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LINGO Antrim Play: Handbook

Developed as an outcome of the Project

An Approach to Recover Hydrocarbons from Currently Off-Limit Areas of the Antrim Formation, MI Using Low-Impact Technologies

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1. Abstract

The Antrim Play Handbook was developed as a project outcome of the U. S. Department of Energy (DOE), National Energy Technology Laboratory, Low Impact Natural Gas and Oil (LINGO) Program. The project under this program titled “An Approach to Recover Hydrocarbons from Currently Off-Limit Areas of the Antrim Formation, MI Using Low-Impact Technologies”, DOE Award Number DE-FC26-06NT42931, was developed through Michigan Technological University, Houghton, Michigan and Jordan Development Company, LLC, Traverse City, Michigan.

The Antrim Play Handbook is focused on the production zone of the Lachine, Paxton, and Norwood members of the Antrim shale in the northern section of Michigan’s Lower Peninsula (Figure 4-1). Localized maps include Antrim County and Benzie County where project interests were developed for well demonstration sites.

The handbook is formatted into the following sections:

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The purpose of this handbook is to provide a through documentation of the methods used in this study as well as the data generated. Sections 4-8 pertain to the geologic characteristics of the Antrim Shale in the study area while sections 9-13 are related to the production characteristics and histories of wells and fields relevant to the study. Section 14 briefly discusses the disposal of co-produced carbon dioxide. Sections 15 and 16 pertain to the project databases and methods. Chapter 17 concludes with a brief discussion of the target formation of the study, the Antrim Shales.
The interim and final reports for this project make mention of and refer to this handbook. The final report is synchronized with this document and it is intended that both documents be used together. The handbook documents and extends the discussions in the final report, but does not repeat the discussions therein.

This handbook was compiled as the project proceeded during the years 2006-2008 by C. Asiala with input from the geologists and engineers at Jordan Development, LLC and under the supervision of Dr. J. R. Wood, the project PI.
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3. Project Location Maps

The Antrim Play Handbook is focused on the production zone of the Lachine, Paxton, and Norwood members of the Antrim shale in the northern section of Michigan’s Lower Peninsula. References to “northern Michigan” or the “northern section of Michigan’s Lower Peninsula” refer to the Lower Peninsula counties of Manistee, Wexford, Missaukee, Roscommon, Ogemaw, Iosco Counties, and all of the Lower Peninsula counties to the north of these county lines (Figure 3-1).

Localized data include Antrim County and Benzie County where project interests were developed for well demonstration sites. The final project demonstration well was drilled in the Colfax 29 project area in eastern Benzie County (Figures 3-1 and 3-2). The Deward Cleaver project area was used to test the concept of the “J” well design originally developed for this project (Figures 3-1 and 3-3), and the Milton Bradley project area was the original project demonstration site (Figures 3-1 and 3-4). Data was collected from vertical wells in this location, but the right of way negotiations were never solved during the timeframe of the project, and the demonstration site was moved to the Colfax 29 area in Benzie County.

The structure contour, isopach, gravity and production maps will cover northern Michigan, Antrim County (Milton Bradley and Deward Cleaver areas), and Benzie County (Colfax 29 area).
3.1. **Northern Michigan (Lower Peninsula)**

Figure 3-1. The area of interest to the LINGO project was the Northern half of the lower peninsula of Michigan where the Antrim production is most prevalent. Specific areas pertaining to the demonstration portion of the project were the Milton Bradley field in west Antrim County, the Deward Cleaver field in southeast Antrim County, and State Colfax field in southeast Benzie County.
3.2. State Colfax 29 Project Area (Benzie County, Michigan)

Figure 3-2. The final project demonstration site resulted in two highly deviated well bores to maximize perforation intervals and gas flow.
Figure 3-3. The Mancelona wells in the DeWard Cleaver field were drilled with the "J-Well" configuration intended for the project demonstration well, and it was discovered that the production from the nearby vertical wells was greater than the "J" well configuration. This resulted in a rework in the design of the well configuration.
3.4. **Milton-Bradley Project Area (Antrim County, Michigan)**

![Map of Milton-Bradley Project Area](image)

**Figure 3-4.** Vertical wells drilled in the Milton Bradley field in west Antrim County, near the planned demonstration site, AG-A-MING 4-12 HD. This demonstration well has not been drilled to date, but is still of interest to the project industry partners.
4. Characteristics of Antrim Shale

“The Antrim is Late Devonian black shale with unusually high quartz and organic content. It serves as both source and reservoir. While gas is found trapped within the Antrim throughout its extent in the Michigan Basin, economic production is limited to areas where the Antrim is highly fractured. Intense fracturing along the northern subcrop of the Antrim Shale provides excellent permeability in an otherwise unattractive reservoir rock. Gas is reservoir in the fractures, the microporosity of the matrix, and through adsorption to the matrix.

The Antrim Shale can be divided into 4 distinct zones: the Upper Antrim which consists of light gray to black shales of fairly low gamma ray readings on gamma ray logs, the Lachine which is black and exhibits high gamma ray readings, the Paxton which is gray with fairly low gamma ray readings, and the Norwood which is black and also exhibits high gamma ray readings.

Natural fractures are the key to the productive characteristics of the Antrim Shale. Regional geologic studies indicate that the shallower the Antrim is, the more highly fractured it is. This phenomenon is widely believed to have been caused by glacial scouring.” (Kelafant, 2000)

The gamma ray log has a distinct signature for recognizing the Lachine-Paxton-Norwood sequence which defines the lower section of the Antrim Shale, and lies above the Traverse Formation (Figure 4-1). The gamma ray values through the Lachine show an increase that rises above 250 gapi over an interval with a thickness range of 75-100 feet. The Lachine member sometimes looks like two segments (see log examples labeled (a) and (b) in Figure 4-1), which has resulted in two sets of formation top picks for the Lachine member. Some geologists and well operators have chosen the top of the Lachine where the highest increase in gamma ray exists (peaking over 250). Others have included the segment above where the gamma increases higher than the Upper Antrim, but is still below 250. Our industry partner has recommended including this upper segment as part of the Lachine member because its organic signature and increase in gamma ray are consistent with the Lachine properties. Also, this segment is normally perforated during the drilling process along with the other high gamma ray intervals in the Lachine and Norwood members.

The gamma ray decreases dramatically through the Paxton member (average thickness of 20-40 feet). The Paxton interval will sometimes include a gamma ray spike and dip, but drillers do not typically produce natural gas in the Paxton.

The Norwood member averages 15-25 feet thick and is represented by high gamma ray values over 250 gapi. When the gamma ray values start to decrease, this signifies the top of the Traverse and/or Squaw Bay formations.
Figure 4-1. Digital (left) and raster (right) presentations of the gamma ray on typical Antrim vertical gas wells.
5. Cross Sections through the Antrim Members (Lachine, Paxton, Norwood)

5.1. Printing Notes

The Cross Sections are formatted to be printed landscape on 19”x13” paper. Figures 5-3 through 5-12 of the handbook may be printed separately on large paper. If these figures will be printed on paper smaller than 19”x13”, then Page Scaling must be set to “Reduce to Printer Margins” in the Print Dialog box for images to be scaled down to the correct page size.

5.2. Antrim Cross Sections Discussion

The cross section lines shown on the location map in Figure 5-1 were chosen to demonstrate the properties of the Lachine, Paxton and Norwood members of the Antrim Shale. Line A-A’ follows the northern border of the current Antrim production area across Michigan. Line B-B’ follows a West to East path through the center of the Antrim production area from Antrim County to Alpena County. Line C-C’ follows a southwest to northeast path which connects the Antrim production in Manistee and Benzie Counties to the southwest corner of Otsego County. Line D-D’ is a localized cross section extending north to south in the Milton Bradley project area in west Antrim County, Michigan (Figure 5-2, left image). Line E-E’ is the cross section line between the two Colfax 29 wells in the LINGO project demonstration area (Figure 5-2, right image).

Figure 5-3 shows an arrangement of the A-A’, B-B’, and C-C’ cross sections relative to subsea depth in feet. The Antrim members (Lachine, Paxton, and Norwood) are deepest in the center of the Michigan Basin and shallow near the west, east, and northern edges of the Antrim production area.

It is typical of Antrim well logging operations to run only the gamma ray logging tool. For most Antrim wells, gamma ray (GR) is the only log available, but the GR signature is well-defined for the Lachine, Paxton, and Norwood members. The cross sections show the intervals of the Lachine, Paxton, and Norwood members on the GR log. The cross section depths are in feet, arrangements of the wells are from West to East, and the distance in feet between each well is shown between the well headers. Each of the cross sections, A through D are presented in pairs in two layouts: the first figure in each pair will display the logs in relation to subsea depth (Figures 5-4 [A-A’], 5-6 [B-B’], 5-8 [C-C’], and 5-10 [D-D’]); the second figure in each pair flattens the logs at the Lachine member (Figures 5-5 [A-A’], 5-7 [B-B’], 5-9 [C-C’], and 5-11 [D-D’]);
Figure 5-12 is the localized cross section of the two horizontal wells drilled for the LINGO project demonstration. The State Colfax #3-28 HD is located 422 meters (1385 feet) to the west of State Colfax #2-28 HD, both horizontal legs were drilled in parallel, to the southeast of the well heads. The cross section displays the wells in true vertical depth looking due north, and displays the well paths along the deviation survey. This cross section includes the gamma ray log and the perforation intervals, which were developed at the peak gamma ray signatures through the Lachine and Norwood members.
5.3. Location Maps of Cross Section Lines

Figure 5-1. Location map of cross sections that demonstrate the properties of the Lachine-Paxton-Norwood members of the Antrim Shale. The cross section lines were chosen to represent the current production areas of the Antrim. D-D’ and E-E’ are localized cross sections over the initial and final demonstration sites.

Cross Section Line Reference Map

- A - A’: Antrim County to Alpena County, North
- B - B’: Antrim County to Alpena County, South
- C - C’: Manistee County to Otsego County
- D - D’: Milton Bradley Project, western Antrim County
- E - E’: Colfax Project, southeast Benzie County

Antrim Production Wells

*: LACHINE-PAXTON-NORWOOD MEMBERS OF ANTRIM SHALE.
Figure 5-2. Path of Cross Section D - D' (left image) in the Milton Bradley field in west Antrim County (original demonstration site), and path of Cross Section E-E' (right image) which includes the two highly deviated Colfax wells in the project demonstration site.
5.4. Cross Sections

Figure 5-3. Cross sections A, B, and C shown in relation to subsea depth.
Figure 5-4. Cross Section A-A': West to east line of wells across the northern edge of the Antrim production region from Antrim County to Alpena County. The wells are positioned in relation to Subsea Depth, the formation tops printed in blue are measured depth values.
Figure 5-5. Cross Section A-A': West to east line of wells across the northern edge of the Antrim production region from Antrim County to Alpena County. The wells are positioned in relation to the Lachine member (depth = 0), the formation tops printed in blue are measured depth values.
Figure 5-6. Cross Section B-B': West to East line of wells across the center of the Antrim production region from Antrim County to Alpena County. The wells are positioned in relation to Subsea Depth, the formation tops printed in blue are measured depth values.
Figure 5-7. Cross Section B-B\(^\prime\): West to east line of wells across the center of the Antrim production region from Antrim County to Alpena County. The wells are positioned in relation to the Lachine member (depth = 0).
Figure 5-8. Cross Section C-C': Southwest to northeast line of wells from Antrim production area in Manistee County to Otsego County. The wells are positioned in relation to Subsea Depth.
Figure 5-9. Cross Section C-C': Southwest to northeast line of wells from Antrim production area in Manistee County to Otsego County. The wells are positioned in relation to Lachine member (depth = 0).
Figure 5-2. Cross Section D-D': North to south line of wells drilled in the Milton Bradley field in west Antrim County in the vicinity of the original project demonstration well. The wells are positioned in relation to Subsea Depth.
Figure 5-3. Cross Section D-D': North to south line of wells drilled in the Milton Bradley field in west Antrim County in the vicinity of the original project demonstration well. The wells are positioned in relation to the Lachine Formation (Depth = 0).
Figure 5-4. Cross Section E-E’. West to east line between the two highly deviated wells drilled in the Colfax field in Benzie County as the project demonstration well. The wells are positioned in relation to the deviated well paths at a 1:1 vertical exaggeration. The red bars symbolize the perforation intervals chosen by the drillers where there were high gamma ray peaks through the Lachine and Norwood formations.
6. Geologic Structural Contour Maps

Antrim gas production is mainly targeted in the Lachine and Norwood members of the Antrim Shale. The Paxton member which lies below the Lachine and above the Norwood typically has a low gamma ray signature, and this indicates low presence of natural gas. The structure contour maps in this section portray the Lachine, Paxton, and Norwood members, contoured by the subsea depths of the formation tops based on the Kelly Bushing elevation. All of the maps were plotted using the NAD83 Michigan Georef coordinate system.

The first set of three maps portray the Antrim members (Figure 6-1 [Lachine], Figure 6-2 [Paxton], Figure 6-3 [Norwood]) over the northern Lower Peninsula of Michigan. The range of elevation was kept constant between the maps to allow for accurate comparison (-610 meters to 213 meters / -2000 feet to 700 feet) with a contour interval of 15.24 meters (50 feet).

The second set of three maps cover Antrim County (Figures 6-4 [Lachine], 6-5 [Paxton], 6-6 [Norwood]), and the third set of three maps cover Benzie County (Figures 6-7 [Lachine], 6-8 [Paxton], 6-9 [Norwood]). The range of elevation was kept constant between all the maps in these two sets to allow for accurate comparison (-305 meters to 183 meters / -1000 feet to 600 feet) with a contour interval of 6.1 meters (20 feet).
Figure 6-1. Structure map of the Lachine member of the Antrim formation in Northern Michigan. Contour Interval is 50 feet.
Figure 6-2. Structure map of the Paxton member of the Antrim formation in Northern Michigan. Contour Interval is 50 feet.
Figure 6-3. Structure map of the Norwood member of the Antrim formation in Northern Michigan. Contour Interval is 50 feet.
Figure 6-4. Structure contour map of Lachine member of the Antrim formation over Antrim County, MI. Contour interval is 20 feet.
Figure 6-5. Structure contour map of Paxton member of the Antrim formation over Antrim County, MI. Contour interval is 20 feet.
Figure 6-6. Structure contour map of Norwood member of the Antrim formation over Antrim County, MI. Contour interval is 20 feet.
Figure 6-7. Structure contour map of Lachine member of the Antrim formation over Benzie County, MI. Contour interval is 20 feet.
Figure 6-8. Structure contour map of Paxton member of the Antrim formation over Benzie County, MI. Contour interval is 20 feet.
Figure 6-9. Structure contour map of the Norwood member of the Antrim formation over Benzie County, MI. Contour interval is 20 feet.
7. Isopach Contour Maps

The isopach thickness contour maps portray the thickness in feet of each Antrim member across the northern Lower Peninsula of Michigan. The Lachine member is approximately 23-30.5 meters (75-100 feet) thick, the Paxton member is 6-12 meters (20-40 feet) thick, and the Norwood member is 4-8 meters (15-25 feet) thick. The thickness of the Lachine is the difference in depth from the Lachine to the Paxton member. The thickness of the Paxton is the difference in depth from the Paxton to the Norwood member. The thickness of the Norwood is the difference in depth from the Norwood to the Traverse formation, which lies directly below the Antrim Shale. The range of elevation was kept constant between this set of maps to allow for accurate comparison (0 meters to 40 meters / 0 feet to 130 feet).

The first set of three maps portray the Antrim member isopach thicknesses (Figure 7-1 [Lachine], Figure 7-2 [Paxton], Figure 7-3 [Norwood]) over the northern Lower Peninsula of Michigan with a contour interval of 3 meters (10 feet).

The second set of three maps cover Antrim County (Figures 7-4 [Lachine], 7-5 [Paxton], 7-6 [Norwood]), and the third set of three maps cover Benzie County (Figures 7-7 [Lachine], 7-8 [Paxton], 7-9 [Norwood]). The contour interval for these maps is 1.5 meters (5 feet).

Figure 7-10 is a spot map that shows the formation recorded in the Michigan DEQ database that lies beneath the Glacial Drift. Figure 7-11 is an isopach thickness map of the Glacial Drift over northern Michigan. The Ellsworth Shale is predominantly located over the western portion of the Michigan Basin, and lies above or in place of the Antrim Shale. Figure 7-12 is an isopach thickness map of the Ellsworth Shale, using the thickness from top of the Ellsworth Shale to the top of the Antrim Shale. Figure 7-13 is an isopach thickness map calculating thickness from the top of the Antrim Shale to the top of the Lachine member.
Figure 7-1. Isopach thickness map of the Lachine member of the Antrim formation over northern Michigan, contour interval is 10 feet.
Figure 7-2. Isopach thickness map of the Paxton member of the Antrim formation over northern Michigan, contour interval is 10 feet.
Figure 7-3. Isopach thickness map of the Norwood member of the Antrim formation over northern Michigan, contour interval is 10 feet.
Figure 7-4. Isopach thickness map of the Lachine member of the Antrim formation over Antrim County, MI. Contour interval is 5 feet.
Figure 7-5. Isopach thickness map of the Paxton member of the Antrim formation over Antrim County, MI. Contour interval is 5 feet.
Figure 7-6. Isopach thickness map of the Norwood member of the Antrim formation over Antrim County, MI. Contour interval is 5 feet.
Figure 7-7. Isopach thickness map of the Lachine member of the Antrim formation over Michigan's Benzie and Grand Traverse Counties, contour interval is 5 feet.
Figure 7-8. Isopach thickness map of the Paxton member of the Antrim formation over Michigan's Benzie and Grand Traverse Counties, contour interval is 5 feet.
Figure 7-9. Isopach thickness map of the Norwood member of the Antrim formation over Michigan's Benzie and Grand Traverse Counties, contour interval is 5 feet.
Figure 7-10. Bedrock formation map showing the formation directly below the Glacial Drift.
Figure 7-11. Glacial Drift Isopach map with a contour interval of 50 feet, using the Inverse to a Power gridding algorithm.
Figure 7-12. Isopach map of the Ellsworth Shale to the top of the Antrim Shale in Northern Michigan. Contour Interval is 25 feet. The Ellsworth Shale exists mostly in the western part of the Michigan Basin.
Figure 7-13. Isopach map of the Antrim Shale to the top of the Lachine member of the Antrim Shale in Northern Michigan. Contour Interval is 25 feet.
8. Gravity Anomaly Maps

“Gravity anomaly maps show how much the Earth’s actual gravity field differs from the gravity field of a uniform, featureless Earth surface. The anomalies highlight variations in the strength of the gravitational force over the surface of the Earth. Gravity anomalies are often due to unusual concentrations of mass in a region. For example, the presence of mountain ranges will usually cause the gravitational force to be more than it would be on a featureless planet — positive gravity anomaly. Conversely, the presence of ocean trenches or even the depression of the landmass that was caused by the presence of glaciers millennia ago can cause negative gravity anomalies.”

