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

ATTACHMENT 3
U.S. Department of Energy
FEDERAL ASSISTANCE REPORTING CHECKLIST AND INSTRUCTIONS

1. Identification Number: **DE-FE0002056**	2. Program/Project Title: **Modeling CO2 Sequestration in Saline Aquifer and Depleted Oil Reservoir to Evaluate Regional CO2 Sequestration Potential of Ozark Plateau Aquifer System, South-Central Kansas**
3. Recipient: University of Kansas Center for Research	

4. Reporting Requirements:	Form	Frequency	No. of Copies	Addresses
A. MANAGEMENT REPORTING				
☒ Progress Report		Q	Electronic Version to NETL>	FITS@NETL.DOE.GOV
☒ Special Status Report		A		
B. SCIENTIFIC/TECHNICAL REPORTING * (Reports/Products must be submitted with appropriate DOE F 241. The 241 forms are available at https://www.osti.gov/elink)				
Report/Product	Form			
☒ Final Scientific/Technical Report	DOE F 241.3	FG	Electronic Version to E-link>	http://www.osti.gov/elink-2413
☒ Conference papers/proceedings/etc.*	DOE F 241.3	A		http://www.osti.gov/elink-2413
☐ Software/Manual	DOE F 241.4			http://www.osti.gov/estsc/241-4pre.jsp
☒ Other (see special instructions) Topical	DOE F 241.3	A		
** Scientific/technical conferences only*				
C. FINANCIAL REPORTING				
☒ SF-425, Federal Financial Report		Q, FG	Electronic Version To NETL>	FITS@NETL.DOE.GOV
D. CLOSEOUT REPORTING				
☐ Patent Certification		FC	Electronic Version To NETL>	FITS@NETL.DOE.GOV
☐ Property Certificate		FC		
☐ Other				
E. OTHER REPORTING				
☒ Annual Indirect Cost Proposal		A	Electronic Version To NETL>	FITS@NETL.DOE.GOV
☒ Annual Inventory Report of Federally Owned Property, if any		A		
☐ Other				
F. AMERICAN RECOVERY AND REINVESTMENT ACT REPORTING				
☐ Reporting and Registration Requirements				http://www.federalreporting.gov

FREQUENCY CODES AND DUE DATES:

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

QUARTERY PROGRESS REPORT

Award Number: DE-FE0002056

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

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

Project Director/Principal Investigator: W. Lynn Watney
Principal Investigator: Saibal Bhattacharya

Fifth Quarter Progress Report

Date of Report: 1-31-2011

Period Covered by the Report: October 1, 2010 through December 31, 2010

Contributors to this Report: Ralph Baker, Robin Barker, Saibal Bhattacharya, Saugata Datta, John Doveton, Martin Dubois, David Fowle, Paul Gerlach, Robert Goldstein, Tom Hansen, Dennis Hedke, Breanna Huff, Mike Killian, Bradley King, Dave Koger, Larry Nicholson, Susan Nissen, Derek Ohl, Abdelmoneam Raef, Jennifer Roberts, Jason Rush, Aimee Scheffer, , John Victorine, Lynn Watney, Dana Wreath, Jianghai Xia

EXECUTIVE SUMMARY

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

The project has two areas of focus, 1) a field-scale study at Wellington Field, Sumner County, Kansas and 2) 20,000 square mile regional study of a 17+ county area in southern Kansas. 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 by the team will assess miscible CO_2-EOR and tertiary oil recovery potential in the Mississippian chat reservoir and CO_2 sequestration potential in the underlying Arbuckle Group saline aquifer. Activities in the regional study are carried out through Bittersweet Energy, another subcontractor. They are characterizing the Arbuckle Group (saline) aquifer in southern Kansas to estimate regional CO_2 sequestration capacity. The key scientific theme is to understand the geologic fundamentals behind the internal stratal architecture, structural deformation, and diagenesis and to evaluate their role on flow units, caprock integrity, aquifer storage, and identification of reservoir compartments and barriers to flow.

Supplemental funding to begin in Year 2 extends the regional assessment of the CO2 sequestration potential to the Arbuckle saline aquifer to southwestern Kansas, referred to as the Western Annex. All or parts of 33 counties are now included in this assessment. CO2-EOR potential is also extended to include assessment of a series of Chester (Upper Mississippian) and Morrow (Lower Pennsylvanian) sandstone oil reservoirs. Industry partnerships are extended to include Anadarko Petroleum Corporation, Cimarex Energy Company, Cisco Energy LLC, Glori Oil Ltd., and Merit Energy Company. Project is also supported by Sunflower Electric Power Corporation.

Project Status: Subtasks completed till date include: 1) 3D seismic survey at Wellington field (Sumner County, KS) processed and p-wave interpreted, 2) Wellington field seismic data merged with donated 3D seismic data from the adjacent Anson and Bates fields, 3) Wellington 3D seismic interpretation includes structure, time slices, volumetric coherency, curvature, and fault mapping 4) two locations chosen for test boreholes in Wellington Field, 5) gravity and magnetic surveys over 17+ county regional study area have been reprocessed and suggested basement faults/fracture trends mapped for validation, 6) remote sensing data over 17+ county regional study area analyzed and surface lineaments mapped, 7) multiple stratigraphic horizons have been mapped over regional study area, 8) multi-township areas selected within regional study area for detailed characterization and simulation studies to evaluate CO_2 sequestration potential in Arbuckle Group saline aquifer, 9) depth-constrained cluster analysis conducted on petrophysical properties to identify Arbuckle flow-units and analysis tool incorporated into Java petrophysical application, 10) initial simulation studies conducted to estimate CO_2 sequestration potential in selected area around Oxy-Chem #10 well, 11) available Arbuckle DST data collected, analyzed,

and mapped showing hydraulic communication with northwestern Ozark uplift outcrop in Missouri, 12) website has been updated to include maps of latest subsurface geology, remote sensing analysis, and reprocessed gravity and magnetic information., and 13) test borehole Berexco KGS Wellington #1-32 has commenced.

ACCOMPLISHMENTS

Methods/Approach

REGIONAL STUDY

ONGOING AND COMPLETED ACTIVITIES concerning all or parts of 33 county study area: 1) Extend stratigraphic correlations at supertypes (deep Arbuckle and basement) wells (132 total) to include Western Annex and remainder of Kansas; 2) extend correlations to type wells (1735 wells); 3) additional scanning and conversion of sample descriptions to ASCII format; 4) release new web applications including updated general profile viewer, new cross section viewer, utility to upload well information to interactive mapper including LAS 3.0 files and premade cross sections, and utility to split LAS 3 files to standard LAS 2 format; and depth-constrained clustering; 5) SW Kansas CO2 Sequestration Consortium established for Western Annex Study; 6) initial fine–scaled 2D simulation at Oxy-Chem well indicates that a) tight shale layers within Arbuckle saline aquifer prevent vertical migration of CO2 plume away from primary caprock, and b) CO2 plume contained within anticline located updip from injector.

Subtask 2.2. Acquire geologic, seismic and engineering data

This three-year activity is currently focused on establishing a digital well log database, establishing initial correlations to define key stratigraphic and hydrostratigraphic (flow) units in the original study area and in the new Western Annex covering a total of 25,000 mi2. In addition, a set of key deep wells will be digitized and correlated to develop a "Kansas type wells" to represent the remainder of Kansas.

Related Activities:

1. Scanning and digitizing of 1400 type wells in the original 20,000 mi study area in southern Kansas is nearly complete -- 90 supertype wells have been digitized and most have been uploaded to the project interactive mapper -- (http://maps.kgs.ku.edu/co2/?pass=project).
2. Identify and begin digitizing additional type wells in Western Annex and areas surrounding original study area in Kansas
3. Inventory and scan Class I Arbuckle disposal wells in Kansas – three of potentially 89 well files have been scanned and uploaded onto database.
4. Creating ASCII files of sample logs starting with 154 Davies Logs and numerous georeports from key wells in the study area. Information will augment log petrophysics to verify lithology of key wells. Well Profile web application -- http://www.kgs.ku.edu/PRS/Ozark/PROFILE/ allows integration of sample & core data with display of wireline logs and saving in LAS 3.0 file format.

Development of Java Web Applications
Contributed by John Victorine

A number of Java Well Applications were created for this quarter.

- General Profile File Viewer
- General Cross Section Viewer
- Upload Log ASCII Standard (LAS) 3.0 File to Kansas Geological Survey Server & LAS3 Database Table.
- Upload Cross Section Files, Control XML File & LAS 3.0 Files, to the Kansas Geological Survey Server & Cross Section Database Tables.
- Log ASCII Standard (LAS) 3.0 File Split

These programs were created to support the need to view the LAS 3.0 & Cross Section Plots, which are launched from the Modeling CO_2 Sequestration Potential in Kansas Map Viewer. The map viewer retrieves the uploaded file data from the KGS Database Table and draws the location of the Well or Cross Section Line on the map for the user to select. The LAS 3.0 File format was selected to store the well data since this format will allow all the ASCII data to reside in one file and not multiple locations.

The Log ASCII Standard (LAS) version 2.0 & 3.0 Files were developed by the Canadian Well Logging Society, the LAS File Description can be found at the LAS File Web Site, http://www.cwls.org/las_info.php.

General Profile LAS 3.0 File Viewer

This program will plot a Log ASCII Standard (LAS) version 3.0 File with minimum capabilities. This program is a subset of the Profile Web Application, except it has limited interactive ability for the general user, they can change the depth scale and depth range of the plot, turn on or off formation tops picks, create & save a Portable Document Format (PDF) & Portable Network Graphic (PNG) Files to their PC and to save the LAS 3.0 to their PC. The LAS 3.0 File that is being displayed is initially created by DOE CO_2 Project Users and has the plot settings saved from the Profile Web Application. When the user selects the file from the DOE CO_2 Map, the LAS 3.0 File has a Plot Control Section that will redisplay the presentation in the same manner that was last viewed & saved by the DOE CO_2 Project User. The General Profile LAS 3.0 File Viewer is only launched from the DOE CO_2 Map Viewer, which only needs to send a Unique Database Table KEY for the specific LAS 3.0 File to the General Profile LAS 3.0 Viewer and the Viewer will retrieve the LAS 3.0 File from the KGS Server. An example can be seen in Figure 1.

General Cross Section Plot Viewer

This program will plot the Cross Section that was saved by the DOE CO_2 Project Users and will appear as a purple line on the DOE CO_2 Map Viewer, which the user can select if the "Cross Section Line" Layer is selected. The user only needs to click on the purple line and the DOE CO_2 Map Viewer will pass the Unique Database Table KEY for the cross section to the General Cross Section Plot Viewer and the Plot Viewer will retrieve the Cross Section Control XML (Extensible Markup Language) File that holds the location and order of the Wells Log ASCII

Standard (LAS) 3.0 Files. The Plot Viewer opens each of the LAS 3.0 Files and displays the Profile Plot Tracks selected for each well. This web application has minimum interactive capabilities, the user can change the depth scale & depth range, change the plot titles, create & save a Portable Document Format (PDF) & Portable Network Graphic (PNG) Files of the Cross Section Plot to their PC and the user can select a common stratigraphic units or flow units on the plot, the user can also datum by elevation, by horizon or by Log depth. An example of a cross section plot is display in Figure 2.

Upload Log ASCII Standard (LAS) version 3.0 File to Kansas Geological Survey Server
This program was designed for the DOE CO_2 Project Users to upload a Log ASCII Standard (LAS) 3.0 File to the KGS Server and to insert a minimum record into the LAS3 Well Header Database Table. Most of the Well information is stored in the LAS 3.0 File and the KGS Qualified Well Headers Database Table. The user only needs to match the LAS 3.0 File with a record in the KGS Qualified Well Headers Table to upload the file. This process was created for Kansas wells only so only the KGS Qualified Well Headers Primary KEY is stored in the LAS3 Well Header table with information the DOE CO_2 Project Users want to include. The DOE CO_2 Map Viewer retrieves this record and provides a link on the Map Viewer so the user can display the LAS 3.0 File in the General Profile LAS 3.0 File Viewer. The User must be part of the DOE CO_2 Project team and they must have permission to log into the Upload LAS 3.0 Web Application to upload the LAS 3.0 File to the KGS Server.

Upload Cross Section Files, Control XML File & LAS 3.0 Files, to the KGS Server
This program was designed for the DOE CO_2 Project Users to upload a Cross Section to the KGS Server and to insert records into the Cross Section Database Table and the ESRI Shape File Database Table. The Cross Section Control XML (Extensible Markup Language) File holds all the information needed to tell the General Cross Section Plot Viewer how to display the cross section and where the Well LAS 3.0 Files reside. The Cross Section Database Table and the ESRI Shape File Database Table holds minimum information to find the Cross Section on the KGS Server and to display a purple line illustrating the cross section position on the DOE CO_2 Map Viewer. The DOE CO_2 Map Viewer retrieves the database record and provides a link on the Map Viewer so the user can display the Cross Section in the General Cross Section Plot Viewer. The User must be part of the DOE CO_2 Project team and they must have permission to log into the Upload Cross Section Web Application to upload the Cross Section Files to the KGS Server.

Log ASCII Standard (LAS) 3.0 File Split
This program was created to assist the geologist that need to run other geological software programs that are unable to read a LAS 3.0 File to split the file into a LAS 2.0 File and a Well Base Fixed Format ASCII Text File. The LAS 3.0 file has the capability to store all ASCII Data in the file, i.e. Log Data, Formation Tops, Measured Core Data, Cuttings Report, etc. The LAS 2.0 file format can only store the Log Data. The Well Base Fixed Format ASCII Text File holds the Summary Header Information and the Formation Tops and Flow Units. The program is simply separating the log data & formation tops data that was stored in the LAS 3.0 File into two

file formats.

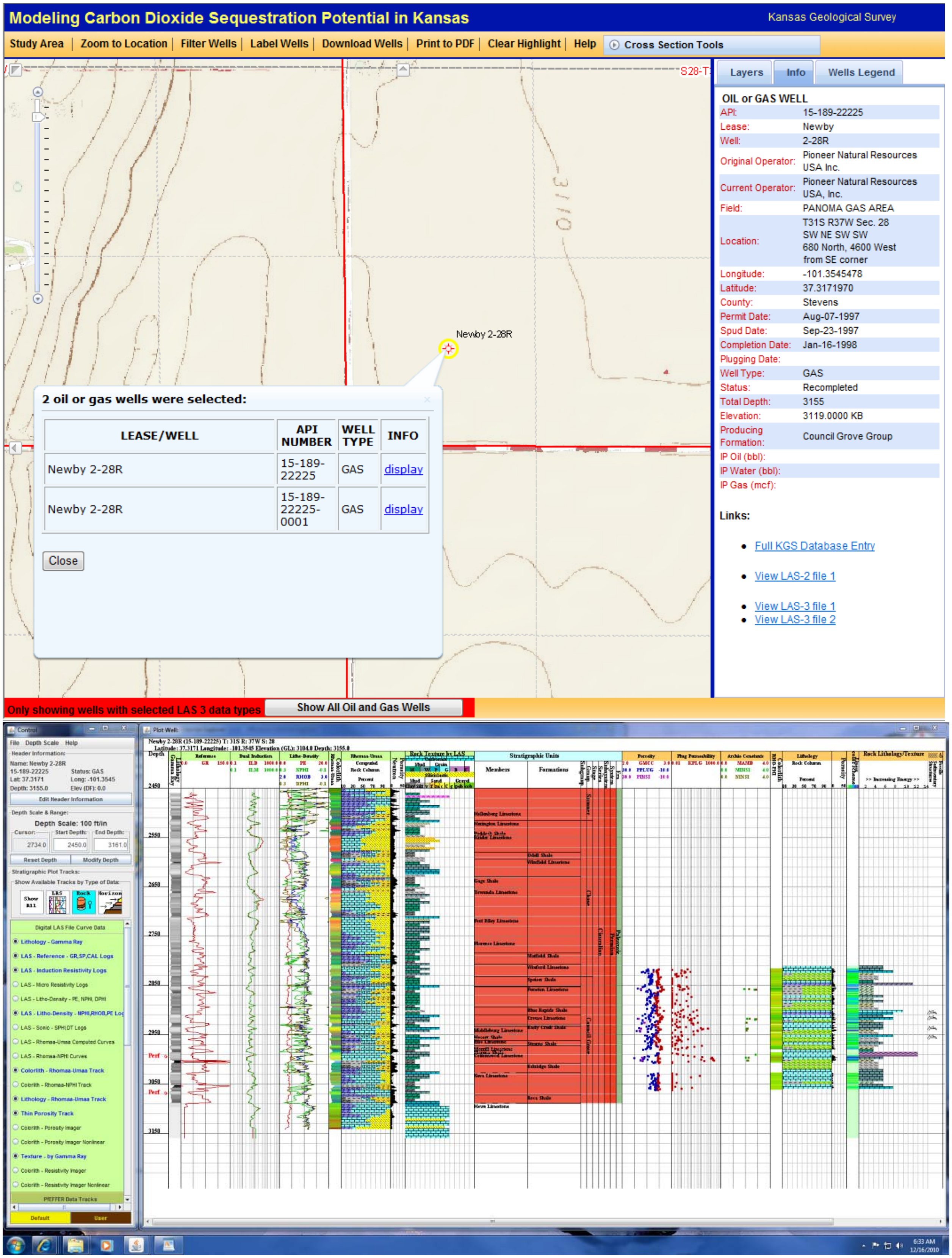


Figure 1: LAS 3.0 General Profile Plot Presentation for the Newby 2-28R Well.

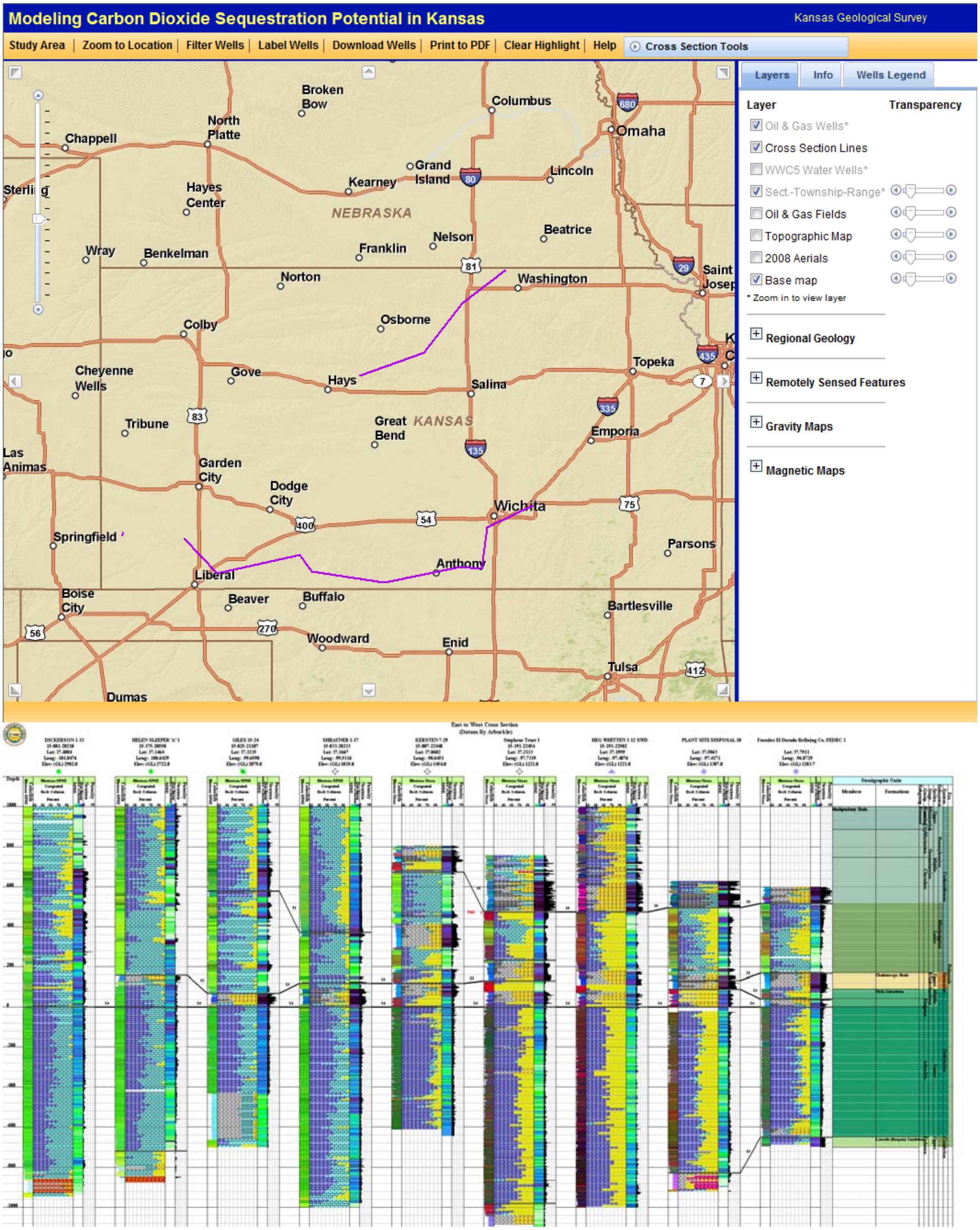


Figure 2: General Cross Section Plot Presentation for the CO2 Project Type Logs.

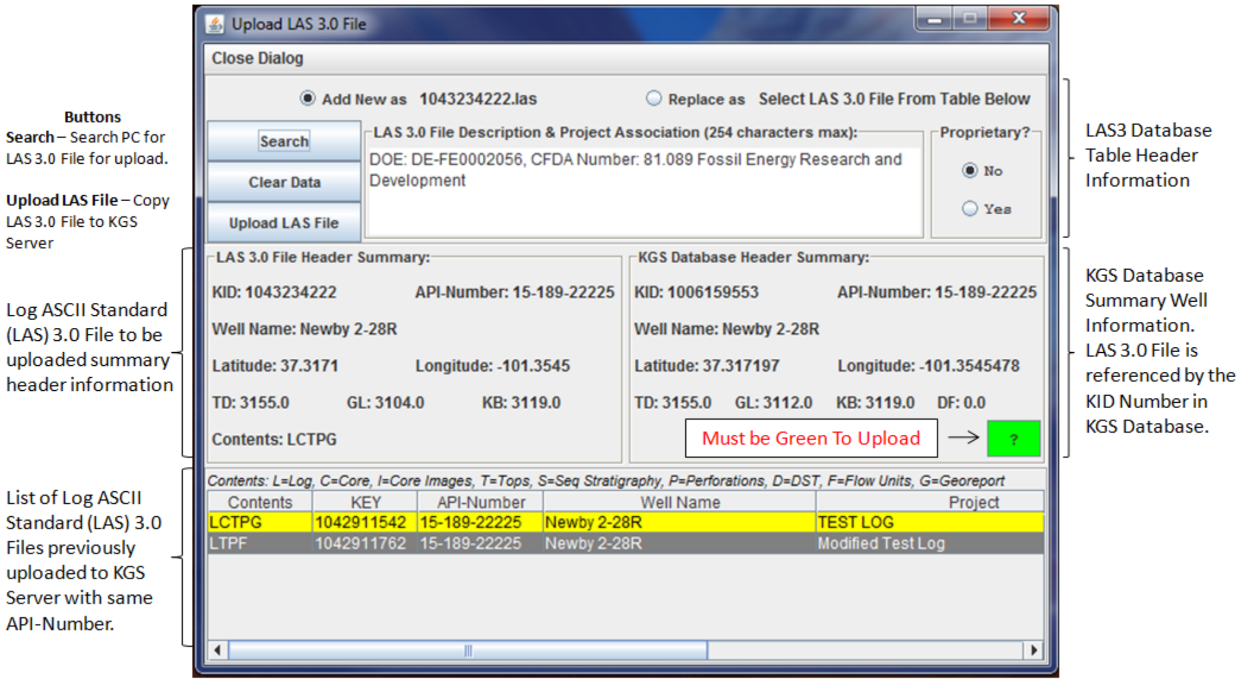


Figure 3: Upload Log ASCII Standard (LAS) version 3.0 File to KGS Server.

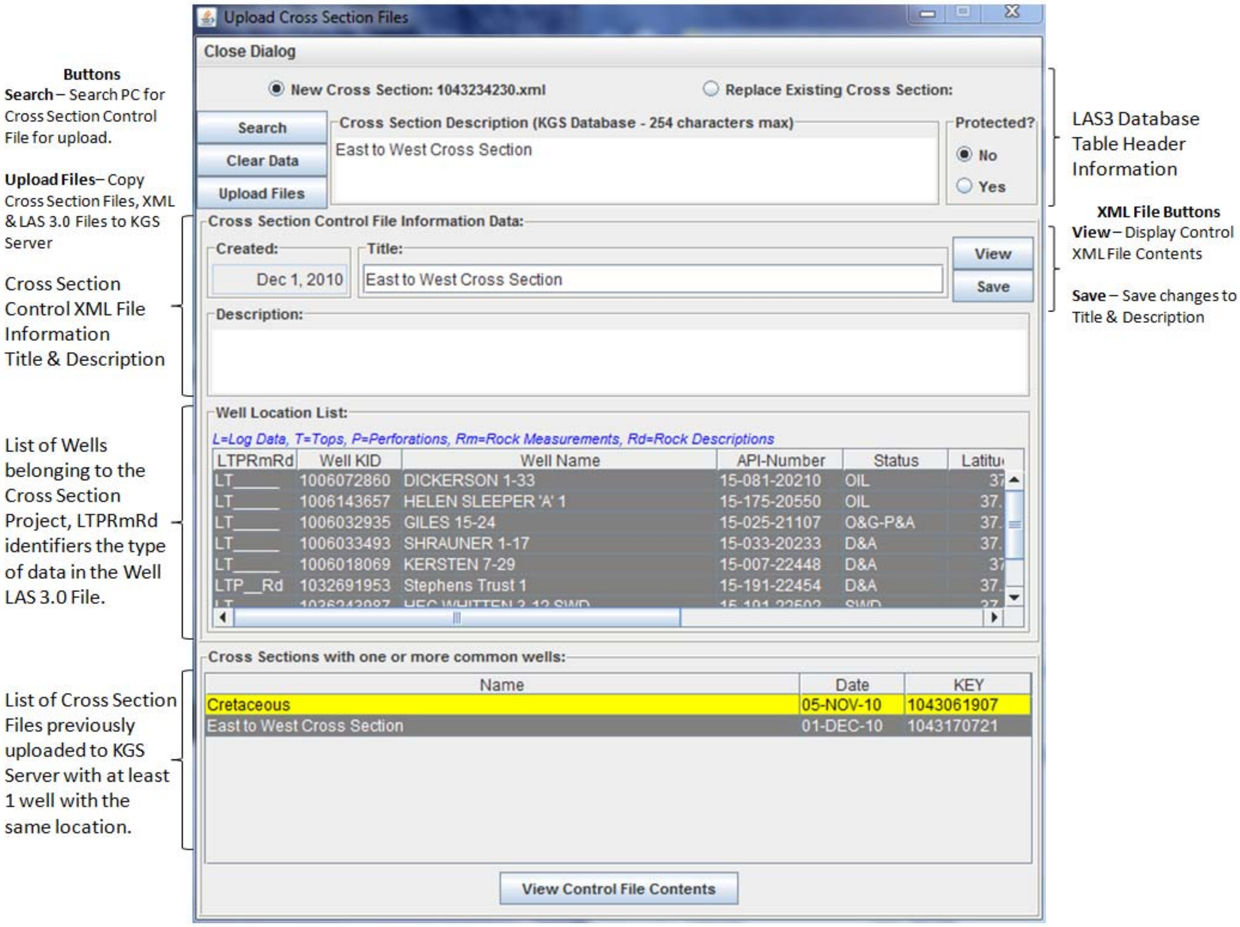


Figure 4: Upload Cross Section Files to KGS Server.

