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:	2. Program/Project Title:
DE-FE0002056	**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**).

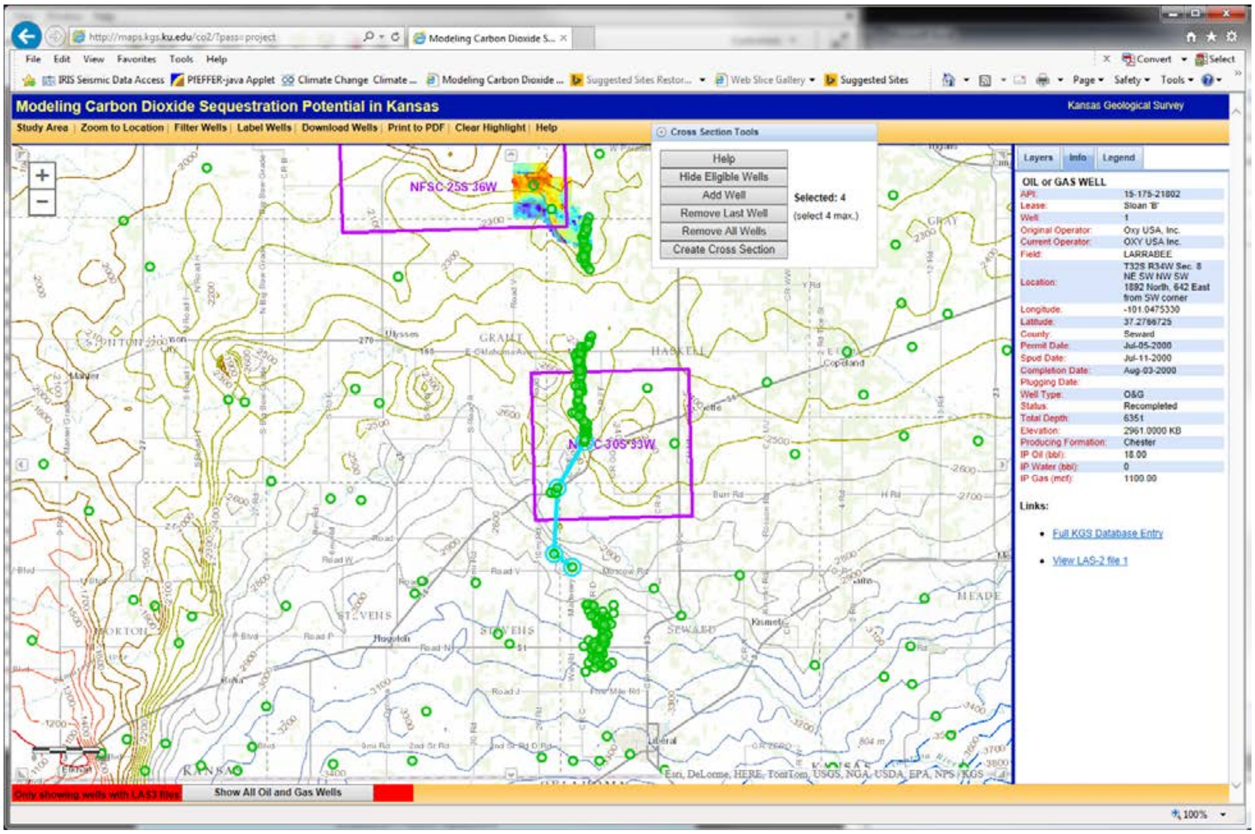


Figure 1. Interactive mapper showing distribution of the type wells in the western sector of the regional study area. Structure map on top of the Meramec Mississippian, field and type wells as green dots circles, and purple square in middle over Cutter and Victory fields corresponding to commercial scale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

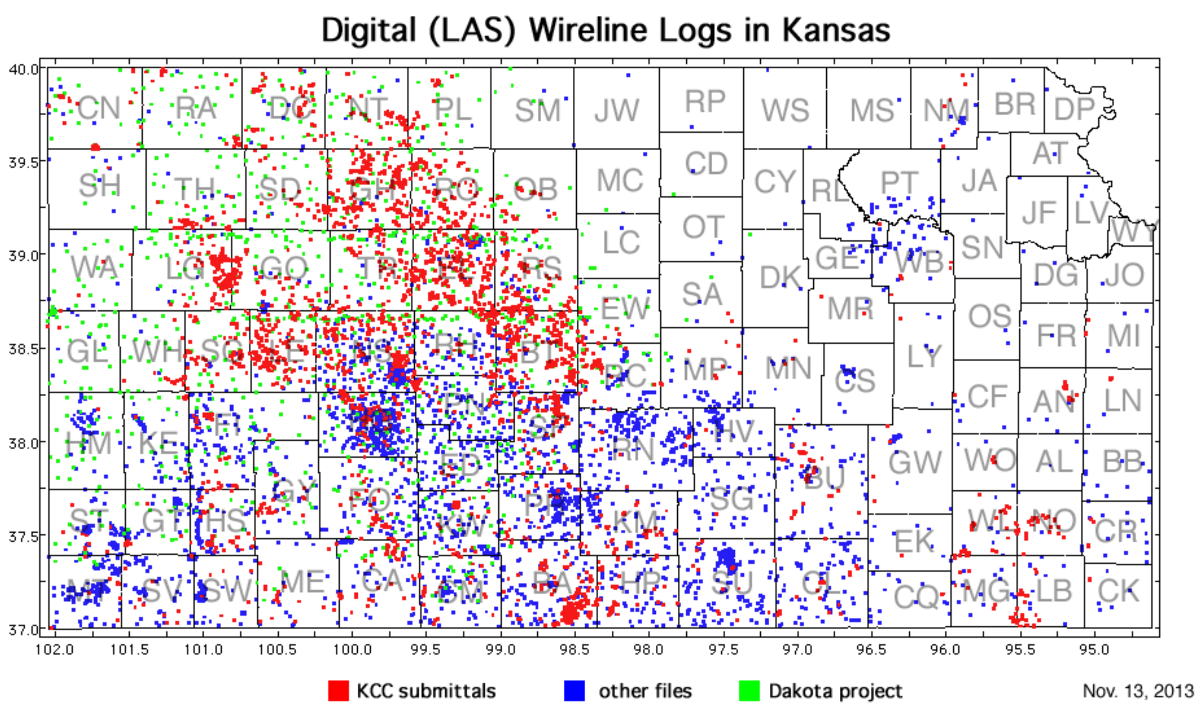


Figure 2. Current distribution of digital (LAS) log files in Kansas. Blue wells in southern Kansas are primarily from wells digitized in this project (DE-FE-0002056).

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 CO_2. 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.

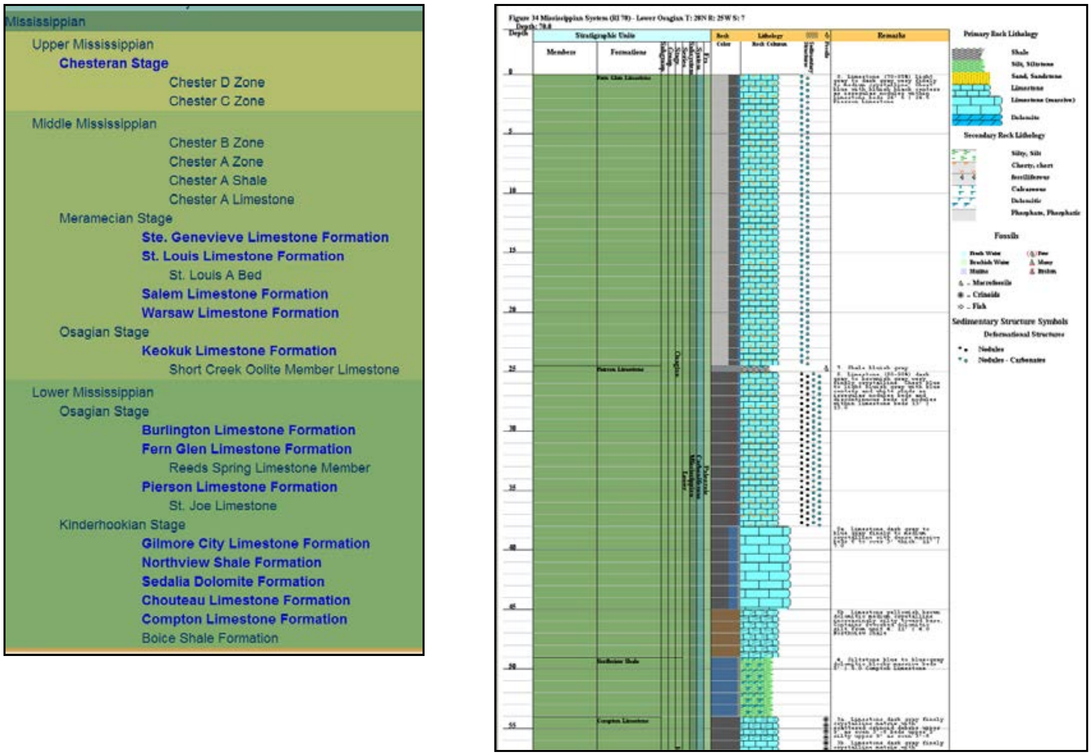
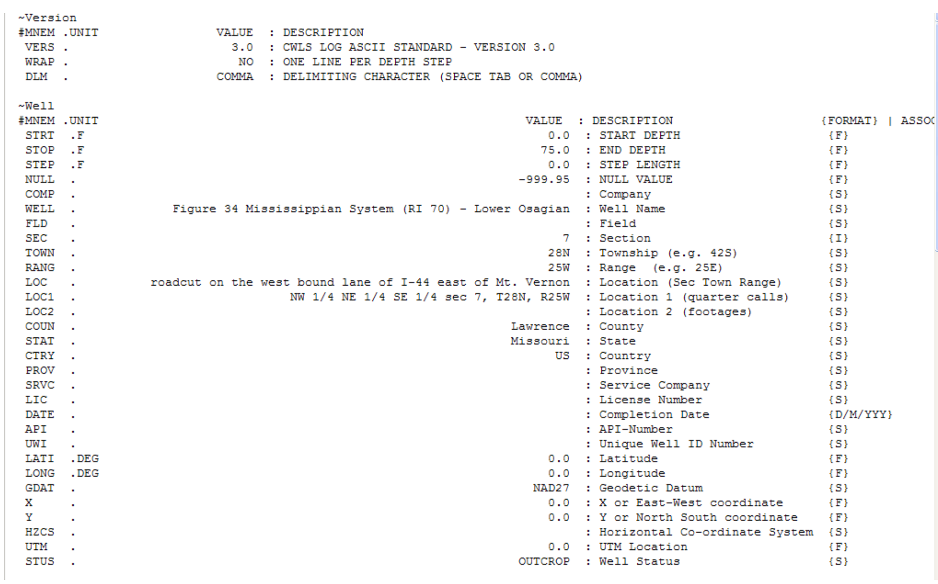


Figure 3. (left) Mississippian stratigraphic column. (right) Portion of reference section of the Mississippian on the right highlighting the Pierson Formation.

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}
```

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

~Tops_Parameter
#MNEM .UNIT           VALUE  : DESCRIPTION                   {FORMAT} | ASSOCIATION
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 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}

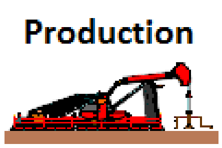
~Tops_Data | Tops_Definition
# TOPT TOPB RANK LVL TOPN TOPA EON ERA SYS SER SSYS SSER STG GRP FORM
 0.0,24.5,"FORMATION","Poor","Fern Glen Limestone","-999.95","Phanerozoic","Paleozoic","Carboniferous","
 24.5,49.08,"FORMATION","Poor","Pierson Limestone","-999.95","Phanerozoic","Paleozoic","Carboniferous","
 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

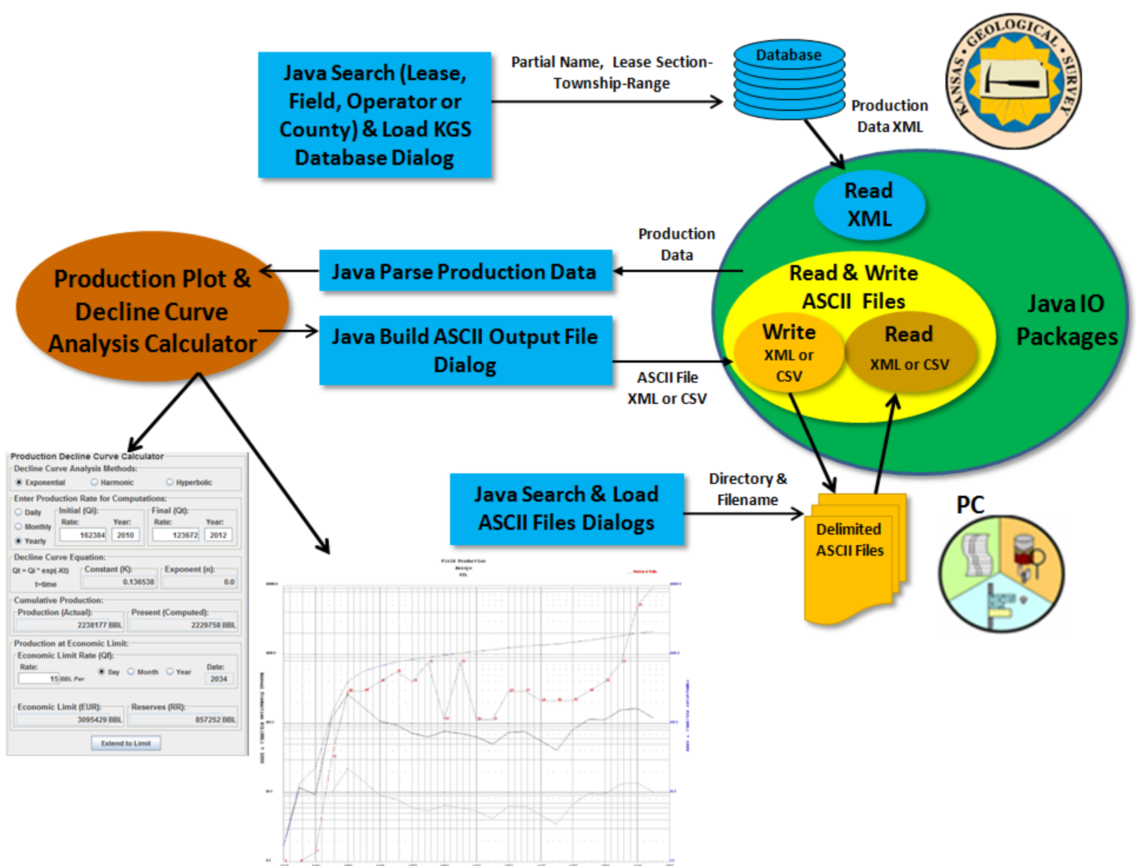


Figure 5. Flow chart showing the linkage of activities and flow of information used to access, manage, and analyze the oil and gas production information in the Production Plot App.

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**.

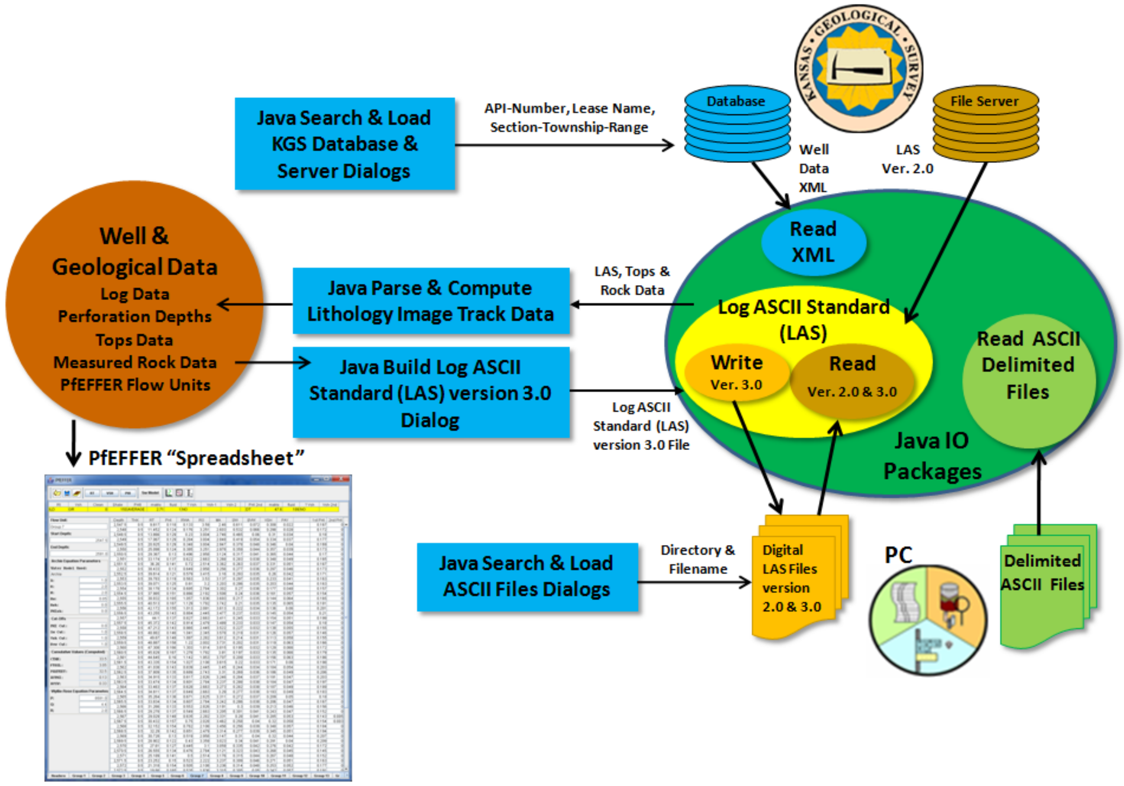


Figure 6. Information flow chart of the web application showing data exchange with PfEFFER-java App.

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.

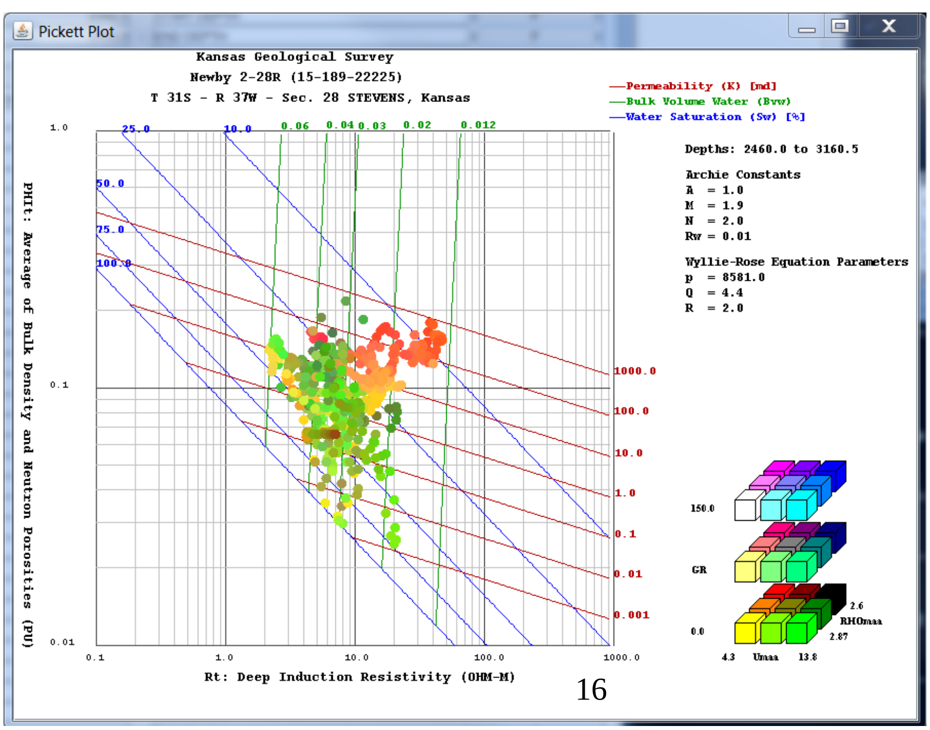


Figure 7. Example of the new version of the Pickett cross plot with rhoma-umma color plot (legend on lower right).

