Volume VI.I

Midwestern Regional Carbon Sequestration Partnership (MRCSP) Phase III (Development Phase)

State Charlton & MRCSP 1 Characterization Well Report

Prepared by:

Battelle
505 King Avenue
Columbus, Ohio 43201

Principal Investigator: Dr. Neeraj Gupta

Authors: Erica Howat, Autumn Haagsma, and Neeraj Gupta

Submitted to:

The U.S. Department of Energy, National Energy Technology Laboratory
Program Manager: Andrea McNemar

DOE MRCSP Project #DE-FC26-05NT42589

September 2020

Notice

Acknowledgements

Sponsorships - This report is part of a series of reports prepared under the Midwestern Regional Carbon Sequestration Partnership (MRCSP) Phase III (Development Phase). These reports summarize and detail the findings of the work conducted under the Phase III project. The primary funding for the MRCSP program is from the US Department of Energy's National Energy Technology Laboratory (NETL) under DOE project number DE-FC26-05NT42589 with Ms. Andrea McNemar as the DOE project manager. The past DOE project managers for MRCSP include Dawn Deel, Lynn Brickett, and Traci Rodosta. Many others in the DOE leadership supported, encouraged, and enabled the MRCSP work including but not limited to Kanwal Mahajan, John Litynski, Darin Damiani, and Sean Plasynski.

The Michigan Basin large-scale test received significant in-kind cost share from Core Energy, LLC, who also provided essential access to the field test site and related data. This contribution by Core Energy CEO Robert Mannes, VP Operations Rick Pardini, and Allan Modroo, VP Exploration, and the entire Core Energy staff is gratefully acknowledged. MRCSP work in Ohio has been supported by the Ohio Coal Development Office in the Ohio Development Services Agency under various grants (CDO D-10-7, CDO-D-13-22, CDO-D-D-13-24, and CDO-D-15-08) with Mr. Greg Payne as the OCDO project manager. Finally, several industry sponsors and numerous technical team members from State Geological Surveys, universities, and field service providers have supported MRCSP through cash and in-kind contributions over the years as listed in the individual reports.

Program Leadership – During the MRCSP Phase III project period, several Battelle staff and external collaborators contributed to the successful completion of the program through their efforts in field work, geological data analysis and interpretation, and/or reporting. The primary project managers over the MRCSP performance period have included Rebecca Wessinger, Neeraj Gupta, Jared Walker, Rod Osborne, Darrell Paul, David Ball. Additional project management support has been provided by Andrew Burchwell, Christa Duffy, Caitlin McNeil, and Jacqueline Gerst over the years.

Principal Investigator: Neeraj Gupta (614-424-3820/ gupta@battelle.org)

Report Authors and Principal Technical Contributors – Erica Howat, Autumn Haagsma, and Neeraj Gupta.

Contributors – Contributors to the field drilling program included Darrell Paul, Neeraj Gupta, Matt Place, Mark Moody, Jackie Gerst and several others at Battelle. The Core Energy staff including Bob Mannes, Rick Pardini, and Bob Tipsword provided field oversight with support from several vendors.

Table of Contents

Page

List of Tables

Page

List of Figures

Page

Acronyms and Abbreviations

CO_2	Carbon Dioxide
EOR	Enhanced Oil Recovery
EPA	Environmental Protection Agency
MD	Measured Depth
MRCSP	Midwest Regional Carbon Sequestration Partnership
MRI	Magnetic Resonance Imaging
MSL	Mean Sea Level
NMR	Nuclear Magnetic Resonance
TVD	True Vertical Depth
UIC	Underground Injection Control

1.0 Introduction

1.1 Background

The goal of the Midwest Regional Carbon Sequestration Partnership (MRCSP) Phase III project was to implement a geologic injection test of sufficient scale to promote understanding of injectivity, capacity, and storage potential at a commercial scale in a reservoir having broad importance to the region. The key aspects that were to be tested included permitting and stakeholder perspectives, CO_2 handling and compression, local transport, site assessment and development, injection and monitoring operations, site closure, or transition to commercial operations, and institutional processes. Specifically, the large-scale injection test planned for Phase III had planned to attempt to inject one million tons of CO_2 at the designated test site. Figure 1-1 shows the location of Phase III activities referenced to a geologic structure map of the MRCSP area.

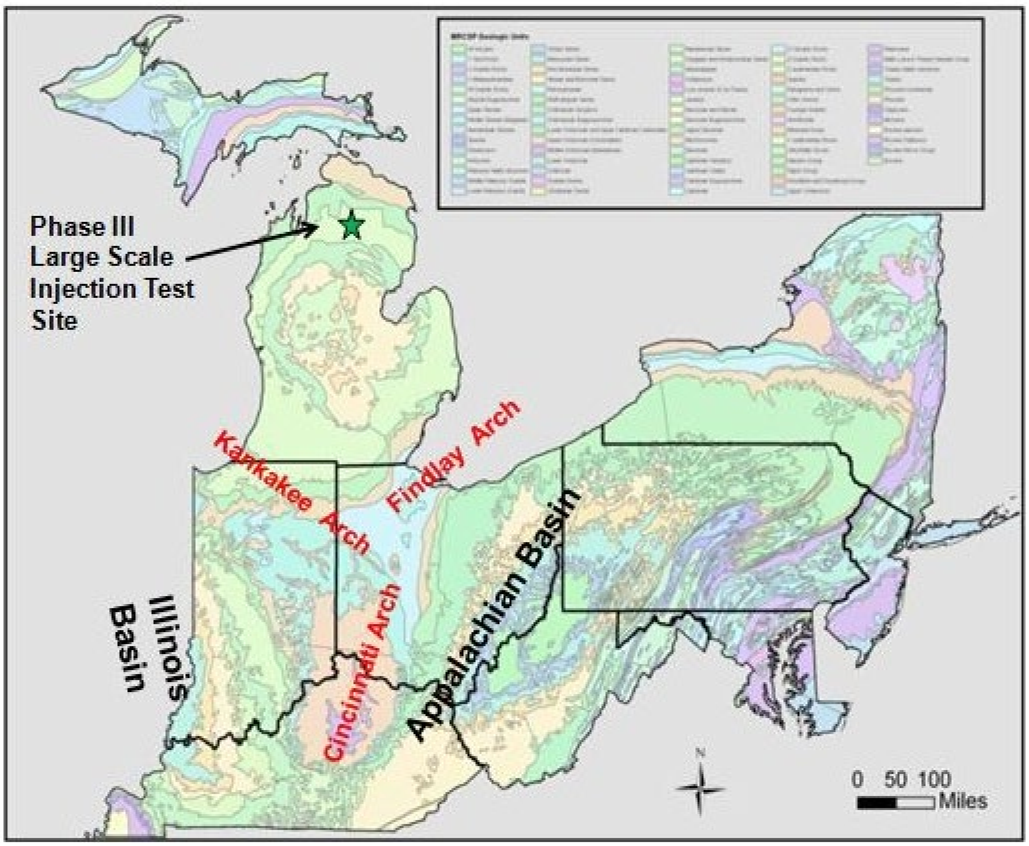


Figure 1-1. MRCSP Phase III Focal Point for Large-Scale Injection Test.

During 2009-10, it was determined that based on the colocation of an adequate source of CO_2 from gas processing operations, willingness of the operator (Core Energy, LLC) to host the project, and presence of a promising deep saline reservoir, the St. Peter Sandstone the Otsego County area in northern lower Michigan can be a viable candidate for the MRCSP large-scale test. The Michigan Department of Natural Resources, who had clear protocols for environmentally safe access to subsurface oil, gas, and fluid storage resources, owns large contiguous tracts of land in the area. Before a final decision on site-selection could be made, it was necessary to validate the site geology with regards to the storage capacity, injectivity, and containment. This required drilling of a deep test well in the vicinity of the CO_2

source in conjunction with the other site assessment, characterization, and project development activities. This report summarizes the data collected during the drilling effort of the State Chester and MRCSP Well No. 1 drilled during early 2011.

The initial goal of this task was to drill and complete a well in the St. Peter sandstone for characterization and evaluation of storage potential. However, as presented in this report, the well was not drilled and completed up to the intended target intervals due to drilling related difficulties. While the drilling issues were being resolved, the new Class VI injection well regulations were finalized by the US EPA. The well design, long-term monitoring, and financial assurance requirements in the new regulations were not readily addressable within the realm of the DOE funded MRCSP project scope. Therefore, the well was placed in temporary abandonment. Instead the MRCSP efforts were shifted to evaluating CO_2 storage and containment using site characterization, modeling, and monitoring in conjunction with the ongoing CO_2-EOR operations in the same area. This report describes work associated with the initial test well, the State Chester and MRCSP Well No. 1, drilled to a depth of about 7,968 feet TVD, and subsequently plugged and designated as temporarily abandoned. A high-level overview of data collected and analyzed is provided for shallower units.

1.2 Methodology

The drilling of the test well was part of the larger effort in developing the overall large-scale test in the study area. A number of other related activities were undertaken before and during the drilling. These include the following:

- Project Conceptualization covering all aspects – CO_2 supply, transport, injection, monitoring, scientific goals, permitting and environmental issues, risk assessment, and overall budget – was completed and presented to the DOE for approval.
- A communication and outreach plan was developed and executed in collaboration with DTE and Core Energy. There was no adverse reaction to the project in the community to date.
- Site access was obtained from Michigan DNR with approval for use of State-owned land site for site characterization well and also obtained general agreement for long-term site use for the injection and monitoring.
- Pore space ownership and liability aspects were researched, and it was determined that the State of Michigan owned the pore space with a roughly one-mile radius of the proposed injection site.
- Short and long-term project risks and liability issues were evaluated and strategies to address these were developed.
- CO_2 Supply Agreement was completed for 1 million tonnes of high purity CO_2.
- Project plans were presented successfully to the international peer-review panel convened by the IEAGHG for the DOE.
- Pre-drilling planning and assessment activities included:
  - Licensing and interpretation of extensive pre-existing 2D seismic data to ensure that no significant features of concern were present in the study area.
  - A detailed assessment of regional and local geology based on all existing data
  - Site characterization plans and well design for the characterization well
  - Field work plans, including safety plans and identification of key service providers was completed
- Requirements under the National Environmental Policy Act (NEPA) were completed. DOE granted the characterization well a categorical exclusion (CX). In addition, a draft NEPA EA for the overall project was substantially completed by the time the project focus was shifted.
- The drilling permit for the test well was obtained from State agencies.

The site characterization data was to be used to assess the suitability of the site for CO_2 injection and to build a design basis for the injection and monitoring wells, and the injection and monitoring operations. The characterization data and results were also to be used to support the Environmental Protection Agency (EPA) Underground Injection Control (UIC) permit application. Finally, the data was to be used to support computer flow models and risk assessments.

The general approach to characterizing the site subsurface was to collect detailed data at each stage of drilling the test well, such as:

- Cuttings samples and record of field observations (mud logs),
- Wireline data (including as appropriate gamma, neutron, resistivity, image, magnetic resonance, elemental analysis, pressure, and temperature logs),
- Full-size and side-wall core samples for detailed rock mechanical, geologic, and reservoir laboratory tests,
- Fluid sampling and analysis, and
- Pressure leak off tests during drilling.

It was planned that upon completion of drilling operations, additional reservoir tests would be completed to further characterize the subsurface geologic conditions and would include:

- Fracture (“Mini-frac”) tests to evaluate formation stimulation programs and to establish fracture pressures for management of injection programs,
- Spinner (flow) tests to identify productive units within the target formation, and
- Short-term reservoir injection tests to develop confidence and accuracy in formation permeability measurements.

The field data were to be analyzed and then used to develop a computer simulation flow model. However, as the well was temporarily abandoned, reservoir testing and modeling were not completed. The original longer-term intent for the test well would be to utilize it as a monitoring well. The current status of the well is undetermined and is under consideration for plugging and abandoning or selling to a commercial interest.

1.3 Regional Information and Site Selection

The Otsego County, Michigan area consists of fields and forests with little cultural development beyond some farms and scattered homes. Surface elevations in the area range from about 1,000 to 1,300 feet above mean sea level (msl) with low relief topography in the area consisting of gently rolling hills and valleys with scattered lakes. The climate in the area is temperate with an average yearly temperature of 42.8 °F. Gaylord, Michigan has an average high and low temperature in January of 25.2 °F and 9.6 °F, respectively, and an average high and low temperature in July of 80 °F and 55 °F, respectively. Gaylord also has an average annual snowfall of 149.2 inches per year and an average annual liquid precipitation of 36.6 inches per year.

Oil and gas production is active in this portion of the Michigan Basin site. As of this writing, natural gas is produced from Antrim shales in the area. This gas contains 10 to 15 percent CO_2, which is removed at gas processing plants before the gas is ready for commercial distribution. Consequently, high purity CO_2 is readily available from the Chester 10 gas processing plants and other nearby plants. The CO_2 is captured, compressed, and injected into Niagaran reefs to flush out residual oil in the rocks, as a method of Enhanced Oil Recovery (EOR). A significant amount of private industry infrastructure is available for testing CO_2 sequestration in saline formations located adjacent to existing EOR operations.

This site was selected for the Phase III large-scale test for numerous reasons. The close proximity of high purity CO_2 was very advantageous for project execution. In addition, the success of the Phase II Michigan Test gave greater confidence in the subsurface geology, the stakeholder environment, and the teaming partners.

Due to the larger scale of the project, the St. Peter Sandstone was identified as the primary injection target. It is stratigraphically located below all of the oil and gas production in Otsego County, which makes it particularly attractive. As there has been a significant amount of exploration and production over the past 60 years in this area, minimizing the existing penetrations in the potential storage area would be advantageous to the project. However, the St. Peter Sandstone formation is not as well characterized as other formations in the area.

