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A Nonconventional CO_2-EOR Target in the Illinois Basin: Oil Reservoirs of the Thick Cypress Sandstone

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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 Milestone Report documenting the completion of production data synthesis and analysis in Noble Field was completed and delivered electronically to US Department of Energy (DOE) project manager Bruce Brown on October 21, 2015.
- A geocellular model was constructed for Kenner West Field, an area analogous to Noble Field with a high concentration of core porosity and permeability data. Core data was compiled and preliminary normalized SP-to-porosity and porosity-to-permeability transforms were developed.
- Field reconnaissance has begun to select outcrops analogous to the thick Cypress Sandstone in the basin interior for detailed study and also select a nearby site from which to collect a core through the entire Cypress interval.
- The project website has been updated and populated with relevant content including all reports and presentations issued to date. A project update detailing some of the field work was published as an article on the Illinois State Geological Survey website, giving a public update of project activities and exposing the project website to a broader audience.

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 (CO_2) 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.
- PI Nathan Webb and co-PI Scott Frailey, along with Nate Grigsby met weekly to discuss project management.
- There were regular meetings with the PI and subtask leaders for active subtasks.
- 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. Forty core images were prepared for website use by Daniel Byers.

Task 2.0–Geology and Reservoir Characterization (on schedule)

Subtask 2.1–Literature Review and Oilfield Selection

- Nathan Webb began site screening to select an area with a Pennsylvanian sandstone that exhibits a relatively thin oil reservoir over a thick aquifer, analogous to those of the thick Cypress Sandstone, for detailed study.

Subtask 2.2–Petrophysical Analysis

- Josh Arneson, Nathan Grigsby, and Scott Frailey continue the use of the Archie and ratio water saturation methods to assess the oil-water contact (OWC) and presence of residual oil zones (ROZs) using well logs. The R_{wa} method was added.
    - The water saturation (S_w) analysis tool, in the form of an Excel spreadsheet, was completed.
    - Forty wells from Noble Field with complete geophysical log suites have been analyzed for refining the S_w analysis tool. An example water saturation profile through the thick Cypress Sandstone is given in Figure 1.
    - S_w cutoff values are being selected to determine different proportions of oil-water saturation below the producing oil-water contact.
    - Preliminary results via a comparison between Archie and Ratio water saturation is the presence of excessive conductivity. This is most likely in the form of water

saturated microporosity or dispersed authigenic clay in the pore space (e.g. pore-lining or pore bridging)

Subtask 2.3–Geologic Model Development

- Volumetric calculations were conducted by Nathan Webb and Nathan Grigsby to determine the original oil in place (OOIP) in the traditional oil reservoir at Noble Field.
- Nathan Webb completed a draft of a report on the geological characterization of the thick Cypress Sandstone at Noble Field. This report is currently in internal review at the Illinois State Geological Survey (ISGS).
- Kalin Howell, John Grube, and Nathan Webb conducted sedimentological studies of southern Illinois outcrops to select locations for detailed study and for taking new core near the outcrop belt of the thick Cypress Sandstone. ISGS field geologists John Nelson and Joe Devera assisted in locating relevant outcrops.
    - Daniel Klen participated in this fieldwork and wrote a project update article for the ISGS website, giving a public update of project activities and exposing the main project website to a broader audience.
- Zohreh Askari 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.
    - Completed sample study of four wells (county no. 23887, 23976, 26248, and 28941) in Noble Field.
    - Forty two drill cuttings were prepared for petrographic evaluation.
- Description, sampling, and analysis of available Cypress Sandstone core is ongoing:
    - Kalin Howell contributed the following work:
        - Described about 247 ft (75.3 m) of core from 10 wells. Photographed about 60 ft (18 m) of core and slabbed two cores.
        - Created a sedimentary facies scheme (Table 1a) to classify and characterize all facies within the thick Cypress Sandstone because reservoir architecture and quality is dictated by facies. To understand reservoir heterogeneity and quality, all lithologies preserved in core were analyzed. Complete characterization of all lithologies present in the

Cypress interval provides stratigraphic context essential for understanding the spatial distribution of reservoir quality rock and interpreting depositional environment. Thorough characterization and classification of all sedimentary facies allows geophysical data to be accurately calibrated.

    - Created a geophysical facies scheme (Table 1b) to compliment the lithologic facies scheme. Understanding how sedimentary facies correspond to geophysical facies allows for subsurface mapping to be conducted with higher confidence where physical samples are unavailable. Specifically, calibrating lithologic facies to geophysical facies will allow for regional scale correlation in the thick Cypress Sandstone to be conducted with a higher degree of certainty.
    - Drafted stratigraphic columns (Figure 2) from core descriptions and assigned lithologic and geophysical facies.
    - Continued correlation and mapping of the thick Cypress Sandstone in Dale Field, an area considered to be geologically analogous to Noble Field.
    - Investigated a method for making three-dimensional (3D) geologic models in GIS and developed a preliminary example model from Dale Field.
- Jaclyn Daum conducted mineral identification and description of petrographic slides from two Noble Field cores. Leveraging Kalin Howell's stratigraphic columns, samples representing a range of sedimentary facies were prioritized for full analysis. Twenty-seven (27) slides were photographed and described with eight slides selected for full analysis.
    - Very fine grained flaser-, wavy-, and lenticular-bedded sandstones compose the nonreservoir facies and show a much higher degree of compaction than reservoir facies (Figure 3). Quartz overgrowths and clay minerals fill pore space. Much of the porosity in the nonreservoir facies is attributed to secondary dissolution of feldspar grains or carbonate cements. Increased detrital clay content means fine clay laminations compartmentalize the reservoir.
    - Reservoir facies are generally coarser grained than the nonreservoir facies, with fine-grained sandstone being most common but medium-grained

sandstone occurring in the cross-bedded facies. In the reservoir facies, the grains are moderately well sorted and range from angular to rounded, with the rounded grains being more prevalent (Figure 4).