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

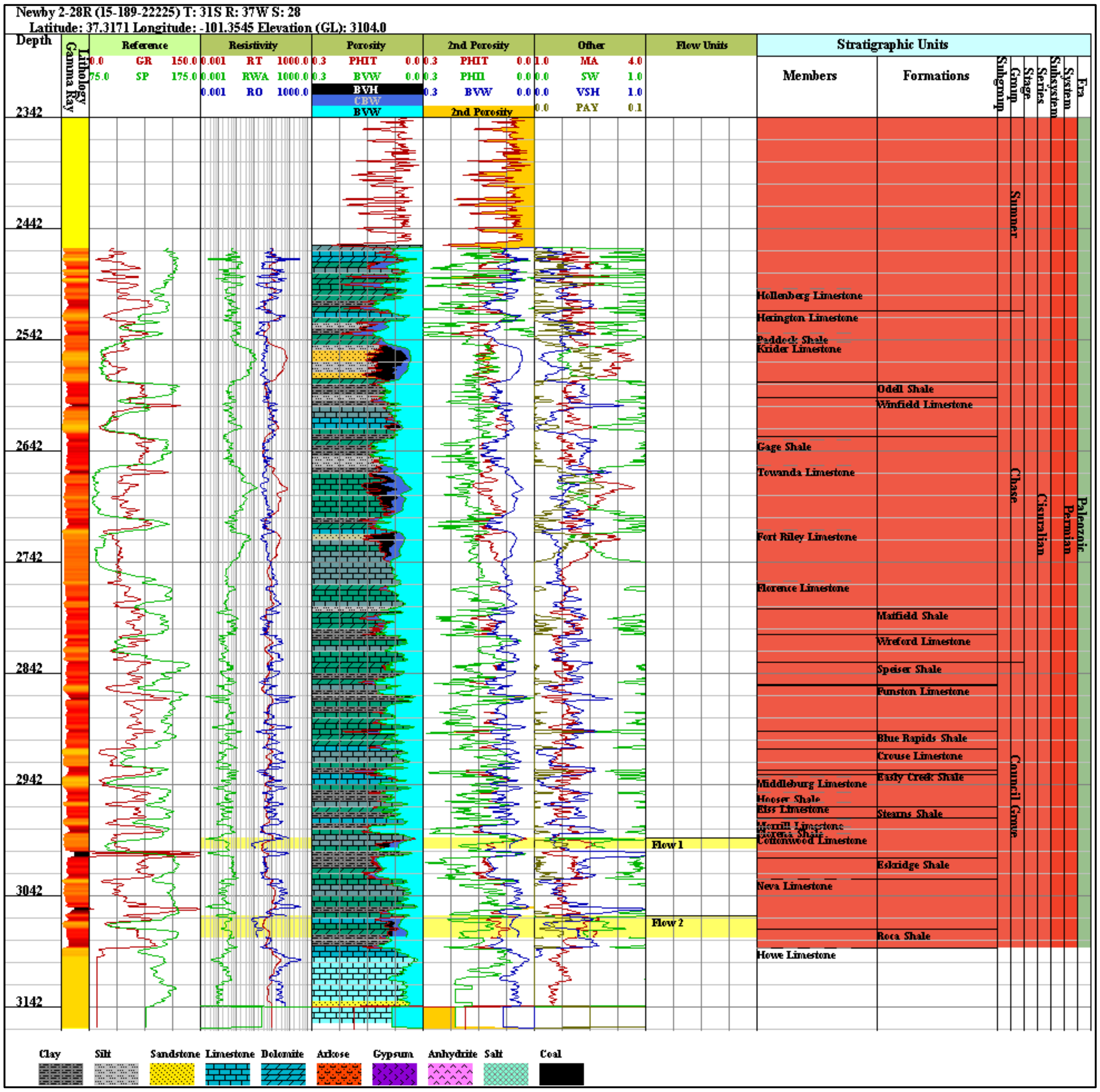
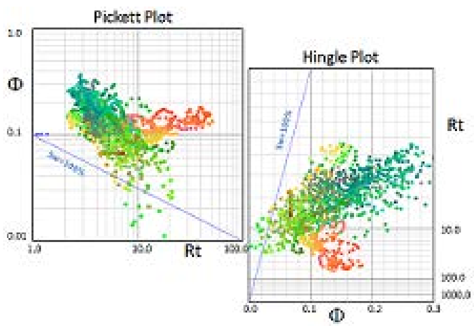


Figure 8. Depth plot showing results of PfEFFER analysis including derivation of Ro, Rwa, BVW, Sw, Ma, Vsh, and hydrocarbon pay/saturation.

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.

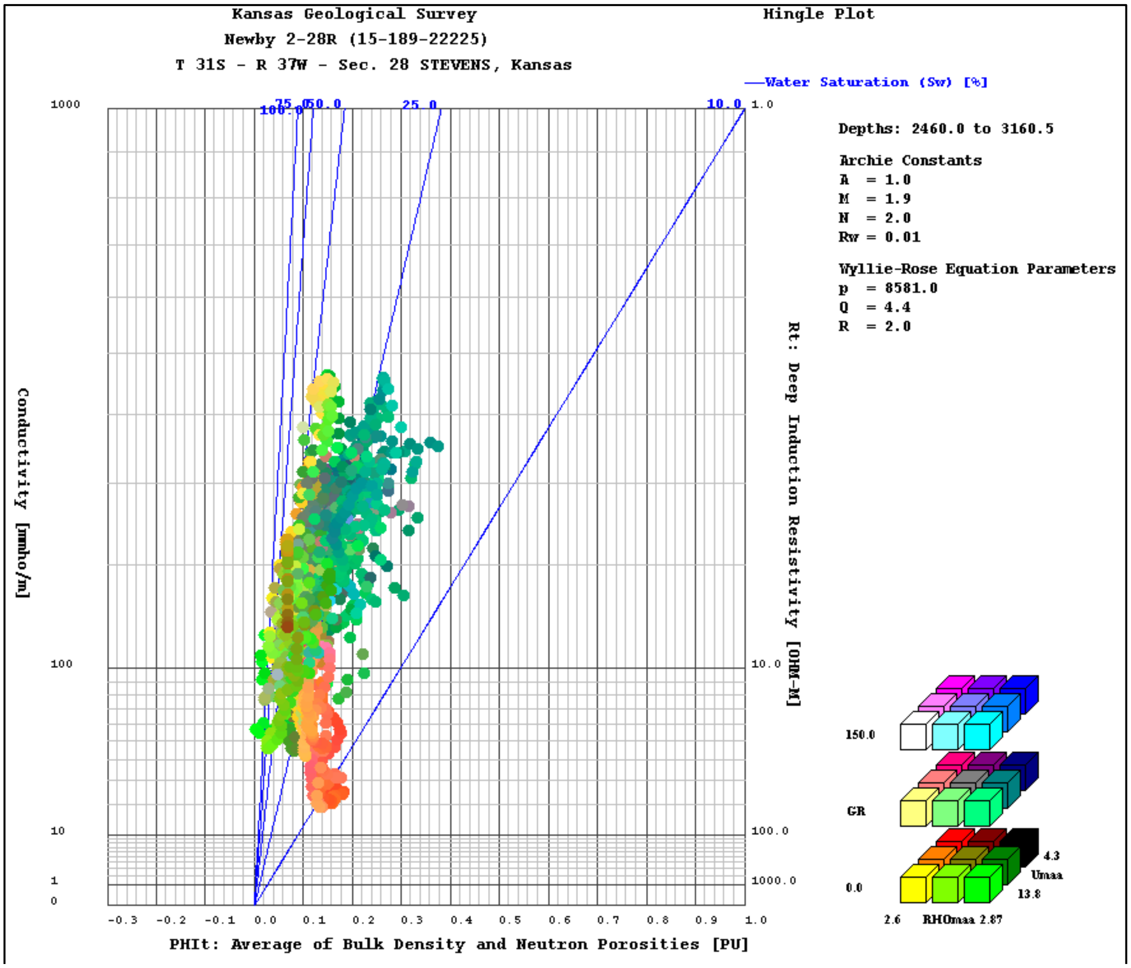


Figure 10. Hingle plot. Linear phi vs. log resistivity.

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.

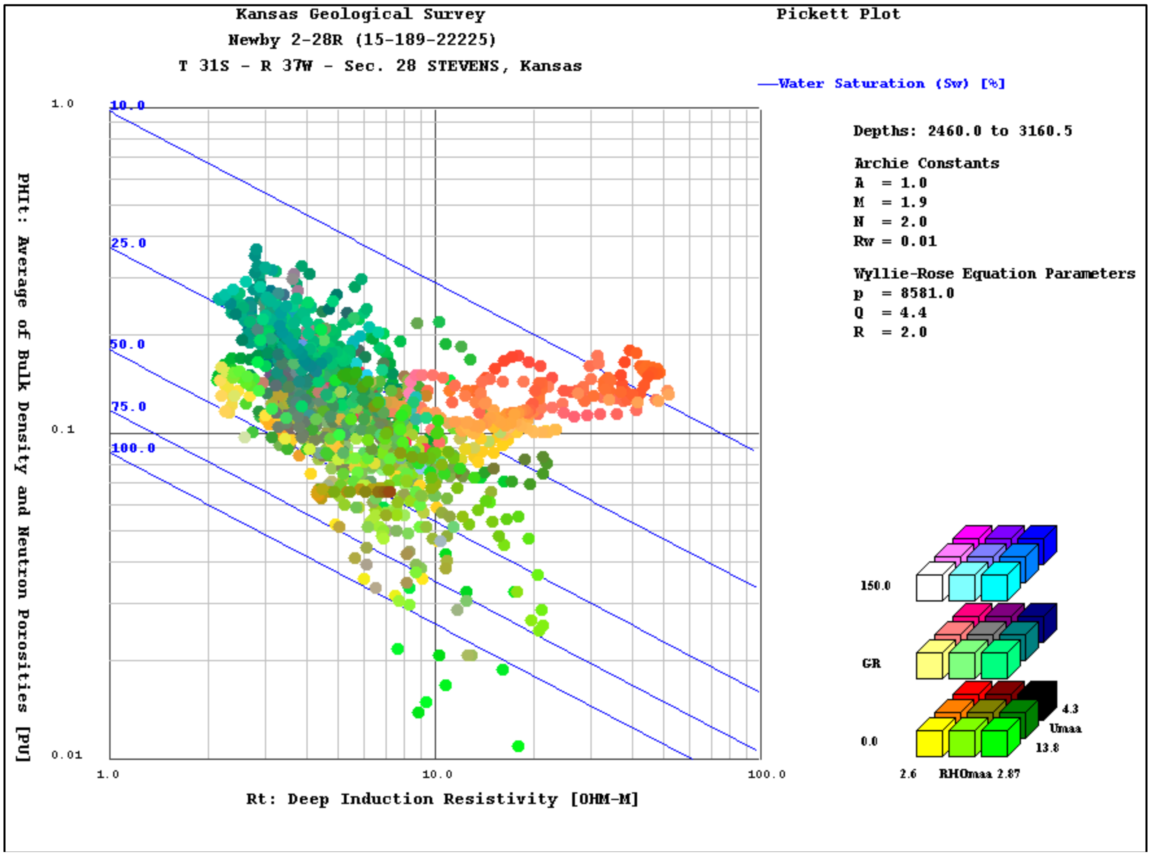


Figure 11. Newly revised Pickett cross plot displaying colors using RHOmaa-Umaa lithology determination.

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).

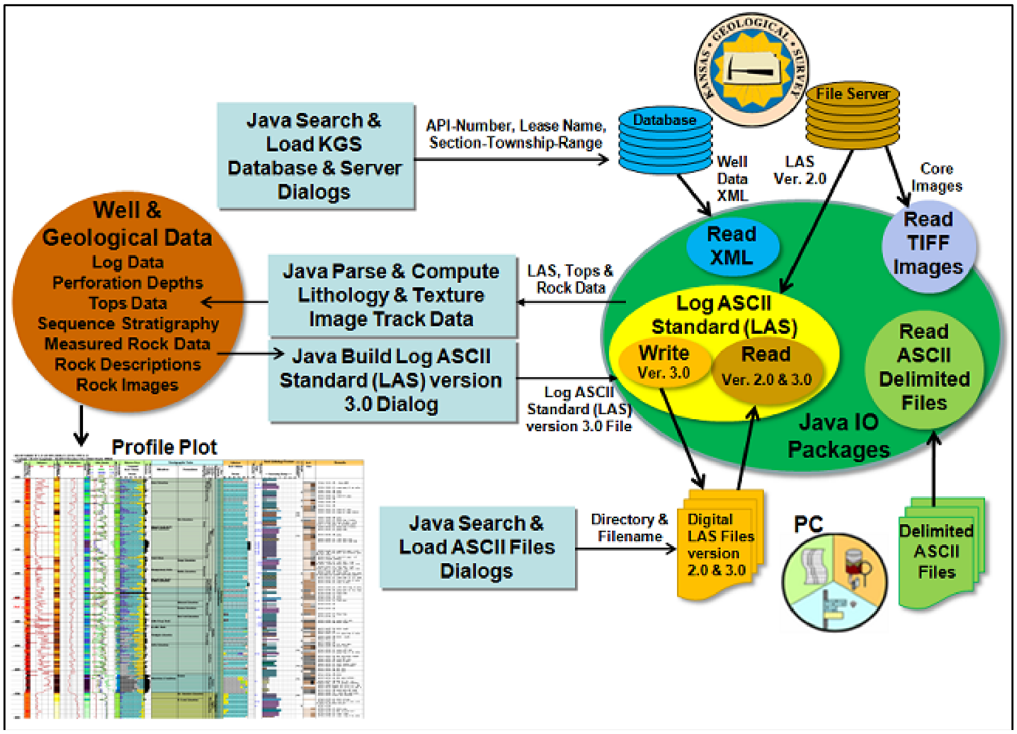
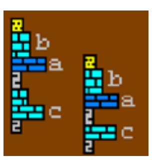


Figure 12. Information flow chart of the web application showing data exchange with the Well Profile.

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**).

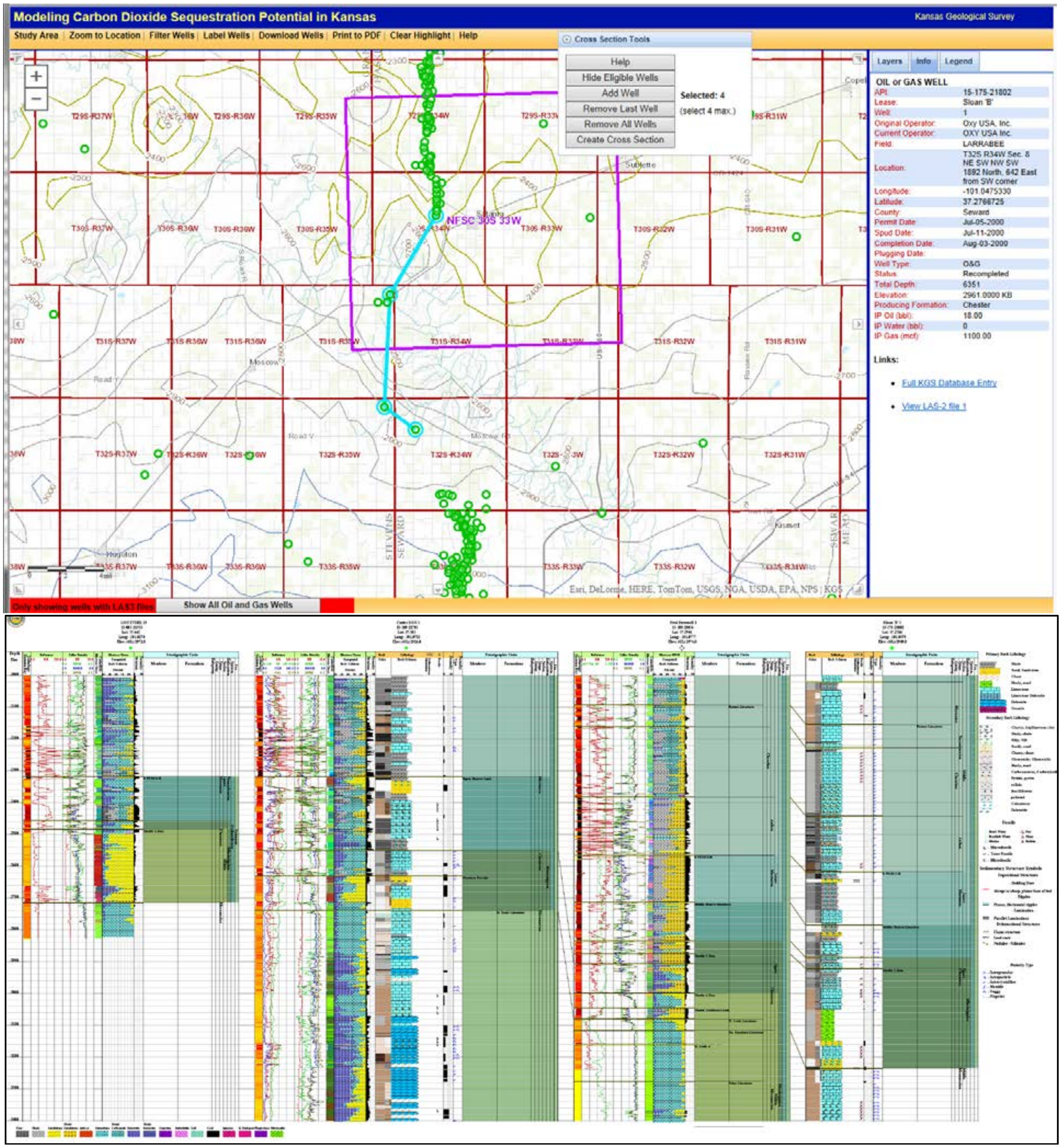


Figure 13. Current status of a the cross section app accessed via ESRI Map Cross Section Java Applet. Four wells shown from north (left) to south (right) using a structural datum.

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.

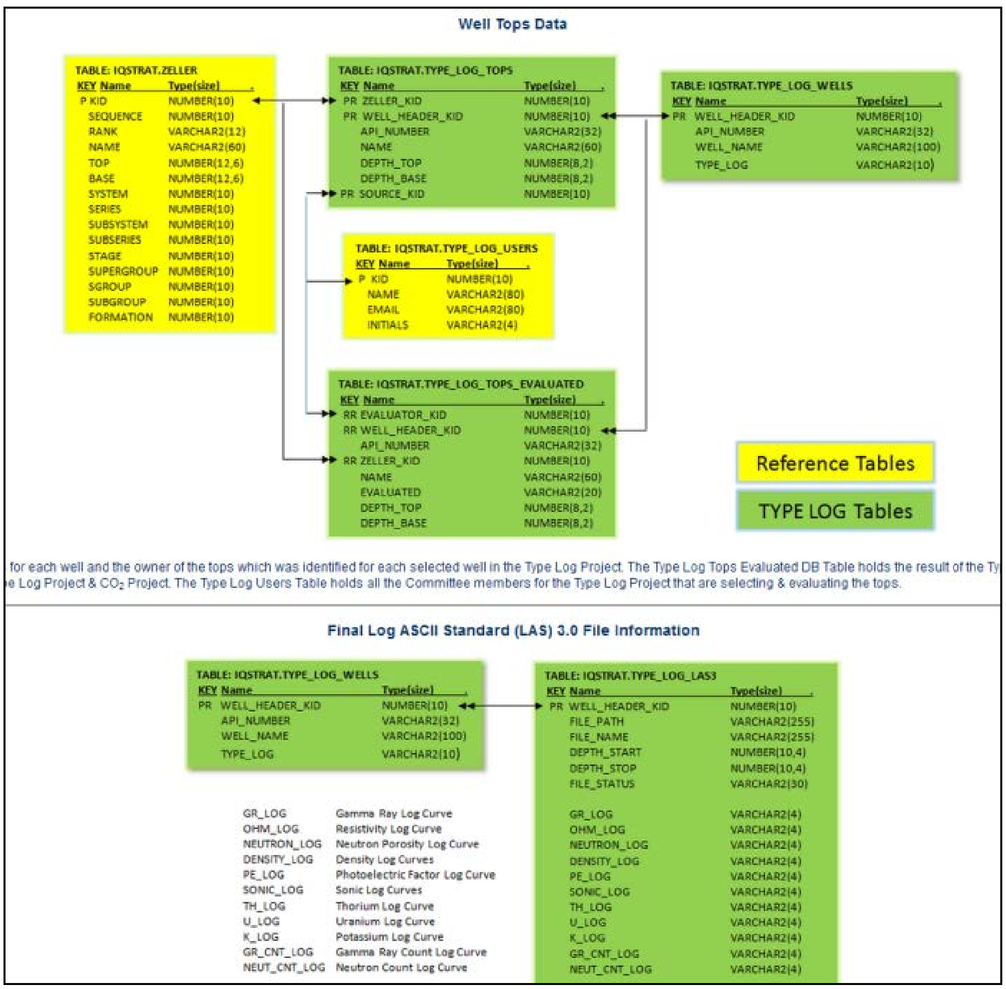


Figure 14. Stratigraphic well tops and LAS 3.0 data tables.