The Chester 10 gas separation and compression facility is located about 12 miles southeast of the town of Gaylord, Michigan (Figure 1-2). The proposed injection site was within 1 mile of this facility, which would minimize the amount of transmission pipeline and would utilize new and existing compressors at the Chester 10 CO_2 production facility. The injection site is located within the Michigan DNRE "Military Land" management area. It is one of six management areas in the state and classified as development with restrictions. The plant is located in Chester Township (T29N R2W) in block 10.

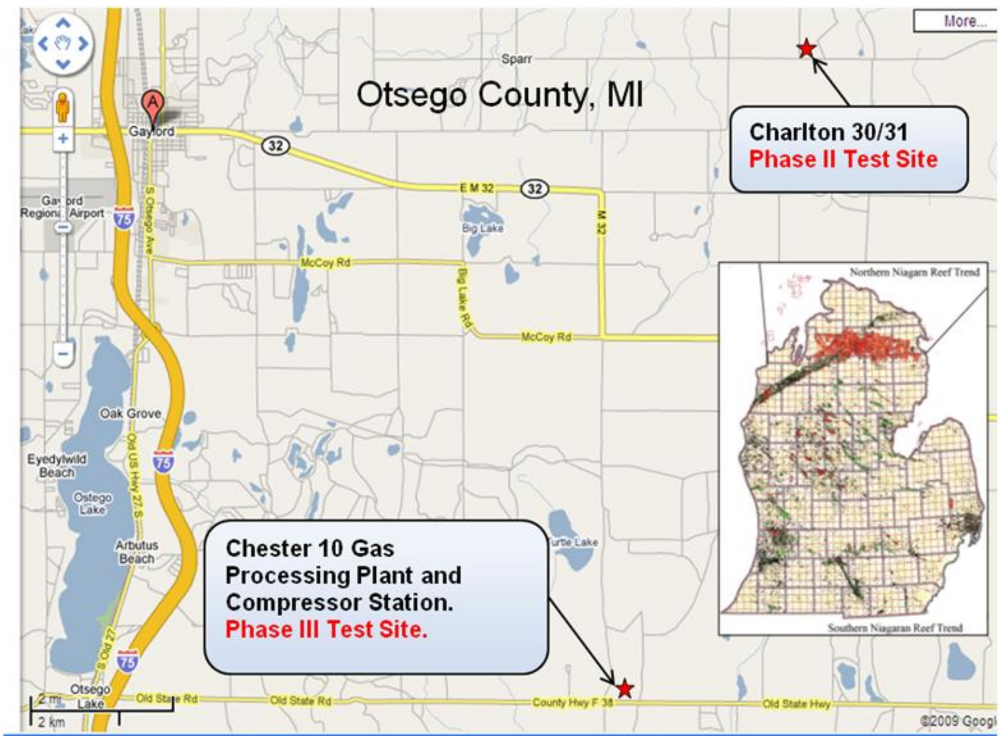
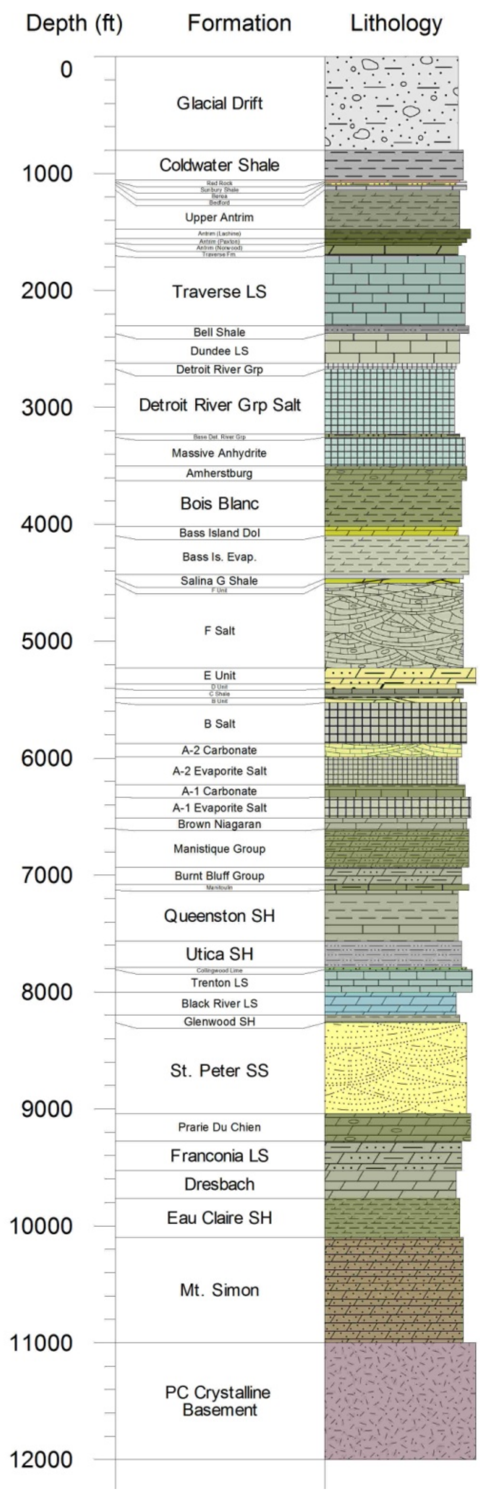


Figure 1-2. Location Map for Phase III Injection Testing.

Figure 1-3. Aerial View of the Phase III Injection Test Site.



Generalized Lithologic Column for Test Site. **Paleozoic sedimentary rocks over 10,000 ft in total thickness underlie a 600 to 800 ft thick glacial layer in the study area. Precambrian crystalline basement rocks underlie the Paleozoic rocks.**

Figure 1-4. Stratigraphic Column for the Study Area.

2.0 Drilling History

After the requisite planning and approvals, the drilling of the well was conducted during March to May 2011. This section describes the activities related to the drilling of the test well. Figure 2-1 summarizes the drilling plan prior to spudding the well. As is typical, actual set points for the casing were different; see Figure 2-2 for the as built diagram.

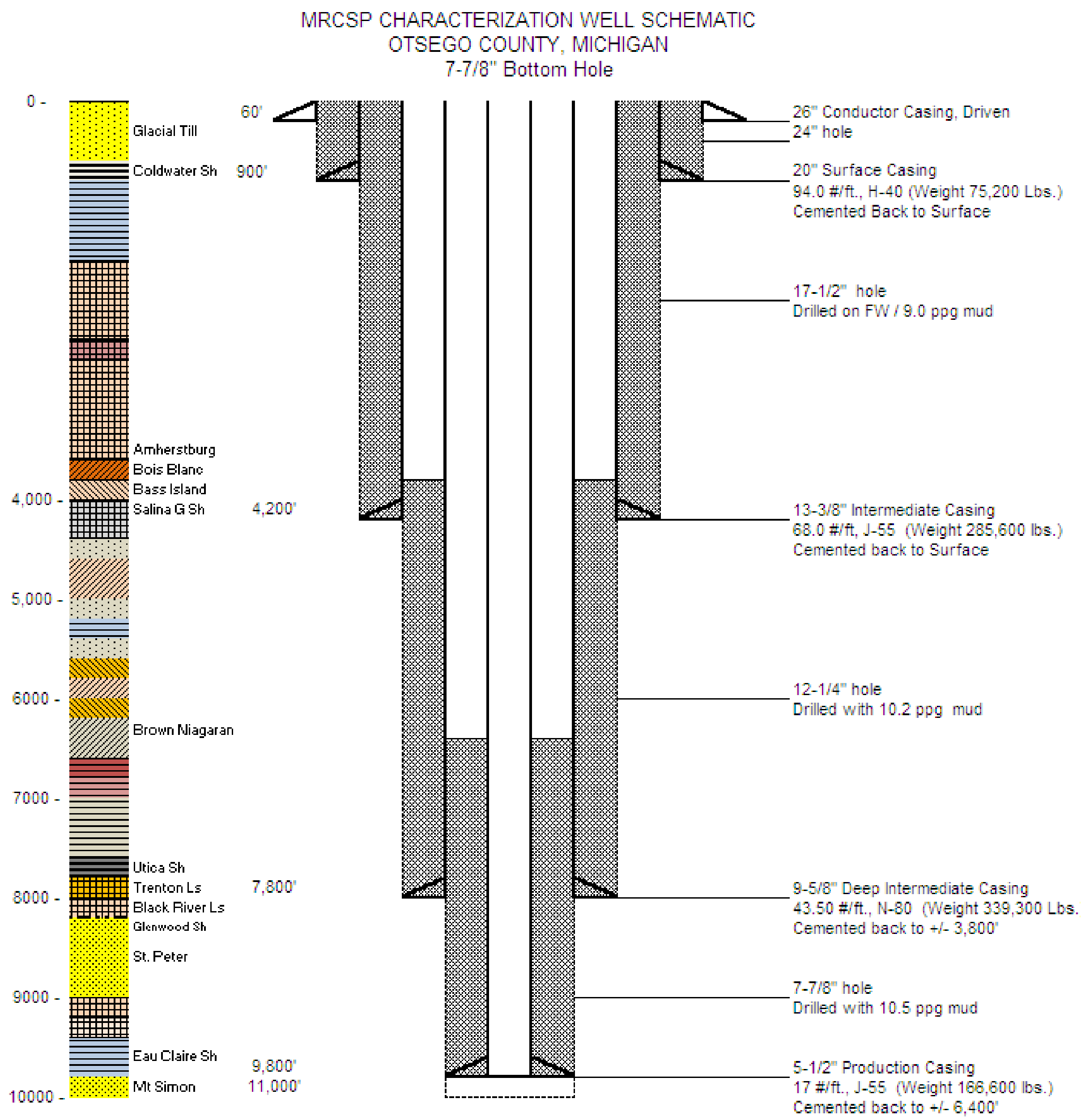


Figure 2-1. Planned Well Design.

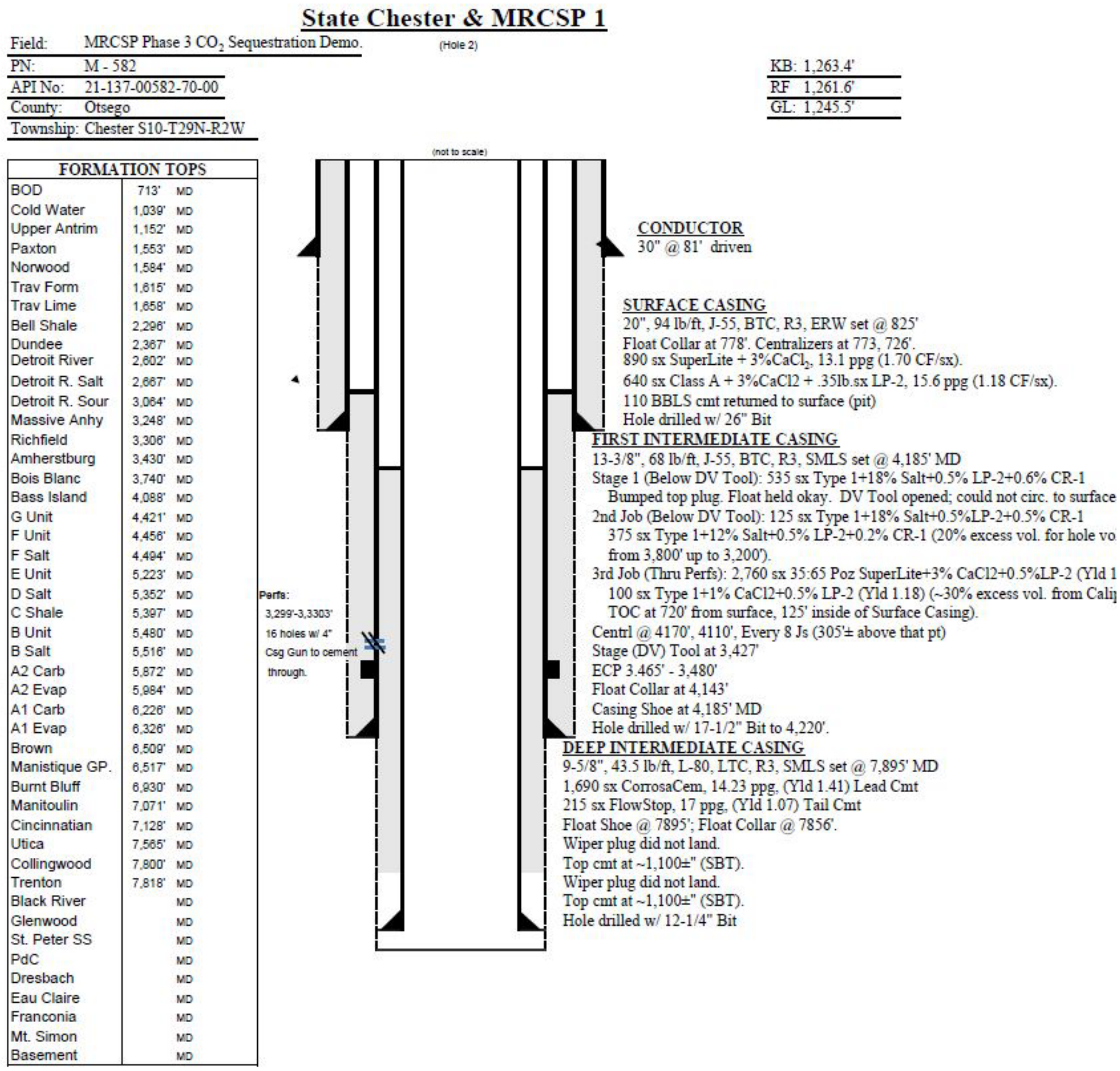


Figure 2-2. As Built Diagram for the State Chester & MRCSP 1 Well.

