Reservoir Characterization of the Silurian “Clinton” Sandstone in the East Canton Oil Field, Ohio

Ronald A. Riley[1], John L. Wicks[2], and Christopher J. Perry[1]
[1]Ohio Division of Geological Survey, Columbus, OH, ron.riley@dnr.state.oh.us, chris.perry@dnr.state.oh.us
[2]J. L. Wicks Exploration, Wooster, OH, jlwicksx@embarqmail.com

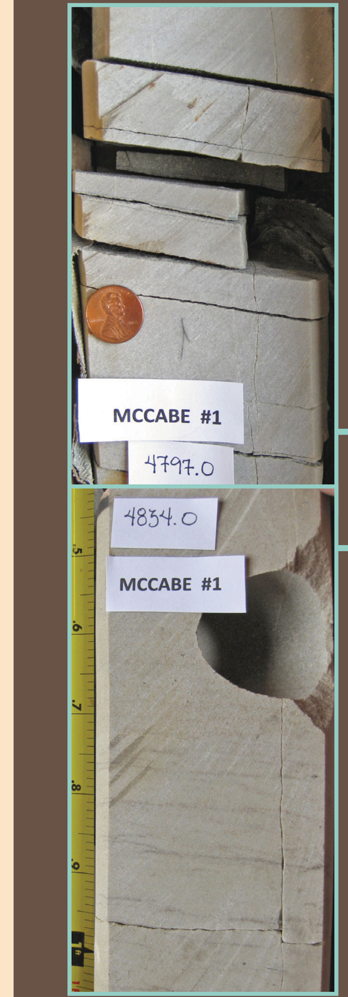
ABSTRACT

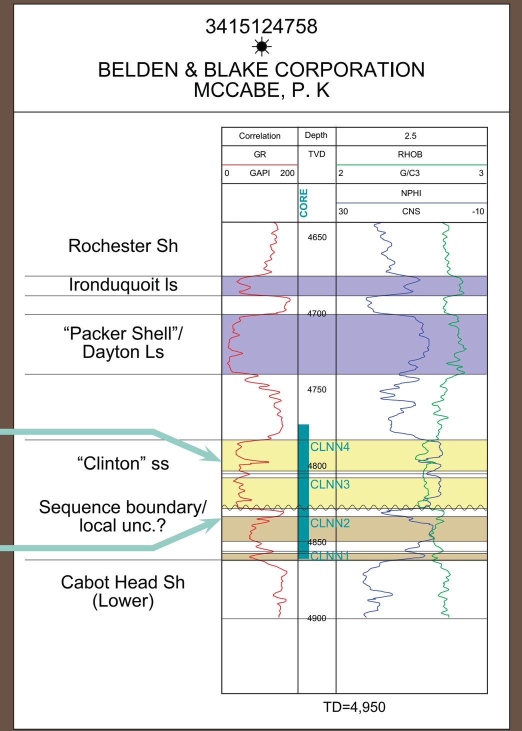
The Ohio Department of Natural Resources (ODNR), Division of Geological Survey, in conjunction with private industry and partially funded by the U. S. Department of Energy, currently is conducting a detailed reservoir characterization of the Silurian “Clinton” sandstone in the mature East Canton oil field. The primary objective is to evaluate the potential for carbon dioxide-enhanced oil recovery (CO_2-EOR). Since 1947, the East Canton oil field has produced approximately 95 million barrels of oil from approximately 3,100 wells within 175,000 acres. It is estimated to have over one billion barrels of original oil-in-place. To date, there have been no secondary recovery efforts in this field because of the tight, heterogeneous nature of this reservoir.

Regional wireline stratigraphic cross sections were generated across and surrounding the East Canton oil field and correlated to four full-diameter cores and published reports to establish the regional “Clinton” sequence stratigraphy and depositional setting. The resulting stratigraphic framework established regionally consistent formation/interval boundaries that were used for development of structure, isopach, and facies maps. Detailed reservoir maps of up to five sandstone units, and surrounding impermeable shale units, within the “Clinton” interval are being mapped and related to production. Reservoir fluid flow regimes are dominantly controlled by (1) stratigraphy within these mappable units and (2) their interaction with natural fractures.

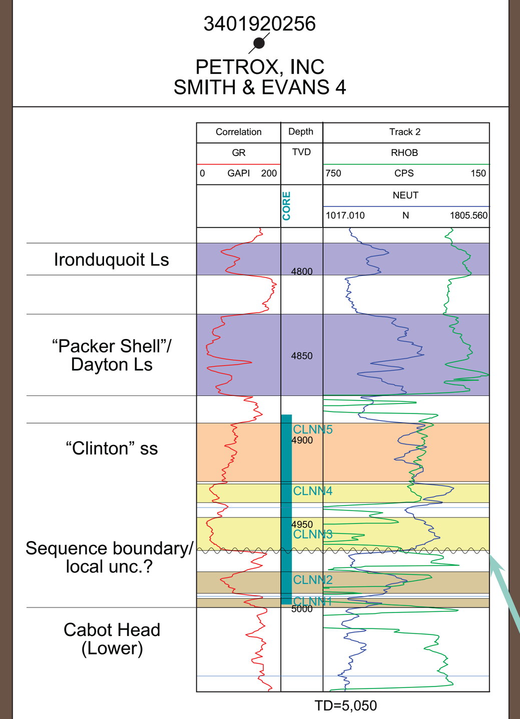
Heterogeneity in the “Clinton” sandstone is controlled by high-stand, fluvial-dominated deltaic deposits; cleaner low-stand, incised-valley-fill successions; and dirtier offshore shelf sands. Detailed mapping of these depositional units and fracture systems is necessary to better understand reservoir compartmentalization, fluid flow, and unswept oil and for planning any future EOR development.