        - Porosity is generally primary intergranular with some secondary porosity resulting from dissolution of feldspar grains. Clay minerals and quartz overgrowths occlude porosity and permeability in cross-bedded sandstone.
    - Shane Butler conducted laboratory analyses of bulk and clay mineralogy samples with the assistance of Eve Mason:
        - Continued processing samples by completing sample submission sheets and taking the first steps in the sample processing standard operating procedure (SOP) as permitted by our laboratory space and facilities. Eighty (80) samples are currently undergoing sample size reduction.
        - Along with Nathan Webb, discussed microporosity in clays with Leo Giannetta, specifically in regard to methods to investigate microporosity in these samples. Giannetta drafted a proposal for conducting this research.
        - Twenty-seven (27) samples from C.T. Montgomery B-34 core were run with the X-ray diffraction (XRD) unit and results for bulk mineral content and <16 micron clay analysis have been completed.
        - Twenty-nine (29) samples from John O. Coen 120 core have been fully processed and are ready to be analyzed.
        - Dmytro Lukhtai completed porosity and permeability laboratory analyses on 84 core plugs and collected an additional 160 plugs for analysis.
- Peter Berger began testing the CO2-brine flow tests of four Cypress Sandstone core plugs. Oil/brine/CO_2 tests are to follow.

Task 3.0–Geocellular and Reservoir Modeling (on schedule)

Subtask 3.1–Historical Production and Injection Data Analysis

- The Milestone Report documenting the production data synthesis and analysis of Noble Field was completed and delivered electronically to DOE project manager Bruce Brown on October 21, 2015.
- Nathan Grigsby is drafting a report detailing methods developed to compile and process

oilfield production data.

Subtask 3.2–Illinois Basin Crude Oil/Brine-CO_2 Fluid Property Characterization

- Peter Berger performed two minimum miscibility pressure (MMP) tests on Cypress oil samples.
- Thirty two (32) samples were selected from three wells in Richland and Clay Counties (county no. 26171, 2397, and 28941) for visible cut tests to identify residual oil saturation. Fang Yang conducted the visible cut tests. Table 2 provides a summary of the results of 21 samples from a well in Noble Field. The oil saturation of each sample was determined based on the oil volume percentage indicated by cut color.

Subtask 3.3–Geocellular Modeling of Interwell Reservoir Characteristics

- Nathan Grigsby contributed the following work:
    - Revised the geocellular model of the thick Cypress Sandstone at Noble Field using data from 126 porosity logs. The previous model captured the distribution of sandstone and shale using only spontaneous potential (SP) logs; however, the SP logs were not able to detect the calcite cement zones identified in core, samples, and on neutron-density porosity logs (Figure 5). The SP based porosity model was enhanced by using the neutron-density logs which included the calcite cement zones. This enhanced model was vetted by senior geologists and approved for reservoir simulations (Figure 6).
    - Digitized SP logs for Kenner West Field, an area analogous to Noble Field with a high concentration of core porosity and permeability data, were received and normalized and a preliminary geocellular model was constructed for the field. Core data was compiled and preliminary normalized SP-to-porosity and porosity-to-permeability transforms were developed.

Subtask 3.4–Reservoir Modeling

- Revised input files for reservoir simulations have been generated by Nathan Grigsby. These input files include the enhanced geocellular model that reflects the geologic heterogeneity, including calcite cemented zones, of the thick Cypress Sandstone at Noble Field and the production and injection history data.

Task 4.0–CO_2 EOR and Storage Development Strategies (on schedule)

Subtask 4.1–Field Development Strategies

- Subtask begins on 4/1/2016.

Subtask 4.2–CO_2 EOR and Storage Resource Assessment

- Regional Cypress Sandstone thickness data is being generated to refine the regional isopach map. This map will provide the basis for conducting volumetric calculations for regional CO_2 EOR and storage resource estimate. Zohreh Askari is working on revisions on a county-by-county basis beginning with Richland and Wayne Counties in the center of the thick Cypress Sandstone fairway and adjacent to Noble Field.
- Nathan Grigsby selected 63 geophysical well logs with complete log suites from 30 wells at different locations in the thick Cypress Sandstone fairway for the regional assessment.

Subtask 4.3–Economic Analysis

- Subtask begins on 4/1/2016.

Table 1a. Draft lithologic facies scheme resulting from description and facies analysis of all cores described to this point. For associated geophysical log facies, see Table 1b.

Facies Symbol	Symbol Meaning	Description	Depositional Process
C	Coal	Bituminous coal, commonly planar bedded and fissile	Plant detritus and/or peat accumulation and coalification
M	Mud	Dark gray shale, planar laminated, finely bedded and commonly fissile, commonly slickensided and bioturbated; ***may or may not contain***: calcite cement, low silt abundance, carbonaceous fragments, pyrite, fenestrate bryozoans, brachiopods, gastropods, crinoids	Low energy suspended sediment fallout
MS	Mud with silt	Light gray shale with homogeneous matrix of silt and mud, planar laminated, finely bedded, more or less bioturbated with rare carbonaceous debris; ***may or may not contain***: calcite cement, silty interbeds and/or laminations, fossil fragments, carbonaceous fragments, pyrite, iron-oxide	Low energy fine sediment fallout >= low energy periodic sedimentation
HL	Heterolithic, Lenticular bedding	0.4–2 in. (1–4 cm) whitish-grey silty lenses encased in mud or silty mud matrix, lenses commonly contain ripples with clay drapes on foresets, lenses range from thick to thin; ***may or may not contain***: calcite cement, bidirectional ripples, carbonaceous fragments, connected lenses	Low energy fine sediment fallout-without-traction > higher energy episodic flows
HW	Heterolithic, Wavy bedding	Whitish-gray silt to very fine sand interbedded in equal proportion with gray mud beds which are commonly wavy, less commonly consists of planar interbeds, commonly contains ripples with mud drapes defining foresets; ***may or may not contain***: calcite cement, bidirectional or sigmoidal ripples, reactivation surfaces, carbonaceous fragments, shaly rip-up clasts	Low energy sediment fallout-without-traction = higher energy episodic flows
HF	Heterolithic, Flaser bedding	Gray shaly flasers encased in a whitish-gray very fine to fine grained sand matrix, flasers range may be simple, bifurcated, wavy, or bifurcated wavy; ***may or may not contain***: calcite cement, asymmetrical or bidirectional ripples, shaly rip-up clasts	Low energy sediment fallout-without traction < higher energy episodic flows
SM	Sandstone, Massive	Whitish-gray very fine to medium grained massive quartz arenite to sublitharenite with angular to subangular grains; ***may or may not contain***: oil staining, calcite cement, microscopic crinoid fragments, iron-oxide staining	Bedload-dominated sedimentation, deformation postdeposition