NASA Earth Observatory,
http://earthobservatory.nasa.gov/Features/GRACE_Revised/page3.php

The University of Texas at El Paso Pan-American Center for Earth and Environmental Studies hosts a website for Gravity and Magnetics Research. The GeoNet Gravity database is available for downloading, and contains data in NAD27, latitude and longitude coordinates.
http://irpsrvgis00.utep.edu/repositorywebsite/

On the GeoNet Gravity and Magnetic Dataset Repository page, latitude and longitude ranges are entered in to download the gravity readings for a certain area. The northern section of Michigan’s Lower Peninsula was downloaded, and then converted to the Michigan GeoRef coordinate system in a separate GIS software package (Global Mapper).

Figure 8-1 is a contour map of the complete Bouguer anomaly value at each gravity point measured, over northern Michigan. Figure 8-2 is the same filled contour map overlaid with elevation line contours. Figures 8-3 and 8-4 are localized Bouger anomaly maps for Antrim and Benzie Counties, respectively.
Figure 8-1. Michigan Bouger Anomaly map created from data obtained from the University of Texas El Paso website for GeoNet Gravity and Magnetic Dataset Repository. (http://irpsrvgis00.utep.edu/repositorywebsite/). Color-filled contours are shown from -60 to 10 mgals with a contour interval of 1 mgal.
Figure 8-2. Michigan Bouguer Anomaly, as shown in Figure 8-1, overlaid by elevation contour lines. The elevations range from 180 to 440 meters and were contoured at a 20 meter interval.
Figure 8-3. Michigan Bouguer Anomaly map zoomed to Antrim County, and created from data obtained from the University of Texas El Paso website for GeoNet – United States Gravity Data Repository System.
Figure 8-4. Michigan Bouguer Anomaly map zoomed to Benzie County, and created from data obtained from the University of Texas El Paso website for GeoNet – United States Gravity Data Repository System.
9. Production Maps and Charts

9.1. Antrim Gas Production in Michigan

The first Antrim gas production recorded in the Annual Summary of Operations for Oil and Gas Fields reports, produced by the Michigan Department of Conservation Geological Survey Division, occurred in the 1947 report in Otsego County. From 1947 to 1986, Antrim gas production remained less than 500,000 mcf per year. In 1986, production increased to over one million, and by 1990, annual Antrim gas production was over 17 million mcf, peaking at 199 million mcf in 1999.

The increase in Antrim gas production was due to several factors (Westbrook, 2005).
- Unconventional gas tax credits encouraged more producers to look into the Antrim Play.
- Deep brine disposal wells were developed to manage the high level of salt water which must be pumped out of an Antrim well to start natural gas production.
- Demand for a low volume, long-term, supply of natural gas in Northern Michigan increased. Steady production with low volumes of gas was a previous producers’ complaint of the Antrim Shale gas.

In 1990, the Michigan Public Service Commission began electronic reporting of the Antrim gas production by month. This also included the volumes of water produced during the processing of the Antrim wells, and in 1997, the percent of CO₂ in the gas volume was added to the reporting. The percentage of CO₂ produced with natural gas varies from 5-30% from well to well. From 1990 to 1998, about half of the natural gas producers reported Antrim gas volumes as “produced gas”, volume of gas which included the carbon dioxide. The remaining producers reported “sales gas”, volume of gas after carbon dioxide has been removed. From 1998-2000, the “produced gas” reporters converted their reporting system to report only “sales gas”. Standardized gas reporting, which does not include carbon dioxide volumes, has been in place since 2000 (Figure 9-1).

Carbon dioxide volumes for this handbook have been calculated using the “sales gas” volumes and CO₂ percentages after the year 2000. Figure 9-2 describes the assumptions, variables, and calculations used to determine the CO₂ volumes, and Table 9-1 displays example calculations.
Timeline of MPSC Antrim Gas Production Reporting Standards

- Half of Reporters record **Sales Gas** (excludes CO₂ volume)
- Half of Reporters record **Produced Gas** (includes CO₂ volume)

- CO₂ percentages begin to be added to Production Reports

- **Produced Gas** Reporters begin conversion to report **Sales Gas** only

- All Gas reported is **Sales Gas** (without CO₂)

Figure 9-1. Timeline showing the process of how the Michigan Public Service Commission has evolved the reporting standards of Antrim natural gas and CO₂ reporting. The most accurate data analysis will be for the years after 2000.
Assumptions for CO₂ Volume Calculations

1. Calculations based on standardized data will be comparable only for data from the year 2000 and onward
2. The Percentage of CO₂ reported is the percent of CO₂ separated from the Produced Gas
3. Gas reported is Sales Gas from 2000 and onward
4. Produced Gas = Sales Gas + CO₂ volume
5. CO₂ is the only gas separated out from the Produced gas to result in the Sales Gas

Variable List

- \( V_{Sales} \): Volume of Sales Gas (mcf) as reported in database (does not include CO₂ volume)
- \( P_{CO2} \): Percentage of CO₂ in Produced Gas as reported in database
- \( V_{CO2} \): Volume of CO₂ (mcf)
- \( V_T \): Volume of Produced Gas (mcf), which is the Total of Sales Gas and Volume of CO₂

Solve equation for \( V_{CO2} \)

\[
V_T = V_{Sales} + V_{CO2}
\]

\[
V_{CO2} = \frac{P_{CO2}}{100} V_T
\]

\[
V_{CO2} = \frac{P_{CO2}}{100} \left( V_{Sales} \cdot \frac{100}{100 - \frac{P_{CO2}}{100}} \right)
\]

Figure 9-2. Assumptions, variables, and calculations used to determine the volume in mcf of carbon dioxide (CO₂) produced with the Antrim gas. Because the standardized reporting began in the year 2000, this calculation is only used on data reported from 2000 to the present.
### Table 9-1. Example data to illustrate CO₂ Volume calculation.

<table>
<thead>
<tr>
<th>Sales Gas (mcf)</th>
<th>Percent of CO₂ in Produced Gas</th>
<th>Volume of CO₂ (mcf)</th>
<th>Produced Gas (mcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPSC value</td>
<td>MPSC value</td>
<td>V&lt;sub&gt;CO₂&lt;/sub&gt; = \frac{P_{CO₂}}{100} \left( \frac{V_{Sales}}{P_{CO₂}} \right)</td>
<td>VT = V&lt;sub&gt;Sales&lt;/sub&gt; + V&lt;sub&gt;CO₂&lt;/sub&gt;</td>
</tr>
<tr>
<td>V&lt;sub&gt;Sales&lt;/sub&gt;</td>
<td>P&lt;sub&gt;CO₂&lt;/sub&gt;</td>
<td>V&lt;sub&gt;CO₂&lt;/sub&gt;</td>
<td>V&lt;sub&gt;T&lt;/sub&gt;</td>
</tr>
<tr>
<td>9,334</td>
<td>10.35</td>
<td>1,077.600669</td>
<td>10,411.60067</td>
</tr>
<tr>
<td>38,468</td>
<td>22</td>
<td>1,0849.94872</td>
<td>49,317.94872</td>
</tr>
</tbody>
</table>

#### 9.2. Production Charts (Antrim gas, water, and CO₂)

The production charts listed below show the trends over time in Antrim production for gas, carbon dioxide, and water. Carbon dioxide is shown as both a percentage of CO₂ and as a calculated volume, using the formula in Table 9-1. The first charts show all Antrim production in Michigan (annual [Figure 9-3] and cumulative [Figure 9-4]), and the subsequent charts show production for Benzie (Figures 9-5 and 9-6) and Antrim Counties (Figures 9-7 and 9-8), and then on a field scale for Colfax 29 (Figures 9-5 and 9-6), Milton Bradley (Figures 9-9 and 9-10), and Deward Cleaver (Figures 9-11 through 9-14). The demonstration well daily production charts for the Colfax wells are included in Section 12. Project Well Histories – Colfax 29 in Benzie County, MI.

- Figure 9-3. Annual Antrim gas (mcf), CO₂ (mcf, calculated), and water (bbls) production in Michigan from 1990 through October 2008.
- Figure 9-4. Cumulative Antrim gas (mcf), CO₂ (mcf), and water (bbls) production in Michigan from 1990 through October 2008.
- Figure 9-5. Monthly Antrim gas (mcf), CO₂ (mcf), and water (bbls) production from the Colfax 29 Field in Benzie County, Michigan from June 2005 through October 2008.
Figure 9-6. Cumulative Antrim gas (mcf), CO₂ (mcf), and water (bbls) production from the Colfax 29 Field in Benzie County, Michigan from June 2005 through October 2008.

Figure 9-7. Annual Antrim gas (mcf), CO₂ (mcf), and water (bbls) production from Antrim County, Michigan from 1990 through October 2008.

Figure 9-8. Cumulative Antrim gas (mcf), CO₂ (mcf), and water (bbls) production from Antrim County, Michigan from 1990 through October 2008.

Figure 9-9. Daily Antrim gas (mcf) and water (bbls) production from the Milton Bradley Field in Antrim County, Michigan from July 2007 through September 2008.

Figure 9-10. Cumulative Antrim gas (mcf) and water (bbls) production from the Milton Bradley Field in Antrim County, Michigan from July 2007 through September 2008.

Figure 9-11. Daily Antrim gas (mcf) production by well from the DeWard Cleaver Field in Antrim County, Michigan from June 2007 through September 2008.

Figure 9-12. Comparison of total Antrim gas (mcf) production by well from the Deward Cleaver Field in Antrim County, Michigan from June 2007 through September 2008. Production from the vertical wells is significantly higher than the horizontal wells with the “J” well configuration in the same field.

Figure 9-13. Monthly Antrim gas (mcf), CO₂ (mcf), and water (bbls) production from the DeWard-Cleaver Field in Antrim County, Michigan from August 2006 through October 2008.

Figure 9-14. Cumulative Antrim gas (mcf), CO₂ (mcf), and water (bbls) production from the DeWard-Cleaver Field in Antrim County, Michigan from August 2006 through October 2008.
Figure 9-3. Annual Antrim gas (mcf), CO₂ (mcf), and water (bbls) production in Michigan from 1990 through October 2008.
Figure 9-4. Cumulative Antrim gas (mcf), CO$_2$ (mcf), and water (bbls) production in Michigan from 1990 through October 2008.
Figure 9-5. Monthly Antrim gas (mcf), CO₂ (mcf), and water (bbls) production from the Colfax 29 Field in Benzie County, Michigan from June 2005 through October 2008.

*To date, Colfax 29 Field is the only Antrim gas production field in Benzie County.

(Source: Michigan Public Service Commission)
Figure 9-6. Cumulative Antrim gas (mcf), CO₂ (mcf), and water (bbls) production from the Colfax 29 Field in Benzie County, Michigan from June 2005 through October 2008.

* To date, Colfax 29 Field is the only Antrim gas production field in Benzie County.
Figure 9-7. Annual Antrim gas (mcf), CO2 (mcf), and water (bbls) production from Antrim County, Michigan from 1990 through October 2008.
Figure 9-8. Cumulative Antrim gas (mcf), CO₂ (mcf), and water (bbls) production from Antrim County, Michigan from 1990 through October 2008.

(Source: Michigan Public Service Commission)
Figure 9-9. Daily Antrim gas (mcf) and water (bbls) production from the Milton Bradley Field in Antrim County, Michigan from July 2007 through September 2008.
Figure 9-10. Cumulative Antrim gas (mcf) and water (bbls) production from the Milton Bradley Field in Antrim County, Michigan from July 2007 through September 2008.
DeWard-Clever
Daily Gas Production (June 2007-Sept. 2008)
Source: Jordan Development Company

Figure 9-11. Daily Antrim gas (mcf) production by well from the DeWard Cleaver Field in Antrim County, Michigan from June 2007 through September 2008.
Figure 9-12. Comparison of total Antrim gas (mcf) production by well from the Deward Cleaver Field in Antrim County, Michigan from June 2007 through September 2008. Production from the vertical wells is significantly higher than the horizontal wells with the “J” well configuration in the same field.
Figure 9-13. Monthly Antrim gas (mcf), CO₂ (mcf), and water (bbls) production from the DeWard-Cleaver Field in Antrim County, Michigan from August 2006 through October 2008.
Figure 9-14. Cumulative Antrim gas (mcf), CO₂ (mcf), and water (bbls) production from the DeWard-Cleaver Field in Antrim County, Michigan from August 2006 through October 2008.
9.3. **Cumulative Production Maps (Antrim gas, water, and CO2)**

The Antrim cumulative production maps show cumulative gas and water in 5-year increments, and CO2 production in 4-year increments. Production data is recorded monthly by production units (PRUs), which may consist of one or more wells connected to a gas line. Production unit locations were determined by assigning each PRU to the section number where most of its wells are located. Then summation queries were used to sum the cumulative production by Section starting with 1990 for gas and water in 5-year increments. The carbon dioxide maps begin in the year 2000 over two four-year increments due to the time delay in standardizing reporting requirements for Sales and Produced gas totals. Symbolized maps were then created to show the trends in Antrim production of gas and co-produced carbon dioxide and water over time.

**Cumulative Production Maps (Antrim gas)**

- **Figure 9-15.** Cumulative Antrim gas (mcf) production by Section-Township-Range location from 1990 through 1994. Colored blocks represent the sum of gas produced by Section. Production is included with the Section totals where most of Production Unit’s wells are located.

- **Figure 9-16.** Cumulative Antrim gas (mcf) production by Section-Township-Range location from 1990 through 1999. Colored blocks represent the sum of gas produced by Section. Production is included with the Section totals where most of Production Unit’s wells are located.

- **Figure 9-17.** Cumulative Antrim gas (mcf) production by Section-Township-Range location from 1990 through 2004. Colored blocks represent the sum of gas produced by Section. Production is included with the Section totals where most of Production Unit’s wells are located.

- **Figure 9-18.** Cumulative Antrim gas (mcf) production by Section-Township-Range location from 1990 through 2007. Colored blocks represent the sum of gas produced by Section. Production is included with the Section totals where most of Production Unit’s wells are located.

**Cumulative Production Maps (co-produced Antrim CO2)**

- **Figure 9-19.** Cumulative Antrim co-produced CO2 production by Section-Township-Range location from 2000 through 2003. Colored blocks represent the sum of CO2 (mcf) produced by Section. Production is included with the Section totals where most of Production Unit’s wells are located.
Figure 9-20. Cumulative Antrim co-produced CO$_2$ production by Section-Township-Range location from 2000 through 2007. Colored blocks represent the sum of CO$_2$ (mcf) produced by Section. Production is included with the Section totals where most of Production Unit’s wells are located.

Cumulative Production Maps (co-produced Antrim water)

Figure 9-21. Cumulative Antrim co-produced water production by Section-Township-Range location from 1990 through 1994. Colored blocks represent the sum of water (bbls) produced by Section. Production is included with the Section totals where most of Production Unit’s wells are located.

Figure 9-22. Cumulative Antrim co-produced water production by Section-Township-Range location from 1990 through 1999. Colored blocks represent the sum of water (bbls) produced by Section. Production is included with the Section totals where most of Production Unit’s wells are located.

Figure 9-23. Cumulative Antrim co-produced water production by Section-Township-Range location from 1990 through 2004. Colored blocks represent the sum of water (bbls) produced by Section. Production is included with the Section totals where most of Production Unit’s wells are located.

Figure 9-24. Cumulative Antrim co-produced water production by Section-Township-Range location from 1990 through 2007. Colored blocks represent the sum of water (bbls) produced by Section. Production is included with the Section totals where most of Production Unit’s wells are located.
Figure 9-15. Cumulative Antrim gas (mcf) production by Section-Township-Range location from 1990 through 1994. Colored blocks represent the sum of gas produced by Section. Production is included with the Section totals where most of Production Unit’s wells are located.
Figure 9-16. Cumulative Antrim gas (mcf) production by Section-Township-Range location from 1990 through 1999. Colored blocks represent the sum of gas produced by Section. Production is included with the Section totals where most of Production Unit’s wells are located.
Figure 9-17. Cumulative Antrim gas (mcf) production by Section-Township-Range location from 1990 through 2004. Colored blocks represent the sum of gas produced by Section. Production is included with the Section totals where most of Production Unit’s wells are located.
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Figure 9-19. Cumulative Antrim co-produced CO$_2$ production by Section-Township-Range location from 2000 through 2003. Colored blocks represent the sum of CO$_2$ (mcf) produced by Section. Production is included with the Section totals where most of Production Unit’s wells are located.
Figure 9-20. Cumulative Antrim co-produced CO₂ production by Section-Township-Range location from 2000 through 2007. Colored blocks represent the sum of CO₂ (mcf) produced by Section. Production is included with the Section totals where most of Production Unit’s wells are located.
Figure 9-21. Cumulative Antrim co-produced water production by Section-Township-Range location from 1990 through 1994. Colored blocks represent the sum of water (bbls) produced by Section. Production is included with the Section totals where most of Production Unit’s wells are located.
Figure 9-22. Cumulative Antrim co-produced water production by Section-Township-Range location from 1990 through 1999. Colored blocks represent the sum of water (bbls) produced by Section. Production is included with the Section totals where most of Production Unit’s wells are located.
Figure 9-23. Cumulative Antrim co-produced water production by Section-Township-Range location from 1990 through 2004. Colored blocks represent the sum of water (bbls) produced by Section. Production is included with the Section totals where most of Production Unit’s wells are located.
Figure 9-24. Cumulative Antrim co-produced water production by Section-Township-Range location from 1990 through 2007. Colored blocks represent the sum of water (bbls) produced by Section. Production is included with the Section totals where most of Production Unit’s wells are located.
## 10. Project Well Histories – Milton Bradley in Antrim County, MI

Preliminary schematics for planned horizontal well

<table>
<thead>
<tr>
<th>No.</th>
<th>Well ID</th>
<th>Operator</th>
<th>County</th>
<th>Project Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>21-009-58153-0000</td>
<td>AG-A-MING 4-12</td>
<td>Antrim County</td>
<td>Milton-Bradley Project</td>
</tr>
<tr>
<td>2.</td>
<td>21-009-57450-0300</td>
<td>State Mancelona #2-12 HD 3</td>
<td>Antrim County</td>
<td>DeWard-Cleaver Project</td>
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<tr>
<td>3.</td>
<td>21-009-57451-0200</td>
<td>State Mancelona #15-13 HD 2</td>
<td>Antrim County</td>
<td>DeWard-Cleaver Project</td>
</tr>
<tr>
<td>4.</td>
<td>21-009-57452-0100</td>
<td>State Mancelona #15-13A HD1</td>
<td>Antrim County</td>
<td>DeWard-Cleaver Project</td>
</tr>
<tr>
<td>5.</td>
<td>21-009-57452-0200</td>
<td>State Mancelona #15-13A HD2</td>
<td>Antrim County</td>
<td>DeWard-Cleaver Project</td>
</tr>
<tr>
<td>6.</td>
<td>21-019-58748-0000</td>
<td>State Colfax #2-28 HD</td>
<td>Benzie County</td>
<td>Colfax 29 Project</td>
</tr>
<tr>
<td>7.</td>
<td>21-019-58749-0000</td>
<td>State Colfax #3-28 HD</td>
<td>Benzie County</td>
<td>Colfax 29 Project</td>
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<tr>
<td>8.</td>
<td>21-055-57778-0000</td>
<td>Hubbell C1-9</td>
<td>Grand Traverse Cty</td>
<td>Whitewater Project</td>
</tr>
</tbody>
</table>
10.1. **AG-A-MING 4-12 HD**

The A-GA-MING 4-12 HD was the original planned demonstration well for the LINGO project. The well was not drilled within the scope of the project because right-of-way negotiations have put this well on hold. The demonstration site for this project was changed to the Colfax #3-28 HD well in southeast Benzie County. Figure 10-1 is the well bore schematic and Figure 10-2 is the planned directional survey for the A-GA-MING 4-12 HD.

