

**US Department of Energy
National Energy Technology Laboratory (NETL)**

Project Number DE-FE0024431

**A Nonconventional CO₂-EOR Target in the Illinois Basin: Oil Reservoirs of
the Thick Cypress Sandstone**

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Submission Date: October 31, 2015

DUNS Number: 04-154-4081

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Grant Period: 10/01/2014–10/31/2018

Reporting Period End Date: 9/30/2015

Report Term: Quarterly

Signature of Submitting Official:

Nathan D. Webb: 

2. ACCOMPLISHMENTS

What was done? What was learned?

Overall, this project is on schedule and within the budget for this quarter. Major accomplishments this quarter include the following:

- The composition and analysis of production history data for the thick Cypress Sandstone at Noble Field was completed and a portion of the comingled production for each lease was assigned to the thick Cypress Sandstone at Noble Field.
- Preliminary results from the geologic characterization and geocellular modeling of Noble Field were presented at the 2015 American Association of Petroleum Geologists (AAPG) Eastern section meeting where industry representatives that actively drill wells in the Illinois Basin were present. As part of the presentation, we openly invited those who might be drilling through the thick Cypress to partner with us for drilling whole core and taking new logs. This is the fifth time the project was presented at industry-related events.

What are the major goals of the project and what was accomplished under these goals?

The major goals of this project include identifying and quantifying nonconventional carbon dioxide (CO₂) storage and enhanced oil recovery (EOR) opportunities in the thick Cypress Sandstone in the Illinois Basin (ILB) through geologic reservoir characterization, three-dimensional geocellular modeling, fluid properties and interaction modeling, and reservoir simulation. A study of the economics of potential storage and EOR programs in the thick Cypress Sandstone will be made with considerations for production of net carbon negative oil. Field development strategies will be recommended with an emphasis on near-term deployment. Accomplishments towards these goals are listed below by task as outlined in the statement of project objectives.

Task 1.0–Project Management and Planning (on schedule)

- Progress on completion of tasks, subtasks, deliverables, and milestones is tracked using Microsoft Project to ensure timely completion. Overall, this project is on schedule.
- The PI and Co-PIs met weekly to discuss project management.

- There were regular meetings with the PI and subtask leaders for active subtasks.
- A number of project staff attended the Eastern section AAPG meeting in Indianapolis, IN, where industry representatives were present to increase operator awareness of the project and to continue establishing connections with potential partners for taking new core and logs.
- New core images, core data (from an existing database, newly digitized, and newly measured), core descriptions, and bulk and clay mineralogy data (existing and newly analyzed) are being assembled in a database to form the basis of the core visualization website.

Task 2.0–Geology and Reservoir Characterization (on schedule)

Subtask 2.1–Literature Review and Oilfield Selection

- A draft literature review of past studies of the Cypress Sandstone is being circulated to staff members for review and refined for inclusion in the final report.
- A draft report detailing the process used to select the oil field study area is being circulated to staff members for review and refined for inclusion in the final report.

Subtask 2.2–Petrophysical Analysis

- Josh Arneson and Scott Frailey are testing various well log methods to assess the presence of residual oil zones (ROZs) and the oil-water contact (OWC). The apparent water resistivity and resistivity-derived porosity methods are being attempted (Figure 1).
 - Logs from six wells in Noble Field with complete log suites, completion data, and verified production from the thick Cypress Sandstone have been analyzed to evaluate the efficacy of the selected petrophysical methodology.
 - Forty-one well logs from across the thick Cypress Sandstone fairway have been digitized for petrophysical analysis. Twenty-four of these digitized well logs have undergone preliminary analysis.

Subtask 2.3–Geologic Model Development

- The geologic mapping of the thick Cypress Sandstone at Noble Field is complete. Volumetric calculations are being conducted to determine the original oil in place (OOIP) and CO₂ storage resource.
- Zohreh Askari has continued the study of drill cuttings through the thick Cypress Sandstone interval in oil fields analogous to Noble Field in Richland, Clay, and Wayne Counties.
 - Sample studies of Podolsky Oil Company Foss #1 (County #23887) in Richland County, interval 2,500–2,800 ft, and Elysium Energy Company Lazaretti #1 (County # 28941) in Clay County, interval 2,580–2,700 ft, were completed. A total of 15 samples from different depths were collected for thin section preparation. An example stratigraphic column of the well was prepared to compare vertical lithologic variations with geophysical logs (Figure 2).
- Description and sampling of available core in the thick Cypress Sandstone has been ongoing:
 - Seventeen cores (721 ft of core) have been described by graduate student Kalin Howell and Nathan Webb. Of that core, 378 ft has been photographed. Figure 3 shows an example graphic log through the Rural Hills Flood 2-S well in Dale Field, one of the few complete thick Cypress Sandstone cores available for detailed study.
 - Shane Butler is conducting laboratory analyses of bulk and clay mineralogy samples.
 - Seventeen samples from Rural Hill Flood 2-S core have been fully processed and results for bulk mineral content and <16 micron clay analysis have been completed (Figure 4).
 - Twenty-seven samples from C.T. Montgomery B-34 core have been fully processed. Results for bulk mineral content and <16 micron clay analysis are currently in the process of X-ray Diffraction (XRD) trace analysis.
 - Twenty-nine samples from John O. Coen 120 core are currently in various stages of process to remove oil and carbonate from the sediment in order

to obtain <16 micron material for clay analysis. Results for bulk mineral content are currently in the process of XRD trace analysis.

