

Oil & Natural Gas Technology

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

Final Report and *LINGO Antrim Play: Handbook*

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ABSTRACT

The goal of this project was to develop and execute a novel drilling and completion program in the Antrim Shale near the western shoreline of Northern Michigan. The target was the gas in the Lower Antrim Formation (Upper Devonian). Another goal was to see if drilling permits could be obtained from the Michigan DNR that would allow exploitation of reserves currently off-limits to exploration.

This project met both of these goals: the DNR (Michigan Department of Natural Resources) issued permits that allow drilling the shallow subsurface for exploration and production. This project obtained drilling permits for the original demonstration well AG-A-MING 4-12 HD (API: 21-009-58153-0000) and AG-A-MING 4-12 HD1 (API: 21-009-58153-0100) as well as for similar Antrim wells in Benzie County, MI, the Colfax 3-28 HD and nearby Colfax 2-28 HD which were substituted for the AG-A-MING well.

This project also developed successful techniques and strategies for producing the shallow gas. In addition to the project demonstration well over 20 wells have been drilled to date into the shallow Antrim as a result of this project's findings. Further, fracture stimulation has proven to be a vital step in improving the deliverability of wells to deem them commercial. Our initial plan was very simple; the "J-well" design. We proposed to drill a vertical or slant well 30.48 meters (100 feet) below the glacial drift, set required casing, then angle back up to tap the resource lying between the base to the drift and the conventional vertical well. The "J"-well design was tested at Mancelona Township in Antrim County in February of 2007 with the St. Mancelona 2-12 HD 3.

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1. EXECUTIVE SUMMARY

The goal of this project was to develop and execute a novel drilling and completion program in the Antrim Shale near the western shoreline of Northern Michigan (Figure 1). The target formation was the gas in the Lower Antrim Formation which is a widespread Upper Devonian (Figure 2) shale that has been a very prolific unconventional (shallow gas) producing horizon (Walter, 1996; Coleman, Liu and Riley, 1988; Dellapenna, 1991), having yielded over 2,000,000,000 MCF to date (Figure 3), about one-third of Michigan's total gas production (Wollensak, 1991). Another goal was to see if drilling permits could be obtained from the Michigan DNR that would allow exploitation of reserves currently off-limits to exploration.

This project was successful in meeting both of these goals: the DNR (Michigan Department of Natural Resources) issued permits starting in January 2007 that opened up the shallow subsurface for exploration and production, in this case shallow gas from the Antrim Formation. We succeeded in obtaining drilling permits from MI-DEQ for two wells, the demonstration well AG-A-MING 4-12 HD (API: 21-009-58153-0000) and AG-A-MING 4-12 HD1 (API: 21-009-58153-0100). These permits were approved in January, 2007 for the location cited above (Antrim County, Michigan, Torch Lake Township, Section 12, T30N-R09W, Figure 4). Due to right-of-way delays for gathering lines in the Torch Lake Field, we obtained permits for similar Antrim wells in Benzie County, MI, the Colfax 3-28 HD and nearby Colfax 2-28 HD wells and shifted the project demonstration well to that area (Figure 5).

This project also developed successful techniques and strategies for producing the shallow gas. In addition to the project demonstration well over 20 wells have been drilled to date into the shallow Antrim as a result of this project's findings. The well schematics and production histories to Sept. 2008 are included in this report.

Statement of Permitting Problem

The central problem in obtaining a DNR permit to drill the shallow Antrim is that a great deal of potentially productive shale lies within areas that are off-limits to gas development due to surface constraints such topography, wetlands, or housing. In addition to these constraints, the Michigan Department of Environmental Quality (MDEQ) requires that 30.48 meters (100 feet) of surface casing be set into bedrock below the glacial drift for all drilling (see Appendix I. State Casing Statute Instruction 1-94). The actual requirement is that casing be set through and 30.48 meters (100 feet) below the lowest aquifer penetrated. This requirement is in effect to protect groundwater resources, and since the glacial drift is everywhere regarded as a potential aquifer, MDEQ routinely requires 30.48 meters (100 feet) of casing below the glacial drift. Further, fracture stimulation cannot be conducted within 15.24 meters (100 feet) of the base of the surface casing string. Fracture stimulations (Apotria, Kaiser and Cain, 1994; Decker, Coates and Wicks, 1992; Briggs and Elmore, 1980) to date have been a vital step in improving the deliverability of wells to deem them commercial. As a result of the permits issued to this project the door has been opened to exploring and producing a large amount of productive Antrim shale can neither be accessed nor completed in a conventional sense due to State regulations. This opens up a vast resource of domestic gas for conventional development at a very opportune time.

Statement of well design

Our initial plan was very simple and was referred to as the “J-well” design. We proposed to drill a vertical or slant well 30.48 meters (100 feet) below the glacial drift, set required casing, then angle back up to tap the resource lying between the base to the drift and the conventional vertical well (Figure 6). The Drilling Prognosis is detailed in the project handbook (*Lingo Antrim Play: Handbook*). Figure 7 is the planned well bore schematic for the demonstration well while Figure 8 is a bedrock subcrop map from the Michigan DEQ map (Bedrock Well Study of Northwest Michigan, 2007) that shows the Antrim subcrop in gray. The “J”-well design was tested at Mancelona Township in Antrim County in February of 2007 with the St. Mancelona 2-12 HD 3. Figures 9a – 9d show the well trajectory with no vertical exaggeration. Approximate acreage that will become available as a result of this project’s success is shown in Figure 10. The areas north of the heavy black line that indicates the cutoff line of where production is limited because of the 1-94 drilling restriction (Appendix I).

2. REPORT DETAILS

2.1 *Experimental Methods*

2.1.1 Data Collection (Task 1.0)

Data for the Lower Peninsula Antrim Trend has been collected from the Michigan DEQ, the Michigan Core Repository at Kalamazoo and from MTU files. These data consist of formation top picks (~629,000), well logs, well locations and production histories.

Well data was collected from our industry partner, Jordan Development Company, L.L.C., from wells in the three areas of interest to this project: Milton-Bradley field (22 vertical wells) in western Antrim County, Deward Cleaver field (2 horizontal and 3 vertical wells) in eastern Antrim County, and the Colfax 29 field (2 horizontal wells) in western Benzie County.

The project database also includes data from the Michigan Department of Environmental Quality (MI-DEQ), Michigan Public Service Commission, and the Census 2000 TIGER/Line data. The data consists of well locations, formation tops and elevations, oil, gas and CO₂ production data, scanned log images, LAS files (266 LAS files in Northern Michigan; 220 with Antrim formation picks), roads, hydrology, and political boundaries, and water well data in Antrim, Charlevoix and Cheboygan Counties.

Digital Oil and Gas Permit Well Files are available through the Michigan DEQ and have been added to our data archives. Oil and Gas Permit Well Files (PWF) are the documents that are generated over the life of a well – from application to plugging. These are the files that were previously on microfilm, and have been scanned in as multiple page tif image files. Currently the files for permits 1 to 47,999 are available.

Project databases have been organized and documented for the Project Handbook. The three databases for well locations, formation tops, and production are available online on the Michigan DEQ website and are updated periodically. A project database has been created that will link to these databases. A set of queries has been developed that will extract the information needed to reproduce the datasets used in the Project Handbook. This will allow future users of the data to include information from new wells for updated mapping. In particular, the formation tops data needs selective queries performed before mapping can take place.

Measured depths (MD) and true vertical depths (TVD) of formation tops (glacial drift base) are stored in a table by API number, formation code, and method obtained. There are multiple records for some formation tops because top picks from multiple sources are stored in the database. When creating structure and isopach maps, gridding algorithms should be used with one value for each x-y coordinate. A set of instructions and database queries will be included in the Project Handbook that will explain how the formation tops are chosen from the database. For example, when a TVD depth is present in a slanted well, it is chosen over MD. Also, we

have developed a sequence of choices for the method obtained. We have also encountered inconsistent data when formation tops are obtained from different sources.

Data Sources

Data Category	Source
Well Locations	Michigan DEQ
Formation Tops	Michigan DEQ
Production Data	Michigan DEQ (Oil-Gas-Water, 1982 – present) Michigan Public Service Commission (Gas, Water, CO ₂ , 1990 – present) Michigan Tech Historic Production (Oil-Gas-Water, Annual by Field 1925-1986)
Gravity Data	Jordan Development Company, LLC
Michigan Bouguer Anomaly Data	University of Texas at El Paso GeoNet - United States Gravity Data Repository System
Digital Well Logs	LAS files – MTU
Raster Logs	Michigan DEQ
Permit Well Files	Michigan DEQ
Base map shape files	Census 2000 TIGER/Line data Michigan Resource Information System (MIRIS)

2.1.2 Mapping (Task 2.0)

The scope of this project focused on the Northern section of the Lower Peninsula of Michigan. When reference is made to “Northern Michigan” in this report, the maps have been prepared from data located north of the 400,000 meter line in the Michigan GeoRef coordinate system.

The maps of Northern Michigan contain some common features. The Antrim subcrop is symbolized on the maps in two ways. Some of the maps indicate the Antrim subcrop with a filled gray shade, and the color contour maps indicate the subcrop with a bright pick outline. The heavy black line that runs through the center of the subcrop indicates the northern border of where Antrim gas wells can be drilled following the State of Michigan regulations requiring 30.48 meters (100 feet) of casing below the glacial drift or any fresh water aquifers. The subcrop area above this line shows the additional Antrim acreage that will become available for exploration and production as a result of the interpretation of the 1-94 Instruction for this project.

Images of the maps and cross sections described below have all been included in the *LINGO Antrim Play: Handbook*, a deliverable of this LINGO project, but representative figures have been chosen and are included in this.

1. Log Curve Profile

A stratigraphic log curve profile has been prepared for the Bargy #16-14 vertical well (Figure 11), which is located in eastern Antrim County, Michigan in the vicinity of the project demonstration area. This profile shows the gamma ray (GR) and density curves (ZDEN) with formation tops to illustrate the signature of the gamma ray as it passes through the Lachine, Paxton and Norwood members of the Antrim Shale.

Several more profiles of Antrim wells across Northern Michigan are included in the project handbook. The project horizontal wells show the gamma ray signature along the directional survey line of the well.

2. Cross Sections: Northern Michigan (Lachine, Paxton, Norwood formations)

- a. Cross Section A-A' (Figure 12): Antrim County to Alpena County, North (West to East)
- b. Cross Section B-B': Antrim County to Alpena County, South (West to East)
- c. Cross Section C-C': Manistee County to Otsego County (Southwest to Northeast)

3. Cross Sections: Northern Michigan (Lachine, Paxton, Norwood formations)

- a. Cross Section D-D': Milton Bradley field, Antrim County (North to South)
- b. Cross Section E-E': Colfax 29 Field, Benzie County (West to East)

4. Structure contour maps: Northern Michigan

- a. Lachine (Figure 13), Paxton, and Norwood members of the Antrim Shale
- b. Top of Antrim Formation

5. Structure contour maps: Michigan Counties

- a. Antrim: Lachine, Paxton, and Norwood members of the Antrim Shale
- b. Benzie: Lachine, Paxton, and Norwood members of the Antrim Shale

6. Isopach contour maps: Northern Michigan

- a. Lachine (Figure 14), Paxton, and Norwood intervals of the Antrim Shale
- b. Ellsworth Shale to Antrim Formation
- c. Antrim Shale to Lachine member of Antrim Shale
- d. Glacial Drift

7. Isopach contour maps: Michigan Counties

- a. Antrim: Lachine, Paxton, and Norwood intervals of the Antrim Shale
- b. Benzie: Lachine, Paxton, and Norwood members of the Antrim Shale

8. Symbolized map of bedrock: Northern Michigan

For each well with formation tops picked, the depth of the Base of the Glacial Drift is equal

to the top of the formation that lies directly beneath the Glacial Drift. This formation was extracted to create a symbolized map that shows the trends of which formation characterizes the bedrock.

9. **Bouguer Gravity Anomaly maps**

The Michigan Bouguer Anomaly maps were created from data 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>). The original data has been converted from NAD27 latitude/longitude coordinates to Michigan GeoRef.

- a. Northern Michigan (Figure 15)
- b. Antrim County, Michigan
- c. Benzie County, Michigan

10. **Antrim Production History maps: Northern Michigan**

The Antrim production history maps show cumulative gas (Figure 9), water, and CO₂ production in 5-year intervals. 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, in 5-year increments. Symbolized maps were then created to show the trends in Antrim production of gas and co-produced carbon dioxide and water over time.

The following maps have been inserted into the Project Handbook, and the Excel spreadsheets used in the creation of the maps have been archived as part of the project deliverables.

- a. Gas (1990-1994, 1990-1999, 1990-2004, 1990-2007)
- b. CO₂ (2000-2003, 2000-2007 [Figure 17])
- c. Water (1990-1994, 1990-1999, 1990-2004, 1990-2007)

2.1.3 **Regulatory (Task 3.0)**

This task was satisfactorily resolved when the Michigan DEQ decided to permit the AG-A-MING demonstration well without modification of the instruction 1-94. The permit was issued on December 14, 2006 for the AG-A-MING well (see map, Figure 4). Under this Permit (58153) the Michigan DEQ, accepted the concept of the “J” well (Figure 7).

2.1.4 **CO₂ Mitigation (Task 4.0)**

CO₂ production data, reported by the Michigan Public Service Commission, is recorded as a percentage of gas produced by month and by producing field. Production data recorded prior to the year 2000 is a combination of **Produced gas** (includes CO₂ volumes) and **Sales Gas** (volumes after CO₂ has been separated) totals. Between 1998 and 2000, the production reporting

was converted to report only **Sales Gas**. Figure 16 is a timeline showing when the standard criterion for reporting CO₂ was switched over. We provide charts and maps showing trends in the data in northern Michigan (Figure 3 and Figure 17), and in each of the three producing fields of interest to this project, the Milton Bradley, the Deward Cleaver, and the Colfax 29.

2.1.5 Synthesis (Task 5.0 Year 2)

The *LINGO Antrim Play: Handbook*, a deliverable of this project, is a documentary of the maps, charts, and well diagrams and histories that have been compiled for this LINGO project (Appendix II). The handbook table of contents is shown below.

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Data Deliverables

The data used to create the maps and charts in the handbook was downloaded from public domain data. The project handbook and our project website <http://www.geo.mtu.edu/svl/LINGO/> contain links to these sites and will also contain detailed documentation of how the data was used to prepare the project handbook.

2.1.6 Demonstration Wells (Task 6.0)

As mentioned above (Executive Summary) we petitioned DOE for permission to switch the project demonstration well to an equivalent Antrim site in Benzie County, MI due to some unforeseen right-of-way issues that did not seem resolvable in the timeframe of this project. For completeness and continuity in this report, we have included descriptions of the work done in the three areas which pertain to this project (Figure 1): the final project demonstration well site, Colfax 29 in Benzie County; the Deward Cleaver area of Antrim County where experimental “J” wells were drilled; and the original demonstration site in the Milton Bradley area of Antrim County.

2.1.6.1 Final Demonstration Site: Colfax 29

In December 2007, a request was sent to the DOE to substitute the State Colfax #3-28 HD in Benzie County (Figure 5) for the AG-A-Ming 4-12 HD well since right-of-way problems precluded timely drilling of the AG-A Ming 4-12 HD.

There were two main objectives for this project. One involved compliance with Michigan well site regulation embodied in Instruction 1-94 (Appendix I) and a second involving using a new horizontal “J” well design (Figure 7) to recover gas from previously off-limit acreage in the Antrim Formation. Both objectives have essentially been achieved in this past year: the Regulatory task has been completely resolved and the originally proposed design of the “J” well has been tested in the field, although not at the proposed demonstration site.

The Colfax #3-28 HD and nearby Colfax #2-28 HD were drilled with the revised configuration (Figure 18). The method employed in the Colfax wells, which is likely to be used in future drilling in the Milton Bradley area (original project demonstration site), was 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. Figure 19 is the record of completion for the project demonstration well, St. Colfax 3-28 HD. The gamma ray log is plotted with the perforation intervals along the deviated well path in Figure 20. 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. Daily production data for the St. Colfax 3-28 HD (Figure 21) and for the St. Colfax 2-28 HD (Figure 22) are averaging 90 and 70 mcf per day, respectively, as of September 30, 2008.

2.1.6.2 Experimental Demonstration Site: Deward Cleaver Project

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 (Figures 23 and 24) began production in June 2007.

These wells revealed problems with the original design of the “J” well (Figure 25), mainly in terms of disappointing production relative to ordinary vertical wells (Figures 26 and 27). However, these wells provided us with an opportunity to redesign and modify the demonstration well before it was drilled. From what was have learned at the Deward Cleaver wells, it was necessary to reduce the ascent angle into the Antrim productive zones as well as case and perforate the well.

Problems and Solution to the original “J” well design

Jordan Energy had the opportunity to use the “J” well design proposed for this project in three wells drilled in the Deward Cleaver project in eastern Antrim County, before the project demonstration well could be drilled. The open hole upward slanting configuration of the Lachine and Norwood laterals are shown in the mud log and well bore cross section in the State Mancelona 15-13 HD2 (Figures 28a-28f) and HD1 (Figures 29a-29f). These wells did not produce as well as expected; in fact they performed worse than simple vertical wells drilled nearby. Figure 26 is an updated plot of average daily production from the State Mancelona 2-12 and State Hayes 4-18 vertical wells compared with average daily production from the State Mancelona #2-12 HD, #15-13 HD, and the #15-13A HD “J” wells. Figure 27 shows actual daily gas production from June 2007 through September 2008 for these same Antrim wells.

Earlier it was reported that the basic problem with the “J” well design appeared to be the development of blockages along the horizontal leg. Two possibilities had been put forward: one, fluids are trapped in undulations in the well bore, resulting in a fluid lock, and two, material sloughs off the well, eventually blocking the gas flow. We suggested it was possible that both mechanisms operated at the same time and reinforced flow restriction. Subsequently Jordan determined that cavings from the hole were really not an issue, but that accumulated debris within the perceived undulations of an open hole well bore was the most likely cause of poor production and that this could be alleviated through the use of a downward sloping cased hole. Subsequently, while wells were drilled at Deward Cleaver (State Mancelona #2-12 HD, #15-13

HD, and the #15-13A HD) with the “J” well approach, the State Colfax 3-28 HD and 2-28 HD have been drilled with a new design, a high- angle cased hole that will be perforated. Figure 7 shows the original configuration of the demonstration well, Figures 9a-9d show the “J” well trajectory for the St. Mancelona 2-12 HD3 with no vertical exaggeration, while Figure 18 shows the current modification. The Colfax wells were completed in mid February 2008 and production began in April and May of 2008, respectively. Daily production data has been collected from the Deward Cleaver and the State Colfax wells (shown in Figures 21, 22, and 27).

Lessons Learned – Bill Quinlan

Deward Cleaver Horizontal Drilling Experience using the “J” well design

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 AG-A-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.

2.1.6.3 Original Demonstration Site: Milton Bradley Project

The original demonstration well, A-GA-MING #4-12HD and #4-12HD1, is part of the Milton Bradley Project in west Antrim County (Figure 1) developed by Jordan Development Company, LLC. In addition to the LINGO demonstration well, Jordan Development is developing the prospect with a series of vertical wells, and one disposal well (see Figure 4). The horizontal section of the demonstration well must remain within the 240 acre boundary set up in the PRU (PRoduction Unit). The vertical wells will be part of one production unit (PRU), and the demonstration well will be the only well in its PRU. (Since the demonstration well will be producing from its lateral, it will have access to as much or more pay as the vertical wells and will drain a similar area. This is an additional benefit of the LINGO well: it will in some cases replace as many as 4-6 wells with consequent economies and less disruption to the environment. The complete specifications for the A-GA-MING 4-12 as provided by Jordan will be included in the final project handbook.

The AG-A-MING #4-12 HD well was not drilled within the scope of this project because right-of-way negotiations have put this well on hold. Jordan Development Company, LLC still has plans to drill this well, but the demonstration site for this project was changed to the Colfax #3-28 HD well in southeast Benzie County. As of September 2008, twenty-two vertical wells have been drilled in the Milton Bradley project area. Average daily production for this set of wells has risen to 2,000 mcf per day (Figure 30).

2.1.7 Well Logging (Task 7.0)

A collection of well logs have been put together into cross sections to show the trends of the gamma ray logs through the Lachine, Paxton, and Norwood formations. Cross Section A – A' displays the gamma ray logs from West to East across the northern line of Antrim producing wells from Antrim County to Alpena County (Figure 12). A second Cross Section B – B' displays wells to the south of line A–A', and Cross Section C–C' displays wells in southwest to northeast direction from Manistee County to Otsego County. We have also created localized

cross sections D–D’ showing the trends in the Milton Bradley project, and E–E’ showing the two horizontal wells in the project demonstration area, Colfax 29. These cross sections are included in the project handbook.

Mud logs, Gamma Ray and Casing Collar logs were run in the Colfax 2-28 and 3-28 wells. The well logs are displayed in a cross section format with the directional survey and formation tops defined as in Figure 20.

2.2 Results and Discussion

In this section we will provide a preliminary discussion of the maps promised as deliverables in this project. Several of these maps are key products in that they outline the additional prospective area that will become available for exploration and production as a result of the novel permitting and drilling undertaken here. We will also provide a preliminary discussion of the maps promised as deliverables in this project. Several of these maps are key products in that they outline the additional prospective area that will become available for exploration and production as a result of the novel permitting and drilling undertaken here. The map images will all be presented in the project deliverable, *LINGO Antrim Play: Handbook*.

The Antrim Formation is mainly a gray to black shale with dominantly black, high gamma-ray facies in the lower sections. These lower sections can be distinguished by gamma-ray and have been termed, the Lachine, Paxton, and Norwood members of the Antrim Formation. In general these facies are high in organic matter (3-12 %) and represent anoxic facies deposited in stagnant bottom waters in closed or nearly closed Devonian seaway. They are thus marine sediments and have sufficient organic content to qualify as high-grade source rock. Some sample will burn if exposed to a flame. These are the sought after sections as they are thought to be the source of the Antrim gas, which has been reported to be biogenic (Walter, et. al, 1996). Consequently, it is of interest to map these facies in terms of how they are impacted by the J-well technology. The history and characteristics of the Antrim Shale Gas Play are outlined in a section of the project handbook.

Structure and isopach maps for the Lachine, Paxton, and Norwood formations in the Northern Michigan Antrim Trend (Figures 13 and 14), and also localized to Antrim County, are presented in the *LINGO Antrim Play: Handbook*. Figure 31 is a spot map showing the identity of the formation immediately under the glacial till (Glacial Till in the Michigan Stratigraphic Code). It is apparent that the sub-till facies distribution is complex and not easily generalized or mapped. At present we feel the spot map as depicted in Figure 31 is the best representation. It is clear to us that prospect development will have to proceed at a very small map scale in the area of interest if the Antrim is to be mapped at the Member level.

Other interpretations are possible but it appears that these erosional edges of the Antrim are “ragged” and unpredictable, possibly due to glacial process in the waning stages of the last glacial retreat. In such cases, detailed information can perhaps be obtained by micro-gravity techniques which have been reported to allow mapping of the till-Antrim contact. We have a detailed map (Figure 10) of the additional Antrim acreage that will become available for exploration and production as a result of the interpretation of the 1-94 Instruction for this project.

All project tasks have been completed. The initial benchmark for the demonstration well was met in December 2006 when the Michigan DEQ issued a permit for the well. The main obstacle in the drilling of the original project demonstration well was in obtaining right-of-way for facilities. A second group had tied up acreage in the vicinity of the proposed demonstration well which prevented access to the gathering facilities and hence delays in drilling. It became clear that the AG-A-Ming well could not be drilled within the timeframe of this project. Our December 2007 request to substitute the St. Colfax 3-28 HD in Benzie County was approved by the DOE. This

well and the nearby St. Colfax 2-28 HD, drilled in the same configuration, have been drilled and well data (i.e., well bore diagrams, mud log, Gamma Ray log, perforation records, and detailed well completion documents, and current production records) have been gathered into a complete well history and analysis.

2.3 Conclusion

There were two main goals of this project: (1) to structure or revise permit requests so that the Michigan DEQ would approve drilling in areas of the Antrim that were too shallow to allow access by vertical wells, and (2) to design a well or system of wells to produce gas economically from these shallow reservoirs. A final goal was to produce a “handbook” reporting the details of the project experiences as well as a map of the potential acreage opened up as a result of this project.

Well permit for access to shallow Antrim

We were successful in arguments to the DEQ that the approach to tapping Antrim gas reserves by drilling a lateral through the required casing zone and then angling back up met regulatory requirements. After listening to our presentation, the DEQ had no objections and was favorably impressed by the further advantage of the approach in lessening environmental impact as a result of requiring fewer wells and (potentially) providing more efficient drainage. DOE required this approval as a critical milestone that had to be met in the first year of the project since the viability of the entire project depended on a favorable result. This was accomplished.

Gas production from the shallow Antrim

This objective was more difficult to achieve: our initial design for the so-called “J-well” did not produce effectively and had to be redesigned (details in handbook). After a series of changes and modifications, we were able to produce the shallow Antrim in three areas of interest: Milton Bradley (original demonstration site), Deward Cleaver (site where “J” design was tested), and Colfax 29 (new demonstration site). Our experiences here will serve as a template for similar development and will provide lessons in “what not to do”. This will also be the first time to our knowledge that a lateral has been used to produce Antrim gas. This project has the potential to be another Crystal Field demonstration that convinces the Michigan gas and oil industry to use laterals to develop Antrim production. (Crystal Field was a DOE-sponsored demonstration project in the 1990’s that was influential in converting the Michigan Oil and Gas Industry to shift to lateral wells for conventional oil production. See DOE Contract No. DE-FC22-94BC14983).

All of the project tasks were completed on schedule. Promised deliverable maps are complete and the last task, drilling of the demonstration well at State Colfax 3-28 HD was completed in April, 2008. The *LINGO Antrim Play: Handbook* contains details of well design, maps of potential Antrim reservoir opened up, and production histories of the shallow Antrim wells that went on-line during the duration of this project.

3. GRAPHICAL MATERIALS

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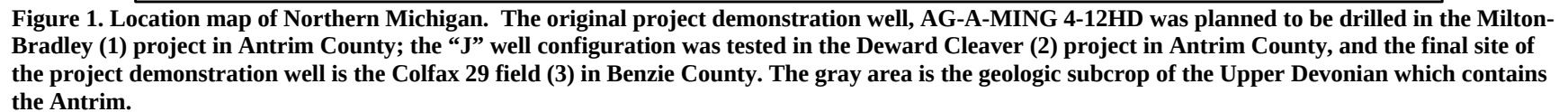
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3.2 FIGURES



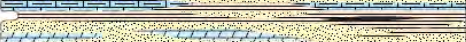
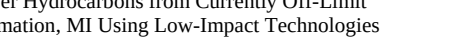
GEOLOGIC TIME				OUTCROP NOMENCLATURE			DOMINANT LITHOLOGY	SUBSURFACE NOMENCLATURE	
ERA	PERIOD	EPOCH	NORTH AMERICAN STAGES	GROUP	FORMATION	MEMBER		FORMATION	GROUP
Cenozoic	Quaternary	pleistocene	Wisconsinan		Glacial Drift			Glacial Drift	
Mesozoic	Jurassic	Middle	Oxfordian		Ionia Fm			Ionia Fm	
		Late	Conemaugh		Grand River Fm			Grand River Fm	
	Pennsylvanian	Early	Pottsville		Saginaw Fm			Saginaw Fm	
					Parma Ss			Parma Ss	
					Bayport Ls			Bayport Ls	
	Mississippian	Late	Meramecian		Michigan Fm			Michigan Fm	
					Marshall Ss			Marshall Ss	
		Early	Kinderhookian		Coldwater Sh			Coldwater Sh	
					Sunbury Sh			Sunbury Sh	
					Ellsworth Sh (western)	Berea Ss (eastern)		Ellsworth Sh (western)	Berea Ss (eastern)
					Bedford Sh			Bedford Sh	
		Late	Chautauquan		Antrim Sh	Upper Mbr		Upper Mbr	Antrim Sh
						Lachine Mbr		Lachine Mbr	
						Paxton Mbr		Paxton Mbr	
						Norwood Mbr		Norwood Mbr	
			Senecan		Squaw Bay Ls			Squaw Bay Ls	
					Thunder Bay Ls	Partridge Point Mbr			
						Potter Farm Mbr			
						Norway Point Mbr			
					Alpena Ls	Four Mile Dam Mbr			
						Newton Creek Mbr			
			Erian	Traverse Gr	Long Lake Ls	Killians Mbr		Traverse Ls	Traverse Gr
						Genshaw Mbr			
					Ferron Point Fm				
					Rockport Quarry Ls				
					Bell Sh			Bell Sh	
					Rogers City Ls				
					Dundee Ls			Dundee Ls	

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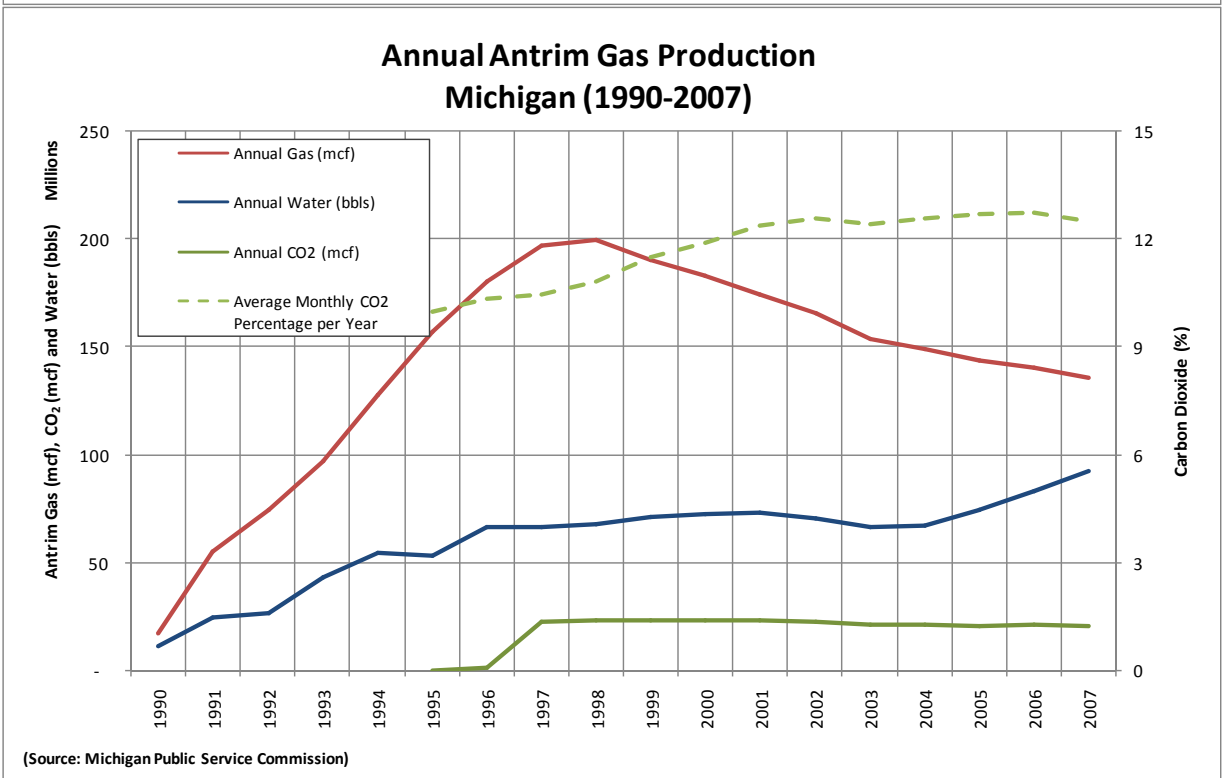
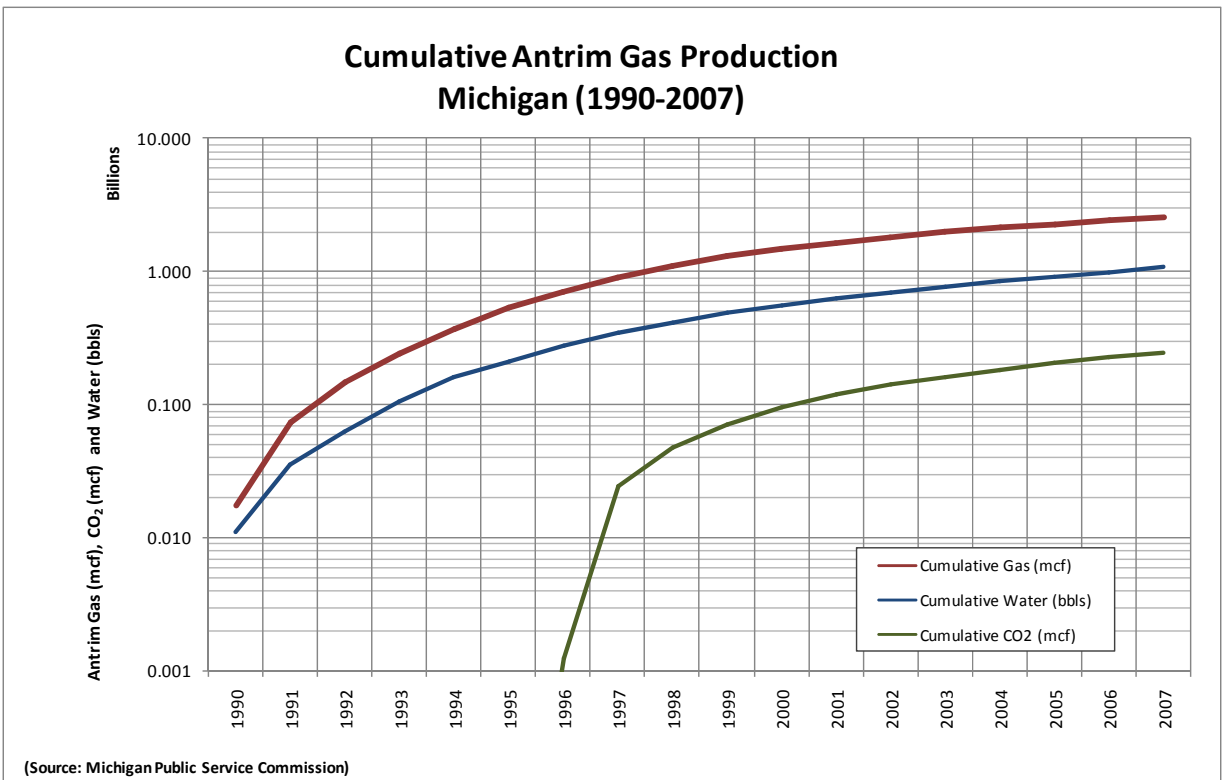


