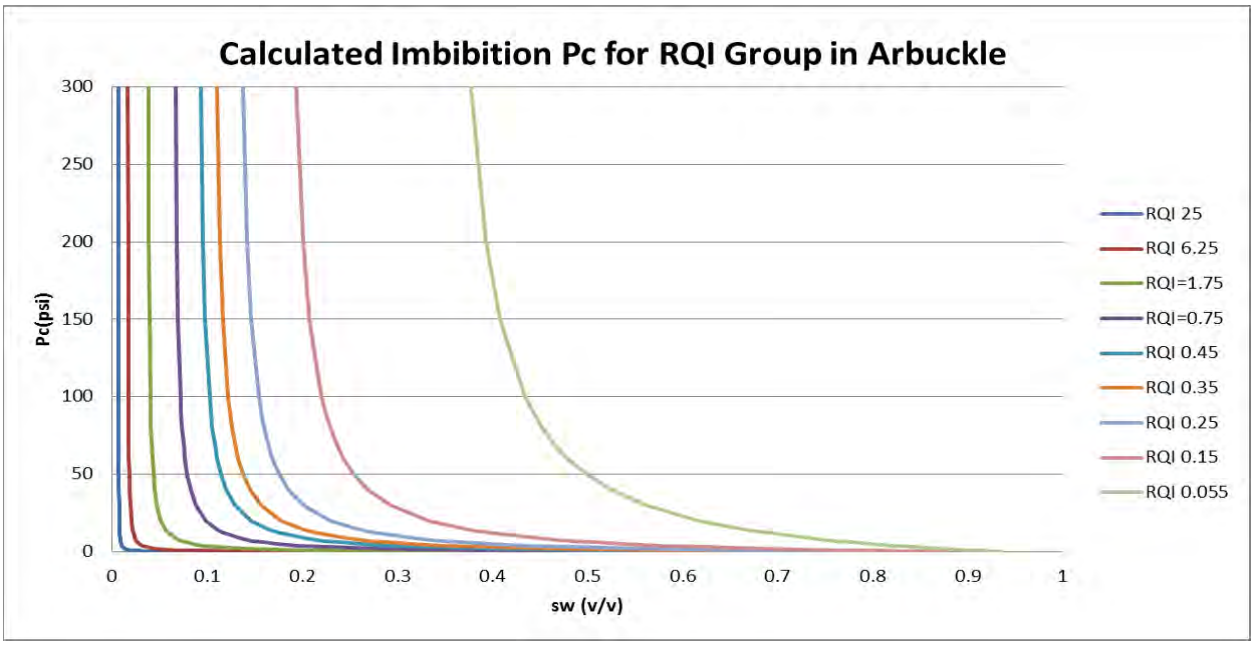


Figure 41. Imbibition Pc curves for reservoir quality indices used for hysteresis modeling to determine capillary entrapment of CO2 in pore space.

Simulation results of the 10 commercial scale injection sites is highlighted with a closer look at three of the sites, Area #5, #6, and #7. Area #5 encompasses all of Wellington Field and the surrounding area (**Figures 42 and 43**). The CO2 plume approximately 30 million tonnes in size is shown on the right side of **Figure 42** and a closer look at the structure is shown in **Figure 43**.

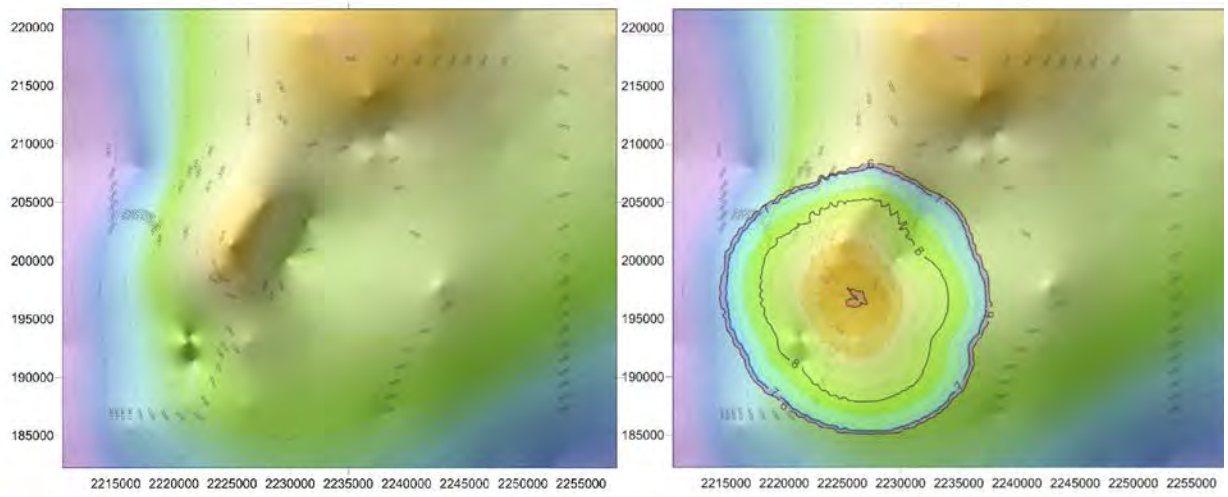


Figure 42. Simulation map of Area 5 (32S 04W) structure (left) including Wellington Field and CO_2 plume at 1/1/2066 (right).

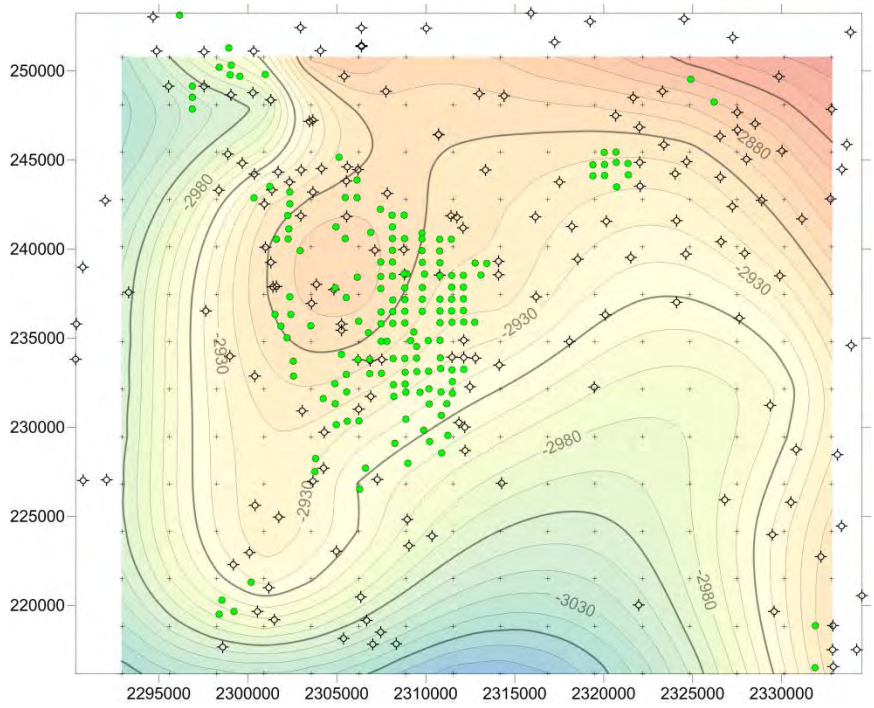


Figure 43. Map of the structure, top of Arbuckle showing all wells including productive Mississippian wells (green dots) in Wellington Field (left center).

Area #6 is in west central Kansas, another isolated structure (**Figure 44**) as is Area #7 (**Figure 45**). Details of the simulations will be share in the final report.

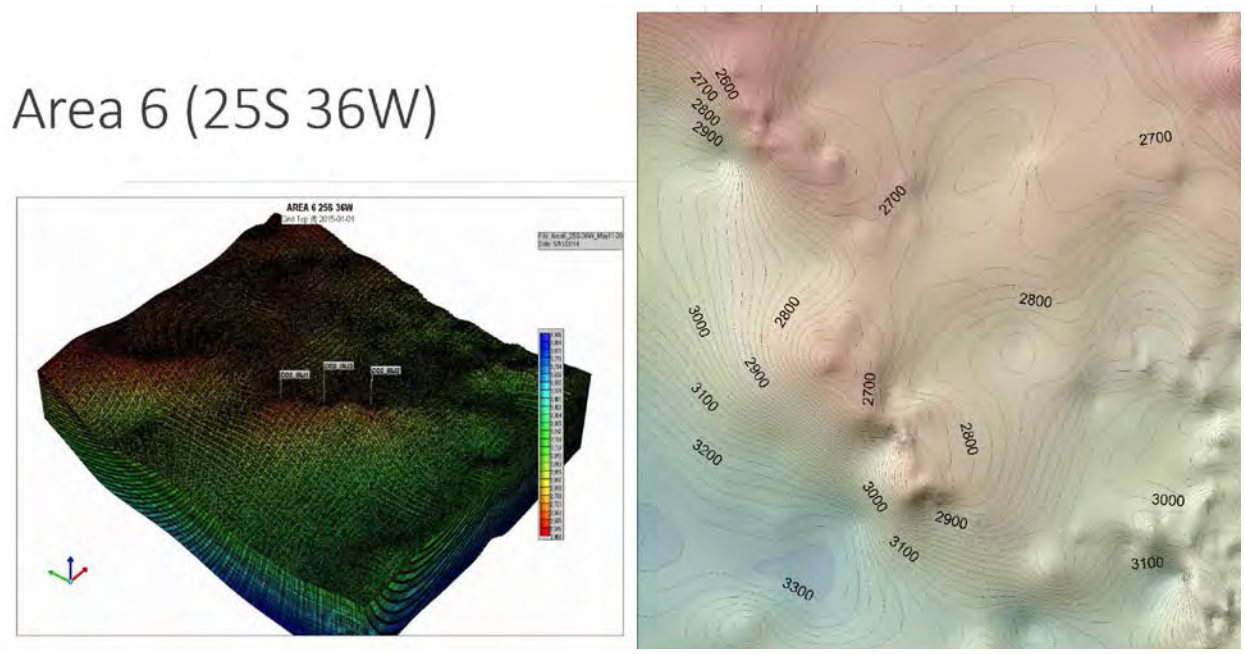


Figure 44. Simulation area #6 – (left) grid volume and (right) structural surface of Arbuckle.

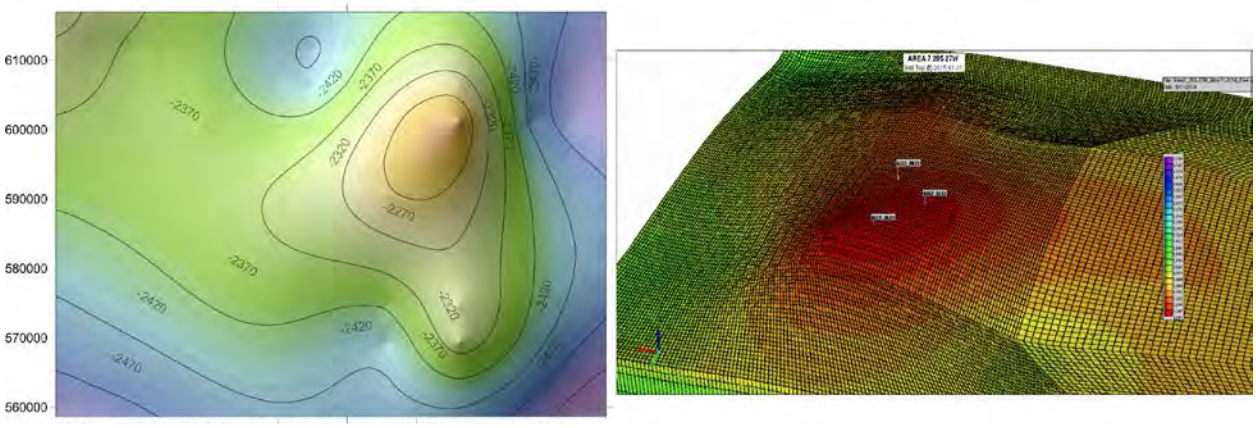


Figure 45. Simulation area #7. – (left) structural surface of Arbuckle and (right) grid volume

Subtask 12.3. Generalized estimates of miscible CO_2-EOR in similar and larger oil fields in approximately 17 counties

Subtask 12.4. Estimate regional CO_2 sequestration potential of OPAS

Task 13: Regional Source-Sink Relationships in approximately 17 Counties in South-Central Kansas

Subtask 13.1. Map major point CO_2 sources in Kansas
Subtask 13.2. Map major CO_2 sinks in Kansas

Task 14: Technology Transfer

Subtask 14.1. Build and maintain project website with interactive access to data and analyses via graphic display and analytical web tools
Subtask 14.2. Link project web-site to relevant DOE databases
Subtask 14.3 Submit project results to peer reviewed journals for publication

Task 15: Extend Regional Study of Ozark Plateau Aquifer System (OPAS) to the Western Border of Kansas – "Western Annex" and extend the type log database to include the whole state of Kansas to address fluid flow under commercial scale CO2 sequestration.

Subtask 15.1. Extend regional study by evaluating CO_2 sequestration potential in 5000 mi^2 area west of the existing 17+ county area and extend the type log database to the whole state of Kansas to address fluid flow under commercial scale CO_2 sequestration.

Subtask 15.2. Create consortium of companies

Subtask 15.3. Encourage development of business plan to sequester emitted CO_2

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

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

Subtask 16.2. Analysis of KGS's gravity and magnetic data
Subtask 16.3. Remote sensing analysis

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

Subtask 17.1. Collect existing seismic, geologic, and engineering data – Chester/Morrow fields
Subtask 17.2. Select Chester/Morrow field to acquire new data

Subtask 17.3. Collect new multicomponent 3D seismic survey
Subtask 17.4. Process multi-component 3D seismic survey
Subtask 17.5. Develop initial geomodel for the selected Chester/Morrow field

Subtask 17.6. Select location for Test Borehole #3
Subtask 17.7. Complete permitting requirements for Test Borehole #3
Subtask 17.8. Drill, retrieve core, log, and run DST – Test Borehole #3
Subtask 17.9. Openhole Wireline Logging – Test Borehole #3
Subtask 17.10. Wellbore Completion – Test Borehole #3
Subtask 17.11. Analyze wireline log - Test Borehole #3
Subtask 17.12. Test and sample fluids (water) from select intervals – Test Borehole #3
Subtask 17.13. Analyze Arbuckle core from Test Borehole #3

Brent Campbell visited LLNL Lab in June to work with Susan Carroll and Megan Smith to analyze a series of core plugs using facilities to permit injection of CO2 saturated brine at reservoir pressures to examine reactions and changes in porosity and permeability that occur during the injection. Measurements of brine effluent and CT scans before and after, and measurements of rates, volume, and differential pressures are used to detect changes. Susan's work on "enhanced porosity and permeability within carbonate CO2 storage reservoirs: An experimental and modeling study" is supported by DOE, but expenses for travel are carried by this project.

The samples selected for analysis come from the Arbuckle from the Cutter KGS #1 and Wellington KGS #1-32 cores and are summarized below in **Figure 46**.

Cutter	Depth	Weight	Length&Dia.	Kmax	Porosity	Description
Sample	Ft.	grams	inches	mD	%	
1 (22-32)	7,209.90	156.67	1 15/16, 1.5	32.668	7.2	Exhibited high permeability (Kmax=32.668), high porosity (7.2%), and a moderately fractured surface area with secondary shaley accumulations along fracture pathway boundaries. New thin sections are being ordered at this depth and water chemistry was sampled and analyzed from a depth within 8' (Swab 3). Isotope data is also available.



Cutter	Depth	Weight	Length&Dia.	Kmax	Porosity	Description
Sample	Ft.	grams	inches	mD	%	
2 (24-7)	7,340.55	168.92	2 1/8, 1.5	20.488	6.7	Light gray fine grained dolomite mudstone; 0.5cm vug infilled with secondary crystalline dolomite along side, otherwise tight; faint fractures extend longitudinally and latitudinally across sample; sparite; tight porosity aside from single vug; white powdery carbonate accumulation on ends (especially within fracture).



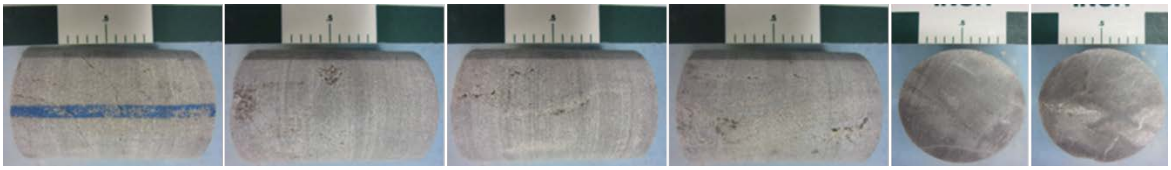
Cutter	Depth	Weight	Length&Dia.	Kmax	Porosity	Description
Sample	Ft.	grams	inches	mD	%	
3 (20-9)	7,098.85	160.51	2 1/8, 1.5	2.849	3.6	Light gray fine grained dolomite mudstone; large (2.5x2x2cm) chert nodule along side-end boundary; similar 2.5x1cm chert nodule along other side/end; pinpoint vugs throughout; white powdery carbonate material along chert-dolomite boundaries and as fracture/vug infillings on ends; possible Fe-oxide stain (from cutting); slightly fractured (especially along dolomite-chert boundary of larger nodule); low vuggy porosity.



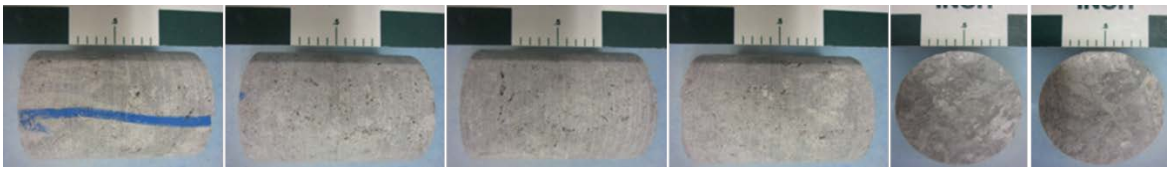
Cutter	Depth	Weight	Length&Dia.	Kmax	Porosity	Description
Sample	Ft.	grams	inches	mD	%	
4 Extra (20-55)	7,144.50	161.79	2 1/16, 1.5	7.904	3	Light gray fine grained dolomite packstone with large 2.5cm vitreous euhedral dolomite infilled vug; mm wide fracture traverses from top to bottom; lighter colored carbonate packstone dispersed throughout in wavy arrangement; folded fracture pathways occur along side.

Cutter	Depth	Weight	Length&Dia.	Kmax	Porosity	Description
Sample	Ft.	grams	inches	mD	%	
5 Extra (20-21)	7,110.35	168.72	2 1/8, 1.5	0.614	2.40%	Light gray fine grained dolomite packstone that is moderately fractured; fractures infilled with chert material that precipitated radially perpendicular to fracture pathways in splotchy fashion; large white ~2cm wide chert nodule; tight aside from fractures.

Wellington	Depth	Weight	Length&Dia.	Kmax	Porosity	Description
Sample	Ft.	grams	inches	mD	%	
1 (13-46)	4,230.30	161.48	2 1/16, 1.5	219.73	2.6	Light grey with sharp contact to light brown, faint but numerous longitudinal fracture, dolomite crystals filling vugs, white chalks material filling some fractures.



Wellington	Depth	Weight	Length&Dia.	Kmax	Porosity	Description
Sample	Ft.	grams	inches	mD	%	
2 (14-4)	4,247.00	156.29	2, 1.5	430.6	8.4	Light-med grey, mottled with white Si rich material, chalk, fine grained, pin point vugs, fluid enhanced discontinuous fractures, Fe-oxidation, no bedding present, some sparite visible.



Weight	Length&Dia.	Kmax	Porosity	Description
grams	inches	mD	%	
145.74	2, 1.5	317.43	4.5	Med gray to bluish grey, fine grained tight, vuggy, interconnected vugs, vugs have chalky material growing (possible anhydrite), some vugs have sparry calcite visible, highly variable mottled, clastic, brecciated, indistinct bedding, possible large fracture filled with dark chert.

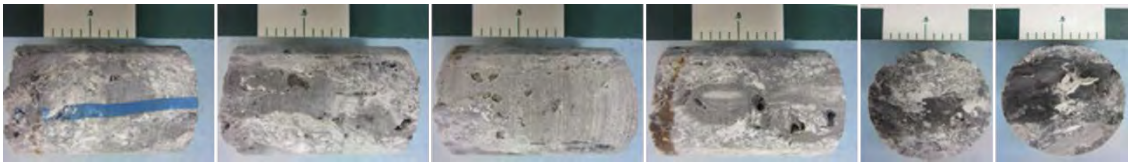


Figure 46. Properties of core plugs taken to LLNL lab for in situ studies of reactions with injection of CO_2 saturated brine.

Subtask 17.14. Analyze Chester/Morrow core from Test Borehole #3
Subtask 17.15. PVT analysis of oil and water from Chester/Morrow oil reservoir
Subtask 17.16. Analyze water samples from Test Borehole #3

Water samples from Cutter KGS #3 (Test Borehole #3) have been analyzed by KSU and the KGS. The following are the results from KSU as summarized in **Figure 47**.

Cutter Unit Symbol	Depth	Depth	Avg Depth	Ba µg/L	Ba mg/L	Al mg/L	Al mg/L	K mg/L	Mg mg/L	Mn mg/L	Si mg/L	Si mg/L	Ag µg/L	Ag mg/L	As µg/L	As mg/L	Be µg/L	Be mg/L	Bi µg/L
SWAB 1	7,543.00	7,532.00	7,537.50	1860	1.86	< 5	0	1460	1190	4.4	< 5	0	< 300	0	< 2000	0	< 100	0	< 1000
SWAB 2	7,442.00	7,430.00	7,436.00	1690	1.69	< 5	0	1360	1140	2.85	8.2	8.2	< 300	0	< 2000	0	< 100	0	< 1000
SWAB 3	7,234.00	7,218.00	7,226.00	1310	1.31	< 5	0	987	896	2.01	20.2	20.2	< 300	0	< 2000	0	< 100	0	< 1000
SWAB 4 FA	7,056.00	7,046.00	7,051.00	< 2000	0	< 10	0	1100	898	2.13	13.2	13.2	< 500	0	< 3000	0	< 200	0	< 2000
SWAB 5	6,904.00	6,880.00	6,892.00	1790	1.79	< 5	0	1410	1470	1.41	< 5	0	< 300	0	< 2000	0	< 100	0	< 1000
SWAB 6	6,686.00	6,676.00	6,681.00	1750	1.75	< 5	0	1250	1300	1.58	6.2	6.2	< 300	0	< 2000	0	< 100	0	< 1000
SWAB 7	6,558.00	6,543.00	6,550.50	< 1000	0	< 5	0	1060	247	5.29	< 5	0	< 300	0	< 2000	0	< 100	0	< 1000
SWAB 8	6,204.00	6,194.00	6,199.00	< 1000	0	< 5	0	814	865	0.93	16.9	16.9	< 300	0	< 2000	0	< 100	0	< 1000
SWAB 9	6,010.00	6,000.00	6,005.00	< 1000	0	< 5	0	803	1020	0.7	16.8	16.8	< 300	0	< 2000	0	< 100	0	< 1000
SWAB 10	5,680.00	5,670.00	5,675.00	< 1000	0	< 5	0	830	363	2.33	28.9	28.9	< 300	0	< 2000	0	< 100	0	< 1000
SWAB 11	5,622.00	5,545.00	5,583.50	< 1000	0	< 5	0	930	1290	0.63	9.6	9.6	< 300	0	< 2000	0	< 100	0	< 1000
DST 1	7,735.00	7,522.00	7,628.50	1610	1.61	< 5	0	1280	1070	4.12	< 5	0	< 300	0	< 2000	0	< 100	0	< 1000
DST 2	7,234.00	7,218.00	7,226.00	1460	1.46	< 5	0	963	858	3.37	11.6	11.6	< 300	0	< 2000	0	< 100	0	< 1000

Ca	Cd		Ce		Co		Cr		Fe		Cu		Li	Mo		Na	Ni	
mg/L	µg/L	mg/L	µg/L	mg/L	µg/L	mg/L	µg/L	mg/L	mg/L	mg/L	µg/L	mg/L	mg/L	µg/L	mg/L	mg/L	µg/L	mg/L
9010	< 100	0	< 2000	0	< 100	0	< 1000	0	< 0.5	0	455	0.455	24.3	< 300	0	52600	< 300	0
8400	< 100	0	< 2000	0	< 100	0	< 1000	0	< 0.5	0	130	0.13	23	< 300	0	49700	< 300	0
6090	< 100	0	< 2000	0	< 100	0	< 1000	0	2.85	2.85	< 100	0	19.6	< 300	0	35600	< 300	0
6510	< 200	0	< 3000	0	< 200	0	< 2000	0	< 1	0	720	0.72	16.2	< 500	0	34700	< 500	0
9100	< 100	0	< 2000	0	< 100	0	< 1000	0	4.43	4.43	< 100	0	23.8	< 300	0	47600	< 300	0
8810	< 100	0	< 2000	0	< 100	0	< 1000	0	7.85	7.85	< 100	0	16.7	< 300	0	40000	< 300	0
2430	< 100	0	< 2000	0	< 100	0	< 1000	0	1.2	1.2	156	0.156	7.23	< 300	0	19800	< 300	0
5410	< 100	0	< 2000	0	< 100	0	< 1000	0	8.82	8.82	< 100	0	21.5	< 300	0	28700	< 300	0
5420	< 100	0	< 2000	0	< 100	0	< 1000	0	7.34	7.34	< 100	0	30	< 300	0	23700	< 300	0
1650	< 100	0	< 2000	0	< 100	0	< 1000	0	4.13	4.13	134	0.134	12	284	0.284	15900	< 300	0
6950	< 100	0	< 2000	0	< 100	0	< 1000	0	1.05	1.05	< 100	0	36.6	< 300	0	29700	< 300	0
7820	< 100	0	< 2000	0	< 100	0	< 1000	0	44.3	44.3	< 100	0	21.7	< 300	0	46600	< 300	0
5640	< 100	0	< 2000	0	< 100	0	< 1000	0	53	53	< 100	0	17.8	< 300	0	34300	< 300	0

P		Pb		Sb		S	Se		Sn		Sr		Te		Ti		Tl	
mg/L	mg/L	µg/L	mg/L	µg/L	mg/L	mg/L	µg/L	mg/L	µg/L	mg/L	µg/L	mg/L	µg/L	mg/L	µg/L	mg/L	µg/L	mg/L
< 1	0	< 500	0	< 500	0	203	< 1000	0	< 500	0	223000	223	< 500	0	< 500	0	< 500	0
< 1	0	< 500	0	< 500	0	206	< 1000	0	< 500	0	213000	213	< 500	0	< 500	0	< 500	0
< 1	0	< 500	0	< 500	0	192	< 1000	0	< 500	0	155000	155	< 500	0	< 500	0	< 500	0
< 2	0	< 1000	0	< 1000	0	264	< 2000	0	< 1000	0	139000	139	< 1000	0	< 1000	0	< 1000	0
< 1	0	< 500	0	< 500	0	178	< 1000	0	< 500	0	229000	229	< 500	0	< 500	0	< 500	0
< 1	0	< 500	0	< 500	0	194	< 1000	0	< 500	0	232000	232	< 500	0	< 500	0	< 500	0
1.37	1.37	< 500	0	< 500	0	446	< 1000	0	< 500	0	73400	73.4	< 500	0	< 500	0	< 500	0
< 1	0	< 500	0	< 500	0	196	< 1000	0	< 500	0	140000	140	< 500	0	< 500	0	< 500	0
< 1	0	< 500	0	< 500	0	277	< 1000	0	< 500	0	146000	146	1100	1.1	< 500	0	< 500	0
< 1	0	< 500	0	< 500	0	731	< 1000	0	< 500	0	51400	51.4	< 500	0	< 500	0	< 500	0
< 1	0	< 500	0	< 500	0	268	< 1000	0	< 500	0	189000	189	< 500	0	< 500	0	< 500	0
< 1	0	< 500	0	< 500	0	189	< 1000	0	< 500	0	200000	200	< 500	0	< 500	0	< 500	0
< 1	0	< 500	0	< 500	0	201	< 1000	0	< 500	0	145000	145	< 500	0	< 500	0	< 500	0

U		V		W		Y		Zn		Br		Cl	F	NO2 (as N)	NO3 (as N)	PO4 (as P)	SO4
mg/L	mg/L	µg/L	mg/L	µg/L	mg/L	µg/L	mg/L	µg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
< 3	0	< 500	0	< 500	0	< 500	0	23700	23.7	< 60	0	107000	< 20	< 20	< 20	< 40	714
< 3	0	< 500	0	< 500	0	< 500	0	34700	34.7	159	159	103000	< 20	< 20	< 20	< 40	603
< 3	0	< 500	0	< 500	0	< 500	0	13200	13.2	< 60	0	78600	< 20	< 20	< 20	< 40	557
19	19	< 1000	0	< 1000	0	< 1000	0	5700	5.7	161	161	72300	< 20	< 20	< 20	< 40	705
< 3	0	< 500	0	< 500	0	< 500	0	22700	22.7	< 60	0	103000	< 20	< 20	< 20	< 40	475
< 3	0	< 500	0	< 500	0	< 500	0	13800	13.8	< 60	0	89800	< 20	< 20	< 20	< 40	734
< 3	0	< 500	0	< 500	0	< 500	0	< 300	0	< 60	0	37900	< 20	< 20	< 20	< 40	1400
< 3	0	< 500	0	< 500	0	< 500	0	11000	11	< 60	0	61100	< 20	< 20	< 20	< 40	832
< 3	0	< 500	0	< 500	0	< 500	0	5210	5.21	121	121	53200	< 20	< 20	< 20	< 40	1100
< 3	0	< 500	0	< 500	0	< 500	0	1000	1	< 60	0	27400	< 20	< 20	< 20	< 40	2560
< 3	0	< 500	0	< 500	0	< 500	0	< 300	0	< 60	0	67300	< 20	< 20	< 20	< 40	1070
< 3	0	< 500	0	< 500	0	< 500	0	3880	3.88	117	117	100000	< 20	< 20	< 20	< 40	750
< 3	0	< 500	0	< 500	0	< 500	0	2290	2.29	< 60	0	73800	< 20	< 20	< 20	< 40	930

Figure 47. Brine analyses from swab and DSTs from Berexco Cutter KGS #1 performed by KSU.

Simulation Studies of Chester/Morrow Oil Fields

All models will be finished in the final two months of the project.

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

Deliverables for the Final Report

1. Reservoir geomodel of Wellington Mississippian Chat reservoir and its CO_2-sequestration and CO_2-EOR potential.
2. Reservoir geomodel of Arbuckle Group saline aquifer underlying Wellington field and its CO_2-sequestration potential
3. Regional geomodel of OPAS covering 17+ counties in south central Kansas and its CO_2-sequestration potential

4. Risk assessment studies related to CO_2 sequestration including characterization of leakage pathways, vertical communication within the Arbuckle Group, and well abandonment histories in the 17+ county study area and the Western Annex.
5. Geomodel and simulations of CO_2 sequestration potential of the Arbuckle Group saline aquifer and of CO_2-EOR in a select Chester/Morrow incised valley sandstone oil reservoir in the Western Annex – a new addition of ~5,000 mi^2 to the regional study.
6. Results and interpretation of the seismic surveys, and interpretation of all laboratory analysis performed in the 17+ county study area and the Western Annex.

PRESENTATIONS AND PUBLICATIONS

Papers were presented in Lawrence at an industrial associates meeting. In addition, the Wellington KGS #1-32 core was displayed and discussed. Presentations included:

Jason Rush --"Basement-Rooted Faults, Paleokarst, and Mississippian Flexures: A Compelling Story for PSDM Seismic Volumetric Curvature

Jason Rush -"The Mississippian at Wellington and Development of a Middle Eastern Giant (Idd El Shargi Field)

W. Lynn Watney, Jason Rush, John Doveton, Mina Fazelalavi, Eugene Holubnyak, Bob Goldstein, Brad King, Jen Roberts, David Fowle, Christa Jackson, George Tsoflias, et al., Overview, current research, and major findings for two long Paleozoic cores – Berexco Wellington KGS #1-32, Sumner County, KS and Berexco Cutter KGS #1, Stevens County, Kansas

W. Lynn Watney, Jason Rush, John Doveton, Mina Fazelalavi, Eugene Holubnyak, Bob Goldstein, Brad King, Jen Roberts, David Fowle, Christa Jackson, George Tsoflias, et al., Overview, current research, and major findings for two long Paleozoic cores – Berexco Wellington KGS #1-32, Sumner County, KS and Berexco Cutter KGS #1, Stevens County, Kansas - four posters (2 each for Wellington and Cutter)

Mina Fazelalavi, W. Lynn Watney, John Doveton, Mohsen Fazelalavi, and Maryem Fazelalavi - Determination of Capillary Pressure Curves in the Mississippian Limestone, Kansas

Yousuf Fadolalkarem and George Tsoflias - Pre-stack Seismic Attribute Analysis of the Mississippian Chert and the Arbuckle at the Wellington Field, South-central Kansas

Christa Jackson, David Fowle, Brian Strazisar, W. Lynn Watney, Aimee Scheffer, and Jennifer Roberts - Geochemical and Microbiological Influences on Reservoir and Seal Material During Exposure to Supercritical CO2, Arbuckle Group, Kansas
Luis Montalvo, Luis Gonzalez, Lynn Watney, Diagenesis and distribution of diagenetic facies in the Mississippian of south-central Kansas

Bradley King and Robert Goldstein -- Controls on Hydrothermal Fluid Flow and Porosity Evolution in the Arbuckle Group and Overlying Units (3 panels)

Presentation at Geological Society of America, Regional Meeting (April 2014) – illustrating the stratigraphic and sedimentologic effects of episodic structural movement at Wellington Field:

DOVETON, John H., Kansas Geological Survey, University of Kansas, 1930 Constant Ave, Lawrence, KS 66047, doveton@kgs.ku.edu, MERRIAM, Daniel F., University of Kansas, 1930 Constant Ave, Campus West, Lawrence, KS 66047, and WATNEY, W. Lynn, Kansas Geological Survey, Univ of Kansas, 1930 Constant Avenue, Lawrence, KS, 66047, 2014, Petrophysical Imagery of the Oread Limestone in Subsurface Kansas, Paper #237642, 48th Annual Meeting, North Central Geological Society of America, Program With Abstracts. (Episodic nature of structural activity at Wellington Field)

The Oread Limestone is recognized widely as an archtypal Pennsylvanian cyclothem that has been investigated extensively over its eastern Kansas outcrop for more than a century. Knowledge of the geology of the Oread in the subsurface has been restricted almost entirely to drill-cuttings, while wireline logs have provided the correlative framework for mapping structure and thickness. The curves of traditional logs are the time-honored medium for correlation, but the rich data of more recent petrophysical measurements are presented increasingly as image logs which portray geology in novel ways. FMI logs are conversions of multiple microresistivity curves into a high-resolution conductivity image of the borehole wall. MRI logs measure magnetic resonance relaxation times that are presented as contour map images of pore-size distribution. Natural and capture gamma-ray spectra logs estimate elemental concentrations of potassium, thorium, uranium, calcium, magnesium, titanium, aluminum, iron, sulfur, and manganese. Interpretations of these logs in the Oread in south-central Kansas present new opportunities in Pennsylvanian cyclothem research that can be integrated with conventional outcrop studies. As a case in point, log imagery of the anomalously thick and variable “Super-Plattsmouth” regressive limestone (anomalously thick and variable) in Sumner County

provides intriguing insights into mound internal architecture (**Figure 48**).

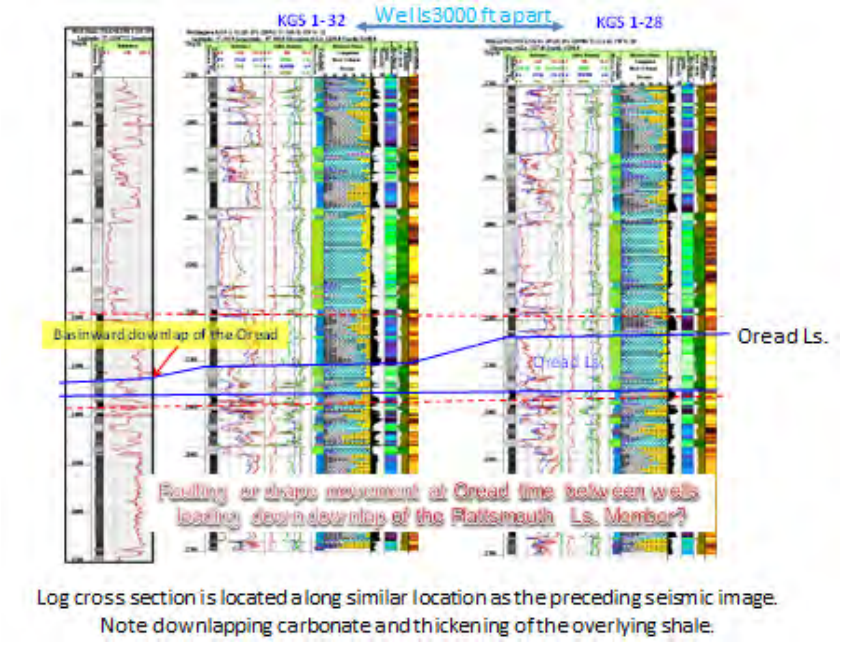


Figure 48. Notable changes in stratigraphy at the Oread Limestone horizon. Paper describes differences between the two wells in the Oread Limestone and overlying Kanwaka Shale.

National Groundwater Association Groundwater Summit

Watney, W.L., 2014, Integrating Modern Suite of Geophysical Logs, Geochemistry, and Seismic Data for Characterizing Deep Aquifers, NGWA Conference on Characterization of Deep Groundwater, May 8, 2014

Watney, W.L., 2014, Using Drill Stem Test Data to Construct Regional Scale Potentiometric Surface in Deep Aquifers, NGWA Conference on Characterization of Deep Groundwater, May 8, 2014

Tiraz Birdie, TBirdie Consulting, Inc., Lawrence, KS, W. Lynn Watney, Ph.D., Kansas Geological Survey, University of Kansas, Lawrence, KS and Paul Gerlach, Charter Consulting, Miramar, FL, Using Drill Stem Test Data to Construct Regional Scale Potentiometric Surface in Deep Aquifers, NGWA Conference on Characterization of Deep Groundwater, May 8, 2014

KEY FINDINGS

1. Type logs are being reviewed and improvements are being incorporated into the database.

2. Extensive analysis of flow units was completed including used of independent methods of using petrophysical data to perform the classification. Flow units were correlated regionally and used in the simulations of the 10 regional commercial scale modeling and eventually in the final CO_2 storage assessment.
3. The step-rate test involving Wellington KGS #1-32 and #1-28 was reexamined as the result of continued analysis and refinement of the 3D seismic volume and Petrel geomodel. The permeability field in the vicinity of these wells remains in the 100 md range that is consistent with the drill stem tests, whole core analysis, and estimates from the nuclear magnetic resonance well log. The effective thickness used in this analysis of 30 ft is considered a minimum (assuming the flow unit does not connect with other layers beyond the wellbore) and leads to higher permeability calculations, the computed value of this iteration suggests permeability in the 100 Darcy range in the vicinity of well 1-28 and is attributed to a fracture or fault.

   The depth-migrated solution of the 3D seismic suggests a zone of discontinuous seismic reflections in the injection zone in the lower Arbuckle that have minor offset (as noted in previous quarterly report). The juxtaposed strata in the Arbuckle are essentially within the framework of existing flow units so low permeability zones are not faulted out placing lower permeable zones with upper permeable layers. Extensive brine geochemistry and microbiology have previously shown that the tripartite hydrostratigraphic divisions that comprise the Arbuckle are not communicating. In other words, the fault/fracture zone is not permitting vertical fluid exchange, but the step rate tests suggests that the lateral flow along the zone would be greatly enhanced and notably affect the fate of a CO_2 plume. This scenario is being examined as a final modeling exercise in this study.

4. Regional simulations are being completed including an assessment of the fate of commercial scale CO_2 (30 million + tonnes) at 10 sites.

5. Total CO_2 storage potential in southern Kansas will be derived by a mega-scale simulation as outlined in this report. The simulation is incorporating the major factors that can trap CO2 to realistically provide a measure of capacity beyond a volumetric-based storage assessment.

PLANS

1. Complete geomodeling and simulations of commercial scale CO2 injection at the 10 regional sites and the regional CO2 assessment.
2. Complete the updates for the Wellington geomodels simulations.
3. Complete the modeling of the SW Kansas fields.
4. Gather results for write final report.

APPENDIX I

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

TWENTIETH QUARTER PROGRESS REPORT

DOE F 4600.2
(5/09)
(All Other Editions are Obsolete)

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			
☒ Other (see special instructions) Topical — DOE F 241.3	A		http://www.osti.gov/estsc/241-4pre.jsp
** 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.

1

QUARTERLY 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

Twentieth Quarter Progress Report

Date of Report: 11-23-14

Period Covered by the Report: July 1, 2014 to September 30, 2014

Contributors to this Report: Clyde Redger, George Tsoflias, Dennis Hedke, Paul Gerlach, Eugene Holubnyak, Gene Williams, Martin Dubois, John Victorine, Tiraz Birdie, Jennifer Raney, Mike Killian, Holly Field, Tandis Bidgoli, Mina Fazelalavi, Jason Rush, Lynn Watney

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		90%
2.0 Characterize the OPAS (Ozark Plateau Aquifer System)	1/1/2010	01/01/10	9/30/2013		95%
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	+++	99%
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	**	99%
11.0 Produced water and wellbore management plans - Risk assessment area	1/1/2012	01/01/12	7/30/2013		99%
12.0 Regional CO2 sequestration potential in OPAS	8/1/2012	02/01/12	9/30/2013	***	99%

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 competed
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	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		99% complete***-emalil summary to come**
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		Completed - **email summary to come****
KGS Milestone 3.4: Regional CO2 Sequestration Potential in OPAS - 17 Counties	12/7/2012		99.9% complete*** -**email summary to come**

TASK SUMMARY IN PREPARATION FOR COMPLETION OF THE PROJECT

This quarterly report is the last, prior to submitting the final report. All of the tasks and subtasks are listed herein with dialog inserted into sections pertaining to significant activities conducted in this last quarter.

Task 1: Program Management and Reporting (PMP)

Task 2. Characterize the OPAS

Subtask 2.1. Acquire geologic, seismic and engineering data
Subtask 2.2. Develop regional correlation framework and integrated geomodel

Type logs were checked for completeness for both digitizing and for stratigraphic correlations over the course of several months. In the process the "type logs" java applet was used to review the wells and to make modifications to the well database. Comments about the experience and recommendations resulted leading to minor modifications to improve the user's experience were made by Holly Field as noted below. This is important in the future to encourage expansion of type logs database both in number of wells and in additional detail in stratigraphic correlations.

Modifications include --

1. Java menu screen has an option to close or "x" out in the upper right hand corner. Closing the window was modified to allow Java to continue running in the background. This prevents the user from having to sign in to the Applet upon each new correlation saving time.
2. In the Applet correlations, it is possible to deselect Tracks on display so that the horizontal distance between the well displays can be shortened. Initially, unselecting the display of the lithologies also removed yellow lines of the "tops". This has now been corrected so that the tops remain visible after a deselection. This is important to maintain the visibility of the tops for continuity of workflow.
3. A webpage was created that chooses CO_2 wells within a county that include a specific top. This allows the user to quickly view wells in a list which gives information on a specific horizon within an area. The URL for this function is http://chasm.kgs.ku.edu/ords/iqstrat.doe_co2_summary_pkg.build_web_page?sCounty=harper&sTops=arbuckle which can be changed to other counties and tops by replacing the county for formation names in question.
4. A request was made to show rejected tops on the Java applet in a differing color from the standard yellow. Also, there is a need to show where a person wanted to place the new or changed top location. John Victorine (programmer) advised that making these changes in the Java correlation displays would likely cause the tops to become clustered or visually convoluted. However, to facilitate the need for clarity on both agreements and recommendations of change from the different applet users, John created charts that

automatically update so that the progress of well changes can be understood without compromising the visual utility of the correlations tool. An example of a chart that shows the horizons and the Source owners for the Cutter KGS 1 well can be found at http://chasm.kgs.ku.edu/ords/iqstrat.type_log_summary_pkg.build_web_page?sKID=1044138961**.**

5. In addition, the number of horizons accepted or rejected for each well within a county is included in the county summary page. For example, Cutter KGS 1 chart reject and accept summaries can be found within the Summary Page for Stevens County. Selecting the number within the reject or accept columns will bring the user to the link above.

Comments were also provided for the future of the Type Logs Applet program.

1. Find a way to make accepting tops less time-consuming. Currently, to accept tops within a well, each top that the user agrees with must be clicked on and accepted. It would be an advantage to be able to select multiple tops on the visual display at once and to then click accepts. A 6,000 ft well may take 15 minutes to accept horizons alone.
2. Furthermore, it is useful to see many wells at once within a correlation, as opposed to being limited currently to two wells. While designing multiple-well correlations was not within the scope of the Type Logs Applet the adaptation to multiple wells is possible since the CO_2 Project General Cross Section Map Applet can utilize data from up to four wells. The use of additional wells in the cross section multiple wells would prevent the need to go back-and-forth between wells, correlating two wells at a time. A geologist that is accustomed to viewing paper logs may find this methodology tedious or more time-consuming if the working cross sections are limited to two wells.
3. Accommodation of short notes linked the horizons that are correlated would help to convey the concept or key element of the correlation.

Subtask 2.3. Subsurface fluid chemistry and flow regime analysis.
Subtask 2.4. Gather and interpret KGS's gravity and magnetic data
Subtask 2.5. Remote sensing analysis for lineaments

Task 3. Geomodel of Mississippian Chat & Arbuckle Group - Wellington field.

Subtask 3.1. Collect geologic & engineering data
Subtask 3.2. Collect 3D seismic data
Subtask 3.3. Process 3D seismic data
Subtask 3.4. Collect gravity and magnetic data
Subtask 3.5. Interpret seismic, gravimetric, and magnetic data
Subtask 3.6. Initial geomodel - Wellington

Task 4: Preparation, Drilling, Data Collection and Analysis – Test Borehole #1

Subtask4.1. Locate Test Borehole #1
Subtask 4.2. Permitting for Test Borehole #1
Subtask 4.3. Drill, retrieve core, and run DST – Test Borehole #1
Subtask 4.4. Openhole Wireline Logging – Test Borehole #1
Subtask 4.5. Wellbore Completion – Test Borehole #1
Subtask 4.6. Analyze wireline log - Test Borehole #1
Subtask 4.7. Test and sample fluids (water) from select intervals – Test Borehole #1
Subtask 4.8. Analyze Arbuckle core from Test Borehole #1
Subtask 4.9. Analyze Mississippian core from Test Borehole #1
Subtask 4.10. PVT analysis of oil and water from Mississippian chat reservoir
Subtask 4.11. Analyze water samples from Test Borehole #1
Subtask 4.12. Microbiological studies on produced water
Subtask 4.13. Correlate log and core properties
Subtask 4.14. Examine diagenetic history of fracture fill

Task 5. Preparation, Drilling, Data Collection, and Analysis - Test Borehole #2

Subtask 5.1. Locate Test Borehole #2
SubTask 5.2. Permitting for Test Borehole #2
Subtask 5.3. Drill, and run DST – Test Borehole #2
Subtask 5.4. Openhole wireline logging - Test Borehole #2
Subtask 5.5. Complete well and perforate selectively to test and sample fluids – Test Borehole #2
Subtask 5.6. Analyze wireline log – Test Borehole #2

Task 6. Update Geomodels

Subtask 6.1. Hydrogeologic studies
Subtask 6.2. 2D shear wave survey
Subtask 6.3. Process & interpret 2D shear
Subtask 6.4. Revise 3D seismic interpretation
Subtask 6.5. Update geomodel - Arbuckle & Miss

Task 7. Evaluate CO2 Sequestration Potential in Arbuckle Group Saline Aquifer - Wellington field

Subtask 7.1. CO2 sequestration potential
Subtask 7.2. Long-term effectiveness of cap rock
Subtask 7.3. CO2 sequestered in brine
Subtask 7.4. CO2 sequestered as residual gas
Subtask 7.5. CO2 sequestered by mineralization
Subtask 7.6. Field management - max CO_2 entrapment
Subtask 7.7. Monte Carlo - total CO_2 sequestration capacity

Task 8. Evaluate CO2 Sequestration Potential by CO2-EOR in Depleted Wellington field

Subtask 8.1. CO2-EOR potential
Subtask 8.2. Long-term effectiveness of cap rock
Subtask 8.3. CO2 sequestered in brine and residual gas
Subtask 8.4. CO2 sequestered by mineralization
Subtask 8.5. Field management - optimize CO2-EOR
Subtask 8.6. Monte Carlo - total CO2 sequestration capacity

Task 9. Characterize leakage pathways - Risk assessment area

Subtask 9.1. Collect reservoir characterization data - external sources
Subtask 9.2. Map fracture-fault network
Subtask 9.3. Verify seal continuity and integrity
Subtask 9.4. Inventory well status
Subtask 9.5. Gather expert advice on well integrity

Affirming possible and previously unrecognized faults has been made easier with the increase in seismic activity in south-central Kanas. The DOE-CO2 mapper has is updated to include the earthquake events since 2011 that are focused around the Mississippian Lime horizontal drilling play. Large volumes of brine are disposed in and around this play extending from north-central Oklahoma into Kansas. Increased seismicity has followed this trend.

The increased in both cumulative brine disposal with some injection wells permitted at high rates (20,000 to 40,000 bbls/day) but lacking daily injection rates and pressures is problematic to understanding or modeling the role of injection and the seismicity or, important to this project, of considering the circumstances in the context of CO2 disposal that has been evaluated in this area. Accordingly, we have elevated the risk of injection of large volumes of fluids pending ongoing analysis outside of this funded program. The fact that the extensive subsurface and surface lineament database exists for the area will be critical to further assessment that will included geomodeling and simulation.

Tandis S. Bidgoli, W. Lynn Watney, Paul Gerlach, and Minh C. Nguyen presented a paper at the 2014 Annual Meeting of the Geological Society of America, titled, "Episodic reactivation of critically-stressed basement faults in southern Kansas: Implications for waste-water disposal and long-term storage of CO_2**".** The paper echoes the concern as the KGS team works with state regulators and chairs a task force on induced seismicity. The paper also lays out an approach to utilizing the data, much of it derived from the regional DOE funded study evaluate seismicity in the context of the geology as described in the abstract -

> *Kansas resides within the stable craton, a characterization that contrasts it with tectonically active portions of the U.S. However, the Proterozoic basement beneath Kansas contains a number of well-defined discontinuities or lineaments, many of which are faults with large offsets that show evidence of reactivation within shallower stratigraphy. Although the role of these faults within the current*

stress regime is not clear, a growing number of researchers argue that the midcontinent crust is critically-stressed and that injecting large volumes of fluid (waste-water or CO_2) poses a high risk for induced seismicity and fluid leakage. The recent uptick in the frequency and size of earthquakes in the southern part of the state has elevated these concerns, but poor knowledge of subsurface faults and their relationship with regional stresses are major obstacles to evaluating the cause of the seismicity and to developing possible mitigating strategies. To address these issues on a broad scale, we use a dense sampling of stratigraphic tops, determined from publically-available well-log data, to construct structure contour maps of 18 regional stratigraphic surfaces. We use a range of surface analysis techniques (e.g., slope, curvature, and residual analysis) combined with thickness variations, determined from isopach maps, to identify potential faults. To evaluate the consistency of the mapped faults, we will compare them to documented surface lineaments and discontinuities determined from analysis of state-wide potential field data. To identify the faults most favorably oriented with respect to in situ stresses and thus, those with the highest potential for reactivation, we will analyze borehole breakouts, drilling-induced fractures, and drilling-enhanced fractures from available well logs (e.g., 4-arm caliper and image logs), which will provide the orientations of the minimum and maximum horizontal stresses. The resulting fault map will identify high and low risk subsurface faults, and ideally provide regional stakeholders some context for recent and future seismic events.

What had been originally mapped as actual and possible faults is a baseline from which additional information will be gathered in the affected area. Data now includes daily injection from selected injection wells and potential opportunities to examine 3D seismic volumes and obtain dynamic and static pressures of the Arbuckle. If it is found that injection is responsible for the earthquake activity, solutions might include limiting rates of injection established by injectivity tests. This is precisely the approach that we have taken with the CO2 storage assessment. The Arbuckle is treated as a reservoir with flow units and baffles, faults and fractures. Flow units are characterized by kv, kh, phi, reservoir quality index, and capillary pressure. These flow units change in thickness and reservoir properties, pinchout, or simply reach permeability barriers, particularly as demonstrated by the regional assessment (**Figure 1**). All simulations, whether for an oil reservoir or the Arbuckle aquifer, utilize conservative injection pressures that are well below the fracture gradient that commonly serves as the recommended rule of thumb pressure maximum. Careful design will be necessary for commercial CO2 injection no matter where the injection is planned.

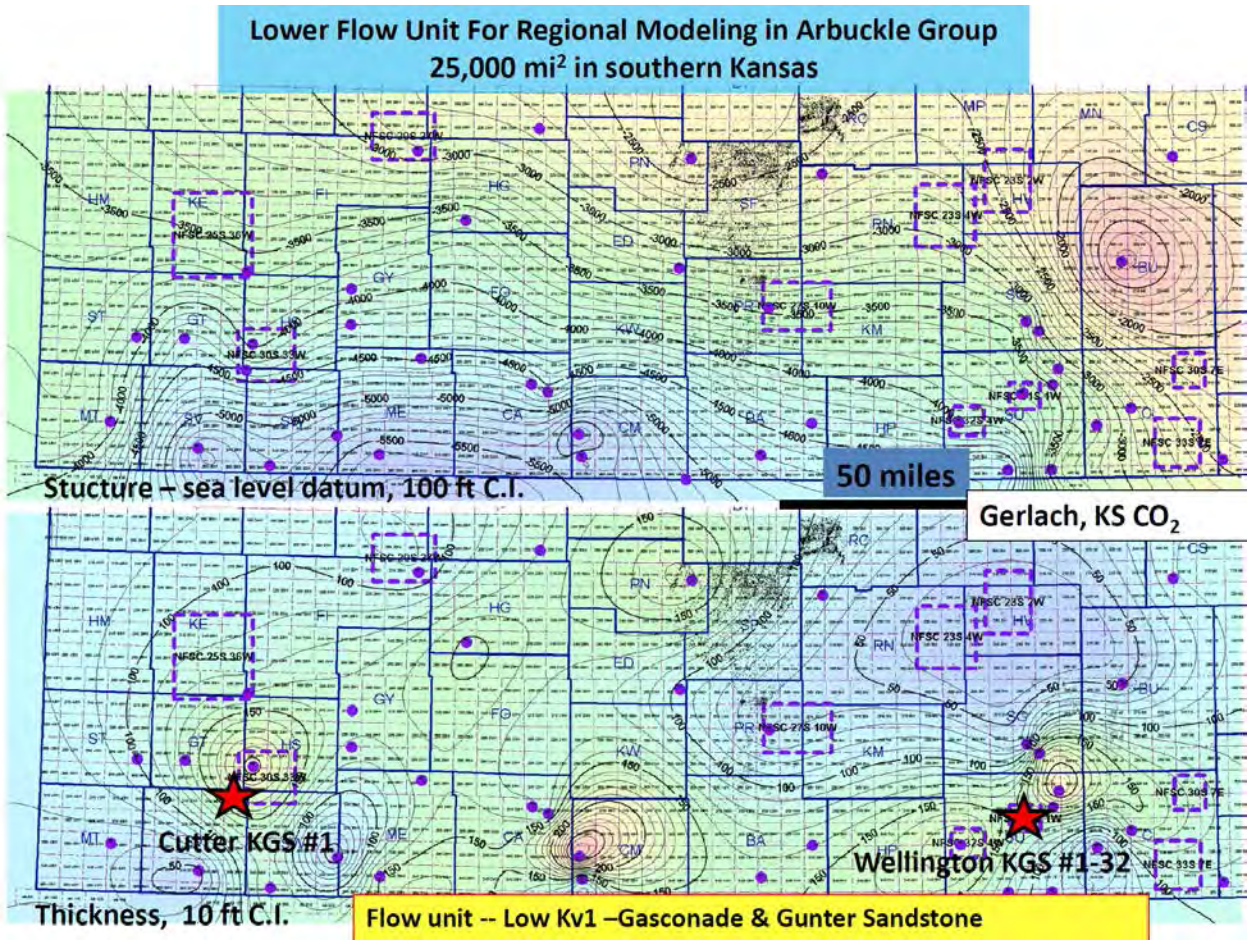


Figure 1. Variability in structure and thickness of a lower flow unit in the Arbuckle in southern Kansas shown to emphasis the fact that the flow units are mappable, and have sufficient control on a regional scale to infer properties for a successful regional simulation and assessment of injectivity and storage.

The regional simulation of the MegaModel for southern Kansas resulted in a regional pressure buildup indicating that with the variable flow unit properties that the system is not fully open when it comes to regional scale CO2 disposal conducted in a 50 year timeframe. However, on the long term the system is open. This indicates that pressures and fluid levels of the Arbuckle will need to be closely monitored and modeled, much like any other aquifer that is used by humans.

The adaptation to the MegaModel to brine injection can be easily done including setting a maximum pore pressure (maybe spatially variable based on fluid levels and overburden above which possible leakage would occur, i.e., fracture-based flow. Leakage could be entered into the model as trends/anisotropy based on actual lineaments of suspected faults or better yet, faults obtained from 3D seismic.

Models and analysis of well tests would 1) evaluate if we have a cumulative increase in pressure and where, 2) define areas with more compartmentalized or directed flow; 3) predict interaction

of pressure in areas with critical faults; 4) provide high-low injection outcomes scenarios; 5) run optimization scenarios to evaluate stabilization/sustainable rates and pressures of disposal to offer management solutions to regulators.

The following is an example of an earthquake swarm coupled with the use of the DOE sponsored Kansas CO2 Interactive Mapper -- **http://maps.kgs.ku.edu/co2/** **(Figures 2-12)**.

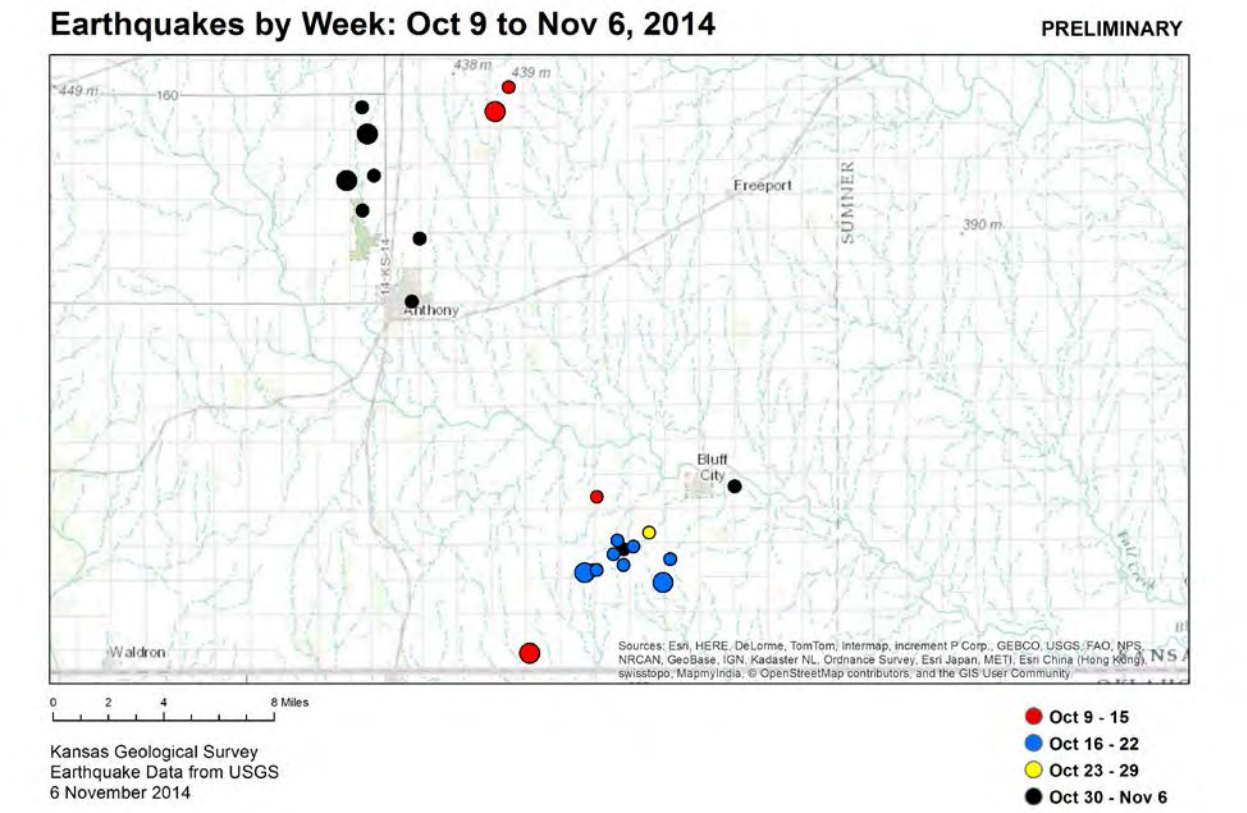
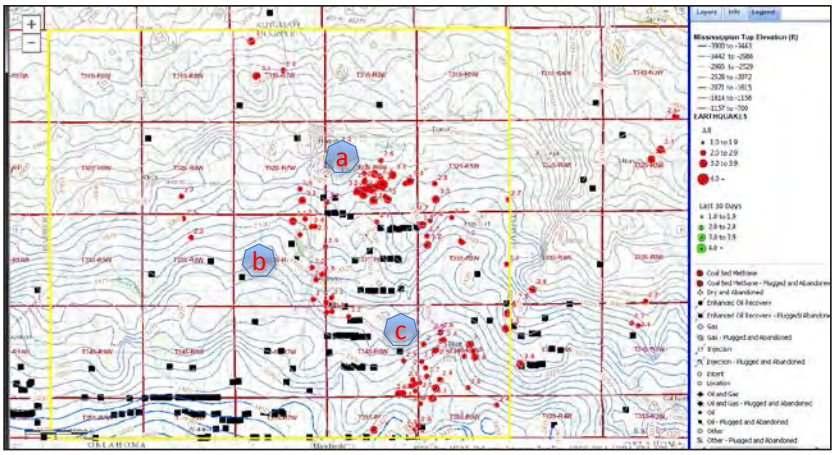
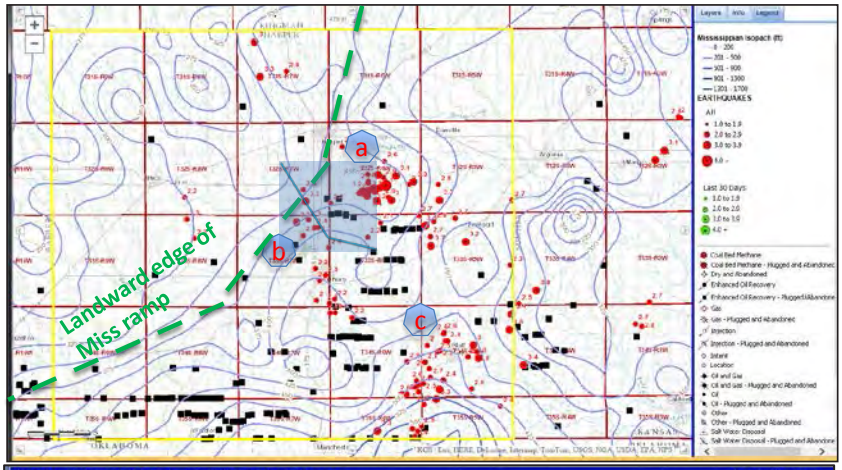
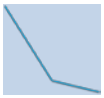


Figure 2. Two earthquake swarms including a 4.3 SE of Anthony in south-central Kansas in Harper County adjacent to Sumner County.





See cross section next page



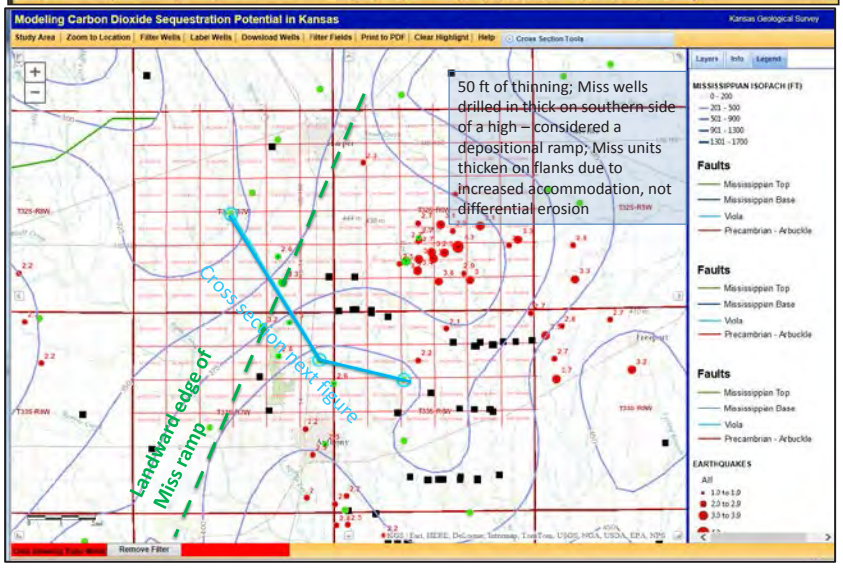


Figure 3. (top) Elevation and isopach of the Mississippian in the area of earthquake clusters (labeled a, b, and c) in Harper County (yellow outline) and western edge of Sumner County. Horizontal wells are black squares and red dots are recent earthquakes, each labeled with their magnitude as determined by USGS. Injection wells are not shown. Mississippian strata thicken along an arch (green dashes) delimiting a thick ramp deposit that is the object of the horizontal drilling and high volume brine extraction. Cluster "a" is a location where the Mississippian is thin, where the landward edge of the ramp extends to the SE. Based on work in this study, the thinning is likely due to small faulting during and post Mississippian deposition, a time when flexure faulting was tectonically active. A cross section in the light blue outline extends across the

Mississippian ramp to illustrate the thickening (Figure 4). (Bottom) Close-up of the Mississippian thinning that locally extend the edge of the ramp.

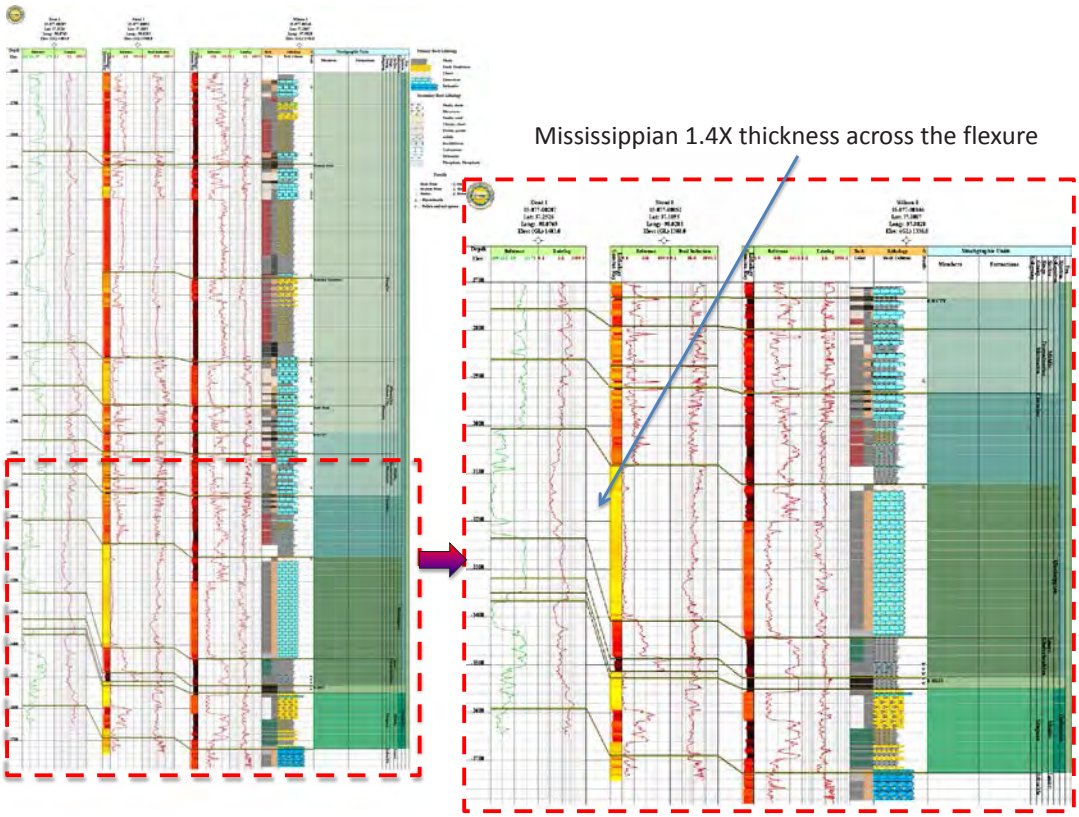


Figure 4. NW-SE structural cross section crossing the inner Mississippian ramp where the Mississippian strata thickens.

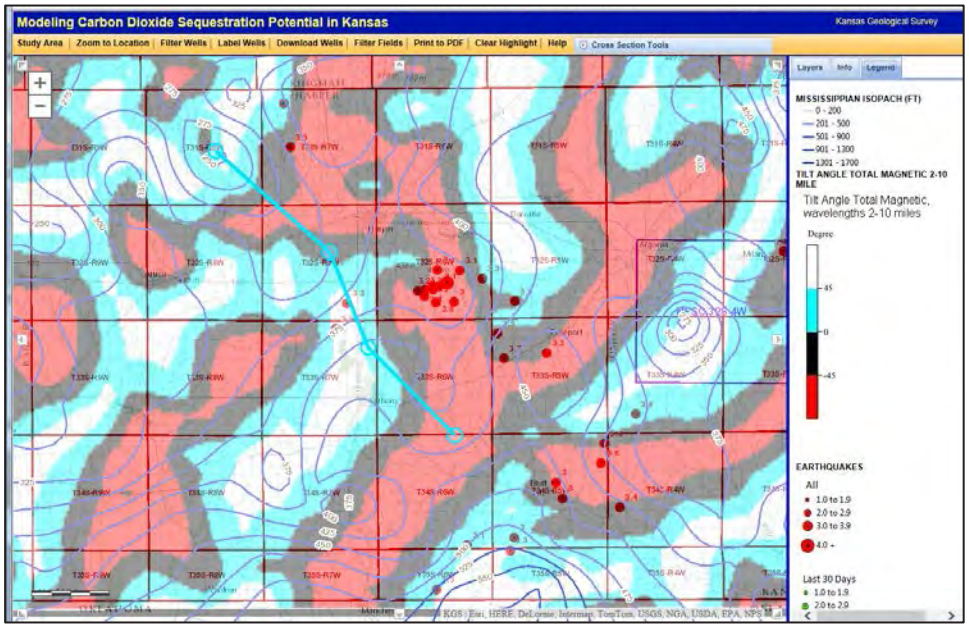


Figure 5. Mississippian isopach superposed on the tilt angle map to the 2-10 mile filter of the total magnetic field. Mississippian ramp parallels the dominant NE-trend. The area is underlain by the Midcontinent Rift. The magnetic negative tilt (red) are likely grabens filled with sediment and the magnetic tilt positives are suggesting either mafic intrusives or beds of extrusive basic volcanics that are steeply dipping in the rift fill. The associations of

potential field and basement rift lithologies have been confirmed in northern Kansas. Note cross section index line. Cross section shown in Figure 6.

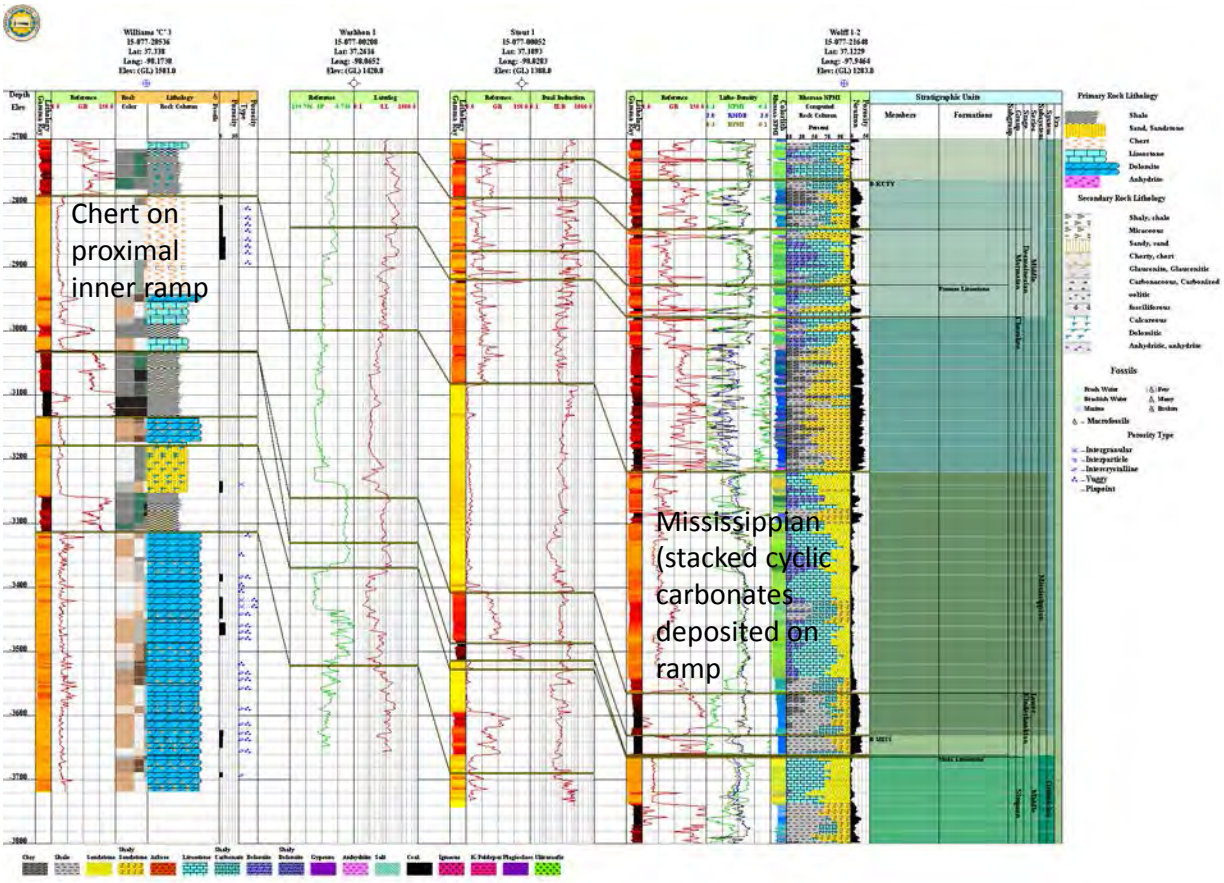


Figure 6. NW-SE structural cross section from proximal to more distal ramp focused on the Mississippian strata. Higher gamma ray intervals (shaly and organic-bearing) in lower portion of the Mississippian and underlying Chattanooga Shale are the likely "unconventional" targets of the horizontal wells drilled in this area from which large volume of brine are also recovered. Note the major changes in lithofacies and thickness. Related work has indicated that concurrent deformation/faulting across the ramp led to a progradational facies succession along the shelf margin. Earthquake clusters are nearby. The role of the suspected faults in the earthquake activity via reactivation appears to be highly likely.

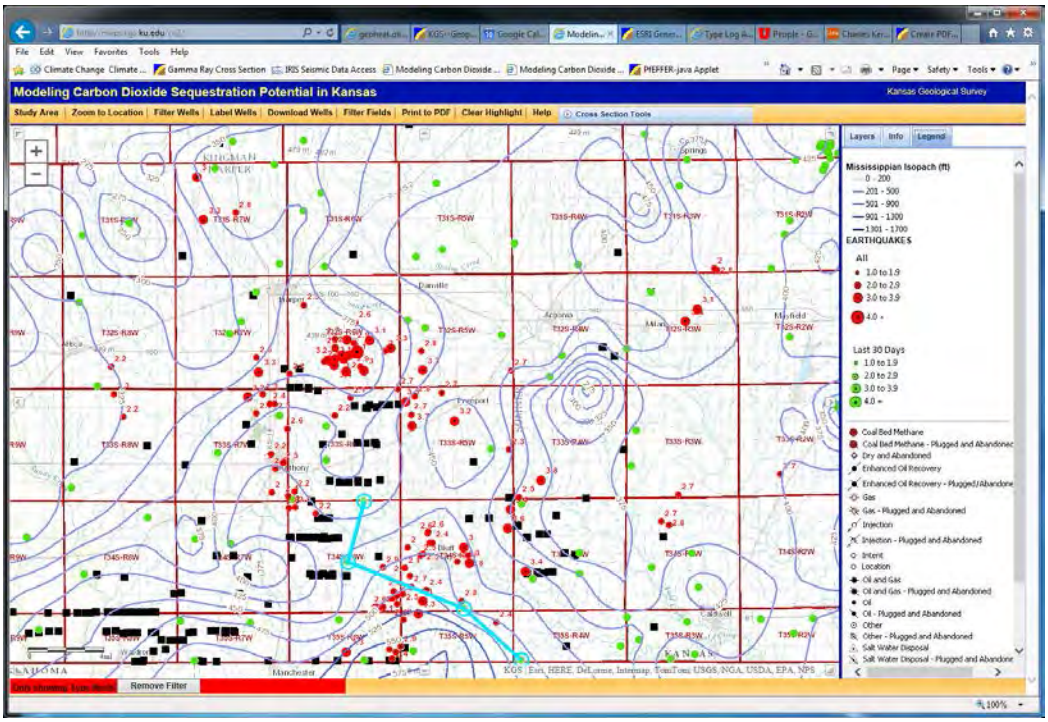


Figure 7. Mississippian isopach again with another cross section located farther south near the Oklahoma border crossing the southern earthquake cluster.

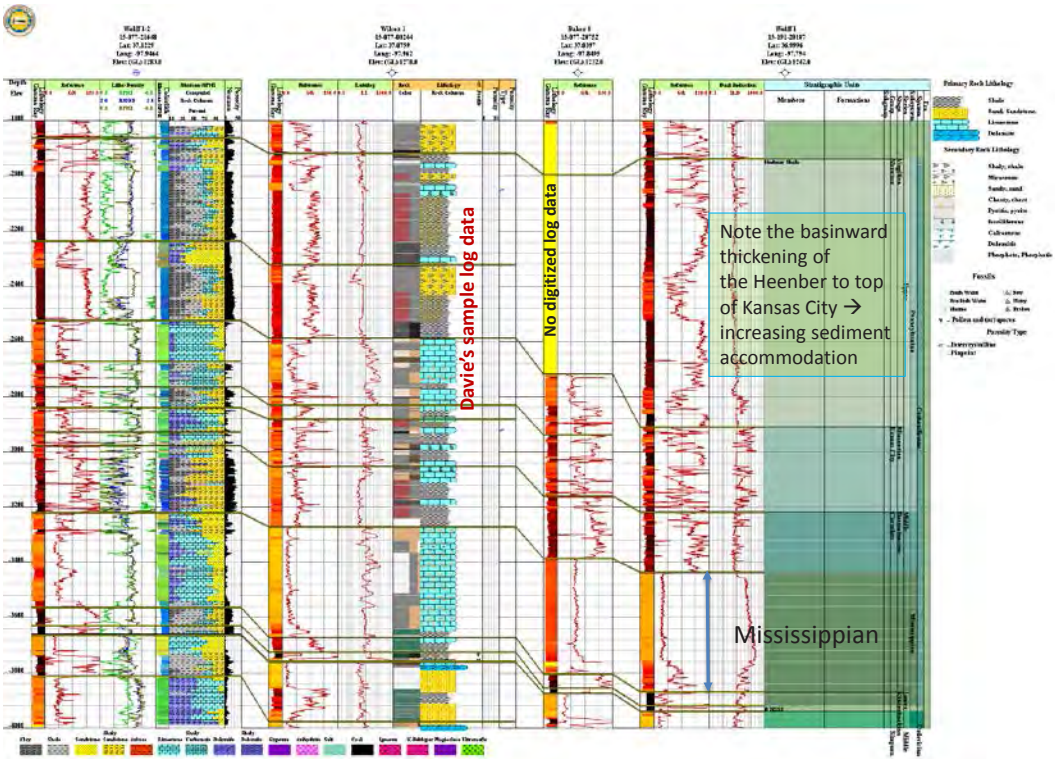


Figure 8. NW-SE structural cross section showing stratigraphic changes continue across the ramp affecting Pennsylvanian age siliciclastics.

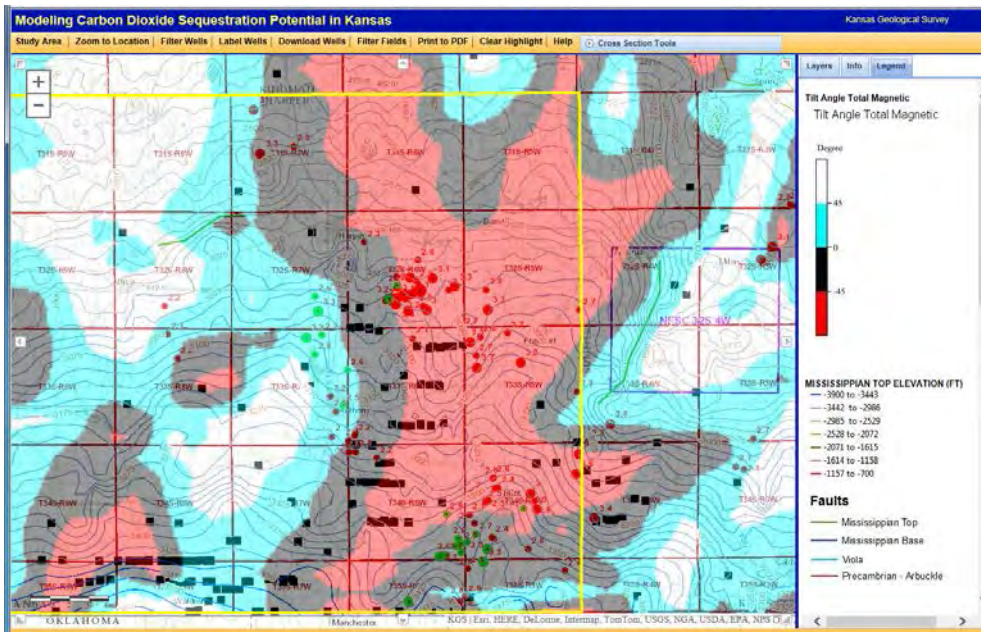


Figure 9. Tilt angle of the total magnetic field without the 2-10 mile filter shown in Figure 5. Horizontal wells and earthquakes are in the tilt angle magnetic low, believed to be comprised of rift-fill sediment. Edge of the sediment fill (inferred rift margin in this area) closely corresponds with the location of the ramp margin on the west and enhanced structural flexure trending more W-E on the south, also the location of an earthquake cluster and more horizontal wells.

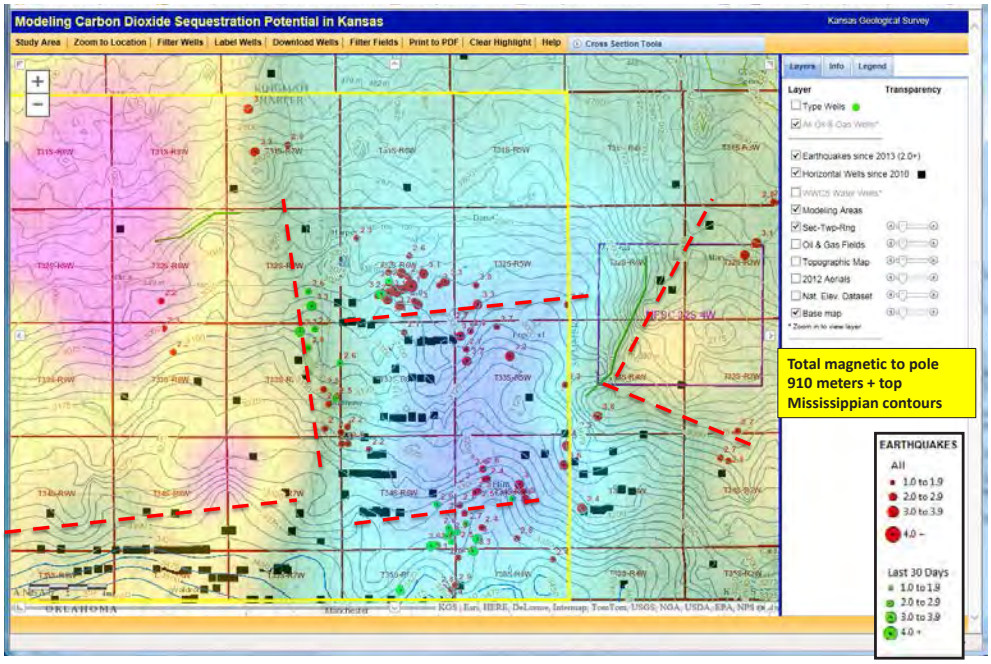


Figure 10. Total magnetic reduce to pole overlain with Mississippian structural contours nicely constrains the Mississippian Lime Play and the locus of earthquake activity. The complexity in understanding which faults move also depends on the stress direction, differential horizontal stress, and the orientation, length, and damage zone of the faults.

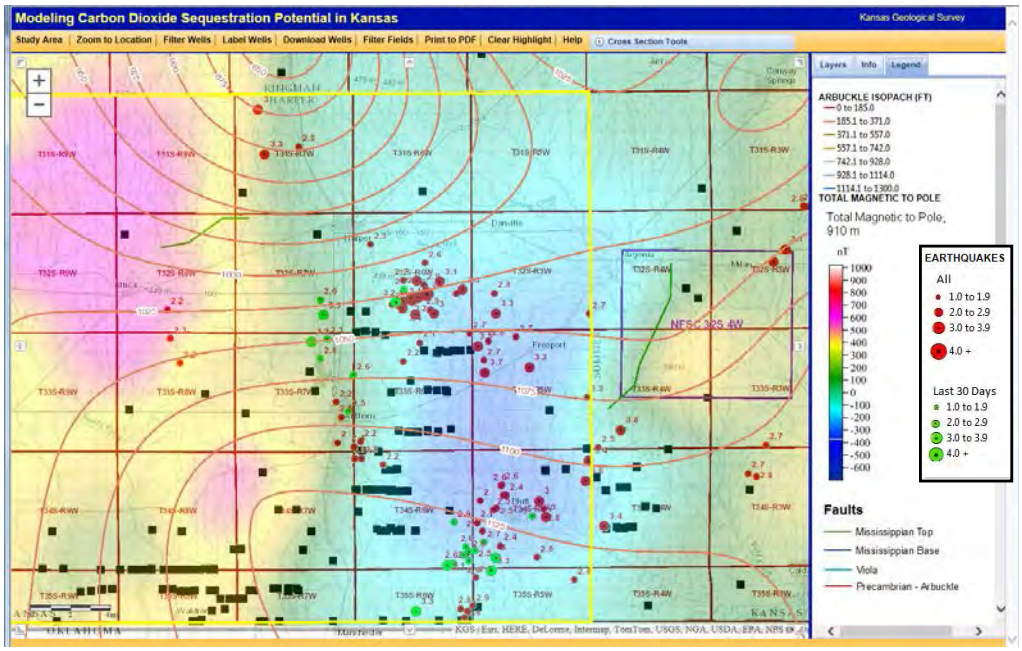


Figure 11. Same magnetic map as in Figure 10, but with an overlay of the Arbuckle isopach map. A notable north to south thickening of the Arbuckle is noted at the site of the northern earthquake cluster. The change is also along a west-east lineament shown in Figure 10. Maximum thickness on the south is confined to the magnetic low corresponding with the underlying rift system. This is not unexpected with a reactivating fault system.

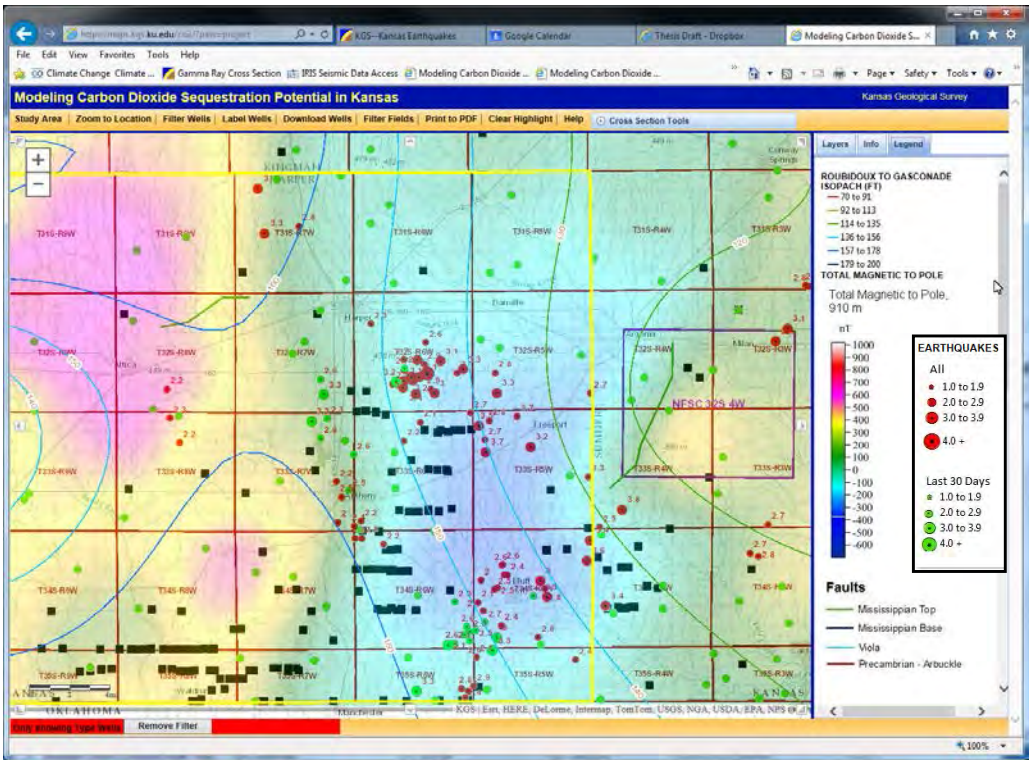


Figure 12. Isopach of the Gasconade interval in the Arbuckle, the highly permeable portion in the lower Arbuckle thickens to the west across the magnetic low, possibly coincidence or

changes in sediment accommodation due to differential subsidence linked to the heterogeneity imposed by the underlying basement rift.

Task 10: Risk Assessment Related to CO_2-EOR in Mississippian Chat Reservoir and CO_2 Sequestration in Arbuckle Aquifers

Subtask 10.1. Model CO_2 plume for 100, 1000, and 5000 yrs after injection stops
Subtask 10.2. Model plume attenuation during and after injection
Subtask 10.3. Model effects of natural aquifer flow on CO_2 plume
Subtask 10.4. Estimate time frame for free phase CO_2 to become negligible
Subtask 10.5. Model effectiveness of cap rocks to contain leakage
Subtask 10.6. Leakage modeling through abandoned wells
Subtask 10.7. Model worst-case CO_2 leakage scenario
Subtask 10.8. Estimate surface environmental effects due to leakage

Leakage and risk have also been addressed by comparing pressures and fluid levels in the Arbuckle with the overlying freshwater aquifers. The distance separating the Arbuckle and from the shallower zones that increase to the west through Kansas and the near constancy of potentiometric surface of the Arbuckle saline aquifer provide a cushion for injection in the Arbuckle. A simplified north-south cross section scaled in feet shows the separation in feet from the shallow freshwater aquifer package (blue) and the Arbuckle (gray) (**Figure 13**).

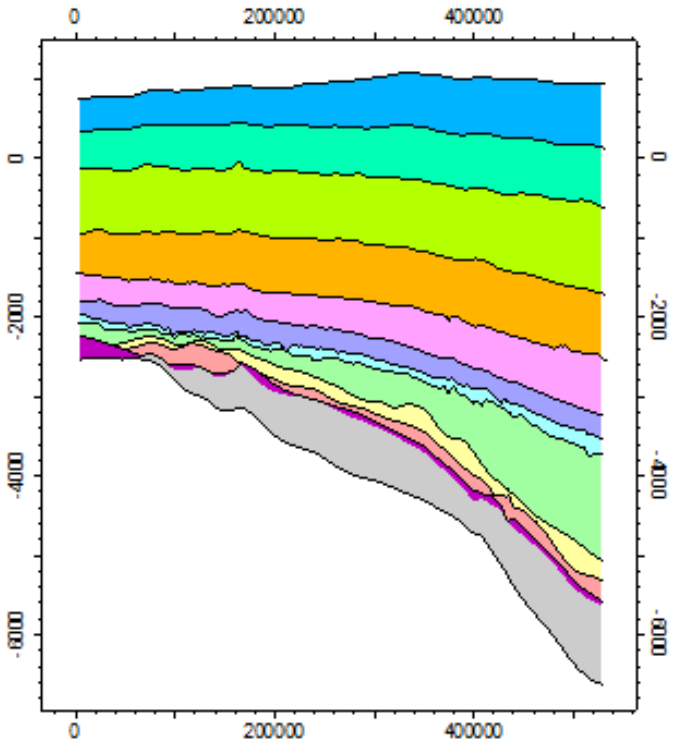


Figure 13. North to south structural cross section illustrating distance between base of near surface aquifers (blue) and the top of the Arbuckle (gray). Scale is in feet.

The confining layers between the shallow freshwater aquifers and the Arbuckle are many and are thick and are comprised of both shales and evaporites (**Figure 14, illustrating the Wellington KGS #1-32**).

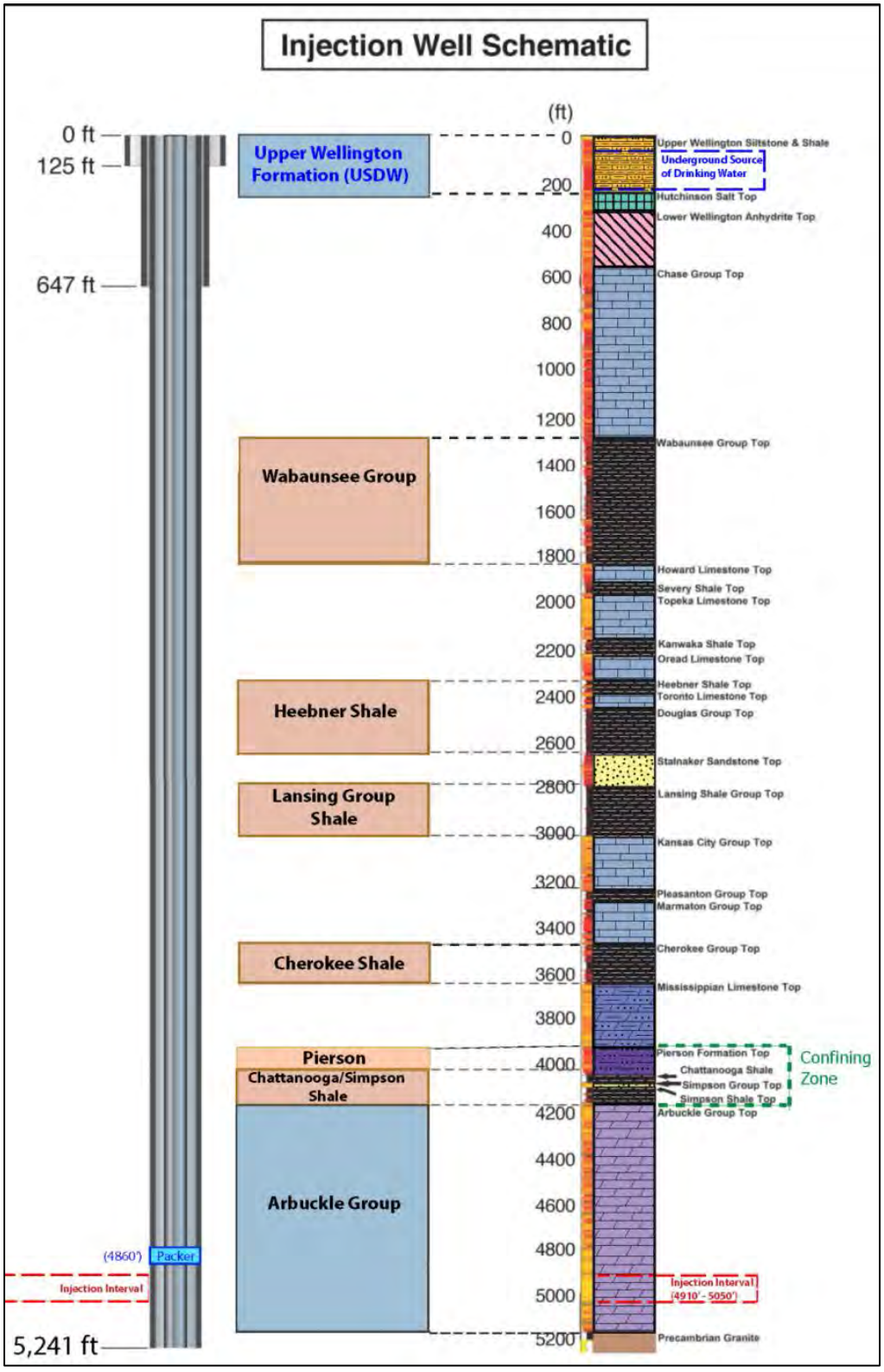


Figure 14. Large degree of hydraulic confinement between Arbuckle and freshwater aquifers. The intervals show no hydraulic connection in central and western Kansas encompassing the area of the regional CO2 assessment.

The following figures illustrate the basic hydrologic framework of the shallow aquifers and the Arbuckle and comparisons between (**Figures 15-25).**

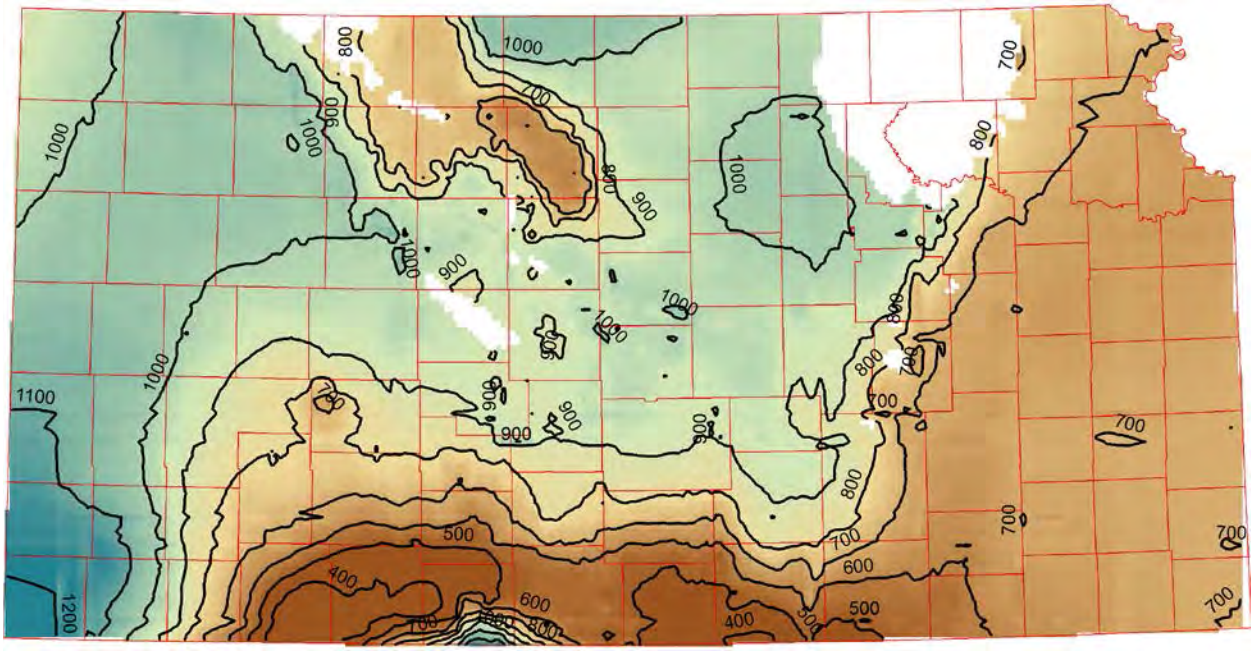


Figure 15. *In situ* groundwater levels for the Arbuckle (ft, msl). In-situ water levels are lower by about 600 ft in SW Kansas due to heavier brines.

Salinity is high in the brines within the Arbuckle in southern Kansas, exceeding 100,000 TDS (Figure 16). The higher brine concentrations closely follow depth of the Arbuckle.

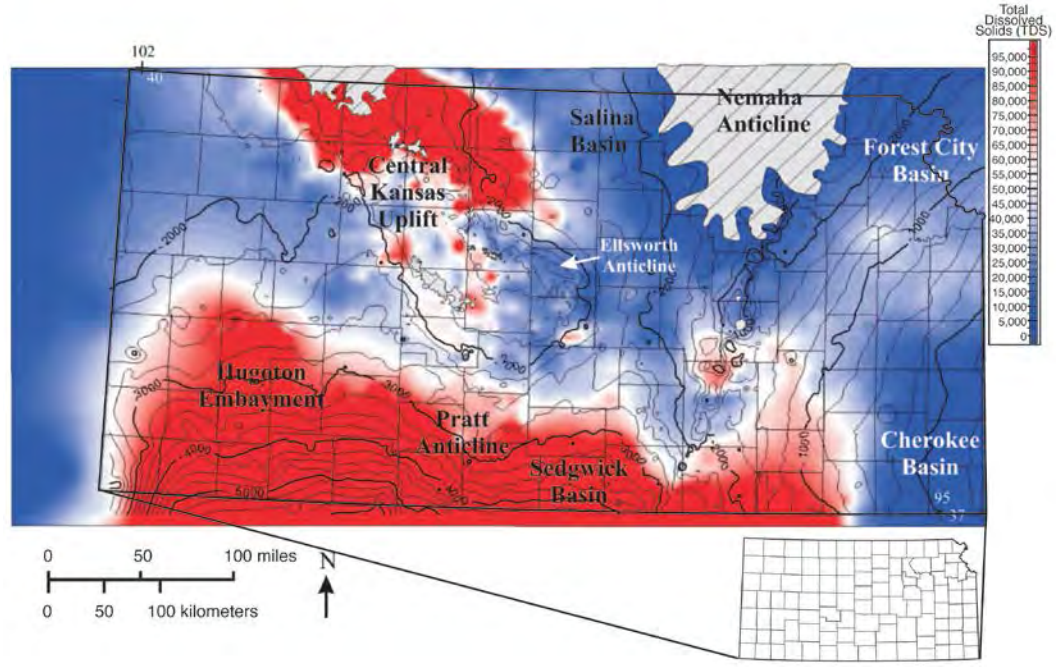


Figure 16. Total Dissolved Solids > 100,000 ppm in SW Kansas.

The equivalent freshwater head of the Arbuckle (Figure 17) removes the effects of the variable salinity the brine and shows very low gradient elevation sloping from west to east. The steepest gradient is there the Arbuckle crosses is and partly truncated by the Nemaha Uplift running NE-ward through the eastern half of Kansas.

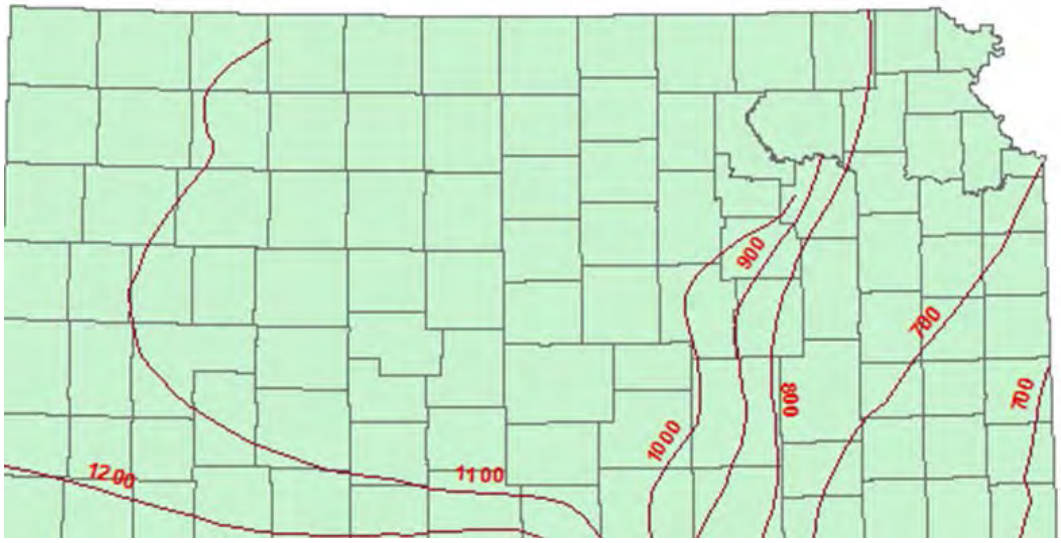


Figure 17. Potentiometric surface of Arbuckle. Merging of two regional flow fields (Rocky Mountains & Anadarko Basin). Groundwater flow across state takes approximately ¼ to ½ million years.

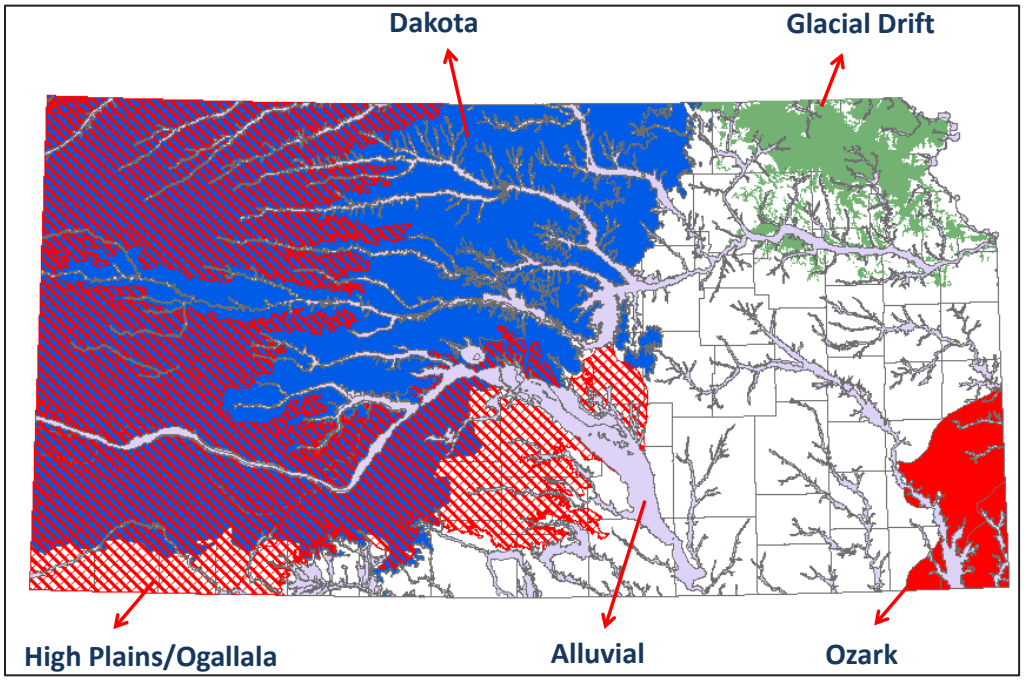


Figure 18. Spatial distribution of the shallow freshwater aquifers in Kansas.

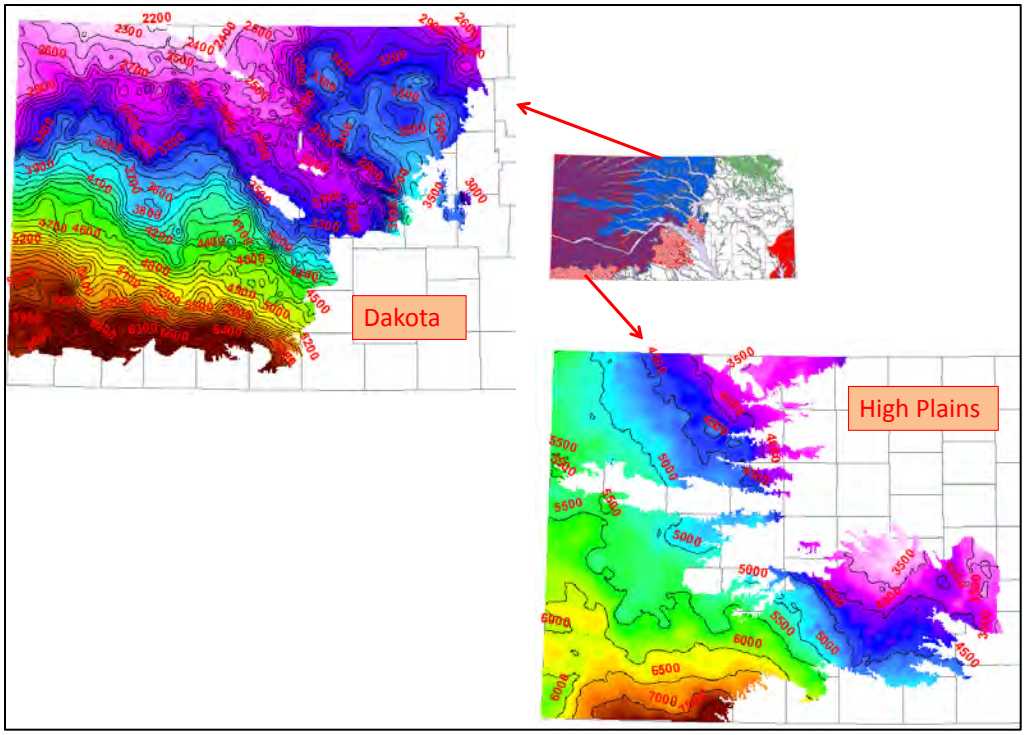


Figure 19. Vertical separation (ft) between Arbuckle and freshwater aquifers. Vertical distances of the top of Arbuckle to the Dakota and High Plains aquifers ranges from 2200 ft to over 6500 ft.

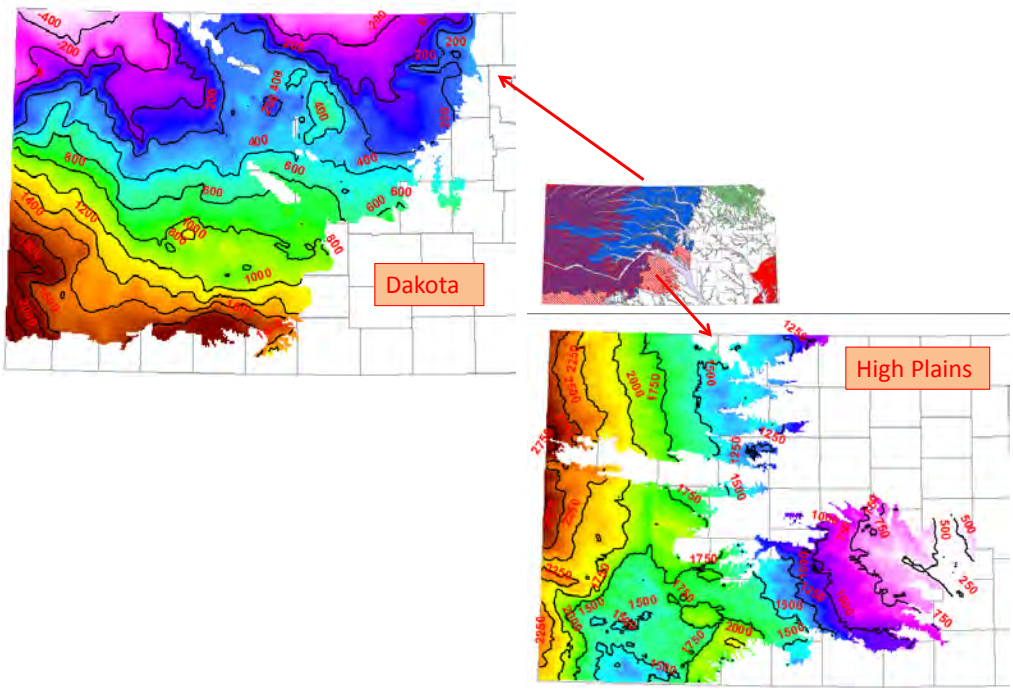


Figure 20. Head difference (in feet) between water levels in Arbuckle and base of freshwater aquifers range from a negative 400 ft (Arbuckle above the shallow zones) in northern Kansas to over 2000 ft in southwestern Kansas.

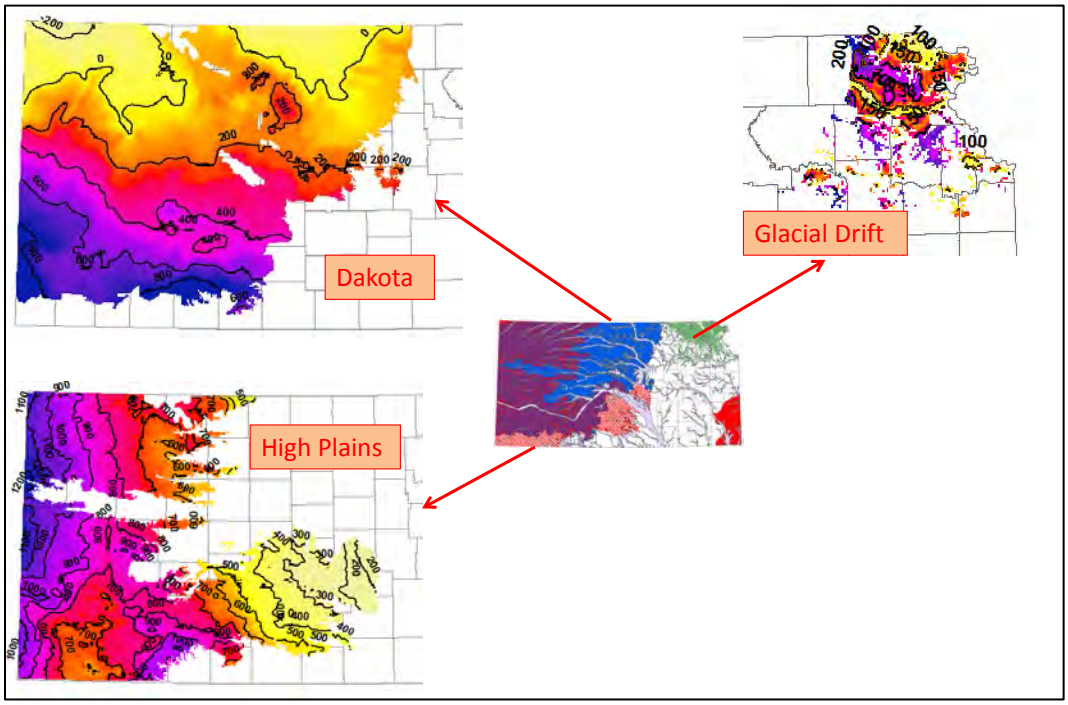


Figure 21. Required increase in pore pressure (psi) for migration of brines from Arbuckle into freshwater aquifers ranges from a negative 200 ft in northwest Kansas to over 700 ft in southwest Kansas.

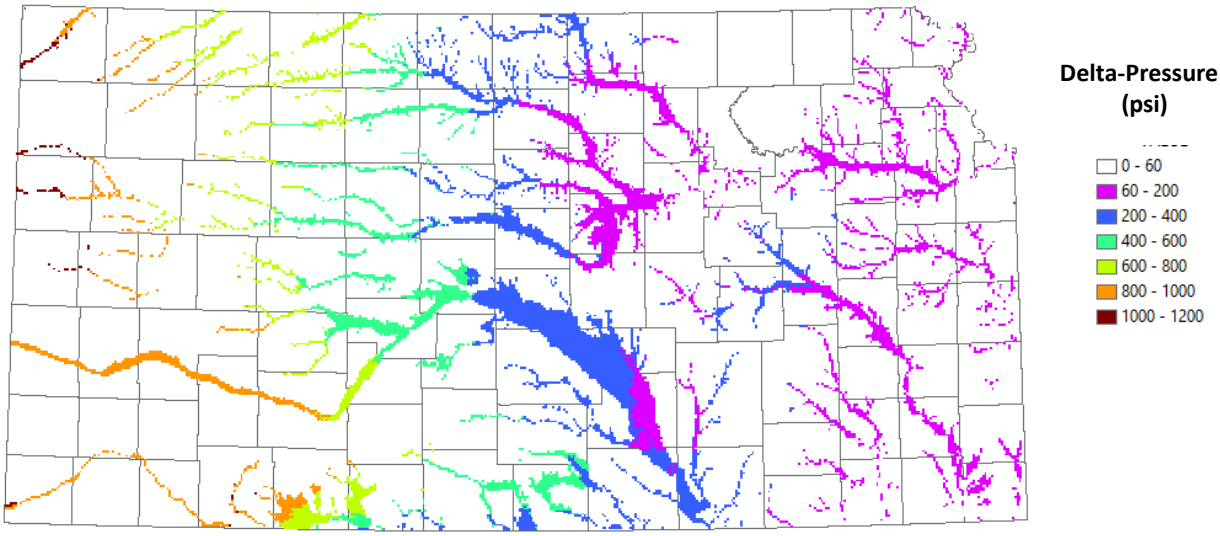


Figure 22. Required increase in pore pressure for migration of brines from Arbuckle into alluvial aquifers ranges from the 60 to 200 ft range in eastern Kansas, east of the Nemaha Uplift to over 1000 ft in far western Kansas.

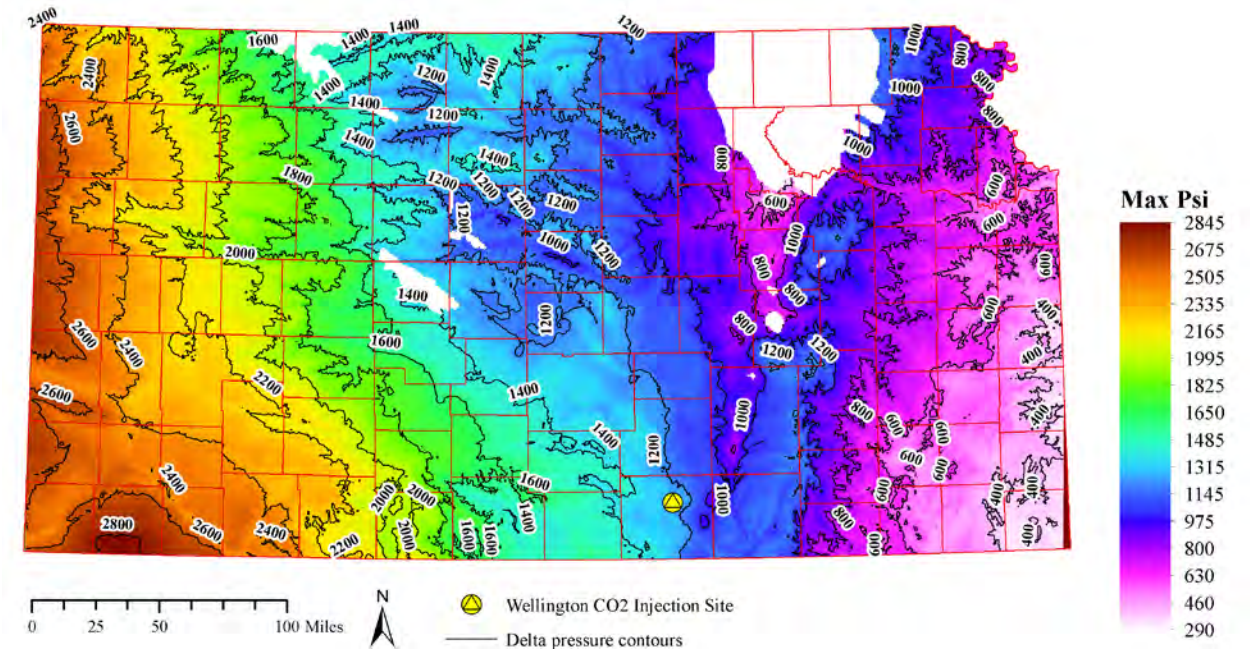


Figure 23. Maximum allowable increase in pore pressure (psi) to prevent fractures. fracture gradient in Kansas ~ 0.75 psi/ft. Values range from 400 ft in southeastern Kansas to over 2800 ft in southwestern Kansas.

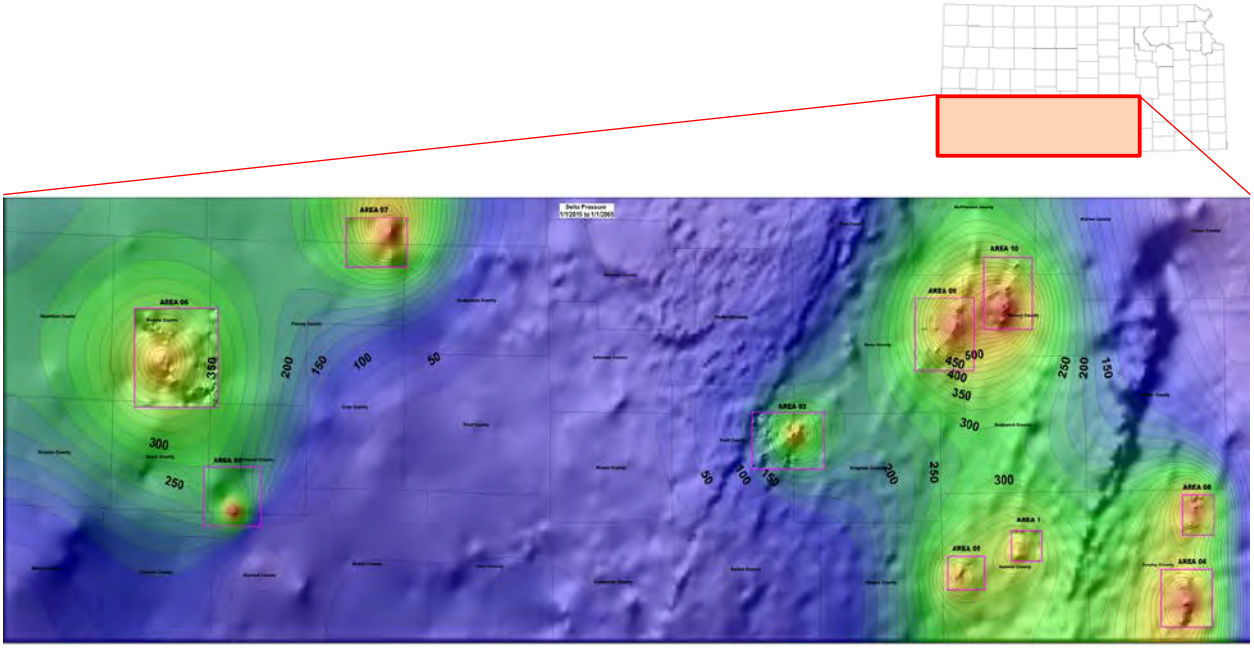


Figure 24. Simulated increase in pore pressures with commercial scale CO2 injection at 10 sites in southern Kansas over a 50 year period. Increase in pressure (psi) range from 400 psi to over nearly 600 psi. Pressures rapidly decrease after injection ceases.

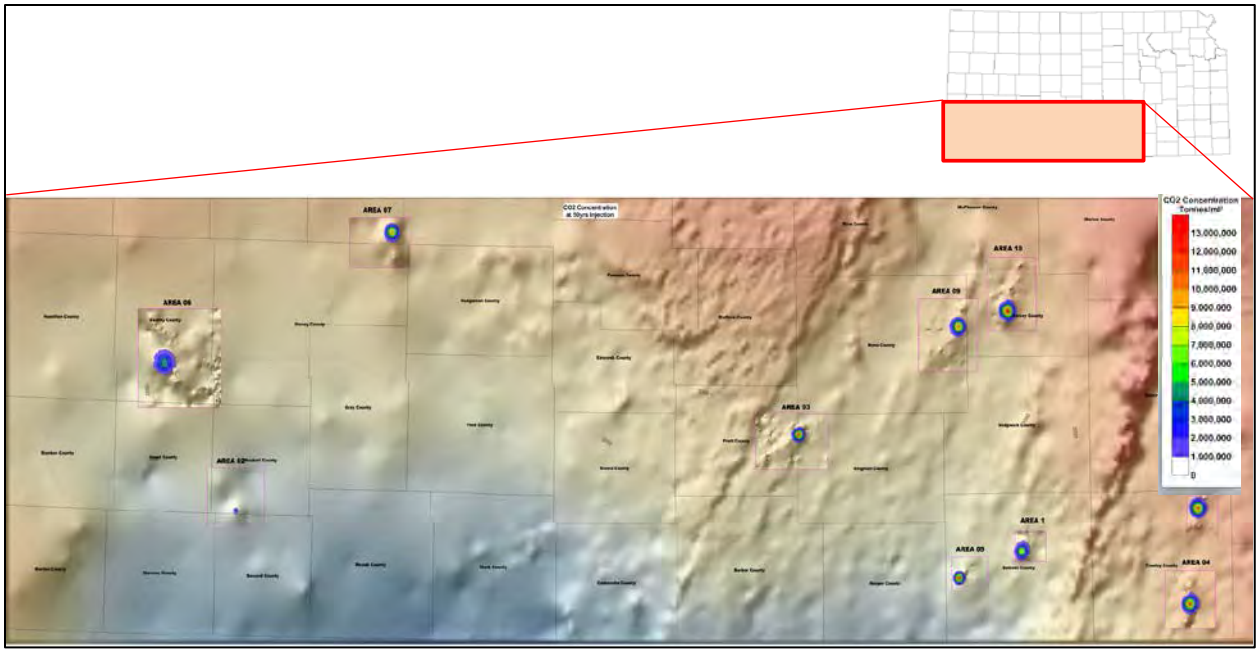


Figure 25. Simulated extent of the CO2 plume using CO2 concentration in tonnes/km2 at end of 50 years of commercial scale injection at the 10 modeling sites.

Conclusions

The saline Arbuckle aquifer has large capacity to store anthropogenic CO2 emission from Kansas and surrounding states for many decades.

CO2 injection however will cause elevated pore pressures.

Pressure constraint maps have been prepared to guide in developing an optimal state wide plan for commercial scale injection of CO2.

Task 11: Produced Water and Wellbore Management Plans

Subtask 11.1. Identify at-risk wells in Wellington Field

Subtask 11.2. Outline Best Practices and well recompletion plans for at-risk wells

Subtask 11.3. Outline Best practices and well completion plans for new CO_2 injector wells

Subtask 11.4. Summarize practices in place for disposal of produced water

Task 12. Regional CO2 Sequestration Potential in OPAS - 17 Counties

Subtask 12.1. Map reservoir compartments in Arbuckle aquifer in a regional context

Subtask 12.3. Generalized estimates of miscible CO_2-EOR in similar and larger oil fields in approximately 17 counties

The combined CO2 sequestration from the four fields studied in western Kansas is + million tonnes (**Table 1**).

Reservoir	Total PV RB	Total HCPV RB	Oil Res BBL RB	Water Res BBL RB	Gas Res BBL RB
Cutter Morrow (1/1/1961)	25,719,145	18,730,543	15,456,000	69,789,100	3,275,690
Pleasant Prairie (1/1/2012)	22,680,000	9,069,100	9,051,400	13,611,000	17,741
Eubank (6/1/2013)	62,751,000	22,662,000	22,131,000	40,089,000	530,650
Shuck (1/1/2013)	44,688,513	17,310,419	17,139,000	27,380,000	173,231
Total	155,838,658	67,772,062	63,777,400	150,869,100	3,997,312
CO2 FVF (RB/MCF)	0.45	0.45	0.45	0.45	0.45
CO2 MCF/Tonne	19.1895	19.1895	19.1895	19.1895	19.1895
PV in CO2 Tonne	18,046,751	7,848,281	7,385,683	17,471,256	462,905
Efficiency for Example	0.05	0.6	0.6	0.2	0.8
Potential Sequester Tonnes	902,338	4,708,968	4,431,410	3,494,251	370,324
			SUM = 8,295,985 tonnes		

Table 1. Total fluid recovery and efficiencies of the four fields studied in western Kansas.

Subtask 12.4. Estimate regional CO_2 sequestration potential of OPAS

(Milestone/Subtask 12.4)

(1) **Estimate of CO2 sequestration in the Arbuckle using total pore volume in the model and formation volume factor at 2000 psi--** We have completed our regional analysis of the Arbuckle Group saline aquifer in south-central Kansas to estimate its potential for CO_2 sequestration. This analysis was performed using data collected from wireline logs, core, seismic surveys, and gravity/magnetics data throughout the 25,000 mi^2 study area, in addition to two characterization wells that were drilled to basement and cored for testing. Information acquired from all core and fluid analyses, petrophysical data, and tests were used to establish a regional correlation framework to assess flow units and stratigraphic subdivisions across the study area. Key properties were used as input parameters to build refined geomodels that could simulate commercial scale injection in 10 sites in southern Kansas. Results from the fine-grid simulations were extrapolated to the entire study region to obtain a more accurate estimate of regional CO_2 sequestration potential. This "Mega Model" simulation contained more than 2 MM coarse and fine grid cells, and provided a realistic measure of capacity beyond a

volumetric-based storage assessment. Additional details will be provided in the final report. An overview of these findings is provided below:

The total pore volume of the MegaModel is 37.34 x 10^{12} ft^3 or 6.65 x 10^{12} RB

Assumptions:
1. CO_2 FVF at 2000+ psi is approximately 0.45 RB/mcf
2. CO_2 Density is 0.1167 lb/ft^3, or 19.19 mcf/tonne
3. P90 Efficiency is 0.4%, P10 Efficiency is 5.0%
   Assuming 100% efficiency (where 100% of the pore volume is saturated with CO_2), the CO_2 volume would be 155.9 billion tonnes.
   At 0.4% efficiency, the CO_2 volume would be **0.62 billion tonnes**.
   At 5% efficiency, the CO_2 volume would be **7.8 billion tonnes**.

Based on the properties of the Arbuckle reservoir, a 5% efficiency factor is appropriate for CO_2 storage. Thus, the final characterization results indicate that the regional storage capacity of the Arbuckle saline aquifer in south central Kansas is approximately **7.8 billion tonnes of CO_2**.

(2) CO2 sequestration in the Arbuckle estimated using effective (net porous and permeable) pore space and the methodology of DOE-NETL National Carbon Sequestration Atlas III.

A new and final P10 estimate of sequestration capacity of 5.3 billion tonnes using the DOE-NETL methodology is similar to that obtained in (1) described above. The DOE-NETL equation used, $G_{CO2} = A_t\ h_g\ \emptyset_{tot}\ \rho E_{saline}$, includes the Esaline factor that ranges between 0.40 and 5.5 percent over the 10th to 90th percent probability range. The P90 value using the DOE-NETL methodology is 60,619,189,540 metric tonnes.

(3) **Estimating CO2 sequestration the Arbuckle using MegaModel with megainjection wells.**

The MegaModel has been completed and a written report on the study and a transfer of the CMG model will be completed as the last step. Pressure at each well is set 40% higher than original pressure to stay within a conservative breakdown pressure of about 1.37 times initial pressure. Model results will be included in the final report.

The following figures summarize the MegaModel grid and provide examples of a two area CO2 plumes. (**Figures 26-29**).

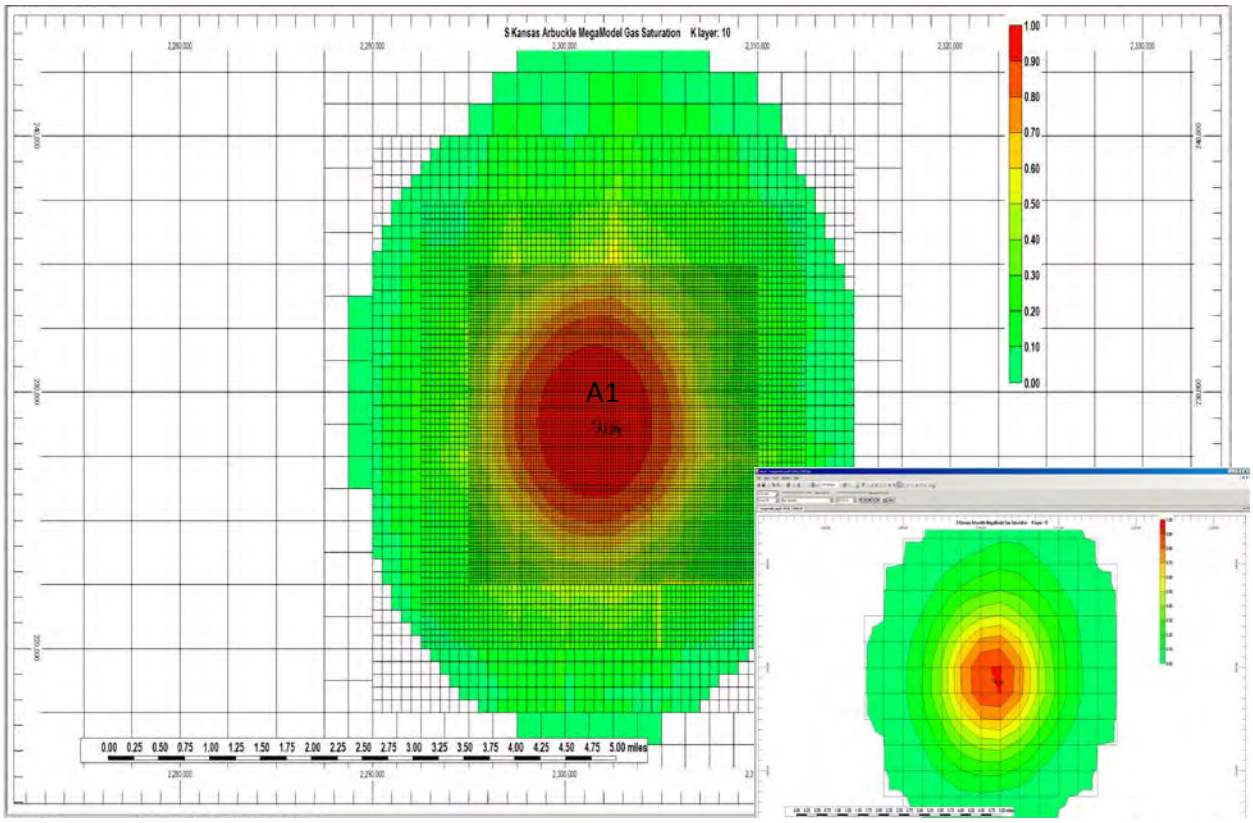


Figure 26. Area #1 Gas saturation.

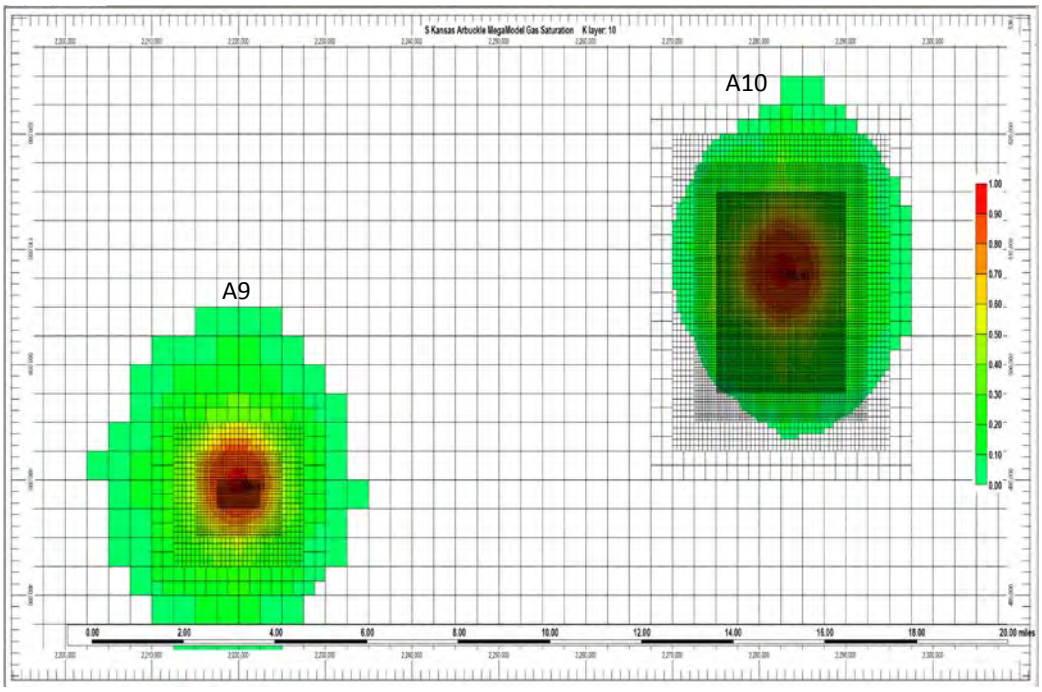


Figure 27. Size of CO2 plume conveyed by gas saturation for Areas 9 and 10.

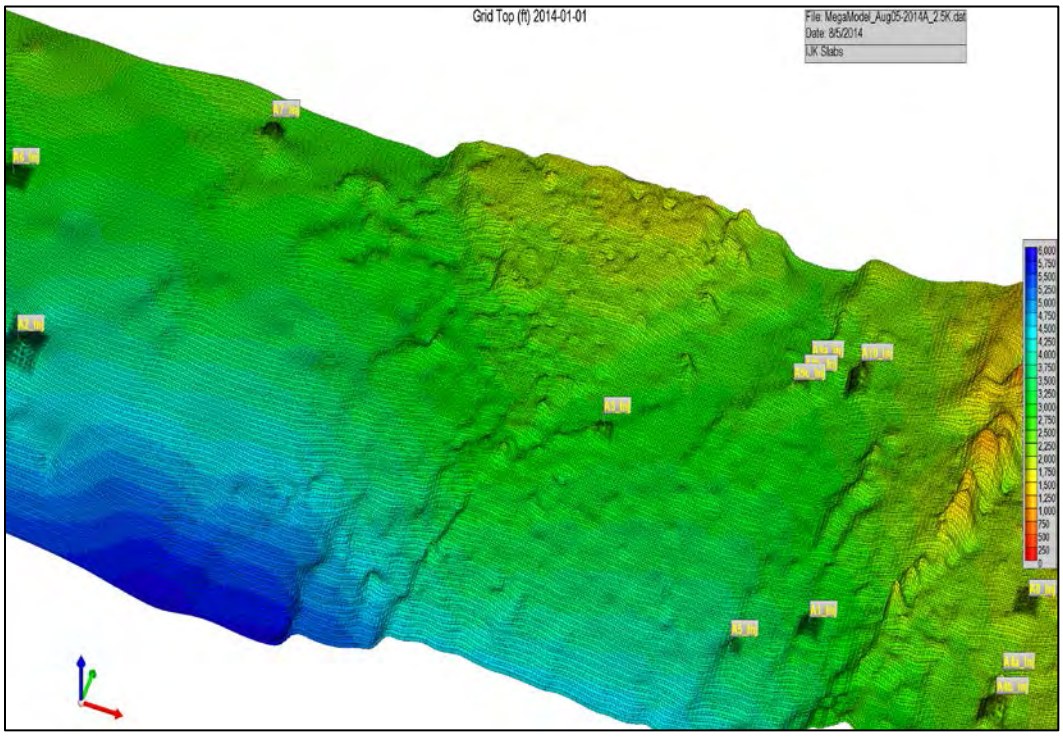


Figure 28. MegaModel showing local refinement with regional coarse grid of 2500 ft x 2500 ft used for the large simulation.

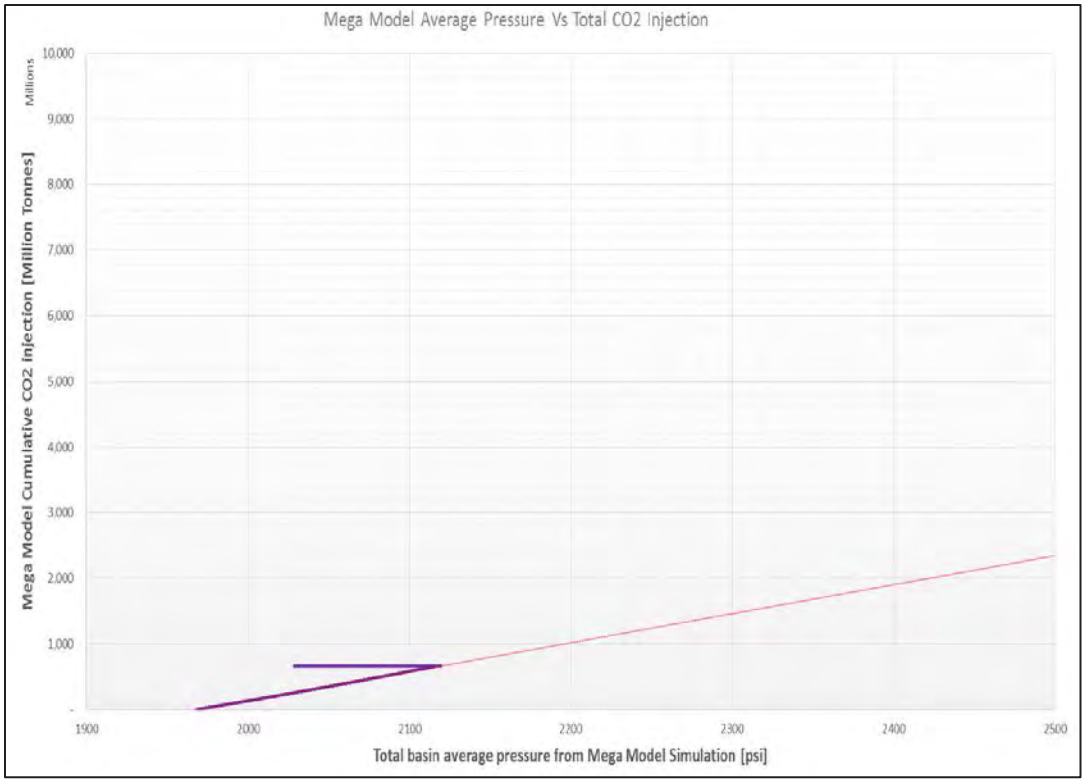


Figure 29. Simultaneous injection at wells per 200 mi2 and associated increase in total basin average pressure from MegaModel simulation (psi).

Task 13: Regional Source-Sink Relationships in approximately 17 Counties in South-Central Kansas

Subtask 13.1. Map major point CO_2 sources in Kansas
Subtask 13.2. Map major CO_2 sinks in Kansas

Task 14: Technology Transfer

Subtask 14.1. Build and maintain project website with interactive access to data and analyses via graphic display and analytical web tools
Subtask 14.2. Link project web-site to relevant DOE databases
Subtask 14.3 Submit project results to peer reviewed journals for publication

Task 15: Extend Regional Study of Ozark Plateau Aquifer System (OPAS) to the Western Border of Kansas – "Western Annex" and extend the type log database to include the whole state of Kansas to address fluid flow under commercial scale CO2 sequestration.

Subtask 15.1. Extend regional study by evaluating CO_2 sequestration potential in 5000 mi^2 area west of the existing 17+ county area and extend the type log database to the whole state of Kansas to address fluid flow under commercial scale CO_2 sequestration.

Subtask 15.2. Create consortium of companies

Subtask 15.3. Encourage development of business plan to sequester emitted CO_2

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

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

Subtask 16.2. Analysis of KGS's gravity and magnetic data

Subtask 16.3. Remote sensing analysis

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

Subtask 17.1. Collect existing seismic, geologic, and engineering data – Chester/Morrow fields
Subtask 17.2. Select Chester/Morrow field to acquire new data

Subtask 17.3. Collect new multicomponent 3D seismic survey
Subtask 17.4. Process multi-component 3D seismic survey
Subtask 17.5. Develop initial geomodel for the selected Chester/Morrow field

Subtask 17.6. Select location for Test Borehole #3
Subtask 17.7. Complete permitting requirements for Test Borehole #3
Subtask 17.8. Drill, retrieve core, log, and run DST – Test Borehole #3
Subtask 17.9. Openhole Wireline Logging – Test Borehole #3
Subtask 17.10. Wellbore Completion – Test Borehole #3
Subtask 17.11. Analyze wireline log - Test Borehole #3
Subtask 17.12. Test and sample fluids (water) from select intervals – Test Borehole #3
Subtask 17.13. Analyze Arbuckle core from Test Borehole #3
Subtask 17.14. Analyze Chester/Morrow core from Test Borehole #3
Subtask 17.15. PVT analysis of oil and water from Chester/Morrow oil reservoir
Subtask 17.16. Analyze water samples from Test Borehole #3

Task 18: Update Geomodels and Conduct Simulation Studies - Evaluate CO_2 Sequestration Potential in Arbuckle Group Saline Aquifer and by CO_2-EOR in Select Chester/Morrow Field in the Western Annex

Subtask 18.1. Update geomodels of the Chester/Morrow sands and Arbuckle Group saline aquifer in selected field

Subtask 18.2. Optimize geomodel for simulation - Flow-unit identification, fracture characterization, and upscaling

Update on Cutter seismic interpretation (draft figures contributed by Clyde Redger)

Converted shear and P-wave in Upper Morrow oil reservoir were analyzed by Clyde Redger as part of this M.S. KU thesis. He also examined the converted wave 3D seismic at Cutter Field to examine the ability to map flow units in the Arbuckle and to examine the use of impedance to map porosity of the flow units. Finally, the fast and slow shear velocities were examined to determine if there is a directional anisotropy. A series of figures provide a perspective of this work that is currently bring incorporated in Mr. Redger's thesis. **Figures 30-47** are focused on the first part of the study dealing with Upper Morrow Sandstone oil reservoir characterization.

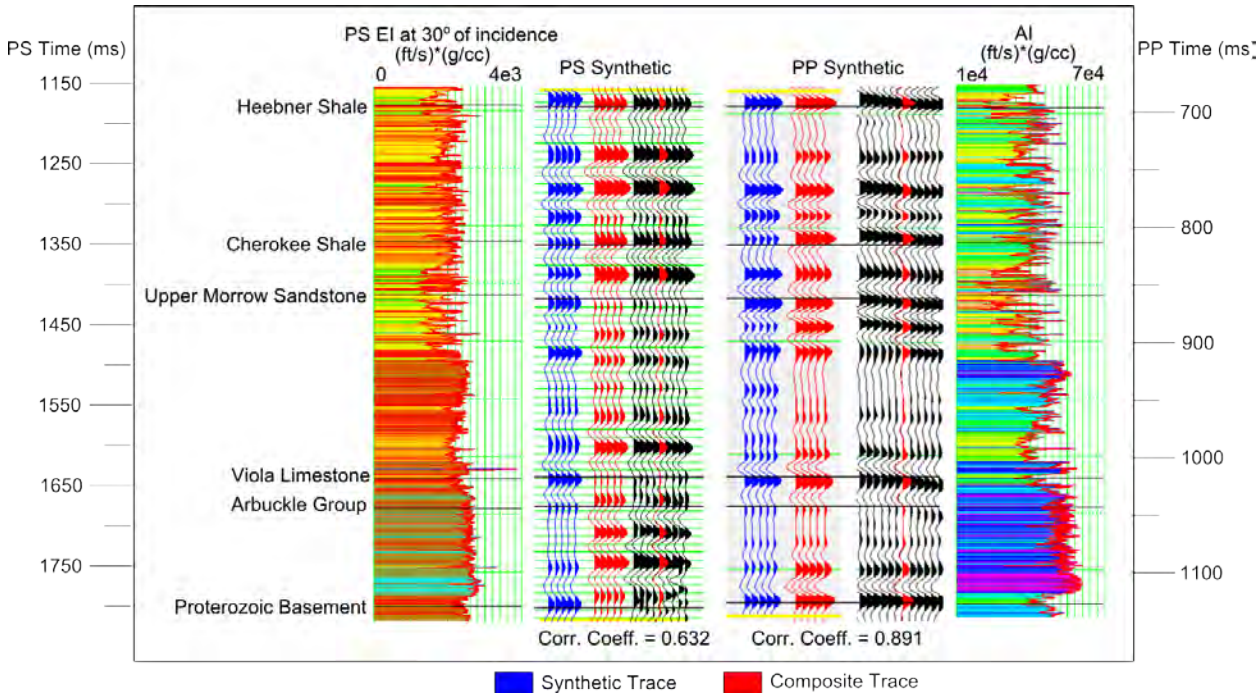


Figure 30. Synthetic seismogram for both converted shear and compression wave based on the Cutter KGS #1 spectral (Halliburton) sonic log compared to the composite trace extracted from the 3D seismic volume at the KGS #1 well location. There is a very good match for both the p- and s-wave data. Similarly, the acoustic impedance that are shown on opposite ends of the figure (left = log), (right – seismic volume) are very similar, again attesting to the quality of the correlations.

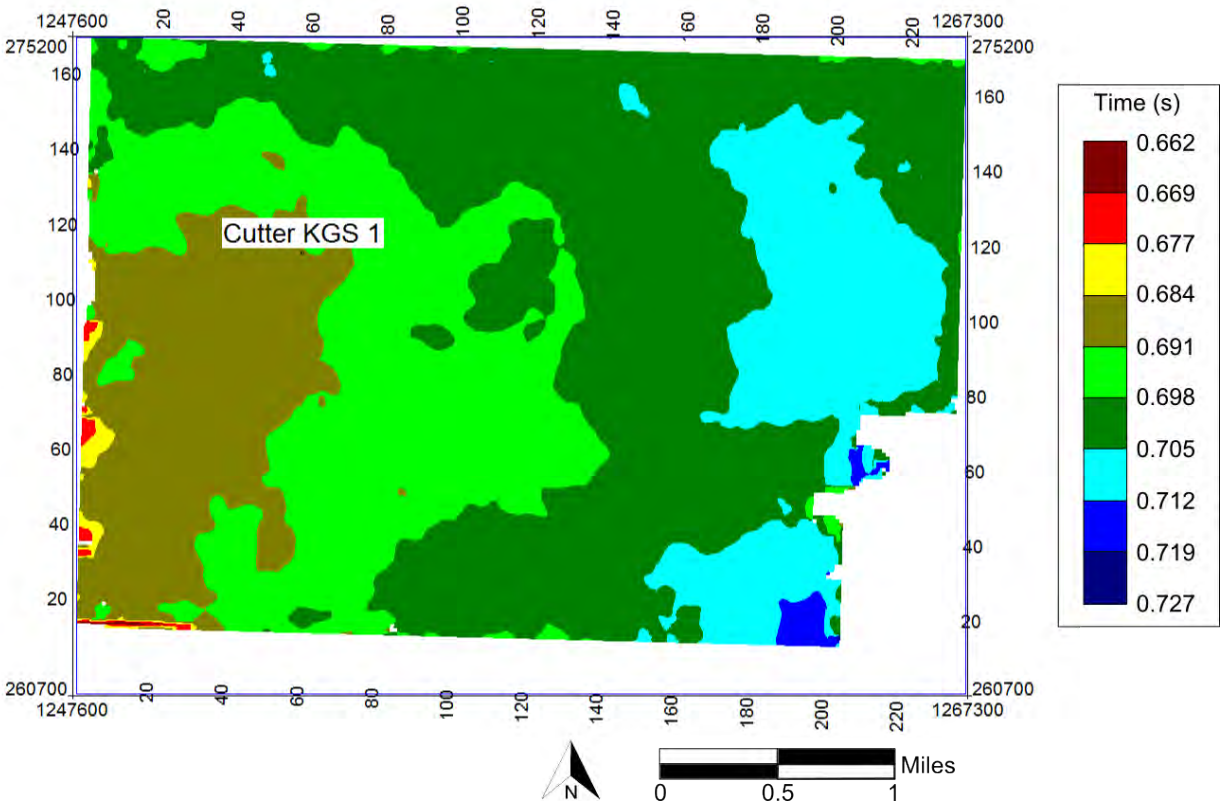


Figure 31. Time surface of the prominent marker, the Heebner Shale, well above the main reservoir, upper Morrow sandstone of Cutter Field suggesting that the location of the west side where the Cutter KGS #1 was drilled is higher.

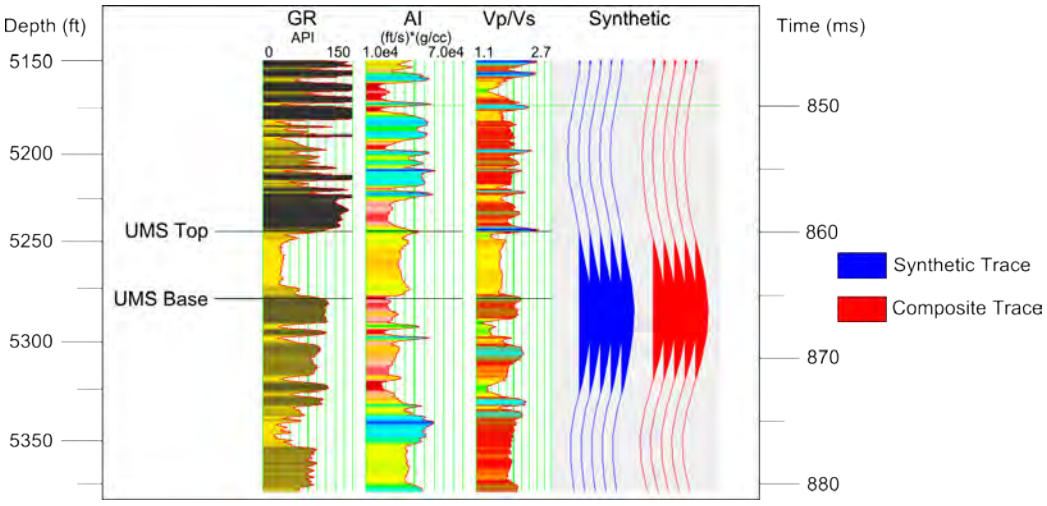


Figure 32. The closeup of the acoustic impedance Vp/Vs ratio and the synthetic waveform illustrate the resolution of the sandstone interval compared to the seismic data. Again, there is close correspondence of the log based and composite seismic trace attesting to the quality of the data.

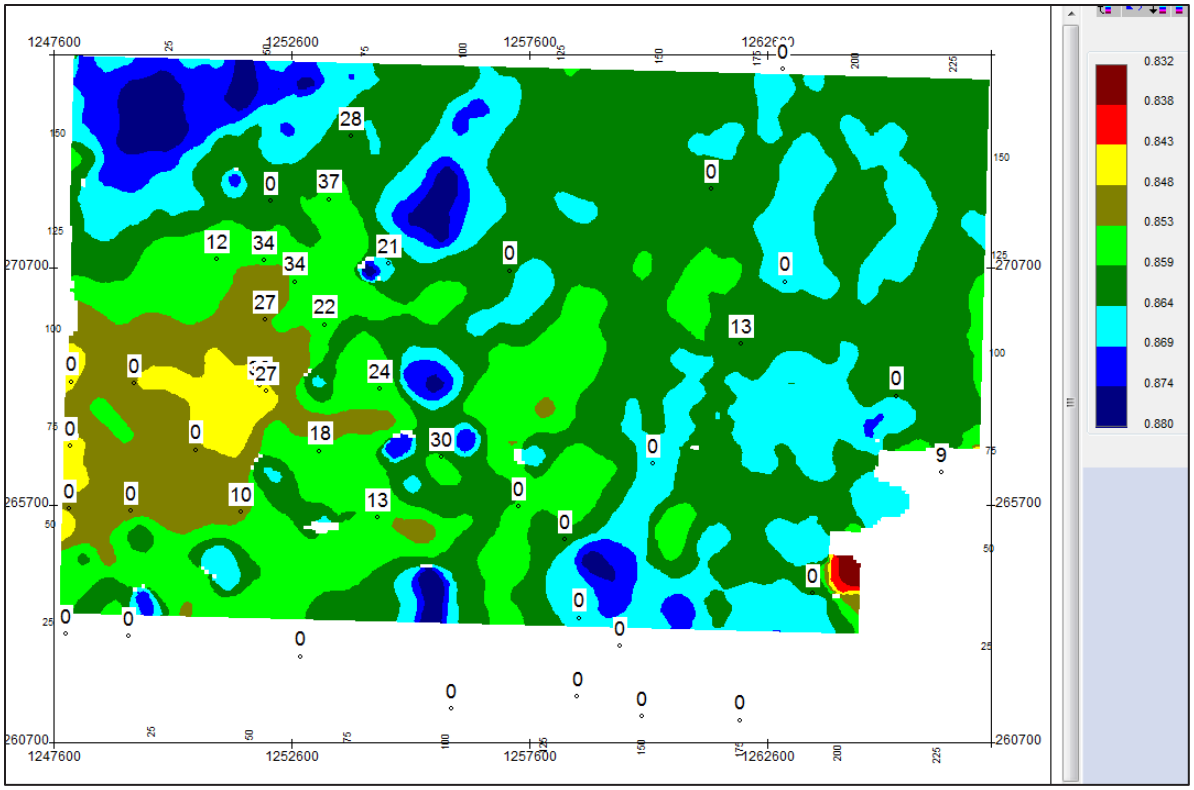


Figure 33. Upper Morrow sandstone (UMS) time structure with labels of the sand thickness from well log data.

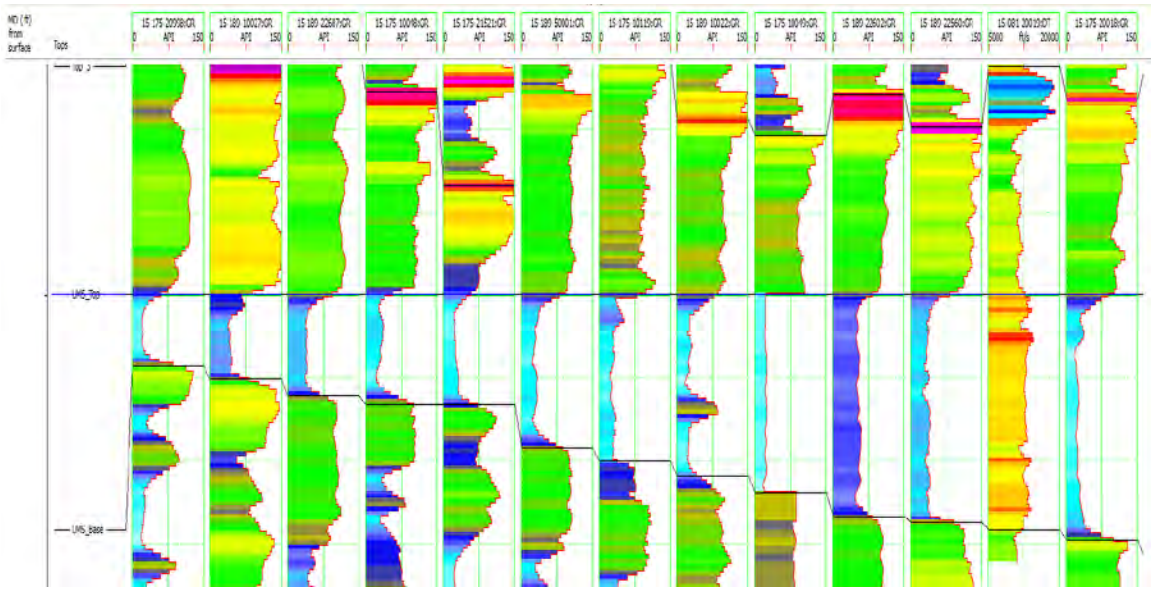


Figure 34. UMS Well Correlations using natural gamma ray from well logs, 17 wells.

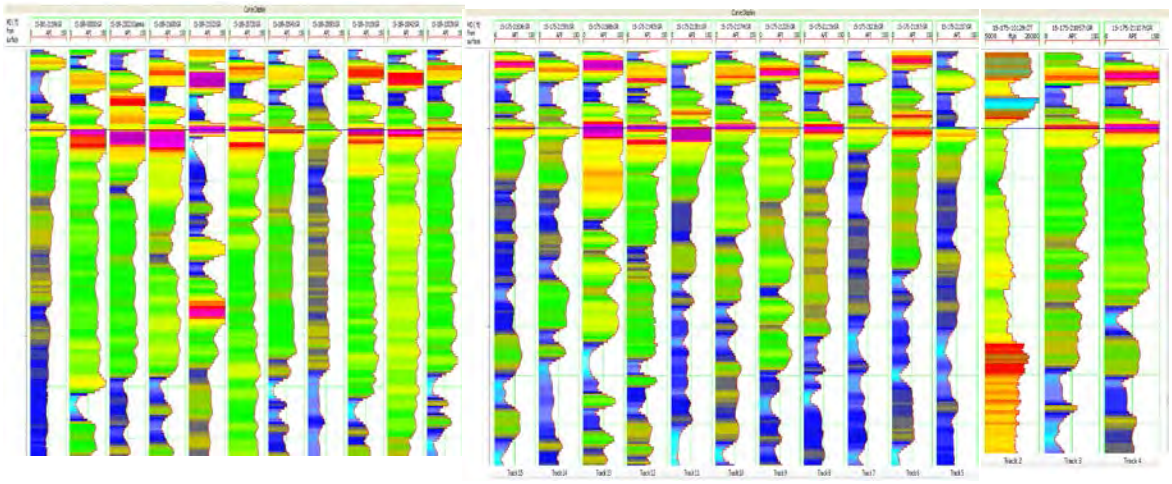


Figure 35. UMS Absent as indicated by gamma ray from well logs, 25 wells.

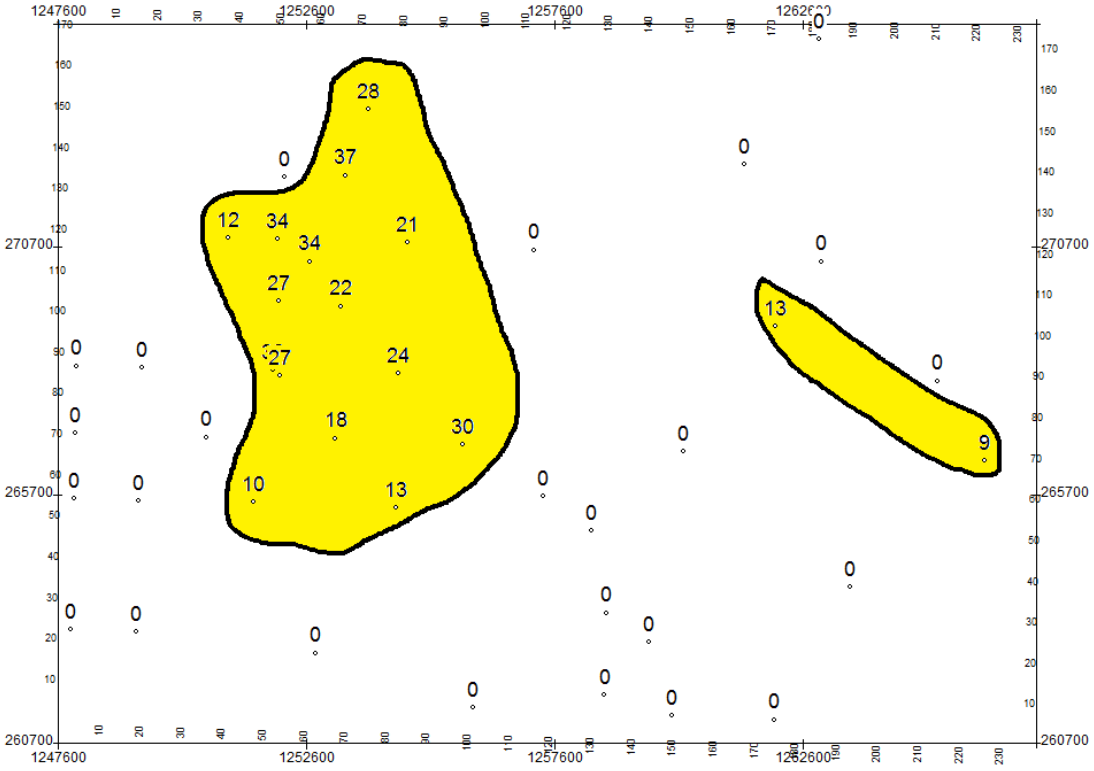


Figure 36. Thickness of UMS based on well logs.

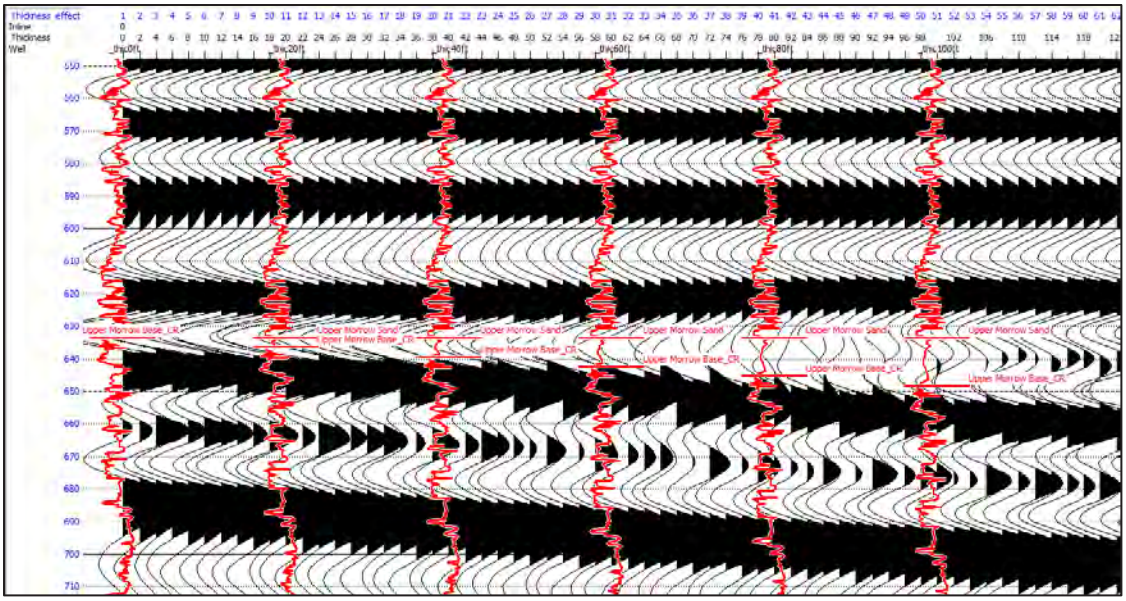


Figure 37. Hampson-Russell software solution of wedge model showing reflection response with increasing thickness of UMS.

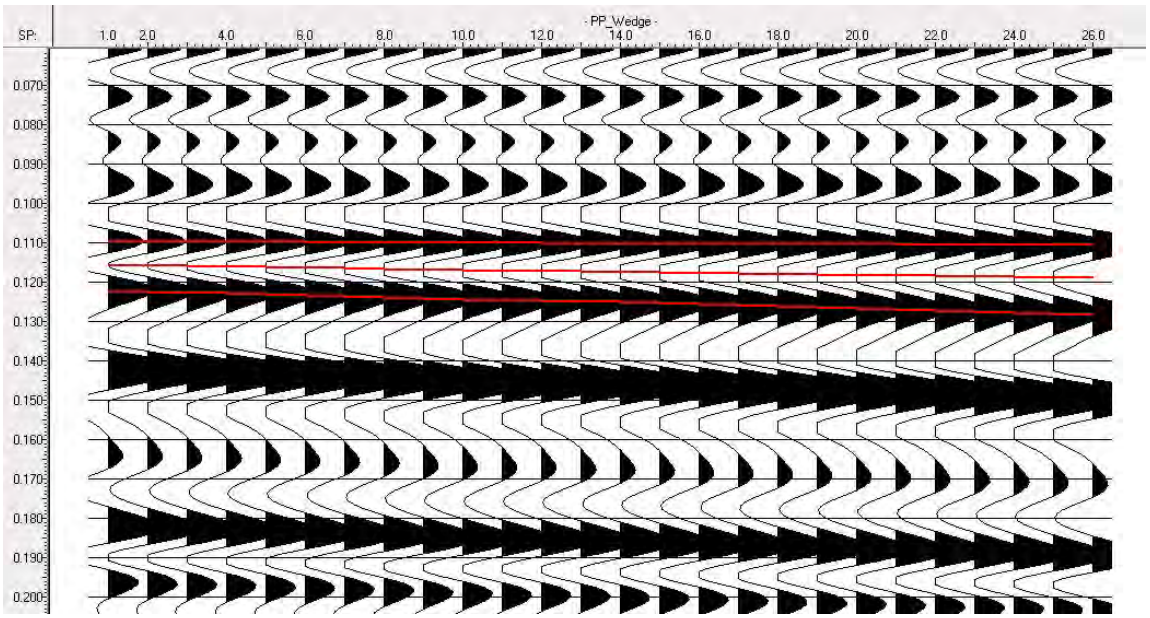


Figure 38. Observed wedge model with actual seismic traces. Changes in the amplitude are much more subdued compared to the model of Figure 37.

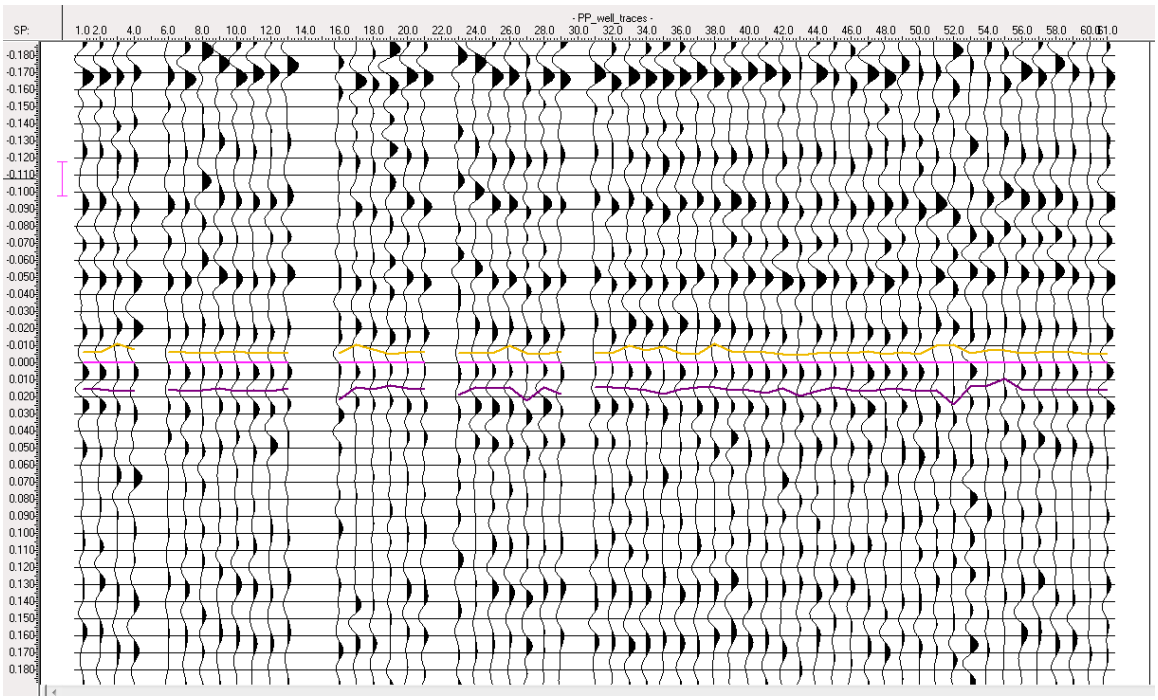


Figure 39. PP Traces extracted from well locations used for instantaneous frequency analysis.

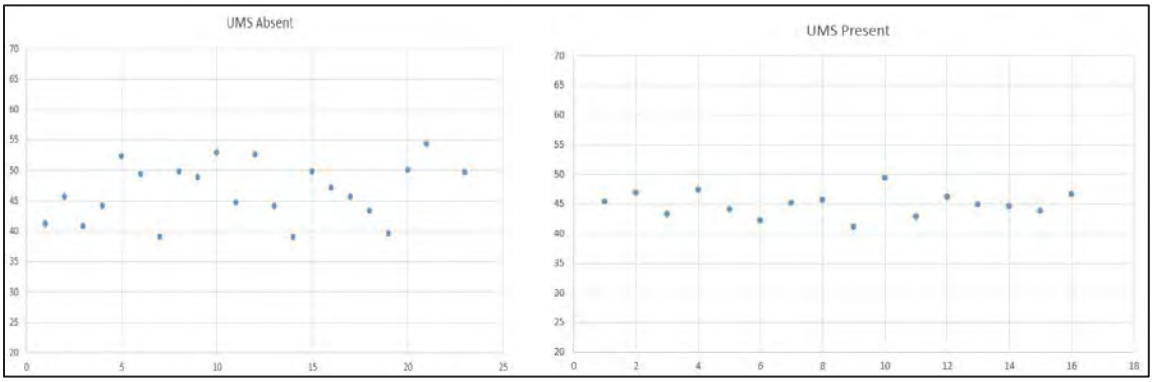


Figure 40. Instantaneous frequency values are more consistent in the presence of sand, but the mean value is essentially the same.

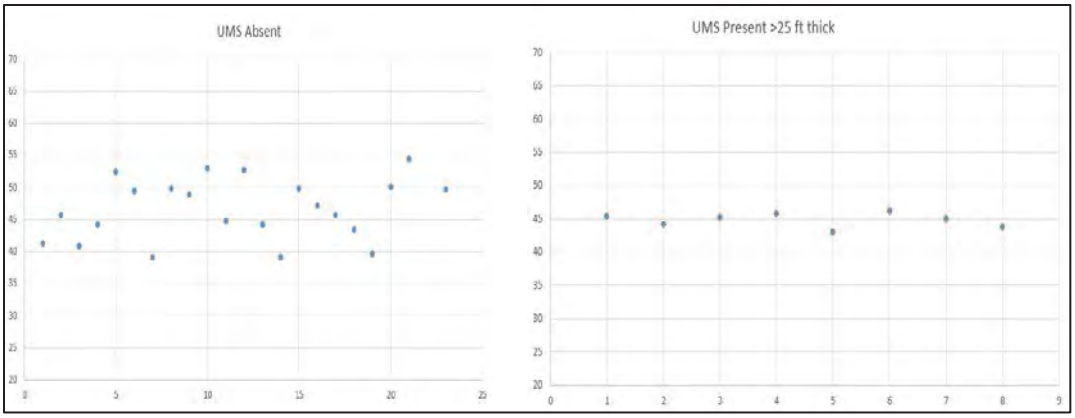


Figure 41. A comparison of instantaneous frequency at wells without sand are compared with wells that have more than 25 ft of sand. The latter has the least variability of all, which is expected.

	UMS Absent	UMS All Wells	UMS >25 ft
Average	46.5	45.0	44.8
Median	46.4	45.1	45.1
STDEV	4.8	2.1	1.1

Table 2. Instantaneous Frequency summary showing the statistics of wells with no sand, all wells with sand, and wells with sand thicker than 25 ft. Wells with the thickest sand have a lower average and median value and the standard deviation is lowest.

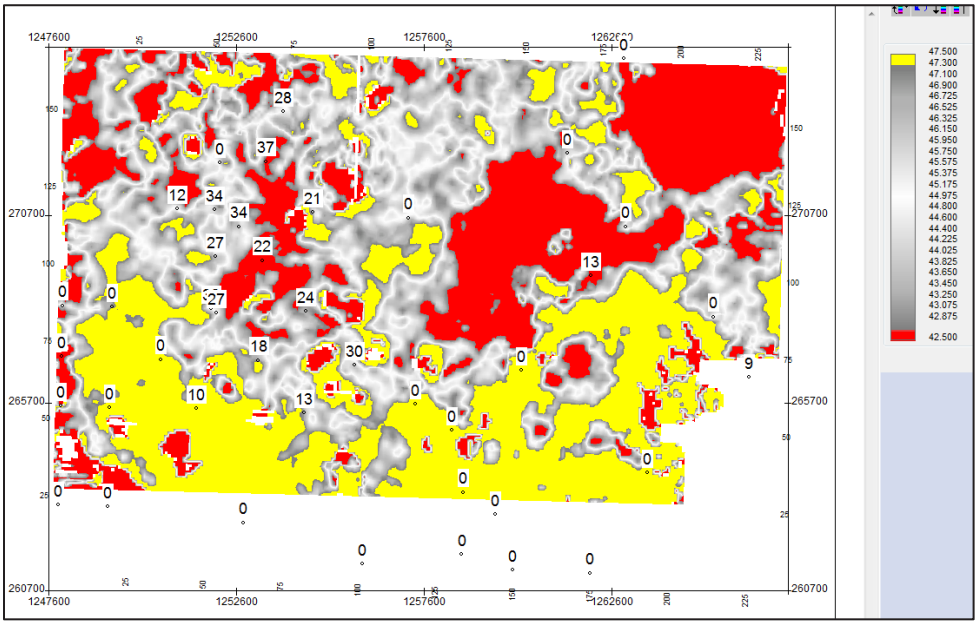


Figure 42. Map of instantaneous frequency indicating lower frequency in areas of thicker sand.

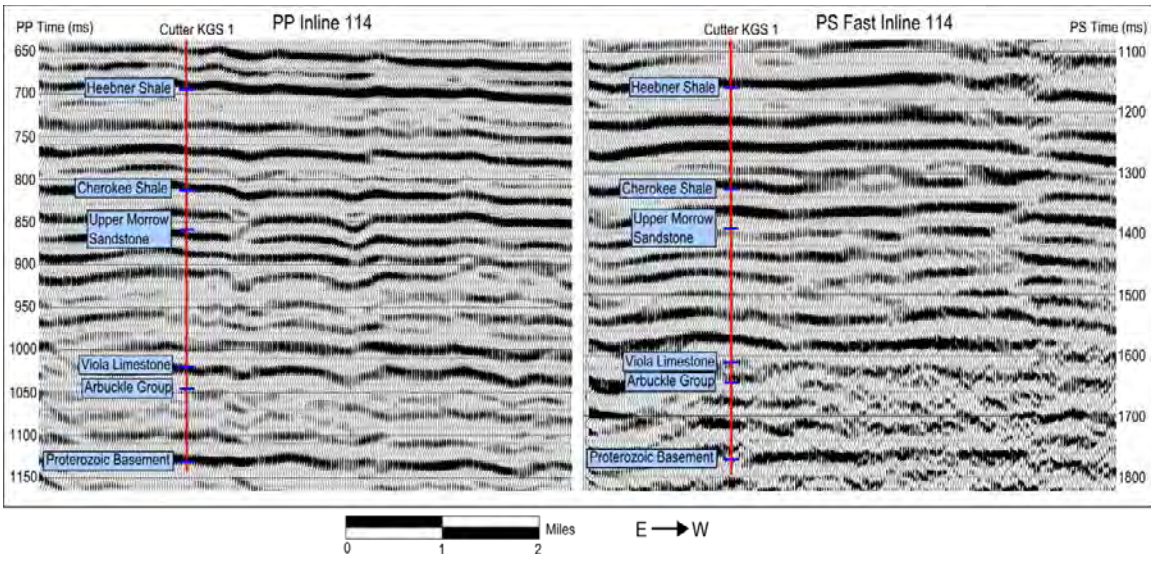


Figure 43. PP (left) and PSV (right) seismic correlation comparing data quality. Both have similar frequency content/resolution. The Viola section and below are noisier in the shear wave domain. Both PP and PSV show a good basement reflector.

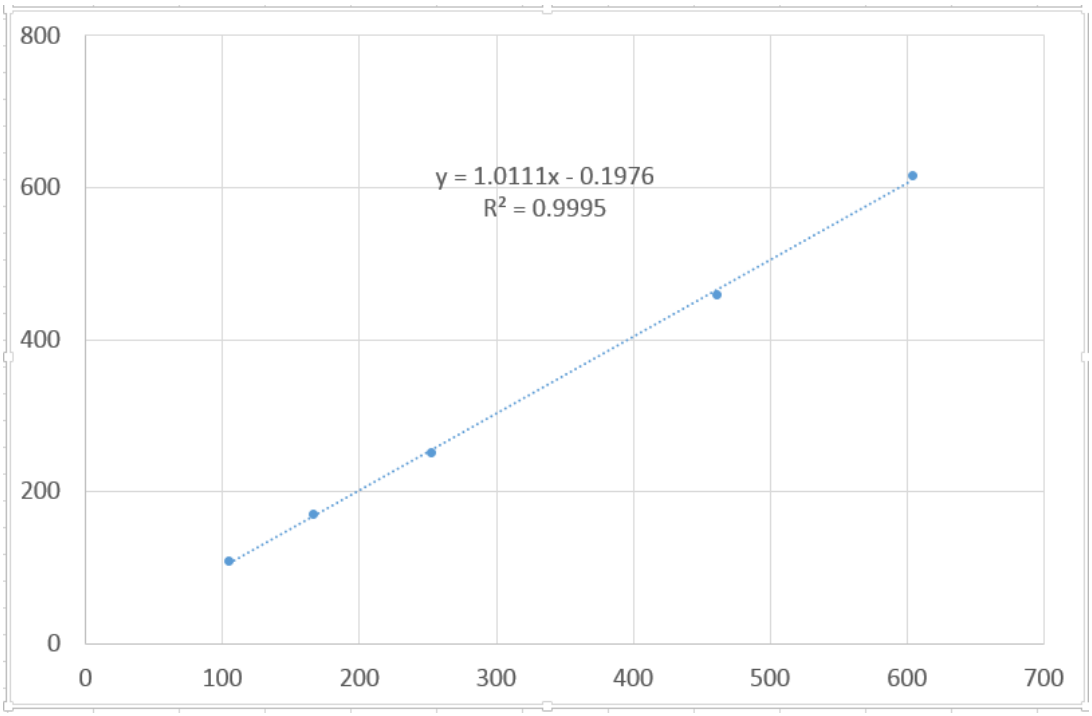


Figure 44. Observed vs estimated TWT P-SV travel times plotted against each other show and excellent correlation.

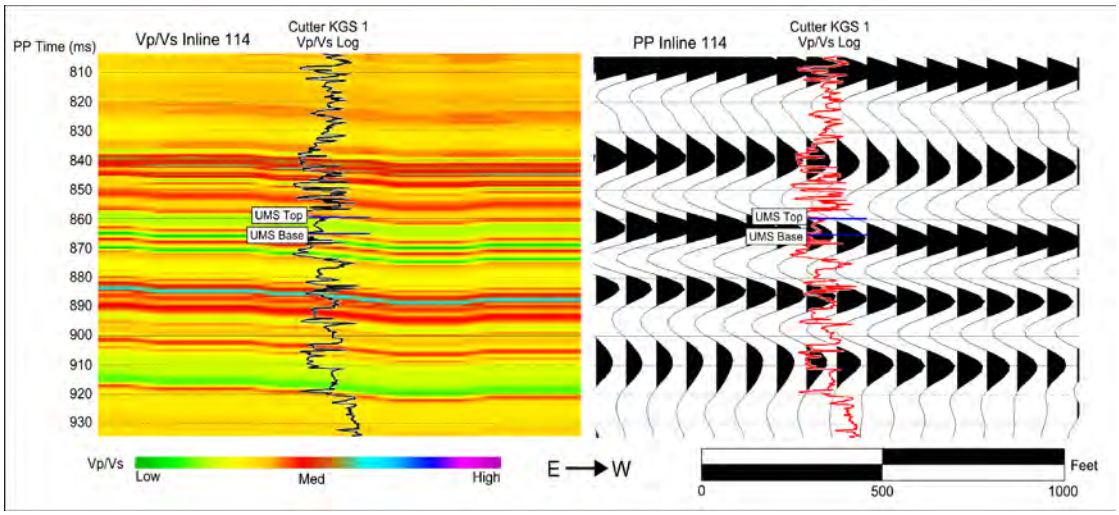


Figure 45. Vp/Vs along inline 114 profile closely compares with the Vp/Vs from the well log (left). The UMS has a low Vs/Vp ratio. On the right, the Vp/Vs log for the Cutter KGS #1 compared to the PP profile that passes through the well. The Vp/Vs profile is more highly resolved.

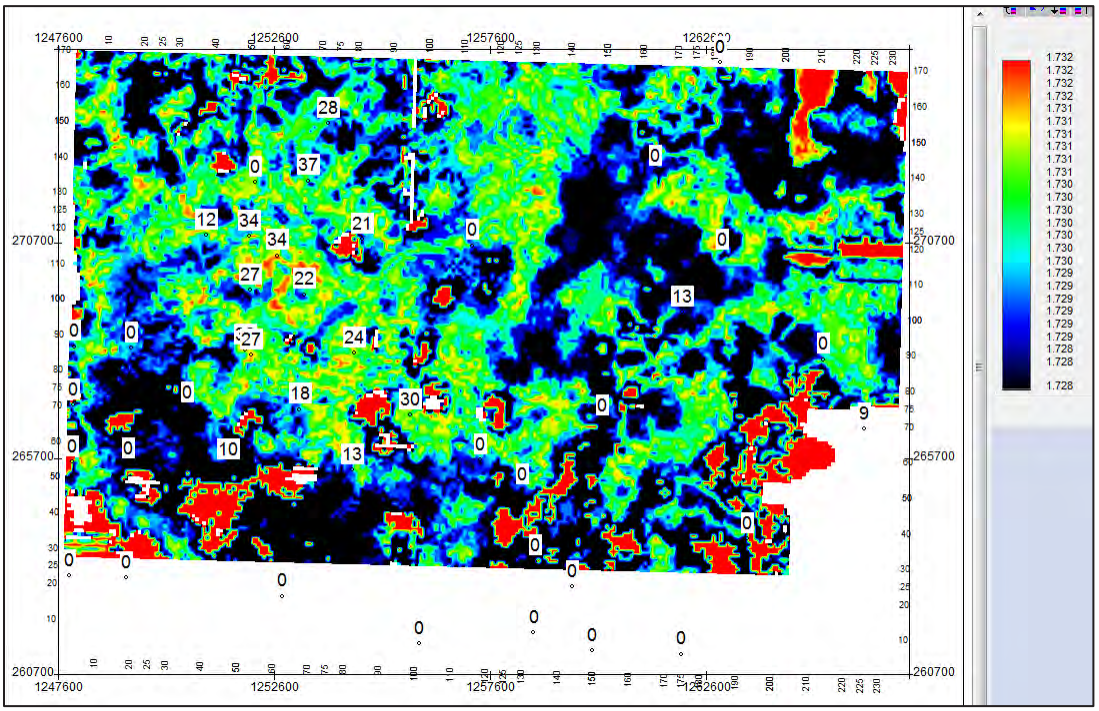


Figure 46. A map of the Vp/Vs Ratio has intermediate to higher values (greens & yellows) where the UMS is thicker. This appears to be counter to what is seen in the profiles.

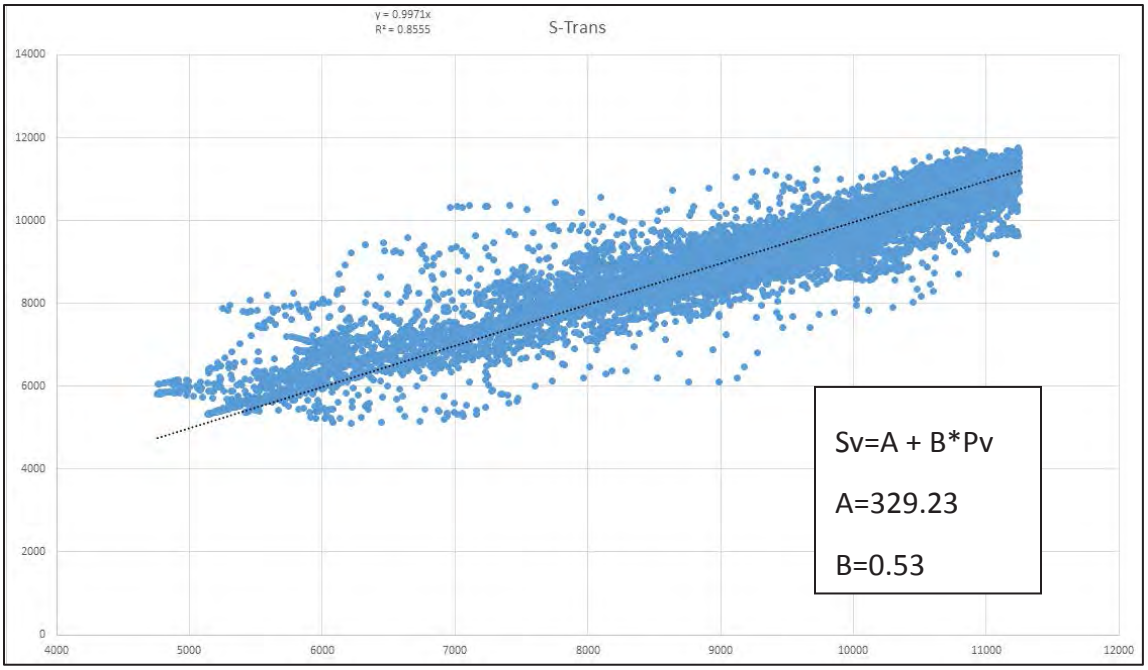


Figure 47. Castagna's Equation for Cutter Field plots the p-wave vs shear wave velocity. The fit of the curve is good and is indicative of a sandstone-shale siliciclastic system.

Remaining work with the Vs/Vp ratio includes:

- Calculate S-wave transforms
- Load additional wells into joint inversion workflow
- Recompute Vp/Vs volume and run joint inversion
- Acoustic Impedance
- Shear Impedance
- Density

The goal will be to improve the resolution of the sandstone that is not distinguished in a conventional p-wave seismic survey. The results to date are very encouraging.

Seismic Inversion, S- and P-Wave Characterization of the Viola-Arbuckle Deep Saline Aquifer beneath Cutter Field – Illustrations provided by Clyde Redger and commentary by L. Watney

The second part of the study conducted by Redger is to examine the Arbuckle saline aquifer to evaluate the structural features, whether flow units can be differentiated and characterized, and to evaluate general anomalies and heterogeneity in this interval. **Figures 48-67** are focused on the seismic inversion, and shear and p-wave velocity and amplitude variation as a means to characterize the heterogeneity of the deep saline aquifer interval.

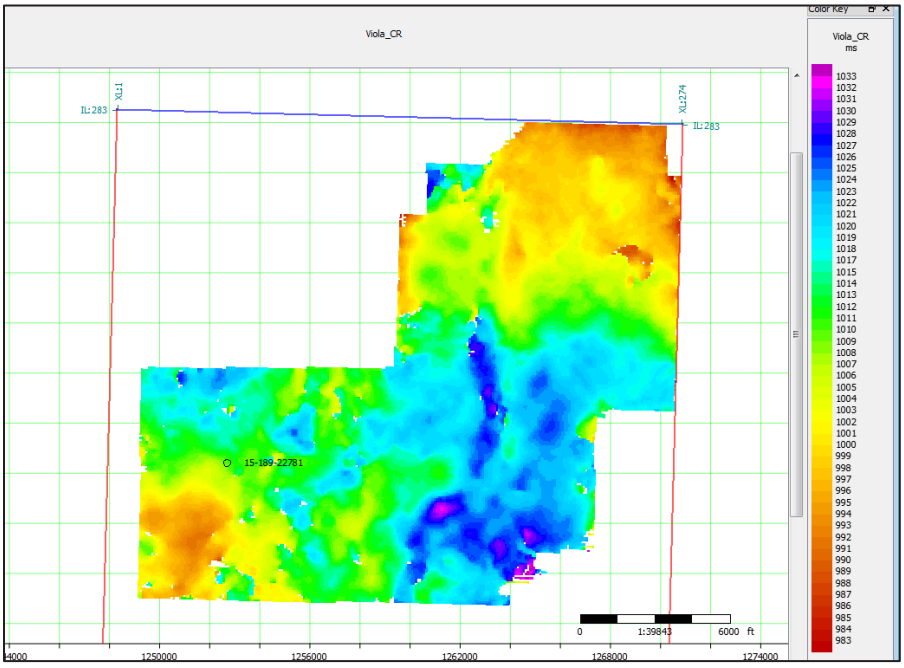


Figure 48. Viola Time Structure utilizes the best deep seismic reflector that is closest to the top of the Arbuckle. Rather than one high to the west as is the case with the shallower strata, the high has shifted to the southwest. This seismic volume shows a merged P-wave surveys that include the converted wave survey at Cutter. The location of the Cutter KGS #1 is shown to aid comparison.

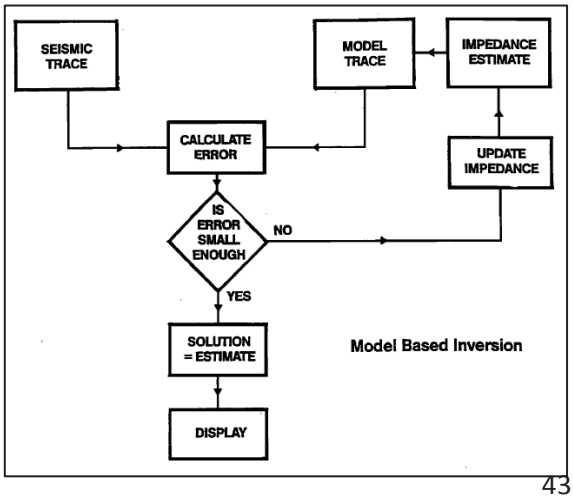


Figure 49. Seismic inversion is a means to convert the seismic reflection data to rock-property description and in this case follows a methodology outlines by Russell (1988).

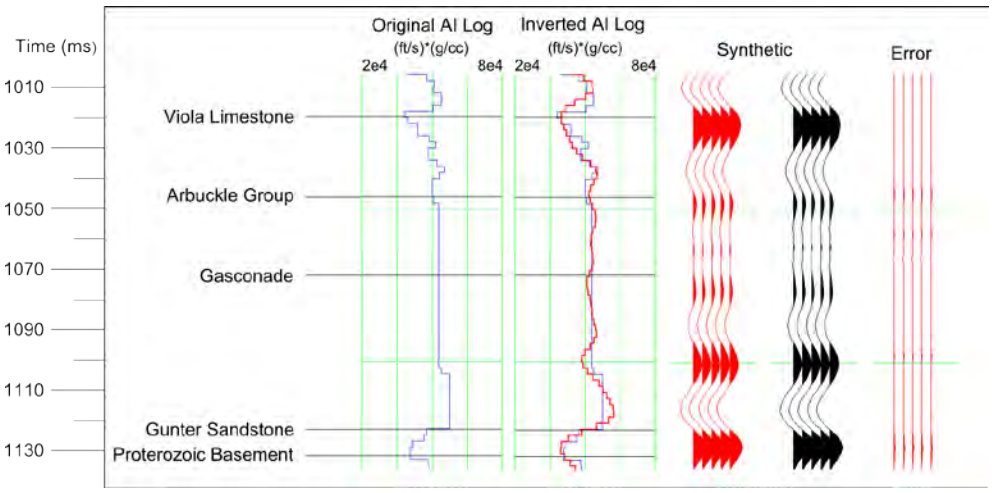


Figure 50. The seismic inversion is illustrated here with the original well log with computed acoustic impedance (left) alongside in inverted seismic trace (right in red). The fit is excellent suggestion the seismic is a good candidate for this inversion procedure.

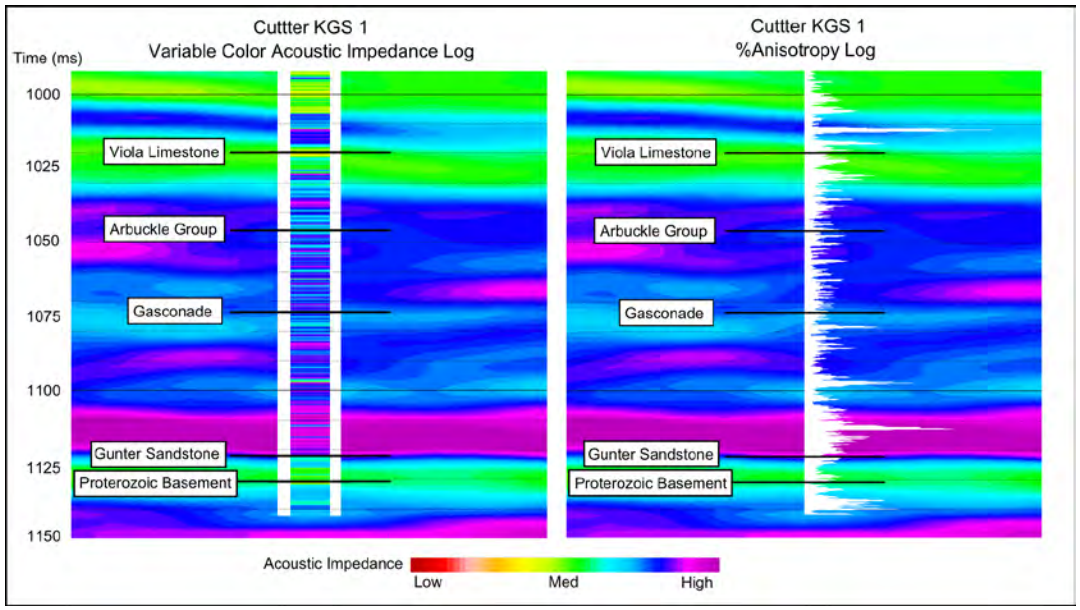


Figure 51. The preliminary inversion results are shown with acoustic impedance profile compared with the acoustic impedance log (left) and the percent anisotropy (right). Notice the close correlation of the log and seismic impedance and the lateral variability of the impedance. While the Viola Limestone that overlies the Arbuckle is uniformity medium impedance – a shaly wackestone, the interior of the Arbuckle suggests variable pods of high and low impedance. The top of the Gasconade Dolomite is regionally correlated and appears to represent a widespread subaerial unconformity overlain sharply by a shaly dolomite representing inundation of the carbonate platform on which the Arbuckle was deposited. The Cutter KGS #1 cut a core through the interval and found an interval of vuggy and brecciated dolomite. This appears to be matched by an interval of lower impedance (lighter blue).

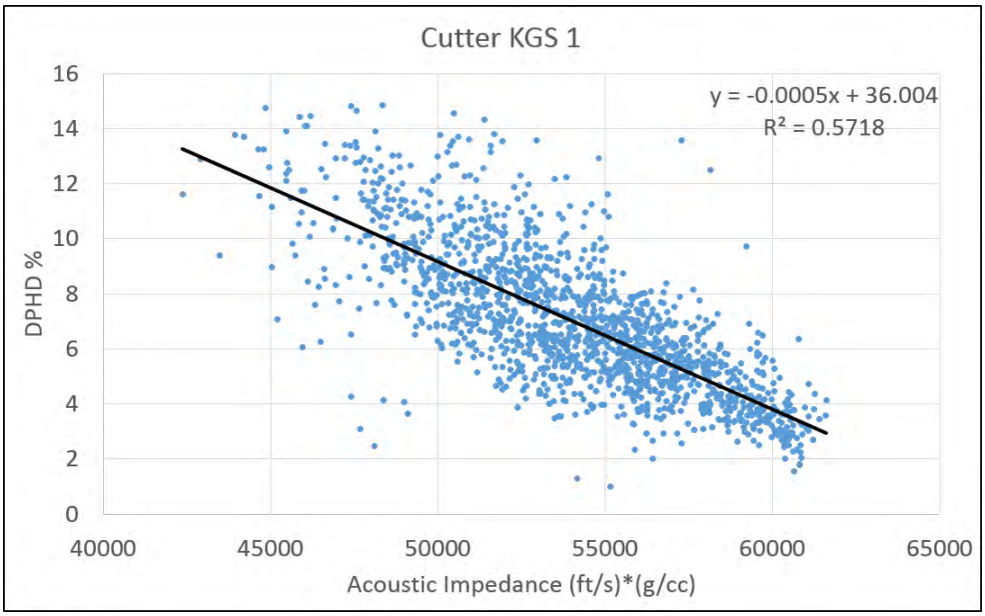
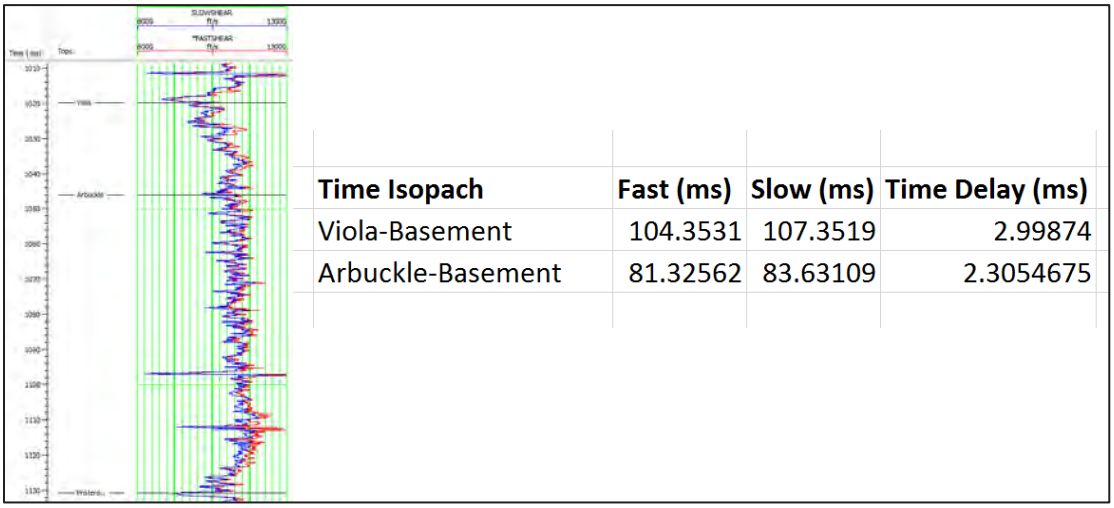


Figure 52. A crossplot of the acoustic impedance vs. density porosity of the Arbuckle interval shows a rather pore fit (R2 of 0.5718). This may reflect the range in the type of pore space in the dolomitic carbonate, from a grainstone with interparticle porosity, vuggy pores in part connected and others non-touching vugs, and also brecciated intervals. To make a better fit would require the distinction between these pore types.



Time Isopach	Fast (ms)	Slow (ms)	Time Delay (ms)
Viola-Basement	104.3531	107.3519	2.99874
Arbuckle-Basement	81.32562	83.63109	2.3054675

Figure 53. Time isopachs between Viola and basement and Arbuckle and basement for fast and slow shear wave velocities are compared in this figure. The greater delay is includes the Viola suggesting greater anisotropy in the Viola than in the Arbuckle to basement interval. This is a rather counterintuitive compared to the impedance profiles, but it can be seen here that magnitude of shear wave variation in the Viola, albeit thinner interval, is considerably greater in the uppermost part of the Viola. The top of the Viola is another major unconformity and is associated with a thick chert breccia.

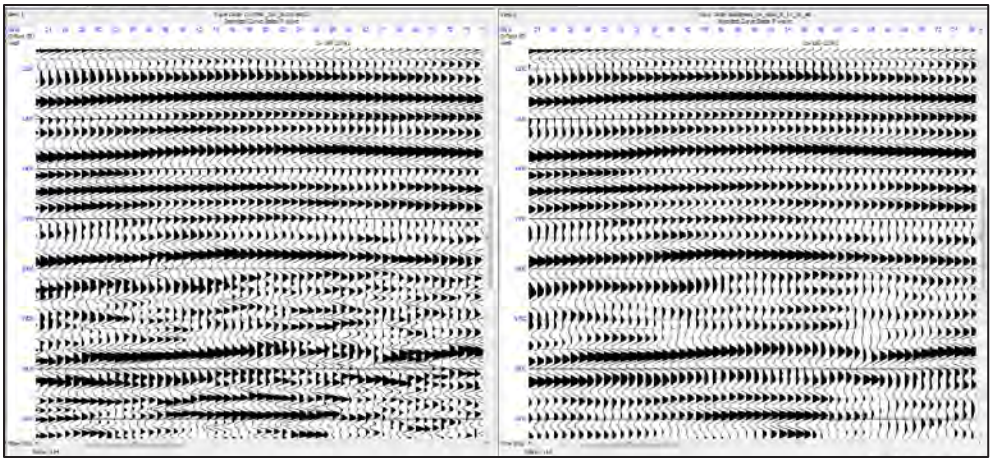


Figure 54. The slow shear amplitude profile (left) is compared with the P-wave amplitude and it is clear that the lower half in the shear wave domain is much more laterally discontinuous.

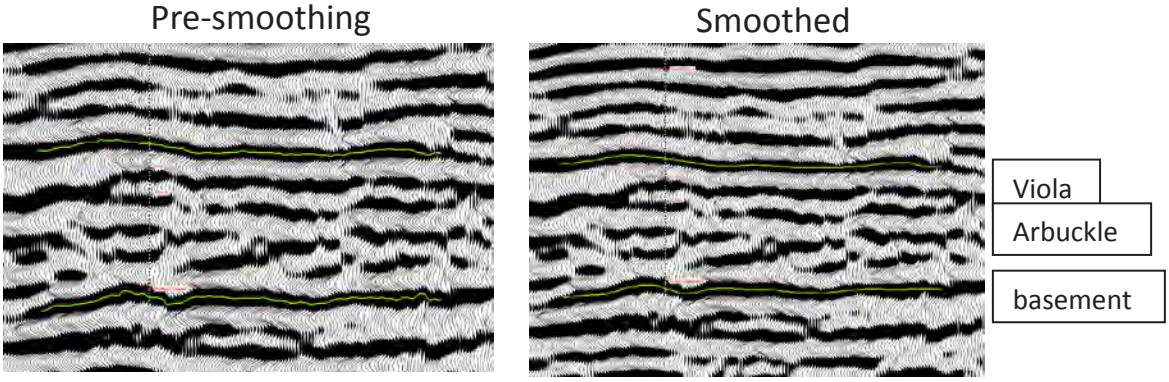


Figure 55. Seismic discontinuities are persistent even with smoothing including apparent dipping reflectors in the near the base of the Arbuckle. Also, the top of Arbuckle appears to be truncated along the base of the Viola Limestone/Simpson Sandstone with corresponding thickening of the Viola interval.

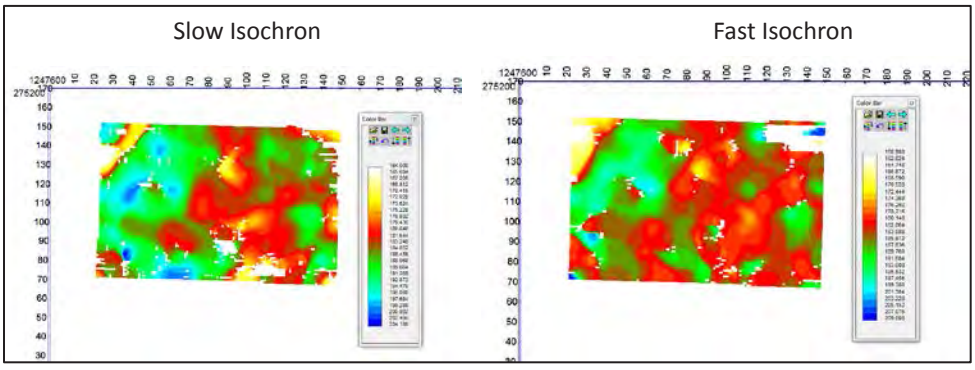


Figure 56. Both slow and fast isochrons along a surface in the Arbuckle show similar lateral variability.

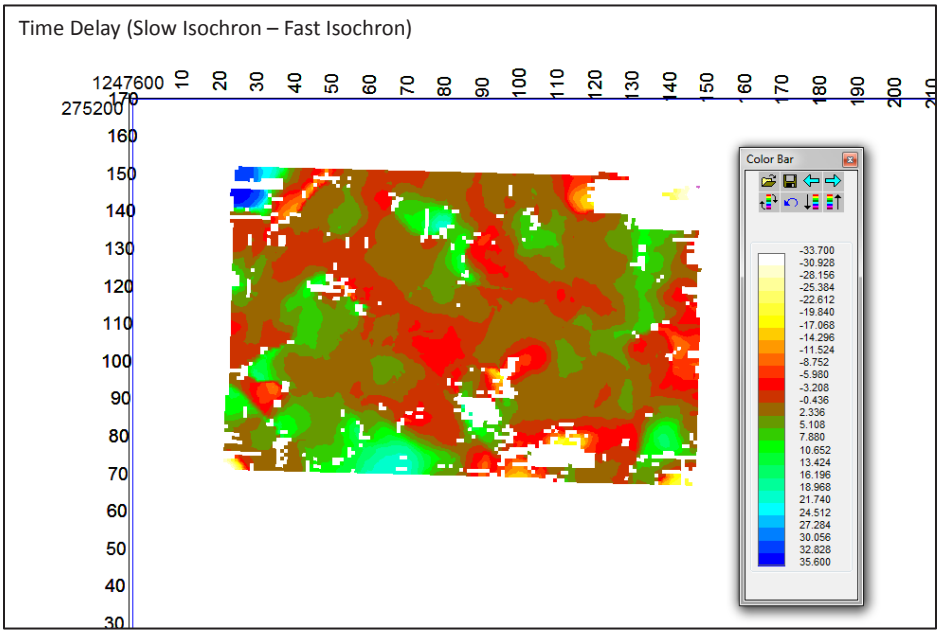


Figure 57. The difference between the slow and fast isochon is small and is questionable as to the significance of the pattern relative to the systematic noise of the interpretation. Yet, there appears to be NE- and NW-trends to the apparent anisotropy.

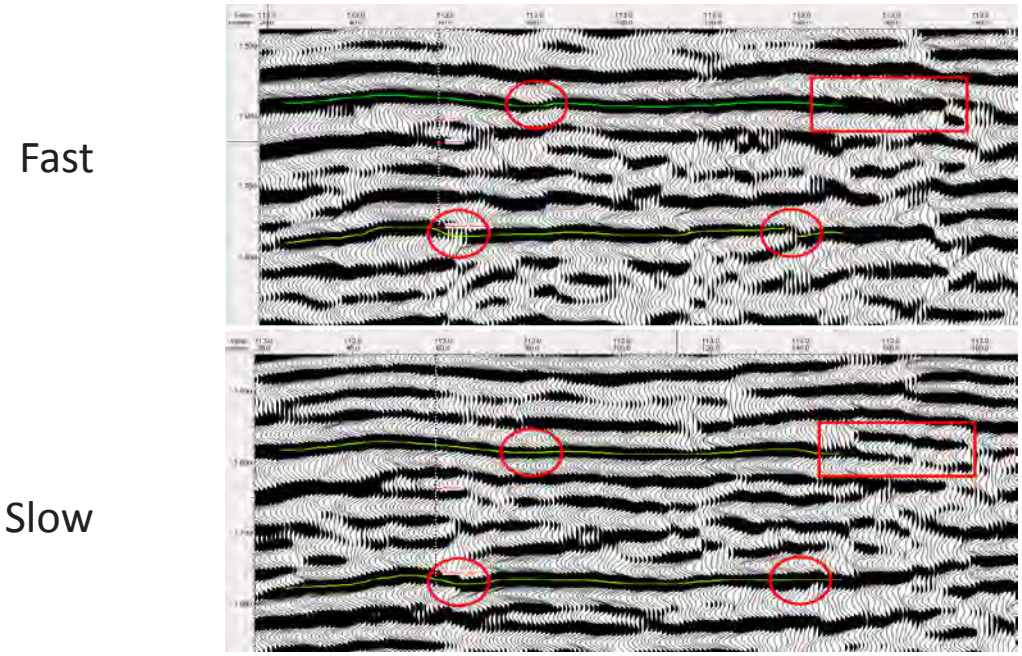


Figure 58. The differences between the fast (top) and slow (bottom) shear wave amplitude sections each show differences in the continuity of reflectors as highlighted in red. The east side of the profile has the most discontinuous reflectors, which is most marked in the slow shear wave domain.

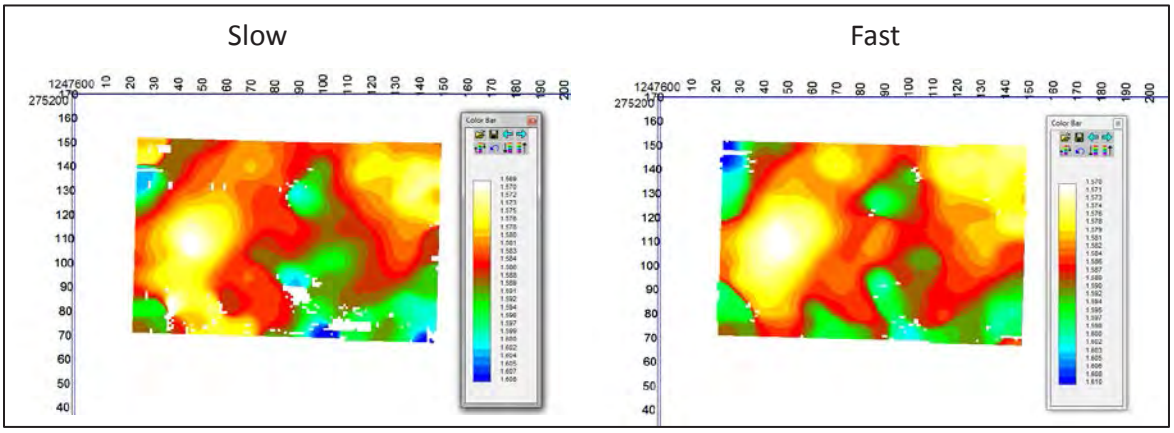


Figure 59. The slow (left) and fast (right) shear wave velocities along the top of the Viola, the prominent chert breccia below a major regional unconformity show similar low (warmer colors) and higher velocities. The pattern is roughly rectilinear with a NE- and NW-trend to the pattern. The lower velocities may reflect the thicker more porous chert at the unconformity.

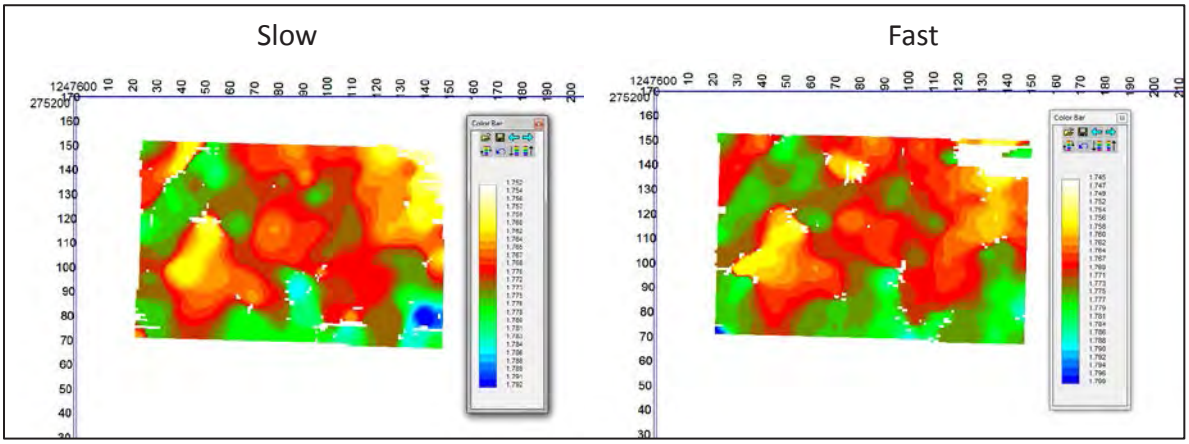


Figure 60. Maps are identical to Figure 59, but the interval is the top of the Proterozoic basement. The weathered surface on the granite may have variable residuum to account for the patterns. The grain again is NE- and NW-pattern.

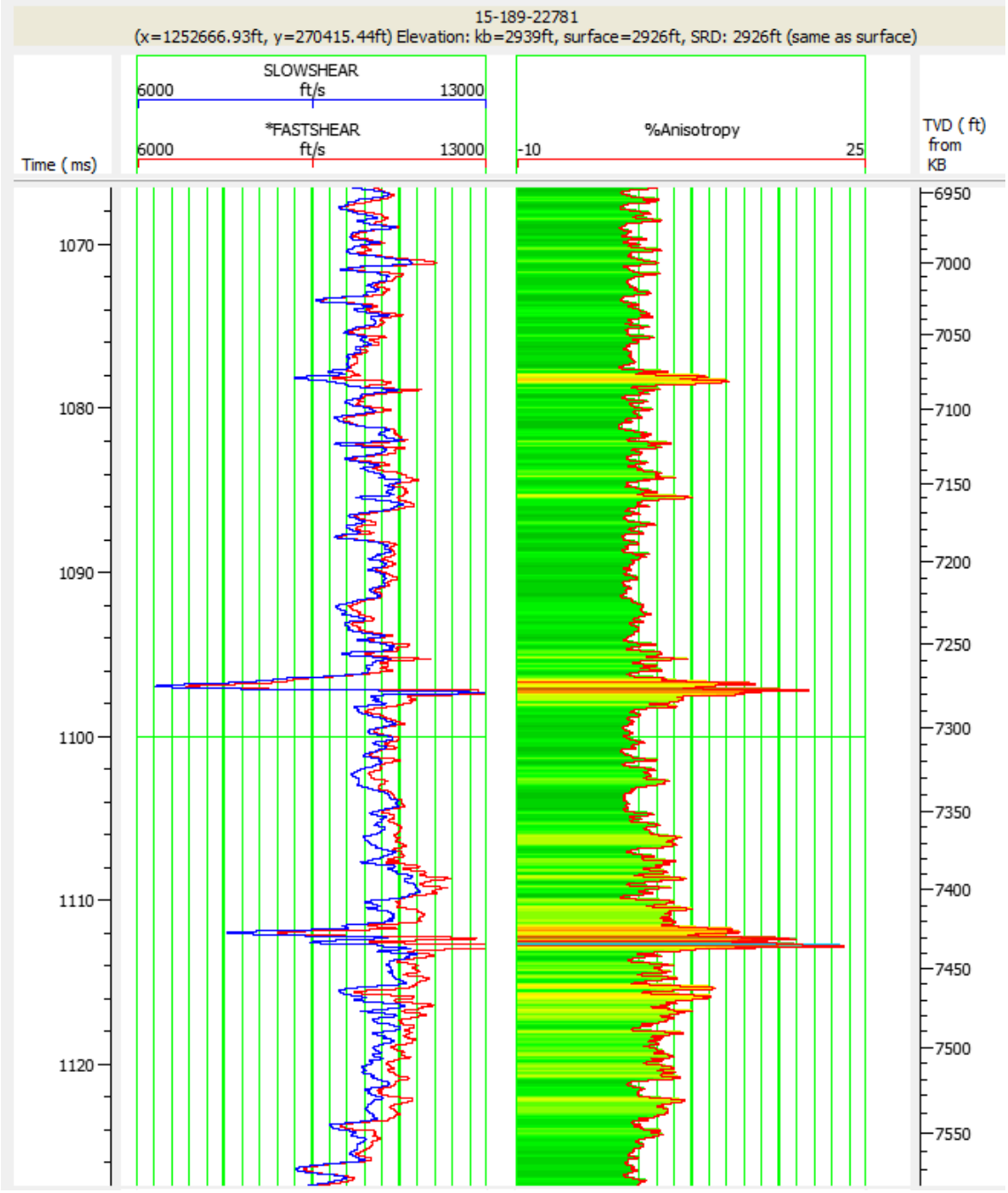


Figure 61. Distinct anomalous intervals are noted in the fast and slow shear wave velocities in the Arbuckle. The % anisotropy from the spectral sonic corresponds closely to lower shear wave velocities. The anomaly at 7425-35 ft is an interval with large vugs as noted in the microresistivity imaging log in Figure 62.

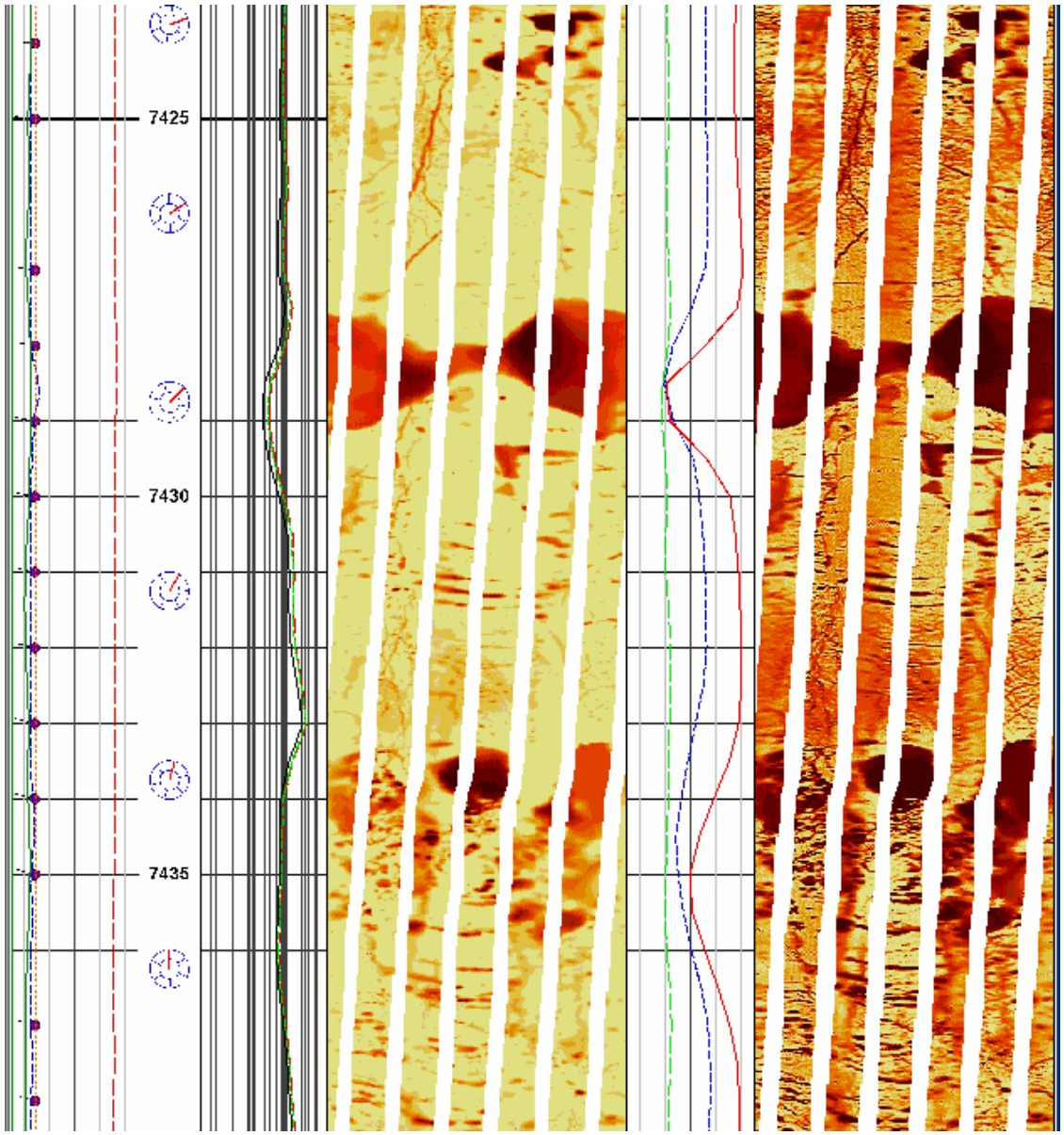


Figure 62. The microresistivity imaging log at 7425-35 ft displays an interval with large and small vugs and some small fractures.

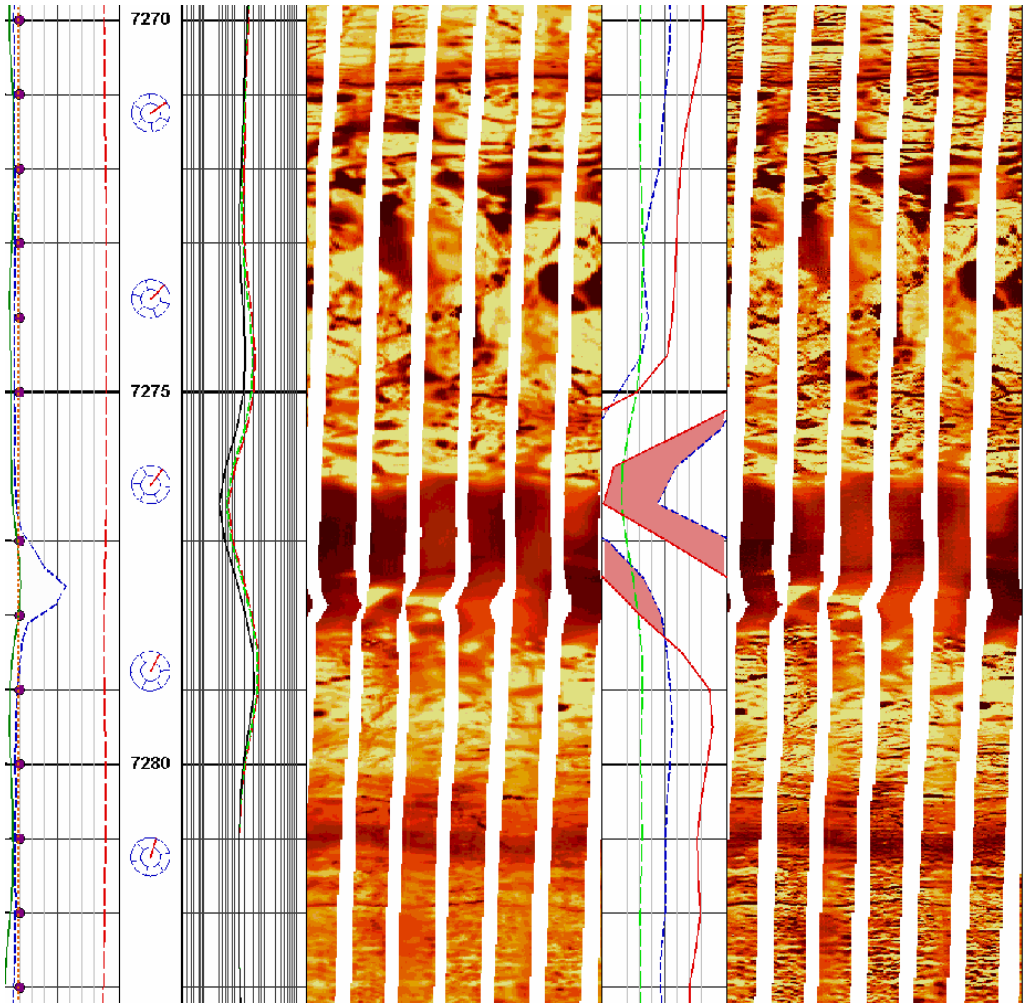


Figure 63. Image log 7270-80 ft corresponds to slow shear wave velocity and high anisotropy.

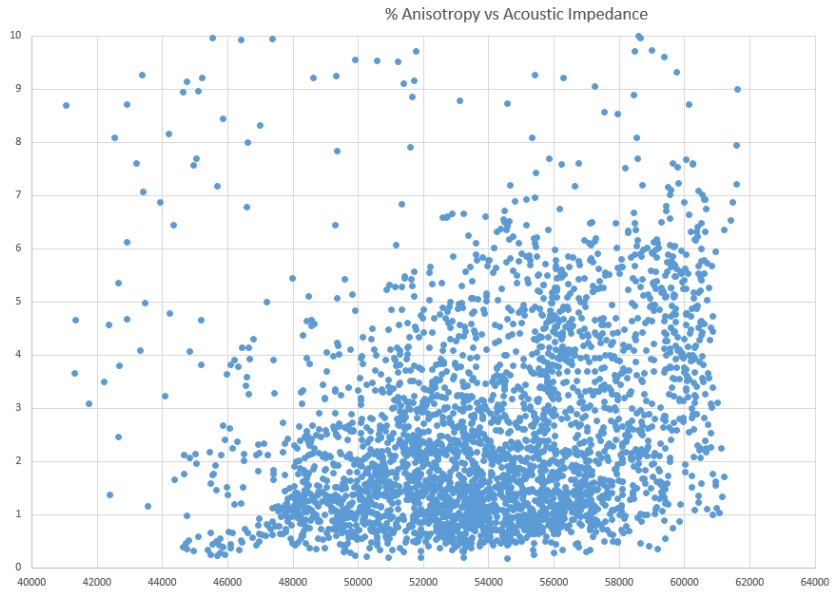


Figure 64.

Percent anisotropy vs. acoustic impedance shows no clear pattern. Again, the variation of impedance based on the pore type might be helpful in resolve some of this variability.

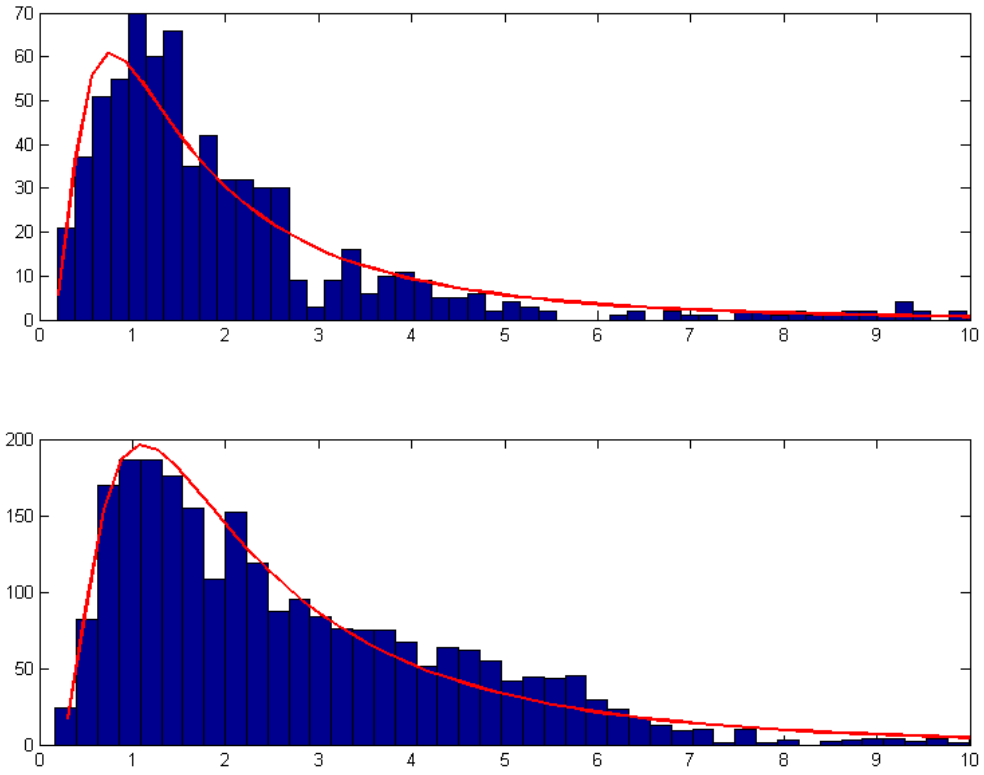
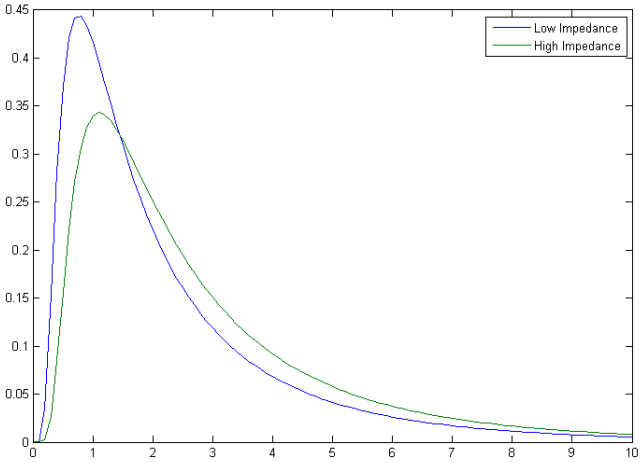


Figure 65. (Top) Low acoustic impedance (40000 – 51000) (ft/s)*(g/cc). (Bottom) High acoustic impedance (51000 – 62000 (ft/s)*(g/cc). Differences are small.



	A	B	C
1	%Anisotropy	Low AI	High AI
2	>1	72.1	84.3
3	>2	40.8	53.5
4	>3	24.4	33.7
5	>4	15.4	21.9
6	>5	10.0	14.6
7	>6	6.7	9.9
8	>7	4.5	6.8
9	>8	3.1	4.8
10	>9	2.2	3.8
11	>10	1.6	2.4

Figure 66. (left) Acoustic impedance vs. percent anisotropy showing low impedance has lower anisotropy. (right) The table to the right indicates that higher anisotropy is correlated with lower acoustic impedance.

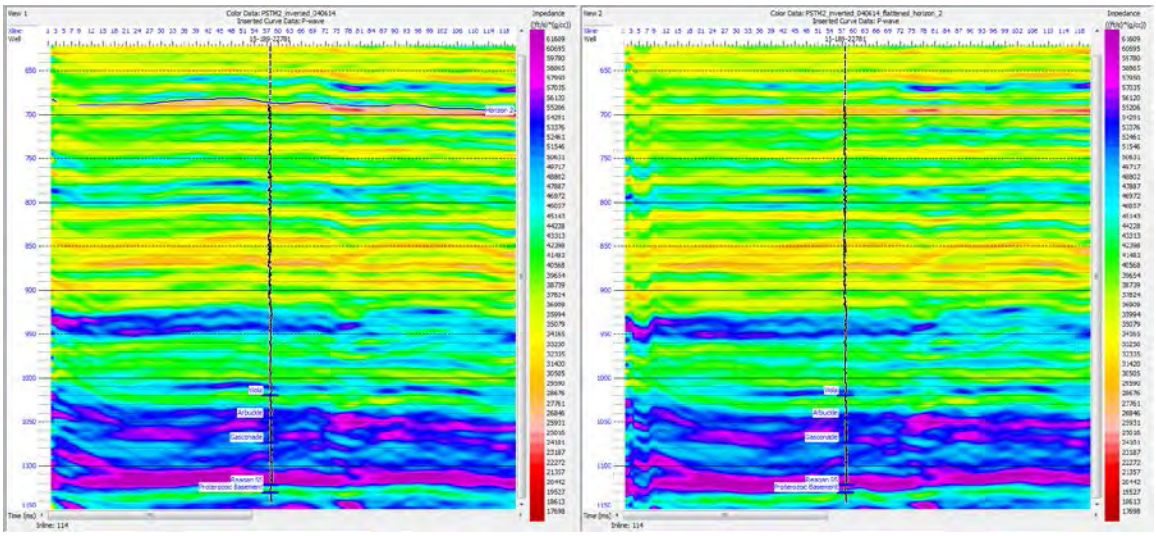


Figure 67. Inversion interpretation of seismic profile through Cutter KGS #1 illustrating 1) highly variable and complex impedance patterns in the Arbuckle (purple/blue high AI), 2) compared to the lower, laterally continuous impedance of the Viola (green AI).

Figures 68-71 illustrate the preliminary steps taken to analyze the inversion information in the Arbuckle so as to compare with Arbuckle flow units that have been correlated across the study area in southern Kansas using core and well log data. The flow units, while related to a succession of petrophysically distinct strata relating to vertical and horizontal permeability and porosity, they are also constrained by the regional stratigraphic divisions that were established earlier based on lithofacies and log character.

As described above the results from seismic inversion can be used to relate to the flow units by resolving porous strata, albeit a complex suite of pore types comprising the Arbuckle. This preliminary analysis sets the stage for additional work that is being conducted as the thesis is completed. The approach should help guide future work analysis of this publically-accessible seismic volume.

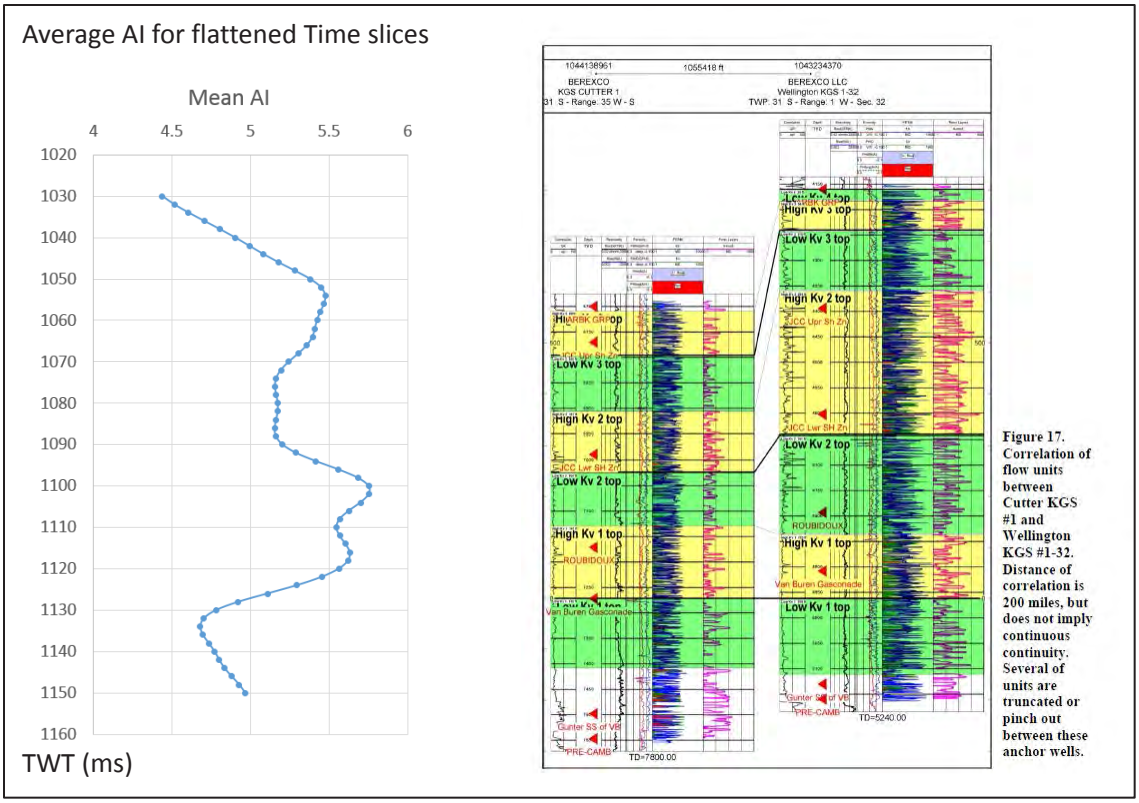


Figure 17. Correlation of flow units between Cutter KGS #1 and Wellington KGS #1-32. Distance of correlation is 200 miles, but does not imply continuous continuity. Several of units are truncated or pinch out between these anchor wells.

Figure 68. A first step taken to compare the flow units with the acoustic impedance (AI) was to obtain the mean AI for flatten time slides with the assumption that the flow units are conformable parallel units, not varying in thickness and not undergoing internal tilting, pinchout, or truncation. As noted previously the amplitude sections suggest that the internal layers in the Arbuckle at not uniform. This is also the case regionally where flow units thin, thicken, and locally pinchout due to changes in sediment accommodation due to varying topography or even episodic structural deformation.

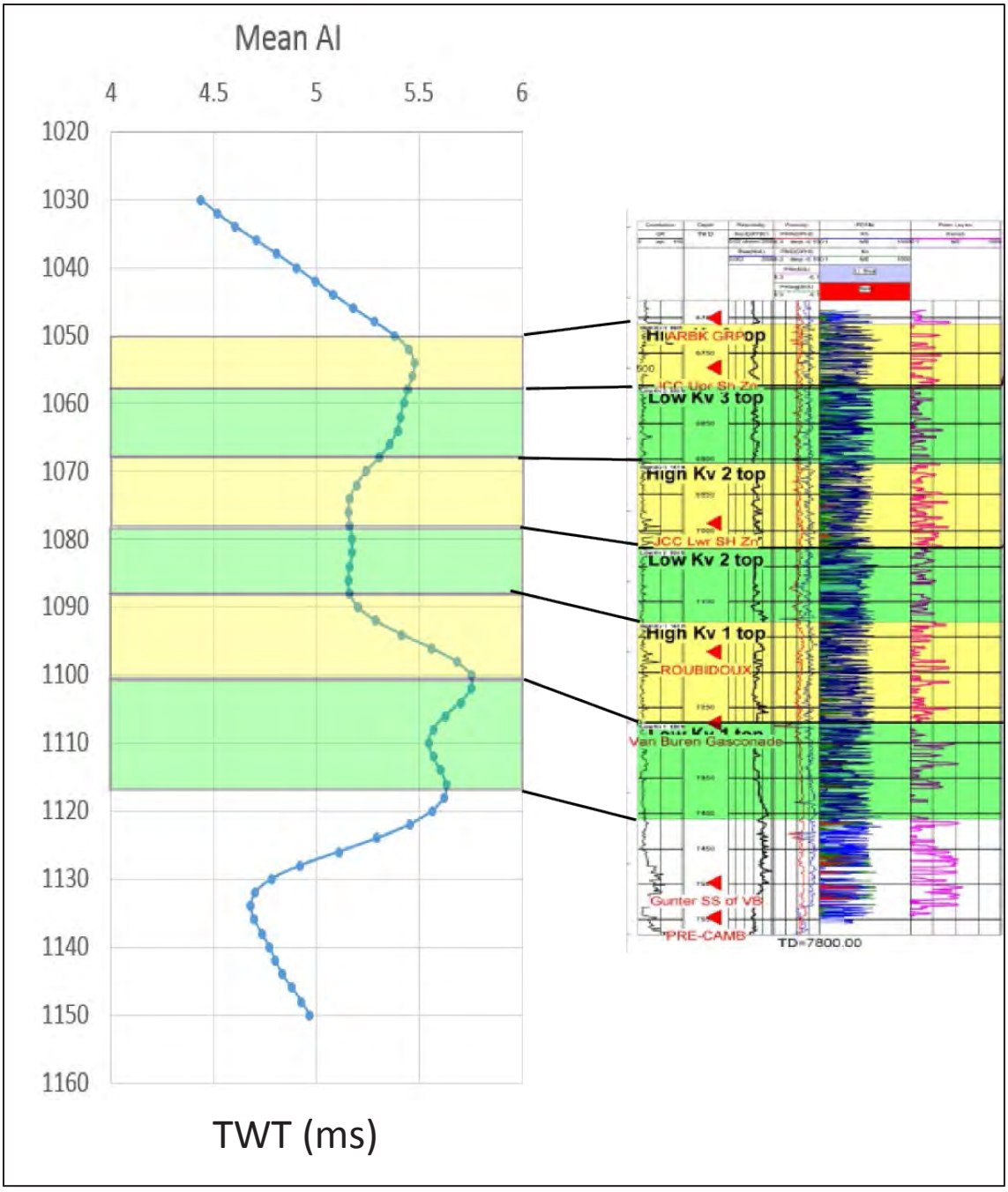


Figure 69. Flow unit correlation using a mean AI profile compared to the petrophysical classification of the Cutter KGS #1. The low quality flow units (green) and high (yellow) vaguely correspond with lower AI, particularly in the internal from the top of the High Kv flow unit to the base of High Kv 1 flow unit. This is also the interval with the better quality reservoir interval, centered around the Roubidoux Formation of the Arbuckle as labeled in the well log profile above.

