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

<table>
<tr><td colspan="1">1. Identification Number:
DE-FE0002056</td><td colspan="3">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</td></tr>
<tr><td colspan="4">3. Recipient:
University of Kansas Center for Research</td></tr>
<tr><td>4. Reporting Requirements:</td><td>Frequency</td><td>No. of Copies</td><td>Addresses</td></tr>
<tr><td>**A. MANAGEMENT REPORTING**
☒ Progress Report
☒ Special Status Report</td><td>Q
A</td><td>Electronic Version to NETL></td><td>FITS@NETL.DOE.GOV</td></tr>
<tr><td>**B. SCIENTIFIC/TECHNICAL REPORTING ***
(Reports/Products must be submitted with appropriate DOE F 241. The 241 forms are available at https://www.osti.gov/elink)
Report/Product — Form
☒ Final Scientific/Technical Report — DOE F 241.3
☒ Conference papers/proceedings/etc.* — DOE F 241.3
☐ Software/Manual — DOE F 241.4
☒ Other (see special instructions)
Topical — DOE F 241.3
* *Scientific/technical conferences only*</td><td>FG
A

A</td><td>Electronic Version to E-link></td><td>http://www.osti.gov/elink-2413
http://www.osti.gov/elink-2413
http://www.osti.gov/estsc/241-4pre.jsp</td></tr>
<tr><td>**C. FINANCIAL REPORTING**
☒ SF-425, Federal Financial Report</td><td>Q, FG</td><td>Electronic Version To NETL></td><td>FITS@NETL.DOE.GOV</td></tr>
<tr><td>**D. CLOSEOUT REPORTING**
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FC</td><td>Electronic Version To NETL></td><td>FITS@NETL.DOE.GOV</td></tr>
<tr><td>**E. OTHER REPORTING**
☒ Annual Indirect Cost Proposal
☒ Annual Inventory Report of Federally Owned Property, if any
☐ Other</td><td>A
A</td><td>Electronic Version To NETL></td><td>FITS@NETL.DOE.GOV</td></tr>
<tr><td>**F. AMERICAN RECOVERY AND REINVESTMENT ACT REPORTING**
☐ Reporting and Registration Requirements</td><td></td><td></td><td>http://www.federalreporting.gov</td></tr>
<tr><td colspan="4">**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.</td></tr>
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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

Third Quarter Progress Report

Date of Report: 10/30/2010

Period Covered by the Report: July 1, 2010 through September 30, 2010

Contributors to this Report: Saibal Bhattacharya, Saugata Datta, John Doveton, Paul Gerlach, Tom Hansen, Dennis Hedke, Robert Hefner, Mike Killian, Dave Koger, Randy Koudele, Abdelmoneam Raef, Jen Roberts, Jason Rush, Aimee Scheffer, John Victorine, Lynn Watney, Dana Wreath

EXECUTIVE SUMMARY

The project "Modeling CO_2 Sequestration in Saline Aquifer and Depleted Oil Reservoir to Evaluate Regional CO_2 Sequestration Potential of Ozark Plateau Aquifer System, South-Central Kansas" is focused on the Paleozoic-age Ozark Plateau Aquifer System (OPAS) in south-central 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 a 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.

Project Status: Subtasks completed till date include: 1) 3D seismic survey at Wellington field (Sumner County, KS) processed, 2) newly collected Wellington field seismic data merged with donated 3D seismic data from the adjacent Anson and Bates fields, 3) geologic horizons identified from initial analysis of Wellington 3D seismic data, 4) two (alternate) locations have been selected from analysis of 3D seismic data based on high structure and distance from possible fractures, 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) Arbuckle, Mississippian, Heebner structure 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 at one selected multi-township area centered around Oxy-Chem #10 well, 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, and 12) website has been updated to include maps of latest subsurface geology, remote sensing analysis, and reprocessed gravity and magnetic information.

ACCOMPLISHMENTS

Methods/Approach

The project will characterize the Ozark Plateau Aquifer System (OPAS), which includes the Mississippian chert/dolomite (chat) reservoirs, and the underlying Arbuckle Saline Aquifer System, in an area covering approximately 17 counties in south-central Kansas in order to estimate its potential for CO_2 sequestration. The major objectives of this project include a) estimation of the CO_2 sequestration potential (tonnage) in the deep saline Arbuckle Saline Aquifer System underlying a 17+ county area in south-central Kansas using an integrated geomodel and reservoir simulation studies, b) estimation of the CO_2 sequestration potential and incremental oil production through implementation of CO_2-EOR in the depleted Wellington oil field in Sumner County, Kansas, c) risk analysis by modeling the development, migration, containment, and long-term fate of free-phase CO_2 plume using flow-unit specific petrophysical and geochemistry data, and d) technology transfer of acquired knowledge.

Phase 1 (Year 1) of the project consists of data collection and geomodel development to build a regional geomodel for the Arbuckle Saline Aquifer System over a 17+ county area and a local geomodel for the Wellington field. Well data will be electronically "mined" and digitized to build a regional Arbuckle Aquifer geomodel that will be in part validated by comparing and integrating it within a larger geomodel being developed to evaluate a Midcontinent-scale petroleum system as part of the USGS's Anadarko Basin Resource Assessment Project. Structural, isopachous, rock properties and their derivative information will be mapped and analyzed in the context of reprocessed regional gravity and magnetic data to characterize stratigraphy and lithofacies of the Paleozoic strata, in particular the Pre-Pennsylvanian. Recent high resolution satellite imagery will be compiled and interpreted to identify and substantiate major structural features and compared with subsurface data including attributes of the Arbuckle Saline Aquifer System to help establish and corroborate compartments. Significant compartments will be identified for more detailed characterization and modeling.

At the Wellington field, surveys including high-resolution gravity/magnetic, a ~11 mi^2 3D multicomponent seismic, and two 4 mi long 2D shear wave seismic surveys will be collected, two new wells will be drilled and logged, including one cored from the Pennsylvanian caprock to the basement, and selected flow-units will be tested for pressure and fluid samples in both of the newly drilled wells. Geochemical analysis will be carried out on flow unit specific water samples along with studies of diagenetic history of fracture fill to determine cap rock integrity and fluid migration through aquifer in general. The newly collected data will be integrated with existing data from the regional study area to build a database of flow-unit specific petrophysical properties and water geo-chemistry. Also, a local geomodel for the Wellington Mississippian depleted oil field and the underlying Arbuckle Saline Aquifer System will be developed.

Major Activities – 4th Quarter

REGIONAL STUDY

Figure 1 outlines the 17+ counties comprising the regional study area.

Subtask 2.2 Acquire geologic, seismic, and engineering data:

A Geotech was hired early July 2010 to help acquire regional data.

Wireline Log Digitizing: Wireline logs from super type and type wells continue to be digitized into LAS (Log ASCII) format and now include 90 Supertype wells that were drilled post 1980 and penetrated Arbuckle to depths greater than 400 ft. Approximately 1400 type wells with penetrations less than 400 ft into Arbuckle have been queued for digitizing. Stratigraphic correlations have been extended to the Upper Pennsylvanian Heebner Shale.

Well Plugging Database: Completion and plugging status of wells within a 10-mile radius around Wellington Field in Sumner County (Figure 1) are being compiled to use in risk appraisal.

Sample Descriptions: Descriptions of sample cuttings are being transcribed into ASCII format for key wells in the regionally mapped area to 1) aid in stratigraphic, lithologic, and facies correlations, 2) confirm lithologies interpreted from well logs, or 3) provide lithologic information when log information is insufficient to interpret lithology, and 4) to provide additional information on rock texture and comments to help assess the nature of caprocks and aquifers. Initially, “Davies” sample descriptions (Figure 2) are being converted to ASCII format to be displayed graphically with the wireline log data. Davies log formats were consistently followed over the course of several decades in the 1950’s and 1960’s prior to the widespread use of wireline logs. Thus these data compliment the wells with wireline logs. Approximately 2/3rd of 155 of the Davies logs of deeper wells that were drilled within the regional study area have been inventoried, scanned, and converted to ASCII format for use in our Well Profile and Cross Section Java applications accessible through the interactive project mapper. Additional sample descriptions/georeports for more recent wells identified as Supertype and Type logs will similarly be converted to ASCII format for use in our analyses.

Subtask 2.3 Develop regional correlation framework and geomodel:

Geologic horizons in Arbuckle are being correlated and mapped along with identification of potential faults/fractures. Structure and isopach maps of adjacent strata have been mapped to provide additional context including latest isopachous maps of the Kaskaskia and Tippecanoe cratonic sequences as defined in stratigraphic context in Figure 3. The cratonic sequences provide a prospective of the changing depositional framework between major craton-wide unconformities that comprise the Ozark Plateau Aquifer System above the lowermost Arbuckle Group. Tippecanoe cratonic sequence isopachous contours is shown as colored contours within the project interactive mapper (Figure 4, upper) and as color-fill contour map with well control in Figure 4 (lower). Kaskaskia cratonic sequence isopachous map is shown in Figure 5 (upper and lower).

Major stratal correlations will continue to be developed including correlation of entire supertype wells. These correlations will be accessible through the interactive mapper. Cross sections with interpreted digital logs will replace the scanned images as shown in cross section in Figure 6. Index map shows super type logs used in stratigraphic cross section that is datumed on the base of the Arbuckle Group, extending across the entire study area from west to east. The mid correlation is the Roubideau Formation and the upper correlation is the top of the Arbuckle.

Class I injection wells in Kansas have been complied into spreadsheet and locations mapped (Figure 7). The injection zone of choice is primarily the Arbuckle Group saline aquifer. Class I wells have a wealth of information that is being methodically scanned and documented for the project. This information will be accessible via the project's interactive map.

Selection of candidate sites to model CO_2 **sequestration potential – in progress**. Regional subsurface mapping to date has led to choosing eight initial sites of interest for more detailed geomodeling and simulation of the deep saline Arbuckle aquifer (see 3rd quarter report). The first simulation exercise has been accomplished at the Oxy-Chem Class I injection site ~20 miles north of Wellington Field in Sedgwick County. The site was selected for modeling due to the wealth of data that is being used to obtain modeling parameters. The model results can also be compared with injection history to verify findings. The site has injection well field with decades of well injection, test, and monitoring data. Moreover, the site has wireline and sample logs of deep basement tests with more recent wells containing modern sets of information. The familiarity of this area with regulators also provides a common ground for discussions and understanding. Structure, isopach, rock and fluid property, and pressures have been developed to run initial test of the modeling. Coring program at Wellington will provide vital information to refine the modeling effort.

Initial geomodeling and simulation results: Plant Site Disposal Well #10 was selected to be the basis to develop a simple geomodel for initial simulation of CO_2 sequestration (Figure 8). Figure 8 is a composite view of the stratigraphic interval including the Ozark Plateau Aquifer System (Mississippian and below) and a portion of the overlying Pennsylvanian strata present in the well. Lithologies are interpreted from the log response and a new feature, a graphical sample log description of the well is included along the right half of the figure, right of the central stratigraphic column. A comparison of the sample/cuttings description put to graphic form compares very closely with the log interpreted lithologies.

A petrophysical flow-unit based geomodel was developed by with further processing of the wireline logs of Well #10 **(Figure 9)**. Computed curves include primary and secondary porosity, apparent cementation exponent, and bulk volume water. All of these variables help to assign the pore type and permeability estimates. Salinity gradient in the Arbuckle is clearly indicated and needs to be factored into simulations. Significant stratification of the Arbuckle Group aquifer is suggested by the contrasting salinity and abrupt variations in silica, and shaly intervals.

Depth-constrained clustering was used to aid in delineation of flow units in Well #10 (Figure 10). The Java routine was built and integrated as a log analysis tool to provide a consistent division of strata based on petrophysical properties. User can set the grouping by the R-squared threshold or providing the number of layers. User has the option to move these into the log analysis side to rename and use as flow units. Correlation between wells with flow unit assignments can be easily carried out.

The petrophysical analysis behind a geomodel is crucial to obtaining a reliable simulation. The in-depth computation and results of the log analysis and flow unit assignment is saved as an LAS 3.0 format (Figure 11). These are ASCII files that can be saved and read so that interested party can see basis of the geomodel and parameters used in the simulation. Access to LAS 3.0 files through the project's interactive map is now being tested where one can point at well and click on the LAS 3.0 in data list and automatically generate the graphic column of the computed log.

The test simulation for CO_2 sequestration was focused around Well #10 as illustrated in the 324 square mile 3D diagram of the geomodel volume (Figure 12). The illustration shows a simple, uniform porosity distribution assigned to each of 7 flow units. The lowermost flow unit defined from the log analysis, JCC-Rou1 was divided into three layers, each with uniform porosity. The Overlying layer JCC1 is a low porosity, low permeability shaly interval and serves as an aquiclude. Similarly, JCC3 is also an aquiclude that is part of the Arbuckle geomodel. The simulated CO_2 injection well is identified in the middle of this geomodel corresponding to Well #10.

Figure 13 shows thickness variation of the five main flow units in the nine townships based on Well #10 and nearby well control. Lower L5 layer was subdivided equally into three layers for the simulation so as to better observe plume behavior within this lowermost aquifer of the Arbuckle Group. Grid cell size is 300 ft.

Injection pressure used in the simulation are less than fracture pressure (<3000 psi) and the period of injection runs from year 2010 to 2060, a typical lifetime of an injection well. The simulator continues to run to observe the fate of the injected CO_2 until the year 2200, i.e., 190 years after initial injection.

Injection rate is a critical aspect of CO_2 sequestration. The depths are great enough in the Arbuckle in southern Kansas so that the CO_2 is injected under supercritical conditions, a highly compressed state acting more as a liquid than a gas. The injection of supercritical fluid in this simulation test was stabilized at 600 tons/day. Total CO_2 injected over the 60 years of injection equaled 10 million tons (Figure 14).

Current limitations of computing power restricted the capability of simulations in 3D for the entire 190 years. Until a more powerful computer arrives, the results are presented in a 2D model. Reduced to one layer deep the flow units were further subdivided to create a 20-layer model to observe in more detail how the CO_2 plume would react to this geomodel construction shown here in Figure 15 as permeability distribution. Permeability was assigned from relating porosity and lithofacies to permeability estimates obtained from previous work at the Kansas Geological Survey (Byrnes et al., 2003). Other parameters assigned to the flow units are summarized in Figure 16 including hydrostatic pressure, fracture pressure, salinity, porosity, and permeability. Depth variation in brine salinity in the Arbuckle Group aquifer is clearly seen in the plot of measured salinity (as total dissolved solids) and depth.

Simulation results for the one cell-wide by 20 layer model of the Arbuckle aquifer is presented as a series of profiles after various stages of CO_2 injection. Figure 17 shows the free phase gas at supercritical conditions after 10 million tons of CO_2 has been injected for 190 years (2200). Note that the free phase, supercritical CO_2 is limited to area within a 2 mile radius. Moreover, the CO_2 plume is trapped within the Arbuckle Group aquifer by the base of the lowermost low permeability (<001 md) aquiclude. The objective is to reduce the size of the free phase as quickly as possible since it is buoyant, can accumulate, and build up pressure beneath a caprock. Trapping the free phase within mid-portion of the Arbuckle within a 2 mile radius of the injector is highly advantageous in that the plume is exposed to fewer wells that may have penetrated the Arbuckle or other possible conduits.

CO_2 is dissolved in solution as a function of salinity and temperature. The test simulation shows the extent of the gas in aqueous phase (as water mole fraction CO_2) after 190 years (Figure 18). Again, the CO_2 in solution is confined beneath the lower aquiclude and within 2 miles of the CO_2 injection well.

A majority of the CO_2 in this simulation is trapped by dynamic trapping in the small pores of the carbonates that comprise a majority of the Arbuckle Group aquifer (Figure 19). Dynamic trapping is also referred to as hysteresis and capillary entrapment whereby residual CO_2 gas is permanently locked away in the smaller pore systems. The amount of CO_2 trapping via this process will not be known until cores are taken and this parameter better defined. The amount trapped in the current simulation is conservative and would likely be higher.

The plot of CO_2 injected over time through 2200 illustrates the cumulative injected CO_2, CO_2 trapped in rock pores, CO_2 dissolved in brine, and supercritical CO_2 (Figure 20). Note the decrease in supercritical CO_2 after injection stops at 2060.

It has been reported that pressure leakage (brine) can occur through an aquitard without CO_2 leakage due to the capillary trapping and immobility of the CO_2 through the caprock. This test simulation shows this phenomenon and suggests that pressures can be dissipated via this loss of brine and may prove to be an important mechanism in managing CO_2 injection and plume dissipation (Figure 21).

In summary, this initial testing of the simulation suggests that the CO_2 plume resulting from commercial scale injection (10 million metric tons) into the Arbuckle Group saline aquifer could be contained within the lower Arbuckle aquifer and within several square miles of the injection well. However, more measurements and refined geomodeling, testing and evaluation are needed.

Subtask 2.4 Subsurface fluid chemistry and flow regime analysis:

Fluid and rock chemistry lab at Kansas State University: Fluid chemistry laboratory is being setup at Kansas State University. Discussions have taken place regarding input needs of CO_2 compositional fluid flow simulator (CMG). Flow chemistry lab measure and simulate into future chemical calculations including mineral species reactions and aqueous species reactions. Reactive surface area, rate constants, and activation energy are important variables that are part of this chemical characterization and modeling. Plugs of the core and fluid samples from the wellsite will be acquired for lab analyses. Analysis of plugs will include X-ray diffraction to determine major mineral content, thin section petrography to characterize texture and pores, and flow cell measurements. Results will be combined with other physical and mechanical measurements being taken by Weatherford Labs. This information will also be integrated with wireline log measurements and displayed in depth using scalable well profile web-based tools.

Open versus closed aquifer system in the Arbuckle – analysis of initial DST data and comparison with hydraulic head at surface exposures of Arbuckle in Missouri: Analysis is ongoing to understand vertical and lateral hydraulic communication within Arbuckle Group saline aquifer system.

DST analyses were collected on over 4000 wells in the regional study area (Figure 22). Some of this data has pressure-time charts and/or lists of pressure and time. Although this has not been done, the pressure data can be plotted on a Horner Plot to determine whether the pressure is stabilized, referred to as P*, or whether the pressure that is recorded is still building. The raw shut-in pressures were initially compiled and analyzed for the Arbuckle Group saline aquifer. Higher pressure are located in the western third of the map where the Arbuckle in deeper. The south-central area has intermediate pressures and the eastern sector has lowest pressures. In plotting the shut-in pressure vs measured depth (lower portion of Figure 22), data points distinguished by mapped region that indicate these areas plot as distinct clusters of points. Essentially, all points lie below a hydrostatic pressure line based on freshwater (0.435 psi/ft) indicative of underpressuring relative to measured depth. Also note that while the mapped areas are distinguished by sets of points, the higher values of each cluster form a trend that roughly parallels the hydrostatic gradient**.** It is usually explained that the scatter of points below this pressure-depth plot are either not stabilized shut-in pressures due to insufficient time or are in error.

Our next step was to assume that the Arbuckle Group aquifer might be in communication with the surface exposures of the Arbuckle in Missouri along the Ozark Uplift. Lowest elevation (+450 ft above sea level) of the surface exposures of the Arbuckle Group occur in central Missouri near Jefferson City in the channel of the Missouri River over 200 miles east of the eastern edge of the study area (Figure 23). Calculated pressures from a column of freshwater at 0.435 psi/ft from the elevation of the surface exposure (450 ft above sea level) to the elevation of the mid-point of the DST intervals was determined to be essentially equal to the observed shut-in pressure or the hydrostatic pressure. The results strongly indicate that the shut-in pressure is related to the depth below the surface exposure of the Arbuckle along the edge of the Ozark Uplift, a considerable distance to the east rather than vertical communication in the subsurface. To illustrate this, the difference was taken between the recorded DST shut-in pressure and the calculated hydrostatic head (Figure 24). The resulting pressure difference is essentially zero.

The implication is that the saline aquifer is connected to surface exposures. Moreover, using a single elevation from the lowest surface exposure of the Arbuckle along the Ozark Uplift to compute difference between the hydrostatic head using freshwater, analogous to Sorenson (2005) approach illustrated in Figure 24, and subtracting this from the DST shut-in pressure produced a resultant map of "zero" with minor deviations due to local pressure/salinity pockets or unstabilized pressure or bad data (Figure 24).

The scatter of data points on the depth-pressure plot (Figure 22) is misleading since the pressure is not tied to surface above the well location, but to the depth to the surface exposure to which it is connected. This is critical knowledge in setting up a simulation model for CO_2 sequestration since we can essentially treat the Arbuckle as an open system. The evaporite Permian caprock above the aquifer system serves to isolate the deep subsurface from the surface hydrologic system. Rather deeper layers communicate laterally with their outcrops. Similar observations have been made by the USGS team studying the Anadarko Basin petroleum system. We are indebted to Phil Nelson and Debra Higley with the USGS for openly sharing their ideas and their methodology. The convergence and consistency of these findings based on Sorenson's (2005) study of gas accumulation and underpressurization of the Hugoton Gas Field gives us confidence that underpressurization of the Arbuckle is the result of hydraulic communication with surface exposures some 200 miles to the east. This confirms that the Arbuckle as an open system.