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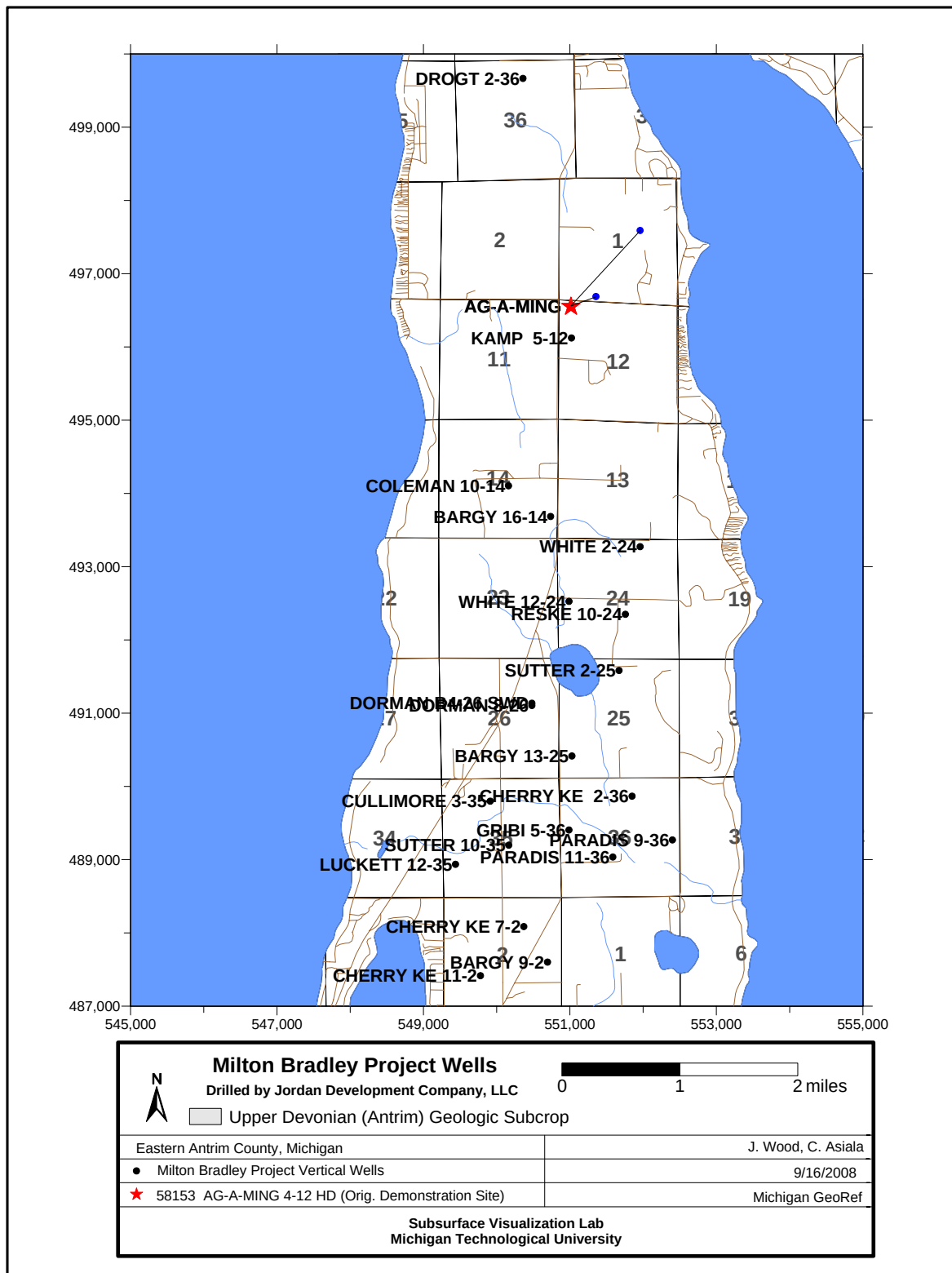


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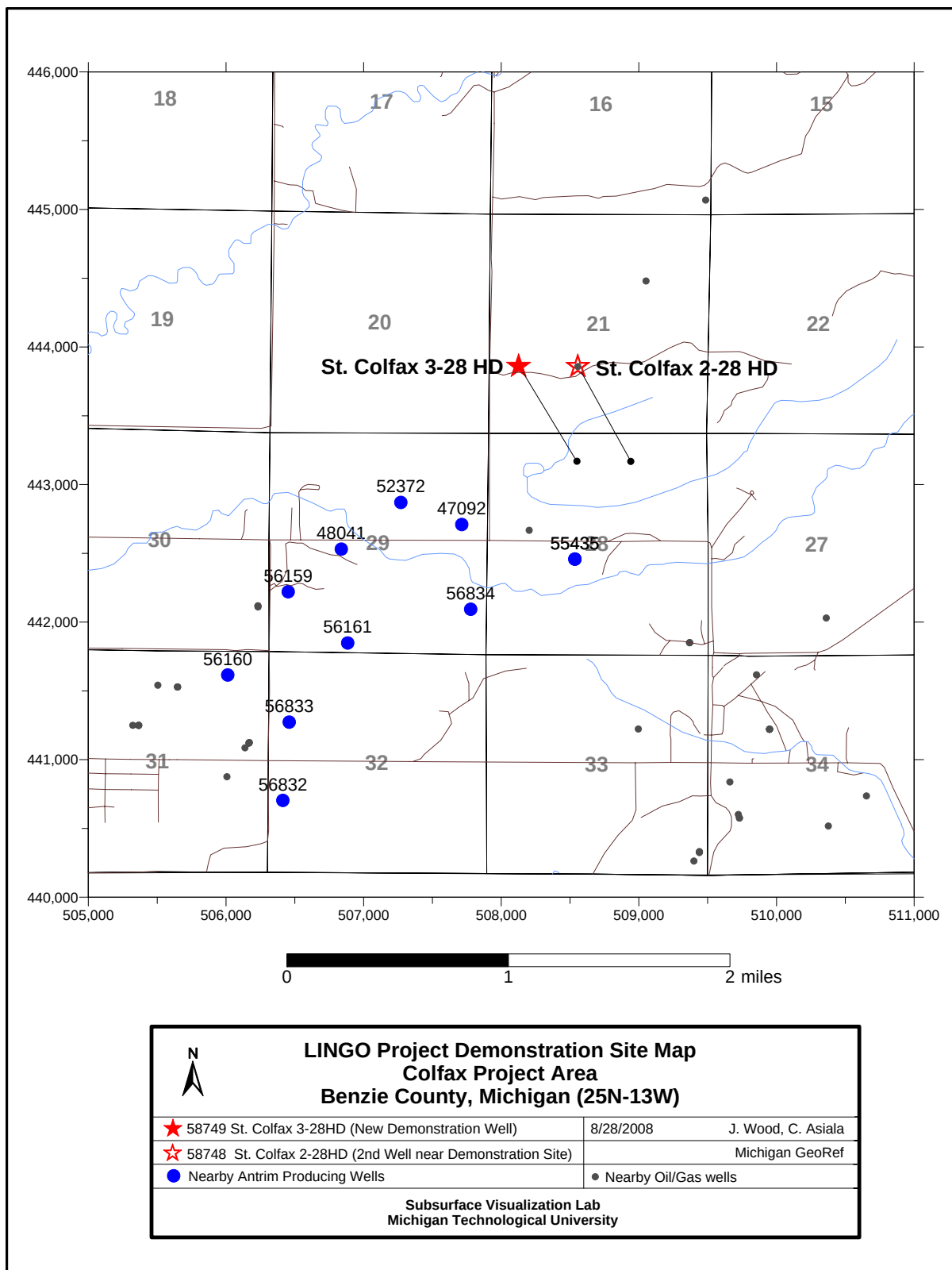


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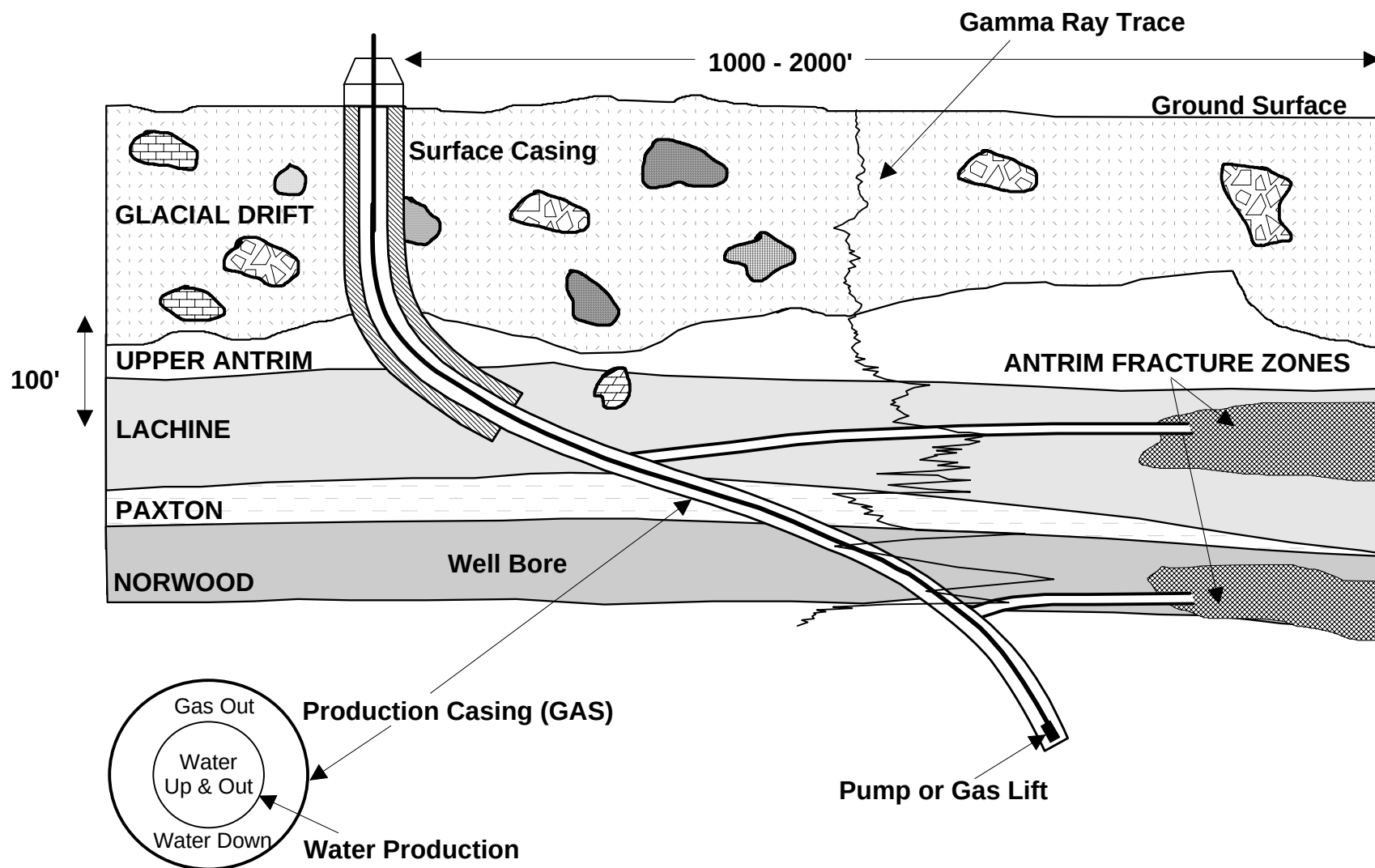
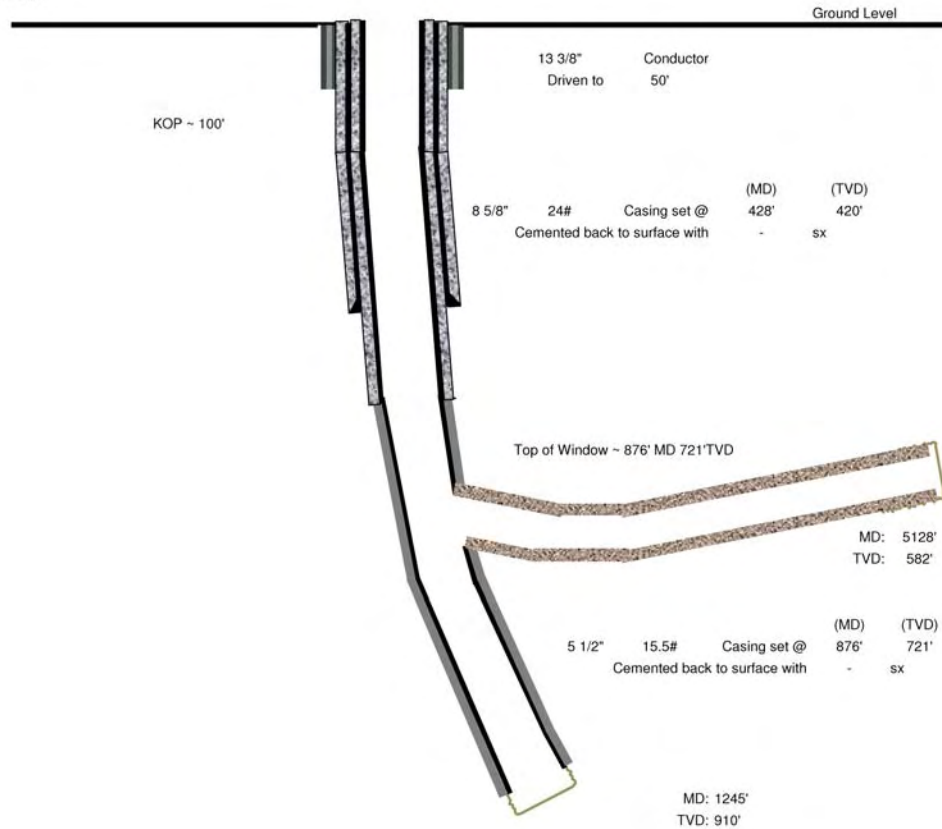


Figure 6. Schematic diagram illustrating the drilling plan to tap the shallow Antrim gas reserves using a slant well in place of a vertical well and casing it so that it satisfies Michigan regulatory statutes. Horizontal wells will branch out to the pay zones of the slant well. Note that the laterals can slope upward to drain water to the pump at the bottom of the slant well. Gas is produced in the outer tubing and goes directly to the surface. Water is drained to the bottom of the slant well and pumped up the inner annulus. The gamma ray log illustrates the highly variable nature of the radioactivity in the Antrim which can be used to locate and guide the drill bit using MWD (Measurement While Drilling) technology.

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

K.B.: ~677
G.L.: ~670



Well Name & Number:	A-GA-MING #4-12HD & HD1			MDEQ#	58153
Section:	12 & 1	Township:	T30N	Range:	R9W
County:	Antrim	State:	Michigan	Surface Hole Location:	NW NW NW
Township:	Mancelona	Country:	United States	Bottom Hole Location:	SE SW NE
Spud Date:	-				
Prepared By:	Benjamin J. Nieto			Last Revision Date:	08/08/07

Figure 7. Well bore schematic of the A-GA-MING demonstration well located in the Milton-Bradley project in western Antrim County, MI.

BEDROCK SUBCROP - N. MICHIGAN

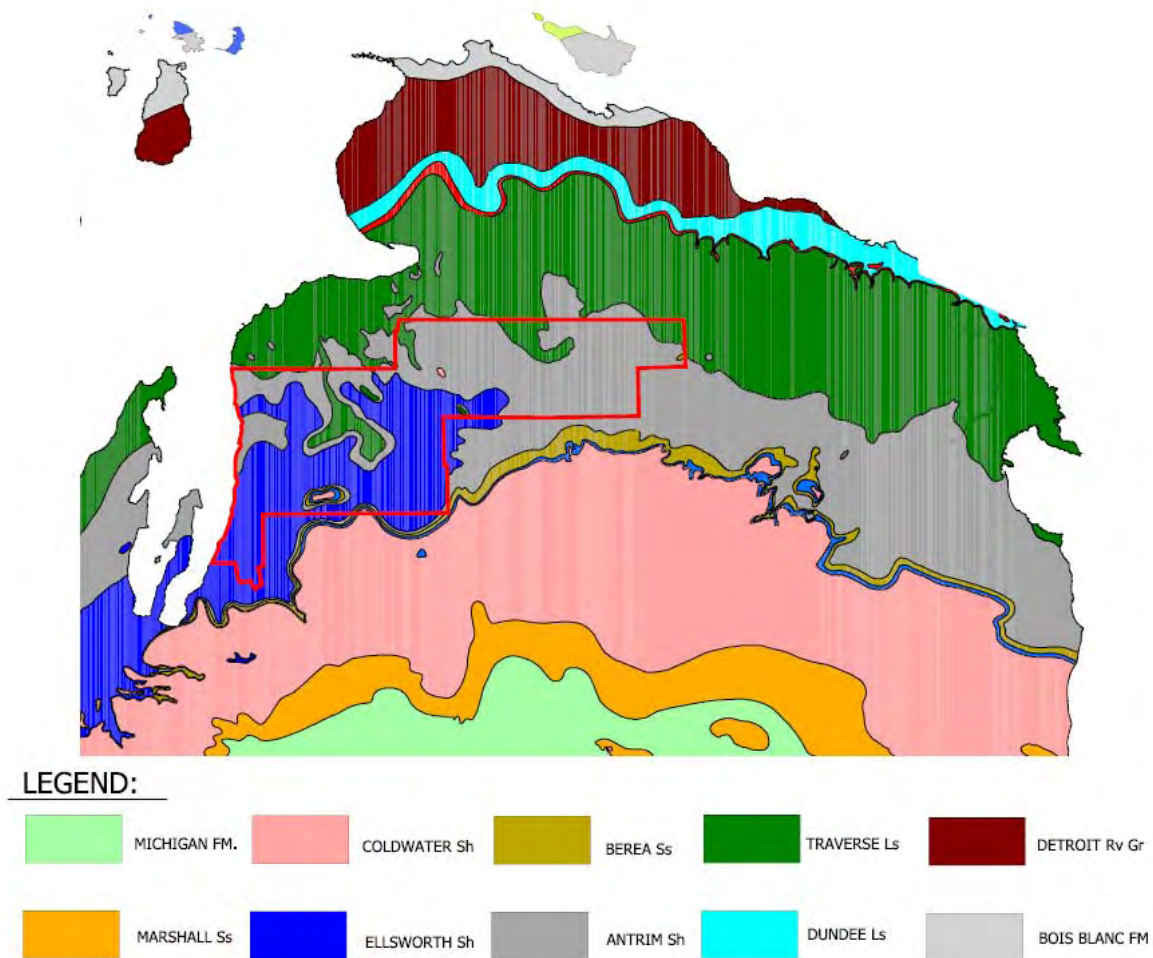


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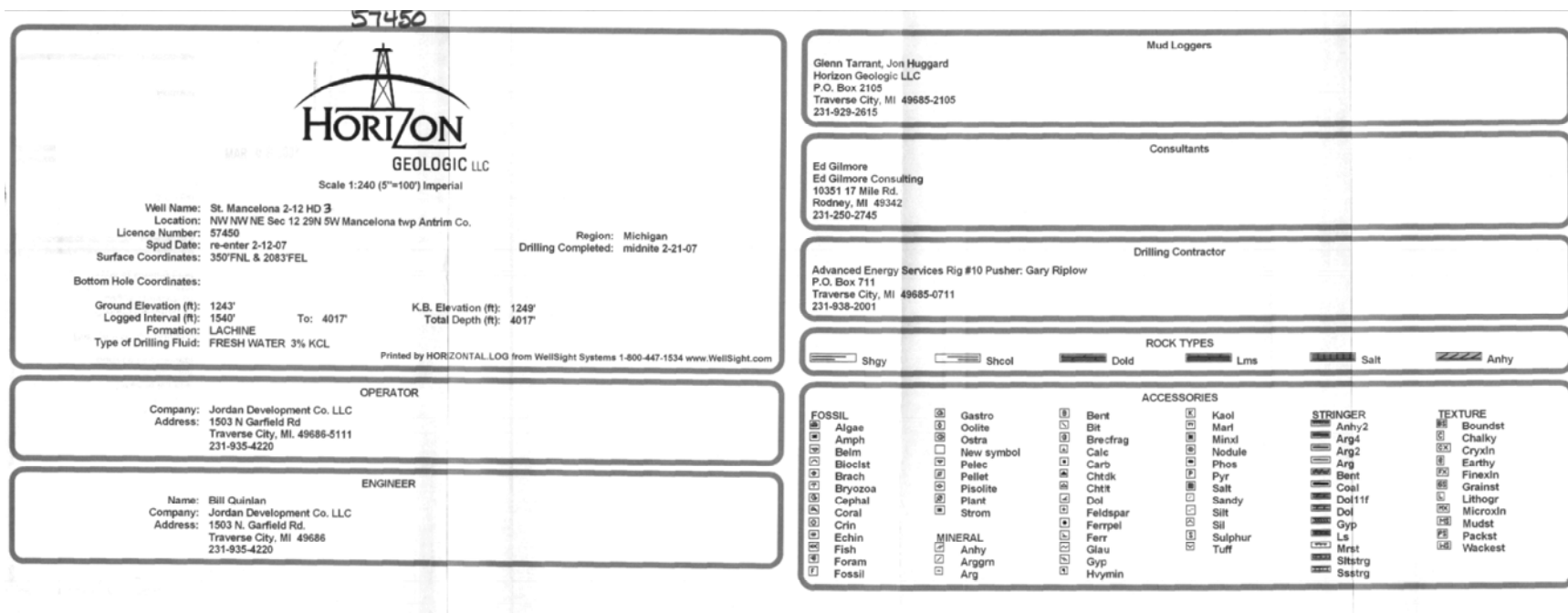


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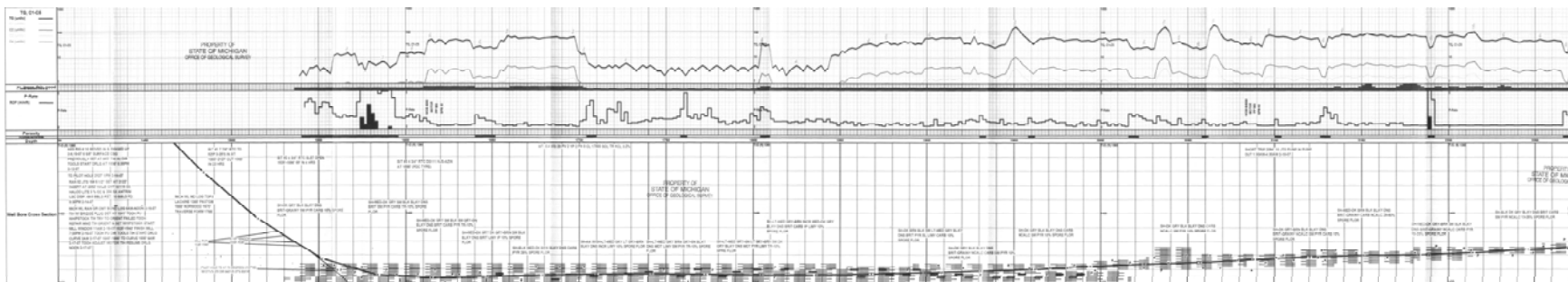


Figure 9b. State Mancelona 2-12 HD: Horizontal leg through the Lachine member, measured depth scale is from 1400 - 2270 feet, well bore on bottom track, vertical scale is 1380-1420 feet, true vertical depth.

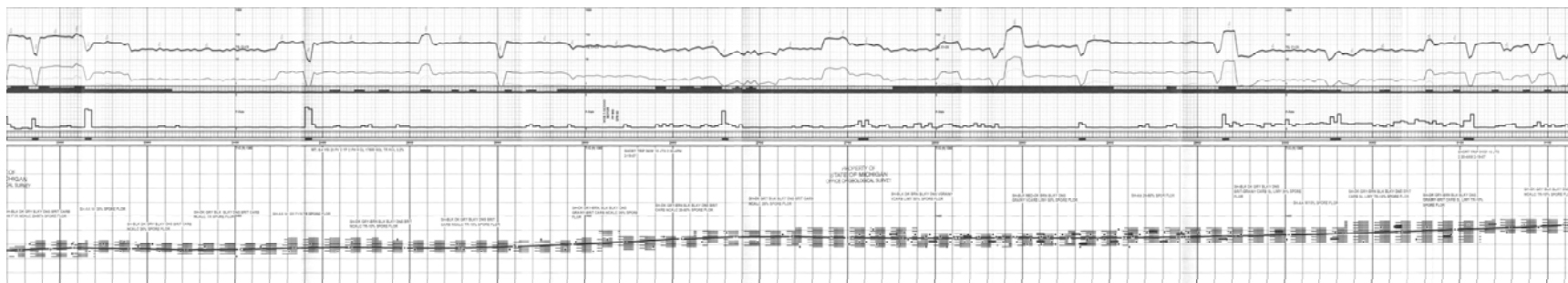


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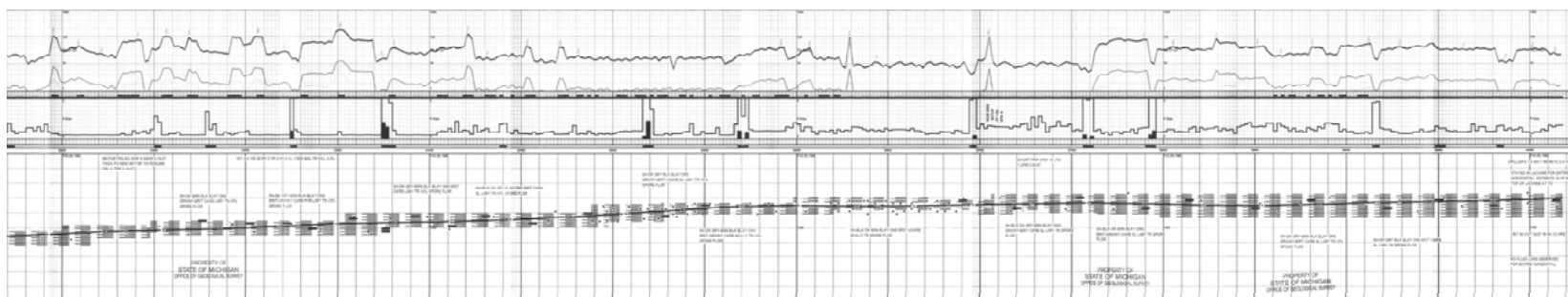


Figure 9d. State Mancelona 2-12 HD: Horizontal leg through the Lachine member, measured depth scale is from 3170 - 4030 feet, well bore on bottom track, vertical scale is 1380-1420 feet, true vertical depth.

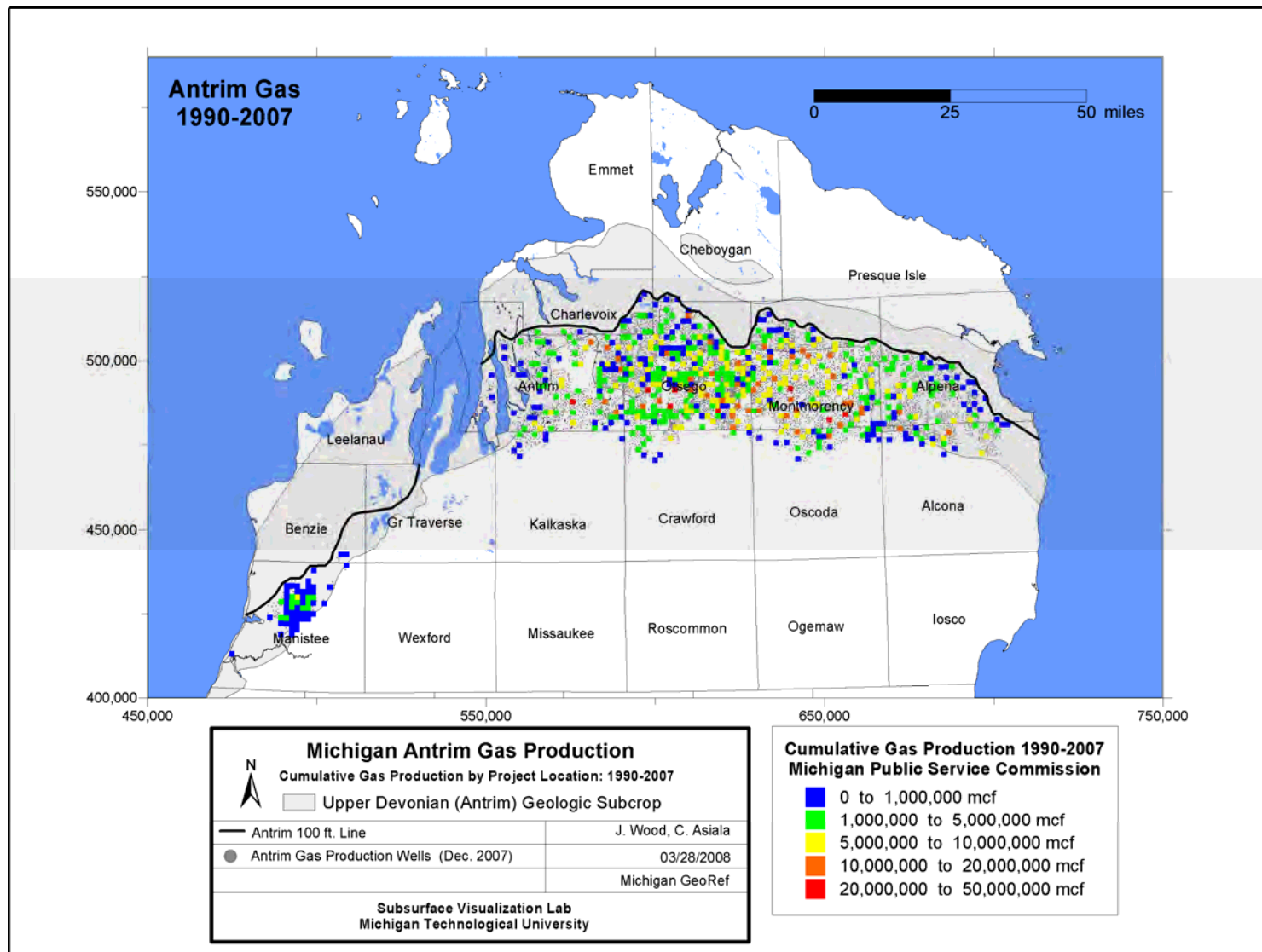


Figure 10. Cumulative Antrim gas production map of Northern Michigan. The gray shaded area is the Antrim subcrop and the black line indicates the cutoff line of where production is limited because of the 1-94 drilling restriction (Appendix I). The gray area above this line shows the area of the Antrim that could be opened up for Antrim gas production through the efforts of this DOE project.