10.1.1. **Well Drilling Acronym List**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD</td>
<td>Base of Drift</td>
</tr>
<tr>
<td>CBL</td>
<td>Cement Bond Log</td>
</tr>
<tr>
<td>CCL</td>
<td>Casing Collar Log</td>
</tr>
<tr>
<td>CIBP</td>
<td>Cast Iron Bridge Plug</td>
</tr>
<tr>
<td>CSG</td>
<td>Casing</td>
</tr>
<tr>
<td>DDC</td>
<td>Directional Drilling Contractors</td>
</tr>
<tr>
<td>ESP</td>
<td>Electrical Submersible Pump</td>
</tr>
<tr>
<td>KCL</td>
<td>Potassium Chloride</td>
</tr>
<tr>
<td>KOP</td>
<td>Kick Off Point</td>
</tr>
<tr>
<td>LT&amp;C</td>
<td>Long Threads and Collars</td>
</tr>
<tr>
<td>MIRU</td>
<td>Move In and Rig Up</td>
</tr>
<tr>
<td>MWD</td>
<td>Measurement While Drilling</td>
</tr>
<tr>
<td>MWL</td>
<td>Measurement Wire Line</td>
</tr>
<tr>
<td>PBTD</td>
<td>Plug Back Total Depth</td>
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<tr>
<td>RD</td>
<td>Rig Down</td>
</tr>
<tr>
<td>RU</td>
<td>Rig Up</td>
</tr>
<tr>
<td>TD</td>
<td>Total Depth</td>
</tr>
<tr>
<td>TIH</td>
<td>Trip In Hole</td>
</tr>
<tr>
<td>TOH</td>
<td>Trip Out of Hole</td>
</tr>
<tr>
<td>TVD</td>
<td>True Vertical Depth</td>
</tr>
</tbody>
</table>

10.1.2. **Drilling Prognosis**

**A-GA-MING #4-12HD**

**DRILLING PROGNOSIS**

_(March 7, 2007)_

1. MIRU.
2. Drill 12-1/4” hole to KOP at approximately 100’.
3. RU DDC. TIH with directional tools to drill surface hole ahead to an angle of approximately 23 degrees at surface casing point (projected to approximately 430’ with BOD at approximately 320’).
   Land pipe as close to minimum set depth requirement as possible to conserve TVD which will be required to build needed angle below surface CSG.
4. Run 32# J-55 8-5/8” CSG to TD and cement to surface.
5. Drill out cement and shoe.
6. TIH with directional tools and 7-7/8” bit. Test CSG and shoe.
7. RU Geologist.
8. Drill ahead on Pilot Hole in accordance with directional drilling plan, building to an angle across the Lachine and Norwood of approximately 65 degrees.
Drill to a TVD depth of approximately 850’ TVD to allow at least 100’ TVD of sump to set production pump. TOH.

9. Run 5-1/2” 15.5# J-55 LT&C CSG to TD and cement to surface.
10. RU MWL. Run Gauge Ring to PBTD.
11. Run Gamma/CCL/CBL. RD MWL
12. TIH with DP and CIBP and set for combined Norwood and Lachine leg. TOH.
13. RU Baker. TIH with Whipstock and one trip milling system.
15. TOH and lay down mills. RD Baker.
16. Circulate hole clean with 3% KCL mud.
16. TIH with 4-3/4” bit and motor and cut curve, landing at the base of the Norwood.
17. TOH.
18. TIH with motor and drill ahead on combined Norwood/Lachine lateral section in accordance with directional plan. Some inclination will also be required to compensate for rise in formation dip in the northerly direction.

***Above all, the entire lateral should be drilled at an incline to allow produced fluid to drain back to the heel during production***

19. Circulate hole clean. Pump out of hole to remove any remaining cuttings. TOH.
20. TIH with 45 degree circulating sub. Rotate and wash to TD. Pump out of hole.
21. Make up retrieving tools. TIH and retrieve Whipstock. TOH.
22. TIH with bit. Drill up CIBP and chase to TD.
23. TOH.
24. TIH with ESP.
25. RD. Release Rig.
10.1.3. Well bore Schematic

A-GA-MING #4-12HD & HD1

Figure 10-1. Well bore schematic planned for the A-GA-MING #4-12 HD well in west Antrim County, MI. This lateral was planned as an open bore hole slanting upwards through the Lachine member of the Antrim formation, but was not drilled due to right-of-way negotiations.
10.1.4. Planned Directional Survey

Figure 10-2. Planned drilling survey for the A-GA-MING 4-12 HD in west Antrim County, MI.
11. Project Well Histories – Deward Cleaver in Antrim County, MI

While the AG-A-MING #4-12 HD well was put on hold, Jordan Development Company, LLC drilled several wells in the Deward Cleaver project area in southeast Antrim County, MI with the “J” well project design. The State Mancelona #2-12 HD3, the State Mancelona #15-13 HD2, and the State Mancelona #15-13A HD1 & HD2 began production in June 2007.

The Deward Cleaver laterals revealed problems with the original design of the “J” well, mainly in terms of disappointing production relative to ordinary vertical wells (Figures 9-11 and 9-12). However, these wells provided an opportunity to redesign and modify the demonstration well before it was drilled. From what was learned at the Deward Cleaver wells (refer to Section 11.4 Deward Cleaver Horizontal Drilling Experience (Lessons Learned)), it was necessary to drill cased holes at a downward slant with perforated intervals in the Lachine and Norwood formations.

The well bore schematic for the State Mancelona #2-12 HD3 is shown in Figure 11-1, and the actual well bore cross section is shown in Figures 11-2a through 11-2d. Figure 11-3 is the well bore schematic for the State Mancelona #15-13 HD2, and Figure 11-4 is the well bore schematic for the State Mancelona #15-13A HD1 (Norwood lateral) and HD2 (Lachine lateral). The actual well bore cross section for the Lachine lateral is shown in Figures 11-5a through 11-5f, and for the Norwood lateral in Figures 11-6a through 11-6f.
11.1. **State Mancelona #2-12 HD3 (21-009-57450-0300)**

11.1.1. **Well Bore Schematic**

State Mancelona #2-12 HD3

![Well bore schematic for State Mancelona #2-12 HD3 in Antrim County, MI. This well tested the “J” well configuration on an open hole which slanted upwards through the Lachine member of the Antrim formation.](image)

Figure 11-1. Well bore schematic for State Mancelona #2-12 HD3 in Antrim County, MI. This well tested the “J” well configuration on an open hole which slanted upwards through the Lachine member of the Antrim formation.
Figure 11-2a. Mud log and well bore cross section of the Lachine lateral in the State Mancelona 2-12 HD3 (API: 21-009-57450-0300) well in the Deward Cleaver project area in east Antrim County, MI. The lateral was drilled with an upward slope in an open uncased hole with no fracturing or perforating. The measured depth of the well ranges from 1470 – 4030 feet and the true vertical depth of the lateral slopes upward on a scale from 1420 to 1380 feet.

Figure 11-2b. State Mancelona 2-12 HD: Horizontal leg through the Lachine member, measured depth scale is from 1400 - 2270 feet, well bore on bottom track, vertical scale is 1380-1420 feet, true vertical depth.
Figure 11-2c. State Mancelona 2-12 HD: Horizontal leg through the Lachine member, measured depth scale is from 2270 - 3170 feet, well bore on bottom track, vertical scale is 1380-1420 feet, true vertical depth.

Figure 11-2d. State Mancelona 2-12 HD: Horizontal leg through the Lachine member, measured depth scale is from 3170 - 4030 feet, well bore on bottom track, vertical scale is 1380-1420 feet, true vertical depth.
11.2. **State Mancelona #15-13 HD2** (21-009-57451-0200)

11.2.1. **Well Bore Schematic**

![Well Bore Schematic](image)

Figure 11-3. Well bore schematic for State Mancelona #15-13 HD2 in Antrim County, MI. This well tested the “J” well configuration on an open hole which slanted upwards through the Lachine member of the Antrim formation.
11.3. **State Mancelona #15-13A HD1 & 2 (21-009-57452-0100, -0200)**

11.3.1. **Well Bore Schematic**

![Well bore schematic for State Mancelona #15-13A HD1 and HD2 in Antrim County, MI. This well tested the “J” well configuration on two open holes which slanted upwards through the Lachine and the Norwood members of the Antrim formation.](image)

**Figure 11-4.** Well bore schematic for State Mancelona #15-13A HD1 and HD2 in Antrim County, MI. This well tested the “J” well configuration on two open holes which slanted upwards through the Lachine and the Norwood members of the Antrim formation.
Figure 11-5a. Mud log and well bore cross section of Lachine leg of the State Mancelona 15-13A HD2 (API: 21-009-57452-0200) well in the Deward Cleaver project area in east Antrim County, MI. The lateral was drilled with an upward slope (the “J” well configuration) in an open uncased hole with no fracturing or perforating through the Lachine member of the Antrim formation. The following segments display the lengths of the log from a measured depth range of 1800-5660 feet, and the center track displays a true vertical depth range of 1560-1660 feet.

Figure 11-5b. Horizontal leg through the Lachine member, 1800-2500 feet, well bore on center track, vertical scale is 1560-1660 feet, true vertical depth.

Figure 11-5c. Horizontal leg through the Lachine member, 2500-3300 feet, well bore on center track, vertical scale is 1560-1660 feet, true vertical depth.
Figure 11-5d. Horizontal leg through the Lachine member, 3300-4100 feet, well bore on center track, vertical scale is 1560-1660 feet, true vertical depth.

Figure 11-5e. Horizontal leg through the Lachine member, 4100-4900 feet, well bore on center track, vertical scale is 1560-1660 feet, true vertical depth.

Figure 11-5f. Horizontal leg through the Lachine member, 4900-5660 feet, well bore on center track, vertical scale is 1560-1660 feet, true vertical depth.
Figure 11-6a. Mud log and well bore cross section of Norwood leg of the State Mancelona 15-13A HD1 (API: 21-009-57452-0100) well in the Deward Cleaver project area in east Antrim County, MI. The lateral was drilled with an upward slope (the “J” well configuration) in an open uncased hole with no fracturing or perforating through the Norwood member of the Antrim formation. The following segments display the lengths of the log from a measured depth range of 2000-5640 feet, and the center track displays a true vertical depth range of 1680-1730 feet.

Figure 11-6b. Horizontal leg through the Norwood member, 2000-2700 feet, well bore on center track, vertical scale is 1680-1730 feet, true vertical depth.

Figure 11-6c. Horizontal leg through the Norwood member, 2700-3500 feet, well bore on center track, vertical scale is 1680-1730 feet, true vertical depth.
Figure 11-6d. Horizontal leg through the Norwood member, 3500-4300 feet, well bore on center track, vertical scale is 1680-1730 feet, true vertical depth.

Figure 11-6e. Horizontal leg through the Norwood member, 4300-5100 feet, well bore on center track, vertical scale is 1680-1730 feet, true vertical depth.

Figure 11-6f. Horizontal leg through the Norwood member, 5100-5640 feet, well bore on center track, vertical scale is 1680-1730 feet, true vertical depth.
11.4. **Deward Cleaver Horizontal Drilling Experience (Lessons Learned)**

Jordan Development Company, LLC (Jordan) drilled three open hole lateral Antrim Shale tests in the Deward Cleaver Field within Mancelona East Township of Antrim County between June of 2006 to July of 2007. The approach used to drill these three wells is identical to the well design originally proposed for the A-Ga-Ming #4-12 HD demonstration well.

The Deward Cleaver wells consisted of directionally drilled pilot holes which were cased, from which open hole laterals were drilled at a 90 degree or greater inclination. The open hole laterals were oriented to allow fluids to drain back out of the laterals and into the pilot holes. An electric submersible pump was then set below the open hole windows within the pilot holes to enable produced water to be removed from the well.

The resultant production from these open hole laterals did not meet anticipated production expectations. Upon review, Jordan has gained a great deal of insight as to improvements in the drilling and completion approach going forward to improve well production.

The first potential weakness in the drilling approach taken in the Deward Cleaver is that the exit for each lateral creates a “lip” at the casing window. This “lip” results in a point of fluid back-up, whereby the produced water draining back to the pilot hole must rise up before entering the casing and being pumped from the hole. The result is a pressure drop which adversely effects production.

The open hole laterals were designed to gradually rise over their length to allow all produced water to drain back to the pilot hole. Jordan and its drilling contractors were very diligent in the effort to accomplish a smooth and gradual incline to the lateral placement. However, it is nearly impossible to avoid slight dips and valleys within the well path. As such, several sumps are formed within the lateral which trap produced fluid, hamper production, and potentially render portions of the lateral unproductive.

Another potential issue with the original design is in the effect of drilling damage within the open hole laterals. During lateral drilling, the ability to efficiently remove cuttings becomes increasingly difficult as the hole extends further out. As a result, cuttings begin to accumulate along the hole and are finely ground to a paste as drilling progresses. This shaley paste causes formation damage which is very difficult to remove as the clay fines are inert to stimulation treatments such as acid.
As formation pressure depletes, the total effect of these drilling and design inefficiencies can greatly hamper gas deliverability. Jordan is now employing a new design which incorporates drilling a 75 to 80 degrees angle hole through the Antrim. This high angle hole is then cased and completed through pipe with eight to fourteen perforated and fracture stimulated zones. A pump is then run in below all zones to lift produced water from the well.

The main advantage of the new design is that fluids drain directly and efficiently into the production casing. In this way, the well is produced in a more conventional means through perforations with no fluid back-ups or traps. In addition, by discretely stimulating multiple zones utilizing fracture treatments, the effect of any drilling damage is completely removed. Jordan views this new drilling and completion approach far superior to the original design for future Antrim Shale development.
12. Project Well Histories – Colfax 29 in Benzie County, MI

The Colfax #3-28 HD (project demonstration well) and nearby Colfax #2-28 HD were drilled in the Colfax 29 Field in Benzie County, MI (Figure 12-1) with a cased hole drilled to near horizontal (75 to 85 degrees) and carried through the Antrim section in a slightly downward inclination. Perforated completion intervals were then shot through the pipe and individually fracture treated. Increasing gamma ray signatures indicate high gas content, and these intervals in the Lachine and Paxton formations along the horizontal well path provided more locations for the perforation zones.

St. Colfax #3-28 HD

Figure 12-2  Well bore schematic  
Figure 12-3  Directional survey of horizontal path  
Figure 12-4  Cross Section of gamma ray log along the directional survey of the horizontal path. Perforation intervals are shown in red.  
Figure 12-5  Daily production graph through December 2008  
Figure 12-6  Record of Drilling document  
Figure 12-7  Formation Record  
Figure 12-8  Record of Well Completion  
Figures 12-9a-g  Daily completion reports while drilling

St. Colfax #2-28 HD

Figure 12-10  Well bore schematic  
Figure 12-11  Directional survey of horizontal path  
Figure 12-12  Cross Section of gamma ray log along the directional survey of the horizontal path. Perforation intervals are shown in red.  
Figure 12-13  Daily production graph through December 2008  
Figure 12-14  Record of Drilling document  
Figure 12-15  Formation Record  
Figure 12-16  Record of Well Completion  
Figures 12-17a-g  Daily completion reports while drilling
Figure 12-1. Topographic map of the LINGO Project demonstration site, the St. Colfax 3-28 HD and St. Colfax 2-28 HD wells in Benzie County, Michigan.
12.1. **St. Colfax 3-28 HD (21-019-58749-0000)**

12.1.1. **Well Drilling Acronym List**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD</td>
<td>Base of Drift</td>
</tr>
<tr>
<td>CBL</td>
<td>Cement Bond Log</td>
</tr>
<tr>
<td>CCL</td>
<td>Casing Collar Log</td>
</tr>
<tr>
<td>CIBP</td>
<td>Cast Iron Bridge Plug</td>
</tr>
<tr>
<td>CSG</td>
<td>Casing</td>
</tr>
<tr>
<td>DDC</td>
<td>Directional Drilling</td>
</tr>
<tr>
<td>ESP</td>
<td>Electrical Submersible Pump</td>
</tr>
<tr>
<td>KCL</td>
<td>Potassium Chloride</td>
</tr>
<tr>
<td>KOP</td>
<td>Kick Off Point</td>
</tr>
<tr>
<td>LT&amp;C</td>
<td>Long Threads and Collars</td>
</tr>
<tr>
<td>MIRU</td>
<td>Move In and Rig Up</td>
</tr>
<tr>
<td>MWD</td>
<td>Measurement While Drilling</td>
</tr>
<tr>
<td>MWL</td>
<td>Measurement Wire Line</td>
</tr>
<tr>
<td>PBTD</td>
<td>Plug Back Total Depth</td>
</tr>
<tr>
<td>RD</td>
<td>Rig Down</td>
</tr>
<tr>
<td>RU</td>
<td>Rig Up</td>
</tr>
<tr>
<td>TD</td>
<td>Total Depth</td>
</tr>
<tr>
<td>TIH</td>
<td>Trip In Hole</td>
</tr>
<tr>
<td>TOH</td>
<td>Trip Out of Hole</td>
</tr>
<tr>
<td>TVD</td>
<td>True Vertical Depth</td>
</tr>
</tbody>
</table>

12.1.2. **Drilling Prognosis**

**STATE COLFAX #3-28 (AKA: State Colfax #12-21 HD)**

**DRILLING PROGNOSIS**

*(December 13, 2007)*

**Note:** Pitless location

1. **MIRU.**

2. Drill 12-1/4” hole to KOP at approximately 500’.

3. **RU DDC.** TIH with directional tools and drill surface hole ahead to an angle of approximately 30 degrees at surface casing point.

