The Ohio Geological Survey CO_2 No. 1 Stratigraphic Test Well: A Diverse Team Achieves Common Objectives and Realizes Added Benefits

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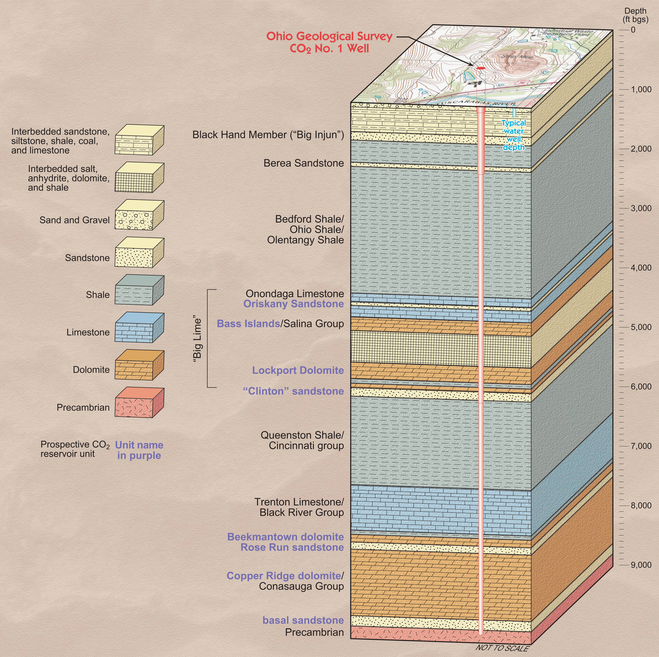
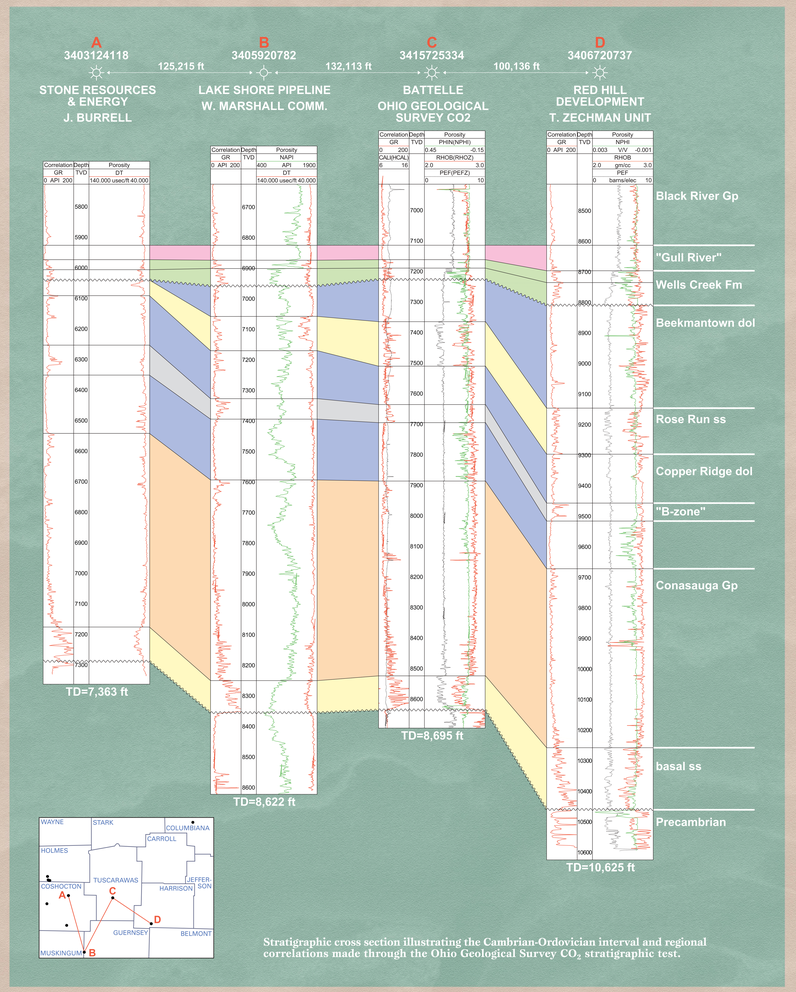
Abstract

The Ohio deep borehole project brought together a diverse group of stakeholders to evaluate CO_2 injectivity and storage potential of deep saline reservoirs and the effectiveness of confining units at the test site. The State of Ohio budgeted approximately $2.3 million from the general revenue and clean coal research funds to meet the project's objectives. The Ohio Air Quality Development Authority (OAQDA) and the Ohio Division of Geological Survey (ODGS) collaborated with the Midwest Regional Carbon Sequestration Partnership (MRCSP) led by Battelle Memorial Institute to drill a stratigraphic test well to the Precambrian in east-central Ohio. Both coal and petroleum interests were directly represented, as well as local government, industry, and service companies.

Field operations were coordinated with oil and gas operators on an existing lease. Drilling commenced on May 10, 2007, and was completed on June 9, 2007, at a total depth of 8,695 feet. Strong gas shows were encountered within the lower Black River Limestone and Beekmantown Formations. An extensive suite of geophysical well logs and sidewall cores were obtained from the borehole. Slug and constant-pressure injectivity testing was conducted from two zones within the basal Cambrian sandstone and from three zones within the Rose Run sandstone. Approximately 3,000 gallons of treated brine was injected into the five zones. The maximum observed downhole pressures were 4,355 psi for the basal Cambrian sandstone and 3,825 psi for the Rose Run interval. Information collected from this project fills data gaps and provides input into continuing local and regional reservoir characterization and modeling efforts.