21009576680000 Bargy #16-14

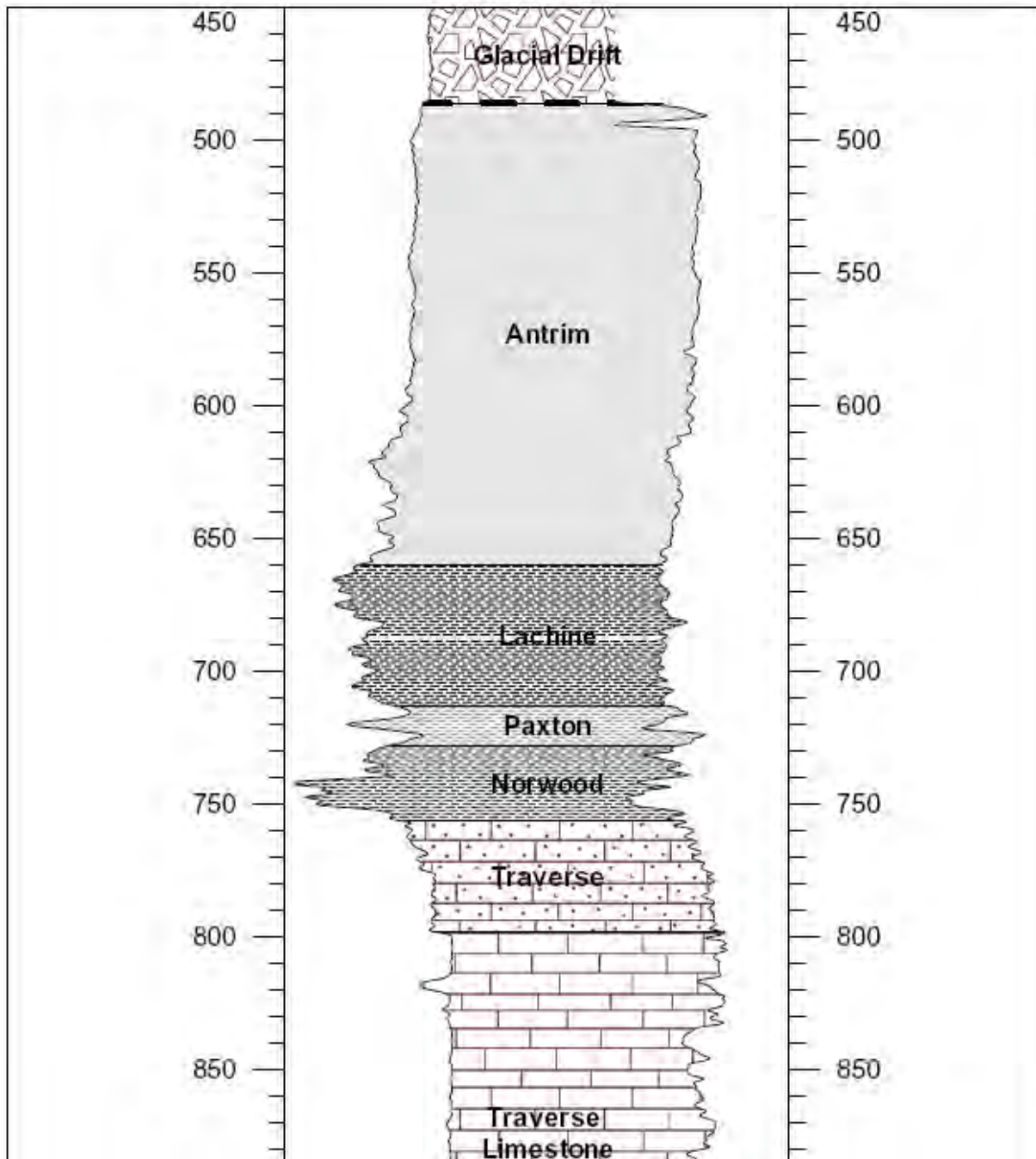
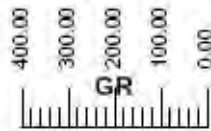
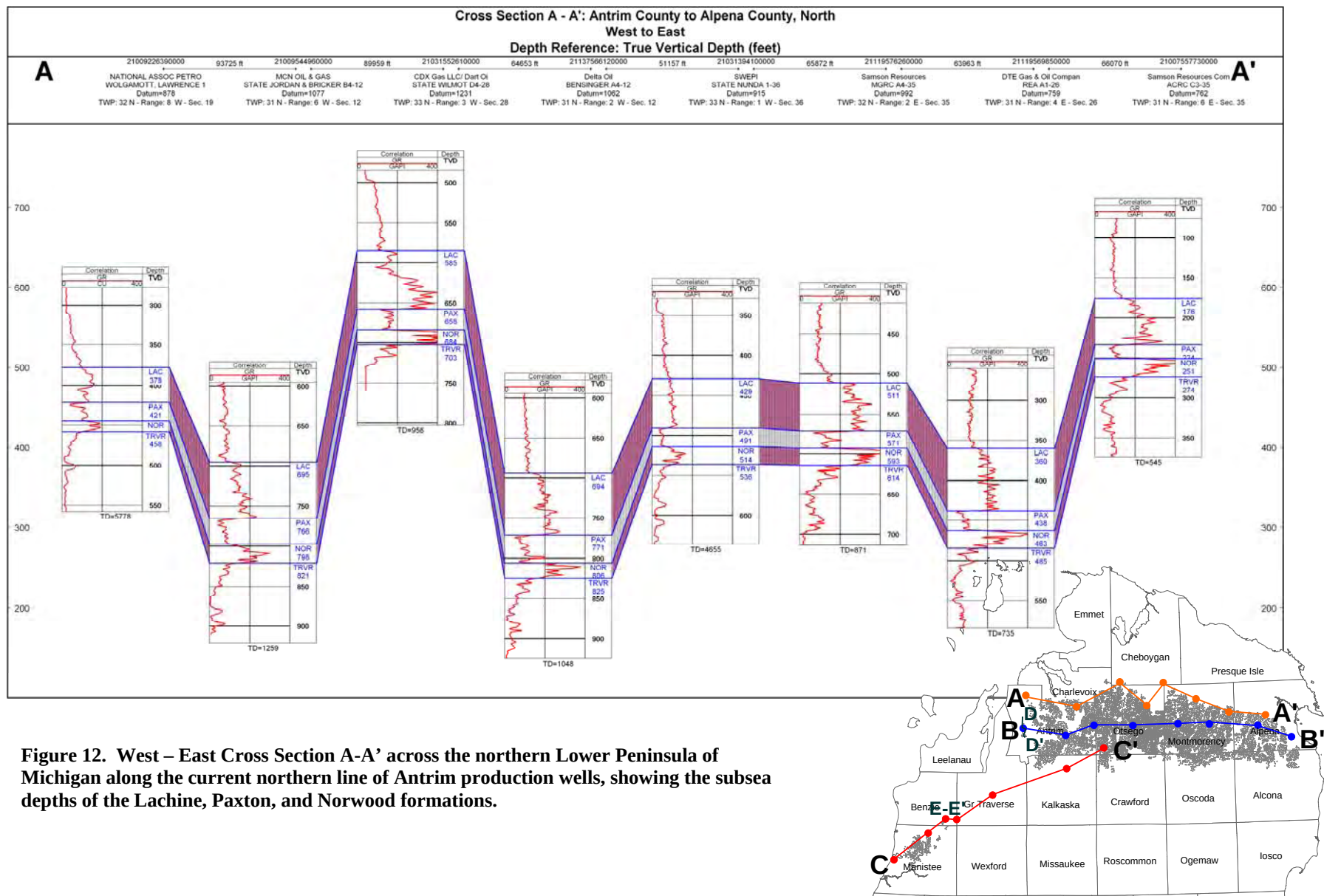


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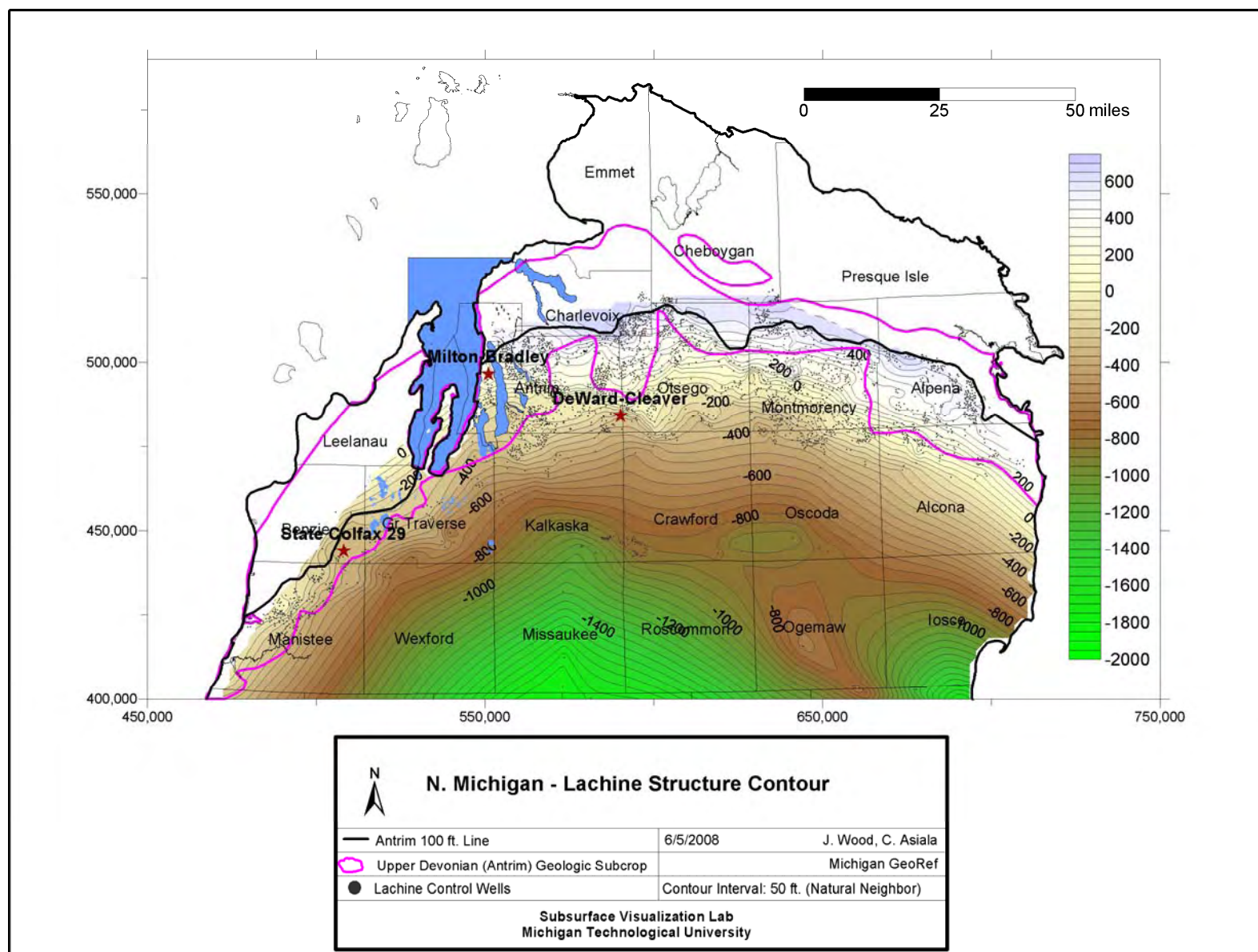


Figure 13. Structure map of the Lachine member of the Antrim formation in Northern Michigan. Contour Interval is 50 feet.

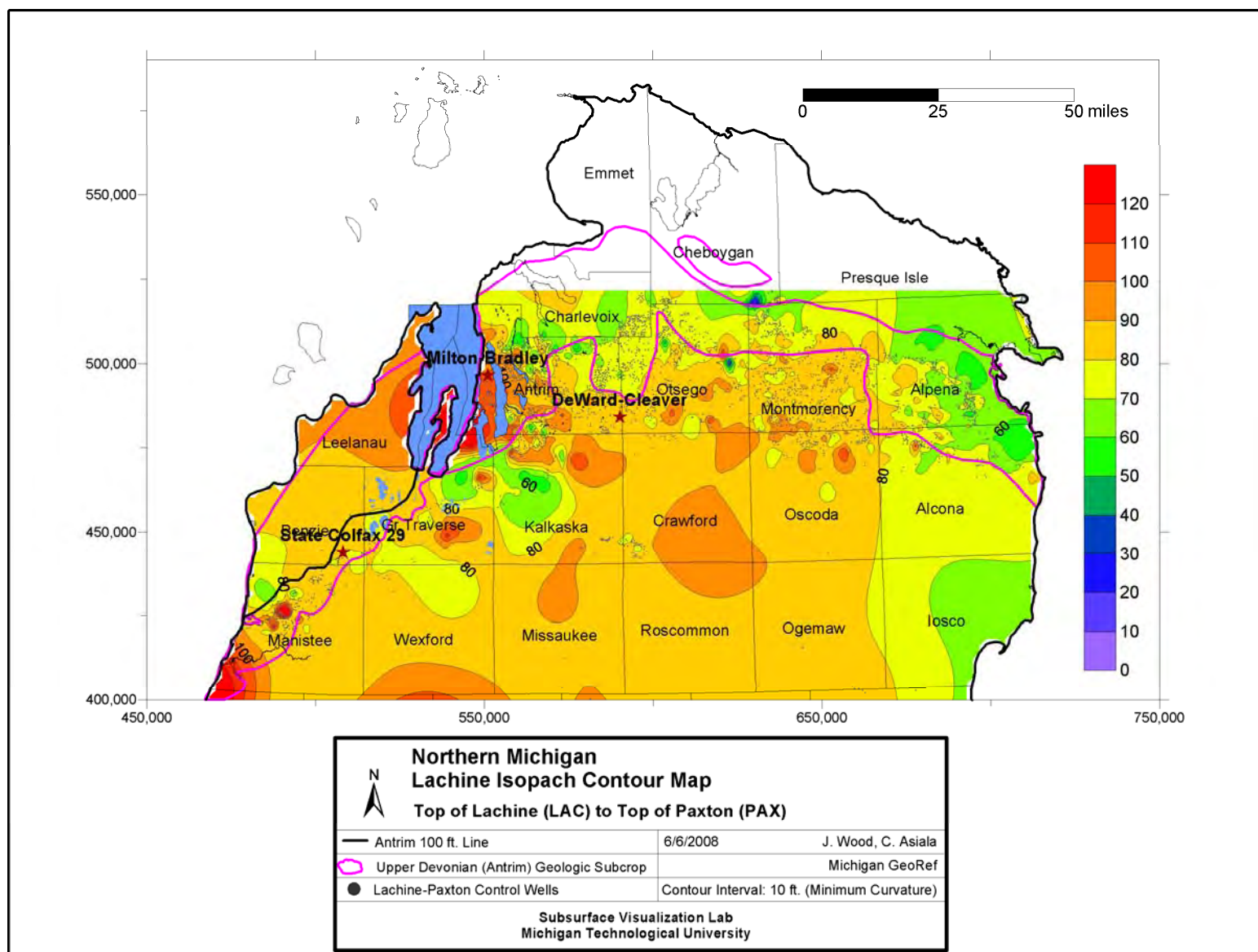


Figure 14. Isopach thickness map of the Lachine member of the Antrim formation over northern Michigan, contour interval is 10 feet.

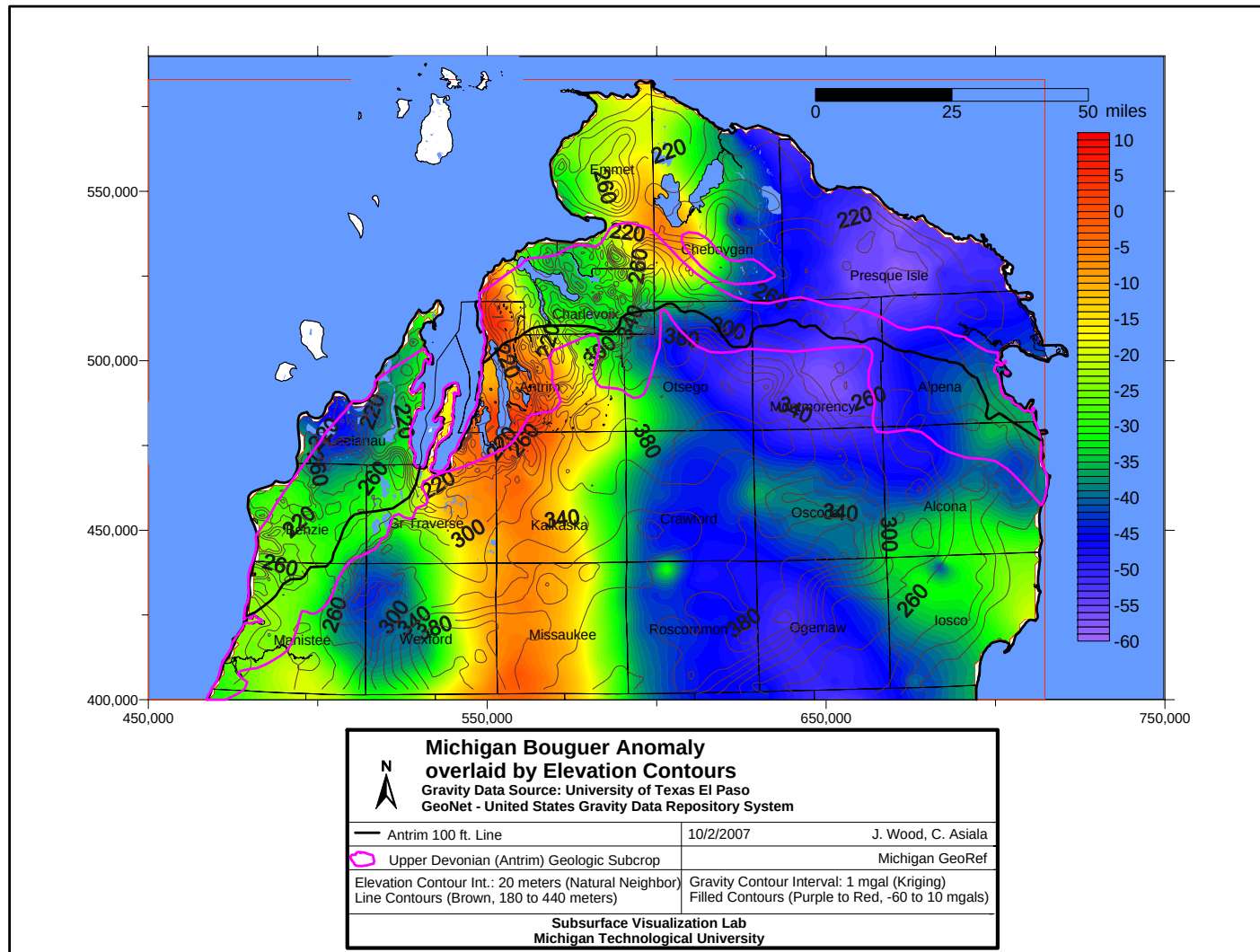


Figure 15. Michigan Bouguer Anomaly map created from data obtained from the University of Texas El Paso website for GeoNet –Gravity and Magnetic Dataset Repository. (<http://irpsrvgis00.utep.edu/repositorywebsite/>). Color-filled contours are shown from -60 to 10 mgals with a contour interval of 1 mgal. The elevation contours overlaid on the Bouguer Anomaly ranges from 180 to 440 meters and were contoured at a 20 meter interval.

Timeline of Michigan Public Service Commission (MPSC) Antrim Gas Production Reporting Standards

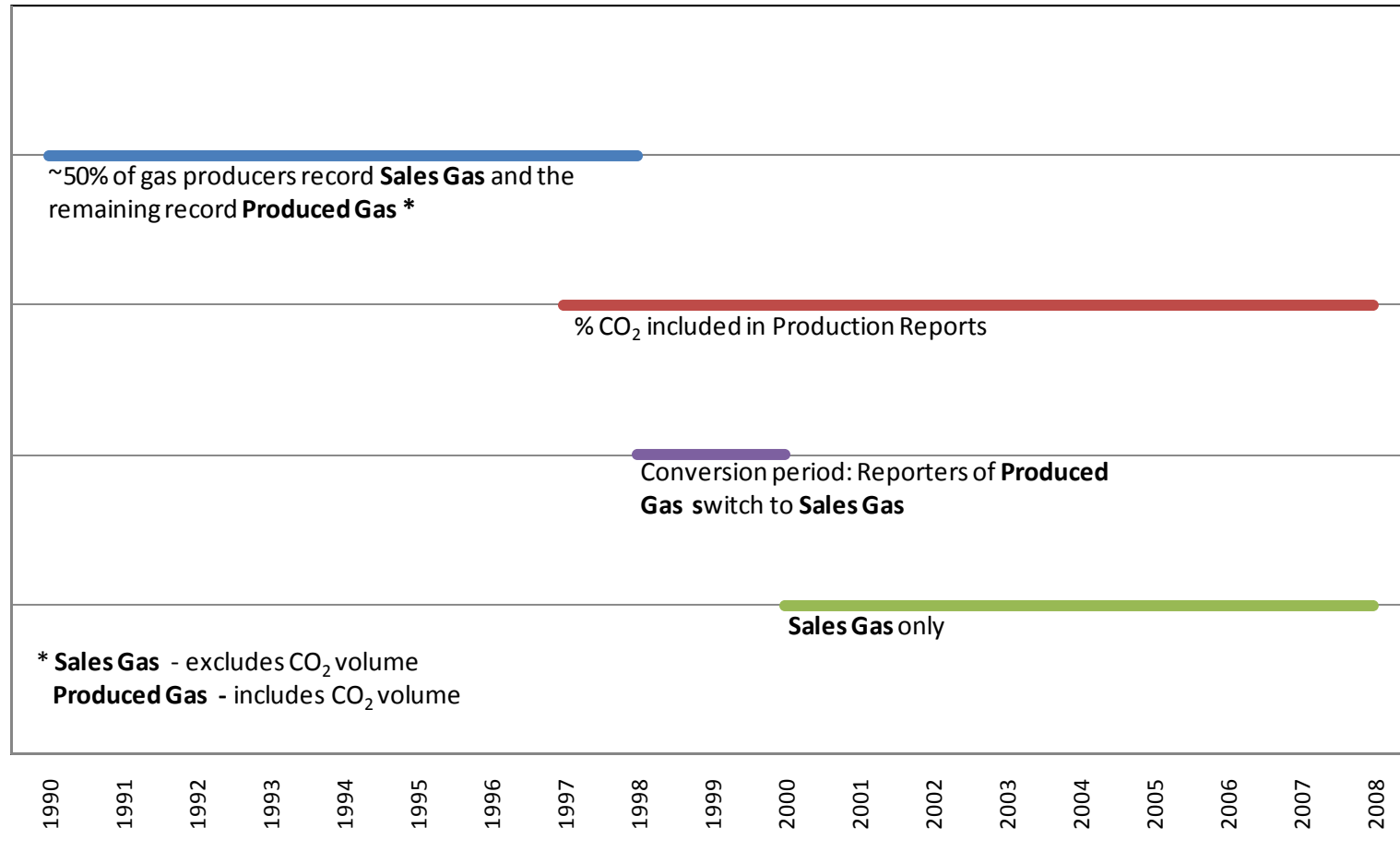


Figure 16. Timeline and definition of how carbon dioxide production has been historically recorded and archived by the Michigan Public Service Commission.

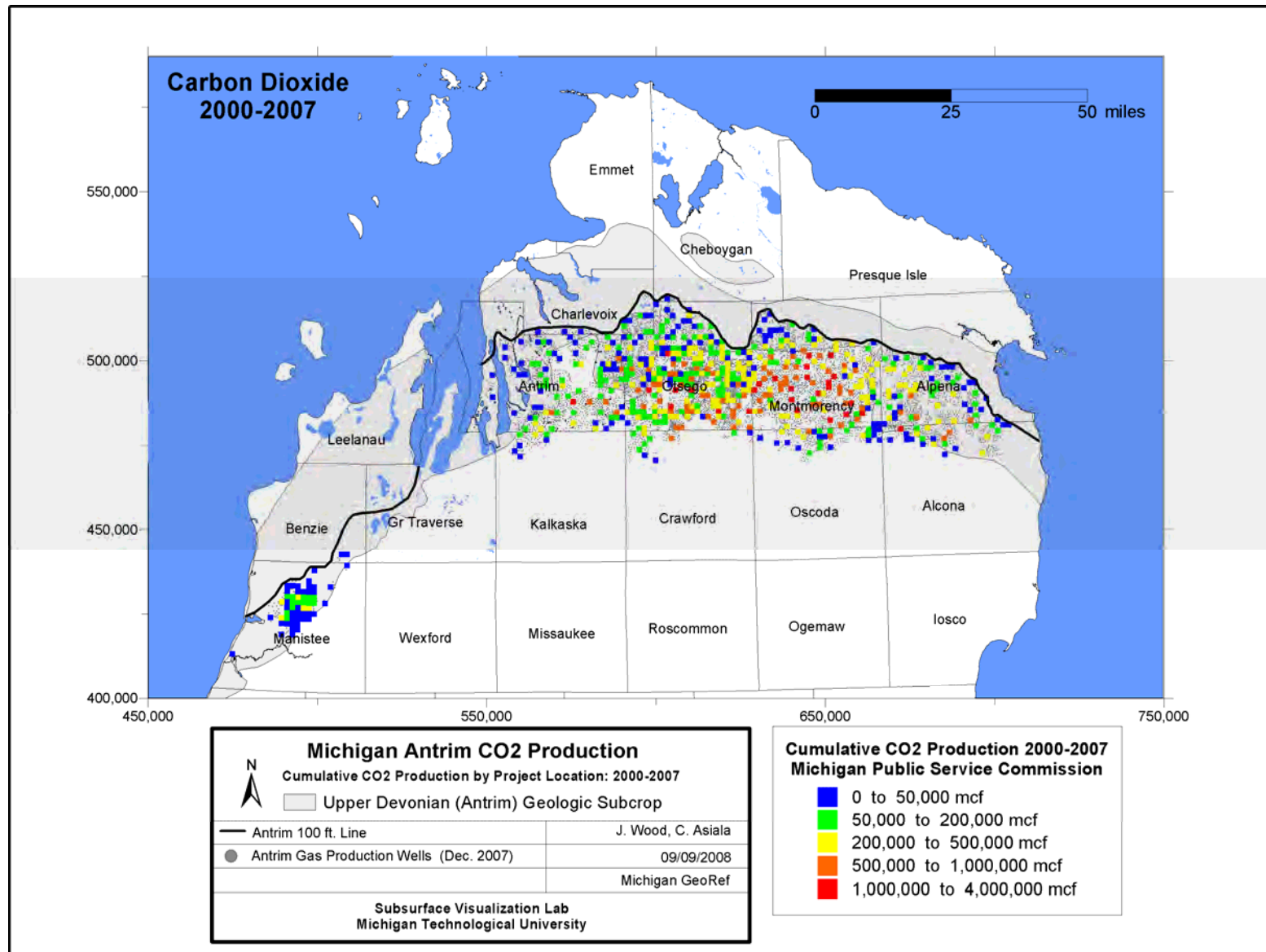
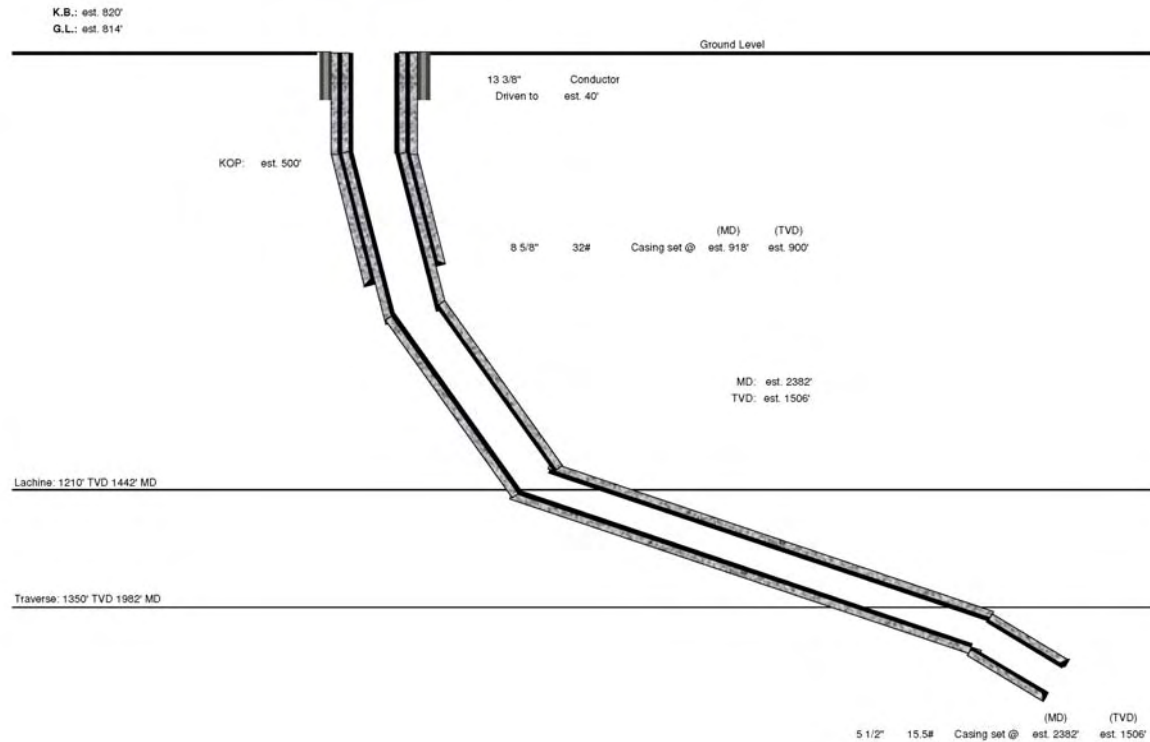


Figure 17. Production map showing the distribution of cumulative CO₂ produced from 2000 through 2007 over northern Michigan.

Colfax 29



Well Name & Number:	St. Colfax #3-28 HD	MDEQ#	58749						
Section:	21	Township:	T25N	Range:	R13W	Surface Hole Location:	SE NW SW	1599' from South & 699' from West	
County:	Benzie	State:	Michigan	Bottom Hole Location:	SE NE NW	660' from North & 2110' from West			
Township:	Colfax	Country:	United States						
Spud Date:	-								
Prepared By:	Benjamin J. Nieto	Last Revision Date:	12-18-2007						

Figure 18. Redesigned well configuration for project demonstration well, St. Colfax 3-28 HD, designed after the initial tests of the original "J" well configuration. This well is 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.



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.		Permit number/deepening permit no. 58749		API number 21-019-58749-00-00	
(Submit 3 copies within 60 days of well completion.) ☒ Part 615 Oil/Gas Well ☐ Part 625 Mineral Well		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 ¼ Section 21 T 25N R 13W		Subsurface location (if directionally drilled) SW ¼ of SE ¼ of SW ¼ Section 21 T 25N R 13W			
Township Colfax		County Benzie		Township Colfax	
Footages: North/South 1599 Ft. from South line and 699 Ft. from West line of Sec.		Footages: North/South 371 Ft. from South line and 1430 Ft. from West line of Sec.			
Part 615 - oil/gas wells					
Date well completed 2-26-2008		Producing formation(s) Antrim Shale		Injection formation(s) N/A	
Part 625 - mineral wells					
		Disposal formation(s) N/A		Solution formation(s) N/A	

COMPLETION INTERVALS(S)

Date	Number holes	Perforation or open hole interval	Open	
			Yes	No
2-25-2008	4 SPF	2026'-2032', 2035'-2040', 1998'-2008', 1836'-1846'	X	
2-26-2008	4 SPF	1794'-1799', 1779'-1784', 1735'-1740', 1721'-1726', 1703'-1708', 1682'-1687', 1649'-1654', 1627'-1632', 1596'-1600', 1577'-1582', 1557'-1562', 1330'-1340'	X	

STIMULATION BY ACID OR FRACTURING

Date	Interval treated	Materials and amount used
2-25-2008	2026'-2032', 2035'-2040'	15% Acid: 700 gals, Sand: 47,157# 20/40 4,700# 12/20
2-25-2008	1998'-2008', 1836'-1846'	15% Acid: 1000 gals, Sand: 50,900# 20/40 5,700# 12/20
2-26-2008	1794'-1799', 1779'-1784'	15% Acid: 1000 gals, Sand: 25,800# 20/40 6,000# 12/20
2-26-2008	1735'-1740', 1721'-1726'	15% Acid: 1000 gals, Sand: 26,700# 20/40 1,600# 12/20
2-26-2008	1703'-1708', 1682'-1687'	15% Acid: 1000 gals, Sand: 25,400# 20/40 4,900# 12/20
2-26-2008	1649'-1654', 1627'-1632'	15% Acid: 1000 gals, Sand: 25,500# 20/40 5,900# 12/20
2-26-2008	1596'-1600', 1577'-1582', 1557'-1562'	15% Acid: 1000 gals, Sand: 25,400# 20/40 5,100# 12/20
2-26-2008	1330'-1340'	15% Acid: 1000 gals, Sand: 26,600# 20/40 7,300# 12/20

PRODUCTION TEST DATA

Oil Bbls/day	Gravity °API	Condensate Bbls/day	Gas MCF/day	Water Bbls/day	H ₂ S Grains/100 ft ³	B.H.P. and depth
N/A	N/A	N/A	150 est.	400 est.	N/A	N/A

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)	Signature	Date
Benjamin J. Nieto, Authorized Agent		

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

EQP 7130 (rev. 8/2004)

Figure 19. Record of Completion for the St. Colfax 3-28HD well in Benzie County, MI.

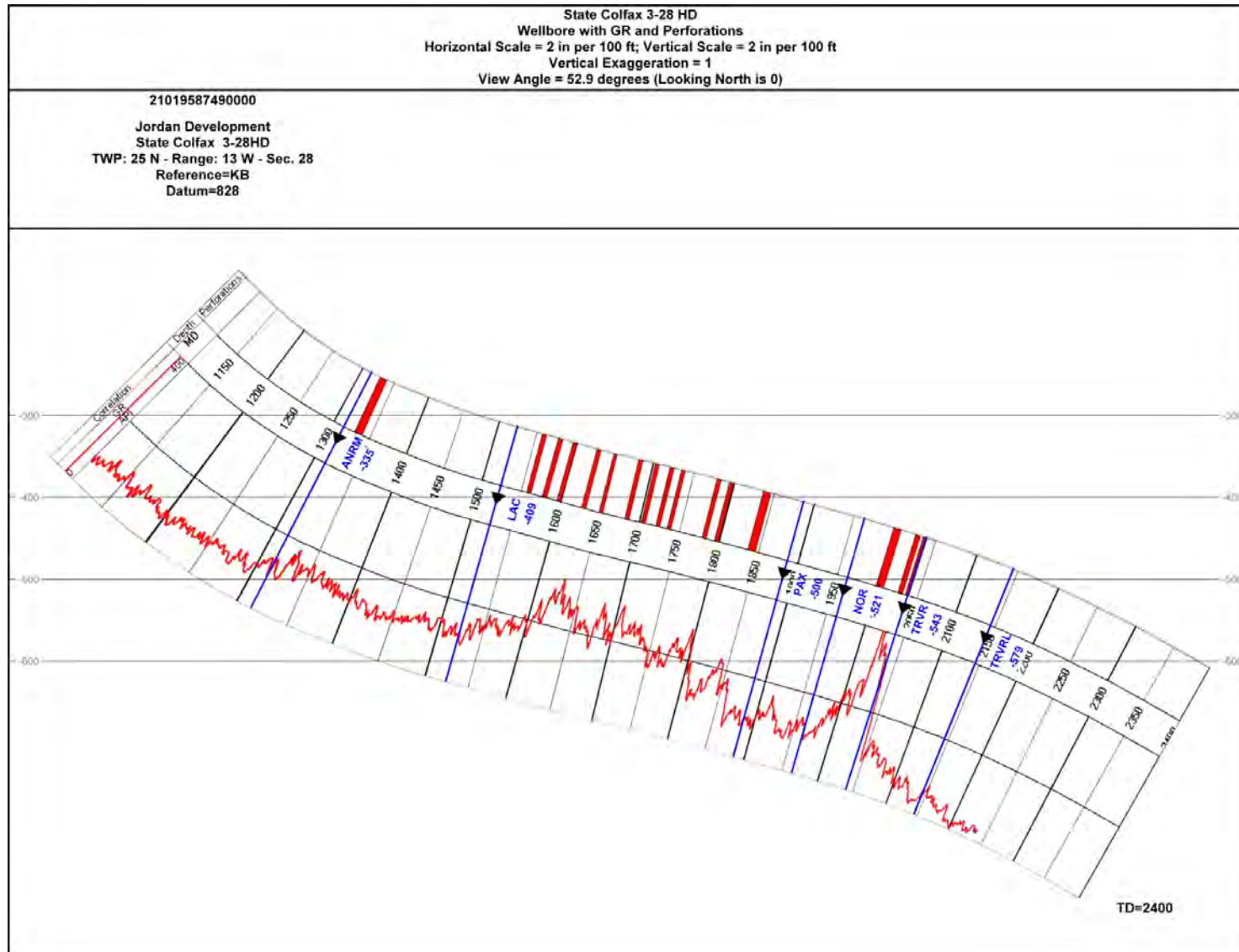


Figure 20. Cross section of Gamma Ray log over the cased well path of the demonstration well, St. Colfax 3-28 HD in Benzie County, MI. Blue lines mark the formation tops of the Antrim, Lachine, Paxton, Norwood, and Traverse formations. The red bars mark the perforation intervals.

