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

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

FREQUENCY CODES AND DUE DATES:

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

QUARTERY PROGRESS REPORT

Award Number: DE-FE0002056

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

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

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

Tenth Quarter Progress Report

Date of Report: May 1, 2012

Period Covered by the Report: January 1, 2012 through March 31, 2012

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

EXECUTIVE SUMMARY

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

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

Project Status: Subtasks completed within current quarter: Subtask 17.1 Collect existing seismic, geologic, and engineering data on Chester/Morrow fields.

Subtasks completed till date include: 1) 3D seismic survey at Wellington field (Sumner County, KS) processed and p-wave interpreted, 2) Wellington field seismic data merged with donated 3D seismic data from the adjacent Anson and Bates fields, 3) Wellington 3D seismic interpretation includes structure, time slices, volumetric coherency, curvature, and fault/flexure mapping, 4) two test boreholes drilled in Wellington Field, 5) gravity and magnetic surveys over 17+ county regional study area have been reprocessed and suggested basement faults/fracture trends mapped for validation, 6) remote sensing data over 17+ county regional study area analyzed and surface lineaments mapped, 7) multiple stratigraphic horizons have been mapped over regional study area, 8) multi-township areas selected within regional study area for detailed characterization and simulation studies to evaluate CO_2 sequestration potential in Arbuckle Group saline aquifer, 9) depth-constrained cluster

analysis conducted on petrophysical properties to identify Arbuckle flow-units and analysis tool incorporated into Java petrophysical application, 10) initial simulation studies of Arbuckle conducted at Oxy-Chem #10 well to north of Wellington Field in Sedgwick County and at Wellington Field in Sumner County to make preliminary estimates of CO_2 sequestration potential, 11) available Arbuckle DST data collected, analyzed, and mapped showing hydraulic communication with northwestern Ozark uplift outcrop in Missouri, 12) website has been updated to include maps of latest subsurface geology, remote sensing analysis, and reprocessed gravity and magnetic information, 13) initial core description made, 14) release new log analysis Java web tool, 15) updated interactive mapper with new legend and map section window.

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

Project Status: Subtasks completed within current quarter:

ONGOING AND COMPLETED ACTIVITIES - REGIONAL STUDY INCLUDING SOUTHWEST KANSAS) - 1) continue quality control, normalization, calibration of digital borehole data; 2) began construction of a 3D geocellullar model of the Arbuckle saline aquifer; 3) characterization and verification of faults using all data types including donated regional 3D seismic in order to complete structural mapping; 4) computing initial estimates of CO2 storage capacity for use in NATCARB carbon sequestration atlas; 5) reviewing new reservoir simulation of Chester sandstone in Pleasant Prairie Field; 6) interpreting and integrating 3D seismic in western Kansas to select location for new basement well.

ONGOING & COMPLETED ACTIVITIES - WELLINGTON FIELD –1) depth-migrated 3D seismic survey received and uploaded into geomodel and seismic inversion and shear wave interpretations forthcoming; 2) calibrating well logs for revised geomodel of the Mississippian reservoir and prepare geomodel for reservoir simulation.

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

Task Name	Planned Start Date	Actual Start Date	Planned Finish Date	Actual Finish Date	% Complete
1.0 Project Management & Planning	12/8/2009	12/08/09	12/7/2012		55%
2.0 Characterize the OPAS (Ozark Plateau Aquifer System)	1/1/2010	01/01/10	6/30/2012		50%
3.0 Initial geomodel of Mississippian Chat & Arbuckle Group - Wellington field	1/1/2010	01/01/10	9/30/2010	09/30/10	100%
4.0 Preparation, Drilling, Data Collection, and Analysis - Well #1	9/15/2010	12/15/10	3/31/2011	08/30/11	100%
5.0 Preparation, Drilling, Data Collection and Analysis - Well #2	1/1/2011	02/20/11	6/30/2011	08/30/11	100%
6.0 Update Geomodels	5/1/2011	05/01/11	9/30/2011	*	90%
7.0 Evaluate CO2 Sequestration Potential in Arbuckle Group Saline Aquifer	8/1/2011	08/01/11	12/31/2011	**	85%
8.0 Evaluate CO2 Sequestration Potential in Depleted Wellington field	10/15/2011		3/31/2012	***	40%
9.0 Characterize leakage pathways - risk assessment area	1/1/2010	01/01/10	6/30/2012	+	60%
10.0 Risk Assessment related to CO2-EOR and CO2 Sequestration in saline aquifer	6/1/2012		9/30/2012	++	20%
11.0 Produced water and wellbore management plans - Risk assessment area	1/1/2012		10/31/2012		40%
12.0 Regional CO2 sequestration potential in OPAS	8/1/2012		12/7/2012		30%
13.0 Regional source sink relationship	1/1/2010		12/7/2012		40%
14.0 Technology Transfer	1/1/2010		12/7/2012		

ACCOMPLISHMENTS

REGIONAL STUDY - INCLUDING SOUTHWEST KANSAS

ONGOING AND COMPLETED ACTIVITIES –

Task 12. Regional CO2 Sequestration Potential in OPAS - 17 Counties
Task 15. Extend Regional Study of Ozark Plateau Aquifer System (OPAS) to the Western Border of Kansas – "Western Annex"

The initial storage capacity of the regional Arbuckle saline formation was computed using Appendix B of the 2010 Carbon Sequestration Atlas of the United States and Canada published by DOE/NETL. Appendix B, "Summary of the Methodology for Development of Geologic Storage Estimates for Carbon Dioxide". The equation used,

$$G_{CO2} = A_t\ h_g\ Ø_{tot}\ \rho\ E_{saline}$$

includes, G_{CO2}, the storage capacity (tonnes), the total area (A_t), gross formation thickness (h_g), and total porosity ($Ø_{tot}$) terms account for the total bulk volume of pore space available. The CO2 density (ρ) converts the reservoir volume of CO2 to mass. Rather than using an irreducible water saturation parameter explicitly, the storage efficiency factor (E_{saline}) reflects the fraction of the total pore volume that will be occupied by the injected CO2. The E_{saline} factors ranges between 0.40 and 5.5 percent over the 10th to 90th percent probability range. CO2 density is averaged over h_g and A_t.

Gerlach with the Bittersweet team produced the necessary grids and the storage calculations using the following procedure:

1. Compute density grid for supercritical CO2 with a grid the same dimensions as those noted above.
   a. Obtain median depth of Arbuckle [(hbase-htop)+htop].
   b. Calculate pressure at median depth of Arbuckle
2. Estimate temperature in degrees C at this depth for use in density conversion equation from Ouyang (2011) and compute density grid.
   Ouyang, Liang-Biao, 2011, New Correlations for Predicting the Density and Viscosity of Supercritical Carbon Dioxide Under Conditions Expected in Carbon Capture and Sequestration Operations: Open Petroleum Engineering Journal, v. 4, p. 13-21.
3. Use $_{Esaline}$ from table in Appendix B (below) for dolomite and compute G_{CO2} for P10 and P90 for dolomite, where E_{saline} for P10 = .0064 and P90 = .055

Table 7: Saline Formation Efficiency Factors For Geologic and Displacement Terms

Saline Formation Efficiency Factors for Geologic and Displacement Terms $E_{saline} = E_{An/At} E_{hn/hg} E_{\phi e/\phi tot} E_v E_d$			
Lithology	P_{10}	P_{50}	P_{90}
Clastics	0.51%	2.0%	5.4%
Dolomite	0.64%	2.2%	5.5%
Limestone	0.40%	1.5%	4.1%

4. Compute grids and use grid to grid calculations to obtain G_{CO2} to create map specified by SWP and NATCARB. Grids were submitted to SWP and NATCARB and are summarized below in a series of maps created by Gerlach in Geographix (**Figure 1-7**).

Approach to be taken for future update of the CO2 storage capacity in the Arbuckle saline formation:

a) Obtaining petrophysical data Arbuckle from individual major hydrostratigraphic units of the Arbuckle (illustrated in **Figures 8-11**),
b) Establish hydrostratigraphic units as flow and storage intervals based on estimates of permeability calibrated from cores and NMR logs ran in new test wells in the western and eastern sectors of the regional study area. Focus on delineating lower flow units for optimizing injection and using higher storage/baffle strata to create separate CO2 plumes for efficient degradation of the free phase (supercritical) CO2.

c) Run simulations of CO2 injection into the lower flow units of the Arbuckle, currently focused on Gasconade to Gunter interval (**Figure 10**), and after estimated time of a commercial injection obtain estimates of storage of CO2 via types of storage related to flow units and baffles, i.e., capillary imbibition.

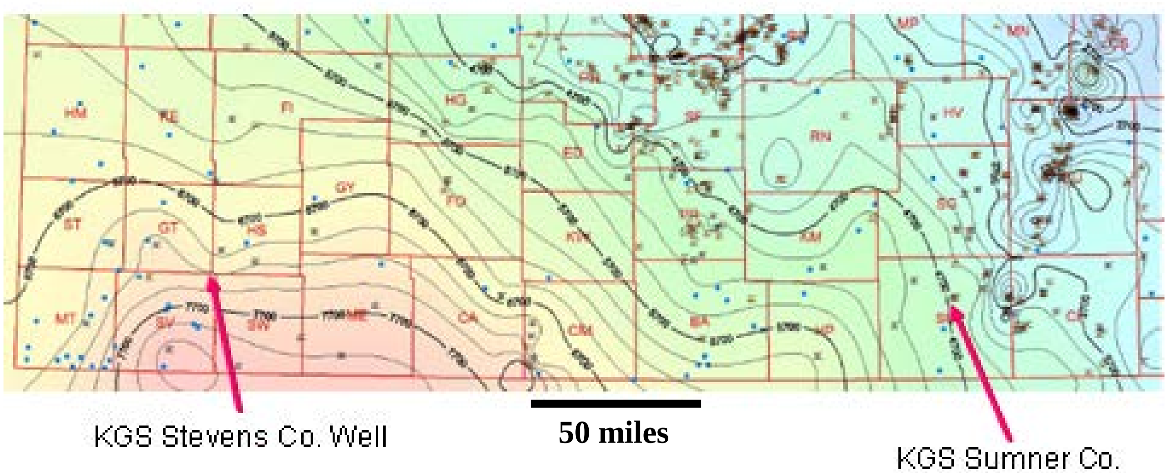


Figure 1. Median depth in feet Arbuckle used to compute density of supercritical CO2.

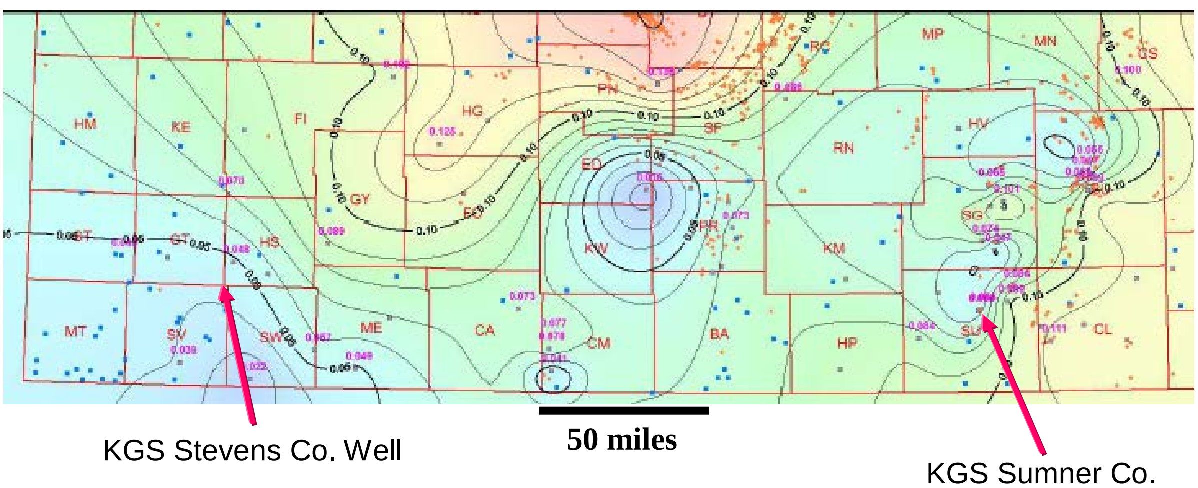


Figure 2. Average fractional porosity in Arbuckle Group using density log with matrix density of 2.8 g/cc. This is a conservative estimate of porosity.

Figure 1 showing median depth illustrates the increase in depth of the Arbuckle into southwestern Kansas into the Hugoton Embayment and porosity in Figure 2 shows a corridor of lower porosity in cooler colored areas covers much of the mapped area. Matrix density of 2.80 g/cc reflects a lithology of silica and dolomite. Average porosity used from the entire Arbuckle does not reveal the fact that the Arbuckle is comprised of distinct hydrostratigraphic units that have both higher porosity and permeability (flow units) and lower porosity zones that could act as baffles to flow and storage through capillary imbibition of the CO2. Future estimates of storage will distinguish between them through the regional stratigraphic correlations that have been previously shown.

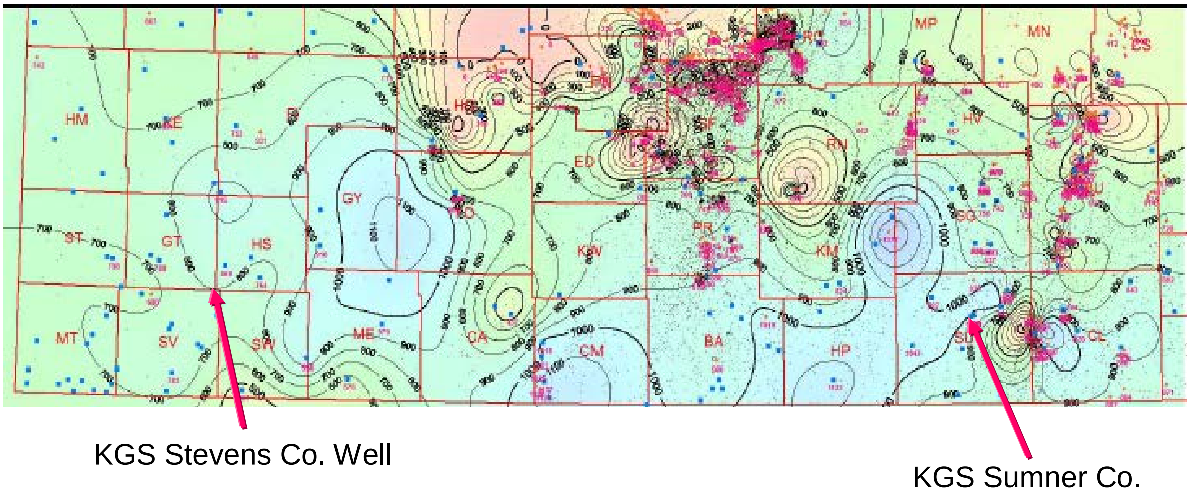


Figure 3. Average thickness of the Arbuckle in feet showing the location for the drilling and coring in the project in Stevens and Sumner counties. Thinner Arbuckle (warmer colors) occurs in the north central region over the Central Kansas Uplift and locally along a narrow northeast-trending Nemaha Uplift where in both locations the Arbuckle is locally very thin or truncated/eroded beneath the basal Pennsylvanian unconformity.

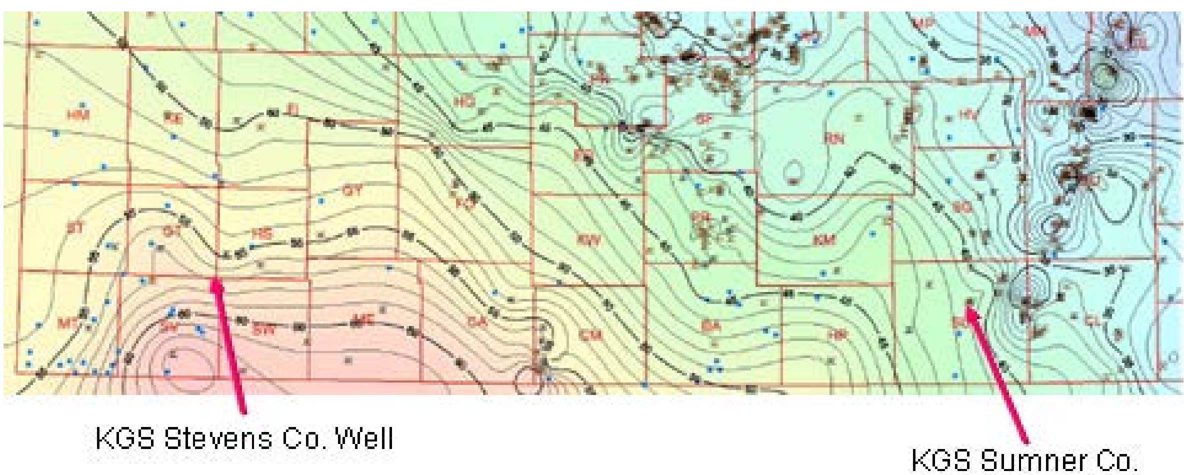


Figure 4. Corrected temperature at the median depth of the Arbuckle in degrees C using the formula, T_{cor} = 12.7 °C + (median depth*0.006111 °C/ft).

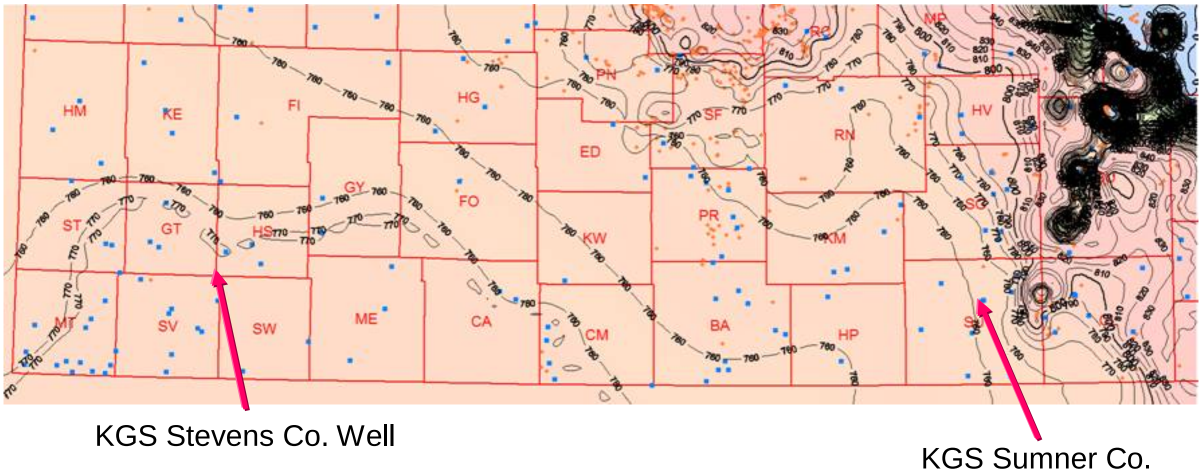


Figure 5. Density of supercritical CO2 in kg/m3 for the regional study area in southern Kansas reflecting increasing depth and temperature to the southwest.

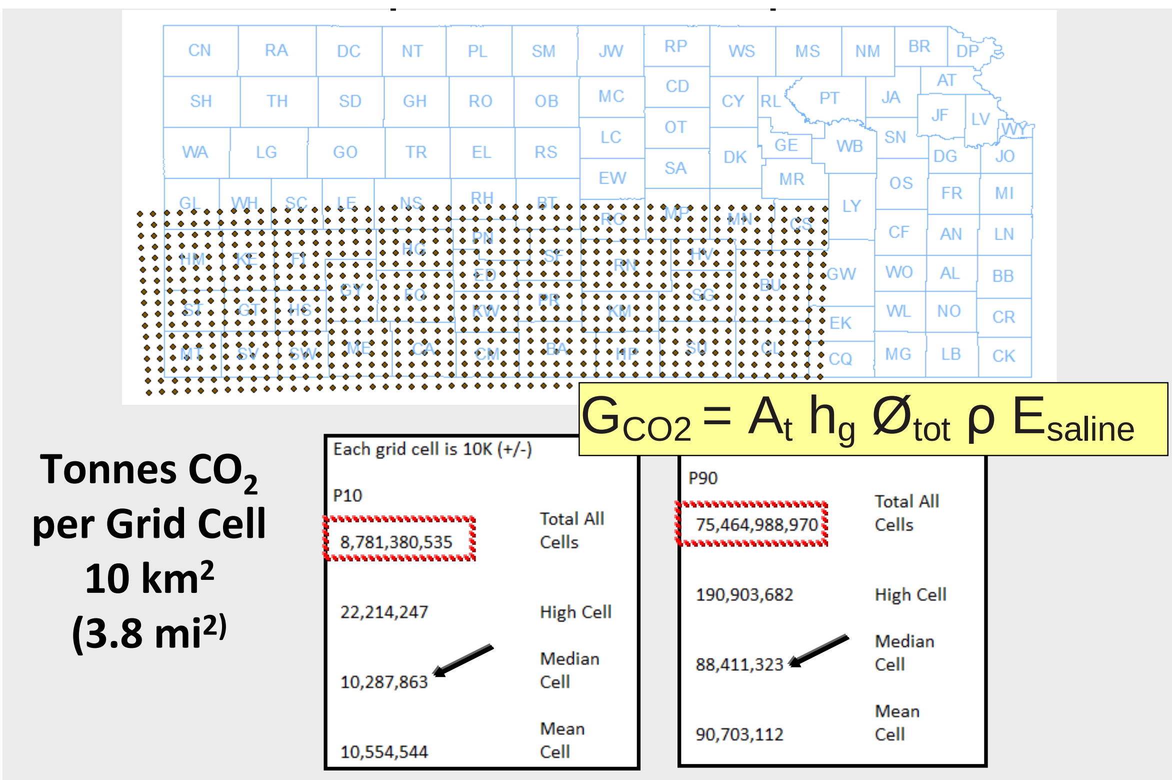


Figure 6. Initial CO2 storage capacity estimate of deep Arbuckle saline formation in southern Kansas. P10 in the low 10% range of probability for storage of 8.8 billion tonnes. P90 estimate of CO2 storage is 75.5 billion tonnes. Grids used were specified by NATCARB as 10 km^2 or 3.8 mi^2.

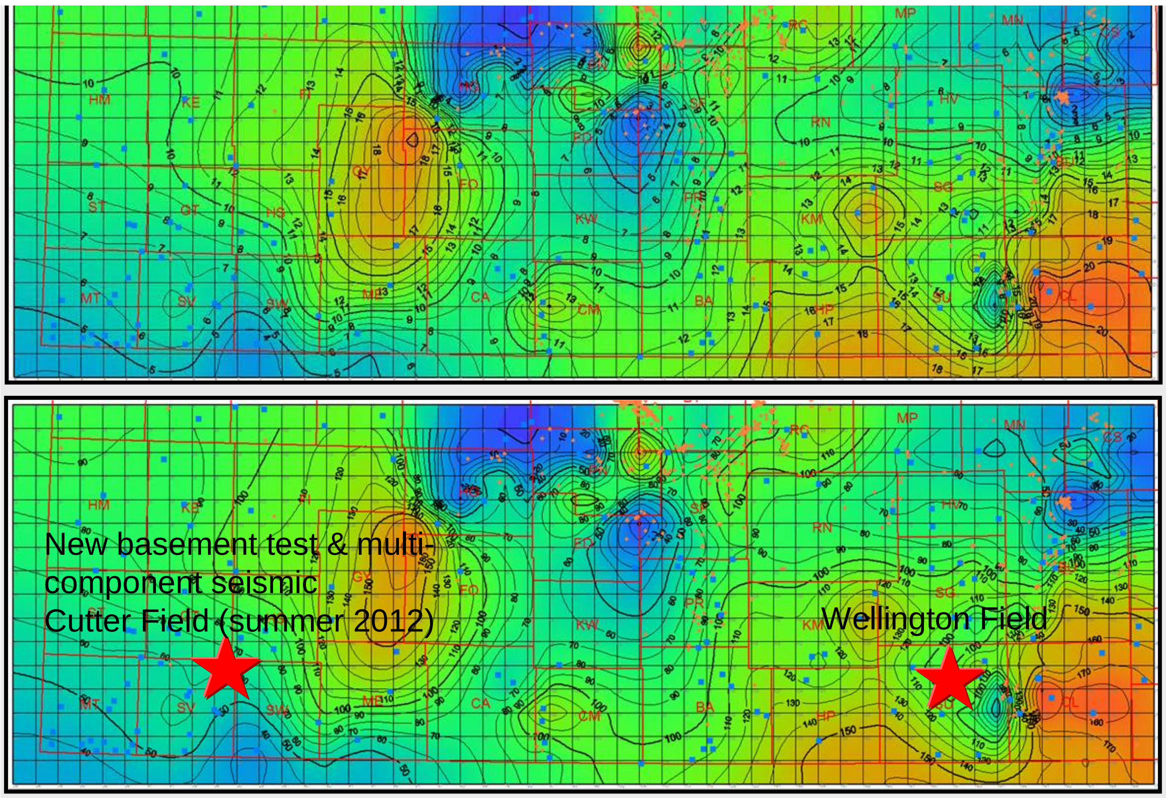


Figure 7. P10 (top) and P90 (bottom) storage volume of CO2 in tonnes (metric tons).

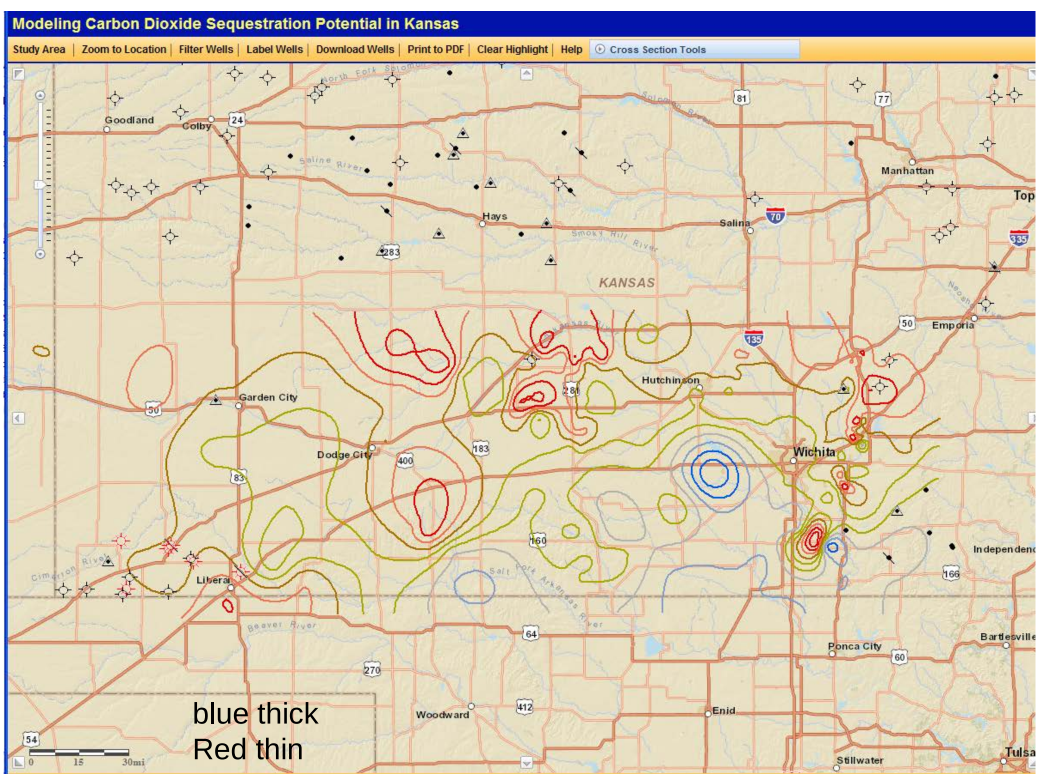


Figure 8. Jefferson City – Rubidoux isopach for southern Kansas study area. Blue contours = thick.