Thus the question if the Arbuckle saline aquifer in southern Kansas is an open or closed system can be addressed with the following additional observations:

- Arbuckle is the preferred disposal zone for produced oil field brine in Kansas
- No loss of injectivity reported due to increased backpressure after 75+ years of injection
- Majority of Arbuckle hydrocarbon reservoirs produce under strong bottom water drives
- Arbuckle serves as preferred disposal zone for Class 1 hazardous liquid waste
- Routine measurements at observations wells show minimal to no increase in reservoir pressure after decades of injection

The conclusion is that overwhelming evidence supports that the Arbuckle is in general an open system. That does not preclude local areas that are extremely underpressured and pressure depleted in local portions of oil fields on the Central Kansas Uplift located outside of the study area, e.g., portions of Bemis-Shuts Field. Also, local karst and dissolution precipitation events may localize porosity and over short time periods may be considered isolated. These observations need to be considered as the regional sequestration capacity is evaluated and modeled.

Subtask 2.5 Interpret KGS's gravity and magnetic data:

The regional gravity and magnetic data in Kansas have been reprocessed for this project and initial results have been uploaded to the project map (Figure 25). Correlation between basement features mapped from gravity data interpretation with structural mapping and surface lineament mapping (from analysis of remote sensing data) is ongoing, A newly reprocessed map of the gravity and magnetic data is called the tilt angle. The gravity tilt angle map is calculated based on the filtered gravity anomalies. The maps shown here have a 2-10 mile filter applied to them. The zero contour (black line, Figure 26) delineates horizontal locations of edges of mass sources at relative shallow depths. Half the distances between –45 degree and +45 degree contours are depths to the edges shown as the blue band in Figure 26. Positive angles are over relatively high-density areas (white in Figure 26) and negative angles over relatively low-density areas (red in Figure 26).

The map in Figure 26 shows a NW-trending surface lineament crossing Wellington Field. The deep-seated gravity anomaly shown by blue-black trend parallels this. The Mississippian structure exhibits a structural nose that also parallels these surface and basement features. The whole area around Wellington appears to be on an upthrown basement structure according to this processed gravity map (red is lower to the northeast). A NW-SE trending surface lineament set and a positive gravity anomaly correspond and define the southern edge of Wellington Field.

Similarly, the magnetic tilt angle map is calculated based on the filtered magnetic anomalies. The zero contours (black/brown lines in Figure 27) delineate spatial locations of edges of magnetic sources at relative shallow depths. Half the distances between –45 degree and +45 degree contours are depths to the edges (blue band). Positive angles (white) are over relatively high-magnetization areas and negative angles (red) over relatively low-magnetization areas. Wellington Field overlies a high magnetization area.

Figure 28 illustrates ability to zoom out to large map area in the project interactive mapper.

Subtask 14.1 Build and maintain project website:

Project website is regularly updated. New and modified Java web tools are being implemented for log analysis. The project website continues to be developed. The projects interactive mapper now has a new general well profile applet to display interpreted well logs with stratigraphic tops, test, and sample information (Figure 29). The user can access the LAS 3.0 file or run the interactive display of the well profile using this new web-based tool.

The LAS 3.0 was originally proposed as an update to LAS 2.0, with just minor changes to handle additional well log data, such as multiple logging runs. However, the project will use the LAS 3.0 format to allow for expanded flexibility to accurately and completely describe other data types and serve as an ASCII archive of the all of the important well data and interpretations needed for the geomodel development for projects super type and selected type wells.

Reference: http://www.cwls.org/docs/LAS_3_File_Structure.PDF

Required Sections of the LAS 3.0:

First Section: identifies information pertaining the file itself

- Delimiters – Space, Tab, Comma
- No Wrapping of Data

Second Section: Well section – contains data that uniquely identifies the Well bore data.

- Primary Section Types

Parameter Data Sections: Intended to hold one dimensional data that relates in general to one of the data types described.

Column Definition Sections: Intended to hold detailed descriptions (name, unit, etc) of each 2D or 3D channels stored in a Column Data section.

Column Data Sections: Intended to hold 2D and 3D indexed and non-indexed channels.

- User Defined Data – Other types of sections can be defined as the user needs.
  - – Always use the above three primary types whenever possible.
  - –Each Profile Generated Data Parameter Section Contains a Unique Identifier Variable.
- IQKGS: Profile Web App Saved Data Indicator

Data Types I LAS 3.0:

Standard Data Types to be included in the LAS 3.0 files --

- Log Data
- Core Data
- Inclinometry Data
- Drilling Data
- Tops Data
- Perforation Data
- Test Data
  - – Drill Stem Test Data (DST)

Profile Defined Data Types

- Plot Control Data

- Sequence Stratigraphy
- PfEFFER Flow Units
- Geologist Report
- Other Data – Generated from Geologist Report
    - – Rock/Mineral Composition
    - – Lithology/Texture
    - – Porosity Type (Future)
    - – Sedimentary Structures
    - – Fossils
    - – Rock Color
- Depth-Constrained Clustering
    - – Tool to define petrophysically distinct flow units using choice of log combinations
- PfEFFER log analysis and Flow Unit Characterization

A web-based tool for wireline log and petrophysical tool named WELLPROFILE has been developed and is being used in the project.

- Data archiving in LAS 3 (ASCII) format – developed and in use
    - – Archive original log and computed data (including flow-units)
    - – Archive formation tops and sample descriptions

Task 14 Technology Transfer:

Five oral presentations on CO_2 sequestration in saline aquifers and CO_2-EOR were presented during the quarter to industry professionals, public, legislators, and regulators. Abstract has been submitted for April 2011 AAPG Annual Meeting in Houston (Figure 30).

WELLINGTON FIELD STUDY, SUMNER COUNTY, KS

Subtask 3.1 Collect geologic and engineering data:

Well level information continues to be collected at Wellington field including oil and water production, water injection, and well completion/plugging history. This is 80% complete.

Wellington Field Production is also being compiled to aid in calibration and validating the simulation modeling to be done. Berexco’s files, KGS website, Kansas Geological Society and Library Records, and Kansas Corporation Commission files have been used in this compilation.

Well logs have been acquired, scanned, and digitized including Anson-Bates field that adjoins Wellington to the north, the location of donated 3D seismic by Noble Energy. Mississippian core analyses have been digitized to aid in calibrating the well log data and compare to well performance.

Initial mapping of Mississippian reservoir is underway with initial porosity mapping being done using Petrel (Figure 31). Cross-sections and flow-unit identification is underway (Figure 32).

Subtask 3.2 Collect 3D seismic data: Completed.

Multi-component 3D seismic over Wellington Field has been completed.

Subtask 3.3 Process 3D seismic data: P-wave processing completed.

Wellington 3D volume has been merged with donated 3D volume from Anson-Bates field to the north.

Synthetic seismograms have been completed and neural net based estimates of seismic impedence have been done on older non sonic well logs (Figure 33).

Interpretation of merged P-wave seismic volume – This interpretation is underway. Initial mapping includes Mississippian time structure and Mississippian amplitude (Figure 34).

Figure 35 includes an arbitrary seismic section that traverses the high amplitude and high time structure of the Mississippian strata in Wellington Field. Annotations on the cross section identify the top Mississippian carbonate interval, Chattanooga Shale caprock, Arbuckle Group, and the Precambrian basement reflectors. The cross section intersects locations of the two proposed test boreholes. The boreholes reside in what appears to be distinct areas of individually coherent seismic events in the Arbuckle Group. Five Arbuckle seismic reflectors can be traced across the section. The hachured lines on the amplitude map denote an area containing dual reflectors at the top of the Mississippian. These reflectors appear to correspond to the location of thick, high porosity Mississippian reservoir, possibly delimiting the top and bottom of the reservoir. Overall quality of the seismic data is excellent.

A well log of the Peasel #144 used to create the synthetic seismogram (Figure 33) is again shown in Figure 36 to delimit the Chattanooga Shale caprock above the Arbuckle Group. The well log is annotated with five informal internal stratigraphic divisions of the Arbuckle. Below this log is a close-up of Ozark Plateau Aquifer System (pre-Pennsylvanian) as seen in the arbitrary seismic section of Figure 35. Note that a similar number of reflectors are present in seismic section within the Arbuckle and as lithologically distinct units delimited on the well log.

Two slices of the 3D Wellington seismic volume are shown in Figure 37. The upper surface of the Mississippian strata and the approximate top of the Arbuckle Group are shown as surfaces. A porosity fence diagram of the Wellington is shown at the bottom of the seismic image.

Volumetric coherency attribute analysis - started

Subtask 3.4 Collection of gravity data: Completed

Subtask 3.5 Interpret seismic, gravimetric, and magnetic data: Ongoing

Subtask 3.6 Initial geomodeling: Initial structure and porosity models completed

Subtask 4.12. Microbiological studies on produced water: In progress.

MS Student employed as part of this project - Geochemical and microbiological characterization of Wellington Field borehole sediments and fluids is underway. Collected geochemical and microbiological samples in August 2010 from production and injection wells in Wellington field. Microbial abundance and characterization via DNA and culture in progress. Preservation techniques field tested and optimized for core sampling.

PhD Student employed as part of this project - Arbuckle reservoir rocks and regional caprocks, from KGS core library, are being used for preliminary experiments using research grade minerals in CO_2 reactor (Figure 38) in collaboration with the Center for Environmentally Beneficial Catalysis. Minerals chosen are based on the mineralogy of caprocks. Preliminary reactions in combining microbes-CO_2-brine-mineral are being examined including dissolution /precipitation, fracture healing, and dominant metabolic reactions. Collaboration is being planned with NETL lab in Pittsburgh (Figure 39).

This past summer, student interned with the Department of Energy under a Mickey Leland Energy Fellowship. Student was assigned to the Rocky Mountain Oilfield Testing Center (RMOTC) in Casper, WY and worked on a project planning a future CO_2 project: 1) Engineered leak of CO_2 and subsequent monitoring; 2) Selected 2 locations and reservoirs at Teapot dome oilfield for shallow injection of CO_2; 3) Calculated the volume of CO_2 needed for each scenario of the experiment; 4) Identified potential leakage conduits and flagged 2 wells for conversion to injection wells; 5) Injection is tentatively scheduled for Summer 2011.

Subtask 9.4 Inventory of well status:

Well completion data initiated in risk assessment area – Ongoing

Major Findings and Conclusions

Initial simulation results of CO_2 injection are providing insights into the size and behavior of a plume developed from injection of large amounts of CO_2 at supercritical conditions. Initial experiments suggest that CO_2 can be contained in the lower portion of the Arbuckle Group saline aquifer below mid-Arbuckle Group shaly strata that are present in the area of initial modeling. Plume size after injecting 10 million tons of CO_2 is within several miles radius of the injection well. The state-of-the-art simulator being utilized accounts for the major processes that contribute to trapping of the CO_2, including hysteresis/capillary entrapment and solution. Mineralization and dissolution will also be included in the modeling once more is understood regarding the kinetics of the reactions with the mineral assemblages that we have comprising the Arbuckle Group.

The other major factor that appears to allow the lower Arbuckle to accommodate considerable amounts of CO_2 in a relatively small area (beside its considerable thickness and moderate levels of porosity) is treating the injection interval as an infinite aquifer. DST data and analysis indicate that the Arbuckle Group aquifer is connected to its surface exposures several hundred miles to the east. The equilibration to these hydraulic conditions is over millennia and injection occurs over 10's of years so local porosity and permeability is still very important regarding injectivity and accommodation of the plume. However, initial modeling under conditions of an infinite aquifer result in dissipation of the pressure front created by injection soon after injection ceases.

Alternatively, under conditions of a closed system, pressures would build and not dissipate unless fluid was locally displaced, e.g., leakage, or reaction of the CO_2 plume with the aquifer leading to a gradual decline in pressure. A long history of brine injection into the Arbuckle Group in the Midcontinent region supports this open aquifer system.

The other implication of lateral connectivity of the aquifer is that the overlying freshwater aquifers are not connected with the deeper saline aquifers. The Permian evaporite caprock that covers essentially our regional study area serves to isolate the two aquifer systems. Work by USGS and Sorenson (2005) further substantiate our conclusions.

In terms of longer time frame beyond terminating CO_2 injection, the issue becomes dissipating the CO_2 plume by the trapping processes. Plume management, e.g., updip migration and mixing with brine, injecting brine over the top of the injected CO_2, appear to accelerate dissipation of the plume based on published literature. Experiments such as this will be conducted in selected sites in the regional study to determine optimum strategies for injection and dissipation of the CO_2 plume (plume management).

Geomodels that serve as input to the simulation must be refined and the initial test simulations must be tailored more closely to rock and fluid parameters to develop more than these tentative, initial interpretations. The required data will be obtained from a new long core to be taken in Test Borehole #1, from reports on existing Class I injection wells, and assimilation of existing lithologic data. Petrophysical analyses of well log data being digitized from key wells in the region will serve as means to develop and extend refinement of geomodels to the region being studied. Resulting improved parameters will provide more robust simulation results.

Key Outcomes and Other Achievements

Sample descriptions of borehole data provide important information in building geomodels that are tailored to rock properties. Many key wells selected as reference wells in this study have paper sample descriptions. These data are now being transcribed to ASCII format for use in a new feature of our web-based well profile to permit a scaleable graphic lithologic log to be used alongside wireline log descriptions so that rock properties can be optimally assigned using as much data as possible. The ASCII sample descriptions are incorporated into the well's LAS 3.0 file format so that this data is archived and accessible by the user for later examination.

Selection of candidate sites for CO_2 sequestration and initial simulation modeling is underway to begin the process of reviewing the geology that is being compiled and analyzed to evaluate optimum conditions for CO_2 sequestration. Initial simulation modeling is also underway to start the process of understanding the characteristics and behavior of a CO_2 plume under various geological conditions and injection scenarios.

Flow unit modeling has been substantially facilitated and made more robust by implementation of depth-constrained clustering software tool as part of the analytical software suite being used to classify flow units and compute and assemble properties of the aquifer and caprock. This software facilitates modification of the geomodel to accommodate new data or refinements needed in the geomodel.

The **processed 3D seismic volume** at Wellington Field is of excellent quality and augments well data in the field such that the team has been able to choose two locations for the test boreholes. Initial amplitude and structure of the Mississippian reservoir show close agreement between maps based on well and seismic data. The Arbuckle and Precambrian basement reflectors are recognized and five internal reflectors in the Arbuckle Group aquifer have been recognized, but are yet to be correlated and mapped. This seismic resolution within the Arbuckle is very encouraging in that the reflectors appear to closely tie to informal internal stratigraphic/petrophysical subdivisions. The lateral changes in the "coherency" of these reflectors helped serve as the basis for choosing the well locations. These changes will continue to be analyzed through seismic attribute analysis and compared with gravity-magnetics, surface lineaments, and with shear-wave processing of the multicomponent 3D survey yet to be accomplished. Areas between reflector coherency are areas of considerable interest in terms of their serving as possible barriers to flow and being conduits for vertical fluid migration. Shear-wave analysis will give us the opportunity to characterize fracture systems and stress regimes that will factor significantly into evaluating the feasibility and capacity of CO_2 sequestration in the Arbuckle Group saline aquifer beneath Wellington Field.

Cost Plan/Status

Costs in the 4th quarter were incurred in Tasks

Baseline Reporting Quarter	Year 1 Starts: 12/8/09 Q1	Q2	Ends: 12/7/10 Q3	Q4
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
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
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
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
Cumulative Variance	**$2,746.83**	**-$242,920.61**	**-$78,763.65**	-$1,185,747.03

SCHEDULE/MILESTONE STATUS

Milestone	Planned Completion Date	Actual Completion Date	Validation
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	80% 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		
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		

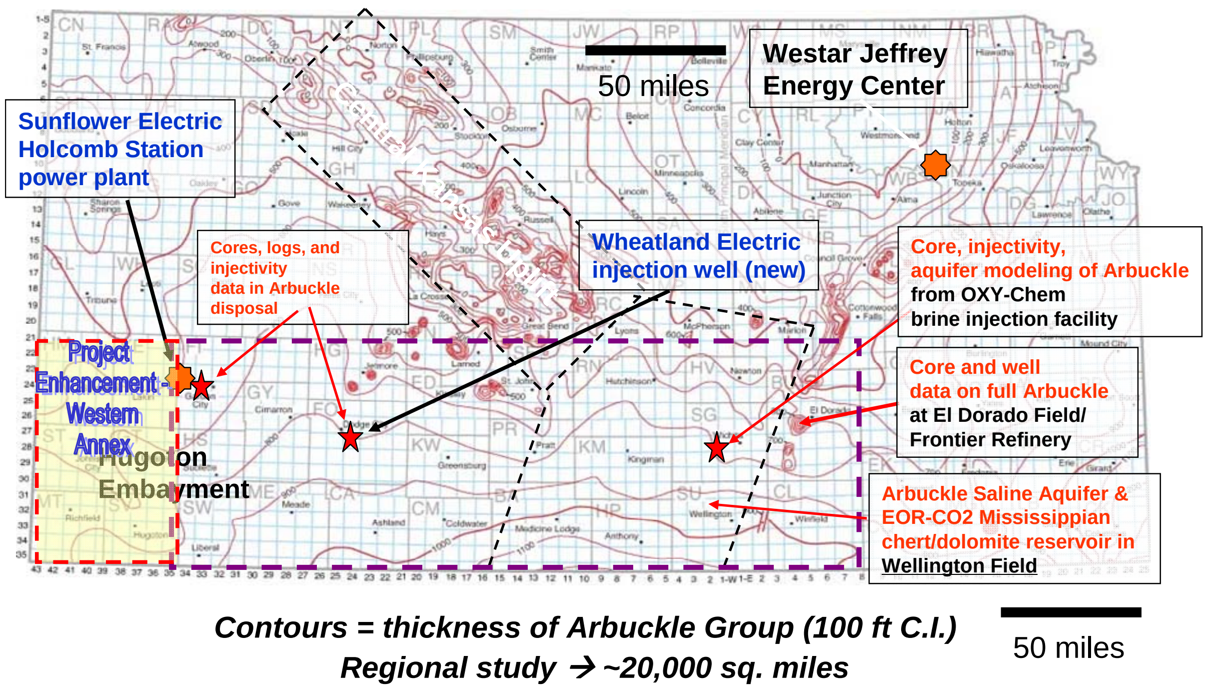

Figure 1. Isopach of Arbuckle Group showing location of regional 20,000 sq. mile study area and location of Wellington Field.

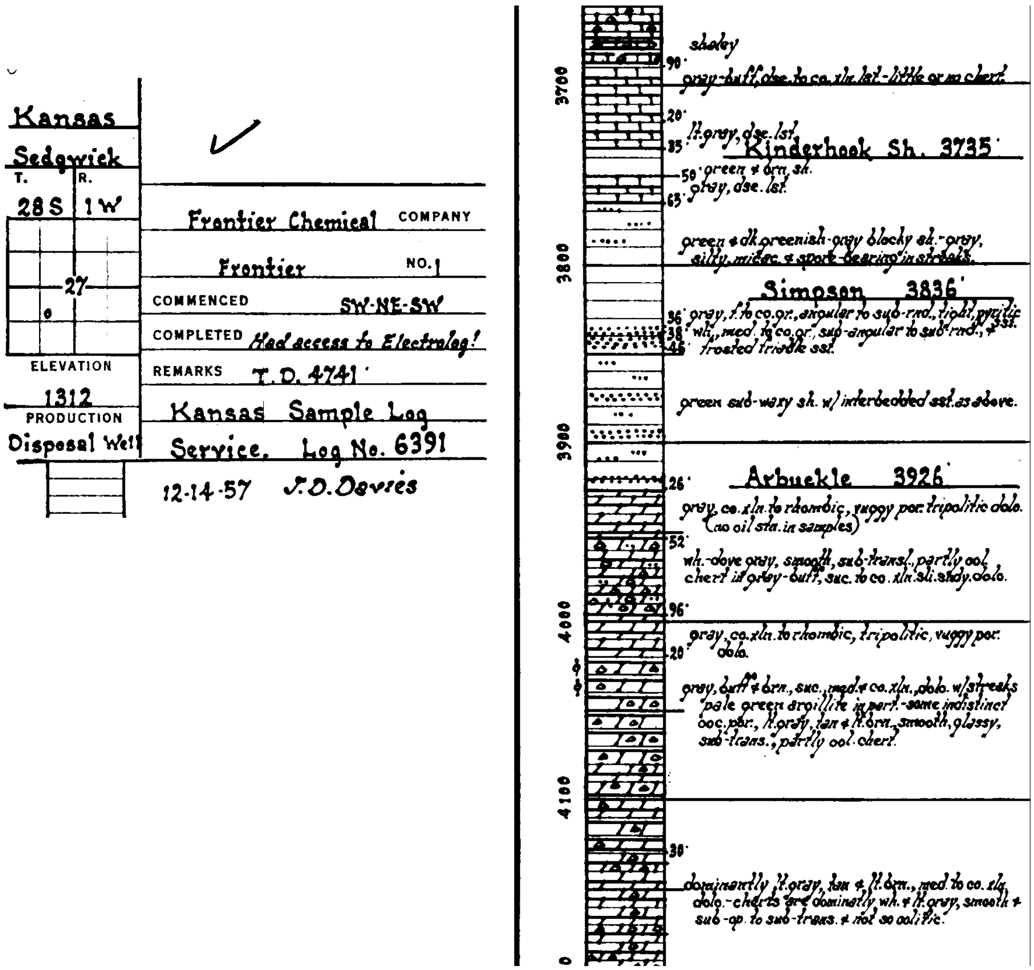

Figure 2. Example of a "Davies" sample log of the Chattanooga caprock (Kinderhook Shale) and upper portion of the Arbuckle Group from disposal well in Sedgwick County.