- 138 plugs have been drilled out from the available Cypress Sandstone core. The plugs have been processed and analyzed for permeability and porosity.
- 130 samples were cut from the available Cypress Sandstone core and sent for thin section preparation.
- Under the supervision of Peter Berger, laboratory equipment was updated to more efficiently process samples and give more reliable results.
 - The mini-permeameter apparatus has been cleaned, refurbished, and recalibrated to quickly evaluate permeability profiles in core and on outcrop. The permeameter apparatus has been calibrated and updated with new pressure tubing and fittings to reduce the chance of gas leakage and to increase its operational life. New pressure outlets have been installed for the core out/in connections on the apparatus. The pressure chamber has been equipped with a new rubber sleeve to keep gas flowing through the plug under high pressure.
- Correlation and mapping of the thick Cypress Sandstone in Dale Field, an area considered to be geologically analogous to Noble Field with three relatively complete thick Cypress Sandstone cores and known production from the Cypress Sandstone, is underway. Preliminary structure and isopach maps have been generated.

Task 3.0–Geocellular and Reservoir Modeling (on schedule)

Subtask 3.1–Historical Production and Injection Data Analysis

- A report detailing methods developed to compile and process production data is being drafted.
- The analysis of historical production and injection data at Noble Field, including assigning a portion of the commingled production for each well to the thick Cypress Sandstone, has been completed. The number of thick Cypress Sandstone wells actively producing in a given year in each lease was used to assign the Cypress Sandstone proportion of the total comingled production for each production history.

- Well locations and waterflood reports were used to define lease boundaries and create a bubble map of the cumulative production from the thick Cypress Sandstone.
- Reservoir simulation input files that reflect the current geocellular model and the compiled historical production data have been generated.

Subtask 3.2–Illinois Basin Crude Oil/Brine-CO₂ Fluid Property Characterization

- Peter Berger received compositional analysis of the previously collected oil sample from Noble Field and measured the viscosity and density of that sample. Additional Cypress brine and oil samples were collected from the nearby Clay City Field.
- Fang Yang reviewed the pressure-volume-temperature (PVT) standard operating procedure and fixed the high-pressure positive displacement pump for future PVT analysis of the collected oil samples. Available PVT-related data from the thick Cypress Sandstone of Noble Field from old records were also collected.

Subtask 3.3–Geocellular Modeling of Interwell Reservoir Characteristics

- Damon Garner created a Microsoft Access database tool to load spontaneous potential (SP) geophysical logs, normalize the SP channel on a scale from 0 to –100 based on the minimum and maximum signals at select depth intervals within individual wells, and rewrite a normalized LAS file. The minimum and maximum SP values were based on thick sand and shale formations. This database expedites the SP log normalization process. 385 digitized SP logs from Noble Field were normalized using this tool.
- Nathan Grigsby used the normalized SP logs to generate an SP to porosity-permeability transform. The logs were used to develop a refined geocellular model (Figure 5) that reflects porosity and permeability distributions within the thick Cypress Sandstone at Noble Field.

Subtask 3.4–Reservoir Modeling

- A draft literature review of EOR techniques in nonconventional ROZs is being written by Roland Okwen and Nathan Webb.
- Preliminary input files for reservoir simulations have been generated by Nathan Grigsby. These input files include the revised geocellular model that reflects the geologic

heterogeneity of the thick Cypress Sandstone at Noble Field and the production and injection history data.

Task 4.0–CO₂ EOR and Storage Development Strategies (on schedule)

Subtask 4.1–Field Development Strategies

- Subtask begins on 4/1/2016.

Subtask 4.2–CO₂ EOR and Storage Resource Assessment

- Existing data for creating an updated basin-wide Cypress Sandstone isopach map was assembled by Nathan Webb. Additional data will be collected over the course of the project to refine the isopach map. This isopach map will provide the basis for conducting volumetric calculations for the regional CO₂ EOR and storage resource estimate.

Subtask 4.3–Economic Analysis

- Subtask begins on 4/1/2016.