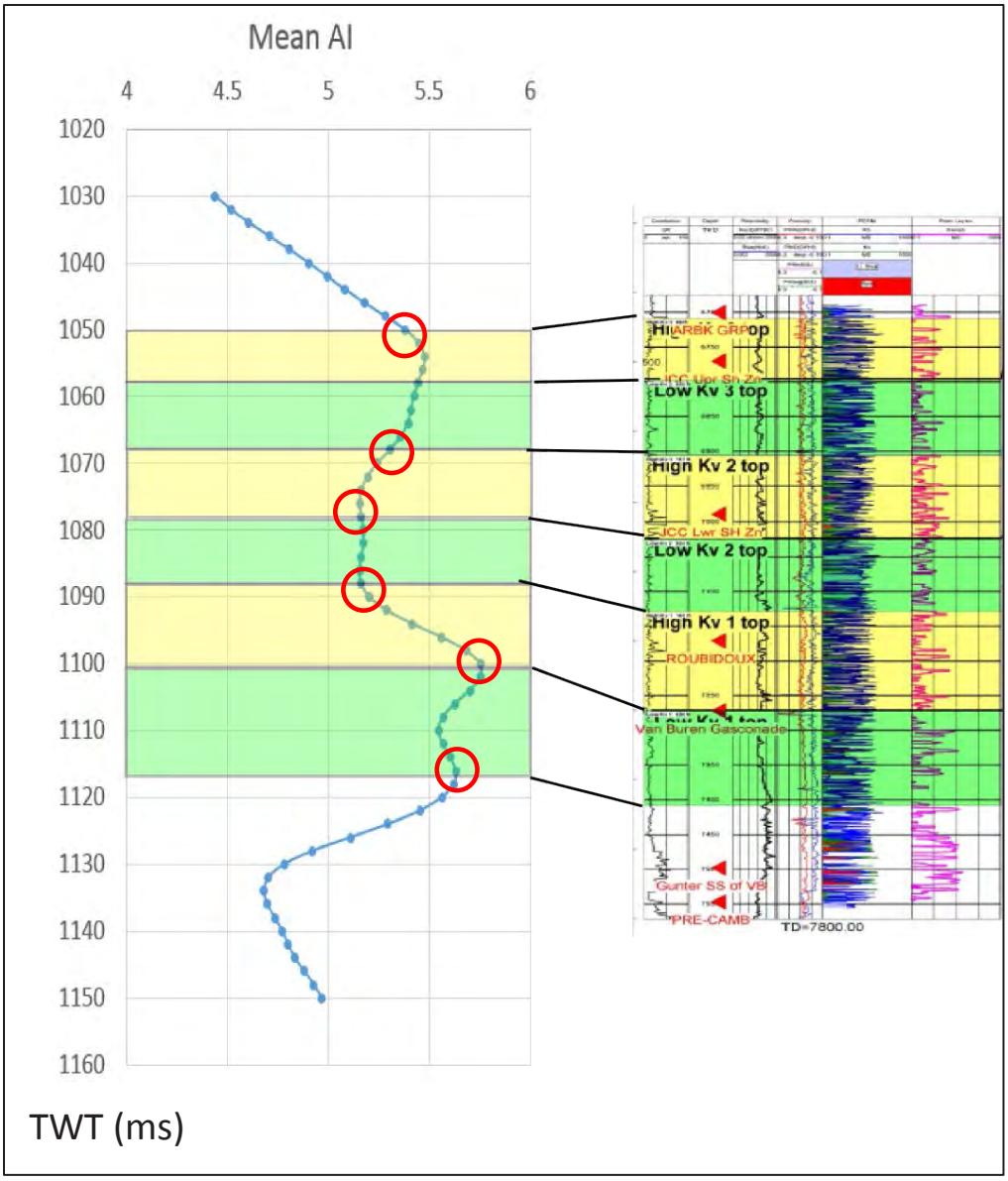
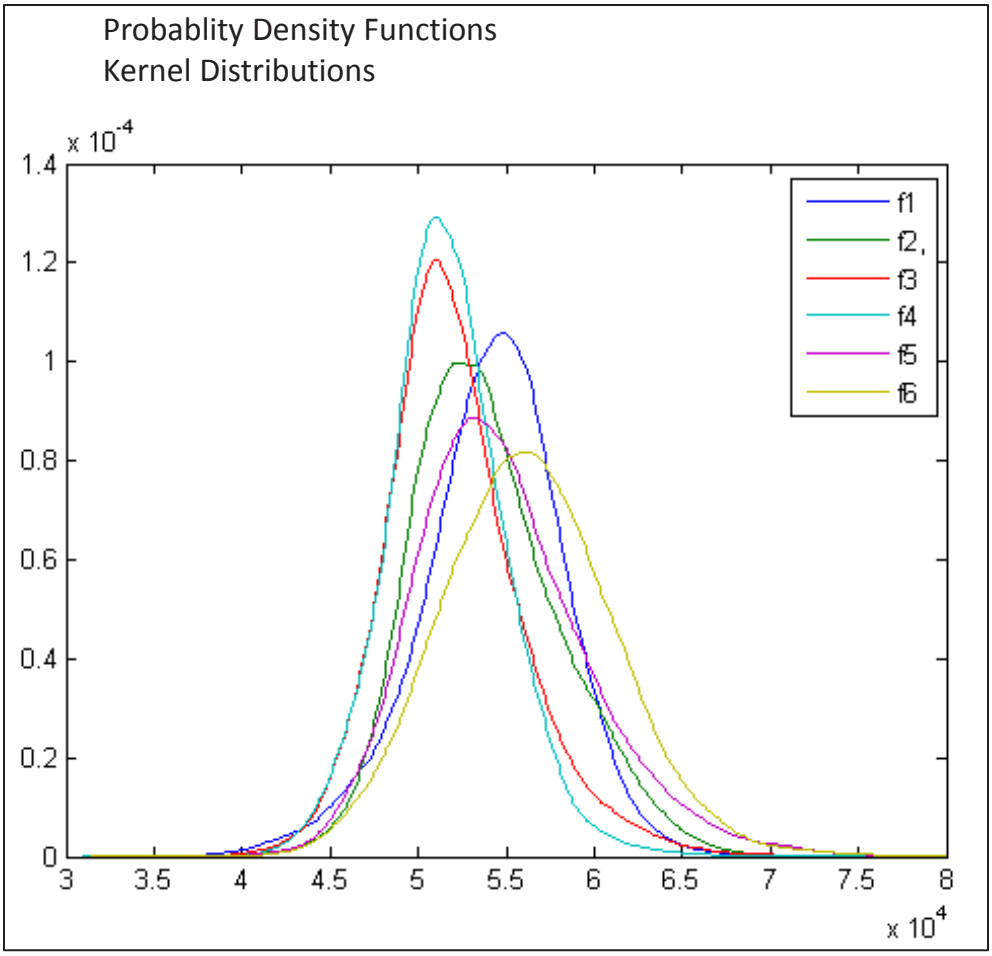


Figure 70. The AI profile highlighted with the inflections of this curve help to illustrate correlations.



$$\hat{f}_h(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right) \quad ; \quad -\infty < x < \infty ,$$

where n is the sample size, $K(\bullet)$ is the kernel smoothing function, h is the bandwidth.

	A	B	C	D	E
1	**Flow Units**	**Depth (ft)**	**Mean AI (ft/s)*(g/cc)**	**Kernel Function**	**Kernel Distribtion Bandwidth**
2	High KV 3 top	6709	54167	Normal	326.274
3	Low Kv 3 top	6796	53893	Normal	350.787
4	High kv 2 top	6905	52038	Normal	297.019
5	Low kv 2 top	7027	51646	Normal	268.222
6	High kv1 top	7130	54771	Normal	374.207
7	Low kv 1 top	7272	56251	Normal	396.754

Figure 71. The AI distributions (upper figure) for each flow unit show no variation (f4 [High Kv 2], and f5 [Low Kv2]) while other flow units do show slight to moderate variation. The lowest mean AI (more porous?) corresponds to a Low Kv 2, while the highest AI (less porous?) corresponds to a low Kv, in Low Kv 1. As previously mentioned it is likely the heterogeneity expressed by the AI profile in Figure 67 may not be captured in the times slice approach to comparing AI and log based flow units.

Update On Analysis of the Regional 3D Seismic (Dennis E. Hedke with contributions by Lynn Watney)

From the powerpoint based report -- Seismic Evidence Related to Significant Regional Structural Domain and the Question of CO2 Leakage Potential, Dennis Hedke, Hedke-Saenger Geoscience, Ltd., October 18, 2014

The volumetric curvature attribute and the amplitude 3D volumes in the seismic volumes that have been donated to this project often show signal disruption below the incised valley systems. This are interpreted to be steeply dipping and/ or chaotic beds. The velocity in the IVF is different than either side, but it does appear to be the cause of the long and vertical disruptions.

The focus of this discussion is the Shuck Field seismic volume and the topic of the signal disruption. This basis of the information conveyed here is also included in the final report on Shuck Field.

Overview

The large 3D seismic volume in the Shuck area provides significant detail to examine a typical Incised Valley Fill system (IVF) that contains important oil and gas reservoirs in the study area as well as assessing the geologic context. This legacy data obtained from earlier 3D seismic efforts, as acquired and delivered by Anadarko Petroleum, provide excellent imaging context for the IVF systems.

General Description

Approximately 79 square miles of surface template 3-dimensional (3D) seismic data, which was designed to yield 82.5' x 110' bins, was analyzed using conventional time and amplitude mapping, as well as post-stack seismic inversion, and volumetric curvature datasets.

Production in the area occurs in multiple zones, but this study will focus primarily on Pennsylvanian Morrow-aged and Mississippian Chester-aged targets that occupy the IVF systems. The northern portion of this study area is approximately 12 miles south of the Cutter field area.

Definition of major geologic controls on reservoir (IVF) via seismic data

The quality of the processed seismic dataset is such that well defined incised valley fill is quite evident in the combined Meramec Time Structure image below (**Figure 72**). The image contains data that covers all or parts of many significant fields including Hitch, Shuck, Archer and Wide Awake, among others.

While geologic structure has some bearing with respect to some production in the area, the more significant control is related to stratigraphic context, and the stratigraphic complexity is notable.

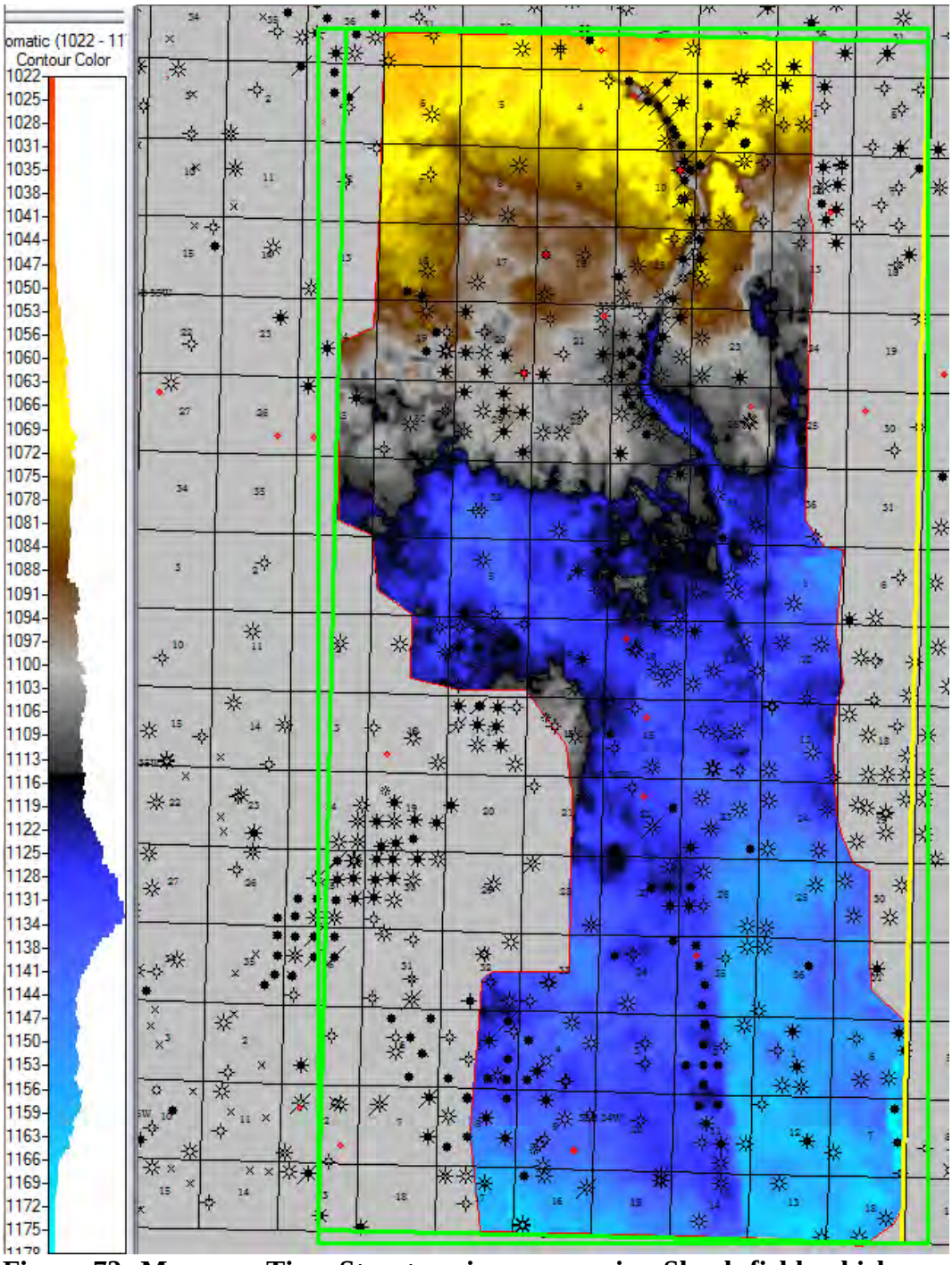


Figure 72: Meramec Time Structure image covering Shuck field, which occupies much of the IVF in the northern reaches, as well as areas outside the IVF, south to Wide Awake field. Boxes are 1 mi2.

The meandering, and in some cases very linear nature of the IVF is clearly visible. With abundant well control, we can construct a fairly reliable Depth Converted Meramec Structure map, as illustrated below in **Figure 73**.

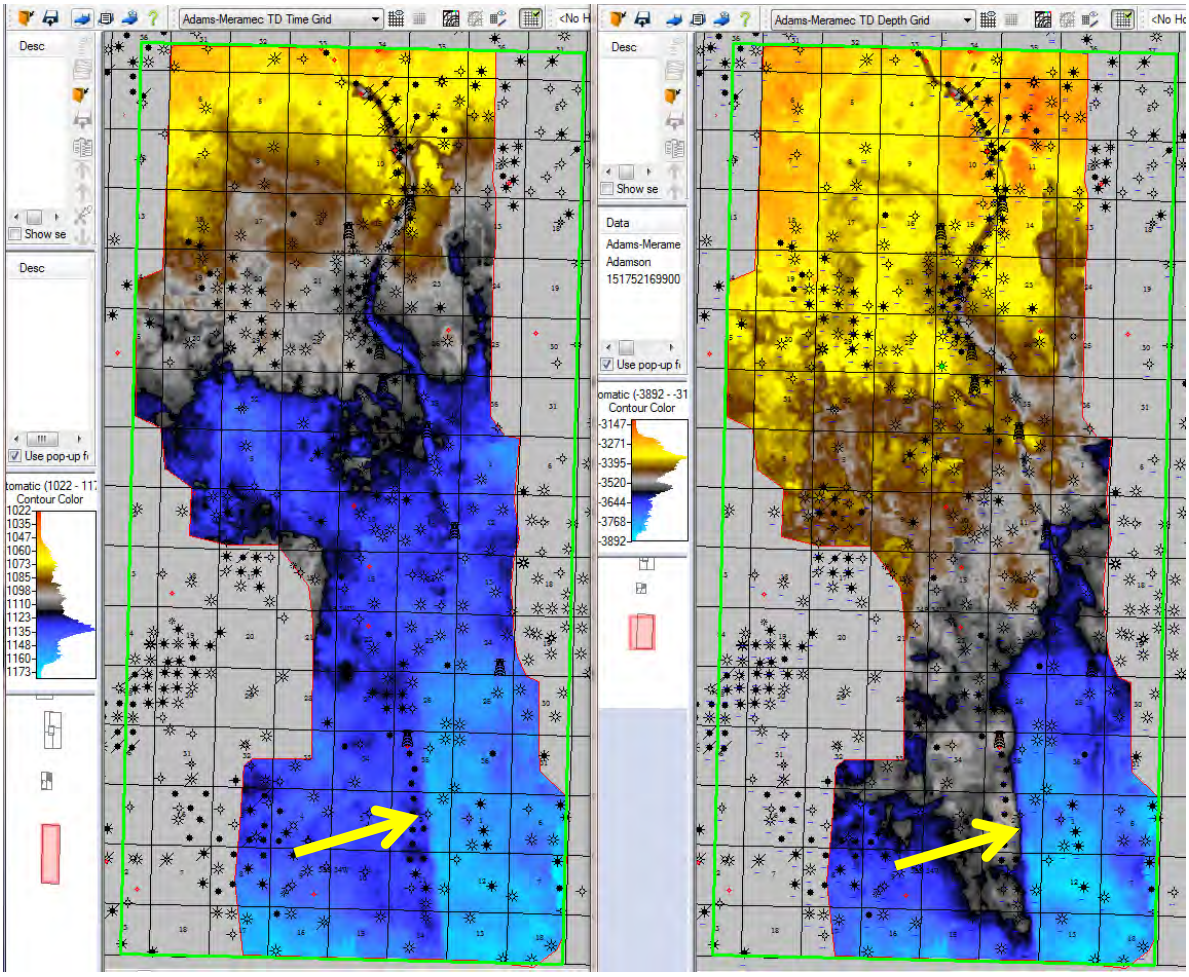


Figure 73: Meramec Time (left) vs Depth (right). Structural relief at Meramec is in excess of 750 feet. Relief from upthrown to downthrown block in lower right is ~240 ft, with producing wells identified to yellow arrow on upthrown side of the southern N-S trending fault.

Meramec Time Structure has been 'corrected' to yield the more accurate geometry and landform definition at Meramec time via Depth Conversion utilizing all available well control at Meramec. For example, the upthrown block in the lower middle part of the time map yielded very little, if any indication of the true structure that supports the production in that upthrown block.

The time relief from north to south is approximately 150 ms, while the depth relief is approximately 750 feet, yielding a rough estimate of 5 ft of structure per millisecond of time. Notice that there are numerous productive wells on the downthrown block in the southeast corner of the map.

The isochron from Morrow to Meramec illustrates similarity with the Meramec Depth map, and is illustrated below in **Figure 74**.

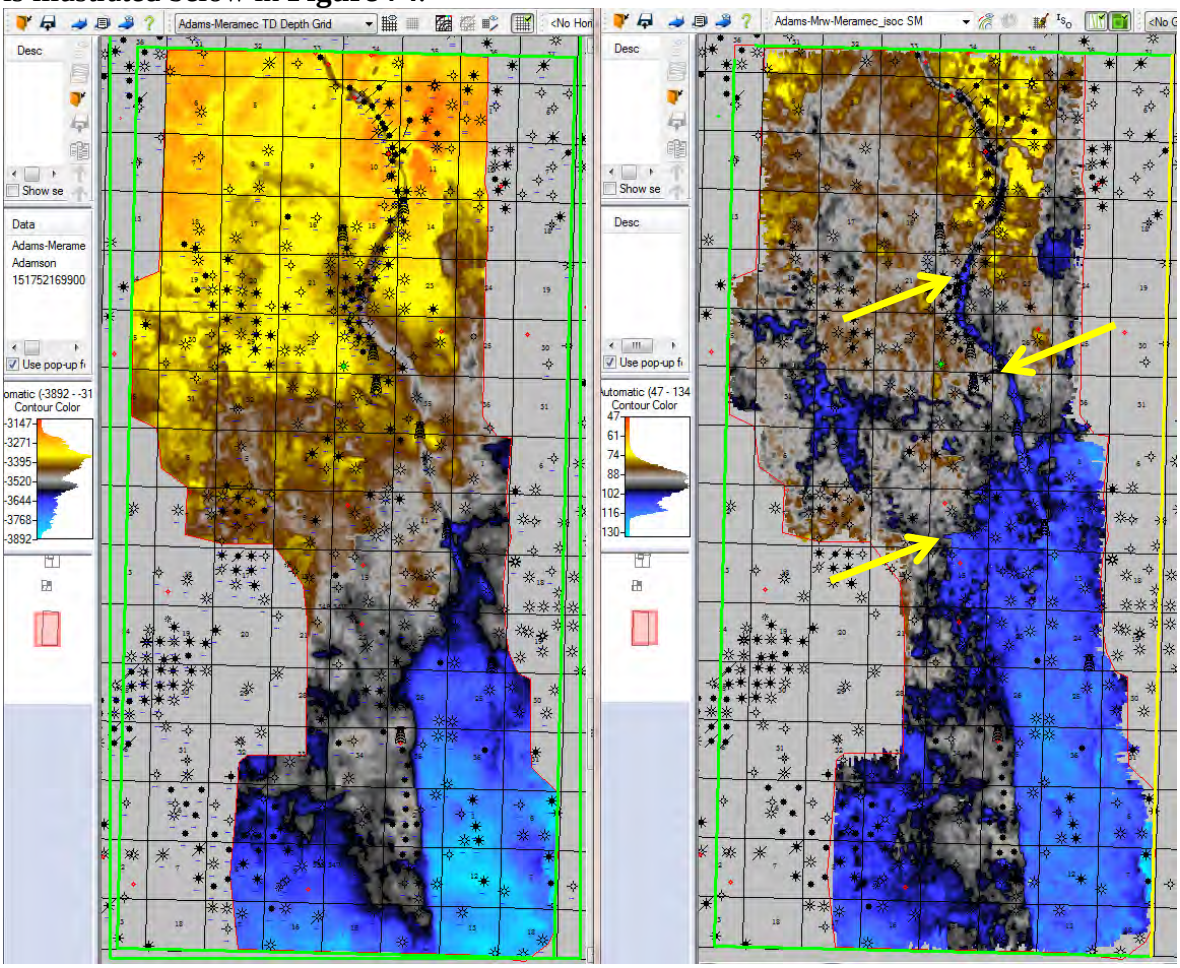


Figure 74: Meramec Depth (left) vs Morrow - Meramec Isochron (right). Mouths of the three tributaries that enter the west side of the main IVF trunk valley are highlighted with yellow arrows on the isochron map. Top and bottom tributaries trend NW as does the upper (northern) reaches of the main IVF.

While there are multiple linkages that can be observed between these two key maps, it is worth noting that the significant tributary feeding in from the west just above center of the isochron map does not traverse the minor 'bridge' that is barely noticeable in the depth context.

It is also the case that the trending of the leftmost meandering system that ultimately reaches up to the northwest corner of the mapped area has a strong parallel relationship to the main IVF system. That relationship is difficult to discern in the Depth map. One can also get a weak sense of where the southern part of the IVF heads after leaving the quasi platform just above the blue region, which is at about 100 ms isochron thickness. We will show evidence later where the system goes once it passes into a thicker stratigraphic package to the south, crossing apparent fall line dividing incised bedrock with different resistance to being incised.

While the IVF is striking enough in its detail, it is worth taking a closer look at the geometry of the meandering system that makes up the main tributary (**Figure 75**).

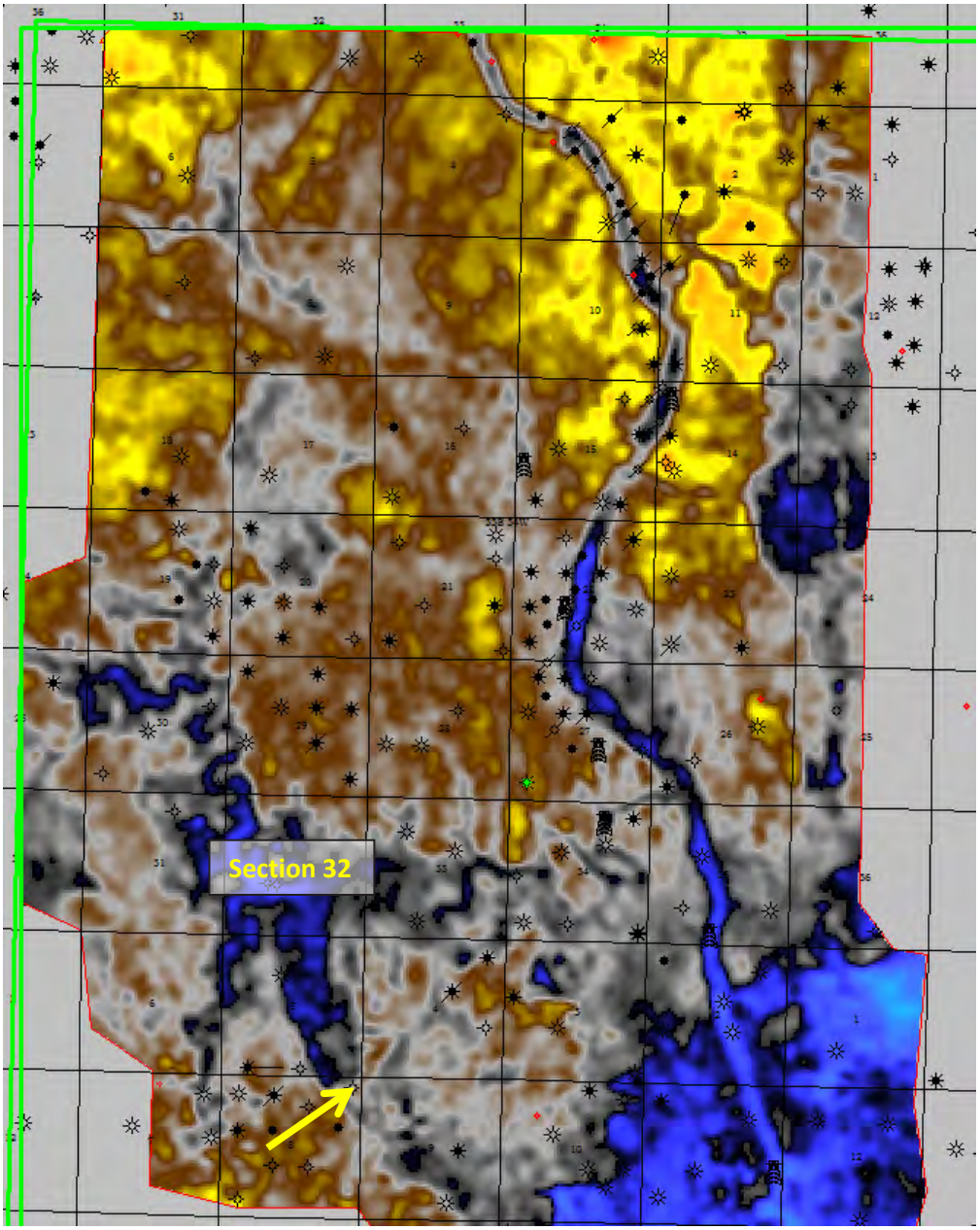


Figure 75. Morrow-Meramec Isochron detail to highlight meander belt. Minimum resolved meander system width is approximately 275 feet in section 34, equivalent to about 3 trace widths in the crossline direction. Derrick symbols are at locations where sonic log control was utilized.

The maximum isopach thickness of the meander system (section 32, **Figure 75**) is approximately 650 feet, while the minimum thickness is approximately 450 feet in the northwest corner of section 34. Please note the 'bridge' mentioned earlier in the northwest corner of section 8 (yellow arrow).

Both the depth map and the isochron map show the existence of another tributary that makes its way through sections 5, 8 & 9, T 33S R34W. Production occurs in this system in section 15 - T33S R34W (Anadarko-Koch 6A). The Morrow - Meramec thickness at that location is 629 feet. Production occurs in Chester, from an overall interval of 5927-6270.

For comparison to a well in the IVF proper, the Anadarko Etzold Unit North 2-5, located approximately E2 E2 NW section 22-T33S R 34W, has a Morrow - Meramec thickness of 709 feet, produces from Chester sands from a single net interval of 6230-6274.

The well with the derrick symbol in the tight meander loop in section 34 contains a Morrow-Meramec interval of 678 ft, and produces from a Morrow sand in an interval from 5962- 5966. Cumulative production from 1997 to present has been about 0.3 BCF gas.

There are dry holes in the IVF in between producing wells, and updip, so the system is more complex than meets the eye.

Acoustic Impedance Inversion Results

Data availability for this area was limited to stacked, off the shelf p-wave 3D. Sonic logs were utilized at the derrick-indexed symbols, totaling 8 discrete locations both within and outside the IVF, and one case within the meander belt. Four of the eight wells had availability of bulk density logs. After extracting a statistically significant wavelet from the actual seismic data (**Figure 76**) the logs were correlated to seismic via creation of a synthetic seismogram, and a model was built to integrate with the 3D volume.



Figure 76. Wavelet extraction.

In general, the quality of model building was high and an example of the inversion analysis, prior to making an inversion run is shown in **Figure 77**.

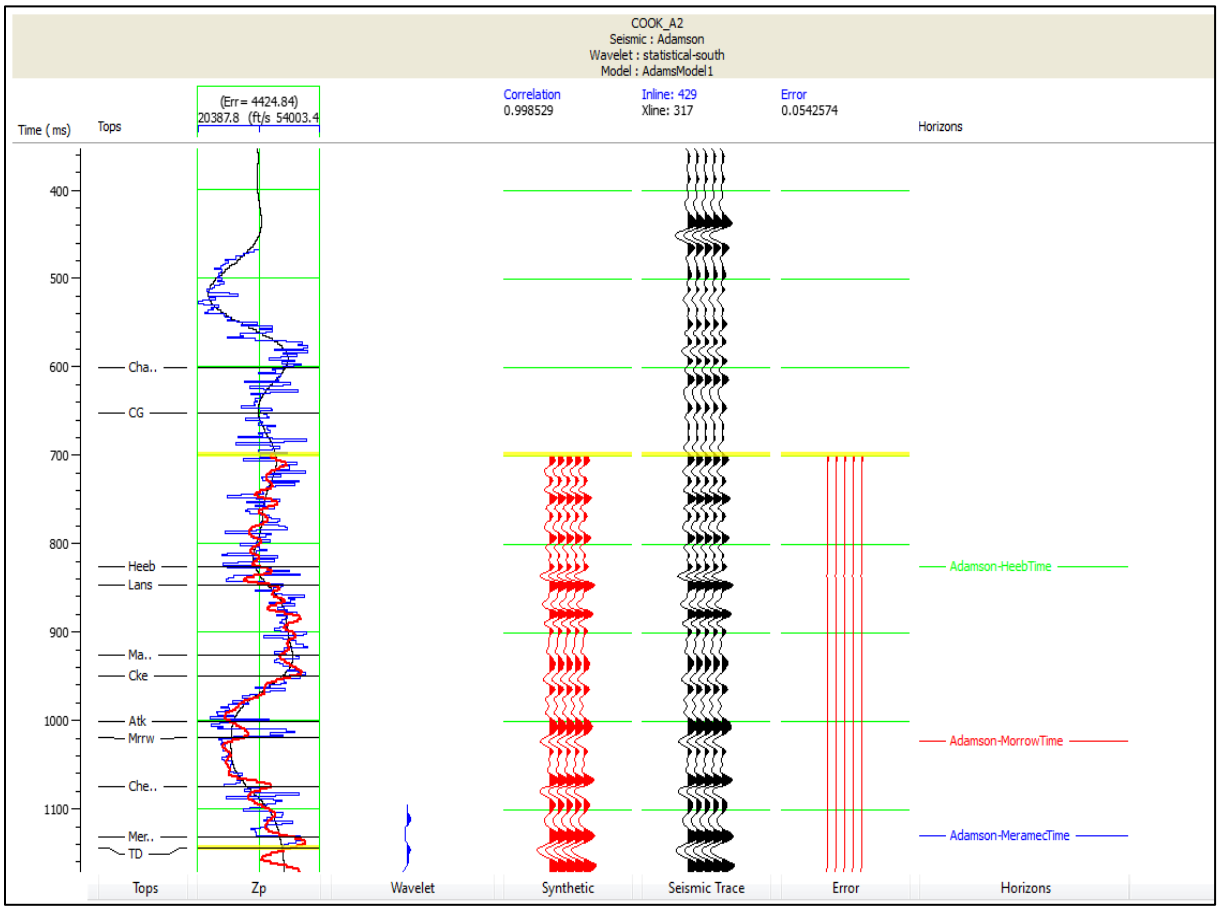


Figure 77: Inversion analysis; blue curve = input log, black = initial model; red = inverted log.

Virtually all wells used in the model building process exhibited quality similar to the well above, which is located in the heart of the IVF system, section 35, T34S R34W. The impedance log in this case (blue curve) is based on both actual sonic and bulk density curves. If a bulk density log is not available, an estimate of density character can be obtained via a Gardner's equation transform[1]. Gardner's relation is generally a good estimate for most lithologies, including clastics and carbonates. It is generally not reliable in evaporites.

[1] $p_b = aV^b$, where p_b=calculated bulk density, a=empirical constant, generally accepted to be 0.23, V= p-wave velocity, b = empirical constant, generally accepted to be 0.25.

Multiple models were built and tested for quality control. One such model is presented below and includes the sonic log control that related to that immediate area (**Figure 78**).

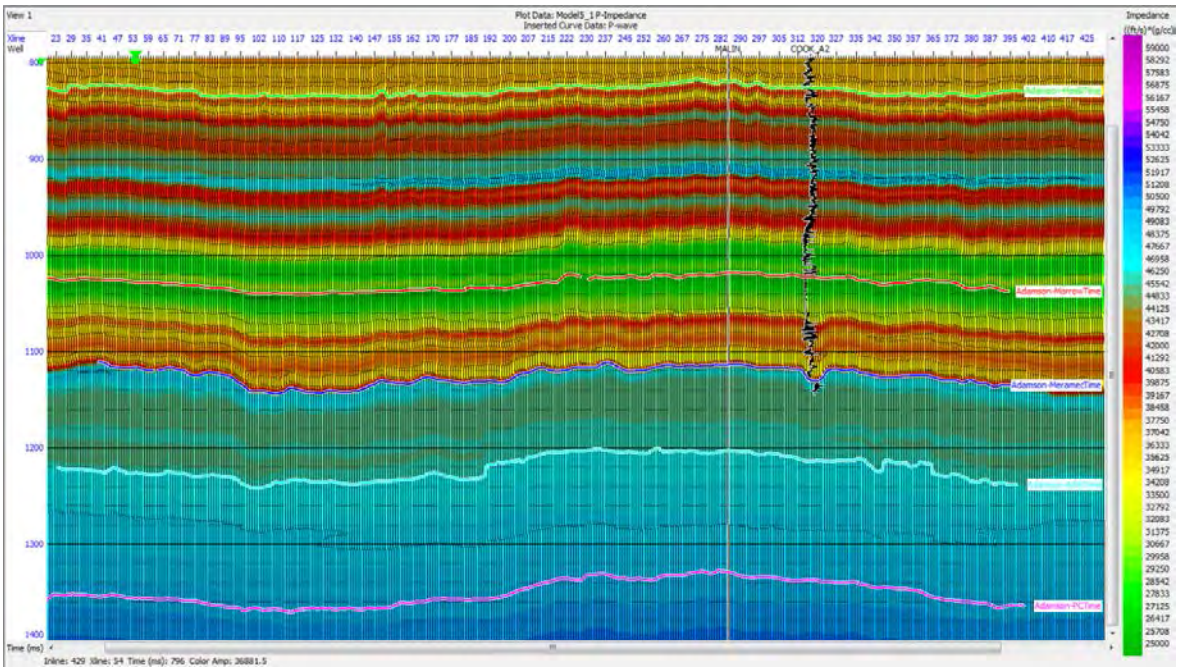


Figure 78: West-East profile illustrating model, including inserted sonic log from Anadarko Cook A2, SE SE SW, Sec 35 - T33S R34W. Topmost horizon =Heebner; Red horizon = Morrow; Horizon near base of inserted log = Meramec; Light blue horizon = Ordovician; Red horizon at base = Pre-Cambrian.

This IVF well also had actual density, so the impedance at this location is of highest quality possible. The sag on the west half of the diagram is in the thickest portion of the meander loop discussed earlier.

The higher impedance zone (red color) approximately midway between Morrow and Meramec is the top Chester. In the model this zone appears to be relatively uniform. Once the model and real data come together it will be seen that sorting out real geology is challenging.

The model is built by incorporating horizon control from prior picking into extrapolated sonic log locations, which are widely spaced. That being said, it is interesting that the model did pick up some contrast in the stratigraphic section between Meramec and Ordovician sediments. Certainly, there is considerable variation in that part of the geological section, which is evident in the inverted outcome.

The horizon characterization is based on correlation of events in the conventional amplitude domain. In that context and event such as Meramec time usually fits in the center of a peak amplitude event. Once an inversion is run, that event is translated to a high impedance correlation, with a generally sharp boundary with the lower impedance sediments above. Conventional amplitude events on inline 429, with emphasis on the stratigraphic section from Morrow to Basement are shown in **Figure 79**.

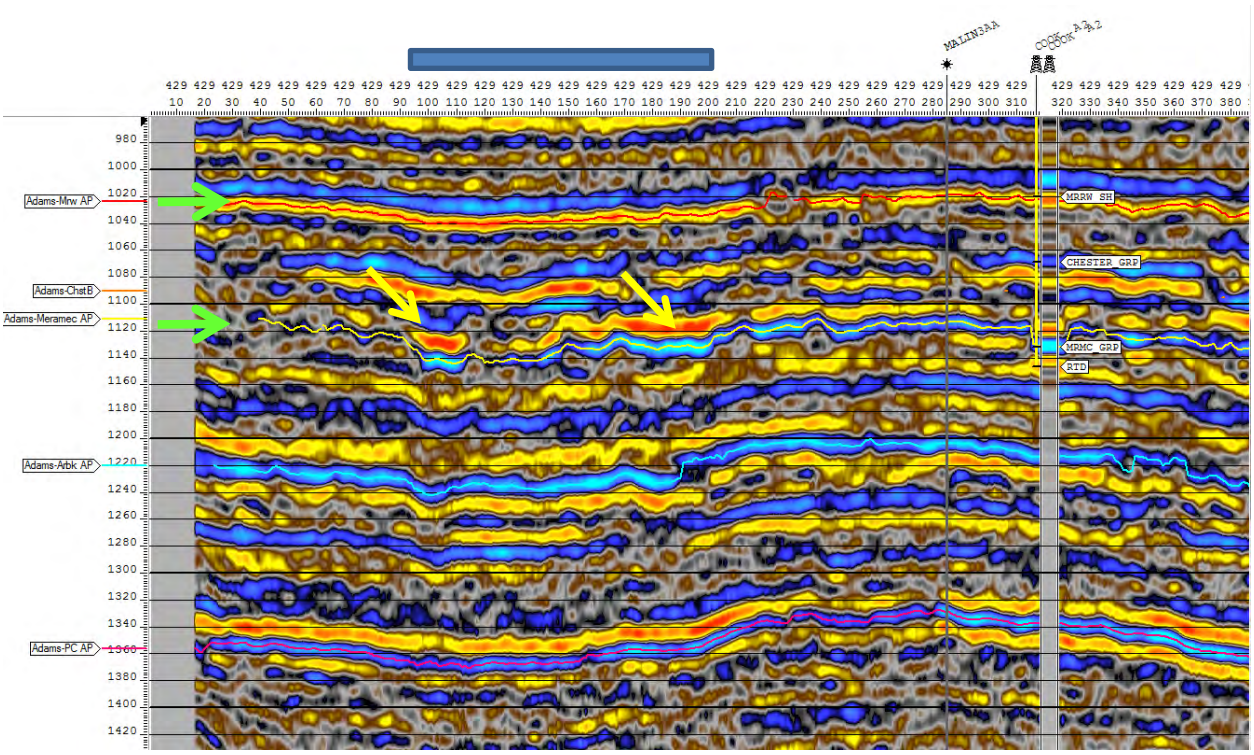


Figure 79. Conventional amplitude (variable density) profile (traces omitted to emphasize details), illustrating complexity between Morrow and Meramec (green arrows), as well as relative complexity throughout the remainder of the stratigraphic section. Blue colors relate to positive amplitude, bright colors to negative amplitude. Alluvial deposits in a meander belt are highlighted with yellow arrows. Blue bar at top delimits possible faulted graben that appears to be Chester in age.

The stratigraphic complexity observable in the conventional amplitude data between the Top Morrow and Top Meramec is obvious. The synthetic seismogram from the Cook A2 is inserted in the variable density display, and the overall quality of the correlation from synthetic to real data is good. The hotter amplitudes on the left part of the profile just above Meramec (yellow arrows) are related to alluvial sediments within the meander belt.

The case can be made for a nearly vertical fault at or near crossline 200, with offset commencing at approximately Chester time, continuing through the Ordovician and likely continuing into Pre-Cambrian, although offset at the unconformity is softened. A similar condition exists on the west edge of the system at around crossline 95 (See blue bar in **Figure 79**).

On the right side of the image (east), the Morrow - Meramec isochron is generally around 95 ms, with the exception of the IVF, where the isochron time thickness is >105 ms. In the meander belt on the middle left (west) portion of the image, the maximum isochron is ~103 ms.

The companion impedance profile is shown below, again without trace overlay to expose as much detail as possible (**Figure 80**).

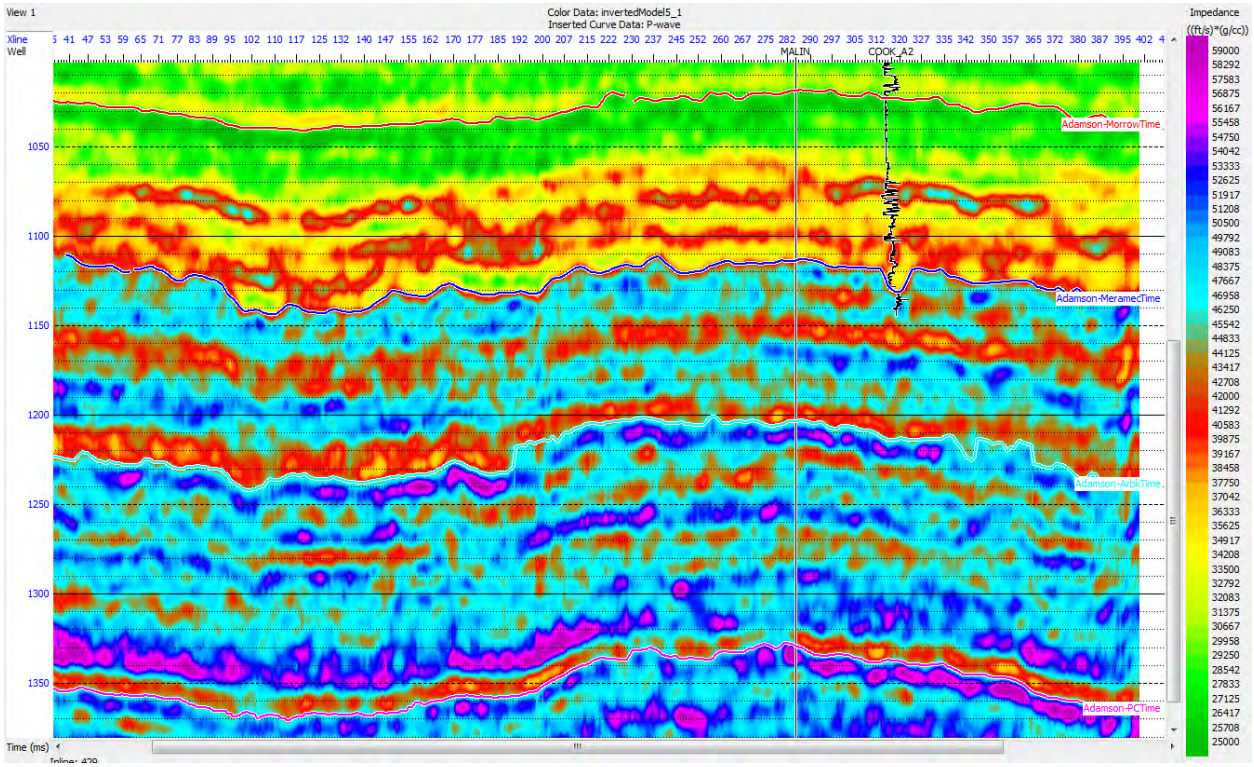


Figure 80: Acoustic impedance on inline profile 429. Cook A2 P-wave log trace overlies profile.

This profile is coincident with the preceding amplitude profile (**Figure 79**). Notice the sharp boundary at the interface with Meramec sediments, at a time of around 1110 ms on the left edge of the profile. Sediments above register in the range of 25,000 - 30,000 impedance units; sediments immediately below are in the 45,000 - 50,000 unit range.

Lighter blue shading in the Chester sequence most likely relates to carbonate rocks, with green shading leaning toward shales. Magenta colors will be tighter, denser carbonates. Generally speaking, the most optimum range for sandstone is from about 30,000 - 35,000 impedance units. In the Cook A2 well, the Lower Chester sands have an impedance range of 33,000 - 34,000 impedance units.

A bounded time horizon slice has been extracted from the 3D volume that covers the lowest 15 milliseconds of the Chester sequence, which will relate to approximately the lowest 90 feet of sediments in the IVF (**Figure 81**). Many of the commercially productive wells in the IVF have come from this part of the system, although some wells will produce from shallower sands in the Chester, and some wells will produce from Morrow sands above Chester.

In map view we can then associate and compare impedance with amplitude (**Figure 81**).

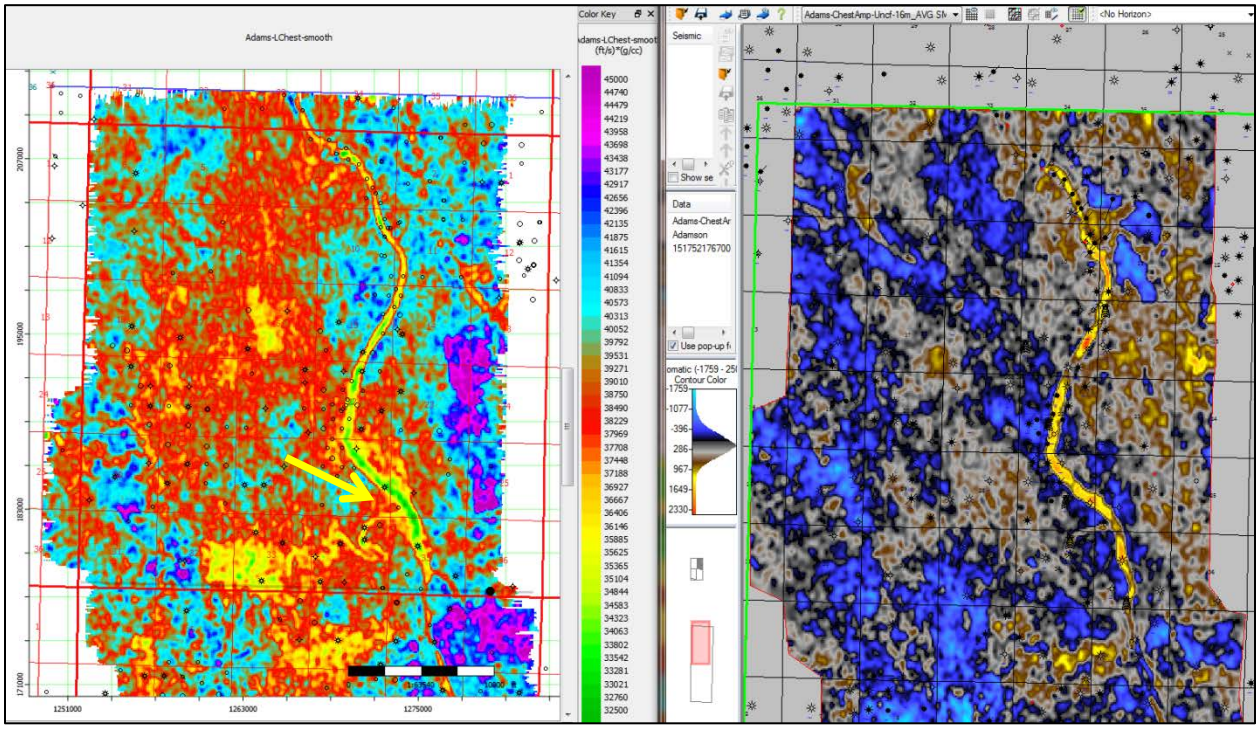


Figure 81: Lower Chester extracted impedance time window (left) vs extracted amplitude window (right). North half of study area. Color scheme for impedance changes with more limited geographic extent. Now, greens are more likely to be sands. Yellow arrow is mouth of a tributary as it enters the main IVF.

The color scale in the impedance map view has been adjusted slightly from the scale that pertained to the impedance profile, such that the lowest impedance on the color scale is now set at 32,500 and the highest at 45,000. This allows for better discrimination of the sand system.

Note that the impedance mapping clearly tracks the tributary feeding the main IVF (yellow arrow **Figure 81**), while the amplitude mapping tends to lose track of this anomalous character. It is also the case that the impedance mapping has a much greater ability to discriminate lithologies overall.

In the case of the southern portion of the 3D volume (**Figure 82**), a significant faulted structure exists with the downthrown block located east of the fault. However, it is worth noting that the lithological character for the most part continues relatively unabated across the fault, certainly implying that the fault post-dated the stratigraphic distribution that existed pre-fault.

On the other hand, it is apparent that a significant stratigraphic discontinuity also occurs, outside and independently of the IVF, in the vicinity of the Archer field, sections 15, 22, 23, 26, 27 T34S R 34W. The NNW -SSE edge defining that system is not at all apparent in the amplitude mapping of the Lower Chester.

It is also important to note that the southward continuation of the IVF is easier to discern again in the impedance domain. It is also apparent that an additional arcuate feature (red arrow) can be identified in sections 23, 24 and 25, T34S R34W, which does not seem to have expression in the amplitude extraction. The Oxy-Gleeson C3 well is located in this feature, and it appears it was completed as a gas well in Chester sediments.

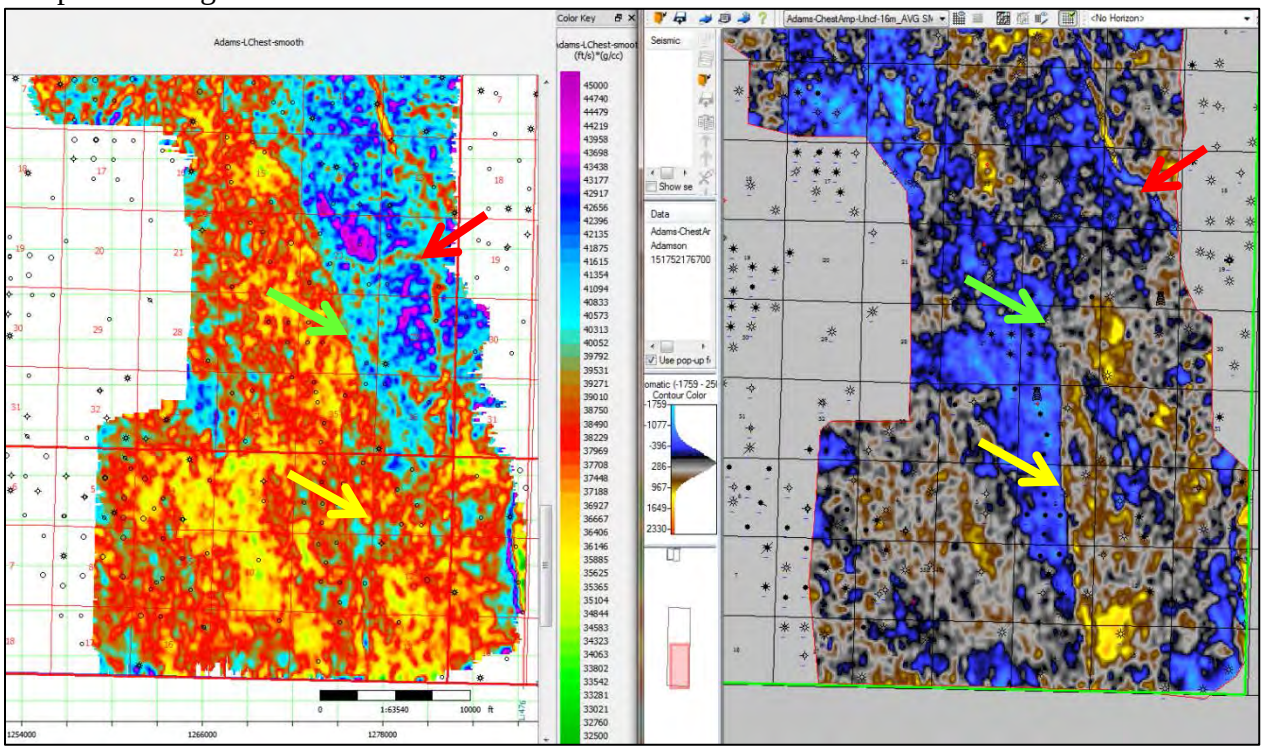


Figure 82: Lower Chester extracted impedance vs amplitude, south half of study area. Color scheme consistent with Figure 81. Green arrow = lithologic discontinuity; yellow arrow fault with no apparent lithologic change across it in this time slice; red arrow = arcuate feature.

Volumetric Curvature Characterization

The 3D volume was also processed to enable volumetric curvature, specifically Most Negative Curvature, in order to evaluate possible preferred orientations related to fracture systems and /or discontinuities (**Figure 83**).

The approach taken was one of maximum resolution, with a 3 trace average in an x-y sense, and a 2 sample smoothing in a vertical sense.

The results have provided an opportunity to view both structural and stratigraphic context simultaneously in some cases, again with focus on the IVF system / Lower Chester sediments. However, the evidence of preferred orientation across a broad vertical range is fairly consistent, and we see the azimuthal expression very well defined in a time slice at 1072 ms. The dominant azimuthal trends seem to be very close to N 45W/S 45E, with the conjugate set generally settling

around N 35-40E/ S35-40W. Locally, these ranges vary, but they do seem to be fairly persistent even into the Basement. Deeper into the volume we see the clear expression of the IVF anomaly, and simultaneously we can note the persistence of the linear anomaly in the south central extremity of the survey.

The big picture grain and the combined structural/stratigraphic look are shown in **Figure 83**.

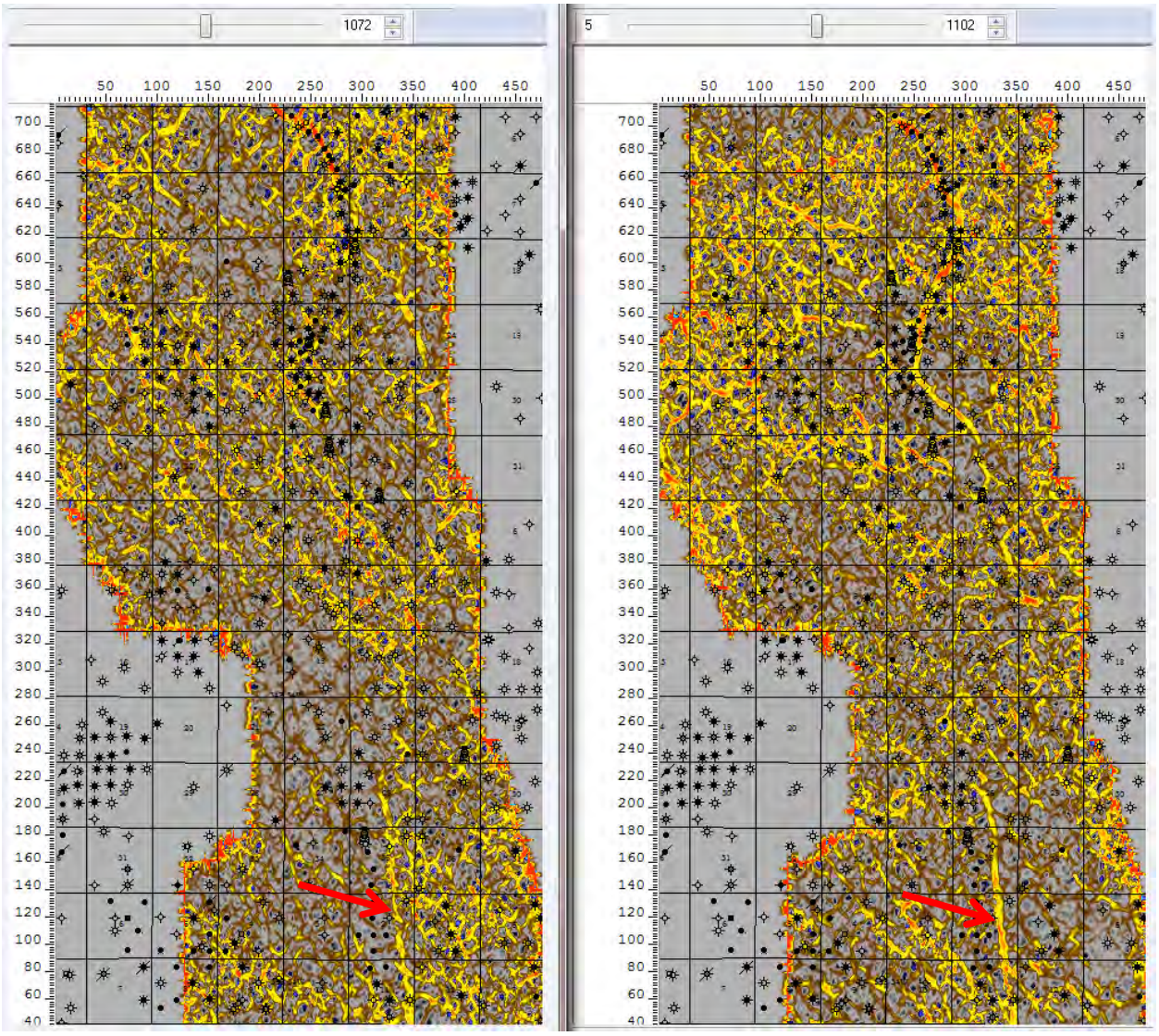


Figure 83: Most negative curvature. Left plate from 1072ms, illustrating the appearance of the dominant NW-SE grain in the middle of the frame, and in the right plate, the combined structural element in the bottom center, and the stratigraphic component related to the IVF in upper right. Red arrow at location of a fault verified with offset.

While these are smaller in scale, we can certainly note that the fault bounding discontinuity in the bottom center is expressed in both plates. This structural element is first seen somewhat defocused at about 1020 ms, which places it at approximately Morrow time. It is virtually continuous through approximately 1140 ms.

The wedge shaped character outlined west of the linear anomaly appears likely to be related to the upthrown block that is expressed on the depth converted Meramec structure map shown earlier.

The IVF anomaly at 1102 ms in **Figure 84** is very clearly expressed and, as in other study areas in the region, the vertical extents of the IVF curvature anomalies can be seen to be well connected over many hundreds of feet. The image below is an extracted north-south profile that transects multiple IVF related features.

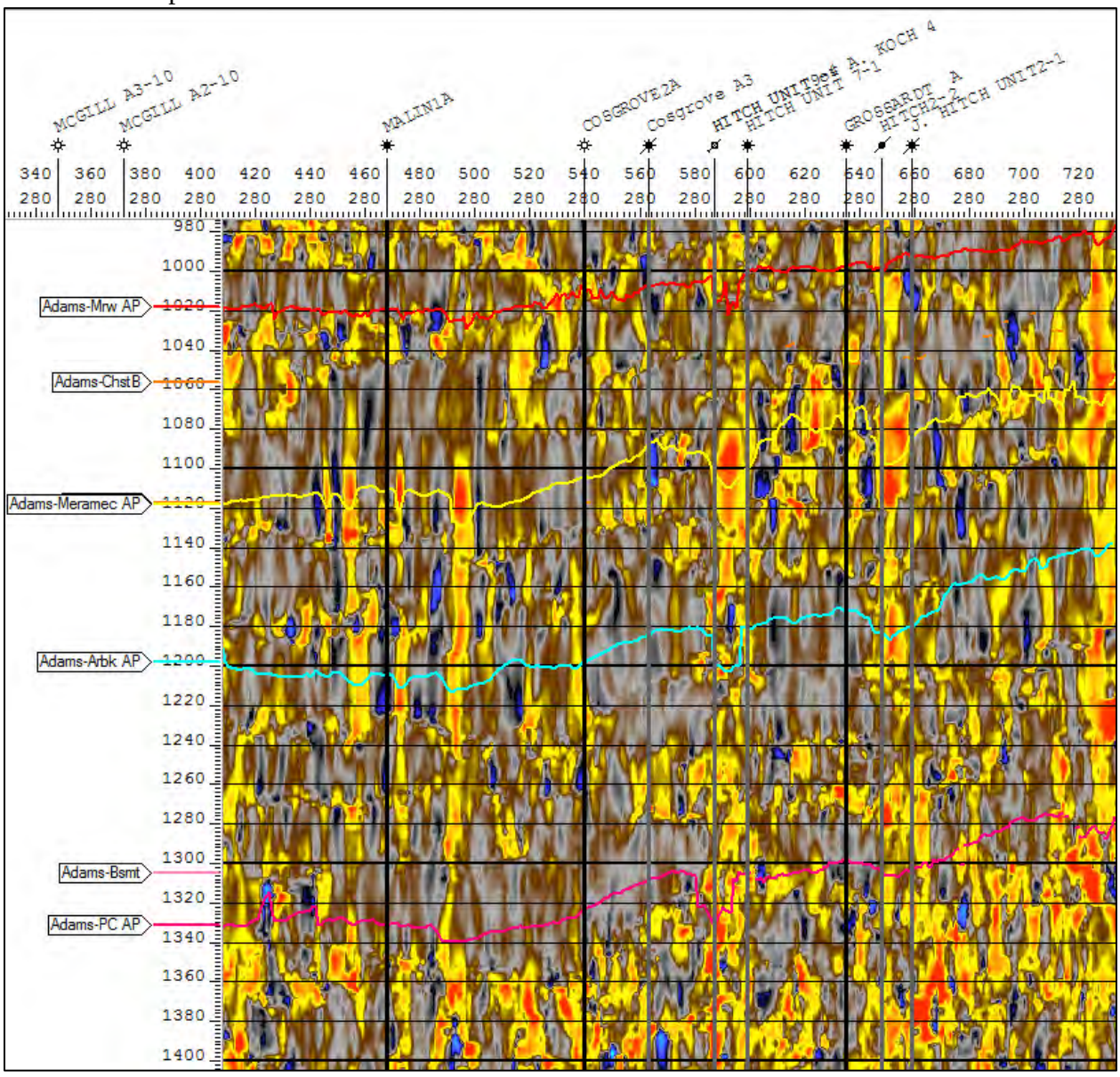


Figure 84: Most negative curvature, vertical profile, crossline 280, south (left) to north (right). Vertical anomalies from Chester to Basement.

The larger vertical anomalies at stations 280/655, 595 and 495 are related to the primary IVF system. The virtually continuous 'pipe' extends in an accentuated sense from just above 1100 ms

well into Basement at 1400 ms, and beyond. At that location, the Meramec occurs at a depth of about 6300 ft, while Basement would likely be penetrated at about 8500 feet below surface. Therefore, the vertical extent of the anomaly appears to exceed 2000 ft.

The smaller anomalies in the vicinity of the Malin-1A well are related to the tight meander belt discussed earlier in section 34, T33S R34W.

Conclusions on the Shuck Field Seismic Discussion

This dataset provides an opportunity to see with high spatial resolution multiple elements that relate to the IVF system, both structurally and stratigraphically. Significant well control afforded the opportunity to truly tune the structural details that related to the IVF and tributaries, as well as the fault block in the southern study area.

Acoustic impedance inversion provides an ability to realistically discern between various lithologies, including sand, shale, and carbonates. While pre-stack data was not available, and therefore presented some limitations in terms of further quantification of for example VpVs ratio, the available post-stack volume did provide some qualitative differentiation of lithologies.

Volumetric curvature, applied at the highest resolution, yielded insight related to likely fracture system background that has likely driven at least in part the genesis of the IVF system. Zones of weakness were in certain time intervals quite obvious. The vertical connectedness of certain anomalous features would seem to suggest that the IVF may very well be sourced from underlying Basement structure.

Shuck / Adamson Seismic Characterization --Documentation that a Prominent N-S Fault in the Southern Portion of the Seismic Survey has a Prominent Strike-Slip Component

The regional seismic volumes were examined together to evaluate fault type, timing, and effect on sedimentation, i.e., evidence for episodic structural activity. A portion of this review is presented here and will be expanded on in the final report. The conclusions are

1) high angle reverse and strike-slip faulting is more common than believed;
2) faulting is clearly linked to the tectonism of the Ouachita-Amarillo-Wichita-Arbuckle system in both timing and apparent stress regime that was imposed on the southern Kansas shelf;
3) peak movement of the faults consistently occurs in late Morrow-Atokan that led to the reorganization of the shelf, uplifts, and the depositional system;
4) evidence for the contribution of tectonics to deposition is complicated by concurrent changes in sea level;
5) faulting greatly diminishes above the Upper Pennsylvanian, but examples have been identified where faults change their sense of movement during the early Tertiary Laramide tectonism associated with the Rocky Mountains and even younger, late Tertiary affecting deposition and deformation of the High Plains Aquifer; and
6) many structure characterized by the 3D seismic show multiple episodes of structural deformation expressed by growth/differential sedimentation across the structure including

lower Paleozoic, e.g., notable thickening of the Arbuckle and Mississippian strata across major faults.

Evidence for a major strike-slip fault in the Shuck Field area is presented in **Figures 85-91.**

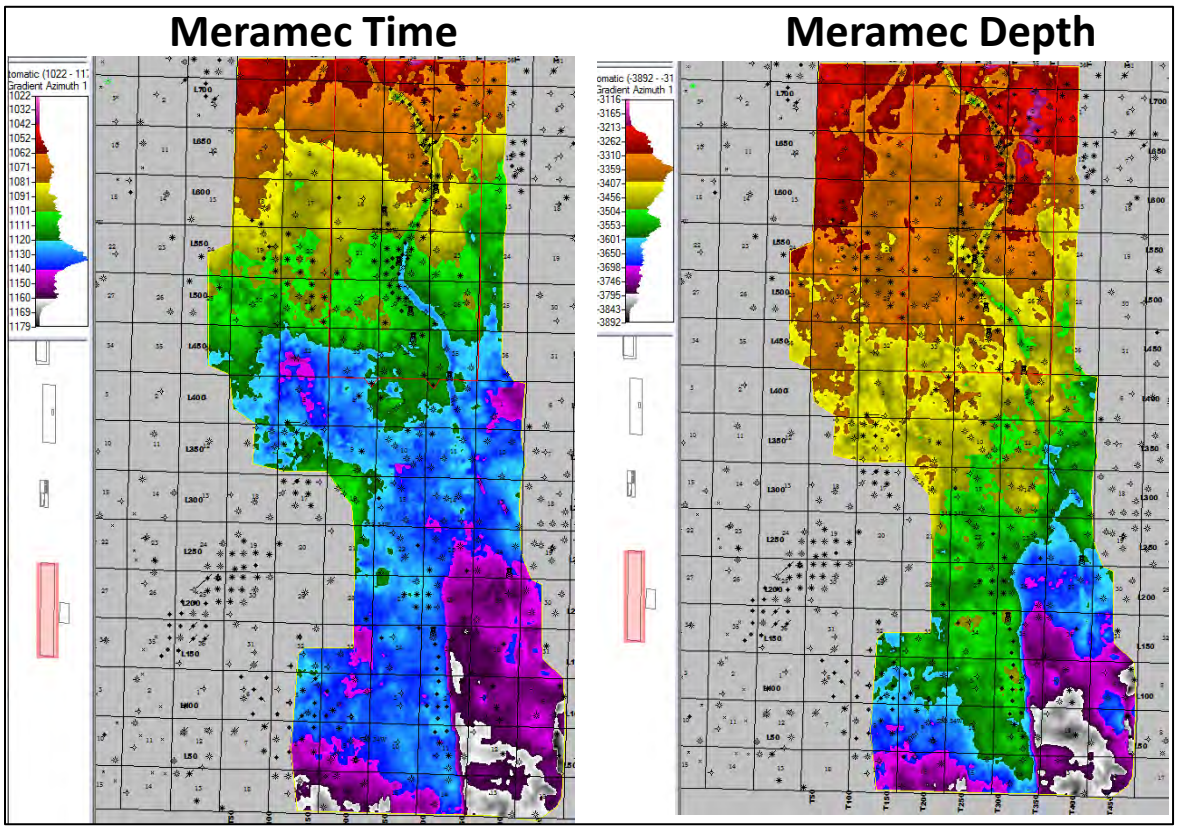


Figure 85. Near surface velocities coupled with real stratigraphic complexity render the overall time structure indications to be of somewhat limited use. However, Depth Converted Structure is reasonably well adjusted due to significant well control availability. The structural nose in the south central portion of the Meramec Depth contains a reverse fault on the east flank.

Depth 1 – Slightly reduced detail **Depth 2 – Slightly increased detail**

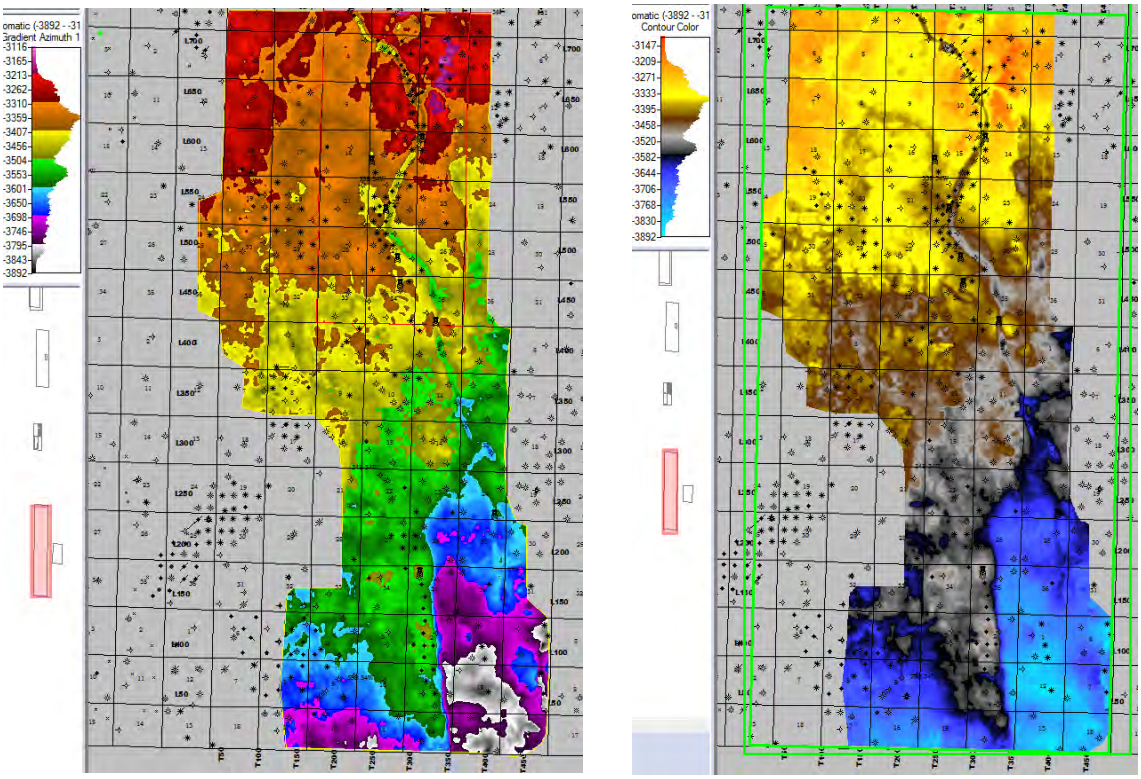


Figure 86. Meramec Depth – Dynamic Range Comparisons.

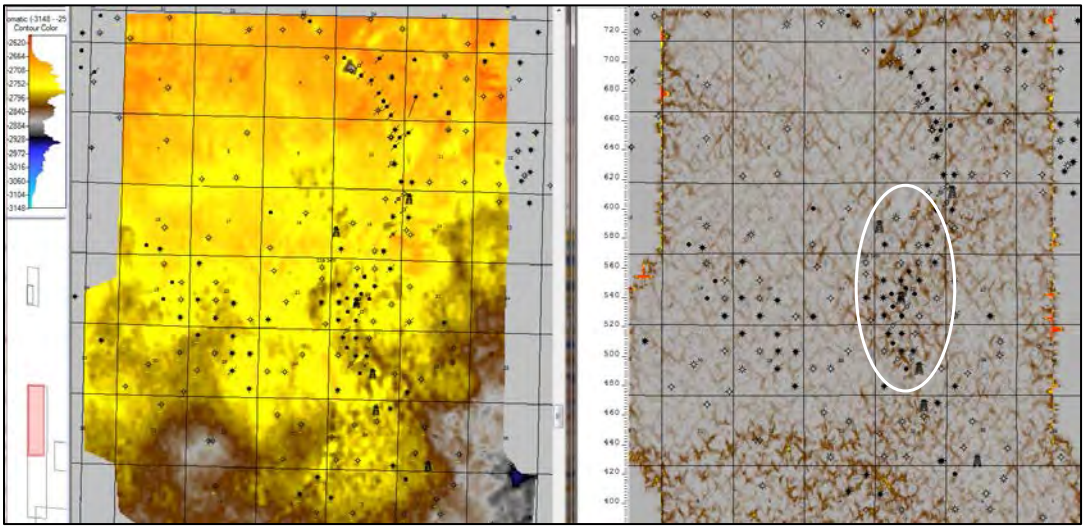


Figure 87. Shuck Area - Morrow Depth Structure w/ Most Negative Curvature 996 ms. Note distinct NW-SE Lattice in VC image, and the correlation of the Karst feature in the NW4 section 3, coalescing the intersection of VC lineaments. Note also the increased chaotic, disturbed VC character in the Shuck Field proper.

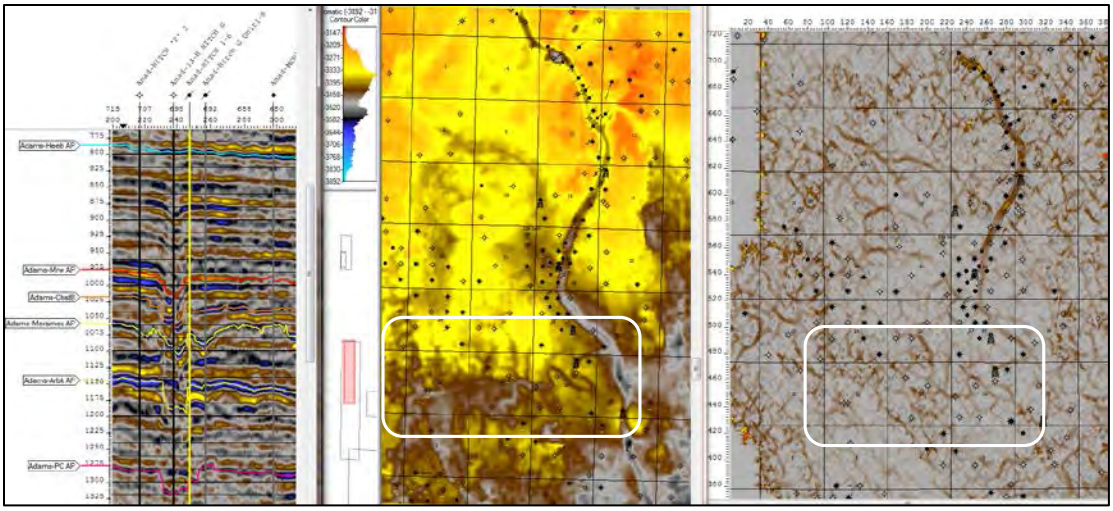


Figure 88. North Shuck Area - Arbitrary Profile Thru Karst Feature w/ VC 1096 ms. Note structural collapse at Anad-13H Hitch G: Top Morrow at 13H (-2884), 1024 ms; that at Hitch 1-6 (-2719), 990 ms. Top Meramec at 13H (-3472), 1095 ms; that at 1-6 (-3398), 1073 ms. Locally, North end trap in IVF occurs at the Karst feature. Lattice structure in VC still evident. Southern meander belt also expressed in VC.

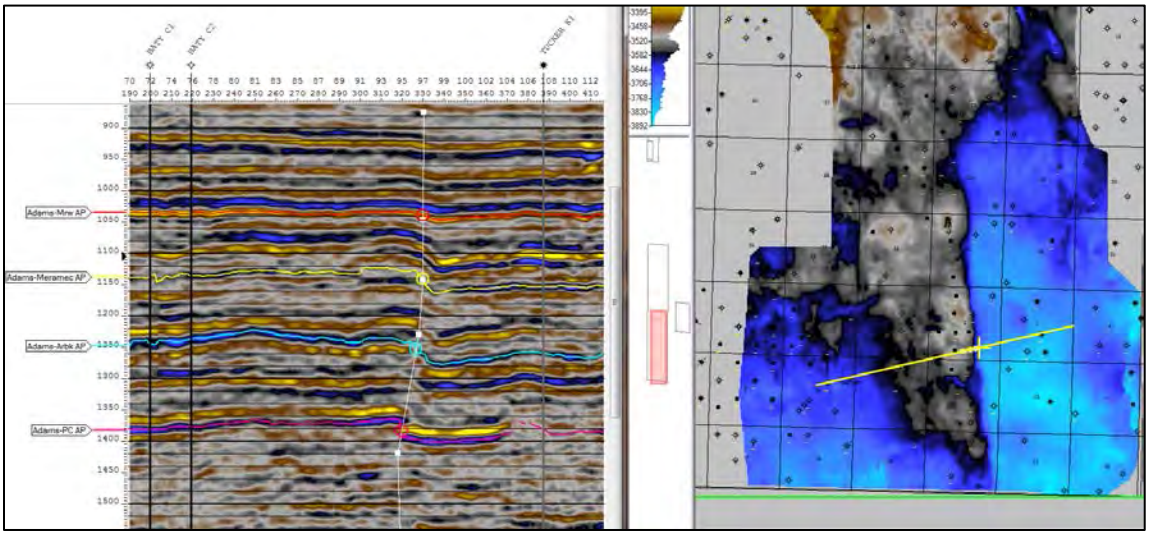


Figure 89. Archer – Liberal West Reverse/Strike-slip Fault -- Horizontal offset from trace 330 (fault tip) to trace 319 (below Precambrian) is approximately 1200 ft. Meramec datum at Baty C1 (-3648), that at Tucker K1 (-3809); Vertical relief 161 ft.

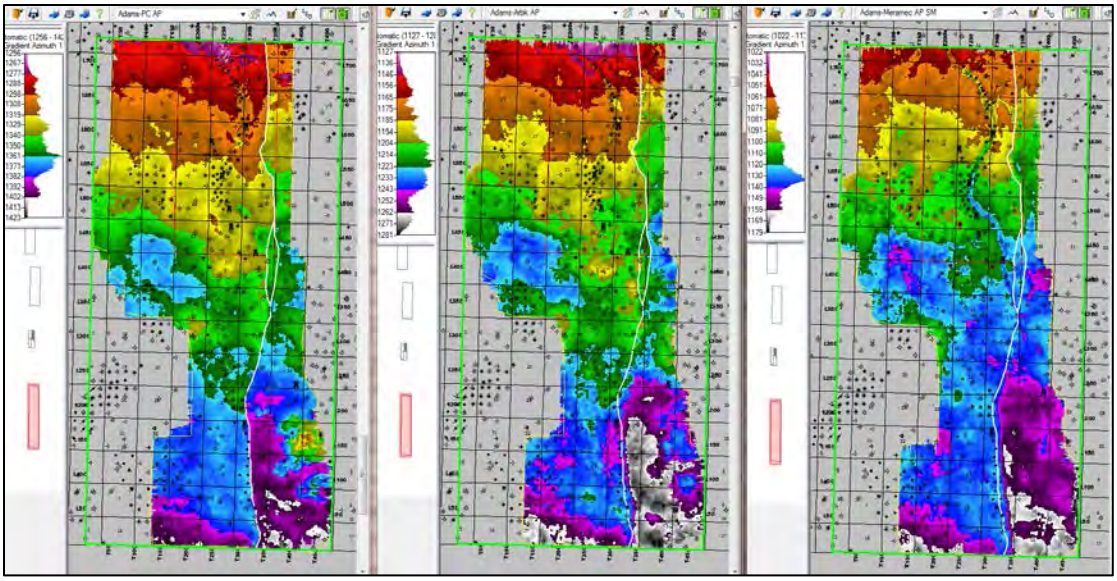


Figure 90. Primary East Bounding Fault - Shuck to Liberal West. Leftmost image is Basement Time, illustrating approximately 2 miles of northward movement of right block relative to left. Lower segment is thrust related, middle region exhibits primarily vertical to normal faulting, northern region returns to slight high angle reverse displacement. Arbuckle Time illustrates the overhang in southern region; Meramec Time illustrates overhang in northern region.

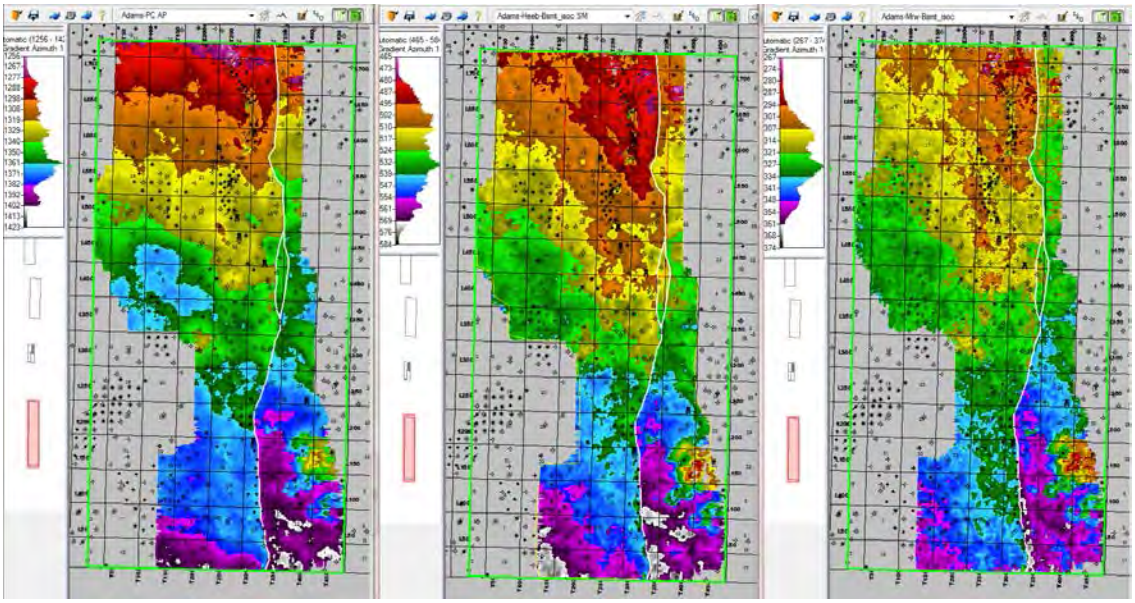


Figure 91. Shuck –West Liberal High-Angle Reverse/Strike-Slip Evidence in Isochrons. Left Image Basement Time, Middle Image Heebner-Basement Isochron, Right Image Morrow-Basement Isochron. It would appear that the corroboration of strike slip movement is evidenced in each of these isochrons, probably more so in the Heebner to Basement.

The structural activity north of Shuck 3D seismic area includes Pleasant Prairie, Eubanks, and Cutter Fields. While the evidence of strike-slip deformation are not proven with clear evidence of lateral movement, the observations from the seismic clearly point to this indicating that tectonic stress was transmitted considerable distances onto the shelf.

Figures 92-117 provide snapshots of the other 3D seismic surveys in the three fields north of Shuck area.

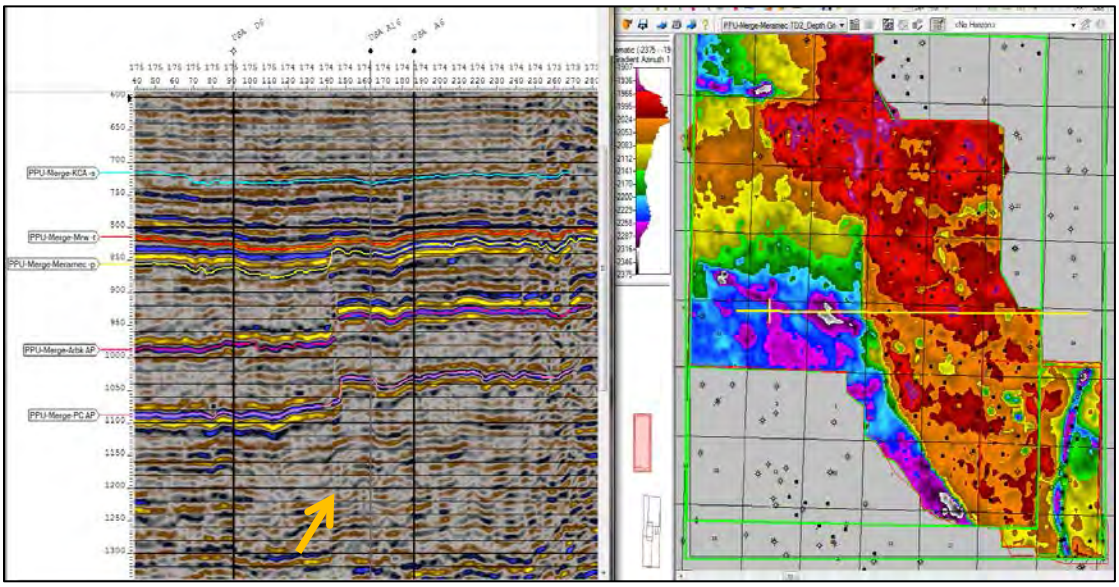


Figure 92. Pleasant Prairie Seismic -- Profile illustrating structure in vicinity of west bounding reverse fault (orange arrow at fault cutting Proterozoic rock. Top Meramec at USA D6 (-2237), at A16 (-2043), at A6 (1999). Note that bounding fault (sta 142 at Meramec, drifts east to sta 147 at PC, implying 550 ft offset. Also, not the increase in the Meramec-Arbuckle isochron west of the bounding fault. Smaller fault immediately east of the bounding fault affects Arbuckle, but not the top of Meramec suggesting an earlier, pre-top Meramec movement.

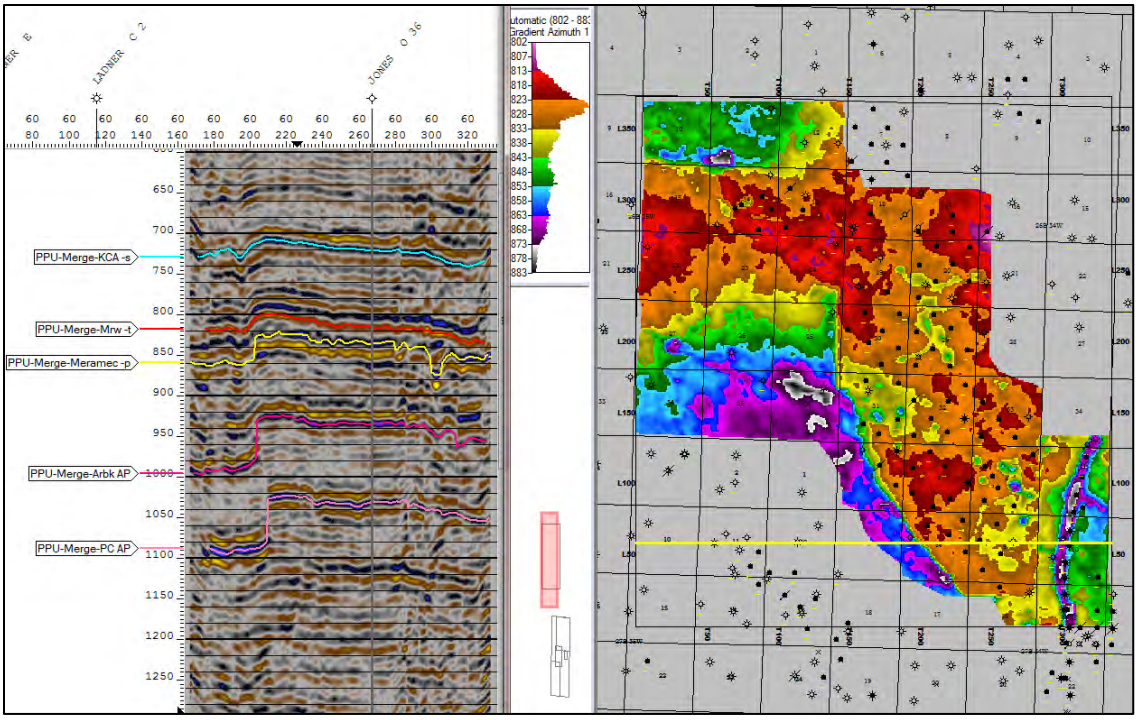


Figure 93. Pleasant Prairie -- West Bounding High Angle Reverse Fault. Fault tip at 650 ms (above KCA horizon) occurs at Crossline 196, tip at Basement at 1028 ms occurs at Crossline 209. West-east offset is 1430 ft. Heart of IVF is seen at Crossline 302. Map is Meramec Time. IVF along west flank of an apparent horst block bounded by high-angle reverse faults. Eastern edge of horst is broken by discontinuous reflectors and staggered offsets indicative of a fracture zone along which the IVF apparently followed due to structurally compromised strata. Note again that the Meramec-Arbuckle isochron thickens across the western bounding fault. Internal reflectors suggest thickening of the Mississippian strata in this interval on the downthrown side, i.e., evidence for concurrent growth of the structure during sedimentation.

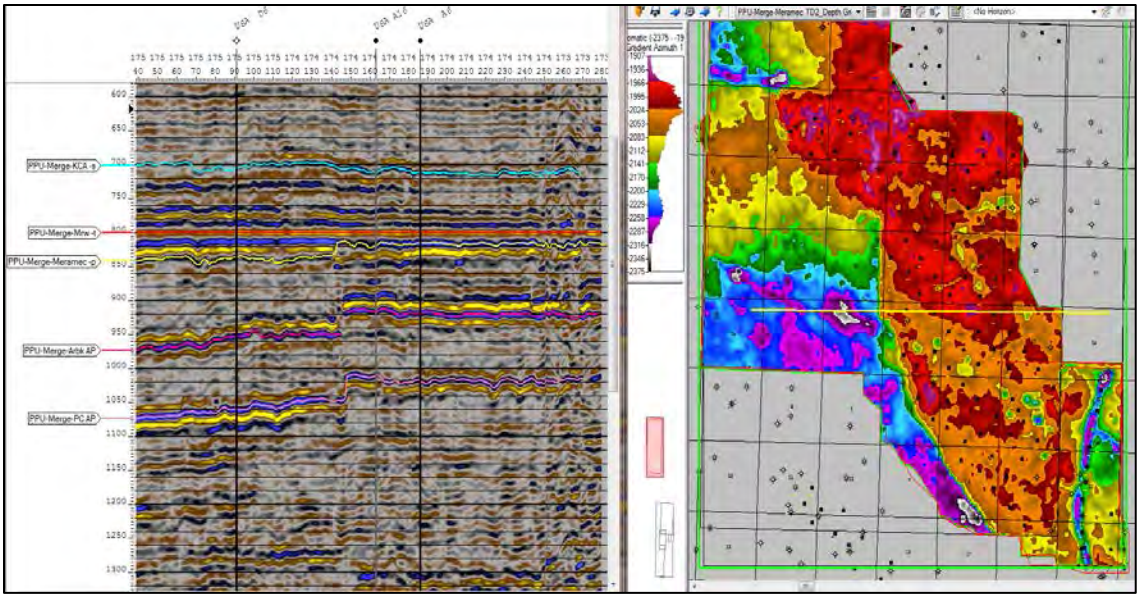


Figure 94. Pleasant Prairie Stratigraphy. West-East Profile Flattened @ Morrow = 800 ms. Note that Meramec – Arbuckle thickens ~ 15 – 30 ms on downthrown side. Arbuckle-PreCambrian also thickens ~ 15 ms on downthrown side. Note also that KCA – Morrow thickens ~ 8 ms on downthrown side. The core of the horst block is intact while the east side again shows discontinuous seismic reflectors.

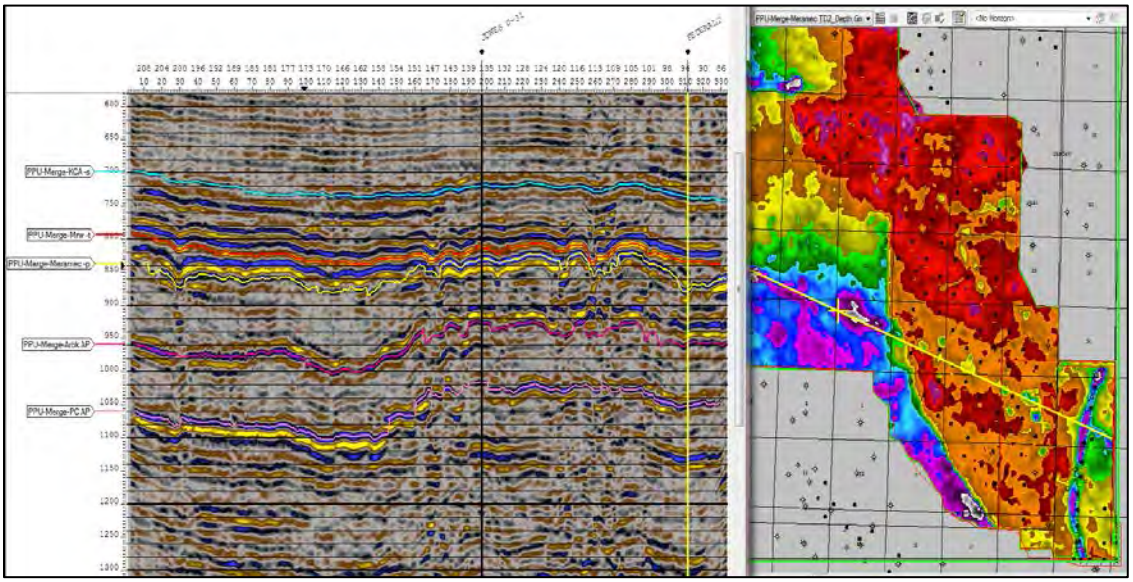


Figure 95. Pleasant Prairie Karst. Arbitrary profile illustrating multiple karst features. In most cases, 'pipes' extend well below Meramec, into Arbuckle/ Prominent features noted at stations 30, 170, 242, 260. IVF system at sta 310, note that profile continues SE of Federal 2 to the IVF tributary. The karst appears to be linked to fragmentation of the horst block especially on the edges. The radiating patterns are also suggestive of a flower structure suggesting strike-slip deformation perpendicular to the plane of the seismic section.

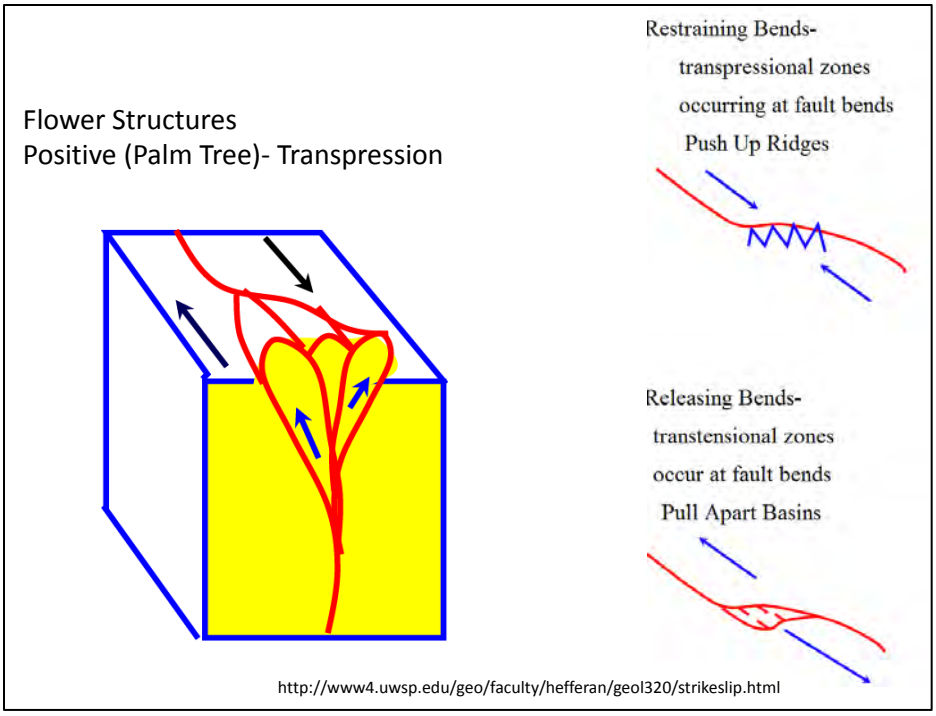


Figure 96. The flower structure results from the accommodation of a change in the direction along a strike-slip fault system, the one shown on the left being a right-lateral fault. A bend in the fault can lead to a push up ridge as illustrated in the upper right. The horst block at Pleasant Prairie with flower structures suggests that it is developed along a restraining bend. The deformation is long lived from the Arbuckle well into the Upper Pennsylvanian.

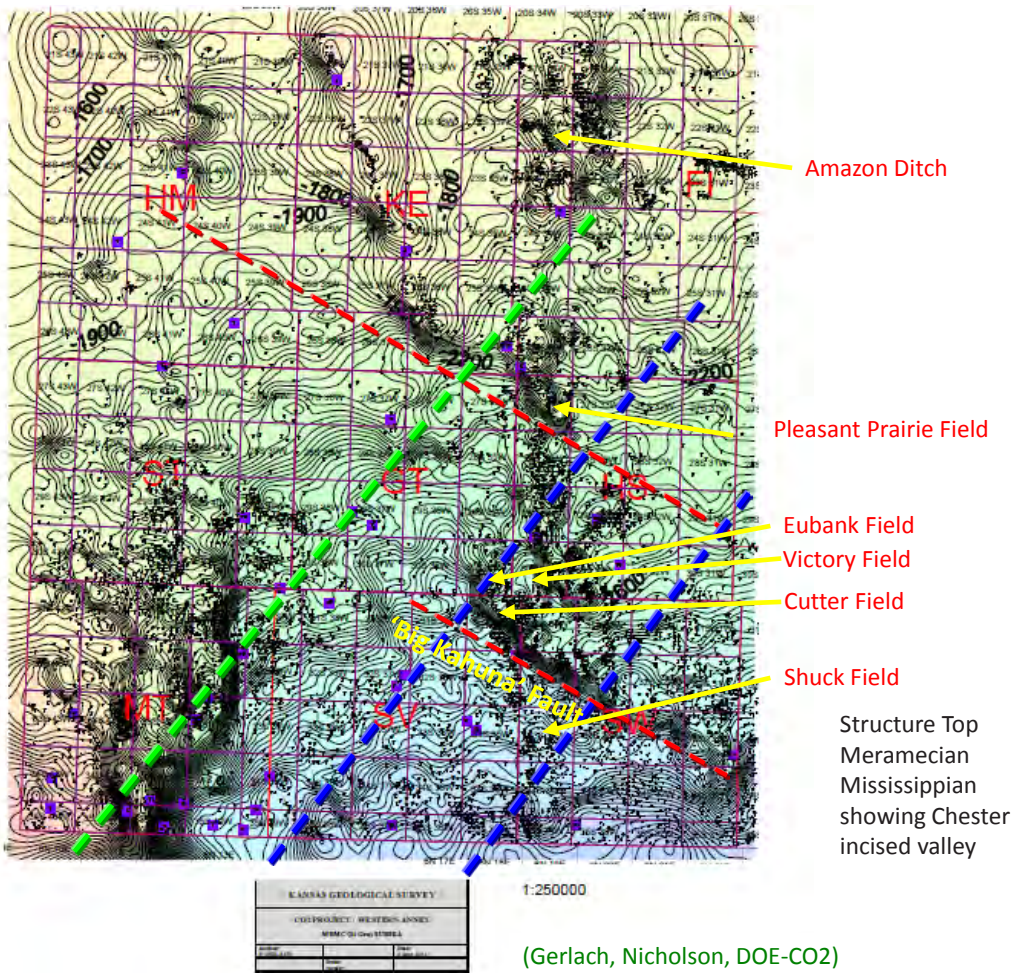


Figure 97. Top of Meramec structure in southwest Kansas with the location of Shuck and Pleasant Prairie fields discussed thus far in this section. Shuck and Pleasant Prairie fields lie along the interaction of lineaments that are long lasting. Shear stress transferred to the shelf from the basin appears to have interacted with these lineaments transferring the stress to inherit weaknesses leading to bending of the faults.

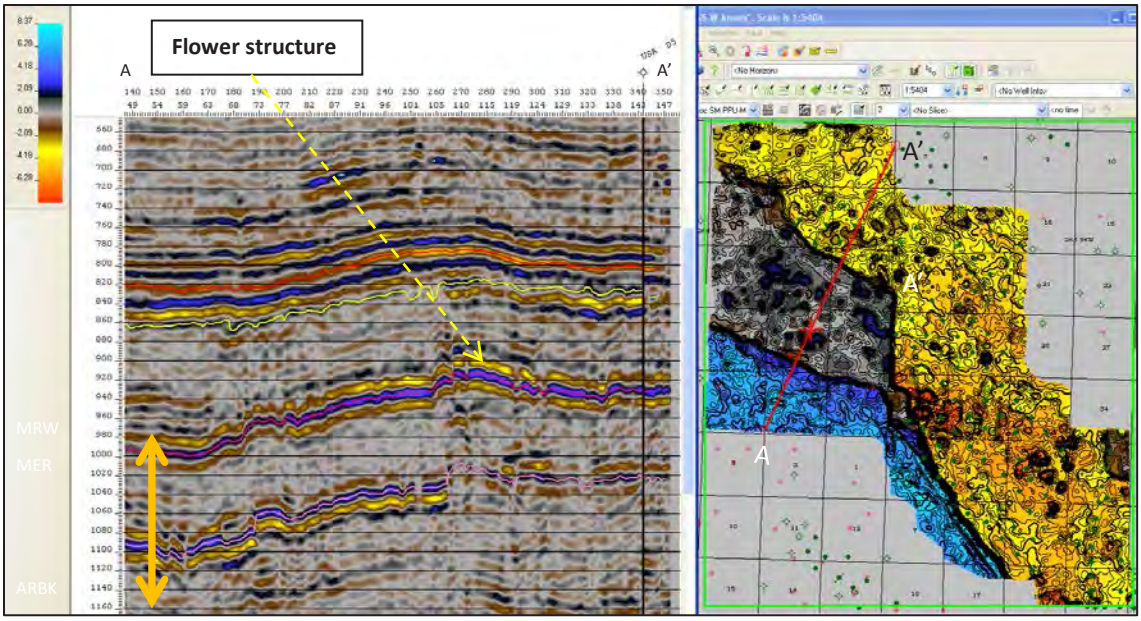


Figure 98. Pleasant Prairie – Morrow - PC Isochron -- Note that while structural arch is clearly exhibited, isochronal thickening occurs in discrete step changes at two fault zones. Radiating fault pattern clearly identify a flower structure along the inner fault zone, not the leading fault. The leading fault zone is comprised of a number of faults, but they are not developed in as clear a radiating pattern. The IVF is not expressed in this isochron. Multiple karst intervals are present including 1) concentration covering the structural terrace between the bounding and inner fault on the northwest, 2) the NW-SE trend in the SE portion of the map that extends east of where the bounding fault would project rather than the bend to the south.

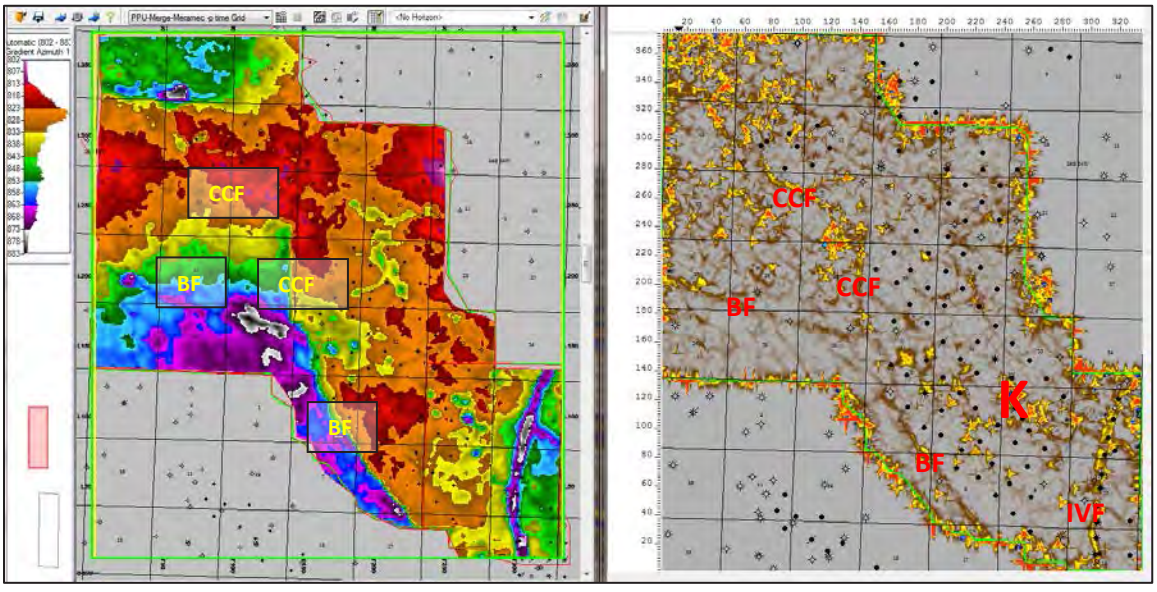


Figure 99. Pleasant Prairie Meramec -- Meramec Time Structure (left) and Most Negative Curvature at 860 ms (right). West bounding fault (BF), cross cutting fault (CCF), karst (K), and IVF are all well expressed.

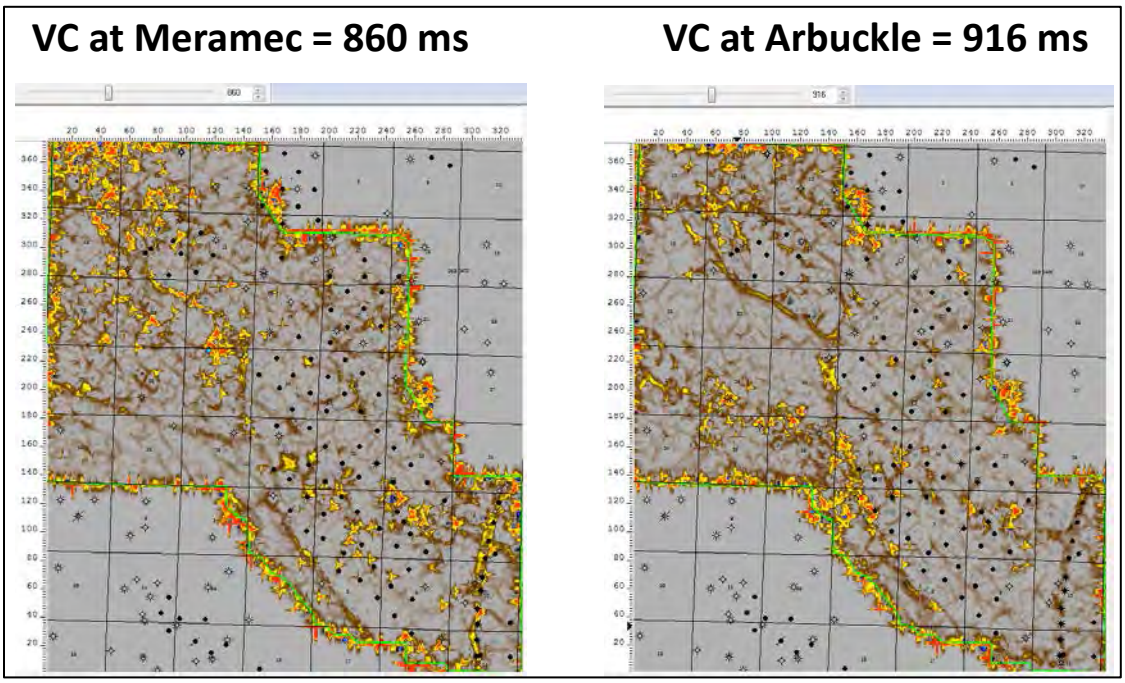


Figure 100. Volumetric curvature at the Meramec and the Arbuckle are very similar reflective of the scale of faulting affecting both horizons. The NW-SE trending karst in the southeast is also similar.

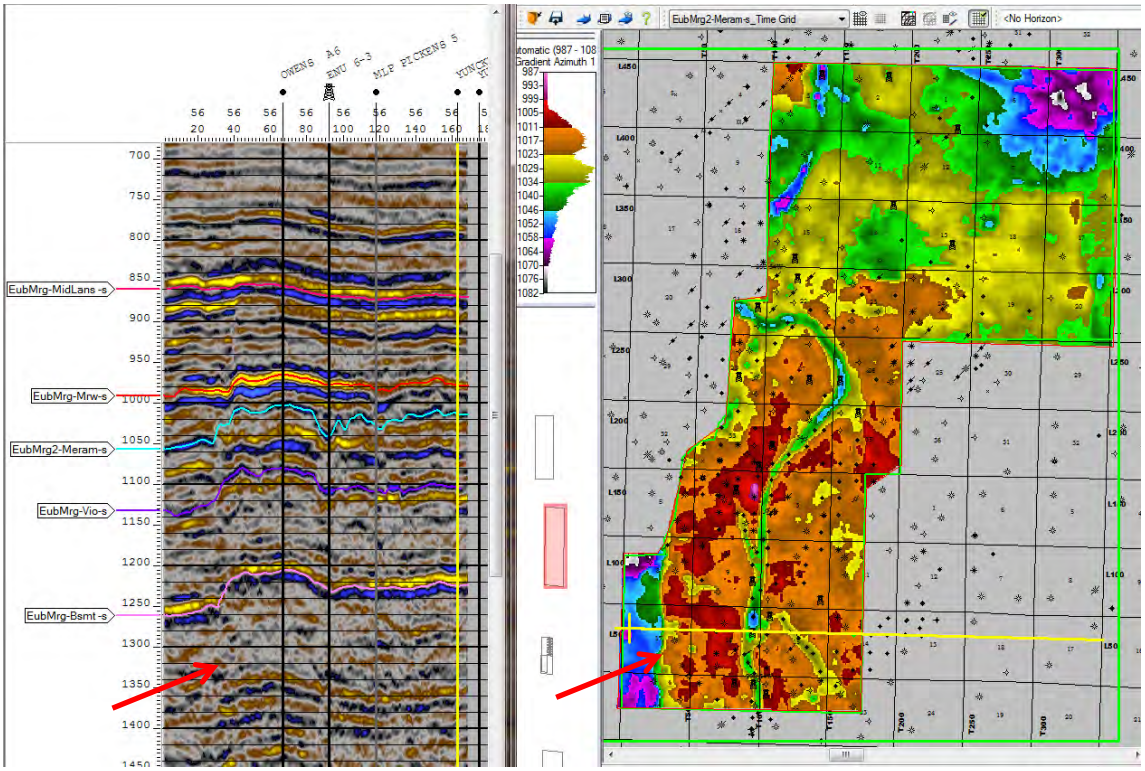


Figure 101. Eubank Seismic Expression – Note west bounding normal fault (red arrows) at approximately crossline 40. Profile crosses elevated structure, IVF and

tributary to IVF. IVF cut (Crossline 92) is not as deep as downthrown block at Meramec. Tributary shallower yet at Crossline 120. Top Meramec at ENU 6-3 (-2563), at Pickens 5 (-2438). Pickens 5 not drilled in deepest Meramec cut in tributary. IVF similar to Shuck and Pleasant Prairie where IVF is on the east edge of the current day structural high. Isocore thinning over the structural highs suggests concurrent structural deformation during sedimentation and probably during the formation of the IVF.

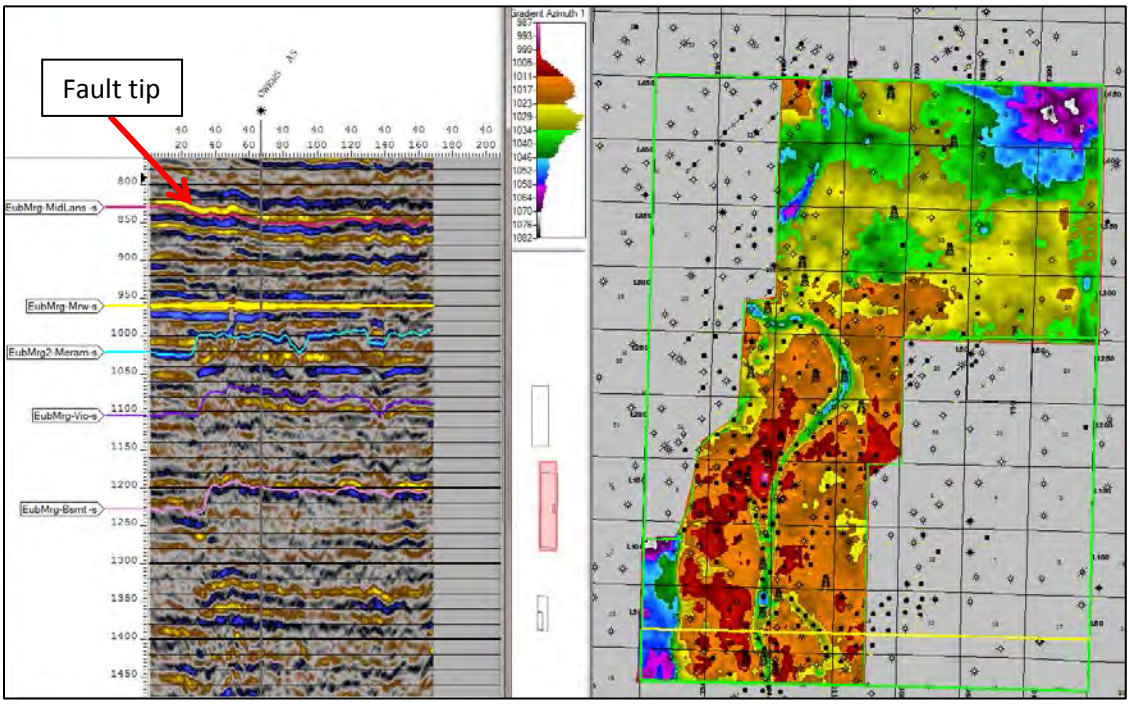


Figure 102. Eubank Seismic Flatten Profile @ Morrow = 960 ms -- Downthrown block thickens at Meramec, but isochron intervals from Meramec to Viola and Meramec to Basement are generally consistent on upthrown and downthrown blocks, although the offset on the basement is greater than at the Meramec. This implies most movement occurred post-Meramec. Note that fault tip (red arrow) at Mid Lansing occurs at Trace 26, tip at Basement occurs at Trace 36, yielding a west-east drift of 1100 ft, a high angle reverse fault. Block on east is extends over block on west. The both the IVF incisions cross the line of section downdip relative to current structure and overlie zones of truncation of seismic horizons, albeit more subtle than in Pleasant Prairie and Shuck.

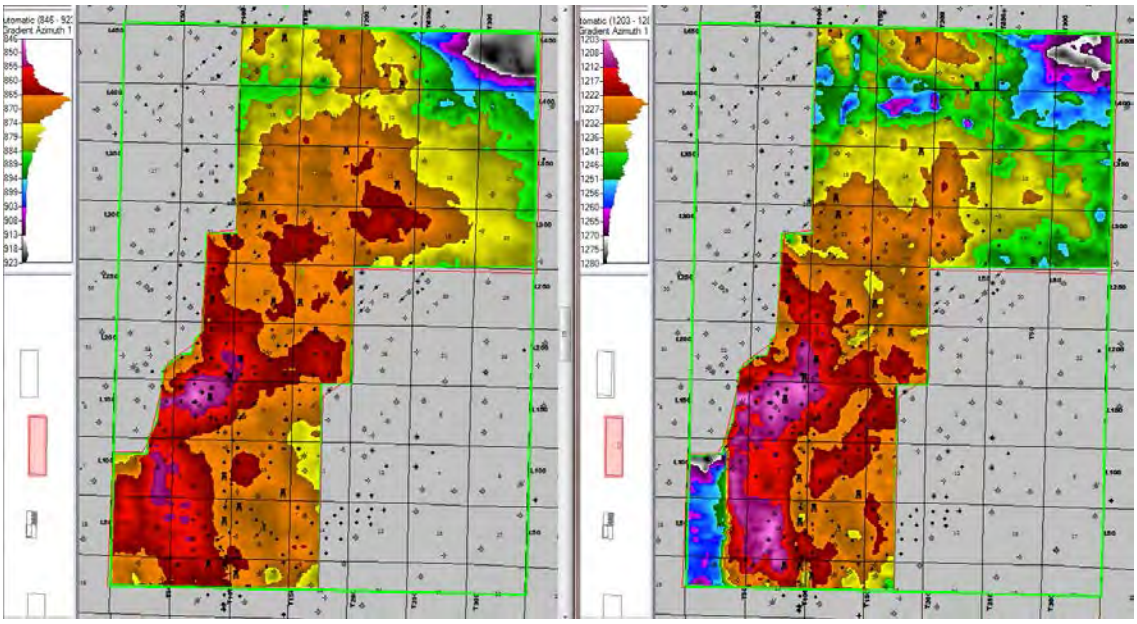


Figure 103. Eubank Structural -- Mid Lansing Time (left), Basement Time (right). Note the persistent expression of the structure deep and shallow even though the major tectonism precedes the Mid Lansing horizon. Also note that the trace of the IVF wraps around the eastern and northern edges of the current day structure strongly suggesting the structural deformation is to some degree through going and episodic. The structure also creates a rectangular block with N-NW and NE-trending edges. These trends parallel the regional lineament trends (Figure 97). The Eubank structure may be another restraining bend with a reverse fault on the west and smaller scale faults and fractures on the east suggesting tensional stress on that side. The would support a right-lateral strike-slip deformation.

Meramec Time Structure **Meramec Depth Structure**

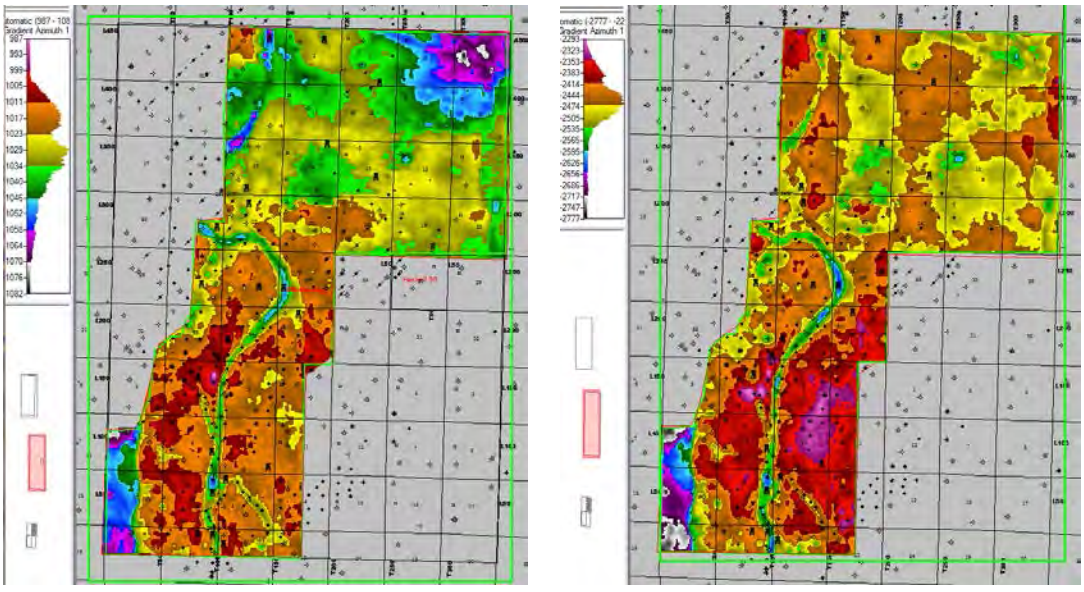


Figure 104. Meramec Time Structure (left) and Meramec Depth Structure (right) – The depth structure places the structural high to the east of the IVF with the IVF bisecting the current day structure.

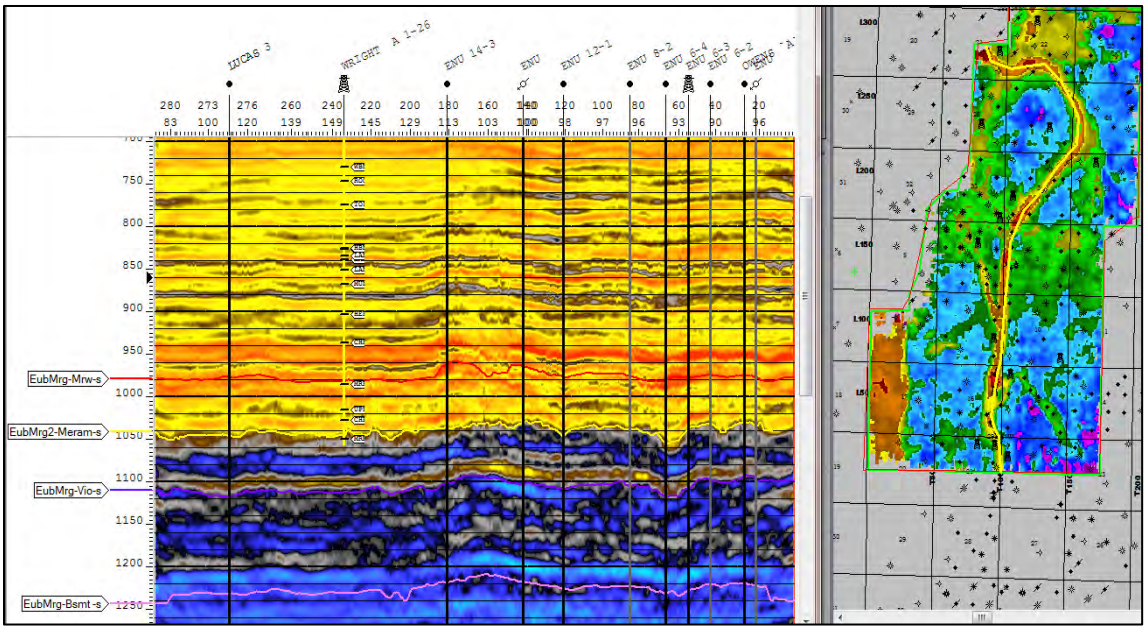


Figure 105. Eubanks Velocity from Impedance Inversion -- Arbitrary Profile thru thalweg (deepest portion) of the IVF, left is north. Map is Morrow – Meramec Isochron (purple and blue areas suggest thining and brown and yellow areas are thicker). Max velocity (light blue) ~25,000 fps; Min velocity (yellow) ~12,500 fps. Morrow & Chester Sands populate lower half of interval between Morrow/Meramec. The IVF crosses two areas of thinning with seeming disregard for the interval thickness. Also, the beds in the Ordovician interval lack continuity compared to shallower intervals, consistent with earlier amplitude profiles and observations from Shuck and Pleasant Prairie fields.

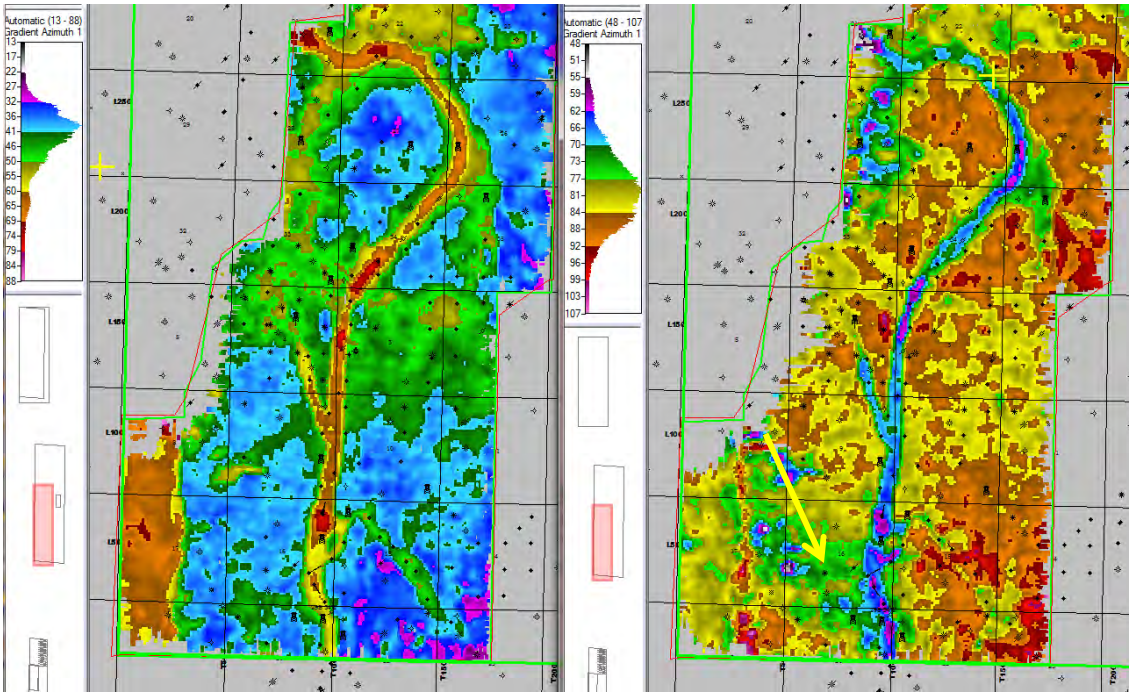


Figure 106. Morrow – Ordovician Stratigraphic Context -- Leftmost map is Morrow-Meramec Isochron. Rightmost map is Meramec-Ordovician Isochron. Both color schemes have blues as thin, yellow-brown as thick. Where IVF occurs thick Morrow-Meramec overlies thin Meramec-Ordovician. West bounding fault not so noticeable on Meramec – Ordovician isochron. The areas of thickening and thinning run are consistent except 1) thickening west of the bounding fault is greater in shallow isochron, the interval encompassing concurrent and maximum structural activity and 2) the SW mapped area between the bounding fault and the IVF on the deeper Meramec-Ordovician isochron (yellow arrow). This rectangular-shaped feature thins in this lower interval suggesting local uplift just prior to or near the time the IFV was formed that is consistent with the regional lineaments (Figure 97). This thinning may be a local structural block as part of a restraining bend, with reverse faulting on the west and more tensional on the east – suggesting right lateral sense to the fault.

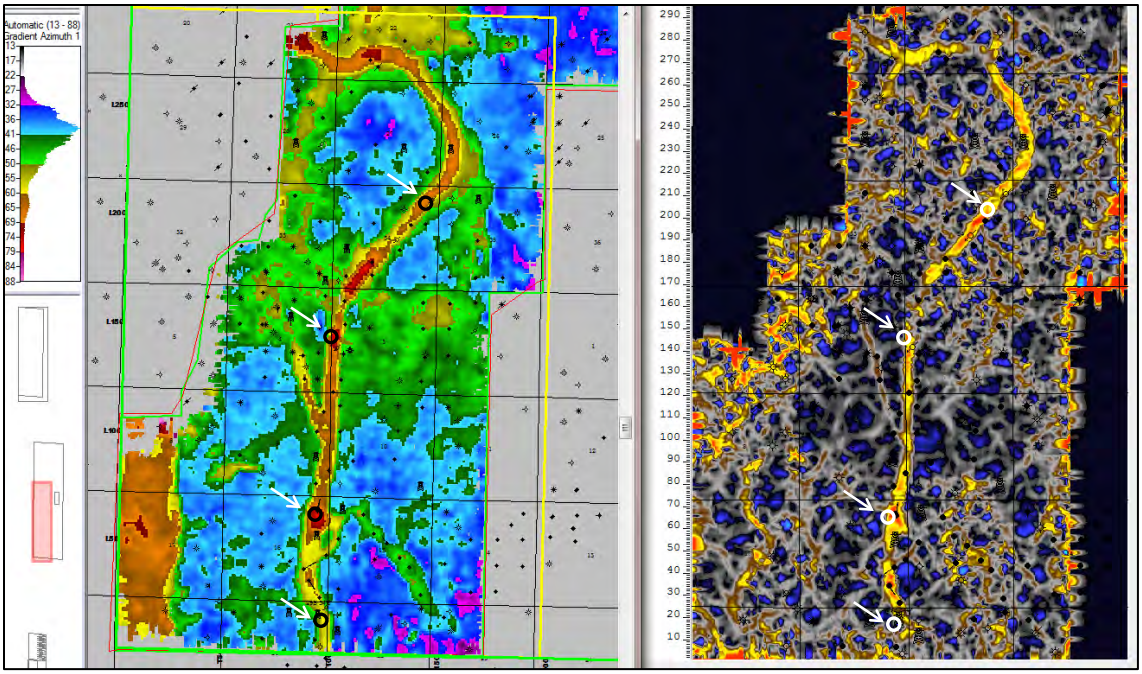


Figure 107. Morrow – Meramec Isochron (as shown previously) -- Most Negative Curvature Near Base IVF Time. NW- and NE-trending lattice fabric of curvature elements in background are generally independent of IVF orientation in south half of map, but are subparallel to the IVF on the north. West bounding fault somewhat expressed W2 section 17. Suggested sinkholes and possible leak points for inferred fluid loss in the IVF sandstone reservoir during waterflood indicated with white arrows. The inferred sinkholes correspond to boundaries where overall VC fabric undergoes change in density and frequency of change. These larger boundaries are also NW- and NE-trending.

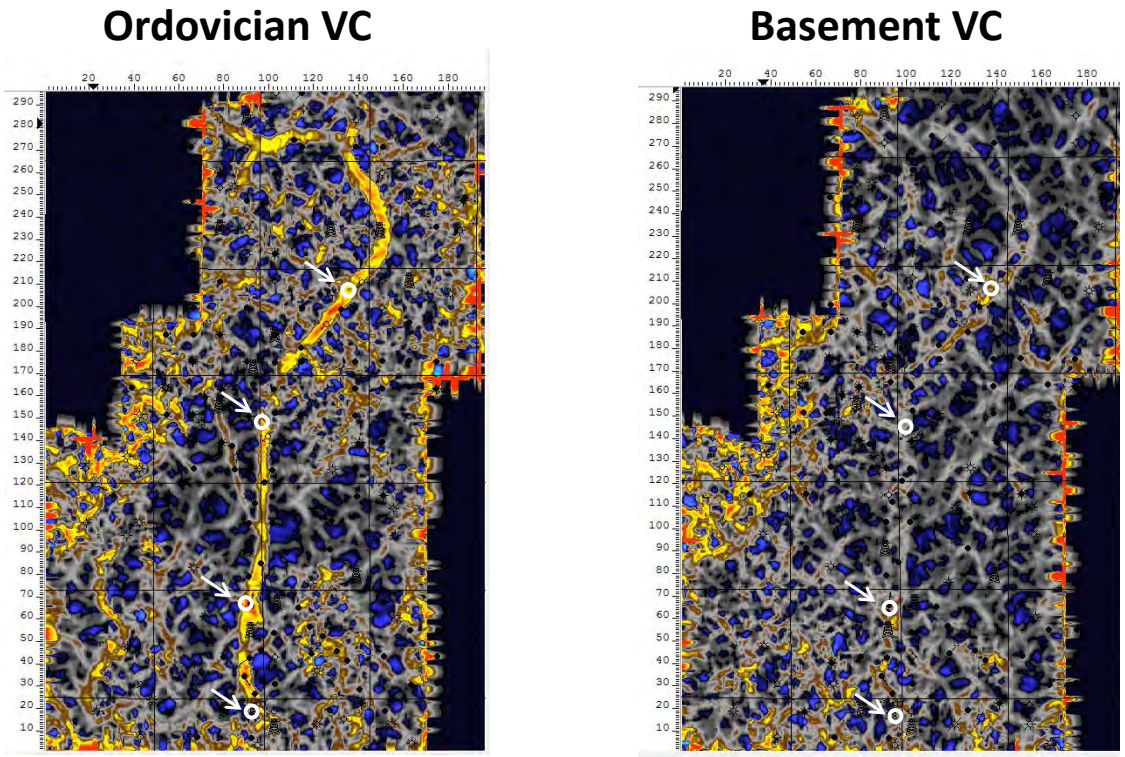


Figure 108. Eubanks Most Negative Curvature -- Basement Lattice Pattern Influences IVF. At the locations indicated by arrows, it would appear that in each instance significant intersections of lattice systems occur. This is evident in both Ordovician as well as Basement VC slices. It would be appropriate to expect that leakage out of IVF into surrounding rock systems could occur if these inferred basement fractures propagated upward, and thereby providing an explanation for volumetric requirements in accounting for 'lost injected fluids'. This leakage could occur either laterally or vertically downward.

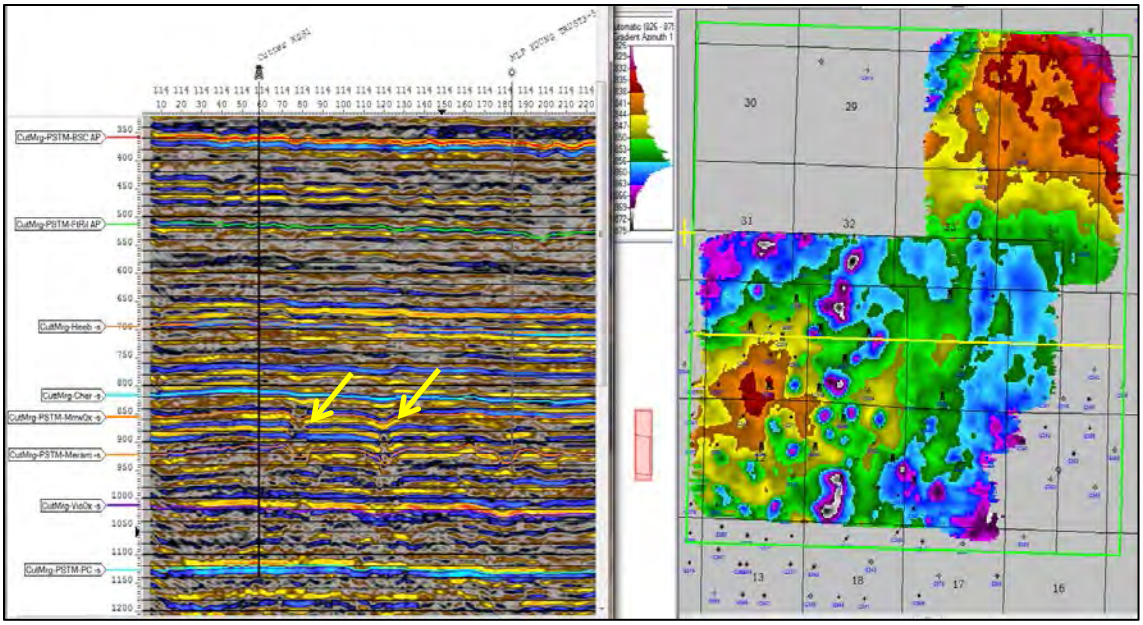


Figure 109. Cutter Amplitude & Morrow Time Structure -- Morrow Time Structure illustrates Karst, which is exemplified in the profile. At traces 80 and 120, apparent collapse well into Mississippian (yellow arrows), and vertical discontinuities appearing to continue up to and above the Stone Corral. IVF at 180.

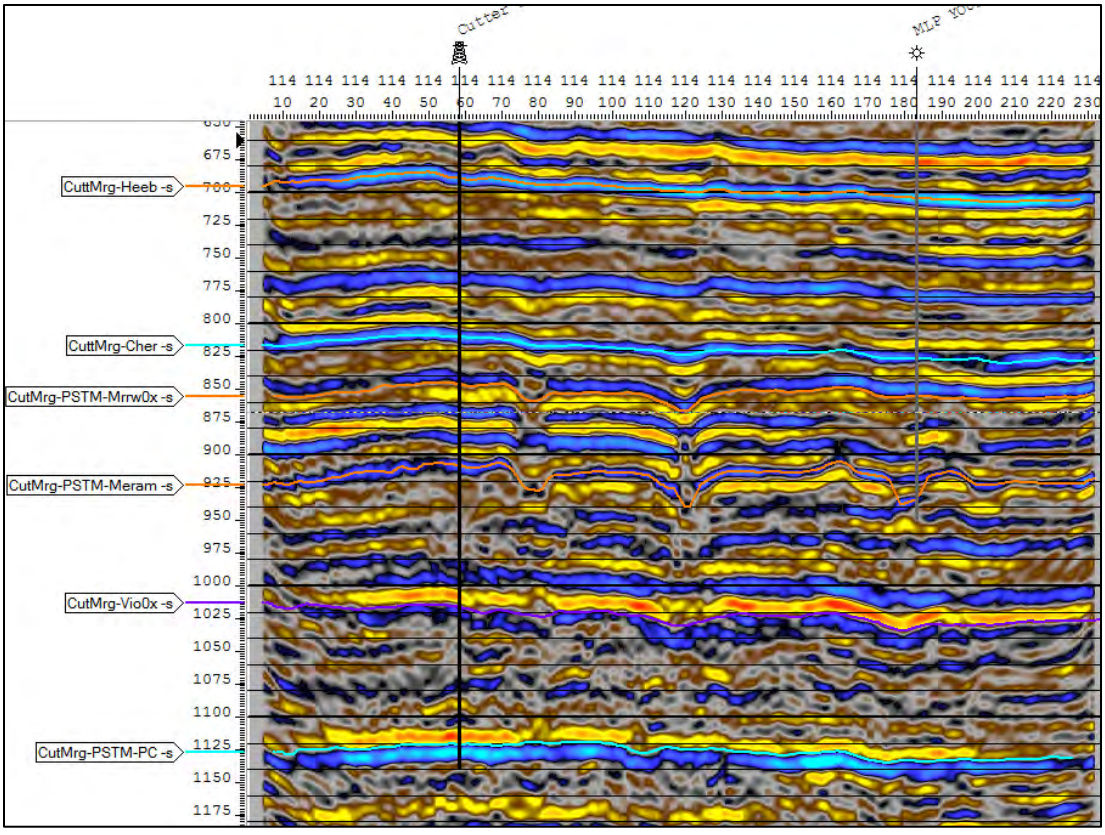


Figure 110. Cutter Amplitude, Inline 114 -- Note the signal disruption at the top of the Viola in two places extending upward to the Top Morrow datum. These features

do not extend further upward and suggest the karst is linked to the uplift and tectonism at in the early Pennsylvanian. These disruptions are circular features (Figure 109, rightside map) that are probable karst pipes. As suggested in the map, a pattern of karst-like features extend along a N-NE trend just east of the Cutter KGS #1 well. Upper Morrow productive sand occurs in the yellow amplitude interval immediately below Morrow Time surface. Morrow datum at KGS 1 (-2268), at MLP Young Trust 3-5 (-2315). Meramec datum at KGS 1 (-2701), at MLP (-2821). Interval at KGS 1 = 433 ft, that at MLP = 506 ft.

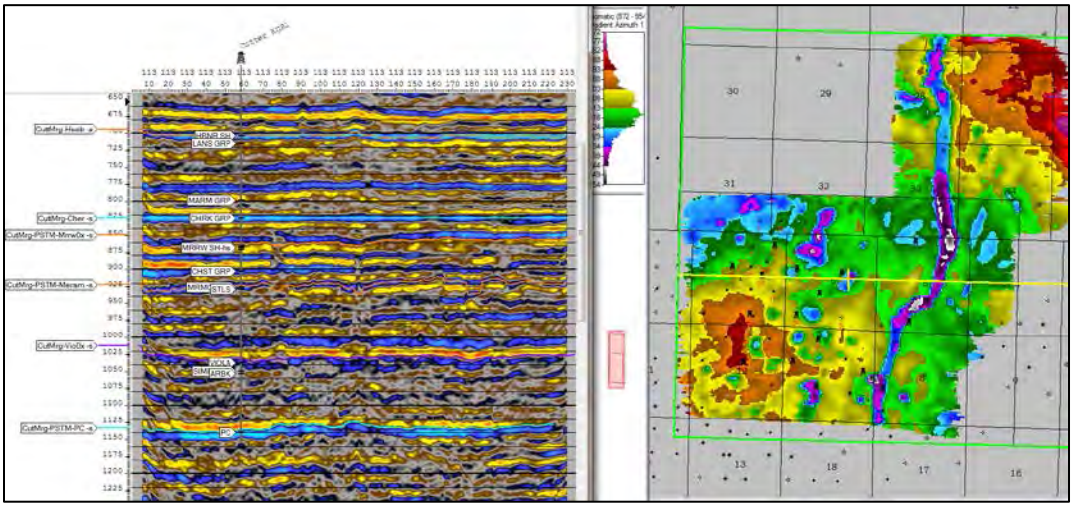


Figure 111. Cutter Seismic, Flattened at Cherokee = 825 ms -- Illustrates very little, if any Pre-Cherokee stratigraphic change in deeper systems. Mississippian-aged karst features had been established much earlier. Note lack of general bed continuity again in Lower Ordovician Arbuckle, as compared to generally consistent bedding in Mississippian beds in most of Lower Mississippian.

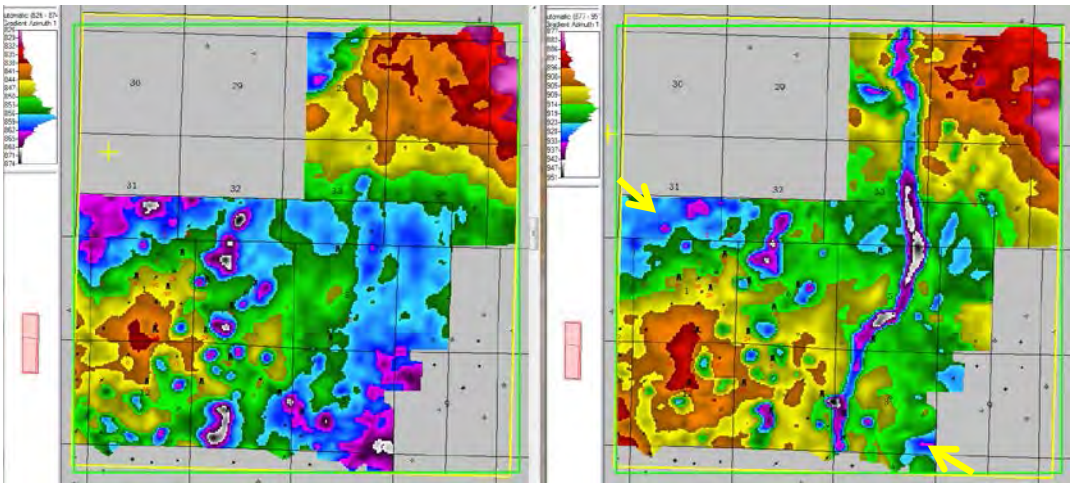


Figure 112. Cutter Morrow Time (left) & Meramec Time Structure (right) -- A dominating karst trends NNE – SSW bisects the Cutter Field Structure. At the Meramec horizon an additional WNW – ESE trend to karst features runs at north end of Cutter, through the IVF (between yellow arrows in map on right).

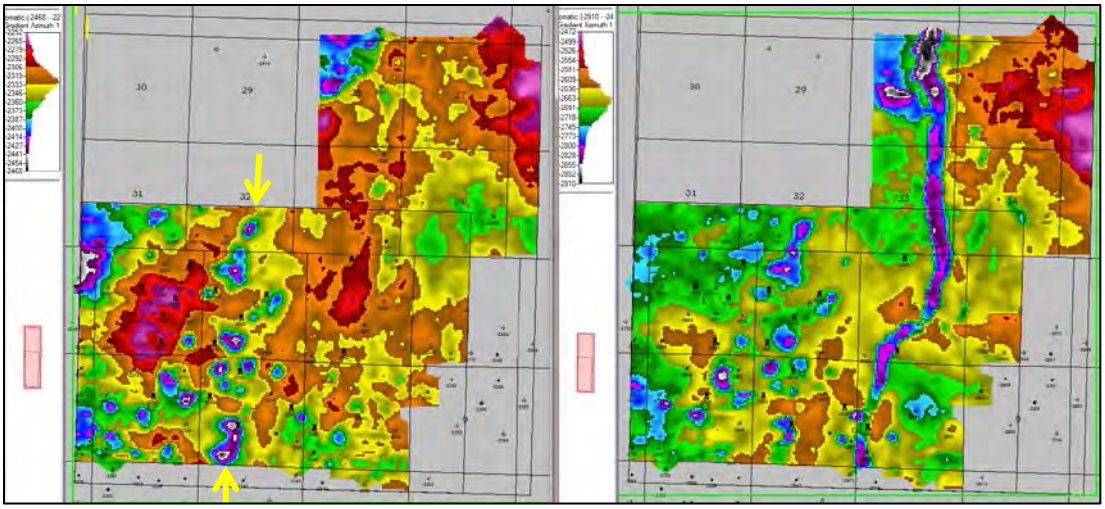


Figure 113. Cutter Morrow Depth & Meramec Depth -- Well defined east edge of Cutter Morrow structure, where karst features are clearly aligned (between yellow arrows). This same dominant lineament persists through Meramec. In a broader context, it would appear that the Cutter Field (Morrow) is separated by this N-S trending karst plain, from another feature to the east that culminates in a structural high in section 5.

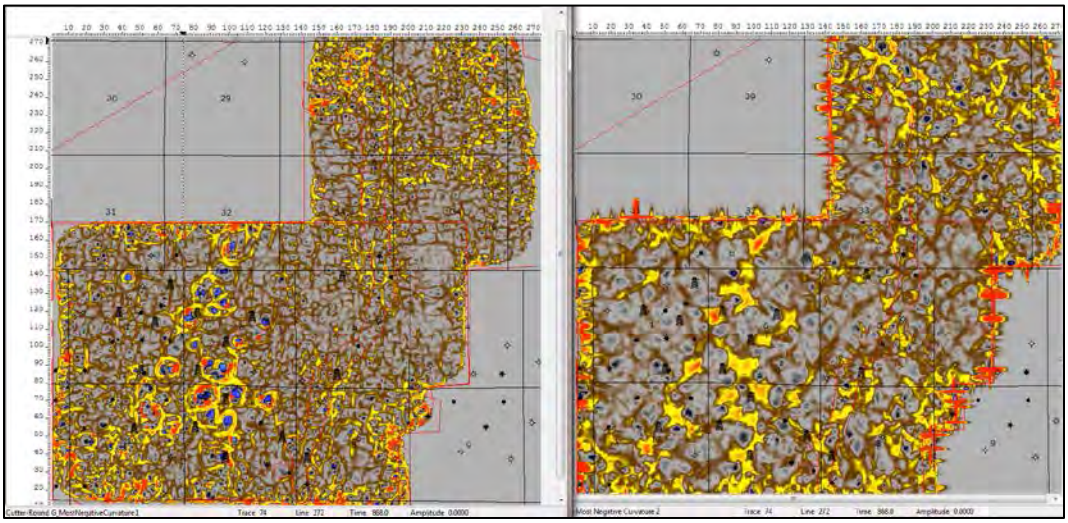


Figure 114. Cutter – Most Negative Curvature. Upper Morrow (868 ms) -- Higher resolution curvature (left) compared to lower resolution (right). Higher resolution manifests the N-S trending sinkholes, while lower resolution manifests apparent underlying fracture systems that trend NW- and NE. Light red outline in eastern image area outlines IVF, includes both Morrow and Chester production.

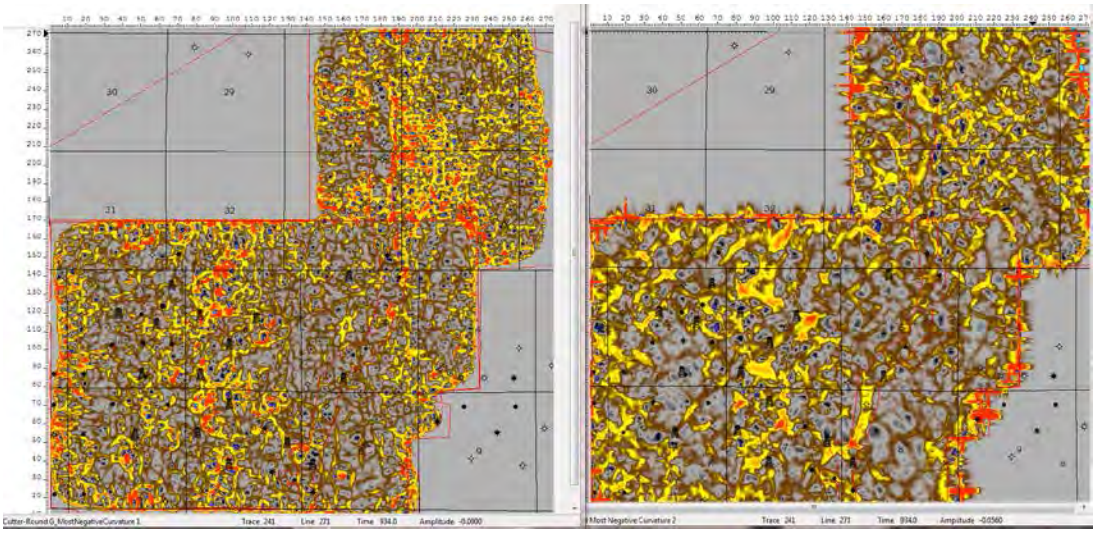


Figure 115. Cutter – Most Negative Curvature Meramec (934 ms) -- Higher resolution image illustrates coalescing of N-S oriented sinkholes expressed higher in stratigraphic section. Lower resolution image continues to express similar trends to those higher in stratigraphic section.

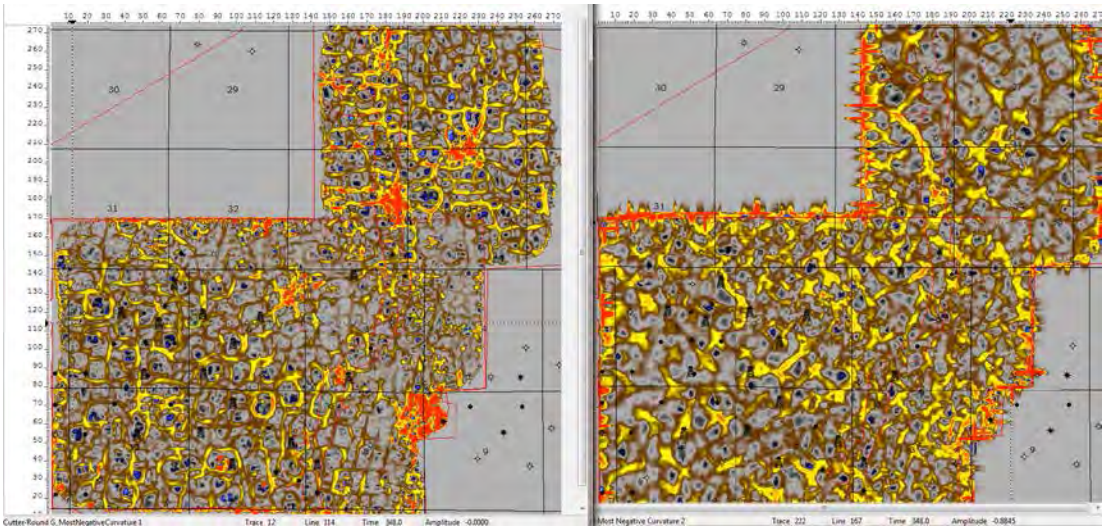


Figure 116. Cutter – Most Negative Curvature Stone Corral (348 ms) -- While the pattern is generally more rectilinear, the expression of NNE – SSW trends persist in the eastern reaches of the higher resolution image. Apparent widespread karst related sinkholes fill the southern portion of the higher resolution image (left), while the lower resolution character expresses much more linearity, consistent with deeper zones.

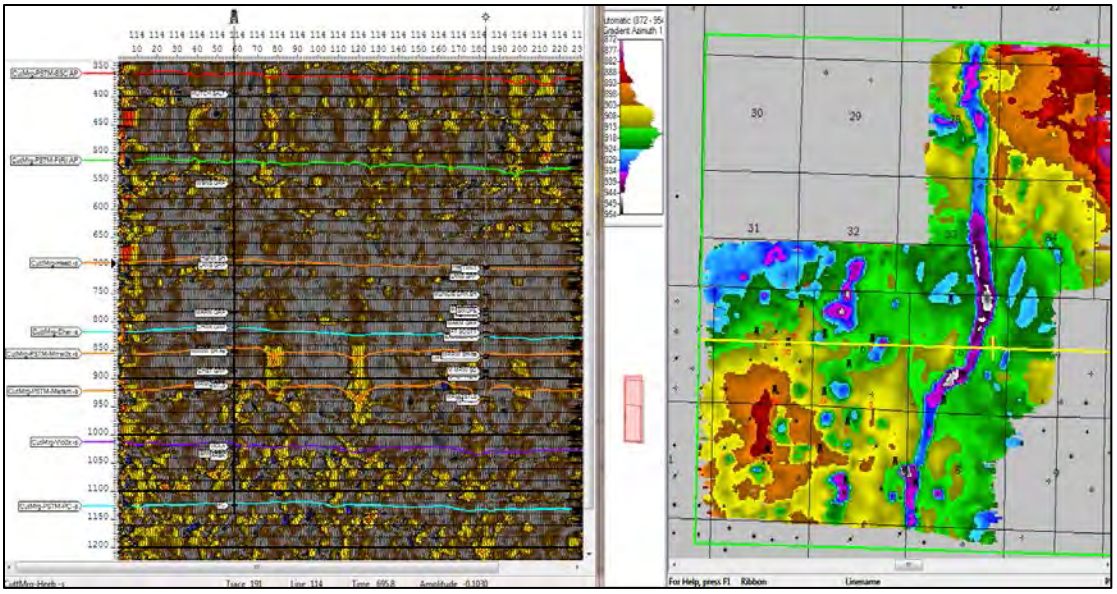


Figure 117. Cutter – Most Negative Curvature Vertical Profile West-East thru Cutter KGS1 -- Image Stretched vertically, covers stratigraphic section from Stone Corral to Basement. Map is Morrow Time with profile location that includes the two karst features that are part of the N-S karst trend. Vertical anomalies are abundant in the pre-Viola interval and into the basement. Less numerous features extend up through the top Morrow horizon. more or less continuo vertical features dim to above the Lower Permian Ft. Riley Limestone and then increase again above that horizon.

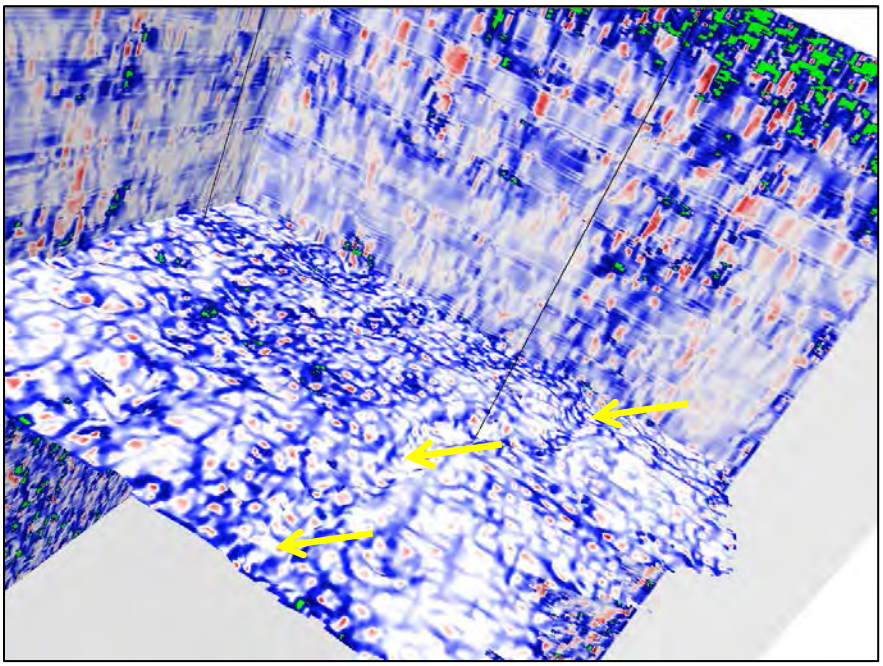


Figure 118. 3D Visualization Most Negative Curvature – Meramec Time surface draped with MNC amplitude overlay. IVF with penetration of MLP Young 1-5; KGS Cutter 1 near west vertical profile; multiple Karst sinks. Note broad disturbed zone north wall profile above IVF (delimited with three yellow arrows).

Conclusions Regarding Risk of Leakage of CO2 as Evidenced in Regional Seismic and Associated Mapping – Contributed by Dennis Hedke and Lynn Watney

1. Based on results from multiple seismic surveys throughout the Western Annex, as well as that at Wellington Field in Sumner County, KS, it is highly improbable that containment of CO2 within any given reservoir or injection zone can be assumed without the due diligence of system characterization to establish evidence for the integrity and continuity caprock/seals suited to the size of injection.

2. Apriori evidence of seals such as oil and gas accumulations, e.g. experience of CO2 use and storage in West Texas, can serve as an initial means to indicate integrity of caprock/seals for containment of stored CO2. However, the detailed analysis of the 3D seismic in the five fields examined in this study also reveal potential breaches in seals along the same structures without hydrocarbon accumulation and warrant the use of 3D seismic to establish why hydrocarbon is not present. Many dry structures with hydrocarbon show or limited fillup suggest breaches to seals that have allowed remigration, e.g., the increasing GOR toward the Anadarko Basin indicating remigration of fluids from the basin.

3. The systematic characterization of the structural framework from a kinematics perspective to ascertain stress-strain history in the context of modern stresses is strongly encouraged. Based on current seismicity, faults appear to be reactivated by large volume brine injection. Size and orientation of faults, basement heterogeneity (size and length of features), maximum and minimum stress direction and magnitudes and critical stress and orientation of larger faults, and an understanding of fluid levels and pore pressure are critical to the characterization.

4. Conventional amplitude data, coupled with processed volumetric curvature data demonstrate probable vertical connectivity from Basement to stratigraphic horizons considerably higher in the section. The distinction of fractures, flexure, and brittle faulting is needed using multiple techniques including geomechanical analytical methods to evaluate the seals and mechanical integrity. The Permian evaporites including halite that lie above most of Kansas reservoirs are a clear indication of the integrity of shallower seals. Oil and gas migration and accumulation over time have been constrained by seals that are both local and regional in extent. Active fracture and fault systems have introduced hydrocarbons into Kansas from both the Anadarko and Arkoma Basins likely during times of strong tectonic forces as well as lessor structural movement and remigration, e.g. the late Tertiary remigration of trillions of feet of natural gas

from the breaching of the Amarillo-Wichita uplift to the updip giant Hugoton oil Field that spans three states and lies above the Western Annex.

5. High angle reverse faults occur in both the northernmost and southernmost study areas, and are likely related to additional structural complexity, and fracture system enhancement. The fault geometries in the northern region such as flower structures also suggest that strike-slip motion has affected these faults in the past.

6. 4D seismic programming planned for the future may be able to monitor CO2 plume movement, but is likely to be at such a scale as to lack the certainty required to confirm or deny leakage.

Subtask 18.3. Simulate potential of CO_2 sequestration in Arbuckle Group saline aquifer

Subtask 18.4. Simulate of CO_2 sequestration potential by CO_2-EOR in the selected Chester/Morrow field

CO2 potentially sequestered at the four Chester/Morrow fields including Cutter, Pleasant Prairie, Eubank, and Shuck was estimated through simulation as summarized in **Table 1**. Total sequestered CO2 is 6.1 million metric tons is based on the crossover of maximum oil recover and minimizing CO2 breakthrough. Reports on the characterization and modeling of these fields will be part of the final report. These Morrow/Chester fields located in southwestern Kansas were the focus of study because of their representativeness of other fields and the strategic orientation that could serve as a basis for extending a CO2 pipeline currently ending in NW Oklahoma.

Reservoir	Co2 Sequestered ton	Co2 Sequestered tonne
Cutter Morrow (1/1/1961)	1,400,000	1,272,727
Pleasant Prairie (1/1/2012)	700,000	636,364
Eubank (6/1/2013)	1,600,000	1,454,545
Shuck (1/1/2013)	3,000,000	2,727,273
Total	6,700,000	6,090,909

Table 1. Estimated sequestered CO2 from simulations of four western Kansas fields.

Based on these results, the maximum displacement of oil and natural gas by CO2 could be to 60% and about 80%, respectively. Displacement of the water in these oil fields would be at least the same as the saline aquifer but probably in the 20% range. Thus, the maximum CO2 that could potentially be sequestered in these fields is about *8 million* tonnes.

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

Deliverables for the Final Report

1. Reservoir geomodel of Wellington Mississippian Chat reservoir and its CO_2-sequestration and CO_2-EOR potential.
2. Reservoir geomodel of Arbuckle Group saline aquifer underlying Wellington field and its CO_2-sequestration potential
3. Regional geomodel of OPAS covering 17+ counties in south central Kansas and its CO_2-sequestration potential
4. Risk assessment studies related to CO_2 sequestration including characterization of leakage pathways, vertical communication within the Arbuckle Group, and well abandonment histories in the 17+ county study area and the Western Annex.
5. Geomodel and simulations of CO_2 sequestration potential of the Arbuckle Group saline aquifer and of CO_2-EOR in a select Chester/Morrow incised valley sandstone oil reservoir in the Western Annex – a new addition of ~5,000 mi^2 to the regional study.
6. Results and interpretation of the seismic surveys, and interpretation of all laboratory analysis performed in the 17+ county study area and the Western Annex.

PRESENTATIONS AND PUBLICATIONS

Tandis S. Bidgoli, W. Lynn Watney, Paul Gerlach, Minh C. Nguyen, 2014, Episodic reactivation of critically-stressed basement faults in southern Kansas: Implications for waste-water disposal and long-term storage of CO_2 (for GSA 2014 annual meeting), **https://gsa.confex.com/gsa/2014AM/webprogram/Paper249152.html**

Tiraz Birdie, Lynn Watney, Paul Gerlach, Michael Killion, Eugene Holubnyak, Jennifer Raney, Tandis Banjoli, Gene Williams, Minh Nguyen, and Brownie Wilson, 2014, The Impacts of Carbon Dioxide Storage in the Saline Arbuckle Aquifer on Freshwater Aquifers in Kansas:

Yevhen Holubnyak, Willard Watney, Jason Rush, and Fatemeh Fazelalavi, 2014, Reservoir Engineering Aspects of Pilot Scale CO2 EOR Project in Upper Mississippian Formation at Wellington Field in Southern Kansas, Energy Procedia 00 (2013) 000–000, 9 p.

Watney, W.L., 2014, "Carbon Storage and Utilization in Kansas – Are We Ready?" at Annual Oil and Gas Seminar, Kansas NextStep, Hays, Kansas,

W. Lynn Watney & Jason Rush (Joint PIs), Jennifer Raney*, 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 Number (DE-FE0002056), U.S. Department of Energy, National Energy Technology Laboratory, Carbon Storage R&D Project Review Meeting, Developing the Technologies and Infrastructure for CCS, August 12-14, 2014.

*presenter

KEY FINDINGS

1. Type logs have been verified.
2. Interactive mapper functioning has been optimized and layers updated for state of Kansas including horizontal wells, earthquakes.
3. "Blind" faults are being verified by induced seismicity resulting from increased brine disposal associated with oil drilling in south-central Kansas.
4. Concerns expressed by regulatory community in Kansas on business as usual regarding permitting of deep fluid disposal.
5. Assessment of CO2 disposal has provided basis to address key parameters associated with fluid disposal including characterization of reservoir/aquifer matrix properties, fractures and faults, data and methodology to assess flow units, aquitards, injectivity, storativity, anisotropy, dual and triple porosity systems that comprise carbonates, seismic calibration and seismic imaging and attribute analysis focused on recognition of faults and karst, geomechanical properties and regional and local stress conditions, critical orientations of faults, 3D geocellular network integrating subsurface information, analysis of pressure and fluid distribution during injection using compositional simulator, and recognition limits to pressure relative to closure pressure.
6. Use of multicomponent seismic has proven the merits of examining anisotropy and reservoir properties via seismic inversion.
7. Regional seismic and regional mapping has clearly shown faults and lineaments of suspected faults that require evaluation prior to considering CO2 storage.
8. Regional simulation of commercial scale CO2 storage using 3D geocellular modeling of conventional petroleum reservoir evaluation will serve as the basis for future discussion and evaluation of CO2 storage and even brine disposal as the nexus of these two technologies converge in Kansas.

PLANS

1. Complete the final report.

APPENDIX II

Small Scale Field Test Demonstrating CO_2 Sequestration in Arbuckle Saline Aquifer and by CO_2-EOR at Wellington Field, Sumner County, Kansas

FIRST QUARTERLY PROGRESS REPORT

U.S. Department of Energy
FEDERAL ASSISTANCE REPORTING CHECKLIST
AND INSTRUCTIONS FOR RD&D PROJECTS

DOE F 4600.2
(03/11)
All Other Editions Are Obsolete

1. Identification Number: **DE-FE0006821**	2. Program/Project Title: **Small Scale Field Test Demonstration CO2 Sequestration**
3. Recipient: **University of Kansas Center for Research, Inc.**	

4. Reporting Requirements:	Frequency	Addressees
A. MANAGEMENT REPORTING		
☒ Research Performance Progress Report (RPPR)	Q	FITS@NETL.DOE.GOV
☒ Special Status Report	A	FITS@NETL.DOE.GOV
B. SCIENTIFIC/TECHNICAL REPORTING		
(Reports/Products must be submitted with appropriate DOE F 241. The 241 forms are available at www.osti.gov/elink)		
Report/Product — Form		
☒ Final Scientific/Technical Report — DOE F 241.3	FG	http://www.osti.gov/elink-2413
☒ Conference papers/proceedings* — DOE F 241.3	A	http://www.osti.gov/elink-2413
☐ Software/Manual — DOE F 241.4		
☐ Other (see special instructions) — DOE F 241.3		
* *Scientific and technical conferences only*		
C. FINANCIAL REPORTING		FITS@NETL.DOE.GOV
☒ SF-425 Federal Financial Report	Q, FG	
D. CLOSEOUT REPORTING		
☒ Patent Certification	FC	FITS@NETL.DOE.GOV
☒ SF-428 & 428B Final Property Report	FC	FITS@NETL.DOE.GOV
☐ Other		mailto:FITS@NETL.DOE.GOV
E. OTHER REPORTING		
☒ Annual Indirect Cost Proposal	O	See block 5 below for instructions.
☐ Audit of For-Profit Recipients		
☒ SF-428 Tangible Personal Property Report Forms Family	A	FITS@NETL.DOE.GOV
☒ Other – see block 5 below	A	FITS@NETL.DOE.GOV

FREQUENCY CODES AND DUE DATES:

A - Within 5 calendar days after events or as specified.
FG- Final; 90 calendar days after the project period ends.
FC- Final; End of Effort.
Y - Yearly; 90 calendar days after the end of the reporting period.
S - Semiannually; within 30 calendar days after end of project year and project half-year.
Q - Quarterly; within 30 days after end of the reporting period.
Y180 – Yearly; 180 days after the end of the recipient's fiscal year
O - Other; See instructions for further details.

5. Special Instructions:

Annual Indirect Cost Proposal – If DOE is the Cognizant Federal Agency, then the proposal should be sent to FITS@NETL.DOE.GOV . Otherwise, it should be sent to the Cognizant Federal Agency.

Other – The Recipient shall provide all deliverables as contained in Section D of Attachment 2 Statement of Project Objectives.

QUARTERLY PROGRESS REPORT

To

DOE-NETL

Brian Dressel, Program Manager

Award Number: DE-FE0006821

SMALL SCALE FIELD TEST DEMONSTRATING CO_2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO_2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS

Project Director/Principal Investigator:
W. Lynn Watney
Senior Scientific Fellow
Kansas Geological Survey

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Joint Principal Investigator:
Jason Rush

Date of Revised Report: February 13, 2012

DUNS Number: 076248616

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

Project/Grant Period: 10/1/2011 through 9/30/2015

First Quarterly Report

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

Signature of Submitting Official:

Willard Lynn Watney

Digitally signed by Willard Lynn Watney
DN: cn=Willard Lynn Watney, o=The University of Kansas, ou=Kansas Geological Survey, email=lwatney@kgs.ku.edu, c=US
Date: 2012.02.14 11:25:44 -06'00'

EXECUTIVE SUMMARY

Project Objectives

The objectives of this project are: (1) inject under supercritical conditions approximately 40,000 metric tons of CO_2 into the Arbuckle saline aquifer; (2) demonstrate the application of state-of-the-art MVA (monitoring, verification, and accounting) tools and techniques to monitor and visualize the injected CO_2 plume; (3) develop a robust Arbuckle geomodel by integrating data collected from the proposed study area, and a multi-component 3D seismic survey; (4) conduct reservoir simulation studies to map CO_2 plume dispersal and estimate tonnage of CO_2 sequestered in solution, as residual gas and by mineralization; (5) integrate MVA data and analysis with reservoir modeling studies to detect CO_2 leakage and to validate the simulation model; (6) develop a rapid-response mitigation plan to minimize CO_2 leakage and a comprehensive risk management strategy; and (7) establish best practice methodologies for MVA and closure. Additionally, approximately 30,000 metric tons of CO_2 shall be injected into the overlying Mississippian to evaluate miscible CO_2-EOR potential in a 5-spot pilot pattern. The CO_2 shall be supplied from the Abengoa Bioenergy ethanol plant at Colwich, Kansas who has operated the facility since 1982 demonstrating reliability and capability to provide an adequate stream and quality of CO_2. The project shall install compression, chilling, and transport facilities at the ethanol plant for truck transport to the injection site.

Project Goals

The proposed small scale injection will advance the science and practice of carbon sequestration in the Midcontinent by refining characterization and modeling, evaluating best practices for MVA tailored to the geologic setting, optimize methods for remediation and risk management, and provide technical information and training to enable additional projects and facilitate discussions on issues of liability and risk management for operators, regulators, and policy makers.

The data gathered as part of this research effort and pilot study will be shared with the Southwest Sequestration Partnership (SWP) and integrated into the National Carbon Sequestration Database and Geographic Information System (NATCARB) and the 6th Edition of the Carbon Sequestration Atlas of the United States and Canada.

Project Deliverables by Task

1.5 Well Drilling and Installation Plan (Can be Appendix to PMP or Quarterly Report)
1.6 MVA Plan (Can be Appendix to PMP or Quarterly Report)
1.7 Public Outreach Plan (Can be Appendix to PMP)
1.8 Arbuckle Injection Permit Application Review go/no go Memo
1.9 Mississippian Injection Permit Application Review go/no go Memo
1.10 Site Development, Operations, and Closure Plan (Can be Appendix to PMP)
2.0 Suitable geology for Injection Arbuckle go/no go Memo
3.0 Suitable geology for Injection Mississippian go/no go Memo
11.2 Capture and Compression Design and Cost Evaluation go/no go Memo
19 Updated Site Characterization/Conceptual Models (Can be Appendix to Quarterly Report)

21 Commercialization Plan (Can be Appendix to Quarterly Report).
30 Best Practices Plan (Can be Appendix to Quarterly or Final Report)

ACCOMPLISHMENTS

ONGOING ACTIVITIES –

TASK 1. PROJECT MANAGEMENT AND REPORTING

Subtask 1.1. Finalize Program Management Plan

PMP Preparation and Completion Update.

This task shall include all work elements required to maintain and revise the PMP, and to manage and report on activities in accordance with the plan. The PMP includes necessary activities to ensure coordination and planning of the project with DOE/NETL and other participants. PMP also includes a funding profile, project milestones, project schedule, organizational structure, and a project specific quality assurance program. The completed PMP will contain the contract agreement and plan to procure the CO_2 for the injection test that guarantees that the CO_2 will be available for the injection project.

The PMP is a living document and will be reviewed and modified at the beginning and end of each task/milestone. The PMP shall be adapted to future activities as necessary. The initial updated PMP was submitted in December 2011. A revised final PMP is still pending due to discussions on developing additional options and schedule for CO2 injection at Wellington Field should a Class VI permit application with EPA be unsuccessful. The final PMP will include a copy of the infrastructure requirements for CO_2 injection, access documents (surface and subsurface), and a completed contract and commitment for supplying CO_2. This information is near completion.

Alternatives CO2 Injection Strategies Considered in December 2011

Concerns over permitting the small-scale injection of CO2 in the saline aquifer based on new guidelines for EPA Class VI injection well raised concerns over long permitting process and uncertainty in project viability facing default requirements for bonding and monitoring for this experimental injection. Options were evaluated including 1) injecting in the top of the Arbuckle were locally the Arbuckle is in contact with a oil-bearing and locally producing Simpson sandstone (occurs locally as thin lenses in the Simpson Shale), 2) eliminating the saline aquifer CO2 disposal aspect of project and direct activities on CO2-EOR in the Mississippian oil reservoir. Discussions among parties including EPA in January 2012 led to the decision by DOE to revise project plan to begin injection in the Mississippian oil reservoir while allowing the project to pursue a Class VI permit to dispose of CO2 in the lower saline Arbuckle aquifer as originally proposed. This decision is based on mutual confidence in a strong application for the permit based on an excellent subsurface database at Wellington and major anticipated refinements in the geomodel. The latter

should lead to robust simulations to predict the CO2 plume development and fate in the saline aquifer to support the details to be presented in the Class VI permit application.

Review of the alterative option to inject into the CO2 into the top of the Arbuckle next to an adjacent oil zone in the Simpson Group provided additional perspective of the caprock interval. The Renn-Erickson #1 well is the lone well in Wellington Field that produces oil from the Simpson sandstone (Figures 1 and 2).

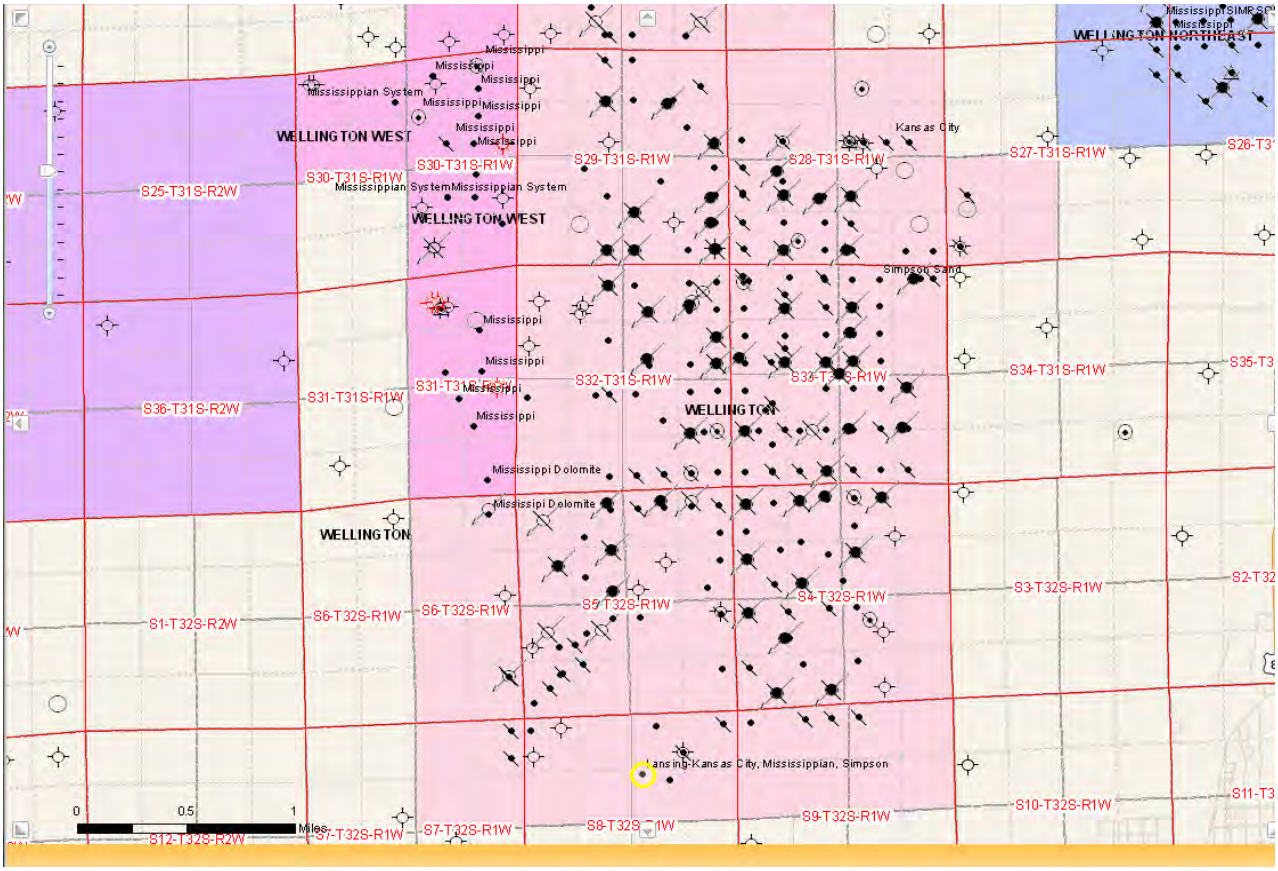


Figure 1. Base map of Wellington Field. Green arrow shows location of Renn-Erickson #1, the only well in Wellington Field that produces from Simpson sandstone overlies the Arbuckle saline aquifer. Well is over two miles south of the site of proposed CO2 injection in the Arbuckle in SW quarter of Section 28.

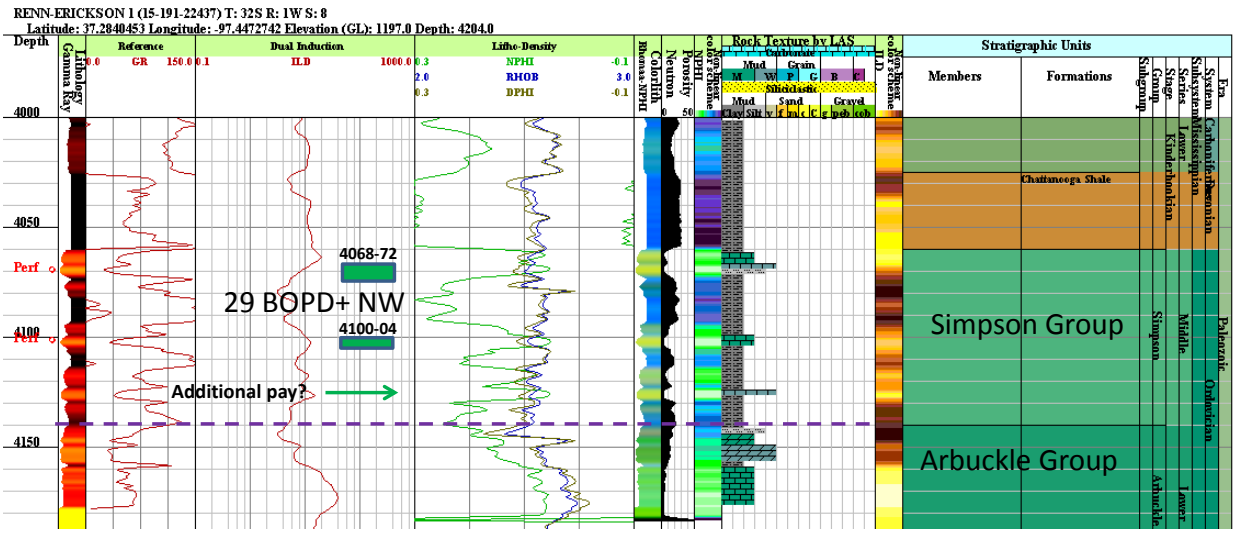


Figure 2. Renn-Erickson #1 well profile showing two perforated intervals in the Simpson sandstone. Producing sands are separated from the top of Arbuckle by shales.

The sample log description of the lower Mississippian to upper Arbuckle interval in the KGS #1-32 (Figure 3) and corresponding well logs (Figures 4 and 5) indicate that the Simpson sandstones are also present above the injection site, but the sands are cemented with low porosity distributed as beds within Simpson Shale.

Berexco Wellington KGS #1-32

No shows in Simpson, but lowermost Simpson Sandstone rests on Arbuckle

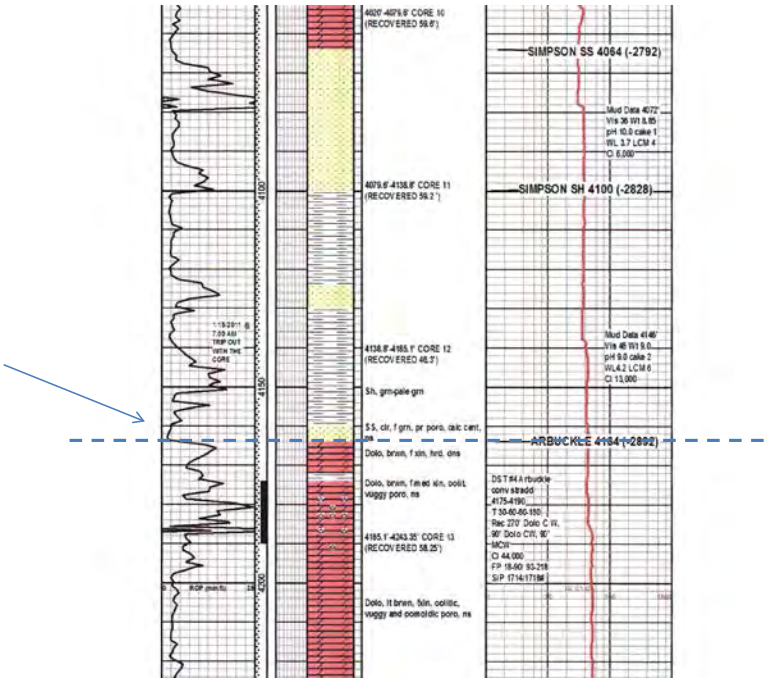


Figure 3. Sample description of interval from lower Mississippian to upper Arbuckle in KGS #1-32. Simpson Group is primarily shale.

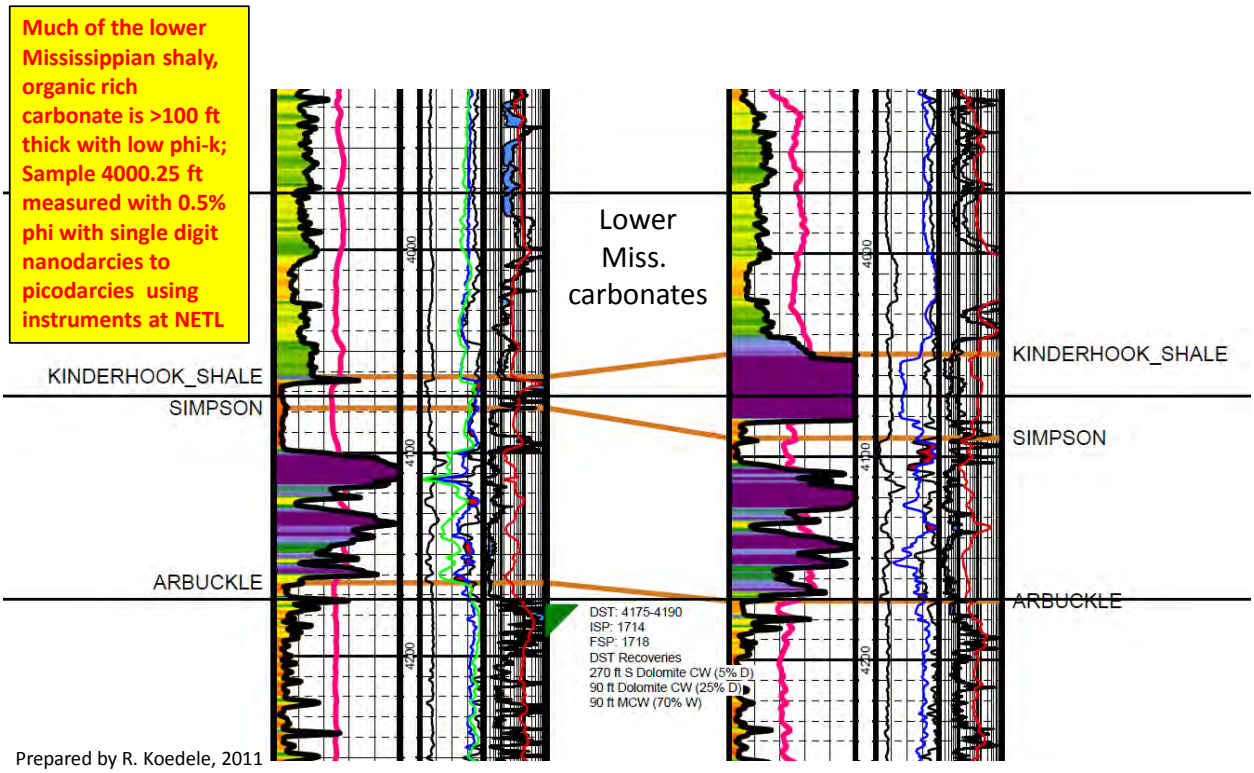


Figure 4. Stratigraphic cross section datumed on top of Arbuckle including wells KGS #1-32 (left) and KGS #1-28 (right). Wells were drilled during the characterization phase of Wellington Field under DOE Project FE0002056. Stratigraphic interval shown extends from lower Mississippian to upper Arbuckle. While upper Simpson Sandstone is thick, it is tight and lower sands are thin within the Simpson Shale. Kinderhook/Chattanooga Shale thins from #1-28 to #1-32 while lower shaly tight carbonates in the lower Mississippian are persistent strata throughout Wellington Field. The lower Mississippian argillaceous organic rich carbonates have been evaluated as caprock lithofacies. Measurements to date confirm this.

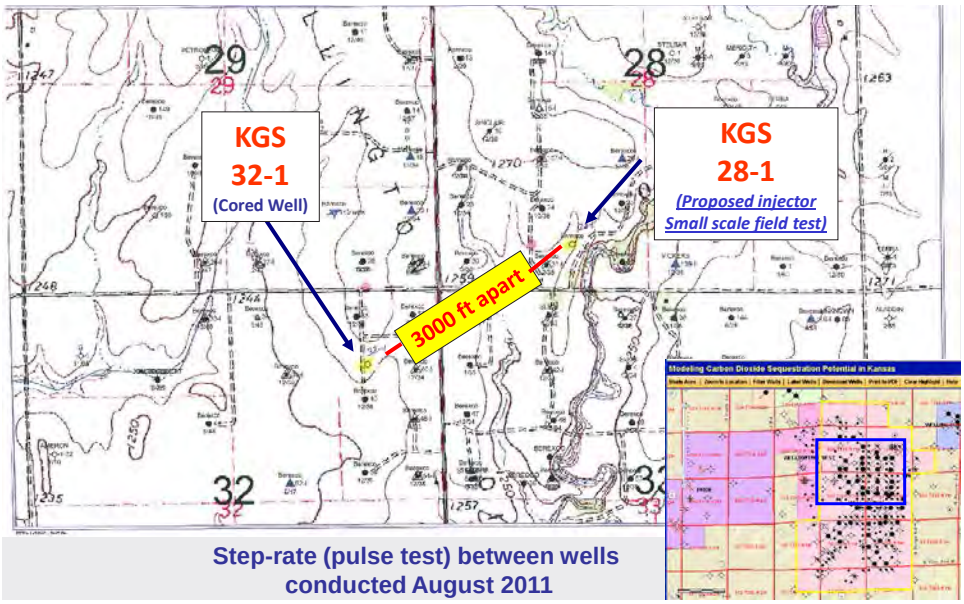


Figure 5. Index map for cross section shown in Figure 4. Two wells drilled in FE0002056 are highlighted.

Primary caprock directly overlying the Arbuckle includes Lower Mississippian carbonates and shale, Devonian shale, and Upper Ordovician shales of the Simpson Group. Caprock on top of the Mississippian oil reservoir are shales in the Cherokee Group. Both are illustrated in Figure 6.

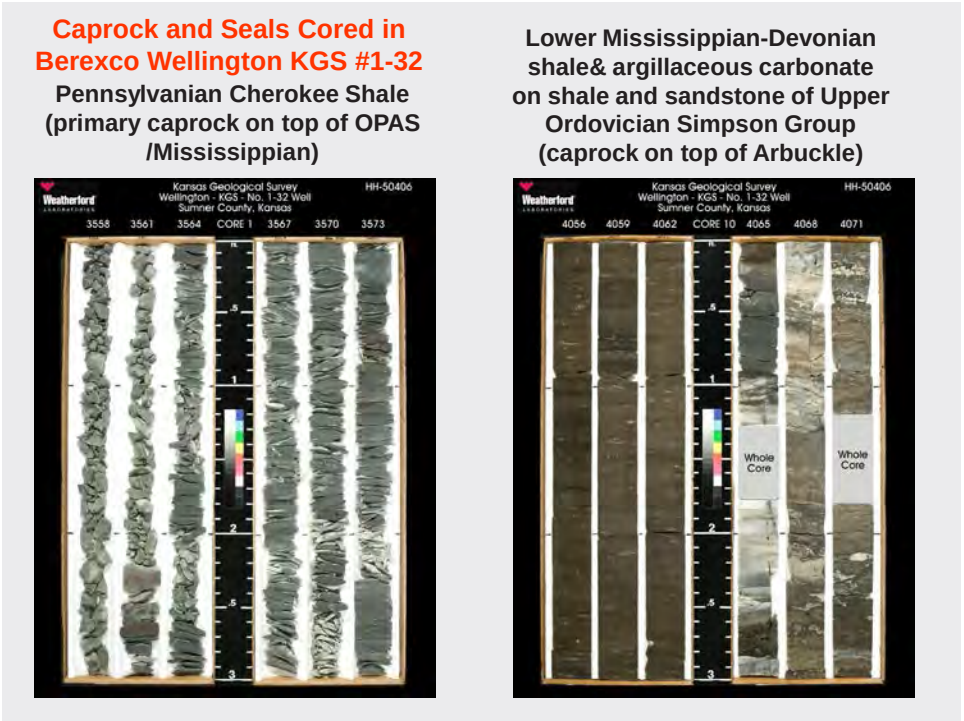


Figure 6. Shales in Cherokee Group overlie the Mississippian oil reservoir and serve as its caprock. Lower Mississippian carbonates and shale, Devonian shale, and Upper Ordovician shales serve as the primary caprock overlying the Arbuckle saline aquifer.

The basement test KGS #1-32 was cored from the shales of the Cherokee Group to the base of the Arbuckle saline aquifer. That was followed up by running an extensive set of wireline logs as illustrated in Figure 7. The logging was done to the surface including logging of shallow 200 ft thick evaporites that lie beneath the surface aquifer.

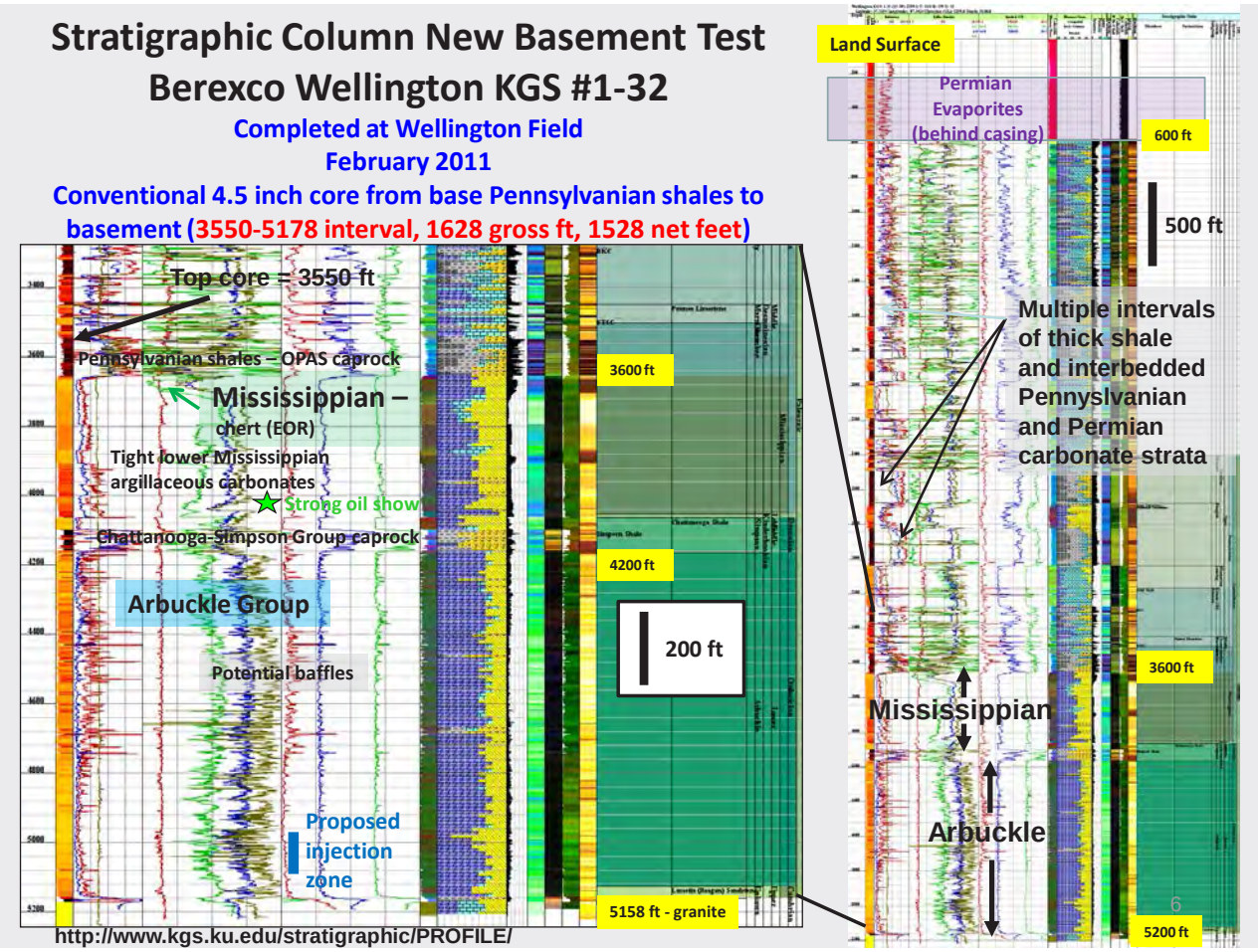


Figure 7. Composite view of the stratigraphy at KGS #1-32 showing interpreted lithologies from the base of the Arbuckle to the land surface. Arbuckle saline aquifer and overlying Mississippian oil reservoir are highlighted on the left. Shallow evaporites are delimited on the upper right.

Schedule and Budget Update

Schedule -- It was a mutual agreement by DOE at the end of January to continue to pursue a Class VI injection permit with EPA for deep saline aquifer injection. The decision was after encouraging discussions with EPA on the use of robust modeling and data serving as an important factor in the recommendations to reduce default monitoring requirements. With that decision made, it was determined that we would modify the project schedule to put field operations for the Mississippian CO2 injection ahead of the Arbuckle to provide longer time for the Class VI permit to be reviewed (Figure 8). Details of the moving the Mississippian CO2 injection ahead of the Arbuckle continue to be discussed including drilling considerations and downhole monitoring. A contingency for not receiving the Class VI permit is also being developed to ensure that the MVA is fully deployed in the context of the Mississippian CO2-EOR option.

A second factor in the modification of the schedule was the delay to finalize the larger subcontracts. Those budgets are nearly completed and should permit field operations to begin in earnest. Contracts are expected to be finalized in February 2012 with subsequent approval by DOE to permit field operations to begin shortly thereafter.

A third factor in the modifying the schedule as been to additional time to complete seismic processing and interpretation to that will be used in the application for the Class VI injection permit. That work and resulting Petrel geomodel and CMG simulations to be constructed from them will not be completed until late March 2012. The refined model will make us better able to use modeling to address our specific objectives in the Class VI permit to reduce excessive default monitoring and bonding. We will leverage the extensive work that has already been done at Wellington Field to work toward a successful final outcome in the permitting.

The provisional schedule for Budget Period 1 is included in Figure 8. The field activities would begin as early as March 2012 with work focused on the Mississippian CO2 injection and surface monitoring activities.

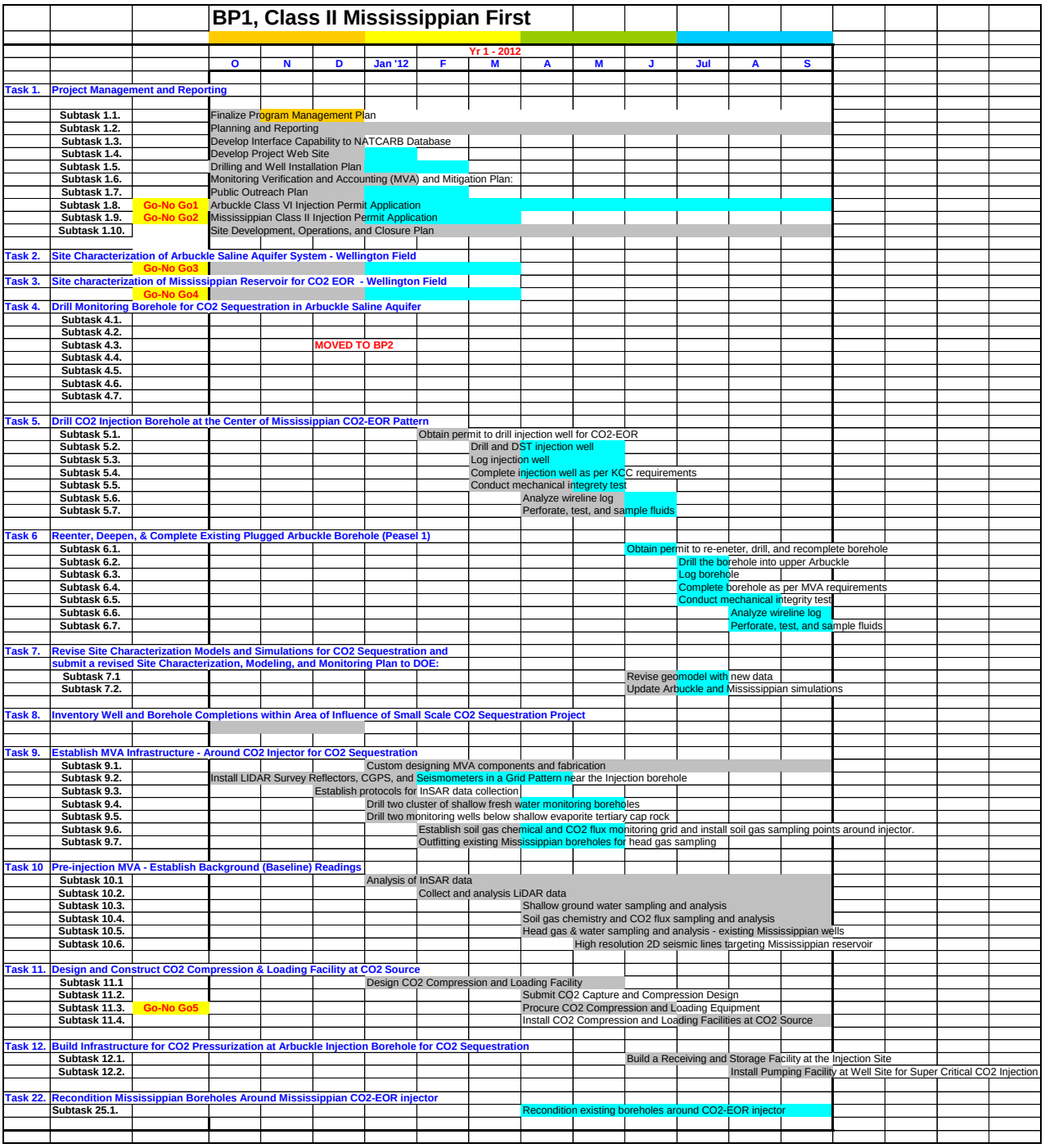


Figure 8. Gantt Chart for BP1. Provisional schedule adjusting for delays in start of field activities.

Project Organization

The PMP includes an organizational chart (Figure 9). The staff, affiliations, and primary responsibility are noted. The selection of the team is based on proven expertise, dependable supplier of CO2, operator of Wellington Field, and a general longer-term interest in the testing and utilization this technology. The assembled team will evaluate cost-effective methodologies that could be later used to implement this technology in this region. Much of the characterization work has been and is being performed under a separate DOE-NETL contract, FE0002056. The existing work will continue in parallel with this contract until August 2013 and refinements to the geomodel and simulations will, in part, be derived from this work. The objective is to avoid overlap and duplication of costs. Moreover, the two years of existing work on Wellington Field has provided the growing wealth of information that has put this field on such as firm base to apply for permits and to optimize the CO2 injection strategy.

Project Team
Small Scale Field Test – Wellington Field (FE0006821)

Name	Project Job Title	Primary Responsibility
Lynn Watney	Project Leader, Joint Principal Investigator	Geology, information synthesis, point of contact
Tiraz Birdie	Consulting Engineer	Reservoir engineer, dynamic modeling, synthesis
Jason Rush	Joint Principal Investigator	Geology, static modeling, data integration, synthesis
John Doveton	Co-Principal Investigator	Log petrophysics, geostatistics
Dave Newell	Co-Principal Investigator	Fluid geochemistry
Rick Miller	Geophysicist	2D seismic aquire & interpretation
		LiDAR support, water well drilling/completion
TBN	Geology Technician	Assemble and analyze data, report writing
TBN	Engineering Technician	Assemble and analyze data, report writing
	KU Department of Geology	
Michael Taylor	Co-Principal Investigator	Structural Geology, analysis of InSAR and LiDAR
TBN	Graduate Research Assistant	Structural Geology, analysis of InSAR and LiDAR
	Kansas State Unversity	
Saugata Datta	Principal Investigator	
TBN	Graduate Research Assistant	Aqueous geochemistry
TBN	3- Undergraduate Research Assistants	
	Lawrence Berkeley National Laboratory	
Tom Daley	Co-Principal Investigator	Geophysicist, analysis of crosshole and CASSM data
Jennifer Lewicki	Co-Principal Investigator	Hydrogeology, analysis of soil gas measuremnts
Barry Freifeld	Co-Principal Investigator	Mechanical Engineer, analysis of U-Tube sampler
	Sandia Technologies, Houston	
Dan Collins	Geologist	Manage CASSM and U-Tube operation
David Freeman	Field Engineer	Manage field install of CASSM and U-Tube
	Berexco, LLC	
Dana Wreath	VP Berexco	Engineering, Manager of Wellington Field
Randy Kouedele	Reservoir engineer	Enginering
Staff of Wellington Field		field operations
Beredco Drilling team		Mississippian and Arbuckle drilling operations
	Abengoa Bioenergy Corp. - Colwich, KS	
Christopher Standlee, Danny Alllison		CO2 supply – Colwich Ethanol Facility

Figure 9. Organizational chart of project team.

How the organizational structure will facilitate the performance of the project

There are six subcontracts in this project -- 1. LBNL, 2. KSU, 3. Sandia Technologies, 4. BEREXCO, 5. Abengoa, and 6. Tiraz Birdie. The KUCR team consists of investigators from the KGS and KU. KUCR investigators include: John Doveton (KGS), Rick Miller (KGS), Dave Newell (KGS), Jason Rush (Joint PI-KGS), Mike Taylor (KU-Geology Dept.), and Lynn Watney (Joint PI-KGS). Watney is the contact PI and function as Project Leader. Rush will assist in project supervision as required. Additionally, Watney will work on regional assessment, reservoir characterization, top seal studies, and commercialization. Rush will conduct reservoir characterization and geocellular modeling. Doveton will perform log analysis. Miller will drill and complete shallow aquifer wells for groundwater sampling and will also design, acquire, and analyze shallow 2D seismic surveys for baseline and detection of CO2 at the depth range of the Mississippian oil reservoir. Newell will analyze soil samples. Taylor will design, install, and analyze LiDAR/INSAR surveys, continuous GPS, and seismometers.
The LBNL Team consists of Tom Daley, Jennifer Lewicki, and Barry Freifeld. Daley will manage the LBNL Team and provide integrative MVA expertise including borehole seismic monitoring (CASSM) and crosswell tomography. Lewicki will analyze soil CO2 flux and soil gas geochemistry. Freifeld (U-tube patent holder) will design monitoring program for multiple U-tube monitoring devices and fiber-optic distributed temperature sensors and wellbore heaters (DTPS) and analyze and interpret data. D. Collins (Sandia Technologies) will provide field supervision during installation of U-tube and borehole seismic (CASSM) monitors. S. Datta (involved in current DOE project FE0002056) from KSU will collect and analyze formation water geochemistry. BEREXCO (D. Wreath) as lease operator will manage and supervise all field-related activities. Abengoa will provide CO2 to the project. The CO2 compression, chilling, and loading unit will be designed and built by Abengoa.

Tiraz Birdie will 1) develop well permitting, drilling, and completion/installation plans, working with other subcontractors, 2) develop Monitoring Verification and Accounting (MVA) and Mitigation Plan as specified by DOE, 3) Site Development, Operations, and Closure Plan (and its updates) as specified by DOE, 4) file permit from KDHE and EPA for the new Arbuckle monitoring well, 5) file permit from KDHE and EPA to convert new drilled well #1-28 to become an Arbuckle CO2 injection well, 6) prior to CO2 injection, update existing simulations for Arbuckle Saline Aquifer and the overlying Mississippian Reservoir at Wellington Field in the vicinity of the CO2 injection wells,) 7) oversee integration of data from MVA operations to characterize CO2 plume movement and monitoring for CO2 leakage, 8) update simulations to match observed plume development using MVA data and evaluate uncertainties and risks, 8) prepare necessary documentation for closure of small scale CO2 sequestration project.

Many of the participants and organizations within Kansas have successfully worked together on past projects as well as the ongoing project at Wellington. We will build an effective partnership and program with the LBNL organization, which has a proven record of working with other organizations on CO2 projects including MVA. PIs at the KGS will supervise the project and ensure objectives are met and results are properly integrated into assessments and best practice manuals.

Description of which elements of the organization are responsible for the individual tasks with their credentials and contact information

The chart below lists tasks and the primary investigator responsible. Tasks frequently have multiple subtasks with different investigator responsible. For information regarding credentials, please review their CVs provided with the original proposal.

Discussion of how communication and decision-making will occur within the context of the organizational structure

Investigator	Task(s)	Element	Institution	Contact Information
Christopher Standlee	11,15,24,30	CO2 source	Abengoa	636-728-0508
Tiraz Birdie	1,2,3,4,5,6,7,8,9,16,17,18,19,20,21,25,26,27,28,29,30	simulation,synthesis, permitting	Birdie Consulting	785-760-3297
Tom Daley	9,10,13,14,16,17,18,19,20,29,30	MVA	LBNL	510-486-7316
Saugata Datta	9,10,16,17,18.19,20,29,30	MVA	KSU-Geology	785-532-2241
Barry Freifeld	9,10,13,14,16,17,18,19,20,29,30	MVA	LBNL	510-486-4381
Jennifer Lewicki	9,10,16,17,18,19,20,29,30	MVA	LBNL	510-495-2818
Rick Miller	9,10,17,18,19,20,29,30	MVA	KGS	785-864-2091
Jason Rush	1,2,3,4,5,6,7,8,9,16,17,18,19,20,21,25,26,27,28,29,30	geomodeling	KGS	785-864-2178
Mike Taylor	9,10,16,17,18,19,20,29	MVA	KU-Geology	785-864-5828
Lynn Watney	1,2,3,4,5,6,7,8,9,16,17,18,19,20,21,25,26,27,28,29,30	project leader	KGS	785-864-2184
Dana Wreath	1,2,3,4,5,6,7,9,12,13,14,15,17,18,22,23,24,25,26,27,28,29	field operations	Berexco	316-265-3511
John Doveton	1,3,4,5,6,7,19,21,25,26,27,28,30	petrophysics	KGS	785-864-2100
David Newell	1,8,16,17,18,19,20,21,29,30	geology, geochemistry	KGS	785-864-2183
Dan Collins	13,14,30	well installation	Sandia Technology	832-286-0471

The bulk of the scientific staff, especially those synthesizing the MVA findings, is located at the University of Kansas campus, which will facilitate effective daily communication. The PIs will coordinate with D. Wreath (BEREXCO) to ensure efficient and successful implementation of on-site objectives. Once field operations have commenced, daily field operation reports will be issued by BEREXCO via e-mail to all investigators and relevant service companies. BEREXCO will handle contracts with traditional oil & gas service companies (e.g., Halliburton, Weatherford) and send call-out sheets. Daily reports will also list upcoming field operations, so the relevant investigator can mobilize equipment and make travel arrangements. PIs will ensure data is appropriately integrated, modeled, and simulated before confirming final injection location and monitoring sites. PIs will follow-up with service companies and subcontractors (Co-PIs) to confirm objectives and schedule. Bi-monthly teleconferences with investigators will be held to communicate project status and to reiterate upcoming deliverables. BEREXCO will contact Abengoa for the delivery of CO2. Abengoa will be responsible for constructing the compression, chilling, and delivery of the CO2. Throughout the project, Watney will ensure effective communication with investigators as well as the DOE Project Manager and will provide written quarterly reports and weekly E-mail updates.

Risk Management

Technical risks include the ability to 1) successfully drill and complete boreholes including installation of equipment for injection and monitoring within budget and timeframe, 2) detect and locate upward migration of CO2 from the plume, 3) sufficiently address environmental, health, and safety impacts in the event of a leak, 3) evaluate and monitor remediation efforts should a leak occur, and 4) provide sufficient evidence that the project can be brought to closure.

Drilling and completion -- Berexco is the industrial partner in the current project who has shown considerable skill in drilling, coring, and completing new wells. The new 1500 ft of core was acquired with a conventional core barrel involving 42 trips in and out of the borehole over the course of 35 days. It was a remarkable feat to recover that amount core (it's the most core recovered by the seasoned coring specialist) and maintain the borehole conditions and progress

under harsh winter weather. Berexco staff arranged to keep core from freezing and handled the cutting and marking of the core in the aluminum liners. With assistance and experience of Sandia Technologies, the installation of the complex downhole equipment in the proposed project should be successful.

Detect and locate CO2 -- Migration of CO2 upwards from the plume could occur via an open fracture system. Fractures as observed in core and inferred from well logs are predominately discontinuous and more zonal in nature and appear to be associated with porous cleaner lithofacies of the Arbuckle (Figure 10). In contrast, the primary caprock consisting of an interval from the top of Arbuckle into the Lower Mississippian has fewer fractures (Figure 6). If an open fracture does breach the primary caprock, the CO2 should be trapped in the significantly underpressured Mississippian reservoir that is blanket-like in distribution over the injection site and surrounding field (Figures 11 and 12). Existing Mississippian boreholes will be monitored to detect the CO2 and a 2D seismic line will be acquired to image the gas (Figure 13). If the overlying seals/caprocks are breached, the 200 ft thick halite/anhydrite evaporite bed at 400 to 600 ft below the surface will likely prevent CO2 from reaching the surface drinking water (Figure 6). Shallow wells and soil gas probes should intercept any CO2 that reaches the surface.

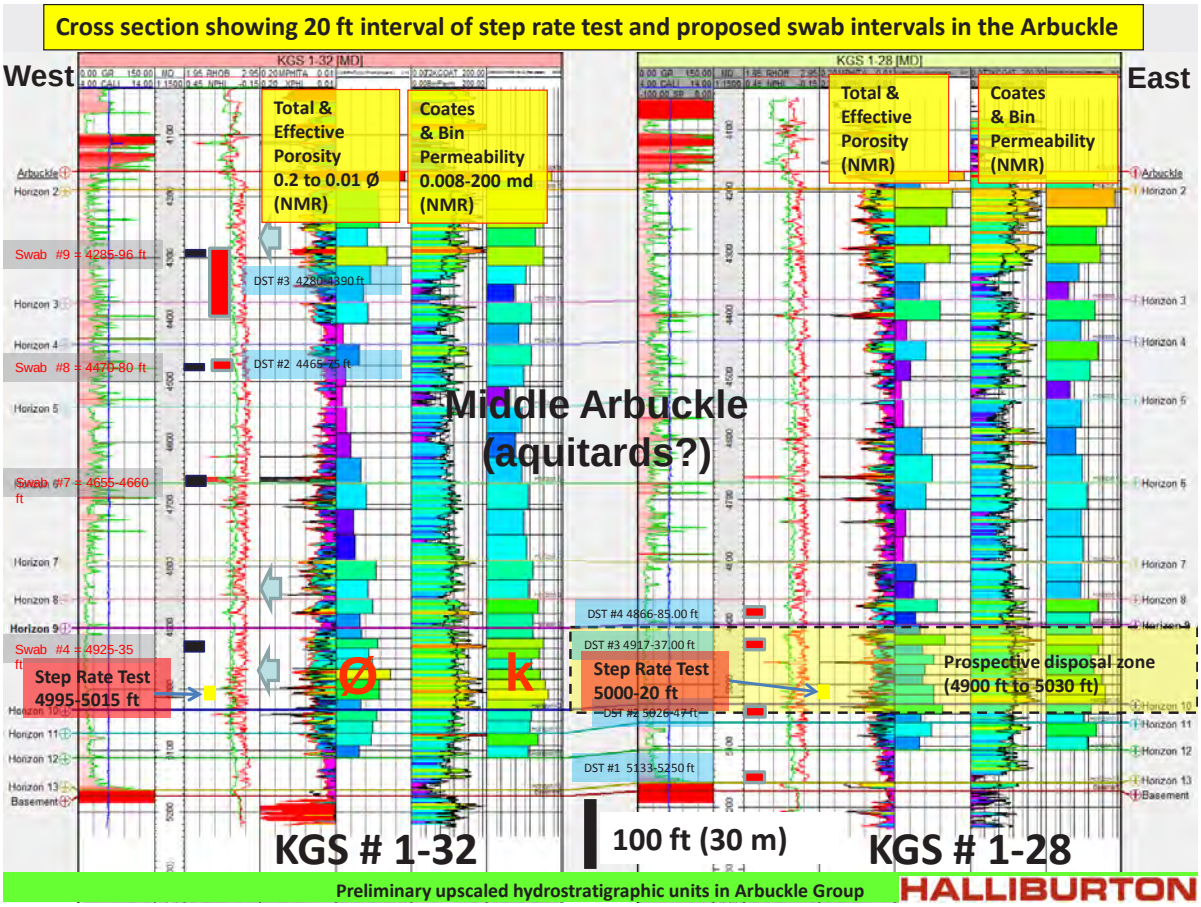


Figure 10. Stratigraphic cross section showing well logs in the Arbuckle saline aquifer. Color blocks are upscaled stratigraphic units with horizontal size proportional to the amount of porosity and permeability as estimated by the nuclear magnetic resonance logging tool. The lower high porosity interval is the proposed injection zone. Middle units in the Arbuckle

have generally lower porosity and permeability and may act as barriers or baffles to vertical CO2 migration.

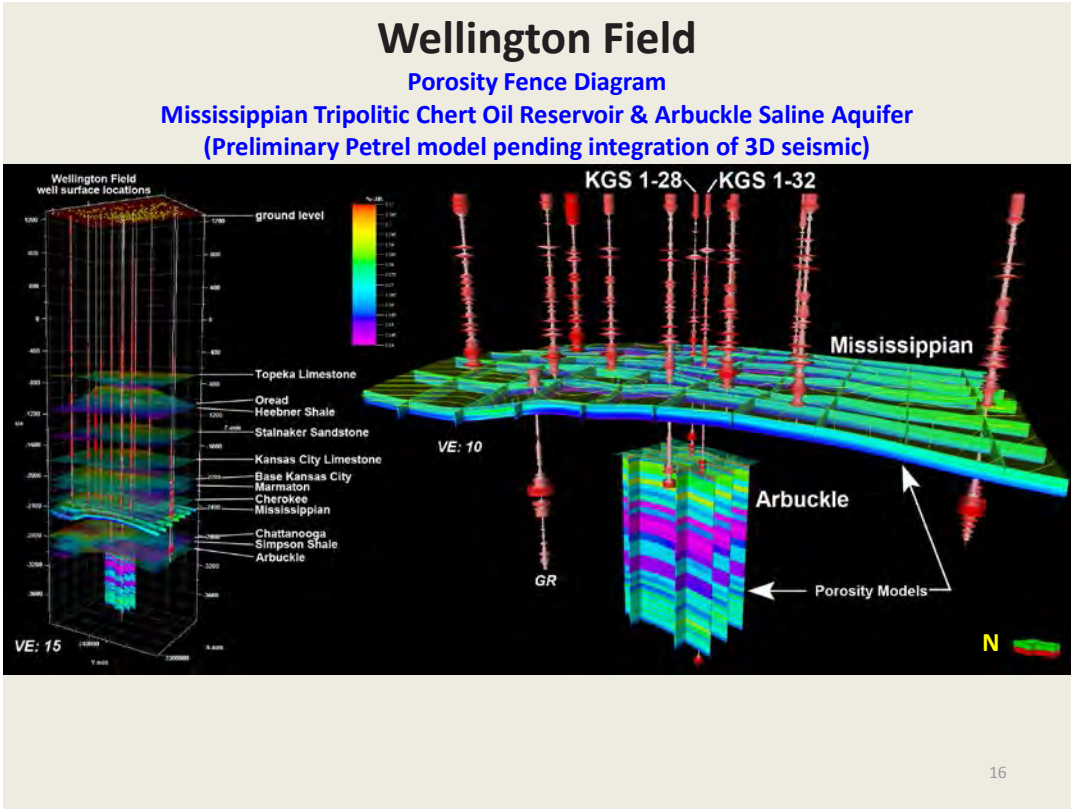


Figure 11. 3D diagram looking east depicting porosity in the Mississippian oil reservoir showing rather uniform distribution over Wellington Field. Arbuckle porosity cube based on newly drilled wells lies below the Mississippian. Intervening strata includes caprocks.

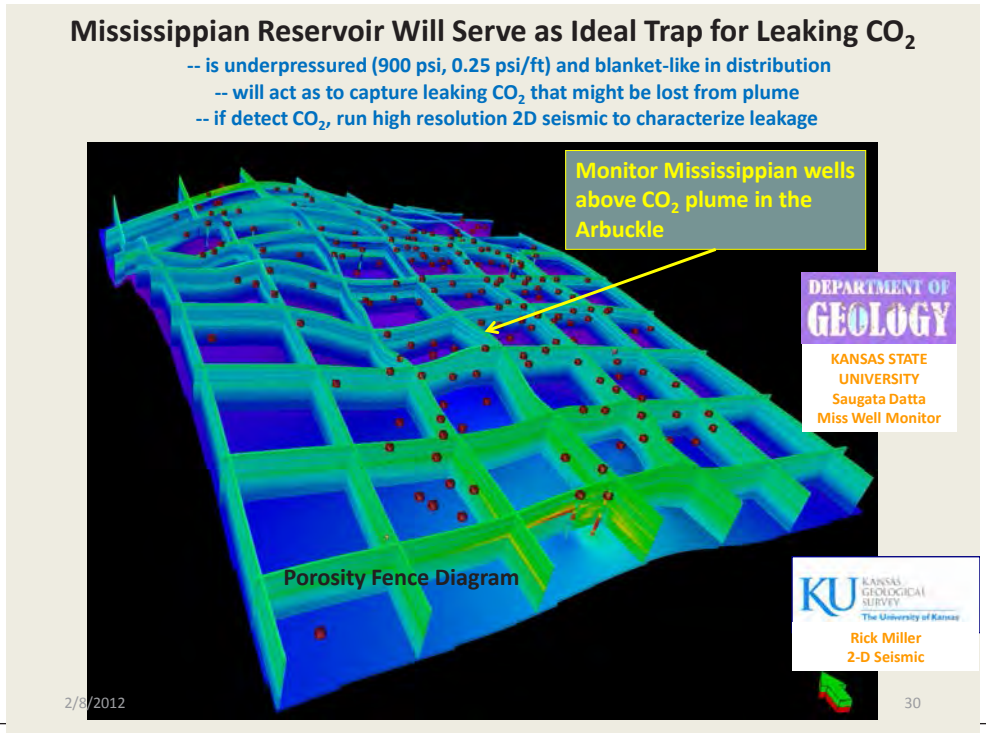


Figure 12. Block diagram of porosity in the Mississippian oil reservoir showing Mississippian well locations. Interval is blanket-like and underpressured overlying area of proposed injection into the underlying Arbuckle.

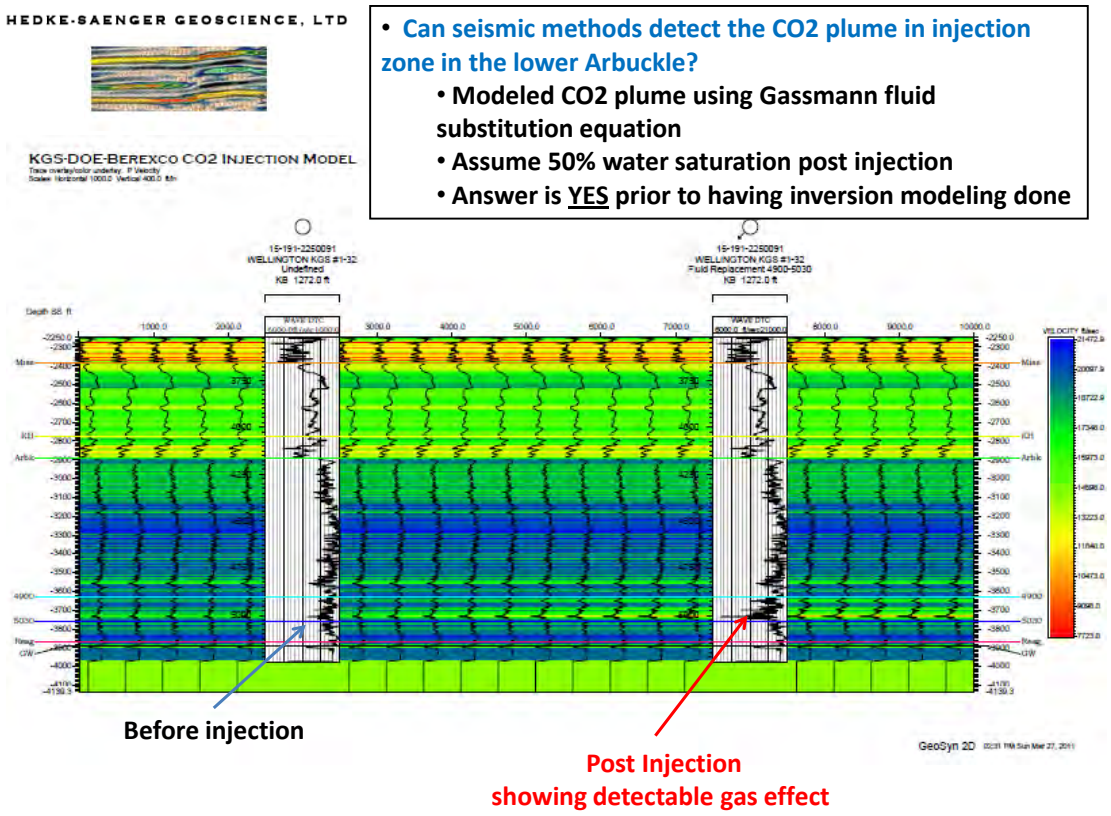


Figure 13. Simulation in seismic effect of injecting supercritical CO2 into the lower Arbuckle depicted on a synthetic seismogram of well before and after injection. Gas effect is noted. 3D seismic survey would be used to assess the CO2 plume during consideration of the bring the project to closure. Accumulation of CO2 in the shallower underpressured Mississippian should similarly be recognizable using high resolution 2D acquisition.

Address environmental, health, and safety impacts in event of leak – Surface leakage of CO2 would be characterized through soil gas and water well analysis to determine concentrations and compare with levels that would be deleterious to nearby residents and livestock. Environmental officials would be alerted immediately to assist in determination of the impact to environment, health, and safety. A 3D view of Wellington Field from surface to the Precambrian basement with the intervening Mississippian oil reservoir and Arbuckle saline aquifer highlighted shows the proportionate distance between surface drinking water and the zone into which CO2 is proposed to be injected (red arrows) Figure 14. The intensity of the red columns along the well traces is proportional to natural gamma ray that indicates the amount of shale. The strata overlying the Mississippian are dominated by shale, which in general, is an ideal caprock/seal. Figure 14 also shows the location and type of monitoring that will be done in this project to measure the CO2 plume and its properties including in situ U-tube fluid sampling in active plume (Figure 15) and cross hole seismic and continuous cross hole seismic (Figure 16). U-tube, in situ seismic and surface based InSAR and LiDAR (Figure 17) will be sued to monitor plume development, compare to simulations as a guide and recognize any anomalous development. These techniques will work together to permit rapid response to any anomalies.

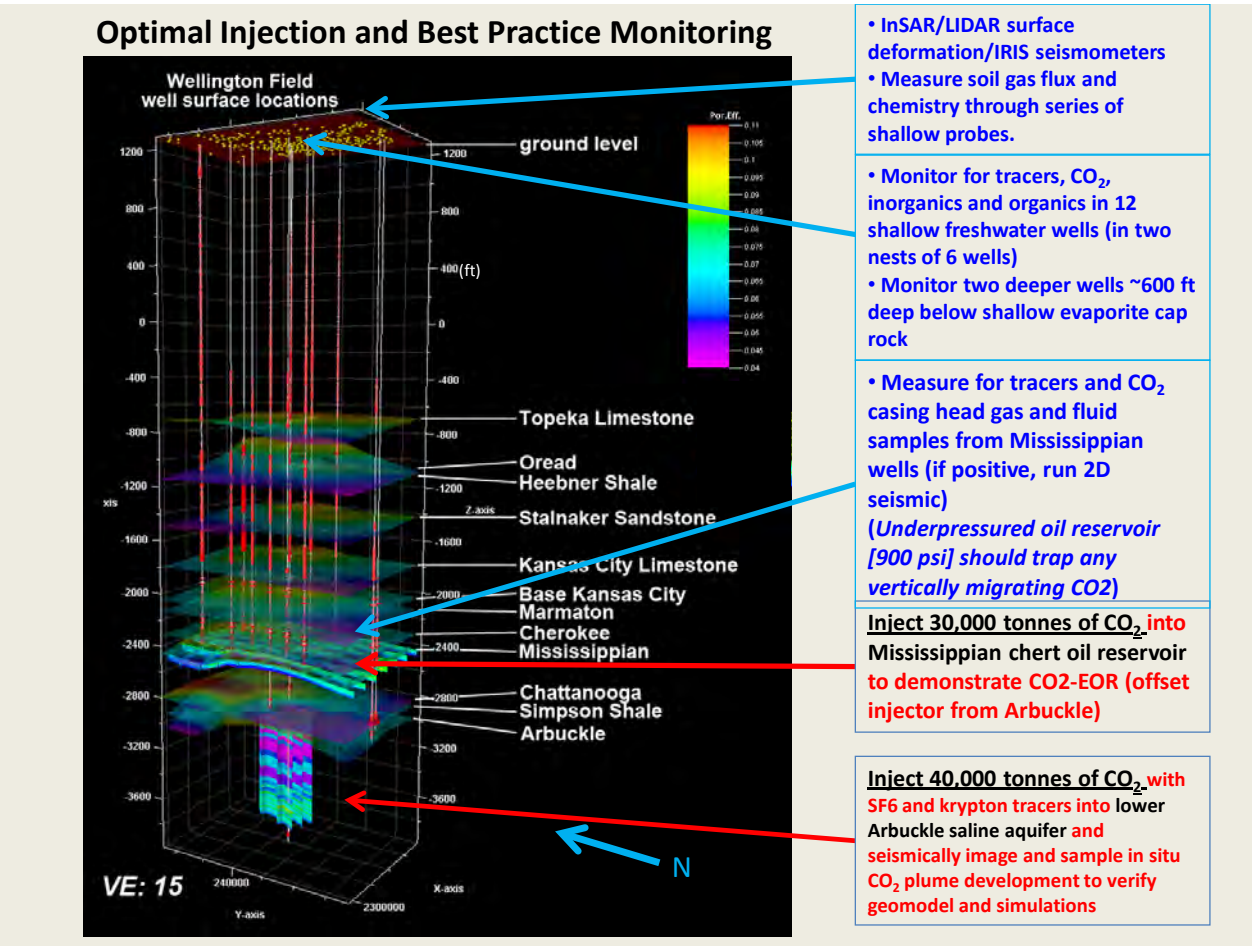


Figure 14. Three dimensional Petrel geomodel of Wellington Field annotated with types of monitoring that will be done prior, during, and after CO2 injection.

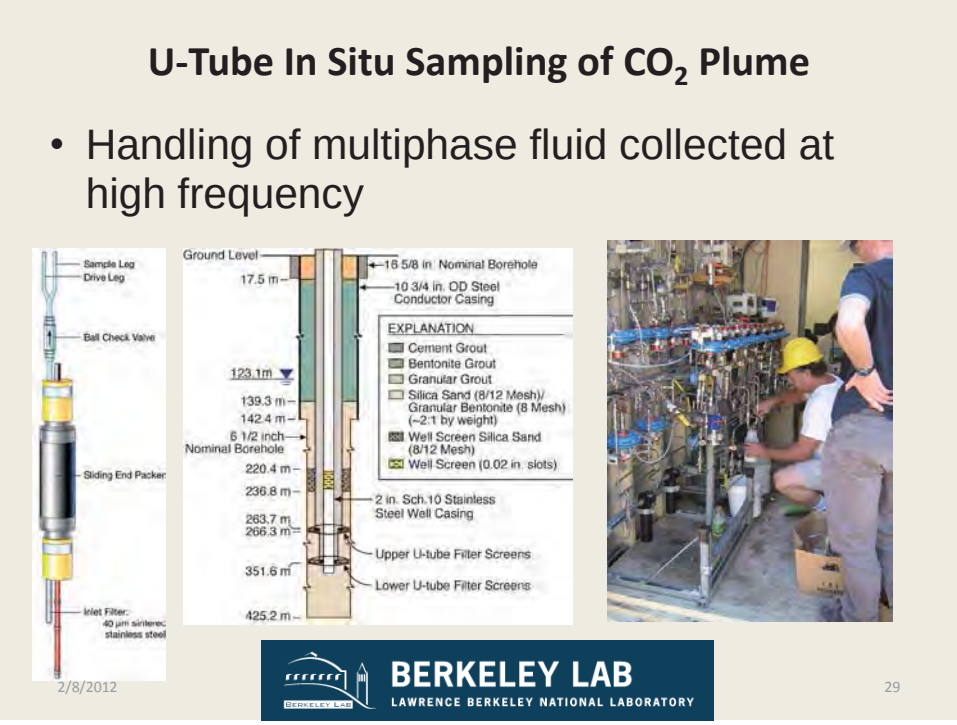


Figure 15. U-Tube sampling installed in monitoring well placed to intercept CO2 plume to obtain compositions of the fluids and compare to simulations.

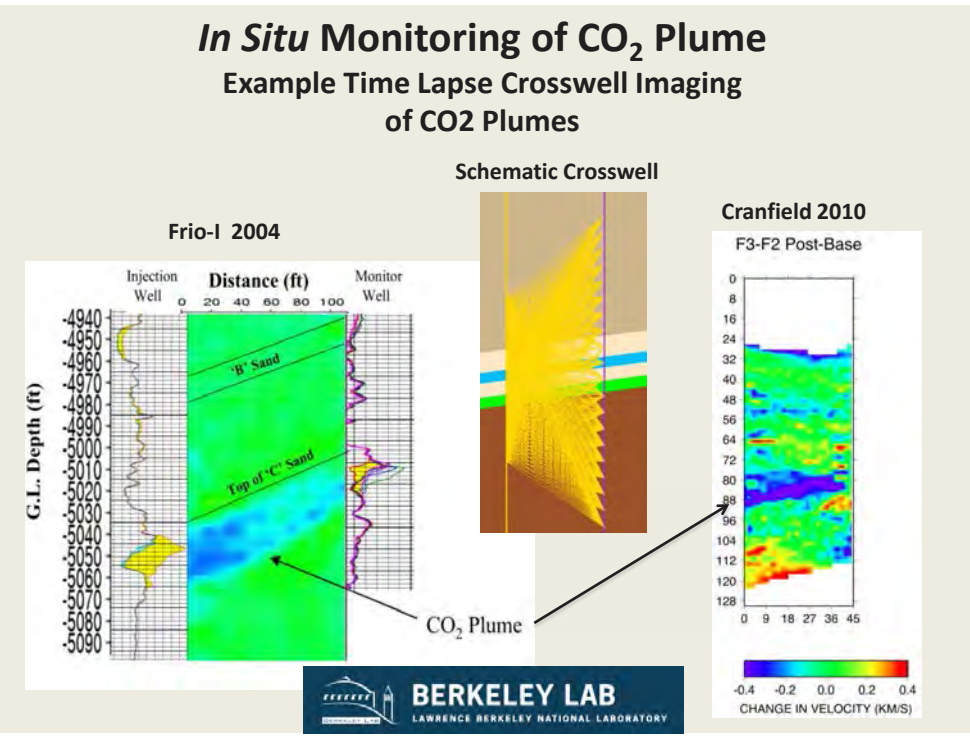


Figure 16. CO2 plume will be monitored in manner done at other CO2 injection sites to compare observed location with that predicted through simulation.

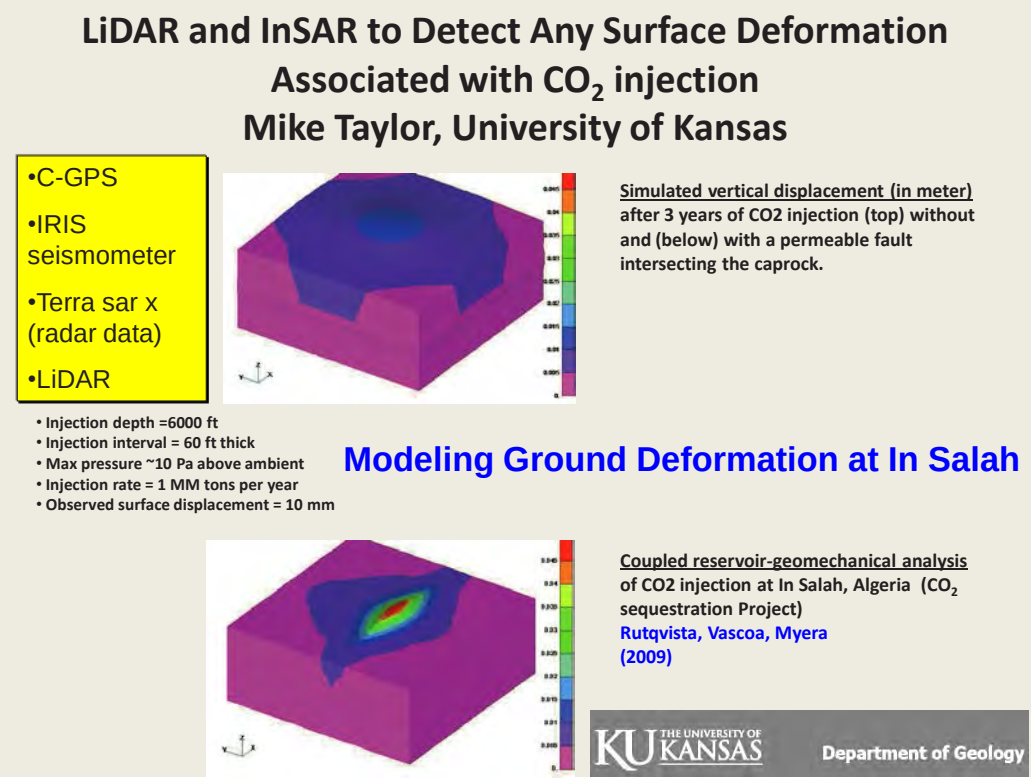


Figure 17. An important part of the monitoring program will be the installation of continuous GPS and seismometers to be able to detect ground motion very accurately. Seismometers will measure instantaneous movement such as microearthquakes. Ground-based LiDAR surveys will be used to measure slight surface ground deformation from plume development as has been noted in large CO2 project at In Salah, Algeria. Satellite based radar (InSAR) will be used to provide another means to examine surface deformation and the combination will resolve this deformation on the scale of millimeters using target that are installed in the vicinity of the injection site.

Evaluate and monitor remediation efforts should a leak occur – If CO2 is detected in the underpressured Mississippian reservoir, the injection will be terminated and the CO2 plume will be blown down in a controlled manner through the injector and observation well. Mississippian monitoring wells will also be used to release any CO2 that has leaked into the reservoir. If CO2 migrates to the base of the shallow evaporite caprock (Figure 18), the gas will be released in the monitoring wells. Shallow freshwater wells will also be used to vent gas that has reached the surface aquifer.

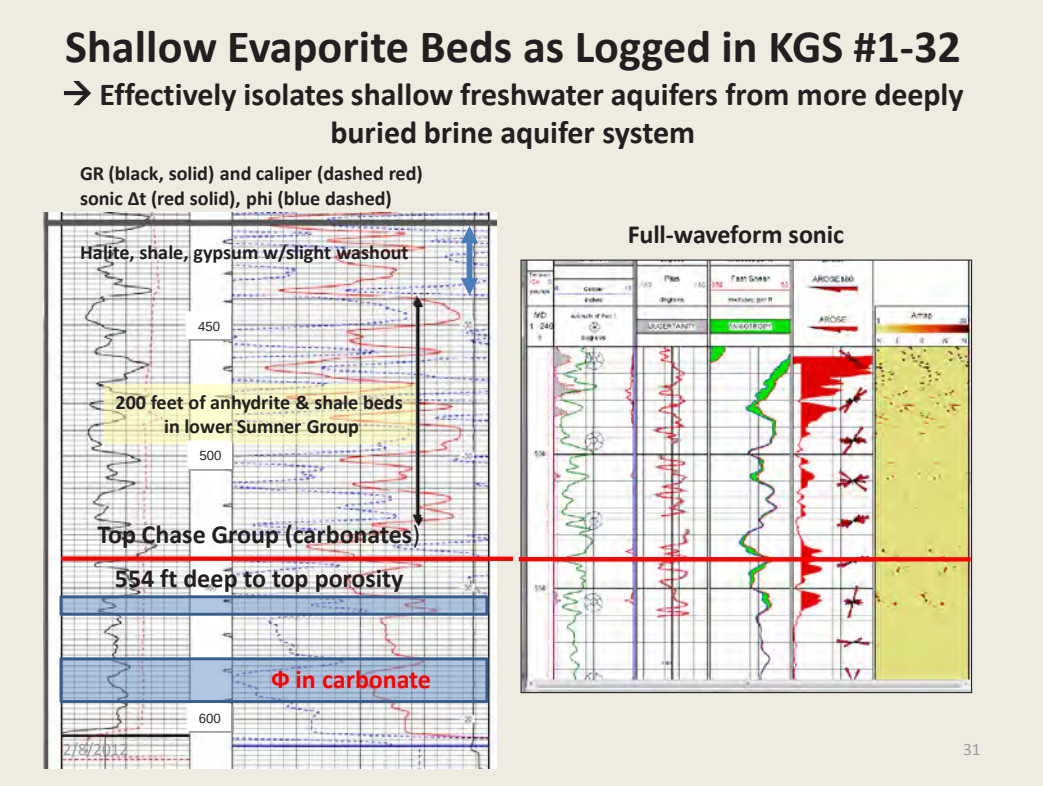


Figure 18. Shallow evaporite beds were characterized by well logs run in the KGS #1-32 and #1-28. Total thickness of the halite, shale, gypsum, and anhydrite is ~200 feet at depth ranging from ~350 feet to 530 ft. Shallow freshwater aquifer overlies evaporite zone and a brine aquifer lies beneath in the Lower Permian Chase Group. Shallow observation wells will be installed in both the shallow freshwater and in the shallow saline aquifer to measure for CO2 directly or indirectly through chemical changes.

Provide sufficient evidence that the project can be brought to closure – If no leaks of CO2 have been observed or when leaks have led to venting and release of the CO2, the acquisition of the repeat 3D seismic survey (Figures 19 and 20) should determine if any gas is observed outside of the volume of the plume to demonstrate containment. Gas remaining in the vicinity of the injection and observation well will then be vented to bring the project to a close.

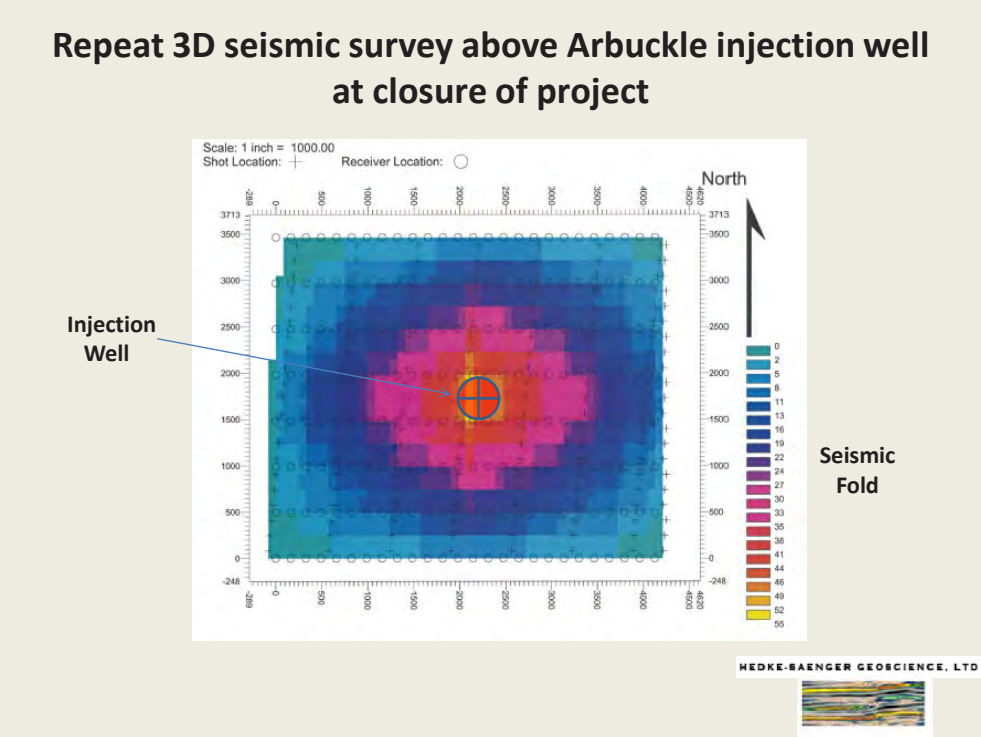


Figure 19. Fold map of scheduled repeat 3D seismic survey at Wellington above the site where CO2 plans to be injected into the Arbuckle saline aquifer. Acquisition parameters will be the same as those used to in original survey so that seismic images can be compared via differencing detect the presence of any remaining CO2 plume. Prior experiments in gas substitution and synthetic seismogram modeling indicate that CO2 can be imaged by this seismic methodology (Figure 12).

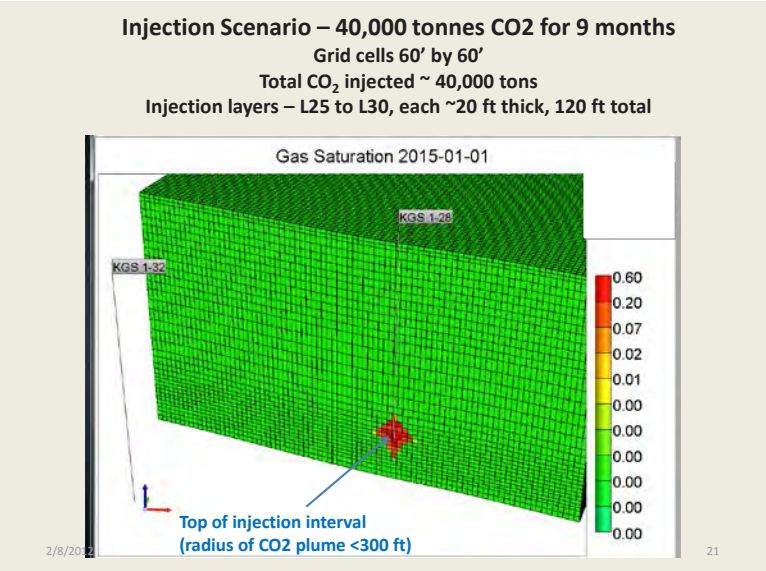


Figure 20. Anticipated size of the CO2 plume based on early modeling is less than 300 feet radius from the injection well and that the CO2 is contained within the lower Arbuckle due to the aquitards overlying the more porous and permeable injection zone. A repeat 3D seismic survey of a square mile should easily capture the plume dimensions within the area of maximum seismic fold (Figure 19).

Process risks include 1) obtaining access to the pore space for CO2 sequestration in the saline aquifer, 2) liability associated with conducting the small scale CO2 injection in the Arbuckle saline aquifer, 3) possible disruptions to the supply and quality of CO2 that could jeopardize the experiment and demonstration and invalidate the refinement of the models.

Access to pore space – A disposal lease and easement agreement has been signed by the landowner and the operating company Berexco to allow Berexco to dispose of CO2 into the Arbuckle formation as part of investigating and determining the feasibility of the subsurface disposal, and actual subsurface disposal of CO2 into the Arbuckle formation.

Liability associated with conducting the small scale CO2 injection in the Arbuckle saline aquifer – Berexco has accepted the liability to inject 40,000 tonnes of CO2 into the Arbuckle and 30,000 tonnes of CO2 into the Mississippian for the purpose of testing and has signed the liability waiver.

Possible disruptions to the supply and quality of CO2 – The primary named source of CO2 for this small scale injection is Abengoa Bioenergy Corporation's ethanol plant in Colwich, Kansas located ~50 miles from the injection site. The plant has been in operation since 1985 is has been upgraded to a modern well equipped plant that has established a solid track record operated 24-7. It is capable of producing approximately 200 tonnes of raw CO2 per day and will deliver up to 70,000 tonnes of CO2 for the small scale injection. Abengoa has signed a commitment letter.

Technical Approach and Understanding

Risks have been classified in the following manner and summarized in the illustration below called Risk Assessment. Those associated with (1) field operations including drilling and wellbore instrument installation, (2) borehole integrity, (3) adequacy of reservoir and top seal characterization, (4) injector location and spacing relative to observation wells, (5) CO_2 procurement and transportation, (6) cost over-runs, and (7) legal issues related to pore space. Potential operational risks are considered minimal. **Risk Group 1**: Over 200 Mississippian wells have been successfully drilled at Wellington Field. This year, the KGS and Berexco successfully drilled two boreholes (KGS 1-28 & KGS 1-32) to the basement as part of the DOE-sponsored site characterization. All proposed downhole instrumentation has been successfully deployed in other projects and no problems are anticipated. **Risk Group 2**: Borehole integrity risks are minimal. Only the two KGS boreholes reach the proposed injection depth in the Arbuckle. A three-stage cement job consisting of CO_2-resistant cement was performed on both boreholes in anticipation of a CO_2 pilot demonstration. The only other nearby Arbuckle well is Peasel-1, which penetrates the uppermost 25-ft approximately 900-ft above the injection depth. Regardless, the Peasel-1 will be deepened and recompleted as an observation well. The wells in the Mississippian are part of an active oil field. These wells have been in place since 1929 with most of the wells drilled in the 1930s and 40s. There is no indication of any leaks from these wells or the reservoir. **Risk Group 3**: Reservoir and top seal characterization have adequately determined sequestration potential and indicate an exceedingly low risk of geologic leakage. A very extensive logging, coring, and drill stem testing program was undertaken for the two research wellbores (KGS 1-28 & KGS 1-32). This data has permitted description of reservoir and top seal architecture, including fracture characterization and preliminary identification of flow layers. Seismic interpretations, reservoir characterization, top seal correlations, and presence of an overlying oil-bearing reservoir indicate

sub-Mississippian strata in the greater Wellington Field area are free of surface-intersecting conductive fractures. The sealing nature of the overlying caprock above the Mississippi is proven with the presence of the oil accumulation over geologic time. Besides numerous shales above the oil reservoir and beneath the shallow surface freshwater aquifer, approximately 200 feet of shallow anhydrite and shale beds are present. **Risk Group 4**: Preliminary simulations indicate injection of 40,000 metric tons of CO_2 will create a plume with a maximum radius of 300-ft after 5-years. A new Arbuckle observation borehole (KGS 2-28) is proposed 300-ft updip of the planned injector (KGS 1-28). This borehole will be outfitted with multiple *in situ* instruments to monitor CO_2 plume dispersal. Wells in the overlying Mississippian oil reservoir will be monitored for any CO2 leakage. The underpressured Mississippian reservoir layer should act as a pressure sink to trap any leakage. Any well that detects CO2 will be followed up by acquisition of high-resolution 2D seismic imaging to determine extent of the CO2. **Risk Group 5**: Abengoa Bioenergy's Colwich ethanol plant located ~50 miles from Wellington Field will provide CO_2 for the project. The Colwich ethanol plant has been in continuous operation for many years without any significant disruption in service. The composition of the CO2 does not significantly vary between operation cycles, and the source is 99% CO_2. Costs are included in the budget for constructing compression, chilling, and loading units at the facility. The CO_2 will have to be trucked from the facility to the injection site. A 3000-3500 psi pump will be used for injecting. **Risk Group 6**: Significant cost over-runs are not anticipated. Berexco, service companies, and subcontractors have a proven record of honoring existing agreements with the KGS in the ongoing project. **Risk Group 7**: Legal issues have been resolved. Berexco assumes all liability involving CO_2 injection. Berexco has agreements with landowners/pore space owners for disposal of CO2 within the Arbuckle. The Kansas Corporation Commission (KCC), Kansas Department of Health and Environment (KDHE), and Region 7 EPA in Kansas City have been kept informed during the entire DOE-sponsored Wellington project. Initial meeting with these regulators have taken place to discuss project's applications for multiple injection permits.