Geology and Well Construction of the Tuscarawas County Stratigraphic Test

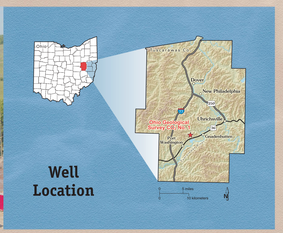




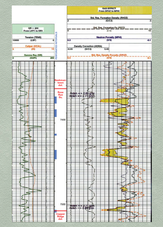
Stratigraphic cross section illustrating the Cambrian-Ordovician interval and regional correlations made through the Ohio Geological Survey CO_2 stratigraphic test.

Ohio Geological Survey CO_2 No. 1 Well Goals

- Verify existence, depth, and thickness of key potential injection formations.
- Obtain detailed formation data from logs and sidewall cores for both potential reservoirs and caprocks.
- Perform injection rate tests.
- Correlate results with existing data to provide a larger understanding of Ohio's CO_2 injection capability.

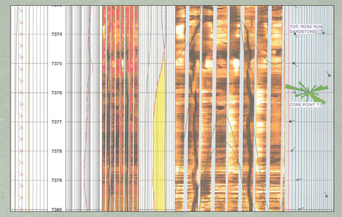


Reservoir Characterization



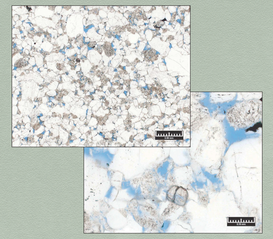
Rose Run sandstone interval

Net sandstone (> 6 % porosity) is 24 ft
Maximum porosity is 13.5 %
Average porosity is 9.5 %
Maximum permeability is 26.6 md (core analyses)

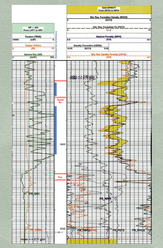


FMI near the top of the Rose Run sandstone. Drilling-induced vertical fractures are displayed. Note the location of a sidewall core.

Sidewall core photos of the Rose Run sandstone at 7,441 feet (end trim and longitudinal view).

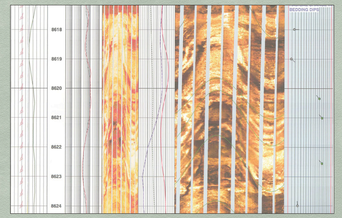


Thin-section photomicrographs of the Rose Run sandstone at 7,441 feet (magnification: 40X in upper photo; 200X in lower photo). This is a subarkose composed dominantly of quartz and feldspar. Pore types include intergranular, grain-moldic, and intragranular (leached feldspar). Cementation includes quartz and feldspar overgrowths.



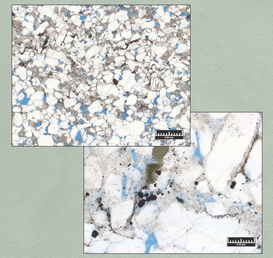
Cambrian basal sandstone interval

Net sandstone (> 6 %) is 56 ft
Maximum porosity is 15 %
Average porosity is 10 %
Maximum permeability is 1.0 md (core analyses)



Precambrian contact with overlying Cambrian basal sandstone is marked by sharp change in dip on FMI log.

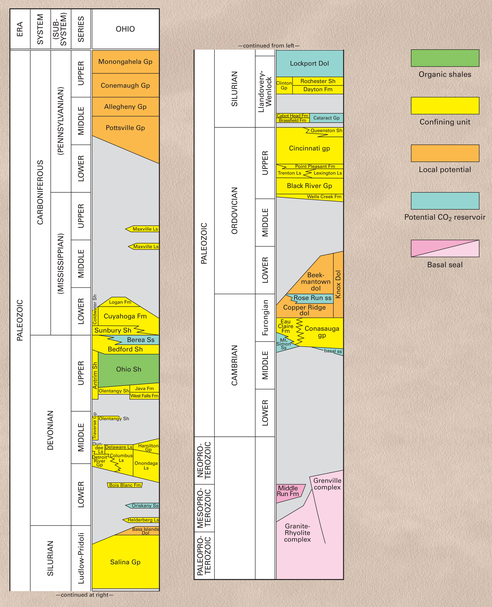
Sidewall core photos of the Cambrian basal sandstone at 8,561 feet (end trim and longitudinal view).



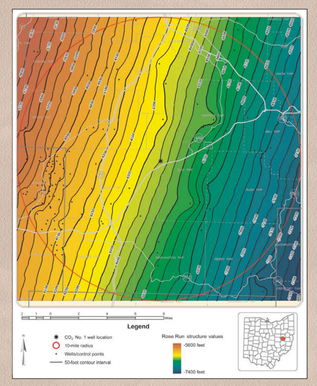
Thin-section photomicrographs of the Cambrian basal sandstone at 8,561 feet (magnification: 40X in upper photo; 200X in lower photo). This arkose consists dominantly of quartz, K-feldspar, and lithic fragments. Authigenic cements include pore-lining clay, quartz overgrowths, feldspar overgrowths, and pyrite.

Mapping Potential Injection Zones

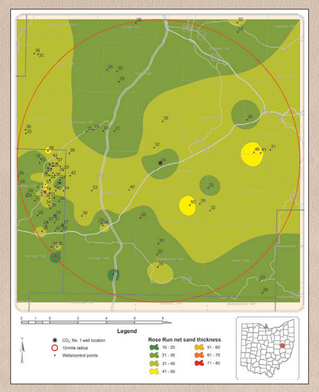
Maps were constructed using available oil and gas well data within a 10-mile radius around the stratigraphic test. Some of these maps are shown at right.



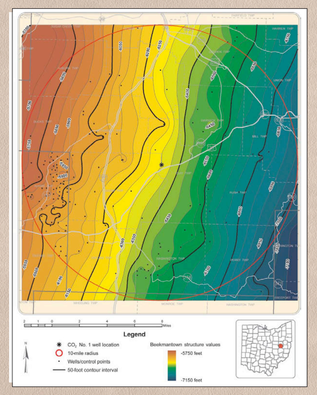
Stratigraphic chart illustrating geologic units found beneath the Tuscarawas County well site. Color-coded potential injection zones and seal units (modified from Wickstrom and others, 2006).