2.1 Conductor to Surface Casing Section

The 30-inch conductor casing was driven to 81 feet TVD on March 5, 2011. The conductor casing stabilizes the unconsolidated glacial till during the drilling of the surface hole. The well was officially spud on March 8, 2011. A 24-inch drilling bit was used to drill out from under the conductor casing to set the surface casing at a depth of 825 feet TVD on March 11, 2011. The base of the unconsolidated glacial till was expected to be approximately 680 feet TVD but was not encountered until 715 feet TVD. The 20-inch surface casing was set approximately 110 feet into the shale bedrock. The surface casing was cemented back to ground level to seal off the alluvial aquifer, which is the main source of fresh water in the region.

2.2 Surface to First Intermediate Casing Section

A 17½-inch bit was used to drill out from under the 20-inch surface casing to a depth of approximately 4,200 feet TVD. Intermediate casing was set at 4,185 feet on April 4, 2011 and was cemented back to ground level with Portland-type cement. The cementing was performed in three stages to overcome the impact of the fluid loss zones in the borehole. The 13⅜-inch intermediate casing was set through the Bass Islands formation.

2.3 Deep Intermediate Casing Section

A 12¼-inch bit was be utilized to drill out from under the 13⅜-inch intermediate casing to a depth of approximately 7,895 feet TVD. The 9⅝-inch deep intermediate casing string was set through the Utica shale formation. The reason for setting the deep intermediate casing string at this depth is to cover the Queenston and Utica shale formations, which are susceptible to heaving and caving if left exposed to the borehole fluids for an extended period of time. Casing through the Queenston and Utica shale formations allowed open hole testing of the targeted St. Peter sandstone and other deeper potential saline formations. The 9⅝-inch deep intermediate casing was set in the Trenton limestone formation at approximately 7,895 feet TVD and planned cementing approximately back to about 3,800 feet, or 400 feet inside the 13⅜-inch intermediate casing with a Portland-type cement.

However, during the casing and cementing operations, there were significant difficulties in accessing the lowest sections of the borehole. Subsequent drilling and logging indicated potential for casing damage below about 7,300 feet. This would have required plugging the lowest section and side-tracking a deviated section to bypass the problem zones. However, subsequently, a decision was made to plug the well and designate it as temporarily abandoned. This was in response to the new guidance from the US EPA that even the research wells such as the MRCSP well had to be permitted under the new Class VI regulations, rather than the experimental Class V regulations. The well design, long-term monitoring, and financial assurance requirements posed by this change created significant uncertainties relative to the approved scope and budget of the program. As a result, the planned 7 7/8-inch hole was not drilled to completion.

3.0 Data Acquisition Effort

This section discusses the data acquired in the course of the test. It includes a description of the mud logging activities as well as the logging program. Table 3-1 lists sample top (determined from drill cuttings) and wireline top data from the State Chester and MRCSP Well No. 1.

Table 3-1. State-Chester and MRCSP No. 1 Well Approximate Formation tops based on Logs and Mudlog Samples.

SFC Elevation = 1,245 feet; KB = 1,264 feet.

Formation	Log Top	Log Subsea	Sample Top	Sample Subsea
BASE GLACIAL DRIFT	715	549	713	551
COLDWATER SH.	715	549	713	551
RED ROCK	1055	209	1039	225
SUNBURY	1061	203	1066	198
BEREA	1069	195	NA	NA
BEDFORD	1087	177	1085	179
UPPER ANTRIM	1138	126	1152	112
ANTRIM (LACHINE)	1466	-202	1457	-193
ANTRIM (PAXTON)	1548	-284	1553	-289
ANTRIM (NORWOOD)	1589	-325	1584	-320
TRAV. FM. (SQUAW BAY)	1611	-347	1615	-351
TRAVERSE LIMESTONE	1702	-438	1658	-394
BELL SHALE	2295	-1031	2296	-1032
DUNDEE	2363	-1099	2367	-1103
DETROIT RIVER ANHY.	2613	-1349	2602	-1338
DETROIT RIVER SALT	2663	-1380	2667	-1403
BASE DET. RIVER SALT	3192	-1909	3196	-1932
MASSIVE ANHYDRITE	3245	-1962	3248	-1984
AMHERSTBURG	3495	-2212	3430	-2166
BOIS BLANC	3625	-2342	3740	-2476
BASS ISLAND DOLOMITE	4011	-2728	4017	-2753
BASS ISLAND ANHYDRITE	4093	-2810	4088	-2824
SALINA G SHALE	4421	-3157	4426	-3162
F UNIT	4456	-3192	4462	-3198
F SALT	4494	-3230	4498	-3234
E UNIT	5223	-3959	5225	-3961
D UNIT	5352	-4088	5357	-4093
C SHALE	5397	-4133	5378	-4114
B UNIT	5480	-4216	5478	-4214
B SALT	5516	-4252	5518	-4254
A-2 CARBONATE	5872	-4608	5868	-4604
A-2 EVAPORITE (SALT)	6326	-5062	5988	-4724
A-1 CARBONATE	6226	-4962	6224	-4960
A-1 EVAPORITE (SALT)	6326	-5062	6328	-5064
BROWN NIAGARAN	6509	-5245	6504	-5240

Formation	Log Top	Log Subsea	Sample Top	Sample Subsea
MANISTIQUE GP.	6517	-5253	6603	-5339
BURNT BLUFF (LIME ISL.)	6930	-5666	6939	-5675
MANITOULIN	7071	-5807	7072	-5808
CINCINNATIAN (QUEENSTON)	7128	-5864	7130	-5866
UTICA	7565	-6301	7563	-6299
COLLINGWOOD LIME	7800	-6536	7792	-6528
TRENTON	7818	-6554	7816	-6552
BLACK RIVER LMST.	NA	NA	NA	NA
GLENWOOD	Not Drilled			
ST. PETER SS.				
PRAIRIE DuCHIEN (“FOSTER”)				
DRESBACH				
EAU CLAIRE				
FRANCONIA				
MT. SIMON/BASAL SAND				
*CRYSTALLINE BASEMENT				

3.1 Mud Logging Activities

Mud logging reports were compiled by Horizon Geologic during drilling. The well’s mud logger report was based on data collected from cuttings, monitoring equipment, and the rig operators. Mud loggers inspected formation cuttings produced during drilling to identify which formation was being drilled, to approximate subsurface elevations for the formation’s top and bottom, and to determine each formation’s lithology. The well was mud logged through the 13-3/8 inch intermediate casing and tagged the top of the Queenston Formation. Examples from the Bass Islands, Collingwood Shale and Brown Niagaran Formations are shown below in Figure 3-1 through Figure 3-3.

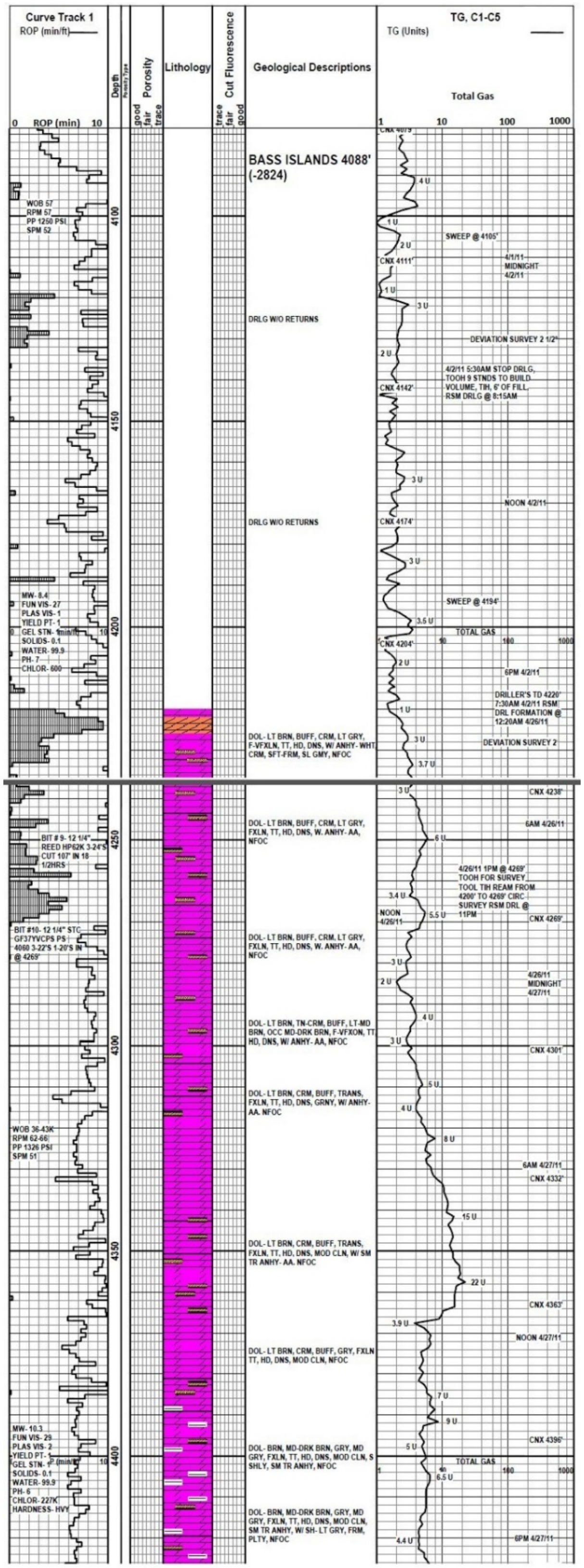


Figure 3-1. Sample Mud Log – Bass Islands Formation.

The recorded mud log is representative for the region

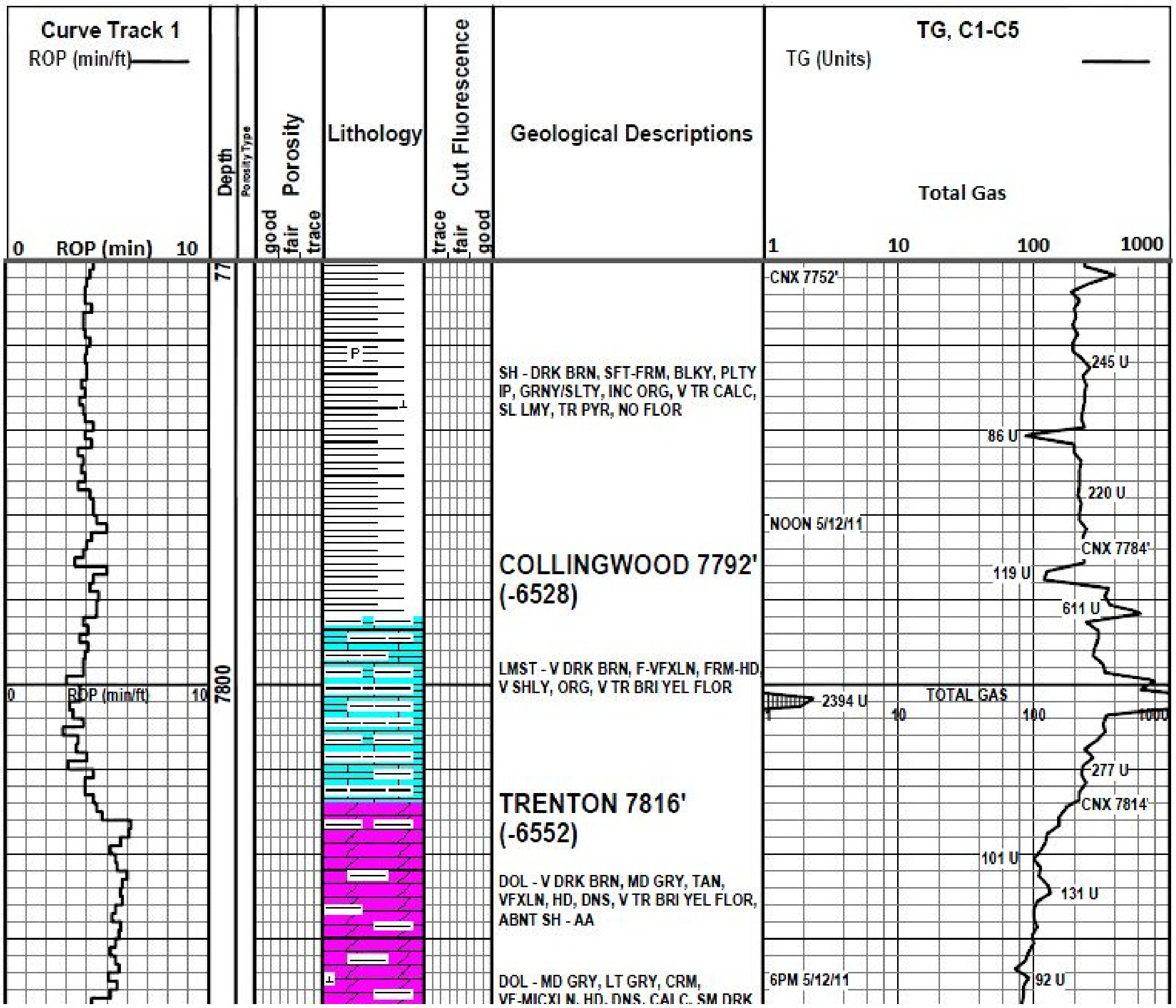


Figure 3-2. Sample Mud Log – Collingwood Shale Formation.

Gas kicks, nearly 1000 TG units total, were recorded near 7,800 feet in the Collingwood, which is a new regional exploration target. It is stratigraphically equivalent to the Utica Formation under development in the Appalachian Basin.