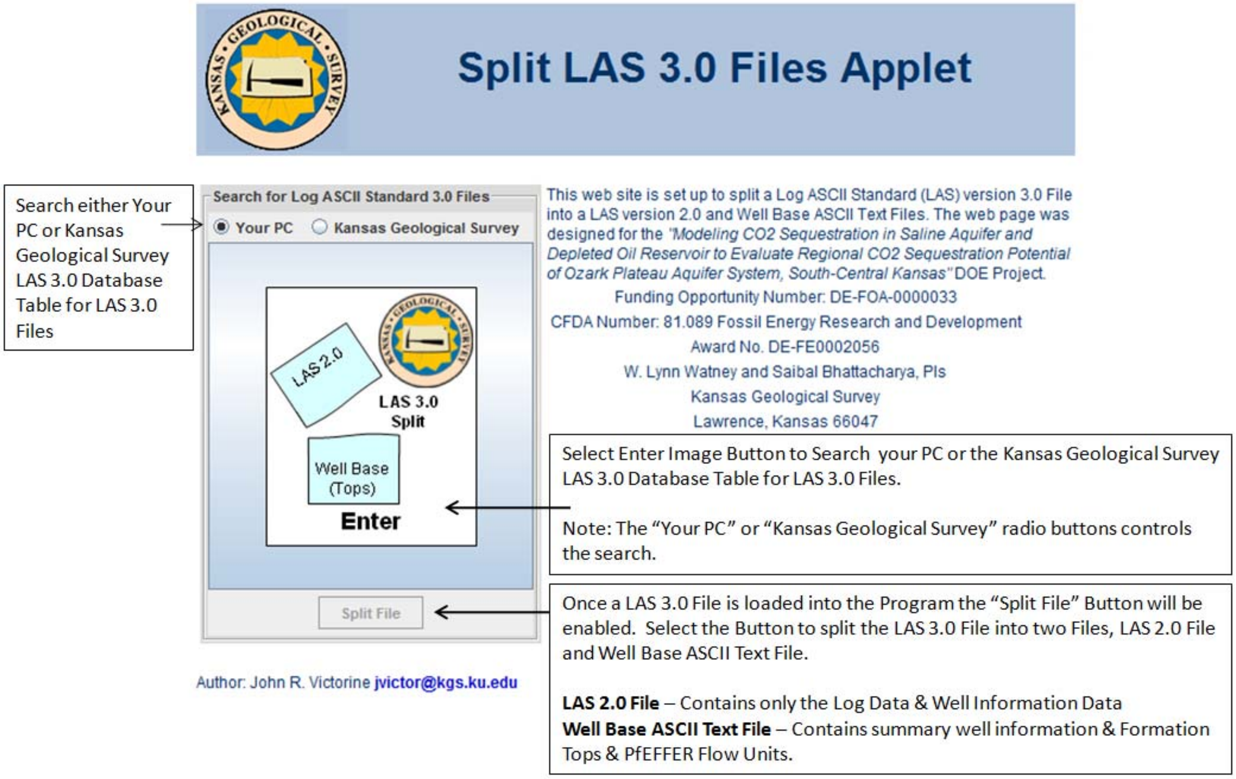


Figure 5: Split LAS 3.0 File into LAS 2.0 & Well Base ASCII Text Files.

ZONATION AND CORRELATION OF LITHOSTRATIGRAPHIC AND FLOW UNITS BY THE DEPTH-CONSTRAINED CLUSTERING OF PETROPHYSICAL LOGS – by John Doveton

A significant component of the evaluation of the Arbuckle Group and overlying Mississippian is the establishment of a framework of internal subdivisions that reflect systematic geological and flow architectural elements. These two related goals require the identification of lithostratigraphic units for internal stratigraphic correlation and mappable flow units for flow simulation based on petrophysical log measurements. The criteria for lithostratigraphic and flow units are similar. Each is defined as a laterally contiguous layer which is relatively homogeneous internally as contrasted with marked differences with adjacent units. Log properties that reflect rock composition should be the focus of lithostratigraphy while those that are controlled by pore volume and fluid properties should be the keys in discriminating flow units. In many cases, lithostratigraphic layers will coincide with discrete flow units; in other cases they will not. The conventional methodology for this work is visual pattern recognition by experienced geologists and engineers, but the results commonly lead to multiple and competing interpretations that can be mired in subjectivity. While the application of a statistical technique does not preclude alternative interpretations, the process can be grounded in a more systematic, consistent, and repeatable approach. The core of the zone clustering method is to minimize variability within units while maximizing variability between units which is a statistical expression of the aims of lithostratigraphic and flow unit subdivision.

Depth-constrained clustering

Given a set of log values, depth-constrained cluster analysis segments the sequence into intervals that are as homogeneous as possible and as distinct as possible from each other in terms of their log characteristics. Each of the logs employed is first standardized to zero mean and unit standard deviation before clustering, in order to ensure that they all have approximately equal weight in the analysis. The clustering employs Ward's method, which, at each step of the process, joins the two subintervals that are most alike in a least-squares sense. The process applies the analysis of variance concept of classical statistics, in that it joins the two groups whose merger produces the least possible increase in the total within-groups sum-of-squares. The sum-of-squares for a single group, *k*, is given by :

$$W_k = \sum_{i=1}^{n_k} \left\| \mathbf{x}_i - \bar{\mathbf{x}}_k \right\|^2$$

where the squared distances are between the vector of standardized log values for data point *i*, x_i, and the vector mean x_k for group *k*. The within-groups sum-of-squares, **W**, is the sum of the W_k values over all groups. At each step of the clustering process, the number of groups is reduced by one and the within-groups sum-of-squares increases. Depth-constrained cluster analysis only allows vertically adjacent subintervals to be joined, producing a sequence of zone memberships. By examining a crossplot of the number of zones versus R-square (the percentage of the variance within the zones divided by the total variance of the log values) as a "scree plot", the fundamental subdivisions that account for systematic components of the log variability can be assessed. The depths of these zones establish boundaries that identify stratal units that are either lithostratigraphic or flow unit (or a combination) according to the type(s) of log used as input for zonation. The application of depth-constrained cluster analysis for the zone subdivision of a single log was first described by Gill (1970) who later extended the method to the simultaneous segmentation of multiple well logs (Gill et al., 1993).

The method and its results can be understood in the context of a case study.

Mississippian section case study

Gamma-ray, neutron porosity, density, and photoelectric factor logs are shown for a Mississippian section (Figure 6). Processing of the digital logs was applied to estimate the volumes of dolomite, chert, calcite, shale, and porosity. In a first pass, lithostratigraphic zonation by clustering was made by using dolomite, chert, and calcite, recalculated as proportions of matrix (and so precluding explicit porosity effects) as inputs. The scree plot and slope plot (Figure 7) show a distinctive fourfold major subdivision of the mineral composition profile, with possibly nine systematic elements when zoned at a finer scale. In a second pass, the Mississippian section was zoned using only porosity as input in order to discriminate potential flow unit architecture. The scree and slope plots showed a distinctive tripartite subdivision and nine units at a finer scale. Comparison of the results from the two clustering analysis of lithostratigraphic and flow units of the Mississippian units (Figure 8) show both concordances and differences, with potentially useful implications for geomodels and flow simulations. Although the subdivision is based on clustering driven by variance partitioning, the visual appearance of the result makes geological and engineering sense, rather than a statistical artifact that is at odds with the goals of useful formation subdivision.

Future work

The methodology described here will be applied to the Arbuckle, both for lithostratigraphic zonation and correlation and isolation of mappable flow units. The lithostratigraphy zones will be integrated as correlative information to supplement traditional internal picks keyed to the classical Arbuckle insoluble residue stratigraphy that were extended into the subsurface from the Ozark outcrop. With this aim in mind, zonation will place particular emphasis on gamma-ray logs as shale estimators and neutron – density porosity differences as a proxy for silica content. Zonal discrimination of flow units will be keyed to log porosity volume and porosity partitioning (interparticle, vug, and fracture) from log-computed Archie cementation exponent values.

References

Gill, D., 1970, Application of a statistical zonation method to reservoir evaluation and digitized-log analysis : AAPG Bull., v. 54, no. 5, p. 719 -729.

Gill, D., Shomrony, A., and Fligelman, H., 1993, Numerical zonation of log suites and logfacies recognition by multivariate clustering: AAPG Bull., v. 77, no. 10, p. 1781 - 1791.

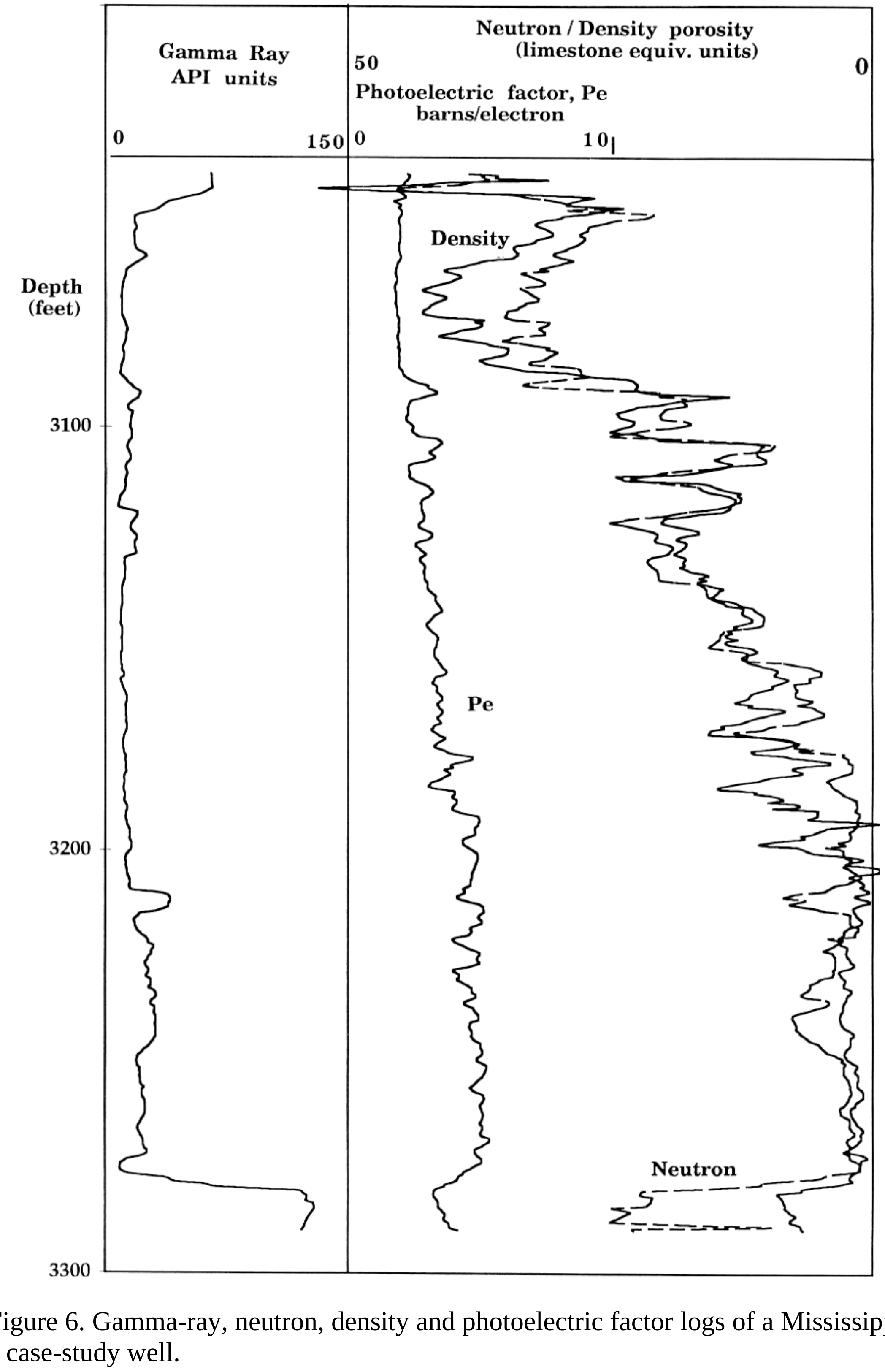


Figure 6. Gamma-ray, neutron, density and photoelectric factor logs of a Mississippian section in a case-study well.

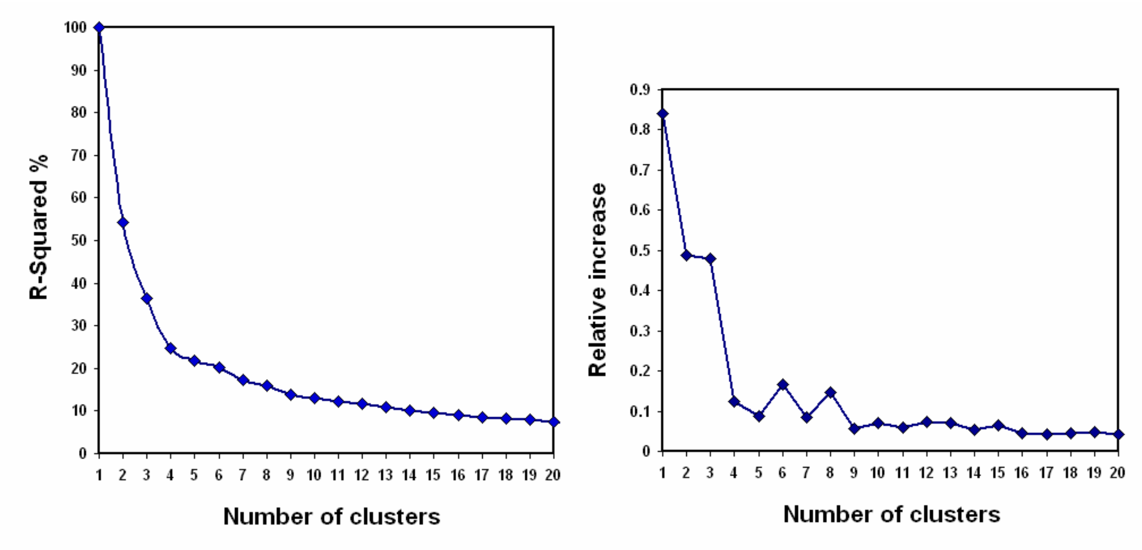


Figure 7. Scree and slope plots of clustered zonation of log-processed volumes of dolomite, chert, and calcite in the Mississippian section.

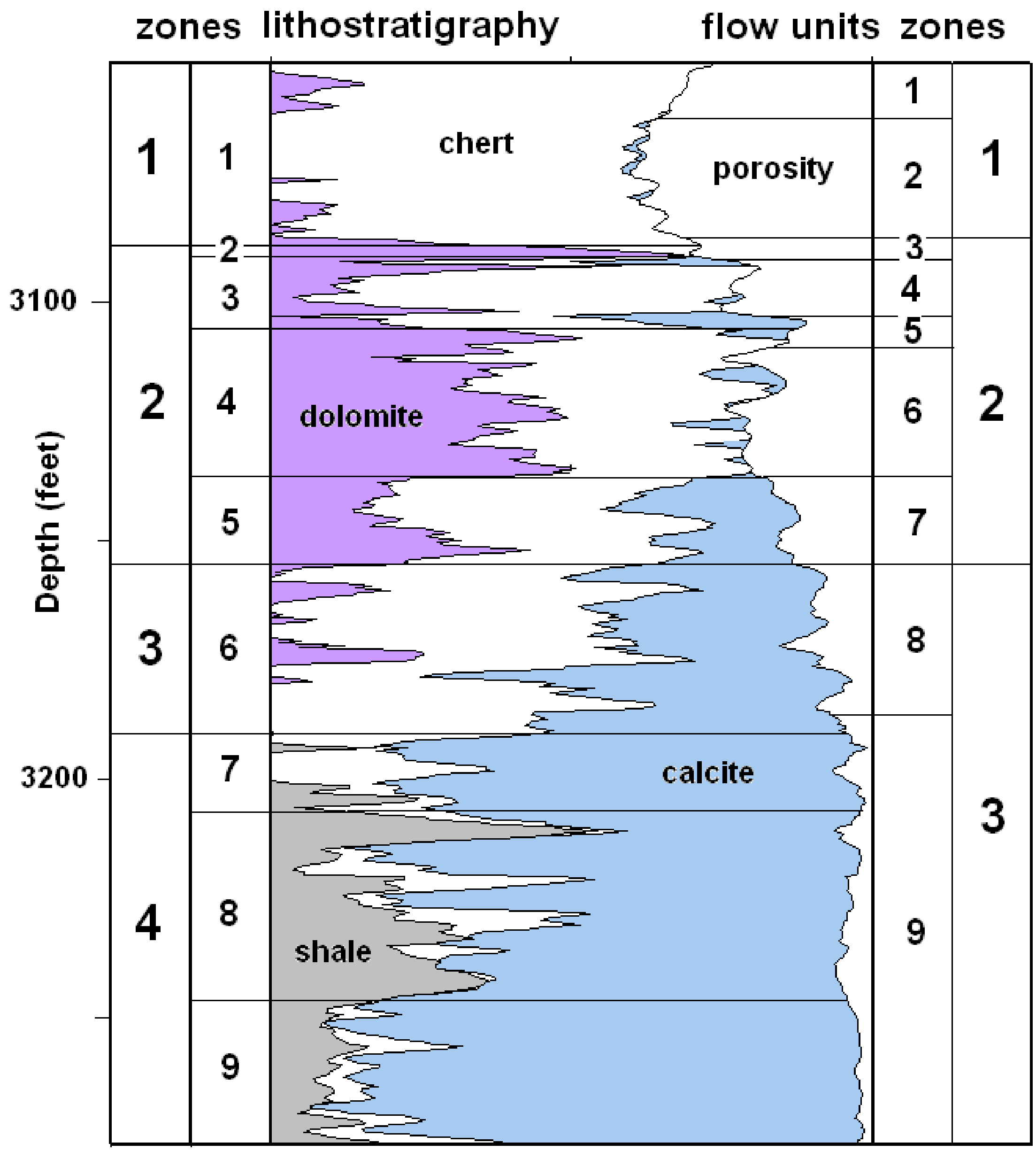


Figure 8. Comparison of nine lithostratigraphic units with nine flow units in Mississippian section estimated from depth-constrained clustering

Subtask 2.4. Subsurface fluid chemistry and flow regime analysis
Contributions by Paul Gerlach and Bittersweet Team.

Analysis of subsurface fluid chemistry and flow regime has been initiated through the examination of the public drill stem test records (Figure 8). Pressure and basic water chemistry have been obtained from 4512 DST records shown in southern Kansas study area (Figure 9). Initial pressure gradient map of Arbuckle shut-in pressures suggests apparent compartments of higher and lower pressure (Figure 10). Estimated formation pressure in the Arbuckle based in elevation of surface exposures of Arbuckle in Missouri (Figure 11) closely approximates the Arbuckle shut-in pressure as suggested by a difference map between these pressures. Differences between hydrostatic head from surface exposure and shut-in pressure are essentially zero (Figure 12). Specific gravity and chlorides increase with depth (Figures 13 and 14). Water resistivity and Ph are also closely linked to depth of Arbuckle (Figures 15 and 16).

Later activities will focus on verifying and validating this DST data. AAPG Abstract on these DST results and preliminary simulation modeling has been accepted for presentation at AAPG Annual Meeting in April 2011. Selected DSTs with ASCII time-pressure being are being used in Horner plot analysis to estimate k*h, k = permeability. Verify salinity measurements obtained from Rwa calculations from well logs.

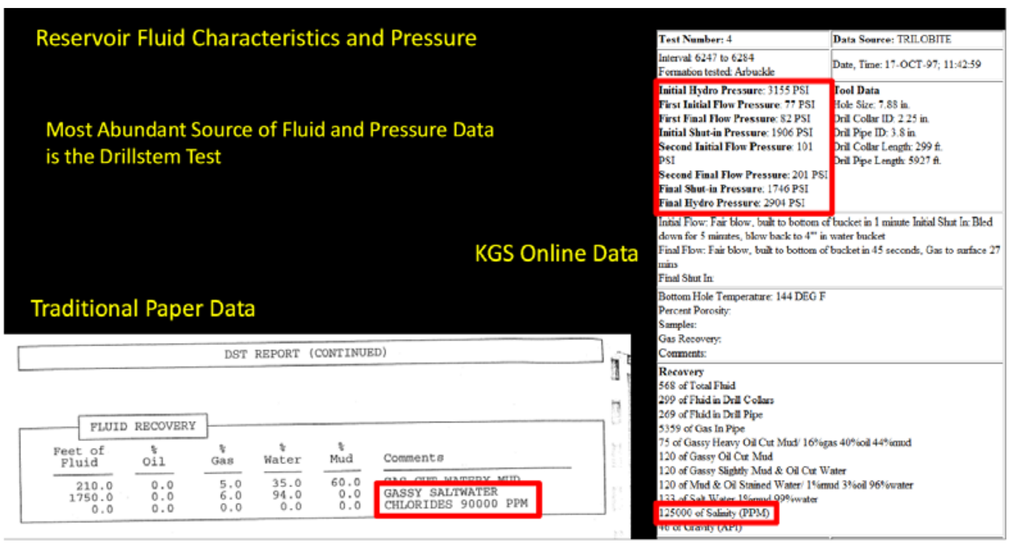


Figure 8. Paper and electronic records of DST measurements.

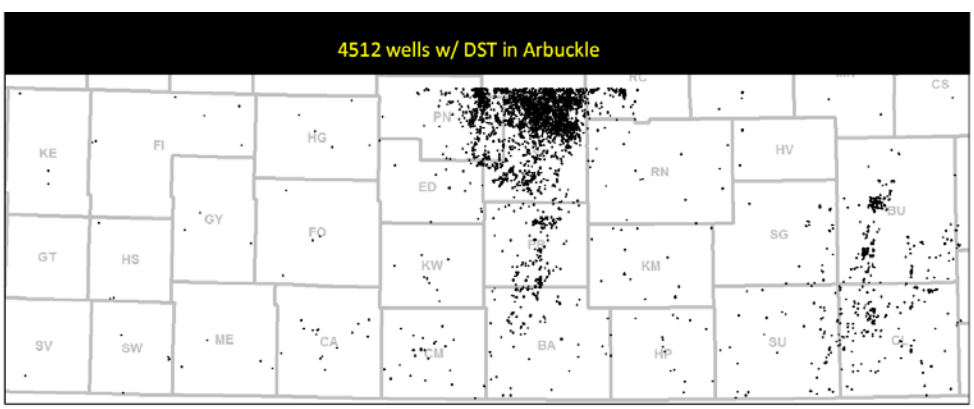


Figure 9. Distribution of wells with DST records.

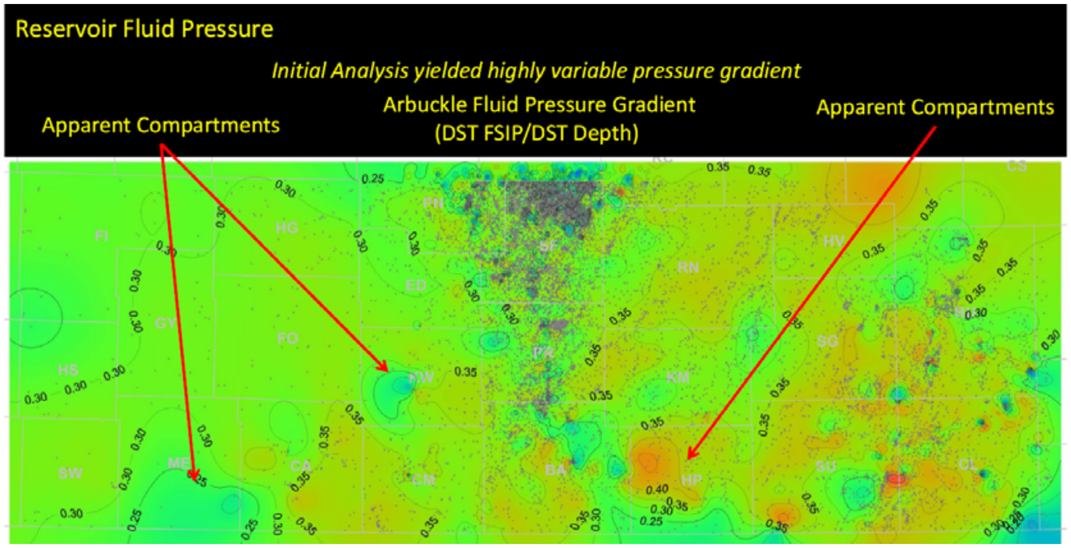


Figure 10. DST final shut-in pressure divided by depth of DST measurement showing apparent anomalies.

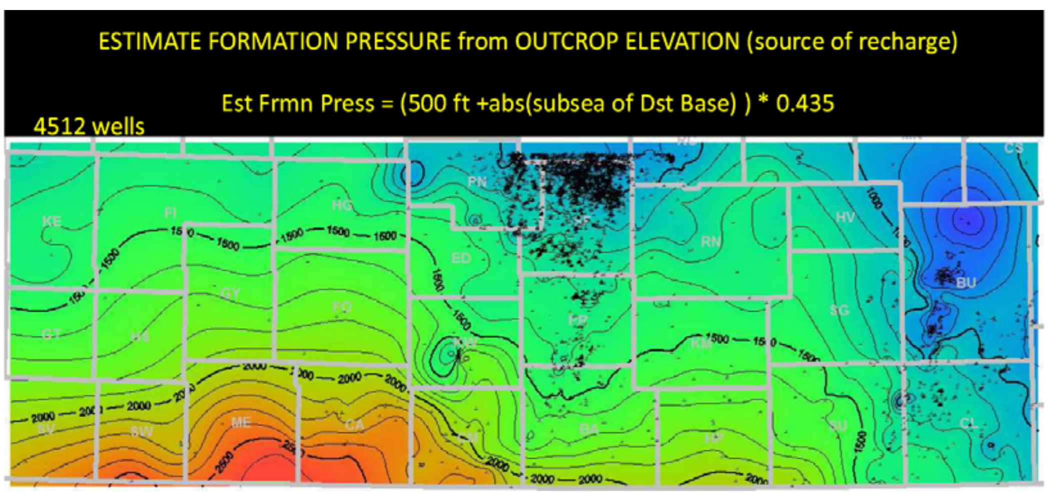


Figure 11. Estimated formation pressures in Arbuckle based on minimum elevation of surface exposures of the Arbuckle Group in Missouri. Hydrostatic head estimated here is proportional to the depth of the DST below the water level defined by elevation of free water level at surface exposure.

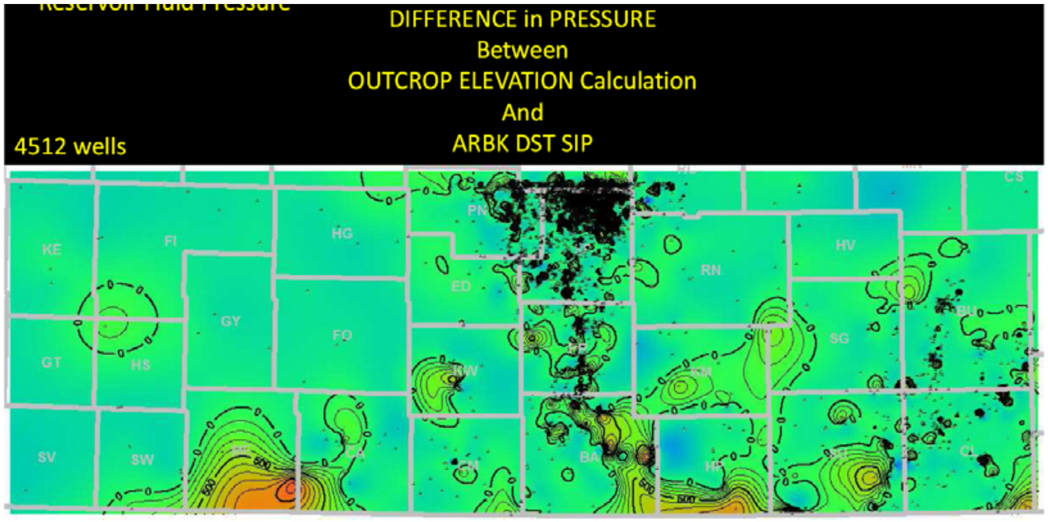


Figure 12. Difference between the pressures estimated from surface exposure of Arbuckle and the Arbuckle shut-in pressures suggest that the subsurface pressure in the Arbuckle is tied to the outcrop.