Facies Symbol	Symbol Meaning	Description	Depositional Process
SRB	Sandstone, Ripple Bedded	Whitish-tan very fine to fine grained ripple-bedded arenite to sublitharenite with angular to subangular grains, commonly bidirectional or asymmetric with laterally migrating foresets; ***may or may not contain***: oil staining, calcite cement, climbing or sigmoidal ripples, shale rip-up clasts, iron-oxide staining	Bedload-dominated sedimentation, low energy traction currents
SRL	Sandstone, Ripple Cross Laminated	Whitish-tan very fine to fine grained ripple bedded arenite to sublitharenite with angular to subangular grains, commonly bidirectional or asymmetric with laterally migrating foresets; ***may or may not contain***: oil staining, calcite cement, climbing or sigmoidal ripples, shale rip-up clasts, iron-oxide staining	Bedload-dominated sedimentation, low energy traction currents with intermittent suspension-dominated sedimentation OR low energy unidirectional to bidirectional traction currents with clay-filled troughs
SP	Sandstone, Planar Bedded	Whitish-tan very fine to fine grained planar bedded arenite to sublitharenite with angular to subangular grains, quartz sandstone, tan to brown, occasional oil staining, very fine to medium grained, planar laminated, shaly carbonaceous laminations; ***may or may not contain*: ** oil staining, calcite cement, shaly laminations, graded beds, carbonaceous debris, shale rip-up clasts, microscopic crinoid fragments, iron-oxide staining	Low to moderate energy sediment fallout-without-traction (possible hypopycnal flow) OR moderate to high energy unidirectional bedload sedimentation
SC	Sandstone, Cross Bedded	Whitish-gray very fine to medium grained cross-bedded arenite to sublitharenite with angular to subangular grains, commonly low angle; ***may or may not contain***: oil staining, calcite cement, shaly laminations, carbonaceous debris, shale rip-up clasts, graded beds, microscopic crinoid fragments, iron-oxide staining	Moderate to high energy unidirectional traction sedimentation
G	Conglomerate	Conglomerate with very fine to medium grained sand matrix, commonly matrix supported; ***may or may not contain***: clasts of clay, sandstone, limestone, carbonaceous debris, crinoids, brachiopods, gastropods, bryozoans, pyrite and iron-oxide concretions	High energy unidirectional traction currents
D	Deformed Bedding	Distorted laminations or bedding in a wide range of lithologies, commonly contains slump structures and/or convolute bedding; ***may or may not be***: intense bioturbation	Post- or syndeposition deformation

Table 1b. Draft geophysical facies scheme. For associated lithologic facies, see Table 1a.

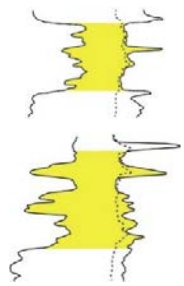
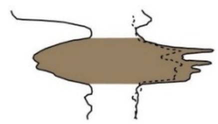
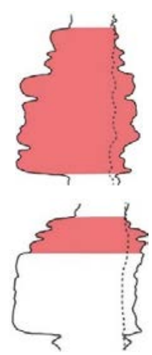
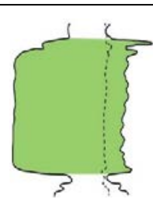
Log Facies	**Thickness, ft (m)**	**SP and Resistivity Signature**	**Lithologic Facies**	**Description**	**Depositional Process**
Smooth Shale (SmS)	1–100 (0.3–30.5)		M, MS, D	Positive Gamma/SP, may be slightly serrated, commonly sharp upper and lower contacts	Uniform low energy suspension-dominated sedimentation
Serrated Shale (SS)	5–100 (2–30.5)		HL, HW, HF, SRB, SRL, SP, D	Serrated Gamma/SP, irregular trend, sandy interbeds vary in thickness from a few feet to up to 15 ft (4.6 m) May contain thicker and more pronounced sand interbeds	Irregular switching between low energy fallout sedimentation and moderate energy, bedload-dominated sedimentation
Hourglass (H)	25–50 (7.6–15)			Roughly symmetrical Gamma/SP response, may be slightly serrated, upper and lower contacts commonly gradational	Increase in bedload sedimentation energy followed by a decrease in bedload-dominated sedimentation energy
Serrated Bell (SB)	5–100 (2–30.5)		HL, HW, HF, SRL, D	Fining up with sharp lower contact and gradational upper contact, commonly serrated, beds may thin upwards Fining up with gradational upper and lower contacts, may occur as thin transition zone between blocky and shale facies, beds may thin upwards	Gradual decrease in bedload-dominated sedimentation energy
Serrated Funnel (SF)	5–50 (2–15)			Coarsening up with gradational lower contact and sharp upper contact, commonly serrated, beds may thicken upwards	Gradual increase in bedload-dominated sedimentation energy
Serrated Cylindrical (SC)	30–100 (9.1–30.5)			Uniformly negative serrated Gamma/SP, typically gradational upper and lower contacts	Irregular switching between high energy bedload-dominated sedimentation and low energy fallout sedimentation
Smooth Cylindrical (SmC)	30–100 (9.1–30.5)		SP, SC, SRL, SR, CONG, SM, D	Uniformly negative Gamma/SP “block” typically with sharp upper and lower contacts, may be slightly serrated	Uniform moderate to high energy bedload-dominated sedimentation

Table 2. Visible cut analysis for well no. 12159267100 in Noble Field at Richland County. Visible cut analysis is performed on old samples from which oil may have vaporized or bio-degraded. Thus, oil saturation results do not reflect actual original oil saturation or remaining oil saturation after production.