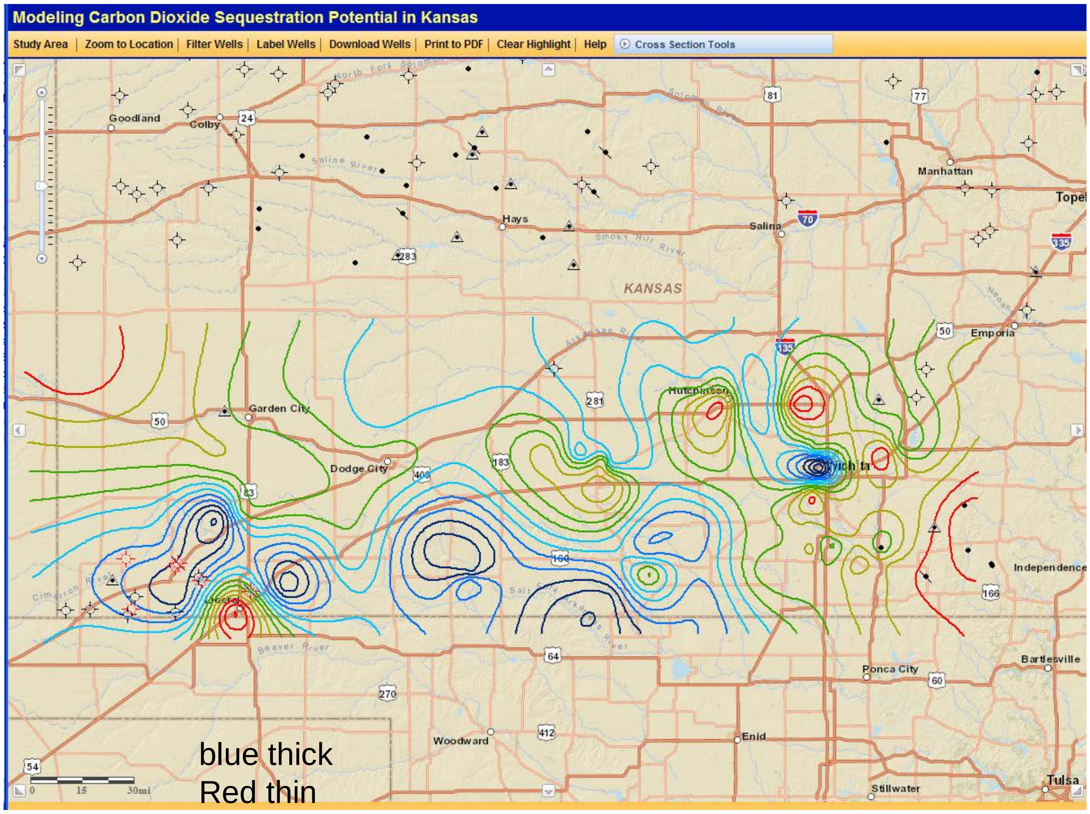


Figure 9. Rubidoux to Gasconade isopach for southern Kansas study area.

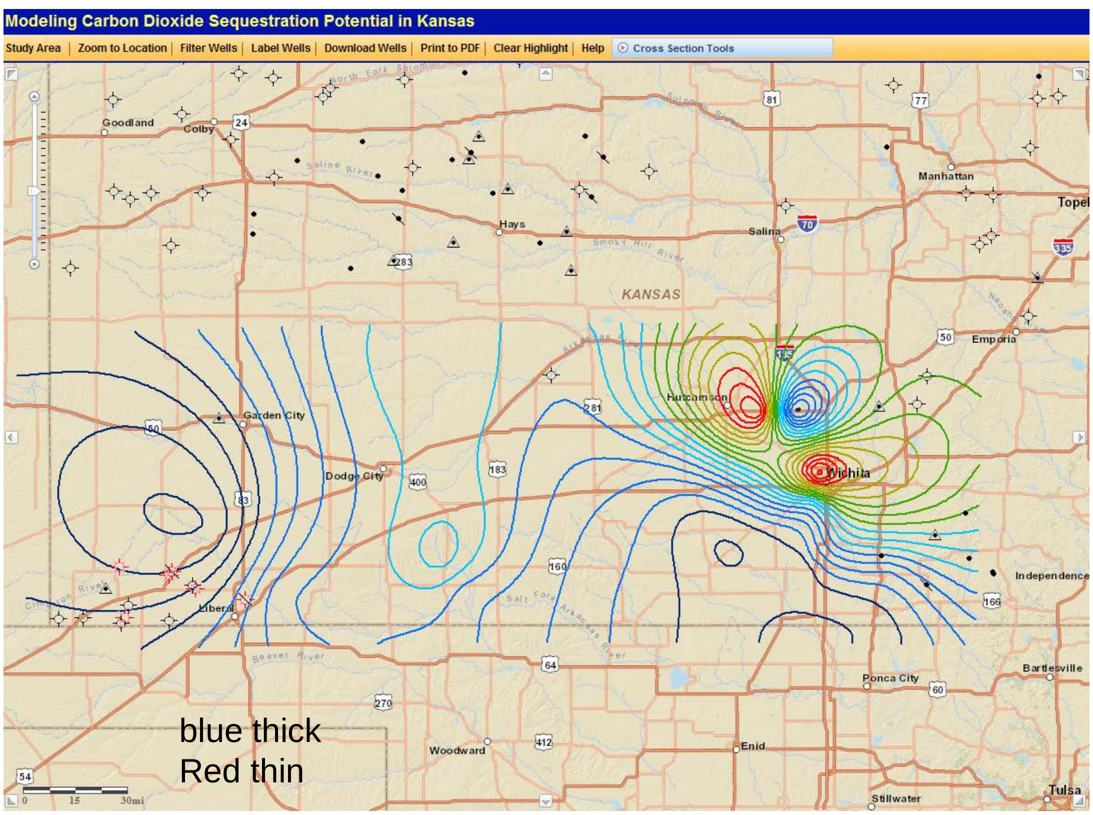


Figure 10. (previous page) Gasconade to Gunter Sandstone isopach in southern Kansas study area. This is the key interval that shows higher porosity in the eastern region that is the zone of interest for CO2 injection at Wellington Field in Sumner County.

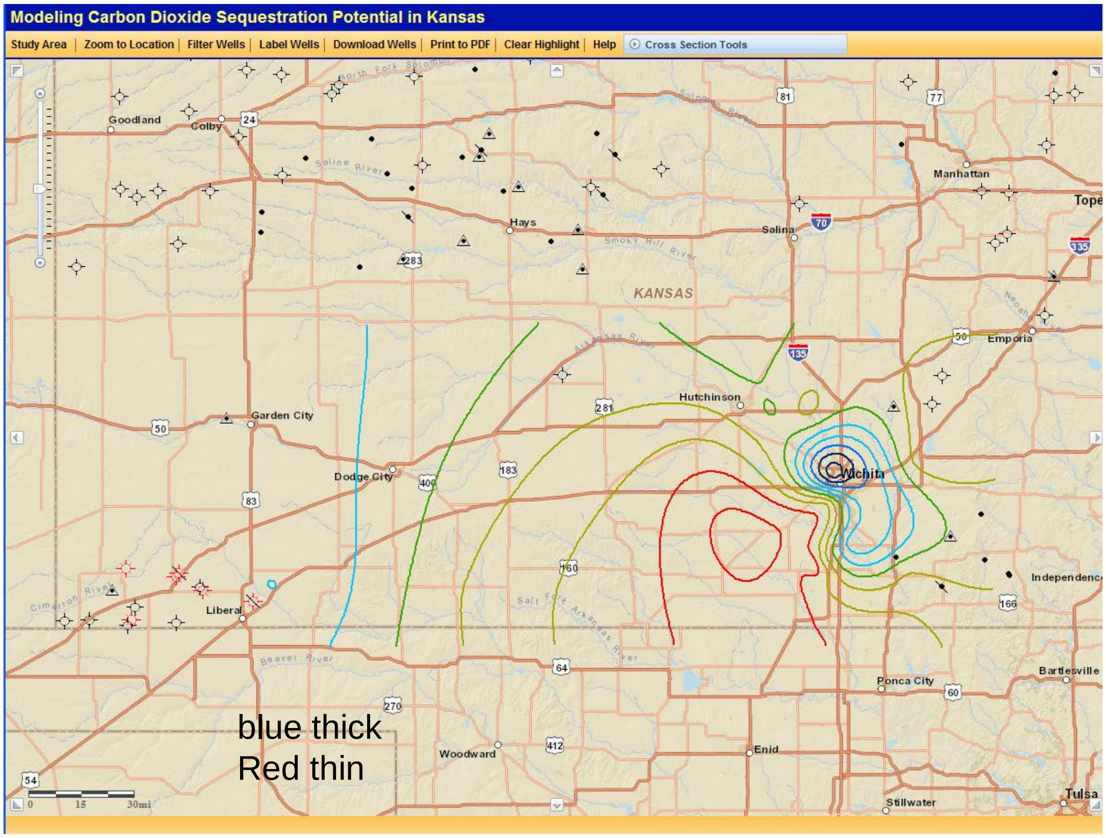


Figure 11. Gunter Sandstone to Precambrian isopach in southern Kansas.

New Java Applet created for use in CO2 storage calculation

In conjunction with the initial estimate of CO2 storage capacity in the Arbuckle, a CO2 applet, **http://www.kgs.ku.edu/PRS/Ozark/CO2/**, was created to predict the Density and Viscosity of Supercritical Carbon Dioxide, the user imports a comma delimited file containing columns of pressure and temperature for supercritical carbon dioxide which will then create a comma delimited file with the contents of the first file with two new columns containing the density and viscosity. The user only needs to identify the header section, the start of the data and the pressure and temperature columns. The program will then parse the pressure and temperature from the file and compute the density and viscosity using Liang-Biao Ouyang[(1)] equations.

This program uses the equations created by Liang-Biao Ouyang[(1)] paper to predict the density and viscosity of supercritical carbon dioxide under conditions in carbon capture and sequestration operations. Liang-Biao Ouyang[(1)] cites examples between the pressures of 1100 to 9000 psia and at temperatures between 40 to 100 deg C.

This method uses the Java BigDecimal Math package to compute the density and viscosity.

DST Analysis Java Applet – "Drill Stem Data Entry and Quantitative Analysis Tool"

The KGS has many paper records of DSTs including time-pressure charts that contain valuable data that can be used to estimate permeability, storage, and engineering "skin" damage associated with the test interval. Permeability measured from our test wells and Class I injection wells in the region are few and this DST data can provide valuable means to calibrate well logs for the regional mapping of permeability in the hydrostratigraphic units. The applet was developed below and being tested so that it is available from the website as a tool that allows the user to work with the image of the paper time-pressure chart and allow them to make a first pass estimate of permeability without use of special software.

For this quarter a Drill Stem Data Entry and Quantitative Analysis Tool is being constructed. This tool allows provides a digitizer to digitize Pressure-Temperature-Time plot for the Shut In Pressure-Temperature-Time data. The digitizer is set up as a 7 step process that allows the user to set the plot limits, enter the summary pressure data if they are not already present, which is a test of the plot limits selected, digitize the pressure vs. time and temperature vs. time for the Shut In regions of the plot. Since only these data are used in the Horner Plot quantitative analysis dialog. Then the data is normalized so the data is equal time units, 1, 2 or 3… minute increments. The problem with DST data is there is no Digitize data to work with this program tries to remedy this with a Digitizer. The program will save this data to a Log ASCII Standard (LAS) version 3.0 file [(2)] under the ~Test Section a standard section in this version.

References:
(1) New Correlations for Predicting the Density and Viscosity of Supercritical Carbon Dioxide Under Conditions Expected in Carbon Capture and Sequestration Operations by Liang-Biao Ouyang The Open Petroleum Engineering Journal, 2011, 4, 13-21

(2) LAS 3.0 Log ASCII Standard Document #1 File Structures by Canadian Well Logging Society: **http://www.cwls.org/las_info.php**

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

Subtask 17.6. Select location for Test Borehole #3

Previous discussion:

Completed review of geology and seismic data at proposed drill sites using following criteria to evaluate the sites --

- 1) provide a useful location in the incised valley fill sandstones for operator,
- 2) avoid fault zones around drill site or within the 10 mi2 around the well so faults are at minimum outside of the multicomponent seismic survey, and
- 3) ideally, we'd have a drill site with a high potential for porous section of lower Arbuckle and shaly or tight layers above the porous interval.

To reduce AFE costs, reduce core from 2100 ft to 1200 ft

- Dana Wreath is working with coring contractors to improve coring bids including reducing amount of aluminum liner.
- Submit revised AFE
  - Dana Wreath plans to submit a bid for drilling in Cutter Field once coring bid has been refined.

Figure 12. Decision made on location to basement test in southwest Kansas.

Quote was accepted from Berexco to drill borehole with 1180 ft of core at a cost of $1,914,340. The quote matches budgeted cost. Interval coring is described in **Figure 13**. The well location is in Cutter Field, Stevens County, Kansas in the SE NE corner of Section 1-Township 31 South–Range 35 West. The well will be spudded by early August 2012. Approximately 10 square miles of multicomponent 3D seismic survey will be designed to include location of the well where the Upper Morrow sandstone is productive on a local structural high with closure. Seismic will also extend east to include the Chester age incised valley. The seismic crew has been identified and reserved to acquire the seismic survey as soon as possible. The initial p-wave survey results will be used to assist in the selection of the drilling location.

Coring Schedule Cutter KGS #1
Est KB 2935'

Depth Interval	Footage	Formation	Core storage
5210-5290	80	Morrow	Alum Bbl
5400-5600	200	Chester	Boxes
6400-6800	400	Kinderhook/Viola/Upper Arb	Alum Bbl
6900-7200	300	Arbuckle	Boxes
7350-7550	200	Lower Arb	Alum Bbl
	1180		

Figure 13. Proposed interval coring schedule in 2340 ft thick anticipated interval. These intervals not cored are represented elsewhere by core in the area in collection stored by the KGS.

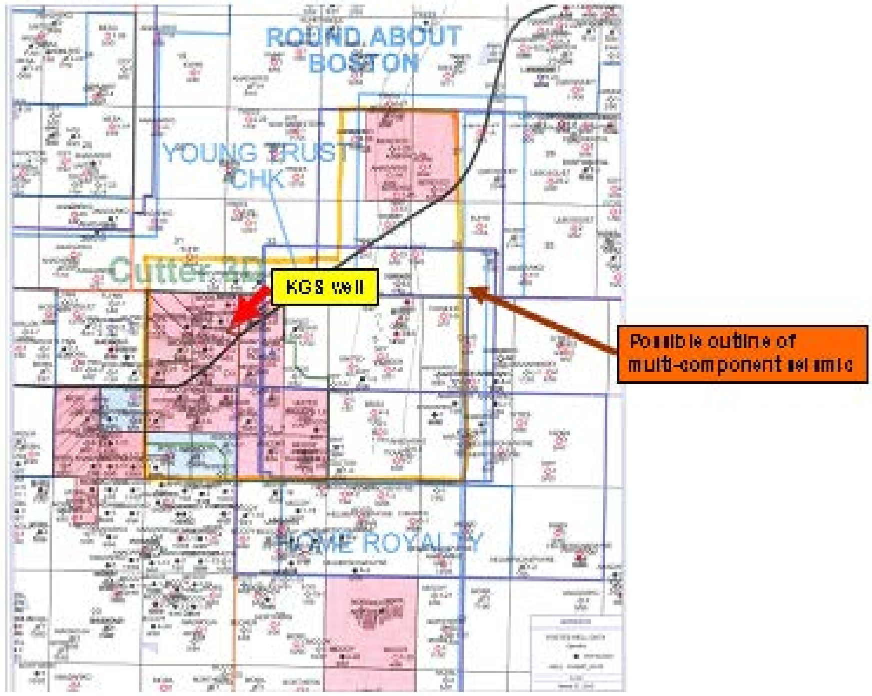


Figure 14. Cutter Field base map with showing KGS well location in Section 1 on the north edge of Cutter Field. The initial outline of the proposed 3D multicomponent seismic survey is outlined by the solid orange line.

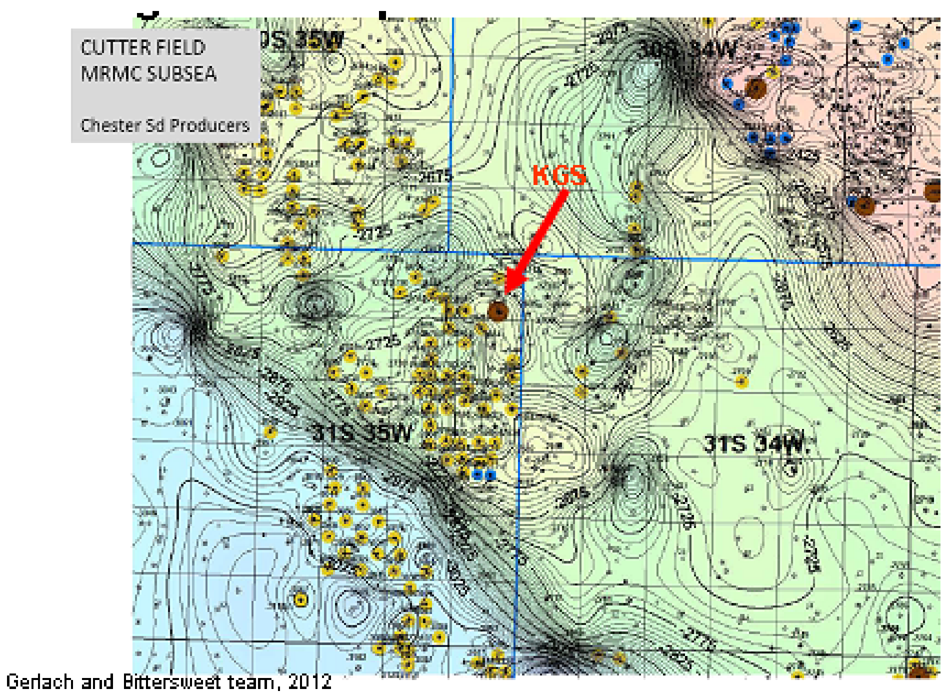


Figure 15. KGS well identified on a top of Meramec (Mississippian) structure map. The new well is located on a broad, relatively flat plateau with a local high. A meandering incised valley system with local producing wells lies to the east and north and northwest of the new well location.

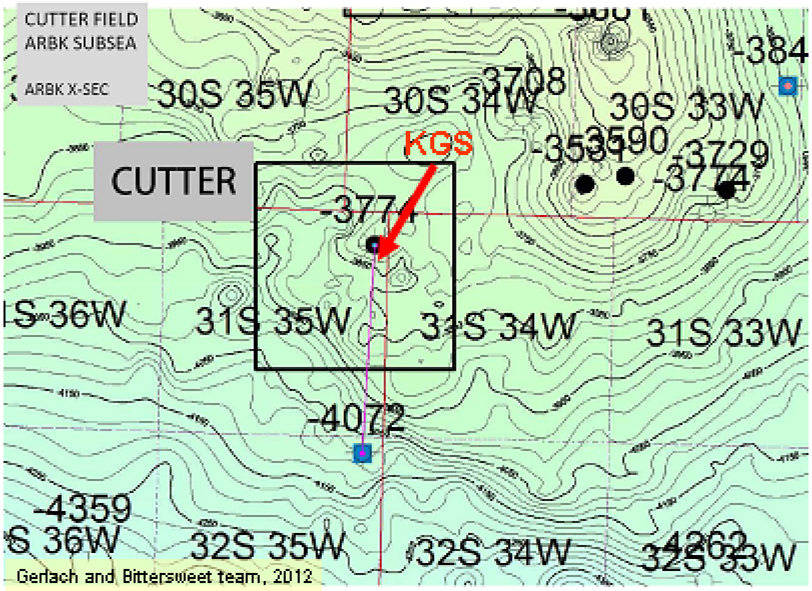


Figure 16. Subregional top Arbuckle structure around Cutter Field and north-south cross section index connecting to well near the new KGS on the north and well the south. Each township labeled on this map is 6 miles on a side.

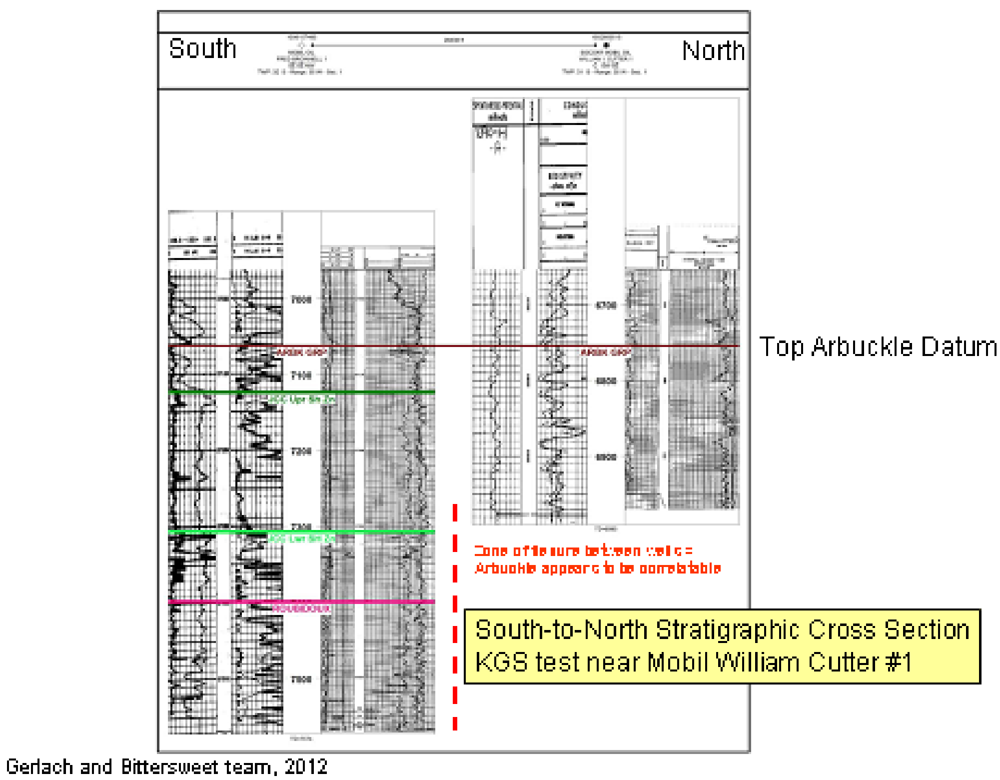


Figure 17. South-north cross section identified with index line in map above in Figure 16.

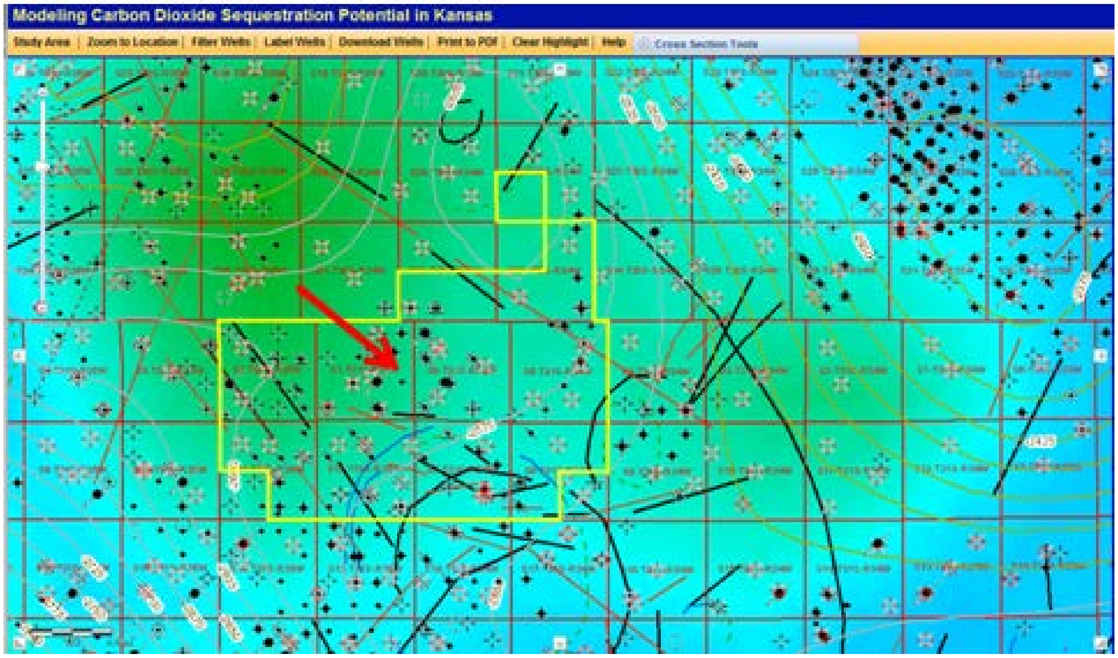


Figure 18. Top Mississippian structure (contours) with color shading depicting the 2-10 mile filtered total magnetic field intensity. Linears and curvi-liners are surface lineaments derived from Landsat satellite imagery.