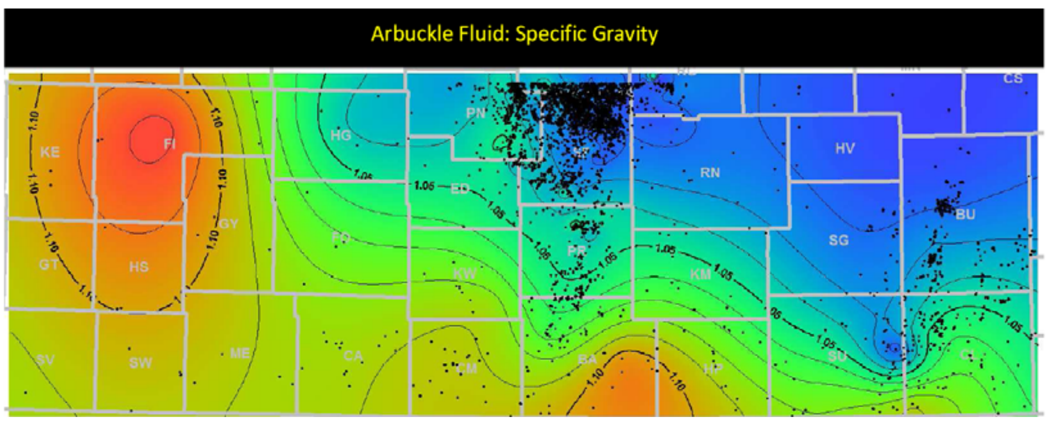


Figure 13. Specific gravity increasing with depth. Fresh water has specific gravity of 1.0 (see Figure 14).

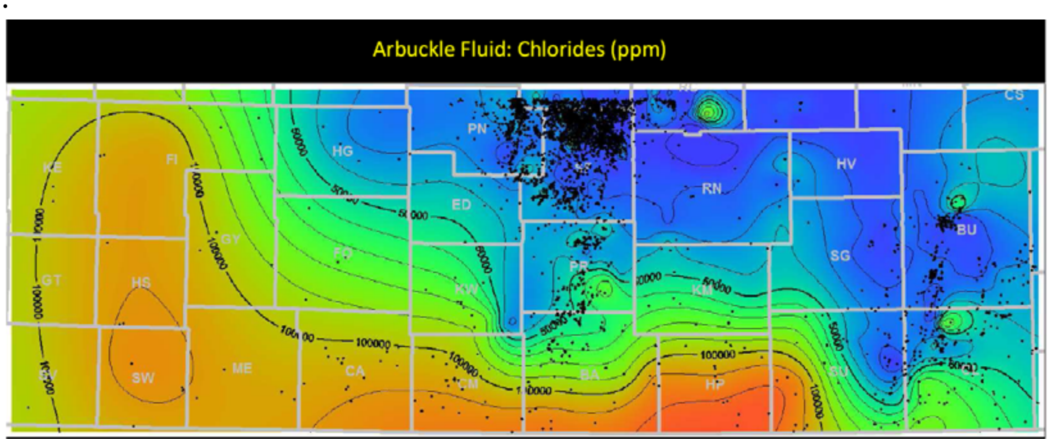


Figure 14. Chloride concentration determined from fluid recovery from Arbuckle DSTs. Chloride concentration increases with depth.

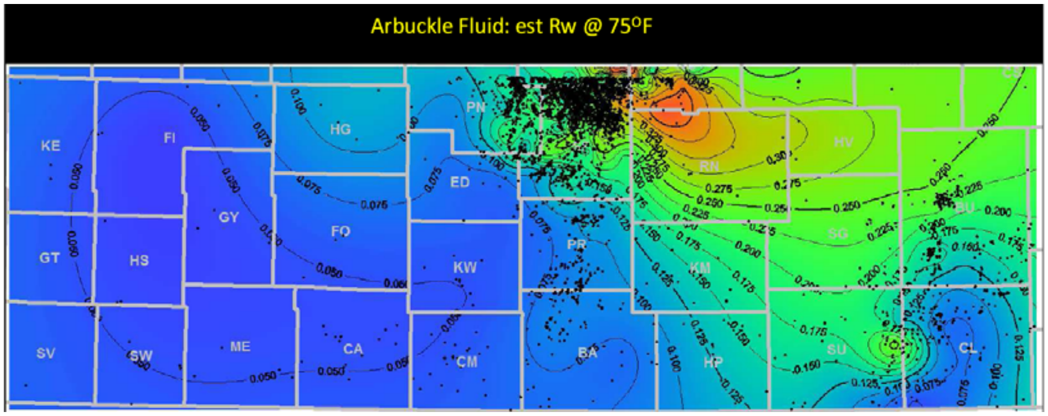


Figure 15. Water resistivity calculated at 75 degrees F decreasing with depth.

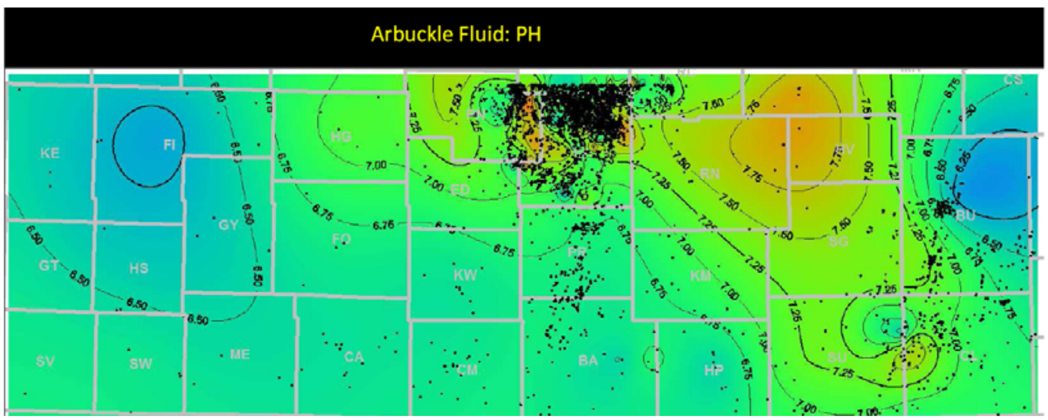


Figure 16. Ph in Arbuckle waters taken from DST measurements.

Subtask 2.5. Gather and interpret KGS's gravity and magnetic data
Contributions by Xia, Baker, Koger, Killion

Gravity and magnetic data have been reprocessed and uploaded to interactive mapper so that these data can be integrated with the remote sensing and subsurface mapping (Figure 16). Regional patterns will be interpreted and local scale information will be used to aid in geomodel development.

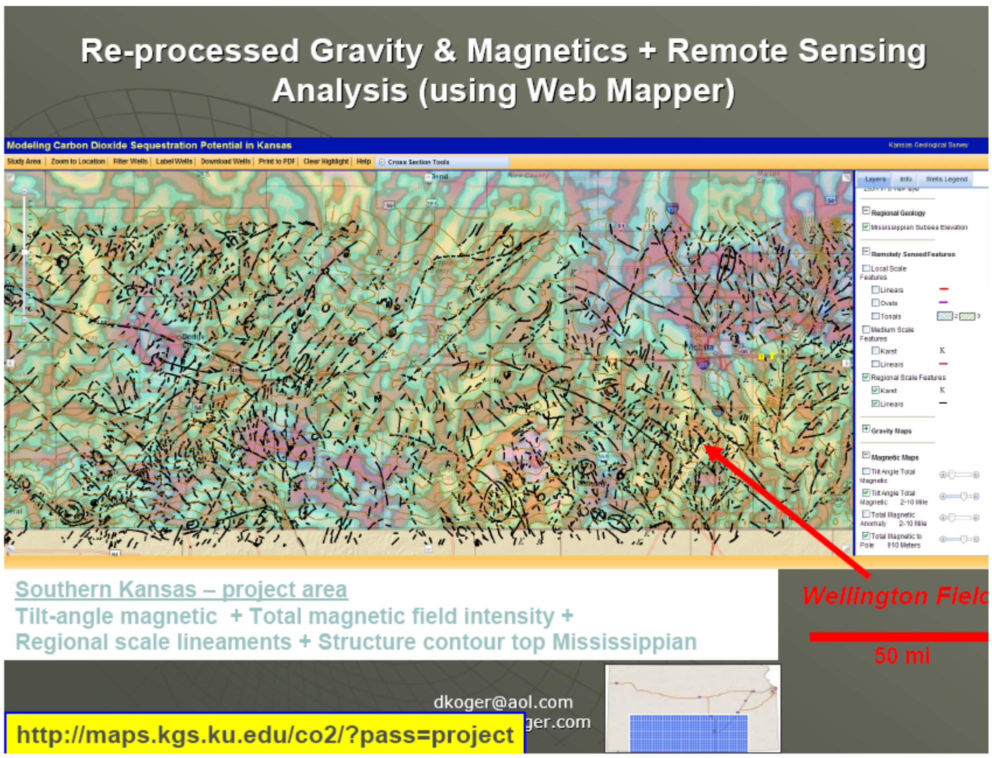


Figure 16. Combined lineaments from remote sensing analysis (dark lines) and reprocessed magnetic including tilt angle (colored linear trends) and total magnetic field intensity (broad areas of tonal color change). Note regional scale.

Subtask 2.8. Analyze water samples from Well #1 (KGS - 1-32) – Identify reactive pathways and reaction constants

Update by Robin Barker and Dr. Saugata Datta, Kansas State University.

The main theme of this research is to model the effects of selected minerals present in the aquifer on CO2 injectivity and short- and long-term fate of the CO2 as CO2 reacts with the brine and minerals. Key reactions will be retrieved and eventually used as input in the simulations of CO2 injection.

Activities include:

- Collect and analyze formation waters at certain depths
- Major elements, cations, anions, trace metals (23), salinity, dissolved oxygen, pH, alkalinity, specific conductivity, redox potential, temperature, total dissolved solids, etc
- Collect well cuttings and core chips as drilling progresses
- Describe mineralogy (a complete depth profile) of formation cores
- Thin section petrography to study textural relation, SEM-EDX, X-Ray Diffraction
- Perform flow-through lab experiments with core plugs and well cuttings to determine reaction pathways and kinetics
- Batch experiments, flow-cell experiments, pressure experiments
- Apply datasets to geochemical models for long time scales
- Geochemists' Workbench (GWB)
- 1000/18000 year time frames

Sample types:

- DST waters
- Formation waters
- Well Cuttings
- Core chips
- Core plugs

Water Sampling:

- Drill Stem test waters are collected for chemical analysis (anions and major and trace elements).

Water Sampling

Water will be collected from the joint breaks (during 1st DST) in 5 gal buckets before being transferred into sample containers

- 250 mL HDPE Nalgene bottles (2)
- 125 mL HDPE Amber Nalgene bottles (2)
- 50 mL centrifuge tubes (2)
- 125 mL glass jars (2)
- 2 gallon HDPE Nalgene jugs (1)
- Water will be stored cold at KSU Geochemistry Lab

Filtration and Acidification will be done based on type of analysis.

Further connate water collection will be done once the well is completed, cased and perforated

- Swabbing will allow the collection of connate waters that we will the flow cell experiments.
- HACH Hydrolab will provide in-situ water quality and parameter characterization, time reaching equilibrium (constant pH, Sp Conductance etc.)

Well Cuttings Sampling

- Well cuttings will be collected at 10 foot intervals.
- Every 50 feet an anaerobic sample is collected in a Remel bag (O_2 impermeable), flushed with nitrogen and stored in dry ice.

Core Chip Sampling

- Small chips are collected from the core sections and stored in an anaerobic environment, flushed with nitrogen and stored cold
- Important as a control against potential chemical alteration during further handling (oxidation, perm tests with saline water, etc).

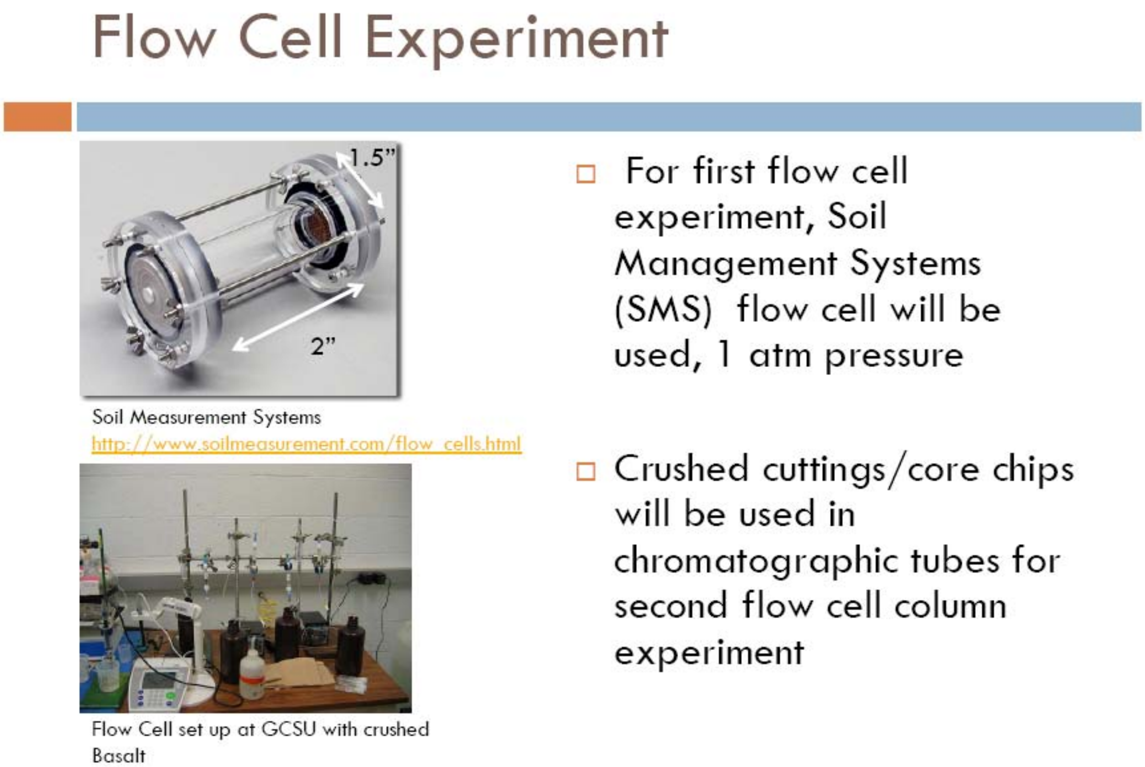
Core Plug Sampling

- Core plugs will be taken from Weatherford Labs in Houston, TX
- Cores will be used in flow experiments
- Part of core plug will be used for detailed mineralogy (depth profile)

Flow Cell Experiment

- Aim: Flow natural brine waters and CO_2 through a formation core to create a dataset that will be used to model and characterize the chemical reactions (water-CO_2-rock interactions).
- Phase 1: In-situ ground water only
- Establish equilibrium
- Phase 2: Brine and CO_2
- Monitor mineralogy of cores before and after flow experiment
- Phase 3: Conduct flow experiments at formation pressure, if possible with NETL ORISE Internship
- Phase 4: Feed geochemical data from Geochemists' Work Bench into Generalised Equation of State Model Reservoir Simulator –GEM (P.I. Bhattacharyya)– essential information: CO_2 solubility parameters, changes with mole fraction of CO_2 in water with time (time series experiments), mineral precipitation

Water Analysis



Water samples will be analyzed for cations, using Dionex ICS 5000 Capillary Reagent-Free Chromatographic System (RFIC) with Eluent Generation Major elements and trace elements will be analyzed high resolution (magnetic sector) inductively coupled plasma mass spectrometry (HR-ICP-MS, Finnigan ELEMENT 2). With results we will determine ionic strength, coefficient of ions in aqueous phases, potential solubility, CO2 mineralization reactions etc.

Geochemical Modeling

- Data sets created through experiments will be used to create long term models for reaction kinetics
- The Geochemists' Workbench software and PHREEQC models will be employed to determine reactive pathways to mineralize CO2
- For example: Ca, Mg and Fe pathways
- Setting up a 3D flow geochemical coupling at 1000/18000 year time scales {short and long term mineral reactions}
- The four main geochemical parameters to be modeled will be (1) major reactive pathways,(2) in situ reaction mechanism/degree of reaction, (3) determination of rate constants and (4) relation of reaction to characteristic surface area (solid core vs crushed core chips).
- measured or calculated under specific pressure, temperature and salinity

Current Progress

- Drilling and coring of KGS-1-32 is underway
- On-site sample collection
- DST water
- Core chips
- Well cuttings
- Will continue until well is completed and cased
- Connate water collection phase begins

WELLINGTON FIELD STUDY, SUMNER COUNTY, KS

ONGOING & COMPLETED ACTIVITIES concerning Wellington Field, Sumner County, KS: 1) finish compiling well/lease production history; 2) finalizing P-wave interpretation, 3) identified locations of test boreholes 1 & 2 using log and seismic derived maps and cross sections including depth, isopachous, amplitude, and volumetric curvature; 4) spudded test borehole #1 (KGS 32-1) in Wellington Field, 5) organized stakeholder meeting at the city of Wellington as part of public outreach.

Subtask 3.1. Collect geologic & engineering data.

Subtask 3.5. Interpret seismic, gravity, and magnetic data.

Seismic interpretation is being conducted by Hedke-Saegner Geoscience, Ltd, Jason Rush at KGS, Berexco and Susan Nissen, Geophysical consultant in collaboration with Geotextures, Inc., and Dr. Raef and student, Derek Ohl, at Kansas State University. Below is the latest information from the subcontract with Kansas State University pertaining to seismic interpretation. Their research emphasis is on seismic attributes and modeling, which is designed to compliment other interpretations.

Rock formation characterization: Seismic Attributes Analysis and Seismic Modeling

By: Abdelmoneam Raef & Derek Ohl, Kansas State University

Summary

Our approach of rock formation characterization based on 3D seismic attributes analysis of the Arbuckle Formation relies on first calibrating and validation key attributes anomalies associated with rock property changes, or structural disturbance, and/or litho-facies variation. This endeavor would be better established for the main capping rock-formations, e.g., Mississippian formation, where ample geophysical and petrophysical well-logs and production data is available. The fact that cap-rocks overlying Arbuckle rock formation and the saline-aquifer Arbuckle formation itself share the same geological setting, makes it possible to have an established seismic attributes validation and calibration, which can be very beneficial to characterizing the Arbuckle formation. In this report we cover some of the ongoing research in support of identifying and understanding key seismic attributes.

The suggestion of new-drilling locations has not been with the aim of optimum hydrocarbon recovery but was with the aim of better characterization of Arbuckle formation and its cap-rocks. Drilling the first well is currently on progress and the planed coring and well-logging would help understand a coherency anomaly and to a lesser extent amplitude anomaly that seems to be either a litho-facies anomaly (channel fill) or sub-seismic resolution faulting; either possibility carry

paramount significance when attempting flow-simulation for CO_2 if similar features are present in the potential sequestration target. A finite difference modeling study is underway to examine potential of various seismic attributes in discriminating the aforementioned possibilities. We have been comparing porosity logs for the Mississippian to compare sense of variability with seismic amplitude variation to qualitatively assign more or less weight to seismic amplitude anomalies in relation to changes within the Mississippian. This comparison would be beneficial when analyzing amplitude anomalies of the Arbuckle.

Since the meeting in late September, we have been working diligently on getting the new Fairfield (seismic processor) data set up. Currently we have the seismic synthetics created, horizons picked, some well logs plotted for intervals of interest, and coherency attributes analyzed. We were very pleased to see that our horizons were very good match to the ones presented at the meeting in late September. We have also been trying to determine the cause of the amplitude anomaly that is present.

Our future analyses would focus on extrapolating lessons learned from characterizing the Mississippian to our endeavor of identifying main controlling rock properties and stratigraphic and structural features of the Arbuckle formation, bearing in mind that minor stratigraphic and structural features that might be insignificant for hydrocarbon field development could turn out to be of paramount importance –due to the high mobility and relative permeability of CO_2– in rock formation characterization for geological carbon sequestration. It is also important for our future analyses to explore seismic spectral sub-bands in litho-facies and structural mapping to enable a comprehensive mapping and detection in rock formation characterization.

Seismic attributes analysis

Amplitude Anomalies

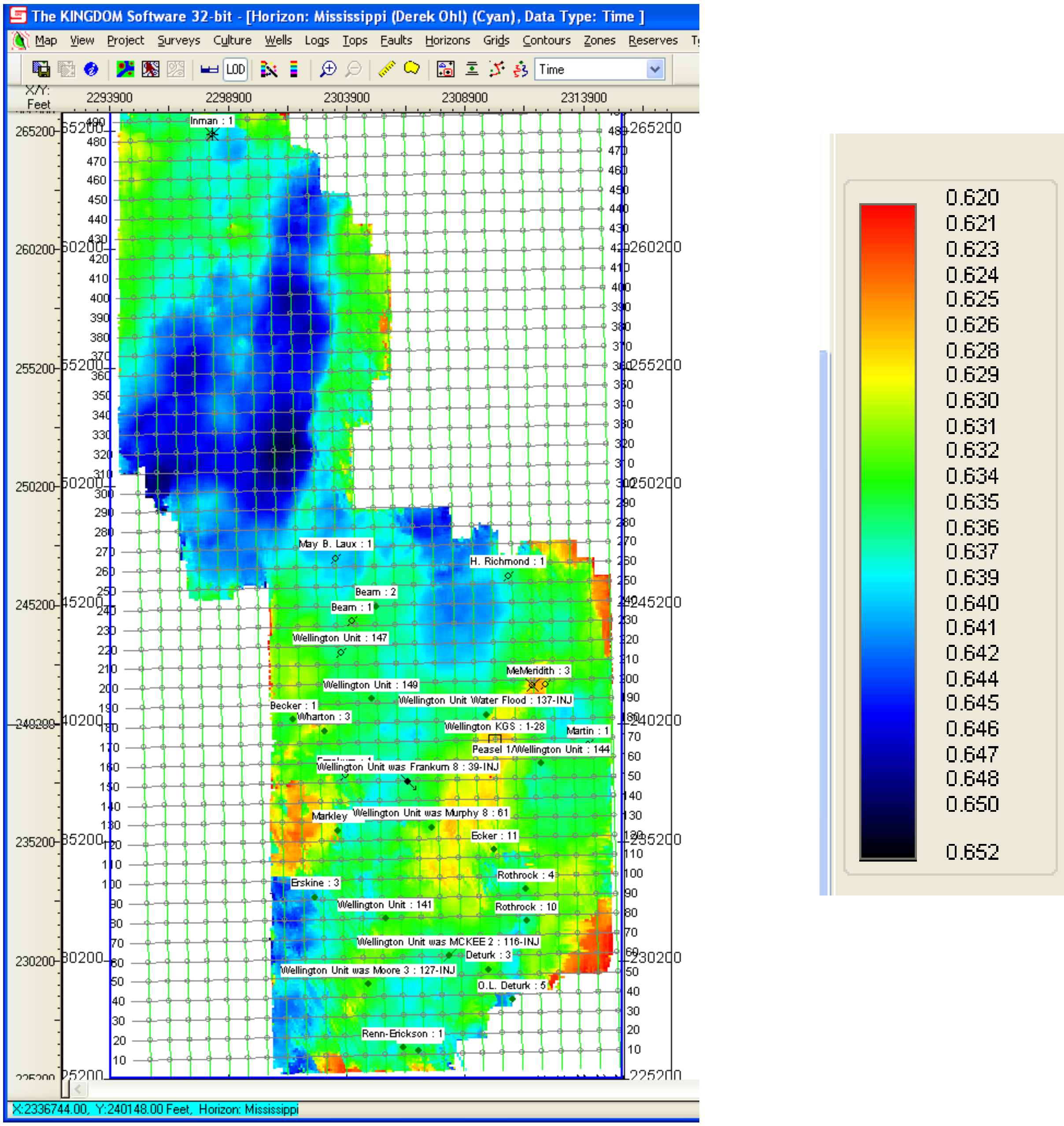


Figure 17. Structural time map with no evident and coherent anomaly in match to the coherency and amplitude anomalies anomalies shown below; below-temporal resolution faulting/folding will not cause temporal anomaly.

Understanding amplitude anomalies are very important to our study and can result from a number of petrophysical, lithofacies, and/or structural scenarios. For example, we are in the process of determining if an amplitude and coherency anomalies are results of channel fill, small scale faulting, change in lithofacies. If the amplitude anomaly is due to a channel fill this could be a major pathway for the CO_2 to migrate along and should not go unnoticed. This amplitude feature could end up hurting the CO_2 modeling and simulation if not accounted for.

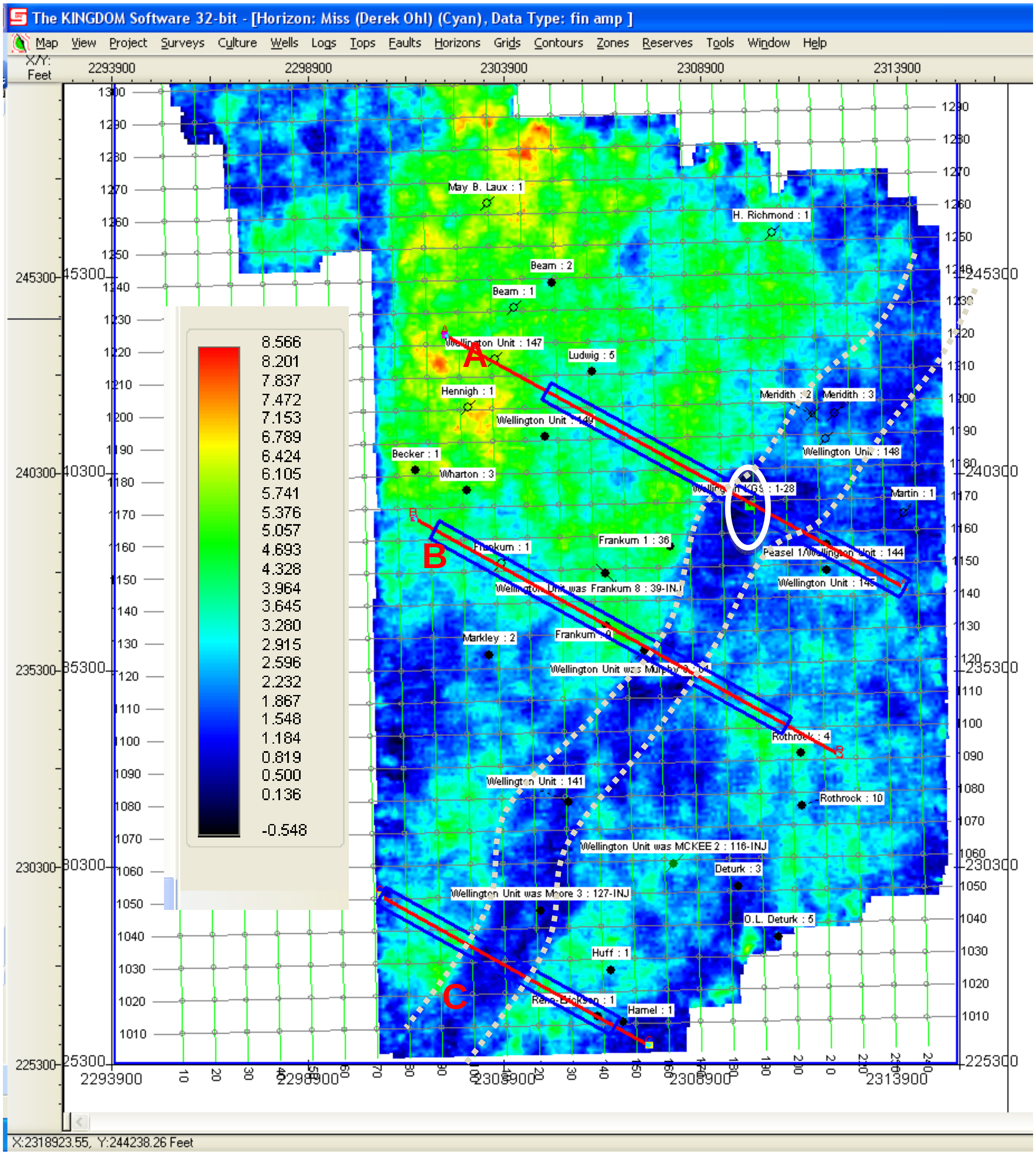


Figure 18. Mississippian horizon (amplitude from Echo) shows the location of three cross-sections running through the amplitude anomaly. The white circle along cross-section A shows the location of the new well that is being drilled.