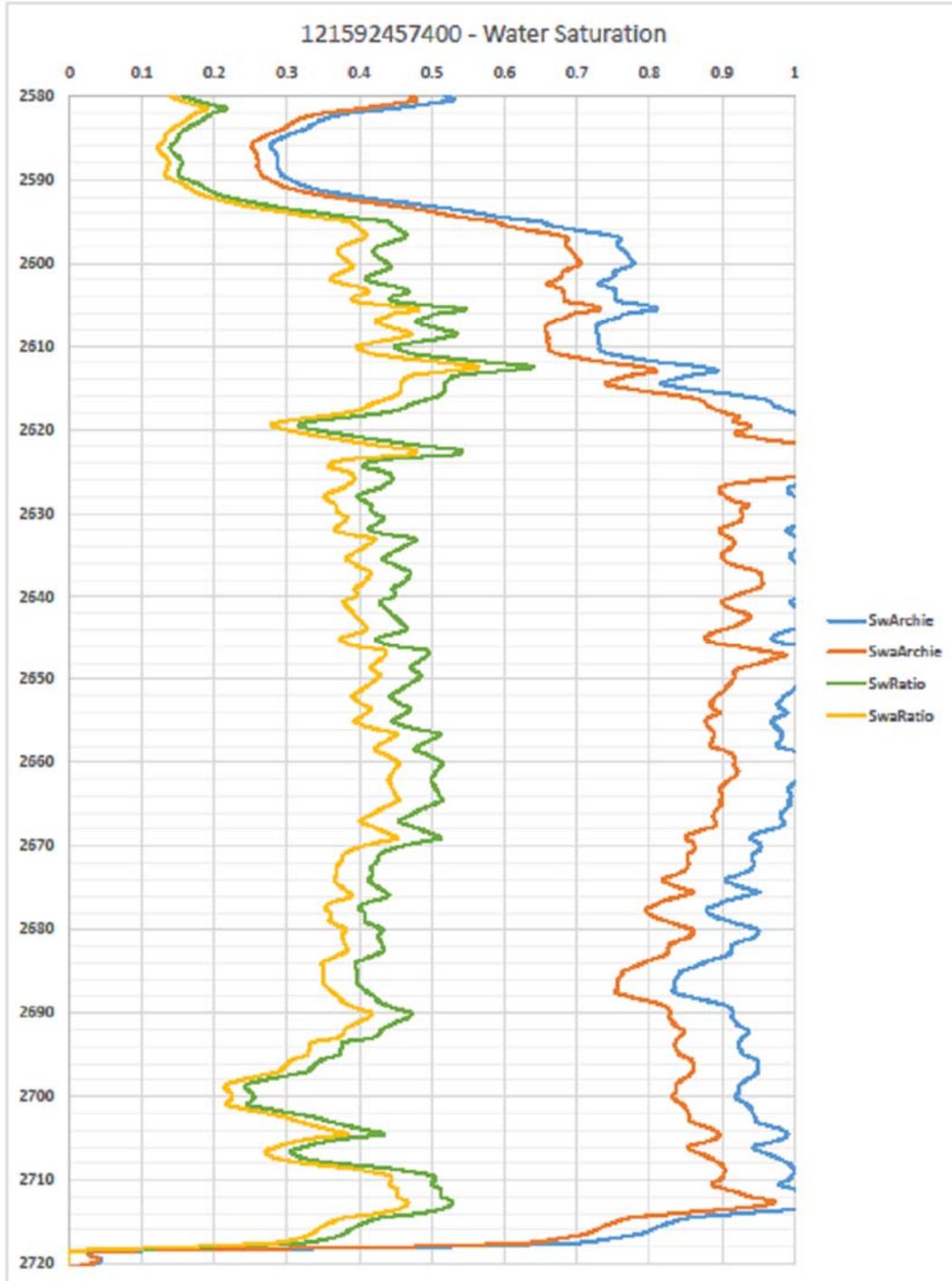


Figure 1 Preliminary results from petrophysical analysis of the Bourne #5 well (API 121592457400) using the ratio water saturation and Archie water saturation methods. The disparity between the water saturation curves may indicate microporosity within the thick Cypress Sandstone, which will require petrographic analysis to confirm. The y-axis is depth in feet and the x-axis is the ratio value.