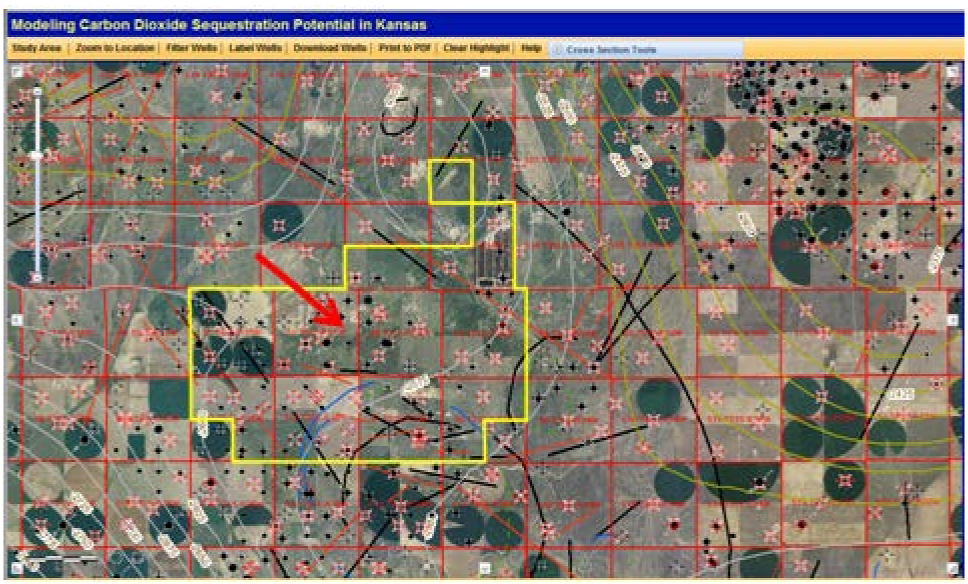


Figure 19. Surface lineaments overlain on 2008 aerial photo and contours of the top of the Mississippian structure.

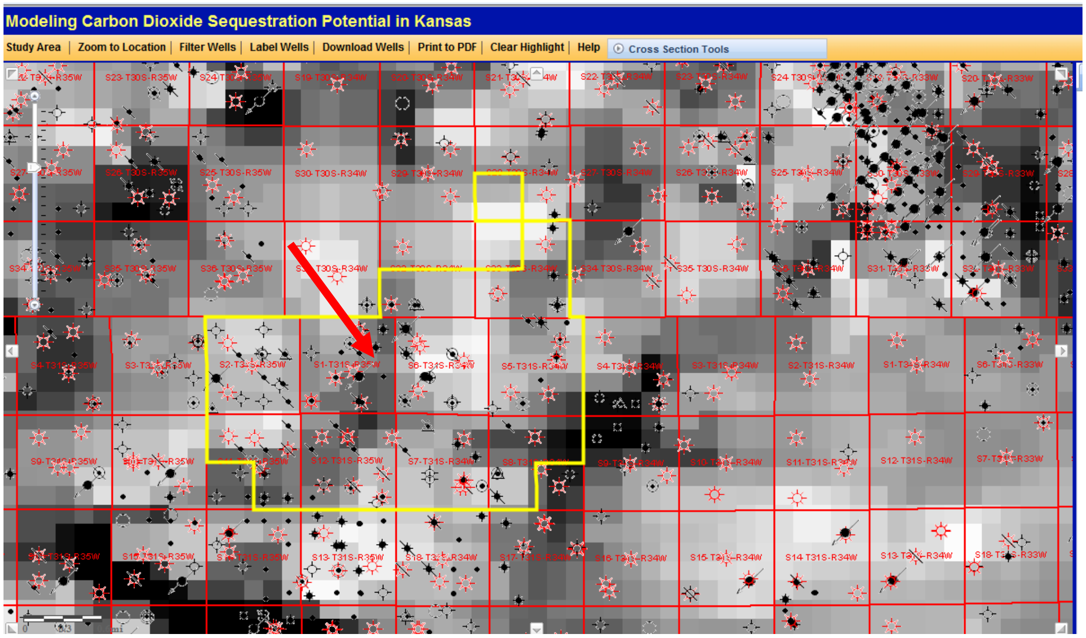


Figure 20. Curvature map of the Top Lower Permian Fort Riley Limestone in Cutter Field area. Arrow identifies the location of new well.

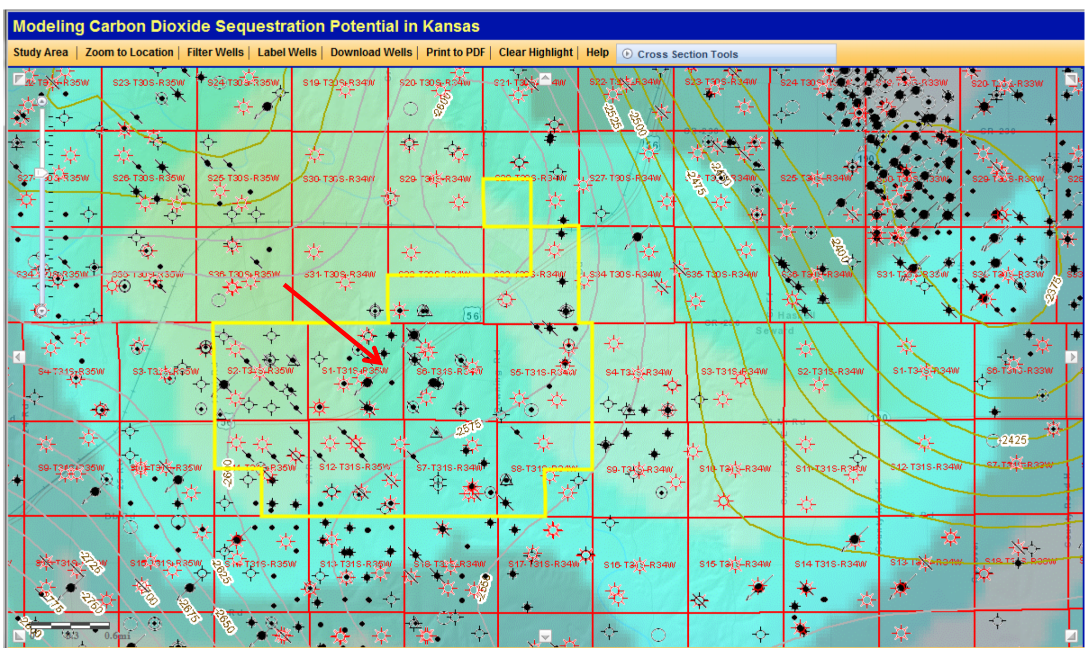


Figure 21. Magnetic anomaly combined with tilt angle and contours of the top of the Mississippian configuration in vicinity of Cutter Field. Well location shown by arrow.

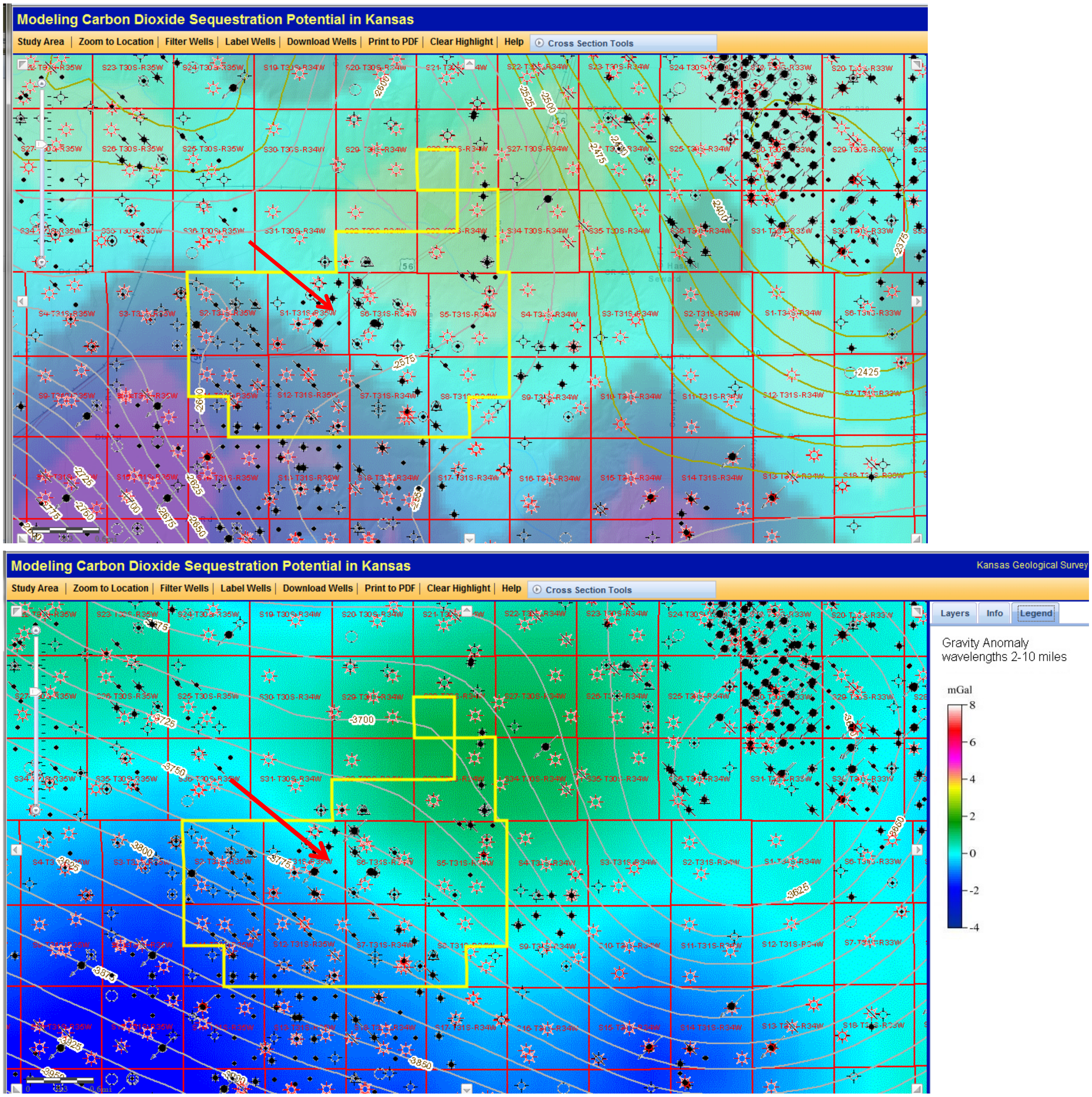


Figure 22 (<u>top</u>) Gravity anomaly combined with its tilt angle with contours of the configuration on the top of the Mississippian. (<u>bottom</u>) Top Arbuckle structure (contours) and 2-10 mile gravity anomaly with location of the new drillsite.

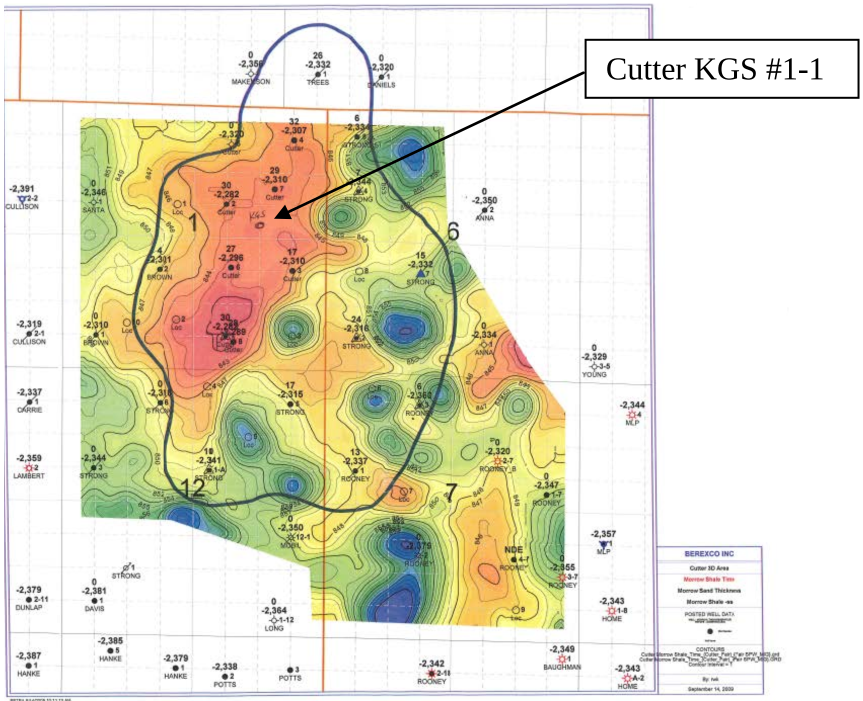


Figure 23. Top Morrow Shale time structure from earlier seismic used to aid in sighting location of Berexco Cutter KGS #1-1 in Cutter Field. Local structural structural closure at the new well location are indicated.

Task 18. Update Geomodels and Conduct Simulation Studies.

Work continues on the characterization and modeling of four Chester and Morrow fields in southwestern Kansas, Pleasant Praire, Eubanks, Cutter, and Shuck fields (**Figures 24-32**). Work on geomodel construction is briefly reviewed followed by highlights from the dynamic modeling of Pleasant Prairie Field, the first the three to be modeled for CO2-EOR.

Near final results of reservoir simulation through the waterflood stage at Pleasant Prairie is proceeding well with good match to oil and water production and injection. Next comes CO2-EOR simulation to maximize for sequestration. The simulation result are summarized in **Figures 33-44.**

March recap

Simulation progressing:

- Another 300 runs using black oil (IMEX) automated with CMOST
- History matched primary and waterflood is very close

Data analysis work continues

- Well mechanical histories and pressure data compiled for Shuck, as far we can go without Anadarko data
- Work is progressing on Cutter

Seismic front

- Interpretation complete for Pleasant Prairie and Wide-Awake (Shuck)
- Eubanks – reprocessing just about complete

Anadarko well data - Eubanks

- Sorenson and Dubois spent 2 days at Anadarko - ID data to be scanned
- KGS (Watney) provided draft CA – waiting on response

Reports

- Draft geological report on Eubanks – nearing completion (Youle)

Goals for April

Simulation:

- Finish Pleasant Prairie black oil
- Complete CO2 compositional simulation

Data analysis work

- Finish Shuck given we get Anadarko data in hand
- Move Cutter along

Seismic

- Complete Eubanks interpretation
- Much work related to deep test well

Anadarko well data - Eubanks

- Keep working with Anadarko

Deep test well

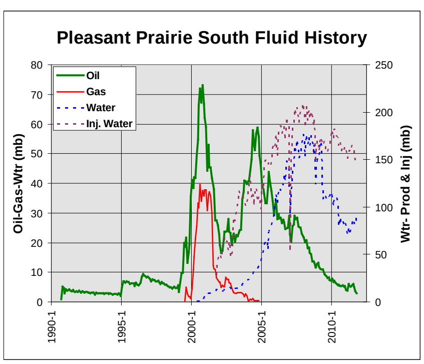
- Collaborate with saline aquifer study group

4

Figure 24. Technical work update as provided by Dubois in internal project review.

- ✓ Data assembly
- ✓ Detailed geology
- ✓ 3D seismic interp.
- ✓ 3D cellular model
- ➢ Hist-match simulation
- ❑ CO2 EOR simulation

Pleasant Prairie South History



1990 first well completed in Chester sand - Kearny County Feedlot 1

1996 second well completed in Chester sand

1999-2001 rapid development of entire field

2001 waterflood initiated (one operator unitized, the second did not)

Well Count:

19 oil wells 6 later converted to injectors)

Waterflood

10 injectors

13 producers (2 of which are not "plumbed into flood")

Fluid statistics

Cum. oil: 4.5 mmbo

Cum. Gas: 0.75 BCF

Primary/Second.~ 1/1

RF ~ 30-35% of OOIP

Map of all deep wells

Chester IVF wells inside pattern polygons

Other wells are outside the narrow valley

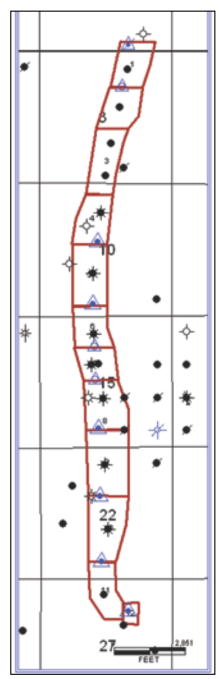


Figure 25. This project is furthest along. Nearing completion of history-matching primary and waterflood (Checks denote complete, arrows –underway, box –yet to do). Pleasant prairie South is the last of the main Chester IVF pools to be found and developed. It is a narrow (~1000 ft wide) deep incision in the Pleasant Prairie faulted anticline. Most of the development took place in 1999 and 2000 and waterflood began in 2001.

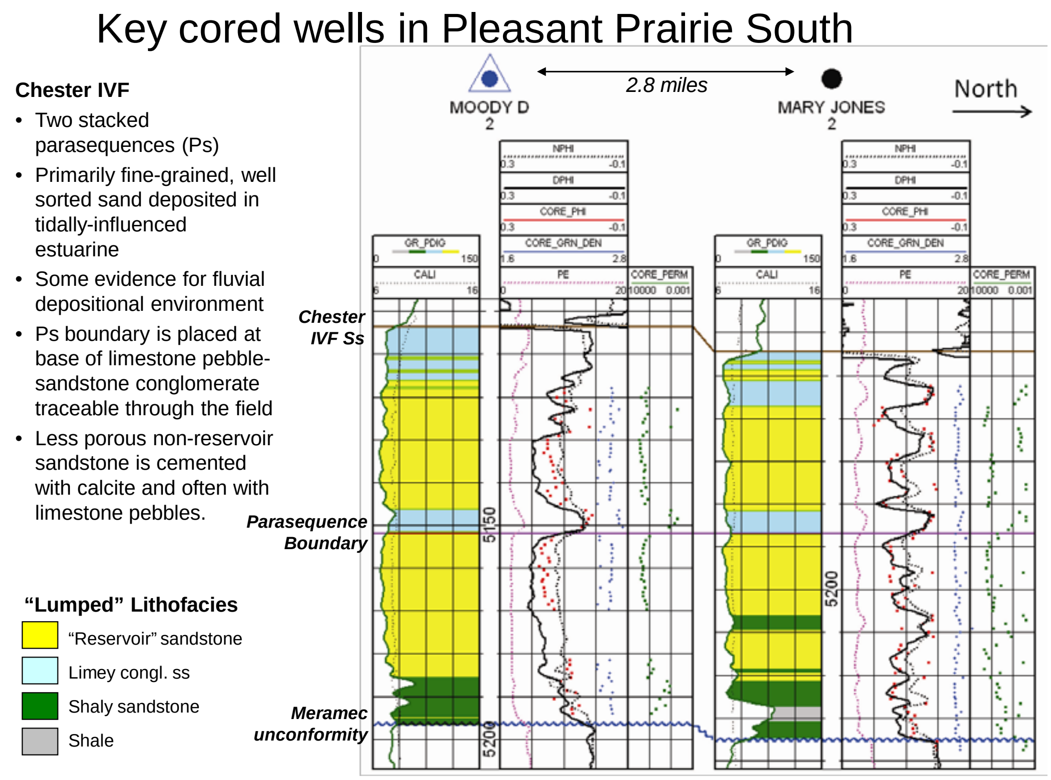


Figure 26. Two wells nearly 3 miles apart have similar log character. A parasequence boundary is traceable throughout the field. 8-10 lithofacies defined in core were lumped to four recognizable in logs without core by neural networks trained on wells with core or by log curve cut-offs (PE, GR, NPH-DPHI difference). The northern well IVF is more tightly cemented with calcite (note permeability differences, signature on PE curve, and slightly higher grain density).

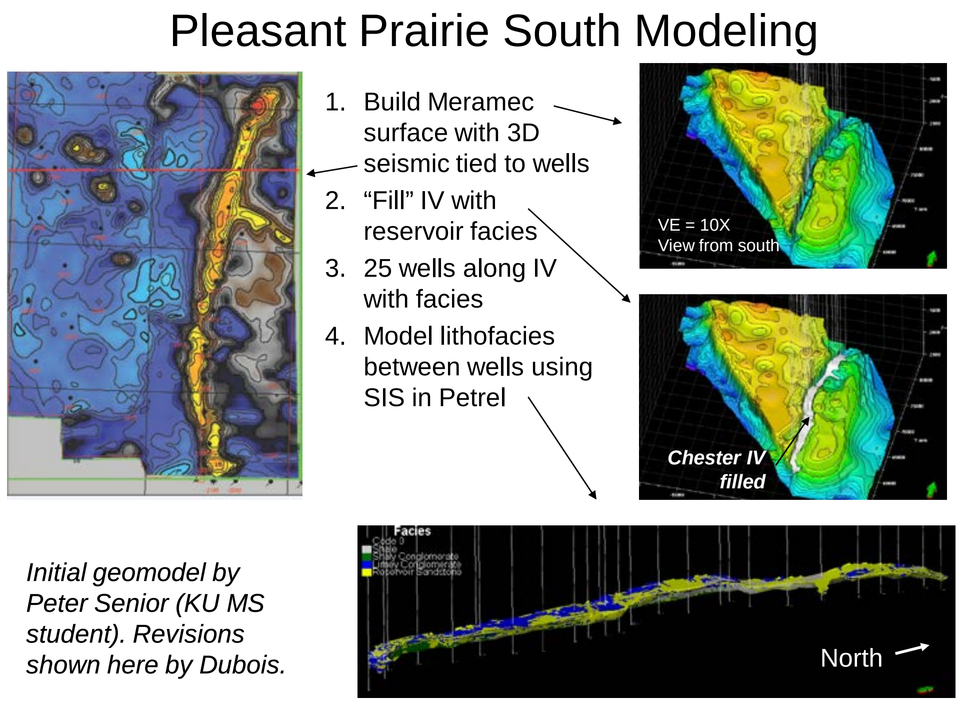


Figure 27. General workflow for the cellular geomodel. The post-Meramecian incision cuts the faulted Pleasant Prairie anticline. The valley is narrow (<1000 ft) but deep (140-180 ft). It appears to be related to deeper seated faulting and karst.

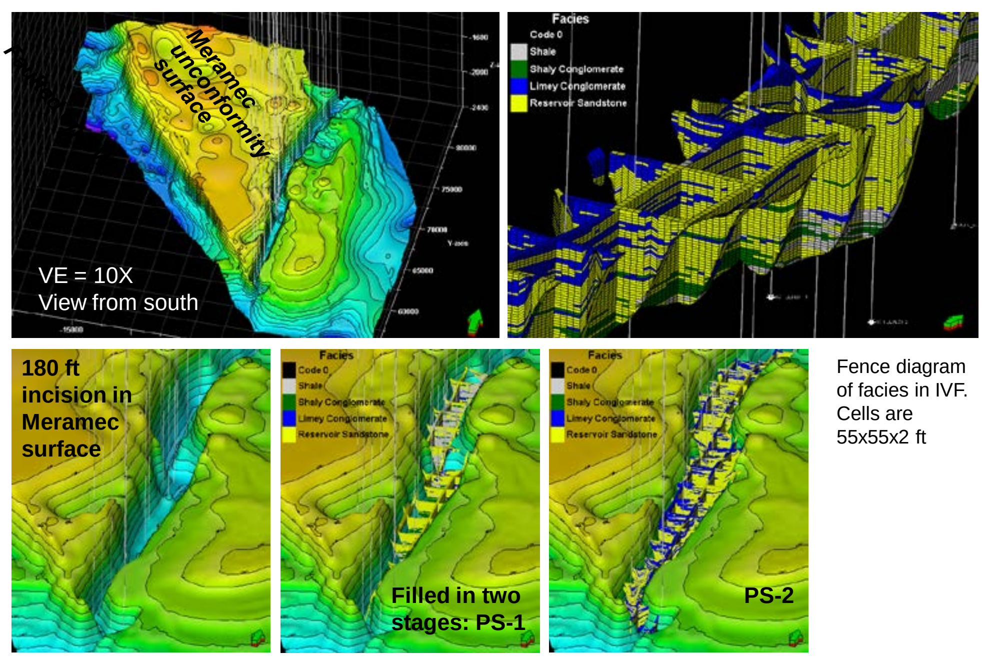


Figure 28. Pleasant Prairie South geocellular model.

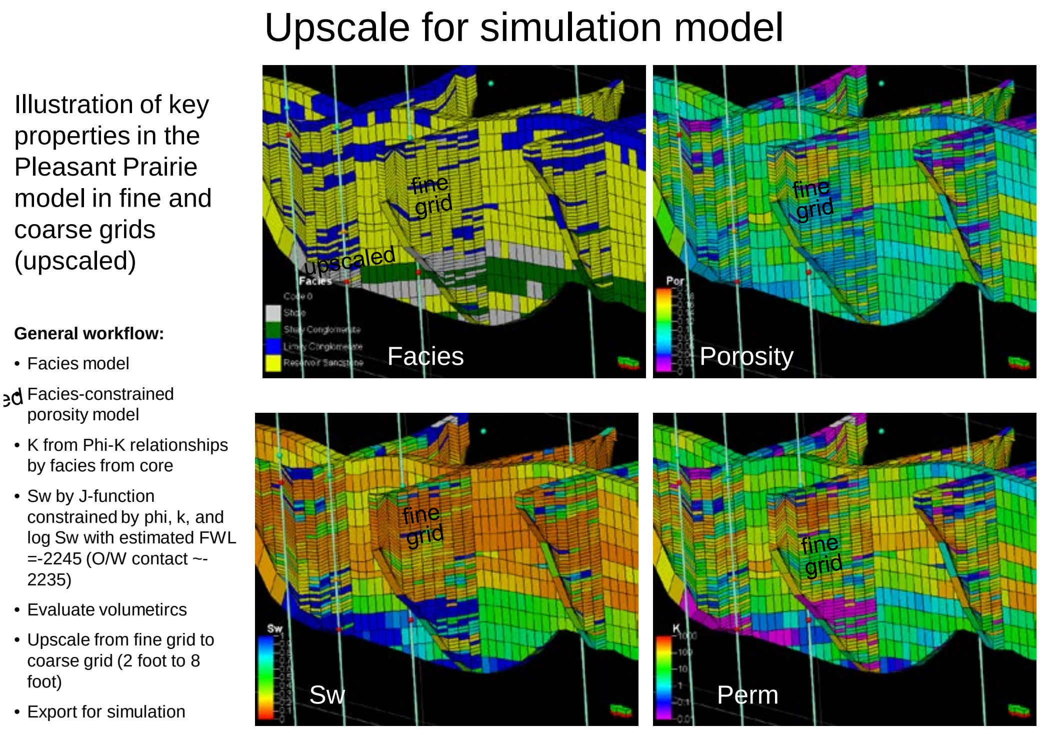


Figure 29. Upscaling of geocellular model for reservoir simulation in Pleasant Prairie South.