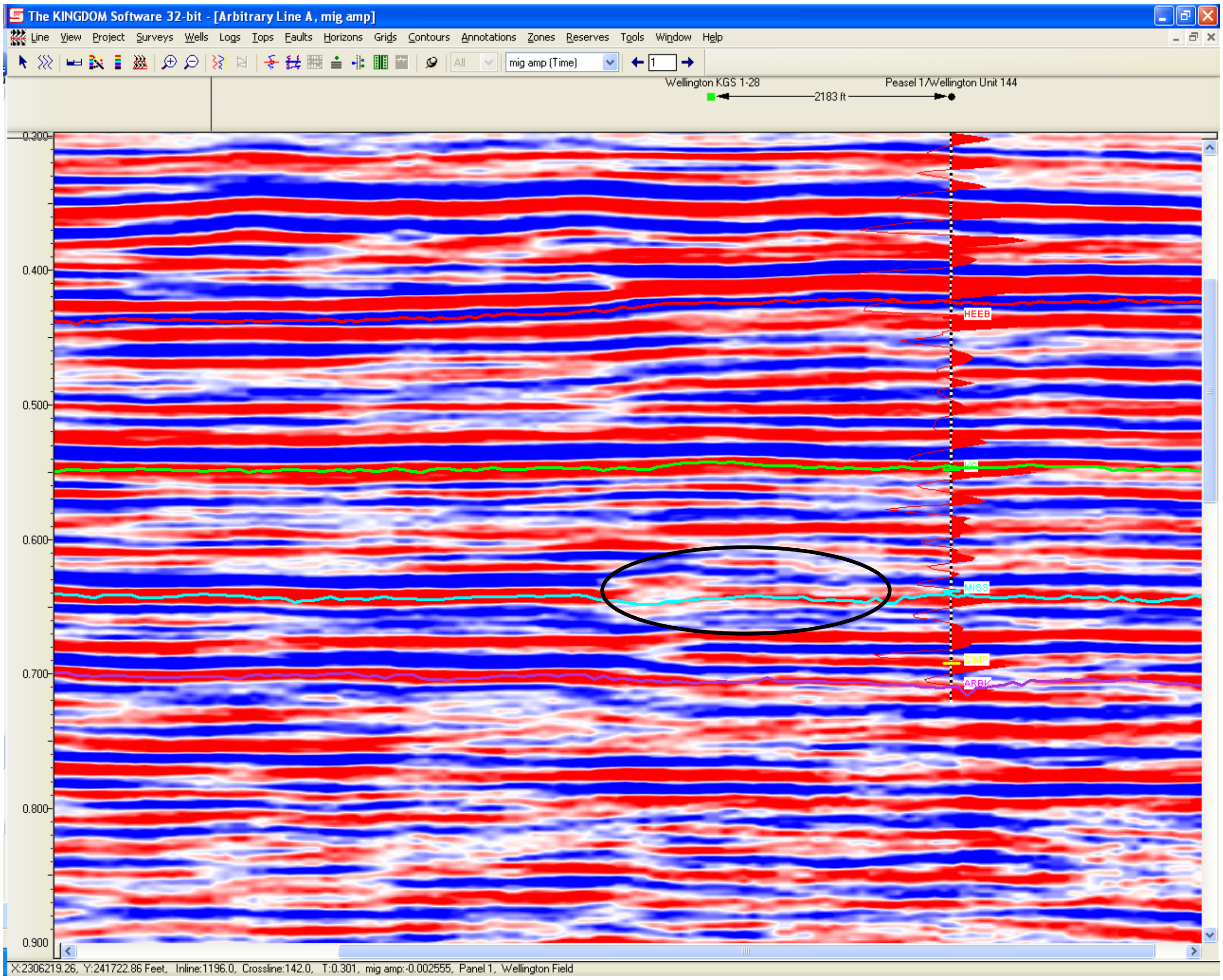


Figure 19. Cross-section A showing the amplitude anomaly circled in black.

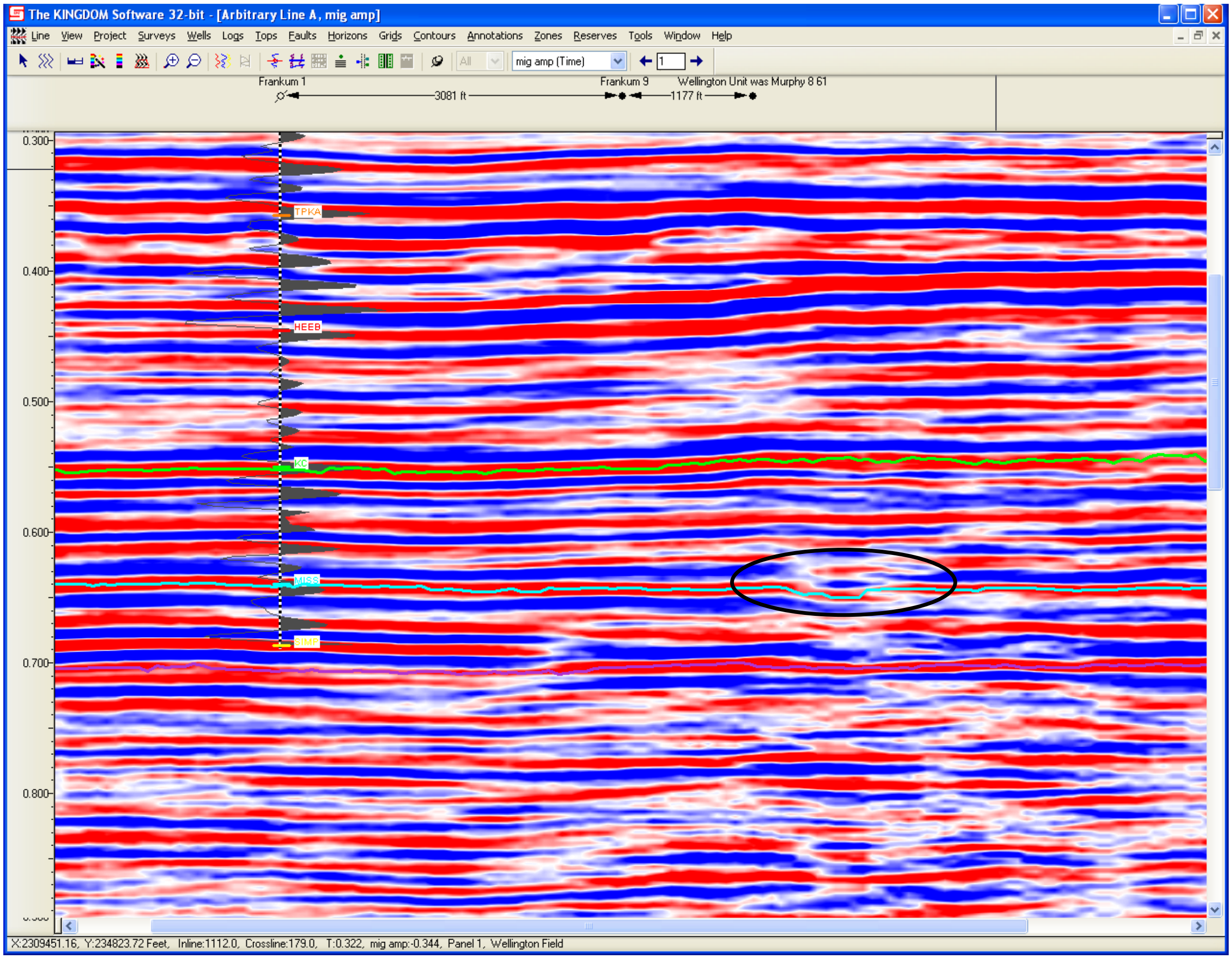


Figure 20. Cross-section B showing the amplitude anomaly circled in black.

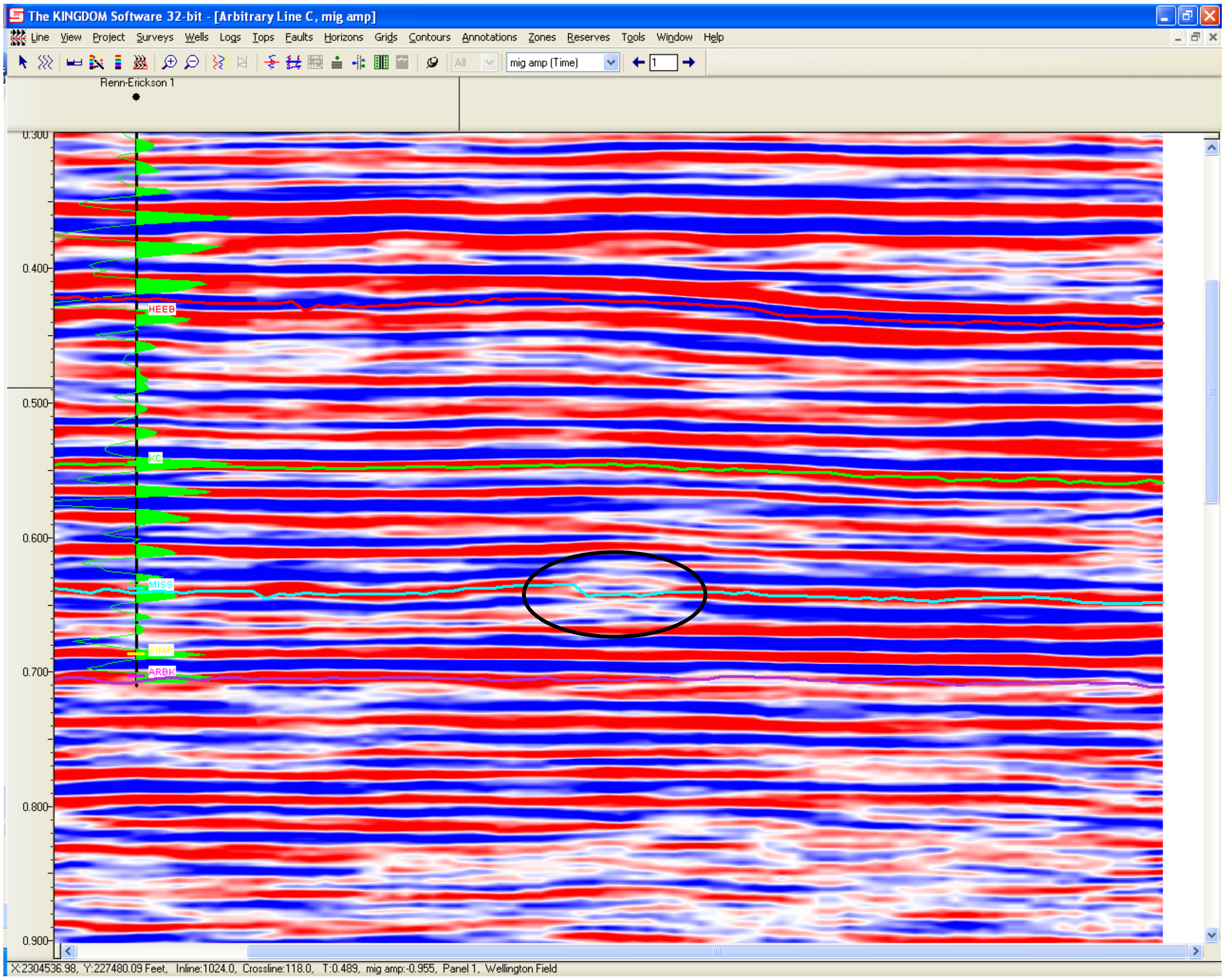


Figure 21. Cross-Section C showing the amplitude anomaly circled in black.

Coherency:

Coherency was run over the top of the Mississippi horizon for both data sets and the results came back fairly similar. As you can see in the following two images, the coherency shows the amplitude anomaly very well in both data sets. While the Fairfield data is not as intense as the Echo data, the anomaly is still present.

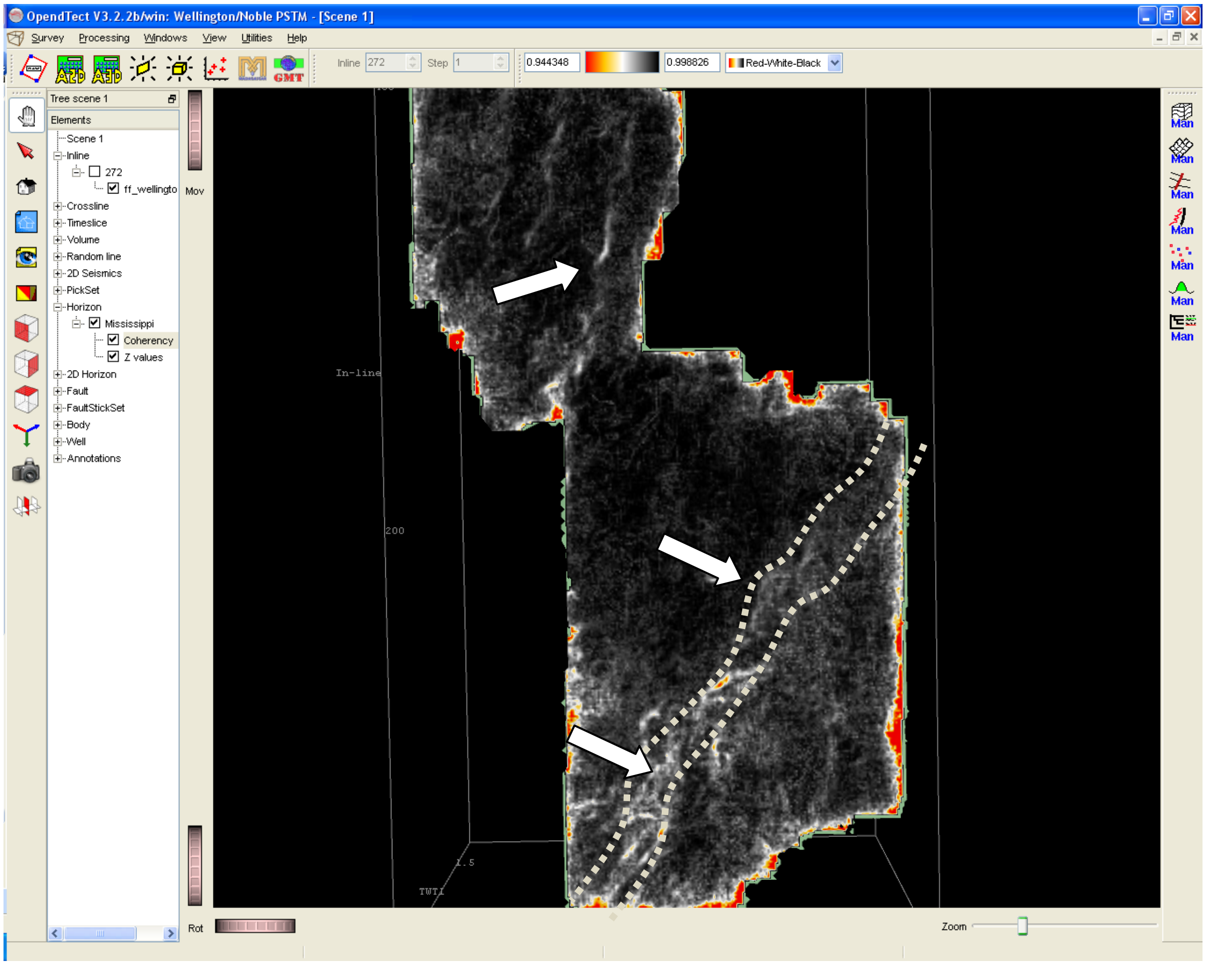


Figure 22. Mississippian horizon (Fairfield processing) with coherency attribute extracted along the top of it.

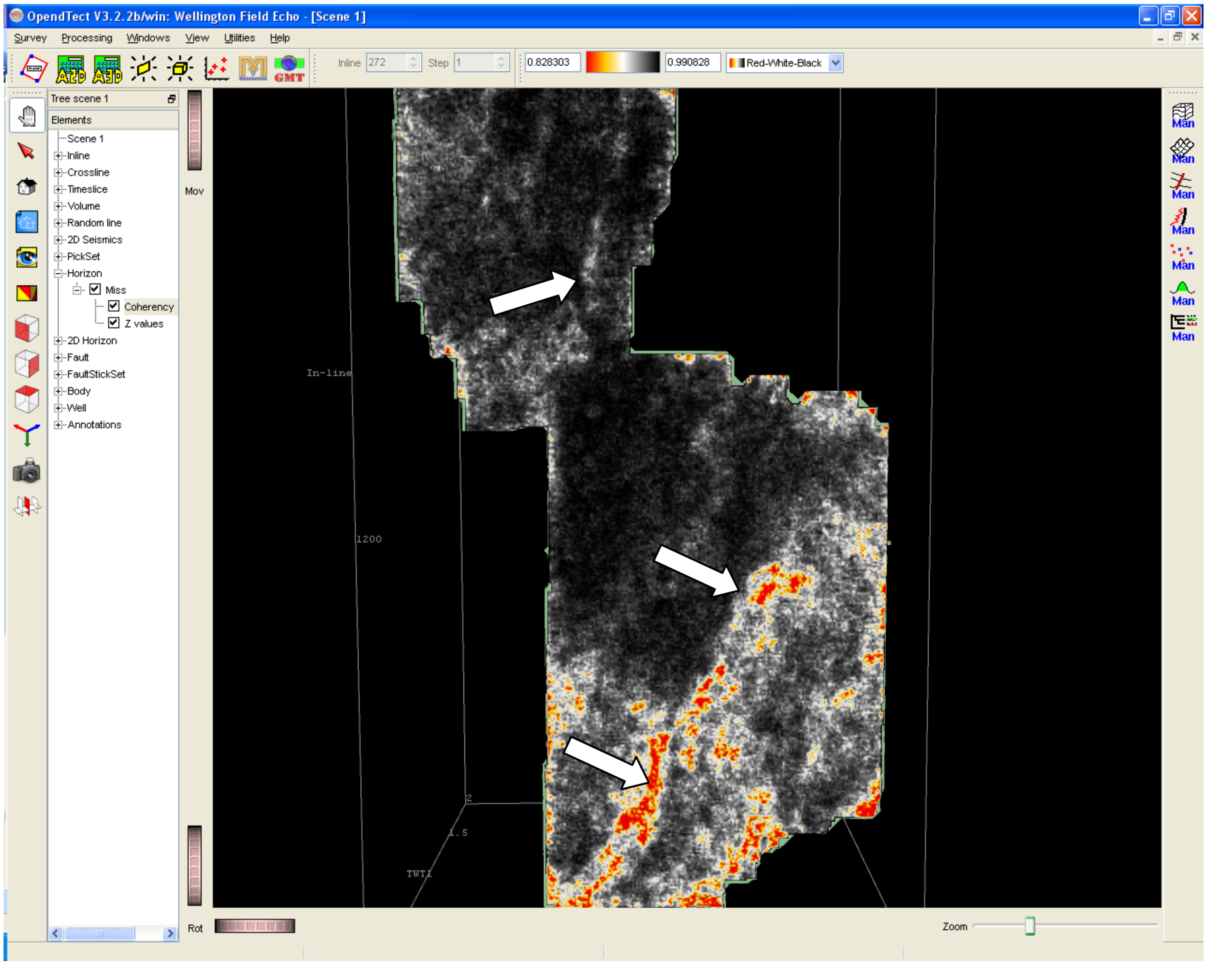


Figure 23. Mississippian horizon (Echo processing) with coherency extracted along the top of it.

Amplitude and porosity

Degree of correlation of seismic amplitudes to porosities (figure below) has been explored using average well-log porosities from well-log and extracted seismic amplitude at the interpreted Mississippian horizon at well locations. Average neutron porosities showed higher correlation coefficient of 0.6 to amplitudes than that of 0.4 for correlation coefficient with density porosities. The consistency of this correlation is likely to enable empirical relationship that can aid predicting porosities based on seismic amplitude attributes. Further analyses are underway to assess the robustness of this approach for application to the underlying Arbuckle if similar setting as to acoustic properties could be established. The multitude of factors that might affect seismic amplitudes renders predicting porosities a less than straightforward undertaking. Validation of any empirical relationship is an essential part of establishing a trustworthy prediction approach.

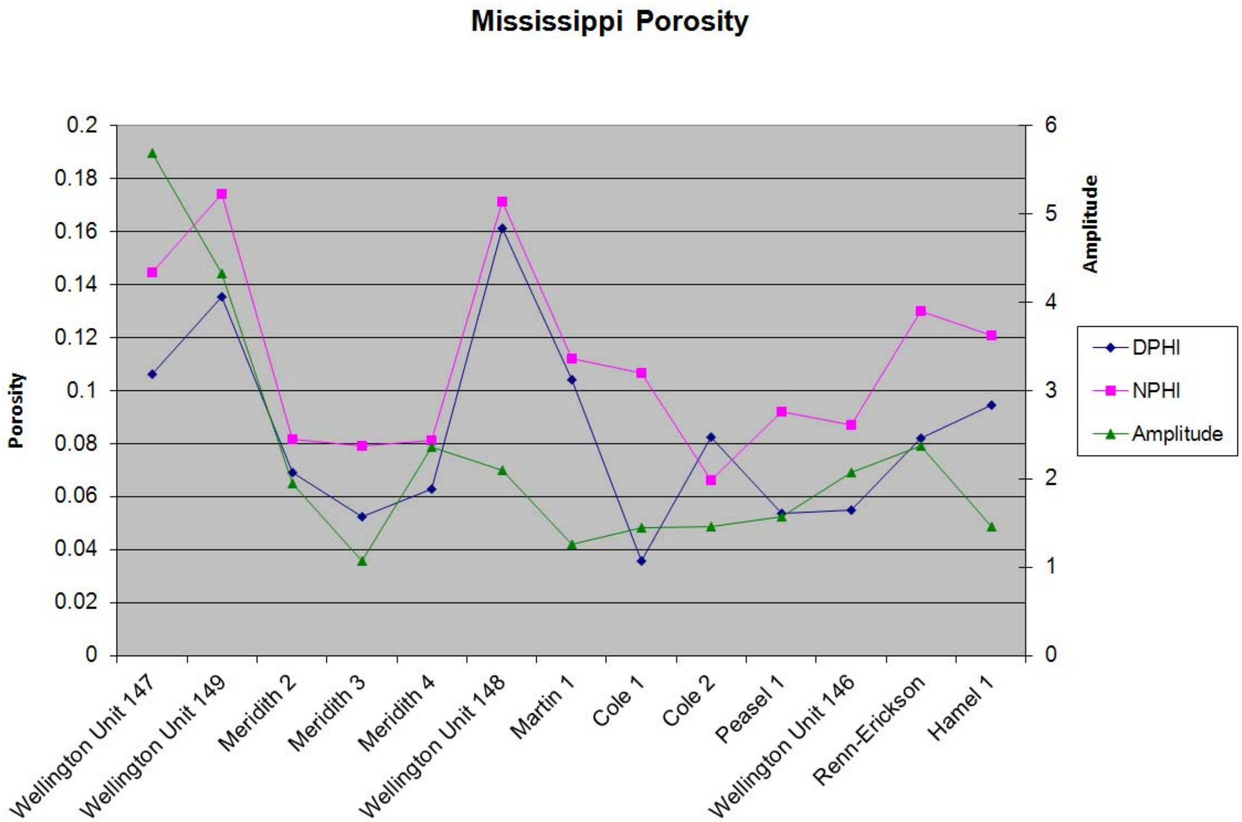


Figure 24. Porosity prediction form amplitude compared to neutron-density porosity logs in Wellington Field.

Finite Difference Modeling

We are also preparing to start Finite Difference Modeling. This will allow us to understand what is happening to seismic waves and their amplitudes when they encounter such things as; channel fills or small-scale faults. In this modeling we will use the velocities from the new sonic log, which will be run within a month or so. Using this sonic log will give us the most up to date information, which we can then compare back to the core samples if necessary. With the results of the Finite Difference Modeling we will better understand seismic attributes that we plan to run in the near future.

This modeling endeavor is likely to help focus future spectral decomposition on spectral sub-bands that best help detecting and/or enhancing subtle feature that might be of paramount significance to better control flow simulation models for geological carbon sequestration. A large number of spectral sub-bands would be explored and compared for best results of rock formation characterization. Wavelet-transform and multi-image fusion is going to be elemental part of our future utilization of spectral analysis and seismic modeling results.

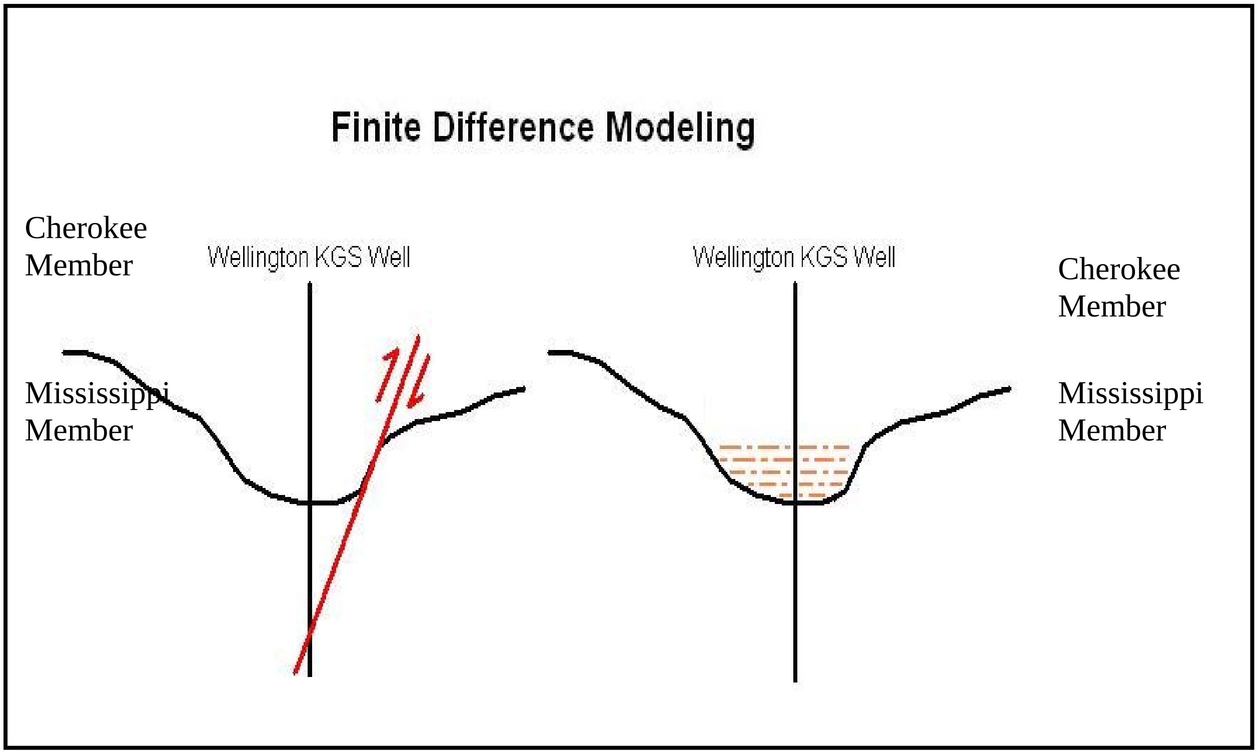


Figure 25. Finite difference modeling options.

Drilling Well Wellington KGS # 1-32:

We are very excited and patiently waiting to receive the data from the new well that is actively being drilled. We are so excited for these new well results because it is being drilled right through the middle of this amplitude anomaly and will hopefully direct us to a certain cause. We are also looking forward to receiving the sonic log from the new well so we can double check our Arbuckle top before we begin characterizing that part of the formation.

Subtask 3.5. Interpret seismic, gravity, and magnetic data (continued).

Initial integration of Magnetic, Gravity, and Remote Sensing Information

Contributions by Jianghai Xia, Dave Koger, Ralph Baker, Mike Killion.

Gravity, magnetics, and remote sensing information have been integrated on the project's interactive map viewer as shown in the following four figures (Figures 27-29). These examples show the rescaling of the map as area as user "zooms in" to Wellington Field to observe lineaments and mag-gravity variations.

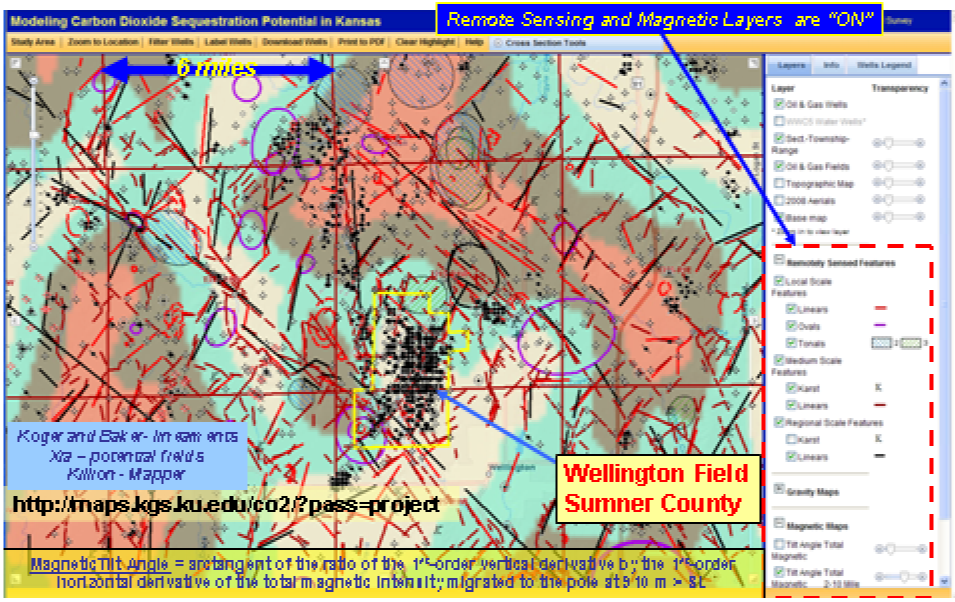


Figure 27. Tilt angle magnetic centered over Wellington Field showing township squares, each 6 miles across.