API #23887
 Podolsky Oil Co.
 Foss #1
 Richland County
 8-3N-9E

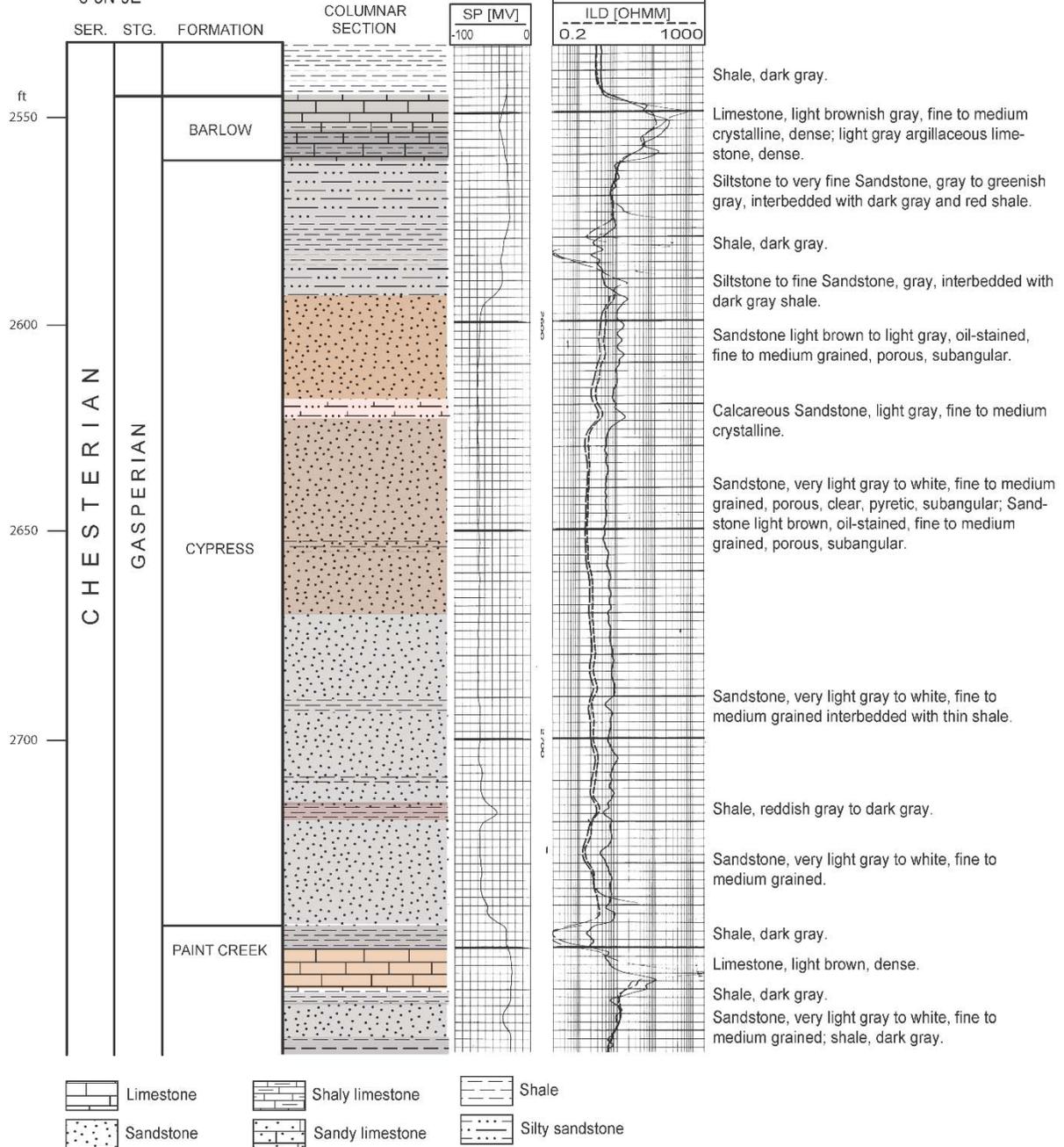


Figure 2 Stratigraphic column and electric log of Podolsky Oil Company, Foss #1 well (API 121592388700), Section 8, T3N, R9E, in Noble Field, Richland County, showing lithologic units of the interval studied, lithologic column, and description of well samples. Sample studies indicate oil stained sandstone below the producing oil-water contact.