CORRELATION OF WIRELINE LOGS TO CORE

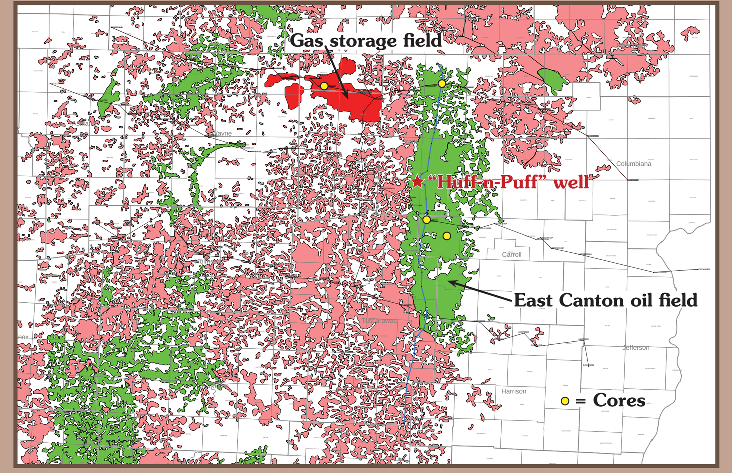




Wireline log of the McCabe #1 cored well showing the formation/unit boundaries of the “Clinton,” overlying, and underlying intervals. The oriented core photos (left) illustrate fractures in the “Clinton” interval, which are important for production in this tight reservoir.

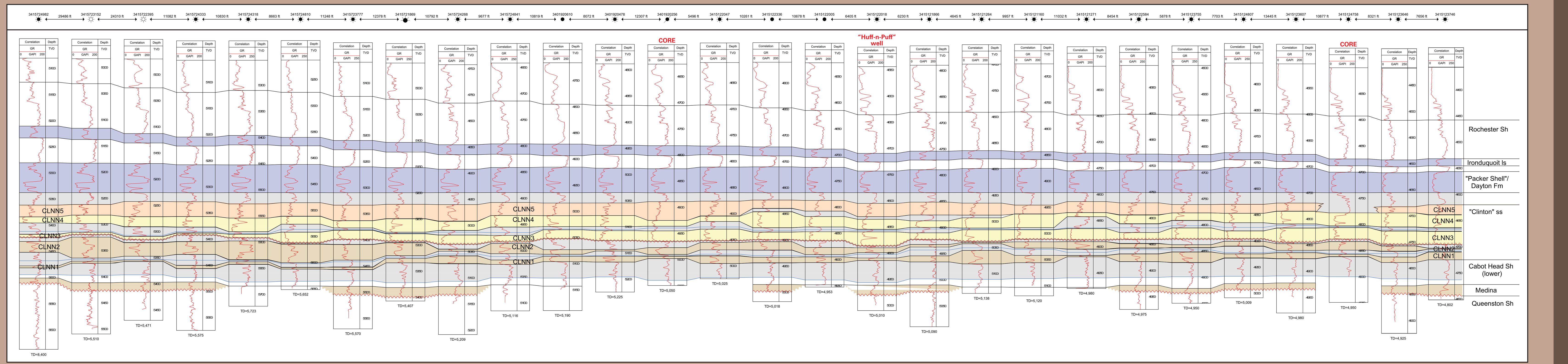


Wireline log of the Smith and Evans #4 cored well showing the formation/unit boundaries of the “Clinton,” overlying, and underlying intervals. The core photograph (right) shows the sharp boundary at the base of the “Clinton” reservoir unit 3 and the underlying shale unit. This sharp contact (S3 of Ryder, 2004) is thought to represent a sequence boundary or a local unconformity.

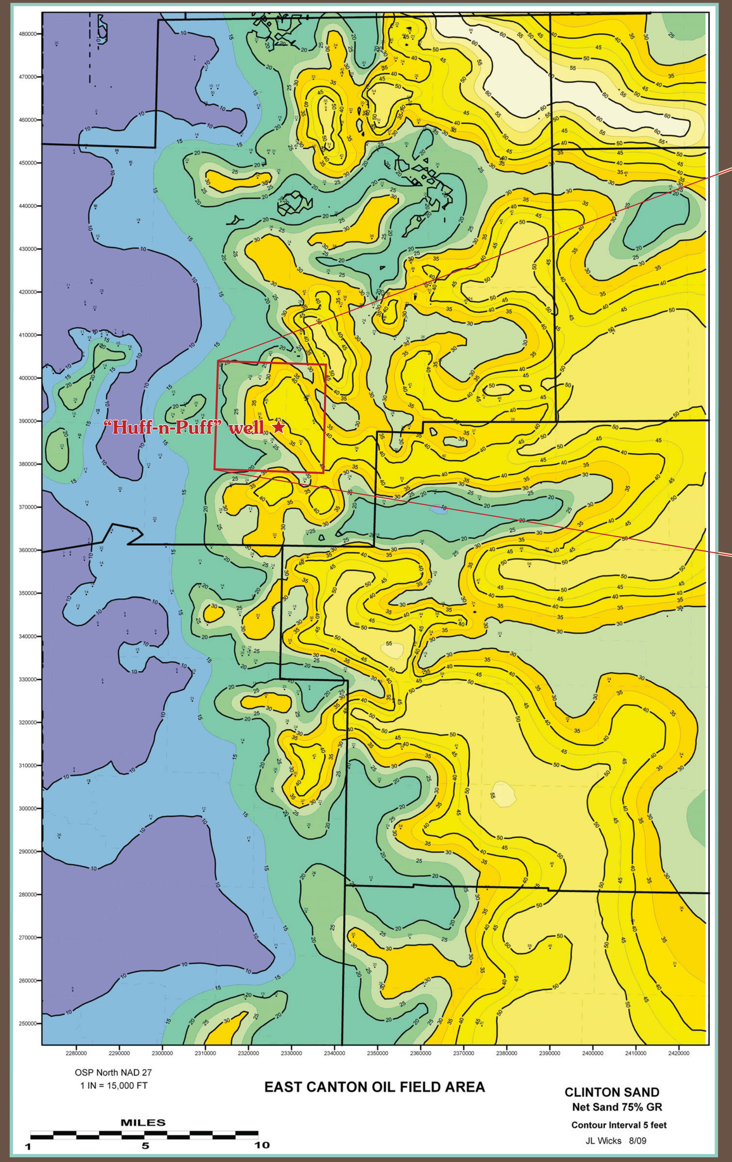


Map of northeast Ohio showing all of the “Clinton” oil and gas fields, “Clinton” cores, and the regional cross section lines.