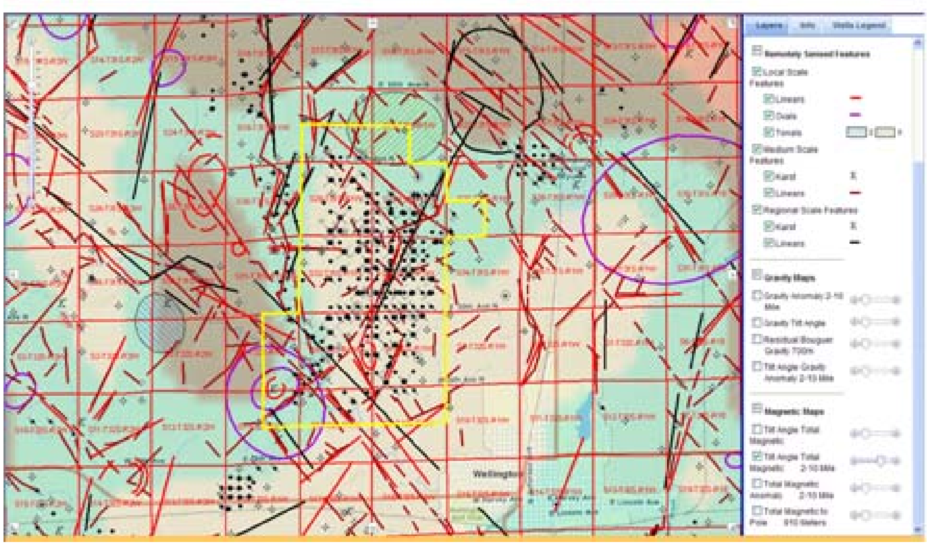


Figure 28. Zoomed in version of Figure 27 showing one-mile section squares.

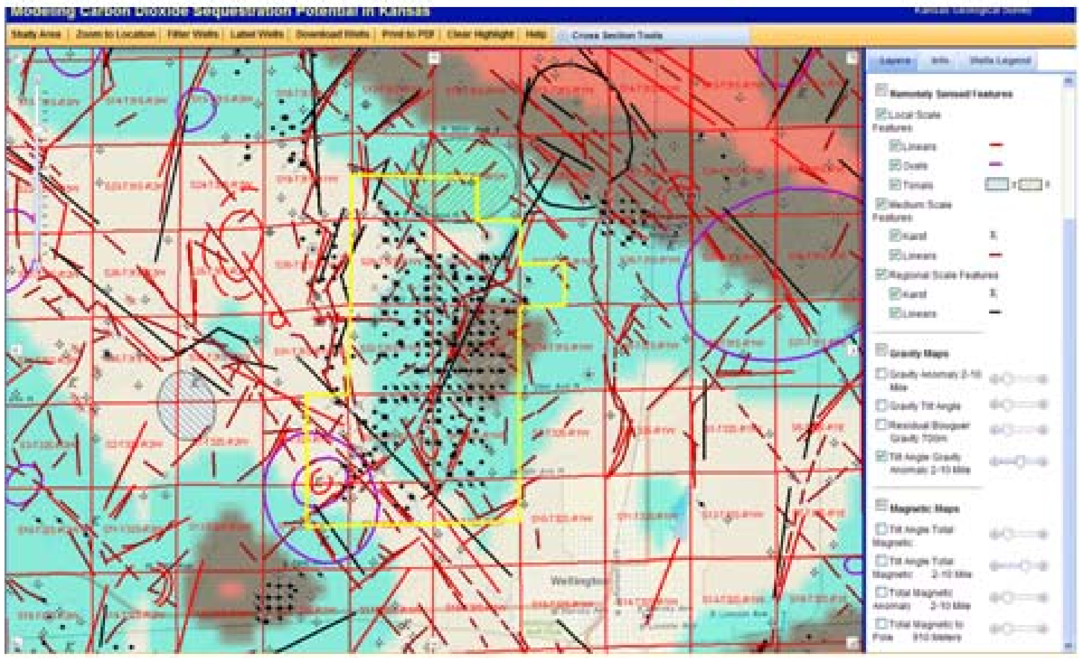


Figure 29. Tilt angle for gravity in same area and scale as Figure 28, generated by clicking off magnetic and selecting gravity.

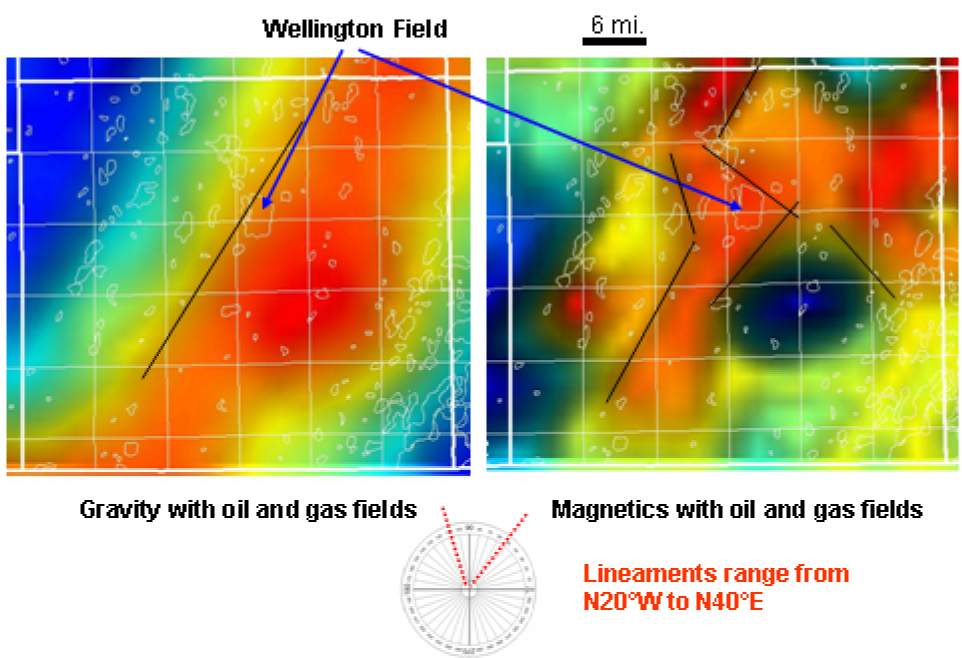


Figure 30. For comparison, entire Sumner County is shown with – **(Left side)** Bouguer anomaly gridded with a two-pass, 8-directional gridding algorithm. A second-order polynomial surface was calculated to remove a regional westward decrease in gravity values caused in part by thickening of the crust resulting in second-order residual grid as shown. (**Right side**) Total

magnetic field intensity reduced to the pole using inclination of 65 degrees and declination of 7 degrees. (Kruger, Open-file Rept. 96-51).

Subtask 3.6. Initial geomodels.

Includes contributions by Jason Rush.

Works continues toward building a quantitative geomodel of the Mississippian reservoir and the deep saline Arbuckle aquifer in Wellington Field. Initial mapping of structure is shown in Figure 31. Lineaments are hand drawn and appear to delimit separate structural blocks for the Wellington and Anson-Bates Fields to the north. Mississippian chert-dolomite reservoir lies along a basal Pennsylvanian unconformity. Mapping has now extended to pay and porosity (Figures 32-33). New production data has been found that will help to refine the geomodeling and lead to better simulations.

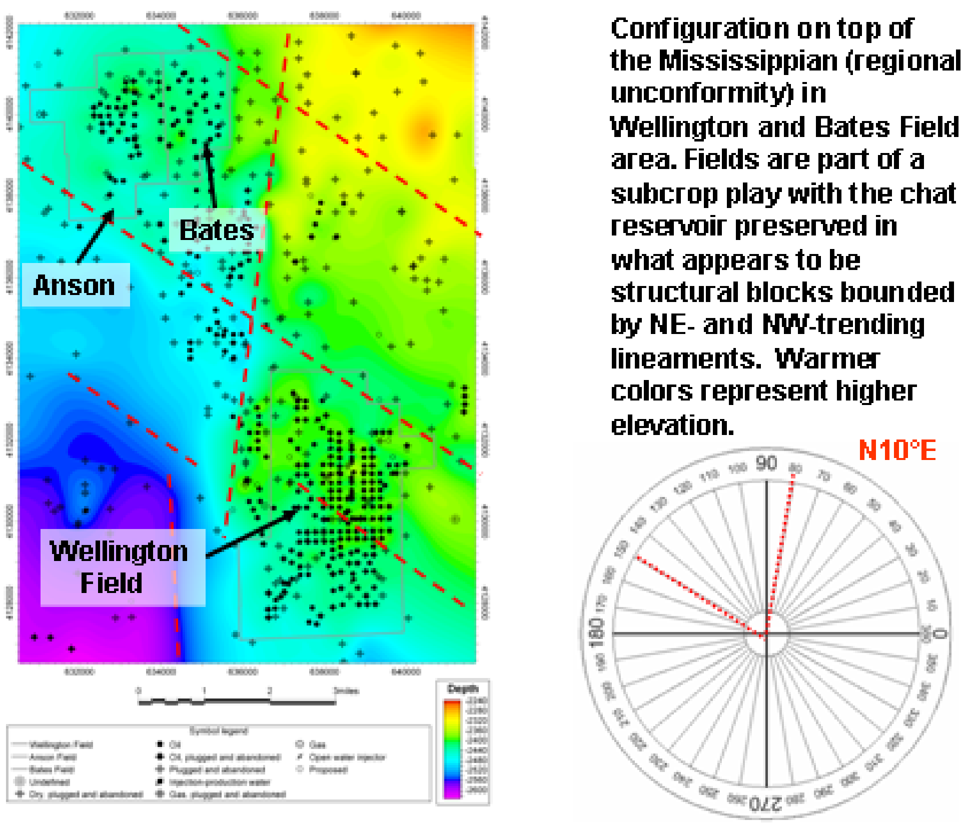


Figure 31. Structural configuration on top of the Mississippian in the Wellington Field area with hand-drawn lineaments. Warm colors are higher elevation.

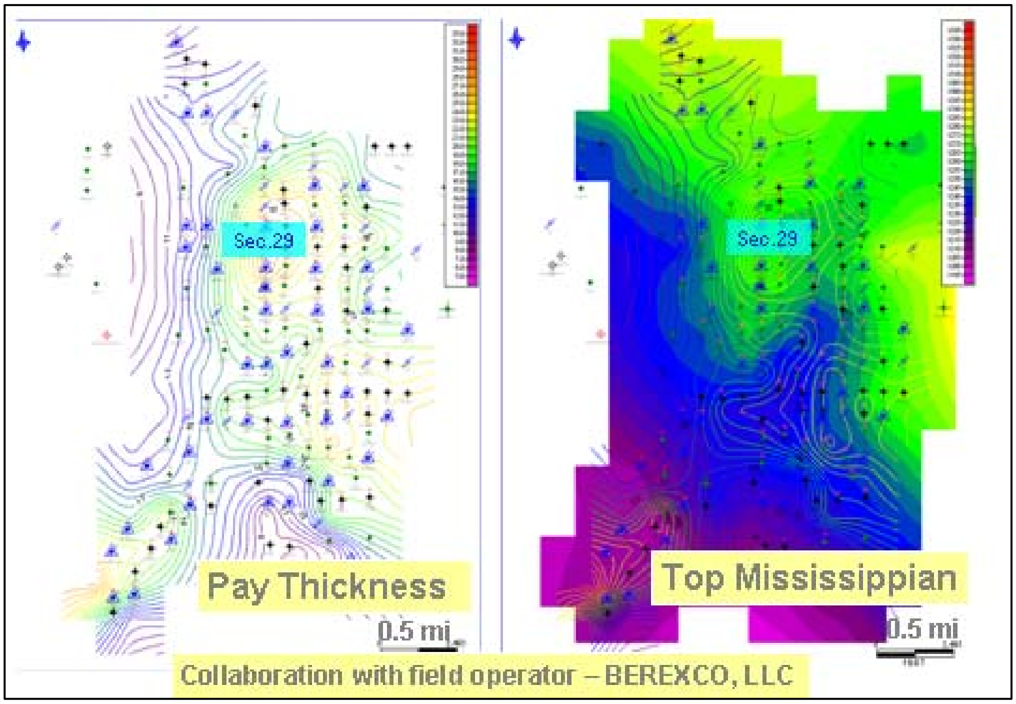


Figure 32. Initial mapping of pay thickness and structure of Wellington Field. Left – pay thickness with warmer contours equal to thicker pay. Right – Structure map with higher elevation depicted by warmer colors.

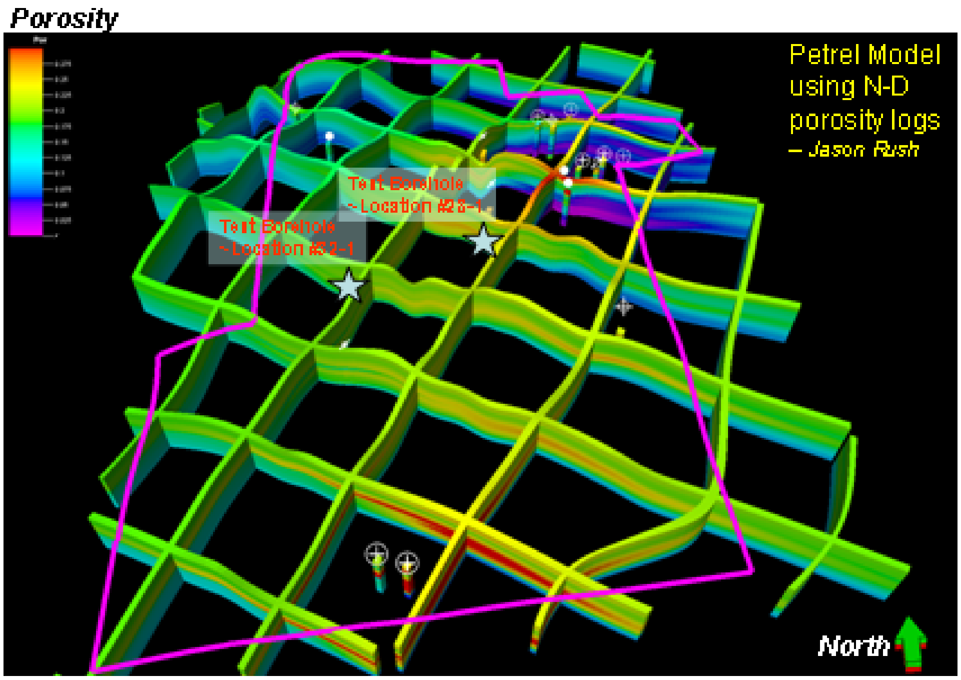


Figure 33. Porosity fence diagram for Mississippian in Wellington Field.

Previous studies provide a perspective of what the chert-dolomite Mississippian reservoir is like at Wellington Field (e.g., Watney et al., 2001). Prior studies will be incorporated into developing a robust geomodel. [Watney, W.L., Guy, W.J., and Byrnes, A.P., 2001, Characterization of the Mississippian Chat in South-Central Kansas, *AAPG Bulletin*, v. 85; no. 1; p. 85-113]. Examples of stratigraphy and lithofacies are shown in Figures 34 and 35.

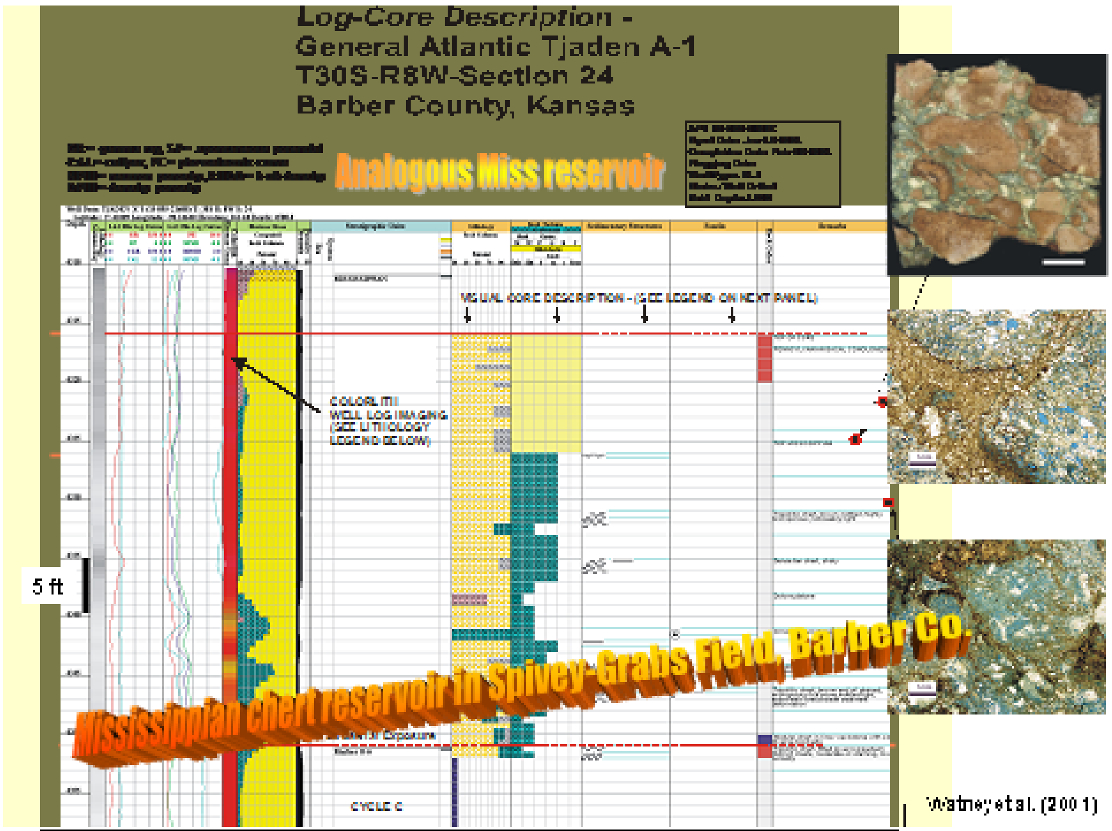


Figure 34. Example of primary reservoir facies in Spivey-Grabs Fields, Barber-Kingman Counties, Ks.

4322.3 ft – Photomicrograph of porous tripolitic chert clasts in Pennsylvanian basal conglomerate. Chert clasts are infilled with terrigenous, argillaceous, siltstone comprised of quartz. Terrigenous quartz silt infilling contrasts with carbonate infill deeper in the Mississippian. Triopolitic chert is distinctively white color and lightweight due to abundant porosity ranging upwards of 50%. A spiculitic bioclastic grainstone served as the host of silicification. This grain-rich fabric is characteristic of the tripolitic zones. Spivey-Grabs and other chert producing fields in this area produce from thickened, clean tripolitic chert intervals associated with fault blocks. Photographed in plane light with blue epoxy impregnation.

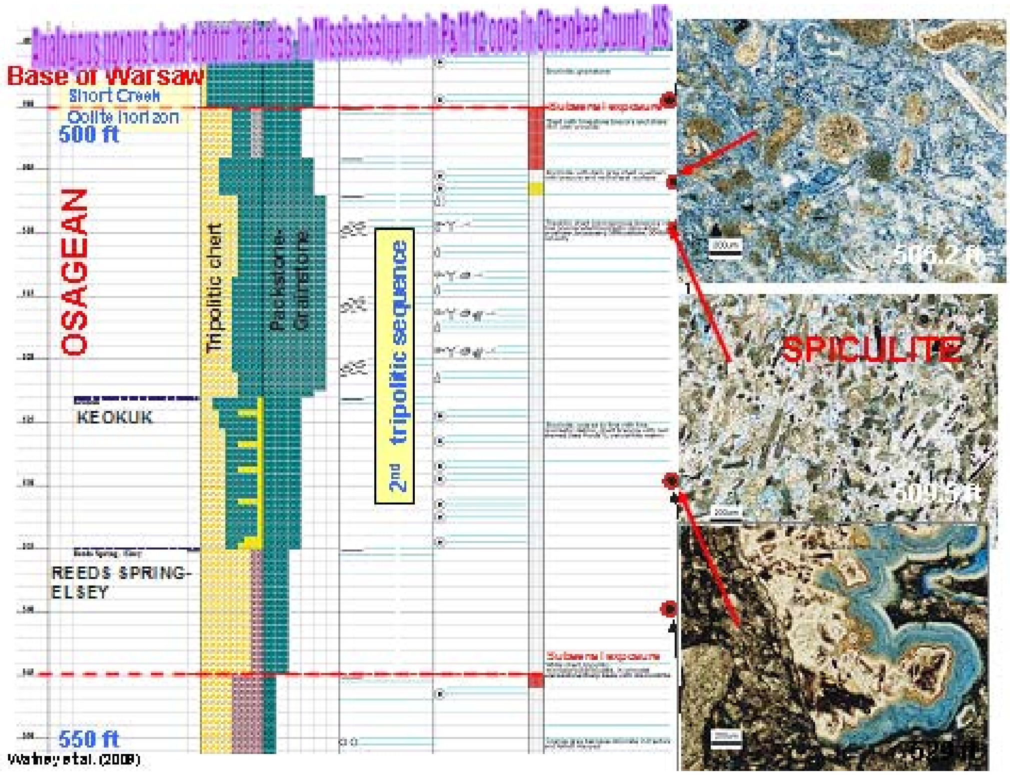


Figure 35. Example of tripolitic chert in Cherokee County Kansas showing unconformity bounded sequence, similar to that shown in Figure 36. Locations are 150 miles apart, and lie on either side of Wellington Field, yet stratigraphy and lithofacies are very similar. Dolomitic facies are present in the lower portion of this core.

505.2 ft – Photomicrograph of tripolitic chert with bioclasts and sponge spicules. Rock is highly porous, often called cotton rock due to its light weight and white color. Blue epoxy dye delimits fine microporosity, along with vugs and biomolds.

509.5 ft – Photomicrograph of tripolitic, microporous chert breccia. This white chert generally contains spicules (monaxon rods) and abundant bioclastics in grainstone to packstone fabric. This chert contrasts sharply with porcelain dense chert nodules and breccias that have replaced dolomudstone and wackestones commonly interbedded with these tripolite deposits. Light weight (due to high porosities upward of 40 to 50%) and white color are distinctive features of this rock, which serves as petroleum reservoirs and host for Pb-Zn mineralization immediately south of the core location.

529 ft – Photomicrograph plane light with blue epoxy fill. Fissure cross cuts tripolitic chert breccia clast. Fissure (left side) is filled with crinoidal, bioclastic, argillaceous wackestone, clearly cross cutting laminated, porous chalcedony. Wackestone resembles overlying bed and suggests dissolution of chert and fissure formation occurred shortly after the early silicification of the chert.

Subtask 4.12. Microbiological studies on produced water.

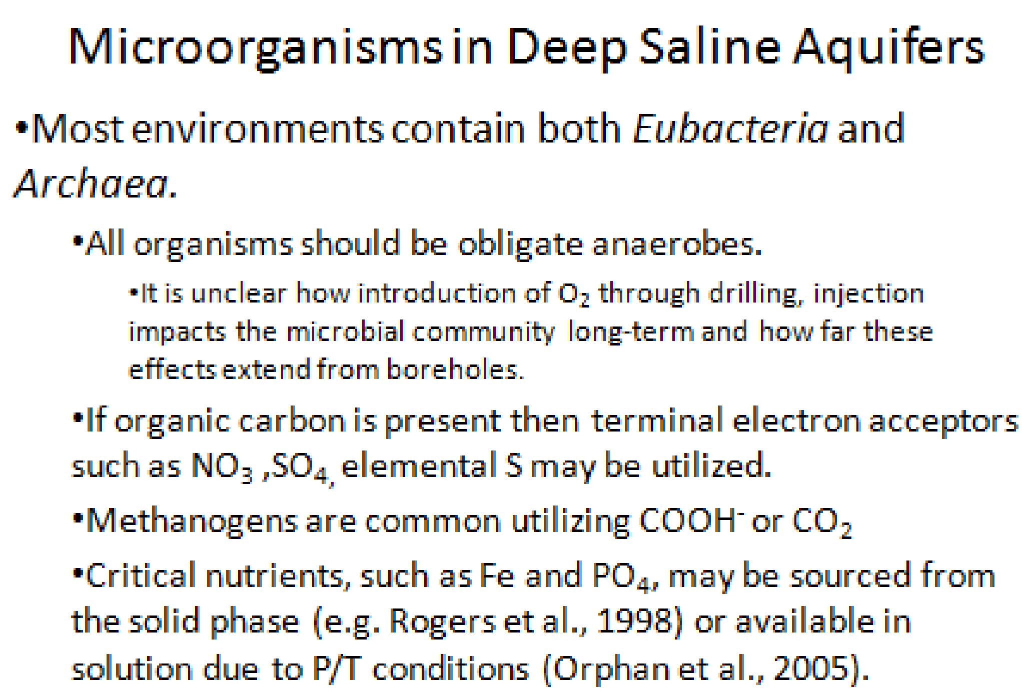
With contributions by Jennifer Roberts, David Fowle, Aimee Scheffer, & Breanna Huff

Microbes are known to be intertwined with the geochemical functioning of natural waters and therefore mineral equilibria in subsurface environments. The microbial community of the reservoir and its caprocks, therefore, could influence:

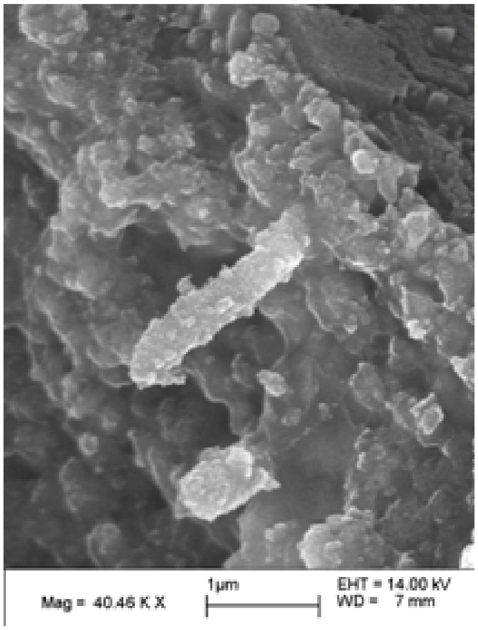
- long-term storage integrity
- reservoir storage capacity
- porosity and permeability
- fracture and microfracture formation and healing

Goals and related activities include: 1) characterize the native microbial communities to a) assess the role of microorganisms in water:rock interaction that influences reservoir properties critical for CO_2 storage and CO_2 sequestration. 2) Evaluate the microbial influence on seal integrity during CO_2 injection to a) assess the role of geologic complexity such as microfracturing in geologic materials reacted with SC-CO_2 and brine under reservoir conditions as a function of microbial biomass and b) determine the propensity for microfractures to "heal" and how this impacts porosity and permeability changes of these materials upon injection of CO_2.

Below are three slides below and next page providing general information about microorganisms in deep aquifers followed by sampling protocol.



Microorganisms in Deep Saline Aquifers



- Mineral equilibria
  - CO_2 reduction, depending on geochemical parameters, can lead to supersaturation of carbonate minerals. Depending on bulk solution pH precipitation could be local or widespread.
    - Microbial precipitation of carbonate minerals is most likely in microenvironments while bulk pH is low, may become more widespread if pH increases ~6.
  - Uptake of nutrients from minerals may cause dissolution of that phase. This is a microscale process that manifests itself on the macroscale (e.g. Bennett et al., 1999).