The following approach will be used to manage and address liability issues after operations and after the project has concluded. Post-injection monitoring will be used to confirm expected plume geometry and conformance to simulation scenarios. Downhole instruments (e.g., CASSM, cross hole seismic tomography, multi-horizon U-tube fluid samplers) in offsetting boreholes and surface monitoring equipment (e.g., 3-D seismic, soil gas probes, and InSAR & LiDAR) will be used to verify plume movement. Just prior to project completion, a repeat 3-D seismic survey will be undertaken and compared with initial survey to verify plume conformance. Berexco the field operator is a highly regarded local Kansas company that has a proven record of going above and beyond State disposal and environmental regulations. Upon conclusion of the project, Berexco will carry out appropriate site and wellbore abandonment as outlined by the EPA and will continue wellsite oversight and maintenance as part of its field operations. Berexco has also accepted liability for long-term storage of the CO_2 and has secured liability insurance policies and agreements with land/pore-space owners and the KCC. Berexco will operate the project under existing health and safety rules and regulations (i.e., OSHA) associated with the oil & gas industry as well state environmental regulations (i.e., KCC) and will continue its role as responsible field operator upon completion of project.

This proposed injection pilot leverages the ongoing DOE-funded Wellington site characterization that includes extensive geocellular modeling and simulation studies. Two wells have been drilled

to basement. The logging program was exhaustive (e.g., triple combo, MRIL, micro-imager, dipole sonic). Continuous core was cut from the Mississippian to basement section. This core is currently undergoing computer axial tomography scanning to identify typical pore throat geometries (from touching vug to micropore scale) and to constrain MRIL interpretations of permeability. Routine and special core analysis will be performed. Core description and analysis will be used to derive the appropriate stratigraphic architecture, rock fabric-based permeability functions, and combined with image analysis for fracture characterization and subsequent discrete fracture network (DFN) modeling. Multi-component 3D seismic was recorded and interpreted during year 1 of existing project. Horizons have been mapped and volumetric curvature has been calculated to determine the potential of surface intersecting conductive fractures. No leakage pathways have been identified in the proposed pilot area. Geocellular and simulation models are updated as new data arrives to ensure simulations can adequately predict injectivity and storage capacity and to support risk assessment. Models will be kept evergreen with new borehole data and refinements (e.g., upscaling, anisotropy) to adequately reflect results from the extensive monitoring program. Risk management is summarized in Figure 21.

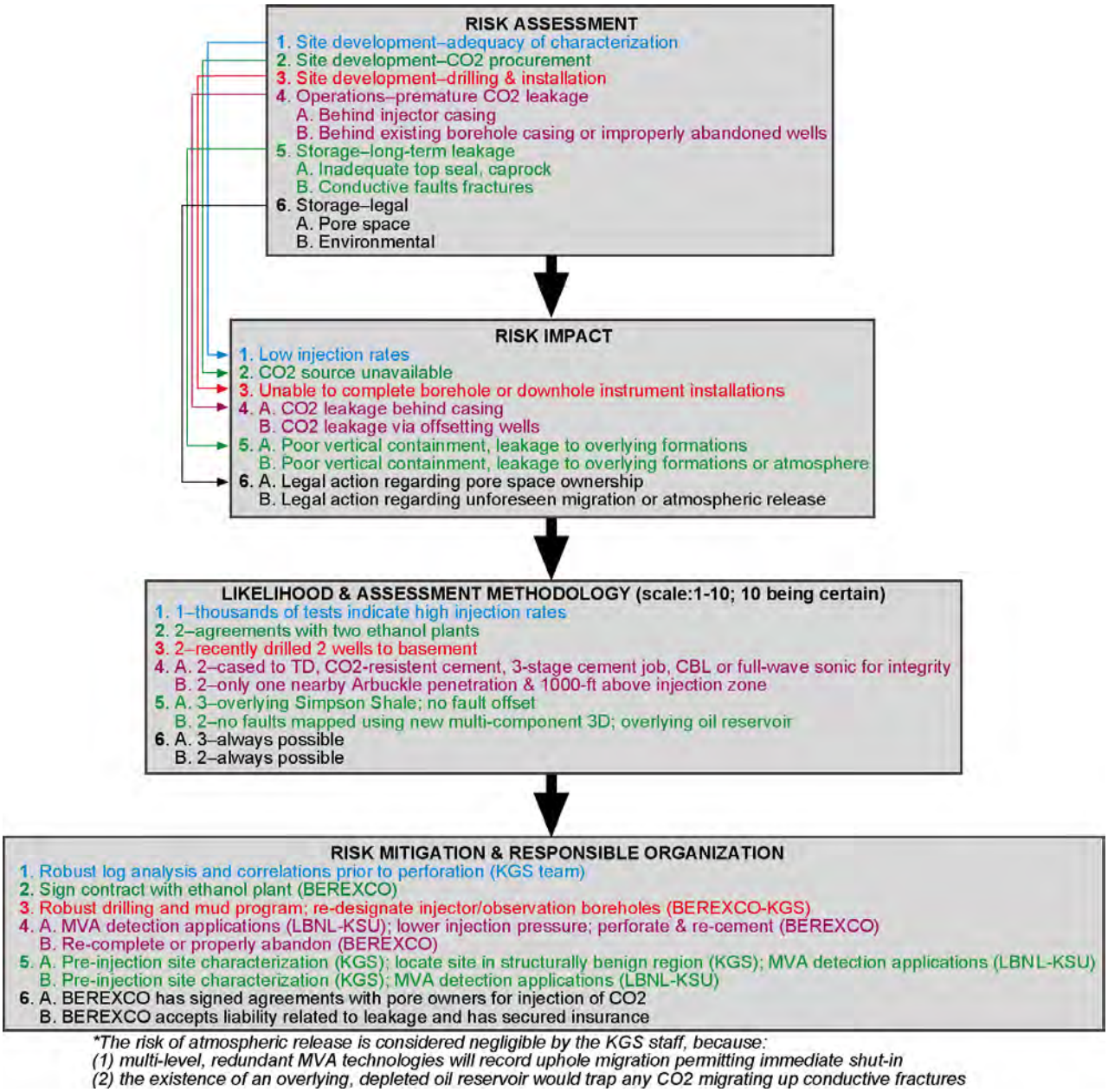


Figure 21. Outline and workflow of the Risk Management Plan described earlier.

Milestone Log

Milestones are under review as we redefine the schedule to start the pilot Mississippian CO2-EOR before the deep saline aquifer test in the Arbuckle.

Project Milestone Log (proposed revision 2-7-12)			
(2 per fiscal year)			
Task	**Budget Period**	**Number**	**Milestone Description**
Task 2.	1	1	Completed a public outreach plan and implement the plan
Task 3.	1	2	Submitted an application for a CO2 injection permit for the Arbuckle
Task 10.	2	3	Pre-injection MVA - establish background (baseline) readings
Task 13.	2	4	Retrofit Arbuckle Injection Well (#1-28) for MVA Tool Installation
Task 18.	3-yr1	5	Compare Simulation Results with MVA Data and Analysis and Submit Update of Site Characterization, Modeling, and Monitoring Plan
Task 22.	3-yr1	6	Recondition Mississippian Boreholes Around Mississippian CO2-EOR injector
Task 27.	3-yr2	7	Evaluate CO2 Sequestration Potential of CO2-EOR Pilot
Task 28.	3-yr2	8	Evaluate Potential of Incremental Oil Recovery and CO2 Sequestration by CO2-EOR - Wellington field

Table. 1. Milestones (in review).

Subtask 1.2. Planning and Reporting

Overall project management of the study is being done by the PI including execution of each phase of the project, subcontractor procurement and management, coordinating staff and outside resources, maintenance of the project budget and collaborating with individual stakeholders and the DOE.

The PI is ensuring compliance with the DOE project auditing requirements of recipients and sub recipients, compiling and submitting reports, including deliverables and periodic reports in accordance with the Federal Assistance Reporting Checklist, to the DOE and making formal presentations to DOE. The Recipient has participated and will continue to participate in annual project review meeting with the DOE.

Subtask 1.3. Develop Interface Capability to NATCARB Database

The Recipient has developed connections that shall allow period update to the NATCARB database with information generated from the project. The DOE project manager will be notified when data are added to the NATCARB database.

Subtask 1.4. Develop Project Web Site

A carbon sequestration web site has been created at the KGS -- http://www.kgs.ku.edu/PRS/Ozark/index.html. A special section of this website will be devoted to the project. This non-secured site is dedicated to apprising the public on the status of the on-going project as well as publishing the acquired data. The format of the site is directed toward both technical and non-technical audiences. Technical data is also conveyed via a web-based interactive mapper -- http://maps.kgs.ku.edu/co2/?pass=project. All presentations will be fully functional through an internet browser (e.g., IE, Firefox, Chrome, and Safari). Project related material which is to be posted on the web site shall be submitted to DOE for review and approval prior to the posting.

Subtask 1.5. Drilling and Well Installation Plan

Well Drilling and Installation Plans will be done for all of the wells and boreholes which describe the drilling and installation methods, the well-borehole designs (casing design, centralizer plan, cement design, etc.), method for determining perforation zones, contingencies for anticipated problems encountered during drilling such as loss circulation zones, completion and development plan. Additionally, the drilling and well installation plan shall include a description of mud logging, wire line logging, coring, swabbing and laboratory analysis of samples that shall be collected, and any other testing that may be performed on the well-borehole.

Components of the Drilling and Well Installation Plan have been considered in developing well costs and will form the basis of these plans. Preparation of the NEPA EQ statements for the wells is underway.

Subtask 1.6. Monitoring Verification and Accounting (MVA) and Mitigation Plan:
An MVA plan has been scoped out as part of the application and continues to be refined. Related detail is being developed in an application for a Class VI (geosequestration) injection permit that describes potential leakage pathways, discussions on detection limits, risk assessment and management, MVA field activities, models being used and their application, and how monitoring methods and techniques will be used to document the amount of injected CO_2 and validate the containment of the injected CO_2. Additionally, mitigation plans to control CO_2 leakage are being developed in consultation with KCC, industry partners, and DOE to effectively manage CO_2 leakage into shallower horizons and/or to the surface. Elements of the mitigation plan will include: a) immediate stoppage of CO_2 injection and release of *in situ* pressure by opening both the injection and observation boreholes. A wellbore management section shall also be included as part of this plan. This section of the MVA Plan shall describe a plan to mitigate potential risks from migration of CO_2 through new or old well bores.

Subtask 1.7. Public Outreach Plan
A detailed Public Outreach Plan is in development to document that describes workshops, presentations, and publications in technical and trade journals to be used to transfer lessons learned best practices, geomodels, simulation results, MVA data and observations to the public, regulators, legislators, and local industry.

Subtask 1.8. Go-No Go1 Arbuckle Injection Permit Application
An application for a Class VI underground injection control (UIC) permit for injecting CO_2 into the Arbuckle Group is underway and will be submitted in the second quarter. The final draft permit, after all negotiations are completed, shall be reviewed and a short report submitted to the DOE with a copy of the permit, indicating any potential implementation issues that may arise. This report shall be used to support a go/no go decision by the DOE on continuing this test injection into the Arbuckle.

Subtask 1.9. Go-No Go2 Mississippian Injection Permit Application
An application for a Class II underground injection control (UIC) permit for injecting CO_2 into the Mississippian Formation will be done in the second quarter. The final draft permit, after all negotiations are completed, shall be reviewed and a short report submitted to the DOE with a copy of the permit, indicating any potential implementation issues that may arise. This report shall be used to support a go/no go decision by the DOE on continuing the project.

Subtask 1.10. Site Development, Operations, and Closure Plan

This plan is underway to provide details of the site development, operations, and site closure for use in management of the infrastructure of the site. A list of available infrastructure in and around Wellington Field related to small scale CO_2 injection is being compiled as part of this plan. The plan will identify all major activities, roles of responsibility, and environmental health and safety

issues that the Applicant will face during all stages of the project. Necessary permits and respective agencies needed for the project and a description of the information required for each permit are being identified. The plan will provide a schedule of when permit applications shall be submitted and anticipated approval dates. A list of responsible persons for completion and negotiation of the permits will be identified for each permit.

Task 2. Site Characterization of Arbuckle Saline Aquifer System - Wellington Field

The existing Site Characterization/Conceptual model will be updated with information gathered during this project for both the Arbuckle and Mississippian Reservoirs. The models will be updated to compare plume movement, lateral extent, and composition from the MVA and tracer analysis and historical information with the simulator-calculated plume geometry. Simulator-calculated plume composition (CO_2 and ionic concentration) and its variation over time will be compared with that obtained from analysis of U-tube samples. Simulator-calculated changes in formation fluids near the observation borehole shall be used to help validate the movement and amount of CO_2 moving between the injector and the observation boreholes in the Arbuckle and also the in situ chemical interactions between mineralogy, formation brine, and CO_2.

A geomodel for the Arbuckle Saline Aquifer system underlying the Wellington Field is being developed at the Kansas Geological Survey (KGS) as part of DOE project DE-FE0002056. Additional details shall be added to the existing geomodel such as the presence/absence of hydraulic communication in different Arbuckle flow-units, delineation of structural discontinuities and flexures, etc. Simulation studies shall be conducted using this model to determine the optimum location of the CO_2 injector and monitoring boreholes based on plume growth and movement, and the existing infrastructure. A summary report will be prepared to describe the geology of the selected area and confirm that it is suitable for CO_2 injection operations. This report shall be submitted to the DOE for review. This report shall be used to support a go/no go decision by the DOE on continuing the project.

Task 3. Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field

The geomodel constructed for the Mississippian Reservoir as part of DOE project DE-FE0002056 will be extracted and used for simulation studies to identify the optimum location of a 5-spot pattern flood to test CO_2-EOR in Wellington Field. The production history of the existing wells will be history matched to validate the model. Criteria used in the selection process for the wells include: 1) maximum use of existing infrastructure of Mississippian wells; 2) tonnage (approximately 30,000 metric tons) of CO_2 necessary to demonstrate incremental oil recovery within the project time frame; and 3) maximization of CO_2 sequestration. A summary report will e prepared to describe the geology of the selected area and confirm that it is suitable for CO_2 injection operations. This report shall be submitted to the DOE for review. This report shall be used to support a go/no go decision by the DOE on continuing the project.

New seismic processing and interpretations are underway and will be integrated in the second quarter for use in applications for the Class VI and Class II injection permits.

Task 8. Inventory Well and Borehole Completions within Area of Influence of Small Scale CO2 Sequestration Project

This inventory was accomplished during the proposal phase to assess need for workover and plugging for budgeting purposes. Berexco has operated the field for a number of years and have extensive information on the well and their completion history. Any concerns were addressed early on in considering this project. It was determined that one well, Peasel #1, will be recompleted and deepened to assume a monitoring role.

Subtask 9.2. Install LIDAR Survey Reflectors, CGPS, and Seismometers in a Grid Pattern near the Injection borehole.

This installation including other field activities are on hold until subcontracts for the other field activities are approved.

Presentations

Presentation to Joint Committee on Energy and Environmental Policy, Kansas Legislature: October 18, 2011 – "Geologic Carbon Sequestration -- Characterizing Pore Space & Managing CO2 Plume"

Joint meeting of state and Region 7 EPA regulators on classification of our CO2 test injection: November 10, 2011: Overview presentation and framework for discussion of injection permit

Kansas Geological Survey Advisory Council: November 18, 2011: Project Update.

Kickoff Meeting: Project Kick Off Meeting was held in Pittsburgh, PA at the Carbon Storage Infrastructure Annual Review Meeting on November 15-17, 2011. The presentation is online at the project website:
http://www.kgs.ku.edu/PRS/Ozark/Reports/2011/Watney_Small_Scale_Field_Test_overview_11-16-11.pdf

Wellington Town Hall Meeting: December 12, 2011: Public meeting was organized by local state legislator, Rep. Vince Wetta from Wellington to provide forum with industry and state representatives on an active horizontal drilling play in southern Kansas and carbon sequestration at Wellington Field. It was estimated 450 people were in attendance. Half hour presentation was given on proposed injection into Arbuckle saline aquifer and the Mississippian oil reservoir. State and federal regulators and other state legislators were in attendance. Presentation was successful in that it reached a many of the stakeholders including visit with landowners near the proposed injection site.

AGU Annual Fall Meeting: Oral presentation was made on December 8, 2011 in a session on carbon sequestration,
-- http://www.kgs.ku.edu/PRS/Ozark/Reports/2011/AGU2011_Watney_v3.pdf

Key Findings

We are in the early stages of revising geomodels, subcontract budgets, and preparing permitting applications.

Plans

1. Revise schedule and impacted planning for CO2 injection to be begin in the Mississippian while application for a Class VI permit is being reviewed by EPA. Revise PMP.

2. Revise geomodel and simulations for the Mississippian oil reservoir and Arbuckle saline aquifer.

3. Finalize large subcontracts for CO2 supply and drilling and CO2 handling at Wellington Field.

4. Submit NEPA EQ's and prepare planning documents.

5. Meet with Biorecro AB on carbon credits for deep saline CO2 injection at Wellington

6. Finalize work on strategies for CO2 source-sink infrastructure in Kansas with the Clinton Climate Initiative, William J. Clinton Foundation.

APPENDIX II

Small Scale Field Test Demonstrating CO_2 Sequestration in Arbuckle Saline Aquifer and by CO_2-EOR at Wellington Field, Sumner County, Kansas

SECOND QUARTERLY PROGRESS REPORT

U.S. Department of Energy
FEDERAL ASSISTANCE REPORTING CHECKLIST
AND INSTRUCTIONS FOR RD&D PROJECTS

DOE F 4600.2
(03/11)
All Other Editions Are Obsolete

1. Identification Number: **DE-FE0006821**	2. Program/Project Title: **Small Scale Field Test Demonstration CO2 Sequestration**	
3. Recipient: **University of Kansas Center for Research, Inc.**		
4. Reporting Requirements:	Frequency	Addressees
A. MANAGEMENT REPORTING		
☒ Research Performance Progress Report (RPPR)	Q	FITS@NETL.DOE.GOV
☒ Special Status Report	A	FITS@NETL.DOE.GOV
B. SCIENTIFIC/TECHNICAL REPORTING		
(Reports/Products must be submitted with appropriate DOE F 241. The 241 forms are available at www.osti.gov/elink)		
Report/Product — Form		
☒ Final Scientific/Technical Report — DOE F 241.3	FG	http://www.osti.gov/elink-2413
☒ Conference papers/proceedings* — DOE F 241.3	A	http://www.osti.gov/elink-2413
☐ Software/Manual — DOE F 241.4		
☐ Other (see special instructions) — DOE F 241.3		
** Scientific and technical conferences only*		
C. FINANCIAL REPORTING		FITS@NETL.DOE.GOV
☒ SF-425 Federal Financial Report	Q, FG	
D. CLOSEOUT REPORTING		
☒ Patent Certification	FC	FITS@NETL.DOE.GOV
☒ SF-428 & 428B Final Property Report	FC	FITS@NETL.DOE.GOV
☐ Other		mailto:FITS@NETL.DOE.GOV
E. OTHER REPORTING		
☒ Annual Indirect Cost Proposal	O	See block 5 below for instructions.
☐ Audit of For-Profit Recipients		
☒ SF-428 Tangible Personal Property Report Forms Family	A	FITS@NETL.DOE.GOV
☒ Other – see block 5 below	A	FITS@NETL.DOE.GOV

FREQUENCY CODES AND DUE DATES:

A - Within 5 calendar days after events or as specified.
FG- Final; 90 calendar days after the project period ends.
FC- Final; End of Effort.
Y - Yearly; 90 calendar days after the end of the reporting period.
S - Semiannually; within 30 calendar days after end of project year and project half-year.
Q - Quarterly; within 30 days after end of the reporting period.
Y180 – Yearly; 180 days after the end of the recipient's fiscal year
O - Other; See instructions for further details.

5. Special Instructions:

Annual Indirect Cost Proposal – If DOE is the Cognizant Federal Agency, then the proposal should be sent to FITS@NETL.DOE.GOV . Otherwise, it should be sent to the Cognizant Federal Agency.

Other – The Recipient shall provide all deliverables as contained in Section D of Attachment 2 Statement of Project Objectives.

QUARTERLY PROGRESS REPORT

To

DOE-NETL

Brian Dressel, Program Manager

Award Number: DE-FE0006821

SMALL SCALE FIELD TEST DEMONSTRATING CO_2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO_2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS

Project Director/Principal Investigator:
W. Lynn Watney
Senior Scientific Fellow
Kansas Geological Survey

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Joint Principal Investigator:
Jason Rush

Date of Revised Report: April 30, 2012

DUNS Number: 076248616

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

Project/Grant Period: 10/1/2011 through 9/30/2015

Second Quarterly Report

Period Covered by the Report: January 1, 2012 through March 31, 2012

Signature of Submitting Official:

Willard Lynn Watney Digitally signed by Willard Lynn Watney
DN: cn=Willard Lynn Watney, o=The University of Kansas, ou=Kansas Geological Survey, email=lwatney@kgs.ku.edu, c=US
Date: 2012.04.30 17:49:00 -05'00'

EXECUTIVE SUMMARY

Project Objectives

The objectives of this project are: (1) inject under supercritical conditions approximately 40,000 metric tons of CO_2 into the Arbuckle saline aquifer; (2) demonstrate the application of state-of-the-art MVA (monitoring, verification, and accounting) tools and techniques to monitor and visualize the injected CO_2 plume; (3) develop a robust Arbuckle geomodel by integrating data collected from the proposed study area, and a multi-component 3D seismic survey; (4) conduct reservoir simulation studies to map CO_2 plume dispersal and estimate tonnage of CO_2 sequestered in solution, as residual gas and by mineralization; (5) integrate MVA data and analysis with reservoir modeling studies to detect CO_2 leakage and to validate the simulation model; (6) develop a rapid-response mitigation plan to minimize CO_2 leakage and a comprehensive risk management strategy; and (7) establish best practice methodologies for MVA and closure. Additionally, approximately 30,000 metric tons of CO_2 shall be injected into the overlying Mississippian to evaluate miscible CO_2-EOR potential in a 5-spot pilot pattern. The CO_2 shall be supplied from the Abengoa Bioenergy ethanol plant at Colwich, Kansas who has operated the facility since 1982 demonstrating reliability and capability to provide an adequate stream and quality of CO_2. The project shall install compression, chilling, and transport facilities at the ethanol plant for truck transport to the injection site.

Project Goals

The proposed small scale injection will advance the science and practice of carbon sequestration in the Midcontinent by refining characterization and modeling, evaluating best practices for MVA tailored to the geologic setting, optimize methods for remediation and risk management, and provide technical information and training to enable additional projects and facilitate discussions on issues of liability and risk management for operators, regulators, and policy makers.

The data gathered as part of this research effort and pilot study will be shared with the Southwest Sequestration Partnership (SWP) and integrated into the National Carbon Sequestration Database and Geographic Information System (NATCARB) and the 6th Edition of the Carbon Sequestration Atlas of the United States and Canada.

Project Deliverables by Task

1.5 Well Drilling and Installation Plan (Can be Appendix to PMP or Quarterly Report)
1.6 MVA Plan (Can be Appendix to PMP or Quarterly Report)
1.7 Public Outreach Plan (Can be Appendix to PMP)
1.8 Arbuckle Injection Permit Application Review go/no go Memo
1.9 Mississippian Injection Permit Application Review go/no go Memo
1.10 Site Development, Operations, and Closure Plan (Can be Appendix to PMP)
2.0 Suitable geology for Injection Arbuckle go/no go Memo

3.0 Suitable geology for Injection Mississippian go/no go Memo
11.2 Capture and Compression Design and Cost Evaluation go/no go Memo
19 Updated Site Characterization/Conceptual Models (Can be Appendix to Quarterly Report)
21 Commercialization Plan (Can be Appendix to Quarterly Report).
30 Best Practices Plan (Can be Appendix to Quarterly or Final Report)

ACCOMPLISHMENTS

ONGOING ACTIVITIES –

TASK 1. PROJECT MANAGEMENT AND REPORTING

Subtask 1.1. Finalize Program Management Plan

A revised Program Management Plan was submitted in February following discussions with EPA on the efficacy of a Class VI permit application for this small scale injection. Modifications were made to the plan in order to begin the pilot CO2-EOR injection in the Mississippian oil reservoir at Wellington Field. This change in order of injection will provide approximately one year for the application and review process for the Class VI Injection in the Arbuckle saline aquifer.

The final PMP will include a copy of the infrastructure requirements for CO2 injection, access documents (surface and subsurface), and a completed contract and commitment for supplying CO2. Contract negotiations with the large subcontractors, Abengoa (supplier of CO2) and Berexco (field activities for small scale test) will be completed next quarter. NEPA environmental questionnaires have been submitted for review for the injection and monitoring boreholes and for the CO2 supply facility.

Subtask 1.5. Drilling and Well Installation Plan

Well Drilling and Installation Plans will be completed early next quarter for all of the wells and boreholes including drilling and installation methods, the well-borehole designs (casing design, centralizer plan, cement design, etc.), method for determining perforation zones, contingencies for anticipated problems encountered during drilling such as loss circulation zones, completion and development plan. Additionally, the drilling and well installation plan will include a description of mud logging, wire line logging, coring, swabbing and laboratory analysis of samples, and any other testing that may be performed on the well-borehole.

Subtask 1.6. Monitoring Verification and Accounting (MVA) and Mitigation Plan:

The MVA and mitigation plans will be completed next quarter as part of the Class VI application and submitted as a separate report.

Subtask 1.7. Public Outreach Plan:

The Public Outreach Plan will also be submitted next quarter as part of the Class VI application. The document will describe workshops, presentations, and publications in technical and trade journals to be used to transfer lessons learned best practices, geomodels, simulation results, MVA data and observations to the public, regulators, legislators, and local industry.

Subtask 1.8. (Go-No Go Decision for CO2 saline formation sequestration) Arbuckle Injection Permit Application

An application for a Class VI underground injection control (UIC) permit for injecting CO_2 into the Arbuckle Group will be submitted next quarter. Substantial progress is being made to ensure timely completion. Key issues to be addressed in the permit application have been addressed as described below.

The final draft permit, after all negotiations are completed, shall be reviewed and a short report submitted to the DOE with a copy of the permit, indicating any potential implementation issues that may arise. This report shall be used to support a go/no go decision by the DOE on continuing this test injection into the Arbuckle.

Key issues in the Class VI injection permit have been discussed with EPA, DOE, and others who are applying for Class VI permit as well as review of pending permits. This has provided an understanding of the course being taken to successfully negotiating the application and to successfully implement the project under these new regulations. Issues identified and addressed include: 1) length of application process with EPA Region 7, 2) monitoring requirements in the context of the funds and duration of the project, and 3) financial assurance requirements. Discussions have included phone conversations, emails, and personal visits with EPA staff in Kansas City's Region 7 and EPA's Washington Headquarters. PI met with key EPA officials from Washington at the Annual Groundwater Protection Council Annual UIC Meeting in Houston in January 2012 to specifically meet and discuss the issues expressed by participants in this project and DOE regarding pursuit of the Class VI permit. The questions posed and comments of EPA are briefly summarized below. Following these discussions, the decision was made by all parties to move ahead with a better understanding by all of the specific attributes of this small scale injection. It was also a joint decision with DOE to delay deployment of the Arbuckle saline formation injection until after the Mississippian CO2-EOR test injection to allow more time to obtain the Class VI injection permit.

Key questions posed to EPA to address decision to proceed or not with application for a Class VI permit –

- What exactly does EPA need to see in our modeling/monitoring results?
- What corresponding relief in the monitoring/bonding obligations can we expect?
- We need a better idea about the expected duration of the Class VI application phases.

- Need concrete numbers associated (to the best extent possible) with these key modeling, monitoring, and application parameters and processes.

Key comments of discussions with EPA --

- Provision in Class VI Final Rule to reduce the monitoring period by demonstrating through modeling/monitoring that there is no danger to the freshwater aquifers.
- 50-yr period monitoring is by default.
- Show by modeling and monitoring that the pressures and plume have "stabilized".
- Up to applicant to demonstrate by modeling that there will be minimal impacts.
- If the pressures and the CO2 plume have stabilized and that no alarming trends have been observed in the monitoring network, then the monitoring can also be shortened.
- Bonding is a function of risk, duration, and type of monitoring needed to reach closure.
- Recognition that saline aquifer beneath oil field inherently reduces uncertainty of containment.

Information shared on project pertinent to making decision to pursue Class VI permit

- Operator of oil field, Berexco, LLC, is single owner of 12 mi2 field (unitized).
- Berexco has purchased pore space from land owner in area of CO2 plume in the Cambro-Ordovician Arbuckle saline formation.
- Berexco has accepted the liability and risk for CO2 injection into saline formation and the overlying oil field.
- Berexco has operated Wellington Field since late 1980's and plans to do so for years to come, ~20 yrs at current operations and longer if CO2-EOR is implemented.
- Berexco has suggested that they could monitor for CO2 after 4-yr project with acceptable cost-effect monitoring technologies and additional funds to do so.
- Mississippian oil reservoir is a continuous stratigraphic layer in Wellington Field that is also currently underpressured relative to underlying saline formation and can act as a pressure trap for any CO2 migrated from beneath.
- Demonstrated sealing caprock above 20 million barrel oil reservoir with 1000's of feet of shale and 200 ft of evaporite separating intervals of CO2 injection from marginal, thin unconfined shallow freshwater overlying Wellington Field and the area of review.
- Comprehensive geologic, geophysical, and geochemical data from existing study (FE0002056) being used to provide a refined geomodel (Petrel-based geocellular static model) and simulation (CMG full compositional simulator) with nearly complete core and extensive core testing being used in calibration of models.

- Proposed CO2 injection interval in Arbuckle ~5000 ft lies ~1300 ft below the Mississippian oil reservoir and ~900 ft below the top of Arbuckle with intervening caprocks and measured high and low permeable hydrostratigraphic units that comprise the mid and upper Arbuckle saline formation.
- Initial basic dynamic model injected 40,000 tonnes of CO2 into lower permeable 120 ft thick Arbuckle over a 12-month period resulted in a CO2 plume with lateral extent under 300 ft radius of injection well with vertical migration within the confines of the lower Arbuckle formation.
- Initial dynamic model does not include geochemical trappings, brine solubility, and imbibition (capillary entrapment mechanisms) that would lead to further degradation of the plume.
- Step-rate flow test in 20 ft interval within proposed injection zone conducted between two boreholes drilled in project DE-FE0002056 confirmed conformable communication of the hydrostratigraphic unit a low injection pressures.
- Small experimental scale of injection relative to others with extensive testing, modeling, monitoring would be a beneficial for this emerging technology and demonstration to stakeholders by providing quantitative parameters on the potential for storage of CO2 in a saline formation.
- Data will be used to further calibrate regional characterization of storage capacity of the Arbuckle saline formation underway in project DE-FE0002056.

It is also understood that EPA officials desire to have test injections of CO2 to evaluate new geologic sequestration regulations. A successful small scale test at Wellington Field will provide this information. EPA continues to develop rule-related guidance for in areas of financial responsibility, public participation, site characterization, area of review and corrective action, well construction, testing and monitoring, and project plan development. Our project will address these new guidelines and contribute to the continuing dialog with stakeholders.

The Class VI application for this small scale injection includes fundamental components that closely address the EPA guidelines and recommendations, focused on reduction of uncertainties.

- The small scale test involves injecting CO2 in deep saline aquifer beneath existing Wellington Field inherit with assurances of the integrity of the caprock overlying the oil field (**Figure 1**).
- Significant past and ongoing characterization in project DOE-FE0002056 will provide 2nd generation static and dynamic models to further improve quantification and prediction of flow, storage, and sealing associated with a CO2 plume. Information to be included in application will sufficiently reduce the risk and uncertainty of the small scale injection, and develop compliance with EPA regulations and anticipated flexibility required for a successful project that meets budget and practical implementation.

- Monitoring, verification, and accounting (MVA) methodologies developed for this study are cost effective and practical, yet state-of-the-art techniques providing a comprehensive system to characterize CO2 plume to be compared with and to calibrate the 2nd generation simulation. *In situ* and remote monitoring of the injection zone; the immediate overlying portions of the saline formation; oil reservoir; shallow, near surface brine formation beneath shallow evaporite; the unconfined freshwater aquifer; soil zone; and surface deformation will all provide means of rapid detection of any unanticipated movement of CO2 plume, so action can be quickly taken to cease operation and mitigate (**Figure 2**).
- Project will utilize best practices in geology and engineering to manage the CO2, protect freshwater aquifers, and avoid contamination of other subsurface natural resources.

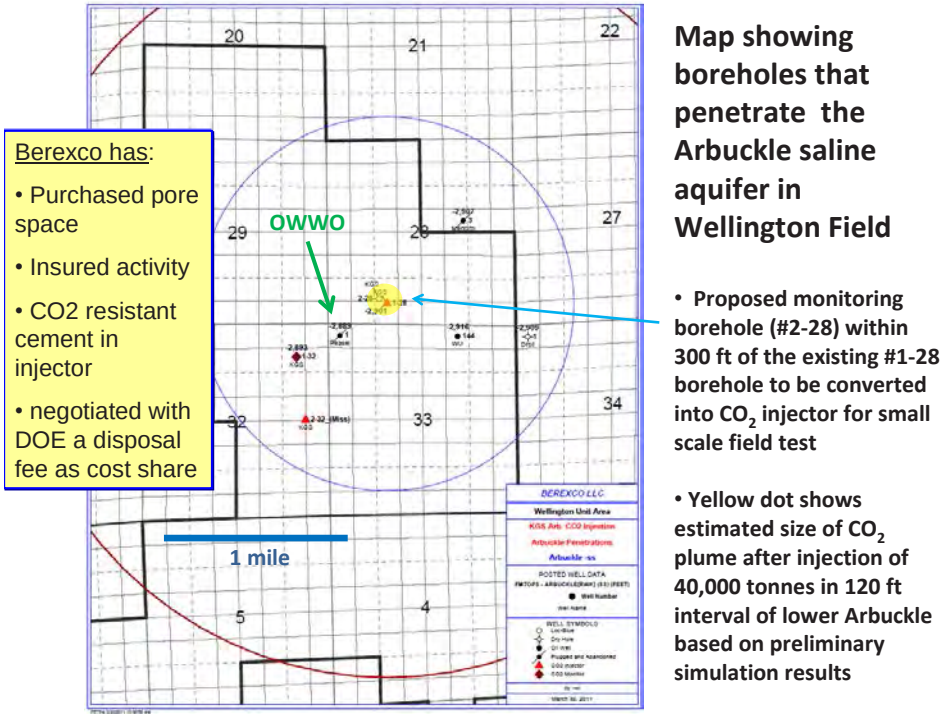


Figure 1. Proposed injection site into Arbuckle saline formation at Wellington Field identifying initially modeled lateral extent of CO2 plume (yellow) and location other Arbuckle boreholes in the area.

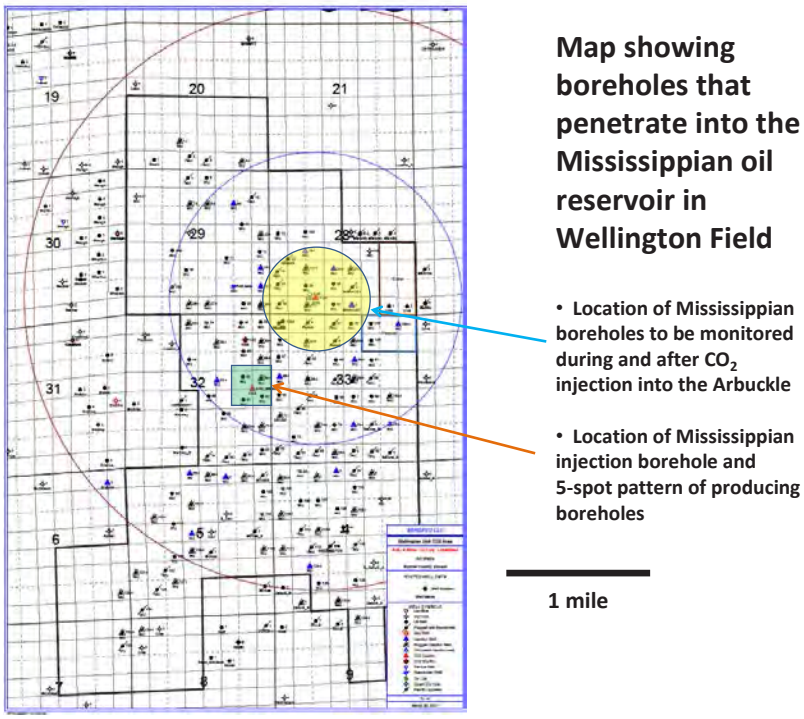


Figure 2. Map locating boreholes penetrating the Mississippian in Wellington field and location of Mississippian wells to be monitored above and beyond the predicted CO2 plume around the location of the Arbuckle injection borehole (yellow-filled circle).

Guidelines from other stakeholder groups such as Carbon Sequestration Council are being reviewed, e.g., resolving means to establish that CO2 storage is "permanent" as noted as follows from the CSC (Van Voorhees, 8-9-11 to MRSCP Partner Meeting):

- Delineate the maximum monitoring area (MMA) – the area expected to contain the free phase CO2 plume until injected CO2 is not expected to migrate in the future in a manner likely to result in surface.
- Identify potential surface leakage pathways in the MMA and assess the likelihood, magnitude, and timing, of surface leakage of CO2 through these pathways.
- Strategy for setting monitoring baselines for surface leakage.
- Strategy for detecting and quantifying any CO2 surface leakage.
- For Class VI, develop emergency and remedial response plan.

Also information provided by the Carbon Sequestration Council (http://www.carbonsequestrationcouncil.org/) cites considerations for obtaining a successful Class VI application including:

- EPA's focus on site selection and characterization.
- Additional focus on performance standards, site specificity, flexibility and adaptability [*up to the application to carefully establish this perspective*].
- Design permit applications to maximize flexibility.
- State permitting programs should use flexibility.

- Permits plans key to adaptation and site specificity.
- Plans define how performance standards apply.
- Plan modifications key adaptations to project learning.

Subtask 1.10. Site Development, Operations, and Closure Plan

A draft of the plan will be developed in the next quarter (*during BP1 as specified by DOE*) to describe the details of the site development, operations, and site closure including:

- list of available infrastructure in and around Wellington Field related to small scale CO2 injection;
- identify all major activities, roles of responsibility, and environmental health and safety issues that the Applicant will face during all stages of the project;
- identify the necessary permits and respective agencies;
- describe the information required for each permit;
- schedule of when permit applications shall be submitted and anticipated approval dates.
- A list of responsible persons for completion and negotiation of the permits shall be identified for each permit.

Task 2. Site Characterization of Arbuckle Saline Aquifer System - Wellington Field

A considerable amount of geologic, geophysical, core and log based petrophysical and geochemical information is being compiled and interpreted in project DE-FE0002056 to quantify the hydrostratigraphic units in the Arbuckle saline formation and overlying caprocks and Mississippian oil reservoir. This information is being used produce the 2nd generation static geocellular model and dynamic simulation for the Class VI application. New models will be obtained in the next quarter for use in the application. Further updates and refinements will be shared with EPA and stakeholders during the evaluation process as per communications with Region 7 EPA officials.

An example for the variability of the permeability in the Arbuckle saline formation, a very key element in the modeling, is illustrated by results of whole core analysis obtained during the quarter from Wellington KGS #1-32 (**Figure 3**).

Seismic processing to obtain conversion of time to depth and to interpret the converted shear wave data in Wellington Field has taken additional time (**Figure 4)**. The depth conversion is now completed and will be used without the shear wave interpretation in the model used in the initial submittal of the Class VI application.

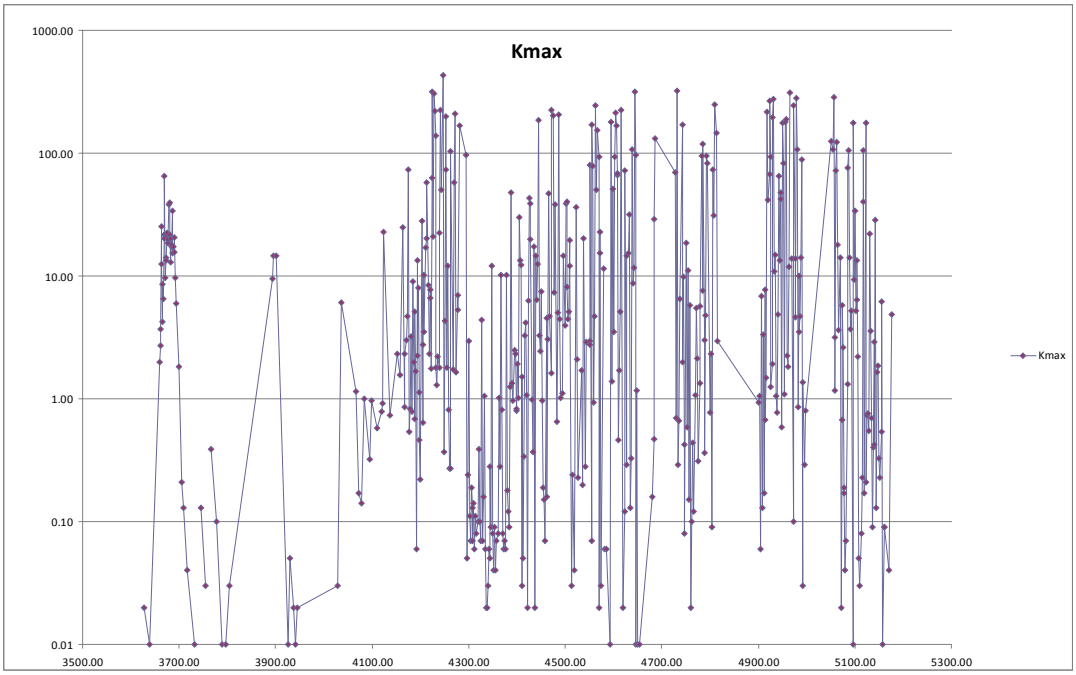


Figure 3. Simple plot (log permeability in millidarcies vs. depth in feet) of whole core analysis of maximum permeability (Kmax) measured in the Mississippian, Chattanooga, and Simpson Group (above 4160 ft depth, left side of plot) and the Arbuckle saline formation, below 4160 ft. Entire 1600 ft interval was cored in this plot from Wellington KGS #1-32. Fewer whole rock samples were analyzed above the Arbuckle in what were visually determined to be low visual permeability. Instead, CT scans were obtained in the low permeable intervals. Entire interval was logged with nuclear magnetic resonance (NMR) tool that is being used to calibrate effective porosity, pore size, and permeability that will be used to quantify the permeability. Moreover, special core analysis of tight zones has being done at NETL labs that have obtained permeability in the microdarcy to picodarcy permeability range in the lower organic argillaceous carbonates of the Mississippian. Note the considerable vertical heterogeneity of permeability in the Arbuckle with Kmax varying from less than 0.10 millidarcy to several hundred millidarcies. No core samples have measured permeability that has reached the 1 Darcy level or above, which is consistent with the estimates of permeability from the NMR tool. Moreover, fracture heights measured in the core indicate that they are closely correlated to the hydrostratigraphic linked lithofacies, i.e., enhance the matrix pores, but closely constrained by the stratigraphic zonation. Larger matrix pores, and particularly, thin inter-formational breccias have more fractures.

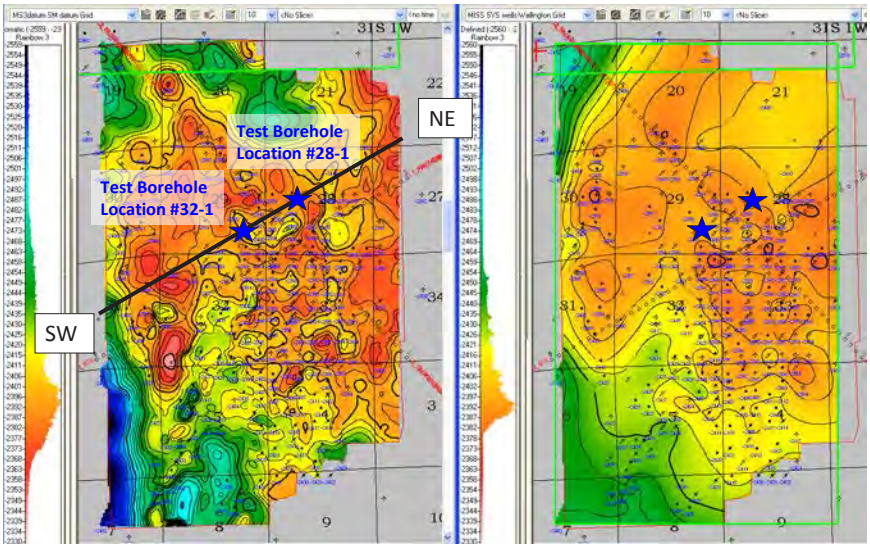
Remaining Seismic Work at Wellington Field

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 4. Prior estimates of the extensive geophysical processing and interpretation being done for Wellington 3D multicomponent seismic survey in project DE-FE0002056. All of the activities will be completed in the next quarter.

Task 3. Site characterization of Mississippian Reservoir for CO2 EOR -Wellington Field

New seismic processing and interpretations as described above are underway and will be integrated in the second quarter for use in the Class II injection permit for the CO2-EOR test injection into the Mississippian oil reservoir at Wellington Field. The new prestack depth migration volume will be of major importance in the simulation of the CO2-EOR flood (**Figures 4 and 5**). The additional seismic profile in **Figure 6** illustrates the detailed information from the seismic in the Paleozoic interval down to the Precambrian surface at the base of the Arbuckle saline formation.



Hedke (Feb. 2012)

Figure 4. Prestack depth migration top Mississippian (left) compared to the Mississippian structure map using well control only (right). Correspondence of the two maps is excellent with additional resolution provided by the seismic data. Both sets of data will be integrated into the geocellular static model of the Mississippian reservoir. Note index line locating the shear wave survey shot at Wellington for calibration of the converted wave of the 3D seismic survey. 2D survey is shown in Figure 5.

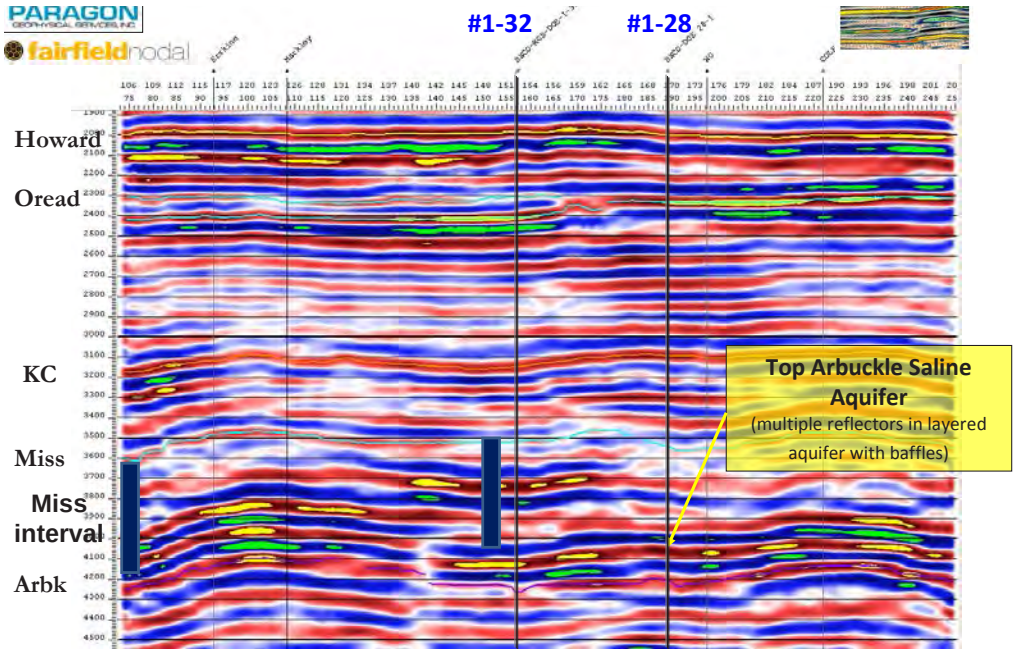


Figure 5. Preview of the converted shear wave, prestack depth migrated multi-component 3D seismic volume in Wellington Field coincident with southwest-to-northeast oriented shear wave line #1 identified in Figure 4.

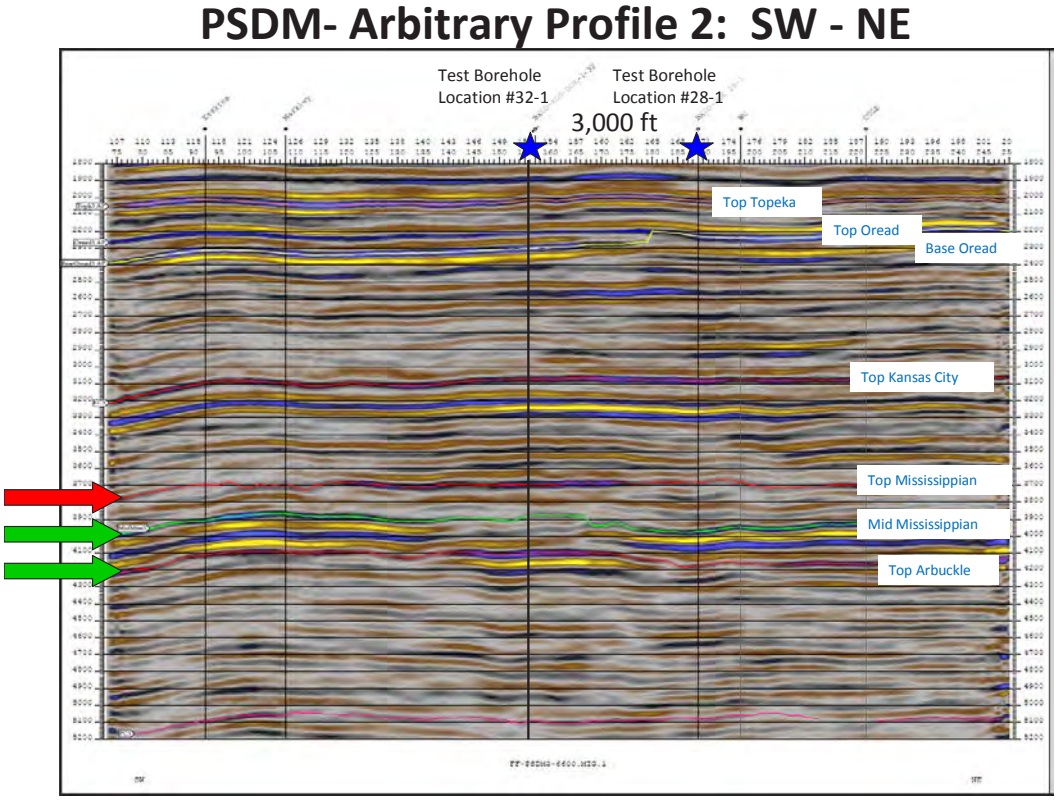


Figure 5. PSDM of an arbitrary profile running southwest to northeast intersecting the two test boreholes drilled under DE-FE0002056. Stratigraphic horizons are identified. Precambrian basement is the lower pink line at the base of the Arbuckle saline formation.

The rich core and log petrophysical database at Wellington KGS #1-32 borehole located 3000 feet southwest of the CO2 injection well, #1-28, provides an exemplary view of the strata extending from the 100 ft thick Cherokee Shale above the Mississippian into the upper Precambrian. These data are summarized in **Figures 6-10**.

The 430-foot thick Mississippian interval includes both the oil reservoir at its top (**Figures 6, 7, and 8**) and a lower 110 ft interval (**Figure 10**, referred to as dark Cowley facies) that is comprised of dark, organic-bearing argillaceous quartz and dolomite siltstone that is being characterized as added caprock to the underlying shales in the Simpson Group and Chattanooga Shale.

- Vertically stacked siliceous dolo-siltites reflect upward-shallowing, retrogradationally/progradationally stacked cycles comprising a depositional sequence.
- Cycles consist of argillaceous dolo- and lime mudstone and wackestones, siliceous dolo-siltites, and increasingly sponge-rich, skeletal wacke–packstones that cap shallowest portions of cycles on higher portions of the ramp.

- Shallowest cycles deposited along higher edges of ramp were affected by bottom currents and were subaerially exposed after deposition.

- Rock properties typically change systematically upward through the reservoir succession with molds and vugs, pore throat size, and connectedness varying between each successive cycle affecting cementation exponent & bound water.

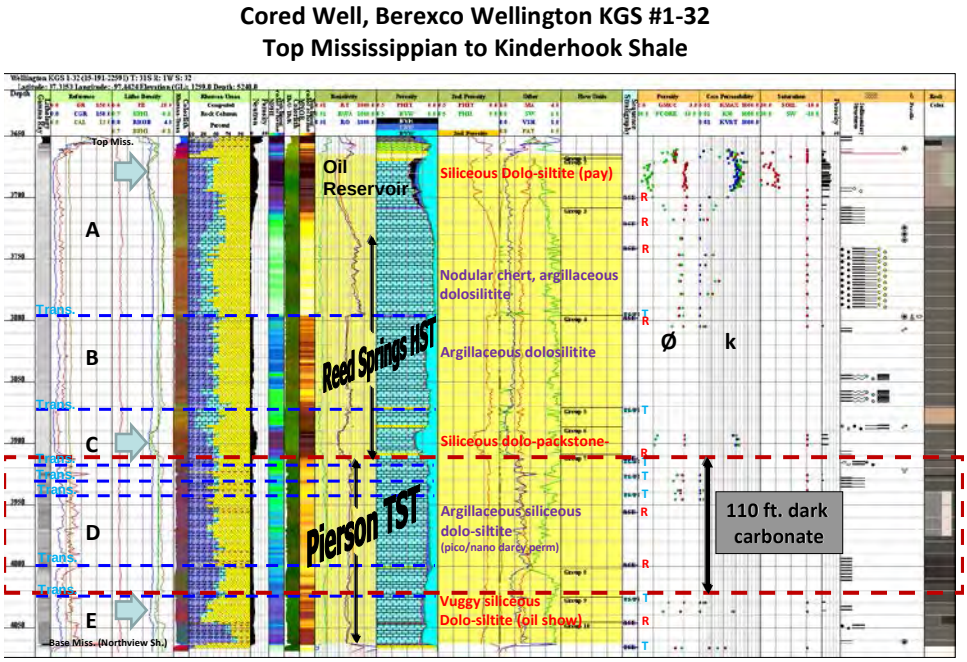


Figure 6. Well log and interpreted lithologic profile from logs on left. Right side illustrates porosity and permeability measurements from core, sedimentary structures, and color for Wellington KGS #1-32 borehole.

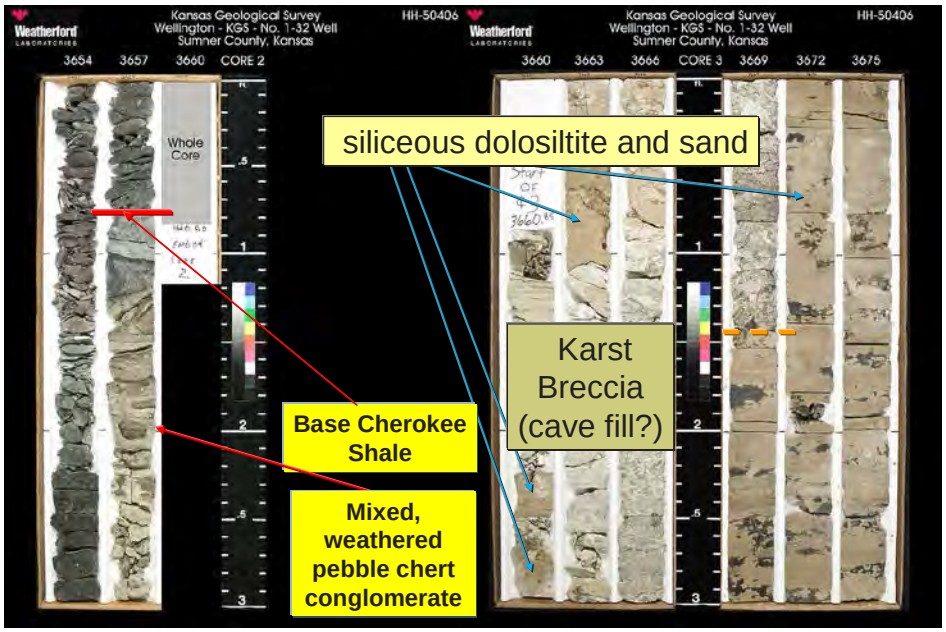


Figure 7. Three boxes of slabbed core (3 ft long) from Wellington KGS #1-32 borehole showing upper portion of the oil reservoir in Wellington Field overlain by shales of the Pennsylvanian Cherokee Group.

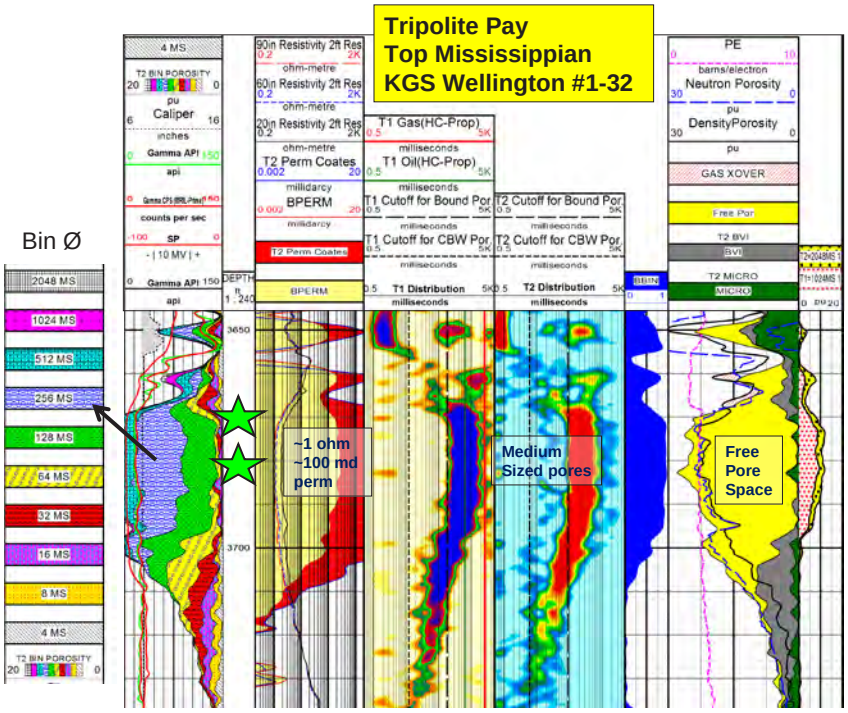
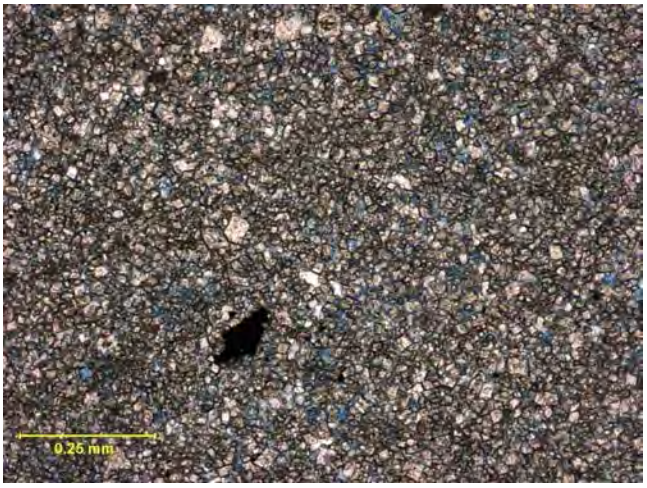


Figure 8. Interpreted nuclear magnetic resonance (NMR) log profile of the Mississippian oil zone in Wellington KGS #1-32 borehole, annotated with summary information: low one ohm-m resistivity, moderate porosity of around 100 md,

medium sized pores (intercrystalline dolomite), most of which is free pore space with minor bound water.

3670.6’



- Plain Light (10x zoom)
- Fine grained dolomite with intercrystalline porosity
- Opaque oxide/sulfide (?) present

TS provided by Datta & Barker, KSU

Figure 9. Thin section photomicrograph with blue epoxy impregnation of Mississippian oil reservoir from Wellington KGS #1-32 borehole. Reservoir is a finely crystalline dolomite with mottling of silica cement and replacement of the dolomite.

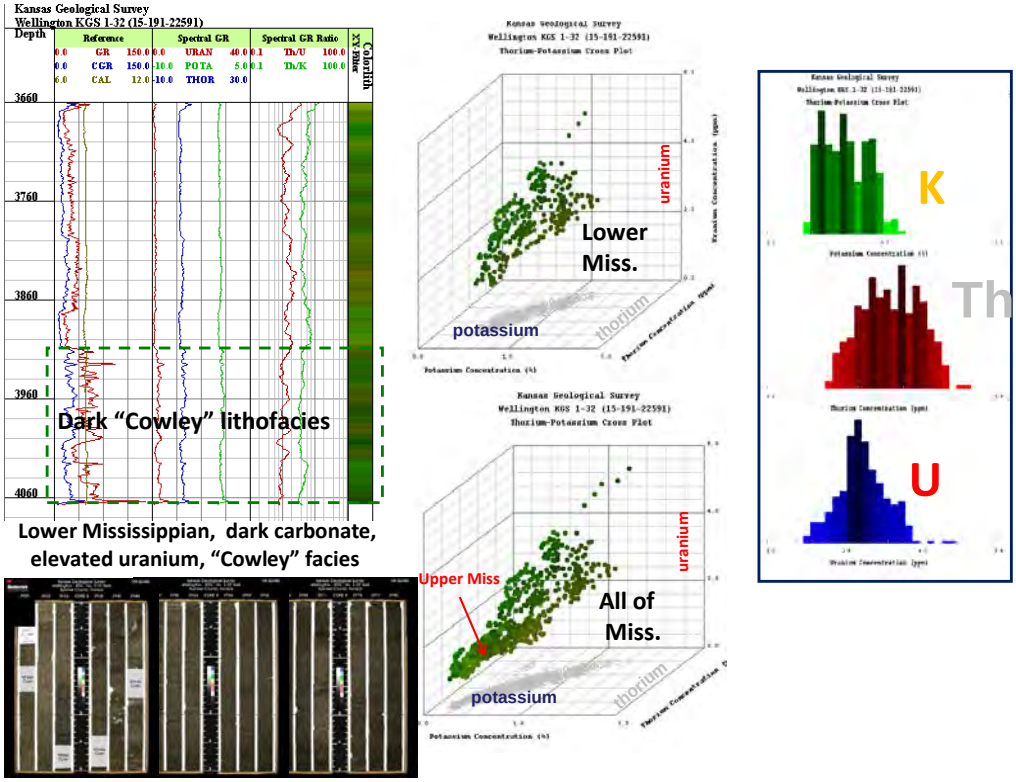


Figure 10. (*previous page*) Spectral gamma ray profile (uranium, potassium, and thorium) of the Mississippian strata in Wellington KGS #1-32 borehole and comparison of these elements in cross plots to right show elevated uranium content in lower Mississippian "Cowley lithofacies. Photos of 3 ft high core boxes illustrating the dark colored, tight, low permeability argillaceous siltstones of the "Cowley" lithofacies shown in lower left.

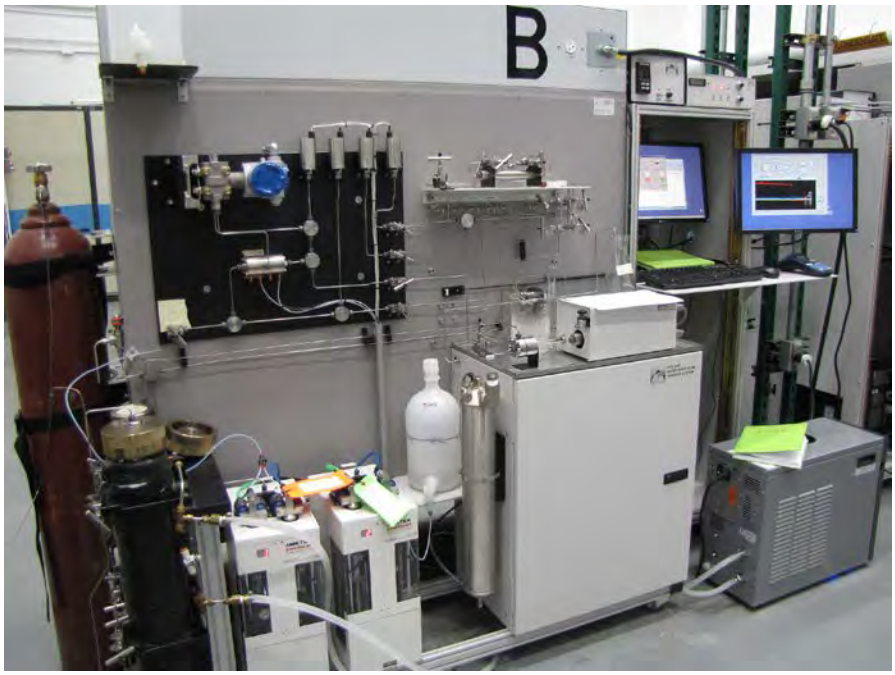


Figure 11. Core flow apparatus used at NETL in Pittsburgh to measure the microdarcy and picodarcy permeability in the lower Mississippian organic bearing, argillaceous quartz/dolomitic siltstones that are being evaluated to serve as additional caprock that overlies the Arbuckle saline formation.

Subtask 9.2. Install LIDAR Survey Reflectors, CGPS, and Seismometers in a Grid Pattern near the Injection borehole.

Mike Taylor constructed a base station on the KU campus in February 2012 and received training during Spring Semester for the operation of the CGPS (continuous GPS that is used to calibrate InSAR and LiDAR surveys), and a seismograph station. The equipment installation in Lawrence is essential for training on the use of equipment and to test materials before being sent to the field before equipment is deployed in Wellington Field. Issues such as earthquakes and fracking are on everyone's mind and these surveys will insure that we are not doing either.



Figure 12. CGPS and seismometer training station installed at KU campus for instruction and testing of equipment before deploying to the field.

Schedule and Budget Update

Schedule - Seismic processing of converted shear wave and interpretation of the seismic at Wellington Field continues. We will update the Petrel geocellular geomodel and run the 2nd generation CMG simulations in the next quarter to include in the application for the Class VI injection permit. Our objective of the new model will be to reduce excessive default monitoring and financial bonding by adequately characterizing the geology of the saline aquifer, caprocks, and overlying oil reservoir.

The provisional schedule to inject CO2 into the Mississippian oil reservoir ahead of the Arbuckle is provided in the series of Gantt charts included in **Figures 12 through 15**.

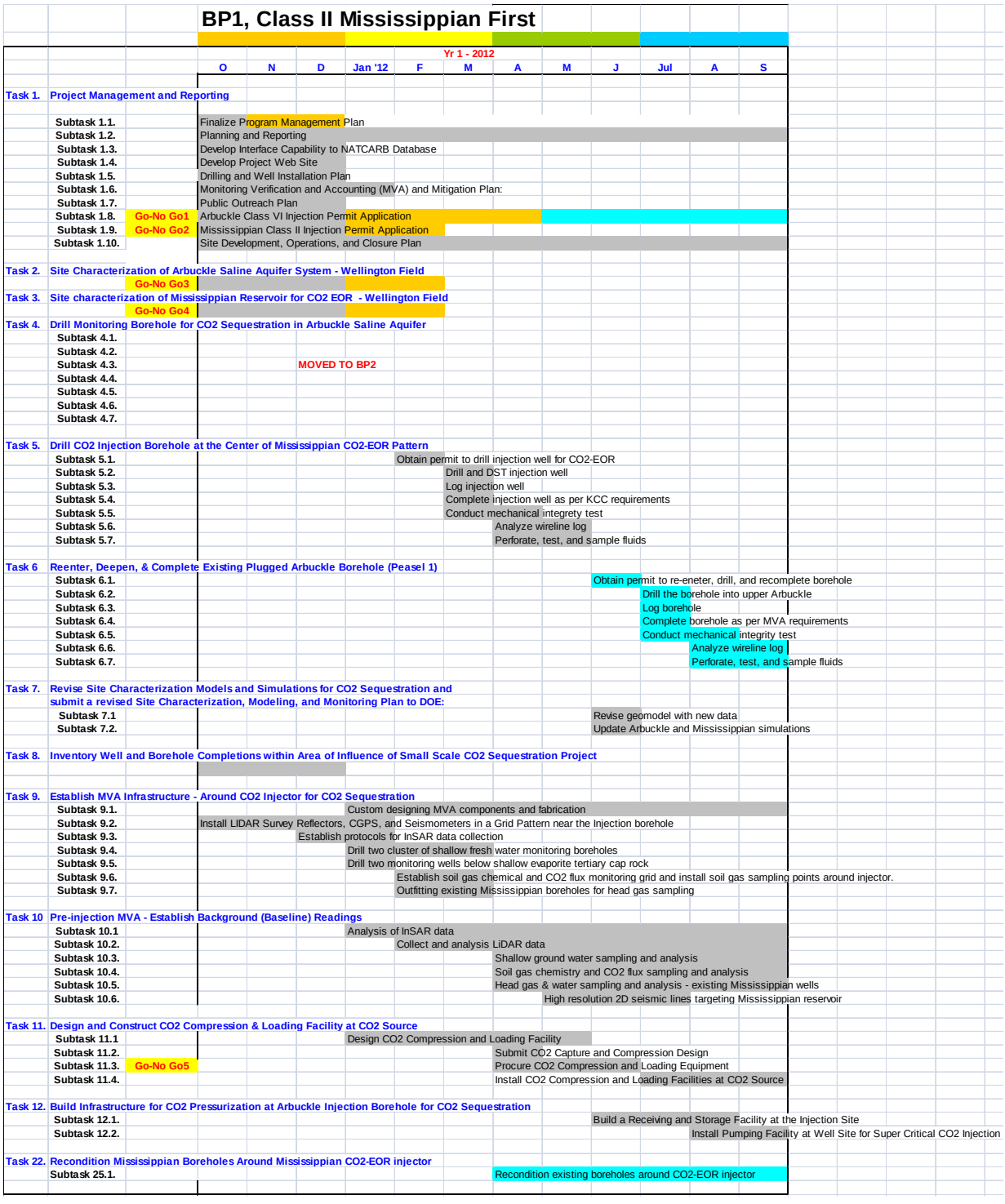


Figure 12. Revised schedule BP1.

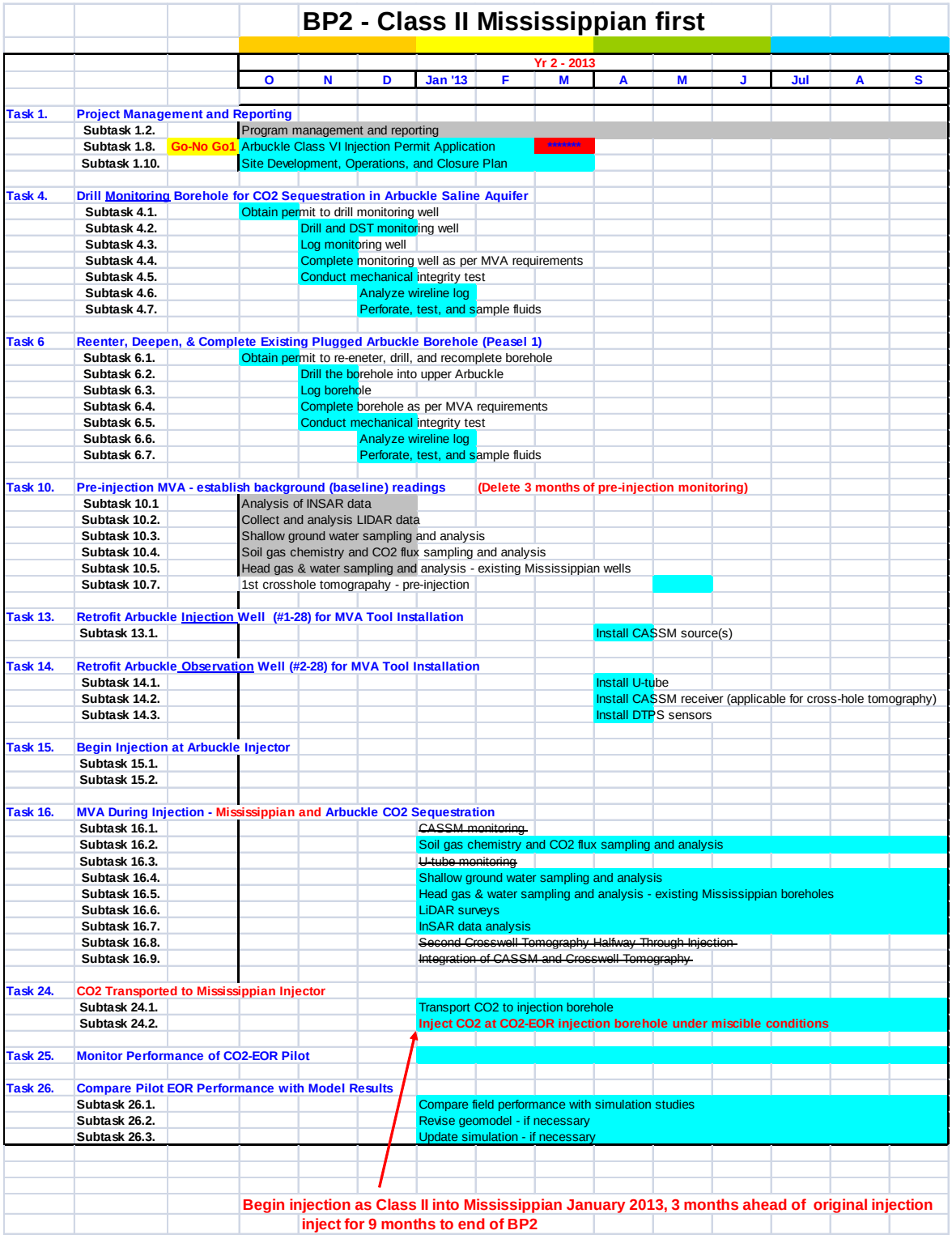


Figure 13. Revised schedule BP2

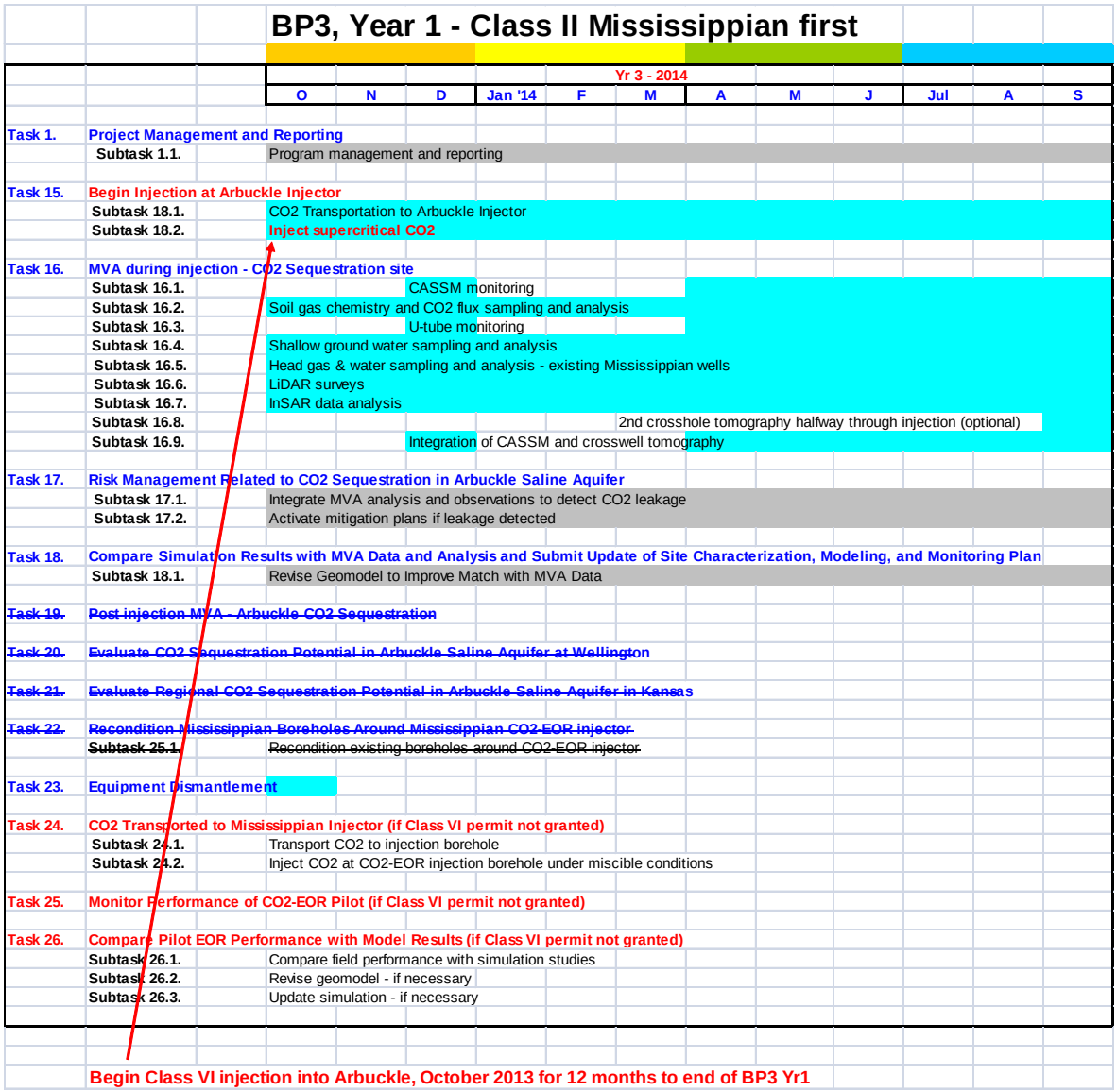


Figure 14. Revised schedule BP3-Year 1.

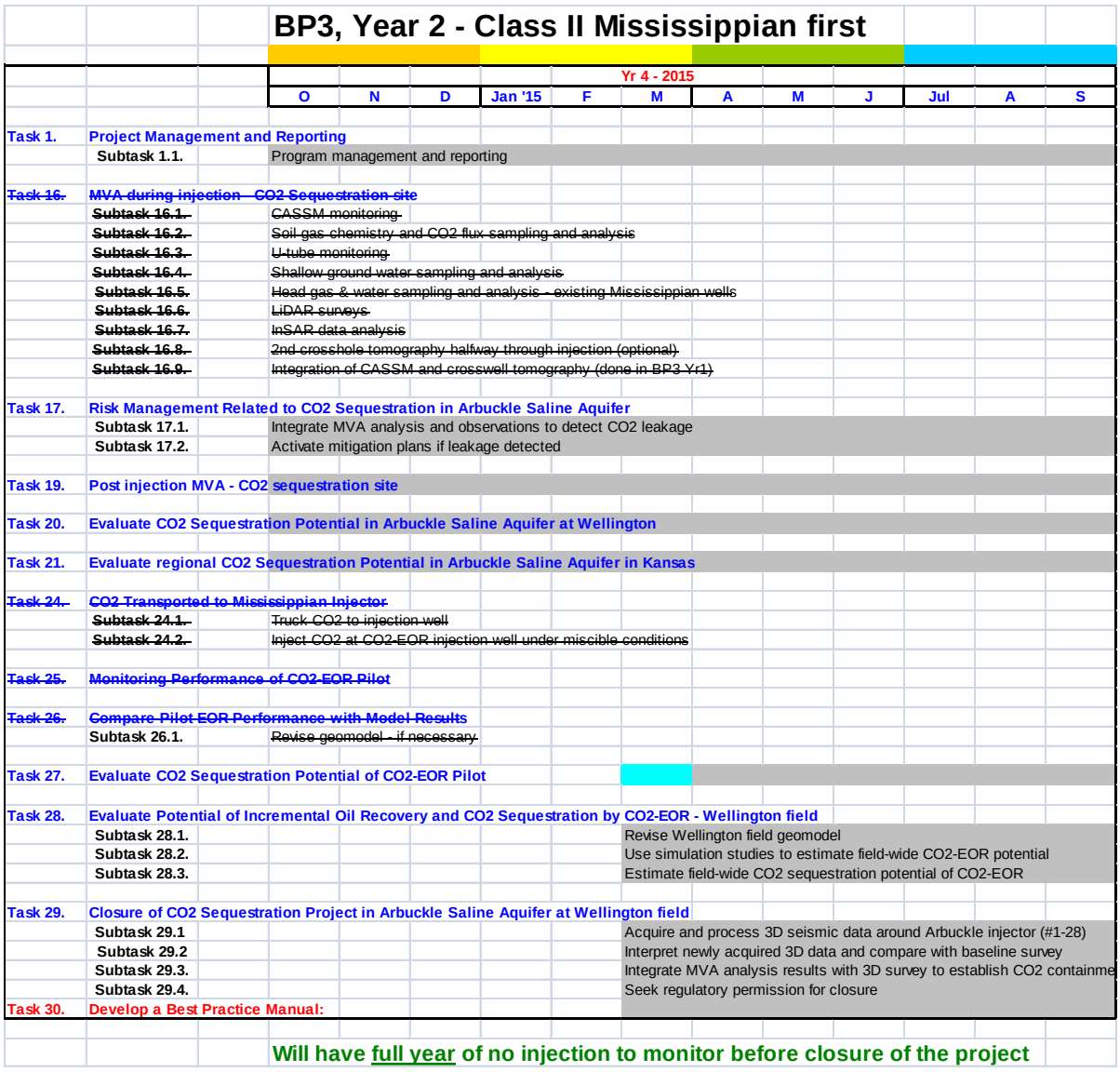


Figure 15. Revised schedule BP3, Year 2.

Presentations

Invited presentation on Mississippian reservoir at AAPG GeoScience Technology Workshop (GTW), "New Directions in Carbonates", February 27-29, 2012, Fort Worth, Texas

Invited presentation on DOE projects including small scale injection to Kansas Geological Society technical meeting, March 6, 2012.

Key Findings

Discussions early in the quarter (January) with EPA and others who are applying for Class VI injection permit have allowed us to move forward to prepare the application. Large contracts are nearing final negotiations so that field operations can begin. Environmental questionnaires for drilling and CO2 source plant have been submitted for review.

Plans

1. Submit revised Program Management Plan
2. Finalize and submit application for Class VI injection permit with updated geomodel and simulation of the Arbuckle saline formation
3. Submit well drilling and installation plan
4. Submit MVA plan.
5. Submit Public Outreach Plan
6. Submit Mississippian Injection Permit Application (Class II injection well under Kansas primacy, regulated by Kansas Corporation Commission) using updated geomodel and simulation of the Mississippian oil reservoir.
7. Once permission granted for field deployment, install LiDAR, InSAR, CGPS, seismometers, groundwater monitoring wells above and below evaporite beds, drilling of Mississippian CO2 injection well, and construction of facility at Abengoa Biofuels ethanol plant to capture CO2.

APPENDIX II

Small Scale Field Test Demonstrating CO_2 Sequestration in Arbuckle Saline Aquifer and by CO_2-EOR at Wellington Field, Sumner County, Kansas

THIRD QUARTERLY PROGRESS REPORT

DOE F 4600.2
(03/11)
All Other Editions Are Obsolete

U.S. Department of Energy
FEDERAL ASSISTANCE REPORTING CHECKLIST
AND INSTRUCTIONS FOR RD&D PROJECTS

1. Identification Number: **DE-FE0006821**	2. Program/Project Title: **Small Scale Field Test Demonstration CO2 Sequestration**	
3. Recipient: **University of Kansas Center for Research, Inc.**		
4. Reporting Requirements:	Frequency	Addressees
A. MANAGEMENT REPORTING		
☒ Research Performance Progress Report (RPPR)	Q	FITS@NETL.DOE.GOV
☒ Special Status Report	A	FITS@NETL.DOE.GOV
B. SCIENTIFIC/TECHNICAL REPORTING		
(Reports/Products must be submitted with appropriate DOE F 241. The 241 forms are available at www.osti.gov/elink)		
Report/Product — Form		
☒ Final Scientific/Technical Report — DOE F 241.3	FG	http://www.osti.gov/elink-2413
☒ Conference papers/proceedings* — DOE F 241.3	A	http://www.osti.gov/elink-2413
☐ Software/Manual — DOE F 241.4		
☐ Other (see special instructions) — DOE F 241.3		
** Scientific and technical conferences only*		
C. FINANCIAL REPORTING		FITS@NETL.DOE.GOV
☒ SF-425 Federal Financial Report	Q, FG	
D. CLOSEOUT REPORTING		
☒ Patent Certification	FC	FITS@NETL.DOE.GOV
☒ SF-428 & 428B Final Property Report	FC	FITS@NETL.DOE.GOV
☐ Other		
E. OTHER REPORTING		
☒ Annual Indirect Cost Proposal	O	See block 5 below for instructions.
☐ Audit of For-Profit Recipients		
☒ SF-428 Tangible Personal Property Report Forms Family	A	FITS@NETL.DOE.GOV
☒ Other – see block 5 below	A	FITS@NETL.DOE.GOV

FREQUENCY CODES AND DUE DATES:

A - Within 5 calendar days after events or as specified.
FG- Final; 90 calendar days after the project period ends.
FC- Final; End of Effort.
Y - Yearly; 90 calendar days after the end of the reporting period.
S - Semiannually; within 30 calendar days after end of project year and project half-year.
Q - Quarterly; within 30 days after end of the reporting period.
Y180 – Yearly; 180 days after the end of the recipient's fiscal year
O - Other; See instructions for further details.

5. Special Instructions:

Annual Indirect Cost Proposal – If DOE is the Cognizant Federal Agency, then the proposal should be sent to FITS@NETL.DOE.GOV . Otherwise, it should be sent to the Cognizant Federal Agency.

Other – The Recipient shall provide all deliverables as contained in Section D of Attachment 2 Statement of Project Objectives.

QUARTERLY PROGRESS REPORT
To
DOE-NETL
Brian Dressel, Program Manager
Award Number: DE-FE0006821

SMALL SCALE FIELD TEST DEMONSTRATING CO_2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO_2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS

Project Director/Principal Investigator:
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Joint Principal Investigator:
Jason Rush

Date of Report: July 30, 2012
Revised 8-5-12

DUNS Number: 076248616

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

Project/Grant Period: 10/1/2011 through 9/30/2015

Third Quarterly Report

Period Covered by the Report: April 1, 2012 through June 30, 2012

Signature of Submitting Official:

Willard Lynn Watney

Digitally signed by Willard Lynn Watney
DN: cn=Willard Lynn Watney, o=The University of Kansas, ou=Kansas Geological Survey, email=lwatney@kgs.ku.edu, c=US
Date: 2012.09.05 18:22:20 -05'00'

EXECUTIVE SUMMARY

Project Objectives

The objectives of this project are: (1) inject under supercritical conditions approximately 40,000 metric tons of CO_2 into the Arbuckle saline aquifer; (2) demonstrate the application of state-of-the-art MVA (monitoring, verification, and accounting) tools and techniques to monitor and visualize the injected CO_2 plume; (3) develop a robust Arbuckle geomodel by integrating data collected from the proposed study area, and a multi-component 3D seismic survey; (4) conduct reservoir simulation studies to map CO_2 plume dispersal and estimate tonnage of CO_2 sequestered in solution, as residual gas and by mineralization; (5) integrate MVA data and analysis with reservoir modeling studies to detect CO_2 leakage and to validate the simulation model; (6) develop a rapid-response mitigation plan to minimize CO_2 leakage and a comprehensive risk management strategy; and (7) establish best practice methodologies for MVA and closure. Additionally, approximately 30,000 metric tons of CO_2 shall be injected into the overlying Mississippian to evaluate miscible CO_2-EOR potential in a 5-spot pilot pattern. The CO_2 shall be supplied from the Abengoa Bioenergy ethanol plant at Colwich, Kansas who has operated the facility since 1982 demonstrating reliability and capability to provide an adequate stream and quality of CO_2. The project shall install compression, chilling, and transport facilities at the ethanol plant for truck transport to the injection site.

Project Goals

The proposed small scale injection will advance the science and practice of carbon sequestration in the Midcontinent by refining characterization and modeling, evaluating best practices for MVA tailored to the geologic setting, optimize methods for remediation and risk management, and provide technical information and training to enable additional projects and facilitate discussions on issues of liability and risk management for operators, regulators, and policy makers.

The data gathered as part of this research effort and pilot study will be shared with the Southwest Sequestration Partnership (SWP) and integrated into the National Carbon Sequestration Database and Geographic Information System (NATCARB) and the 6th Edition of the Carbon Sequestration Atlas of the United States and Canada.

Project Deliverables by Task

1.5 Well Drilling and Installation Plan (Can be Appendix to PMP or Quarterly Report)
1.6 MVA Plan (Can be Appendix to PMP or Quarterly Report)
1.7 Public Outreach Plan (Can be Appendix to PMP)
1.8 Arbuckle Injection Permit Application Review go/no go Memo
1.9 Mississippian Injection Permit Application Review go/no go Memo
1.10 Site Development, Operations, and Closure Plan (Can be Appendix to PMP)

2.0 Suitable geology for Injection Arbuckle go/no go Memo
3.0 Suitable geology for Injection Mississippian go/no go Memo
11.2 Capture and Compression Design and Cost Evaluation go/no go Memo
19 Updated Site Characterization/Conceptual Models (Can be Appendix to Quarterly Report)
21 Commercialization Plan (Can be Appendix to Quarterly Report).
30 Best Practices Plan (Can be Appendix to Quarterly or Final Report)

ACCOMPLISHMENTS

1. Completed NEPA, budget/contract reviews during the quarter. NEPA statements have been approved and budget/contract review nearly complete.
2. Significant progress made in compiling information and characterizing site for use in the application for Class VI CO2 injection permit in the Arbuckle.
3. Conducted area of review of wells and USDW.
4. Incorporated depth-migrated seismic into initial Petrel geocellular model, but obtaining reprocessed seismic volume for use in revising the Petrel model for eventual use in simulation modeling for the Class VI permit application.
5. Completed geochemical and isotopic analyses of the brines samples in two wells previously drilled in DE-FE0002056. Results indicate that the Upper and Lower Arbuckle are hydraulically isolated by a mid Arbuckle barrier. This tight ~300 ft thick interval is also recognized on well logs, core, and 3D impedance mapping. While potentially reducing the injection interval to the ~300 ft thick lower Arbuckle, the mid Arbuckle will likely serve as an interval to "pancake" the CO2 plume into thin layers of higher porosity and higher permeability intervals mixed with tight rock. Multiple layers perhaps accesses by localized fractures will facilitate mixing of CO2 and brine, promote capillary entrapment of the CO2, and limit or eliminate free phase CO2 from accumulated beneath the primary caprock. The net effect could be to notably increase CO2 storage.
6. Initial geomechanical modeling of the caprock interval is very positive. The 120 ft-thick lower Mississippian-age dark argillaceous siltstones are tight and have relatively minor evidence of fracturing based on a fully cored, logged, and seismically imaged and analyzed interval.
7. Two preliminary coupled dynamic models of the small scale CO2 injection in the Arbuckle have been completed. Between solubility trapping and capillary effects the 40,000 tons will be likely be rapidly trapped in the lower Arbuckle where the CO2 is injected. Further analysis will continue. Pressures are such that CO2 escape from a worst case scenario of open wells in the AOR will likely not cause a leak of CO2 to the surface due to relatively low pressure beyond the injection well. However, more modeling is needed to firmly conclude this.

8. The geomechanical component in the simulation run under CMG software is based on a complete suite of mechanical tests from core analysis. Initial results indicate mechanical integrity in this rock system will not be compromised by the 40,000 ton injection into the lower Arbuckle over 9 month timeframe.
9. Reprocessing of the 3D seismic will be used to discretely map fractures and faults. Yet, current geomechanical modeling indicates that reactivation of these structures is unlikely. An updated geomodel from Petrel based on a new seismic volume will used as input into final simulations including sensitivity analyses, as required by EPA for use in the Class VI application. These will be the results to confirm the Area of Review.

Milestone Status Report

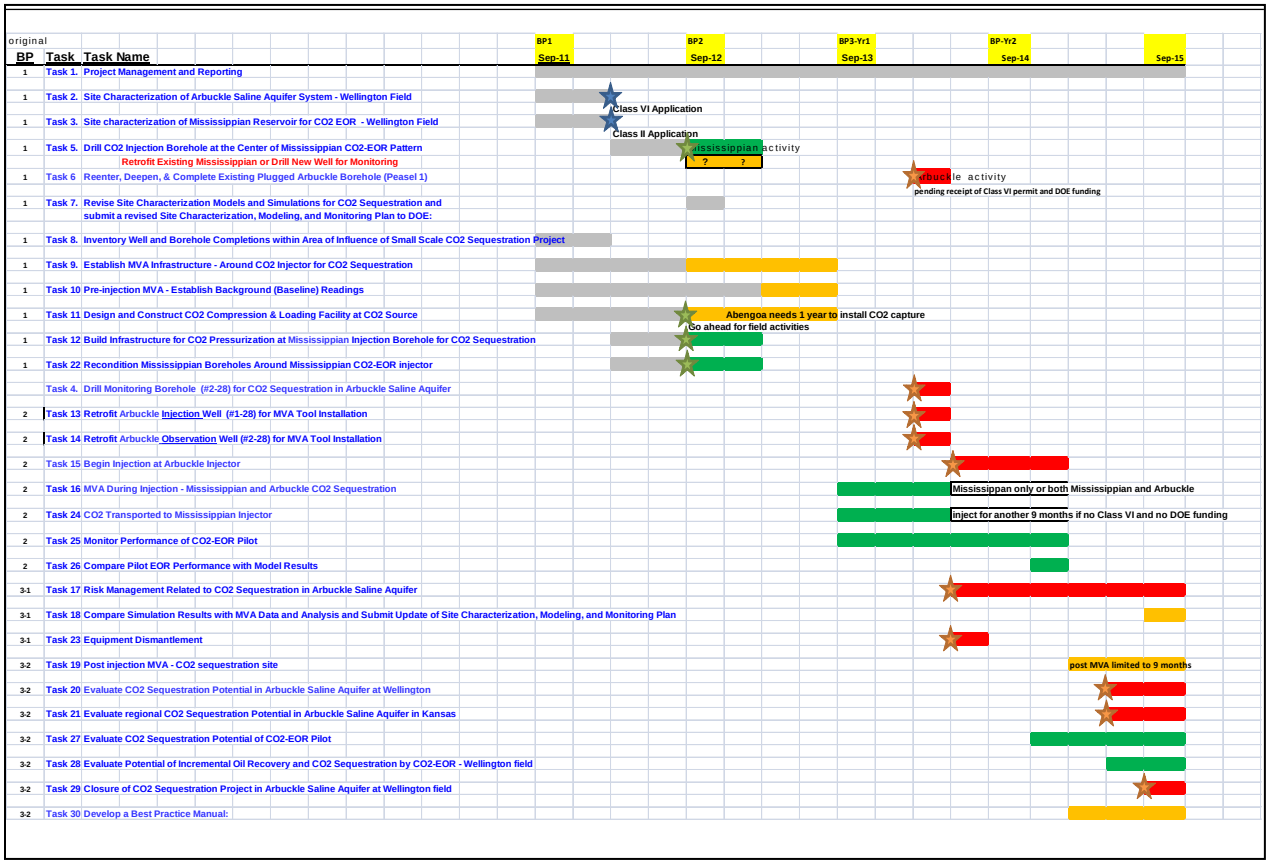
Task	Budget Period	Number	Milestone Description
Task 2.	1	1	Site Characterization of Arbuckle Saline Aquifer System - Wellington Field
Task 3.	1	2	Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field
Task 10.	2	3	Pre-injection MVA - establish background (baseline) readings
Task 13.	2	4	Retrofit Arbuckle Injection Well (#1-28) for MVA Tool Installation
Task 18.	3-yr1	5	Compare Simulation Results with MVA Data and Analysis and Submit Update of Site Characterization, Modeling, and Monitoring Plan
Task 22.	3-yr1	6	Recondition Mississippian Boreholes Around Mississippian CO2-EOR injector
Task 27.	3-yr2	7	Evaluate CO2 Sequestration Potential of CO2-EOR Pilot
Task 28.	3-yr2	8	Evaluate Potential of Incremental Oil Recovery and CO2 Sequestration by CO2-EOR - Wellington field

Budget Period #1 includes two milestones, Milestone 1 (Task 2) -- Site Characterization of Arbuckle Saline Aquifer System - Wellington Field, and Milestone 2 (Task 3.) -- Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field. Planned completion for Milestone 1 and 2 were set for 3/1/12, but as explained below were delayed for the following reasons: 1) core analysis measurements were not obtained until February 2012, 2) seismic processing and analysis required more iteration, 3) calibration of well logs could not be completed until core analyses were available, 4) data integration into Petrel required steps 1-3 to be completed, and 5) dynamic modeling requiring steps 1-4 could only proceed using generalized geomodel prior to the integrated geocellular model from Petrel becoming available. Milestone 1 will be completed in next quarter for use in the application for a Class VI injection permit. Milestone 2 will require an additional quarter due to above delays.

Project Schedule

An abbreviated Gantt Chart follows that describes suggested changes to accommodate delays in obtaining Milestones 1 and 2 and concerns about receiving a Class VI injection permit from EPA. The Gantt Chart is based on the scenario with CO2 initially being injected into the Mississippian oil reservoir under a Class II permit from the State of Kansas followed by injection into the Arbuckle saline aquifer, if the Class VI permit is granted. If the Class VI application is not forthcoming from EPA, all the CO2 would be injected into the Mississippian oil reservoir for CO2-EOR. Under this scenario MVA technologies would be deployed in an observation well near the Mississippian CO2 injection well to insure 99% efficacy of CO2 storage in the oil reservoir.

The Field Work Proposal (FWP) with Lawrence Berkley National Lab has been approved, but activities to date have been limited to planning discussions regarding deployment of MVA technologies that they are responsible for. Field activities are being deferred until the submittal of the Class VI permit application.



ONGOING ACTIVITIES –

TASK 1. PROJECT MANAGEMENT AND REPORTING

Subtask 1.5. Drilling and Well Installation Plan

Well Drilling and Installation topics have focused material necessary for application for a Class VI injection permit. Completed wells and boreholes including drilling and installation methods, the well-borehole designs (casing design, centralizer plan, cement design, etc.) (e.g., **Figure 1**), method for determining perforation zones, contingencies for anticipated problems encountered during drilling such as loss circulation zones, completion and development plan. Additionally, the drilling and well installation plan will include a description of mud logging, wire line logging, coring, swabbing and laboratory analysis of samples, and any other testing that may be performed on the well-borehole.

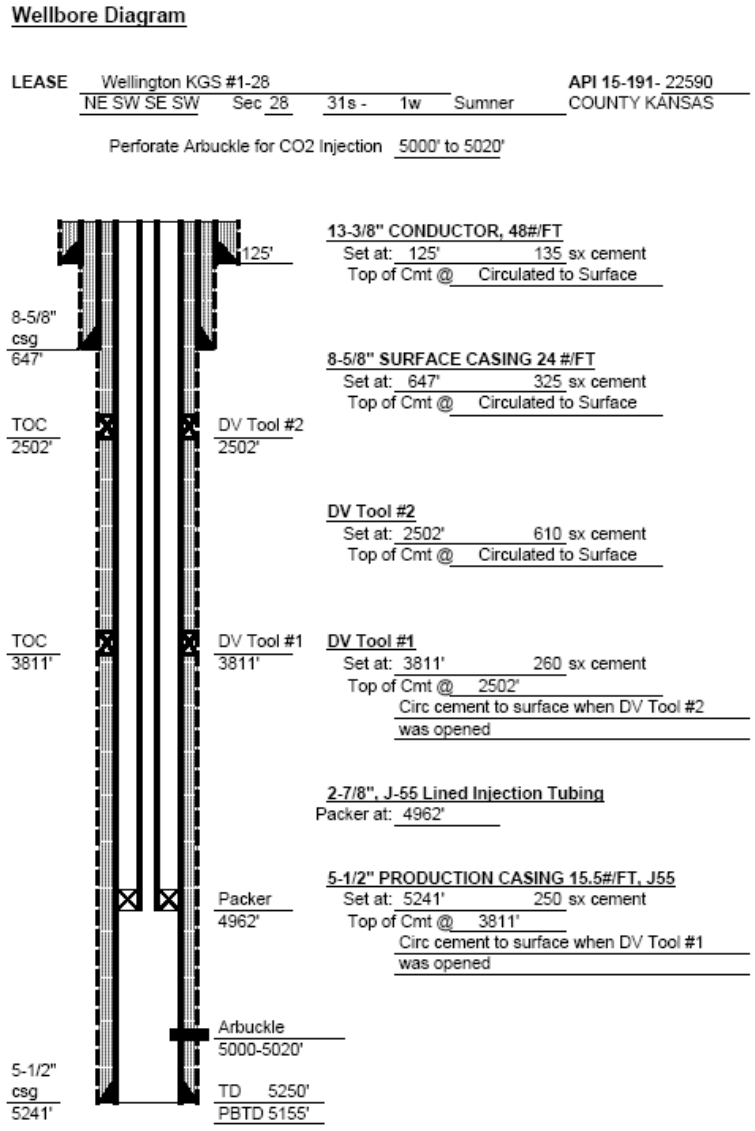


Figure 1. Wellbore diagram CO1 injection well, Berexco Wellington KGS #1-28.

Subtask 1.6. Monitoring Verification and Accounting (MVA) and Mitigation Plan

The MVA and mitigation plans will be completed as part of the Class VI application and submitted as a separate report. MVA plan will now include equipting same technologies and methodologies for the Mississippian CO2 injection ahead of the Arbuckle. This will require adapting the MVA to the CO2-EOR to establish 99% sequestration of the CO2.

Subtask 1.7. Public Outreach Plan:

The Public Outreach Plan will also be submitted as part of the Class VI application. The DOE document will describe workshops, presentations, and publications in technical and trade journals to be used to transfer lessons learned best practices, geomodels, simulation results, MVA data and observations to the public, regulators, legislators, and local industry. The PI is actively discussing the project with stakeholders.

Subtask 1.8. (Go-No Go Decision for CO2 saline formation sequestration) Arbuckle Injection Permit Application

Effort during the third quarter was focused on firming up key elements of the application for a Class VI injection permit including interpreting and integrating new seismic data and review of the tests and expanding characterization to include an understanding of the USDW and regional flow and pressure within the Arbuckle saline aquifer.

Key topics discussed and evaluated among the team and DOE program manager related to Subtask 1.8 include:

- **Location and timing of project** – Field activities will get underway including installation of wells and equipment to inject and monitor CO2 in the Mississippian as soon as the application for the Class VI inject permit is administratively accepted by EPA. Application is approximately one month from submittal to EPA.

- **Site of Arbuckle saline formation injection** – Initially, 30,000 tons of CO2 will be injected into the Mississippian oil reservoir accompanied by a complete deployment of MVA technologies. MVA will focus on CO2-EOR to verify 99% sequestration of the CO2 in the oil reservoir. As soon as the Class VI permit is approved by EPA, DOE will determine if CO2 injection into the Arbuckle saline formation will be deployed. Additional funds would be required to capture additional CO2, if the amount injected into the Mississippian had exceeded the allocated 30,000 tons. Additional funds would also be needed to deploy MVA for the Arbuckle CO2 injection and extend the monitoring period.

- **Injection zone** – The characterization of the lower Arbuckle, Gasconade Dolomite to Gunter Sandstone Member has determined that this interval has sufficient permeability and net porous thickness of strata in the interval to accommodate the 40,000 tons of CO2 to be injected during the small scale test (**Figure 2**). The assessment is based on analysis of core, wireline logs, interference test, and continuity of impedance/porosity mapping from 3D seismic and new coupled flow

and geomechanical dynamic modeling. Similarly, the excellent response of the waterflood in the Mississippian oil reservoir strongly suggests that the 30,000 ton CO2 injection will have a favorable response.

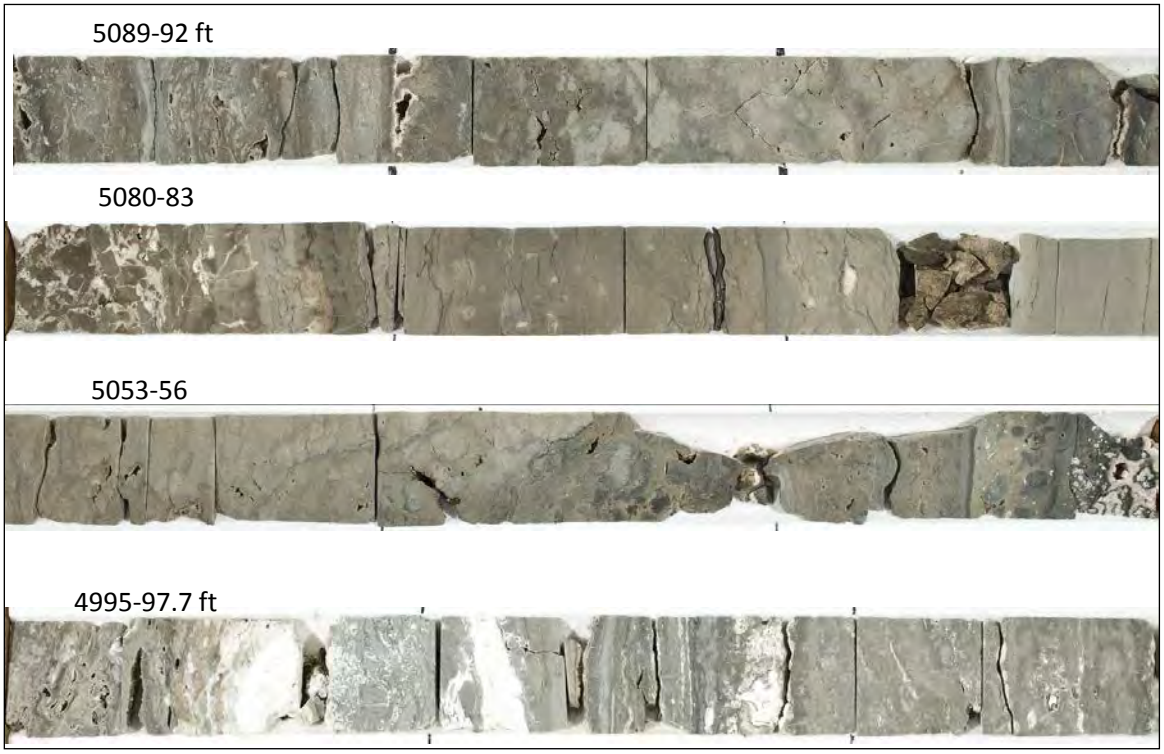


Figure 2. Representative samples from the injection zone in KGS #1-32 core.

- **Baffle and trapping of CO2 in the Arbuckle saline formation** – The comprehensive set of measurements from wells #1-32 and #1-28 and inversion and impedance analysis of the 3D seismic indicate that the middle ~300 ft interval of the Arbuckle (lower Jefferson City Cotter down to near the top of the Roubidoux Formation) is predominantly tight, slightly argillaceous dolomite with thin alternating shales and permeable intervals (**Figure 3**). Moreover, major and minor element, cation and anion geochemical and isotopic (carbon and deuterium) analyses of formation brines using multiple limited interval drill stem tests and perforation of casing and swabbing indicate that brines in the upper and lower Arbuckle are not in communication on the scale of geologic time. This isolation of the hydrostratigraphic units is at least the case for the local area studied. Core, wireline logs, seismic, and geochemistry together corroborate the extensive continuity of the tight mid Arbuckle interval. The result should be at least baffling of the CO2 that is injected beneath and flow of CO2 into thinner permeable intervals leading to CO2 trapping in the finer pores and mixing and solution of the CO2 into the brine making it heavier and further decreasing the buoyant, free phase CO2.

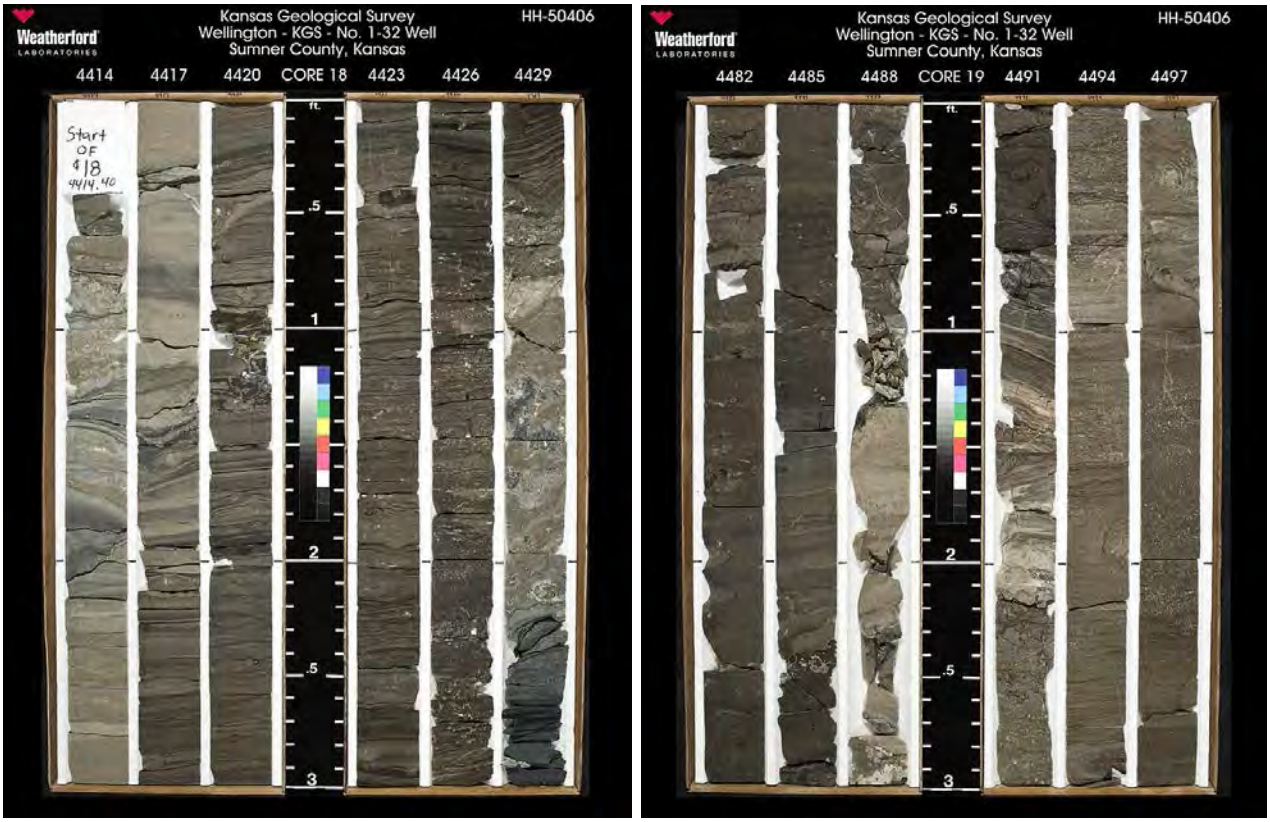


Figure 3. Mid Arbuckle barrier/baffle interval lower Jefferson City-Cotter. Note shale at 4431 ft an abundant darker laminated micritic dolostone that dominates the baffle/barrier in the mid Arbuckle.

- **Primary caprock interval** – A very important elements besides injectivity and storage in the saline aquifer where the CO2 injection will take place is the integrity of the primary caprock. The caprock interval that is being intensely studied includes the 1) ~120 ft thick, Middle and Lower Mississippian-age tight, dark argillaceous dolosiltite that is tentatively correlated to the Pierson Formation and 2) the black, clay-rich Upper Devonian Chattanooga Shale (**Figure 4**). The underlying Simpson Group shales and sandstones rest on the Arbuckle and appear to be locally sealing since oil is locally trapped in the sandstones on this structural dome in Wellington Field, albeit off to the edge of the structure and not near the injection site.

  An abundance of data is being synthesized from existing study for use in the application for injection including 1) core analysis consisting of mechanical tests,

CO2 “soak” tests of plug samples to examine reaction via geochemical and CT scans of plugs, capillary pressure, and helical CT scans of whole core; 2) and wireline logs including dipole sonic, density, microimaging, and NMR; and 3) 3D seismic imaging to correlate to well calibration data and map properties for use in buiding a refined geomodel. The latter activity, specifically, the geomechanical dynamic modeling is only now beginning due to recent receipt of final mechanical measurements from the lab during the quarter.

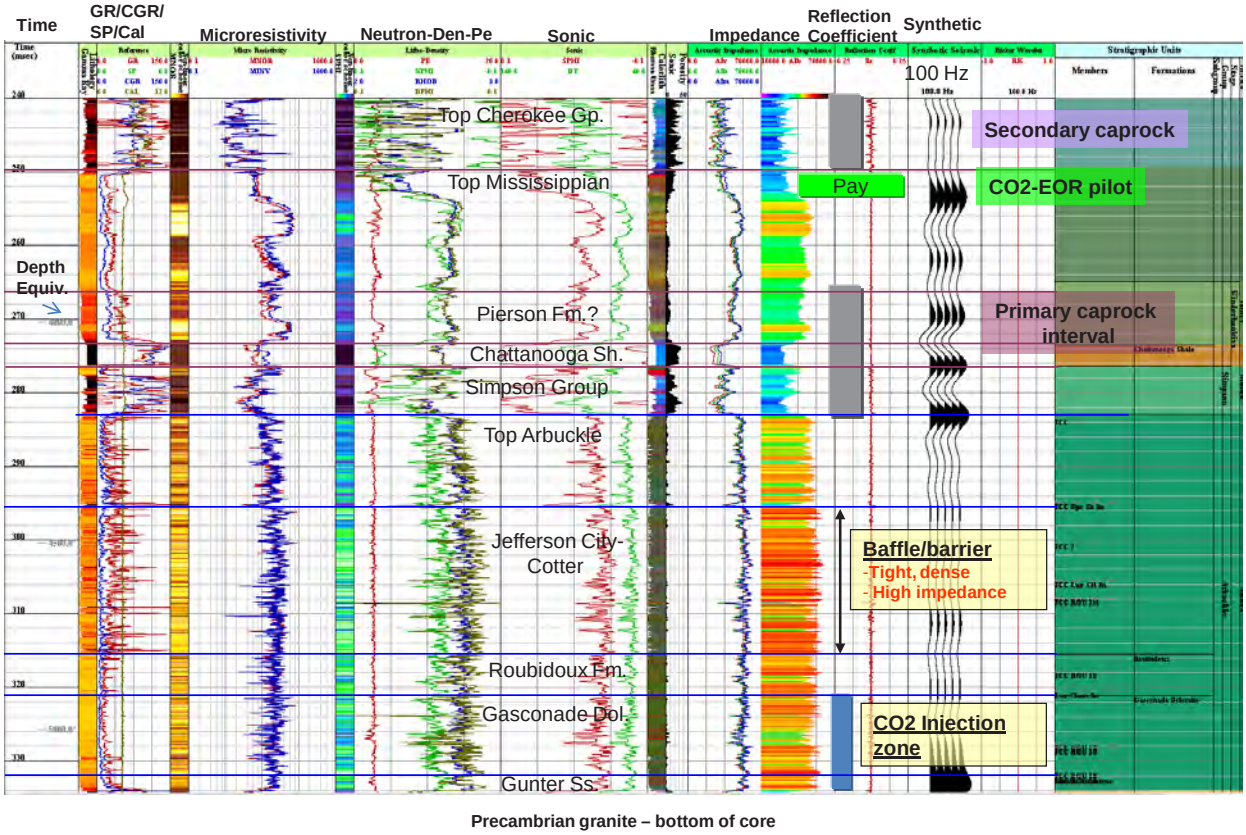


Figure 4. Synthetic seismogram, impedance, and triple combo log suite KGS #1-28 (CO2 injection well in Arbuckle at Wellington Field). Vertical scale is in 2-way seismic travel time with tick marks and depth noted alongside this scale. The illustration identifies the Arbuckle injection zone, baffle/barrier in mid Arbuckle, primary caprock interval (Pierson, Chattanooga, and where predominately shale, the Simpson Group), pay and CO2-EOR test interval in the Mississippian, and the secondary caprock of the Arbuckle and primary caprock of the Mississippian injection.

The primary caprock as noted above continues to be studied at a micro to macro field-wide level. The interval has generally lower seismic impedance and can be distinguished from surrounding strata (Figure 4). The relatively thick (120 ft) silty lower Mississippian that is tentatively correlated to the Pierson Formation is mappable with seismic, an

activity that is still being refined, and is distinctively dark and tight argillaceous dolomite siltstone. The higher organic content (one sample is 1% TOC) is enough to give the rock a dark gray-brown to black color (**Figure 5**). Measurements of permeability from two samples of this interval were carried out in the NETL lab in Pittsburgh during fall 2011 and results indicated pico- and nano-darcy permeability.

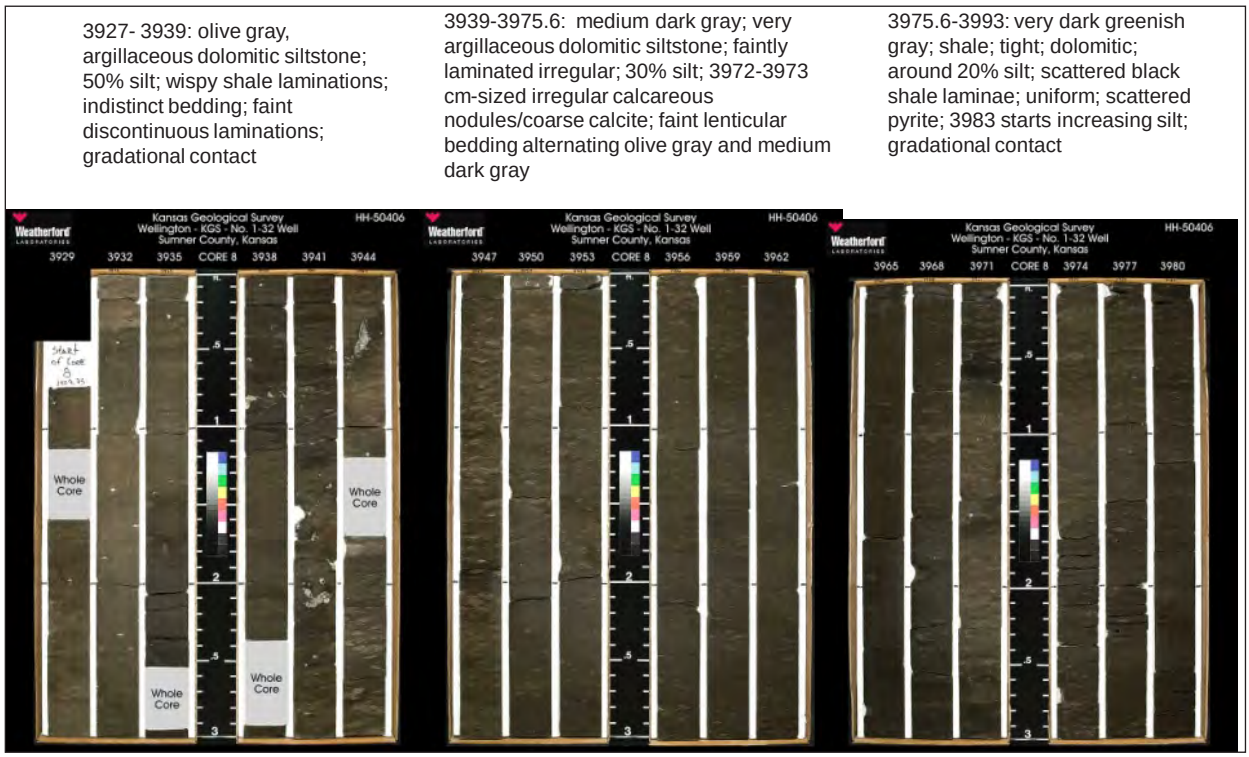


Figure 5. Representative samples from the lower Mississippian Pierson Formation that overlies the Chattanooga Shale is being evaluated as part of the primary caprock overlying the Arbuckle.

The complexity of the stratigraphic succession of the dark fined-grained interval of the Pierson Formation is illustrated by the spectral gamma ray spectral imaging tool, Java freeware app developed at the KGS with DOE support of the characterization project , DE-FE0002056, http://www.kgs.ku.edu/stratigraphic/ KIMELEON/ (**Figure 6**). The more organic rich intervals generally ties very closely to the higher uranium interval, the middle track in Figure 6. The organic matter may be an important contributor to both the integrity of the caprock providing an additional means to trap CO2 that may move along fractures within the interval.

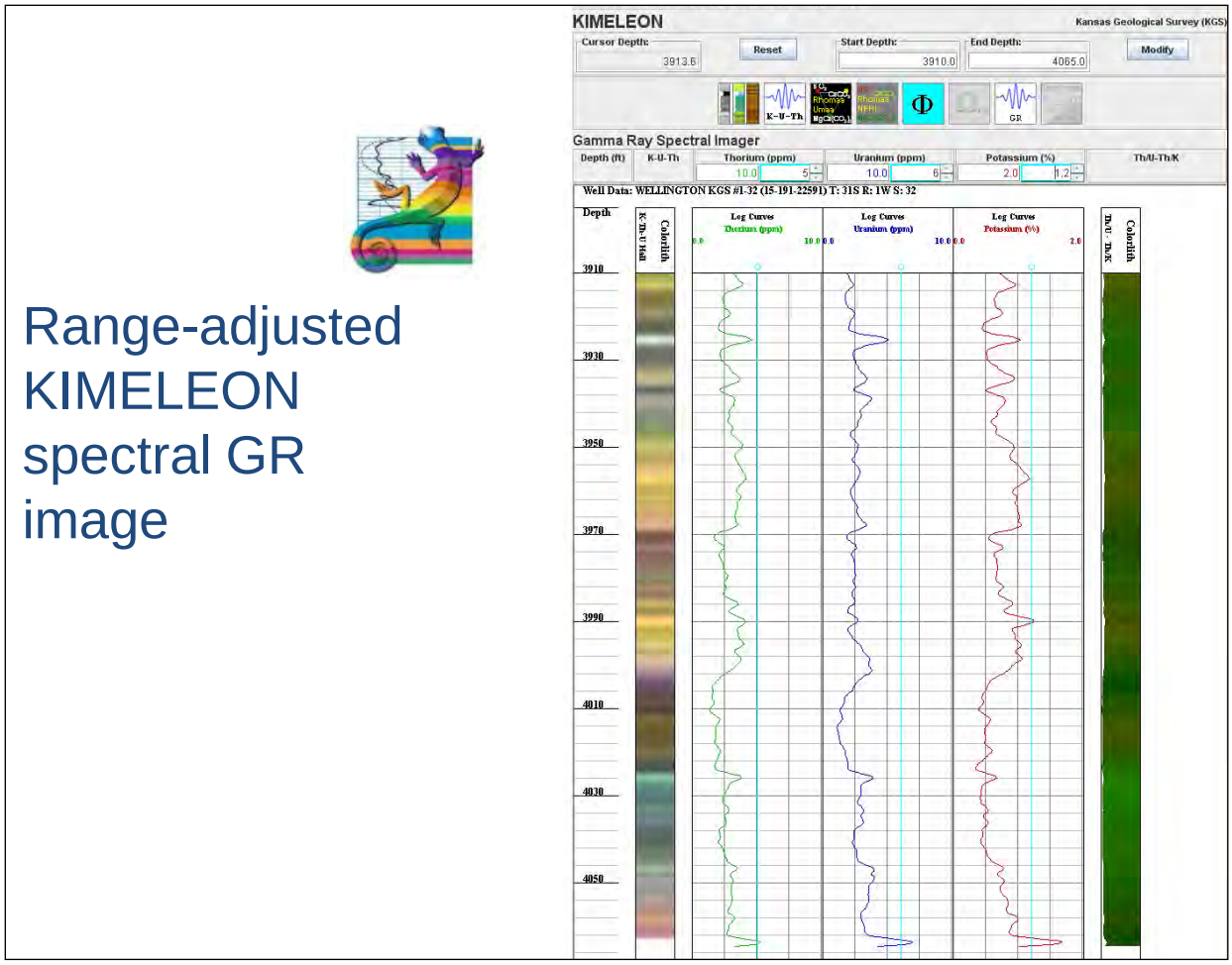


Figure 6. Gamma ray spectral imager of the portion of the lower Mississippian Pierson Formation that appears to be able to serve as part of the primary caprock. A complex succession of strata are denoted via potassium, uranium, and thorium distribution.

The caprock is further examined using the nuclear magnetic resonance (NMR) imaging tool (**Figure 7**). The tool is a mature technology, but not often used to help define pore size distribution, water/hydrocarbon saturation, and estimate permeability. It was run in both wells drilled under DE-FE0002056, KGS #1-32 and #1-28. It has been compared with porosity and permeability from core analysis and used to compare Kh from drill stem tests and step-rate test. Together with the sonic, density, and resistivity logs, it provides a means to substantially increase the understanding of both porous and permeable rocks and distinguish them from low porosity and low permeability rocks. Such is the case for the interval considered as the primary caprock for the Arbuckle.

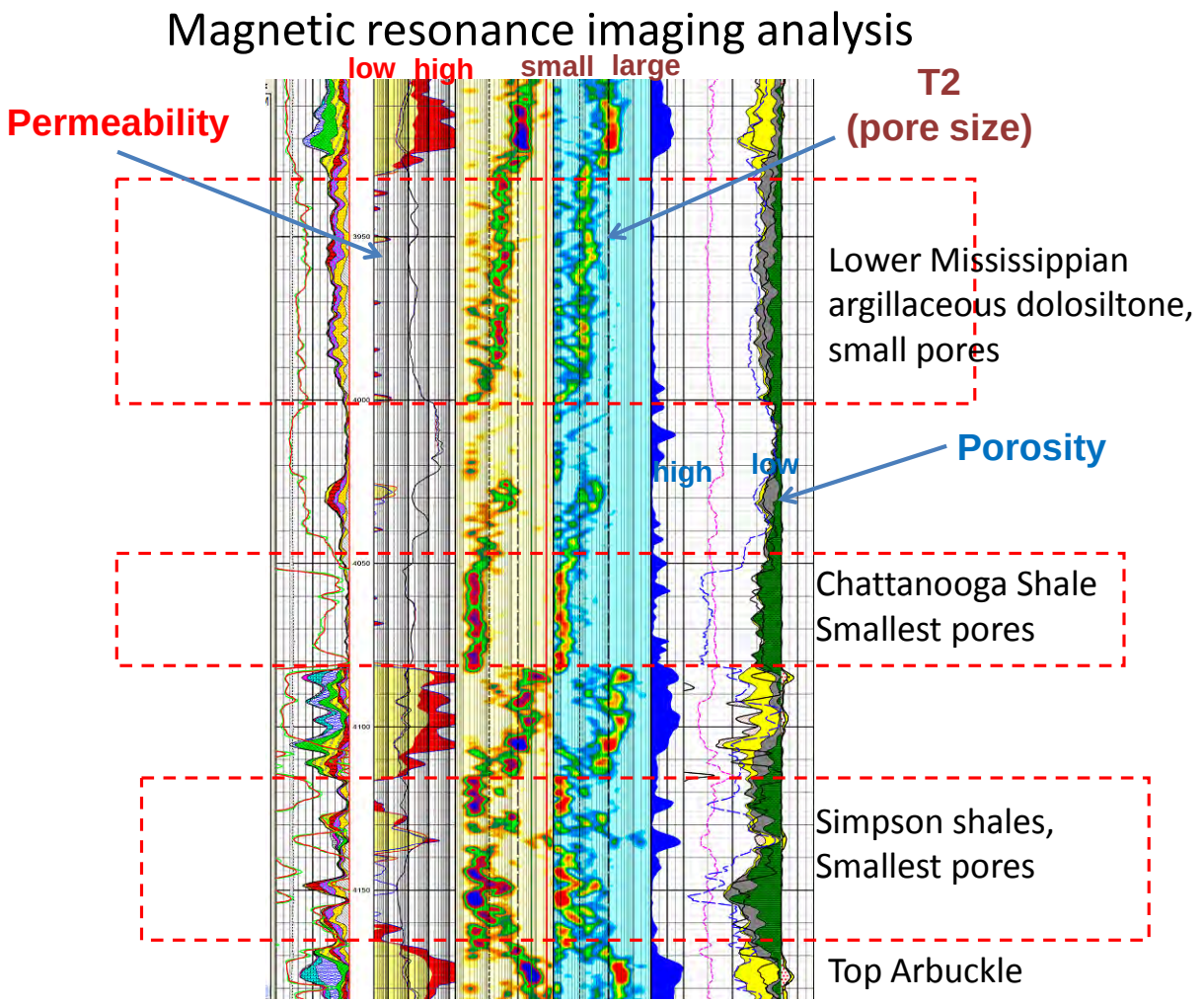


Figure 7. Magnetic resonance imaging profile in well KGS #1-28 from the interval being considered as the primary caprock for the Arbuckle CO2 injection at Wellington Field. The NMR is very useful in allowing continuous comparison of properties of the matrix pore system that comprises this interval.

Fracture and fault characterization is being completed for the application for Class VI injection. The 1600 ft of core taken from KGS #1-32 was described over the course of a week by Lorenz and Cooper. Figure 8, 9, and 10 summarize the fracture distribution as visually described from the interval extending from the Cherokee shale, the secondary caprock above the Mississippian, to below the CO2 injection zone near the base of the Arbuckle. The fracture summary show that both the primary (particularly the lower Mississippian Pierson Formation) and secondary caprock have low fracture densityand lack the horizontal high porosity enhanced fractures(HZ HPZ) seen the Arbuckle. Fracture heights are also less than 1 ft in the caprocks compared to several feet common to the mid Arbuckle baffle/barrier and the lower injection zone of the Arbuckle. Finally, remmant porosity varies but tends to be higher in the mid Arbuckle baffle/barrier as the brine geochemistry and microbial population suggests that the interval is more isolated

and less cement due to smaller pore volumes of brine passing through might be a logical conclusion.

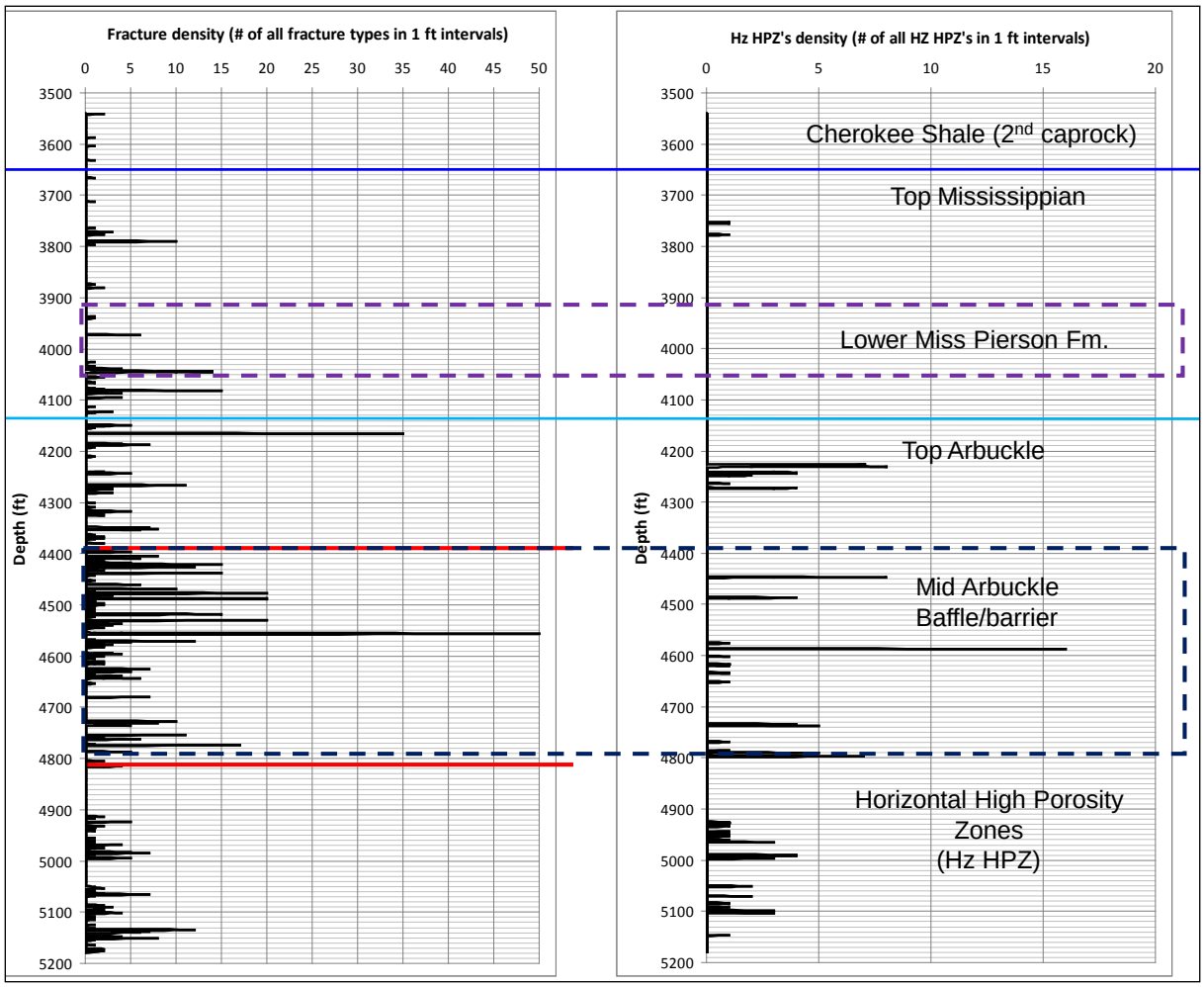


Figure 8. Fracture characterization of KGS #1-32 core by Lorenz and Cooper showing fracture density (# fractures in 1 ft intervals) (left) and frequency of horizontal high porosity zones (Hz HPZ) (right).

Additional fracture characterization has been made with the microresisitivity imaging tool, the spectral (oriented dipole) sonic, and 3D seismic. The spectral sonic establishes the fracture intensity, the imaging logs similar map the fracture and recognizing open, partial, closed. The seismic is being used to recognize discrete fracture networks that are resolvable with the seismic.

A final version of the 3D seismic data will be depth migrated and used to map faults, fractures, and apparent porosity. The seismic time-impedance presented as an arbitrary section through Wellington Field that includes available velocity control is shown in Figure 11. The injection zone and upper Arbuckle have lower impedance than the middle

Arbuckle baffle/barrier, and the lower Mississippian and Cherokee shale have lower impedance indicative of their shaly nature. The higher low impedance interval above the Cherokee is the upper Pennsylvanian shale that dominates the southern portion of the Kansas and is clearly a thick rather uniform interval of strata that can serve to prevent CO2 from moving upward toward the USDW. This entire interval up to the level of the Heebner Shale (**Figure 11**) is deep enough for CO2 to be in a supercritical state.

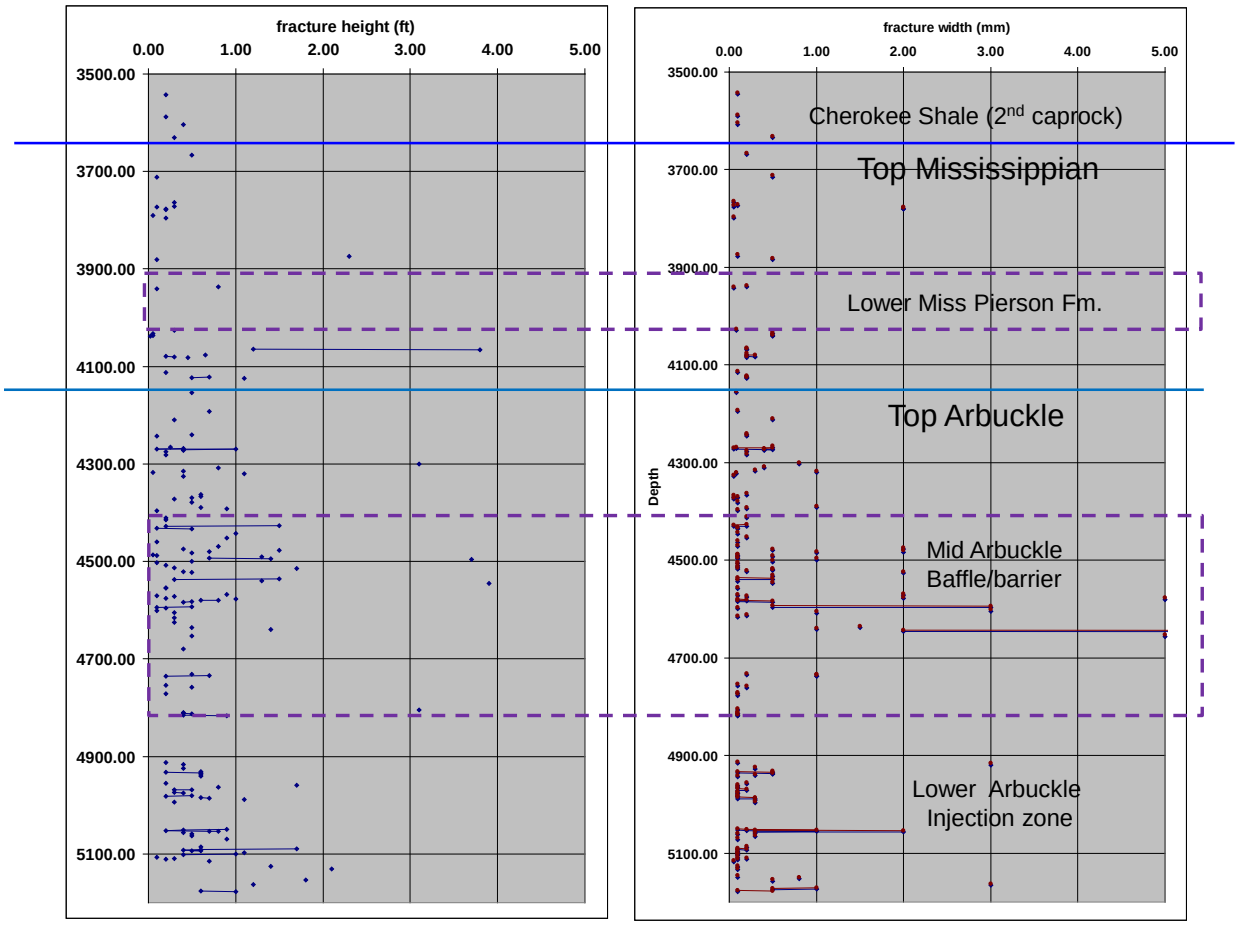


Figure 9. Fracture height (left) and fracture width (right).

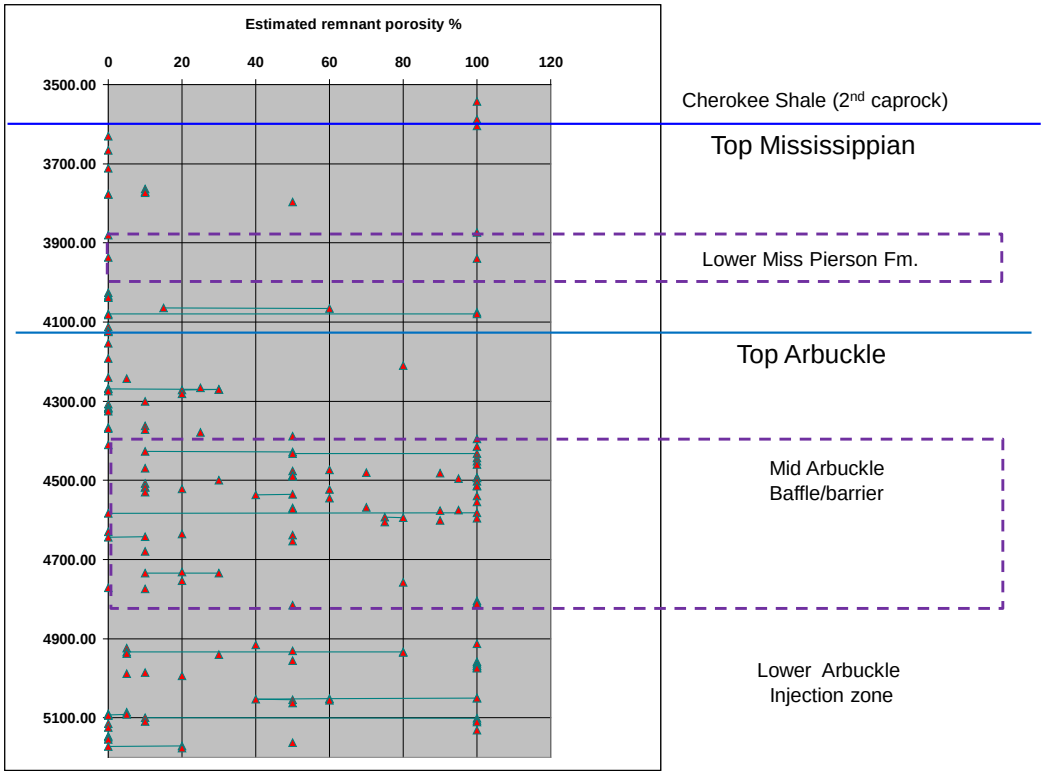


Figure 10. Estimated remnant porosity (%) from the fractures described by Lorenz and Cooper for the core taken from KGS #1-32.

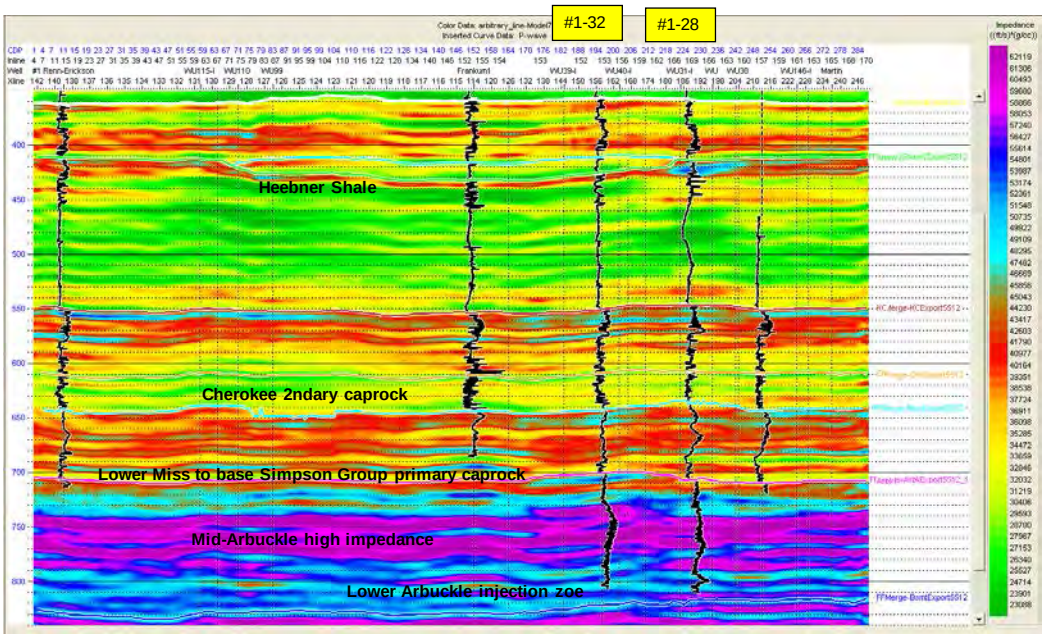


Figure 11. Arbitrary seismic section in time from 3D volume showing seismic impedance profile in Wellington Field including new wells drilled through the Arbuckle (KGS #1-32 and KGS #1-28). Porosity in the injection interval as inferred impedance, the mid Arbuckle baffle, and the caprocks are rather continuous.

The static geomodel used in the Class VI application will include a combination of the information obtained from the wireline logs, core analyses, and seismic data. Once a final version of the seismic interpretation is made the results will be imported into Petrel geocellular model for additional processing and visualization. The updated Petrel geomodel will be imported into CMG to conduct the dynamic model.

The iteration of dynamic model to be used for the Class VI injection permit is based on both the geomechanical and physical properties that have been obtained from the characterization project, DE-FE0002056. The models will dictate 1) the area of review; 2) the location, size, and composition of the CO2 plume over time; 3) design the injection profile so that conformable sweep is obtained in multiple flow units, plume is observable in the observation well, but injection is designed to limit longer lateral migration; 4) the extent of the free phase CO2 both vertically and laterally as the plume interacts with the flow units baffles, barriers, and fracture systems; 5) the pressure field and the stresses imposed on the caprock to understand and avoid parting existing fractures or create new fractures. The dynamic model and its updated versions during injection will predict the degradation of the plume and its location so that the project can be brought to closure.

An initial coupled geomechanical and flow model is currently being tested and refined, integration appropriate data that has been analyzed, but short of having a refined Petrel model that includes the latest seismic interpretation. Thus this model is isotropic with no compartments or larger scale fractures. The mature model will have included shallower caprock and seals to demonstrate that the CO2 injection will not affect the USDW.

Goals of modeling –

- To evaluate different injection scenarios for selection of optimal operation procedures
- To understand a pressure response of Arbuckle reservoir as a result of CO2 injection
- To project the reservoir injectivity and transmissibility properties
- To estimate a degree of CO2 solubility in the in-situ brine
- To correlate reservoir and cap-rock properties with existing data analyses and other modeling results

Model Parameters --

- 40,000 metric tons of CO2 injection into lower Arbuckle zone where middle Arbuckle is considered as impermeable barrier
- Closed boundaries
- Dual porosity/permeability (**Table 1, Figure 12**)

- 3D "Layered Cake" (50x50x46 cells) model with homogeneous properties within each layer representing geologic formations:
  - Chattanooga Shale (low porosity no perm)
  - Upper Arbuckle (high porosity and perm)
  - Lower Arbuckle (lower porosity and perm)
  - Arbuckle injection zone (high porosity and perm)
- CO2 solubility in water is considered
- 3 cases of permeability estimations were considered (P10; P50; & P90) (**Table 1, Figure 12**).

Case Name	Perm – Matrix, Top Arbuckle, md	Perm – Fractures, Top Arbuckle, md	Perm – Matrix, Mid. Arbuckle, md	Perm – Fractures, Mid Arbuckle, md	Perm – Matrix, Inj. Arbuckle, md	Perm – Fractures, Inj Arbuckle, md	Fracture spacing, m	CO_2 Injected, MT
High Permeability	1000	1500	1e-7	1e-7	**600**	**1500**	3	40
Mid. Permeability	500	1000	1e-7	1e-7	**300**	**1000**	3	40
Low Permeability	200	500	1e-7	1e-7	**100**	**500**	3	40

Table 1. Permeability applied in the dual-porosity model.

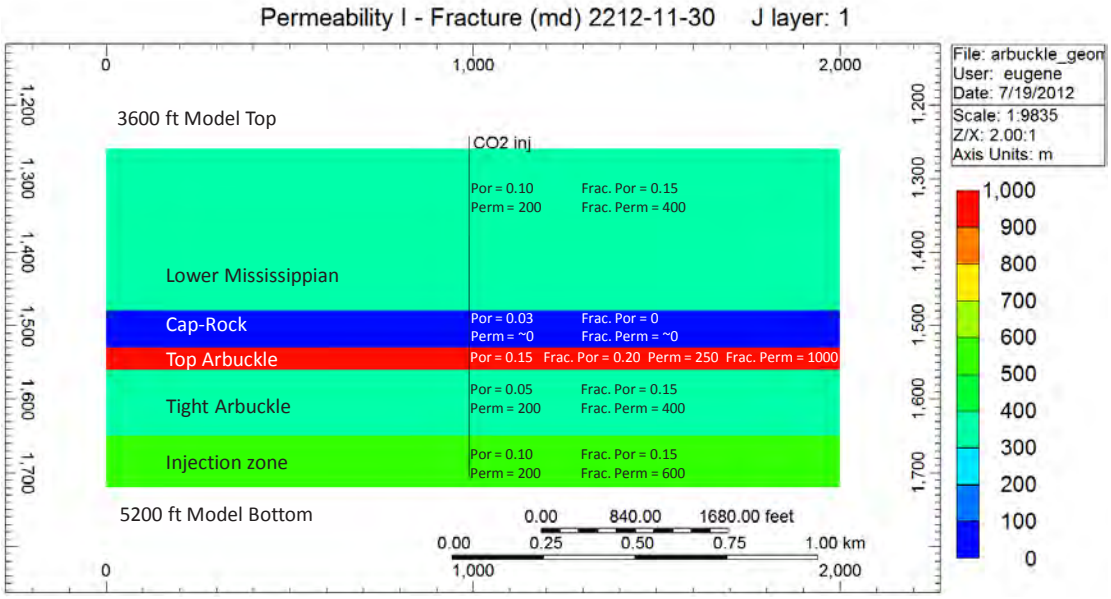


Figure 12. Model parameter permeability shown for stratigraphic divisions used in this initial coupled geomechanical-flow simulation.

Rock Type	Poisson's Ratio	Young's Modulus *10^6, kPa	Cohesion, kPa	Fracture spacing, m	Rock Compressibility, 1/kPa
Cap-rock - Matrix	0.25	4.997	689285	3	5.8e-7
Cap-rock - Fractures	0.25	4.997	689285	3	5.8e-6
Arbuckle - Matrix	0.30	9.720	689285	3	5.8e-7
Arbuckle - Fractures	0.30	9.720	689285	3	5.8e-6

Table 2. Geomechanical model parameters used in initial coupled simulation. Properties obtained from mechanical measurements to core from KGS #1-32.

The modeled injection was also carried out using three injection scenarios.

The modeled injection scenarios --

- 9 months, 70 kt CO2 injection
  - Projected amount of CO2 at projected rate
- 3 months, 100 kt CO2 injection
  - Rapid pressure increase to brake a cap-rock
- 1 months, 70 kt CO2 injection
  - Projected amount of CO2 in shorter time period, or "economically safe"

The results are very encouraging (**Figures 13 and 14**). The pressure exerted on the caprock is minimal and the plume undergoes degradation in the lower Arbuckle, as currently modeled. The pressure/stress regimen from the injected CO2 was not sufficient to compromise the cap-rock integrity in this modeling configuration. Additional configurations will be examined including fracture & fault scenarios once the new Petrel model is available.

Interim results –

- The pressure response to 40 kt CO2 injection is minimal for all three estimated permeability cases (~400 kPa or ~60 psi max) even if closed boundaries model is utilized
- It is suggested to investigate a higher injection rate and higher volume of injected CO2 scenarios
- Additional attention and analysis are required for permeability estimations
- It is projected that most of the injected CO2 will be dissolved in water

- It insures CO2 containment and reduces its mobility

- Geochemical investigations will be critical, especially if additional/commercial scale injection is projected.

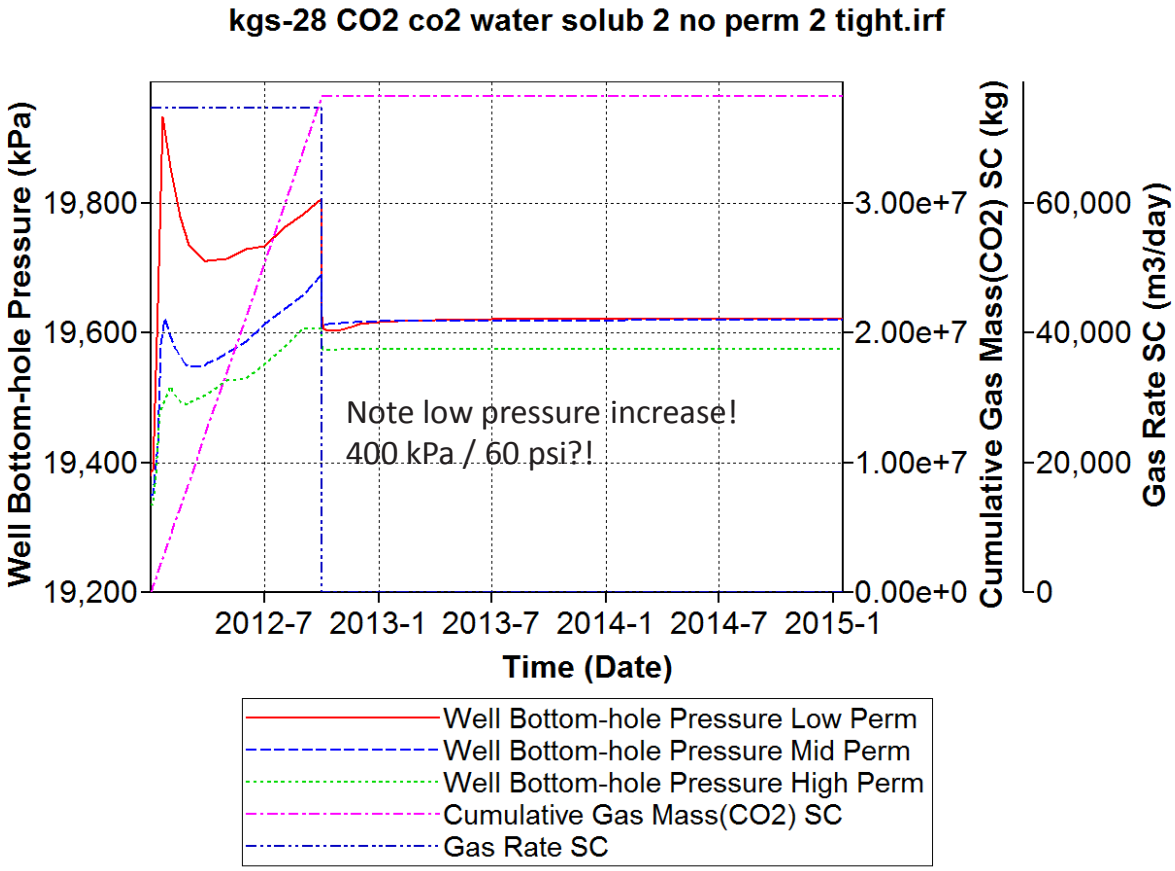


Figure 13. Pressure response comparison for 3-cases = 40 Kt CO2, pressure, cumulative gas, and gas rate plot. Small pressure increase noted in the current model.

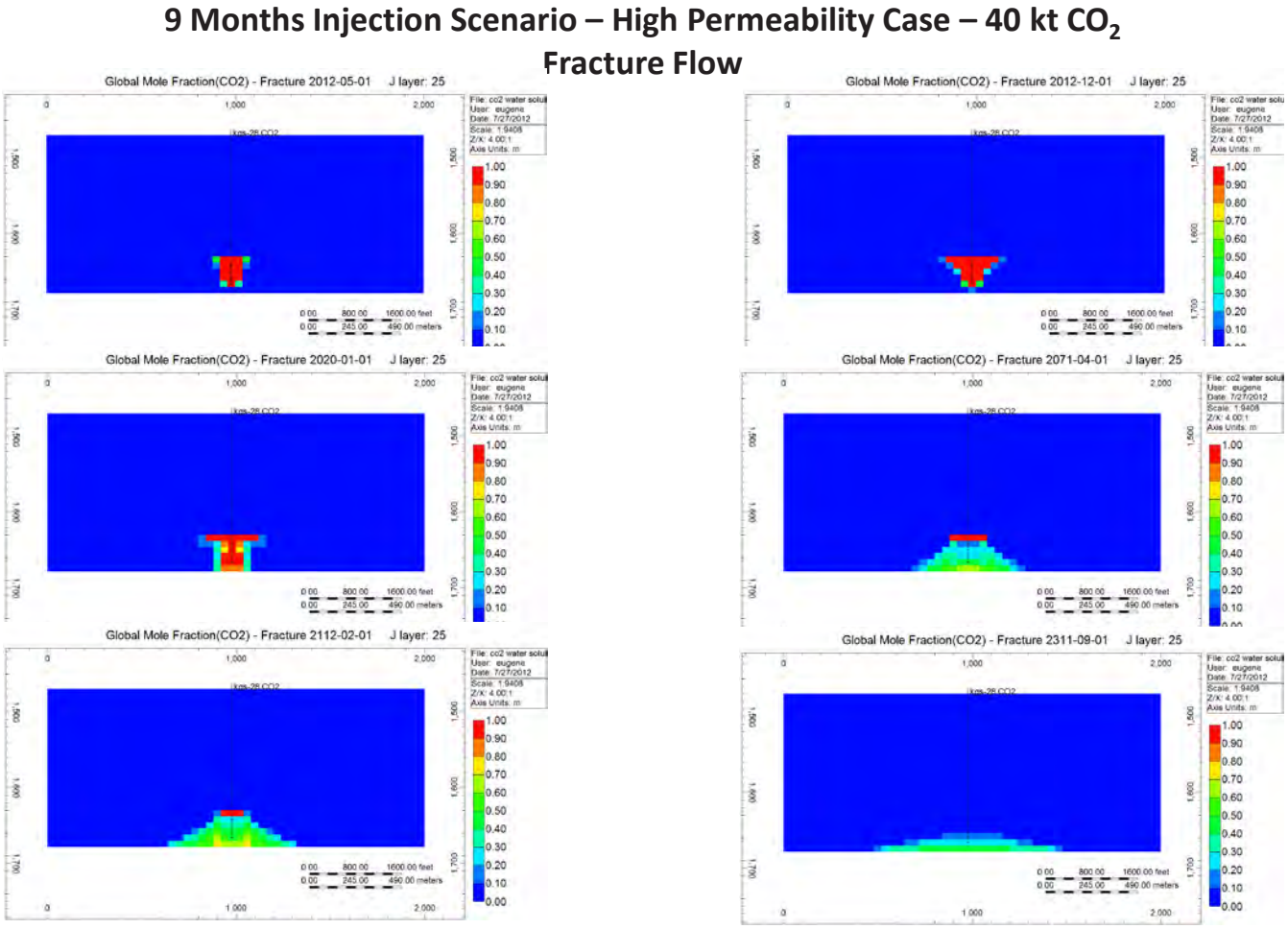


Figure 14. Nine month injection scenario – high permeability case – 40 kt CO2 with fracture flow. CO2 plume develops in the lower Arbuckle below and top of the plume is defined by the base of the tight mid Arbuckle. See model parameters in Figure 12.

- **USDW**

Regional and local review and characterization of the freshwater has been completed. It will be demonstrated in the Class VI application that considerable seals exists above the primary (lower Mississippian argillaceous dolosiltstone, Chattanooga Shale), and secondary caprock (Cherokee shale) by multiple thick shales and finally 200 ft thick evaporite near the surface below the USDW (**Figures 15, 16, 17, 18, 19**).

Geochemical and isotopic studies of brines in the Arbuckle and Mississippian show no linkage to the USDW. Mississippian and Arbuckle brines also do not appear to be hydraulically connected in this area even though they are considered to be part of the same regional hydrogeologic aquifer system (**Figures 20 and 21**).

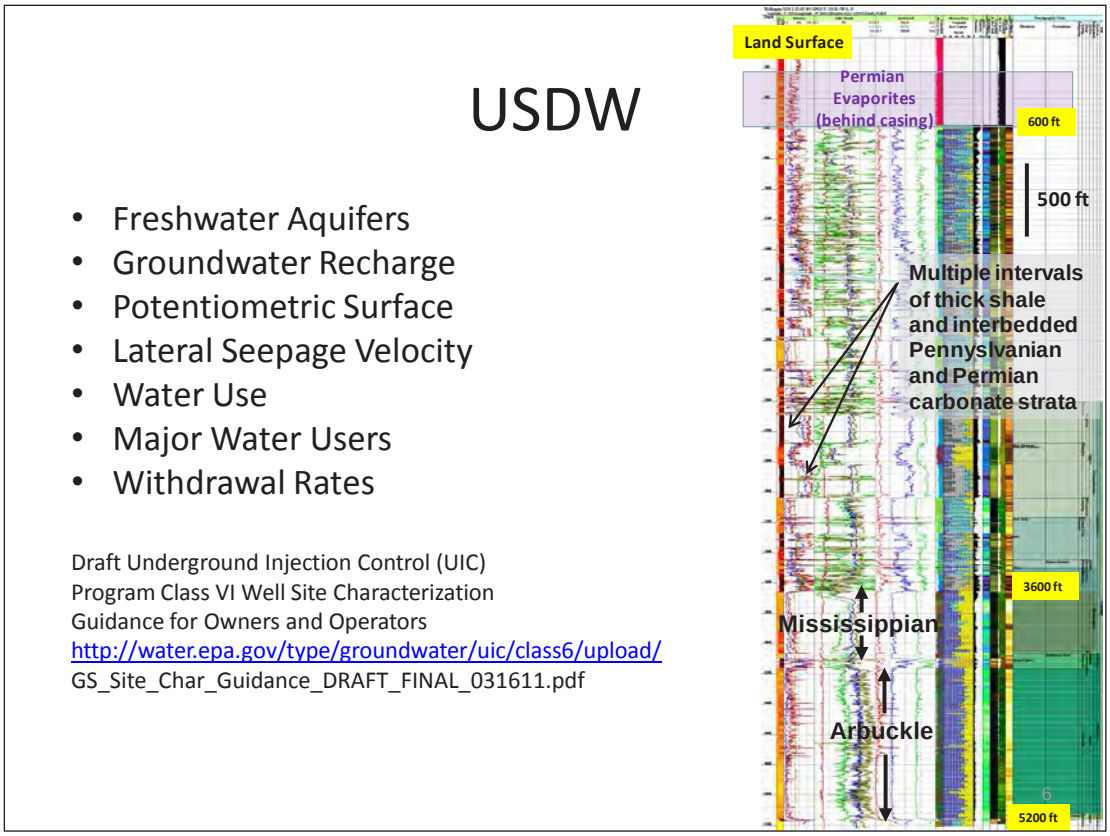


Figure 15. Stratigrahic colume showing the stratigraphic succession in KGS #1-32 highlighting the CO2 injection intervals (Mississippian and Arbuckle), overlying thick shales, near surface evaporites, and the land surface. USDW is very thin aluvium, coluvium, and Permian Ninnescah Shale.

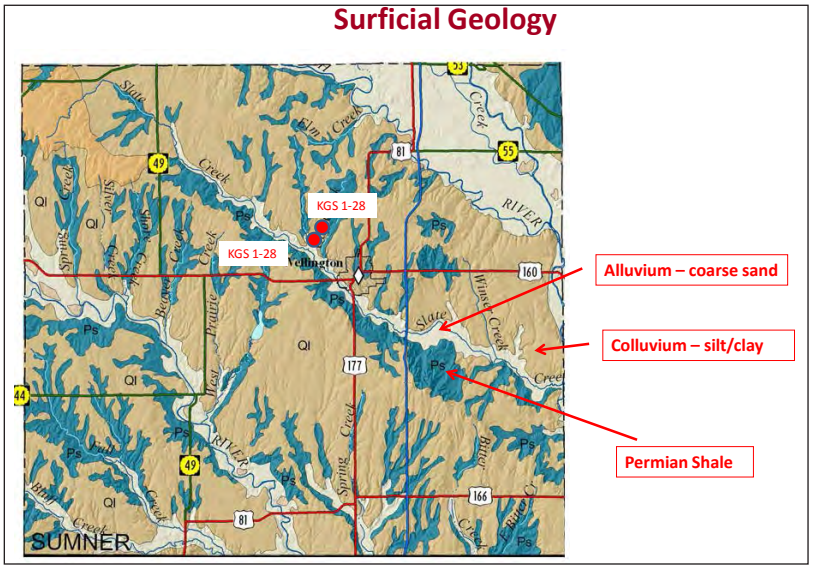


Figure 16. Surficial geologic map of Sumner County showing wells and surface USDW deposits – alluvium, coluvium,and Permian shales (Ninnescah Shale).

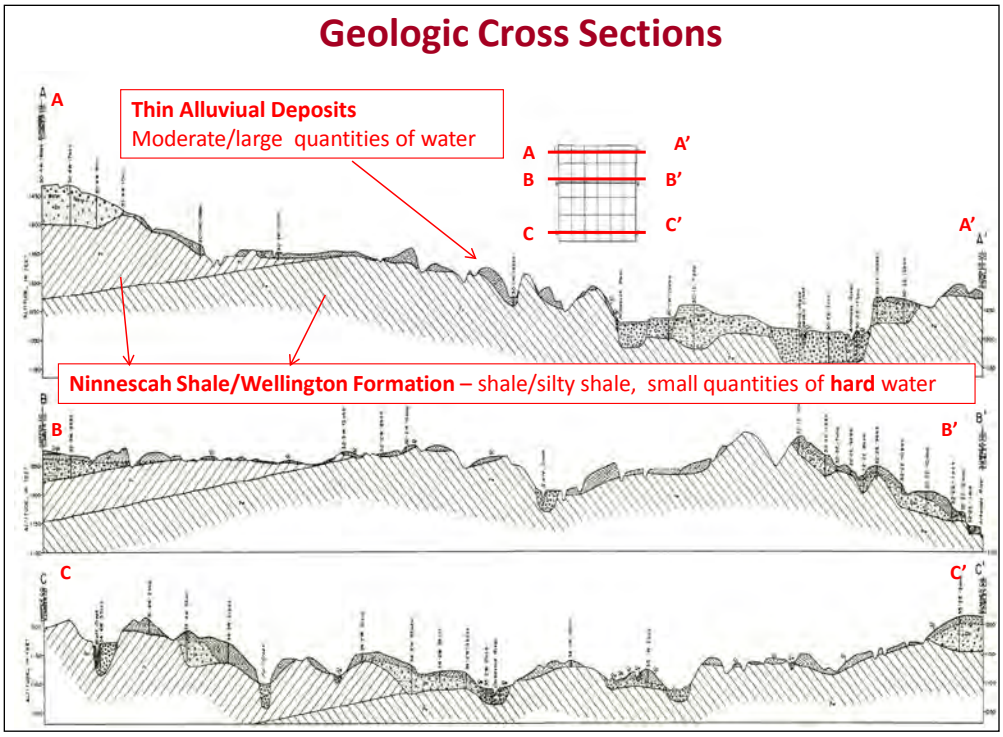


Figure 17. Cross sections through the shallow USDW deposits in Sumner County.

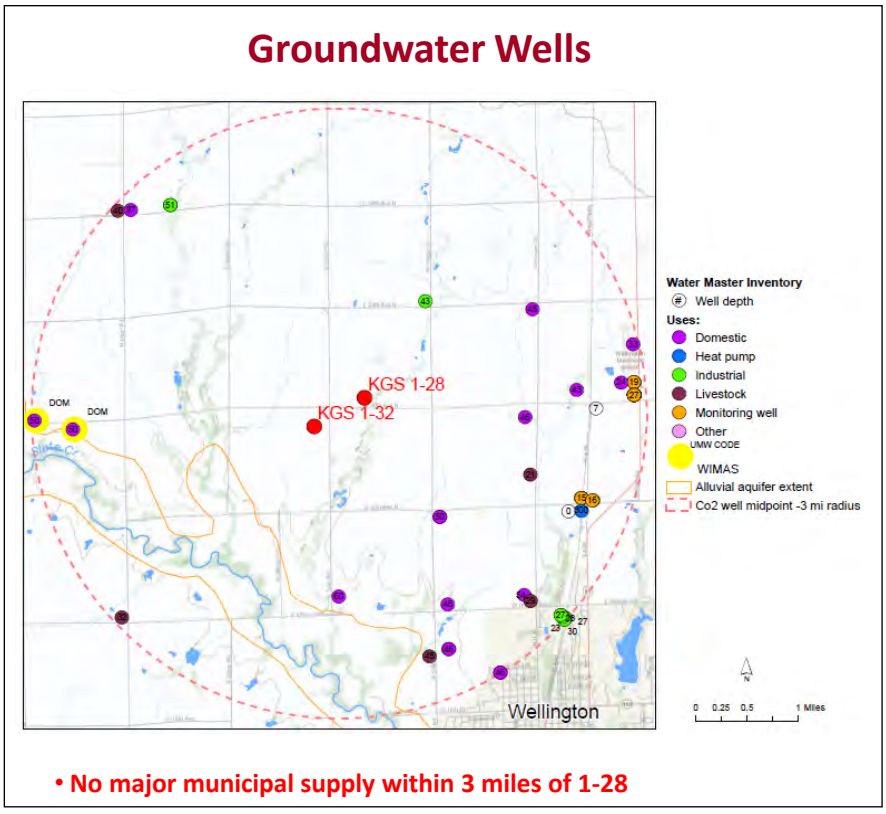


Figure 18. Groundwater wells in a three-mile radius around the CO2 small scale injection site.

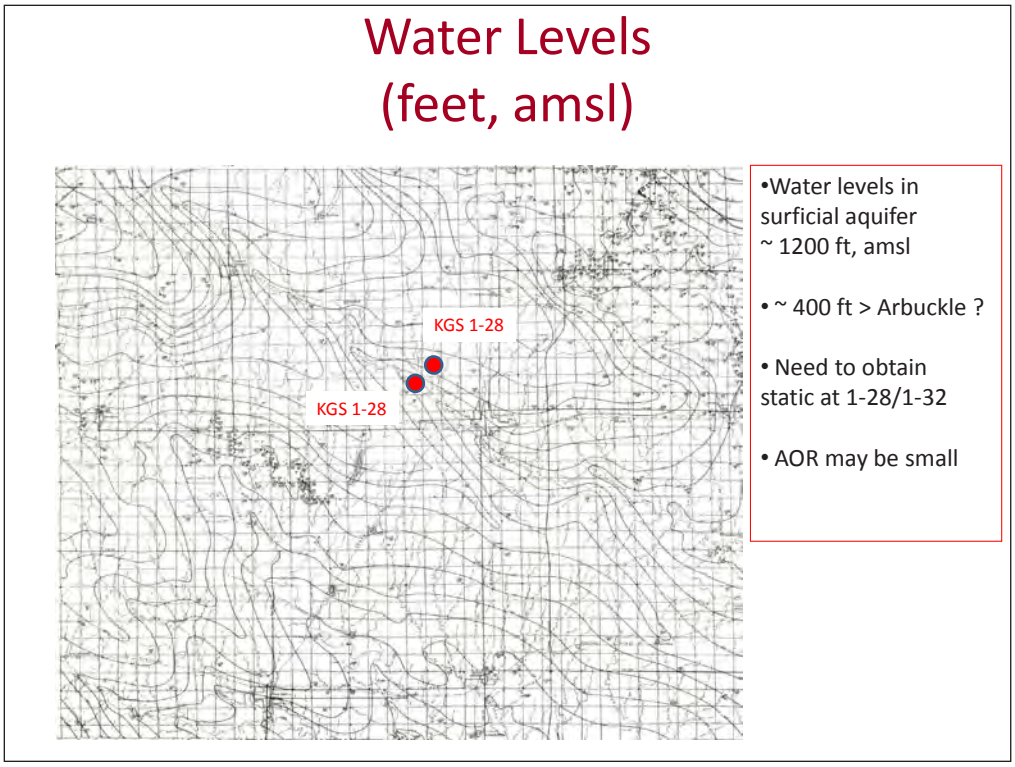


Figure 19. Water level map of Sumner County and location of two wells drilled in DE-FE0002056.

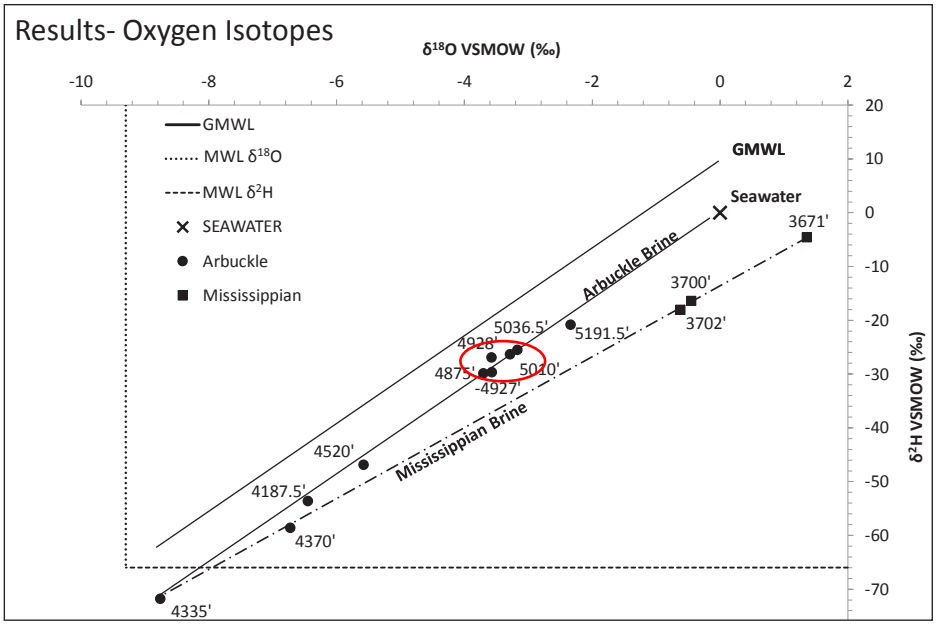


Figure 20. The upper Arbuckle is isotopically depleted form other brines and meteoric water. Lower Arbuckle brines all cluster together suggesting a high rate of mixing. Values of upper brines differ substantially from those of the lower brines.

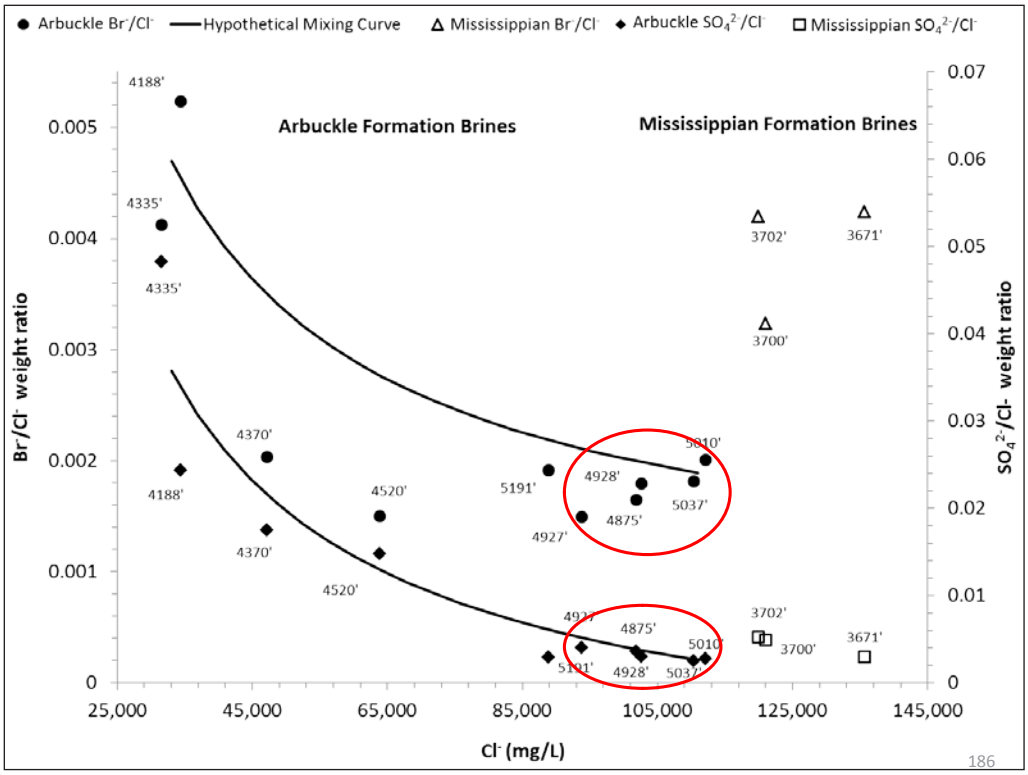


Figure 21. Bromine and chloride are conservative during water/rock interactions and are very useful for detecting sources of brine and mixing. Lower Arbuckle brines vary substantially from upper Arbuckle. Lower brines also cluster together suggesting mixing. Upper Arbuckle brines are spaced out suggesting multiple baffles may be separating sampled intervals.

Specific topics also being addressed for the Class VI injection application include --

Maps and cross-sections of the AoR [§146.82(a)(3)(i)].

Regional maps and cross sections are readily available using DE-FE0002056's web-based interactive project mapper, http://maps.kgs.ku.edu/co2/?pass=project. (**Figures 22 and 23**).

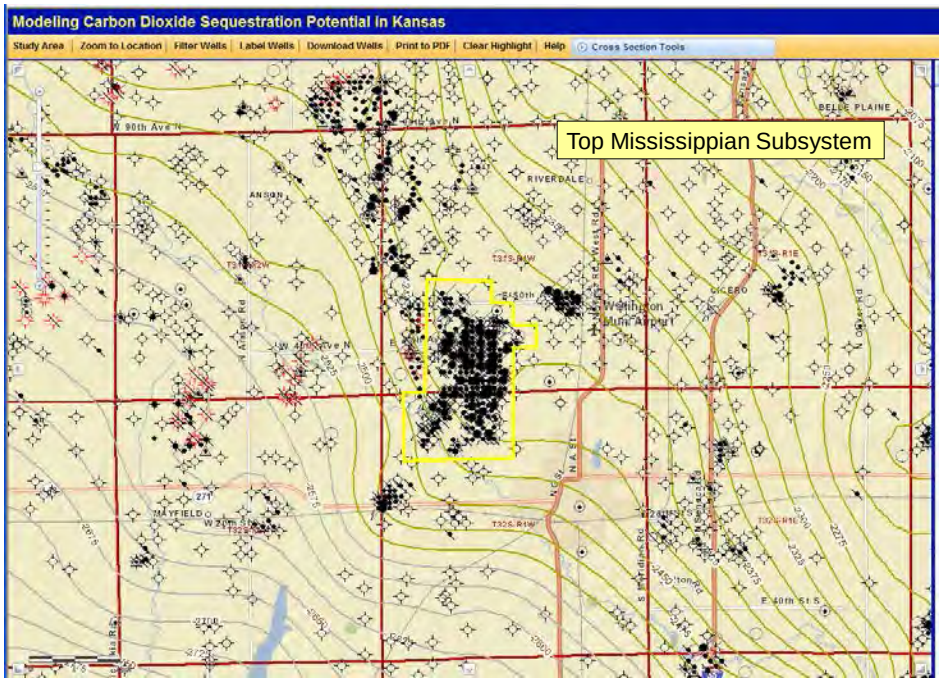

Modeling Carbon Dioxide Sequestration Potential in Kansas
Study Area
Zoom to Location
Filter Wells
Label Wells
Download Wells
Print to PDF
Clear Highlight
Help
Cross Section Tools
Top Mississippian Subsystem
RIVERDALE
BELLE PLAINE
MAYFIELD
ANSON
VICEBO

Figure 22.

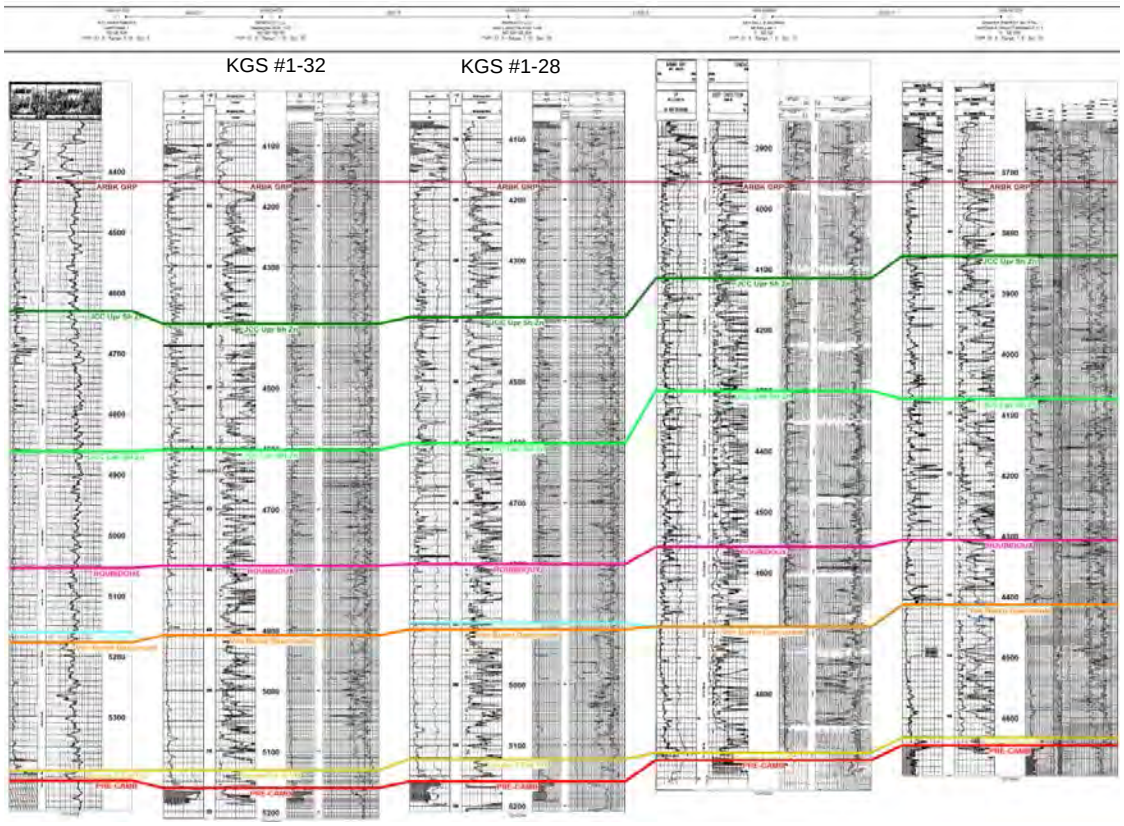

KGS #1-32
KGS #1-28

Figure 23. (*Previous page*) Subregional cross section in the region of new well #1-32 and #1-28 datumed on top of the Arbuckle showing major subdivisions of the Arbuckle saline formation.

The location, orientation, and properties of known or suspected faults and fractures that may transect the confining zone(s) in the AoR [§146.82(a)(3)(ii)].

This topic continues to be reviewed with the new seismic processing and will be incorporated into Petrel as a discrete fracture network.

Data on the depth, areal extent, and thickness of the injection and confining zone(s) [§146.82(a)(3)(iii)]..

Maps and cross sections of the 1) Arbuckle injection interval – Gasconade to Gunter, 2) baffle/storage interval in upper Arbuckle, 3) Chattanooga Shale, and 4) lower Mississippian "Pierson" to base of Simpson Group will refined in new Petrel model using latest depth-migrated seismic data.

Information on lithology and facies changes [§146.82(a)(3)(iii)].

Lithology and facies work done to date are based on core, samples, and well logs. New seismic will be inverted and will be used to obtained refined 3D distribution of these rock properties in addition to porosity using Petrel geocellular modeling.

Information on the seismic history of the area, including the presence and depth of seismic sources [§146.82(a)(3)(v)].

Seismic occurrence map prepared by US Geological Survey will be used to convey historical earthquakes and to access risk of future earthquakes. Area has no record of earthquakes that have occurred near the site, nor are the risks for seismic activity elevated at the site.

Geologic and topographic maps and cross-sections illustrating regional geology, hydrogeology, and the geologic structure of the local area [§146.82(a)(3)(vi)].

This data is readily available. See Figure 16.

Maps and stratigraphic cross-sections indicating the general vertical and lateral limits of all USDWs, water wells, and springs within the AoR, their positions relative to the injection zone(s), and the direction of water movement (where known) [§146.82(a)(5)].

See Figures 17, 18, and 19. In additional, regional inventory of over 3700 drill stem tests from the Arbuckle have established a reliable static shut-in pressure that has been converted to equivalent freshwater head (**Figure 24**).

Baseline geochemical data on subsurface formations, including all USDWs in the area of review [§146.82(a)(6)].

This information has been identified and will be summarized in the Class VI application.

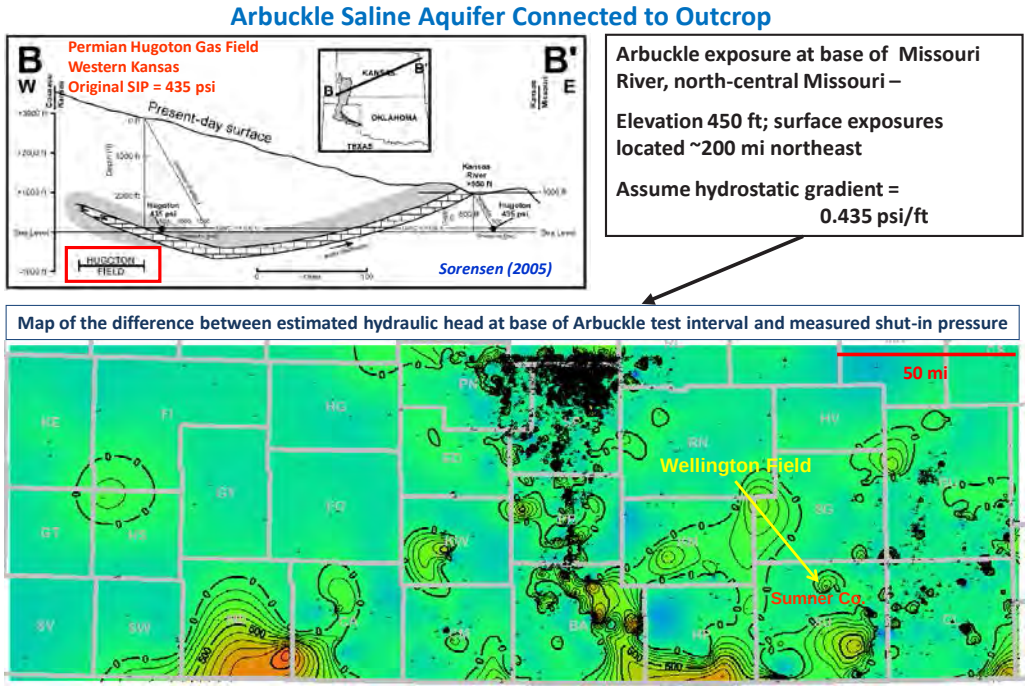


Figure 24. Arbuckle shut-in pressures are a reflection of the saline formation being hydraulically connected to the surface exposures of the unit in Missouri ~150 miles east of the injection site.

Regional Geology –

Regional geologic mapping is well underway in DE-FE0002056 for the Arbuckle based on stratigraphic tops correlated from hundreds of key wells. Reference wireline logs that penetrate deeply into the Arbuckle with good suites of wireline logs provide lithology, porosity, and eventually will be used to estimate permeability (**Figure 25**). The regional extent of the mapping extends over 25,000 mi2 includes regions of the Arbuckle in southern Kansas where CO2 would be in a supercritical state in the saline formation.

The regional mapping is also being used to identify significant fracture and fault systems in relationship to degree of flexure and evaluation of any accompanying stratigraphic changes (**Figure 26**).

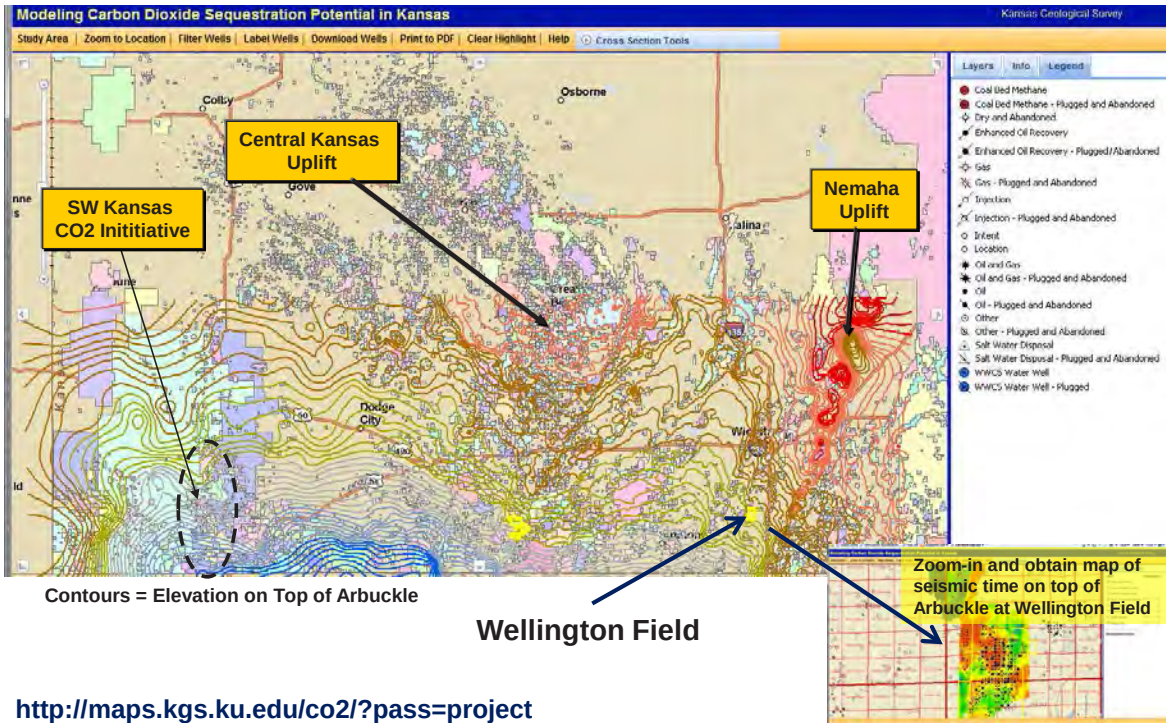


Figure 25. Regional mapping has been accomplished to provide regional context the Wellington small scale test injection and background needed for the Class VI CO2 injection application.

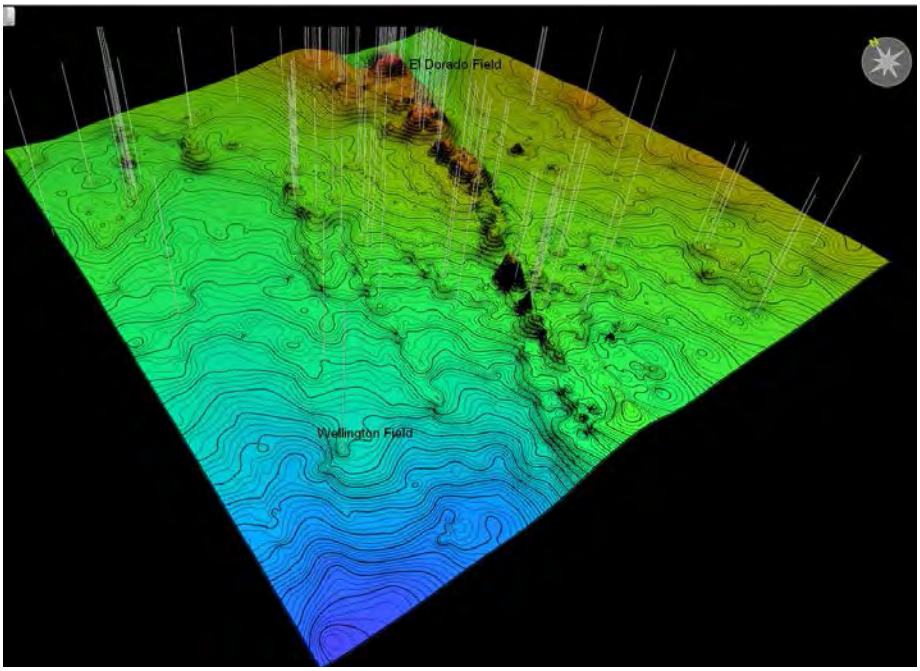


Figure 26. Three dimensional perspective of the top of the Arbuckle in south-central Kansas.

Subtask 1.10. Site Development, Operations, and Closure Plan

A site development plan has been delayed until next quarter to describe the details of the site development, operations, and site closure including:

- list of available infrastructure in and around Wellington Field related to small scale CO2 injection;
- identify all major activities, roles of responsibility, and environmental health and safety issues that the Applicant will face during all stages of the project;
- identify the necessary permits and respective agencies;
- describe the information required for each permit;
- schedule of when permit applications shall be submitted and anticipated approval dates.
- A list of responsible persons for completion and negotiation of the permits shall be identified for each permit.

TASK 2. SITE CHARACTERIZATION OF ARBUCKLE SALINE AQUIFER SYSTEM - WELLINGTON FIELD

Information regarding site characterization has been conveyed above, built on studies being conducted in DOE contract DE-FE0002056.

Key Findings

(as described in accomplishments)

1. Completed NEPA, budget/contract reviews during the quarter. NEPA statements have been approved and budget/contract review nearly complete.
2. Significant progress made in compiling information and characterizing site for use in the application for Class VI CO2 injection permit in the Arbuckle.
3. Conducted area of review of wells and USDW.
4. Incorporated depth-migrated seismic into initial Petrel geocellular model, but obtaining reprocessed seismic volume for use in revising the Petrel model for eventual use in simulation modeling for the Class VI permit application.
5. Completed geochemical and isotopic analyses of the brines samples in two wells previously drilled in DE-FE0002056. Results indicate that the Upper and Lower Arbuckle are hydraulically isolated by a mid Arbuckle barrier. This tight ~300 ft thick interval is also recognized on well logs, core, and 3D impedance mapping. While potentially reducing the injection interval to the ~300 ft thick lower Arbuckle, the mid Arbuckle will likely serve as an interval to "pancake" the CO2 plume into thin layers of higher porosity and higher permeability intervals mixed with tight rock. Multiple layers perhaps accesses by localized fractures will facilitate mixing of CO2 and brine, promote capillary entrapment of the CO2, and limit or eliminate free phase CO2 from accumulated beneath the primary caprock. The net effect could be to notably increase CO2 storage.
6. Initial geomechanical modeling of the caprock interval is very positive. The 120 ft-thick lower Mississippian-age dark argillaceous siltstones are tight and have relatively minor evidence of fracturing based on a fully cored, logged, and seismically imaged and analyzed interval.
7. Two preliminary coupled dynamic models of the small scale CO2 injection in the Arbuckle have been completed. Between solubility trapping and capillary effects the 40,000 tons will be likely be rapidly trapped in the lower Arbuckle where the CO2 is injected. Further analysis will continue. Pressures are such that CO2 escape from a worst case scenario of open wells in the AOR will likely not cause a leak of CO2 to the surface due to relatively low pressure beyond the injection well. However, more modeling is needed to firmly conclude this.
8. The geomechanical component in the simulation run under CMG software is based on a complete suite of mechanical tests from core analysis. Initial results indicate mechanical integrity in this rock system will not be compromised by the 40,000 ton injection into the lower Arbuckle over 9 month timeframe.
9. Reprocessing of the 3D seismic will be used to discretely map fractures and faults. Yet, current geomechanical modeling indicates that reactivation of these structures is unlikely. An updated geomodel from Petrel based on a new seismic volume will used as input into

final simulations including sensitivity analyses, as required by EPA for use in the Class VI application. These will be the results to confirm the Area of Review.

Plans

1. Top priority is to finalize and submit application for Class VI injection permit to EPA with updated geomodel and simulation of the Arbuckle saline formation so that field activities can begin.

2. Submit updated management plan, well drilling and installation plan, MVA plan, Public Outreach Plan based on material included in Class VI application.

6. Submit Mississippian Injection Permit Application (Class II injection well under Kansas primacy, regulated by Kansas Corporation Commission) using updated geomodel and simulation of the Mississippian oil reservoir.

7. Once permission granted for field deployment, install LiDAR, InSAR, CGPS, seismometers, groundwater monitoring wells above and below evaporite beds, drilling of Mississippian CO2 injection well, and construction of facility at Abengoa Biofuels ethanol plant to capture CO2.

PRODUCTS

Publications, conference papers, and presentations

Watney, W.L. et al., 2011, Small Scale Field Test Demonstrating CO2 sequestration in Arbuckle Saline Aquifer and by CO2-EOR at Wellington field, Sumner County, Kansas --Presentation to KCC-KDHE-EPA, Wichita

Barker, R., Watney, L., Bhattacharya, S., Strazisar, B., Kelly, L., Ford, S., Datta, S., 2011, Analytical description of the mineralogy and geochemistry of the Arbuckle deep saline aquifer in south central Kansas and implications for CO2 sequestration, T125. Assessing Potential Impacts of Geological Carbon Sequestration on Groundwater Quality: Geochemical and Hydrological Approaches, Annual GSA, Minneapolis.

Barker, R., Watney, L., Bhattacharyya, S., Strazisar, B., Kelly, L., Ford, S., Datta, S., 2011, Geochemical and mineralogical characterization of the Arbuckle aquifer with laboratory flow cell experiments under supercritical conditions: Implications for CO2 sequestration: AGU, GC30: Carbon Sequestration 3. Mineral Carbonation Under Low Temperature Conditions, San Francisco.

W. Lynn Watney, Jason Rush, 2011, GC44A-02. Modeling CO2 Sequestration in Saline Aquifer and Depleted Oil Reservoirs to Evaluate Regional CO2 Sequestration Potential of Ozark Plateau Aquifer System, South-Central Kansas, AUG Fall Meeting, San Francisco.

Watney, W.L., 2012, Business Implications of A Class VI Permit – The Long View? -- A Kansas Perspective, PUTTING THE BUSINESS ELEMENTS TOGETHER FOR CO2 EOR USING CAPTURED CARBON, April 4-5, 2012 - Golden, Colorado, sponsored by Permian Basin CCUS Center and Colorado PTTC.

Scheffer, A.A., Gulliver, D., Roberts, J.A., Fowle, D., Watney, W.L., Doveton, J., Stotler, R., Whittemore, D., ms. in review, Geochemical, Microbiological, and Permeability Characteristics Indicating Vertical Zonation of the Arbuckle Saline Aquifer, a potential CO2 storage reservoir.

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS:

A project organization chart follows. The work authorized in this budget period include office tasks related to preparation of reports and application for a Class VI permit to inject CO2 into the Arbuckle saline aquifer. Tasks associated with reservoir characterization and modeling are funded in contract DE-FE0002056.

ORGANIZATION CHART

Name	Project Job Title	Primary Responsibility
Kansas Geological Survey		
Lynn Watney	Project Leader, Joint Principal Investigator	Geology, information synthesis, point of contact
Tiraz Birdie	Consulting Engineer	Reservoir engineer, dynamic modeling, synthesis
Jason Rush	Joint Principal Investigator	Geology, static modeling, data integration, synthesis
John Doveton	Co-Principal Investigator	Log petrophysics, geostatistics
Dave Newell	Co-Principal Investigator	Fluid geochemistry
Rick Miller	Geophysicist	2D seismic aquire & interpretation
		LiDAR support, water well drilling/completion
TBN	Geology Technician	Assemble and analyze data, report writing
TBN	Engineering Technician	Assemble and analyze data, report writing
KU Department of Geology		
Michael Taylor	Co-Principal Investigator	Structural Geology, analysis of InSAR and LiDAR
TBN	Graduate Research Assistant	Structural Geology, analysis of InSAR and LiDAR
Kansas State Unversity		
Saugata Datta	Principal Investigator	Aqueous geochemistry
TBN	Graduate Research Assistant	
TBN	3- Undergraduate Research Assistants	
Lawrence Berkeley National Laboratory		
Tom Daley	Co-Principal Investigator	Geophysicist, analysis of crosshole and CASSM data
Jennifer Lewicki	Co-Principal Investigator	Hydrogeology, analysis of soil gas measuremnts
Barry Freifeld	Co-Principal Investigator	Mechanical Engineer, analysis of U-Tube sampler
Sandia Technologies, Houston		
Dan Collins	Geologist	Manage CASSM and U-Tube operation
David Freeman	Field Engineer	Manage field install of CASSM and U-Tube
Berexco, LLC		
Dana Wreath	VP Berexco	Engineering, Manager of Wellington Field
Randy Kouedele	Reservoir engineer	Enginering
Staff of Wellington Field		field operations
Beredco Drilling team		Mississippian and Arbuckle drilling operations
Abengoa Bioenergy Corp. - Colwich, KS		
Christopher Standlee, Danny Alllison		CO2 supply – Colwich Ethanol Facility

IMPACT

The project has been discussed in public venues – presentations at professional meetings, legislative committees, and town hall meeting, and has provided information on the project via the website to encourage a dialog on the merits and economies related to carbon management in Kansas. Kansans are realizing the potential for an important collaboration between the two of the largest economies in Kansas – agriculture and related ethanol industry and the petroleum industry to advance energy and contribute to a viable rural economy.

The small scale field test at Wellington Field as designed integrates two petroleum business activities: 1) use of CO2 for enhanced oil recovery and revitalizing many older mature oil fields and 2) disposal/storage of CO2 in the underlying saline aquifer for the longer term. It has been conveyed to the local petroleum industry that drilling and oil production infrastructure of an active oil field are important components that could lead to a successful carbon sequestration project including 1) knowledge about the subsurface including injection zones and caprock, 2) knowledge about abandoned wells, 3) access and suitability of land with greater likelihood for participation by landowner, and 4) access to insurance and investors to facilitate economic success.

CHANGES/PROBLEMS

The delays in activities prerequisite to completing the application for a Class VI injection permit have slowed progress. Yet, review of other applications for Class VI injection and getting reports from those who have applied for Class VI and failed to date have strongly influenced our approach to completing the Class VI permit application. We have a considerable amount of new data from DE-FE0002056 that factoring into a very strong application that we intend to submit at the end of September. Essentially, all of the key requirements of the permitting requested by EPA have been addressed.

APPENDIX II

Small Scale Field Test Demonstrating CO_2 Sequestration in Arbuckle Saline Aquifer and by CO_2-EOR at Wellington Field, Sumner County, Kansas

FOURTH QUARTERLY PROGRESS REPORT

DOE F 4600.2
(03/11)
All Other Editions Are Obsolete

U.S. Department of Energy
FEDERAL ASSISTANCE REPORTING CHECKLIST
AND INSTRUCTIONS FOR RD&D PROJECTS

1. Identification Number: **DE-FE0006821**	2. Program/Project Title: **Small Scale Field Test Demonstration CO2 Sequestration**

3. Recipient:
University of Kansas Center for Research, Inc.

4. Reporting Requirements:	Frequency	Addressees
A. MANAGEMENT REPORTING		
☒ Research Performance Progress Report (RPPR)	Q	FITS@NETL.DOE.GOV
☒ Special Status Report	A	FITS@NETL.DOE.GOV
B. SCIENTIFIC/TECHNICAL REPORTING		
(Reports/Products must be submitted with appropriate DOE F 241. The 241 forms are available at www.osti.gov/elink)		
Report/Product — Form		
☒ Final Scientific/Technical Report — DOE F 241.3	FG	http://www.osti.gov/elink-2413
☒ Conference papers/proceedings* — DOE F 241.3	A	http://www.osti.gov/elink-2413
☐ Software/Manual — DOE F 241.4		
☐ Other (see special instructions) — DOE F 241.3		
** Scientific and technical conferences only*		
C. FINANCIAL REPORTING		FITS@NETL.DOE.GOV
☒ SF-425 Federal Financial Report	Q, FG	
D. CLOSEOUT REPORTING		
☒ Patent Certification	FC	FITS@NETL.DOE.GOV
☒ SF-428 & 428B Final Property Report	FC	FITS@NETL.DOE.GOV
☐ Other		
E. OTHER REPORTING		See block 5 below for instructions.
☒ Annual Indirect Cost Proposal	O	
☐ Audit of For-Profit Recipients		
☒ SF-428 Tangible Personal Property Report Forms Family	A	FITS@NETL.DOE.GOV
☒ Other – see block 5 below	A	FITS@NETL.DOE.GOV

FREQUENCY CODES AND DUE DATES:

A - Within 5 calendar days after events or as specified.
FG- Final; 90 calendar days after the project period ends.
FC- Final; End of Effort.
Y - Yearly; 90 calendar days after the end of the reporting period.
S - Semiannually; within 30 calendar days after end of project year and project half-year.
Q - Quarterly; within 30 days after end of the reporting period.
Y180 – Yearly; 180 days after the end of the recipient's fiscal year
O - Other; See instructions for further details.

5. Special Instructions:

Annual Indirect Cost Proposal – If DOE is the Cognizant Federal Agency, then the proposal should be sent to FITS@NETL.DOE.GOV . Otherwise, it should be sent to the Cognizant Federal Agency.

Other – The Recipient shall provide all deliverables as contained in Section D of Attachment 2 Statement of Project Objectives.

QUARTERLY PROGRESS REPORT
To
DOE-NETL
Brian Dressel, Program Manager
Award Number: DE-FE0006821

SMALL SCALE FIELD TEST DEMONSTRATING CO_2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO_2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS

Project Director/Principal Investigator:
W. Lynn Watney
Senior Scientific Fellow
Kansas Geological Survey

Ph: 785-864-2184, Fax: 785-864-5317
lwatney@kgs.ku.edu

Joint Principal Investigator:
Jason Rush

Date of Report: November 1, 2012
Revised 11-11-12

DUNS Number: 076248616

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

Project/Grant Period: 10/1/2011 through 9/30/2015

Fourth Quarterly Report

Period Covered by the Report: July 1, 2012 through September 30, 2012

Signature of Submitting Official:

Willard Lynn Watney

Digitally signed by Willard Lynn Watney
DN: cn=Willard Lynn Watney, o=The University of Kansas, ou=Kansas Geological Survey, email=lwatney@kgs.ku.edu, c=US
Date: 2012.11.11 14:01:15 -06'00'

EXECUTIVE SUMMARY

Project Objectives

The objectives of this project are: (1) inject under supercritical conditions approximately 40,000 metric tons of CO_2 into the Arbuckle saline aquifer; (2) demonstrate the application of state-of-the-art MVA (monitoring, verification, and accounting) tools and techniques to monitor and visualize the injected CO_2 plume; (3) develop a robust Arbuckle geomodel by integrating data collected from the proposed study area, and a multi-component 3D seismic survey; (4) conduct reservoir simulation studies to map CO_2 plume dispersal and estimate tonnage of CO_2 sequestered in solution, as residual gas and by mineralization; (5) integrate MVA data and analysis with reservoir modeling studies to detect CO_2 leakage and to validate the simulation model; (6) develop a rapid-response mitigation plan to minimize CO_2 leakage and a comprehensive risk management strategy; and (7) establish best practice methodologies for MVA and closure. Additionally, approximately 30,000 metric tons of CO_2 shall be injected into the overlying Mississippian to evaluate miscible CO_2-EOR potential in a 5-spot pilot pattern. The CO_2 shall be supplied from the Abengoa Bioenergy ethanol plant at Colwich, Kansas who has operated the facility since 1982 demonstrating reliability and capability to provide an adequate stream and quality of CO_2. The project shall install compression, chilling, and transport facilities at the ethanol plant for truck transport to the injection site.

Project Goals

The proposed small scale injection will advance the science and practice of carbon sequestration in the Midcontinent by refining characterization and modeling, evaluating best practices for MVA tailored to the geologic setting, optimize methods for remediation and risk management, and provide technical information and training to enable additional projects and facilitate discussions on issues of liability and risk management for operators, regulators, and policy makers.

The data gathered as part of this research effort and pilot study will be shared with the Southwest Sequestration Partnership (SWP) and integrated into the National Carbon Sequestration Database and Geographic Information System (NATCARB) and the 6th Edition of the Carbon Sequestration Atlas of the United States and Canada.

Project Deliverables by Task

1.5 Well Drilling and Installation Plan (Can be Appendix to PMP or Quarterly Report)
1.6 MVA Plan (Can be Appendix to PMP or Quarterly Report)
1.7 Public Outreach Plan (Can be Appendix to PMP)
1.8 Arbuckle Injection Permit Application Review go/no go Memo
1.9 Mississippian Injection Permit Application Review go/no go Memo
1.10 Site Development, Operations, and Closure Plan (Can be Appendix to PMP)

2.0 Suitable geology for Injection Arbuckle go/no go Memo
3.0 Suitable geology for Injection Mississippian go/no go Memo
11.2 Capture and Compression Design and Cost Evaluation go/no go Memo
19 Updated Site Characterization/Conceptual Models (Can be Appendix to Quarterly Report)
21 Commercialization Plan (Can be Appendix to Quarterly Report).
30 Best Practices Plan (Can be Appendix to Quarterly or Final Report)

ACCOMPLISHMENTS

1. **Completed Milestone 1 (Task 2)** -- Site Characterization of Arbuckle Saline Aquifer System - Wellington Field.
2. **Significant progress and nearing completion of Milestone 2 (Task 3) --** Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field
3. **Subtask 1.8 Arbuckle Injection Permit Application** – An update on the status of the Class VI application is attached. We solidified the geomodel for the simulation and basic input for the simulation. We have a well define plume by CO2 saturation and pressure and accordingly, have a stabilized AOR. Pressures and size of CO2 plume are nominal/minor. Class VI injection application will be submitted for internal review followed by official submittal to EPA to obtain the permit during the 5th quarter.

Milestone Status Report

Task	Budget Period	Number	Milestone Description
Task 2.	1	1	Site Characterization of Arbuckle Saline Aquifer System - Wellington Field
Task 3.	1	2	Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field
Task 10.	2	3	Pre-injection MVA - establish background (baseline) readings
Task 13.	2	4	Retrofit Arbuckle Injection Well (#1-28) for MVA Tool Installation
Task 18.	3-yr1	5	Compare Simulation Results with MVA Data and Analysis and Submit Update of Site Characterization, Modeling, and Monitoring Plan
Task 22.	3-yr1	6	Recondition Mississippian Boreholes Around Mississippian CO2-EOR injector
Task 27.	3-yr2	7	Evaluate CO2 Sequestration Potential of CO2-EOR Pilot
Task 28.	3-yr2	8	Evaluate Potential of Incremental Oil Recovery and CO2 Sequestration by CO2-EOR - Wellington field

Project Schedule

Abengoa Biofuels informed us in mid August 2012 that the Colwich Ethanol Facility would be shut down for one year because of the severe drought in the Midwest. The dry weather severely impacted their dryland feedstock base (mainly milo and sorghum) and the resulting high grain prices. The facility will remains closed until the next harvest. Abengoa, DOE, and partners agreed that the plant reopening will be revisited on October 1, 2013 after the next harvest cycle to determine if they will reopen. During DOE site visit in September 2012, Abengoa official gave us a tour of the ethanol plant and relayed that every effort is being taken to keep the plant in a condition so that it can be reopened next year.

A request was made and DOE extended Budget Period 1 for an additional year at no cost until October 1, 2013. The project will make every effort to evaluate alternative sources, but as yet the economics are not close to meeting the arrangements made with Abengoa and the Colwich

ethanol facility. Both Abengoa and Berexco, the oil field industry partner, are committed to working with each other to link the ethanol-based CO2 with oil field operations in the area.

Geologic CO2 will not be part with the Kansas market due to demand along existing pipelines in Texas, New Mexico, Colorado, and Wyoming. Anthropogenic is the only viable source to provide the CO2 needed for CO2-EOR. Both Abengoa and Berexco are keenly interested in the saline aquifer storage in order to obtain enhanced prices for ethanol, obtain deposal fees, and with the case at Wellington, the income generated by carbon trading through Biorecro in Sweden.

A condensed version of the Gantt Chart tracks tasks based on the one year no cost extension of Budget Period 1 (Figure 1).

Activities of Lawrence Berkeley National Lab

No work has been completed or funds expended during this quarter by LBNL.

ONGOING ACTIVITIES –

TASK 1. PROJECT MANAGEMENT AND REPORTING

Permit Status and Activities

Continued progress was made on the Class VI application permit. With the Petrel geomodel and accompanying CMG based dynamic simulation expected to be completed in Q1 2013, we are on track to submit the permit in the present quarter. The sections of the Class VI permit application and the associated percent completion is presented in Table 1.

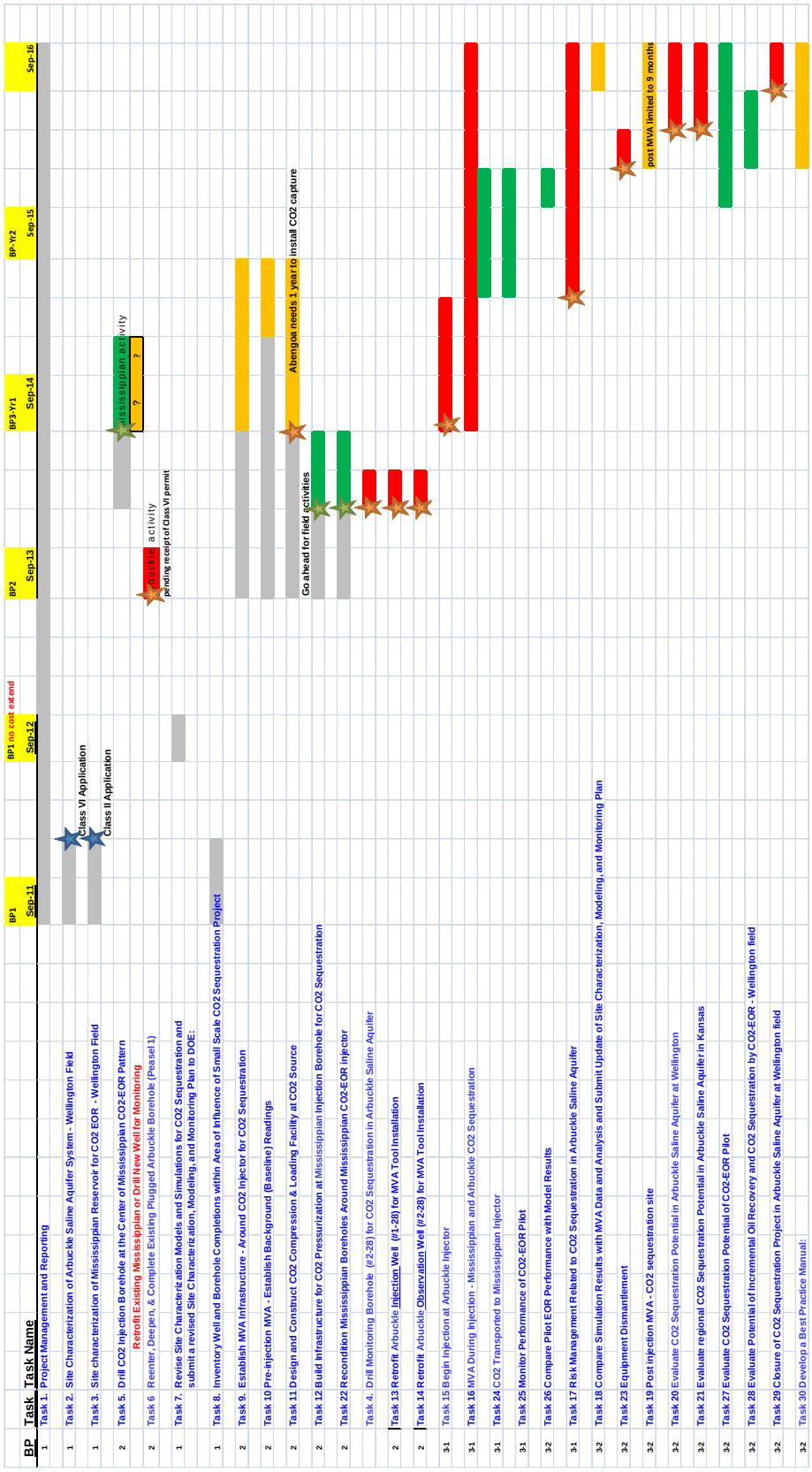

BP
Task
Task Name
BP1
Sep-11
BP1 no cost ext end
Sep-12
BP2
Sep-13
BP3-Yr1
Sep-14
BP-Yr2
Sep-15
Sep-16
1 Task 1. Project Management and Reporting
1 Task 2. Site Characterization of Arbuckle Saline Aquifer System - Wellington Field
Class VI Application
1 Task 3. Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field
Class II Application
2 Task 5. Drill CO2 Injection Borehole at the Center of Mississippian CO2-EOR Pattern
Mississippian activity
? ?
2 Task 6 Reenter, Deepen, & Complete Existing Plugged Arbuckle Borehole (Pease1)
Arbuckle activity
pending receipt of Class VI permit
1 Task 7. Revise Site Characterization Models and Simulations for CO2 Sequestration and submit a revised Site Characterization, Modeling, and Monitoring Plan to DOE:
1 Task 8. Inventory Well and Borehole Completions within Area of Influence of Small Scale CO2 Sequestration Project
2 Task 9. Establish MVA Infrastructure - Around CO2 Injector for CO2 Sequestration
2 Task 10 Pre-injection MVA - Establish Background (Baseline) Readings
2 Task 11 Design and Construct CO2 Compression & Loading Facility at CO2 Source
Abengoa needs 1 year to install CO2 capture
Go ahead for field activities
2 Task 12 Build Infrastructure for CO2 Pressurization at Mississippian Injection Borehole for CO2 Sequestration
2 Task 22 Recondition Mississippian Boreholes Around Mississippian CO2-EOR injector
Task 4. Drill Monitoring Borehole (#2-28) for CO2 Sequestration in Arbuckle Saline Aquifer
2 Task 13 Retrofit Arbuckle Injection Well (#1-28) for MVA Tool Installation
2 Task 14 Retrofit Arbuckle Observation Well (#2-28) for MVA Tool Installation
31 Task 15 Begin Injection at Arbuckle Injector
31 Task 16 MVA During Injection - Mississippian and Arbuckle CO2 Sequestration
31 Task 24 CO2 Transported to Mississippian Injector
31 Task 25 Monitor Performance of CO2-EOR Pilot
32 Task 26 Compare Pilot EOR Performance with Model Results
31 Task 17 Risk Management Related to CO2 Sequestration in Arbuckle Saline Aquifer
32 Task 18 Compare Simulation Results with MVA Data and Analysis and Submit Update of Site Characterization, Modeling, and Monitoring Plan
32 Task 23 Equipment Dismantlement
32 Task 19 Post injection MVA - CO2 sequestration site
post MVA limited to 9 months
32 Task 20 Evaluate CO2 Sequestration Potential in Arbuckle Saline Aquifer at Wellington
32 Task 21 Evaluate regional CO2 Sequestration Potential in Arbuckle Saline Aquifer in Kansas
32 Task 27 Evaluate CO2 Sequestration Potential of CO2-EOR Pilot
32 Task 28 Evaluate Potential of Incremental Oil Recovery and CO2 Sequestration by CO2-EOR - Wellington field
32 Task 29 Closure of CO2 Sequestration Project in Arbuckle Saline Aquifer at Wellington field
32 Task 30 Develop a Best Practice Manual:

Figure 1. Condensed version of the project Gantt Chart.

Table 1. Status of the Class VI permit application.

Section	Percent Complete
Project Overview	**90%**
Geologic Sequestration of Carbon Dioxide	**90%**
Regional Scale Geologic and Hydrogeologic Background	**75%**
Local Scale Geologic and Hydrolgeologic Background	**40%**
Flow and Transport Model Simulations and AOR Delineation	**60%**
Potential Capture in Depleted Mississippian Formation	**60%**
Geomechanical Stability Investigations	**50%**
Injection Well Design	**60%**
Monitoring Well Design	**60%**
Site Operations	**20%**
Monitoring Verification and Accounting Activities	**65%**
Post Injection Site Care	**50%**
Site Closure	**50%**
Risk Management and Mitigation Plan	**20%**
Financial Assurances	**40%**

A brief discussion of some of the activities conducted in Q4 2012 in support of the Class VI permit application is provided below.

Based on the literature review and the theoretical basis governing fault failure, a technical approach was developed to evaluate the potential for fault failure should such features be present in the study area. It should be noted that the EPA does not require a geomechanical analysis, and it is up to the discretion of the local director to request a stability analysis. Some efforts were however expanded in Q4 to develop the analytical approach to preempt any concern by the EPA based on their interpretation of the seismic data, and thereby minimize the potential for delays.

The EPA Class VI rule was carefully reviewed to ensure that material and construction requirements were met during construction of the project injection and monitoring wells (1-28 and 1-32 respectively). Specifications governing testing of mechanical integrity were also identified and are to be finalized with Berexco prior to inclusion in the permit application.

Conversations were held with Joesph Tiaggo and Bruce Kobelski of US EPA regarding financial requirements. The wellfield operator, Berexco was informed of the findings and the consensus is that Berexco will be able to meet the financial requirements.

The default EPA post injection monitoring period is 50 years. The Post Injection Site Care and the Site Closure sections are being carefully crafted in order to provide a strong justification for early site closure (preferably coinciding with the end of the DOE funding period). We are hopeful that the EPA may grant this waiver subject to field validation of the extent of plume migration and pressure dissipation.

The monitoring, verification, and accounting (MVA) aspects are key components of the Wellington project. During the planning stage, various MVA activities were identified but described only in general terms without design details as the anticipated plume and pressure impacts were not available due to the absence of a reservoir model based on integration of the various geophysical data collected at the site. With the preliminary impacts now available, key investigators at the Kansas State University, Kansas University, Kansas Geological Survey, and Lawrence Berkley and Sandia laboratories, have been contacted in order to finalize the MVA design and data sampling plans. For example, the anticipated vertical displacement at the surface is expected to be in the sub-mm scale and Mike Taylor at KU has been notified of the projections. He is currently developing plans in order to capture such minor displacements using ultra sensitive remote sensing techniques.

During Q4, contact was also made with Susan Collins at LBNL to make a presentation on the risk profile methodology being developed for quantifying risk potential at underground carbon storage sites in support of large-scale CCUS projects. The following set of questions were identified by the KGS group and forwarded to Susan for addressing during her visit:

- How are uncertainties in well penetrations/construction to be handled
- How are uncertainties in faults characterization to be handled
- What technical approach is to be implemented to evaluate and assign risk factors (what stochastic framework is to be applied for the overall analyses)
- What will the simulation system consist of – both software and hardware
- What are the lateral and vertical extent and continuity of the subsurface flow systems that are to be modeled
- What simulations approaches are to be implemented to efficiently handle the problem of dual scales of interest (large scale pressure propagation and the relatively small scale plume migration)
- What level of information (and source) is to be used to characterize the subsurface formations in Kansas
- What uncertainty techniques are to be used for both capacity estimation (if that is to be attempted) and geomechanical stability
- How are uncertainties in regional stress fields to be addressed/evaluated in estimating risks of geomechanical failure
- What activities have been completed so far and what are the findings.

- How can we assist in their efforts since we plan on conducting regional simulations as well.

The step rate test conducted at KGS 1-32 (with monitoring at KGS #1-28) was analyzed by three different participants on the project; Ken Cooper, Gene Williams, and Tiraz Birdie. Working independently, all three came to the same conclusions that the Arbuckle is not a homogenous aquifer because the observations at the injection and monitor well could not be matched with the same set of hydrogeologic parameters (for example, see Figure 2).

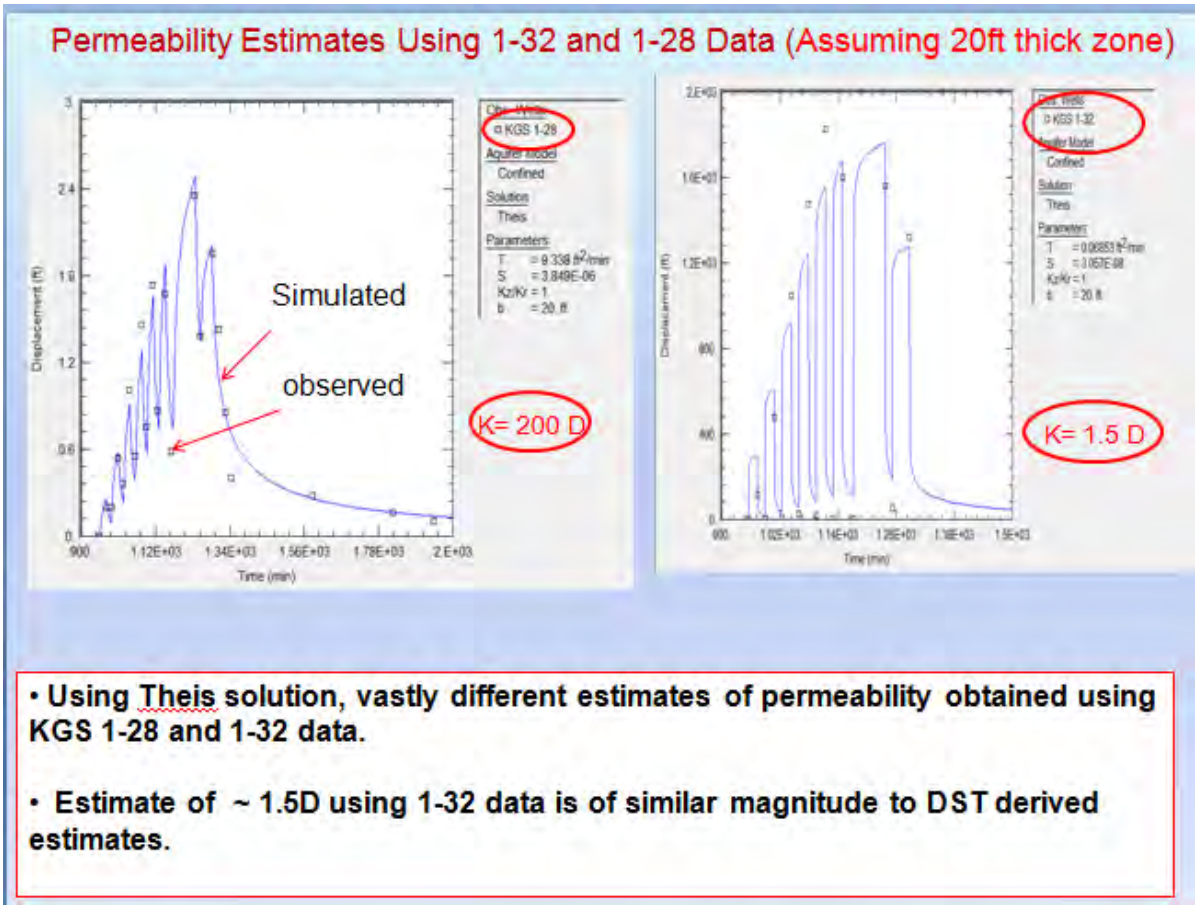


Figure 2. Calibrated hydrogeologic parameters derived from the step rate test at injection well 1-32 and observation well 1-28.

Using the USGS modeling code MODFLOW, it was later demonstrated that observed pressures at KGS 1-32 and 1-28 during the step rate test could be simultaneously reproduced with the same matrix petrophysical properties by incorporating baffle like features between 1-28 and 1-32 (Figure 3). This information may be recalled in the future during live calibration of the reservoir model as CO2 is injected.

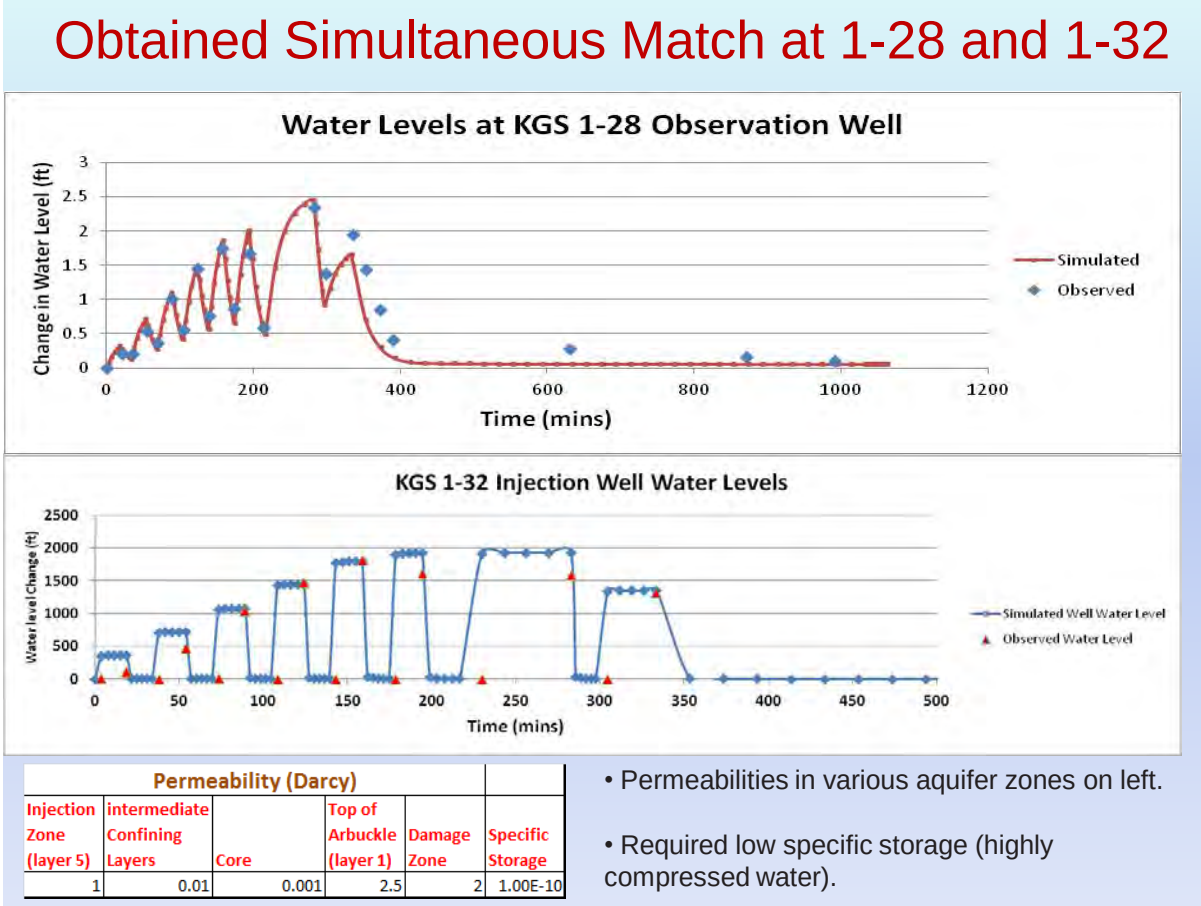


Figure 3. MOFLOW calibrated observed and simulated water levels at KGS 1-28 and 1-32.

Subtask 1.6. Monitoring Verification and Accounting (MVA) and Mitigation Plan

The MVA and mitigation plans will be completed as part of the Class VI application and submitted as a separate report. MVA plan will now include equipping same technologies and methodologies for the Mississippian CO2 injection ahead of the Arbuckle. This will require adapting the MVA to the CO2-EOR to establish 99% sequestration of the CO2.

Subtask 1.7. Public Outreach Plan:

The Public Outreach Plan will also be submitted as part of the Class VI application. The DOE document will describe workshops, presentations, and publications in technical and trade journals to be used to transfer lessons learned best practices, geomodels, simulation results, MVA data and observations to the public, regulators, legislators, and local industry. The PI is actively discussing the project with stakeholders.

Subtask 1.8. (Go-No Go Decision for CO2 saline formation sequestration) Arbuckle Injection Permit Application

Effort during the fourth quarter was focused on the Class VI injection permit including revision the geomodel and running simulations. The following is a review of the geomodeling and simulation activities as they pertain to the Class VI application.

Dynamic Simulation Model

On completion of the Petrel based geomodel in September 2012, the heterogeneous flow and transport properties from the geomodel were imported into the CMG dynamic model and simulations conducted in order to estimate the pressure and plume extent resulting from injecting 40 KT of CO2 for a period of nine months. The geomodel incorporates the injection interval, the middle transitional zone, the upper high permeability and porosity interval, and a portion of the sealing unit (Simpson Shale). It is developed using a complex combination of well logs, core data, seismic surveys, literature information, depositional analogs, and statistics. Due to availability of log data at only two sites (KGS 1-28 and KGS 1-32), the model also relied on seismic data, SRT, and DST information.

Reservoir properties (porosity and permeability) were distributed in the CMG simulation model by upscaling via arithmetic mean methods. Initial reservoir conditions were specified using known information about the pressure and temperature distribution. Fluid saturations were distributed using the sequential Gaussian simulation algorithm. The Carter-Tracer aquifer boundary conditions were specified along the lateral extent of the simulation model. Although observations suggest that the flow in Arbuckle reservoir is controlled by a combination of matrix and fractures, this initial set of model run considers flow only in the formation matrix.

The effective porosity derived in the geomodel (Figure 4) was deemed to be quite representative of the formation due to the extensive set of processing and synthesis conducted for this property by the KGS team led by John Doveton. The effective hydraulic conductivity (Figure 5) on the other is not directly derived from logs and therefore uncertainties in this parameter was explored by conducting three scenarios in which the base case model permeability was varied from the Petrel derived distribution of this property.

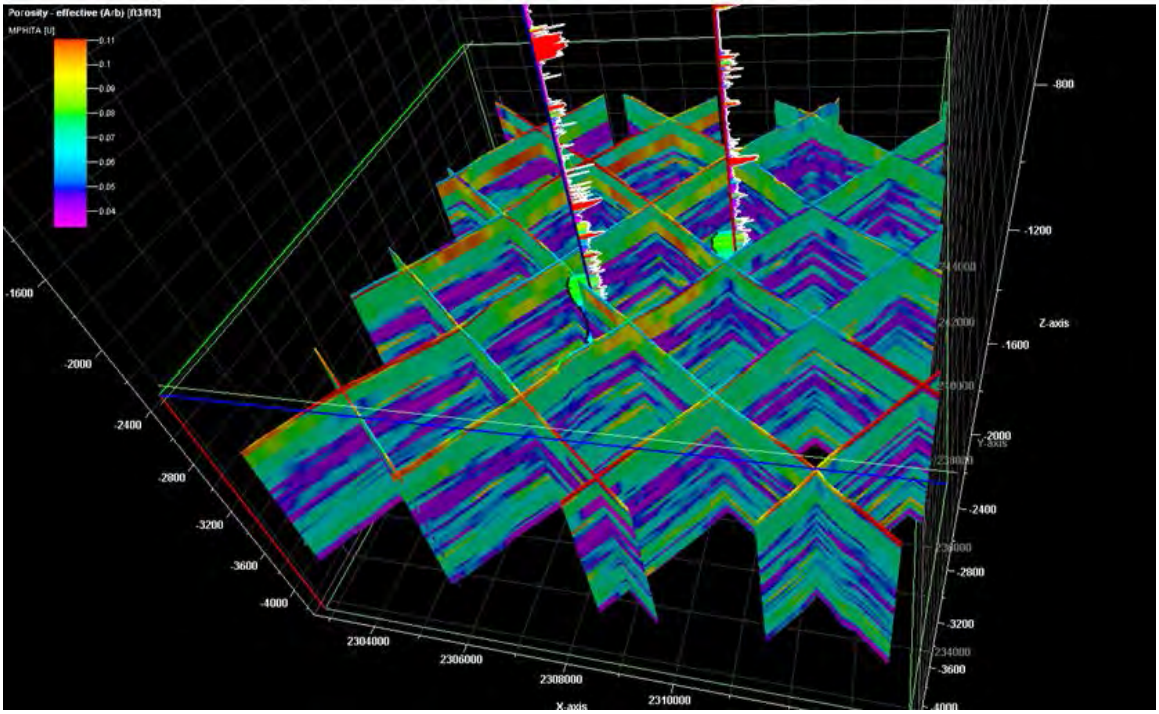


Figure 4. Petrel model based distribution of effective porosity in the Arbuckle aquifer

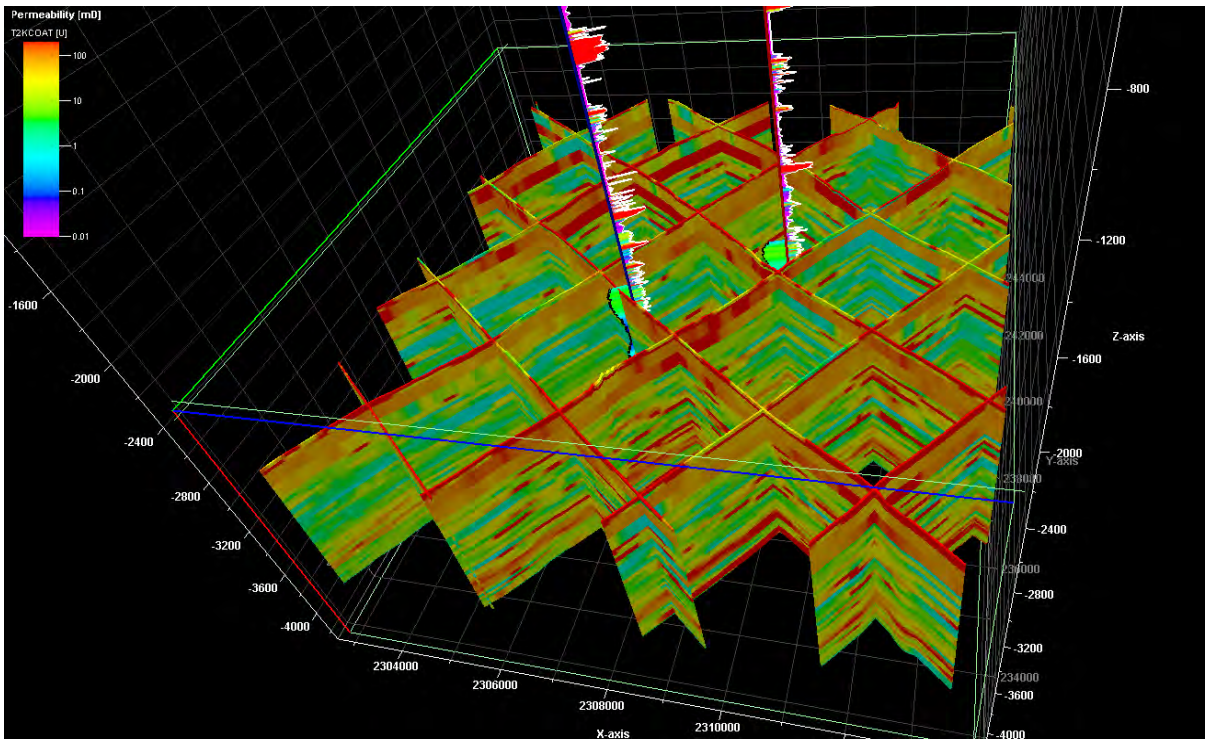


Figure 5. Petrel model based distribution of hydraulic permeability of the Arbuckle aquifer

The simulations were conducted by also assuming two different conditions in the mid Arbuckle: a no-flow barrier, and a finite but low permeability matrix in this zone. The reservoir medium was assumed to be porous; without fractures. Sequestration of CO2 was primarily by dilution due to dispersion/diffusion and residual trapping. This is expected to provide conservative results as solubility and geochemical trappings are not considered. These processes will be considered in the next round of simulations.

The vertical migration of CO2 within a cross section through the injection well (1-28) is presented in Figure 6a and 6b for the case with a permeable mid Arbuckle. By the end of the injection period of 9 months, the CO2 plume is contained within the lower Arbuckle and is approximately 500 feet wide with a saturation of about 40%. The plume extent remains fairly stable up to 5 years. By the 10th year the CO2 concentration in the plume starts to reduce, and by year 30 the CO2 saturation further reduces, but the plume has extended into the mid Arbuckle. By the 100th year, the plume has CO2 saturation of less than 20% and has stabilized with minor amounts trapped at the top of the upper Arbuckle under the Simpson Shale. The maximal horizontal extent of the plume at 5, 10, and 100 years is presented in Figure 7. The plume has the widest extent (of 600 feet) in the lower Arbuckle in the 5th and 10th year. By the 100th year, the plume has migrated into the upper Arbuckle and the widest extent is underneath the Simpson Shale.

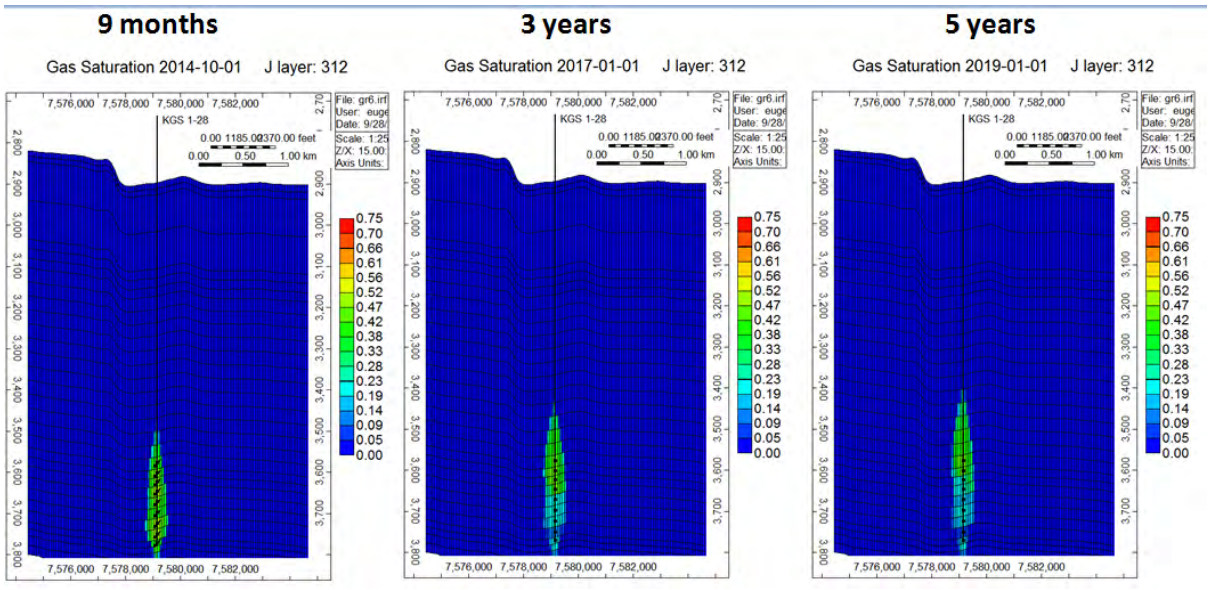


Figure 6a. CO2 saturation at 9 months, 3 and 5 years for the case with permeable mid Arbuckle.

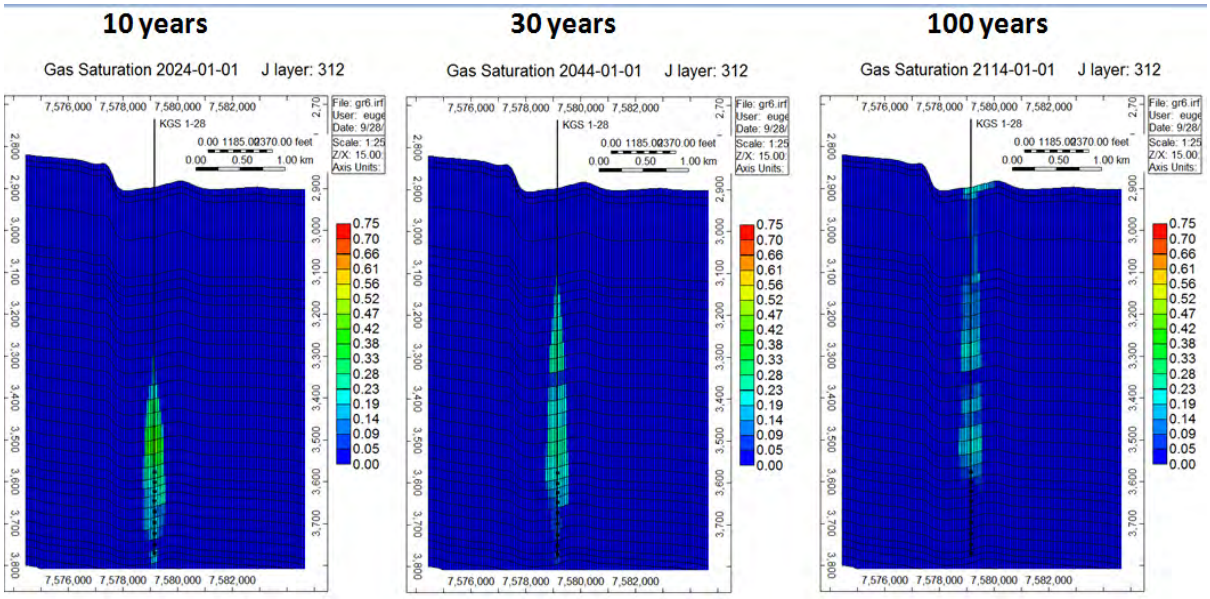


Figure 6b. CO2 saturation at 10, 30, and 100 years for the case with permeable mid Arbuckle.