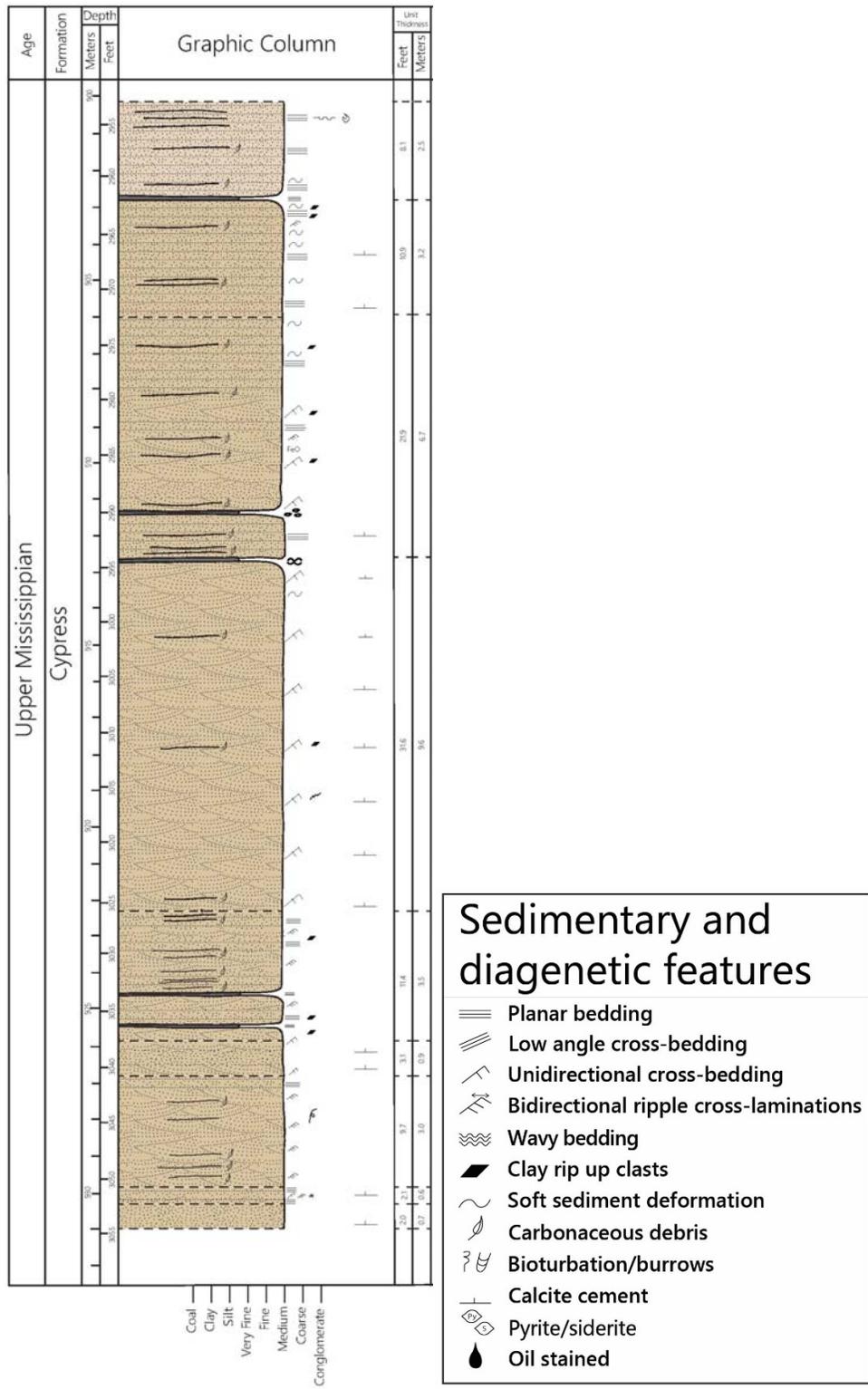


Figure 3 Example graphic log through the Rural Hills Flood 2-S well (API 120650139400) in Dale Field. The log shows dominantly cross-bedded and planar-bedded, medium-grained sandstone. Thick sandstone bodies are punctuated by thin interbeds of shale. Common zones of calcite cement occur within the sandstone bodies, especially in the lower two-thirds of the formation. Both the shale interbeds and the calcite-cemented zones create baffles to vertical fluid flow within the reservoir.