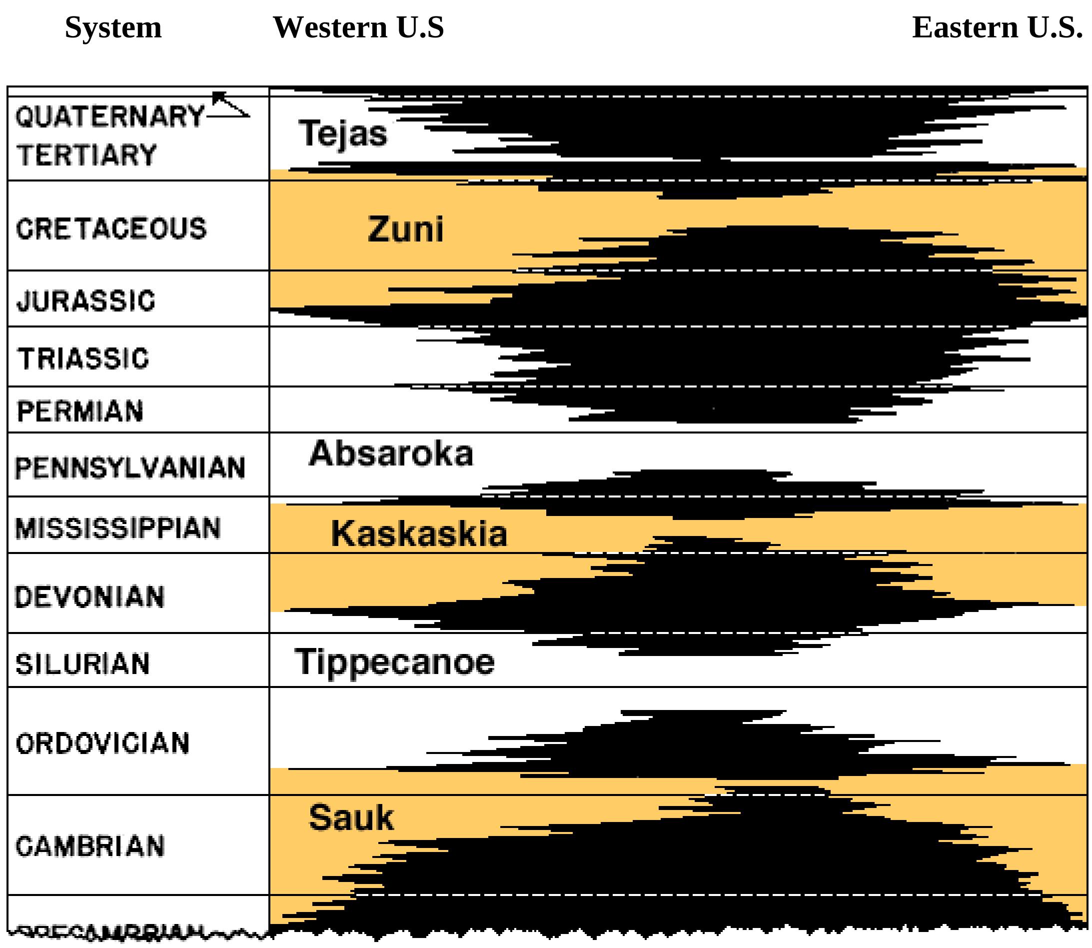

Figure 3. Age and distribution of cratonic sequences via diagrammatic west-to-east cross time-stratigraphic section across the U.S. mainland. Cratonic sequences delineate major sets of strata that lie between major continent-wide erosional/unconformities (Sloss, 1964).

Sloss, L.L., 1964, Tectonic Cycles of the North American Craton by D.F. Merriam, ed., 1964, Symposium on cyclic sedimentation: Kansas Geological Survey, Bulletin 169, pp. 449-459.

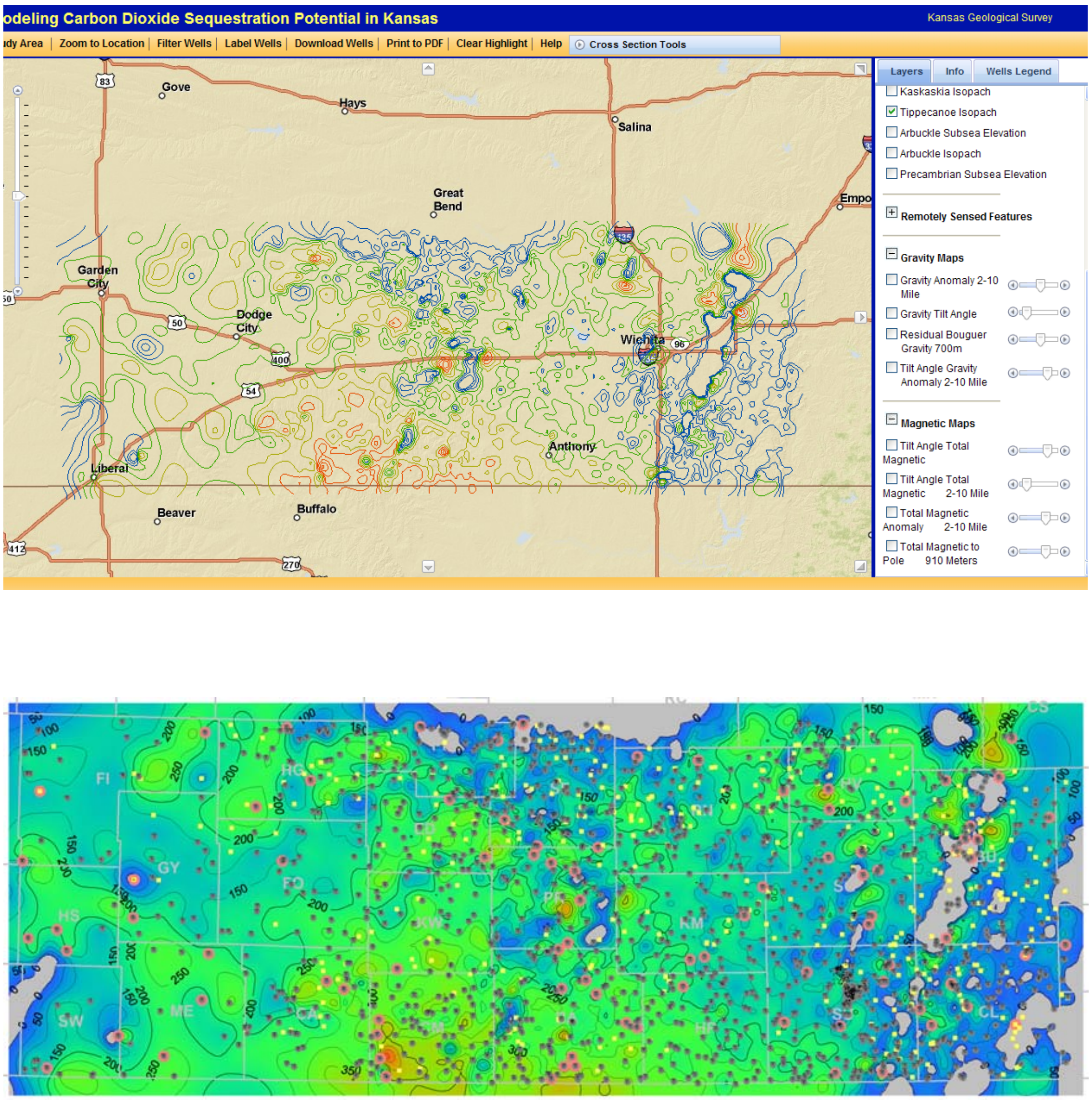

Figure 4. (*Upper)* – Isopachous contours of Tippecanoe cratonic sequence (Lower Ordovician base Simpson Group to Lower Devonian base of Chattanooga/Hunton) shown on interactive mapper. (*Lower*) Color filled version of isopach.

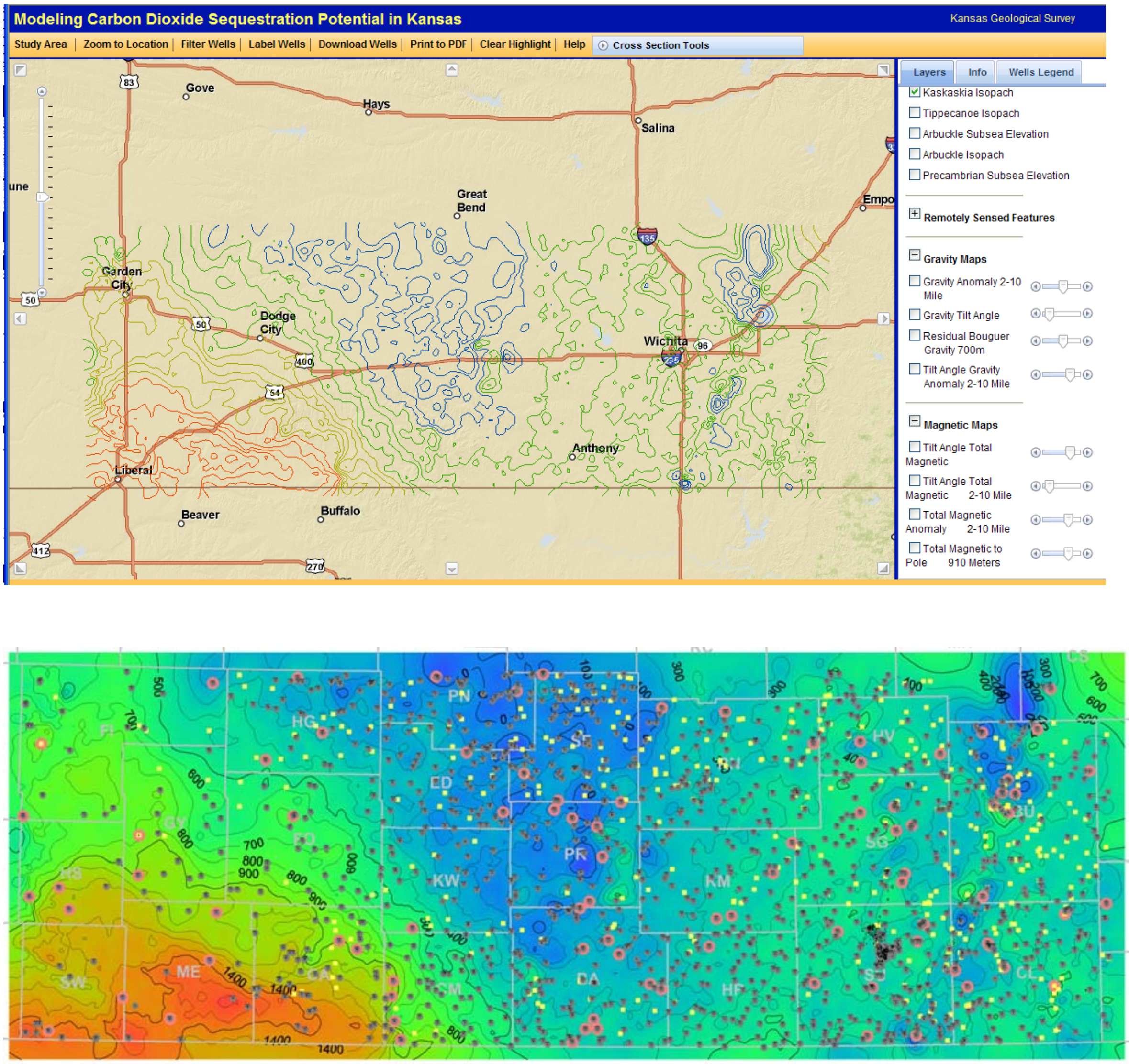

Figure 5. (*Upper*) – Isopachous color contour map of Kaskaskia cratonic sequence (late Devonian base Chattanooga Shale to base of Pennsylvanian) as shown on project interactive mapper. (*Lower*) Color fill isopachous map of map in upper showing well control.

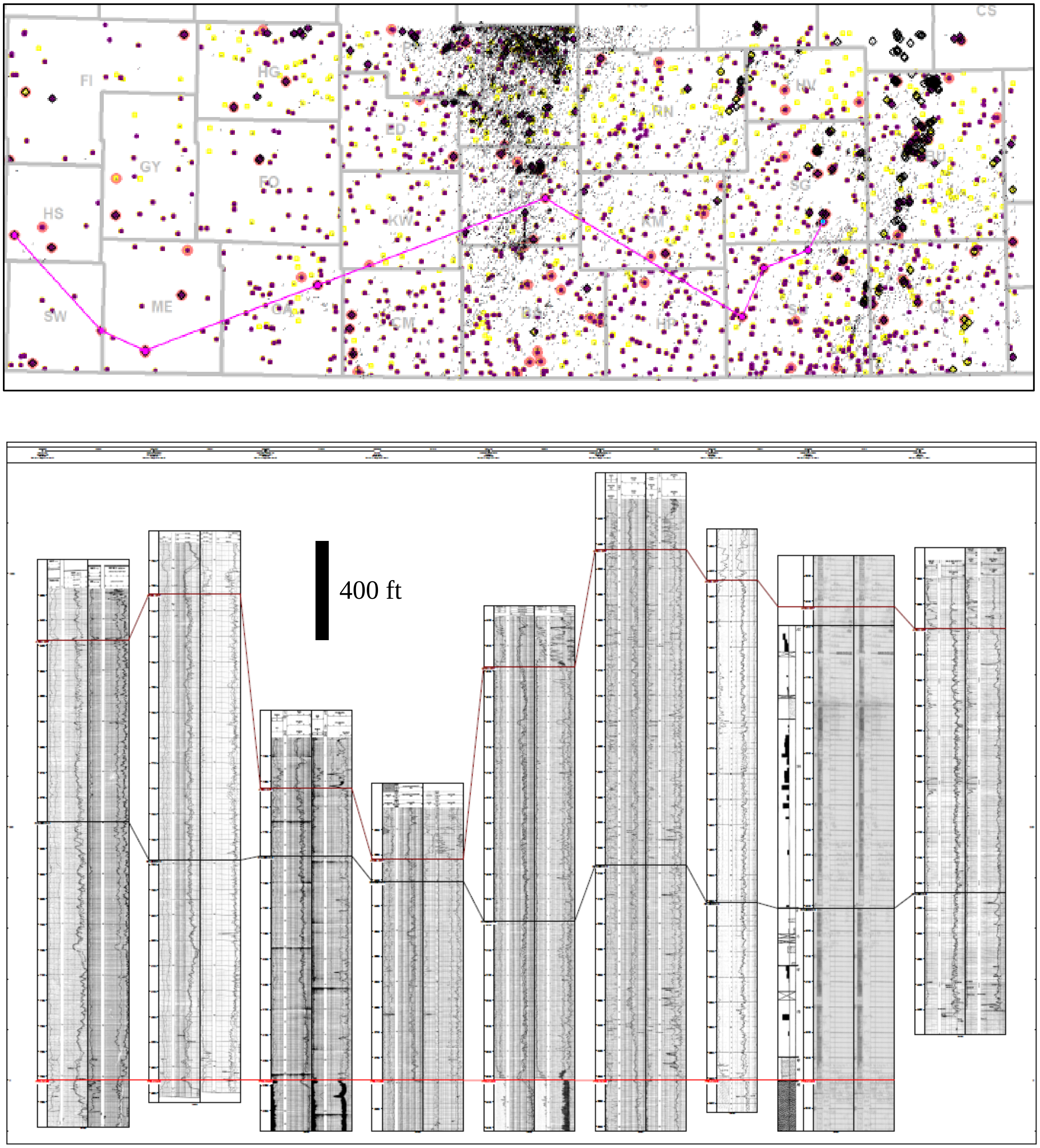

Figure 6. (Upper) Index map of regional study area showing super type wells (pink dots) and type wells (magenta and yellow) and red (Precambrian tests) with line of section for cross section. (Lower) Stratigraphic well log cross section of Arbuckle datumed on based of Arbuckle.

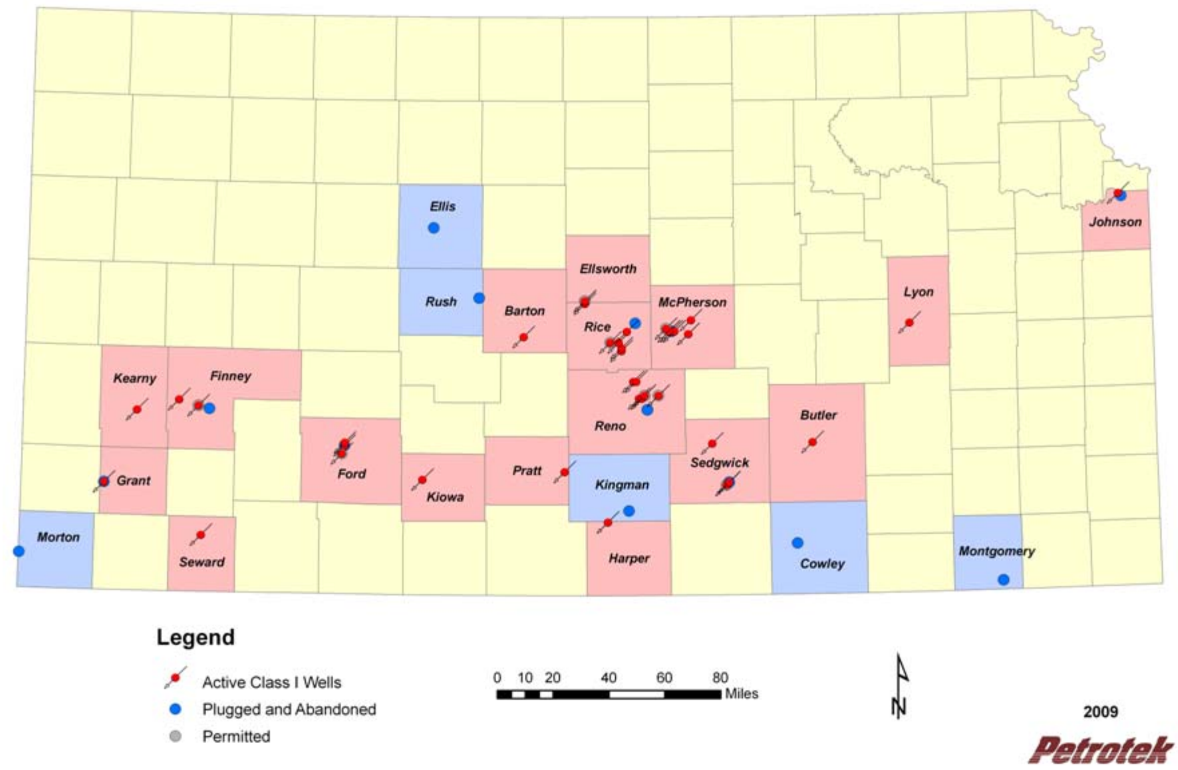

Figure 7. Locations of Class I wells in Kansas.