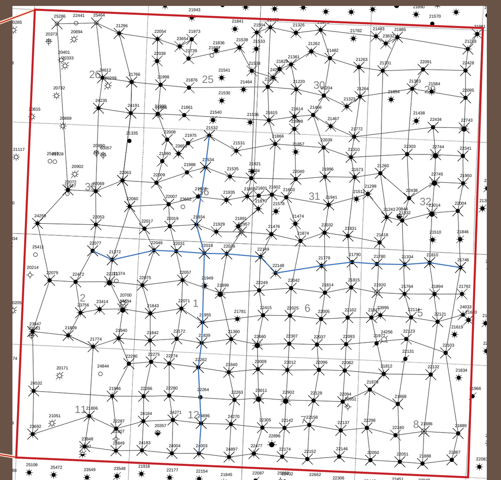
REGIONAL CORRELATIONS TO ESTABLISH THE STRATIGRAPHIC FRAMEWORK



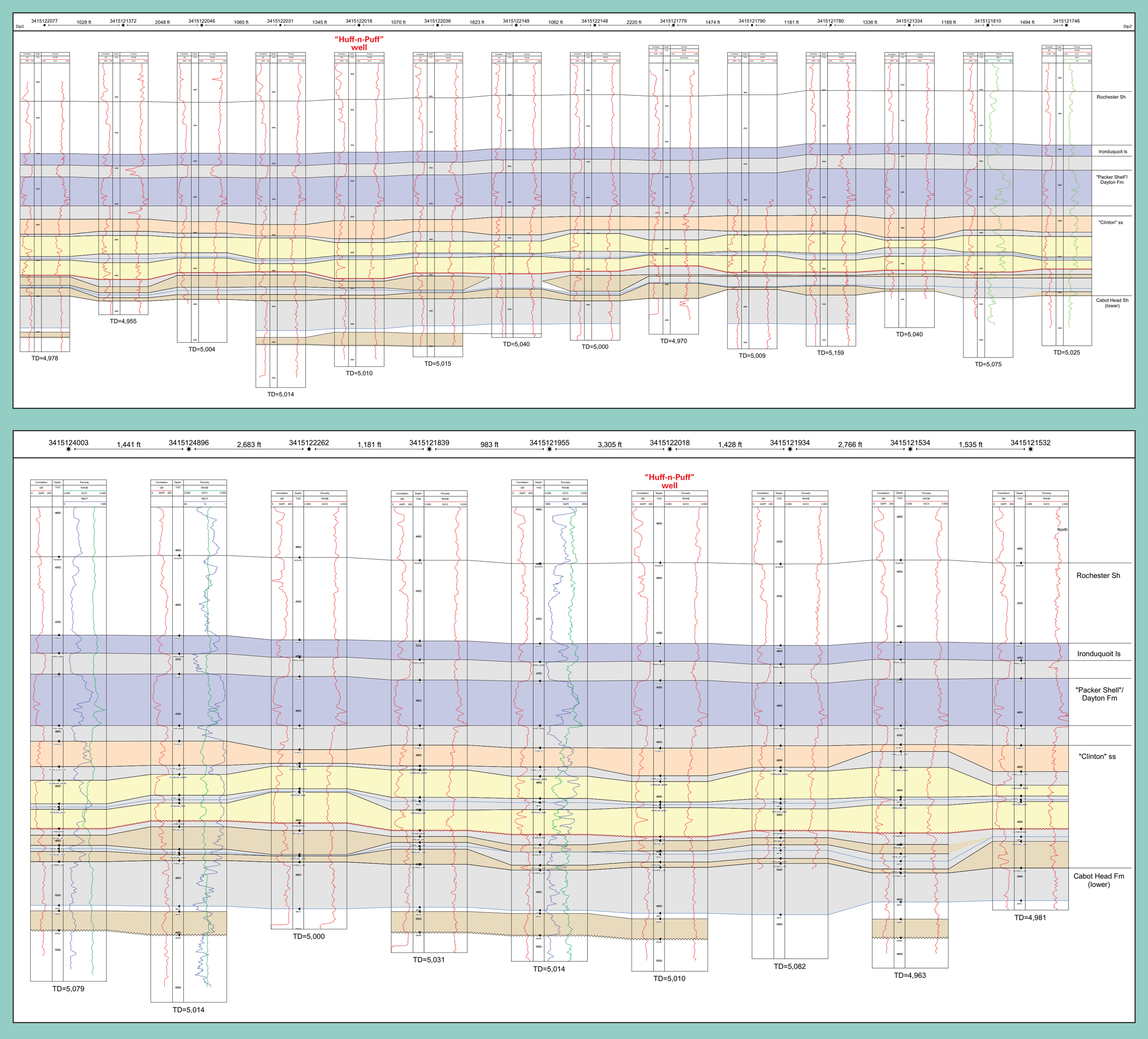
Regional stratigraphic cross section trending north–south (see blue line in the map at left) through the East Canton oil field illustrating the “Clinton” interval and the five individual sandstone units. Datum is the base of the “Packer Shell”/Dayton Formation.