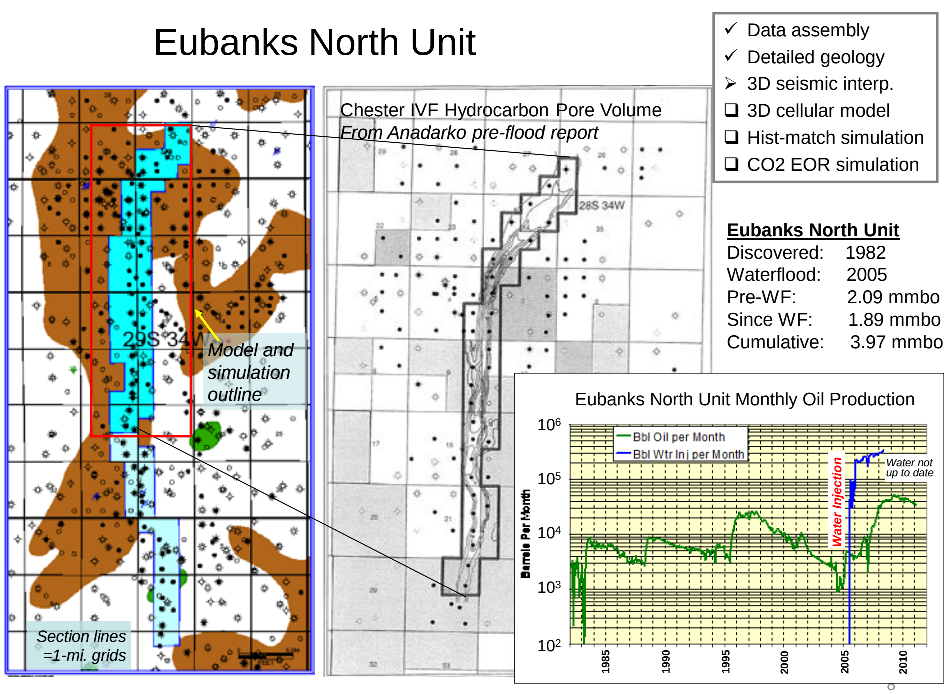


Figure 30. Eubank North Unit map, unit boundaries, and production curve.

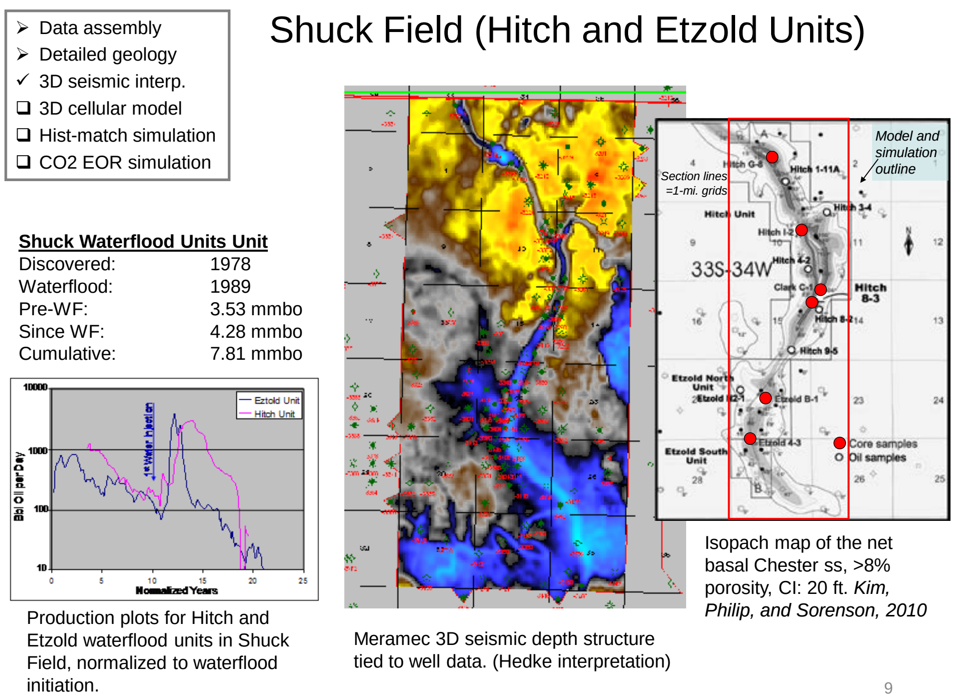


Figure 31. Shuck Field (Hitch and Etzold Units) with vital statistics and maps including seismic image of the Meramec surface into which the incised valley is cut. Reservoir sandstone fills the narrow valley.

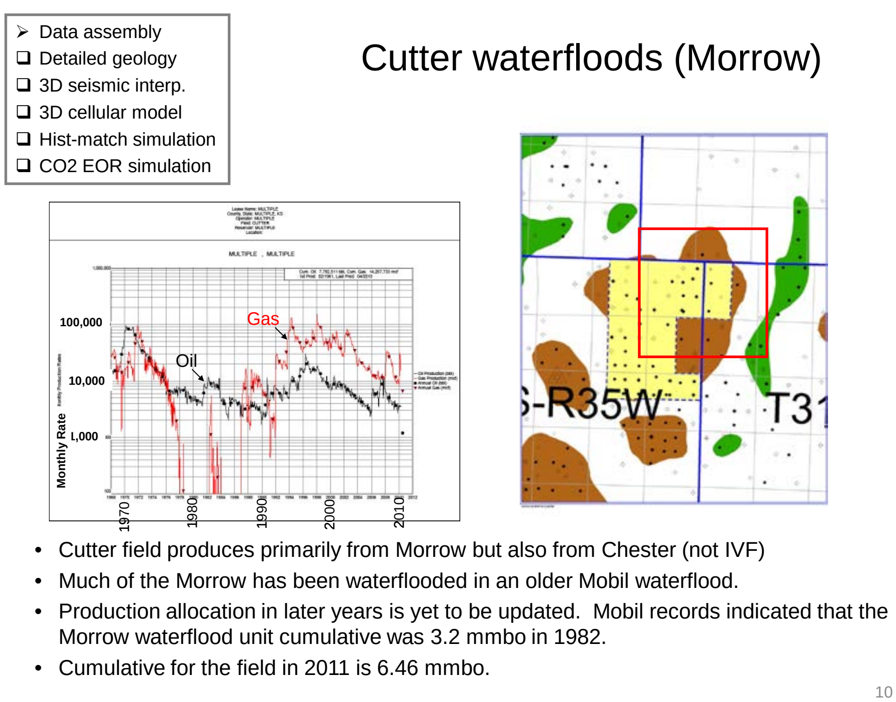
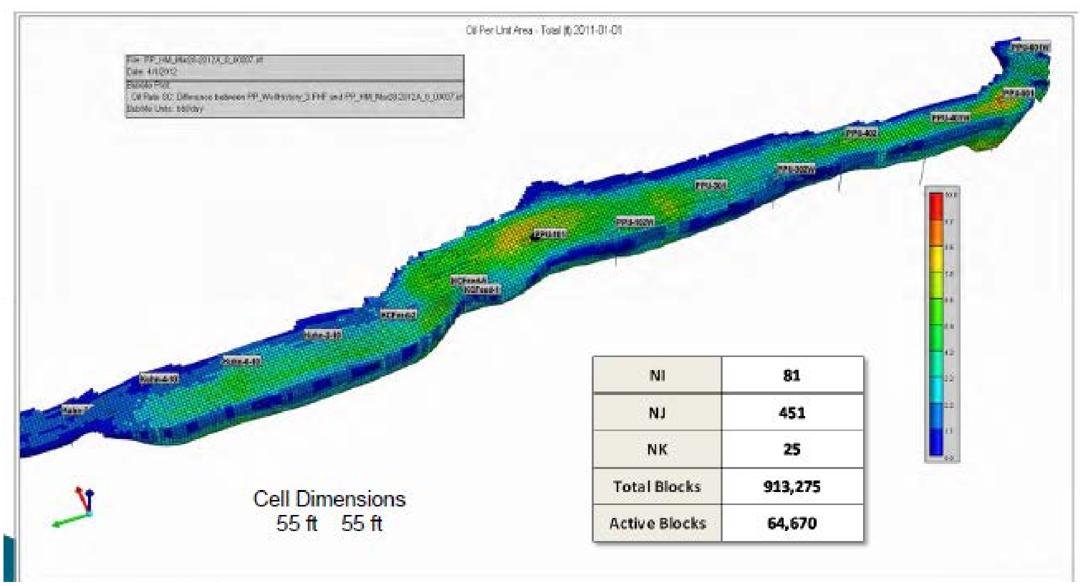


Figure 32. Cutter Field vital statistics. Cutter field will be the site of the new borehole, the Berexco Cutter KGS #1-1.

Subtask 18.2. Optimize geomodel for simulation - Flow-unit identification, fracture charaterization, and upscaling.

Dynamic Modeling Status summary - Gene Williams

- Simulation model imported from petrel export (RESCUE format)
- PVT EOS determined using WINPROP based on several Chester PVT reports in the area and the CO2 swelling tests at Wellington
  - IMEX Black Oil PVT exported for Black-Oil history match stage
- Saturation functions using Gravity Stable (VE) and Corey functions.
  - Capillary pressure assigned based on RESCUE initial water saturations
- Initialization using DWOC -2245 ft SS, Pressure 1389 psia at DWOC
- Well production data from records of Cimarex, Oxy and KGS.
  - September 1990 to December 2011
  - Only Oil for Oxy from May 2009 – assume constant liquid and water injection rates
- Initial history matching using black oil simulation (IMEX) and CMOST
- Convert history matched model to EOS simulation (GEM)
  - Working through convergence issues with GEM
- Prediction cases using GEM
  - NFA
  - CO2 Injection Cases



NI	81
NJ	451
NK	25
Total Blocks	913,275
Active Blocks	64,670

Figure 33. Pleasant Prairie Simulation model framework in longitudinal profile showing grid blocks.

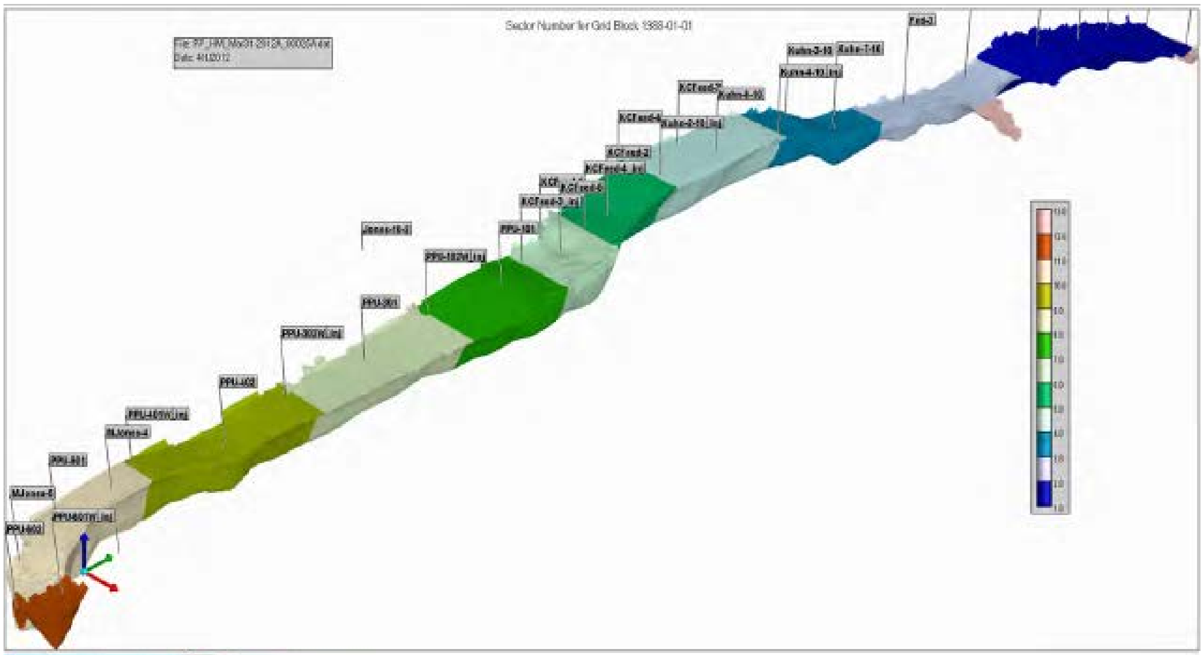


Figure 34. Model sectors (polygons)

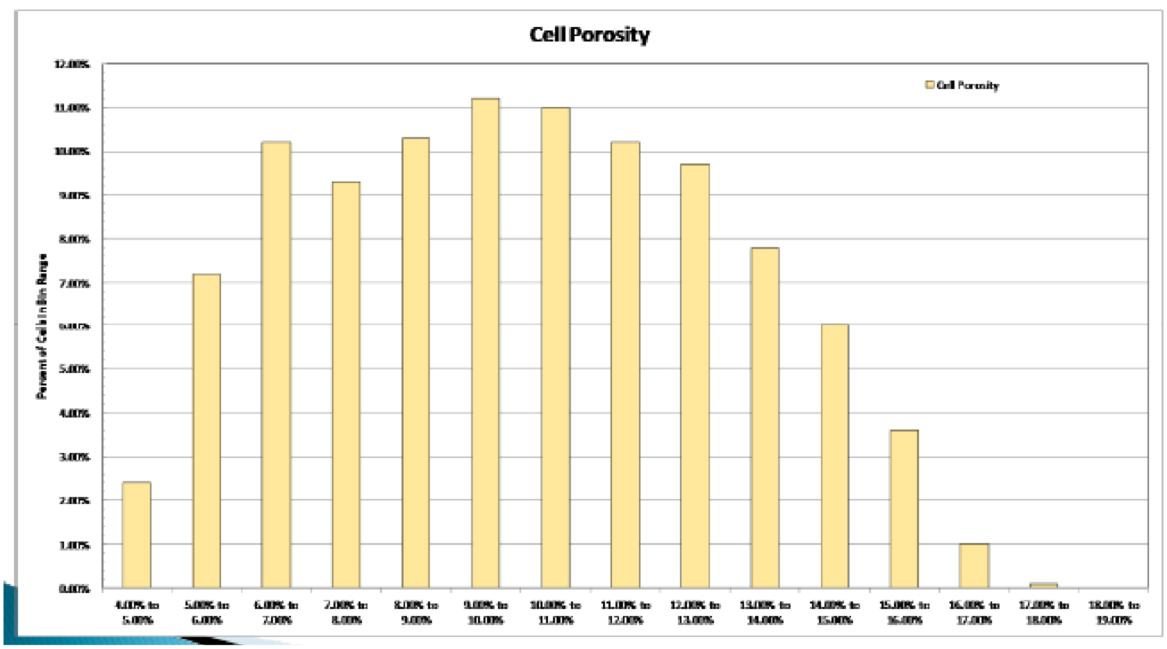


Figure 35. Model parameters – porosity. Range is 5-19%. Maximum frequency at 10%.

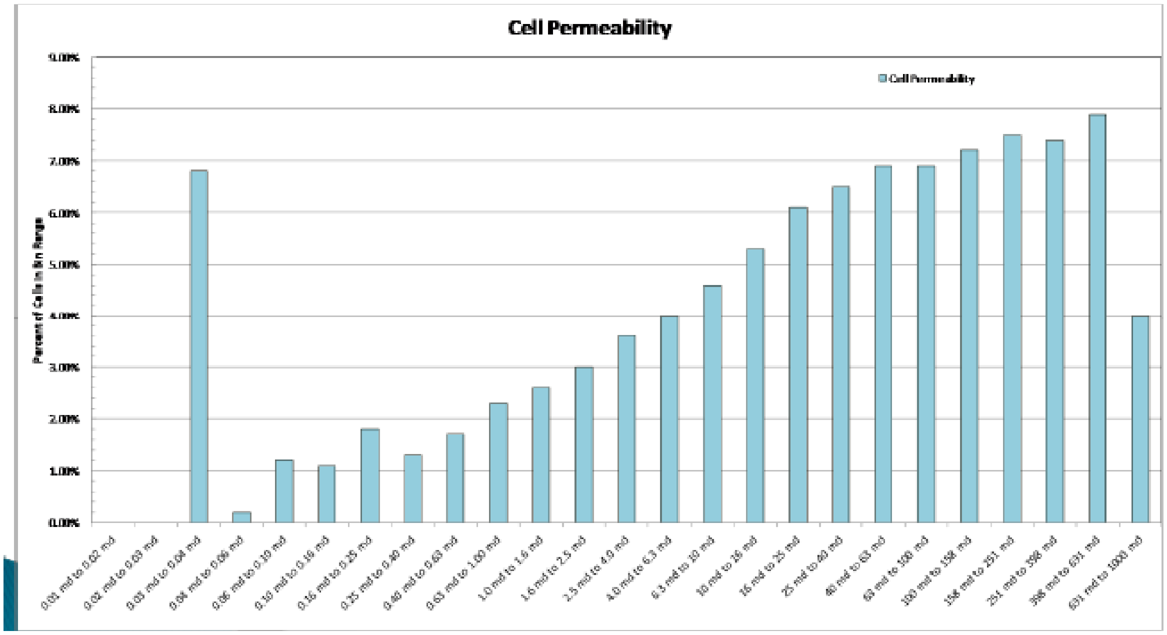


Figure 36. Model permeability. Range is from (0.01 to 0.1) md to (631 to 1) darcy. Reservoir permeability is skewed to higher values over 10 md.

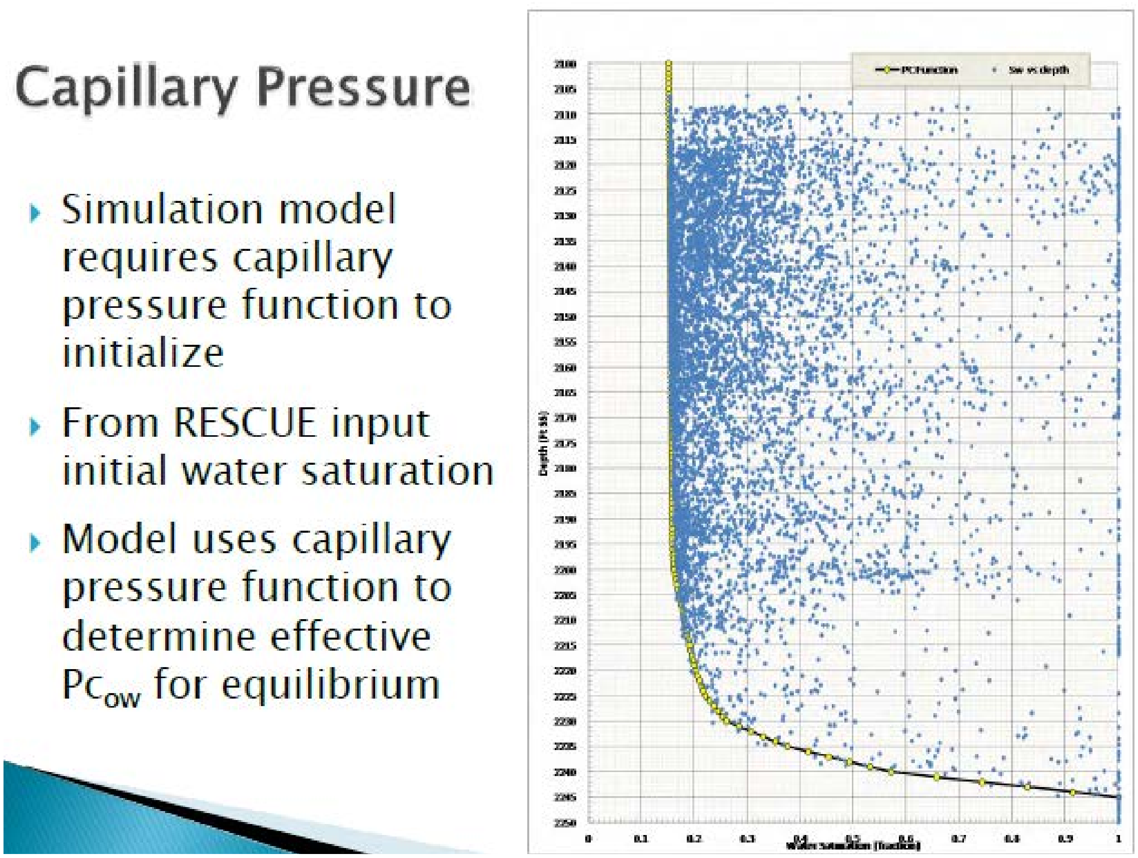


Figure 37. Capillary pressure shown as water saturation (x axis, fractional) vs. depth (y axis, feet).

			Initial Entire Field
	Total Pore Volume.	M rbbl	27,199
	HC. Pore Volume	M rbbl	18,368
Fluids In Place			
	Stock Tank Oil	M STB	15,105
	Mobile STO	M STB	9,865
	Total Gas	MM SCF	5,113
	Free Gas	MM SCF	
	Water	M STB	8,706
	Reservoir Oil	M rbbl	18,368
	Reservoir Gas	M rbbl	
	Reservoir Water	M rbbl	8,831
	Water Influx	M STB	
Average Pressure			
	Total Pore Volume	psia	1,365
	HC. Pore Volume	psia	1,362
	Pore Vol. at Datum	psia	1,389
Average P/Z			
	Total Pore Volume	psia	1,632
	HC. Pore Volume	psia	1,629
Average Saturation %			
	Oil		67.532
	Gas		
	Water		32.468

Figure 38. Initialization parameters for the simulation model.

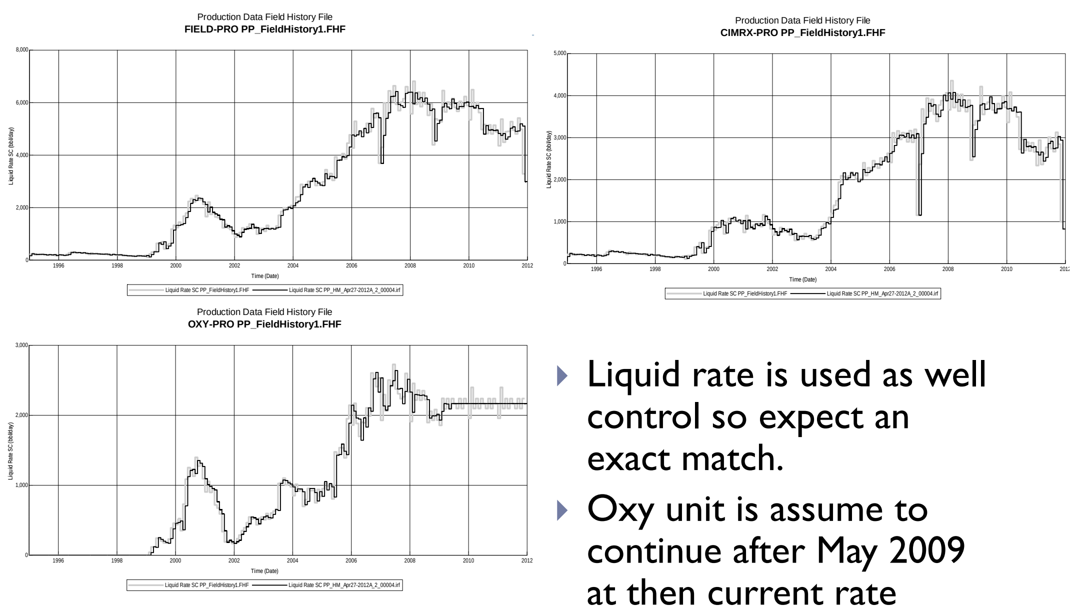


Figure 39. Liquid Production Match is very good.

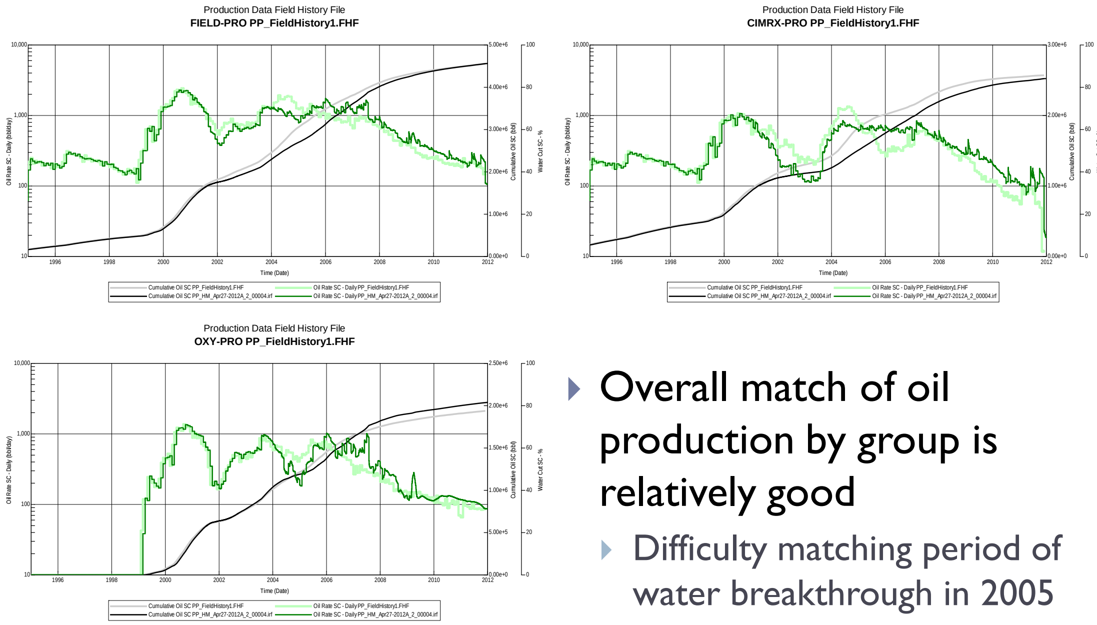


Figure 40. Oil production match.