W100728243202: PLANT SITE DISPOSAL 10

Section: 27 Township: 28S Range: 1W

Operator: VULCAN CHEMICALS   Field: UNKNOWN

SEDGWICK County, Kansas

Latitude: 37.5923   Longitude: -97.4181

Total Depth: 4866.0 Ground Level: 1282.0 Kelly Bushing: 1297.0

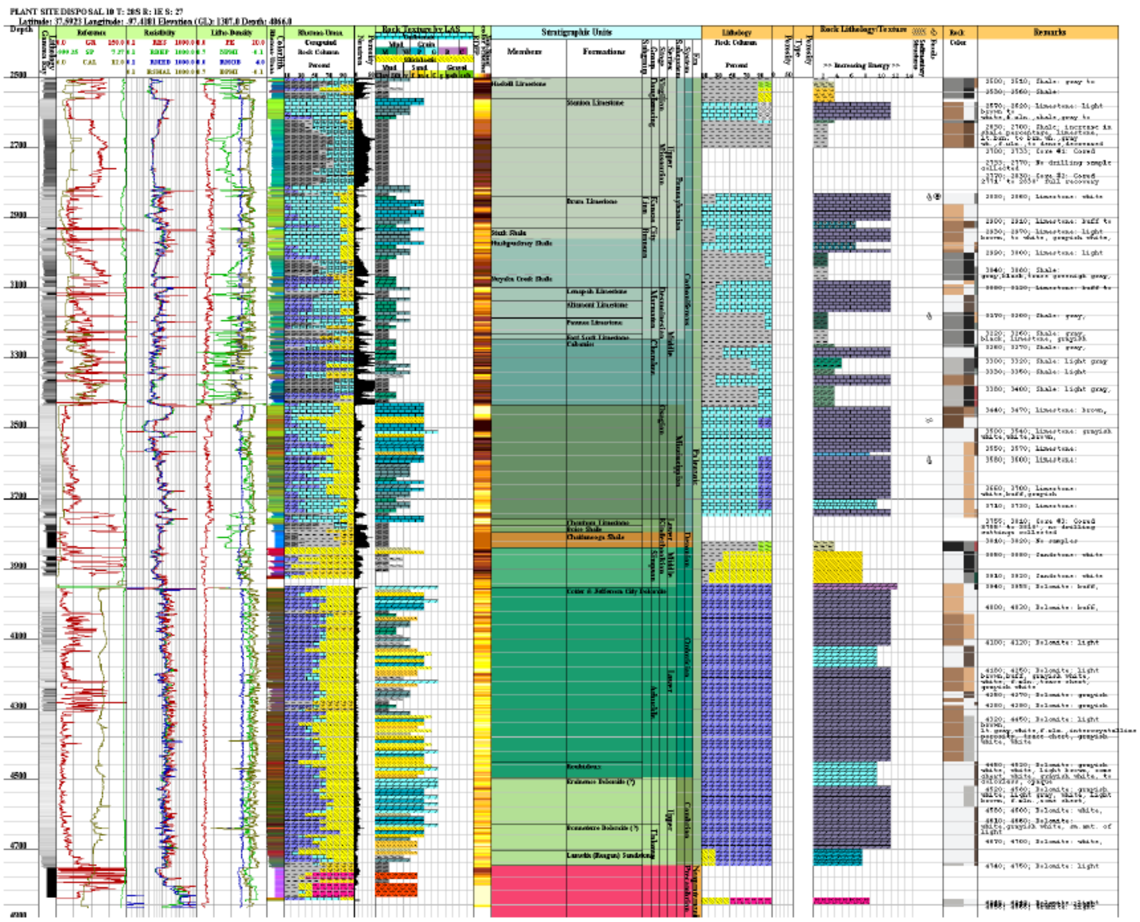

Figure 8. Composite wireline log, stratigraphic correlation, and sample description for the Oxy-Chem Plant Site Disposal Well #10 used to develop rock properties for the geomodel used in initial testing of the CO_2 sequestration simulator.

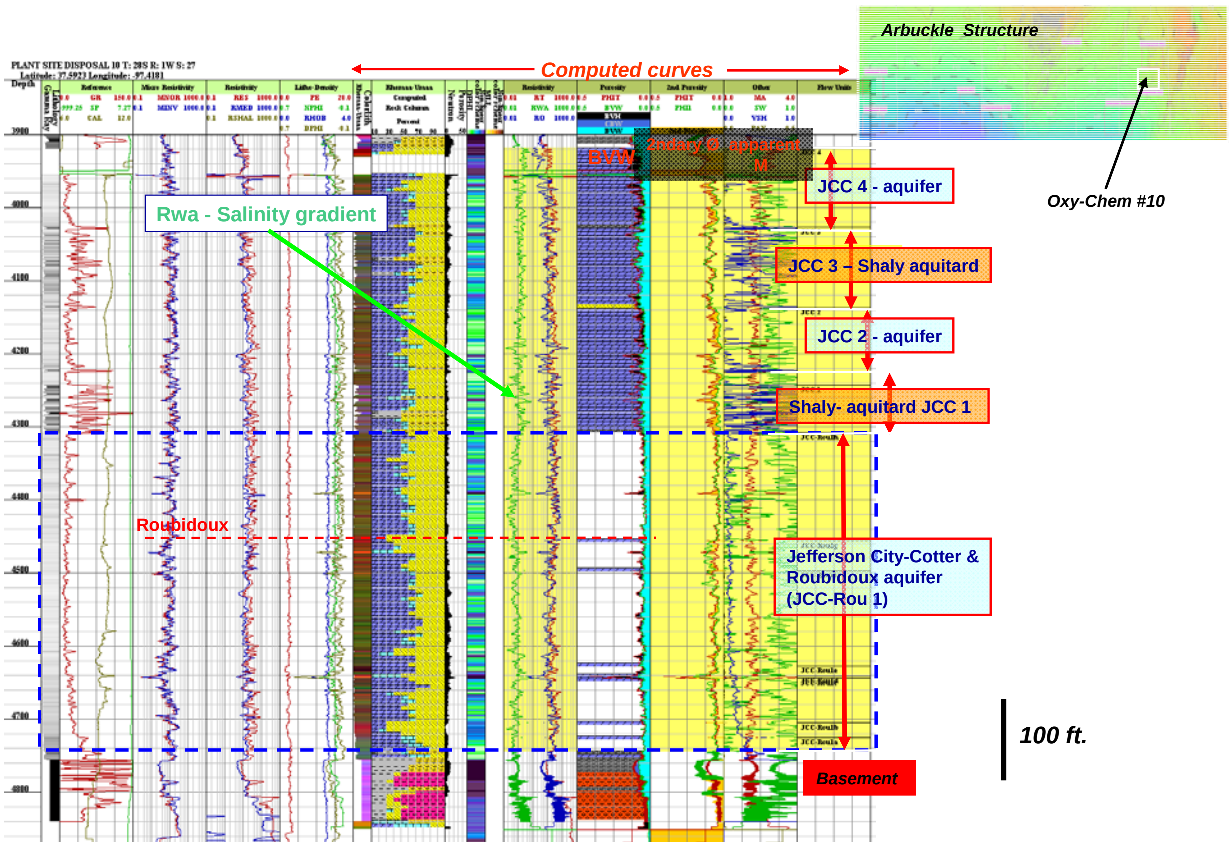

Figure 9. Lithologic and flow unit data for the Arbuckle saline aquifer computed and assigned for Well #10. Provisional aquifer flow units (hydrostratigraphic units) are labeled along the right margin.

Depth-constrained cluster analysis –

Flow Unit subdivision in JCC-Rou1 (Lowermost Jefferson City-Roubidoux)

Divided into 8 layers

Oxy-Chem Brine Disposal Well #10

Cluster Analysis - Group Means

Number of Clusters = 8 R-squared = 50.32 %

Start	End	Group (edit)	GR	PE	DPHI	NPHI	SPHI
4308.0	4456.0	Group 1	17.653	2.549	0.039	0.082	0.039
4456.25	4496.75	Group 2	13.208	2.323	0.065	0.082	0.1
4497.0	4627.0	Group 3	13.259	2.636	0.046	0.117	0.057
4627.25	4641.25	Group 4	15.254	2.02	0.059	0.133	0.07
4641.5	4644.25	Group 5	25.18	2.744	0.459	0.218	0.155
4644.5	4705.25	Group 6	24.371	2.483	0.042	0.099	0.07
4705.5	4725.25	Group 7	32.127	2.193	0.062	0.055	0.057
4725.5	4745.0	Group 8	48.269	3.02	0.018	0.084	0.052

GR Gamma Ray
PE Photoelectric factor
DPHI Density porosity
NPHI Neutron porosity
SPHI Sonic porosity