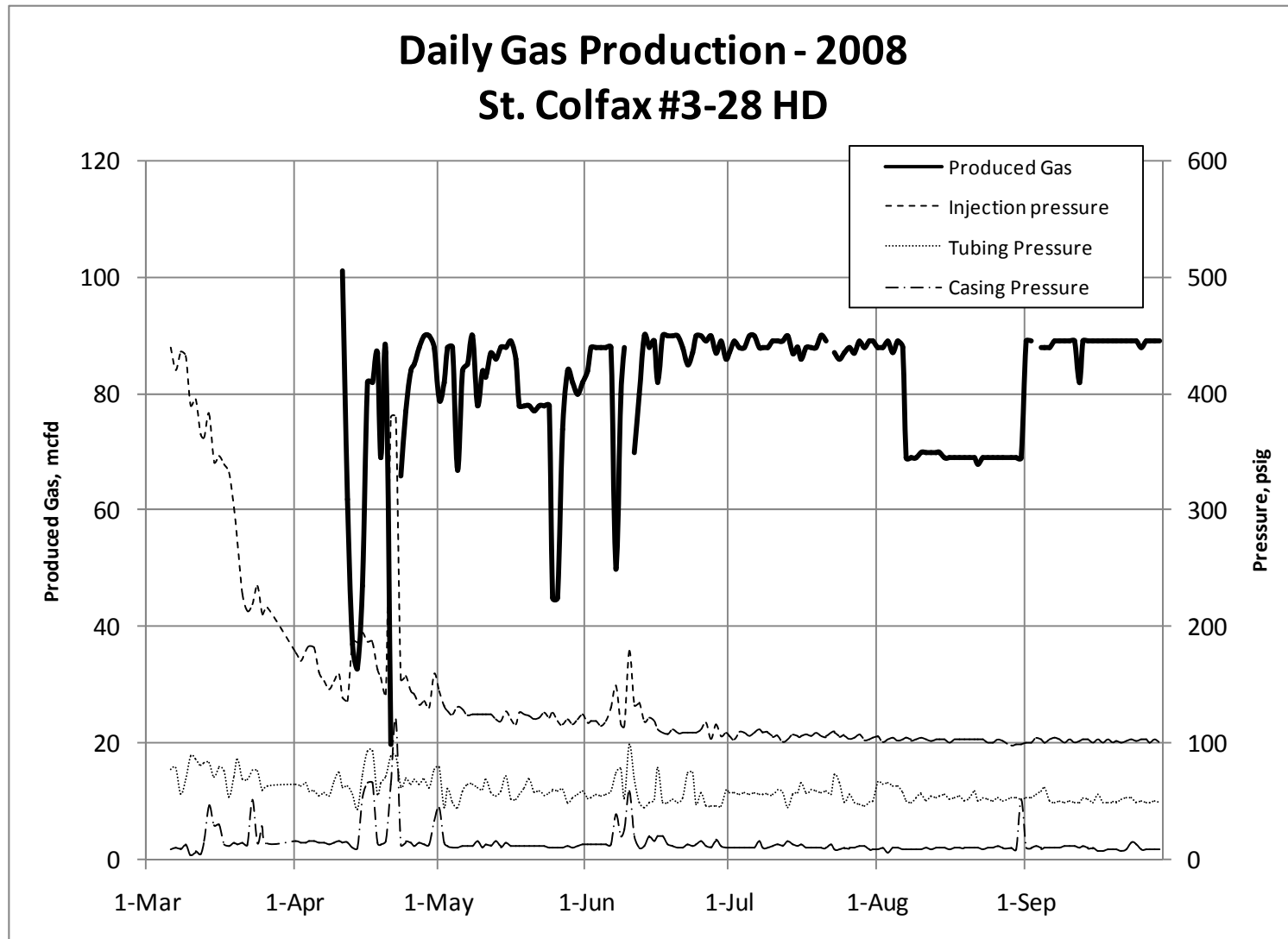


Figure 21. Daily gas production and injection pressure data for the project demonstration well, Colfax 3-28 HD in Benzie County, MI. The lateral for this well was drilled with a cased hole downward sloping configuration with perforated completion intervals shot through the pipe and individually fracture treated.

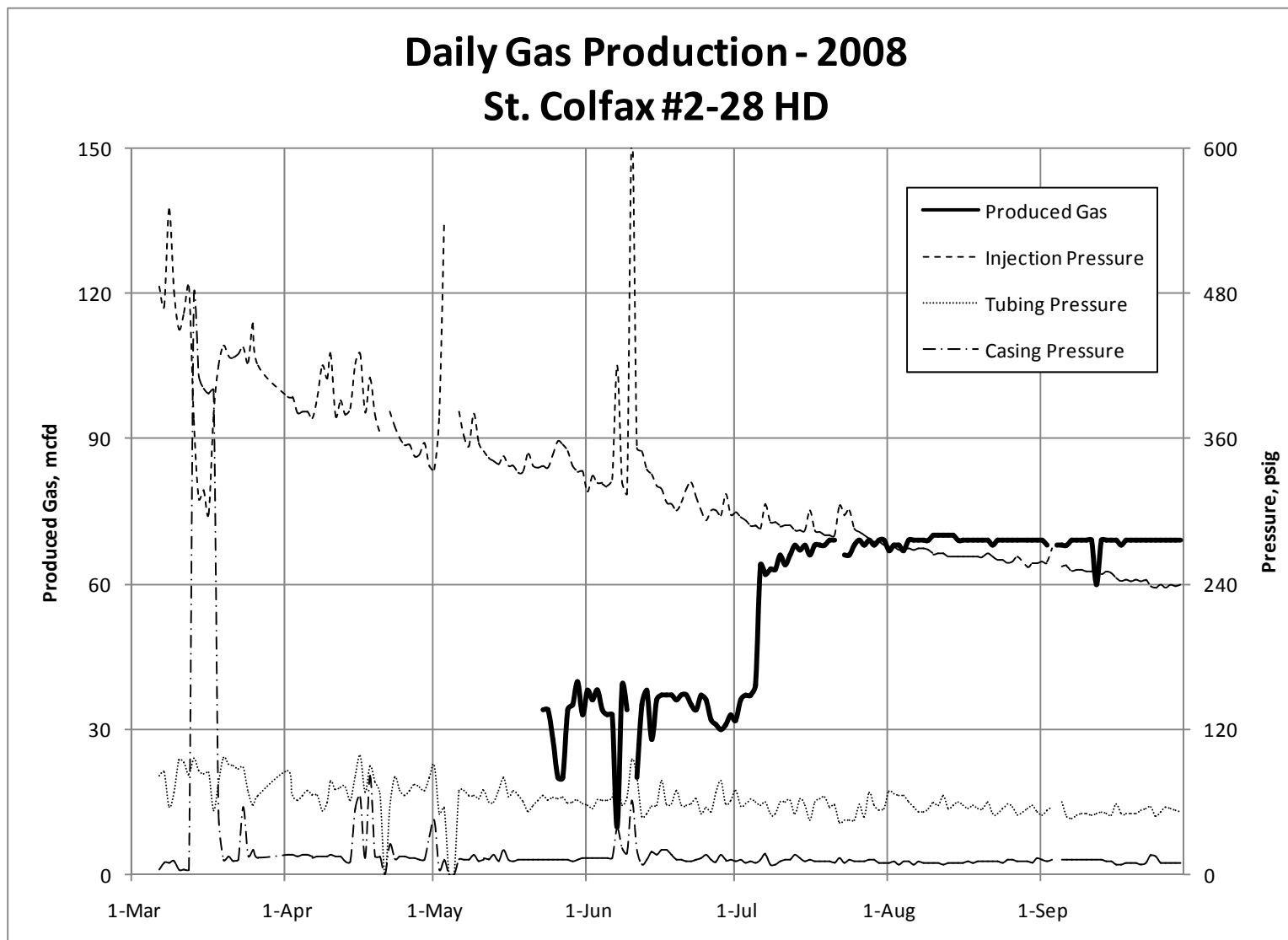


Figure 22. Daily gas production and injection pressure data for the Colfax 2-28 HD, the well drilled near the project demonstration well in Benzie County, MI with the same cased hole downward sloping configuration.

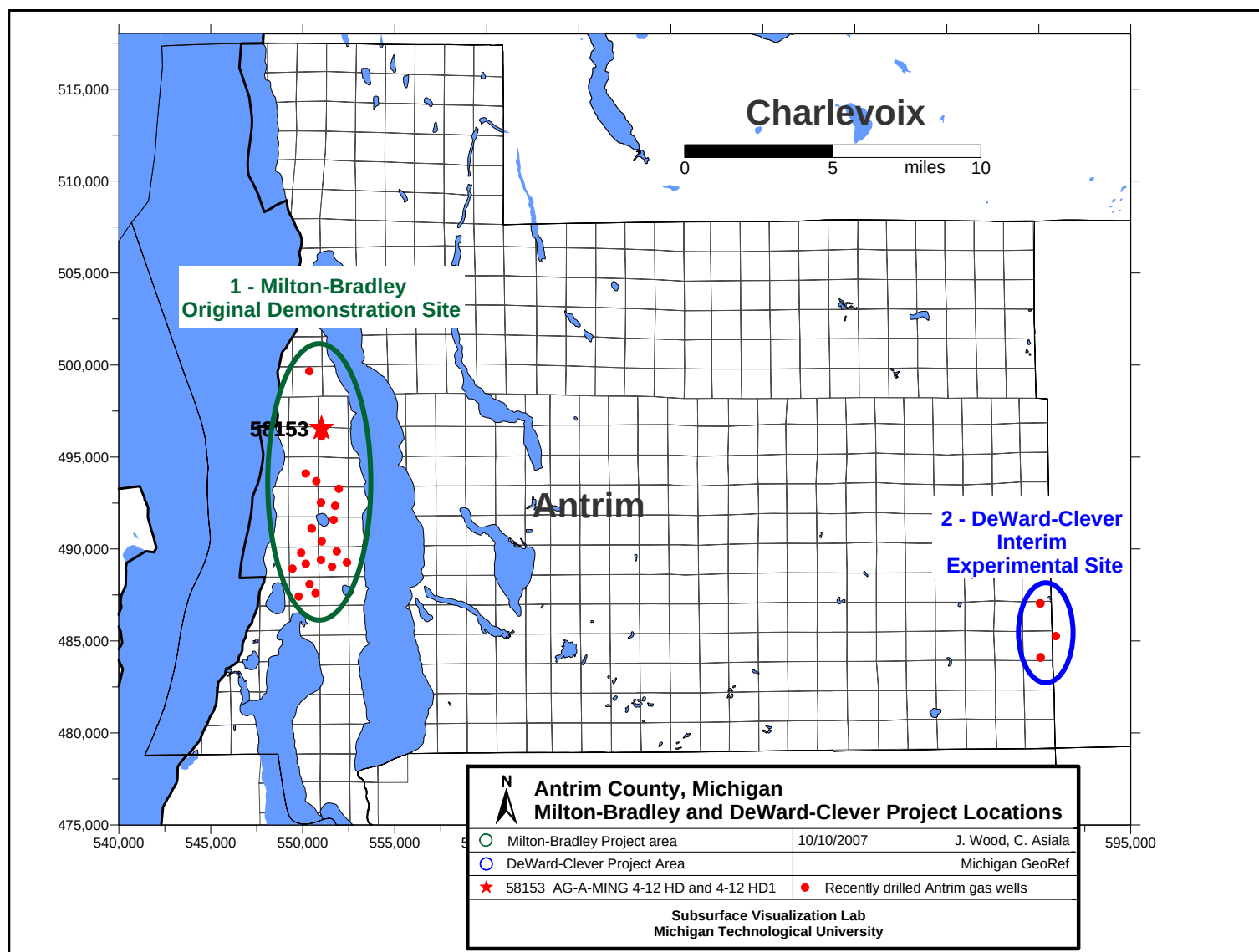


Figure 23. Location map comparing the locations of the DOE LINGO project area, Milton-Bradley, to the Deward Clever project area, where the "J" well configuration for the horizontal wells has been put to practice.

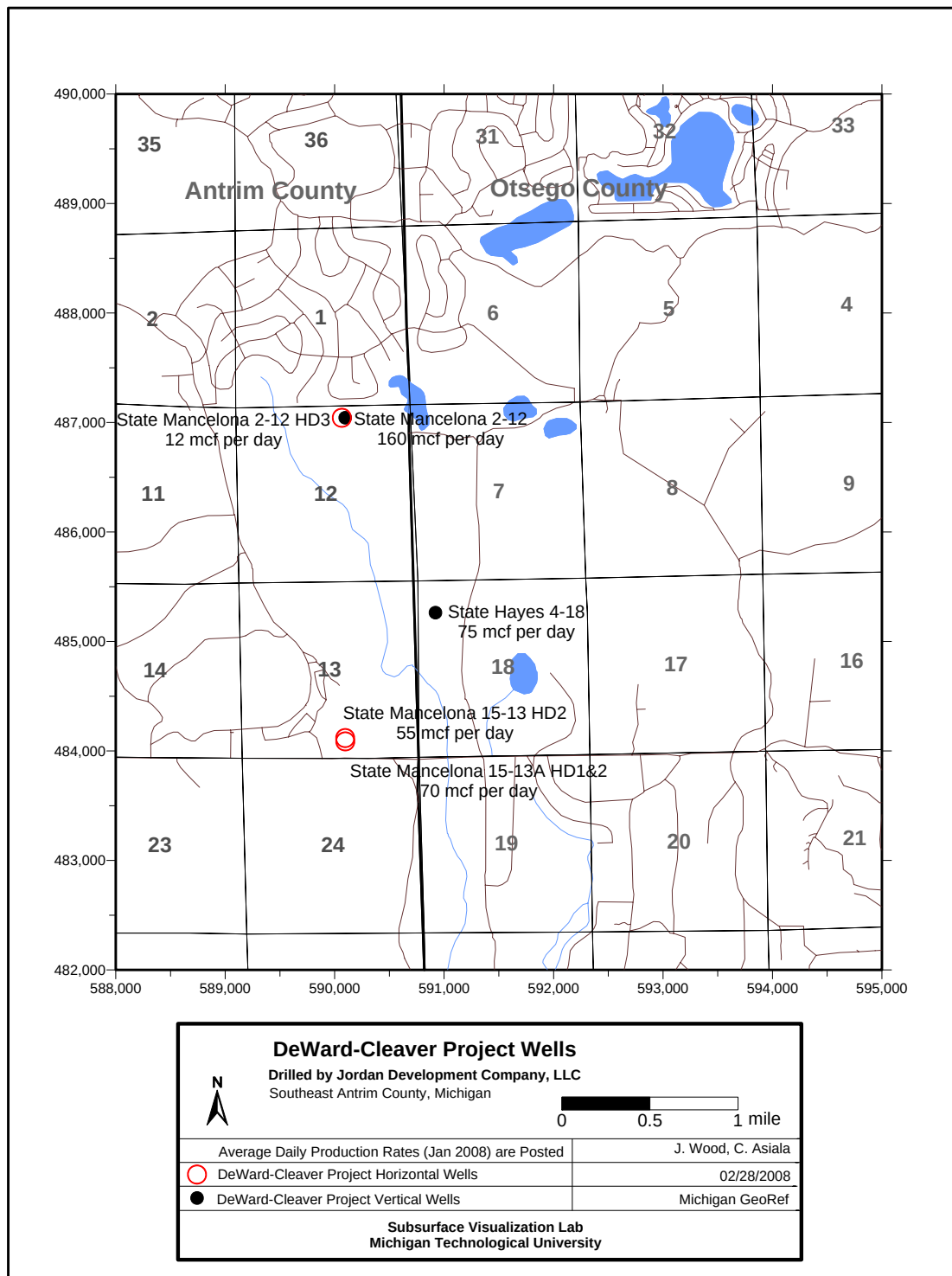


Figure 24. Location map of the Deward Cleaver project where the "J" well configuration has been tested.

State Mancelona #15-13A HD1 & HD2

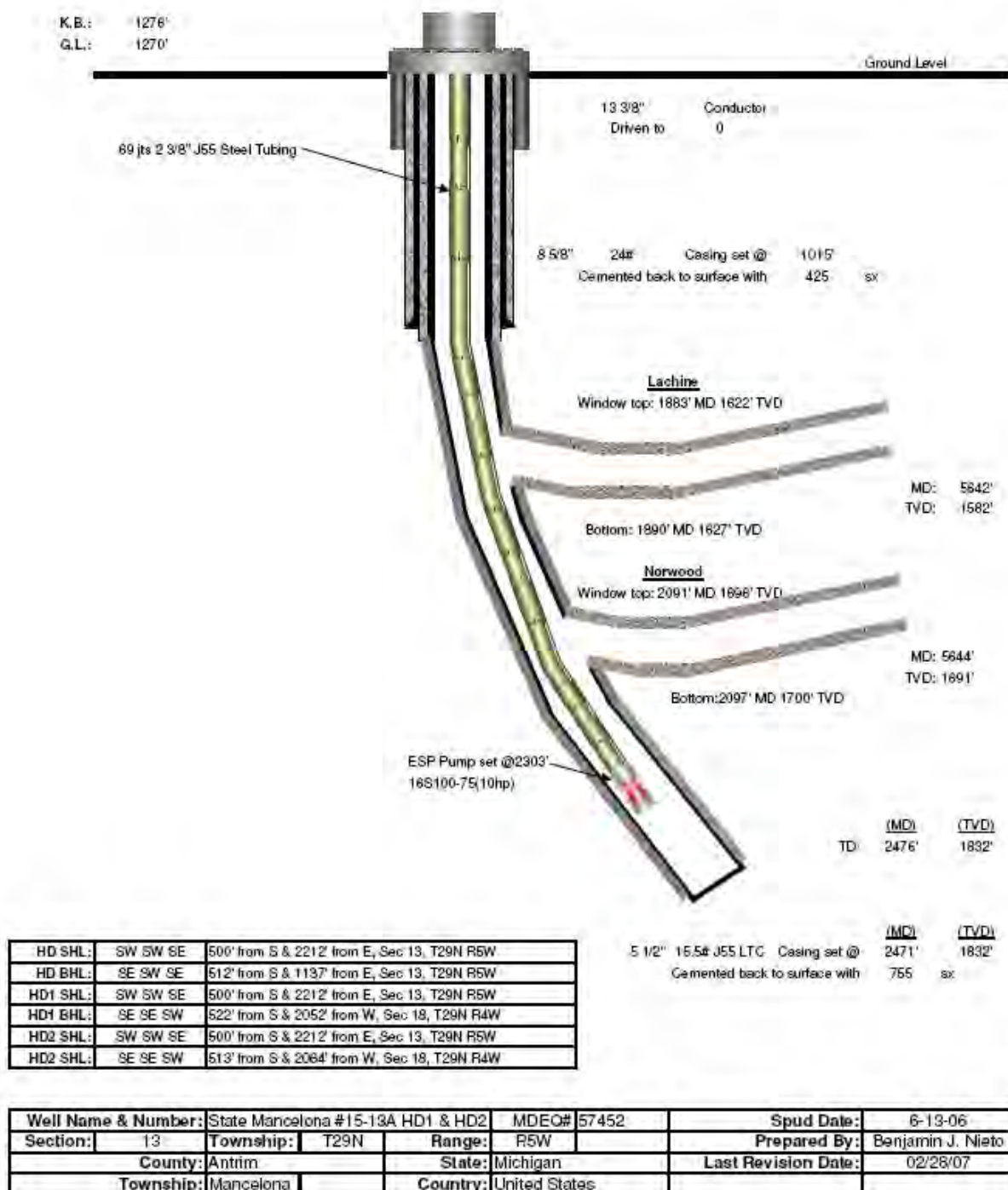


Figure 25. Well bore schematic of the "J" well configuration of the State Mancelona #15-13A HD1 & HD2 (Permit 57452) horizontal wells in the Deward Clever project in southeast Antrim County, MI.

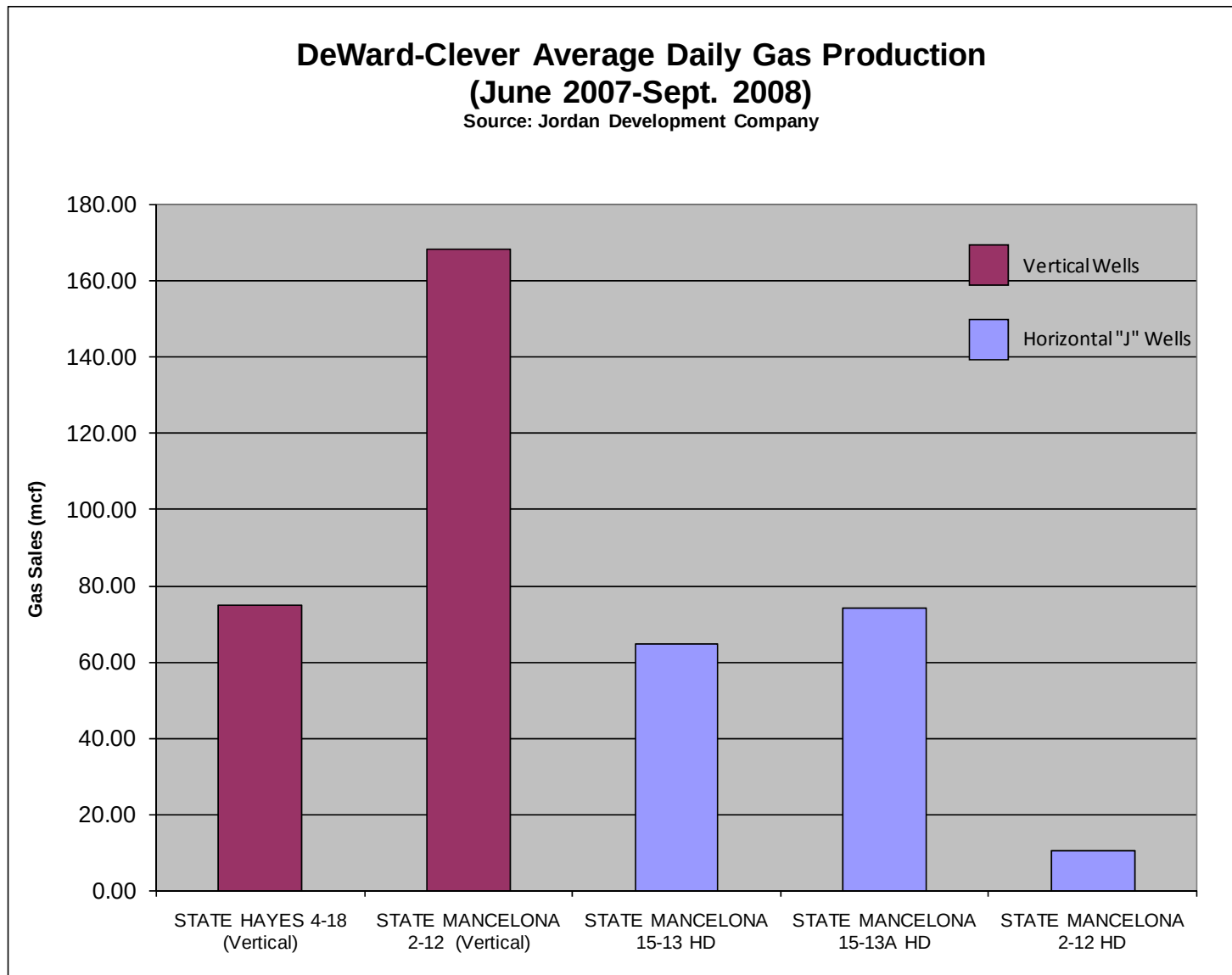


Figure 26. Comparison of average daily Antrim gas production for the Deward Clever project wells located in southeast Antrim County. The horizontal wells are using the “J” well configuration originally planned for the LINGO project demonstration well.

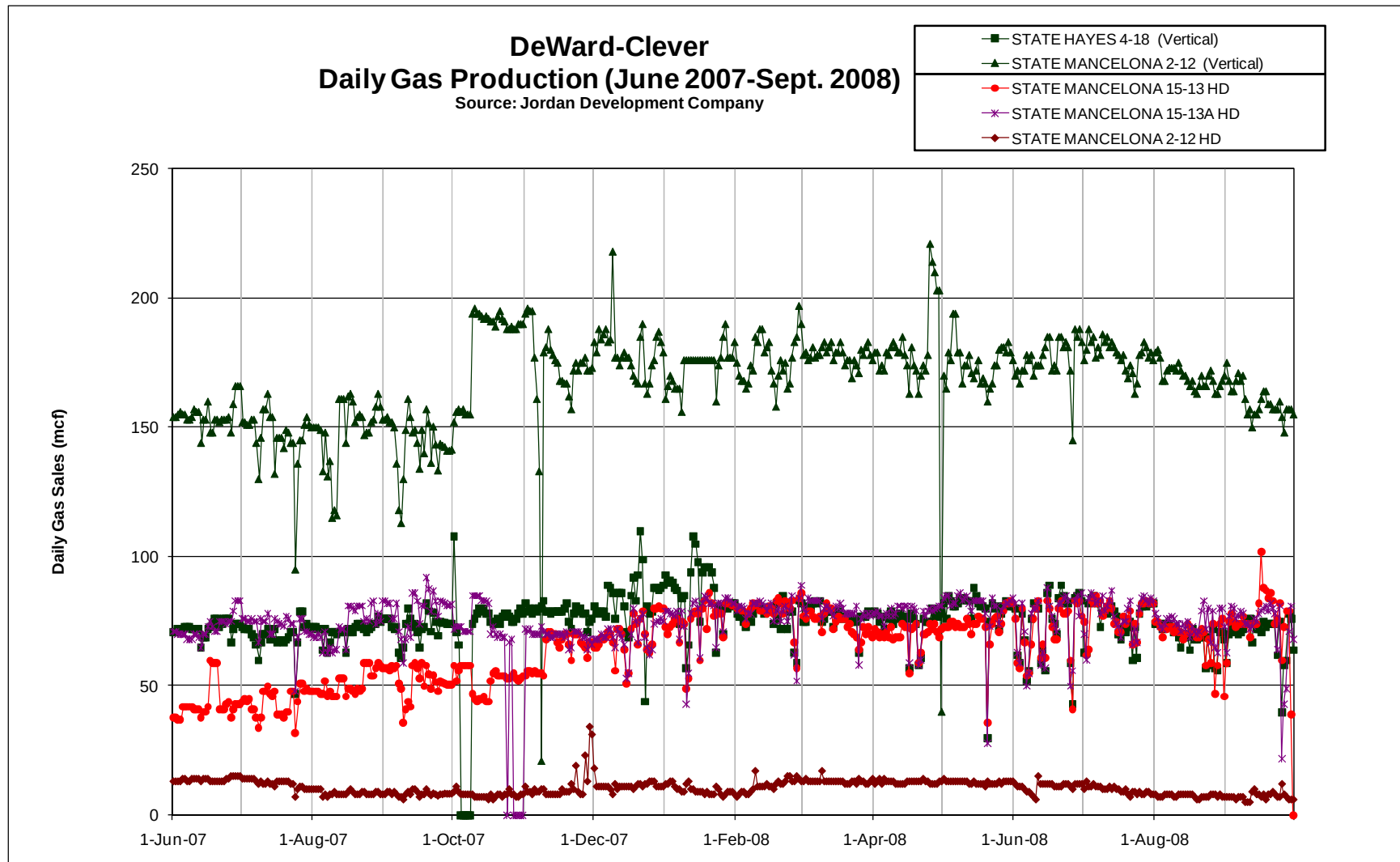


Figure 27. Daily Antrim gas production for the Deward Clever project wells located in southeast Antrim County. The horizontal wells are using the “J” well configuration planned for the LINGO project demonstration well.

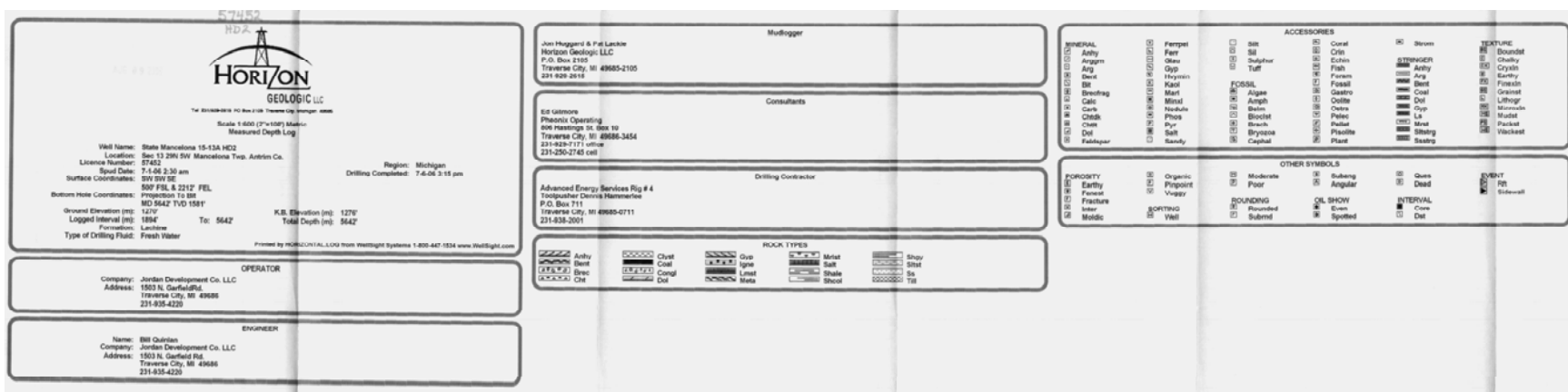


Figure 28a. Mud log and well bore cross section of Lachine leg of the State Mancelona 15-13A HD2 (API: 21-009-57452-0200) well in the Deward Cleaver project area in east Antrim County, MI. The lateral was drilled with an upward slope (the “J” well configuration) in an open uncased hole with no fracturing 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.

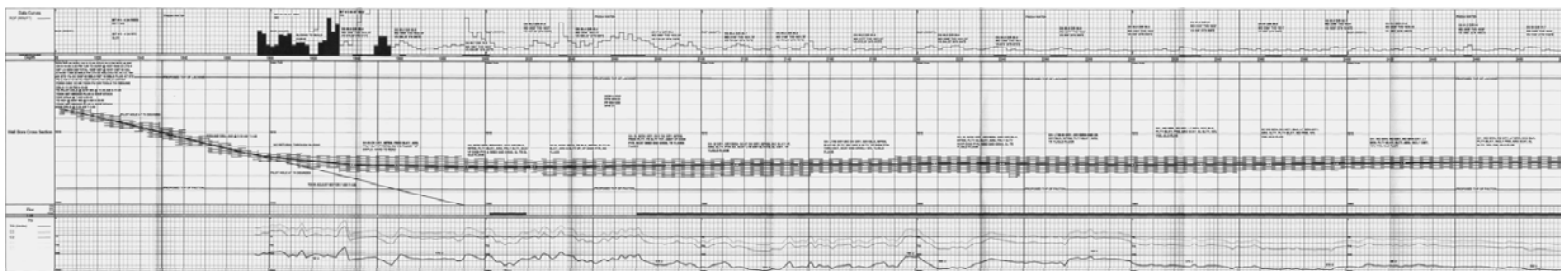


Figure 28b. Horizontal leg through the Lachine member, 1800-2500 feet, well bore on center track, vertical scale is 1560-1660 feet, true vertical depth.

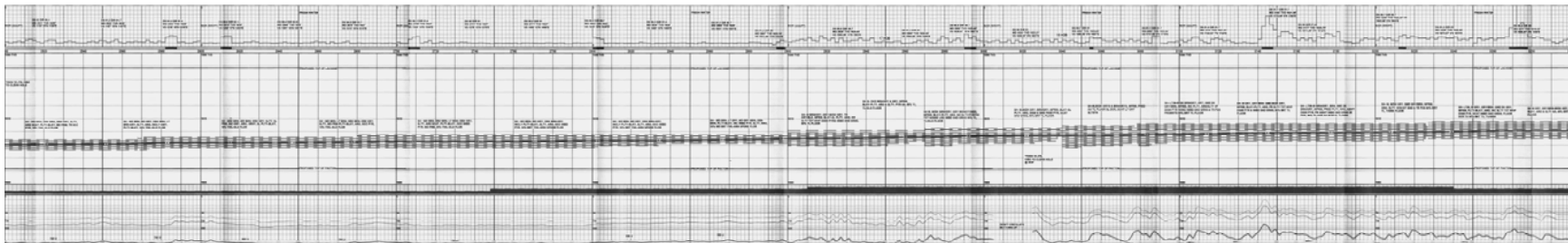


Figure 28c. Horizontal leg through the Lachine member, 2500-3300 feet, well bore on center track, vertical scale is 1560-1660 feet, true vertical depth.