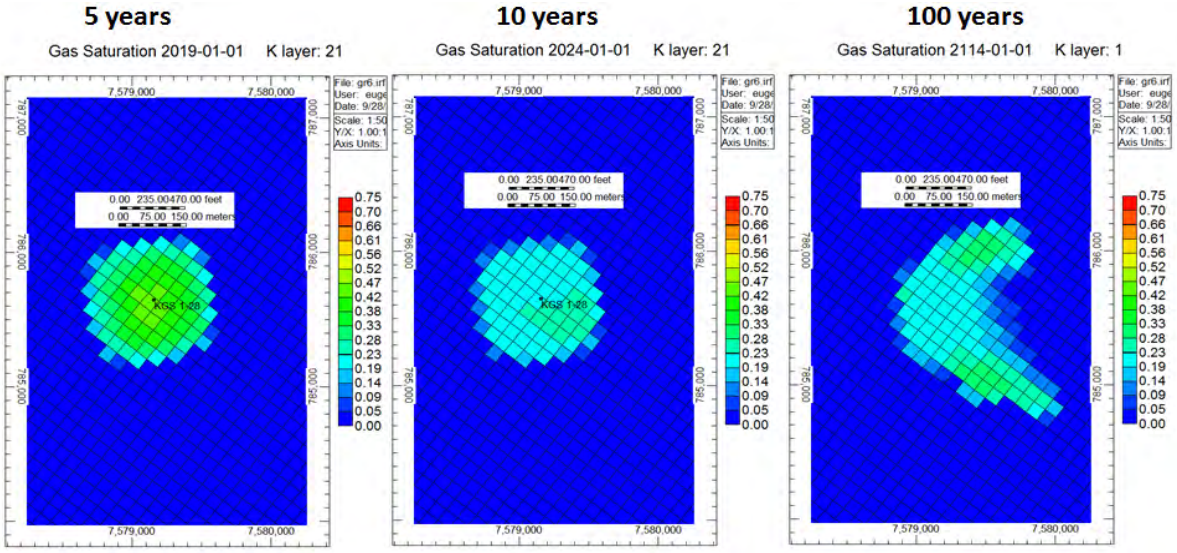


Figure 7. Maximal horizontal extent of CO2 plume at 5, 10, and 100 years for the case with permeable mid Arbuckle.

The vertical migration of the CO2 plume for the case in which the mid Arbuckle is a barrier is presented in Figures 8a and 8b. The saturation in the center of the plume is approximately 50% at the end of the injection period. By the end 5th and 10th years, the plume extent increases only

slightly but the concentration in the lower Arbuckle has reduced slightly. The plume extent and saturations at the end of 30, 70, and 100 years are presented in Figure 8b from which a stable plume can be inferred as the solubility aspects are not presently active in the model. The maximal extent of the CO2 plume after 9 months and at the end of years 3 and 5 is approximately the same at about 600 feet with a saturation of approximately 50% in the center of the plume (Figure 10a). By the end of 100 years, the plume extent has grown to over 1,000 feet but the saturations have dropped to 40% (Figure 10b).

The bottomhole pressures for the various permeability cases are presented in Figure 11. For all cases, the pressure initially increases substantially due to capillary effects prior to stabilizing at a lower level. The largest pressure increase is for the low permeability (base) case, but even for this case the pressure increase is under 100 psi; which is lower than the approximately 200 psi threshold for defining the EPA (pressure based) Area of Review. On cessation of injection, the pressure drops very rapidly to pre-injection levels. The vertical distribution of the pressure prior to and following injection is presented in Figure 12. A pressure increase of about 100 psi can be noted at the injection well at the end of 10 months. By the end of the first year, pressures have dropped to pre-injection levels. The maximal pressure response corresponding to an alternate low permeability case in which the injection pressures are nearly 2400 psi is presented in Figure 13 for illustrative purposes.

With the preliminary dynamic model under operation, simulations were conducted at a commercial level injection rate of 14 MT for a period of 15 years. The vertical extent of the plume for this case increases is presented in Figure 14a and 14b. The plume is approximately 0.5 mile wide by 9 months, and increases to 1 mile by the end of 5 years. By the end of 30, 70, and 100 years, the plume extent does not grow significantly but saturation levels have started to lower. The maximal horizontal plume extent is presented in Figures 14c and 14d. The plume grows from about 0.5 mile width at the end of 9 months to well over 2 miles wide at the end of 100 years. The highest saturation in the plume remains at 50% during this entire period. It should be noted that the CO2 concentrations will be lower in future simulations as solubility and geochemical trapping mechanisms are activated. The well bottom hole pressures are presented in Figure 15 from which a fairly high (pressure) build up of approximately 4,100 psi can be

noted. The background pressure does not revert to pre-injection levels yet as the model requires some additional "tweaking". The maximal pressure response at the end of the injection period is presented in Figure 16.

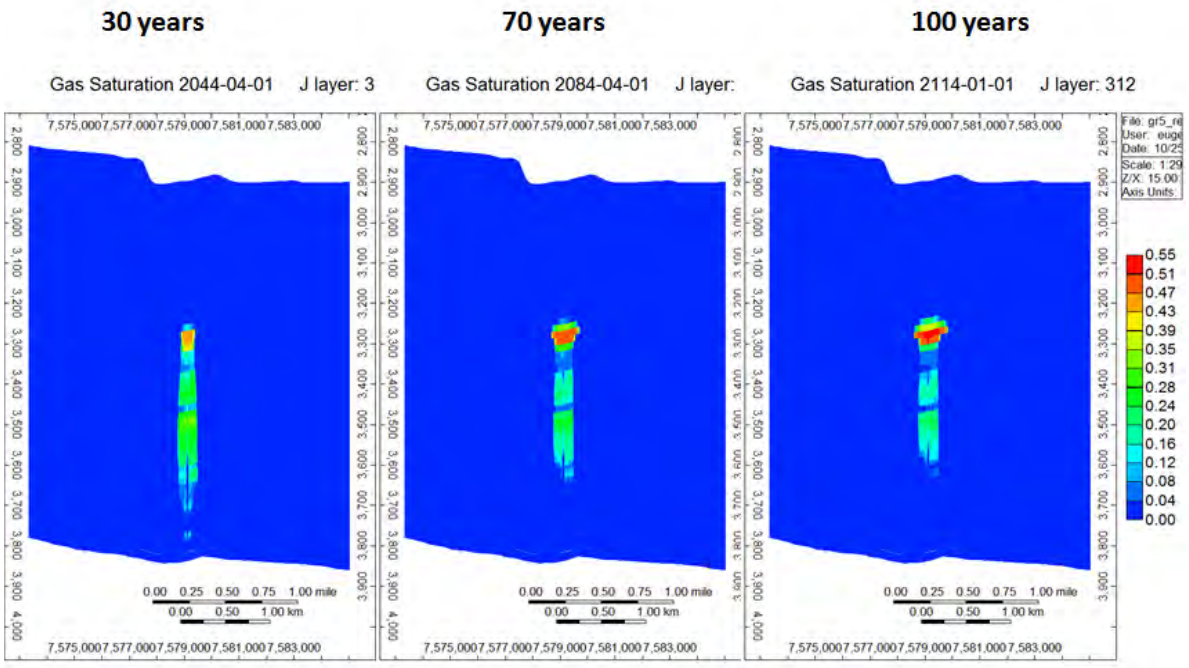


Figure 8a. CO2 saturation in the Arbuckle at 9 months, 3 years, and 5 years for the case with the mid Arbuckle as a barrier.

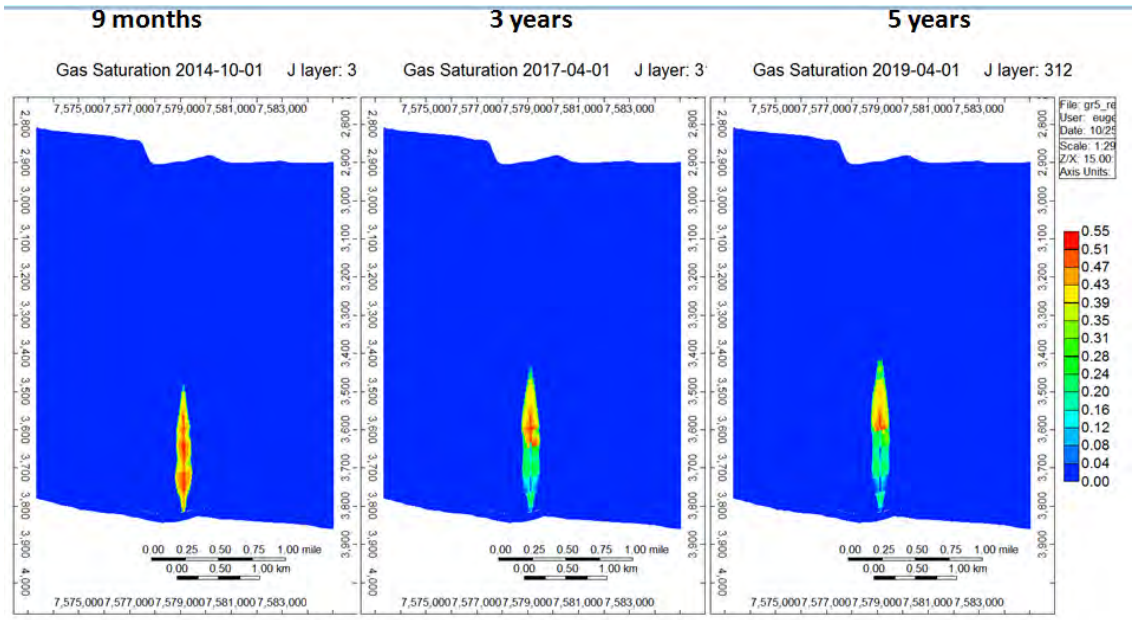


Figure 8b. CO2 saturation in the Arbuckle at 30, 70, and 100 years for the case with the mid Arbuckle as a barrier.

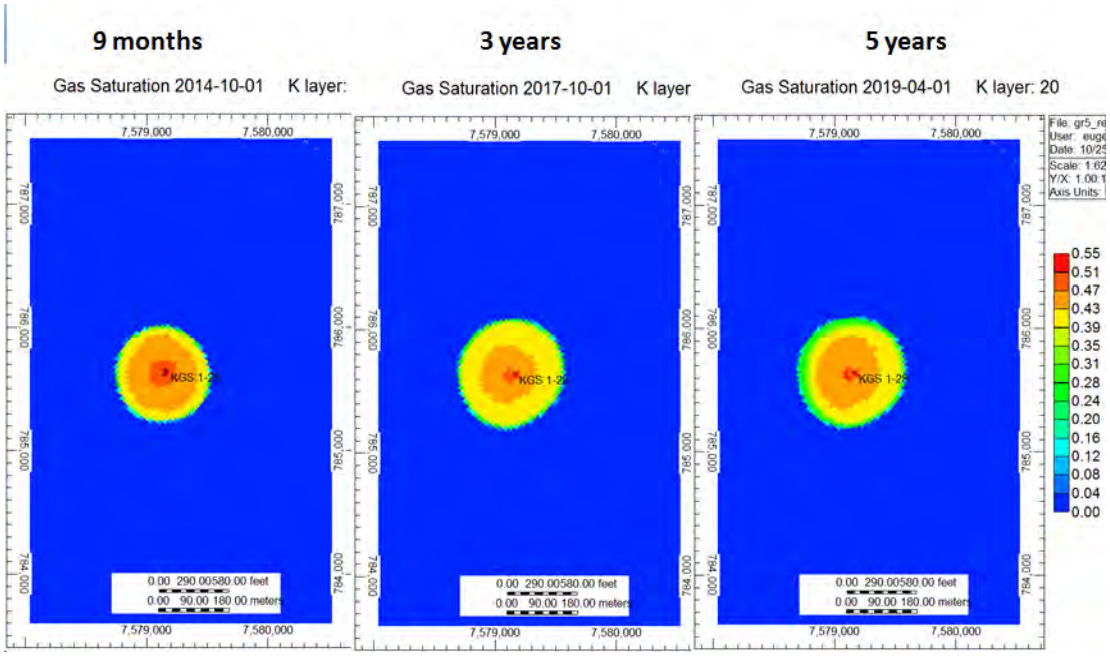


Figure 9a. Maximal horizontal extent of CO2 plume at 9 months, 3 years, and 5 years for the case with mid Arbuckle as a barrier.

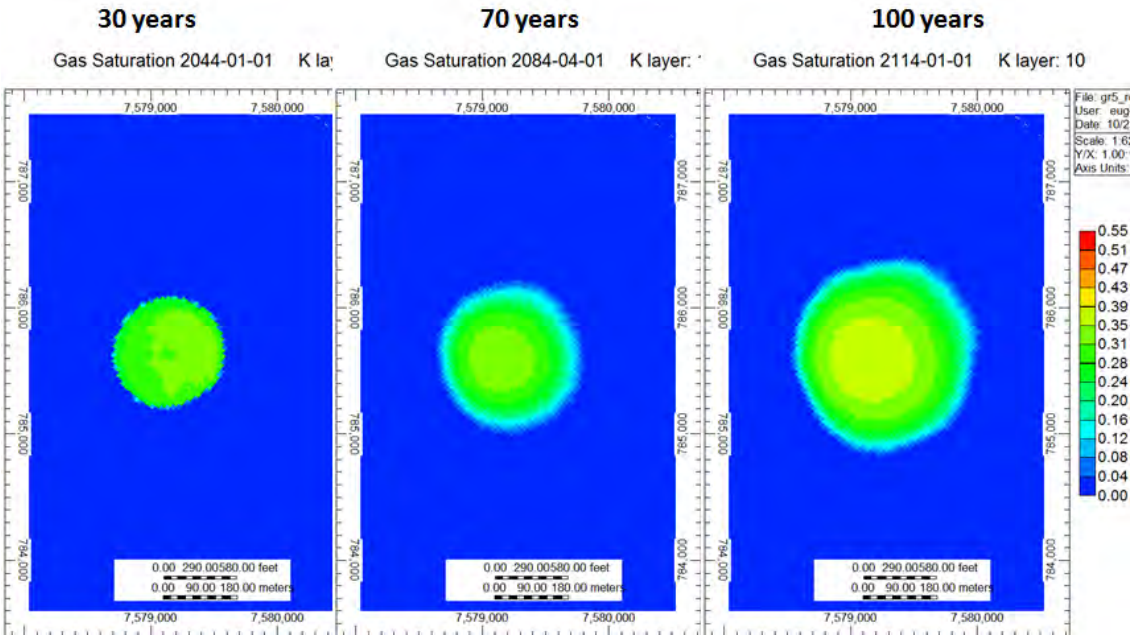


Figure 9b. Maximal horizontal extent of CO2 plume at 30 years, 70 years, and 100 years for the case with mid Arbuckle as a barrier.

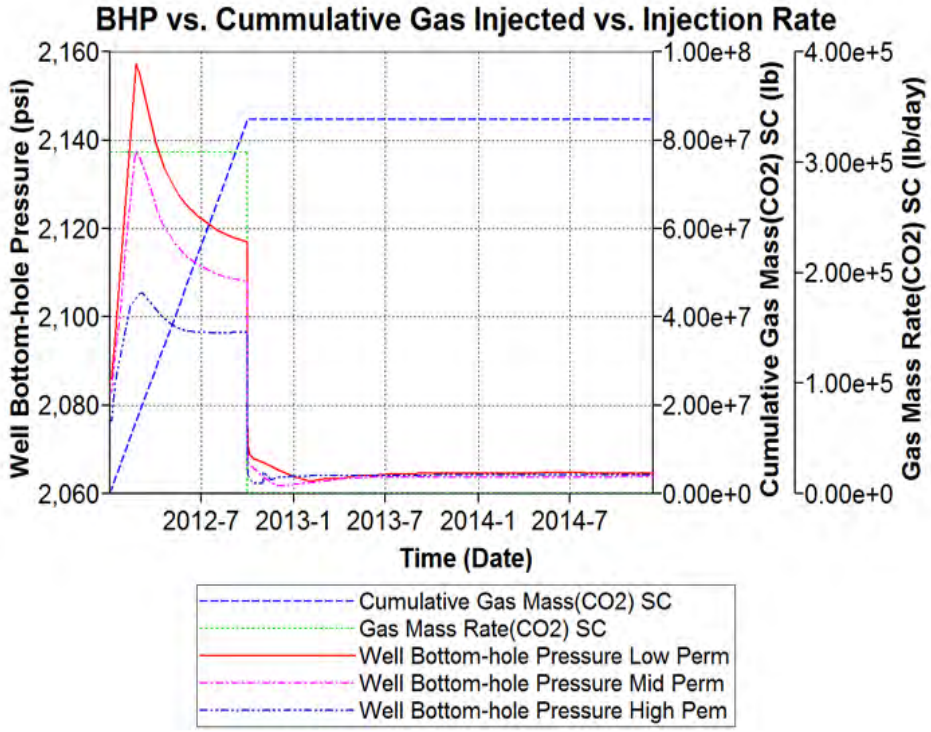


Figure 10. Well bottom-hole pressures for the low, medium, and high permeability cases.

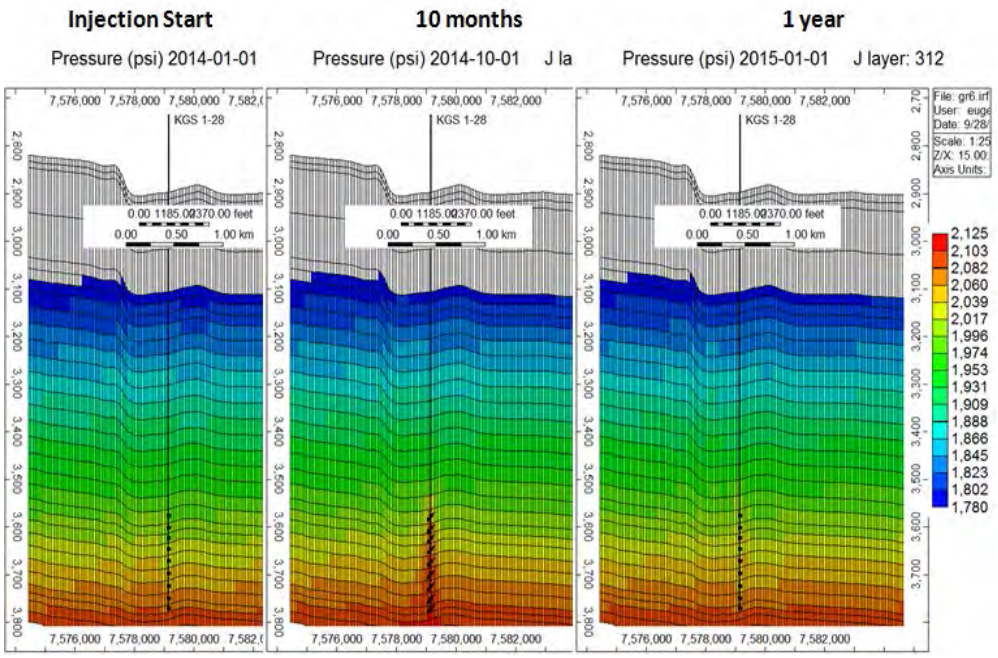


Figure 11. Vertical pressure profile at the start of injection, at 10 and 12 months

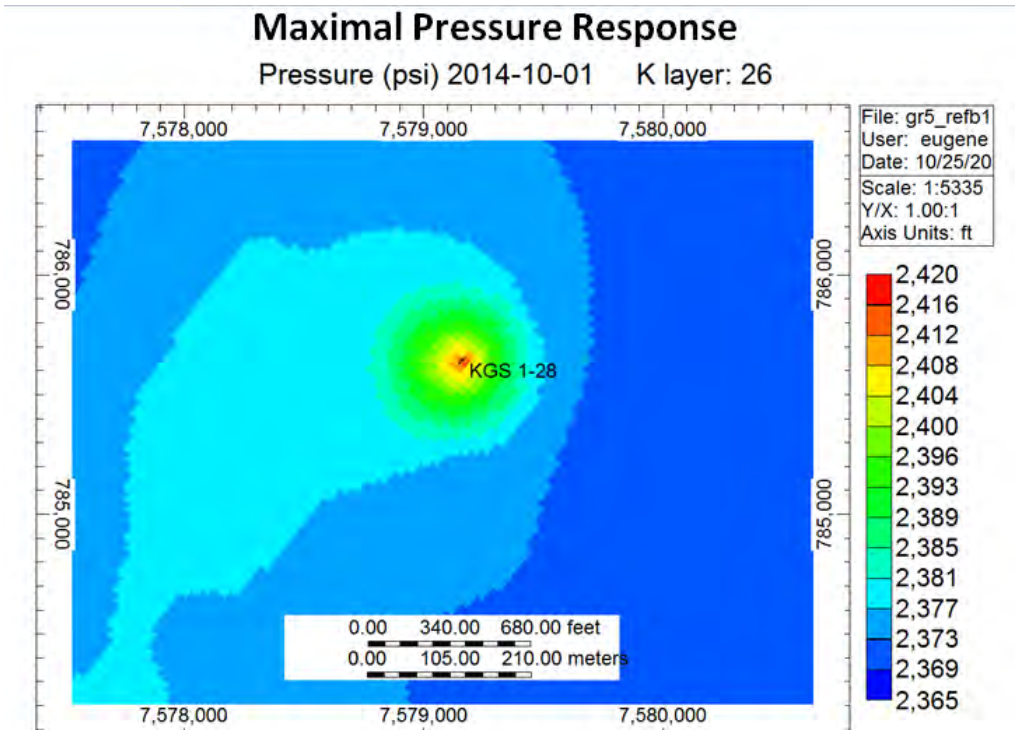


Figure 12. Maximal pressure response in the lower Arbuckle for an alternate case with lower permeability

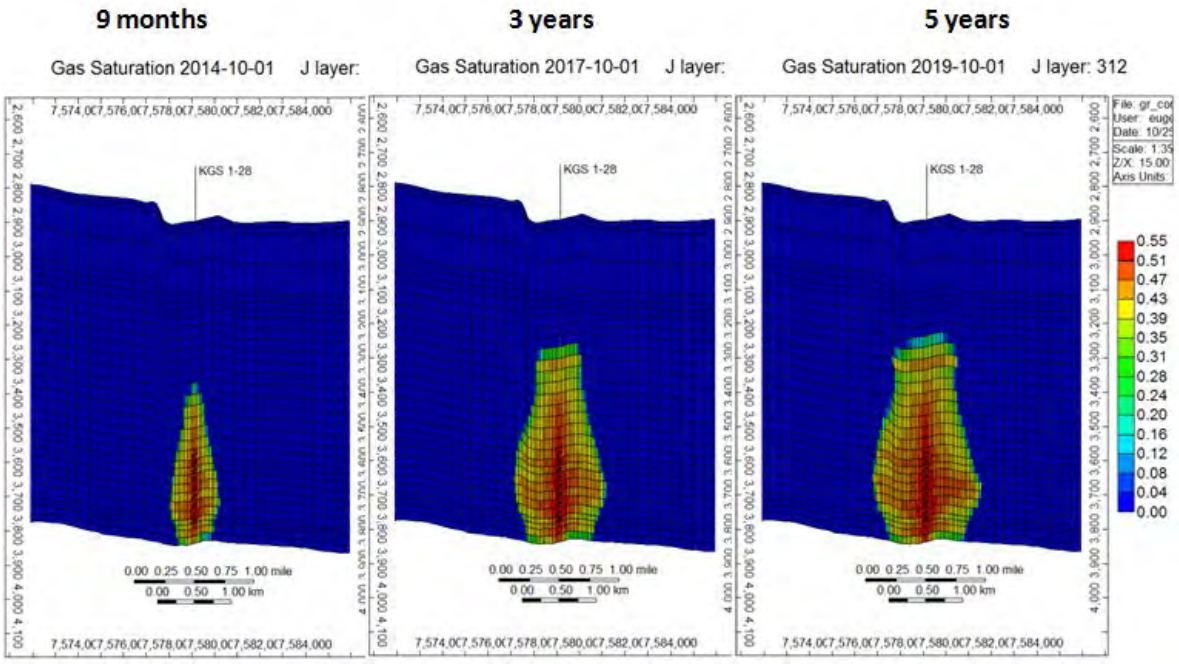


Figure 13a. Vertical distribution of CO2 saturation at 9 months, 3 years, and 5 years with commercial level injection rate of 14 MT over 15 years.

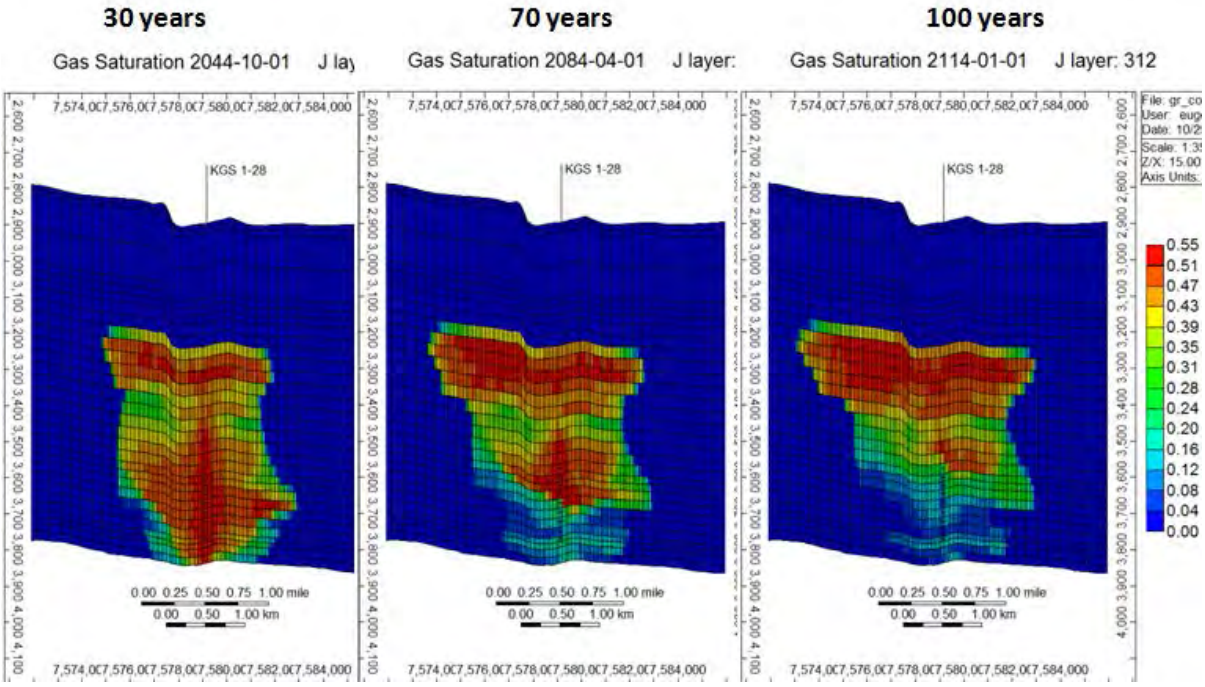


Figure 13b. Vertical distribution of CO2 saturation at 30, 70, and 100 years with commercial level injection rate of 14 MT over 15 years.

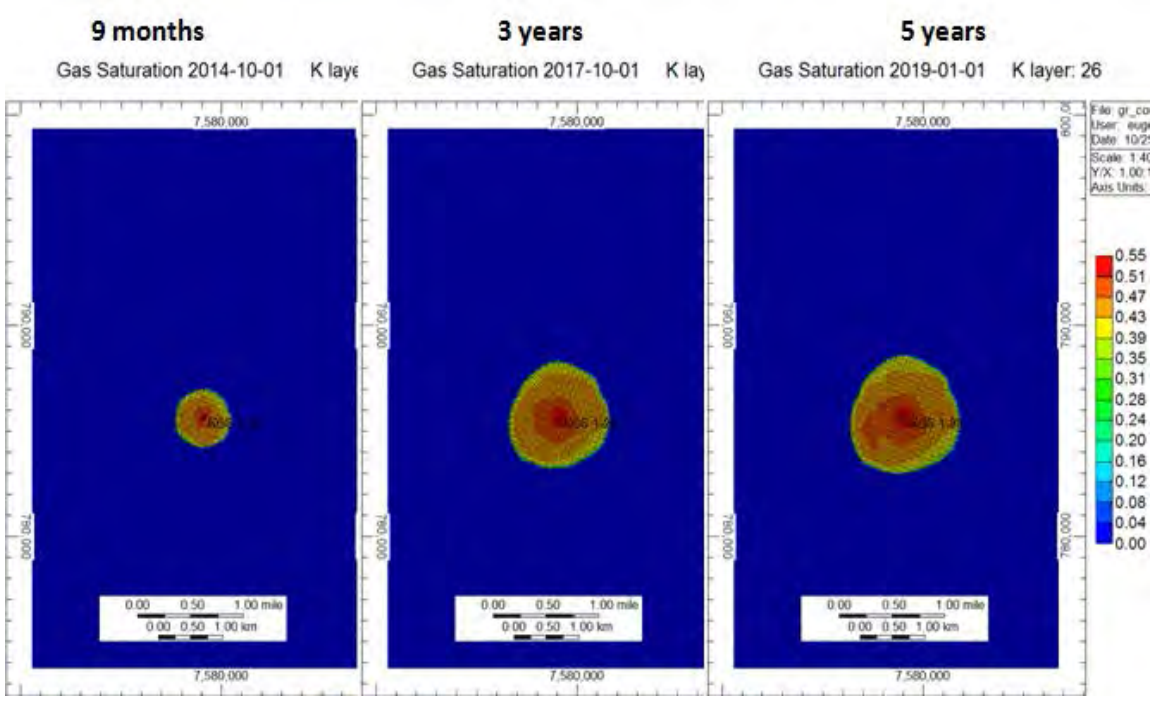


Figure 13c. Horizontal extent of the plume at 9 months, 3 years, and 5 years for the commercial level injection case.

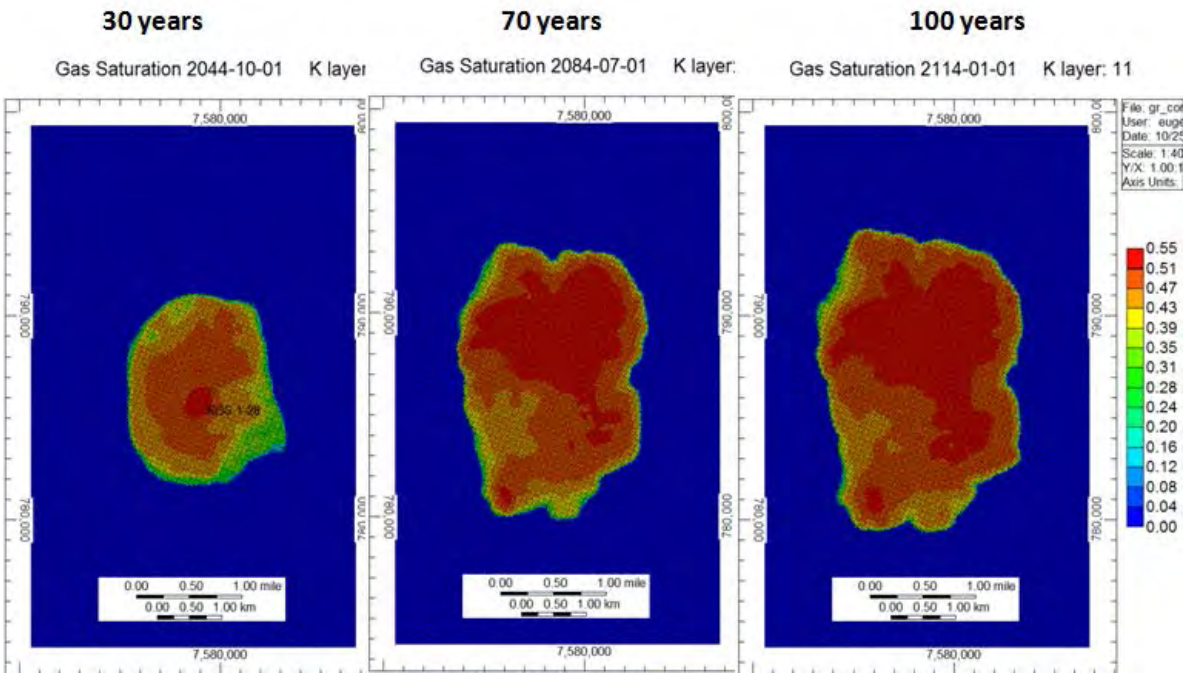


Figure 13d. Horizontal extent of the plume extent at 30, 70, and 100 years for the commercial level injection case.

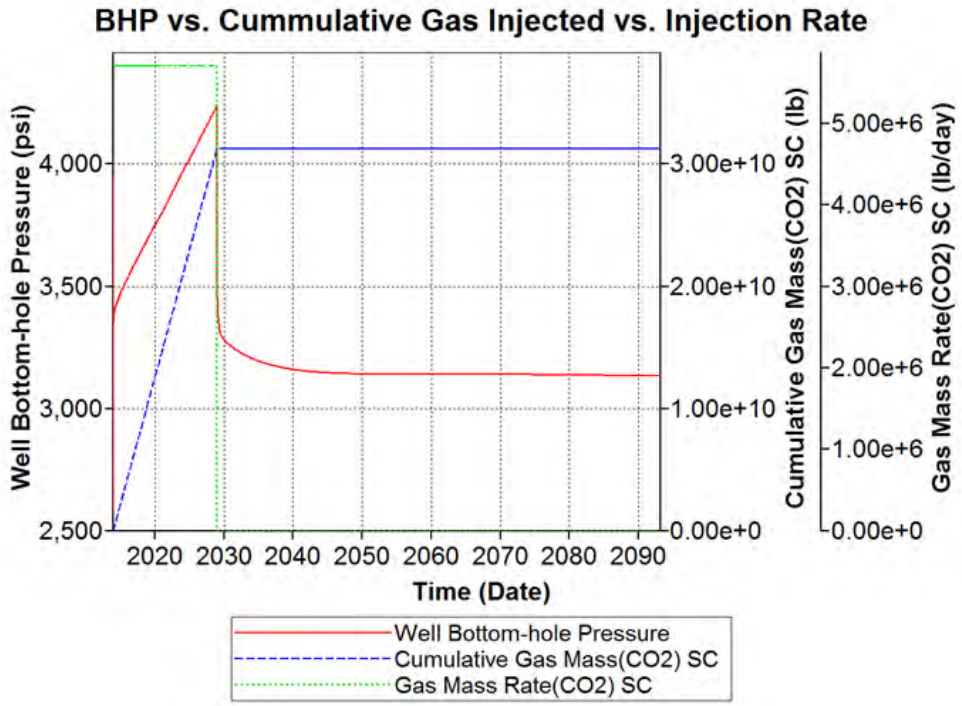


Figure 14. Bottomhole pressures for the commercial scale injection rate of 15 MT over 15 years.

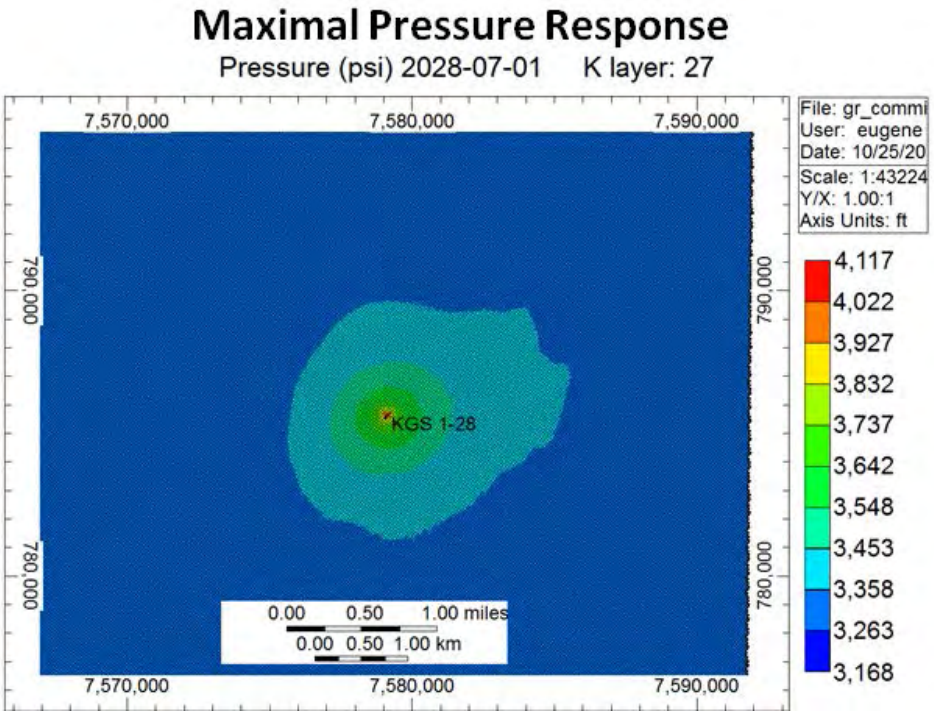


Figure 15. Maximal pressure response for commercial rate injection case

Geomechanical simulations were also conducted with the dynamic model in order to estimate the vertical displacement at the surface due to injection of CO2. The permeability distribution for this run is presented in Figure 15; which on based on the laboratory derived values of the geotechnical properties as shown in Figure 16. The vertical displacement at the end of the injection period is presented in Figure 17. Approximately 4 mm of vertical displacement is projected at the top of the Arbuckle.

The above simulations represent the initial set of runs derived from the Petrel geomodel. The following enhancements to the dynamic model are currently underway which will improve the predictive capabilities of the reservoir model and also strengthen the permit application:

- Develop dual porosity/permeability model
- Implement CO_2 Solubility
- Incorporate temperature effects and more detailed geomechanical modeling which consider scaling effects.

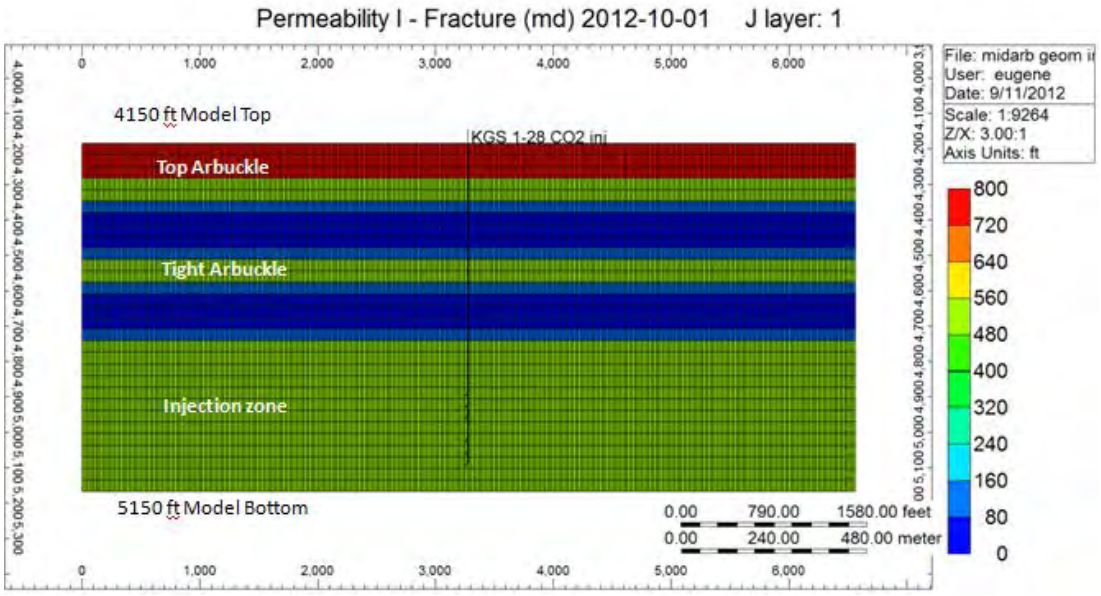


Figure 16. Hydraulic permeability distribution in geomechanical simulation model

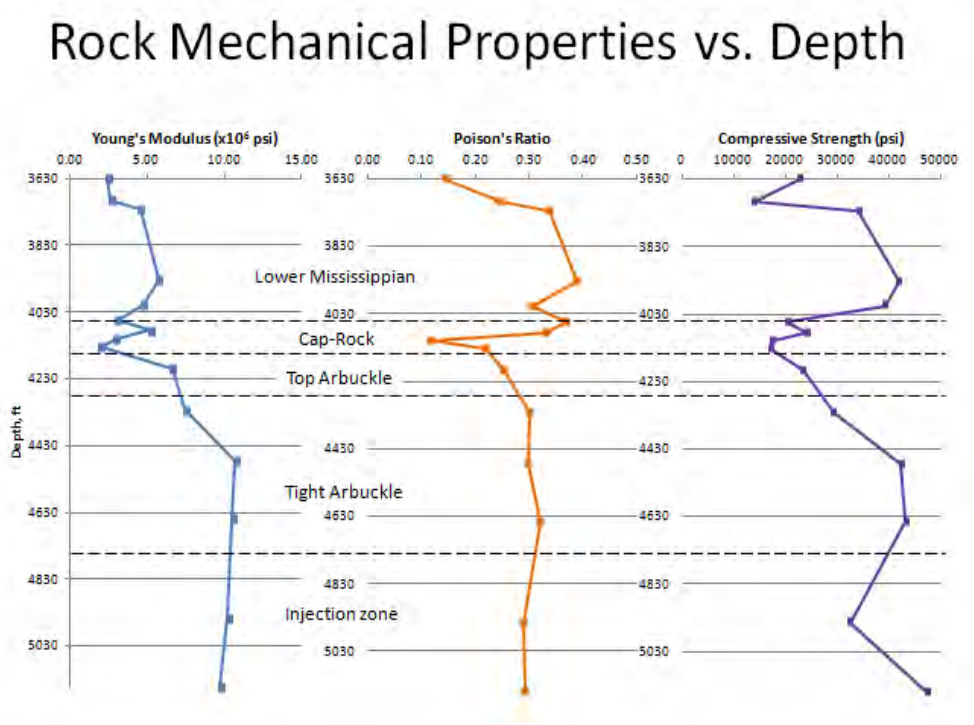


Figure 17. Laboratory derived geotechnical properties derived from core samples.

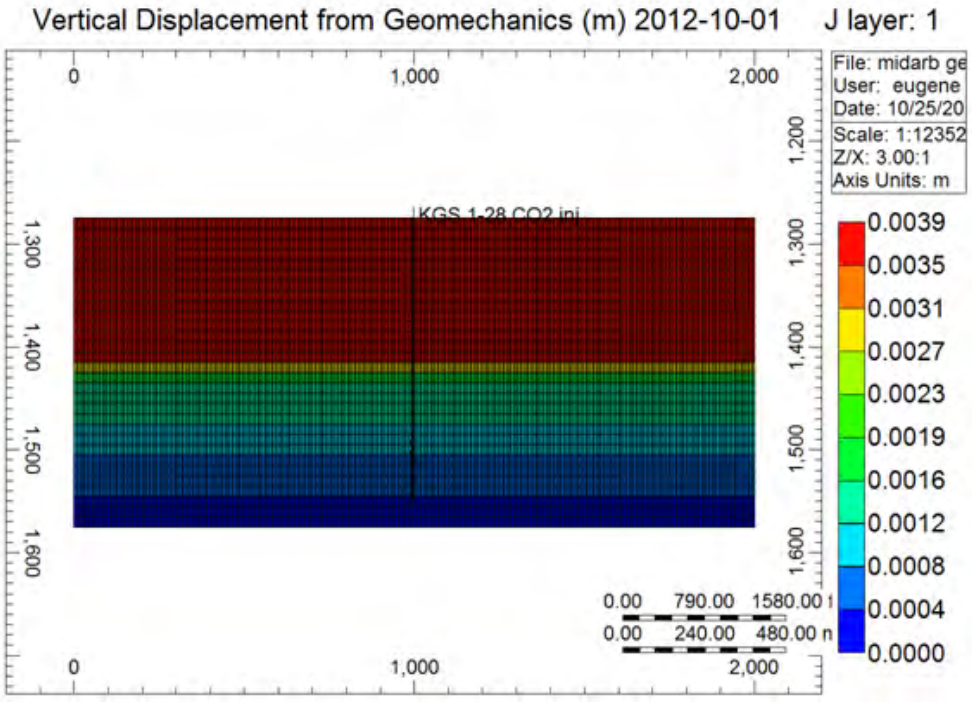


Figure 18. Simulated vertical displacement in the Arbuckle reservoir at the end of the (40 KT) injection period.

Key Findings

1. Significant progress made in compiling information and characterizing site for use in the application for Class VI CO2 injection permit in the Arbuckle.
2. Final revision of the geomodel and penultimate version of the simulation resulting in small CO2 plume footprint and low pressure.
3. Initial geomechanical modeling indicated small mm-scale deformation.

Plans

1. Top priority remains to finalize and submit application for Class VI injection permit to EPA with updated geomodel and simulation of the Arbuckle saline formation so that field activities can begin.

2. Submit updated management plan, well drilling and installation plan, MVA plan, Public Outreach Plan based on material included in Class VI application.

6. Submit Mississippian Injection Permit Application (Class II injection well under Kansas primacy, regulated by Kansas Corporation Commission) using updated geomodel and simulation of the Mississippian oil reservoir.

PRODUCTS

Publications, conference papers, and presentations

Scheffer, A.A., Gulliver, D., Roberts, J.A., Fowle, D., Watney, W.L., Doveton, J., Stotler, R., Whittemore, D., ms. in review, Geochemical, Microbiological, and Permeability Characteristics Indicating Vertical Zonation of the Arbuckle Saline Aquifer, a potential CO2 storage reservoir.

Barker, R., Watney, W., Rush, J., Strazisar, B., Scheffer, A., Bhattacharya, S., Wreath, D., and Datta, S*., in review, GEOCHEMICAL AND MINERALOGICAL CHARACTERIZATION OF THE ARBUCKLE AQUIFER: STUDYING MINERAL REACTIONS AND ITS IMPLICATIONS FOR CO2 SEQUESTRATION, , Chemical Geology.

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS:

A project organization chart follows. The work authorized in this budget period includes office tasks related to preparation of reports and application for a Class VI permit to inject CO2 into the Arbuckle saline aquifer. Tasks associated with reservoir characterization and modeling are funded in contract DE-FE0002056.

ORGANIZATION CHART

Name	Project Job Title	Primary Responsibility
	Kansas Geological Survey	
Lynn Watney	Project Leader, Joint Principal Investigator	Geology, information synthesis, point of contact
Yevhen Holubnyak	Petroleum Engineer	Reservoir engineer, dynamic modeling, synthesis
Jason Rush	Joint Principal Investigator	Geology, static modeling, data integration, synthesis
John Doveton	Co-Principal Investigator	Log petrophysics, geostatistics
Dave Newell	Co-Principal Investigator	Fluid geochemistry
Rick Miller	Geophysicist	2D seismic acquire & interpretation
		LiDAR/InSAR support, water well drilling/completion
TBN	Geology Technician	Assemble and analyze data, report writing
Tiraz Birdie	President, TBirdie Consulting, Inc.	Hydrogeologic modeling, permitting, MVA, integration
	KU Department of Geology	
Michael Taylor	Co-Principal Investigator	Structural Geology, analysis of InSAR, LiDAR, seismometer array
TBN	Graduate Research Assistant	Structural Geology, analysis of InSAR and LiDAR, seismometer array
	Kansas State Unversity	
Saugata Datta	Principal Investigator	
TBN	Graduate Research Assistant	Aqueous geochemistry
TBN	3- Undergraduate Research Assistants	
	Lawrence Berkeley National Laboratory	
Tom Daley	Co-Principal Investigator	Geophysicist, analysis of crosshole and CASSM data
		Hydrogeology, analysis of soil gas measurements
Barry Freifeld	Co-Principal Investigator	Mechanical Engineer, analysis of U-Tube sampler
	Sandia Technologies, Houston	
Dan Collins	Geologist	Manage CASSM and U-Tube operation
David Freeman	Field Engineer	Manage field install of CASSM and U-Tube
	Berexco, LLC	
Dana Wreath	VP Berexco, LLC	Engineering, Manager of Wellington Field
Randy Koudele	Reservoir engineer	Engineering
Staff of Wellington Field		Field operations
Beredco Drilling team		Mississippian and Arbuckle drilling operations
	Abengoa Bioenergy Corp.	
Christopher Standlee, Danny Alllison		CO2 supply Colwich Ethanol Facility

IMPACT

The project has been discussed in public venues – presentations at professional meetings, legislative committees, and town hall meeting, and has provided information on the project via the website to encourage a dialog on the merits and economies related to carbon management in Kansas. Kansans are realizing the potential for an important collaboration between the two of the largest economies in Kansas – agriculture and related ethanol industry and the petroleum industry to advance energy and contribute to a viable rural economy.

The small scale field test at Wellington Field as designed integrates two petroleum business activities: 1) use of CO2 for enhanced oil recovery and revitalizing many older mature oil fields and 2) disposal/storage of CO2 in the underlying saline aquifer for the longer term. It has been conveyed to the local petroleum industry that drilling and oil production infrastructure of an active oil field are important components that could lead to a successful carbon sequestration project including 1) knowledge about the subsurface including injection zones and caprock, 2) knowledge about abandoned wells, 3) access and suitability of land with greater likelihood for participation by landowner, and 4) access to insurance and investors to facilitate economic success.

CHANGES/PROBLEMS

Geomodels and simulations have led to revisions in the CO2 plume and determination of the AOR. The consensus of the team is that we have reached the goal of developing a predictive model to include in the Class VI injection application.

The CO2 source at Colwich Ethanol facility has proven to be susceptible to the exception drought that has gripped the Midcontinent. Although it the opinion of the partners, alternative sources of CO2 will be sought to ensure that BP2 starts on October 1, 2013.

APPENDIX II

Small Scale Field Test Demonstrating CO_2 Sequestration in Arbuckle Saline Aquifer and by CO_2-EOR at Wellington Field, Sumner County, Kansas

FIFTH QUARTERLY PROGRESS REPORT

DOE F 4600.2
(03/11)
All Other Editions Are Obsolete

U.S. Department of Energy
FEDERAL ASSISTANCE REPORTING CHECKLIST
AND INSTRUCTIONS FOR RD&D PROJECTS

1. Identification Number: **DE-FE0006821**	2. Program/Project Title: **Small Scale Field Test Demonstration CO2 Sequestration**
3. Recipient: **University of Kansas Center for Research, Inc.**	

4. Reporting Requirements:	Frequency	Addressees
A. MANAGEMENT REPORTING		
☒ Research Performance Progress Report (RPPR)	Q	FITS@NETL.DOE.GOV
☒ Special Status Report	A	FITS@NETL.DOE.GOV
B. SCIENTIFIC/TECHNICAL REPORTING		
(Reports/Products must be submitted with appropriate DOE F 241. The 241 forms are available at www.osti.gov/elink)		
Report/Product — Form		
☒ Final Scientific/Technical Report — DOE F 241.3	FG	http://www.osti.gov/elink-2413
☒ Conference papers/proceedings* — DOE F 241.3	A	http://www.osti.gov/elink-2413
☐ Software/Manual — DOE F 241.4		
☐ Other (see special instructions) — DOE F 241.3		
** Scientific and technical conferences only*		
C. FINANCIAL REPORTING		FITS@NETL.DOE.GOV
☒ SF-425 Federal Financial Report	Q, FG	
D. CLOSEOUT REPORTING		
☒ Patent Certification	FC	FITS@NETL.DOE.GOV
☒ SF-428 & 428B Final Property Report	FC	FITS@NETL.DOE.GOV
☐ Other		
E. OTHER REPORTING		See block 5 below for instructions.
☒ Annual Indirect Cost Proposal	O	
☐ Audit of For-Profit Recipients		
☒ SF-428 Tangible Personal Property Report Forms Family	A	FITS@NETL.DOE.GOV
☒ Other – see block 5 below	A	FITS@NETL.DOE.GOV

FREQUENCY CODES AND DUE DATES:

A - Within 5 calendar days after events or as specified.
FG- Final; 90 calendar days after the project period ends.
FC- Final; End of Effort.
Y - Yearly; 90 calendar days after the end of the reporting period.
S - Semiannually; within 30 calendar days after end of project year and project half-year.
Q - Quarterly; within 30 days after end of the reporting period.
Y180 – Yearly; 180 days after the end of the recipient's fiscal year
O - Other; See instructions for further details.

5. Special Instructions:

Annual Indirect Cost Proposal – If DOE is the Cognizant Federal Agency, then the proposal should be sent to FITS@NETL.DOE.GOV . Otherwise, it should be sent to the Cognizant Federal Agency.

Other – The Recipient shall provide all deliverables as contained in Section D of Attachment 2 Statement of Project Objectives.

QUARTERLY PROGRESS REPORT
To
DOE-NETL
Brian Dressel, Program Manager
Award Number: DE-FE0006821

SMALL SCALE FIELD TEST DEMONSTRATING CO_2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO_2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS

Project Director/Principal Investigator:
W. Lynn Watney
Senior Scientific Fellow
Kansas Geological Survey

Ph: 785-864-2184, Fax: 785-864-5317
lwatney@kgs.ku.edu

Joint Principal Investigator:
Jason Rush

Date of Report: January 31, 2013

DUNS Number: 076248616

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

Project/Grant Period: 10/1/2011 through 9/30/2015

Fifth Quarterly Report

Period Covered by the Report: October 1, 2012 through December 31, 2012

Signature of Submitting Official:

Willard Lynn Watney

Digitally signed by Willard Lynn Watney
DN: cn=Willard Lynn Watney, o=The University of Kansas, ou=Kansas Geological Survey, email=lwatney@kgs.ku.edu, c=US
Date: 2013.02.01 14:53:21 -06'00'

EXECUTIVE SUMMARY

Project Objectives

The objectives of this project are: (1) inject under supercritical conditions approximately 40,000 metric tons of CO_2 into the Arbuckle saline aquifer; (2) demonstrate the application of state-of-the-art MVA (monitoring, verification, and accounting) tools and techniques to monitor and visualize the injected CO_2 plume; (3) develop a robust Arbuckle geomodel by integrating data collected from the proposed study area, and a multi-component 3D seismic survey; (4) conduct reservoir simulation studies to map CO_2 plume dispersal and estimate tonnage of CO_2 sequestered in solution, as residual gas and by mineralization; (5) integrate MVA data and analysis with reservoir modeling studies to detect CO_2 leakage and to validate the simulation model; (6) develop a rapid-response mitigation plan to minimize CO_2 leakage and a comprehensive risk management strategy; and (7) establish best practice methodologies for MVA and closure. Additionally, approximately 30,000 metric tons of CO_2 shall be injected into the overlying Mississippian to evaluate miscible CO_2-EOR potential in a 5-spot pilot pattern. The CO_2 shall be supplied from the Abengoa Bioenergy ethanol plant at Colwich, Kansas who has operated the facility since 1982 demonstrating reliability and capability to provide an adequate stream and quality of CO_2. The project shall install compression, chilling, and transport facilities at the ethanol plant for truck transport to the injection site.

Project Goals

The proposed small scale injection will advance the science and practice of carbon sequestration in the Midcontinent by refining characterization and modeling, evaluating best practices for MVA tailored to the geologic setting, optimize methods for remediation and risk management, and provide technical information and training to enable additional projects and facilitate discussions on issues of liability and risk management for operators, regulators, and policy makers.

The data gathered as part of this research effort and pilot study will be shared with the Southwest Sequestration Partnership (SWP) and integrated into the National Carbon Sequestration Database and Geographic Information System (NATCARB) and the 6th Edition of the Carbon Sequestration Atlas of the United States and Canada.

Project Deliverables by Task

1.5 Well Drilling and Installation Plan (Can be Appendix to PMP or Quarterly Report)
1.6 MVA Plan (Can be Appendix to PMP or Quarterly Report)
1.7 Public Outreach Plan (Can be Appendix to PMP)
1.8 Arbuckle Injection Permit Application Review go/no go Memo
1.9 Mississippian Injection Permit Application Review go/no go Memo

1.10 Site Development, Operations, and Closure Plan (Can be Appendix to PMP)
2.0 Suitable geology for Injection Arbuckle go/no go Memo
3.0 Suitable geology for Injection Mississippian go/no go Memo
11.2 Capture and Compression Design and Cost Evaluation go/no go Memo
19 Updated Site Characterization/Conceptual Models (Can be Appendix to Quarterly Report)
21 Commercialization Plan (Can be Appendix to Quarterly Report).
30 Best Practices Plan (Can be Appendix to Quarterly or Final Report)

ACCOMPLISHMENTS

1. **Completed Milestone 1 (Task 2)** -- Site Characterization of Arbuckle Saline Aquifer System - Wellington Field.
2. **Significant progress and nearing completion of Milestone 2 (Task 3) --** Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field
3. **Subtask 1.8 Arbuckle Injection Permit Application** – The permit application consists of 15 chapters (sections). The completion status for each section, along with the remaining tasks is described in Table 1 below. The first draft of each section has been completed. The process involved aggregating information from many investigators/specialists into a coherent document which summarizes the suitability of the Wellington site for conducting not only the small-scale pilot test, but potentially for long-term commercial scale carbon capture and sequestration (CCS).

Milestone Status Report

Task	Budget Period	Number	Milestone Description
Task 2.	1	1	Site Characterization of Arbuckle Saline Aquifer System - Wellington Field
Task 3.	1	2	Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field
Task 10.	2	3	Pre-injection MVA - establish background (baseline) readings
Task 13.	2	4	Retrofit Arbuckle Injection Well (#1-28) for MVA Tool Installation
Task 18.	3-yr1	5	Compare Simulation Results with MVA Data and Analysis and Submit Update of Site Characterization, Modeling, and Monitoring Plan
Task 22.	3-yr1	6	Recondition Mississippian Boreholes Around Mississippian CO2-EOR injector
Task 27.	3-yr2	7	Evaluate CO2 Sequestration Potential of CO2-EOR Pilot
Task 28.	3-yr2	8	Evaluate Potential of Incremental Oil Recovery and CO2 Sequestration by CO2-EOR - Wellington field

Project Schedule

Abengoa Biofuels informed us in mid August 2012 that the Colwich Ethanol Facility would be shut down for one year because of the severe drought in the Midwest. The dry weather severely impacted their dryland feedstock base (mainly milo and sorghum) and the resulting high grain prices. The facility will remains closed until the next harvest. Abengoa, DOE, and partners agreed that the plant reopening will be revisited on October 1, 2013 after the next harvest cycle to determine if they will reopen. During DOE site visit in September 2012, Abengoa official gave us a tour of the ethanol plant and relayed that every effort is being taken to keep the plant in a condition so that it can be reopened next year.

A request was made and DOE extended Budget Period 1 for an additional year at no cost until October 1, 2013. The project will make every effort to evaluate alternative sources, but as yet the

economics are not close to meeting the arrangements made with Abengoa and the Colwich ethanol facility. Both Abengoa and Berexco, the oil field industry partner, are committed to working with each other to link the ethanol-based CO2 with oil field operations in the area.

Geologic CO2 will not be part with the Kansas market due to demand along existing pipelines in Texas, New Mexico, Colorado, and Wyoming. Anthropogenic is the only viable source to provide the CO2 needed for CO2-EOR. Both Abengoa and Berexco are keenly interested in the saline aquifer storage in order to obtain enhanced prices for ethanol, obtain deposal fees, and with the case at Wellington, the income generated by carbon trading through Biorecro in Sweden.

The KGS is committed to starting injection at the Wellington site in the first quarter of FY2014. Therefore, contacts were made with alternative anthropogenic CO2 producers to supply the source in the event that the Abengoa plant remains shut indefinitely. The suppliers include Airgas and FloCO2, and each have indicated an ability to provide CO2 in the event of continued shutdown of the Abengoa facility. Other options are being investigated.

The Class VI permit application documented is expected to be completed in February 2013. Construction of monitoring wells and installation of monitoring equipment will commence on approval of the permit.

A condensed version of the Gantt Chart tracks tasks based on the one year no cost extension of Budget Period 1 (Figure 1).

Activities of Lawrence Berkeley National Lab

No work has been completed or funds expended during this quarter by LBNL.

ONGOING ACTIVITIES –

TASK 1. PROJECT MANAGEMENT AND REPORTING

Permit Status and Activities

As of January 2013, the first draft of all permit sections has been completed. KGS graphics and GIS personnel are working on completing the figures for the application report. A few sections have minor tasks outstanding as indicated and explained in Table 1. The goal is to finalize the sections for internal and external review in February 2013; after which the application will be submitted to EPA. KGS will seek a permit kickoff meeting with EPA in order to expedite the review process. The contents of each section will be summarized and presented in Power Point

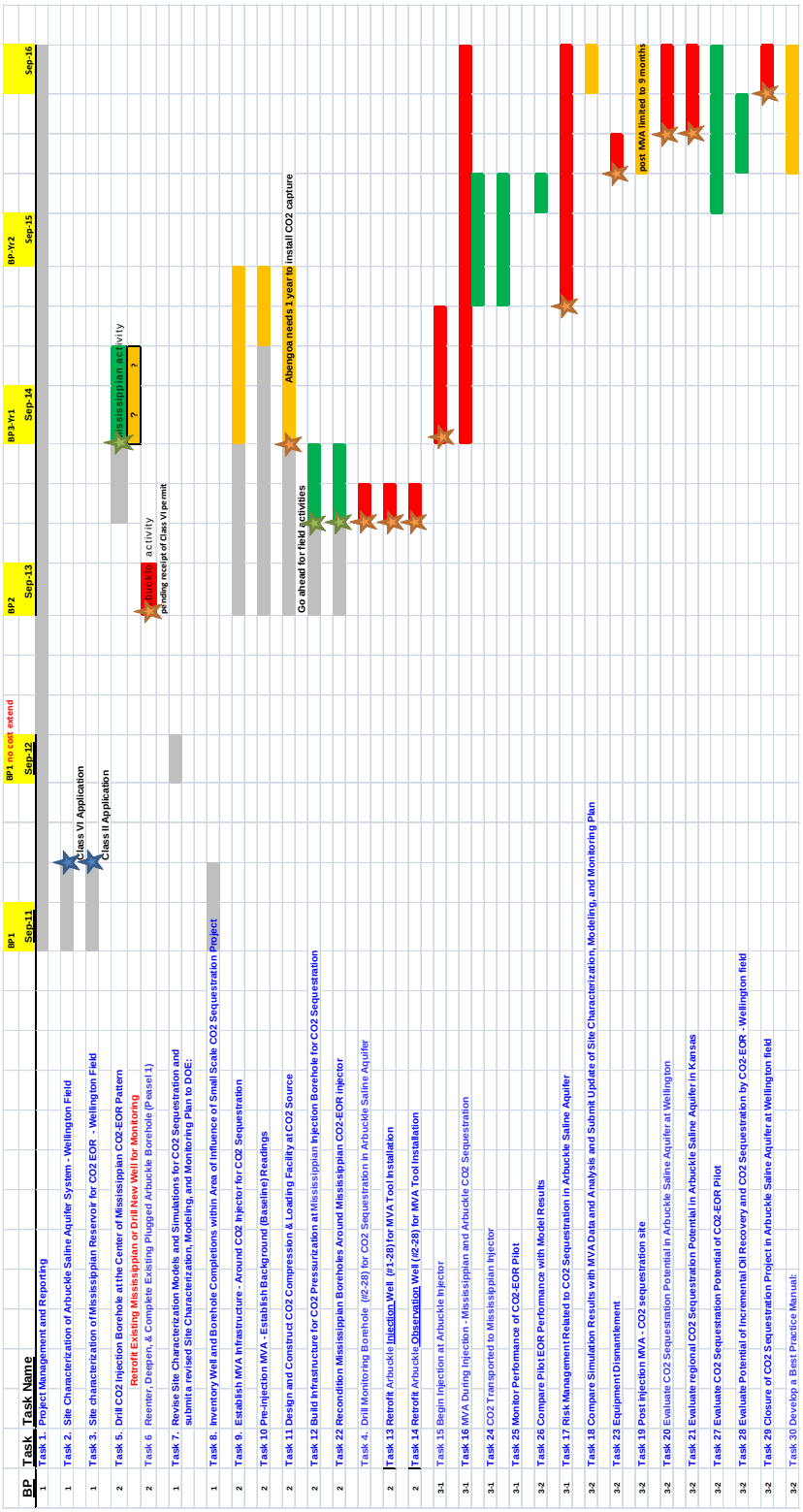

BP
Task
Task Name
BP1
Sep-11
BP1 no cost extend
Sep-12
BP2
Sep-13
BP3-Yr1
Sep-14
BP-Yr2
Sep-15
Sep-16
1 Task 1: Project Management and Reporting
1 Task 2: Site Characterization of Arbuckle Saline Aquifer System - Wellington Field
Class VI Application
1 Task 3: Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field
Class II Application
2 Task 5: Drill CO2 Injection Borehole at the Center of Mississippian CO2-EOR Pattern
Retrofit Existing Mississippian or Drill New Well for Monitoring
Mississippian activity
? ?
2 Task 6 Reenter, Deepen, & Complete Existing Plugged Arbuckle Borehole (Passel 1)
Arbuckle activity
pending receipt of Class VI permit
1 Task 7: Revise Site Characterization Models and Simulations for CO2 Sequestration and submit a revised Site Characterization, Modeling, and Monitoring Plan to DOE:
1 Task 8: Inventory Well and Borehole Completions within Area of Influence of Small Scale CO2 Sequestration Project
2 Task 9: Establish MVA Infrastructure - Around CO2 Injector for CO2 Sequestration
2 Task 10 Pre-injection MVA - Establish Background (Baseline) Readings
2 Task 11 Design and Construct CO2 Compression & Loading Facility at CO2 Source
Abengoa needs 1 year to install CO2 capture
2 Task 12 Build Infrastructure for CO2 Pressurization at Mississippian Injection Borehole for CO2 Sequestration
Go ahead for field activities
2 Task 22 Recondition Mississippian Boreholes Around Mississippian CO2-EOR injector
Task 4: Drill Monitoring Borehole (#2-28) for CO2 Sequestration in Arbuckle Saline Aquifer
2 Task 13 Retrofit Arbuckle Injection Well (#1-28) for MVA Tool Installation
2 Task 14 Retrofit Arbuckle Observation Well (#2-28) for MVA Tool Installation
3-1 Task 15 Begin Injection at Arbuckle Injector
3-1 Task 16 MVA During Injection - Mississippian and Arbuckle CO2 Sequestration
3-1 Task 24 CO2 Transported to Mississippian Injector
3-1 Task 25 Monitor Performance of CO2-EOR Pilot
3-2 Task 26 Compare Pilot EOR Performance with Model Results
3-1 Task 17 Risk Management Related to CO2 Sequestration in Arbuckle Saline Aquifer
3-2 Task 18 Compare Simulation Results with MVA Data and Analysis and Submit Update of Site Characterization, Modeling, and Monitoring Plan
3-2 Task 23 Equipment Dismantlement
post MVA limited to 9 months
3-2 Task 19 Post injection MVA - CO2 sequestration site
3-2 Task 20 Evaluate CO2 Sequestration Potential in Arbuckle Saline Aquifer at Wellington
3-2 Task 21 Evaluate regional CO2 Sequestration Potential in Arbuckle Saline Aquifer in Kansas
3-2 Task 27 Evaluate CO2 Sequestration Potential of CO2-EOR Pilot
3-2 Task 28 Evaluate Potential of Incremental Oil Recovery and CO2 Sequestration by CO2-EOR : Wellington field
3-2 Task 29 Closure of CO2 Sequestration Project in Arbuckle Saline Aquifer at Wellington field
3-2 Task 30 Develop a Best Practice Manual:

Figure 1. Condensed version of the project Gantt Chart.

format, which will provide the reviewer's an opportunity to better understand the application contents and seek technical clarification.

Table 1 Status of Class VI permit application

Section	Percent Complete	Remaining Tasks
Project Overview	**95%**	GIS and graphics personnel working on finalizing figures.
Local Scale Geologic and Hydrolgeologic Background	**90%**	Need to incorporate Chattanooga shale analyses conducted by Mina Fazelalawi to demonstrate the presence of competent caprock.
Regional Scale Geologic and Hydrogeologic Background	**95%**	GIS and graphics personnel working on finalizing figures.
Geologic Sequestration of Carbon Dioxide	**95%**	GIS and graphics personnel working on finalizing figures.
Flow and Transport Model Simulations and AOR Delineation	**85%**	Eugene revising model in order utilize Simpson and Chattanooga shale as caprock, and also to incorporate variations in vertical anisotropy and dispersion/diffusion. GIS and graphics personnel working to work on finalizing figures.
Potential Capture in Depleted Mississippian Formation	**90%**	Paul Gerlach may potentially add a map showing how extensively the Mississippian is under pressurized in Sumner County. GIS and graphics personnel working on finalizing figures.
Geomechanical Stability Investigations	**95%**	GIS and graphics personnel working on finalizing figures.
Injection Well Design	**90%**	GIS and graphics personnel working on finalizing figures. Tiraz Birdie to add discussion on type of cement information forwarded by Dana.

Monitoring Well Design	**80%**	GIS and graphics personnel working on finalizing figures. Tiraz Birdie to add some discussion on type of cement information forwarded by Dana, and the proposed well 2-28.
Site Operations	**75%**	A draft has been completed assuming that liquid CO2 will be injected at 250 psi and -10F. Wellbore simulations are being conducted to determine if these surface operating conditions will function effectively. Also, discussions are being conducted with infrastructure suppliers to design surface facilities.
Monitoring Verification and Accounting Activities	**90%**	GIS and graphics personnel to work on finalizing figures. Awaiting write up from Sugata on groundwater chemistry monitoring.
Post Injection Site Care	**90%**	First draft complete. Awaiting final modeling results to specify closure time frame.
Site Closure	**95%**	Final writeup after completing modeling section
Risk Management and Mitigation Plan	**90%**	Need to describe automatic shutdown system after finalizing surface facilities plans. Need to ensure that onsite Programmable Logic Controller or computer can implement a shutdown plan.
Financial Assurances	**70%**	Draft complete. Berexco to provide P&L, balance sheet, and cash flow metrics. Berexco to also complete cost estimates for closure and monitoring activities.

The bulk of the efforts in first quarter of FY 2013 were expended towards finalizing the draft of the of the permit application. This involved:

- Compiling background information on the regional hydrogeology,
- Synthesizing the numerous physical, chemical, and biological data sets acquired during drilling of wells 1-32 and 1-28, and utilizing the same to develop a conceptual model of the stratification within the Arbuckle aquifer and characterizing the overlying formations,
- Establishing the EPA Area of Review,
- Conducting flow and transport simulations in order to determine the eventual fate of the CO2,

- Compiling historical information on oil and gas development in Kansas and documentation the resulting under pressurization in the Mississippian reservoir, which will serve as a trap for any CO2 that may potentially escape from the caprock or faults,
- Developing geomechanical approaches to quantatively demonstrate that the caprock and formation integrity will not be compromised due to injection,
- Developing write up on Nuclear Magentic Resonance to communicate the strength of the technique for characterizing geologic formations,
- Documenting procedure for integrating seismic data and geophysical data in Petrel and eventually upscaling in the CMG reservoir model.
- Conducting discussions with Joe Tiago (EPA contact for financial aspects of Class VI wells) in order to ensure proper compilation and reporting of financial information to demonstrate strength of Berexco for undertaking sequestration activities,
- Demonstrating to EPA that the construction practices, materials utilized, and design of wells KGS 1-28 and 1-32 are in accordance with the Class VI specifications.

Key Findings

1. Geomechanical analyses indicates that it will be virtually impossible to encounter stress related failure along existing fracture and fault planes due to CO2 injection.

2. Reservoir simulation results indicate that the pressure front will dissipate very rapidly after cessation of injection. The plume is expected to stabilize within three years of cessation of injection; coinciding with the end of the DOE funding. This conclusion is significant as it provides support for a request to the EPA to waive the default 50-year monitoring period after cessation of pumpage. The site operator, Berexco, had previously expressed concern regarding carrying liability beyond the 5-year project period.

3. Significant amount of time was spent in the 5th quarter to determine the optimal CO2 phase and temperature-pressure combination for injecting CO2 at the site. While the analyses and final design of the injection facilities is still being conducted, the findings

point to suitability of injecting in the liquid state. A consequence of injecting in the liquid state is rapid infiltration of the CO2 into the formation. This may result in the need to inject CO2 for a few hours each day rather than injecting continuously. The details of the injecting facilities and operating parameters (pressure/temperature) are currently being established.

Plans

1. Top priority remains to finalize and submit application for Class VI injection permit to the EPA in February 2013. A day long permit kickoff meeting is to be requested with the EPA in order to communicate the project findings and contents of the permit document to EPA reviewers, and provide them an opportunity to ask questions/seek clarification. This will expedite the EPA review process. On obtaining the permit, field activities shall commence in conjunction with construction of new monitoring wells, and deepening of the existing Peasel well.

2. Submit updated management plan, well drilling and installation plan, MVA plan, Public Outreach Plan based on material included in Class VI application.

3. Submit Mississippian Injection Permit Application (Class II injection well under Kansas primacy, regulated by Kansas Corporation Commission) using updated geomodel and simulation of the Mississippian oil reservoir.

PRODUCTS

Publications, conference papers, and presentations

Scheffer, A.A., Gulliver, D., Roberts, J.A., Fowle, D., Watney, W.L., Doveton, J., Stotler, R., Whittemore, D., ms. in review, Geochemical, Microbiological, and Permeability Characteristics Indicating Vertical Zonation of the Arbuckle Saline Aquifer, a potential CO2 storage reservoir.

Barker, R., Watney, W., Rush, J., Strazisar, B., Scheffer, A., Bhattacharya, S., Wreath, D., and Datta, S*., in review, GEOCHEMICAL AND MINERALOGICAL CHARACTERIZATION OF THE ARBUCKLE AQUIFER: STUDYING MINERAL REACTIONS AND ITS IMPLICATIONS FOR CO2 SEQUESTRATION, , Chemical Geology.

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS:

A project organization chart follows. The work authorized in this budget period includes office tasks related to preparation of reports and application for a Class VI permit to inject CO2 into the Arbuckle saline aquifer. Tasks associated with reservoir characterization and modeling are funded in contract DE-FE0002056.

ORGANIZATION CHART

Name	Project Job Title	Primary Responsibility
Kansas Geological Survey		
Lynn Watney	Project Leader, Joint Principal Investigator	Geology, information synthesis, point of contact
Yevhen Holubnyak	Petroleum Engineer	Reservoir engineer, dynamic modeling, synthesis
Jason Rush	Joint Principal Investigator	Geology, static modeling, data integration, synthesis
John Doveton	Co-Principal Investigator	Log petrophysics, geostatistics
Dave Newell	Co-Principal Investigator	Fluid geochemistry
Rick Miller	Geophysicist	2D seismic acquire & interpretation
		LiDAR/InSAR support, water well drilling/completion
TBN	Geology Technician	Assemble and analyze data, report writing
Tiraz Birdie	President, TBirdie Consulting, Inc.	Hydrogeologic modeling, permitting, MVA, integration
KU Department of Geology		
Michael Taylor	Co-Principal Investigator	Structural Geology, analysis of InSAR, LiDAR, seismometer array
TBN	Graduate Research Assistant	Structural Geology, analysis of InSAR and LiDAR, seismometer array
Kansas State Unversity		
Saugata Datta	Principal Investigator	
TBN	Graduate Research Assistant	Aqueous geochemistry
TBN	3- Undergraduate Research Assistants	
Lawrence Berkeley National Laboratory		
Tom Daley	Co-Principal Investigator	Geophysicist, analysis of crosshole and CASSM data
		Hydrogeology, analysis of soil gas measurements
Barry Freifeld	Co-Principal Investigator	Mechanical Engineer, analysis of U-Tube sampler
Sandia Technologies, Houston		
Dan Collins	Geologist	Manage CASSM and U-Tube operation
David Freeman	Field Engineer	Manage field install of CASSM and U-Tube
Berexco, LLC		
Dana Wreath	VP Berexco, LLC	Engineering, Manager of Wellington Field
Randy Koudele	Reservoir engineer	Engineering
Staff of Wellington Field		Field operations
Beredco Drilling team		Mississippian and Arbuckle drilling operations
Abengoa Bioenergy Corp.		
Christopher Standlee, Danny Alllison		CO2 supply Colwich Ethanol Facility

IMPACT

The project has been discussed in public venues – presentations at professional meetings, legislative committees, and town hall meeting, and has provided information on the project via the website to encourage a dialog on the merits and economies related to carbon management in Kansas. Kansans are realizing the potential for an important collaboration between the two of the largest economies in Kansas – agriculture and related ethanol industry and the petroleum industry to advance energy and contribute to a viable rural economy.

The small scale field test at Wellington Field as designed integrates two petroleum business activities: 1) use of CO2 for enhanced oil recovery and revitalizing many older mature oil fields and 2) disposal/storage of CO2 in the underlying saline aquifer for the longer term. It

has been conveyed to the local petroleum industry that drilling and oil production infrastructure of an active oil field are important components that could lead to a successful carbon sequestration project including 1) knowledge about the subsurface including injection zones and caprock, 2) knowledge about abandoned wells, 3) access and suitability of land with greater likelihood for participation by landowner, and 4) access to insurance and investors to facilitate economic success.

CHANGES/PROBLEMS

KGS is committed to starting BP2 on October 1, 2013. To ensure this, discussions are ongoing with alternative suppliers to deliver the source CO2 should the Abengoa facility remain out of operation in calendar year 2013.

The composition of the surface facilities is still under consideration. Wellbore modeling is being conducted to ensure that suitable operating parameters (pressure and temperature) are established so as to avoid undesirable phase changes during injection, and to economize the cost and operations of the surface facilities. This may require a staggered plan for injection which was not anticipated at commencement of the project. The pros and cons of such on/off operations are being established.

The Class VI rule requires the annulus to be pressurized to at least 100 psi over and above the tubing pressure. This will involve incurring additional cost on the project. A waiver is to be sought based on analyses conducted for demonstrating that the integrity of the tubing will not be comprised by maintaining hydrostatic pressure in the annulus.

APPENDIX II

Small Scale Field Test Demonstrating CO_2 Sequestration in Arbuckle Saline Aquifer and by CO_2-EOR at Wellington Field, Sumner County, Kansas

SIXTH QUARTERLY PROGRESS REPORT

DOE F 4600.2
(03/11)
All Other Editions Are Obsolete

U.S. Department of Energy
FEDERAL ASSISTANCE REPORTING CHECKLIST
AND INSTRUCTIONS FOR RD&D PROJECTS

1. Identification Number: **DE-FE0006821**	2. Program/Project Title: **Small Scale Field Test Demonstration CO2 Sequestration**

3. Recipient: **University of Kansas Center for Research, Inc.**

4. Reporting Requirements:	Frequency	Addressees
A. MANAGEMENT REPORTING		
☒ Research Performance Progress Report (RPPR)	Q	FITS@NETL.DOE.GOV
☒ Special Status Report	A	FITS@NETL.DOE.GOV
B. SCIENTIFIC/TECHNICAL REPORTING		
(Reports/Products must be submitted with appropriate DOE F 241. The 241 forms are available at www.osti.gov/elink)		
Report/Product — Form		
☒ Final Scientific/Technical Report — DOE F 241.3	FG	http://www.osti.gov/elink-2413
☒ Conference papers/proceedings* — DOE F 241.3	A	http://www.osti.gov/elink-2413
☐ Software/Manual — DOE F 241.4		
☐ Other (see special instructions) — DOE F 241.3		
** Scientific and technical conferences only*		
C. FINANCIAL REPORTING		FITS@NETL.DOE.GOV
☒ SF-425 Federal Financial Report	Q, FG	
D. CLOSEOUT REPORTING		
☒ Patent Certification	FC	FITS@NETL.DOE.GOV
☒ SF-428 & 428B Final Property Report	FC	FITS@NETL.DOE.GOV
☐ Other		
E. OTHER REPORTING		See block 5 below for instructions.
☒ Annual Indirect Cost Proposal	O	
☐ Audit of For-Profit Recipients		
☒ SF-428 Tangible Personal Property Report Forms Family	A	FITS@NETL.DOE.GOV
☒ Other – see block 5 below	A	FITS@NETL.DOE.GOV

FREQUENCY CODES AND DUE DATES:

A - Within 5 calendar days after events or as specified.
FG- Final; 90 calendar days after the project period ends.
FC- Final; End of Effort.
Y - Yearly; 90 calendar days after the end of the reporting period.
S - Semiannually; within 30 calendar days after end of project year and project half-year.
Q - Quarterly; within 30 days after end of the reporting period.
Y180 – Yearly; 180 days after the end of the recipient's fiscal year
O - Other; See instructions for further details.

5. Special Instructions:

Annual Indirect Cost Proposal – If DOE is the Cognizant Federal Agency, then the proposal should be sent to FITS@NETL.DOE.GOV . Otherwise, it should be sent to the Cognizant Federal Agency.

Other – The Recipient shall provide all deliverables as contained in Section D of Attachment 2 Statement of Project Objectives.

QUARTERLY PROGRESS REPORT
To
DOE-NETL
Brian Dressel, Program Manager
Award Number: DE-FE0006821

SMALL SCALE FIELD TEST DEMONSTRATING CO_2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO_2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS

Project Director/Principal Investigator:
W. Lynn Watney
Senior Scientific Fellow
Kansas Geological Survey

Ph: 785-864-2184, Fax: 785-864-5317
lwatney@kgs.ku.edu

Joint Principal Investigator:
Jason Rush

Date of Report: May 5, 2013

DUNS Number: 076248616

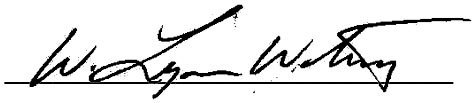
Recipient: University of Kansas Center for Research &
Kansas Geological Survey
1930 Constant Avenue
Lawrence, KS 66047

Project/Grant Period: 10/1/2011 through 9/30/2015

Sixth Quarterly Report

Period Covered by the Report: January 1, 2013 through March 31, 2013

Signature of Submitting Official:



EXECUTIVE SUMMARY

Project Objectives

The objectives of this project are: (1) inject under supercritical conditions approximately 40,000 metric tons of CO_2 into the Arbuckle saline aquifer; (2) demonstrate the application of state-of-the-art MVA (monitoring, verification, and accounting) tools and techniques to monitor and visualize the injected CO_2 plume; (3) develop a robust Arbuckle geomodel by integrating data collected from the proposed study area, and a multi-component 3D seismic survey; (4) conduct reservoir simulation studies to map CO_2 plume dispersal and estimate tonnage of CO_2 sequestered in solution, as residual gas and by mineralization; (5) integrate MVA data and analysis with reservoir modeling studies to detect CO_2 leakage and to validate the simulation model; (6) develop a rapid-response mitigation plan to minimize CO_2 leakage and a comprehensive risk management strategy; and (7) establish best practice methodologies for MVA and closure. Additionally, approximately 30,000 metric tons of CO_2 shall be injected into the overlying Mississippian to evaluate miscible CO_2-EOR potential in a 5-spot pilot pattern. The CO_2 shall be supplied from the Abengoa Bioenergy ethanol plant at Colwich, Kansas who has operated the facility since 1982 demonstrating reliability and capability to provide an adequate stream and quality of CO_2. The project shall install compression, chilling, and transport facilities at the ethanol plant for truck transport to the injection site.

Project Goals

The proposed small scale injection will advance the science and practice of carbon sequestration in the Midcontinent by refining characterization and modeling, evaluating best practices for MVA tailored to the geologic setting, optimize methods for remediation and risk management, and provide technical information and training to enable additional projects and facilitate discussions on issues of liability and risk management for operators, regulators, and policy makers.

The data gathered as part of this research effort and pilot study will be shared with the Southwest Sequestration Partnership (SWP) and integrated into the National Carbon Sequestration Database and Geographic Information System (NATCARB) and the 6th Edition of the Carbon Sequestration Atlas of the United States and Canada.

Project Deliverables by Task

1.5 Well Drilling and Installation Plan (Can be Appendix to PMP or Quarterly Report)
1.6 MVA Plan (Can be Appendix to PMP or Quarterly Report)
1.7 Public Outreach Plan (Can be Appendix to PMP)
1.8 Arbuckle Injection Permit Application Review go/no go Memo
1.9 Mississippian Injection Permit Application Review go/no go Memo
1.10 Site Development, Operations, and Closure Plan (Can be Appendix to PMP)

2.0 Suitable geology for Injection Arbuckle go/no go Memo
3.0 Suitable geology for Injection Mississippian go/no go Memo
11.2 Capture and Compression Design and Cost Evaluation go/no go Memo
19 Updated Site Characterization/Conceptual Models (Can be Appendix to Quarterly Report)
21 Commercialization Plan (Can be Appendix to Quarterly Report).
30 Best Practices Plan (Can be Appendix to Quarterly or Final Report)

ACCOMPLISHMENTS

1. **Continued progress of Milestone 2 (Task 3) --** Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field
2. **Subtask 1.8 Arbuckle Injection Permit Application** – The permit application consists of 15 chapters (sections). The completion status for each section, along with the remaining tasks is described in Table 1 below. The revised and near final draft of each section is nearly completed. The process involved aggregating information from many investigators/specialists into a coherent document which summarizes the suitability of the Wellington site for conducting not only the small-scale pilot test, but potentially for long-term commercial scale carbon capture and sequestration (CCS).

Milestone Status Report

Task	Budget Period	Number	Milestone Description
Task 2.	1	1	Site Characterization of Arbuckle Saline Aquifer System - Wellington Field
Task 3.	1	2	Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field
Task 10.	2	3	Pre-injection MVA - establish background (baseline) readings
Task 13.	2	4	Retrofit Arbuckle Injection Well (#1-28) for MVA Tool Installation
Task 18.	3-yr1	5	Compare Simulation Results with MVA Data and Analysis and Submit Update of Site Characterization, Modeling, and Monitoring Plan
Task 22.	3-yr1	6	Recondition Mississippian Boreholes Around Mississippian CO2-EOR injector
Task 27.	3-yr2	7	Evaluate CO2 Sequestration Potential of CO2-EOR Pilot
Task 28.	3-yr2	8	Evaluate Potential of Incremental Oil Recovery and CO2 Sequestration by CO2-EOR - Wellington field

Project Schedule

Abengoa Biofuels informed us in mid August 2012 that the Colwich Ethanol Facility would be shut down for one year because of the severe drought in the Midwest. This shut down has status has not changed in spite of snowfall and rainfall late winter and spring 2013. The dry weather severely impacted their dryland feedstock base (mainly milo and sorghum) and the resulting high grain prices. The facility will remain closed until the next harvest. Abengoa, DOE, and partners agreed that the plant reopening will be revisited on October 1, 2013 after the next harvest cycle to determine if they will reopen. During DOE site visit in September 2012, Abengoa official gave us a tour of the ethanol plant and relayed that every effort is being taken to keep the plant in a condition so that it can be reopened next year.

A request was made and DOE extended Budget Period 1 for an additional year at no cost until October 1, 2013. The project will make every effort to evaluate alternative sources, but as yet the economics are not close to meeting the arrangements made with Abengoa and the Colwich

ethanol facility. Both Abengoa and Berexco, the oil field industry partner, are committed to working with each other to link the ethanol-based CO2 with oil field operations in the area.

Geologic CO2 will not be part with the Kansas market due to demand along existing pipelines in Texas, New Mexico, Colorado, and Wyoming. Anthropogenic is the only viable source to provide the CO2 needed for CO2-EOR. Both Abengoa and Berexco are keenly interested in the saline aquifer storage in order to obtain enhanced prices for ethanol, obtain deposal fees, and with the case at Wellington, the income generated by carbon trading through Biorecro in Sweden.

The KGS is committed to starting injection at the Wellington site in the first quarter of FY2014. Therefore, contacts were made with alternative anthropogenic CO2 producers to supply the source in the event that the Abengoa plant remains shut indefinitely. The suppliers include Airgas and FloCO2, and each have indicated an ability to provide CO2 in the event of continued shutdown of the Abengoa facility. We have also had discussions with Pioneer Energy who is interested in generating the CO2 onsite from conversion of pipeline natural gas to hydrogen and CO2. Excess energy will be used to create electricity. Discussions will begin next quarter with a company in Oklahoma who recently completed a CO2 pipeline ~70 miles south of Wellington.

The Class VI UIC geosequestration permit application will be submitted to EPA during May 2013. Construction of monitoring wells and installation of monitoring equipment will commence on approval of the permit, if permission is granted from DOE.

A condensed version of the Gantt Chart tracks tasks based on the one year no cost extension of Budget Period 1 (Figure 1). The PMP and Gantt Chart will be updated during the next quarter.

Activities of Lawrence Berkeley National Lab

No work has been completed or funds expended during this quarter by LBNL.

ONGOING ACTIVITIES –

TASK 1. PROJECT MANAGEMENT AND REPORTING

Permit Status and Activities

As of March 2013, drafts of all permit sections have been completed and major sections have been reviewed. KGS graphics and GIS personnel are completing figures for the application report. The status of each section are listed in Table 1. The goal is to finalize the sections for internal and external review in early May 2013; after which the application will be submitted to EPA. Additional exchange of technical information along with the review process have

extended the preparation time, but reviews indicate agreement with the approach, but for minor modifications. No further delays are expected.

Once submitted KGS will seek a permit kickoff meeting with EPA soon after the submittal of the application in order to expedite the review process. The contents of each section will be summarized and presented in Power Point format, which will provide the reviewer's an opportunity to better understand the application contents and seek technical clarification.

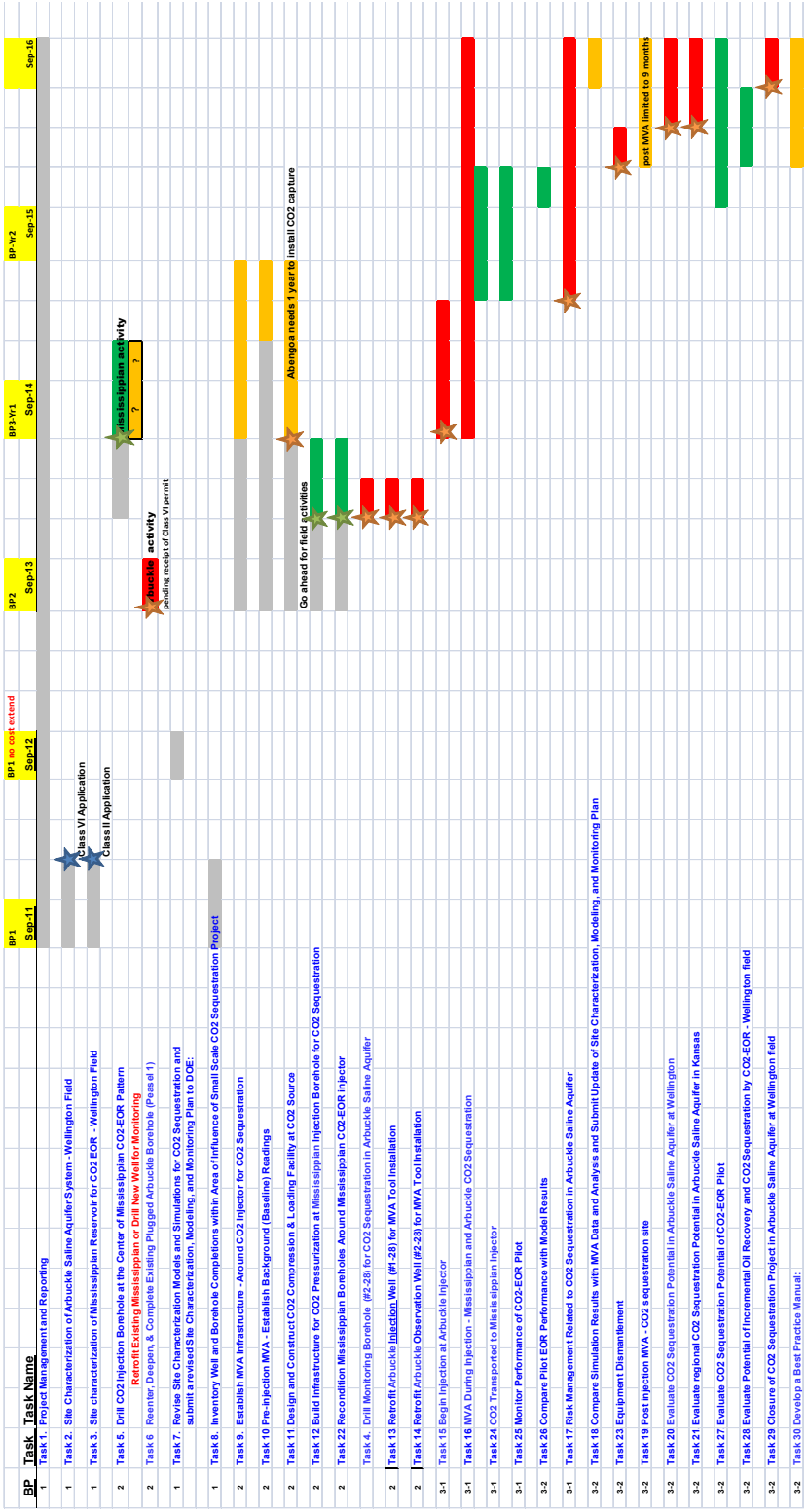


Figure 1. Condensed version of the project Gantt Chart.

Table 1. Status of Class VI permit application

Section	Percent Complete	Remaining Tasks
Project Overview	**98%**	GIS and graphics personnel working on finalizing figures.
Local Scale Geologic and Hydrolgeologic Background	**98%**	Completed except for addressing editing from reviewers.
Regional Scale Geologic and Hydrogeologic Background	**95%**	GIS and graphics personnel working on finalizing figures.
Geologic Sequestration of Carbon Dioxide	**95%**	GIS and graphics personnel working on finalizing figures.
Flow and Transport Model Simulations and AOR Delineation	**95%**	GIS and graphics personnel working to work on finalizing figures.
Potential Capture in Depleted Mississippian Formation	**98%**	GIS and graphics personnel working on finalizing figures.
Geomechanical Stability Investigations	**98%**	GIS and graphics personnel working on finalizing figures.
Injection Well Design	**90%**	GIS and graphics personnel working on finalizing figures. Tiraz Birdie to add discussion on type of cement information forwarded by Dana.
Monitoring Well Design	**80%**	GIS and graphics personnel working on finalizing figures. Tiraz Birdie to add some discussion on type of cement information forwarded by Dana, and the proposed well 2-28.
Site Operations	**90%**	GIS and graphics personnel working on finalizing figures. Information will be forward by Dana.

Monitoring Verification and Accounting Activities	**95%**	GIS and graphics personnel to work on finalizing figures.
Post Injection Site Care	**95%**	First draft complete.
Site Closure	**95%**	Final writeup is being completing with access to final modeling results.
Risk Management and Mitigation Plan	**90%**	Need to describe automatic shutdown system after finalizing surface facilities plans. Need to ensure that onsite Programmable Logic Controller or computer can implement a shutdown plan.
Financial Assurances	**70%**	Draft complete. Berexco to provide P&L, balance sheet, and cash flow metrics. Berexco to also complete cost estimates for closure and monitoring activities. Berexco will provide information after they they are in receipt of the entire applicaition.

The bulk of the efforts in second quarter of FY 2013 were expended towards finalizing the draft of the of the permit application. This involved:

- Finalized compiling background information on the regional hydrogeology,
- Finalized synthesizing the numerous physical, chemical, and biological data sets acquired during drilling of wells 1-32 and 1-28, and utilizing the same to develop a conceptual model of the stratification within the Arbuckle aquifer and characterizing the overlying formations,
- Established the EPA Area of Review,
- Completed conducting flow and transport simulations in order to determine the eventual fate of the CO2,
- Completed the compilation of historical information on oil and gas development in Kansas and documentation the resulting under pressurization in the Mississippian reservoir, which will serve as a trap for any CO2 that may potentially escape from the caprock or faults,
- Developed geomechanical approaches to quantatively demonstrate that the caprock and formation integrity will not be compromised due to injection,

- Completed write up on Nuclear Magentic Resonance to communicate the strength of the technique for characterizing geologic formations,
- Completed and documented procedure for integrating seismic data and geophysical data in Petrel and developed a new upscaled CMG reservoir model.
- Demonstrating to EPA that the construction practices, materials utilized, and design of wells KGS 1-28 and 1-32 are in accordance with the Class VI specifications.

Key Findings

1. Geomechanical analysis and low pressure of CO2 injection into the Arbuckle continue to find that it will be virtually impossible to encounter stress related failure along existing fracture and fault planes due to CO2 injection.

2. Simulation results indicate that area of review is within 1000 ft of the injection well, Wellington KGS #1-28.

3. Underpressurization of the Mississippian is throughout the area around Wellington Field and supports the hydraulic isolation of the Mississippian from units above and below and adds addition assurance that the Mississippian is a pressure trap for any CO2 that might leak from the underlying Arbuckle. Results are consistent with the stable isotope data that indicates that the Mississippian and Arbuckle hydrostatigraphic units are isolated.

4. The primary and secondary caprock are most adequate for this small scale test injection based on a combination of geomechanical measurements and modeling, capillary entry pressure, and continuity of the combined caprocks based on seismic imaging.

Plans

1. Top priority remains to finalize and submit application for Class VI injection permit to the EPA in May 2013. A day long or half-day permit kickoff meeting is to be requested with the EPA in order to communicate the project findings and contents of the permit document to EPA reviewers, and provide them an opportunity to ask questions/seek clarification. This will

expedite the EPA review process. On obtaining the permit, field activities shall commence in conjunction with construction of new monitoring wells, and deepening of the existing Peasel well.

2. Submit updated management plan, well drilling and installation plan, MVA plan, Public Outreach Plan based on material included in Class VI application.

3. Submit Mississippian Injection Permit Application (Class II injection well under Kansas primacy, regulated by Kansas Corporation Commission) using updated geomodel and simulation of the Mississippian oil reservoir.

PRODUCTS

Publications, conference papers, and presentations

January 31st, AAPG Mississippian Forum, Oklahoma City, OK, Mississippian Carbonate and Chert Reservoirs in Kansas: Integrating Log, Core, and Seismic Information -- Lynn Watney (based primarily on Wellington Field) – discussion of caprock and Arbuckle as a disposal zone for brine and CO2

February 18-19, Applied Geoscience Conference, Houston, TX, Mississippian Exploration: Stratigraphy, Petrology, and Reservoir Properties -- Lynn Watney (based on new data from Wellington Field, considerations for CCUS, and regional mapping) – include caprock and disposal of brine and CO2

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

A project organization chart follows. The work authorized in this budget period includes office tasks related to preparation of reports and application for a Class VI permit to inject CO2 into the Arbuckle saline aquifer. Tasks associated with reservoir characterization and modeling are funded in contract DE-FE0002056.

ORGANIZATION CHART

Name	Project Job Title	Primary Responsibility
	Kansas Geological Survey	
Lynn Watney	Project Leader, Joint Principal Investigator	Geology, information synthesis, point of contact
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John Doveton	Co-Principal Investigator	Log petrophysics, geostatistics
Dave Newell	Co-Principal Investigator	Fluid geochemistry
Rick Miller	Geophysicist	2D seismic acquire & interpretation
		LiDAR/InSAR support, water well drilling/completion
TBN	Geology Technician	Assemble and analyze data, report writing
Tiraz Birdie	President, TBirdie Consulting, Inc.	Hydrogeologic modeling, permitting, MVA, integration
	KU Department of Geology	
Michael Taylor	Co-Principal Investigator	Structural Geology, analysis of InSAR, LiDAR, seismometer array
TBN	Graduate Research Assistant	Structural Geology, analysis of InSAR and LiDAR, seismometer array
	Kansas State Unversity	
Saugata Datta	Principal Investigator	
TBN	Graduate Research Assistant	Aqueous geochemistry
TBN	3- Undergraduate Research Assistants	
	Lawrence Berkeley National Laboratory	
Tom Daley	Co-Principal Investigator	Geophysicist, analysis of crosshole and CASSM data
		Hydrogeology, analysis of soil gas measurements
Barry Freifeld	Co-Principal Investigator	Mechanical Engineer, analysis of U-Tube sampler
	Sandia Technologies, Houston	
Dan Collins	Geologist	Manage CASSM and U-Tube operation
David Freeman	Field Engineer	Manage field install of CASSM and U-Tube
	Berexco, LLC	
Dana Wreath	VP Berexco, LLC	Engineering, Manager of Wellington Field
Randy Koudele	Reservoir engineer	Engineering
Staff of Wellington Field		Field operations
Beredco Drilling team		Mississippian and Arbuckle drilling operations
	Abengoa Bioenergy Corp.	
Christopher Standlee, Danny Alllison		CO2 supply Colwich Ethanol Facility

IMPACT

The project has been discussed in public venues – presentations at professional meetings, legislative committees, and town hall meeting, and has provided information on the project via the website to encourage a dialog on the merits and economies related to carbon management in Kansas. Kansans are realizing the potential for an important collaboration between the two of the largest economies in Kansas – agriculture and related ethanol industry and the petroleum industry to advance energy and contribute to a viable rural economy.

The small scale field test at Wellington Field as designed integrates two petroleum business activities: 1) use of CO2 for enhanced oil recovery and revitalizing many older mature oil fields and 2) disposal/storage of CO2 in the underlying saline aquifer for the longer term. It has been conveyed to the local petroleum industry that drilling and oil production infrastructure of an active oil field are important components that could lead to a successful carbon sequestration project including 1) knowledge about the subsurface including injection zones and caprock, 2) knowledge about abandoned wells, 3) access and suitability of land with greater likelihood for participation by landowner, and 4) access to insurance and investors to facilitate economic success.

CHANGES/PROBLEMS

KGS is committed to starting BP2 on October 1, 2013. To ensure this, discussions are ongoing with alternative suppliers to deliver the source CO2 should the Abengoa facility remain out of operation in calendar year 2013.

The PMP and schedule will be updated in the next quarter.

APPENDIX II

Small Scale Field Test Demonstrating CO_2 Sequestration in Arbuckle Saline Aquifer and by CO_2-EOR at Wellington Field, Sumner County, Kansas

SEVENTH QUARTERLY PROGRESS REPORT

DOE F 4600.2
(03/11)
All Other Editions Are Obsolete

U.S. Department of Energy
FEDERAL ASSISTANCE REPORTING CHECKLIST
AND INSTRUCTIONS FOR RD&D PROJECTS

1. Identification Number: **DE-FE0006821**	2. Program/Project Title: **Small Scale Field Test Demonstration CO2 Sequestration**
3. Recipient: **University of Kansas Center for Research, Inc.**	

4. Reporting Requirements:	Frequency	Addressees
A. MANAGEMENT REPORTING		
☒ Research Performance Progress Report (RPPR)	Q	FITS@NETL.DOE.GOV
☒ Special Status Report	A	FITS@NETL.DOE.GOV
B. SCIENTIFIC/TECHNICAL REPORTING		
(Reports/Products must be submitted with appropriate DOE F 241. The 241 forms are available at www.osti.gov/elink)		
Report/Product — Form		
☒ Final Scientific/Technical Report — DOE F 241.3	FG	http://www.osti.gov/elink-2413
☒ Conference papers/proceedings* — DOE F 241.3	A	http://www.osti.gov/elink-2413
☐ Software/Manual — DOE F 241.4		
☐ Other (see special instructions) — DOE F 241.3		
** Scientific and technical conferences only*		
C. FINANCIAL REPORTING		FITS@NETL.DOE.GOV
☒ SF-425 Federal Financial Report	Q, FG	
D. CLOSEOUT REPORTING		
☒ Patent Certification	FC	FITS@NETL.DOE.GOV
☒ SF-428 & 428B Final Property Report	FC	FITS@NETL.DOE.GOV
☐ Other		
E. OTHER REPORTING		See block 5 below for instructions.
☒ Annual Indirect Cost Proposal	O	
☐ Audit of For-Profit Recipients		
☒ SF-428 Tangible Personal Property Report Forms Family	A	FITS@NETL.DOE.GOV
☒ Other – see block 5 below	A	FITS@NETL.DOE.GOV

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FC- Final; End of Effort.
Y - Yearly; 90 calendar days after the end of the reporting period.
S - Semiannually; within 30 calendar days after end of project year and project half-year.
Q - Quarterly; within 30 days after end of the reporting period.
Y180 – Yearly; 180 days after the end of the recipient's fiscal year
O - Other; See instructions for further details.

5. Special Instructions:

Annual Indirect Cost Proposal – If DOE is the Cognizant Federal Agency, then the proposal should be sent to FITS@NETL.DOE.GOV . Otherwise, it should be sent to the Cognizant Federal Agency.

Other – The Recipient shall provide all deliverables as contained in Section D of Attachment 2 Statement of Project Objectives.

QUARTERLY PROGRESS REPORT
To
DOE-NETL
Brian Dressel, Program Manager
Award Number: DE-FE0006821

SMALL SCALE FIELD TEST DEMONSTRATING CO_2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO_2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS

Project Director/Principal Investigator:
W. Lynn Watney
Senior Scientific Fellow
Kansas Geological Survey

Ph: 785-864-2184, Fax: 785-864-5317
lwatney@kgs.ku.edu

Joint Principal Investigator:
Jason Rush

Prepared by Tiraz Birdie and Lynn Watney
Date of Report: August 6, 2013
DUNS Number: 076248616

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

Project/Grant Period: 10/1/2011 through 9/30/2015

Seventh Quarterly Report

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

Signature of Submitting Official:

W. Lynn Watney Digitally signed by W. Lynn Watney DN: cn=W. Lynn Watney, o=The University of Kansas, ou=Kansas Geological Survey, email=lwatney@kgs.ku.edu, c=US Date: 2013.08.06 15:32:00 -05'00'

EXECUTIVE SUMMARY

Project Objectives

The objectives of this project are: (1) inject under supercritical conditions approximately 40,000 metric tons of CO_2 into the Arbuckle saline aquifer; (2) demonstrate the application of state-of-the-art MVA (monitoring, verification, and accounting) tools and techniques to monitor and visualize the injected CO_2 plume; (3) develop a robust Arbuckle geomodel by integrating data collected from the proposed study area, and a multi-component 3D seismic survey; (4) conduct reservoir simulation studies to map CO_2 plume dispersal and estimate tonnage of CO_2 sequestered in solution, as residual gas and by mineralization; (5) integrate MVA data and analysis with reservoir modeling studies to detect CO_2 leakage and to validate the simulation model; (6) develop a rapid-response mitigation plan to minimize CO_2 leakage and a comprehensive risk management strategy; and (7) establish best practice methodologies for MVA and closure. Additionally, approximately 30,000 metric tons of CO_2 shall be injected into the overlying Mississippian to evaluate miscible CO_2-EOR potential in a 5-spot pilot pattern. An alternative supplier for the Abengoa Bioenergy ethanol plant at Colwich, Kansas is being sought. The project was informed in late July 2013 that the Colwich plant will not reopen in 2013 and opening in 2014 is questionable due to conditions beyond their control. Discussions with three sources of compressed CO2 are in progress.

Project Goals

The proposed small scale injection will advance the science and practice of carbon sequestration in the Midcontinent by refining characterization and modeling, evaluating best practices for MVA tailored to the geologic setting, optimize methods for remediation and risk management, and provide technical information and training to enable additional projects and facilitate discussions on issues of liability and risk management for operators, regulators, and policy makers.

The data gathered as part of this research effort and pilot study will be shared with the Southwest Sequestration Partnership (SWP) and integrated into the National Carbon Sequestration Database and Geographic Information System (NATCARB) and the 6th Edition of the Carbon Sequestration Atlas of the United States and Canada.

Project Deliverables by Task

1.5 Well Drilling and Installation Plan (Can be Appendix to PMP or Quarterly Report)
1.6 MVA Plan (Can be Appendix to PMP or Quarterly Report)
1.7 Public Outreach Plan (Can be Appendix to PMP)
1.8 Arbuckle Injection Permit Application Review go/no go Memo
1.9 Mississippian Injection Permit Application Review go/no go Memo
1.10 Site Development, Operations, and Closure Plan (Can be Appendix to PMP)

2.0 Suitable geology for Injection Arbuckle go/no go Memo
3.0 Suitable geology for Injection Mississippian go/no go Memo
11.2 Capture and Compression Design and Cost Evaluation go/no go Memo
19 Updated Site Characterization/Conceptual Models (Can be Appendix to Quarterly Report)
21 Commercialization Plan (Can be Appendix to Quarterly Report).
30 Best Practices Plan (Can be Appendix to Quarterly or Final Report)

ACCOMPLISHMENTS

1. **Continued progress of Milestone 2 (Task 3) --** Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field.
2. **Subtask 1.8 Arbuckle Injection Permit Application** – The permit application consists of 14 chapters (sections). Drafts for all section have been completed by KGS and forwarded to Petrotek Engineering Corporation for review. Petrotek has extensive experience with permitting of injection wells, with one of their staff member being a former EPA reviewer. KGS has been receiving technical comments from Petrotek and incorporating the same in the Class VI draft document. The completion status for each section is described in Table 1 below. The draft of the permit application is expected to be complete in August, following which it will be forwarded Berexco, the oilfield operator, for review by their legal team prior to submitting the application to the EPA Region VII Director.

   The permit document contains extensive amount of raw, processed, and analyzed technical information along with model simulation results which summarizes the suitability of the Wellington site for conducting not only the small-scale pilot test, but potentially long-term commercial scale carbon capture and sequestration (CCS).

Milestone Status Report

Task	Budget Period	Number	Milestone Description
Task 2.	1	1	Site Characterization of Arbuckle Saline Aquifer System - Wellington Field
Task 3.	1	2	Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field
Task 10.	2	3	Pre-injection MVA - establish background (baseline) readings
Task 13.	2	4	Retrofit Arbuckle Injection Well (#1-28) for MVA Tool Installation
Task 18.	3-yr1	5	Compare Simulation Results with MVA Data and Analysis and Submit Update of Site Characterization, Modeling, and Monitoring Plan
Task 22.	3-yr1	6	Recondition Mississippian Boreholes Around Mississippian CO2-EOR injector
Task 27.	3-yr2	7	Evaluate CO2 Sequestration Potential of CO2-EOR Pilot
Task 28.	3-yr2	8	Evaluate Potential of Incremental Oil Recovery and CO2 Sequestration by CO2-EOR - Wellington field

Project Schedule

Abengoa Biofuels informed us in late July that the Colwich Ethanol Facility would remain shut for the rest of the year because of the drought in the Midwest. However, Abengoa did indicate that may be possible for them to supply the CO_2 from their newly constructed cellulosic ethanol plant at Hugoton, Kansas. KGS has ongoing discussions with Abengoa and other potential

suppliers of anthropogenic CO_2 including Praxair, Airgas, Chaparral Energy, and Trenton Agri Products, LLC. Geologic CO2 has not been an option for the Wellington project, due to demand for this product along existing pipelines in Texas, New Mexico, Colorado, and Wyoming. Anthropogenic is the only viable source to provide the CO2 needed for CO2-EOR. Berexco are keenly interested in the saline aquifer storage in order to obtain enhanced prices for ethanol, obtain deposal fees, and with the case at Wellington, the income generated by carbon trading through Biorecro in Sweden.

The KGS is committed to starting injection at the Wellington site in the first quarter of FY2014 by first injecting in the Mississippian oil and gas reservoir. Therefore, contacts were made with alternative anthropogenic CO2 producers as noted above. We have also had discussions with Pioneer Energy who is interested in generating the CO2 onsite from conversion of pipeline natural gas to hydrogen and CO2. Excess energy will be used to create electricity. However, this latter option is still in the prototype stage.

The Class VI UIC geosequestration permit application is planned to be submitted to EPA in late summer/early fall 2013. Construction of monitoring wells and installation of monitoring equipment will commence on approval of the permit, if permission is granted from DOE.

A condensed version of the Gantt Chart tracks tasks based on the one year no cost extension of Budget Period 1 (Figure 1). The PMP and Gantt Chart will be updated during the next quarter.

Activities of Lawrence Berkeley National Lab

No work has been completed or funds expended during this quarter by LBNL.

ONGOING ACTIVITIES –

TASK 1. PROJECT MANAGEMENT AND REPORTING

Permit Status and Activities

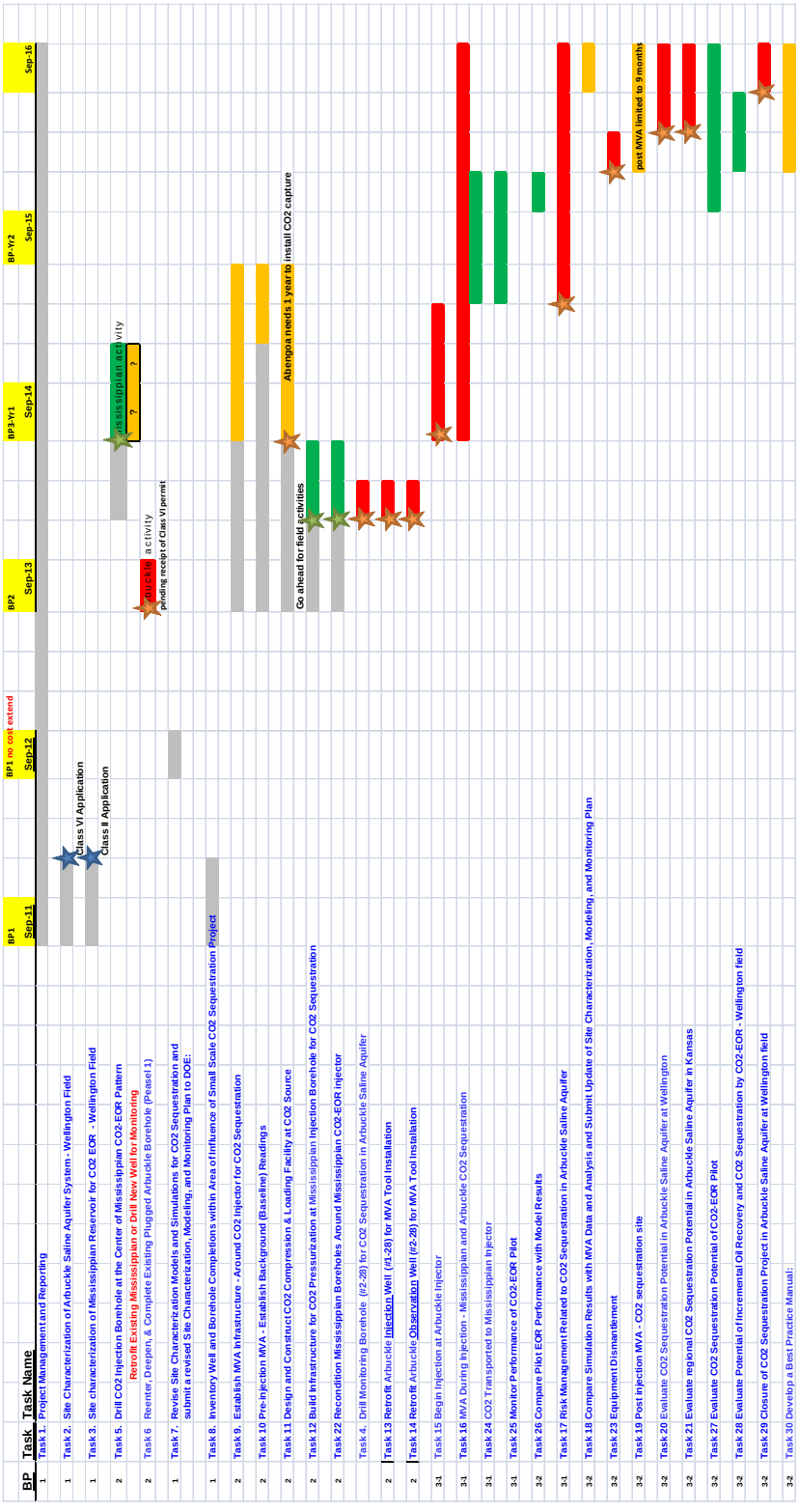


Figure 1. Condensed version of the project Gantt Chart.

Table 1. Status of Class VI permit application

Section	Status
Project Overview	Review completed by Petrotek and suggestions implemented by KGS. Document production staff at KGS incorporating write up in draft permit application for review by Berexco and DOE.
CO2 Sequestration Potential of Arbuckle Group	Review completed by Petrotek and suggestions implemented by KGS. Document production staff at KGS incorporating write up in draft permit application for review by Berexco and DOE.
Regional Geology and Hydrogeology	Review completed by Petrotek. KGS implementing suggestions.
Local Geology and Hydrolgeology	Partial review completed by Petrotek. KGS implementing suggestions.
Reservoir Modeling and Area of Review	KGS modeler working on completing alternative models and sensitivity scenarios.
Geomechanical and Caprock Stability Investigations	Review completed by Petrotek. KGS implementing suggestions.
Trapping Potential of Mississippian Formation	Review completed by Petrotek. KGS implementing suggestions.
System Design, Construction, and Operations	Petrotek conducting review.
Area of Review and Corrective Action Plan	KGS staff awaiting completion of modeling runs prior in order to finalize this section

Testing and Monitoring Plan	Petrotek reviewing write up by KGS
Well Plugging Plan	Petrotek reviewing write up by KGS
Post Injection Site Care and Site Closure Plans	Review completed by Petrotek. KGS implementing suggestions..
Emergency Remedial Response Plan	Review completed by Petrotek. KGS implementing suggestions.
Financial Assurances	Petrotek reviewing write up by KGS

The bulk of the EPA Class VI permit application efforts in third quarter of FY 2013 were expended towards finalizing the draft of the permit application. This involved:

- Providing a draft version of the permit application to Petrotek Engineering Corporation for review. Petrotek has been conducting the review on a section by section basis, and their comments are incorporated in the draft permit document as soon as they are received.

- Revising the upper confining zone by including the argillaceous Pierson Formation in the lower Mississippian as part of the confining zone. Initially, only the underlying Simpson Group and the Chattanooga Shale were considered as part of the confining zone as the concern was that there would be many existing wells requiring corrective action, especially during commercial scale injection of CO_2. However, in order to expedite the Class VI permit application, it was decided to include the low permeability Pierson Formation as part of the upper confining zone.

- Preparing a vertical permeability profile throughout the Arbuckle from core data, which was not possible to construct previously due to lack of an appropriate technical methodology. A KGS staff member, working with external engineers, has developed a new methodology for estimating vertical permeability throughout the cored interval and extrapolating the same at nearby wells.

- Developing a new 3-D Petrel based geo-model by KGS staff using the vertical permeability distribution at the proposed injection and monitoring wells (KGS 1-28 and KGS 1-32) as described above, and up-scaling the same to the reservoir model.

- Updating the CMG reservoir simulation model by utilizing the updated geomodel which incorporated the new vertical permeability distribution. In order to properly simulate flow in the high permeability intervals within the stratified Arbuckle aquifer, the model was discretized in 72 layers versus the 33 layers employed in the previous model. The KGS modeler is currently working on completing alternative model runs and conducting sensitivity scenarios.

- Characterizing and documenting fractures within the upper confining zone by synthesizing the data obtained from (core based) fracture studies, XMRI logs, and CT scans. The findings convincingly demonstrate that the upper confining zone is free of transmissive fractures which should allay EPA concerns of CO_2 migration from the caprock above the Arbuckle aquifer.

- Revising the Class VI testing and monitoring plan to be submitted to the EPA by scaling down the scope of activities. A minimum amount of monitoring activities necessary for obtaining a Class VI permit is proposed to the EPA, without committing to conducting all monitoring, verification, and accounting activities as stated in the PMP. This was done after considering the potential for a reduced set of monitoring activities for the project in the event that there is a budget shortfall due to the high cost of CO2 procurement.

- Preparing for the DOE Program Review in Wichita which focused on discussing and communicating the following,
  1) Wellington serves as a calibration site for the Mississippian reservoir, and summarizing the information necessary to describe and model this reservoir,
  2) Collaborative research at Wellington to evaluate utilization for EOR in the Mississippian and storage of CO2 in underlying saline aquifer,
  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) Benefits to industry and state,
  5) Share results and information with the petroleum industry and public to develop and optimize for new CO2 projects.

Key Findings

1. The new simulation results indicate that the CO2 plume will stabilize within a year of cessation of injection. This finding will support a KGS/Berexco petition to EPA to allow closure of the Wellington site in 1.5 years following injection, instead of the default 50 year post-injection period.

2. Unlike the previous model results, the pressure induced in the injection zone may cause the brines to migrate into the USDW if artificial penetrations are not properly sealed.

3. The revised vertical permeability distribution in the Arbuckle has resulted in the CO2 remaining confined in the lower Arbuckle injection zone. This will mitigate concerns pertaining to caprock integrity. In the previous model, the plume migrated to the top of the Arbuckle, albeit at low pressures.

4. The simulation results were compared with sequestration volume estimates using equation utilized by researchers for preparing the US CO2 geologic sequestration

capacity atlas, and found to generally be in good agreement. This provides an independent validation of the simulation results.

Plans

1. Negotiate the prospect of injecting CO_2 first in the Mississippian reservoir with the DOE so as to resume project activities in FY2014 starting October 1, 2013.

2. Submit Mississippian Injection Permit Application (Class II injection well under Kansas primacy, regulated by Kansas Corporation Commission) using updated geomodel and simulation of the Mississippian oil reservoir.

3. Top priority remains to finalize and submit application for Class VI injection permit to the EPA in late summer/early fall 2013. A day long or half-day permit kickoff meeting is to be requested with the EPA in order to communicate the project findings and contents of the permit document to EPA reviewers, and provide them an opportunity to ask questions/seek clarification. This will expedite the EPA review process. On obtaining the permit, field activities shall commence in conjunction with construction of new monitoring wells, and deepening of the existing Peasel well.

4. Submit updated management plan, well drilling and installation plan, MVA plan, Public Outreach Plan based on material included in Class VI application.

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PRODUCTS

Publications, conference papers, and presentations

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.

Lyle, S., Buchanan, R., Watney, L., Rush, J., Raney J., and Brian Dressel, DOE Project Manager, 2013, Presentation to the KGS Annual Kansas Field Conference participants including Kansas legislators and state officials, morning of Tuesday, June 4th, 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.



Rex Buchanan, Interim Director of KGS, addressing field conference participants with Watney and Dressel (in background looking on) .



Portion of the Mississippian oil reservoir and caprock and the lower Arbuckle injection zone were displayed along with posters relating to the project and the core.



Discussions with field conference attendees after the conference . Shane Lyle, organizer of field conference, in the foreground center.

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

A project organization chart follows. The work authorized in this budget period includes office tasks related to preparation of reports and application for a Class VI permit to inject CO2 into the Arbuckle saline aquifer. Tasks associated with reservoir characterization and modeling are funded in contract DE-FE0002056.

ORGANIZATION CHART

Name	Project Job Title	Primary Responsibility
	Kansas Geological Survey	
Lynn Watney	Project Leader, Joint Principal Investigator	Geology, information synthesis, point of contact
Yevhen Holubnyak	Petroleum Engineer	Reservoir engineer, dynamic modeling, synthesis
Jason Rush	Joint Principal Investigator	Geology, static modeling, data integration, synthesis
John Doveton	Co-Principal Investigator	Log petrophysics, geostatistics
Dave Newell	Co-Principal Investigator	Fluid geochemistry
Rick Miller	Geophysicist	2D seismic acquire & interpretation
		LiDAR/InSAR support, water well drilling/completion
TBN	Geology Technician	Assemble and analyze data, report writing
Tiraz Birdie	President, TBirdie Consulting, Inc.	Hydrogeologic modeling, permitting, MVA, integration
	KU Department of Geology	
Michael Taylor	Co-Principal Investigator	Structural Geology, analysis of InSAR, LiDAR, seismometer array
TBN	Graduate Research Assistant	Structural Geology, analysis of InSAR and LiDAR, seismometer array
	Kansas State University	
Saugata Datta	Principal Investigator	
TBN	Graduate Research Assistant	Aqueous geochemistry
TBN	3- Undergraduate Research Assistants	
	Lawrence Berkeley National Laboratory	
Tom Daley	Co-Principal Investigator	Geophysicist, analysis of crosshole and CASSM data
		Hydrogeology, analysis of soil gas measurements
Barry Freifeld	Co-Principal Investigator	Mechanical Engineer, analysis of U-Tube sampler
	Sandia Technologies, Houston	
Dan Collins	Geologist	Manage CASSM and U-Tube operation
David Freeman	Field Engineer	Manage field install of CASSM and U-Tube
	Berexco, LLC	
Dana Wreath	VP Berexco, LLC	Engineering, Manager of Wellington Field
Randy Koudele	Reservoir engineer	Engineering
Staff of Wellington Field		Field operations
Beredco Drilling team		Mississippian and Arbuckle drilling operations
	Abengoa Bioenergy Corp.	
Christopher Standlee, Danny Alllison		CO2 supply Colwich Ethanol Facility

IMPACT

The project has been discussed in public venues – presentations at professional meetings, legislative committees, and town hall meeting, and has provided information on the project via the website to encourage a dialog on the merits and economies related to carbon management in Kansas. Kansans are realizing the potential for an important collaboration between the two of the largest economies in Kansas – agriculture and related ethanol industry and the petroleum industry to advance energy and contribute to a viable rural economy.

The small scale field test at Wellington Field as designed integrates two petroleum business activities: 1) use of CO2 for enhanced oil recovery and revitalizing many older mature oil fields and 2) disposal/storage of CO2 in the underlying saline aquifer for the longer term. It has been conveyed to the local petroleum industry that drilling and oil production infrastructure of an active oil field are important components that could lead to a successful carbon sequestration project including 1) knowledge about the subsurface including injection zones and caprock, 2) knowledge about abandoned wells, 3) access and suitability of land with greater likelihood for participation by landowner, and 4) access to insurance and investors to facilitate economic success.

CHANGES/PROBLEMS

KGS is committed to starting BP2 on October 1, 2013 by injecting first in the Mississippian reservoir as part of the EOR initiative, pending discussions and approval by DOE. To ensure this, discussions are ongoing with alternative suppliers to deliver the source CO2 since the Abengoa facility will remain out of operation for the remainder of 2013.

APPENDIX II

Small Scale Field Test Demonstrating CO_2 Sequestration in Arbuckle Saline Aquifer and by CO_2-EOR at Wellington Field, Sumner County, Kansas

EIGHTH QUARTERLY PROGRESS REPORT

DOE F 4600.2
(03/11)
All Other Editions Are Obsolete

U.S. Department of Energy
FEDERAL ASSISTANCE REPORTING CHECKLIST
AND INSTRUCTIONS FOR RD&D PROJECTS

1. Identification Number: **DE-FE0006821**	2. Program/Project Title: **Small Scale Field Test Demonstration CO2 Sequestration**

3. Recipient: **University of Kansas Center for Research, Inc.**

4. Reporting Requirements:	Frequency	Addressees
A. MANAGEMENT REPORTING		
☒ Research Performance Progress Report (RPPR)	Q	FITS@NETL.DOE.GOV
☒ Special Status Report	A	FITS@NETL.DOE.GOV
B. SCIENTIFIC/TECHNICAL REPORTING		
(Reports/Products must be submitted with appropriate DOE F 241. The 241 forms are available at www.osti.gov/elink)		
Report/Product — Form		
☒ Final Scientific/Technical Report — DOE F 241.3	FG	http://www.osti.gov/elink-2413
☒ Conference papers/proceedings* — DOE F 241.3	A	http://www.osti.gov/elink-2413
☐ Software/Manual — DOE F 241.4		
☐ Other (see special instructions) — DOE F 241.3		
** Scientific and technical conferences only*		
C. FINANCIAL REPORTING		
☒ SF-425 Federal Financial Report	Q, FG	FITS@NETL.DOE.GOV
D. CLOSEOUT REPORTING		
☒ Patent Certification	FC	FITS@NETL.DOE.GOV
☒ SF-428 & 428B Final Property Report	FC	FITS@NETL.DOE.GOV
☐ Other		
E. OTHER REPORTING		
☒ Annual Indirect Cost Proposal	O	See block 5 below for instructions.
☐ Audit of For-Profit Recipients		
☒ SF-428 Tangible Personal Property Report Forms Family	A	FITS@NETL.DOE.GOV
☒ Other – see block 5 below	A	FITS@NETL.DOE.GOV

FREQUENCY CODES AND DUE DATES:

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1

QUARTERLY PROGRESS REPORT
To
DOE-NETL
Brian Dressel, Program Manager
Award Number: DE-FE0006821

SMALL SCALE FIELD TEST DEMONSTRATING CO_2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO_2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS

Project Director/Principal Investigator:
W. Lynn Watney
Senior Scientific Fellow
Kansas Geological Survey

Ph: 785-864-2184, Fax: 785-864-5317
lwatney@kgs.ku.edu

Joint Principal Investigator:
Jason Rush

Prepared by Lynn Watney
Date of Report: November 5, 2013
DUNS Number: 076248616

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

Project/Grant Period: 10/1/2011 through 9/30/2015

Eighth Quarterly Report

Period Covered by the Report: July 1, 2013 through September 30, 2013

Signature of Submitting Official:



EXECUTIVE SUMMARY

Project Objectives

The objectives of this project are to understand the processes that occur when a maximum of 70,000 metric tonnes of CO_2 are injected into two different formations to evaluate the response in different lithofacies and depositional environments. The evaluation will be accomplished through the use of both *in situ* and indirect MVA (monitoring, verification, and accounting) technologies. The project will optimize for carbon storage accounting for 99% of the CO_2 using lab and field testing and comprehensive characterization and modeling techniques.

CO_2 will be injected under supercritical conditions to demonstrate state-of-the-art MVA tools and techniques to monitor and visualize the injected CO_2 plume and to refine geomodels developed using nearly continuous core, exhaustive wireline logs, and well tests and a multi-component 3D seismic survey. Reservoir simulation studies will map the injected CO_2 plume and estimate tonnage of CO_2 stored in solution, as residual gas, and by mineralization and integrate MVA results and reservoir models shall be used to evaluate CO_2 leakage. A rapid-response mitigation plan will be developed to minimize CO_2 leakage and provide comprehensive risk management strategy. A documentation of best practice methodologies for MVA and application for closure of the carbon storage test will complete the project. The CO_2 shall be supplied from a reliable facility and have an adequate delivery and quality of CO_2. The project shall install compression, chilling, and transport facilities at the ethanol plant for truck transport to the injection site.

Scope of Work

Budget Period 1 includes updating reservoirs models at Wellington Field and filing Class II and Class VI injection permit applications. Static 3D geocellular models of the Mississippian and Arbuckle shall integrate petrophysical information from core, wireline logs, and well tests with spatial and attribute information from their respective 3D seismic volumes. Dynamic models (composition simulations) of these reservoirs shall incorporate this information with laboratory data obtained from rock and fluid analyses to predict the properties of the CO2 plume through time. The results will be used as the basis to establish the MVA and as a basis to compare with actual CO2 injection. The small scale field test shall evaluate the accuracy of the models as a means to refine them in order to improve the predictions of the behavior and fate of CO2 and optimizing carbon storage.

Budget Period 2 includes drilling and equipping a new borehole into the Mississippian reservoir for use in the first phase of CO2 injection; establishing MVA infrastructure and acquiring baseline data; establishing source of CO2 and transportation to the injection site; building injection facilities in the oil field; and injecting CO2 into the Mississippian-age spiculitic cherty dolomitic open marine carbonate reservoir as part of the small scale carbon storage project.

In Budget Period 3, contingent on securing a Class VI injection permit, the drilling and completion of an observation well will be done to monitor injection of CO2 under supercritical conditions into the Lower Ordovician Arbuckle shallow (peritidal) marine dolomitic reservoir. Monitoring during pre-injection, during injection, and post injection will be accomplished with

MVA tools and techniques to visualize CO2 plume movement and will be used to reconcile simulation results. Necessary documentation will be submitted for closure of the small scale carbon storage project.

Project Goals

The proposed small scale injection will advance the science and practice of carbon sequestration in the Midcontinent by refining characterization and modeling, evaluating best practices for MVA tailored to the geologic setting, optimize methods for remediation and risk management, and provide technical information and training to enable additional projects and facilitate discussions on issues of liability and risk management for operators, regulators, and policy makers.

The data gathered as part of this research effort and pilot study will be shared with the Southwest Sequestration Partnership (SWP) and integrated into the National Carbon Sequestration Database and Geographic Information System (NATCARB) and the 6th Edition of the Carbon Sequestration Atlas of the United States and Canada.

Project Deliverables by Task

1.5 Well Drilling and Installation Plan (Can be Appendix to PMP or Quarterly Report)
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19 Updated Site Characterization/Conceptual Models (Can be Appendix to Quarterly Report)
21 Commercialization Plan (Can be Appendix to Quarterly Report).
30 Best Practices Plan (Can be Appendix to Quarterly or Final Report)

ACCOMPLISHMENTS

1. **Continued progress of Milestone 2 (Task 3) --** Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field.
    - Ran new Petrel model of Mississippian
    - Ran new CMG simulations to refine location of Mississippian CO2 injector
    - Geomodel includes new petrophysical facies for the Mississippian (Mina), and stratigraphic interpretation of Lynn with inverted seismic with both phi and k properties distributed through the model by Jason.

2. **Subtask 1.8 Arbuckle Injection Permit Application** – The permit application consists of 14 chapters (sections). Drafts for all section were completed by KGS on October 10 and forwarded to DOE and Berexco for review. The executive summary of the permit application is included below relay the content.

   The permit document contains an extensive amount of raw, processed, and analyzed technical information along with model simulation results which summarizes the suitability of the Wellington site for conducting not only the small-scale pilot test, but potentially long-term commercial scale carbon capture and sequestration (CCS).

Milestone Status Report

Task	Budget Period	Number	Milestone Description
Task 2.	1	1	Site Characterization of Arbuckle Saline Aquifer System - Wellington Field
Task 3.	1	2	Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field
Task 10.	2	3	Pre-injection MVA - establish background (baseline) readings
Task 13.	2	4	Retrofit Arbuckle Injection Well (#1-28) for MVA Tool Installation
Task 18.	3-yr1	5	Compare Simulation Results with MVA Data and Analysis and Submit Update of Site Characterization, Modeling, and Monitoring Plan
Task 22.	3-yr1	6	Recondition Mississippian Boreholes Around Mississippian CO2-EOR injector
Task 27.	3-yr2	7	Evaluate CO2 Sequestration Potential of CO2-EOR Pilot
Task 28.	3-yr2	8	Evaluate Potential of Incremental Oil Recovery and CO2 Sequestration by CO2-EOR - Wellington field

Project Schedule

Abengoa Biofuels informed us in late July that the Colwich Ethanol Facility would remain shut for the rest of the year because of prior drought in the Midwest and current economics. KGS aggressively engaged in discussions with potential suppliers of anthropogenic CO_2 including Praxair, Airgas, Linde, POET Biofuels, Chaparral Energy, and Trenton Agri Products, LLC. Geologic CO2 is not an option for the Wellington project, due to demand for this product along existing pipelines in Texas, New Mexico, Colorado, and Wyoming. Anthropogenic CO2 will be the only viable option for CO2-EOR and as required disposal of the CO2 in the deep saline Arbuckle aquifer below. Berexco is keenly interested in the saline aquifer storage from multiple viewpoints increasingly expressed by others in the petroleum industry – incentives to CO2 suppliers such as enhanced prices for ethanol by sequestration of the CO2 that is injected, obtaining deposal fees to inject CO2 and manage with general operation of the oil field, and with the case at Wellington, obtaining income generated by carbon trading (Biorecro in Sweden).

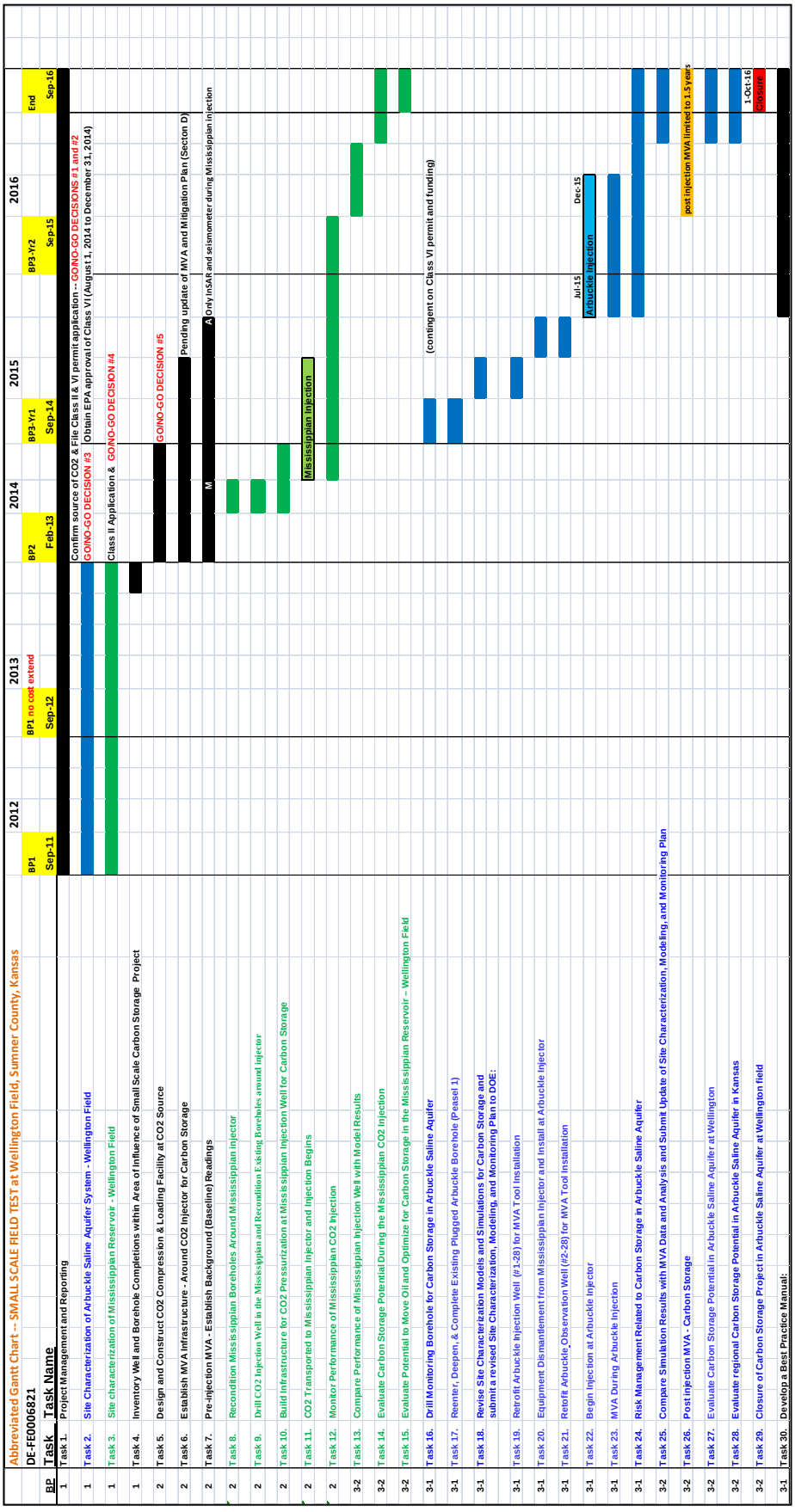
Meetings and conference calls have been held with potential suppliers of CO2 during through September and October. We are currently finalizing quotes for CO2 and are confident that we will have KU contract signed by mid November for one of the suppliers. We will be ready to revise the budget to bring CO2 to Wellington in 2014.

KGS injection at the Wellington site should commence in FY2014 on a schedule depending if the CO2 capture facility will need to be constructed. Our expectation now is that the CO2 will be ready to inject by October 2014. We now plan to first inject into the Mississippian oil and gas reservoir and geomodeling and simulation are well enough along to refine the location and injection schedule.

On October 10, 2013 the Class VI UIC geosequestration permit application was submitted to DOE and Berexco for interval review prior to submitting to EPA. Revised document should be submitted to EPA in December 2013.

A new SOPO was drafted and reviewed by DOE 10/29/13 and will be submitted to DOE for official acceptance once the CO2 source is selected. The Gantt Chart and schedule will also be modified depending on CO2 source and availability of the CO2 for delivery. A decision on the supply by mid November will provide sufficient time to revise the budget and begin Budget Period 2.

A condensed version of the Gantt Chart follows. The PMP and Gantt Chart will be updated as soon as a CO2 source is finalized.


Abbreviated Gantt Chart -- SMALL SCALE FIELD TEST at Wellington Field, Sumner County, Kansas
DE-FE0006821
BP
Task
Task Name
BP1
Sep-11
2012
2013
BP1 no cost extend
Sep-12
BP2
Feb-13
2014
BP3-Yr1
Sep-14
2015
BP3-Yr2
Sep-15
2016
End
Sep-16
1 Task 1. Project Management and Reporting
1 Task 2. Site Characterization of Arbuckle Saline Aquifer System - Wellington Field
1 Task 3. Site characterization of Mississippian Reservoir - Wellington Field
1 Task 4. Inventory Well and Borehole Completions within Area of Influence of Small Scale Carbon Storage Project
2 Task 5. Design and Construct CO2 Compression & Loading Facility at CO2 Source
2 Task 6. Establish MVA Infrastructure - Around CO2 Injector for Carbon Storage
2 Task 7. Pre-injection MVA - Establish Background (Baseline) Readings
2 Task 8. Recondition Mississippian Boreholes Around Mississippian injector
2 Task 9. Drill CO2 Injection Well in the Mississippian and Recondition Existing Boreholes around injector
2 Task 10. Build Infrastructure for CO2 Pressurization at Mississippian Injection Well for Carbon Storage
2 Task 11. CO2 Transported to Mississippian Injector and Injection Begins
2 Task 12. Monitor Performance of Mississippian CO2 Injection
3-2 Task 13. Compare Performance of Mississippian Injection Well with Model Results
3-2 Task 14. Evaluate Carbon Storage Potential During the Mississippian CO2 Injection
3-2 Task 15. Evaluate Potential to Move Oil and Optimize for Carbon Storage in the Mississippian Reservoir -- Wellington Field
3-1 Task 16. Drill Monitoring Borehole for Carbon Storage in Arbuckle Saline Aquifer
3-1 Task 17. Reenter, Deepen, & Complete Existing Plugged Arbuckle Borehole (Pease 1)
3-1 Task 18. Revise Site Characterization Models and Simulations for Carbon Storage and submit a revised Site Characterization, Modeling, and Monitoring Plan to DOE:
3-1 Task 19. Retrofit Arbuckle Injection Well (#1-28) for MVA Tool Installation
3-1 Task 20. Equipment Dismantlement from Mississippian Injector and Install at Arbuckle Injector
3-1 Task 21. Retofit Arbuckle Observation Well (#2-28) for MVA Tool Installation
3-1 Task 22. Begin Injection at Arbuckle Injector
3-1 Task 23. MVA During Arbuckle Injection
3-1 Task 24. Risk Management Related to Carbon Storage in Arbuckle Saline Aquifer
3-2 Task 25. Compare Simulation Results with MVA Data and Analysis and Submit Update of Site Characterization, Modeling, and Monitoring Plan
3-2 Task 26. Post injection MVA - Carbon Storage
3-2 Task 27. Evaluate Carbon Storage Potential in Arbuckle Saline Aquifer at Wellington
3-2 Task 28. Evaluate regional Carbon Storage Potential in Arbuckle Saline Aquifer in Kansas
3-2 Task 29. Closure of Carbon Storage Project in Arbuckle Saline Aquifer at Wellington field
3-1 Task 30. Develop a Best Practice Manual:
Confirm source of CO2 & File Class II & VI permit application -- GO/NO-GO DECISIONS #1 and #2
GO/NO-GO DECISION #3
Obtain EPA approval of Class VI (August 11, 2014 to December 31, 2014)
Class II Application &
GO/NO-GO DECISION #4
GO/NO-GO DECISION #5
Pending update of MVA and Mitigation Plan (Section D)
M
A
Only InSAR and seismometer during Mississippian injection
Mississippian injection
(contingent on Class VI permit and funding)
Jul-15
Dec-15
Arbuckle injection
post injection MVA limited to 1.5 years
1-Oct-16
Closure

Activities of Lawrence Berkeley National Lab

No work has been completed or funds expended during this quarter by LBNL.

ONGOING ACTIVITIES –

TASK 1. PROJECT MANAGEMENT AND REPORTING

Subtask 1.8. Arbuckle Injection Permit Application

Permit Status and Activities

The table below is undergoing weekly updates to inform DOE on the status of the CO2 supply and permits to drill Arbuckle and Mississippian wells.

Schedule for DE-FE0006821 - Contracting new CO2 source, rescheduling with revised budget and SOPO	%COMPLETION
1) Complete negotiations by Dana Wreath (Berexo) and KGS with CO2 suppliers to receive final bids for the CO2, ensuring reliable safe delivery, maximize volume of CO2, option to be involved in the onsite injection	90%
September 6, 2013 (best); ~~October 6 (worst)~~ November 15 with KU contract	
2) Complete DOE budget review of CO2 costs and revise Berexco subcontract completed via a 9.2 form; formalize schedule and update SOPO and Gantt Chart	10%
October 30, 2013 (best); ~~November 30, 2013 (worst)~~ beginning November 18	
3) Obtain Class II permit to inject CO2 into the Mississippian	50%
September 30, 2013 (best); November 30, 2013 (worst)	
4) Obtain permission from DOE to commence field activities – drill Mississippian injection well (**revised BP2**)	
November 15, 2013 (best); December 1, 2013	
5) Begin drilling of Mississippian injection well	
~~December 1, 2013 (best); February 1, 2014~~ after February 1, 2014 with start of BP2 and negotiated budget	
6) Establish surface facilities to inject CO2 and complete MVA activities slated for the Mississippian (InSAR, passive seismic, sample fluids from production wells in 5-spot)	
March 1, 2014 (best); April 1, 2014 (worst)	
7) Begin injection of CO2 into the Mississippian	
April 1, 2014 (best); June 1, 2014 (worst) October 1 '14 (~~with mobility control~~) October 1 if skid is built	
8) Complete injection in the Mississippian	
January 1, 2015 (best); March 1, 2015 (worst) July 30, 2015 (~~with mobility control~~)	
9) Submit Class VI permit to EPA to inject into Arbuckle	
November 1, 2013 (best), December 31st, 2013 (worst) -- submitted to DOE and Berexco 10/10/13	
10) Obtain Class VI permit to inject into Arbuckle	
August 1, 2014 (best), December 31, 2014 (worst)	
11) Drill observation well into Arbuckle	
October 1, 2014 (best), March 1, 2015 (worst)	
12) Install MVA equipment in observation well	
November 1, 2014 (best), April 1, 2015 (worst)	
13) Install shallow and deep groundwater monitoring wells	
September 1, 2014 (best), March 1, 2015 (worst)	
14) Begin injection of CO2 into the Arbuckle saline aquifer	
February 1, 2015 (best), July 1, 2015 (worst) August 1, 2015 (~~with mobility control~~)	
15) Complete injection of CO2 into the Arbuckle saline aquifer (20k tonnes of CO2)	
October 1, 2015 (best), January 1, 2016 (worst)	
16) Complete post injection monitoring of the Arbuckle	
August 1, 2015 (best), October 1, 2016 (worst)	
17) Run repeat 3D seismic survey over Arbuckle injection site	
August 1, 2015(best), October 1, 2016 (worst)	
18) Apply for closure of the Arbuckle injection site	
August 1, 2016 (best), October 1, 2016 (worst)	
19) Project end.	
September 30, 2016 (best), February 1, 2017 (worst)	

The draft of the Executive Summary of the Class VI application is included here to show the basis of the application that is being internally reviewed.

Draft Executive Summary

A small scale pilot carbon capture and storage (CCS) project is proposed by Berexco, Inc and Kansas Geological Survey at the Wellington oilfield approximately four miles northwest of the City of Wellington in Sumner County, Kansas (Figure ES-1). The project is part of a US Department of Energy (DOE) funded pilot scale study to demonstrate the ability of the 4,000 feet deep Cambrian-Ordovician age Arbuckle saline aquifer to accept and retain carbon dioxide (CO_2) for permanent geologic sequestration. Approximately 40,000 tons of anthropogenic CO_2 is to be injected in the Arbuckle aquifer over a period of 9 months. The details of the project and EPA Underground Injection Control (UIC) Class VI construction, operations, monitoring, well plugging, Area of Review (AoR), post-injection site care and site closure, emergency remedial/response, and financial responsibility plans are summarized below.

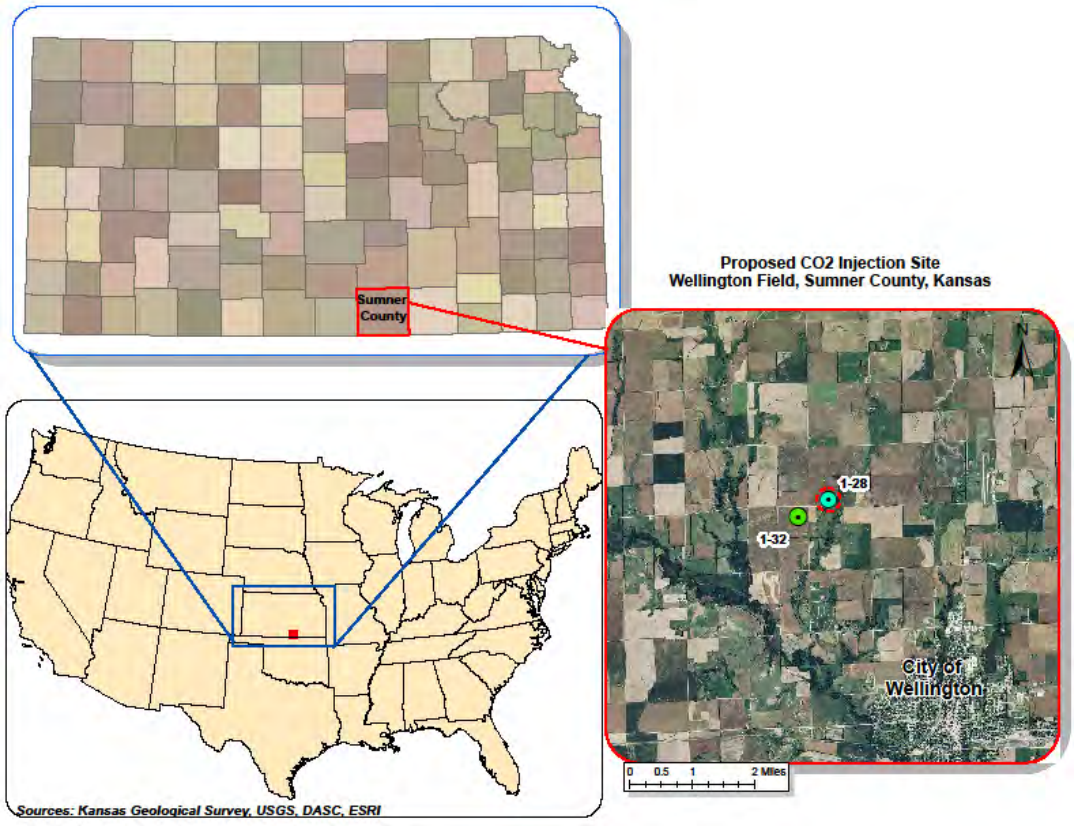


Figure ES-1 *Location of small-scale CO2 storage site at Wellington, Kansas*

Site Setting

The Wellington sequestration site is located in a rural area where land is used primarily for (non-irrigated) crop cultivation (Figure ES-2). CO_2 injection is to occur at the recently completed well (KGS 1-28) which was constructed per EPA UIC Class VI specifications. There are no potable water wells in the vicinity of the injection well. The EPA AoR based on the maximum extent of plume migration is only 1,750 feet from the well as shown in Figure ES-2.

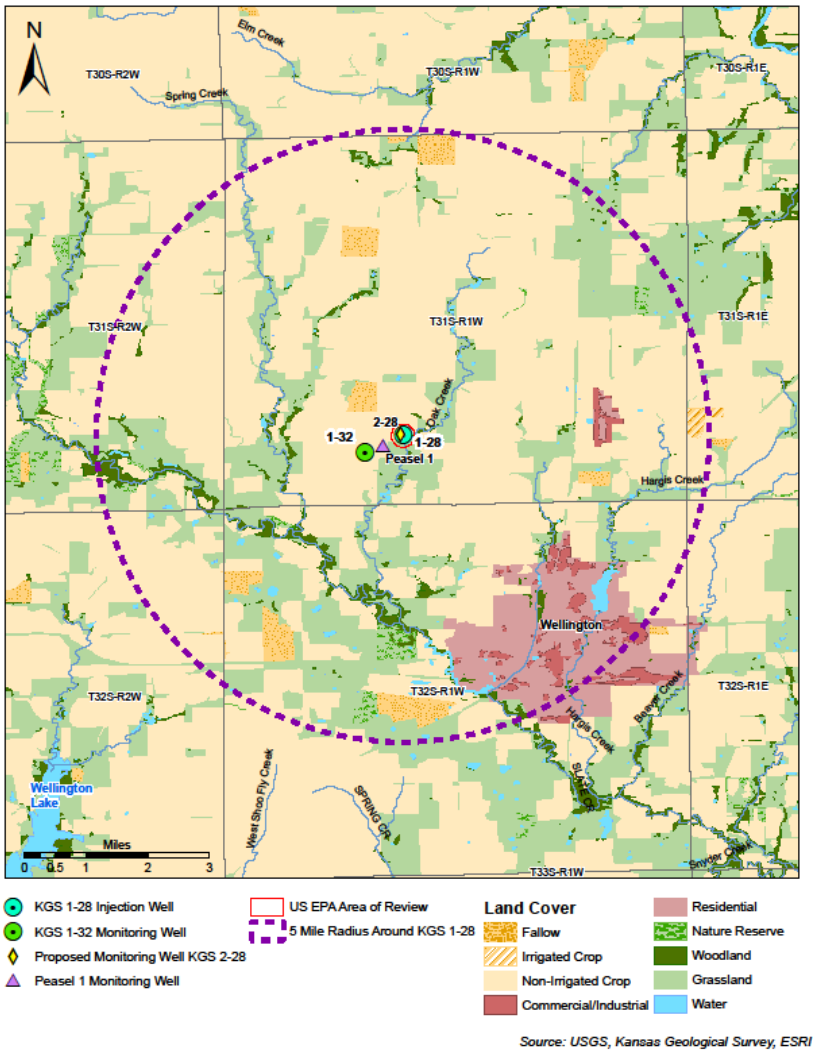


Figure ES-2 Land use in the vicinity of the Wellington small-scale CO_2 storage site

Geology

Arbuckle Group (Injection Zone)

The geologic column at the injection well site is presented in Figure ES-3. The injection is to occur in the 1,000 ft thick regionally extensive Arbuckle Group of Cambrian-Ordovician period located approximately 4,160 feet below ground at the Wellington site. The injection is to occur near the base of the Arbuckle Group, which has relatively higher permeability as compared to the rest of the formation.

Simpson Group/Chattanooga Shale/Pierson Formation (Upper Confining Zone)

The Ordovician and Devonian shales within the Simpson Group and Chattanooga Shale, along with the argillaceous siltstone in the Pierson Formation of Mississippian subsystem, have the characteristics of caprock and will therefore function as the top confining zone and effectively prevent upward migration of CO_2. The 240 feet thick confining zone has a minimum number of communicative fractures. There are several thick layers of shale above the upper confining zone as well as shown in Figure ES-3, which can potentially provide additional impedance to flow, but which are not relied in this application to demonstrate confinement potential.

Precambrian Granitic Basement (Lower Confining Zone)

Precambrian-age basement granites underlie the Arbuckle Group throughout Kansas, and are expected to provide hydraulic confinement at the base of the injection zone.

Upper Wellington Formation (USDW)

The lowermost and only Underground Sources of Drinking Water (USDW) extends from land surface to 250 feet below ground and comprises of Permian shales in the Upper Wellington Formation as shown in Figure ES-3. Below the Upper Wellington are the Hutchinson Salt Beds which overlies bedrock shales in the Lower Wellington Formation. The USDW (Upper Wellington formation) lies approximately 4,500 feet above the top of the injection zone in the lower

Arbuckle aquifer. There are no groundwater withdrawals in the vicinity of the Wellington CO_2 storage site.

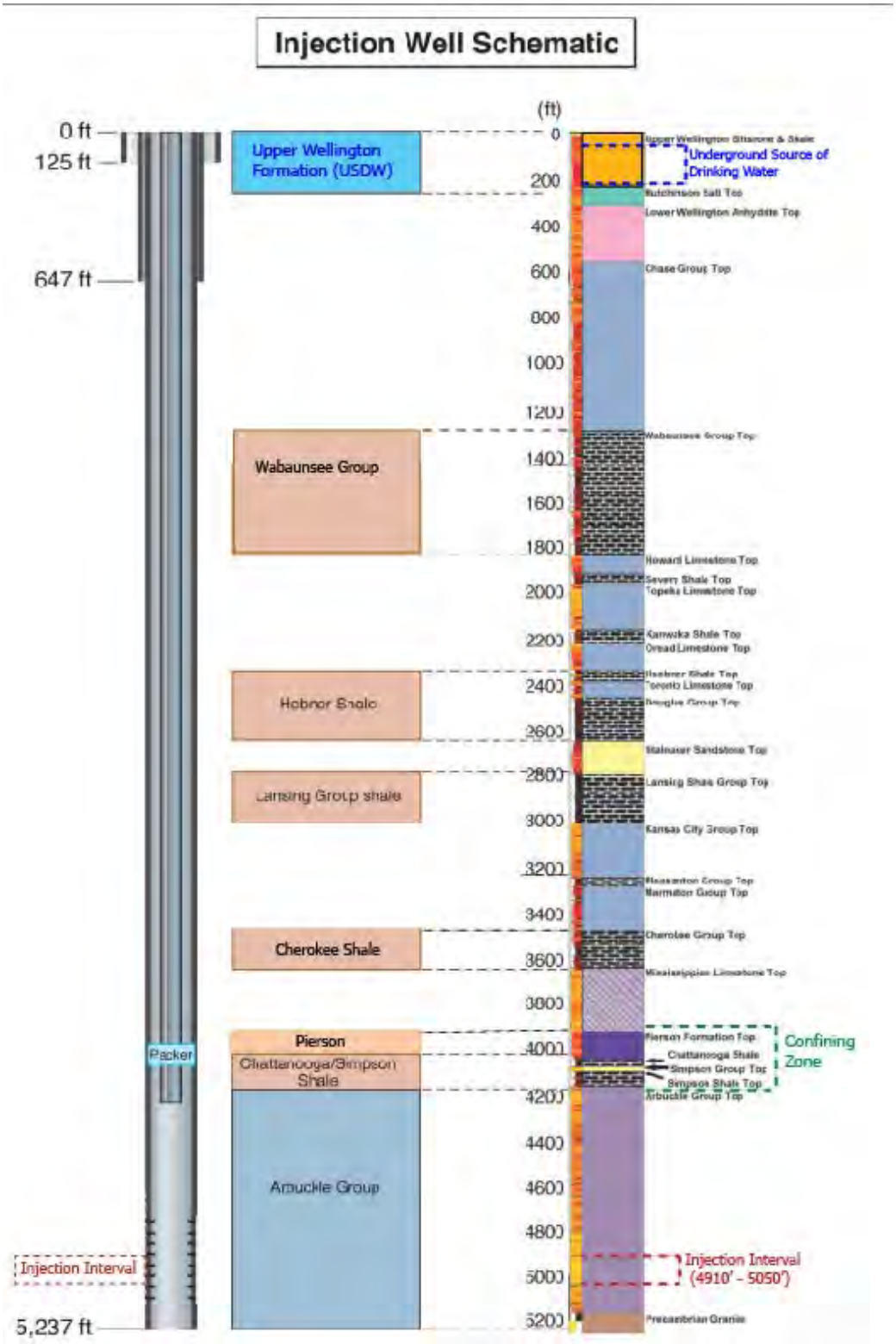


Figure ES-3 Schematic of injection well showing geologic formations at Wellington sequestration site *(Jennifer to prepare better figure and also show Injection Zone and Precambrian basement*).

Estimated Sequestration Capacity of Arbuckle Group

The total amount of CO_2 that could be stored in the Arbuckle Group within Kansas is estimated by the US DOE to be as high 89.5 billion metric tons, the equivalent of several years of annual CO_2 emissions (approximately 6 billion metric ton/year)for the entire United States. Approximately 300,000-360,000 metric tons of CO_2 per square mile can be stored in the Arbuckle aquifer at the Wellington site as shown in Figure ES-4. Only 40,000 tons of CO_2 will be injected into the Arbuckle during a period of 9 months, which as per DOE estimates should be stored in an area of $1/10^{th}$ of a square mile.

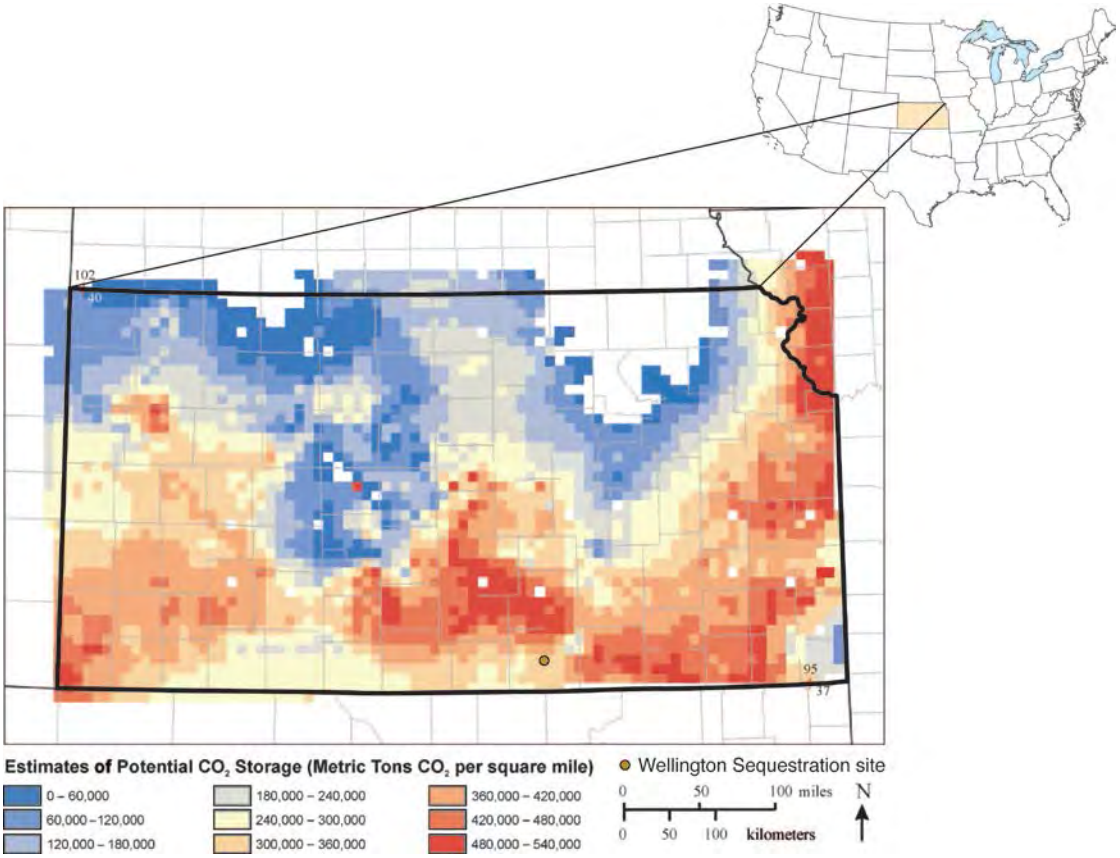


Figure ES-4 Map showing the estimated sequestration potential in the Arbuckle saline aquifer in metric tons CO_2 per square mile.

Modeling

During construction of the injection well (KGS 1-28) and the geologic characterization well (KGS 1-32) shown in Figure ES-1, an extensive suite of geophysical logs were obtained to understand the geology and hydrogeology, and derive petrophysical properties. The data was used to develop a reservoir simulation model of the Arbuckle Group. An extensive set of computer simulations were conducted using the base case model and nine alternative models in order to account for parametric uncertainty and to bracket the impacts of CO_2 injection on subsurface fluid pressures and extent of CO_2 plume migration. The underlying motivation was to determine if the injected CO_2 could negatively impact the USDW, or potentially escape into the atmosphere through existing wells or faults/fractures that may either be present, reactivated, or created by the injected fluid.

Simulation results indicate that the maximum pressure induced in the Arbuckle aquifer are insufficient to cause vertical migration of the brines into the USDW due to under-pressurization of the Arbuckle aquifer. The (pre-injection) heads in the Arbuckle injection zone are approximately 600 feet lower than heads in the USDW. Simulation results also indicate that the pressures induced due to injection will dissipate within three months of cessation of injection. Also, the maximum pressure induced at the top of the Arbuckle are insufficient to cause Arbuckle fluids to migrate upward due to the high entry pressure of the confining zone.

Simulations results also indicate that the CO_2 will largely remain confined in the lower Arbuckle injection zone and not migrate even into the mid-Arbuckle (Figure ES-5a). Laterally, the maximum extent of the plume is expected to be approximately 1,750 feet from the injection well as shown in Figure ES-5b, and the plume growth is expected to cease in less than a year of cessation of injection. Therefore, a post-injection monitoring period of one year is proposed as indicated below.

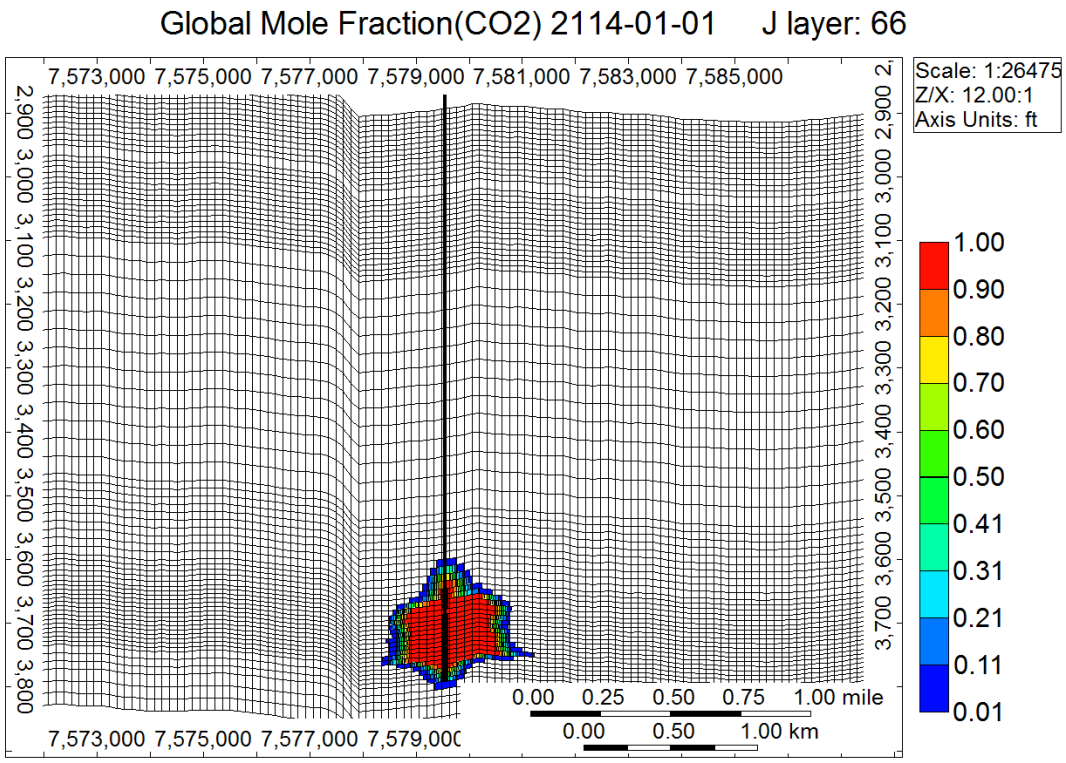


Figure ES-5a Vertical extent of CO_2 plume migration at the end of 100 years following injection (Jenn to improve figure and also show the injection interval and other Arbuckle zones).

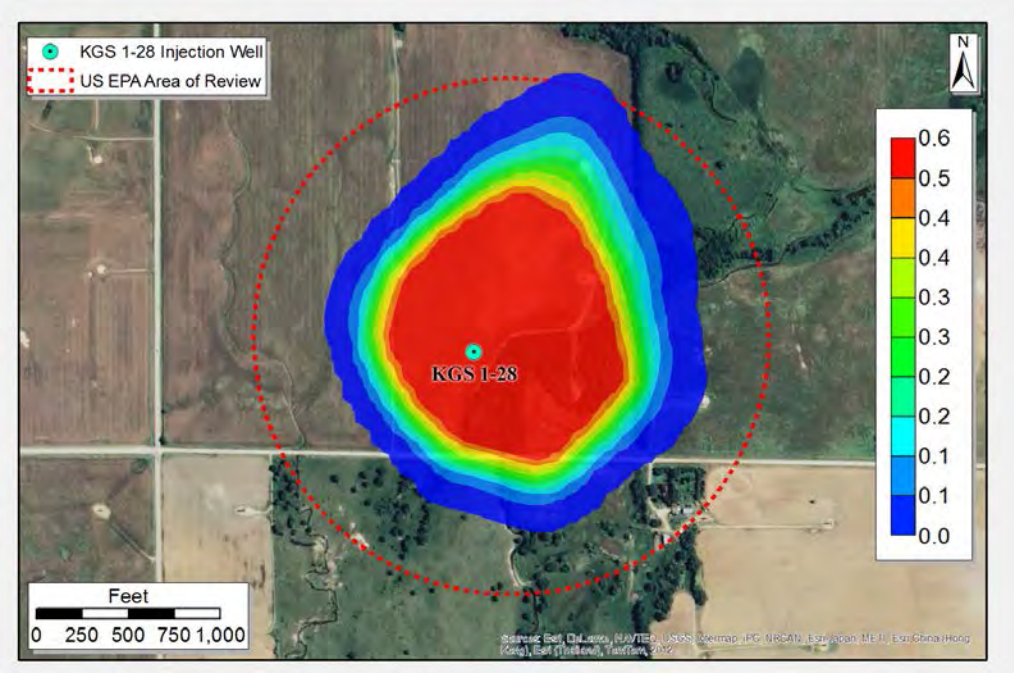


Figure ES-5b Maximum extent of CO_2 plume migration (Jenn to improve figure and also show 2-28 and 1-32).

AoR and Corrective Action

The EPA AoR derived for the Wellington project is based on EPA's *Maximum Extent of the Separate-phase Plume or Pressure-front (MESPOP)* methodology. It was determined that the pressures to be induced due to injection of CO_2 at Wellington are insufficient to cause brines from the Arbuckle Group to migrate vertically into the USDW through any natural or artificial penetration. Therefore, the AoR is based on the maximum extent of plume migration, which as shown in Figure ES-5 extends approximately 1,750 feet from the injection well. There are no existing or abandoned wells (other than the proposed injection well) either in the Arbuckle Group or the overlying confining zone within the AoR. Therefore, no well corrective action is required.

Following commencement of injection, if significant deviations in the projected formation pressures and plume migration patterns are observed, then the reservoir model may be recalibrated which will trigger an automatic revaluation of the AoR and Corrective Action Plan. This iterative process may continue until field based observations and model projections are in agreement.

CO_2 Compatibility in Injection Zone and Well

Geochemical analyses suggests that the injection of anthropogenic CO_2 should not cause any compatibility problems with formation waters and minerals in the Arbuckle Group, which could result in reduced pore space, excessive formation/well pressures, or any hindrance to injection operations or geologic storage.

The tubing, casing, packer, and cement of the injection well are also designed for CO_2 injection operations. The chemical composition of the injectate should cause no adverse reactions or degradation of the well components for the short nine month duration of injection. The low water content of the injected CO_2 and the low temperatures will result in only a mildly corrosive environment. Quarterly monitoring for corrosion using coupons however is to be conducted in order to provide early warning of a deteriorating environment.

Testing and Monitoring Plan

A total of five monitoring wells will be used for tracking the CO_2 plume and pressure front. The locations of these monitoring wells and the formations they will monitor are shown in Figure ES-6. One monitoring well is located in the Arbuckle aquifer. Two existing Mississippian wells will be used to check if CO_2 has escaped upward from the primary confining zone (base of Simpson Group to top of Pierson Formation) at the site. Two shallow wells will monitor water quality in the Upper Wellington Formation (lowermost USDW). Both direct and indirect measurement methods will be used to monitor the movement of the pressure and plume fronts, identify potential risks to USDWs, and to verify predictions of plume movement.

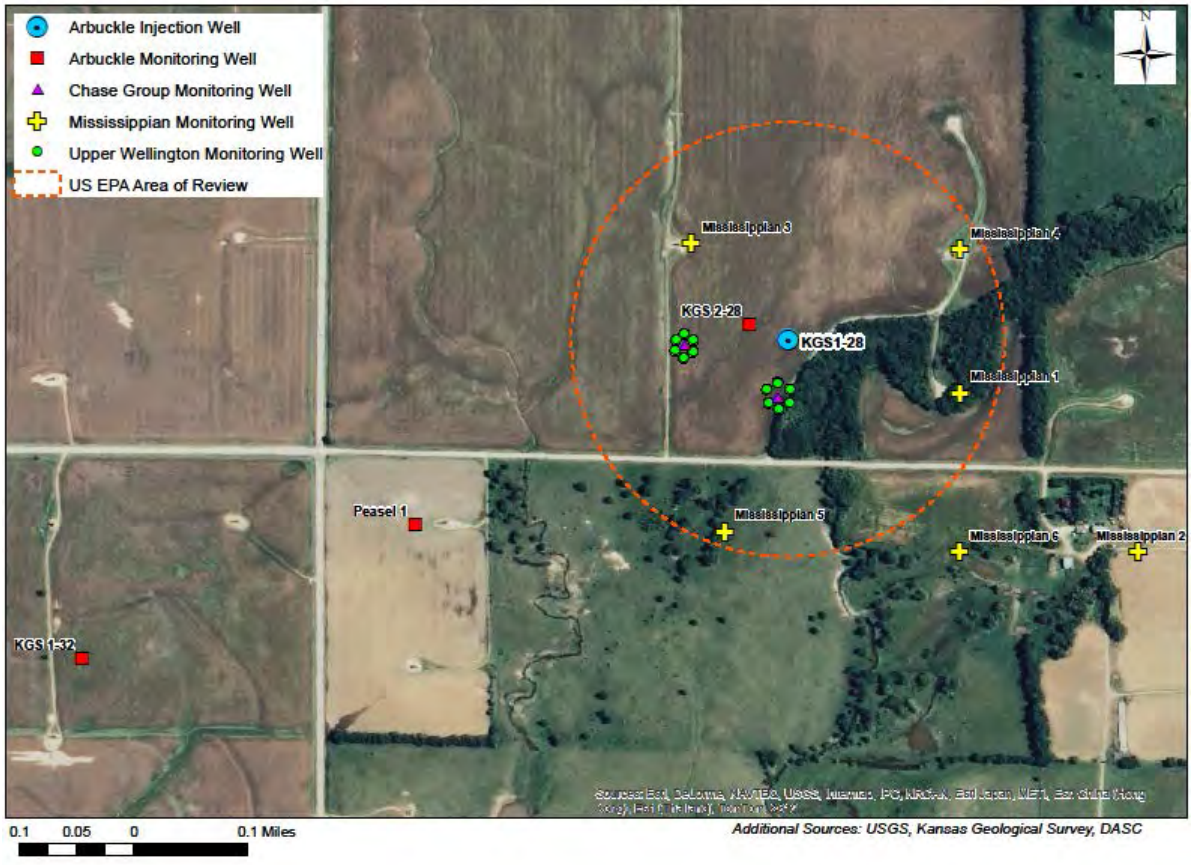


Figure ES-6 Location of monitoring wells in the Arbuckle, Mississippian, and Wellington formations (Jenn to only show final wells that have been selected).

Injection Well Monitoring

The surface and bottomhole pressures and temperatures will be monitored continuously at the injection well. The chemical composition of the injectate will be tested quarterly in order to ensure that it does not qualify as hazardous waste with regard to corrosivity or toxicity. Due to the short nine month period of injection, corrosion is not expected to occur in the Wellington injection or observation wells. However, corrosion coupons will be used for monitoring loss of material in the Arbuckle injection and monitoring wells on a quarterly basis.

Internal and external Mechanical Integrity Tests (MITs) will be conducted prior to, during, and following injection. Temperature logs will be used to demonstrate external MIT. Prior to commencing injection, an Annulus Pressure Test will also be conducted at the injection well in order to demonstrate internal MIT. The test will provide information necessary to determine whether there is a failure of the casing-cement bond, injection tubing, and packers.

A pre-injection pressure fall-off test will be conducted in order to estimate formation properties in the vicinity of the injection well. This information will serve as a baseline in the event of any changes in the near-wellbore environment that may impact injectivity and result in pressure increases.

Pressure Front Monitoring

Pressure transducers will be installed in the Arbuckle injection and monitoring wells (KGS 1-28 and KGS 2-28). The acquired pressure data will be compared with model based prediction of the pressure front, and if necessary, the simulation model will be recalibrated to conform to field data. In addition to direct monitoring, the pressure front will also be tracked areally by monitoring surface deformation using InSAR (Interferometric Synthetic Aperture Radar) remote sensing technique.

Monitoring the Plume Front

Various direct and indirect MVA tools and techniques shall be used to monitor the plume front. The crosswell tomography, U-tube, and continuous active source seismic

monitoring (CASSM) technology shall be used to monitor and visualize the movement of the CO_2 plume. Sampling and analysis of water and casing head gas from existing Mississippian wells/boreholes around the Arbuckle injector shall be used to determine if injected CO_2 has breached the confining zone and escaped into the overlying Mississippian Reservoir. Shallow groundwater sampling and analysis will help confirm if any injected CO_2 has reached the USDW. The newly acquired data will be compared with the existing baseline seismic data in order to track the plume movement. The monitored data will also be used revise the simulation model, update site characterization, and potentially revise the monitoring plan if deemed necessary.

A 3-D seismic survey will also be undertaken prior to closure, in order to validate the absence of CO_2 outside the containment strata and confirm that future leakage risks are minimal to non-existent.

Geomechanical Failure and Seismic Risk

Simulation results indicate that the pressures induced due to CO_2 injection at KGS 1-28 are insufficient to initiate new fracture, propagate existing fractures, or cause slippage along any existing fault planes. There are no documented faults in the vicinity of the injection well, with the closest fault approximately 12.5 miles southeast of the site where negligible pressures will be induced due to injection. The Wellington storage site (and all of Kansas) is in a low seismic hazard area as defined by the United States Geological Survey. Historical record indicates that most earthquakes in Kansas are small with the largest measured at 4.0 on the Richter scale, which is not of sufficient strength to cause any infrastructure damage.

CO_2 Trapping Potential of the Mississippian Oil Field

The Mississippian oil reservoir lies immediately above the primary upper confining zone. It is a highly under-pressurized system which is likely a consequence of oil and gas production that has occurred in this formation since the early 1900s. Due to this under-pressurization, any CO_2 that may escape from the primary confining zone is likely to be trapped in the Mississippian formation. This under-pressurization could not have existed in the absence of a competent low permeability confining zone between the Arbuckle and the Mississippian systems, which essentially provides a hydraulic seal between the two formations.

Injection Well Construction

The 5,241 ft deep injection well (KGS 1-28) penetrates the top of the pre-Cambrian basement rock at a depth of approximately 5,160 feet. The well will be perforated between 4910 – 5050 feet for injection into the highly permeable lower Arbuckle zone as shown in Figure ES-3. The injection well was constructed in accordance with UIC Class VI construction guidelines using CO_2 resistant cement and corrosion resistant material in the production casing and injection tubing. The tubing and the casing are designed to withstand axial, burst, and collapse stresses. Cement bond and variable density logs were acquired after setting and cementing the surface casing and long-string casing. These logs do not indicate any loss of mechanical integrity.

Injection Well Plugging Plan

The injection well and potentially the Arbuckle monitoring well (KGS 2-28) will be plugged as per UIC Class VI specifications to the top of the Pierson Formation, which corresponds to the top of the confining zone. Both wells may be used in the future for CO_2 Enhanced Oil Recovery (EOR) injection or other oilfield operations in the locally producing Mississippian formation, so plugging will only occur to the base of the intended oil recovery zone (top of Pierson Formation). The Arbuckle monitoring well KGS 2-28 will be plugged as a Class VI well in the event that the CO_2 plume reaches this well, or is expected to reach this well at any time in the future.

Surface Facilities and Operations

The planned volume of CO_2 injection is 150 tonnes per day. The CO_2 will be transported to the site in trucks in liquid state at a pressure of approximately 250 pounds per square inch (psi) and temperature of -10^{o} F. The surface facilities at the Wellington injection site will consist of a storage tank, a pump, a programmable logic controller (PLC), and wellhead. The bottomhole and wellhead pressures and temperatures will be continuously monitored along with the flow rate and the data fed continuously to the PLC. The PLC will manipulate the control valve in order to not exceed the maximum specified flow rate and to ensure that the bottom hole pressure in the injection well does not exceed the maximum allowable pressure, which corresponds to 90% of the fracture pressure. The PLC will be programmed to initiate shutdown if the operating ranges are exceeded.

Post Injection Site Care and Site Closure Plan (PISC)

Due to the expected stabilization of the pressure and plume fronts in less than a year following cessation of injection, it is proposed that site be closed one year after cessation of injection. Upon cessation of injection, the most recently acquired field data will be used to refine the reservoir model if necessary, and update simulation results and the projected pressure front and plume movement. The revised projections will be used to determine whether the monitoring, AoR, and PISC plans are adequate to ensure accurate tracking of the plume/pressure front and support closure of the site. If necessary, this process of data acquisition and model refinement/projections may continue in order to determine whether or not the injected CO_2could migrate out of the storage formation into the USDW. Once a determination of no negative impacts to the USDW is made, an application for site closure will be filed with the EPA Director.

Emergency Remedial Response Plan

An Emergency Remedial Response Plan has been prepared and will be implemented if Berexco obtains evidence that the injected CO_2 stream and/or associated pressure front may endanger the USDW. Specific plans are outlined for a variety of emergency conditions related to testing, monitoring, and mechanical failure. The plans involve immediate cessation of injection, identification and characterization of the failure, notification of the EPA UIC Program Director within 24 hours, and implementation of the appropriate response and remedial action. In addition to executing an automatic shutdown, the PLC will also notify Berexco of a shutdown over cellular network.

Financial Responsibility Plan

Due to its extensive experience in subsurface oil and gas operations and strong financial position, Berexco, is opting for the self-insurance option to demonstrate Financial Responsibility to carry out CO_2 storage activities related to performing well corrective action, injection well plugging, post-injection site care, site closure and implementing an emergency/remedial plan . Berexco meets or exceeds all minimum financial coverage criteria to demonstrate financial strength and ability to complete sequestration activities. It should also be noted that the Wellington projected is part of a cooperative agreement with the US DOE. The US DOE has obligated approximately 11 million dollars for this project. Therefore, financial risks to Berexco are minimal.

Conclusions and Risks to USDW

Detailed AoR, Construction and Operations, Testing and Monitoring, Injection Well Plugging, Post-Injection Site Care and Site Closure, Emergency and Remedial Response, and Financial Responsibility plans have been prepared and documented in this application to fulfill all 40 CFR Part 146 requirements for developing and operating a Class VI CO_2 geologic sequestration project.

The modeling based projections for the small-scale pilot project indicate that the subsurface pressures induced due to CO_2 injection will be insufficient to cause vertical migration of brines from the injection zone into the USDW. Additionally, the injected CO_2 is expected to be contained within the injection zone in the lower portions of the Arbuckle, and the plume to stabilize within one year of cessation of injection. Therefore, risk of contamination of the USDW from injection operations at Wellington is minimal.

--- end of Executive Summary --

Subtask 1.9 Mississippian Injection Permit Application

Petrel model of Mississippian updated week of 9/23/14 and will run CMG simulation after that/use to refine location of Miss CO2 injector

9/30/13 geomodel has integrated petrophysical facies for the Mississippian (Mina), and stratigraphic interpretation of Lynn with inverted seismic with both phi and k distributed

10/11/13 - CMG simulation underway and initial results to be presented next week

10/29/13 -- Initial simulations by Eugene and more to come to use in confirming location of Mississippian injection well

Key Findings

1. We have a portfolio of viable CO2 suppliers, one whom will provide CO2 to Wellington Field. Contacts will be maintained with other suppliers as part of continuing discussions on handling anthropogenic CO2 in Kansas.
2. The Class VI geosequestration permit application has met fundamental guidelines of EPA and the document provides a clear representation of this information needed for an expeditious review toward approval of the small scale field test.

Plans

1. Complete negotiations, select CO2 supplier, and negotiate the budget in next quarter so that BP 2 and field activities can begin on February 1, 2014.
2. Finalize refined model of the Mississippian so that Mississippian Injection Permit Application can be submitted.
3. Submit application for Class VI injection permit to the EPA in next quarter.
4. Submit updated management plan, SOPO and Gantt Chart with selection of CO2 source.
5. Submit well drilling and installation plan, MVA plan, Public Outreach Plan based on material included in Class VI application as part of next quarterly report.

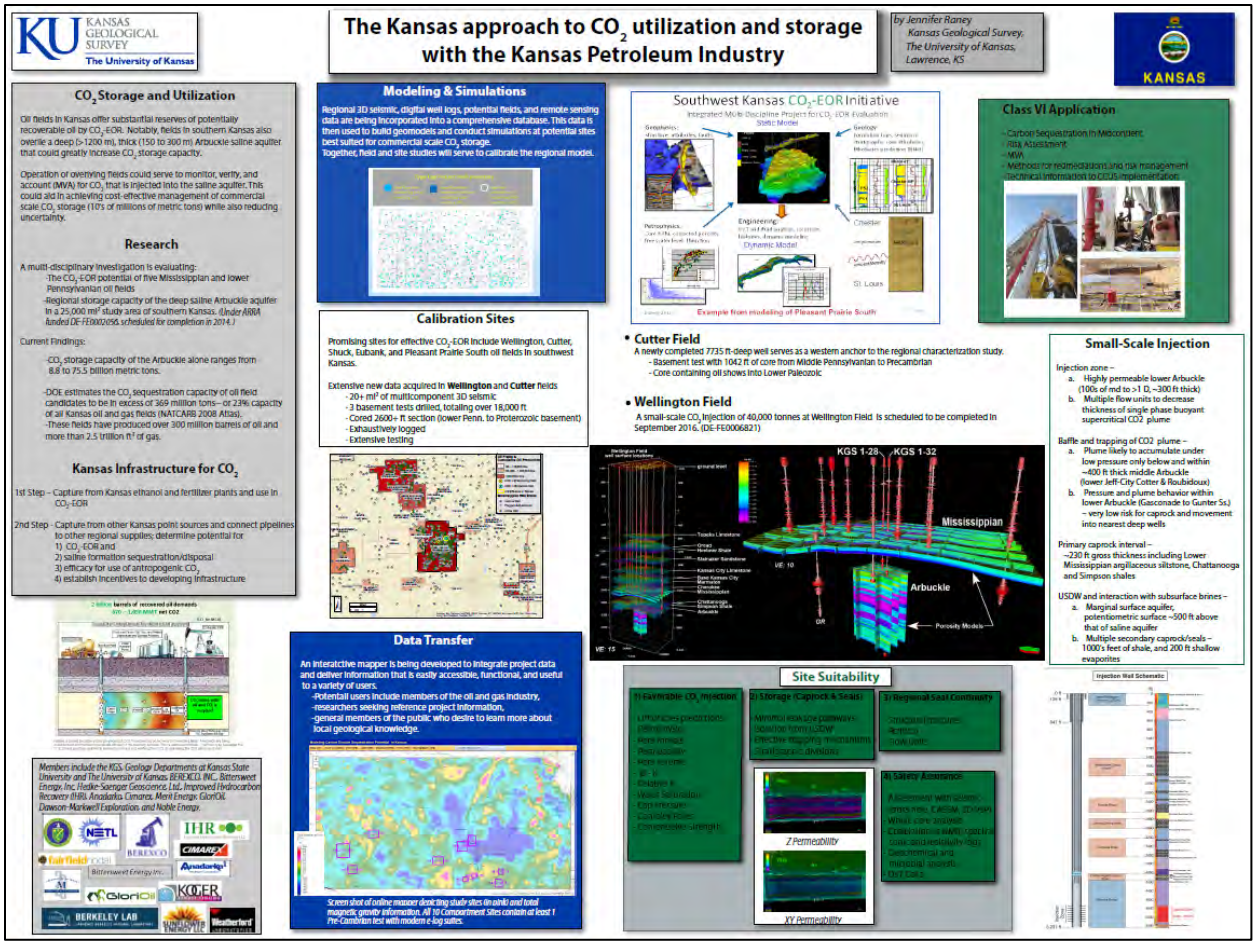
PRODUCTS

Publications, conference papers, and presentations

DOE Annual review meeting, August 20 & 21, 2013, Pittsburgh, PA

W. Lynn Watney and Jason Rush, Joint PIs, 2013, *Small scale field test demonstrating CO2 sequestration in Arbuckle saline aquifer and by CO2-EOR at Wellington field, Sumner County, Kansas DE-FE0006821*.
http://www.kgs.ku.edu/PRS/Ozark/Reports/2013/Watney_DE-FE0006821_FY13_Carbon_Storage_Review_v3.pdf

Jennifer Raney, 2013, *The Kansas approach to CO2 utilization and storage with the Kansas petroleum industry.* (see below)



Presentations, Midcontinent AAPG

Brent Campbell, 2013, Geochemical assessment of secondary oil recovery, and assessing potential quantification of CO2 sequestration in the underlying saline Arbuckle aquifer, AAPG Mid-Continent Section Meeting, Wichita.

John Doveton, 2013, Pore size and textural analysis of carbonates from nuclear magnetic resonance logging : an Arbuckle case study, AAPG Mid-Continent Section Meeting, Wichita.

Yevhen Holubnyak, 2013, Reservoir Engineering Aspects of Pilot Scale CO2 EOR Project in Upper Mississippian Formation at Wellington Field in Southern Kansas, AAPG Mid-Continent Section Meeting, Wichita.

Yevhen Holubnyak, 2013, Dynamic Modeling of CO2 Geological Storage in the Arbuckle Saline Aquifer, AAPG Mid-Continent Section Meeting, Wichita.

W. Lynn Watney, 2013, Seismic attribute analysis of the Mississippian chert at the Wellington Field, south-central Kansas, AAPG Mid-Continent Section Meeting, Wichita.

W. Lynn Watney, 2013, Evaluating CO2 Utilization and Storage in Kansas, AAPG Mid-Continent Section Meeting, Wichita.

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

A project organization chart follows. The work authorized in this budget period includes office tasks related to preparation of reports and application for a Class VI permit to inject CO2 into the Arbuckle saline aquifer. Tasks associated with reservoir characterization and modeling are funded in contract DE-FE0002056.

ORGANIZATION CHART

Name	Project Job Title	Primary Responsibility
Kansas Geological Survey		
Lynn Watney	Project Leader, Joint Principal Investigator	Geology, information synthesis, point of contact
Yevhen Holubnyak	Petroleum Engineer	Reservoir engineer, dynamic modeling, synthesis
Jason Rush	Joint Principal Investigator	Geology, static modeling, data integration, synthesis
John Doveton	Co-Principal Investigator	Log petrophysics, geostatistics
Dave Newell	Co-Principal Investigator	Fluid geochemistry
Rick Miller	Geophysicist	2D seismic acquire & interpretation
		LiDAR/InSAR support, water well drilling/completion
TBN	Geology Technician	Assemble and analyze data, report writing
Tiraz Birdie	President, TBirdie Consulting, Inc.	Hydrogeologic modeling, permitting, MVA, integration
KU Department of Geology		
Michael Taylor	Co-Principal Investigator	Structural Geology, analysis of InSAR, LiDAR, seismometer array
TBN	Graduate Research Assistant	Structural Geology, analysis of InSAR and LiDAR, seismometer array
Kansas State University		
Saugata Datta	Principal Investigator	
TBN	Graduate Research Assistant	Aqueous geochemistry
TBN	3- Undergraduate Research Assistants	
Lawrence Berkeley National Laboratory		
Tom Daley	Co-Principal Investigator	Geophysicist, analysis of crosshole and CASSM data
		Hydrogeology, analysis of soil gas measurements
Barry Freifeld	Co-Principal Investigator	Mechanical Engineer, analysis of U-Tube sampler
Sandia Technologies, Houston		
Dan Collins	Geologist	Manage CASSM and U-Tube operation
David Freeman	Field Engineer	Manage field install of CASSM and U-Tube
Berexco, LLC		
Dana Wreath	VP Berexco, LLC	Engineering, Manager of Wellington Field
Randy Koudele	Reservoir engineer	Engineering
Staff of Wellington Field		Field operations
Beredco Drilling team		Mississippian and Arbuckle drilling operations
Abengoa Bioenergy Corp.		
Christopher Standlee, Danny Alllison		CO2 supply Colwich Ethanol Facility

IMPACT

The project has been discussed in public venues – presentations at professional meetings, legislative committees, and town hall meeting, and has provided information on the project via the website to encourage a dialog on the merits and economies related to carbon management in Kansas. Kansans are realizing the potential for an important collaboration between the two of the largest economies in Kansas – agriculture and related ethanol industry and the petroleum industry to advance energy and contribute to a viable rural economy.

The small scale field test at Wellington Field as designed integrates two petroleum business activities: 1) use of CO2 for enhanced oil recovery and revitalizing many older mature oil fields and 2) disposal/storage of CO2 in the underlying saline aquifer for the longer term. It has been conveyed to the local petroleum industry that drilling and oil production infrastructure of an active oil field are important components that could lead to a successful carbon sequestration project including 1) knowledge about the subsurface including injection zones and caprock, 2) knowledge about abandoned wells, 3) access and suitability of land with greater likelihood for participation by landowner, and 4) access to insurance and investors to facilitate economic success.

CHANGES/PROBLEMS

KGS is committed to starting BP2 on February 1, 2014 with a new CO2 supplier on board and beginning field activities to inject CO2 into the Mississippian reservoir.

BUDGETARY INFORMATION

Cost Status Report

See next page for the cost status for quarters 1-8.

APPENDIX II

Small Scale Field Test Demonstrating CO_2 Sequestration in Arbuckle Saline Aquifer and by CO_2-EOR at Wellington Field, Sumner County, Kansas

NINTH QUARTERLY PROGRESS REPORT

DOE F 4600.2
(03/11)
All Other Editions Are Obsolete

U.S. Department of Energy
FEDERAL ASSISTANCE REPORTING CHECKLIST
AND INSTRUCTIONS FOR RD&D PROJECTS

1. Identification Number: **DE-FE0006821**	2. Program/Project Title: **Small Scale Field Test Demonstration CO2 Sequestration**

3. Recipient: **University of Kansas Center for Research, Inc.**

4. Reporting Requirements:	Frequency	Addressees
A. MANAGEMENT REPORTING		
☒ Research Performance Progress Report (RPPR)	Q	FITS@NETL.DOE.GOV
☒ Special Status Report	A	FITS@NETL.DOE.GOV
B. SCIENTIFIC/TECHNICAL REPORTING		
(Reports/Products must be submitted with appropriate DOE F 241. The 241 forms are available at www.osti.gov/elink)		
Report/Product — Form		
☒ Final Scientific/Technical Report — DOE F 241.3	FG	http://www.osti.gov/elink-2413
☒ Conference papers/proceedings* — DOE F 241.3	A	http://www.osti.gov/elink-2413
☐ Software/Manual — DOE F 241.4		
☐ Other (see special instructions) — DOE F 241.3		
** Scientific and technical conferences only*		
C. FINANCIAL REPORTING		FITS@NETL.DOE.GOV
☒ SF-425 Federal Financial Report	Q, FG	
D. CLOSEOUT REPORTING		
☒ Patent Certification	FC	FITS@NETL.DOE.GOV
☒ SF-428 & 428B Final Property Report	FC	FITS@NETL.DOE.GOV
☐ Other		
E. OTHER REPORTING		See block 5 below for instructions.
☒ Annual Indirect Cost Proposal	O	
☐ Audit of For-Profit Recipients		FITS@NETL.DOE.GOV
☒ SF-428 Tangible Personal Property Report Forms Family	A	FITS@NETL.DOE.GOV
☒ Other – see block 5 below	A	

FREQUENCY CODES AND DUE DATES:

A - Within 5 calendar days after events or as specified.
FG- Final; 90 calendar days after the project period ends.
FC- Final; End of Effort.
Y - Yearly; 90 calendar days after the end of the reporting period.
S - Semiannually; within 30 calendar days after end of project year and project half-year.
Q - Quarterly; within 30 days after end of the reporting period.
Y180 – Yearly; 180 days after the end of the recipient's fiscal year
O - Other; See instructions for further details.

5. Special Instructions:

Annual Indirect Cost Proposal – If DOE is the Cognizant Federal Agency, then the proposal should be sent to FITS@NETL.DOE.GOV . Otherwise, it should be sent to the Cognizant Federal Agency.

Other – The Recipient shall provide all deliverables as contained in Section D of Attachment 2 Statement of Project Objectives.

QUARTERLY PROGRESS REPORT
To
DOE-NETL
Brian Dressel, Program Manager
Award Number: DE-FE0006821

SMALL SCALE FIELD TEST DEMONSTRATING CO_2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO_2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS

Project Director/Principal Investigator:
W. Lynn Watney
Senior Scientific Fellow
Kansas Geological Survey

Ph: 785-864-2184, Fax: 785-864-5317
lwatney@kgs.ku.edu

Joint Principal Investigator:
Jason Rush

Prepared by Lynn Watney
Date of Report: March 10, 2014 (revised)
DUNS Number: 076248616

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

Project/Grant Period: 10/1/2011 through 9/30/2015

Ninth Quarterly Report

Period Covered by the Report: October 1, 2013 through December 31, 2013

Signature of Submitting Official:

Willard Lynn Watney

Digitally signed by Willard Lynn Watney
DN: cn=Willard Lynn Watney, o=The University of Kansas, ou=Kansas Geological Survey, email=lwatney@kgs.ku.edu, c=US
Date: 2014.03.10 16:25:07 -05'00'

EXECUTIVE SUMMARY

Project Objectives

The objectives of this project are to understand the processes that occur when a maximum of 70,000 metric tonnes of CO_2 are injected into two different formations to evaluate the response in different lithofacies and depositional environments. The evaluation will be accomplished through the use of both *in situ* and indirect MVA (monitoring, verification, and accounting) technologies. The project will optimize for carbon storage accounting for 99% of the CO_2 using lab and field testing and comprehensive characterization and modeling techniques.

CO_2 will be injected under supercritical conditions to demonstrate state-of-the-art MVA tools and techniques to monitor and visualize the injected CO_2 plume and to refine geomodels developed using nearly continuous core, exhaustive wireline logs, and well tests and a multi-component 3D seismic survey. Reservoir simulation studies will map the injected CO_2 plume and estimate tonnage of CO_2 stored in solution, as residual gas, and by mineralization and integrate MVA results and reservoir models shall be used to evaluate CO_2 leakage. A rapid-response mitigation plan will be developed to minimize CO_2 leakage and provide comprehensive risk management strategy. A documentation of best practice methodologies for MVA and application for closure of the carbon storage test will complete the project. The CO_2 shall be supplied from a reliable facility and have an adequate delivery and quality of CO_2. The project shall install compression, chilling, and transport facilities at the ethanol plant for truck transport to the injection site.

Scope of Work

Budget Period 1 includes updating reservoirs models at Wellington Field and filing Class II and Class VI injection permit applications. Static 3D geocellular models of the Mississippian and Arbuckle shall integrate petrophysical information from core, wireline logs, and well tests with spatial and attribute information from their respective 3D seismic volumes. Dynamic models (composition simulations) of these reservoirs shall incorporate this information with laboratory data obtained from rock and fluid analyses to predict the properties of the CO2 plume through time. The results will be used as the basis to establish the MVA and as a basis to compare with actual CO2 injection. The small scale field test shall evaluate the accuracy of the models as a means to refine them in order to improve the predictions of the behavior and fate of CO2 and optimizing carbon storage.

Budget Period 2 includes drilling and equipping a new borehole into the Mississippian reservoir for use in the first phase of CO2 injection; establishing MVA infrastructure and acquiring baseline data; establishing source of CO2 and transportation to the injection site; building injection facilities in the oil field; and injecting CO2 into the Mississippian-age spiculitic cherty dolomitic open marine carbonate reservoir as part of the small scale carbon storage project.

In Budget Period 3, contingent on securing a Class VI injection permit, the drilling and completion of an observation well will be done to monitor injection of CO2 under supercritical conditions into the Lower Ordovician Arbuckle shallow (peritidal) marine dolomitic reservoir. Monitoring during pre-injection, during injection, and post injection will be accomplished with MVA tools and techniques to visualize CO2 plume movement and will be used to reconcile simulation results. Necessary documentation will be submitted for closure of the small scale carbon storage project.

Project Goals

The proposed small scale injection will advance the science and practice of carbon sequestration in the Midcontinent by refining characterization and modeling, evaluating best practices for MVA tailored to the geologic setting, optimize methods for remediation and risk management, and provide technical information and training to enable additional projects and facilitate discussions on issues of liability and risk management for operators, regulators, and policy makers.

The data gathered as part of this research effort and pilot study will be shared with the Southwest Sequestration Partnership (SWP) and integrated into the National Carbon Sequestration Database and Geographic Information System (NATCARB) and the 6th Edition of the Carbon Sequestration Atlas of the United States and Canada.

Project Deliverables by Task

1.5 Well Drilling and Installation Plan (Can be Appendix to PMP or Quarterly Report)
1.6 MVA Plan (Can be Appendix to PMP or Quarterly Report)
1.7 Public Outreach Plan (Can be Appendix to PMP)
1.8 Arbuckle Injection Permit Application Review go/no go Memo
1.9 Mississippian Injection Permit Application Review go/no go Memo
1.10 Site Development, Operations, and Closure Plan (Can be Appendix to PMP)
2.0 Suitable geology for Injection Arbuckle go/no go Memo
3.0 Suitable geology for Injection Mississippian go/no go Memo
11.2 Capture and Compression Design and Cost Evaluation go/no go Memo
19 Updated Site Characterization/Conceptual Models (Can be Appendix to Quarterly Report)
21 Commercialization Plan (Can be Appendix to Quarterly Report).
30 Best Practices Plan (Can be Appendix to Quarterly or Final Report)

ACCOMPLISHMENTS

1. Completed Well Drilling and Installation Plan Subtask 1.5. (See Appendix A-1 Drilling and Well Installation Plan
2. Completed Subtask 1.6. MVA Plan (See Appendix A-2 Testing and Monitoring Plan)
3. Completed Subtask 1.7. Public Outreach Plan (See Appendix A-3 Wellington Public Outreach)
4. Completed Subtask 1.8. Arbuckle Injection Permit Application Review go/no go Memo (See Appendix A-4 Permit Application)
5. Completed Subtask 1.10. Site Development, Operations, and Closure Plan (Please see Appendix A-5 Operations and Closure Plan and Appendix A-6 Post-Injection Site Care and Site Closure Plan)

Milestone Status Report

Task	Budget Period	Number	Milestone Description
Task 2.	1	1	Site Characterization of Arbuckle Saline Aquifer System - Wellington Field
Task 3.	1	2	Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field
Task 10.	2	3	Pre-injection MVA - establish background (baseline) readings
Task 13.	2	4	Retrofit Arbuckle Injection Well (#1-28) for MVA Tool Installation
Task 18.	3-yr1	5	Compare Simulation Results with MVA Data and Analysis and Submit Update of Site Characterization, Modeling, and Monitoring Plan
Task 22.	3-yr1	6	Recondition Mississippian Boreholes Around Mississippian CO2-EOR injector
Task 27.	3-yr2	7	Evaluate CO2 Sequestration Potential of CO2-EOR Pilot
Task 28.	3-yr2	8	Evaluate Potential of Incremental Oil Recovery and CO2 Sequestration by CO2-EOR - Wellington field

Task 2, Site characterization of the Arbuckle saline aquifer system in Wellington Field, has been completed and incorporated into the Class VI injection application.

Task 3, Site characterization of the Mississippian reservoir for CO2-EOR in Wellington Field will be completed in the first quarter of 2014 for use in selecting drilling site for use in the Class II application to also be submitted in the first quarter of 2014.

Project Schedule

CO2 Supply -- Discussion with three industrial suppliers reestablished as complications developed with primary supplier. Costs have been revisited based on daily supply and combining sources.

Some of the deliberations with suppliers are provided as exerpts below:

> 10/11/13 -- Very productive meeting with Company A and their CO2-EOR Director in Wichita, hosted by Berexco. A field trip was taken to Wellington. Company A and will provide quote to supply 50,000 tonnes from fertilizer plant in Oklahoma. Continued discussions with Company B to supply CO2 from ethanol plant. At time of negotiations, the source hinged on this company becoming a contractor under KUCR.
>
> 10/21/2013 -- Teleconference with Company C expecting to receive official quote during week of October 28th from a fertilizer plant in Kansas.
>
> 10/22/2013 -- Received quote for CO2 from Company D from another fertilizer plant in Oklahoma.
>
> 10/29/201 -- KUCR working with Company B on a subcontract details.
>
> 11/20/2013 -- Company B reviewing KUCR subcontract and will present to management in December.
>
> 12/10/2013 -- Second option to presented to Company B to purchase CO2. Relayed delays to Robert Trautz, PI of FOA 798 - Fiber Optic Cable acoustic monitoring. Update options spreadsheet with new market cost of CO2 based on CO2 prices.

Advantages of an industrial supplier include and thus are being seriously considered:

1. CO2 injection in the Mississippian oil reservoir could begin in late summer;

2. Schedule would accommodate the fiber optic project FOA 798;

3 The outlay of funds from DOE could initially be limited to the CO2 Mississippian until Class VI application is approved.

5. Industrial sources are well established trusted companies with experience in utilizing CO2 in the oil field, minimizing potential for the delay in startup and disruptions along the way.

6. The industrial sources would help to keep project within five years.

Class VI Injection application – October 10, 2013 --- Class VI application submitted to DOE and Berexco on for review prior to submitting to EPA. **10/29/2013** -- Berexco received a binder with Class VI application in print form. DOE returned reviews through Section 4. Dennis Hedke provided a final prestack depth migration volume for Wellington that will improve the Arbuckle geomodel. New seismic volume is merged with Noble's seismic distributing to Dana, Jason, and George T. at KU. **11/20/13** -- DOE review of the Class VI application is complete and revisions are being completed. Berexco continues to review. **12/10/13** -- DOE completed review and penultimate revision being prepared pending receipt of review from Berexco.

Class II CO2-EOR injection application -- 10/11/13 - CMG simulation underway and initial results to be presented next week. 10/29/13 -- Initial simulations by Eugene and more to come to use in confirming location of Mississippian injection well. 12/10/13 -- Final simulations expected later in December so that decisions can be made about precise well location. Anticipate receipt of Class II permit to inject in Mississippian will require 1 month.

Revision of SOPO -- 10/29/13 – SOPO has been revised to be submitted pending selection of CO2 source. Gantt Chart/schedule will change depending on source(s) that is selected. SOPO now deploys Mississippian infrastructure first. 12/10/2013 -- Revising KU side of budget including removal of LiDAR from budget and replacing with IRIS-PASSCAL seismometer installation. State of Kansas will provide cost to install15 seismometers into bedrock at locations suited to monitor both the Mississippian and Arbuckle injections. Rick Miller will join Watney as lead to install equipment, obtain, process, and interpret the data. Plans are to deploy seismometers in Spring 2014 to acquire background data.

Activities of Lawrence Berkeley National Lab

No work has been completed or funds expended during this quarter by LBNL.

ONGOING ACTIVITIES –

1) Complete negotiations by Dana Wreath (Berexco) and KGS with CO2 suppliers to receive final bids for the CO2, ensuring reliable safe delivery, maximize volume of CO2, option to be involved in the onsite injection.

2) Complete DOE budget review of CO2 costs and revise Berexco subcontract completed via a 9.2 form; formalize schedule and update SOPO and Gantt Chart and begin BP2

3) Complete and submit Class VI injection application to EPA

4) Complete modeling and set the well location in order to submit Class II permit to State for Mississippian test injection.

4) Obtain permission from DOE to commence field activities – drill Mississippian injection well (revised BP2)

5) Preparations to begin BP2 to commence field work and deploy MVA activities suited for the Mississippian including InSAR, seismometers/passive seismic, adapt producing wells to permit sampling fluids.

TASK 1. PROJECT MANAGEMENT AND REPORTING

Subtask 1.5 Well Drilling and Installation Plan (See Appendix A-1)

Subtask 1.6. MVA Plan (See Appendix A-2 Testing and Monitoring Plan)

Subtask 1.7. Public Outreach Plan (See Appendix A-3 Wellington Public Outreach)

Subtask 1.8. Arbuckle Injection Permit Application Review go/no go Memo (See Appendix A-4 Permit Application)

Subtask 1.10. Site Development, Operations, and Closure Plan (Please see Appendix A-5 Operations and Closure Plan and Appendix A-6 Post-Injection Site Care and Site Closure Plan)

Key Findings

1. At the time of the writing, all of the questions and comments for internal reviews for the Class VI injection application have been addressed and final copy will be provided to Berexco for signature and then will be submitted to Region 7 EPA on March 1. EPA has been informed of this submission date.
2. CO2 supplier will be settled in first quarter 2014.

Plans for First Quarter 2014

1. Choose CO2 source with DOE and Berexco based on summary for vendor, delivery schedule, total amount, daily delivery, and costs.
2. Submit Class VI and Class injection applications.

3. Complete SOPO and budgeting and reevaluating what MVA is deployed for Mississippian test.
4. Submit no cost extension.

PRODUCTS

Publications, conference papers, and presentations

Yevhen Holubnyak, Jennifer Raney, Lynn Watney, Jason Rush, Mina Fazelalavi, and John Doveton, 2013, Dynamic Simulation of Pilot Scale CO2 Injection in the Arbuckle Saline Aquifer at Wellington Field in Southern Kansas: American Geophysical Union, Fall Meeting, San Francisco.

Jennifer Raney, 2013, Using improved Technology for Widespread Application of a Geological Carbon Storage Study: American Geophysical Union, Fall Meeting, San Francisco.

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A project organization chart follows. The work authorized in this budget period includes office tasks related to preparation of reports and application for a Class VI permit to inject CO2 into the Arbuckle saline aquifer. Tasks associated with reservoir characterization and modeling are funded in contract DE-FE0002056.

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TBN	Graduate Research Assistant	Structural Geology, analysis of InSAR and LiDAR, seismometer array
Kansas State University		
Saugata Datta	Principal Investigator	
TBN	Graduate Research Assistant	Aqueous geochemistry
TBN	3- Undergraduate Research Assistants	
Lawrence Berkeley National Laboratory		
Tom Daley	Co-Principal Investigator	Geophysicist, analysis of crosshole and CASSM data
		Hydrogeology, analysis of soil gas measurements
Barry Freifeld	Co-Principal Investigator	Mechanical Engineer, analysis of U-Tube sampler
Sandia Technologies, Houston		
Dan Collins	Geologist	Manage CASSM and U-Tube operation
David Freeman	Field Engineer	Manage field install of CASSM and U-Tube
Berexco, LLC		
Dana Wreath	VP Berexco, LLC	Engineering, Manager of Wellington Field
Randy Koudele	Reservoir engineer	Engineering
Staff of Wellington Field		Field operations
Beredco Drilling team		Mississippian and Arbuckle drilling operations
Abengoa Bioenergy Corp.		
Christopher Standlee, Danny Alllison		CO_2 supply Colwich Ethanol Facility

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CHANGES/PROBLEMS

KGS is committed to starting BP2 on March 31, 2014 by finalizing contract with CO2 supplier, submitting Class II and IV applications. beginning field activities to inject CO2 into the Mississippian reservoir.

BUDGETARY INFORMATION

Cost Status Report

See figure on the following page for the cost status for quarters 1-9.

Appendix A-1

Drilling and Well Installation Plan

A-1.1 Introduction

A total of twenty three wells will be used to monitor pressures and track the CO2 plume in the subsurface. The locations of these monitoring wells and the formations that they will monitor are shown in Figure A-1.1. Three monitoring wells will be located in the Arbuckle aquifer, six in the Mississippian system, two in the Chase Group underlying the Wellington Formation at the top, and twelve in the Upper Wellington Formation which is the lowermost (and only) Underground Source of Drinking Water (USDW) that is to be protected as a resource of potable water. Of the three Arbuckle wells, two (KGS #1-32 and Peasel-1) are existing wells. All six Mississippian wells are existing wells that will be retrofitted with gas sampling ports to collect casing head gas to detect and measure breakthrough or off-pattern migration of CO2. The remaining monitoring will be either new wells or retrofitted (Peasel-1) as summarized below:

Table A-1.1 Summary of new monitoring wells to be constructed/retrofitted at the Wellington CO2 storage site.

Geologic Formation	**Number of new wells or wells to be reworked**
Upper Wellington Formation (USDW)	12 new wells
Chase Group (Immediately below USDW)	2 new wells
Arbuckle Group (Injection Zone)	1 new well (KGS #2-28) - 1 retrofitted (Peasel-1)

The well design and construction plans for the new monitoring wells, and the Peasel-1 Arbuckle well which is to be reworked are discussed below.

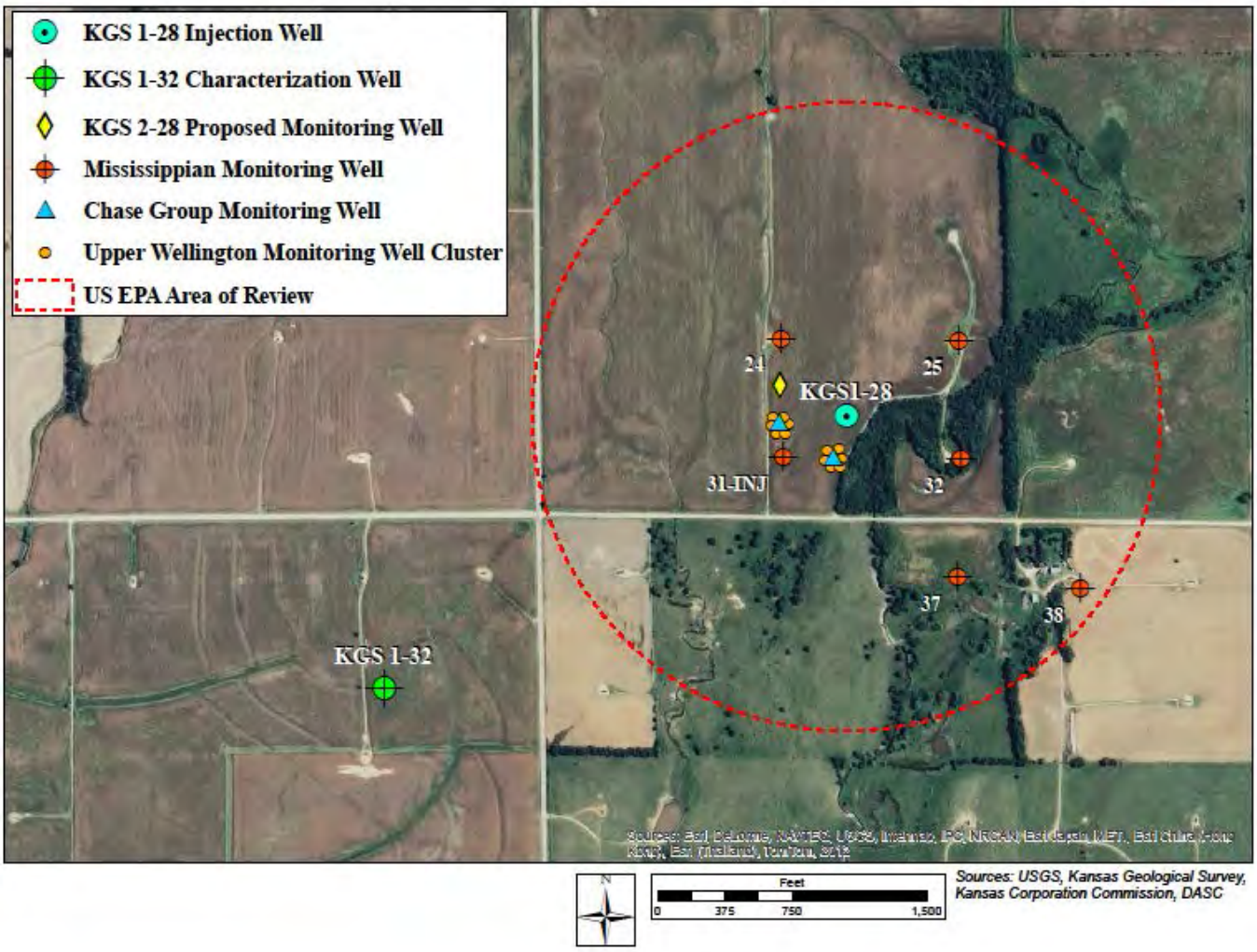


Figure A-1.1—Location of monitoring wells in the Arbuckle, Mississippian, and Wellington Formations.

A-1.2 KGS #2-28 Arbuckle Monitoring Well

One new monitoring well (KGS #2-28) is to be constructed to monitor the CO_2 plume and pressure front in the Arbuckle Group. The well will be constructed approximately 350 feet up dip of the injection well KGS #1-28, and will be used to facilitate direct and indirect monitoring of both the pressure front and CO_2 plume in the Arbuckle. The well will be constructed in full compliance with EPA Class VI standards to ensure containment of CO_2, and a full suite of geophysical logs will be obtained at the site. It is expected that the plume will reach this well in approximately 60–75 days after commencement of injection.

There is remarkable similarity in the geologic formations at existing Arbuckle well sites KGS #1-28 and KGS #1-32 which are located approximately 3,500 feet apart as shown in Figure A-1.1. Therefore, the

geologic horizons at KGS #2-28 are also expected to be very similar to that at KGS #1-28. Hence, the proposed design of KGS #2-28, presented in Figure A-1.2, is very similar to the injection well, KGS #1-28. The well is expected to be approximately 5,200 feet deep, penetrating the top of the Pre-Cambrian granitic basement rock underlying the Arbuckle aquifer. The well will be perforated in the injection zone at approximately the same interval (4910-5050 ft, KB) as the injection well (KGS #1-28). The final depth and perforation interval however will be established on completion of drilling and will be specified in the well completion report. The wellbore trajectory will be monitored to ensure that the deviations are minimal.

A-1.2.1 KGS #2-28 wellbore and casing

The planned borehole and casing specifications at KGS #2-28 are shown in Table A-1.2 and Figure A-1.2. The conductor casing is expected to run between the surface and 125 feet. The surface casing, designed to provide a continuous cement sheath in order to fully isolate the USDW from the well, runs from the surface to a depth of approximately 650 feet, well below the lowermost USDW (Upper Wellington Formation) which is expected to be in the top 250 feet at the site. The production casing will be constructed from carbon and chrome steels and is expected to run from the surface to the bottom of the well. Corrosion of carbon steel casing is not expected during the life of this well. However, the potential for corrosion of casing material will be addressed by using CO_2-resistant cement as discussed below, and the well be also monitored for signs of corrosion.

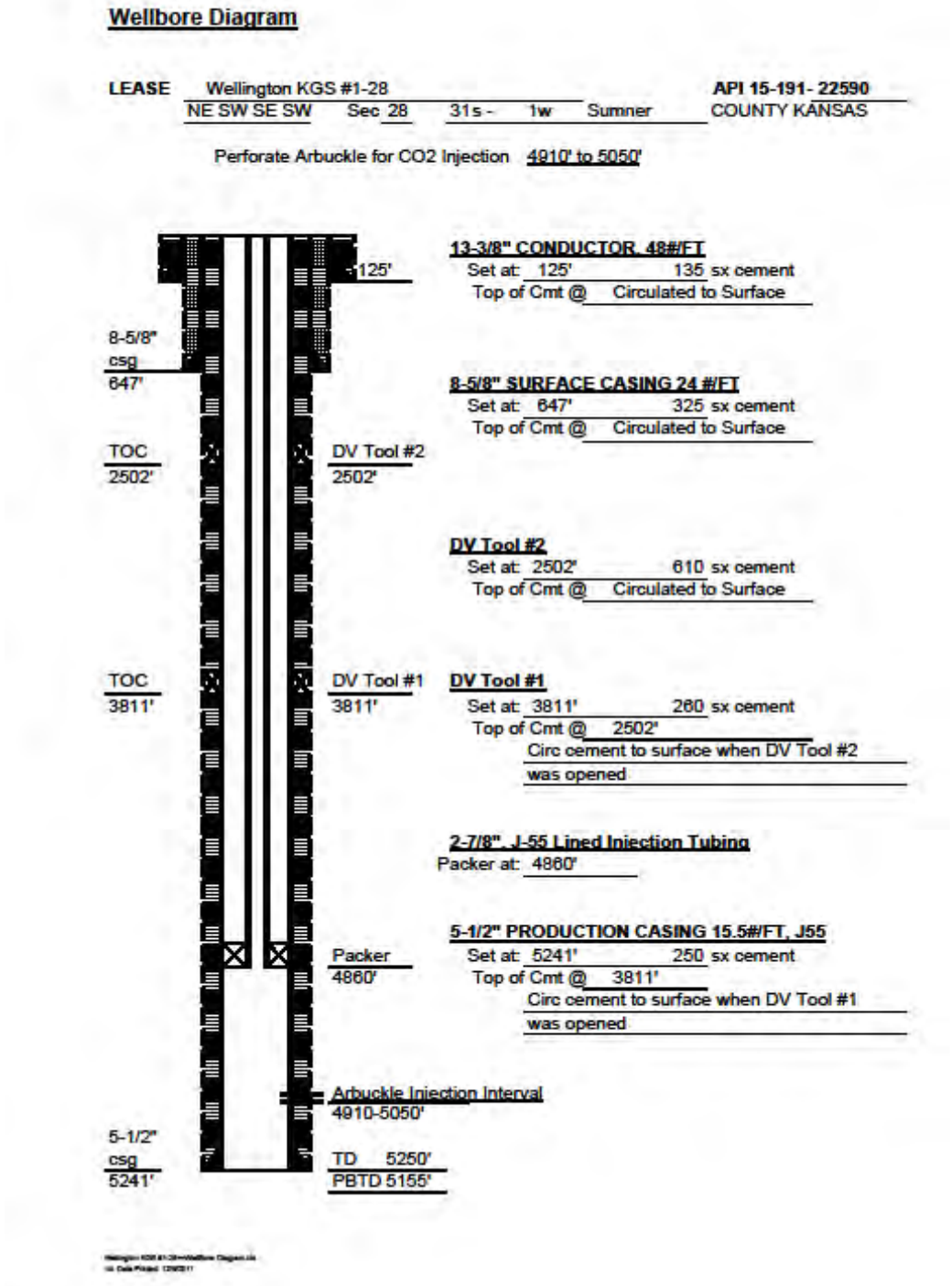


Figure A-1.2—Schematic of the proposed Arbuckle monitoring well KGS #2-28.

Table A-1.2—Borehole and casing specifications at KGS #2-28.

Casing	Depth Interval (ft)	Borehole Diameter (inches)	Size OD/ID (in)	Weight (lb/ft)	Grade	Collapse Pressure (psi)	Burst Pressure (psi)	Tensile Yield (lbs)	Thread Yield (lbs)
Conductor	surface-125	17.5	13-3/8 and 12.615	54	J55	1,130	2730	853,000	514,00
Surface	surface- ~ 650	12.25	8-5/8 and 7.92	24	J55	1,370	2950	381,000	244,000
Production	surface- ~ 5300	7.875	5-1/2 and (4.892)	15.5	J55	4,040	4810	248,000	222,000

A-1.2.2 KGS #2-28 Tubing

The tubing will consist of a 2-7/8 inch steel string. It is expected to be approximately 5,000 ft long and weigh approximately 32,000 lbs which is substantially less the maximum allowable joint yield strength of approximately 72,580 lbs (Table A-1.3). This provides a safety margin at the uppermost joint of slightly over 40,000 lbs if one assumes the axial load is only being carried by that joint

Table A-1.3 —Tubing specifications at KGS #2-28.

Depth (ft)	Wall Thickness (inches)	Inside Diameter (inches)	Weight (lb/ft)	Grade (API)	Burst Strength (psi)	Collapse Strength (psi)	Joint yield strength (lb)
Surface - ~ 5,000	0.217	2.441	6.4	J55	7,260	7,680	72,580

There will be approximately 2 ½ inches of spacing between the production casing and the tubing, which is sufficient for work-over tools and conducting the testing and monitoring activities.

A-1.2.3 KGS #2-28 Cement

The conductor and surface casing cement job will be completed in a single stage. The cementing for the production casing will be accomplished in three stages using two DV tools at

approximately 3,800 ft (DV #1) and 2,500 ft (DV #2) to ensure proper cement adherence (Figure A-1.2). The cement will be circulated to the surface by opening DV Tool #1 and DV Tool #2 during cementing of the lowest and middle stages respectively. The lower cement stage covers the entire Arbuckle formations. Centralizers are expected to be utilized to properly align the casing and to ensure that they are completed sealed.

As shown in Table A-1.4, common portland cement will be used to seal the space in the borehole for the conductor casings, and 60/40 POZ cement is to be used for the surface casing. For the conductor casing, CO2 resistant cement AA-2 will be used in the bottom stage, while a combination of AA-2 and (CO2 resistant) A-Con will be used in the middle stage, and AA-Con in the top stage. Note that the cement quantities specified in Table A-1.4 are estimates and may be adjusted as a result of hole conditions, final depths, etc.

Table A-1.4 Cement specifications for Arbuckle monitoring well KGS #2-28.

Purpose of String	Size Hole Drilled (inches)	Size Casing Set (inches)	Weight (lb/ft)	Setting Depth (bls, ft)	Type of Cement	Number of Sacks Used	Type and Percent Additives
Conductor	17.5	13.375	48	125	Common	135	3%cc, ¼# flake
Surface	12.25	8.625	24	App. 650	60/40 POZ	325	3%cc, ¼# flake
Production	7.875	5.50	15.5	App. 5300	AA-2	250	10% salt, 6 #gils, C-44
1st DV Tool	7.875	5.50	15.5	App.3800	A-Con & AA-2	260	10% salt, 6 #gils, C-44
2nd DV Tool	7.875	5.50	15.5	App.2500	A-Con	610	10% salt, 6 #gils, C-44

A-1.2.4 KGS #2-28 Geophysical Data Acquisition and Analyses

A modern suite of wireline logs such as "triple combo", full-wave and sonic shall be acquired at the monitoring borehole to obtain necessary petrophysical information (i.e., porosity, saturation, sonic velocity, etc). The triple combo logs will include neutron density, gamma ray, caliper, SP, photo electric, and resistivity logs. Analysis of wireline logs will involve calibration with core measurements to predict porosity and permeability; estimation of rock mechanical properties from dipole sonic waveforms, and evaluation of formation invasion and resistivity to help in flow-unit identification.

The wireline data acquired at this site shall be integrated with log and core data from existing Arbuckle wells KGS #1-32 and KGS #1-28 in order to update the regional geomodel based porosity and permeability distributions in the Arbuckle aquifer, if necessary. Based on available budget, the following logs will be obtained:

- Array Compensated True Resistivity
- Drilling Time and Sample Log
- Temperature Log
- Compensated Spectral Natural Gamma Ray
- Microlog
- Spectral Density Dual Spaced Neutron Log
- Annular Hole Volume Plot
- Extended Range Micro Imager Correlation Plot
- Radial Cement Bond Log
- Composite Plot
- Magnetic Resonance Imaging Log

The geophysical data will be used to establish the stratigraphy at the site and if it appears that the geologic formations at KGS #2-28 are offset with respect to KGS #1-28, then the perforation in the injection interval in the new monitoring well will be offset accordingly.

A-1.2.5 Borehole Testing

Drill Stem Test

A Drill Stem Test (DST) shall be run across the injection interval to estimate formation hydrogeologic properties and to sample groundwater.

A-1.2.6 Demonstration of Mechanical Integrity

Mechanical integrity tests shall be carried out at the monitoring borehole to ensure proper setting of the cement and to minimize the risk of leakage around the well bore. A cement bond log will first be obtained after setting and cementing the surface casing and long-string casing. A thermal log will also be acquired to ensure integrity of the cement and casing. The absence of temperature spikes in the log will indicate the absence of substantial leaks in the cement and/or casing. An annulus pressure test will be conducted to ensure that there are no leaks in the packer, tubing, and casing. The annulus will be monitored daily for leaks during injection by checking the fluid level in the annulus.

A-1.3 Peasel-1

Peasel well-1 is a plugged and abandoned oil well located approximately 1,700 feet southeast of the injection well KGS #1-28 (Figure A-1.1). It was constructed on December 2, 1929 and drilled to a depth of 4,193 feet penetrating approximately 40 feet into the Arbuckle Group. It was plugged on September 30, 1947. It is to be redrilled and deepened for monitoring purposes; primarily pressure, as the CO_2 plume is not expected to reach this well.

A-1.3.1 Work Plan for Deepening Peasel-1

The well will be recompleted in stages using Berexco's triple derrick workover rig and related equipment. The cement will first be drilled till a depth of 1,630 feet (top of 8-5/8 inch casing) using thin mud. The hole will be cleaned completely. The drill bit will then be lowered to penetrate the top of the 8-5/8 inch casing and drilling continued to 3,240 feet where a cement plug will be placed. Drilling will resume to the top of the 7 inch casing at 3,270 feet and eventually till the bottom of the 7 inch casing at 3,670 feet. The cement in the 7 inch casing will be drilled out till bottom of the open hole at 4,193 feet (top of Arbuckle). An

additional 300 feet of new hole will be drilled till a depth of approximately 4,500 feet. Open hole logs will be run from 4,500 ft to 3,670 ft, followed by installation of 4 ½ inch production casing till 4,500 feet and placing CO_2 resistant cement in the entire string from bottom to top. Preparation for completion and testing will commence thereafter by cleaning the site and mobilizing Berexco's completion rig and related equipment. The casing will be cleaned to total depth and pressure tested, followed by running gamma-ray neutron and cement bond log from surface to total depth. Select Arbuckle intervals will be perforated, and a 2-7/8 inch tubing

installed.

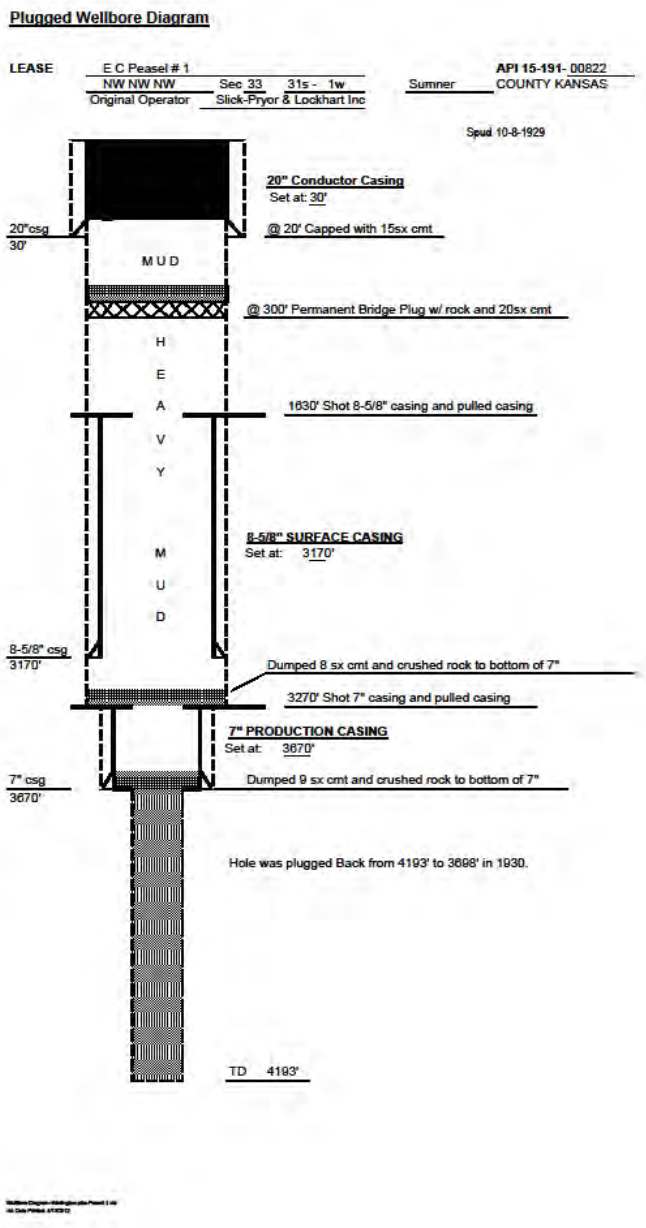


Figure A-1.3 well schematic of Peasel-1 showing construction details.

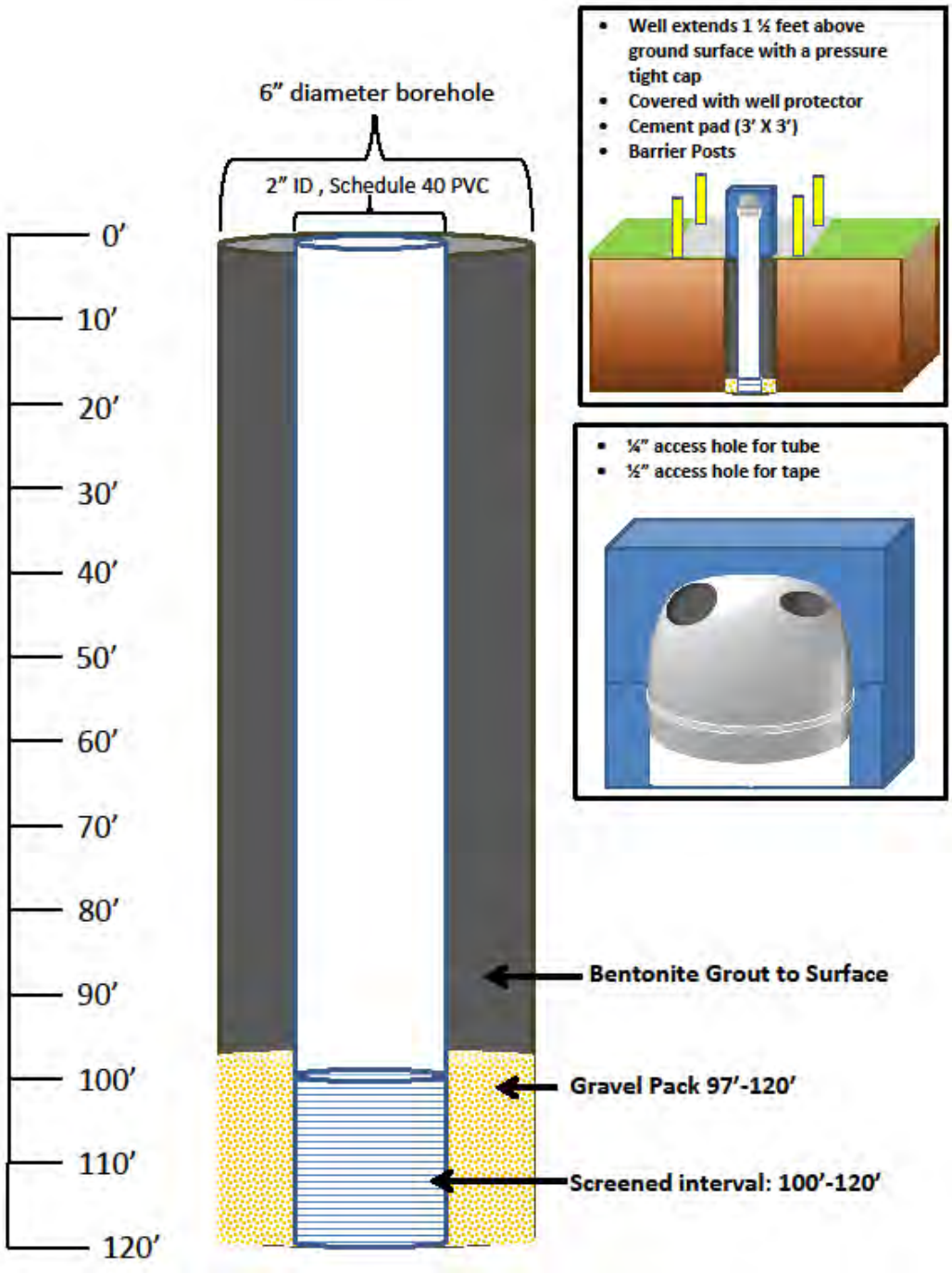
A-1.4 Upper Wellington Formation (lowermost USDW) Monitoring Wells

Two cluster of 2 inch PVC shallow wells (Figure A-1.1) will be installed in the in the Upper Wellington Formation, which is the lowermost USDW at the site. The well clusters are located in close proximity to the injection well so that any leakage through the confining zone is expected to be detected early in order to implement corrective measures. The Upper Wellington formation is present from near land surface to approximately 250 feet below ground at the injection well site. Groundwater movement at the site is primarily toward Slate Creek south of the site. The general dip of the geologic formations in the subsurface is to the northwest. Therefore, one cluster of wells is to be placed due south downstream of the injection well, and the second cluster is to be located west of the injection well. These sites are expected to intercept any plume that may potentially move in to the USDW. Both monitoring sites are located in close proximity to paved roads in the area, thereby providing easy access.

A-1.4.1 Upper Wellington Well Design

The six wells in each cluster will be completed at different depths depending on lithology at the site, but the top of the screen is expected to be placed at 20 ft, 40 ft, 60 ft, 80 ft, 100 ft, and 120 ft (Figure A-1.4). The final screen intervals will be established following drilling at the site. Each well in the cluster will be approximately 15 feet from an adjacent well and will be constructed of 2 inch (internal diameter) Schedule 40 PVC constructed in a 6-inch diameter boring, and gravel packed across a 10 to 20 ft interval depending on screen location and lithology which will be decided after completion of the drilling. The well will be fully grouted above and below the screened interval. Approximately 2-3 feet of bentonite seal will be placed on top of the gravel pack in order to assure a good seal before grouting. Each well will extend about 1 ½ feet above ground surface with a pressure tight cap which will have a cap with a hole for a ¼ inch tub and ½ inch access hole for tape. The wells will have a steel protective housing and a (3 ft x 3 ft) cement pad.

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FigureA-1.4 —Typical schematic of Upper Wellington Formation monitoring well showing screened interval at 100-120 feet below land surface.

A-1.4.2 Upper Wellington Borehole Logs

Samples of soil in the Wellington Formation shall be collected and analyzed by X-ray diffraction to obtain major mineralogy. Samples in the USDW and the underlying salts/bedrock shall be collected during drilling to estimate soil porosity and permeability.

A-1.5 Chase Group Monitoring Wells

Because of its buoyancy, the injected CO_2 is expected to move upward from the injection zone if it breaches the multiple confining units above the Arbuckle. Therefore, one 5-inch PVC monitoring wells will be installed at the top of the Chase Group underlying the Wellington Formation at approximately 550 feet below ground for detecting CO_2. As shown in Figure A-1.1, one of the wells will be placed in the center of the Upper Wellington monitoring cluster south of the injection well, and the other will be located in the center of the Upper Wellington monitoring well cluster in the west. Both monitoring wells are located in close proximity to roads in the area.

A-1.5.1 Well Design

A typical schematic of the Chase monitoring well is shown in Figure A-1.5. The Chase Group wells will be screened throughout the upper 60 ft of the Chase Group. The final screen intervals will be selected following drilling at the site. Each well will be constructed of 5 inch (internal diameter) Schedule 40 PVC constructed in an 8 inch (or greater) wide borehole, and gravel packed throughout the screened interval. The well will be fully grouted from the top of the Chase Group to the surface. Each well will extend about 1.5 feet above ground surface with a pressure tight cap which will have a cap with a hole for a ¼ inch tub and ½ inch access hole for tape. The wells will have a well protector and a (3' x 3') cement pad.

A-1.5.2 Borehole Logs

Samples of soil and shallow bedrock shall be analyzed by X-ray diffraction to obtain major mineralogy. Samples of the evaporite cap rock shall be collected during drilling to determine the extent of porosity and permeability, and to assess approximate mineralogical changes via geochemical modeling (Geochemists WorkBench, SOLMINEQ and MINTEQA2).

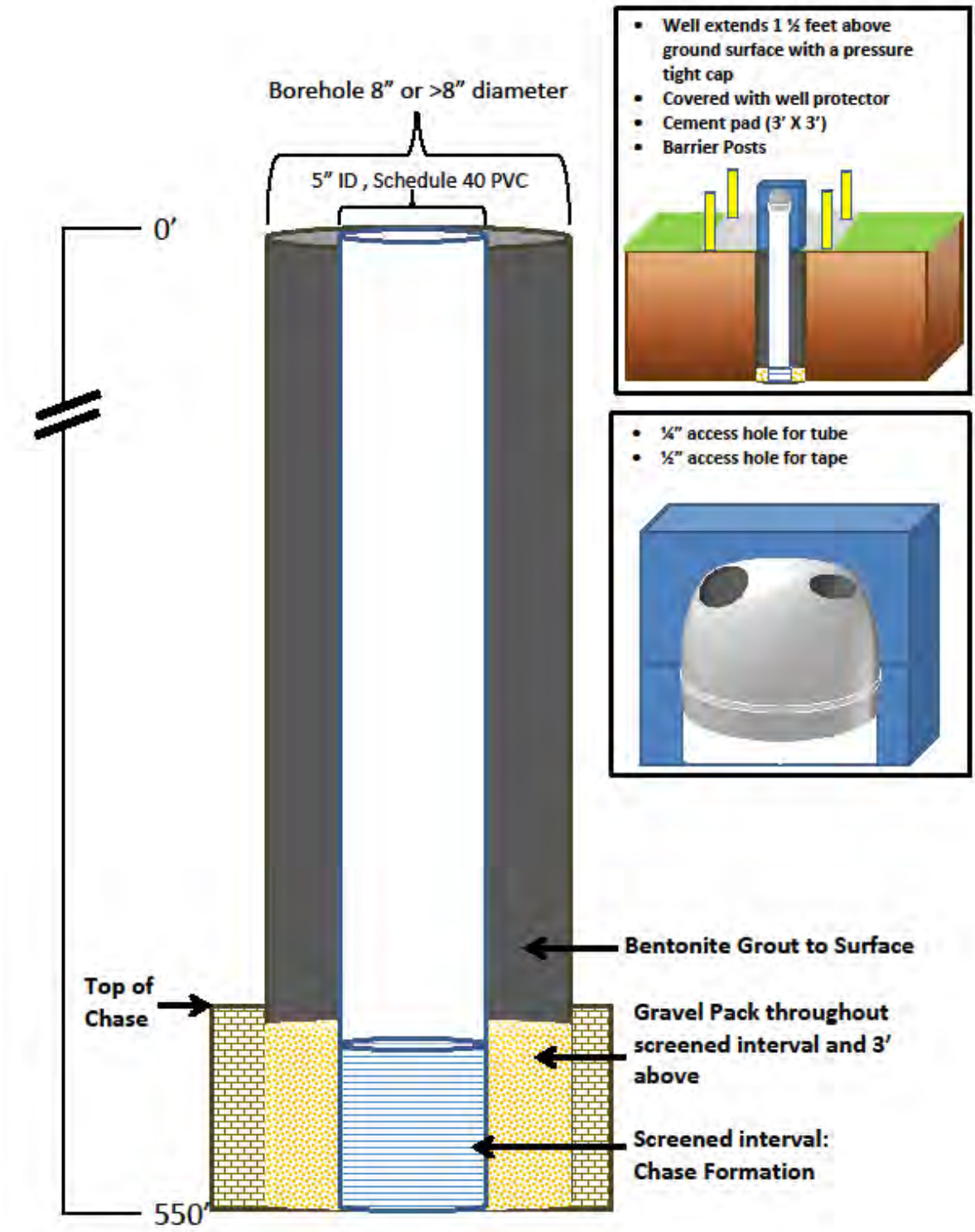


Figure A-1.5 Typical schematic of Chase Group monitoring well with estimated depth at 550 feet.

Appendix A-2

Monitoring, Verification, and Accounting Plan

A-2.1 Introduction

The Monitoring, Verification, and Acceptance Plan for the Wellington project is developed to comply with EPA Class VI rule which requires the owner/operator to prepare, maintain and comply with a testing and monitoring plan to verify that geologic injection and storage of CO_2 is operating as permitted and is not endangering USDWs.

In addition to testing and monitoring at the injection well site (KGS #1-28), monitoring will also be conducted at the Arbuckle observation wells (KGS #2-28, KGS #1-32, and Peasel-1), six existing Mississippian wells above the primary confining zone, twelve new upper Wellington Formation (USDW) wells, and two new Chase Group wells at the base of the Wellington Formation (Figure A-2.1). The construction plans for the new Arbuckle, Wellington Formation and Chase Group monitoring wells is presented in Appendix A-1. Information about the six existing Mississippian wells chosen for monitoring purposes is presented in Section A-1.2. The MVA activities are described in sections A-2.3 to A-2.5. A schedule of the testing and monitoring activities prior to, during, and after injection are listed Table A-1.1.