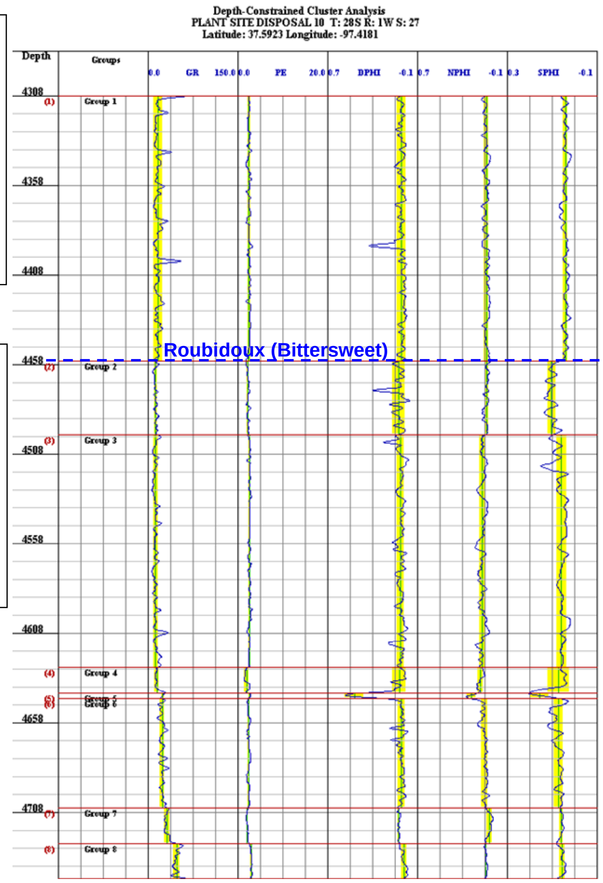

Figure 10. Depth-constrained clustering of Arbuckle Group in Well #10 using gamma ray, photoelectric, neutron, density, and sonic porosity. Red lines delineate the group boundaries and the yellow band represents 1 sigma variation. All curves are factored equally in the assignment.

```
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2_FLUID 2_VSH 2_SH C_PHI C_SW C_VSH C_BVW P Q R V_THK V_FT V_PAY V_PHI V_SW
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999.25",2.8,1.0,"NO",0.0,0.0,"DT",47.5,185.0,"NO",0.0,0.08,0.5,0.3,0.08,8581.0,4.4,2.0,109.0,1533.58,42.5,36.14,0.39
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Flow unit parameters

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 IQKGS .                    : Profile Web App Saved Data Indicator {S}

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 DEPTH .F                    : Depth                     {F}
 THK   .F                  : Thickness                   {F}
 RT    .OHM-M                : Total Resistivity           {F}
 PHIT  .PU                  : Total Porosity             {F}
 VSH   .FRAC                 : V-Shale                   {F}
 PHI1  .PU                  : 1st Porosity              {F}
 PHI2  .PU                  : 2nd Porosity               {F}
 RWA   .OHM-M                 : Water Resistivity            {F}
 RO    .OHM-M                : Water Saturated Rock Resistivity {F}
 MA    .FRAC                 : Archie Cementation          {F}
 SW    .FRAC                 : Water Saturation           {F}
 BVW   .PU                  : Bulk Volume Water           {F}
 PAY   .F                  : Pay                        {F}

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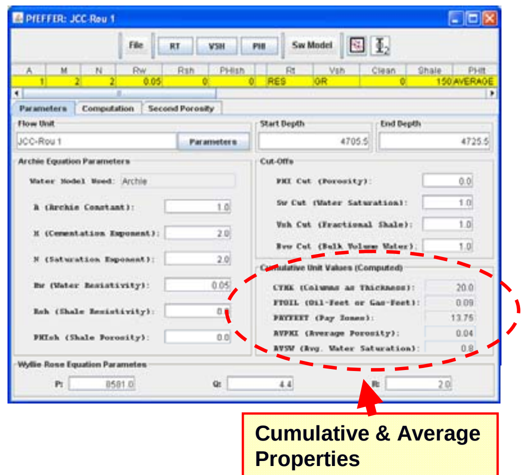


0.25 ft log analysis

Figure 11. Example of an LAS 3.0 file containing original LAS 2.0 from wireline logs and computed flow unit information for use as an archive documentation of information used to develop the flow unit.

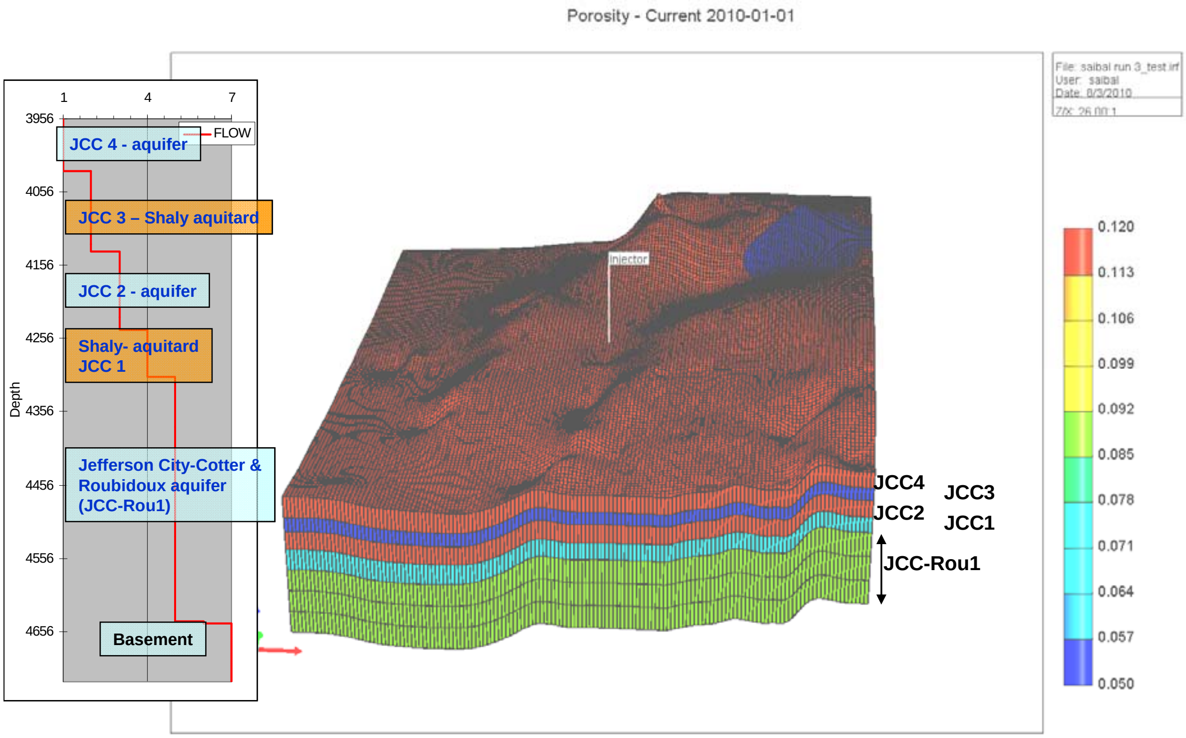


Figure 12. 3D geomodel showing structure and porosity distribution within the seven flow units of this nine township sized (324 sq. mi) volume in the vicinity of Well #10 (center of geomodel). Well #10 serves as the simulated CO_2 injection well in the test. The flow unit breakdown in the depth profile on the left margin is based on the Disposal Well #10 (Figures 9 and 10). Rock property information used in this initial modeling exercise is derived from Disposal Well #10 including porosity.

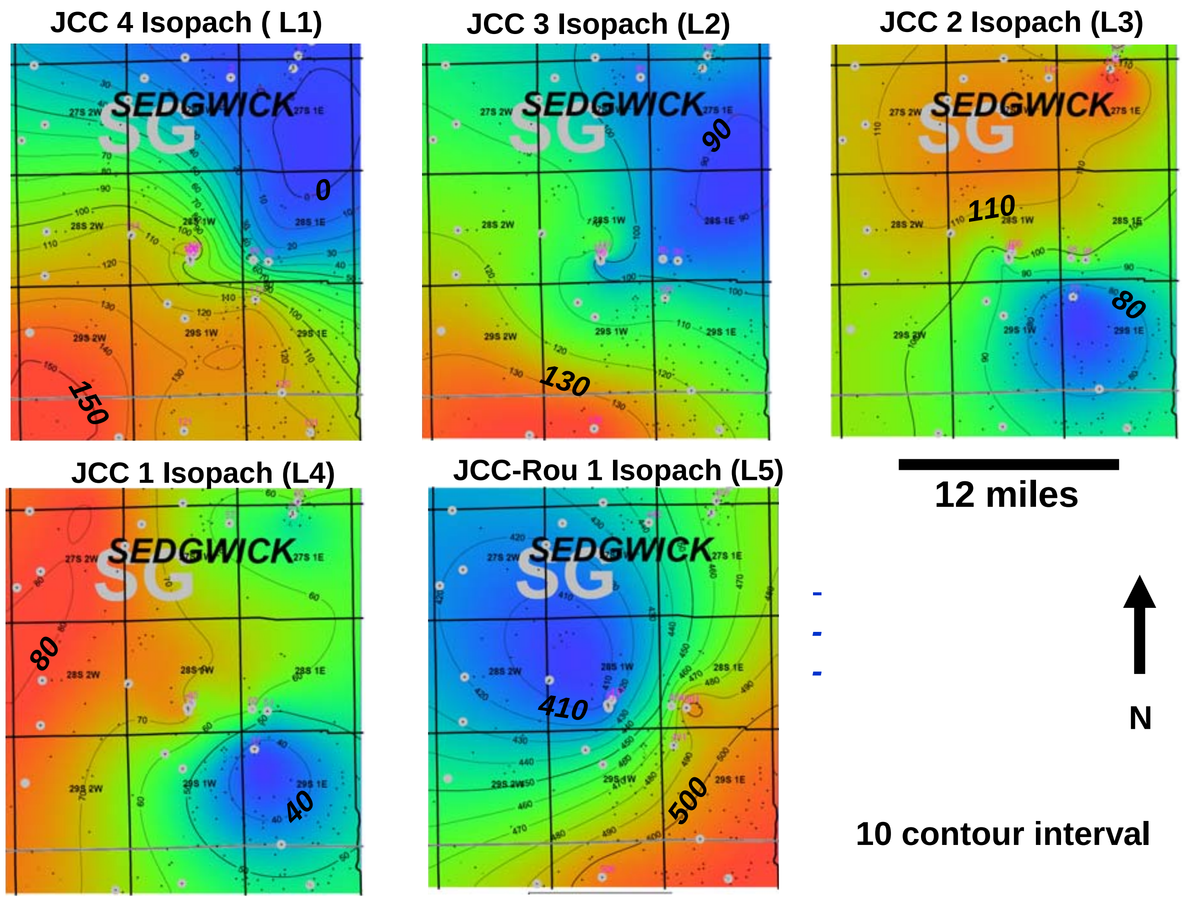


Figure 13. Information from five flow units were input into simulation including thickness data shown here. Thicknesses are derived from correlation of flow units to available well control in the area. Area covers 9 townships covering 324 sq. mi. Size of grid cells in this initial simulation are 330 ft.

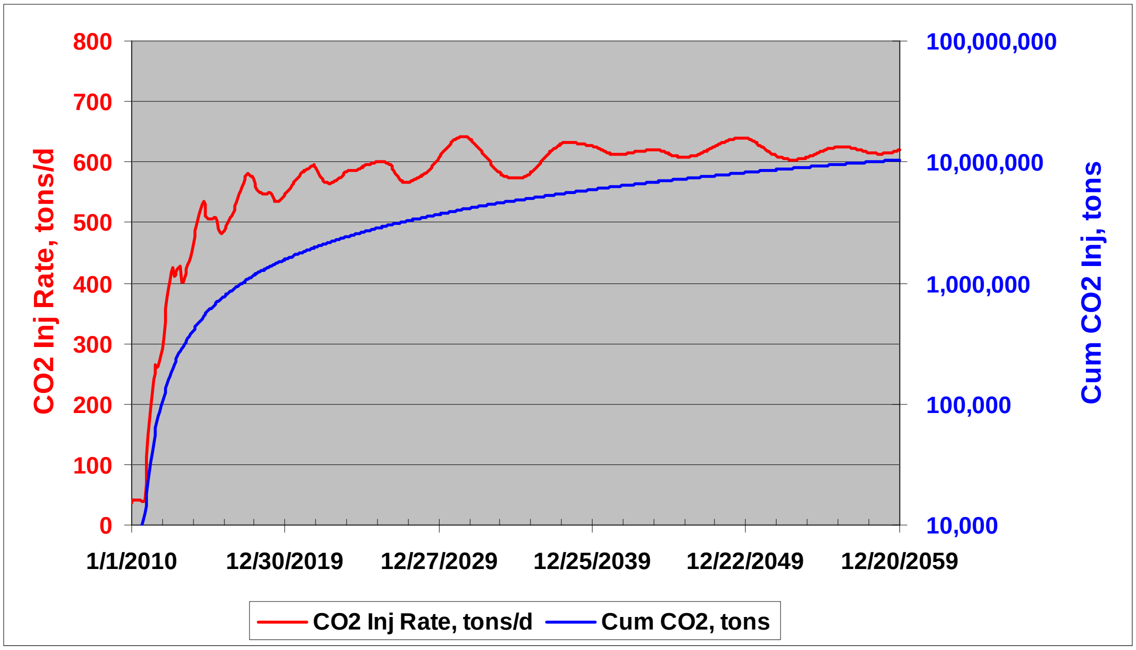


Figure 14. Simulated CO_2 injection rate in tons/day vs. time through the course of injection, 50 years. Total CO_2 injected shown as cumulative CO2 in tons.

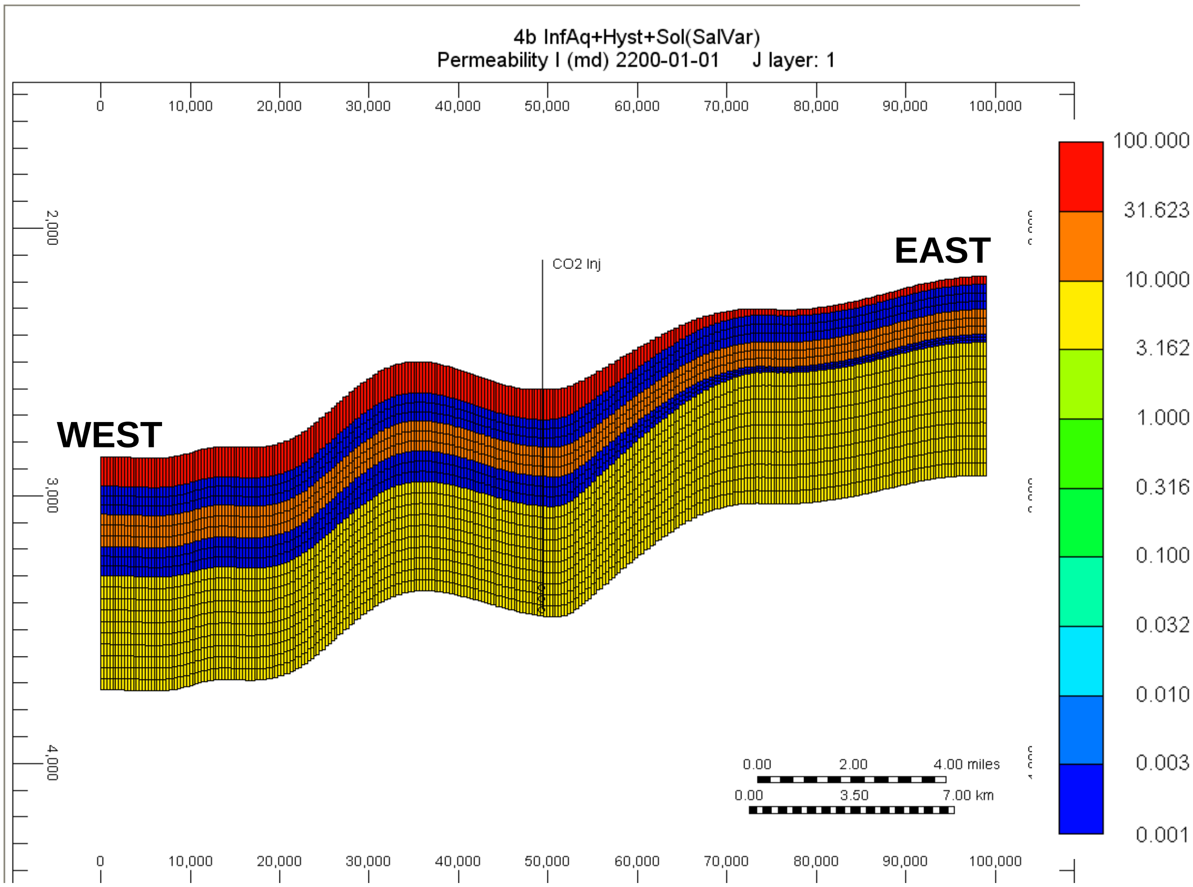


Figure 15. 2D simulation of CO_2 injection into the Arbuckle at the Oxy-Chem site used in latest experiment is 20 layers. Permeability distribution is shown here with low permeability in aquitards separating lower aquifer from upper portion of Arbuckle.

Flow units	Layers	Oxy-Chem #10 Avg Depth	Pr - Hyd Head	Frac Pr	Sumner CO ppm	Phi	K, md
1	1	2658.5	1245	3009	100079	0.12	100
2	2	2732	1277	3065	105363	0.05	0.001
2	3	2765.5	1292	3090	107863	0.05	0.001
2	4	2799	1307	3115	110422	0.05	0.001
3	5	2834.5	1322	3141	113201	0.12	20
3	6	2871	1338	3169	116130	0.12	20