Sample Number	Cutting Depth, ft (m)	Porosity, (%)	Calculated bulk volume, in^3 (ml)	Observed bulk volume, in^3 (ml)	Solvent volume, in^3 (ml)	Oil volume percentage, %	Oil saturation (calculated bulk volume), %	Oil saturation (observed bulk volume), %
1	2575~2580 (784.9~786.4)	18.2	0.06 (1.0)	0.09 (1.5)	0.1 (2)	0	0	0
2	2580~2585 (786.4~787.9)	18.2	0.04 (0.6)	0.06 (1.0)	0.1 (2)	0.12	2.4	1.3
3	2585~2590 (787.9~789.4)	18.7	0.05 (0.8)	0.08 (1.3)	0.1 (2)	0.05	0.7	0.4
4	2590~2595 (789.4~791)	18.5	0.05 (0.9)	0.09 (1.5)	0.1 (2)	0.08	1.0	0.6
5	2595~2560 (791~780.3)	17.4	0.05 (0.9)	0.09 (1.5)	0.1 (2)	0.18	2.3	1.4
6	2600~2605 (792.5~794.0)	17.5	0.05 (0.9)	0.09 (1.5)	0.1 (2)	0.22	2.7	1.7
7	2605~2610 (794.0~795.5)	13.2	0.05 (0.8)	0.09 (1.5)	0.1 (2)	0.2	3.6	2.0
8	2610~2615 (795.5~797.1)	12.1	0.05 (0.9)	0.09 (1.5)	0.1 (2)	0.05	1.0	0.5
9	2615~2620 (797.1~798.6)	15.4	0.05 (0.9)	0.09 (1.5)	0.1 (2)	0	0	0
10	2620~2625 (798.6~800.1)	14.4	0.05 (0.9)	0.09 (1.5)	0.1 (2)	0	0	0
11	2625~2630 (800.1~801.6)	14.9	0.05 (0.9)	0.09 (1.5)	0.1 (2)	0	0	0
12	2630~2635 (801.6~803.1)	15.3	0.05 (0.8)	0.09 (1.5)	0.1 (2)	0	0	0
13	2635~2640 (803.1~804.7)	15.8	0.05 (0.9)	0.09 (1.5)	0.1 (2)	0	0	0
14	2640~2645 (804.7~806.2)	16.9	0.05 (0.8)	0.09 (1.5)	0.1 (2)	0	0	0
15	2645~2650 (806.2~807.7)	17.1	0.05 (0.8)	0.09 (1.5)	0.1 (2)	0	0	0
16	2650~2655 (807.7~809.2)	17.2	0.05 (0.8)	0.09 (1.5)	0.1 (2)	0	0	0
17	2660~2665 (810.8~812.3)	16.5	0.05 (0.8)	0.09 (1.5)	0.1 (2)	0	0	0
18	2670~2675 (813.8~815.3)	14.7	0.05 (0.9)	0.09 (1.5)	0.1 (2)	0	0	0
19	2680~2685 (816.9~818.4)	16.2	0.05 (0.8)	0.09 (1.5)	0.1 (2)	0	0	0
20	2685~2690 (818.4~819.9)	15.8	0.05 (0.8)	0.09 (1.5)	0.1 (2)	0	0	0
21	2690~2695 (819.9~821.4)	14.7	0.05 (0.8)	0.09 (1.5)	0.1 (2)	0	0	0