Table A-1.1 List of monitoring activities to be conducted at the Wellington storage site

Monitoring Activity	Pre-Injection	Injection	Post-Injection
CO_2 Fluid Chemical Analysis	**x**	x	**-**
CO_2 Injection Rate and Volume[1]	-	x	-
CO_2 Injection Pressure at Wellhead[1]	-	x	-
CO_2 Injection Pressure at Well Bottom[1]	x	x	x
Internal MIT (Annulus Pressure Test)	x	-	-
External MIT (Temperature Log)	x	x	x
Continuous Annular Pressure	-	x	-
Corrosion	-	x	x
Pressure Fall Off Test	x	-	-
Pressure in Arbuckle Monitoring Well (Direct Arbuckle Monitoring)	x	x	x
INSAR (Indirect Arbuckle Pressure Monitoring)	x	x	x
USDW Geochemistry	x	x	x
Mississippian Geochemistry	x	x	x
U-Tube (Direct Arbuckle Geochemistry Monitoring)	x	x	x
CASSM (Indirect Arbuckle Plume Front Monitoring)	x	x	x
Crosswell Seismic (Indirect Arbuckle Plume Front Monitoring)	x	x	-
3D Seismic Survey (Indirect Arbuckle Plume Front Monitoring)	x	-	x
[1] Monitored continuously			

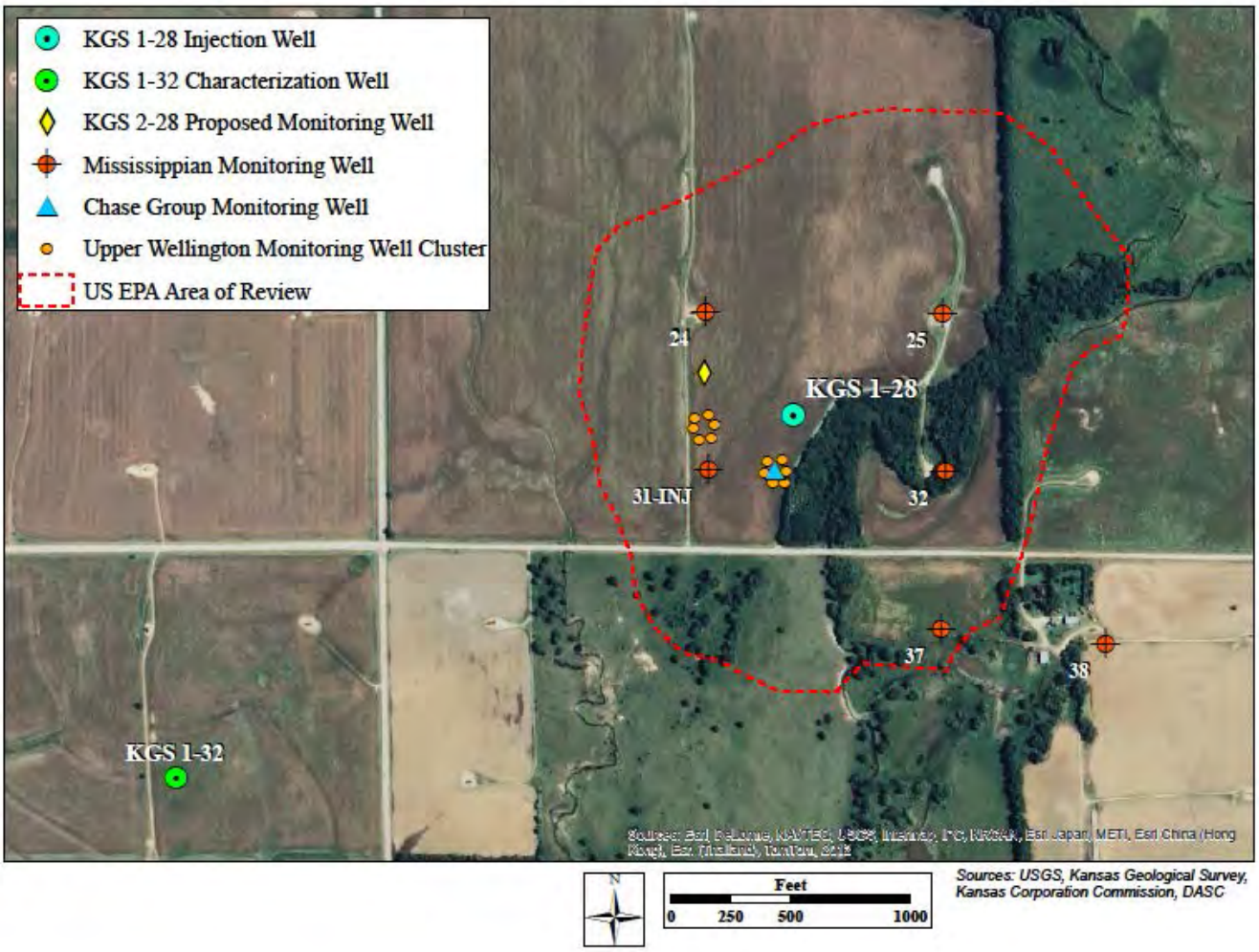


Figure A-2.1—Location of monitoring wells in the Arbuckle Group, Mississippian System, Chase Group, and Wellington Formation.

A-2.2 Mississippian Monitoring Wells

There are several active oil wells around the CO_2 injection well, KGS #1-28, that are producing from the upper Mississippian formation above the Pierson Group, which is part of the upper confining zone. The locations of the Mississippian wells that will be used as monitoring wells are presented in Figure A-1.1. Well construction details of these two wells are presented in Table A-2.2. No geophysical logs are available for these wells in the KGS database.

Casing head gas and groundwater sampling of the Mississippian wells will be conducted during the pre-injection phase to establish respective background (baseline) readings. Thereafter, water and casing head gas shall be sampled on a periodic basis during the injection and post-injection phases, analyzed, and compared with the baseline survey data to detect the presence of CO_2 in the Mississippian *Reservoir.*

Table A-2.2 Well data for Mississippian wells to be used for CO_2 monitoring.

API Well Number	Lease Name	Well Class	Operator Name	Total Depth	Status	Spud Date	Completion Date	API Number	Elevation (ft, msl)	NAD83 Latitude	NAD83 Longitude
10045	WELLINGTON UNIT, was KAMAS 6	Producing	Sinclair Prairie Oil	3678	OIL	2/1/36	10/1/36	15-191-10045	1246	37.31883	-97.4316
10106	ERKER	Spudded	STELBAR OIL CORP	3680	OIL	11/17/36	12/16/36	15-191-10106	1235	37.31708	-97.43459
10055	WELLINGTON UNIT, was FRANK KAMAS 9	Producing	Sinclair Prairie Oil	3707	OIL	12/14/36	10/1/37	15-191-10055	1264	37.32071	-97.43501
10054	WELLINGTON UNIT was Kamas 7	Producing	Sinclair Prairie Oil	3681	OIL	3/26/36	10/1/88	15-191-10054	1258	37.32064	-97.4316
22590	WELLINGTON KGS 1-28	Inactive	BEREXCO LLC	5250	CO2 Injection	2/20/11	8/24/11	15-191-22590	1257	37.31951	-97.43378
10051	FRANK KAMAS	Recomplete	Sinclair Prairie Oil	3704	OIL	12/30/35	10/1/36	15-191-10051	1257	37.3189	-97.43501

A-2.3 Testing and Monitoring at Injection Well Site

A-2.3.1 Carbon Dioxide Stream Analysis

The Class VI Rule requires that the injected carbon dioxide stream be analyzed with sufficient frequency to yield data representative of its chemical and physical characteristics. Monitoring the chemical composition is accomplished to verify that the injectate does not qualify as hazardous waste with regard to corrosivity or toxicity, as well as to ensure that the delivered carbon dioxide stream meets the specifications outlined in the EPA permit. The monitoring plans are presented below. Small quantities of SF6 and Kr (Krypton) shall be periodically co-injected with CO2 to facilitate estimation of the travel time between injection and monitoring wells.

A-2.3.1.1 Sampling Location and Method

The CO_2 stream is expected to be composed of high purity (99+ %) CO_2. The CO2 will be delivered at near atmospheric pressure. After collection at the plant, the CO2 will be dehydrated and compressed to a liquid state at temperature and pressure of approximately -10^{O}F and 350 psi and transported in trucks to the site for injection. Carbon dioxide injectate samples will be collected immediately upstream of the injection well head in a lined sample bottle and transported to a National Environmental Laboratory Accreditation Program (NELAP) accredited laboratory for

analysis.

A-2.3.1.2 Fluid Analysis

The exact chemical composition of CO2 will be ascertained prior to injection once the CO_2 source has been finalized. The CO_2 stream is expected to have high levels of CO_2 with only trace levels of other constituents or impurities such as nitrogen, oxygen, methanol, acetaldehyde and hydrogen sulfide. The analytical suite will be established when the first pre-injection sample is collected and at a minimum, will include nitrogen, oxygen, methanol, acetaldehyde, and hydrogen sulfide. The samples will be analyzed using standardized ASTM procedures for gas chromatography, mass spectrometry, detector tubes, and photo ionization. The sample will be tested using ASTM 5954, ASTM 6228, ASTM 5504 or equivalent procedures. For permitting

purposes, it is proposed that the CO_2 stream will not exceed the minimum specification specified in Table A-2.3.

Table A-2.3 Minimum CO_2 Stream Acceptance Specifications

Component	**Quantity**
CO_2	97% dry basis
Inert Constituents	1%
Trace Constituents	2%
Oxygen	<20 ppm
Total Sulphur	< 25 ppm
Arsenic	< 5 ppm [a]
Selenium	< 1 ppm [a]
Mercury	< 2 ppb [b]
Hydrogen Sulfide	< 20 ppm
Water Vapor	< 30 lb/mm scf
(a)Resource Conservation and Recovery Act (RCRA) standard	
(b) Safe Drinking Water Act standard	

Carbon dioxide grab samples will be collected immediately upstream of the well head in a pre-cleaned lined sample bottle and transported to a National Environmental Laboratory Accreditation Program (NELAP) accredited laboratory for analysis. The bottle will be flushed with inline CO_2 prior to sample collection, labeled, and transported to the laboratory in accordance with EPA guidelines. A Chain of Custody form will document:

- [a] Sampling date
- Analytical detection limit
- Location of the sample
- Type of container
- Sampler name and signature
- Other comments/notes
- Shipping information (name, address, and point of contact at laboratory, including phone number).
- Name and signature of personnel involved in the chain of custody

The laboratory report will include the analytical results as well as detection limits established for the method employed to detect each chemical constituent presented in Table A-2.3.

A-2.3.1.3 Sampling Frequency

The CO2 will be sampled at five periods: prior to commencement of injection, once each month for the first three months of injection, and again six months following commencement of injection. Injection is to cease at the end of nine months of operation. If there is significant variation in the quarterly sample results, then a final sample will be collected and analyzed at the end of the injection period (9 months).

A-2.3.1.4 Quality Assurance/Quality Control

The samples will be analyzed using standardized ASTM procedures for gas chromatography, mass spectrometry, detector tubes, and photo ionization. The sample will be tested using ASTM 5954, ASTM 6228, ASTM 5504 or equivalent procedures. The sample integrity and security will be documented through maintenance of a field sampling record and a Chain of Custody form as described above. The laboratory report will provide documentation of instrument calibration, analytical results, and detection limits established for methods employed. For data validation purposes, the following samples will be analyzed with each batch of collected samples:

- One or two field duplicates
- One equipment rinsate
- One matrix spike (when appropriate for the analytical method)
- One trip blank

A-2.3.2 Continuous Recording of Operational Parameters

A-2.3.2.1 Continuous Monitoring of Injection Rate/Volume

The Class VI Rule requires the installation and use of continuous recording devices to monitor injection rate and volume. The monthly average, maximum, and minimum values will be reported in semi-annual reports to the EPA. This information will be used to verify compliance with the operational conditions of the permit and to assist in AoR reevaluations.

The injection rate will be continuously monitored using the Orifice-Plate differential meter which uses Bernoulli's equation to determine flow by measuring the pressure drop across a plate with a hole. It is the standard flow measuring device in the oil and gas industry and typically achieves an accuracy of two to four percent of the full scale reading. The mass rate will be calculated using the CO_2 density which will be calculated using equations of state and pressure and temperature readings. Cumulative injection volume and mass will be continuously calculated and reported in semi-annual reports. It should also be noted that since the CO_2 will be transported to the site via trucks, which will be weighed, an indirect measurement of the CO_2 mass will also be available.

A-2.3.2.2 Continuous Monitoring of Injection Pressure

The Class VI Rule requires the installation and use of continuous recording devices to monitor injection pressure. Injection pressure will be measured at both the wellhead and the center of the perforations in the injection zone (bottom hole pressure). Bottom hole pressure is equal to wellhead pressure plus the hydrostatic pressure that exists due to the weight of the fluid column between the wellhead and bottom hole, minus frictional losses. The two sources of pressure data will therefore be used to check the accuracy of the individual pressure measurements. Injection pressure is monitored to ensure that the fracture pressure of the formation and the burst pressure of the well tubing are not exceeded and that the owner or operator is in compliance with the permit. A standard oil-filled pressure gauge will be installed at the wellhead, and a pressure transducer will be placed near the perforation to monitor the bottom hole pressure.

A-2.3.2.3 Continuous Monitoring of Temperature

Surface and bottom hole temperature will be monitored continuously in the injection well using the same data logger that measures pressure in order to fulfill EPA's injection well operating requirements.

A-2.3.2.4 Continuous Monitoring of Annulus Pressure and Volume

Since a waiver will be sought from pressurizing the annulus due to low injection pressures, continuous monitoring of the annulus will involve a daily inspection of the water level in the annulus. A rise or drop in water level of beyond the range expected due to thermal expansion/contraction will be considered a failure of the internal MIT triggering a system wide shut-off, which will halt injection immediately and limit the amount of leakage. The shutoff will be reported to the EPA within 24 hours. The cause(s) of the pressure drop will be investigated to identify the location of leakage and repair the well. An Annulus Pressure Test will be conducted following investigation/remediation to ensure well integrity.

A-2.3.2.5 Operating Range for Key Injection Parameters

- CO2 Injection Flow Rate: 150 metric tons/day (+/- 5%)
- Wellhead Inlet Pressure: < 1,500 psig
- Bottom hole Pressure: < 2,636 psig @ 5,050 ft
- Annulus Pressure at Surface: 0 psig
- Wellhead CO_2 Temperature: -10^{o} to $+30^{o}$ F
- Bottom Hole CO_2 Temperature: 10 - 70^{o} F @ 5,050 ft

A-2.3.3 Corrosion Monitoring

The Class VI Rule requires quarterly monitoring of well materials for corrosion in order to detect loss of material in the casing, tubing and packer which may compromise the mechanical integrity of wells. However, due to the short period of injection (nine months), corrosion is not expected to occur in the Wellington injection or observation wells.

A-2.3.3.1 Corrosion Detection Method and Sampling

Corrosion coupons will be used for monitoring loss of material in the injection well. Coupons are very simple to use and analyze, and they provide a direct measurement of material lost to corrosion. Two pre-weighed, dimensionally measured, and photographed coupons made of representative injection well construction material will be placed in the flow line and the wellhead. These coupons will be removed every quarter, cleaned and reweighed. The samples will be visually inspected under magnification for loss of mass, thickness, cracking, pitting, or other signs of corrosion.

The average corrosion rate in the well will be calculated from the weight loss of the coupon.
The coupon will be weighed to an accuracy of +/- 0.1 of a milligram. The weight will be used to calculate the corrosion rate in mils/year, where a mil is equal to a thousandth of an inch. If the coupons are found to have more than 3 mils/year of loss, corrective action will be taken in consultation with the EPA Region 7 Director and the coupons will be monitored more frequently. However, as mentioned above, no corrosion of the well material is expected given the short duration of injection.

A-2.3.3.2 Corrosion Reporting

Dimensional and mass data, along with a calculated corrosion rate (in mils/yr), will be submitted to the EPA Program Director every six months in semi-annual reports which will include the following information:

- A description of the corrosion monitoring technique;
- Measurement of mass and thickness loss from corrosion coupons;
- Assessment of additional corrosion, including pitting, in the corrosion coupons and the overall corrosion trends;
- Any necessary changes to the project Testing and Monitoring Plan to continue protection of USDWs.

A-2.3.4 Mechanical Integrity Testing

Internal and external Mechanical Integrity Tests (MITs) will be conducted prior to, during, and following injection. Internal tests will be conducted to ensure the absence of any leaks in the injection tubing, packer or casing, and external tests will be conducted to ensure the absence of any leaks through channels adjacent to the wellbore that may result in significant fluid movement into a USDW. The Class VI Rule requires that internal mechanical integrity be demonstrated continuously during injection, and external MIT be conducted prior to injection, at least once per year during the injection phase, and prior to injection well plugging after the cessation of injection.

A-2.3.4.1 Internal MIT with Annulus Pressure Test

Prior to commencing injection, an Annulus Pressure Test will be conducted at the injection well KGS 1-28 in order to demonstrate internal MIT. The test will provide information necessary to determine whether there is a failure of the casing-cement bond, injection tubing, and packers.

The test will consist of pressurizing the corrosion resistant fluid of the annulus and then isolating the annular space from the source of pressure by a closed valve, or by disconnecting the pressure source entirely. Pressure measurements taken during isolation of the annulus will be analyzed for any change in pressure in order to detect leakage. Because the annulus exchanges heat with its surroundings, small pressure changes that are not due to leakage may occur during the test.

After the test period, the valve to the annulus will be opened and amount of returned fluid measured in a container. This will be a confirmatory exercise to determine whether the full length of the annulus was tested as the amount of captured liquid should be in conformance with the size of the annulus and the test pressure. The data obtained, including recorded charts from the tests and volume of liquid used, shall be submitted to the EPA within 30 days of test completion.

Failure of the pressure to stabilize within a range of 5 percent of the injection pressure will constitute a failure to demonstrate mechanical integrity. If this occurs, the causes of the pressure

drop will be investigated and corrective measured implemented as necessary. An Annulus Pressure test will be conducted following any well remediation activities in order to confirm well integrity.

A-2.3.4.2 External MIT Using Temperature Logs

A temperature log will be used to demonstrate external MIT in the injection well (KGS 1-28), and its use is based on the principle that fluid leaking from the well will cause a temperature anomaly adjacent to the wellbore. The log will be obtained from the surface to the bottom of the well using a wireline logging tool.

Temperature logs will be obtained prior to commencement of injection, after 6 months of injection, and prior to closure of the site. The pre-injection log, along with the temperature log obtained during well

construction, will serve as a baseline for the subsequent monitoring during the injection and post injection phases.

The well will be shut during the injection phase for a period of 36 hours prior to obtaining the temperature log. During the shut-in period, the temperature within the wellbore will typically migrate towards ambient geothermal conditions, but will not fully equilibrate to ambient conditions. If there has been a leak of fluid out of the well, the temperature within the wellbore at this location will change to a lesser extent and be measured as an anomaly because the temperature of the surrounding formation will have been modified by the leaking fluid.

Leaks will be identified from injection and post-injection logs by noting relative differences between the collected temperature log and the baseline (and previous) logs. Since lithology and injectate characteristics will be similar, the thermal effects along the wellbore are expected to be very similar. After the temperature effects caused by injection, casing joints, packers, well diameter, casing string differences and cement have dissipated, the temperature profiles are expected to be similar, although not identical. The log and associated report will be submitted to the EPA within 30 days of test completion. If interpretation of the data indicates a noncompliance, a report will be submitted to EPA within 24 hours of testing. If necessary, radioactive tracer, noise, oxygen activation or other logs approved by the EPA Program Director may be used to further define the nature of the fluid movement.

A-2.3.5 Pressure Fall-Off Testing

The Class VI Rule requires pressure fall-off testing of the injection well prior to commencing injection and at least once every five years. Pressure fall-off tests are used to measure formation properties in the vicinity of the injection well. The objective of periodic testing is to monitor for any changes in the near-wellbore environment that may impact injectivity and pressure increase. Anomalous pressure drops during the test may also be indicative of fluid leakage through the wellbore.

A pressure fall-off test will be conducted prior to commencement of injection at the Wellington site. However, a pressure fall-off test following commencement of injection is not proposed for this project because, a) injection is to occur for a short period of 9 months, b) extensive testing/monitoring to track the carbon dioxide plume will be performed, and c) the site is expected to close within 5 years of commencement of injection.

A steady rate of water flow will be maintained during the injection phase of the Pressure Fall-Off test. This will be followed by a shut-in period, the duration of which will be determined on the site in order to obtain sufficient transient response for analyzing the data. The bottom hole pressure will be continuously recorded during the entire test by pressure transducers for a sufficient period to make valid observation of a pressure fall-off curve. Pressures will be measured at a frequency that is sufficient to measure the changes in bottom hole pressure throughout the test period, including rapidly changing pressures immediately following cessation of injection. The magnitude of the bottomhole pressure will be adjusted so as to not exceed 90% of the fracture gradient.

A-2.4 Groundwater Geochemical Monitoring Above the Confining Zone

Groundwater quality in the USDW (Upper Wellington Formation), the Chase Group, and the upper Mississippian System above the confining zone will be directly monitored. The location of the Mississippian and USDW monitoring wells are presented in Figure A-2.1. All monitoring wells presented in Figure A-2.1 are located in close proximity to paved roads and fully accessible by a truck. Berexco is the operator of the Wellington oil field and has permission to physically monitor all well sites.

Baseline data will be collected from the monitoring wells prior to injection and monitoring will be conducted as per the schedule presented in Table A-2.4 below. An increase in the concentration of dissolved carbon dioxide will indicate the presence of separate-phase or dissolved-phase carbon dioxide. The concentration of carbon dioxide will be used to ascertain if separate-phase carbon dioxide may be present, based on accepted mass-transfer relations and equilibrium constants.

A-2.4.1 Monitoring Wells Above the Confining Zone: Sampling Frequency, Analytical Suites, QA/QC, and Reporting Requirements

A-2.4.1.1 Mississippian Wells

Gas sampling ports shall be installed in the two existing Mississippian wells (#24 and #32) shown in Figure A-2.1 in order to collect head gas to detect and measure amount of early breakthrough or off pattern migration of CO2. These two wells will be sampled 3 times prior to injection in order to establish baseline CO_2 concentration. The analytical suite to be monitored and the monitoring frequency is presented in Table A-2.4 below for monitoring wells within and above the injection zone. Produced water and casing head gas shall be sampled, analyzed, and compared with the baseline survey data to determine the presence of CO_2 and other parameters in the Mississippian Reservoir. The (inorganic) indicator parameters are known to be associated with chemical reactions in the presence of CO_2 and therefore expected to provide information regarding the presence of the injectate in the hydrogeologic formations. The sampling and testing will continue every 3 months during the post injection phase.

Table A-2.4 Geochemical analytical suite to be monitored in the Mississippian, Chase, and Upper Wellington (USDW) wells at the Wellington site.

Field Parameters	Pre-Injection	During injection	Post-Injection
pH	Once a week for 3 weeks	Every 3 months	Every 6 months
Specific Conductivity	Once a week for 3 weeks	Every 3 months	Every 6 months
Temperature	Once a week for 3 weeks	Every 3 months	Every 6 months
Dissolved Oxygen	Once a week for 3 weeks	Every 3 months	Every 6 months
Gas-Water Ratio	Once a week for 3 weeks	Every 3 months	Every 6 months
Depth to Water	Once a week for 3 weeks	Every 3 months	Every 6 months
TDS/Salinity	Once a week for 3 weeks	Every 3 months	Every 6 months
Indicator Parameters			
Alkalinity	Once a week for 3 weeks	Every 3 months	Every 6 months
Bromide	Once a week for 3 weeks	Every 3 months	Every 6 months
Calcium, Iron, Magnesium, Potassium, Dissolved Silica	Once a week for 3 weeks	Every 3 months	Every 6 months
Chloride	Once a week for 3 weeks	Every 3 months	Every 6 months
Sodium	Once a week for 3 weeks	Every 3 months	Every 6 months
Total CO	Once a week for 3 weeks	Every 3 months	Every 6 months
Total Fe	Once a week for 3 weeks	Every 3 months	Every 6 months
Total Fe (II)	Once a week for 3 weeks	Every 3 months	Every 6 months
Total NH_4^+	Once a week for 3 weeks	Every 3 months	Every 6 months
Total NO_3^{2-}	Once a week for 3 weeks	Every 3 months	Every 6 months
Total SO_4^{2-}	Once a week for 3 weeks	Every 3 months	Every 6 months
Total PO_4^{3-}	Once a week for 3 weeks	Every 3 months	Every 6 months
Total HCO_3^-	Once a week for 3 weeks	Every 3 months	Every 6 months
Total CO_2	Once a week for 3 weeks	Every 3 months	Every 6 months
Concentration of Organics			
DOC	Once a week for 3 weeks	Every 3 months	Every 6 months
TOC	Once a week for 3 weeks	Every 3 months	Every 6 months
DIC	Once a week for 3 weeks	Every 3 months	Every 6 months
Stable Isotopes			
$\delta 18O$	Once a week for 3 weeks	Every 3 months	Every 6 months
δD	Once a week for 3 weeks	Every 3 months	Every 6 months
$\delta 13C$ for Carbonates in System	Once a week for 3 weeks	Every 3 months	Every 6 months

10.4.1.2 Upper Wellington Formation (USDW)

Samples shall be collected prior to injection. This information will constitute baseline data for future comparison during the injection and post-injection phases. The different constituents that are to be tested during the injection phase, and the testing frequency is provided in Table A-2.4. Water quality parameters shall be repeatedly checked for any changes with time for ph, conductivity, alkalinity, DO and redox values. During the post-injection period, the same tests described above for the injection period will be conducted periodically. The sampling frequency may be increased if the results of monitoring indicate possible fluid leakage or endangerment of USDWs.

10.4.1.3 Sampling and Analysis Procedures and Quality Assurance/Quality Control (QA/QC)

The following sampling, handling, and analyses QA/QC procedures will be followed to ensure the acquisition of high quality data:

- Static water levels in the USDW (Upper Wellington) will be determined using an electronic water level indicator before any purging or sampling activities. Dedicated pumps (e.g., bladder pumps) will be installed in each monitoring well to minimize potential cross contamination between wells and minimize the introduction of atmospheric CO2.

- Each USDW (Upper Wellington) monitoring well will be purged using a submersible pump, or the samples obtained using a low flow sampling technique. Samples will be field preserved as required by the analytical method.

- The pumps, tubing, and any other downhole accessories will be rinsed with deionized water and placed in bags for travel to the field site. During pump deployment and at other times, care will be taken to ensure that equipment to be used inside the monitoring wells remains clean and does not come in contact with potentially contaminating materials.

- All field and downhole equipment will be properly calibrated according to the manufacturer specifications.

- Exposure of the samples to ambient air will be minimized.

- Groundwater pH, temperature, specific conductance, and dissolved oxygen will be monitored in the field using hand held portable probes.

- For data validation purposes, the following samples will be analyzed with each batch of collected samples:

    - One or two field duplicates, sometimes triplicates, depending on the accuracy of instruments provided to analyze the waters
    - One equipment rinsate
    - One matrix spike (when appropriate for the analytical method)
    - One trip blank

- A chain-of-custody record shall be completed and accompany every sample. All sample bottles will be labeled with durable labels and indelible markings. A unique sample identification number, sampling date, and analyte(s) will be recorded on the sample bottles as well as sampling records written for each well. Sampling records (e.g., a field logbook, individual well sampling sheet) will indicate the sampling personnel, date, time, sample location/well, unique sample identification number, collection procedure, measured field parameters, and additional comments as needed.

- Where appropriate, ASTM Method D6911-03 (2003) will be followed for packaging of samples. Immediately upon sample collection, containers shall be placed in an insulated cooler and cooled to 4 degrees Celsius. Upon receipt at the Kansas State laboratory, the samples will be accepted and tracked by the laboratory from arrival through completed analysis.

- All groundwater quality results will be entered into a database or spreadsheet with periodic data review and analysis.

A-2.4.1.4 Groundwater Quality Data Reporting

The following information will be submitted with all quarterly and semi-annual monitoring reports to the EPA:

• The most up-to-date historical database of all ground water monitoring results,

• Interpretation of any changing trends and evaluation of fluid leakage and migration. This may include graphs of relevant trends and interpretative diagrams,

• A map showing all monitoring wells, indicating those wells that are believed to be in the location of the separate-phase carbon dioxide plume,

• The date, time, location, and depth of all ground water samples collected and analyzed,

- Copies of laboratory analytical reports,
- A description of sampling equipment,
- Chain of custody records,
- The name and contact information for the laboratory manager at Kansas State University,
- Identification of data gaps,
- Presentation, synthesis and interpretation of the entire historical data set,
- Documentation of the monitoring well construction specifications, sampling procedure, laboratory analytical procedure and QA/QC standards.

A-2.5 Carbon Dioxide Plume and Pressure Front Tracking

Identification of the position of the injected CO2 plume and the presence or absence of elevated pressure (i.e., the pressure front) is integral to protection of USDWs for Class VI projects. Monitoring the movement of the carbon dioxide and the pressure front is necessary to both identify potential risks to USDWs posed by injection activities and to verify predictions of plume movement in order to ensure that the plume is adequately confined. Monitoring movement of the plume and the pressure front also provides necessary data for comparison to model predictions, and inform reevaluation of the AoR. Both direct and indirect measurement methods will be used to monitor the movement of the pressure and plume fronts as discussed in the following sections.

A-2.5.1 Monitoring Pressure Front

The Class VI Rule requires that fluid pressure be directly monitored within the injection zone. This type of monitoring provides observations of increases in formation pressures and support tracking the migration of the pressure front.

A-2.5.1.1 Direct Arbuckle Pressure Monitoring

Pressure transducers in the injection zone will be installed in the Arbuckle monitoring well KGS #2-28 and the injection well (KGS #1-28). The transducers will record pressures continuously every 30 seconds in both the injection and monitoring wells. The system will have a battery backup or alternative power supply to ensure continued collection of data during power failures. The electronic data from the continuous recorder will be stored on multiple sources of data storage media for redundancy. The data will be backed up on an electronic media storage device. There will be a separate alarm system that will monitor surface and bottom hole pressures in the injection well and trigger a system shutoff and notification to Berexco if a violation of the injection pressure limits occurs.

Pressure time series at each Arbuckle monitoring and the injection well will be constructed and used to monitor the growth of the pressure front. Spatial patterns will also be analyzed by constructing maps that represent contours of pressure. The pressure data will be compared with model based prediction of the pressure front, and if necessary, the simulation model will be recalibrated to conform to field data. The EPA Program Director will be kept updated of pressure observations via quarterly reporting of the pressure time series, and will also be consulted during model reevaluation if warranted by the data. Based on modeling results, the pressure in the Arbuckle are expected to stabilize to nearly pre-injection levels within 2 months of cessation of injection. Therefore, the frequency for pressure monitoring will be successively reduced during the post-injection phase based on the observed field conditions. If field conditions warrant a revision of the proposed post-injection monitoring frequency, a revised pressure monitoring plan will be submitted to the EPA for review and comment.

A-2.5.1.2 Indirect Monitoring of Pressure Front by Surface Displacement

In addition to direct monitoring, the pressure front will also be tracked by monitoring surface deformation as a result of CO2 injection using the InSAR approach (Interferometric Synthetic Aperture Radar). This technique will provide an independent means to corroborate the pressure front constructed from direct monitoring of pressures in the Arbuckle injection and monitoring wells. InSAR is a radar technique that measures the phase difference between successive satellite orbits. Tropospheric effects between satellite orbits will be removed using data acquired by the MODIS satellite. Once tropospheric effects are removed, any phase differences between the images will be proportional to small differences in distance between the satellite antenna positions and the ground, which could indicate surface deformation associated with elevated pressures due to carbon dioxide injection at depth.

Archives of InSAR data will be downloaded prior to injection in order to establish a range of baseline surface deformation at the Wellington Field related to seasonal effects (e.g., freeze-thaw cycles and dry vs. wet seasons). During the 9-month injection period and 60 days following injection, InSAR measurements shall be collected approximately every 20 days. Following the injection period, data collection and analysis will continue, but will decrease incrementally to eventually every 12 months until project closure. The InSAR data can provide a time-series of deformation and subsequent relaxation of the ground surface. The InSAR time-series will establish incremental deformation of the land surface due to CO_2 injection and will be compared with plume dimensions obtained from simulation studies and other direct/indirect monitoring data discussed below.

In addition to InSAR data, Continuous GPS (CGPS) data will also be acquired at cemented platforms for purposes of calibration and verification of the vertical component of the surface displacement field using InSAR. The CGPS data will provide 3 components of the surface displacement (i.e., Northing, Easting and vertical) to add tighter constraints to the deformation field detected using InSAR. CGPS data shall be downloaded via a laptop on a monthly basis. All data files (24-hour periods) will be recovered for archiving and analysis to enable detection of surface accelerations related to subsurface deformation.

A-2.5.2 Monitoring the Plume Front

Various direct and indirect MVA tools and techniques shall be used to monitor, verify, and account for injected CO_2 in the Arbuckle saline aquifer. The crosswell tomography, U-tube, 3-D seismic, and continuous active source seismic monitoring (CASSM) technology shall be used to monitor and visualize the movement of the CO_2 plume. The monitored data will also be used revise the simulation model, update site characterization, and potentially refine the monitoring plan if necessary. Each of the plume monitoring techniques mentioned above, along with the monitoring plan, is discussed below.

A-2.5.2.1 Direct Geochemical Monitoring of the Plume Front: U-Tube Sampling

Understanding the geochemistry of reservoir gases is critical to understanding how carbon is sequestered in geological formations. The U-tube sampler is able to collect continuous samples of reservoir fluids near in-situ temperatures and pressures. This innovative apparatus has greatly enhanced the success of CO2 injection pilot studies at the Frio Brine Pilot, Dayton, TX, the SECARB Cranfield Test, Cranfield, Mississippi, and the CO2CRC Otway Project, Victoria, Australia by significantly improving the quality and quantity of samples that can be collected from deep storage reservoirs during supercritical CO2 injections. Such sampling is difficult because dissolved gasses and supercritical fluids which exist at high pressures and temperatures in the reservoir quickly exsolve or flash to gas as they are brought to the surface for analysis. The U-tube sampler will be installed in monitoring well KGS #2-28.

The U-tube (Figure A-2.2), which is constructed of stainless steel tubing and fixed within the borehole with tubing strings that reach to the surface, shall be installed in the Arbuckle observation borehole (KGS #2-28). The perforated interval will be isolated using a packer with feed through to accommodate the U-tube sampling system and other permanent instruments. The drive leg of the U-tube is connected to a source of compressed nitrogen and the other attached to a sampling manifold contained in a trailer on site. After first flushing the loop of tubing with N2 gas, the sample and drive legs are vented and pressure in the U-tube will decrease, allowing subsurface fluids to enter the sampling inlet due the pressure differential between the U-tube (atmospheric) and the reservoir. To recover the sample N2 gas is again used on the drive leg to increase the pressure in the tubing, closing the check valve and forcing fluid up to a high pressure sampling cylinder. Inside the cylinder, brine, dissolved gases, and supercritical fluids will be collected at near in-situ conditions allowing accurate quantification of the relative concentrations of each component.

The U-tube surface sampling instrumentation will consists of a supply of N_2, a high pressure gas booster, and a valve panel to facilitate collection of mixed phase and separate phase subsamples. Samples shall be collected on a weekly basis until breakthrough in order to identify the arrival of the CO_2 plume and co-injected tracers (e.g. sulfur hexafluoride). Following breakthrough, samples will be collected initially on an increased sampling frequency and then gradually decreased as geochemical changes slow. Subsamples shall be collected and sent to laboratories for analysis of constituents such as pH, EC, alkalinity, cation and anion chemistry, dissolved gases and isotopic composition as presented in Table A-2.5. If hydrocarbons are present in the subsurface, they shall also be analyzed and may be used in equilibrium thermodynamic

models to aid in the estimation of the rate of CO_2 dissolution into the formation brines. Tracer gases including SF_6 (sulfur hexafluoride) and Kr (krypton) shall be periodically co-injected with the CO_2 to facilitate estimation of the travel time between the injection and monitoring wells/boreholes. Approximately 55 kg of SF6 and 230 ft^3 of Kr 230 will be injected every eight weeks at KGS #1-28. The resulting data in the Arbuckle observation well (KGS #2-28) will provide key data for calibration and validation purposes.

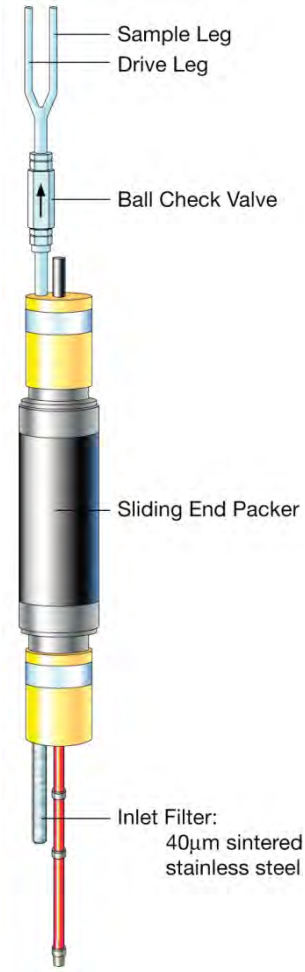


Figure A-2.2 Schematic of the U-tube sampling device.

Table A-2.5 Geochemical analytical suite to be monitored in the Arbuckle monitoring well (KGS #2-28).

Field Parameters	**Pre-Injection**	**During injection**	**Post-Injection**
pH	Once a week for 3 weeks	Every 45 days	Every 6 months
Specific Conductivity	Once a week for 3 weeks	Every 45 days	Every 6 months
Temperature	Once a week for 3 weeks	Every 45 days	Every 6 months
Dissolved Oxygen	Once a week for 3 weeks	Every 45 days	Every 6 months
Gas-Water Ratio	Once a week for 3 weeks	Every 45 days	Every 6 months
Depth to Water	Once a week for 3 weeks	Every 45 days	Every 6 months
TDS/Salinity	Once a week for 3 weeks	Every 45 days	Every 6 months
Indicator Parameters			
Alkalinity	Once a week for 3 weeks	Every 45 days	Every 6 months
Bromide	Once a week for 3 weeks	Every 45 days	Every 6 months
Calcium, Iron, Magnesium, Potassium- um, Dissolved Silica	Once a week for 3 weeks	Every 45 days	Every 6 months
Chloride	Once a week for 3 weeks	Every 45 days	Every 6 months
Sodium	Once a week for 3 weeks	Every 45 days	Every 6 months
Total CO_2	Once a week for 3 weeks	Every 45 days	Every 6 months
Total Fe	Once a week for 3 weeks	Every 45 days	Every 6 months
Total Fe (II)	Once a week for 3 weeks	Every 45 days	Every 6 months
Total NH_4+	Once a week for 3 weeks	Every 45 days	Every 6 months
Total NO_3^{2-}	Once a week for 3 weeks	Every 45 days	Every 6 months

Field Parameters	**Pre-Injection**	**During injection**	**Post-Injection**
Total SO_4^{2-}	Once a week for 3 weeks	Every 45 days	Every 6 months
Total PO_4^{3-}	Once a week for 3 weeks	Every 45 days	Every 6 months
Total HCO_3^-	Once a week for 3 weeks	Every 45 days	Every 6 months
Total CO_2	Once a week for 3 weeks	Every 45 days	Every 6 months
Concentration of Organics		Every 45 days	
DOC	Once a week for 3 weeks	Every 45 days	Every 6 months
TOC	Once a week for 3 weeks	Every 45 days	Every 6 months
DIC	Once a week for 3 weeks	Every 45 days	Every 6 months
Stable Isotopes		Every 45 days	
δ18O	Once a week for 3 weeks	Every 45 days	Every 6 months
δD	Once a week for 3 weeks	Every 45 days	Every 6 months
δ13C for Carbonates in System	Once a week for 3 weeks	Every 45 days	Every 6 months

A-2.5.2.2 Indirect Geochemical Monitoring of the Plume Front: Seismic Surveys

Both borehole and surface seismic methods will be used to track the CO2 plume. Surface seismic data has the advantage of being laterally extensive, but borehole seismic methods (especially crosswell, which will be utilized at Wellington) produce higher resolution images but at less penetration (distance from transmitting and receiving equipment relative to target) than surface seismic methods because seismic waves only pass through weathered surface horizons once (for surface to borehole) or not at all (for cross well), minimizing attenuation and distortion. The higher resolution provided by the borehole seismic may be useful where the carbon dioxide plume is predicted to be thin or complex in shape. The seismic plume tracking techniques and monitoring plans to be employed on the Wellington project are discussed below.

A-2.5.2.2.1 High Resolution Seismic Survey

A 3D seismic survey has already been acquired and processed. This information will provide a baseline to compare with a final 3-D seismic acquisition prior to site closure. The 3D data shall be interpreted and compared with the baseline survey to map the final extent of the CO_2 plume to demonstrate containment in support of site closure.

A-2.5.2.2.2 Croswell Seismic Methods

Crosswell seismic methods deploy sources and receivers in several different wells, producing a survey that images the plane between the wells. The equipment is generally deployed in wells not more than 1500 feet apart. A seismic source is deployed down one well and seismic sensors are deployed down additional wells. Crosswell surveys using several wells are able to generate three-dimensional crosswell surveys. The crosswell seismic technique measures velocity and attenuation characteristics to model CO_2 saturations and/or pressure changes during CO_2 injection. As illustrated in Figure A-2.3, this technique, in continuous monitoring mode can provide information on how the CO_2 is migrating in the subsurface.

By measuring changes in travel-time and signal amplitude between the wells, tomographic techniques are also used to map velocity and attenuation variations in the section between the wells. These can be used to model CO_2 saturations and/or pressure changes. In addition, cross-hole data can be useful for assessing how effectively the pore space in the storage reservoir is being exploited, which is useful for storage prediction modeling. Because cross-hole seismic utilizes much higher frequencies than surface seismic (up to 1000 Hz or more), it interrogates rock and fluid properties at a much finer scale but with much shorter interrogation distances thereby limiting well separation. Therefore the method provides valuable ancillary information for the quantitative assessment of surface seismic in proximity to appropriately spaced wells. The technology has been successfully utilized to capture the CO_2 plume at the Frio experimental sequestration site in Texas (Figure A-2.4).

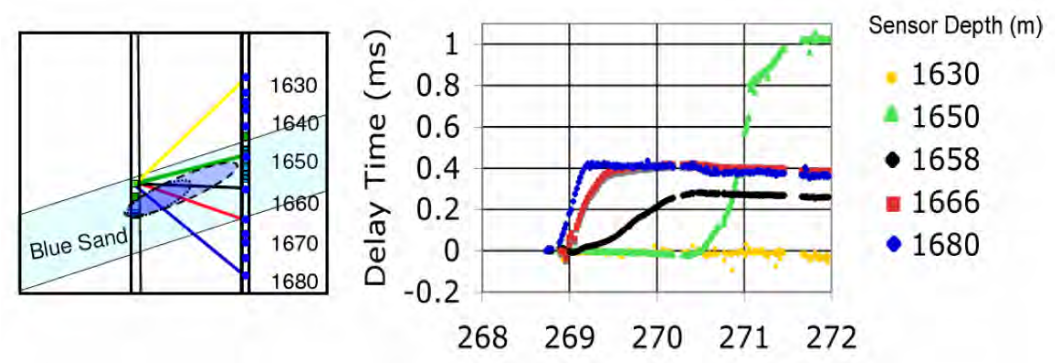


Figure A-2.3 Schematic of continuous active-source seismic monitoring (CASSM) Frio-II experiment with conceptual CO_2 plume after one day (inner short dash) and after two days (outer long dash), with measured delay times at three sensor depths over three and a half days of CO_2 injection (right).

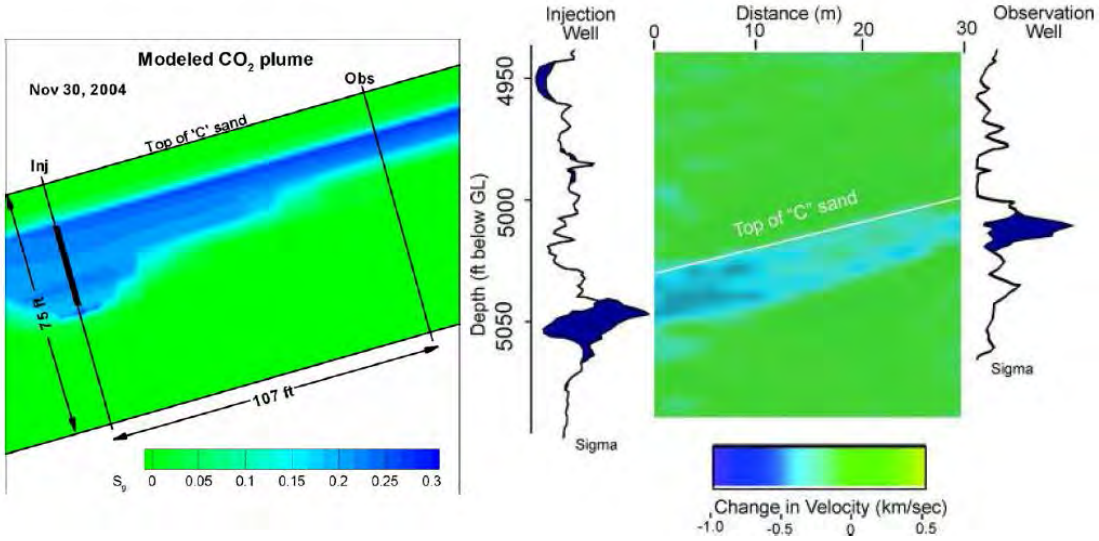


Figure A-2.4 Cross-hole seismic imaging at the Frio experimental site in Texas. Velocity tomography (right) compared with reservoir flow simulation (left); (Images courtesy of Tom Daley (LBNL), Christine Doughty (LBNL) and Susan Hovorka (University of Texas)).

The Arbuckle injection well (KGS #1-28) shall be fitted with the continuous active-source seismic monitoring (CASSM) sources that in combination with the CASSM receivers placed in the Arbuckle observation borehole, KGS #2-28, will enable a real-time monitoring of the CO_2 plume front from the injector well. The Piezotube CASSM source, a hollow cylinder, shall be installed on production tubing in the injection well either above or below the packer (or both). A specially designed source carrier shall be used, acting as a 'pup' joint of tubing. The installation shall include attaching the cable to power the CASSM

source, which shall run to the surface. The CASSM receivers shall be installed on production tubing in the monitoring borehole (KGS #2-28), along with other monitoring instrumentation (Pressure/temperature gauge, U-tube, etc). The CASSM receivers shall be an array of hydrophones or similar sensors, with spatial distribution such that the expected vertical extent of the plume is monitored. The CASSM system will provide monitoring along specific source-sensor ray paths, complimenting the full crosswell tomography survey to be acquired separately.

Pre-injection crosswell tomography survey shall be carried out before the subsurface seismic velocity field is perturbed by the CO_2 injection, and will thus be a 'baseline' for the later surveys and for calculating time lapse changes. The second crosswell tomography survey shall be conducted approximately half way through the injection to estimate the plume location between the Arbuckle injector and observation boreholes.

The CASSM surveys shall be acquired at a temporal resolution on the order of 10-30 minutes, allowing estimation of plume growth in real time, until the instruments are removed for the full crosswell survey. The crosswell survey(s) shall be useful as 'bookends' to the CASSM survey, providing a detailed spatial description of the CO_2 distribution and the seismic wave field. This plan will alleviate the shortcoming of the relatively sparse spatial sampling of the CASSM which leaves uncertainty in some aspects of the interpretation of the seismic waveform and the CO_2 distribution (CASSM focuses on the first arrival only, while crosswell allows understanding of later arriving phases and provides imaging in the entire 2D plane between wells).

A-2.6 Reporting of Monitoring Results to EPA

Results of monitoring activities will be submitted to the EPA as per schedule defined below. Data will be submitted in electronic form directly to EPA's geologic sequestration database where they can then be accessed by the UIC Program Director.

Prior-to-Injection Report

- CO2 stream analyses
- Descriptive report of initial MIT
- Baseline InSAR data
- Groundwater geochemistry analyses of USDW
- Groundwater geochemistry analyses of Mississippian formation
- Background U-tube geochemistry

Semi-annual Report

- Quarterly carbon dioxide stream characteristics (physical, chemical, other) detailing the list of chemicals analyzed, a description of the sampling methodology and the name of the certified laboratory performing analysis, sample dates and times, and interpretation of the results with respect to regulatory requirements and past results. Any changes to the physical, chemical, and

other relevant characteristics of the carbon dioxide stream from the proposed operating data will also be documented;

- Description of any event(s) that exceeded operating parameters for annular pressure or injection pressure and corresponding action;
- Description of any event(s) which triggered a shut-off device and the corresponding response undertaken;
- Monthly volume and/or mass of carbon dioxide injected over the reporting period;
- Cumulative volume of carbon dioxide injected over the project life;
- Monthly annulus fluid volume added to the injection well;
- If pressure or flow rate exceeded permit limits during the reporting period, an explanation of the event(s), including the cause of the excursion, the length of the excursion, and response to the excursion;
- Identification of data gaps, if any;
- Any necessary changes to the project Testing and Monitoring Plan to continue protection of USDWs;

- Continuous measurement of flow rate and pressure in injection well including:
    - Tabular data of all flow rate measurements
    - Monthly average, maximum, and minimum value for flow rate and volume, injection pressure, and annular pressure
    - Total volume (mass) injected each month
    - Cumulative volume (mass) for the project
    - Demonstration of gauge calibration according to manufacturer specifications
- MIT Results
- Corrosion monitoring information including a description of the techniques used for corrosion monitoring, measurement of mass and thickness loss from corrosion coupons along with a calculated corrosion rate
- Bottom hole pressure results in all monitoring wells including a synthesis and interpretation of the entire historical data set
- InSAR data
- Groundwater geochemistry sampling results and analyses of USDW

- Groundwater geochemistry sampling results and analyses of Mississippian Formation
- U-tube geochemistry results and analyses
- CASSM results
- Seismic results and analyses.

Results to be reported within 30 days of event occurrence

- Results of periodic external MITs;
- Any well work performed;
- Any test of the injection well as required by the EPA;
- If conducted, pressure fall-off test results including raw data collected during the fall-off test in a tabular format, measured injection rates and pressures, demonstration of gauge calibration according to manufacturer specifications, diagnostic curves of test results, noting any flow regimes, description of quantitative analysis of pressure-test results, calculated parameter values from analysis, including transmissivity and skin factor.

Information to be reported within 24 hours of occurrence

- Any evidence that the carbon dioxide stream or associated pressure front has or may cause endangerment to a USDW;
- Any non-compliance with permit condition(s), or malfunction of the injection system, that may cause fluid migration to a USDW;
- Any triggering of a shut-off system either downhole or on the surface;
- Any failure to maintain mechanical integrity;
- Any release of carbon dioxide to the atmosphere;
- A description of any event that exceeds operating parameters for annulus pressure or injection pressure.

30 Days Notification

- Any well workover, or testing in compliance with EPA directives;
- Any well stimulation activities, other than stimulation for formation testing at the injection well;
- Any other injection well testing.

A-2.7 Periodic Review of Monitoring Plan

The testing and monitoring plan will be periodically reviewed to incorporate a) monitoring data, b) operational data, and c) most recent area of review reevaluation. Specifically, a review will be conducted if there is:

- model revision that affect the predicted movement of the plume and pressure fronts (ie, size and shape of AoR,
- evidence of leaching/mobilization of metals or organic constituents in the subsurface which may indicate a need to modify ground water monitoring parameters or analyses,
- operational parameters are outside the expected operating range,
- Area of Review reevaluation,
- well construction, mechanical integrity, and corrosion testing data indicates a need to modify the well testing regime, e.g., by revising MITs or corrosion monitoring activities,
- five years have elapsed since commencement of injection and site closure has not occurred,

The outcome of the review may be an amended testing and monitoring plan which will be submitted to the EPA Director for approval. If an amended plan is not required, then a justification for the same in the form of a report will be submitted to the EPA Director for approval. The amended plans or demonstrations that no amendment is required shall be submitted to the Director for approval as follows:

(1) Within one year of an area of review reevaluation;

(2) Following any significant changes to the facility, such as addition of monitoring wells or newly permitted injection wells within the area of review, on a schedule determined by the EPA Director; or

A-2.8 Period of Data Retention

All data collected in support of this Class VI application (including background geologic/hydrogeologic data and analyses, geophysical logs, modeling results, well design and plugging information/reports) as well as all operating information (including all testing/monitoring activities, AoR re-evaluation, corrective action records, post-injection data, and site closure records including data and information used in support of the alternative site care time frame) will be retained for at least 10 years following site closure.

A-2.9 Quality Assurance Plan

All Quality Assurance and Quality Control (QA/QC) measures will be documented in semi-annual MVA reports and all intermediate reports submitted to the EPA that contains field data.

Data obtained from externally contracted laboratories such as for CO_2 stream analyses, water quality testing, temperature/geophysical logs, and corrosion data will be accompanied with the QA/QC protocol and results followed by the respective laboratories.

Quality Assurance/Quality control procedures to be followed for obtaining and handling CO_2 source samples are documented in Section A-2.3.1.4. QA/QC procedures to be followed during acquisition of groundwater quality data above the injection zone is documented in Sections A-2.4.1.3. As discussed in Section A-2.5.1.2, the continuous GPS station will be utilized to calibrate and verify the InSAR satellite data. Instruments installed locally such as pressure transducers and flow meters shall be calibrated as per manufacturer's recommendations and the procedure and results documented in reports submitted to EPA.

Appendix A-3

Public Outreach Summary

Public outreach is an integral part of the Wellington project. Being a federally funded pilot project, KGS follows all guidelines in the DOE/NETL publication, Best Practices for Public Outreach and Education for Carbon Storage Projects. The goal of the outreach program is to establish communication between KGS and the host community in order to provide a means to solicit community input, build trust, and ensure the community that the project will be executed safely and responsibly. Specific goals include:

- Educate citizens how CO_2 storage works, how it can contribute to global climate change mitigation, and that the project is part of a national strategy to reduce greenhouse gas emissions,
- Assure the community that KGS and the project operator, Berexco, have the appropriate expertise to safely execute the project,
- Allow the public to express their views,
- Proactively and constructively address community concerns.

Key constituents include public officials, legislators, environmental regulators, business interests, landowners and neighbors, civic groups, environmental groups, educators, and the media. The venues and means for communication/outreach include:

- Meetings or focus groups with stakeholders and the public,
- Community events and open houses,
- Interviews with community leaders,
- Conducting site visits and tours,
- Reporting of monitoring data to the regulatory agency,
- Interactions with the media.

The Principal Investigator of the project, Lynn Watney, has already conducted several meetings with citizens and legislators to inform them of the proposed project. The key messages that are being communicated include:

- There is a well understood approach to site selection and characterization to ensure that geologic conditions are suitable for long term storage without leaks,
- Why Wellington, KS is a safe place to store CO_2,
- Standard practices will be followed to guarantee safety and to ensure that CO_2 storage will not cause harm to health or jeopardize the environment,
- How a computer simulation of subsurface CO_2 location is developed, validated, and calibrated, and what the results indicate,
- Role of EPA in overseeing/regulating CO_2 storage,
- Potential costs and benefits to the community from CO_2 storage,
- Natural geologic CO_2 storage has occurred for millions of years,
- Engineered geologic storage of CO_2 has been safely practiced for 40 years. Over three billion cubic feet (176 thousand metric tons) of natural CO_2 is injected daily into west Texas oil fields to recover additional oil. The limited supply of natural CO_2 hinders expansion of this technology in Kansas, and the use of anthropogenic and largely ignored CO_2 is a natural next step,
- Injection and reservoir monitoring are mature technologies. The experience in the oil and gas exploration and development industry is being used to ensure sequestration success. Injection and reservoir management in Kansas oil fields has been ongoing for decades since oil production peaked in 1956,
- There are similarities between the major expansion of oil and natural gas systems after World War II with respect to pipeline and natural gas storage, and the expected deployment of CO_2 storage projects,

In order to facilitate the outreach efforts, KGS has developed a dedicated web site for the project (http://www.kgs.ku.edu/PRS/Ozark/small_scale.html).

Appendix A-4

Class VI Injection Well Permit for KGS #1-28

KGS is in the final stages of completing the EPA Class VI injection well permit application for submittal to the EPA Region 7 UIC Director. The permit will be filed by the site operator, Berexco, Inc. of Wichita, KS. KGS is in the process of incorporating final comments by Berexco which were received on January 24th, 2014. An executive summary of the permit application is provided below:

Executive Summary

A small scale pilot carbon capture and storage (CCS) project is proposed by Berexco, Inc and Kansas Geological Survey at the Wellington oilfield approximately four miles northwest of the City of Wellington in Sumner County, Kansas (Figure ES-1). The project is part of a US Department of Energy (DOE) funded pilot scale study to demonstrate the ability of the 4,000 feet deep Cambrian-Ordovician age Arbuckle saline aquifer to accept and retain carbon dioxide (CO_2) for permanent geologic sequestration. Approximately 40,000 tons of CO_2 is to be injected in the Arbuckle aquifer over a period of 9 months. The details of the project and EPA Underground Injection Control (UIC) Class VI construction, operations, monitoring, well plugging, Area of Review (AoR), post-injection site care and site closure, emergency remedial/response, and financial responsibility plans are summarized below.

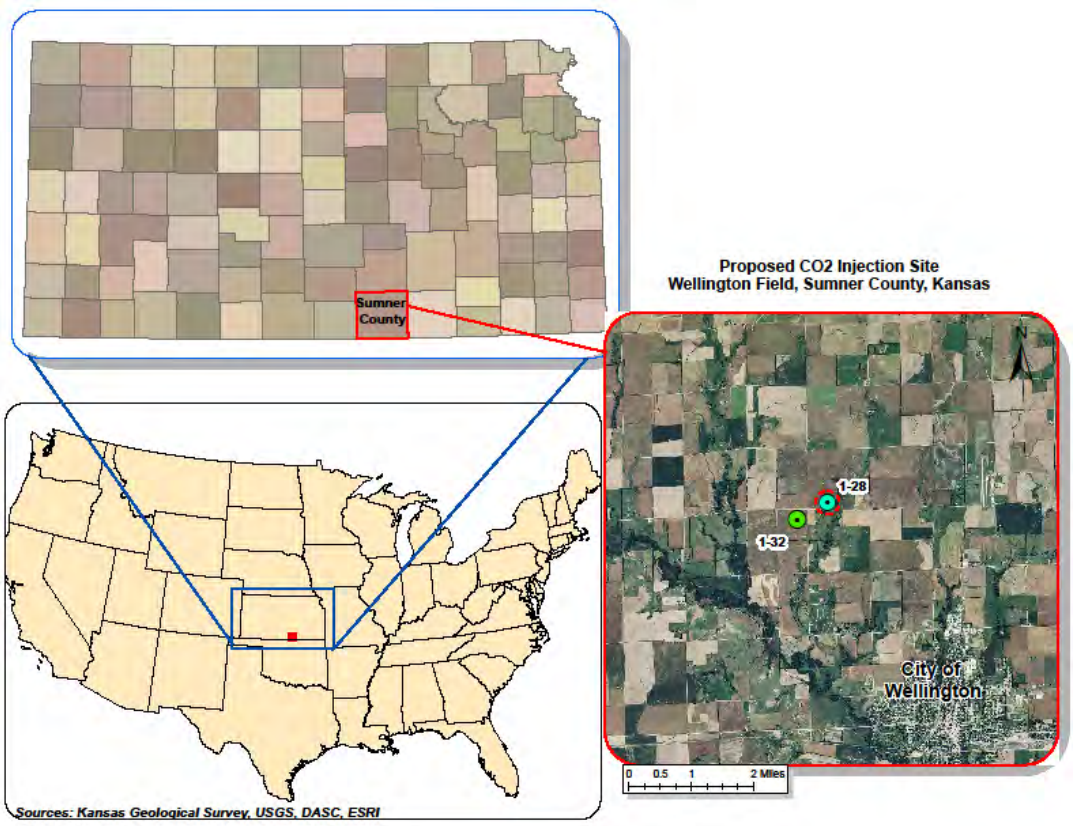


Figure ES-1 Location of small-scale CO2 storage site at Wellington, Kansas

Site Setting

The Wellington sequestration site is located in a rural area where land is used primarily for (non-irrigated) crop cultivation (Figure ES-2). CO_2 injection is to occur at the recently completed well (KGS #1-28) which was constructed per EPA UIC Class VI specifications. There are no potable water wells in the vicinity of the injection well. The EPA AoR based on the maximum extent of plume migration is only 1,750 feet from the well as shown in Figure ES-2.

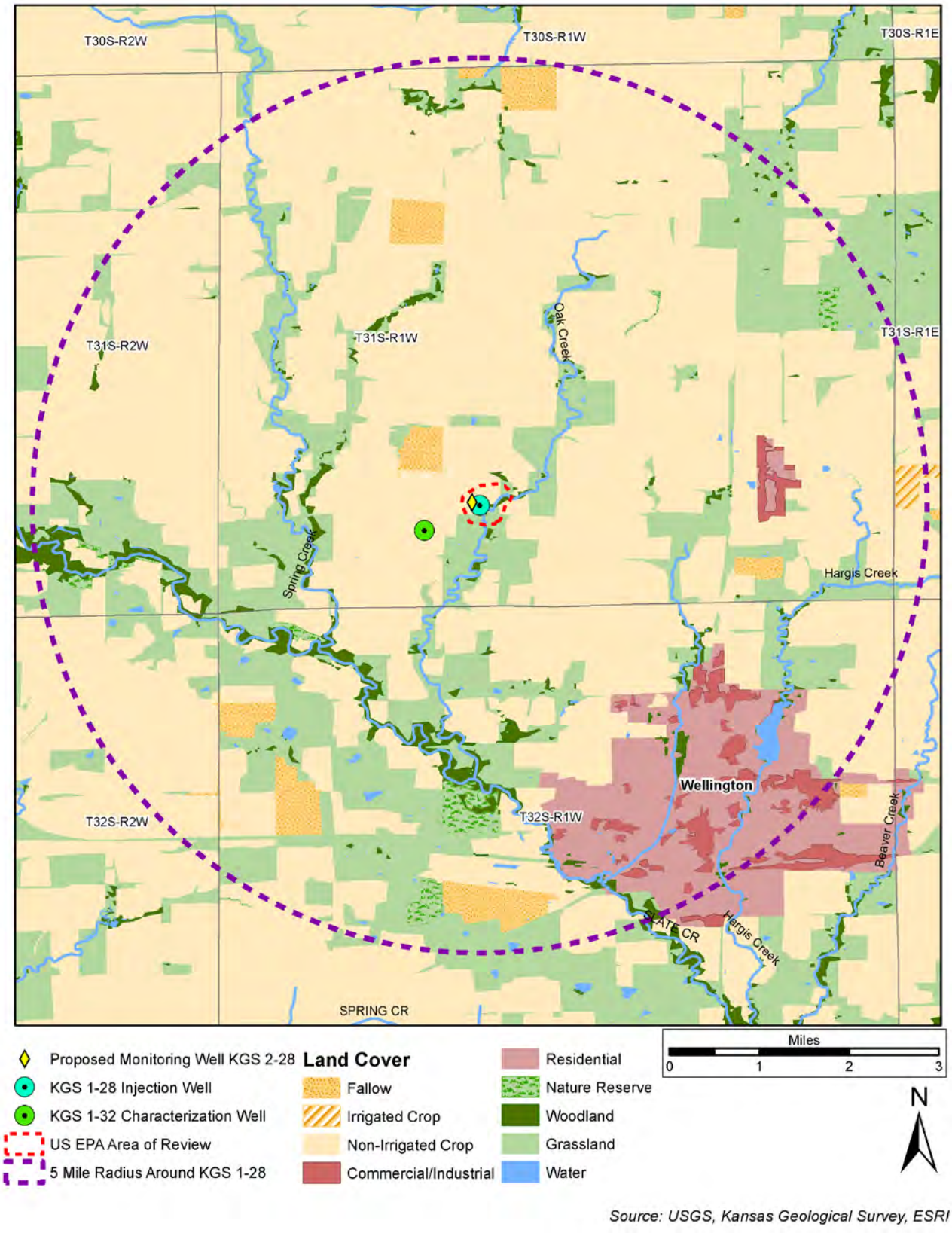


Figure ES-2 Land use in the vicinity of the Wellington small-scale CO_2 storage site

Geology

Arbuckle Group (Injection Zone)

The geologic column at the injection well site is presented in Figure ES-3. The injection is to occur in the 1,000 ft thick regionally extensive Arbuckle Group of Cambrian-Ordovician period located approximately 4,160 feet below ground at the Wellington site. The injection is to occur near the base of the Arbuckle Group, which has relatively higher permeability as compared to the rest of the formation.

Simpson Group/Chattanooga Shale/Pierson Formation (Upper Confining Zone)

The Ordovician and Devonian shales within the Simpson Group and Chattanooga Shale, along with the argillaceous siltstone in the Pierson Formation of Mississippian subsystem, have the characteristics of caprock and will therefore function as the top confining zone and effectively prevent upward migration of CO_2. The 240 feet thick confining zone has no known communicative fractures between the Arbuckle injection zone and Mississippian oil and gas reservoir overlying the confining zone. There are several thick layers of shale above the upper confining zone as well as shown in Figure ES-3, which can potentially provide additional impedance to flow, but which are not relied in this application to demonstrate confinement potential.

Precambrian Granitic Basement (Lower Confining Zone)

Precambrian-age basement granites underlie the Arbuckle Group throughout Kansas, and are expected to provide hydraulic confinement at the base of the injection zone.

Upper Wellington Formation (USDW)

The lowermost and only Underground Sources of Drinking Water (USDW) extends from land surface to 250 feet below ground and comprises of Permian shales in the Upper Wellington Formation as shown in Figure ES-3. Below the Upper Wellington are the Hutchinson Salt Beds which overlies bedrock shales in the Lower Wellington Formation. The USDW (Upper Wellington formation) lies approximately 4,500 feet above the top of the injection zone in the lower Arbuckle aquifer. There are no groundwater withdrawals in the vicinity of the Wellington CO_2 storage site.

Estimated Sequestration Capacity of Arbuckle Group

The total amount of CO_2 that could be stored in the Arbuckle Group within Kansas is estimated by the US DOE to be as high 89.5 billion metric tons, the equivalent of several years of annual CO_2 emissions (approximately 6 billion metric ton/year) for the entire United States. Approximately 300,000-360,000 metric tons of CO_2 per square mile can be stored in the Arbuckle aquifer at the Wellington site as shown in Figure ES-4. Only around 40,000 metric tons of CO_2 will be injected into the Arbuckle during a period of 9 months, which as per DOE estimates should be stored in an area of $1/10^{th}$ of a square mile.

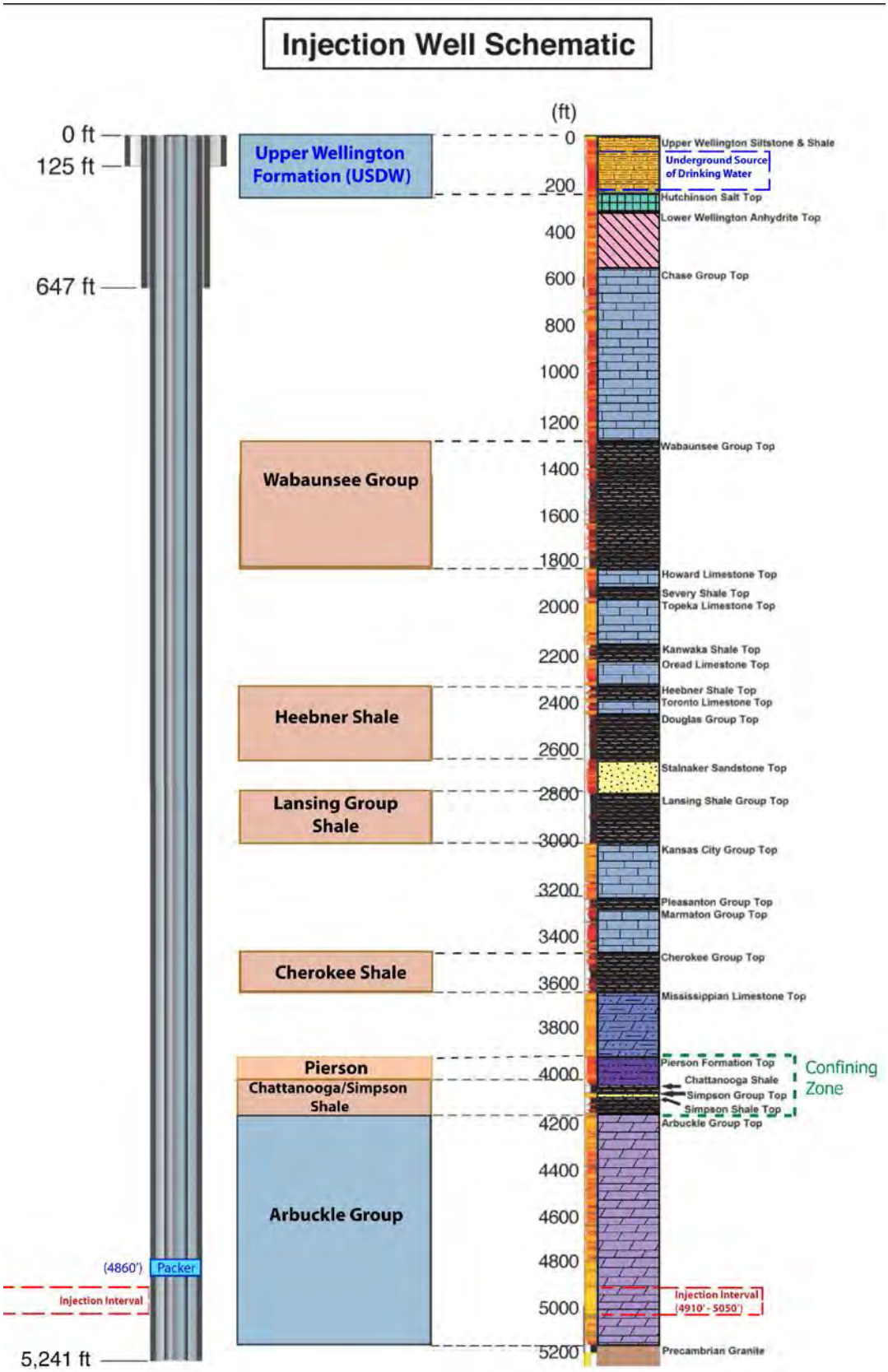


Figure ES-3 Schematic of injection well showing geologic formations at Wellington sequestration site.

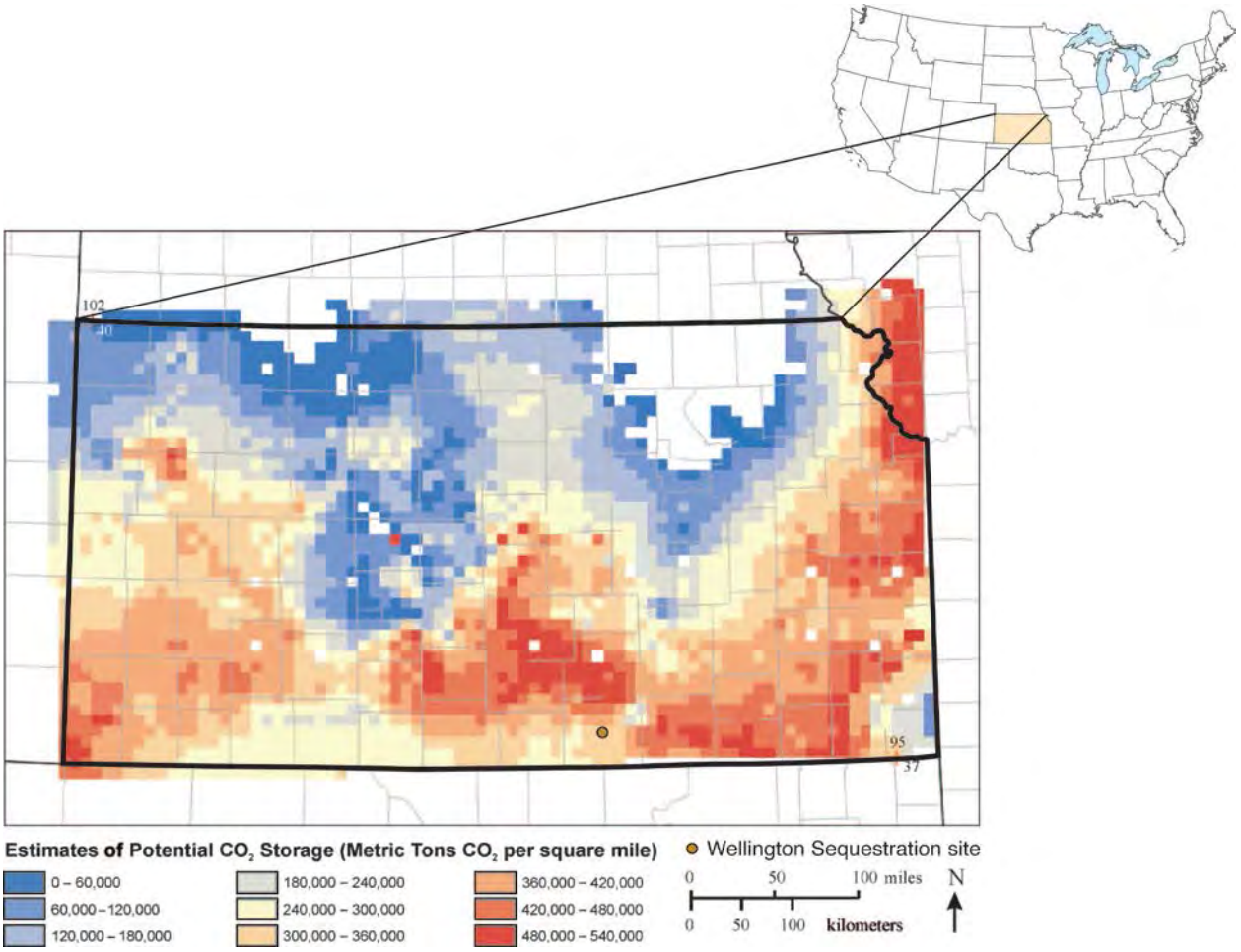


Figure ES-4 Map showing the estimated sequestration potential in the Arbuckle saline aquifer in metric tons CO_2 per square mile.

Modeling

During construction of the injection well (KGS #1-28) and the geologic characterization well (KGS #1-32) shown in Figure ES-1, an extensive suite of geophysical logs were obtained to understand the geology and hydrogeology, and derive petrophysical properties. These included the Array Compensated True Resistivity, Temperature, Compensated Spectral Natural Gamma Ray, Microlog, Spectral Density Dual Spaced Neutron, Annular Hole Volume Plot, Extended Range Micro Imager Correlation Plot, Radial Cement Bond, Composite Plot, and Magnetic Resonance Imaging logs. The data was used to develop a reservoir simulation model of the Arbuckle Group. An extensive set of computer simulations were conducted using the base case model and nine alternative models in order to account for parametric uncertainty and to bracket the impacts of CO_2 injection on subsurface fluid pressures and extent of CO_2 plume migration. The underlying motivation was to determine if the injected CO_2 could negatively impact the USDW, or potentially escape into the

atmosphere through existing wells or faults/fractures that may either be present, reactivated, or created by the injected fluid.

Simulation results indicate that the maximum pressure induced in the Arbuckle aquifer are insufficient to cause vertical migration of the brines into the USDW due to under-pressurization of the Arbuckle aquifer. The (pre-injection) heads in the Arbuckle injection zone are approximately 600 feet lower than heads in the USDW. Simulation results also indicate that the pressures induced due to injection will dissipate within three months of cessation of injection. Also, the maximum pressures induced at the top of the Arbuckle are insufficient to cause Arbuckle fluids to migrate upward due to the high entry pressure of the confining zone.

Simulations results indicate that the CO_2 will largely remain confined in the lower Arbuckle injection zone and not migrate even into the mid-Arbuckle (Figure ES-5a). The induced pore pressures drop to levels below that necessary to cause vertical migration of the brine at a distance of a few tens of feet from the injection well. Laterally, the maximum extent of the plume (with CO_2 saturation of less than 1%) is expected to be approximately 1,750 feet from the injection well as shown in Figure ES-5b, and the plume growth is expected to cease in less than a year of cessation of injection. Therefore, a post-injection monitoring period of one year is proposed as indicated below.

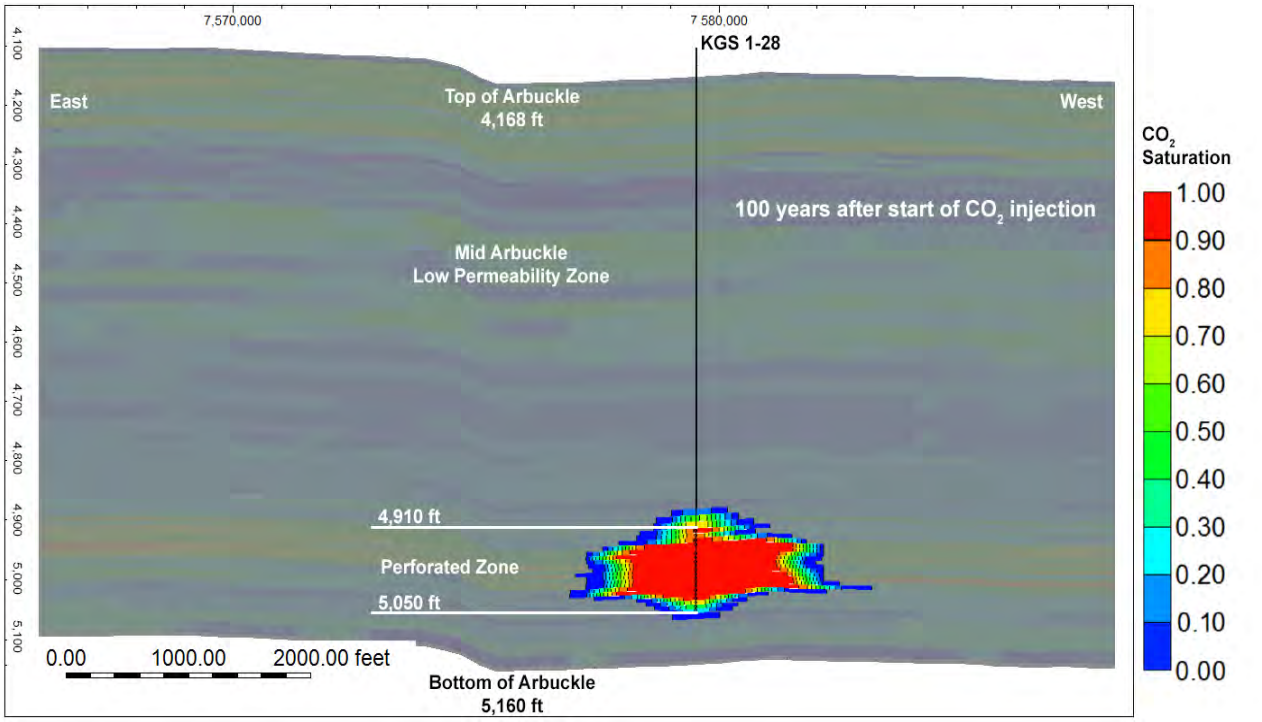


Figure ES-5a Vertical extent of CO_2 plume migration at the end of 100 years following injection

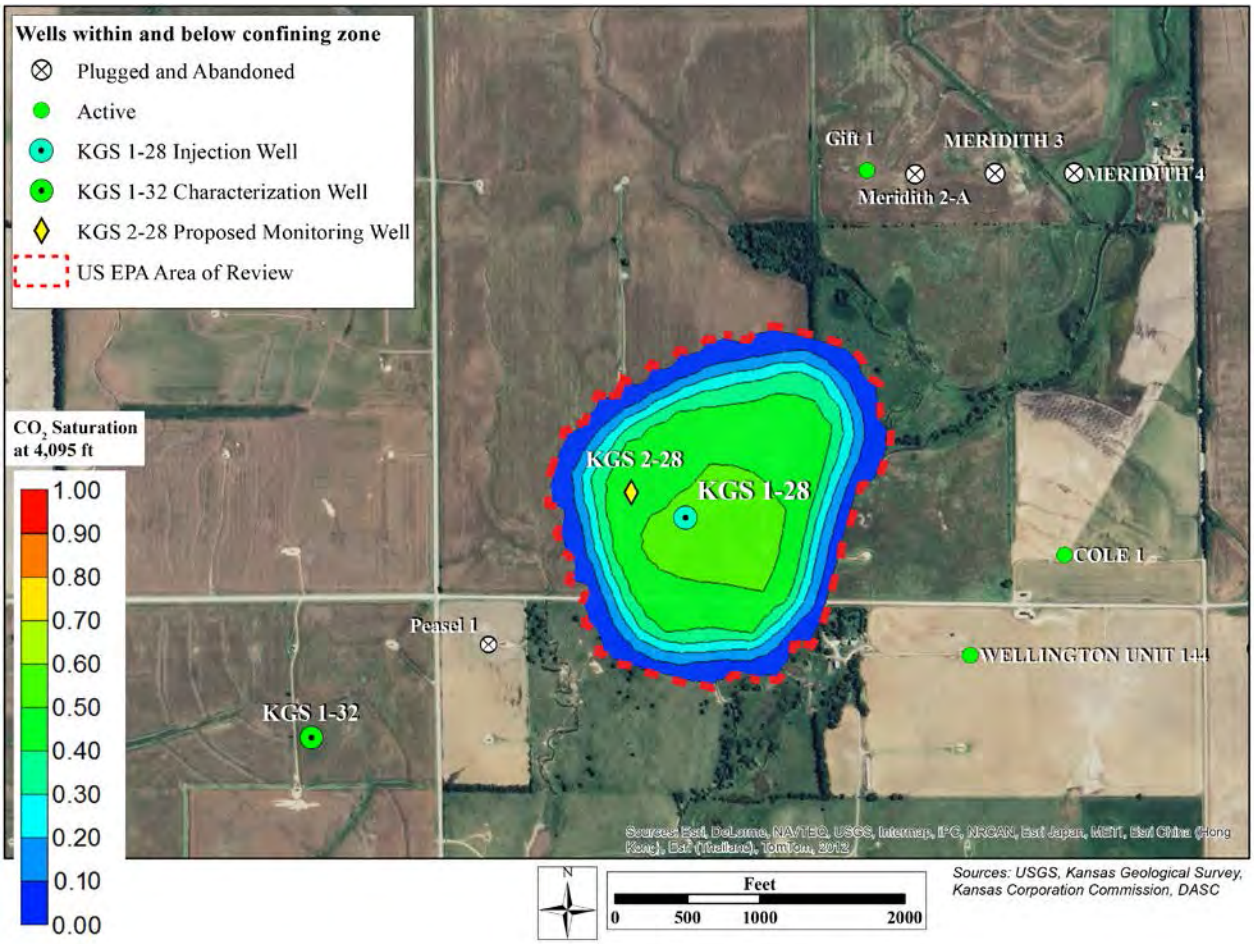


Figure ES-5b Maximum lateral extent of CO_2 plume migration.

AoR and Corrective Action

The EPA AoR derived for the Wellington project is based on EPA's *Maximum Extent of the Separate-phase Plume or Pressure-front (MESPOP)* methodology. It was determined that the pressures to be induced due to injection of CO_2 at Wellington are insufficient to cause brines from the Arbuckle Group to migrate vertically into the USDW through any natural or artificial penetration. Therefore, the AoR is based on the maximum extent of plume migration, which as shown in Figure ES-5b extends approximately 1,750 feet from the injection well. There are no existing or abandoned wells (other than the proposed injection well) either in the Arbuckle Group or the overlying confining zone within the AoR. Therefore, no well corrective action is required.

Following commencement of injection, if significant deviations in the projected formation pressures and plume migration patterns are observed, then the reservoir model may be recalibrated which will trigger an automatic revaluation of the AoR and Corrective Action Plan. This iterative process may continue until field based observations and model projections are in agreement.

CO_2 Compatibility in Injection Zone and Well

Geochemical analyses suggests that the injection of anthropogenic CO_2 should not cause any compatibility problems with formation waters and minerals in the Arbuckle Group, which could result in reduced pore space, excessive formation/well pressures, or any hindrance to injection operations or geologic storage.

The tubing, casing, packer, and cement of the injection well are also designed for CO_2 injection operations (Figure ES-6). The chemical composition of the injectate should cause no adverse reactions or degradation of the well components for the short nine month duration of injection. The low water content of the injected CO_2 and the low temperatures will result in only a mildly corrosive environment. Quarterly monitoring for corrosion using coupons however is to be conducted in order to provide early warning of a deteriorating environment.

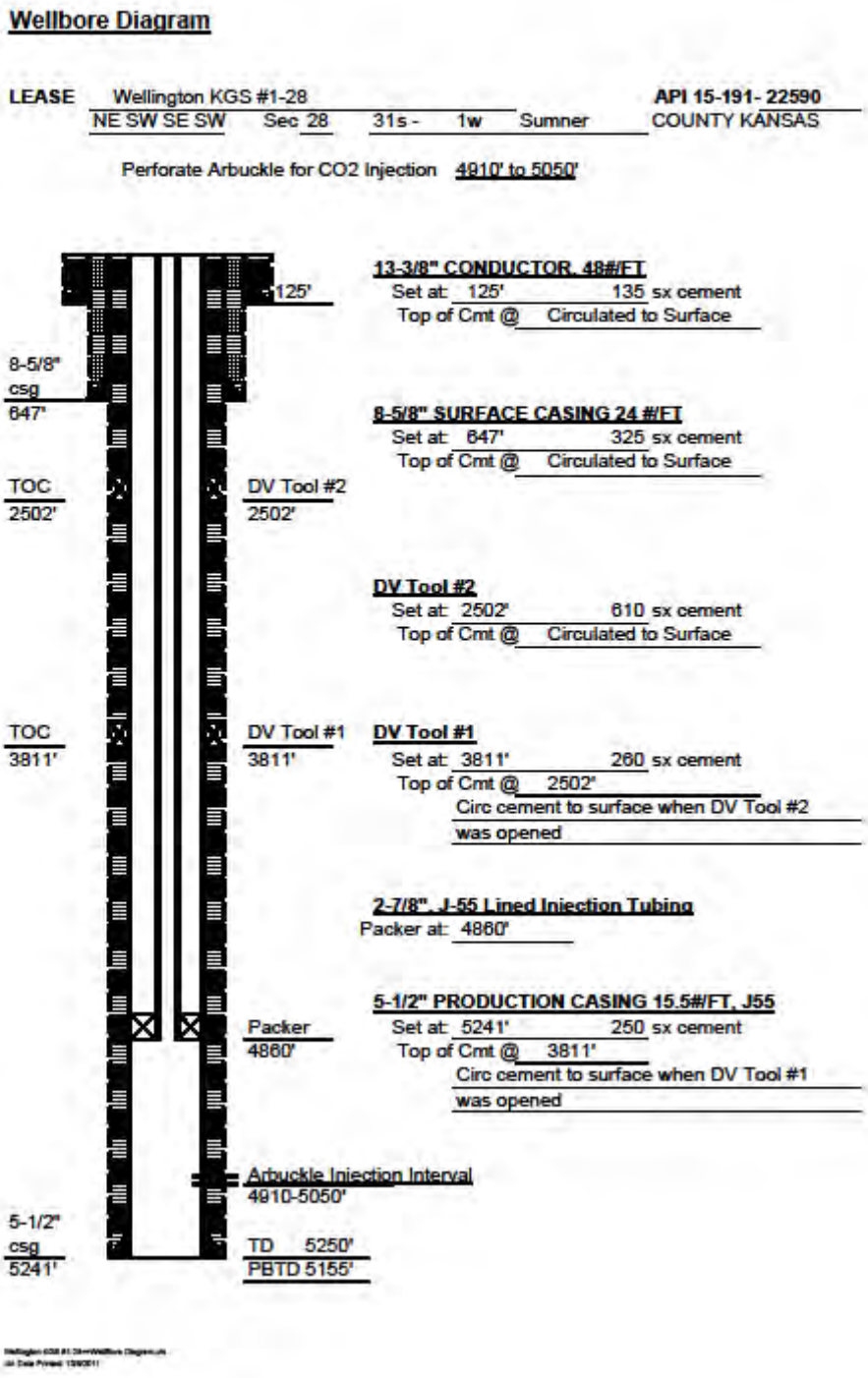


Figure ES-6 Well construction details of injection well KGS #1-28.

Testing and Monitoring Plan

A number of monitoring wells will be used for tracking the CO_2 plume and pressure front. The locations of these monitoring wells and the formations they will monitor are shown in Figure ES-7. Three monitoring wells are located in the Arbuckle aquifer. Five existing Mississippian wells will be used to check if CO_2 has escaped upward from the primary confining zone (base of Simpson Group to top of Pierson Formation) at the site. Twelve shallow wells in the Upper Wellington Formation (USDW), and one in the Chase Group under the Wellington Formation, will be monitored to protect potable water supply in the area. Both direct and indirect measurement methods will be used to monitor the movement of the pressure and plume fronts, identify potential risks to USDWs, and to verify predictions of plume movement.

Injection Well Monitoring

The surface and bottomhole pressures and temperatures will be monitored continuously at the injection well. The chemical composition of the injectate will be tested quarterly in order to ensure that it does not qualify as hazardous waste with regard to corrosivity or toxicity. Due to the short nine month period of injection, corrosion is not expected to occur in the Wellington injection or observation wells. However, corrosion coupons will be used for monitoring loss of material in the Arbuckle injection and monitoring wells on a quarterly basis.

Internal and external Mechanical Integrity Tests (MITs) will be conducted prior to, during, and following injection. Temperature logs will be used to demonstrate external MIT. Prior to commencing injection, an Annulus Pressure Test will also be conducted at the injection well to demonstrate internal mechanical integrity. The test will provide information necessary to determine whether there is a failure of the casing-cement bond, injection tubing, and packers.

A pre-injection pressure fall-off test will be conducted in order to estimate formation properties in the vicinity of the injection well. This information will serve as a baseline in the event of any changes in the near-wellbore environment that may impact injectivity and result in pressure increases.

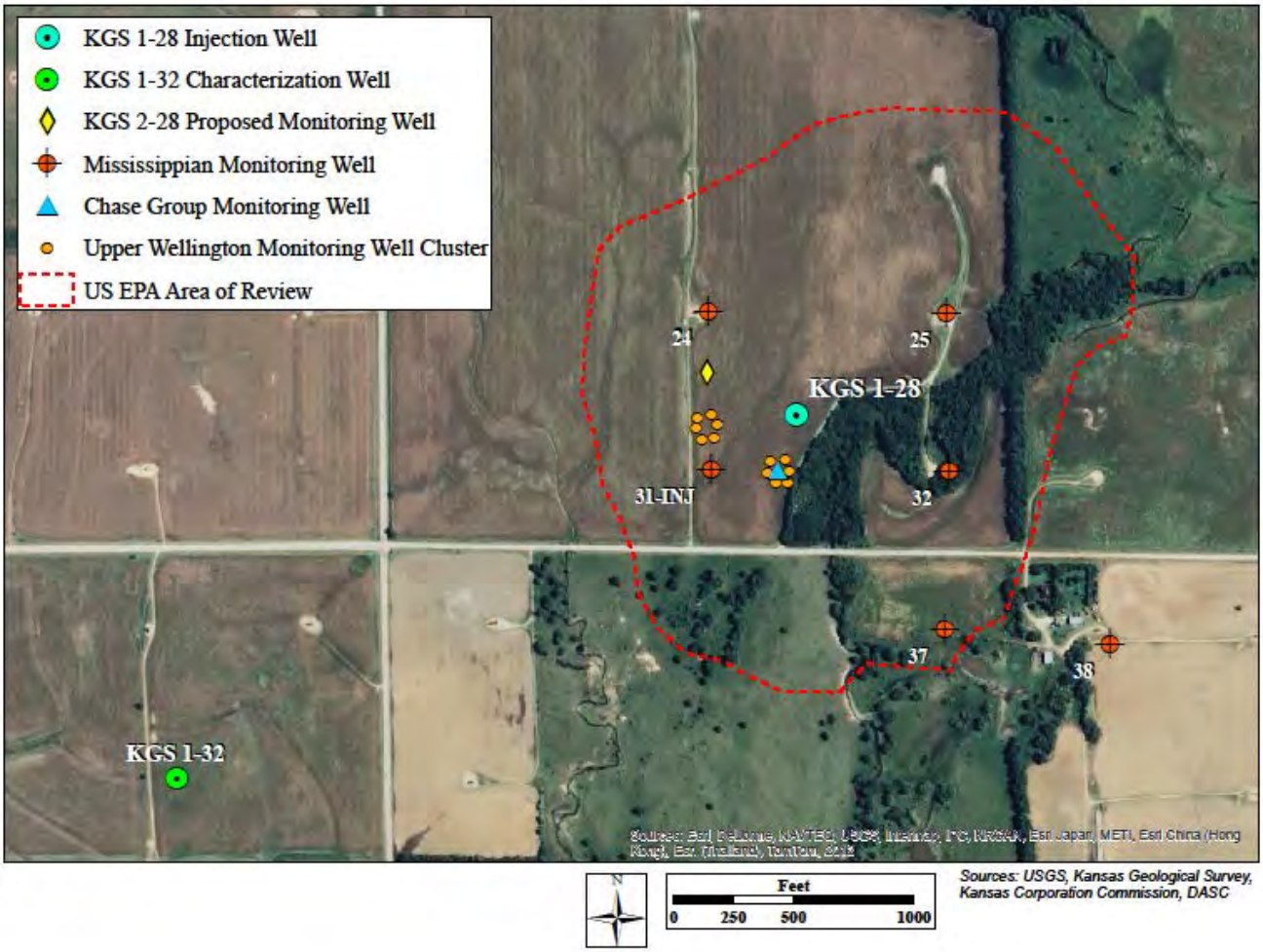


Figure ES-7 Location of monitoring wells in the Arbuckle, Mississippian, and Wellington formations

Pressure Front Monitoring

Pressure transducers will be installed in the Arbuckle injection and monitoring wells (KGS #1-28, KGS #2-28, KGS #1-32, and Peasel-1). The acquired pressure data will be compared with model based prediction of the pressure front, and if necessary, the simulation model will be recalibrated to conform to field data. In addition to direct monitoring, the pressure front will also be tracked areally by monitoring surface deformation using InSAR (Interferometric Synthetic Aperture Radar) remote sensing technique.

Monitoring the Plume Front

Various direct and indirect MVA tools and techniques shall be used to monitor the plume front. The crosswell tomography, U-tube, and continuous active source seismic monitoring

(CASSM) technology shall be used to monitor and visualize the movement of the CO_2 plume. Sampling and analysis of water and casing head gas from existing Mississippian wells/boreholes around the Arbuckle injector shall be used to determine if injected CO_2 has breached the confining zone and escaped into the overlying Mississippian Reservoir. Shallow groundwater sampling and analysis will help confirm if any injected CO_2 has reached the USDW. The newly acquired data will be compared with the existing baseline seismic data in order to track the plume movement. The monitored data will also be used revise the simulation model, update site characterization, and potentially revise the monitoring plan if deemed necessary.

A 3-D seismic survey will also be undertaken prior to closure, in order to validate the absence of CO_2 outside the containment strata and confirm that future leakage risks are minimal to non-existent.

Geomechanical Failure and Seismic Risk

Simulation results indicate that the pressures induced due to CO_2 injection at KGS 1-28 are insufficient to initiate new fracture, propagate existing fractures, or cause slippage along any existing fault planes. There are no documented faults in the vicinity of the injection well, with the closest fault approximately 12.5 miles southeast of the site where negligible pressures will be induced due to injection. The Wellington storage site (and all of Kansas) is in a low seismic hazard area as defined by the United States Geological Survey. Historical record indicates that most earthquakes in Kansas are small with the largest measured at 4.0 on the Richter scale, which is not of sufficient strength to cause any infrastructure damage.

CO_2 Trapping Potential of the Mississippian Oil Field

The Mississippian oil reservoir lies immediately above the primary upper confining zone. It is a highly under-pressurized system which is likely a consequence of oil and gas production that has occurred in this formation since the early 1900s. Due to this under-pressurization, any CO_2 that may escape from the primary confining zone is likely to be trapped in the Mississippian formation. This under-pressurization could not have existed in the absence of a competent low permeability confining zone between the Arbuckle and the Mississippian systems, which essentially provides a hydraulic seal between the two formations.

Injection Well Construction

The 5,241 ft deep injection well (KGS 1-28) penetrates the top of the pre-Cambrian basement rock at a depth of approximately 5,160 feet. The well will be perforated between 4910 – 5050 feet for injection into

the highly permeable lower Arbuckle zone as shown in figures ES-3 and ES-6. The injection well was constructed in accordance with UIC Class VI construction guidelines using CO_2 resistant cement and corrosion resistant material in the production casing and injection tubing. The tubing and the casing are designed to withstand axial, burst, and collapse stresses. Cement bond and variable density logs were acquired after setting and cementing the surface casing and long-string casing. These logs do not indicate any loss of mechanical integrity.

Injection Well Plugging Plan

The injection well and potentially the Arbuckle monitoring well (KGS #2-28) will be plugged as per UIC Class VI specifications to the top of the Pierson Formation, which corresponds to the top of the confining zone. Both wells may be used in the future for CO_2 Enhanced Oil Recovery (EOR) injection or other oilfield operations in the locally producing Mississippian formation, so plugging will only occur to the base of the intended oil recovery zone (top of Pierson Formation). The Arbuckle monitoring well KGS #2-28 will be plugged as a Class VI well in the event that the CO_2 plume reaches this well, or is expected to reach this well at any time in the future.

Surface Facilities and Operations

The planned volume of CO_2 injection is 150 metric tons per day. The CO_2 will be transported to the site in trucks in liquid state at a pressure of approximately 250 pounds per square inch (psi) and temperature of -10^{o} F. The surface facilities at the Wellington injection site will consist of a storage tank, a pump, a programmable logic controller (PLC), and wellhead. The bottom hole and wellhead pressures and temperatures will be continuously monitored along with the flow rate and the data fed continuously to the PLC. The PLC will manipulate the control valve in order to not exceed the maximum specified flow rate and to ensure that the bottom hole pressure in the injection well does not exceed the maximum allowable pressure, which corresponds to 90% of the fracture pressure. The PLC will be programmed to initiate shutdown if the operating ranges are exceeded.

Post Injection Site Care and Site Closure Plan (PISC)

Due to the expected stabilization of the pressure and plume fronts in less than a year following cessation of injection, it is proposed that site be closed one year after cessation of injection. Upon cessation of injection, the most recently acquired field data will be used to refine the reservoir model if necessary, and update simulation results and the projected pressure front and plume movement. The revised projections will be used to determine whether the monitoring, AoR, and PISC plans are adequate to ensure accurate tracking of the plume/pressure front and support closure of the site. If necessary, this process of data acquisition and model refinement/projections may continue in order to determine whether or not the

injected CO_2 could migrate out of the storage formation into the USDW. Once a determination of no negative impacts to the USDW is made, an application for site closure will be filed with the EPA Director.

Emergency Remedial Response Plan

An Emergency Remedial Response Plan has been prepared and will be implemented if Berexco obtains evidence that the injected CO_2 stream and/or associated pressure front may endanger the USDW. Specific plans are outlined for a variety of emergency conditions related to testing, monitoring, and mechanical failure. The plans involve immediate cessation of injection, identification and characterization of the failure, notification of the EPA UIC Program Director within 24 hours, and implementation of the appropriate response and remedial action. In addition to executing an automatic shutdown, the PLC will also notify Berexco of a shutdown over cellular network.

Financial Responsibility Plan

Due to its extensive experience in subsurface oil and gas operations and strong financial position, Berexco, is opting for the self-insurance option to demonstrate Financial Responsibility to carry out CO_2 storage activities related to performing well corrective action, injection well plugging, post-injection site care, site closure and implementing an emergency/remedial plan . Berexco meets or exceeds all minimum financial coverage criteria to demonstrate financial strength and ability to complete sequestration activities. It should also be noted that the Wellington projected is part of a cooperative agreement with the US DOE. The US DOE has accepted a proposal to provide approximately 11 million dollars of financial assistance for this project. Therefore, financial risks to Berexco are minimal.

Conclusions and Risks to USDW

Detailed AoR, Construction and Operations, Testing and Monitoring, Injection Well Plugging, Post-Injection Site Care and Site Closure, Emergency and Remedial Response, and Financial Responsibility plans have been prepared and documented in this application to fulfill all EPA requirements for developing and operating a Class VI CO_2 geologic sequestration project.

The modeling based projections for the small-scale pilot project indicate that the subsurface pressures induced due to CO_2 injection will be insufficient to cause vertical migration of brines from the injection zone into the USDW. Additionally, the injected CO_2 is expected to be contained within the injection zone in the lower portions of the Arbuckle, and the plume to stabilize within one year of cessation of injection. Therefore, risk of contamination of the USDW from injection operations at Wellington is minimal.

Appendix A-5

System Design and Operations

A-5.1 Introduction

This section documents all steps undertaken to ensure that the injection well (KGS #1-28) and the proposed monitoring well (KGS #2-28) are constructed and completed to:

1) Prevent the movement of fluid into or between Underground Sources of Drinking Water (USDWs),

2) Permit the use of appropriate testing devices and workover tools,

3) Permit continuous monitoring of the annulus space between the injection tubing and long string casing.

Additional operational and construction information provided in this section include:

(1) Proposed operating data for the CO_2 site,

(2) Proposed pre-operational formation testing program to obtain an understanding of physical characteristics of the injection zone,

(3) Proposed stimulation program, a description of stimulation fluids to be used and a determination that stimulation will not interfere with containment,

(4) Schematics of the subsurface construction details of the well.

A-5.2 Background

Well KGS #1-28 is located in central Sumner County and will be used to inject CO_2 into the Arbuckle Group. The well design and construction details are provided in Figure A-5.1. The 5,241 foot deep well penetrated the top of the pre-Cambrian basement rock at a depth of approximately 5,165 feet. The well has subsequently been plugged to a depth of 5,155 feet. As shown in Figure A-5.1, the well will be perforated between 4,910 – 5,050 feet for injection into a higher permeable interval within the lower portion of the Arbuckle Group.

A-5.3 Operational Information Relevant to Well Construction

Surface facilities at the site will consist of a CO_2 storage tank, an injection skid, wellhead, necessary piping and instrumentation, and a programmable logic controller (PLC) or programmable chart recorder for automated injection operation and monitoring. Information pertaining to the surface equipment and the operational plans are also specified below. Approximately 150-300 tons of CO_2 will be transported to the well site on a daily basis. This will likely take place by delivery in one to ten trucks operating daily between the Wellington sequestration site and the CO_2 source selected for project supply. The controller will be programmed to automatically control the injection flow rate based on the operational parameters discussed below, intended pilot scale research activities, and the operational limits specified in Table A-5.1. Critical issues regarding typical operating conditions and limits are presented in the following subsections.

A-5.3.1 Temperatures

The temperature of the CO_2 during transportation and in the site storage tank is expected to be between approximately -10^o and 10^o F at delivery. This temperature may increase depending on ambient conditions and the duration of CO_2 storage in the tanks. As the CO_2 is stored and travels through surface equipment and approximately 4,900 ft down the injection tubing, the temperature will rise depending on ambient conditions, the injection rate, and the temperature in the formations surrounding the well. Near the wellbore, formation temperatures will gradually change over time as the cool CO2 is injected in the well. The bottom hole temperatures cannot be predicted with certainty, but for purposes of selecting appropriate monitoring gauges and estimating CO_2 density with depth, a temperature range of 10^o to 70^o F at the bottom hole, and -10^o F to +30^o F at the surface is estimated (Table A-5.1).

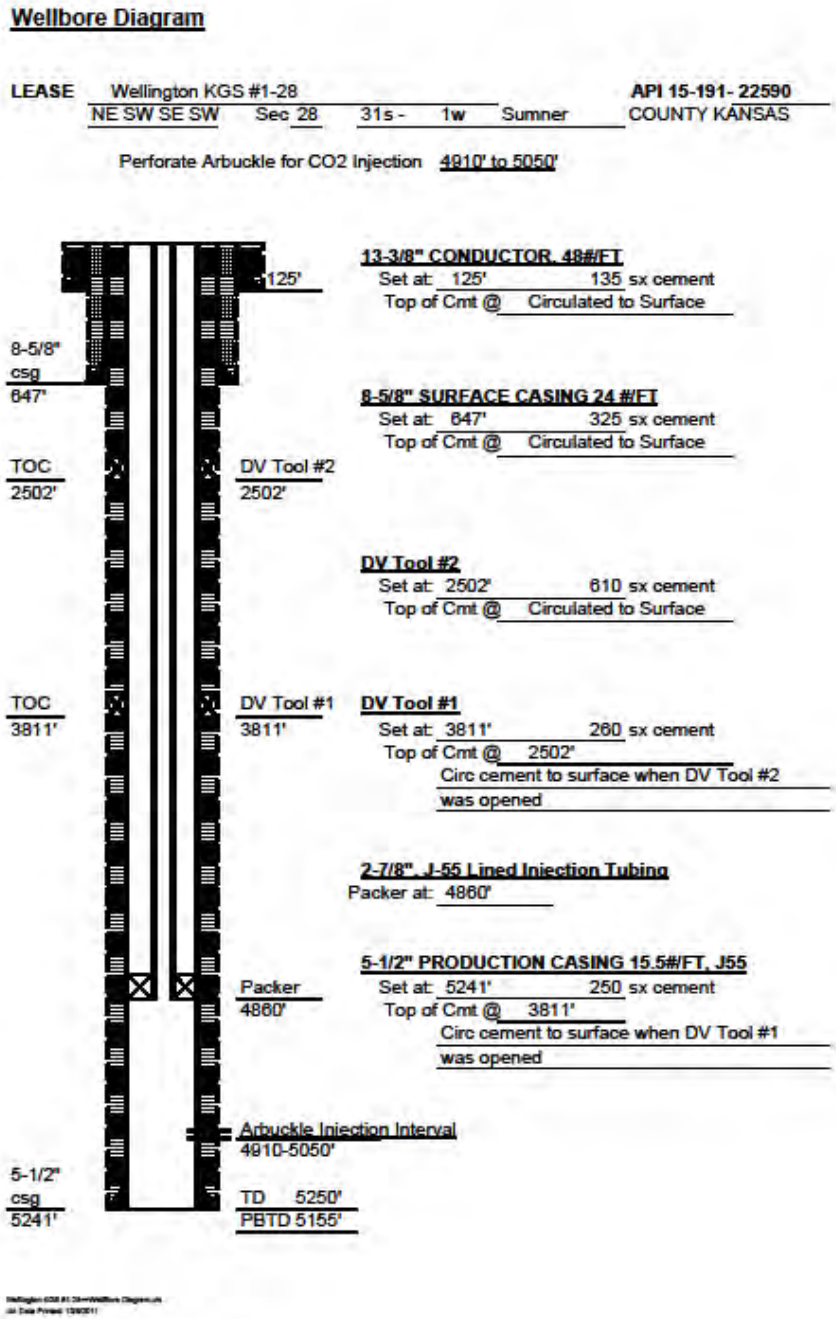


Figure A-5.1—Well design and construction details KGS #1-28

Table A-5.1—Probable Operational Conditions at KGS 1-28.

Parameter	Lower Limit	Average	Upper Limit
Injection Rate	0	150 tons/day	300 tons/day (Intermittent or continuous)
Surface Temperature	-10°F	+0°F - +20°F	+30°F
Bottom hole Temperature	+10°F	+20° F - +40°F	+70° F
Surface Pressure	0 psi	100 - 800 psi	1,500 psi
Bottom hole Pressure @ 5,050 ft (bottom of perforation)	2,200 psi	2,600 psi	2,636 psi

A-5.3.2 Pressure

In order to inject CO_2 into the Arbuckle injection interval, the injection pressure at the down hole perforations must be greater than reservoir pressure. The pressure to be applied at the surface (wellhead) will be a function of the bottom hole pressure necessary to inject the desired rate of CO_2 into the Arbuckle, the friction loss generated as the CO_2 is pumped down the tubing and through the perforated completion, and the density of the CO_2 in the tubing. Each of these components that define wellhead pressure will change with time. This short-term small scale pilot injection may utilize variable rates, and the specific injection rates sustainable will be, in part, determined by the CO_2 supply and the pilot scale testing experiments being conducted. The surface pressure will be limited to ensure that the maximum permitted injection pressure is not exceeded. Friction loss will then be highly variable, depending both on the experimental injection rates used, the condition of the perforations over time, and the density/viscosity of the CO_2 injected. The density is a function of both and pressure and temperature, and is expected to range between 46 lb/cu-ft and 59 lb/cu-ft (specific gravity of 0.75 and 0.95) due to temperature and pressure variation in the borehole. As a final variable, pressure rise will be generated in the injection zone as more CO_2 is displaced into the Arbuckle but this will vary depending on recent injected volume, conditions and instantaneous injection rate. At the end of the pilot scale injection, a maximum bottom hole pressure of less than 2,602 psi at a reference depth of 5,050 feet has been projected at possible pilot flow rates from the simulation results. This is less than the 2,636 psi pressure at a depth of 4,910 feet conservatively estimated as an allowable bottomhole injection pressure using 90% of pressure calculated at depth with a gradient of 0.58 psi/ft.

Wellhead pressures may be variable, but are generally not expected to exceed 800 psi when the effects of variable fluid density along with perforation and tubing friction loss are included in calculations. Bottomhole pressure will be a primary operational issue of concern, and will need to be adjusted based on operations. Since the well is being used for a pilot study, a downhole pressure transducer is planned for monitoring bottomhole pressure. This will be a point of compliance and the PLC or well controller will be programmed to keep bottomhole pressure at 4,930 feet at values of less than a pressure gradient of 0.52 psi/ft. It is noted that the fracture gradient has been estimated as 0.58 psi for this area based on site specific testing.

Without any friction loss included, maximum wellhead pressure could range from 472 to 814 psi, assuming that the maximum bottomhole pressure of 2,600 psi was sustained at the perforations and the average specific gravity of fluid in the wellbore ranges from 0.79 to 0.95. Depending on injection rate and final well completion materials, friction loss may require a larger wellhead pressure to sustain the required downhole injection pressure at the perforations. At higher flow rates, at least several hundred psi of tubing friction loss is likely. Although wellhead pressure may vary from 100 to 1,500 psi depending on flow rate, temperature, fluid density and viscosity, the system will typically be operated at wellhead pressures of less than 800 psi.

A-5.3.3 Injection Rate

The planned volume of CO_2 injection is 150 tons per day. However, depending on the formation properties and the need to maintain the CO_2 in liquid state at the pump (which will require a certain minimum pressure based on the temperature), an operating volume of 150-300 tons per day might potentially be injected into the aquifer during batch operations during a 24 hours period in order to achieve the desired daily injection volume. Under these circumstances, the injection will not be continuous but intermittent and instantaneous rate will be higher, as required to sustain required injection pressures. The PLC or well controller will be programmed to keep a running total of the injected CO2 and will cease operations if the injection exceeds over 300 tons within a 24 hour period. The flow rate however will also be controlled so as not to exceed the maximum bottom hole pressure of 2,636 psi as specified in Table A-5.1.

A-5.4 Request for Low-Pressure Annular System

The Class VI Rule requires that the annulus be filled with a non-corrosive fluid and that the annular pressure between the tubing and the casing be maintained at a pressure higher than the injection pressure. The owner or operator must maintain on the annulus a pressure that exceeds the operating injection pressure, unless the Director determines that such requirement might harm the integrity of the well or endanger USDWs. Conditions at the small-scale Wellington injection site are such that that a casing annulus filled with non-pressurized corrosion resistant fluid will not jeopardize the integrity of the tubing or casing and will satisfy all objectives for monitoring continuous well integrity.

If a positive pressure annulus (>100 psi above maximum wellhead injection pressure) is required, the high annulus pressures (up to 1,600 psi) resulting at the Wellington site have the potential to threaten well integrity and would not be protective of the USDW. Installation of an annular pressure system, where surface annular pressures are 100 psi greater than surface injection pressures would create the following conditions:

- Annulus pressure of up to 1,600 psi at surface,
- Annulus pressure 3,735 psi at the packer (this exceeds formation frac pressure),
- 1235 psi differential during operations.

Some of the risks associated with the pressured annulus include:

- High differential pressure across casing could cause casing leaks,
- Annulus pressure is greater frac pressure for the entire length of the tubing string,
- High differential across tubing could cause leaks
- High annular pressure could create a micro-annulus outside or damage cement isolation capacity,
- Cycling of pressures will put additional stresses on the cement,
- High annular pressures at the surface create additional hazards for those working near the surface equipment.

It is proposed that KGS #1-28 well be equipped with a low pressure annular system designed around atmospheric pressure. The annular pressure will be continuously monitored at the surface to detect anomalies or changes. The annular pressure will be monitored to evaluate potential leakage through the injection tubing, casing or around the injection packer. Additionally, a set of operating limits or a minimum and maximum pressure range would be employed within a sensitive enough range to react to pressure losses. It is proposed to use annulus pressure monitoring limits set at -5.0 psi to +100 psi. If there is an identified leak in the production casing, fluid would be lost from the annulus and a negative pressure would be observed. If a leak is present in the tubing, a positive pressure deflection would be observed. Anomalies can be suggestive of potential fluid leaks that could develop in either the injection tubing or the production casing or be associated with thermal effects. This operating range is set to reduce false alarms resulting from other variations in operating conditions such as thermal effects and continuously monitor and record values.

If a slowly developing vacuum condition is observed in the annulus indicating a possible annulus leak, the well annulus could be refilled with fluid. Upon stabilized injection conditions (temperature and rate) being maintained, the continued loss of annulus fluid would indicate a leak from the casing into an under-pressured formation. Upon development of a continued positive annulus pressure trend, the pressure could be bled from the system and the fluid tested for CO_2. If the positive pressure returned under stable operating conditions (temperature and rate) then a leak would be indicated. The presence of CO_2 gas in the annular fluid would confirm a tubing/packer leak.

A-5.5 CO_2 Compatibility with Injection Well Components

The tubing, casing, packer, and cement of the injection well are all designed to withstand CO_2 service. Similar completions have been used in Kansas and other states. The chemical composition of the injectate should cause no adverse reactions or degradation of the well components for the short nine month duration of injection. The low water content (expected to be less than 50 ppm) and the low temperatures will result in only a mildly corrosive environment. Quarterly monitoring for corrosion using coupon will also provide early warning of a deteriorating environment. The annulus pressure will be monitored daily to detect any leakage from the tubing, casing, or the packer. The annulus fluid will not react negatively with the injected CO_2 should a leak occur in the packer. The CO_2 resistant cement between the injection casing and the borehole reduces the potential for fluid migration into the USDW.

A-5.6 Design and Service Life

Due to the CO_2 resistant properties of the cement and casing, the design life of the well is expected to exceed 10 years. However, the lower segment of the well within the Arbuckle is planned to be plugged at closure within a year of cessation of CO_2 injection. Thereafter, the well will be used in the Mississippian reservoir either as an injection, production, or monitoring well.

A-5.7 Demonstration of Mechanical Integrity

Prior to commencing injection, an Annulus Pressure Test will be conducted at the injection well in order to demonstrate internal mechanical integrity. Testing has already been conducted to provide information necessary to determine the integrity of the casing and casing-cement bond. The casing, injection tubing, and packer will be further evaluated by means of a pressure test after completion activities are completed and before injection begins. The details of the test are provided in Appendix A-2 (MVA activities). Also, discussed in Appendix A-2 are additional tests that are to be conducted to demonstrate mechanical integrity including daily monitoring of the annular system, and obtaining/ analyzing temperature logs during the pre-injection, injection, and post injection phases.

A-5.8 Stimulation Plan

If needed to promote additional injection capacity, standard acid stimulation of the Arbuckle will be completed using standard oilfield practices. Although design parameters may vary depending on conditions encountered, a typical stimulation might involve pumping lease brine as a buffer followed by 1,000 to 2,000 gallons of 15% HCL with iron controls and other additives such as surfactants. This would then be displaced to the perforations by pumping lease brine as displacement fluid. Due to the cooling effect of CO_2 injection, a short soak time might occur, followed by further displacement of the spending acid into the injection interval using additional lease brine. Flushing would continue by pumping 20 tons of CO_2.

A-5.9 Annulus Testing

Prior to starting injection operations, the annulus and tubing/packer integrity will be tested by applying a minimum pressure of 500 psi at the surface to the annulus for a period of 60 minutes. After stabilization, the pressure will be recorded a minimum of every 10 minutes during isolation. Failure of the pressure to remain within five percent (5%) of the starting value would indicate lack of mechanical integrity. At the end of the test, the liquid returned from the annulus will be captured in a container and measured in order to ensure that the entire length of the annulus was tested.

A-5.10 Description of Surface Facilities and Injection Operations

The CO_2 will be delivered to the site in trucks operating daily between the selected CO_2 supplier/vendor and the Wellington site. Each truck will transport approximately 20 tons of CO_2 in liquid state at a pressure of approximately 250 psi and temperature of approximately -10^{o} F.

The surface facilities at the Wellington injection site will consist of a storage tank, a pump, a programmable logic controller (PLC) or suitable equivalent, and flowlines to the wellhead (Figure E-5.2). The injection pump and the controller will be mounted on a skid. The CO_2 will be stored in a pressure vessel adjacent to the injection well (KGS #1-28). The storage tank will be connected to the injection pump skid.

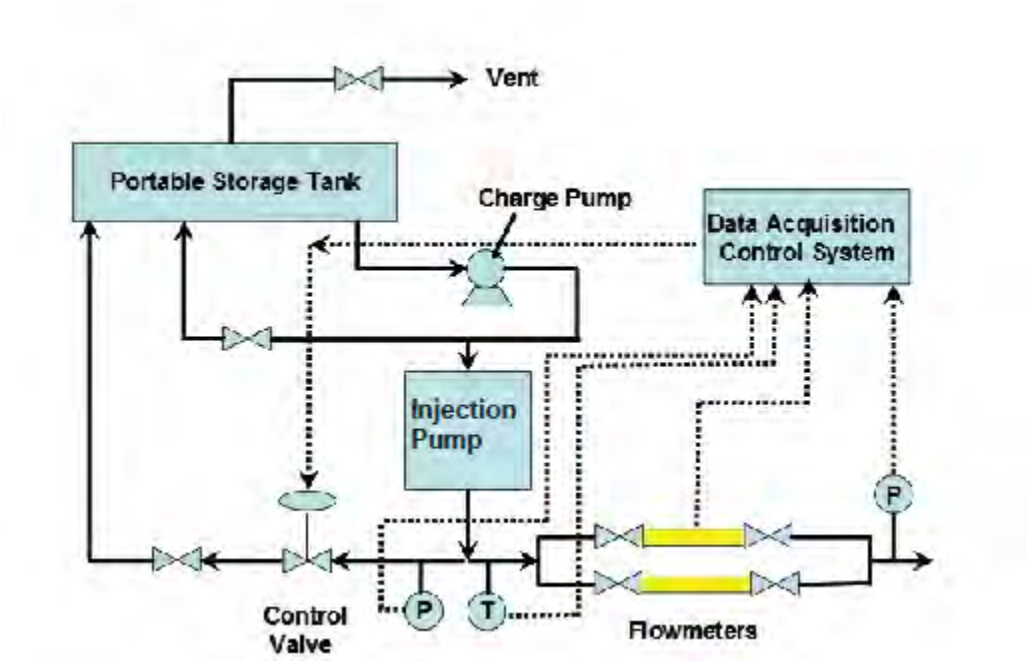


Figure A-5.2—Flow schematic of CO2 Injection Skid and Portable Storage Tank

The wellhead assembly will consist of a master valve, a swab valve and flow line valves. The well annulus will also have connections and valves necessary for access and testing. Wetter surfaces will be coated, lined or alloys suitable for short-term CO_2 service as available at the time of completion. The bottomhole and wellhead pressures and temperatures will be continuously monitored along with the flow rate at the wellhead and the data fed continuously to the PLC or controller. The controller will manipulate a control valve in the flow line and/or the pump to ensure that the maximum specified flow rate and the bottom hole pressure in the injection well does not exceed the maximum allowable pressure. The CO_2 in the storage tank may experience an increase in pressure as the vessel heats up, which may require occasional venting of the CO_2 in order to relieve the pressure.

The control system will be programmed to initiate shutdown if emergency events occur. All operating data (pressure, temperature, and flow rates) will be digitally stored by the control system.

A-5.11 Shut off System

The PLC or control system used to operate and monitor the well will process flow rate, annulus and injection pressure transducer data. Set points will be programmed to alert operators regarding well conditions of concern. In the event of an emergency, the system will be shutoff. Depending on the event, the system may be either shutoff manually or automatically. Events triggering a shutoff include conditions such as high pressure at the wellhead or bottom hole transducer, exceeding the daily injection volume, or annulus pressure that indicates communication to the injection tubing above a set point based on well operating temperature and pressure. Automatic shutoff will occur if the operational parameters that are being continuously monitored exceed permit limits by the controller cutting the run permissive signal and power to the pump on the skid and closing a valve in the flow-line. Manual shutoff will occur in the event of failure of well mechanical integrity, detection of CO_2 during MVA activities, surface infrastructure damage, etc. The controller will have commercially available alarm capabilities to notify Berexco of a shutdown over cellular network.

Appendix A-6

Post-Injection Site Care and Site Closure Plan

A-6.1 Introduction

A detailed plan has been developed to satisfy EPA's Class VI requirements for post-injection site care and site closure. The plan addresses the following EPA data/information requirements:

(i) The predicted position of the carbon dioxide plume and associated pressure front at site closure,

(ii) The pressure differential between pre-injection and predicted post-injection pressures in the injection zone;

(iii) A description of post-injection monitoring location, methods, and proposed frequency; (iv) A proposed schedule for submitting post-injection site care monitoring results to the EPA Director,

(v) The duration of the post-injection site care timeframe and, if approved by the Director, the demonstration of the alternative post-injection site care timeframe that ensures non-endangerment of USDWs.

The monitoring activities presented in the Testing and Monitoring Plan (Appendix A-2, subtask 1.6) will continue during the post-injection phase to meet EPA's post-injection site care (PISC) requirements. Both direct and indirect data will be acquired during the post-injection period. Direct data will be acquired in the injection well and the monitoring wells in Arbuckle Group, Mississippian System, Chase Group beneath the Wellington Formation (USDW), and the Wellington Formation at locations shown in Figure A-2.1. A detailed description of the planned monitoring activities is documented in Appendix A-2. A summary of the post-injection monitoring frequency is provided in Section A-6.2 below.

Upon cessation of injection, the most recently acquired data and modeling results will be reviewed with respect to the most recent PISC plan. Depending on the rate and extent of plume movement observed during the injection phase, the frequency and spatial extent of the monitoring activities may be modified, and the PISC plan resubmitted to the EPA Director for review and approval.

If the preliminary plans do not need to be altered, there will be no modification to the monitoring plan and the well and sampling locations/frequencies will be maintained.

If significant differences are noted between observed and model simulated plume and pressure front are noted during the post-injection period, and if these differences are deemed to have the potential to alter the basis for the permit, the model will be recalibrated and revised plume and pressure projections obtained. The existing post-injection monitoring plan will be reviewed along with the latest model projections and the testing/monitoring plan adjusted and provided to EPA for review in order to ensure accurate tracking of the plume/pressure front in support eventual site closure. If necessary, this process of data acquisition and model refinement/projections may continue in order to determine whether or not the injected CO_2 poses any contamination potential to the USDW. Once a determination of no negative impacts to the USDW is made, an application for site closure will be filed with the EPA Director.

A-6.2 PISC Monitoring Activities and Schedule for Submitting PISC Results and Reevaluation

Various tools will be used to monitor, verify, and account for the injected CO_2, and the techniques will extend into the post-injection site care time frame. A summary of the monitoring techniques to be employed and the monitoring schedule is presented in Table A-6.1. A detailed explanation of each testing and monitoring method is provided in Appendix A-2 (Testing and Monitoring Plan).

Table A-6.1—Schedule of monitoring activities to be conducted during the PISC phase.

Monitoring Activity	Monitoring Frequency
External MIT (Temperature Log)	Prior to closure
Corrosion	quarterly
Pressure in Arbuckle Injection and Monitoring Wells	Hourly
InSAR	Three measurements every 20 days following cessation of injection, and decreasing incrementally to 12 months interval until closure, should closure last beyond 1 year.
USDW Geochemistry	30-75 days
Mississippian Geochemistry	30-75 days
Arbuckle Geochemistry	30-75 days
3D Seismic Survey	Prior to Closure
CASSM	weekly

The PISC monitoring data along with any updated reservoir modeling results, and any updated PISC and Site Closure plan will be submitted bi-annually to the EPA. In the event that the monitored data is in substantial deviation from the projections, an analysis will be conducted to explain the deviation. If necessary, the reservoir model may be recalibrated to obtain fresh projection of the future plume trajectory and pore pressures. The findings of the reevaluation (including a potentially revised PISC and Site Closure plan) will be submitted to the EPA. Prior to authorization for site closure, a demonstration will be made to the EPA Director, based on monitoring and other site-specific data, that no additional monitoring is needed to ensure that the geologic sequestration project does not pose an endangerment to USDWs.

A-6.3 Alternative Post-injection Site Care and Site Closure Time Frame

The default time frame for post-injection site care is 50 years. However, due to small extent of the CO_2 plume in the subsurface for this pilot-scale project, which will result in pressures in the injection zone to revert to pre-injection levels within 3 months of cessation of pumpage, KGS/Berexco is requesting to close the site at the end of a one year post-injection period. This proposed post-injection site care time frame will however be re-evaluated and justified to the EPA based on site-specific data obtained the injection and post-injection phases.

The site specific conditions that support a request for early closure are provided below:

- The results of computational modeling of the project indicate that the sequestered CO_2 will not migrate above the primary confining zone and not spread laterally within the injection zone (Arbuckle aquifer) to any natural or artificial penetration that extends into the confining zone other than KGS #1-28 and #2-28, both of which will be constructed to Class VI (injection well) specifications.

- The results of computational modeling indicate that formation pressures are generally not adequate to force the CO_2 - brine mixture within the Arbuckle to penetrate into the USDW. A pressure increase of approximately 327 psi is required for brines in the injection interval to migrate into the USDW. The pressure increase however drops to less than 327 psi within 100 feet of the injection well, which has been constructed per Class VI guidelines as documented. Therefore, there are no existing or abandoned wells through which the Arbuckle brines can be expected to

migrate into the USDW. There are also no known or mapped faults within the AoR at the Wellington site through which the brines in the Arbuckle could migrate upward either.

- During operations, the predicted rate of carbon dioxide plume migration is minimal and projections show that the free-phase plume will migrate laterally at a rate of approximately 150 ft per month during the injection period, dropping to 5 feet per year during the next 30 years, and slowing further to less than 1 foot per year during the next 60 years prior to stabilizing. The lateral migration rate of the free phase CO_2 has a maximum spread of approximately 1,750 feet from the injection well at 100 years. There may be some additional movement of the plume beyond 100 years, but this is expected to be minimal and at very low concentrations. Also, the plume is expected to remain confined in the injection interval within the lower Arbuckle and not migrate even into the middle or upper Arbuckle.

- The sequestration processes that were simulated include structural, hydrodynamic, solubility, and residual trapping. The model ignores sequestration due to capillary entrapment and mineralization, and therefore the results are expected to be on the conservative side.

- The hydrogeologic properties of the Arbuckle aquifer Group were derived by means of sophisticated analyses involving the construction of a geomodel utilizing Schlumberger's Petrel modeling software. The data in the geomodel were anchored to core and log data for porosity and permeability as derived at the injection well site (KGS #1-28) and the geologic characterization well (KGS #1-32). Therefore the reservoir model is expected to realistically represent the hydrogeologic properties of the Arbuckle aquifer. However, in order to account for uncertainties, and to obtain conservative results, a set of nine alternative models were derived and used in the simulations by increasing and decreasing the key hydrogeologic properties by 25%. The model based limits on maximum induced pressure and maximum extent of plume migration are based on these alternative models, which ensures some conservatism built into the projections.

- The shales and siltstone in the primary confining zone are expected to provide a tight hydraulic seal with permeabilities at the nano-Darcy level. The lack of hydraulic connection between the injection zone (Arbuckle) and the overlying formations is also documented and confirmed by the geochemical data which indicates vastly different geochemistry in the injection zone and overlying Arbuckle and Mississippian reservoir formations. The Drill Stem Test (DST) data

also indicates substantial under-pressurization in the Mississippian Formation that overlies the confining zone (Simpson/Chattanooga/Pierson) suggesting lack of transmissive features in the primary confining zone. Furthermore, the region wide under-pressurization of the Mississippian Formation with respect to the injection zone (Arbuckle aquifer), could only exist in the absence of hydraulic conduits in the confining zone. Even if the CO_2 were to escape from the confining zone, it would be hydraulically trapped in the under-pressurized Mississippian oil reservoir above the confining zone.

- There are no abandoned wells that penetrate the primary confining zone within the AoR. The only existing well within the AoR that penetrates the confining zone is the injection well (KGS #1-28) which was constructed per Class VI specifications. The Arbuckle monitoring well (KGS 2-28), to be located approximately 300 feet northwest of KGS 1-28 and within the AoR, will also be in compliance with Class VI construction requirements. The CO_2 plume is expected to reach this well in approximately 60 days.

- The distance between the injection zone and the base of the USDW is in excess of 4,500 feet. There are multiple confining (shale) zones between the injection zone and the USDW.

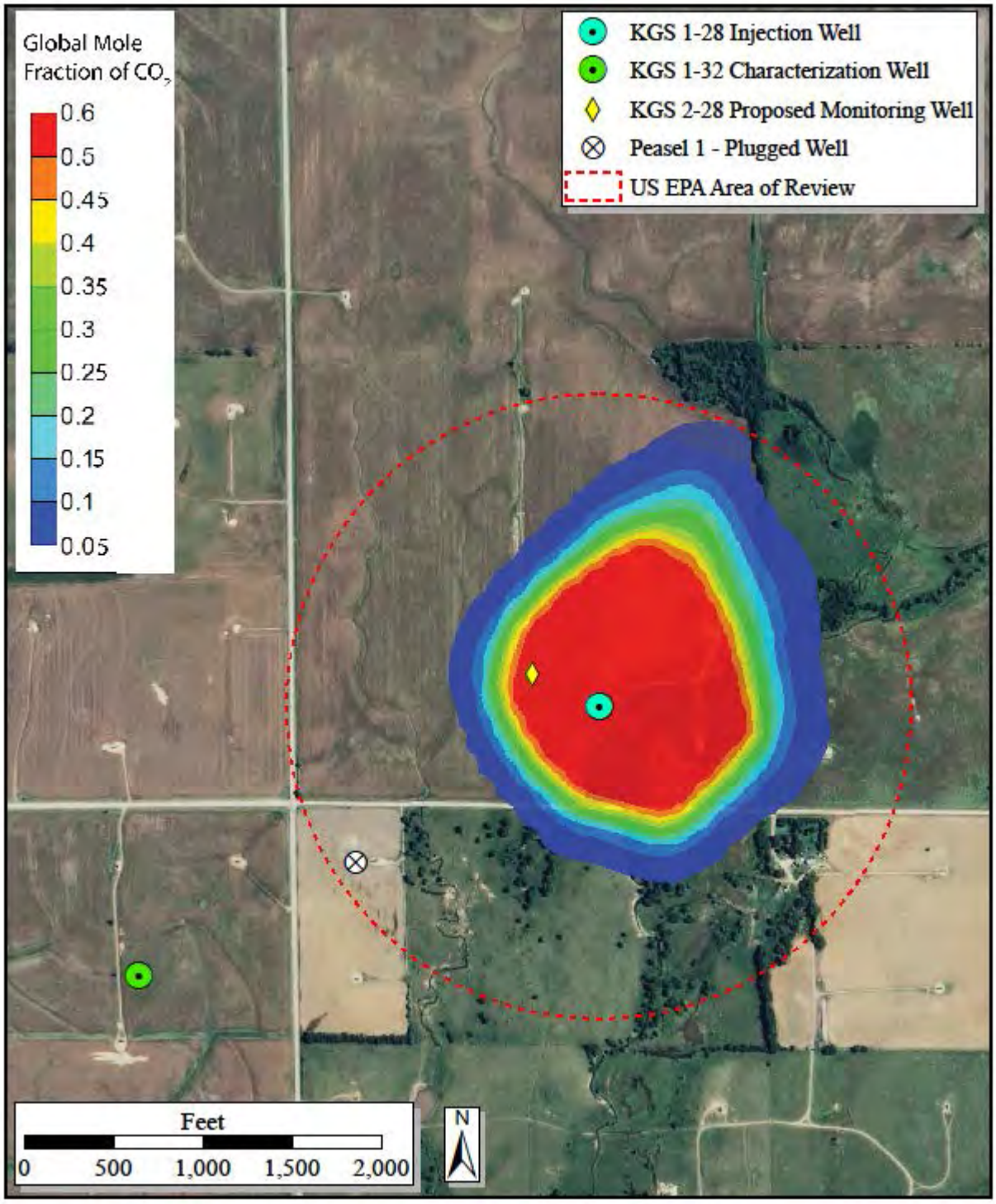


Figure A-6.1—Extent of plume migration at the end of 1 year following cessation of injection for the alternative model resulting in the largest extent of plume migration.

A-6.4 Criteria for Demonstration of Alternative Post Injection Site Care Timeframe.

Care has been taken to ensure acquisition of quality data, and to promote careful processing of the acquired data. The geophysical logs were acquired and analyzed by reputable vendors such as Weatherford and Schlumberger. Laboratory tests to estimate formation properties such as permeability/porosity and rock elasticity/strength were conducted by certified laboratories such as Weatherford Laboratories. Data synthesis and interpretation was conducted by, professional staff at KGS who are experts in their field, and professionally certified external consultants.

The geologic and reservoir models developed for the project are based on carefully processed core and geophysical data. The reservoir model is also based on available field data such as injection tests. However, a set of alternative conceptual models were also developed in order to incorporate conservatism in the simulation results. QA/QC measures to be implemented while conducting testing and monitoring activities during the pre-injection, injection, and post-injection phases is documented extensively in Appendix A-2. All analyses and QA/QC for project data meet and will continue to meet the following required standards:

(i) All analyses and tests performed to support the demonstration will be accurate, reproducible, and performed in accordance with the established quality assurance standards;

(ii) Estimation techniques will be appropriate and EPA-certified test protocols will be used where available;

(iii) Reservoir model will be appropriate and tailored to the site conditions, composition of the carbon dioxide stream, and injection and site conditions over the life of the geologic sequestration project;

(iv) Reservoir model will be reviewed to ensure that it is conformance with newly acquired monitoring and geophysical data;

(v) Reasonably conservative values and modeling assumptions will be used and disclosed to the Director whenever values are estimated on the basis of known, historical information instead of site-specific measurements;

(vi) An analysis will be performed to identify and assess aspects of the alternative post-injection site care timeframe demonstration that contribute significantly to uncertainty. Sensitivity analyses will be conducted to determine the effect that significant uncertainty may contribute to the modeling demonstration.

(vii) The quality assurance and quality control measures will address all aspects of the demonstration.

A-6.5 Site Closure Activities

Prior to authorization for site closure, KGS/Berexco will submit to the EPA Director for review and approval a demonstration, based on monitoring and other site-specific data, that no additional monitoring is needed to ensure that the geologic sequestration project does not pose an endangerment to USDWs. If the demonstration cannot be made (*i.e.,* additional monitoring is needed to ensure that the geologic sequestration project does not pose an endangerment to USDWs), or if the Director does not approve the demonstration, an updated PISC plan will be submitted to the Director to continue post-injection site care until a demonstration can be made and approved by the Director.

The following activities shall be carried out prior to requesting site closure:

- A 3D seismic survey shall be acquired over the area of approximately one square mile. The new 3D data shall be interpreted and compared with the baseline survey in order to detect the presence of CO_2 outside the expected plume containment area as modeled by reservoir simulation studies.
- The non-seismic MVA data and its analyses conducted during the post-injection phase shall be integrated with the newly acquired 3D seismic data in order to validate the absence of CO_2 outside the containment strata, thus confirming that future leakage risks are minimal to non-existent.

- All monitoring data and other site-specific data shall be accounted for and utilized in the simulation model to demonstrate to the EPA in the form of a report that the pressures have abated, the plume growth has slowed, and that no additional monitoring is needed to ensure that the sequestration project does not pose an endangerment to USDWs. If the EPA does not approve the demonstration, an amended plan will be submitted to the Director for continuing PISC until a demonstration of safe site closure is made and approved by the Director.

KGS/Berexco will notify the EPA Region 7 Director of its intent to close the site at least 120 days prior to the closure date. Any revisions to the PISC and Site Closure plans will accompany the notice. Once the EPA has approved closure of the site, all monitoring wells included in the permit application may be plugged. The Wellington monitoring wells and the Arbuckle geologic characterization well (KGS #1-32) will be plugged following standard industry practices. A site closure report will be prepared within 90 days of closure and submitted to the EPA Director, documenting the following:

- plugging of the injection and monitoring wells,
- location of the sealed injection well on a plat of survey that has been submitted to the local zoning authority. A copy of the plat will also be submitted to the EPA Regional Office,
- notifications of closure to State and local authorities,
- records documenting the nature, composition, and volume of the injected CO_2,
- all pre-injection, during injection, and post-injection monitoring records,
- KGS/Berexco will submit certifications to the Region 7 Program Director that all geologic sequestration activities have been completed in accordance with the Post-Injection Site Care and Site Closure Plan.

Berexco will record a notation to the property deed on which the injection well (KGS #1-28) was located that:

- property was used for carbon dioxide sequestration,
- name of the agency with which the survey plat was filed, as well as the address of the EPA Region 7 office which received a copy of the plat survey,
- the volume of fluid injected,
- the formation into which the fluid was injected,
- the period over which the injection occurred.

All PISC records will be retained by KGS/Berexco for a period of 10 years following which the records will be delivered to the EPA Director for EPA's retention.

APPENDIX II

Small Scale Field Test Demonstrating CO_2 Sequestration in Arbuckle Saline Aquifer and by CO_2-EOR at Wellington Field, Sumner County, Kansas

TENTH QUARTERLY PROGRESS REPORT

DOE F 4600.2
(03/11)
All Other Editions Are Obsolete

U.S. Department of Energy
FEDERAL ASSISTANCE REPORTING CHECKLIST
AND INSTRUCTIONS FOR RD&D PROJECTS

1. Identification Number: **DE-FE0006821**	2. Program/Project Title: **Small Scale Field Test Demonstration CO2 Sequestration**
3. Recipient: **University of Kansas Center for Research, Inc.**	

4. Reporting Requirements:	Frequency	Addressees
A. MANAGEMENT REPORTING		
☒ Research Performance Progress Report (RPPR)	Q	FITS@NETL.DOE.GOV
☒ Special Status Report	A	FITS@NETL.DOE.GOV
B. SCIENTIFIC/TECHNICAL REPORTING		
(Reports/Products must be submitted with appropriate DOE F 241. The 241 forms are available at www.osti.gov/elink)		
Report/Product — Form		
☒ Final Scientific/Technical Report — DOE F 241.3	FG	http://www.osti.gov/elink-2413
☒ Conference papers/proceedings* — DOE F 241.3	A	http://www.osti.gov/elink-2413
☐ Software/Manual — DOE F 241.4		
☐ Other (see special instructions) — DOE F 241.3		
** Scientific and technical conferences only*		
C. FINANCIAL REPORTING		FITS@NETL.DOE.GOV
☒ SF-425 Federal Financial Report	Q, FG	
D. CLOSEOUT REPORTING		
☒ Patent Certification	FC	FITS@NETL.DOE.GOV
☒ SF-428 & 428B Final Property Report	FC	FITS@NETL.DOE.GOV
☐ Other		
E. OTHER REPORTING		
☒ Annual Indirect Cost Proposal	O	See block 5 below for instructions.
☐ Audit of For-Profit Recipients		
☒ SF-428 Tangible Personal Property Report Forms Family	A	FITS@NETL.DOE.GOV
☒ Other – see block 5 below	A	FITS@NETL.DOE.GOV

FREQUENCY CODES AND DUE DATES:

A - Within 5 calendar days after events or as specified.
FG- Final; 90 calendar days after the project period ends.
FC- Final; End of Effort.
Y - Yearly; 90 calendar days after the end of the reporting period.
S - Semiannually; within 30 calendar days after end of project year and project half-year.
Q - Quarterly; within 30 days after end of the reporting period.
Y180 – Yearly; 180 days after the end of the recipient's fiscal year
O - Other; See instructions for further details.

5. Special Instructions:

Annual Indirect Cost Proposal – If DOE is the Cognizant Federal Agency, then the proposal should be sent to FITS@NETL.DOE.GOV . Otherwise, it should be sent to the Cognizant Federal Agency.

Other – The Recipient shall provide all deliverables as contained in Section D of Attachment 2 Statement of Project Objectives.

QUARTERLY PROGRESS REPORT

To

DOE-NETL
Brian Dressel, Program Manager
Award Number: DE-FE0006821

SMALL SCALE FIELD TEST DEMONSTRATING CO_2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO_2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS

Project Director/Principal Investigator:
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Senior Scientific Fellow
Kansas Geological Survey

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Joint Principal Investigator:
Jason Rush

Prepared by Lynn Watney
Date of Report: March 10, 2014 (revised)
DUNS Number: 076248616

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

Project/Grant Period: 10/1/2011 through 9/30/2015
Tenth Quarterly Report
Period Covered by the Report: January 1, 2014 through March 31, 2014

Signature of Submitting Official:

Willard Lynn Watney

Digitally signed by Willard Lynn Watney
DN: cn=Willard Lynn Watney, o=The University of Kansas, ou=Kansas Geological Survey, email=lwatney@kgs.ku.edu, c=US
Date: 2014.05.07 22:45:24 -05'00'

EXECUTIVE SUMMARY

Project Objectives

The objectives of this project are to understand the processes that occur when a maximum of 70,000 metric tonnes of CO_2 are injected into two different formations to evaluate the response in different lithofacies and depositional environments. The evaluation will be accomplished through the use of both *in situ* and indirect MVA (monitoring, verification, and accounting) technologies. The project will optimize for carbon storage accounting for 99% of the CO_2 using lab and field testing and comprehensive characterization and modeling techniques.

CO_2 will be injected under supercritical conditions to demonstrate state-of-the-art MVA tools and techniques to monitor and visualize the injected CO_2 plume and to refine geomodels developed using nearly continuous core, exhaustive wireline logs, and well tests and a multi-component 3D seismic survey. Reservoir simulation studies will map the injected CO_2 plume and estimate tonnage of CO_2 stored in solution, as residual gas, and by mineralization and integrate MVA results and reservoir models shall be used to evaluate CO_2 leakage. A rapid-response mitigation plan will be developed to minimize CO_2 leakage and provide comprehensive risk management strategy. A documentation of best practice methodologies for MVA and application for closure of the carbon storage test will complete the project. The CO_2 shall be supplied from a reliable facility and have an adequate delivery and quality of CO_2. The project shall install compression, chilling, and transport facilities at the ethanol plant for truck transport to the injection site.

Scope of Work

Budget Period 1 includes updating reservoirs models at Wellington Field and filing Class II and Class VI injection permit applications. Static 3D geocellular models of the Mississippian and Arbuckle shall integrate petrophysical information from core, wireline logs, and well tests with spatial and attribute information from their respective 3D seismic volumes. Dynamic models (composition simulations) of these reservoirs shall incorporate this information with laboratory data obtained from rock and fluid analyses to predict the properties of the CO2 plume through time. The results will be used as the basis to establish the MVA and as a basis to compare with actual CO2 injection. The small scale field test shall evaluate the accuracy of the models as a means to refine them in order to improve the predictions of the behavior and fate of CO2 and optimizing carbon storage.

Budget Period 2 includes drilling and equipping a new borehole into the Mississippian reservoir for use in the first phase of CO2 injection; establishing MVA infrastructure and acquiring baseline data; establishing source of CO2 and transportation to the injection site; building injection facilities in the oil field; and injecting CO2 into the Mississippian-age spiculitic cherty dolomitic open marine carbonate reservoir as part of the small scale carbon storage project.

In Budget Period 3, contingent on securing a Class VI injection permit, the drilling and completion of an observation well will be done to monitor injection of CO2 under supercritical conditions into the Lower Ordovician Arbuckle shallow (peritidal) marine dolomitic reservoir. Monitoring during pre-injection, during injection, and post injection will be accomplished with

MVA tools and techniques to visualize CO2 plume movement and will be used to reconcile simulation results. Necessary documentation will be submitted for closure of the small scale carbon storage project.

Project Goals

The proposed small scale injection will advance the science and practice of carbon sequestration in the Midcontinent by refining characterization and modeling, evaluating best practices for MVA tailored to the geologic setting, optimize methods for remediation and risk management, and provide technical information and training to enable additional projects and facilitate discussions on issues of liability and risk management for operators, regulators, and policy makers.

The data gathered as part of this research effort and pilot study will be shared with the Southwest Sequestration Partnership (SWP) and integrated into the National Carbon Sequestration Database and Geographic Information System (NATCARB) and the 6th Edition of the Carbon Sequestration Atlas of the United States and Canada.

Project Deliverables by Task

1.5 Well Drilling and Installation Plan (Can be Appendix to PMP or Quarterly Report)
1.6 MVA Plan (Can be Appendix to PMP or Quarterly Report)
1.7 Public Outreach Plan (Can be Appendix to PMP)
1.8 Arbuckle Injection Permit Application Review go/no go Memo
1.9 Mississippian Injection Permit Application Review go/no go Memo
1.10 Site Development, Operations, and Closure Plan (Can be Appendix to PMP)
2.0 Suitable geology for Injection Arbuckle go/no go Memo
3.0 Suitable geology for Injection Mississippian go/no go Memo
11.2 Capture and Compression Design and Cost Evaluation go/no go Memo
19 Updated Site Characterization/Conceptual Models (Appendix to Quarterly Report)
21 Commercialization Plan (Can be Appendix to Quarterly Report).
30 Best Practices Plan (Can be Appendix to Quarterly or Final Report)

ACCOMPLISHMENTS

1. **Continued progress of Milestone 2 (Task 3) - Site characterization of Mississippian Reservoir for CO2 EOR – Wellington Field**
   Adjustments to Mississippian and existing Arbuckle Injection models with reduced CO2 volumes were performed to establish that size of plume has changed minimally to ensure that scientific information derived from the investigation will be maximized.
2. **Subtask 1.6. MVA Infrastructure–** Designs are nearly complete to deploy a temporary network of 15 seismometer stations donated on behalf of IRIS. These stations will record passive seismic data in close proximity to the Mississippian and Arbuckle injector

locations. Five 3-component broadband accelerometers purchased by the KGS will supplement the existing MVA design.

3. **Subtask 1.8 Arbuckle Injection Permit Application –** The completed permit application has 14 chapters (sections) and includes revisions with refined technical information and the most up to date model simulation results. Edits have been incorporated in the document and submitted to Berexco for final review. Once Berexco has signed the document, the Arbuckle Injection Permit and the Mississippian Permit Application will be submitted to EPA and state regulators, respectively (Subtask 1.9).
4. **Task 5.2 CO2 Capture and Compression Design and Cost Evaluation –** Due to schedule concerns, ongoing negotiations with the primary replacement supplier have been terminated. Alternatively, two industrial suppliers have been confirmed and will combine resources to maximize efficiency and volume of CO2 delivered. (Subtask 5.2) A final cost report has been submitted to DOE which includes all feasible supply costs broken down by volume delivered, overall quantity injected, vendor, injection duration, etc. The DOE is reviewing these materials and will determine if the project may proceed.
5. **Task 26. Updated Site Characterization/Conceptual Models –** Modifications to the Arbuckle injection simulation have been run using a reduced volume of CO2. The model confirmed that the new extent and behavior of the plume will still easily be depicted with existing MVA design.
6. **Task 28. Commercialization Plan –** Ongoing discussions have arranged for a CCUS conference to be held in the upcoming year. Support for the conference has been granted by various suppliers, Kansas operators, and other members of industry.
7. **Task 3. Site Characterization of Mississippian Reservoir for CO2 EOR –** Drilling location for Mississippian injector well KGS 2-32 has been reviewed and confirmed by Berexco and KGS personnel. The agreed upon site location is shown in **Figure 1**. Preliminary sensitivity analyses have been performed as part of the iterative simulations necessary to construct the full scale model.

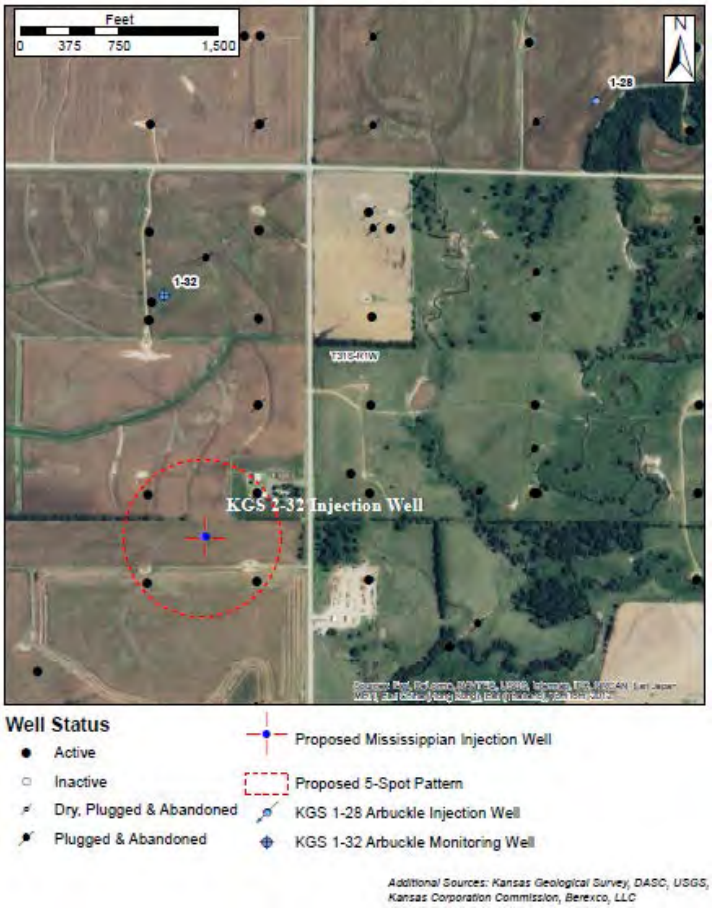


Figure 1. Drilling location for Mississippian injector well KGS 2-32.

MILESTONE STATUS REPORT

Task	Budget Period	Number	Milestone Description
Task 2.	1	1	Site Characterization of Arbuckle Saline Aquifer System - Wellington Field
Task 3.	1	2	Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field
Task 10.	2	3	Pre-injection MVA - establish background (baseline) readings
Task 13.	2	4	Retrofit Arbuckle Injection Well (#1-28) for MVA Tool Installation
Task 18.	3-yr1	5	Compare Simulation Results with MVA Data and Analysis and Submit Update of Site Characterization, Modeling, and Monitoring Plan
Task 22.	3-yr1	6	Recondition Mississippian Boreholes Around Mississippian CO2-EOR injector
Task 27.	3-yr2	7	Evaluate CO2 Sequestration Potential of CO2-EOR Pilot
Task 28.	3-yr2	8	Evaluate Potential of Incremental Oil Recovery and CO2 Sequestration by CO2-EOR - Wellington field

PROJECT SCHEDULE

CCUS Commercialization –

(1/21/2014) Lynn Watney and Rex Buchanan (the KGS interim director) held a meeting with Governor Sam Brownback on implementing CO2 utilization and storage in Kansas. Governor Brownback, along with the Kansas State Department of Commerce, expressed support for a CCUS conference to encourage the development of these opportunities among industry, regulators, and stakeholders. Pending a successful EOR test at Wellington Field (as

recommended by the Dept. of Commerce), these parties will set a schedule and hold a meeting in the upcoming year.

(2/4/14) A meeting was held with the Department of Commerce on the economic implications of CCUS. Department of Commerce officials have agreed to meet in the interim with key oil and gas operators and CO2 suppliers to discuss the issues and opportunities to use anthropogenic CO2 for CO2-EOR.

CO2 Supply –

(1/21/14) As of late January, no feedback or updates from meetings were provided from the lead alternative CO2 supplier. Due to major concerns regarding schedule, reliability, and economic viability, negotiations with the primary supplier were suspended, and other industrial sources were pursued as a backup plan.

(1/25/14) Discussion with three industrial suppliers was reestablished as complications developed with the primary supplier. Costs have been revisited based on daily supply restrictions and attempts have been made to reduce expenses by combining sources. Ongoing negotiations have included meetings, conference calls, and general correspondence with suppliers to obtain a finalized quote with an additional 8-10% under the already discounted price.

(1/30/14) One of the two alternative suppliers confirmed their reduced pricing for the Wellington injection.

(2/18/14) An official memo was submitted to DOE to outline the available options regarding CO2 suppliers. Due to supply restrictions in the vicinity of the proposed injection site, it was determined that the original anticipated volume of CO2 must be reduced to remain within budget.

(2/20/14) After much deliberation, two experienced and motivated suppliers were confirmed to optimally supply and deliver a maximum volume of CO2 to the injection site. Both parties have been closely involved in the study, and are eager to begin injection in hopes of establishing a future CCUS market in Kansas. This cost evaluation has been submitted to DOE for approval.

(2/27/14) A conference call was held with DOE to provide project updates, review work status, and comment on anticipated submission of Class VI application.

(3/15/14) Extensive evaluation has been performed to ensure that the reduced volume of CO2 can still be adequately detected and modeled in the subsurface. Results indicate that the reduced volume will have no negative impact on the science gained from the experiment. This decision has been technically based using the planned high-level MVA techniques that will be performed in BP2, such as the seismic resolution and simulated plume extent.

Class VI Injection application –

(1/17/2014) - Capillary Pressure calculations included into Arbuckle reservoir assumptions (see appendix for "Drainage Capillary Pressure Curves" report).

(1/25/14) – A morning-long meeting was held with Dana Wreath from Berexco to record his final comments pertaining to the Class VI application submitted in October. These revisions were included in the final draft and returned the following month.

(2/16/14) – Email correspondence with Kurt Hildebrandt from EPA confirmed that they are prepared to move forward with the Class VI application review as expeditiously as possible.

(2/19/14) – Final Arbuckle simulation figures included into Class VI document.

(2/28/14) – The final draft of the Class VI application was mailed to Dana Wreath for approval.

Class II CO2-EOR injection –

(2/26/14) -- 15 Seismometer stations arrived at the KGS from IRIS-PASSCAL to be deployed as a temporary seismic array near Wellington Field during Mississippian and Arbuckle injections.

(3/3/14) -- Final production estimates for the Mississippian reservoir model completed.

(3/15/14) -- Lead reservoir engineer, Eugene Holubnyak, completed a class on the latest geomechanical modeling tools to enhance the Wellington simulation. Topics included measuring the extent and amount of ground deformation. A newly appointed Ph.D. structural geologist with experience in Petrel is aiding these efforts to build on the geomechanical interpretation.

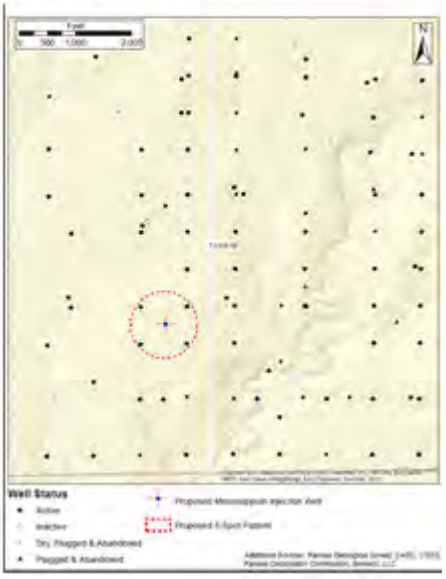
(3-15-14 to 3-30-14) The first stages of the CMG iteration modeling leading to the construction of the full field scale Mississippian oil field model have been completed. The methodology used in the EOR simulation included the following details:

- Simple 5-spot "layered-cake" model
- IMAX black-oil water-flood model with historical water flood based on current field conditions
- Sensitivity analysis with CMOST for water-flood model
- Preliminary PVT analysis without sensitivity analysis for CO2 EOR model
- Base case reservoir conditions assumed an initial water injection rate at 250 bbls/day followed by a CO2 injection at 110 tons/day, with infinite Carter-Tracy boundary

conditions and no leakage into the aquifer. Estimates from these calculations are outlined below (Mina Fazelalavi):

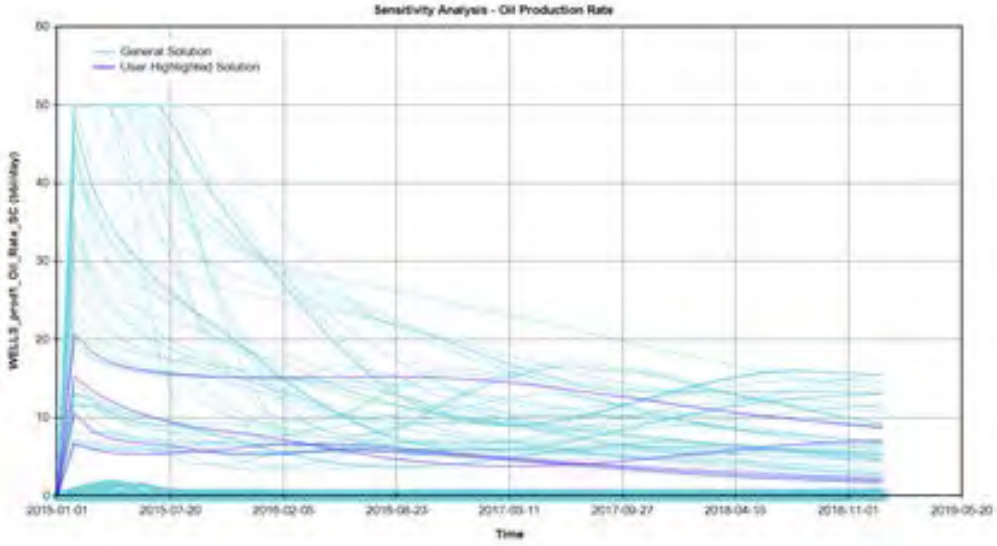
Estimation of Initial Oil in Place and Remaining Oil in Place

Description	Unit	Values
Area	ft 2	6.08E+05
Porosity cut off	%	5
Average thickness after porosity cut off	ft	40
Bulk volume	ft3	2.43E+07
Water saturation cut-off	%	67.00
Net bulk volume after sw cut off	ft3	1.78E+07
Average porosity	%	15.00
Net pore volume	ft3	2.68E+06
Average swi	v/v	0.33
Hydrocarbon pore volume	ft3	1.78E+06
Formation volume factor	bbl/STB	1.15
Initial Oil in place	STB	2.76E+05
Cumulative oil production for polygon:	BO	7.18E+04
Recovery factor	%	26
Remaining oil in place	STB	2.04E+05

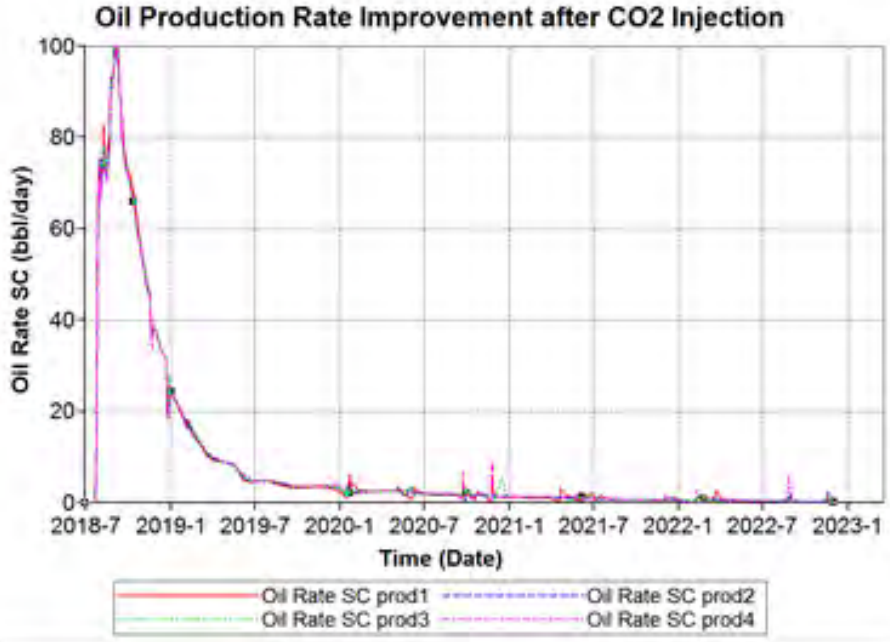


Water-Flood sensitivity analysis was run to obtain production estimates for a water-flood compared to results for the planned CO2 injection. Preliminary sensitivity analysis showed a substantial increase in oil production in response to CO2 injection, followed by a decline curve that is typical of similar wells. An increase in oil production was also observed after water injection, but higher volumes were required to achieve the desired results. These results are promising for the expected economic benefits of CO2 utilization in EOR activities throughout the state.

Water-Flood CMOST Sensitivity Analysis



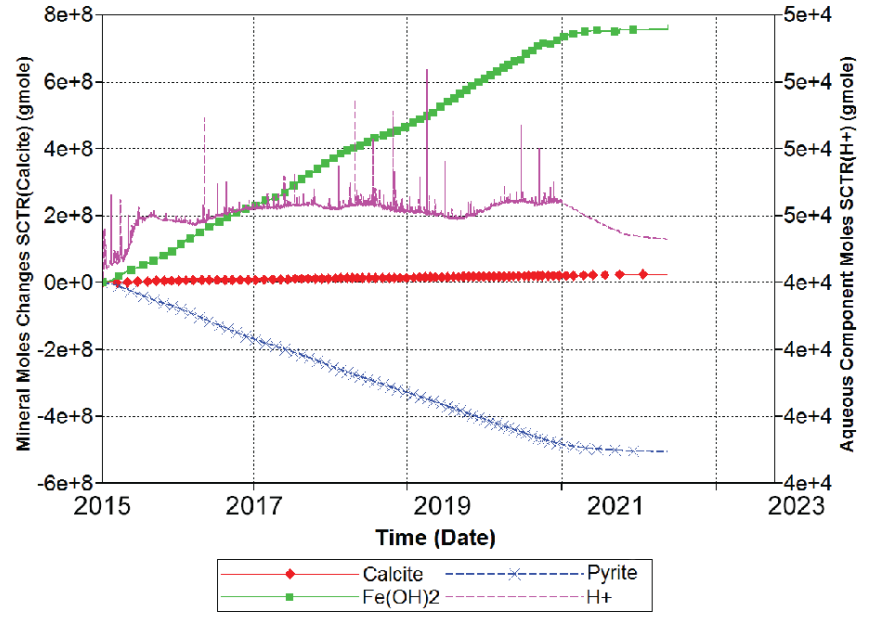
Expected Production Improvement After CO2 Injection

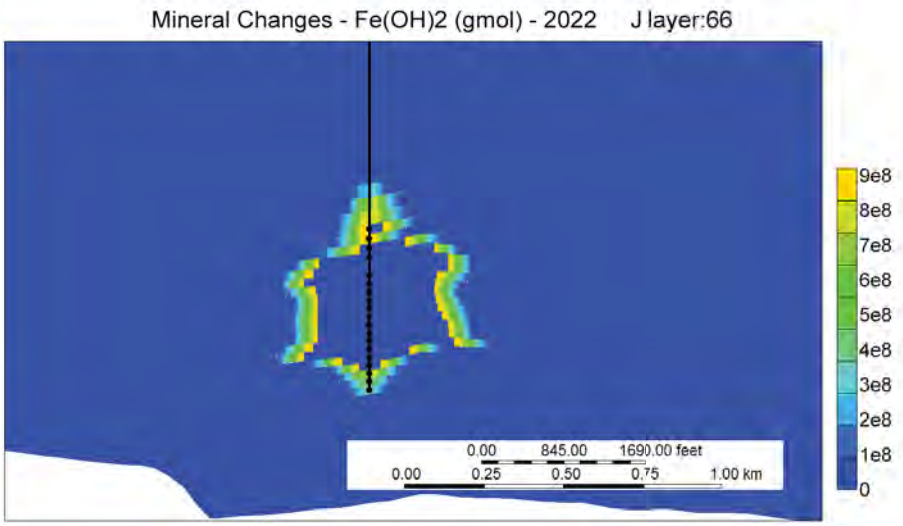


Mineral changes in Arbuckle model --

(Eugene 3/30/14) "CO2-brine-mineral reactions will be between minerals dolomite, calcite, chert, pyrite, anhydrite and argillaceous clay material. Small and large scale heterogeneity of mineral occurrences is observed throughout the formation which will create complex mineral-brine-CO2 interactions. Heterogeneous mineralogy occurs predominantly at the chert/carbonate interface where previous fractures and flow paths have been in filled with argillaceous and pyritic materials. These zones will be highly reactive upon the injection of CO2 and will release cations from non carbonate minerals, increasing the possibility of mineral trapping mechanisms in the long run. Fluctuations in brine chemistry observed during supercritical flow experiment showed the effect of heterogeneity on geochemical reactions. Complex reactions will develop in the aquifer with different kinetic rates as CO2 migrates through heterogeneous material."

Preliminary Numerical Modeling Results:





Several changes were made for the final Class VI Arbuckle model --

An updated vertical permeability model was prepared and applied to geocellular model, which provided a better estimation of vertical CO2 movement in the reservoir. Currently, dynamic simulations of CO2 injection in Lower Arbuckle reservoir predict that CO2 will stay contained within lower portion of the Arbuckle Fm and will not continue to move up towards the primary cap-rock. These modeling predictions are in agreement with geochemical fluid analysis (especially Br/Cl isotope analysis) which indicates that fluids of upper Arbuckle Fm are not mixing with fluids of lower Arbuckle Formation.

The scale ratio of vertical vs. horizontal model extent for the report was updated to match an aerial model views.

Revision of SOPO –

SOPO has been temporarily revised to account for schedule changes due to newly acquired CO2 source. The SOPO maintains the deployment of the Mississippian injection to be implemented first, commencing by 10/1/2014. Changes to budgetary items include removal of second seismic survey and removal of one of the proposed deep surface monitoring wells to bolster funds in other MVA technologies.

Some of the excerpts from a memo regarding the uniqueness and scientific value of the planned activities are listed below. Topics include the 1) Proactive response to seismicity in the area surrounding the injection site, 2) level of confidence to detect the CO2 plume/scientific importance of the Mississippian injection, 3) Readiness of the CO2 suppliers and EPA for a Class VI well.

1) Seismicity and Enhanced Monitoring

- The KGS has taken receipt of 15 IRIS-PASCAL seismometers for passive monitoring of the Mississippian and Arbuckle injections and to provide a networked site for earthquake monitoring in southern Kansas. KGS personnel will receive field and data handling training from PASSCAL in late April and are scheduled to scheduled deploy the stations in May to establish baseline observations,
- As of 3/7/14 – KGS will privately purchase 5 active accelerometers to install at Wellington Field alongside the IRIS seismometers. The KU Department of Geology plans to purchase additional accelerometers and is seeking necessary campus co-funding to also participate in this collaborative investigation at Wellington Field. The active, 24-bit, 3 component state-of-the art accelerometers will be placed with the seismometer array to 1) increase the bandwidth/frequency range of the events that will be monitored, 2) increase the sensitivity of the passive seismic monitoring to detect events as small a as -2.0 magnitude or less, and 3) and record 3-components of movement.

2) Uniqueness of the CO2-EOR test at Wellington Field

1. Extensive technical information available for this oil field that is and will continue to be all public domain including -
    a. 12 mi^2 multicomponent seismic that is uniquely available for ongoing and continued research
        i. Demonstrated mapping of phi-k mapping aided by seismic
        ii. Well suited for integrating geomechanical analysis, discrete fracture network
    b. 2D shear and p-wave seismic calibration lines adding to uniqueness and rigor of the seismic program,
    c. 1600 ft of continuous core providing unique view of entire caprock, strata comprising reservoir, and context stratigraphic data for continued analysis
    d. Two newly drilled basement wells, 3000 ft apart, with well testing, extensive whole core C/A including geomechanical analysis, geochemical analyses, petrophysical analysis
        i. Established unique petrophysical analysis techniques to predict capillary pressure, relative permeability, and kv and kh using extensive datasets

2. Highly constrained integrated Petrel model and CMG simulations and a skilled research team (KGS and beyond) with expertise in geology, engineering , and geophysics working with high quality data
    a. Well suited to conducted experiments directed toward next generation CO2-EOR in smaller (<50 million bbls) carbonate reservoirs common to the upper Midcontinent.
    b. Utilization of very high resolution seismic from KGS vibroseis to image the smaller quantities of CO2
    c. Will deploy in May the latest in passive seismic monitoring for dual purpose --
        i. installing five 3-component accelerometers purchased with KGS funds (decided on six 4/2/14) to aid in detecting CO2 and provide unique potential to adjust the CO2 flood in real-time
        ii. Plans for additional accelerometers to examine effects of suspected small fault the possibly would affect fluid flow; use monitoring to run experiment under pre-CO2 waterflood to define whether conductive or barrier to flow; incorporate a unique approach in seismic diffraction modeling by LLBL personnel to characterize faults based on another field test using near surface analog in SE Kansas with faulted Mississippian strata that will be seismically imaged and cored via slant hole.
        iii. Use of 15 IRIS seismometers along with accelerometers to understand the recent increase in earthquake activity in the area, integrate data with the existing seismic network coordinating with USGS, state agencies, and Oklahoma Geological Survey
3. Unique integration of Wellington Field with the Kansas CO2 Initiative engaging the entire community – petroleum industry, CO2 suppliers, lawmakers and regulators – over the course of next year with Wellington Field serving as the focal point
    a. Use of Wellington Field as a calibration site and field demonstration to engage petroleum industry in overcoming need and requirements in use of anthropogenic sources of CO2
    b. Test best practice, cost-effective monitoring to aid in applying next-generation CO2-EOR methods, refine model predictions, and to permit CO2 use to be optimized for CO2 sequestration
    c. Uniquely couple the oil field and the underlying saline aquifer to increase the CO2 sequestration capacity using Wellington to help calibration with Cutter field, 8 other sites in Kansas being completed in DE-FE0002056.

3) Readiness of the CO2 suppliers and EPA for a Class VI well.

CO2 Suppliers --

- Aggressive pursuit of CO2 sources and notable price discounts -- Following continued shutdown of the Abengoa plant in Colwich, KS, announced late July 2013, alternate sources of CO_2 were sought and two of the most favorable suppliers were secured.
- Industrial supplier's margin is breakeven, rates and amounts of CO2 meet project needs.
- Suppliers are leaders in CO2 capture and supply, an excellent partner for this project

EPA Class VI Review --

EPA decision is model-based and model is rigorous and clear about the safety of the test -- The simulation results summarized in the Executive Summary of the Class VI application indicate that the plume will stabilize within a few months of cessation of injection, and pressures will also drop to ambient conditions very rapidly. Therefore, KGS remains confident that the EPA will approve the permit in within a year or less. Also,

a. Overlying underpressured oil field and its caprocks minimize potential for leak of CO2
b. Exemplary database demonstrates distinct hydrostratigraphic units that comprise the Arbuckle – two basement tests, multicomponent seismic, exhaustive logs, core (1600 ft), seismic, lab tests, pulse test, geochemically and microbially distinction of units in Arbuckle demonstrating their hydraulic isolation.
c. Arbuckle core plugs also being analyzed by Susan Carroll at LLNL and coordination with us to help upscale their work on reactive transport models and reaction kinetics.
d. Our view is that industry partner, data used, and team assembled to analyze the information used to create the geomodels and simulations of the Mississippian and Arbuckle are top notch and prepared to take on the challenges of the small scale tests.

The EPA Region 7 Director has personally expressed interest in this project and has provided commitments to expedite the approval process.

ACTIVITIES OF LAWRENCE BERKELEY NATIONAL LAB

Plans have been scheduled with Susan Carroll at Lawrence Livermore National Laboratory to perform supercritical CO2 flow through experiments using seven total core plugs taken on behalf of DE-FE0002056. LLNL is operating from a separate contract with DOE-NETL through Traci Rodosta. Three core plugs taken from the Upper Arbuckle of the Wellington core will be analyzed starting June 23rd, and will be sent for pre-experimental flow through analysis and imaging. The following table lists the details of the Wellington core samples to be analyzed:

March '14 Wellington Thin Section Order

Order No.	Sample No.	Formation Name	Depth
23	13-41	Upper Arbuckle	4225.7'
24	13-46	Upper Arbuckle	4230.3'
25	14-4	Upper Arbuckle	4247'

ONGOING ACTIVITIES

1) Complete Class VI review by Berexco and submit application to EPA.
2) Complete modeling of Mississippian injection and submit Class II permit to State.
3) Complete DOE cost evaluation review of alternative CO2 suppliers.
4) Complete DOE review of documentation of the uniqueness of the CO2-EOR test to be performed at Wellington Field.
5) Receipt and planning for installation of 15 seismometer stations from IRIS PASSCAL. Field training scheduled in April for KGS staff to provide networked site for earthquake monitoring in southern Kansas.
6) KGS plans to independently purchase five 3-component accelerometers to aid in detection of fluid movement and seismic events to adjust the CO2 flood in real time.
7) Collaboration with LLBL to arrange in situ micro CT imaging of CO2 with plans to examine oil reservoir, obtain reaction kinetics suited for improving injection simulations with discussions of upscaling results to geomodel using NMR technology.
8) Additional refinement of the dynamic Mississippian model and inclusion of CO2-mineral-brine interaction.

TASK 1. PROJECT MANAGEMENT AND REPORTING

Subtask 1.5 Well Drilling and Installation Plan – To be adapted from materials submitted in the Class VI application, and upon DOE approval of proposed changes.

Subtask 1.6 MVA - Updated monitoring plan adapted from Section 11 of Class VI application.

Subtask 1.7. Public Outreach Plan - To be adapted from material submitted in the Class VI application.

KEY FINDINGS

1. Two industrial suppliers have been confirmed to jointly deliver CO2 to the injection site.
2. A decreased volume of CO2 injected into the Arbuckle Saline Aquifer will still be successfully monitored with current MVA technology
3. Installation of a temporary seismometer array in conjunction with continuous recording from five multicomponent broadband accelerometers should provide precise delineation of injected fluid movement to refine reservoir scale modeling and assist in steering the injectate and optimize contact with the reservoir.

Plans for First Quarter 2014

1. Receive final Class VI comments from Berexco, and submit to EPA.
2. Submit Class II Injection application upon approval from DOE.
3. Procure and enter a contractual agreement with CO2 suppliers.
4. Deploy MVA technology to establish pre-injection baseline readings.
5. Install 15 IRIS-PASCAL seismometers and receive training to deploy at Wellington for passive monitoring of Mississippian and Arbuckle injections and provide a networked site for earthquake monitoring in southern Kansas.
6. Drill Mississippian Injection Well and commence field preparation for injection activities.

PRODUCTS

Publications, conference papers, and presentations

Fazelalavi, Mohsen., Fazelalavi, Mina., Fazelalavi, Maryam., Determination of Reservoir Permeability Based on Irreducible Water Saturation and Porosity from Log Data and FZI (Flow Zone Indicator) from Core Data. Paper number: 17429-IPTC to the 7th International Petroleum Technology Conference (IPTC)

Watney, Lynn, Rush, Jason, Raney, Jennifer, "Carbon Storage and Utilization in Kansas – Are We Ready?" Presentation to the University of Kansas Department of Geology Colloquium Series (January 2014)

Holubnyak, Yeven, "Pilot-Scale CO2 Geological Storage Project and CO2 EOR at Wellington Field in Southern Kansas." Presentation to the University of Kansas Department of Geology Colloquium Series (March 2014)

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

A project organization chart follows. The work authorized in this budget period includes office tasks related to preparation of reports and application for a Class VI permit to inject CO2 into the Arbuckle saline aquifer. Tasks associated with reservoir characterization and modeling are funded in contract DE-FE0002056.

ORGANIZATION CHART

Name	Project Job Title	Primary Responsibility
Kansas Geological Survey		
Lynn Watney	Project Leader, Joint Principal Investigator	Geology, information synthesis, point of contact
Yevhen Holubnyak	Petroleum Engineer	Reservoir engineer, dynamic modeling, synthesis
Jason Rush	Joint Principal Investigator	Geology, static modeling, data integration, synthesis
John Doveton	Co-Principal Investigator	Log petrophysics, geostatistics
Dave Newell	Co-Principal Investigator	Fluid geochemistry
Rick Miller	Geophysicist	2D seismic acquire & interpretation
		LiDAR/InSAR support, water well drilling/completion
TBN	Geology Technician	Assemble and analyze data, report writing
Tiraz Birdie	President, TBirdie Consulting, Inc.	Hydrogeologic modeling, permitting, MVA, integration
KU Department of Geology		
Michael Taylor	Co-Principal Investigator	Structural Geology, analysis of InSAR, LiDAR, seismometer array
TBN	Graduate Research Assistant	Structural Geology, analysis of InSAR and LiDAR, seismometer array
Kansas State University		
Saugata Datta	Principal Investigator	
TBN	Graduate Research Assistant	Aqueous geochemistry
TBN	3- Undergraduate Research Assistants	
Lawrence Berkeley National Laboratory		
Tom Daley	Co-Principal Investigator	Geophysicist, analysis of crosshole and CASSM data
		Hydrogeology, analysis of soil gas measurements
Barry Freifeld	Co-Principal Investigator	Mechanical Engineer, analysis of U-Tube sampler
Sandia Technologies, Houston		
Dan Collins	Geologist	Manage CASSM and U-Tube operation
David Freeman	Field Engineer	Manage field install of CASSM and U-Tube
Berexco, LLC		
Dana Wreath	VP Berexco, LLC	Engineering, Manager of Wellington Field
Randy Koudele	Reservoir engineer	Engineering
Staff of Wellington Field		Field operations
Beredco Drilling team		Mississippian and Arbuckle drilling operations
Abengoa Bioenergy Corp.		
Christopher Standlee, Danny Alllison		CO2 supply Colwich Ethanol Facility

IMPACT

Key personnel have been actively engaged with industry, regulatory agencies, and stakeholders to address the significance of this kind of demonstration project in Kansas. Both high-level elected officials and top oil and gas operators have expressed support to expand the carbon market throughout the state. These groups are anxiously awaiting a successful trial of the field experiment to justify future investment into the infrastructure

required for commercial level CCUS. Furthermore, some of the country's largest CO2 providers have confirmed their participation in the project, and are confident that the engagement will grant their business a leading edge on a burgeoning industry. Awareness and support for the Wellington CO2 project is growing stronger and more widespread. Successful field activities will provide evidence necessary to move CCUS even closer to commercialization.

CHANGES/PROBLEMS

Two industrial suppliers will now jointly deliver a reduced volume of CO2 to the injection site. Transport limitations have prevented the available funds from being sufficient to procure the original volume of CO2 to be injected. Adjustments to the injection simulations have been run to account for this decreased volume. The KGS is awaiting approval from DOE of the cost evaluation report, and to approve the documentation that the science of the tasks to be performed will not be impacted by the decrease in CO2.

Enhancements to the original MVA plan include the installation of 15 seismometer stations, and five broadband accelerometers to monitor fluid movement and detect any seismic events in the vicinity of the study area.

BUDGETARY INFORMATION

Cost Status Report

See figure on the following page for the cost status for quarters 1-10.

APPENDIX II

Small Scale Field Test Demonstrating CO_2 Sequestration in Arbuckle Saline Aquifer and by CO_2-EOR at Wellington Field, Sumner County, Kansas

ELEVENTH QUARTERLY PROGRESS REPORT

DOE F 4600.2
(03/11)
All Other Editions Are Obsolete

U.S. Department of Energy
FEDERAL ASSISTANCE REPORTING CHECKLIST
AND INSTRUCTIONS FOR RD&D PROJECTS

1. Identification Number: **DE-FE0006821**	2. Program/Project Title: **Small Scale Field Test Demonstration CO2 Sequestration**

3. Recipient:
University of Kansas Center for Research, Inc.

4. Reporting Requirements:	Frequency	Addressees
A. MANAGEMENT REPORTING		
☒ Research Performance Progress Report (RPPR)	Q	FITS@NETL.DOE.GOV
☒ Special Status Report	A	FITS@NETL.DOE.GOV
B. SCIENTIFIC/TECHNICAL REPORTING		
(Reports/Products must be submitted with appropriate DOE F 241. The 241 forms are available at www.osti.gov/elink)		
Report/Product — Form		
☒ Final Scientific/Technical Report — DOE F 241.3	FG	http://www.osti.gov/elink-2413
☒ Conference papers/proceedings* — DOE F 241.3	A	http://www.osti.gov/elink-2413
☐ Software/Manual — DOE F 241.4		
☐ Other (see special instructions) — DOE F 241.3		
** Scientific and technical conferences only*		
C. FINANCIAL REPORTING		FITS@NETL.DOE.GOV
☒ SF-425 Federal Financial Report	Q, FG	
D. CLOSEOUT REPORTING		
☒ Patent Certification	FC	FITS@NETL.DOE.GOV
☒ SF-428 & 428B Final Property Report	FC	FITS@NETL.DOE.GOV
☐ Other		
E. OTHER REPORTING		
☒ Annual Indirect Cost Proposal	O	See block 5 below for instructions.
☐ Audit of For-Profit Recipients		
☒ SF-428 Tangible Personal Property Report Forms Family	A	FITS@NETL.DOE.GOV
☒ Other – see block 5 below	A	FITS@NETL.DOE.GOV

FREQUENCY CODES AND DUE DATES:

A - Within 5 calendar days after events or as specified.
FG- Final; 90 calendar days after the project period ends.
FC- Final; End of Effort.
Y - Yearly; 90 calendar days after the end of the reporting period.
S - Semiannually; within 30 calendar days after end of project year and project half-year.
Q - Quarterly; within 30 days after end of the reporting period.
Y180 – Yearly; 180 days after the end of the recipient's fiscal year
O - Other; See instructions for further details.

5. Special Instructions:

Annual Indirect Cost Proposal – If DOE is the Cognizant Federal Agency, then the proposal should be sent to FITS@NETL.DOE.GOV . Otherwise, it should be sent to the Cognizant Federal Agency.

Other – The Recipient shall provide all deliverables as contained in Section D of Attachment 2 Statement of Project Objectives.

QUARTERLY PROGRESS REPORT
To
DOE-NETL
Brian Dressel, Program Manager
Award Number: DE-FE0006821

SMALL SCALE FIELD TEST DEMONSTRATING CO_2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO_2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS

Project Director/Principal Investigator:
W. Lynn Watney
Senior Scientific Fellow
Kansas Geological Survey

Ph: 785-864-2184, Fax: 785-864-5317
lwatney@kgs.ku.edu

Joint Principal Investigator:
Jason Rush

Prepared by Lynn Watney and Tiraz Birdie
Date of Report: August 7, 2014
DUNS Number: 076248616

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

Project/Grant Period: 10/1/2011 through 9/30/2016

Eleventh Quarterly Report

Period Covered by the Report: April 1, 2014 through June 30, 2014

Signature of Submitting Official:

W. Lynn Watney

Digitally signed by W. Lynn Watney
DN: cn=W. Lynn Watney, o=The University of Kansas, ou=Kansas Geological Survey, email=lwatney@kgs.ku.edu, c=US
Date: 2014.09.04 20:26:19 -05'00'

EXECUTIVE SUMMARY

Project Objectives

The objectives of this project are to understand the processes that occur when a maximum of 70,000 metric tonnes of CO_2 are injected into two different formations to evaluate the response in different lithofacies and depositional environments. The evaluation will be accomplished through the use of both *in situ* and indirect MVA (monitoring, verification, and accounting) technologies. The project will optimize for carbon storage accounting for 99% of the CO_2 using lab and field testing and comprehensive characterization and modeling techniques.

CO_2 will be injected under supercritical conditions to demonstrate state-of-the-art MVA tools and techniques to monitor and visualize the injected CO_2 plume and to refine geomodels developed using nearly continuous core, exhaustive wireline logs, and well tests and a multi-component 3D seismic survey. Reservoir simulation studies will map the injected CO_2 plume and estimate tonnage of CO_2 stored in solution, as residual gas, and by mineralization and integrate MVA results and reservoir models shall be used to evaluate CO_2 leakage. A rapid-response mitigation plan will be developed to minimize CO_2 leakage and provide comprehensive risk management strategy. A documentation of best practice methodologies for MVA and application for closure of the carbon storage test will complete the project. The CO_2 shall be supplied from a reliable facility and have an adequate delivery and quality of CO_2.

Scope of Work

Budget Period 1 includes updating reservoirs models at Wellington Field and filing Class II and Class VI injection permit application. Static 3D geocellular models of the Mississippian and Arbuckle shall integrate petrophysical information from core, wireline logs, and well tests with spatial and attribute information from their respective 3D seismic volumes. Dynamic models (composition simulations) of these reservoirs shall incorporate this information with laboratory data obtained from rock and fluid analyses to predict the properties of the CO_2 plume through time. The results will be used as the basis to establish the MVA and as a basis to compare with actual CO_2 injection. The small scale field test shall evaluate the accuracy of the models as a means to refine them in order to improve the predictions of the behavior and fate of CO_2 and optimizing carbon storage.

Budget Period 2 includes completing a Class II underground injection control permit; drilling and equipping a new borehole into the Mississippian reservoir for use in the first phase of CO_2 injection; establishing MVA infrastructure and acquiring baseline data; establishing source of CO_2 and transportation to the injection site; building injection facilities in the oil field; and injecting CO_2 into the Mississippian-age spiculitic cherty dolomitic open marine carbonate reservoir as part of the small scale carbon storage project.

In Budget Period 3, contingent on securing a Class VI injection permit, the drilling and completion of an observation well will be done to monitor injection of CO_2 under supercritical conditions into the Lower Ordovician Arbuckle shallow (peritidal) marine dolomitic reservoir. Monitoring during pre-injection, during injection, and post injection will be accomplished with MVA tools and

techniques to visualize CO_2 plume movement and will be used to reconcile simulation results. Necessary documentation will be submitted for closure of the small scale carbon storage project.

Project Goals

The proposed small scale injection will advance the science and practice of carbon sequestration in the Midcontinent by refining characterization and modeling, evaluating best practices for MVA tailored to the geologic setting, optimize methods for remediation and risk management, and provide technical information and training to enable additional projects and facilitate discussions on issues of liability and risk management for operators, regulators, and policy makers.

The data gathered as part of this research effort and pilot study will be shared with the Southwest Sequestration Partnership (SWP) and integrated into the National Carbon Sequestration Database and Geographic Information System (NATCARB) and the 6th Edition of the Carbon Sequestration Atlas of the United States and Canada.

Project Deliverables by Task

1.5 Well Drilling and Installation Plan (Can be Appendix to PMP or Quarterly Report)
1.6 MVA Plan (Can be Appendix to PMP or Quarterly Report)
1.7 Public Outreach Plan (Can be Appendix to PMP)
1.8 Arbuckle Injection Permit Application Review go/no go Memo
1.9 Mississippian Injection Permit Application Review go/no go Memo
1.10 Site Development, Operations, and Closure Plan (Can be Appendix to PMP)
2.0 Suitable geology for Injection Arbuckle go/no go Memo
3.0 Suitable geology for Injection Mississippian go/no go Memo
11.2 Capture and Compression Design and Cost Evaluation go/no go Memo
19 Updated Site Characterization/Conceptual Models (Can be Appendix to Quarterly Report)
21 Commercialization Plan (Can be Appendix to Quarterly Report).
30 Best Practices Plan (Can be Appendix to Quarterly or Final Report)

ACCOMPLISHMENTS

1. **Class VI application submitted and accepted by EPA and Deliverable in Subtask 1.8 "Arbuckle Injection Permit Application Review go/no go Memo" was submitted.**

   -- Permit application was submitted to EPA and accepted on June 19th.

2. **CO2 suppliers have been secured.**

   -- Praxair and Linde Group have been secured as vendors to supply CO_2 under the Berexco subcontract.

3. **Science further enhanced with receipt of 15 seismometers for IRIS-PASSCAL Seismic array deployment and three active 3-component active seismometers purchased with KGS funds to compliment other monitoring including high-resolution seismic, high-resolution cGPS/InSAR, and downhole U-tube sampling and CASSM.**

4. **Important science questions directed toward to improved prediction and evaluation of dynamic changes in the CO_2 plumes are anticipated using recent refinements in existing Petrel-CMG models.**

5. **Increased relevancy of this project to the DOE Portfolio.**

6. **With submittal of the Class VI application, securing CO_2 supply, and level of scientific study related to the Mississippian injection, DOE agreed to proceed with plans for Mississippian injection ahead of the Arbuckle.**

Milestone Status Report

Task	Budget Period	Number	Milestone Description
Task 2.	1	1	Site Characterization of Arbuckle Saline Aquifer System - Wellington Field
Task 3.	1	2	Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field
Task 10.	2	3	Pre-injection MVA - establish background (baseline) readings
Task 13.	2	4	Retrofit Arbuckle Injection Well (#1-28) for MVA Tool Installation
Task 18.	3-yr1	5	Compare Simulation Results with MVA Data and Analysis and Submit Update of Site Characterization, Modeling, and Monitoring Plan
Task 22.	3-yr1	6	Recondition Mississippian Boreholes Around Mississippian CO2-EOR injector
Task 27.	3-yr2	7	Evaluate CO2 Sequestration Potential of CO2-EOR Pilot
Task 28.	3-yr2	8	Evaluate Potential of Incremental Oil Recovery and CO2 Sequestration by CO2-EOR - Wellington field

Project Schedule

Decision was made by DOE in May to move forward with the Mississippian injection as highlighted in the schedule shown in **Figure 1**.

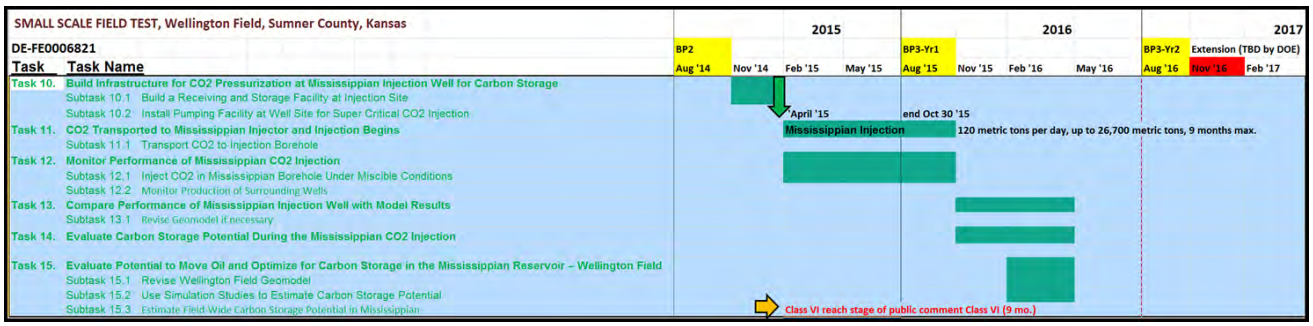


Figure 1. Budget period 2 would begin with preparations to injection CO_2 into the Mississippian oil reservoir.

Decision to move forward was made after Berexco's CFO signed the Class VI permit and the Class VI permit application was submitted to EPA. It is understood that the permit must be submitted to the EPA and deemed administratively complete prior to conducting any field work.

The SOPO was revised and the full schedule of the project was modified to fit the end date of funding, September 30, 2016. The portion of the schedule with the Arbuckle injection is shown in **Figure 2**.

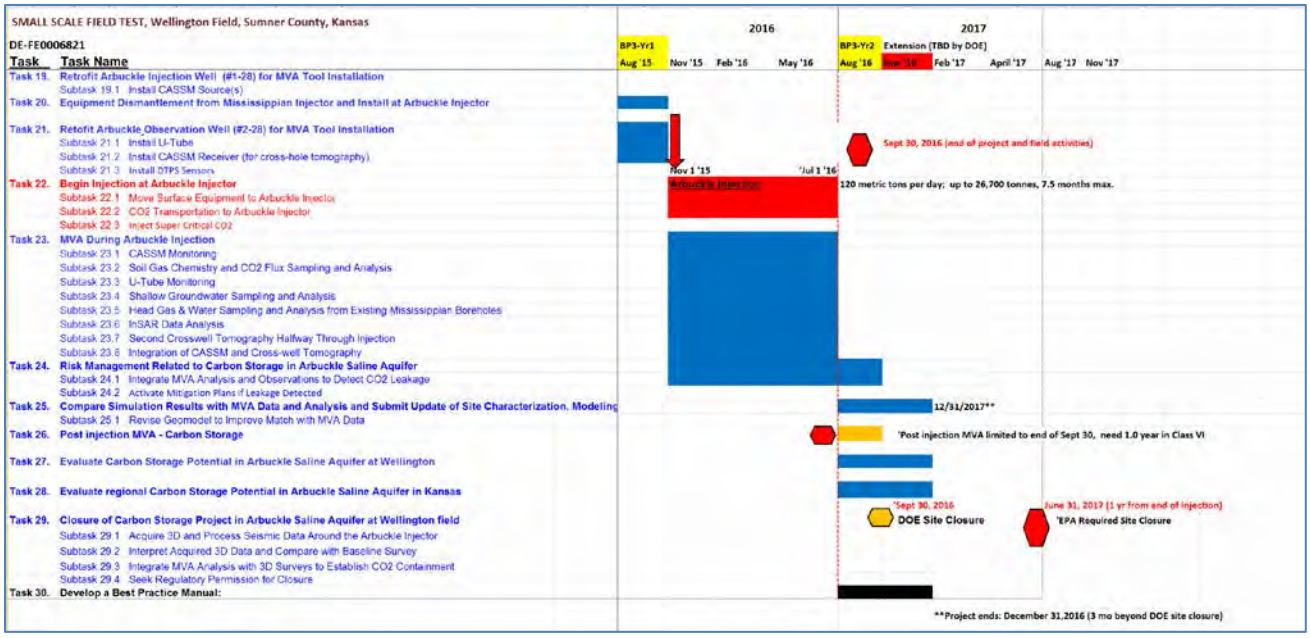


Figure 2. Project schedule for pre- and post-Arbuckle injection at Wellington Field.

Activities of Lawrence Berkeley National Lab

No work has been completed or funds expended during this quarter by LBNL.

ONGOING ACTIVITIES

TASK 1. PROJECT MANAGEMENT AND REPORTING

Subtask 1.7. Public Outreach Plan

Please see Appendix A.

Subtask 1.8. Arbuckle Injection Permit Application Review go/no go Memo (See Appendix A-4 Permit Application)

1. Class VI Injection Application submitted and accepted.

Subtask 1.8 Arbuckle Injection Permit Application:

As noted in SOPO: During the first budget period the Recipient shall submit an application for a Class VI underground injection control (UIC) permit for injecting CO_2 into the Arbuckle Group. The final draft permit, after all negotiations are completed, shall be reviewed and a short report submitted to the DOE with a copy of the permit, indicating any potential implementation issues that may arise. This report shall be used to support a go/no go decision by the DOE on continuing the project.

GO/NO-GO DECISION POINT #1

This deliverable was met by administrative acceptance of Class VI application by EPA on June 19 and Memorandum shared with Program Manager on June 27th. Application was submitted by Jennifer Raney, KGS, on behalf of Berexco, LLC, the project's industry partner and operator of Wellington Field.

The following is the electronic confirmation of a successful upload of the application to EPA website.

EPA Class VI UIC Permit Application Upload

This permit application is for:

Project ID: R07-KS-0001

Project Name: Kansas Small Scale Test Wellington Field

General Information

Number of proposed Class VI wells: 1

Brief description of the project: US Department of Energy sponsored pilot scale project to gain a better scientific understanding of the carbon storage process by incorporating advanced characterization, modeling, and monitoring techniques.

Other relevant environmental permits, including state permits

Permit Type(s) and ID: Kansas Corporation Commission drilling permits: Notice of Intent to Drill (C-1), Well Completion Form (ACO-1), Temporary Abandonment (CP-111)

Facility Information

Facility name: Wellington Field Small Scale Carbon Capture and Storage Project

Facility mailing address: 2020 N. Bramblewood Street Wichita, KS 67206

Facility location: Latitude: 37.319485 Longitude: -97.433459

Up to four Standard Industrial Classification (SIC) codes for the products/services provided by the facility [40 CFR 144.31(e)]: 1311, 1321, 1381, 1382

Facility located on Indian lands [40 CFR 144.31(e)]: No

Facility contact information

Contact person: Dana Wreath, Vice President Berexco LLC

Contact phone number: 316-265-3311

Contact email: dwreath@berexco.com

Owner/Operator Information

Operator's name: Dana Wreath

Operator's address: Berexco LLC 2020 North Bramblewood Dr. Wichita, KS 67206

Operator's phone number: 316-265-3311

Operator's status: Private

Ownership status: NOT Owner

Owner's name: Kansas Geological Survey

Owner's address: 1930 Constant Ave Lawrence, Kansas 66047

Owner's phone number: 785-864-2184

Permit Application

Site Characterization Information: https://epa.velo.pnnl.gov/alfresco/service/velo/getFile/projects/Submissions/R07-Ks-0001/PermitApp/Submission-06-19-2014-131321/A-----Site--Characterization--Information.pdf

Proposed Project Plans

Proposed AoR and Corrective Action Plan: https://epa.velo.pnnl.gov/alfresco/service/velo/getFile/projects/Submissions/R07-Ks-0001/PermitApp/Submission-06-17-2014-143933/B-----Proposed--Area--of--Review--and--Corrective--Action--Plan.pdf

Proposed Testing and Monitoring Plan: https://epa.velo.pnnl.gov/alfresco/service/velo/getFile/projects/Submissions/R07-Ks-0001/PermitApp/Submission-06-17-2014-143933/C-----Proposed--Testing--and--Monitoring--Plan.pdf

Proposed Injection Well Plugging Plan: https://epa.velo.pnnl.gov/alfresco/service/velo/getFile/projects/Submissions/R07-Ks-0001/PermitApp/Submission-06-17-2014-143933/D-----Proposed--Injection--Well--Plugging--Plan.pdf

Proposed PISC and Site Closure Plan: https://epa.velo.pnnl.gov/alfresco/service/velo/getFile/projects/Submissions/R07-Ks-0001/PermitApp/Submission-06-17-2014-143933/E-----Proposed--PISC--and--Site--Closure--Plan.pdf

Proposed Emergency and Remedial Response Plan: https://epa.velo.pnnl.gov/alfresco/service/velo/getFile/projects/Submissions/R07-Ks-0001/PermitApp/Submission-06-17-2014-143933/F-----Proposed--Emergency--and--Remedial--Response--Plan.pdf

Financial Responsibility Demonstration: https://epa.velo.pnnl.gov/alfresco/service/velo/getFile/projects/Submissions/R07-Ks-0001/PermitApp/Submission-06-17-2014-143933/G-----Financial--Responsibility--Demonstration.pdf

Proposed Formation Testing Program: https://epa.velo.pnnl.gov/alfresco/service/velo/getFile/projects/Submissions/R07-Ks-0001/PermitApp/Submission-06-17-2014-143933/H-----Proposed--Formation--Testing--Program.pdf

Proposed Well Construction
Information: https://epa.velo.pnnl.gov/alfresco/service/velo/getFile/projects/Submissions/R07-Ks-0001/PermitApp/Submission-06-17-2014-143933/I-----Proposed--Injection--Well--Construction--Information.pdf

Proposed Operating
Information: https://epa.velo.pnnl.gov/alfresco/service/velo/getFile/projects/Submissions/R07-Ks-0001/PermitApp/Submission-06-17-2014-143933/J-----Proposed--Operating--Information.pdf

List of Contacts for States, Tribes, Territories within the
AoR: https://epa.velo.pnnl.gov/alfresco/service/velo/getFile/projects/Submissions/R07-Ks-0001/PermitApp/Submission-06-17-2014-143933/K-----List--of--Contacts--within--the--AoR.pdf

YES - Other Information Required

Other Required
Information: https://epa.velo.pnnl.gov/alfresco/service/velo/getFile/projects/Submissions/R07-Ks-0001/PermitApp/Submission-06-19-2014-131321/L-----Other--Required--Information--by--UIC--Director.zip

YES - Alternative PISC Timeframe Requested

Alternative PISC Timeframe
Demonstration: https://epa.velo.pnnl.gov/alfresco/service/velo/getFile/projects/Submissions/R07-Ks-0001/PermitApp/Submission-06-17-2014-143933/M-----Alternative--PISC--Timeframe.pdf

Complete Submission

Authorized submission made by: Jennifer Raney

Optional comments regarding this submission: Third attempt to officially submit KGS Class VI application. File "A - Site Characterization Information" was resubmitted to resolve upload errors. No changes were made to the actual file.

For confirmation a read-only copy of your submission will be emailed to: lwatney@kgs.ku.edu

If you have any questions, please contact your permitting authority.

2. CO_2 suppliers have been secured.

Task 5. Secure CO2 source -- GO/NO-GO DECISION #5

Subtask 5.1 CO_2 Supply
Subtask 5.2 CO_2 Transportation

Linde Group and Praxair expressed interest to participating since last fall and both are very interested in commercialization opportunities, initially in the CCUS field. KGS has had multiple contacts with their company representatives that led to reaching this field deployment phase. Both companies have an international presence and both companies have worked with DOE on similar

types of projects. The familiarity and expertise that they bring to the project from CO_2 source to sink are vital to the project and CO_2 utilization in Kansas.

Linde and Praxair have a nonbinding agreement to supply CO_2 under the subcontract with Berexco with and official contract to be negotiated by Berexco and KGS at a date closer to the actual injection. Details on costs, volume, and rate have been conveyed to Program Manager as part of current budget negotiations.

3. Science further enhanced with receipt of 15 seismometers for IRIS-PASSCAL seismic array deployment and three active 3-component active seismometers purchased with KGS funds to compliment other monitoring including high-resolution seismic, high-resolution cGPS/InSAR, and downhole U-tube sampling and CASSM.

Task 6. Establish MVA Infrastructure - Around CO_2 Injector for Carbon Storage
Subtask 6.2. Install CGPS and Seismometers near Injection Borehole

The Kansas Geological Survey took receipt of 15 IRIS seismometers in March 2014 and three 3-component active accelerometers in June 2014 to be installed as a passive seismic array for the Mississippian and Arbuckle CO_2 injection. KGS funds were used to purchase the accelerometers and the IRIS equipment was donated to the KGS for 3-yrs of data recording. Equipment will be installed in an array as shown in **Figure 3**. All of this monitoring equipment is to be fully active during the month of August.

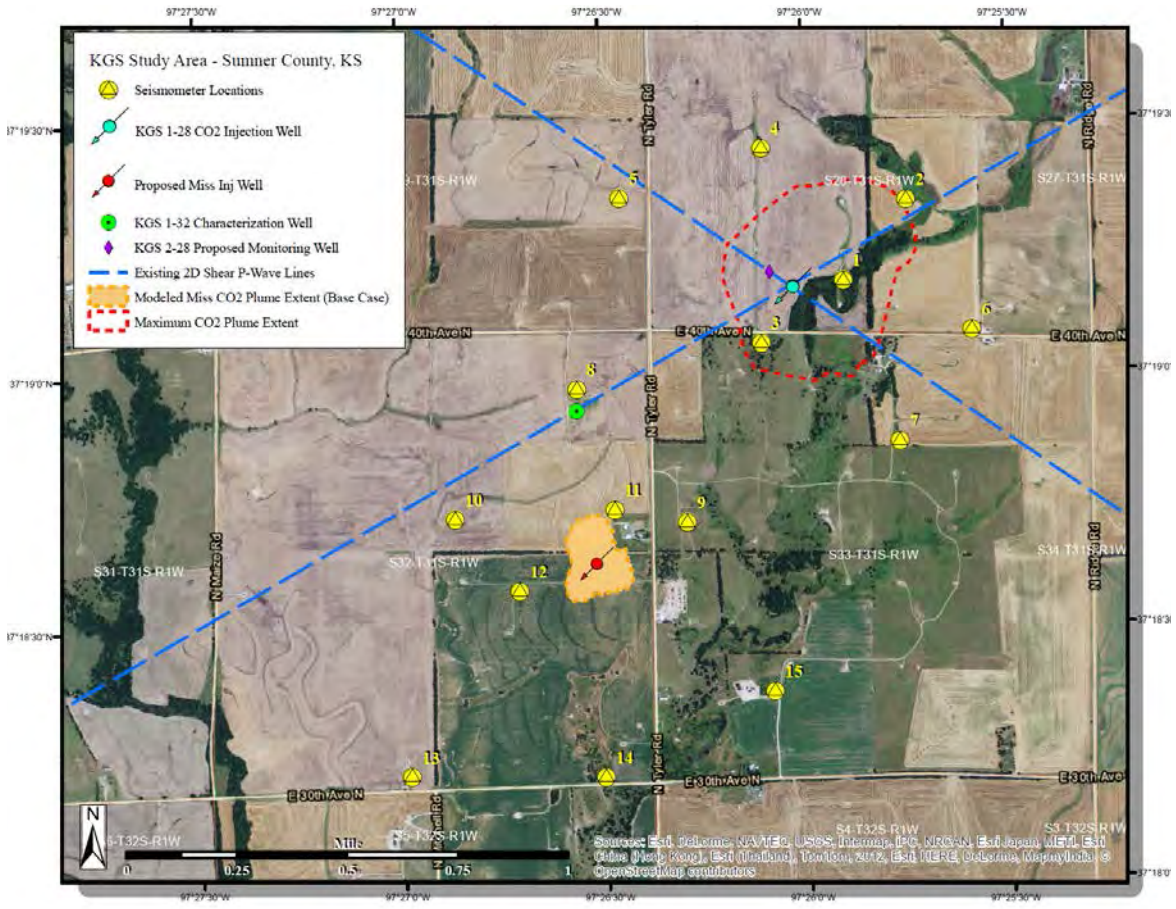


Figure 3. Location of IRIS seismometers, CO_2 injection wells, and CO_2 plumes for the Mississippian and Arbuckle injections.

The passive seismic deployment will complement the extensive technical information available for this oil field that is and will continue to be public domain. Existing data in place includes:

a. 12 mi^2 multicomponent seismic that is uniquely available for ongoing and continued research
    i. Demonstrated mapping of phi-k mapping aided by seismic
    ii. Well suited for integrating geomechanical analysis, discrete fracture network
b. 2D shear and p-wave seismic calibration lines adding to uniqueness and rigor of the seismic program (see **Figure 3**),
c. 1600 ft of continuous core providing unique view of entire caprock, strata comprising reservoir, and context stratigraphic data for continued analysis
d. Two newly drilled basement wells, 3000 ft apart, with well testing, extensive whole core C/A including geomechanical analysis, geochemical analyses, petrophysical analysis
    i. Established unique petrophysical analysis techniques to predict capillary pressure, relative permeability, and kv and kh using extensive datasets

e. Three research groups, each with a different focus, are conducting laboratory studies of the rock under *in situ* conditions with CO_2
    i. KU – in situ work with caprock, reservoir, and brines studying both microbial and isotope that is rather unique including effects of CO_2 on microbial community
    ii. KSU – focus on understanding brines and reactions with CO_2
    iii. Lawrence Livermore (Susan Carroll) – in situ micro CT imaging of CO_2 with plans to examine oil reservoir; objective is to obtain reaction kinetics suited for improving simulation with discussions of upscaling results to geomodel using NMR technology

4. Important science questions directed toward improved prediction and evaluation of dynamic changes in the CO_2 plumes are anticipated using recent refinements in existing Petrel-CMG models

Task 2. Site Characterization of Arbuckle Saline Aquifer System - Wellington Field (GO/NO-GO DECISION #3)

Task 3. Site characterization of Mississippian Reservoir - Wellington Field -- (Class II Application & GO/NO-GO DECISION #4)

The active, 24-bit, 3 component state-of-the art accelerometers will be placed with the seismometer array to 1) increase the bandwidth/frequency range of the events that will be monitored, 2) increase the sensitivity of the passive seismic monitoring by measuring far field, lower frequency events that will compliment seismometers and increase understanding of the mechanisms, and 3) and record 3-components of movement.

The accelerometers are the technology of choice to optimize detection of fluid movement and will further enhance the opportunity to bolster the science for the Mississippian test. Assurances for success in their use to image the CO_2 plume in the Mississippian include:

1. Rick Miller will install installation the accelerometers with advice of Tom Daley at LBNL and George Tsoflias in KU Geology. Daley has extensive experience in installation, monitoring, and interpretation of accelerometers.
2. The accelerometer deployment in the shallower Mississippian will establish baseline acoustic properties that will be highly beneficial to optimize installation and recording for the other high-resolution surface and downhole seismic technologies to be used in monitoring the Arbuckle injection.
3. Surface-based passive seismic monitoring will help to locate the CO_2 plume, but also provide precise timing of events. Understanding acoustics and testing of the surface passive seismic during the Mississippian will provide the encouragement to use CASSM and pseudo 3D seismic with fiber optic cable in a passive mode.

4. The shallower nature of the Mississippian injection will be a critical test of detection levels and resolution. Monitoring would commence prior to and during pressurization of the Mississippian reservoir. Short-term experiments such as varying water injection rates prior to the startup of the CO_2 injection will assist in evaluating the seismic array.
5. We anticipate the seismometer array will generate at point cloud of seismic events from which we can track the CO_2 movement.

Events detected by microseismic methods in the Mississippian can be verified by: a) tracer and sampling of produced fluid to detect the direction of the CO_2 front, b) high resolution 2D seismic lines to image the CO_2 front (*The IVI Minivib II used as the source is a high-frequency 15,000-lb vibrator that has a factory-specified sweep range from 15 Hz to 300 Hz*), and c) InSAR coupled with continuous GPS to detect surface ground motion associated with the CO_2 plume down to sub mm levels. This redundancy of methods will help to evaluate the effectiveness of the monitoring methods. A conservative tracer will also permit understanding of the distribution of CO_2 within the reservoir and the sweep efficiency of the CO_2 and oil bank.

A comparison between modeled and actual Mississippian CO_2 injection will improve the understanding of the behavior of CO_2 in brine, oil, in the carbonate matrix. Moreover, fractures will likely be most easily detected by the passive seismic array if a portion of the CO_2 plume undergoes focused flow along a system. The early detection of these deviations in the oil reservoir could permit real-time modification of the injection pattern to increase the contact of CO_2 with the reservoir leading to both additional oil recovery and increased trapping of the CO_2 in the reservoir.

Coupled with improved detection of the characteristics of the injected plume, better characterization of the effects of CO_2 on the matrix carbonate will likely provide more accurate and predictable fluid flow simulations. Imaging, NMR scanning and characterization, and reactive transport modeling of core samples from Wellington by Susan Carroll, Megan Smith, and colleagues at LLNL, is currently underway and will continue in the early portion of this project. KSU is now an active collaborator with that team to aid KGS in integrating this information into the reservoir simulator.

Other considerations in monitoring of the Mississippian and the Arbuckle:

- *Opportunity for multiple experiments* – Anticipated routine shutdown and startup of the CO_2 injection in the Arbuckle would offer unparalleled experiments to evaluate the utility of the passive seismic monitoring.
- *Improved understanding of seismicity* -- Monitoring both Mississippian and Arbuckle injections with seismometers, 2D seismic, InSAR will likely be very useful in understanding stress-strain and geomechanical behavior in general associated with the Wellington structure (dome). There is added interest in this monitoring due to the increased seismicity that is occurring in the OK-KS region. This interest spans state, federal, academic, and industry and a proactive response by the DOE-KGS team to address seismicity in addition to fluid monitoring with the seismometer deployment will help the

community understand the mechanisms of the nearly seismic events. Information gained from this project and its predecessor DE-FE0002056 is absolutely critical to KGS and DOE's participation in this discussion.

5. Increased relevancy of this project to the DOE Portfolio

Depositional environment – Marine shelf sandstone (Lower Ordovician Gunter Sandstone) and peritidal shelf carbonate (Lower Ordovician Arbuckle Group). This highly dolomitized aquifer is an archetype example of the peritidal carbonate with #1-32 having cut core from most of the 1000 ft Arbuckle interval and enhanced DOE's portfolio of primary sandstone reservoirs.

Vast storage capacity of the Arbuckle -- Many sites beneath developed oil fields provide infrastructure and potential for improved economics for carbon storage by first taking advantage of incremental oil production gained by injecting CO_2. The existing infrastructure and data used to characterize the oil field markedly reduces the uncertainty for the storage of CO_2. When the oil field sites reach depletion of oil, they could be be converted to saline aquifer storage. Nine sites that lie beneath oil fields in southern Kansas that are very similar to Wellington's geologic setting have been modeled in DE-FE0002056 to evaluate commercial scale (>30 MM tonnes) injection. What is learned in this small scale test could be readily transferred to these other areas.

Order of injection – Injecting in the oil field first is well suited for Kansas and similar oil-rich states due to the widespread distribution of the oil fields across the state and potential economic benefits. This is coupled with the wide expanse of the thick underlying saline aquifer beneath these fields. Thus -

- Kansas needs a successful CO_2 injection into an oil reservoir where data are shared openly with the public to permit better more rigorous scoping models to reduce uncertainties for economic interests and to encourage continued interest and generate new interest by the CO_2 suppliers.
- The Class VI permit is expected in a timeframe that is consistent with the revised schedule for Arbuckle injection following the Mississippian.
- Costs for the Arbuckle injection are avoided until needed after the Class VI is approved and the benefits of the Mississippian injection are realized up front to gain experience, understanding, and set the stage for a successful Arbuckle test.

6. With submittal of the Class VI application, securing CO_2 supply, and level of scientific study related to the Mississippian injection, DOE agreed to proceed with plans for Mississippian injection ahead of the Arbuckle.

A. Addressed concerns about detection of CO_2 plume from injection of 26,300 metric tons of CO_2

2. Seismic detection of the CO_2 injected into the Mississippian reservoir in Wellington Field -- Many examples are available of the high-resolution seismic studies in the literature using the KGS Vibroseis. Also, the recognition by peers attests to the quality of the work by the KGS seismic team under Rick Miller.

3. The KGS successfully obtained a 4D seismic survey using the Vibroseis to monitor a very small scale CO_2 injection (110MMCF, 5810 metric tons) at Hall-Gurney Field in Russell County Kansas. Watney served on this team as a Co-I as the geologist and the work was published and reported on as being able to resolve CO_2 that was injected into a 15 ft thick bed of oomoldic grainstone. The shallow peritidal carbonate is complex, consisting of stacked and shingled ooid shoals that underwent early diagenesis and oomoldic developing that further complicated this reservoir. The high-resolution Vibroseis served as the seismic source that resolved the CO_2 plume. While the project got cut short of injecting the full amount of CO_2 due to extreme budget issues in 2001, the team believed the test was a technical success for such a small scale test.

4. Key observations from the seismic aspect at Hall-Gurney Field include –
   - accurate indication of solvent "CO_2" breakthrough in well 12,
   - predicted delayed response in well 13,
   - interpretation of a permeability barrier between wells 13 and CO2I#1, and

• The final report on Hall-Gurney Field is found at **–**
http://www.kgs.ku.edu/CO2/Reports/Final_Report_March2010.pdf
TITLE: FIELD DEMONSTRATION OF CARBON DIOXIDE MISCIBLE FLOODING IN
THE LANSING-KANSAS CITY FORMATION, CENTRAL KANSAS
DOE Contract No. DE-AC26-00BC15124

B. Seismic detection of the CO_2 injected into the Arbuckle saline aquifer in Wellington Field

-- Based on the previous experience of DOE in other projects, the detection of sub 100,000 metric ton injections of CO_2 have not been detectable using surface-based seismic surveys. This is a concern for both detecting and characterizing the CO_2 plume in both the Mississippian and Arbuckle injections, of 26,357 metric tonnes each. We considered this risk in monitoring reduced amounts of CO_2 and conclude that we will be able to resolve the CO_2 plume via four surface based seismic methods and two downhole seismic methods.

5. The surface based seismic methods include: a) a repeat optimized 1 square mile conventional 3D seismic survey to be used to close the Arbuckle injection, b) if funded in another contract, repeat pseudo VSP surveys of the Arbuckle injection using borehole and surface fiber optic cable using the same high resolution research-grade vibroseis of the KGS as described above, c) 2D seismic surveys using KGS vibroseis to monitor CO_2 injection in the Mississippian, and d) passive microseismic survey using 15 IRIS seismometers and 3 active three-component accelerometers to monitor both the Mississippian and the Arbuckle injections.
6. Two downhole seismic monitoring methods include two crosshole tomography surveys and a series of CASSM surveys, both types as 2D imaging between the Arbuckle injector and nearby observation well.

7. Dense Plume within Arbuckle reservoir— The injection plan has been carefully designed to control and focus plume growth within a permeable flow unit within the Arbuckle in such a way that the highest level of detection will occur with the selected monitoring technology.
8. The perforation depth (4910'-5050' feet) within the injection wellbore targets a narrow interval of the Arbuckle reservoir which has demonstrated higher homogeneity and greater porosity and permeability than surrounding layers. This injection method will encourage growth of a densely saturated CO_2 plume in close proximity to the wellbore, meaning that CO_2 will not be dispersed into thinner stratigraphic units based on extensive whole core Kv measurements, nuclear magnetic resonance logging, and 3D seismic information. Flow unit mapping has been carefully addressed in both the field and regional Arbuckle mapping (contract DE-FE0002056). All modeling simulations have confirmed this behavior, and we can confidently predict that the smaller, dense CO_2 plume will be easily detected by downhole measurements. The injection test will be the means to validate the model. Being a dolomitic carbonate on a structure and results from a 2000 ft horizontal well drilled in the Arbuckle in Bemis-Shutts oil field (DE-FE0004566), fractures are likely to be affecting the plume development and is a topic of keen interest by the team.
9. This level of MVA technology combined with a highly experienced team will provide an unparalleled experiment to demonstrate the performance of the most advanced technologies for monitoring CO_2.
10. A new member of the KGS staff, Tandis Bidgoli, enhances expertise in quantitative structural analysis and geomechanical characterization and modeling.
11. Additional testing as required by EPA will also be performed as described in **Table 1**.

Table 1. Listing of monitoring activities to be conducted at Wellington Field.

Monitoring Activity	Pre-Injection	Injection	Post-Injection
CO_2 Fluid Chemical Analysis	x	x	-
CO_2 Injection Rate and Volume[1]	-	x	-
CO_2 Injection Pressure at Wellhead[1]	-	x	-
CO_2 Injection Pressure at Well Bottom[1]	x	x	x
Internal MIT (Anulus Pressure Test)	x	-	-
External MIT (Temperature Log)	x	x	x
Continuous Annular Pressure	-	x	-
Corrosion	-	x	x
Pressure Fall Off Test	x	-	-
Pressure in Arbuckle Monitoring Well (Direct Arbuckle Monitoring)	x	x	x
INSAR (Indirect Arbuckle Pressure Monitoring)	x	x	x
USDW Geochemistry	x	x	x
Mississippian Geochemistry	x	x	x
U-Tube (Direct Arbuckle Geochemistry Monitoring)	x	x	x
CASSM (Indirect Arbuckle Plume-Front Monitoring)	x	x	x[2]
Crosswell Seismic (Indirect Arbuckle Plume-Front Monitoring)	x	x	-
3D Seismic Survey (Indirect Arbuckle Plume-Front Monitoring)	x	-	x

[1] Monitored continuously
[2] If CO_2 plume is detected at KGS 2-28 during the injection phase, then CASSM will not be conducted during the post-injection phase.

12.

3D multicomponent survey at Wellington

The fold of the multi-component 3D seismic survey at Wellington is around 40 with the spacing of the geophones optimized to resolve the deep reflectors in the Arbuckle. As noted above, this has not compromised resolution in the Mississippian. The quality of the data is very good and with exhaustive well log suites, core, and test data, the behavior of the CO_2 plume should be detected by multiple, independent methods of monitoring as described above.

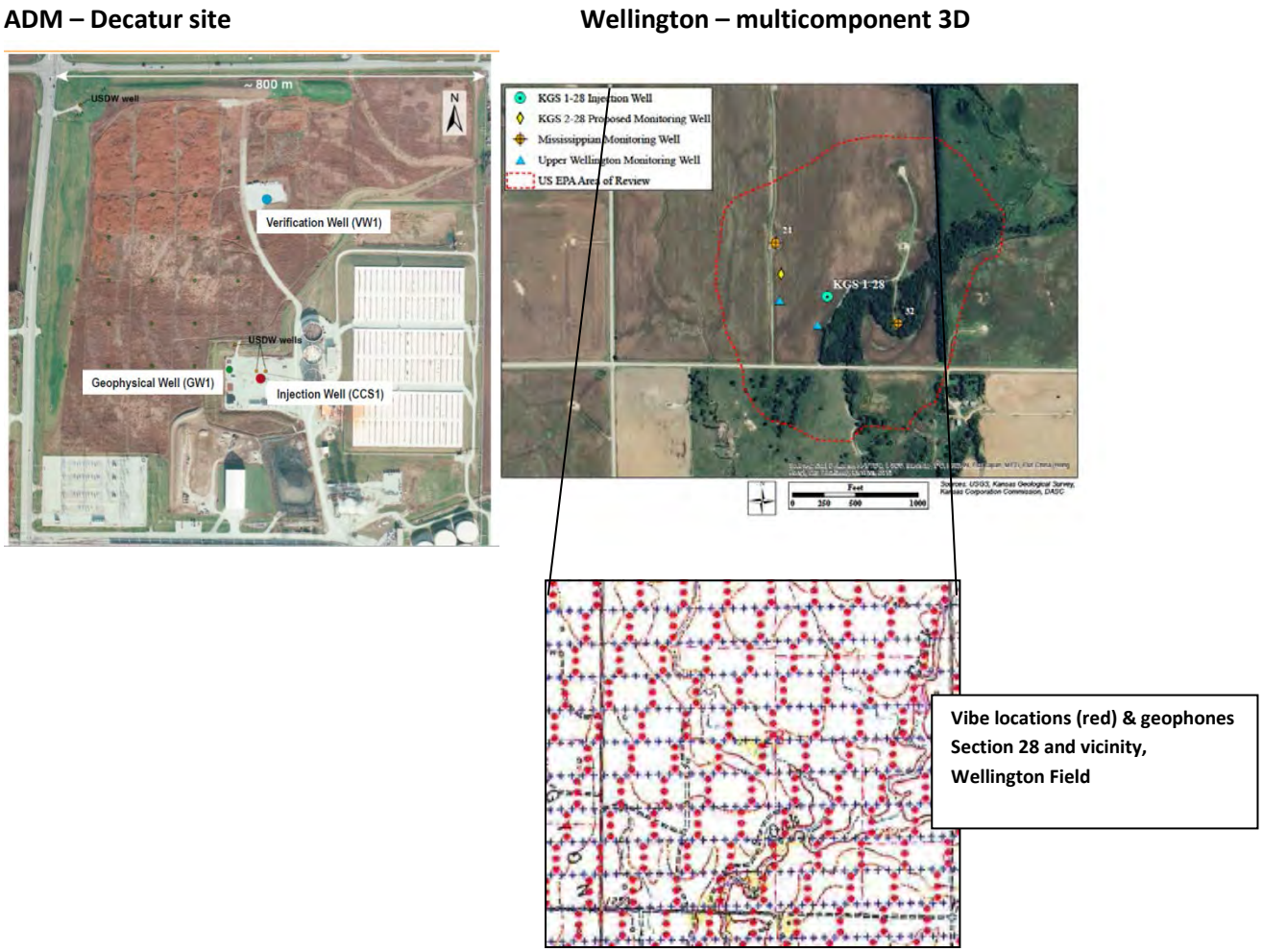


Figure 4. Comparison of the Decatur project injection site and the Arbuckle injection site at Wellington with the seismic acquisition inset for Wellington. Key point -- Land surrounding the Wellington site is almost exclusively used as farmland and is completely undeveloped within the Area of Review.

The 3D multicomponent seismic is "well behaved" and continues to provide valuable information at the attribute and inversion works continues including work on the shear wave data. What is learned can be applied to the repeat 3D multicomponent survey to successfully close the CO_2 injection into the Arbuckle.

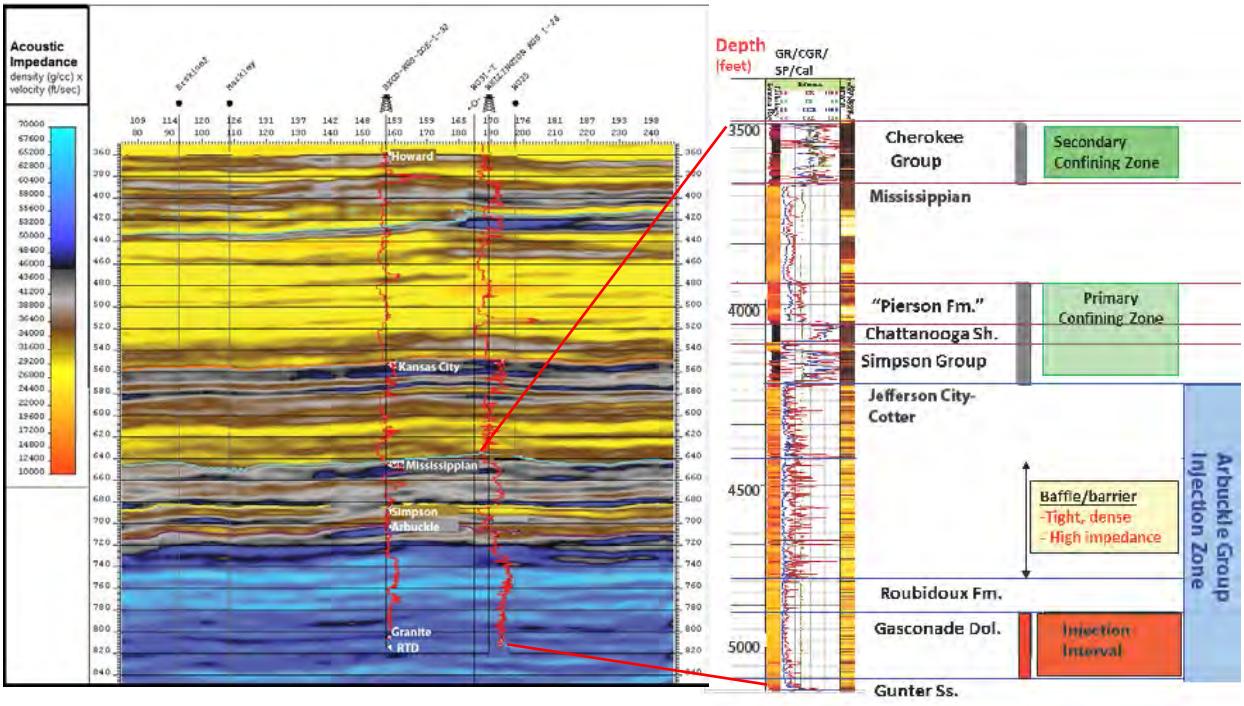


Figure 5. Seismic impedance and stratigraphic profile from well log of the #1-28 injection well at Wellington (information from DE-FE0002056).

The hydrogeologic layer/flow unit that will be perforated to inject CO_2 should allow the CO_2 move in a conformable manner, confined above and below by fluid flow barriers as deemed by core, log, and testing (**Figure 5**).

The simulated plume is based on injection into a confined flow unit based on many lines of evidence. The core-log-seismic calibration gives us confidence of the predicted plume characteristics. The confinement and the expected conformance of the plume to this flow unit will be very important for its seismic detection with multiple surface and subsurface, active and passive seismic sources (**Figures 6 and 7**).

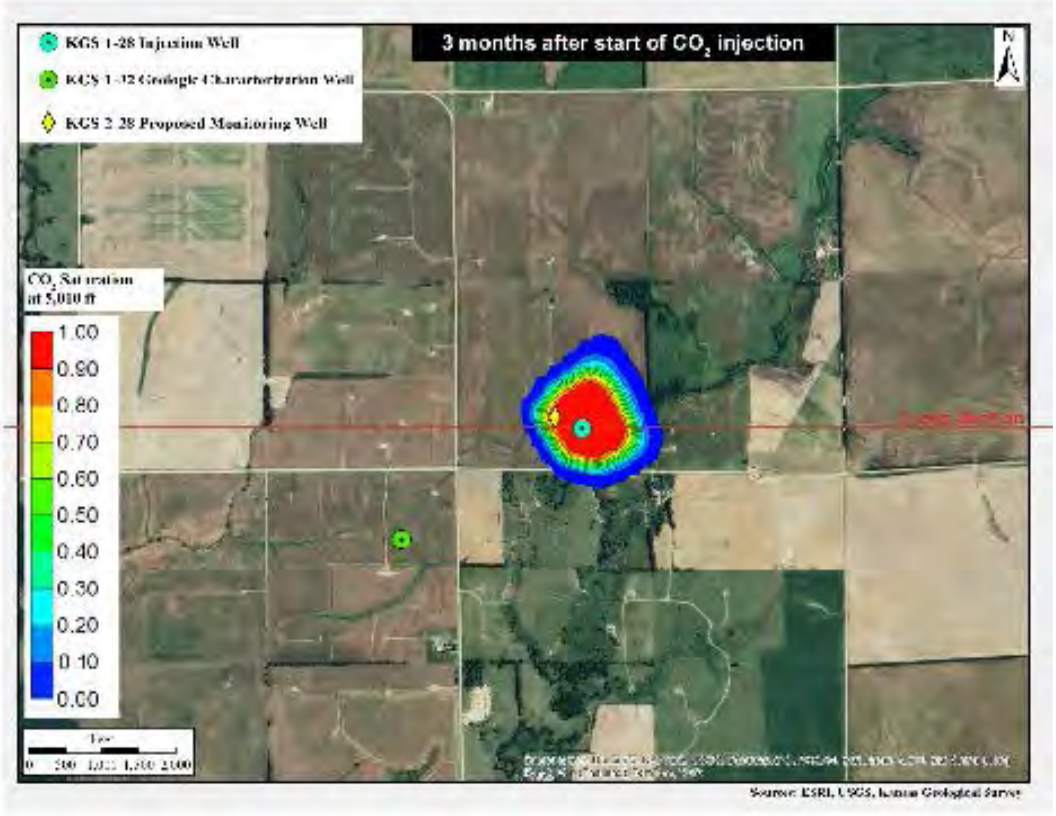


Figure 6. Three months injection at Wellington.

One year of CO_2 injection has a significant area of CO_2 with modeled saturations near one (**Figure 7**). Gassman fluid substitution models indicate gas concentrations need only to be less than 10% to provide seismically resolvable changes in seismic velocity. Resolution of our 3D seismic is adequate to resolve this velocity change and other seismic will also assist the same.

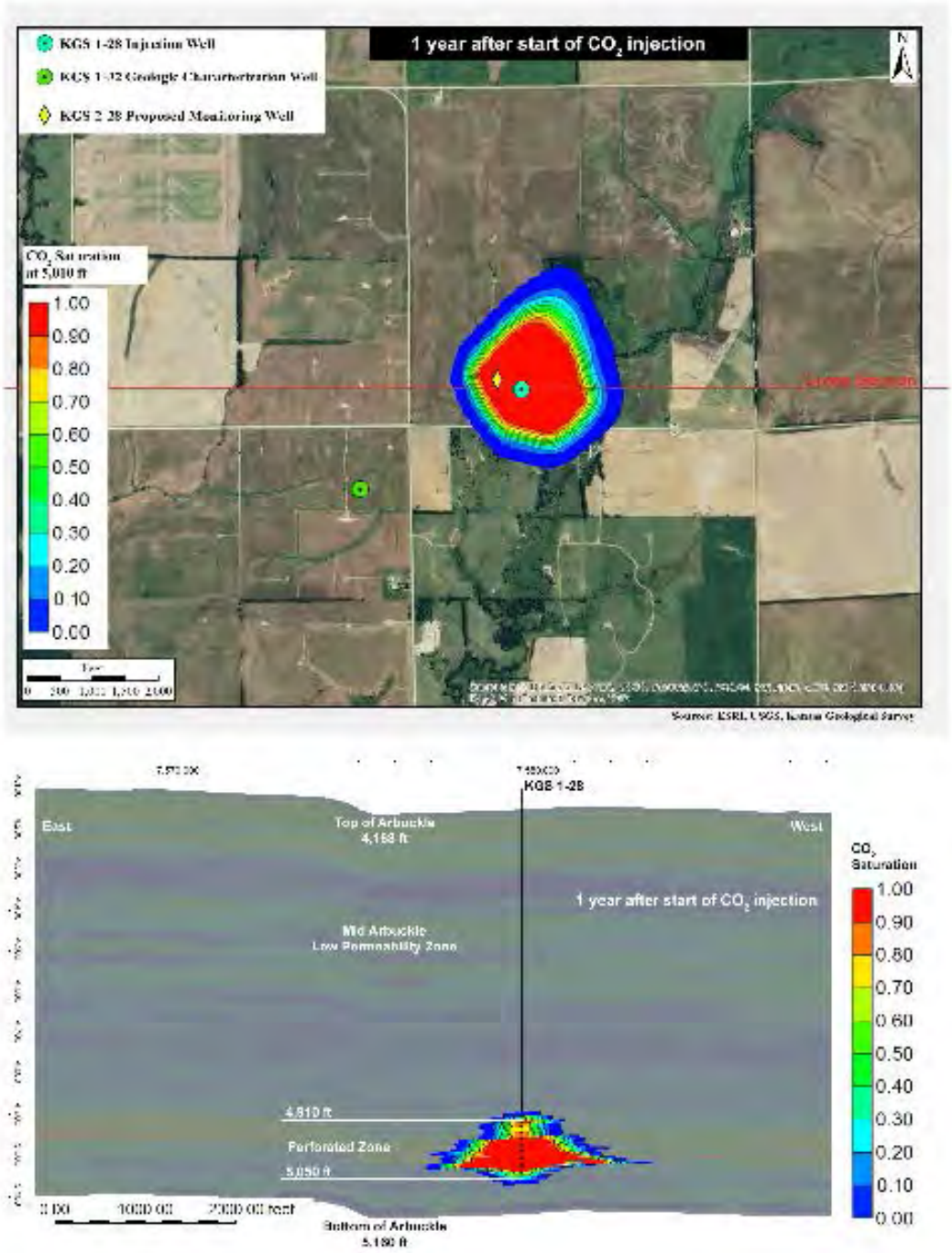


Figure 7. One year of injection of CO2 into the Arbuckle at Wellington.

Seismic resolution at Wellington appear to be considerably greater compared to other projects in the DOE portfolio as attested by results of detailed analysis of the seismic, e.g. the velocity inversion at Wellington in the Mississippian (**Figure 8**). In this example, we are getting a match between seismic well log derived porosity at a resolution of 2 ft!

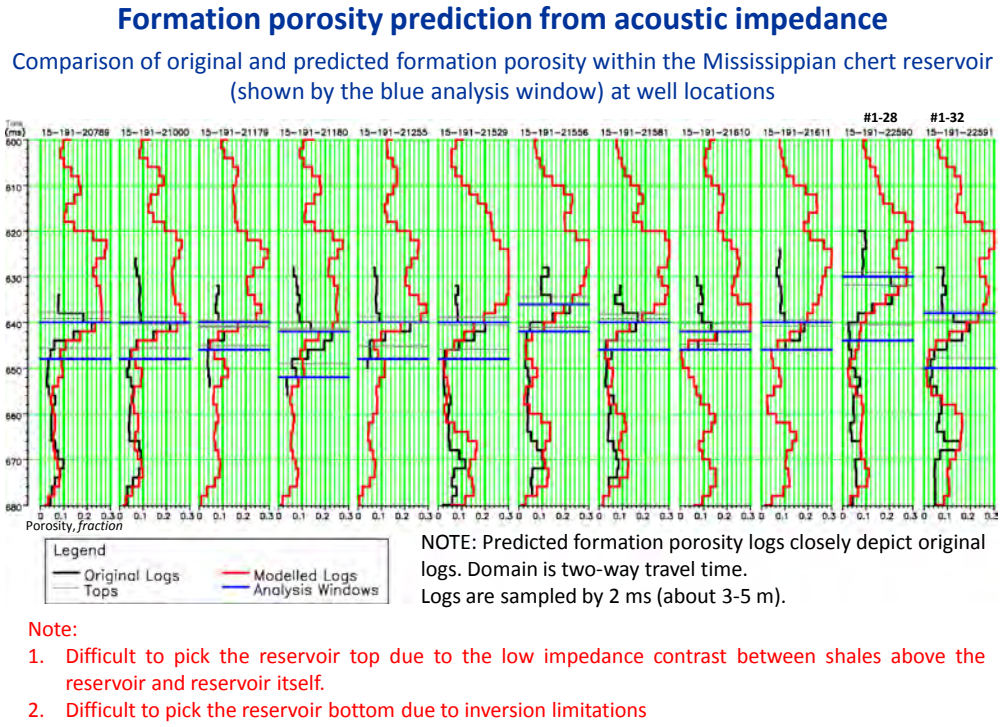


Figure 8. Comparison between seismic and log porosity profiles.

The following is a brief summary of each type of seismic recording to support our conclusion on being able to observe the CO_2 plumes.

A. 1 square mile conventional 3D seismic survey

The conventional 3D survey was acquired by Paragon Geophysical out of Wichita, Kansas with processing done by Fairfield-Nodal in Denver CO office. Fairfield conducted a series of 28 sweep tests before the survey was started to optimize sweep time and frequency range (**Figure 9**) (funded under DE-FE0002056). The field record of Sweep Test #23 was selected for the survey (**Figure 10**).

RECORDING PARAMETERS

SAMPLE RATE	2	ms	
LOW CUT FILTER/SLOPE	3	hz	
ANTI-ALIAS FRQ./SLOPE	187	hz	.8 Nyquist, Linear
PREAMP GAIN	36	db	(G-6)
NOISE EDIT	Diversity Stack		
DATA TO TAPE TYPE	Correlated after stack		
RECORD LENGTH	3	sec	
LINE TYPE	3D		
ACTIVE LINES	18		
ACTIVE CHAN / LINE	64		
MAXIMUM ACTIVE CHAN	1152		
ROLL ON / OFF	Roll on Roll off with 10 Lines live		
RP / SQUARE MILE	346		
RCV LINE INTERVAL	495		
RCV GROUP INTERVAL	165		
TOTAL RCV LINES	49		
TOTAL RCV GROUPS	3822		
RCV ORIENTATION	W-E		
SP/ SQUARE MILE	256		
SRC LINE INTERVAL	660		
SRC POINT INTERVAL	165		
TOTAL SRC LINES	22		
TOTAL SRC POINTS	2825		
SRC ORIENTATION	SW - NE Staggered Brick		
TOTAL SQUARE MILES	11.05		

SOURCE PARAMETERS

ENERGY SRC TYPE	Vibrators	
VIBRATORS		
TYPE / MODEL	ION AHV-I V	
INSTRUMENTS	Pelton - Vib Pro	
HOLD DOWN WEIGHT	60.00	lbs
DRIVE LEVEL	80	%
PHASE LOCK	Ground Force	
FORCE CONTROL	Fundamental Grnd Force	
NUMBER VIBRATORS	2	
PATTERN	40 ft. centered on stake	

SWEEP

NUM. SWEEPS	2	
MOVE UP	Stacked	
START FREQ.	6	hz
END FREQ.	150	hz
SWEEP LENGTH	40	sec
NON LINEARITY	+3db/oct	post corr.
START TAPER	300	ms
END TAPER	300	ms



40 ft

One copy of field data to:

Lynn Watney
Kansas Geological Survey
1930 Constant Avenue - Campus West
The University of Kansas
Lawrence, KS 66047
Ph: 785-864-2184

PROCESSING

Fairfield Industries
1776 Lincoln St. #1200, Denver, CO 80203
Attn: Bruce Karr 720-963-2119
bkarr@fairfield.com

Echo Geophysical Corporation
1999 Broadway, # 3100, Denver,CO 80202
Attn: Rick Steineck 720-528-9299
rsteineck@echogeo.com

Figure 9. Configuration selected for the original 3D seismic acquisition for Wellington Field.

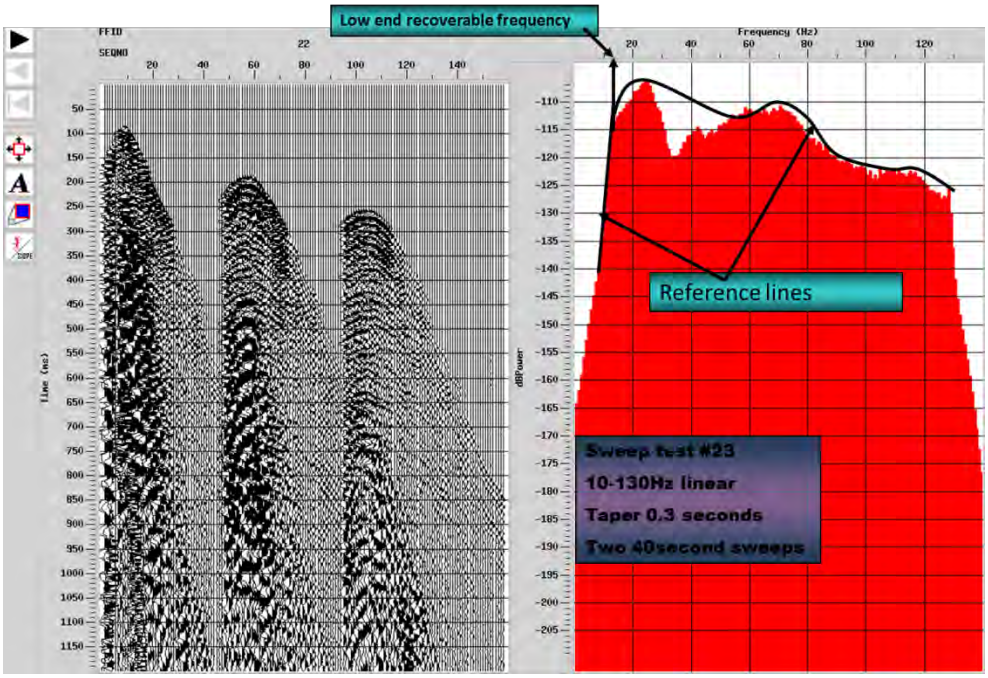


Figure 10. Sweep test used in the original 3D seismic survey at Wellington.

The extended sweep test to establish the best design for the 3D survey involved a team who are intimately familiar with the geophysical framework, working daily in Kansas with the local petroleum industry. The team knew that this was to be a showcase for the quality of work that they routinely conduct in this region.

A fluid substitution was used with log derived impedance to examine whether CO_2 could be observed in the Arbuckle using parameters of the conventional repeat 3D seismic survey as described above. The fold map of a 1-mile square 3D survey is shown in **Figure 11**. This seismic survey is expected to have at least 20-fold data up to 1320 ft from the CO_2 injection well and 49 fold at the center. Increasing the size of the 3D survey will bring the fold of the area encompassed by the plume to full fold or ~46 fold as the original multi-component 3D survey. The level of this fold is important since it has led to a solid baseline seismic survey that has been used to build our geomodels and simulation. This is not a partial 3D survey with data gaps or a low fold VSP, so it is not easy to compare our results with other projects unless we sort out the details of the seismic utilized starting from the ground up.

In addition, the 3D survey was a multi-component acquired with digital 3-component geophones. The repeat 3D survey will be acquired in exactly the same manner and processed for the converted (shear wave). The presence of CO_2 will be further resolved with ongoing analysis of Vs/Vp ratio and AVO (under DE-FE0002056). Moreover, the dynamics of the CO_2 behavior will likely have an opportunity to be resolved with this kind of acquisition and processing. It should be noted that the basis for the multi-component survey was the use of 4D, multi-component acquisition in Vacuum Field in New Mexico that was used image the CO_2 movement and distinguish fracture vs. matrix flow. This research was conducted by Tom Davis' Reservoir Characterization Project (http://rcp.mines.edu/) at Colorado School of Mines. Their go-to acquisition company is the same Wichita-based company, Paragon, that was contracted for Wellington and Cutter fields 3D multi-component surveys in DE-FE0002056. We consulted with CSM before we deployed and it is no accident that we have a reliable seismic acquisition group.

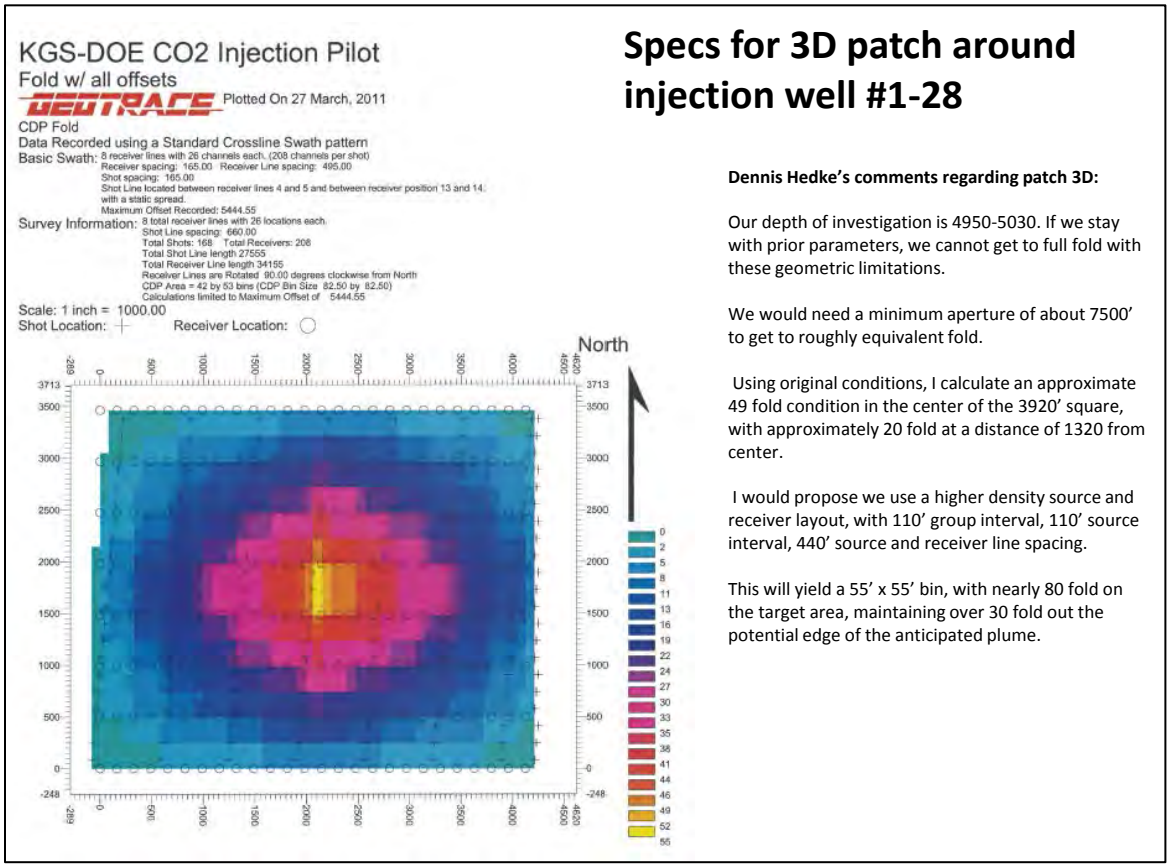


Figure 11. Fold map used to plan the repeat 3D seismic survey to image the Arbuckle CO2 plume.