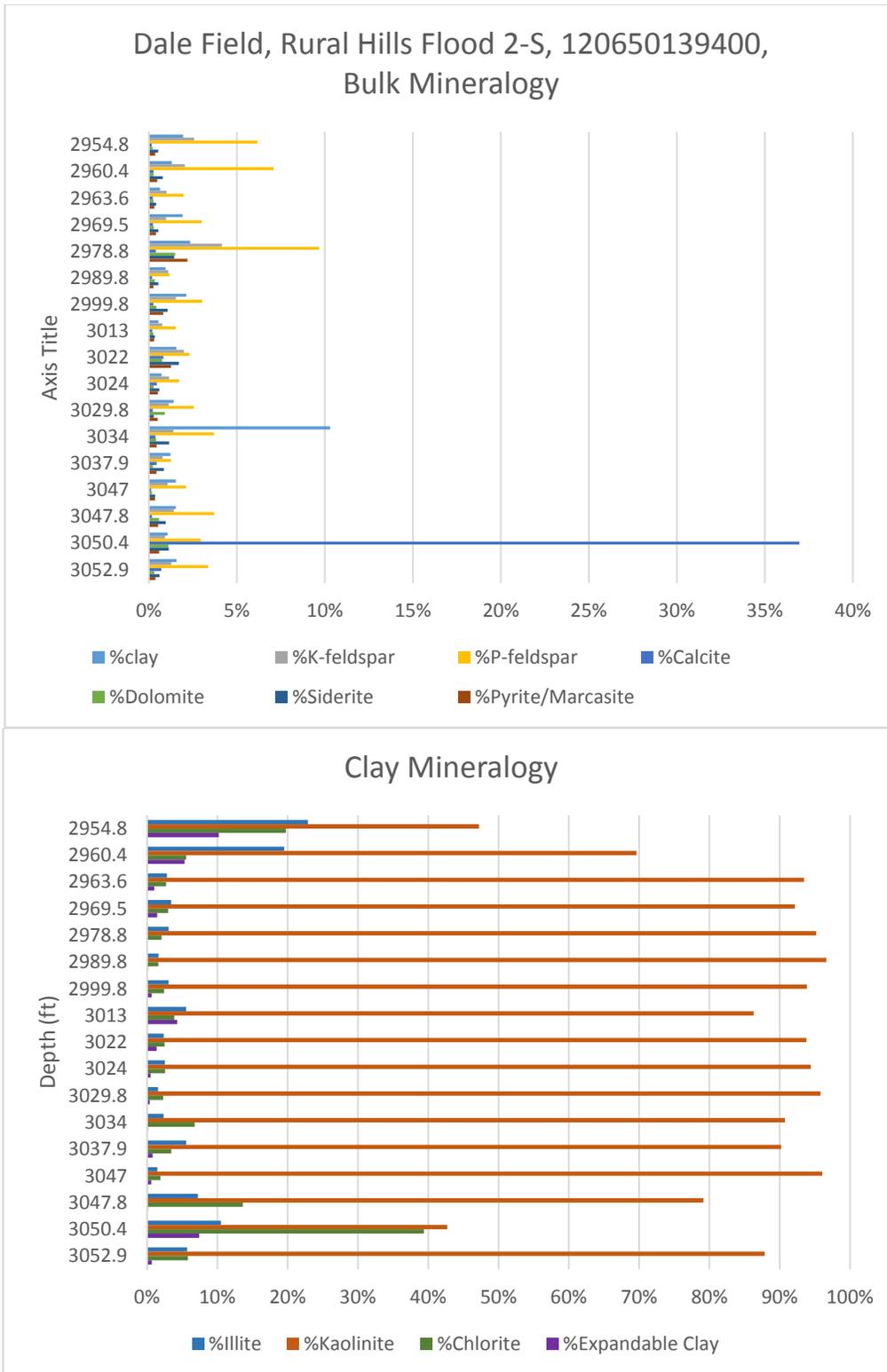


Figure 4 Example results of bulk mineralogy (with quartz omitted to show minor constituents) and clay mineralogical analysis from the Rural Hills Flood 2-S well (API 120650139400) showing total bulk mineralogy (above) and the relative abundance of clay minerals within the clay fraction (below).

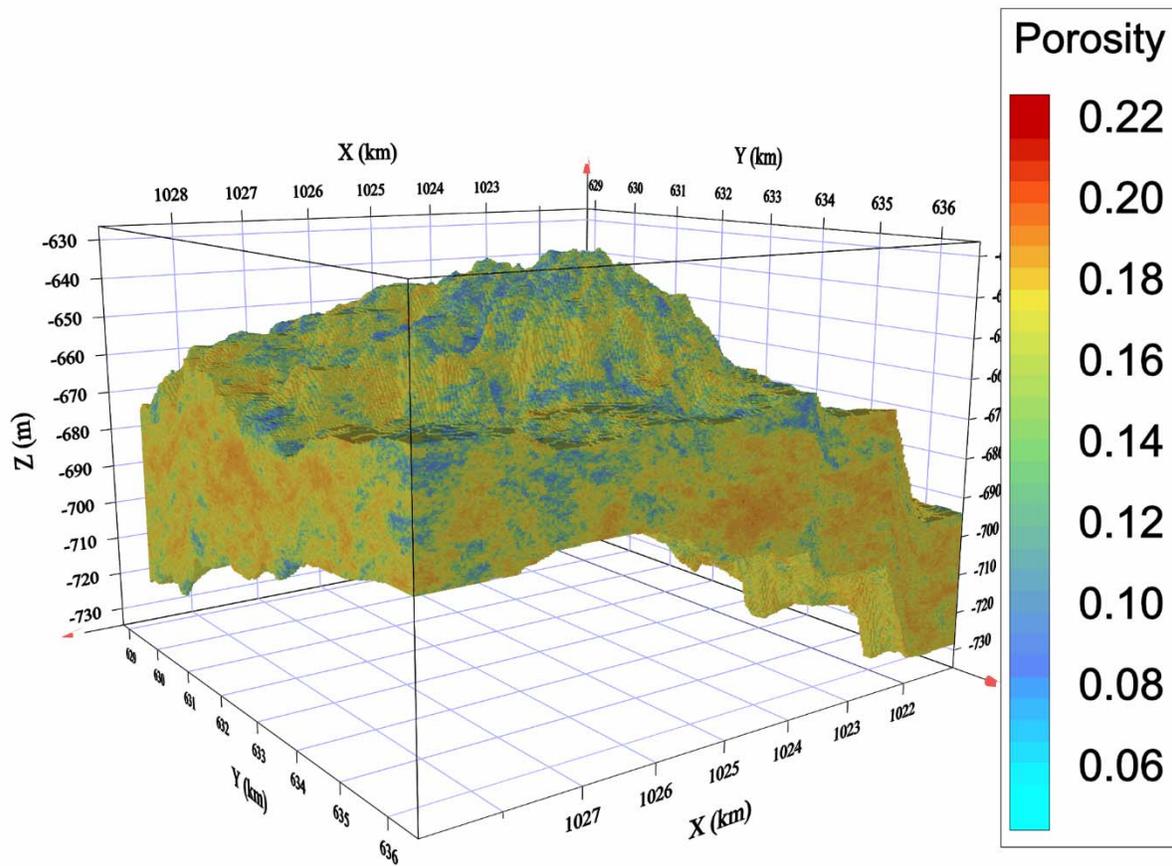


Figure 5 Image of the geocellular model colored by porosity (50× vertical exaggeration). A preliminary simple geocellular model provides the reservoir engineers a model with which to run sensitivity analyses. The geocellular model was created using Geovariances Isatis software.

What opportunities for training and professional development has the project provided?