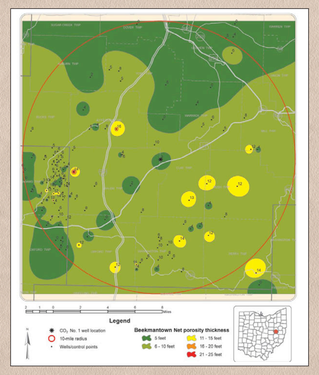
Structure on top of the Rose Run sandstone within the CO_2 well AOI.



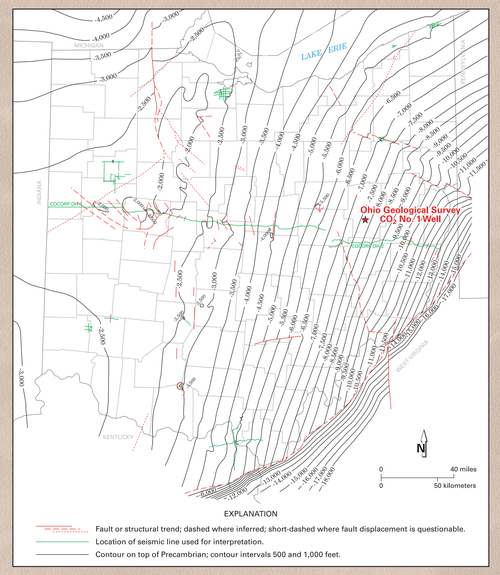
Net porosity thickness (>6% porosity) of the Rose Run sandstone within the AOI.



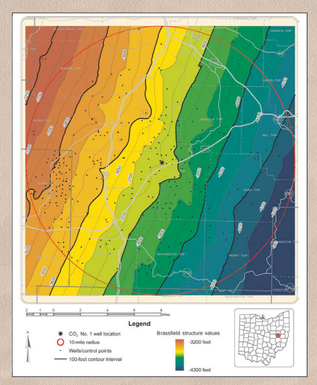
Structure on top of the Beekmantown dolomite within the AOI.



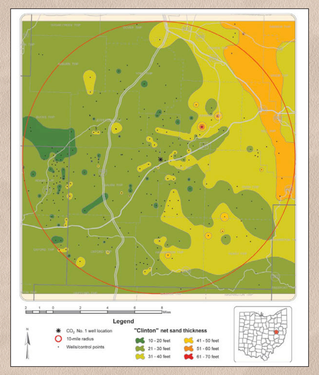
Net porosity thickness (>4% porosity) of the Beekmantown dolomite within the AOI.



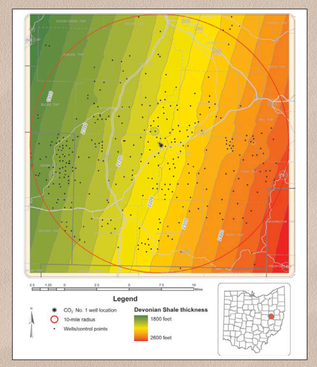
Structure on the Precambrian unconformity in Ohio. Major structural trends and faults and location of COCORP seismic profile are shown (modified from Baranoski, 2002).



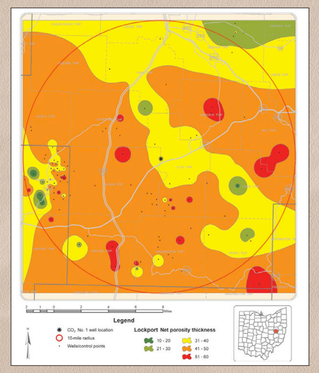
Structure on top of the Brassfield Formation ("Packer Shell") within the AOI.



Net sandstone thickness (>50% shale free) of the "Clinton" sandstone within the AOI.



Thickness of the Devonian Shale interval within the AOI.



Net porosity thickness (>4% porosity) of the Lockport Dolomite in the AOI.