Microbial Characterization of Arbuckle Fluids and Core Material

- Quantification:
  - Direct counts (fluids)
  - Most probable number (fluids)
- Identification:
  - 16srRNA with clone libraries (fluids and rock)
    - Collaboration with researchers at Carnegie Mellon/NETL
  - Most probable number (fluids)

- Drilling mud is an environmental contaminant. Without tracer we must use knowledge of environment to discern native organisms from "mudbugs" (i.e. contaminants are likely aerobes)

Sampling/handling protocol for Core chips (for DNA analysis):

- Be on site while they are pulling the core.
- Prepare the sterile sampling board. (I made this out of plywood and cover it in a plastic sheet and sterilize it with ethanol before each sample)
- As they cut the core into 3-foot sections, I tell them which I would like to sample and they bring it over to me.
- The fresh cut face of the core is never touched.
- We use a ethanol rinsed chisel to break off a small chip of core onto the sampling board.
- With gloved hands, we pick up the chip and place it into a sterile sampling bag.
- Place the sample on dry ice until it can be delivered to Lawrence and placed in the -80 C freezer.

Sampling/handling protocol for DST water samples:

- The drillers collect buckets of water from the collars above the DST tool.
- Measure temperature and pH of the waters immediately (in the doghouse of the rig)
- Then bring the buckets down to the tent for sampling.
- First we collect several liters of raw sample to use in the CO2 reactor experiments at NETL and the Center for Beneficial Catalysis at KU.
- We collect raw samples for microscopic direct counts of organisms.
- We then put a submersible pump in each bucket of water and run the water through a 12.4 cm filter. (both a prefilter and a 0.2 um filter to catch
- microbes)
- We sample for several geochemical parameters that will help us determine which metabolisms are present and nutrient availability. (cations, anions, DOC, DIC, alkalinity)
- We then collect the filters for analysis for DNA and suspended solids.
- We place the water samples on ice until the can be delivered to Lawrence.
- Samples are analyzed for Fe2+ in the hotel room. (speciation of iron is helpful but needs to be measured as quickly as possible before changes occur)
- Alkalinity needs to be measured within 48 hours. (A lab mate picked up the samples from the field and measured it for me in the lab within a day)
- Microbial media prepared before the beginning of field work is inoculated in the hotel room on the same day as the DST waters are collected.

Analysis of microbial communities will be determined using these samples. While sterile techniques are not always possible during field sampling, techniques that minimize sample contamination with non-sterile fluids and/or solids are preferred. This protocol may change slightly depending on which tracer is used.

Detailed protocols for sampling, sample handling, and shipping are provided next.

<u>Mud Tracer for Contamination Prevention</u>
A small amount (~100 grams) of tracer will be added to the drilling mud to detect contamination of the reservoir fluids and rocks by the drilling mud. This tracer will be an inert, stable compound that will not impact chemical analyses, porosity etc.

<u>Produced Water Samples</u>
Approximately 10 water samples, one from each separate aquitard unit within the Arbuckle Aquifer, will be collected from each well. These will be collected in triplicate for a total of 30 water samples. Each sample will require approximately 5-10 gallons of raw sample. This raw sample water will be put into 5 gallon buckets and pumped through a filter using a submersible pump to remove any large debris or loose sediment. Samples, listed in Table 2, will then be filled with the filtered water. Ideal water samples are taken from the depth of the production zone and remain unfiltered and free of preservation additives. Unfiltered, non-preserved shallow aquifer samples are also of interest. Both will be collected for this study. Sampling location will depend on access to the well on site but collecting flowing water samples after 10-20 well volumes have been purged is preferred.

The sampler will wear disposable latex or nitrile gloves and eye protection during water collection to prevent contamination of sample water and reduce risk of exposure. 2 to 5 liters of produced water will be collected in sterile 1 L plastic bottles provided to the sampler. Bottles will be filled to the top and capped immediately, with zero headspace. The bottle should be labeled with the sample location, name of sampler, time, and date. Parafilm will be wrapped along the rim of the cap to further seal the sample from exposure, and samples will immediately be placed on ice in a provided cooler.

The sampler should be supplied with gloves, coolers, sample bottles, parafilm, labels, and pre-paid FedEx labels. Samples will be stored in a cooler on ice and taken to the laboratory as soon as possible to be stored and analyzed.

<u>Sediment Samples</u>
Ideal sediment samples are retrieved via coring to prevent contamination from overlying rock units. Core samples will be collected in Houston, Texas after drilling is completed. Rock chip samples from each of the 10 aquitard units of the Arbuckle Aquifer will be collected. An assortment of rock chip sizes will be selected, including the largest possible in attempts to collected rock samples that are not fully penetrated by drilling mud. These samples will be rinsed with deionized water and stored in 8 oz sterile glass jars filled with reservoir fluids to avoid dehydration of the sample. Sediment cores are taken from the depth of the production zone and remain intact to minimize contamination from the drill rig. Shallow aquifer sediment cores are also of interest.

The sampler will wear disposable latex or nitrile gloves and eye protection during sediment collection to prevent contamination of sample sediment and reduce risk of exposure. Sediment cores will be wrapped in sterile plastic wrap immediately. The cores will then be wrapped in foil, and labeled with the sample depth and location, name of sampler, time, and date. The sediment sample will be immediately placed on ice in a provided cooler.

If sediment samples are not intact cores, samples will be collected in sterile 8 oz jars. Jars will be filled to the top and immediately capped. The jar should be labeled with sample location and depth, name of sampler, time, and date. Parafilm will be wrapped around the rim of the cap to further seal the sample from exposure, and samples will immediately be placed on ice in a provided cooler.

The sampler should be supplied with gloves, coolers, sterile plastic wrap, foil, jars with caps, parafilm, labels, and pre-paid FedEx labels.

Shipping

One set of microbial samples should be shipped overnight to our collaborator at NETL in a cooler on ice. The shipping address is as follows:
Attn: Djuna Gulliver (x7247), Barbara Kutchko (x5149)
Chemical Handling Facility,
National Energy Technology Laboratory
626 Cochrans Mill Rd
Pittsburgh, PA 15236

Biological Sampling Kits

Vessel	Analysis to be done	Preservation
10mL glass sealed serum vial	DAPI stain/enumeration	5% Gluteraldehyde (add appropriate mL 50% glutar)
Sterile baggies	DNA, Lipid Biomass Analysis	100% EtOH on ice, store on ice
50mL Falcon tubes	SEM/TEM	5% Glutaraldehyde
60 mL sterile syringes/needles	Injecting fluid	n/a
Squirt bottles for H2O and EtOH	n/a	n/a
Gloves and safety glasses	n/a	n/a
Large 142 cm filter holder and .45 filters	DNA Collection	Ice
5 gallon Carboy	n/a	n/a

Table 1: Biological Sampling Kits

Geochemical Sampling Kits

Vessel	Analysis to be done	Preservation
60 mL glass sealed serum vial	Headspace gas analysis	Mercuric Chloride, store on ice
60 mL Nalgene bottle	Cations	FA (2% nitric), store on ice
30 mL Nalgene bottle	Anions	FU, store on ice
15 mL Nalgene bottle	Iron	FU, store on ice
I L Amber glass	EXTRA RAW	RU, store on ice

bottles	SAMPLE	
40 mL amber VOA vial	DOC/isotopes	Mercuric Chloride
60 mL non-sterile syringes and needles	Injecting fluid	n/a
50 mL Round-bottom Tubes	DIC/Alkalinity	No headspace

The microbial studies are being conducted in collaboration with DOE NETL labs in Pittsburgh where Aimee Scheffer will have an internship during the fall 2011 (Figure 36).

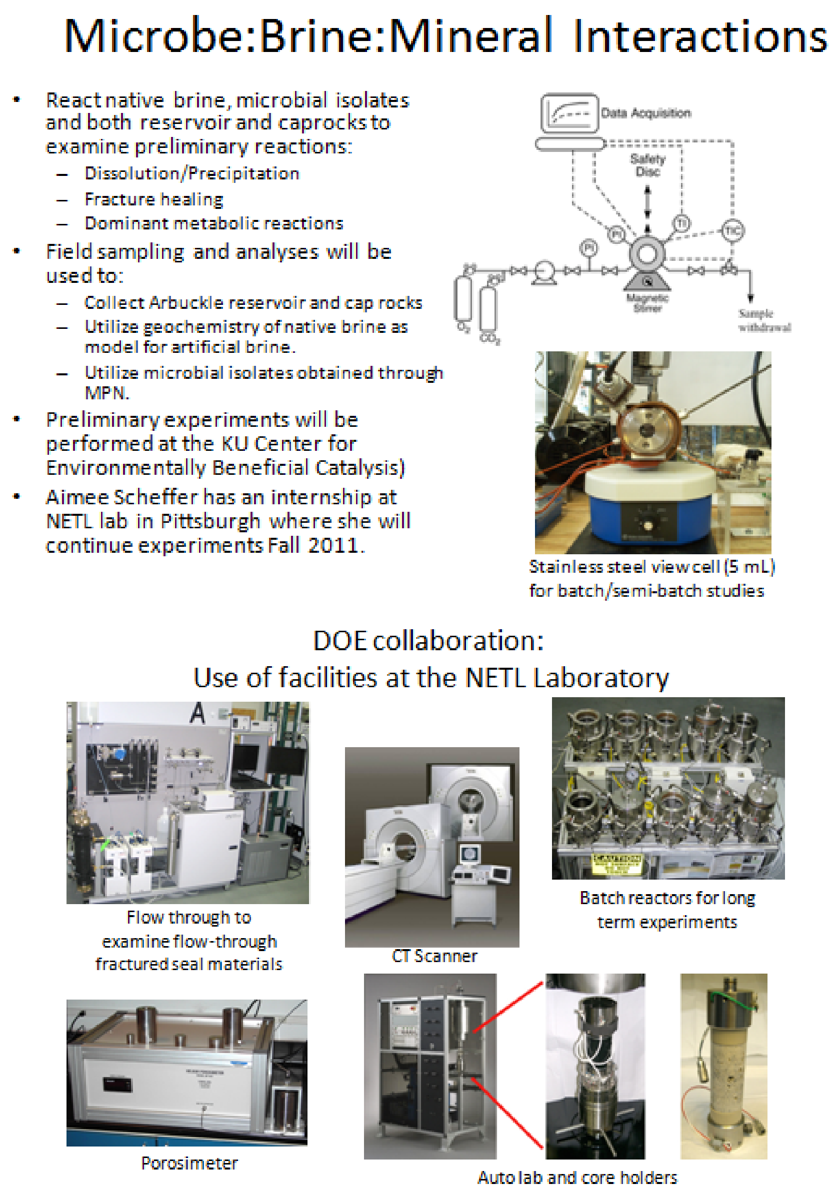


Figure 36. Microbe:Brine:Mineral Interactions and DOE collaboration to facilitate these studies

Subtask 4.14. Diagenetic history of fracture fill.

Contributed by Robert Goldstein and Bradley King, KU Geology.

- Provide insight into fluid flow history of reservoir rock and cap rock formations via fluid inclusion studies.
- Fluid inclusions can be used to evaluate the detailed spatial, temporal, tectonic, and fluid composition history of a system and are capable of linking thermal history to fluid flow.
- There is potential for trapping fluid inclusions during much of the history of a sediment or sedimentary rock, providing a vast amount of information regarding the fluid flow history.
- Directly apply this data as a predictive element of fluid flow behavior of carbon dioxide within reservoir and cap rock formations.
- Modeling of gathered data will provide a visual understanding of the possible behavior of injected carbon dioxide.

Fluid Inclusions

• Fluid inclusions are tiny fluid-filled cavities sealed within mineral phases and typically contain smaller gas bubbles within the inclusion associated with temperature during mineralization and subsequent cooling.

- They can be formed during mineral growth as irregularities develop during passive precipitation of minerals from a fluid.
- Inclusions can also be trapped as micro-cracks and other deformation features heal.
- Extensive petrographic evaluation of fluid inclusions is necessary to establish a paragenesis of fluid inclusion entrapment relative to other deformational, depositional, and diagenetic fabrics.

Current undertakings…

- Familiarity of reservoir rock and cap rock formations was gained through extensive study of previously acquired core during the Fall 2010 semester.
- Sampling of related cores containing relevant reservoir and cap rock formations has been conducted (Augusta and Vulcan).
- Butler and Sedgwick Counties, Kansas
- Numerous thin sections have been created from samples and have been petrographically studied for familiarization with fluid inclusion identification.

Timeline for Future Work

- Further sampling of reservoir rock and cap rock formations will be necessary for a firm understanding of the stratigraphic column.
- Experience with the microscope heating plate will be a priority for the beginning of the Spring 2011 semester. This will include the heating and cooling of fluid inclusion gas bubbles, providing homogenization temperatures.
- Core descriptions of the Wellington core, as well as sampling, will be conducted throughout the Spring 2011 semester.
- The Wellington core will furnish essential data regarding the entirety of the Arbuckle Group

Subtask 4.15. 2D shear survey.

2D shear wave survey will commence as soon as drilling is completed at Wellington.

Subtask 4.16. Process and interpret 2D shear.

2D shear survey is ready to deploy and interpret to aid in calibrating the converted shear wave of the 3D multicomponent survey.

Subtask 4.1. Locate test borehole #1 (KGS 32-1).

(See below)

Subtask 5.1. Locate test borehole #2 (KGS 28-1).
Contributions by Dana Wreath, Dennis Hedke, and Susan Nissen.

Locations have been selected, pre-spud meeting has been held, and Berexco KGS Wellington #1-32 has commenced at end of December at Wellington Field (Figures 37 and 38). Locations for the boreholes are based on: 1) subsurface data and 2) seismic interpretations – P-wave time and structure, volumetric curvature and coherency, amplitude mapping (Figures 39-41).

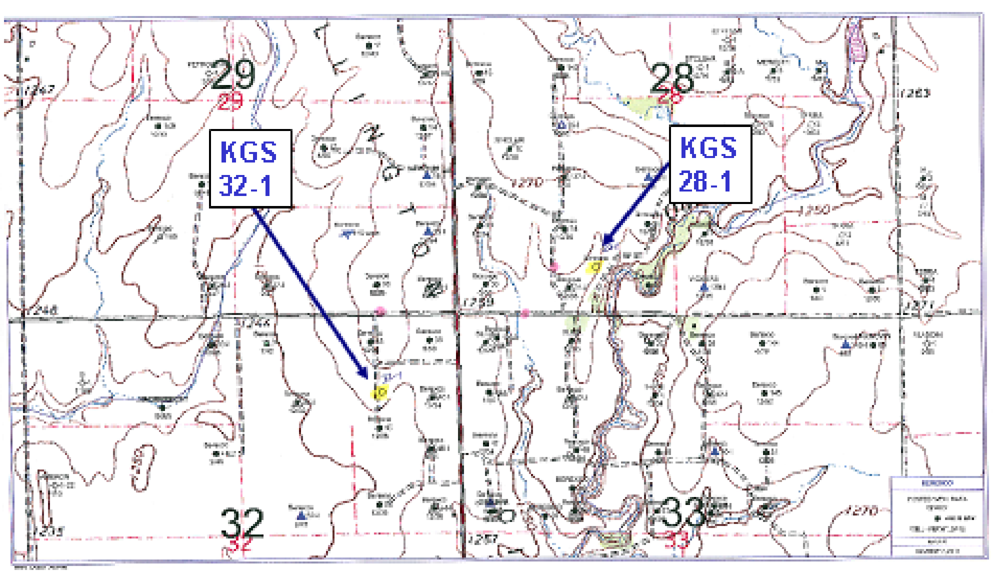


Figure 37. Topographic with well locations in Wellington Field showing locations of wells to be drilled with support of the study.

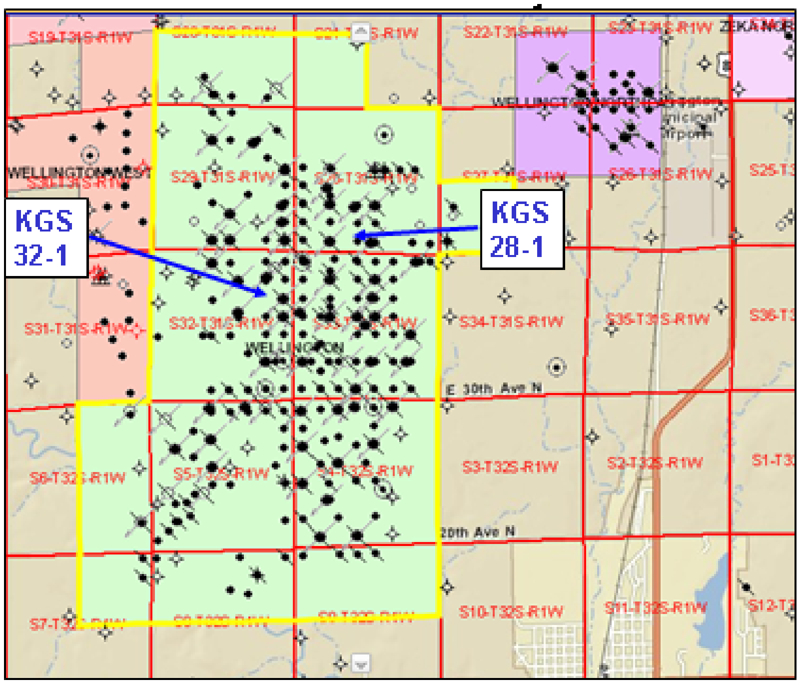


Figure 38. Two new boreholes to be drilled, located on area defined as Wellington Field. Squares are one mile on a side.

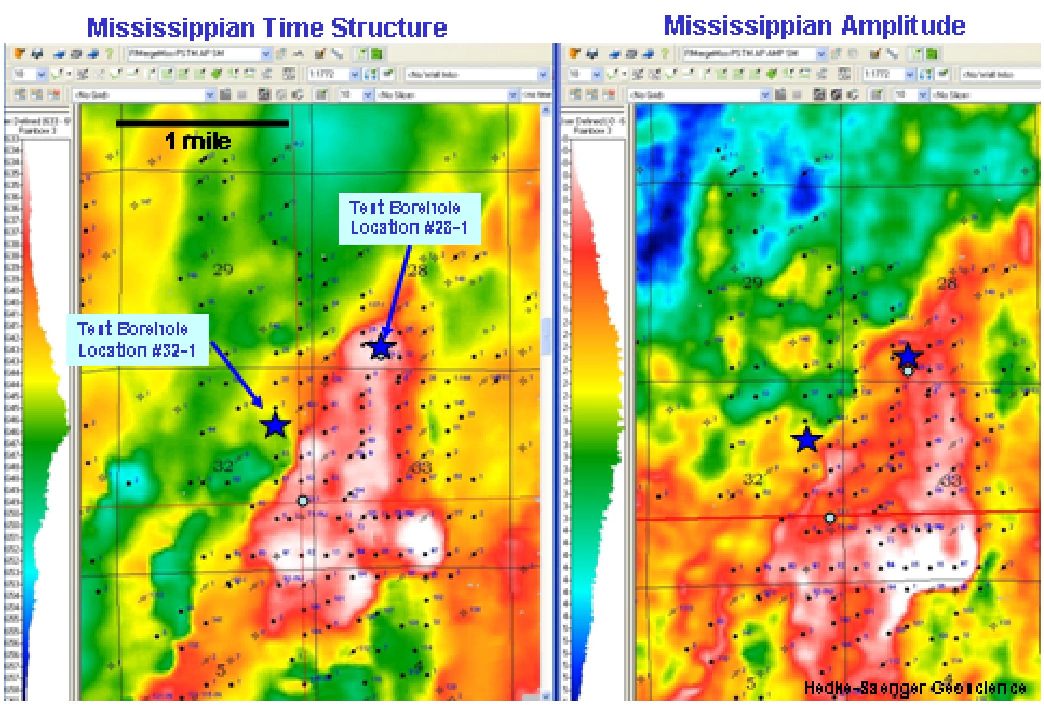


Figure 39. Test borehole #1-32 is located off the highest structure on the top of the Mississippian limestone, the oil reservoir for Wellington Field. Seismic maps including Mississippian time and converted depth structure indicate highs in warm colors and lows in cooler colors.

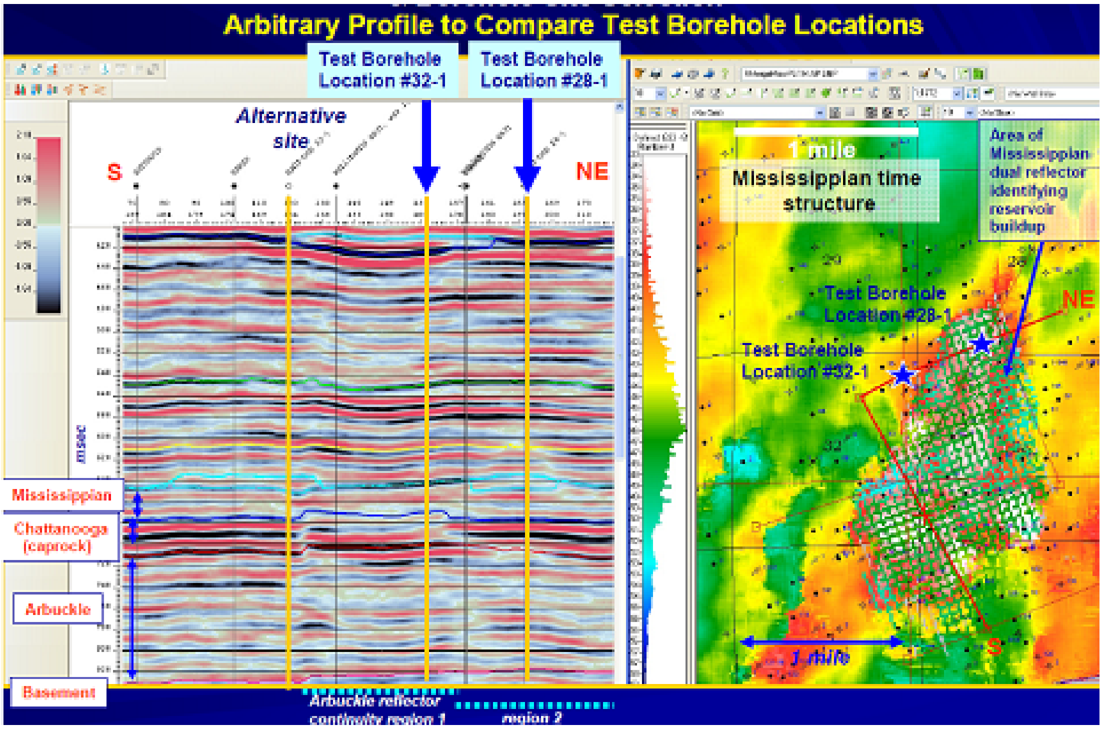
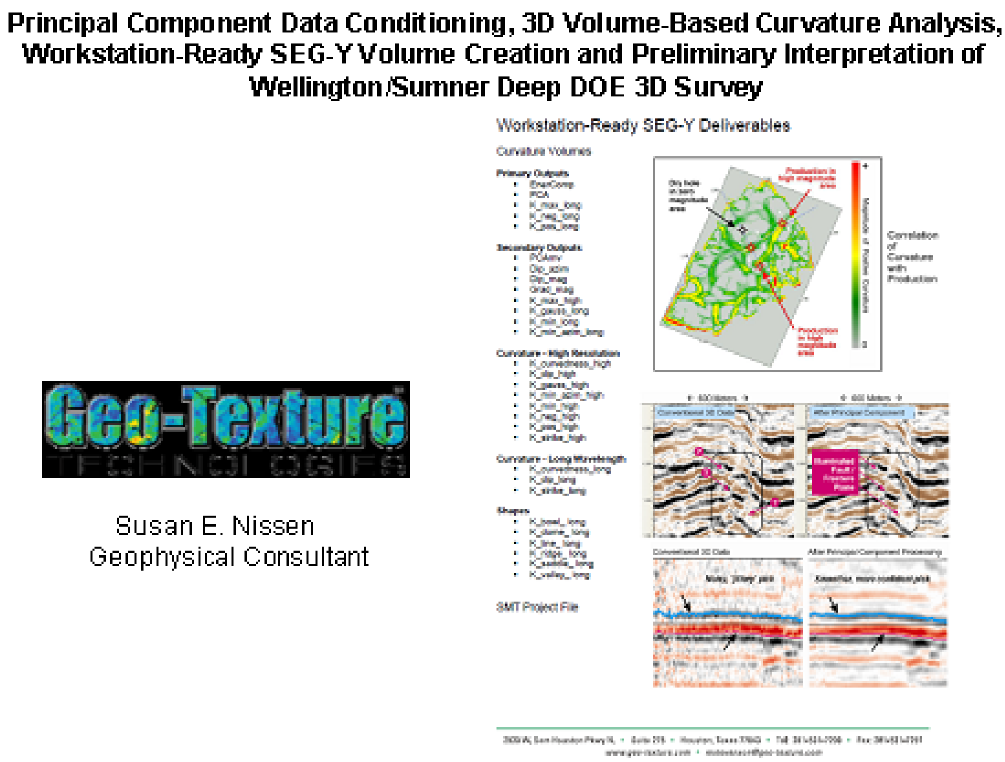


Figure 40. South to Northeast seismic profile crosses locations of test boreholes #1-32 and #1-28 and indicates that the Arbuckle contains seven notable internal reflectors. Secondly, these reflectors are truncated or more sharply dipping along a vertical trend between these two wells. The sharp vertical disruption is also observed south of test borehole #1-32. Location of the same vertical disruption occurs in two places, south of borehole #1-32 near the alternative borehole location and northeast of #1-32 between this borehole and #1-28. The Mississippian time structure map on the right shows the line of section and the sharp northeast trending feature that crosses the map from corner to corner. Additional analyses of the seismic data including fault tracing and volumetric curvature suggest the presence of a fault at least through a portion of the stratigraphic section. Processing of the converted s-wave of the seismic will help to characterize the fault as a barrier or a conduit based measurements of slowness of shear wave and an understanding of the stress regime.

The same vertical disruption affects the Mississippian and planned analysis of the oil production will help to establish any affects of the disruption. After wells have been cased and perforated it is possible that a transient pressure test could be conducted to determine whether boreholes #1-32 and #1-28 are communicating in the Mississippian oil reservoir. A similar test could be run in the Arbuckle, but the large volume of the Arbuckle could preclude the detection of the pressure pulse.



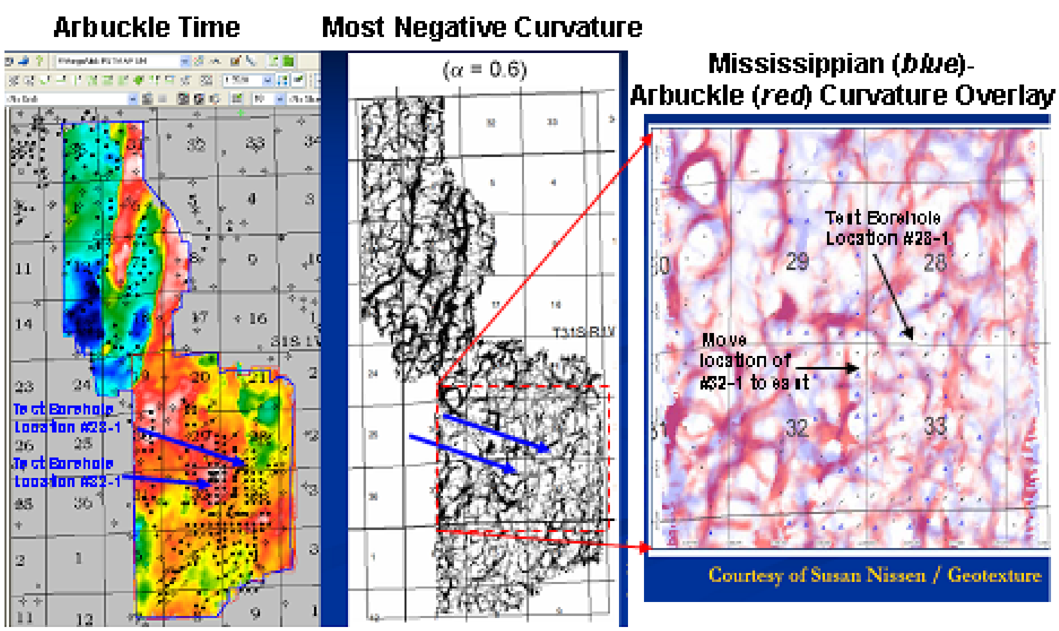


Figure 41. (Top) Volumetric coherency and curvature were used to help refine the location of the tests boreholes. (Bottom) Arbuckle time, most negative curvature for Arbuckle and combined curvature of Mississippian (blue) and Arbuckle (red) showing locations of new test boreholes.