Four undergraduate students, one recent BS graduate, and one MS student are currently employed in research roles on the project. Under the advisement of project staff and professors in the University of Illinois' Department of Geology, each student is developing skills in a particular discipline, such as petrophysical analysis, mineralogical analysis using XRD, thin section petrography, stratigraphy and sedimentology, etc. The students are learning the various techniques for their respective disciplines, and meeting and sharing their findings with each other to both better understand their roles in the larger framework of the project and to gain experience in presenting their research.

Fang Yang, a reservoir engineer on the project, is developing new skills in PVT analysis under the advisement of project staff.

How have the results been disseminated to communities of interest?

Preliminary results from the geologic characterization and geocellular modeling of Noble Field were presented at the 2015 AAPG Eastern section meeting where industry representatives that actively drill wells in the Illinois Basin were present. As part of the presentation, we openly invited those who might be drilling through the thick Cypress to partner with us for drilling whole core and taking new logs. This is the fifth time the project was presented at industry-related events.

What do you plan to do during the next reporting period to accomplish the goals?

Task 1.0–Project Management and Planning (on schedule)

- Progress on completion of tasks, subtasks, deliverables, and milestones will continue to be tracked using Microsoft Project to ensure timely completion.
- The PI and Co-PIs will continue to meet weekly to discuss project management.
- Regular meetings with the PI and subtask leaders will continue for active subtasks.
- Work will continue to populate the website with project content.

Task 2.0–Geology and Reservoir Characterization (on schedule)

Subtask 2.1–Literature Review and Oilfield Selection

- Subtask concluded on 6/30/2015.

- Additional material will be added to the literature review if additional sources are discovered.
- Site screening will begin to select an area with a Pennsylvanian sandstone that exhibits a relatively thin oil over a thick aquifer, analogous to those of the thick Cypress Sandstone, for detailed study.
- Scouting in the field will begin to select a location for taking a new core near the outcrop belt of the thick Cypress Sandstone.

Subtask 2.2–Petrophysical Analysis

- An explanation for the disparity between ratio and Archie water saturation methods will be sought through analysis of mineralogical and petrographic data.
- An initial estimate of the water saturation profile within the thick Cypress Sandstone in Noble Field and other locations within the basin will be developed.

Subtask 2.3–Geologic Model Development

- A report on the geological characterization of the thick Cypress Sandstone at Noble Field will be drafted.
- Detailed facies analysis and sampling of all available thick Cypress Sandstone core will continue.
- cursory geologic mapping and characterization of other areas that have production from the thick Cypress Sandstone and adequate reservoir data will be conducted in order to compare the reservoir properties of the thick Cypress Sandstone in different areas within the fairway. Studies at Loudon and Dale Fields will continue and a study of the small Kenner West field will be conducted.

Task 3.0–Geocellular and Reservoir Modeling (on schedule)

Subtask 3.1–Historical Production and Injection Data Analysis

- Leases in Noble Field will be grouped into classes representing their relative degree of productivity. This will allow the wells to be evaluated to determine if there are specific log signatures or reservoir properties that may be indicative of their productive potential. Identifying characteristic log signatures or reservoir properties of highly productive thick

Cypress Sandstone oil reservoirs will aid in the construction of the regional resource estimation (Task 4).

Subtask 3.2–Illinois Basin Crude Oil/Brine-CO₂ Fluid Property Characterization

- Minimum miscibility pressure and other laboratory tests will be performed on oil samples.

Subtask 3.3–Geocellular Modeling of Interwell Reservoir Characteristics

- Additional models will be created for Noble Field making use of different geophysical log data types.
 - Models will make use of different log types to better represent facies and heterogeneity within the thick Cypress Sandstone reservoir.

Subtask 3.4–Reservoir Modeling

- A compositional fluid model for crude oil at Noble Field will be developed.
- Iterative revision of reservoir parameters and the geocellular model will be conducted to obtain a reasonable history match of Noble Field data.
- The reservoir simulation input files will be refined as the history matching progresses.

Task 4.0–CO₂ EOR and Storage Development Strategies (on schedule)

- The PI and subtask leaders working on Task 4 will continue to meet regularly to stay updated on progress and data availability and to develop the methods for conducting the resource assessment and economic analysis.

Subtask 4.1–Field Development Strategies

- Subtask begins on 4/1/2016.

Subtask 4.2–CO₂ EOR and Storage Resource Assessment

- Work will begin to update and refine basin-wide Cypress Sandstone isopach and facies maps with increased data density, allowing for greater detail in future volumetric calculations.

Subtask 4.3–Economic Analysis

- Subtask begins on 4/1/2016.