Status of Long-term goals of GEMINI

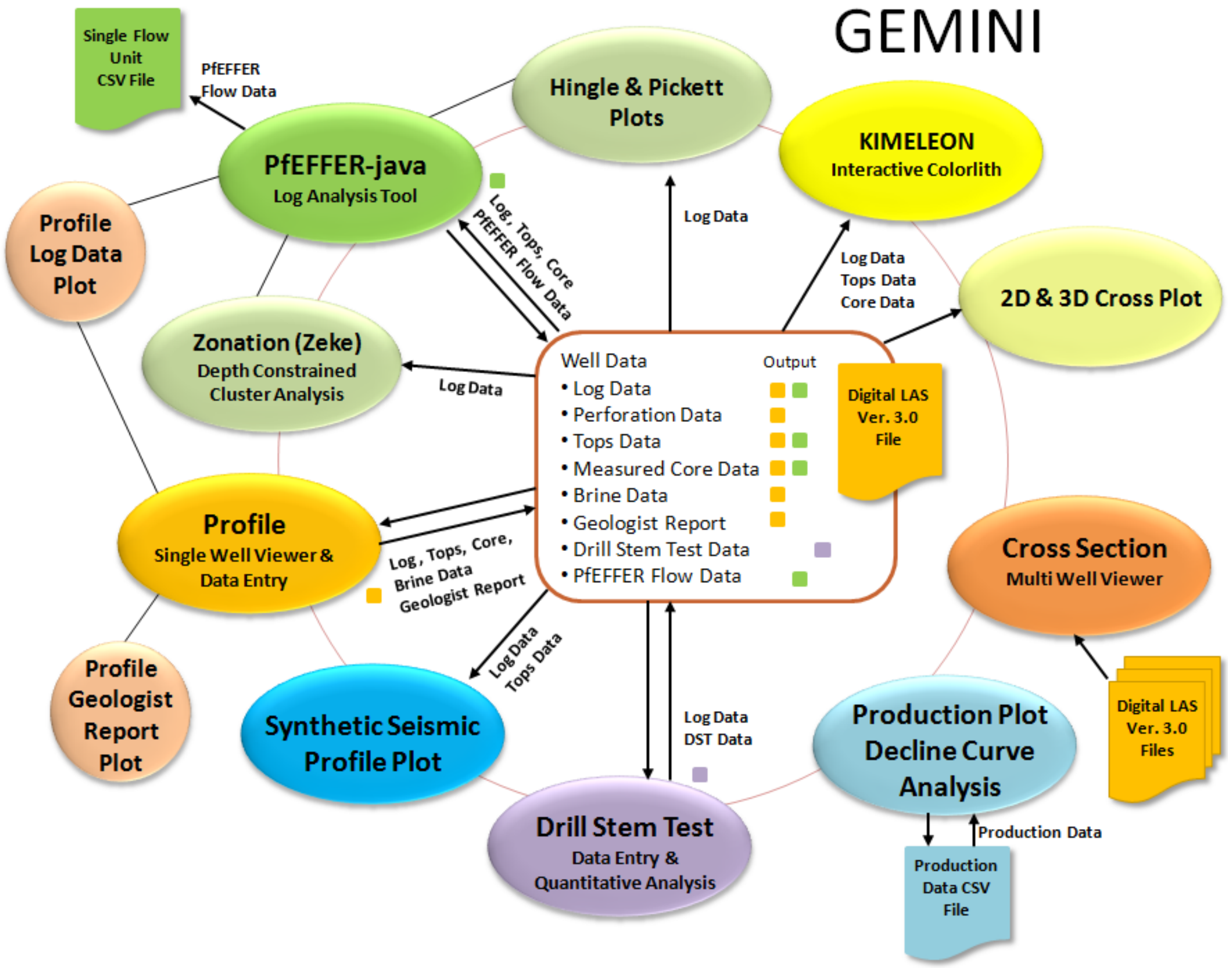


Figure 15. Complete layout of the Java web applications that comprise GEMINI.

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.

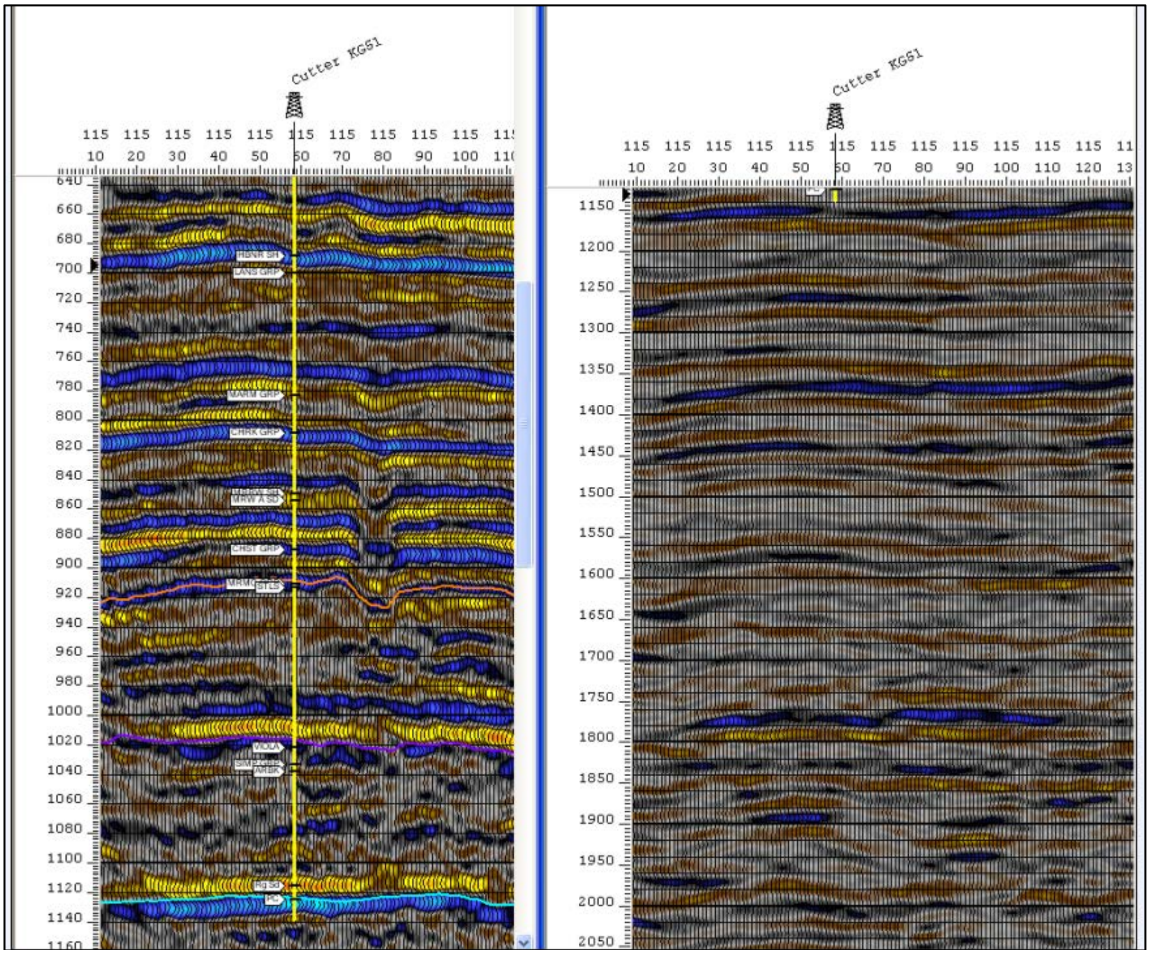


Figure 16. Arbitrary section in Cutter Field including the Cutter KGS #1 well and log ties to the seismic profile. Data quality is very good.

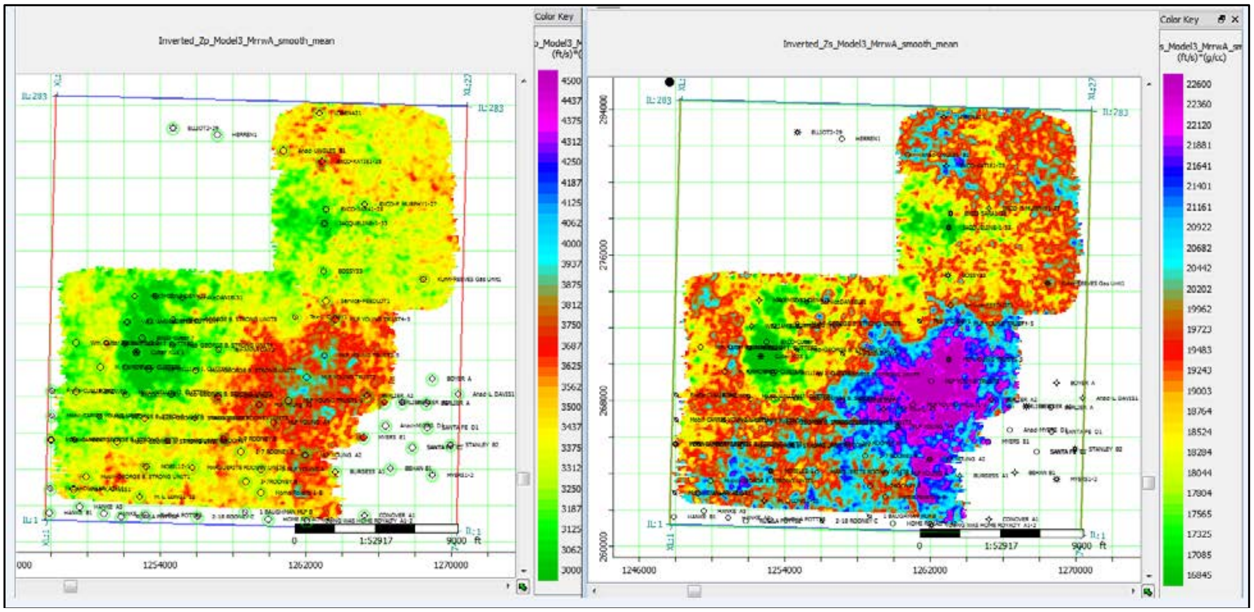


Figure 17. Preliminary prestack impedance models (p-wave on left and shear-impedance on right) of the Morrowan interval containing the lenticular sandstone oil reservoir generally in the northwestern corner of Cutter Field. This work continues toward resolving the lithological changes (sandstone, shale, 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.

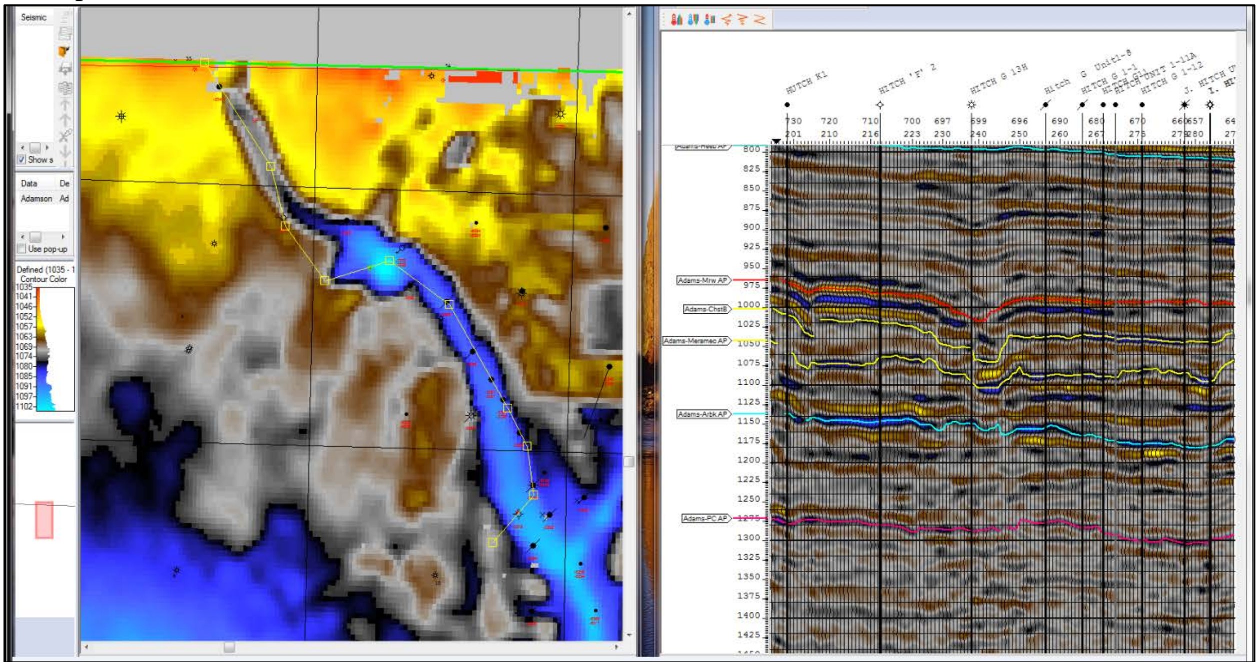


Figure 18. Meramec amplitude slice at Shuck Field showing seismic line along the axis of the Chester age incised valley, the location of the sandstone oil reservoir.

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.

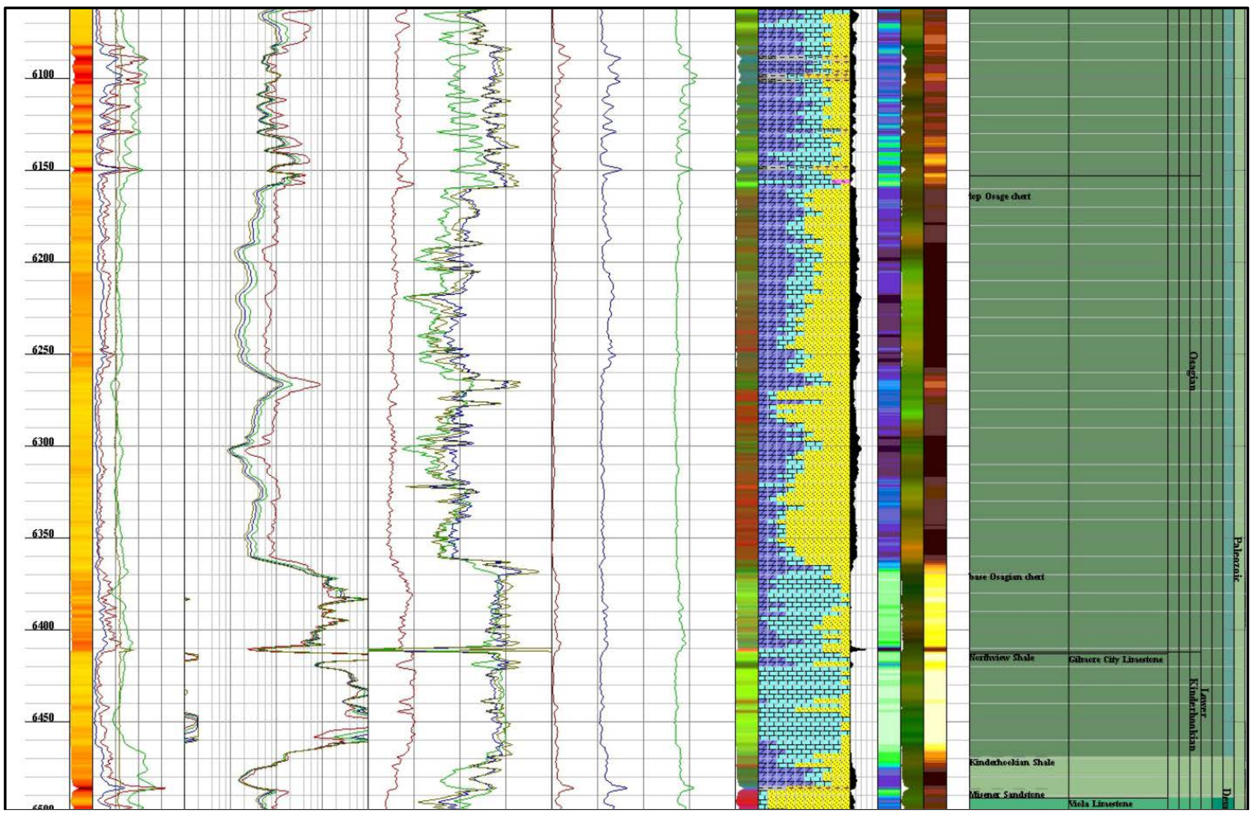


Figure 19. Mississippian Osage to top to Viola in the Cutter KGS #1 well.

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

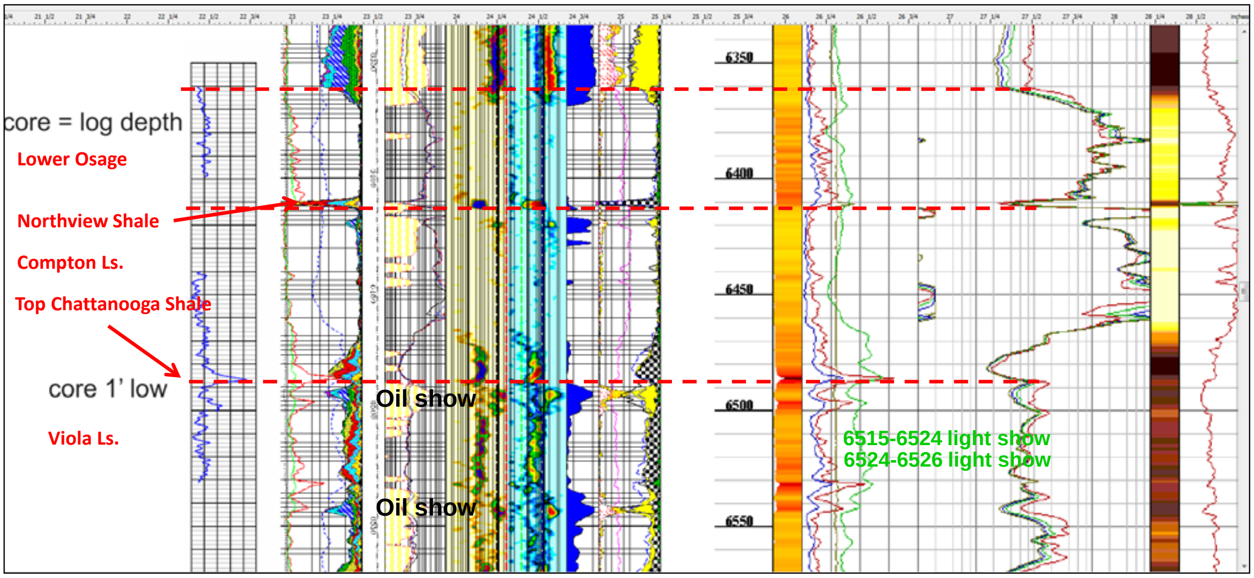
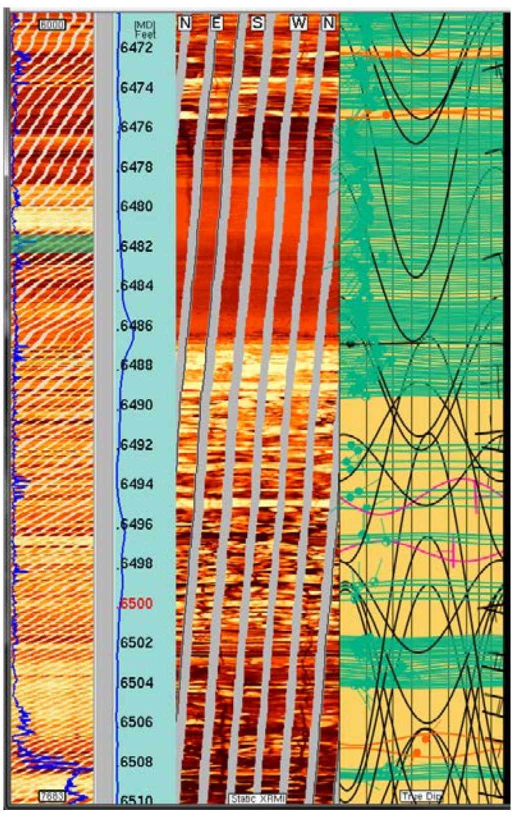


Figure 20. Tight rock is present above the Viola and oil shows are noted in the uppermost Viola Limestone, presumably contained by the overlying seal. Other oil shows were described in previous quarterly reports. The logs shown include nuclear magnetic resonance (NMR) on the left the gamma ray–resistivity 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.

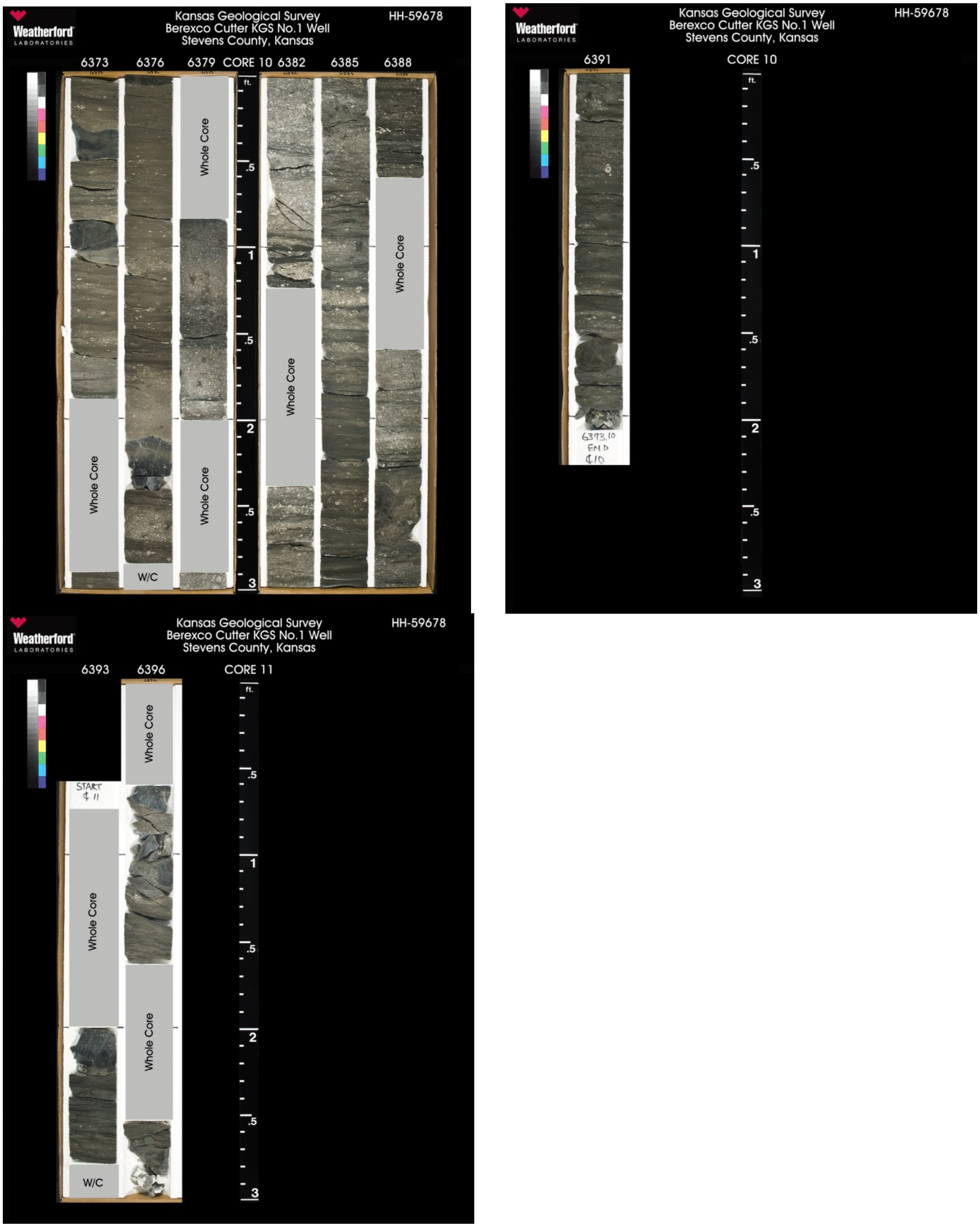


Figure 22. Lower most Osage Mississippian limestone. Very shaly and tight.