   **Note:** Surface CSG point shall be 100’ TVD below BOD.

4. Run 32# J-55 8-5/8” CSG to TD and cement to surface.

5. Drill out cement and shoe.

6. TIH with directional tools and 7-7/8” bit. Test CSG and shoe.

   **Consider drilling out with a minimum 7% brine solution (8.8 #/gallon or greater) of light brine or KCL.**
7. RU Geologist and Hotwire.

8. Drill ahead in accordance with directional drilling plan, building to an angle across the Lachine and Norwood of approximately 75 degrees.

9. Once the base of the Lachine has been reached, allow bit angle to fall while drilling approximately 400’ md of rat hole.

10. RD Mud Logger.

11. Run 5-1/2” 15.5# J-55 LT&C CSG to TD and cement to surface.

12. RD MO
12.1.3. **Well bore Schematic**

**Figure 12-2.** Planned well bore schematic for the project demonstration well, State Colfax 3-28 HD in Benzie County, MI.
12.1.4. Directional Survey

Job Number: DR 078179
Company: JORDAN DEVELOPMENT
Lease/Well: SPF 328, M2-22, Colfax 3-28 HD
Location: COLFAK TWP., BENZIE CO.
State/Country: MICHIGAN / USA
File name: C:\WINSERVE\200898-20072007\COL328.SVY

Figure 12-3. Diagram of directional survey of the State Colfax 3-28 HD well in Benzie County, MI.

Lingo Antrim Play: Handbook
DE-FC26-06NT42931
12.1.5. **Gamma Ray Log along Well Path**

Figure 12-4. Gamma ray log and perforation intervals along the deviation survey of the State Colfax 3-28 HD well in Benzie County. High gamma ray peaks indicate good perforation zones.
12.1.6. Colfax 3-28 HD Daily Production Data

Figure 12-5. Daily gas production and pressure data of the State Colfax 3-28 HD well in Benzie County, MI. Production began in April of 2008, and has averaged 90 mcf/day at the end of 2008.
12.1.7. Record of Well Drilling

DEQ
MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY - OFFICE OF GEOLOGICAL SURVEY
RECORD OF WELL DRILLING OR DEEPENING

Required by authority of Part 415, Subdivision of Wells, or Part 416, Mineral Wells, of Act 415, PA 1961, as amended. Non-submission and/or falsification of this information may result in fines and/or imprisonment.

58749

API number
21-019-58749-00-00

Well name and number
State Colfax #3-28 HD

Name and address of permittee:
Jordan Development Company, L.L.C.
1503 Garfield Road North
Traverse City, MI 49686

Surface location
SE 1/4 of NW 1/4 of SW 1/4 Section 21 T25N R13W

Township
Colfax

County
Benzie

Footages North/South East/West
1599 ft. from South line and 699 ft. from West line of sec.

Name and address of drilling contractor
Advanced Enerav Services, L.L.C.
P.O. Box 85
5876 Puffer Rd.
South Boardman, Michigan 49680

Directionally drilled (check one)
X Yes ☐ No

Subsurface location (if directionally drilled)
SW1/4 of SE1/4 of SW 1/4 Section 21 T 25N R 13W

Date drilling began
12-27-2007

Date drilling completed
1-1-2008

Driller 2400' MD Log N/A

Footages North/South East/West
371 ft. from South line and 1430' ft. from West line of sec.

Traverse Limestone

Elevations
K.B. 827.7 ft. R.F. ft. R.T. ft. Grd 822 ft

Feet drilled - cable tools Feet drilled - rotary tools

from N/A to from Surface to 2400'

Casing, Casing Liners and Cementing, Operating Strings

Water Fill Up (F.U.) or Lost Circulation (L.C.) (X)

Size Where set Cement T.O.C. Ft. pulled Formation F.U. L.C. Depth Amount
13 3/8" 70' Driven N/A N/A N/A
8 5/8" 794' MD 370ax Surface N/A N/A
5 1/2" 2399' MD 365ax Surface N/A N/A

Gross Pay Intervals

All Other Oil and Gas Shows Observed or Logged

From To Formation Oil or Gas Depth Samples Odor Pits Mud Gas Log Fill Up
Antrim Shale Gas 1524' 2038' N/A
N/A

Depth Correction

Deviation Survey

Plugged Back

Depth Correction Run at Degrees Yes No Depth
See Directional Survey

Geophysical / Mechanical Logs (list each type run)

Brand

Log types

Logged intervals

None

Notice: Report complete sample and formation record, coring record, and drill stem test information on reverse side.

CERTIFICATION: "I state that I am authorized by said owner. This report was prepared under my supervision and direction. The facts stated herein are true, accurate and complete to the best of my knowledge."

Date
Benjamin J. Nieto, Authorized Agent
Signature

Submit to:
OFFICE OF GEOLOGICAL SURVEY,
MICHIGAN DEPT OF ENVIRONMENTAL QUALITY
PO BOX 30256, LANSING, MI 48909-7756

Figure 12-6. St. Colfax 3-28 HD Record of Well Drilling.
<table>
<thead>
<tr>
<th>Elevation Used (FT)</th>
<th>Formation (Type, Color, Hardness)</th>
<th>From</th>
<th>To</th>
</tr>
</thead>
<tbody>
<tr>
<td>827.7 KB</td>
<td>Fm Tops TVD</td>
<td>667'</td>
<td>674'</td>
</tr>
<tr>
<td></td>
<td>BOD</td>
<td>1163'</td>
<td>1237'</td>
</tr>
<tr>
<td></td>
<td>ELLSWORTH- SH-MD GRY, LT GRY, PLTY/BLKY, GRNY, ST-FRM, DNS, S.LIMY, NO FLOR</td>
<td>1314'</td>
<td>1163'</td>
</tr>
<tr>
<td></td>
<td>UPPER ANTRIM- SH-MD GRY, LT GRY, DRK BRN, PLTY/BLKY, GRNY, SFT-FRM, DNS, SL LMY, 5% YWL SPORE FLOR</td>
<td>1524'</td>
<td>1237'</td>
</tr>
<tr>
<td></td>
<td>LACHINE-SH DRK BRN, DRK GRY, BLK, HD, DNS, PLTY/BLKY, GRNY, DNS, TR FLOR</td>
<td>1810'</td>
<td>1308'</td>
</tr>
<tr>
<td></td>
<td>PAXTON- SH GRY, DRK BRN, LT GRY, MD, FRM-HD, DNS, GRNY PLTY/BLKY, SPORE FLR</td>
<td>1902'</td>
<td>1349'</td>
</tr>
<tr>
<td></td>
<td>NORWOOD- SH- DRK BRN, DRK GRY, BLK, OCC MD GRY, HD, PLTY/BLKY, BRT, DNS, 5-10% YWL SPR FLR</td>
<td>2038'</td>
<td>1371'</td>
</tr>
<tr>
<td></td>
<td>TRAVERSE FORMATION- SH-DRK BRN, MD BRN, BLK, MD GRY, LT GRY, B/U, HD, LMST-LT BRN, MD GRY, LT GRY, BLU BLK, MD, FRM- HD, MICXLN, BLKY/PLTY SM TR YWL SPORE FLOR</td>
<td>2144'</td>
<td>1407'</td>
</tr>
<tr>
<td></td>
<td>TRAVERSE LIMESTONE- LMST-DRK BRN, MD BRN, BLK, MICXLN, TT, HD, DNS SH- MD GRY, LT GRY, BLU, BLK, MD, FM- HD, BLKY/PLTY, SM TR YWL SPORE FLOR</td>
<td>2400'</td>
<td>1522'</td>
</tr>
</tbody>
</table>

**Figure 12-7. St. Colfax 3-28 HD Formation Record of horizontal lateral.**
12.1.8. Record of Well Completion

**MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY – OFFICE OF GEOLOGICAL SURVEY**

**RECORD OF WELL COMPLETION**

By authority of Part 615 or Part 625 of Act 451 PA 1994, as amended. Non-submission and/or falsification of this information may result in fines and/or imprisonment.

(Submit 3 copies within 60 days of well completion.)

- **Part 615 Oil/Gas Well**
- **Part 625 Mineral Well**

**Permit number/deepening permit no.** 58749
**API number** 21-019-58749-00-00

**Type of well** (after completion)
- **Gas**

**Well name & number** State Colfax #3-28 HD

**Name and address of permittee**
- **Jordan Development Company, L.L.C.**
- **1503 Garfield Road North**
- **Traverse City, MI 49686**

**Directionally drilled (check one)**
- **Yes**
- **No**

**Previous permit numbers** N/A

**Total depth of well** M.D. 2400' T.V.D. 1522'

**Surface location**
- SE ¼ of NW ¼ of SW ½ Section 21 T 25N R 13W

**Subsurface location (if directionally drilled)**
- SW ¼ of SE ¼ of SW ½ Section 21 T 25N R 13W

**Footage**
- North/South: 1599 ft. from South line and 699 ft. from West line of Sec.
- East/West: 371 ft. from South line and 1430 ft. from West line of Sec.

** completions**
- **Part 615 - oil/gas wells**
- **Part 625 - mineral wells**

**Date well completed** 2-26-2008
**Producing formation(s)** Antrim Shale
**Injection formation(s)** N/A
**Date of first injection** N/A
**Disposal formation(s)** N/A
**Solution formation(s)** N/A

**COMPLETION INTERVALS(S)**

<table>
<thead>
<tr>
<th>Date</th>
<th>Number of holes</th>
<th>Perforation or open hole interval</th>
<th>Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-25-2008</td>
<td>4 SPF</td>
<td>2026'-2032', 2035'-2040', 1998'-2008', 1836'-1846'</td>
<td>X</td>
</tr>
<tr>
<td>2-26-2008</td>
<td>4 SPF</td>
<td>1794'-1799', 1779'-1784', 1735'-1740', 1721'-1726', 1703'-1708', 1682'-1687', 1649'-1654', 1627'-1632', 1596'-1600', 1577'-1582', 1557'-1562', 1330'-1340'</td>
<td>X</td>
</tr>
</tbody>
</table>

**STIMULATION BY ACID OR FRACTURING**

<table>
<thead>
<tr>
<th>Date</th>
<th>Interval treated</th>
<th>Materials and amount used</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-25-2008</td>
<td>2026'-2032', 2035'-2040'</td>
<td>15% Acid; 700 gals, Sand: 47.157#/2040 4,700#/12/20</td>
</tr>
<tr>
<td>2-25-2008</td>
<td>1998'-2008', 1836'-1846'</td>
<td>15% Acid; 1000 gals, Sand: 50.900#/2040 5,700#/12/20</td>
</tr>
<tr>
<td>2-26-2008</td>
<td>1794'-1799', 1779'-1784'</td>
<td>15% Acid; 1000 gals, Sand: 25.800#/2040 6,000#/12/20</td>
</tr>
<tr>
<td>2-26-2008</td>
<td>1735'-1740', 1721'-1726'</td>
<td>15% Acid; 1000 gals, Sand: 26.700#/2040 1,600#/12/20</td>
</tr>
<tr>
<td>2-26-2008</td>
<td>1703'-1708', 1682'-1687'</td>
<td>15% Acid; 1000 gals, Sand: 25.400#/2040 4,900#/12/20</td>
</tr>
<tr>
<td>2-26-2008</td>
<td>1649'-1654', 1627'-1632'</td>
<td>15% Acid; 1000 gals, Sand: 25.300#/2040 5,900#/12/20</td>
</tr>
<tr>
<td>2-26-2008</td>
<td>1596'-1600', 1577'-1582', 1557'-1562'</td>
<td>15% Acid; 1000 gals, Sand: 25.400#/2040 5,100#/12/20</td>
</tr>
<tr>
<td>2-26-2008</td>
<td>1330'-1340'</td>
<td>15% Acid; 1000 gals, Sand: 26,600#/2040 7,300#/12/20</td>
</tr>
</tbody>
</table>

**PRODUCTION TEST DATA**

<table>
<thead>
<tr>
<th>Oil Bbls/day</th>
<th>Gravity °API</th>
<th>Condensate Bbls/day</th>
<th>Gas MCF/day</th>
<th>Water Bbls/day</th>
<th>H₂S Grains/100 ft³</th>
<th>B.H.P. and depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>150 est.</td>
<td>400 est.</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**CERTIFICATION**

I state that I am authorized by said owner. This report was prepared under my supervision and direction. The facts stated herein are true, accurate and complete to the best of my knowledge.

**Name and title (print or type)**
- **Benjamin J. Nieto, Authorized Agent**

Submit to:
- **OFFICE OF GEOLOGICAL SURVEY**
- **MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY**
- **PO BOX 30256**
- **LANSDING MI 48909-7756**

EOP 7130 (rev. 8/2004)

Figure 12-8. St. Colfax 3-28 HD Record of Well Completion with perforation and fracturing data.
12.1.9. Completion Report

TIME TICKET - Consulting

Date: 2/24/2008  Employee: Dale Schellie

Well name/number: St. Colfax 3-28 HD  Rig: Advanced #124

RATE: $325.00

Description of work performed:

7:00-10:30  3 1/2 hrs  Rig up workover rig. Tighten up frac valve. Spot tubing trailer and half tank.

10:30-12:30  2 hrs  Stand 75 joints of 2 3/8” tubing in derrick.

12:30-4:00  3 1/2 hrs  Hook up and fill frac tanks.

4:00-7:00  15 hrs  Fill frac tanks.

Figure 12-9a. St. Colfax 3-28 HD Daily Completion Report while drilling, 2/24/2008.
**TIME TICKET - Consulting**

<table>
<thead>
<tr>
<th>Date</th>
<th>2/25/2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Employee</td>
<td>Dale Schellie</td>
</tr>
<tr>
<td>Well name/number</td>
<td>St. Colfax 3-28 HD</td>
</tr>
<tr>
<td>Rig</td>
<td>Advanced #124</td>
</tr>
<tr>
<td>RATE</td>
<td>$650.00</td>
</tr>
</tbody>
</table>

**Description of work performed:**

6:30-9:30 3 hrs  Rig up Halliburton and Michigan Wireline. Pressure test lines to 4200 PSI. Break formation at 1948 PSI. Pumped 300 gallons 15% acid I.S.I.P. 1310 PSI.

9:30-10:30 1 hr  Rig up Michigan Wireline. Pick up perf gun. Pump perf gun down hole. Perforate 2026'-2032' 4 S.P.F. Rig down Michigan Wireline.

10:30-12:00 1 1/2 hr  Rig up Halliburton. Perfs 2035'-2040' and 2026'-2032' 4 S.P.F. Pumped 700 gallons 15% acid I.S.I.P. 1180 PSI. Pumped 19157 #20/40 sand and pumped none #12/20 sand. Couldn't get sand out of sand dump. Abort job.

12:00-1:30 1 1/2 hr  Work on sand dump and mix gel

1:30-2:00 1/2 hr  2nd job, pumped 26000 #20/40 sand and pumped 4700 #12/20 sand. Zone pressured up with 5 BBL flush left. Were able to reestablish 8 B.P.M. rate to finish flushing stage. Monitor shut in pressures. Shut in wellhead. Rig down Halliburton.

2:00-3:30 1 1/2 hr  Rig up Michigan Wireline. Pick up perf gun. Pump perf gun down hole. Perf 1998'-2008' 4 S.P.F. Pick up plug and pump plug down hole, set plug at 2019'. Rig down Michigan Wireline.

3:30-4:00 1/2 hr  Rig up Halliburton. Perfs 1998'-2008' 4 S.P.F. Break formation at 1784 PSI. Pumped 1000 gallons 15% acid I.S.I.P. 1200 PSI. Pumped 25500 #20/40 sand and pumped 1600 #12/20 sand. Monitor shut in pressures. Shut in wellhead. Rig down Halliburton.

4:00-5:30 1 1/2 hr  Rig up Michigan Wireline. Pick up perf gun. Pump perf gun down hole. Perf 1836'-1846' 4 S.P.F. Pick up plug, pump plug down hole. Set plug at 1910'. Rig down Michigan Wireline.

5:30-6:00 1/2 hr  Rig up Halliburton. Perf 1836'-1846' 4 S.P.F. Break formation at 1797 PSI. Pumped 1000 gallons 15% acid I.S.I.P. 869 PSI.

6:00-6:30 1/2 hr  Pumped 25400 #20/40 sand and pumped 4100 #12/20 sand. Monitor shut in pressures. Shut in wellhead.

6:30-8:30 2 hrs  Mix gel and transfer, mix clay water.

Fill four frac tanks through night with water well.

**Figure 12-9b. St. Colfax 3-28 HD Daily Completion Report while drilling, 2/25/2008.**
TIME TICKET - Consulting

Date: 2/26/2008

Well name/number: St. Colfax 3-28 HD

Employee: Dale Schellie

Rig: Advanced #124

RATE: $650.00

Description of work performed:

7:00-8:30 1 1/2 hr Rig up Michigan Wireline. Pick up dual fire perf gun. Pump dual fire perf gun down hole. Perfs 1794'-1799' and 1779'-1784' 4 S.P.F. Pick up plug. Pump plug down hole. Set plug at 1811'. Rig down Michigan Wireline.

8:30-9:30 1 hr Rig up Halliburton. Perfs 1794'-1799' and 1779'-1784' 4 S.P.F. Break formation at 1414 PSI. Pumped 1000 gallons 15% acid I.S.I.P. 1049 PSI. Pumped 25800 #20/40 sand and pumped 6000 #12/20 sand. Monitor shut in pressure. Shut in wellhead. Rig down Halliburton.