3	7	2907.5	1354	3196	119135	0.12	20
4	8	2944.5	1370	3224	122261	0.06	0.001
4	9	2981.5	1386	3252	125469	0.06	0.001
4	10	3019	1402	3280	128806	0.06	0.001
5	11	3058.5	1419	3309	132418	0.09	10
5	12	3099.5	1437	3340	136273	0.09	10
5	13	3140.5	1455	3371	140241	0.09	10
5	14	3181.5	1473	3402	144324	0.09	10
5	15	3222.5	1491	3432	148526	0.09	10
5	16	3263.5	1509	3463	152851	0.09	10
5	17	3304	1526	3494	157246	0.09	10
5	18	3344.5	1544	3524	161768	0.09	10
5	19	3385.5	1562	3555	166478	0.09	10
5	20	3426.5	1580	3585	171325	0.09	10

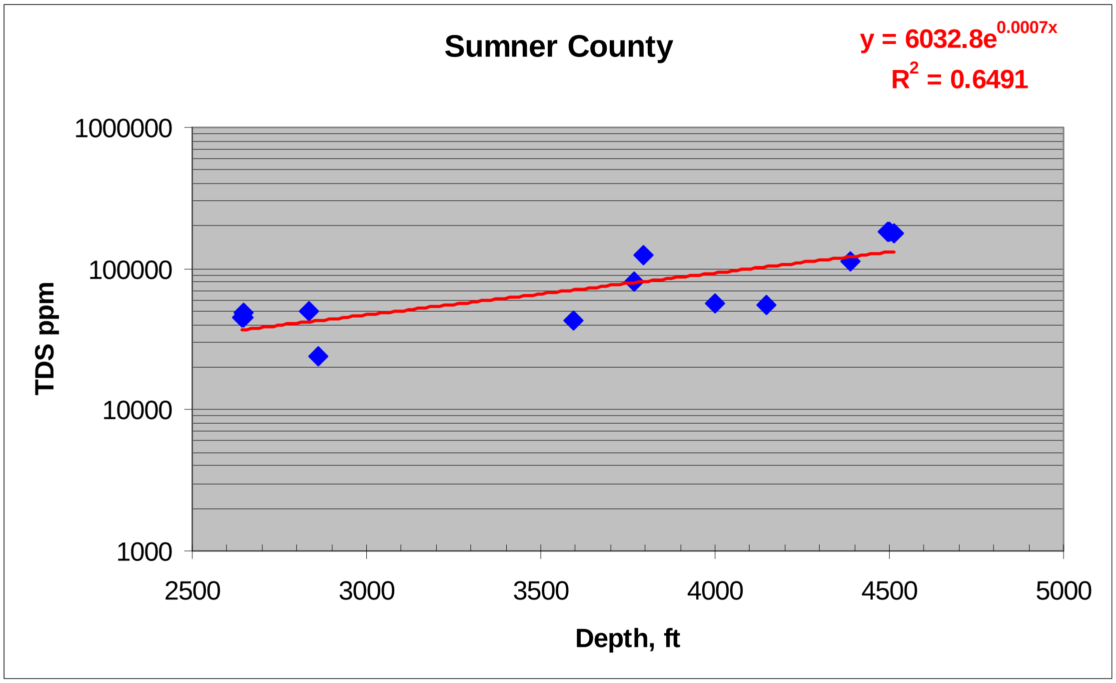


Figure 16. Upper – Flow unit input data for the 20-layer model. Lower – Salinity vs depth plot from the Arbuckle in Sumner County based on complied brine data showing trend of increasing salinity with depth.

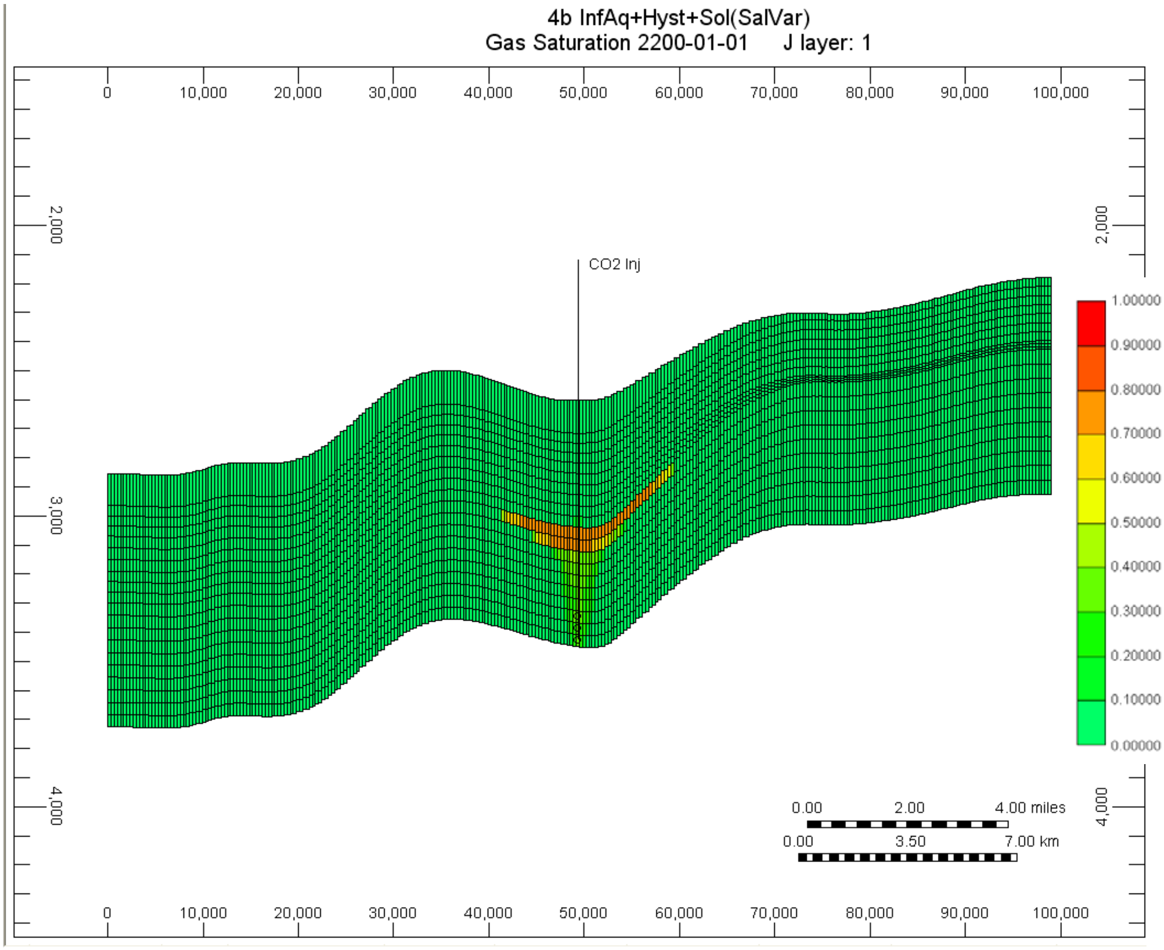


Figure 17. Simulation results for one cell-wide by 20 layer model of the Arbuckle aquifer shows the free phase gas at supercritical conditions after CO_2 has been injected for 190 years (2200).

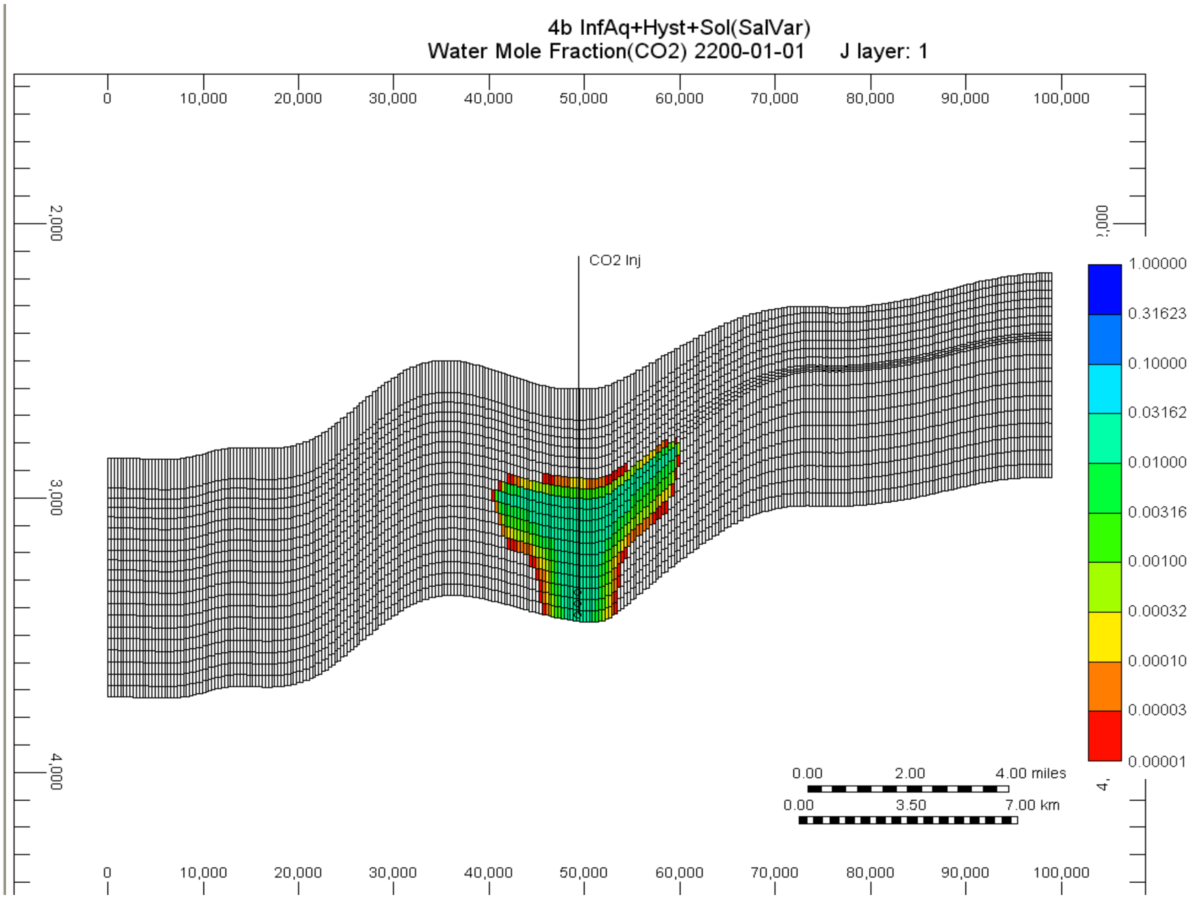


Figure 18. Mole fraction of CO2 (gas in aqueous solution) after 190 years confined beneath lowermost aquiclude and within 2 mile radius of the injection well.

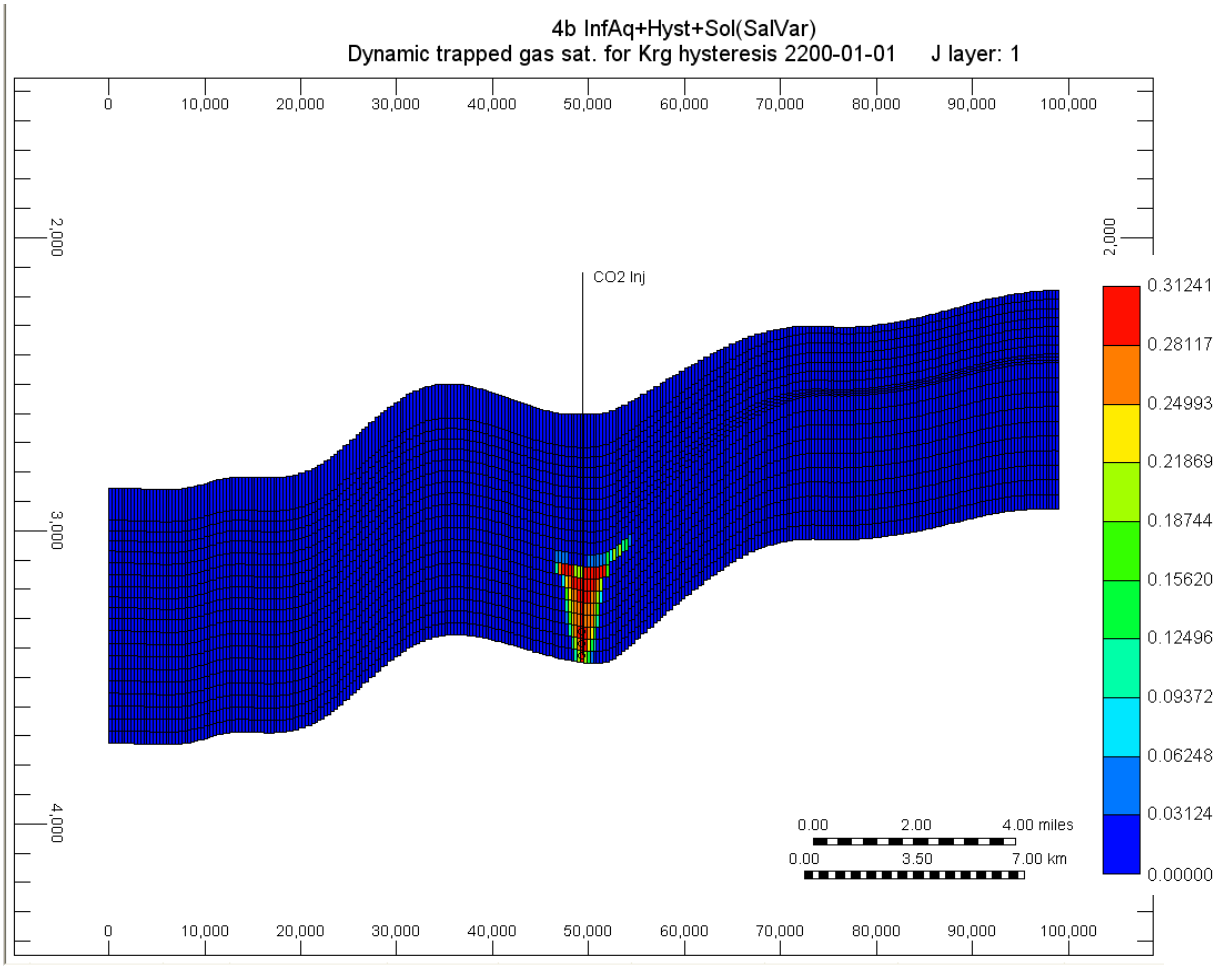


Figure 19. Dynamic trapping of CO_2 (hysteresis and capillary entrapment). Residual gas trapping is the dominant trapping mechanism for CO2 sequestration. CO2 would not be released unless the Arbuckle were dewatered so this form of CO2 sequestration is safe.

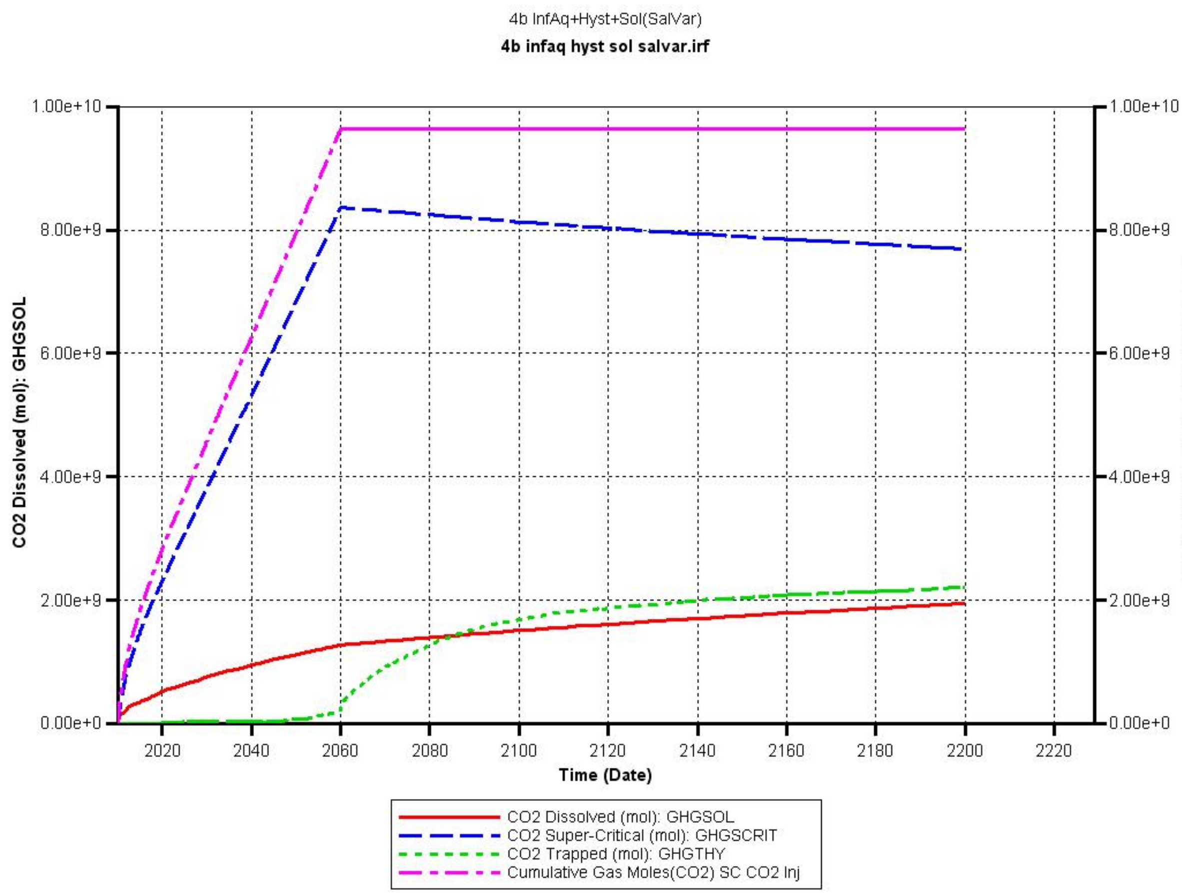


Figure 20. Plot of CO_2 injected over time to end of current modeling, year 2200.

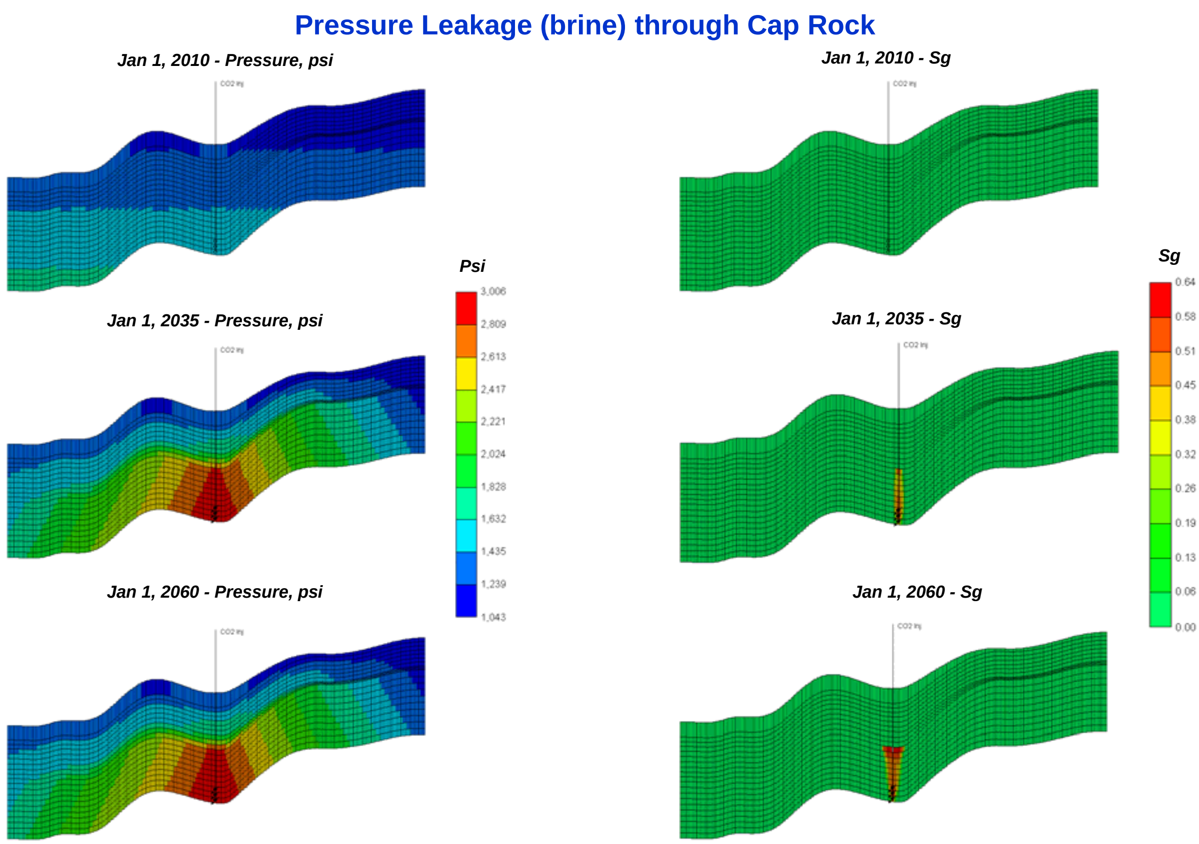


Figure 21. Pressure leakage (brine) through the lower aquitard that serves as a caprock in this simulation experiment.

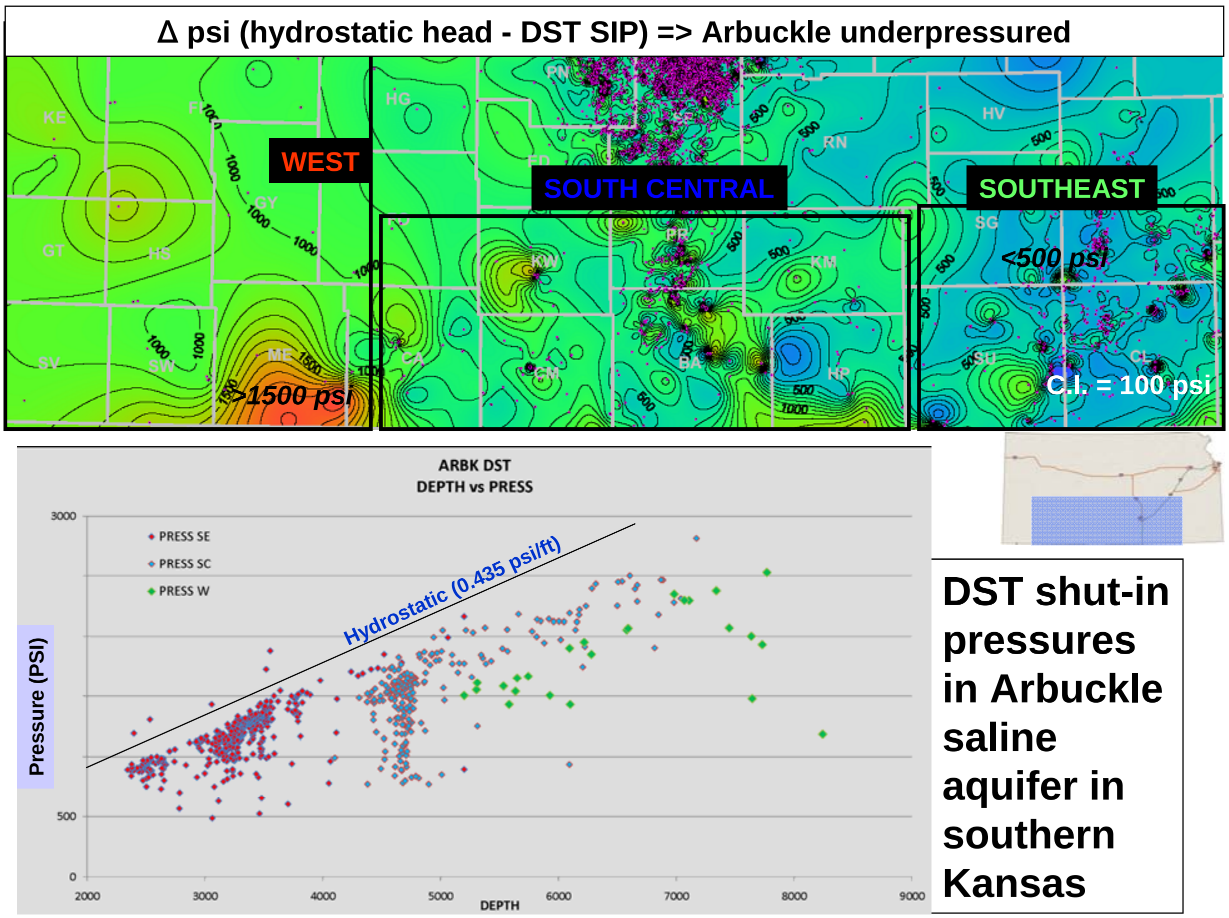


Figure 22. (Upper) DST shut-in pressures for the Arbuckle Group saline aquifer as mapped in regional study area. DST data points (wells) are shown as small purple dots. (Lower) Plot of the observed DST pressure vs. measured depth (below the surface) for wells in the mapped area

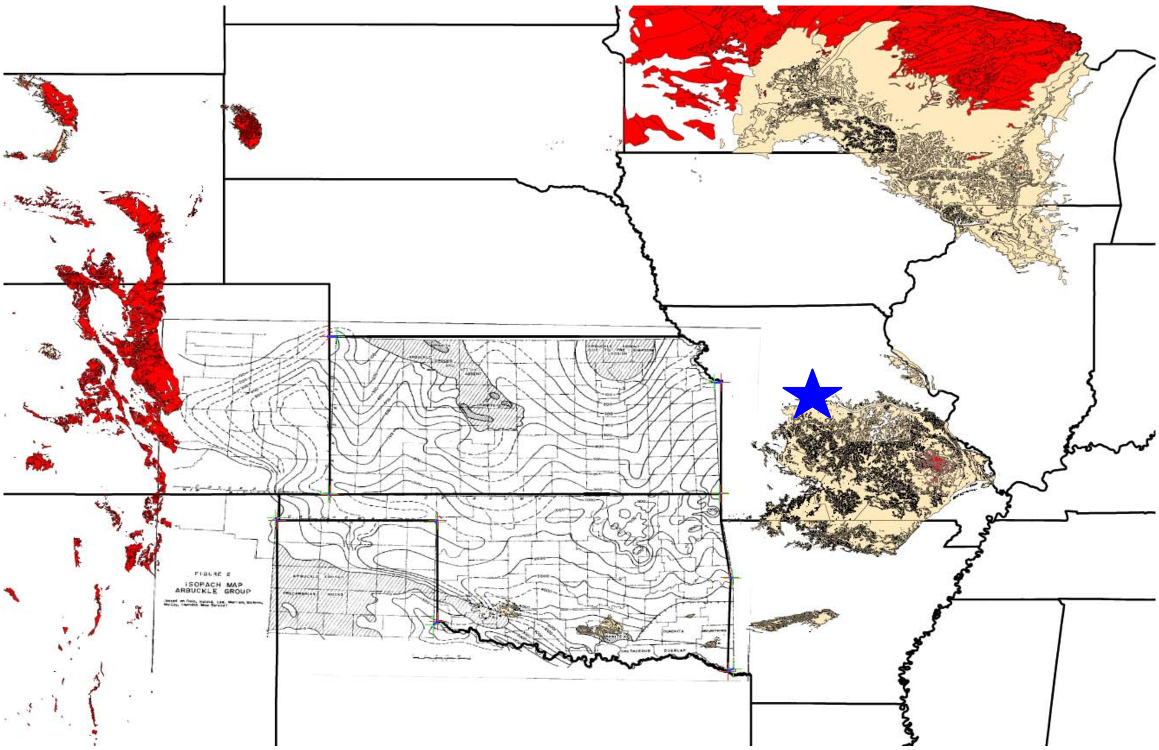


Figure 23. Midcontinent region showing isopach of the Arbuckle in gray contours increasing from Kansas into the Anadarko Basin in Oklahoma. Surrounding surface exposures of the Arbuckle Group are shown in brown shaded areas including the Ozark Uplift in south-central Missouri and northern Arkansas. Information from AAPG and USGS. Location of surface elevation (+45 ft above sea level) of the Arbuckle used to compute hydrostatic head from meteoric recharge area is located near Jefferson City Missouri at the base of the valley of the Missouri River in central Missouri shown here with the blue star.

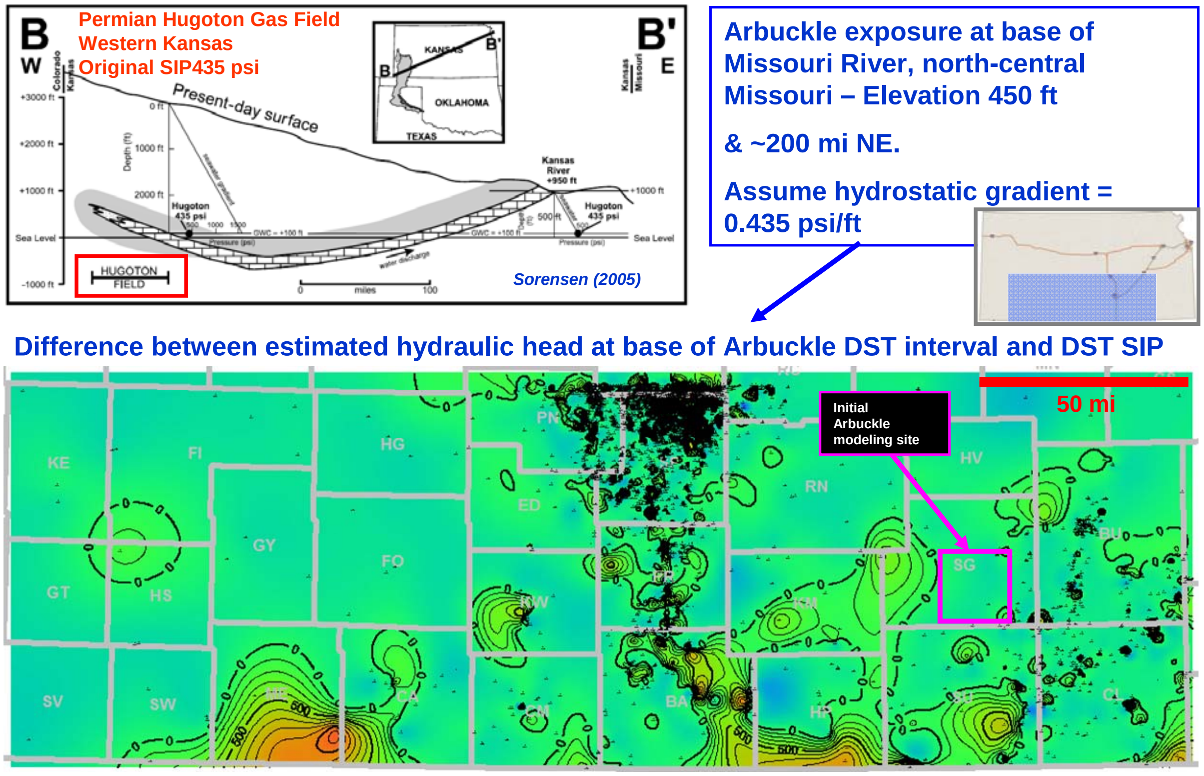
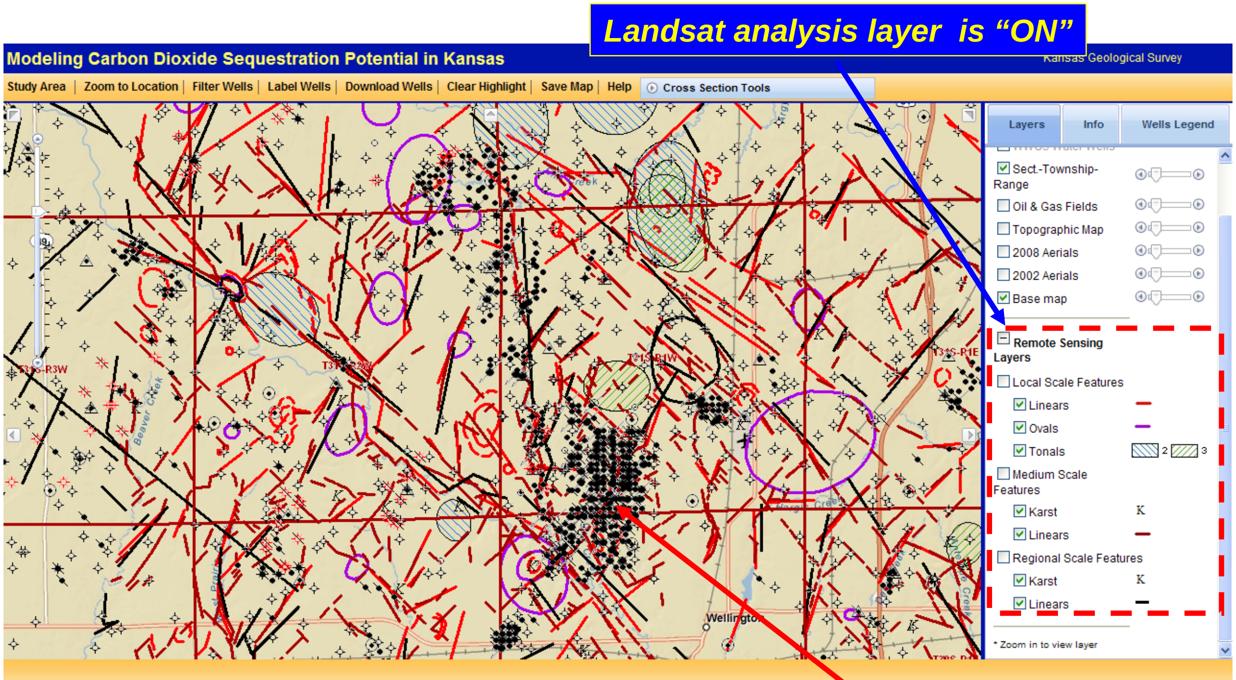


Figure 24. (Upper left) Hydrostatic pressure at gas/water contact in Hugton Gas Field in western Kansas is equal to the hydrostatic head of column of freshwater at the elevation of the surface exposure of the reservoir unit (Permian Chase Group) at the Kansas River in eastern Kansas (Sorenson, 2005). (Lower) Map of pressure difference between estimated hydraulic head of water column (based on surface elevation of Arbuckle exposures in central Missouri and elevation of the DST) and the DST shut-in pressure. Approach is analogous to Sorenson (2005).



Koger and Baker- geol
Killion - mapper

3 miles

http://maps.kgs.ku.edu/co2/?pass=project

Wellington Field
Sumner County

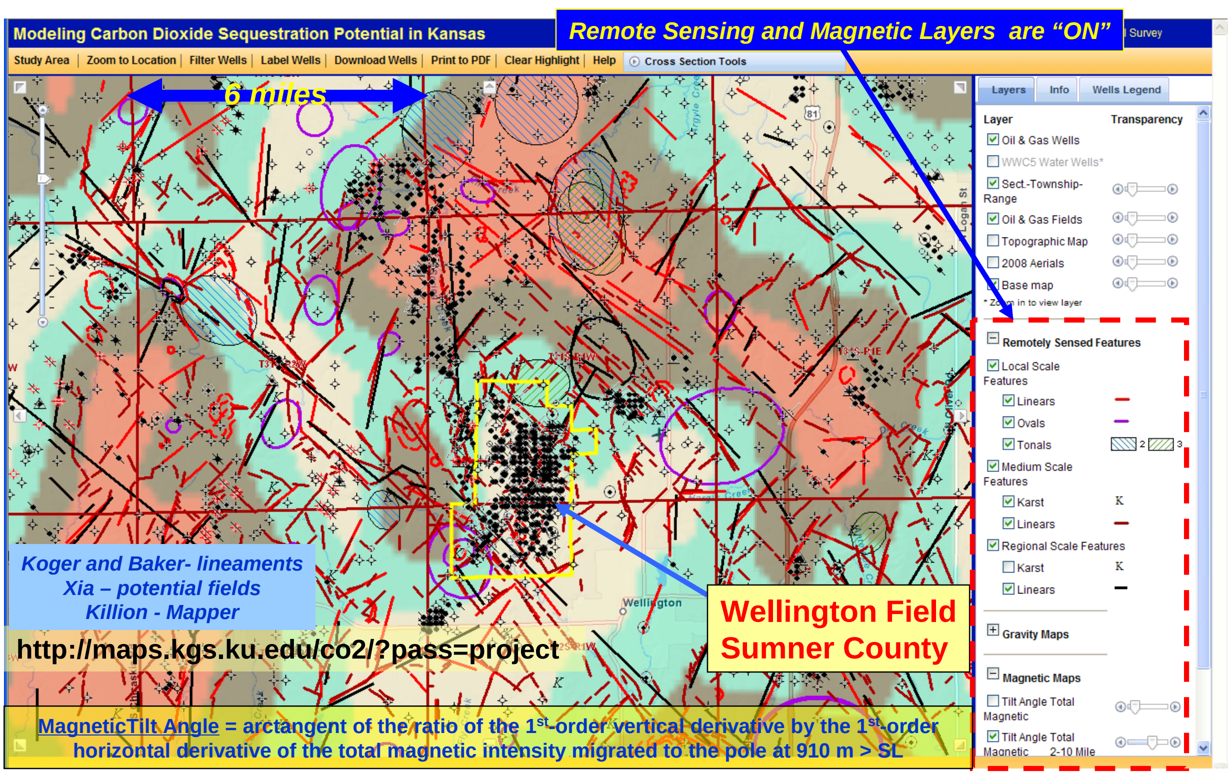