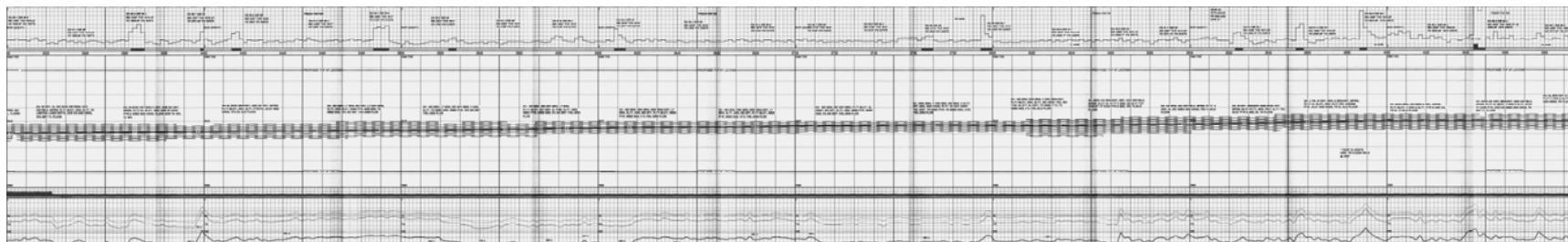


Figure 28d. Horizontal leg through the Lachine member, 3300-4100 feet, well bore on center track, vertical scale is 1560-1660 feet, true vertical depth.

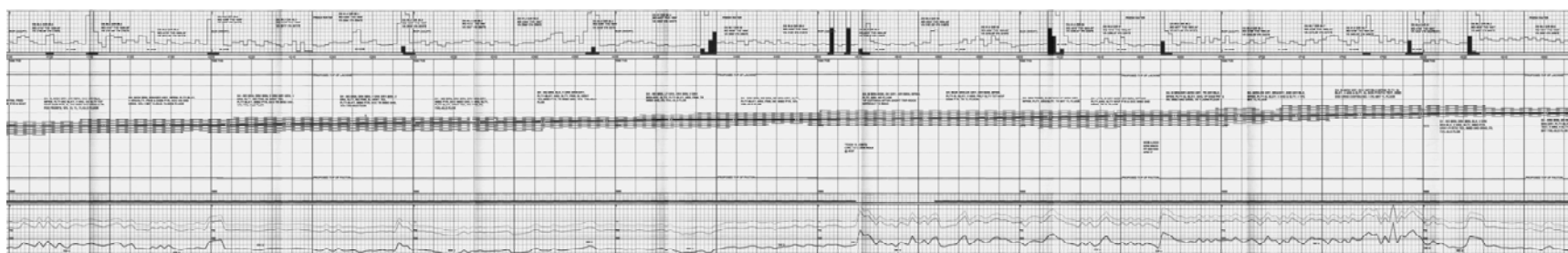


Figure 28e. Horizontal leg through the Lachine member, 4100-4900 feet, well bore on center track, vertical scale is 1560-1660 feet, true vertical depth.

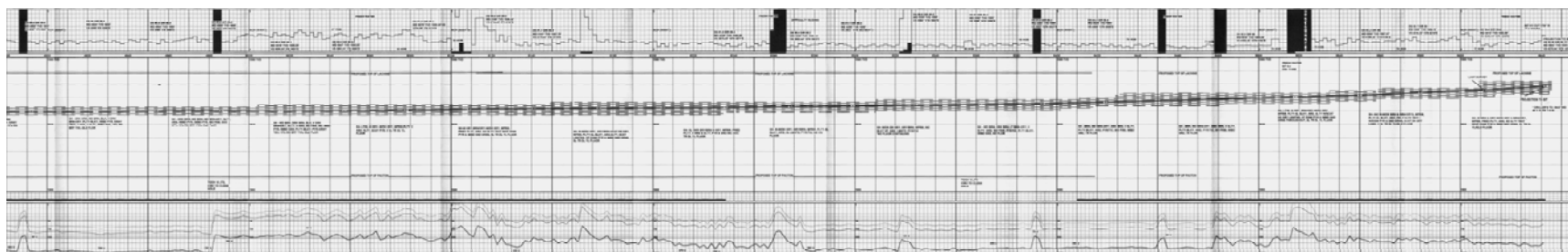


Figure 28f. Horizontal leg through the Lachine member, 4900-5660 feet, well bore on center track, vertical scale is 1560-1660 feet, true vertical depth.

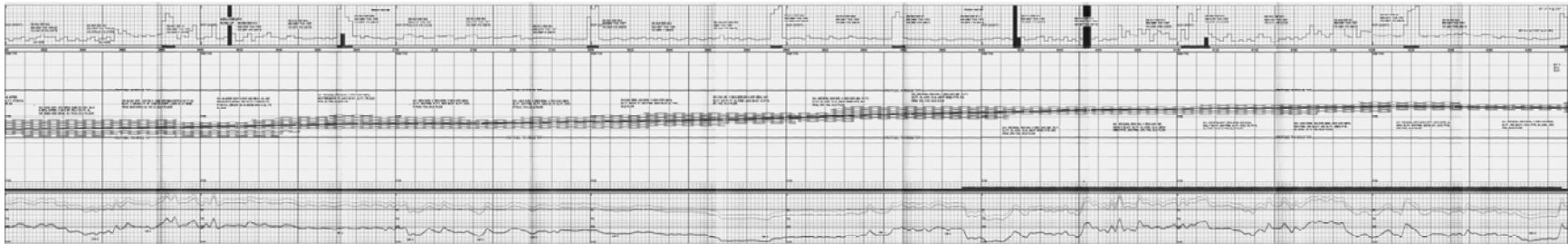


Figure 29d. Horizontal leg through the Lachine member, 3500-4300 feet, well bore on center track, vertical scale is 1680-1730 feet, true vertical depth.



Figure 29e. Horizontal leg through the Lachine member, 4300-5100 feet, well bore on center track, vertical scale is 1680-1730 feet, true vertical depth.



Figure 29f. Horizontal leg through the Lachine member, 5100-5640 feet, well bore on center track, vertical scale is 1680-1730 feet, true vertical depth.

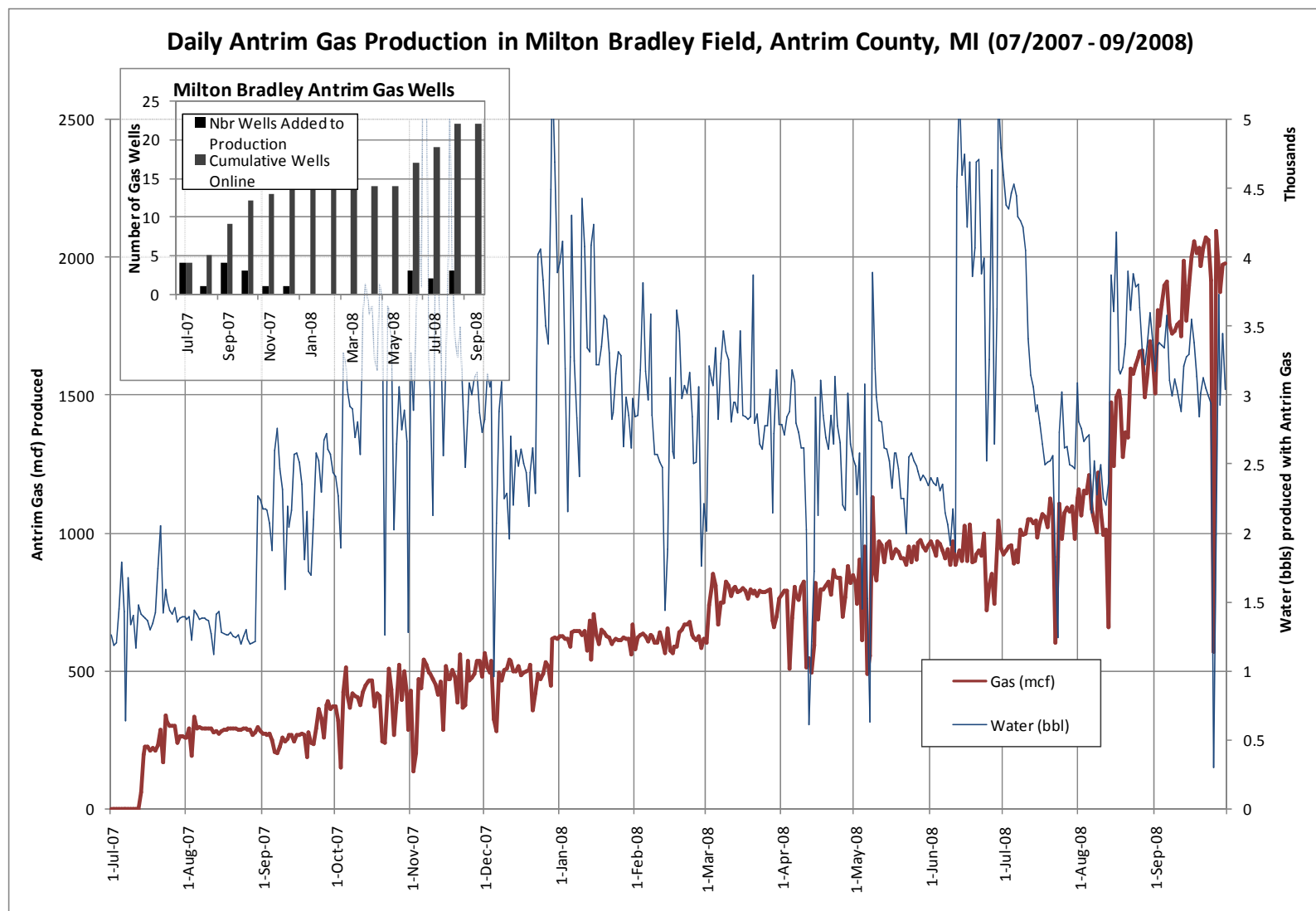


Figure 30. Antrim gas, and water produced with Antrim gas, from the vertical wells in the Milton Bradley project area in Antrim County, MI, the location of the AG-A-MING 4-12HD, the original LINGO project demonstration well. The inset chart shows the total number of vertical wells added to the project per month, and the cumulative number of wells put on the production line through September 30, 2008.

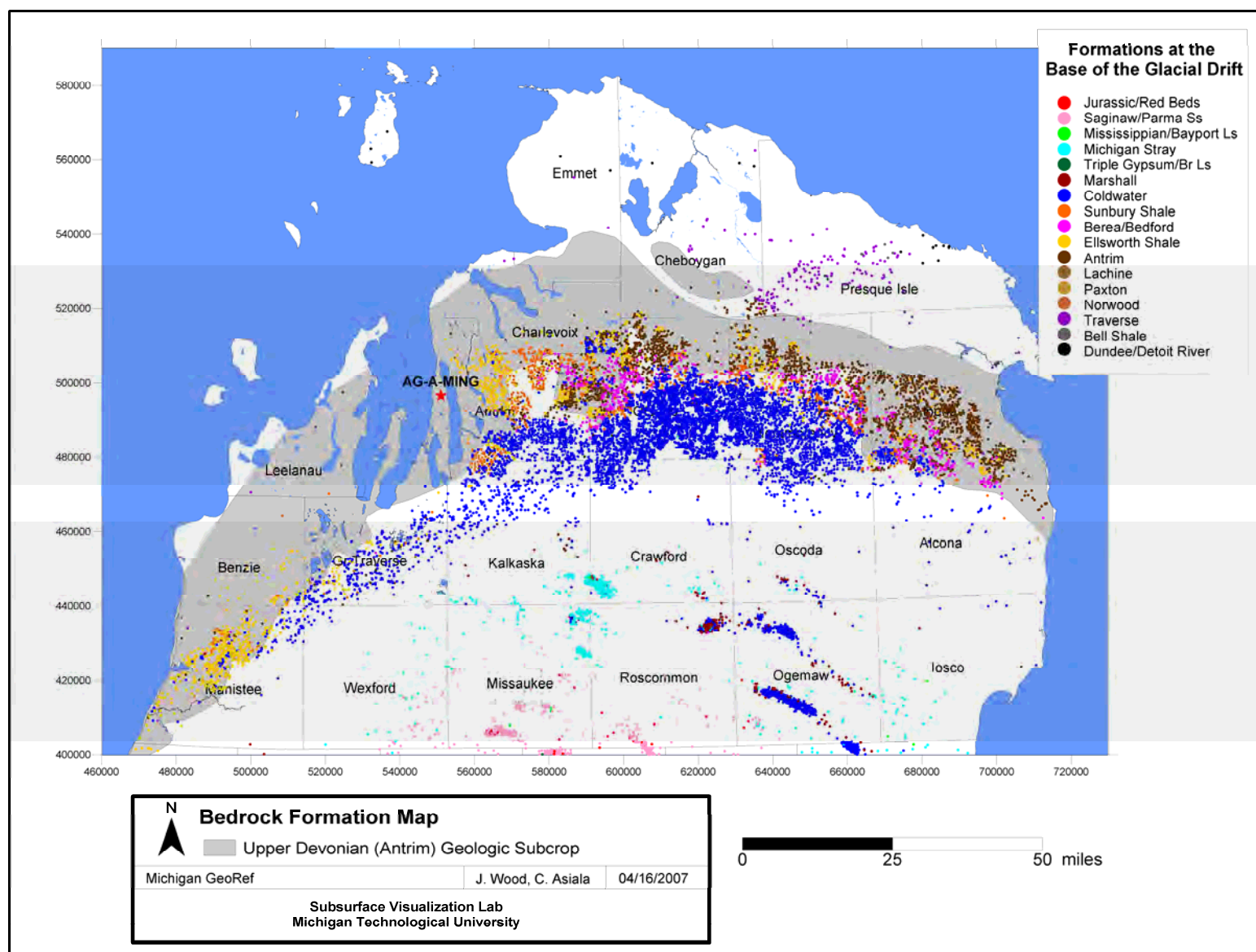


Figure 31. Bedrock formation spot map showing the formation directly below the Glacial Drift based on formation top picks recorded in the Michigan DEQ formations database.

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6. LIST OF ACRONYMS AND ABBREVIATIONS

ANRM:	Antrim Formation
LAC:	Lachine member of Antrim Formation
PAX:	Paxton member of Antrim Formation
NOR:	Norwood member of Antrim Formation
TRVR:	Traverse Formation
BOD:	Base of Glacial Drift
LINGO:	Low Impact Natural Gas and Oil
DEQ:	Michigan Department of Environmental Quality

7. 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.

APPENDIX I. State Casing Statute Instruction 1-94

STATE OF MICHIGAN DEPARTMENT OF NATURAL RESOURCES

SUPERVISOR OF WELLS INSTRUCTION 1-94 CERTIFICATION OF CASING AND SEALING OF SURFACE CASING

INTRODUCTION

The Supervisor of Wells Act, 1939 PA 61, as amended (Act 61), prohibits oil field practices which may cause pollution, damage to or destruction of fresh water supplies. The purpose of these instructions is to further ensure the protection of fresh ground water. For all wells drilled pursuant to Act 61 after the effective date of these instructions, the Supervisor of Wells will require that a knowledgeable geologist or mud logger determine the proper depth to set surface casing to ensure that the casing will properly seal and protect all fresh water aquifers. The following requirements are issued in conjunction with and in addition to the provisions of Rule 301, 302, 303, 306, and 309 of the Rules promulgated pursuant to Act 61 (Rules), Supervisor's Instruction No. 1-87 (S.I. 1-87) and Special Order No. 2-73, amended (S.O. 2-73). This instruction shall become effective January 15, 1994.

INSTRUCTION

1. Casing shall be run from the surface to a depth no less than:

- a. 100 feet into competent bedrock and
- b. 100 feet below all fresh water aquifers occurring below the glacial drift.

The casing shall be cemented in accordance with the Rules, S.O. 2-73, S.I. 1-87, and Supervisor of Wells requirements.

2. Each application and permit to drill shall provide geologic and depth information necessary to comply with the surface casing requirements stated in #1 above.

3. A knowledgeable geologist or mud logger on site shall determine the proper depth as provided in item #1 at which to set surface casing. To further ensure the protection of fresh ground water supplies, the running of casing and the cementing operation shall be supervised by the drilling rig tool pusher and/or a qualified representative of the permittee.

4. The geologist or mud logger shall enter into the drilling rig daily log book the following:

- a. The depth to bedrock.
- b. The base of other fresh water aquifers as specified by the permit to drill.
- c. The total depth of the surface casing hole.
- d. The signature and name of the geologist/mud logger.

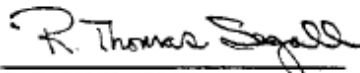
5. The drilling rig tool pusher or qualified representative of the permittee shall enter in the drilling rig daily log book the following:

- a. Depth where surface casing was set.
- b. Amount and volume of cement used.
- c. Amount and volume of cement circulated to surface.
- d. Amount and volume of additional cement used if grouted.
- e. Any problems encountered while running or cementing the surface casing.
- f. The signature and name of the person certifying this information.

6. Within thirty days of the completion of the drilling operation, the permittee of the drilling operation shall furnish a certification of the proper sealing and protection of fresh water aquifers on a form prescribed by the Supervisor of Wells. The certification shall be signed by the geologist or mud logger who determined the depth to set the surface casing and by the permittee or a company officer. The certification shall describe any unusual hole conditions or problems encountered during the drilling or while running or cementing the casing.

Date:

12/15/93



R. THOMAS SEGALL
ASSISTANT SUPERVISOR OF WELLS

APPENDIX II. LINGO Antrim Play: Handbook

Oil & Natural Gas Technology

DOE Award No.: DE-FC26-06NT42931

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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Prepared for:
United States Department of Energy
National Energy Technology Laboratory

February 2009



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:

1. Abstract
2. Table of Contents
3. Project Location Maps
4. Characteristics of the Antrim Shale
5. Cross Sections through the Antrim Members (Lachine, Paxton, Norwood)
6. Geologic Structural Contour Maps
7. Isopach Contour Maps
8. Gravity Anomaly Maps
9. Production Maps and Charts
10. Project Well Histories – Milton Bradley in Antrim County, MI
11. Project Well Histories – Deward Cleaver in Antrim County, MI
12. Project Well Histories – Colfax 29 in Benzie County, MI
13. Project Well Histories – Whitewater 9 in Grand Traverse County, MI
14. Best Practices for Co-produced CO₂ Disposal
15. Project Databases
16. Database Methods defined for Map Inputs
17. ANTRIM SHALE, Late Devonian
18. Bibliography
19. Acknowledgments

The purpose of this handbook is to provide a thorough 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)

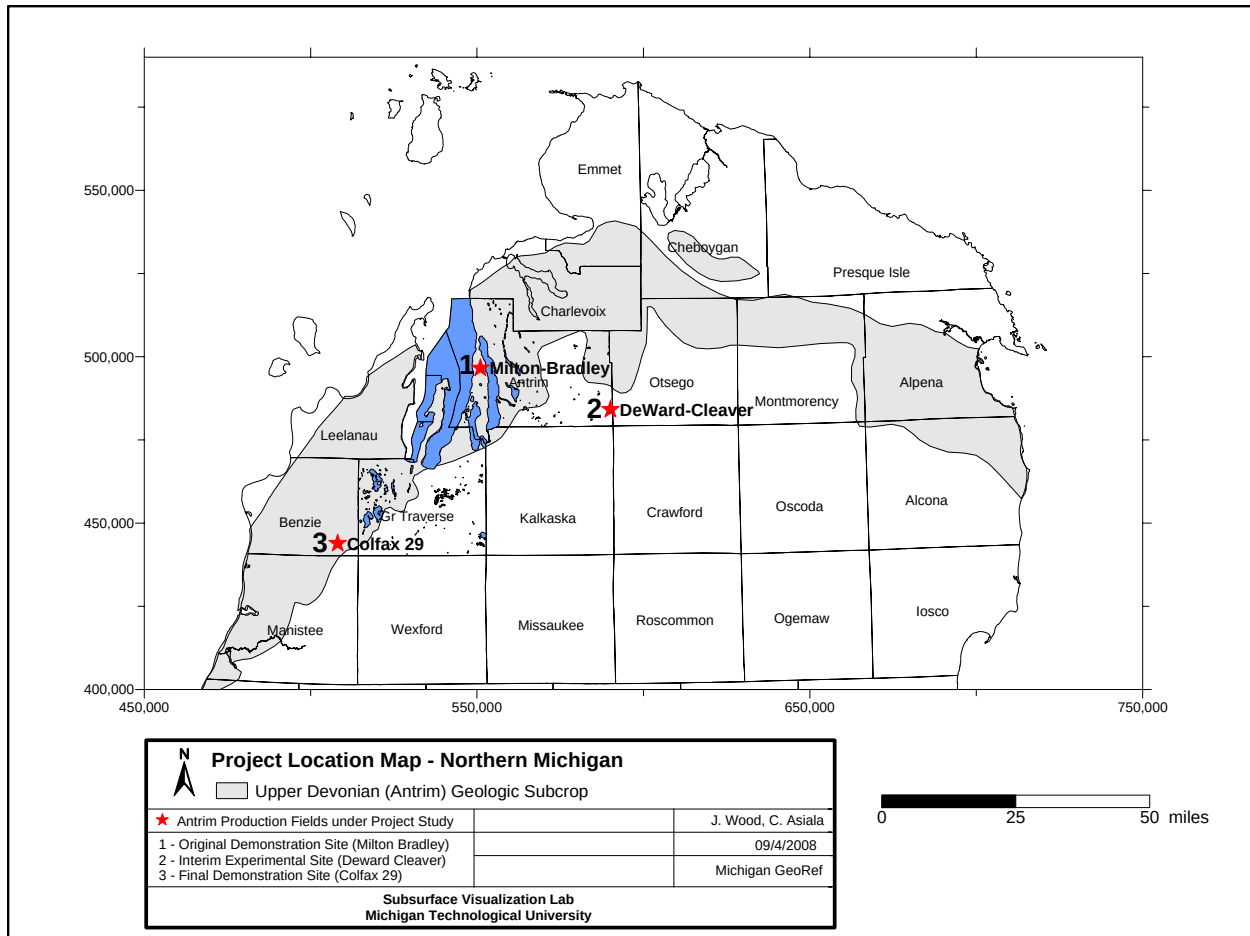


Figure 3-1. The area of interest to the LINGO project was the Northern half of the lower peninsula of Michigan where the Antrim production is most prevalent. Specific areas pertaining to the demonstration portion of the project were the Milton Bradley field in west Antrim County, the Deward Cleaver field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

3.2. State Colfax 29 Project Area (Benzie County, Michigan)

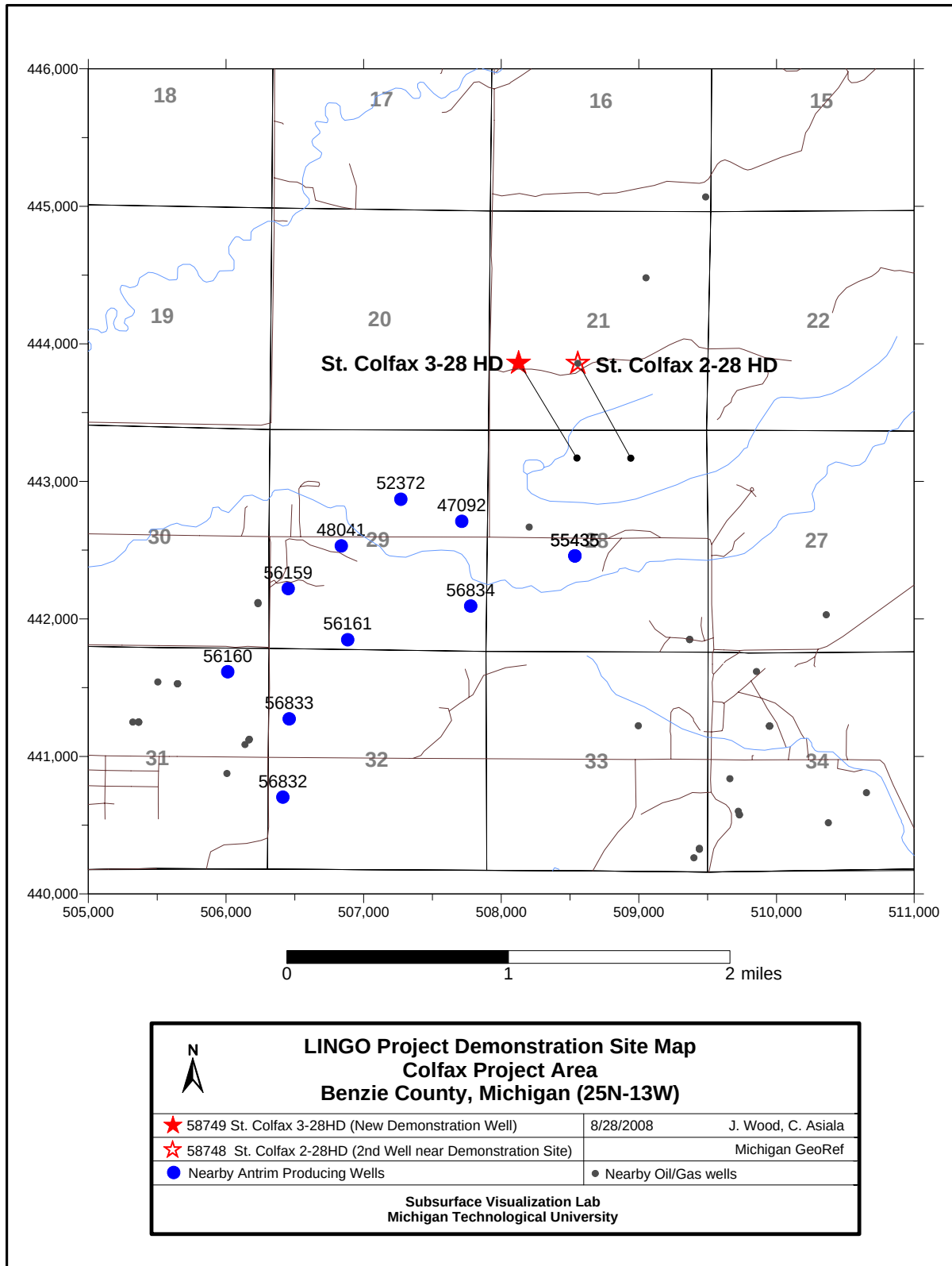


Figure 3-2. The final project demonstration site resulted in two highly deviated well bores to maximize perforation intervals and gas flow.

3.3. Deward-Cleaver Project Area (Antrim County, Michigan)

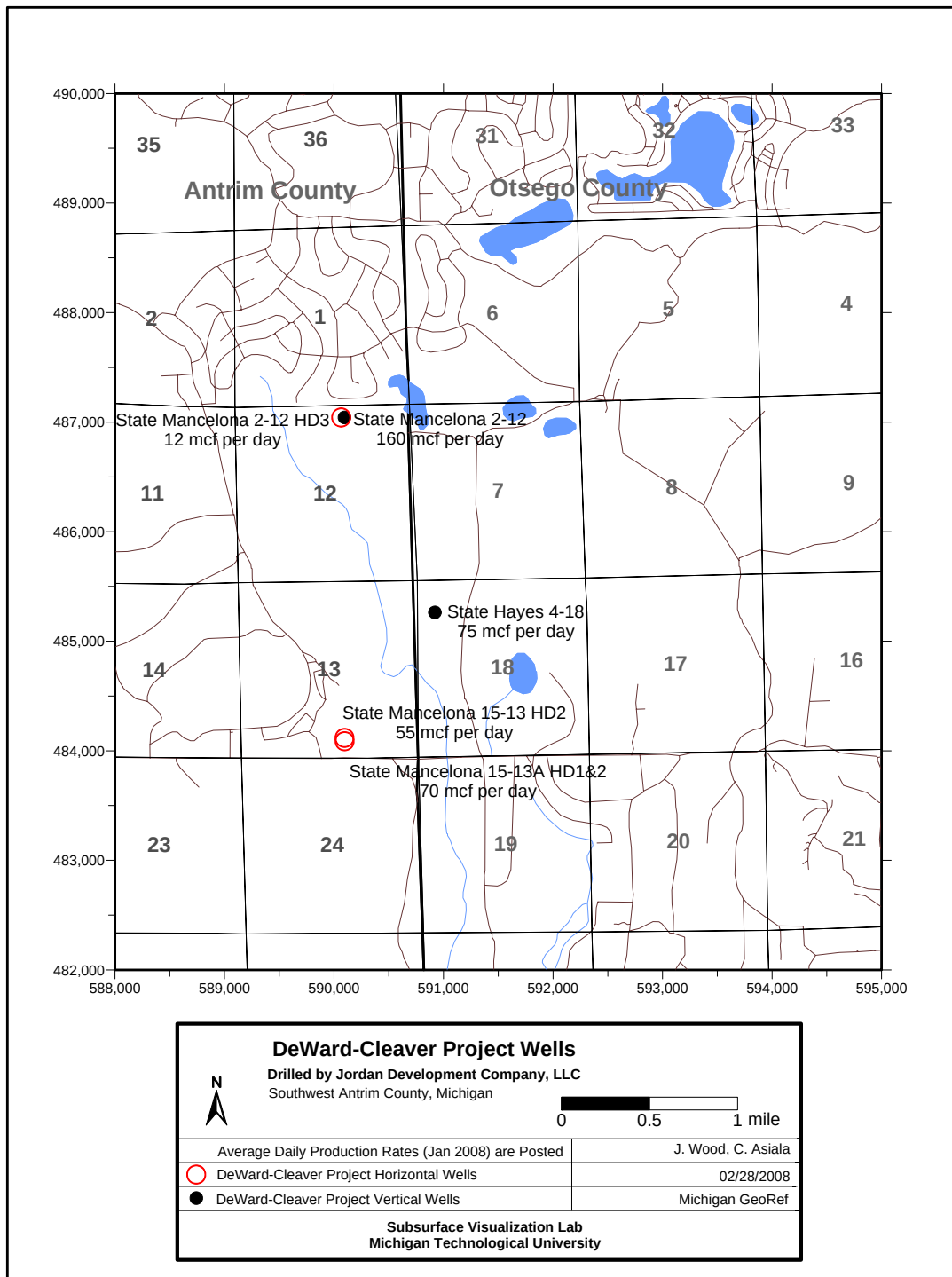


Figure 3-3. The Mancelona wells in the DeWard Cleaver field were drilled with the "J-Well" configuration intended for the project demonstration well, and it was discovered that the production from the nearby vertical wells was greater than the "J" well configuration. This resulted in a rework in the design of the well configuration.

3.4. Milton-Bradley Project Area (Antrim County, Michigan)

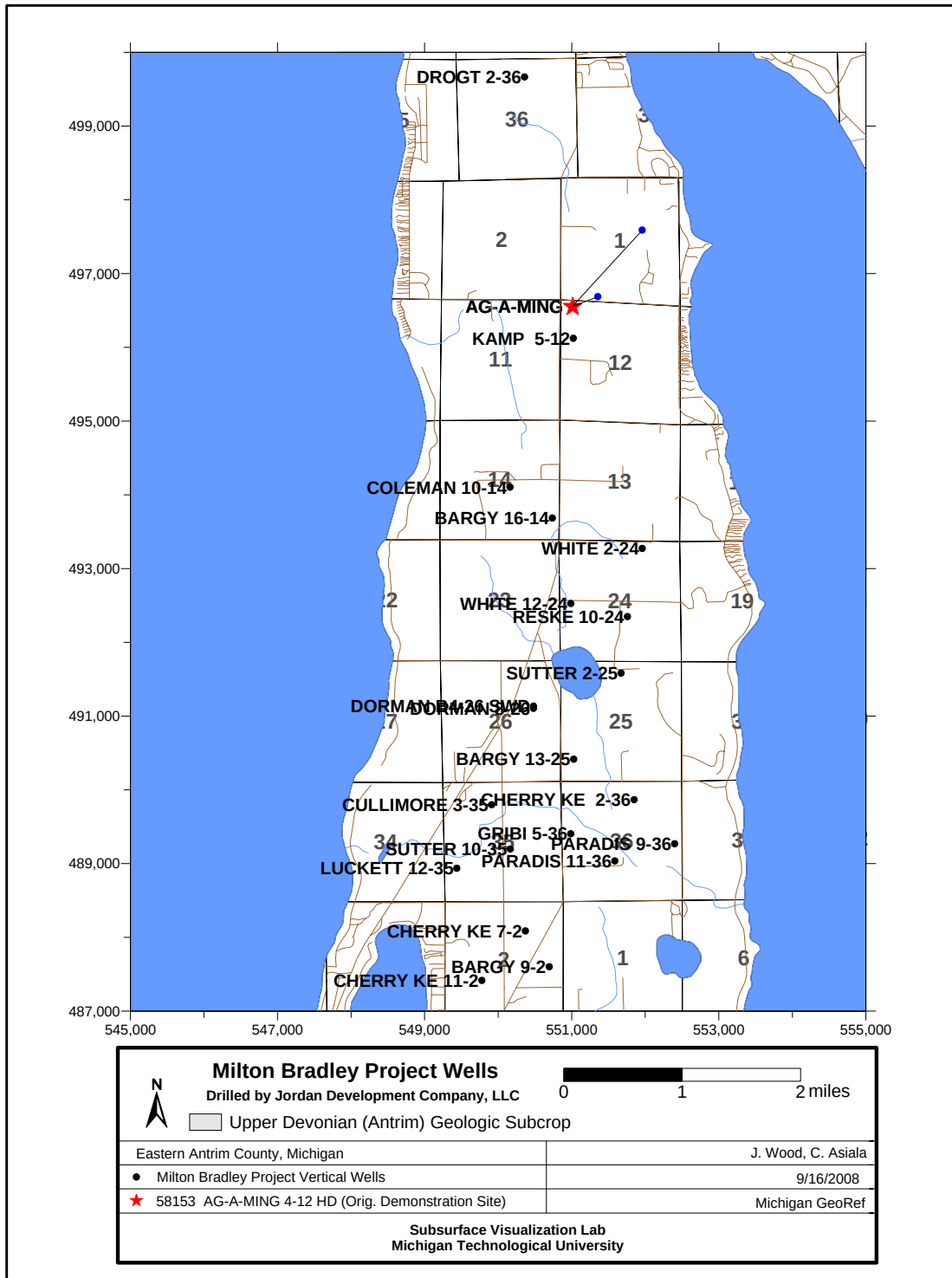


Figure 3-4. Vertical wells drilled in the Milton Bradley field in west Antrim County, near the planned demonstration site, AG-A-MING 4-12 HD. This demonstration well has not been drilled to date, but is still of interest to the project industry partners.