The fluid substitution was accomplished by using Gassman equation ranging the gas composition between zero and 50% saturation. The seismic impedance was calculated using the well log data of KGS #1-32 at Wellington. **Figure 12** shows the changing velocity as gas is substituted in the injection interval in the lower Arbuckle at a depth of 4950 and 5053. It is primarily the lower portion of the injection interval near 5000 ft that undergoes a most reduction in velocity as the gas concentration is increased to 50% illustrated as a

brightening (**Figure 12**)

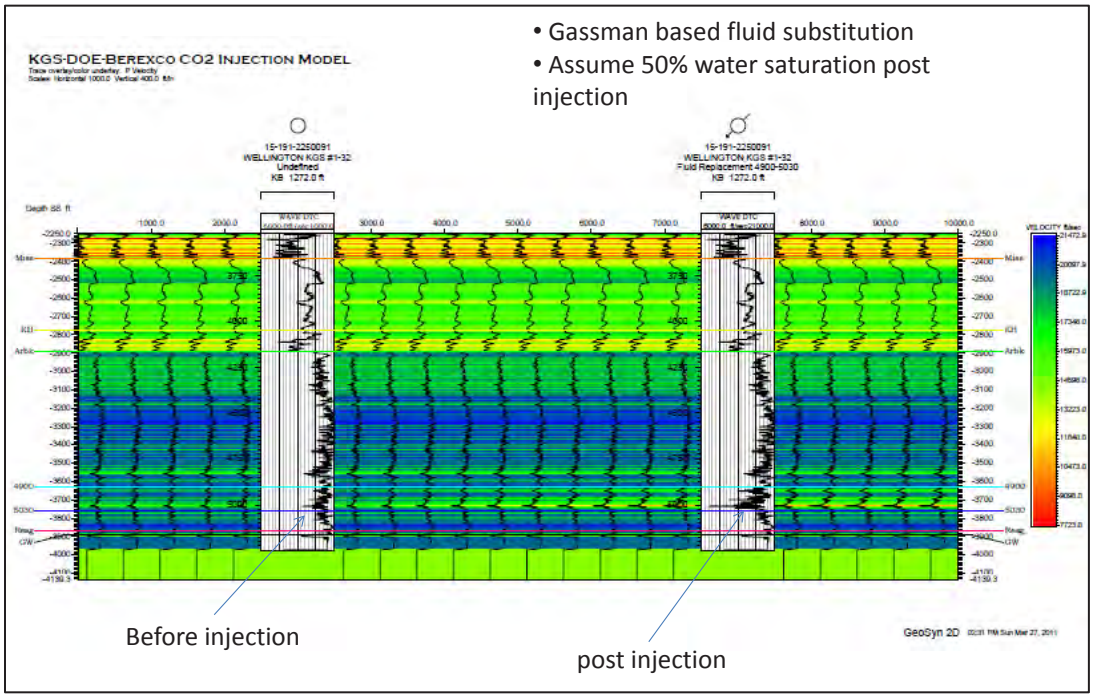


Figure 12. Velocity structure from sonic log in well #1-32 focused on the Arbuckle interval as the injection interval (4950-5030) underwent substitution of brine to 50% gas moving from left to right side of the illustration. Note brightening toward the right corresponding to a decrease in the velocity of the injection interval.

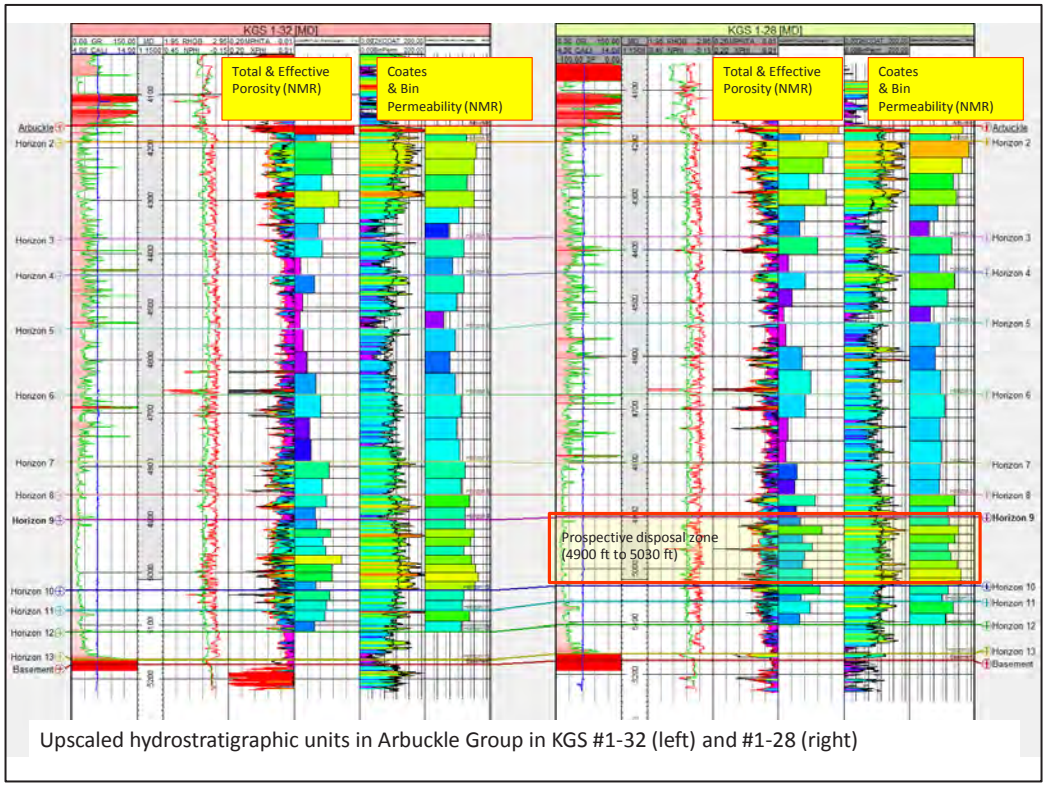


Figure 13. Stratigraphic well log cross section between wells #1-32 and #1-28 highlighting the injection interval in the lower Arbuckle. NMR derived porosity and permeability clearly identify the injection interval.

The injection interval has the largest pores including vugs that have been documented in core, well logs, and whole core analysis (**Figure 13**). Water chemistry indicates that the brine in the injection unit is distinct and a separate hydrostratigraphic unit from overlying strata and we have some certainty that cross flow and migration of the CO_2 injected into this interval will not occur.

The isolation of the injection interval in the timeframe of this small scale test is further indicated by the seismic data showing a higher impedance/baffle interval that continuously overlies the injection zone in the area of the injection well. An arbitrary section through the 3D survey showing seismic impedance illustrates this relationship (**Figure 14**). We anticipate conformance and a plume that is rather well behaved, vs. a less confined diffuse vertically migrating plume. The choice of the injection interval is clear - a) perforate an interval that should concentrate the CO_2, b) optimize for conformance so that CO_2 plume has best opportunity to be predicted and to be seen with the monitoring methods including seismic.

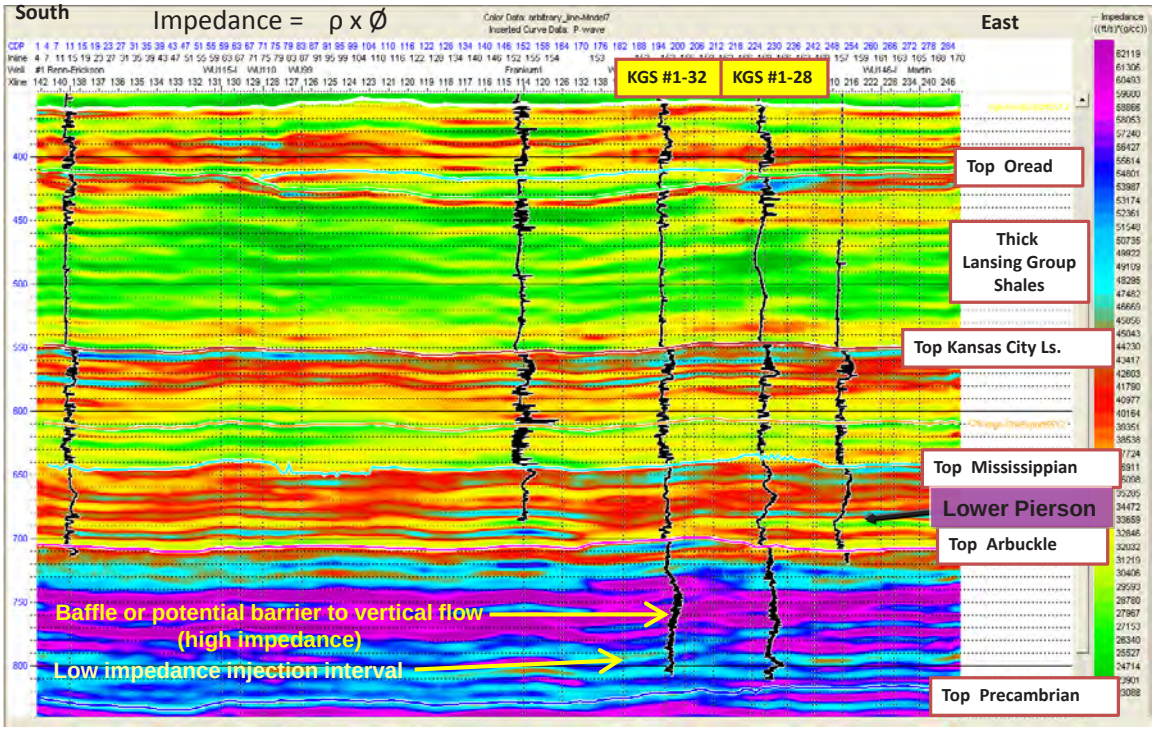


Figure 14. Arbitrary section showing impedance inversion for Wellington 3D seismic. Note the clear distinction and continuity of the injection zone and the overlying baffle/barrier.

Key Findings

1. Highly constrained integrated Petrel model and CMG simulations and a skilled research team (KGS and beyond) with expertise in geology, engineering , and geophysics working with high quality data
    a. Well suited to conducted experiments directed toward next generation CO_2-EOR in smaller (<50 million bbls) carbonate reservoirs common to the upper Midcontinent.
    b. Utilization of very high resolution seismic from KGS vibroseis to image the smaller quantities of CO_2 utilizing a solid multicomponent 3D survey as the baseline.
    c. Will deploy the passive seismic monitoring before BP2 begins for dual purpose --
        i. installing three 3-component accelerometers purchased with KGS funds to aid in detecting CO_2 and provide unique potential to adjust the CO_2 flood in real-time; also staff to handle data being hired by KGS (unique timely leveraging and commitment)
        ii. Use of 15 IRIS seismometers and 3 accelerometers to understand the recent increase in earthquake activity in the area, integrate data with the existing seismic network coordinating with USGS, state agencies, and Oklahoma Geological Survey; provide knowledge and insights to improve the science
2. Unique integration of Wellington Field with the Kansas CO_2 Initiative engaging the entire community – petroleum industry, CO_2 suppliers, lawmakers and regulators – over the course of the next year with Wellington Field serving as the focal point
    a. Use of Wellington Field as a calibration site and field demonstration to engage petroleum industry in overcoming need and requirements in use of anthropogenic sources of CO_2
    b. Test best practice, cost-effective monitoring to aid in applying next-generation CO_2-EOR methods, refine model predictions, and to permit CO_2 use to be optimized for CO_2 sequestration
    c. Uniquely couple the oil field and the underlying saline aquifer to increase the CO_2 sequestration capacity using Wellington to help calibration with Cutter field, 8 other sites in Kansas being completed in DE-FE0002056.

Plans for Third Quarter 2014 (anticipated start of BP2, September 1, 2014)

Begin field activities as per revised schedule shown in **Figure 15**.

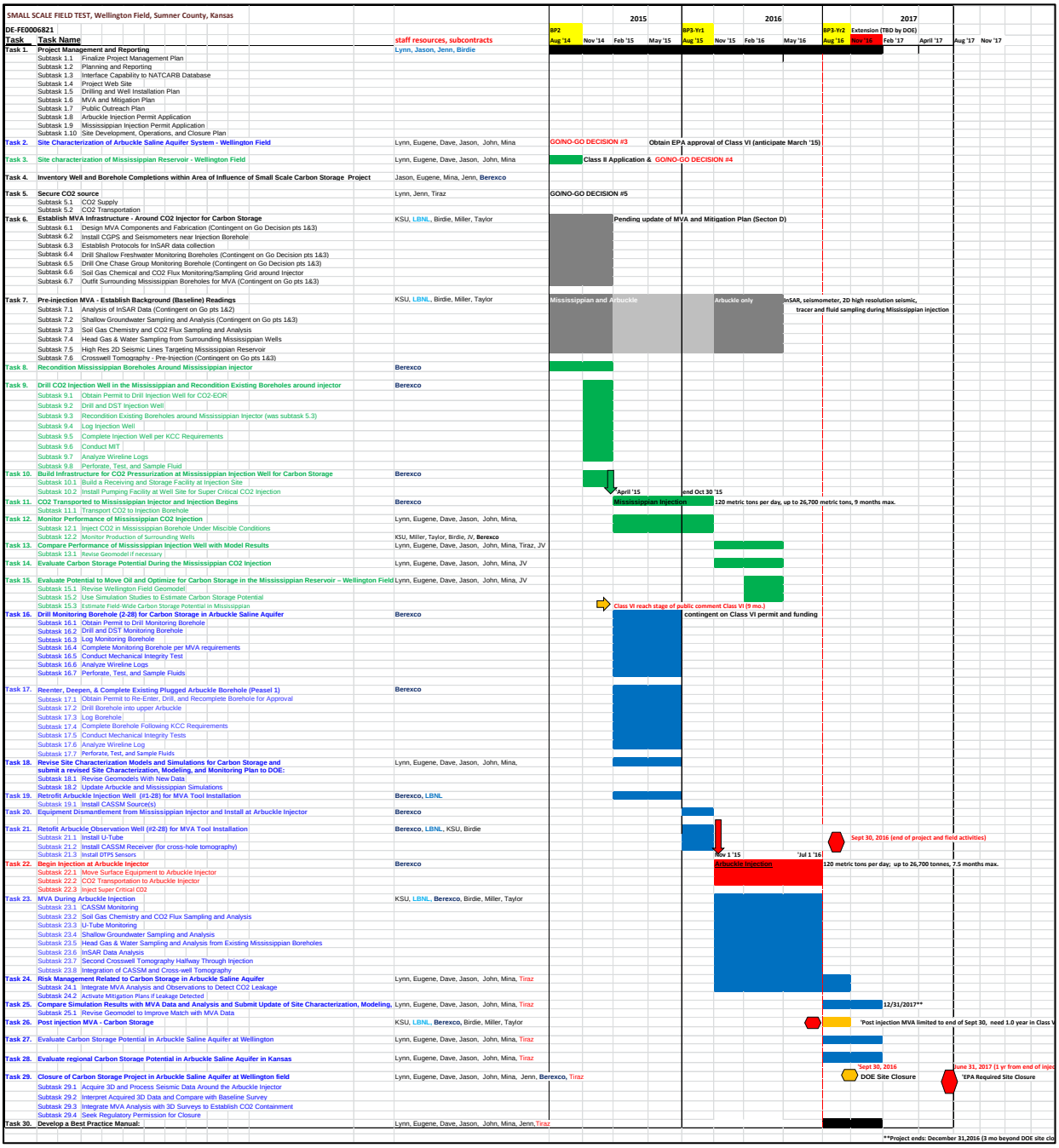


Figure 15. Revised Gantt chart.

PRODUCTS

Publications, conference papers, and presentations

Papers were presented in Lawrence at an industrial associates meeting. In addition, the Wellington KGS #1-32 core was displayed and discussed. Presentations included:

Jason Rush --"Basement-Rooted Faults, Paleokarst, and Mississippian Flexures: A Compelling Story for PSDM Seismic Volumetric Curvature

Jason Rush -"The Mississippian at Wellington and Development of a Middle Eastern Giant (Idd El Shargi Field)

W. Lynn Watney, Jason Rush, John Doveton, Mina Fazelalavi, Eugene Holubnyak, Bob Goldstein, Brad King, Jen Roberts, David Fowle, Christa Jackson, George Tsoflias, et al., Overview, current research, and major findings for two long Paleozoic cores – Berexco Wellington KGS #1-32, Sumner County, KS and Berexco Cutter KGS #1, Stevens County, Kansas

W. Lynn Watney, Jason Rush, John Doveton, Mina Fazelalavi, Eugene Holubnyak, Bob Goldstein, Brad King, Jen Roberts, David Fowle, Christa Jackson, George Tsoflias, et al., Overview, current research, and major findings for two long Paleozoic cores – Berexco Wellington KGS #1-32, Sumner County, KS and Berexco Cutter KGS #1, Stevens County, Kansas - four posters (2 each for Wellington and Cutter)

Mina Fazelalavi, W. Lynn Watney, John Doveton, Mohsen Fazelalavi, and Maryem Fazelalavi - Determination of Capillary Pressure Curves in the Mississippian Limestone, Kansas

Yousuf Fadolalkarem and George Tsoflias - Pre-stack Seismic Attribute Analysis of the Mississippian Chert and the Arbuckle at the Wellington Field, South-central Kansas

Christa Jackson, David Fowle, Brian Strazisar, W. Lynn Watney, Aimee Scheffer, and Jennifer Roberts - Geochemical and Microbiological Influences on Reservoir and Seal Material During Exposure to Supercritical CO2, Arbuckle Group, Kansas
Luis Montalvo, Luis Gonzalez, Lynn Watney, Diagenesis and distribution of diagenetic facies in the Mississippian of south-central Kansas

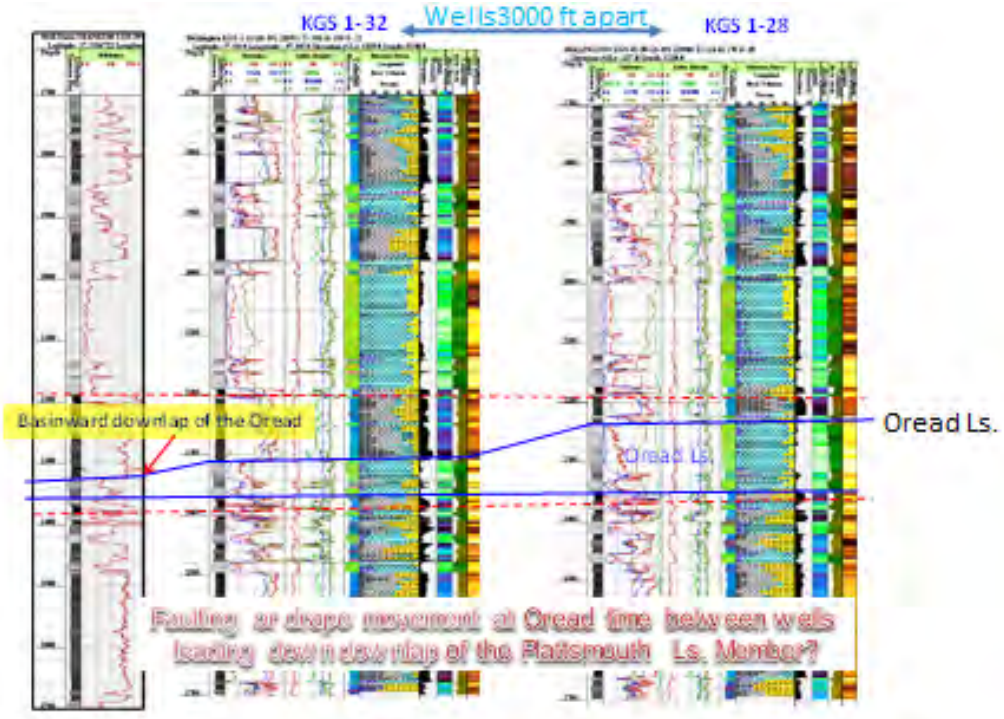
Bradley King and Robert Goldstein -- Controls on Hydrothermal Fluid Flow and Porosity Evolution in the Arbuckle Group and Overlying Units (3 panels)

Presentation at Geological Society of America, Regional Meeting (April 2014) – illustrating the stratigraphic and sedimentologic effects of episodic structural movement at Wellington Field:

DOVETON, John H., Kansas Geological Survey, University of Kansas, 1930 Constant Ave, Lawrence, KS 66047, doveton@kgs.ku.edu, MERRIAM, Daniel F., University of Kansas, 1930 Constant Ave, Campus West, Lawrence, KS 66047, and WATNEY, W. Lynn, Kansas Geological Survey, Univ of Kansas, 1930 Constant Avenue, Lawrence, KS, 66047, 2014,

Petrophysical Imagery of the Oread Limestone in Subsurface Kansas, Paper #237642, 48th Annual Meeting, North Central Geological Society of America, Program With Abstracts. (Episodic nature of structural activity at Wellington Field)

The Oread Limestone is recognized widely as an archtypal Pennsylvanian cyclothem that has been investigated extensively over its eastern Kansas outcrop for more than a century. Knowledge of the geology of the Oread in the subsurface has been restricted almost entirely to drill-cuttings, while wireline logs have provided the correlative framework for mapping structure and thickness. The curves of traditional logs are the time-honored medium for correlation, but the rich data of more recent petrophysical measurements are presented increasingly as image logs which portray geology in novel ways. FMI logs are conversions of multiple microresistivity curves into a high-resolution conductivity image of the borehole wall. MRI logs measure magnetic resonance relaxation times that are presented as contour map images of pore-size distribution. Natural and capture gamma-ray spectra logs estimate elemental concentrations of potassium, thorium, uranium, calcium, magnesium, titanium, aluminum, iron, sulfur, and manganese. Interpretations of these logs in the Oread in south-central Kansas present new opportunities in Pennsylvanian cyclothem research that can be integrated with conventional outcrop studies. As a case in point, log imagery of the anomalously thick and variable "Super-Plattsmouth" regressive limestone (anomalously thick and variable) in Sumner County provides intriguing insights into mound internal architecture (**Figure 16**).



Log cross section is located along similar location as the preceding seismic image.
Note downlapping carbonate and thickening of the overlying shale.

Figure 16. Notable changes in stratigraphy at the Oread Limestone horizon. Paper describes differences between the two wells in the Oread Limestone and overlying Kanwaka Shale.

National Groundwater Association Groundwater Summit

Watney, W.L., 2014, Integrating Modern Suite of Geophysical Logs, Geochemistry, and Seismic Data for Characterizing Deep Aquifers, NGWA Conference on Characterization of Deep Groundwater, May 8, 2014

Watney, W.L., 2014, Using Drill Stem Test Data to Construct Regional Scale Potentiometric Surface in Deep Aquifers, NGWA Conference on Characterization of Deep Groundwater, May 8, 2014

Tiraz Birdie, TBirdie Consulting, Inc., Lawrence, KS, W. Lynn Watney, Ph.D., Kansas Geological Survey, University of Kansas, Lawrence, KS and Paul Gerlach, Charter Consulting, Miramar, FL, Using Drill Stem Test Data to Construct Regional Scale Potentiometric Surface in Deep Aquifers, NGWA Conference on Characterization of Deep Groundwater, May 8, 2014

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

A project organization chart follows (**Figure 17**). The work authorized in this budget period includes office tasks related to preparation of reports and application for a Class VI permit to inject CO_2 into the Arbuckle saline aquifer. Tasks associated with reservoir characterization and modeling are funded in contract DE-FE0002056.

ORGANIZATION CHART

Name	Project Job Title	Primary Responsibility
Kansas Geological Survey		
Lynn Watney	Project Leader. Joint Principal Investigator	Geology, information synthesis, point of contact
Yevhen Holubnyak	Petroleum Engineer	Reservoir engineer, dynamic modeling, synthesis
Jason Rush	Joint Principal Investigator	Geology, static modeling, data integration, synthesis
John Doveton	Co-Principal Investigator	Log petrophysics, geostatistics
Dave Newell	Co-Principal Investigator	Fluid geochemistry
Rick Miller	Geophysicist	2D seismic acquire & interpretation
		LiDAR/InSAR support, water well drilling/completion
TBN	Geology Technician	Assemble and analyze data, report writing
Tiraz Birdie	President, TBirdie Consulting, Inc.	Hydrogeologic modeling, permitting, MVA, integration
KU Department of Geology		
Michael Taylor	Co-Principal Investigator	Structural Geology, analysis of InSAR, LiDAR, seismometer array
TBN	Graduate Research Assistant	Structural Geology, analysis of InSAR and LiDAR, seismometer array
Kansas State University		
Saugata Datta	Principal Investigator	
TBN	Graduate Research Assistant	Aqueous geochemistry
TBN	3- Undergraduate Research Assistants	
Lawrence Berkeley National Laboratory		
Tom Daley	Co-Principal Investigator	Geophysicist, analysis of crosshole and CASSM data
		Hydrogeology, analysis of soil gas measurements
Barry Freifeld	Co-Principal Investigator	Mechanical Engineer, analysis of U-Tube sampler
Sandia Technologies, Houston		
Dan Collins	Geologist	Manage CASSM and U-Tube operation
David Freeman	Field Engineer	Manage field install of CASSM and U-Tube
Berexco, LLC		
Dana Wreath	VP Berexco, LLC	Engineering, Manager of Wellington Field
Randy Koudele	Reservoir engineer	Engineering
Staff of Wellington Field		Field operations
Beredco Drilling team		Mississippian and Arbuckle drilling operations
Abengoa Bioenergy Corp.		
Christopher Standlee, Danny Alllison		CO_2 supply Colwich Ethanol Facility

Figure 17. Organizational Chart.

IMPACT

See earlier discussion.

CHANGES/PROBLEMS

Please refer to earlier discussion.

BUDGETARY INFORMATION

Cost Status Report

See figure on the following page for the cost status for quarters 1-9.

APPENDIX A

PUBLIC OUTREACH PLAN

To

DOE-NETL
Brian Dressel, Program Manager
Award Number: DE-FE0006821

SMALL SCALE FIELD TEST DEMONSTRATING CO_2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO_2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS

Project Director/Principal Investigator:

W. Lynn Watney
Senior Scientific Fellow
Kansas Geological Survey

Ph: 785-864-2184, Fax: 785-864-5317
lwatney@kgs.ku.edu

Joint Principal Investigator:
Jason Rush

Prepared by Lynn Watney and Tiraz Birdie
Date of Report: August 7, 2014
DUNS Number: 076248616

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

Project/Grant Period: 10/1/2011 through 9/30/2016

Signature of Submitting Official:

W. Lynn Watney Digitally signed by W. Lynn Watney
DN: cn=W. Lynn Watney, o=The University of Kansas, ou=Kansas Geological Survey, email=lwatney@kgs.ku.edu, c=US
Date: 2014.09.04 20:26:58 -05'00'

Tiraz Birdie[1], Jennifer Raney[2], and Lynn Watney[2]

Executive Summary

A Public Outreach Plan has been developed for the Wellington project with the goal of establishing communication between KGS and the host community in order to provide a means to solicit community input, build trust, and assure the general public and all stake holders that the project will be executed safely and responsibly.

The outreach activities and communications will be conducted through the project web site, project fact sheet, technical publications, site visits, tours, workshops, community events, and open houses. Key constituents include public officials, legislators, environmental regulators, business interests, landowners and neighbors, civic groups, educators, and the media. All communication with the stakeholders will be managed by the project's Principal Investigator, Lynn Watney. The Principal Investigator of the project, Lynn Watney, has already conducted several meeting with citizens and legislators to inform them of the proposed project. He has met separately with the Kansas Governor, Kansas state representative, officials of the Kansas Department of Commerce, and the general public and local officials at the proposed injection site. Additionally, a number of technical presentations have been and workshops held to inform the scientific and technical communities of the project goals and benefits.

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Public Outreach Plan

1. Introduction

Public outreach is an integral part of the Wellington CO_2 project. Being a federally funded pilot project, KGS intends to follow all guidelines in the DOE/NETL publication, Best Practices for Public Outreach and Education for Carbon Storage Projects (DOE, 2009). The goal of the outreach program is to establish communication between KGS and the host community in order to provide a means to solicit community input, build trust, and assure the community that the project will be executed safely and responsibly. Specific goals include:

- Educate citizens how CO_2 storage works, how it can contribute to global climate change mitigation, and that the project is part of a national strategy to reduce greenhouse gas emissions.
- Assure the community that KGS and the project operator, Berexco, have the appropriate expertise to safely execute the project.
- Allow the public to express their views.
- Proactively and constructively address community concerns.

2. Outreach Team

All communication with the stakeholders will be managed by the project's Principal Investigator, Lynn Watney. Project team members, Jennifer Raney and Tiraz Birdie, along with the KGS document production staff will assist in preparing the necessary outreach material, conducting surveys with stakeholders, and other outreach activities.

3. Key Outreach Messages

The Principal Investigator of the project, Lynn Watney, has already conducted several meeting with citizens and legislators to inform them of the proposed project. The key messages that are being communicated include:

- There is a well understood approach to site selection and characterization to ensure that geologic conditions are suitable for long term storage without leaks.
- Why Wellington, KS is a safe place to store CO_2.
- Standard practices will be followed to guarantee safety and to ensure that CO_2 storage will not cause harm to health or jeopardize the environment.
- How a computer simulation of the Wellington Field subsurface is developed, validated, and calibrated, and what simulated CO_2 injection results indicate.

- Role of EPA in overseeing/regulating CO_2 storage.
- Potential costs and benefits to the community from CO_2 storage.
- Natural geologic CO_2 storage has occurred for millions of years.
- Engineered geologic storage of CO_2 has been safely practiced for 40 years. Over three billion cubic feet (176 thousand metric tons) of natural CO_2 is injected daily into west Texas oil fields to recover additional oil. The limited supply of natural CO_2 hinders expansion of this technology in Kansas, and the use of anthropogenic and largely ignored CO_2 is a natural next step.
- Injection and reservoir monitoring are mature technologies. The experience in the oil and gas exploration and development industry is being used to ensure sequestration success. Injection and reservoir management in Kansas oil fields has been ongoing for decades since oil production peaked in 1956.
- There are similarities between the major expansion of oil and natural gas systems after World War II with respect to pipeline and natural gas storage, and the expected deployment of CO_2 storage projects.

4. Methods of Communication

4.1 Project web site

In order to facilitate the outreach efforts, KGS has developed a dedicated web site for the project (http://www.kgs.ku.edu/PRS/Ozark/small_scale.html). In addition to a planned future Outreach page, the web site also contains geologic characterization data, model simulation results, permit documents, and compliance documents submitted to the EPA.

4.2 Printed Project Fact Sheet

A project fact sheet is under preparation which will emphasize the following:

- project goals emphasizing small pilot-scale test and DOE collaboration,
- project team partners,
- how CSS works – invoking the analogy with safe natural gas storage over millennia,
- why the site has necessary geologic characteristic for successful storage – multiple confining zones, a porous injection zone, and absence of open faults and fractures in the caprock,
- preliminary modeling results and the small footprint of the of the plume,

- implausibility of CO_2 escaping into shallow aquifers or atmosphere,
- the depleted Mississippian oil and gas reservoir above the Mississippian providing an additional level of protection against CO_2 escape in the unlikely event of caprock breach,
- EPA oversight and regulatory compliance – EPA permitting process -transparent collaboration between KGS/Berexco and EPA,
- Extensive and state of the art monitoring of plume movement, pore pressures, and seismic activity in order to ensure safety and regulatory compliance,
- post-injection site care and site closure plan,
- emergency remedial response plan,
- project timeline,
- economic benefits of CCS and EOR,
- planned outreach activities, and
- Frequently Asked Questions

4.3 Web Based Project Fact Sheet

The web based project fact sheet will be the same as the printed fact sheet except that it will have more details, videos, interactive features, and frequently asked questions section.

4.4 Technical Publications and Presentations

KGS plans to publish at least four publications annually in peer reviewed scientific/technical journals, and make four presentations annually at technical conferences. The goal of these efforts will be to disseminate project findings during the pre-injection, injection, and post-injection phases.

4.5 Site Visits, Tours, Workshops, Community Events, and Open Houses

Workshops and other outreach events will be held periodically to inform the public, academic community, and stake holders of the objectives and benefits of CCS and progress on the Wellington project.

5. Project Stakeholders

Key constituents include public officials, legislators, environmental regulators, business interests, landowners and neighbors, civic groups, educators, and the media.
The following stakeholders have been identified who may be most affected and interested in the project operations and outcome.

Elected Officials	Kasha Kelly (KS State Representative - District 80) Steve Abrams, (KS Senate – District 32) Mike Pompeo, (US House of Representatives, District 4) Jerry Moran (US Senate) Pat Roberts (US Senate) (Mayor - Wellington)	kasha.kelley@house.ks.gov Steve.Abrams@senate.ks.gov (202) 225-6216 (202) 224-6521 (202) 224-4774
Safety Officials	Bill Hellard (City of Wellington Safety Officer); James Fair, Sumner County Emergency Management	620-326-7376, jfair@co.sumner.ks.us
Environmental Regulators	Mike Tate, Chief, Bureau of Water (Kansas Department of Health and Environment) Thomas Day, Acting Executive Director, (Kansas Corporate Commission) Kurt Hildebrandt, (US EPA Region 7 UIC Director)	(785)296-5500, mtate@kdheks.gov (785) 271-3190; District 2, (316) 630-4000 (913)-551-7413
Business Community	Shelley Hansel-Williams (Wellington Chamber of Commerce	
Media	James Jordan (Wellington Daily News)	
Land Owners/ Farmers		
Law Enforcement	Darren Chambers (Sheriff)	
Emergency Organizations	Jay Fair (Sumner County Emergency Management)	219 W 8th St, Wellington, KS 67152 jayfair@co.sumner.ks.us
Environmental Groups	Clean Air Task force: Dr. Bruce Hill	bruce@catf.us (603)466-2448 sanderson@environmentaldefense.org

	Environmental Defense fund: Scott Anderson Natural Resources Defense Council: George Peridas	(512) 699-1077 gperidas@nrdc.org (415) 875-6181
Economic Development	Kansas Independent Oil and Gas Association (KIOGA); Kansas Geological Society	
Oil and Gas Operators	Kansas Independent Oil and Gas Association (KIOGA); Kansas Geological Society	
US Department of Energy	Brian Dressel	Brian.dressel@netl.doe.gov
Education Groups	(KU, WSU, Kansas State U., Emporia State U.)	
Geologic Interest Groups	Kansas Geological Society, Wichita Chapter of Society of Petroleum Engineers	

6. Completed Outreach Activities

6.1 Meeting with Legislators

The Wellington project PI, Lynn Watney, met with Kansas House Energy and Utilities in Topeka in 2012 and 2013 on the topic of carbon management in Kansas.

6.2 Meeting with Kansas State Governor

Lynn Watney met with the governor of Kansas in December 2013 to discuss reception for a Governor's Conference on "Implementing CO2 Utilization and Storage (CCUS) in Kansas" Follow up meeting in February 2014 with Kansas Department of Commerce on Governor's Conference with decision to first meet with stakeholders to establish level of interest and to demonstrate positive results with CO_2-EOR test at Wellington Field.

6.3 Meeting with Stakeholders

The above meeting with stakeholders will be conducted once Wellington test begins in anticipation of the CO_2 injections. Information contacts with stakeholders have been gained through meetings with CO_2 suppliers and petroleum industry representatives and also through presentations and short courses conducted by Watney.

6.4 Publications in Technical Journal

Several papers pertaining to the implementation of the monitoring and plans for small scale injections at the Wellington project will be published in technical journals and publically accessible media.

6.5 Presentations at Scientific Conferences

The Wellington project team has made the following presentations about the suitability of the site for CSS purposes based on detailed characterization of the injection zone and caprock, and associated computer model simulation results:

NETL Carbon Storage R&D Meeting
Watney, Lynn, Rush, Jason, Raney, Jennifer, Small Scale Field Test Demonstrating CO_2 Sequestration in Arbuckle Saline Aquifer and by CO_2 –EOR at Wellington Field Sumner County, Kansas. Presentation at the annual NETL Carbon Storage R&D meeting in Pittsburgh, PA (August 2014)

National Groundwater Association Groundwater Summit
Watney, W.L., 2014, Integrating Modern Suite of Geophysical Logs, Geochemistry, and Seismic Data for Characterizing Deep Aquifers, NGWA Conference on Characterization of Deep Groundwater, May 8, 2014

Watney, W.L., 2014, Using Drill Stem Test Data to Construct Regional Scale Potentiometric Surface in Deep Aquifers, NGWA Conference on Characterization of Deep Groundwater, May 8, 2014

Tiraz Birdie, TBirdie Consulting, Inc., Lawrence, KS, W. Lynn Watney, Ph.D., Kansas Geological Survey, University of Kansas, Lawrence, KS and Paul Gerlach, Charter Consulting, Miramar, FL, Using Drill Stem Test Data to Construct Regional Scale Potentiometric Surface in Deep Aquifers, NGWA Conference on Characterization of Deep Groundwater, May 8, 2014

Geological Society of America, Regional Meeting
DOVETON, John H., Kansas Geological Survey, University of Kansas, 1930 Constant Ave, Lawrence, KS 66047, doveton@kgs.ku.edu, MERRIAM, Daniel F., University of Kansas, 1930 Constant Ave, Campus West, Lawrence, KS 66047, and WATNEY, W. Lynn, Kansas Geological Survey, Univ of Kansas, 1930 Constant Avenue, Lawrence, KS, 66047, 2014, Petrophysical Imagery of the Oread Limestone in Subsurface Kansas, Paper #237642, 48th Annual Meeting, North Central Geological Society of America, Program With Abstracts. (Episodic nature of structural activity at Wellington Field) Presentation at Geological Society of America, Regional Meeting (April 2014) – illustrating the stratigraphic and sedimentologic effects of episodic structural movement at Wellington Field.

6.6 Workshops

To date, the following workshops have been conducted in order to acquaint target audiences with the Wellington project objectives and plans:

University of Kansas Core Workshop
W. Lynn Watney, Jason Rush, John Doveton, Mina Fazelalavi, Eugene Holubnyak, Bob Goldstein, Brad King, Jen Roberts, David Fowle, Christa Jackson, George Tsoflias, et al., Overview, current research, and major findings for two long Paleozoic cores – Berexco Wellington KGS #1-32, Sumner County, KS and Berexco Cutter KGS #1, Stevens County, Kansas - four posters (2 each for Wellington and Cutter). Presented at a research and industrial associates core workshop at the University of Kansas.

KU KICK Meeting
W. Lynn Watney, Jason Rush, John Doveton, Mina Fazelalavi, Eugene Holubnyak, Bob Goldstein, Brad King, Jen Roberts, David Fowle, Christa Jackson, George Tsoflias, et al., Overview, current research, and major findings for two long Paleozoic cores – Berexco Wellington KGS #1-32, Sumner County, KS and Berexco Cutter KGS #1, Stevens County, Kansas. Presentation at a KU KICK meeting in Lawrence, KS.

7. Future Outreach Activities

Stage	Activities
Current (pre-permit)	Complete Project Fact Sheet and mail to identified stake holders
Current (pre-permit)	Initial meeting with stakeholders
Current (pre-permit)	Post a brief summary of permit contents on the project web page
Ongoing and Public Comment Period	Borrow physical CCS model developed by Midwest Geological Sequestration Consortium and NETL in order to inform stakeholders and general public of how storage occurs in the subsurface

Public Comment	Participate with EPA in public comment process, proactively inform stakeholders of EPA's opinion of the safety and feasibility of the project
Permit Approval	Announcement to press and stakeholders.
Injection	Post quarterly reports submitted to EPA on web site and summarize findings
Post Injection	Post quarterly reports submitted to EPA on web site and summarize findings
Site Closure	Announce site closure activities and communicate successful closure and future monitoring plans
Ongoing	Publication of technical findings/research pertaining to CCS and Wellington project in scientific and technical journals, conferences, and workshops
Ongoing	Site visits and tours, interaction with media, community events and open houses
Crisis Communication	Prepare list of responders, responsibilities for specific tasks in the event of an emergency, how emergencies will be handled including safety procedures to be followed

8. Press Release Template

The following template will be followed for formal communication with media

- Release Date
- Contact information
- Headline
- Body Text (To be limited to 1-2 pages)

APPENDIX II

Small Scale Field Test Demonstrating CO_2 Sequestration in Arbuckle Saline Aquifer and by CO_2-EOR at Wellington Field, Sumner County, Kansas

TWELFTH QUARTERLY PROGRESS REPORT

DOE F 4600.2
(03/11)
All Other Editions Are Obsolete

U.S. Department of Energy
FEDERAL ASSISTANCE REPORTING CHECKLIST
AND INSTRUCTIONS FOR RD&D PROJECTS

1. Identification Number: **DE-FE0006821**	2. Program/Project Title: **Small Scale Field Test Demonstration CO2 Sequestration**

3. Recipient: **University of Kansas Center for Research, Inc.**

4. Reporting Requirements:	Frequency	Addressees
A. MANAGEMENT REPORTING		
☒ Research Performance Progress Report (RPPR)	Q	FITS@NETL.DOE.GOV
☒ Special Status Report	A	FITS@NETL.DOE.GOV
B. SCIENTIFIC/TECHNICAL REPORTING		
(Reports/Products must be submitted with appropriate DOE F 241. The 241 forms are available at www.osti.gov/elink)		
Report/Product — Form		
☒ Final Scientific/Technical Report — DOE F 241.3	FG	http://www.osti.gov/elink-2413
☒ Conference papers/proceedings* — DOE F 241.3	A	http://www.osti.gov/elink-2413
☐ Software/Manual — DOE F 241.4		
☐ Other (see special instructions) — DOE F 241.3		
** Scientific and technical conferences only*		
C. FINANCIAL REPORTING		FITS@NETL.DOE.GOV
☒ SF-425 Federal Financial Report	Q, FG	
D. CLOSEOUT REPORTING		
☒ Patent Certification	FC	FITS@NETL.DOE.GOV
☒ SF-428 & 428B Final Property Report	FC	FITS@NETL.DOE.GOV
☐ Other		
E. OTHER REPORTING		See block 5 below for instructions.
☒ Annual Indirect Cost Proposal	O	
☐ Audit of For-Profit Recipients		FITS@NETL.DOE.GOV
☒ SF-428 Tangible Personal Property Report Forms Family	A	FITS@NETL.DOE.GOV
☒ Other – see block 5 below	A	

FREQUENCY CODES AND DUE DATES:

A - Within 5 calendar days after events or as specified.
FG- Final; 90 calendar days after the project period ends.
FC- Final; End of Effort.
Y - Yearly; 90 calendar days after the end of the reporting period.
S - Semiannually; within 30 calendar days after end of project year and project half-year.
Q - Quarterly; within 30 days after end of the reporting period.
Y180 – Yearly; 180 days after the end of the recipient's fiscal year
O - Other; See instructions for further details.

5. Special Instructions:

Annual Indirect Cost Proposal – If DOE is the Cognizant Federal Agency, then the proposal should be sent to FITS@NETL.DOE.GOV . Otherwise, it should be sent to the Cognizant Federal Agency.

Other – The Recipient shall provide all deliverables as contained in Section D of Attachment 2 Statement of Project Objectives.

1

QUARTERLY PROGRESS REPORT
To
DOE-NETL
Brian Dressel, Program Manager
Award Number: DE-FE0006821

SMALL SCALE FIELD TEST DEMONSTRATING CO_2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO_2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS

Project Director/Principal Investigator:
W. Lynn Watney
Senior Scientific Fellow
Kansas Geological Survey

Ph: 785-864-2184, Fax: 785-864-5317
lwatney@kgs.ku.edu

Joint Principal Investigator:
Jason Rush

Prepared by Lynn Watney
Date of Report: November 4, 2014
DUNS Number: 076248616

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

Project/Grant Period: 10/1/2011 through 9/30/2016

Twelfth Quarterly Report

Period Covered by the Report: July 1, 2014 through September 30, 2014

Signature of Submitting Official:

W. Lynn Watney Digitally signed by W. Lynn Watney
DN: cn=W. Lynn Watney, o=The University of Kansas, ou=Kansas Geological Survey, email=lwatney@kgs.ku.edu, c=US
Date: 2014.11.04 07:25:16 -06'00'

EXECUTIVE SUMMARY

Project Objectives

The objectives of this project are to understand the processes that occur when a maximum of 70,000 metric tonnes of CO_2 are injected into two different formations to evaluate the response in different lithofacies and depositional environments. The evaluation will be accomplished through the use of both *in situ* and indirect MVA (monitoring, verification, and accounting) technologies. The project will optimize for carbon storage accounting for 99% of the CO_2 using lab and field testing and comprehensive characterization and modeling techniques.

CO_2 will be injected under supercritical conditions to demonstrate state-of-the-art MVA tools and techniques to monitor and visualize the injected CO_2 plume and to refine geomodels developed using nearly continuous core, exhaustive wireline logs, and well tests and a multi-component 3D seismic survey. Reservoir simulation studies will map the injected CO_2 plume and estimate tonnage of CO_2 stored in solution, as residual gas, and by mineralization and integrate MVA results and reservoir models shall be used to evaluate CO_2 leakage. A rapid-response mitigation plan will be developed to minimize CO_2 leakage and provide comprehensive risk management strategy. A documentation of best practice methodologies for MVA and application for closure of the carbon storage test will complete the project. The CO_2 shall be supplied from a reliable facility and have an adequate delivery and quality of CO_2.

Scope of Work

Budget Period 1 includes updating reservoirs models at Wellington Field and filing Class II and Class VI injection permit application. Static 3D geocellular models of the Mississippian and Arbuckle shall integrate petrophysical information from core, wireline logs, and well tests with spatial and attribute information from their respective 3D seismic volumes. Dynamic models (composition simulations) of these reservoirs shall incorporate this information with laboratory data obtained from rock and fluid analyses to predict the properties of the CO_2 plume through time. The results will be used as the basis to establish the MVA and as a basis to compare with actual CO_2 injection. The small scale field test shall evaluate the accuracy of the models as a means to refine them in order to improve the predictions of the behavior and fate of CO_2 and optimizing carbon storage.

Budget Period 2 includes completing a Class II underground injection control permit; drilling and equipping a new borehole into the Mississippian reservoir for use in the first phase of CO_2 injection; establishing MVA infrastructure and acquiring baseline data; establishing source of CO_2 and transportation to the injection site; building injection facilities in the oil field; and injecting CO_2 into the Mississippian-age spiculitic cherty dolomitic open marine carbonate reservoir as part of the small scale carbon storage project.

In Budget Period 3, contingent on securing a Class VI injection permit, the drilling and completion of an observation well will be done to monitor injection of CO_2 under supercritical conditions into the Lower Ordovician Arbuckle shallow (peritidal) marine dolomitic reservoir. Monitoring during

pre-injection, during injection, and post injection will be accomplished with MVA tools and techniques to visualize CO_2 plume movement and will be used to reconcile simulation results. Necessary documentation will be submitted for closure of the small scale carbon storage project.

Project Goals

The proposed small scale injection will advance the science and practice of carbon sequestration in the Midcontinent by refining characterization and modeling, evaluating best practices for MVA tailored to the geologic setting, optimize methods for remediation and risk management, and provide technical information and training to enable additional projects and facilitate discussions on issues of liability and risk management for operators, regulators, and policy makers.

The data gathered as part of this research effort and pilot study will be shared with the Southwest Sequestration Partnership (SWP) and integrated into the National Carbon Sequestration Database and Geographic Information System (NATCARB) and the 6th Edition of the Carbon Sequestration Atlas of the United States and Canada.

Project Deliverables by Task

1.5 Well Drilling and Installation Plan (Can be Appendix to PMP or Quarterly Report)
1.6 MVA Plan (Can be Appendix to PMP or Quarterly Report)
1.7 Public Outreach Plan (Can be Appendix to PMP)
1.8 Arbuckle Injection Permit Application Review go/no go Memo
1.9 Mississippian Injection Permit Application Review go/no go Memo
1.10 Site Development, Operations, and Closure Plan (Can be Appendix to PMP)
2.0 Suitable geology for Injection Arbuckle go/no go Memo
3.0 Suitable geology for Injection Mississippian go/no go Memo
11.2 Capture and Compression Design and Cost Evaluation go/no go Memo
19 Updated Site Characterization/Conceptual Models (Can be Appendix to Quarterly Report)
21 Commercialization Plan (Can be Appendix to Quarterly Report).
30 Best Practices Plan (Can be Appendix to Quarterly or Final Report)

ACCOMPLISHMENTS

1. **1st formal meeting on August 20th with Region 7 EPA in Lenexa, KS and tele-connection with Washington office to discuss the Wellington Class VI application.**

   Introduce Wellington team and reaffirm tight schedule and commitment to work closely with EPA to meet requests.

2. **Completed review of Berexco subcontract and permission received from DOE on September 22nd to begin field activities associated with BP2.**

3. 15 seismometers seismic array from IRIS-PASSCAL are installed and operational.

Installation completed using KGS funds prior to start BP2 and system is now operational. DOE funds are being used to install cellular network and for acquisition and processing of the microseismic data. Resolution of recording appears to be excellent.

4. cGPS installed and operational as instrumentation

cGPS is necessary to obtain baseline x-y-z ground motion to calibrate InSAR.

Milestone Status Report

Task	Budget Period	Number	Milestone Description
Task 2.	1	1	Site Characterization of Arbuckle Saline Aquifer System - Wellington Field
Task 3.	1	2	Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field
Task 10.	2	3	Pre-injection MVA - establish background (baseline) readings
Task 13.	2	4	Retrofit Arbuckle Injection Well (#1-28) for MVA Tool Installation
Task 18.	3-yr1	5	Compare Simulation Results with MVA Data and Analysis and Submit Update of Site Characterization, Modeling, and Monitoring Plan
Task 22.	3-yr1	6	Recondition Mississippian Boreholes Around Mississippian CO2-EOR injector
Task 27.	3-yr2	7	Evaluate CO2 Sequestration Potential of CO2-EOR Pilot
Task 28.	3-yr2	8	Evaluate Potential of Incremental Oil Recovery and CO2 Sequestration by CO2-EOR - Wellington field

Task 2 -- Arbuckle model framework was requested and shared with EPA to rebuild an independent simulation of the CO2 injection. EPA consultant will use software from DOE's Pacific Northwest National Lab.

Task 3 – Mississippian geomodel and simulations slightly modified and three alternative locations of the Class II Mississippian injection well were obtained including original location. Original location confirmed for Class II well.

Task 10 – Fifteen seismometers and cGPS are installed and operational. Installation of first two groundwater monitoring wells is underway to establish background analyses in AOR for EPA Class VI application.

Project Schedule

Detailed planning for the Mississippian CO2 injection is underway (**Figure 1)** and described in following list.

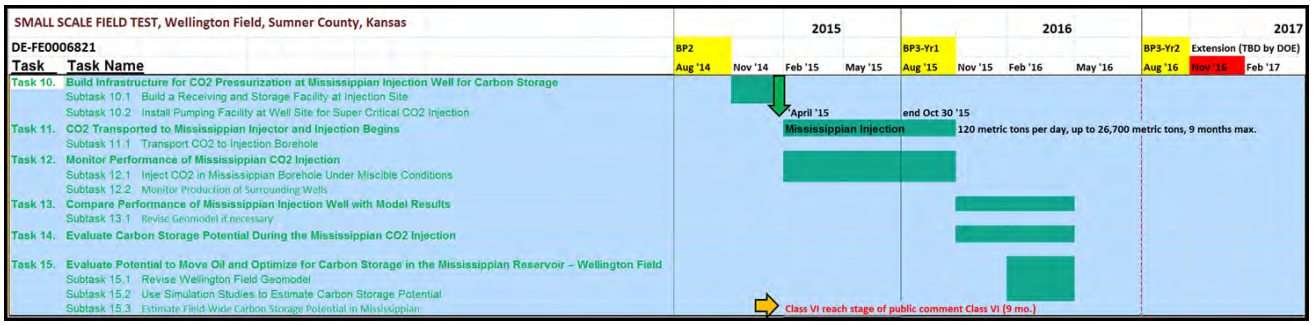


Figure 1. Budget period 2 begin with preparations to injection CO_2 into the Mississippian oil reservoir.

BP2 activities are underway or planned as summarized below:

a) MVA implementation – seismometer array (installed Sept 2014), cGPS (installed Sept 2014), shallow USDW wells (Oct-Nov. 2014), soil gas (late 2014), re-pressuring Mississippian and sampling producing wells (~March 2015)
b) Class II application (to be filed Nov. 2014) and Public Outreach (Dec 2014)
c) Drill Mississippian injection well, #2-32 (~Feb 2015)
d) Inject CO2 (~April 2015) 120 metric tons per day, up to 26,000 metric tons, 8 months max.
e) EPA permit (March 2015)
f) Order fabrication of CASSM and U-Tube 8-9 months lead time (March 2015)
g) Drill #2-28 Arbuckle monitoring well (summer 2015)
h) Equip #2-28 with CAASM and U-Tube, and #1-28 for injection (Oct-Nov 2015)
i) Inject CO2 in #1-28 (Nov 2015) -- 120 metric tons per day; up to 26,000 tonnes, 7.5 months max.
j) Post injection monitoring begin (July 2016) DOE project currently ends Sept 2016; extension for post injection site care defined by EPA using remaining funds

The SOPO was revised and the full schedule of the project was modified to fit the end date of funding, September 30, 2016. The portion of the schedule with the Arbuckle injection is shown in **Figure 2**.

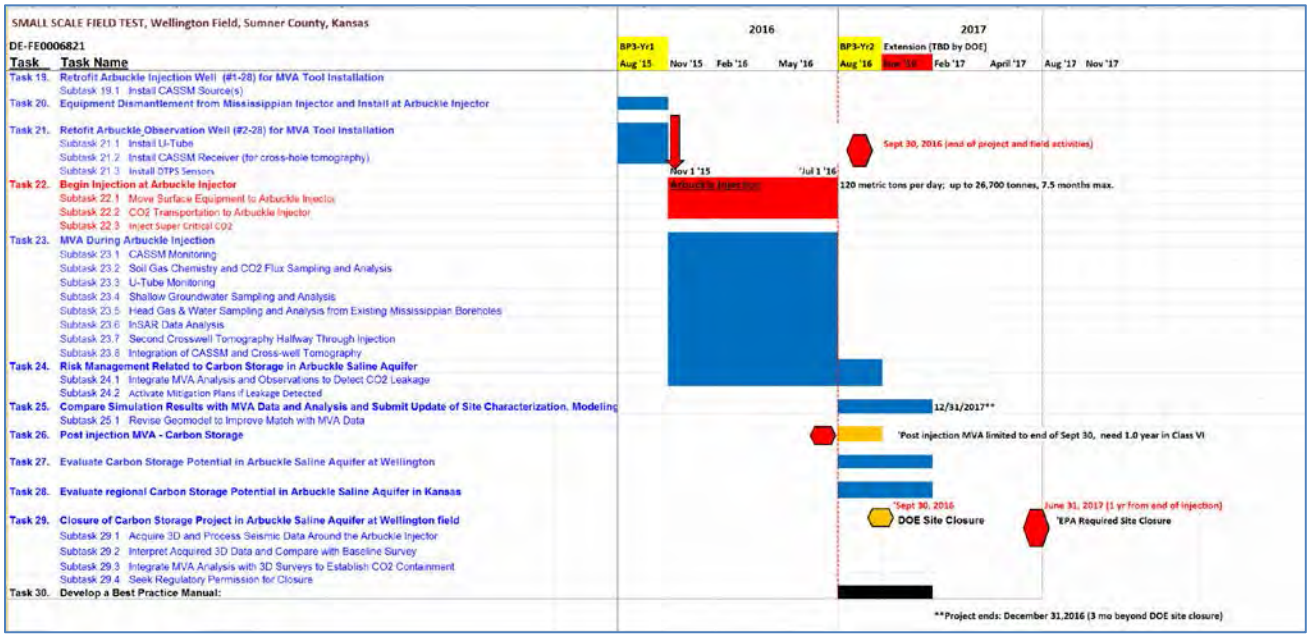


Figure 2. Project schedule for pre- and post-Arbuckle injection at Wellington Field.

Activities of Lawrence Berkeley National Lab

Recent discussions with Tom Daley and Barry Freifeld at LBNL involve moving from soil gas assessment to soil gas analysis to save on cost. These analyses will insure basic characterization of CO_2 in soil in the immediate vicinity of the Arbuckle injection well. LBNL is also developing installation details and diagrams tailored to Arbuckle injection and monitoring wells so that this can be reviewed by Berexco and used to update costs for fabrication of materials for CASSM and U-Tube.

ONGOING ACTIVITIES

TASK 1. PROJECT MANAGEMENT AND REPORTING

Scheduled activities include –

- Hold kickoff meeting on October 15
- Establish invoicing protocol – cost center billing for Berexco accepted by Berexco, KGS, DOE, KUCR
- Hold scheduled conference calls with team (bimonthly)
- Press release -- to be reviewed by key parties
- Project fact sheet – draft being reviewed
- Increase visibility of the project on the website

- Meet with landowners to discuss the project closer to time when the Mississippian well will be drilled
- Meet with public in Wellington town hall meeting to discuss the project and answer questions
- Complete USDW wells
- Install cellular network for remote communication with seismometers
- Install 3 accelerometer/broadband seismometers.

Subtask 1.7. Public Outreach Plan

A public information circular, project fact sheet, and press release in development and will be released next quarter. Informal meetings planned with local landowners prior to formal public meeting.

Subtask 1.8. Arbuckle Injection Permit Application Review go/no go Memo

EPA is reviewing application and questions being addressed are on the topics of financial assurance, quality of the USDW in the AOR of the Arbuckle CO_2 injection. We have coordinated with EPA to approve plans to drill two tests of the USDW this fall. Wells will be both completed in November 2014. Domestic well water from the aquifer in the area will also be sampled and analyzed.

State regulators at Kansas Corporation Commission and Kansas Department of Health and Environment have been asked to review the Class VI application. Request has been made to again have a face-to-face meeting with Region 7 EPA.

TASK 2. SITE CHARACTERIZATION OF ARBUCKLE SALINE AQUIFER SYSTEM - WELLINGTON FIELD (GO/NO-GO DECISION #3)

Additional analysis of the geomodel continues to refine the smaller scale heterogeneity in the Arbuckle, but not significant changes have been made.

TASK 3. SITE CHARACTERIZATION OF MISSISSIPPIAN RESERVOIR - WELLINGTON FIELD (CLASS II APPLICATION & GO/NO-GO DECISION #4)

The Mississippian model was updated after slight modification of the seismic interpretation and recognition of small (~50 ft or less displacement) faults that affect the lateral continuity of the flow units that comprise the Mississippian reservoir (**Figures 3-8).** Original location of injection well was confirmed. The porosity model now includes small faults that trend NE that modify the porosity and permeability distribution (**Figures 3 and 4**). The zone of faulting also delineates the basic flow unit structure of the reservoir, aggrading east half and a progradational west half. It is important to note that the overlying seismic reflectors are

continuous, indicating the caprock is undisturbed. Thus, the fault system is an inherited feature (**Figure 5**). The simulated CO2 plume reflects a preferred NE-trend geometry controlled by both the flow unit distribution, where progradational units strike in this direction, but also the permeability anisotropy (**Figure 6**). The isopach map of the small faults is noted in the lower portion of **Figure 6**. Note that the southern blue thick has been removed after a modification of the seismic correlation. However, the remaining portion of the map has not changed. The CO2 will be closely monitored with the geophysics, InSAR, and geochemistry of producing wells surrounding the injection well to test the simulation model.

Alternative site for CO2 injection into the Mississippian reservoir are illustrated in **Figures 7 and 8**. The consensus is to stay with the initial area.

Area in vicinity of CO_2 will be re-pressurized to obtain optimal miscibility, between 1600-1700 psi. Pressure will be near the original of 1650 psi. To raise pressure, will shut down surrounding wells and may increase injection in water wells. The Miss injection well will be drilled before we start to pressurize the reservoir. Then we can directly measure the pressure as soon as it is drilled. We will likely want to run Step Rate Test before the injection begins. It will be important to continue discussion of the geomodel before Mississippian injection)

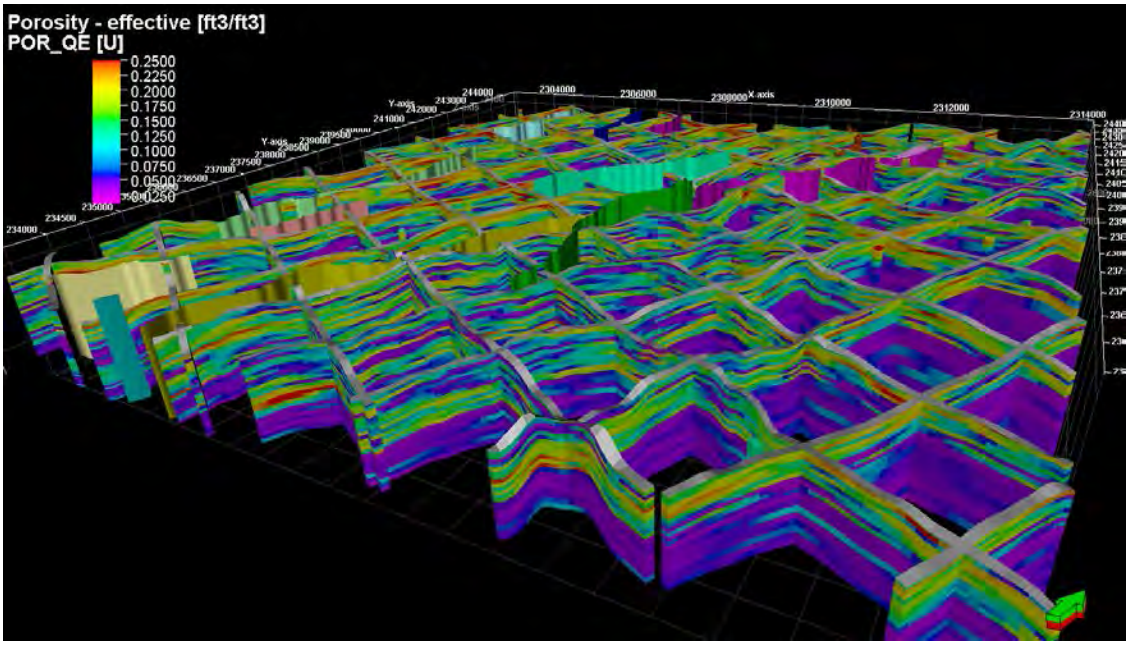


Figure 3. Porosity fence diagram from Petrel for Mississippian reservoir showing small faults cutting SW-NW (Holubnyak, 2014). Near side (east side of Wellington) is

aggradational while far side (west side) is progradational to the west suggesting flexural bend along area of faulting.

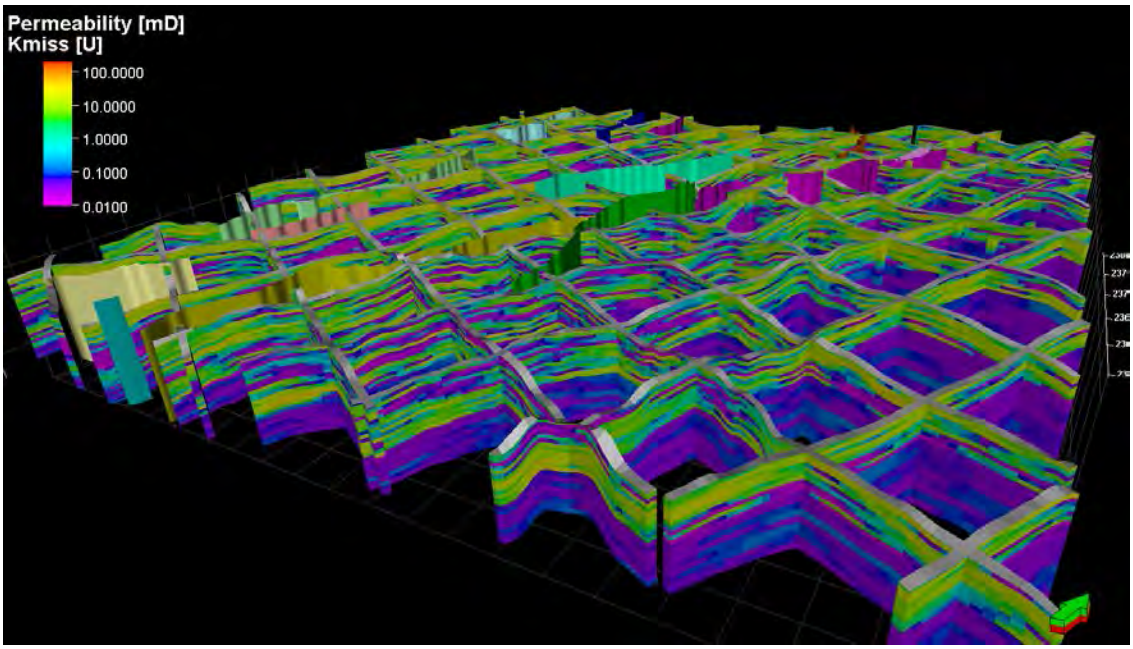


Figure 4. Permeability model of the Mississippian reservoir. See explanation in Figure 3. (Holubnyak, 2014)

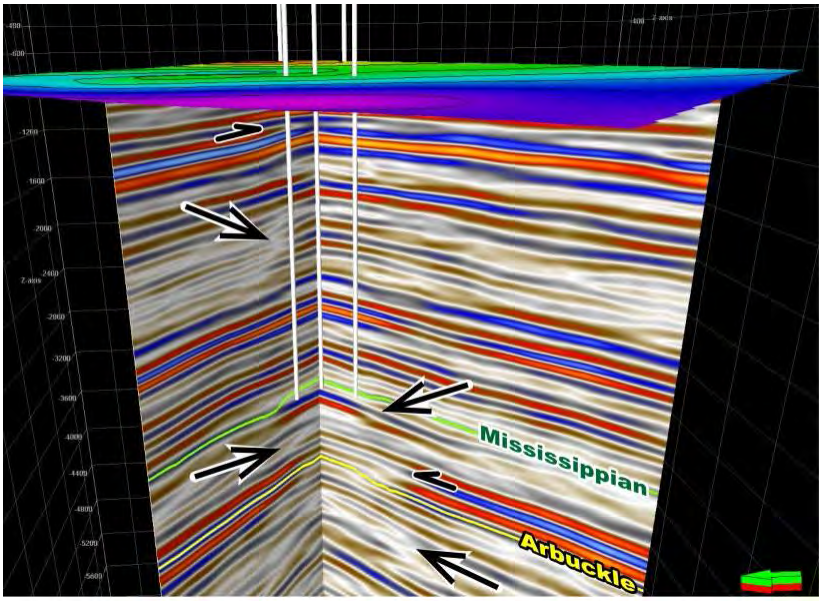
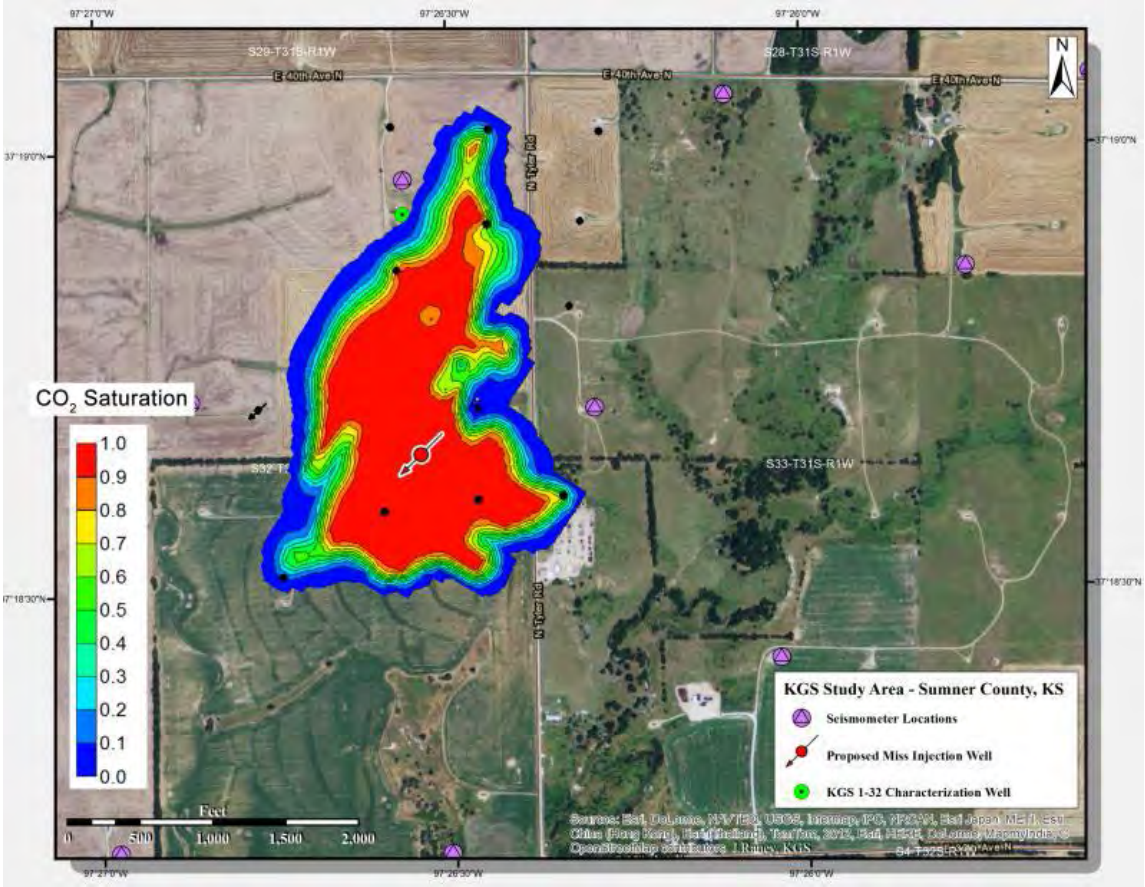


Figure 5. Slices from a pre-stack depth-migrated seismic amplitude volume in Wellington Field highlighting suspected faults based on termination of seismic reflections. A 5-spot well injection pattern is shown that is impacted by the two faults (right) (Holubnyak, 2014)



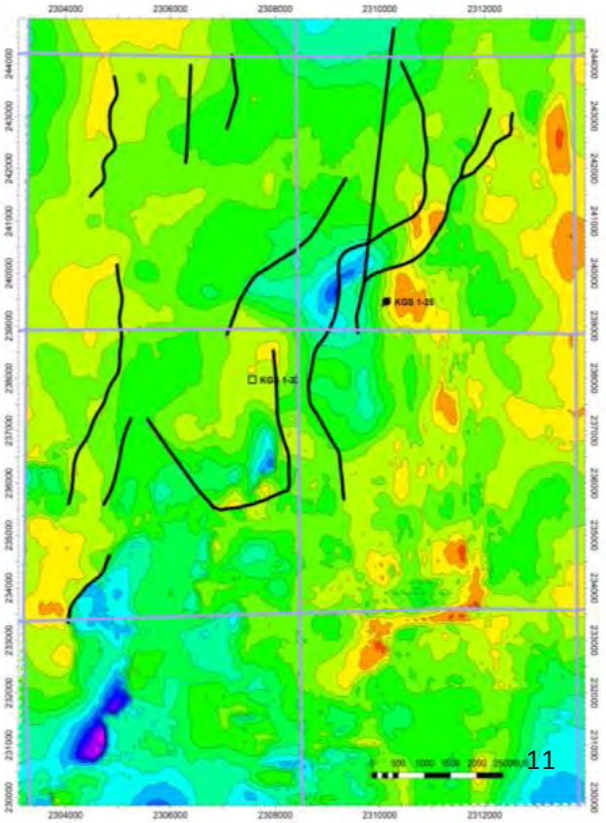


Figure 6. CO2 spatial distribution in the accepted case where the injector location coincides with structural elements (See Figure 4 and 5). Isopach map with mapped faults for the Wellington Field with warmer colors representing higher structures and cooler – lower structures (below). KGS #1-32 (on southwest) and KGS #1-28 (on northeast) are identified on the map. Holubnyak (2014).

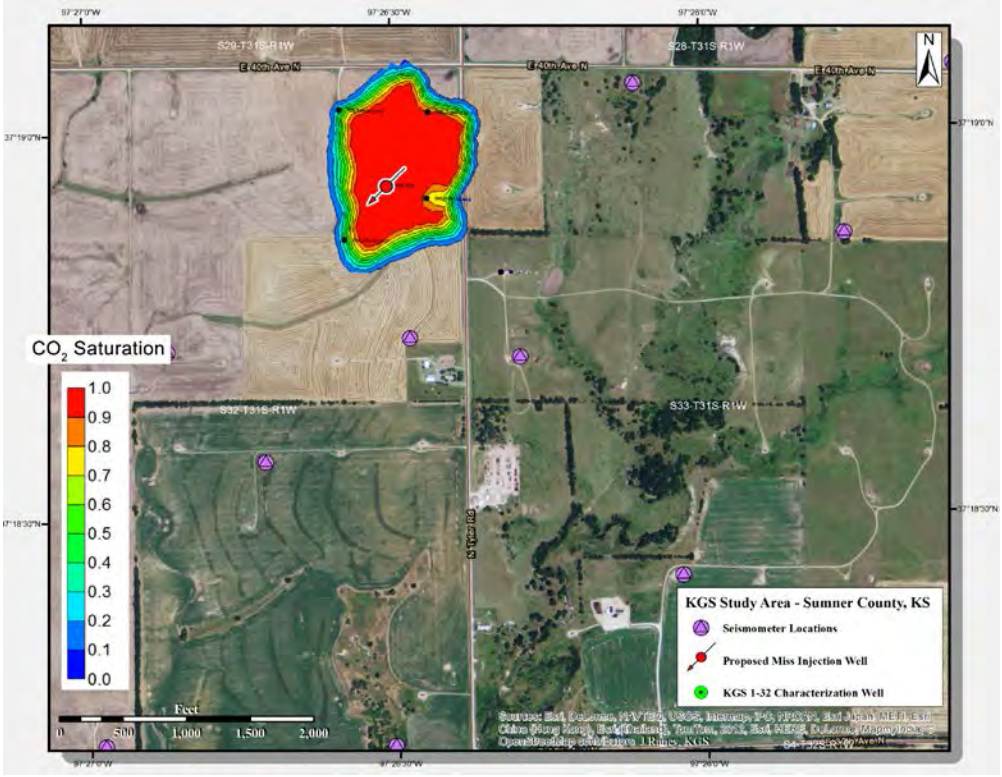


Figure 7. Alternative Mississippian CO_2 injection site near KGS #1-32.

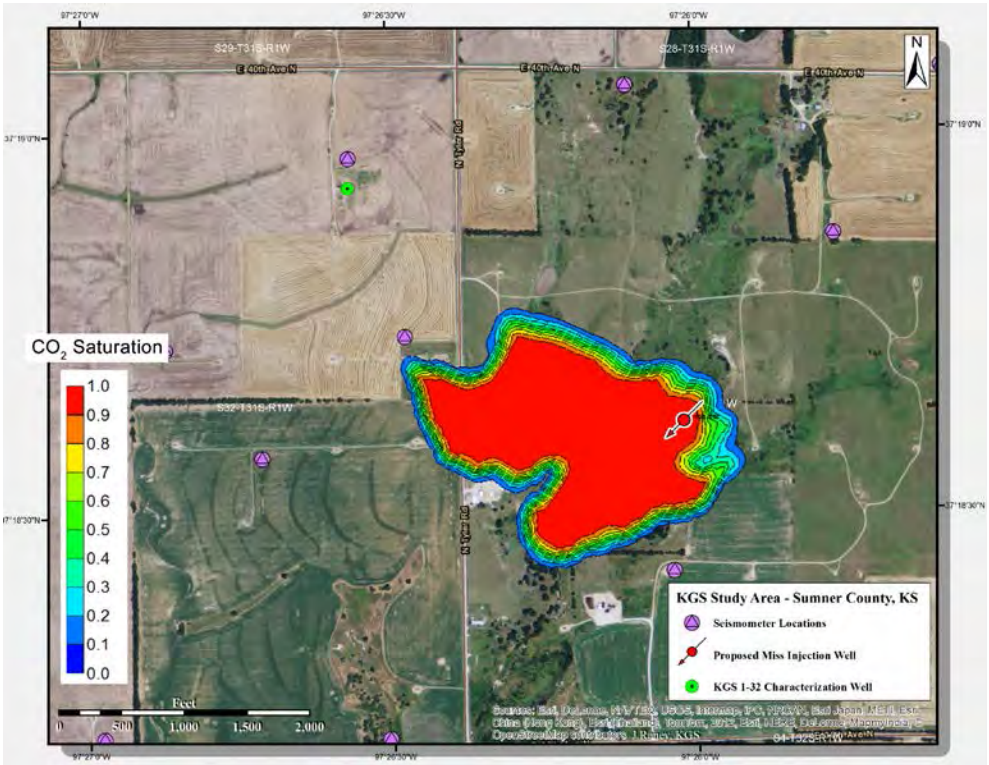


Figure 8. Alternative Mississippian CO_2 injection site in Section 33, east of preferred site.

TASK 5. SECURE CO2 SOURCE -- GO/NO-GO DECISION #5

Subtask 5.1 CO_2 Supply
Subtask 5.2 CO_2 Transportation

Mississippian injection continues to be planned for April 2015. CO2 delivery trucks have off road capability. Mississippian injection well will be drilled by late winter 2014/2015 with plans to drill Arbuckle monitoring well in Oct 2015. Final contractional agreement is needed between Berexco and Linde and Praxair who will be contacted in the coming weeks. We do not foresee any injectivity problems and Berexco is prepared for a flexible volume delivery and quantity stored on location.

TASK 6. ESTABLISH MVA INFRASTRUCTURE - AROUND CO_2 INJECTOR FOR CARBON STORAGE

Subtask 6.1. Design MVA Components and Fabrication (Contingent on Go Decision pts 1&3)

LBNL will get new price quotes on equipment including for CAASM - piezotube source installed in injection tubing above the injection zone in the injection well and the sensors installed in the monitoring well. CASSM will provide the opportunity to also monitor any vertical CO_2 movement above the injection zone.

CASSM is more of a sparse survey, which is useful when integrated with the crosswell survey. CASSM and crosswell were used at Cranfield (100,000 tonnes) and Frio (1500 tonnes). CO_2 showed up nicely in each. Seismic velocity changes were detected a few hundred meters around the borehole. The changes in velocity seen with CASSM are less than a microsecond. The changes that we should expect will be on the order of milliseconds. CASSM will be installed in the annulus on the injection well. Clamps will be all the way up the casing. U-tube is another line that is clamped to the tubing. Action: Share designs of U-Tube and CASSM tailored to Arbuckle wells.

The repeat 3D seismic survey will be used to close the Arbuckle injection by observing the difference in travel times. The resolution of this change will depend on the thickness of the plume. It can be difficult to see the reflection from the surface seismic, but would likely see from reflection of the downhole surveys at the level of the Arbuckle. The crosshole seismic will deploy 10-20 sources from a range of depths, and then move the phones to another depth. Action: Will need to update the fluid substitution model with a revised rock physics model using what we know now since original modeling done in 2011 just after the first 3D survey.

Installation of temperature and pressure gauges in the injection well is being considered versus using wireline to periodically measure temperature and pressure. Action: Investigate options for packers to insure that there will be no leaks and problems with the mechanical

integrity tests. Based on successes in past, hydraulic packers may be the best option with pass-throughs.

Possible acquisition of a VSP was again discussed. Usually 100 sensors are needed for a VSP. Two hydrophones to be installed downhole in temporarily abandoned wells with internal KU funding applied are probably not enough to obtain useful data.

KGS will acquire a high resolution 2D seismic baseline, but VSP could also be accomplished using the same vibroseis. In any case, a check-shot survey with between 5-20 hydrophones useful for additional calibration. A check shot survey could also be run with the crosswell seismic survey. This would benefit all geophysicists. Distributed acoustic fiber optic may also be an option.

Subtask 6.2. Install CGPS and Seismometers near Injection Borehole

CGPS and seismometers have this installed, are recording, and being maintained by Rick Miller's team (**Figure 9**). Data will be shared internally among PI's of science team and eventually to public via website with support from John Victorine. $27,000 is needed to install and operate the three accelerometers and looking elsewhere for funds.

Seismic network:

- CGPS is installed at seismometer station #8 (**Figure 10**)
- have the 15 IRIS stations for 3 years
- Sheriff has serial #s and locations of all their equipment to keep an eye out.
- Data storage onsite for now -- max they can run right now is 2 weeks before they run out of room to record data. Currently they are running out every 10 days while getting background.
- Will go to telemetry system, cell phone modem to send data.
- Cement pad on each seismometer station is below frost line to minimize temperature fluctuations on equipment.
- Waiting for recursion relationships to be able to put data out to public. Still don't have enough to see the types of events we expect to see.

Rick is involved in a separate project to increase the aperture of our seismic network with a portable seismic array obtained with state funding to improve monitoring of small earthquakes in southern Kansas. The Wellington array would serve as part of this system.

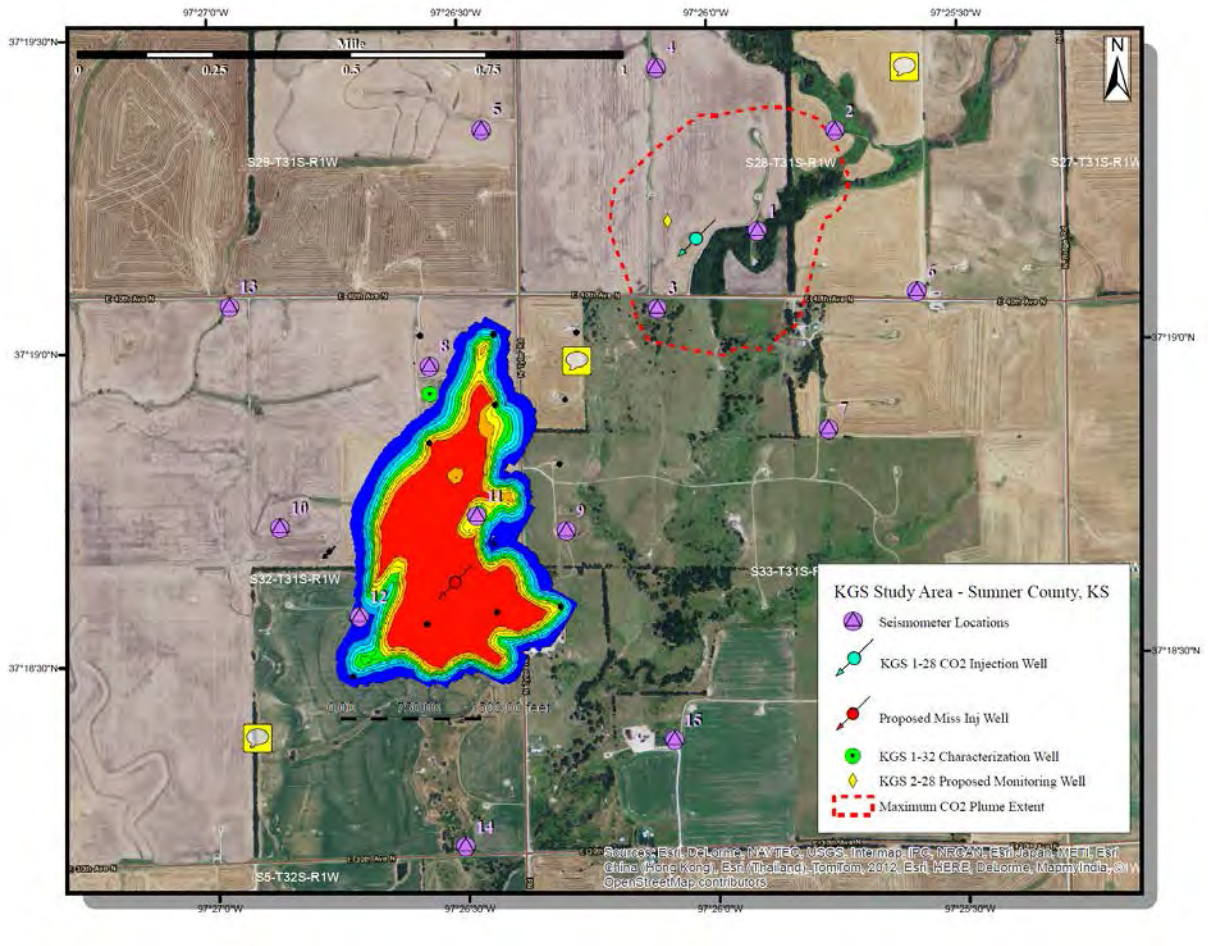


Figure 9. Location of IRIS seismometers, CO_2 injection wells, and CO_2 plumes for the Mississippian and Arbuckle injections.



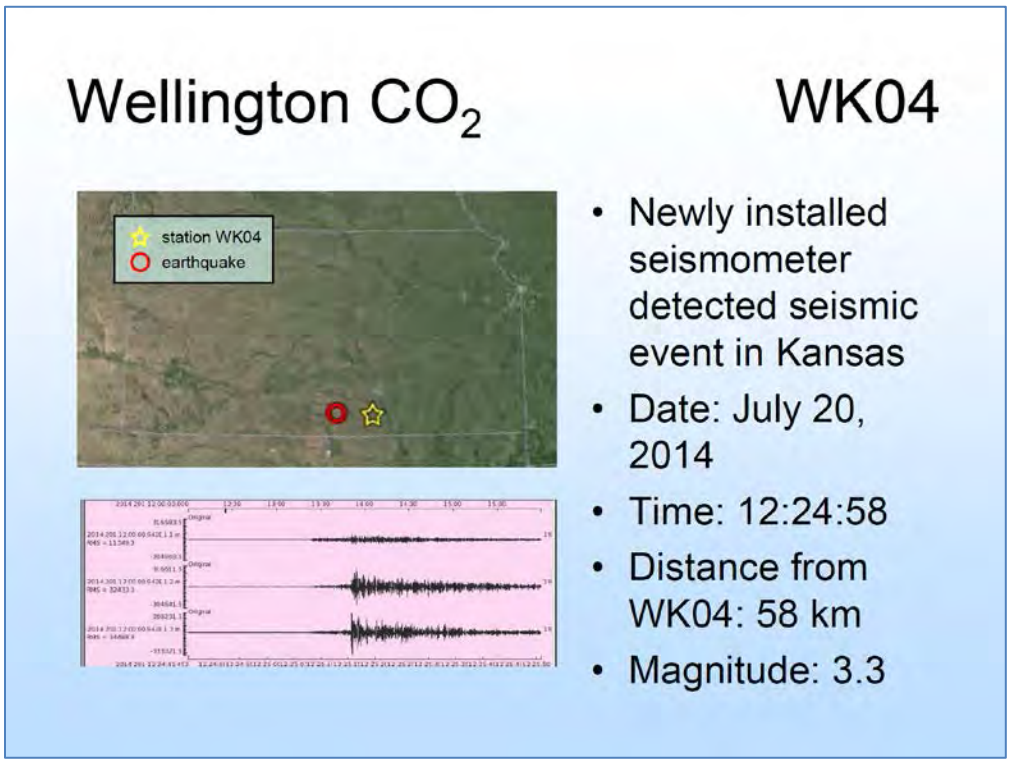


Figure 10. Example of a seismometer vault and a record of nearby earthquake.

Subtask 6.3. Establish Protocols for InSAR data collection

Mike Taylor, Co-I is in charge of acquisition and processing of the CGPS data and using this information to interpret InSAR. The satellite based radar sees through clouds. Each pass of the satellite, ~30 days between passes, can potentially measure displacement of ground surface to mm-scale. With CGPS, Mike can solve for 3 components of the displacement. Right now, these data are manually downloaded.

We do not expect displacement due to earthquakes. Rather the deformation will be a result of pressure changes and very small ground displacement. With a map of subsurface faults, the team will have an idea how they will respond to the injection.

We have a good baseline to observe the repressurization of the Mississippian. If we are raising pressures in an area covering 60-80-100 acres of the field, we should see this in the InSAR data. Berexco is very interested in the use of this technology to monitor waterflooding. The CGPS is anchored 20 feet in cement. It should give us an excellent baseline on millimeter to submillimeter ground motion. We need an accurate baseline measurement of the stresses to understand the pressure changes and for the deformation modeling.

Subtask 6.4. Drill Shallow Freshwater Monitoring Boreholes (Contingent on Go Decision pts 1&3)

Rick Miller's team is installing water wells. Will adjust location of wells based on what we find when drilling. Plans are illustrated in **Figures 11-18.**

ACTION ITEMS: EASTERN and SOUTHERN wells will be drilled this fall. No clusters on the east or the south. Obtain EPA, landowner, and team approval. (All approved via email, in-person meeting & email, and email, respectively). (UPDATE: Approvals obtained to commence activities)

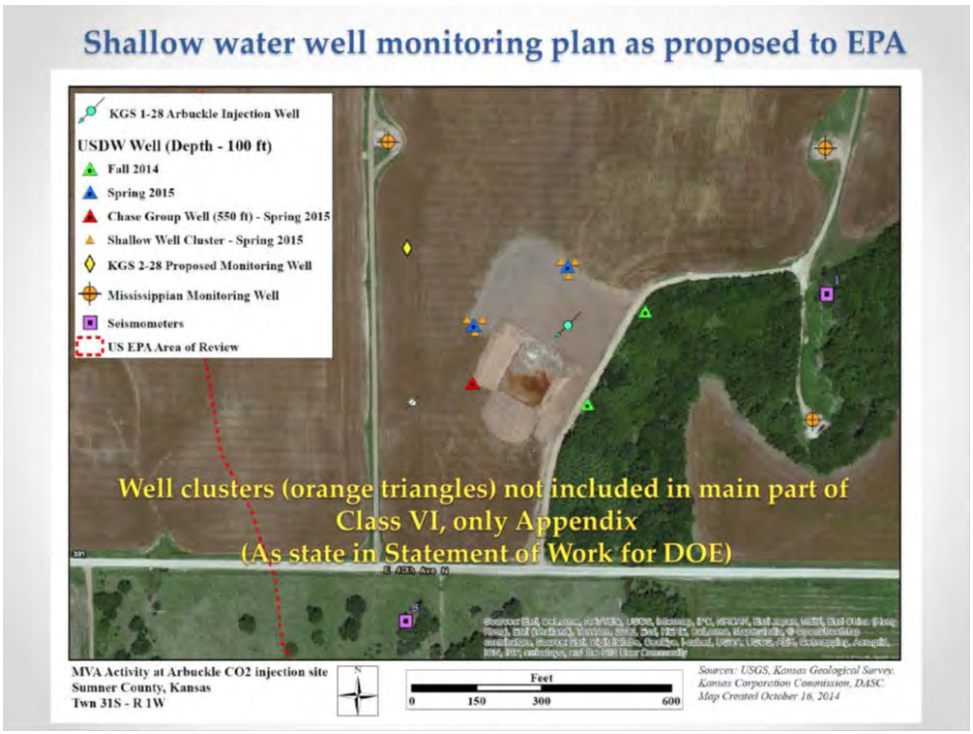


Figure 11. Shallow well monitoring basemap.

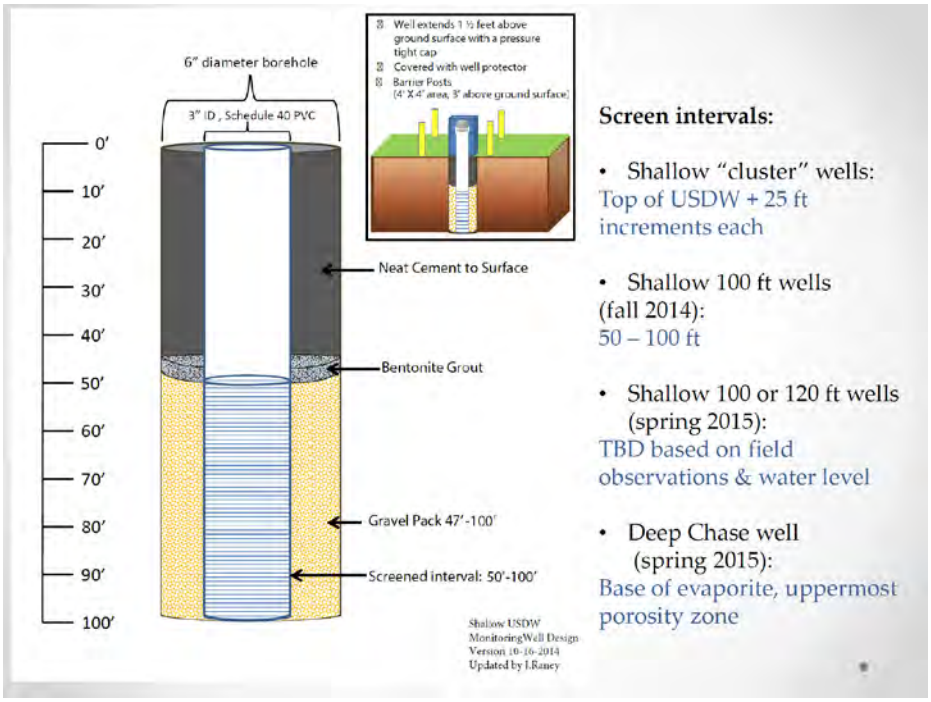


Figure 12. Installation design of 100 ft deep UDSW well, October 2014.

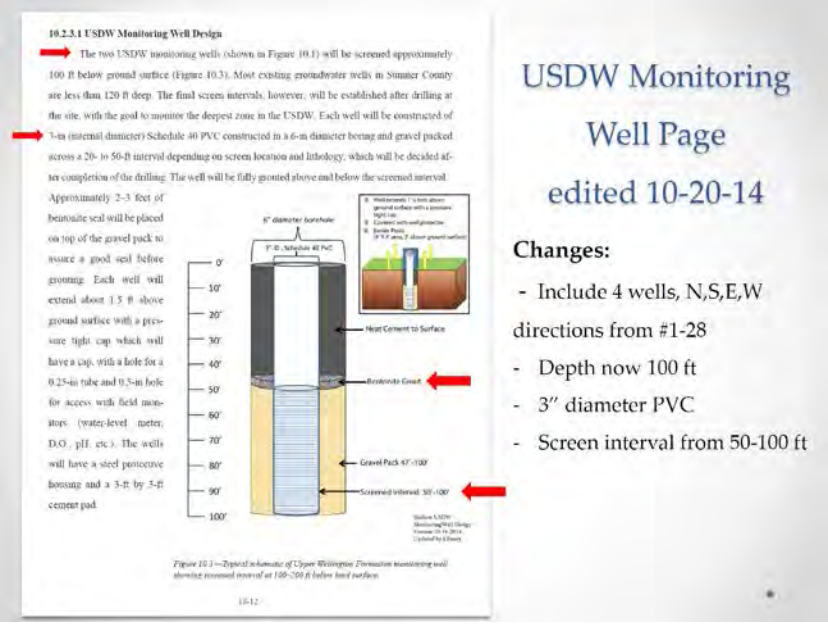


Figure 13. Page from Appendix of Class VI application where additional well detail is described.

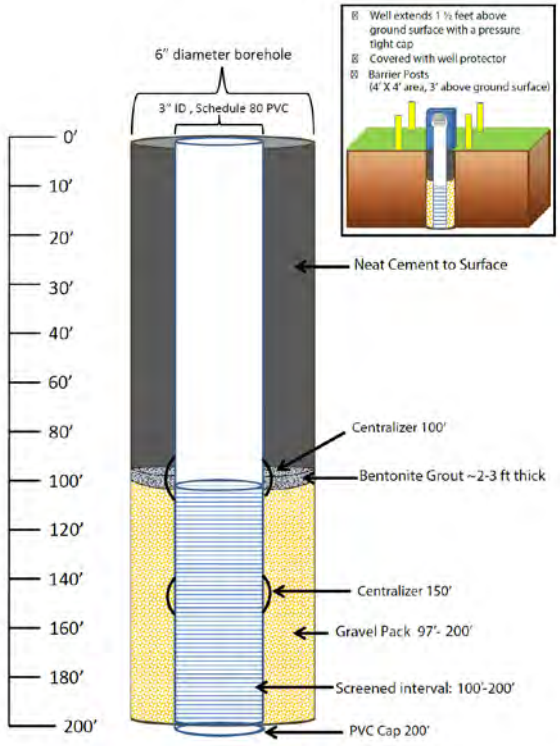


Figure 14. Wellbore diagram of 200 ft UDSW well to be drilled in October 2014.

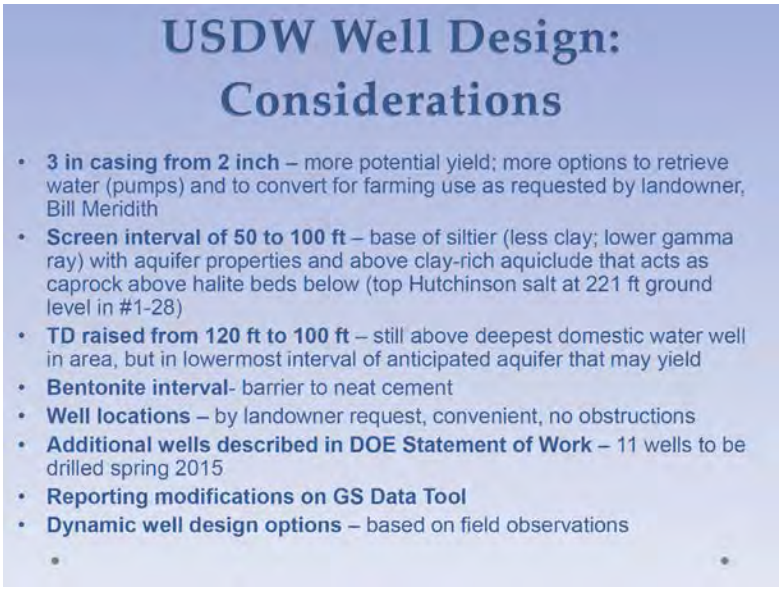


Figure 15. Considerations discussed for UDSW wells.

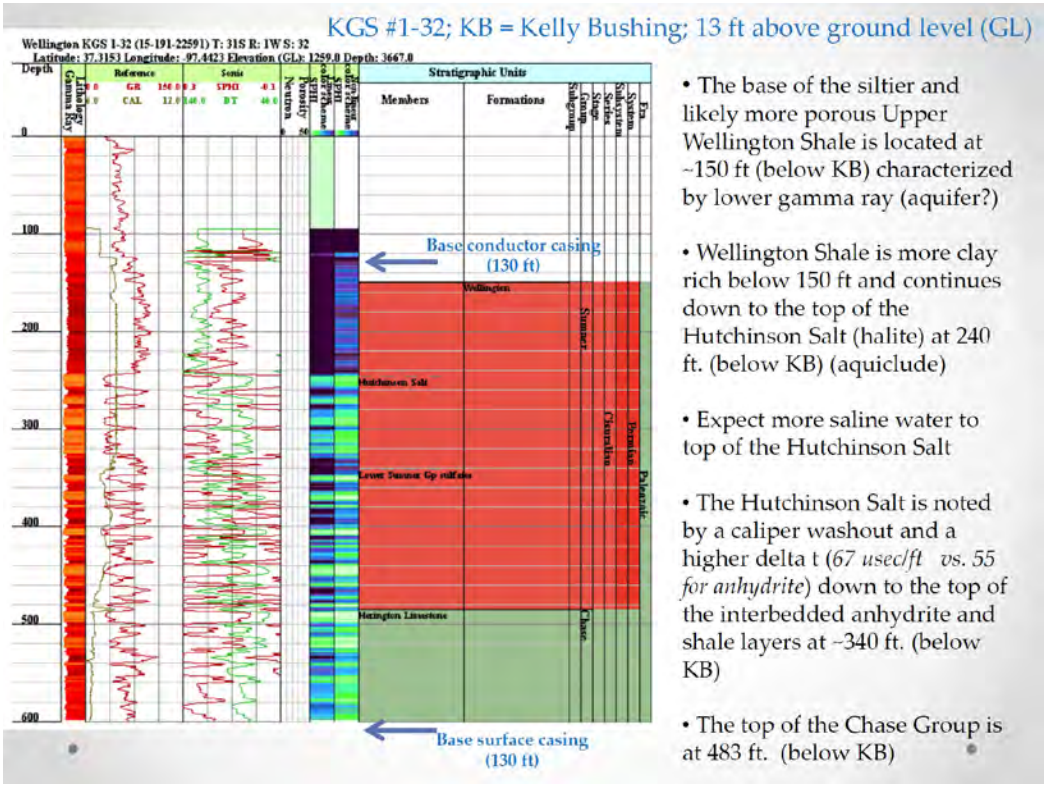


Figure 16. Basis for selection of the depths of the USDW wells.

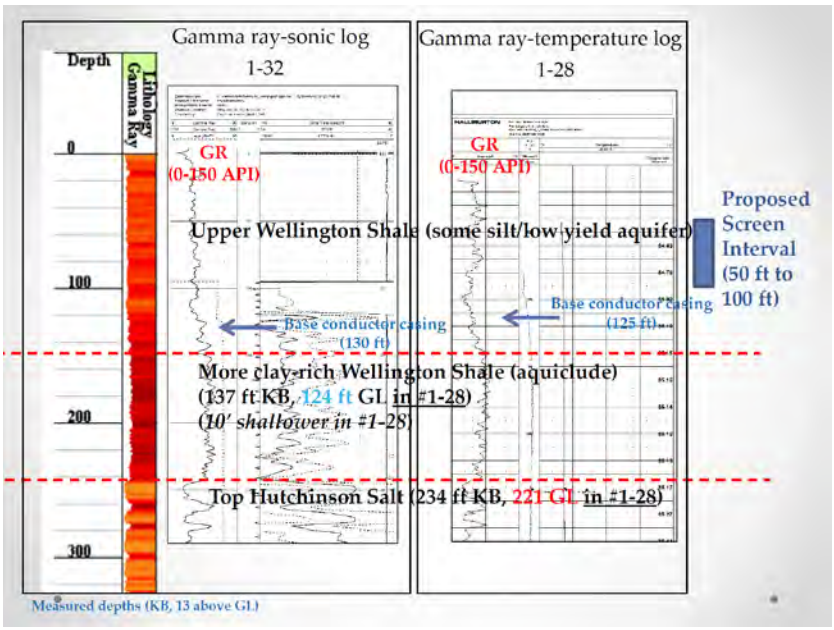


Figure 17. As Figure 16.

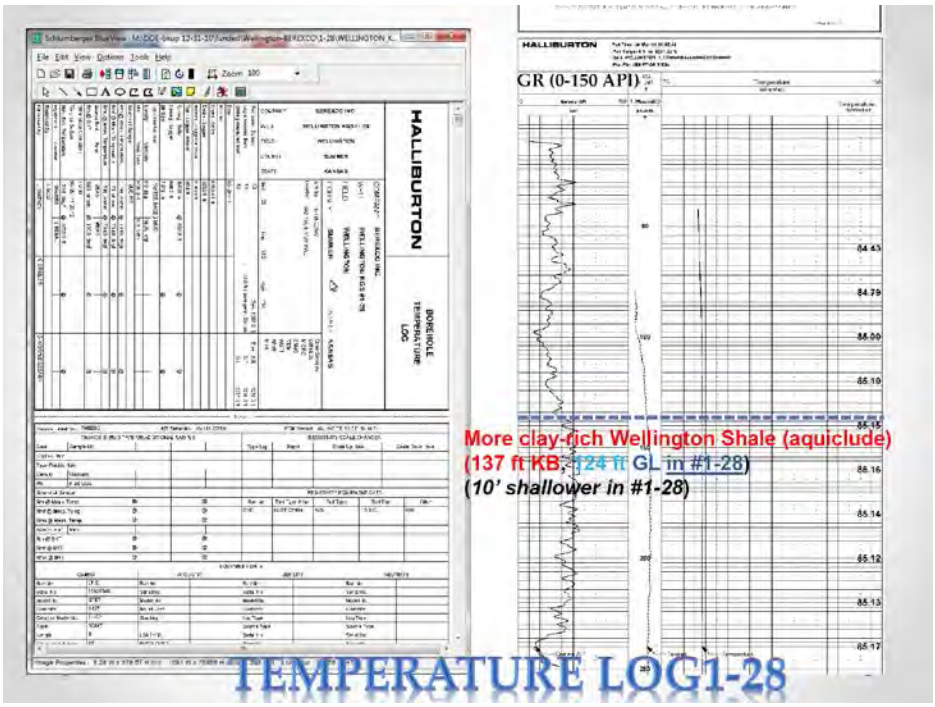


Figure 18. As Figure 16.

Subtask 6.6. Soil Gas Chemical and CO2 Flux Monitoring/Sampling Grid around Injector

Discussions with LBNL on soil gas sampling led to the recommendation that we use lysimeters to sample the soil gas with 2 installed at each of the wells (4 total). LBNL related that the P-Site at Cranfield has an example of lysimeter design. (~5 meter depth. $200 each). KSU will be asked to use field-GC to sample lysimeters after further discussion.

Subtask 6.7. Outfit Surrounding Mississippian Boreholes for MVA (Contingent on Go pts 1&3)

Details are being discussed with Berexco, KSU, and KGS.

Subtask 7.5 High Res 2D Seismic Lines Targeting Mississippian Reservoir

Rick Miller will acquire a baseline 2D high-resolution seismic designed to go through both CO2 flood areas. Because of permitting/access issues, will need to arrange for costs for the farmers. Will be harder to acquire data during the winter months, but will be easier to get access. **Action** -- Discuss permitting issues for Rick's high resolution seismic with Berexco.

Action items: 1) Estimate timing for 2D seismic baseline survey for Rick's team since needs to be a baseline before repressurization. 2) Eugene to provide Berexco with pressurization instructions.

TASK 8. RECONDITION MISSISSIPPIAN BOREHOLES AROUND MISSISSIPPIAN INJECTOR RE-PRESSURING MISSISSIPPIAN AND SAMPLING PRODUCING WELLS (NOV 2015)

Need to do this a few months ahead of CO2 injection, most likely in a Jan-Feb. 2015 timeframe. KCC Class II permit needed for injection. It is good for 1 year. Nothing stopping us for the Class II well and Berexco will soon submit the application. It is possible that we may need to do a Step Rate Test to get the pressure data that KCC needs.

For repressurization – the injection site can be quickly repressurized, but the duration of this process is currently considered to be month.

Key Findings

1. The field activities have just begun and data is being received from the cGPS and seismometers.
2. The UDSW well plan has been completed with agreement by USEPA.
3. The geomodel and simulations of the Mississippian reservoir have been refreshed and will be used to drive the discussion of the repressurization design and location of the Mississippian monitoring wells. The small fault architecture in the Mississippian will also be useful for validation with the planned high-resolution 2D seismic baseline to be acquired this fall-winter running between the Mississippian and the Arbuckle injection sites.
4. Soil gas sampling modification is proposed to use lysimeters near the CO2 injection wells.
5. U-Tube and CASSM design work is proceeding so the costs can be refreshed and installation can be thoroughly discussed.
6. CO2 supply and surface equipment continues to be discussed.

Plans for Fourth Quarter 2014 (BP2 start date -- September 22, 2014)

a. Update Gantt chart.
b. Repressurization schedule will be finalized, more likely after Feb 2015 after drill the Mississippian injection well is drilled in order to directly monitor pressure and evaluate how repressurization should go.
c. Check into continuous bottom hole monitoring for temperature and pressure in injection well.
d. Continue discussion of the geomodel before Mississippian injection
e. Jason and Eugene discuss seismic interpretation with KU Geology
f. Establish a structural and geomechanical framework as a baseline for the microseismic and InSAR before the Mississippian injection begins.
g. Discuss permitting issues for Rick's high resolution seismic with Dana
h. Update the fluid substitution model to anticipate resolution of the CO2 using seismic.
i. Update DOE on the interaction with EPA on UDSW water well installation and upcoming discussions regarding the Class VI application.
j. Obtain contractual arrangements w/ CO2 suppliers.
k. Class II Permit Mississippian Injection well to drill the well around February 2015. Permit will be shared with DOE.

PRODUCTS

23

Publications, conference papers, and presentations

Yevhen Holubnyak*, Willard Watney, Jason Rush, and Fatemeh Fazelalavi, 2014, Reservoir Engineering Aspects of Pilot Scale CO2 EOR Project in Upper Mississippian Formation at Wellington Field in Southern Kansas, Energy Procedia 00 (2013) 000–000, 9 p.

Watney, W.L., 2014, "Carbon Storage and Utilization in Kansas – Are We Ready?" at Annual Oil and Gas Seminar, Kansas NextStep, Hays, Kansas.

Watney, W.L., Rush, J., and Raney, J., 2014, SMALL SCALE FIELD TEST DEMONSTRATING CO2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO2-EOR AT WELLINGTON FIELD SUMNER COUNTY, KANSAS DE-FE0006821Present update of project at DOE review meeting in Pittsburgh, Carbon Storage R&D Project Review Meeting Developing the Technologies and Infrastructure for CCS

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

A project organization chart follows (**Figure 19**). The work authorized in this budget period includes tasks discussed above.

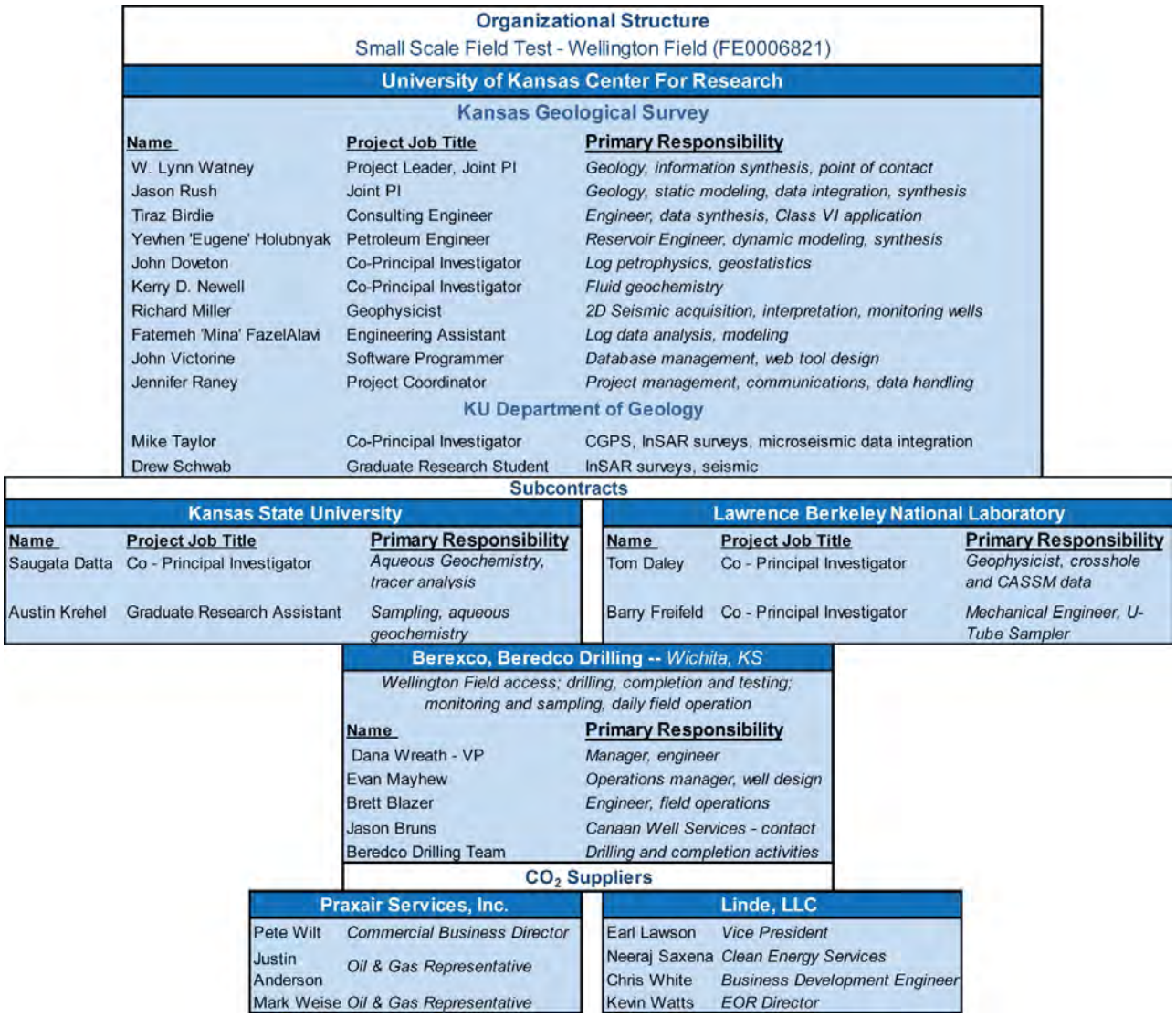


Figure 19. Organizational Chart.

IMPACT

See earlier discussion.

CHANGES/PROBLEMS

Please refer to earlier discussion.

APPENDIX II

Small Scale Field Test Demonstrating CO_2 Sequestration in Arbuckle Saline Aquifer and by CO_2-EOR at Wellington Field, Sumner County, Kansas

THIRTEENTH QUARTERLY PROGRESS REPORT

DOE F 4600.2
(03/11)
All Other Editions Are Obsolete

U.S. Department of Energy
FEDERAL ASSISTANCE REPORTING CHECKLIST
AND INSTRUCTIONS FOR RD&D PROJECTS

1. Identification Number: **DE-FE0006821**	2. Program/Project Title: **Small Scale Field Test Demonstration CO2 Sequestration**

3. Recipient: **University of Kansas Center for Research, Inc.**

4. Reporting Requirements:	Frequency	Addressees
A. MANAGEMENT REPORTING		
☒ Research Performance Progress Report (RPPR)	Q	FITS@NETL.DOE.GOV
☒ Special Status Report	A	FITS@NETL.DOE.GOV
B. SCIENTIFIC/TECHNICAL REPORTING		
(Reports/Products must be submitted with appropriate DOE F 241. The 241 forms are available at www.osti.gov/elink)		
Report/Product — Form		
☒ Final Scientific/Technical Report — DOE F 241.3	FG	http://www.osti.gov/elink-2413
☒ Conference papers/proceedings* — DOE F 241.3	A	http://www.osti.gov/elink-2413
☐ Software/Manual — DOE F 241.4		
☐ Other (see special instructions) — DOE F 241.3		
** Scientific and technical conferences only*		
C. FINANCIAL REPORTING		FITS@NETL.DOE.GOV
☒ SF-425 Federal Financial Report	Q, FG	
D. CLOSEOUT REPORTING		
☒ Patent Certification	FC	FITS@NETL.DOE.GOV
☒ SF-428 & 428B Final Property Report	FC	FITS@NETL.DOE.GOV
☐ Other		
E. OTHER REPORTING		See block 5 below for instructions.
☒ Annual Indirect Cost Proposal	O	
☐ Audit of For-Profit Recipients		FITS@NETL.DOE.GOV
☒ SF-428 Tangible Personal Property Report Forms Family	A	FITS@NETL.DOE.GOV
☒ Other – see block 5 below	A	

FREQUENCY CODES AND DUE DATES:

A - Within 5 calendar days after events or as specified.
FG- Final; 90 calendar days after the project period ends.
FC- Final; End of Effort.
Y - Yearly; 90 calendar days after the end of the reporting period.
S - Semiannually; within 30 calendar days after end of project year and project half-year.
Q - Quarterly; within 30 days after end of the reporting period.
Y180 – Yearly; 180 days after the end of the recipient's fiscal year
O - Other; See instructions for further details.

5. Special Instructions:

Annual Indirect Cost Proposal – If DOE is the Cognizant Federal Agency, then the proposal should be sent to FITS@NETL.DOE.GOV . Otherwise, it should be sent to the Cognizant Federal Agency.

Other – The Recipient shall provide all deliverables as contained in Section D of Attachment 2 Statement of Project Objectives.

1

QUARTERLY PROGRESS REPORT
To
DOE-NETL
Brian Dressel, Program Manager
Award Number: DE-FE0006821

SMALL SCALE FIELD TEST DEMONSTRATING CO_2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO_2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS

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Date of Report: February 15, 2015
DUNS Number: 076248616

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Project/Grant Period: 10/1/2011 through 9/30/2016

Thirteenth Quarterly Report

Period Covered by the Report: October 1, 2014 through December 31, 2014

Signature of Submitting Official:

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EXECUTIVE SUMMARY

Project Objectives

The objectives of this project are to understand the processes that occur when a maximum of 70,000 metric tonnes of CO_2 are injected into two different formations to evaluate the response in different lithofacies and depositional environments. The evaluation will be accomplished through the use of both *in situ* and indirect MVA (monitoring, verification, and accounting) technologies. The project will optimize for carbon storage accounting for 99% of the CO_2 using lab and field testing and comprehensive characterization and modeling techniques.

CO_2 will be injected under supercritical conditions to demonstrate state-of-the-art MVA tools and techniques to monitor and visualize the injected CO_2 plume and to refine geomodels developed using nearly continuous core, exhaustive wireline logs, and well tests and a multi-component 3D seismic survey. Reservoir simulation studies will map the injected CO_2 plume and estimate tonnage of CO_2 stored in solution, as residual gas, and by mineralization and integrate MVA results and reservoir models shall be used to evaluate CO_2 leakage. A rapid-response mitigation plan will be developed to minimize CO_2 leakage and provide comprehensive risk management strategy. A documentation of best practice methodologies for MVA and application for closure of the carbon storage test will complete the project. The CO_2 shall be supplied from a reliable facility and have an adequate delivery and quality of CO_2.

Scope of Work

Budget Period 1 includes updating reservoirs models at Wellington Field and filing Class II and Class VI injection permit application. Static 3D geocellular models of the Mississippian and Arbuckle shall integrate petrophysical information from core, wireline logs, and well tests with spatial and attribute information from their respective 3D seismic volumes. Dynamic models (composition simulations) of these reservoirs shall incorporate this information with laboratory data obtained from rock and fluid analyses to predict the properties of the CO_2 plume through time. The results will be used as the basis to establish the MVA and as a basis to compare with actual CO_2 injection. The small scale field test shall evaluate the accuracy of the models as a means to refine them in order to improve the predictions of the behavior and fate of CO_2 and optimizing carbon storage.

Budget Period 2 includes completing a Class II underground injection control permit; drilling and equipping a new borehole into the Mississippian reservoir for use in the first phase of CO_2 injection; establishing MVA infrastructure and acquiring baseline data; establishing source of CO_2 and transportation to the injection site; building injection facilities in the oil field; and injecting CO_2 into the Mississippian-age spiculitic cherty dolomitic open marine carbonate reservoir as part of the small scale carbon storage project.

In Budget Period 3, contingent on securing a Class VI injection permit, the drilling and completion of an observation well will be done to monitor injection of CO_2 under supercritical conditions into the Lower Ordovician Arbuckle shallow (peritidal) marine dolomitic reservoir. Monitoring during

pre-injection, during injection, and post injection will be accomplished with MVA tools and techniques to visualize CO_2 plume movement and will be used to reconcile simulation results. Necessary documentation will be submitted for closure of the small scale carbon storage project.

Project Goals

The proposed small scale injection will advance the science and practice of carbon sequestration in the Midcontinent by refining characterization and modeling, evaluating best practices for MVA tailored to the geologic setting, optimize methods for remediation and risk management, and provide technical information and training to enable additional projects and facilitate discussions on issues of liability and risk management for operators, regulators, and policy makers.

The data gathered as part of this research effort and pilot study will be shared with the Southwest Sequestration Partnership (SWP) and integrated into the National Carbon Sequestration Database and Geographic Information System (NATCARB) and the 6th Edition of the Carbon Sequestration Atlas of the United States and Canada.

Project Deliverables by Task

1.5 Well Drilling and Installation Plan (Can be Appendix to PMP or Quarterly Report)
1.6 MVA Plan (Can be Appendix to PMP or Quarterly Report)
1.7 Public Outreach Plan (Can be Appendix to PMP)
1.8 Arbuckle Injection Permit Application Review go/no go Memo
1.9 Mississippian Injection Permit Application Review go/no go Memo
1.10 Site Development, Operations, and Closure Plan (Can be Appendix to PMP)
2.0 Suitable geology for Injection Arbuckle go/no go Memo
3.0 Suitable geology for Injection Mississippian go/no go Memo
11.2 Capture and Compression Design and Cost Evaluation go/no go Memo
19 Updated Site Characterization/Conceptual Models (Can be Appendix to Quarterly Report)
21 Commercialization Plan (Can be Appendix to Quarterly Report).
30 Best Practices Plan (Can be Appendix to Quarterly or Final Report)

ACCOMPLISHMENTS

1. **Kickoff meeting with team on October 15, 2014 to implement plans for BP2.**
2. **Teleconferenced with Region 7 EPA in Lenexa, KS Washington office during the quarter to respond to questions Wellington Class VI application.**
3. **Obtained completion plans, drilled, and began testing of two of the shallow water wells to evaluate presence of USDW.**
4. **Started processing of data obtained from cGPS data to provide baseline for InSAR.**
5. **Instituted cost-center based billing through discussions with KGS, KUCR, and DOE to expedite invoicing and justification for DOE.**
6. **15 seismometers seismic array from IRIS-PASSCAL were placed on a cellular network.**

Milestone Status Report

Task	Budget Period	Number	Milestone Description
Task 2.	1	1	Site Characterization of Arbuckle Saline Aquifer System - Wellington Field
Task 3.	1	2	Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field
Task 10.	2	3	Pre-injection MVA - establish background (baseline) readings
Task 13.	2	4	Retrofit Arbuckle Injection Well (#1-28) for MVA Tool Installation
Task 18.	3-yr1	5	Compare Simulation Results with MVA Data and Analysis and Submit Update of Site Characterization, Modeling, and Monitoring Plan
Task 22.	3-yr1	6	Recondition Mississippian Boreholes Around Mississippian CO2-EOR injector
Task 27.	3-yr2	7	Evaluate CO2 Sequestration Potential of CO2-EOR Pilot
Task 28.	3-yr2	8	Evaluate Potential of Incremental Oil Recovery and CO2 Sequestration by CO2-EOR - Wellington field

Task 2 – Received written questions from EPA's on initial review of the projects Class VI application on December 23, 2014 including the Arbuckle simulation.

Task 3 – Mississippian geomodel and simulations slightly modified and three alternative locations of the Class II Mississippian injection well were obtained including original location. Original location confirmed for Class II well for filing Class II injection permit with the Kansas Corporation Commission in January 2015.

Task 10 – Two shallow water wells were drilled to evaluate for the presence of USDW in the project AOR. Initial fundings indicate low yield and saltwater, but further drilling and testing is being requested by EPA.

Project Schedule

BP2 activities are underway or planned as summarized below:

a) MVA implementation – seismometer array (installed Sept 2014), cGPS (installed Sept 2014), shallow USDW wells (Oct-Nov. 2014), soil gas (late 2014), re-pressuring Mississippian and sampling producing wells (~March 2015)
b) Class II application (to be filed Nov. 2014) and Public Outreach (Dec 2014)
c) Drill Mississippian injection well, #2-32 (~March 2015)
d) Inject CO2 (~April 2015) 120 metric tons per day, up to 26,000 metric tons, 8 months max.
e) EPA permit (March, now possibly April 2015)
f) Order fabrication of CASSM and U-Tube 8-9 months lead time (March 2015)
g) Drill #2-28 Arbuckle monitoring well (summer 2015)
h) Equip #2-28 with CAASM and U-Tube, and #1-28 for injection (Oct-Nov 2015)
i) Possibly deploy fiber optics in #2-28 in same timeframe -- DE-FEOO12700 -- Distributed Fiber Optic Arrays: Integrated Temperature and Seismic Sensing for Detection of CO2 Flow, Leakage and Subsurface Distribution - Rob Trautz, EPRI, PI
j) Inject CO2 in #1-28 (Nov 2015) -- 120 metric tons per day; up to 26,000 tonnes, 7.5 months max.
k) Post injection monitoring begin (July 2016) DOE project currently ends Sept 2016; extension for post injection site care defined by EPA using remaining funds

Activities of Lawrence Berkeley National Lab

Discussions on CAASM and U-Tube install began again at the Kickoff meeting and subsequent meetings were held with Tom Daley and Barry Freifeld at LBNL. LBNL continues to update the installation details and will soon supply diagrams tailored to equipping the Arbuckle injection and monitoring wells.

ONGOING ACTIVITIES

TASK 1. PROJECT MANAGEMENT AND REPORTING

Completed activities include –

- **Held kickoff meeting on October 15**

A.M. Session --
Discussed main activities in the morning session that are and will be performed in Budget Period 2 (ending August 31, 2015):

- MVA implementation – seismometer array (Sept 2015), InSAR and cgps (Sept 2015), shallow USDW wells (Oct 2015), soil gas (November 2015), re-pressuring Mississippian and sampling producing wells (Nov 2015)
- Class II application (Nov 2015) and Public Outreach (Dec 2015)
- Drill Mississippian injection well, #2-32 (by Feb. 2015)
- Inject CO2 (April 2015) 120 metric tons per day, up to 26,000 metric tons, approximately 8 months max.
- EPA permit (March 2015)
- Drill #2-28 Arbuckle monitoring well (March 2015)
- Equip #2-28 with CAASM and U-Tube, and #1-28 for injection (by Oct 2015)
- Inject CO2 in #1-28 (Nov 2015) -- 120 metric tons per day; up to 26,000 tonnes, 7.5 months max.
- Post injection monitoring begin (July 2016)
- DOE project currently ends Sept 30, 2016; extension for post injection site care to be defined by EPA using remaining funds.

Afternoon schedule of kickoff meeting:

12:00-12:15 -- Current status of the project -- Lynn Watney (KGS), Jennifer Raney (KGS), Tiraz Birdie (Birdie Consulting)
Main activities that are and will be performed in Budget Period 2 (ending August 31, 2015)
MVA implementation – seismometer array (Sept 2015), InSAR and cgps (Sept 2015), shallow USDW wells (Oct 2015), soil gas (November 2015), re-pressuring Mississippian and sampling producing wells (Nov 2015)
Class II application (Nov 2015) and Public Outreach (Dec 2015)
Drill Mississippian injection well, #2-32 (by Feb 2015)
Inject CO2 (April 2015) 120 metric tons per day, up to 26,000 metric tons, 8 months max.

EPA permit (March 2015)
Drill #2-28 Arbuckle monitoring well (March 2015)
Equip #2-28 with CAASM and U-Tube, and #1-28 for injection (Oct-Nov 2015)
Inject CO2 in #1-28 (Nov 2015) -- 120 metric tons per day; up to 26,000 tonnes, 7.5 months max.
Post injection monitoring begin (July 2016)
DOE project currently ends Sept 2016; extension for post injection site care defined by EPA using remaining funds
Brief summaries by Key Personnel
12:15-12:25 – Dana Wreath (Berexco, LLC), V.P. and Wellington Field operator
12:25-12:35 – Chris White (Linde LLC), Business Development Engineer, Oil and Gas Services
12:35-12:45 – Pete Wilt (Praxair Services, Inc.) Commercial Business Director - Oil and Gas Services with Justin Anderson and Mark Weise
12:45-12:55 -- Jason Rush (KGS, Joint P.I.) and Dave Newell, Wellington geomodel and performance
12:55-1:05 -- Eugene Holubnyak (KGS), Wellington simulation and field performance with Mina Fazelalavi
1:05-1:15 -- John Doveton (KGS), Petrophysical modeling & mechanical stratigraphy with Mina Fazelalavi and John Victorine
1:15-1:25 -- Rick Miller (KGS), water well drilling, seismometer install and operation, 2D high resolution seismic with Shelby Peterie
1:25-1:35 -- Mike Taylor (KU), InSAR, fault mapping with Drew Schwab, M.S. student; with support by Tandis Bidgoli
1:35-1:45 -- Saugata Datta (KSU), fluid and tracer sampling, water wells, Mississippian and Arbuckle monitoring wells with Austin Krehel, M.S. student
1:45-1:55 – Tom Daley (LBNL), continuous active seismic monitoring of Arbuckle injection, crosshole seismic, soil gas
1:55-2:05 – Barry Freifeld (LBNL), U-Tube insitu sampling of Arbuckle, soil gas

- Established invoicing protocol – cost center billing for Berexco accepted by Berexco, KGS, DOE, KUCR
- Holding scheduled conference calls with team (bimonthly)
- Prepared to file Class II injection permit for CO2-EOR well, Wellington KGS #2-32
- Press release prepared for Class II injection, but holding off until Class II permit is granted
- Install cellular network for remote communication with seismometers
- Install 3 accelerometer/broadband seismometers.
- PMP was revised on December 17th remove soil gas sampling grid and comment on go/no go decisions with respect to Class VI requirements and PISC

Subtask 1.7. Public Outreach Plan

Completed drafts of Public Information Circular, Fact Sheet, and KGS Press Release for upcoming work at Wellington. Press release (reviewed by key parties, project fact sheet,

website-visibility, and meet with public at Wellington to discuss the project and answer questions.)

Subtask 1.8. Arbuckle Injection Permit Application Review go/no go Memo

General Permit Application: EPA continues to review our permit application. Two wells were drilled to evaluate the presence of the USDW (**Figures 1 and 2**). Wells were completed in November 2014. Sample descriptions of 200 ft test well shows fine grained aquiclude that has yielded salty water. **Figure 3** provides a cross section of shallow interval above the Hutchinson Salt layer between KGS #1-32, KGS #-28, and USDW #2. **Figure 4** illustrates the very fine unconsolidated sand present in the top 14 ft of USDW #2. The bedrock strata beneath the sandy material is dominated by dark gray gypsiferous shale (**Figure 5**). The yield of both wells is very low as indicated by low recovery of the fluid levels after bailing (**Figure 6 and 7**).

Teleconference with EPA led to comments 11-26-14 that included alternative sampling locations, a request to submit a Quality Assurance Project Plan, and a recommendation to review ADM's approved plan.

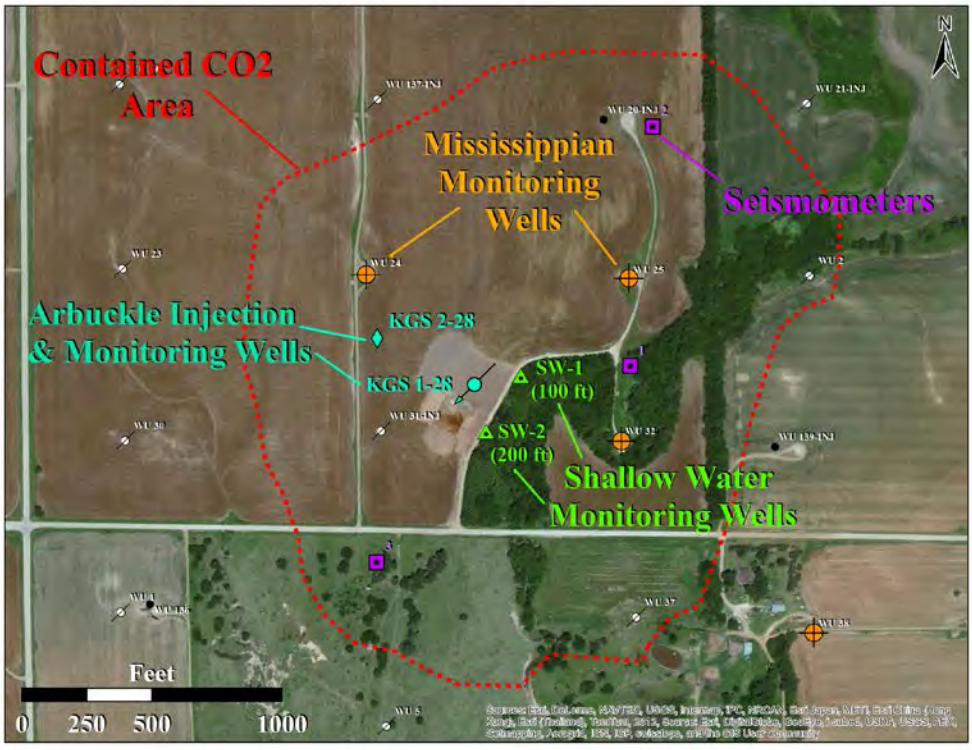


Figure 1. Base map at Wellington showing locations of USDW #1 and #2, located east of the Arbuckle injection well #1-28.

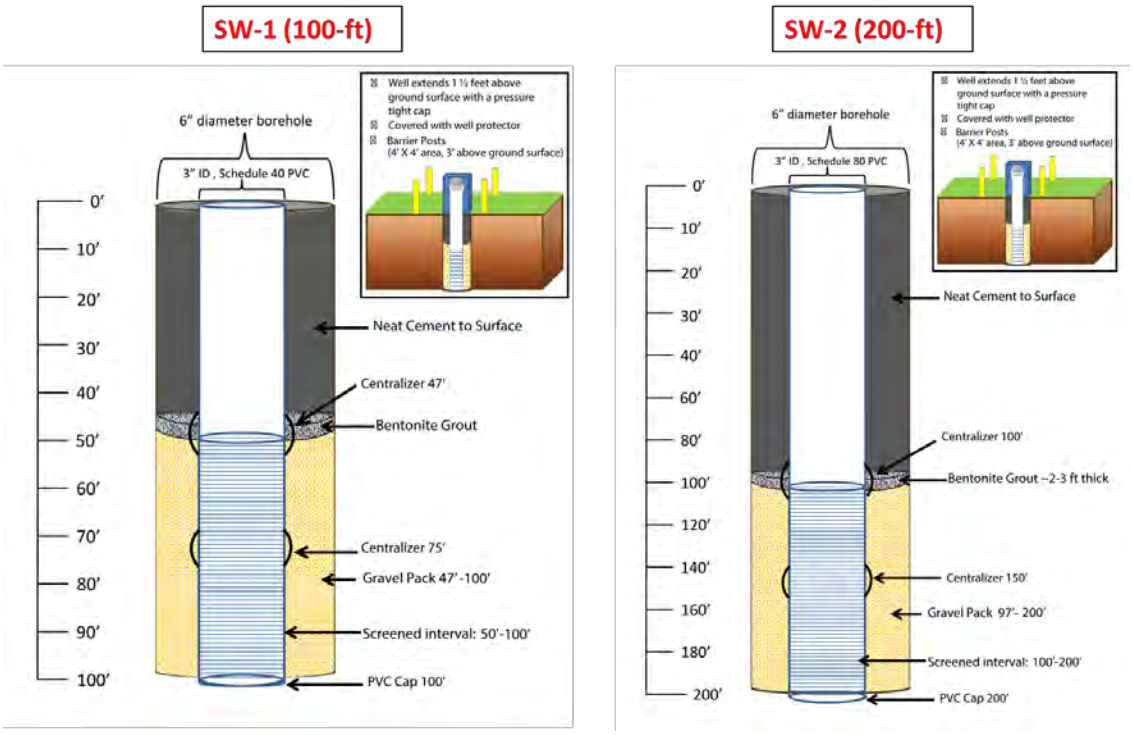


Figure 2. Completion diagrams of UDSW #1 and #2.

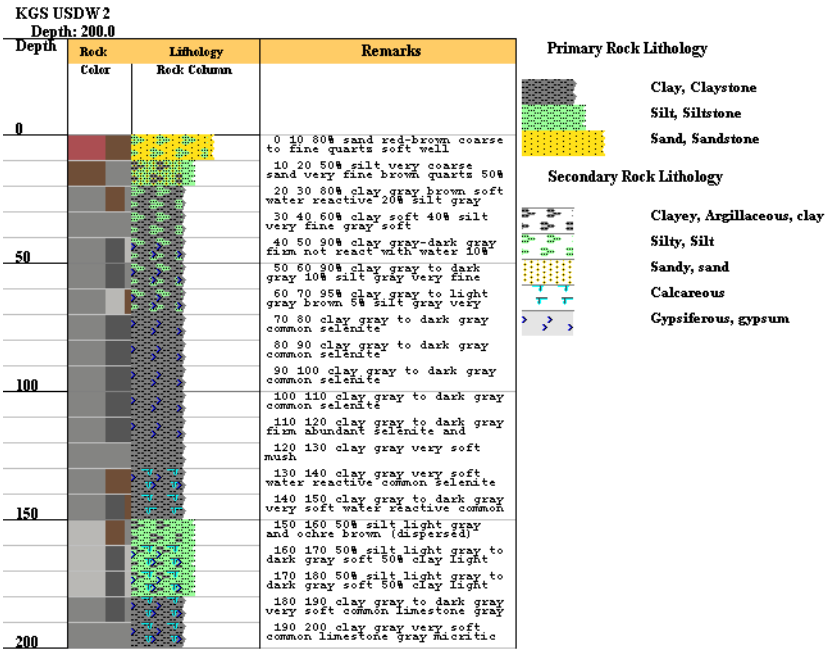


Figure 3. Sample description of deepest USDW monitoring well. Uppermost 10 ft has silt and sand and clay or silt below. Yield of this well has been low and water is briny.

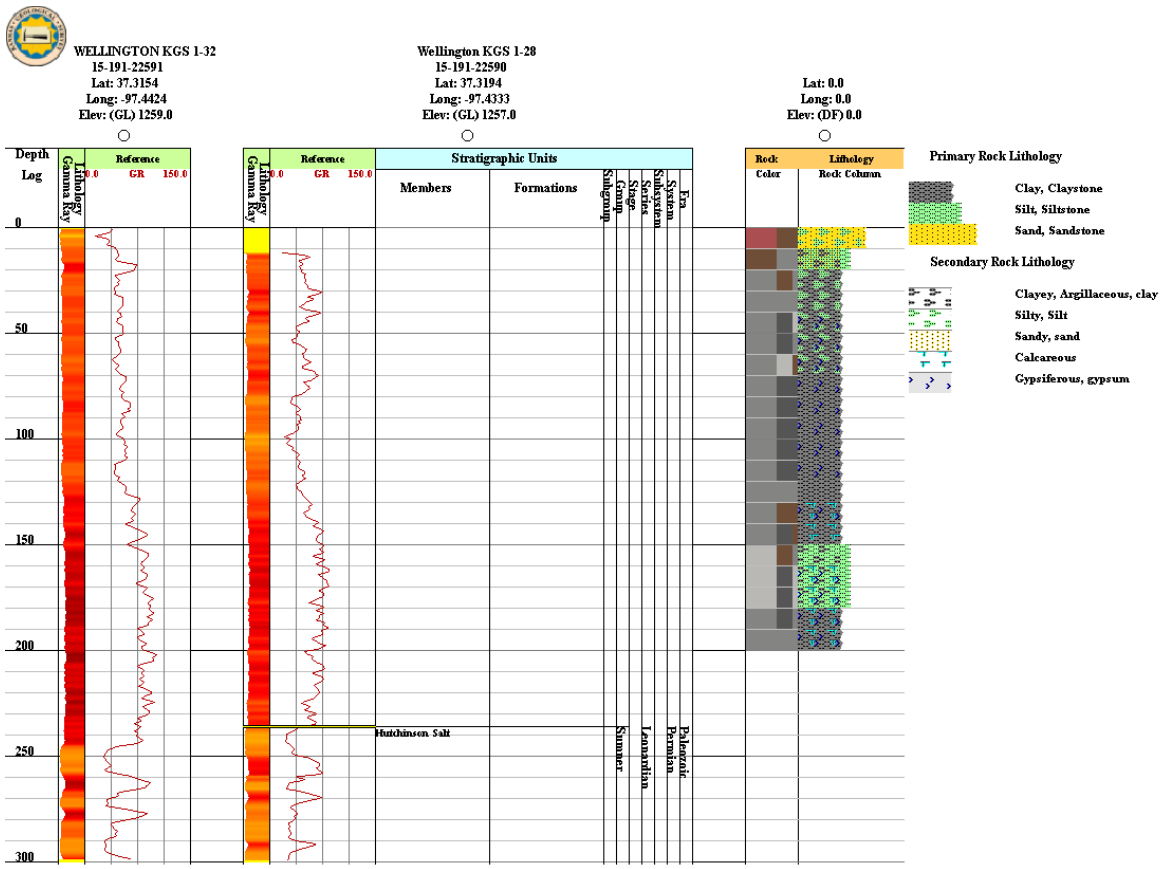


Figure 3. Cross section showing the extent of the Wellington Shale that is sampled in the deeper USDW monitoring well.

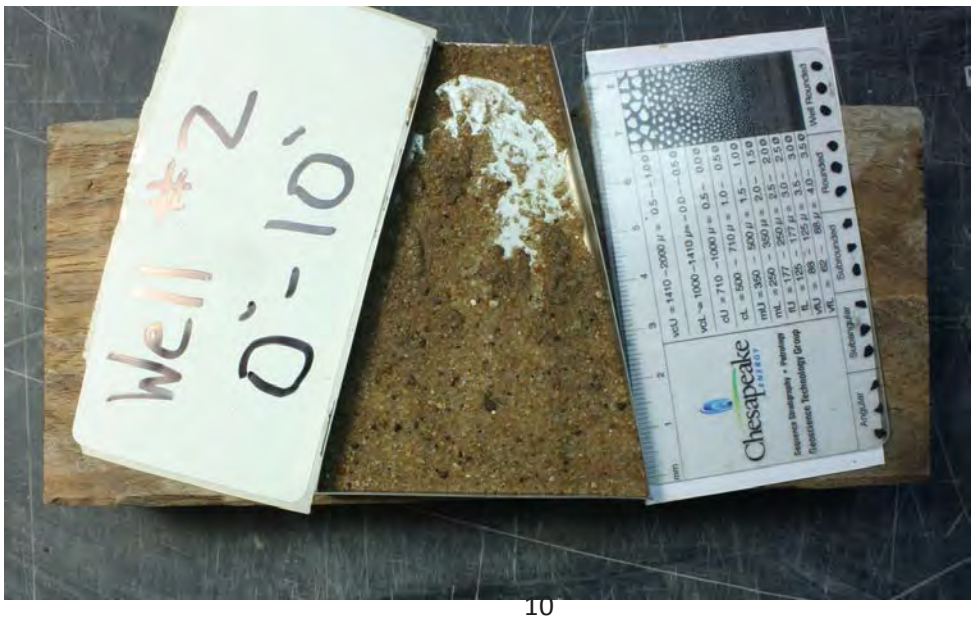
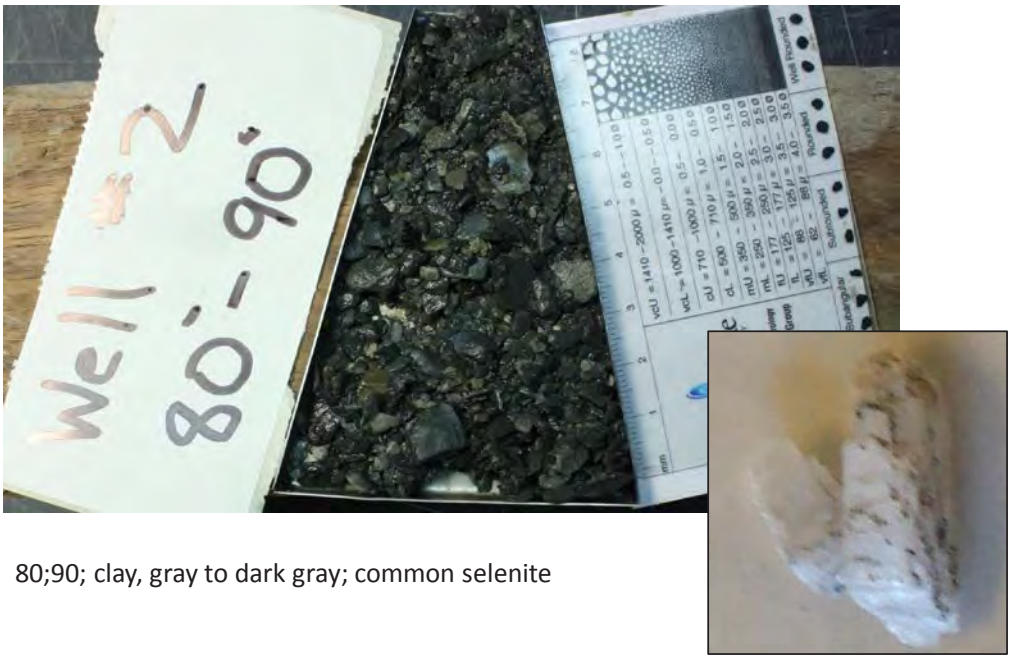


Figure 4. Sand, fine to coarse grained mixed with silt and clay, ochre to dark yellow. Loose, friable, separate grains.



80;90; clay, gray to dark gray; common selenite

Figure 5. Representative sample below 14 ft. consisting of dark gray silty clay to claystone containing scattered gypsum as noted in the inset photo.

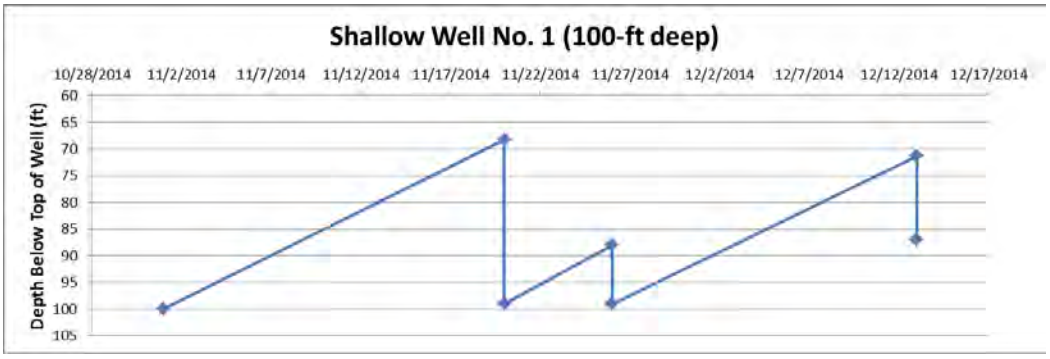


Figure 6. Changes change in fluid level fill up in shallow 100 ft deep USDW Well #1.

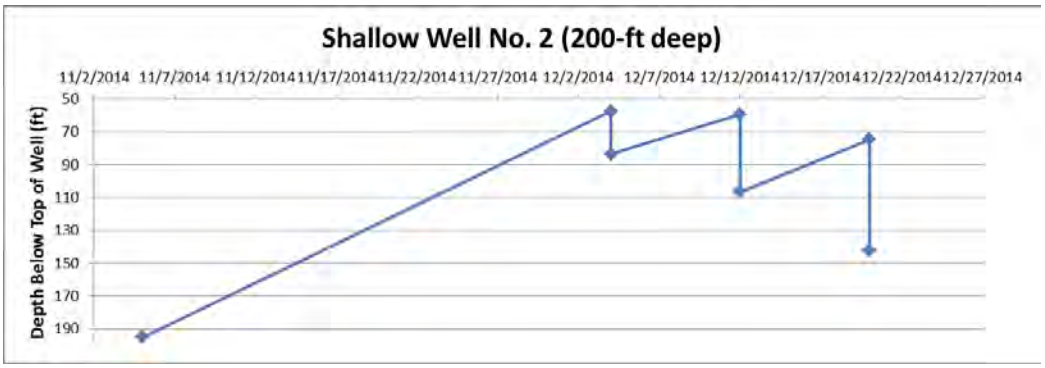


Figure 7. Slow buildup of water level in well #2 indicating low yield.

State regulators at Kansas Corporation Commission and Kansas Department of Health and Environment have been asked to review the Class VI application. Request has been made to again have a face-to-face meeting with Region 7 EPA.

On December 19, 2014 EPA provided a review of the entire Class VI application and with "*Request for Additional Information #1*" covering the major topics in a set of tables. Team is addressing questions. This is not a note of deficiencies, but is treated as an informal communication. The questions are part of four tables. The team is currently working on the responses to the questions.

- Table 1. AoR and Corrective Action – 28 questions
- Table 2. Testing and Monitoring (Ground Water/Plume/Pressure-Front Monitoring) – 18 questions
- Table 3. Testing and Monitoring (Other Monitoring) – 20 questions.
- Table 4. Testing and Monitoring (PISC and Site Closure) – 15 questions.

We have also approached EPA about reducing financial assurance and it was agreed to discuss topic in January 2015.

Seismicity -- EPA has asked us as part of the questions to comment on the increase in seismicity in the area to the west and south of Wellington. In addition to answering the question, the KGS has taken an active role including 1) deploying new seismometers in the region, 2) contributing to developing a response plan with the state regulators that affect brine disposal wells in the vicinity of the earthquakes as part of the *Induced Seismicity Task Force* appointed by the state, 3) obtaining information from petroleum industry on well activities to help evaluate the science behind seismicity. A presentation on earthquakes was made on December 2nd to the Kansas Geological Society -- http://www.kgs.ku.edu/PRS/Seismicity/KS_Geo_Society_Talk_12022014.pdf

The presentation was followed up by an endorsement of the KGS efforts by the Kansas Geological Society and the Kansas Independent Oil and Gas Association to seek a better scientific understanding of earthquakes. In addition a seminar at KU was developed for the

Spring 2015 semester to discuss induced seismicity. In addition, numerous inquiries of the press have been made concerning the earthquake, e.g.,

http://cjonline.com/news/2015-01-04/earthquake-monitors-being-installed-south-central-kansas -- Interviews with KGS geophysics team who set up the Wellington seismometers. http://www.wibwnewsnow.com/four-seismic-monitoring-stations-installed-south-central-kansas/ - interview with KGS Tandis Bidgoli.

Our response to EPA on earthquakes is that 1) the volume and rate of CO2 injected is orders of magnitude less than the brine disposal in south-central Kansas and central Oklahoma; 2) the monitoring of the injection including pressure, 3) seismicity monitoring with the 15-seismometer array, and 4) tracking plume movement in this highly characterized and tested location should avail them of any concerns of the project's injecion creating earthquakes. Geomechanical modeling of stress-strain during injection is being conveyed to EPA in writing, but will also be explained in a teleconference.

TASK 2. SITE CHARACTERIZATION OF ARBUCKLE SALINE AQUIFER SYSTEM - WELLINGTON FIELD (GO/NO-GO DECISION #3)

Additional analysis of the geomodel are being made as theses from DE-FE0002056 are completed.

TASK 3. SITE CHARACTERIZATION OF MISSISSIPPIAN RESERVOIR - WELLINGTON FIELD (CLASS II APPLICATION & GO/NO-GO DECISION #4)

The following figures (Figure 8-illustrate the refinement in the Mississippian geomodel that was recently done for verifying the location of the Class II injector.

Wellington Field

- **Contours are top Mississippian**
- **NE-SW fault**
  - **20+ ft of reflector offset** is best imaged at this depth (2810-ft TVDSS)
  - Fault tips out at top Mississippian
  - **Within the Mississippian, the fault may record strike/slip movement** as opposed to vertical offset in older strata
  - **Fault is discontinuous**
  - **Fault underwent episode of later movement** just prior to deposition of upper Pennsylvanian Oread Limestone

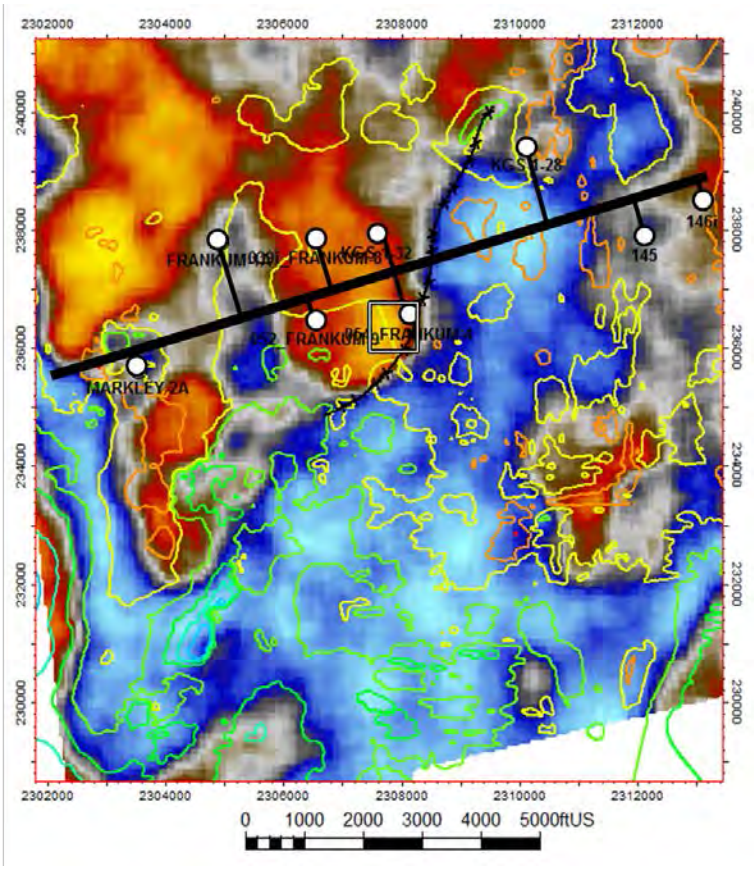


Figure 8. Geomodel of the top of the Mississippian resevoir at Wellington field.

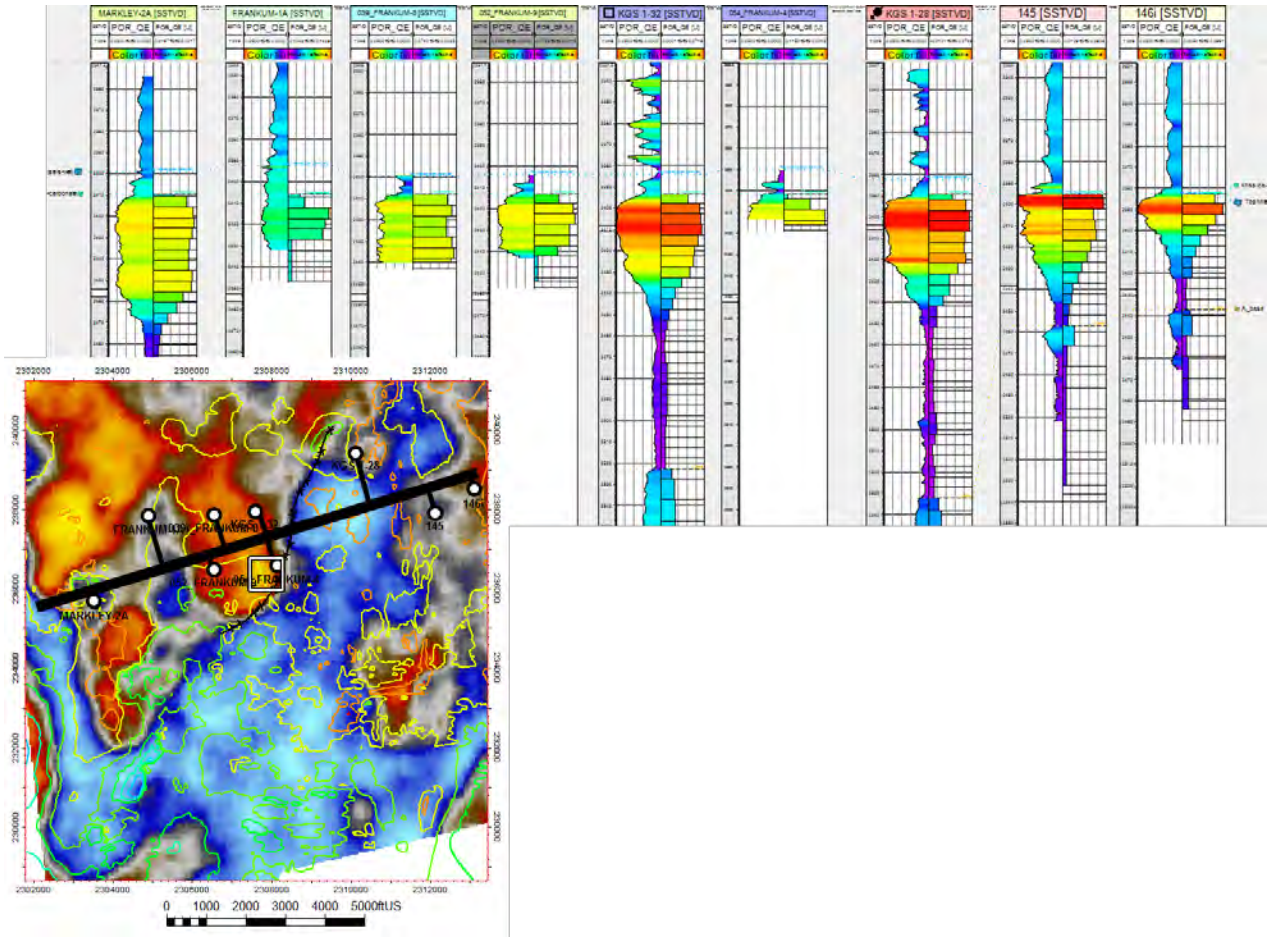


Figure 9. SW-NE cross section in upper most Mississippian at Wellngton Field showing variation in porosity of the pay zone. Hotter colors are higher values of porosity. The index map is the structure at the top of the Mississippian. Note the small yellow box in the central portion of the map. This is the location of the CO2 pilot.

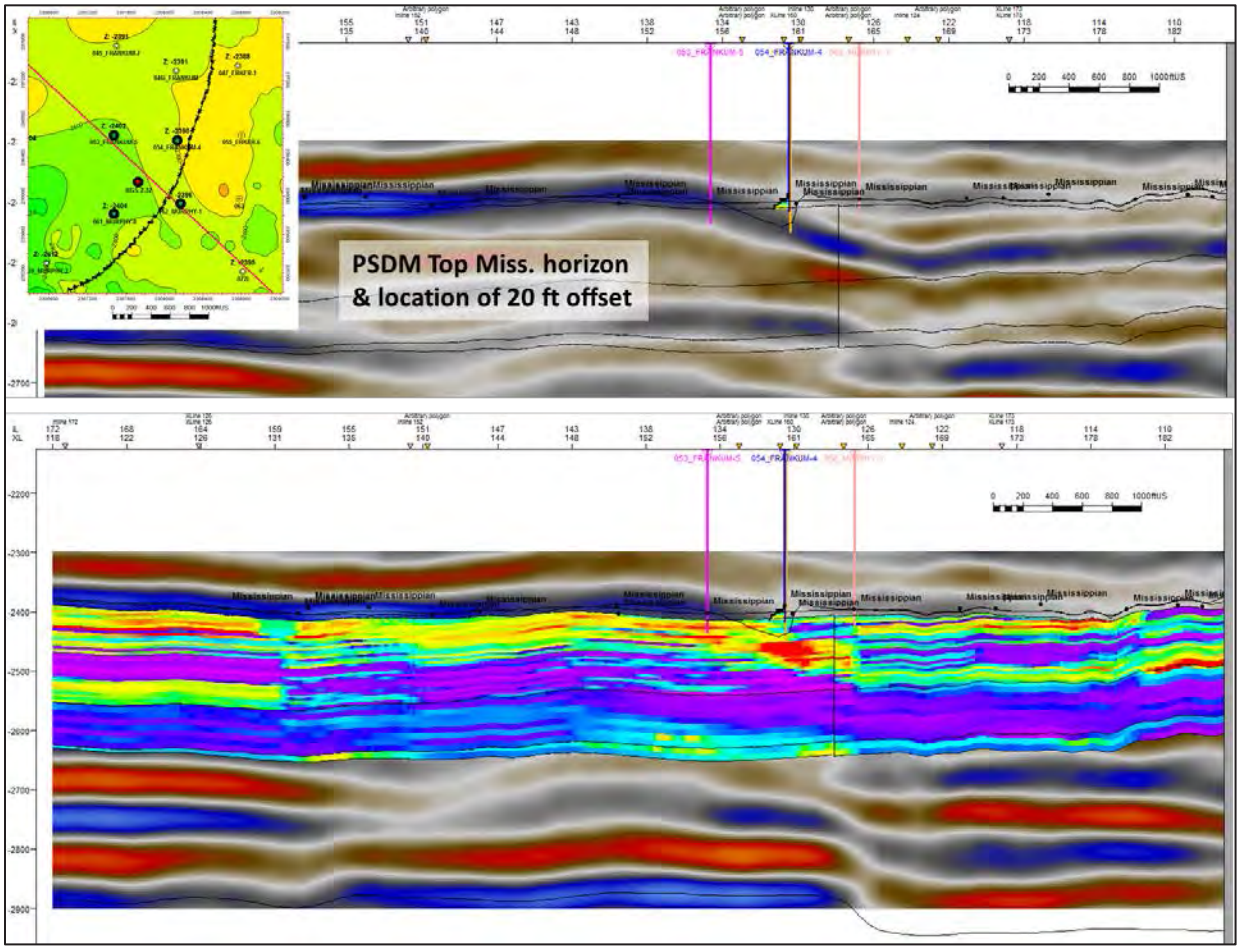


Figure 10. PSDM seismic line projected through 5-spot CO2 EOR, amplitude top and porosity section on bottom. Top Mississippian is constrained by well control. Note offlapping, progradational layering consistent with Mississippian depositional model. Doublet amplitude developed in the upper section on the right (east of the CO2-EOR site) complicates the interpretation. PSDM seismic Mississippian correlation and attribute work. Logging program for KGS 2-32 includes a sonic, which will aid future interpretation and depth-migration. Currently, sonic logs are absent where doublet is present.

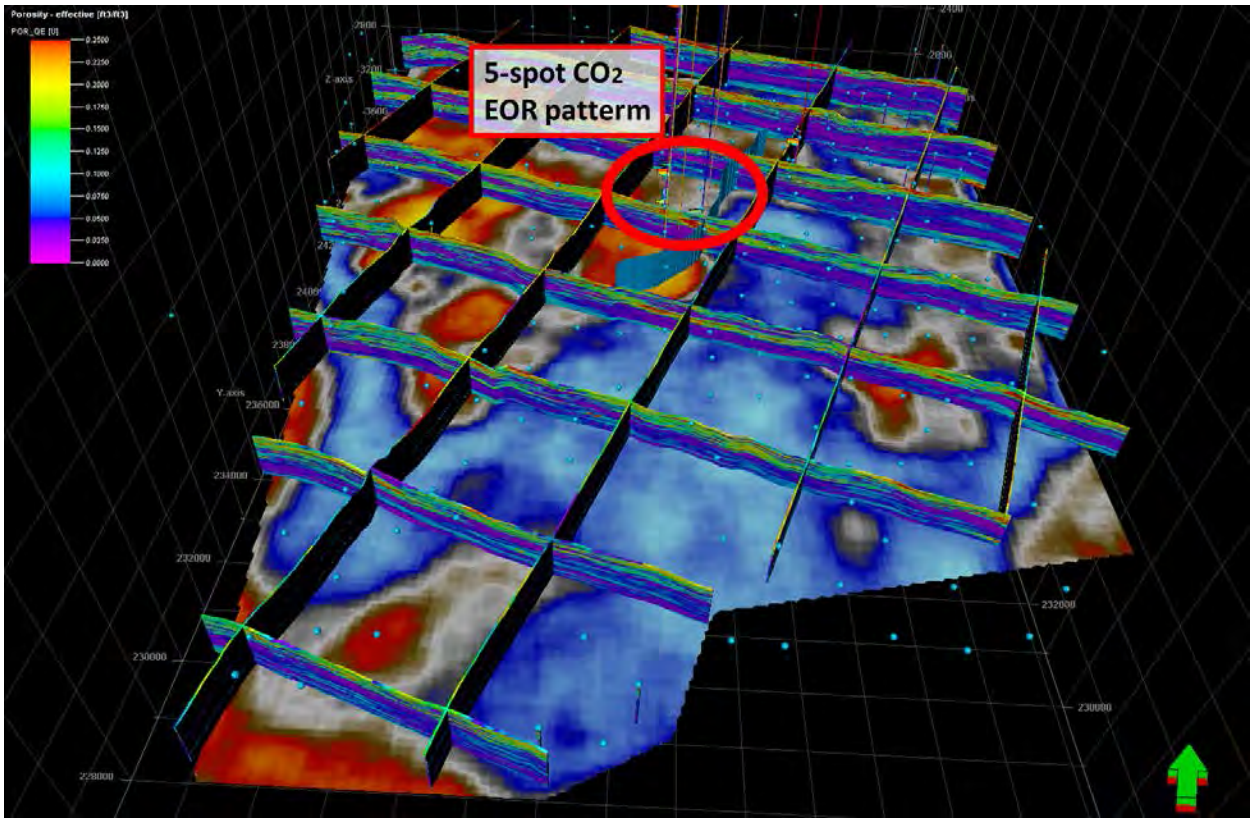


Figure 11. -2810 seismic horizon. Porosity model is conditioned to seismic porosity attribute. Layering style generates offlapping, westward-progradational geometries from a persistently (?) positive block along westward side of fault. Location of the CO2-EOR pilot area is shown.

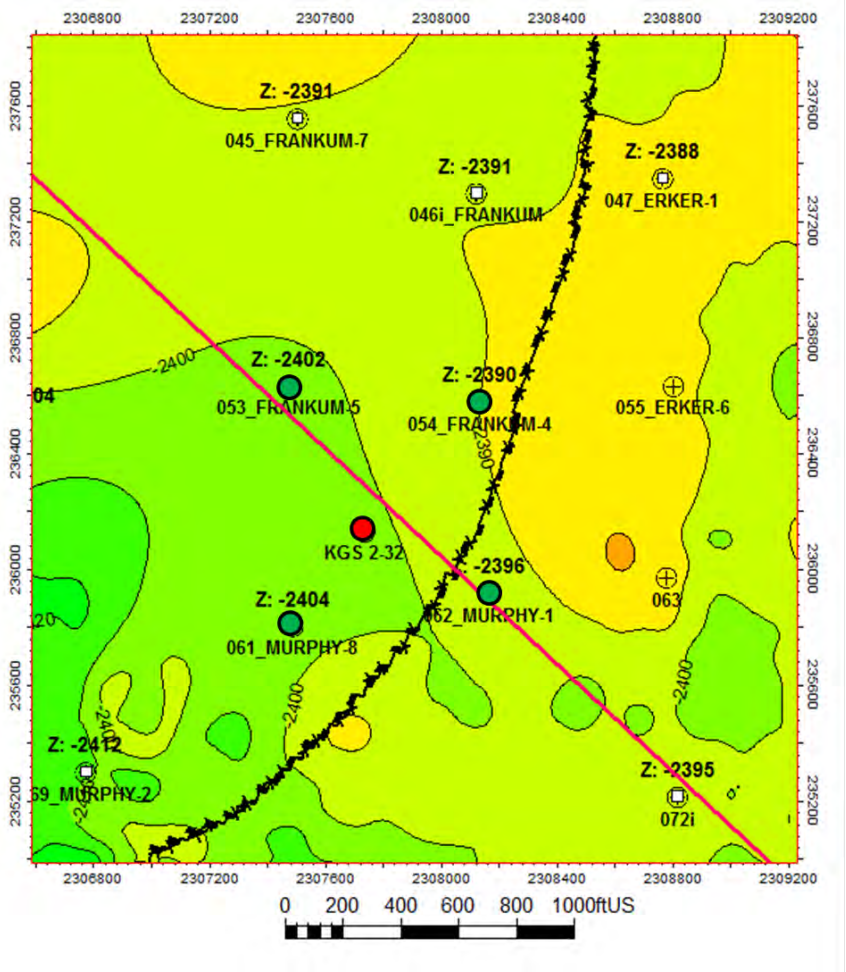


Figure 13. Structure map of CO2 EOR pilot area. Location of fault with small offset is identified by black hachured line.

TASK 5. SECURE CO2 SOURCE -- GO/NO-GO DECISION #5

Subtask 5.1 CO_2 Supply
Subtask 5.2 CO_2 Transportation

TASK 6. ESTABLISH MVA INFRASTRUCTURE - AROUND CO_2 INJECTOR FOR CARBON STORAGE

Subtask 6.1. Design MVA Components and Fabrication (Contingent on Go Decision pts 1&3)

Discussions continue on updating costs to fabricate and install CASSM and U-Tube apparatus.

Subtask 6.2. Install CGPS and Seismometers near Injection Borehole

The resolution of the seismometer array is high based in initial records (Figure 14). The objective is to refine location of events and new approaches are being tested. The reporting of felt earthquakes over 2.5 will certainly be met. What is being explored is the resolution limit and the potential use of the seismometer array to observe CO2 movement.

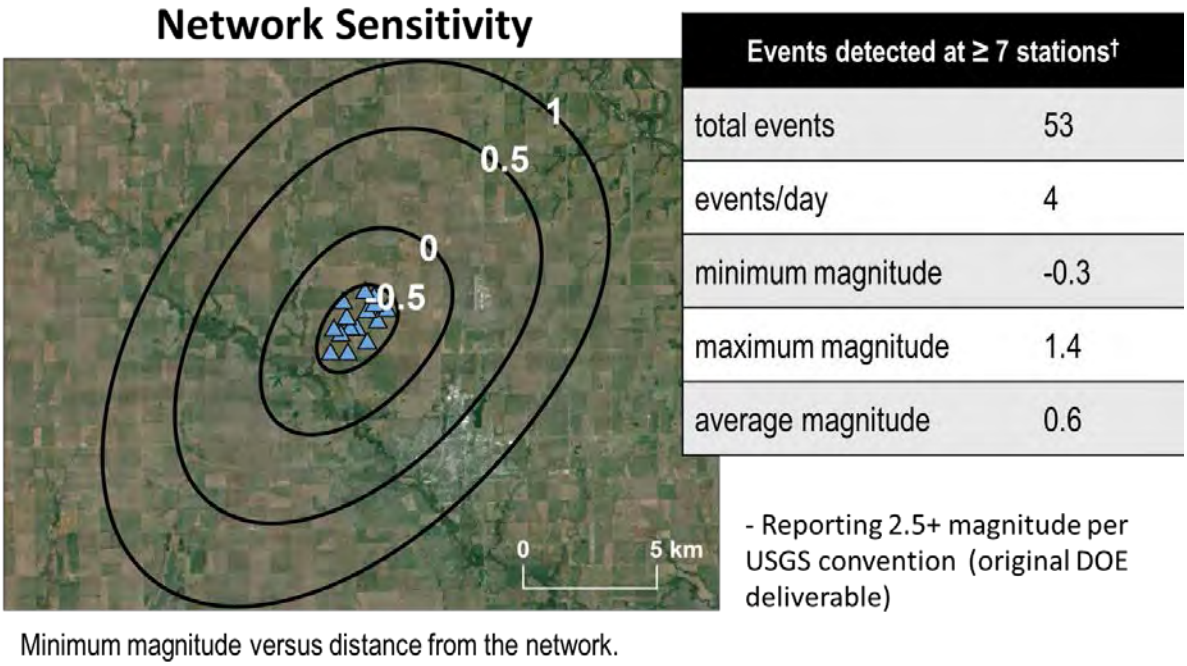


Figure 14. Sensitivity of the seismometer array installed at Wellington.

cGPS data is being acquired and analysis has begun. The data quality looks fine, but the information needs to be reduced to define a stable base line. This data can be post-processed to establish the baseline to aid in the analysis of the SAR data to quantify the motion that occurs during a time-lapse. At this point, it is not certain what the resolution of the ground motion will be.

Subtask 6.3. Establish Protocols for InSAR data collection

See above.

Subtask 6.4. Drill Shallow Freshwater Monitoring Boreholes (Contingent on Go Decision pts 1&3)

See discussion above.

Subtask 6.6. Soil Gas Sampling around Injector

Subtask 6.7. Outfit Surrounding Mississippian Boreholes for MVA (Contingent on Go pts 1&3)

Sampling will be done at Misissippian wells before the Mississippian reservoir is pressurized before CO2 is injected.

Subtask 7.5 High Res 2D Seismic Lines Targeting Mississippian Reservoir

TASK 8. RECONDITION MISSISSIPPIAN BOREHOLES AROUND MISSISSIPPIAN INJECTOR RE-PRESSURING MISSISSIPPIAN AND SAMPLING PRODUCING WELLS

This activity is anticipated to begin when the Class II well is drilled.

Key Findings

1. Shallow water wells #1 and #2 have yielded only saltwater in small amounts.
2. EPA is requesting additional sampling and testing to confirm that a USDW is not present in the AOR.
3. EPA has submitted questions to obtain additional information on our application for Class VI permit.
4. Cellular network is active for the 15 seismometers at Wellington.
5. The geomodel of the Mississippian reservoir was modified slightly in preparation to inject CO2.

Plans for Fourth Quarter 2014 (BP2 start date -- September 22, 2014)

1. Obtain Class II permit in March.
2. Drill Mississippian CO_2 injection well in March.
3. Complete updating costs.
4. Determine whether USDW is present in the project's AOR.
5. Obtain more details from EPA on granting the Class VI permit.

PRODUCTS

Publications, conference papers, and presentations

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

A project organization chart follows (**Figure 19**). The work authorized in this budget period includes tasks discussed above.

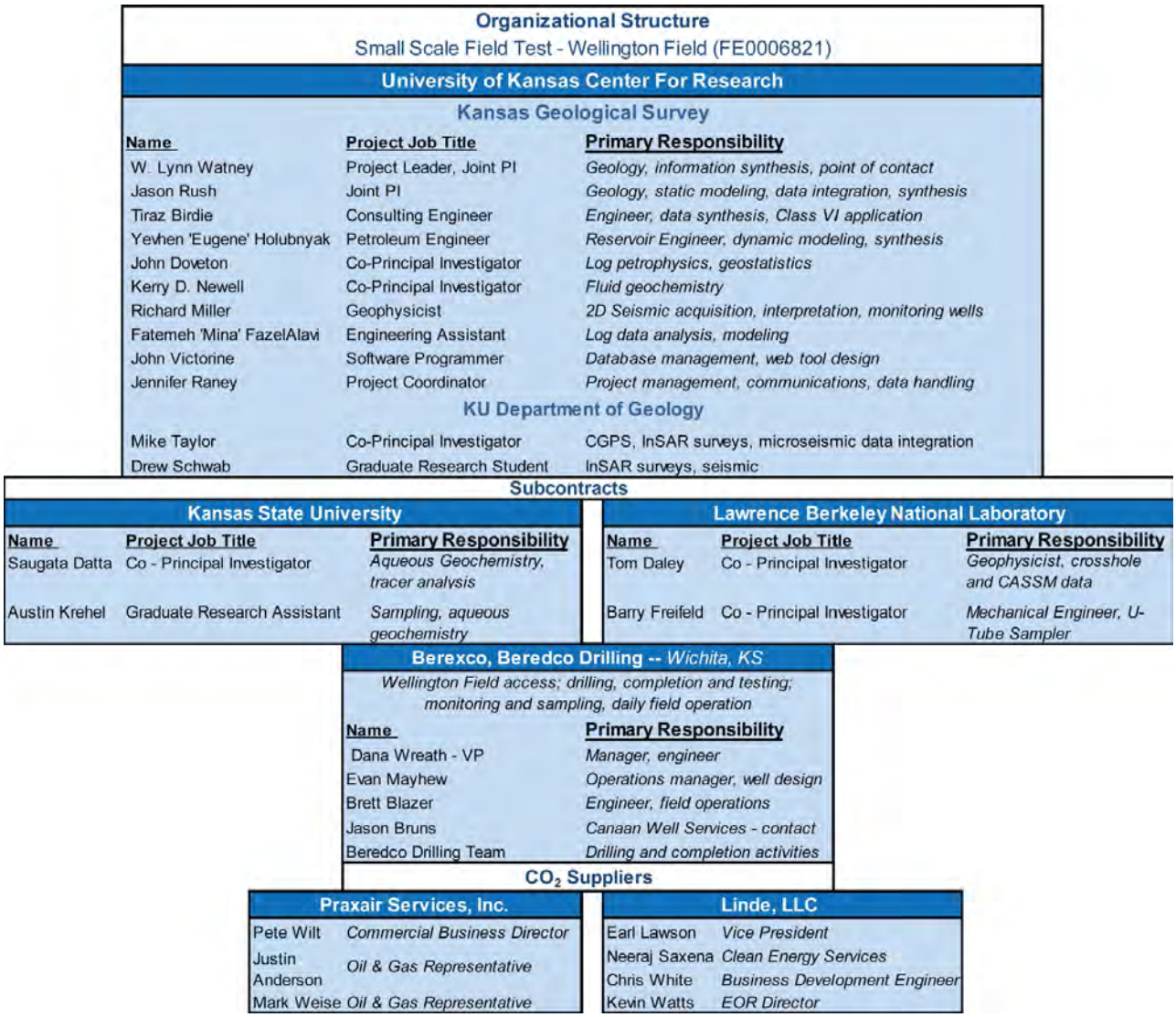


Figure 19. Organizational Chart.

IMPACT

See earlier discussion.

CHANGES/PROBLEMS

Please refer to earlier discussion.

BUDGETARY INFORMATION

Cost Status Report

See table below and on the following page for the cost status for quarters 1-13.

APPENDIX II

Small Scale Field Test Demonstrating CO_2 Sequestration in Arbuckle Saline Aquifer and by CO_2-EOR at Wellington Field, Sumner County, Kansas

FOURTEENTH QUARTERLY PROGRESS REPORT

DOE F 4600.2
(03/11)
All Other Editions Are Obsolete

U.S. Department of Energy
FEDERAL ASSISTANCE REPORTING CHECKLIST
AND INSTRUCTIONS FOR RD&D PROJECTS

1. Identification Number: **DE-FE0006821**	2. Program/Project Title: **Small Scale Field Test Demonstration CO2 Sequestration**

3. Recipient: **University of Kansas Center for Research, Inc.**

4. Reporting Requirements:	Frequency	Addressees
A. MANAGEMENT REPORTING		
☒ Research Performance Progress Report (RPPR)	Q	FITS@NETL.DOE.GOV
☒ Special Status Report	A	FITS@NETL.DOE.GOV
B. SCIENTIFIC/TECHNICAL REPORTING		
(Reports/Products must be submitted with appropriate DOE F 241. The 241 forms are available at www.osti.gov/elink)		
Report/Product — Form		
☒ Final Scientific/Technical Report — DOE F 241.3	FG	http://www.osti.gov/elink-2413
☒ Conference papers/proceedings* — DOE F 241.3	A	http://www.osti.gov/elink-2413
☐ Software/Manual — DOE F 241.4		
☐ Other (see special instructions) — DOE F 241.3		
** Scientific and technical conferences only*		
C. FINANCIAL REPORTING		FITS@NETL.DOE.GOV
☒ SF-425 Federal Financial Report	Q, FG	
D. CLOSEOUT REPORTING		
☒ Patent Certification	FC	FITS@NETL.DOE.GOV
☒ SF-428 & 428B Final Property Report	FC	FITS@NETL.DOE.GOV
☐ Other		
E. OTHER REPORTING		See block 5 below for instructions.
☒ Annual Indirect Cost Proposal	O	
☐ Audit of For-Profit Recipients		FITS@NETL.DOE.GOV
☒ SF-428 Tangible Personal Property Report Forms Family	A	FITS@NETL.DOE.GOV
☒ Other – see block 5 below	A	

FREQUENCY CODES AND DUE DATES:

A - Within 5 calendar days after events or as specified.
FG- Final; 90 calendar days after the project period ends.
FC- Final; End of Effort.
Y - Yearly; 90 calendar days after the end of the reporting period.
S - Semiannually; within 30 calendar days after end of project year and project half-year.
Q - Quarterly; within 30 days after end of the reporting period.
Y180 – Yearly; 180 days after the end of the recipient's fiscal year
O - Other; See instructions for further details.

5. Special Instructions:

Annual Indirect Cost Proposal – If DOE is the Cognizant Federal Agency, then the proposal should be sent to FITS@NETL.DOE.GOV . Otherwise, it should be sent to the Cognizant Federal Agency.

Other – The Recipient shall provide all deliverables as contained in Section D of Attachment 2 Statement of Project Objectives.

1

QUARTERLY PROGRESS REPORT
To
DOE-NETL
Brian Dressel, Program Manager
Award Number: DE-FE0006821

SMALL SCALE FIELD TEST DEMONSTRATING CO_2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO_2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS

Project Director/Principal Investigator:
W. Lynn Watney
Senior Scientific Fellow
Kansas Geological Survey

Ph: 785-864-2184, Fax: 785-864-5317
lwatney@kgs.ku.edu

Joint Principal Investigator:
Jason Rush

Prepared by Lynn Watney
Date of Report: May 11, 2015
DUNS Number: 076248616

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

Project/Grant Period: 10/1/2011 through 9/30/2016

Fourteenth Quarterly Report

Period Covered by the Report: January 1, 2015 through March 31, 2015

Signature of Submitting Official:

_____

EXECUTIVE SUMMARY

Project Objectives

The objectives of this project are to understand the processes that occur when a maximum of 70,000 metric tonnes of CO_2 are injected into two different formations to evaluate the response in different lithofacies and depositional environments. The evaluation will be accomplished through the use of both *in situ* and indirect MVA (monitoring, verification, and accounting) technologies. The project will optimize for carbon storage accounting for 99% of the CO_2 using lab and field testing and comprehensive characterization and modeling techniques.

CO_2 will be injected under supercritical conditions to demonstrate state-of-the-art MVA tools and techniques to monitor and visualize the injected CO_2 plume and to refine geomodels developed using nearly continuous core, exhaustive wireline logs, and well tests and a multi-component 3D seismic survey. Reservoir simulation studies will map the injected CO_2 plume and estimate tonnage of CO_2 stored in solution, as residual gas, and by mineralization and integrate MVA results and reservoir models shall be used to evaluate CO_2 leakage. A rapid-response mitigation plan will be developed to minimize CO_2 leakage and provide comprehensive risk management strategy. A documentation of best practice methodologies for MVA and application for closure of the carbon storage test will complete the project. The CO_2 shall be supplied from a reliable facility and have an adequate delivery and quality of CO_2.

Scope of Work

Budget Period 1 includes updating reservoirs models at Wellington Field and filing Class II and Class VI injection permit application. Static 3D geocellular models of the Mississippian and Arbuckle shall integrate petrophysical information from core, wireline logs, and well tests with spatial and attribute information from their respective 3D seismic volumes. Dynamic models (composition simulations) of these reservoirs shall incorporate this information with laboratory data obtained from rock and fluid analyses to predict the properties of the CO_2 plume through time. The results will be used as the basis to establish the MVA and as a basis to compare with actual CO_2 injection. The small scale field test shall evaluate the accuracy of the models as a means to refine them in order to improve the predictions of the behavior and fate of CO_2 and optimizing carbon storage.

Budget Period 2 includes completing a Class II underground injection control permit; drilling and equipping a new borehole into the Mississippian reservoir for use in the first phase of CO_2 injection; establishing MVA infrastructure and acquiring baseline data; establishing source of CO_2 and transportation to the injection site; building injection facilities in the oil field; and injecting CO_2 into the Mississippian-age spiculitic cherty dolomitic open marine carbonate reservoir as part of the small scale carbon storage project.

In Budget Period 3, contingent on securing a Class VI injection permit, the drilling and completion of an observation well will be done to monitor injection of CO_2 under supercritical conditions into

the Lower Ordovician Arbuckle shallow (peritidal) marine dolomitic reservoir. Monitoring during pre-injection, during injection, and post injection will be accomplished with MVA tools and techniques to visualize CO_2 plume movement and will be used to reconcile simulation results. Necessary documentation will be submitted for closure of the small scale carbon storage project.

Project Goals

The proposed small scale injection will advance the science and practice of carbon sequestration in the Midcontinent by refining characterization and modeling, evaluating best practices for MVA tailored to the geologic setting, optimize methods for remediation and risk management, and provide technical information and training to enable additional projects and facilitate discussions on issues of liability and risk management for operators, regulators, and policy makers.

The data gathered as part of this research effort and pilot study will be shared with the Southwest Sequestration Partnership (SWP) and integrated into the National Carbon Sequestration Database and Geographic Information System (NATCARB) and the 6th Edition of the Carbon Sequestration Atlas of the United States and Canada.

Project Deliverables by Task

1.5 Well Drilling and Installation Plan (Can be Appendix to PMP or Quarterly Report)
1.6 MVA Plan (Can be Appendix to PMP or Quarterly Report)
1.7 Public Outreach Plan (Can be Appendix to PMP)
1.8 Arbuckle Injection Permit Application Review go/no go Memo
1.9 Mississippian Injection Permit Application Review go/no go Memo
1.10 Site Development, Operations, and Closure Plan (Can be Appendix to PMP)
2.0 Suitable geology for Injection Arbuckle go/no go Memo
3.0 Suitable geology for Injection Mississippian go/no go Memo
11.2 Capture and Compression Design and Cost Evaluation go/no go Memo
19 Updated Site Characterization/Conceptual Models (Can be Appendix to Quarterly Report)
21 Commercialization Plan (Can be Appendix to Quarterly Report).
30 Best Practices Plan (Can be Appendix to Quarterly or Final Report)

ACCOMPLISHMENTS

1. **Participated in DOE peer review in Pittsburgh on March 5.**
2. **Class II application was filed with Kansas Corporation Commission in January and approved in February 2015.**
3. **Continued conference calls and written communications with EPA regarding review of Class VI application. Submitted responses to requests from EPA for additional information (RAI) in regards to the application. Responded to inquiries regarding**

evaluation of surface water with drilling, completion, testing, and analyses fit for purpose to evaluate the presence of a USDW.

4. **Drilled and completed three shallow water wells and conducted extensive sampling, pumping, and lab work to evaluate surface waters in AOR. Findings to date is that the shallow bedrock in the AOR is primarily a low yield, brine saturated aquiclude that overlies and is in equilibrium with diffusive dissolution from the underlying shallow Hutchinson salt. Surface water in AOR and immediately vicinity is limited to thin surficial colluvium and alluvial lenses.**
5. **Drilled Berexco Wellington KGS #2-32 in March 2015. Surface sampling and wireline logging above surface casing enhanced understanding of the presence of surface aquifer and aquitard system. The Mississippian oil reservoir was cored, evaluated with modern wireline logs, and is undergoing testing. The reservoir at #2-32 consists of an evenly porous (20-25% porosity) interval that is ~60 ft thick. The upper 40 ft is at residual oil saturation indicating that location has been effectively waterflooded and is in communication with one or more injection wells.**
6. **KGS #2-28 will be further tested, cores will be analyzed, and models will be adjusted to determine how the reservoir is re-pressured and what the anticipated CO2 plume will be.**

Milestone Status Report

Task	Budget Period	Number	Milestone Description
Task 2.	1	1	Site Characterization of Arbuckle Saline Aquifer System - Wellington Field
Task 3.	1	2	Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field
Task 10.	2	3	Pre-injection MVA - establish background (baseline) readings
Task 13.	2	4	Retrofit Arbuckle Injection Well (#1-28) for MVA Tool Installation
Task 18.	3-yr1	5	Compare Simulation Results with MVA Data and Analysis and Submit Update of Site Characterization, Modeling, and Monitoring Plan
Task 22.	3-yr1	6	Recondition Mississippian Boreholes Around Mississippian CO2-EOR injector
Task 27.	3-yr2	7	Evaluate CO2 Sequestration Potential of CO2-EOR Pilot
Task 28.	3-yr2	8	Evaluate Potential of Incremental Oil Recovery and CO2 Sequestration by CO2-EOR - Wellington field

Task 2 – Site Characterization of Arbuckle Saline Aquifer System - Wellington Field

Focus of efforts in January to early March were directed to complete responses to questions from EPA on the Class VI application submitted to us on December 24, 2014. All responses submitted to EPA on March 4, 2015, including:

- Table 1. AoR and Corrective Action
- Table 2. Testing and Monitoring (Ground Water/Plume/Pressure-Front Monitoring)
- Table 3. Testing and Monitoring (Other Monitoring)
- Table 4. Testing and Monitoring (PISC and Site Closure)

On March 3rd, provided updated Gantt chart to DOE with best and worst case scenarios for approval of Class VI application (**Figure 1**):

> Scenario #1: Most probable - Complete review of Class VI in May. Begin fabrication of U-tube & CASSM in May and complete in October. Install and test CASSM U-tube in Nov-Dec. Inject CO2 in Arbuckle in January 2017 through August. Close September 2017 with carryover funds.

> Scenario #2: Worst case -- Complete EPA review for public comment in July. Begin fabrication of CASSM & U-tube in July and complete in December. Install and test CASSM & U-tube in Jan.-Feb. 2016. Inject CO2 in March 2016 and complete Oct. 30, 2016. PISC through Nov.2017 with carryover funds.

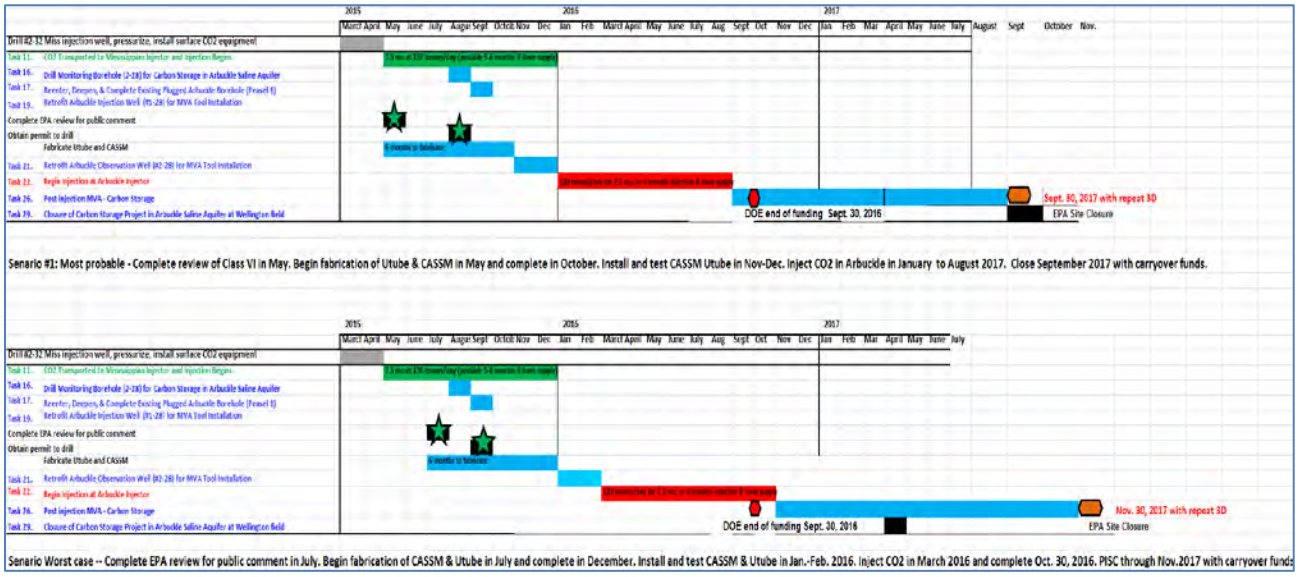


Figure 1. Suggested Class VI and injection schedules for best and worst case.

Updates to the Arbuckle model showed lower pressures (~60%) and much smaller free phase CO2 than previous versions. This decrease in pressure and free phase was noted in the model after introducing capillary pressure (**Figure 2**). It is expected that the notable plume will be a near wellbore event with dilute CO_2 in solution beyond with a similar AoR. This has been presented to EPA to support ongoing requests to reduce EPA requirements for financial assurance and PISC.

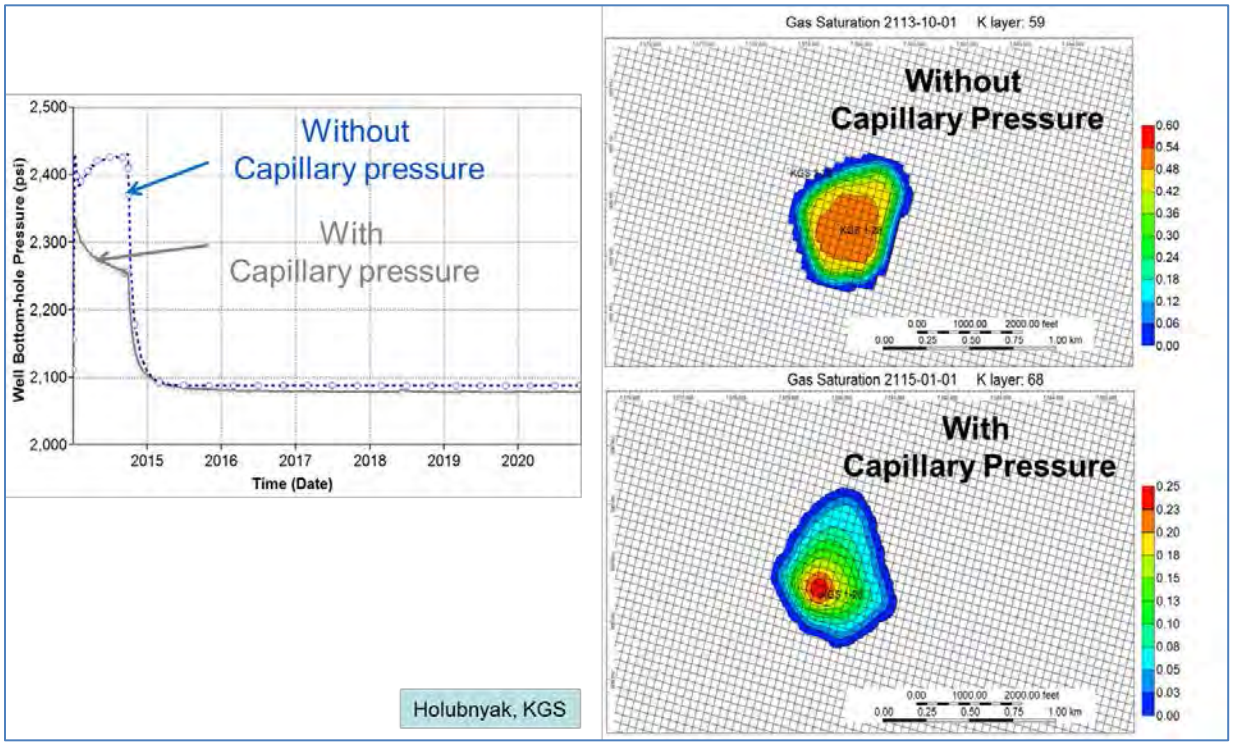


Figure 2. Simulation of Arbuckle CO2 Injection bottom hole pressure and free-phase CO_2 maximum plume.

Task 3 – Site characterization of Mississippian Reservoir - Wellington Field

Class II application to obtain a permit to inject CO2 into the Mississippian oil reservoir was filed with Kansas Corporation Commission in January and the permit was received in February. An "Intent to drill" application was then filed to drill the Mississippian injection well during March. See more discussion below.

The pilot CO_2-EOR injection at Wellington Field will serve as a calibration site and field demonstration to engage petroleum industry on merits of CO_2-EOR in Kansas and

- Convey requirements for using and storing anthropogenic sources of CO_2
- Test best practices
- Cost-effective characterization, modeling, and monitoring to aid in applying next-generation CO_2-EOR methods
- Refine model realizations to optimize for commercial scale CO_2 sequestration
- Managing operation, reduce economic and environmental risks, compliance with regulations
- Couple the oil field and the underlying saline aquifer to increase the CO_2 sequestration capacity

- Relay experience with Class VI geosequestration with EPA so as to understand requirements for using CCUS in carbon storage.

Task 6. Establish MVA Infrastructure

Subtask 6.2. Install CGPS and seismometers near injection borehole

Obtained initial data from CGPS and SAR – Data has been collected from the cGPS since August 2014 and a steady baseline is being recorded (**Figure 3**).

Figure 4 is the first scene of the side looking satellite-based radar for Wellington. Subsequent scenes are being taken on a monthly interval to capture any changes during re-pressuring the Mississippian and the CO2 injection. The cGPS appears to be showing the stability we need to refine the estimates of any ground deformation.

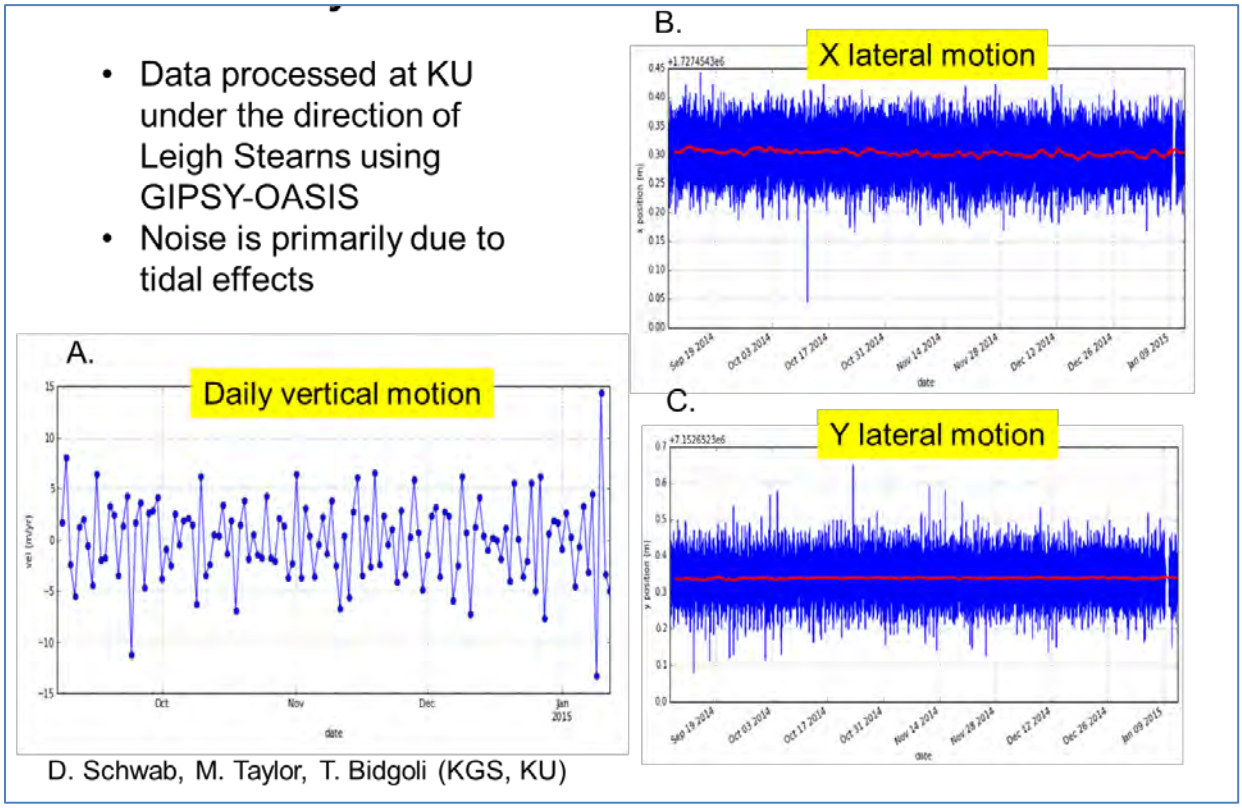


Figure 3. Data from August 2014 to February 2015 being obtained from continuous GPS instrument installed at Wellington Field.

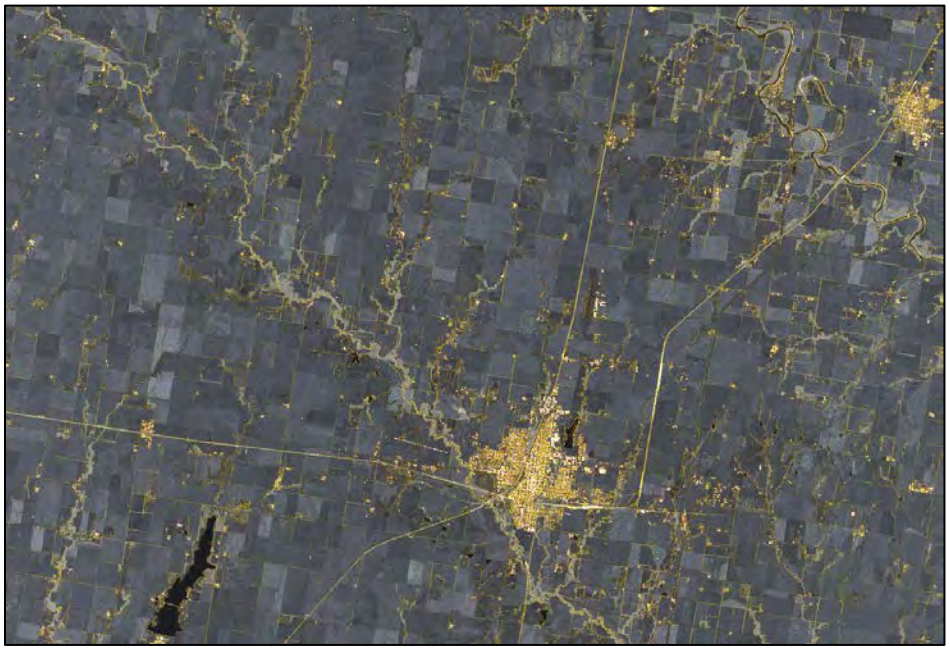


Figure 4. This is the first SAR acquisition from Terrasar-X illustrated in low resolution.

Wellington townsite is the bright area is located below the middle of the image. Future scenes will be used to create the interferometry used to deduce the changes in surface elevation.

Concurrent with this monitoring we are examining microseismic events and sampling the Mississippian wells for baseline and changes in brine chemistry as well as oil and CO_2 that are recovered.

For the past quarter, efforts have been made by J. Victorine to calibrate the velocity field at Wellington to obtain more precise location of hypocenters of microseismic events beneath Wellington (**Figure 5**). "Davies" sample logs and the sonic logs provide a useful means to obtain a good average Vp and Vs velocities. It is further necessary to compute accurate time differences for small events under the sensors.

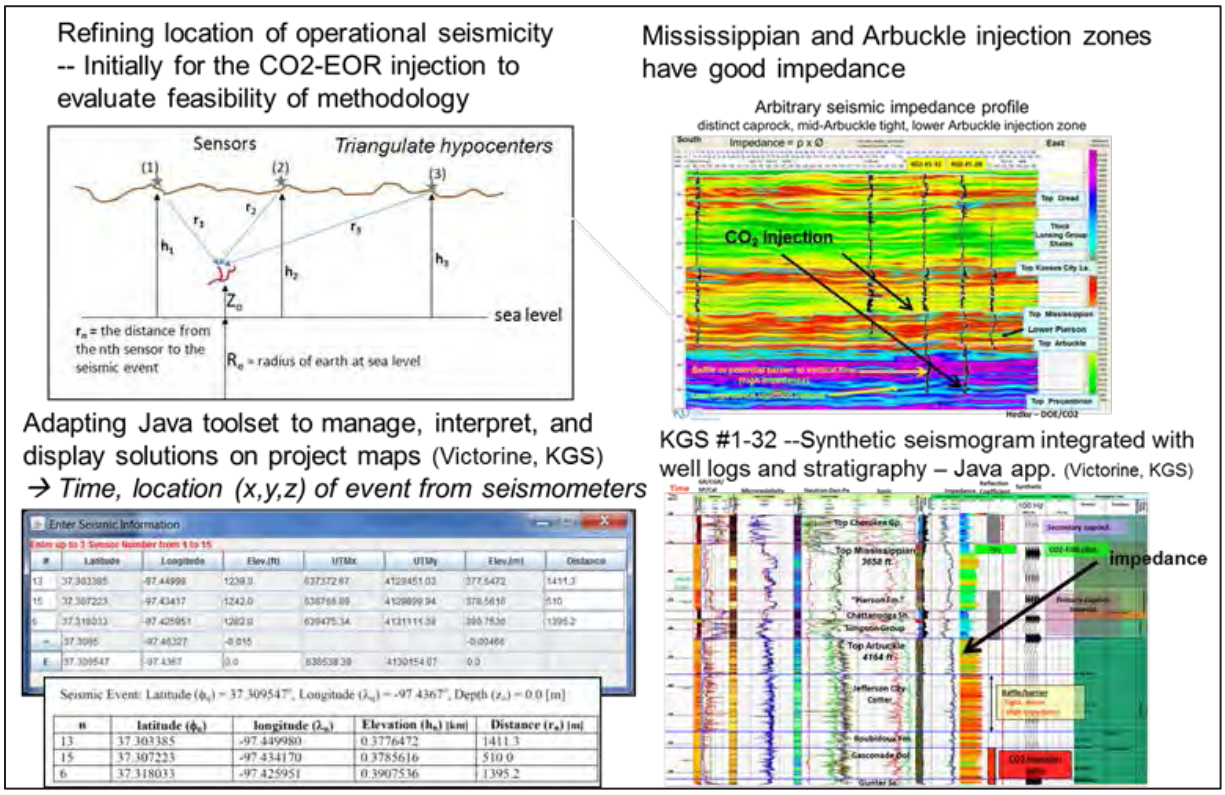
A first step was create a Java program to find the microseismic events and compute the time difference from the data stream. The problem is finding the event first, identifying when the event started and then computing the time difference of the shear (s) and compression (p) waves (**Figure 5**). Effort was initially focused on finding an event determining the primary and secondary frequencies and building a Gaussian Sine filter to pass through the raw data. The objective was to create two "pulses" for the s and p waves. Then, the time difference could be computed from the center of the pulses.

When the time differences are obtained and he will use average Vp and Vs velocities to predict the distances to the seismic events to be conveyed as 3D plots of the events over time. John also plans to incorporate the petrophysical data into this display along with faults other discontinuities as they are delimited by the microseismicity so we can get a geologic reference. Importantly, for DOE and the team, he will create summary web pages of the microseismic events with the location, depth,

and distance from faults. Resolution of the event signals that are obtained will help in the study of the mechanisms.

We plan to use the time and location of the shot points from the high resolution 2D seismic surveys to further establish the velocities along the reflection ray paths.

Characterizing microseismic events is a nontrivial exercise due to the low signal to noise and velocity variation along oblique ray paths at these shallow depths of the Mississippian.



n	latitude (ϕ_n)	longitude (λ_n)	Elevation (h_n) [km]	Distance (r_n) [m]
13	37.303385	-97.449980	0.3776472	1411.3
15	37.307223	-97.434170	0.3785616	510.0
6	37.318033	-97.425951	0.3907536	1395.2

Figure 5. Resolution of Hypocenters from IRIS Seismometer Array at Wellington. Seismic information is abundant including velocity of the interval being examined to resolve operational microseismicity.

The microseismicity has the potential to help resolve the heterogeneities in this Mississippian carbonate oil reservoir. Success can then be carried to the Arbuckle injection. Potential benefits include:

– **Microseismicity**
- Expanded and refined seismometer array augmented by KGS investment to record field operational seismic events down to -0.5 M,
- 1+M events sufficient to observe barriers or conduits of flow,
- fracture orientation,
- understand earthquake focal mechanisms and stress regime,

– improve geomechanical model

– Information from microseismicity could enhance understanding of factors impacting CO_2 storage

- Capillary entrapment – defined using reservoir quality index
- CO_2 miscibility
- Fracture and parting pressure
- Permeability – kv & kh, relative permeability
- Geochemical reactions – employ reactive transport models

Crosswell seismic survey to calibrate CASSM -- The recording of the crosswell seismic was revisited in March with the intent of involving the acquisition of the original 3D seismic volume and the logging company who has done the work at Wellington. Contacts were make and the original objectives were conveyed including –

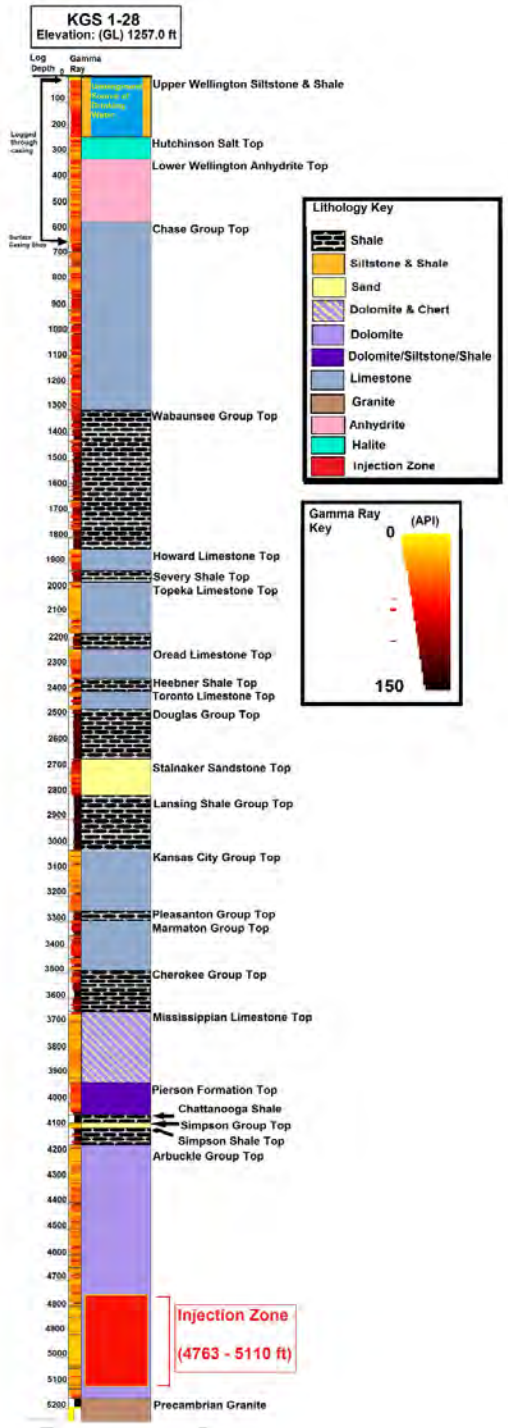
The following are additional answers to your initial questions --

A. Objectives of the survey

1. The crosswell tomography technology shall be used to monitor and visualize the movement of the CO_2 plume generated by injecting ~26,000 metric tons of CO2 in supercritical state into the lower Arbuckle saline aquifer in Berexco Wellington KGS #1-28 and observing the CO_2 plume in the Berexco Wellington KGS #2-28, yet to be drilled. The vertical and lateral extent of the CO_2 plume is shown below.
2. Two crosswell tomography surveys will provide 'bookends' to compare results with continuous active seismic (CASSM) survey overseen by Tom Daley at LBNL. CASSM geophones will be installed in Wellington KSG #2-28. The CASSM and cross well surveys will provide a detailed spatial description of the CO_2 distribution and the seismic wave field. The relatively sparse spatial sampling of the CASSM leaves uncertainty in some aspects of the interpretation of the seismic waveform (*CASSM focuses on the first arrival only, while crosswell allows understanding of later arriving phases*).
3. In addition, Wellington will likely be a designated site for DE-FEOO12700, "Distributed Fiber Optic Arrays: Integrated Temperature and Seismic Sensing for Detection of CO_2 Flow, Leakage and Subsurface Distribution." Rob Trautz, EPRI, is PI. The KGS minivibe will be used to acquire multiple VSP with a continuous fiber installed in well #2-28 and a fiber installed in a surface trench. Crosswell tomography will be used to evaluate the fiber project in an analogous manner to CASSM.
4. We also wish to use the crosswell tomography to refine our acquisition parameters for the repeat 3D that will be acquired by Paragon at the end of the injection to verify the location of the CO_2 plume.

The CASSM receivers shall be installed on production tubing in the monitoring borehole, along with other monitoring instrumentation (P/T gauge, U-tube, etc.) (**Figures 6 and 7**). The CASSM receivers are expected to be an array of hydrophones, with spatial distribution such that the expected vertical extent of the plume is monitored.

Different MVA tools shall be used to attempt to monitor, verify, and account for 99% of injected CO_2. The **crosswell tomography**, U-tube, and CASSM technology shall be used to monitor and visualize the movement of the CO_2 plume. Sampling and analysis of produced water and casing head gas from existing Mississippian wells and boreholes around the Arbuckle injector will be used to note patterns and trends in sample concentrations.



CASSM Monitoring: System performance shall be assessed by confirming a temporal resolution on the order of 10-30 minutes, allowing estimation of plume growth in real time, and potentially guiding other experiments depending on plume growth rates.

Figure 6 includes key formation tops for Wellington KGS #1-28, expected to the very similar since surface elevations of #2-28 is essentially the same as #1-28

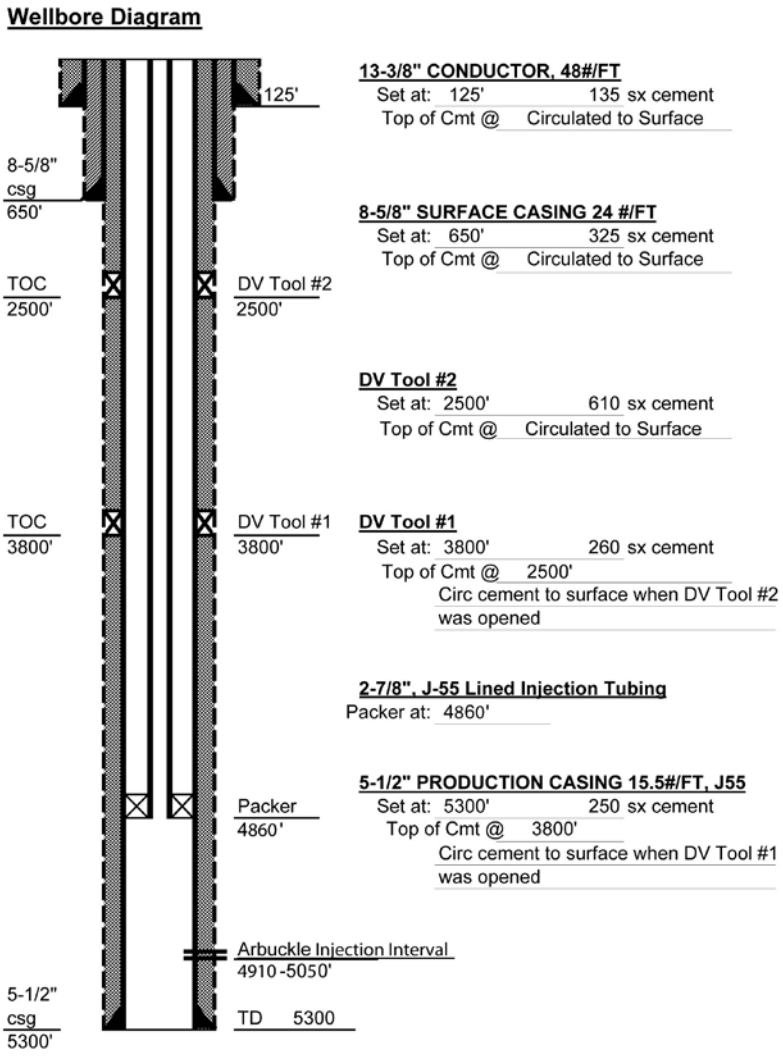


Figure 7. Current mechanical design of the Arbuckle monitoring well #2-28.

Task 7. Pre-injection MVA - Establish Background (Baseline) Readings

Subtask 7.2. Shallow Groundwater Sampling and Analysis

During the quarter the KGS/KSU team continued to evaluate the shallow groundwater in the AOR of the proposed Arbuckle injection well, KGS #1-28. EPA has been kept current activities of other relevant activities including --

- Peer-review of project underway, presenting on March 5th in Pittsburgh

  - Class VI permit needed in March timeframe to allow 7 mo. minimum to fabricate and test downhole MVA equipment in Arbuckle well before October 2015 injection
  - discussion of risks in obtaining permit and alternatives
- Drill, log, and test Mississippian injection well in March, following by pressurizing of reservoir followed by CO_2 injection
  - equivalent amounts and rates of CO_2 to be injected into the Mississippian as the Arbuckle
  - higher differential pressures in the Mississippian injection in addition to elevating reservoir pressure around the injection to initial reservoir pressure.
- Class II permit application approved by KCC
- Similar monitoring to be accomplished for Mississippian CO_2-EOR pilot
  - validate models (same methodology as used for the Arbuckle)
  - seismometer coverage same in both pilot areas, research – evaluate use to resolve operational seismicity
  - 2D high resolution seismic survey by KGS between #1-28 and Mississippian injector, #2-32
  - cGPS-InSAR coverage throughout Wellington Field area to establish baseline
  - sampling and analysis of Mississippian monitoring wells for fluids, gas, and tracer analogous to Arbuckle test, verify predicted CO_2 plume movement and compositional changes

Wellington Field is in a location of margin bedrock aquifers east of the High Plains and Dakota and west of the large alluvial aquifers associated with the Arkansas River Valley (**Figure 8**). Thus, is has been necessary to undertake origin work to delineate the extent and quality of the aquifer present in the AOR.

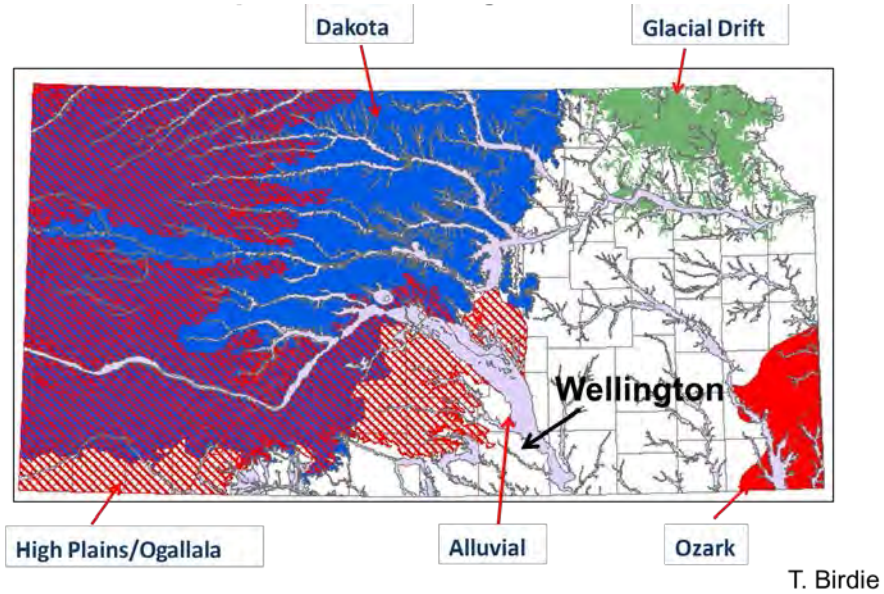


Figure 8. Wellington Field has minor surface bedrock aquifers that have required evaluation of the specific development in the AOR.

Three shallow water wells have been drilled within the Arbuckle AOR (**Figure 9**). SW-1 and SW-2 were drilled in late 2014 and completed and samples in early 2015 **(Figure 10).**

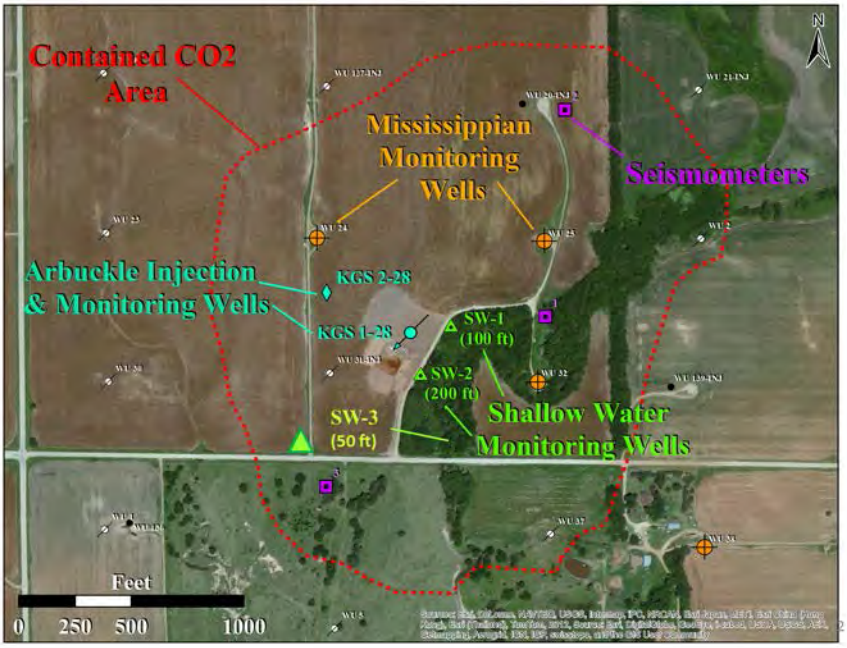


Figure 9. Test/monitoring wells for shallow water in CO2 AOR.

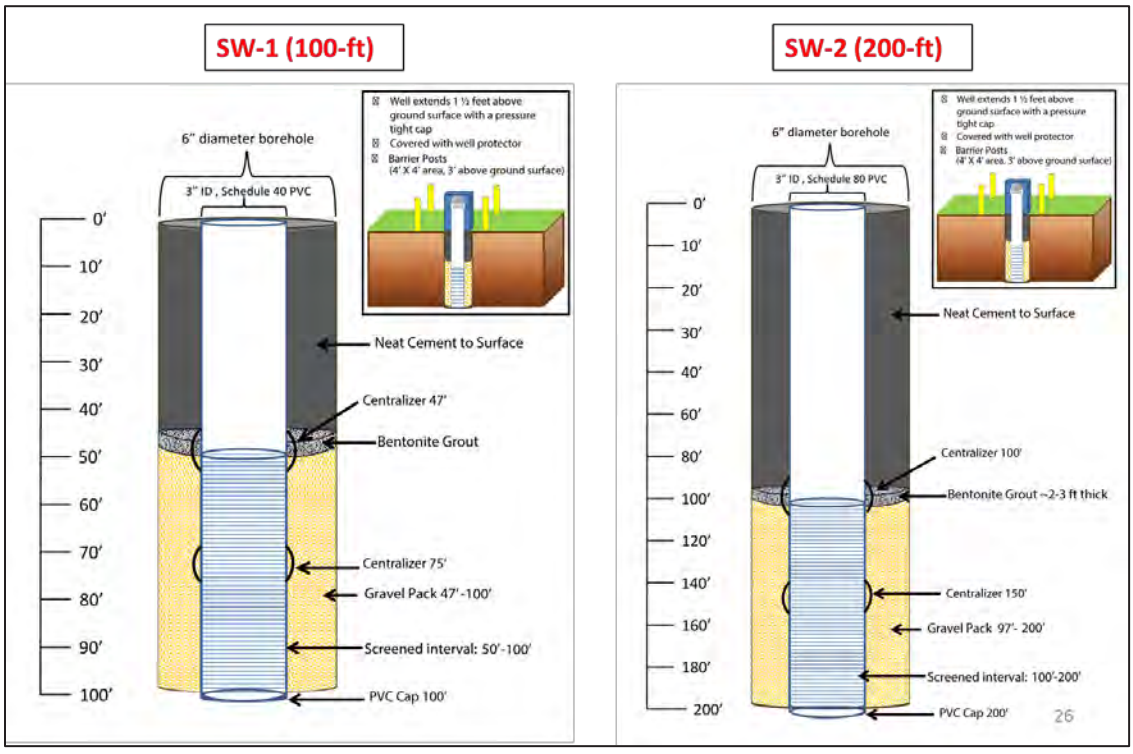


Figure 10. Well design for SW-1 and SW-2.

Initial results of first two shallow water wells, SW-1 and SW-2 were conveyed to EPA in January --

1. Negligible yield from 100-ft and 200-ft wells (SW1 yield ~.75 gal/day, low perm ~0 .01 md).
2. Highly saline water (TDS of water from 100 ft, 200 ft well was much greater than 10,000 TDS.
3. Due to low well yield and water quality conditions, the shallow formation at Wellington appears at this point to not qualify as a USDW (top of shale is ~13ft in SW1; ~10-20 ft in SW2)**.**
4. Wellington Shale in the AOR is an effective aquiclude that has prevented freshwater from directly contacting and dissolving the Hutchinson Salt (continuity of this interval in the Wellington Field).
5. Large scale mitigation strategies for Wellington Shale are unwarranted due to effects that pumping would likely have on the aquiclude (particle track monitoring).
6. Recommend EPA modify or replace the mitigation requirements due to local conditions of subsurface strata within AOR.
7. Financial assurance requirements to plug and mitigate the Wellington Shale aquiclude need to reflect lack of USDW contamination risks, reducing the need for extensive pollution mitigation.
8. Suggest modified approach to applying financial requirements for plugging and mitigation -
   A) Separate bonding for plugging and;
   B) Use of operator insurance for pollution mitigation, following the approach used by EPA to permit a Berexco Class II well in Montana.
9. Consider exempting the Wellington Shale as an aquifer in the AOR – implications of reduced permitting requirements.

SW-2 is the deepest of the shallow water wells at 200 ft (**Figure 11**). The uppermost 15 ft contains silt, sand, and clay. Shale below 15 ft contains increasing amounts of gypsum whose abundance remains steady with depth. Total depth of well is ~35 ft above the top of the Lower Permian Hutchison Salt member.

Photos of the cutting samples from SW-2 are shown in **Figures 12-31**. The samples illustrate the shallow sandy and silty interval that is then underlain by predominantly fine grained gray to dark gray shale with interbeds of limestone and ochre colored shale near the base of the well. Gypsum is abundant throughout the entire well except in the silty, sandy interval above 40 ft.

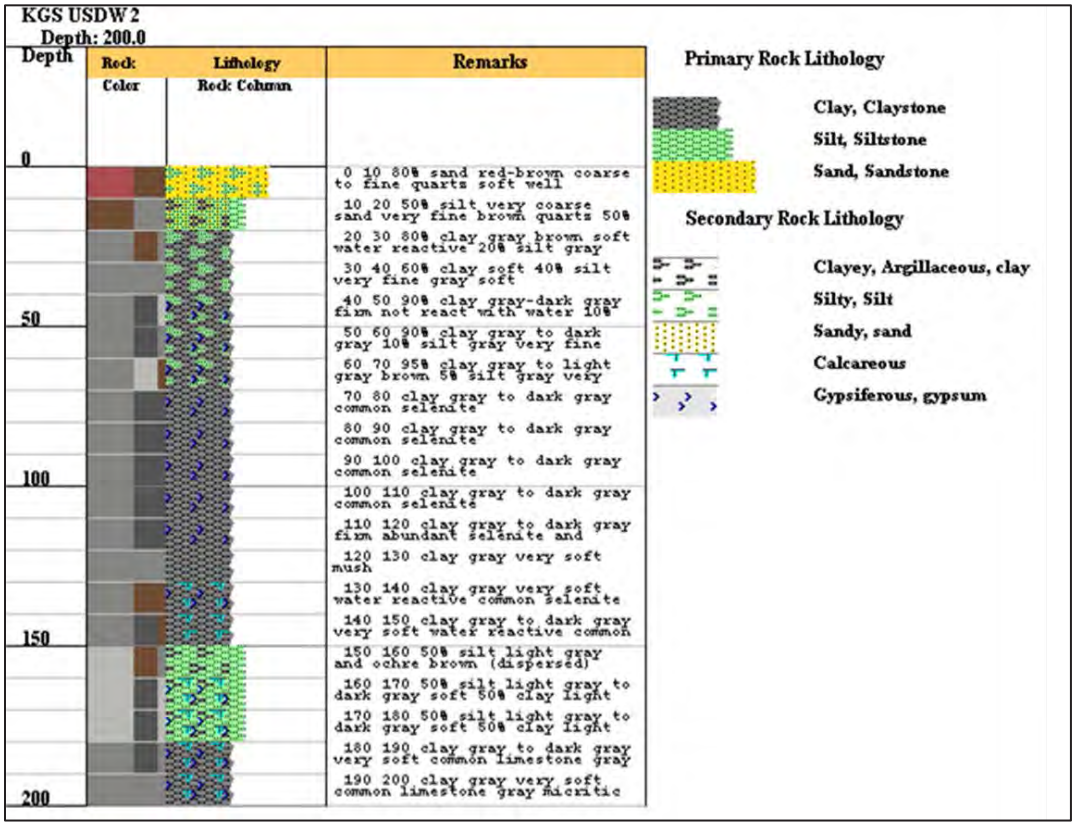


Figure 11. Sample description of deepest USDW monitoring well, SW-2.



Figure 12. SW-2 Well Cuttings (0-10 feet). 0;10; 80% sand, red-brown, coarse to fine; quartz, soft, well rounded; 20% silt, brown, clayey, dispersed.



Figure 13. SW-2 Well Cuttings (10-20 feet). 10;20; 50% silt, very coarse, sand, very fine, brown, quartz, 50% clay, gray, soft.



Figure 14. SW-2 Well Cuttings (20-30 feet). 20;30; 80% clay, gray brown, soft, water reactive, 20% silt, gray, more firm.



Figure 15. SW-2 Well Cuttings (30-40 feet). 30;40; 60% clay, soft, 40% silt, very fine, gray, soft.

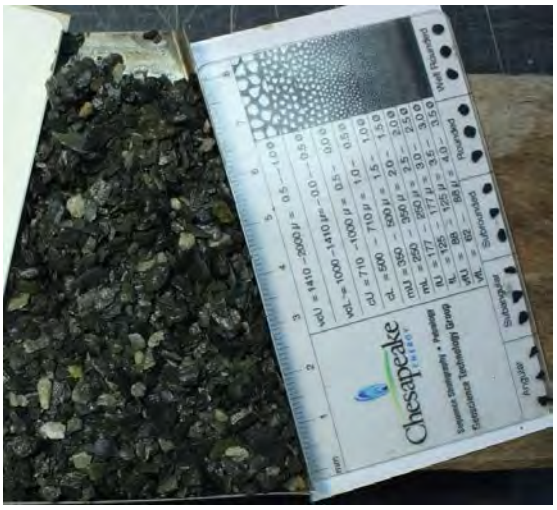


Figure 16. SW-2 Well Cuttings (40-50 feet). 40;50; 90% clay, gray-dark gray; firm, not react with water, 10% silt, light gray, very fine, quartz, rare selenite crystals.



Figure 17. SW-2 Well Cuttings (50-60 feet). 50;60; 90% clay, gray to dark gray, 10% silt, gray, very fine, firm, rate selenite crystals.

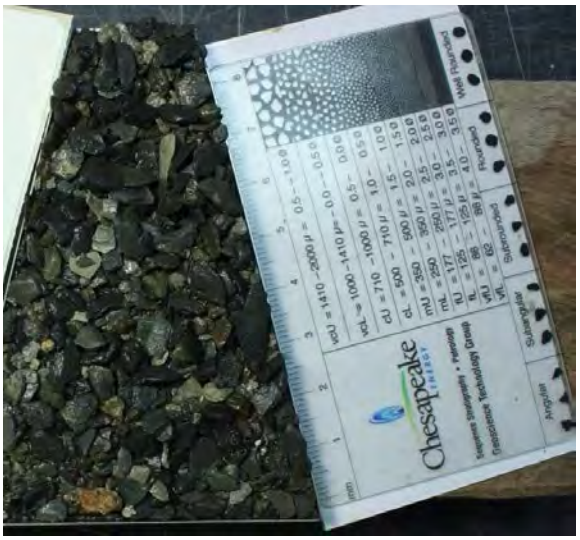


Figure 18. SW-2 Well Cuttings (60-70 feet). 60;70; 95% clay, gray to light gray, brown, 5% silt, gray, very fine, firm, frequent selenite.

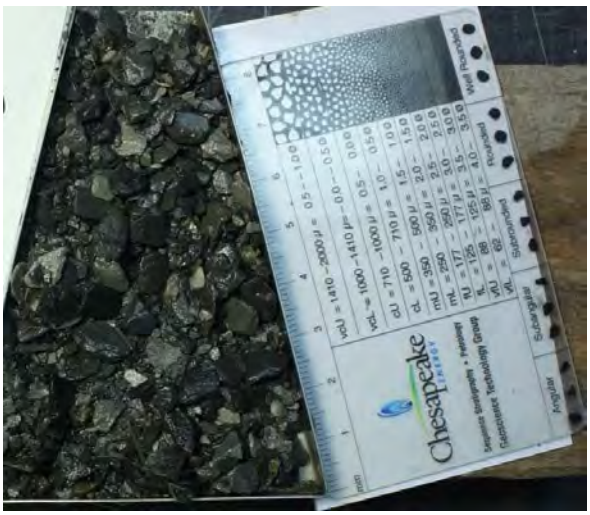


Figure 19. SW-2 Well Cuttings (70-80 feet). 70;80; clay, gray to dark gray; common selenite.

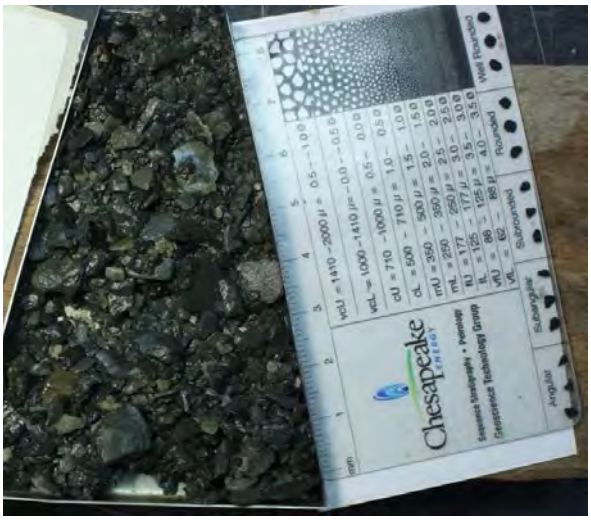


Figure 20. SW-2 Well Cuttings (80-90 feet). 80;90; clay, gray to dark gray; common selenite.



Figure 21. Satin spar crystals in sample cutting from 80-90 ft.



Figure 22. SW-2 Well Cuttings (90-100 feet). 90;100; clay, gray to dark gray; common selenite.

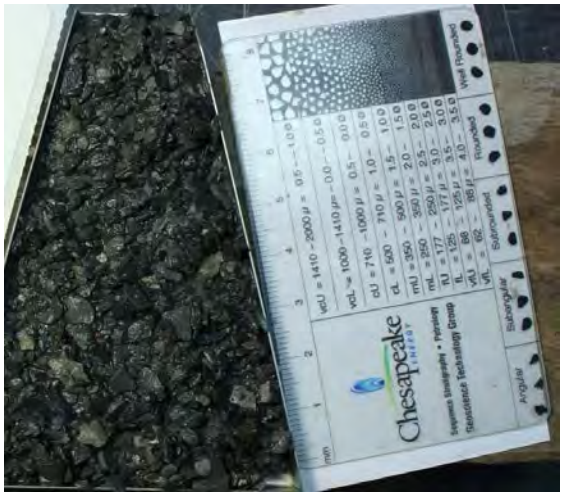


Figure 23. SW-2 Well Cuttings (100-110 feet). 100;110; clay, gray to dark gray; common selenite.



Figure 24. SW-2 Well Cuttings (110-120 feet). 110;120; clay, gray to dark gray, firm, abundant selenite and alabaster.



Figure 25. SW-2 Well Cuttings (120-130 feet). 120;130; clay, gray, very soft, mush (water reactive).

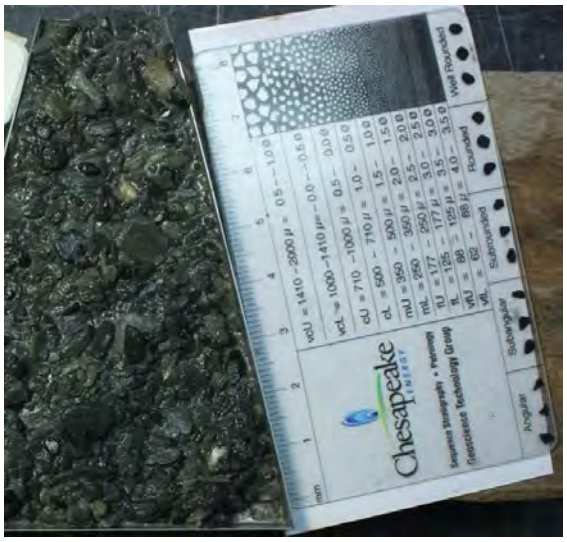


Figure 26. SW-2 Well Cuttings (130-140 feet). 130;140; clay, gray, very soft, water reactive, common selenite, rare limestone, brown, micrite.



Figure 27. SW-2 Well Cuttings (140-150 feet). 140;150; clay, gray to dark gray, very soft, water reactive, common limestone, brown, micrite.



Figure 28. SW-2 Well Cuttings (150-160 feet). 150;160; 50% silt, light gray and ochre brown (dispersed), very fine, 50% clay, light gray, possible water source.



Figure 29. SW-2 Well Cuttings (160-170 feet). 160;170; 50% silt, light gray to ochre, soft, 50% clay, light gray to dark gray, very soft, common limestone, gray, micritic, common selenite.



Figure 30. SW-2 Well Cuttings (170-180 feet). 170;180; 50% silt, light gray to dark gray, soft, 50% clay, light gray to dark gray, very soft, common limestone, gray, micritic, common selenite.

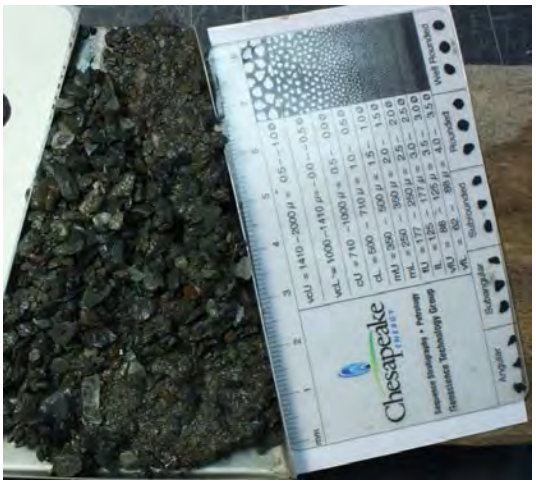


Figure 31. SW-2 Well Cuttings (180-190 feet). 180;190; clay, gray to dark gray, very soft, common limestone, gray, micritic, common selenite.

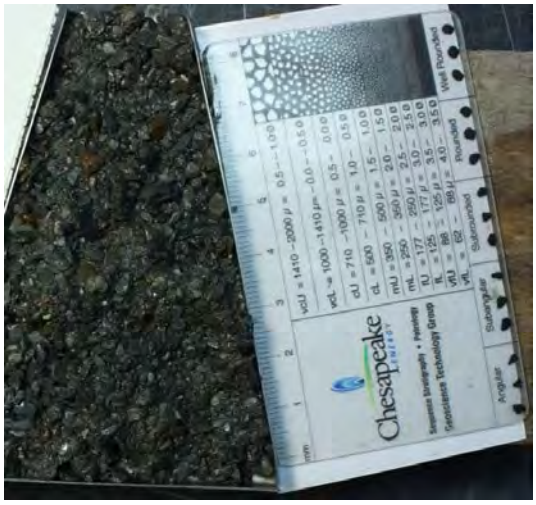


Figure 32. SW-2 Well Cuttings (190-200 feet). 190;200; clay, gray, very soft, common limestone, gray, micritic, common selenite.

A cross section of the Wellington shale is shown in **Figure 34** with an index map in **Figure 33**. The cross section illustrates its lateral continuity and vertical consistency explaining the preservation of the Hutchinson salt that is at depth of ~250 ft below the land surface.

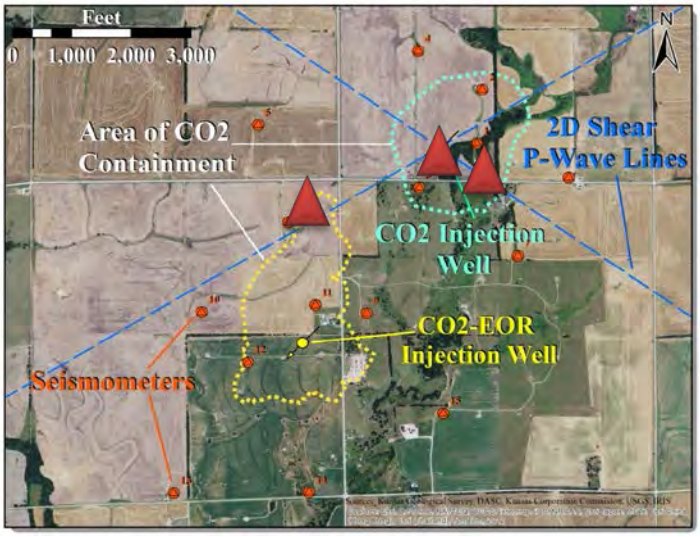


Figure 33. Adjoining small-scale pilot CO2 injection into Mississippian. Map serves as index for following cross section. Cross section in next figure runs from KGS #1-32 (left triangle) to KGS #1-28 (center) to SW-triangle on the right) located within 200 ft SE of #1-28.

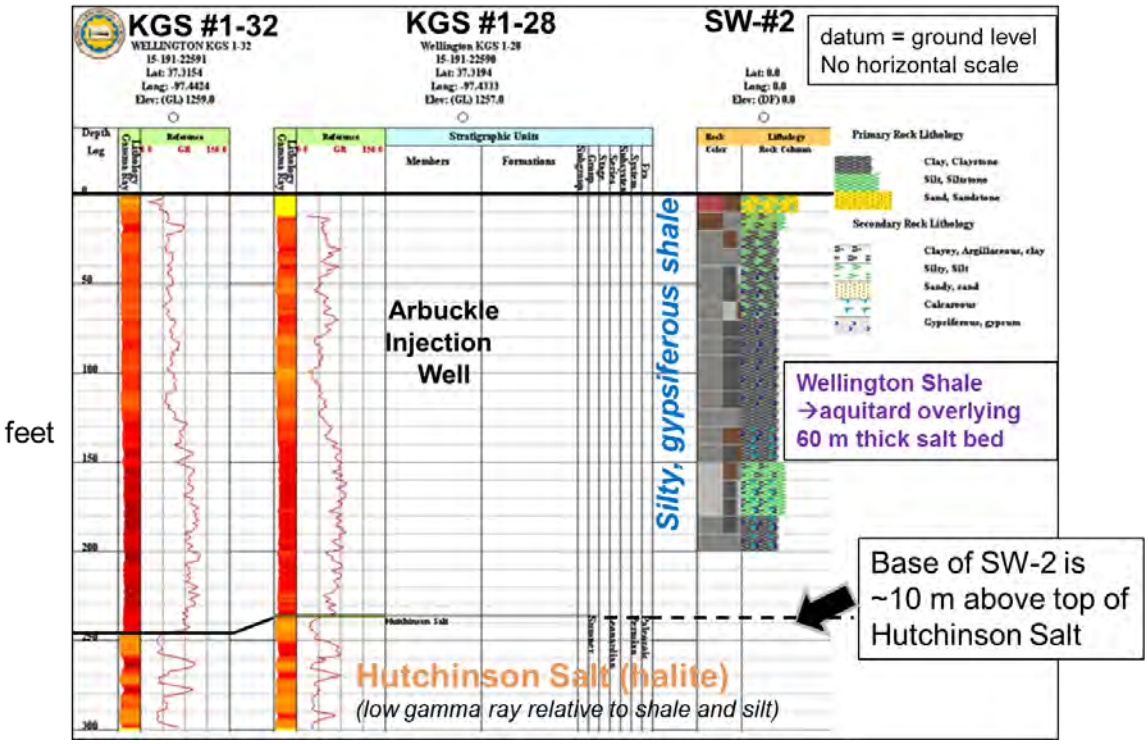


Figure 34. Gamma ray and sample log cross section between KGS #1-32, KGS #1-28, and SW-2. The datum of the cross section is ground level.

The strata near the top of the Hutchinson salt are preserved in core near Hutchinson Kansas and suggest a mixture of gypsum, halite, and shale forming chaotic and brecciated interval attesting that at least locally that dissolution along the top of the salt bed occurred after it was deposited (**Figure 35 and 36**). By closer examination, it can be inferred that the dissolution occurred early shortly after deposition since the strata overlying this contact are not significantly deformed.

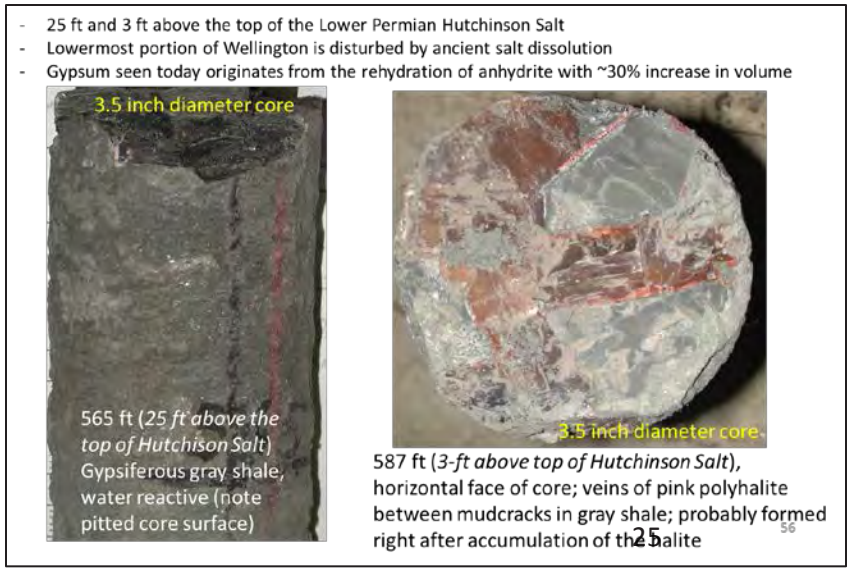


Figure 35. Example of Wellington Shale immediately above the Hutchinson Salt from Yaggy Q-5 corehole Hutchinson, Kansas.



Figure 36. Paleodissolution on top of Hutchinson Salt Member. Mixture of halite, gypsum, and shale from Yaggy Q-5 corehole Hutchinson, Kansas. Contorted bedding in gypsum (A), sharp irregular contacts between gypsum and halite (B), and mixed lithology (gypsum, halite, and shale) breccia (C), and veins of red halite (D) indicative of zones of paleodissolution that developed near the top of the Hutchinson Salt Member shortly after deposition.

A core of the Hutchinson Salt itself reveals relatively clean halite beds with varying amounts of dark gray shale laminations (**Figure 37**). The shale and halite beds can be traced considerable distances attesting to the evaporitic basin in which the halite was precipitated.

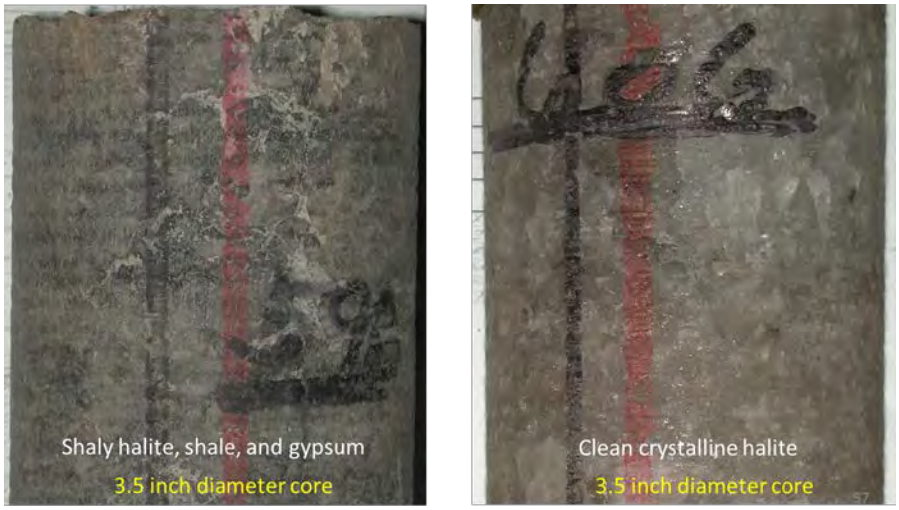


Figure 37. Examples of halite in the upper Hutchison Salt from Yaggy Q-5 corehole Hutchinson, Kansas.