Figure 25. (Upper map, previous page) – Interactive project mapper showing surface lineaments/linears, ovals, tonals, and karst as interpreted from Landsat imagery for area around Wellington Field. (Lower map, previous page) – Same as upper map, but includes overlay of magnetic tilt angle computed from reprocessed regional aereomagnetic data for Kansas. Brown tinted area suggests location of basement faults, red tinted areas are suggested downthrown areas, and white and blue tinted areas are inferred structurally positive areas. Approximate depth to the magnetic anomaly is indicated by the width of the light blue tinted area, in this case, on the order of 1.5 miles (~8000 ft), well into the Precambrian basement.

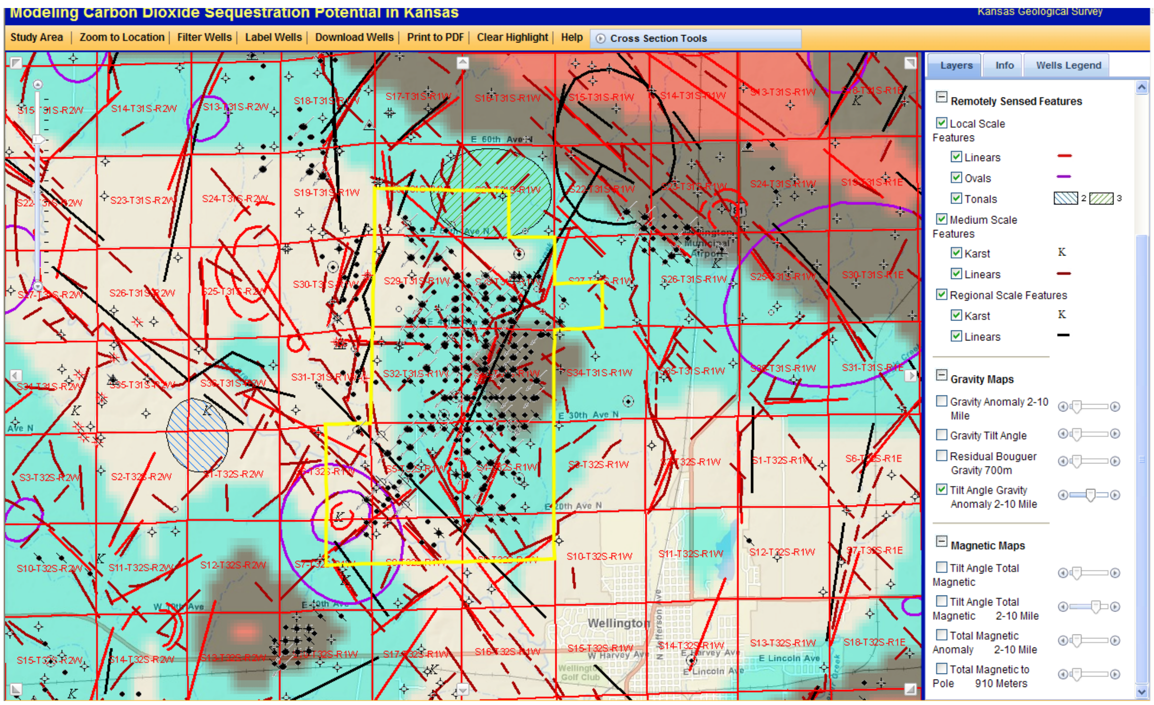


Figure 26. Gravity tilt angle map with surface lineaments in vicinity of Wellington Field in Sumner County as captured from the project interactive map. The zero contour (black line) delineates horizontal locations of edges of mass sources at relative shallow depths. Half the distances between –45 degree and +45 degree contours are depths to the edges shown as the blue band. Positive angles are over relatively high-density areas (white) and negative angles over relatively low-density areas (red).

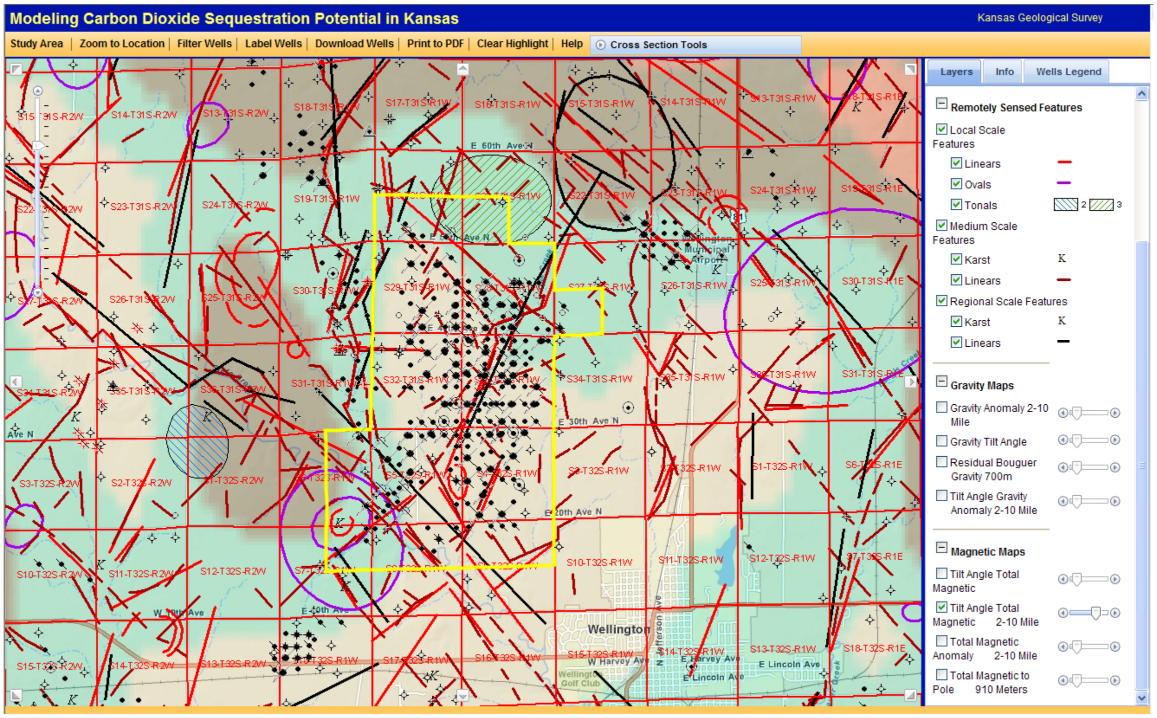


Figure 27. Magnetic tilt angle map with surface lineaments in vicinity of Wellington Field in Sumner County as captured from the project interactive map. Same scene as Figure 26 except this is processed magnetic data.

Figure 28. Regional magnetic tilt angle with overlay of surface lineaments, the latter delimiting the regional study area in southern Kansas.

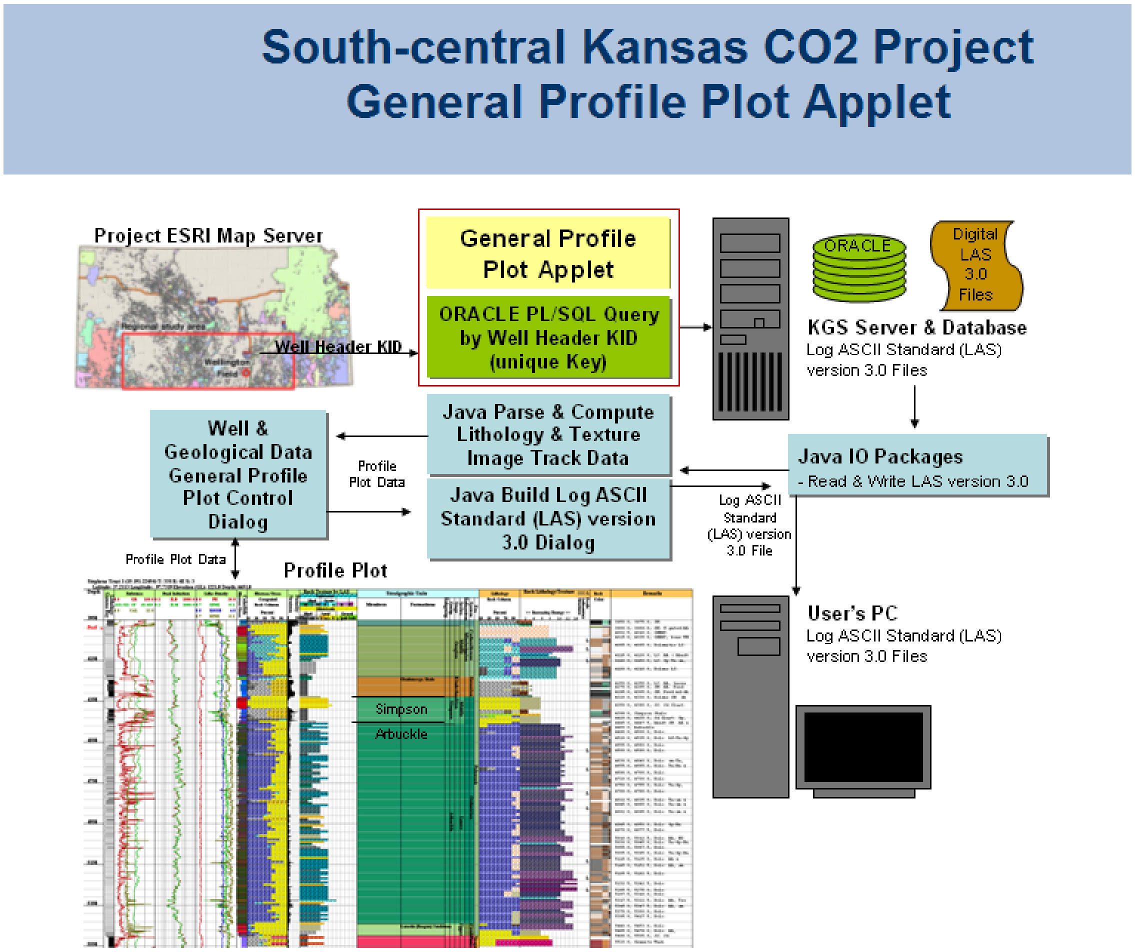


Figure 29. The project interactive mapper has a new general well profile applet to display interpreted well logs with stratigraphic tops, test, and sample information. The activities carried out by the applet are shown above.

CONTROL ID: 986344

TITLE: Evaluation of CO2 Sequestration Potential in Ozark Plateau Aquifer System (OPAS) in southern Kansas – Initial Studies

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ABSTRACT BODY: The Paleozoic-age Ozark Plateau Aquifer System (OPAS) in southern Kansas is centrally located to multiple major point sources of CO2 emissions and is considered a prime candidate for CO2 sequestration. The OPAS consists of the thick (>800 ft) and deeply buried (>3500 ft) Arbuckle Group saline aquifer and overlying Mississippian carbonate reservoirs, such as Wellington field (Sumner County), many of which are in various stages of depletion. The Arbuckle saline aquifer consists of siliceous dolomite with interbedded shales, and appears to be well suited for supercritical CO2 sequestration because multiple regional caprocks isolate it from shallow freshwater aquifers. Demonstration of CO2-EOR potential in depleted Mississippian fields should spur infrastructure development for commercial scale CO2 sequestration in the OPAS.

This study focuses on 1) developing a regional (≈ 20,000 mi2) geomodel for the Arbuckle saline aquifer, 2) constructing a local geomodel of the Mississippian reservoir and the underlying Arbuckle saline aquifer at Wellington field, 3) estimating the CO2 sequestration capacity of the OPAS, and 4) evaluating CO2-EOR potential of Wellington field. The regional Arbuckle geomodel was constructed utilizing wireline logs from 95 type wells and 1400 key wells, 5 cores, DSTs, and gravity/magnetic and remote sensing data. The detailed Wellington geomodel integrates existing geologic and engineering data with newly acquired data: multi-component 3D seismic survey (10 mi2), gravity/magnetic surveys, and core and wireline logs from 2 wells drilled to basement.