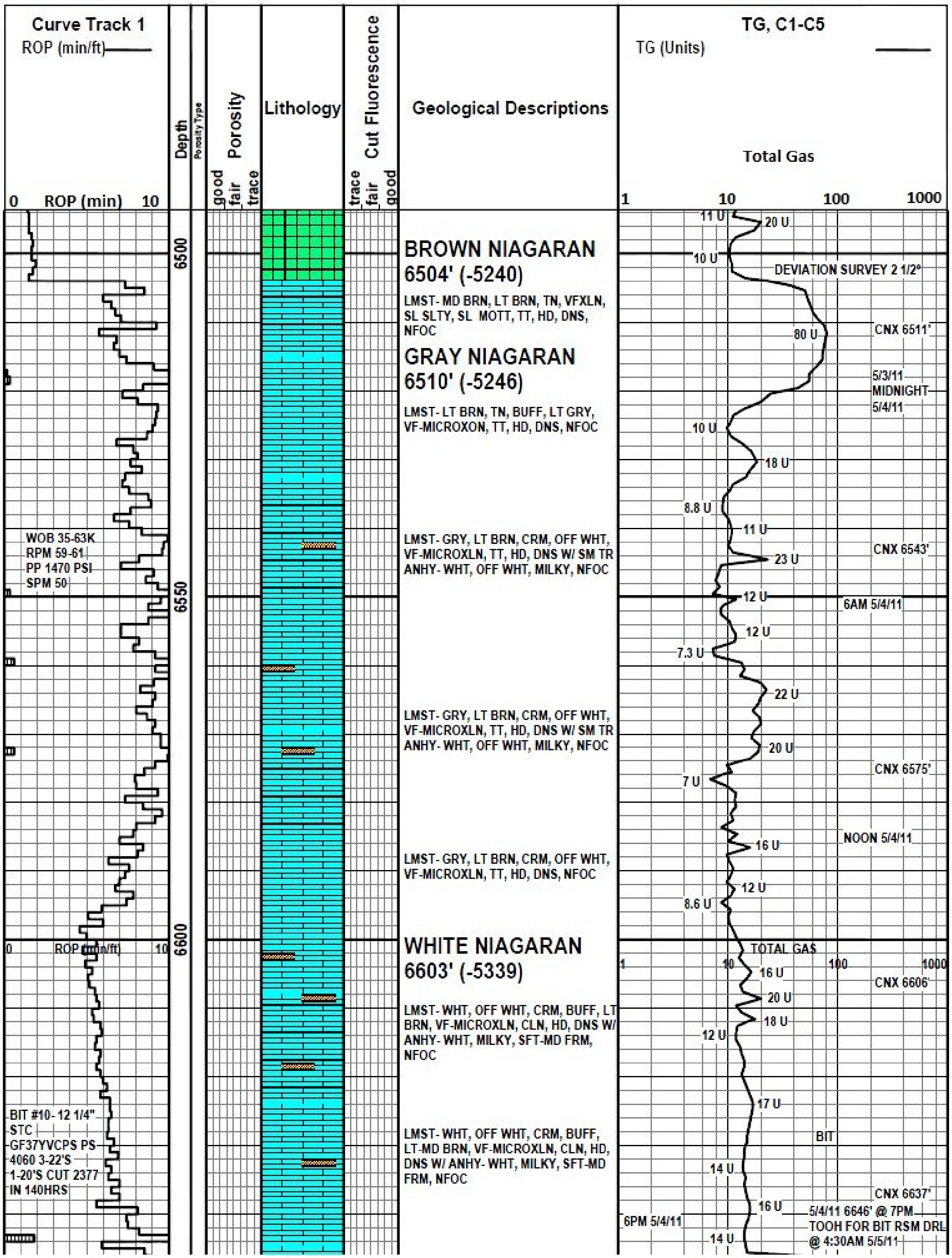


Figure 3-3. Sample Mud Log – Brown Niagaran Formation.

A small gas kick, around 100 TG units, was recorded in the Brown Niagaran. The Brown Niagaran is a regional target where the reefs are well developed. However, at this location, the formation is very thin and likely not productive.

3.2 Logging Program Objectives

A suite of wireline logs was used to obtain data from the rock formations in the test well. Continuous logs of petrophysical properties were obtained by lowering tools on wireline cables within the borehole. Interpretation of wireline logs was the main method used to interpret the stratigraphy, and to identify potential CO_2 storage reservoirs and caprocks in the well. The individual logs are described below, followed by a breakdown of logs by casing section. Baker Hughes was the logging provider for the open hole logs and cement bond logs.

3.2.1 Triple Combo Log Suite

Triple combo is a combination of the gamma ray tool, the resistivity tool and the combined density and neutron tools. The gamma ray tool measures the total natural radioactivity of the formations drilled and is measured in API units. The measurement can be made in both open hole and through casing. Gamma ray logs are used because shale and sandstone typically have different gamma ray signatures that can be correlated readily between wells. The resistivity tool measures the resistivity of the formation, expressed in ohm-m. The resistivity log is fundamental in formation evaluation because all formation waters conduct electricity, whereas more crystalline rock formations do not. Low resistivity can be used as an indirect indication that the rock will have some porosity. The density tool measures the bulk density of the formation, based on the reduction in gamma ray flux between a source and a detector due to Compton scattering. For a given rock material, lower densities will indicate better porosity. The neutron log refers to a log of porosity based on the effect of the formation on fast neutrons emitted by a source. Hydrogen has by far the biggest effect in slowing down and capturing neutrons. Since hydrogen is found mainly in the pore fluids, the neutron porosity log responds principally to porosity. However, the matrix and the type of fluid also have an effect. The log is calibrated to read the correct porosity assuming that the pores are filled with fresh water, and for a given matrix (limestone, sandstone or dolomite). It is presented in units of porosity (vol/vol or p.u.) for the matrix chosen.

3.2.2 Sonic Log

A sonic log transmits an acoustical signal into the rocks surrounding the borehole and measures the speed of the wave through the formations. For geologic applications, both compressional (P) and shear (S) wave speed is of interest. The P and S wave velocities can then be used as a basis for other calculations, such as geomechanical properties.

3.2.3 Elemental Spectroscopy Log

Elemental spectroscopy refers to a log of the yields of different elements in the formation, as measured by capture gamma ray spectroscopy using a pulsed neutron generator. The main purpose of the log is to determine lithology and the principal outputs are the relative yields of silicon, calcium, iron, sulfur, titanium, and gadolinium.

3.2.4 Nuclear Magnetic Resonance Log

A nuclear magnetic resonance (NMR) tool works by the same principles as a magnetic resonance imaging (MRI) tool used in medicine. When a magnetic field is applied, the hydrogen atoms present in the pore fluid (present in either brine or hydrocarbon) react. The basic core and log measurement is the T2 decay, whereas the hydrogen response is measured. The distribution of the T2 amplitudes versus time directly relates to total pore volume and pore space size distribution. The relationship between T2, pore size, and permeability has been experimentally determined and then mathematically approximated. Two separate approximations are used to give a measurement of permeability at a given depth within the formation. This tool works exceedingly well in an inter-granular porosity system, however it will give false permeability measurements in secondary porosity systems, such as vugular or fracture porosity.

3.2.5 Resistivity Image Log

A resistivity image log takes pad measurements (borehole wall surface) of the resistivity of a formation and prints these images. This gives an assessment of the formation on a very fine scale (1 foot is represented by 1 inch of data). The data can be used for fracture assessment, identification of bedding planes, introduction of fluid, and determination of vugular porosity.

3.3 Wireline Logs by Casing Section

This section describes the activities related to acquiring wireline logs. Figure 3-4 shows the depth locations of the different logs that were planned for the well.

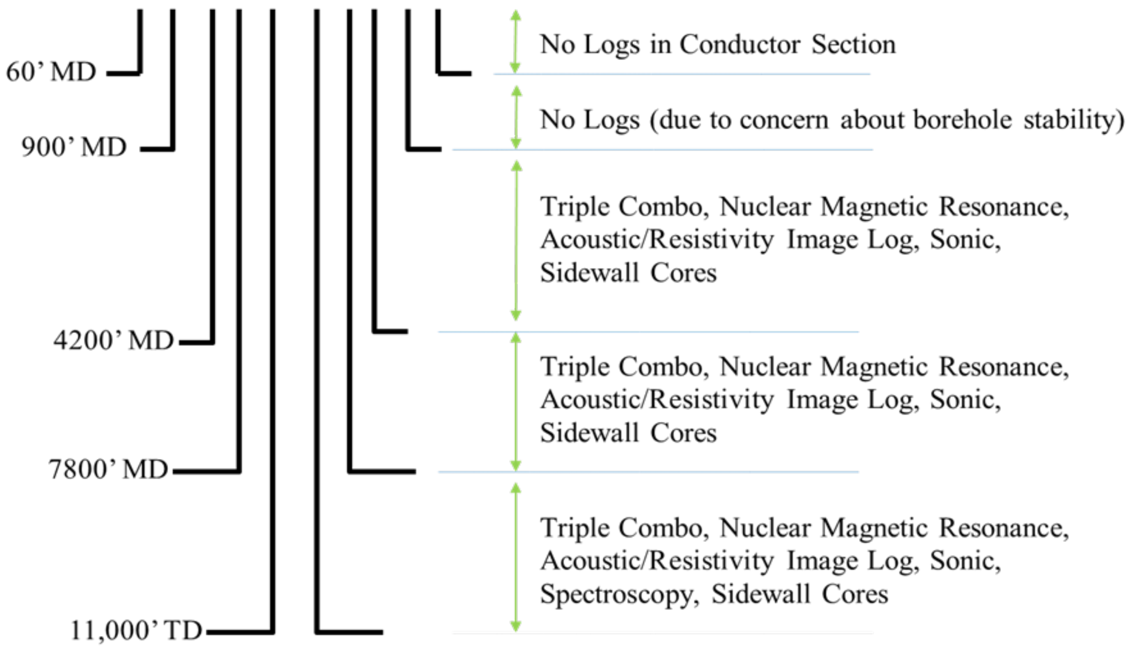


Figure 3-4. Planned Wireline Log Acquisition.

3.3.1 Conductor and Surface Casing

No logs were run in either the conductor or surface casing of the well.

3.3.2 First Intermediate Casing (~4200)

The plan for the first intermediate casing was to reach through the bottom of the secondary injection target, the Bass Islands Dolomite. The triple combo and sonic logs were to be run over the entire interval. Additionally, an image log, nuclear magnetic resonance log, and spectroscopy log were to be run over approximately 1,500 feet of the bottom portion of this casing string to fully characterize the Bass Islands.

A lost circulation zone was encountered in the top of the Sylvania sand at approximately 3,640 feet. The Dundee Formation was also taking some drilling fluid previous to drilling into the Sylvania, but it was ruled out as the major thief zone (formation taking fluid/lost circulation). The drillers were able to restore circulation several times. However, as the drillers made it back to bottom with the drill bit, they immediately lost circulation again. The lost circulation zone was deemed to be too high of a risk for getting the logging tools stuck in the well and the decision was made to reduce logging for this section of the well. Only the gamma ray and caliper logs were run in the open hole for this section. In addition, segmented bond logs were run to evaluate the cement quality.

3.3.3 Deep Intermediate Casing

The deep intermediate casing sealed off the Devonian Shale sequence. The triple combo (gamma ray, density, and neutron logs) and sonic logs were run over the entire interval, including the cased hole section in the first intermediate interval. The resistivity logs were in the deep intermediate section only. Acoustic and resistivity image logs were run in the lower 1,500 feet (6,468 to 7,968) Additionally, nuclear magnetic resonance log, and spectroscopy log were planned to be run over the approximately 1,500-foot bottom portion of the first intermediate casing string, to fully characterize the Bass Islands. The hole size was too large to acquire useful NMR data and the borehole salinity was too high to acquire the spectroscopy data, so both of those logging tools were dropped from this section of the hole.

3.3.4 Deep Casing

The deep casing string had planned to reach to the total depth of the well, which was to be the St. Peter Sandstone, our primary injection target, or the Precambrian basement. All logs (the triple combo, sonic, image lag, NMR, and spectroscopy logs) were planned to be run over the entire interval. However, drilling of this section of the well was discontinued and the well logs were not run.

Cement bond logs were run as appropriate throughout the well to determine presence and quality of cement.

3.4 Core Collection and Analysis

Core analysis is the acquisition of data measured on core material for determining parameters used for developing and managing a reservoir from initial discovery to mature field development. There are two main reasons for core analysis. First, core analysis data are used by petrophysicists to calibrate wireline logs in the determination of reservoir properties. Such data include routine core analyses as well as special core analysis. Secondly, reservoir engineers use core analysis measurements such as relative permeability and pore volume compressibility to provide input parameters for reservoir computer simulation. Core analysis data are also used to determine injectivity and to quantify acoustic rock properties.

The well had been allocated 120 feet of whole core. The primary target for whole core was the St. Peter sandstone in the Deep Casing Total Depth section. Since the well was temporarily abandoned before the deep casing string was drilled, no whole core was collected. The well was also allocated several dozen side wall cores in both the intermediate and deep casing sections. The locations of side wall cores were chosen after reviewing the triple combo (gamma ray, resistivity, density, and neutron) logging run. Some side wall cores were also dedicated to the cap rock sections in accordance with UIC permit application procedures. 30 sidewall cores were collected from the intermediate casing string and no cores were collected in the deep string since it was not drilled.

Sidewall core analysis included permeability, porosity, grain density on all cores. Thin section preparation and descriptions, as well as X-ray diffraction, were performed on 17 samples.

Table 3-2. Sidewall Core Depths.

Sample Number	Sample Depth (feet)
30	4230.0
29	4260.0
28	4300.0
27	5946.0
26	6290.0
25	6510.0
24	6514.0
23	6522.0
22	7135.0
21	7234.0
20	7380.0
19	7414.0
18	7475.0
17	7590.0
16	7605.0
15	7643.0
14	7700.0
13	7725.0
12	7775.0
11	7795.0
10	7807.0
9	7810.0
8	7814.0
7	7831.0
6	7845.0
5	7865.0
4	7880.0
3	7895.0
2	7910.0
1	7925.0

4.0 Results

4.1 Wireline Logs

This section includes examples of the results of the wireline logs run in the well. Triple Combo, Sonic, and Image Log snapshots are presented. Additionally, neutron-density crossplots are shown for formations of interest. Some general observations from the field review of intermediate logging are including below.