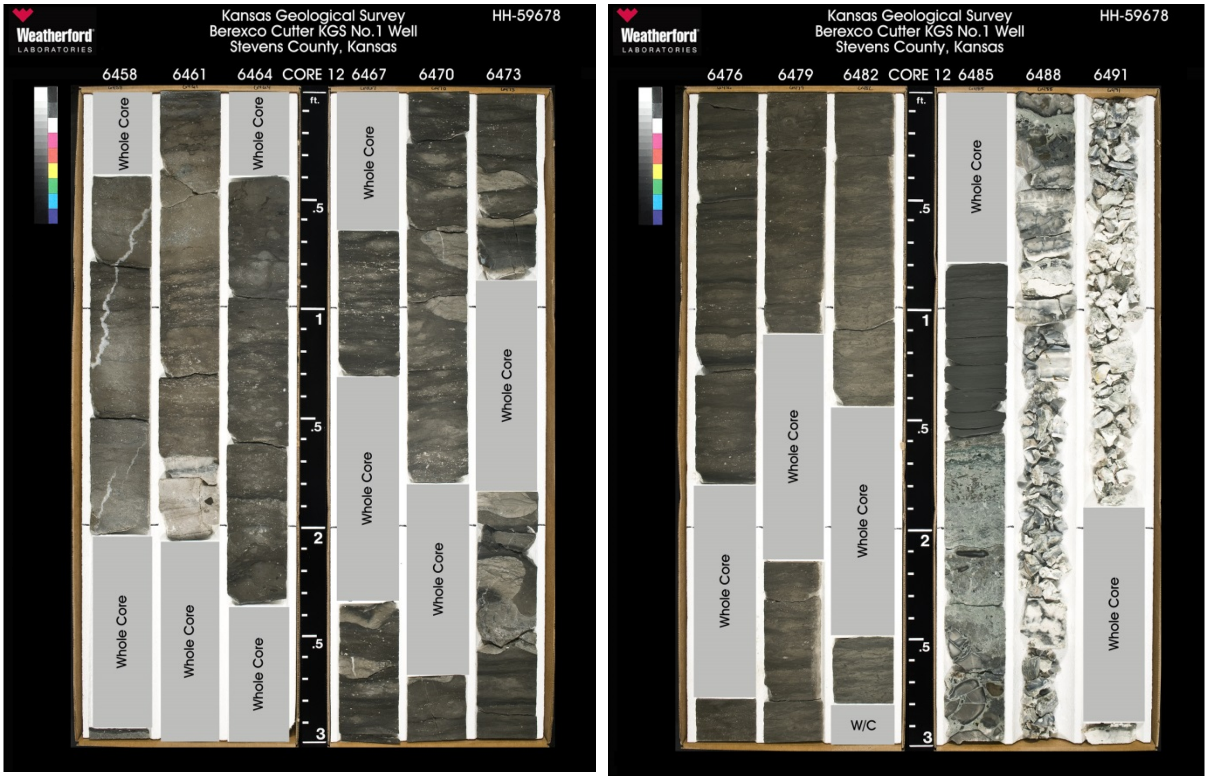


Figure 23. Lower Kinderhook Mississippian Limestone and shale resting on the top of the porous cherty Viola Limestone.

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**.

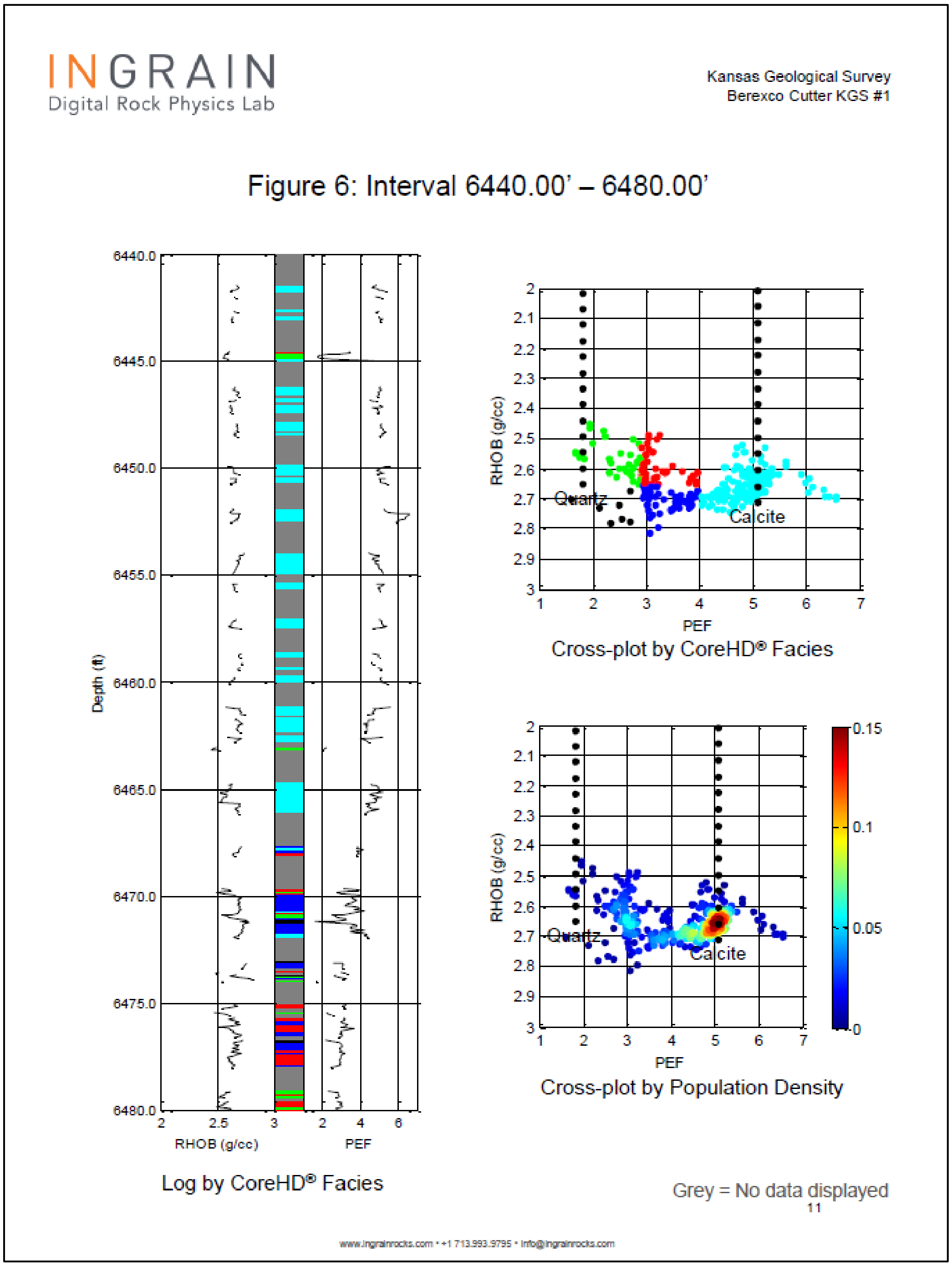


Figure 24. Bulk density and PEF measured by Ingrain for the Kinderhook limestone (light blue) and the shale below (dark blue and red). Misener sandstone at base is green colored interval.

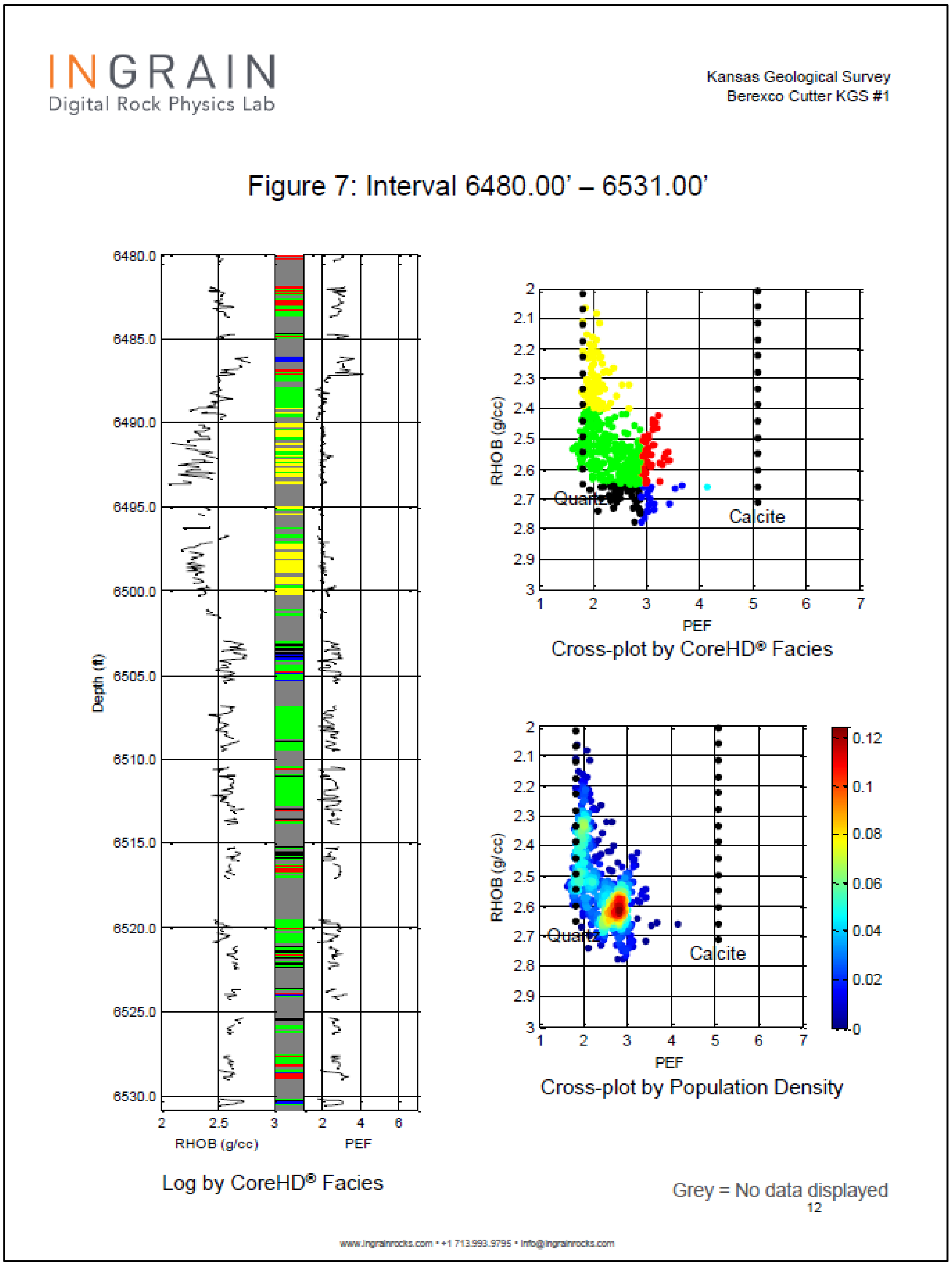


Figure 25. Ingrain's bulk density and PEF for the Viola Limestone (upper yellow-green) and the sandier interval at the base believed to be the Lower Ordovician Simpson Sandstone based on regional correlations.

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.

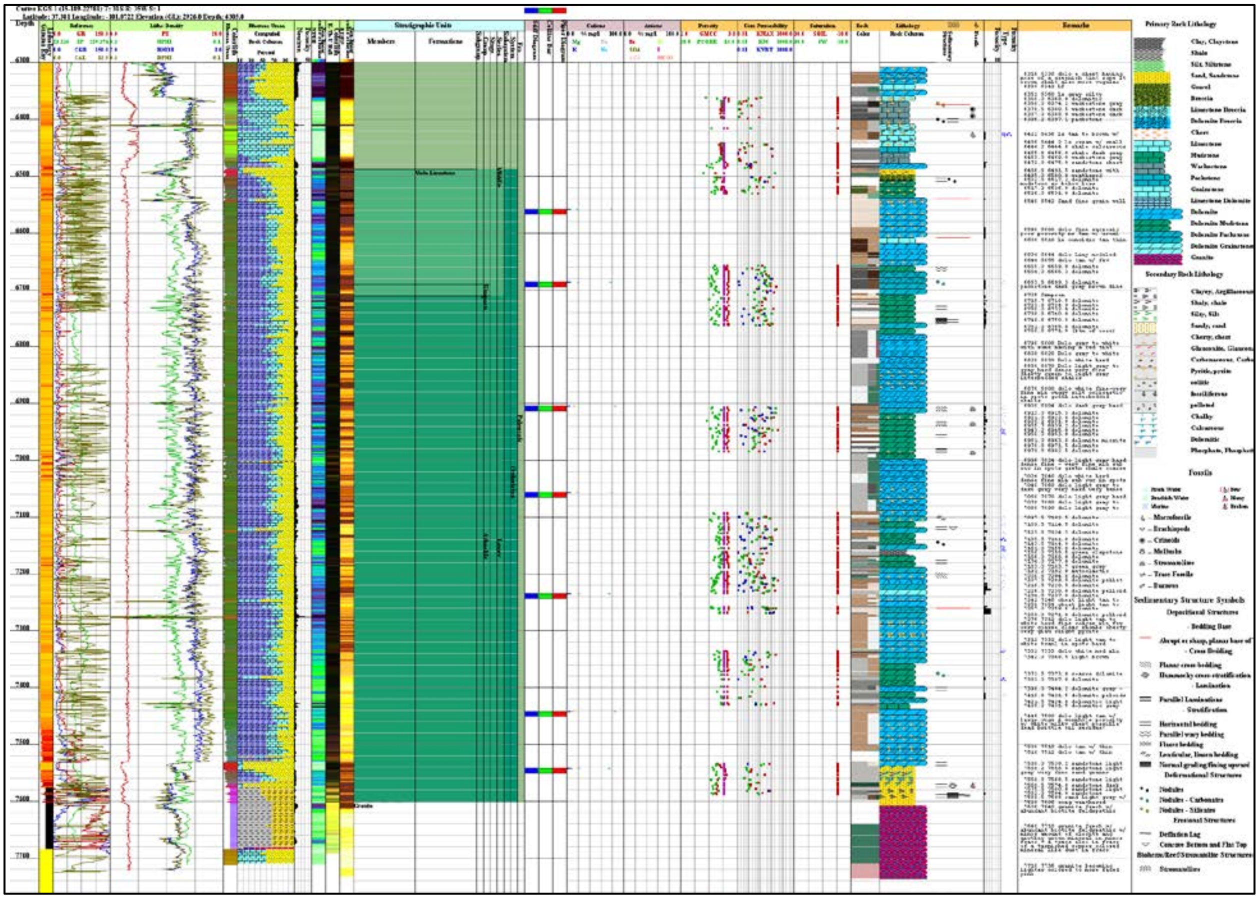


Figure 26. Lower Paleozoic portion of the Cutter KGS #1 cored interval, showing the porosity and permeability analysis alongside with well logs curves and lithology solution on the left and the core description on the right.

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.

Weatherford LABORATORIES

FULL DIAMETER CORE ANALYSIS

KANSAS GEOLOGICAL SURVEY	A.P.I. NUMBER : 15-189-22781	FILE NO. : HH-59678
BEREXCO CUTTER KGS # 1	FIELD : Cutter	DATE : September 19, 2013
STEVENS COUNTY, KANSAS	LOCATION :	ANALYSTS : WH, SB, JR

MODIFIED DEAN STARK EXTRACTION

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

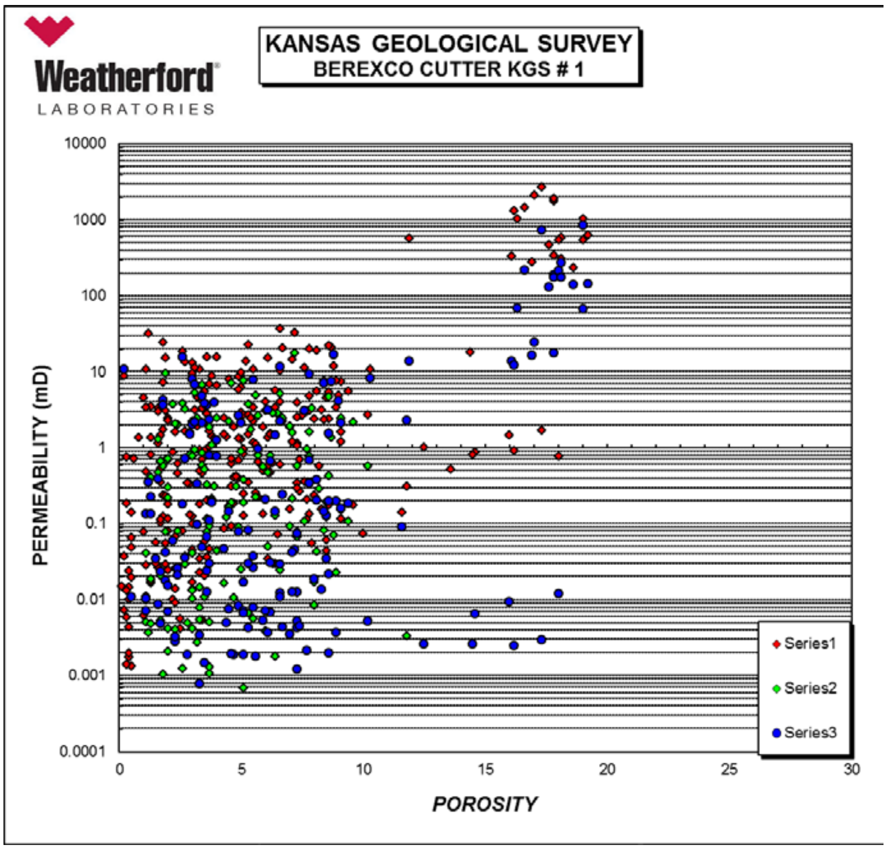


Figure 27. Routine porosity and permeability plot for the Cutter KGS #1 core.