The regional Arbuckle geomodel has helped to understand factors, such as lateral continuity of Arbuckle strata including caprocks and shale beds, and relationship between underpressurization and hydraulic connectivity to the outcrop (northwestern flank of Ozark Uplift), critical to modeling sequestration capacity of the OPAS. Arbuckle flow units, indentified by depth-constrained cluster analysis of petrophysical data and mapped over a 9-Township area over a monoclinal structure, were used in simulation studies, with CO2 injected in bottom Arbuckle flow unit, to demonstrate sequestration of significant tonnage of CO2 by solution, residual gas saturation, and mineralization. Intermediate shaly layers in Arbuckle appear to prevent vertical migration of free-phase CO2 to the lowermost caprock. Simultaneous brine injection from shallow Arbuckle flow-units increased residual gas trapping of CO2.

CURRENT THEME: Theme 10: Energy and Environmental Horizons: Creating Growth

CURRENT SUB-CATEGORY: 5) (DEG) CO2 capture and sequestration

Figure 30. Abstact submitted for presentation at April 2011 AAPG Annual Meeting in Houston.

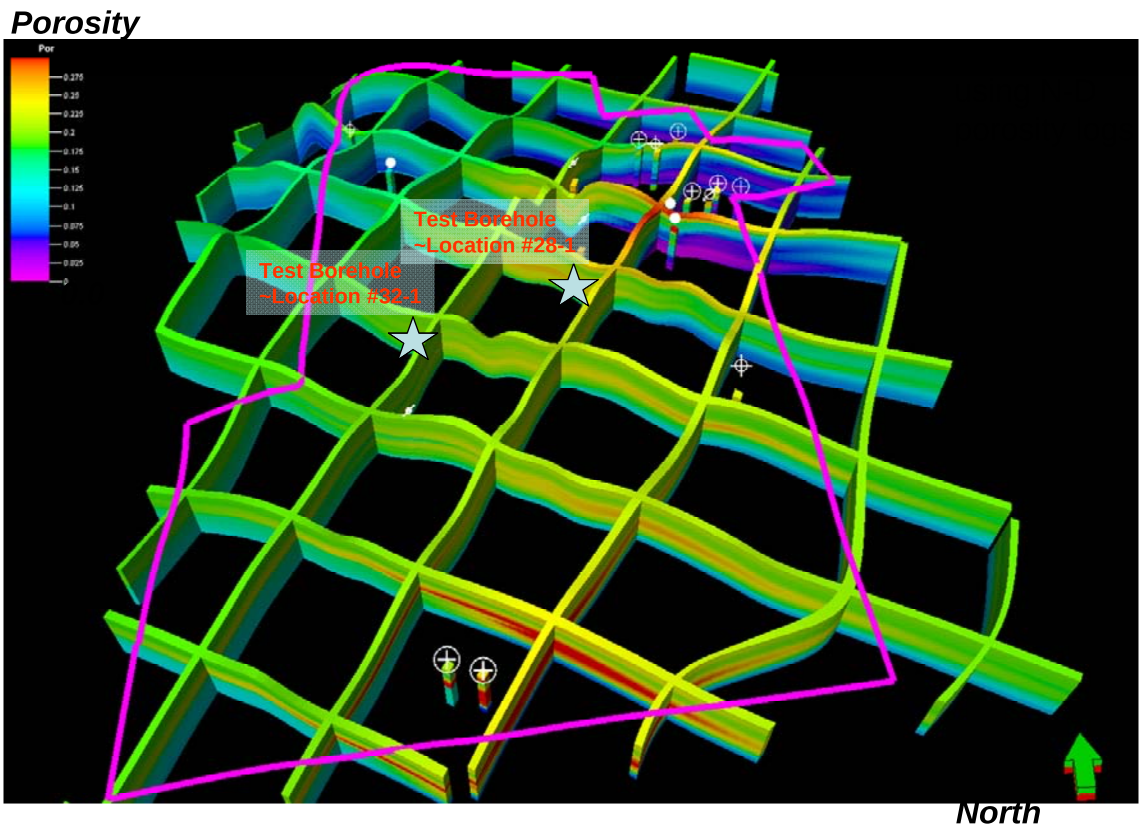


Figure 31. Petrel 3D fence diagram depicting porosity variation and structural relief in the Mississippian chert-dolomite reservoir of Wellington Field. Shown are locations of two test boreholes that will be acquired in next quarter.

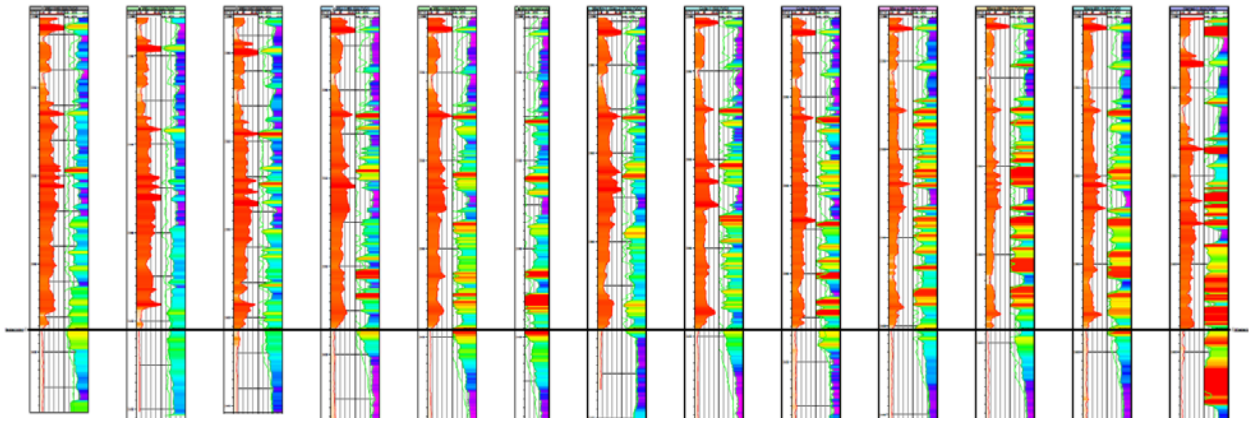


Figure 32. Arbitrary cross section of gamma ray and porosity logs through Wellington Field datumed on the top of the Mississippian. This shows the variability of character along the top of the Mississippian and difficulty that it poses for mapping the horizon in the seismic, besides using well logs.

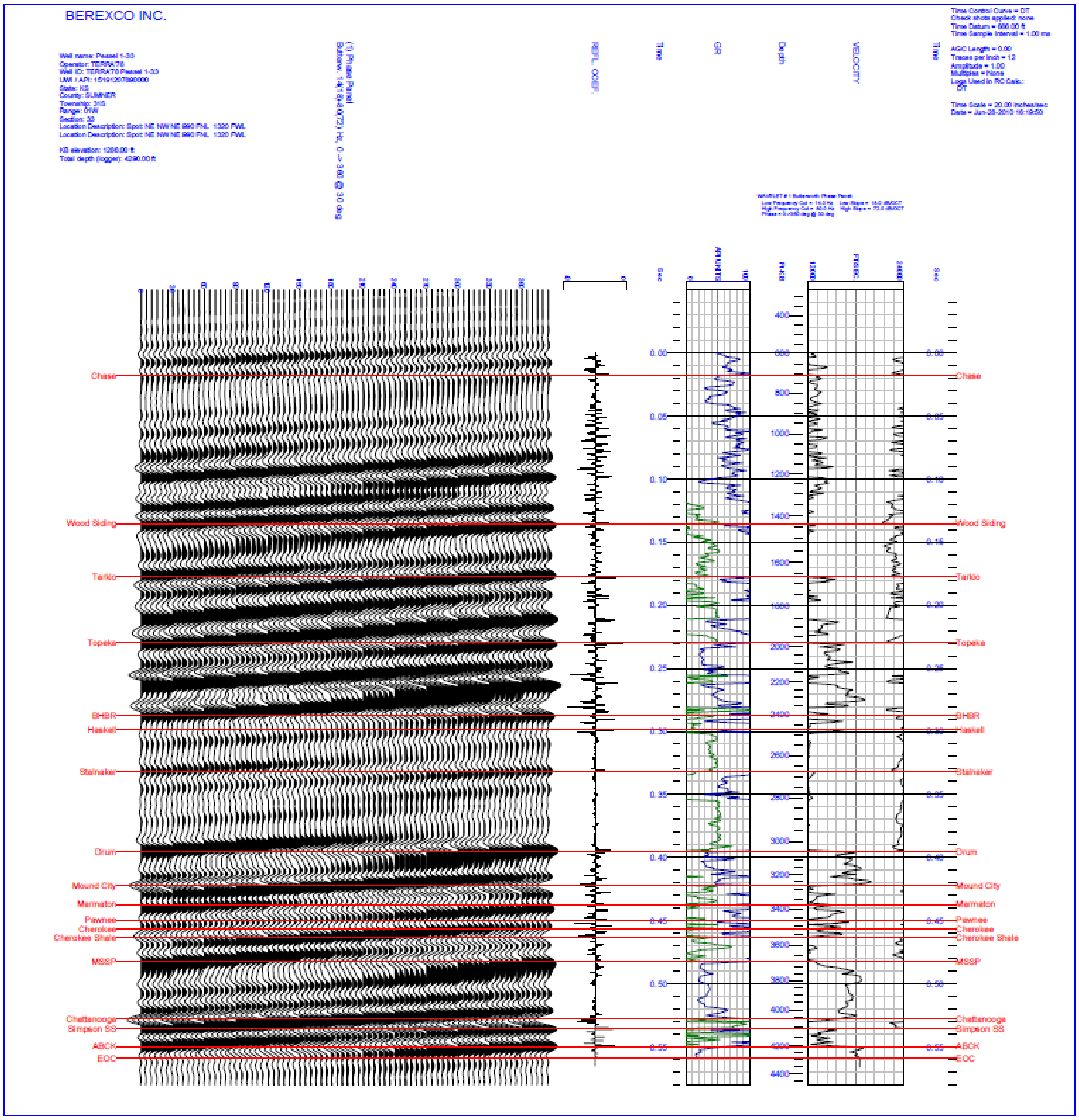


Figure 33. Example of synthetic seismogram used to establish stratigraphic correlations between well logs and seismic reflections.

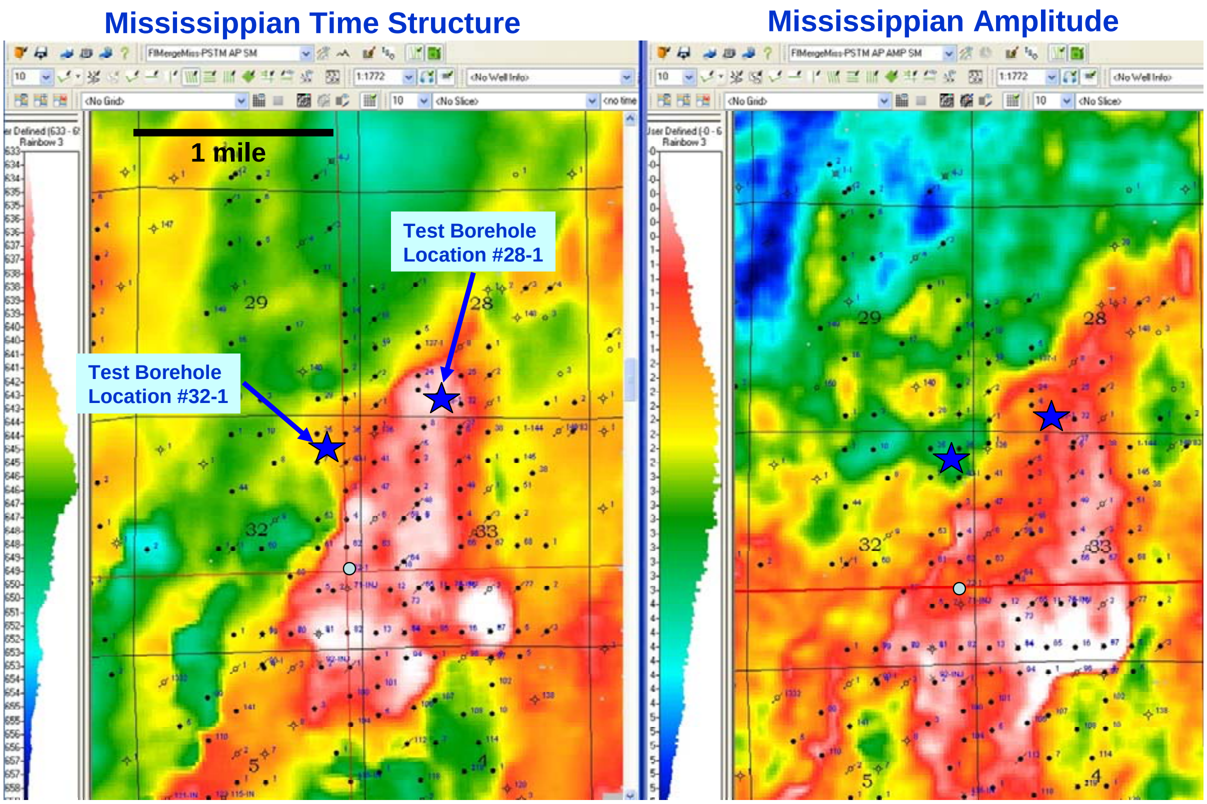


Figure 34. Mississippian time structure and Mississippian amplitude maps from 3D seismic interpretation at Wellington Field. High structure, high amplitude locations (red, white) are locations selected for two borehole tests, located as blue stars. The area of high amplitude closely corresponds to the higher porosity (see Figure 30).

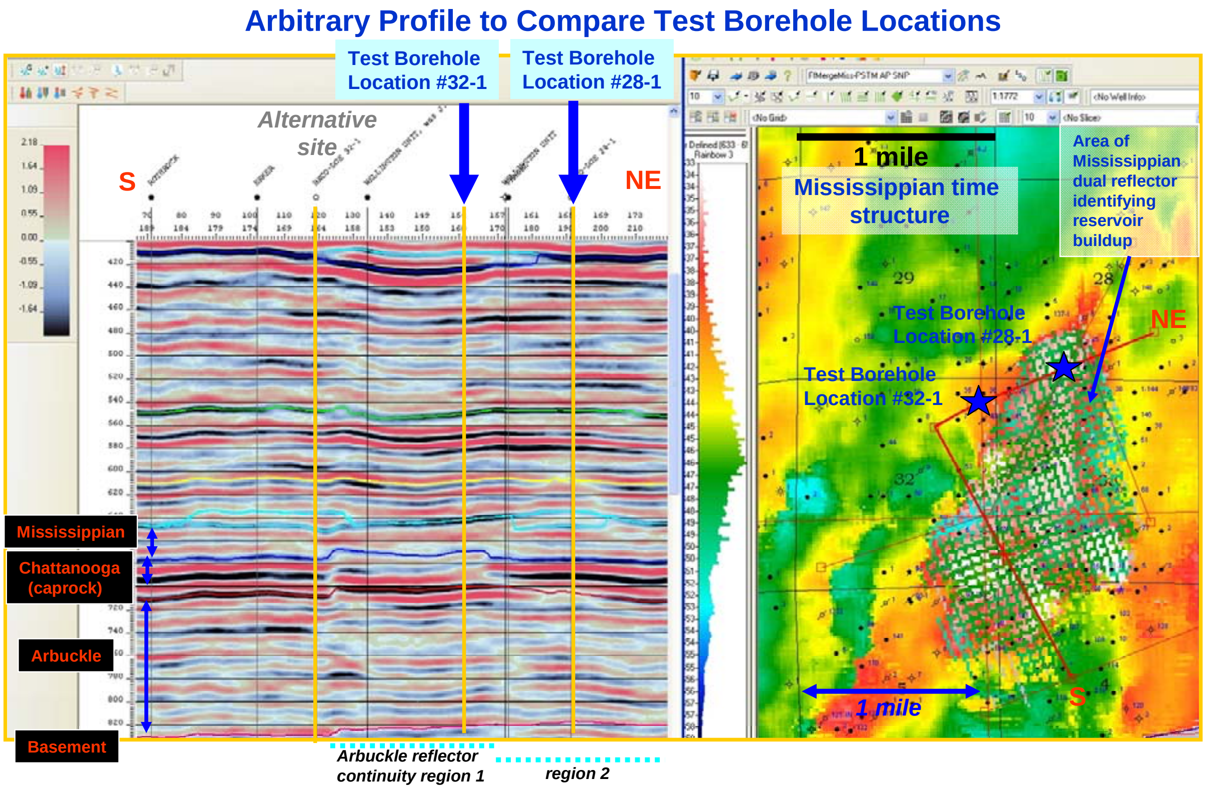


Figure 35. (Left) Arbitrary seismic section that traverses the high amplitude and high time structure of the Mississippian in Wellington Field. (Right) Mississippian time structure with hachured lines on the amplitude map that denote an area that contains dual reflectors in the uppermost Mississippian strata. The dual reflectors appear to correspond to the location of thick, high porosity Mississippian reservoir.

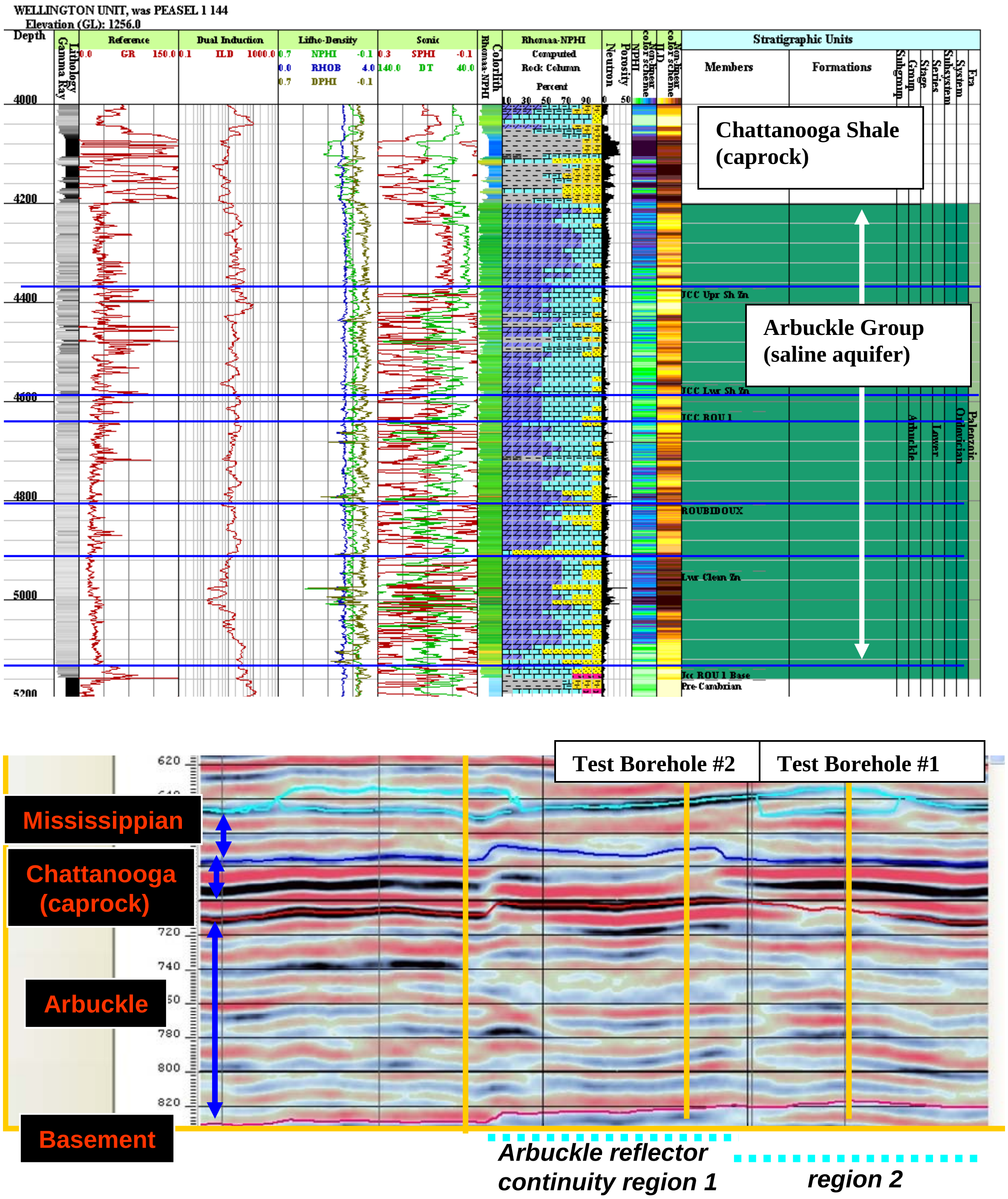


Figure 36. (Top) Wellington Peasel 144 well log showing Chattanooga Shale caprock above the Arbuckle Group with five informal stratigraphic divisions. (Bottom) Close-up of Ozark Plateau Aquifer System (pre-Pennsylvanian) alongarbitrary seismic section shown in Figure 34. Note similar number of reflectors in seismic section within in the Arbuckle and number of lithologically distinct units on the well log.

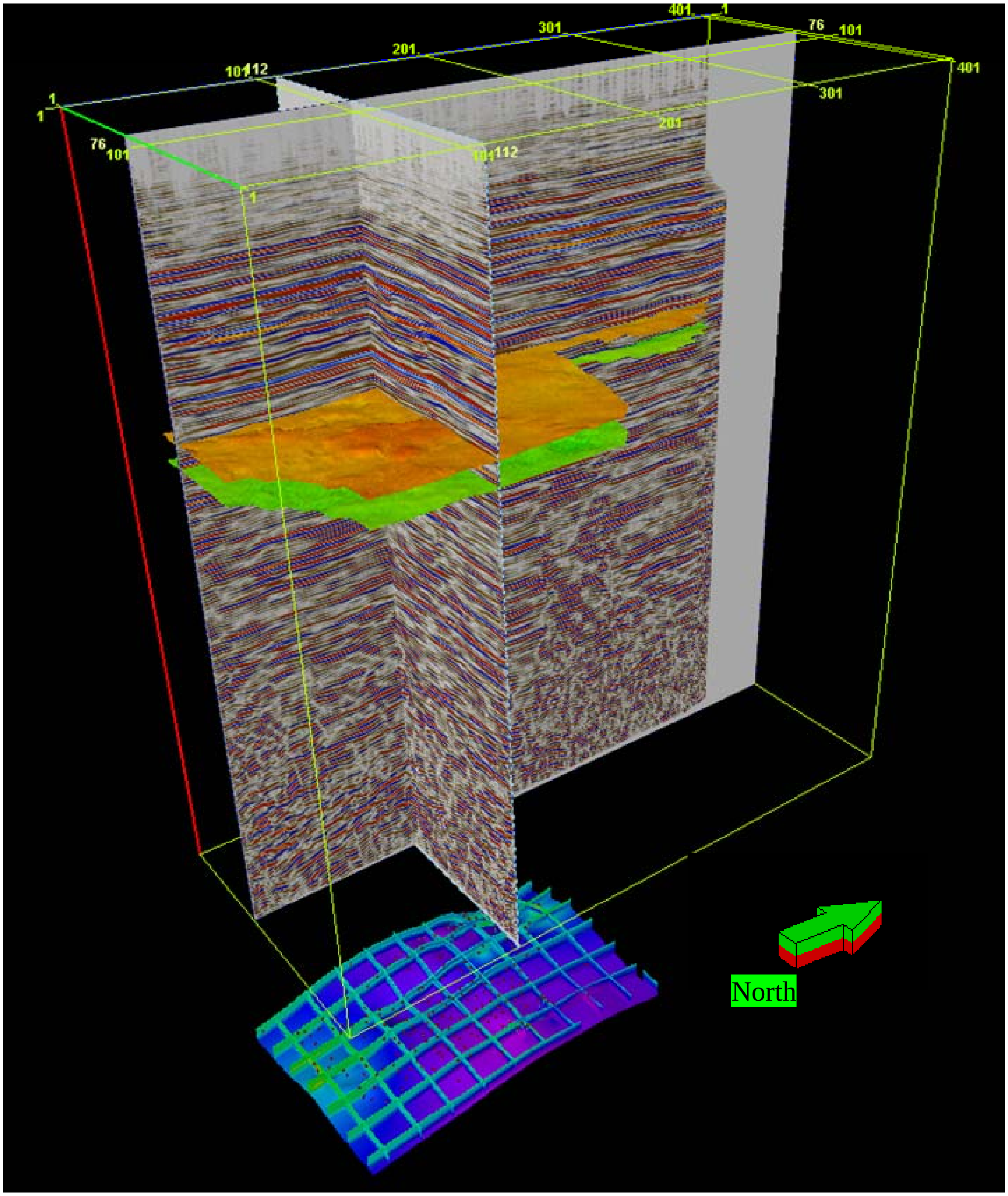
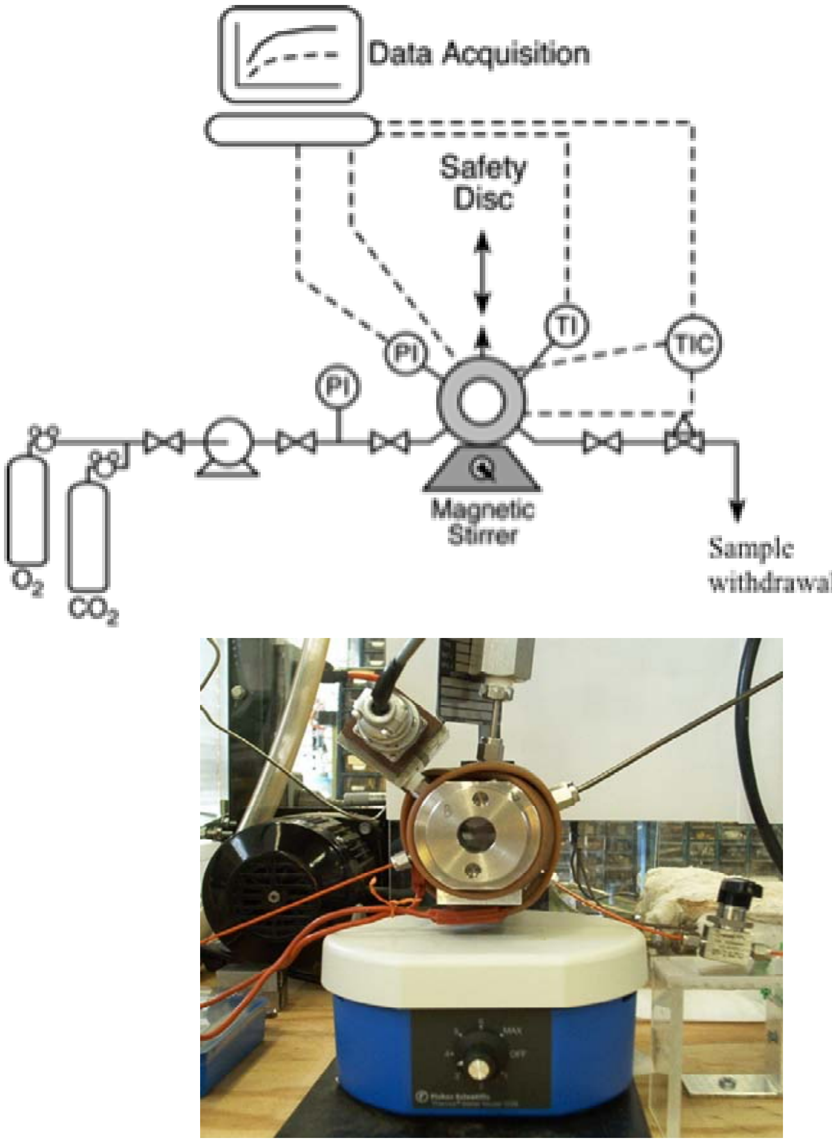


Figure 37. Two slices of the 3D Wellington seismic volume showing the upper surface (orange) of the Mississippian strata and the approximate top (green) of the Arbuckle Group. A porosity fence diagram of the Wellington is shown at the bottom of the seismic image.



Stainless steel view cell (5 mL)
for batch/semi-batch studies

Figure 38. CO2 reactor to experiment with CO2, minerals, and microbes.

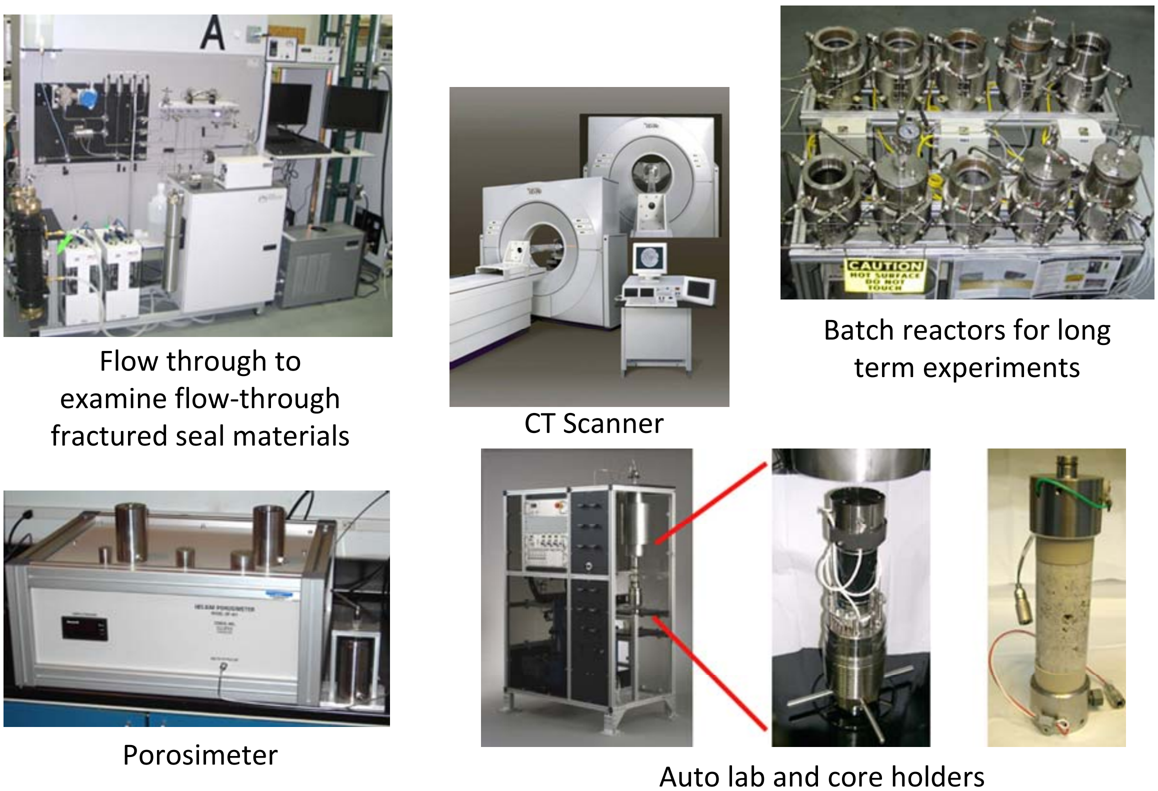


Figure 39. Example of equipment in CO2 lab operated by NETL in Pittsburgh, PA.