The logging interval started in the Bass Island anhydrite and went through the top of the Trenton. The Bass Islands Anhydrite are mostly tight with a few thin zones of decent porosity. At the base of the Bass Island Anhydrite the Salina evaporite series begins and consists of salts and Anhydrites for the next 2000 feet all the way down to the Brown Niagaran at 6509. The Brown Niagaran is thin (8 feet) with low porosity. The underlying Gray Niagaran is much thicker (414 feet) with mostly consistent low porosity throughout with a few exceptions. There are 5 approximately 10 -15 feet thick zones of higher porosity (> 10 % NPHI) but overall, this unit appears to be tight averaging around 3% for the majority. The Cincinnatian shale section underlies the Manitoulin and appears to be a mostly homogeneous tight rock that looks to be a limey nonorganic shale. The Underlying Utica has a much higher API count and higher looking porosity although some could be a neutron response to the shale. At the base of the Utica the thin (18 feet) Collingwood does have a neutron density cross over (an indication of gas) and looks good from an oil/gas perspective. The top of the Trenton looks to have around 5-7 % porosity. These observations are consistent with the prognosis that the deep intermediate section consists of the containment intervals for the most part, rather than potential storage reservoirs.

4.1.1 Log Example

Triple Combo Examples

The Bass Islands is 82 feet thick at the well site. The Gamma Ray log is irregular, indicating a formation that is not “clean” or not free of the influence of formations other than dolomite. Similarly, the PE is very scattered, bouncing between 6 and 10. Neutron Porosity ranges between 4 and 10 % with a small portion of higher porosity above 10% around 4280 (Figure 4-1). The Brown Niagaran is very thin at the well location, only measuring 6 ft thick. PE is consistent with limestone formation, measuring at 5. Porosity values are around 2% (Figure 4-2).

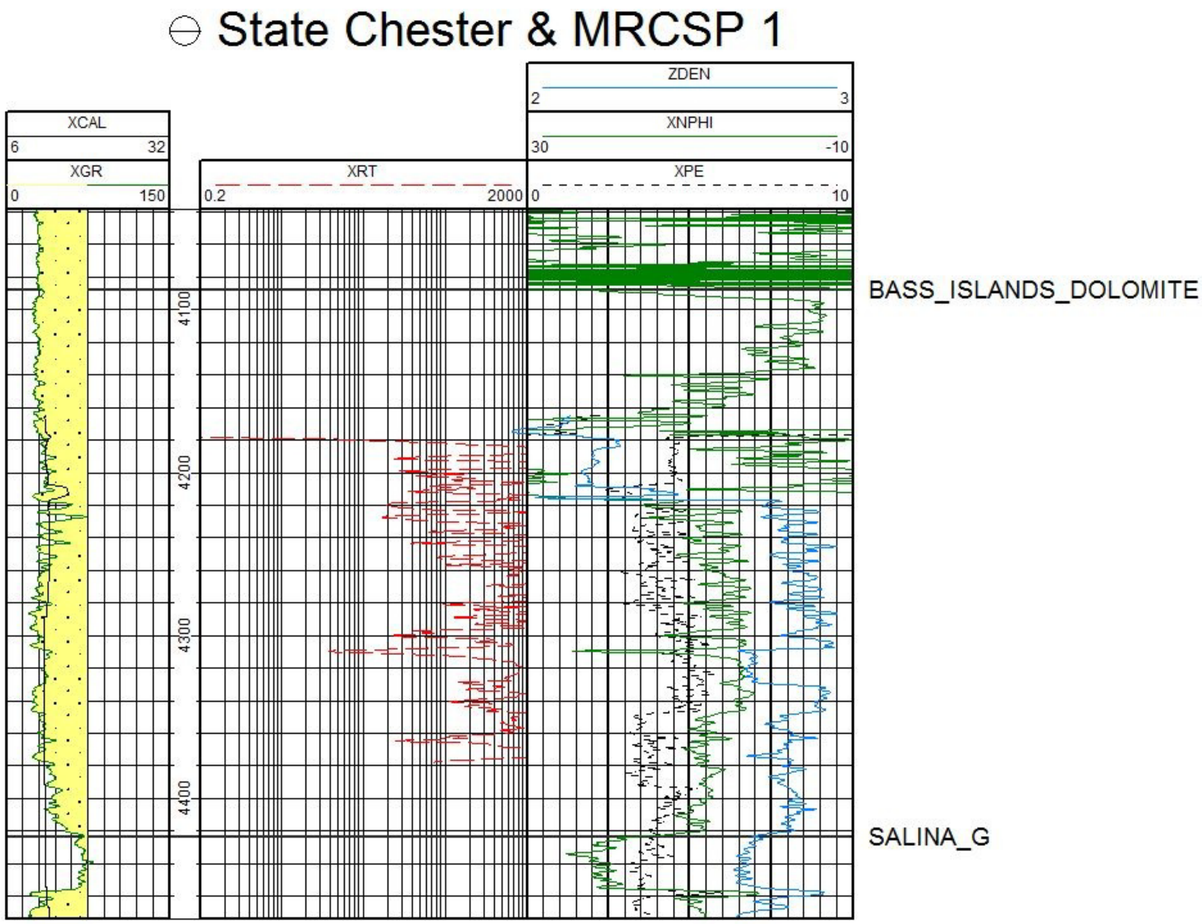


Figure 4-1. Example Triple Combo Log from the Bass Islands Formation.

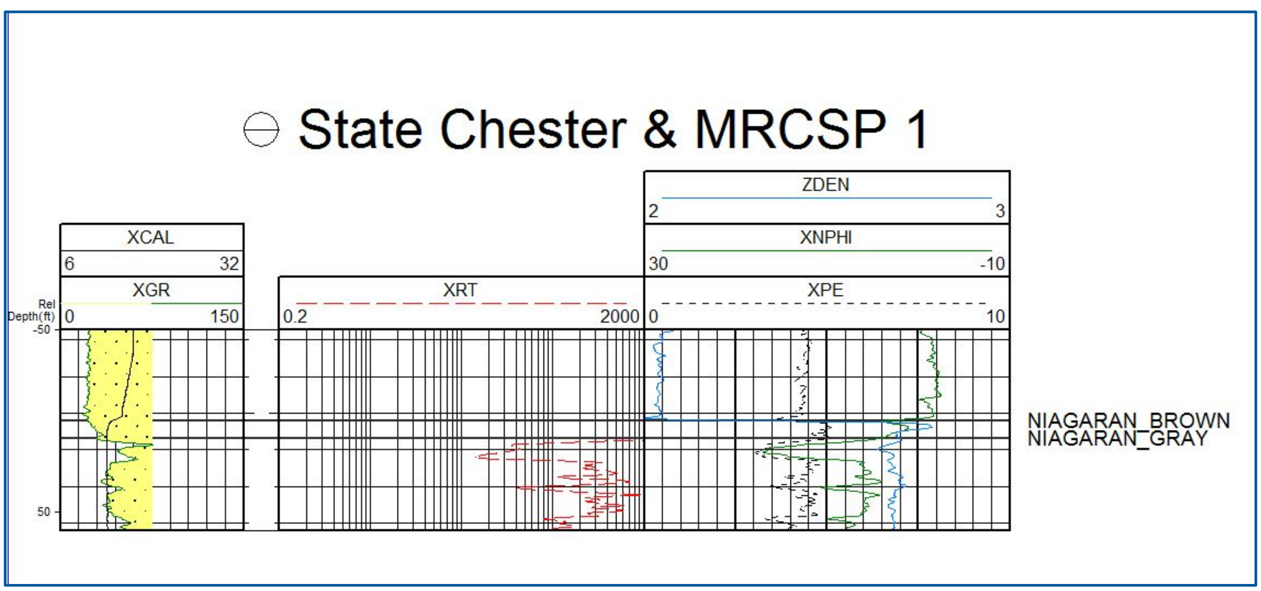


Figure 4-2. Example Triple Combo Log from the Niagaran Formation.

Image Log Examples

Resistivity and acoustic images are both mostly static between 6505 and 6515, indicating relative homogeneity over the top ten feet of the interval. A sidewall core hole is visible at around 6512 in the acoustic image in Figure 4-3. In Figure 4-4, the image is taken in the upper-mid portion of the Utica Shale. Bedding plane are clearly visible in the resistivity image along with some potential fractures around 7620.

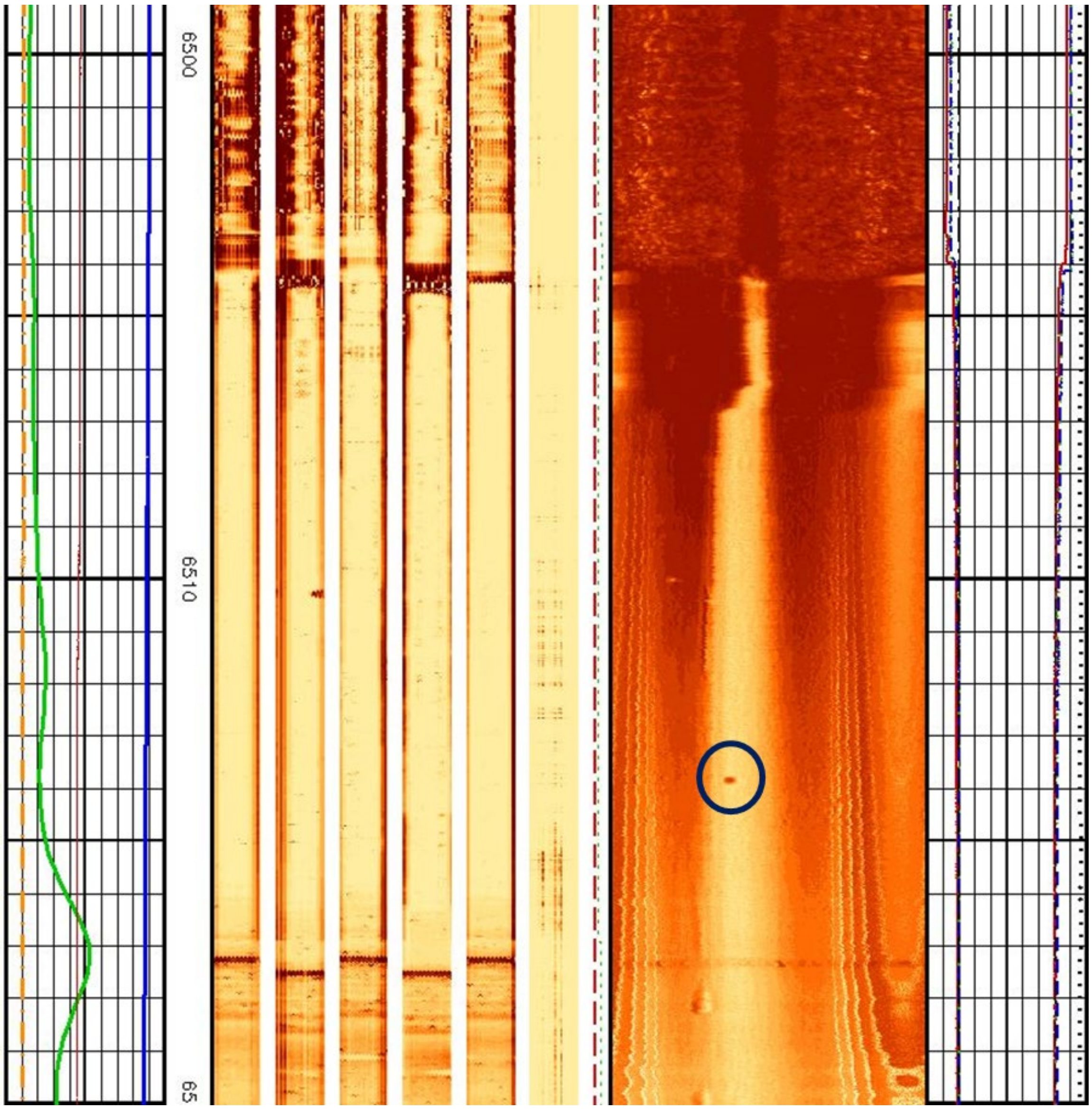


Figure 4-3. Image Log from Brown Niagaran Formation showing location of the sidewall core circled in black.