9:30-10:30 1 hr Rig up Michigan Wireline. Pick up dual fire perf gun. Pump dual fire perf gun down hole. Perfs 1735'-1740' and 1721'-1726' 4 S.P.F. Pick up plug. Pump plug down hole. Set plug at 1766'. Rig down Michigan Wireline.

10:30-11:00 1/2 hr Rig up Halliburton. Perfs 1735'-1740' and 1721'-1726' 4 S.P.F. Break formation at 1430 PSI. Pumped 1000 gallons 15% acid I.S.I.P. 1329 PSI.

11:00-12:00 1 hr Pumped 26700 #20/40 sand and pumped 1600 #12/20 sand. Monitor shut in pressure. Shut in wellhead. Rig down Halliburton.

12:00-1:00 1 hr Rig up Michigan Wireline. Pick up dual fire perf gun. Pump dual fire perf gun down hole. Perfs 1703'-1708' and 1682'-1687' 4 S.P.F. Pick up plug. Pump plug down hole. Set plug at 1715'. Rig down Michigan Wireline.

1:00-1:30 1/2 hr Rig up Halliburton. Perfs 1703'-1708' and 1682'-1687' 4 S.P.F. Break formation at 1284 PSI. Pumped 1000 gallons 15% acid I.S.I.P. 1090 PSI. Pumped 25400 #20/40 sand and pumped 4900 #12/20 sand. Monitor shut in pressures. Shut in wellhead. Rig down Halliburton.

1:30-2:30 1 hr Rig up Michigan Wireline. Pick up dual fire perf gun. Pump dual fire perf gun down hole. Perfs 1649'-1654' and 1627'-1632' 4 S.P.F. Pick up plug. Pump plug down hole. Set plug at 1672'. Rig down Michigan Wireline.

2:30-3:30 1 hr Rig up Halliburton. Perfs 1649'-1654' and 1627'-1632' 4 S.P.F. Break formation at 1315 PSI. Pumped 1000 gallons 15% acid I.S.I.P. 998 PSI. Pumped 25500 #20/40 sand and pumped 5900 #12/20 sand. Monitor shut in pressures. Shut in wellhead. Rig down Halliburton.

3:30-4:30 1 hr Rig up Michigan Wireline. Pick up dual fire perf gun. Pump dual fire perf gun down hole. Perfs 1595'-1600' and 1577'-1582' 4 S.P.F. Pick up dual fire perf gun and plug. Pump dual fire perf gun and plug down hole. Set plug at 1615'. Perfs 1557'-1562' 4 S.P.F. Rig down Michigan Wireline.

4:30-5:30 1 hr Rig up Halliburton. Perfs 1595'-1600', 1577'-1582' and 1557'-1562 4 S.P.F. Break formation at 1144 PSI. Pumped 1000 gallons 15% acid I.S.I.P. 913 PSI. Pumped 25400 #20/40 sand and pumped 5100 #12/20 sand. Monitor shut in pressures. Shut in wellhead. Rig down Halliburton.

5:30-6:30 1 hr Rig up Michigan Wireline. Pick up perf gun. Pump perf gun down hole. Perfs 1330'-1340' 4 S.P.F. Pick up plug. Pump plug down hole. Set plug at 1370'. Rig down Michigan Wireline.

6:30-7:30 1 hr Rig up Halliburton. Perfs 1330'-1340' 4 S.P.F. Break formation at 2216 PSI. Pumped 1000 gallons 15% acid I.S.I.P. 867 PSI. Pumped 26600 #20/40 sand and pumped 7300 #12/20 sand. Monitor shut in pressures. Shut in wellhead.

7:30-10:30 3 hrs Rig down Halliburton.

Figure 12-9c. St. Colfax 3-28 HD Daily Completion Report while drilling, 2/26/2008.
### TIME TICKET - Consulting

<table>
<thead>
<tr>
<th>Date</th>
<th>2/27/2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Employee</td>
<td>Dale Schellie</td>
</tr>
<tr>
<td>Well name/number</td>
<td>St. Colfax 3-28 HD</td>
</tr>
<tr>
<td>Rig</td>
<td>Advanced #124</td>
</tr>
<tr>
<td>RATE</td>
<td>$650.00</td>
</tr>
</tbody>
</table>

#### Description of work performed:

- **7:00-12:00** 5 hrs  Finish moving Halliburton and Michigan Wireline off location. Flow back well. Lay down 2 3/8" tubing string out of derrick.
- **12:00-1:30** 1 1/2 hrs  Remove frac valve and nipple up.
- **1:30-3:00** 1 1/2 hrs  Trip in hole to 1st plug.
- **3:00-3:30** 1/2 hr  Wash down to and release 1st plug.
- **3:30-4:30** 1 hr  Trip out of hole with 1st plug and lay down.
- **4:30-5:30** 1 hr  Start in hole after 2nd plug.
- **5:30-7:30** 2 hrs  Replace rig air compressor.

Figure 12-9d. St. Colfax 3-28 HD Daily Completion Report while drilling, 2/27/2008.
TIME TICKET - Consulting

Date: 2/28/2008  Employee: Dale Schellie

Well name/number: St. Colfax 3-28 HD  Rig: Advanced #124

RATE: $650.00

Description of work performed:

7:00-9:30  2 1/2 hrs  Start rig and trip in hole to 2nd plug. Thaw out frac tank headers.

9:30-10:00  1/2 hr  Wash down to and release 2nd plug.

10:00-11:00  1 hr  Trip out of hole and lay down 2nd plug.

11:00-12:00  1 hr  Trip in hole to 3rd plug.

12:00-12:30  1/2 hr  Wash 10’ sand down to and release 3rd plug.

12:30-2:00  1 1/2 hr  Trip out of hole with 3rd plug and lay down.

2:00-3:00  1 hr  Trip in hole to 4th plug.

3:00-3:30  1/2 hr  Wash 15’ sand down to and release 4th plug.

3:30-4:00  1/2 hr’  Trip out of hole with 4th plug and lay down.

4:00-4:30  1/2 hr  Trip in hole to 5th plug.

4:30-5:00  1/2 hr  Wash 20’ sand down to and release 5th plug.

5:00-5:30  1/2 hr  Trip out of hole with 5th plug and lay down.

5:30-6:00  1/2 hr  Trip in hole to 6th plug.

6:00-6:30  1/2 hr  Wash 12’ sand down to and release 6th plug.

6:30-7:30  1 hr  Trip out of hole with 6th plug and lay down. Shut B.O.P. and brine up pump. Drain hoses. Shut down for the night.

Figure 12-9e. St. Colfax 3-28 HD Daily Completion Report while drilling, 2/28/2008.
### TIME TICKET - Consulting

**Date:** 2/29/2008  
**Employee:** Dale Schellie  
**Well name/number:** St. Colfax 3-28 HD  
**Rig:** Advanced #124  
**RATE:** $650.00

**Description of work performed:**

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:30-8:00</td>
<td>1/2 HR Trip in hole to 7th plug.</td>
</tr>
<tr>
<td>8:00-8:30</td>
<td>1/2 hr Wash 15'sand down to and release plug.</td>
</tr>
<tr>
<td>8:30-9:30</td>
<td>1 hr Trip out of hole with 7th plug and lay down.</td>
</tr>
<tr>
<td>9:30-10:30</td>
<td>1 hr Trip in hole to 8th plug.</td>
</tr>
<tr>
<td>10:30-11:00</td>
<td>1/2 hr Wash 5' of sand down to and release plug.</td>
</tr>
<tr>
<td>11:00-12:30</td>
<td>1 1/2 hr Trip out of hole with 8th plug and lay down.</td>
</tr>
<tr>
<td>12:30-2:30</td>
<td>2 hrs Trip in hoel with seating nipple to wash to bottom.</td>
</tr>
<tr>
<td>2:30-5:30</td>
<td>3 hrs Reverse circulate hole clean at 2360'. Work and turn tubing.</td>
</tr>
</tbody>
</table>

Figure 12-9f. St. Colfax 3-28 HD Daily Completion Report while drilling, 2/29/2008.
The document contains a time ticket for a consulting job performed on March 1, 2008, by Dale Schellie, the employee. The well name/number is St. Colfax 3-28 HD, with the rig being Advanced #124. The rate charged is $650.00.

**Date:** 3/1/2008  
**Employee:** Dale Schellie  
**Well name/number:** St. Colfax 3-28 HD  
**Rig:** Advanced #124  
**Rate:** $650.00

### Description of work performed:

<table>
<thead>
<tr>
<th>Time</th>
<th>Duration</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:00-10:30</td>
<td>3 1/2 hrs</td>
<td>Reverse circulate hole clean. Work and turn tubing while reverse circulating.</td>
</tr>
<tr>
<td>10:30-12:00</td>
<td>1 1/2 hrs</td>
<td>Nipple down B.O.P. and install wellhead. Flush tubing with 40 barrels of water.</td>
</tr>
<tr>
<td>12:00-3:00</td>
<td>3 hrs</td>
<td>Pick up standing valve and perforated joint and trip in hole with 1.9 tubing.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Seating check valve assembly. Cut and thread 1.9 tubing.</td>
</tr>
<tr>
<td>3:00-6:00</td>
<td>3 hrs</td>
<td>Clean half tank with A-1. Rig down workover rig. Plumb up wellhead and move equipment off location.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>74 joints of 2 7/8&quot; tubing set at 2324.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>68 joints of 1.9 steel tubing set at 2324'</td>
</tr>
</tbody>
</table>

Figure 12-9g. St. Colfax 3-28 HD Daily Completion Report while drilling, 3/1/2008.
12.2. **State Colfax #2-28 HD (21-019-58748-0000)**

12.2.1. **Well Drilling Acronym List**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD</td>
<td>Base of Drift</td>
</tr>
<tr>
<td>CBL</td>
<td>Cement Bond Log</td>
</tr>
<tr>
<td>CCL</td>
<td>Casing Collar Log</td>
</tr>
<tr>
<td>CIBP</td>
<td>Cast Iron Bridge Plug</td>
</tr>
<tr>
<td>CSG</td>
<td>Casing</td>
</tr>
<tr>
<td>DDC</td>
<td>Directional Drilling Contractors</td>
</tr>
<tr>
<td>ESP</td>
<td>Electrical Submersible Pump</td>
</tr>
<tr>
<td>KCL</td>
<td>Potassium Chloride</td>
</tr>
<tr>
<td>KOP</td>
<td>Kick Off Point</td>
</tr>
<tr>
<td>LT&amp;C</td>
<td>Long Threads and Collars</td>
</tr>
<tr>
<td>MIRU</td>
<td>Move In and Rig Up</td>
</tr>
<tr>
<td>MWD</td>
<td>Measurement While Drilling</td>
</tr>
<tr>
<td>MWL</td>
<td>Measurement Wire Line</td>
</tr>
<tr>
<td>PBTD</td>
<td>Plug Back Total Depth</td>
</tr>
<tr>
<td>RD</td>
<td>Rig Down</td>
</tr>
<tr>
<td>RU</td>
<td>Rig Up</td>
</tr>
<tr>
<td>TD</td>
<td>Total Depth</td>
</tr>
<tr>
<td>TIH</td>
<td>Trip In Hole</td>
</tr>
<tr>
<td>TOH</td>
<td>Trip Out of Hole</td>
</tr>
<tr>
<td>TVD</td>
<td>True Vertical Depth</td>
</tr>
</tbody>
</table>

12.2.2. **Drilling Prognosis**

STATE COLFAX #2-28 HD (AKA: State Colfax #11-21 HD)  
**DRILLING PROGNOSIS**  
(December 13, 2007)

Note: Pitless location

1. MIRU.
2. Drill 12-1/4” hole to KOP at approximately 500’.
3. RU DDC. TIH with directional tools and drill surface hole ahead to an angle of approximately 30 degrees at surface casing point.
   
   Note: Surface CSG point shall be 100’ TVD below BOD.
4. Run 32# J-55 8-5/8” CSG to TD and cement to surface.
5. Drill out cement and shoe.
6. TIH with directional tools and 7-7/8” bit. Test CSG and shoe.
   
   **Consider drilling out with a minimum 7% brine solution (8.8 #/gallon or greater) of light brine or KCL.**
7. RU Geologist and Hotwire.
8. Drill ahead in accordance with directional drilling plan, building to an angle across the Lachine and Norwood of approximately 75 degrees.

9. Once the base of the Lachine has been reached, allow bit angle to fall while drilling approximately 400’ md of rat hole.

10. RD Mud Logger.

11. Run 5-1/2” 15.5# J-55 LT&C CSG to TD and cement to surface.

12. RD MO
12.2.3. Well Bore Schematic

Colfax 29

Figure 12-10. Planned well bore schematic for the project demonstration well, State Colfax 2-28 HD in Benzie County, MI.
12.2.4. Directional Survey

Figure 12-11. Diagram of directional survey performed on the State Colfax 2-28 HD well in Benzie County, MI.
12.2.5. Gamma Ray Log along Well Path

Figure 122-12. Gamma Ray log and perforation intervals shown along the deviation survey of the State Colfax 2-28 HD well in Benzie County, MI. This lateral shows that multiple perforation zones allow greater access to gas resources along the well path as compared to vertical wells.
12.2.6. **Colfax 2-28 HD Daily Production Data**

![Graph: Daily Gas Production - 2008 St. Colfax #2-28 HD](image)

**Figure 12-13.** Daily gas production at the St. Colfax 2-28 HD well in Benzie County, MI. This well was drilled near the project demonstration well, and shows a sharp increase in production in October when a pump was installed to pump out the gas.
12.2.7. Record of Well Drilling

Michigan Department of Environmental Quality - Office of Geological Survey

Record of Well Drilling or Deepening

Required by authority of Part 615, Subpart A, Well Drilling or Part 616, Subpart A, Mineral Wells, of Act 411, PA 1986, as amended. Non-submission and/or falsification of this information may result in fines and/or imprisonment.

**Record of Well Drilling**

**(Submit 3 copies within 60 days of drilling completion.)**

- **API number:** 21-019-58748-00-00
- **Well name and number:** State Colfax #2-28 HD
- **Part 615 Oil/Gas Well**
- **Part 625 Mineral Well**
- **Name and address of permittee:** Jordan Development Company, L.L.C.
  1503 Garfield Road North
  Traverse City, MI 49686
- **Surface location:** SE 1/4 of NE 1/4 of SW 1/4 Section 21, T25N R13W
- **Township:** Benzie
- **County:**
- **Colfax:**
- **Footages:**
  - North/South: 1598 ft.
  - East/West: 2110 ft.
- **Location:**
  - Directionally drilled - check one:
    - Yes
    - No
- **Previous permit numbers:**
- **Subsurface location:**
  - If directionally drilled:
    - SW1/4 of SE 1/4 Section 21, T25N R13W
- **Date drilling began:** 1-2-2008
- **Date drilling completed:** 1-6-2008
- **Driller:** 2713’ MD
- **Log N/A**
- **Formation at total depth:** Traverse Limestone
- **Date of well:**
  - From:
    - K.B. 893.7 ft. R.F.
    - 95 ft. from South line
  - To:
    - R.T.
    - 2997 ft. from West line
  - Grid 825 ft.
  - Feet drilled - cable tools
  - Feet drilled - rotary tools
- **Elevations:**
- **Casing, Casing Liners and Operating Strings**

<table>
<thead>
<tr>
<th>Size</th>
<th>Where set</th>
<th>Cement</th>
<th>T.O.C.</th>
<th>Ft. pulled</th>
<th>Formation</th>
<th>F.U.</th>
<th>L.C.</th>
<th>Depth</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 3/8”</td>
<td>7’</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 5/8”</td>
<td>802’ MD</td>
<td>310’ax</td>
<td>Surface</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 1/2”</td>
<td>2712’ MD</td>
<td>445’ax</td>
<td>Surface</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Water Fill Up (F.U.) or Lost Circulation (L.C.)**

**Gross Pay Intervals**

**All Other Oil and Gas Shows Observed or Logged**

<table>
<thead>
<tr>
<th>Formation</th>
<th>Oil or Gas</th>
<th>From</th>
<th>To</th>
<th>Where Observed (X)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antrim Shale</td>
<td>Gas</td>
<td>1477’</td>
<td>2227’</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**Depth Correction**

**Deviation Survey**

**Plugged Back**

**Geophysical / Mechanical Logs**

**Notice:** Report complete sample and formation record, coring record, and drill stem test information on reverse side.

**Certification:** I state that I am authorized by said owner. This report was prepared under my supervision and direction. The facts stated herein are true, accurate and complete to the best of my knowledge.

**Date:**

**Name and title (print):** Benjamin J. Nieto, Authorized Agent

**Signature:**

(Michigan Department of Environmental Quality)

126 Michigan Technological University

DE-FC26-06NT42931

Figure 12-14. St. Colfax 2-28 HD Record of Well Drilling.
# Formation Record

![Image](https://via.placeholder.com/150)

## Table of Formations

<table>
<thead>
<tr>
<th>Level</th>
<th>From</th>
<th>To</th>
<th>Formation Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>MD 665'</td>
<td>1152'</td>
<td>BOD ELLSWORTH- SH-MGRRY, LT GRY, PLTY/BLKY, GRNY, ST-FRM, DNS, S LIMY, NO FLOR</td>
<td></td>
</tr>
<tr>
<td>MD 665'</td>
<td>1281'</td>
<td>UPPER ANTRIM- SH-MD GRY, LT GRY, DRK BRN, PLTY/BLKY, GRNY, SFT-FRM, DNS, SL LMY, SM TR SPORE FLOR</td>
<td></td>
</tr>
<tr>
<td>MD 665'</td>
<td>1477'</td>
<td>LACHINE-SH DRK BRN, DRK GRY, BLK, HD, DNS, BRTLE, PLTY/BLKY, GRNY, DNS, NO FLOR</td>
<td></td>
</tr>
<tr>
<td>MD 665'</td>
<td>1886'</td>
<td>PAXTON- SH GRY, DRK BRN, LT GRY, MD, FRM-HD, DNS, GRNY, PLTY/BLKY, 5% YWL SPORE FLR NORWOOD- SH- DRK BRN, DRK GRY, BLK, OCC MD GRY, HD, PLTY/BLKY, BRT, DNS, 5% YWL SPR FLR</td>
<td></td>
</tr>
<tr>
<td>MD 665'</td>
<td>2116'</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>MD 665'</td>
<td>2227'</td>
<td>TRAVERSE FORMATION- SH-DRK BRN, MD BRN, BLK, MD GRY, LT GRY, B/U, HD, L MST-DRK BRN, MD GRY, LT GRY, BLU BLK, MD, FRM-HD, BLKY/PLTY, SM TR YWL SPORE FLOR</td>
<td></td>
</tr>
<tr>
<td>MD 665'</td>
<td>2390'</td>
<td>TRAVERSE LIMESTONE- L MST-DRK BRN, MD BRN, BLKY, MICXLN, TT, HD, DNS SH-MD GRY, LT GRY, LT GRY, BLU BLK, MD, FM-HD, BLKY/PLTY, SM TR YWL SPORE FLOR</td>
<td></td>
</tr>
<tr>
<td>MD 665'</td>
<td>2713'</td>
<td>1524' TD LIST ATTACHMENTS Certification of Casing and Sealing of Surface Hole Directional Survey Mud Log</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 12-15.** St. Colfax 2-28 HD Formation Record of horizontal lateral.
12.2.8. Record of Well Completion

MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY – OFFICE OF GEOLOGICAL SURVEY

RECORD OF WELL COMPLETION

By authority of Part 615 or Part 625 of Act 451 PA 1994, as amended. Non-submission and/or falsification of this information may result in fines and/or imprisonment.