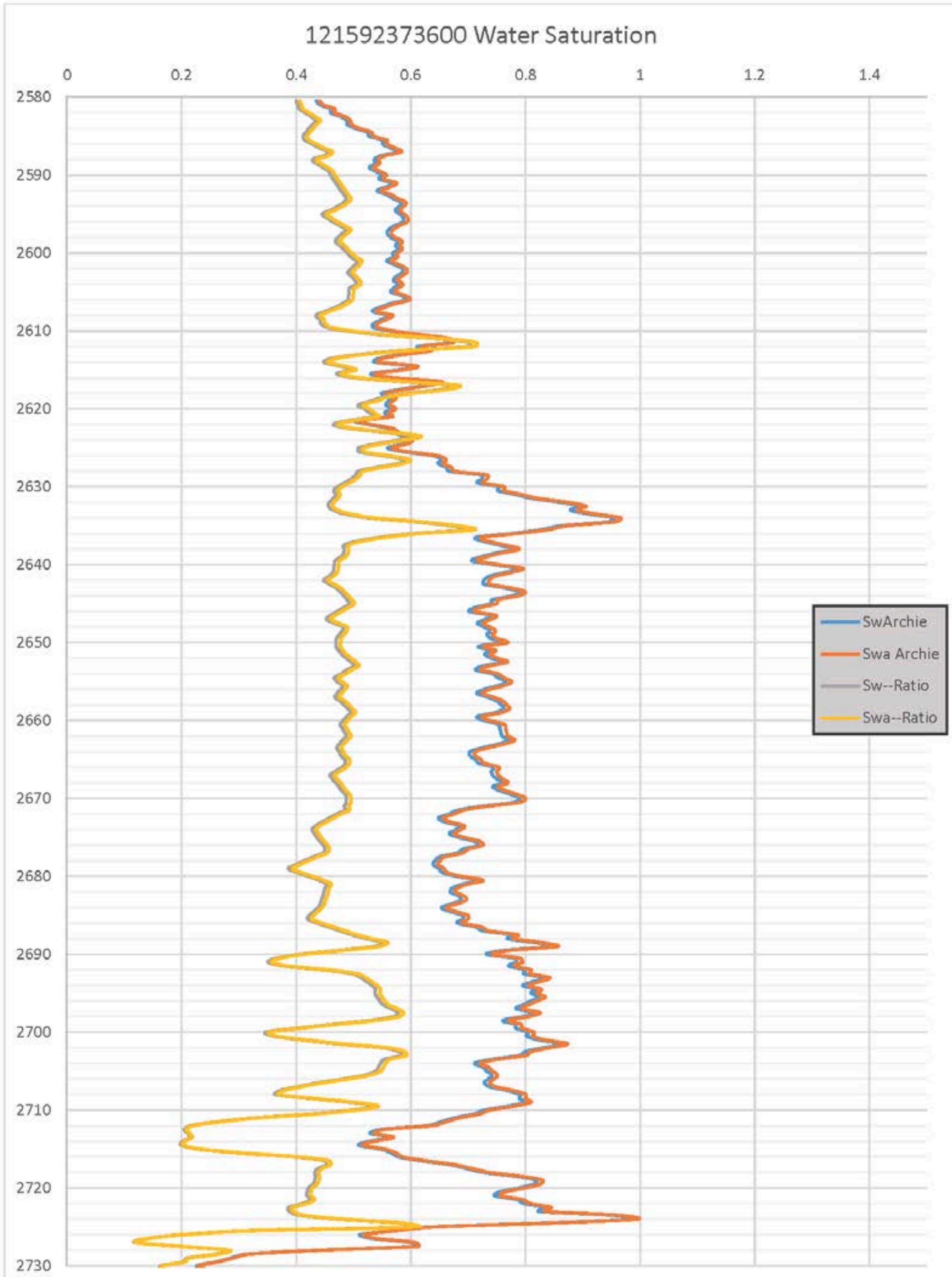


Figure 1. Example water saturation ratios taken from one of the wells being analyzed to refine the S_w analysis tool. Errors in records or geological reasons could explain the disparity between the Archie (Sw Archie and Swa Archie) and ratio water saturation (Sw Ratio and Swa Ratio) methods. Both ideas are being investigated.

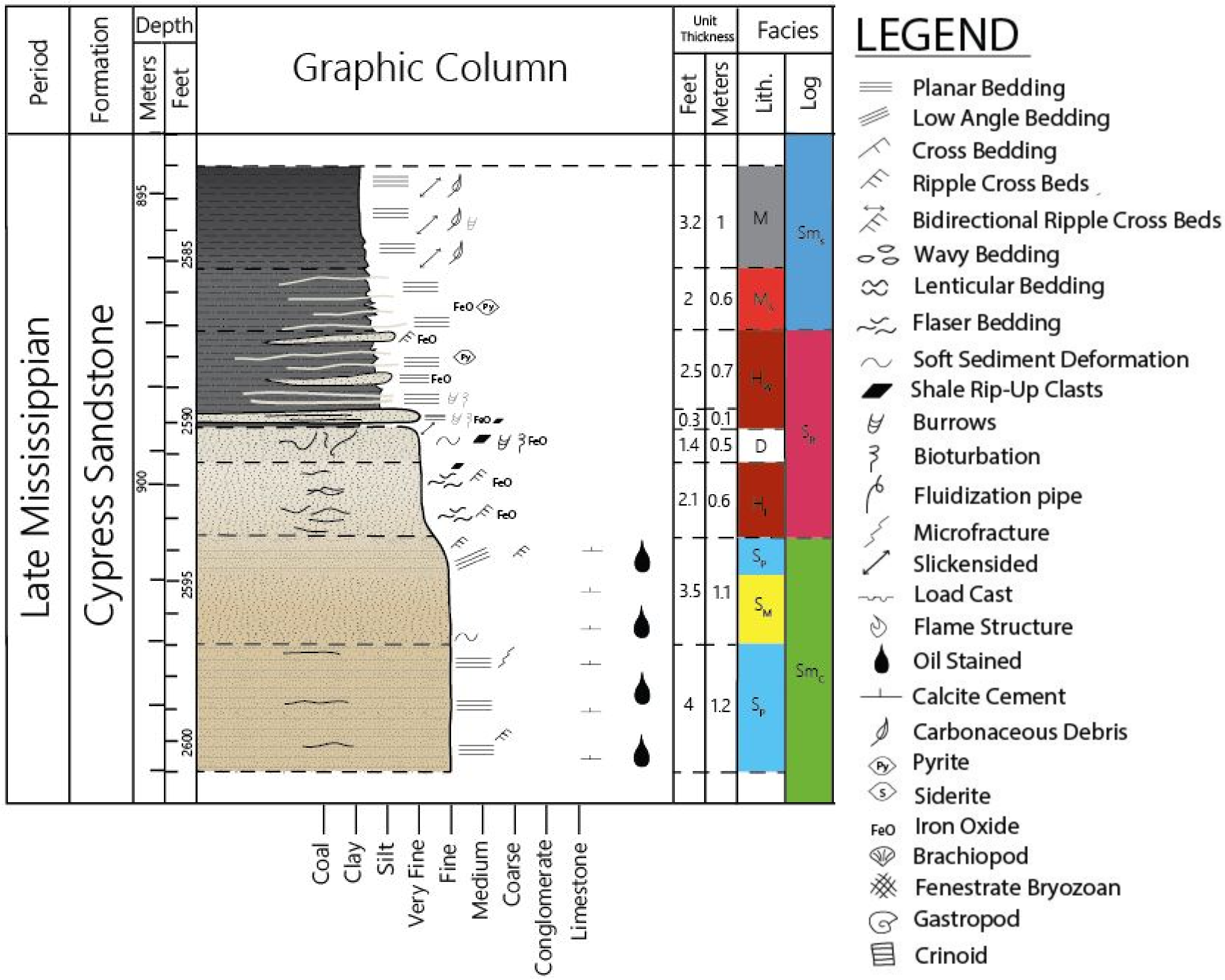


Figure 2. Example of one of the stratigraphic columns. Lithologic and log facies interpretations have been applied (Tables 1 and 2, respectively).