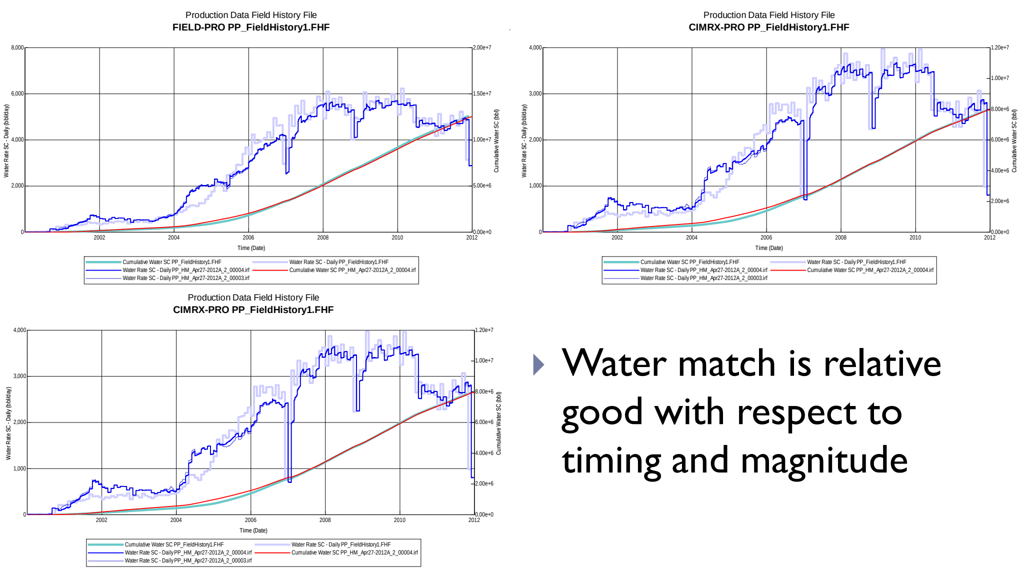
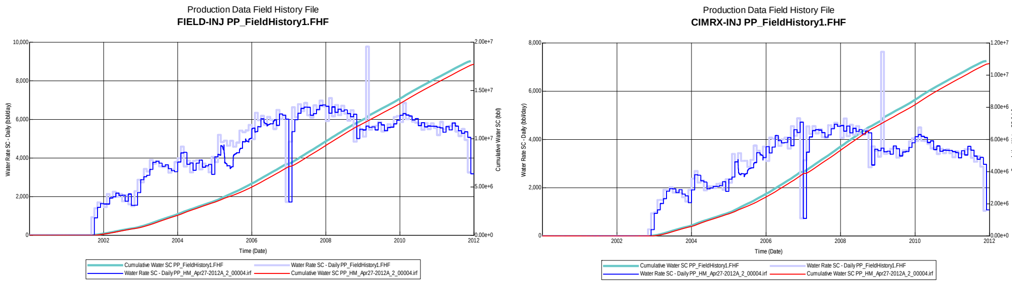
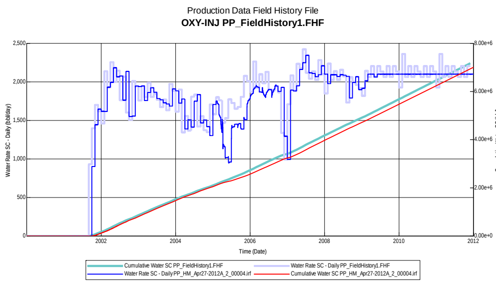


Figure 41. Water production match.





- Water injection rate is specified but there is a maximum BHP limitation that causes some wells to not meet objective
- OXY unit wells are assumed to continue injection rates after may 2009 at then current rates

Figure 42. Water injection match.

Summary of EOS Simulation Status

Model has been converted to EOS and intialized in CMG software GEM.

In Place volumes provide and excellent match between Black oil and EOS simulations.

Convergence problems with EOS simulations are being worked.

Significant time step cutting and very small time-steps.

History match to current model run-time is consistent with black oil model.

Equation of State

		FIELD
Bulk Volume		
	Total Bulk Volume.	1,067,430
Pore Volumes		
	Total Pore Volume.	106,963
	HC. Pore Volume	71,475
Originally in Place		
	Stock Tank Oil	10,670
	Gas at Surface	3,472
	Water at Surface	6,346
Currently in Place		
	Stock Tank Oil	10,670
	Gas at Surface	3,472
	Water at Surface	6,346
	Reservoir Oil	12,730
	Reservoir Gas	0
	Reservoir Water	6,321
	Cum Water Influx	0
Average Pressures		
	Total PV Ave.	1,366
	HC PV Ave.	1,363
	HC PV Ave. Datum P	1,389
Average Temperature		
	Bulk Vol Ave.	129
Ave. Saturations		
	Oil	0.66822
	Gas	0
	Water	0.33178

Black Oil

			SECTOR-0
			Entire
			Field
	Total Pore Volume.	M rbbl	19,051
	HC. Pore Volume	M rbbl	12,730
Fluids in Place			
	Stock Tank Oil	M STB	10,469
	Mobile STO	M STB	6,632
	Total Gas	MM SCF	3,544
	Free Gas	MM SCF	
	Water	M STB	6,232
	Reservoir Oil	M rbbl	12,730
	Reservoir Gas	M rbbl	
	Reservoir Water	M rbbl	6,321
Average Pressure			
	Total Pore Volume	psia	1,365
	HC. Pore Volume	psia	1,363
	Pore Vol. at Datum	psia	1,389
Average Saturation %			
	Oil		66.822
	Gas		
	Water		33.178

Figure 43. Comparison of initial volumes with black oil simulation results. The later area very close the EOS numbers.

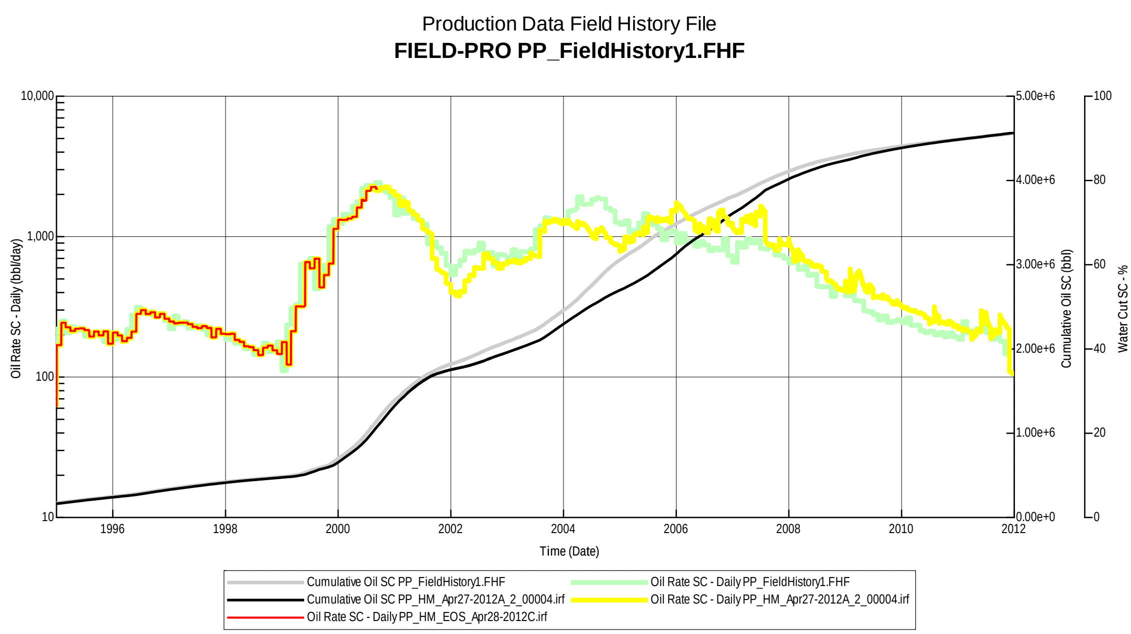


Figure 44. Equation of State (EOS) simulation model comparison.

WELLINGTON FIELD

ONGOING AND COMPLETED ACTIVITIES –

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 44**).

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 45)**. 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.

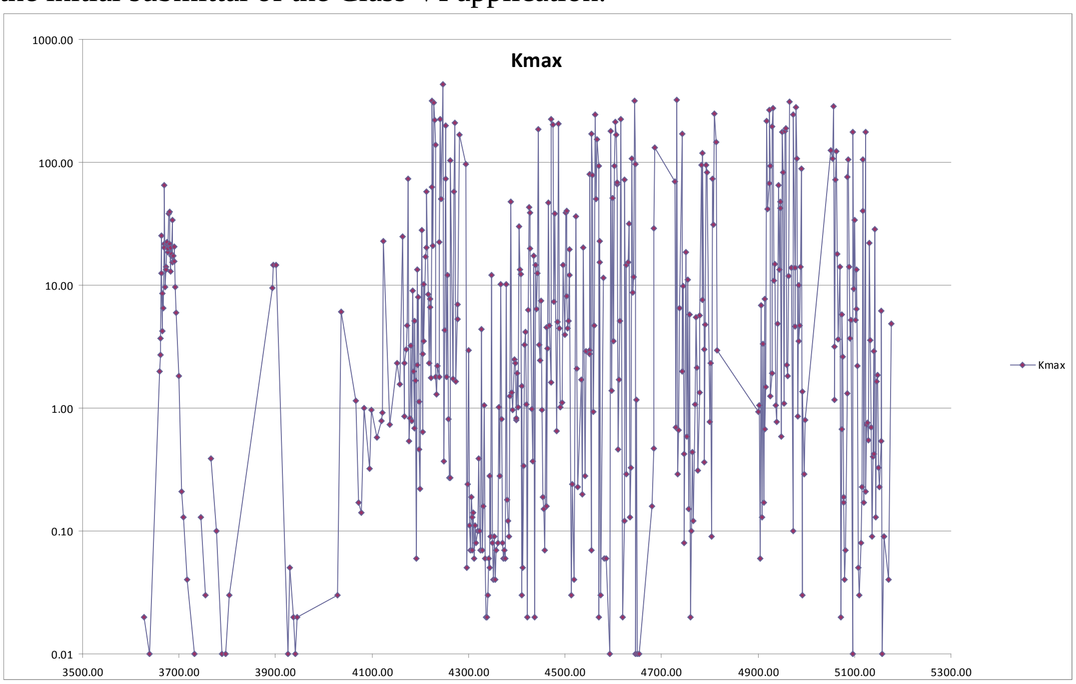


Figure 44. Simple plot (log permeability in millidarcies vs. depth in feet) of whole core analysis of maximum permeability (Kmax) measured in the Mississippian, Chattanooga, and Simpson Group (above 4160 ft depth, left side of plot) and the Arbuckle saline formation, below 4160 ft. Entire 1600 ft interval 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 45. 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 46 and 47**). The additional seismic profile in **Figure 48** illustrates the detailed information from the seismic in the Paleozoic interval down to the Precambrian surface at the base of the Arbuckle saline formation.

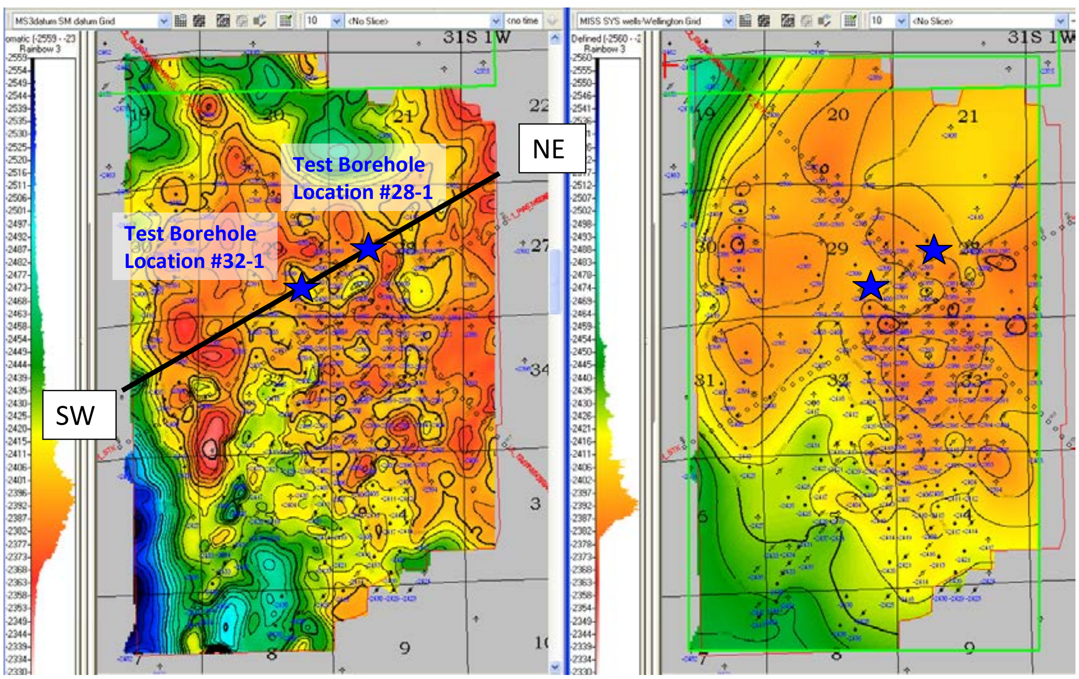


Figure 46. Prestack depth migration top Mississippian (left) compared to the Mississippian structure map using well control only (right). Correspondence of the two maps is excellent with additional resolution provided by the seismic data. Both sets of data will be integrated into the geocellular static 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 47.

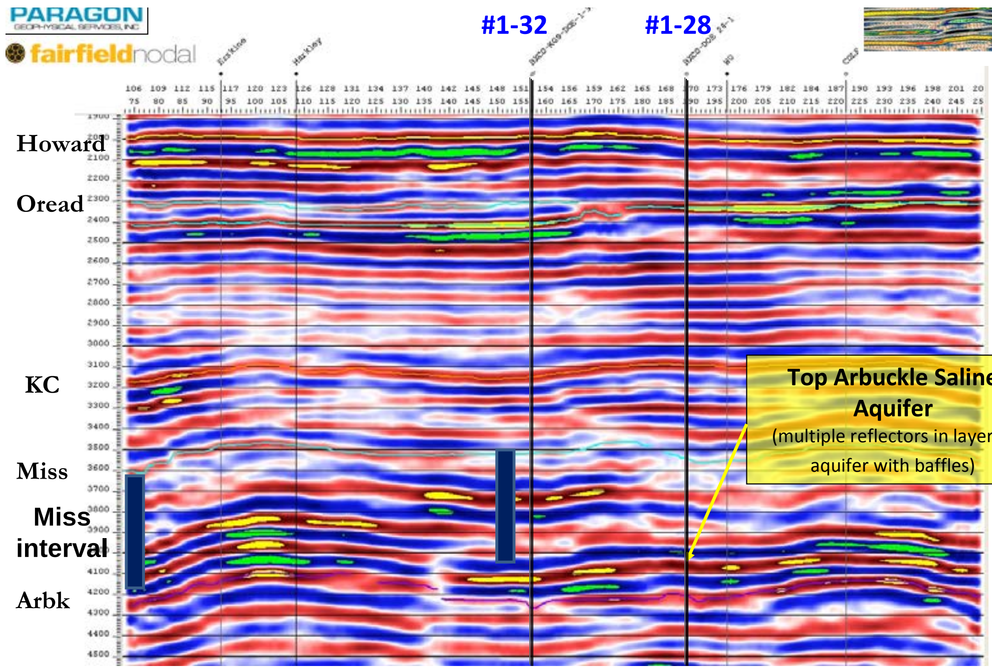


Figure 47. Preview of the converted shear wave, prestack depth migrated multi-component 3D seismic volume in Wellington Field coincident with southwest-to-northeast oriented shear wave line #1 identified in Figure 46.

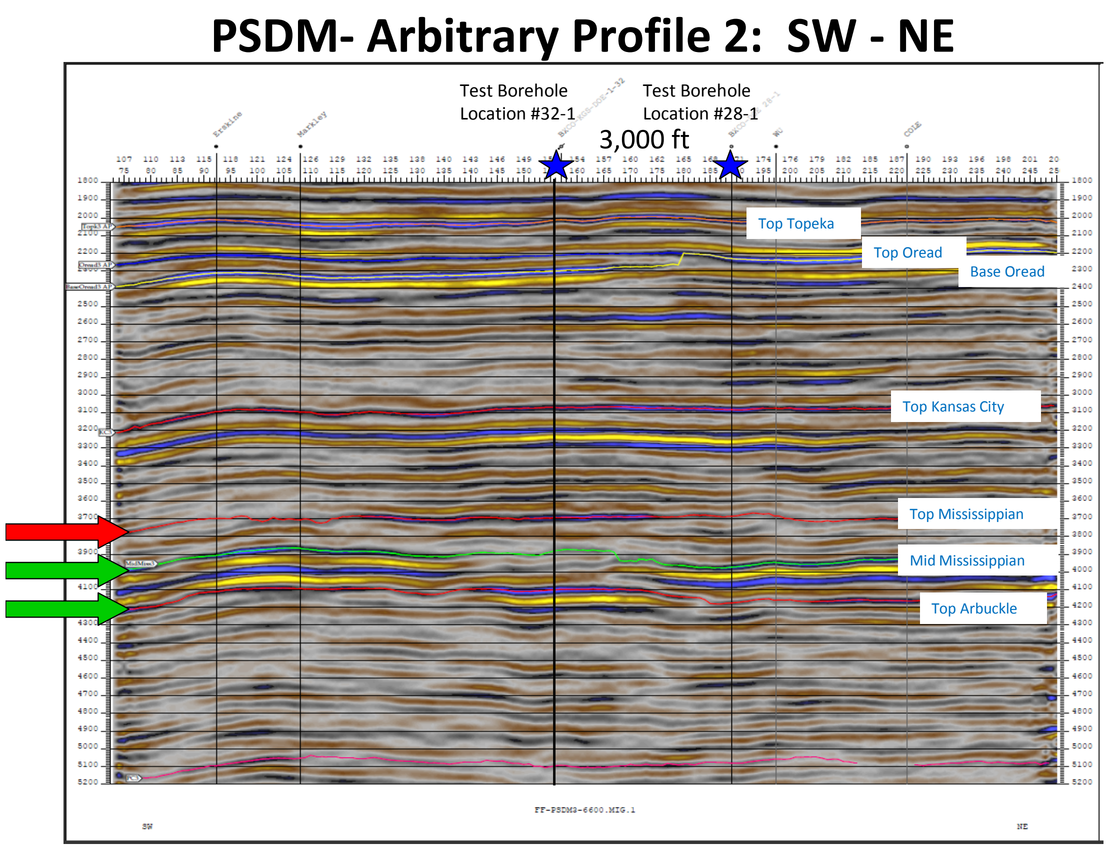


Figure 48. PSDM of an arbitrary profile running southwest to northeast intersecting the two test boreholes drilled under DE-FE0002056. Stratigraphic horizons are identified. Precambrian basement is the lower pink line at the base of the Arbuckle saline formation.

Subtask 6.4. Revise 3D seismic interpretation

<u>Seismic attribute analysis of the top of the Mississippian</u>

Contributed by Ayrat Sirazhiev and George Tsoflias,
Dept. of Geology, The University of Kansas

SUMMARY

The past quarter focused on assessing the utility of seismic attribute analysis for determining properties of the Mississippian chert at the Wellington Field. The reservoir exhibits variable thickness, typically below seismic resolution, and a gradational porosity reduction with depth. We examined if seismic waveform integration, expected to result from the ramp velocity function corresponding to the gradational porosity decrease below the Mississippian top, can be used reliably as a seismic attribute for predicting reservoir properties. We examined possible relationships between seismic attributes (amplitude and frequency) and reservoir porosity and thickness at the well locations using synthetic seismic models and preliminary interpretation of field seismic. We identified a characteristic reduction of seismic waveform amplitude and frequency associated with increasing thickness of the gradational porosity decrease interval which will be used to map seismically reservoir properties at the Wellington field.

RESERVOIR ARCHITECTURE

Characteristic architecture of the Mississippian reservoir can be observed on porosity and sonic logs (Fig. 1). The high-porosity (25-30%) section of the reservoir (up to 30 ft thick) beneath the unconformity surface is followed by the interval (up to 30-40 ft thick) of gradational porosity decrease (from 25-30% to 4-6%). The velocity profile shows the sharp velocity increase at the top of the reservoir (step velocity function) with constant velocity of 12500 ft/sec corresponding to high-porosity interval followed by the gradational velocity increase to 17000 ft/sec (ramp velocity function) corresponding to gradational decrease in porosity (**Figure 48**). This ramp velocity function is hypothesized to cause seismic waveform integration and result in a characteristic decrease of signal amplitude and frequency as the thickness of the ramp increases (Sengbush et al., 1961). We used seismic modeling and field seismic data to test this hypothesis at the Wellington field.

WELL-LOG INTERPRETATION

The neutron porosity logs were used for the detailed analysis of the Mississippian reservoir. We picked the top and the bottom of the high-porosity interval and the bottom of the following interval with a gradational porosity decrease. Pseudo-sonic logs were generated for these wells using the multilinear transform of neutron porosity and gamma ray logs in order to tie them to seismic data (Hampson et al., 2001).

SYNTHETIC SEISMIC DATA

A synthetic seismic section was produced for a three layer model of the Mississippian at the Wellington field: 1) a thick layer with constant velocity of 12000 ft/sec, 2) a thin layer with velocity linearly increasing with depth from 12000 to 16200 ft/sec, 3) a thick layer with constant velocity of 16200 ft/sec (**Figure 49a, 49b**). The thickness of the middle layer increases from 5 ft to 150 ft. Instantaneous amplitude and frequency attributes were calculated (**Figure 49c, 49d**).

SEISMIC DATA INTERPRETATION

The 3D PSTM seismic data were conventionally interpreted by creating synthetic seismograms from sonic logs and picking seismic horizons associated with the major seismic reflections from the tops of the Lecompton Limestone, the Kansas-City Group, the Mississippian System, and the Arbuckle Group. Instantaneous amplitude and frequency volumes were calculated from seismic data. These attributes were analyzed for the Mississippian reflector at the well locations with known reservoir properties in order to identify possible relationships.

PRELIMINARY RESULTS

The synthetic seismic section of the ramp velocity function shows the characteristic decrease in signal amplitude and frequency with increasing thickness of the layer with gradational velocity increase (**Figure 49, 51**). For the ramp thickness increasing from 5 to 65 ft (~1/4 wavelength) decrease in amplitude (50%) and frequency (10 Hz or ~25%) is observed.

The seismic response of the Mississippian reservoir with laterally varying reservoir properties exhibits characteristic features (**Figure 50**). As indicated by the neutron porosity curves, the thickness of the interval with gradational porosity (decrease from 25-30% to 4-6%) increases from right to left from 11 to 39 ft (**Figure 50a**). At the same locations, seismic decrease in frequency (20%) and amplitude (26%) of the Mississippian reflection is observed (**Figure 50c, 50d, 52a, 52b**). Further to the right end of the section significant reductions in signal amplitude (50%) and frequency (50%) occur. This observation is consistent with the expected wavelet integration effect of a ramp velocity function (**Figure 49, 51**). Results from this study will be used for predicting Mississippian reservoir porosity and thickness over the 3D seismic area at Wellington field.

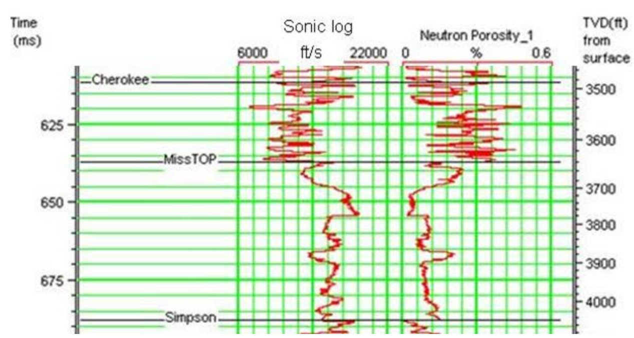


Figure 48: Characteristic architecture of the Mississippian chert reservoir at the Wellington Field. Note the interval with constant velocity (12500 ft/sec) and porosity (25%) values below the Mississippian top (labeled as MissTOP) followed by the interval with gradational velocity increase (from 12500 to 17000 ft/sec) and corresponding porosity decrease (from 25 to 4%).

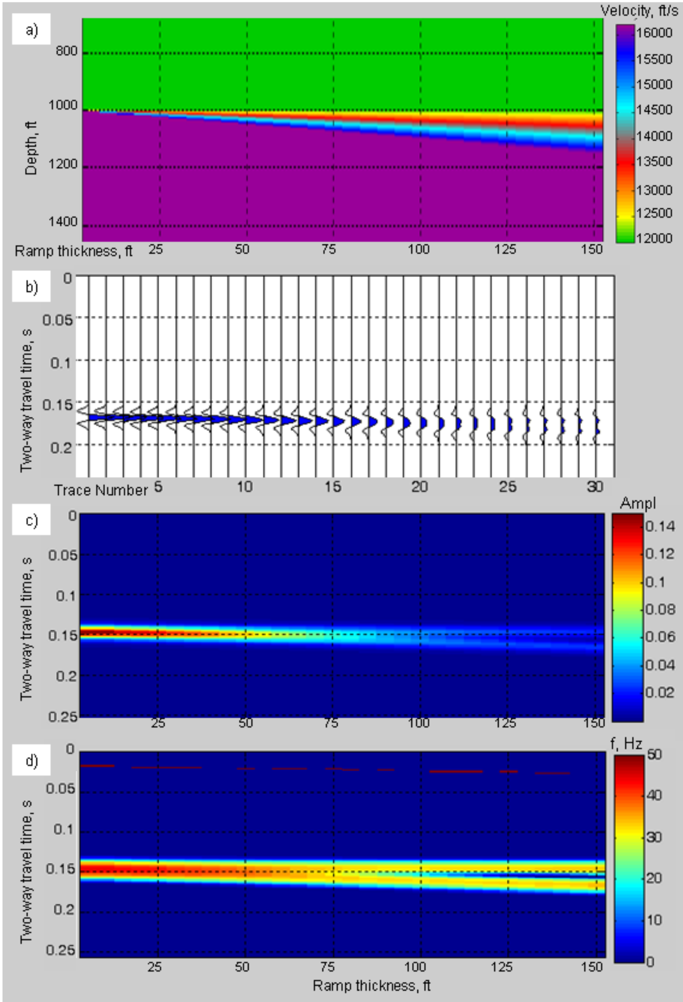


Figure 49: Wedge model of a ramp velocity function: a) depth-velocity model; b) synthetic seismic section (55 Hz Ricker wavelet); c) amplitude envelope section; d) instantaneous frequency section. Note the decrease in waveform amplitude and frequency as the thickness of the ramp velocity layer increases.