(Submit 3 copies within 60 days of well completion.)

Part 615 Oil/Gas Well
Part 625 Mineral Well

Permit number/deepening permit no. API number
58748 21-019-58748-00-00

Type of well (after completion)
Gas

Well name & number
State Colfax #2-28 HD

Name and address of permittee
Jordan Development Company, L.L.C.
1503 Garfield Road North
Traverse City, MI 49686

Directionally drilled (check one) Yes ☑ No ☐
Previous permit numbers N/A
Total depth of well M.D. 2713’ T.V.D. 1524’

Surface location
SE ¼ of NE ¼ of SW ¼ Section 21 T 25N R 13W
Subsurface location (if directionally drilled)
SW ¾ of SW ¾ of SE ¾ Section 21 T 25N R 13W

Township
Colfax
County
Benzie

Footages:
598 ft. from South line and 2110 ft. from West line of Sec.
95 ft. from South line and 2997 ft. from West line of Sec.

Part 615 - oil/gas wells
Part 625 - mineral wells

Date well completed
2-23-2008

Producing formation(s)
Antrim Shale

Injection formation(s) N/A

Date of first injection N/A

Disposal formation(s) N/A

Solution formation(s) N/A

COMPLETION INTERVALS(S)

<table>
<thead>
<tr>
<th>Date</th>
<th>Number holes</th>
<th>Perforation or open hole interval</th>
<th>Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-20-2008</td>
<td>4 SPF</td>
<td>2210'-2215'</td>
<td>X</td>
</tr>
<tr>
<td>2-22-2008</td>
<td>4 SPF</td>
<td>1923'-1928',1905'-1910',1892'-1902',1842'-1852',1829'-1834', 1782'-1787',1766'-1771',1742'-1752',1713'-1718',1703'-1708', 1684'-1689'</td>
<td>X</td>
</tr>
<tr>
<td>2-23-2008</td>
<td>4 SPF</td>
<td>1659'-1664',1633'-1638',1616'-1626',1592'-1597',1570'-1575', 1543'-1548',1542'-1547',1322'-1332',1310'-1315'</td>
<td>X</td>
</tr>
</tbody>
</table>

STIMULATION BY ACID OR FRACTURING

<table>
<thead>
<tr>
<th>Date</th>
<th>Interval treated</th>
<th>Materials and amount used</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-22-2008</td>
<td>1923'-1928',1905'-1910',1892'-1902'</td>
<td>15% Acid: 1000 gals, Sand: 27,000# 2040 6,000# 12/20</td>
</tr>
<tr>
<td>2-22-2008</td>
<td>1842'-1852',1829'-1834'</td>
<td>15% Acid: 1000 gals, Sand: 26,000# 2040 5,300# 12/20</td>
</tr>
<tr>
<td>2-22-2008</td>
<td>1782'-1787',1766'-1771',1742'-1752'</td>
<td>15% Acid: 1000 gals, Sand: 26,300# 2040 4,100# 12/20</td>
</tr>
<tr>
<td>2-22-2008</td>
<td>1713'-1718',1703'-1708',1684'-1689'</td>
<td>15% Acid: 1000 gals, Sand: 25,500# 2040 5,000# 12/20</td>
</tr>
<tr>
<td>2-23-2008</td>
<td>1659'-1664',1633'-1638',1616'-1626'</td>
<td>15% Acid: 1000 gals, Sand: 27,700# 2040 6,000# 12/20</td>
</tr>
<tr>
<td>2-23-2008</td>
<td>1592'-1597',1570'-1575',1543'-1548'</td>
<td>15% Acid: 1000 gals, Sand: 19,600# 2040</td>
</tr>
<tr>
<td>2-23-2008</td>
<td>1342'-1347',1322'-1332',1310'-1315'</td>
<td>15% Acid: 1000 gals, Sand: 26,000# 2040 6,700# 12/20</td>
</tr>
</tbody>
</table>

PRODUCTION TEST DATA

<table>
<thead>
<tr>
<th>Oil Bbls/day</th>
<th>Gravity °API</th>
<th>Condensate Bbls/day</th>
<th>Gas MCF/day</th>
<th>Water Bbls/day</th>
<th>H2S Grains/100 ft3</th>
<th>B.H.P. and depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>150 est.</td>
<td>400 est.</td>
<td>N/A</td>
<td>N/A</td>
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</table>

CERTIFICATION: “I state that I am authorized by said owner. This report was prepared under my supervision and direction. The facts stated herein are true, accurate and complete to the best of my knowledge.”

Name and title (print or type) Benjamin J. Nieto, Authorized Agent

Submit to: OFFICE OF GEOLOGICAL SURVEY
MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY
PO BOX 30256
LANING MI 48909-7756

EQP 7130 (rev. 8/2004)

Figure 12-16. St. Colfax 2-28 HD Record of Well Completion including perforation and fracturing data.
## 12.2.9. Completion Report

**North Central Production Inc**  
PO Box 1133  
Gaylord MI 49734  
Ph: 989-732-6772  
Fax: 989-732-3024  
Email: dalemark@voyager.net

**TIME TICKET - Consulting**

<table>
<thead>
<tr>
<th>Date</th>
<th>2/20/2008</th>
<th>Employee:</th>
<th>Dale Schellie</th>
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<td>Well name/number:</td>
<td>St. Colfax 2-28 HD</td>
<td>Rig:</td>
<td>Advanced #124</td>
</tr>
<tr>
<td>RATE:</td>
<td>$650.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Description of work performed:**

- **7:00-9:00** 2 hrs  Rig up Michigan Wireline
- **9:00-12:00** 3 hrs  Pick up perf gun and gamma ray tool and push in hole with 2 3/8" tubing.  Log repeat section
- **12:00-1:00** 1 hr  Push tools back down hole. Stand 17 joints back in derrick. Short in gamma ray.
- **1:00-3:00** 2 hrs  Trip out of hole with 2 3/8" tubing.
- **3:00-4:00** 1 hr  Re-head wireline tool
- **4:00-5:30** 1 1/2 hrs  Push gamma ray and perf gun in hole
- **5:30-7:30** 2 hrs  Perforate 2210’- 2215’ 4 S.P.F.  Trip out of hole. Log with gamma ray to 750’  Nipple down Hydril and shut in well for the night.

Figure 12-17a. St. Colfax 2-28 HD Daily completion report, 2/20/2008.
TIME TICKET - Consulting

Date: 2/22/2008
Employee: Dale Schellie

Well name/number: St. Colfax 2-28 HD
Rig: Advanced #124

RATE: $650.00

Description of work performed:

7:00-11:30 4 1/2 hrs Fill frac tanks; rig up Michigan Wireline; pump down dual fire perf gun.
  Perf 1923' - 1928' and 1905' - 1910' 4 S.P.F. Pick up plug and dual fire perf gun. Pump plug and dual fire perf gun down hole. Set plug at 1975'.
  Perf 1892' - 1902' 4 S.P.F. Rig down Michigan Wireline.

11:30-1:00 1 1/2 hr Rig up Halliburton. Perf 1923' - 1928', 1905' - 1910' and 1892' - 1902' 4 S.P.F.
  Break formation at 1081 PSI. Pumped 1000 gallons 15% acid I.S.I.P. 1899 psi
  Pumped 27,000 # 20/40 sand and pump 6,000# 12/20 sand. Monitor shut in pressures. Rig down Halliburton. Shut in head.

1:00-2:30 1 1/2 hr Rig up Michigan Wireline. Pick up dual fire perf gun. Pump dual fire perf gun down hole. Perf 1842'-1852' and 1829-1834 4 S.P.F. Pick up plug. Pump plug down hole. Set plug at 1870' Rig down Michigan Wireline.

2:30-3:30 1 hr Rig up Halliburton. Perf 1842'-1852' and 1829'-1834' 4 S.P.F. Break formation at 1344 PSI. Pumped 1,000 gallons 15% acid I.S.I.P. 808 PSI
  Pumped 26,000# 20/40 sand, pumped 5,300# 12/20 sand. Monitor shut in pressures. Shut in head. Rig down Halliburton.

3:30-4:30 1 hr Rig up Michigan Wireline. Pick up dual fire perf gun. Pump dual fire perf gun down hole. Perf 1782'-1787' and 1766'-1771' 4 S.P.F. Pick up plug and dual fire perf guns. Pump plug and dual fire perf gun down hole. Set plug at 1812' and perf 1742'-1752' 4 S.P.F. Rig down Michigan Wireline.

4:30-6:30 2 hrs Rig up Halliburton. Perf 1782'-1787', 1766'-1771' and 1742'-1752' 4 S.P.F.
  Break formation at 1038 PSI. Pumped 1000 gallons 15% acid I.S.I.P. 1048 PSI. Pumped 26300# 20/40 sand and pumped 4100# 12/20 sand. Monitor shut in pressures. Shut in head; Rig down Halliburton.

6:30-7:30 1 hr Rig up Michigan Wireline. Pick up dual fire perf gun. Pump dual fire perf gun down hole. Perf 1713'-1718' and 1703'-1708' 4 S.P.F. Pick up plug and pick up dual fire perf gun. Pump plug and dual fire perf gun down hole. Set plug at 1730'. Perf at 1684'-1698' 4 S.P.F. Rig down Michigan Wireline.

7:30-10:00 2 1/2 hrs Rig up Halliburton. Perf 1713'-1718', 1703'-1708' and 1684'-1698' 4 S.P.F.
  Broke formation at 1130 PSI. Pumped 1000 gallons 15% acid I.S.I.P. 1111 psi
  Pumped 25500# 20/40 sand and pumped 5000# 12/20 sand. Monitor shut in pressure. Shut in head. Rig down Halliburton, iron off head. Shut down for the night. Brine up pump trucks and high pressure lines. Drain suction lines.

Figure 12-17b. St. Colfax 2-28 HD Daily completion report, 2/22/2008.
**TIME TICKET - Consulting**

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<td>Advanced #124</td>
</tr>
<tr>
<td>RATE</td>
<td>$650.00</td>
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**Description of work performed:**

- Fill frac tanks with water well throughout the night
- **7:00-9:30** 2 1/2 hrs  
  - Rig up Michigan Wireline. Pick up dual fire perf gun. Pump dual fire perf gun down hole.  
  - Perf 1659'-1664' and 1633'-1638' 4 S.P.F. Pick up plug and dual fire perf gun. Pump plug and dual fire perf gun down hole. Set plug at 1672' Perf 1616'-1626' 4 S.P.F. Rig down Michigan Wireline.

- **9:30-11:00** 1 1/2 hr  
  - Rig up Halliburton. Perf 1659'-1664', 1633'-1638' and 1616'-1626' 4 S.P.F. Break formation at 1267 PSI. Pumped 1000 gallons 15% acid I.S.I.P 894 PSI. Pumped 27700# 20/40 sand and pumped 6000# 12/20 sand. Monitor shut in pressure. Shut in well head. Rig down Halliburton.

- **11:00-12:30** 1 1/2 hr  
  - Rig up Michigan Wireline. Pick up dual fire perf gun. Pump dual fire perf gun down hole.  
  - Perf 1592'-1597 and 1570'-1575' 4 S.P.F. Pick up plug and pick up dual fire perf gun. Pump plug and dual fire perf gun down hole. Set plug at 1608' Perf at 1543'-1548' 4 S.P.F. Rig down Michigan Wireline.

- **12:30-1:30** 1 hr  
  - Rig up Halliburton. Perfs 1592'-1597', 1570'-1575' and 1543'-1548' 4 S.P.F. Break formation at 1141 PSI. Pumped 1000 gallons 15% acid I.S.I.P. 1180 PSI. Pumped 19600# 20/40 sand and pumped none #12/20 sand. Monitor shut in pressure. Shut in wellhead. Rig down Halliburton.  
  - We were only able to get to 1.50# 20/40 sand on this zone. Any higher would have screens us out. No 12/20 in this zone.

- **1:30-2:30** 1 hr  
  - Rig up Michigan Wireline. Pick up dual fire perf gun. Pump dual fire perf gun down hole.  
  - Perf 1342'-1347' and 1322'-1332 4 S.P.F. Pick up plug and pick up dual fire perf gun. Pump plug and dual fire perf gun down hole. Set plug at 1375' and perfs at 1310'-1315' 4 S.P.F. Rig down Michigan Wireline.

- **2:30-3:00** 1/2 hr  
  - Rig up Halliburton. Perfs 1342'-1347', 1322'-1332' and 1310'-1315' 4 S.P.F. Break formation at 1080 PSI. Pumped 1000 gallons 15% acid I.S.I.P 896 PSI.

- **3:00-4:00** 1 hr  
  - Pumped 26000# 20/40 sand and pumped 6700# 12/20 sand. Monitor shut in pressures. Shut in well.

- **4:00-5:30** 1 1/2 hr  
  - Rig down Halliburton. Lay down 2 3/8" tubing out of derrick.

- **5:30-8:00** 2 1/2 hrs  
  - Rig down workover rig. Move to St. Colfax 3-28 and spot. Move and spot tubing trailer. Spot half tank in place.

**Figure 12-17c. St. Colfax 2-28 HD Daily completion report, 2/23/2008.**
**TIME TICKET - Consulting**

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<td>Advanced #124</td>
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<tr>
<td>RATE</td>
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**Description of work performed:**

- 7:00-10:30  3 1/2 hrs  Flow well back. Rig up workover rig.
- 10:30-11:30  1 hr  Remove frac valve and nipple up B.O.P.
- 11:30-12:30  1 hr  Pick up on-off tool and trip in hole with 2 7/8" tubing.
- 12:30-1:00  1/2 hr  Wash down to first plug and release.
- 1:00-3:00  2 hrs  Trip out of hole with first plug.
- 3:00-4:00  1 hr  Trip in hole to second plug.
- 4:00-4:30  1/2 hr  Wash down to second plug and release.
- 4:30-5:30  1 hr  Trip out of hole with second plug.
- 5:30-7:00  1 1/2 hr  Trip in hole to third plug. Shut in B.O.P. and drain pump.

*Figure 12-17d. St. Colfax 2-28 HD Daily completion report, 2/24/2008.*
TIME TICKET - Consulting

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<td>Advanced #124</td>
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<tr>
<td>RATE</td>
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**Description of work performed:**

- **7:00-8:00** 1 hr Wash down to release 3rd plug.
- **8:00-9:30** 1/12 hr Trip out of hole with 3rd plug and lay down.
- **9:30-11:30** 2 hrs Trip in hole and wash down and release 4th plug. 45' of sand on top of this plug.
- **11:30-1:00** 1 1/2 hr Trip out of hole and lay down plug.
- **1:00-2:30** 1 1/2 hr Trip in hole to 5th plug. 75' of sand on 5th plug.
- **2:30-3:30** 1 hr Wash down to and release 5th plug.
- **3:30-4:30** 1 hr Trip out of hole with 5th plug and lay down.
- **4:30-6:00** 1 1/2 hr Trip in hole to 6th plug. 45' of sand on top of plug.
- **6:00-8:00** 2 hrs Wash down to and release 6th plug. Start tripping out of hole. Shut in well for the night.

**Figure 12-17e. St. Colfax 2-28 HD Daily completion report, 2/25/2008.**
TIME TICKET - Consulting

Date: 2/26/2008  Employee: Dale Schellie

Well name/number: St. Colfax 2-28 HD  Rig: Advanced #124

RATE: $325.00

**Description of work performed:**

- 7:00-7:30  1/2 hr  Trip out of hole with plug #6 and lay down.
- 7:30-8:30  1 hr  Trip in hole.
- 8:30-11:00  2 1/2 hr  Circulate 90' of sand off plug.
- 11:00-12:30  1 1/2 hr  J-on plug and release. Trip out of hole.
- 12:30-1:30  1 hr  Trip in hole to 8th plug.
- 1:30-3:30  2 hrs  Circulate 10' of fill off plug. Wash and release packer.
- 3:30-4:30  1 hr  Trip out of hole with 8th packer and lay down.
- 4:30-5:00  1/2 hr  Nipple down B.O.P.
- 5:00-6:30  1 1/2 hr  Trip in hole.
- 6:30-7:30  1 hr  Circulate out 20' of sand from below Norwood perfs. Circulate at 2700' T.D. Shut in well for the night.

Figure 12-17f. St. Colfax 2-28 HD Daily completion report, 2/26/2008.
**TIME TICKET - Consulting**

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<td>Rig</td>
<td>Advanced #124</td>
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<tr>
<td>RATE</td>
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**Description of work performed:**

- **7:00-10:00**  
  3 hrs  
  Reverse circulate hole clean. Small pieces of cement but no sand return.

- **10:00-11:00**  
  1 hr  
  Change out working head to wellhead.

- **11:00-2:00**  
  3 hrs  
  Pick up lift assembly and check valves, tripin hole, 2 7/8" seating nipple at 2647.26. Ran 78 joints of 1.9 steel tubing. Seat no-go in seating nipple.

- **2:00-6:00**  
  4 hrs  
  Cut and thread 1.9 steel tubing and pack off wellhead. Rig down workover rig. Clean sand out of half tank. Release light plant and generator. Pull pump out of water well.

*Figure 12-17g. St. Colfax 2-28 HD Daily completion report, 2/27/2008.*
13. Project Well Histories – Whitewater 9 in Grand Traverse County, MI

The Hubbell C1-9 well in the Whitewater 9 Field in Grand Traverse was drilled with the same cased hole, downward slanting configuration as the Colfax 29 wells. Production data is not yet available for this well, but the well bore schematic (Figure 13-1) and the cross sections of the gamma ray log with perforation intervals are shown in Figure 13-2. Figure 13-3 is the cross section of the Hubbell C1-9 horizontal well compared to the adjacent vertical brine disposal well, the Hubbell B1-9 SWD.