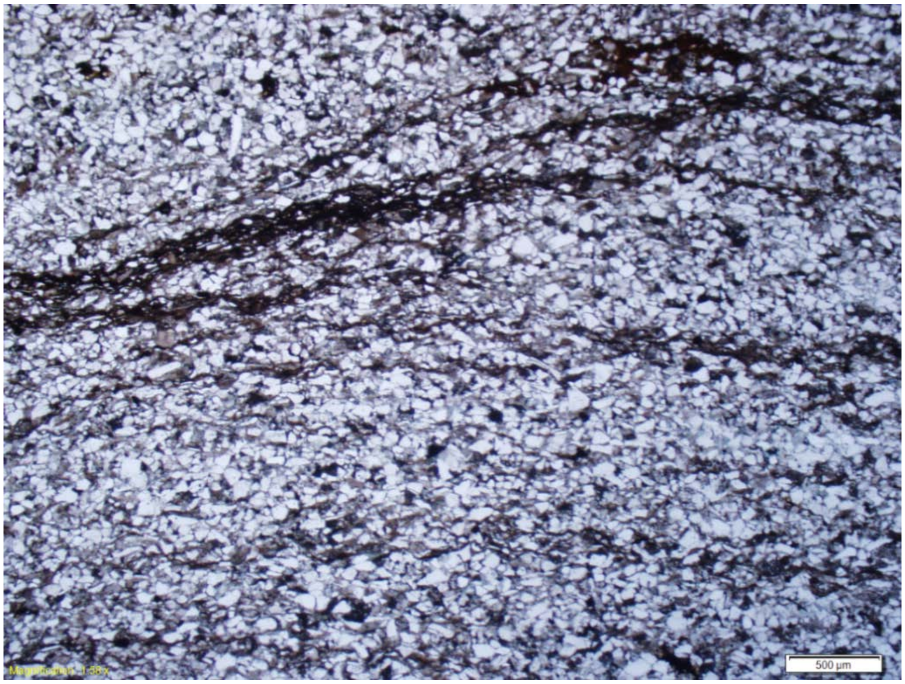


Figure 3. Example photomicrograph of wavy bedded sandstone from the Montgomery B-34 well at 2,580.5 ft (786.54 m) showing the laminations across the slide. The light blue represents the pore space within the rock. Porosity is 10.2% and permeability is 1.1 mD (0.001 μm^2).

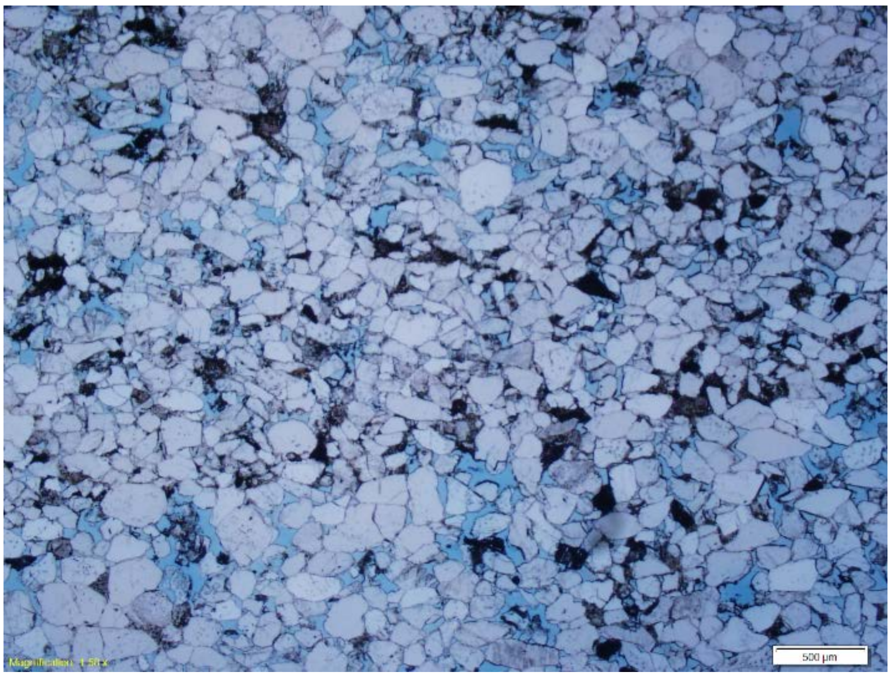


Figure 4. Example photomicrographs of cross-bedded sandstone. Images are from the Montgomery B-34 well at 2,596.5 ft (791.41 m). The very fine grained sandstone in the wavy bedded facies (Figure 3) shows a stark contrast with the fine- to medium-grained sandstone of the cross-bedded facies. Porosity is 18.4% and permeability is 1,821 mD (1.797 μm^2).