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)	Sample	Sample		Leco	SRA			Tmax		Meas.	HI	OI	S2/S3	S1/TOC*	PI	Notes		Lab ID
	Top	Type	Prep	*	TOC	S1	S2	S3	(°C)	**	% Ro				100		Checks	Pyrogram	
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

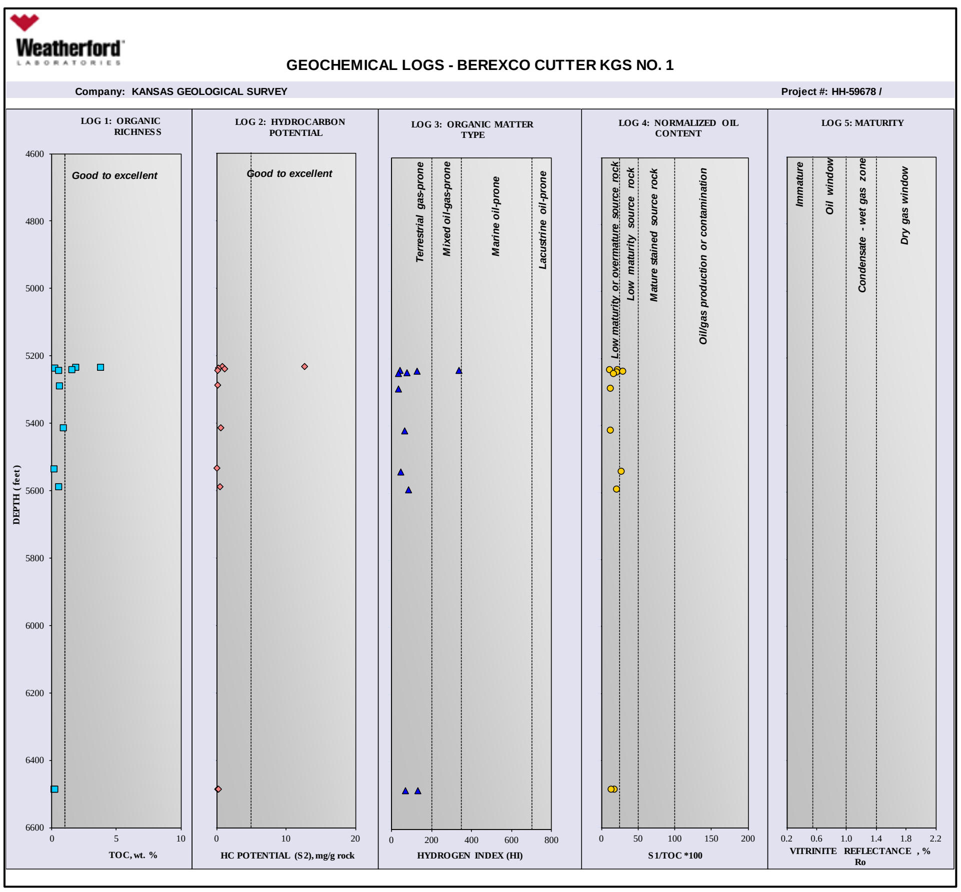


Figure 28. (upper) Total organic carbon (TOC) and organic richness and thermal maturity of the Atokan and Morrow shales from the Berexco Cutter KGS #1 core.

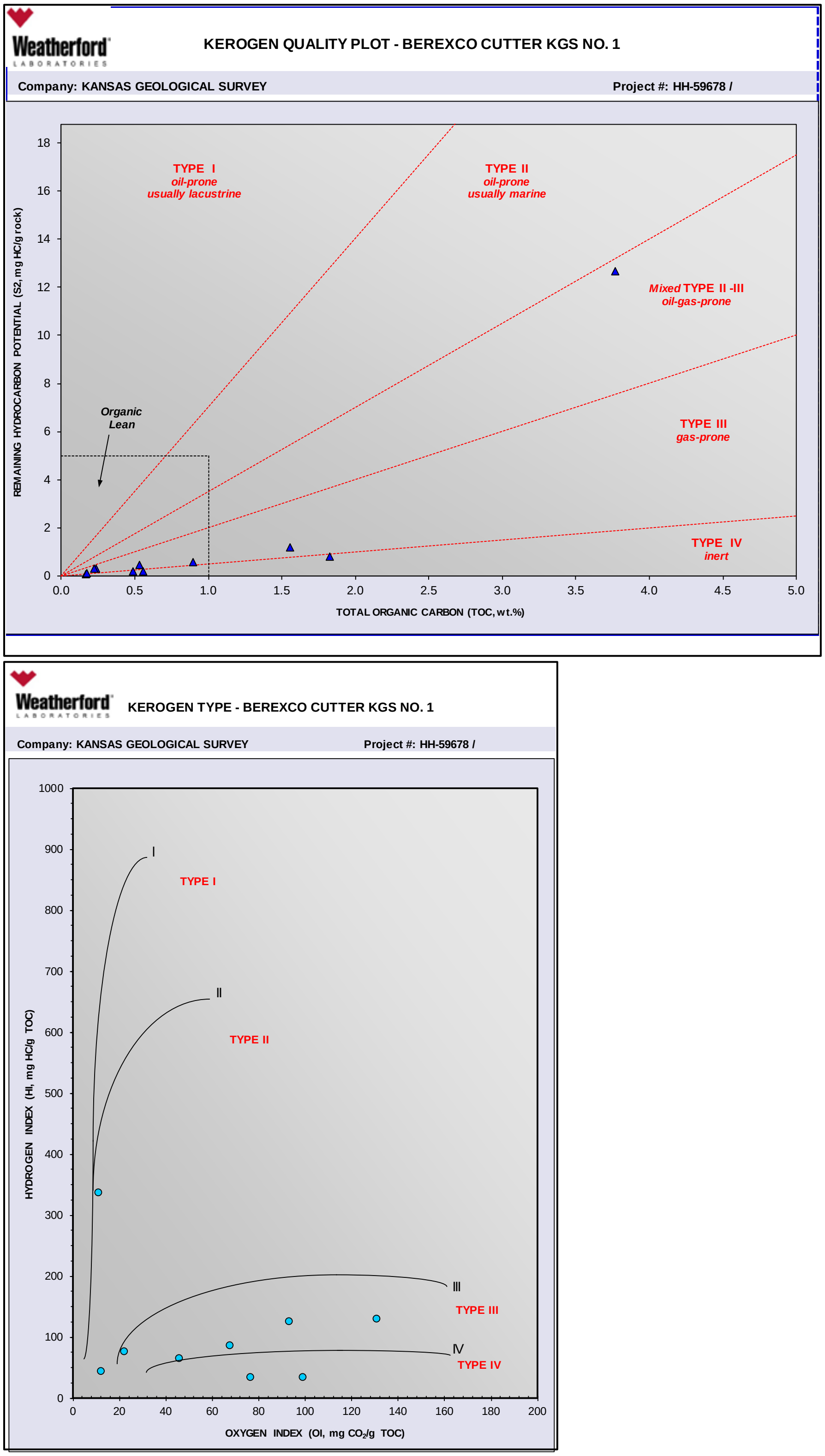
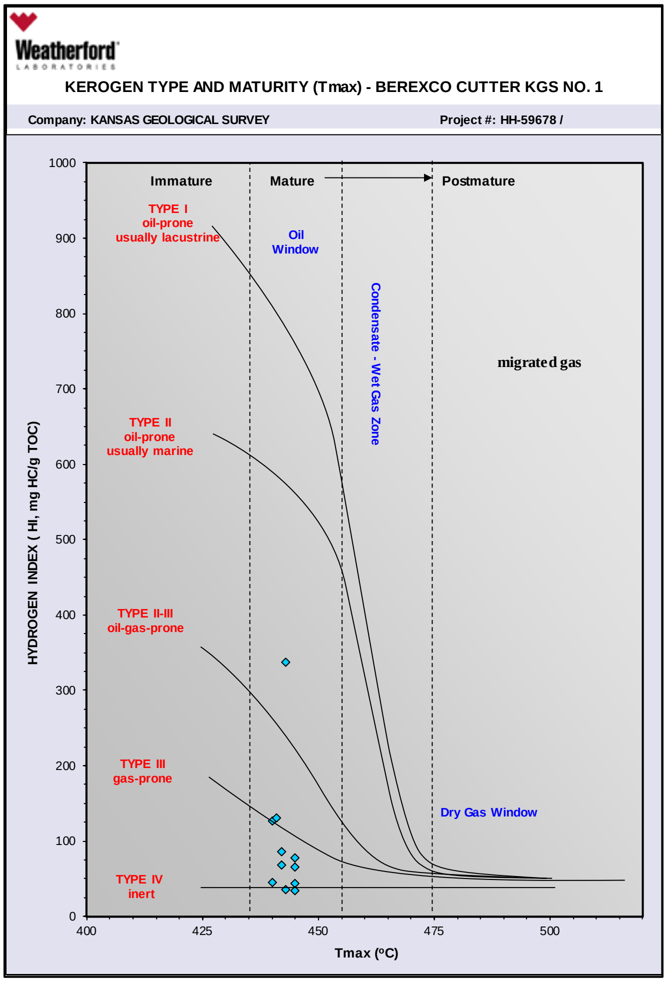


Figure 29. Plots of kerogen type and quality for Atokan and Morrow shales from the Cutter KGS #1.



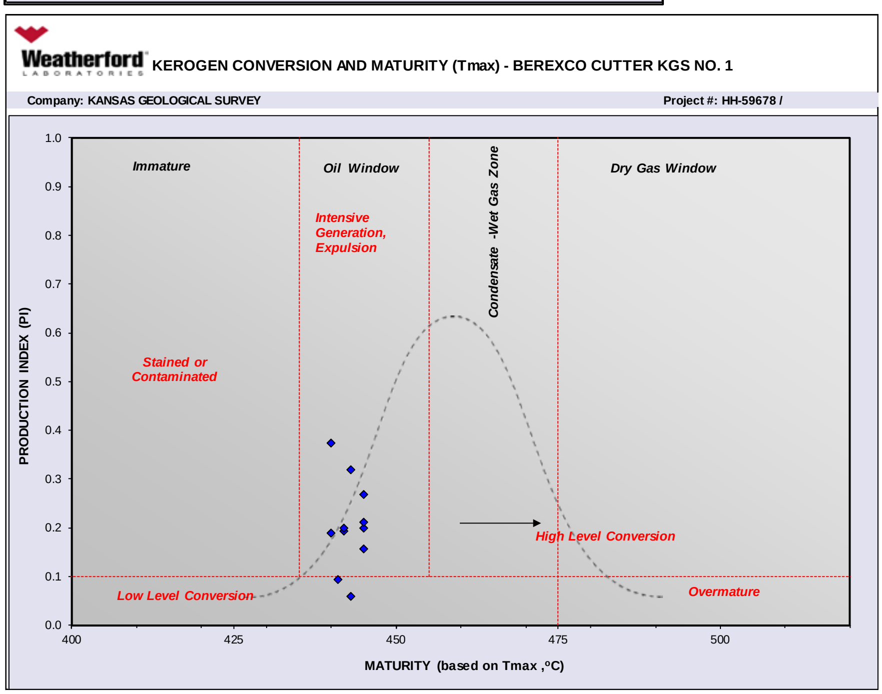


Figure 30. Organic type and maturity (Tmax) and kerogen conversion and maturity for Atokan and Morrow shales from the Cutter KGS #1.

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).

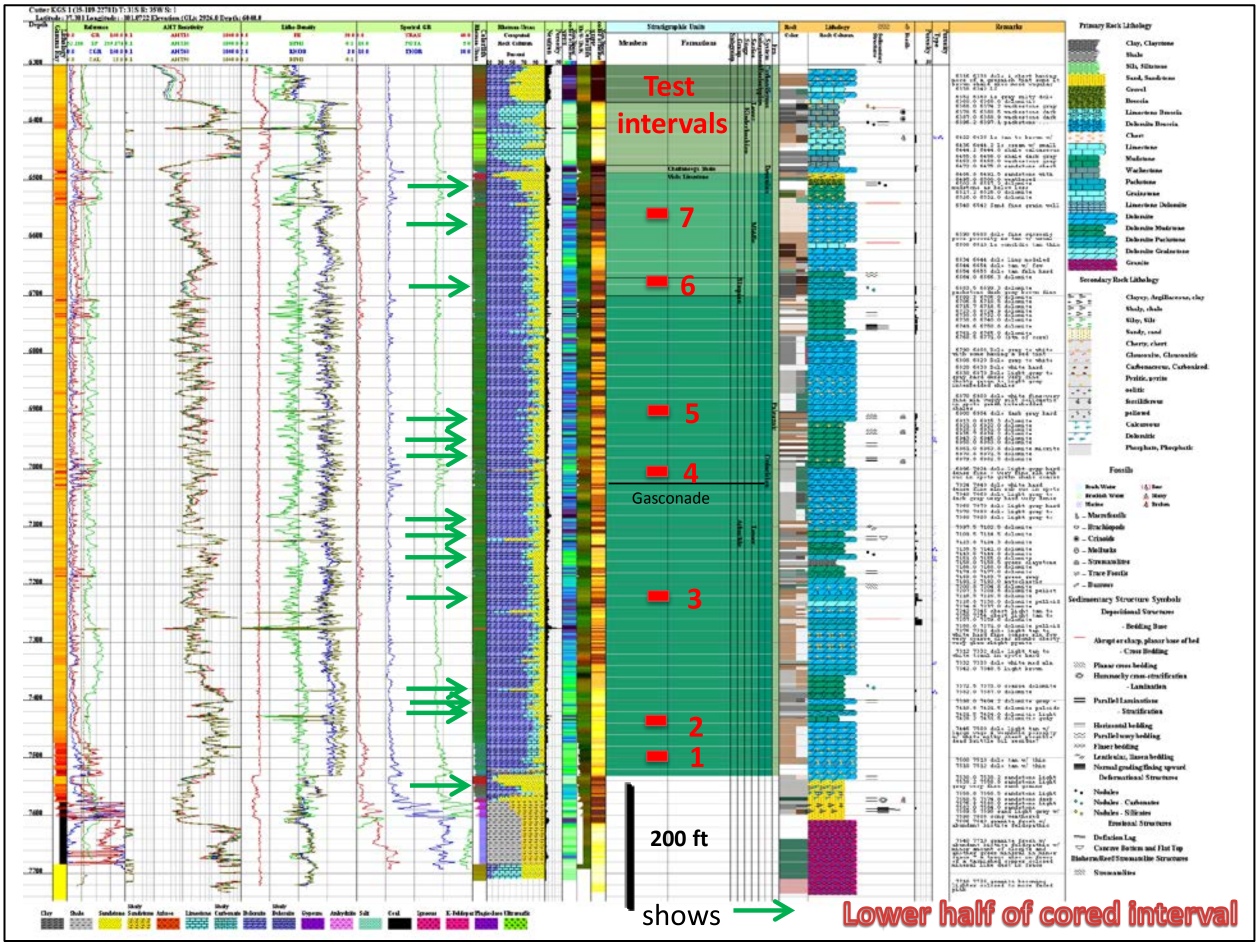


Figure 31. Lower Paleozoic profile log and core profile of the Cutter KGS #1 showing locations of the brine samples (red) and oil shows, mainly from core fluorescence (green arrows).

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	111	< 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	11500	< 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.

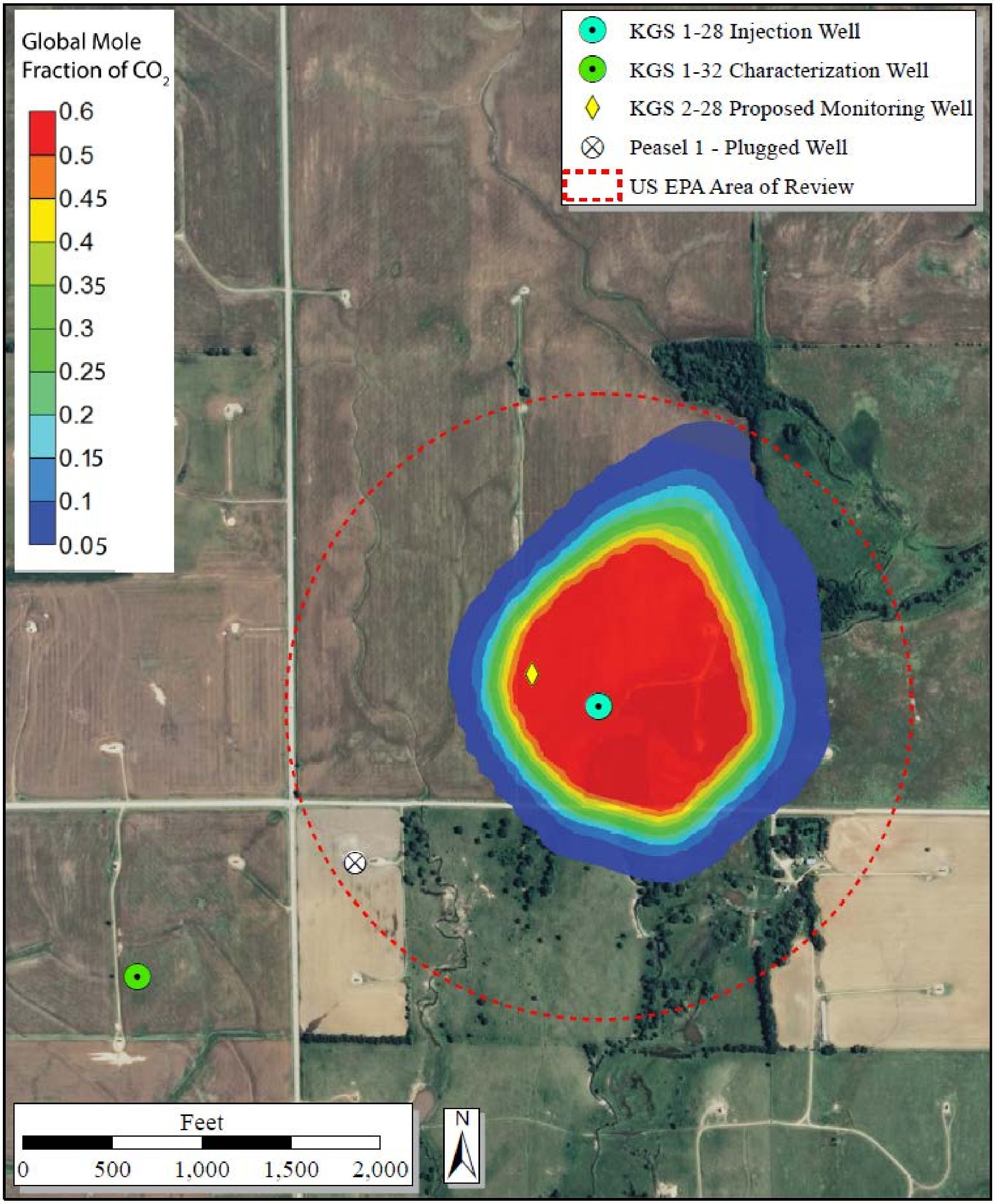


Figure 36. Footprint of a 40,000 metric ton CO2 plume limited to the lower Arbuckle saline aquifer.

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**).

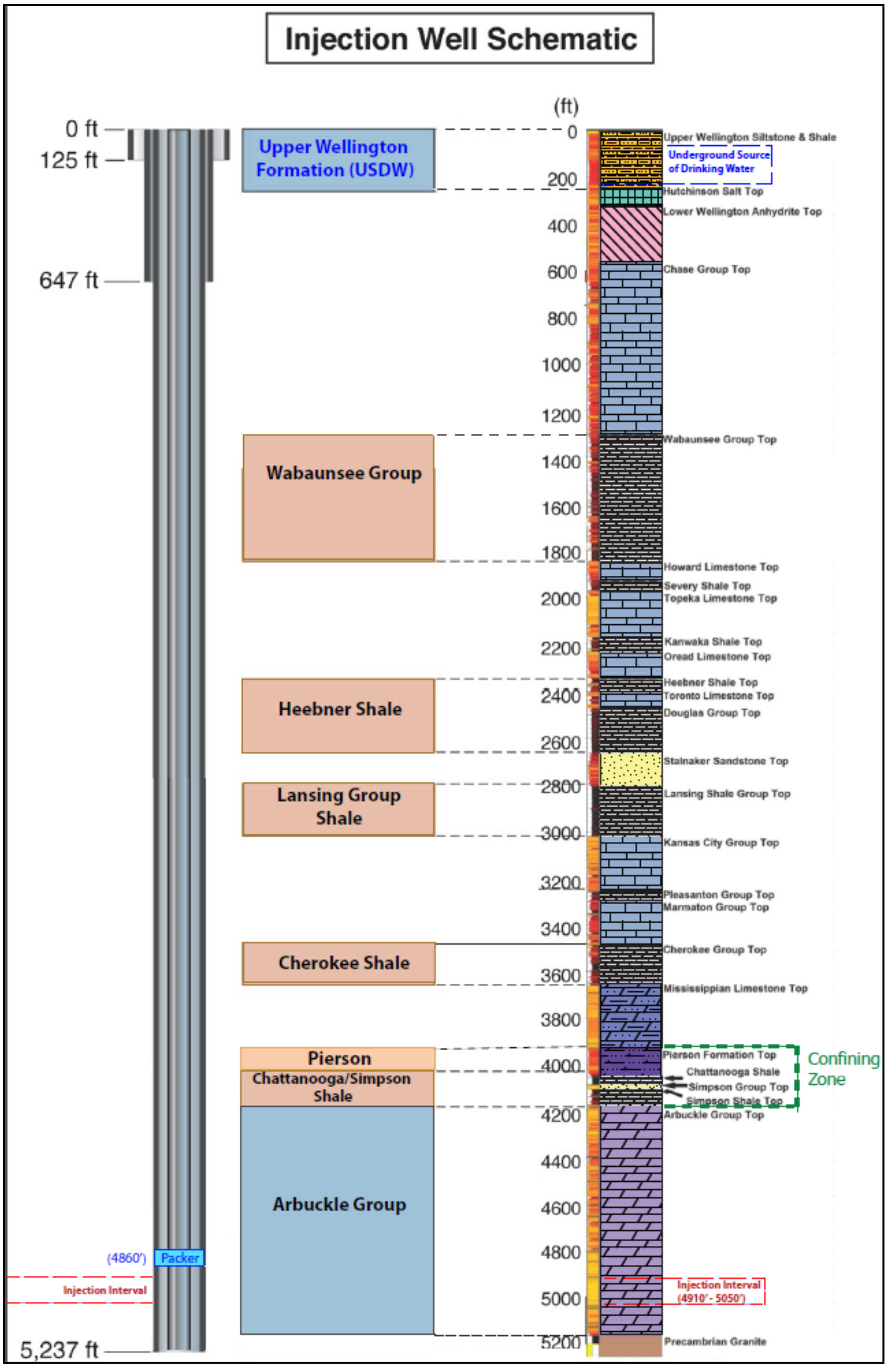


Figure 37. Well bore schematic for the injection well with the location of the injection zone shown in the lowermost Arbuckle saline aquifer.