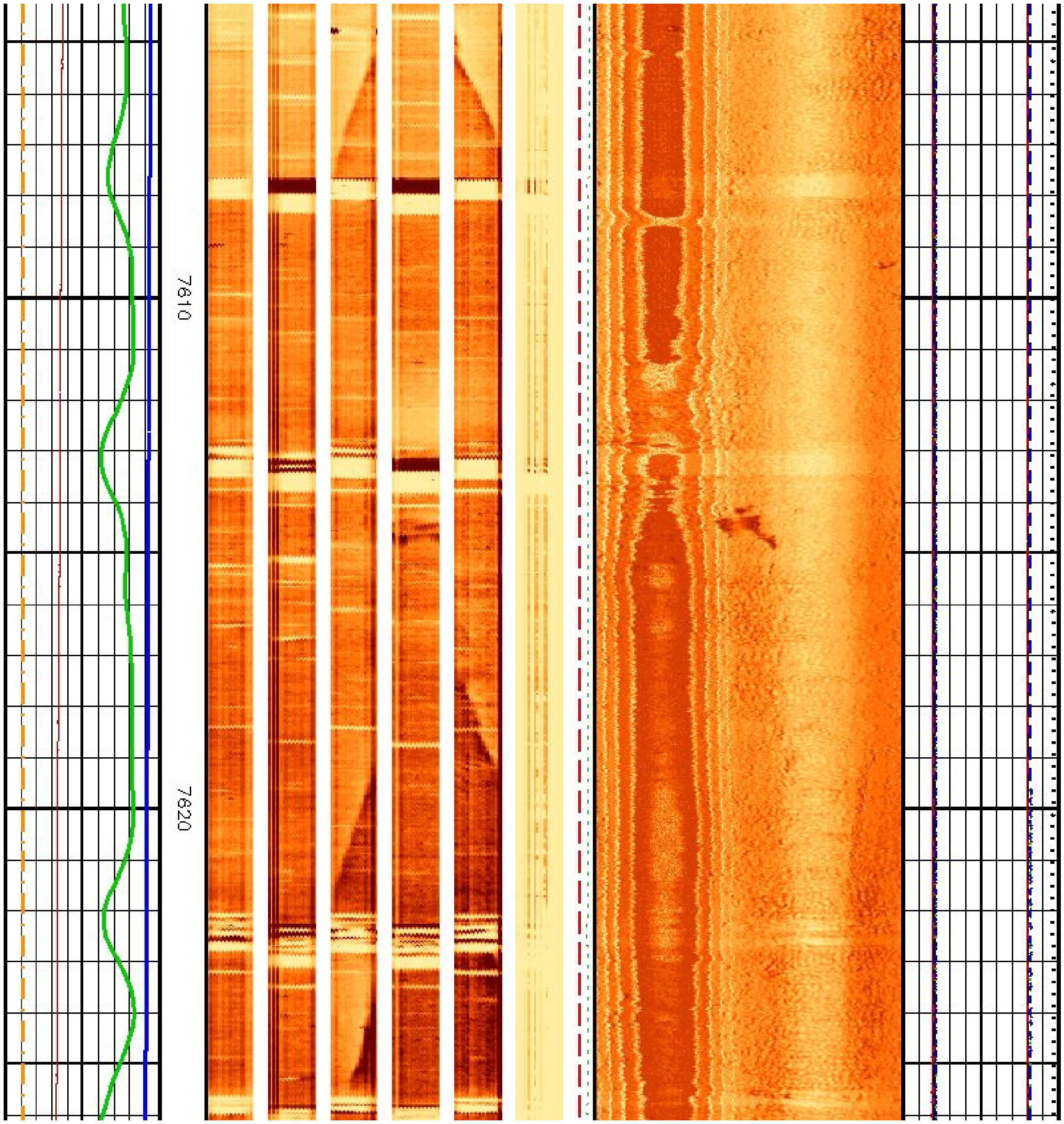


Figure 4-4. Image Log from Utica Shale.

4.1.2 Cross Plots

Sample cross plots are show in Figures 4-5 through 4-8 for the A2 Carbonate, A2 Evaporite, Gray Niagaran, and Trenton Limestone formations. The A2 Carbonate exhibited a scatter of cross plot points between limestone and dolomite indicating a larger range of porosities from 0 to 15%. A few scattered data points show the influence of sale and anhydrite. The majority of the data plotted between 5 and 10% porosity (Figure 4-5).

The A2 evaporite cross plot yielded a tight cluster around salt with a few data points towards limestone and dolomite. This indicates a dominantly salt formation with potential for interbedded carbonate (Figure 4-6).

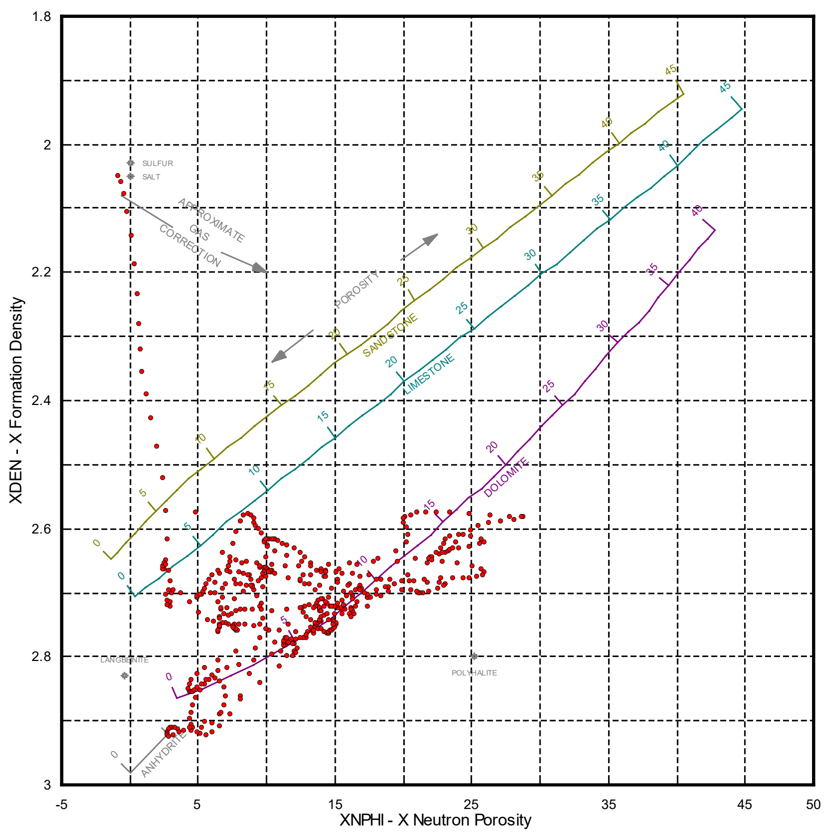


Figure 4-5. Neutron density cross plot for the A2 Carbonate formation.

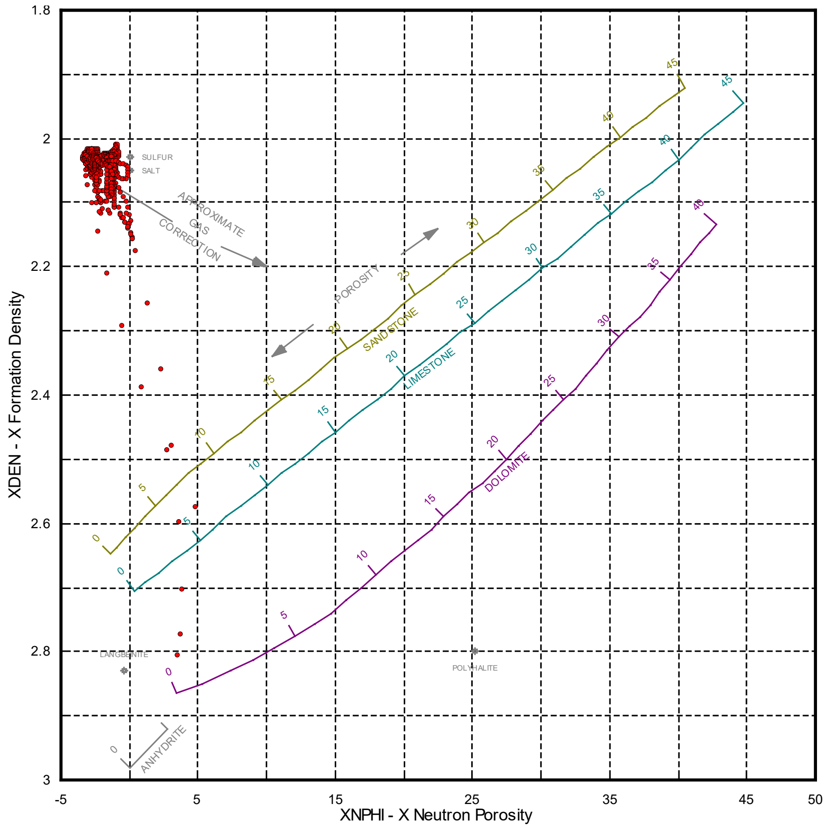


Figure 4-6. Neutron density cross plot of the A2 Evaporite formation.

The Gray Niagaran plotted between a limestone and dolomite with most data clustering below 5% porosity. Few scattered data points extended up towards 10-12% indicating potential for thin intervals of porosity (Figure 4-7). The Trenton limestone plotted between limestone and dolomite with porosity ranging from 5-15% (Figure 4-8).

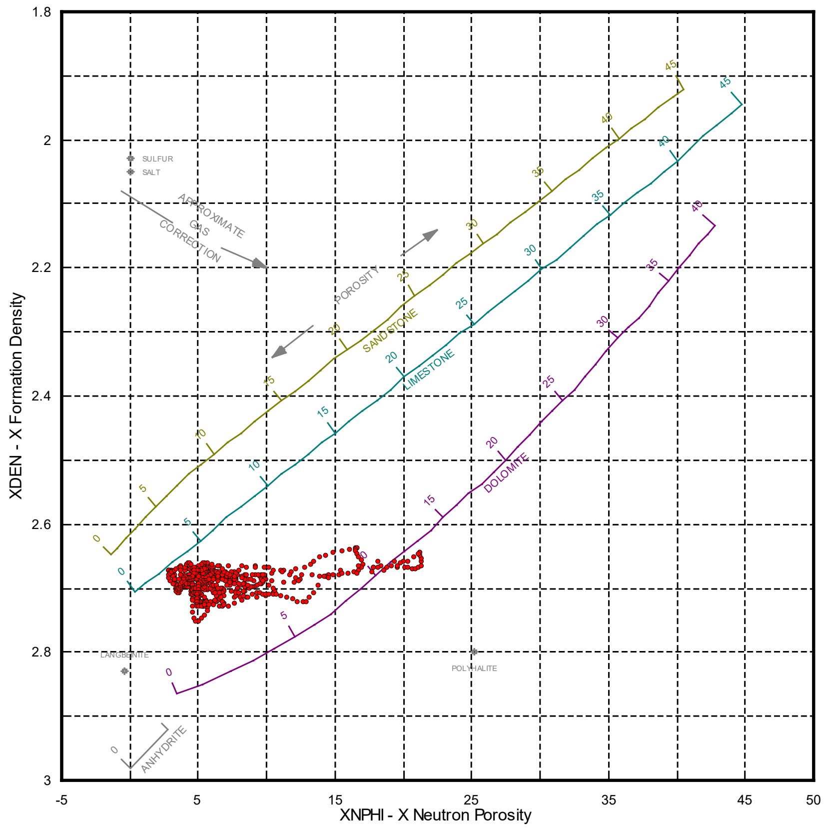


Figure 4-7. Neutron density cross plot of the Gray Niagaran formation.

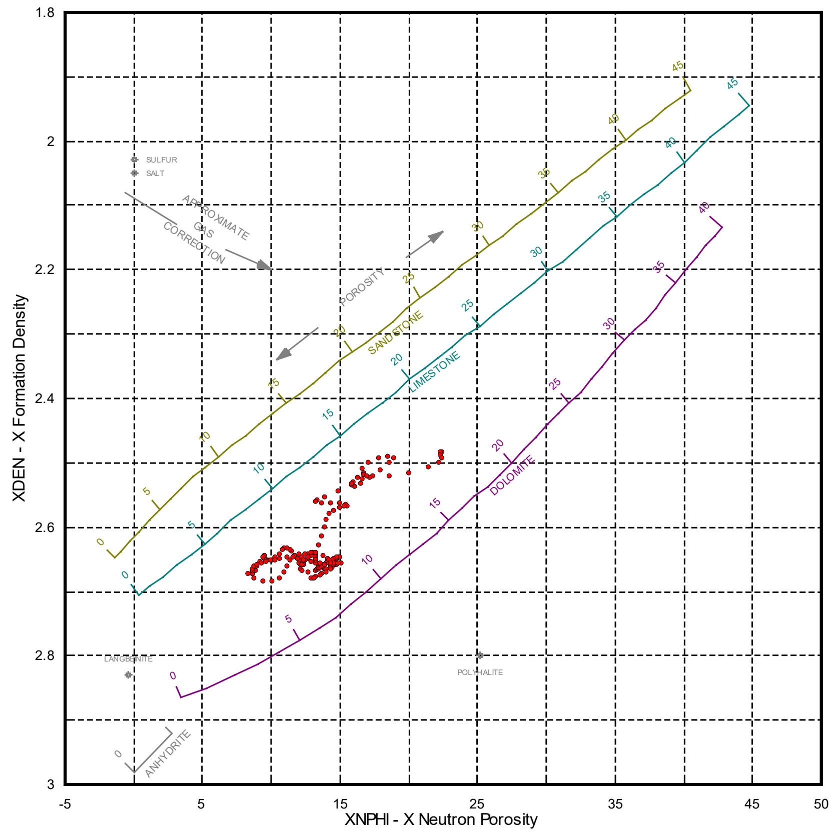


Figure 4-8. Neutron porosity cross plot of the Trenton Limestone formation.

4.2 Core Data

This section presents a summary of activities related to acquisition and analysis of core data.

Table 4-1. Summary of Rotary Sidewall Core Collection and Requested Analyses.

ID Number	Rotary Core Sample Formation, Depth	Porosity, Permeability, Density	Plug Photography	Thin Section	XRD
#1	Trenton: 7925 ft	X	X		
#2	Trenton: 7910 ft	X	X		
#3	Trenton: 7895 ft	X	X		
#4	Trenton: 7880 ft	X	X		
#5	Trenton: 7865 ft	X	X		
#6	Trenton: 7845 ft	X	X	X	X
#7	Trenton: 7831 ft	X	X	X	X
#8	Collingwood: 7814 ft	X	X	X	X
#9	Collingwood: 7810 ft	X	X	X	X
#10	Collingwood: 7807 ft	X	X	X	X
#11	Utica: 7795 ft	X	X		X
#12	Utica: 7775 ft	X	X	X	X
#13	Utica: 7725 ft	X	X		X
#14	Utica: 7700 ft	X	X		X
#15	Utica: 7643 ft	X	X		X
#16	Utica: 7605 ft	X	X	X	X
#17	Utica: 7590 ft	X	X		X
#18	Queenstown: 7475 ft	X	X		
#19	Queenstown: 7414 ft	X	X	X	X
#20	Queenstown: 7380 ft	X	X	X	X
#21	Queenstown: 7234 ft	X	X		
#22	Queenstown: 7135 ft	X	X		
#23	Gr Niagaran: 6522 ft	X	X		
#24	Br Niagaran: 6514 ft	X	X		
#25	Br Niagaran: 6510 ft	X	X		
#26	A1 Carbonate: 6510 ft	X	X		
#27	A2 Carbonate: 5946 ft	X	X		
#28	Bass Island Anhydrate: 4300 ft	X	X		
#29	Bass Island Anhydrate: 4260 ft	X	X		
#30	Bass Island Anhydrate: 4230 ft	X	X		

Each core sample was analyzed for porosity and permeability and the results are shown in Table 4-2 below. As expected, all of these samples show very low porosity and permeability significantly below 1 milliDarcy (md). This is consistent with the expectation that the deep intermediate borehole section in the area represents a very thick containment interval, rather than a reservoir interval.