Porosity and Permeability Analyses

Summary of Rotary Core Analyses Results
Vacuum Dried at 180°F

Ohio Divison Of Geological Survey
CO2 No. 1 Well

Tuscarawas County, Ohio
File: HH-38266

Formation	Sample Number	Sample Depth, feet	Net Confining Stress, psi	Permeability, millidarcys		Porosity percent[1]		Grain Density, gm/cc	Fluid Saturations, percent		
				to Air	Klinken-berg	Ambient	NCS		Water	Oil	Total
Rochester Sh	1-1R	4605	1350	+		6.4		2.78	58	0	58
Clinton ss	1-2R	4760	1400	+		5.8	5.7	2.67			**
Clinton ss	1-3R	4771	1400	0.017	0.0069	6.9	6.8	2.65			**
Clinton ss	1-4R	4776	1400	+		8.6		2.67			**
Clinton ss	1-5R	4790	1400	+		7.8	7.7	2.7			**
Clinton ss	1-6R	4816	1400	+		4.1		2.8			**
Clinton ss	1-7R	4821	1400	+		4.3	4.2	2.72			**
Clinton ss	1-8R	4834	1400	+		3.6	3.5	2.66			**
Clinton ss	1-9R	4840	1400	0.015	0.0061	5.8	5.7	2.66			**
Cincinnati Gp	1-10R	6064	1750	+		4.9	4.8	2.78			**
Utica	1-11R	6141	1800	0.0011	0.0002	5.2	5.1	2.7			**
Point Pleasant	1-12R	6282	1800	0.0014	0.0003	4.3	4.2	2.7			**
Trenton Ls	1-13R	6336	1850	0.0005	0.0001	5.1	5	2.61			**
Trenton Ls	1-14R	6396	1850	0.0011	0.0002	2.9	2.8	2.69			**
Trenton Ls	1-15R	6490	1900	0.0014	0.0003	3.2	3.1	2.69			**
Black River Gp	1-16R	6524	1900	0.015	0.0058	3.6	3.5	2.75			**
Black River Gp	1-17R	6566	1900	0.0016	0.0003	1.6	1.5	2.73			**
Black River Gp	1-18R	6620	1900	0.0015	0.0003	1.7	1.6	2.71			**
Black River Gp	1-19R	6750	2000	0.015	0.0057	5.2	5.1	2.71			**
Black River Gp	1-20R	6794	2000	0.409	0.286	8.4	8.3	2.7			**
Black River Gp	1-21R	6808	2000	0.052	0.027	4.8	4.7	2.71			**
Black River Gp	1-22R	6844	2000	0.0081	0.0027	4.6	4.4	2.71			**
Black River Gp	1-23R	6871	2000	0.545	0.482	13.2	13	2.73			*
Black River Gp	1-24R	6936	2000	0.061	0.032	8.5	8.3	2.73			**
Black River Gp	1-25R	6940	2000	0.0008	0.0001	1.4	1.3	2.71			**
Black River Gp	1-26R	7030	2050	0.0006	0.0001	1.3	1.2	2.73			**
Black River Gp	1-27R	7128	2100	0.033	0.016	5.5	5.4	2.74			**
Black River Gp	1-28R	7142	2100	0.0012	0.0002	2.3	2.2	2.76			**
Wells Creek	1-29R	7192	2100	0.0015	0.0003	3.8	3.7	2.82			**
Beekmantown	1-30R	7226	2100	0.0015	0.0003	2.2	2.1	2.83			**
Beekmantown	1-31R	7231	2100	0.941	0.726	9.4	9.2	2.84			*
Beekmantown	1-32R	7235	2100	0.0009	0.0002	4	3.9	2.85			**
Beekmantown	1-33R	7248	2100		<0.0001	1.5	1.4	2.8			**
Beekmantown	1-34R	7296	2100	0.007	0.0022	3.5	3.3	2.84			**
Beekmantown	1-35R	7328	2100	0.017	0.0067	2	1.8	2.83			**
Beekmantown	1-36R	7365	2150	0.016	0.0065	5.8	5.6	2.66	82.1	0	82.1
Rose Run	1-37R	7377	2150	0.045	0.023	6.2	6.1	2.64			**
Rose Run	1-38R	7387	2150	0.012	0.0044	6	5.9	2.66			**
Rose Run	1-39R	7392	2150	16.8	13.8	10.8	10.7	2.64	42	0	42
Rose Run	1-40R	7414	2150	0.0034	0.0009	3.4	3.3	2.67			**
Rose Run	1-41R	7426	2150	0.134	0.081	6.8	6.7	2.62	82	0	82
Rose Run	1-42R	7434	2150	31.6	26.6	9.2	9.1	2.68	75.6	0	75.6
Rose Run	1-43R	7441	2150	0.983	0.766	7.3	7.2	2.61	76.2	0	76.2
Rose Run	1-44R	7459	2150	0.001	0.0002	1.3	1.2	2.82			**
Rose Run	1-45R	7480	2200	0.0086	0.0029	4.3	4.2	2.74			**
Rose Run	1-46R	7495	2200	0.033	0.015	8.5	8.4	2.62	60.3	0	60.3
Rose Run	1-47R	7506	2200	1.79	1.4	8.3	8.2	2.71	64.3	0	64.3
Copper Ridge	1-48R	7528	2200	0.036	0.017	2.1	2	2.83			**
Copper Ridge	1-49R	7579	2200	0.0022	0.0005	2	1.9	2.83			**
Copper Ridge	1-50R	7692	2250	0.0005	0.0001	1.4	1.3	2.81			**
Copper Ridge	1-51R	7730	2250	0.0008	0.0001	1.4	1.3	2.83			**
Copper Ridge	1-52R	7742	2250	0.0021	0.0004	1	0.9	2.81			**
Copper Ridge	1-53R	7818	2300	0.004	0.0011	3.8	3.7	2.86			**
Copper Ridge	1-54R	7868	2300	0.0003	<0.0001	1.9	1.8	2.84			**

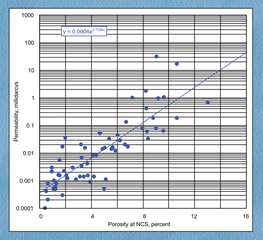
Summary of Rotary Core Analyses Results—continued
Vacuum Dried at 180°F