2) **Microbiological studies on produced water (Subtask 4.12) and studies of in situ CO_2 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 CO_2 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 CO_2 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 CO_2-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 CO_2 flow experiments suggest that there is a potential for entry of CO_2 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 CO_2 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 CO_2 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.

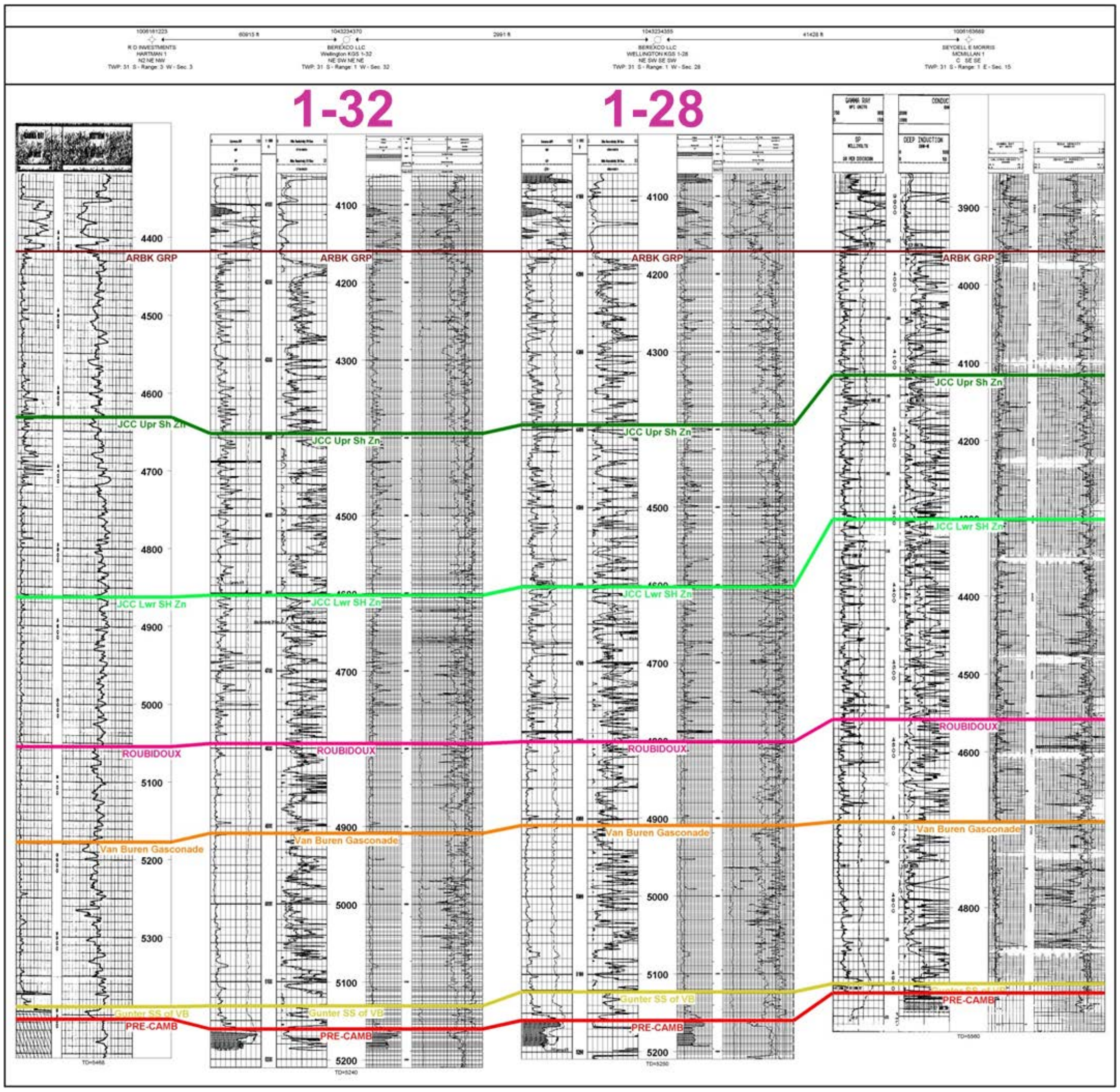


Figure 38. Well log cross section with the datum at the top of the Arbuckle showing the major correlations in Wellington KGS #1-32 and #1-28.

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.

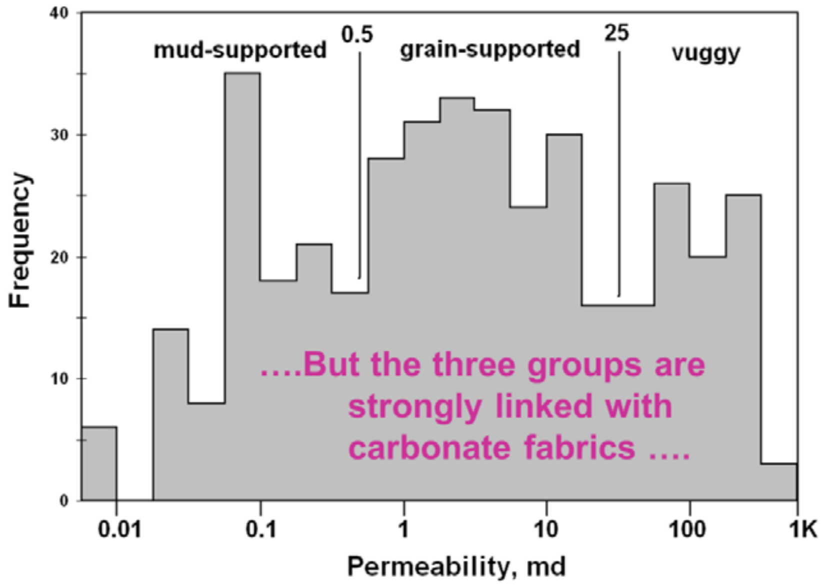


Figure 39. Classification of permeability from Wellington KGS #1-32.

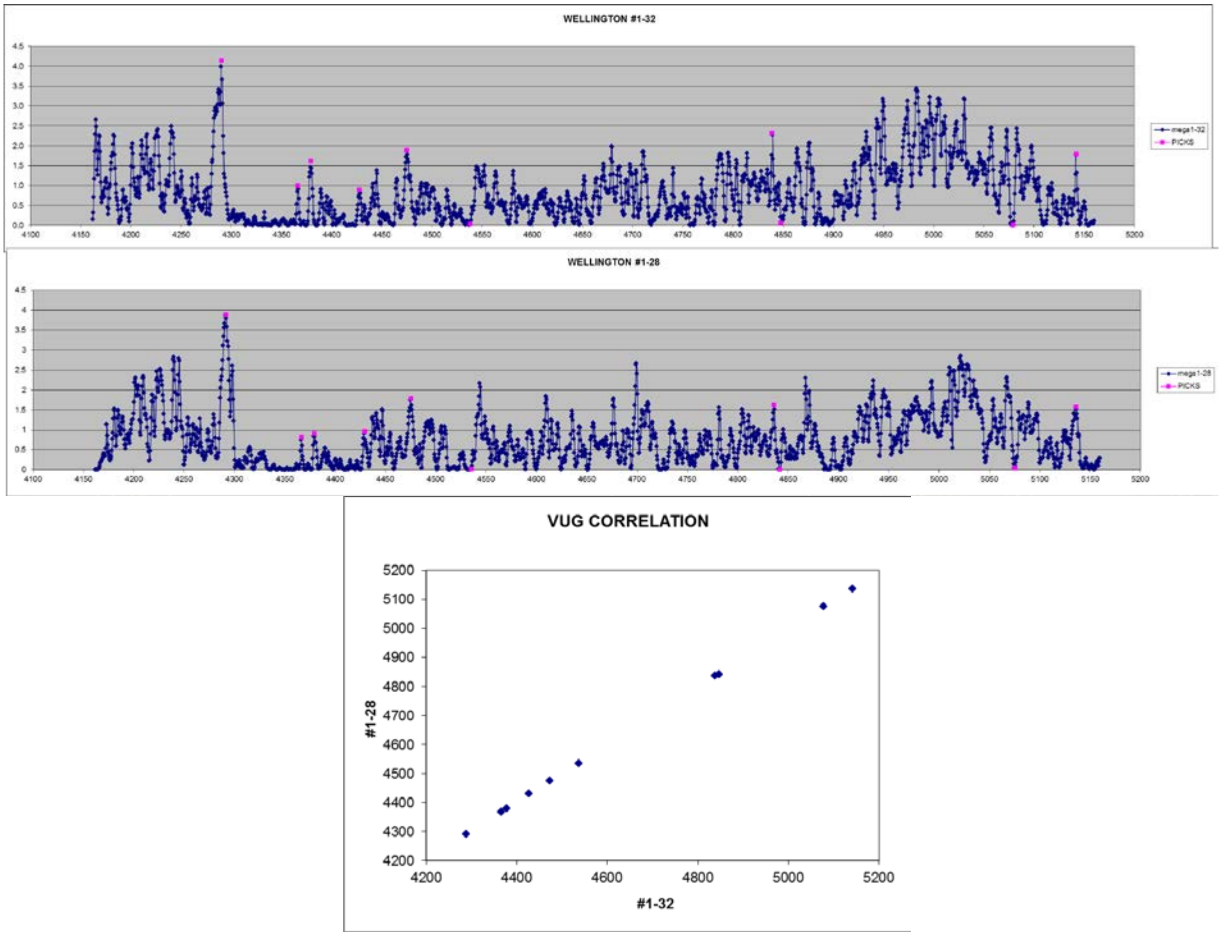
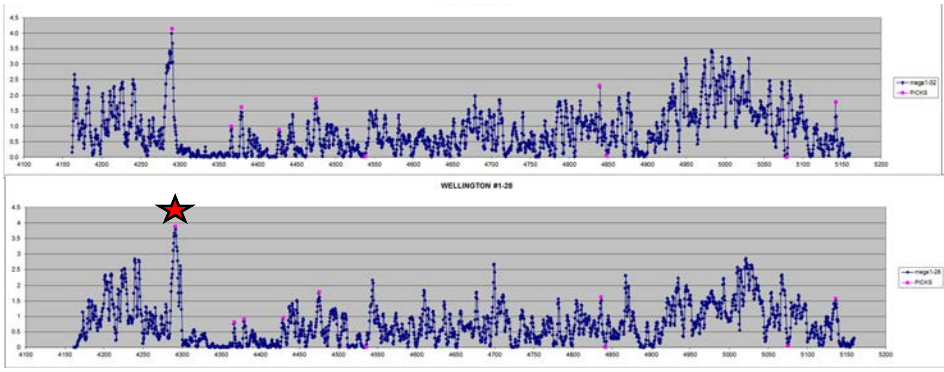
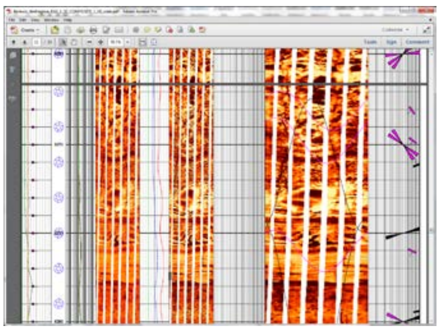


Figure 40. Correlation of vugs between Wellington KGS #1-32 and #1-28 is very high as noted in the plot or vugs and correlation of vugs by depth.

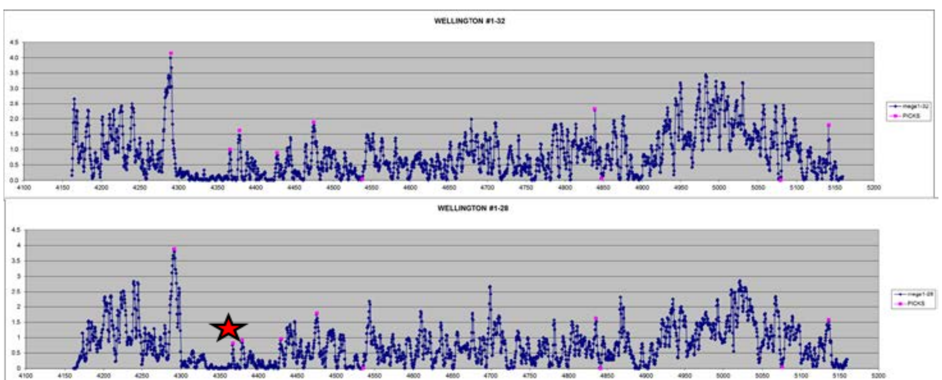
The major vuggy zones classified by modern triple combo log suites is confirmed through a series of figures that identify the vuggy zone and which are confirmed with the microresistivity imaging log **Figures 41-50**. Figures also compare non-vuggy zones for contrast, which are dominated instead by small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

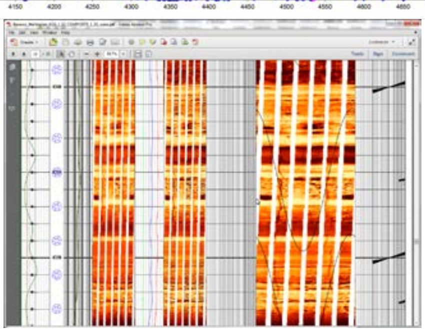




4291.5
NO RECOVERY BUT ADJOINING ROCK BETWEEN 4281 TO 4294 IS Dolo, lt brown, fxln, oolitic, vuggy and oomoldic poro, ns

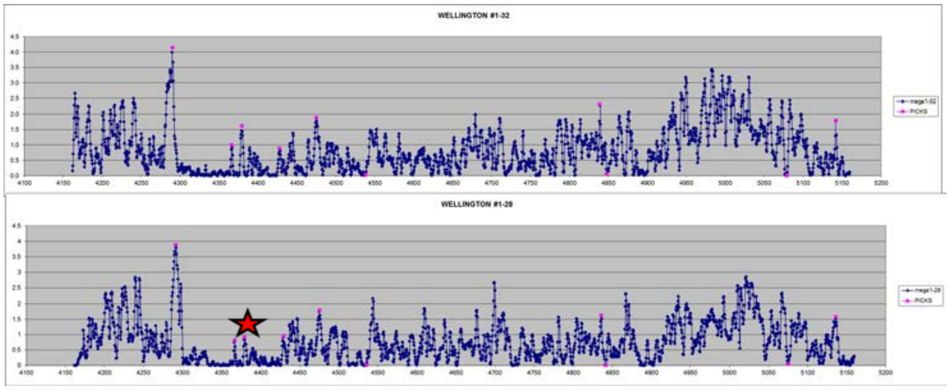
Figure 41. Very vuggy rock confirmed by MRI.

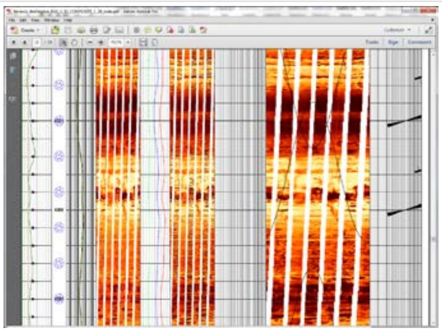




4366.5 FT -- 4365.5; 4367.2; 5Y6/1; light olive gray; dolo packstone; coarse; crinoid? coated grain; wavy bedded with mud chip conglomerate at base from reworking of bottom lithology; occasional darkened lithoclast within the grainstone; pinpoint interparticle porosity abundant; coated grains; small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

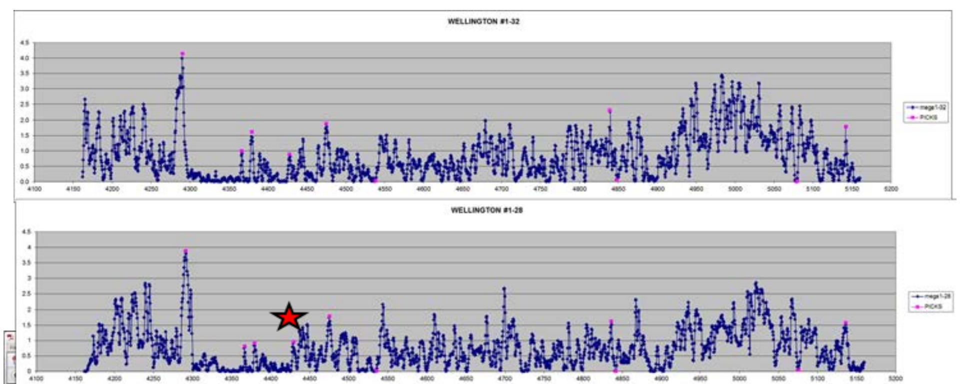
Figure 42. Interval dominated by finer pores as confirmed by MRI.

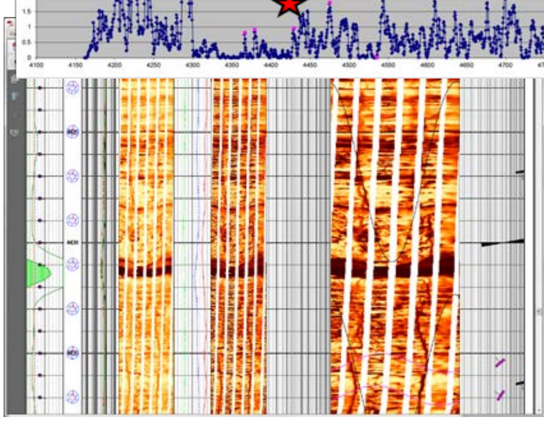




4379.5 ft -- 4377.8; 4380; 5YR 4/1; brownish gray; medium pelleted dolo packstone; coarse grainstone ; vugs; indistinct bedding; very porous; matrix porosity; scattered bioclasts; crinoids; sharp contact

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.

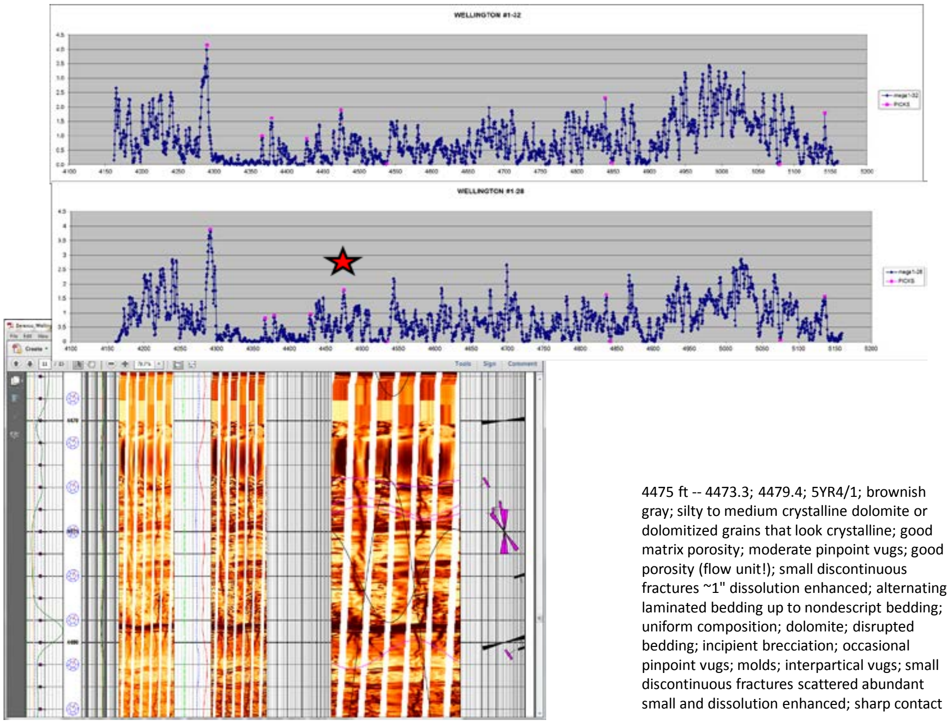


Figure 45. Pinpoint vugs and dissolution enhanced fractures, i.e., moderate vugs.