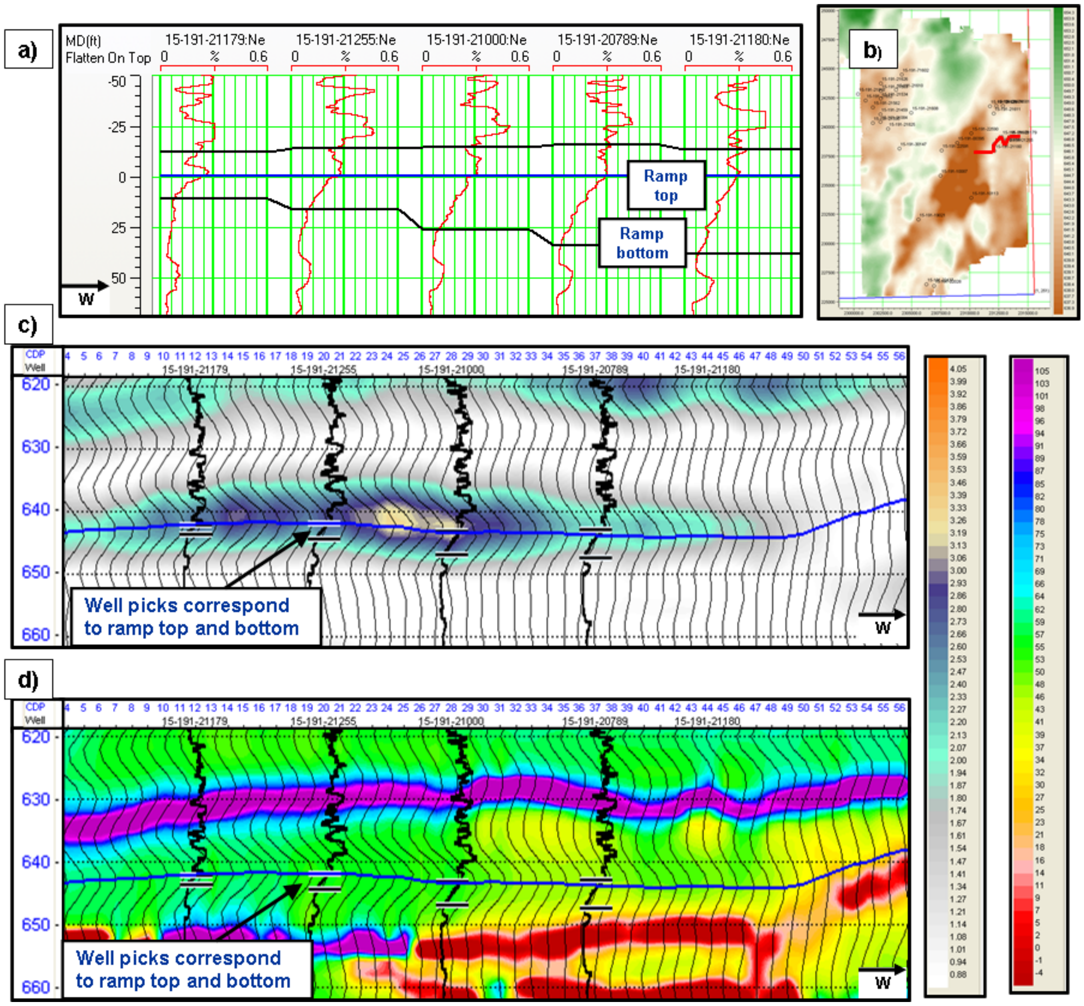


Figure 50: Seismic attribute analysis: a) well log cross-section (neutron porosity logs); b) Mississippian horizon time map with red line showing cross-section and seismic path location; c) amplitude envelope section with overlaid neutron porosity logs; d) instantaneous frequency section with overlaid neutron porosity logs. Note seismic amplitude and frequency reduction with increasing velocity ramp thickness.

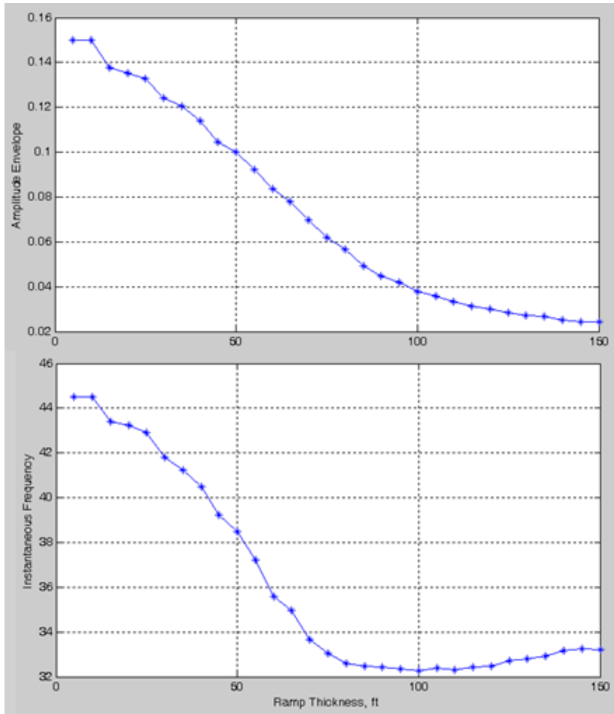


Figure 51: a) Amplitude envelope and b) instantaneous frequency versus ramp thickness (correspond to figures 2c and 2d respectively).

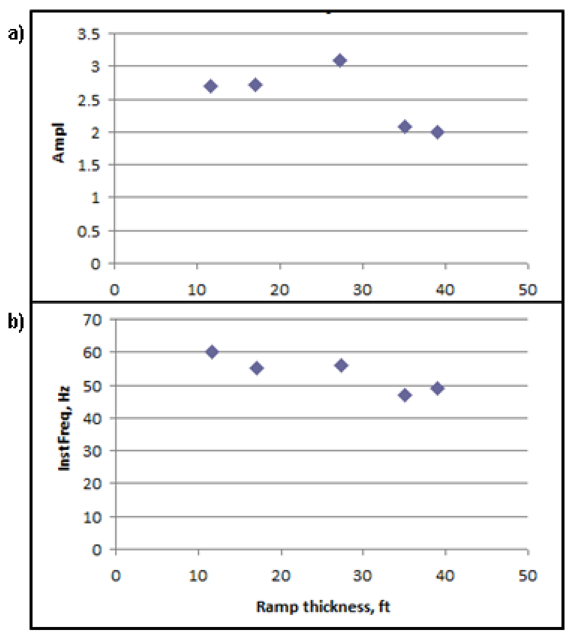


Figure 52: a) Amplitude envelope and b) instantaneous frequency versus ramp thickness at the well locations (correspond to figures 3c and 3d respectively).

REFERENCES

Hampson, D., J. S. Schuelke, and J. A. Quirein, 2001, Use of multiattribute transforms to predict log properties from seismic data: Geophysics, 66, p. 220-236.

Sengbush, R. L., P. L. Lawrence, and F. J. McDonal, 1961, Interpretation of synthetic seismograms: Geophysics, 26, 138-157.

Subtask 4.13. Correlate log & core - extend to OPAS

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 53-57**.

The 430-foot thick Mississippian interval includes both the oil reservoir at its top (**Figures 53, 54, and 55**) and a lower 110 ft interval (**Figure 57**, 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.

- <u>Vertically stacked siliceous dolo-siltites</u> 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.

- <u>Shallowest cycles deposited along higher edges of ramp were affected by bottom currents and were subaerially exposed after deposition.</u>

- <u>Rock properties typically change systematically upward</u> through the reservoir succession with molds and vugs, pore throat size, and connectedness varying between each successive cycle affecting cementation exponent & bound water.

Cored Well, Berexco Wellington KGS #1-32
Top Mississippian to Kinderhook Shale

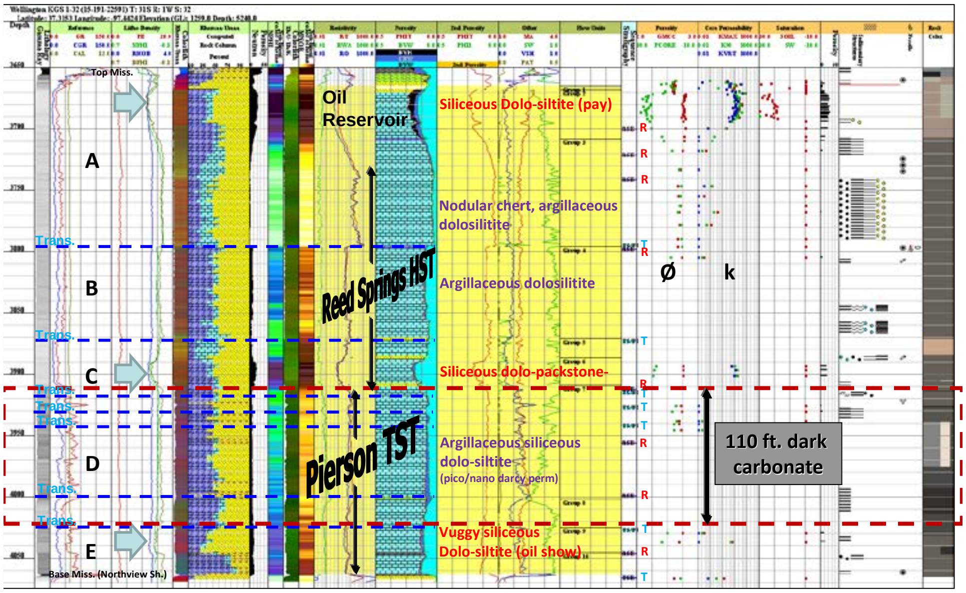


Figure 53. Well log and interpreted lithologic profile from logs on left. Right side illustrates porosity and permeability measurements from core, sedimentary structures, and color for Wellington KGS #1-32 borehole.

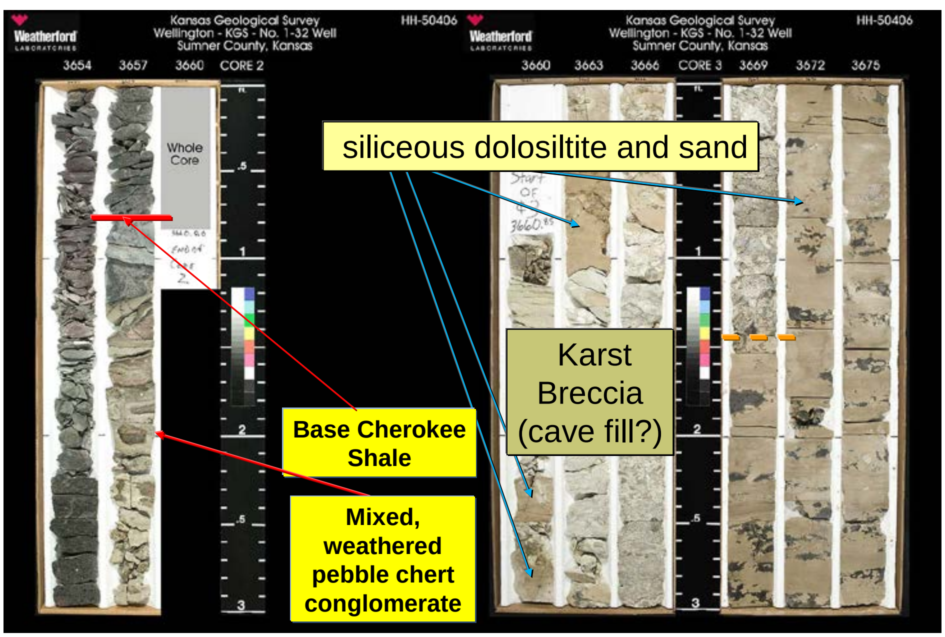


Figure 54. Three boxes of slabbed core (3 ft long) from Wellington KGS #1-32 borehole showing upper portion of the oil reservoir in Wellington Field overlain by shales of the Pennsylvanian Cherokee Group.

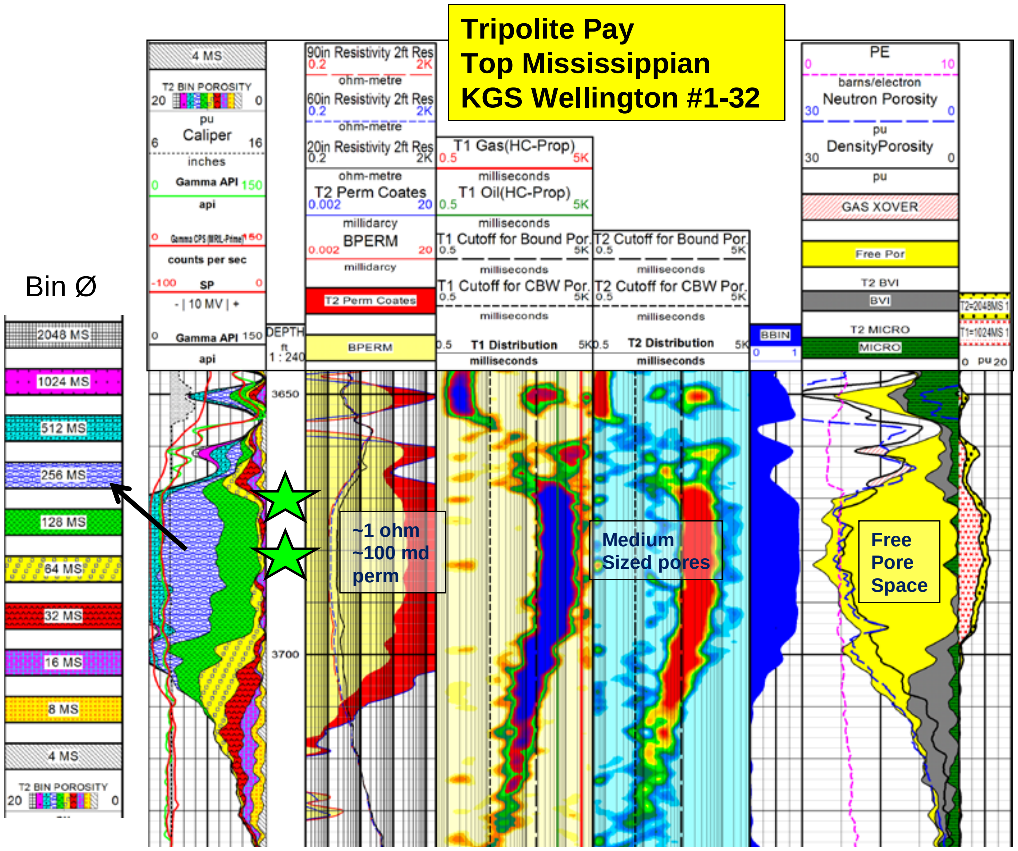


Figure 55. Interpreted nuclear magnetic resonance (NMR) log profile of the Mississippian oil zone in Wellington KGS #1-32 borehole, annotated with summary information: low one ohm-m resistivity, moderate porosity of around 100 md, medium sized pores (intercrystalline dolomite), most of which is free 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 56. 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.

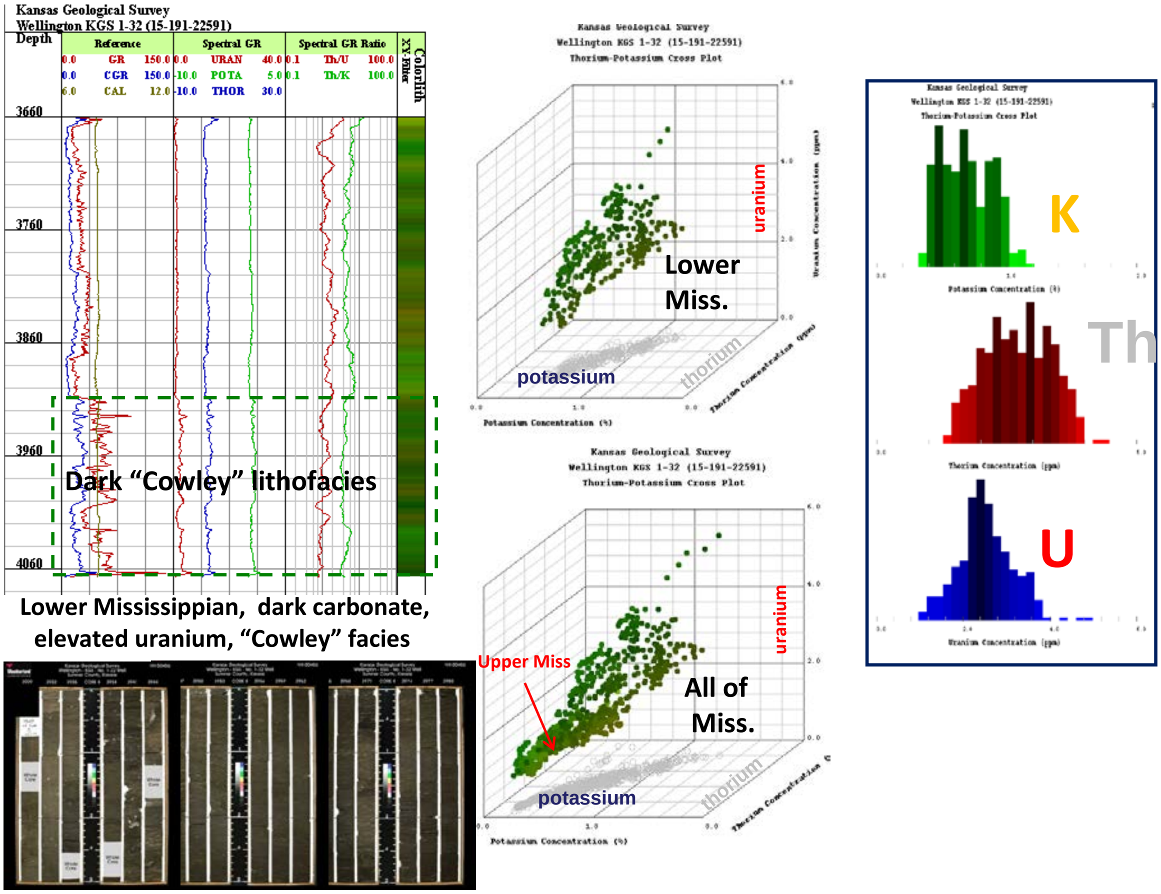


Figure 57. Spectral gamma ray profile (uranium, potassium, and thorium) of the Mississippian strata in Wellington KGS #1-32 borehole and comparison of these elements in cross plots to right show elevated uranium content in lower Mississippian "Cowley lithofacies. Photos of 3 ft high core boxes illustrating the dark colored, tight, low permeability argillaceous siltstones of the "Cowley" lithofacies shown in lower left.

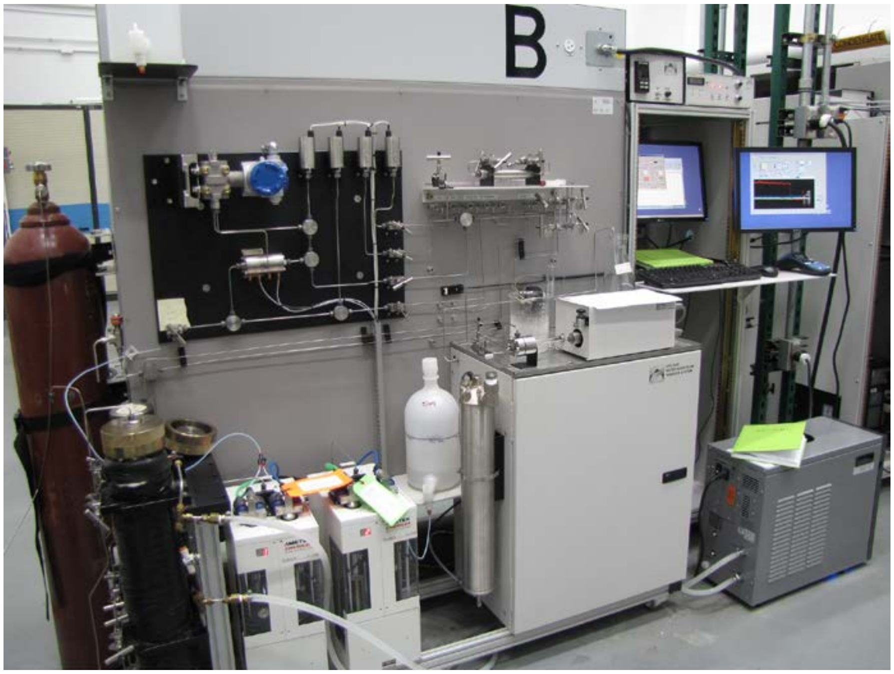


Figure 58. Core flow apparatus used at NETL in Pittsburgh to measure the microdarcy and picodarcy permeability in the lower Mississippian organic bearing, argillaceous quartz/dolomitic siltstones that are being evaluated to serve as additional caprock that overlies the Arbuckle saline formation.

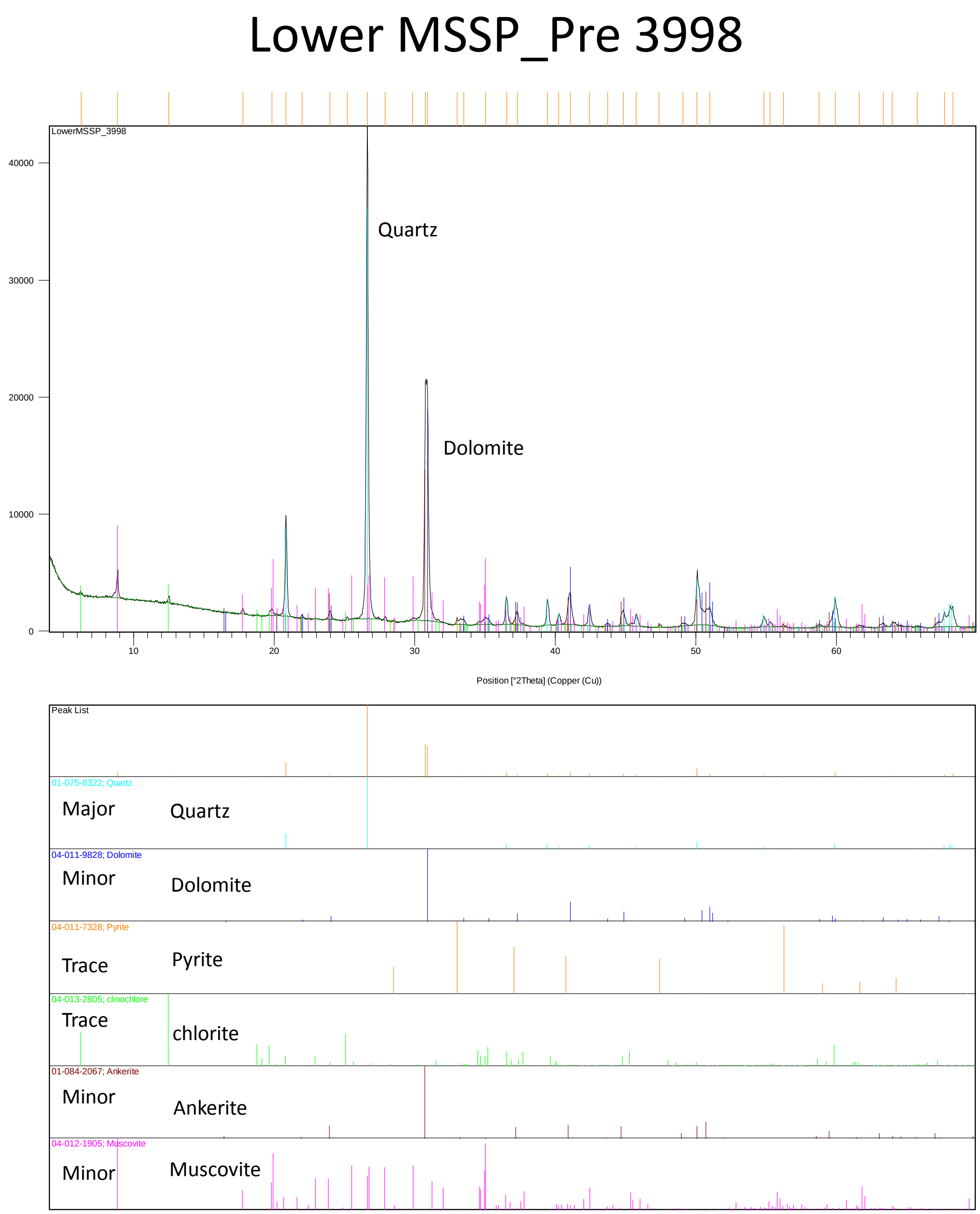


Figure 59. Lower Mississippian – 3998 x-ray diffraction (see key in figure below).

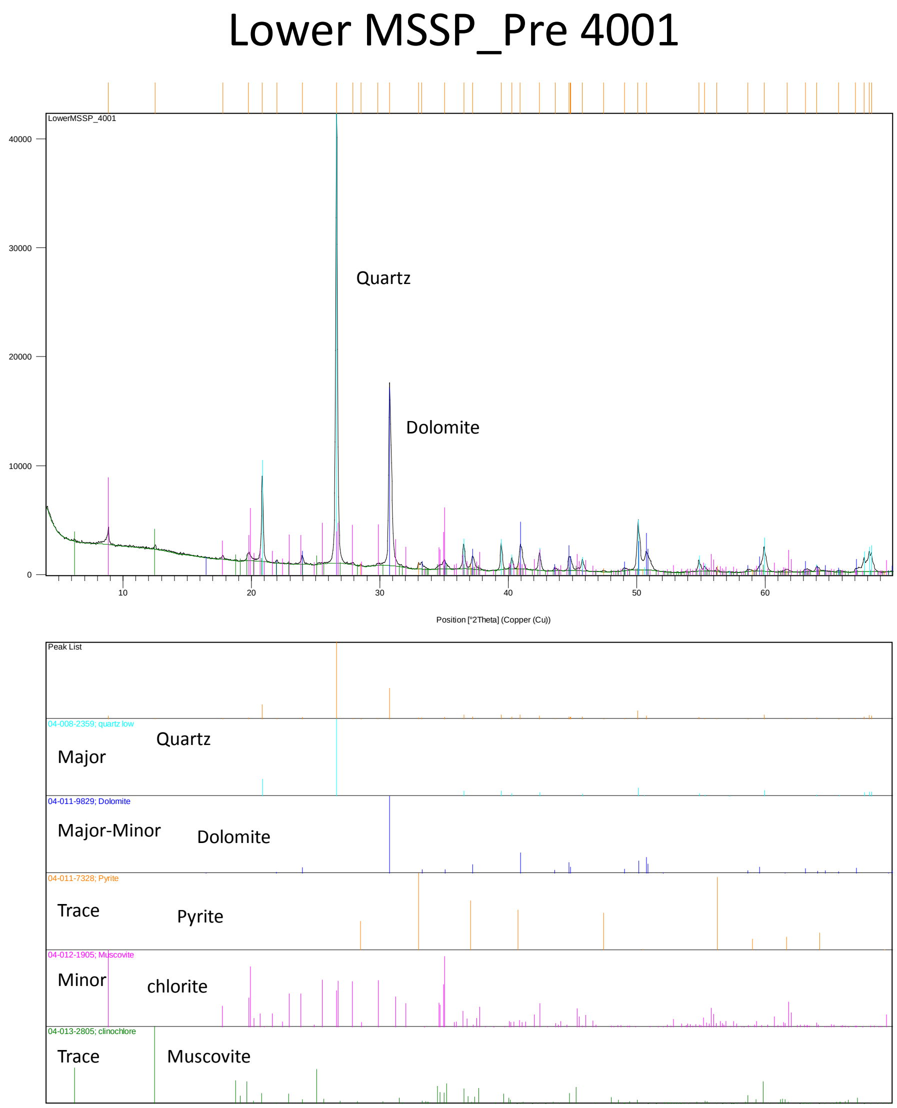


Figure 60. Lower Mississippian, 4001 ft. Potential caprock.