Ohio Divison Of Geological Survey
CO2 No. 1 Well

Tuscarawas County, Ohio
File: HH-38266

Formation	Sample Number	Sample Depth, feet	Net Confining Stress, psi	Permeability, millidarcys		Porosity percent[1]		Grain Density, gm/cc	Fluid Saturations, percent		
				to Air	Klinken-berg	Ambient	NCS		Water	Oil	Total
Conasauga	1-55R	7931	2300	0.003	0.0007	2.7	2.6	2.82			**
Conasauga	1-56R	7991	2300	0.0054	0.0016	1.7	1.6	2.84			**
Conasauga	1-57R	8014	2300	0.0029	0.0007	1.1	1	2.82			**
Conasauga	1-58R	8066	2350	0.053	0.027	4.8	4.7	2.84			**
Conasauga	1-59R	8138	2350	+		1.3		2.84			**
Conasauga	1-60R	8176	2400	0.0002	<0.0001	0.7	0.6	2.85			**
Conasauga	1-61R	8274	2400	0.0004	<0.0001	0.6	0.5	2.84			**
Conasauga	1-62R	8350	2400	0.0001	<0.0001	0.5	0.4	2.85			**
Conasauga	1-63R	8421	2450	0.02	0.0085	3.4	3.2	2.69			**
Conasauga	1-64R	8451	2450	0.02	0.0084	6.7	6.6	2.63	58.9	0	58.9
Conasauga	1-65R	8467	2450	0.0084	0.0028	4.3	4.2	2.62			**
Conasauga	1-66R	8495	2450	0.0008	0.0001	0.7	0.6	2.81			**
basal ss	1-67R	8528	2450	+		2.8	2.7	2.71			**
basal ss	1-68R	8538	2500	0.014	0.0052	5.1	4.9	2.62			**
basal ss	1-69R	8544	2500	0.0014	0.0003	3.5	3.4	2.67			**
basal ss	1-70R	8549	2500	0.0005	0.0001	1.2	1.1	2.79			**
basal ss	1-71R	8555	2500	0.078	0.044	10.7	9	2.63			**
basal ss	1-72R	8561	2500	1.06	0.836	9.8	9.6	2.6	62.3	0	62.3
basal ss	1-73R	8570	2500	0.014	0.0056	5.7	5.6	2.62			**
basal ss	1-74R	8583	2500	0.028	0.013	6.3	6.2	2.62			**
basal ss	1-75R	8585	2500	0.062	0.033	9.7	9.6	2.57	64	0	64
basal ss	1-76R	8590	2500	0.185	0.118	10.9	10.7	2.62			**
basal ss	1-77R	8603	2500	0.188	0.12	9	8.8	2.62			**
basal ss	1-78R	8610	2500	0.079	0.044	8.2	8	2.6	58.2	0	58.2
basal ss	1-79R	8628	2500		<0.0001	1.7	1.6	2.75			**
Precambrian	1-80R	8643	2500		<0.0001	0.3	0.2	3.07			**
Precambrian	1-81R	8659	2500		<0.0001	0.6	0.5	2.98			**
Precambrian	1-82R	8688	2500		<0.0001	0.4	0.3	2.69			**
Average values:				0.829	0.724	4.6	4.4	2.73	65.3	0	65.3

+Indicates sample is unsuitable for this type of measurement
* Water captured from DS and weight loss other than water were below detectable limits
** Unable to report saturation levels due to insufficient pore volume



Rock Mechanics Data

Triaxial compressive tests with concurrent acoustic velocities were conducted on 2 samples in the Rose Run sandstone (7,441 feet) and Cambrian basal sandstone (8,561 feet). In this procedure the confining pressure is increased to the desired hydrostatic testing pressure. Ultrasonic velocities are measured at the hydrostatic confining pressure. The axial load is increased at a constant rate until the specimen fails or axial strain reaches a desired amount of strain while confining pressure is held constant. Results of triaxial compressive strengths provide measurements of compressive strength, Young's modulus, and Poisson's ratio. Ultrasonic velocities and dynamic elastic tests provide measurements of compressional and shear velocity, Young's modulus, Poisson's ratio, bulk modulus, and shear modulus. These results are summarized in the adjacent tables.

By relating the rock stresses to reservoir properties, 3D models can be developed that predict the geomechanical behavior of the reservoir during production and injection. The removal of hydrocarbons from a reservoir or the injection of fluids changes the rock stresses and geomechanics environment, potentially affecting compaction and subsidence, well and completion integrity, cap-rock and fault-seal integrity, fracture behavior, CO_2 disposal, and seismic reflection imaging. Integration of rock mechanic data with other data from logs, cores, injection tests, and seismic reflection lines will enable better modeling for reservoir analyses and engineering designs.

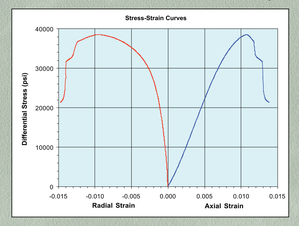
Summary of Triaxial Compressive Test
saturated with 2% KCl

Formation	Sample No.	Depth (ft)	Confining Pressure (psi)	Compressive Strength (psi)	Young's Modulus (x106 psi)	Static Poisson's Ratio
Rose Run ss	1-43R	7441	2600	41110	4.82	0.38
Cambrian basal ss	1-72R	8561	2950	45360	5.65	0.25

Summary of Ultrasonic Velocities and Dynamic Elastic Parameters

Formation	Sample No.	Depth (ft)	Confining Pressure (psi)	Bulk Density (g/cc)	Ultrasonic Wave Velocity				Dynamic Elastic Parameter			
					Compressional		Shear		Young's Modulus ($x10^6$ psi)	Poisson's Ratio	Bulk Modulus ($x10^6$ psi)	Shear Modulus ($x10^6$ psi)
					ft/sec	µsec/ft	ft/sec	µsec/ft				
Rose Run ss	1-43R	7441.00	2600	2.50	15282	65.44	9261	107.98	7.00	0.21	4.02	2.89
Cambrian basal ss	1-72R	8561.00	2950	2.45	14839	67.39	9176	108.98	6.62	0.19	3.56	2.78

Result of Triaxial Compressive Test

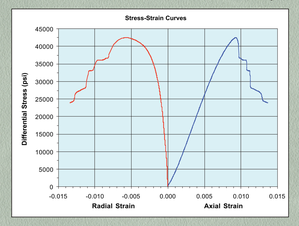


Company	Ohio GS
Project Title	CO2 No. 1
OMNI Project No.	HH-38266
Date	Mar., 2008

Sample No.	1-43R
Depth (ft)	7441.00
Saturation State	2% KCl
Confining Pressure (psi)	2600
Bulk Density* (g/cc)	2.50
Compressive Strength (psi)	41110
Young's Modulus ($x10^6$ psi)	4.82
Poisson's Ratio	0.38

* saturated

Result of Triaxial Compressive Test



Company	Ohio GS
Project Title	CO2 No. 1
OMNI Project No.	HH-38266
Date	Mar., 2008

Sample No.	1-72R
Depth (ft)	8561.00
Saturation State	2% KCl
Confining Pressure (psi)	2950
Bulk Density* (g/cc)	2.45
Compressive Strength (psi)	45360
Young's Modulus ($x10^6$ psi)	5.65
Poisson's Ratio	0.25