Continuous coring will commence in the Cherokee Shale (secondary caprock) and extend down through the Arbuckle into the Precambrian basement (Figure 42). Depth of surface casing was set at 600 ft., extra deep, to isolate the halite and anhydrite/gypsum strata that occur near the surface at the location of Wellington #1—31 (Figure 43).

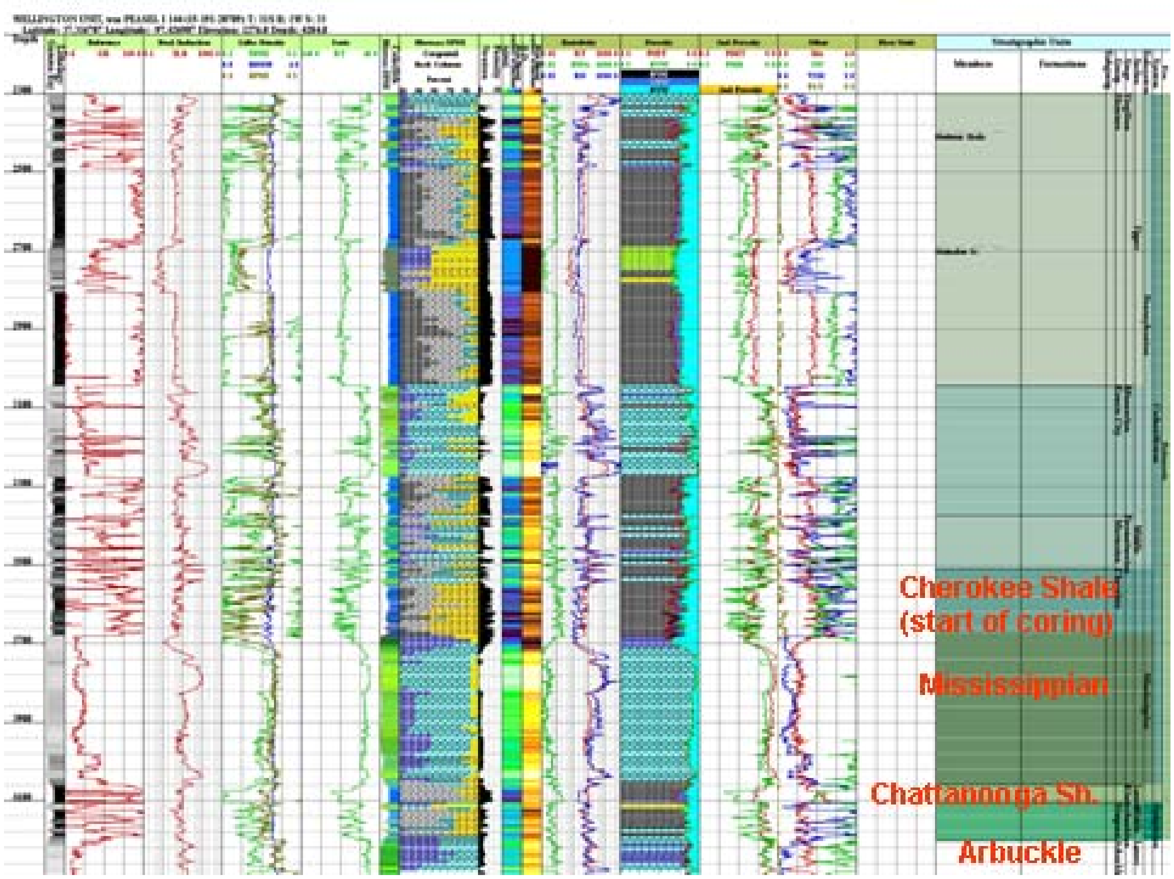
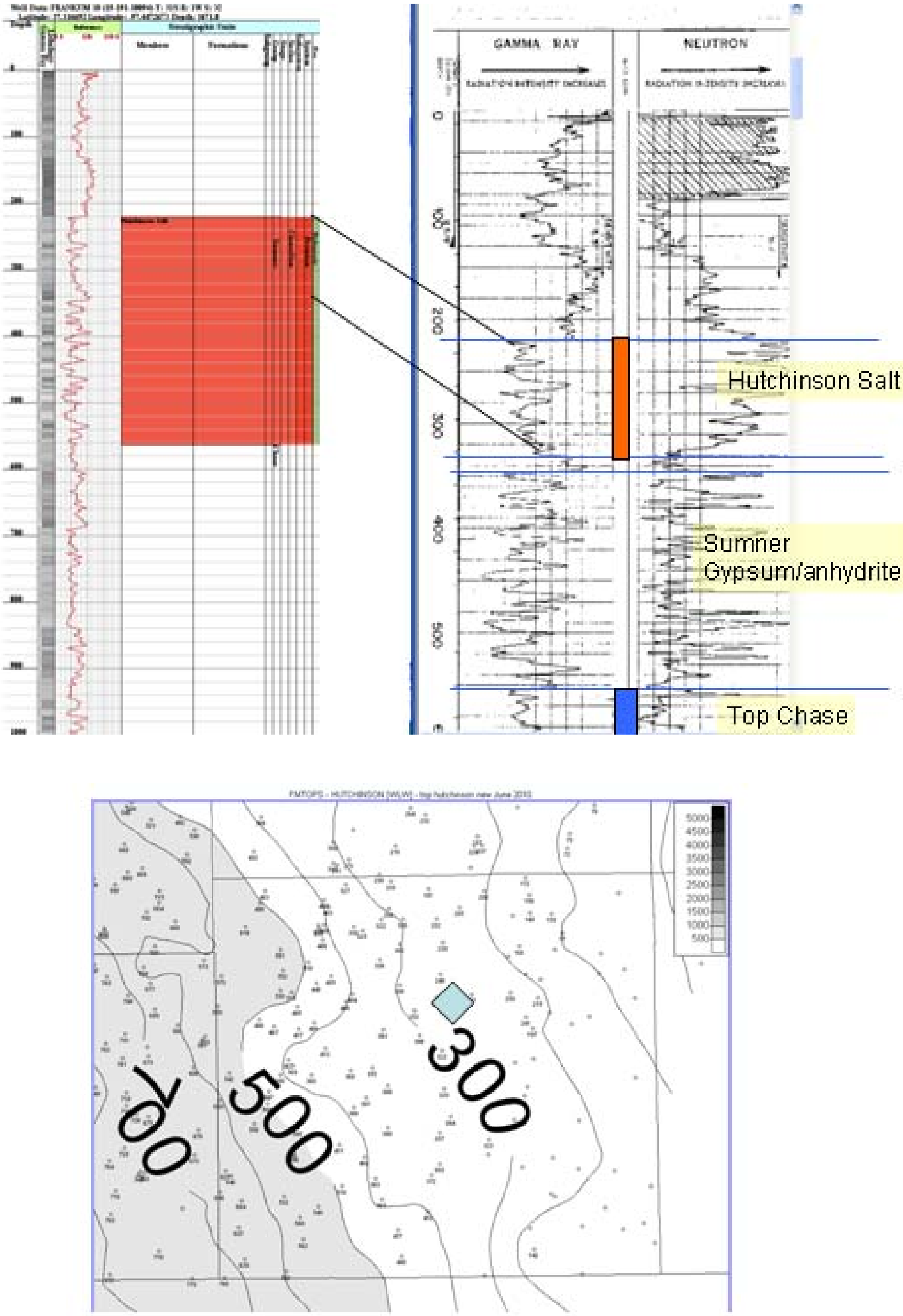


Figure 42. Peasel Wellington Unit #144 showing lithologies of stratigraphic section above the Arbuckle and location where coring will commence.



Measured depth to top of salt in Wellington Co.

Figure 43. Upper half shows the location of the halite and evaporate interval that occur near the surface at Wellington #1-32. Casing will be set at 600 ft in solid carbonate to isolate the salt section.

WESTERN ANNEX

Subtask 15. Extend Regional Study of Ozark Plateau Aquifer System to the Western Border of Kansas – "Western Annex".
Contributions from Paul Gerlach and Bittersweet Team.

The original area of the regional study has been expanded with supplemental funding to include what is referred to as the Western Annex. Figures 44-46.

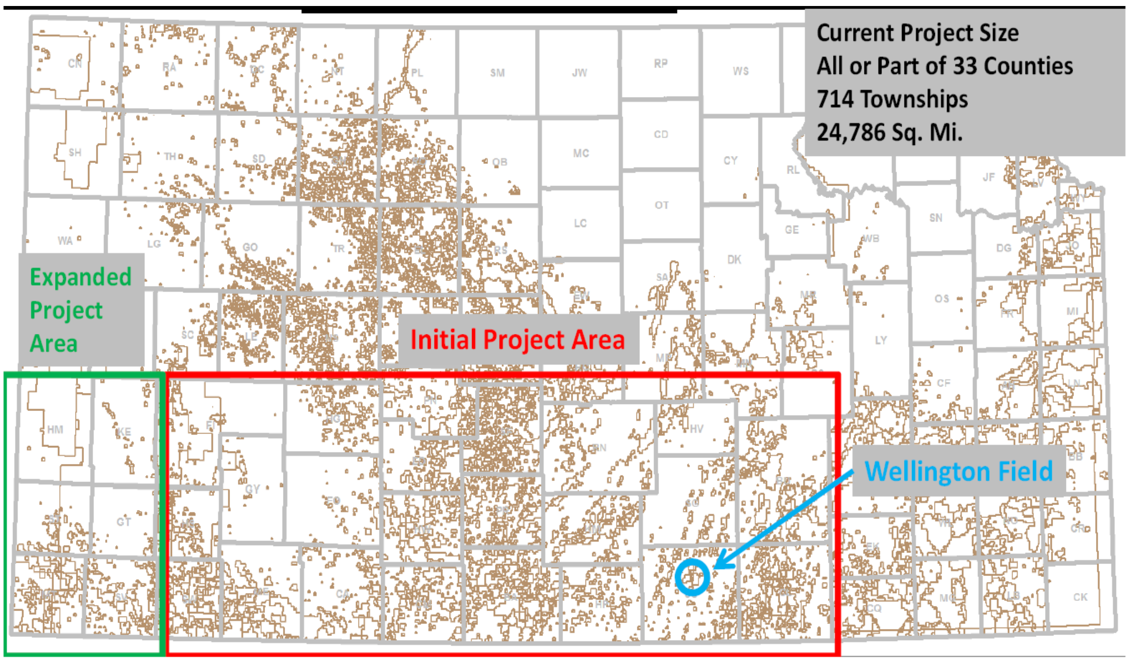


Figure 44. Initial area and expanded project area shown with outlines of oil and gas fields.

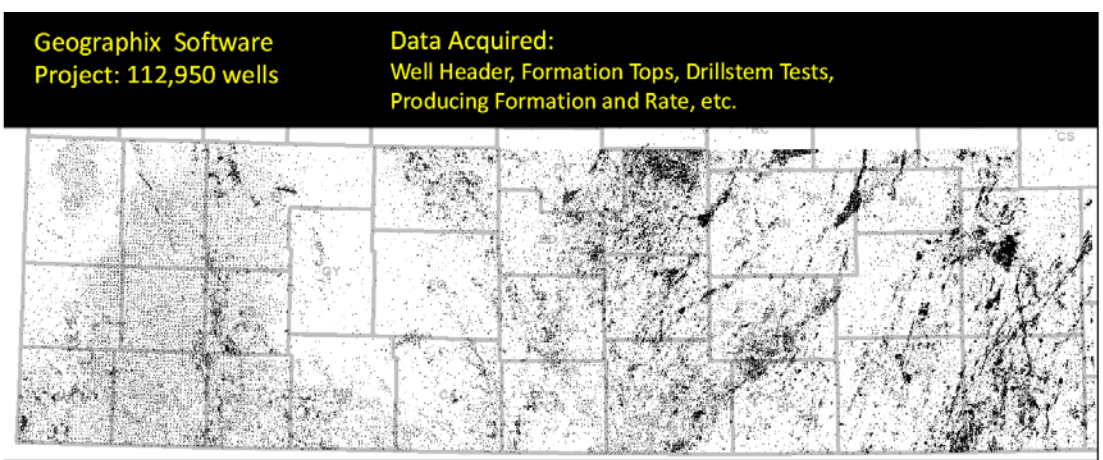


Figure. 45. Total well data available in the study area of southern Kansas as indexed in Figure 44.

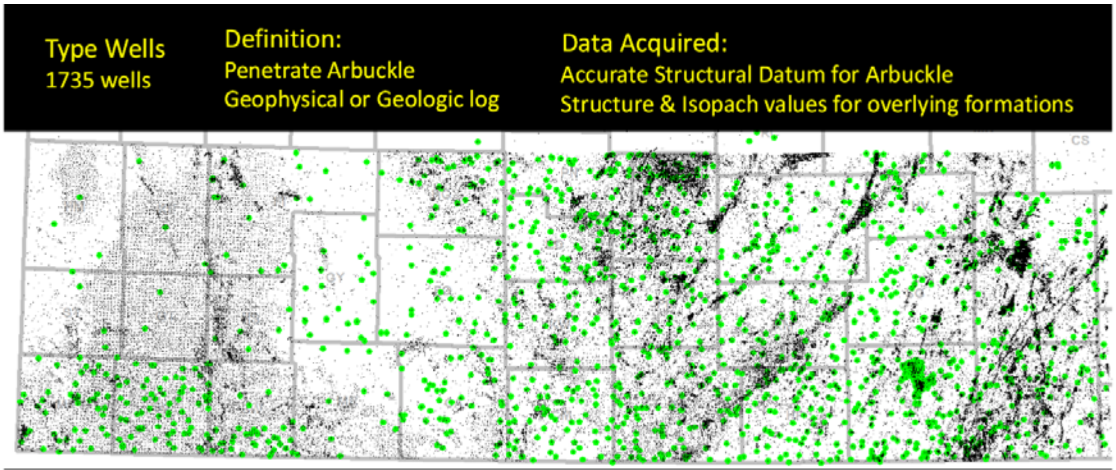


Figure 46. Type wells (as defined in this figure heading) shown in study area by green dots. This subset of wells serve as keys for correlation and provide properties for the strata being modeled as do the supertype wells that have even more complete information. Many of these wells will have wireline logs and sample descriptions digitized to LAS format.

Subtask 2.3. Develop regional correlation framework and integrated geomodel

Update prepared by Paul Gerlach and Bittersweet Team.

Continued work on regional stratigraphic correlations of 124 supertypes and 1735 type logs within Geographix software. Decision was made with Bittersweet team to extend correlations of key wells through the entire logged intervals so that shallower, secondary and tertiary caprocks can be characterized up through the Permian evaporites. Latest efforts in correlation within the Arbuckle Group as continued to make use insoluble residues that have been integrated with modern logs and their lithologic solutions (Figures 47-51).

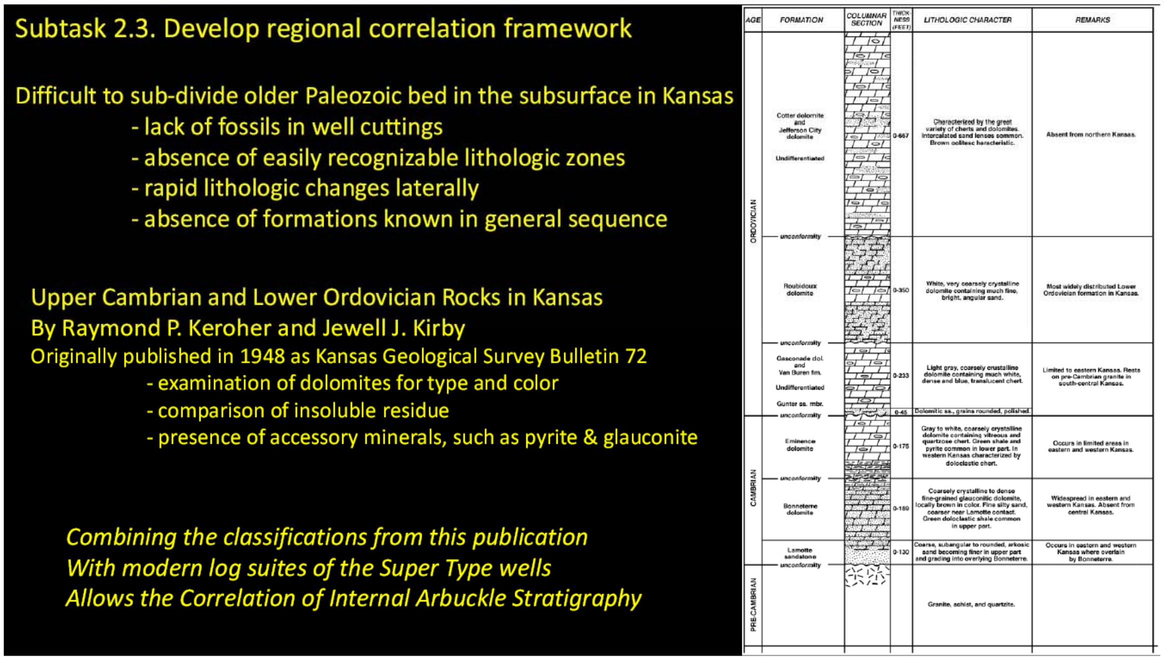


Figure 47. Obtaining lithostratigraphic is currently the focus for establishing internal correlations in the Arbuckle. Sample (cuttings) descriptions and lithologic solutions of modern well logs are important to this end.

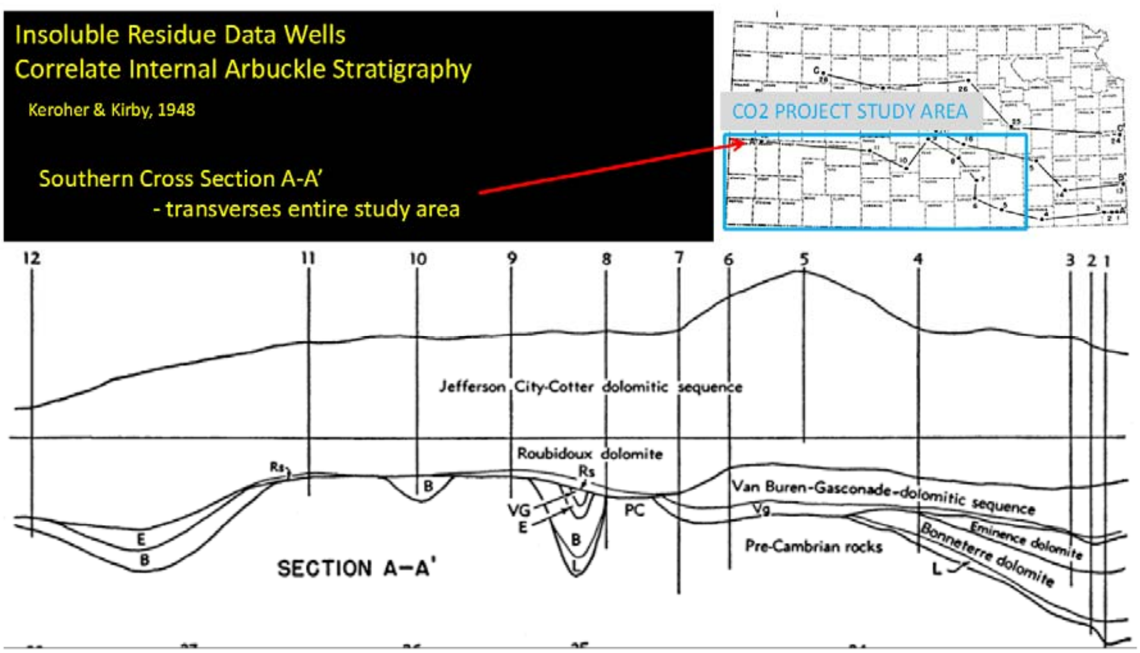


Figure 48. Regional correlation of insoluble residues is being translated to lithostratigraphy and petrophysical log response to establish a robust, consistent stratigraphic framework. Additional, refined correlation will be made as local stratigraphic information avails itself.

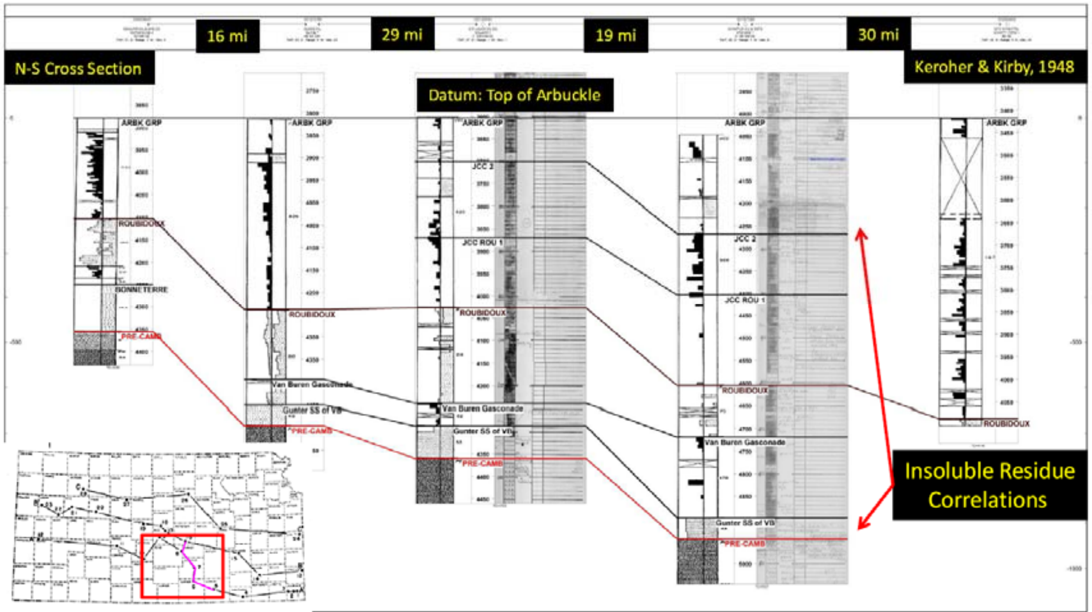


Figure 49. Example of related insoluble residue (black and white depth plot) with sample log descriptions. Petrophysical logs can similarly be compared via curves and lithologic interpretation.

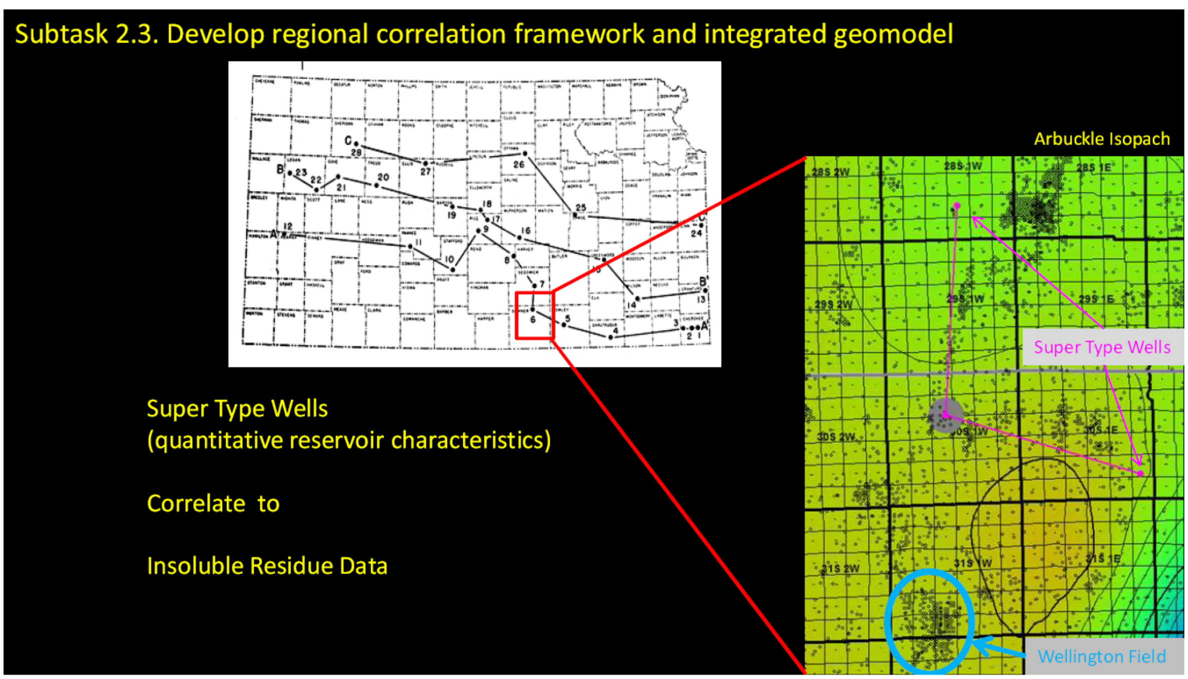


Figure 50. Example of regional stratigraphic framework using supertype wells in vicinity of Wellington Field in south-central Kansas.

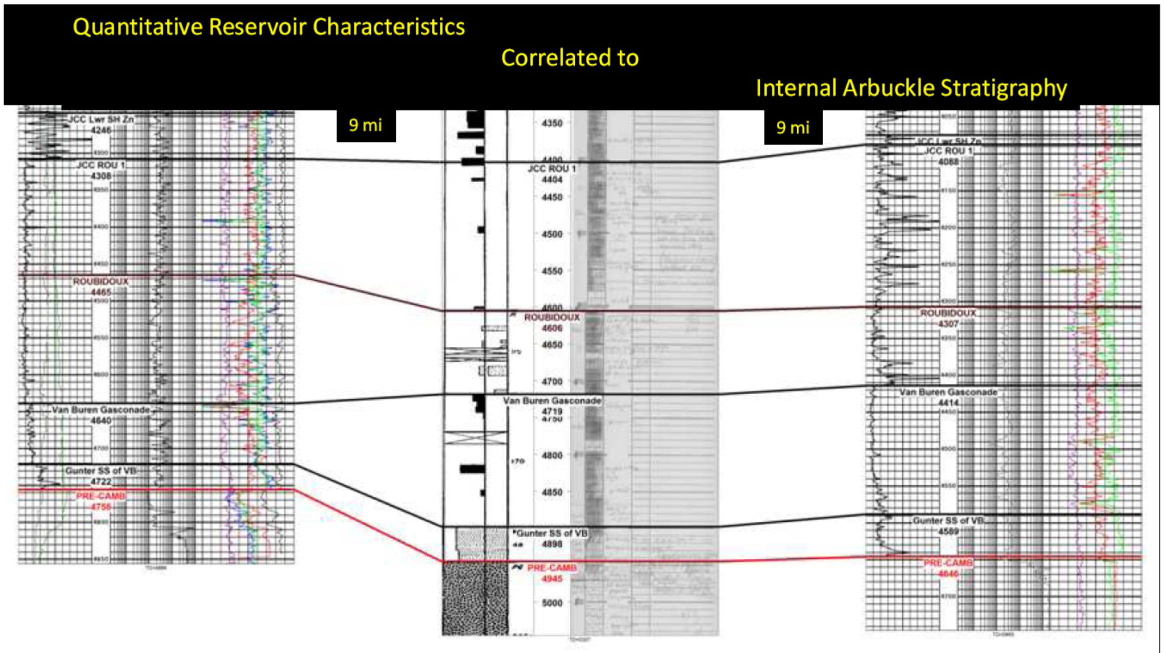


Figure 51. Cross section of supertype wells in vicinity of Wellington Field. Index map is Figure 50.

Regional maps are being updated to extend the original regional study area to the Western Annex. The series of maps below show the progress that has been made (Figures 51-57).