Table 4-2. Rotary Sidewall Core Permeability and Porosity Results

Battelle - Core CO2 Services	DATE : 06-Jul-2011	FILE NO. : Hou-110637
State Chester & MRCSP 1	FORMATION :	LABORATORY : Corpus Christi
Chester TWP Field	DRLG. FLUID : Water Based Mud	API WELL NO. :
Otsego County, Michigan		ANALYST : KS

C M S - 3 0 0 T E S T D A T A

Sample Number	Sample Depth (feet)	Confining Stress (psi)	Pore Volume (cc)	Porosity (%)	K∞ (md)	K_{air} (md)	b factor (psi)	Beta (ft^{-1})	Alpha (microns)	Grain Density (gm/cc)
30	4230.0	1000	0.045	0.37	0.0003	0.001	216.54	9.27E+16	8.45E+04	2.860
29	4260.0	1000	0.188	1.54	0.0003	0.001	215.71	8.99E+16	8.33E+04	3.025
28	4300.0	1000	0.319	2.98	0.0005	0.001	190.65	3.45E+16	5.29E+04	2.810
27	5946.0	1000	1.195	9.78	0.014	0.018	20.92	5.21E+12	2.44E+02	2.818
26	6290.0	1000	0.131	1.20	0.001	0.003	155.92	7.13E+15	2.49E+04	2.784
25	6510.0	1000	0.051	0.37	0.0005	0.001	186.36	2.81E+16	4.76E+04	2.746
24	6514.0	1000	0.076	0.54	0.0002	0.001	226.22	1.29E+17	9.83E+04	2.729
23	6522.0	1000	0.487	4.49	0.0003	0.001	205.27	6.13E+16	6.96E+04	2.809
22	7135.0		Porosity (ambient) : 4.52%			Permeability (---) : Split sample - No test				2.821
21	7234.0	1000	0.385	3.64	0.012	0.012	4.19	2.85E+14	1.07E+04	2.788
20	7380.0	1000	0.059	0.55	0.0005	0.001	189.34	3.27E+16	5.15E+04	2.729
19	7414.0		Porosity (ambient) : 1.38%			Permeability (cms @ 1000 psi) : Too tight - Test a				2.747
18	7475.0		Porosity (ambient) : 2.72%			Permeability (ambient) : <0.01 md			(Short s	2.762
17	7590.0		Porosity (ambient) : 5.16%			Permeability (---) : Split sample - No test				2.776
16	7605.0		Porosity (ambient) : 7.32%			Permeability (---) : Split sample - No test				2.820
15	7643.0		Porosity (ambient) : 1.97%			Permeability (---) : Split sample - No test				2.741
14	7700.0		Porosity (ambient) : 7.71%			Permeability (---) : Split sample - No test				2.752
13	7725.0		Porosity (ambient) : 8.51%			Permeability (---) : Split sample - No test				2.816
12	7775.0		Porosity (ambient) : 7.26%			Permeability (ambient) : 0.06 md			(Short sa	2.771
11	7795.0		Porosity (ambient) : 9.63%			Permeability (---) : Split sample - No test				2.771
10	7807.0	1000	0.150	1.39	0.0001	0.0004	257.60	3.61E+17	1.62E+05	2.597
9	7810.0	1000	0.251	2.30	0.0002	0.001	239.63	2.05E+17	1.24E+05	2.589
8	7814.0	1000	0.193	1.77	0.0002	0.001	229.82	1.49E+17	1.06E+05	2.669
7	7831.0	1000	0.057	0.54	0.0003	0.001	214.55	8.71E+16	8.24E+04	2.711
6	7845.0	1000	0.263	2.54	0.001	0.002	162.99	9.99E+15	2.92E+04	2.736
5	7865.0		Porosity (ambient) : 2.24%			Permeability (ambient) : <0.01 md			(Short s	2.749
4	7880.0	1000	0.221	2.05	0.0003	0.001	220.35	1.07E+17	9.10E+04	2.805
3	7895.0	1000	0.213	2.00	0.001	0.002	166.36	1.17E+16	3.16E+04	2.763
2	7910.0		Porosity (ambient) : 4.04%			Permeability (---) : Split sample - No test				2.683
1	7925.0	1000	0.199	1.61	0.0003	0.001	210.49	7.43E+16	7.60E+04	2.717

Table 4-3 gives the results of the mineralogy analysis from the Collingwood and Utica section. The purpose of these analysis was to evaluate the gas production potential for these zones. The mineralogy indicates presence of calcite, Fe-dolomite, pyrite, and chlorite (Fe-rich variety). During a phone consultation with the laboratory supervisor, she reported that contact with drilling fluids comprised of 2 to 4% by weight KCL and a pH of 9 or 10 would be benign because the samples have low amount of illite/smectite which minimizes concerns of swelling resulting from contact with drilling fluids (Ashley Fife, Laboratory Supervisor, personal communication, June 6, 2011).

Table 4-3. Mineralogy Results for the Utica Shale Rotary Sidewall Cores.

Note: Results are based on the XRD Analysis Performed by Core Laboratories.

Depth	Whole Rock Mineralogy (Weight %)							Clay (Phyllosilicate) Mineralogy (Weight %)		
	Quartz	K Feldspar	Plagio-clase	Calcite	Fe-Dolomite	Pyrite	Total Clay	Illite / Smectite *	Illite & Mica**	Chlorite
7590	22.6	2.0	1.8	22.3	4.0	0.5	46.8	3.5	27.2	16.1
7605	29.2	1.6	0.8	15.7	4.5	1.0	47.1	3.7	26.8	16.6
7643	24.8	2.6	1.1	16.7	6.7	4.5	43.6	2.9	25.5	15.2
7700	31.7	2.7	1.4	4.1	1.8	5.4	53.0	5.8	29.8	17.4
7725	28.3	2.1	1.3	5.3	1.6	4.2	57.3	5.9	31.8	19.6
7775	40.0	3.3	0.0	5.3	5.0	3.3	43.0	3.8	24.8	14.4
7795	31.9	2.6	0.0	3.9	2.4	3.4	55.8	6.5	33.1	16.2

* Mixed-Layer Illite/Smectite Contains 10-15% Smectite Layers.

** Includes Biotite.

4.2.1 Example Thin Sections

Figure 4-9 is an example thin section from the Bass Islands dolomite which shows no visible porosity and was classified as a bioclast rich dolostone. The resulting core analysis measured permeability of .00083 mD with a porosity of 1.54% at this depth.

Figure 4-10 is an example thin section from the Niagaran formation which shows no visible porosity and was classified as a bryozoan packstone. The resulting core analysis measured permeability of .00066 mD with a porosity of .54%.

Figure 4-11 is an example thin section from the Collingwood which shows no visible porosity and was classified as a fossiliferous mudstone. The resulting core analysis measured permeability of .00013 mD with a porosity of 1.4%.

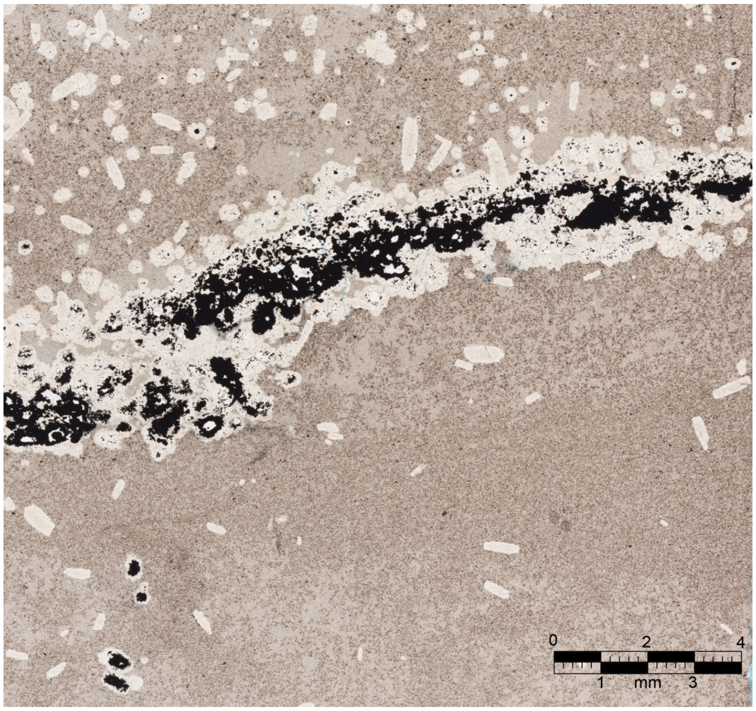


Figure 4-9. Bass Islands thin section: Depth 4,2360 feet, bioclast rich dolostone.

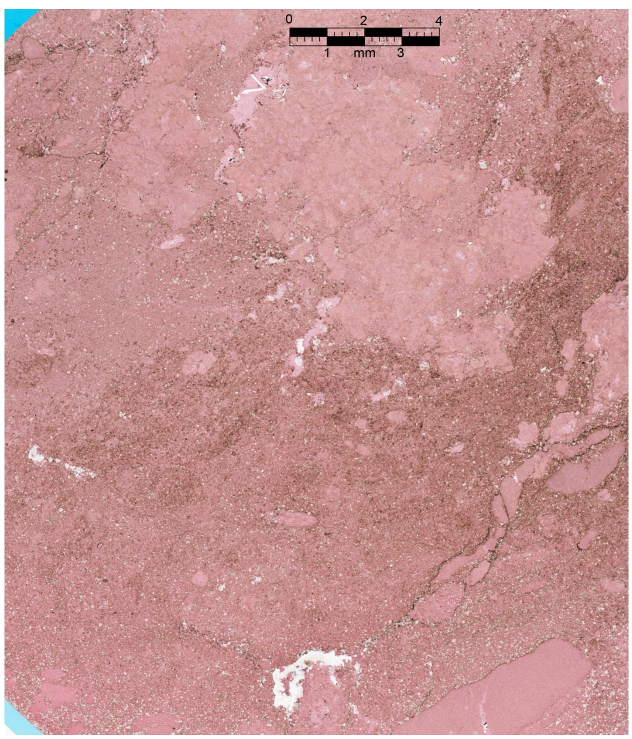


Figure 4-10. Niagaran thin section: Depth 6,514 feet, bryozoan packstone.

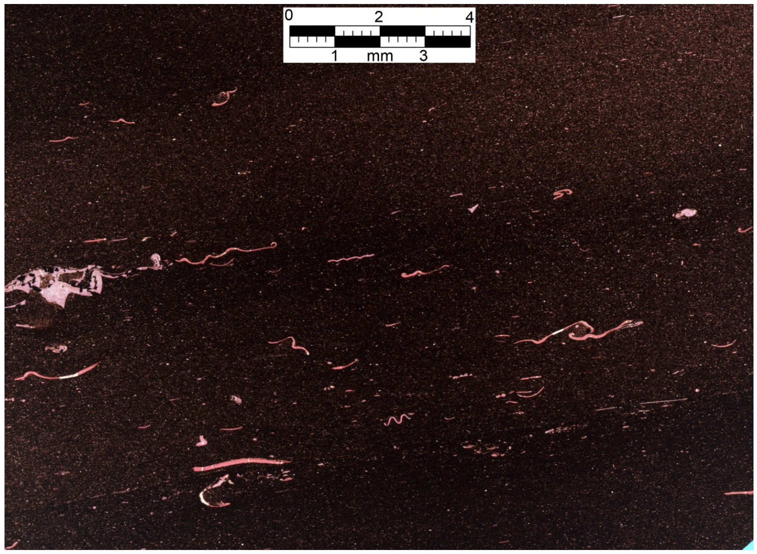


Figure 4-11. Collingwood thin section: depth 7,807 feet, fossiliferous mudstone.

4.3 Test Results for Total Organic Carbon

Samples from the State Chester and MRCSP Well No. 1 were analyzed by Core Laboratories for total organic carbon. Results are provided in Table 4-4. Figures 4-12 through 4-14 shows the plotted measurement results with depth. These data also indicate generally low organic carbon content and low potential of natural gas in the selected zones.

Table 4-4. Results of Total Organic Carbon Analysis of Samples from State Chester and MRCSP Well No. 1.