Regional net sandstone map of the “Clinton” interval based on a gamma ray curve cutoff of 75%. Also shown are the 16-section area of interest and the “Huff-n-Puff” test.

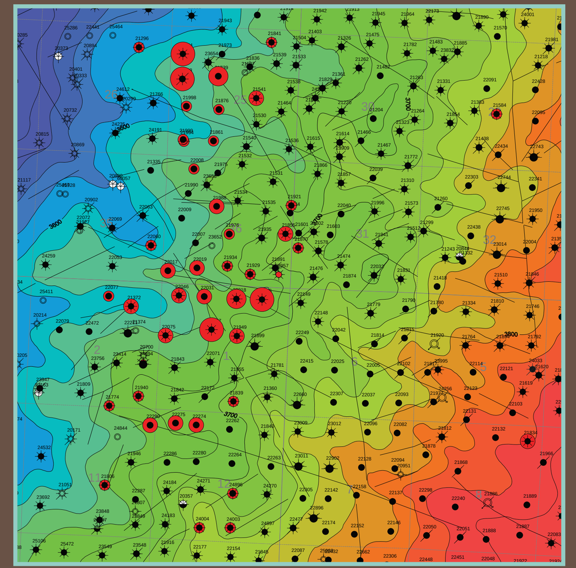


Location map of the area of interest showing all the “Clinton” penetrations and the cross section lines. Also shown is the CO_2 cyclic test (“Huff-n-Puff”).

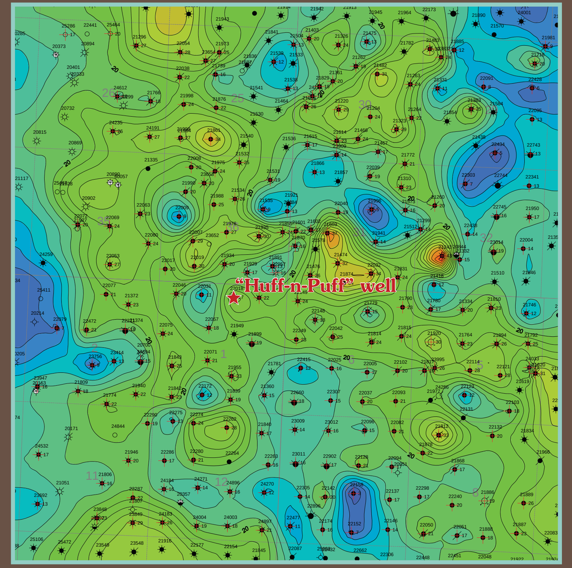


Detailed stratigraphic cross sections trending east–west (upper figure) and north–south (lower figure) through the area of interest (see blue line in the map at left). These sections illustrate the heterogeneity of the “Clinton” interval and the five sandstone units that were correlated and mapped. Datum is the base of the “Packer Shell”/ Dayton Formation.

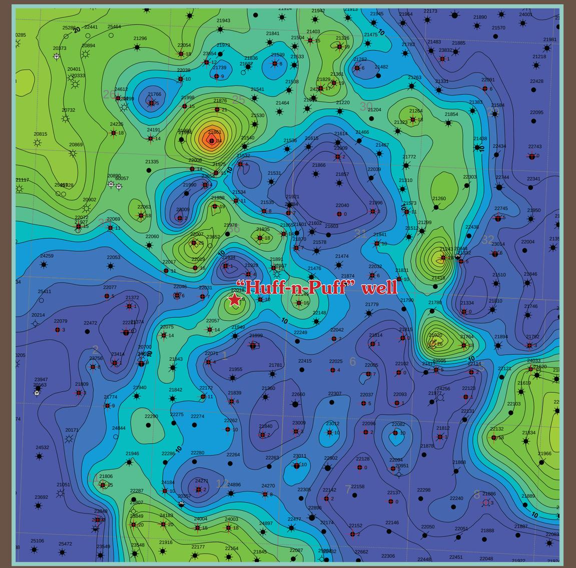
RESERVOIR CHARACTERISTICS AND MAPPING OF THE “CLINTON” SANDSTONE



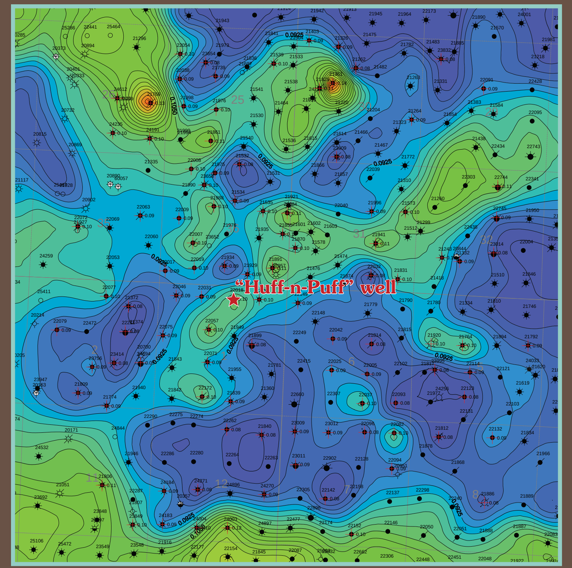
Structure map on the base of the “Packer Shell”/ Dayton Formation with interpreted lineaments from structure contours, LiDAR, and DEM. Also shown is a bubble map of cumulative production (red circles).