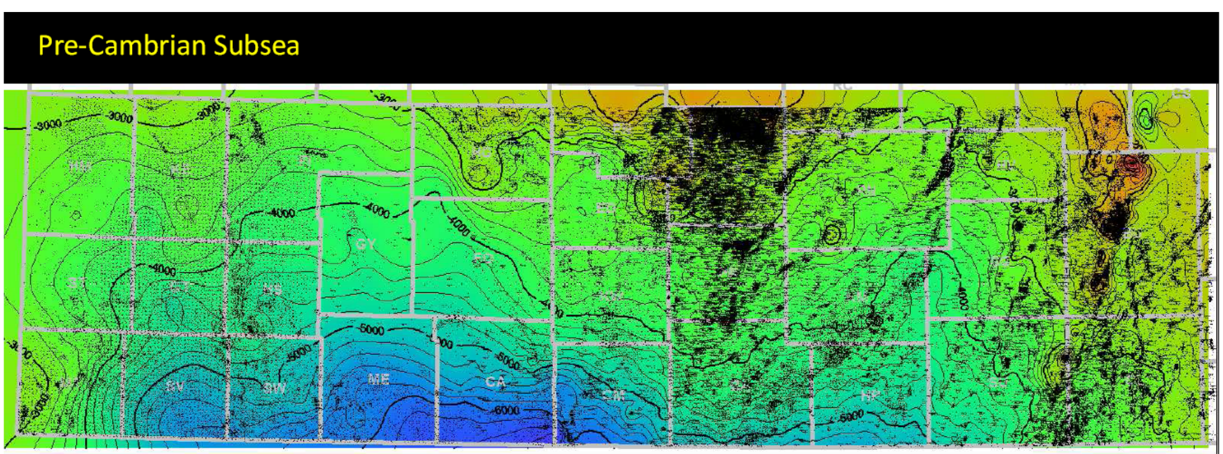


Figure 51. Structure map of Precambrian surface now delimited Hugoton Embayment in western area, Pratt Anticline in central, Sedgwick Basin in east central bordered by Nemaha Uplift on the east. Blue color indicates greater depths and orange is higher elevation.

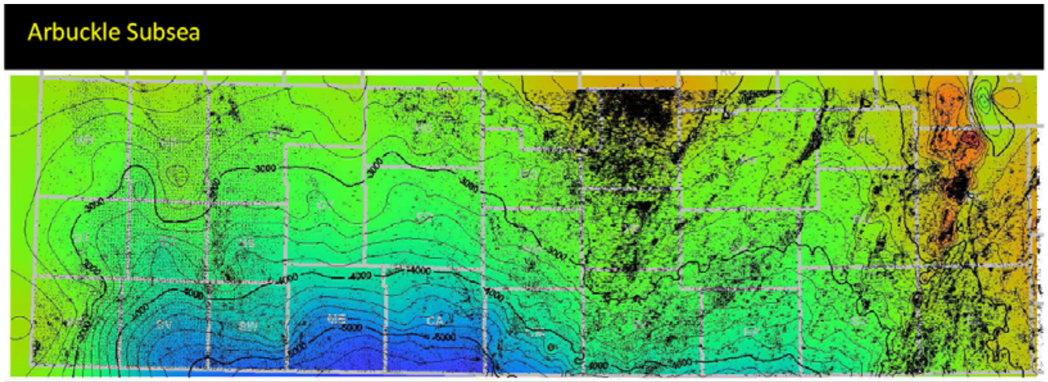


Figure 52. Structure contour top Arbuckle in greater study area.

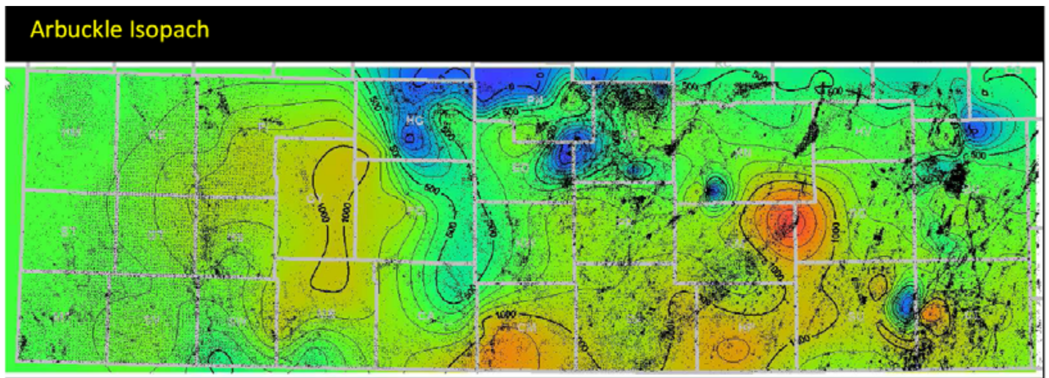


Figure 53. Arbuckle isopach map. Warmer colors are areas of greater thickness.

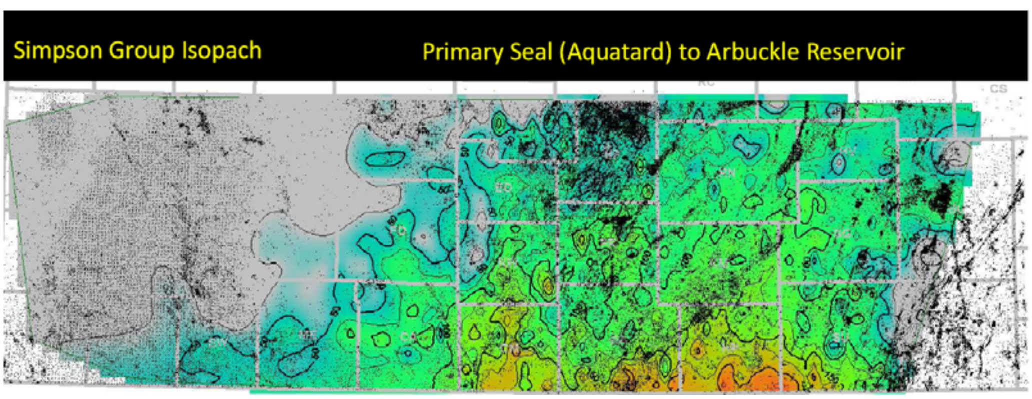


Figure 54. Simpson Group isopach. Shale and sandstone strata overlie the Arbuckle in the eastern 2/3rd of the area.

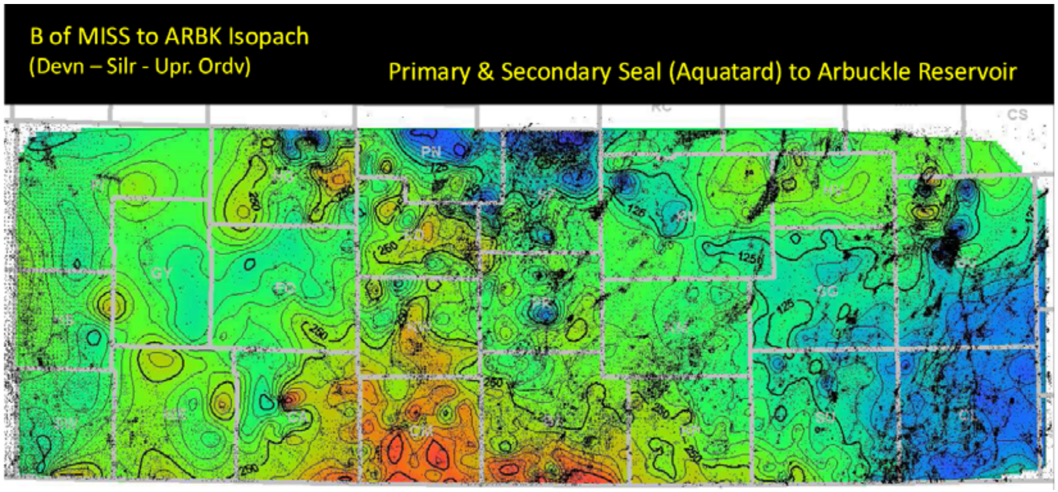


Figure 55. Base of Mississippian to Arbuckle isopach showing areas of thickening in orange in south-central mapped area. Interval contains the primary and secondary caprocks of the Chattanooga Shale and shales in the Simpson Group. Eastern thin is related to what was an active Chautauqua Arch and related erosion during this period of deposition.

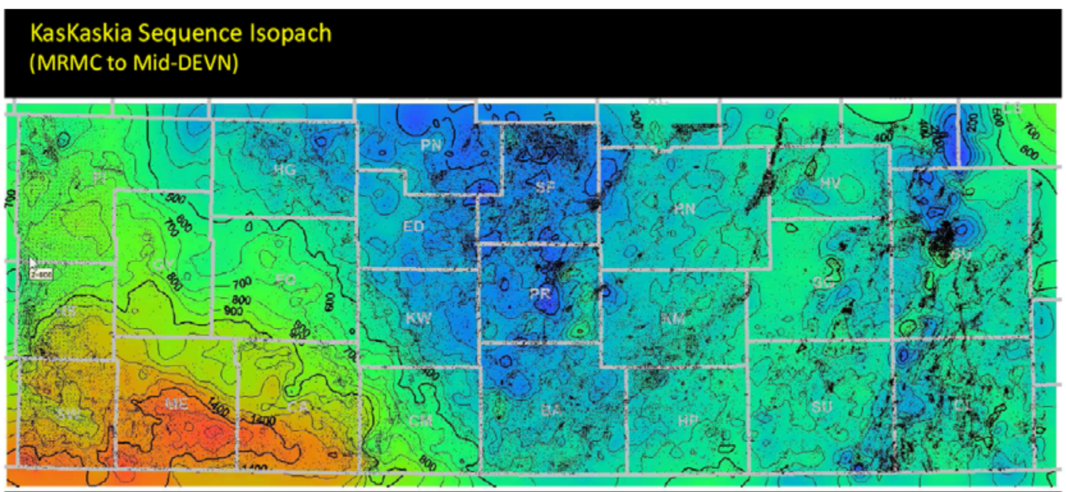


Figure 56. Isopach of a major cratonic depositional sequence that includes the Mississippian to Mid-Devonian, an interval overlying the Arbuckle. Thickness greatly increases in area of Western Annex. Blue area of thinning primarily reflects post Mississippian, pre-Pennsylvanian erosion.

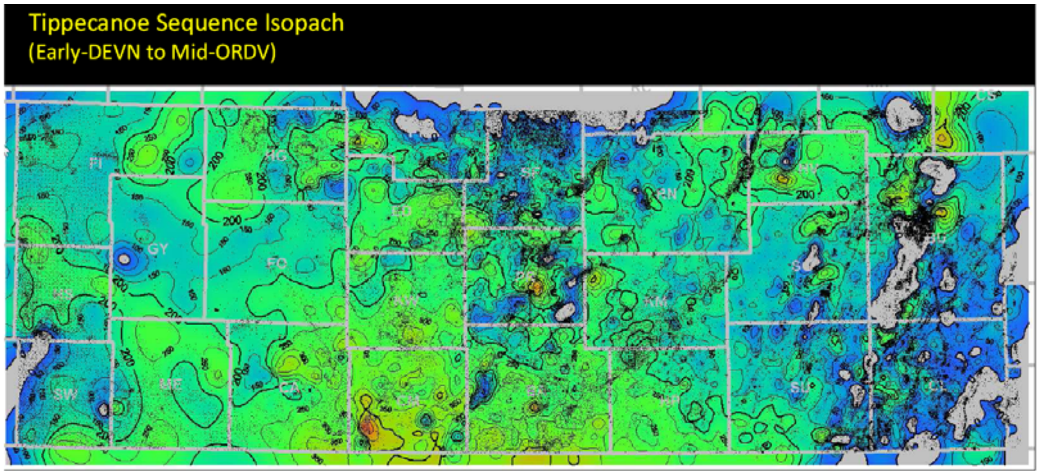


Figure 57. Tippecanoe cratonic sequence of interval between Kaskaskia cratonic sequence (Figure 56) and the Arbuckle including the Simpson Group. Thickening is in south central region bounded by distinct edges trending northwest and northeasterly.

Subtask 17. Acquire (New) Data at a Select Chester/Morrow Field to Model CO2 Sequestration Potential in the Western Annex.
Contribution by Martin K. Dubois, manager of the CO2-EOR component of the Western Annex.

Accompany the characterization of the CO2 sequestration potential of the Arbuckle in the new Western Annex area, a series of proximal Chester/Morrow fields will be examined for their potential for improving oil recovery utilizing CO2 injection.

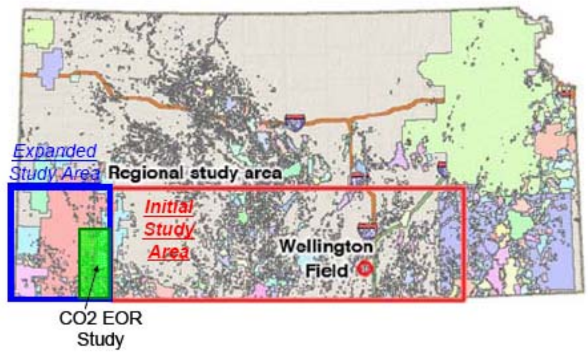
Sequestration has possible future economic benefit to petroleum companies that could also provide the impetus to enhance the potential to utilize anthropogenic CO2 --

- CO2 EOR infrastructure build-out could provide groundwork for sequestered CO2 infrastructure (e.g.: Pipeline ROW)
- Industry providing well and 3D seismic data and access to subsurface necessary for saline aquifer sequestration study
- Development of good relationships between state and federal agencies and petroleum industry (future CO2 sequestration companies)
- Facilitate relationship-building between petroleum industry and anthropogenic sources of CO2

Six oil companies with support from an energy utility are collaborating in this evaluation for CO2-EOR and aquifer CO2 sequestration (Figures 58-59).

Presentation Focus:

CO2 Enhanced Oil Recovery (EOR) part of the “larger” sequestration project



Industry partners:
- Anadarko Petroleum Corp.
- Berexco LLC
- Cimarex Energy Company
- Cisco Energy LLC
- Glori Oil Limited
- Merit Energy Company

Support by:
Sunflower Electric Power Corp.

Formation of Consortium - support Regional CO2 Sequestration Project

- Six petroleum companies with operations in region committed to participate (October 2010)
- Data License Agreements are circulating now – anticipate being in place at start of Budget Period 2
- Letter of support by Sunflower Energy

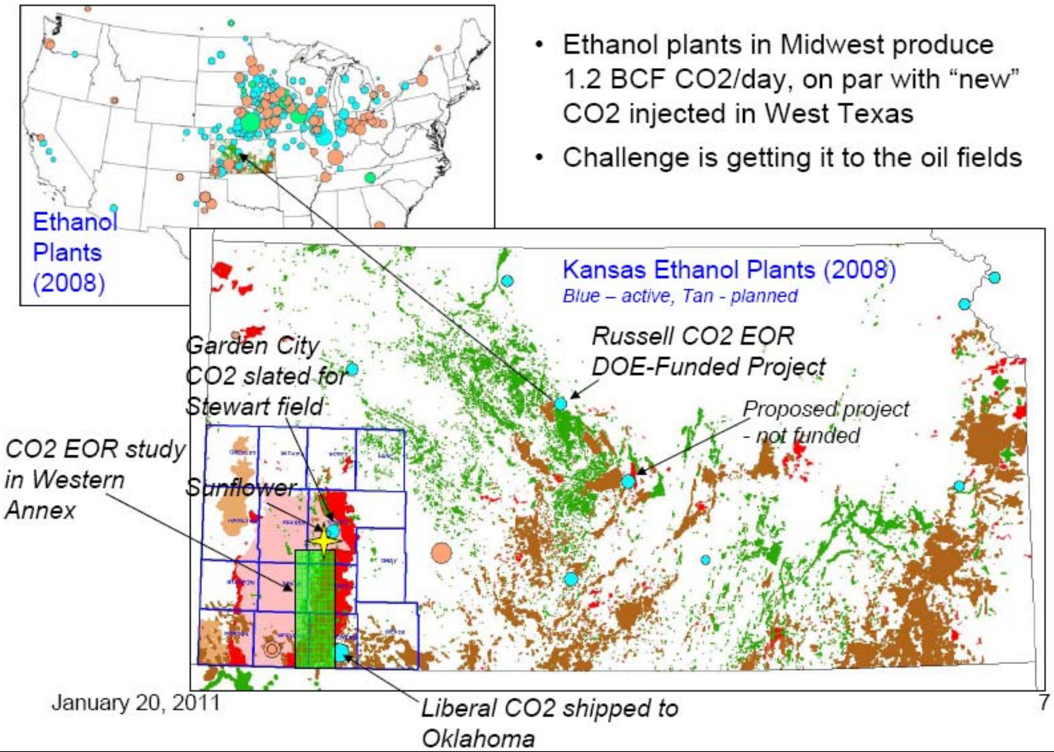
Project Scope (EOR focus)

Overarching Objective:

- Develop technical basis for the study area to be "**CO2 EOR ready**."
- Evaluate potential for Arbuckle saline aquifer to be a future carbon sequestration reservoir.

1. **Form consortium** of operators having assets that may be amenable to CO2 EOR and partner with KGS and DOE.
2. **East side of Hugoton embayment centered around Chester IVF**
3. **Primary targets: Chester and Morrow waterfloods**
   - Pool and integrate data (3D seismic, well, geologic, reservoir, PVT, fluid properties)
   - Fill critical data gaps
   - Stratigraphic test well
   - Multi-component 3D seismic survey
   - Detailed, multidiscipline reservoir model for Morrow and Chester reservoir systems
   - 3D cellular geo- and property models, and history matched compositional simulations for selected candidate fields
   - **Secondary targets:** Other waterfloods (e.g.: L-KC in Victory)
4. **Extend KGS's current DOE-funded Arbuckle saline aquifer study**

Figure 58. Framework for the CO2-EOR initiative in the Western Annex.



- Ethanol plants in Midwest produce 1.2 BCF CO_2/day, on par with "new" CO_2 injected in West Texas
- Challenge is getting it to the oil fields

January 20, 2011

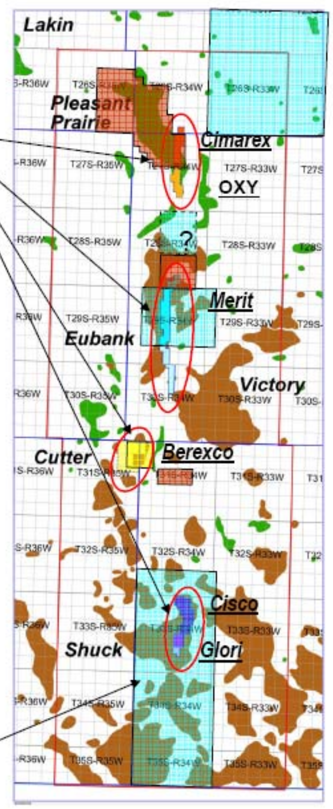
7

Key drivers for project

- Excellent waterflood fields - technically sound candidates for CO_2 EOR
- 24 mmbo produced from four fields to be studied (circled)
- Primary and secondary waterfloods to recover ~40% of OOIP (60 mmbo)
- No single pool nor single oil operator has sufficient oil resource to justify CO_2 infrastructure
- Combined there may be sufficient resource base to justify a project

- Underlying saline aquifer (Arbuckle) is probably an excellent candidate for CO_2 sequestration
- Relatively few penetrations indicate favorable reservoir conditions, but are too widespread to characterize the reservoir with confidence
- Key operators own significant 3D seismic and other proprietary data and agree to partner with the KGS and DOE to characterize the Arbuckle and evaluate the feasibility for concurrent CO_2 EOR and storage in depleted oil reservoirs

- **Object of EOR study** – Make fields "CO_2 EOR ready" by demonstrating technical feasibility.
- **General scope** – Characterize and model the fields and conduct CO_2 EOR and storage forecast through compositional simulations



200 miles of 3D seismic color coded by operator

January 20, 2011

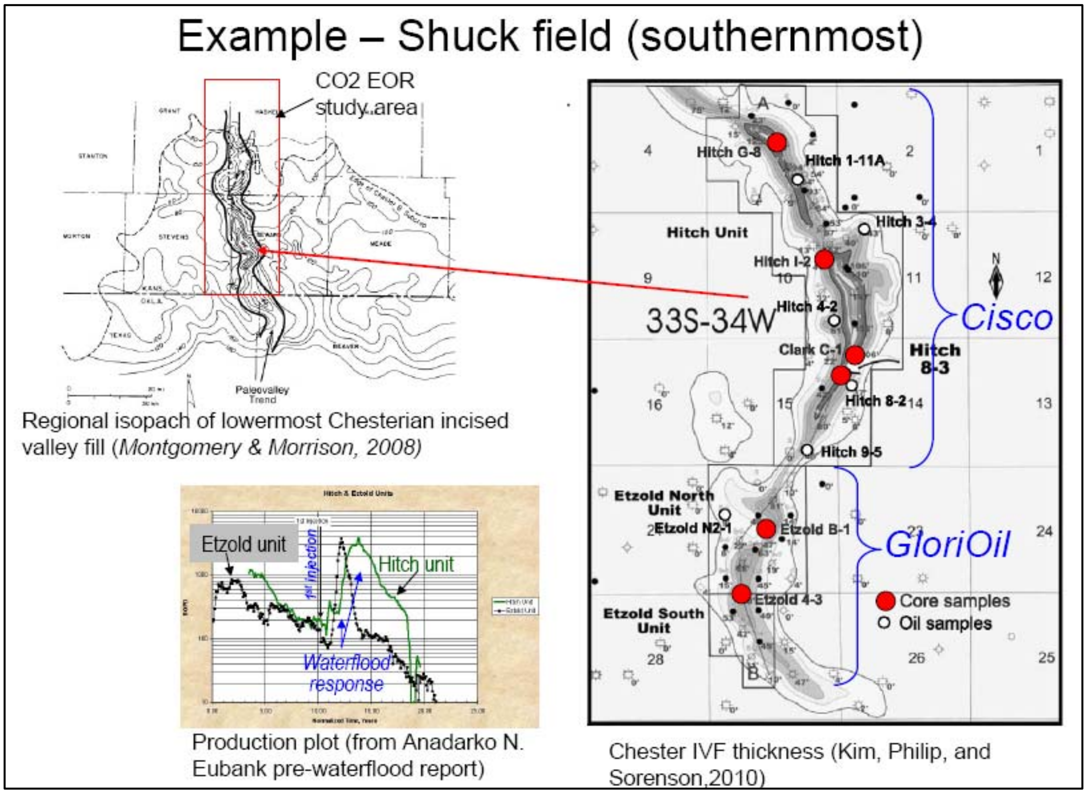


Figure 59. Three part figure (previous page top) showing ethanol plants in midcontinent and vicinity of the Western Annex. Ethanol and fertilizer plants are interested in marketing their CO2. (Previous page bottom) Key drivers for the Western Annex CO2-EOR initiative. (Figure above) Example of geologic and production framework that are favorable towards CO2-EOR recovery – restricted channel form sandstone bodies with good waterflood response.

Partners are committed and data license agreements will be in place by the beginning of Budget Period 2.

- Skilled and experienced technical team, with demonstrated
- ability to work with the KGS and on DOE projects, has been
- assembled
- Discussions and plans for integration of data and technical
- work with the “larger” CO2 sequestration are ongoing
- There is a high likelihood that the project will be successful in
- meeting its objectives

Key Findings

1. Staked two well locations.
2. Web tools for petrophysical analysis are online and ready to work with digital well data.
3. Preliminary seismic interpretations are converging with remote sensing and magnetic and gravity data, which will all play a significant role in the geomodels that, are developed for the Mississippian oil reservoir and the Arbuckle saline aquifer at Wellington Field.
4. New data from test boreholes will introduce the microbial, geochemistry, fluid inclusion, engineering/testing, modern petrophysical logging, and petrography to the database. This will all help to further understanding and constraint of geomodels and aid in framing efforts for simulation of CO2 injection and assessment of capacities. Integrated data will serve as a base of understanding for regional geomodeling efforts.
5. The Arbuckle hydrologic system is taking shape based on findings from analysis of DST data and continuing efforts in regional stratigraphic correlation. Petrophysical analysis of the digital data will now begin in earnest as the digital data become available. This all will further quantify rock and fluid properties of this aquifer system.
6. The access to the project using the website and the interactive project mapper is increasingly serving as an important vehicle to access the complex dataset.

Plans

1. Drill, core, test, log, and complete the two test boreholes in Wellington Field. Berexco KGS Wellington #1-32 has been spudded.
2. Run 2D shear wave surveys at Wellington and process the multicomponent 3D seismic survey for the converted shear wave.
3. Obtain full volume depth migration of the multicomponent 3D survey for input into Petrel.
4. Complete assembly of well production data in Wellington to begin refining Mississippian geomodel and input for simulation.
5. Complete digitizing of well logs, add headers, and upload to database. Make ready for petrophysical analysis.
6. Assemble new well and seismic data from Western Annex and begin geomodel development in Budget Period 2.
7. Additions steps will be taken to establish a workflow to maximize and systematize the integration of the data to aid in developing robust interpretations.

Cost Plan/Status

Costs in the 5th quarter were incurred in Tasks.

COST PLAN/STATUS

Baseline Reporting Quarter	Year 1 Starts: 12/8/09 Q1	Q2	Ends: 2/7/11 Q3	Q4	10/1 - 12/31/10 Q5
Baseline Cost Plan (from SF-424A)	(from 424A, Sec. D)				
Federal Share	$1,273.10	$330,271.41	$330,271.41	$1,302,953.72	
Non-Federal Share					
Total Planned (Federal and Non-Federal)	$1,273.10	$330,271.41	$330,271.41	$1,302,953.72	
Cumulative Baseline Cost	$1,273.10	$331,544.51	$661,815.92	$1,964,769.64	
Actual Incurred Costs					
Federal Share	$4,019.93	$84,603.97	$494,428.37	$111,405.52	$238,618.77
Non-Federal Share				$84,564.82	
Total Incurred Costs-Quarterly (Federal and Non-Federal)	$4,019.93	$84,603.97	$494,428.37	$195,970.34	$238,618.77
Cumulative Incurred Costs	$4,019.93	$88,623.90	$583,052.27	$779,022.61	
Variance					
Federal Share	$2,746.83	-$245,667.44	$164,156.96	-$1,191,548.20	$238,618.77
Non-Federal Share				$84,564.82	
Total Variance-Quarterly Federal and Non-Federal)	$2,746.83	-$245,667.44	$164,156.96	-$1,106,983.38	$238,618.77
Cumulative Variance	**$2,746.83**	**-$242,920.61**	**-$78,763.65**	-$1,185,747.03	-$947,128.26

SCHEDULE/MILESTONE STATUS

Milestone	Planned Completion Date	Actual Completion Date	Validation
FOA Milestone: Updated Project Management Plan	3/31/2010	03/31/10	Completed
HQ Milestone: Kick-off Meeting Held	3/31/2010	03/31/10	Completed
FOA Milestone: Submit Site Characterization Plan	5/28/2010		
HQ Milestone: Semi-Annual Progress Report on data availability and field contractors	9/30/2010		
HQ Milestone: Annual Review Meeting attended	3/31/2011		
Milestone: Annual Review Meeting attended	3/30/2012		
FOA Milestone: Notification to Project Manager that reservoir data collection has been initiated	9/15/2010	01/01/10	Completed
HQ Milestone: Begin collection of formation information from geologic surveys and private vendors	9/30/2010	01/01/10	Started
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	8/3/2010		
FOA Milestone: Notification to Project Manager that well logging has been completed	8/3/2010		
HQ Milestone: Establish database links to NATCARB and Regional Partnerships	12/31/2010		
FOA Milestone: Notification to Project Manager that activities to populate database with geologic characterization data has begun	12/31/2010		
FOA Milestone: Notification to Project Manager that actvities on the lessons learned document on site characterization have been initiated	7/15/2012		
KGS Milestone 1.1: Hire geology consultants for OPAS modeling	**3/31/2010**	03/31/10	Completed
KGS Milestone 1.2: Acquire/analyze seismic, geologic and engineering data - Wellington field	**6/30/2010**	06/30/10	90% Completed*
KGS Milestone 1.3: Develop initial geomodel for Wellington field	**9/30/2010**	09/30/10	Completed
KGS Milestone 1.4: Locate and initiate drilling of Well #1 at Wellington field	**12/31/2010**	12/30/10	Completed
KGS Milestone 2.1: Complete Well#1 at Wellington - DST, core, log, case, perforate, test zones	**3/31/2011**		
KGS Milestone 2.2: Complete Well#2 at Wellington - Drill, DST, log, case, perforate, test zones	**6/30/2011**		
KGS Milestone 2.3: Update Wellington geomodels - Arbuckle & Mississippian	**9/30/2011**		
KGS Milestone 2.4: Evaluate CO2 Sequestration Potential of Arbuckle Group Saline Aquifer - Wellington field	**12/31/2011**		
KGS Milestone 3.1: CO2 sequestration & EOR potential - Wellington field	**3/31/2012**		
KGS Milestone 3.2: Characterize leakage pathways - Risk assessment area	**6/30/2012**		
KGS Milestone 3.3: Risk assessment related to CO2-EOR and CO2-sequestration	**9/30/2012**		
KGS Milestone 3.4: Regional CO2 Sequestration Potential in OPAS - 17 Counties	**12/7/2012**		