Core Laboratories – Thomas Gentzis														Job # 110637GC, State Chester & MRCSP #1
Project RCOR-111206-#				Source Rock Analysis										
		Depth (ft)		Leco	Rock-Eval						S2/S3	S1/TOC		
Sample ID #	Rock ID	Upper	Median	TOC (wt% HC)	S1 (mg HC/g)	S2 (mg HC/g)	S3 (mg CO_2/g)	Tmax (°C)	Hydrogen Index (S2x100/TOC)	Oxygen Index (S3x100/TOC)	Conc. (mg HC/mg CO_2)	Norm. Oil Content	Production Index (S1/(S1+S2))	Experimental Notations
001	27	5,946	5,946	0.55	2.78	1.09	0.49	432	198	89	2	505	0.72	Low Temp S2 Shoulder
002	26	6,290	6,290	0.60	0.24	0.33	0.26	434	55	43	1	40	0.42	
003	25	6,510	6,510	0.17	0.09	0.09	0.07	0	53	41	1	53	0.50	
004	24	6,514	6,514	0.10	0.11	0.07	0.05	0	70	50	1	110	0.61	
005	23	6,522	6,522	0.31	1.84	0.60	0.38	421	194	123	2	594	0.75	Low Temp S2 Shoulder
006	17	7,590	7,590	0.12	0.10	0.04	0.41	0	33	342	0	83	0.71	
007	16	7,605	7,605	0.13	0.12	0.09	0.30	0	69	231	0	92	0.57	
008	15	7,643	7,643	0.20	0.22	0.17	0.12	432	85	60	1	110	0.56	
009	14	7,700	7,700	0.90	0.42	0.58	0.19	434	64	21	3	47	0.42	Low Temp S2 Shoulder
010	13	7,725	7,725	0.53	0.45	0.28	0.16	439	53	30	2	85	0.62	
011	12	7,775	7,775	0.81	0.72	0.71	0.23	441	88	28	3	89	0.50	Low Temp S2 Shoulder
012	11	7,795	7,795	1.33	1.40	1.49	0.18	438	112	14	8	105	0.48	Low Temp S2 Shoulder

Data provided by Geomark Research Ltd using Rock-Eval 2 and Leco TOC

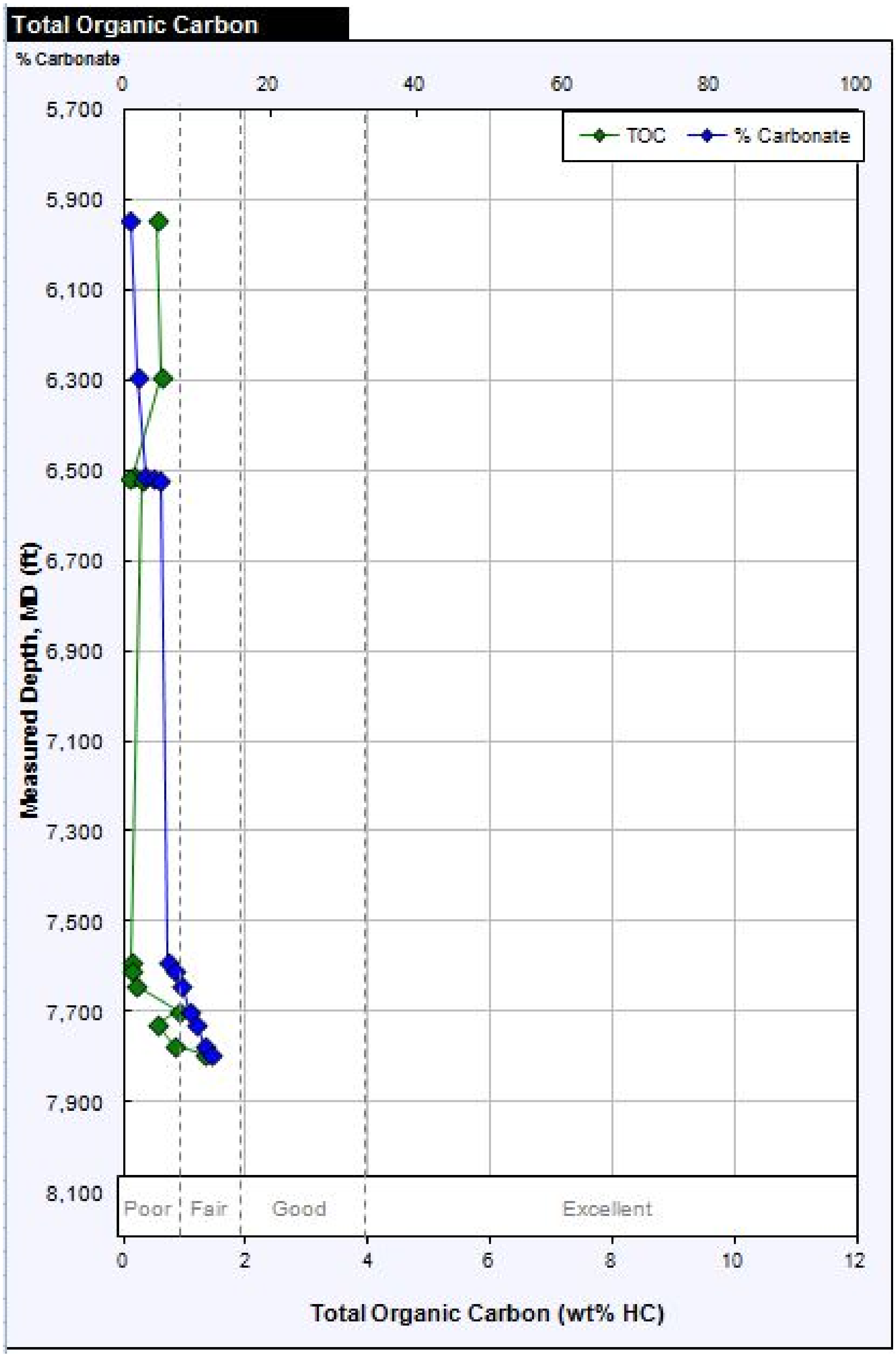


Figure 4-12. Analysis Results for Total Organic Carbon.

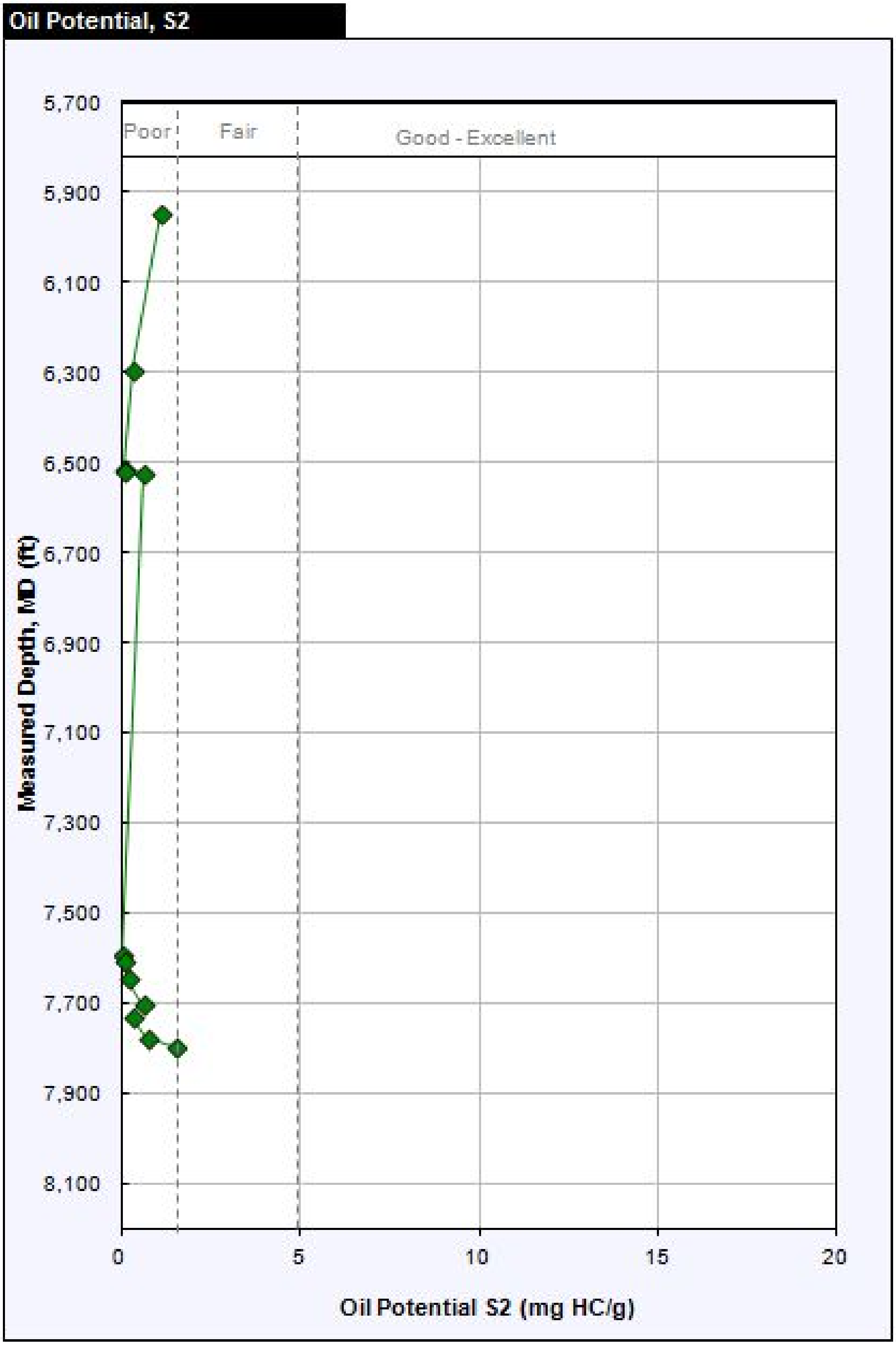


Figure 4-13. Analysis Results for Oil Potential.

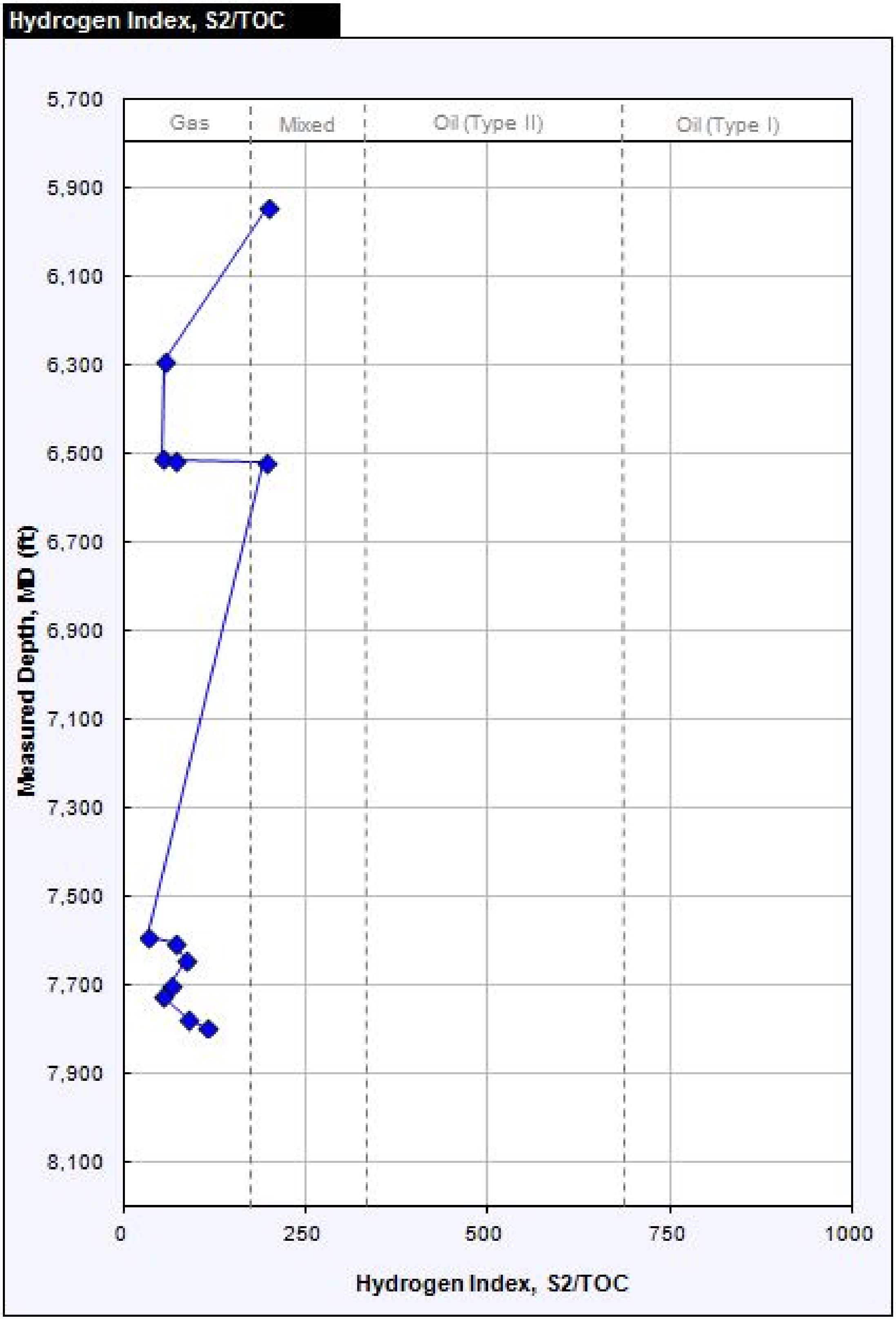


Figure 4-14. Analysis Results for Hydrogen Index.

5.0 Summary

This report summarizes the drilling activities undertaken during 2011 in an effort to characterize the CO_2 storage potential in the St. Peter Sandstone in Otsego County in northern Michigan. As discussed in the report, the drilling of the well was suspended after the deep intermediate section, while the need to side-track the well to bypass a damaged casing zone was being evaluated. The immediate reason was the changes in the EPA requirements for permitting of the CO_2 injection wells, which could not be met within the project framework. However, the drilling up to the deep intermediate section enabled collection of wireline logs and sidewall core samples from approximately 7,900 feet depth. As anticipated in the prognosis, vast majority of the logged interval consists for the rocks needed for containment of CO_2. This is confirmed by the permeability analysis of the sidewall cores.

The well was placed in temporary abandonment status, as the MRCSP large-scale test focus shifted to evaluating CO_2 injection and storage in the CO_2-EOR complex in the same area. This allowed MRCSP to meet all its research objectives, within the timeframe of the project, using the commercial CO_2-EOR permits obtained by Core Energy.

BATTELLE

It can be done