Water samples were taken and analyzed according to the specifications of EPA. This resulted in the standardization of the methodologies and the manner in which the data were recorded, starting from the field **(Figure 38).**



DATE
LOCATION
TIME
CONTRIBUTORS
WELL ID:
WEATHER
COMMENTS

	Before Going to Field:
	Make DIC Vials
	Charge PDA
	Charge UV Spectrophotometer
	Calibrate Hydrolab
	Calibrate multimeter
	Calibrate conductivity meter

	Field Sampling and Testing Checklist
	Plastic Bags
	Rubber Bands
	Electric Tape
	Duct Tape
	Masking Tape
	Sharpies
	Gloves
	Kim Wipes
	Paper Towels
	Field Notebook
	Notebook with testing instructions & manuals
	Pens, Pencils
	Labels
	DI Water Sprayer Bottles
	Cooler
	Tape measure
	Beakers (50, 125, 250 ml)
	Extra batteries (AA, AAA)
	Safety Glasses
	GPS
	Whatman 45 Papers
	Pippette
	Pippette Tips
	Small volume syringe (<10mL)
	Syringes
	Syringe Filters
	Rubber Stoppers DIC
	Metal Caps DIC
	Crimper Tool DIC
	HNO3 Acid
	pH buffer solution 4, 7, 10
	conductivity solution (1.412 ms/cm) to calibrate conductivity meter (Cat. 013620HY)
	ORP standard solution to calibrate multimeter (Zobell's 013060HY)
	DI water + container
	Tap water + container
	Bailers
	Bailer String
	5-gallon buckets
	Water meter
	Tarp

	All bottles
	Extra DIC Hg-charged vials
	All kits
	Spectrophotometer
	Multimeter
	Conductivity meter
	Hydro Lab
	HACH PDA (for hydrolab)
	Bottles (1 sampling)
	(1) 500 mL amber plastic HDPE bottle (UA, UF)
	(1) 250 mL amber plastic bottle (A, F)
	(1) 250 mL transparent glass bottle (UA, UF)
	(1) 125 mL amber glass bottle (UA, F) - **Sr Isotope**
	(1) 125 mL amber plastic bottle (UA, F)
	(1) 60 mL transparent glass bottle (UA, F) - **Stable Isotope**
	(1) 60 mL transparent glass bottle (A, F) - **DOC**
	(2) 50 mL centrifuge tubes (UA, UF)
	(1) 20 mL $HgCl_2$ charged transparent glass vial with crimp and seal (UA, UF) - **DIC**
	(1) 15 mL centrifuge tube (UA, UF)
	2 x 500mL amber plast HDPE bottles (for monitoring wells, above & below interval)
	All Spectrophotometer
	TNT 865 Sulfate
	TNT 864 Sulfate
	TNT 843 Phosphorous
	TNT 844 Phosphorous
	TNT 835 Nitrate
	TNT 870 Total Alkalinity
	TNT 830 Ammonia
	TNT 831 Ammonia
	TNT 832 Ammonia
	TNT 858 Iron
	TNT 839 Nitrite
	TNT 840 Nitrite
	Extra vials and rubber caps, rectangular and conical vials
	Sulfide Reagents 1 and 2
	SulfaVer 4 AccuVac Sulfate
	FerroVer AccuVac Iron

	Kits
	HACH
	Alkalinity (small)
	As Test Kit
	As E2 Test Kit
	Chloride (2 small kits)
	Dissolved Oxygen (small)
	Dissolved Oxygen (large)
	Ferrous Iron (Fe 2+)
	Mn
	PO4
	SO4
	SO4 Colorimeter
	LaMotte
	Chloride
	CHEMetrics
	Dissolved Oxygen

Figure 38. Water sampling forms shared by Austin Krehel (KSU).

Initial water analyses from SW-1 and SW-2 indicate elevated chlorides (**Figures 39 and 40**) with salinity increasing with depth. This gradient toward higher salinity is interpreted as diffusion of dissolved NaCl from the indigenous halite, but mainly from the Hutchinson Salt Bed itself.

Moreover, this diffusion is expected from long term exposure of the salt steadily reducing concentrations of brine by meteoric waters as erosion has brought the bed of halite in closer proximity to the land surface.

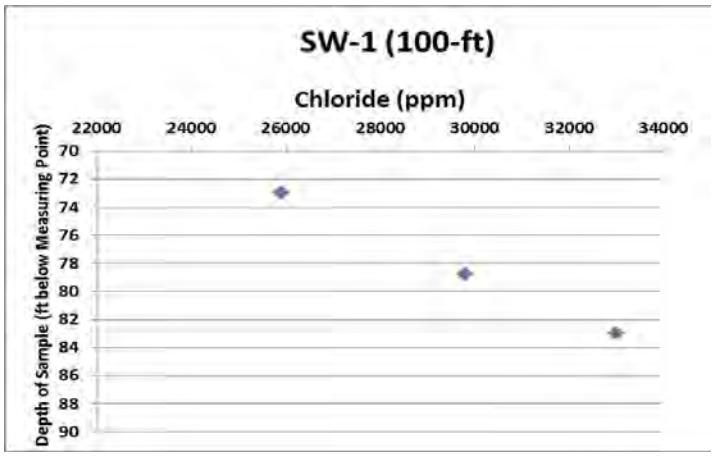


Figure 39. Groundwater Salinity in SW-1 (100-ft Well, Dec 14). Well Screened 50-100 ft. TDS > 10,000 ppm increasing with depth. Time series changes in salinity will be evaluating after continued monitoring.

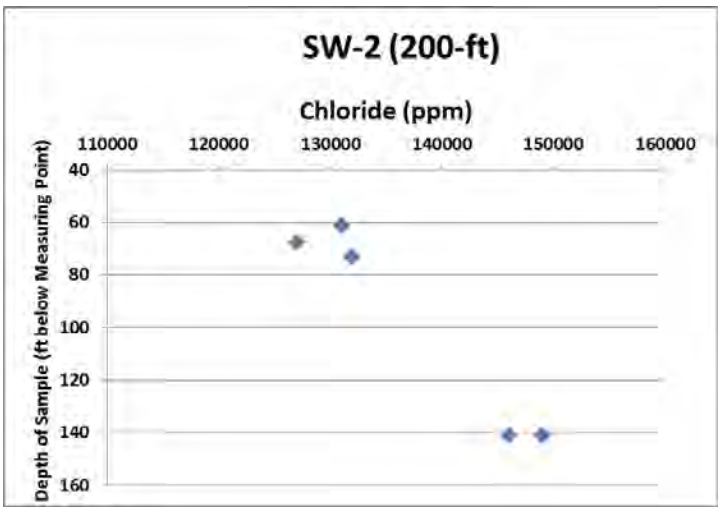


Figure 40. Groundwater Salinity in SW-2 (200-ft Well on Dec. 14, 2014). Well Screened 100-200 ft. TDS > 10,000 ppm with increasing salinity with depth.

The SW-1 well as bailed over a span of time from early November to mid December (**Figure 41 and 42**). The recovery rates of this well were analyzed using a standard hydrologic software indicating an estimated permeability of ~0.1 millidarcies (**Figure 43**). The analysis confirmed that the interval screened in this well (50 to 100 ft) is tight and is an aquiclude that has contributed to limiting the infiltration of meteoric water from the surface. The yield from this well was estimated at 0.75 gal/day using another hydrologic model (**Figure 44**). Pumping such as well would result in drawing in poor quality water into the borehole from depth and could lead to salt water intrusion during extended pumping. Besides salt water intrusion, the concern is extended to the possible dissolution of the salt bed below. Thus, mitigation of CO2 from this interval is not deemed feasible. A particle track model shows preliminary simulation of the pumping (**Figure 45**).

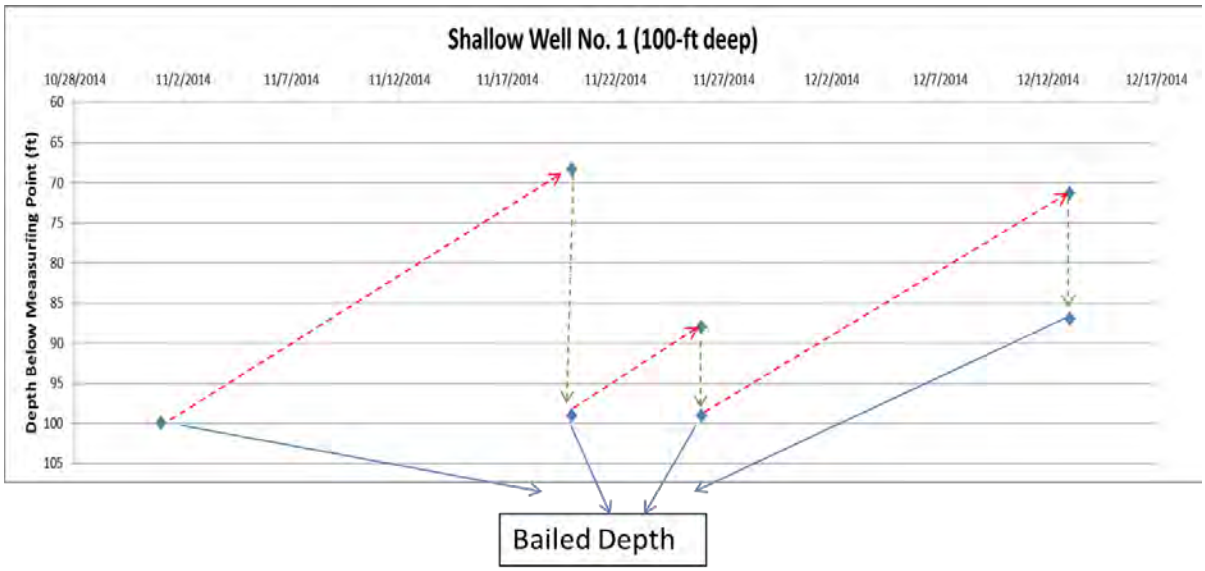


Figure 41. Well Bailing Summary (100-ft Well). Average Daily Recovery Rate = 1 .7 ft/day; similar recovery slopes. Expect recovery to continue gradually, ultimately to reach a static fluid level. Continue purging and monitoring to obtain 3 well volumes of fluid.

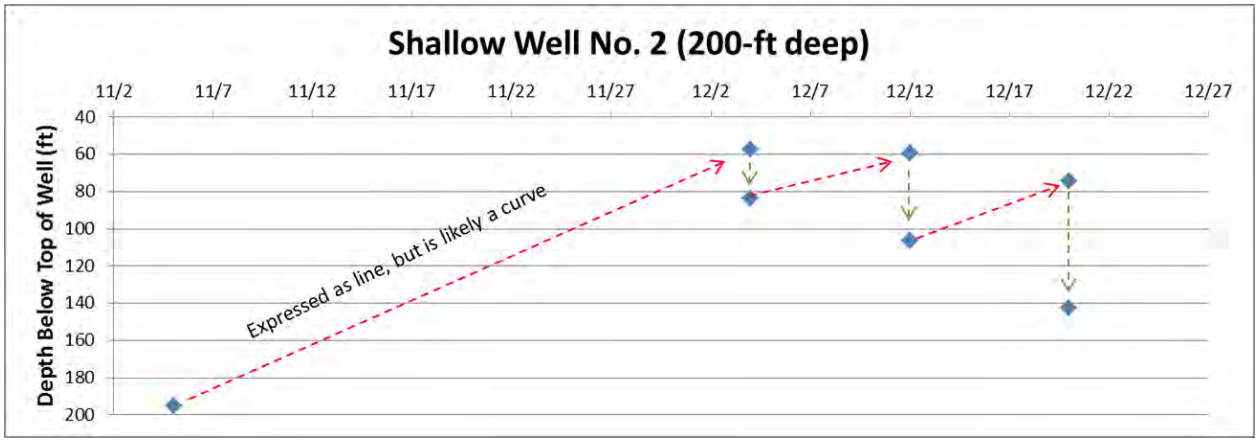


Figure 42. Well Bailing Summary SW-2 (200-ft Well). Average Daily Recovery Rate= 3.9 ft/day. Have had difficulty in bailing well below 140 ft. Continue to purge and monitor water levels to obtain 3 well volumes of fluid (consider pumping to lower fluid level to base of well).

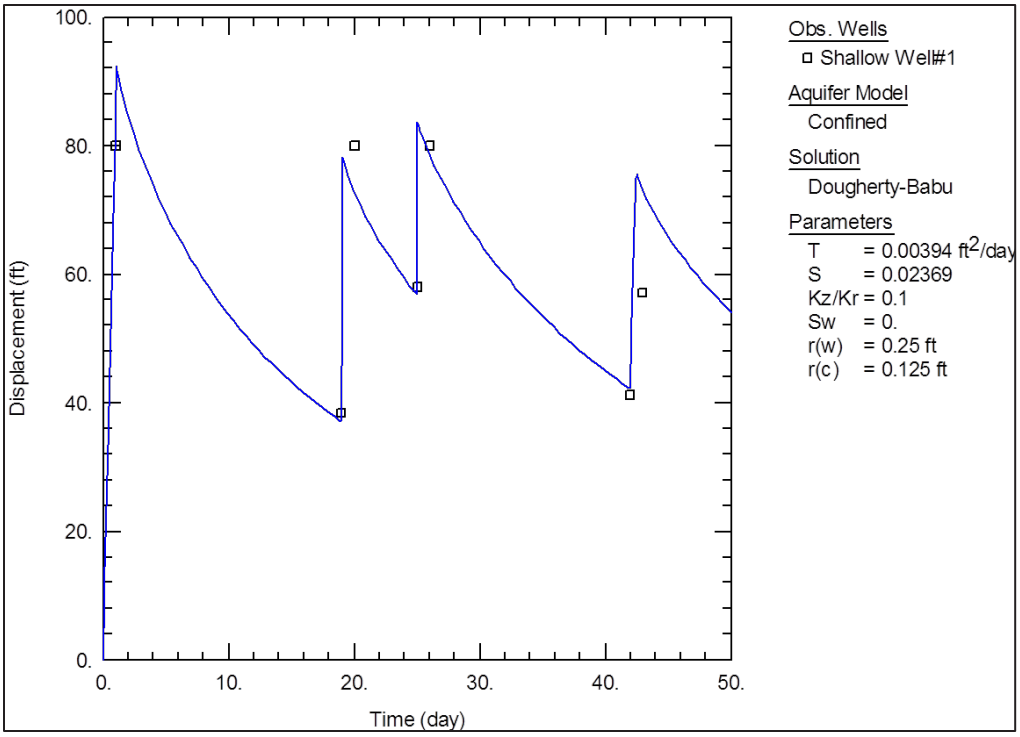


Figure 43. Permeability Estimation in USDW well #1 → Wellington Shale is an aquitard. Low Permeability of 0.00005 ft/day ~0.01 md an aquitard with properties equivalent to our caprock.

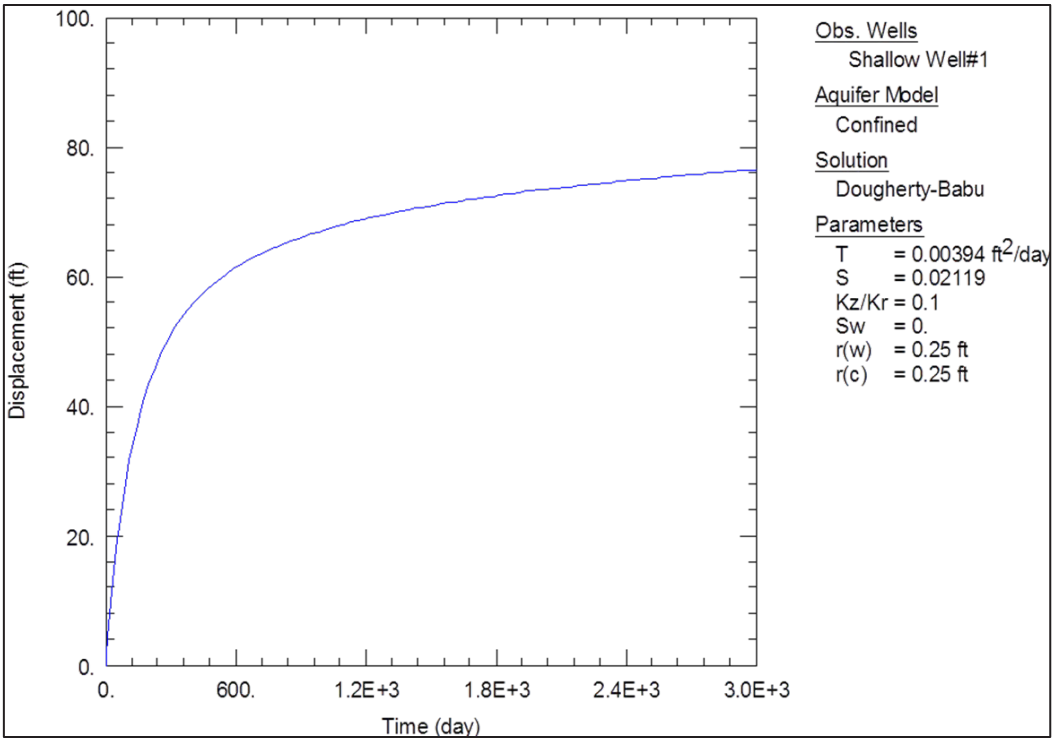


Figure 44. Well Yield Estimate. for 6-inch wellbore producing from screened interval in SW-1 with an 80 ft drawdown (Forward Modeling). Low Yield of 0.75 gal/day.

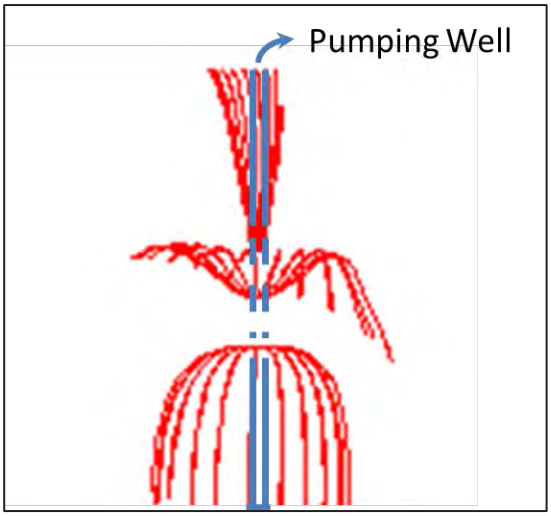


Figure 45. Particle Track Modeling. Preliminary simulations of pumping are expressed by particle tracking.

The result of the conversation with EPA on January 15th is that information gathered to that point suggests no USDW. EPA requested that we drill another shallow water well (UDSW Well #3) on the opposite (west) side of the AOR (**Figure 46**). The SW-3 was drilled in early February to a depth of 50 ft. The well was screened from 25 ft to bottom. The well was pumped over a 2 week interval to check if saltwater (> 10,000 ppm) is induced in the well.

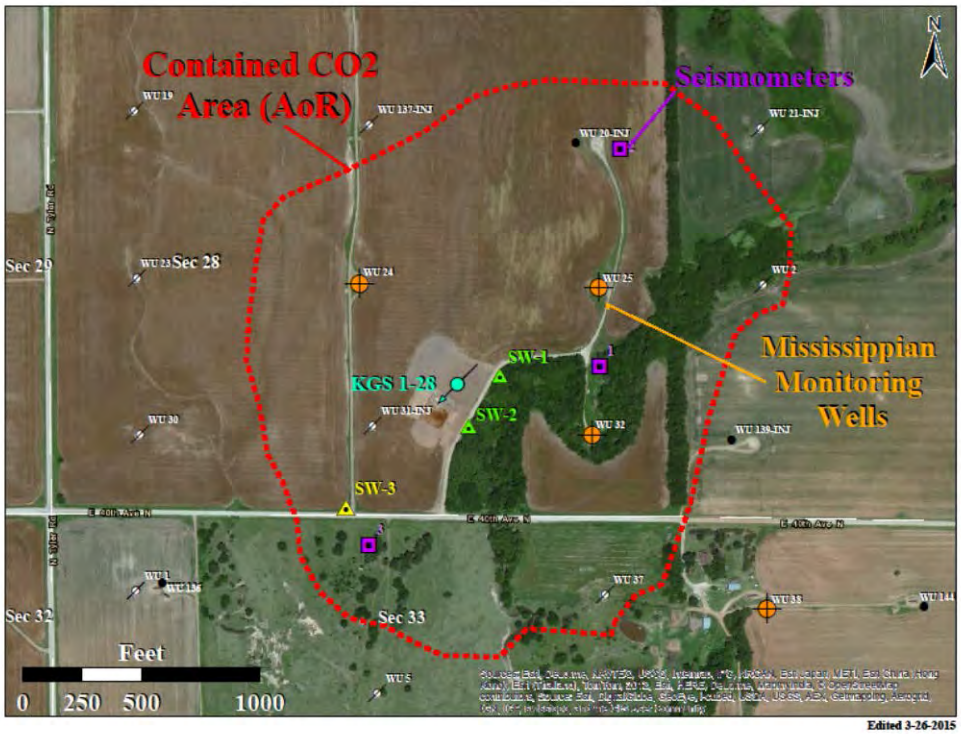


Figure 46. Location of SW-3 in the southwestern AOR.

Well Construction Objective of SW-3 as modified from that conveyed to EPA

The objective of constructing monitoring well SW-3 was to determine groundwater quality in the Upper Wellington Formation overlying the Hutchinson Salt beds. A related goal was to determine if there is an Underground Source of Drinking Water (USDW) with the Area of Review of the Wellington CO_2 storage site. The USDW is defined by the EPA as:

> "Underground source of drinking water (USDW) means an aquifer or its portion:
> Which supplies any public water system; or Which contains a sufficient quantity of ground water to supply a public water system; and
> Currently supplies drinking water for human consumption; or
> Contains fewer than 10,000 mg/l total dissolved solids; and
> Which is not an exempted aquifer."

The well can be used to monitor water quality in the Upper Wellington Formation during CO_2 storage activities in order to ensure that CO_2 remains confined in the injection zone within the Arbuckle Group and does not escape into any shallower formations or the atmosphere. A generalized stratigraphic column of the Wellington formations is presented in **Figure 47**. The thickness of the Upper Wellington, Hutchinson Salt Beds, and the Lower Wellington formations is variable in the area, but is consistent through Wellington Field area. At some locations, the Upper Wellington member may be thin or absent, but only the upper shale member is present at Wellington. The Upper Wellington shale overlies the Hutchinson Salt Beds, which suggests the likelihood of inducing highly saline water from production wells in the Upper Wellington Formation.

Site Description and Location

The monitoring well is located in the midst of cropland approximately 750 feet southwest of the proposed CO_2 injection well KGS 1-28. The monitoring well location and depth information is presented in Table 1.

Table 1 Location, well depth, and ground elevation at monitoring well SW-3.

Completion Date	Latitude	Longitude	Section	Ground Elevation (ft, msl)	Well depth (ft)	Height of Measuring Point Above Ground (ft)
2/8/2015	37.318081	-97.435420	T31S R1W S29 SE SW SW	xx	50	1.5

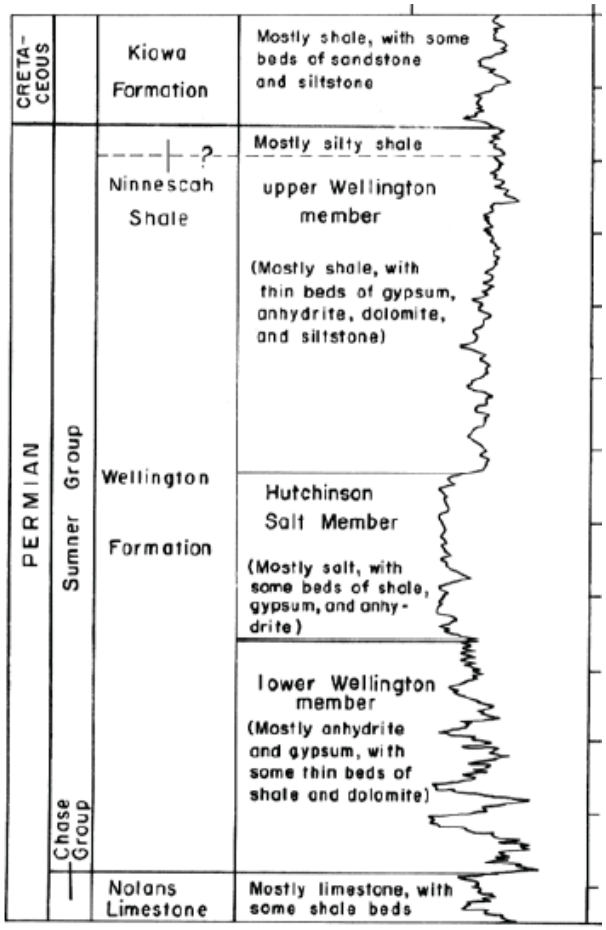


Figure 47. Stratigraphic relationship of bedrock in central Kansas (from Gogel, 1981)

Well Construction

The well design specifications are provided in **Figure 48**. Construction at the site started on February 8, 2015 using a rotary drill bit and completed on February 9, 2015. The 6.5- inch borehole was drilled to a depth of 50 feet. The well was completed using a 4-inch Schedule 40 PVC pipe with a 10 slot (0.010) screen from 25-50 feet. Approximately three feet of bentonite was used between the gravel pack and the cement grout to prevent cement grout from coming in contact with the gravel pack, which can impact the pH of water samples.

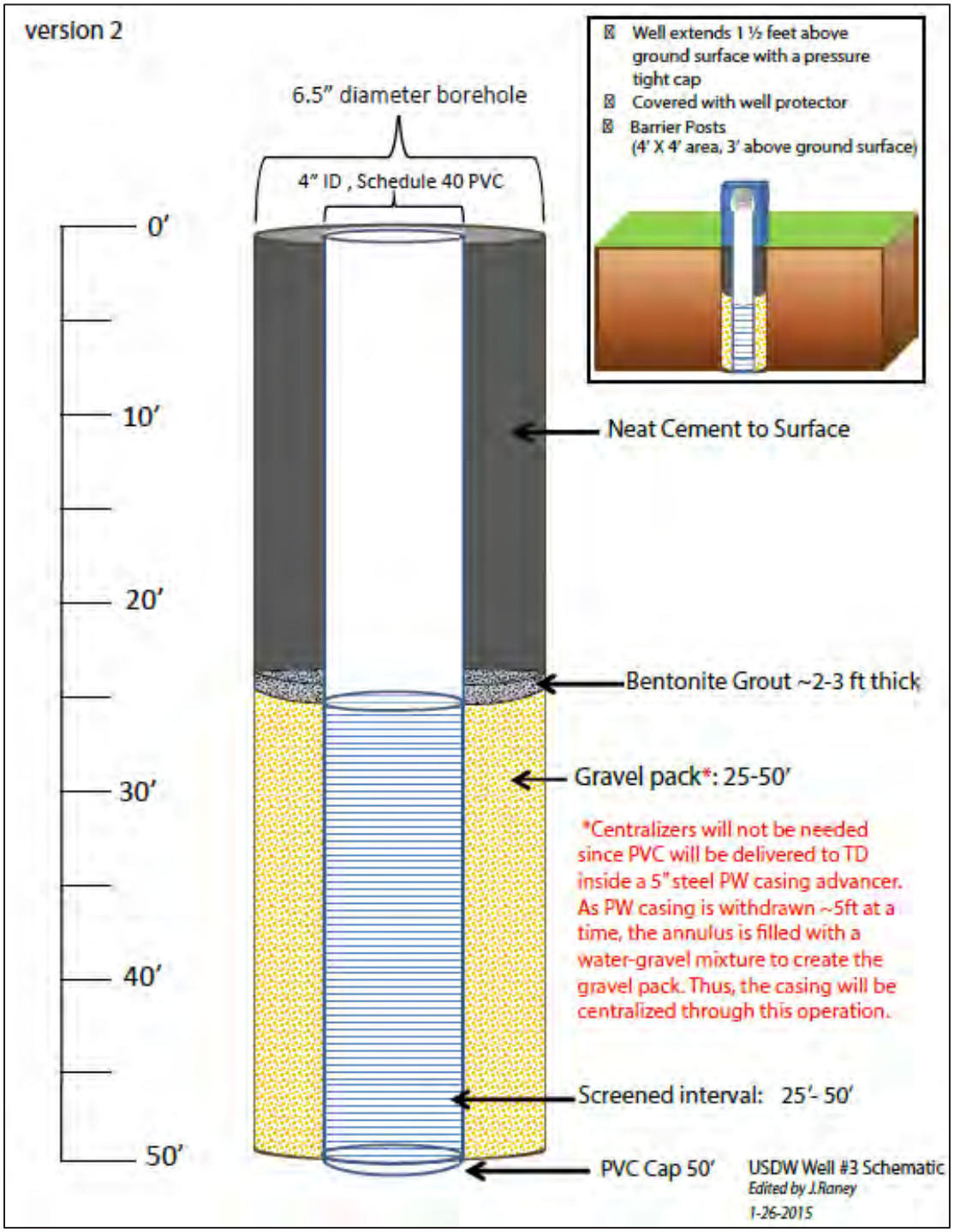
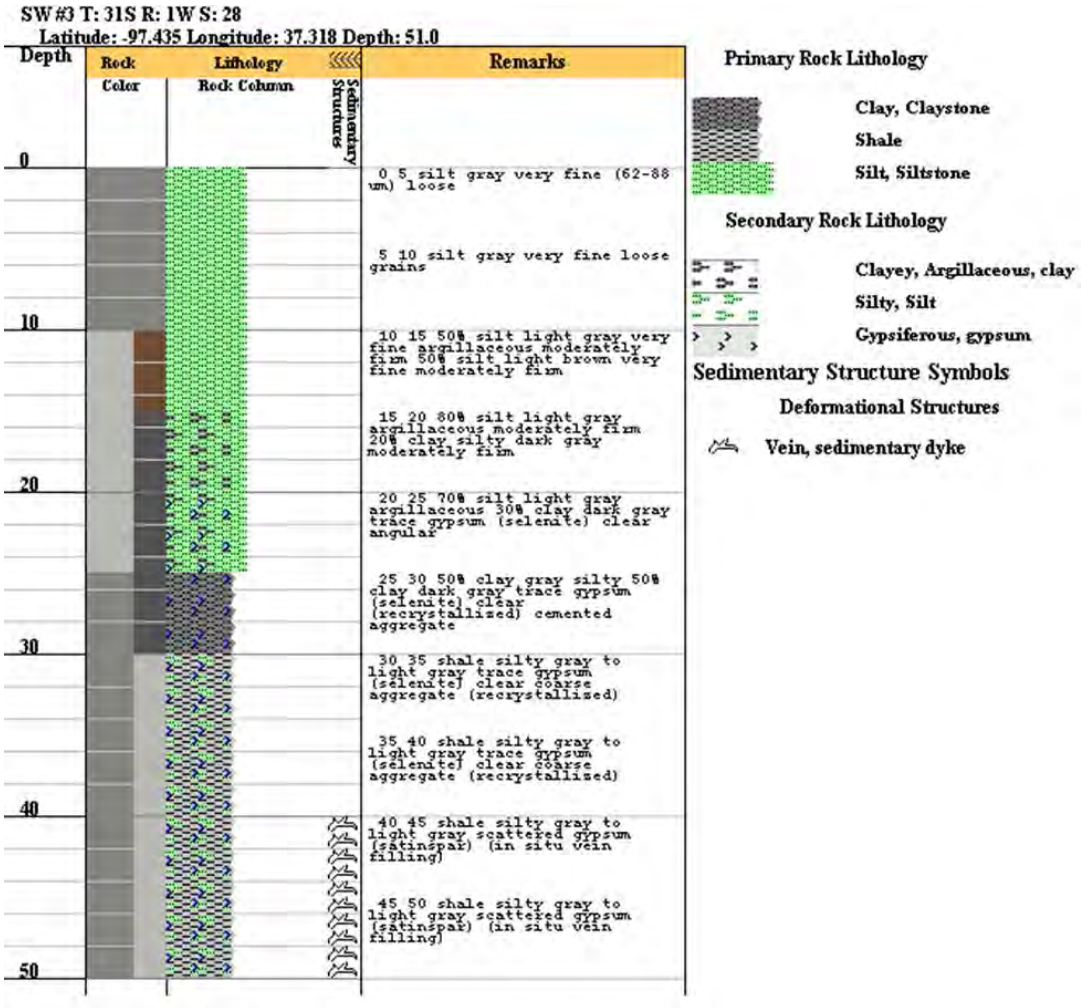


Figure 48. The UDSW Well #3 was to be drilled to 50 ft and screened from 25 ft to bottom.



CUTTINGS DESCRIPTION

KGS SW #3 well (50 ft TD)

Longitude: -97.435, Latitude: 37.318
Located 690 ft south-southwest of Wellington KGS #1-28
County: Sumner County
Screen interval: 25-50 ft
Total Depth: 50 ft; Elevation: 1255 Ground level
0;5; silt, gray, very fine (62-88 um), loose
5;10; silt, gray, very fine, loose grains
10;15; 50% silt, light gray, very fine, argillaceous, moderately firm, 50% silt, light brown, very fine, moderately firm
15;20; 80% silt, light gray, argillaceous, moderately firm, 20% clay, silty, dark gray, moderately firm
20;25; 70% silt, light gray, argillaceous, 30% clay, dark gray, trace gypsum (selenite), clear, angular
25;30; 50% clay, gray, silty, 50% clay, dark gray; trace gypsum (selenite), clear (recrystallized) cemented aggregate
30;35; shale, silty, gray to light gray, trace gypsum (selenite), clear, coarse aggregate (recrystallized)
35;40; shale, silty, gray to light gray, trace gypsum (selenite), clear, coarse aggregate (recrystallized)
40;45; shale, silty, gray to light gray, scattered gypsum (satinspar) (in situ vein filling)
45;50; shale, silty, gray to light gray, scattered gypsum (satinspar) (in situ vein filling)

Figure 49. Graphic section of SW-3 shallow water well.

The drilled cuttings were described and are reported in the graphic column and depth listing in **Figure 49**. The results of the drilling are summarized as follows:

1. Silt to 25 ft
2. Silty shale 25-50 ft
3. First gypsum @ 20-25 ft
   - Recrystallized
4. Satin spar @40-50 ft
   (interpreted as precipitated by early burial diagenesis, unrecrystallized by surface processes as see in wells #1 and #2).

The first gypsum is in the 20-25 ft sample described as recrystallized that consists of loose clusters of corroded selenite crystals in a framework of alabaster that make up individual cuttings pieces. The recrystallization indicates that the gypsum has likely undergone frequent partial dissolution and recrystallization. This is attributed to changing saturation conditions of the brine that resides at these shallow depths. The salinity of the brine likely changes seasonally as wet and dry conditions alternate. In contrast, at 40 ft, satin spar is present indicating vein filling gypsum that is common in cores of the Upper Wellington shale that have not been affected by recent meteoric water. This indicates that gypsum is stable at 40 ft below the surface.

SW-3 has a similar lithologic profile as SW-2, but SW-3 has slightly more and thicker silt to around 25 ft, but SW-3 contains less sand-sized particles (**Figure 50**).

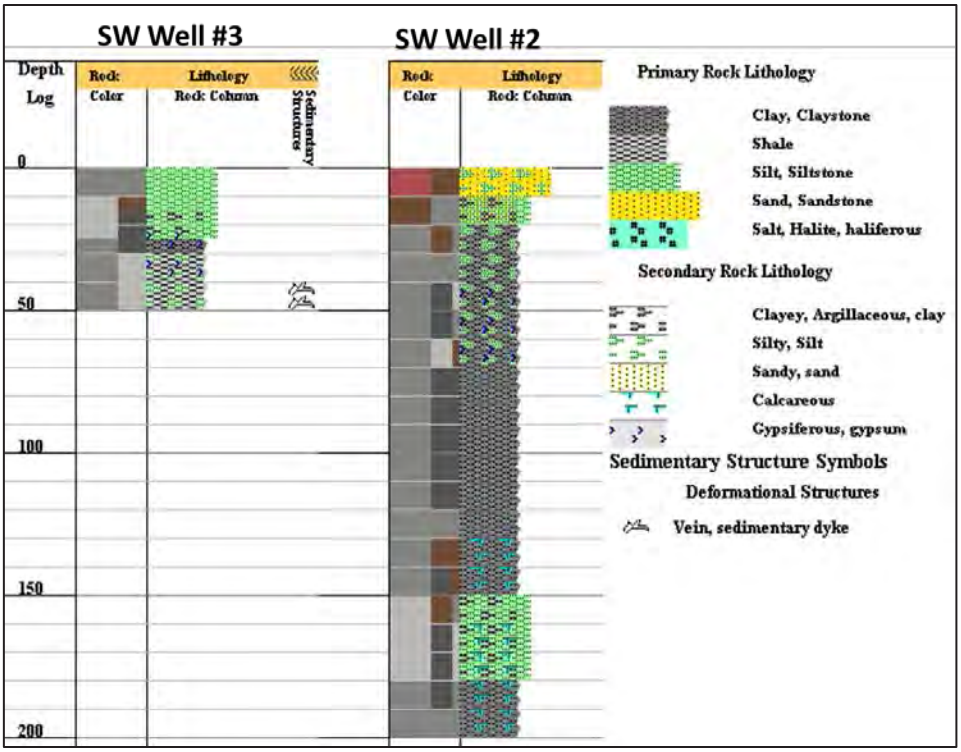


Figure 50. Graphic profile of SW Well #3.

Well Development, SW-3

February 8 and 9, 2015
Following construction of the well, approximately 150 gallons of was removed on February 8, 2015 using an air bailer. This was followed by withdrawal of an additional 300 gallons on February 8, 2015. One well volume consists of approximately 26 gallons. Therefore, a total of 11.5 well volumes of groundwater was extracted from well immediately after construction of the well.

February 19, 2015
The site was visited on February 19, 2015 to obtain water quality samples using a hand bailer. Approximately 0.37 gallons was extracted during each bailing operation. A total of 50 bails (18.5 gallons) was removed prior to obtaining the water quality samples; the results of which are discussed below.

March 12, 2015
Based on the recommendation of EPA, a separate visit was made to the site on March 12, 2015 in order to purge the well with a surge-block. Surging was initiated at 7:30 am with the block at a depth of 25 ft (i.e., top of screen) and applying 25 vigorous up and down strokes. This process was repeated four additional times by lowering the surging start depth by 5-feet each time.

Accordingly, the final (surging) start depth was 45 feet below ground. After the final surging operation, the well was allowed to settle for approximately one hour.

Initial water quality measurements were taken after an hour using a bailer to extract approximately 3 gallons of water before starting pumpage. The water was extremely *dirty* and dark grey in color. Pumping began at 9:15am at an average rate of 25 gallons every 9 minutes. Water quality measurements were then taken at the 25, 50, 100, and 150 gallon marks. The following parameters were measured at each of these gallon marks: turbidity, specific conductance, temperature, pH, salinity, dissolved oxygen, and redox potential. The turbidity trends are presented in **Figure 51**. The salinity parameters are presented and discussed below in the Water Quality section. The entire suite of water quality data for the sample collected on March 12, 2015 is presented in Appendix G. As can be noted from **Figure 51**, the water stayed fairly turbid until the 150 gallon mark, when it cleared up significantly. At 175 gallons the pump unexpectedly shut off, and the water collection tank was emptied into a large truck. An additional 25 gallons was pumped with another pump. Due to the higher horse-power of this pump, it increased the sediment intake significantly and caused the turbidity to increase. This is reflected in the sudden spike in turbidity (**Figure 51**).

The original pump was successfully run again at the 200 gallon mark. The water appeared turbid until the 225 and 250 gallon mark. Additional measurements were taken at 300, 325, 350, 375, 400, and 425 gallons marks. The water in these last 6 measurements was very clear and seemed to remain constantly clear as pumping continued (**Figure 7**).

Figure 51. Turbidity in SW-3 following surging operations on March 12, 2015.

Well Water Levels and Well Yield

Water levels were measured during several trips to the site as documented in **Table 2**. The water levels are consistently in the 11-12 feet (below measuring point) range. The measuring point is approximately 18 inches above ground.

The well has not been operated continuously for an extended period in order to derive a sustainable yield. However, during the well development and sampling operations conducted on March 19 and March 27, a yield of greater than 3 GPM was estimated.

Table 2. Water level measurements at SW-3

Date	Water Level (ft below Measuring Point*)	Notes
2/9/2015	~ 10’	Estimated by driller
2/19/2015 12 noon	11’-0.25”	Prior to bailing
2/19/2015 ~ 5 pm	11’-0.75”	After 20 bailing cycles
3/12/2015 (7:30am)	11’-5”	Prior to commencing pumpage
3/17/2015 (8:10 am)	11’-4”	Prior to commencing pumpage

3/17/2015 (10:00 am)	12'-5"	After pumping 200 gallons

* Measuring point approximately 18 inches above ground.

Water Quality Sampling

The water quality in SW-3 was determined during four separate trips to the site. The purpose of the first three trips was to obtain an initial estimate of the TDS at the site. Therefore a strict sampling protocol was not followed during these visits. During the last two trips, the sampling, handling, and transportation procedure forwarded to the EPA in the proposed QASP (KGS, 2015) were followed. The water quality results derived during each site visit are documented below. A TDS of greater than 10,000 mg/l was measured during each visit. Further explanation of field activities and observations are documented below.

Table 3. TDS estimated during site visits and from laboratory sample

Date	TDS (mg/l)	Depth (ft below MP)	Notes
2/11/15	24,027	~ 11-12	Bailing operation. Sample analyzed in lab by Baker-Hughes
2/19/15	25,195	~ 12	Bailing operation. TDS estimated from specific conductivity
3/12/15	24,924		After pumping 425 gallons. TDS estimated from specific conductivity
3/17/15	31,500		After pumping 100 gallons of groundwater. TDS derived from lab based concentration of cations and anions
3/17/15	28,200		After pumping 200 gallons of groundwater. TDS derived from lab based concentration of cations and anions

Feb 11, 2015

In order to obtain a preliminary estimate of water quality, a sample was collected at the water table (~ 11 ft) and forwarded to Baker Hughes for laboratory analysis.. A TDS value of 24,027 mg/l was estimated for the sample.

Feb 19, 2015

After bailing 18.5 gallons (~ 0.7 well volumes), a sample was collected and a specific conductance of 37,600 micro-siemens/cm and salinity=18,800 mg/l was measured using a portable meter. Based on a TDS/conductivity ratio of 0.67, a TDS value of 25,195 mg/l was derived.

March 12th 2015

During the site visit on March 12, 2015, up to 425 gallons was pumped from SW-3. The TDS estimated from specific conductance (TDS = 0.67 conductance) is presented in **Table 4** and also displayed in **Figure 52** along with the specific conductance and salinity data. The TDS appears to stabilize at approximately 25,000 mg/l.

Table 4. TDS estimated from specific conductance during site visit on March 12, 2015

Estimated TDS (in mg/L) based on conductance		
	0 gallons	30,552
	25 gallons	29,480
	50 gallons	27,604
	100 gallons	28,140
	150 gallons	27,001
	225 gallons	27,068
	250 gallons	26,063
	300 gallons	25,259
	325 gallons	24,924
	350 gallons	25,125
	375 gallons	24,857
	400 gallons	25,125
	425 gallons	24,924

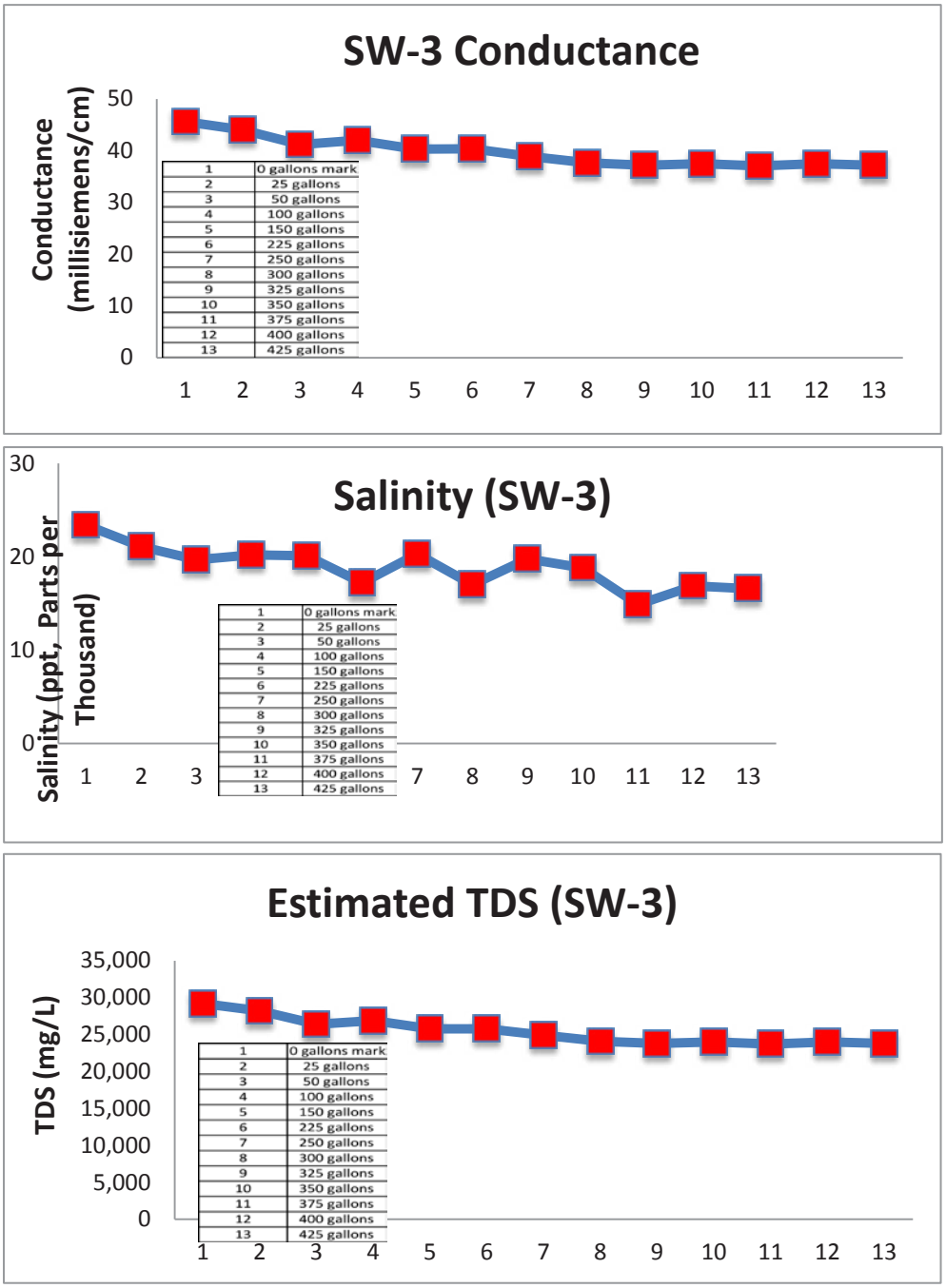


Figure 52. Temporal trends for various salinity parameters in SW-3 following surging operations on March 12, 2015.

<u>March 19th 2015</u>

During the site visit on March 17, 2015, up to 200 gallons was pumped from SW-3. The TDS estimated from specific conductance (TDS = 0.67 conductance) is presented in **Table 4** and also displayed in **Figure 53** along with the specific conductance and salinity data. The TDS appears to fluctuate in the 29,000-30,000 mg/l range.

Table 4. Estimated TDS at SW-3 on March 17, 2015

Estimated TDS (mg/l) based on conductance	
0 gallons mark	18,157
25 gallons	30,820
50 gallons	31,892
100 gallons	30,820
150 gallons	28,877
200 gallons	28,140

Groundwater samples were also collected on March 17, 2015 at the 100 and 200 gallon mark and forwarded to Continental Analytical Services (CAS) in Salina, KS for laboratory based concentration measurements of key parameters. A TDS value of 31,500 mg/l and 28,200 mg/l was estimated at the 100 and 200 gallon mark from key parameters as indicated in **Tables 5 and 6**.

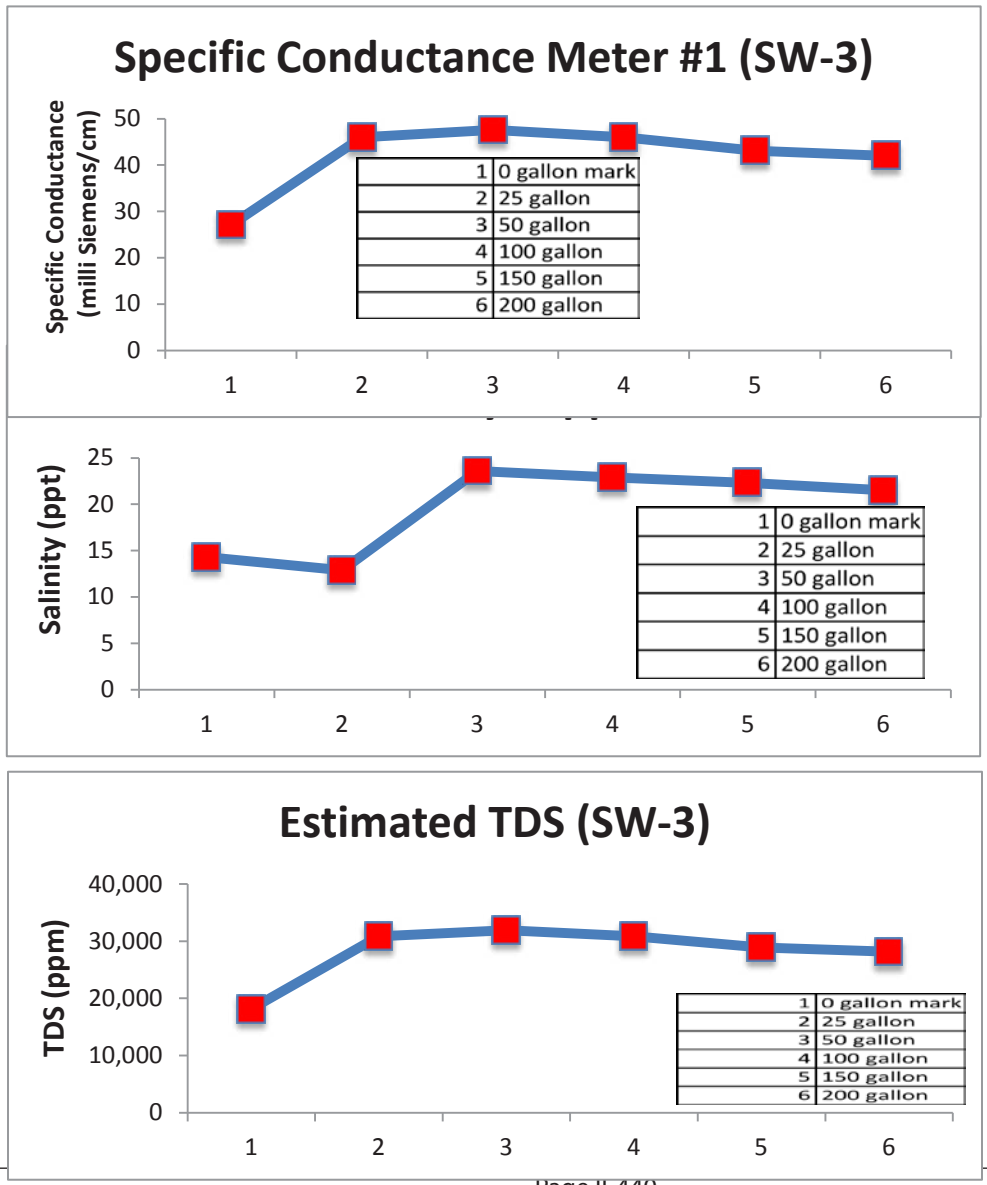


Figure 53. Temporal trends for various salinity parameters in SW-3 during pumping on March 19, 2015.

Table 5. Estimation of TDS (mg/l) using major cations and anions concentration at the 100 gallon mark.

Cation (mg/l)		**Anion (mg/l)**	
Ca	4270	**Cl**	18400
Mg	1510	**SO_4**	1330
K	23.6	**PO_4**	ND(0.050)
Na	4720	**Alkalinity**	88
Dissolved Silica	19.1	**Br**	56
Fe	1.6		
Mn	126 ug/L		
Al	ND(500)M (ug/L)		
	Total Dissolved Solids	**31500 mg/L**	
	ND=non detected		

Table 6. Estimation of TDS (mg/l) using major cations and anions at the 100 gallon mark.

Cation (mg/l)		**Anion (mg/L)**	
Ca	3820	**Cl**	17200
Mg	1380	**SO_4**	1260
K	21.3	**PO_4**	ND(0.050)
Na	3860	**Alkalinity**	101
Dissolved Silica	19.3	**Br**	52
Fe	1.54		
Mn	107 ug/L		
Al	ND(500)M (ug/L)		
	Total Dissolved Solids	**28200 mg/L**	
	ND= non detected		

An (ion) charge balance analysis was conducted in order to ensure that the major constituents in the groundwater samples used to estimate TDS were accounted for in the determination of TDS. The charge balance for the samples at 100 and 200 gallon mark are presented in **Tables 7** and **8.**

Table 7. Charge balance for sample at 100 gallon mark at SW-3 collected on March 17, 2015

Cation				**Anion**			
	mg/L		**meq/L**	**mg/L**			**meq/L**
Ca^{++}	*4270*	**as Ca**	213.5	**Alk**	88	**as $CaCO_3$**	1.8
Mg^{++}	*1510.0*	**as Mg**	125.8	**Cl^-**	*18400*	**as Cl**	518.3
Na^+	*4720*	**as Na**	205.2	**$SO4^=$**	*1330*	**as SO_4**	27.7
K^+	*23.6*	**as K**	0.6	**$NO3^-$**	*0.5*	**as NO_3**	0.0
NH_4^+	*0.0*	**as NH_4**	0.0	**F^-**	*0.7*	**as F**	0.0
		□cations	**545.16**			□anions	**547.82**

Financial Assurance Talking Points

- Lack of a significant USDW
  - Lack thickness (possibly limited to uppermost 13 ft)
  - Limited long-term yield of any freshwater in the AOR for domestic use due to limitations in storage and drawdown limitations of the shallow zone without encroachment of brine.
- Concerns about technical feasibility of mitigation
  - Salt water intrusion from pumping aquiclude with shallow halite.
  - Integrity of the shale-halite unit in the area indicates sealing nature of this caprock that can be disturbed by pumping
  - No significant salt dissolution in the immediate area due to natural processes or otherwise
    - Previous work indicates lack of strength of the thin (200 ft) shale to support a cavern if the halite is dissolving
    - Infer that no fractures or faults or leaking wells have allowed the bed of halite to dissolve in the immediate vicinity of Wellington Field
    - Thus recommend minimal invasive action such as drilling into the shale bed

Alternatives for financial assurance

1. Large scale mitigation strategies for upper Wellington Shale are unwarranted due to effects that pumping would likely have on the aquiclude.
2. Recommend that it is appropriate in the AOR to modify or replace the migration model used by EPA.
3. Financial assurance requirements to plug and mitigate the Wellington aquiclude needs to reflect the reduced risk of USDW contamination.
   - Bonding for plugging

- Operator insurance for pollution mitigation, in this case, no more risk than a Class II disposal/EOR

Data Table and Java Program for Archiving and Display of Water Chemistry

A Brine Summary Web Page was created by J. Victorine that will allow the user to create Sample Concentration Plots and Piper Diagram for individual water samples. The Java-based software later provide the means to compare analyses spatially (with well location) and through time to detect differences important for monitoring. This would be useful for any water that is being analyzed and will be made accessible to the team to permit rapid comparison with other monitoring methods.

A series of Oracle database tables were created to store the brine information that will be input from a comma delimited format. The Comma Separated Values (CSV) ASCII File are in 3 sections:

(1) The Header Section is the Basic Sample information, Well name, lab, sample dates, etc.
(2) The Data Section with each cations and anions on a separate line, the row order of the anions and cations are not important.
(3) The Other Data Section with data like Resistivity, conductivity, temperature, pressure, etc. The row order of the other data is not important.

An example analyses from Continental Analytical Services was input and reported as follows:

--HEADER SECTION:
Well name, Sampled_Date, Lab Name, Lab_Number, Amount_Fluid, Amount_Fluid_Units, Recieved_Date, Reported_Date, File_Number, Order_Number, Description
KGS SW #3, 03/17/2015 10:00,Continental Analytical Services Inc., 15031047,100, gallons, 03/18/2015, 03/27/2015, 6692,124904, 100 gallon pumped

-- DATA SECTION
Mnemonic, Analysis, Value, Units, Dilation_Factor, LoQ, Book_Page, QC_Batch, INST_Batch, Prepared_Date, Analyzed_Date, Analyst, Method
Al, Aluminum Dissolved ICP,ND(500) M,ug/L, 5.0,500,7443/218,03/23/15 07:45, 03/24/15 14:35, 150323-3,2IP4083,KMW,6010B
Ca, Calcium Dissolved ICP,4270,mg/L, 10.0,5,7443/221,03/23/15 07:45,03/26/15 18:03, 150323-3,3IP4085,KMW,6010B
Fe, Iron, Dissolved ICP,1.60,mg/L, 1.0,0.10,7443/217,03/23/15 07:45,03/23/15 15:59, 150323-3,3IP4082,KMW,6010B
Mg, Magnesium Dissolved ICP,1510,mg/L,5.0,0.5,7443/218,03/23/15 07:45, 03/24/15 14:35, 150323-3,2IP4083,KMW,6010B
K,Potassium Dissolved ICP,23.6,mg/L,1.0,0.3,7443/217,03/23/15 07:45, 03/23/15 15:59, 150323-3,3IP4082,KMW,6010B
Cl, Chloride,18400,mg/L, 1000,1000,7277/696, N/A,03/23/15 17:13,1IC2082, 2IC2082,MLL,300 0/9056A

PO4,Orthophosphate as P D-React,ND(0.050), mg/L,1.0,0.050,7182/384,N/A,03/18/15 14:04,150318-3, 150318-3,JND,4500-P(E)-1999
SO4,Sulfate,1330,mg/L,100,100,7277/697,N/A,03/24/15 18:32,1IC2083,2IC2083,MLL,3000/9056A
Br,Bromide,56,mg/L,10,5,7277/697,N/A,03/24/15 16:38,1IC2083,2IC2083,MLL,3000/9056A

-- OTHER DATA SECTION
Analysis, Value, Units
Specific conductance meter 1, 46, mS/cm
Avg Temp, 16.7, degrees C
Specific conductance meter #2,45.8, mS/cm
pH, 7.23,
Est TDS based on conductance,30820, mg/L

. . .

The units for the anions and cations are mg/L or ug/L, 'u' is not the Greek mu. In other words no Greek symbols are use since they can not be parsed without knowing the actual character, which for Greek mu is not always the same between editors.

The ASCII lab results can be parsed into this format and a series of scripts will be created to push into the database. XML files will be built to plot the data.

Examples from the new Brine Summary Web Page are shown in **Figures 53 through 50**. Plots provide a means to rapidly review and compare water data "on the fly" from an active database. Tools are available to plot and export the data as well for reporting.

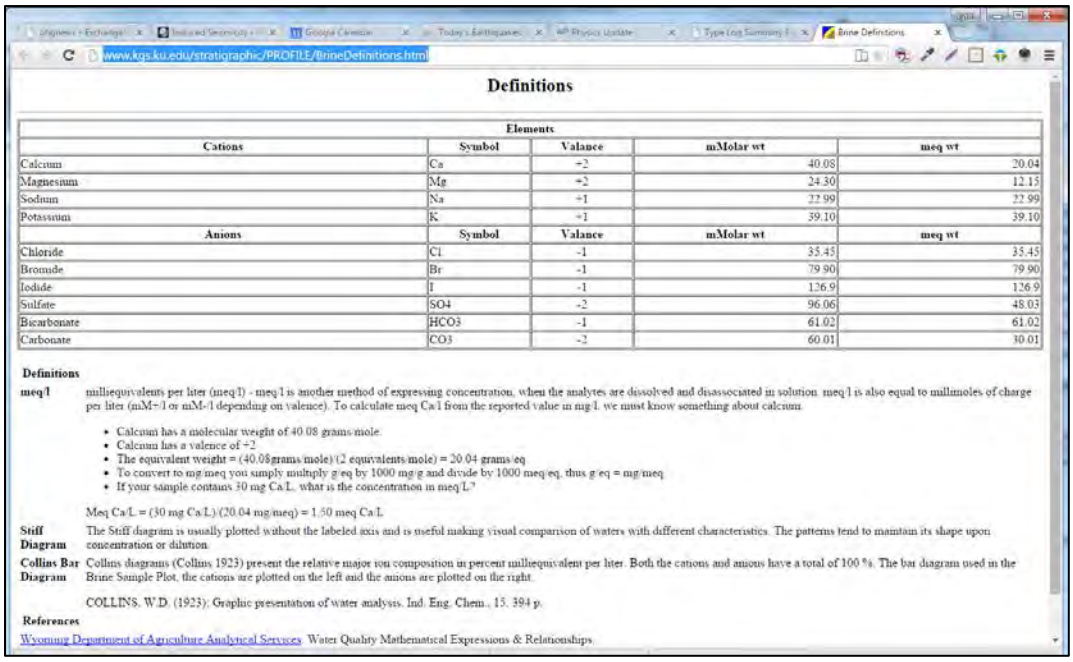
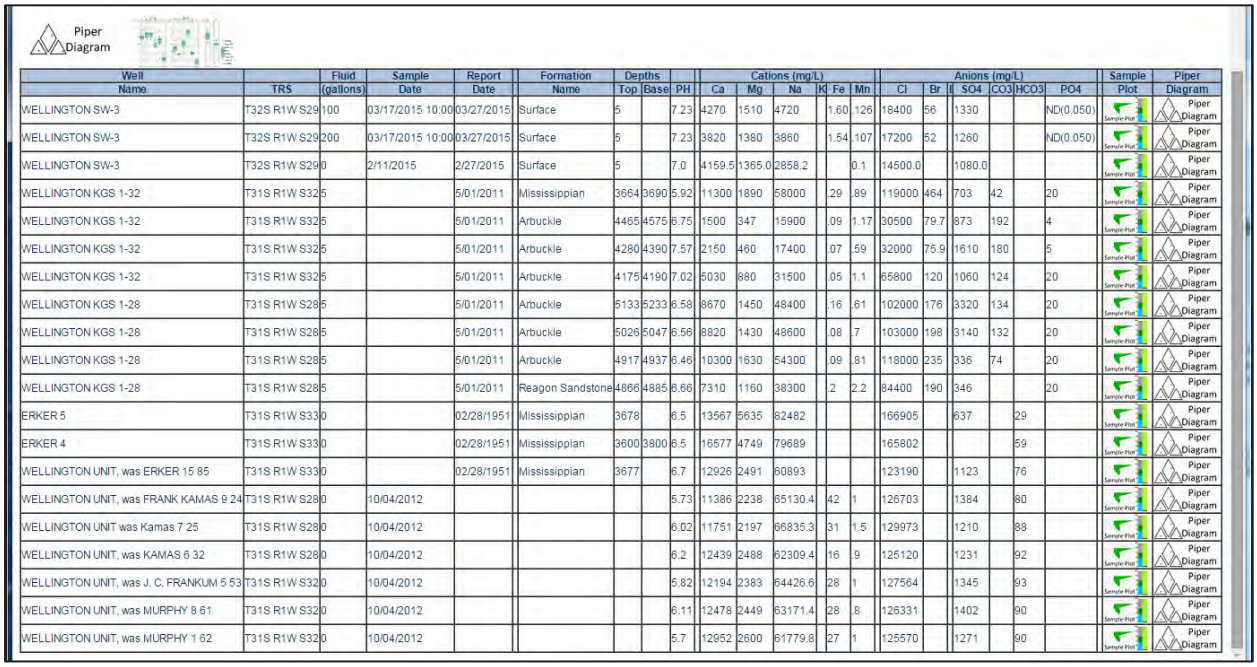


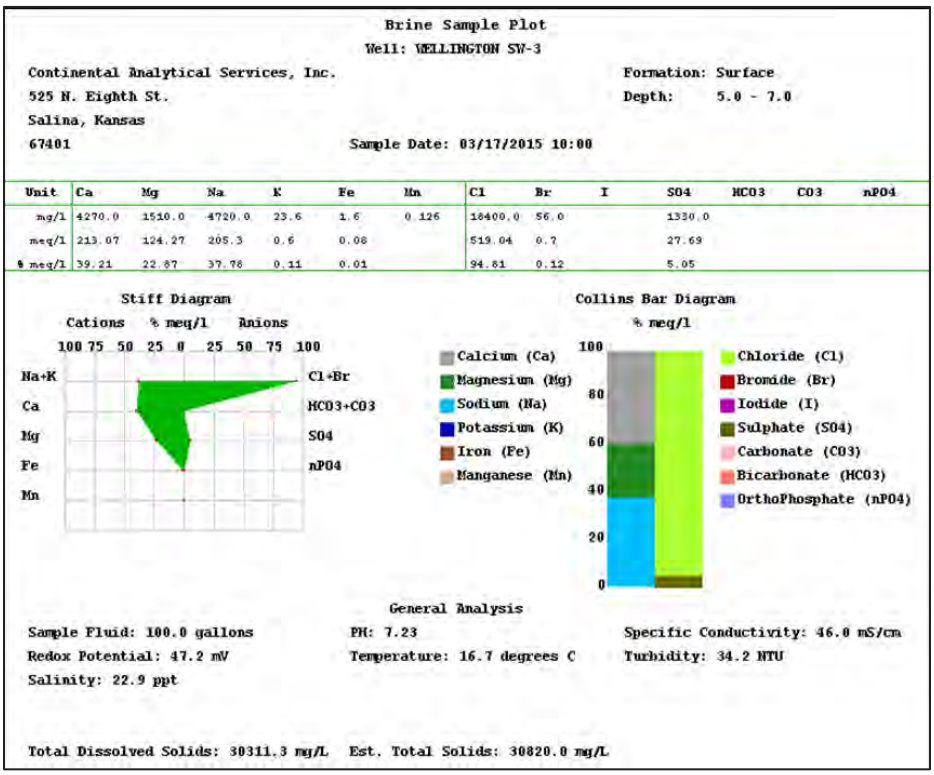
Figure 53. Definitions page from the Brine Summary Web Page.



Piper Diagram

Well Name	TRS	Fluid (gallons)	Sample Date	Report Date	Formation Name	Depths Top	Depths Base	PH	Cations (mg/L) Ca	Mg	Na	K	Fe	Mn	Anions (mg/L) Cl	Br	I	SO4	CO3	HCO3	PO4	Sample Plot	Piper Diagram
WELLINGTON SW-3	T32S R1W S29	100	03/17/2015 10:00	03/27/2015	Surface	5		7.23	4270	1510	4720		1.60	.126	18400	56		1330			ND(0.050)		
WELLINGTON SW-3	T32S R1W S29	200	03/17/2015 10:00	03/27/2015	Surface	5		7.23	3820	1380	3860		1.54	.107	17200	52		1260			ND(0.050)		
WELLINGTON SW-3	T32S R1W S29	0	2/11/2015	2/27/2015	Surface	5		7.0	4159.5	1365.0	2858.2			0.1	14500.0			1080.0					
WELLINGTON KGS 1-32	T31S R1W S32	5		5/01/2011	Mississippian	3664	3690	5.92	11300	1890	58000		.29	.89	119000	464		703	42		20		
WELLINGTON KGS 1-32	T31S R1W S32	5		5/01/2011	Arbuckle	4465	4575	6.75	1500	347	15900		.09	1.17	30500	79.7		873	192		4		
WELLINGTON KGS 1-32	T31S R1W S32	5		5/01/2011	Arbuckle	4280	4390	7.57	2150	460	17400		.07	.59	32000	75.9		1610	180		5		
WELLINGTON KGS 1-32	T31S R1W S32	5		5/01/2011	Arbuckle	4175	4190	7.02	5030	880	31500		.05	1.1	65800	120		1060	124		20		
WELLINGTON KGS 1-28	T31S R1W S28	5		5/01/2011	Arbuckle	5133	5233	6.58	8670	1450	48400		.16	.61	102000	176		3320	134		20		
WELLINGTON KGS 1-28	T31S R1W S28	5		5/01/2011	Arbuckle	5026	5047	6.56	8820	1430	48600		.08	.7	103000	198		3140	132		20		
WELLINGTON KGS 1-28	T31S R1W S28	5		5/01/2011	Arbuckle	4917	4937	6.46	10300	1630	54300		.09	.81	118000	235		336	74		20		
WELLINGTON KGS 1-28	T31S R1W S28	5		5/01/2011	Reagon Sandstone	4866	4885	6.66	7310	1160	38300		.2	2.2	84400	190		346			20		
ERKER 5	T31S R1W S33	0		02/28/1951	Mississippian	3678		6.5	13567	5635	82482				166905			637		29			
ERKER 4	T31S R1W S33	0		02/28/1951	Mississippian	3600	3800	6.5	16577	4749	79689				165802					59			
WELLINGTON UNIT, was ERKER 15 85	T31S R1W S33	0		02/28/1951	Mississippian	3677		6.7	12926	2491	60893				123190			1123		76			
WELLINGTON UNIT, was FRANK KAMAS 9 24	T31S R1W S28	0	10/04/2012					5.73	11386	2238	65130.4		42	1	126703			1384		80			
WELLINGTON UNIT was Kamas 7 25	T31S R1W S28	0	10/04/2012					6.02	11751	2197	66835.3		31	1.5	129973			1210		88			
WELLINGTON UNIT, was KAMAS 6 32	T31S R1W S28	0	10/04/2012					6.2	12439	2488	62309.4		16	.9	125120			1231		92			
WELLINGTON UNIT, was J. C. FRANKUM 5 53	T31S R1W S32	0	10/04/2012					5.82	12194	2383	64426.6		28	1	127564			1345		93			
WELLINGTON UNIT, was MURPHY 8 61	T31S R1W S32	0	10/04/2012					6.11	12478	2449	63171.4		28	.8	126331			1402		90			
WELLINGTON UNIT, was MURPHY 1 62	T31S R1W S32	0	10/04/2012					5.7	12952	2600	61779.8		27	1	125570			1271		90			

Figure 54. List of water well samples obtained to date for Wellington Field as displayed from the Brine Summary Web Page.



Brine Sample Plot
Well: WELLINGTON SW-3

Continental Analytical Services, Inc.
525 N. Eighth St.
Salina, Kansas
67401

Formation: Surface
Depth: 5.0 - 7.0

Sample Date: 03/17/2015 10:00

Unit	Ca	Mg	Na	K	Fe	Mn	Cl	Br	I	SO4	HCO3	CO3	nPO4
mg/l	4270.0	1510.0	4720.0	23.6	1.6	0.126	18400.0	56.0		1330.0			
meq/l	213.07	124.27	205.3	0.6	0.08		519.04	0.7		27.69			
% meq/l	39.21	22.87	37.78	0.11	0.01		94.81	0.12		5.05			

Stiff Diagram

Cations % meq/l Anions

100 75 50 25 0 25 50 75 100

Na+K
Ca
Mg
Fe
Mn

Cl+Br
HCO3+CO3
SO4
nPO4

Collins Bar Diagram

% meq/l

Calcium (Ca)
Magnesium (Mg)
Sodium (Na)
Potassium (K)
Iron (Fe)
Manganese (Mn)

100
80
60
40
20
0

Chloride (Cl)
Bromide (Br)
Iodide (I)
Sulphate (SO4)
Carbonate (CO3)
Bicarbonate (HCO3)
OrthoPhosphate (nPO4)

General Analysis

Sample Fluid: 100.0 gallons
Redox Potential: 47.2 mV
Salinity: 22.9 ppt

PH: 7.23
Temperature: 16.7 degrees C

Specific Conductivity: 46.0 mS/cm
Turbidity: 34.2 NTU

Total Dissolved Solids: 30311.3 mg/L Est. Total Solids: 30820.0 mg/L

Figure 55. Default brine sample plot generated for SW-3 using Java software accessed from the Brine Summary Web Page (right two columns of table shown in Figure 54). Compare patterns to Mississippian water shown in Figure 57.

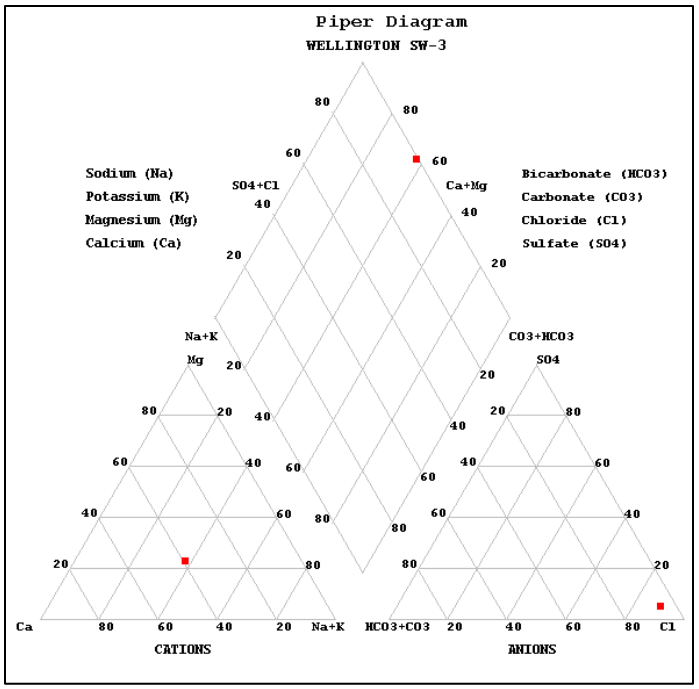


Figure 56. Piper diagram for SW-3 brine sample.

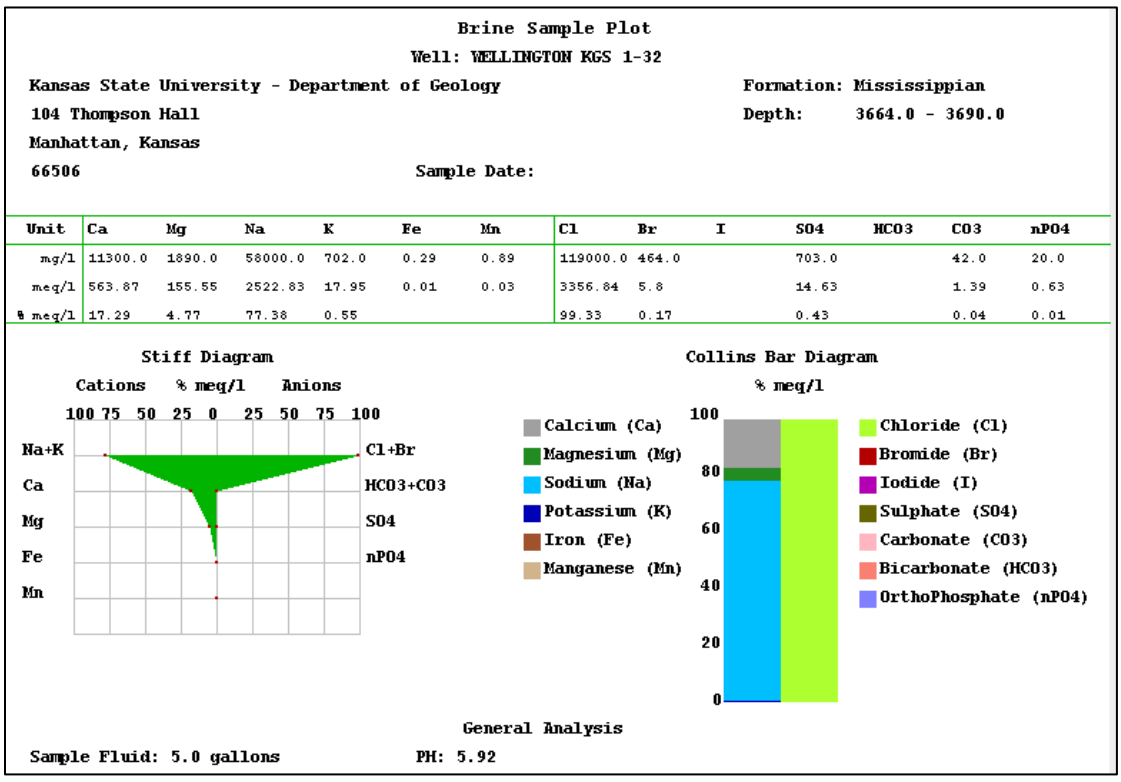


Figure 57. Default brine sample plot generated for Wellington #1-32 Mississippian brine sample using Java software accessed from the Brine Summary Web Page (right two columns of table shown in Figure 54). Compare patterns to surface water shown in Figure 55.

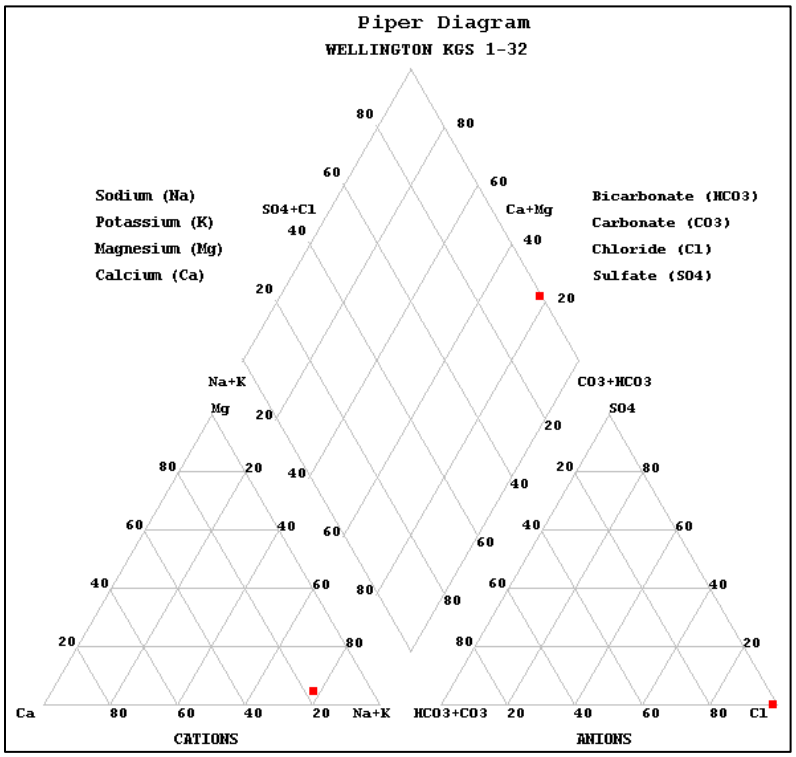


Figure 58. Piper diagram for Wellington Mississippian brine sample.

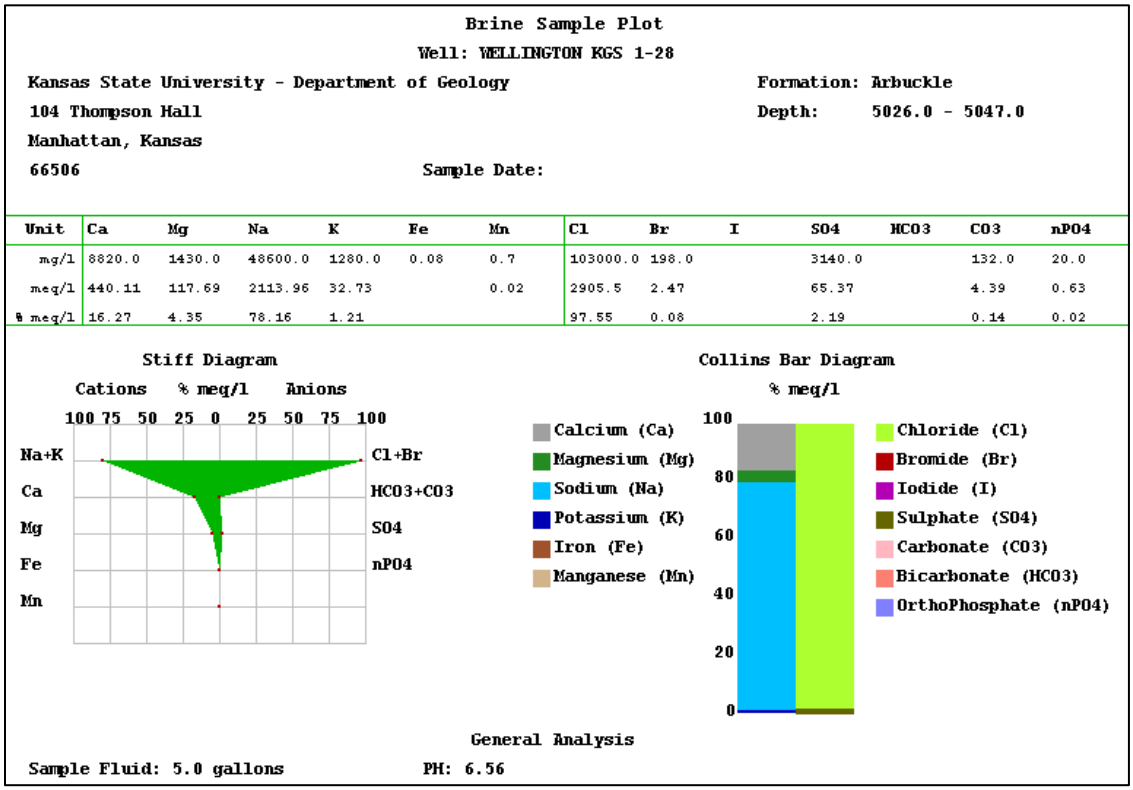


Figure 59. Default brine sample plot generated for Wellington #1-32 Arbuckle brine sample using Java software accessed from the Brine Summary Web Page (right two columns of table shown in Figure 54). Compare patterns to Mississippian water shown in Figure 57.

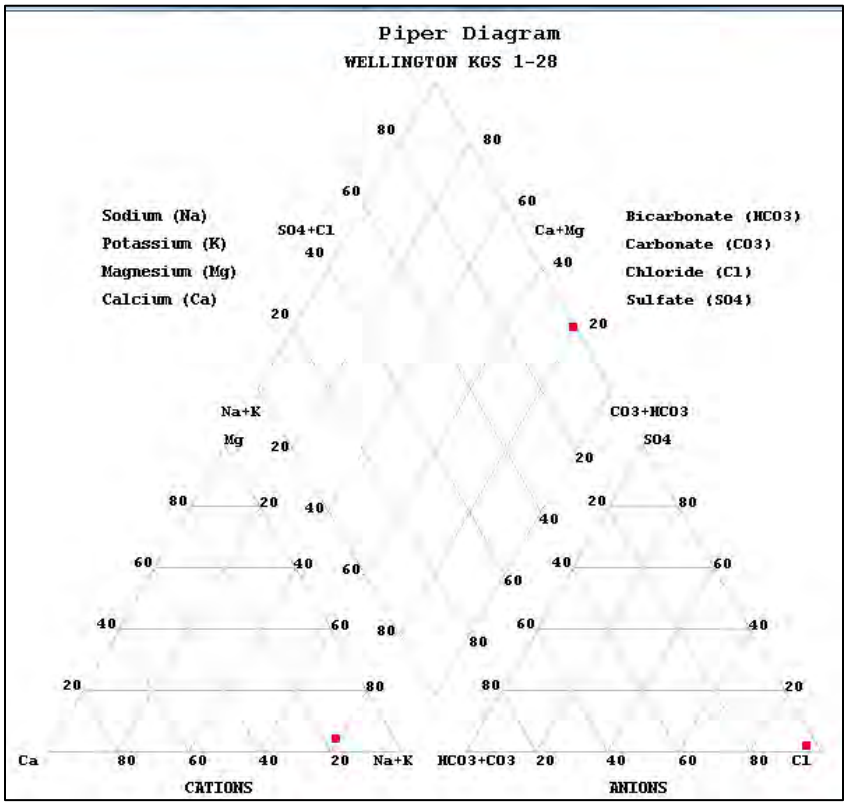


Figure 60. Piper diagram for Wellington Arbuckle brine sample.



Figure 61. Illustration of in the field sampling water from SW-3, Chance Reese, KSU.

Photos in **Figure 61** illustrate some of the equipment used by Chance Reese to sample SW-3. Initial readings of water quality indicate high salinity values. The third photo was taken after 10-11 bail volumes were disposed. The water clarity was fairly consistent throughout the bailing process, and became slightly murkier over time.

Future Communications with EPA - Seismicity in South-Central Kansas, Defining Safe Injection, Implications for Wellington Field Test

Recent earthquakes in south-central Kansas dramatically increased since 2013 from less than 2 to over 30 in one month during a time volumes of brine disposal increased nearly 10-fold in Harper County the focus of the seismic activity. Increased volumes resulted from a few wells with large rates of injection at elevated surface pressures. Kansas' induced seismicity committee comprised of state regulating agencies for Class I and II injection wells and the KGS reviewed the seismicity and on March 19, the Kansas Corporation Commission signed an order reducing saltwater injection rates in proximity to four seismically active zones in Harper and eastern Sumner County (**Figure 62**). The seismic zone in closest proximity to Wellington is located 15 miles to the west.

Since the injection rates were reduced in wells in proximity to the seismicity, the frequency and size of the earthquakes have diminished (**Figures 63-65**). The geologic maps generated from http://maps.kgs.ku.edu/co2/ indicate the focus of the western zone of continuing seismic activity corresponds to a subtle Mississippian structure ridge and a sharp linear change in the total magnetic field intensity that is confirmed from nearby wells to be the boundary between granite (magnetic high) and a deep rift valley sedimentary succession (magnetic low). The Proterozoic rift valley trends northeast extending through the central portion of Kansas. Wellington Field lies outside of the rift valley and its bounding faults and west of the Nemaha Uplift. While seismicity has occurred nearby, Wellington has not experienced the felt earthquakes that are over 2.5 magnitude.

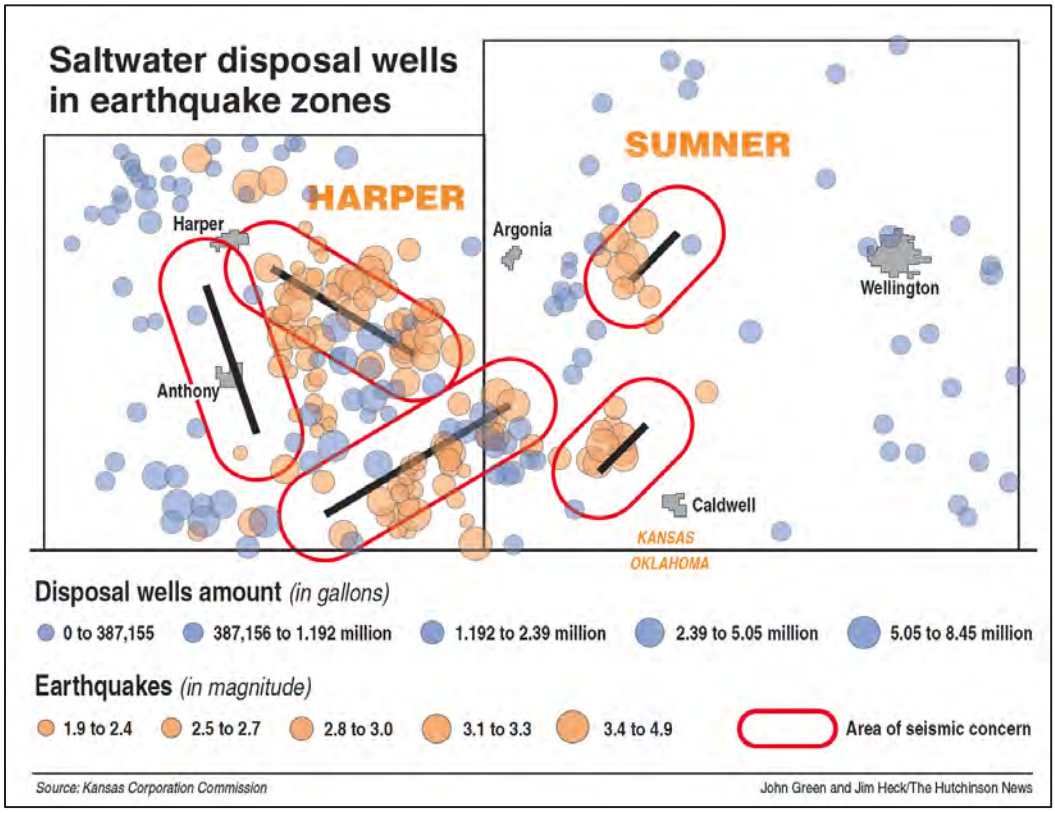


Figure 62. Map of disposal wells, earthquakes, and lineaments there brine injection was reduced in Harper and Sumner counties in south-central Kansas. Illustration is from the Hutchinson News. Wellington Field is located immediately NW of Wellington Field.

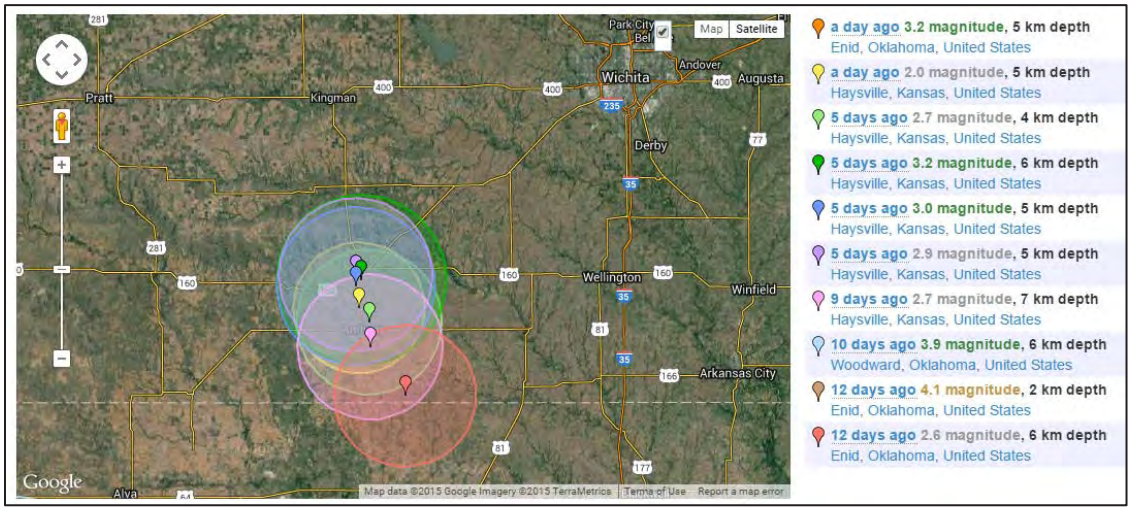


Figure 63. Recent earthquakes 5-11-15. http://earthquaketrack.com/us-ks-wichita/recent are limited to the western most NW-SE trending seismic lineament extending near Harper and Anthony Kansas in western Harper County.

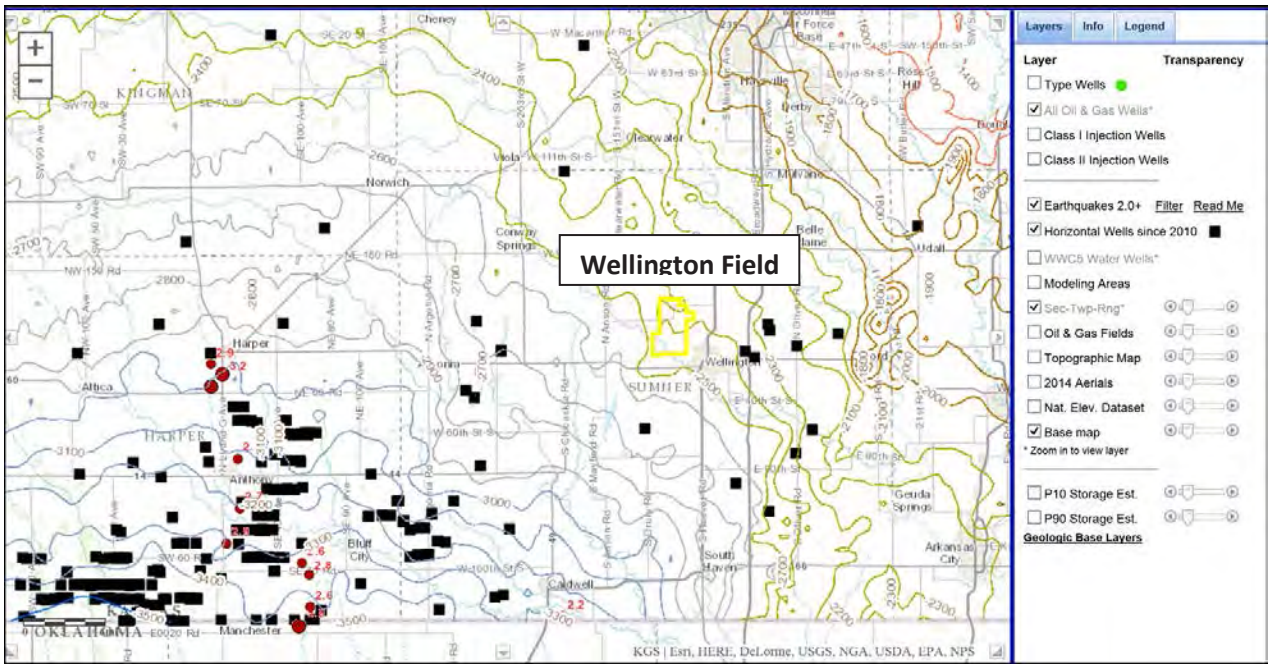


Figure 64. Mississippian structure, earthquakes in past month (4-10 to 5-10-15), Mississippian horizontal wells (black squares), yellow outline of Wellington Field.

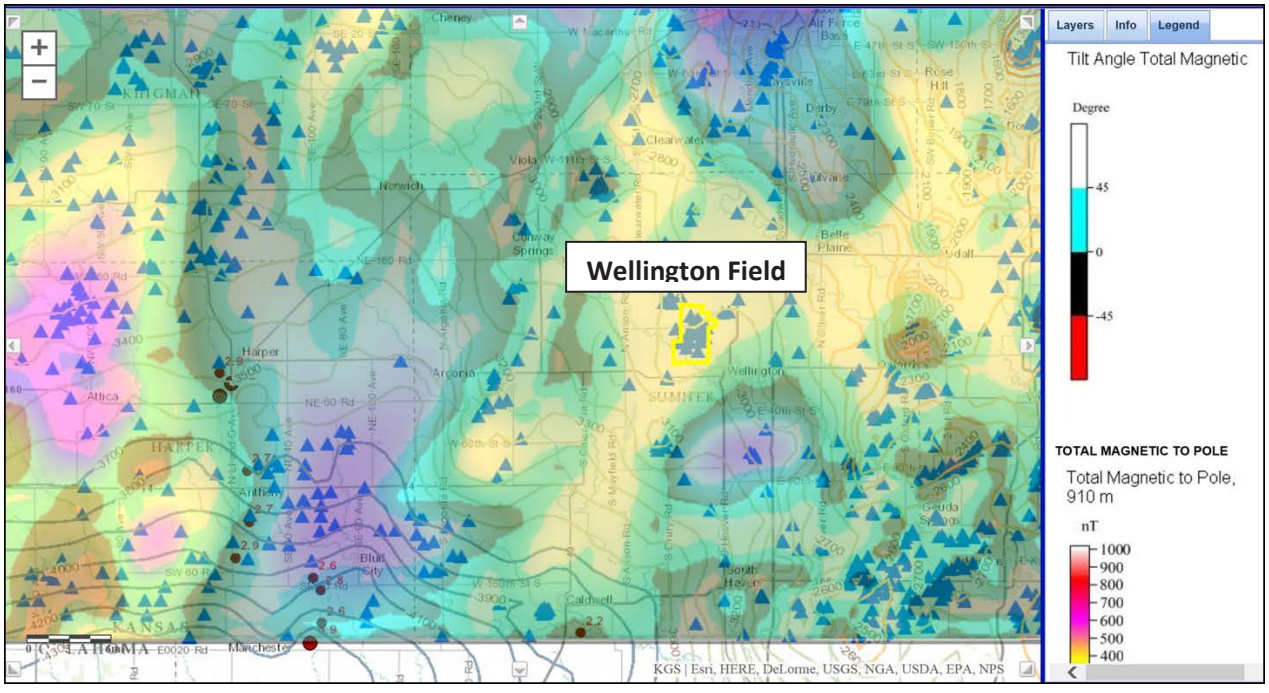


Figure 65. Arbuckle structure, Total magnetic and tilt angle of total magnetic, earthquakes in past month (4-10 to 5-10-15), Class II wells, yellow outline of Wellington Field

Project Schedule

BP2 activities continue on schedule:

1. Class VI Application:

- EPA received our responses to Tables 1, 3, and the QASP document and third round of discussions are
- We are updating our report of the evaluation of the surface waters as new information becomes available.
- Rick Miller/KGS will acquire baseline high-resolution seismic data
- Work continues on establishing baseline for Mississippian water use with both the Mississippian and Arbuckle injections.
    - Incorporating data obtained by Berexco related to previous well maintenance
    - Incorporating analyses of Mississippian brine from 2056 activities
    - New sampling starting soon to provide a longer term (6+ mo.) baseline for the Arbuckle injection.
- Preparation of a report updating the EPA in on the potential for seismicity at Wellington -- Updates of fault mapping and geomechanical analysis in relationship to creating felt seismicity during the Arbuckle injection.

2. Mississippian CO2 injection --

- Mississippian injection well, KGS #2-32, was successfully completed last week. Mississippian was perforated 3663-3706 ft. acidized and a brine injectivity test was conducted indicating #150 psi surface pressure and 4 barrels per minute (5760 bbls per day). This is roughly 10x that rate that CO2 would be injected so well has more than adequate injectivity.
- Mississippian at KGS #2-32 is at residual oil saturation, estimated by Mina to be between 23 and 30% based on NMR log.
- A 5-well interference test will be done to test communication between KGS #2-32 and surrounding wells and evaluate the effects of a small fault east of #2-32, provide important geomechanical parameters via leakoff test in steps E-G of the pulse test schedule. Pulse test is designed and will be analyzed by Mina Fazelalavi, Pressure sampling rate is 1 second and duration of the recording will extend until the next day.

- Pending review of the existing reservoir model with new results of the interference test and initial review of the seismic data, the methodology of the repressurization of reservoir will be done
- Discussions with Linde and Praxair CO2 supply continue
- Considerations being given regarding running a single well tracer to evaluate residual oil near the injector prior to CO2 injection
- A date for CO2 injection into the Mississippian has not been set, but nominally we are looking at up to 60 days due to well completion, receipt of core analysis, completing baseline data, and installation of surface equipment for injection.

Activities of Lawrence Berkeley National Lab

Discussions regarding costs of equipment and fabrication times in terms of project timing and budget.

ONGOING ACTIVITIES

Task 1. Project Management and Reporting

Completed activities include –

Subtask 1.7. Public Outreach Plan

Completed drafts of Public Information Circular, Fact Sheet, and KGS Press Release for upcoming work at Wellington. Press release (reviewed by key parties, project fact sheet, website-visibility, and meet with public at Wellington to discuss the project and answer questions.)

Subtask 1.8. Arbuckle Injection Permit Application Review go/no go Memo

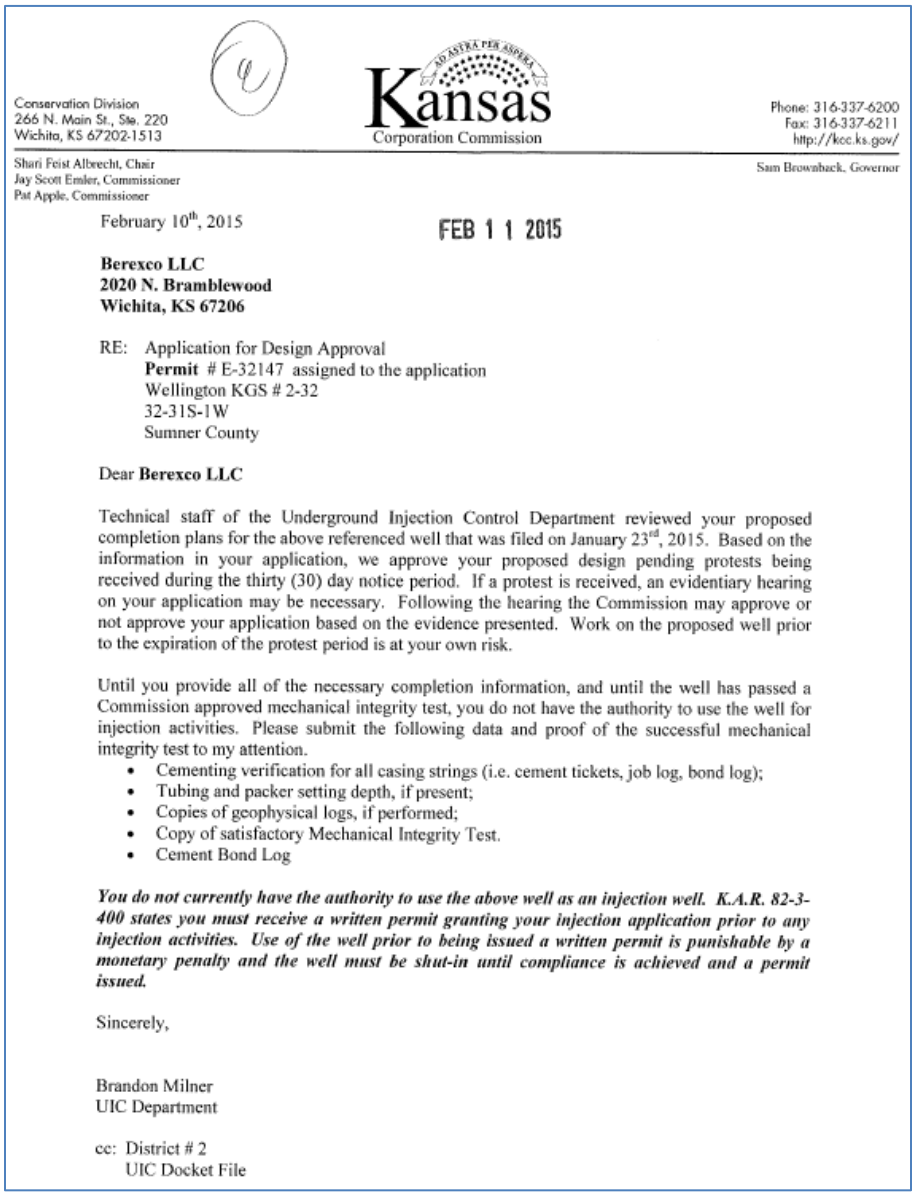
General Permit Application:

Seismicity

Task 3. Site characterization of Mississippian Reservoir - Wellington Field (Class II Application & GO/NO-GO DECISION #4)

Drilling and Completion of Berexco Wellington KGS #2-32

Class II permit to inject CO_2 in the Mississippian for the CO_2-EOR pilot and a permit to drill was received from the Kansas Corporation Commission (**Figures 65-67**).



Conservation Division
266 N. Main St., Ste. 220
Wichita, KS 67202-1513

Kansas
Corporation Commission

Phone: 316-337-6200
Fax: 316-337-6211
http://kcc.ks.gov/

Shari Feist Albrecht, Chair
Jay Scott Emler, Commissioner
Pat Apple, Commissioner

Sam Brownback, Governor

February 10th, 2015

FEB 1 1 2015

Berexco LLC
2020 N. Bramblewood
Wichita, KS 67206

RE: Application for Design Approval
Permit # E-32147 assigned to the application
Wellington KGS # 2-32
32-31S-1W
Sumner County

Dear **Berexco LLC**

Technical staff of the Underground Injection Control Department reviewed your proposed completion plans for the above referenced well that was filed on January 23rd, 2015. Based on the information in your application, we approve your proposed design pending protests being received during the thirty (30) day notice period. If a protest is received, an evidentiary hearing on your application may be necessary. Following the hearing the Commission may approve or not approve your application based on the evidence presented. Work on the proposed well prior to the expiration of the protest period is at your own risk.

Until you provide all of the necessary completion information, and until the well has passed a Commission approved mechanical integrity test, you do not have the authority to use the well for injection activities. Please submit the following data and proof of the successful mechanical integrity test to my attention.

- Cementing verification for all casing strings (i.e. cement tickets, job log, bond log);
- Tubing and packer setting depth, if present;
- Copies of geophysical logs, if performed;
- Copy of satisfactory Mechanical Integrity Test.
- Cement Bond Log

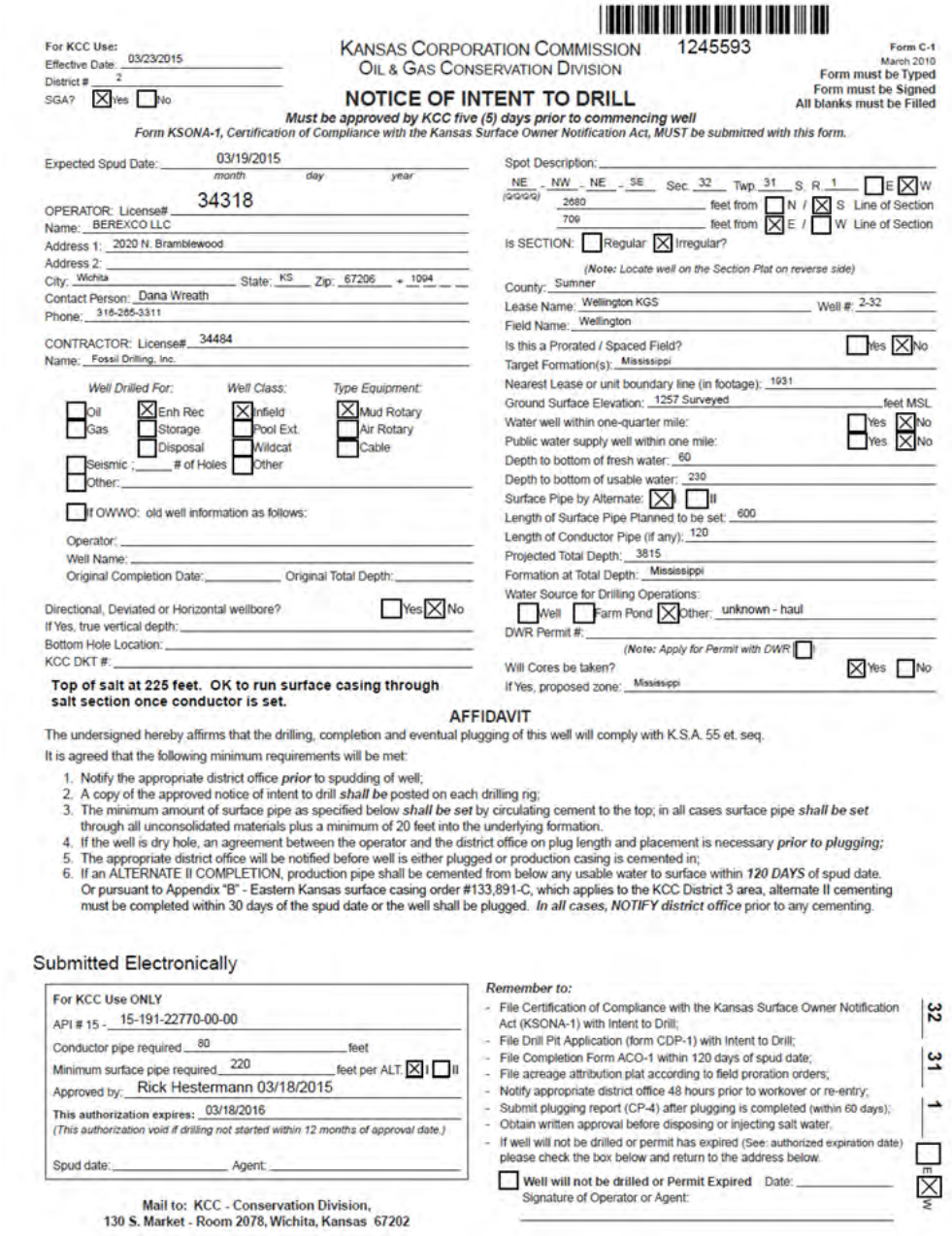
You do not currently have the authority to use the above well as an injection well. K.A.R. 82-3-400 states you must receive a written permit granting your injection application prior to any injection activities. Use of the well prior to being issued a written permit is punishable by a monetary penalty and the well must be shut-in until compliance is achieved and a permit issued.

Sincerely,

Brandon Milner
UIC Department

cc: District # 2
UIC Docket File

Figure 65. Letter from KCC approving design for Berexco Wellingtion KGS #2-32.



For KCC Use:
Effective Date: 03/23/2015
District # 2
SGA? ☒ Yes ☐ No

KANSAS CORPORATION COMMISSION
OIL & GAS CONSERVATION DIVISION
1245593

Form C-1
March 2010
Form must be Typed
Form must be Signed
All blanks must be Filled

NOTICE OF INTENT TO DRILL

Must be approved by KCC five (5) days prior to commencing well

Form KSONA-1, Certification of Compliance with the Kansas Surface Owner Notification Act, MUST be submitted with this form.

Expected Spud Date: 03/19/2015 (month / day / year)

OPERATOR: License# 34318
Name: BEREXCO LLC
Address 1: 2020 N. Bramblewood
Address 2:
City: Wichita State: KS Zip: 67206 + 1094
Contact Person: Dana Wreath
Phone: 316-265-3311

CONTRACTOR: License# 34484
Name: Fossil Drilling, Inc.

Spot Description:
NE - NW - NE - SE Sec. 32 Twp. 31 S. R. 1 ☐ E ☒ W
2680 feet from ☐ N / ☒ S Line of Section
709 feet from ☒ E / ☐ W Line of Section
Is SECTION: ☐ Regular ☒ Irregular?
(Note: Locate well on the Section Plat on reverse side)

County: Sumner
Lease Name: Wellington KGS Well #: 2-32
Field Name: Wellington
Is this a Prorated / Spaced Field? ☐ Yes ☒ No
Target Formation(s): Mississippi
Nearest Lease or unit boundary line (in footage): 1931
Ground Surface Elevation: 1257 Surveyed feet MSL
Water well within one-quarter mile: ☐ Yes ☒ No
Public water supply well within one mile: ☐ Yes ☒ No
Depth to bottom of fresh water: 60
Depth to bottom of usable water: 230
Surface Pipe by Alternate: ☒ I ☐ II
Length of Surface Pipe Planned to be set: 600
Length of Conductor Pipe (if any): 120
Projected Total Depth: 3815
Formation at Total Depth: Mississippi
Water Source for Drilling Operations:
☐ Well ☐ Farm Pond ☒ Other: unknown - haul
DWR Permit #:
(Note: Apply for Permit with DWR ☐)
Will Cores be taken? ☒ Yes ☐ No
If Yes, proposed zone: Mississippi

Well Drilled For: ☐ Oil ☐ Gas ☒ Enh Rec ☐ Storage ☐ Disposal ☐ Seismic ; ____ # of Holes ☐ Other
Well Class: ☒ Infield ☐ Pool Ext. ☐ Wildcat ☐ Other
Type Equipment: ☒ Mud Rotary ☐ Air Rotary ☐ Cable

☐ If OWWO: old well information as follows:
Operator:
Well Name:
Original Completion Date: ____ Original Total Depth: ____

Directional, Deviated or Horizontal wellbore? ☐ Yes ☒ No
If Yes, true vertical depth:
Bottom Hole Location:
KCC DKT #:

Top of salt at 225 feet. OK to run surface casing through salt section once conductor is set.

AFFIDAVIT

The undersigned hereby affirms that the drilling, completion and eventual plugging of this well will comply with K.S.A. 55 et. seq.

It is agreed that the following minimum requirements will be met:

1. Notify the appropriate district office *prior* to spudding of well;
2. A copy of the approved notice of intent to drill *shall be* posted on each drilling rig;
3. The minimum amount of surface pipe as specified below *shall be set* by circulating cement to the top; in all cases surface pipe *shall be set* through all unconsolidated materials plus a minimum of 20 feet into the underlying formation.
4. If the well is dry hole, an agreement between the operator and the district office on plug length and placement is necessary *prior to plugging;*
5. The appropriate district office will be notified before well is either plugged or production casing is cemented in;
6. If an ALTERNATE II COMPLETION, production pipe shall be cemented from below any usable water to surface within *120 DAYS* of spud date. Or pursuant to Appendix "B" - Eastern Kansas surface casing order #133,891-C, which applies to the KCC District 3 area, alternate II cementing must be completed within 30 days of the spud date or the well shall be plugged. *In all cases, NOTIFY district office* prior to any cementing.

Submitted Electronically

For KCC Use ONLY
API # 15 - 15-191-22770-00-00
Conductor pipe required 80 feet
Minimum surface pipe required 220 feet per ALT: ☒ I ☐ II
Approved by: Rick Hestermann 03/18/2015
This authorization expires: 03/18/2016
(This authorization void if drilling not started within 12 months of approval date.)
Spud date: ____ Agent: ____

Mail to: KCC - Conservation Division,
130 S. Market - Room 2078, Wichita, Kansas 67202

Remember to:
- File Certification of Compliance with the Kansas Surface Owner Notification Act (KSONA-1) with Intent to Drill;
- File Drill Pit Application (form CDP-1) with Intent to Drill;
- File Completion Form ACO-1 within 120 days of spud date;
- File acreage attribution plat according to field proration orders;
- Notify appropriate district office 48 hours prior to workover or re-entry;
- Submit plugging report (CP-4) after plugging is completed (within 60 days);
- Obtain written approval before disposing or injecting salt water.
- If well will not be drilled or permit has expired (See: authorized expiration date) please check the box below and return to the address below.

☐ **Well will not be drilled or Permit Expired** Date: ____
Signature of Operator or Agent:

32 31 1 E ☒ W

Figure 65. Approved intent to drill for the Berexco KGS #2-32.

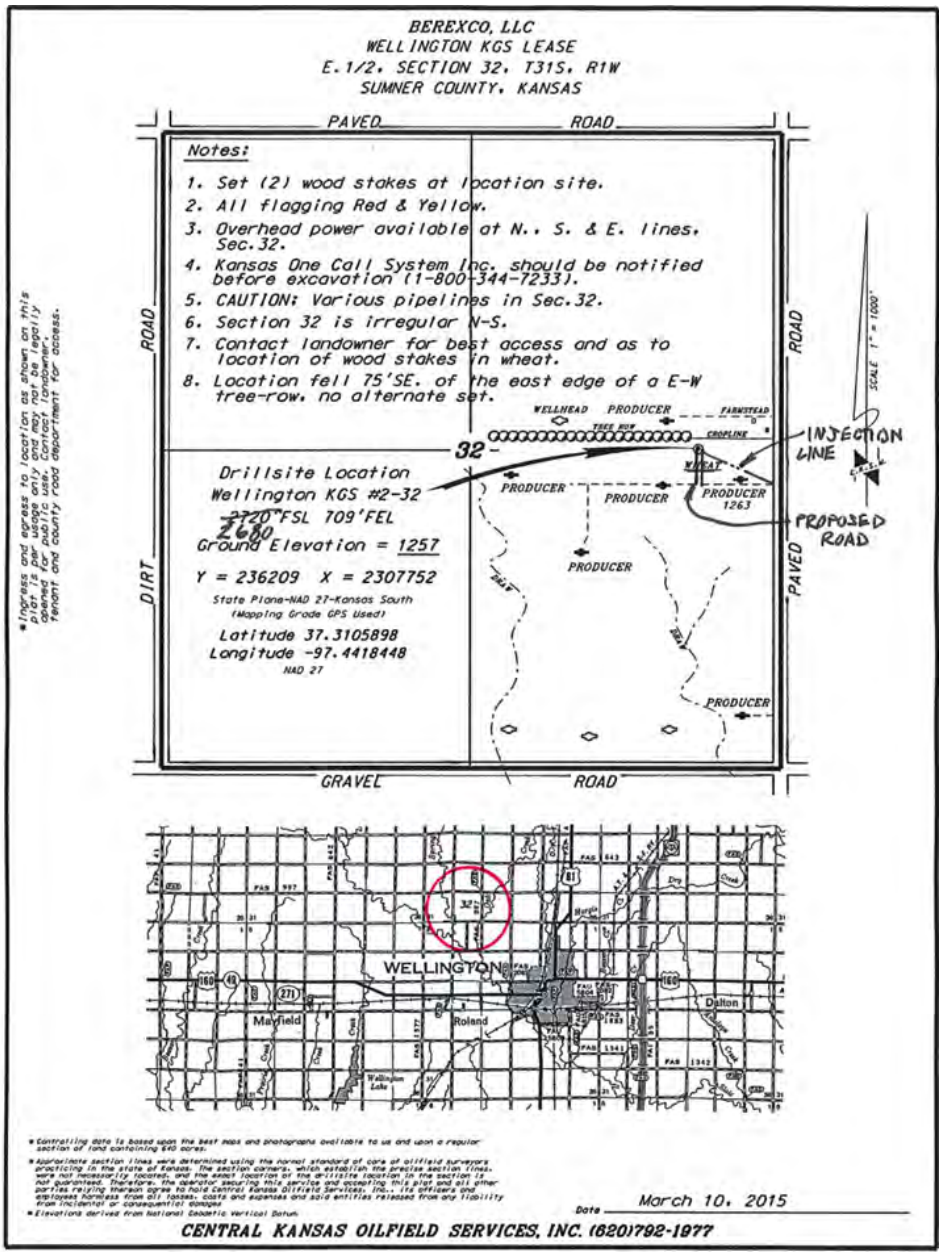


Figure 67. Plat map accompanying the Intent to Drill.

The Berexco Wellington KGS #2-32 spudded 3/20/15, logged on 3/29-15, and cased for completion on 3/30/15. Key contractors involved in the drilling and testing of the well are noted in **Figure 68**. Centralizers were run every other collar up to 3000 ft when the casing was cemented. CO_2 resistant cement was circulated to surface. A structure map on the top of the Mississippian shows relatively level surface with relief in the area of ~30 ft across a distance of 1000 ft. The slope a slope of <2 degrees (**Figure 69**). A trace of a pre-Pennsylvanian fault is shown by black dashed line that lies to the east of KGS #2-32.



Figure 68. Berexco Wellington KGS #2-32 was drilled and completed in March 2015.

The well was initially drilled to 140 ft and conductor pipe was set in the Wellington Shale. Cutting samples were collected every 10 ft from below the conductor pipe to total depth. Surface casing was set at 650 ft in the top of the Chase Group carbonates after Halliburton logged the interval from 650 ft to the base of the conductor pipe (**Figures 70 and 71**). Wireline logs include a modern log suite including GR, SP, caliper, Φneutron, Φdensity, p-wave sonic, microlog, and array resistivity capable of distinguishing lithology, porosity, and fluid content.

This shallow logging interval includes the lower portion of the upper Wellington shale that has been the focus of shallow water well drilling and water sampling to the northwest surrounding KGS #1-28 (**Figure 72**). The logged and sampled interval incldues 75 ft. of Hutchinson Salt and 250 ft of underlying lower Wellington anhydrite and shale interbeds that overlie the top of Chase Group carbonates at 560 ft. The evaporitic interval is the ultimate "caprock" that separate the surface aquifers from aquifers below. The evaporate interval covers broad regions of central Kansas including all of Wellington Field.

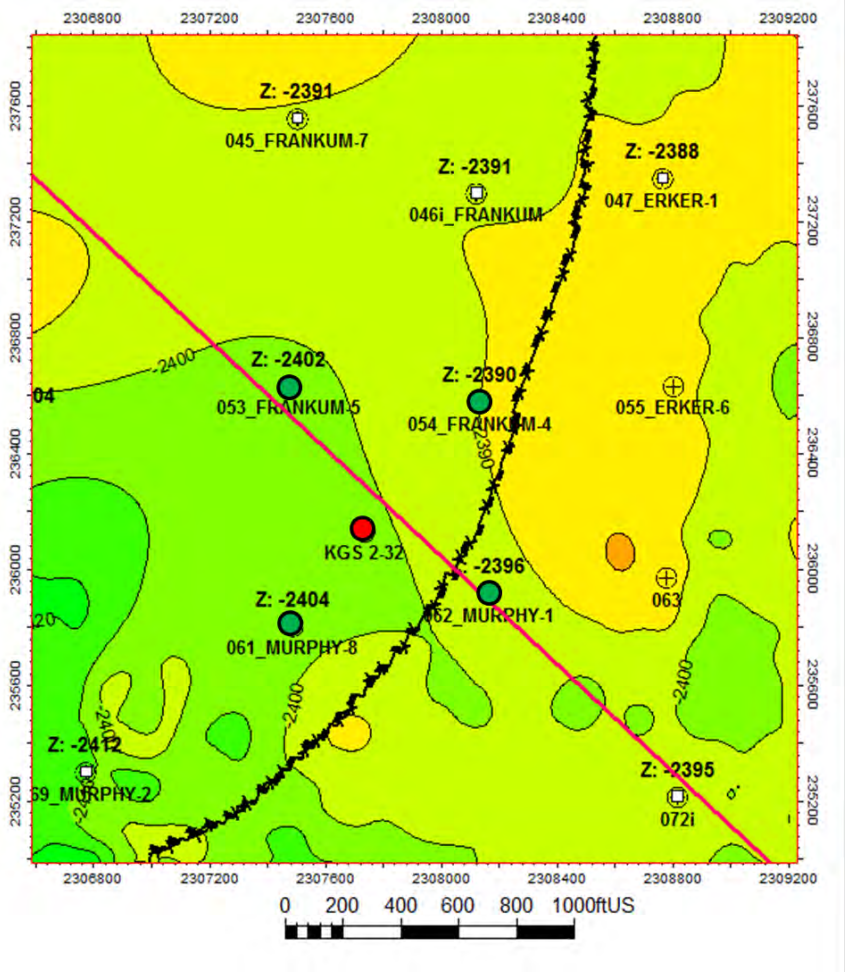


Figure 69. Structure map of CO2 EOR pilot area. Location of fault with small offset in the Mississippianis identified by black hachured line.

Figure 72 is a cross section between KGS #2-32 and the water wells SW #3 and SW #2 located near KGS #1-28 to the northeast. The lithologic description log (georeport) of KGS #2-32 is included as a graphic column along the right side of #2-32 to allow comparison of the full lithologic section to allow comparison to the shallower wells. The cross section puts the significance of the evaporate interval in perspective to the proximity to the surface water and while serving as an excellent barrier precluding communication of the surface water with the underlying fluids, the proximity of the halite bed to the surface and long term geologic dissolution of the salt has locally provided natural contamination of meteoric water as noted at Wellington Field.

The sample descriptions on a 10 ft basis for the shallow section is included in **Table 8**.

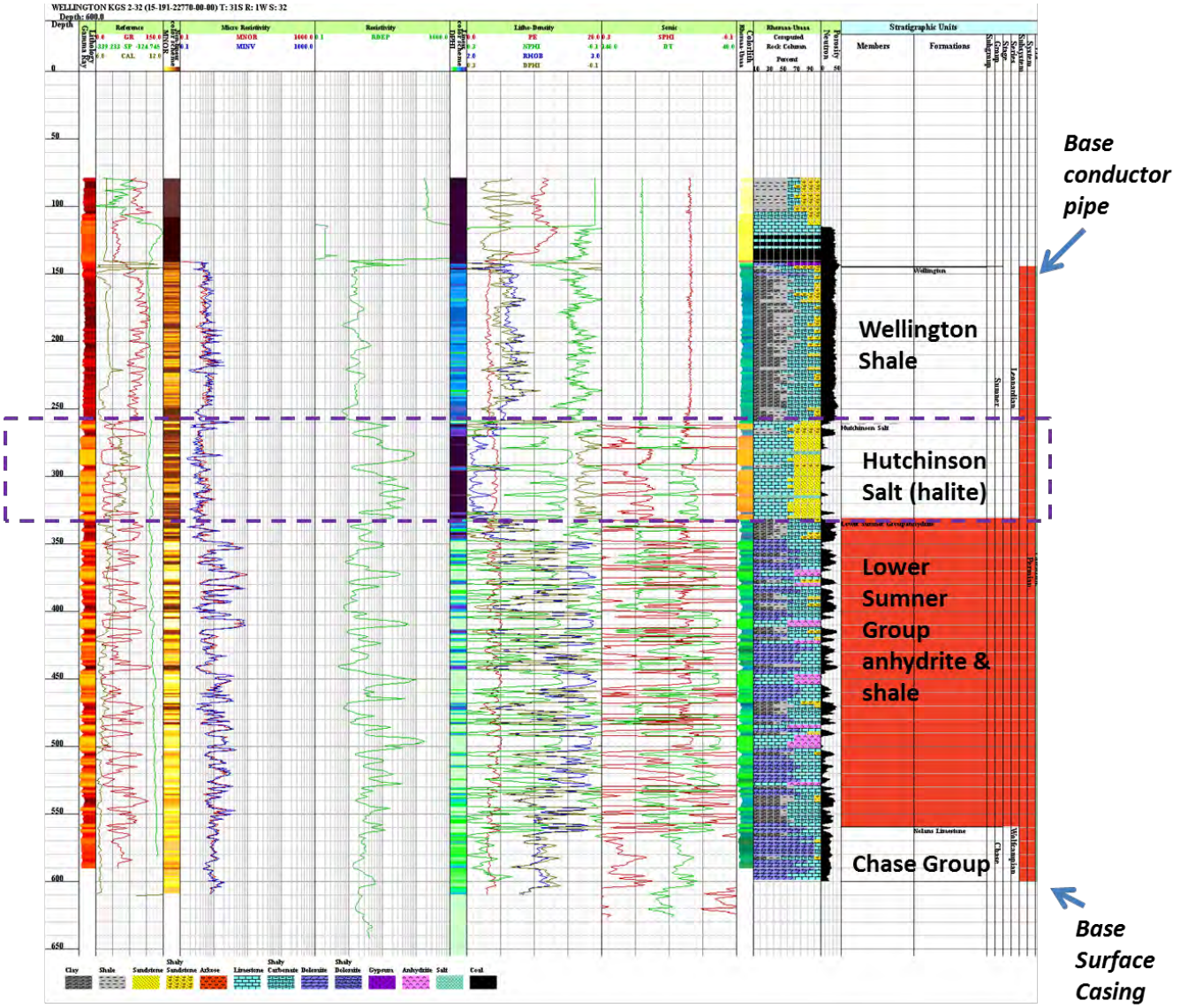


Figure 70. Array of well logs and lithologic interpretation of the upper logging interval in KGS #2-32.

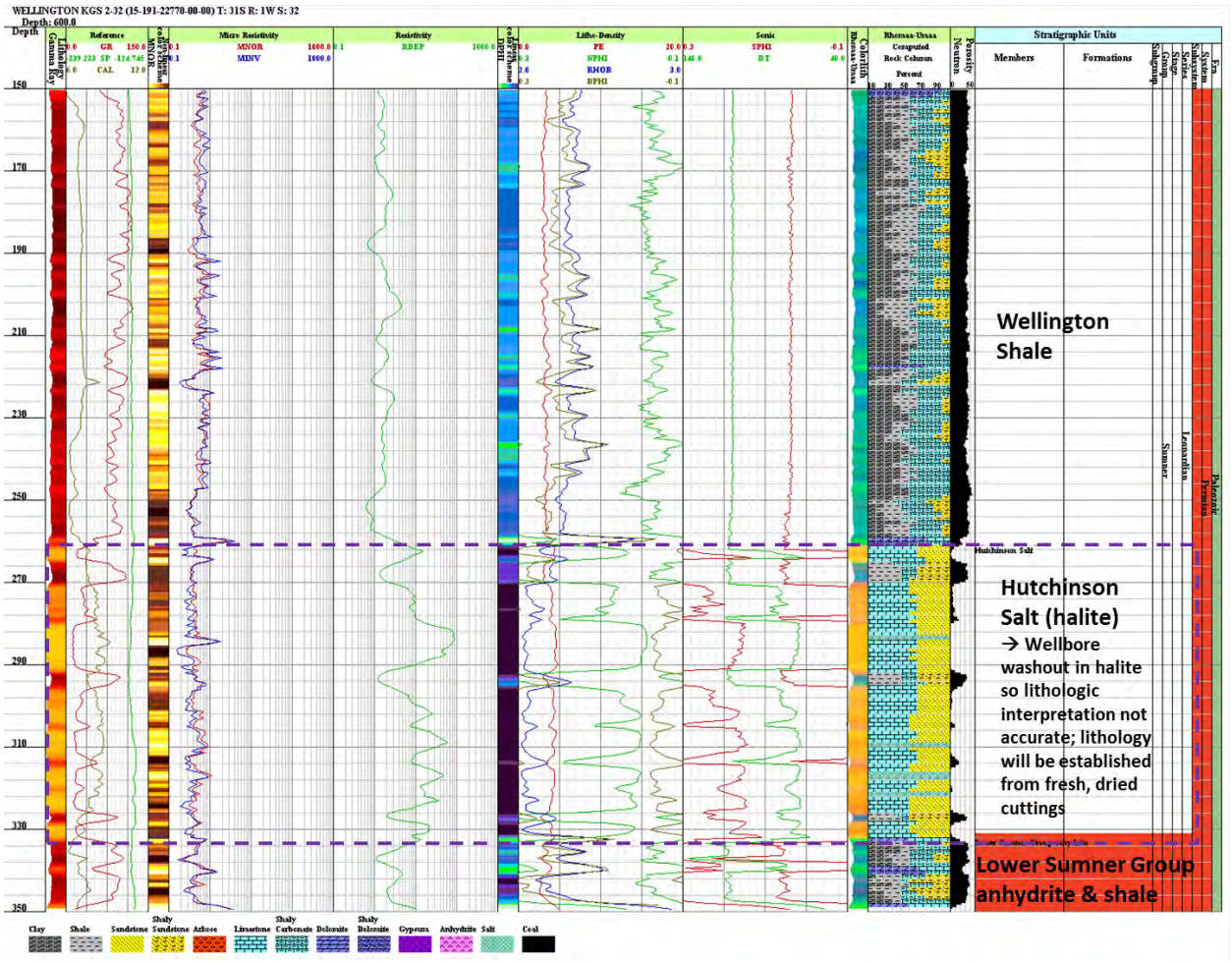


Figure 71. Close-up look at the upper Wellington shale and the Hutchinson Salt. The lithologic interpretation of the Hutchinson Salt interval is in error due to washout of the borehole at the depths of the halite intervals. The brown curve in the first track on the left illustrates the washout. This is a typical response in wells drilled with freshwater mud.

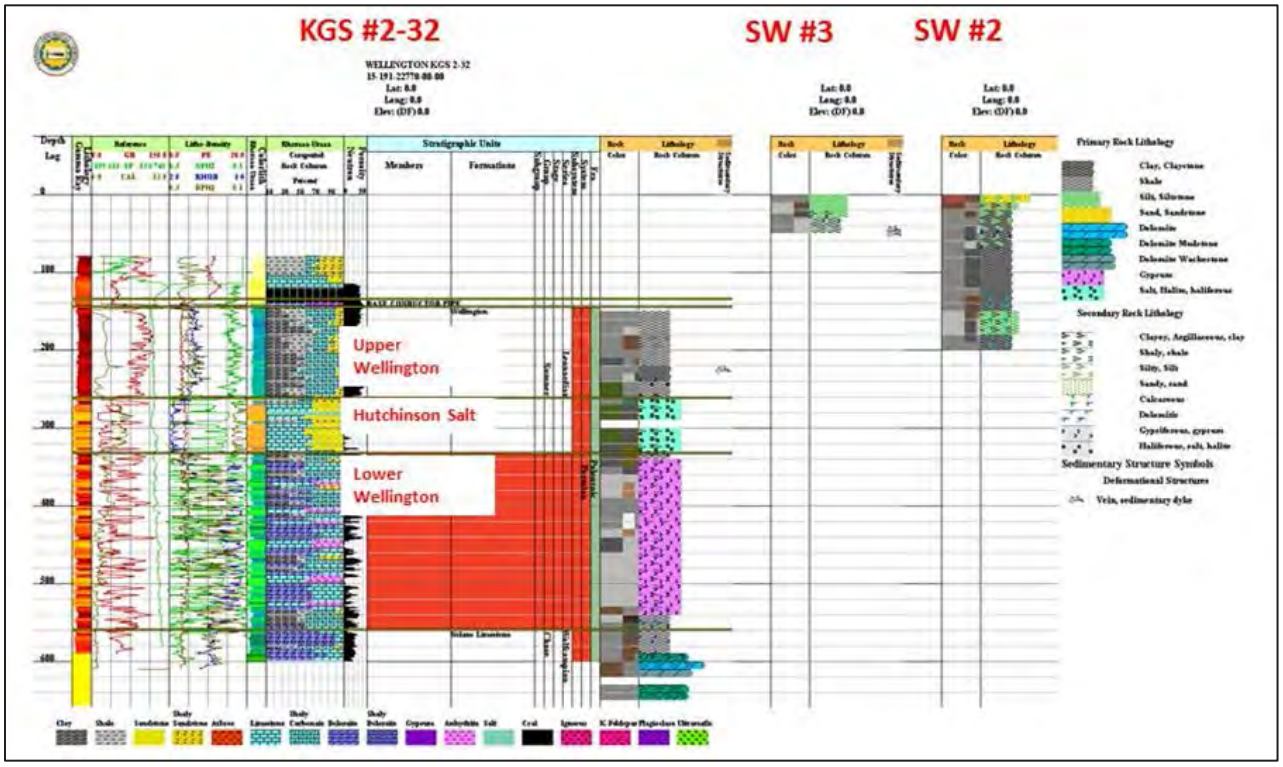


Figure 72. Cross section Wellington KGS #2-32 to SW-3 to SW-2. Comparison lithologies at recently constructed wells at Wellington (KGS 2-32, SW-2, and SW-3) emphasizing similar rock types within the Wellington formation.

Table 8. Cuttings description.

Cuttings description, Shallow interval
Berexco Wellington KGS #2-32
15-191-22770-00-00
1W-31S-Sec32
County: Sumner County
KB:1266
GL: 1257
Depth interval: 150-650 ft
CL: 42,000
RM: 0.527
150;160; Shale, gray, moderately firm (Wellington Shale)
160;170; Shale, gray, moderately firm, scattered satin spar (vein fill, not recrystallized)
170;180; Shale, gray to light gray, moderately firm, scattered satin spar
180;190; 70% shale, gray, 30% claystone, brown, common satin spar
190;200; 60% shale, gray, 40% claystone, brown
200;210; 90% shale, gray, 10% satin spar
210;220; 60% shale, dark gray, 20% gray shale, 10% brown shale, 10% satin spar
220;230; 90% claystone, gray, 5% alabaster (depositional type vs. vein fill), 5% satin spar
230;240; 90% claystone, gray-light gray, olive green, trace red claystone, scattered gypsum, trace halite (dissolved smoothed edges of clear crystals)
240;250; 80% shale, olive green, 10% shale, gray, scattered alabaster, trace halite
250;260; 80% shale, olive green, 10% shale, gray, scattered alabaster, trace halite

260;270; 90% shale, gray-green, 10% shale, brown, scattered alabaster and satin spar
270;280; 70% shale, olive green, 20% shale, dark gray, 10% shale, brown, trace gypsum
280;290; 70% shale, olive green, 20% shale, dark gray, 10% shale, brown, trace gypsum
290:300; 70% shale, olive green, 20% shale, dark gray, 10% shale, brown, scattered halite, clear, smooth, trace gypsum
300;310; 70% shale, olive green, 20% shale, dark gray, 10% shale, brown, scattered halite, clear, smooth, trace gypsum
310;320; 70% shale, olive green, 20% shale, dark gray, 10% shale, brown, scattered halite, clear, smooth, trace gypsum
320;330; 60% shale, dark gray; 30% shale, olive gay, 10% gypsum
330;340; 60% shale, dark gray; 30% shale, olive gay, 10% gypsum
340;350; 60% shale, dark gray; 30% shale, olive gay, 10% gypsum, trace halite
350;360; 70% shale, gray, 30% shale, dark gray, 10% alabaster
360;370; 70% shale, light gray, 20% gypsum, alabaster
370;380; 70% gypsum, alabaster, light gray, light brown, dense, 30% claystone, light gray
380;390; 70% gypsum, alabaster, light gray, light brown, dense, 30% claystone, light gray
390;400; 80% gypsum, alabaster, 20% claystone, gray
400;410; 80% gypsum, alabaster, 20% claystone, gray, scattered claystone, gray
410;420; 80% gypsum, alabaster, gray, white, scattered dolomite, microcrystalline, dense, gray
420;430; 80% gypsum, alabaster, gray, white, scattered dolomite, gray, light brown, microcrystalline, dense
430;440; 90% gypsum, alabaster, light gray, light brown, 10% shale, light gray
440;450; 70% gypsum, alabaster, 10% shale, dark gray, 10% shale, light gray
450;460; 70% gypsum, alabaster, 10% shale, dark gray, 10% shale, light gray, scattered alabaster, translucent
460;470; 95% gypsum, alabaster, 5% shale, light gray
470;480; 95% gypsum, alabaster, 5% shale, light gray
480;490; 95% gypsum, alabaster, 5% shale, light gray
490;500; 95% gypsum, alabaster, 5% shale, light gray
500;510; 95% gypsum, alabaster, 5% shale, light gray
510;520; 90% gypsum, alabaster, 10% shale, light gray
520;530; 80% gypsum, alabaster, 20% shale, light gray
530;540; 80% gypsum, alabaster, 10% dolomite, brown, microcrystalline, 10% shale, gray
540;550; 70% gypsum, alabaster, 25% shale, light to dark gray, 5% dolomite, brown, dark brown, peloid packstone
550;560; 70% shale, gray to dark gray, olive green, 30% gypsum, alabaster, trace dolomite, brown, mottled, microcystaline
560;570; 50% shale, gray to dark gray, 45% gypsum, alabaster, 5% dolomite, micrite
570;580; 60% gypsum, alabaster, 25% shale, gray, 15% dolomite, brown, micrite
580;590; 70% shale, gray, 25% gypsum, alabaster, 5% dolomite, brown, micrite
590;600; 60% dolomite, gray, brown, micrite and microcrystalline, 35% shale, gray, 5% gypsum, alabaster
600;610; 50% dolomite, brown, 50% shale, gray
610;620; 60% dolomite, brown, gray, wackestone-grainstone, peloid, bioclastic, porosity
620-630; 50% dolomite, micrite, 50% shale, gray
630;640; 50% dolomite, micrite, 50% shale, gray
640;650; 50% dolomite, micrite, 50% shale, gray

The second logging run was at total depth of the well in the upper portion of the Mississippian including the full section of the oil reservoir (**Figure 73**). Ninety feet of core were taken as shown the figure below from the top of the reservoir to the base of the porous zone.

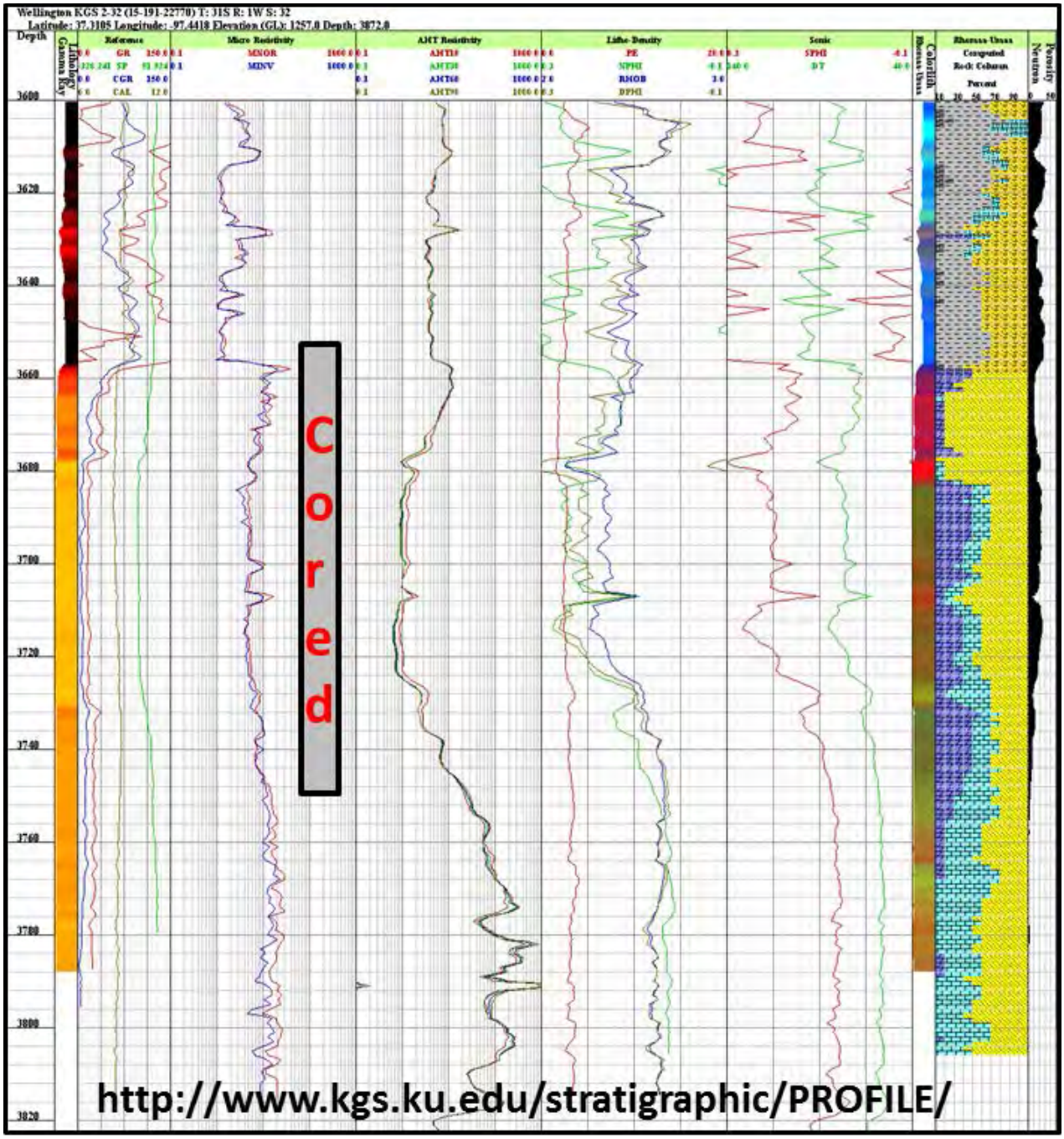
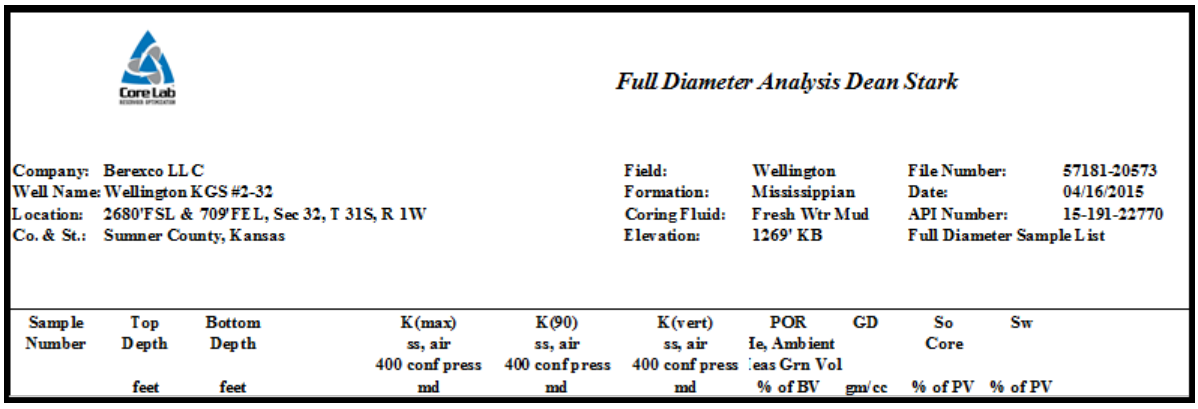


Figure 73. Ninety feet of core were acquired extending from the Middle Pennsylvanian Cherokee Shale through the main porous interval of the Mississippian oil reservoir.

The core is being analyzed by Core Lab in Midland including standard porosity and permeability measurements and fluid saturation (**Figure 74**).



Full Diameter Analysis Dean Stark

Company:	Berexco LLC	Field:	Wellington	File Number:	57181-20573
Well Name:	Wellington KGS #2-32	Formation:	Mississippian	Date:	04/16/2015
Location:	2680'FSL & 709'FEL, Sec 32, T 31S, R 1W	Coring Fluid:	Fresh Wtr Mud	API Number:	15-191-22770
Co. & St.:	Sumner County, Kansas	Elevation:	1269' KB	Full Diameter Sample List	

Sample Number	Top Depth	Bottom Depth	K(max) ss, air 400 conf press	K(90) ss, air 400 conf press	K(vert) ss, air 400 conf press	POR Ie, Ambient Ieas Grn Vol	GD	So Core	Sw
	feet	feet	md	md	md	% of BV	gm/cc	% of PV	% of PV

Figure 74. Core was delivered to Core Lab in Midland TX where whole core analysis was to be done on the Mississippian at 1-ft intervals. Two preserved 1 1/2 inch diameter plug samples were also taken for relative permeability measurements.

The standard log analysis using porosity and resistivity logs indicates oil saturation of 30% (**Figure 75**). This indicates that the reservoir at the site of this injection well has been swept the waterflood and is close to residual oil saturation. The analysis of the magnetic resonance imaging log (**Figure 76**) also indicates an oil saturation of the same and suggests the saturation is at residual.

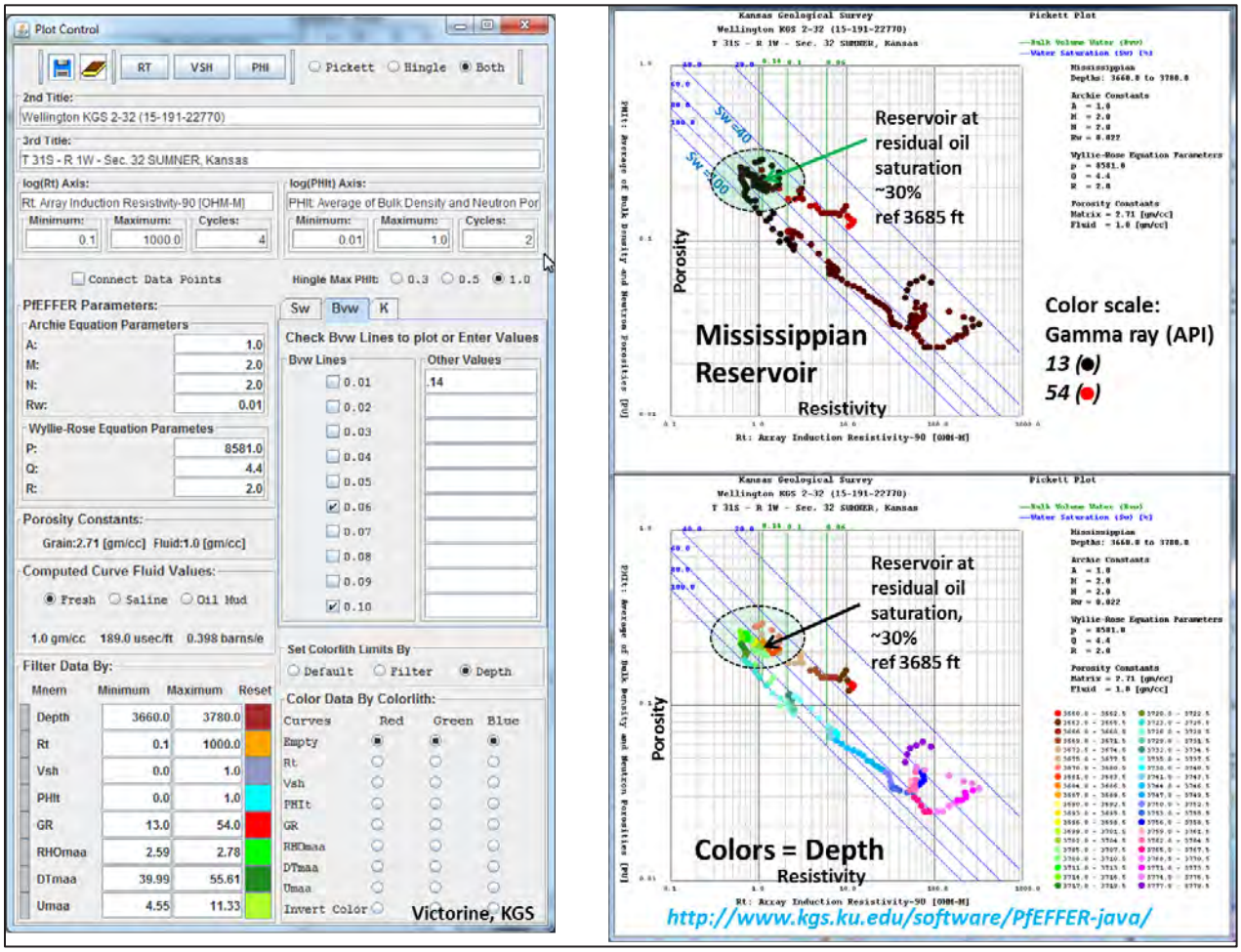


Figure 75. Log analysis with the KGS web-based Java applet was used to estimate the oil saturation that is believed to be at residual ~30% which is also consistent with the nuclear magnetic resonance log (MRIL) of Halliburton.

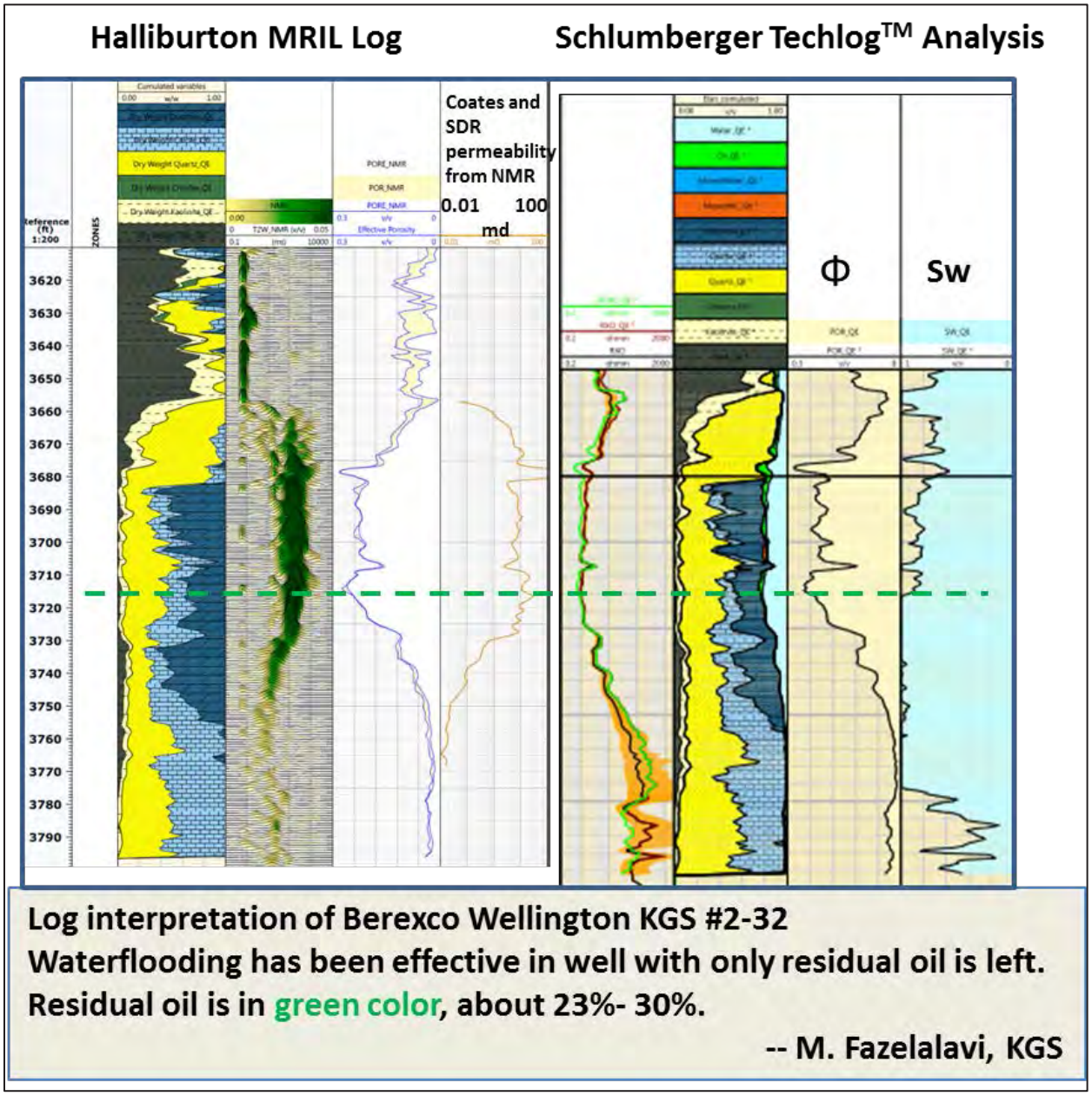


Figure 76. Residual oil determined from analysis if MRIL log. Base of residual oil is ~3715 ft.

The combination of MRIL and formation microresisitity log as shown in **Figure 77** confirms and helps to quantify the pore architecture of the Mississippian siliceous dolomitic reservoir and along with core analysis including capillary pressure measurements will help to refine the reservoir model.

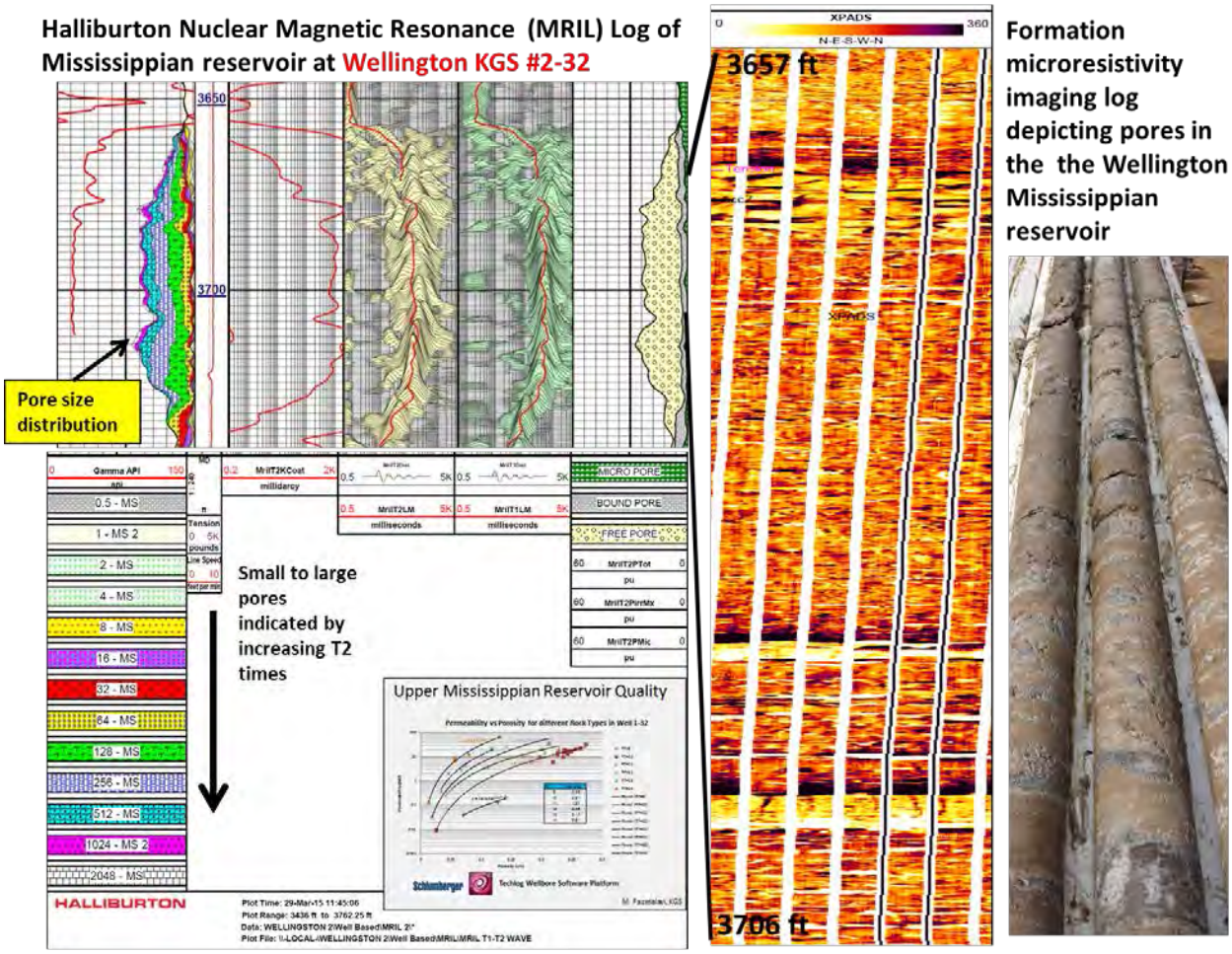


Figure 77. MRIL log output showing pore size distribution compared with the formation microresistivity imaging log and core of the Mississippian oil reservoir in KGS #2-32.

Subtask 6.3. Establish Protocols for InSAR data collection

See earlier.

Subtask 6.4. Drill Shallow Freshwater Monitoring Boreholes (Contingent on Go Decision pts 1&3)

See earlier discussion.

Subtask 6.7. Outfit Surrounding Mississippian Boreholes for MVA (Contingent on Go pts 1&3)

Sampling will be done at Mississippian wells before the Mississippian reservoir is pressurized before CO_2 is injected.

Subtask 7.5 High Res 2D Seismic Lines Targeting Mississippian Reservoir

To be carried out next quarter prior to injecting CO_2.

Task 8. Recondition Mississippian Boreholes Around Mississippian injector re-pressuring Mississippian and sampling producing wells

This activity has begun and baseline sampling of the Mississippian wells will be done in the next quarter.

Key Findings

1. Shallow water wells #1, #2, and #3 have yielded only saltwater in relatively small amounts.
2. EPA continues to review the Class VI application following a well defined schedule.
3. The CO2-EOR injection well was drilled, cored, and tested and is yielding considerable information about the Mississippian reservoir and further documentation of the shallow beds related to surface water and nearby evaporate beds.
4. Methodology to record, integrate, interpret, and display information obtained from the project
5. The seismic network at Wellington is vital to ensuring safe injection and information gained from the instrumentation will aid in the understanding of the seismicity in the region. Work done previously under DOE contract DE-FE0002056 is providing a regional framework to help understand the that mechanisms of regional seismicity, some of which has been attributed to injection of brine under large volumes, rates, and pressures.

Plans for Fifteenth Quarter 2015

1. Complete preparations for CO2 injection to the Mississippian.
2. Inject CO2 into the Mississippian.
3. Continue to respond to EPA’s review of the Class VI permit application.

PRODUCTS

Publications, conference papers, and presentations

- Dennis Hedke and Lynn Watney, 2015, Deep-seated Karst at Cutter Field and Evidence Indicating Strike-Slip Movement in Basement Rocks in the Hugoton Embayment“, January 7, 2015 Kansas Geological Society Technical Presentation.
- Yevhen Holubnyak, 2015, Storage Capacity Estimations for Arbuckle Saline Aquifer in South Central and South-Western Kansas, 14th Carbon Capture, Utilization, and Storage Conference, Pittsburgh, PA.
- Evaluating Risks of Induced Seismicity for CO2 Geological Storage in the Arbuckle Saline Aquifer, South-Central Kansas 14th Carbon Capture, Utilization, and Storage Conference, Pittsburgh, PA.

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

A project organization chart follows (**Figure 19**). The work authorized in this budget period includes tasks discussed above.

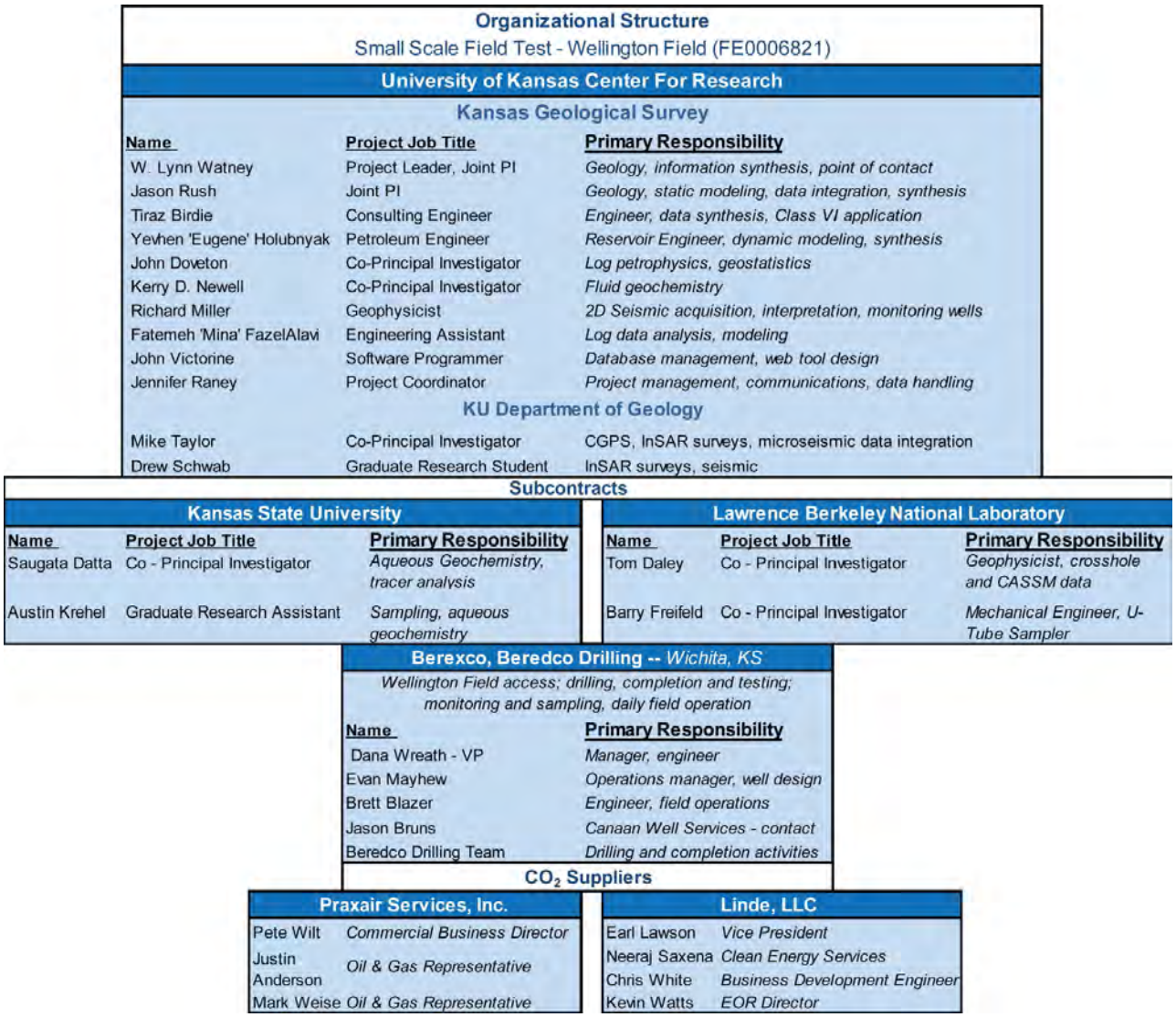


Figure 19. Organizational Chart.

IMPACT

See earlier discussion.

CHANGES/PROBLEMS

Please refer to earlier discussion.

APPENDIX II

Small Scale Field Test Demonstrating CO_2 Sequestration in Arbuckle Saline Aquifer and by CO_2-EOR at Wellington Field, Sumner County, Kansas

FIFTEENTH QUARTERLY PROGRESS REPORT

DOE F 4600.2
(03/11)
All Other Editions Are Obsolete

U.S. Department of Energy
FEDERAL ASSISTANCE REPORTING CHECKLIST
AND INSTRUCTIONS FOR RD&D PROJECTS

1. Identification Number: **DE-FE0006821**	2. Program/Project Title: **Small Scale Field Test Demonstration CO2 Sequestration**
3. Recipient: **University of Kansas Center for Research, Inc.**	

4. Reporting Requirements:	Frequency	Addressees
A. MANAGEMENT REPORTING		
☒ Research Performance Progress Report (RPPR)	Q	FITS@NETL.DOE.GOV
☒ Special Status Report	A	FITS@NETL.DOE.GOV
B. SCIENTIFIC/TECHNICAL REPORTING		
(Reports/Products must be submitted with appropriate DOE F 241. The 241 forms are available at www.osti.gov/elink)		
Report/Product — Form		
☒ Final Scientific/Technical Report — DOE F 241.3	FG	http://www.osti.gov/elink-2413
☒ Conference papers/proceedings* — DOE F 241.3	A	http://www.osti.gov/elink-2413
☐ Software/Manual — DOE F 241.4		
☐ Other (see special instructions) — DOE F 241.3		
** Scientific and technical conferences only*		
C. FINANCIAL REPORTING		FITS@NETL.DOE.GOV
☒ SF-425 Federal Financial Report	Q, FG	
D. CLOSEOUT REPORTING		
☒ Patent Certification	FC	FITS@NETL.DOE.GOV
☒ SF-428 & 428B Final Property Report	FC	FITS@NETL.DOE.GOV
☐ Other		
E. OTHER REPORTING		See block 5 below for instructions.
☒ Annual Indirect Cost Proposal	O	
☐ Audit of For-Profit Recipients		FITS@NETL.DOE.GOV
☒ SF-428 Tangible Personal Property Report Forms Family	A	
☒ Other – see block 5 below	A	FITS@NETL.DOE.GOV

FREQUENCY CODES AND DUE DATES:

A - Within 5 calendar days after events or as specified.
FG- Final; 90 calendar days after the project period ends.
FC- Final; End of Effort.
Y - Yearly; 90 calendar days after the end of the reporting period.
S - Semiannually; within 30 calendar days after end of project year and project half-year.
Q - Quarterly; within 30 days after end of the reporting period.
Y180 – Yearly; 180 days after the end of the recipient's fiscal year
O - Other; See instructions for further details.

5. Special Instructions:

Annual Indirect Cost Proposal – If DOE is the Cognizant Federal Agency, then the proposal should be sent to FITS@NETL.DOE.GOV . Otherwise, it should be sent to the Cognizant Federal Agency.

Other – The Recipient shall provide all deliverables as contained in Section D of Attachment 2 Statement of Project Objectives.

QUARTERLY PROGRESS REPORT
To
DOE-NETL
Brian Dressel, Program Manager
Award Number: DE-FE0006821

SMALL SCALE FIELD TEST DEMONSTRATING CO_2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO_2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS

Project Director/Principal Investigator:
W. Lynn Watney
Senior Scientific Fellow
Kansas Geological Survey

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lwatney@kgs.ku.edu

Joint Principal Investigator:
Jason Rush

Prepared by Lynn Watney
Date of Report: August 11, 2015
DUNS Number: 076248616

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

Project/Grant Period: 10/1/2011 through 9/30/2016

Fifteenth Quarterly Report

Period Covered by the Report: April 1, 2015 through June 30, 2015

Signature of Submitting Official:

Willard Lynn Watney

Digitally signed by Willard Lynn Watney
DN: cn=Willard Lynn Watney, o=University of Kansas, ou=Kansas Geological Survey, email=lwatney@kgs.ku.edu, c=US
Date: 2015.08.11 16:50:24 -05'00'

EXECUTIVE SUMMARY

Project Objectives

The objectives of this project are to understand the processes that occur when a maximum of 70,000 metric tonnes of CO_2 are injected into two different formations to evaluate the response in different lithofacies and depositional environments. The evaluation will be accomplished through the use of both *in situ* and indirect MVA (monitoring, verification, and accounting) technologies. The project will optimize for carbon storage accounting for 99% of the CO_2 using lab and field testing and comprehensive characterization and modeling techniques.

CO_2 will be injected under supercritical conditions to demonstrate state-of-the-art MVA tools and techniques to monitor and visualize the injected CO_2 plume and to refine geomodels developed using nearly continuous core, exhaustive wireline logs, and well tests and a multi-component 3D seismic survey. Reservoir simulation studies will map the injected CO_2 plume and estimate tonnage of CO_2 stored in solution, as residual gas, and by mineralization and integrate MVA results and reservoir models shall be used to evaluate CO_2 leakage. A rapid-response mitigation plan will be developed to minimize CO_2 leakage and provide comprehensive risk management strategy. A documentation of best practice methodologies for MVA and application for closure of the carbon storage test will complete the project. The CO_2 shall be supplied from a reliable facility and have an adequate delivery and quality of CO_2.

Scope of Work

Budget Period 1 includes updating reservoirs models at Wellington Field and filing Class II and Class VI injection permit application. Static 3D geocellular models of the Mississippian and Arbuckle shall integrate petrophysical information from core, wireline logs, and well tests with spatial and attribute information from their respective 3D seismic volumes. Dynamic models (composition simulations) of these reservoirs shall incorporate this information with laboratory data obtained from rock and fluid analyses to predict the properties of the CO_2 plume through time. The results will be used as the basis to establish the MVA and as a basis to compare with actual CO_2 injection. The small scale field test shall evaluate the accuracy of the models as a means to refine them in order to improve the predictions of the behavior and fate of CO_2 and optimizing carbon storage.

Budget Period 2 includes completing a Class II underground injection control permit; drilling and equipping a new borehole into the Mississippian reservoir for use in the first phase of CO_2 injection; establishing MVA infrastructure and acquiring baseline data; establishing source of CO_2 and transportation to the injection site; building injection facilities in the oil field; and injecting CO_2 into the Mississippian-age spiculitic cherty dolomitic open marine carbonate reservoir as part of the small scale carbon storage project.

In Budget Period 3, contingent on securing a Class VI injection permit, the drilling and completion of an observation well will be done to monitor injection of CO_2 under supercritical conditions into the Lower Ordovician Arbuckle shallow (peritidal) marine dolomitic reservoir. Monitoring during pre-injection, during injection, and post injection will be accomplished with MVA tools and techniques to visualize CO_2 plume movement and will be used to reconcile simulation results. Necessary documentation will be submitted for closure of the small scale carbon storage project.

Project Goals

The proposed small scale injection will advance the science and practice of carbon sequestration in the Midcontinent by refining characterization and modeling, evaluating best practices for MVA tailored to the geologic setting, optimize methods for remediation and risk management, and provide technical information and training to enable additional projects and facilitate discussions on issues of liability and risk management for operators, regulators, and policy makers.

The data gathered as part of this research effort and pilot study will be shared with the Southwest Sequestration Partnership (SWP) and integrated into the National Carbon Sequestration Database and Geographic Information System (NATCARB) and the 6th Edition of the Carbon Sequestration Atlas of the United States and Canada.

Project Deliverables by Task

1.5 Well Drilling and Installation Plan (Can be Appendix to PMP or Quarterly Report)
1.6 MVA Plan (Can be Appendix to PMP or Quarterly Report)
1.7 Public Outreach Plan (Can be Appendix to PMP)
1.8 Arbuckle Injection Permit Application Review go/no go Memo
1.9 Mississippian Injection Permit Application Review go/no go Memo
1.10 Site Development, Operations, and Closure Plan (Can be Appendix to PMP)
2.0 Suitable geology for Injection Arbuckle go/no go Memo
3.0 Suitable geology for Injection Mississippian go/no go Memo
11.2 Capture and Compression Design and Cost Evaluation go/no go Memo
19 Updated Site Characterization/Conceptual Models (Can be Appendix to Quarterly Report)
21 Commercialization Plan (Can be Appendix to Quarterly Report).
30 Best Practices Plan (Can be Appendix to Quarterly or Final Report)

ACCOMPLISHMENTS

1. **The review of the Class VI application has made significant progress, and is nearing the final stages to be approved by EPA.**

   EPA has undergone numerous revisions of the Class VI permit application, and we are nearing the final round of responses to fulfill the requirements due by federal regulations. The KGS has been in close and frequent communication with EPA throughout the review process, and both parties have openly discussed the limited schedule that is imposed on the project for a December 2016 deadline. EPA has agreed to cooperate with us to the best of their ability to ensure we receive approval of the Class VI permit by the necessary date.

2. **Freshwater monitoring boreholes have been sampled and indicate no presence of a USDW at the Wellington site.**

   The wells have been sampled according to QASP requirements established by EPA for the evaluating the USDW above the Arbuckle injection in the AOR established by simulation of injection of 40,000 tonnes of CO2. EPA has requested that wells drilled late 2014 and early

2015 be re-purged and resampled to confirm that the wells exceed 10,000 TDS (no USDW at the site) and to sample two nearby domestic wells that are used for non-human consumption.

3. CO2 suppliers have been secured.

Linde and Praxair are suppliers for the CO2 for the Mississippian CO2-EOR and the Arbuckle saline aquifer small-scale injection. The CO2 market is favorable and suppliers have adequate CO2 available from several fertilizer plants. CO_2 supply and pumping/storage equipment availability reflects a shift in the CO_2 market to the buyer side that will benefit the project.

4. Performed workovers and obtained baseline sampling on surrounding Mississippian Boreholes for production and MVA during CO2-EOR.

Wells to be affected by and monitored during the CO2-EOR to evaluate the performance were checked, reconditioned as needed, and pressure tested. This work was completed during the spring and early summer 2015. Equipping and sampling of Mississippian monitoring wells was accomplished in the summer of 2015. Baseline analyses including prior brine analyses have now online and accessible as lists of wells, their analyses, and standard plots and maps of brine chemistry

Java web tools have been developed in 2015 to maintain the geochemical data obtained from fluid sampling of the monitoring wells. Baseline sampling of and existing recent brine analyses from the Mississippian has been compiled so that they can be analyzed temporally and spatially. Brine data obtained for KGS #2-32 during initial completion is illustrated with Java apps in following sections. Displays include database entry screens, lists of brine analyses, standard Piper and bar charts, and mapping of constituents in order to compare temporally and spatially between wells.

5. MVA components in place to monitor the Mississippian CO2-EOR injection, and revisited design and updated costs to fabricate U-Tube and CASSM for Arbuckle monitoring.

The design plans for the U-Tube and CASSM have been re-established to update costs pending actual fabrication that will occur during BP3 after receipt of the Class VI permit. Other MVA activities have been designed and are implemented for monitoring of the Mississippian CO2-EOR including installation and operation of infrastructure for data acquisition for 1) cGPS and InSAR to detect ground motion resulting from pressure changes when CO2 is injected, 2) an 18-seismometer array to monitor small (micro) seismic events down to -1 magnitude, 3) protocol and implementation of baseline fluid sampling in Mississippian monitoring wells near the sites of the CO2-EOR and the Arbuckle injection.

6. Conducted pulse test at KGS 2-32 Mississippian well

A variable rate pulse test was conducted on 5/12/15 between the closest four wells surrounding the injection well #2-32 and #2-32. Importantly, the test results established that there is

communication between the KGS #2-32 and well immediately east, even though the two locations are believed to reside in separate progradational wedges of the spiculitic dolomite reservoir. Also, it was determined that the dominant flow is matrix not fracture.

7. Installed three new broadband seismometers near injection borehole

Seismometer Array – We are operating, archiving data, and interpreting baseline information obtained from fifteen Mark Products L-22 3-component seismometers with IRIS Ref-Tek R-130 Data Acquisition Systems (DAS) obtained from loan of NSF's IRIS program. Three new broadband, high sensitivity Nanometrics Trillium Compact Posthole seismometers purchased by KGS were installed and are now operational. The new Nanometrics systems have been configured for continuous data collection into an onboard recoding medium (SD card) at maximum sensitivity of 2 volts peak to peak with a sampling rate of 250 Hz, necessary to detect and analyze small microseismic events (**Figure 1**). An optimized methodology was developed to process the large data stream and to adjust the recording by processing earthquake data (signal/coda) from the region and comparing to other interpretations. It is confirmed that the seismometers array records a highly resolved, high frequency spectra.

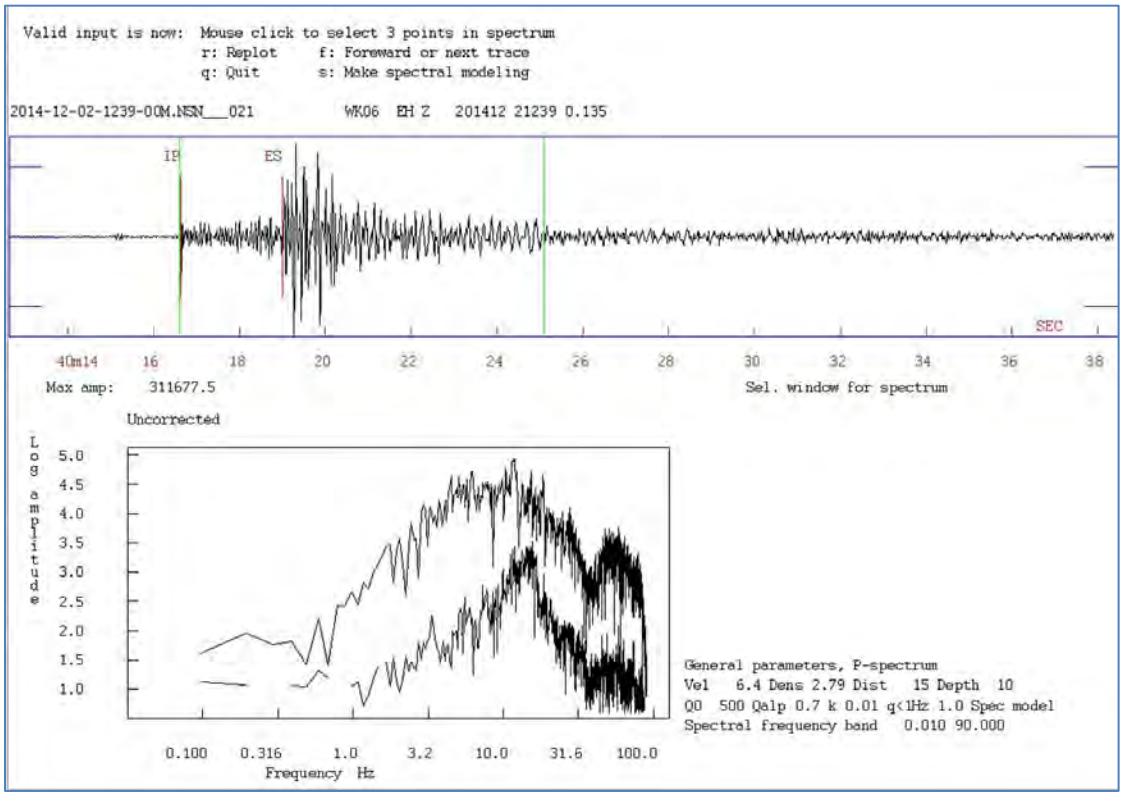


Figure 1. A record of waveforms (coda) of a 3.0 earthquake located ~15 miles west of Wellington to illustrate signal over the noise and preservation of the high frequency range (>10 Hz) which is usually attenuated significantly or absent in most recordings of earthquakes.

8. Establish Protocols for InSAR data collection

The InSAR data collection is underway following standard protocols. The satellite antenna has been set to record radar images over Wellington Field (**Figure 2**). The images are processed to generate interferograms and scenes are compared to establish persistent point scatterers as described later.

Motion of the scatterers provides the means to detect surface motion between scenes obtained roughly every 20 days.

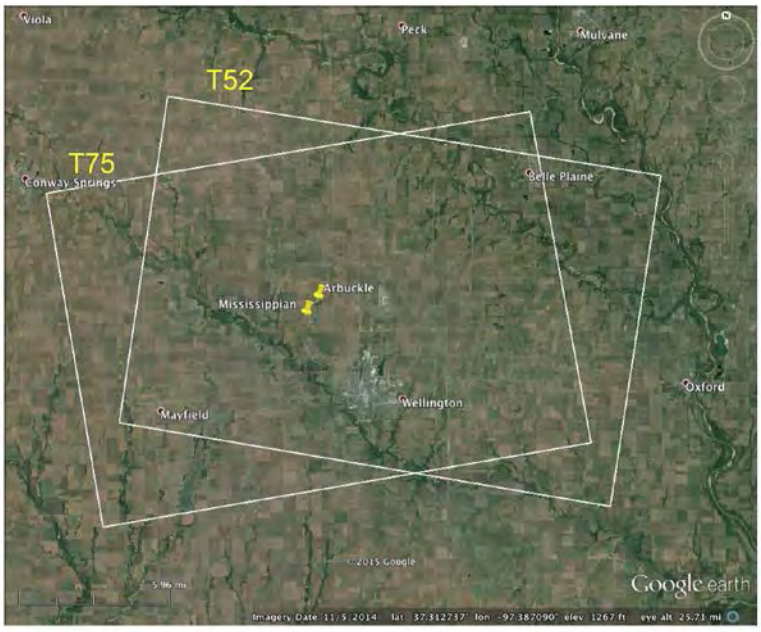


Figure 2. Footprints of a single ascending and descending pair of radarsat acquisitions obtained on an approximate 20-day interval.

Milestone Status Report

Task	Budget Period	Number	Milestone Description
Task 2.	1	1	Site Characterization of Arbuckle Saline Aquifer System - Wellington Field
Task 3.	1	2	Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field
Task 10.	2	3	Pre-injection MVA - establish background (baseline) readings
Task 13.	2	4	Retrofit Arbuckle Injection Well (#1-28) for MVA Tool Installation
Task 18.	3-yr1	5	Compare Simulation Results with MVA Data and Analysis and Submit Update of Site Characterization, Modeling, and Monitoring Plan
Task 22.	3-yr1	6	Recondition Mississippian Boreholes Around Mississippian CO2-EOR injector
Task 27.	3-yr2	7	Evaluate CO2 Sequestration Potential of CO2-EOR Pilot
Task 28.	3-yr2	8	Evaluate Potential of Incremental Oil Recovery and CO2 Sequestration by CO2-EOR - Wellington field

Project Schedule

Task 2 – Site Characterization of Arbuckle Saline Aquifer System - Wellington Field

Activities with this task were focused on addressing Requests for Additional Information (RAI) from EPA related to their review of the Wellington Class VI application. Activities are addressed as a timeline.

April 15-16, 2015

We received comments EPA on Table 3 of the RAI and the QASP and the team met with EPA to discuss .injection well monitoring (e.g., MIT's, injectate sampling, continuous monitoring of pressure/temperature/rate/volume) and discuss a schedule that EPA wishes to follow for the review of the Wellington Class VI permit. Above Confining Zone (ACZ), groundwater sampling, and Plume and Pressure Front monitoring were to be addressed in a later call in early May.

April 20

Meeting with EPA focused on financial assurance and PISC. It was conveyed by the team that our analyses to date from the shallow water wells installed that a fresh, usable shallow aquifer is not present in our AOR. A number of items were resolved during the meeting. Other items were addressed later with additional detail regarding questions related to modeling of the AoR.

The Wellington Shale is an aquiclude based on our drilling of shale in the AOR. The shale, beginning at a depth of 10 to 15 ft below the surface contains gypsum crystals. The uppermost argillaceous silt and sand above the Wellington Shale contains brine, apparently derived from a mixing of rainwater and groundwater. The lack of prospects for viable groundwater in the Wellington Shale due to low yield is also deemed in too close a proximity to the underlying 200 ft thick Hutchinson halite bed to be remediated. Moreover, unless a well is leaking from beneath, the Wellington Shale is acting as an aquiclude and protects the halite from meteoric infiltration and dissolution as occurs closer to the land surface east of Wellington Field.

We conveyed that local seismicity is being discussed with state regulators on at least a weekly basis. Action was taken by state regulators on March 17th to reduce brine injection in three areas southwest of Wellington Field. The basis is that the KGS assessment of seismicity along lineaments and what is believed to be likely do to unsafe levels of high volume brine injection wells in a 3 mile radius of the seismically defined lineaments.

April 29

Response to comments (51 questions) from EPA on QASP (Quality Assurance Surveillance Plan) submitted this week to EPA.

Second iteration of responses to EPA's RAI Tables 1 (AoR and Corrective Action, 28 questions) and Table 3 (Testing and Monitoring, 20 questions) submitted to EPA.

EPA has requested a conference call during the week of May 11th to discuss "Above Confining Zone and Plume/Pressure Front tracking monitoring". It would be highly beneficial for us to discuss the availability of acoustic fiber optic cable for use at Wellington Field to obtain a pseudo 3D VSP.

May 11th was deemed to be an important meeting so invitations to all members of the team who have technologies related to the Class VI injection into the Arbuckle were invited to address the readiness and capabilities –

- In situ CASSM, U-Tube, and crosswell seismic
- Surface based InSAR & cGPS, seismometers, 2D high resolution seismic to image any CO2 migrated into overlying Mississippian, repeat 3D seismic to close the project
- New InSAR scenes and cGPS records will be shared
- Seismometers are recording operational microseismicity and sensitivity has been estimated at magnitudes down to -1.

Clarifications and update of the well completion report on the third shallow water well, SW #3, was submitted to EPA this week. Results --

- The 50 ft well confirms TDS of surface water is well above 10,000 ppm as noted in Figure 1 and also previously observed in the 200-ft and 100-ft well SW #1 and SW#2 (**Figure 3**).
- The surface bedrock, Wellington Shale, is a shale aquitard lying beneath unconsolidated surficial silt and clay at ~20 ft.
- Shale contains gypsum beginning at 20 ft and brine includes Ca and SO4 in a predominately NaCl brine suggesting source of ions is from dissolution of gypsum and halite inherent to bedrock in the are
- Cuttings description and logging of KGS #2-32 in March confirms base of Wellington Shale at 260 ft overlying halite of Hutchinson Salt
- Aquiclude and shallow depth of halite precludes need for any mitigation of the shallow ground water.

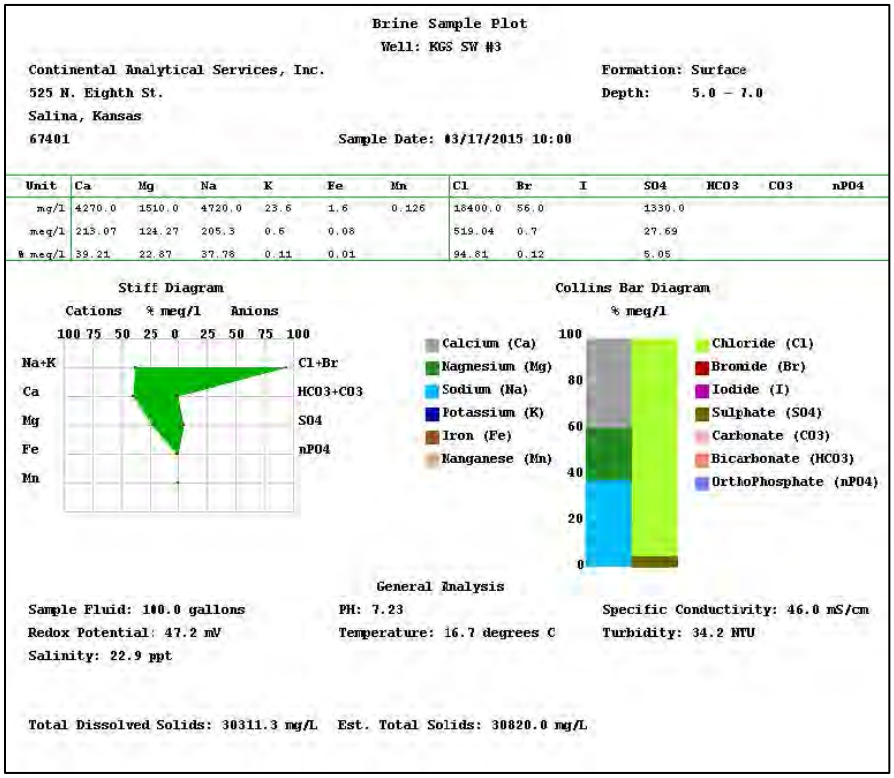


Figure 3. Java app prototype to display water/brine analyses stored in Oracle database for in tracking chemical changes in scientific monitoring and for EPA compliance. Example of brine from SW #3.

- KGS team also met with state regulators overseeing Class I wells including at ~20,000 barrels of hazardous waste within 30 miles of Wellington. This compares to roughly 500 bbls equivalent CO2 per day to be injected in the Arbuckle.

April 30

Discussions with EPA have taken on a more productive and deliberate path in the last month with EPA offering a schedule. We have been very clear about of time constraints. The EPA schedule was endorsed by DOE Headquarters as discussions continued on responses to RAI's.

Our next conference call with EPA is tentatively set for **May 15th** when the topic will be **Above Confining Zone and Plume/Pressure Front tracking monitoring**. With DOE approval, we will introduce highlights of **DE-FE-OO12700** (R. Trautz, Distribute Fiber Optics) to EPA at this meeting as an additional means to monitor the CO2 plume in the Arbuckle. Pseudo VSP monitoring with the acoustic fiber would significantly improve our ability to monitor the CO2 plume, detect any leakage, and close the project

May 7

EPA received our responses to Tables 1, 3, and the QASP document.

We are updating our report of the evaluation of the surface waters in the AOR after receiving comments from EPA. The revision will be submitted to EPA this week as we prepare for a conference call with EPA on May 15th

Discuss with EPA the potential for using the 100-ft and 200-ft shallow wells as observation wells.

Finalized plans for location and acquisition of high resolution 2D seismic by R. Miller, KGS include: 1)further characterization of the confining zone above the Arbuckle, 2) heterogeneity in the Mississippian reservoir, 3) use vibroseis seismic source to obtain interval velocity by high resolution recording from seismometers in an effort to refine hypocenters of potential microseismic activity associated with movement of CO2 along fractures during the Mississippian CO2-EOR, 4) use of baseline to model the seismic response of CO2 plume in the Mississippian reservoir that would be later tested by repeating the seismic line over the Mississippian injection well.

Work continues on establishing baseline for Mississippian water use with both the Mississippian and Arbuckle injections.

- Incorporating data obtained by Berexco related to previous well maintenance
- Incorporating analyses of Mississippian brine from DE-FE0002056 activities
- New sampling starting soon to provide a longer term (6+ mo.) baseline for the Arbuckle injection.

Mississippian injection well, KGS #2-32, was successfully completed last week. Mississippian was perforated 3663-3706 ft. acidized and a brine injectivity test was conducted indicating #150 psi surface pressure and 4 barrels per minute (5760 bbls per day). This is roughly 10x that rate that CO2 would be injected so well has more than adequate injectivity.

Mississippian at KGS #2-32 is at residual oil saturation, estimated by Mina to be between 23 and 30% based on NMR log.

A 5-well interference test will commence on Monday of next week designed to:

Test communication between KGS #2-32 and surrounding wells and evaluate the effects of a small fault east of #2-32

Provide important geomechanical parameters via leakoff test in steps E-G of the pulse test schedule. Pulse test is designed and will be analyzed by Mina.

Pressure sampling rate is 1 second and duration of the recording will extend until the next day.

May 8

Berexco reviewed equipment and schedules for CO2. We still have some work to do on negotiating price. Plans have been reviewed to reduce costs that should translate into a better deal on CO2. More efficient field operations will translate into buying more CO2.

May 12

A pulse test was conducted between the closest four wells surrounding the injection well #2-32 and #2-32 (**Figure 4**). Importantly, the test results established that there is communication between the KGS #2-32 and well immediately east, even though the two locations are believed to reside in separate progradational wedges of the spiculitic dolomite reservoir.

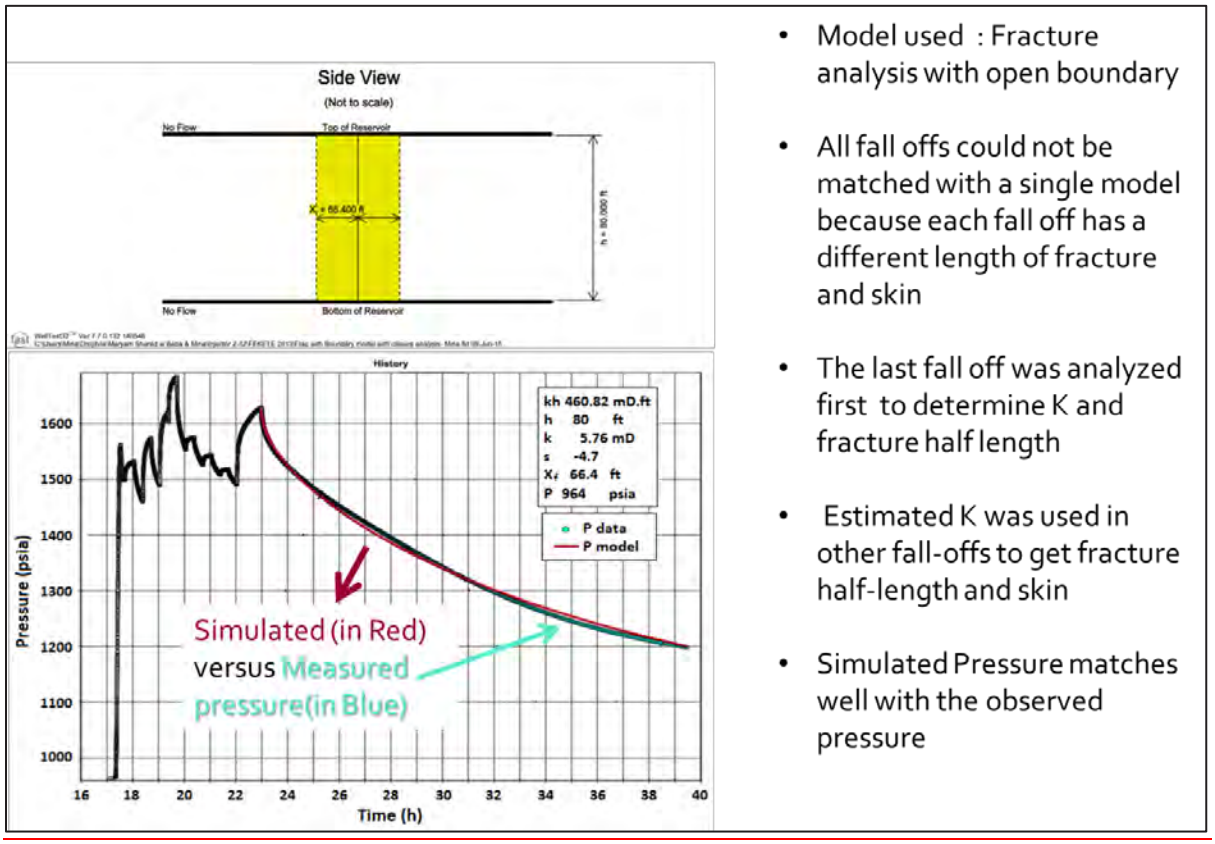


Figure 4. Pulse test simulation compared to actual data.

Effective permeability from the pulse test was 5.8 mD which will be equivalent to 17.8 mD in absolute permeability. Average log calculated absolute permeability for the equivalent interval of the pulse test and DST test is 19 mD. The two absolute permeabilities from the pulse test and logs are in agreements but permeability from DST is unreliable. The comparison of permeability obtained from whole-core and computed from well logs using the Fazelalavi method is illustrated in **Figure 5**.

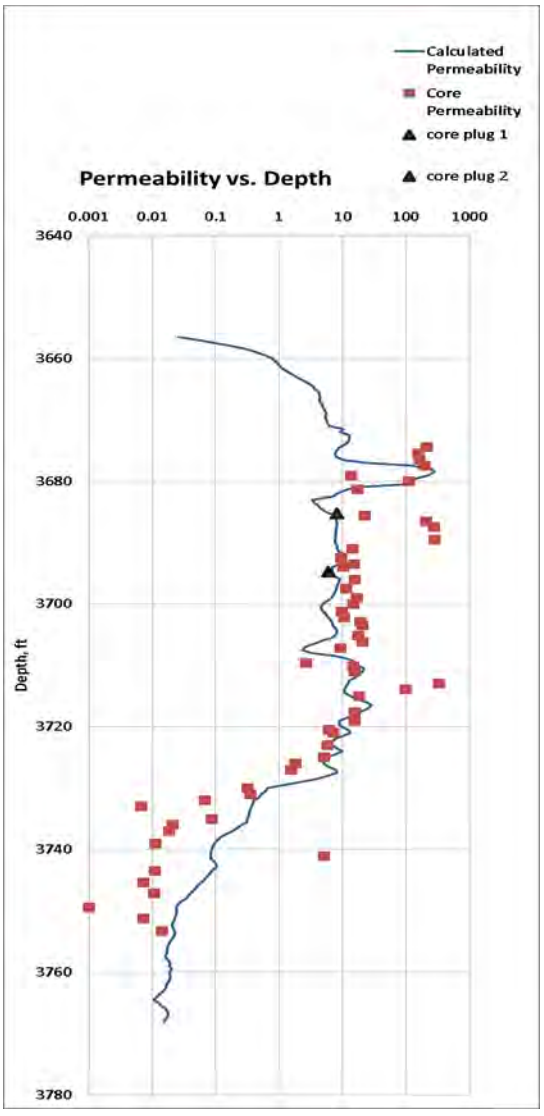
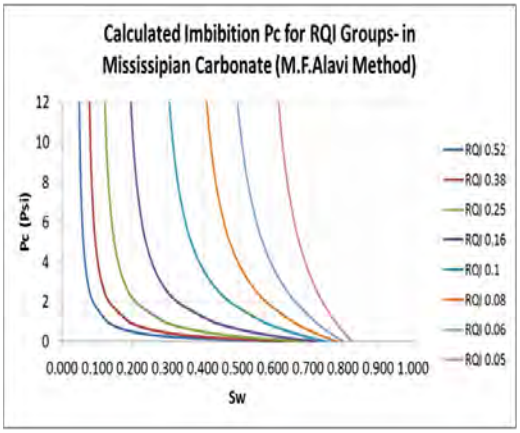


Figure 5. Comparison of calculated and measured permeability from logs and whole core from KGS #2-32 reveal a close match confirming again the accuracy of the log-derived permeability method in the primary reservoir interval with permeability over 0.1 md.

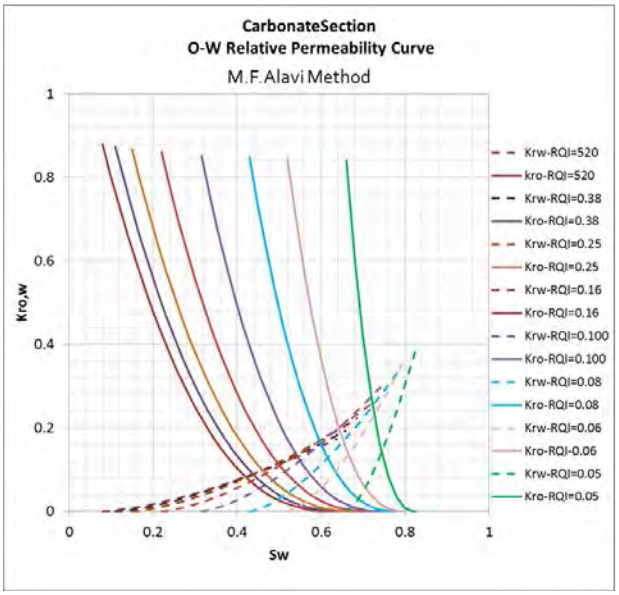
Additional log-based estimates of capillary pressure and relative permeability have confirmed accuracy and reliability when compared with corresponding core analyses from KGS #2-32 (**Figures 6 and7**).



- 8 Pc curves were calculated for 8 RQI ranges
- In this Technique, endpoints of Pc curves are related to RQI
- It was shown that endpoints of Pc curves (Sor and Swir) have stronger relations with RQI than K, ϕ or FZI

RT	From	To	Avg RQI
1	0.450	0.590	0.520
2	0.315	0.450	0.380
3	0.205	0.315	0.250
4	0.130	0.205	0.160
5	0.090	0.130	0.100
6	0.070	0.090	0.080
7	0.055	0.070	0.060
8	0.045	0.055	0.050

Figure 6. Log-derived computed capillary pressure curves for eight rock type (RQI, reservoir quality index).



- 8 Relative permeability curves for brine and oil were calculated for each RQI range
- Endpoints of relative permeability curves are related to RQI
- These endpoints have a stronger relationship with RQI than K , ϕ or FZI (Flow Zone Indicator)
- Corey exponents used for oil and water are 2.5 and 1.5

Figure 7. Log-derived relative permeability curves were calibrated with core derived data and show close correspondence.

RAI Table 5 sent to the KGS on 5-11-15 in preparation for prepare for May 15 meeting. We have been compiling specific information and responses to questions that have been addressed in the tables in order to expedite the review of the Testing and Monitoring and PISC Plan development. All relevant parties have been asked to participate in the meeting to ensure that we are able to offer sufficient detail in each area of expertise.

May 15

EPA meeting discussed responses to RAI Table 5.

1. Plume Monitoring

- Question: Validation of AoR modeling predictions with U-tube sampling results

General Response: Barry Freifeld, LBNL, described his validation methods in conjunction with other monitoring data. He went into detail about the specific benefits and limitations of each, and explained how those observations would relate to our other monitoring techniques.

- Questions: Seismic Surveys

  - Methodology
  - Comparison of results with model predictions,
  - Coverage of plume migration with seismic monitoring, and
  - Adequacy of well-based plume monitoring methods to detect leakage.

General Responses: G. Tsoflias, KU Geology, provided detail regarding the microseismic monitoring and 3D seismic evaluation used to refine his analysis. He explained his experience in 3D seismic surveys and how refining the acquisition would increase the ability to detect and monitor the CO2 plume in the formation. R. Miller described the procedures for the 3D and 2D seismic survey and coverage including details on how the 2D seismic surveys would clearly resolve gaseous CO2 at depth including Arbuckle and explained that these same methodologies should easily be able to detect migration into shallower intervals.

R. Trautz gave an overview of his funded Fiber Optic proposal and what the deployment could mean for our project – emphasizing tentatively scheduled for Wellington and experimental nature needing validation.

The EPA appreciated the helpful clarification and now understood the 2D seismic as more of an above confining zone monitoring technique. B. Freifeld, LBNL described downhole monitoring techniques and detection capability of the plume or potential CO2 leakage.

- Questions: CASSM and Cross-well Tomography

  - Baseline monitoring schedule
  - Design and placement of downhole sensors
  - Comparison of results with AoR modeling predictions

General Responses: B. Freifeld, LBNL, responded with specific designs tailored to Wellington and frequency of sampling events.

2. Pressure-Front Monitoring

- Questions: InSAR and GPS

  - Thresholds of observed pressure increases requiring further investigation
  - Existing observations of baseline data

General Response: M. Taylor, KU Geology, presented images of collected InSAR data and analysis of baseline cGPS to date. He will continue to process radar scenes, but their use for pressure monitoring yet is indeterminate. An interferometery comparison of two scenes from Wellington was presented. Detection of ground motion below 1 mm is questionable even though scene resolution is very good. Discussion addressed the experimental nature of this methodology.

- Questions: Passive Seismic Monitoring

    - Additional details on resolution and detection capability of seismometer array

General Response: Rick Miller will explain the ability to identify x,y,z coordinates of microseismic events, and clarify that the detection capability of the network far exceeds EPA reporting requirements for M2.5+ earthquakes. Details on John Victorine's processing tools will also be introduced as a means to identify the location and depth of observed earthquakes.

A large portion of the discussion centered on quantifying deviations in field observations from the predictive models that would trigger further investigation to characterize leakage.

- There was some confusion on the level of detail that the EPA required for each of the technologies, and it was argued that defining a specific threshold would be extremely difficult with the level of uncertainty surrounding the planned injection.

- To resolve this issue, the team prepared an ***Operational Plan for Safe and Effective Injection*** that was submitted to EPA as part of the response to the RAI Table 5 questions as part of the Class VI application and specifically, the section on ***Emergency and Remedial Response Plan***

3. Groundwater/Geochemical Monitoring Above the Confining Zone

- Questions:

    - Shallow Water Well locations
    - Above Confining Zone Pressure Monitoring

General Responses: D. Wreath, Berexco, clarified operating conditions in the field including waterflooding causing normal fluctuations in pressure in the well annulus of wells completed in the Mississippian oil reservoir making it extremely difficult to accurately identify leakage based on pressure monitoring alone. As a precaution, the annulus of the Mississippian monitoring wells will be checked daily for escaping gas. In the unlikely event that gas is observed during the Arbuckle test, samples will be collected and tested to detect the presence of any escaped CO2.

May 18th

Establish communication with Sumner County Economic Development Commission www.gosumner.com. Set general plans to meet with Sumner County Commissioners and Wellington City Council in late August, early Sept. before meeting with the public regarding progress related to CO2-EOR pilot injection and saline aquifer pilot test. Will update and share the *Wellington Field Fact Sheet* and the *FAQ document.*

May 21

The ***Operational Plan for Safe and Effective Injection*** outlines a workflow that uses the most reliable and most responsive monitoring methods to detect anomalies during injection that may trigger some kind of corrective action. Preset thresholds of injection pressure, temperature, injection profile monitoring, chemical composition, and passive seismic monitoring will provide the primary means prevent leakage of CO_2 accompanied by our 2nd tier monitor to evaluate the progress of the plume.

The passive seismic monitoring described in the ***Operational Plan for Safe and Effective Injection*** parallels the approach taken by ADM for their Class VI permit at Decatur, Ill using known performance of the seismometer array installed and operating at Wellington.

The ***Operational Plan for Safe and Effective Injection*** also incorporates methodologies from Kansas' Induced Seismicity Task Force to evaluate brine injection and take action to mitigate recent seismicity associated with high rate, pressure, and volume brine injection in Class II wells located southwest of Wellington Field.

We plan to share a draft of the plan early next week.

May 22

Interval review of the geomechanical analysis of the Arbuckle injection – "*Supplement to Section 6 of Wellington Class VI Permit Application*"

May 26

In the ongoing discussions with EPA regarding seismicity comparison made of commercial brine and hazard waste disposal with Wellington, important to note the relative differences between the injection rates in the Arbuckle at Wellington vs. nearby Class I wells (~18 mi north of Wellington) (**Figure 8**). At the CO_2 site, we will be injecting about 25,000 tons which equates to about 6 million gallons (MG) of fluid. By contrast, at the OxyChem site north of Wellington, they have been injecting about 700 million gallons per year (nearly 100 times more every year). Additionally, the injection per well at the OxyChem site is as high as 175 MG/yr. All this injection at OxyChem has occurred without any major earthquakes.

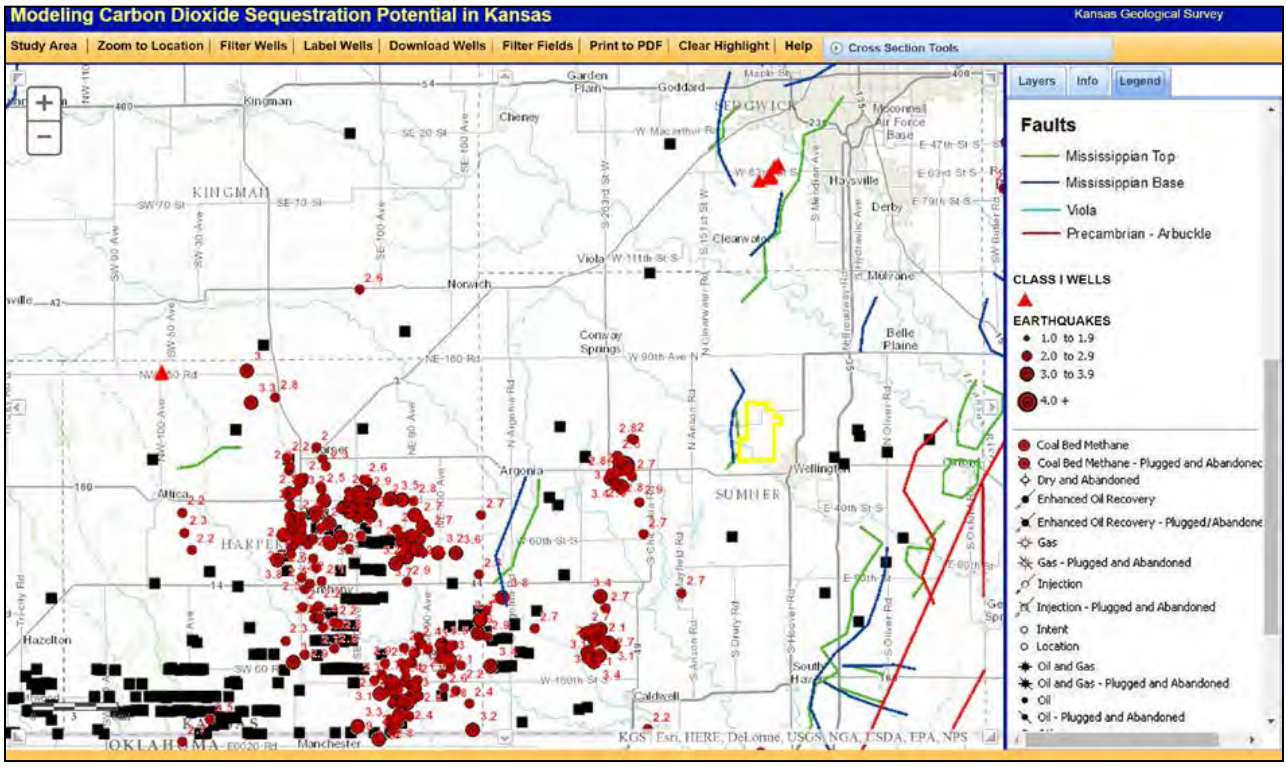


Figure 8. Location map of Class 1 wells near Wichita north of Wellington on base map with oil fields (colored squares). Map also shows inferred faults and recent (since 2011) earthquakes located west and southwest of Wellington Field.

May 29

RAI Table #6 was received by KGS on 5-19-15 and RAI Table #5 was submitted to EPA today.

The latest version of the ***Operational Plan for Safe and Effective Injection (OPSEI)*** outlines a *"…workflow for deploying day-to-day operation of the Arbuckle CO_2 injection. The workflow integrates system operation, testing and monitoring, and emergency and remedial response that are necessary for prudent operation to satisfy both DOE and EPA criteria for success, namely, to understand the behavior, fate, and storage of CO_2; and to conduct the test safely, meeting or exceeding GS permit requirements. Moreover, the workflow is focused in early detection of multiple changes in data types to validate that changes are occurring in the behavior CO_2 injection that warrants better understanding, analysis, and action. The operational plan incorporates and cross references information already part of the GS Permit as described in Sections 8, 10, and 13, and provides more details of operating activities that will ensure success.*

This document also defines our operation strategy toward successfully conducting the research for DOE to satisfy the SOPO and PMP requirements and to ensure safety first for EPA. ***OPSEI*** stems

from the conference call with EPA held on 5-15-15. Conveying the operational plan to EPA at this time is critical to completing the Class VI review by providing a strategy that will minimize risks and emphasize safety of the pilot test.

OPSEI provides a bridge between well, monitoring, and response items initially submitted to EPA for the Geosequestration (GS) Class VI Permit Application, namely,

- *Section 8 -- System Design, Construction, and Operation*
- *Section 10 -- Proposed Testing and Monitoring Plan*
- *Section 13 -- Proposed Emergency and Remedial Response*
-

The ISSTF incorporates the Seismic Action Plan and it will be very important for the state regulators to be fully cognizant of the activities related to CO2 injection into the Arbuckle at Wellington Field. We look at the injection as a key element in understanding the behavior of fluid injection in the Arbuckle with minimal risk for seismicity due to rates, volume, and pressures of the CO_2 injection. Moreover, we are utilizing work done by the KGS to share with the Kansas' Induced Seismicity Task Force who are building regional static and dynamic models of larger scale brine disposal in the south-central Kansas that includes the Wellington area. These results are allowing us to compare sizes of injection between Wellington and nearby UIC Class I and II disposal wells. All of this is important information to convey to the public in terms of relaying the focus and coordination between federal and state agencies to better understanding on what are safe injection parameters to ensure public safety in the future, an objective of the induced seismicity task force.

June 5

The updated grid file requested in Table 1 RAI was uploaded to the GS Data Tool, along with the original rescue file to verify that errors in cell values were due to conversion issues between the requested file formats.

Well completion reports for SW #1 and #2 have been completed and are under review by S. Datta and when submitted to EPA will serve as information to determine the presence of a USDW at the Wellington site.

Task 3 – Site characterization of Mississippian Reservoir - Wellington Field

May during month –Excessive rain has pushed back deploying the 2D seismic. At this point, our plan is to wait until the wheat has been harvested mid-June. This will also avoid paying damages to landowners. However, now that the new seismometers have been installed, it will be a good opportunity to calibrate them with the various tests that occurred around the Mississippian injection.

May 4

- **Completion of Mississippian injection well and discussion of variable rate pulse test test**

May 11

Request the 3D velocity volume from Fairfield-Nodal of Wellington to use in computing hypocenter location of microseismicity.

May 11-12
Conduct variable rate pulse test on Wellington KGS #2-32

May 19

KGS received capillary injection pressure analyses on Wellington #2-32 Mississippian reservoir samples (**Figure 5**).

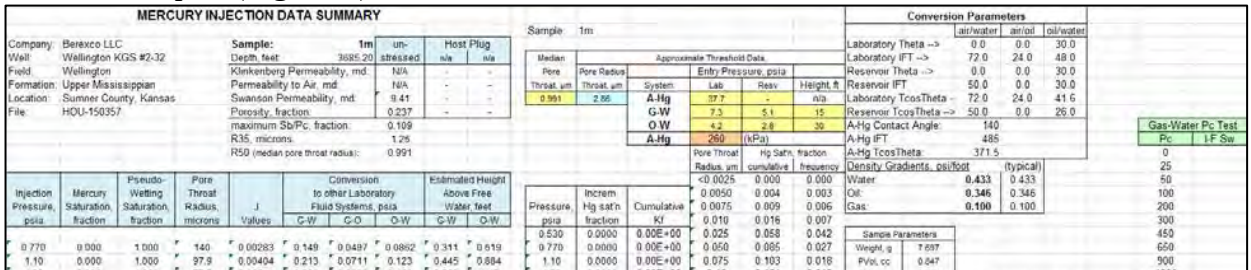


Figure 5. Capillary pressure data for a sample from core analysis done by Core Lab on the Mississippian of KGS #2-32.

May 26

Mina Falzelalavi provided pressure-temp plots on interference test in KGS #2-32 and initial assessment. It appears that the response in the nearby wells may have been impacted by nearby production/injection to the east and northwest. Jenn Raney and Mina obtained operational information on these wells from Berexco so she can perform further analysis. They will work with Eugene to see how he handles these wells in his simulation.

Based in these preliminary findings of the inference test, Eugene indicates pre-pressurization will take considerably less than 20 days. We will make sure that the simulation most closely reflects the conditions of the field.

Task 7. Pre-injection MVA - Establish Background (Baseline) Readings

Seismometer array – R. Miller compiled baseline reports for seismicity around Wellington. We plan to present these to EPA to demonstrate the variation in what has been observed and what is expected during the injection. Rick is also establishing a case for using the passive seismic data more strongly to support the pressure front monitoring of the plumes (in lieu of exclusively using the InSAR as the primary technology). Recent communication from G. Tsoflias, expresses his reservations on pressure front detection until we have a real test. He is the primary collaborator whose team will carry out the microseismic event detection. He states,

> "*…microseismic will image the pressure front only if the pressure front induces fracturing of the formation on the order of -1.0 or greater magnitude earthquake event. Until we establish what the likelihood is for the pressure front to cause such events as it diffuses away from the injection borehole, unless it re-activates existing fault(s) and fractures. The seismometer network at the surface is likely to detect induced seismicity at times of rapid pressure regime change, most likely near the injection borehole and in regions where existing fault(s) and fractures get re-activated. Moreover, previous discussions of using microseismic to monitor the pressure front were in reference to a borehole seismic installation. That work was proposed for a KU internal funding initiative by Mike Taylor but it was not funded. In my opinion a fair statement is that we will use the seismometer network to monitor for seismicity induced by the pressure front. But we should not commit to a pressure front map derived from microseismic until we have had the chance to look at some data from the Mississippian injection…"*
>
> Berexco reserved two Mississippian wells into which the borehole seismic could be installed at optimal locations on the edge of the modeled pressure front.

High Res 2D Seismic Lines Targeting Mississippian Reservoir -- Acquisition of the baseline high-resolution 2D seismic survey was set to begin on May 14th, but wet ground has prevented deployment to the date of filing this report. Lines will connect our key wells and evaluate inferred small fault that some seismic interpretations indicate affect the Mississippian reservoir

(**Figure 6**). Specific objectives set this this 2D survey include: 1) further characterization of the confining zone above the Arbuckle, 2) further resolve heterogeneity in the Mississippian reservoir, 3) use of seismic source to obtain velocity volume to location of hypocenters of microseismic activity anticipated with the Mississippian injection, 4) use of baseline to model the seismic response of CO_2 plume in the Mississippian that would be later tested by repeating the seismic line over the Mississippian injection well.

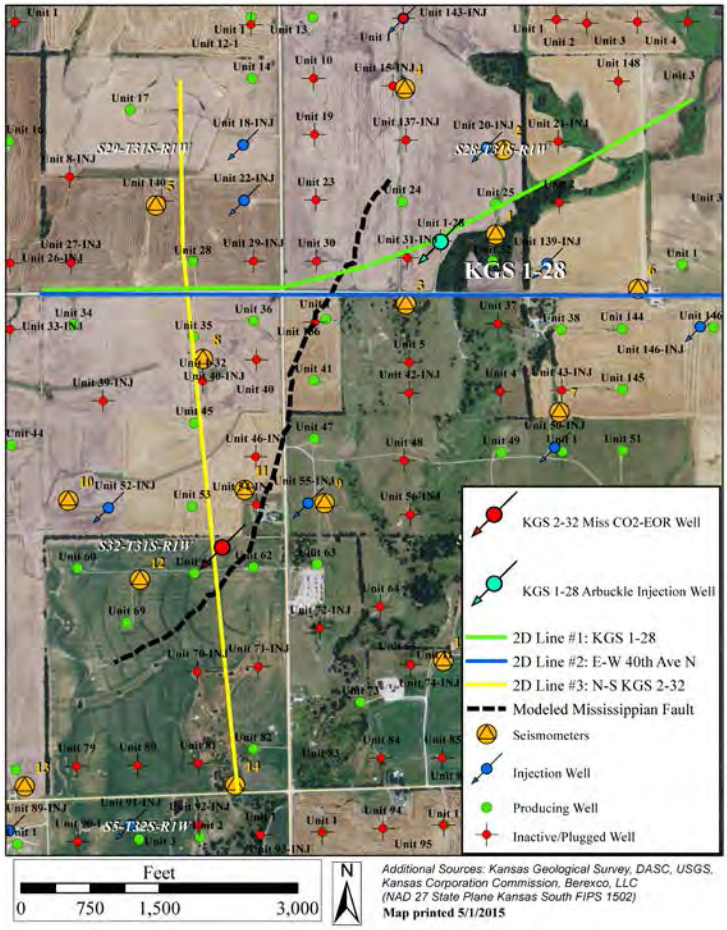


Figure 6. Index map of the high resolution 2-D surveys.

cGPS-InSAR is operational. Question now on whether persistent scatterers in the SAR images are sufficient to detect ground motion from either a Mississippian or Arbuckle injection. Accordingly, we relegating the use of InSAR to detect the CO2 pressure front to be uncertain at this point until sufficient background are obtained and the method tested during repressurization and injection in the Mississippian.

The latest SAR images are encouraging based on what M. Taylor shared earlier, but at this point levels of detection; any kind of calibration to pressure is only speculative. The April 2015 SAR image was compared to the 2014 aerial photos of the drill sites, KGS #1-32 and

#2-32. The SAR image shows strong point scatterers at the wellsite and other nearby wells **(see Figures 7-13)**.

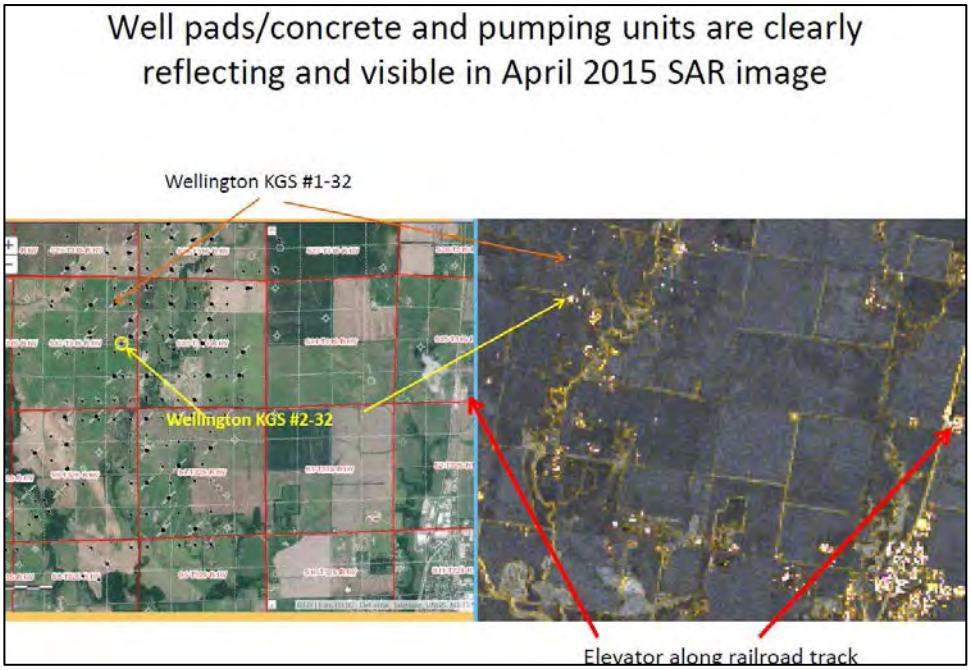


Figure 7. Aerial view from 2014 compared to SAR image with KGS #1-32 and #2-32 shown.

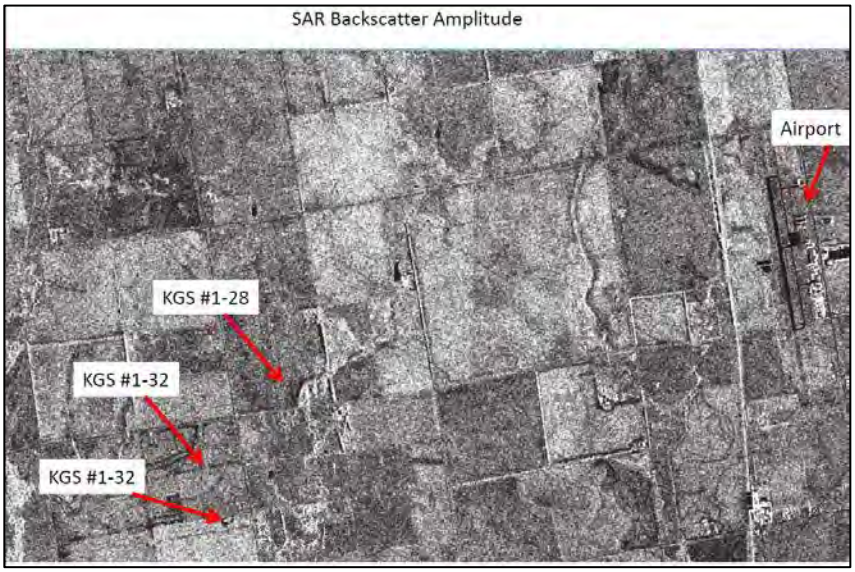


Figure 8. Unprocessed SAR from Wellington Field area (acquired April 2015)

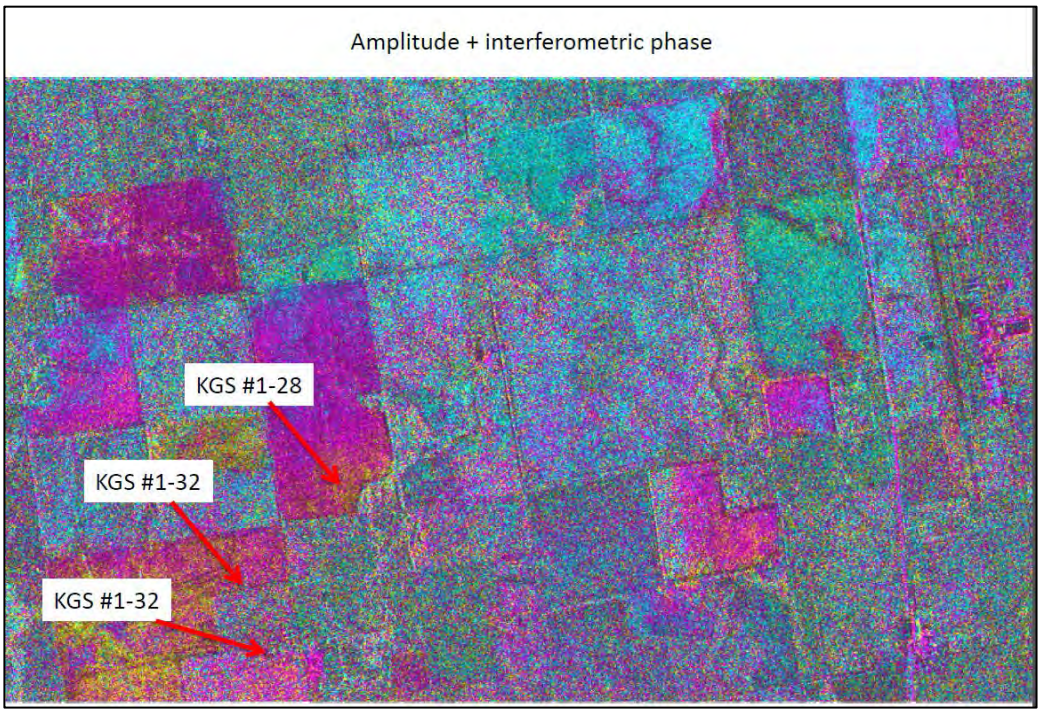


Figure 9. Processed SAR acquired April 2015.

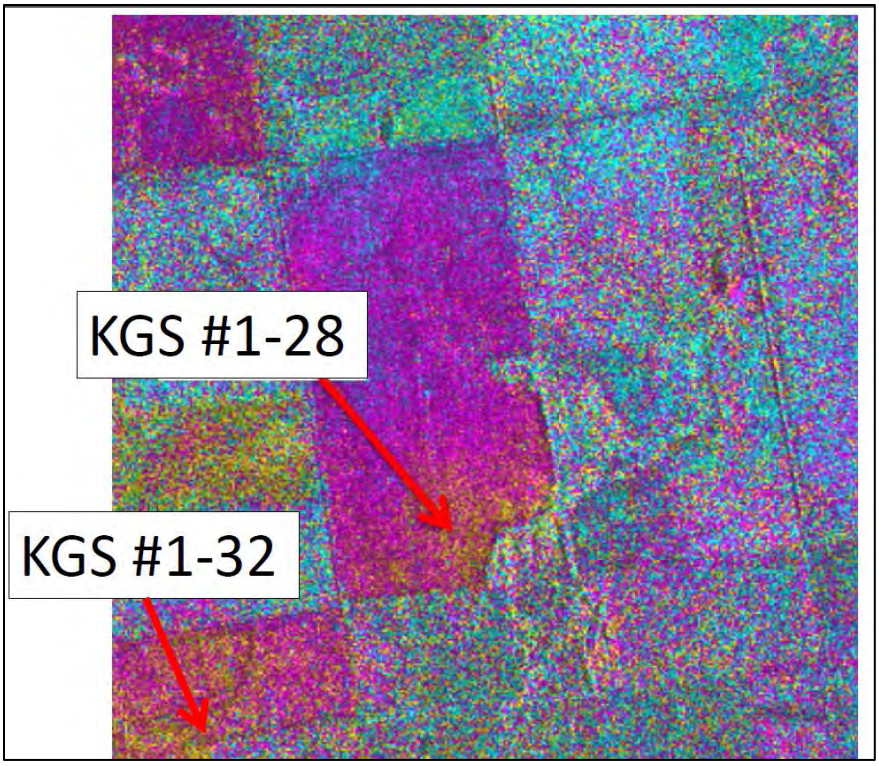


Figure 10. Close-up of SAR from April 2015.

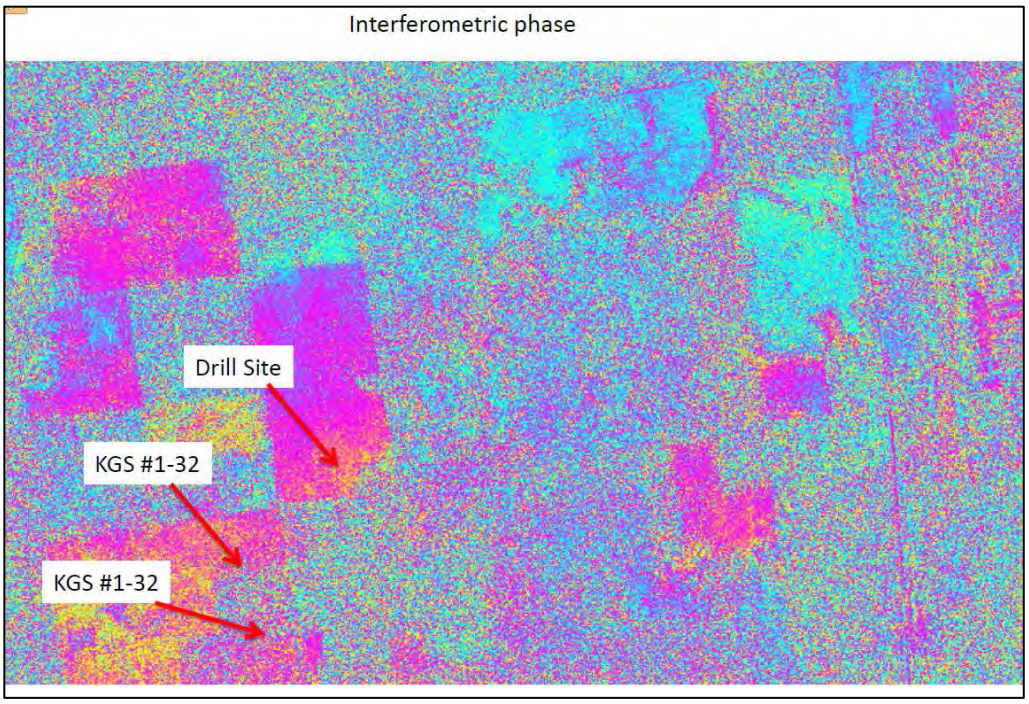


Figure 11. Processed SAR from 2015.

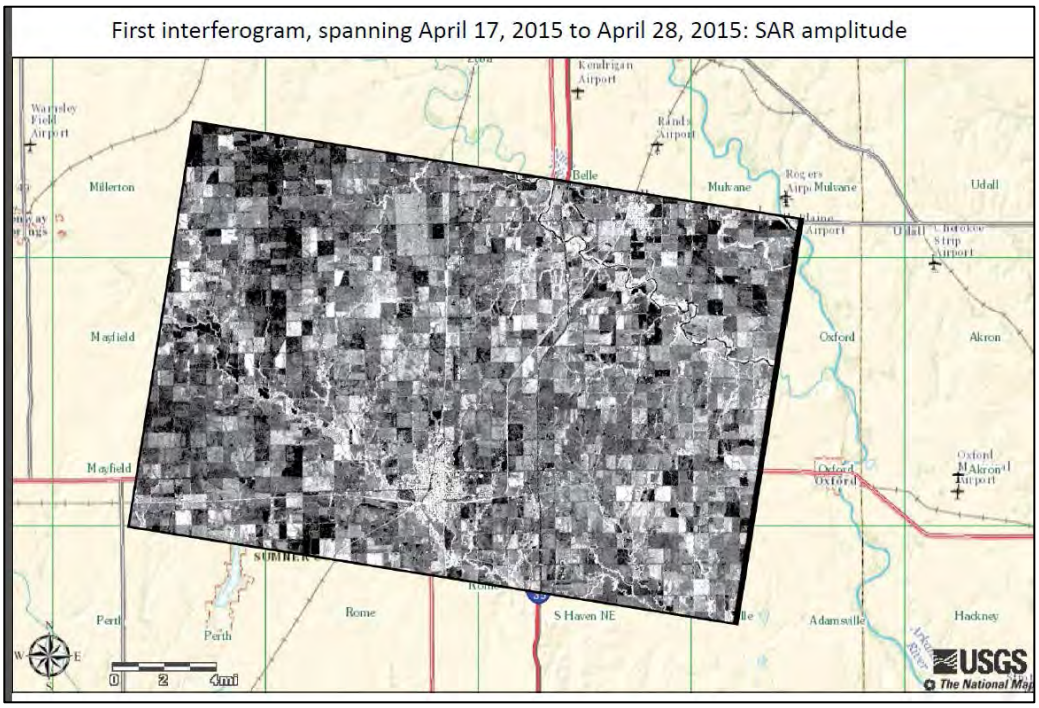


Figure 12. Reference map of area covered by SAR scene, April 2015.

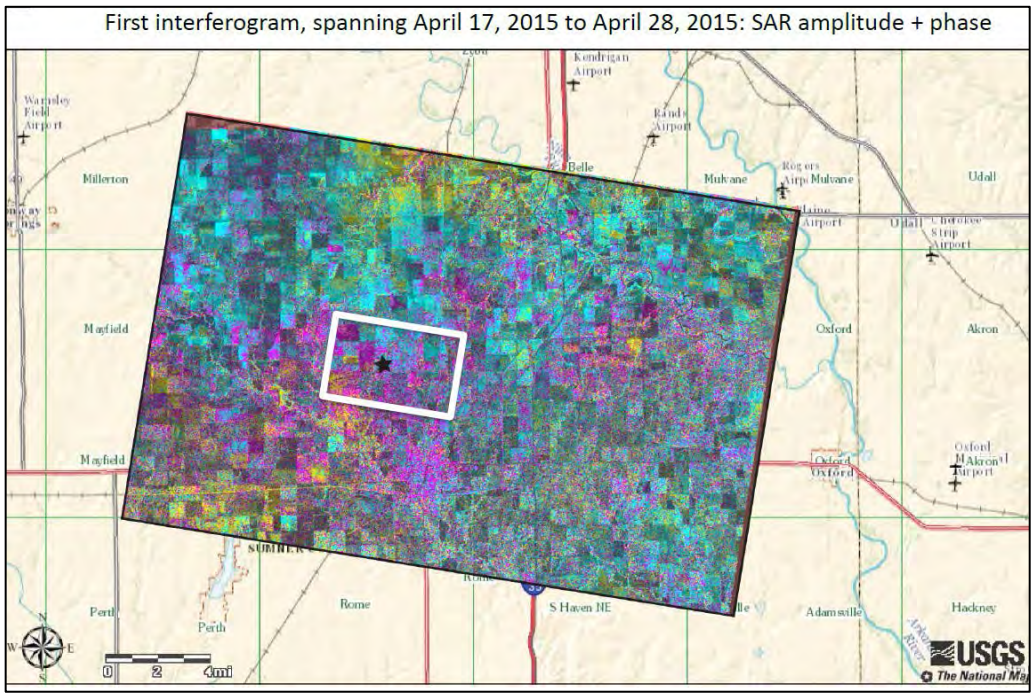


Figure 13. Interferogram for SAR.

Subtask 7.4 Head Gas & Water Sampling from Surrounding Mississippian Wells

S. Datta, C. Reese, and B. Campbell began sampling the Mississippian wells this quarter to obtain baseline fluid analyses. Standardized reporting for the analyses established reside on a KGS Oracle database. The brine and other baseline analysis of fluids from the Mississippian and accessed, processed, and results of analyses displayed using Java software (**Figures 14-18**).

The new approach for the GIS display used KML files created using ORACLE stored procedure. The web page is at **http://www.kgs.ku.edu/PRS/Ozark/Software/google-maps/brine_data_by_wells.html.** The markers and the well information are displayed in the upper right hand corner with a link to a Brine Data Summary Web Page for a specific well. The Brine Data Summary Web Page by Well Header KID will show all brine samples for that well.

A brine analysis lab is being set up in Wellington to expedite analysis of Mississippian wells to accelerate establishment of the baseline before CO2 injection begins. Details of the wells to be sampled and the sampling protocol have been established.

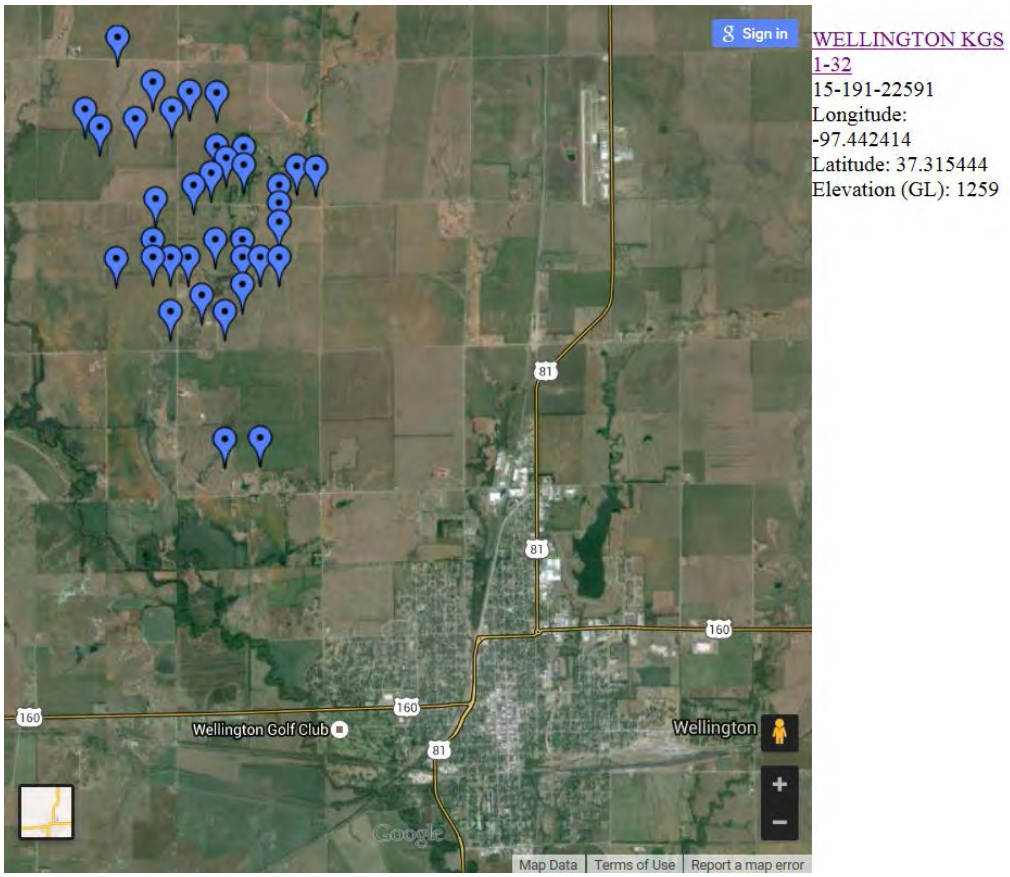


Figure 14. Google map based access to the brine data is being examined as a means to quickly share results with the team and permit comparison of other MVA data such as microseismic and InSAR during the Mississippian CO2 injection.

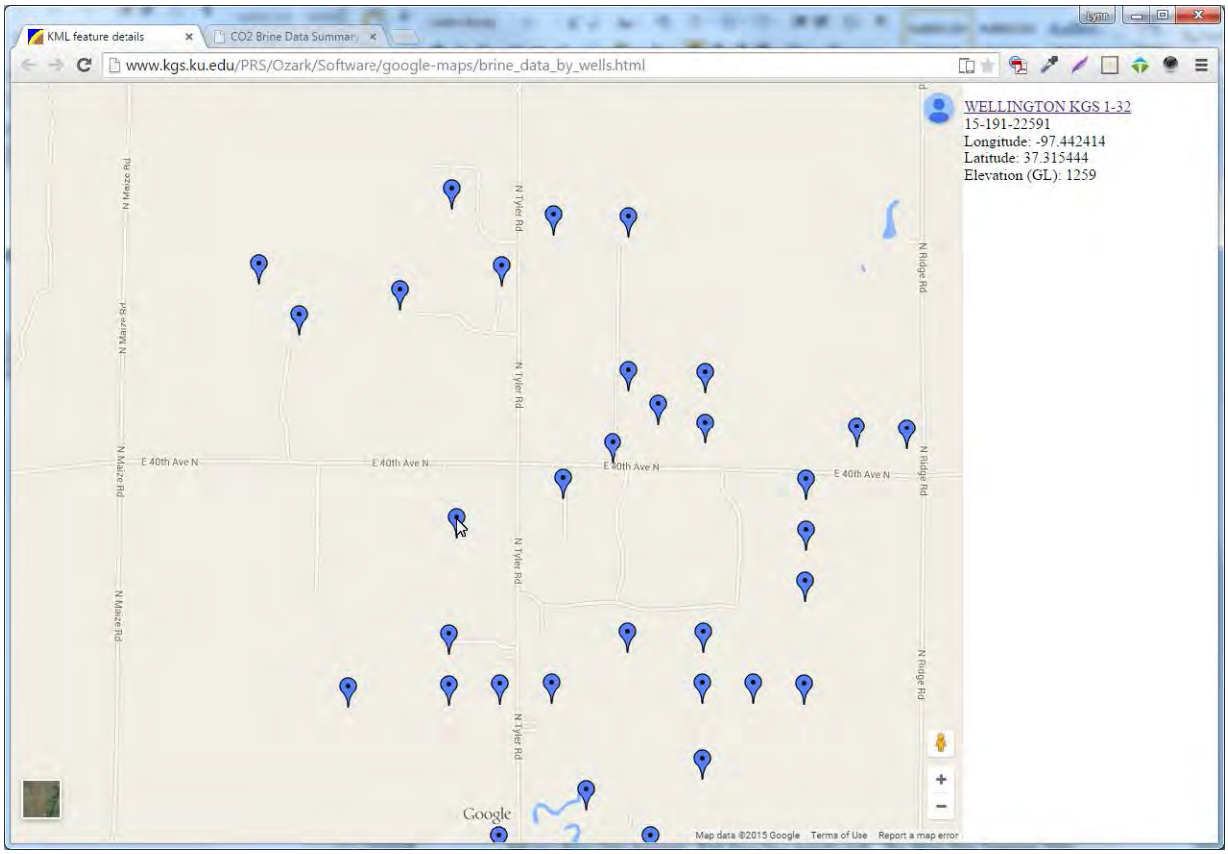
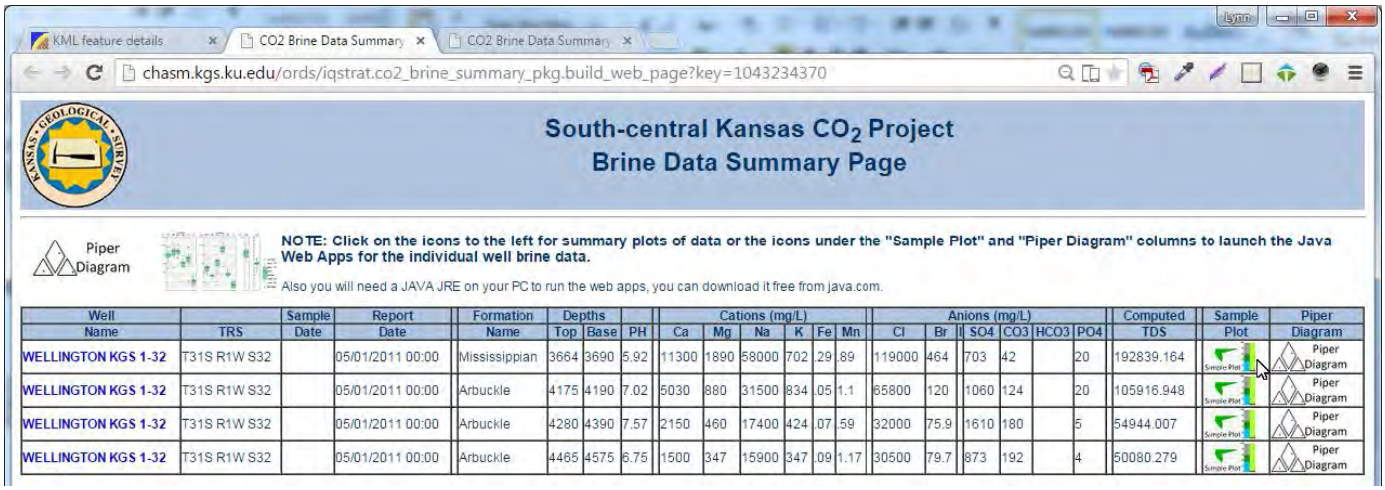


Figure 15. Well KGS #1-32 water samples were selected in this interactive map as noted in the upper right corner of the map.



Well Name	TRS	Sample Date	Report Date	Formation Name	Depths Top	Depths Base	PH	Cations (mg/L) Ca	Mg	Na	K	Fe	Mn	Anions (mg/L) Cl	Br	SO4	CO3	HCO3	PO4	Computed TDS	Sample Plot	Piper Diagram
WELLINGTON KGS 1-32	T31S R1W S32		05/01/2011 00:00	Mississippian	3664	3690	5.92	11300	1890	58000	702	.29	.89	119000	464	703	42		20	192839.164	Simple Plot	Piper Diagram
WELLINGTON KGS 1-32	T31S R1W S32		05/01/2011 00:00	Arbuckle	4175	4190	7.02	5030	880	31500	834	.05	1.1	65800	120	1060	124		20	105916.948	Simple Plot	Piper Diagram
WELLINGTON KGS 1-32	T31S R1W S32		05/01/2011 00:00	Arbuckle	4280	4390	7.57	2150	460	17400	424	.07	.59	32000	75.9	1610	180		5	54944.007	Simple Plot	Piper Diagram
WELLINGTON KGS 1-32	T31S R1W S32		05/01/2011 00:00	Arbuckle	4465	4575	6.75	1500	347	15900	347	.09	1.17	30500	79.7	873	192		4	50080.279	Simple Plot	Piper Diagram

Figure 16. Click on KGS 1-32 well samples in Figure 15 and obtain the list of samples available. Idea is to permit comparison of brine data both temporally and spatially.