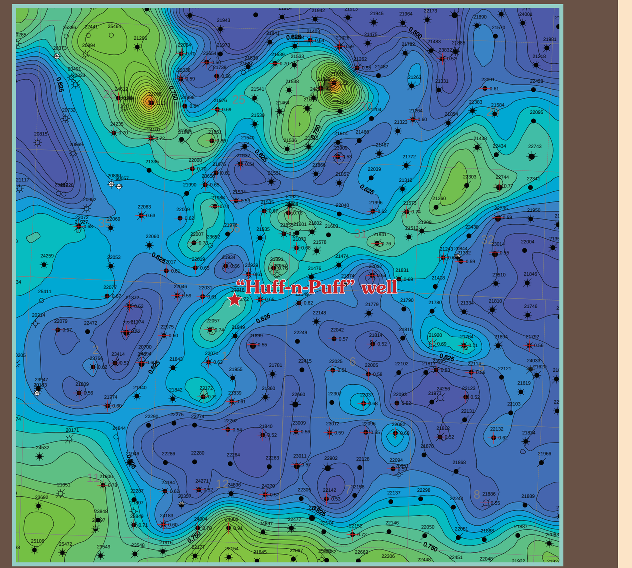
Gross sandstone map of the “Clinton” unit 3 using a RHOB cutoff of 2.55 gm/cc.



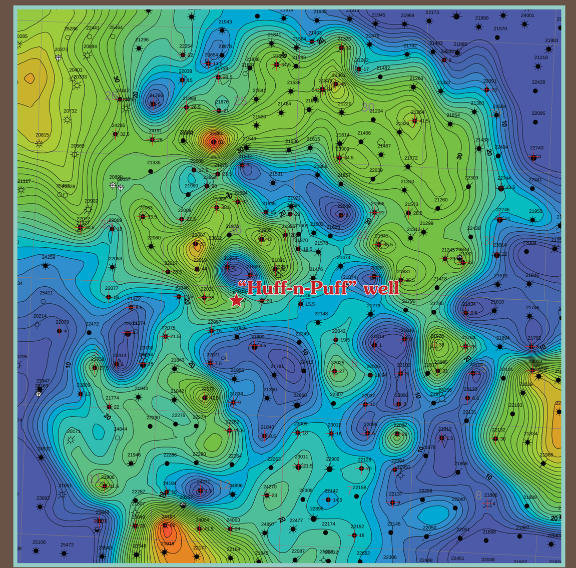
Net sandstone map of the “Clinton” unit 3 using a RHOB cutoff of 2.55 gm/cc.



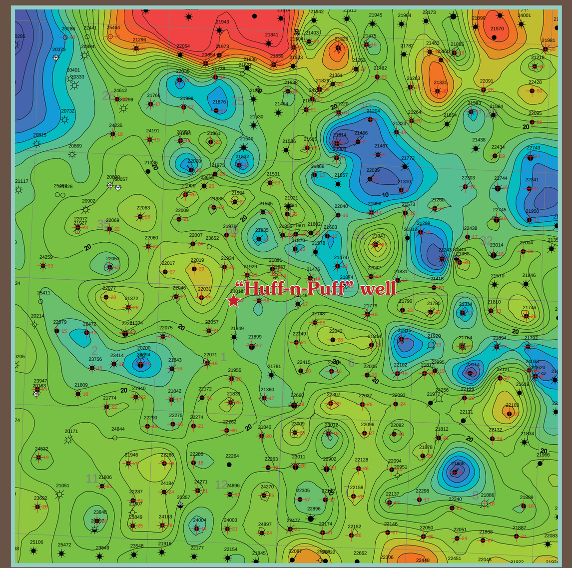
Average porosity map of the “Clinton” unit 3 using a RHOB cutoff of 2.55 gm/cc.



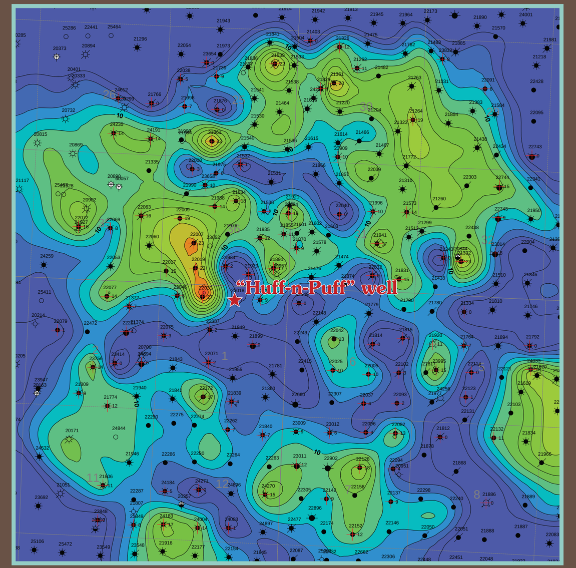
Calculated permeability map of the “Clinton” 3 unit using core to log correlations.



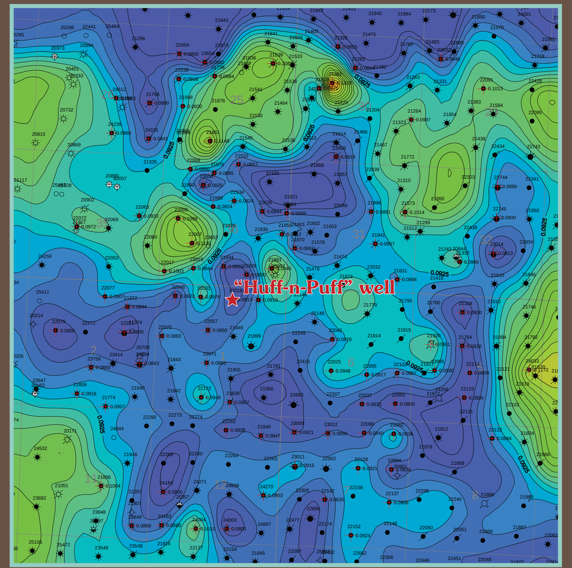
Net sandstone map of the entire “Clinton” interval using a RHOB cutoff of 2.55 gm/cc.