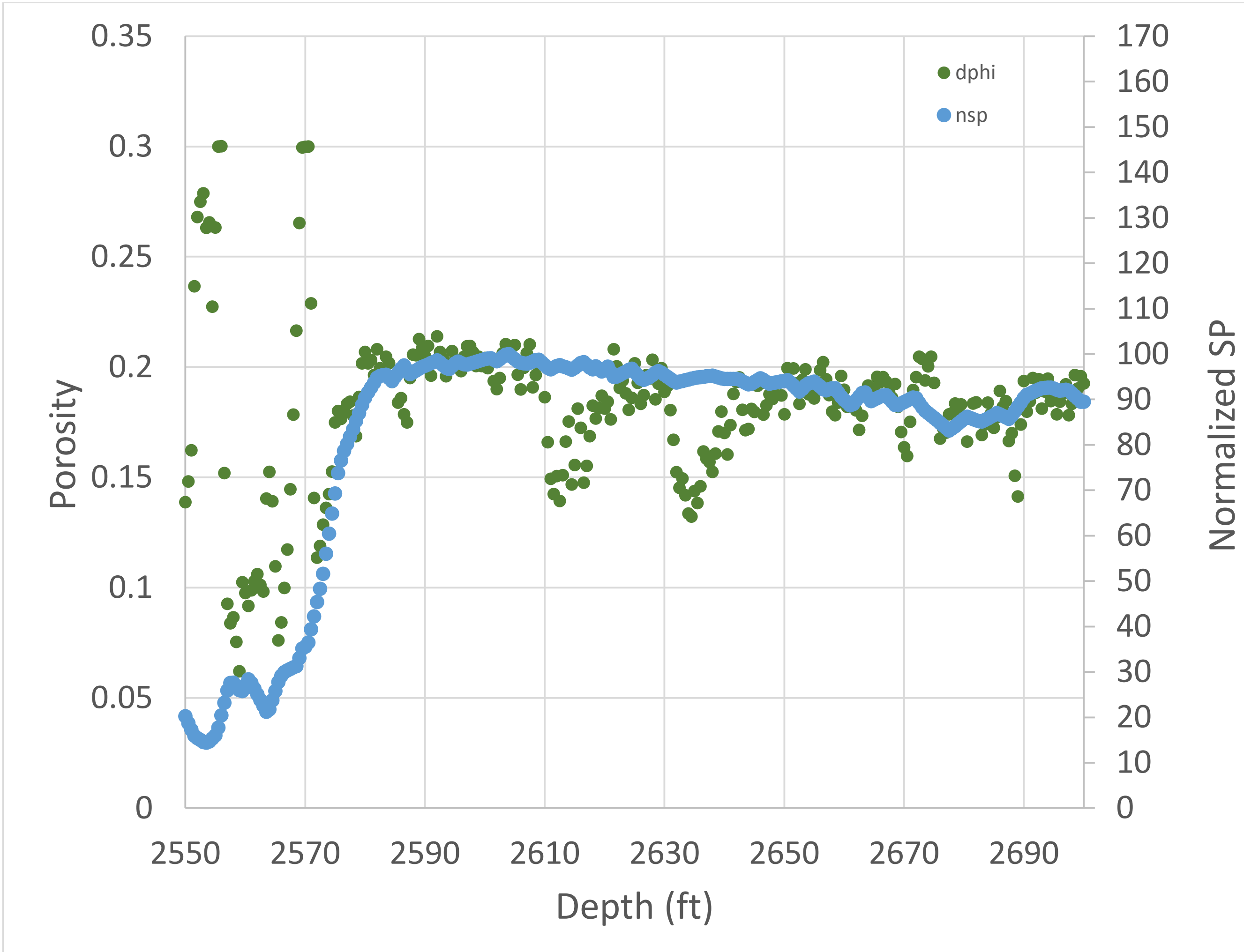


Figure 5. Digitized log data from the thick Cypress. Porosity values from the log are green dots with units on the left *y*-axis and normalized SP are the blue dots with units on the right *y*-axis. The normalized SP is able to closely approximate the porosity log except for two calcite cement layers that occur just below 2,610 and 2,630 ft (795.5 and 801.6 m). The area on the far left side of the graph (depths 2,550–2,570 ft [777.2–783.3 m]) represents the upper, shale-rich Cypress not included in the model. Shale disrupts neutron porosity logs and shows up as incorrectly high porosity values (depths 2,550–2,570 ft [777.2–783.3 m]).

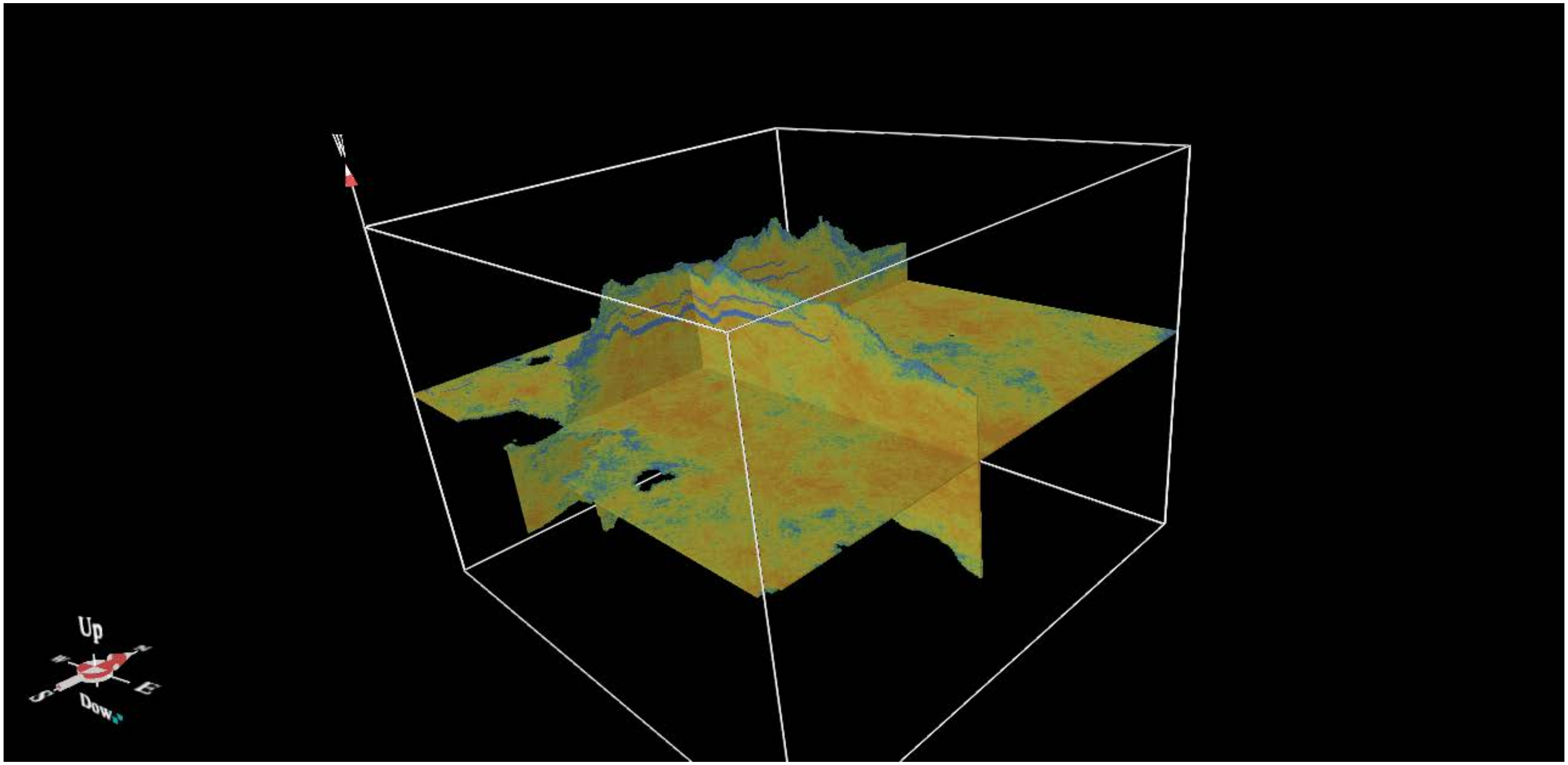


Figure 6. *X*-, *y*-, and *z*-axis slices of the porosity distribution with two low-porosity cement layers (shown in blue) near the top.