Project Milestone Log

Task	Calendar Year	Milestone Title/Description	Planned Completion Date	Actual Completion Date	Verification Method	Comments
1.0	1	Project Management Plan	12/31/2014	12/15/2014	PMP File	100% Complete
1.0	1	Kickoff Meeting	12/31/2014	12/4/2014	Presentation File	100% Complete
2.0	2	Final selection of oilfields for study	3/31/2015	3/20/2015	Agreement between ISGS and DOE project manager to proceed with specific areas of study	100% Complete
2.0	2	Oilfield data synthesis and analysis	10/31/2015		Wells/leases grouped into classes representing relative degree of productivity	95% Complete
2.0	3	Analogous Lower Pennsylvanian study areas selected	4/30/2016		Agreement between ISGS and DOE project manager to proceed with specific areas of study	0% Complete
2.0, 3.0	3	Complete petrophysical analysis, geologic and geocellular modeling of the thick Cypress	10/31/2016		Completion of draft topical report on geology of the thick Cypress in the ILB	15% Complete
2.0	4	Complete new coring near outcrop belt	9/30/2017		Send DOE confirmation that core has been obtained and is in ISGS warehouse	0% Complete
4.0	3	Complete guidelines to develop thin oil zones and store CO ₂ in the thick Cypress	12/31/2016		Completion of draft topical report on guidelines to develop thin oil zones in the thick Cypress	0% Complete
4.0	4	Complete estimates of CO ₂ -EOR and storage potential and economic analysis of implementing program	8/30/2017		Completion of draft topical report on CO ₂ -EOR, storage, and economics of the thick Cypress in the ILB	0% Complete
All	4	Document project results	10/31/2017		Complete final report	In progress

3. PRODUCTS

What has the project produced?

Webb, Nathan D., and Grigsby, Nathan P., 2015, Geological characterization and modeling of the Cypress Sandstone at Noble Field, southeastern Illinois, Eastern Section AAPG Meeting, Indianapolis, Indiana, September 20–22.

Webb, Nathan D., 2016, The Mississippian thick Cypress Sandstone: A nonconventional CO₂-EOR target in the Illinois Basin, AAPG Annual Convention and Exhibition, Calgary, Alberta, Canada, submitted and under review.

4. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Nothing to report.

5. IMPACT

Nothing to report.

6. CHANGES/PROBLEMS

Changes in approach and reasons for change

There have been no changes in approach on this project.

Actual or anticipated problems or delays and actions or plans to resolve them

There are currently no anticipated problems or delays in the project.

Changes that have a significant impact on expenditures

As no changes have been made or are anticipated, none are expected to impact expenditures.

Significant changes in use or care of human subjects, vertebrate animals, and/or Biohazards

Not applicable.

Change of primary performance site location from that originally proposed
Not applicable.

7. Special Reporting Requirements

Nothing to report.

8. Budgetary Information

Financial Reporting Table

Baseline Reporting	Budget Period 1 11/01/14 - 10/31/17												Budget Period 2 11/01/17 - 10/31/18					Total	
	FY15 Q1	FY15 Q2	FY15 Q3	FY15 Q4	FY16 Q1	FY16 Q2	FY16 Q3	FY16 Q4	FY17 Q1	FY17 Q2	FY17 Q3	FY17 Q4	FY18 Q1	FY18 Q2	FY18 Q3	FY18 Q4	FY19 Q1		
Baseline Federal Share	192,267.00	192,267.00	192,265.00	193,061.00	205,360.00	205,360.00	205,360.00	205,359.00	121,852.00	121,852.00	121,853.00	121,852.00	58,543.00	117,085.00	175,628.00	175,628.00	117,085.00	58,544.00	2,781,221.00
Baseline non-Federal Share	30,889.00	46,334.00	46,334.00	46,334.00	44,028.00	44,028.00	44,028.00	44,028.00	44,028.00	44,028.00	44,028.00	44,028.00	15,444.00	29,253.00	43,880.00	43,880.00	43,880.00	14,627.00	713,079.00
Total Baseline Cumulative Cost	223,156.00	238,601.00	238,599.00	239,395.00	249,388.00	249,388.00	249,388.00	249,387.00	165,880.00	165,880.00	165,881.00	165,880.00	73,987.00	146,338.00	219,508.00	219,508.00	160,965.00	73,171.00	3,494,300.00
Actual Federal Share	9,661.16	82,632.97	112,826.77	147,249.60															352,370.50
Actual non-Federal Share	29,328.11	48,918.02	47,154.94	43,687.53															169,088.60
Total Actual Cumulative Cost	38,989.27	131,550.99	159,981.71	190,937.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	521,459.10
Variance Federal Share	182,605.84	109,634.03	79,438.23	45,811.40	205,360.00	205,360.00	205,360.00	205,359.00	121,852.00	121,852.00	121,853.00	121,852.00	58,543.00	117,085.00	175,628.00	175,628.00	117,085.00	58,544.00	2,428,850.50
Variance non-Federal Share	1,560.89	(2,584.02)	(820.94)	2,646.47	44,028.00	44,028.00	44,028.00	44,028.00	44,028.00	44,028.00	44,028.00	44,028.00	15,444.00	29,253.00	43,880.00	43,880.00	43,880.00	14,627.00	543,990.40
Total Variance Cumulative Cost	184,166.73	107,050.01	78,617.29	48,457.87	249,388.00	249,388.00	249,388.00	249,387.00	165,880.00	165,880.00	165,881.00	165,880.00	73,987.00	146,338.00	219,508.00	219,508.00	160,965.00	73,171.00	2,972,840.90