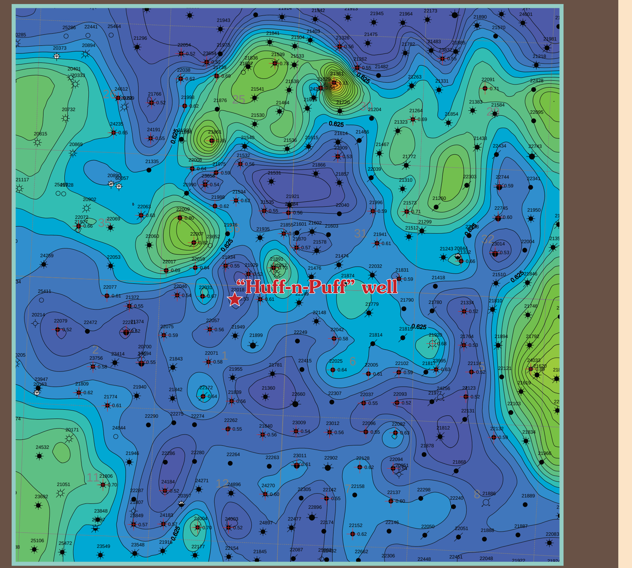
Gross sandstone map of the “Clinton” unit 4 using a RHOB cutoff of 2.55 gm/cc.



Net sandstone map of the “Clinton” unit 4 using a RHOB cutoff of 2.55 gm/cc.



Average porosity map of the “Clinton” unit 4 using a RHOB cutoff of 2.55 gm/cc.



Calculated permeability map of the “Clinton” 4 unit using core to log correlations.

SIMULATION AND MODELING FOR A CO_2 INJECTION FULL-PANEL PILOT

As part of this project, Fekete Associates Inc. is conducting a CO_2-EOR simulation of the “Clinton” reservoir in the area of interest in the East Canton oil field. The primary objective is to construct a reservoir simulation model that will be used for designing a CO_2 injection pilot test and also will examine the effects of natural and hydraulic fractures and well spacing. The study includes analyses of the CO_2 cyclic test (“Huff-n-Puff”) performed in August and September of 2008. The simulation model will incorporate (1) reservoir characterization, detailed mapping, and production and fracture analyses performed by the ODNR, Division of Geological Survey and J. L. Wicks Exploration and (2) “Clinton” fluid properties and relative permeability data from published reports. The work process is as follows:

- Develop static model
    - Maps
    - Original oil-in-place
    - Pressure vs. temperature
    - Saturation functions
- Construct dynamic model
    - Production data
    - Pressure data
- Analyze Huff-n-Puff test
- Generate simulation model
    - Input data
    - Grid blocks
    - Well control
- Perform history matching
    - Scope
    - Modifications
    - Results
- Design pilot test
    - Scope
    - Results

References Cited

Ohio Division of Geological Survey, 1990 (rev. 2000, 2004), Generalized column of bedrock units in Ohio: Ohio Department of Natural Resources, Division of Geological Survey, 1 p.

Ryder, R.T., 2004, Stratigraphic framework and depositional sequences in the Lower Silurian regional oil and gas accumulation, Appalachian basin—from Ashland County, Ohio, through Southwestern Pennsylvania, to Preston County, West Virginia: U.S. Geological Survey Miscellaneous Investigations Series Map I–2810, scale 1:1,000,000, 2 sheets, accompanying pamphlet 8 p.

Holtz, Mark, 2008, Appendix G—Praxair CO2 huff n' puff, Sicakfoose-Morris unit #1 well, *in* Wicks, J.L., Riley, R.A., Melzer, Steve, Perry, C.J., 2009, Results of the Sickafoose-Morris cyclic CO_2 test, East Canton oil field, Ohio: U.S. DOE Quarterly Report, prepared for DOE cooperative agreement No. DE-NT0005115, 18 p.

Reservoir Characterization of the Silurian "Clinton" Sandstone in the East Canton Oil Field, Ohio

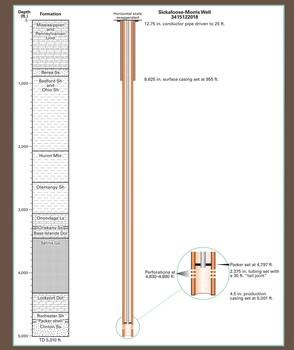
Ronald A. Riley[1], John L. Wicks[2], and Christopher J. Perry[1]
[1]Ohio Division of Geological Survey, Columbus, OH, ron.riley@dnr.state.oh.us, chris.perry@dnr.state.oh.us
[2]J. L. Wicks Exploration, Wooster, OH, jlwicksx@embarqmail.com

CO_2 CYCLIC TEST ("HUFF-N-PUFF") FOR ASSESSMENT OF ENHANCED OIL RECOVERY AND SEQUESTRATION POTENTIAL IN THE EAST CANTON OIL FIELD

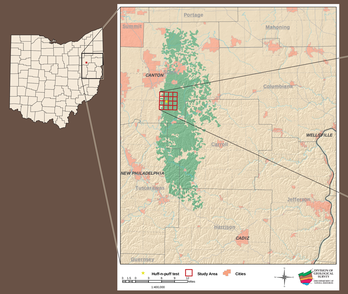
A collaborative effort, partially funded by the U. S. Department of Energy, between private industry, state agency, and university currently is being conducted to assess carbon dioxide-enhanced oil recovery (CO_2-EOR) and sequestration potential in eastern Ohio. Participants involved in this project include Baard Energy, the Ohio Department of Natural Resources (ODNR), Division of Geological Survey, Wright State University, Dominion, Range Resources Corp., J. L. Wicks Exploration, and Melzer Consulting. Baard Energy is planning to build the Ohio River Clean Fuels (ORCF) plant in Wellsville, Ohio, with projected operations commencing in 2012. Plans include the ability to capture, purify, and use or sequester the CO_2 produced by the ORCF plant. Available data indicate the East Canton oil field (ECOF) is the best EOR candidate within a 50-mile radius of the ORCF plant using the estimated CO_2 quantities produced by the proposed plant. The ultimate objective of this project is to estimate the reserve growth potential from the ECOF using CO_2 flooding methods and to approximate the amount of CO_2 that can be injected annually and eventually sequestered over the life of the project.