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 reservoired 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.

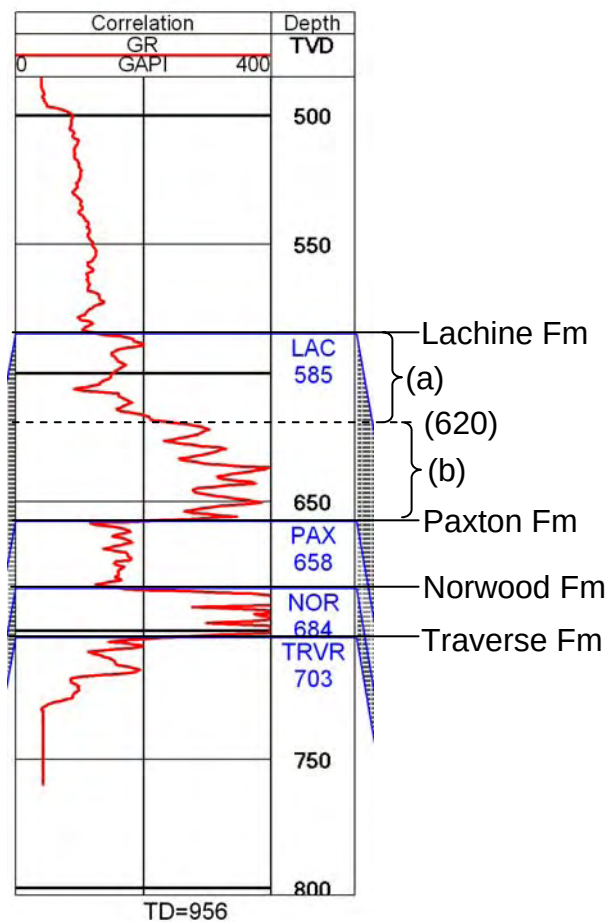
Natural fractures are the key to the productive characteristics of the Antrim Shale. Regional geologic studies indicate that the shallower the Antrim is, the more highly fractured it is. This phenomenon is widely believed to have been caused by glacial scouring.” (Kelafant, 2000)

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.

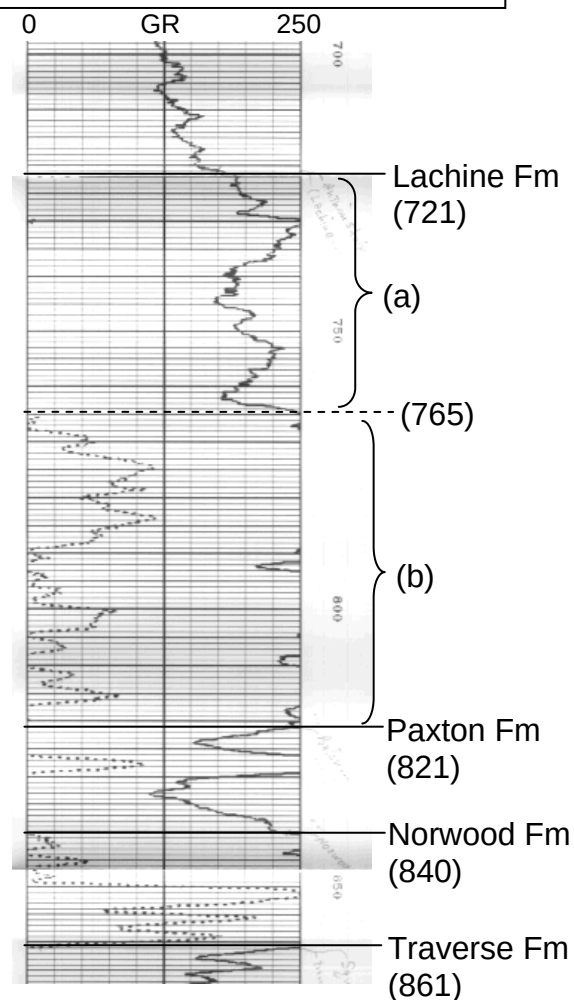
The Norwood member averages 15-25 feet thick and is represented by high gamma ray values over 250 gapi. When the gamma ray values start to decrease, this signifies the top of the Traverse and/or Squaw Bay formations.

21-031-55261-0000
STATE WILMOT D4-28
Cheboygan County, Michigan



Digital representation of gamma ray values

21-009-57815-0000
DORMAN 8-26
Antrim County, Michigan



Scanned image of paper gamma ray log

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

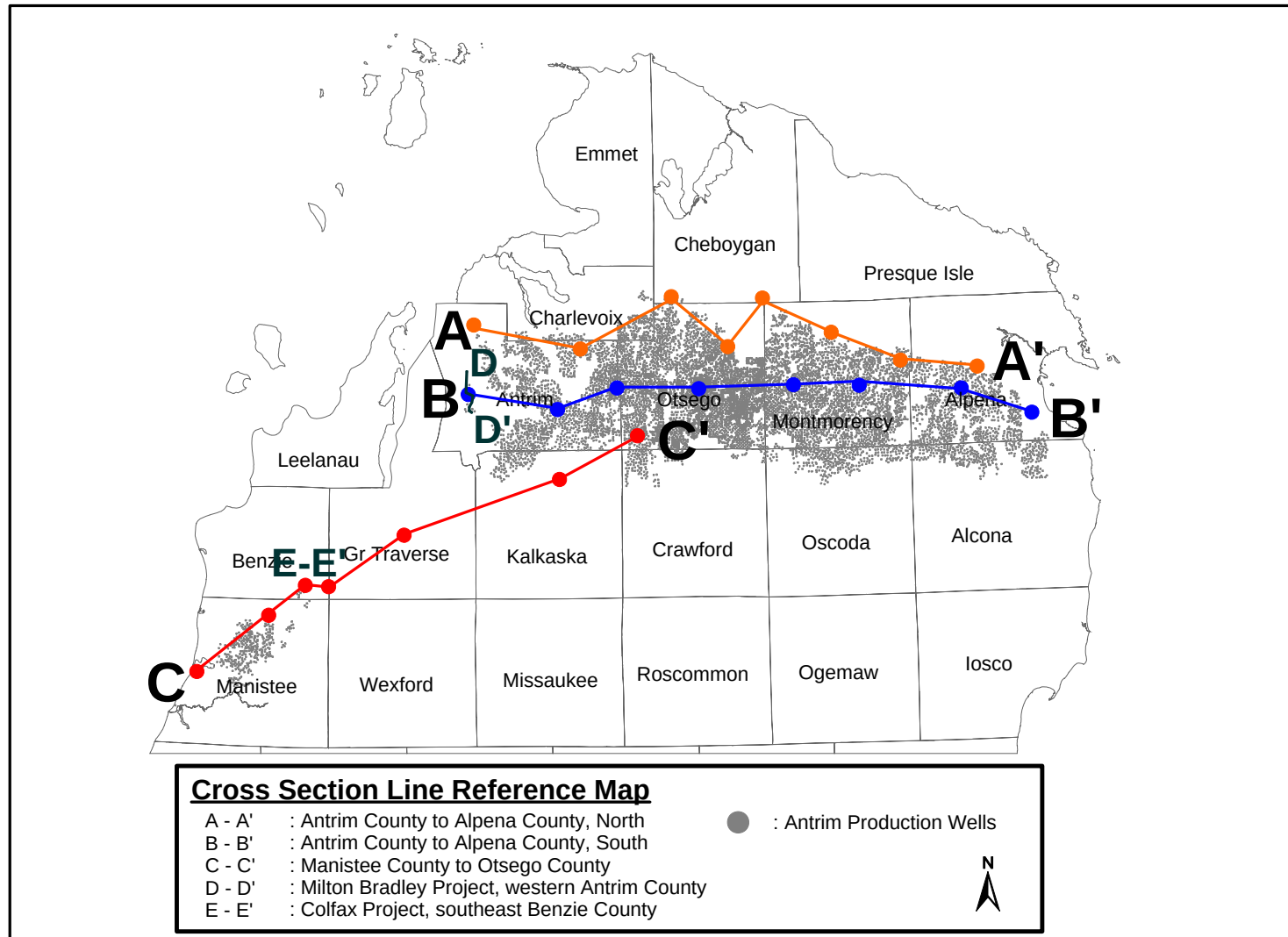


Figure 5-1. Location map of cross sections that demonstrate the properties of the Lachine-Paxton-Norwood members of the Antrim Shale. The cross section lines were chosen to represent the current production areas of the Antrim. D-D' and E-E' are localized cross sections over the initial and final demonstration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

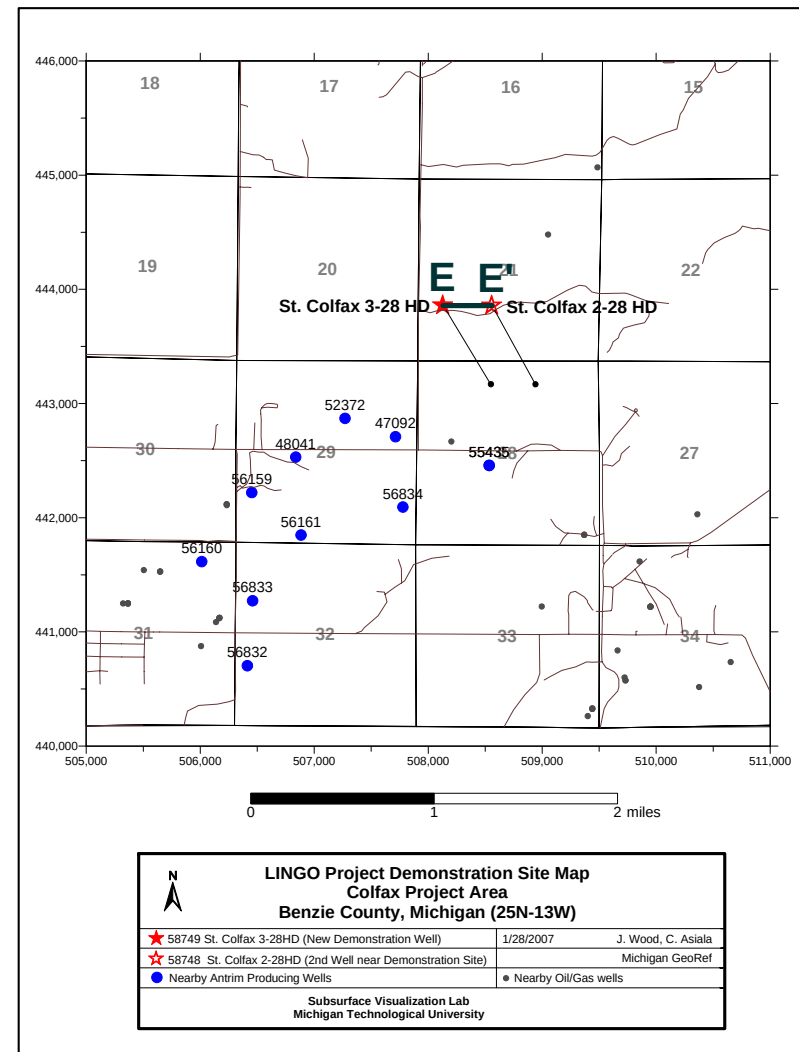
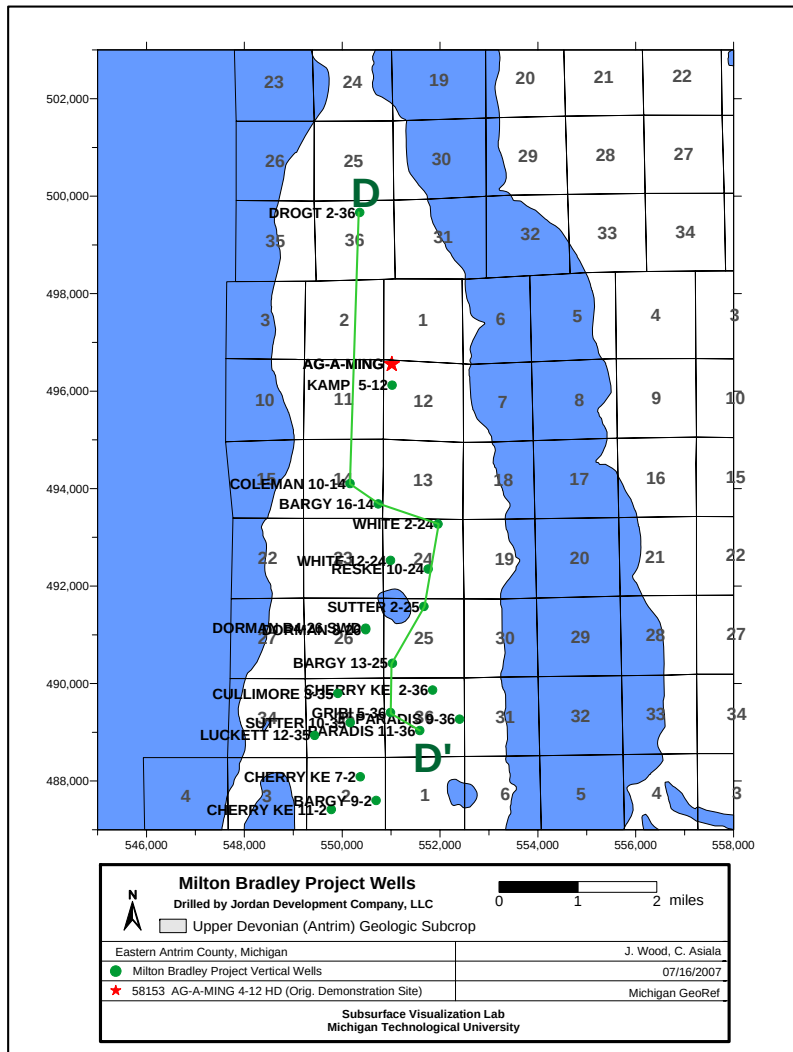
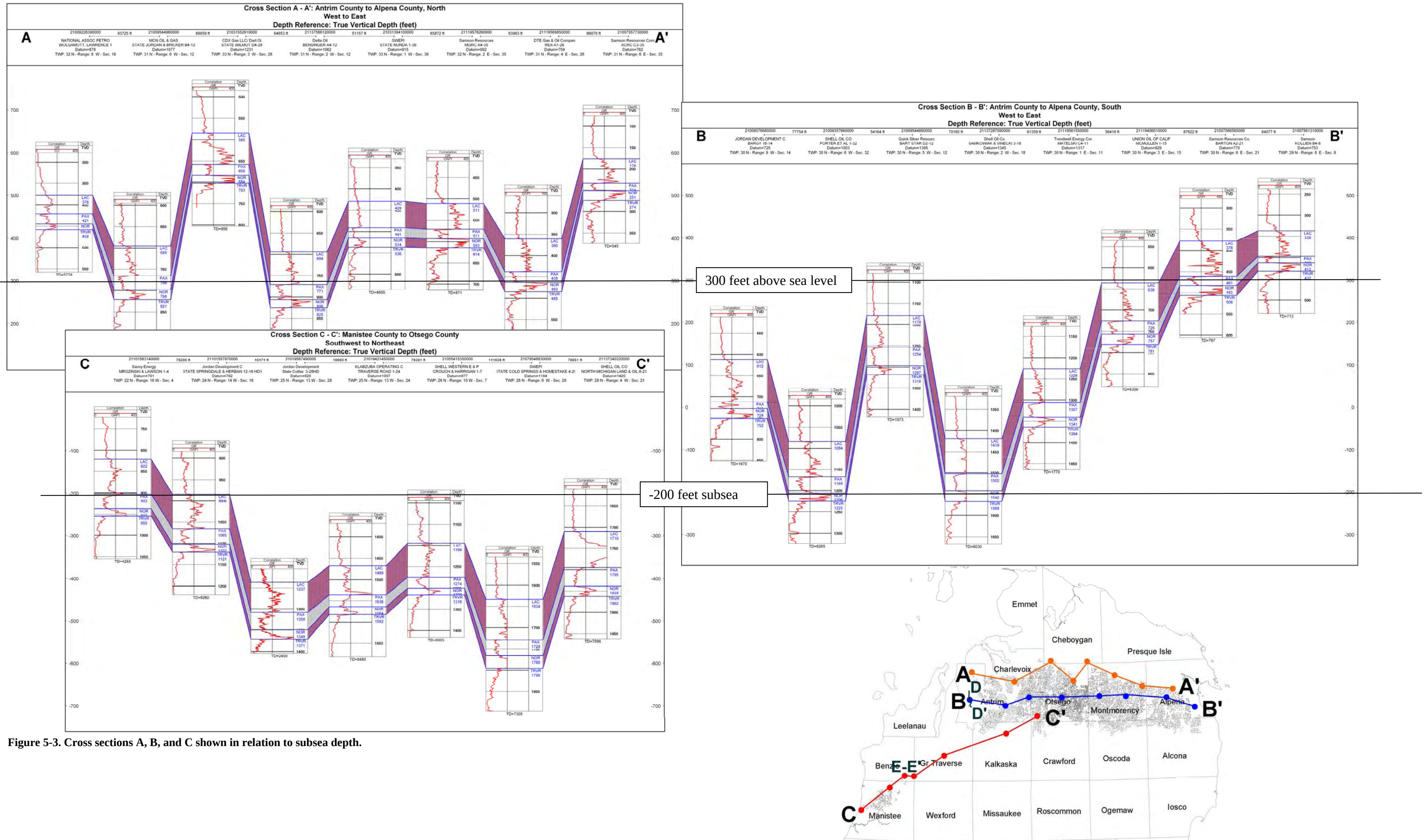


Figure 5-2. Path of Cross Section D - D' (left image) in the Milton Bradley field in west Antrim County (original demonstration site), and path of Cross Section E-E' (right image) which includes the two highly deviated Colfax wells in the project demonstration site.

5.4. Cross Sections



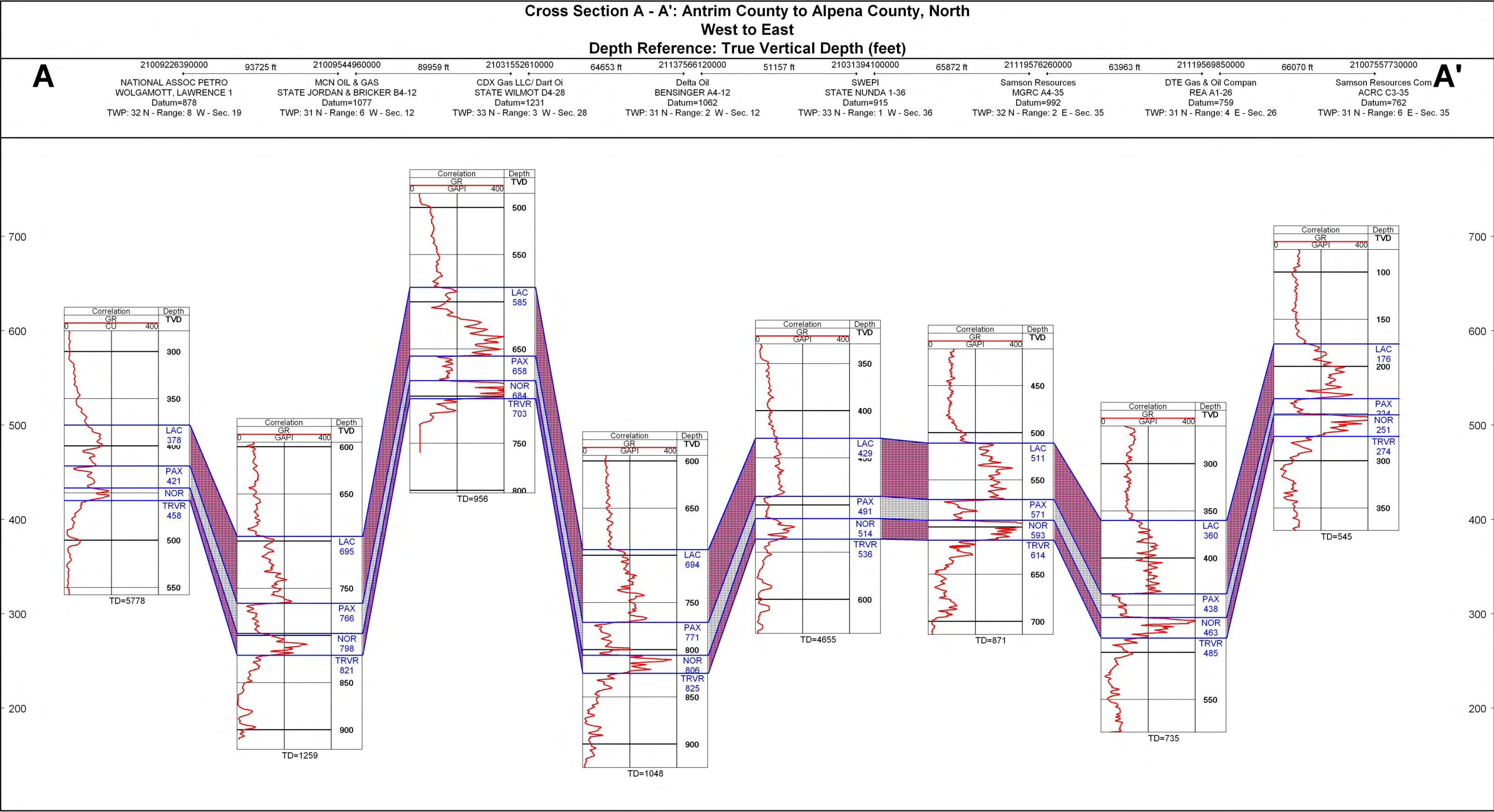


Figure 5-4. Cross Section A-A': West to east line of wells across the northern edge of the Antrim production region from Antrim County to Alpena County. The wells are positioned in relation to Subsea Depth, the formation tops printed in blue are measured depth values.

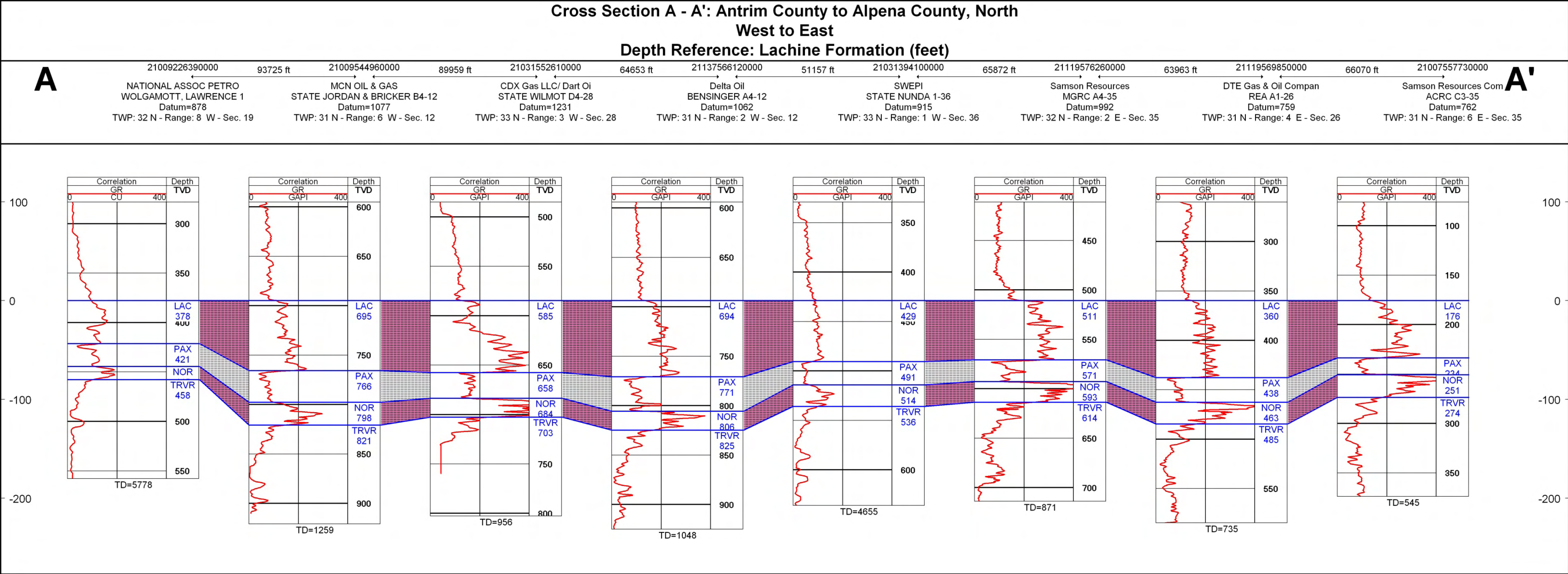
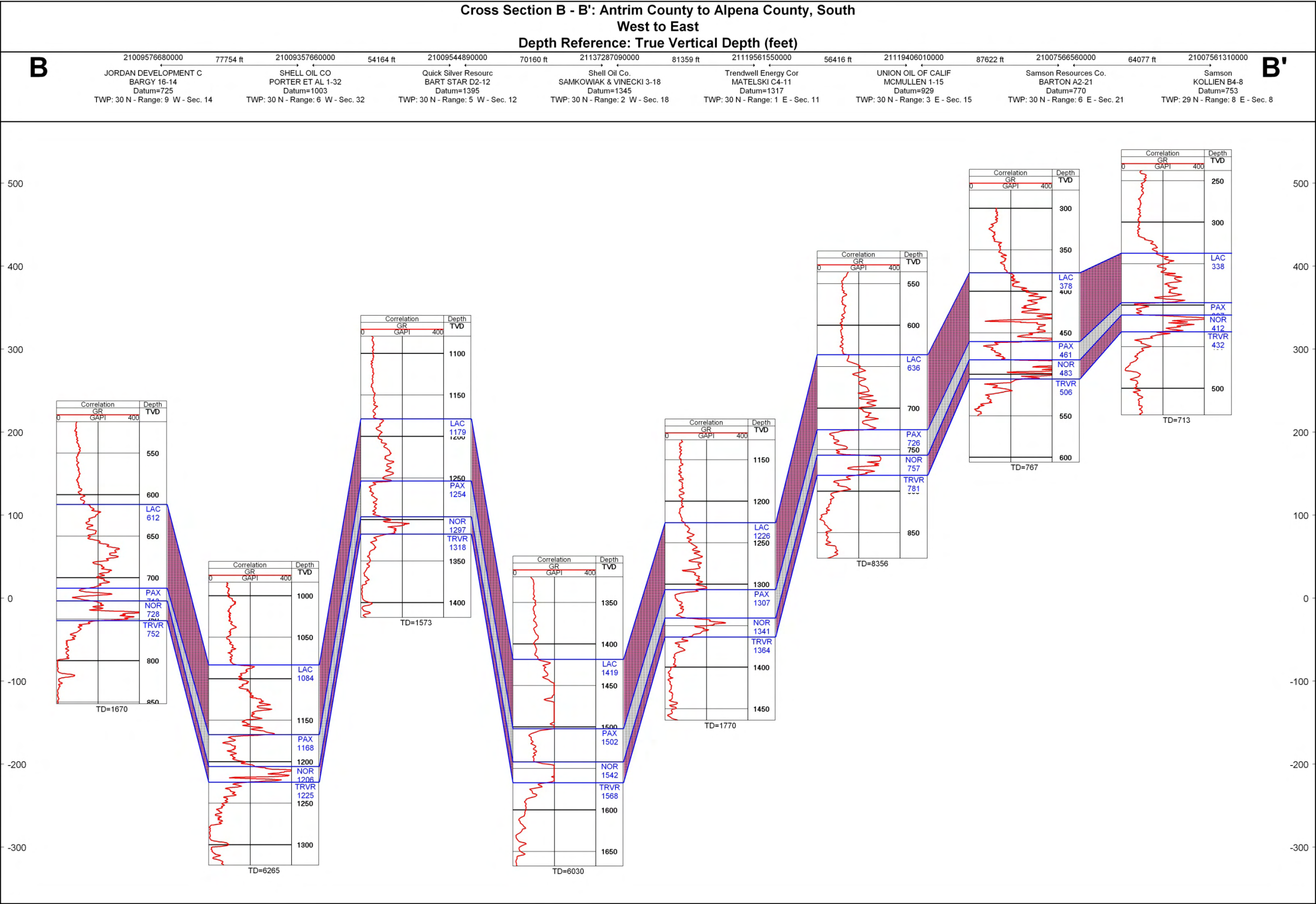


Figure 5-5. Cross Section A-A': West to east line of wells across the northern edge of the Antrim production region from Antrim County to Alpena County. The wells are positioned in relation to the Lachine member (depth = 0), the formation tops printed in blue are measured depth values.



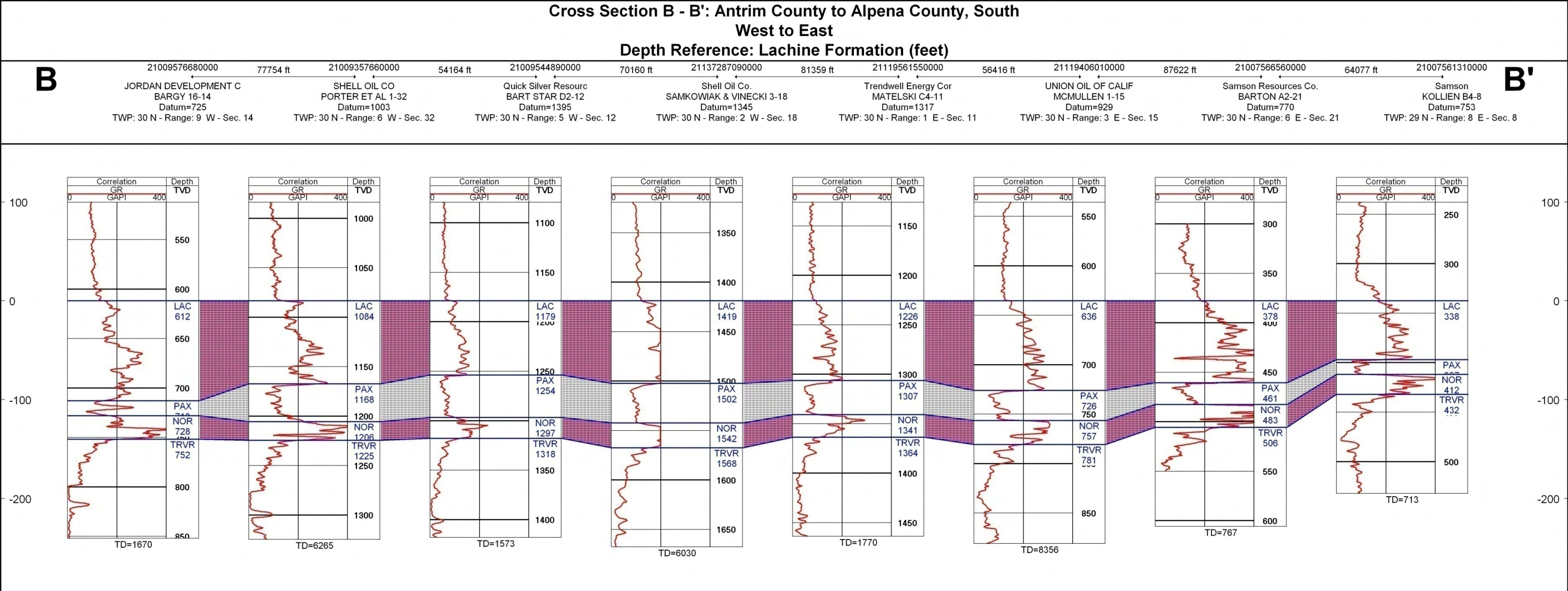


Figure 5-7. Cross Section B-B': West to east line of wells across the center of the Antrim production region from Antrim County to Alpena County. The wells are positioned in relation to the Lachine member (depth = 0).