* saturated

Injection Testing Results in the Cambrian Basal Sandstone and the Rose Run Sandstone

Ohio Borehole Test Summary/ Activity Log: basal sand

Formation	Perforated Test Interval Depth, ft bKB[a]	Borehole Test Activity	Test Date/Time[b]	Comments*
Basal Sand	8,526 - 8,531 8,536 - 8,542 8,554 - 8,566 8,566 - 8,576	Swab Development of Basal Sand Perforated Zones	7/19/07 (15:30 - 18:30) 7/20/07 (08:00 - 11:30)	Total volume of fluid ***removed*** from interval? 3,970 gallons (94.5 barrels); pH increased from 1 to 6 and fluid weight density from 8.5 to 10.3 lb/gal during the course of fluid removal
		Aborted Injection Test	7/20/07 (17:18 - 20:52)	Injection rate at ~2 gpm and then test aborted due to inadvertent closing of downhole shut-in tool; Injection Vol.: 430 gal Max. Surface Inj. Pressure: < 0 psi Max. Downhole Obs. Pressure: 3,405 psi Avg. Fluid Weight Density: ~9.8 lb/gal
		Constant-Pressure Injection Test	7/22/07 (10:08 - 19:01)	Injection rates varied from 2.42 to 0.61 gpm during the course of the test; Injection Vol.: 555 gal Max. Surface Inj. Pressure: 3 psi Max. Downhole Obs. Pressure: 4,355 psi Avg. Fluid Weight Density: ~9.8 lb/gal
		Slug Injection Test	7/23/07 07:03 - 09:56	Injection Vol.: 85 gal Max. Surface Inj. Pressure: < 0 psi Max. Downhole Obs. Pressure: 4,340 psi Avg. Fluid Weight Density: ~9.8 lb/gal
		Basal Sand Test Interval Summary: **Total Injection Volume: 1,070 gallons** **Total Injection Period: 15.3 hours (1.1gal/min_RAR)** **Maximum Surface Injection Pressure: 3 psi** **Maximum Observed Downhole Pressure: 4,355 psi**		

(a) **ft bKB:** feet below original Kelly Bushing datum; note: packers used to isolate perforated test intervals within cemented well casing string

(b) Observed surface test time

*Note: **Injection Volume** represents volume injected into test system during the active injection period; the actual volume injected into the test zone may be slightly less than this amount. **Maximum Surface Injection Pressure** represents the maximum surface pressure observed during the injection test; **Maximum Observed Downhole Injection Pressure** represents the maximum pressure observed with the downhole pressure gauge located in proximity/above the top perforated test interval.; except for Rose Run #1 where probe depth setting was ~495 above top perforated interval. **Average Fluid Weight Density** represents the average of the injection fluid weight density measured at the surface during the test

Ohio Borehole Test Summary/ Activity Log: Rose Run #1

Formation	Perforated Test Interval Depth, ft bKB[a]	Borehole Test Activity	Test Date/Time[b]	Comments*
Rose Run #1	7,506 - 7,509	Constant-Pressure Injection Test	7/26/07 (18:10) - 7/27/07 (08:42)	After test system fill-up, the test was maintained at a constant surface pressure of 50 psi. Injection rates varied from 0.2 to 0.07 gpm during the course of the constant-pressure injection test: Injection Vol.: 245 gal Max. Surface Inj. Pressure: 50 psi Max. Downhole Obs. Pressure: 3,680 psi Avg. Fluid Weight Density: ~9.8 lb/gal
		Slug Injection Test	7/28/07 (07:22 - 10:01)	Injection Vol.: 5 gal Max. Surface Inj. Pressure: < 0 psi Max. Downhole Obs. Pressure: 3,635 psi Avg. Fluid Weight Density: ~9.8 lb/gal
		Rose Run #1 Test Interval Summary: **Total Injection Volume: 250 gallons** **Total Injection Period: 17.2 hours** **Maximum Surface Injection Pressure: 50 psi** **Maximum Observed Downhole Pressure: 3,680 psi**		

(a) **ft bKB:** feet below original Kelly Bushing datum; note: packers used to isolate perforated test intervals within cemented well casing string

(b) Observed surface test time

*Note: **Injection Volume** represents volume injected into test system during the active injection period; the actual volume injected into the test zone may be slightly less than this amount. **Maximum Surface Injection Pressure** represents the maximum surface pressure observed during the injection test; **Maximum Observed Downhole Injection Pressure** represents the maximum pressure observed with the downhole pressure gauge located in proximity/above the top perforated test interval.; except for Rose Run #1 where probe depth setting was ~495 above top perforated interval. **Average Fluid Weight Density** represents the average of the injection fluid weight density measured at the surface during the test

Ohio Borehole Test Summary/ Activity Log: Rose Run #2

Formation	Perforated Test Interval Depth, ft bKB[a]	Borehole Test Activity	Test Date/Time[b]	Comments*
Rose Run #2	7,416 - 7,418 7,435 - 7,446	Constant-Pressure Injection Test #1	7/29/07 (14:00) - 7/30/07 (10:00)	After test system fill-up, the test was maintained at a constant surface pressure of 50 psi. Injection rates varied from 3.2 to 1.0 gpm during the course of the constant-pressure injection test: Injection Vol.: 245 gal Max. Surface Inj. Pressure: 50 psi Max. Downhole Obs. Pressure: 3,825 psi Avg. Fluid Weight Density: ~9.8 lb/gal
		Slug Injection Test	7/31/07 (09:25 - 10:15)	Injection Vol.: 45 gal Max. Surface Inj. Pressure: < 0 psi Max. Downhole Obs. Pressure: 3,785 psi Avg. Fluid Weight Density: ~9.8 lb/gal
		Constant-Pressure Injection Test #2	7/31/07 (12:17 - 20:03)	After test system fill-up, the test was maintained at a constant surface pressure of 50 psi. Injection rates varied from 1.2 to 1.0 gpm during the course of the constant-pressure injection test: Injection Vol.: 530 gal Max. Surface Inj. Pressure: 50 psi Max. Downhole Obs. Pressure: 3,825 psi Avg. Fluid Weight Density: ~9.8 lb/gal
		Rose Run #2 Test Interval Summary: **Total Injection Volume: 820 gallons** **Total Injection Period: 28.6 hours** **Maximum Surface Injection Pressure: 50 psi** **Maximum Observed Downhole Pressure: 3,825 psi**		