The ECOF has produced nearly 95 million barrels of oil from the Silurian "Clinton" sandstone since it was discovered in 1947. It contains approximately 3,100 wells at 40-acre spacing within 175,000 proven acres over an area of 40 miles (north–south) by 12 miles (east–west). The field has never been waterflooded and primary recovery is estimated at 9% of original oil-in-place. A CO_2 cyclic test ("Huff-n-Puff") was performed on a "Clinton" well within the field in August 2008 using 81 tons of CO_2. Results were encouraging and demonstrated that the rock matrix porosity accepted the CO_2, oil was mobilized, and production was increased.

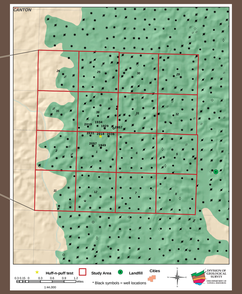
The primary tasks for this project include performing a detailed reservoir characterization in a selected area of the ECOF; simulation modeling and design of a proposed full-panel, CO_2 pilot flood in this selected area; assessing the quantity and recoverability of remaining oil-in-place within this pilot area; conducting a study in a portion of the Stark-Summit gas storage field and integrating with the "Clinton" reservoir model being developed; and assessing sequestration capacity of saline aquifers, near the ORCF site.



Sickafoose-Morris #1 well completion diagram with perforations and test set-up.



Map showing location of East Canton oil field and Sickafoose-Morris #1 well (permit number 2018). Proposed detailed-study area is outlined in red.



Map showing location of the Sickafoose-Morris #1 well (permit number 2018) and surrounding wells. Observation wells that were tested for gas analyses are labeled with permit numbers.

SITE OPERATIONS

Photograph of the Sickafoose-Morris #1 well huff-n-puff equipment and site layout.

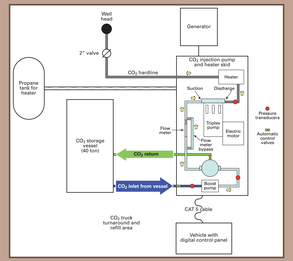
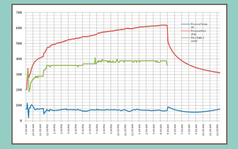


Diagram illustrating the Sickafoose-Morris #1 well huff-n-puff equipment and site layout.

SUMMARY OF PRODUCTION AND CLINTON RESERVOIR CHARACTERISTICS

Completion Date	1969
Initial Production	115 BOPD
Cumulative Production	60,000 BO
Gross Sandstone	110 ft
Net Sandstone	52 ft (> 6 %)
Porosity Range	4–14 %
Completion technique	F/W 5,100 bbl water + 75,000 lb sd proppant + 100 scf of N

CO_2 INJECTION RATE

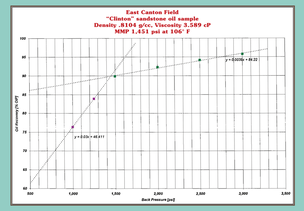


Graph of the Sickafoose-Morris #1 well CO_2 injection operation process temperature, pressure, and flow rate versus time, conducted on August 19 and 20, 2008.

Pressure (psi)	Effective Injection Radius (ft)	CO2 Volume Subsurface (cf)
1300	34	5986
700	68	24236
300	114	67425

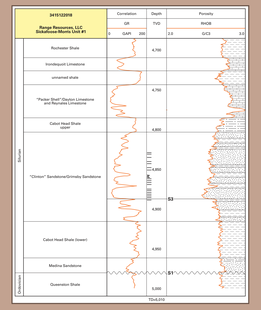
Estimated radius and volume of CO_2 within the formation through the range of pressures encountered by the cyclic test (Holtz, 2008).

MMP ANALYSIS

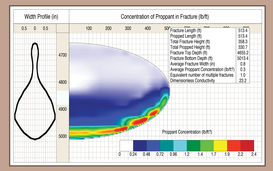


Minimum miscibility pressure (MMP) from oil sample of the #2 Thouvenin-Hall Unit (APINO 3415122019) from the "Clinton" sandstone in the East Canton oil field in Stark County, Ohio.

CO_2 CYCLIC TEST WELL



Sickafoose-Morris #1 wireline well log and lithology. Stratigraphic nomenclature is from the ODNR Division of Geological Survey (2004) and Ryder (2004).

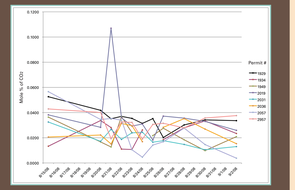


Halliburton model of the Sickafoose-Morris #1 hydrofracture produced in 1969. Stage profile for the Sickafoose-Morris #1 well in the East Canton oil field in Stark County, Ohio; "Clinton" sandstone—single stage water frac from 4,830 to 4,890 ft; 18 holes. Model created on November 25, 2008.

GAS AND OIL SAMPLING IN OFFSET WELLS

Photograph Sickafoose-Morris #1 (permit number 2018) oil sample taken on January 5, 2009. The high pressure hose connected to the tubing valve was purged and filled with oil prior to attaching it to the sample cylinder. The sample cylinder was filled with water that was slowly drained out the bottom of the vessel until it was fully displaced with oil.