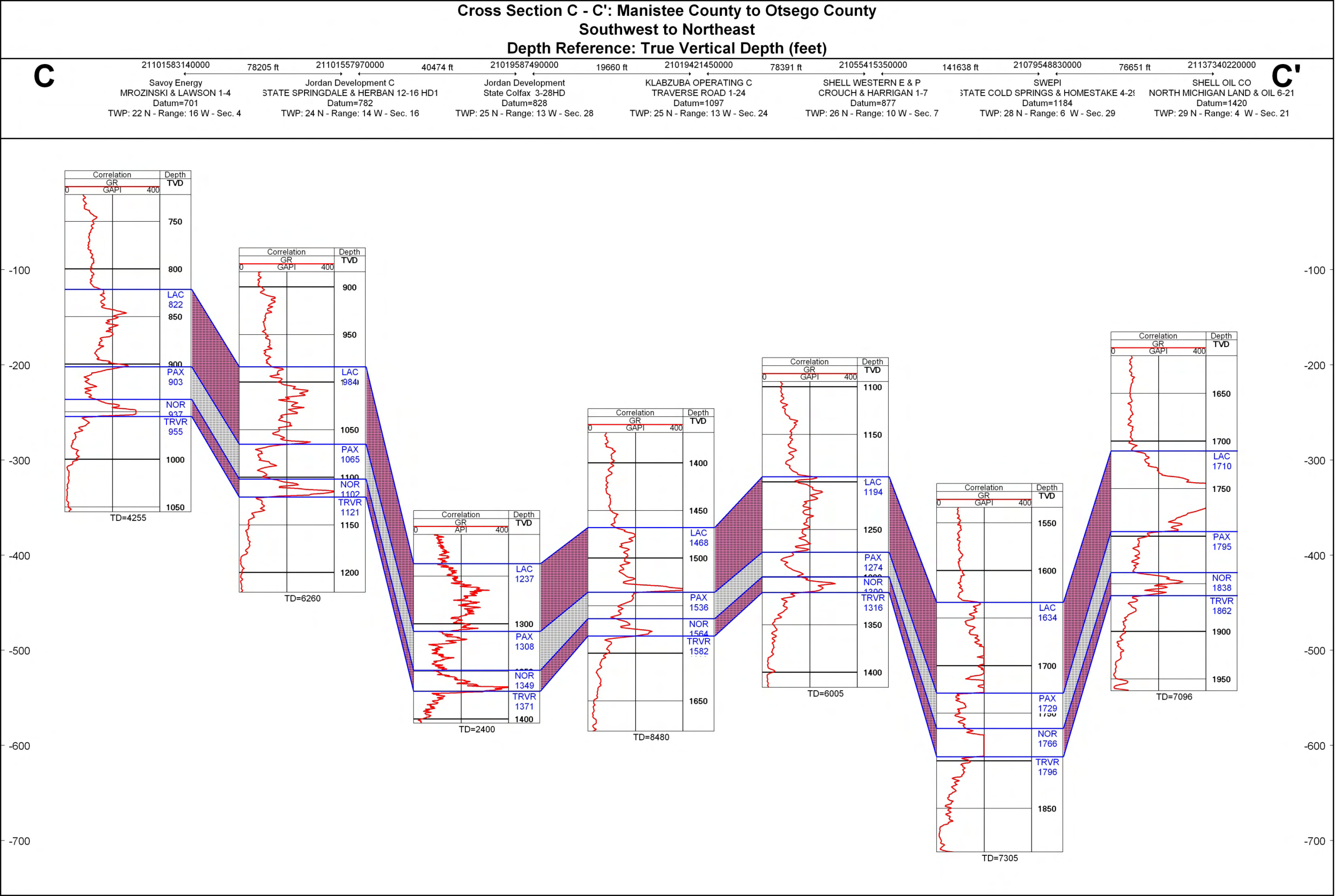


Figure 5-8. Cross Section C-C': Southwest to northeast line of wells from Antrim production area in Manistee County to Otsego County. The wells are positioned in relation to Subsea Depth.

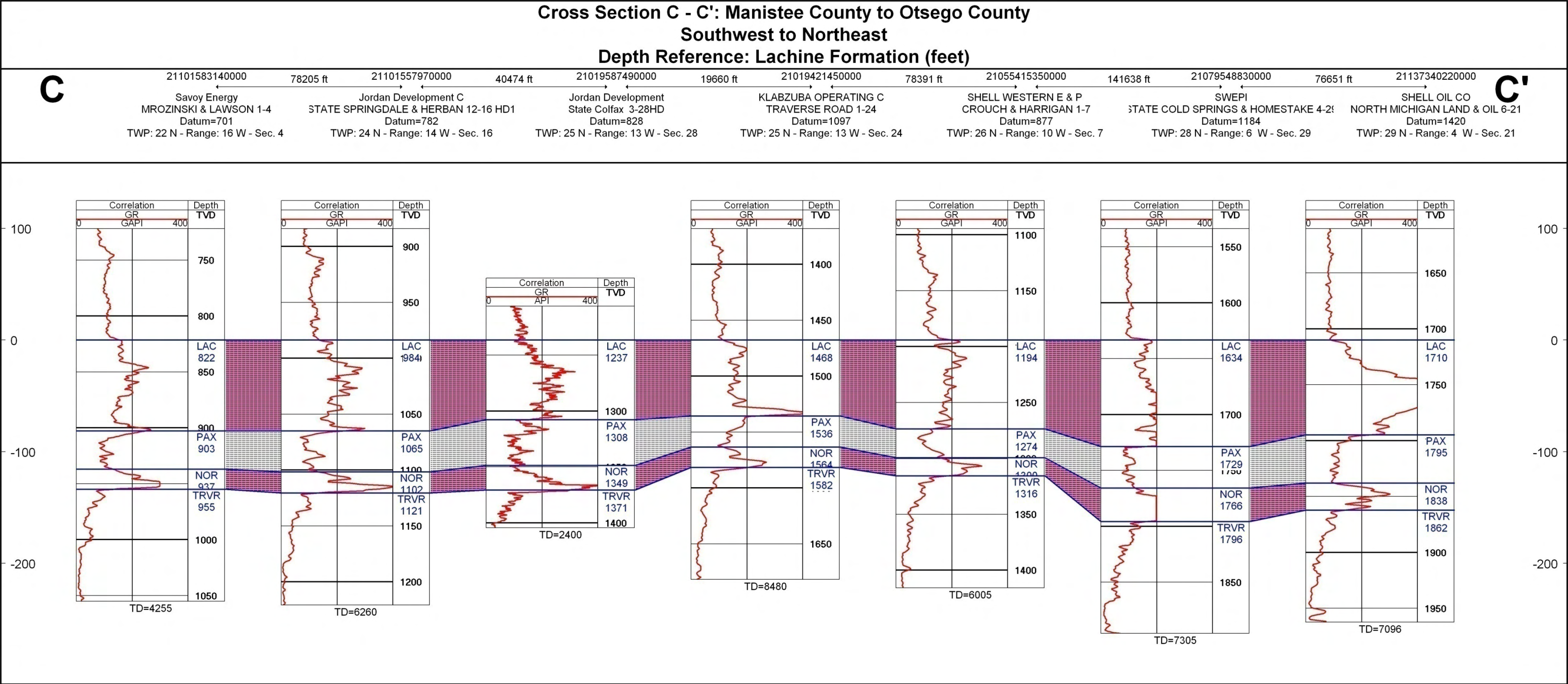


Figure 5-9. Cross Section C-C': Southwest to northeast line of wells from Antrim production area in Manistee County to Otsego County. The wells are positioned in relation to Lachine member (depth = 0).

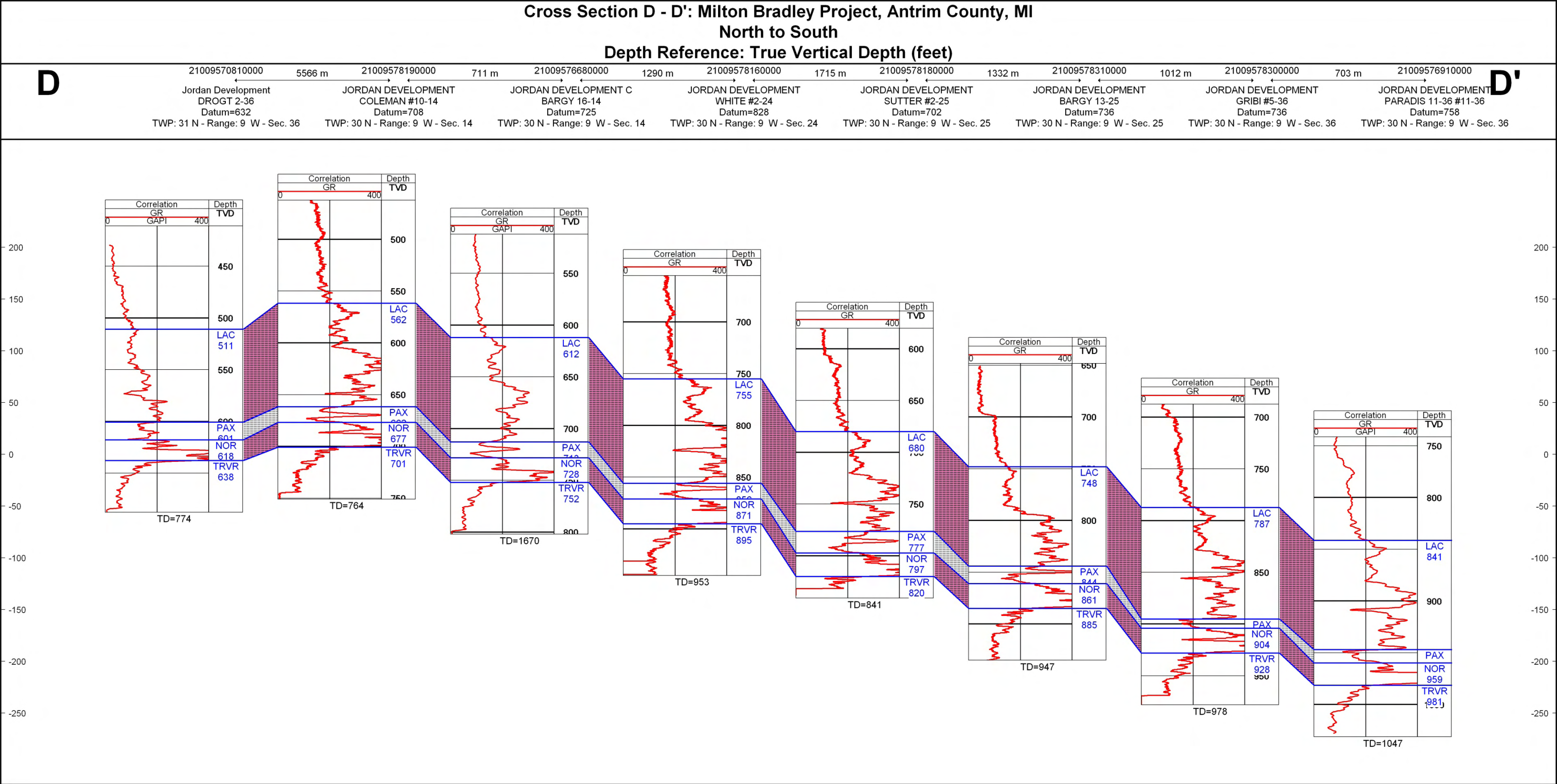
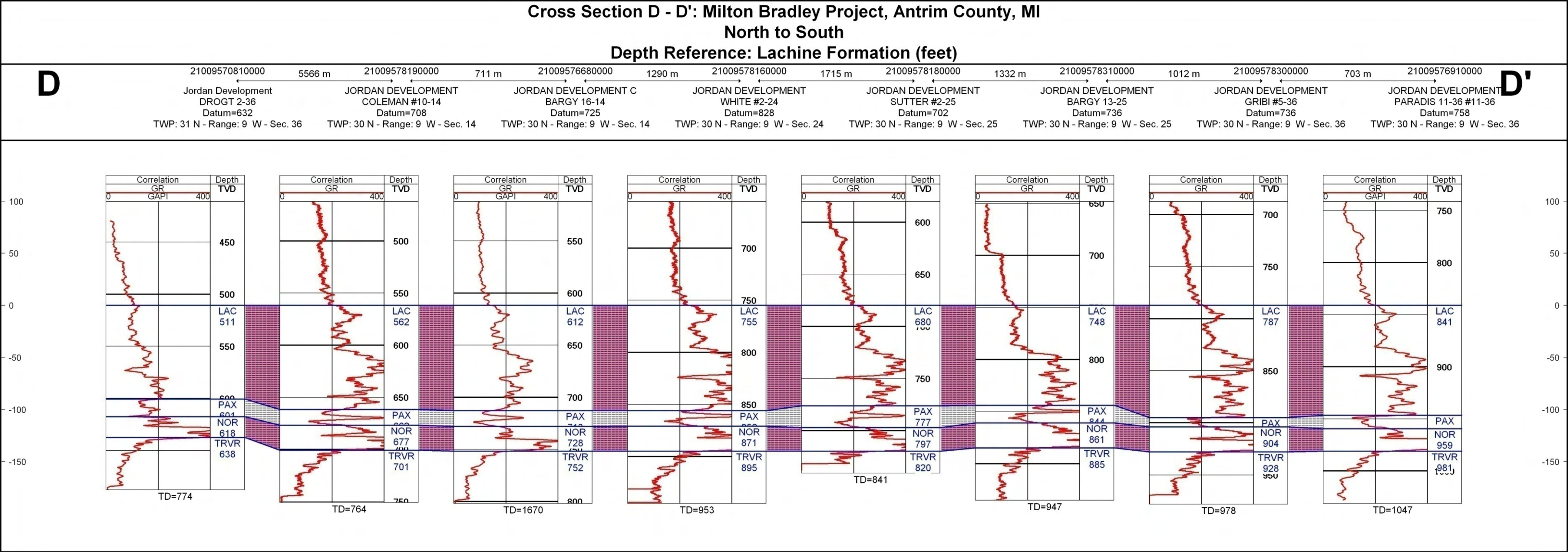


Figure 5-2. Cross Section D-D': North to south line of wells drilled in the Milton Bradley field in west Antrim County in the vicinity of the original project demonstration well. The wells are positioned in relation to Subsea Depth.



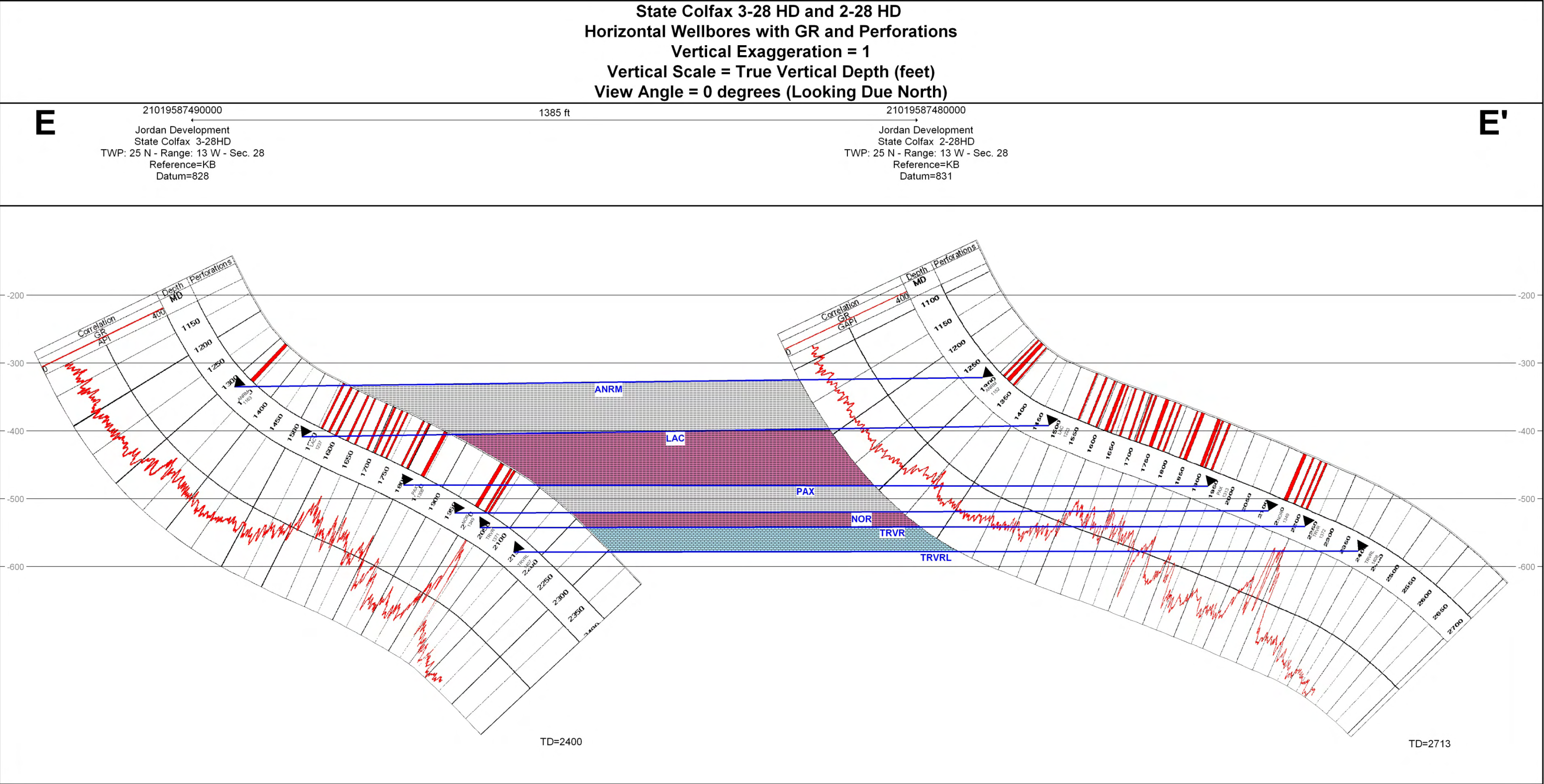


Figure 5-4. Cross Section E-E': West to east line between the two highly deviated wells drilled in the Colfax field in Benzie County as the project demonstration well. The wells are positioned in relation to the deviated well paths at a 1:1 vertical exaggeration. The red bars symbolize the perforation 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).

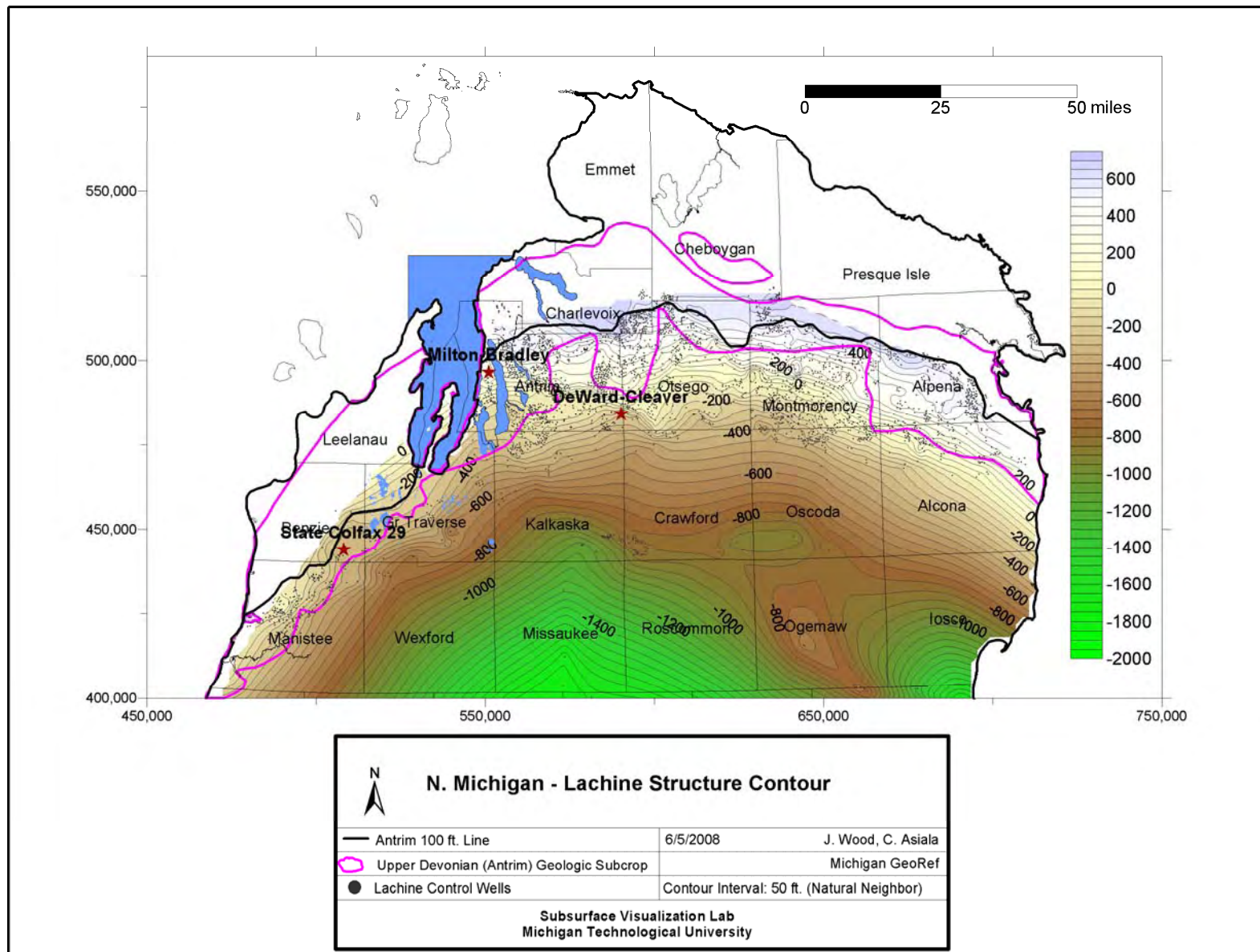


Figure 6-1. Structure map of the Lachine member of the Antrim formation in Northern Michigan. Contour Interval is 50 feet.

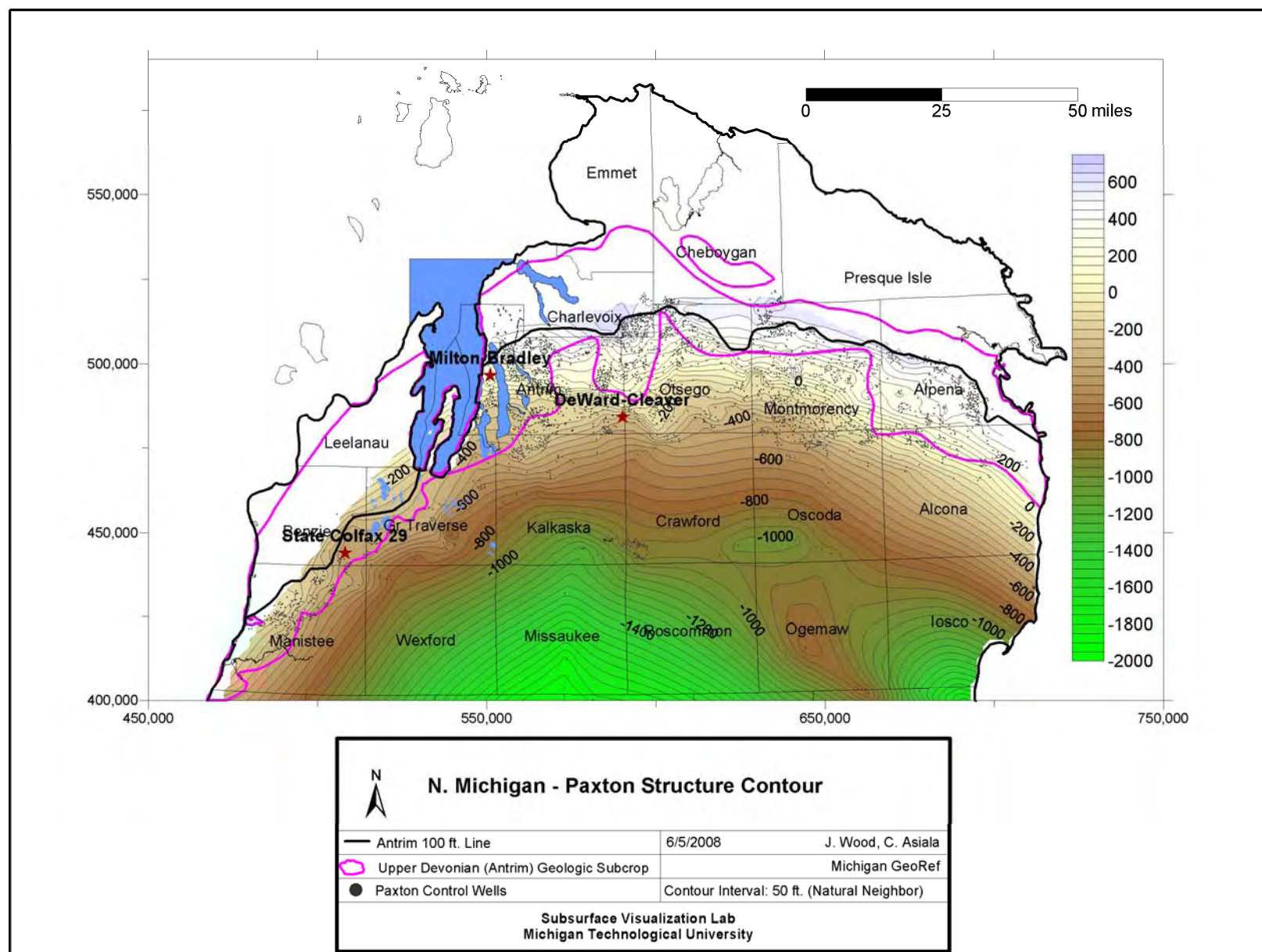


Figure 6-2. Structure map of the Paxton member of the Antrim formation in Northern Michigan. Contour Interval is 50 feet.

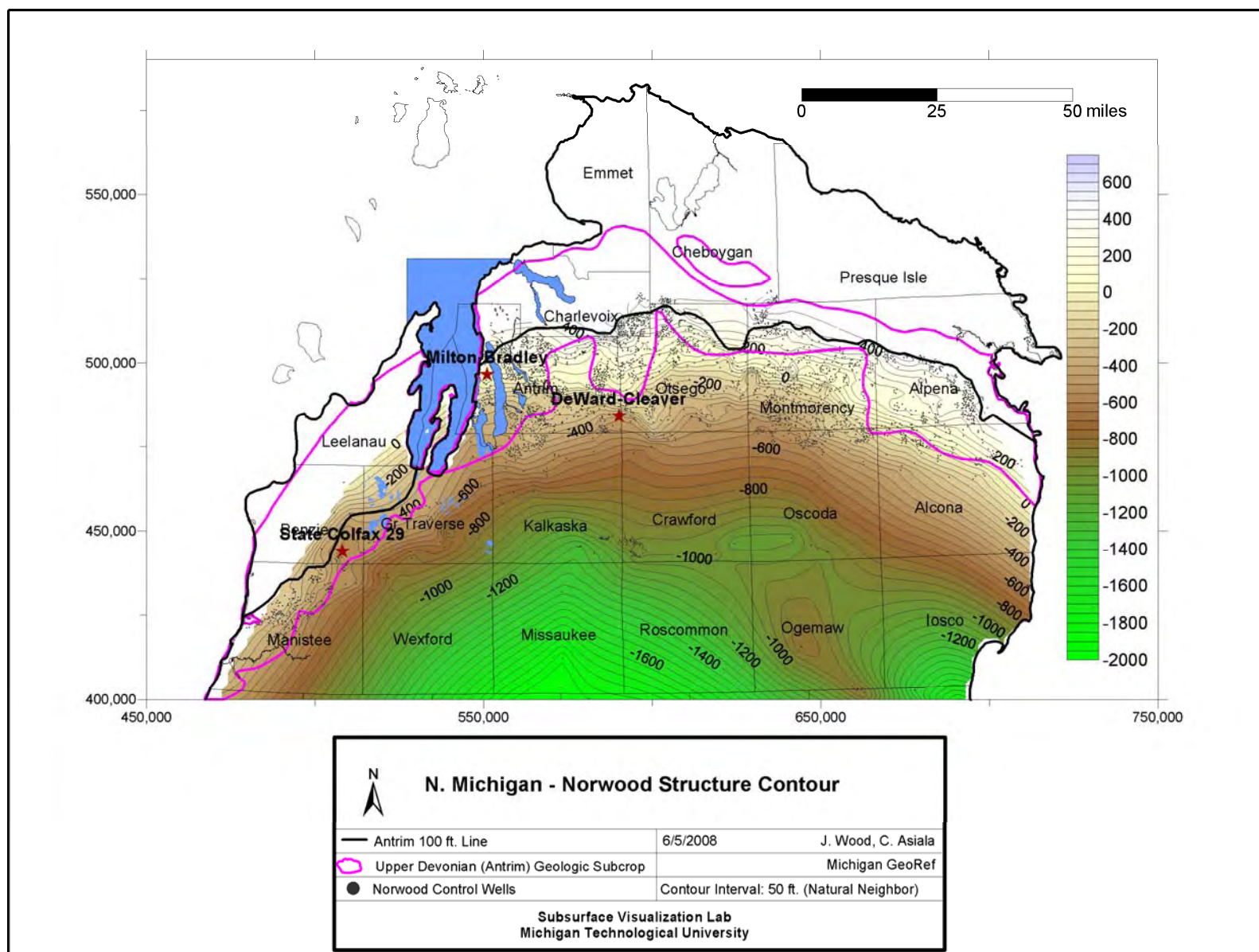


Figure 6-3. Structure map of the Norwood member of the Antrim formation in Northern Michigan. Contour Interval is 50 feet.

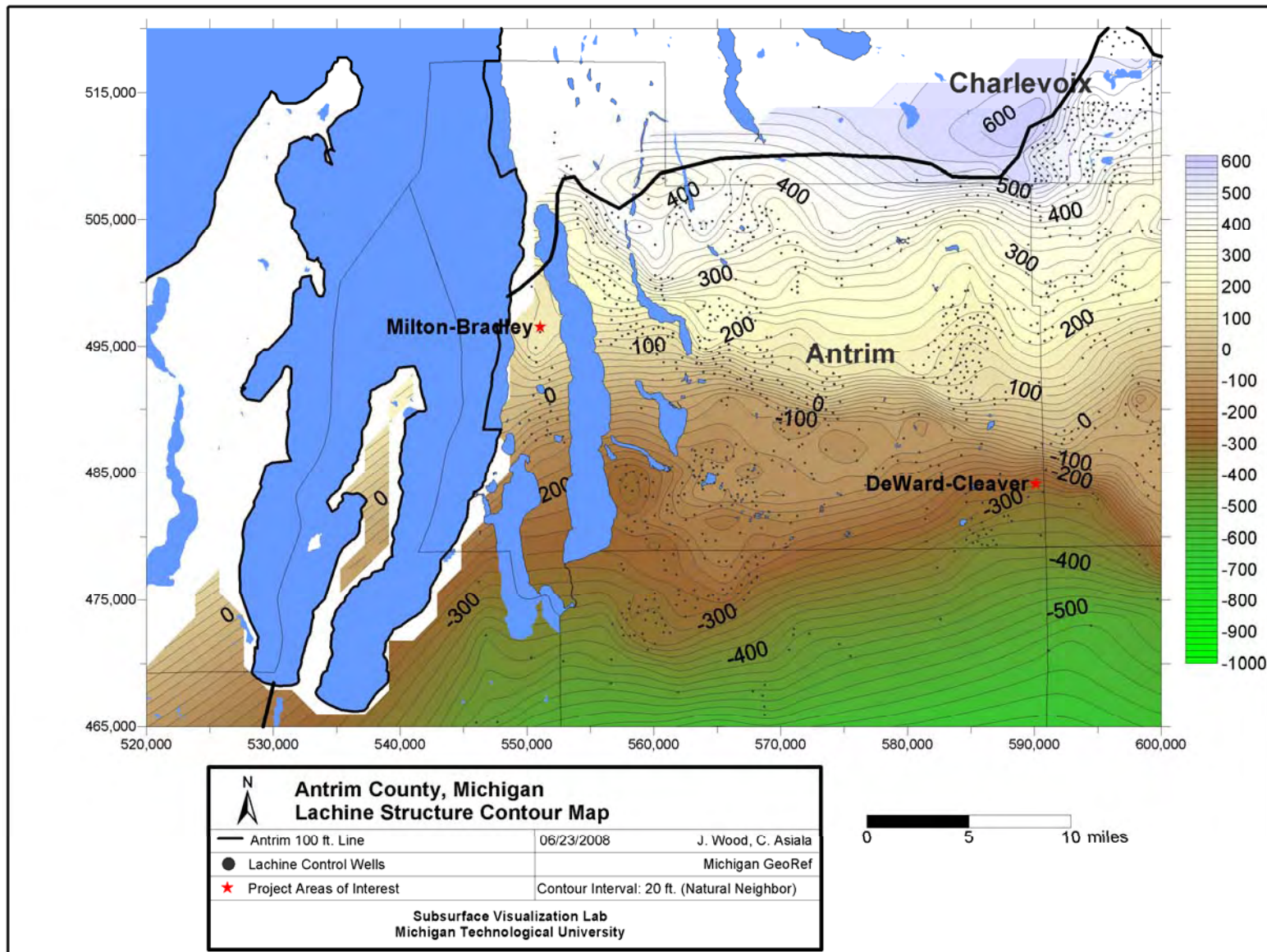


Figure 6-4. Structure contour map of Lachine member of the Antrim formation over Antrim County, MI. Contour interval is 20 feet.