(a) **ft bKB:** feet below original Kelly Bushing datum; note: packers used to isolate perforated test intervals within cemented well casing string

(b) Observed surface test time

*Note: **Injection Volume** represents volume injected into test system during the active injection period; the actual volume injected into the test zone may be slightly less than this amount. **Maximum Surface Injection Pressure** represents the maximum surface pressure observed during the injection test; **Maximum Observed Downhole Injection Pressure** represents the maximum pressure observed with the downhole pressure gauge located in proximity/above the top perforated test interval.; except for Rose Run #1 where probe depth setting was ~495 above top perforated interval. **Average Fluid Weight Density** represents the average of the injection fluid weight density measured at the surface during the test

Ohio Borehole Test Summary/ Activity Log: Rose Run #3

Formation	Perforated Test Interval Depth, ft bKB[a]	Borehole Test Activity	Test Date/Time[b]	Comments*
Rose Run #3	7,377 - 7,380 7,387 - 7,396	Constant-Pressure Injection Test	8/1/0 (11:36)- 8/2/07 (07:36)	After test system fill-up, the test was maintained at a constant surface pressure of 50 psi. Injection rates varied from 0.55 to 0.17 gpm during the course of the constant-pressure injection test: Injection Vol.: 265 gal Max. Surface Inj. Pressure: 50 psi Max. Downhole Obs. Pressure: 3,780 psi Avg. Fluid Weight Density: ~9.8 lb/gal
		Slug Injection Test	8/3/07 (07:46 - 9:47)	Injection Vol.: 30 gal Max. Surface Inj. Pressure: < 0 psi Max. Downhole Obs. Pressure: 3,745 psi Avg. Fluid Weight Density: ~9.8 lb/gal
		Rose Run #3 Test Interval Summary: **Total Injection Volume: 295 gallons** **Total Injection Period: 22.0 hours** **Maximum Surface Injection Pressure: 50 psi** **Maximum Observed Downhole Pressure: 3,780 psi**		

(a) **ft bKB:** feet below original Kelly Bushing datum; note: packers used to isolate perforated test intervals within cemented well casing string

(b) Observed surface test time

*Note: **Injection Volume** represents volume injected into test system during the active injection period; the actual volume injected into the test zone may be slightly less than this amount. **Maximum Surface Injection Pressure** represents the maximum surface pressure observed during the injection test; **Maximum Observed Downhole Injection Pressure** represents the maximum pressure observed with the downhole pressure gauge located in proximity/above the top perforated test interval.; except for Rose Run #1 where probe depth setting was ~495 above top perforated interval. **Average Fluid Weight Density** represents the average of the injection fluid weight density measured at the surface during the test

Ohio Borehole Test Summary/ Activity Log: Composite Rose Run

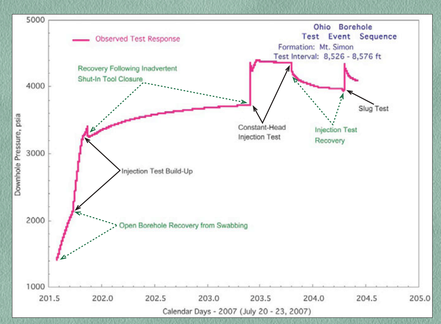
Formation	Perforated Test Interval Depth, ft bKB[a]	Borehole Test Activity	Test Date/Time[b]	Comments*
Composite Rose Run	7,377 - 7,380 7,387 - 7,396 7,416 - 7,418 7,435 - 7,446 7,506 - 7,509	Swab Development of Composite Rose Run Perforated Zone	7/24/07 (16:00 - 18:15) - 7/25/07 (07:00 - 13:05)	Set bridge plug at 7,530 ft and initiated development of composite Rose Run perforated interval. Total volume of fluid ***removed*** from interval?10,330 gallons (246 barrels); pH increased from 1 to 5 and weight from 8.6 to 10.1 lb/gal during the course of fluid removal
		Constant-Pressure Injection Test	8/3/07 (17:25) - 8/4/07 (17:34)	After test system fill-up, the test was maintained at a constant surface pressure of 50 psi. Injection rates varied from 2.12 to 0.82 gpm during the course of the constant-pressure injection test: Injection Vol.: 1,450 gal Max. Surface Inj. Pressure: 50 psi Max. Downhole Obs. Pressure: 3,790 psi Avg. Fluid Weight Density: ~9.8 lb/gal
		Slug Injection Test	8/6/07 (06:33 - 8:33)	Injection Vol.: 65 gal Max. Surface Inj. Pressure: < 0 psi Max. Downhole Obs. Pressure: 3,740 psi Avg. Fluid Weight Density: ~9.8 lb/gal
		Composite Rose Run Test Interval Summary: **Total Injection Volume: 1,515 gallons** **Total Injection Period: 26.2 hours** **Maximum Surface Injection Pressure: 50 psi** **Maximum Observed Downhole Pressure: 3,790 psi**		

(a) **ft bKB:** feet below original Kelly Bushing datum; note: packers used to isolate perforated test intervals within cemented well casing string