- **Phases marked as “clinochlore” are a type of chlorite**
- **Semi-quant where muscovite/illite is present is highly unreliable, thus reported as major-minor-trace (roughly based on scattering factors and peak intensities), where:**
  - **Major ~ > 25%**
  - **Minor ~ 5-25%**
  - **Trace < 5%**

Contribution by Mina FazelAlavi summarizing main activities in normalizing, calibrating, and verifying well log data in Wellington Field

- Well 1-28 and 1-32 were analyzed in terms of porosity and water saturation using spreadsheet multi mineral model.
- Wells 1-28 and 1-32 were selected as key wells because they had modern conventional logs, geochemical logs and NMR log. Well 1-32 has also core data.
- Well 22581 was analyzed using multi mineral model in spreadsheet. This well had Neutron, Density, PEF, GR and resistivity log. This well was reprocessed later using Techlog.
- Wells with API number of 10082, 10094, 10084, 10080 and 10097 were normalized with key well (well 1-32). These wells need to be reprocessed by TechLog or normalized again since well 1-32 was reprocessed with Techlog with better results.
- Core data of well 1-32 was analyzed by Flow Zone Index (FZI) method to determine rock types and permeability/porosity correlations, **Figure 61**.
- Equivalent water salinity of the formation was calculated from water chemical analysis of well 1-32 using Schlumberger chart (Total dissolved solids concentrations were converted to ppm NaCl). Water resistivity at formation temperature was then calculated using chart book of Schlumberger. Water resistivity was also found from picket plot and Rwa method. Finally 0.027 ohm meter was selected and used as water resistivity for Mississippian formation.
- Cuddy method was applied to BWV of well 1-32 to determine free water level. The effort was inconclusive because certain intervals of the well might have been invaded by injection water. This method is applicable when there is no change in initial water saturation by production or water injection.
- Attended a week long Techlog training workshop in Houston, Texas from 3/4/2012-3/9/2012.
- Conventional logs of well 1-32 and 1-28 were reprocessed by TechLog for determination of porosity, mineralogy and water saturation. Interpretation results were improved and matched NMR and core analysis results, **Figure 62** and **Figure 63**.
- Geochemical logs of well 1-32 and 1-28 were analyzed by TechLog for determination of minerals and clay types. A more detailed analysis of clay and mineral types were obtained, **Figure 4** and **Figure 65**. It was also found that Mg log reading was not accurate in Mississippian formation. Uncertainty of Mg had to be increased to obtain a proper match between actual and predicted curves of other logs.
- Convention and geochemical logs of well 1-32 and 1-28 were combined and analyzed by Techlog, **Figure 66** and **Figure 67**. Results from this analysis was compared with above interpretations which were good.
- Well Tjaden A-1 was analyzed with Techlog for KICC annual review meeting.
- Well Frankum 1, Frankum 1-32 and Meridith 2 were analyzed using Techlog.
- Geochemical analysis of formation water at different depths were posted on composite log of well 1-32.

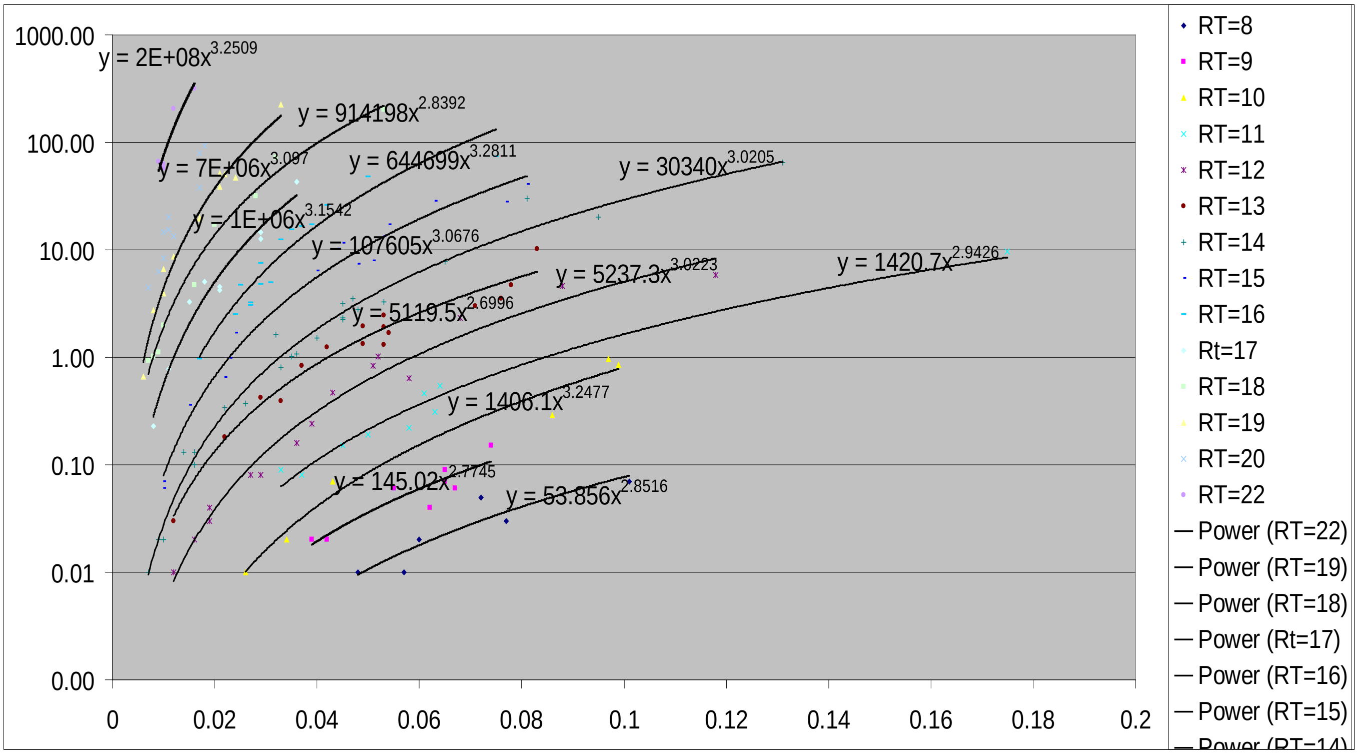


Figure 61: Rock types and permeability/porosity correlation for well 1-32

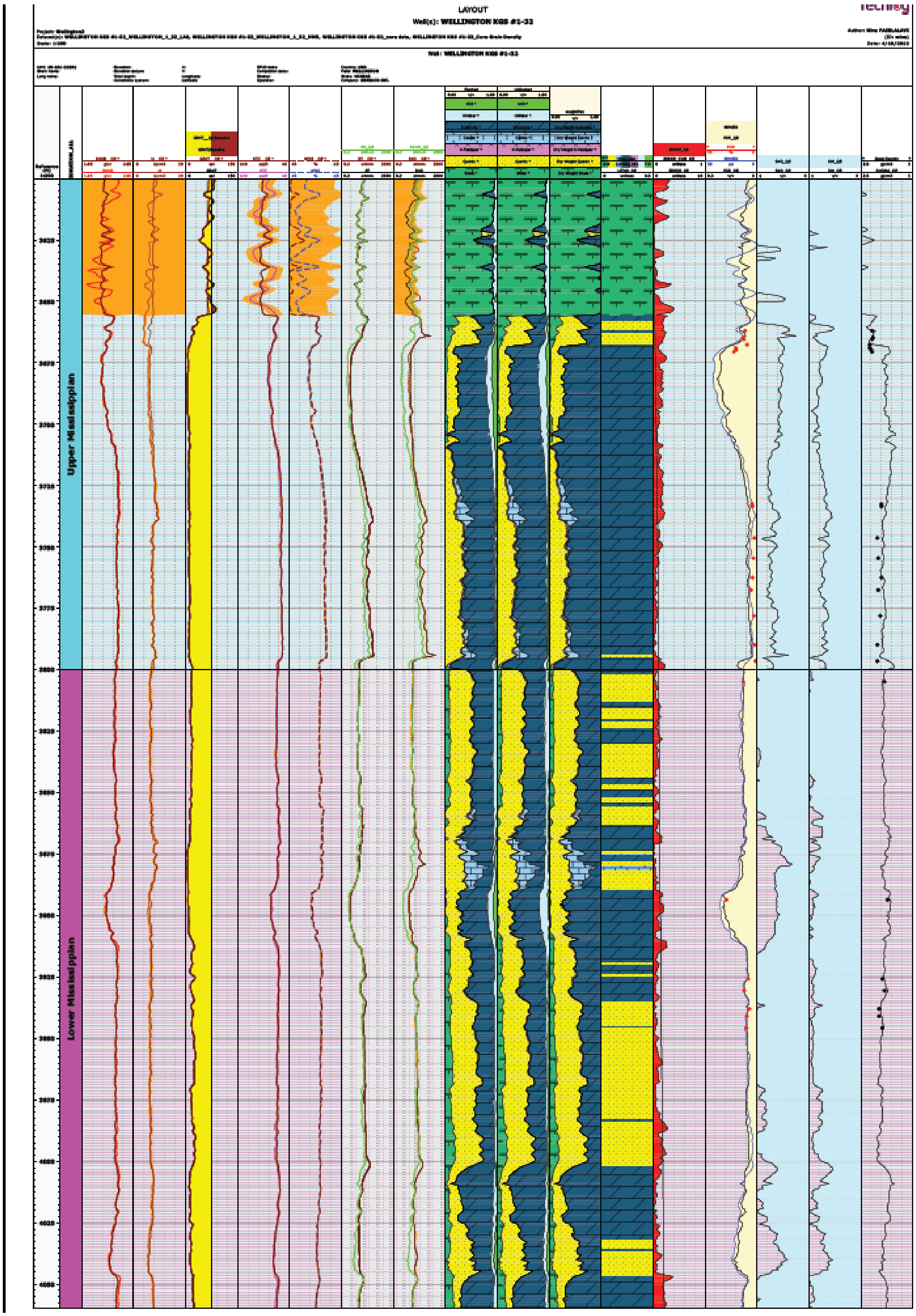


Figure 62: Well 1-32- Conventional log analysis results

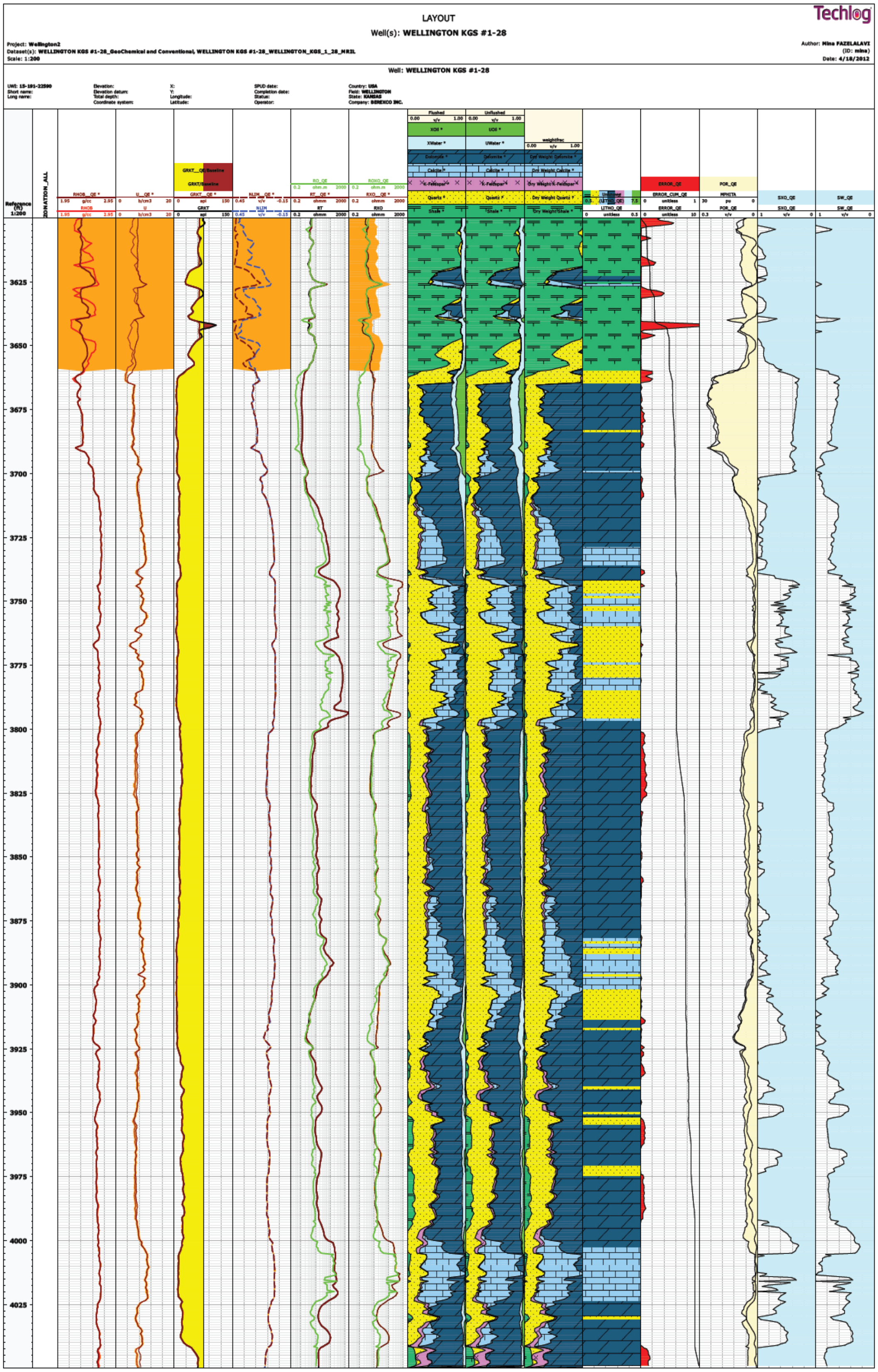


Figure 63: Well 1-28-Coventional log analysis results

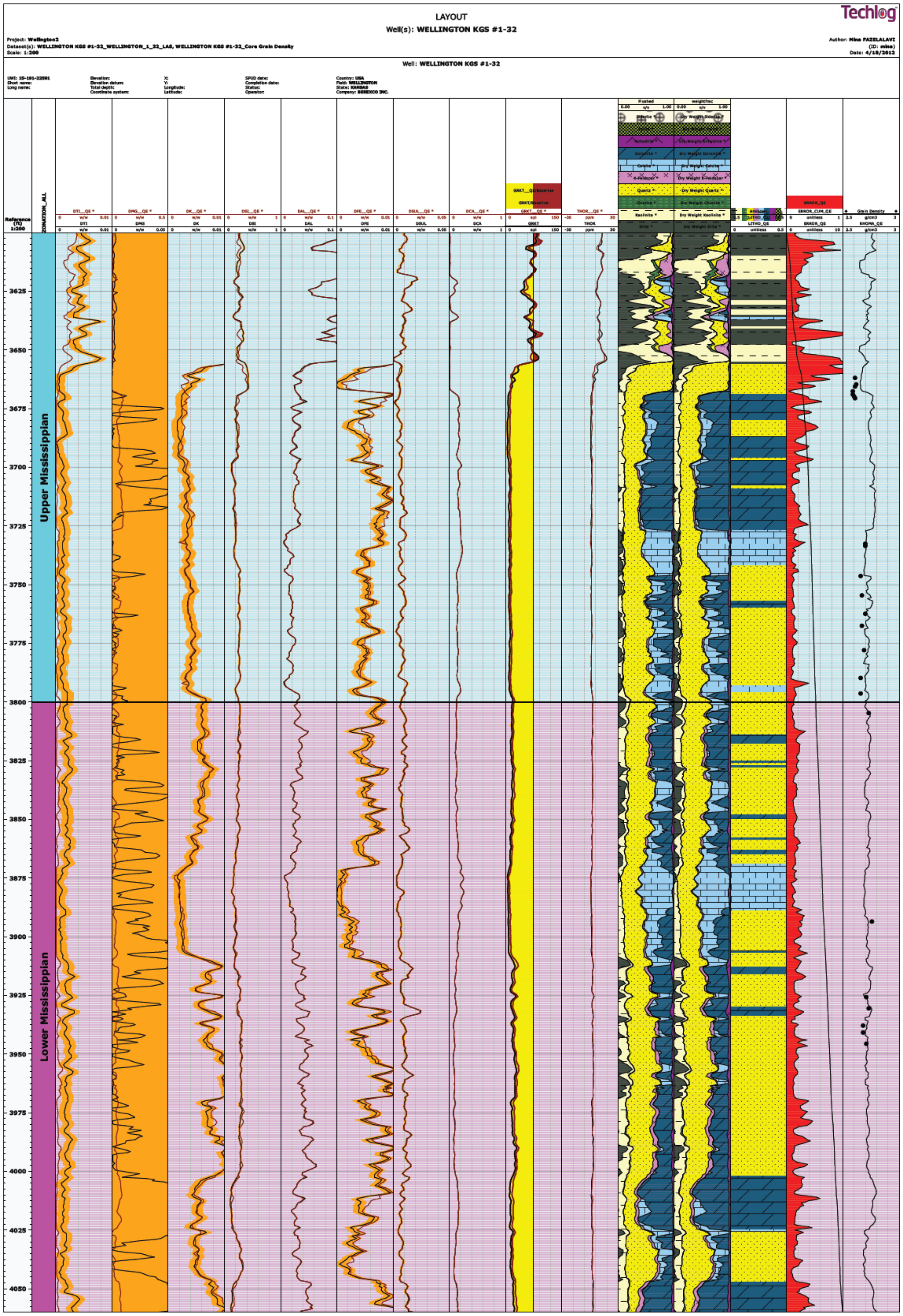


Figure 64: Well 1-32- GeoChemical log analysis results

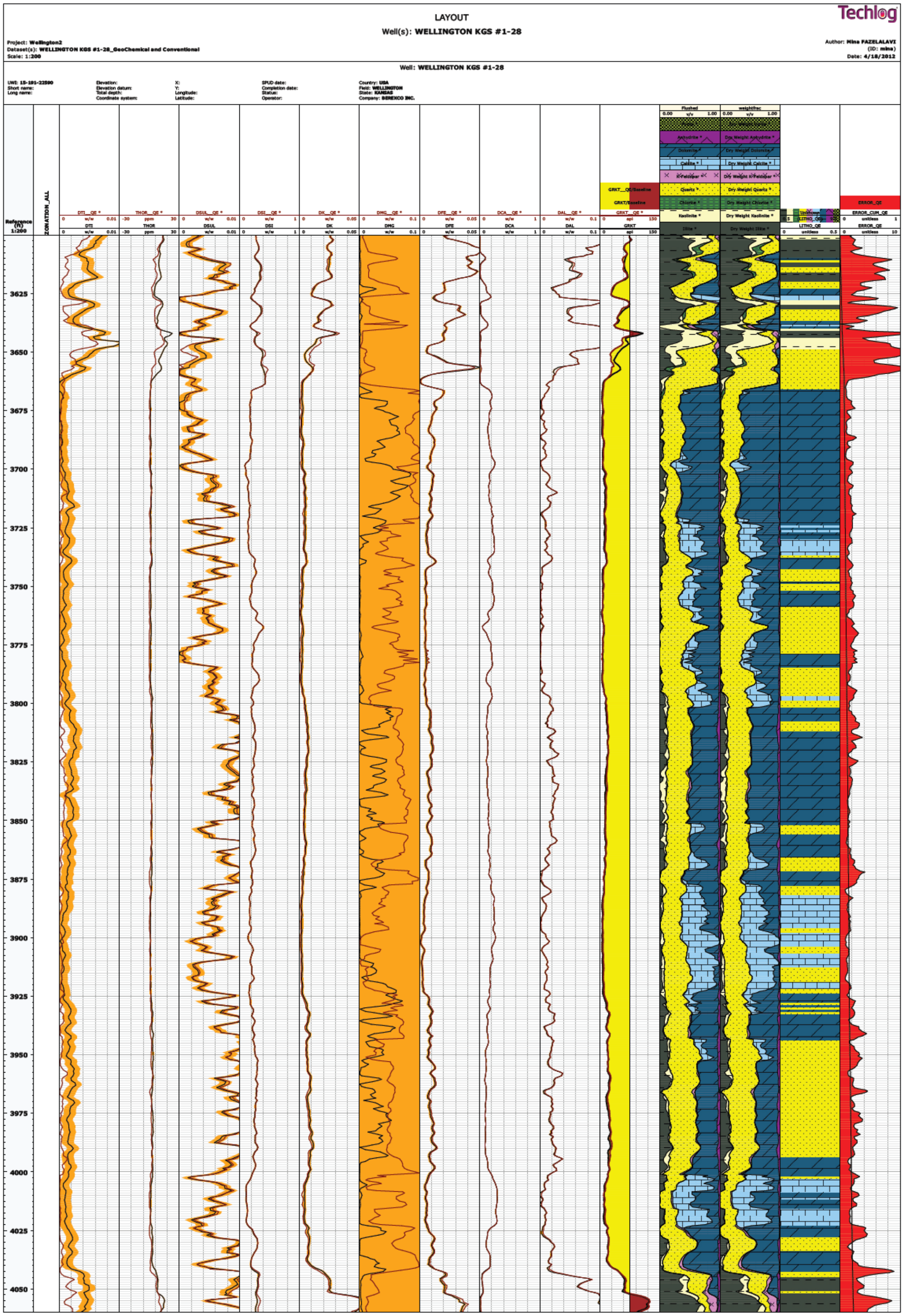


Figure 65: Well 1-28- GeoChemical log analysis results

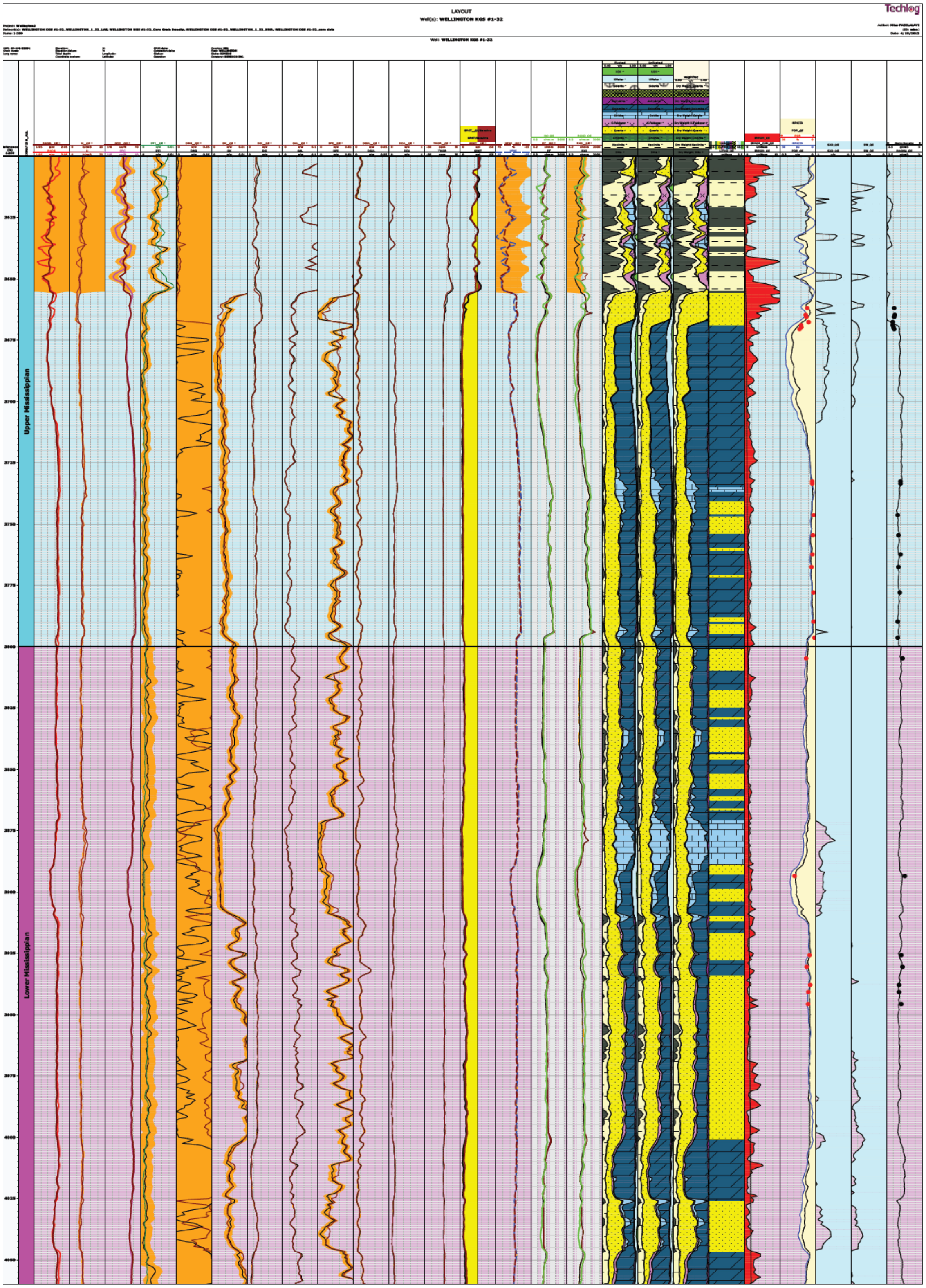


Figure 66: Well 1-32- Combination of GeoChemical log and Conventional log analysis results