13.1. 21-055-57778-0000 Hubbell C1-9

O.I.L. Energy Corp.
Whitewater 9

Figure 13-1. Well bore schematic for the Hubbell C1-9 well in Grand Traverse County. The design of this well is similar to the project demonstration well, Colfax #3-28 HD, in Benzie County.
Figure 13-2. Gamma Ray log and perforation intervals shown along the deviation survey of the well path for the Hubbell C1-9 well in Grand Traverse County, MI.
Figure 13-3. Gamma Ray log and perforation intervals shown along the deviation survey of the well path for the Hubbell C1-9 well in Grand Traverse County, MI and shown in relation to subsea depth with the nearby brine disposal well, Hubbell B1-9 SWD.

Carbon dioxide (CO₂) is a natural byproduct of natural gas production in the Antrim Shale. Gas produced from the Antrim Shale contains 5-30% CO₂, which is chemically removed in CO₂ treating facilities before gas is sold. CO₂ is removed or diluted to a lower percentage (not more than 2%) to increase the heating capacity of the natural gas to the standards required for commercial natural gas.

The dilution process involves blending previously treated Antrim gas or non-Antrim gas (Niagaran Reef or Prairie du Chien gas) containing a low percentage of CO₂ (less than 0.75%) with Antrim natural gas containing a high percentage of CO₂ to bring the combined percentage to 2% or less. Extracted CO₂ is either vented into the atmosphere, injected into Enhanced Oil Recovery (EOR) flood projects in Niagaran Reef oil fields, or sequestered into deep geologic formations.

Natural gas producers transport their gas to receipt points. MichCon then transports the untreated natural gas to CO₂ treatment facilities, which remove or blend gases to reduce the amount of CO₂. MichCon then delivers the gas back to the producers at delivery points (Figure 14-1).

During the time this project was active, all co-produced carbon dioxide was separated from the gas stream and vented to the atmosphere. The production graphs in Figures 9-3 and 9-4 and the maps in Figures 9-19 and 9-20 show roughly how much of this CO₂ was ultimately vented. It appears that the exploitation of these immature source rocks, such as the Antrim, carries a double carbon dioxide penalty, one when the gas is produced and another when it is burned.

We had hoped to address the disposal of the produced (not burned) CO₂ in a more comprehensive way, but as of 2009 the only way to economically dispose of it is to vent it to the atmosphere. Even though CO₂ is separated from the gas stream (to render it marketable) the costs of compression, transport and injection (into nearby reefs) have proven a decisive detriment. Previous DOE studies, such as the Dover 36 CO₂ injection project carried out by this team, showed that is technically feasible to reinject the co-produced carbon dioxide but it was economically unpractical, mainly due to the high compression costs. Another problem, related to the compression costs, is that once the CO₂ is compressed it becomes a valuable commodity in its own right and is valuable for reinjection numerous times for oil recovery.

We did not have an opportunity to explore disposal of the LINGO carbon dioxide, but we feel that it would be similar, at least in 2009, to the Dover project mentioned above. To date there does not appear to have been any technique(s) developed, beyond compression and injection into an EOR project that producers in the Michigan Basin are willing to consider. Considering all the shallow immature shale gas that is either being produced or likely to be produced, this appears to be a serious problem that needs to be addressed in its own right. Since the separation, compression, transportation and injection processes all cost money and add to the cost of operations, producers have no incentive to do any of these things. It would appear that a
consumption tax would be about the only answer, and the only solution we can suggest that would have a good chance of removing the co-produced carbon dioxide.

Figure 14-1. Map showing the locations of the pipelines, CO₂ Treating Plants (triangles), and Delivery Points (squares) under the operation of the MichCon Gathering Company.
15. Project Databases

15.1. API Numbers explanation

**Source:** The Michigan Department of Environmental Quality (MI DEQ)

**url:** [http://www.michigan.gov/deq/0,1607,7-135-3311_4111_4231-143930--,00.html](http://www.michigan.gov/deq/0,1607,7-135-3311_4111_4231-143930--,00.html)

The API number is a number the American Petroleum Institute uses to identify oil and gas wells throughout the country. The number is 14 digits which are essentially broken into four parts. Example: 21-137-44190-0000

The first two digits are 21 which is the code for Michigan.

The next three digits are the API county number, starting with 001 for Alcona, and stepping up by two for each county until the last county, Wexford, number 165 is reached. In the example the 137 represents Otsego County. There is a table of counties in the well location download.

The next five digits are the permit number. This is a sequential permit number issued by the Geological Survey. Until 1998 the permit number was the only identification the Geological Survey used and for our purposes it is still pretty much all we need to identify a well. In the example the permit number is 44190.

The last four digits are for different kicks of the same well; for example, horizontal drills, lost holes, or directional drills off the main hole. Someone visiting the site would only see one well, but there may be several API numbers for that one well, all having different bottom hole locations. The main number usually ends of four zeros. There are special cases where the last four digits start with 7 (some brine disposal wells) 8 (some mineral wells) and 9 (wells drilled before permits were issued). There are a few inconsistencies with the last four digits since Michigan didn't use API numbers until 1998 and they had to be retroactively assigned.

If looking at formation tops, it usually is only necessary to use the 0000 kick as any other kicks should pretty much contain the same data (or be null).
15.2. Well Locations Database

Source: The Michigan Department of Environmental Quality (MI DEQ)

url: http://www.michigan.gov/deq/0,1607,7-135-3311_4111_4231-97870--,00.html

Database Name: ogs-well-locations_222016_7.zip

Database Type: Zipped file of a Microsoft Access database.

Start Date of Electronic Database: 1982

Data: Well locations for permitted oil and gas wells that are not confidential. It does not include locations for mineral wells, confidential wells, or wells with permits higher than 59,501 (Update from September 30, 2008). This database is updated and reposted periodically by the MI DEQ.

Database Tables: Company, Counties, well locations, Well Status Codes, Well Type Codes

DEQ Contact: Roger Nelson, 517-241-1502, nelsonrs@michigan.gov

How coordinates are determined:
In the Well Coordinates table is there a Source_Loc field for both the surface and bottom hole locations. The code represents how the lat/longs were determined.

C = Calculated by computer using the footages from the section lines.
G = GPSed by field staff.
M = Manually taken by plotting on a map. In these cases the computer couldn't calculate and there was no GPS reading.

The coordinate systems used:
X-Y data is in NAD 1983 Michigan GeoRef meters
Lat-long is NAD 1983

Abbreviations and explanation
Wh_ = well head -prefix used in column headings for surface locations
BH_ = bottom hole - prefix used on column headings for bottom of the hole

Slant = can be V (vertical), D (directional), or H (Horizontal)
for Vertical wells, the surface and bottom hole locations should be the same

Twpn = Township Number
Twpd = Township Direction - combine with Twpn to get the Town as 27N

RngN = Range Number
RngD = Range Direction - combine with RngN to get the Range as 6W
15.3. Formation Tops

Source: The Michigan Department of Environmental Quality (MI DEQ)

url: http://www.michigan.gov/deq/0,1607,7-135-3311_4111_4231-143855--,00.html

Database Name: ogs-oilandgas-formationtops_247657_7.zip

Database Type: Zipped file of a Microsoft Access database.

Start Date of Electronic Database: 1982

Data: Formations tops are the depth at which a formation is found, except for the glacial drift. In this case only, it is the bottom of the formation. Well elevations are also recorded in this database (Update from September 4, 2008). The database is updated and reposted periodically by the MI DEQ.

Database Tables: Elevations, Formation codes, FormationTops, Method Obtained, Reference point codes

DEQ Contact: Roger Nelson, 517-241-1502, nelsonrs@michigan.gov

All wells do not have data.
Wells that have a status of LOC (location), TP (terminated permit), or type of PW (permitted well) either have not been drilled yet or the company has not yet reported the information to the MI DEQ. Older wells may have data in the paper files that hasn't been entered in the computer. Wells have been drilled since 1929, but the MI DEQ began the electronic database in 1982.

Elevation Data
There are three elevations: Kelly Bushing, GRound level, & Drilling rig Floor. Ref_Tops gives a code that tells which elevation was used in picking the tops Location_ID is the same as the API number.

Formation Tops Data
AAPG_Cd is the formation identification code
Top_ is Measured Depth
TVD is True Vertical Depth (for deviated or horizontal well bores)
Meth_Obtnd is the method of how the data was gathered.

Meth_Obtnd Definition
G Michigan Geological Survey (MIGS) L Company Log Picks
Picks S Sample Picks
GL MIGS & Company Log Picks GLS MIGS & Company & Sample Picks
C Well Card LS Company & Sample Picks
GS MIGS and Sample Picks
15.4. Production Data

15.4.1. Michigan DEQ Production Data

Source: The Michigan Department of Environmental Quality (MI DEQ)

url: http://www.michigan.gov/deq/0,1607,7-135-3311_4111-4231-97834--,00.html

Database Name: ogs-oilandgas-production_217831_7.zip

Database Type: Zipped file of a Microsoft Access database.

Start Date of Electronic Database: 1982

Data: Oil, Gas, and water production is tracked monthly by Production Unit (PRU). PRUs consist of one or more wells in a Field identified by Producing Formation. (Update from September 8, 2008). This database is updated and reposted periodically by the MI DEQ.

Database Tables: Companies, Counties, date of first production, Fields, Production, Products and units, PRU Master PRU Wells, Well Status Codes, Well Type Codes.

DEQ Contact: Roger Nelson, 517-241-1502, nelsonrs@michigan.gov

About the Data

Michigan started issuing permits for wells in 1927. There were some wells drilled before then, and a few of them are still producing. Computerized tracking of oil and gas production began in Michigan in 1982, but oil production for the Albion-Scipio field goes back to 1969 (gas production is missing). Prior information is only available from microfilm.

At first, only prorated wells (wells that had production regulated) were tracked. These were wells in the Salina, Niagaran, and deeper formations.

In 1997, rules were changed to track production on all wells in Michigan. The production information you download is not all the production in the State, but does include everything in the MI DEQ database.

Cumulative production is not available. If a prorated well started producing after 1982, a cumulative can be found by running a query that totals the monthly production. If a well is not prorated but started producing since 1997 a cumulative can be calculated similarly.

PRUs: Production in Michigan is kept by PRUs or PRoduction Units. A PRU may have only one well, in which case the production for that PRU is the well production. A lot of PRUs have more than one well, especially in the Antrim formation. There is no way to break out production by individual well in these cases. To find out what wells are in a PRU, check the PRU Wells table.
Because of electronic filing of production, we have been able to change some of our PRUs with lots of wells in them to individual well PRUs. This may result in some confusion since PRU numbers have changed for various permit numbers. We believe that most people would rather have the individual well production when we can provide it. Electronic filing has helped us do this. Most of these changes took place near the end of 2004. Consult the PRU Wells table to find the Permit Number - PRU relationships.

**Units and Definitions**

Gas is measured in mcf (thousand cubic feet) at 14.73 psi

**Liquids** (oil, water, ngls, condensate) are in (42 gallon) bbls.

Oil is crude oil. Water is also called brine.

ngls (Natural Gas Liquids) and condensate are both very light hydrocarbons that drop out of gas during processing.
15.4.2. Michigan Public Service Commission Gas Production Data

Source: Michigan Public Service Commission (MPSC)

url: http://www.cis.state.mi.us/mpsc/gas/prodrpts.htm

Database Name: awells.csv
aprod_a_thru_g.csv
aprod_h_thru_m.csv
aprod_n_thru_s.csv
aprod_t.csv
aprod_u_thru_z.csv

Database Type: multiple comma separated value (csv) files.

Starting Date of Electronic Database: 1990

Data: Antrim Gas, co-produced Carbon dioxide, and Water production is tracked monthly by Project (FieldName). The MPSC reports production from 1990. (Update from July 10, 2007). This database is updated and reposted periodically by the MPSC.

MPSC Contacts: Office Phone: 517.241.6191
Patricia Poli, 517.241.6141, pmpoli@michigan.gov
John King, Supv., 517.241.6132, jtking@michigan.gov

Definitions Location is the Section-Township-Range of the section that contains most of the wells in the project.

FieldName does not refer to oil or gas fields, but to gas-producing projects. These are similar to and partially correspond to the MI DEQ production units. For example, the MPSC shows 632 projects in 2005 producing 143,917,496 mcf, and the MI DEQ shows 1196 Antrim Production Units in 2005 producing 143,945,692 mcf.

Antrim Production- what is reported
In the past, Antrim monthly production volumes reported to the MPSC have been either produced gas or sales gas. Produced gas volumes include carbon dioxide gas. Currently, a few Antrim projects produce gas with as much as 30% carbon dioxide. Sales gas volumes do not include the carbon dioxide gas. MPSC staff have been working with producers to standardize Antrim gas production reporting so that all producers report sales gas volumes. Prior to June 1998, about one-half of the Antrim production reporters were reporting produced gas volumes with the other half reporting sales volumes. Since June 1998, the producers that were previously reporting produced gas volumes have switched or are working on making the change to reporting a sales gas volume. Specifically, the MPSC is requiring a "delivered volume", which is the...
volume of the gas at the delivery point where the gas leaves Michigan Consolidated Gas Company's (or a Michigan Consolidated Gas Company affiliate) pipeline system. All producers should be reporting delivered volumes by January 2000.

**Additional Production Data**
The above data files are for Antrim Gas Production only. The MPSC maintains separate sets of gas production data files for the following:

- **Casinghead:** gas produced from oil wells
- **Dry Gas:** non-Antrim and non-PdC
- **PDC:** Prairie du Chein (PdC) formation
15.4.3. Michigan Tech Historic Production Data

Source: Michigan Technological University (MTU) and the Geological Survey Division of the Michigan Department of Natural Resources

url: http://www.geo.mtu.edu/svl/LINGO/downloads/

Database Name: MI_Annual_Oil-Gas_Production.mdb

Database Type: Microsoft Access 2003 database

Starting Date of Electronic Database: 2004

Data: Annual oil and gas production data was keyed in from publications created by the Geological Survey Division of the Michigan Department of Natural Resources. These publications contain annual oil and gas production summaries by Field and producing formation for years 1925 through 1986. The MI DEQ production data is then queried and added to this database to get a complete annual production history by field. (Update from July 10, 2007). This database is updated and reposted periodically by MTU.

MTU Contacts: Carol J. Asiala, 906-487-2033, cjasiala@mtu.edu
James R. Wood, 906-487-2894, jrw@mtu.edu
15.5. **Well Logs**
The LAS files used in the project cross sections are available for download under the “Data Downloads” link on the LINGO website [http://www.geo.mtu.edu/svl/LINGO/](http://www.geo.mtu.edu/svl/LINGO/)

15.5.1. **Michigan DEQ Raster Log Images**

**Source:** The Michigan Department of Environmental Quality (MI DEQ)

**url:** [http://www.michigan.gov/deq/0,1607,7-135-3311_4112_32722-150609--,00.html](http://www.michigan.gov/deq/0,1607,7-135-3311_4112_32722-150609--,00.html)

**Database Name:** RasterLog inventory m09 d11 y2008.xls (name changes with date of latest update)

**Database Type:** Excel reference spreadsheet and collection of TIF image files

**Start Date of Electronic Database:** 2005

**DEQ Contact:** Steve Wilson, wilsons15@michigan.gov

**About the Data**
As of September 2008, the Office of Geological Survey has converted 57,449 paper wire-line logs to digital files. These geophysical logs are one of the tools commonly used in the interpretation of subsurface information in the exploration for oil and gas and, more recently, carbon sequestration activities. The resulting digital files are called RasterLogs (digital Raster files of the geophysical Logs). The digital files are in an ‘industry standard' TIF format.

15.6. **Gravity Data**

**Michigan Bouguer Anomaly Data**
Michigan Bouguer Anomaly data was obtained from the University of Texas at El Paso website for GeoNet – United States Gravity Data Repository System. ([http://paces.geo.utep.edu/research/gravmag/gravmag.shtml](http://paces.geo.utep.edu/research/gravmag/gravmag.shtml)).

The original data was in NAD27 latitude/longitude coordinates. The Software program, Global Mapper, was used to convert the coordinate system to NAD83 Michigan GeoRef.
16. Database Methods defined for Map Inputs

16.1. Database Methods for creating Lachine, Paxton and Norwood formation tables

16.1.1. Create Working Database

a) Create New Database “MTU_DEQ_Master.mdb” or download the working database from 2008 located under the “Data Downloads” link on the LINGO website http://www.geo.mtu.edu/svl/LINGO/

b) Download MI DEQ databases
Well Locations

Formations and Elevations

c) Link the following tables to MTU_DEQ_Master.mdb

Well Locations database: well locations and Counties
Formation tops database: Formation codes, Method Obtained

d) Import the following tables to MTU_DEQ_Master.mdb

Formations tops database: FormationTops, Elevations

e) Add 2 fields (Elevation and Elevation_Source) to Elevations table

With update queries,
set Elevation_Source to Ref_Tops
set Elevation to the elevation (Elev_GR, Elev_KB or Elev_DF) that corresponds to Ref_Tops

For the remaining records that do not have Ref_Tops defined, fill in Elevation and Elevation_Source with KB, GR, and DF (in that order) if they are not null.

f) Import Excel Spreadsheets

MTU_TopsCorrections.xls: These tops have been corrected and set for the Antrim, Lachine, Paxton, Norwood, and Traverse formations. The Meth Obtnd code is set to “M” to signify that the tops were selected by MTU Staff and students. Append these to the imported table, FormationTops.

<table>
<thead>
<tr>
<th>API_WellNo</th>
<th>Fmtn_Cd</th>
<th>Top_</th>
<th>TVD</th>
<th>Meth_Obtnd</th>
</tr>
</thead>
</table>

LINGO Antrim Play: Handbook
DE-FC26-06NT42931
Run Query: **AppendCorrectionsToFMTops**
(Appends corrected tops from **MTU_TopsCorrections** to the table, **FormationTops**, with the Method Obtained Code set to M)

**MTU_MethodObtained.xls**: One more record was added: “M” for MTU selected formation top picks. BestMatch1st sets the codes to the preferred order for selecting one of multiple top picks in the database.