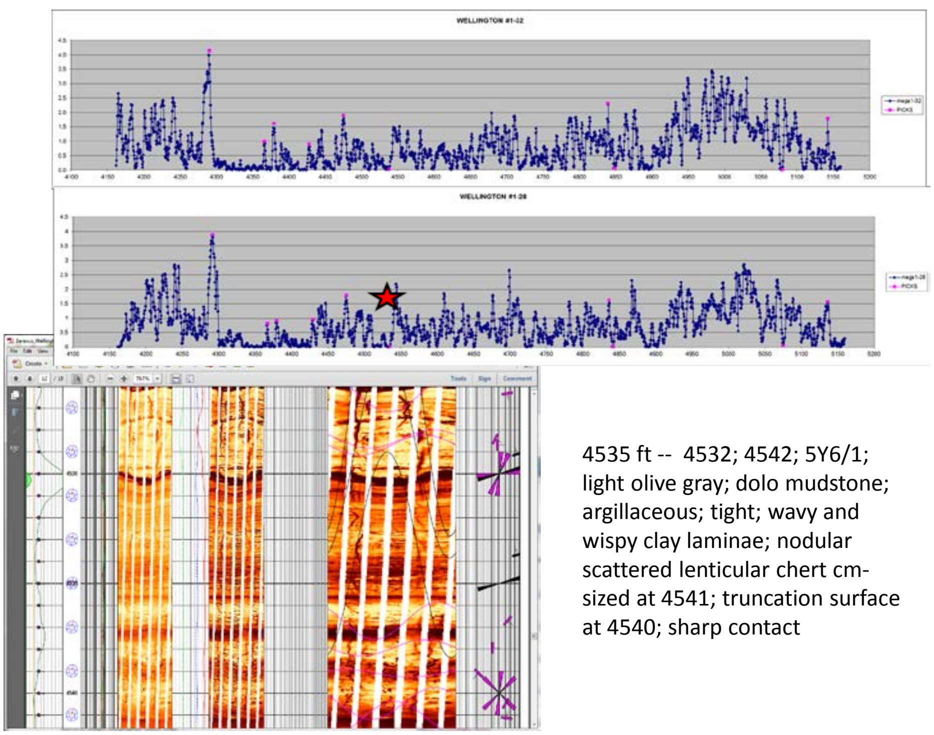
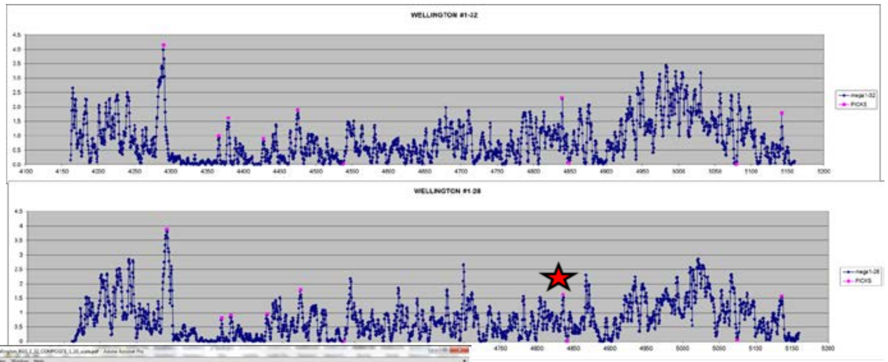
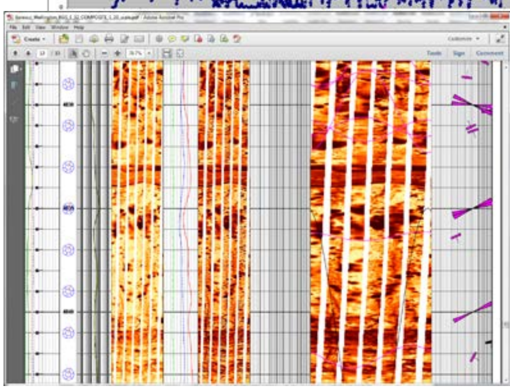


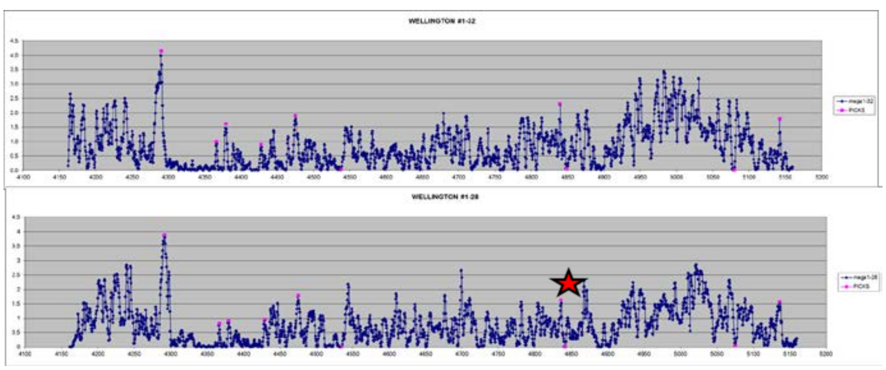
Figure 46. No vugs in laminated sediment.

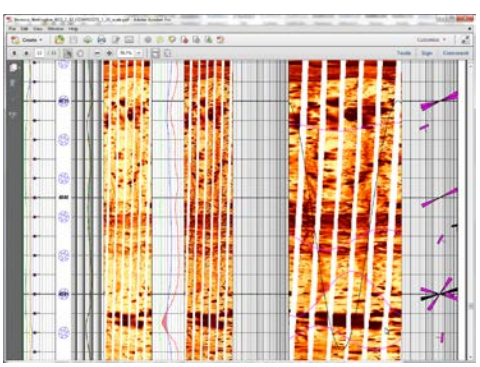




4836 ft -- 4830.0; 4850.0; Dolo, tan, f-med xln, hrd, dns, scrtd vuggy poro, fract, lots of uphole, blk & grn sh

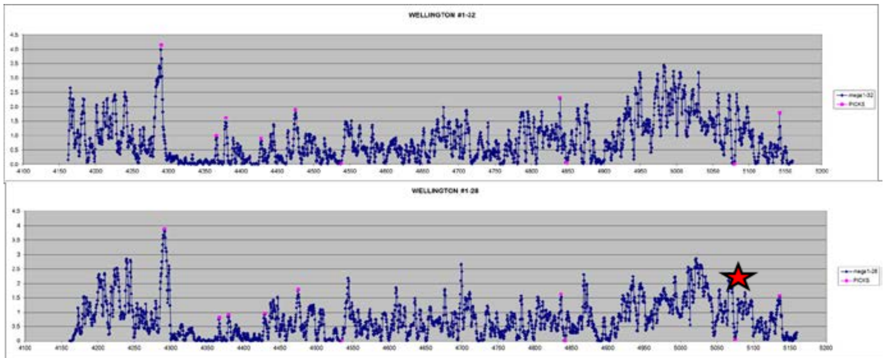
Figure 47. Moderately vuggy.

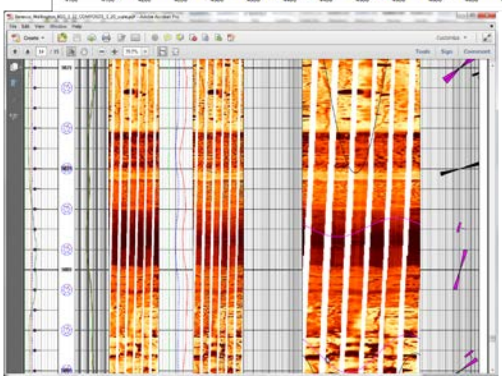




4841.5 ft -- Dolo, tan, f-med xln, hrd, dns, scrtd vuggy poro, fract, lots of uphole, blk & grn sh

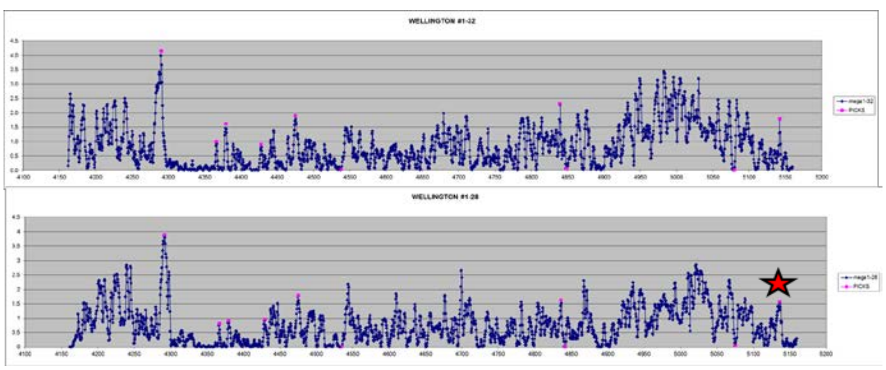
Figure 48. Moderately vuggy pores with fractures.

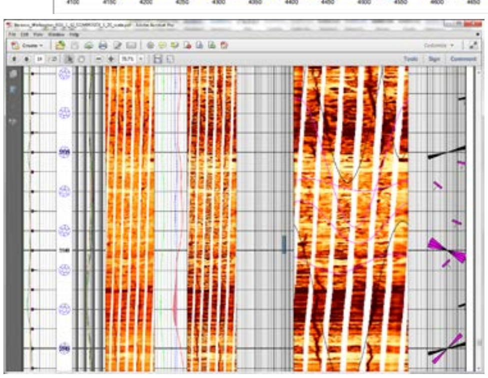




5079.5 ft -- 5058; 5080; 5Y4/1; olive gray; solid argillaceous finely crystalline micritic dolomite; stylolites; occasional cm-bedded with shale; contact at 5075.6 is transitional with clasts from below being incorporated into overlying packstone;

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.

1	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)**

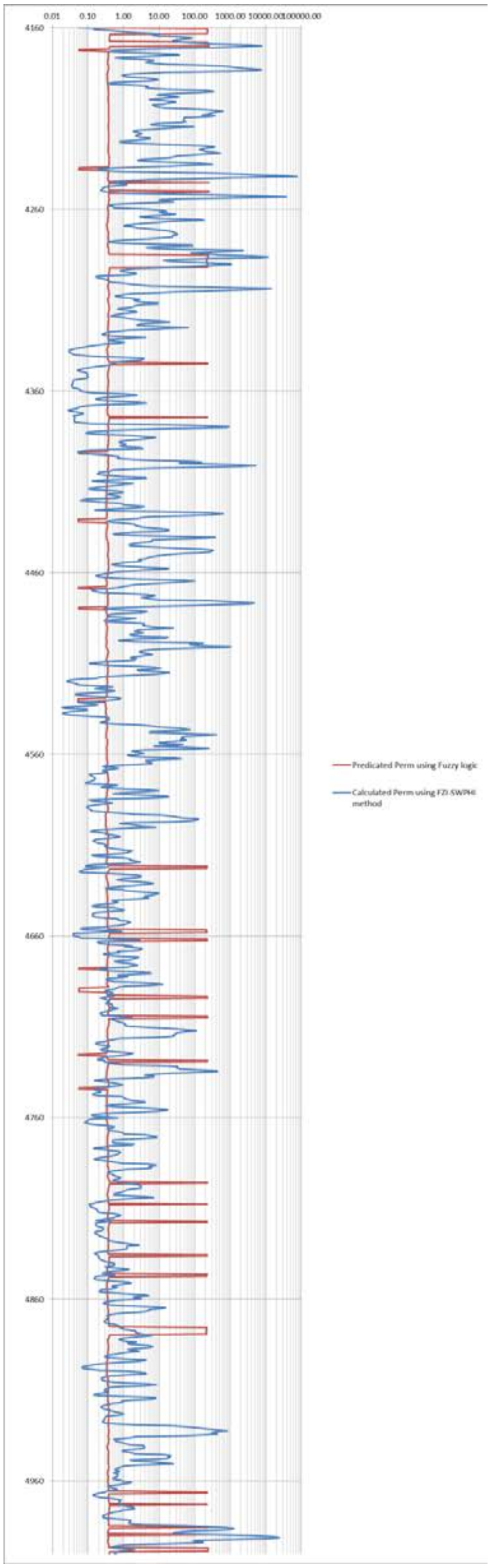


Figure 52. Computed permeability (red) vs. actual permeability (blue).

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

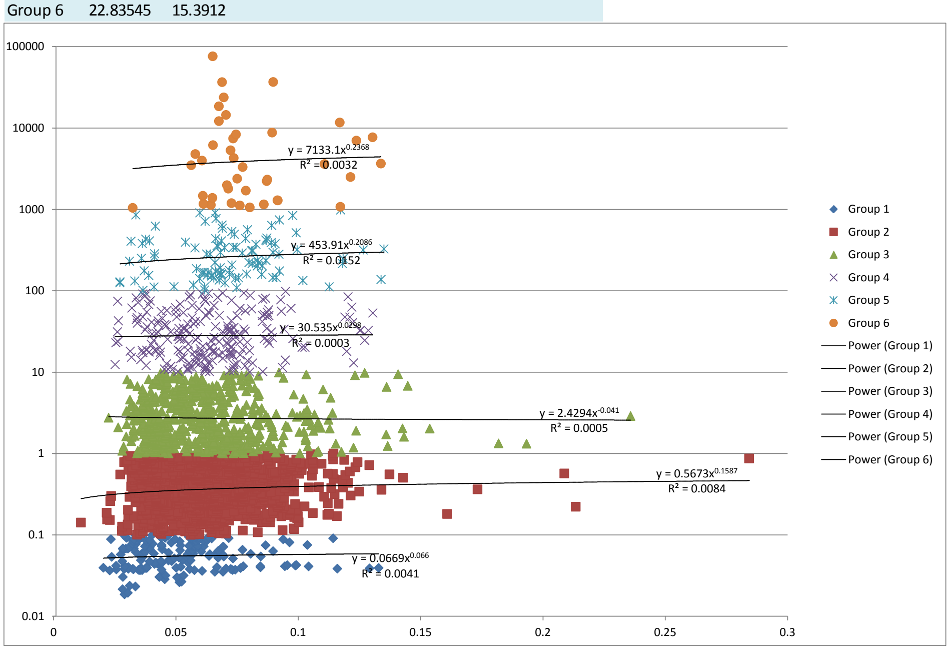


Figure 53. Plot of equations for six groups of permeability on a phi-k plot.

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 CO_2-brine system (**Figure 54**).

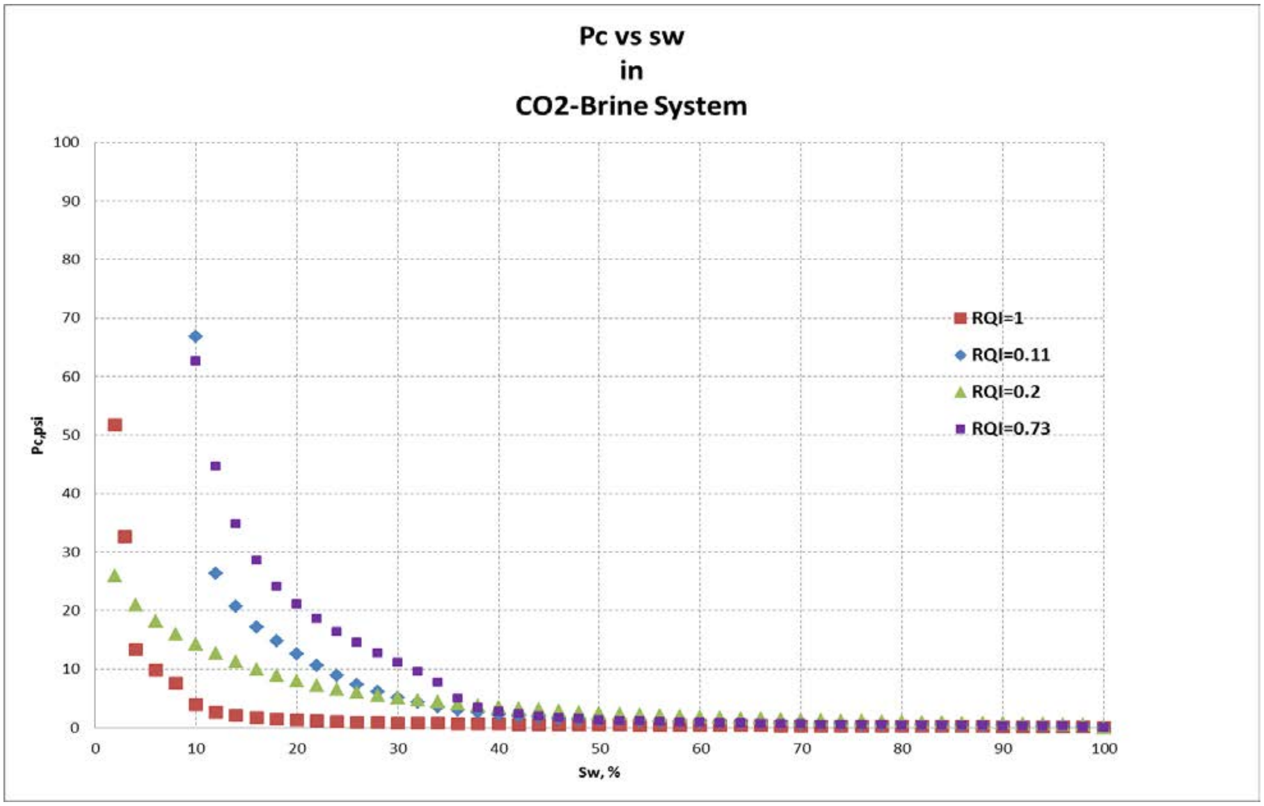


Figure 54: PC curves generated from NMR

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:

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

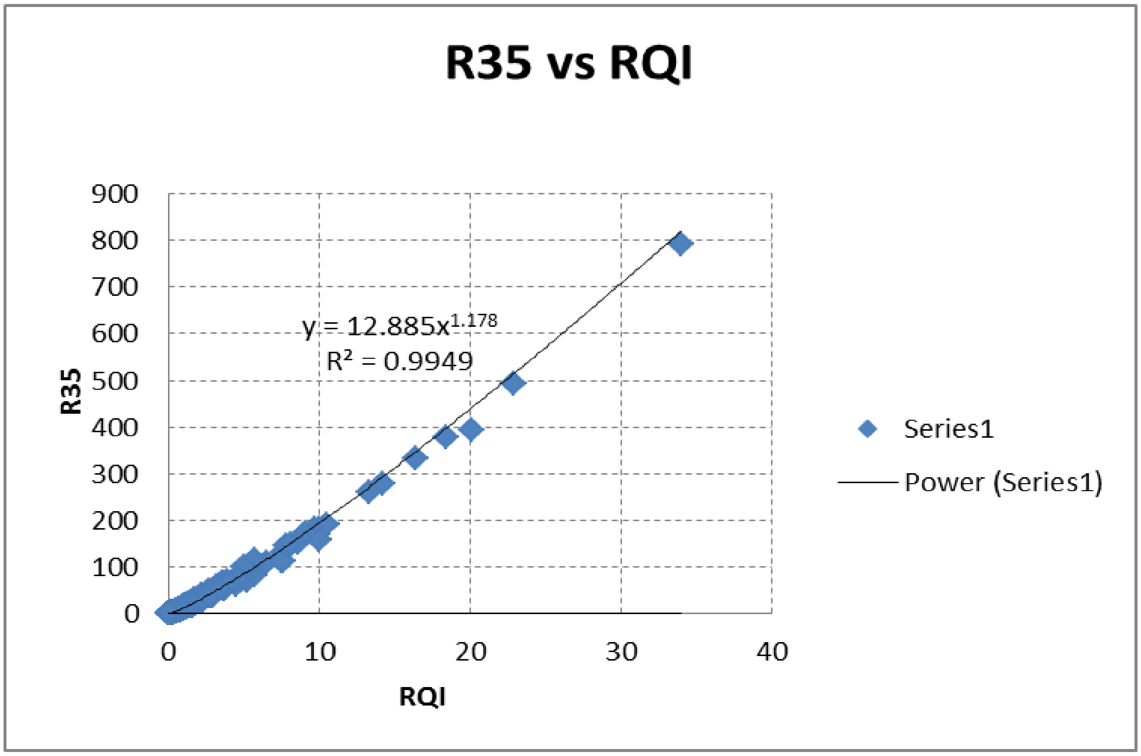


Figure 55: R35 versus RQI

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.

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

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

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

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:

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

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**.

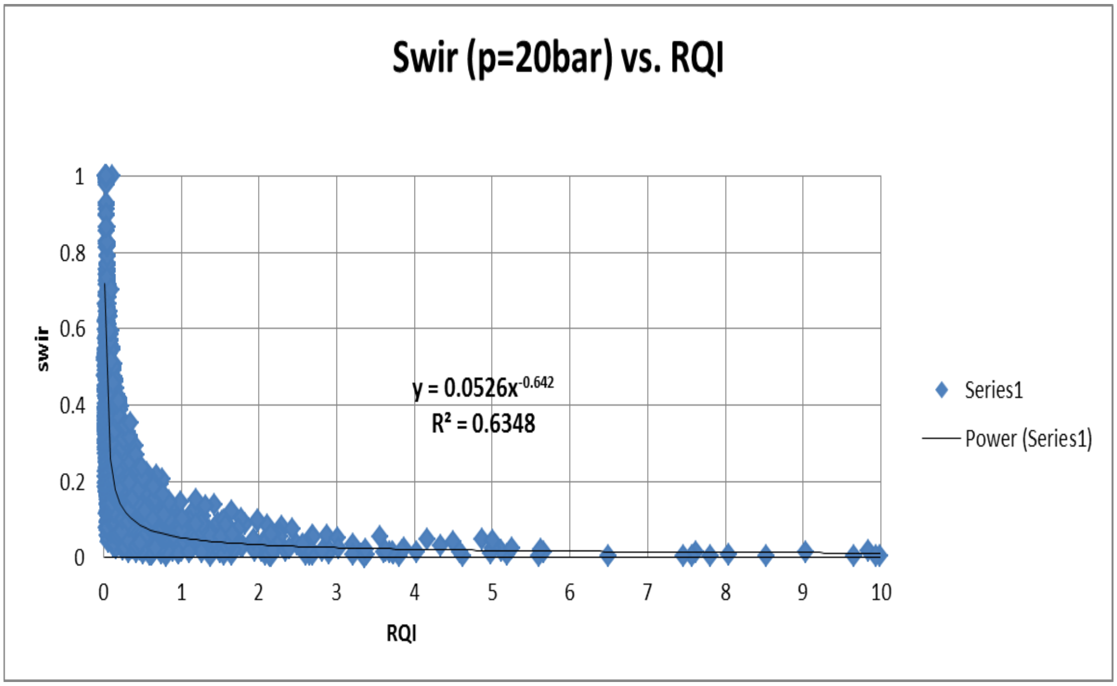


Figure 56: Irreducible water saturation vs. RQI

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

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

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.