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 at Urbana-Champaign's 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.

Specific examples are given below:

- Kalin Howell, MS student on the project, completed a 15 page National Science Foundation-style research proposal for his thesis project, including refining and establishing research methods and hypotheses. He also taught Dmytro Lukhtai, an undergraduate student, how to sample cores for porosity and permeability plugs.
- Jaclyn Daum, an undergraduate student, learned the different processes for thin section analysis using Cypress Sandstone slides from a previous study. She worked on photographing slides, mineral identification, point-counting grains, grain-size analysis, and put all of these together into individual "mini reports" for each thin section. Each thin section represented a certain depth belonging to a certain well. She is now applying lessons learned to new slides obtained as part of this project.
- Fang Yang, a reservoir engineer on the project, is developing new skills in pressure-volume-temperature (PVT) analysis under the advisement of project staff.

How have the results been disseminated to communities of interest?

The main project website, part of the ISGS website, was established to disseminate project information and findings to the public and other interested parties. The website hosts a project summary, staff bios, and downloadable reports and presentations produced from the project.

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 to select an area with a Pennsylvanian sandstone that exhibits a relatively thin oil reservoir over a thick aquifer, analogous to those of the thick Cypress Sandstone, for detailed study will conclude.
- Field investigations of outcrops for detailed sedimentological study and for selecting a location for taking a thick Cypress Sandstone core near the outcrop belt will continue.

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.
- Prototype Mapping will be developed from Josh Arneson's work.
    - Maps will be constructed based on S_w cutoff values for the 40 wells from Noble Field. This oil distribution map of Noble Field will serve as a template for the regional resource assessment.
- Additional visible cut analysis of core and samples will be conducted to calibrate the S_w tool with physical evidence of oil saturation.
- Partners will be sought for running cased-hole logs in existing wells.

- Microporosity of clay minerals in the thick Cypress will be quantified using Scanning Electron Microscope (SEM) Back-Scatter Electron (BSE) techniques. Leo Giannetta will be the main contributor of this work.
    - Objectives of the study include
        - quantifying the percentage of microporosity present in clay minerals of the Cypress Sandstone;
        - calculating new values for water saturation using microporosity data; and
        - identifying clay mineral morphologies in the thick Cypress Sandstone.
    - This work will allow project members to
        - estimate effective porosity by correcting for microporosity in clay, providing a more accurate representation of reservoir quality;
        - enhance petrophysical evaluations by calculating effective water saturation values; and
        - determine whether clays are detrital or digenetic, which may aid in the interpretation of depositional environment.
    - Multiple wells with Cypress Sandstone core will be selected from around the Illinois Basin for analysis. Samples will be chosen from specific wells and depths that have already undergone standard petrographic study.
    - Analyses will be conducted at the University of Illinois at Urbana-Champaign's Center for Microanalysis of Materials (CMM) located in the Frederick Seitz Materials Research Laboratory (MRL).

Subtask 2.3–Geologic Model Development

- A report on the geological characterization of the thick Cypress Sandstone at Noble Field will be revised according to the internal ISGS review.
- 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, Dale, and Kenner West Fields will continue.

Task 3.0–Geocellular and Reservoir Modeling (on schedule)

Subtask 3.1–Historical Production and Injection Data Analysis

- The report detailing methods developed to compile and process oilfield production data will be completed.

Subtask 3.2–Illinois Basin Crude Oil/Brine-CO_2 *Fluid Property Characterization*

- Core flood experiments will be completed.
- Work will begin on modeling CO_2/brine interactions in Cypress Sandstone reservoirs.

Subtask 3.3–Geocellular Modeling of Interwell Reservoir Characteristics

- The geocellular model of Kenner West Field will be developed as additional data is digitized.

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–CO_2 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–CO_2 *EOR and Storage Resource Assessment*

- Work will continue on updating and refining 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	10/21/2015	Wells/leases grouped into classes representing relative degree of productivity	100% 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	30% 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	50% 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	5% Complete
4.0	3	Complete guidelines to develop thin oil zones and store CO_2 in the thick Cypress	12/31/2017		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	8/30/2018		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	10/31/2018		Complete final report	In progress

3. PRODUCTS

What has the project produced?

a. Publications, conference papers and presentations

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 (*accepted*), The Mississippian thick Cypress Sandstone: A nonconventional CO_2-EOR target in the Illinois Basin: AAPG Annual Convention and Exhibition, Calgary, Alberta, Canada.

b. Website(s) or other Internet site(s)

A link to the project website is given here: http://www.isgs.illinois.edu/research/oil-gas/doe

This main project website, part of the ISGS website, was established to disseminate project information and findings to the public and other interested parties. The website hosts a project summary, staff bios, and downloadable reports and presentations produced from the project.

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 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	124,049.33														476,419.83
Actual non-Federal Share	29,328.11	48,918.02	47,154.94	43,687.53	43,602.72														212,691.32
Total Actual Cumulative Cost	38,989.27	131,550.99	159,981.71	190,937.13	167,652.05	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	689,111.15
Variance Federal Share	182,605.84	109,634.03	79,438.23	45,811.40	81,310.67	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	2,304,801.17
Variance non-Federal Share	1,560.89	(2,584.02)	(820.94)	2,646.47	425.28	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	500,387.68
Total Variance Cumulative Cost	184,166.73	107,050.01	78,617.29	48,457.87	81,735.95	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	2,805,188.85