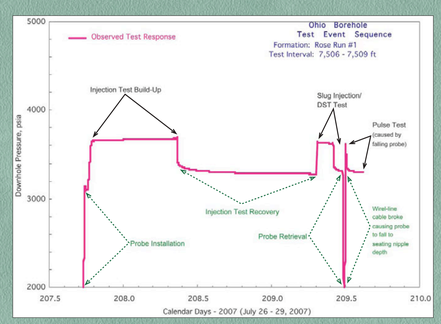
(b) Observed surface test time

*Note: **Injection Volume** represents volume injected into test system during the active injection period; the actual volume injected into the test zone may be slightly less than this amount. **Maximum Surface Injection Pressure** represents the maximum surface pressure observed during the injection test; **Maximum Observed Downhole Injection Pressure** represents the maximum pressure observed with the downhole pressure gauge located in proximity/above the top perforated test interval.; except for Rose Run #1 where probe depth setting was ~495 above top perforated interval. **Average Fluid Weight Density** represents the average of the injection fluid weight density measured at the surface during the test

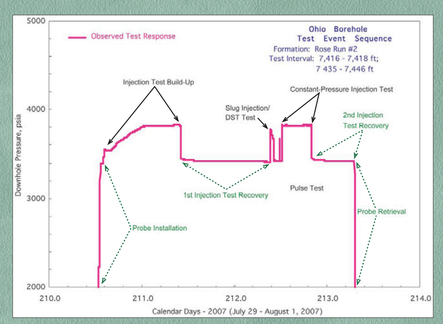
Ohio Well Test Event Pressure History Plot: basal sand



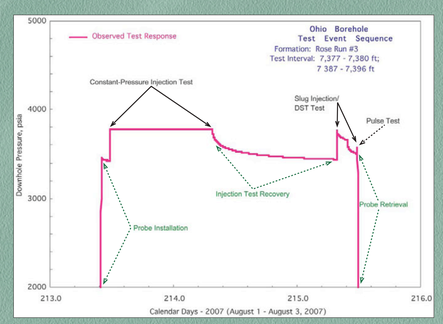
Ohio Well Test Event Pressure History Plot: Rose Run #1



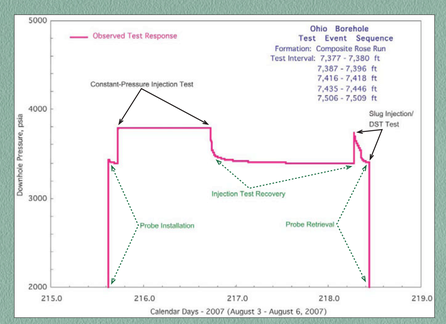
Ohio Well Test Event Pressure History Plot: Rose Run #2



Ohio Well Test Event Pressure History Plot: Rose Run #3



Ohio Well Test Event Pressure History Plot: Composite Rose Run



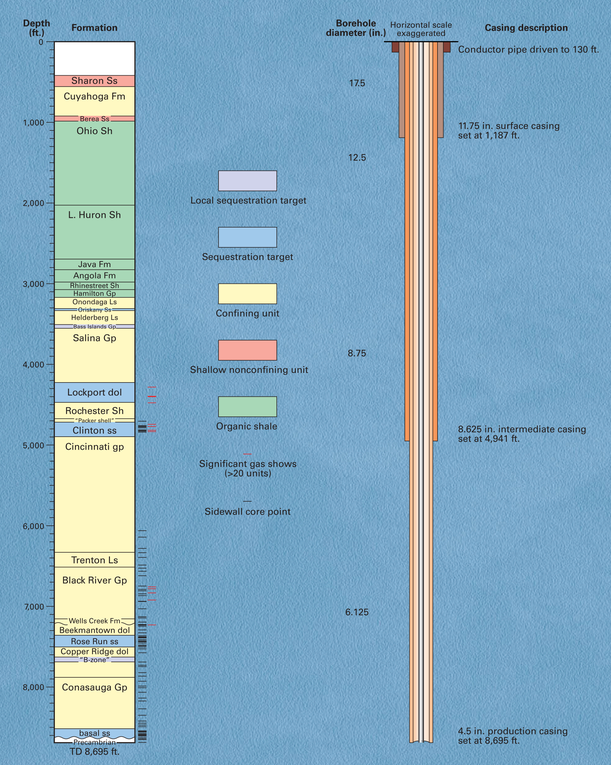
Summary

Wireline Logs and Coring Conducted on the Ohio Geological Survey CO_2 No. 1 Well

- Gamma Ray, Lithodensity Compensated Neutron, PEF
- Laterolog
- CMR (Combinable Magnetic Resonance)
- Sonic Porosity
- Pressure Express
- Sidewall Cores (82)
- Perf Log
- Cement Bond Log
- FMI (Formation Micro Imager—processed interpretation)
- FracCADE Advisor (processed interpretation)
- Dipole Sonic (processed interpretation)
- Injection tests were performed in the Cambrian basal sandstone and the Rose Run sandstone

Results

- At this site, reservoir quality for the Cambrian basal sandstone was less than expected. Wireline logs indicated 56 feet of net sandstone (>6%). The average porosity was 10% with a maximum of 15%. However, core analyses indicated relatively low permeabilities with a maximum permeability of 1.0 md, and most were <0.1 md. Results form this well will be correlated to other wells to identify areas of better reservoir quality.
- Reservoir quality of the Rose Run sandstone was more promising in regards to permeability. Logs indicated a net sandstone thickness of 24 feet (>6% porosity). The average porosity was 9.5% with a maximum of 13.5%. Core analyses indicated permeability values with measurements of 1.40, 13.8 and 26.6 md in selected zones.
- Log, core, and injectivity tests from this well will be correlated to other wells in the region and used to provide models for regional and site specific injection potential.
- Issues involving sequestration in oil and gas producing areas are being examined. This well was turned over to the operator who controlled the lease, which resulted in significant production from the Beekmantown dolomite. This well will provide additional data for exploration of this and other producing reservoirs.
- Other states are now attempting to fund similar research wells for CO_2 sequestration research.
- Efforts such as this are keeping Ohio at the forefront of carbon sequestration research in the U.S.



Summary diagram showing potential injection zones, confining units, sidewall cores, and significant gas shows.