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

$$a = 1.07$$

$$b = 34.82$$

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.

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

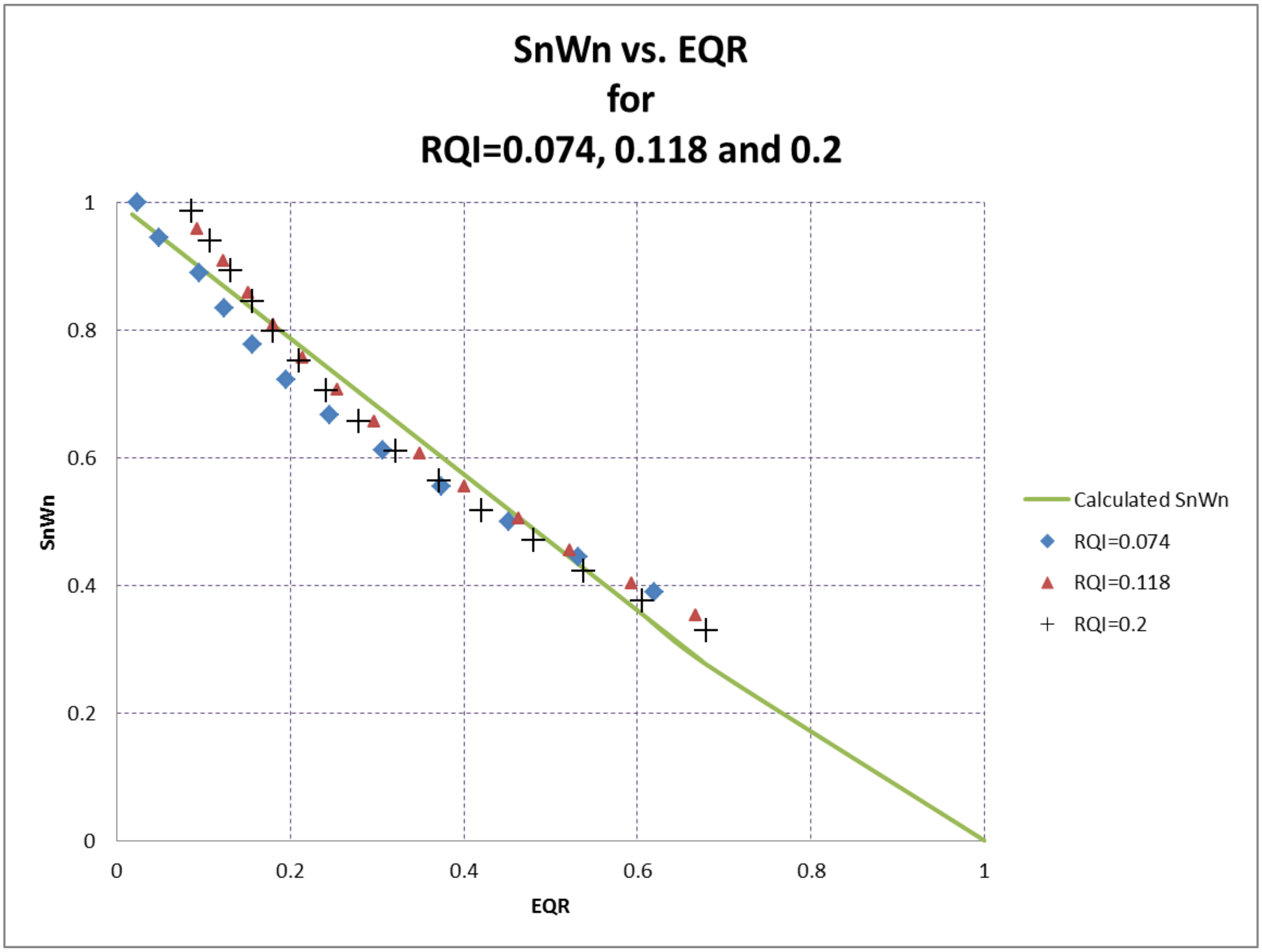


Figure 57: Snwn vs. EQI for RQI 1, 5.19 and 20

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.

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

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.

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

d. Calculation of Drainage Capillary Pressure Curves

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

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

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 1.07	b 34.82	Drainage PcTable in Arbuckle							
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

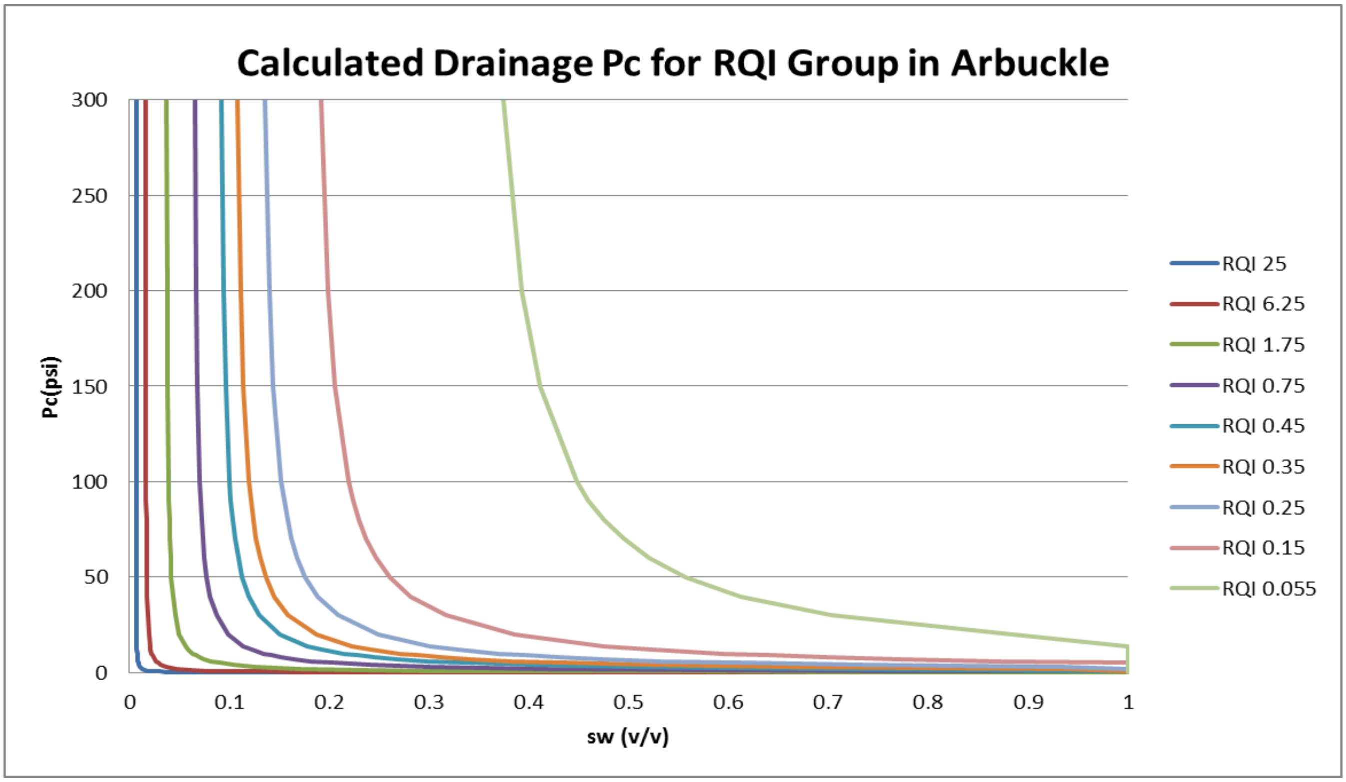


Figure 58: Nine Pc curves for 9 rock types for the specified RQI

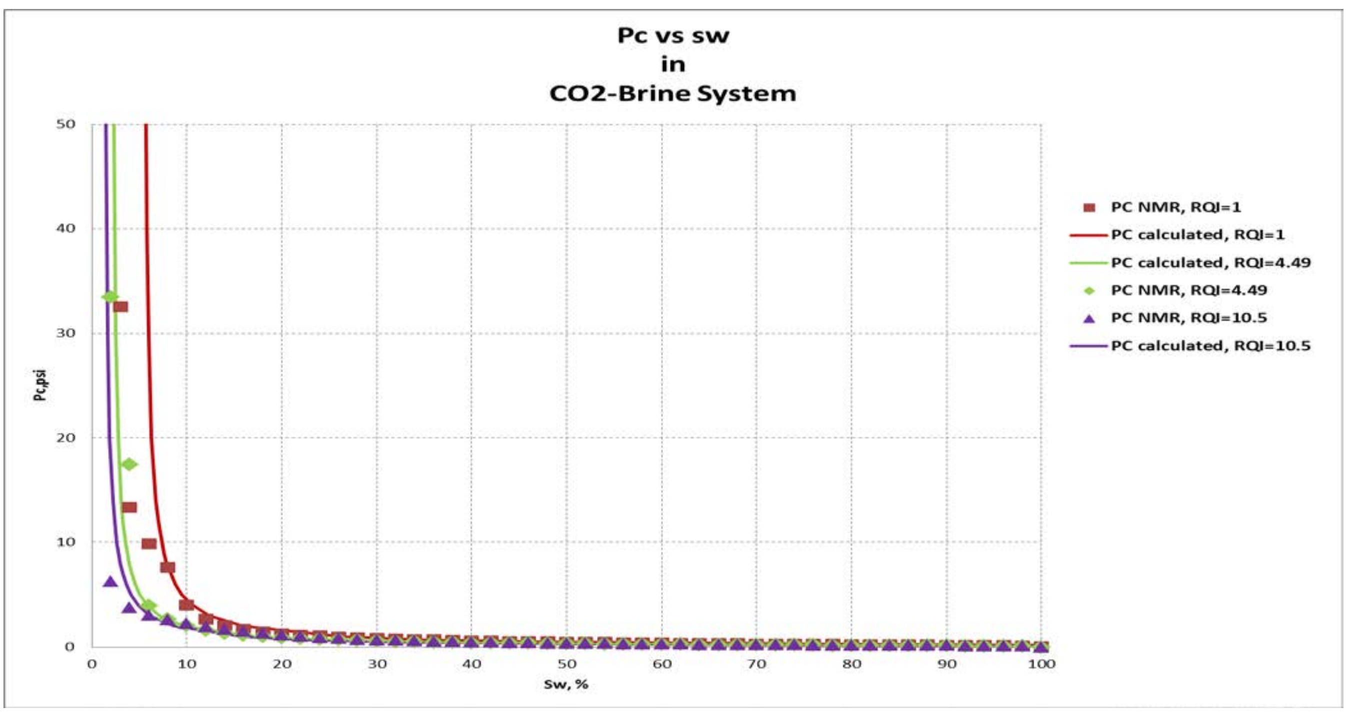


Figure 59: Calculated PC compared with generated PC from NMR

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**).

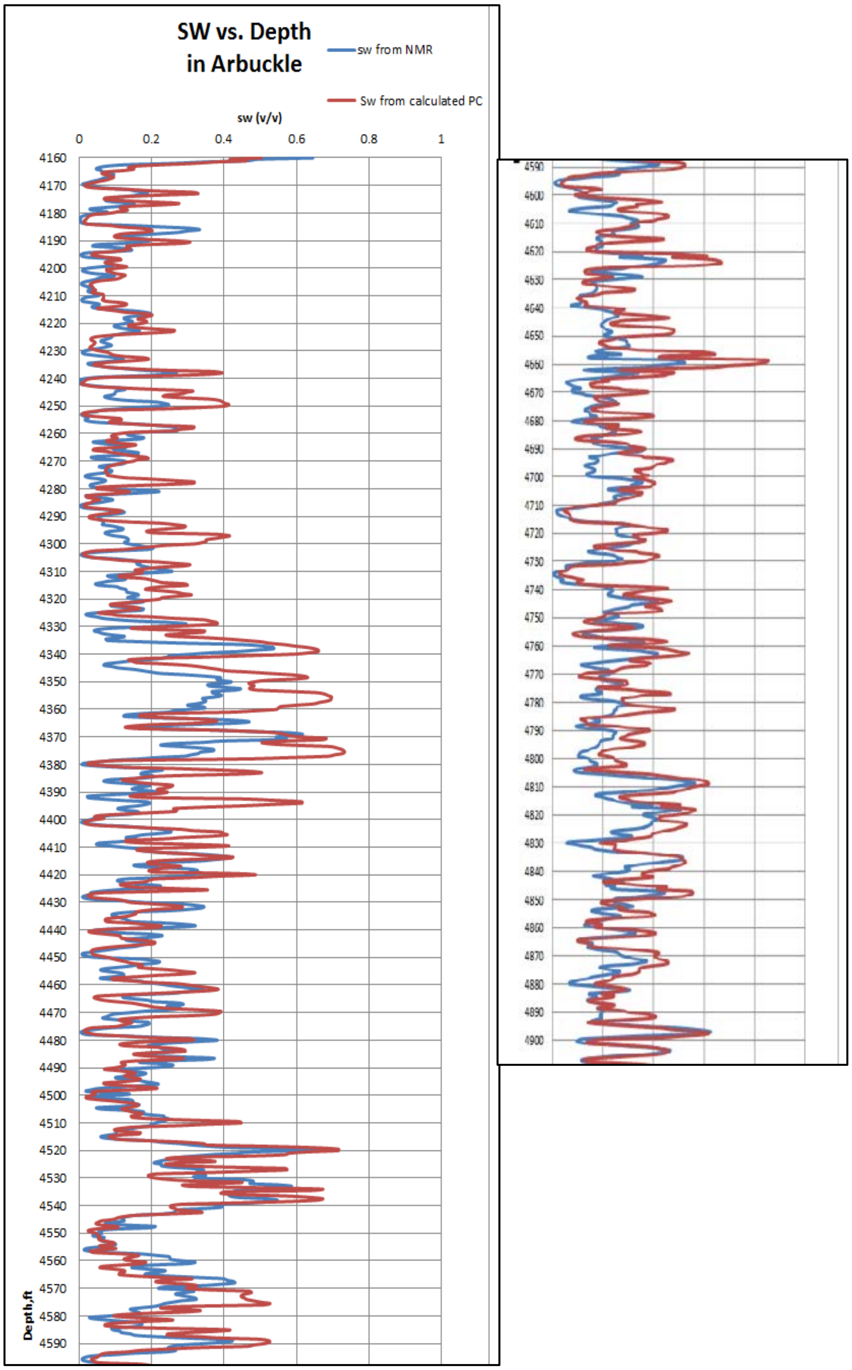


Figure 60. Computer water saturation in the upper Arbuckle with supercritical CO2.

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.

SPENDING PLAN

Please see next page.

COST PLAN/STATUS

	BP 1 Starts: 12/8/09	Ends: 2/7/11				BP2 Starts 2/8/11	Ends 8/7/12			
	12/8/09-12/31/09	1/1/10-3/31/10	4/1/10-6/30/10	7/1/10-9/30/10	10/1 - 12/31/10	1/1/11 - 3/31/11	4/1/11 - 6/30/11	7/1/11-9/30/11	10/1/11 - 12/31/11	1/1/12 - 3/31/12
Baseline Reporting Quarter	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Baseline Cost Plan (from SF-424A)	(from 424A, Sec. D)									
Federal Share	$1,007,622.75	$1,007,622.75	$1,007,622.75	$1,007,622.75	$0.00	$0.00	$0.00	$1,169,543.00	$1,169,543.00	$1,169,543.00
Non-Federal Share	$277,260.75	$277,260.75	$277,260.75	$277,260.75	$0.00	$0.00	$0.00	$303,182.75	$303,182.75	$303,182.75
Total Planned (Federal and Non-Federal)	$1,284,883.50	$1,284,883.50	$1,284,883.50	$1,284,883.50	$0.00	$0.00	$0.00	$1,472,725.75	$1,472,725.75	$1,472,725.75
Cumulative Baseline Cost	$1,284,883.50	$2,569,767.00	$3,854,650.50	$5,139,534.00	$5,139,534.00	$5,139,534.00	$5,139,534.00	$6,612,259.75	$8,084,985.50	$9,557,711.25
Actual Incurred Costs										
Federal Share	$4,019.93	$84,603.97	$494,428.37	$111,405.52	$238,675.97	$1,902,936.55	$625,853.17	$275,754.50	$523,196.12	$453,026.11
Non-Federal Share	$0.00	$43,980.04	$40,584.78	$13,195.88	$526,210.30	$35,887.34	$414,511.02	$20,247.24	$16,687.00	$61,683.20
Total Incurred Costs-Quarterly (Federal and Non-Federal)	$4,019.93	$84,603.97	$535,013.15	$124,601.40	$764,886.27	$1,938,823.89	$1,040,364.19	$296,001.74	$539,883.12	$514,709.31
Cumulative Incurred Costs	$4,019.93	$88,623.90	$623,637.05	$748,238.45	$1,513,124.72	$3,451,948.61	$4,492,312.80	$4,788,314.54	$5,328,197.66	$5,842,906.97
Variance										
Federal Share	$1,003,602.82	$923,018.78	$513,194.38	$896,217.23	-$238,675.97	-$1,902,936.55	-$625,853.17	$893,788.50	$646,346.88	$716,516.89
Non-Federal Share	$277,260.75	$233,280.71	$236,675.97	$264,064.87	-$526,210.30	-$35,887.34	-$414,511.02	$282,935.51	$286,495.75	$241,499.55
Total Variance-Quarterly Federal and Non-Federal)	$1,280,863.57	$1,156,299.49	$749,870.35	$1,160,282.10	-$764,886.27	-$1,938,823.89	-$1,040,364.19	$1,176,724.01	$932,842.63	$958,016.44
Cumulative Variance	**$1,280,863.57**	**$2,437,163.06**	**$3,187,033.41**	**$4,347,315.51**	**$3,582,429.24**	**$1,643,605.35**	**$603,241.16**	**$1,779,965.17**	**$2,712,807.80**	**$3,670,824.24**

		BP3 Starts 8/8/12	Ends 9/30/14							
	4/1/12 - 6/30/12	7/1/12 - 9/30/12	10/1/12 - 12/31/12	1/1/13 - 3/31/13	4/1/13 - 6/30/13	7/1/13 - 9/30/13	10/1/13 - 12/31/13	1/1/14 - 3/31/14	4/1/14 - 6/30/14	7/1/14 - 9/30/14
Baseline Reporting Quarter	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20
Baseline Cost Plan (from SF-424A)										
Federal Share	$1,169,543.00	$316,409.00	$316,409.00	$316,409.00	$316,409.00	$0.00	$0.00	$0.00	$0.00	$0.00
Non-Federal Share	$303,182.75	$81,854.50	$81,854.50	$81,854.50	$81,854.50	$0.00	$0.00	$0.00	$0.00	$0.00
Total Planned (Federal and Non-Federal)	$1,472,725.75	$398,263.50	$398,263.50	$398,263.50	$398,263.50	$0.00	$0.00	$0.00	$0.00	$0.00
Cumulative Baseline Cost	$11,030,437.00	$11,428,700.50	$11,826,964.00	$12,225,227.50	$12,623,491.00	$12,623,491.00	$12,623,491.00	$12,623,491.00	$12,623,491.00	$12,623,491.00
Actual Incurred Costs										
Federal Share	$238,793.52	$1,282,545.00	$1,314,156.54	$395,319.33	$299,454.96	$465,714.15	$190,945.64			
Non-Federal Share	$150,646.51	$221,053.41	$121,637.40	-$65,989.76	$23,362.67	$34,263.50	$1,055,092.86			
Total Incurred Costs-Quarterly (Federal and Non-Federal)	$389,440.03	$1,503,598.41	$1,435,793.94	$329,329.57	$322,817.63	$499,977.65	$1,246,038.50			
Cumulative Incurred Costs	$6,232,347.00	$7,735,945.41	$9,171,739.35	$9,501,068.92	$9,823,886.55	$10,323,864.20	$11,569,902.70			
Variance										
Federal Share	$930,749.48	-$966,136.00	-$997,747.54	-$78,910.33	$16,954.04	-$465,714.15	-$190,945.64			
Non-Federal Share	$152,536.24	-$139,198.91	-$39,782.90	$147,844.26	$58,491.83	-$34,263.50	-$1,055,092.86			
Total Variance-Quarterly Federal and Non-Federal)	$1,083,285.72	-$1,105,334.91	-$1,037,530.44	$68,933.93	$75,445.87	-$499,977.65	-$1,246,038.50			
Cumulative Variance	**$4,754,109.96**	**$3,648,775.05**	**$2,611,244.61**	**$2,680,178.54**	**$2,755,624.41**	**$2,255,646.76**	**$1,009,608.26**			