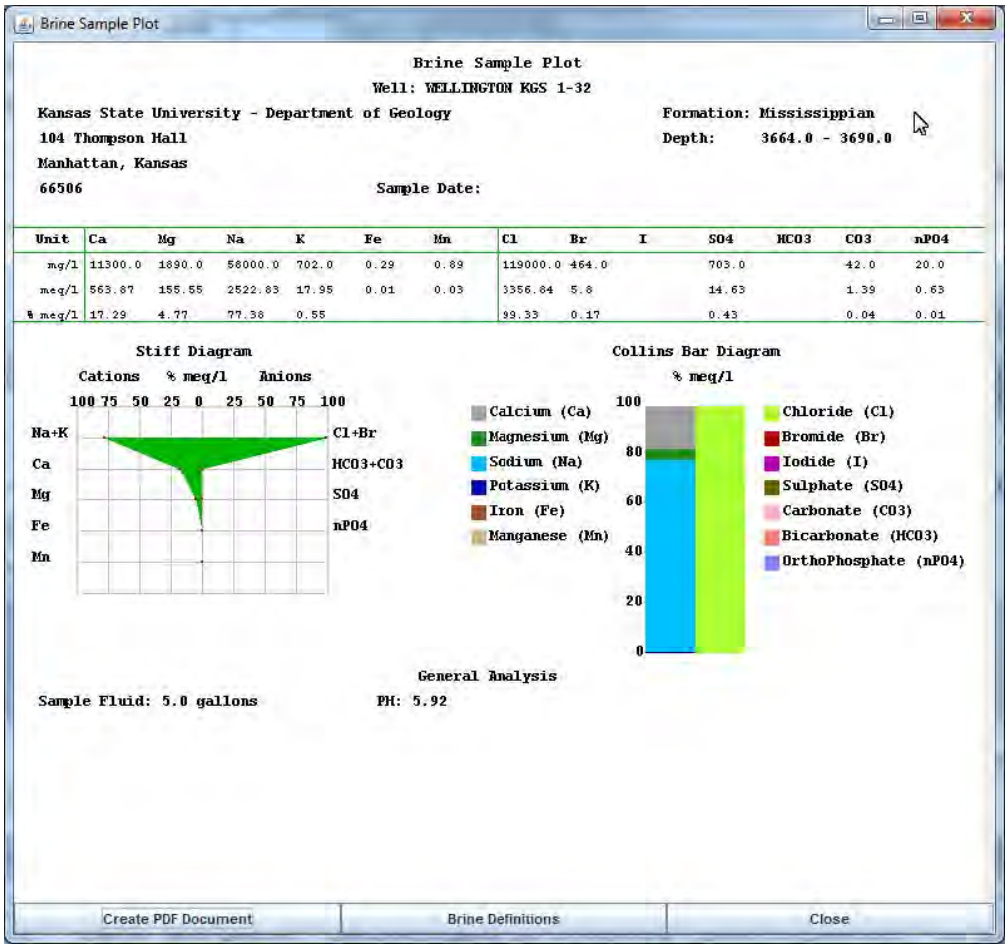


Figure 17. Brine sample plot of Mississippian analysis at KGS #1-32.

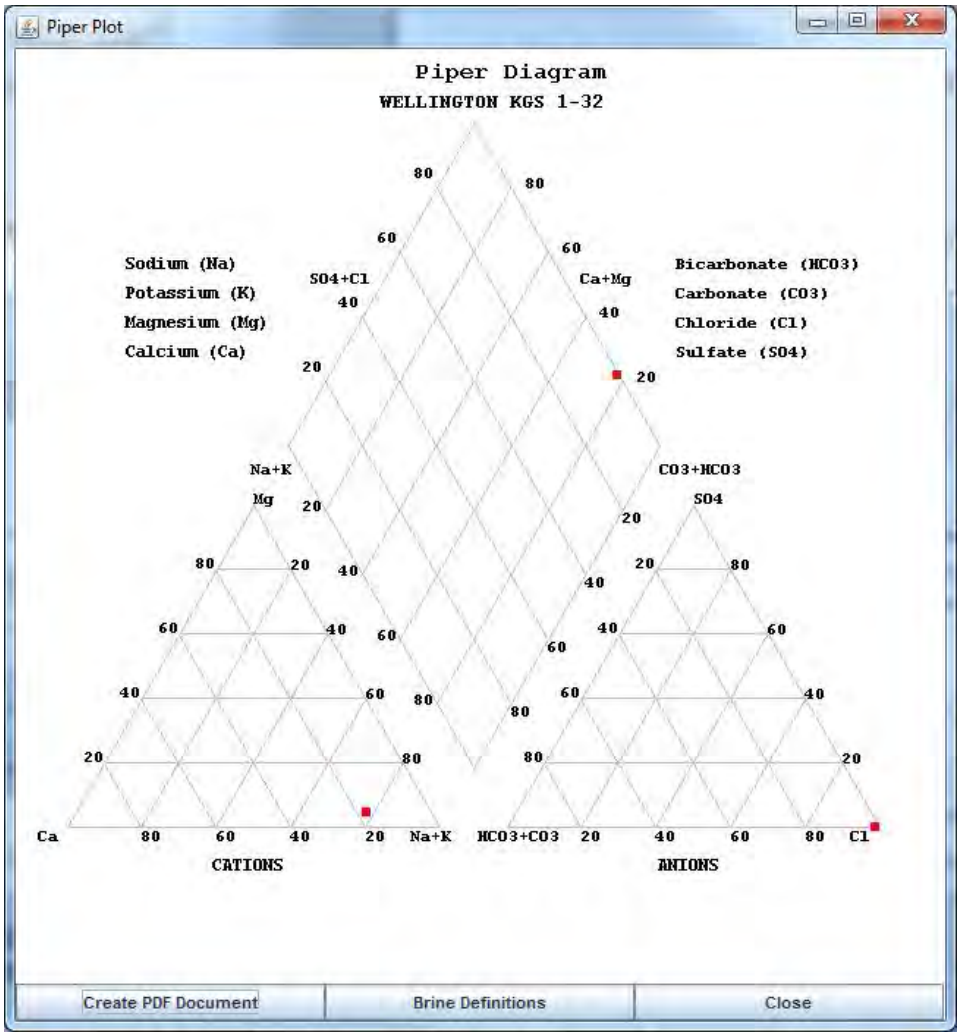


Figure 18. Piper diagram of Mississippian analysis at KGS #1-32.

Project schedule for pre- and post-Arbuckle injection at Wellington Field.

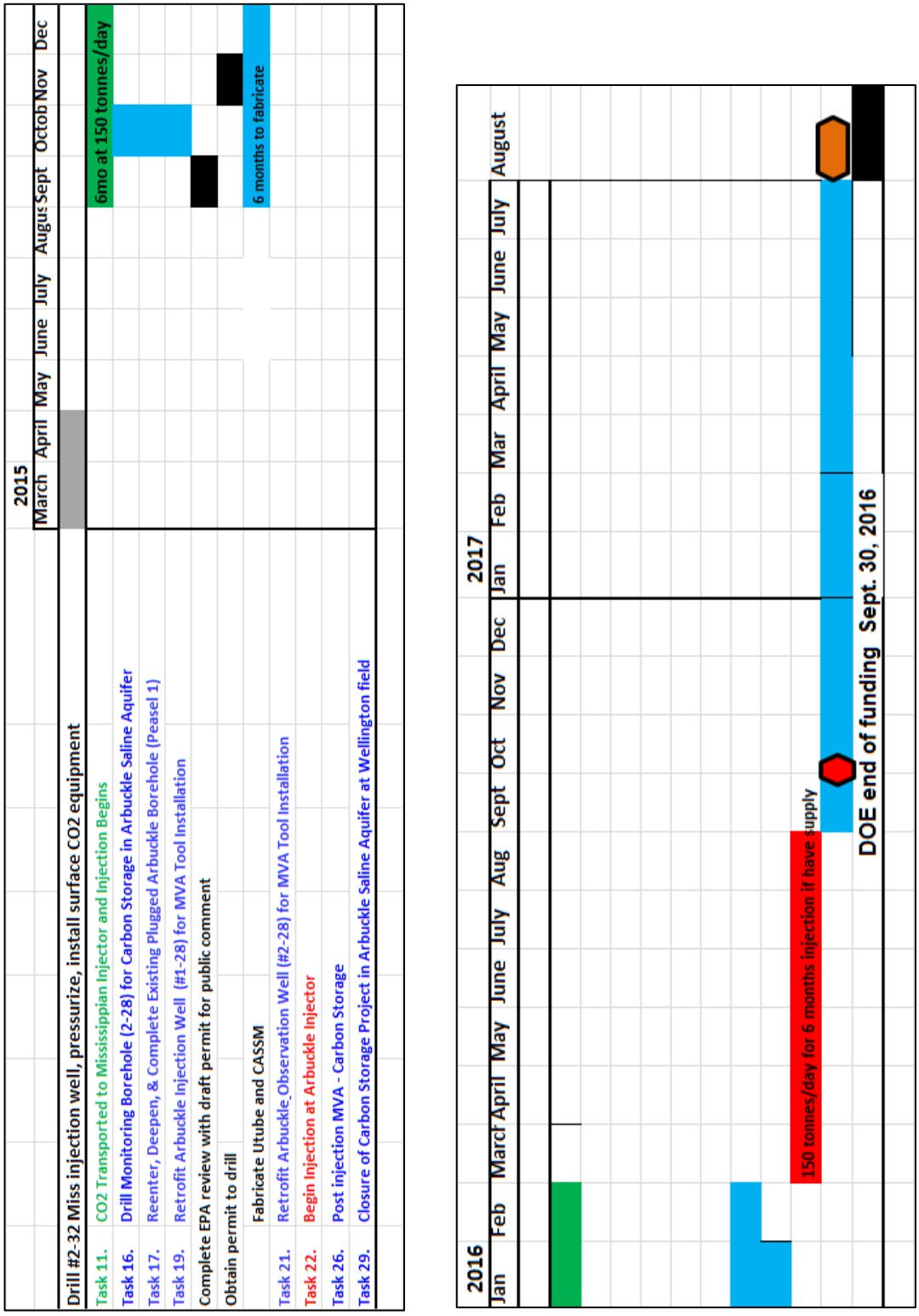


Figure 19. Revised Gantt chart.

Activities of Lawrence Berkeley National Lab

No work has been completed or funds expended during this quarter by LBNL.

Key Findings

1. Review by EPA and responses to RAI's for Class VI application have reached the final stages currently focused on 1) resolution of grid transformation of the simulation that will confirm the AOR and 2) the final field testing and analyses of the water and the local geohydrology to the presence of a USDW in the AOR.
2. The Mississippian CO2-EOR activities including completion and testing of the CO2 injection well, KGS #2-32, and establishing the baseline MVA measurements are complete as of the time this report is submitted.
3. Addressed safe CO2 injection with an operational plan that outlines use of monitoring activities and thresholds to detect anomalies, operate safely, acquire necessary data, and complete the injection successfully to evaluate the MVA technologies.

Plans for Fourth Quarter 2015

1. Complete preparations for CO2 injection to the Mississippian.
2. Inject CO2 into the Mississippian.
3. Continue to respond to EPA's review of the Class VI permit application.

PRODUCTS

Publications, conference papers, and presentations

L. Watney, April 14, 2015, *A Maturing Mississippian Lime Play in the Midcontinent – A Perspective on What We Know and Need to Know,* KU Interdisciplinary Carbonate Consortium.

L. Watney, May 5, 2015, *CO_2-EOR in the Wellington Field, Sumner County, South Central Kansas -- Southwest Kansas CO_2-EOR Initiative CO_2 utilization in oil fields and storage in Arbuckle saline aquifer in southern: Kansas, Implementing CO_2 Utilization and Storage (CCUS) in Kansas,* KU TORP Improved Oil Recovery Conference, Wichita.

L. Watney, June 18 2015, invited presentation to Kansas Society of Professional Engineers, "Local Earthquake Activity, Wichita.

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

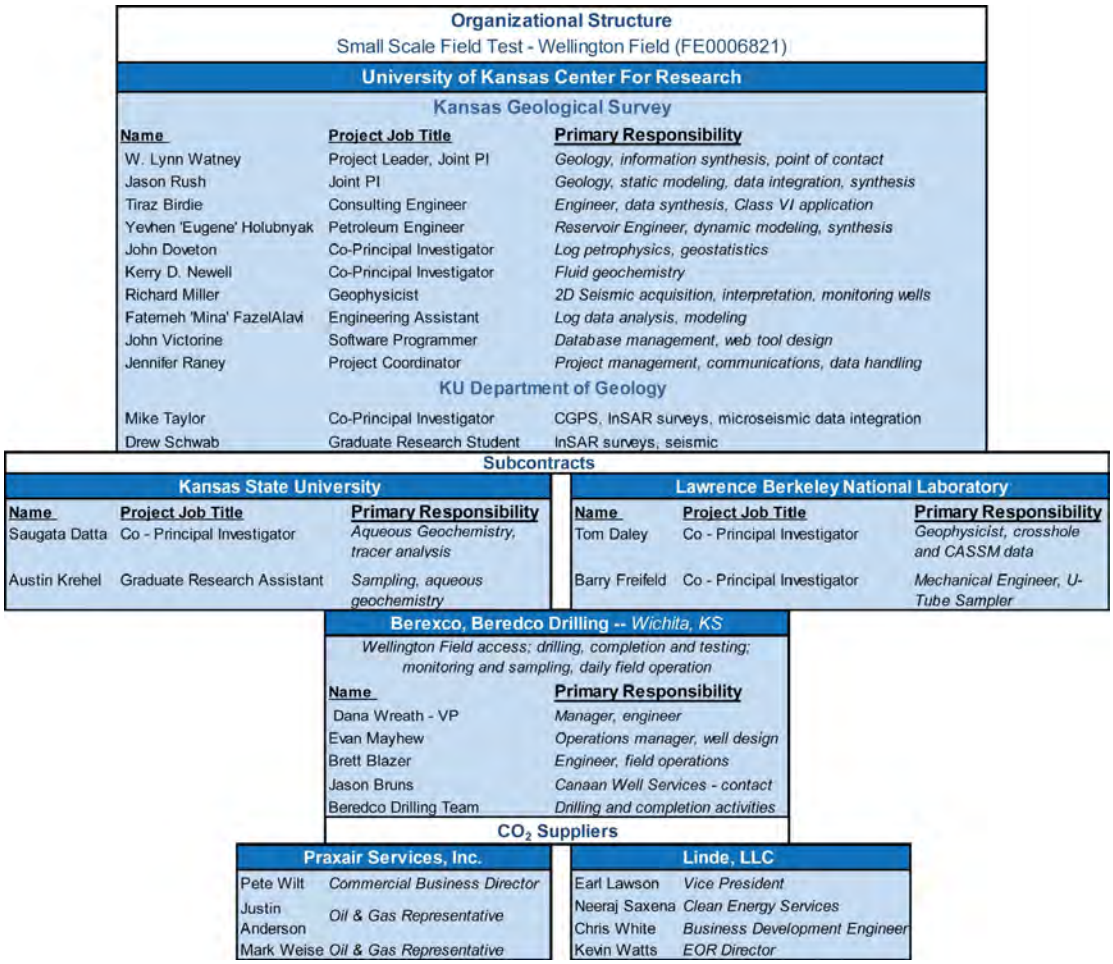


Figure 20. Organizational Chart.

IMPACT

Discussions with EPA around the Class VI application have established a means to effectively manage injection in an area what has been affected by induced seismicity.

CHANGES/PROBLEMS

No significant change or problems.

BUDGETARY INFORMATION

APPENDIX III

Thesis: Pre-stack Seismic Attribute Analysis
of the Mississippian Chert and the Arbuckle Group
at the Wellington Field, South-Central Kansas

By Yousuf Fadolalkarem

Pre-stack Seismic Attribute Analysis of the Mississippian Chert and the Arbuckle Group at the Wellington Field, South-central Kansas

By

Yousuf Fadolalkarem
BSc Geophysics, University of Leeds, 2007

Advisory Committee

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George Tsoflias, Chairperson

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W. Lynn Watney, Committee member

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Ross Black, Committee member

Date Defended _____

The Thesis Committee for Yousuf Fadolalkarem certifies that this is the approved version of the following thesis:

Pre-stack Seismic Attribute Analysis of the Mississippian Chert and the Arbuckle Group at the Wellington Field, South-central Kansas

Advisory Committee

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George Tsoflias, Chairperson

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Ross Black, Committee member

Date Approved: _____

ABSTRACT

At the Wellington Field, south-central Kansas, the Mississippian reservoir is a microporous cherty dolomite, and the deeper Cambrian-Ordovician Arbuckle Group is a thick succession of interbedded dolomudstones, pack-grainstones, vuggy brecciated zones, and thin dolomudstone and shale beds. The Mississippian chert reservoir and individual Arbuckle reservoir units are highly heterogeneous and typically below seismic resolution.

In this study I used 3D pre-stack depth migrated seismic data to map the main structural and stratigraphic features at the Mississippian and the Arbuckle reservoirs. A post-Mississippian normal fault that is striking NE-SW and dipping SE divides Wellington field diagonally into two parts. It cuts through the Mississippian and the Arbuckle Group down to the basement. The normal fault created accommodation space above the Mississippian chert reservoir in the southeastern part of the Wellington Field. The accommodation space allowed for depositing a layer that is thick enough to be resolved resulting in a localized double reflector in the seismic data.

Furthermore, I conducted a pre-stack seismic attribute analysis of the Mississippian chert reservoir and the Arbuckle Group to extend previous work done using post-stack seismic data. The good porosity zones in both the Mississippian and the Arbuckle Group exhibit Class IV AVO response. This AVO classification was employed to identify the porous zones in the Wellington Field 3D seismic volume using the AVO intercept-gradient crossplotting technique.

Simultaneous AVO inversion of pre-stack data showed better results than the model-based inversion of post-stack data for both the Mississippian reservoir and the Arbuckle Group. The inverted P-impedance by simultaneous AVO Inversion showed better correlation with the real P-impedance from well logs, and lower RMS inversion error. Also, Simultaneous AVO

Inversion resolved features that were not resolved by post-stack model-based inversion. Thickness resolution limit of simultaneous AVO inversion within the Mississippian chert reservoir was determined using wedge modeling as 10 m, which corresponds to 1/8 of a wavelength. In the Arbuckle, the low impedance zones in the inverted P-impedance volume show good contrast with the surrounding higher impedance zones, which makes it easy to define and trace the low impedance zones around the Wellington Field.

In addition to the P-impedance, simultaneous AVO Inversion provided estimates of S-impedance and density, unlike the post-stack model-based inversion that inverts for P-impedance only. Inverted S-impedance was of good quality, but inverted density had the lowest recovery quality because density recovery depends mainly on the far offset data amplitude that can be easily distorted by noises.

For porosity prediction at Wellington, multi-attribute linear regression analysis employed attributes from simultaneous AVO inversion results and attributes from post-stack seismic data to derive multi-attribute transforms that are used to predict porosity. A multi-attribute transform derived within the Mississippian chert reservoir only provided reliable porosity prediction within the Mississippian chert reservoir, but it did not provide meaningful porosity values outside the Mississippian reservoir. Another multi-attribute transform derived within a larger window, between the top of the Cherokee Group and the top of Reagan Sandstone, provided valid porosity values around the Mississippian chert reservoir that helped in determining the top and the base of the reservoirs. This multi-attribute transform also provided the best porosity prediction for the Arbuckle Group.

The estimated porosity volume shows thinner Mississippian reservoir in the northwestern part of the Wellington Field, which is consistent with the well logs that show thinner

Mississippian reservoir overlain by reworked Mississippian chert indicating longer subaerial exposure. This observation suggests that the post-Mississippian normal fault lowered the southeastern part of the Wellington field area that remained underwater, which helped in the preservation of thicker Mississippian reservoir, while the northwestern part of the Wellington Field which represents the foot wall of the post-Mississippian normal fault was exposed resulting in the thinning of the Mississippian reservoir by erosion, and the deposition of thicker reworked Mississippian chert.

Based on inverted impedance and estimated porosity, the Arbuckle Group has five main low impedance zones that show high porosity values in the porosity prediction volume. These zones extend laterally across the Wellington field, and they are separated vertically by high impedance and low porosity zones. The five porous low impedance zones are almost parallel to each other and have the same geometry trend. They are generally higher in the western and northwestern parts of the Wellington field, and they are deeper in the eastern and southeastern parts of the Wellington field. The depth change of the five zones in the Wellington field is attributed to the post-Mississippian normal fault.

ACKNOWLEDGMENTS

I would like to express my gratitude to all the people who have been around me during my MS program at the University of Kansas. I would like to thank Saudi Aramco Oil Company for sponsoring my MS program at the University of Kansas.

I truly enjoyed working with my academic adviser Dr. George Tsoflias who has taught me how to conduct an independent research under minor supervision, properly manage my time, and maintain high standards of professional ethics. I am thankful to my MS thesis committee, Dr. Ross Black and Dr. Lynn Watney, for their interest in my research project, fruitful discussions and helpful comments. Also, I thank Mina FazelAlavi for all the supportive efforts and informative discussions.

Last but not least, I am grateful to my wonderful wife Wejdan Hameda who has been very supportive and patient, my parents, Khalid and Fatma, older sister Dalia and younger sisters Dareen and Duaa.

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CHAPTER 1: INTRODUCTION

Mississippian chert reservoirs, such as reservoirs at the Wellington Field in south-central Kansas, are highly heterogeneous, and unit thicknesses are typically below seismic resolution. In the Wellington Field, the Mississippian reservoir is microporous cherty dolomite reservoir that exhibits downward gradational porosity decrease resulting in a corresponding increase in velocity. The deeper Cambrian-Ordovician Arbuckle Group, however, is a thick succession of interbedded dolomudstones, pack-grainstones, vuggy brecciated zones, and thin dolomudstone and shale beds (Watney et al., 2013). The Arbuckle aquifers are highly heterogeneous and compartmentalized with individual reservoir units below seismic resolution. Therefore, it is challenging to identify reservoirs or predict their properties from the seismic data.

Post-stack seismic attribute analysis was employed at the Mississippian chert reservoir at the Wellington Field using well data and 3D pre-stack time migrated (PSTM) seismic data. Different analysis techniques were tested for the Mississippian reservoir characterization by Sirazhiev (2012). Post-stack seismic signal amplitude and frequency relationships with reservoir thickness were investigated. Raw seismic amplitude and amplitude envelope attributes taken at the peak of the Mississippian reflection could be used to predict the thickness of the reservoir in the southeastern part of the Wellington Field. However, the Mississippian cherty dolomite reservoir thins with high variability of porosity distribution to the North and Northwestern part of the Wellington Field. Also, the Mississippian reservoir in the northwestern region of the Wellington Field seismic survey shows higher amplitude and frequency content than the southeastern region. Neither amplitude nor frequency of the post-stack seismic data could be used for predicting the reservoir thickness in this part of the field. Synthetic seismic wedge modeling showed that seismic amplitude attributes provide reliable prediction of reservoir

thickness within the range of 5-25 m, underestimating thicknesses more than 25 m and not resolving thicknesses below 5 m. The resolvable thickness range 5-25 m corresponds to 1/16λ-5/16λ.

Also, model-based inversion of the post-stack seismic data was performed to estimate the resolving power of post-stack model-based inversion at the Mississippian reservoir. Post-stack model-based inversion results in P-impedance volume only. The inverted P-impedance showed good correlation within the Mississippian reservoir with original P-impedance from the well logs. The inverted P-impedance volume was incorporated in the multi-attribute linear regression analysis described by Hampson et al. (2001) for porosity prediction. The resulting porosity model provided reliable porosity prediction within the Mississippian reservoir, but it was difficult at some places to delineate the top and base of the reservoir.

In this study I conduct pre-stack seismic attribute analysis of the Mississippian reservoir and the Arbuckle Group at the Wellington Field, south-central Kansas, using 3D pre-stack migrated seismic gathers. I examine pre-stack seismic attributes on both real and synthetic seismic data in order to find additional attributes that can help in identifying the porous reservoir zones, and to find out if using pre-stack seismic data for inversion and porosity prediction can improve the reservoir characterization.

This study investigates the AVO class response of the Mississippian reservoir and the porous zones of Arbuckle Group. I examine if the AVO classification can be used for identifying the porous zones around the Wellington Field in both the Mississippian and the Arbuckle. Also, I perform the simultaneous AVO inversion of the pre-stack migrated gathers that inverts for the P-impedance (Z_P), S-wave impedance (Z_S) and density (ρ) simultaneously, unlike the post-stack model-based inversion of post-stack seismic data that inverts for P-impedance only. The

resolving power of the resulting inversion volumes is evaluated by correlating the inversion results with real well log real data. Also, I compare the pre-stack simultaneous AVO inversion results and the post-stack model-based inversion results.

For porosity prediction, I incorporate inverted Z_P and Z_S by pre-stack simultaneous AVO inversion, formation porosity well logs and post-stack seismic data in the multi-attribute linear-regression analysis to derive multi-attribute transforms that are used to predict porosity values in the seismic survey volume of the Wellington Field. The reliability of porosity prediction is tested by blind wells that are excluded from the analysis. Also, the porosity prediction is evaluated by correlating predicted porosity traces with formation porosity well logs.

CHAPTER 2: FIELD SITE AND GEOLOGICAL SETTING

2.1: Field Site

The Wellington Field is part of the mature Midcontinent US petroleum province. It is located in Sumner County, south-central KS (Figure 2.1). The field was discovered in 1929. The field area is about 22.6 km^2. More than 250 wells were drilled in the Wellington Field. As of July 2014, the cumulative oil production from the Mississippian chert exceeded 20.7 million barrels of oil. The Wellington Field is experiencing a decrease in secondary production currently with 47 producing wells and 15 water injection wells (KGS, 2014).

2.2: Geological Setting

The local geology of the Wellington Field is composed of interbedded clastics and carbonates with distinct acoustic impedance changes that are favorable for subsurface imaging using seismic reflection. Good agreement is observed between synthetic and field seismic data as shown in Figure 2.2.

The Cambrian-Ordovician Arbuckle Group in Kansas is composed of shallow-shelf dolomite with scattered beds that contain chert and sand. These rocks were deposited by cyclic shallow seas. During this time, thick beds of calcium carbonate sediments were deposited in a shallow marine environment. During regressions, these rocks came into contact with meteoric water resulting in lithification and localized dissolution and extensive dolomitization (Jorgensen, 1989). The Arbuckle Group thickens from north to south in Kansas (Figure 2.3). The Wellington Field is located to the south in the Sedgwick Basin where the Arbuckle is thick, and off of the Kansas uplifts where Arbuckle is usually thin or eroded (Franseen et al., 2000). Favorable reservoir qualities such as fractures and faults are related to deep-seated basement structural elements and are enhanced by localized and stratigraphically specific karstification. The

Arbuckle has complex vertical and lateral heterogeneities including nonporous and porous horizons such as mud-dominated and grain-supported strata containing variable amount of connected and non connected interparticle porosity. Productive zones are controlled by different factors such as depositional facies, dolomitization, silicification, or intra-formational exposure events (Franseen et al., 2003). At the Wellington Field, the Arbuckle overlies thin Reagan Sandstones or basement, and the Arbuckle is overlain by the Simpson shales. The Chattanooga Shale, which is locally absent, was eroded over the portion of the Wellington Field. The Simpson Group is bound by two major unconformities (Watney et al., 2013).

The Mississippian carbonate shelf extended over a large area of the central and southwestern United States (Figure 2.4; Montgomery et al., 1998). During the Osagean, the outer shelf and shelf margin covered southern Kansas. Transgressive- regressive cycles resulted in the deposition of silica and carbonate-rich sediments including the sponge-rich shelf margin deposits along the shelf margin at the location of the Wellington Field (Watney et al., 2001; Franseen, 2006). Locally, biohermal buildups of mud-dominated limestone also developed on the shelf margin with oval or irregular shapes reaching thicknesses up to 48 meters. These bioherms exemplified the topographic relief that existed along the shelf margin/ramp (Montgomery et al., 1998). Carbonate strata with varying abundance of spiculite typify the Mississippian strata at the Wellington Field with accumulations forming low relief dolomitized bioherms. The progradation of these strata along the shelf margin filled in around the larger mud-dominated bioherms and advanced the shelf margin basinward, southward into Oklahoma. Subaerial exposure and meteoric water led to dissolution of spiculites and carbonate skeletal debris and their silicification and often, net porosity formation (Watney et al., 2001). The Mississippian reservoir at the Wellington Field is composed of microporous intercrystalline and vuggy cherty dolomites

with less chert, more dolomitic content and less vuggy pore space compared to the tripolitic chert reservoirs of the surrounding fields. Localized topography associated with buildups and facies change to more interparticle porosity resulted in focused early diagenesis that decreased downward with depth from a surface of subaerial exposure (Montgomery et al., 1998; Watney et al., 2001). Overlying the chert reservoirs are chert conglomerates with thicknesses up to 3 meters. These chert conglomerates have less porosity and permeability values due to dominance of impermeable siliciclastic clay rich that comprise these strata (Montgomery et al., 1998; Watney et al., 2001). The Mississippian is overlain by the Lower Pennsylvanian shales of the Cherokee Group, which provide the seal of the Mississippian reservoir in the Wellington Field (Figure 2.2).

2.3: Reservoir Architecture at the Wellington Field

2.3.1: Mississippian

Based on core analysis at well #15-191-22591 at the Wellington Field, the Mississippian strata consist of a succession of parasequences that are shallowing upward changing from dark shales and shaly carbonates to porous pale yellowish brown cherts and cherty dolomites that are less argillaceous. The reservoir at the Wellington Field has microporous and vuggy cherty dolomites. Comparing to the tripolitic chert reservoirs at the surrounding fields, however, the Mississippian reservoir has less cherty, more dolomitic content, and less vuggy pore space. The upper part of the reservoir is affected by brecciation and karstification due to Pennsylvanian weathering along the Pennsylvanian unconformity (Watney et al., 2013).The lower Pennsylvanian Cherokee Group thick shale provides a cap rock over the Mississippian (Figure 2.2).

According to well logs, the reservoir has a characteristic architecture (Figure 2.5). The Mississippian chert at the Wellington Field is characterized by downward gradational porosity from high porosity values (25%) at the top of the reservoir down to 4-6% at the base of the reservoir. The gradational porosity reduction is caused by depositional shallowing upward and diagenetic alteration due to water infiltration that is limited in depth (Watney et al., 2013). The downward porosity decrease is accompanied by gradational density increase (from 2.31 to 2.67 g/cc) and gradational velocity increase (from 3800 to 5300 m/s) (Figure 2.5). This gradational velocity increase gives a ramp-transition velocity function.

2.3.2: Arbuckle

The lower Ordovician Arbuckle Group is a thick succession of interbedded dolomudstones, pack-grainstones, vuggy brecciated zones, and thin dolomudstone and shale beds (Watney et al., 2013). The Arbuckle was fully penetrated by the two wells #15-191-22591 and #15-191-2259. The Arbuckle Group is divided into 15 flow units based on Lorenz crossplotting, which is a common method in reservoir modeling (Figure 2.6) (Rahimpour-Bonab, et al., 2012; M. FazelAlavi, 2014, personal communication). Based on core analysis at well #15-191-22591, highly permeable vuggy brecciated intervals are frequently present. These intervals are prominent in the lower part of the Arbuckle in the Roubidoux and Gasconade (Figure 2.7) (Watney, et al., 2013). A brecciated zone between the tops of flow units FU14 and FU15 was chosen to be the CO_2 injection zone in the lower part of the Arbuckle at both wells #15-191-22591 and #15-191-22590. This zone is about 25 m thick showing low velocity and high porosity values between the tops of flow units FU14 and FU15 on the well logs in Figure 2.6. This injection zone was perforated at both wells, and a pulse test was conducted which showed communication within the zone between the two wells (Watney et al., 2013). Based on the

analysis of brines obtained by drill stem tests and swabbing perforations, the Arbuckle is composed of three hydrostratigraphic units. The middle hydrostratigraphic unit is dominated by low permeability and low porosity. Based on stable isotope data and brine chemistry, the lower Arbuckle highly permeable interval and the CO_2 injection zone are isolated from the top of the Arbuckle (Watney et al., 2013).

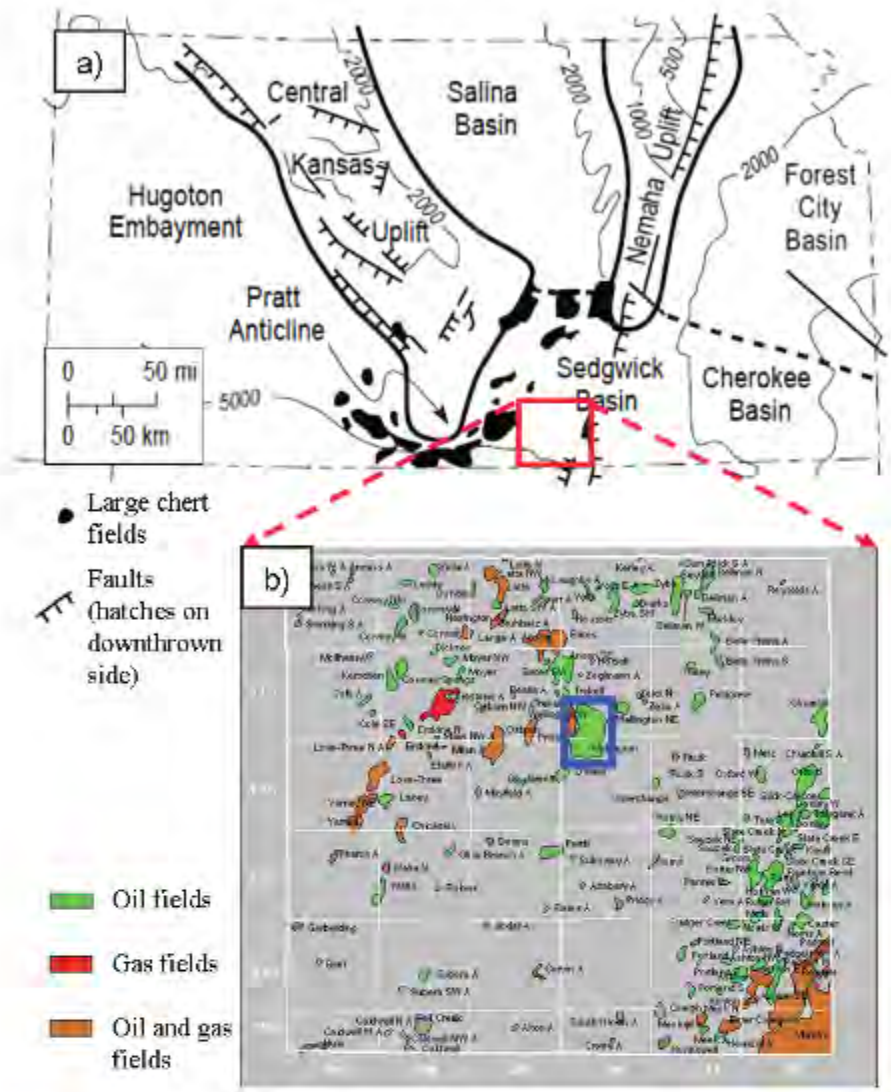


Figure 2.1. Wellington Field location: a) Location of Sumner County (red box) within the major tectonic elements during the late Mississippian-early Pennsylvanian time in Kansas. Modified from Montgomery et al. (1998); b) Oil and gas fields located within Sumner County. The Wellington Field is outlined with the blue box. From Sirazhiev (2012).

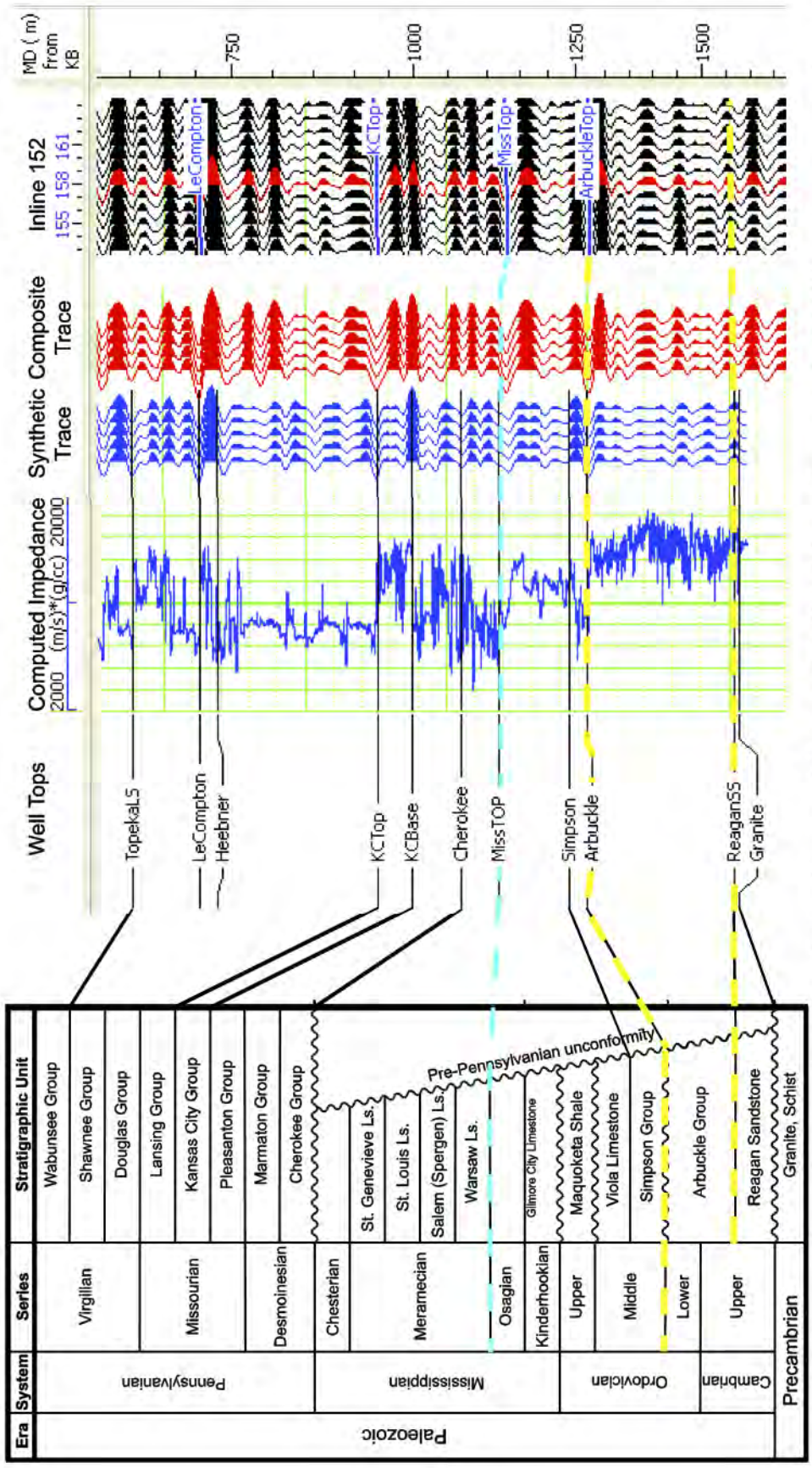


Figure 2.2. From left to right: stratigraphic column for central Kansas (Modified from Nissen et al. (2009)); well tops, impedance log, synthetic seismic traces (blue) and real seismic traces (red) at well #15-191-22591; part of inline #152. The Mississippian reservoir top is identified by the blue dashed line, and the thick Arbuckle Group is between the yellow dashed lines. Modified from From Sirazhiev (2012).

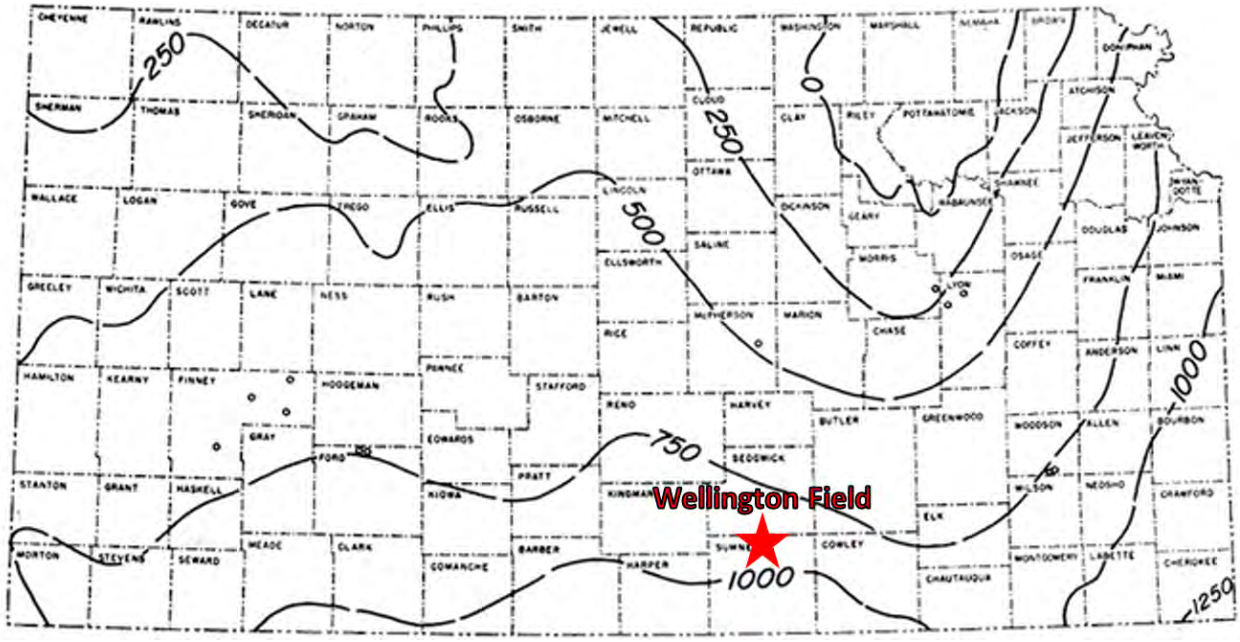


Figure 2.3. Kansas Arbuckle Group isopach map. Modified from Merriam (1963).

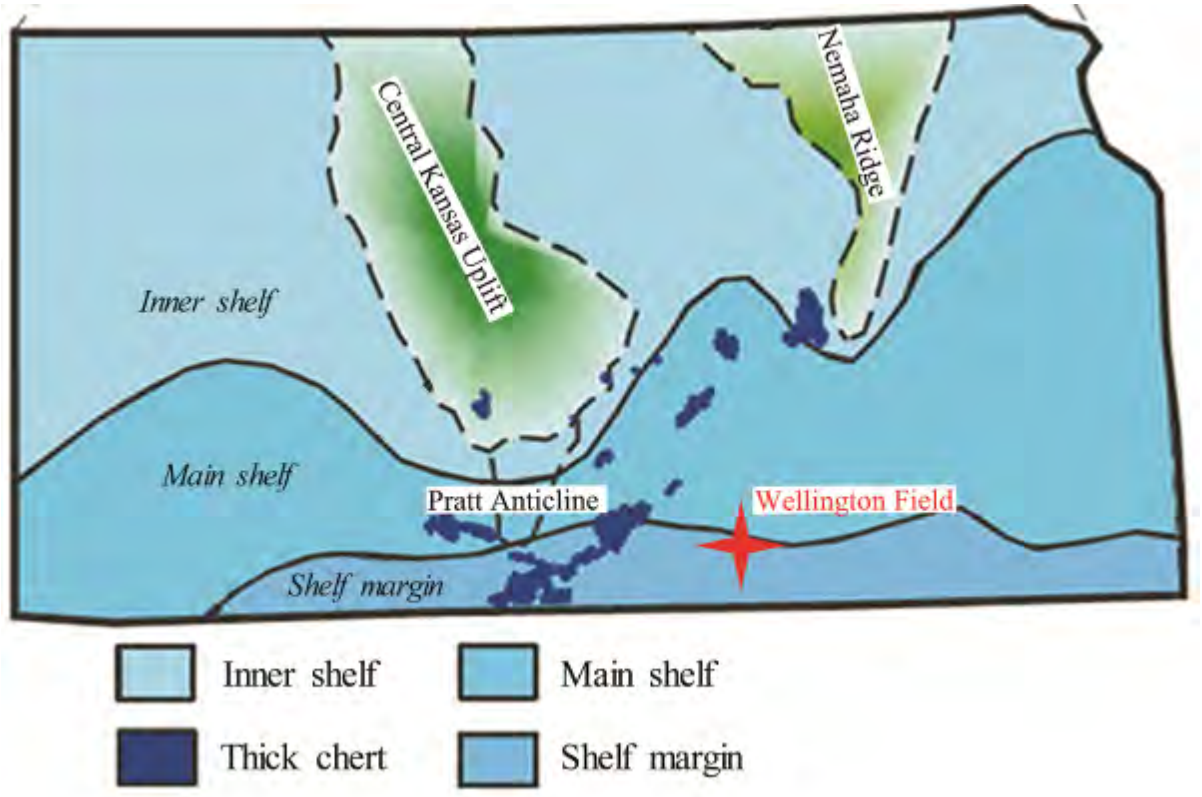


Figure 2.4. Paleogeographic and depositional conditions in Kansas during the Mississippian time. Red star shows the location of the Wellington Field. From Sirazhiev (2012), originally from Franseen (2006).

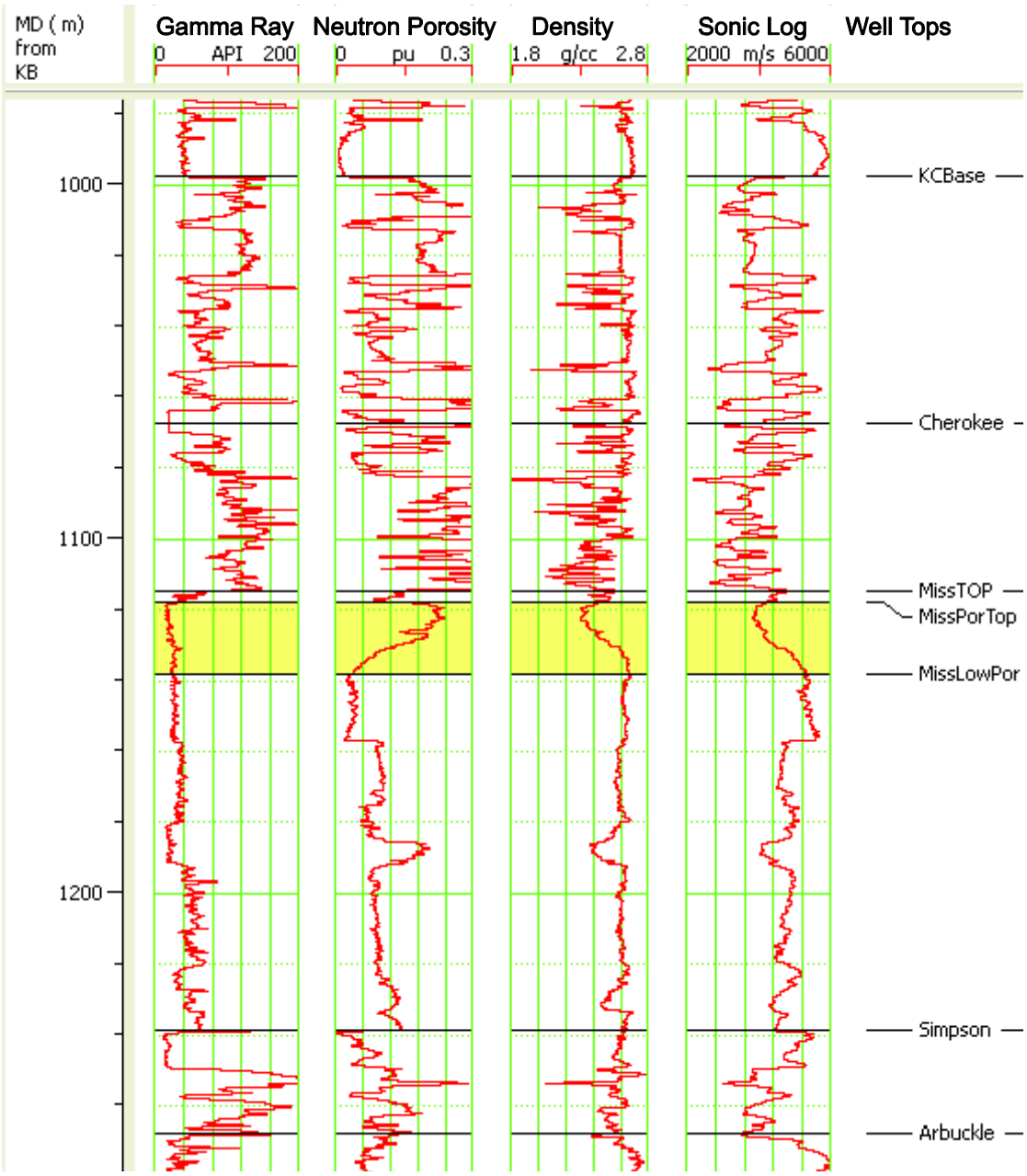


Figure 2.5. Characteristic architecture of the Mississippian chert reservoir at the Wellington Field according to the well logs at well #15-191-22591. Note the interval (highlighted in yellow) with downward porosity reduction (from 25 to 4%) and corresponding gradational velocity (from 3800 to 5300 m/s) and density (from 2.31 to 2.67 g/cc) increases. From Sirazhiev (2012).

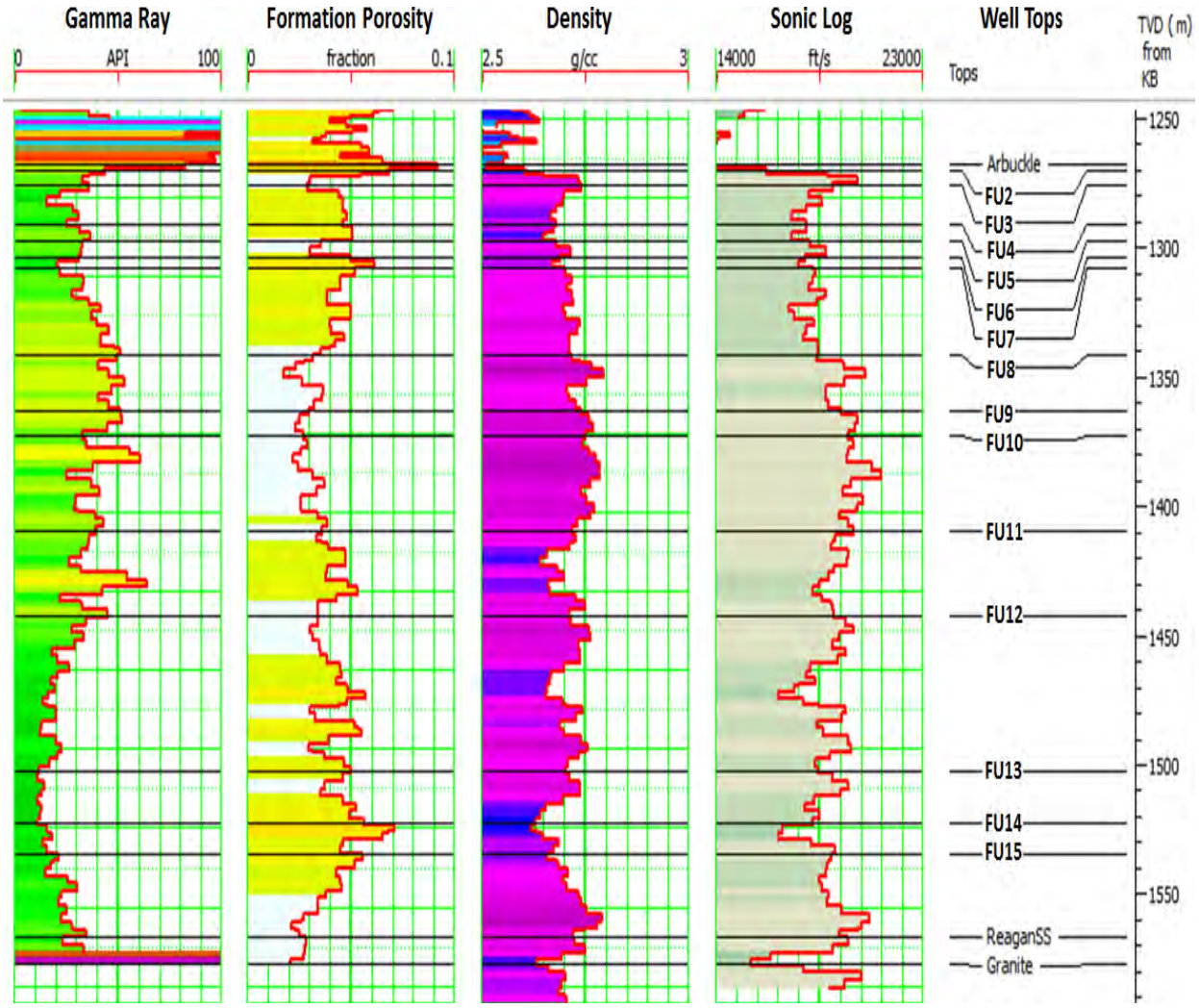


Figure 2.6. Well logs of well #15-121-22591 within the thick Arbuckle Group. The Arbuckle Group is divided into 15 flow units based on Lorenz crossplotting (M. FazelAlavi, 2014, personal communication).

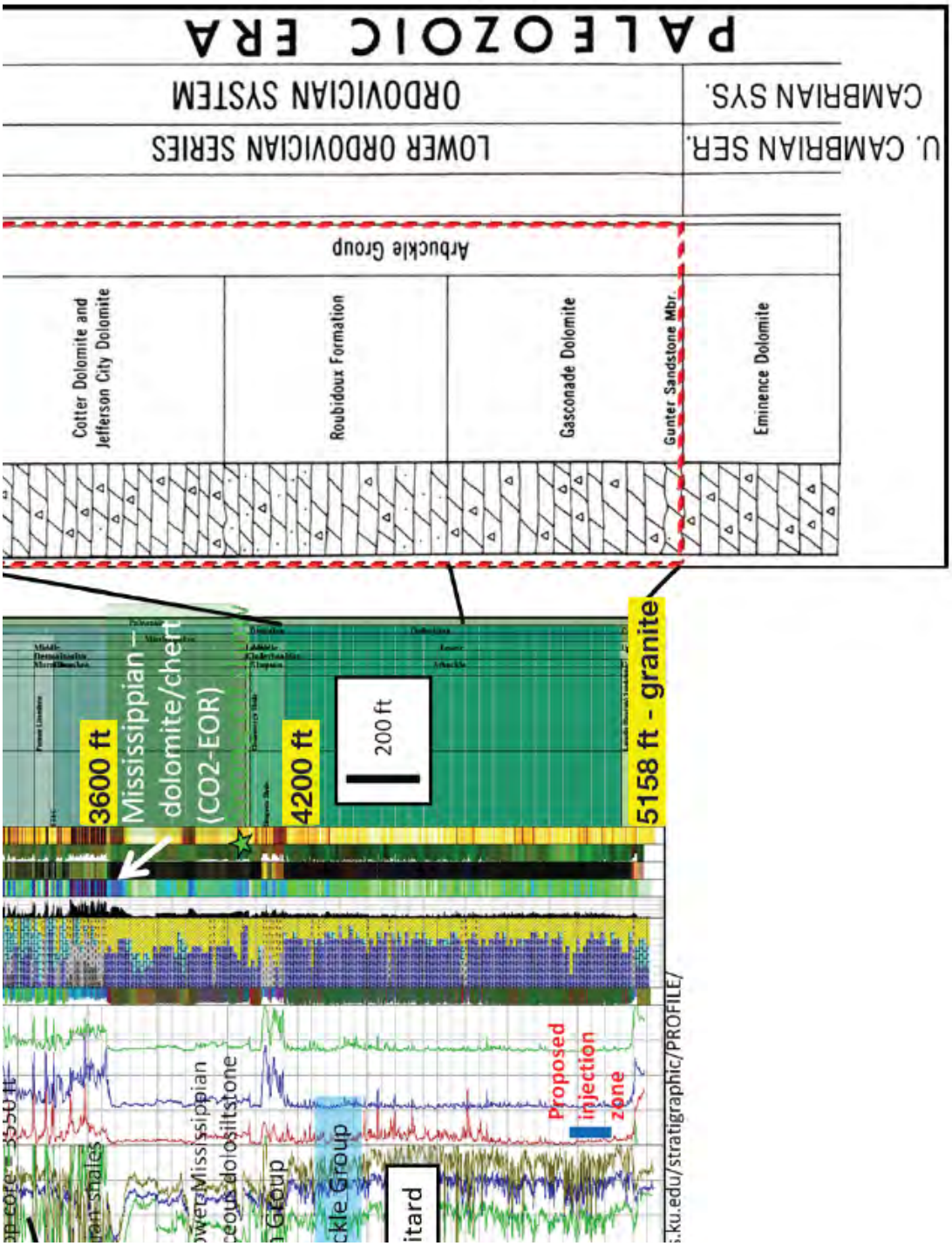


Figure 2.7. The cored interval of well #15-121-22591 with well log, computed lithology and stratigraphic correlations of the Arbuckle Group. From Watney et al. (2013).

CHAPTER 3: SEISMIC DATA INTERPRETATION

3.1: Seismic Data

For conducting pre-stack data analysis, 3D pre-stack time migrated offset gathers were used (Table 3.1). This data was acquired by Paragon Geophysical Services Inc. in 2010 at the Wellington Field. P-wave data processing was performed by FairfieldNodal in 2010-2011. The Wellington Field data was merged while processing with 3D seismic data from the adjacent Anson-Bates Field. The seismic data has a total number of 542 inlines and 251 crosslines. For this study, only the data covering the Wellington Field was utilized. This data set covers an area of about 28.5 km^2 (Figure 3.1). These seismic gathers needed further processing and data conditioning before performing the pre-stack data analysis and inversion. F-K filtering was applied to the gathers to remove low-frequency coherent linear noise that greatly affected amplitude variation with offset (Appendix A). After that, a Trim Statics correction was applied to the data to correct for residual move-out errors that affect the estimation of the gradient and any other related attributes (Appendix B). Then, AVO offset scaling was applied to correct for processing artifacts and amplitude distortion by the previous processing steps applied on the data, which affected the mean gradient trend of the real data (Appendix C). Figure 3.2a shows an offset gather at the location of well #15-121-20789 after processing. For AVO analysis and inversion, the data needed to be converted to angle gathers as shown in Figure 3.2b.

Seismic data	3D pre-stack time migrated gathers
Processing operations done	NMO Correction, Radon Filtering, Time Variable Filtering, Trace Equalization
BANDPASS FILTER	10-128 Hz
CDP Number of Traces	58 traces
Offset Range	from 139 m (456 ft) to 1523.5 m (4997 ft)
Trace Length	1200 ms
Number of inlines	542 (used range 1-289)
Number of crosslines	251 (used range 73-251)
Bin size	25.146 m (82.5 ft)
Polarity	SEG reversed

Table 3.1. Overview of the pre-stack migrated seismic gathers of the Wellington Field.

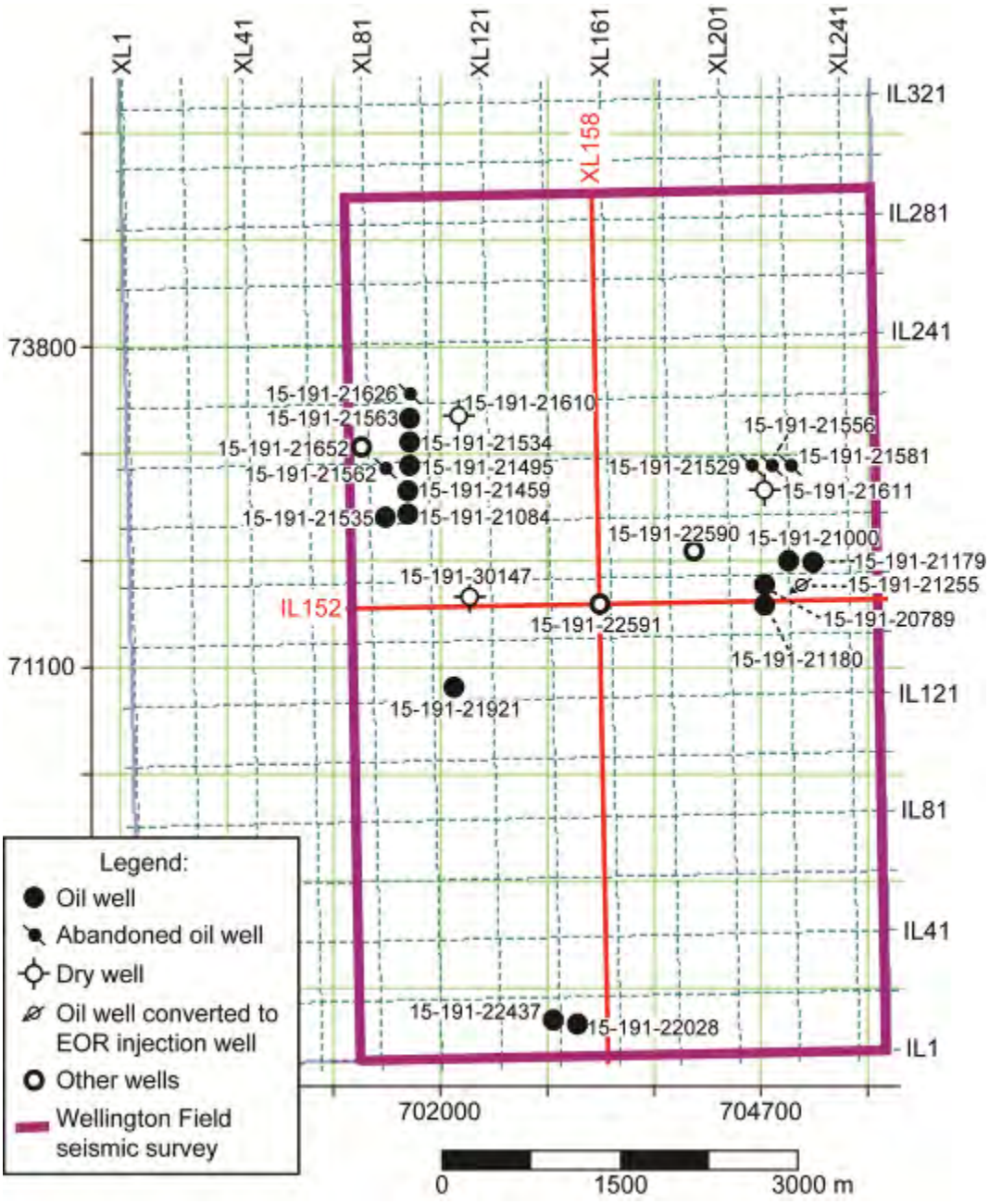
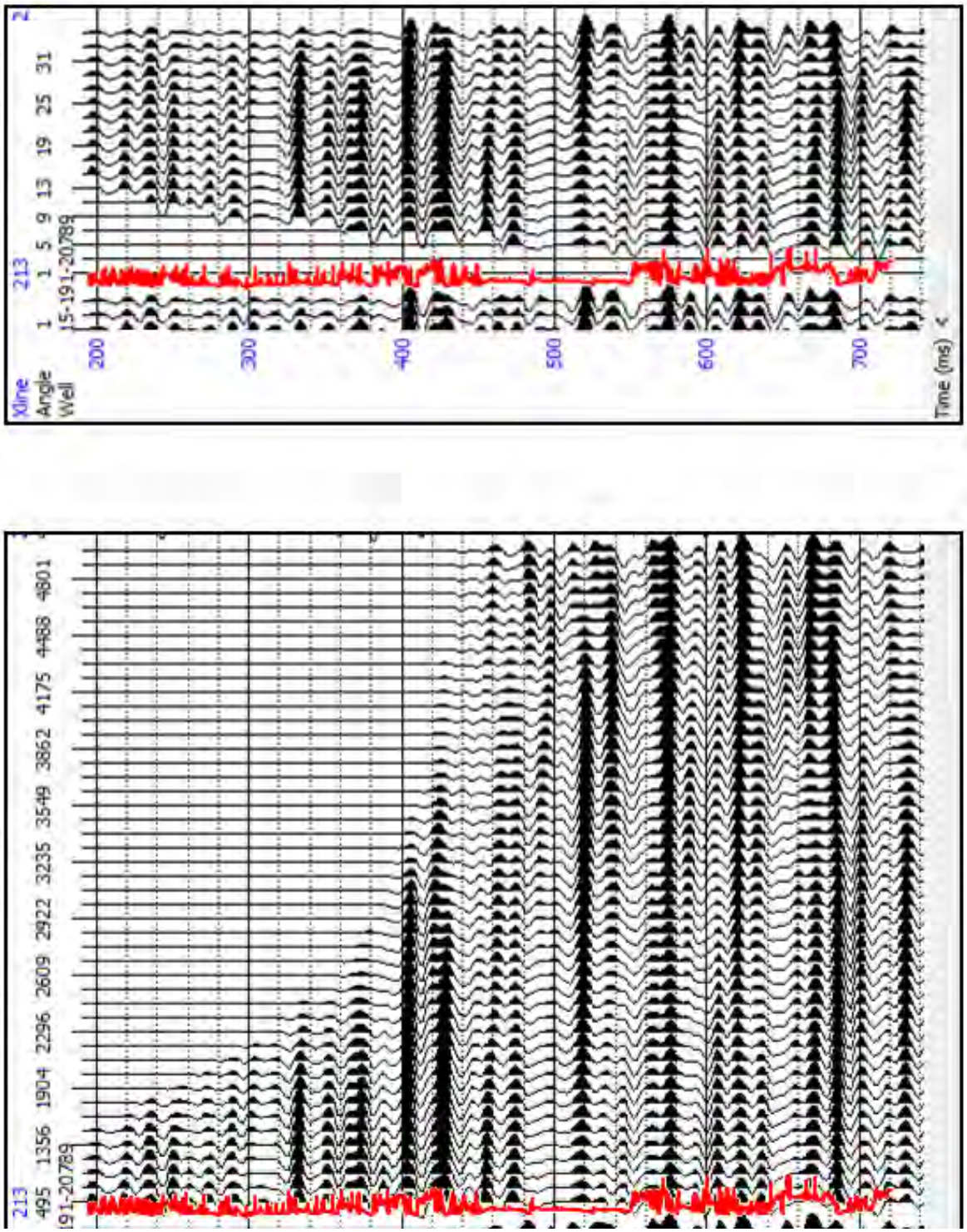


Figure 3.1. Basemap of the Wellington Field seismic survey used in this research with well locations. From Sirazhiev (2012).



(a) (b)

Figure 3.2. (a) Offset gather at well #15-191-20789. (b) Angle gather at well #15-191-20789.

3.2: Post-stack Seismic Interpretation

In addition to the pre-stack seismic gathers, post-stack time and depth-migrated versions of the same seismic data were used. The post-stack seismic data was used for interpreting time horizons that are needed for guiding the analysis of the AVO attributes; Intercept (A) and Gradient (B), and for building the initial models for the simultaneous AVO inversion of pre-stack data as described in sections 4.1 and 5.1. The depth converted seismic was used for structural interpretation because it corrects for seismic imaging distortion due to the lateral and vertical velocity variations.

Figure 3.3 shows the location of Wellington Field wells. The color coding shows the available well logs at each well. For interpreting the seismic horizons, the wells that have original sonic logs were tied to the seismic data. These wells are #15-121-22590, #15-121-22591, #15-121-20789 and #15-121-30147. These wells were tied to the pre-stack and post-stack seismic data to identify the corresponding time reflections of the different tops.

In Figure 3.3, the wells colored green and purple have formation porosity well logs which are needed for the multi-attribute linear regression analysis for porosity prediction as described later in section 6.1. These formation porosity logs need to be tied correctly to the seismic data for porosity prediction. Only wells #15-121-22590, #15-121-22591, #15-121-20789 have original P-wave sonic logs. The other wells have pseudo-sonic logs that were generated in the previous work on the Wellington Field done by Sirazhiev (2012) for establishing the time-depth relationship needed to tie the well logs to the seismic data. Eleven wells that have a good tie with seismic data were selected to be used in the multi-attribute linear regression analysis for porosity prediction. By using the original density logs, P-wave sonic logs and pseudo-sonic logs of these

wells, P-impedance logs were calculated for these eleven wells that will be used for evaluating the simultaneous AVO inversion results later in section 5.2.

A statistical wavelet was extracted from the window between 300 and 800 ms of the seismic data for two purposes (Figure 3.4). The first purpose is to tie the wells to the seismic data by generating a synthetic seismogram. The second purpose is to measure the resolution limit of the seismic data. The extracted wavelet shows a dominant frequency of 55 Hz and the average velocity calculated within the Mississippian reservoir at well #15-121-22591 is about 4450 m/s. From the wavelength equation ($\lambda = V_{average}/f$), the wavelength λ is 81 m. So, the seismic resolution limit ($\lambda/4$) is about 20 m.

Figure 3.5 is a two-way time post-stack PSTM seismic cross section of Line A whose location is shown on the Map in Figure 3.3. Most of the results will be demonstrated on Line A because it is a representative line of the Wellington Field that extends in an east-west direction. Also, Line A includes wells #15-121-22590 and #15-121-22591 that penetrated both the Mississippian and the Arbuckle. As shown in Figure 3.5, six horizons were interpreted on the post-stack seismic data. Five of these horizons are the tops of the Oread Limestone, the Kansas-City Group, the Mississippian System, the Arbuckle Group and the basement. The additional horizon (Horizon_1) was picked to illustrate the thinning of the Oread Limestone that is overlapped by shale. Horizon_1 is the top of this shale (Figure 3.5). These thickness changes cause time delay of the seismic reflections below the thicker part of the shale. The time delay causes the time difference between the Mississippian top at well #15-121-22590 and the Mississippian top at well #15-121-22591 (Figure 3.5).

At the location of well #15-121-22590, there is a double reflector at the top of the Mississippian (Figure 3.5). The reason of this double reflector is the presence of a low

impedance layer overlying the Mississippian reservoir that is thick enough to be resolved and cause a localized double reflector. Figure 3.6 is an isochron map of the double reflector. The thicker layer above the Mississippian reservoir at well #15-121-22590 is attributed to a normal fault that is dipping to the SE (Figure 3.7). Figure 3.7 is a depth migrated seismic section of Inline #169 that shows the normal fault. Showing the fault on Inline #169, which extends E-W, is better than showing the fault on the Arbitrary Line A because Line A is oblique to the fault strike (Figure 3.6). Also, it is better to interpret the fault using the depth-migrated seismic data because the fault position is distorted by the time delay caused by the thinning of the Oread Limestone that was onlapped by a large section of shale (Figure 3.5). The normal fault created more accommodation space for thicker sediments to be deposited which caused the localized double reflector. The fault extends along the NW boundary of the localized double reflector between the two wells #15-121-22590 and #15-121-22591 (Figure 3.6). The same normal fault extends down to the basement cutting through the deeper Arbuckle Group as shown in Figure 3.8 which is a depth migrated seismic cross section along Line B that extends NW-SE perpendicular to the fault strike. The fault is interpreted to be of post-Mississippian early Pennsylvanian age because it cuts through the Mississippian and the underlying layers down to the basement, and there is a filled basin structure on the hanging wall above the Mississippian reservoir overlain by the flat layers that are not cut by the fault.

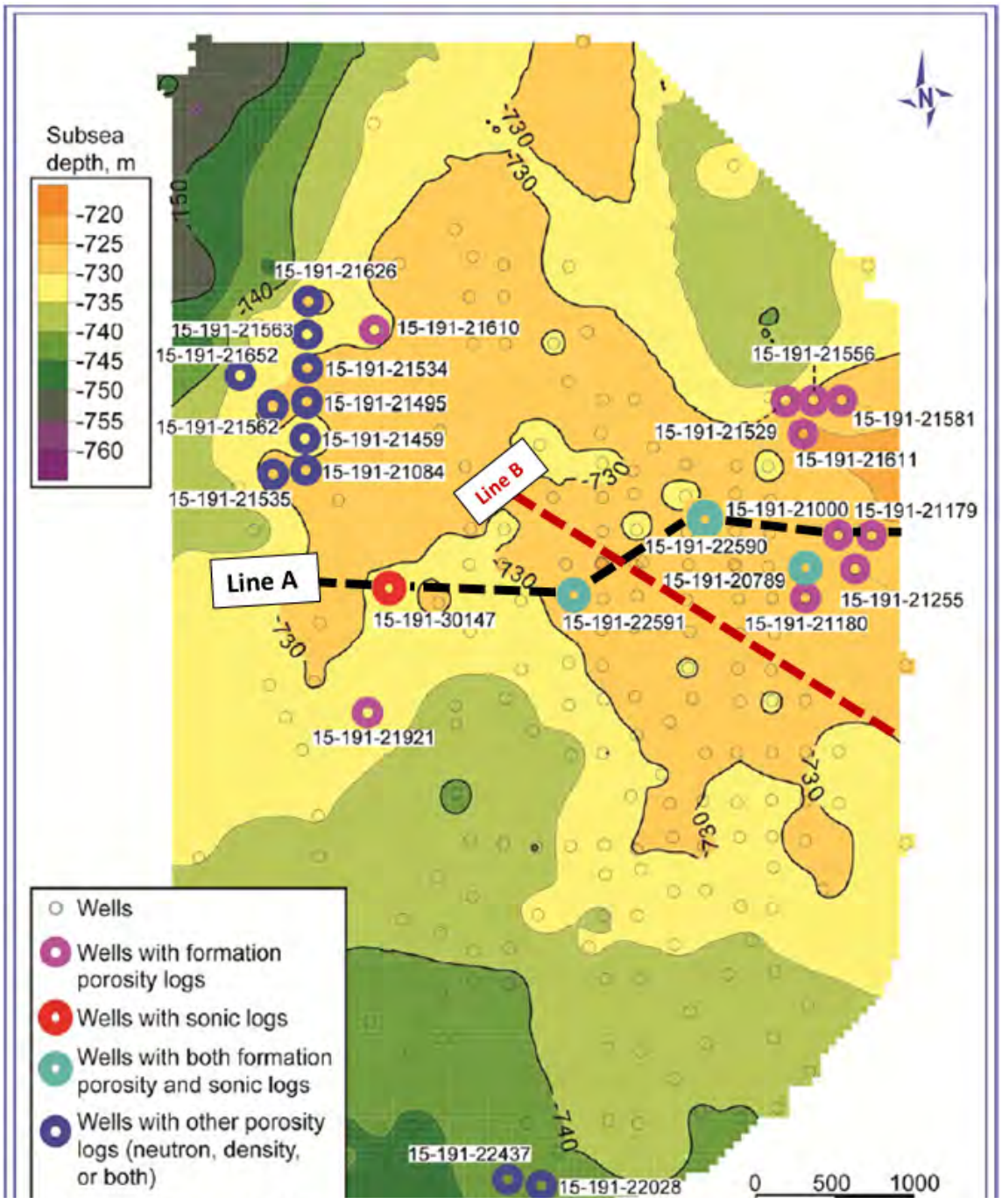


Figure 3.3. Mississippian depth map at the Wellington Field based on well data. Line A and Line B are locations of the cross sections on which seismic data, inversion results, and porosity prediction results are demonstrated. Modified from Sirazhiev (2012).

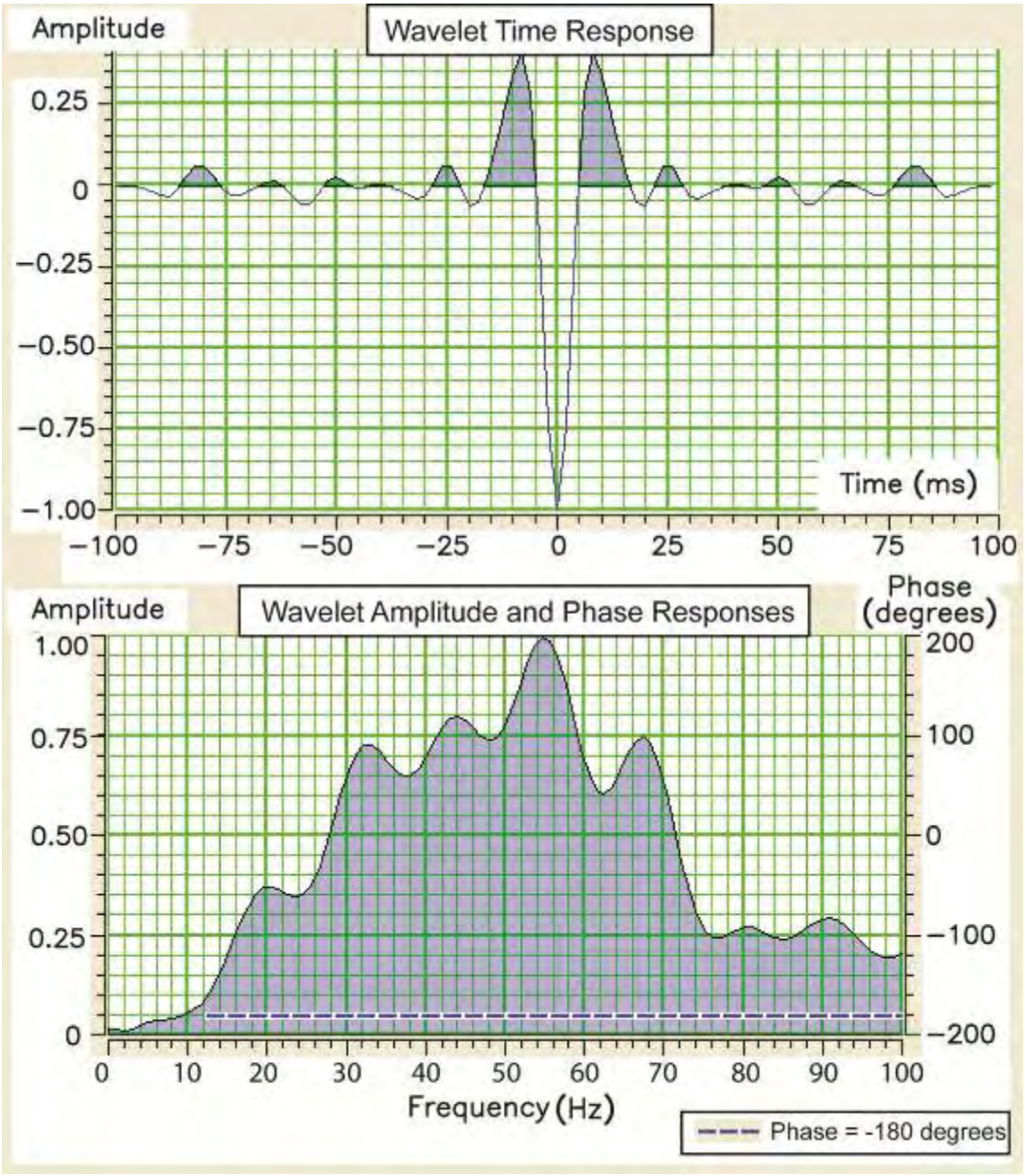


Figure 3.4. (Top) Null-phase statistical wavelet extracted from the seismic data in the time window 300-800 ms. (Bottom) Statistical wavelet amplitude and phase spectra. The wavelet has reverse polarity. From Sirazhiev (2012).

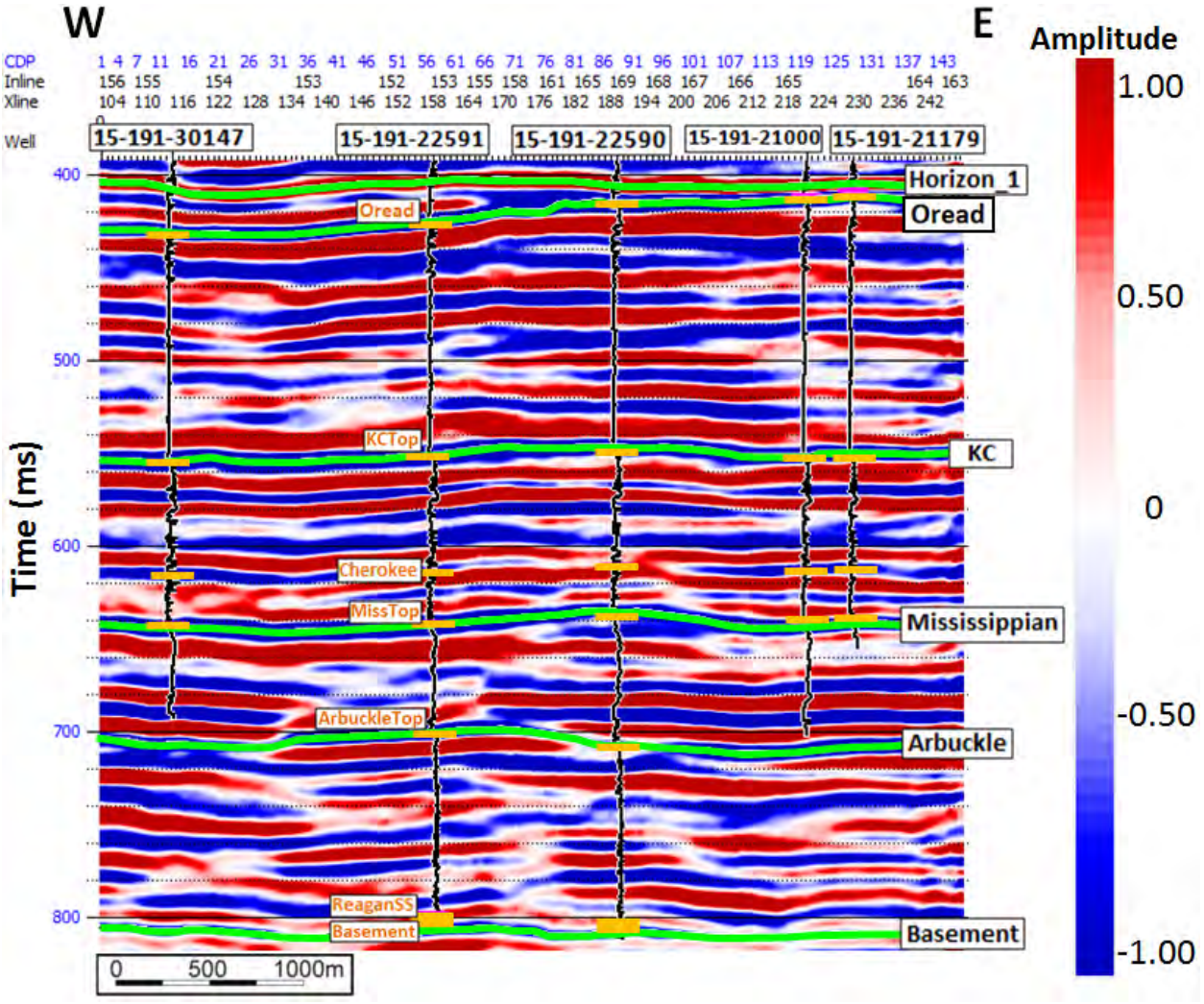


Figure 3.5. Time migrated seismic amplitude cross section. Cross section location is Line A shown in Figure 3.3.

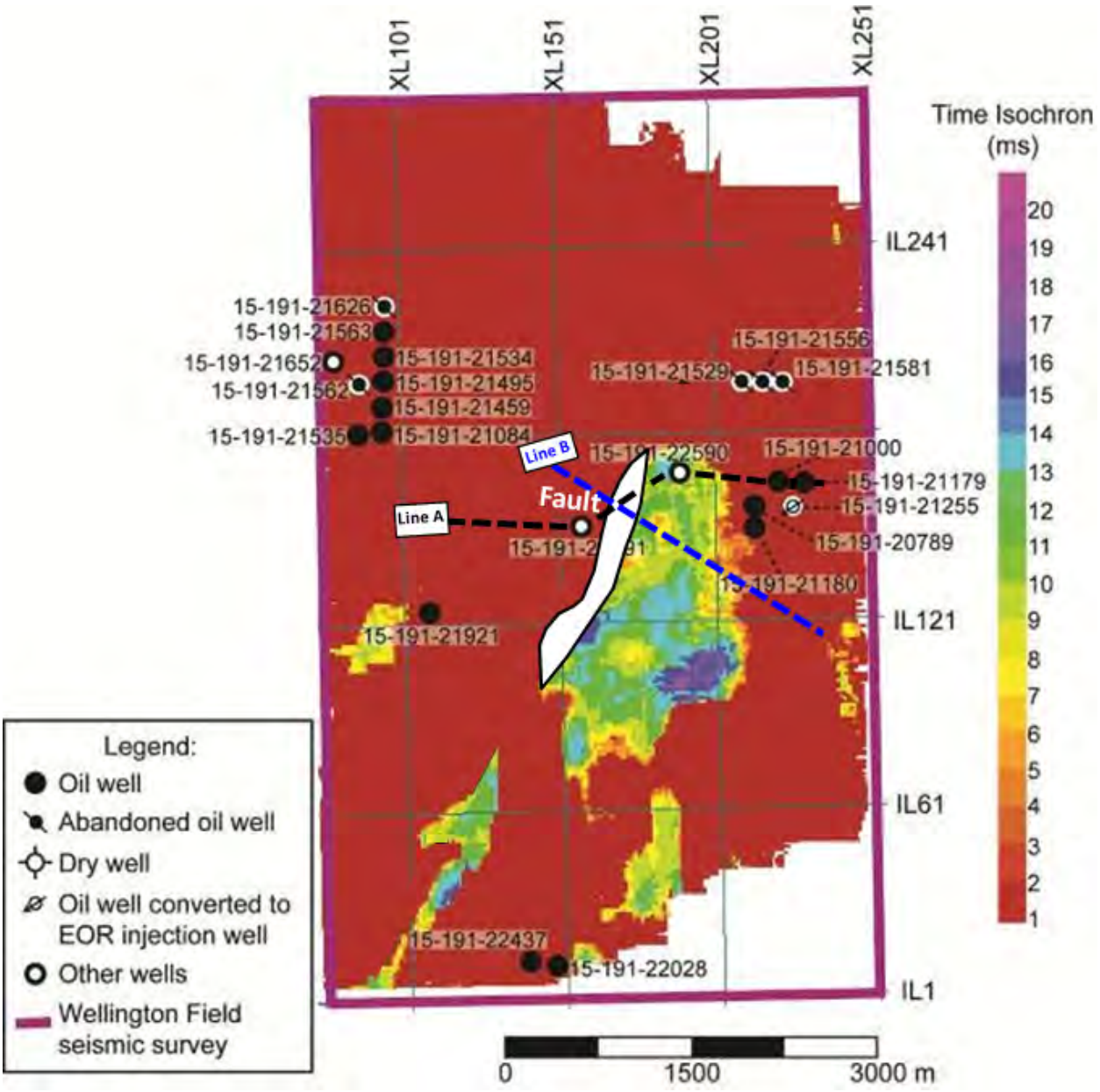


Figure 3.6. Double reflector isochron map bounded by post-Mississippian normal fault striking NE-SW and dipping SE. Modified from Sirazhiev (2012).

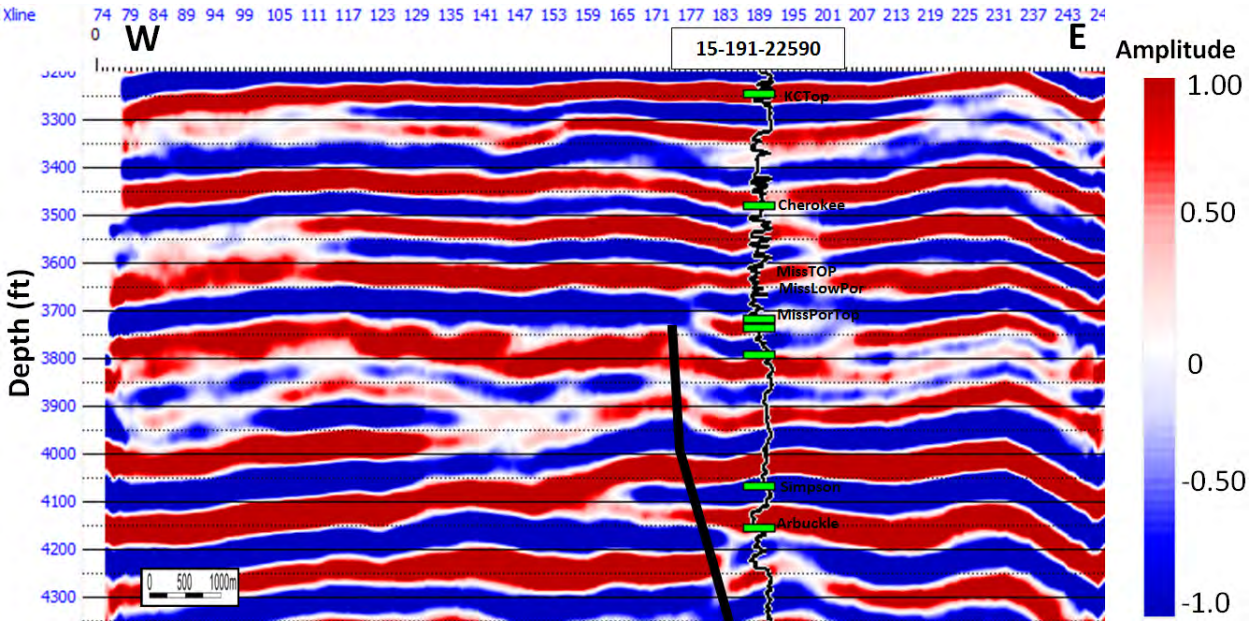


Figure 3.7. Depth migrated seismic section at inline #169 with post-Mississippian normal fault to the left of well #15-121-22590.

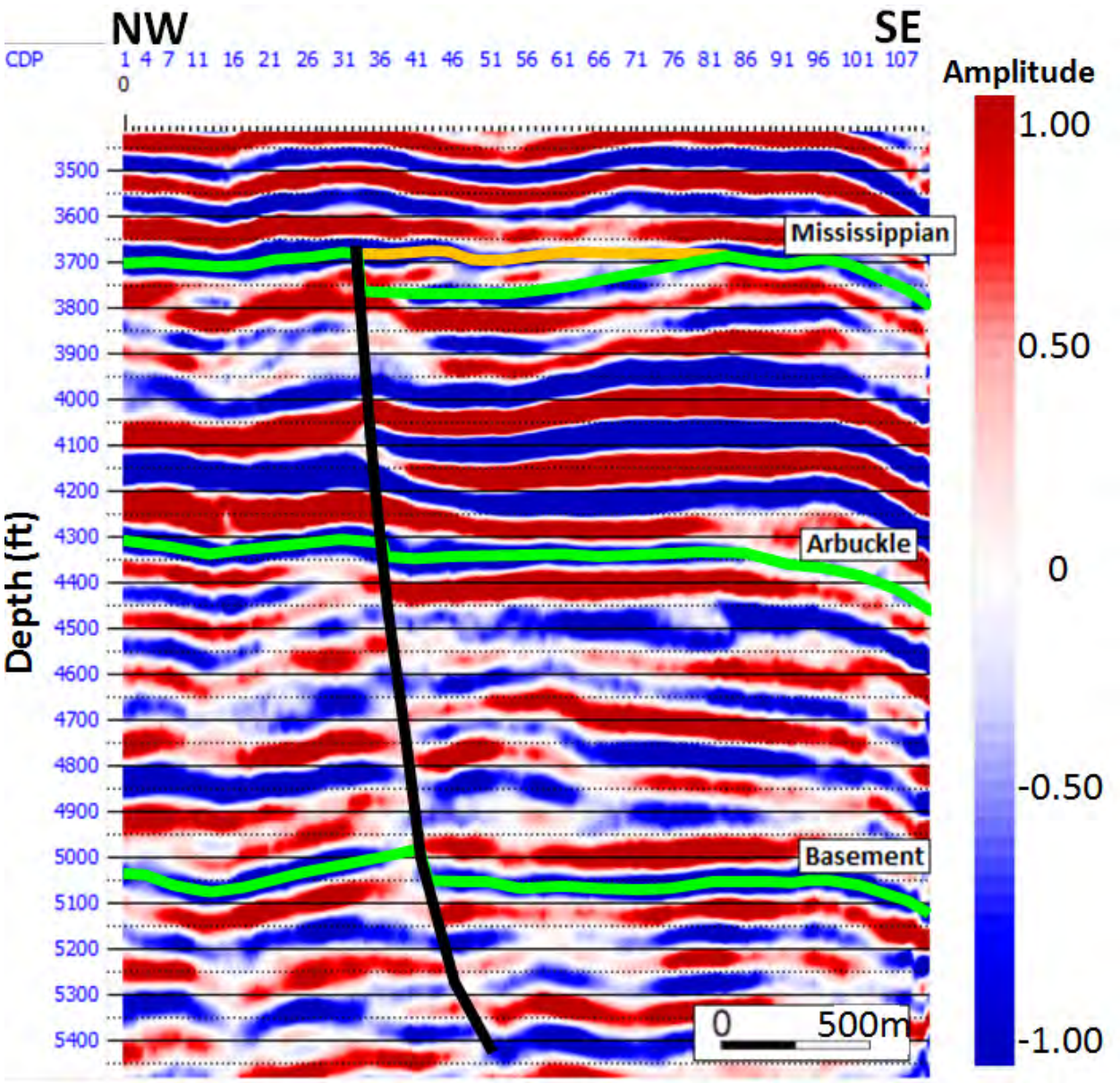


Figure 3.8. Depth migrated seismic section with post-Mississippian normal fault dipping to the SE. Cross section location is Line B shown in Figure 3.3.

CHAPTER 4: RESERVOIR AVO CLASSIFICATION

4.1: Mississippian Reservoir AVO Classification

The AVO attributes, intercept (A) and gradient (B), were analyzed at the Mississippian reservoir using the Hampson-Russell software. Figure 4.1 shows the angle gathers at the locations of wells #15-121-22591, #15-121-22590 and #15-121-20789. The Mississippian reservoir reflections picked at the three well locations are indicated by the red, the blue and the yellow lines, respectively. To the right of Figure 4.1 are the AVO crossplots of the reflection amplitudes with their trend lines. The trend lines show Class IV AVO response that is characterized by negative intercept (A) and positive gradient (B) (Figure 4.2; Avseth et al., 2005). The A-B crossplots of the Mississippian reservoir at 11 wells are plotted in the fourth quadrant in the typical location of Class IV AVO crossplots (Figures 4.2-4.3). Using the 3D volume of migrated seismic gathers, I created two AVO seismic attributes volumes for the whole Wellington Field area. These volumes are the Intercept (A) volume and the gradient (B) volume. Figure 4.4 is the intercept (A) cross section of Line A with P-wave sonic logs and green markers of the Mississippian reservoir posted at the well locations. The figure shows that the Mississippian reservoir at all of the well locations has negative intercept (A) values indicated by the negative blue event within the Mississippian reservoir. Figure 4.5 is the gradient (B) cross section of Line A. The figure shows that the Mississippian reservoir at the well locations has positive gradient (B) values indicated by the positive red event within the Mississippian reservoir. The intercept (A) and gradient (B) of Line A were crossplotted within a 60 ms window around the Mississippian horizon (Figure 4.6). Then, the plots falling within in the Class IV zone were highlighted by the red polygon (Figure 4.6). The seismic data on Line A corresponding to these Class IV points are shown in red on the seismic cross section in Figure 4.7. The crossplot

polygon highlighted the Class IV AVO zones between the markers of the top and base of the Mississippian reservoir at all of the well locations. All of the wells in Figure 4.7 have good porosity values within the Mississippian reservoir including well #15-121-30147 that has high calculated porosity of 24% at the top of the reservoir even though it was reported as a dry well possible due to poor localized porosity connectivity. This well was sidetracked later and produced oil from the Mississippian reservoir. The same observation holds for the two wells #15-121-21611 and #15-121-21610 that have porosity values of 25% and 20% respectively at the top of the Mississippian reservoir but the wells were reported as dry wells. Therefore, the Mississippian reservoir at these two wells showed a Class IV AVO response that was highlighted by the crossplotting technique.

The A-B crossplotting technique at the Mississippian reservoir consistently identifies a Class IV AVO response that highlights reservoirs with good porosity, even those that are not necessarily productive due to potentially localized porosity connectivity.

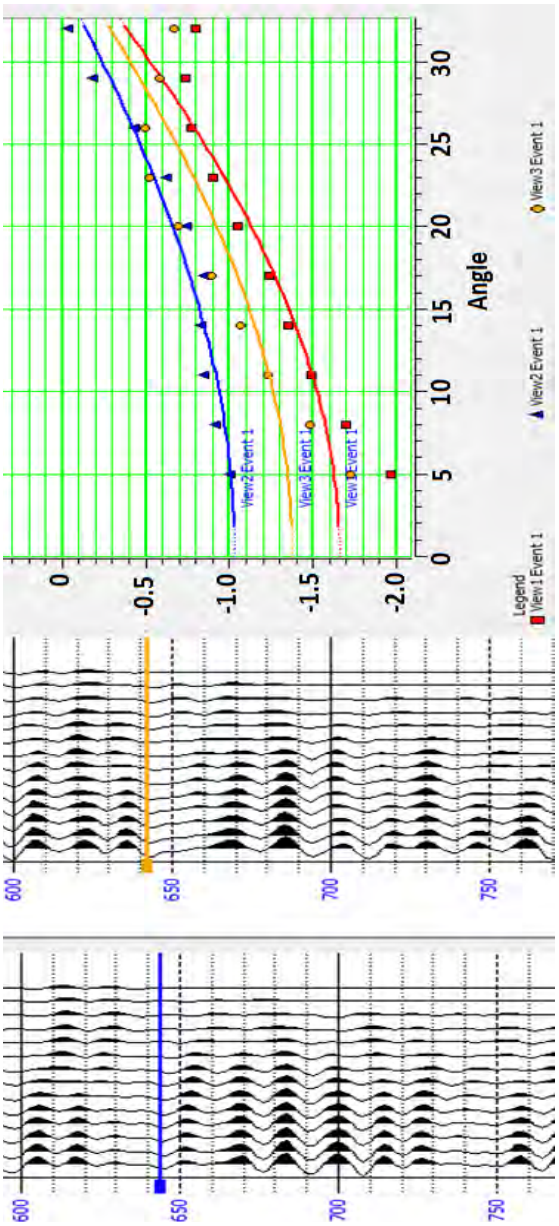


Figure 4.1. (Left) Seismic angle gathers at wells #15-121-22591, #15-121-22590 and #15-121-20789 with picked Mississippian reservoir events. (Right) AVO crossplots of the picked seismic traces with their trend lines that show Class IV AVO response.

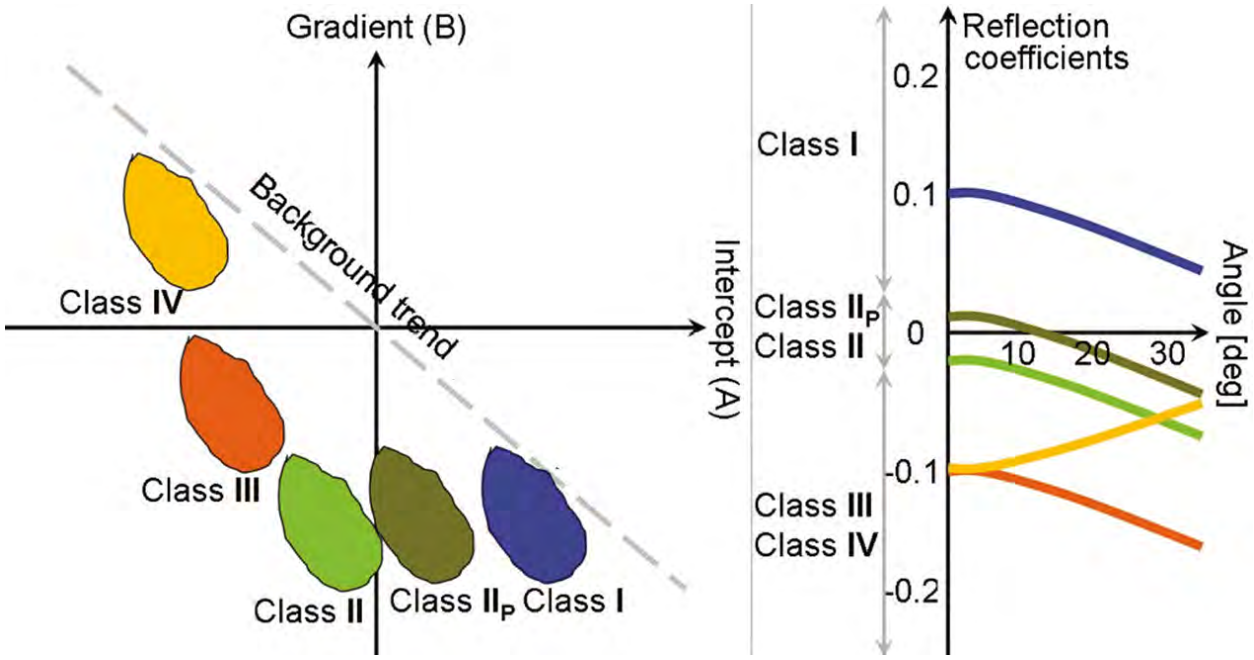


Figure 4.2. AVO classes. Modified from Avseth et al., (2005).

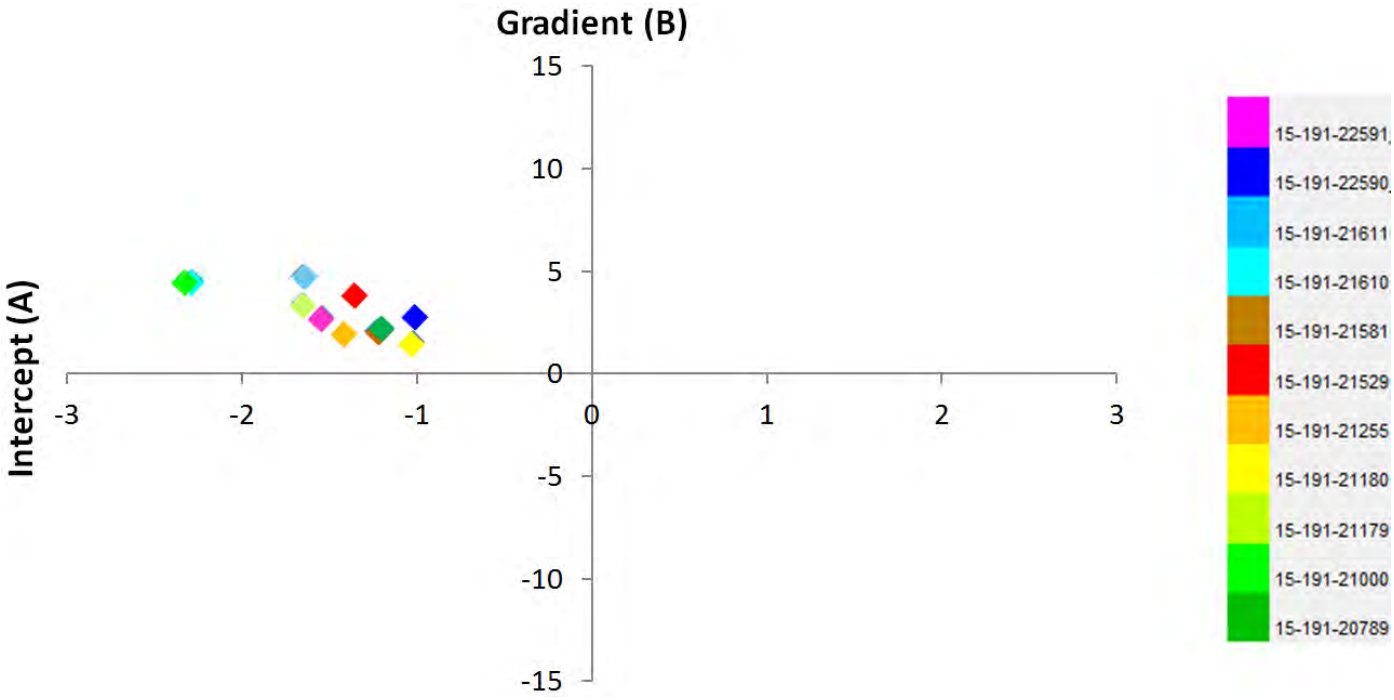


Figure 4.3. Mississippian chert reservoir A-B crossplots at 11 wells are plotted in the fourth quadrant in the typical location of Class IV AVO crossplots.

Figure 4.4. Intercept (A) cross section with P-wave sonic logs posted at the well locations. The Mississippian reservoir at all of the well locations has negative intercept (A) values indicated by the negative blue event within the Mississippian reservoir. The cross section color scale is limited manually between -1 and +1 to emphasize the sign of the Intercept (A) values. The range of the Intercept (A) values extends beyond the color scale range of this cross section. Cross section location is Line A shown in Figure 3.3.

Figure 4.5. Gradient (B) cross section with P-wave sonic logs posted at the well locations. The Mississippian reservoir at all of the well locations has positive intercept (B) values indicated by the positive red event within the Mississippian reservoir. The cross section color scale is limited manually between -1 and +1 to emphasize the sign of the Gradient (B) values. The range of the Gradient (B) values extends beyond the color scale range of this cross section. Cross section location is Line A shown in Figure 3.3.

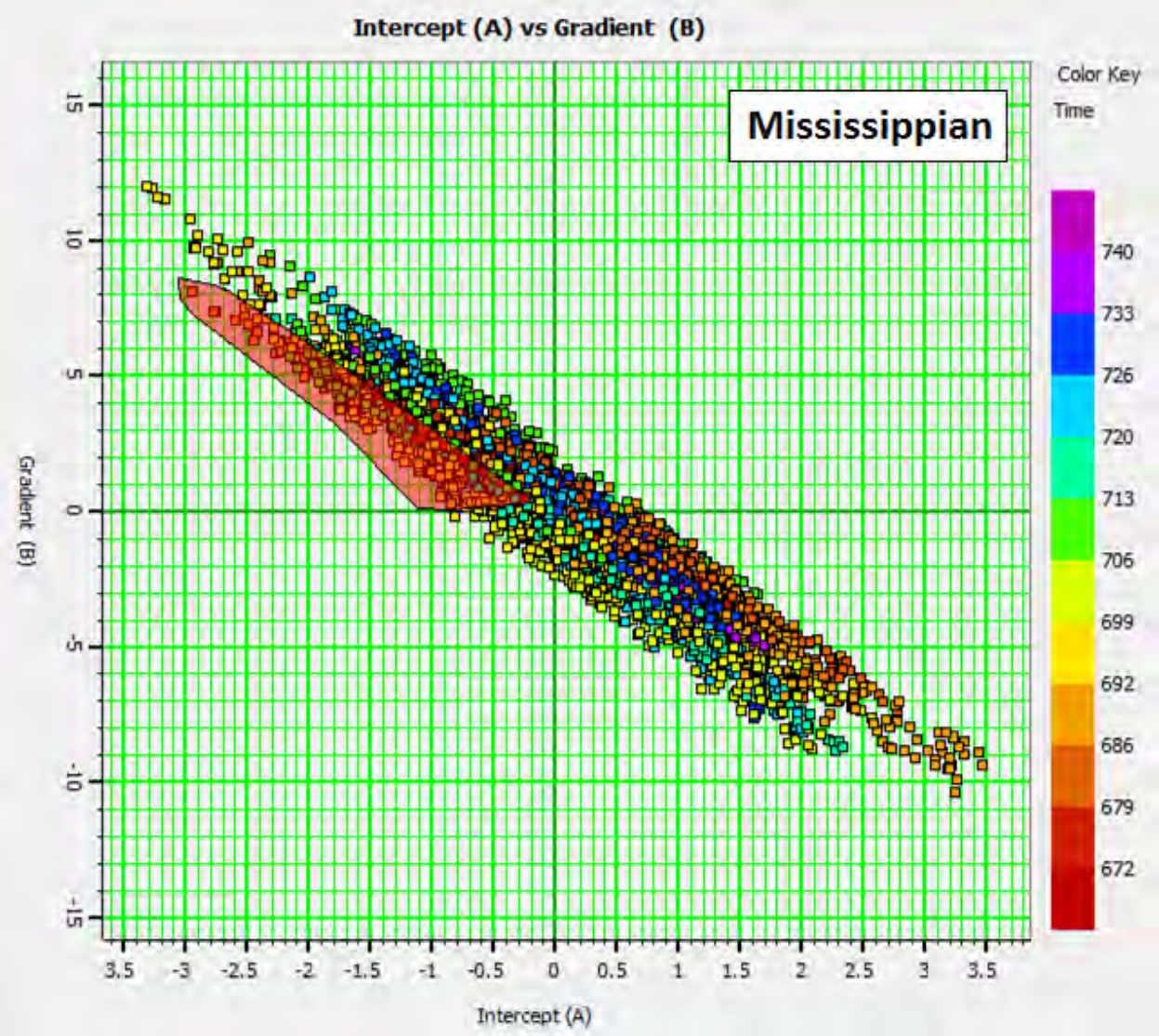


Figure 4.6. A-B crossplots within a 60 ms window around the Mississippian horizon. The red polygon highlights Class IV AVO crossplots.

Figure 4.7. Class IV AVO highlighted zones on the seismic section that correspond to the A-B crossplots highlighted by the red polygon in Figure 4.6. Cross section location is Line A shown in Figure 3.3.

4.2: Arbuckle Porous Zones AVO Classification

The A-B crossplotting technique was used for identifying the AVO class of the porous zones in the Arbuckle. The porous zones in the Arbuckle show Class IV AVO response as well. The AVO class was determined by A-B crossplotting for the time window between the Arbuckle horizon and the Basement horizon (Figure 4.8). When the Class IV crossplots were highlighted, the porous zones were highlighted at the locations of wells #15-121-22591 and #15-121-22590. Figure 4.9a and Figure 4.10a show the corresponding highlighted zones of the crossplots in the red polygon in Figure 4.8 along seismic Inline #152 and Inline #169 with porosity logs posted at the well locations #15-121-22591 and #15-121-22590. The arrows point at the high porosity zones that were highlighted by the red polygon of Figure 4.8 where the porosity logs show high porosity values. The same highlighted zones show low impedance values in the P-impedance and S-impedance volumes that were created by the simultaneous AVO inversion of pre-stack data as described in section 5.1 (Figure 4.9b,c) and (Figure 4.10b,c).

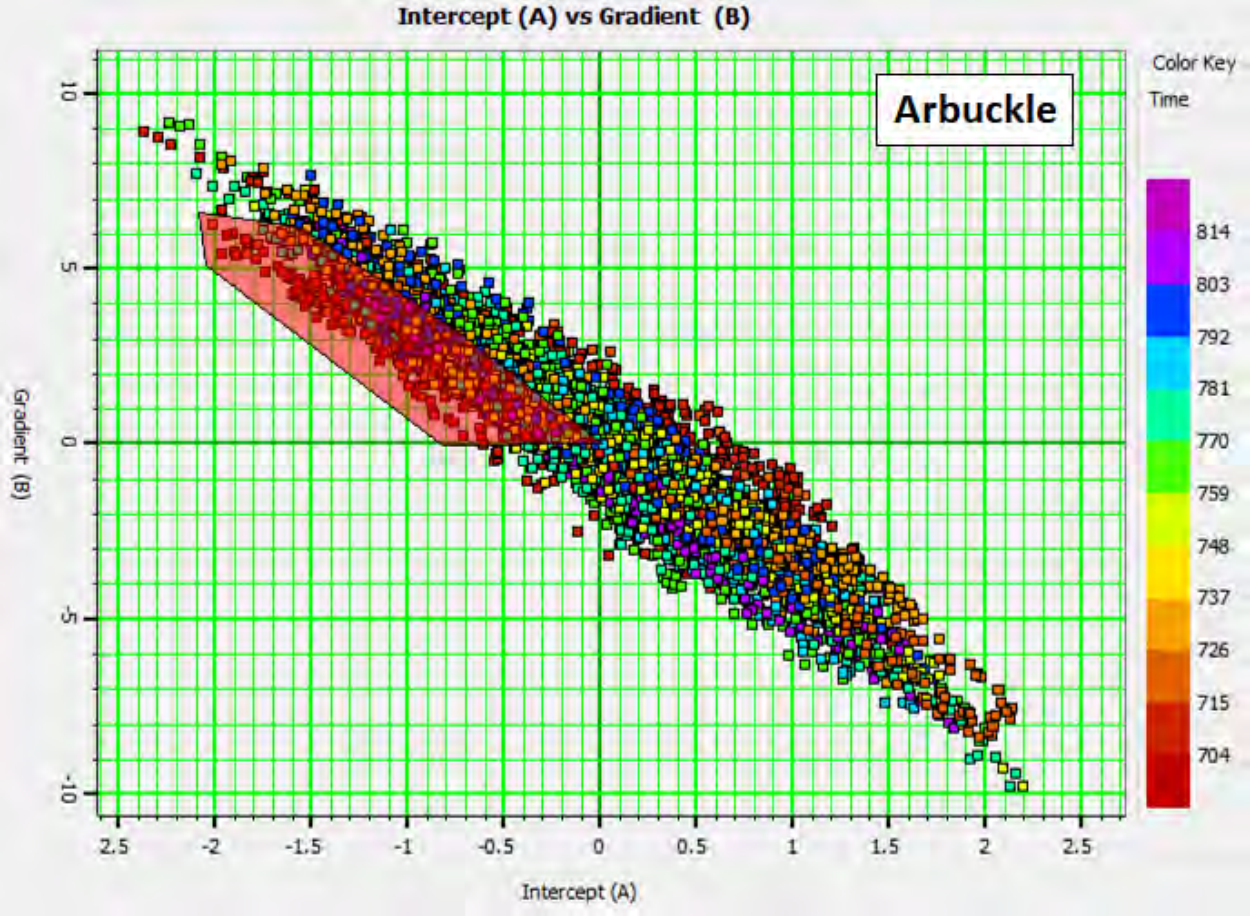


Figure 4.8. A-B crossplots of the time window between the Arbuckle top horizon and basement horizon. The red polygon highlights Class IV AVO crossplots.

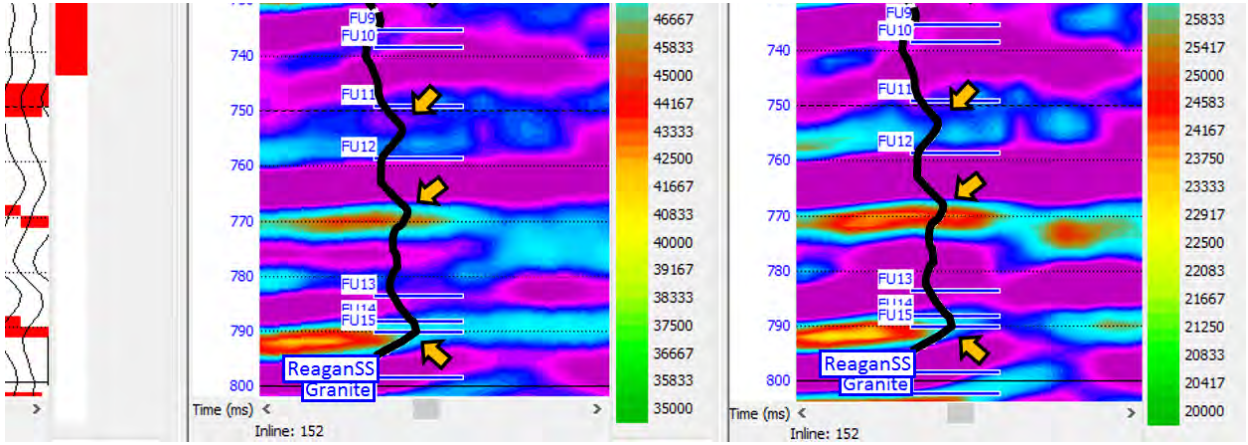


Figure 4.9. a) Class IV AVO highlighted zones on Inline #152 that correspond to the A-B crossplots highlighted by the red polygon in Figure 4.8. b) P-impedance (Z_P) inverted by simultaneous AVO inversion at Inline #152. c) S-impedance (Z_S) inverted by simultaneous AVO inversion at Inline #152. Black curves are formation porosity logs of well #15-121-22591. The arrows point at the high porosity zones on the porosity logs that were highlighted by the red polygon on the seismic sections. The same highlighted zones show low P-impedance and S-impedance.

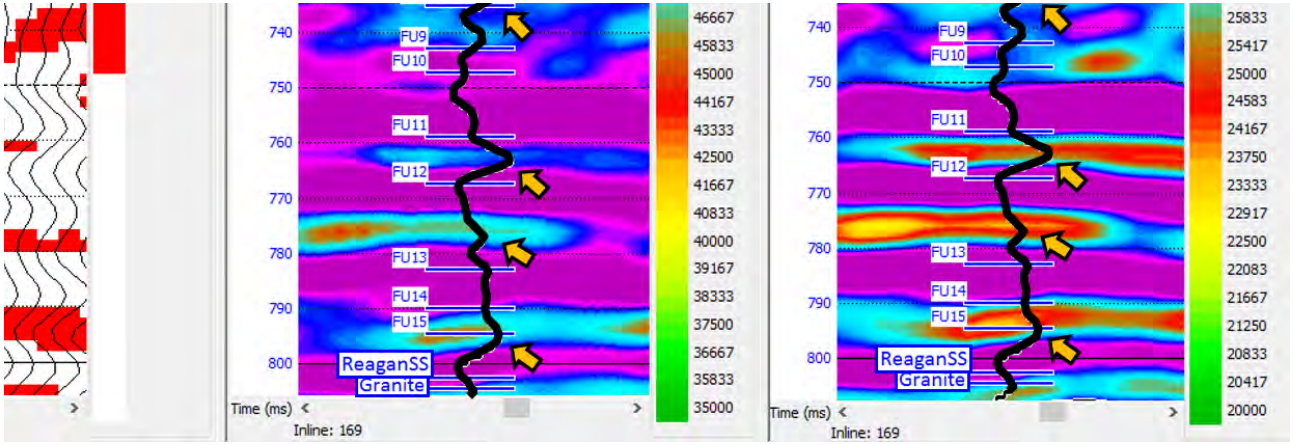


Figure 4.10. a) Class IV AVO highlighted zones on Inline #169 that correspond to the A-B crossplots highlighted by the red polygon in Figure 4.8. b) P-impedance (Z_P) inverted by simultaneous AVO inversion at Inline #169. c) S-impedance (Z_S) inverted by simultaneous AVO inversion at Inline #169. Black curves are formation porosity logs of well #15-121-22590. The arrows point at the high porosity zones on the porosity logs that were highlighted by the red polygon on the seismic sections. The same highlighted zones show low P-impedance and S-impedance.

CHAPTER 5: SIMULTANEOUS AVO INVERSION

5.1: Wellington Field Simultaneous AVO Inversion of Pre-stack Migrated Seismic Gathers

In a previous work on the Wellington Field by Sirazhiev (2012), model-based inversion was applied using the 3D post-stack seismic data to invert for P-impedance volume that was incorporated in the multi-attribute linear regression analysis for porosity prediction. In the present study the pre-stack migrated seismic gathers were used to apply the simultaneous AVO inversion method developed by Hampson et al. (2005). Simultaneous AVO inversion was applied to the pre-stack angle gathers after they were processed and converted from offset gathers to angle gathers as described in section 3.1 and appendices A, B and C. It is called simultaneous AVO inversion because it inverts for P-impedance (Z_P), S-impedance (Z_S) and density (ρ) at the same time, unlike the post-stack model-based inversion that inverts for P-impedance only.

Simultaneous AVO inversion in principle solves the equation written by Fatti et al. (1994) which describes the reflection amplitude change with angle θ in the pre-stack migrated seismic gathers in terms of P-wave reflectivity (R_P), S-wave reflectivity (R_S) and density reflectivity (R_D)

$$R_{PP}(\theta) = c_1 R_P + c_2 R_S + c_3 R_D \qquad (1)$$

Where

$c_1 = 1 + tan^2\theta$ $\qquad$ $R_P = \frac{1}{2}\left[\frac{\Delta V_P}{V_P} + \frac{\Delta \rho}{\rho}\right]$

$c_2 = -8\gamma^2 sin^2\theta$ $\qquad$ $R_S = \frac{1}{2}\left[\frac{\Delta V_S}{V_S} + \frac{\Delta \rho}{\rho}\right]$

$c_3 = -\frac{1}{2}tan^2\theta + 2\gamma^2 sin^2\theta$ $\qquad$ $R_D = \frac{\Delta \rho}{\rho}$

$\gamma = \frac{V_S}{V_P}$

This form of Fatti equation solves best for Z_P, but it does not solve as well for Z_S because the c_2 factor that defines the S-wave is smaller than the c_1 factor. Also, this form does not solve very well for density because the c_3 factor is very small (Simmons et al., 1996). To lower the effect of this problem, the Fatti equation is rewritten in a form that has independent variables to make the system more stable.

For obtaining the independent variables, we need first to define linear relationships between Z_P, Z_S and density using the well logs of wells #15-121-22591 and well #15-121-22590 (Hampson et al., 2005). The linear relationships were defined by the fit line of the crossplots of $\ln(Z_P)$ vs $\ln(\rho)$, and the fit line of the crossplots of $\ln(Z_S)$ vs $\ln(Z_P)$ (Figure 5.1). The relationships are described by the following two equations written by Hampson et al. (2005):

$$\ln(Z_S) = k * \ln(Z_P) - k_c + \Delta L_S \qquad (2)$$

Where, $k = 1.073$
$k_c = 1.36$
$\Delta L_S =$ the deviation away from the stright line

$$\ln(\rho) = m * \ln(Z_P) - m_c + \Delta L_D \qquad (3)$$

where, m = 0.303
$m_c = 2.29$
$\Delta L_D =$ the deviation away from the straight line

The deviations away from the straight lines, shown as ΔL_S and ΔL_D in figure 5.1, are the desired fluid anomalies. ΔL_S and ΔL_D are independent variables of $\ln(Z_P)$, unlike $\ln(Z_S)$ and $\ln(\rho)$. Using these independent variables, it was shown by Hampson et al., (2005) that the Fatti equation can be written alternatively in a way that describes the seismic traces at each angle in the angle gathers

$$s_\theta = \hat{c}_1 W_\theta D L_P + \hat{c}_2 W_\theta D \Delta L_S + W_\theta c_3 D \Delta L_D \qquad (4)$$

Where,

$\hat{c}_1 = (1/2)c_1 + (1/2)kc_2 + mc_3$

$\hat{c}_2 = (1/2)c_2$

$W(\theta) =$ wavelet at angle θ

$D =$ Derivative operator

$L_P = \ln(Z_P)$

The simultaneous AVO inversion started with low frequency initial Z_P, Z_S and density model volumes that were created using the P-impedance and S-impedance and density logs of wells #15-121-22591 and #15-121-22590. The well logs were low-pass filtered with a high cut of 15 Hz. Then, the low pass filtered well log curves were interpolated around the seismic survey area using the horizons, which were interpreted on the post-stack seismic data, to create a low frequency initial trace at each CDP in the survey area.

Using equation (4), synthetic seismic gathers were created at each CDP by convolving the reflectivity of the initial Z_P, Z_S and density models with angle-dependent wavelets that were extracted from the real seismic gathers. The initial models values were changed simultaneously and iteratively until the synthetic gathers matched the real gathers with the smallest least-squared error (Hampson et al., 2005).

Before applying the inversion to the entire seismic volume, simultaneous AVO inversion was evaluated at wells #15-121-22591 and #15-121-22590 by comparing the inverted Z_P, Z_S and density with the original well logs (Figures 5.2-5.3). The red curves are the inverted logs, the blue curves are the real well logs, and the black smooth curves are the initial low-frequency models from which simultaneous AVO inversion starts. There is generally a good agreement between the real and inverted logs. The correlation between the red synthetic seismic gather of the red inverted logs with the black real seismic gather is 0.93 at well #15-121-22590 and 0.91 at well #15-121-22591 (Figures 5.2-5.3). Based on this good agreement, the simultaneous AVO

inversion was applied to the gathers of the 3D seismic data set to create Z_P, $Z_{S,}$ and density volumes. The inversion results were evaluated within the Mississippian chert reservoir and the Arbuckle Group.

Figure 5.1: Cross plots of ln(ρ) vs. ln(Z_P) and ln(Z_S) vs. ln(Z_P) calculated from the logs of wells #15-121-22591 and #15-121-22590. The deviations away from the best fit lines, ΔLD and ΔLS, are the desired fluid anomalies which are independent of ln(Z_P).

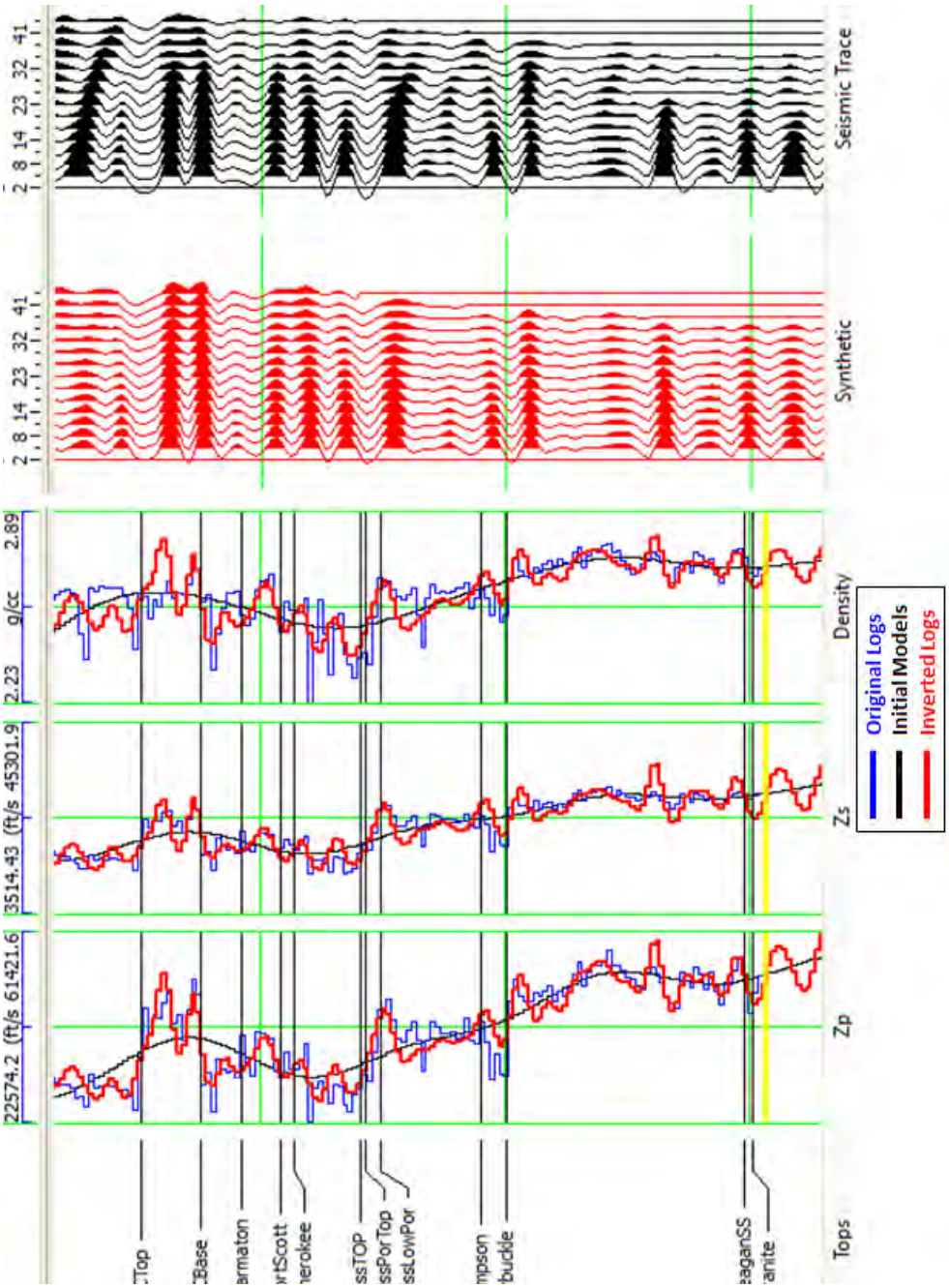


Figure 5.2. Analysis of simultaneous AVO inversion at well location #15-191-22591. From left to right: 1) Well tops. 2) Inverted traces (red), original well logs (blue) and initial models (black) of Z_P, Z_S and density. 3) Synthetic seismic gather (red) 4) Real seismic gather (black). The inverted traces (red) show a good match with the original logs (blue). The synthetic seismic gather shows a high correlation of 0.91 with the real seismic gather (black) at the well location. Synthetic and seismic traces are displayed in SEG reversed polarity.

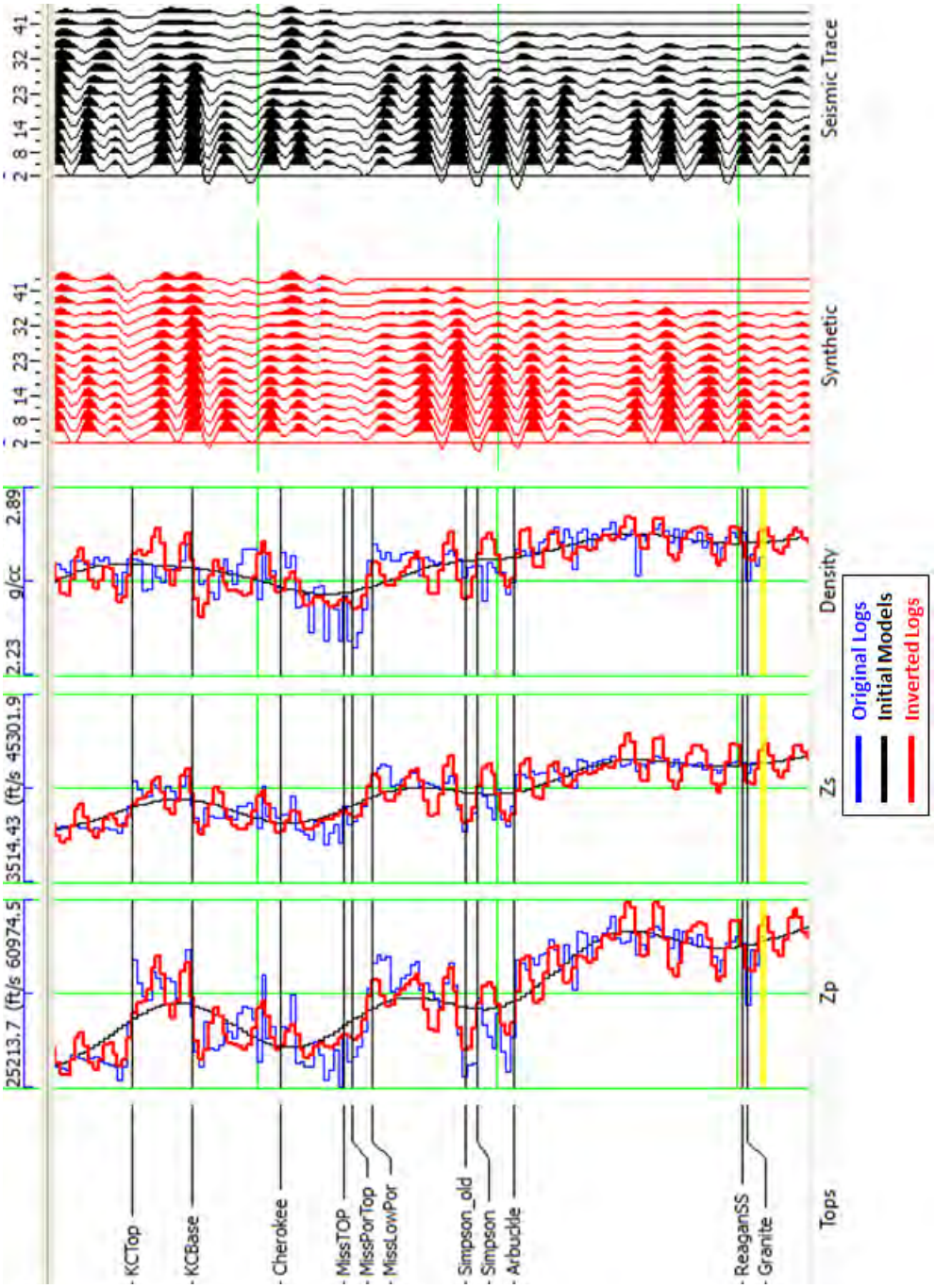


Figure 5.3. Analysis of simultaneous AVO inversion at well location #15-191-22590. From left to right: 1) Well tops. 2) Inverted traces (red), original well logs (blue) and initial models (black) of Z_P, Z_S and density. 3) Synthetic seismic gather (red) 4) Real seismic gather (black). The inverted traces (red) show a good match with the original logs (blue). The synthetic seismic gather shows a high correlation of 0.93 with the real seismic gather (black) at the well location. Synthetic and seismic traces are displayed in SEG reversed polarity.

5.2: Simultaneous AVO Inversion Evaluation within the Mississippian Reservoir

The simultaneous AVO inversion for Z_P and density was evaluated within the Mississippian reservoir at the eleven wells that have a good tie to the seismic data and have P-impedance and density logs. The evaluation was done by comparing inverted seismic traces at these well locations with the original well logs. Inverted Z_S, however, was evaluated within the Mississippian reservoir at wells #15-191-22591 and #15-191-22590 because they are the only wells that have original S-impedance logs.

Figure 5.4 shows inverted Z_P traces (red) and original P-impedance logs (black) at the eleven well locations. As mentioned earlier, the gradational downward porosity decrease within the Mississippian reservoir results in a corresponding increase in acoustic impedance. Therefore, the Mississippian reservoir corresponds to the transitional impedance boundary marked by the blue lines in figure 5.4. The inverted Z_P traces and the original P-impedance logs show generally good agreement within the Mississippian reservoir with an overall 0.85 correlation coefficient and RMS inversion error of 953 (m/s)*(g/cc). Figure 5.5 is a crossplot of the inverted Z_P traces against the original P-impedance logs within the Mississippian reservoir at the eleven well locations showing a best fit line that has a slope of 0.91. The linear relationship between the inverted and the original P-impedances supports the good agreement between them. A few outliers shifted away from the best fit line due to the high impedance parts at the reservoir base that were underestimated by inversion as visually evident for wells #15-121-21581, #15-121-20789 and #15-121-21255 (Figure 5.4). For a quick comparison between the simultaneous AVO inversion and post-stack model-based inversion results, the post-stack model-based inverted P-impedance traces were crossplotted against the original P-impedance well logs for the same group of wells (Figure 5.6). The crossplot shows a lower overall correlation of 0.77 with higher

RMS inversion error of 1080 (m/s)*(g/cc), and a best fit line that has a lower slope of 0.76 indicating less agreement between the post-stack model-based inversion traces and the original logs.

Figure 5.7 is a cross section at Line A of inverted Z_P by simultaneous AVO inversion. The posted P-impedance well logs show the ramp-transition within the Mississippian reservoir from the overlying low impedance rocks to the underlying high impedance rocks. The inverted Z_P cross section shows the expected impedance variation around and within the Mississippian reservoir (Figure 5.7). By referring to the impedance color scale in Figure 5.7, the cross section shows that impedance changes from green to yellow at the top of the Mississippian reservoir. Then, impedance changes gradually downward from yellow to red within the Mississippian until it becomes blue at the base of the reservoir. So, inverted Z_P provides good contrast at the top and the bottom of the Mississippian reservoir that helps in picking the top and the base of the Mississippian reservoir. However, it becomes challenging to determine the top of the Mississippian reservoir on the inverted Z_P data at some places where the overlying layer has impedance values that are equal to the impedance values at the top of the Mississippian reservoir such as the location of well #15-121-22590.

In Figure 5.8a the inverted Z_S traces (red) show a good match with the well S-impedance logs (black) within the Mississippian reservoir at wells #15-191-22591 and #15-191-22590. The inverted Z_S and original S-impedance logs have an overall correlation of 0.93 for both wells. Because inverted Z_S was only analyzed at wells #15-191-22591 and #15-191-22590, another evaluation was done for inverted Z_P within the Mississippian reservoir at only these two wells to compare it with inverted Z_S (Figure 5.8b). Inverted Z_P shows a correlation of 0.94 for both wells indicating that inverted Z_S and inverted Z_P results are similar in quality. The inverted Z_S cross

section of Line A in Figure 5.9 shows the same details depicted in the Z_P impedance cross section of Line A (Figure 5.7).

The inverted density traces at the Mississippian reservoir show generally that they have the same trends with the densities measured by the original well logs, however the results were not as good as those observed fro the Z_P and Z_S impedance inversions (Figure 5.10). The inverted and real densities at the Mississippian reservoir show an overall correlation of 0.65. Therefore, the inverted and the real density crossplots are more scattered as shown in Figure 5.11. The reduced quality of density estimation by inversion might be due to the fact that density recovery mainly depends on the far offsets amplitudes that are usually affected by noise and wave attenuation (Chopra et al., 2010). The inverted density cross section of Line A in Figure 5.12 shows gradation within the Mississippian that is consistent with ramp-transition of density as shown on the overlain density logs. However, the density cross section is not expected to show density values that are close to the real density values as illustrated by the crossplot in figure 5.11. Also, the density cross section shows weaker contrast at the top of the Mississippian reservoir. Therefore, inverted density would not be efficient for picking the top of the Mississippian reservoir.

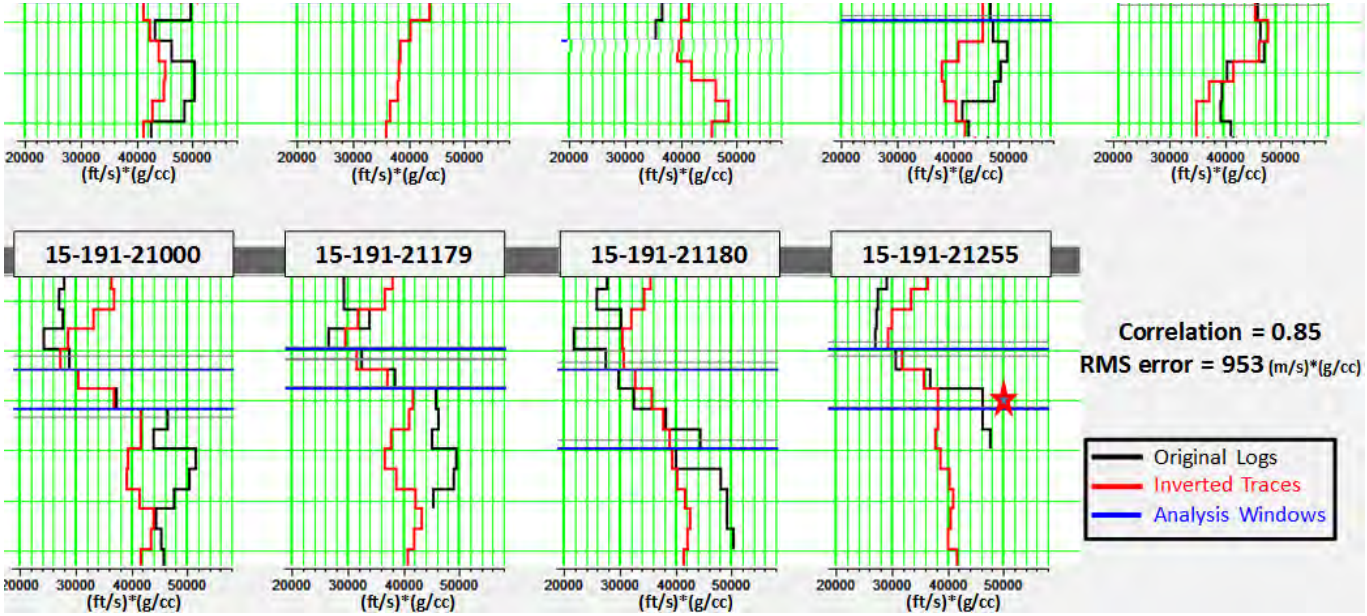


Figure 5.4. Analysis of inverted Z_P by simultaneous AVO inversion within the Mississippian chert reservoir (shown by the blue horizontal lines of the analysis window) at 11 well locations. The inverted Z_P traces (red) show a good agreement with the original P-impedance logs (black) with an overall correlation of 0.85 for all wells. The total RMS error for all wells is 953 (m/s)*(g/cc). Red stars mark the underestimated high impedance parts near the reservoir base as discussed in section 5.2.

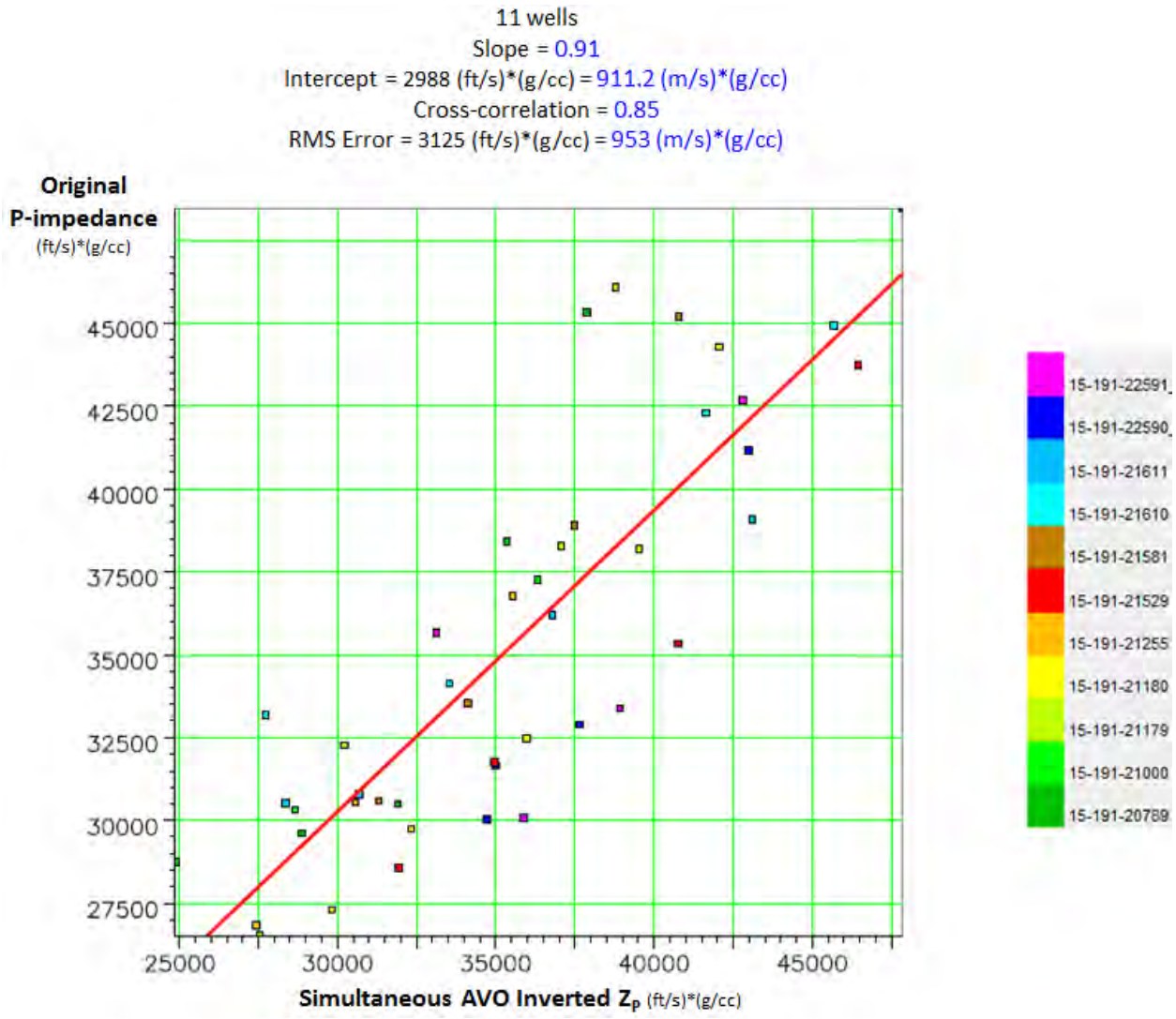


Figure 5.5. Crossplot of the inverted Z_P by simultaneous AVO inversion versus the original P-impedance logs within the Mississippian chert reservoir (the analysis window shown with blue horizontal lines in Figure 5.4) at 11 well locations. The red line shows the line of perfect correlation between inverted and original P-impedance values. The total RMS error for the 11 wells is 953 (m/s)*(g/cc).

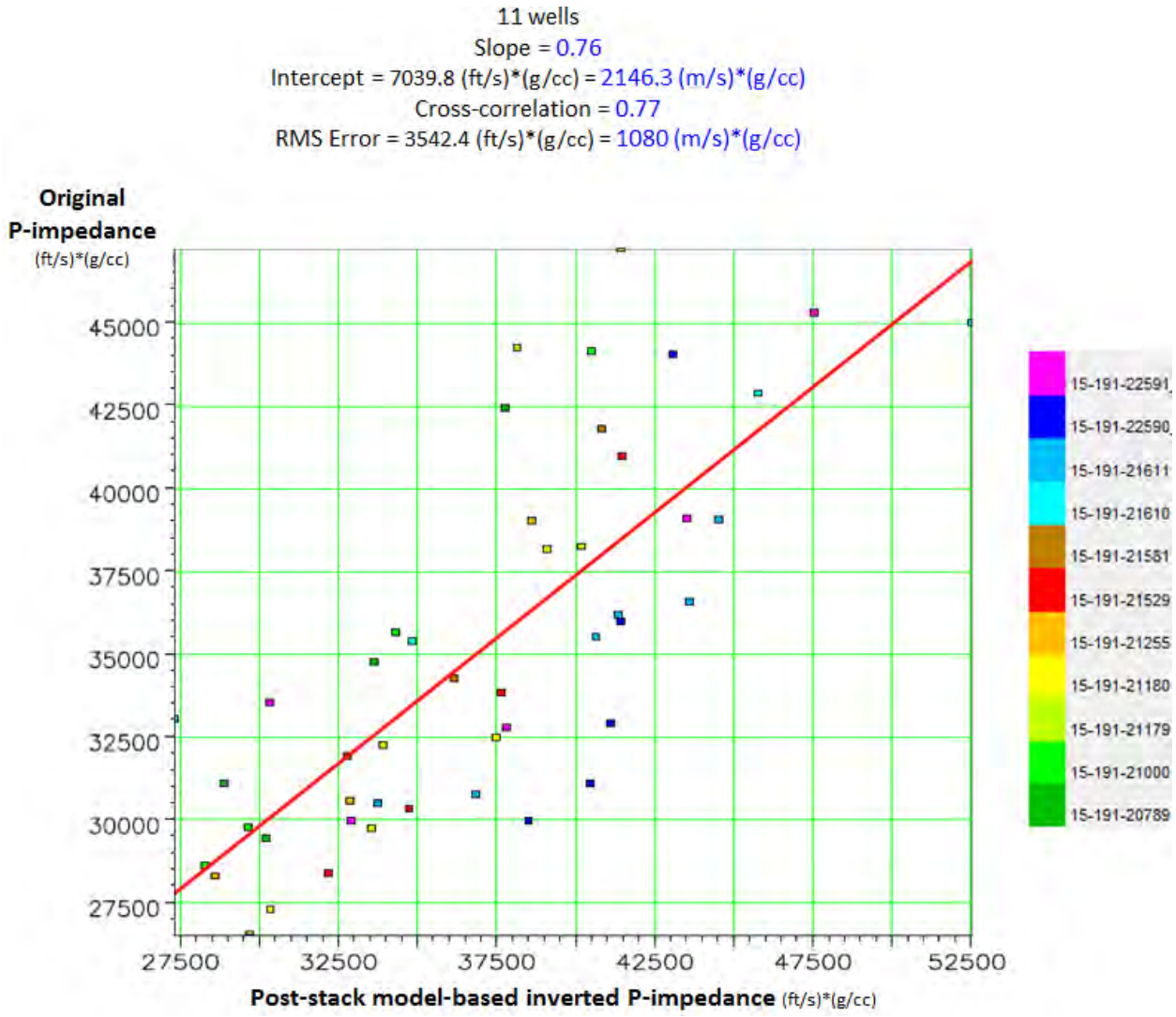
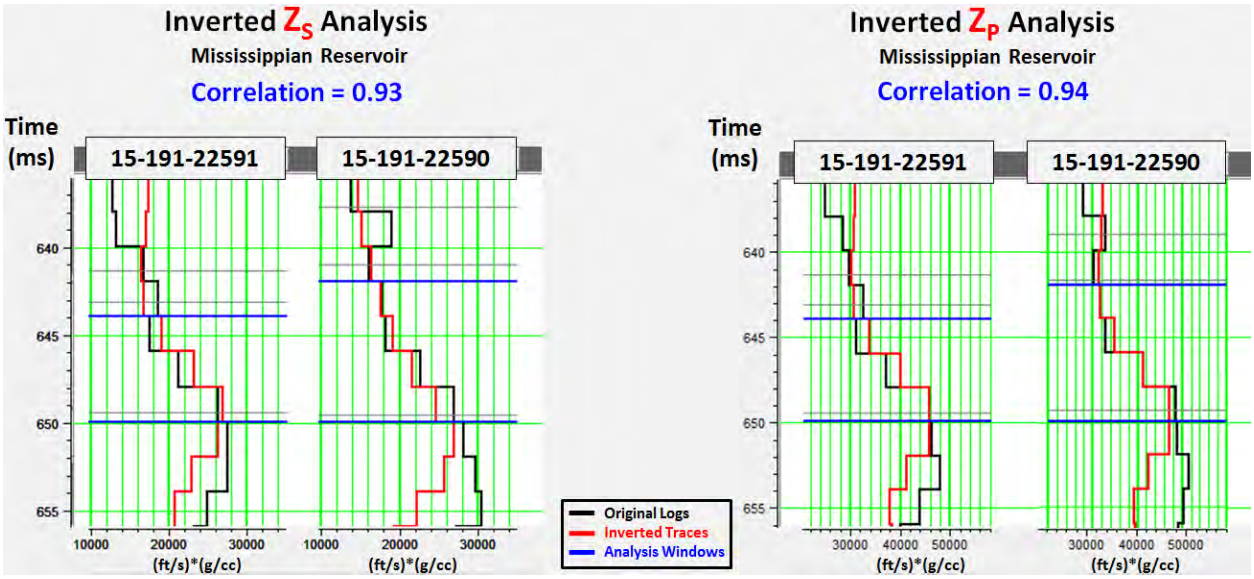


Figure 5.6. Crossplot of the inverted P-impedance by post-stack model-based inversion versus the original P-impedance logs within the Mississippian chert reservoir at 11 well locations. The red line shows the line of perfect correlation between inverted and original P-impedance values. The total RMS error for the 11 wells is 1080 (m/s)*(g/cc).

Figure 5.7. Simultaneous AVO inverted Z_P cross section with P-impedance well logs posted at well locations. Cross section location is Line A shown in Figure 3.3.



(a) (b)

Figure 5.8. a) Analysis of inverted Z_S by simultaneous AVO inversion within the Mississippian chert reservoir at wells #15-191-22591 and #15-191-22590. b) Analysis of inverted Z_P by simultaneous AVO inversion within the Mississippian chert reservoir at wells #15-191-22591 and #15-191-22590.

Figure 5.9. Simultaneous AVO inverted Z_S cross section with S-impedance well logs posted at well locations. Cross section location is Line A shown in Figure 3.3.

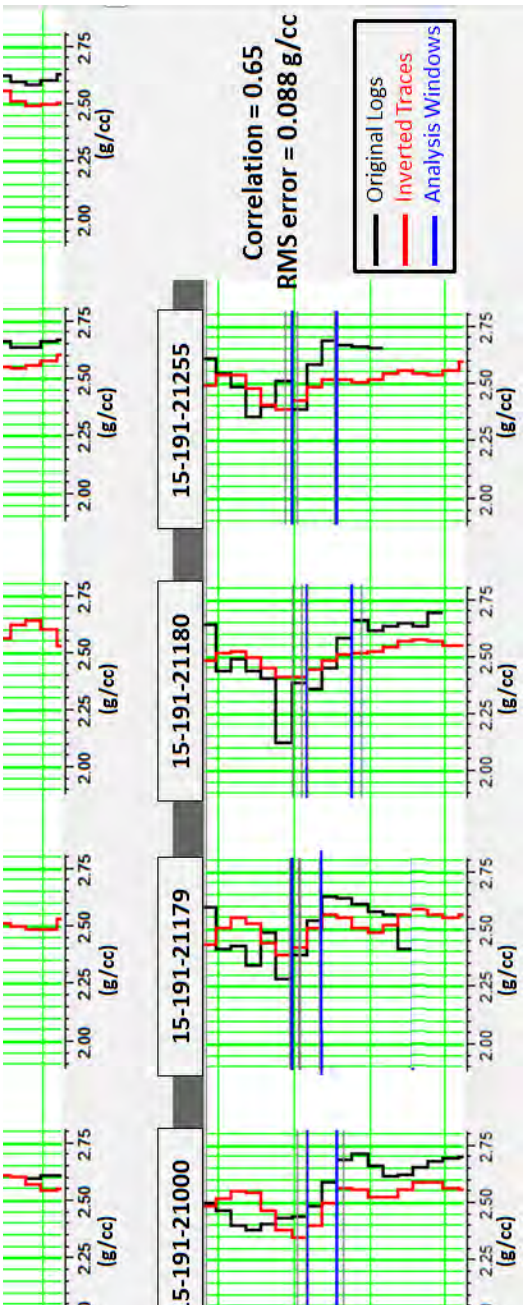


Figure 5.10. Analysis of the inverted density by simultaneous AVO inversion within the Mississippian chert reservoir (shown by the blue horizontal lines of the analysis window) at 11 well locations. Inverted densities have the same trends of the original densities with less agreement than that of inverted Z_P and Z_S impedances with original wells logs (Figure 5.4) and (Figure 5.8). The inverted and original densities at the Mississippian show an overall correlation of 0.65.

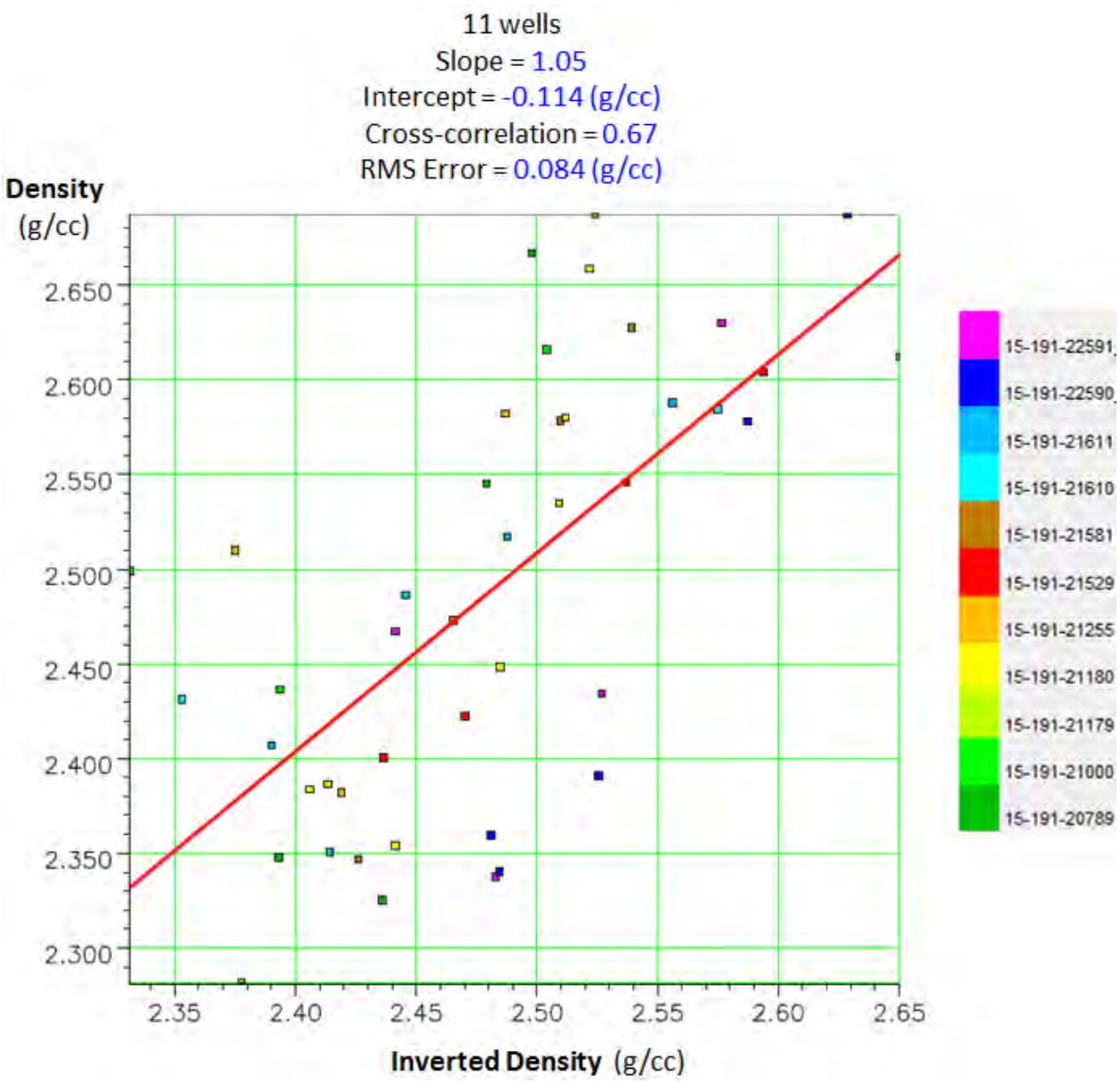


Figure 5.11. Crossplot of the inverted density by simultaneous AVO inversion versus the original density logs within the Mississippian chert reservoir at 11 well locations. The inverted and original densities crossplots are more scattered than the crossplots of inverted and original impedances indicating less quality of density recovery by inversion.

Figure 5.12. Simultaneous AVO inverted density cross section with density well logs posted at well locations. Cross section location is Line A shown in Figure 3.3.

5.3: Simultaneous AVO inversion of Synthetic Wedge Model of the Mississippian Reservoir

A wedge model was created using the P-wave, S-wave and density logs of well #15-121-22590 to test the power of recovering impedance values using simultaneous AVO inversion within a reservoir characterized by downward gradational porosity decrease and downward velocity increase such as the Mississippian reservoir in the Wellington Field. The original thickness of the Mississippian reservoir at well #15-121-22590 is about 15 m. In the wedge model, the Mississippian reservoir was stretched and squeezed so that the Mississippian reservoir has an increasing thickness from 0 to 60 m. The wedge model was made by creating 61 P-wave, S-wave and density logs from well #15-121-22590 with modified thicknesses of the Mississippian reservoir starting from a thickness of 0 m up to 60 m with 1 m thickness increment from one well to the other. Then, these logs were used to make depth-velocity models with 1 m separation between each model on a single line. The depth-velocity models were convolved with the statistical wavelet extracted earlier from the Wellington seismic data to create synthetic pre-stack seismic angle gathers (0 to 45 degrees) at the locations of the depth-velocity models (Figure 5.13).

For applying the simultaneous AVO inversion to the synthetic wedge mode gathers, initial Z_P, Z_S and density models were built using only the low-pass filtered original logs of well #15-121-22590 that were interpolated by three horizons interpreted on post-stack seismic section of the wedge model. Simultaneous AVO inversion was applied to the wedge model as explained earlier in Section 5.1 to invert for Z_P, Z_S and density wedge models.

Since inverted Z_P provided the best results as demonstrated in section 5.2, it was sufficient to evaluate the inversion applied using inverted Z_P only (Figure 5.14). The inverted Z_P was evaluated at each trace location of the wedge model because the P-impedance well logs were

available at all of the trace locations. Figure 5.15 is a crossplot of the RMS inversion error calculated within the Mississippian reservoir versus the wedge thickness.

Figure 5.16 shows inverted Z_P traces and P-impedance well logs for the wedge thickness range 0-8 m. At 0 m reservoir thickness, the inverted Z_P trace shows a step velocity function that represents a sharp impedance boundary. Starting from 1 m thickness, inverted Z_P shows a transitional impedance boundary that has a constant time thickness for reservoir thicknesses between 1-4 m as shown between the blue markers in Figure 5.16. In the transitional zone between the blue markers for reservoir thicknesses 1-4 m, there is a noticeable separation between the real and inverted values which resulted in the high RMS error for thicknesses between 1-4 m as shown in Figure 5.15. So, a transitional layer can exist for reservoir thicknesses 1-4 m in the inverted impedance cross section indicating the presence of the reservoir, but it does not provide reliable thickness or reliable impedance values within this thickness range. As thickness increases, the agreement between inverted and real impedances improves, and the inversion RMS error decreases (Figures 5.15 – 5.17). The inversion RMS error decreases dramatically at the reservoir thickness of 5 m, and the RMS error keeps decreasing as thickness increases until the error starts having steady RMS error with slight variations from the reservoir thickness of 10 m Figure 5.15. The inverted and real impedances have almost similar values for reservoir thicknesses that are greater than or equal to 10 m, which correspond to thicknesses that are greater than or equal to $1/8\lambda$ in terms of wavelength (Figure 5.15 – 5.17).

Figure 5.13. Synthetic seismic gathers section of the Mississippian reservoir wedge model constructed at well #15-191-22590. Synthetic P-wave sonic logs calculated by stretching and squeezing the original log within the Mississippian reservoir are shown in light green for every 5th trace (original reservoir thickness is 15 m). Well top shown in white – MissTop, the top of the reworked Mississippian chert; well tops shown in yellow – MissPorTop and MissLowPor, the top and the base of the chert reservoir.

Figure 5.14. Wedge model inverted Z_P by simultaneous AVO inversion of the synthetic gathers in Figure 5.13. P-impedance logs are shown for every 5th trace.

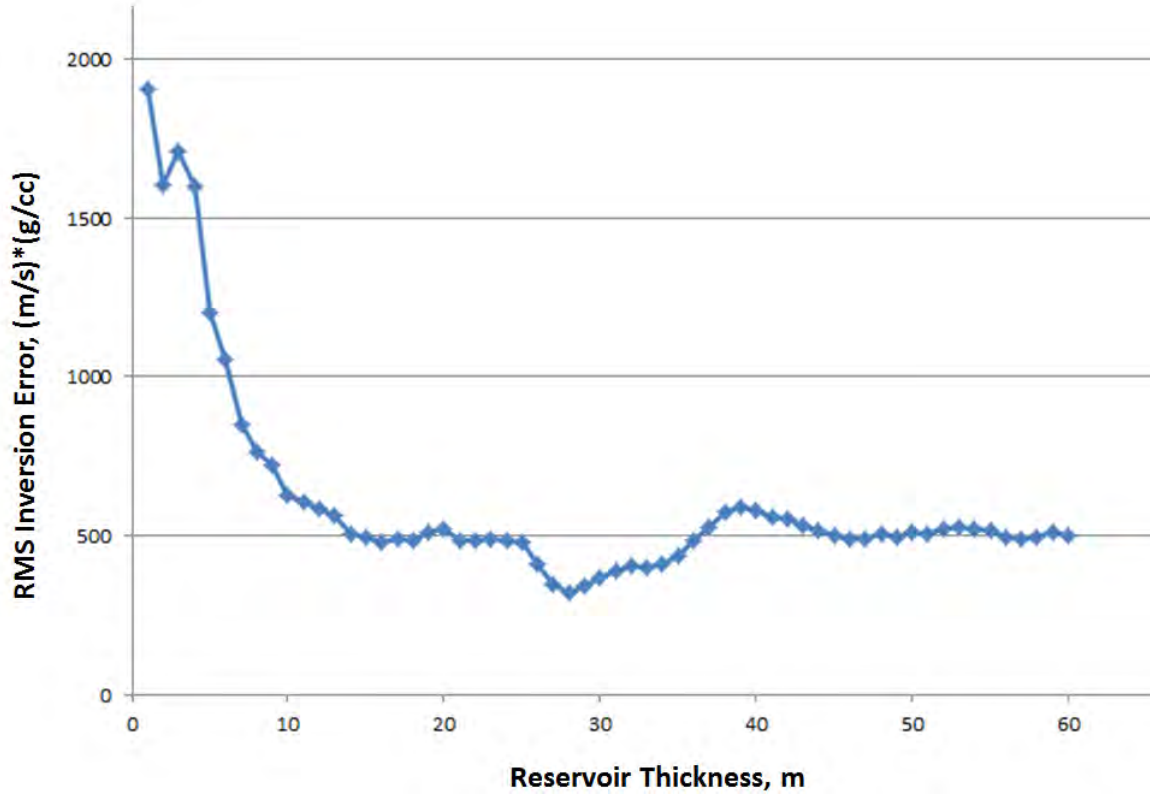


Figure 5.15. Crossplot of the RMS error of the simultaneous AVO inversion of the synthetic wedge model (shown in Figure 5.14) versus the wedge thickness. The RMS prediction errors were calculated within the Mississippian chert reservoir at each trace.

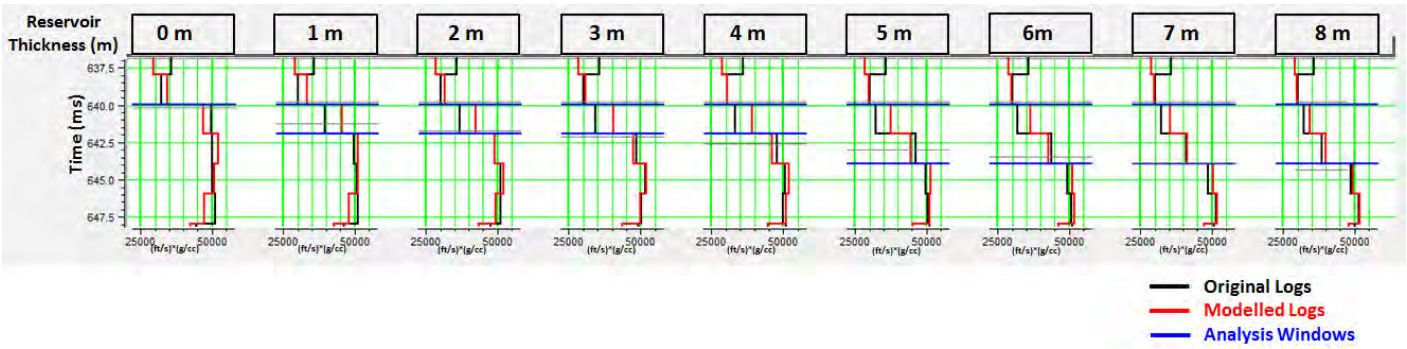


Figure 5.16. Analysis of inverted Z_P by simultaneous AVO inversion of the synthetic wedge model (shown in Figure 5.14) within the reservoir interval for the wedge thickness range 0-8 m. Red curves are inverted Z_P traces, and black curves are original P-impedance logs.

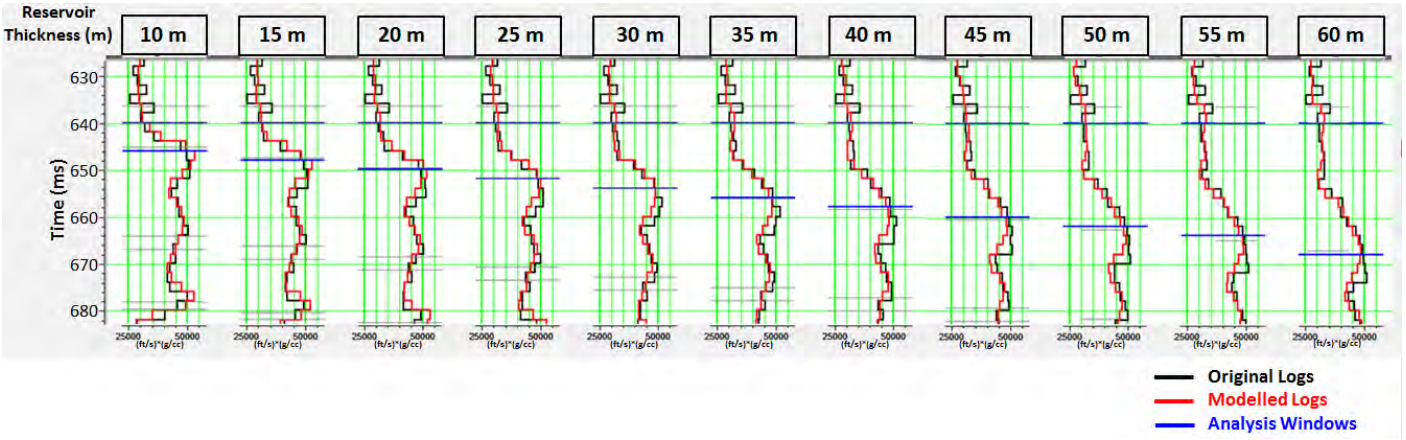


Figure 5.17. Analysis of inverted Z_P by simultaneous AVO inversion of the synthetic wedge model (shown in Figure 5.14) within the reservoir interval for the wedge thickness range 10-60 m with 5 m step. Red curves are inverted Z_P traces, and black curves are original P-impedance logs.

5.4: Simultaneous AVO Inversion Evaluation within the Arbuckle

The inverted Z_P, Z_S and density evaluation within the Arbuckle was done at wells #15-121-22590 and #15-121-22591 because the Arbuckle was penetrated by these two wells. Figure 5.18 shows the inverted Z_P traces (red) and the original P-impedance well logs (black) at wells #15-121-22590 and #15-121-22591. Generally, the inverted Z_P traces have the same trend of the original P-impedance logs. They have an acceptable overall correlation of 0.72 with the original P-impedance wells logs, and RMS inversion error of 813 (m/s)*(g/cc). However, there are some features that appear on the well logs that were not resolved by the inversion resulting in mismatches between inverted and original well logs especially at well #15-121-22590. This inversion resolution limit is due to the difference in frequency content between seismic data and well logs. Well logs usually have higher frequency bandwidth than seismic data. The Wellington Field seismic data has maximum useable frequency between 100 Hz and 128 Hz as shown in the amplitude spectrum of the seismic data in Figure 5.19. Therefore, the original well logs were low-pass filtered with a maximum frequency of 100 Hz and a maximum high cut of 128 Hz for inversion evaluation and porosity prediction evaluation within the Arbuckle in this research because seismic traces will never have better resolution than the filtered original well logs.

The inverted Z_P traces in Figure 5.20 show better agreement with the filtered P-impedance logs at both wells with higher overall correlation of 0.83 and lower RMS error of 568 (m/s)*(g/cc) (Figure 5.20). For comparing the simultaneous AVO inversion results with the post-stack model-based inversion results, the inverted P-impedance by model-based inversion of post-stack seismic data was evaluated within the Arbuckle at wells #15-121-22590 and #15-121-22591 (Figure 5.21). Visually, the post-stack model-based inverted P-impedance traces have the same trend of the original P-impedance logs. However, the post-stack model-based inverted

impedance traces showed a lower overall correlation of 0.66 with the original logs and a higher RMS inversion error of 820 (m/s)*(g/cc).

The simultaneous AVO inverted Z_S traces show a good agreement with the original S-impedance logs at both wells. The inverted Z_S traces have an overall correlation of 0.74 with the original S-impedance logs (Figure 5.22). A great advantage of the simultaneous AVO inversion for Z_P and Zs within the Arbuckle is that there is a good correlation between the inverted impedance traces at the different well locations, which makes it easy to match the corresponding tops of Arbuckle flow units between the different well locations on the inverted data. Figure 5.23 shows the inverted Z_P traces at well #15-121-22590 and well #15-121-22591. Both traces show the same trend that made it easy to relate the corresponding tops of the flow units at the two well locations. This advantage has shown an effect when interpreting the impedance volumes. For example, there is a low impedance zone between the tops of flow units FU11 and FU12 at both wells (Figure 5.23). The simultaneous AVO inverted Z_P cross section of Line A in Figure 5.24a shows, in the white box between the wells, that this low impedance zone is continuous between the two wells. However, the same low impedance zone in the post-stack model-based inversion in Figure 5.24b does not seem continuous between the two wells. Actually, the low impedance zone between the tops of flow units FU11 and FU12 at well #15-121-22591 to the left might be mistaken for being related to the shallower low impedance zone between the tops of flow units FU8 and FU10 at well #15-121-22590 to the right (Figure 5.24b).

By looking at the two P-impedance cross sections in Figures 5.24a, b, the low impedance zones are better defined in the simultaneous AVO inverted Z_P cross section compared to the post-stack model-based inversion cross section. The low impedance zones in the simultaneous AVO inverted impedance cross section show better contrast with the surrounding higher

impedance zones, which makes it easy to identify and follow the low impedance zones around the field. The low impedance zones were picked by the dashed lines on the simultaneous AVO inverted Z_P cross section in Figure 5.24a because it has better depiction of the subsurface features, and the same dashed lines are overlain on the post-stack model-based inverted impedance cross section in Figure 5.24b. The injection zone chosen for the CO_2 sequestration is the bottom picked low impedance zone near the top of flow unit FU15 (Figure 5.24a). The inverted Z_S cross section of Line A in Figure 5.25 exhibits the same impedance trends shown by the Z_P cross section.

Finally, inverted and original densities show a good visual agreement between their trends in the Arbuckle at wells #15-121-22590 and #15-121-22591 with an overall correlation of 0.64 that is acceptable, but lower than the correlation of inverted Z_P and inverted Z_S with the original logs (Figure 5.26). An inverted density cross section along Line A is shown in Figure 5.27. Inverted density trends are in overall agreement with inverted Z_P and inverted Z_S shown in Figure 5.24a and Figure 5.25.

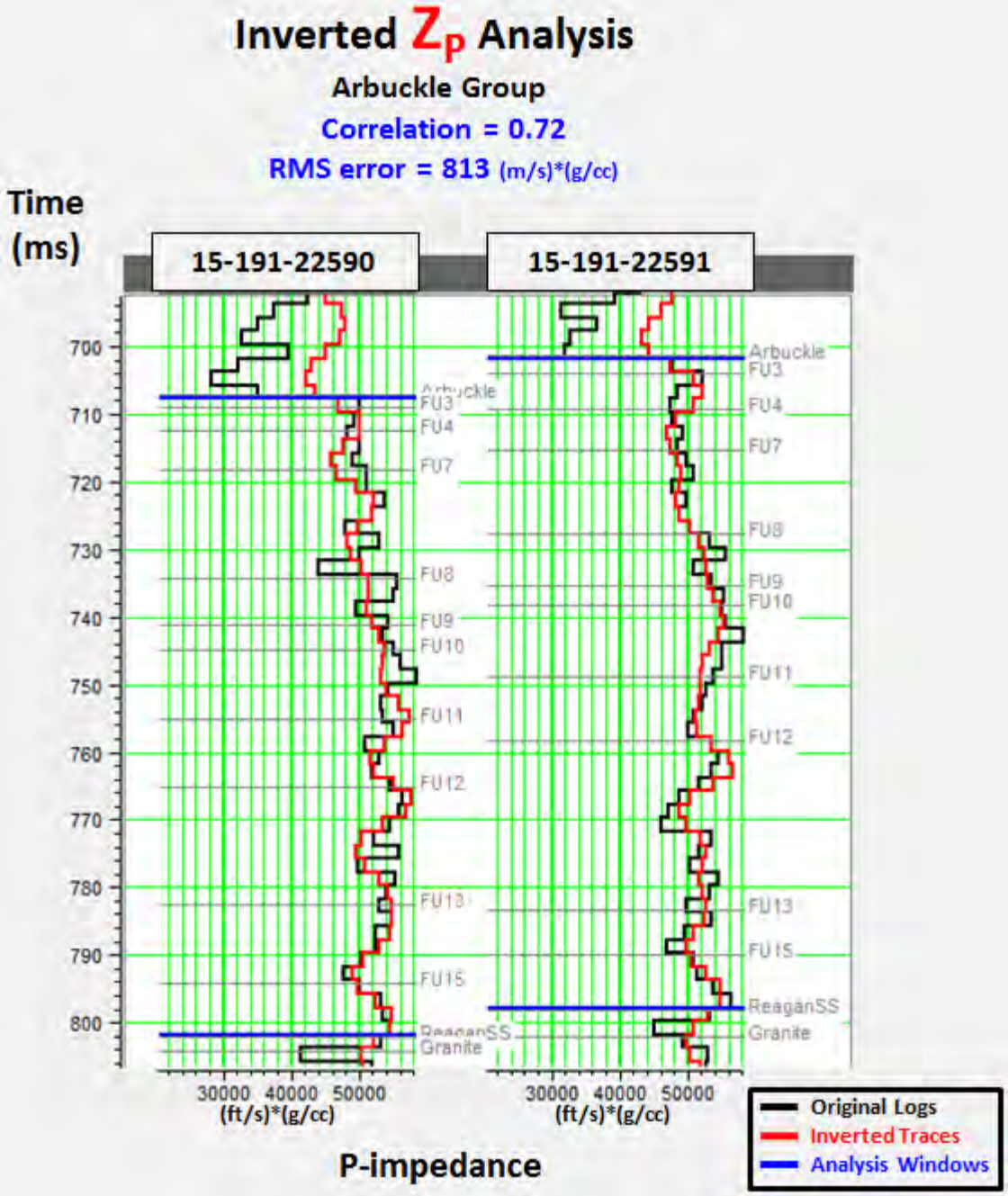


Figure 5.18. Analysis of inverted Z_P by simultaneous AVO inversion within the Arbuckle Group at wells #15-121-22590 and #15-121-22591. Red curves are inverted Z_P traces and black curves original P-impedance logs. Overall correlation between inverted and original logs is 0.72 for all wells. The total RMS error for all wells is 813 (m/s)*(g/cc).

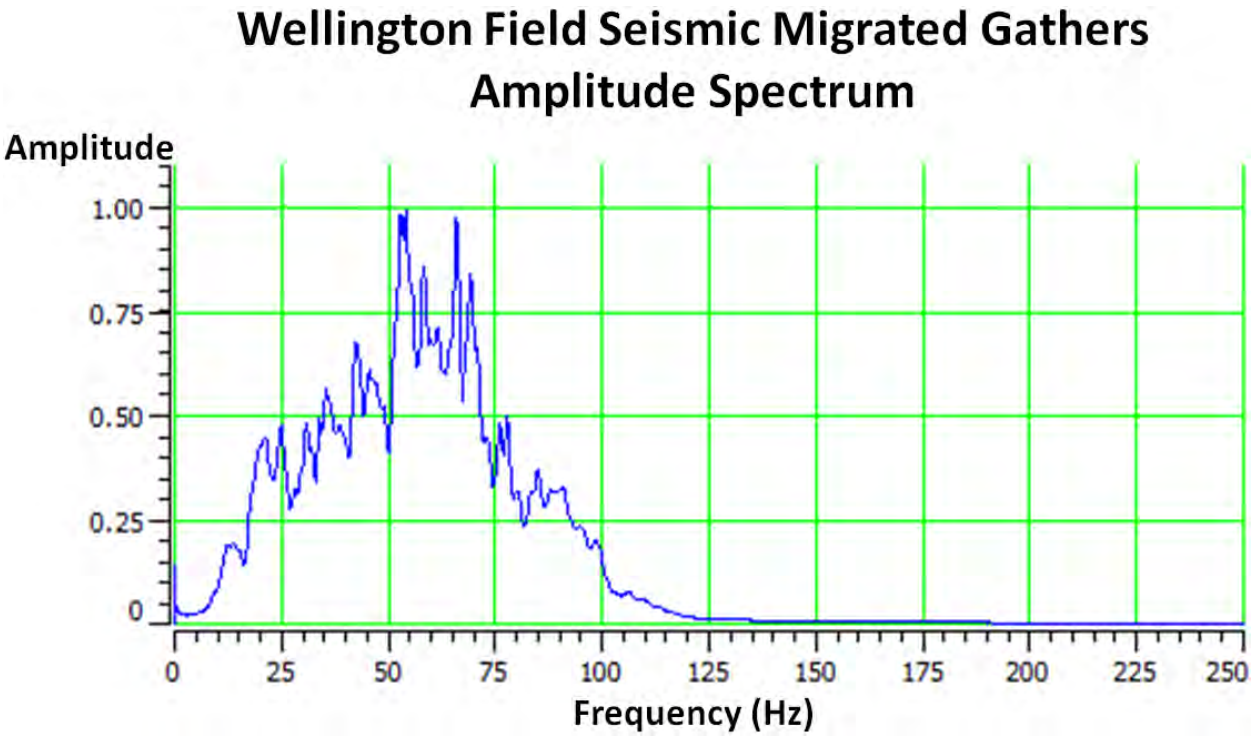


Figure 5.19. Amplitude spectrum of the Wellington Field seismic gathers. The data has frequency content ranging between 10 Hz and 128 Hz.

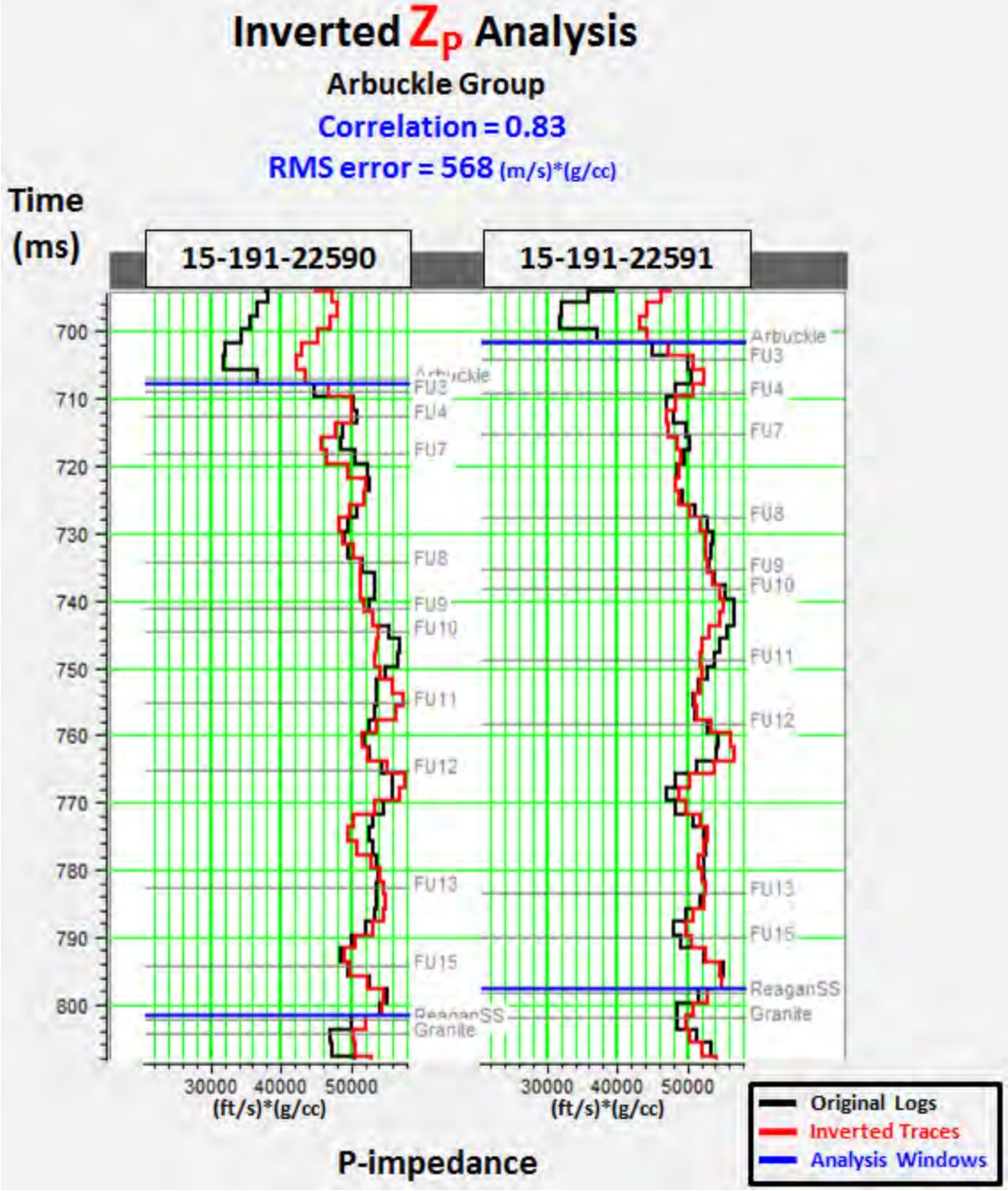


Figure 5.20. Analysis of inverted Z_P by simultaneous AVO inversion within the Arbuckle Group at wells #15-121-22590 and #15-121-22591. Red curves are inverted Z_P traces, and black curves are filtered original P-impedance logs. Overall correlation between inverted and original logs is 0.83 for all wells. The total RMS error for all wells is 568 (m/s)*(g/cc).

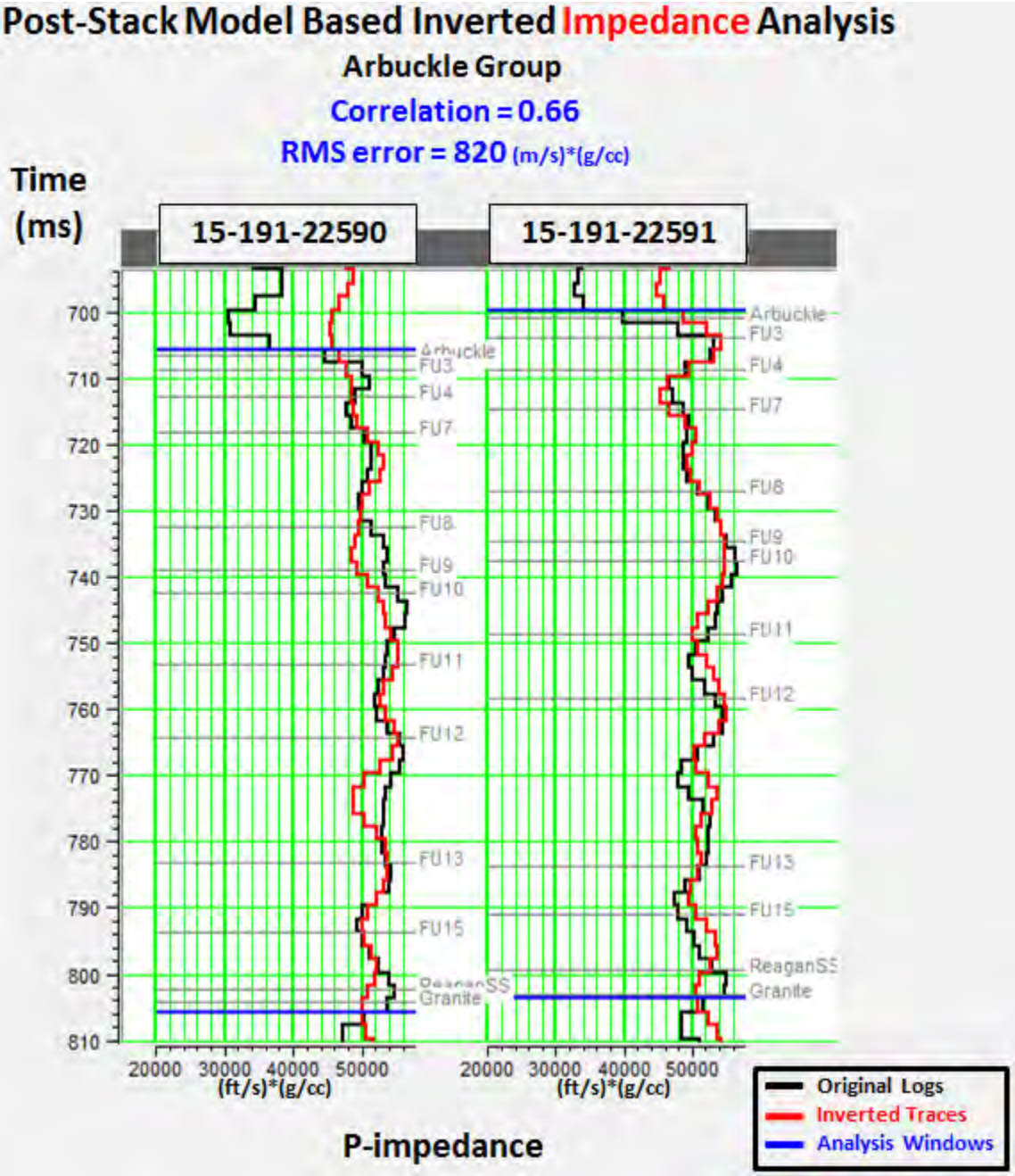


Figure 5.21. Analysis of inverted P-impedance by post-stack model-based inversion within the Arbuckle Group at wells #15-121-22590 and #15-121-22591. Red curves are inverted P-impedance traces, and black curves are filtered original P-impedance logs. Overall correlation between inverted and original logs is 0.66 for all wells. The total RMS error for all wells is 820 (m/s)*(g/cc).

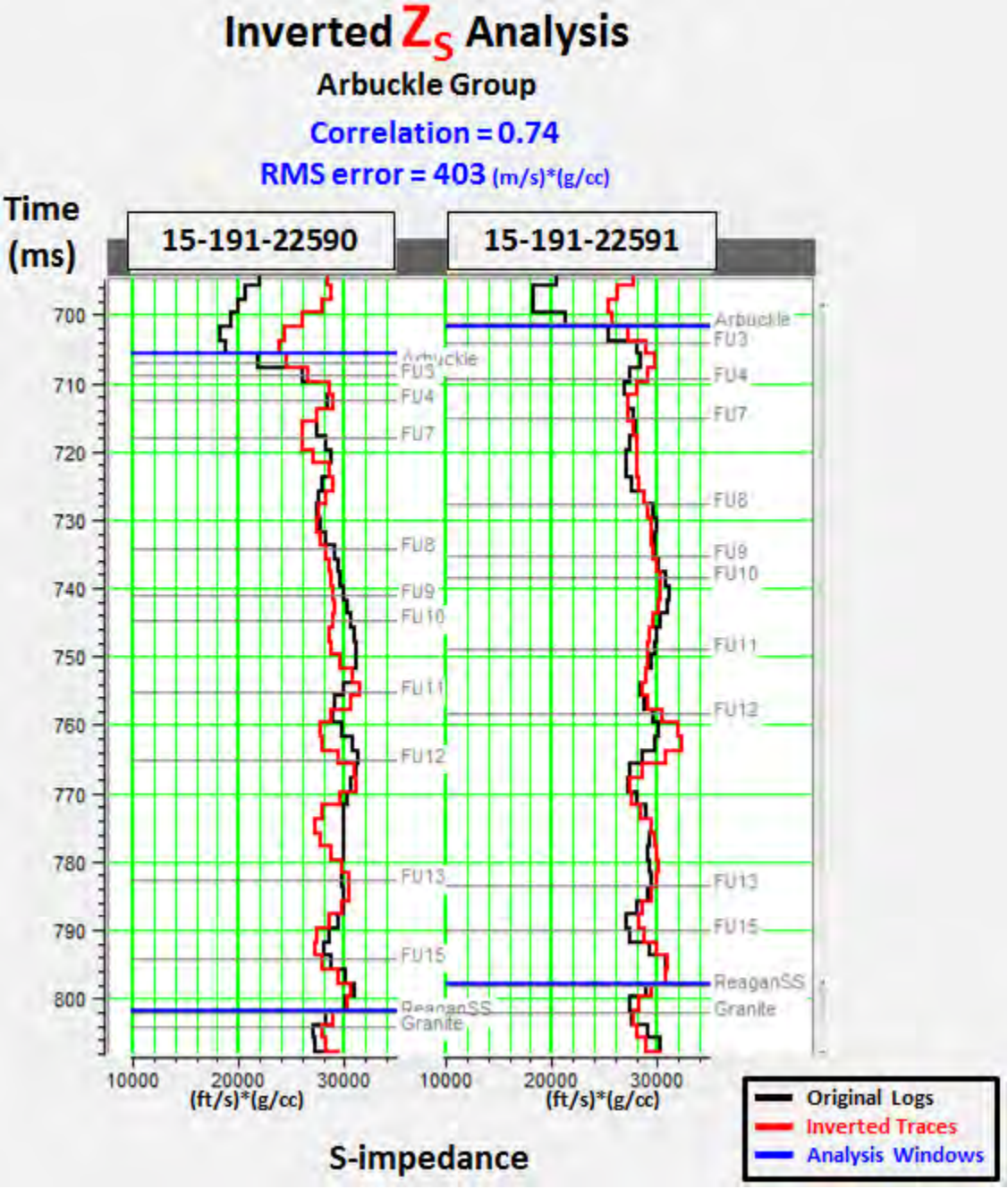


Figure 5.22. Analysis of inverted Z_S by simultaneous AVO inversion within the Arbuckle Group at wells #15-121-22590 and #15-121-22591. Red curves are inverted Z_S traces, and black curves are filtered original S-impedance logs. Overall correlation between inverted and original logs is 0.74 for all wells. The total RMS error for all wells is 403 (m/s)*(g/cc).

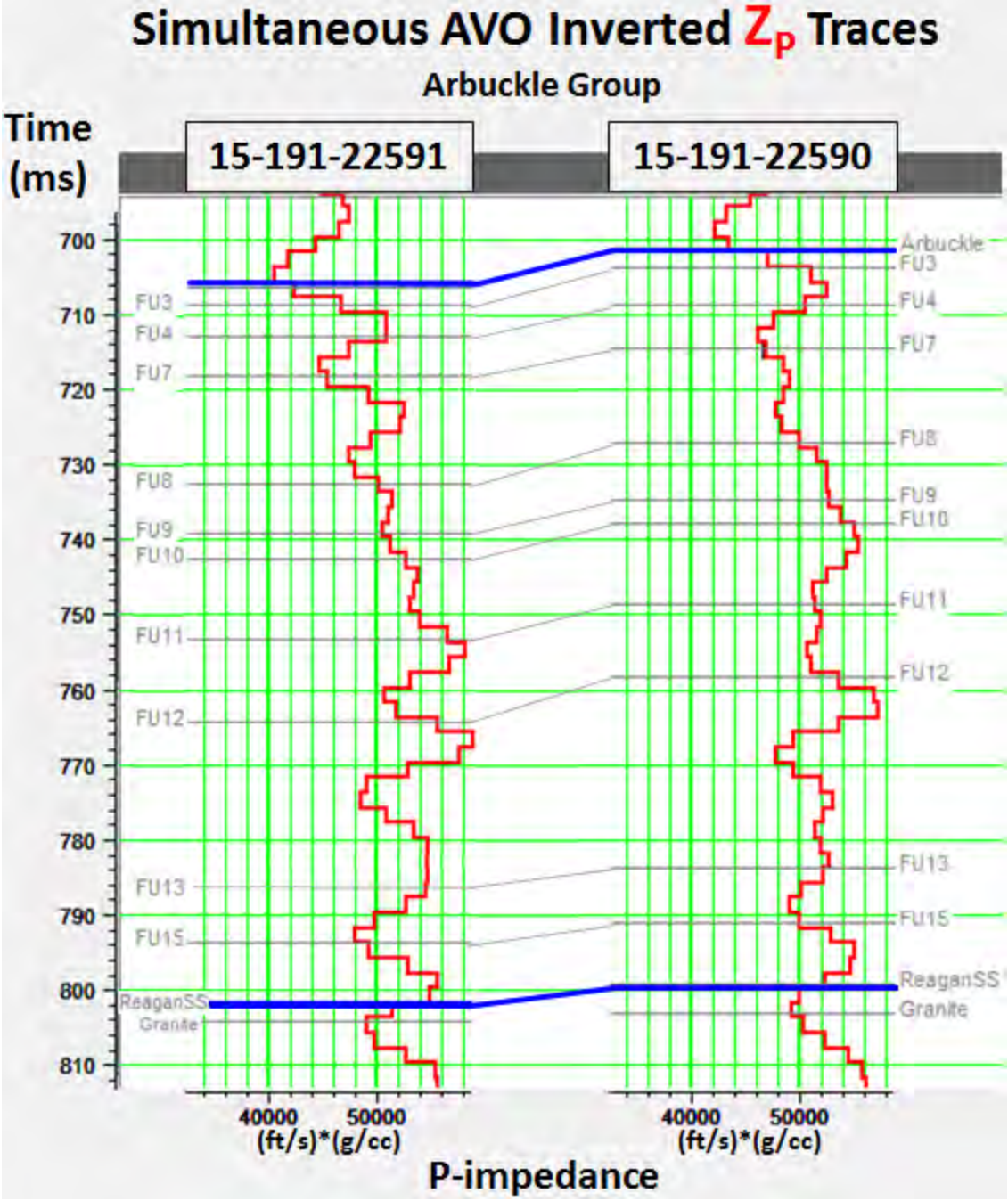
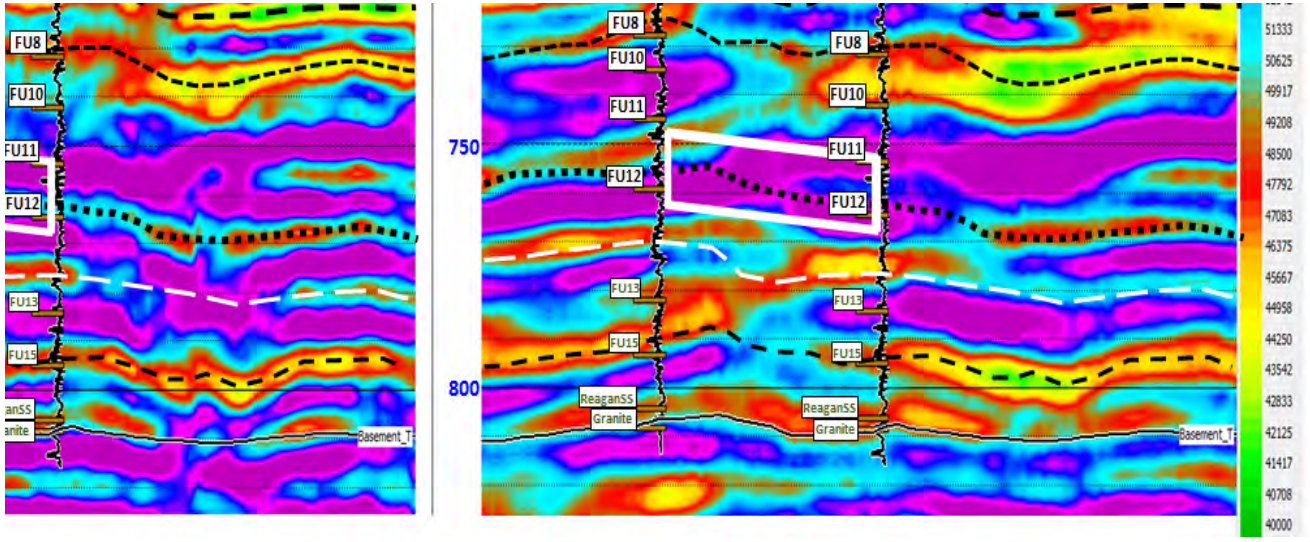


Figure 5.23. Simultaneous AVO inverted Z_P traces at well #15-121-22590 and well #15-121-22591. Both traces show the same trend that made it easy to relate the corresponding tops of the flow units at the two well locations.



(a) (b)

Figure 5.24. a) Simultaneous AVO inverted Z_P cross section. b) Post-stack model-based inverted P-impedance cross section. Cross sections location is Line A shown in Figure 3.3. The low impedance zones are picked by the dashed lines on the simultaneous AVO inverted Z_P cross section because it has better depiction of the subsurface features, and the same dashed lines are overlain on the post-stack model-based inverted P-impedance cross section.

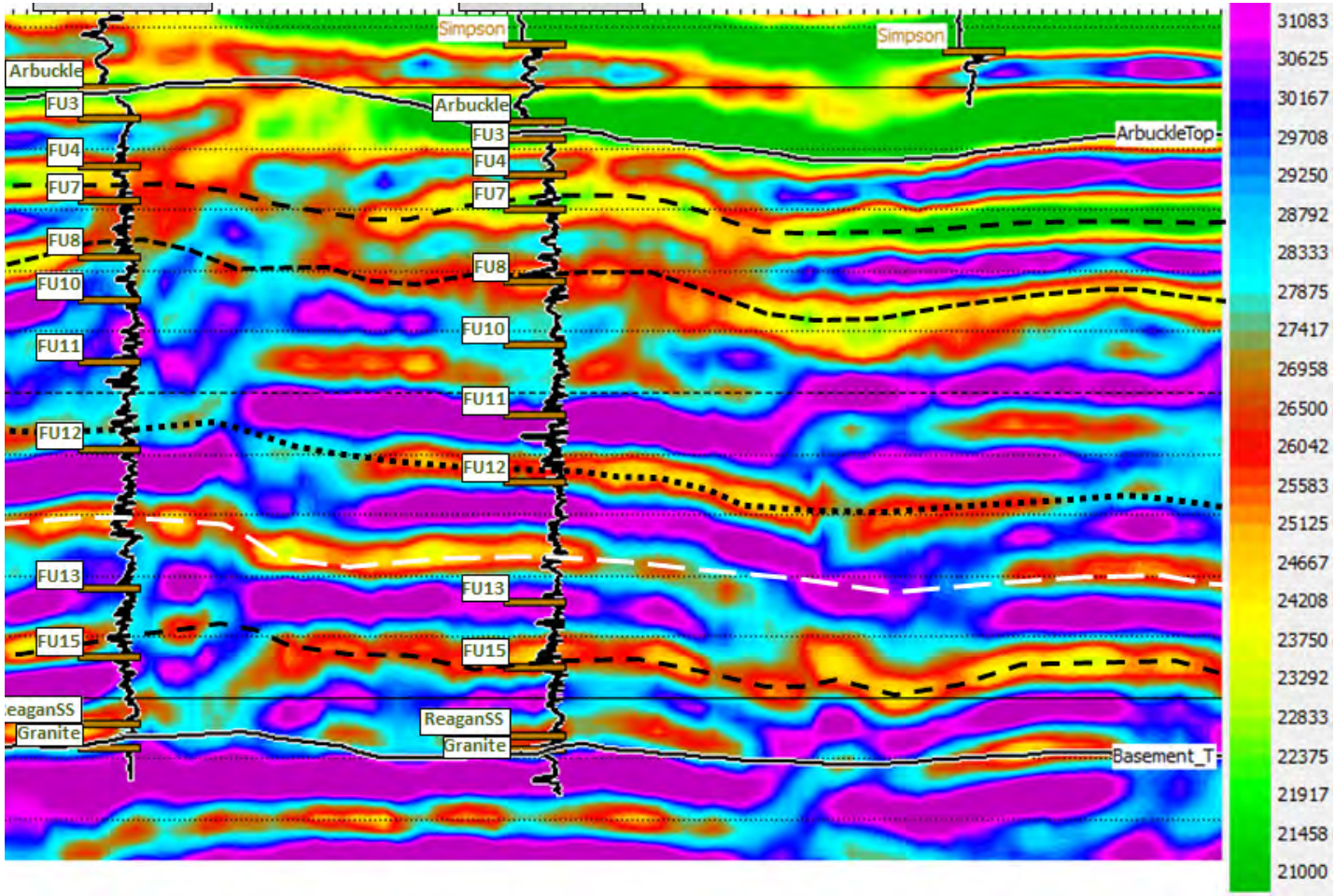


Figure 5.25: Simultaneous AVO inverted Z_S cross section with S-impedance well logs posted at well locations. Cross section location is Line A shown in Figure 3.3.

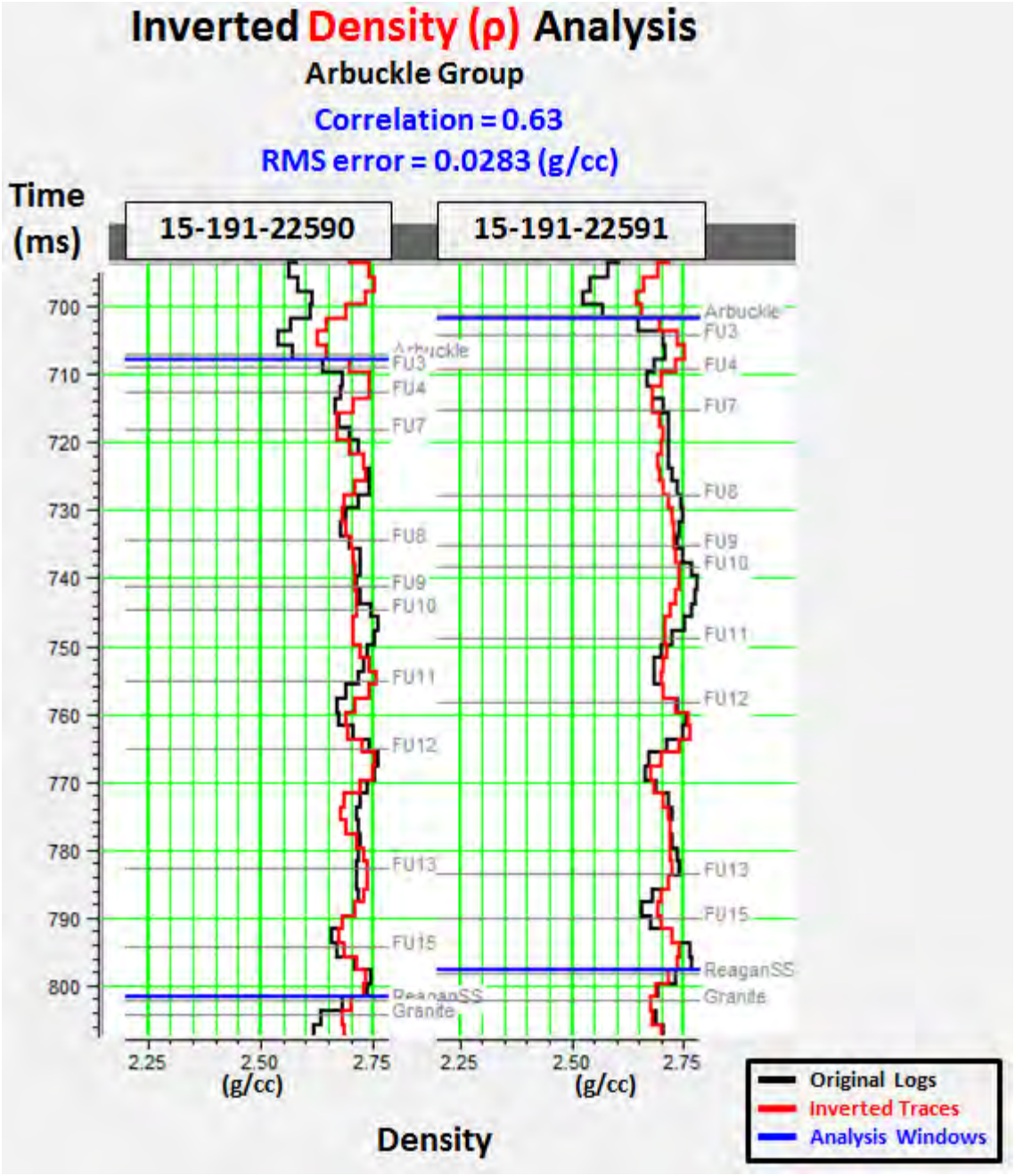


Figure 5.26. Analysis of inverted density by simultaneous AVO inversion within the Arbuckle Group at wells #15-121-22590 and #15-121-22591. Red curves are inverted density traces, and black curves are filtered original density logs. Overall correlation between inverted and original logs is 0.63 for all wells. The total RMS error for all wells is 0.0283 (g/cc).

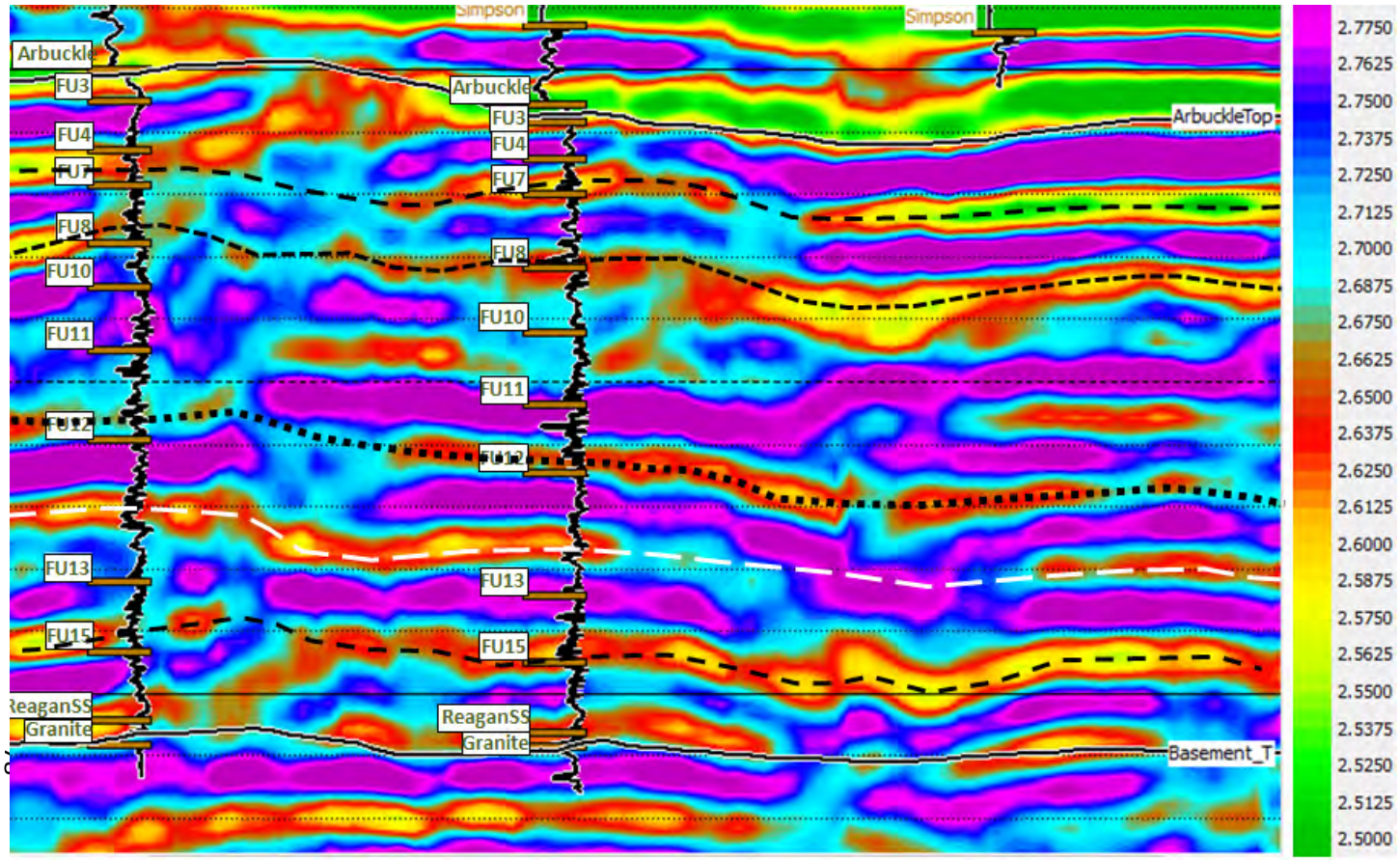


Figure 5.27. Simultaneous AVO inverted density cross section. Cross section location is Line A shown in Figure 3.3.

CHAPTER 6: POROSITY PREDICTION

Three sets of data were used for porosity prediction. The data used were the simultaneous AVO inverted Z_P and Z_S volumes, the post-stack seismic data and formation porosity logs of the eleven wells that are tied to the seismic data. The software used for porosity prediction was the Hampson-Russell EMERGE software that finds the relationship between the formation porosity logs and the seismic attributes at the well locations by multi-attribute linear regression analysis described by Hampson et al. (2001). The software uses this relationship to estimate the porosity at all locations of the seismic volume.

6.1: Multi-attribute Linear Regression Analysis

For porosity prediction, EMERGE software applies multilinear regression analysis to find a relationship between the formation porosity logs and a combination of attributes. EMERGE differentiates between two types of attributes. The internal attributes listed in Table 6.1 are the group of attributes calculated automatically by EMERGE from the post-stack seismic data. The external attributes are the attributes determined by the user which, for this study, were the inverted Z_P and Z_S by simultaneous AVO inversion. The best combination of attributes for porosity prediction is determined by the step-wise regression method which identifies these attributes in steps by trial and error. In the first step, the linear relationship between the formation porosity logs and each attribute is defined by solving the equation for a **single-attribute transform**:

$$\phi(t)=w_0+w_1 .A_1(t) \qquad (5)$$

where $\phi(t)$ – formation porosity values known from well logs,

$A_1(t)$ – a seismic attribute value,

w_0 and w_1 – unknown weights.

Instantaneous attributes:	Amplitude envelope
	Amplitude weighted cosine phase
	Amplitude weighted frequency
	Amplitude weighted phase
	Apparent polarity
	Cosine instantaneous phase
	Instantaneous frequency
	Instantaneous phase
Windowed frequency attributes	Average frequency
	Dominant frequency
Filter slice attributes	Filter 5/10 – 15/20 Hz
	Filter 15/20 – 25/30 Hz
	Filter 25/30 – 35/40 Hz
	Filter 35/40 – 45/50 Hz
	Filter 45/50 – 55/60 Hz
	Filter 55/60 – 65/70 Hz
Derivative attributes	Derivative
	Derivative instantaneous amplitude
	Second derivative
	Second derivative instantaneous amplitude
Integrate attributes	Integrate
	Integrate absolute amplitude

Table 6.1. Internal seismic attributes used in the multi-attribute linear regression analysis.

The weights w_0 and w_1 are calculated by the least-squares minimization approach for each attribute (Hampson et al., 2001). Then, the best attribute that results in the lowest RMS error is chosen to be $A^1_1(t)$. In the second step, another attribute is determined by solving the equation for

two-attribute transform in which the known first best attribute $A^1_1(t)$ is paired with another attribute:

$$\phi(t)=w_0+w_1 .A^1_1(t)+w_2 .A_2(t) \qquad (6)$$

where $\phi(t)$ – formation porosity values known from well logs,

$A^1_1(t)$ – the best single attribute,

$A_2(t)$ – seismic attribute value,

w_0, w_1 and w_2 – unknown weights.

The attribute that results in the lowest RMS values is chosen to be the second attribute $A^2_2(t)$. This process can go on as long as desired to find N seismic attributes to derive a **multi-attribute transform**:

$$\phi(t)=w_0+w_1 \cdot A^1_1(t) +\ldots+ w_N \cdot A^N_N(t) \qquad (7)$$

The higher the number of attributes in the multi-attribute transform the lower the prediction error. However, using a large number of attributes in the transform could result in overfitting the data at the well locations, but the porosity prediction interpolation between the wells would be erroneous (Kalkomey, 1997). Therefore, the validation error is calculated by leaving out wells. When a multi-attribute transform is derived, its validity for porosity prediction is tested by solving for the regression coefficients using porosities from all wells except one well, which is called the blind well. Then, by using the derived coefficients, the prediction error is calculated at the location of the blind well. This process is repeated for all wells to calculate an average validation error (Hampson et al., 2001).

So far, the method is limited because it only correlates each target sample with the corresponding samples on the seismic attribute ignoring the big difference in the frequency content between the well logs and seismic data. Therefore, the crossplot regression was extended

to include neighboring samples by convolutional operators that allow predicting each target sample by a weighted average of samples on each attribute. The number of averaged samples on each attribute is the length of the convolutional operator. The weights on the individual samples are determined by the shape of the convolutional operator (Hampson et al., 2001). Therefore, when using convolutional operators, the multi-attribute transform in equation (7) is replaced by:

$$\phi(t)=w_0+w_1*A^1_1(t) +\ldots+ w_N *A^N_N(t) \qquad (8)$$

(*) Represents convolution by an operator

6.2: Mississippian Reservoir Porosity Prediction

Two multi-attribute transforms were derived in this study. The first multi-attribute transform was derived within the Mississippian reservoir only. Therefore, the porosity prediction volume will not be valid outside the Mississippian reservoir using this transform. A group of attributes and different convolutional operator lengths was tested for optimum porosity prediction. During the process of deriving the transform by step-wise regression, the validation error is measured every time an additional attribute is added to the transform in order to make a cross-validation curve that shows the maximum number of attributes with the lowest validation error. Also, using convolutional operators means adding more attributes that decrease the prediction error but not necessarily the validation error. Therefore, cross-validation is applied for convolutional operators as well (Hampson et al., 2001). Figure 6.1 shows the porosity prediction validation error curves created by crossplotting the number of attributes in the transform against the validation error. Each curve represents a different convolutional operator length. According to the validation error plot in Figure 6.1, the light blue curve shows that the lowest validation error is achieved when the five attributes listed in Table 6.2 are used with 5-point-convolutional operator for porosity prediction within the Mississippian reservoir.

The resulting porosity prediction was evaluated within the Mississippian reservoir. Figure 6.2 shows porosity prediction traces (red) and original porosity logs (black) at well locations. The Mississippian reservoir is marked by the blue markers at the different wells. Figure 6.2 shows good agreement between predicted and original porosity logs within the Mississippian reservoir with an overall cross correlation of 0.90. The crossplotting of predicted and original porosity logs shows a linear relationship that supports the good agreement (Figure 6.3). Figure 6.4 is a cross section of the predicted porosity of Line A with well porosity logs overlain on the section. The derived transform was the best transform for quantitative porosity values prediction within the Mississippian reservoir, but it does not provide meaningful results outside the Mississippian reservoir.

However, the second multi-attribute transform, which was derived within a larger window that includes the surrounding background formations resulted in an acceptable valid porosity prediction within the Mississippian reservoir and around it. The second multi-attribute transform was derived between the Cherokee Group top above the Mississippian and the Reagan Sandstone top at the base of the Arbuckle. Therefore, the resulting porosity prediction volume by the second transform helps identify porosity differences between the Mississippian reservoir and the surrounding formations, and it helps determine the top and the base of the Mississippian reservoir that can be easily delineated across the Wellington field (Figure 6.5). The derivation of the second multi-attribute transform will be discussed in more details in section 6.3. The porosity prediction results were compared with the results of the A-B crossplotting technique described in section 4.1 (Figure 6.6). The same Class IV AVO highlighted zone shows higher porosity values in the porosity prediction cross section as shown in Figure 6.6.

Number of attributes	Seismic Attribute	Prediction Error porosity fraction	Validation error porosity fraction
1	Instantaneous Phase	0.039852	0.045785
2	$1/(Z_S)$	0.031128	0.044479
3	Apparent Polarity (Z_P)	0.025288	0.040763
4	Amplitude Weighted Frequency (Z_P)	0.021179	0.034428
5	Second Derivative	0.018626	0.032762

Table 6.2: Attributes of the first multi-attribute transform derived within the Mississippian chert reservoir for porosity prediction. Note that the prediction error decreases with increasing number of attributes. Validation error was used to determine the optimum number of seismic attributes.

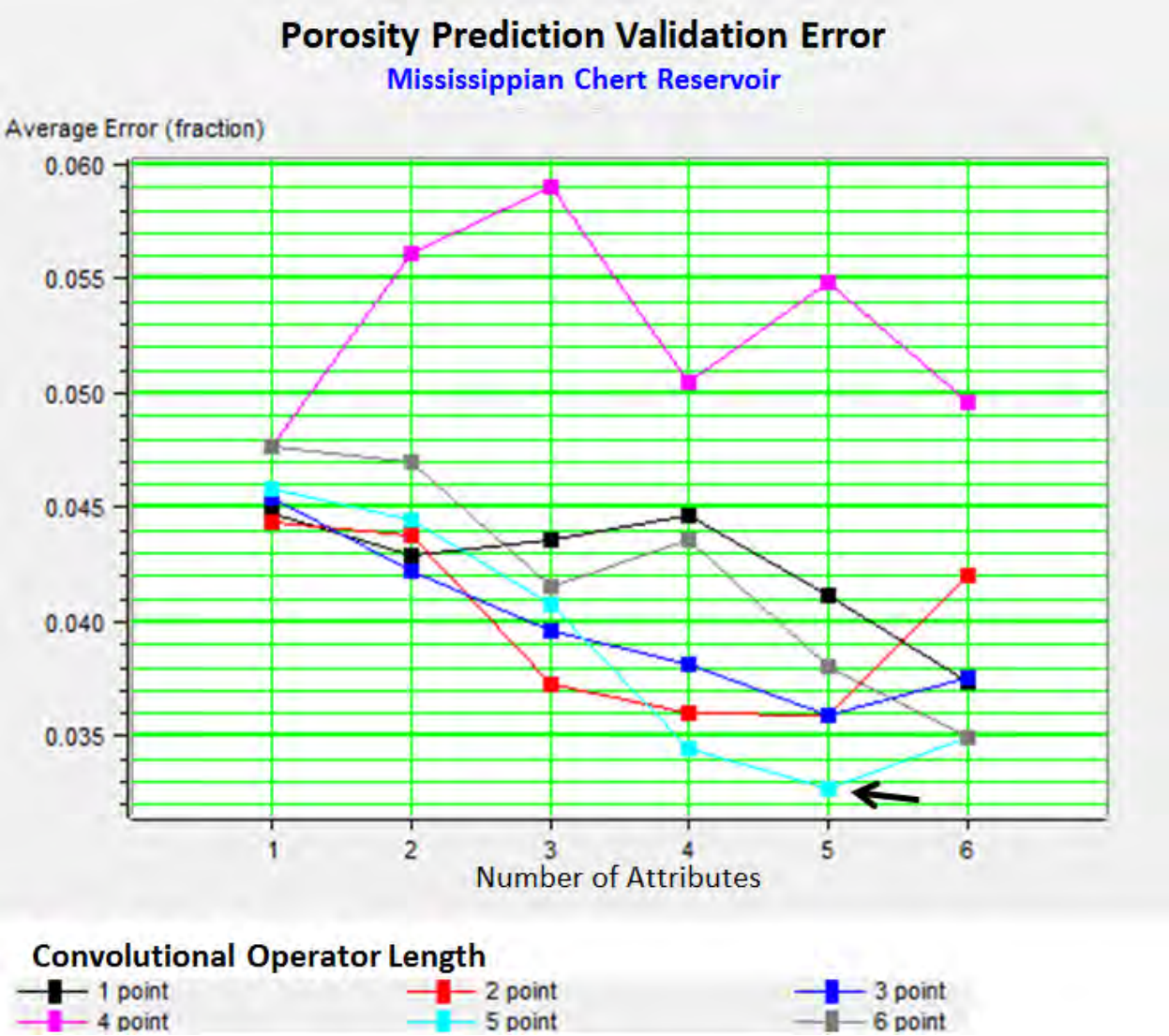


Figure 6.1. Average RMS validation error versus the number of seismic attributes used for deriving multi-attribute transforms within the Mississippian chert reservoir only. Each curve represents the convolutional operator length. The lowest RMS validation error is achieved when the five attributes listed in Table 6.2 are used with 5-point-convolutional operator.

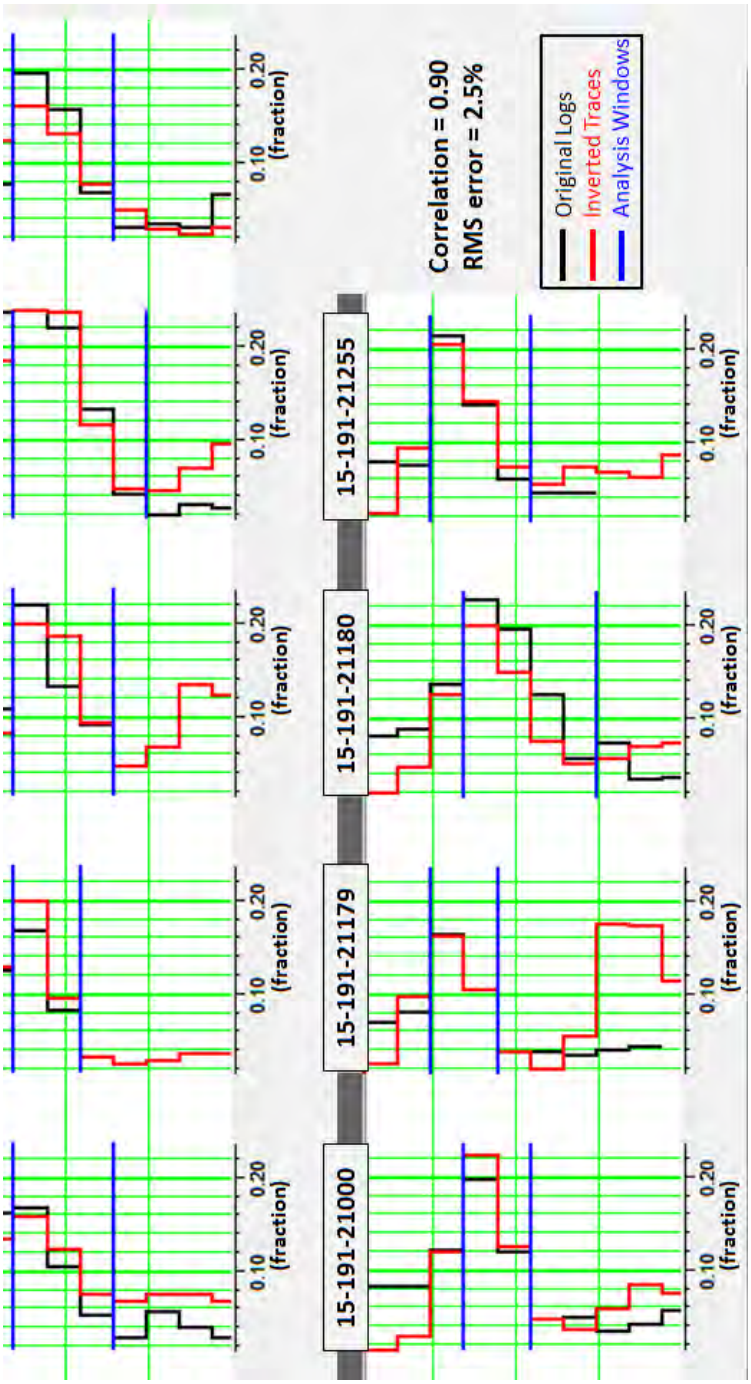


Figure 6.2. Analysis of the predicted porosity by the first multi-attribute transform within the Mississippian reservoir (shown by the blue horizontal lines of the analysis window) at 11 well locations. The predicted porosity traces (red) show a good agreement with the original formation porosity logs (black) with an overall correlation of 0.90 for all wells. The total RMS error for all wells is 2.5%.

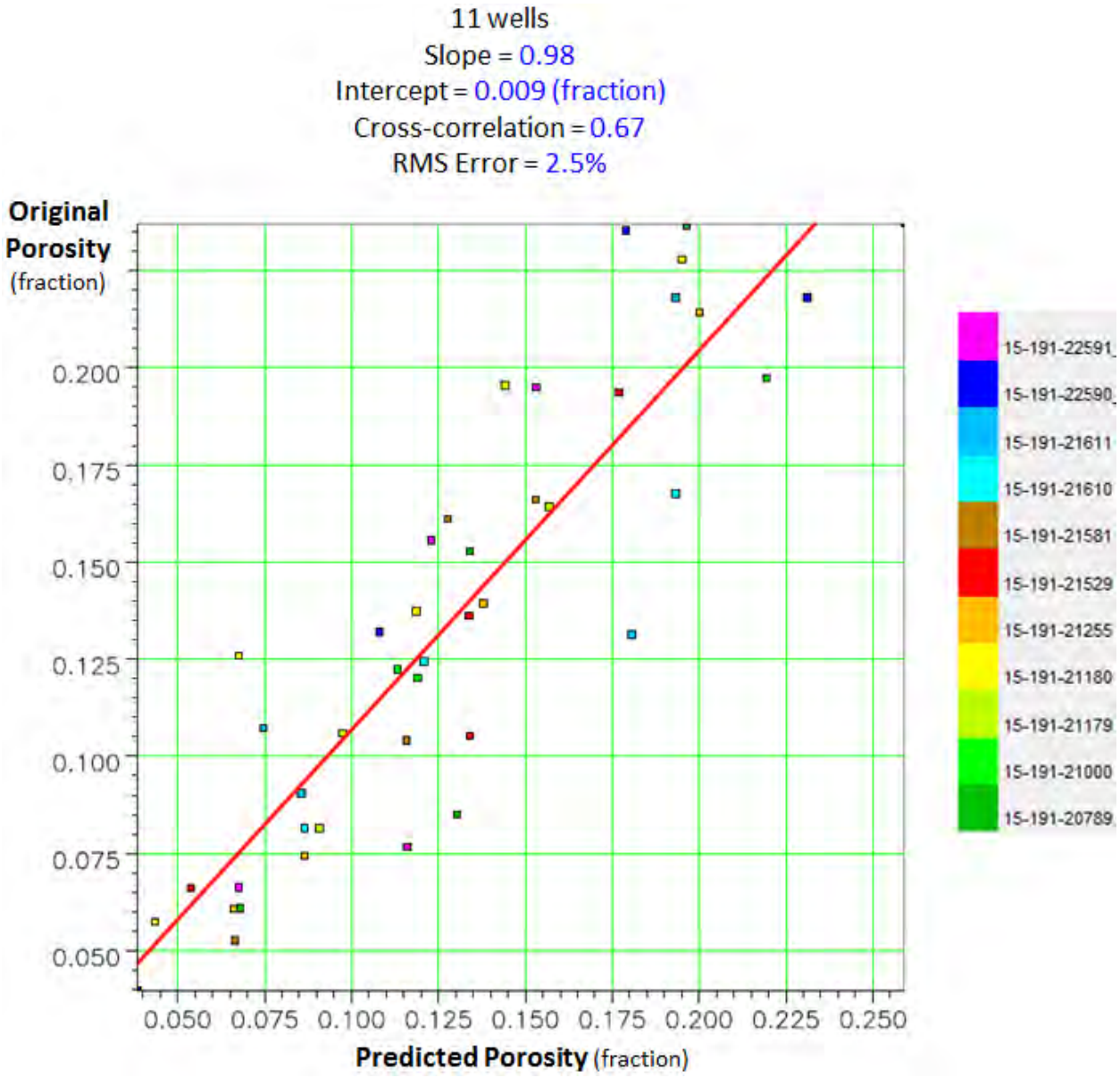


Figure 6.3. Crossplot of the predicted porosity by the first multi-attribute transform versus the original formation porosity logs within the Mississippian chert reservoir (the analysis window shown with blue horizontal lines in Figure 6.2) at 11 well locations. The red line shows the line of perfect correlation between predicted and original porosity values. The total RMS error for the 11 wells is 2.5%.

Figure 6.4. Cross section of predicted porosity by the first multi-attribute transform with formation porosity logs posted at well locations. The first multi-attribute transform derived with the Mississippian chert reservoir is the best transform for quantitative porosity values prediction within the Mississippian reservoir, but it does not provide meaningful results outside the Mississippian chert reservoir. Cross section location is Line A shown in Figure 3.3.

Figure 6.5. Cross section of predicted porosity by the second multi-attribute transform with formation porosity logs posted at well locations. The second multi-attribute transform derived between the Cherokee formation top and the Reagan Sandstone top provides valid results outside the Mississippian chert reservoir. Cross section location is Line A shown in Figure 3.3.

Figure 6.6. (Top) Cross section of predicted porosity by the second multi-attribute transform with formation porosity logs. (Bottom) Cross section of Class IV AVO highlighted zone by the A-B crossplotting technique with formation porosity logs. The same Class IV AVO highlighted zone shows high porosity values in the porosity prediction cross section. Cross section location is Line A shown in Figure 3.3.

6.3: Arbuckle Group Porosity Prediction

When the multi-attribute transform was derived within the Arbuckle Group only, it resulted in a porosity prediction volume that has high correlation with formation porosity logs at wells #15-121-22590 and #15-121-2259, but the resulting volume did not provide reasonable porosity values away from the two wells. This might be due to limited well control within the Arbuckle. Unlike the Mississippian reservoir, the optimum porosity prediction quality within the Arbuckle was achieved when the multi-attribute transform was derived between the Cherokee Group top and the Reagan Sandstone top using the eleven wells that have formation porosity logs including the wells that did not penetrate the Arbuckle Group.

According to the validation error plot in Figure 6.7, the light blue curve shows that the lowest validation error is achieved when the seven attributes listed in Table 6.3 are used with 5-point convolutional operator for porosity prediction between the Cherokee Group top and the Reagan Sandstone top.

The resulting porosity prediction volume was analyzed within the Arbuckle Group. Figure 6.8 shows the porosity prediction traces (red) and the original formation porosity logs (black) at wells #15-121-22590 and #15-121-2259. The blue markers represent the analysis window between the Arbuckle top and the Reagan Sandstone. The overall correlation of the predicted porosity traces with the original formation porosity logs is 0.67.

The results of the porosity prediction in the Arbuckle show good agreement with the results of the A-B crossplotting technique (Figures 6.9-6.10). In Figures 6.9-6.10, the highlighted Class IV AVO zones show higher porosity values than the zones that were not highlighted on the corresponding porosity prediction sections.

Number of attributes	Seismic Attribute	Prediction Error porosity fraction	Validation error porosity fraction
1	$1/(Z_S)$	0.031697	0.033091
2	$1/(Z_P)$	0.029556	0.032147
3	Filter 35/40-45/50	0.028154	0.030998
4	Instantaneous Phase	0.026858	0.030423
5	Second Derivative	0.026060	0.029963
6	Filter 35/40-45/50 (Z_P)	0.025368	0.029856
7	Average Frequency	0.024891	0.029135

Table 6.3: Attributes of the second multi-attribute transform derived between the Cherokee Group top and the Reagan Sandstone top for porosity prediction. Note that the prediction error decreases with increasing number of attributes. Validation error was used to determine the optimum number of seismic attributes.

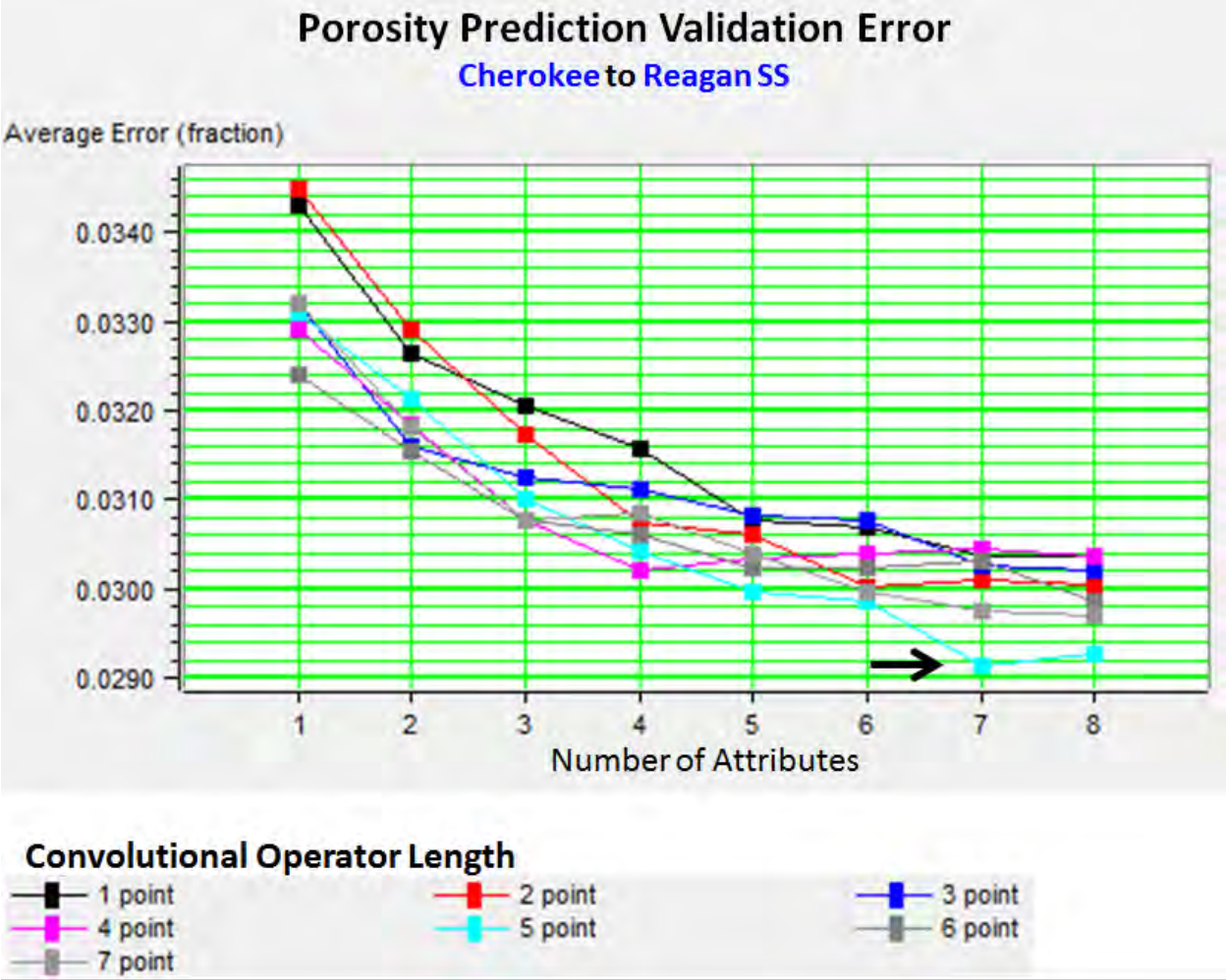


Figure 6.7: Average RMS validation error versus the number of seismic attributes used for deriving multi-attribute transforms between the Cherokee Group top and the Reagan Sandstone top. Each curve represents the convolutional operator length. The lowest RMS validation error is achieved when the seven attributes listed in Table 6.3 are used with 5-point-convolutional operator.

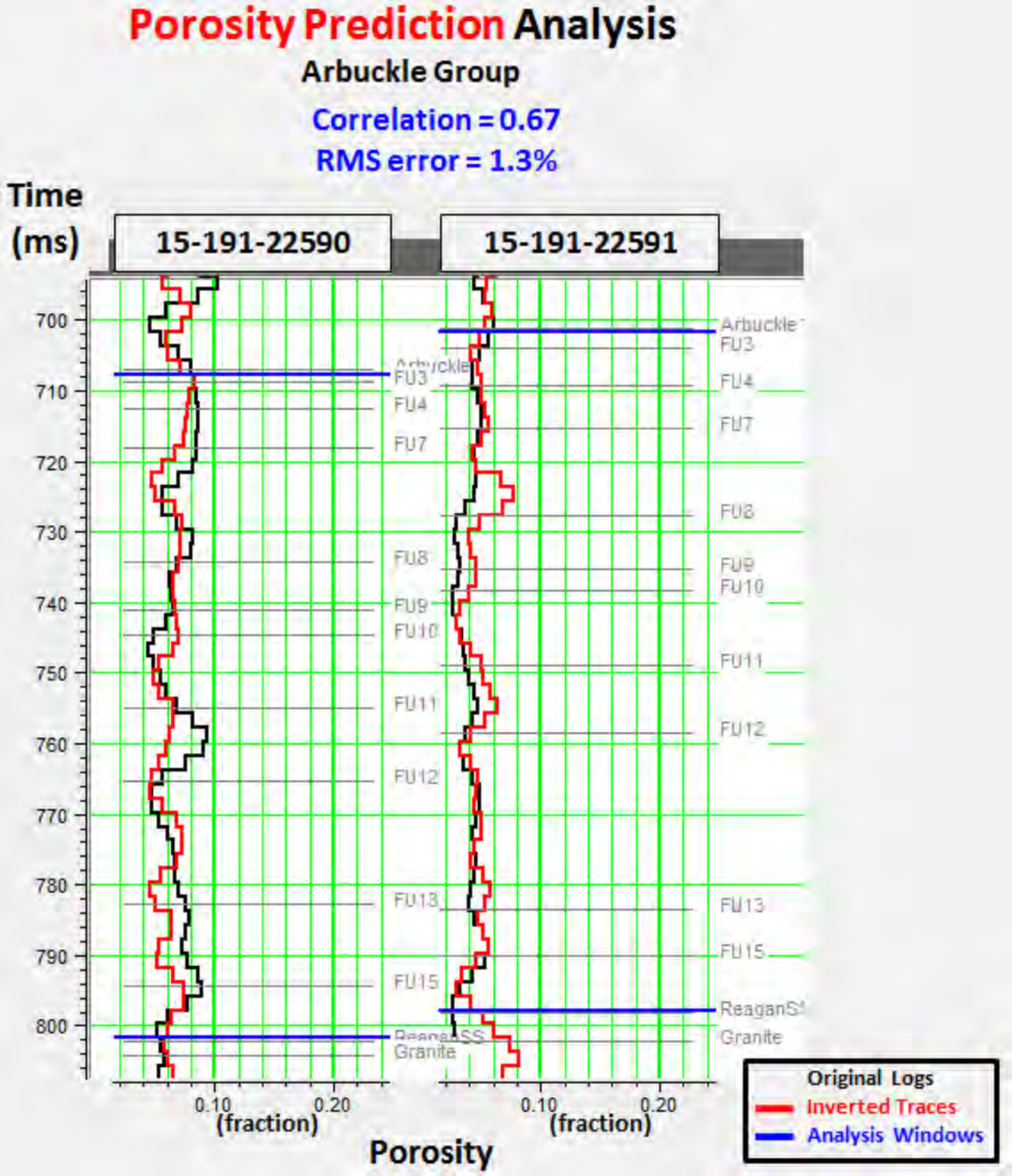


Figure 6.8. Analysis of predicted porosity by the second multi-attribute transform within the Arbuckle Group at wells #15-121-22590 and #15-121-22590. Red curves are predicted porosity traces and black curves are filtered original formation porosity logs. Overall correlation between inverted and original logs is 0.67 for all wells. The total RMS error for all wells is 1.3%.

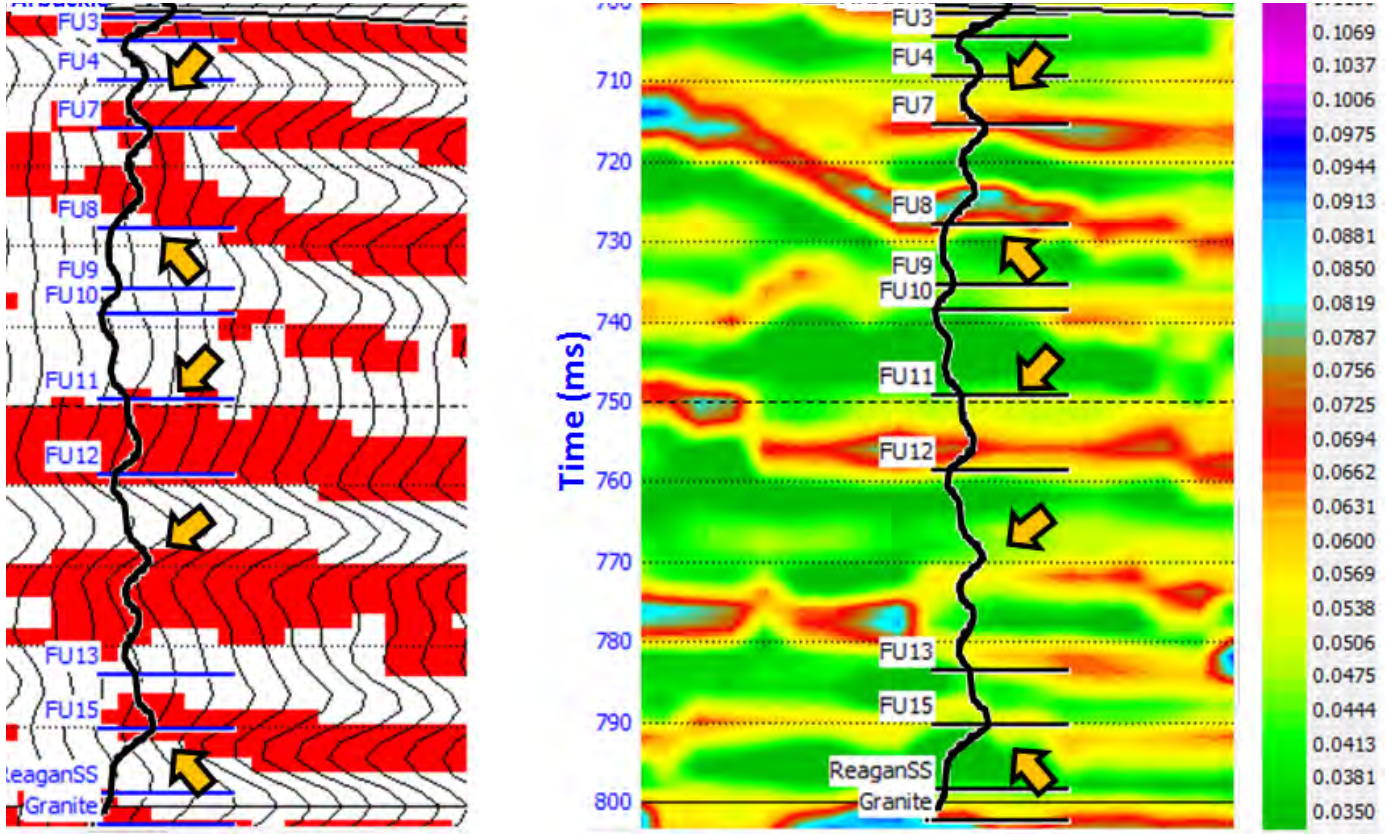


Figure 6.9. (Left) Cross section of Class IV AVO highlighted zone by the A-B crossplotting technique along inline #152. (Right) Cross section of predicted porosity by the second multi-attribute transform along inline #152. The same Class IV AVO highlighted zones show high porosity values in the porosity prediction cross section. Black curves are formation porosity logs of well #15-121-22591.