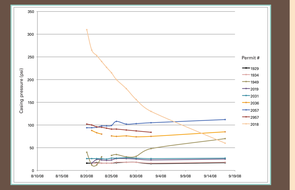
Photograph of gas sample collection at the Adelman #1 well (permit number 1929). The bullplug is screwed into the 2-inch outlet from the casing valve, which reduces to ¼ inch for attachment of the hose leading to the sample container. Pressure is read off the gauge near the sample cylinder valve.



Mole percentages of CO_2 measured in the wells offset to the Sickafoose-Morris #1 well prior to the CO_2 injection and during the "soak" period.

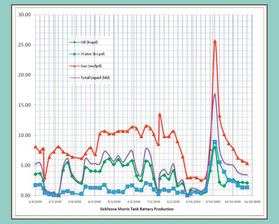
Close-up photograph of the sample container used for sampling of gas. It is 13-inches long with a 2.5-inch diameter. The cylinder is rated to 1,800 psi. There are inlet/outlet valves at each end. Caps are placed over the valve nipples after the sample is taken as a precaution to prevent leakage.

Photograph of oil sample cylinders filled under pressure at the Thouvenin-Hall #2 well (permit number 2019). These samples are in a crate ready to ship to SCAL, Inc. for testing of minimum miscibility pressure (MMP).

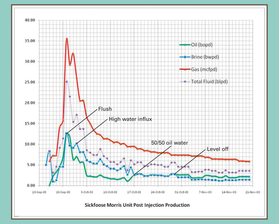


Casing pressures from the observation wells. The measurements for permit number 1949 were also taken off of the tubing on several occasions because of operational problems, which resulted in some variation of pressure readings.

PRODUCTION ANALYSIS



Sickafoose tank battery production from July 11, 2008, to September 19, 2008.



Graph of the Sickafoose-Morris #1 well production for the 60-day period following the CO_2 injection and 32-day "soak" period.

Date	Sickafoose Morris 2018		Sickafoose 2036		Brenner 2057		PER DAY TOTAL		5 WEEK AVERAGE	
	Gas (mcf)	Fluid (bbl)	Gas (mcf)	Fluid (bbl)	Gas (mcf)	Fluid (bbl)	Gas (mcf)	Fluid (bbl)	Gas (mcf)	Fluid (bbl)
7/18/08	3	1.42	3	1.42	3	1.46	9	4.3		
7/25/08	3	1.14	3	1.14	3	1.17	9	3.45		
8/1/08	4	1.72	4	1.72	4	1.77	12	5.21		
8/7/08	3	0.67	3	0.67	3	0.69	9	2.03		
8/15/08	2	0.86	2	0.86	2	0.88	6	2.6	9	3.52
8/22/08	shutin	shutin	shutin	shutin	shutin	shutin	shutin	shutin		
8/27/08	shutin	shutin	1.5	0.39	1.5	0.4	3	0.79		
9/5/08	shutin	shutin	1.5	0.67	1.5	0.67	3	1.34		
9/12/08	shutin	shutin	1.5	0.35	1.5	0.35	3	0.7		
9/19/08	shutin	shutin	1.5	0.71	1.5	0.72	3	1.43	3	1.07
Estimated Sickafoose-Morris average daily production prior to test									6.00	2.45
Estimate by fluid type: at est 2% water cut:									1.84	bopd
									0.61	bwpd
									6.00	mcfpd

*Production split equally among the 3 wells

2008 production from the Sickafoose tank battery commingling production from the Sickafoose-Morris #1 (permit number 2018), Sickafoose #1 (permit number 2036) and the Brenner #1 (permit number 2057) wells. The Sickafoose-Morris #1 was shut in after August 15, 2008, and turned on September 22, 2008. The Sickafoose #1 and Brenner #1 wells were shut in after September 22, 2008.

RESULTS OF CO_2 CYCLIC TEST ("HUFF-N-PUFF")

- Clearly demonstrated the capacity of the "Clinton" sandstone in East Canton oil field to accept significant volumes of injected CO_2. Approximately 81 tons (1.39 MMCFG) of CO_2 were injected into the test well during a 20-hour period.
- CO_2 was injected at a maximum surface injection pressure of 617 psi (1,300 psi bottom-hole pressure), which is below MMP of 1,450 psi. Results demonstrate that even under immiscible conditions CO_2 diffuses into the oil in the pore space, enhancing oil mobility. Injection of larger volumes of CO_2 at or above MMP is clearly feasible; moving to a pilot flood phase is appropriate and higher efficiency recoveries are anticipated.
- After the test well was returned to production, it produced 174 bbl of oil during a 60-day period (September 22 to November 21, 2008). This is an estimated 58% increase in oil production over pre-injection estimates.
- Majority of the injected CO_2 entered the matrix porosity where it diffused into the oil. Evidence includes: (A) the volume of injected CO_2 greatly exceeded capacity of the hydro-frac, (B) gradual injection and pressure rate build-up during the test, (C) the gradual flashout of the CO_2, and (D) a large amount of CO_2 off-gassed from wellhead oil samples 3½ months after injection.
- Multiple lines of evidence indicated the injected CO_2 did not channel off but stayed within matrix porosity near the test well: (A) absence of CO_2 found in gas samples from offset wells, (B) the persistent but gradual decrease of CO_2 in fluid samples taken from the injection well after production was restarted, and (C) a standard calculation of radius of influence. Holtz (2008) calculated the radius of influence to be approximately 68 ft.
- Most of the CO_2 was probably pushed into and then diffused within the higher permeability "Clinton" sandstone zones that communicate with the hydrofrac system near the borehole.