<table>
<thead>
<tr>
<th>Meth_Obtnd</th>
<th>Definition</th>
<th>BestMatch1st</th>
<th>BestMatch2nd</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>MTU</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>GLS</td>
<td>MIGS &amp; Company &amp; Sample Picks</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>GS</td>
<td>MIGS and Sample Picks</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>GL</td>
<td>MIGS &amp; Company Log Picks</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>G</td>
<td>MIGS Picks</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>L</td>
<td>Company Log Picks</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>LS</td>
<td>Company &amp; Sample Picks</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>S</td>
<td>Sample Picks</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>C</td>
<td>Well Card</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>No Method</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

**MTU_ExcludeFromMapping.xls**: List of wells that will be excluded from the structure and isopach maps and the reasons why they were removed.

<table>
<thead>
<tr>
<th>API</th>
<th>ExcludeReason</th>
</tr>
</thead>
<tbody>
<tr>
<td>21079570510100</td>
<td>Horizontal Well - Incorrect TVD</td>
</tr>
<tr>
<td>21079576770000</td>
<td>Horizontal Well - Incorrect TVD</td>
</tr>
<tr>
<td>21101548880000</td>
<td>Deviated Well - TVD depths are for L picks, but G picks match log</td>
</tr>
<tr>
<td>21119576140000</td>
<td>Horizontal Well - No TVD</td>
</tr>
<tr>
<td>21119576140100</td>
<td>Horizontal Well - Incorrect TVD</td>
</tr>
<tr>
<td>21135471400200</td>
<td>Horizontal Well - No TVD</td>
</tr>
</tbody>
</table>
16.1.2. Create Tables/Queries to create Structure Contour data

**a)** For each formation, LAC, PAX, NOR, TRVR2, run a Make Table query to select all of the Formation Tops for one formation (ex. Structure_LAC)

Select tables: FormationTops JOIN to well locations by API_WellNo
JOIN to MethodObtained by Meth_Obtnd
JOIN to Elevations by Location_ID

Include X, Y coordinates, LAC_SS (Elevation – MD), MD, TVD, SS_MD (Elevation – MD), SS_TVD (Elevation –TVD), API, Slant, Fmtn_Cd, MD, TVD, Meth_Obtnd, BestMatch1st, Elevation
Where Fmtn_Cd = “LAC”
Sort by API number and BestMatch1st

**Query in SQL**

```
FROM ((FormationTops INNER JOIN [well locations] ON FormationTops.API_WellNo = [well locations].API_WellNo)
INNER JOIN Elevations_Master ON FormationTops.API_WellNo = Elevations_Master.Location_ID) INNER JOIN [Method Obtained_MTU] ON FormationTops.Meth_Obtnd = [Method Obtained_MTU].Meth_Obtnd
WHERE (((FormationTops.Fmtn_Cd)="LAC")
ORDER BY FormationTops.API_WellNo, [Method Obtained_MTU].BestMatch1st;
```

**b)** Run update query for each formation to update the subsea depth (LAC_SS) to subsea TVD is the well is deviated or horizontal (ex. UpdateStructure_LAC_TVD_SS)

```
UPDATE Structure_MI_LAC
SET Structure_MI_LAC.LAC_SS = [LAC_SS-TVD]
WHERE ((Not (Structure_MI_LAC.[LAC_SS-TVD]) Is Null));
```

**c)** Set up a totals Query for each formation to select the first occurrence of the Formation top pick based on the BestMatch1st (ex. MTU_Lachine_Subsea)

d) Create an unmatched query for each formation, joining query from Step 9 (MTU_Lachine_Subsea) to table ExcludeFromMapping.

e) Export the above query as MTU_Lachine_Subsea.xls, to an excel spreadsheet to be used in Surfer to (1) Post control wells, and (2) create grid file to create the structure contour map. (ex. MTU_Lachine_Subsea_ExcludeFromMap)

MTU_Lachine_SubSea.xls
MTU_Paxton_SubSea.xls
MTU_Norwood_SubSea.xls

16.1.3. Create Tables/Queries to create Isopach Contour data

a) Create Make Table Query for each formation (Isopach_MI_LAC-PAX) to create table (ISO_LAC-PAX). This table joins the MTU_Lachine_SubSea_ExcludeFromMap and MTU_Paxton_SubSea_ExcludeFromMap queries on API and Firstof BestMatch1st to make certain that the 2 depths used to calculate the isopach thickness are from the same
SELECT MTU_Lachine_SubSea_ExcludeFromMap.*,  
[MTU_Lachine_SubSea_ExcludeFromMap].FirstOfLAC_SS-  
[MTU_Paxton_SubSea_ExcludeFromMap].FirstOfPAX_SS AS LAC_ISO,  
MTU_Paxton_SubSea_ExcludeFromMap.FirstOfPAX_SS AS PAX_SS,  
MTU_Paxton_SubSea_ExcludeFromMap.FirstOfPAX_MD,  
MTU_Paxton_SubSea_ExcludeFromMap.FirstOfTVD AS PAX_TVD,  
MTU_Paxton_SubSea_ExcludeFromMap.FirstOfMeth_Obtnd,  
MTU_Paxton_SubSea_ExcludeFromMap.FirstOfBestMatch1st INTO [ISO_LAC-PAX]  
FROM MTU_Lachine_SubSea_ExcludeFromMap INNER JOIN  
MTU_Paxton_SubSea_ExcludeFromMap ON  
(MTU_Lachine_SubSea_ExcludeFromMap.FirstOfBestMatch1st =  
MTU_Paxton_SubSea_ExcludeFromMap.FirstOfBestMatch1st) AND  
(MTU_Lachine_SubSea_ExcludeFromMap.API_WellNo =  
MTU_Paxton_SubSea_ExcludeFromMap.API_WellNo)  
ORDER BY [MTU_Lachine_SubSea_ExcludeFromMap].FirstOfLAC_SS- 
[MTU_Paxton_SubSea_ExcludeFromMap].FirstOfPAX_SS DESC;

b) Create Update query (Update_ISO-LAC_withMDs) to update the isopach thickness  
with the difference between the measured depths if there were no elevation data available  
to calculate subsea depths.

[FirstOfTop_]  
WHERE ((([ISO_LAC-PAX].LAC_ISO) Is Null));

c) Export Isopach tables to Excel, ISO_LAC-PAX, ISO_PAX-NOR, and ISO_NOR- 
TRVR2 to be used in Surfer to (1) Post control wells, and (2) create grid file to create the  
isopach contour maps.

ISO_LAC-PAX.xls  
ISO_PAX-NOR.xls  
ISO_NOR-TRVR2.xls
16.2. Production Data (Gas, Water, CO₂)

Source: Michigan Public Service Commission (MPSC)

url: http://www.cis.state.mi.us/mpsc/gas/prodrpts.htm

Database (as of October 2008) used in Production Charts and Tables can be downloaded at http://www.geo.mtu.edu/LINGO/ under the “Data Downloads” link.

16.2.1. Update database to Current MPSC data

a) Download the following ASCII files from the above website:

- awells.csv
- aprod_a_thru_g.csv
- aprod_h_thru_m.csv
- aprod_n_thru_s.csv
- aprod_t.csv
- aprod_u_thru_z.csv

b) In MS Access Database, AntrimGasProd, import new tables

Replace table, “AntrimWells”, with awells.csv
Replace table, “AntrimProd”, by importing the remaining files, and append each imported file to “AntrimProd”

Add the following fields to the “AntimProd” table:
- Section
- TWN
- RNG
- ProdYear
- CO2Volume

c) Update newly added fields

Use update query below to (1) extract the correct value from the “Location” field into “Section”, “TWN”, and “RNG”; (2) Fill in ProdYear; and (3) calculate CO2Volume.

UPDATE AntrimProd
SET AntrimProd.[Section] = Left([Location],InStr([Location],"-")-1),
AntrimProd.TWN = Mid([Location],InStr([Location],"-")+1,InStrRev([Location],"-")-
InStr([Location],"-")-1),
AntrimProd.RNG = Right([Location],Len([Location])-InStrRev([Location],"-")),

AntrimProd.ProdYear = [Year]
AntrimProd.CO2Volume = [CO2Volume]
AntrimProd.ProdYear = Year([Date]),
AntrimProd.CO2Volume = Round(([Gas]*([CO2]/100))/(1-([CO2]/100)),3);

query to make sure any one digit TWN & RNG numbers are zero-filled.

UPDATE AntrimProd SET AntrimProd.RNG = "0" & [RNG]
WHERE (((Len([RNG]))=2));

UPDATE AntrimProd SET AntrimProd.TWN = "0" & [TWN]
WHERE (((Len([TWN]))=2));

16.2.2. Section Locations

“SectionLocations” is a table compiled from a series of MIRIS section tables. Separate tables from the Michigan lower peninsula counties north of the Michigan Georef 400,000 Y coordinate were appended into one table (Alcona, Alpena, Antrim, Benzie, Charlevoix, Cheboygan, Grand Traverse, Iosco, Kalkaska, Leelanau, Manistee, Missaukee, Montmorency, Ogemaw, Oscoda, Otsego, Roscommon, and Wexford). This table contains the Michigan Georef coordinates for the center of each section.

16.2.3. Production by Section over Range of Production Years

Gas, Water, and CO2Volume were totaled in summation queries to show production by section, and by intervals of cumulative producing years. Gas and Water were summed over the intervals of 1990-1994, 1990-1999, 1990-2004, and 1990-2007. CO₂ Volumes were summed over 2000-2003 and 2000-2007. The results of this query were then used to plot production trends on maps over the Antrim production area in Northern Michigan.

SELECT AntrimProd.Location, SectionLocations.TWNRNGSEC,
SectionLocations.X_COORD, SectionLocations.Y_COORD, Sum(AntrimProd.Gas) AS
SumOfGas, Sum(AntrimProd.CO2Volume) AS SumOfCO2Volume, Sum(AntrimProd.Water)
AS SumOfWater

FROM AntrimProd
INNER JOIN SectionLocations ON (AntrimProd.Section = SectionLocations.SEC) AND
(AntrimProd.TWN = SectionLocations.TOWN) AND
(AntrimProd.RNG = SectionLocations.RANGE)
WHERE (((Year([Date])) Between 2000 And 2007))
GROUP BY AntrimProd.Location, SectionLocations.TWNRNGSEC,
SectionLocations.X_COORD, SectionLocations.Y_COORD;
17. ANTRIM SHALE, Late Devonian

17.1. Antrim Shale Definitions

Related terms: Antrim Formation, Dark Antrim (Lower Antrim), Ellsworth Shale, Huron Group, Huron Shale, Kettle Point Formation, Light Antrim (Upper Antrim), Middle Antrim (Ellsworth Formation), St. Clair Shale, Squaw Bay Limestone, Traverse Formation, Upper Member.

Lithology: Black to brown shale, middle portion gray to greenish gray, 60-650 feet (18-198.2 meters): Southern Peninsula of Michigan, NE Indiana, NW Ohio.

Type locality: Shore of Grand Traverse Bay about half mile south of the pier off Norwood, Antrim County, Michigan: Lane (1902).


Remarks: Gutschick and Sandberg (1991a,b) have proposed a revised type locality in the Paxton Quarry, Alpena Co., Michigan. They have four members: Upper Member (unnamed, top), Lachine Member, Paxton Member, and Norwood Member (base), formal term. In western Michigan the Upper Member grades upward into the Ellsworth Shale. An extensive gas zone in the northern part of the Northern Peninsula of Michigan.

17.2. **Unconventional Gas Production from the Antrim Shale, Michigan Basin, USA**

Authors: William B. Harrison, III, Western Michigan University
Wayne Goodman, Northern Lights Energy

Presented by Dr. William B. Harrison, III, Western Michigan University
Annual DOE project meeting in March 2007, Tampa, FL

17.2.1. **Antrim Shale Play: Origins and History**

Late 1920’s: Michigan’s commercial production begins in Devonian strata (Saginaw area). Drillers regularly note shows in Antrim.

1940: Rinehart & Hickok complete an Antrim test in Otsego County (34-30N-3W); it produces minor gas for 2 yr.

1965: Independent Murrell Welch proves economic viability of Antrim gas with successful pool development in south Chester twp., Otsego County (29N-2W).

1969: First Niagaran pinnacle discoveries in N. Michigan. Antrim shows recorded in essentially all Niagaran wells as the play grows - labeled “nuisance shows”.


1987: Underutilized Niagaran infrastructure, improved completion techniques, concept of Antrim “projects” with many wells feeding a central production facility (CPF), and non- conventional fuels tax incentives trigger modern play levels and production growth.

1992: Antrim wells must be completed or in progress by 01/01/93 to qualify for NCF section 29 tax credits, which expired 12/31/02. Drilling reaches peak in1992 with 1189 completed wells. Industry and regulatory agencies agree to voluntary 80-acre Antrim spacing on all new projects.

1995: Establishment of uniform spacing plan (USP) option for Antrim projects allows greater operator discretion in locating individual wells within a project. 80-acre spacing is mandated play-wide.
17.2.2. Antrim Completions and Project Operations

1. After drilling and logging, selected high interest zone(s) in the Lachine Member (core and thin section photos are shown in Appendix Figures 18-1 and 18-2) and Norwood Member pays are identified for stimulation.

2. The optimal pay in the thinner (15-22’ thick), lower Norwood Member pay is selectively perforated and stimulated with a light sand-nitrogen frac. Two sand sizes are typically used.

3. Optimal intervals in the higher Lachine pay (overall thickness 55-80’) are selectively perforated; either a single or multistage sand-nitrogen frac of the Lachine is performed, with frac size(s) larger than for the Norwood.

4. Wells are flowed back to the project’s Central Production Facility (CPF) via PVC flowlines, either single (all fluids commingled) or dual phase (some gas/water separation at the wellhead).

5. At the CPF, dewatering of the gas is accomplished, typically via glycol treatment at dehy towers. Gas is compressed to sales line pressure (typically around 1300 PSIA) via a 4-stage compressor and sent out via stainless steel sales lines. (In areas lacking electricity, some of the dewatered, compressed gas is returned to the well via pipeline to power for drillstring gas lift systems.)

6. Each Antrim project typically injects formation water into a single salt water disposal (SWD) well, in underlying Devonian carbonates of the Dundee Formation or upper Detroit River Formation. SWD’s are typically located at the CPF facility and controlled by Federal EPA regulations.

7. Gas is sent via the sales lines to large CO₂ removal facilities to reduce the 5-30% CO₂ content of Antrim gas to sales quality. It is sent to common carrier residential and commercial use lines from the CO₂ facility.

17.2.3. Antrim Drilling, Logging, and Evaluation

1. Antrim wells in Northern Michigan are drilled to depths ranging from 600-2000’ (true vertical). Horizontal wells comprise about 1% of all wells to date, with varying commercial success. Directional drilling has been an effective means to reach drainage areas with restricted surface accessibility. Antrim tests are conventionally drilled with a water-based mud system—air drilling has not become a practice in the play.

2. By State statute, surface casing is required to a depth 100’ (vertical) below the base of the Glacial Drift, the regional fresh water aquifer. (Drift depth range in the play area: 300-1100.’)

3. Production casing is typically run through the entire Antrim pay section and into a varying amount of “rathole” drilled into the Traverse Group. (Many wells drilled into the early 1990’s were open-hole completions, this is very uncommon today.)

4. In early 1990’s, many wells were not open hole logged. Evaluation and completion was defined by sample logs, ROP logs or cased hole gamma ray/collar correlation logs that identified the “hot” zones.

5. Many operators continue to use open hole logging in only a limited fashion, relying chiefly on mudlogs, ROP logs, and cased hole GR logs. Others evaluate the quality of Antrim pay by induction logs and porosity logs akin to the evaluation used in “conventional” reservoirs.
6. The advent of open hole fracture indicator logs has made their use both widespread and effective in Antrim evaluation. This includes such tools as the UBI (Schlumberger), CAST (Halliburton), and CBIL (Baker).
7. Coring and use of core data is extremely limited. No new cores in the main play area since the mid 1990’s.

### 17.2.4. Conclusions

1. The Upper Devonian Antrim Shale is a major gas producer in the Michigan Basin (Appendix Figure 18-3).
2. The Antrim Shale is classic black shale that produces natural gas by desorption processes into a complex network of fractures.
3. The distribution of high total organic carbon and natural fractures are keys to good productivity.
4. Gas in place can be measured by geochemical rock analyses and suggest 0.5 to 1.0 BCF per 40 acres in the northern part of the basin.
5. Variable production history of project areas can be explained by reservoir rock properties measurable from core, logs and drill cuttings.

### 17.2.5. Slide Figures

Figures 17-1 through 17-16 are the slide images from Dr. Harrison’s presentation, “Unconventional Gas Production from the Antrim Shale, Michigan Basin, USA”
Figure 17-1. Geologic Setting of the Michigan Basin.
Figure 17-2. Subcrop area of the Antrim Shale in Michigan.
Figure 17-3. Oil and Gas Well Locations in Northern Michigan.
Figure 17-4. Annual Antrim gas (mcf) production in Michigan with associated water (bbls) carbon dioxide (mcf) and percentage of CO₂.
Figure 17-5. Cumulative Antrim Gas (mcf) production in Michigan with associated water (bbls) and carbon dioxide (mcf).
Figure 17-6. Number of Michigan Yearly Antrim Completions.
Figure 177-7. Antrim Surface Production and Processing Facilities.
**Figure 17-8. Core and Log Analysis of Murell Welch - St. Chester #18 in Otsego County, Michigan.**
Figure 17-9. Fracture Orientations for Murell Welch - St. Chester #18 Core in South Chester Township, Otsego County, Michigan (from Dellapenna, 1991).
Figure 17-10. Fracture Analysis Data for Murell Welcha - St. Chester #18 Core in South Chester Township, Otsego County, Michigan (from Dellapenna, 1991).
Figure 17-11. Total Organic content from Latuszek B1-32 in Otsego County, Michigan (from Dellapenna, 1991).
Figure 17-12. Core photo of Lachine Member.
Figure 17-13. Thin Section of lachine member in Welch - St. Chester #18 in Otsego County, Michigan.
Figure 17-14. Thin Section of lachine member in Welch - St. Chester #18 in Otsego County, Michigan.
Figure 17-15. Core photo of Paxton member, a lighter gray shale.
Figure 17-16. Thin Section of paxton member in Welch - St. Chester #18 in Otsego County, Michigan.
18. Bibliography


19. Acknowledgments

We thank Landmark Graphics Corporation for the use of their software in producing the cross section images used in this report. We also thank Neuralog, Inc for the use of their digitizing software.