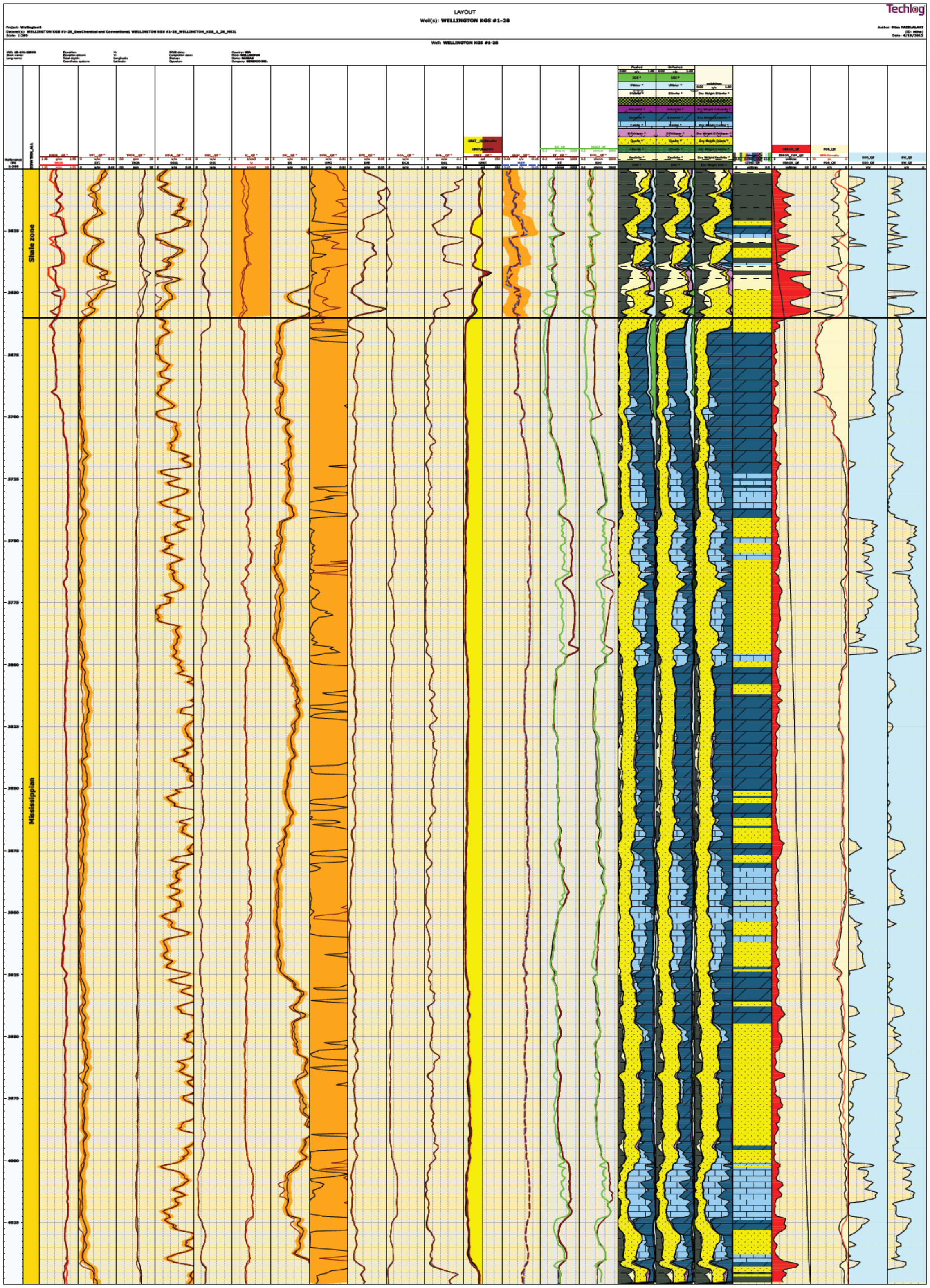
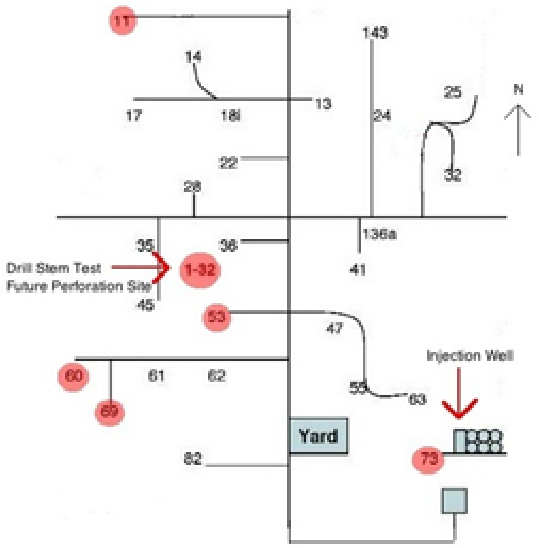


Figure 67: Well 1-28- Combination of GeoChemical log and Conventional log analysis results

Subtask 4.12. Microbiological studies on produced water

Geochemical and Microbial Characterization of Mississippian Reservoir Brine- Wellington Oil Field, Kansas contributed by Breanna Huff, Jennifer Roberts, David Fowle



Sampled Wells and Total Depths

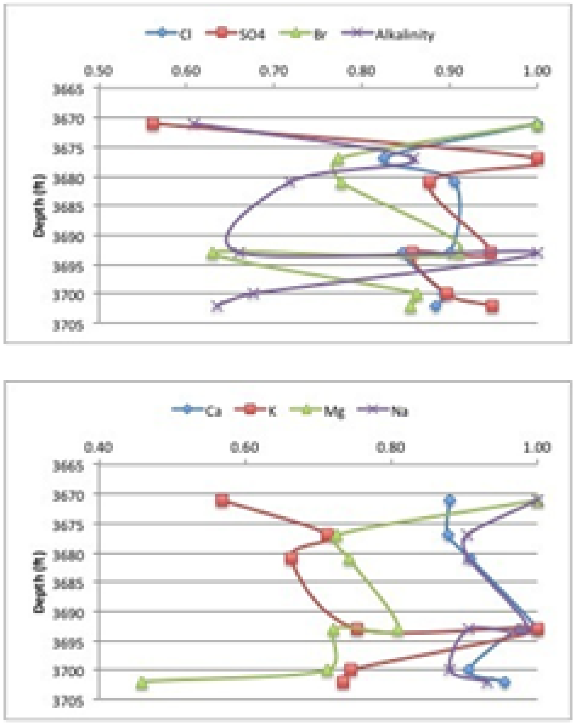
Sample Well	Total Depth (ft)
Well 11	3702
Well 53	3693
Well 60	3700
Well 63	3693
Well 73	3671
Injection Well	3681
DST	3677

Figure 68. Field site.

Sample Collection

- Collected production fluids for geochemical analysis, microbial cultivation, biomass, and DNA
  - Onsite:
    - pH and temperature measured uphole
    - Alkalinity and ferrous iron
    - Inoculated culture vials with production fluid
  - Lab:
    - Gas analysis
    - Total lipid biomass of aqueous and oil phases
    - DNA of aqueous and oil phases
    - Cations and anions

Figure 69. Sample collection.



- pH ranges from 5.4 to 6.3
- Temperature from 23-32 °C
  - DST-41 °C
- Salinity varies from 14-20%
- Major ions vary with depth
  -lithological/mineralogical variations?

Figure 70. Geochemistry.

- Carbon and phosphate sources available
- Sulfate, iron (II), and methane redox species present
- Biogeochemistry is consistent with most of cultivation analysis
  - Sulfate reducing bacteria were not identified, although geochemistry suggests that they are present and active

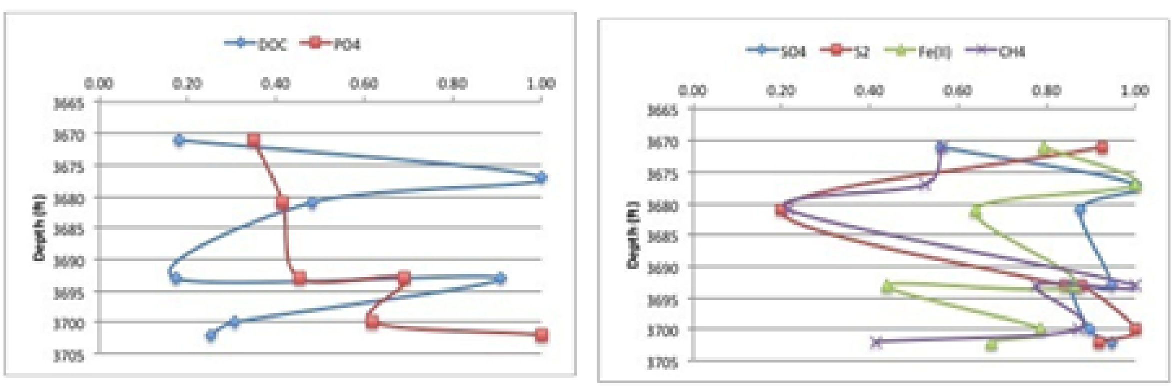


Figure 72. Nutrient and energy sources.

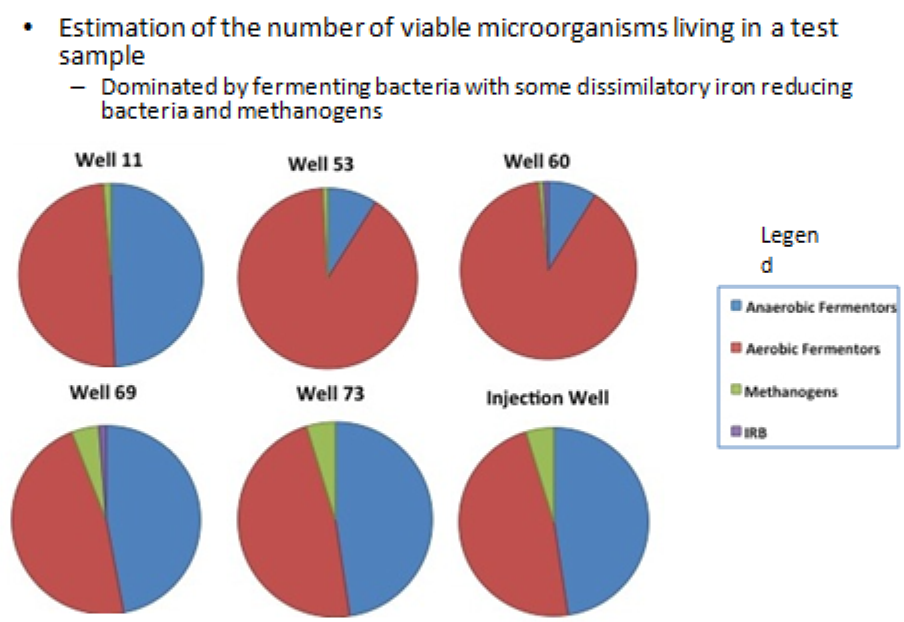


Figure 73. Most probable number (MPN) analysis.

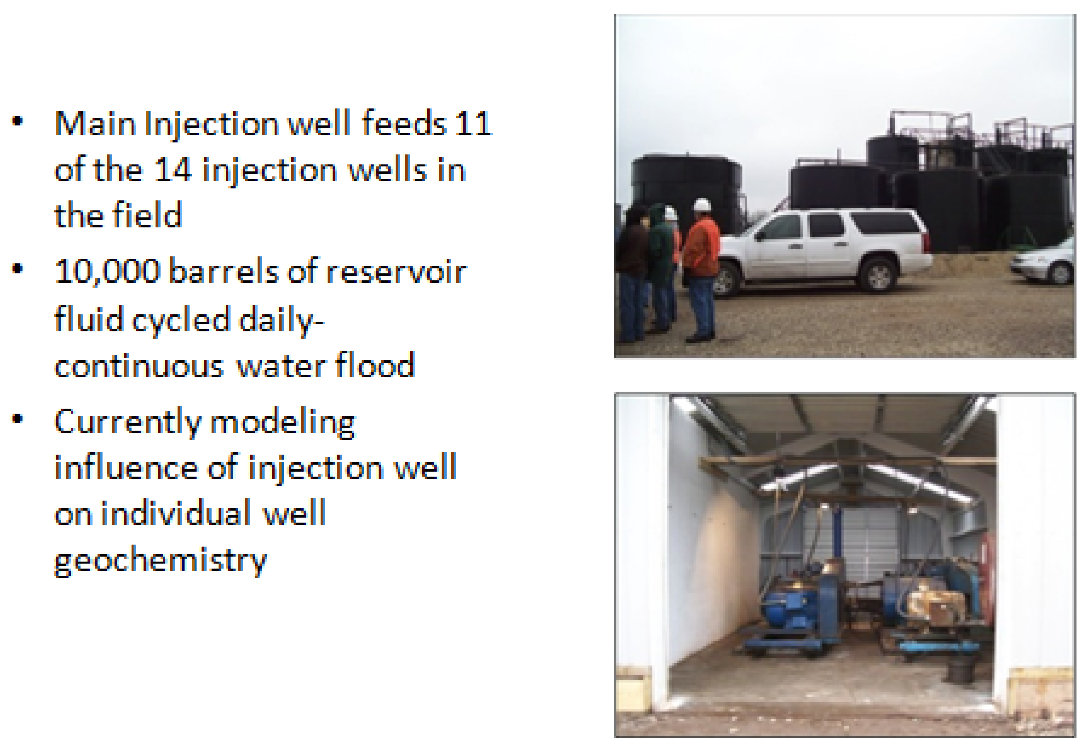
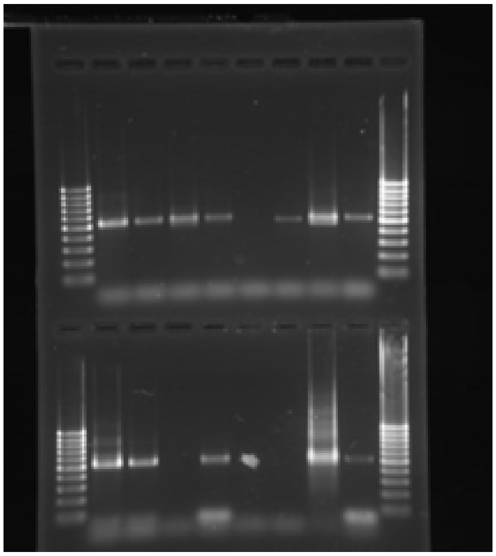


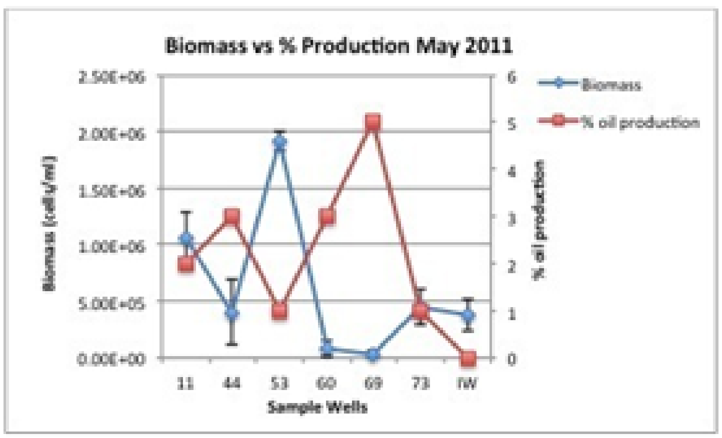
Figure 74. Influence of injection well.



BAC 5F/519R

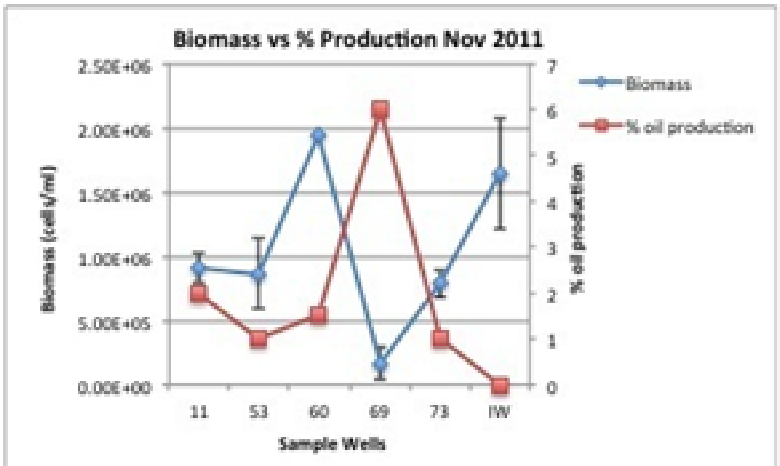
- Injection Well, Well 73 aqueous, Well 60 oil, and DST all positive for bacteria
- Well 60 oil and Injection Well positive for *Archaea*
- Next step: run Denaturing Gradient Gel Electrophoresis analysis to get a clearer fingerprint on similarities/differences in microbial communities between producing wells and injection well

Figure 75. Preliminary DNA results.



Sample Well	May 2011 Production	Biomass (cells/ml)
Well 11	2	1.06E+06
Well 44	3	4.03E+05
Well 53	1	1.92E+06
Well 60	1.5	8.41E+04
Well 69	5	3.00E+04
Well 73	1	4.42E+05
Injection	NA	3.80E+05

Figure 76. Biomass vs. % oil production. on May 2011.



Sample Well	Nov 2011 Production	Biomass (cells/ml)
Well 11	2	9.03E+05
Well 53	1	8.67E+05
Well 60	1.5	1.95E+06
Well 69	6	1.66E+05
Well 73	1	7.90E+05
Injection Well	NA	1.64E+06

Figure 77. Biomass vs. % oil production. on November 2011.

Conclusions:

- Large differences in geochemistry from well to well were not found yet disparities that are present may be attributed to lithological and mineralogical variations, or possibly microbiological activity.
- What is the microbiology of the production fluids?

-MPN analysis of reservoir fluids tested positive for fermentative bacteria, iron reducers, and methanogens, consistent with the presence of ferrous iron and methane, but not sulfate or nitrate.
-nitrate and sulfate reducing bacteria were not identified and their absence may be due to culture media bias or treatment of the production wells with anti corrosion compounds.
-non culture based analysis will determine their presence/absence.

- Is there a spatial geochemical/microbial influence between injection well and production wells?

-geochemical data between wells is fairly consistent, suggesting mixing and homogenization, however modeling is underway to distinguish differences.
-DGGE will identify microbial “fingerprints” associated with individual wells or influence of injection well.

- Anti-correlation of biomass concentration and % oil production from producing wells suggest that microbial growth may clog the near vicinity of the borehole.

Future Work

DGGE-community fingerprint and possibly sequence individual bands for more in depth microbial characterization
Modeling in Geochemists Workbench to better understand aqueous geochemistry between wells and influence of injection well (if any)
Use well logs and geochemical data to understand differences in geochemistry with varying depths

Subtask 4.14. Diagenetic history of fracture fill
Contributed by Brad King and Robert Goldstein

Purpose:

- Understand diagenetic effects on carbonate reservoir quality
- Identify conduits for hydrothermal fluid flow within and above the Arbuckle Group
- Diagnose fluid-flow controls
- Provide a predictive tool for understanding fluid-flow behavior of carbon dioxide-rich fluids within reservoir and seal units following injection.

Initial findings:

- Extensive replacement dolomite and multiple generations of dolomite cement precipitation modify porosity within the Arbuckle Group
- Replacement silica and multiple generations of silica precipitation reduce porosity to a lesser degree, relative to dolomite
- Fractures and vugs are partially to fully occluded with dolomite, silica, calcite, and sulfides and have been conduits for fluid flow
- Fluid inclusion observations suggest elevated temperatures and phase separation during formation, providing possible links to a hydrothermal system that is outgassing

Figure 78. Dolomite replacement and precipitation.

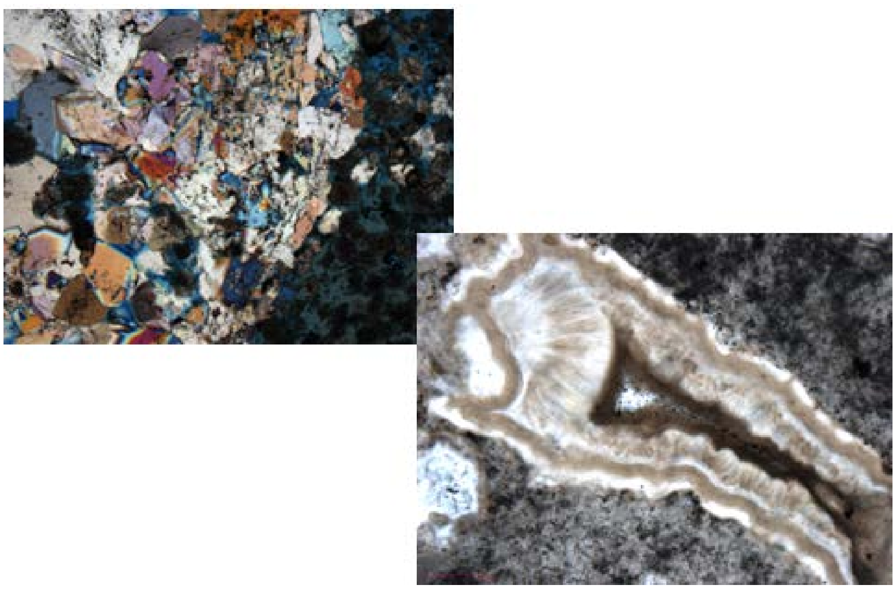


Figure 79. Silica replacement and precipitation.

Future Work:

- From fluid inclusions, obtain temperatures, salinities, and compositions of fluids that have precipitated, migrated through, or recrystallized mineral phases

- Refine understanding of flow paths, composition, and temperature using $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$
- Synthesize driving forces behind past fluid migration events and establish the likelihood of recurrence, including time scale(s) for recurrence
- Apply these data as a predictive tool for understanding fluid flow behavior of carbon dioxide-rich fluids within reservoir and seal units following injection

Presentations

Made invited presentation focused on Mississippian portion of the Wellington #1-32 core and log suite at Geoscience Technology Workshop, "New Directions in Carbonates" organized by AAPG, Ft. Worth, TX February 27-28.

Summarized DOE sponsored research on CO2 sequestration and CO2-EOR to technical meeting of the Kansas Geological Society, Wichita, March 6, 2012.

Key Findings

1. Initial CO2 storage capacity estimate of deep Arbuckle saline formation in southern Kansas -- P10 in the low 10% range of probability is 8.8 billion tonnes. P90 estimate of CO2 storage is 75.5 billion tonnes.
2. Set plan for refining storage estimate using continued petrophysical analysis.
3. New Java Applet created for use in CO2 storage calculation.
4. New DST Analysis Java Applet – "Drill Stem Data Entry and Quantitative Analysis Tool" to aid in estimating permeability.
5. Decision made on location to drill basement test in southwest Kansas based on regional and local geology.
6. Decision made on outline of 3D seismic around new drillsite to include Missippian structural plateau and incised valley system.
7. Near final results of reservoir simulation through the waterflood stage at Pleasant Prairie is proceeding well with good match to production. Next comes CO2-EOR simulation to maximize for sequestration.
8. Low permeable tight slightly organic rick, very dark argillaceous dolomitic siltstones in the lower Mississippian appear to be good caprock with further studies underway.
9. Established lower Mississippian is quartz dominated, dolomitic silt with pyrite, chlorite, ankerite, and muscovite identified in XRD.
10. Identified a characteristic reduction of seismic waveform amplitude and frequency associated with increasing thickness of the gradational porosity decrease interval which will be used to map seismically reservoir properties at the Wellington field.
11. Integrated core, NMR, and geochemical logs to refine lithology, porosity, and permeability solutions of the entire Pennsylvanian to basement interval in KGS #1-32. Extended correlations to #1-28. Will develop correlations that can be extended to log suites that are less than optimal.

12. Continued work on microbial components being related to substrate and brine composition and stratigraphic isolation.
13. Anti-correlation of biomass concentration and % oil production from producing wells suggest that microbial growth may clog the near vicinity of the borehole.
14. Fractures and vugs in the Arbuckle are partially to fully occluded with dolomite, silica, calcite, and sulfides and have been conduits for fluid flow.
15. Fluid inclusion observations in Arbuckle samples suggest elevated temperatures and phase separation during formation, providing possible links to a hydrothermal system that is outgassing.

Plans

1. Build new geomodels with latest data and build simulations in SW fields and Wellington.
2. Obtain another set of swab samples in Wellington #1-32.
3. Refine quantitative analysis of LAS files on regional level and incorporate analysis into Petrel for geocellular geomodel development.
4. Continue to refine core-log integration for improved geomodeling.
5. Refine understanding of the promising caprock in the lower Mississippian.

Cost Plan/Status

/09 Ends: 2/7/11				BP2 Starts 2/8/11	Ends 8/7/12			
1/1/10-3/31/10 Q2	4/1/10-6/30/10 Q3	7/1/10-9/30/10 Q4	10/1 - 12/31/10 Q5	1/1/11 - 3/31/11 Q6	4/1/11 - 6/30/11 Q7	7/1/11-9/30/11 Q8	10/1/11 - 12/31/11 Q9	1/1/12 - 3/31/12 Q10
$1,007,622.75	$1,007,622.75	$1,007,622.75	$0.00	$0.00	$0.00	$1,169,543.00	$1,169,543.00	$1,169,543.00
$277,260.75	$277,260.75	$277,260.75	$0.00	$0.00	$0.00	$303,182.75	$303,182.75	$303,182.75
$1,284,883.50	$1,284,883.50	$1,284,883.50	$0.00	$0.00	$0.00	$1,472,725.75	$1,472,725.75	$1,472,725.75
$2,569,767.00	$3,854,650.50	$5,139,534.00	$5,139,534.00	$5,139,534.00	$5,139,534.00	$6,612,259.75	$8,084,985.50	$9,557,711.25
$84,603.97	$494,428.37	$111,405.52	$238,675.97	$1,902,936.55	$625,853.17	$275,754.50	$523,196.12	$453,026.11
$43,980.04	$40,584.78	$13,195.88	$526,210.30	$35,887.31	$414,511.02	$20,247.24	$16,687.00	$61,683.20
$84,603.97	$535,013.15	$124,601.40	$764,886.27	$1,938,823.86	$1,040,364.19	$296,001.74	$539,883.12	$514,709.31
$88,623.90	$623,637.05	$748,238.45	$1,513,124.72	$3,451,948.58	$4,492,312.77	$4,788,314.51	$5,328,197.63	$5,842,906.94
$923,018.78	$513,194.38	$896,217.23	-$238,675.97	-$1,902,936.55	-$625,853.17	$893,788.50	$646,346.88	$716,516.89
$233,280.71	$236,675.97	$264,064.87	-$526,210.30	-$35,887.31	-$414,511.02	$282,935.51	$286,495.75	$241,499.55
$1,156,299.49	$749,870.35	$1,160,282.10	-$764,886.27	-$1,938,823.86	-$1,040,364.19	$1,176,724.01	$932,842.63	$958,016.44
$2,437,163.06	**$3,187,033.41**	**$4,347,315.51**	**$3,582,429.24**	**$1,643,605.38**	**$603,241.19**	**$1,779,965.20**	**$2,712,807.83**	**$3,670,824.27**