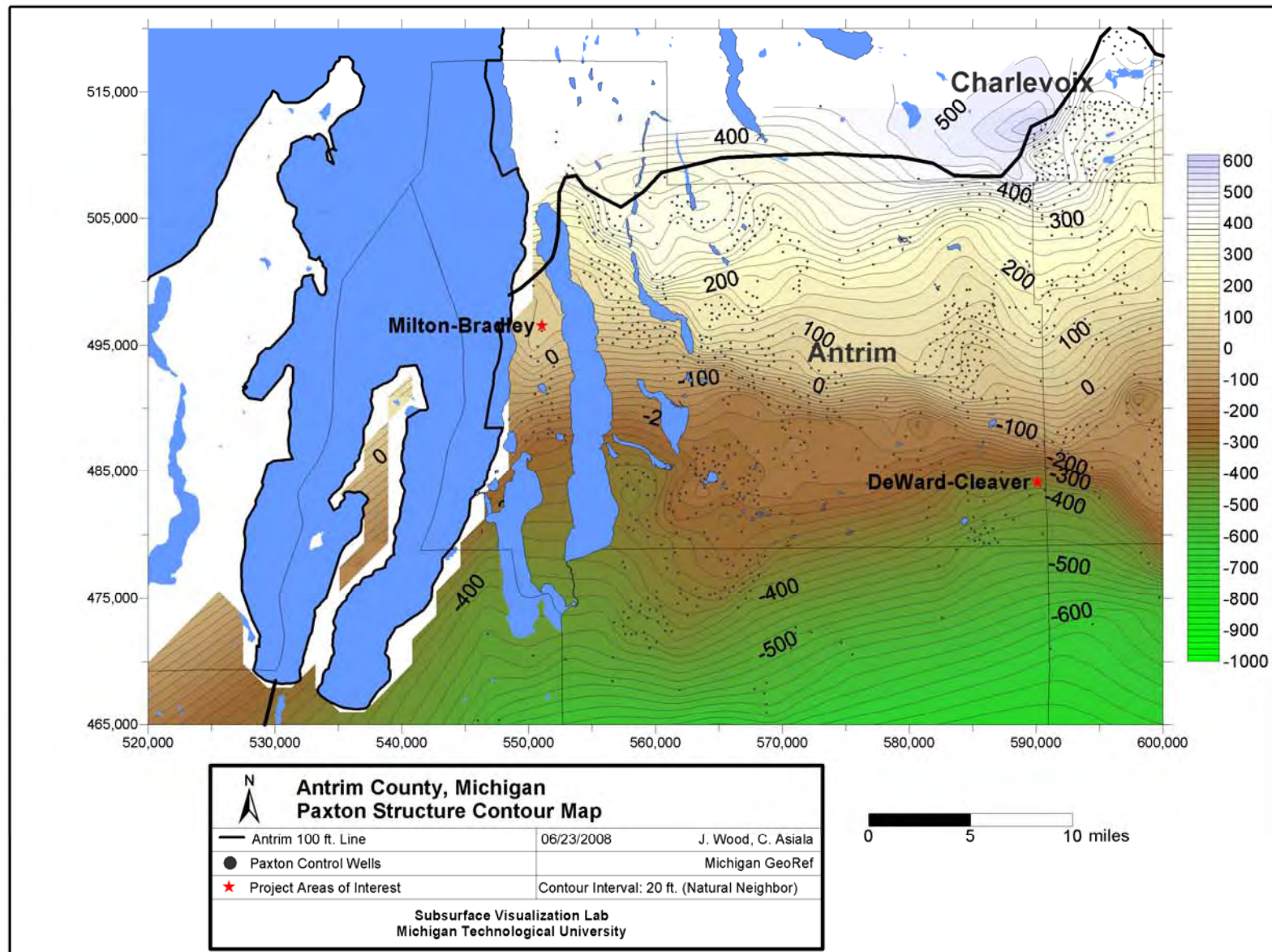


Figure 6-5. Structure contour map of Paxton member of the Antrim formation over Antrim County, MI. Contour interval is 20 feet.

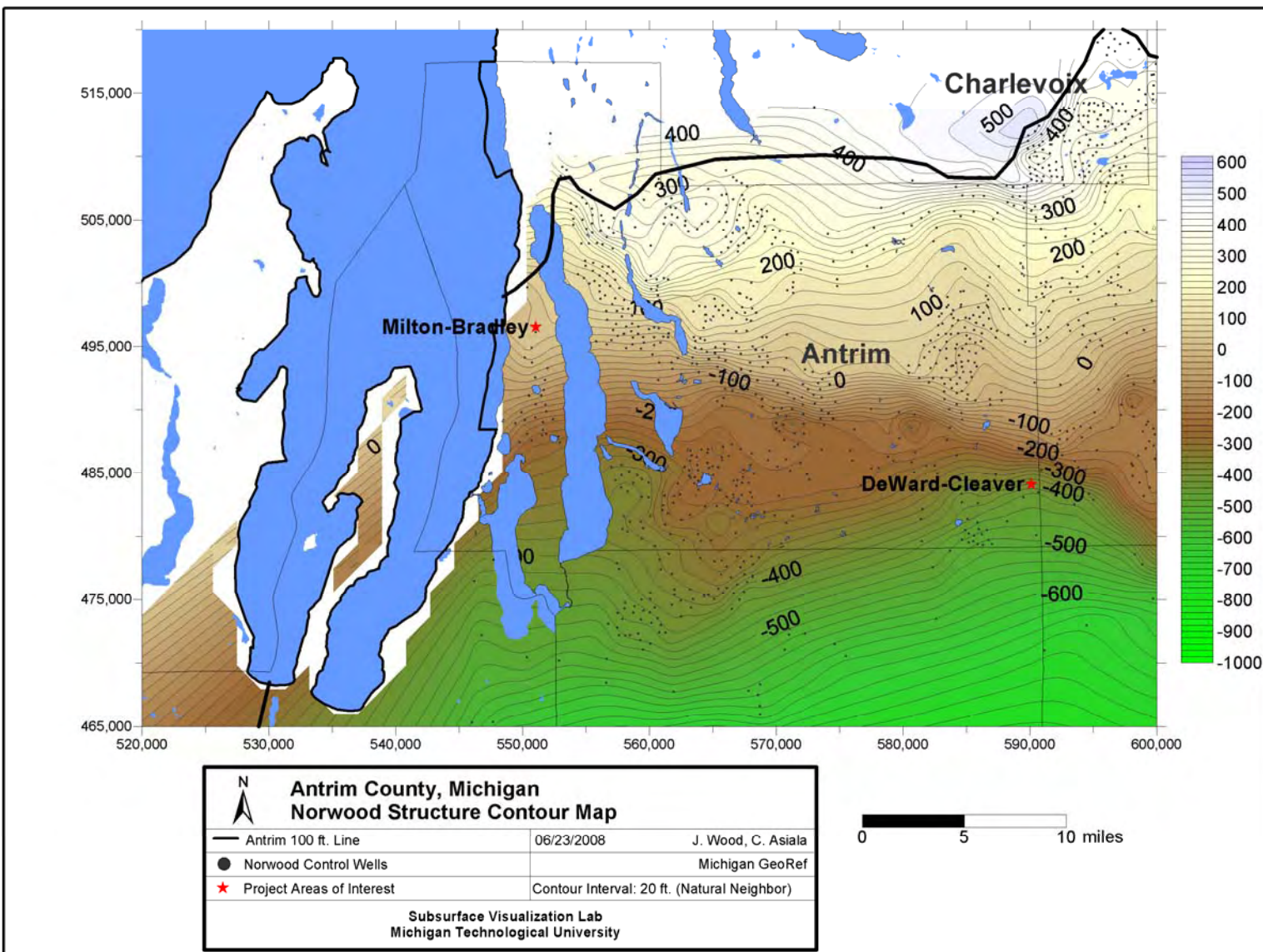


Figure 6-6. Structure contour map of Norwood member of the Antrim formation over Antrim County, MI. Contour interval is 20 feet.

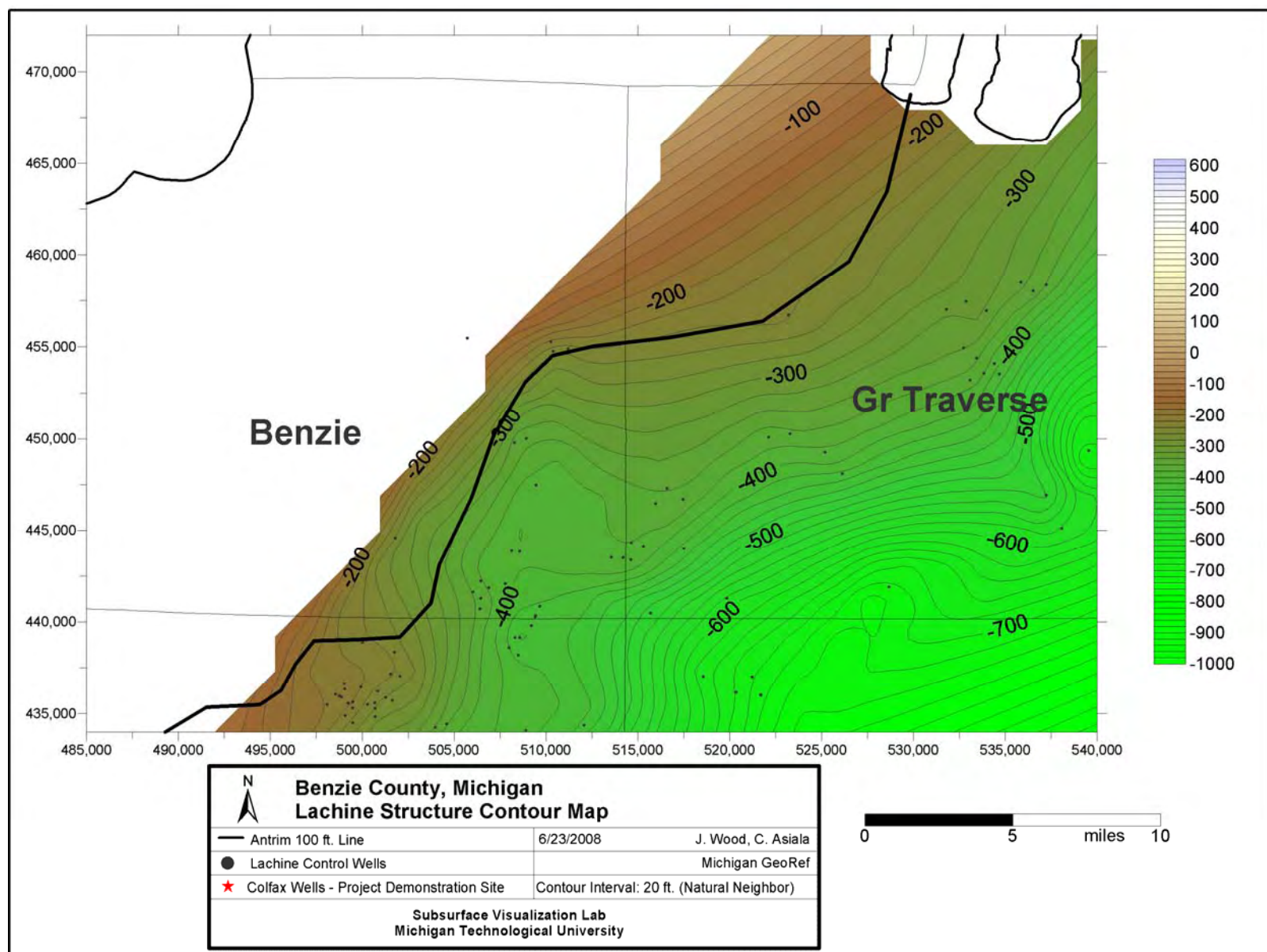


Figure 6-7. Structure contour map of Lachine member of the Antrim formation over Benzie County, MI. Contour interval is 20 feet.

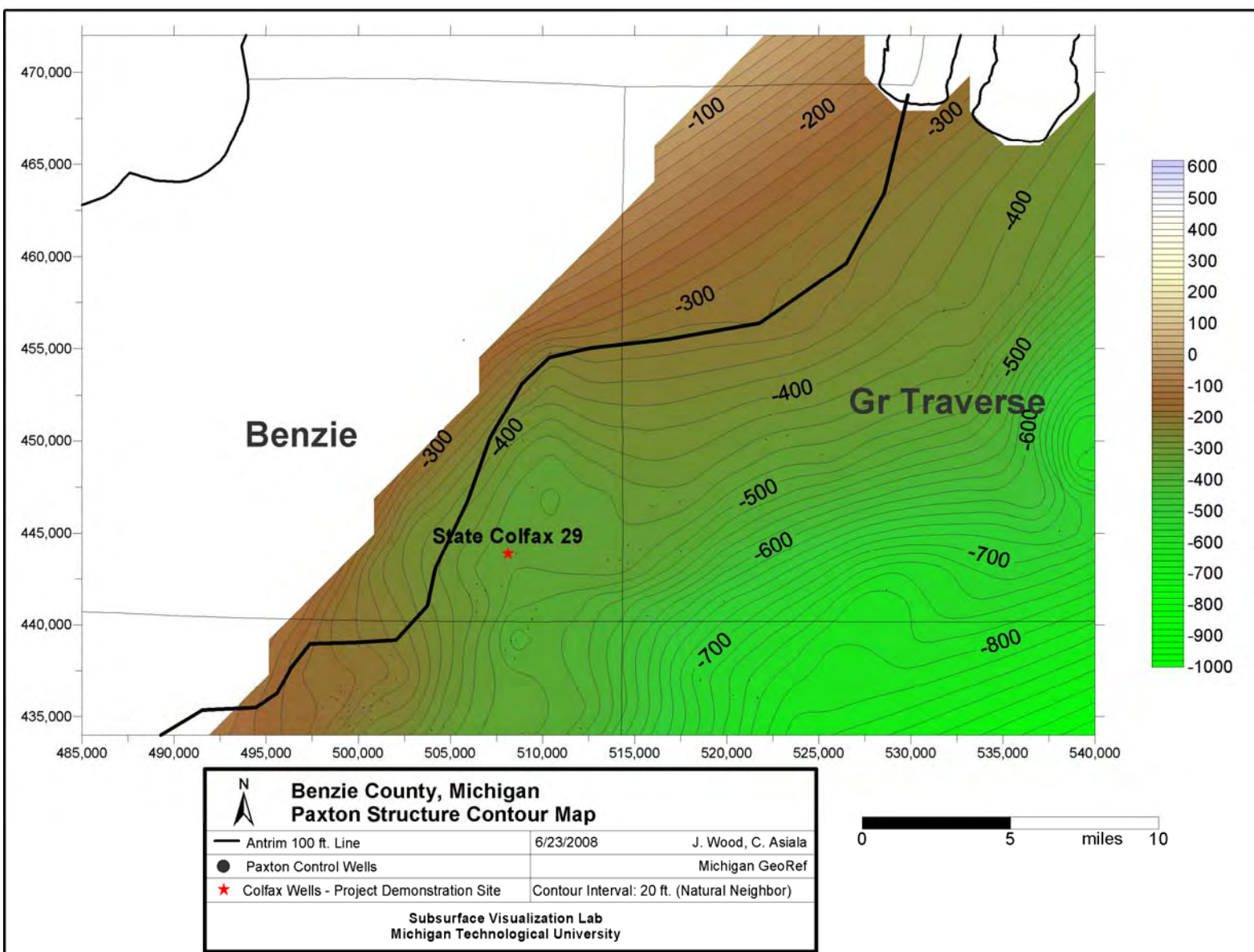


Figure 6-8. Structure contour map of Paxton member of the Antrim formation over Benzie County, MI. Contour interval is 20 feet.

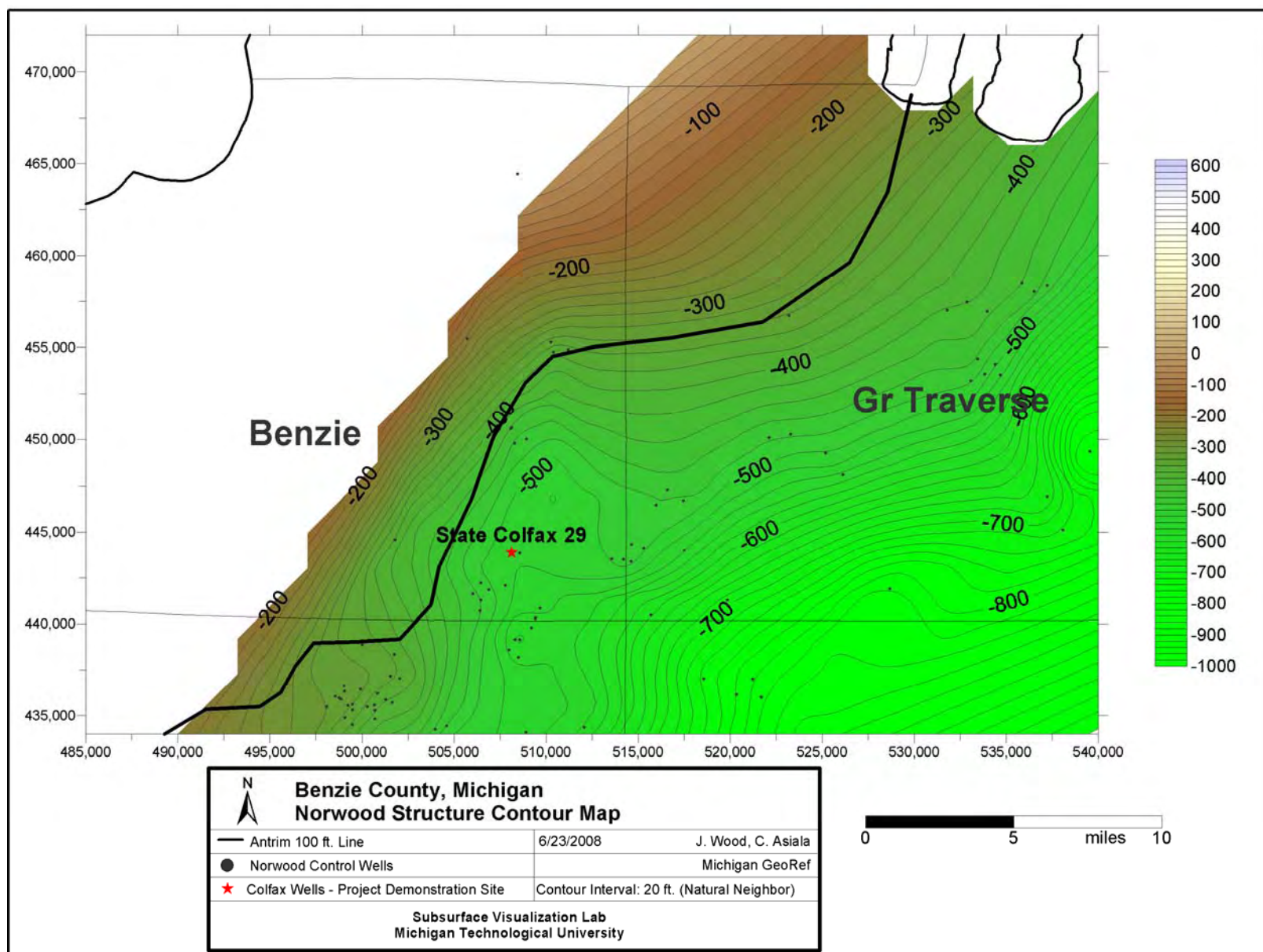


Figure 6-9. Structure contour map of the Norwood member of the Antrim formation over Benzie County, MI. Contour interval is 20 feet.

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.

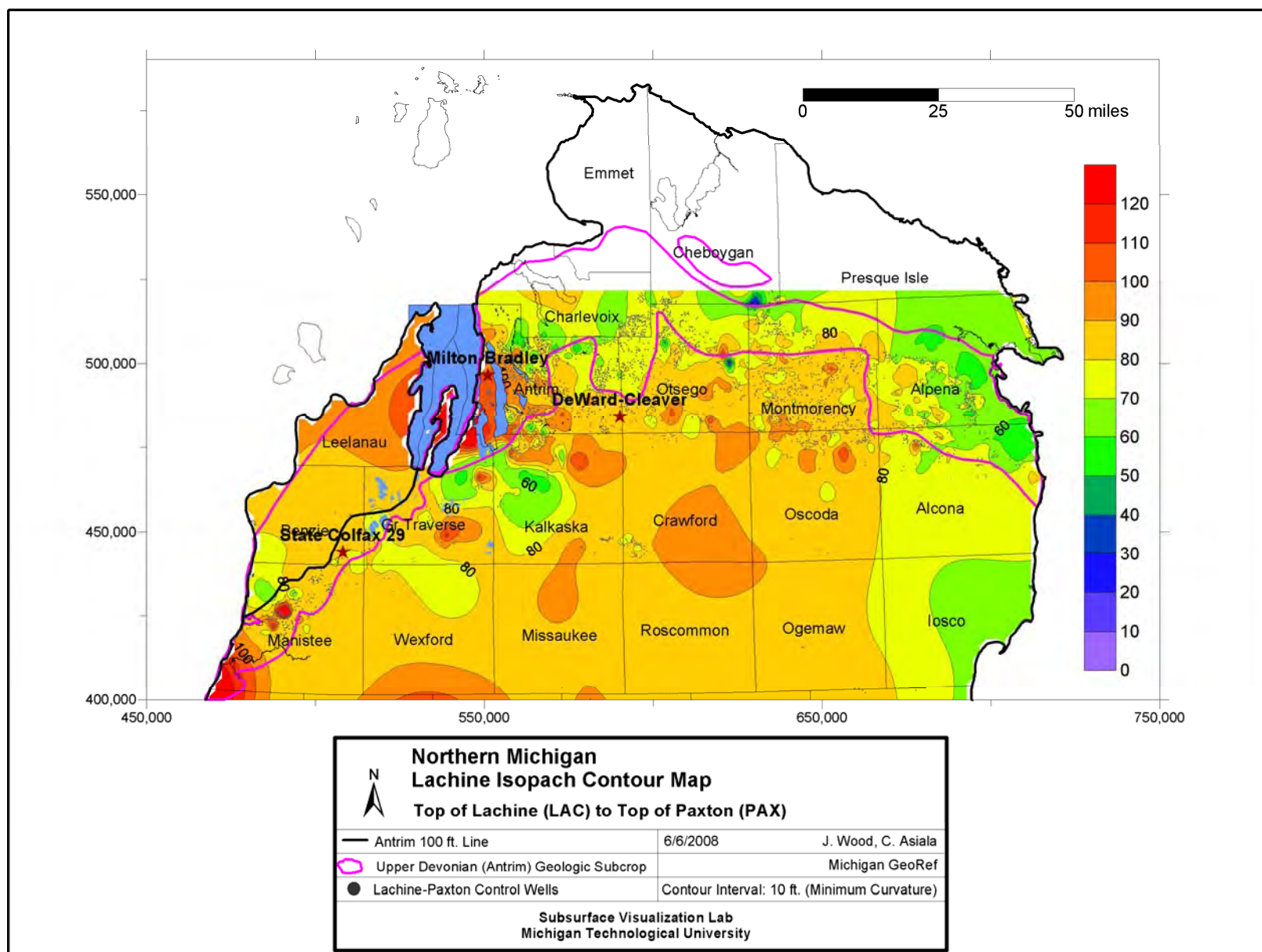


Figure 7-1. Isopach thickness map of the Lachine member of the Antrim formation over northern Michigan, contour interval is 10 feet.

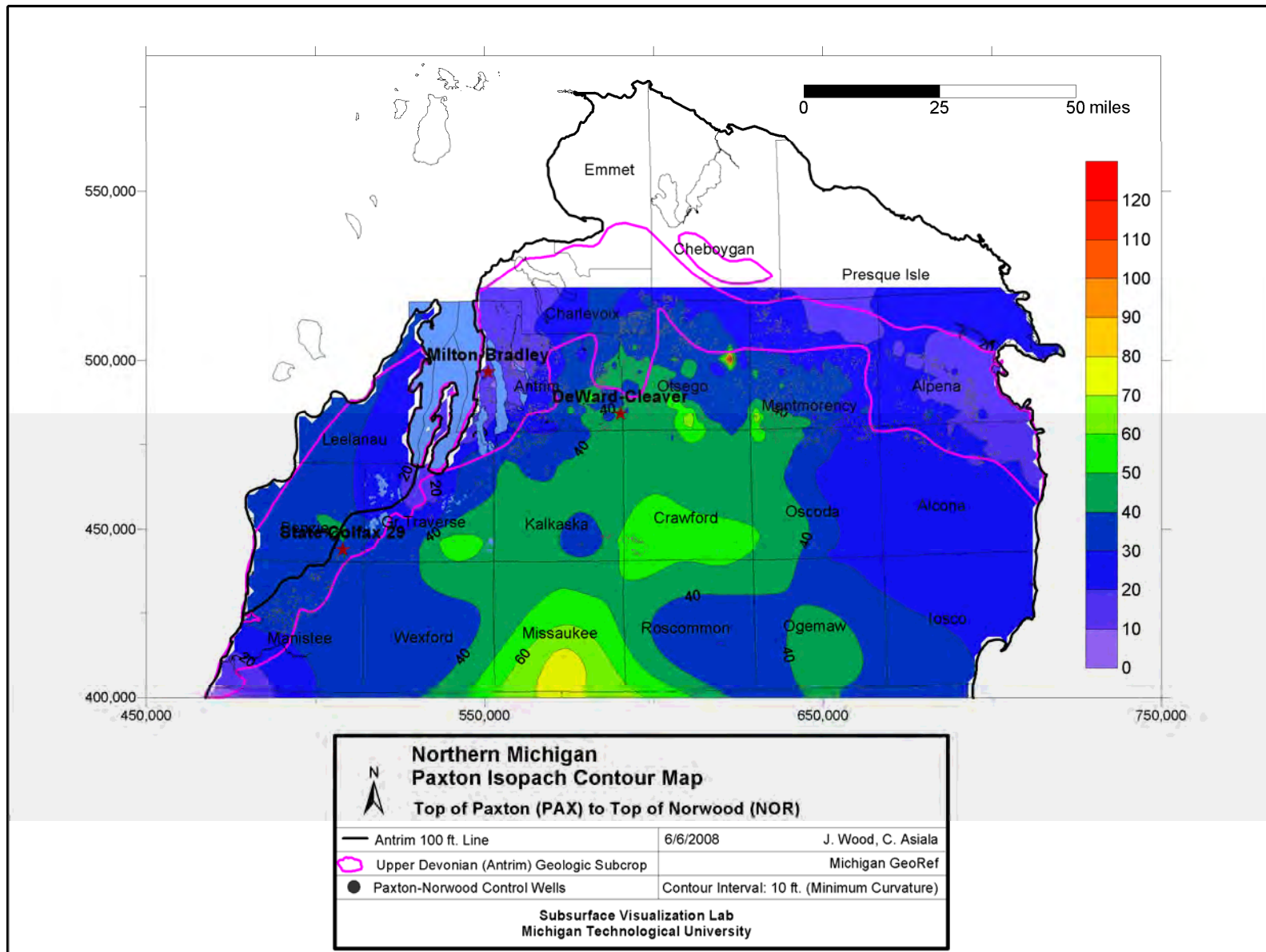


Figure 7-2. Isopach thickness map of the Paxton member of the Antrim formation over northern Michigan, contour interval is 10 feet.

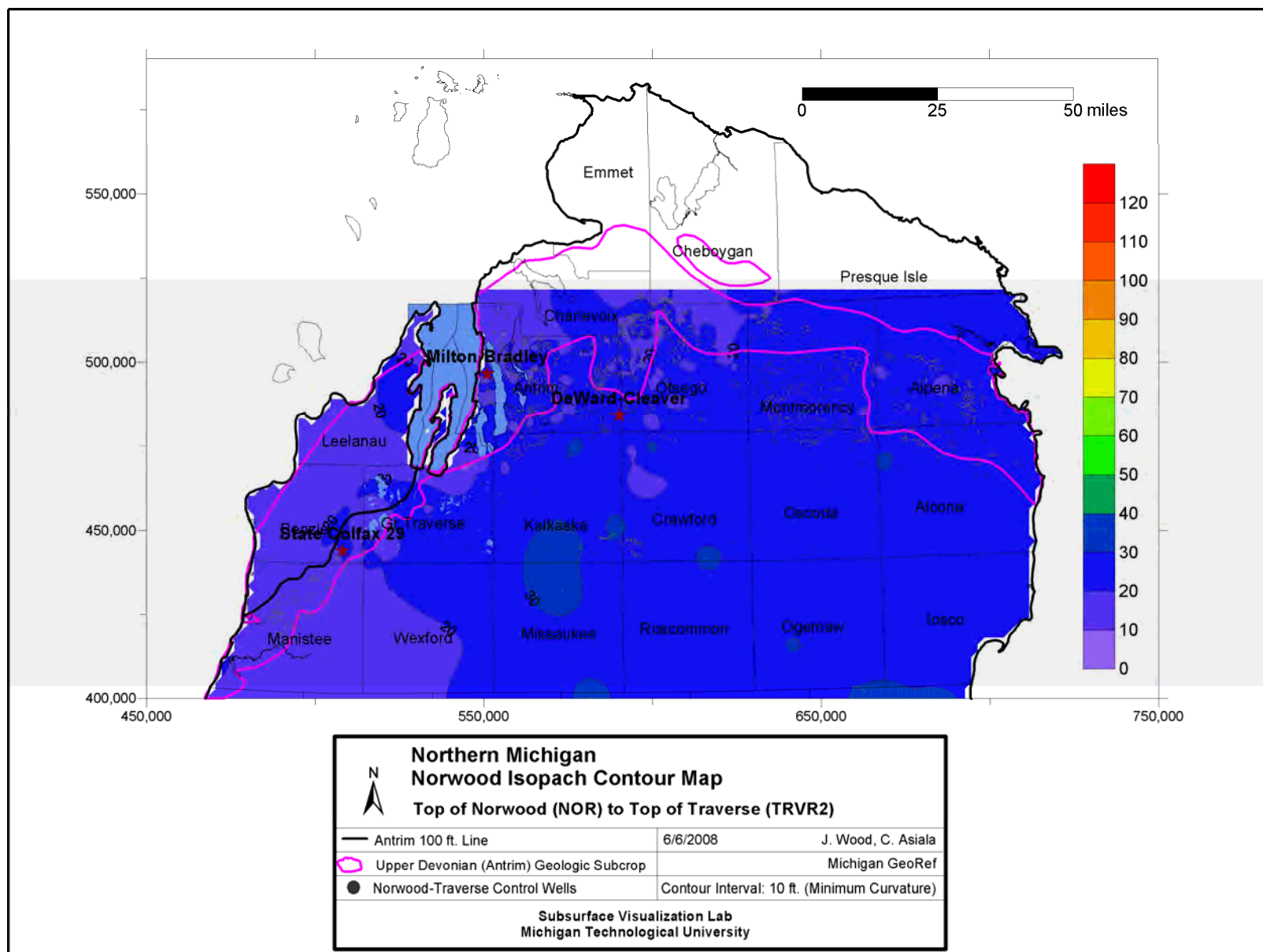


Figure 7-3. Isopach thickness map of the Norwood member of the Antrim formation over northern Michigan, contour interval is 10 feet.

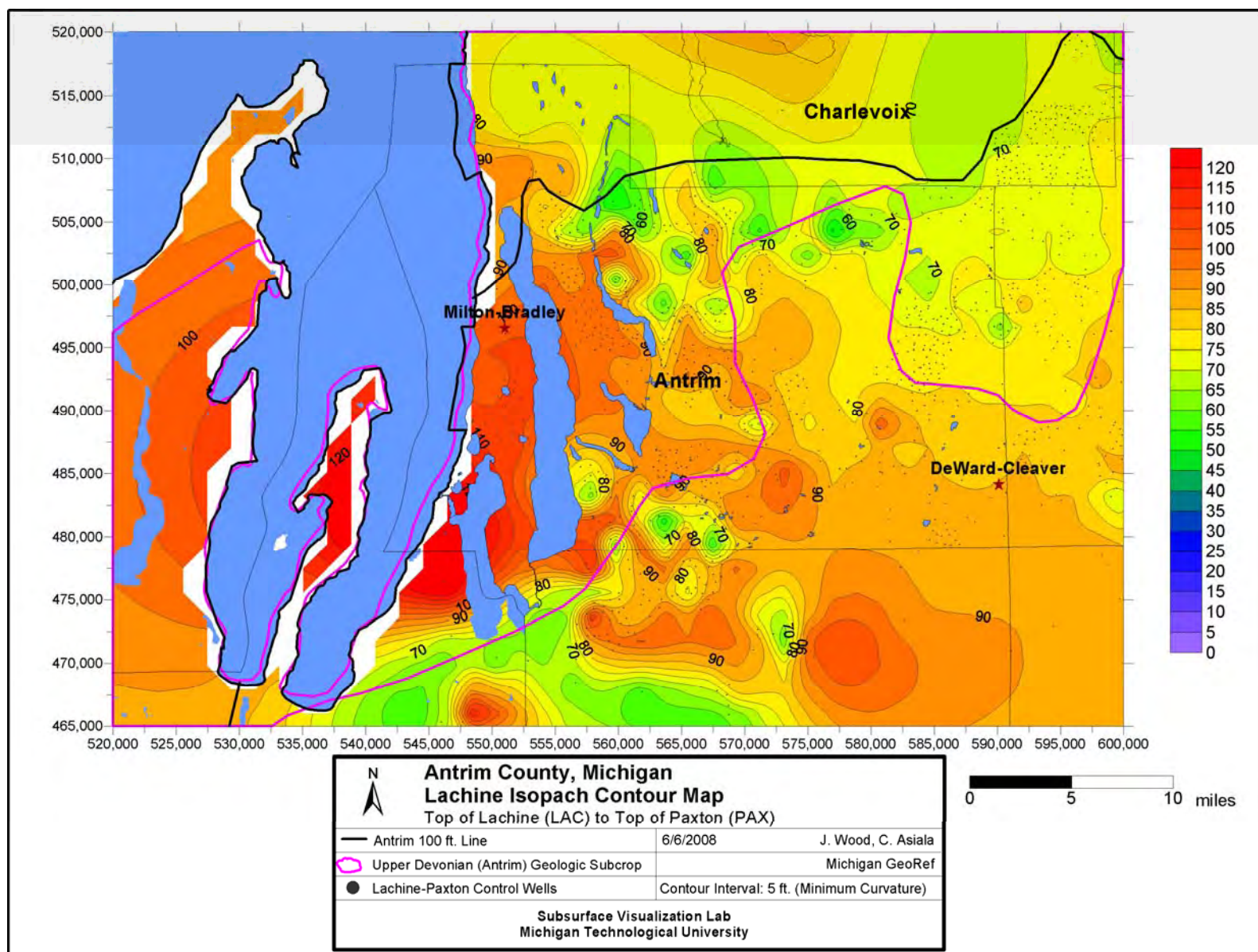


Figure 7-4. Isopach thickness map of the Lachine member of the Antrim formation over Antrim County, MI. Contour interval is 5 feet.

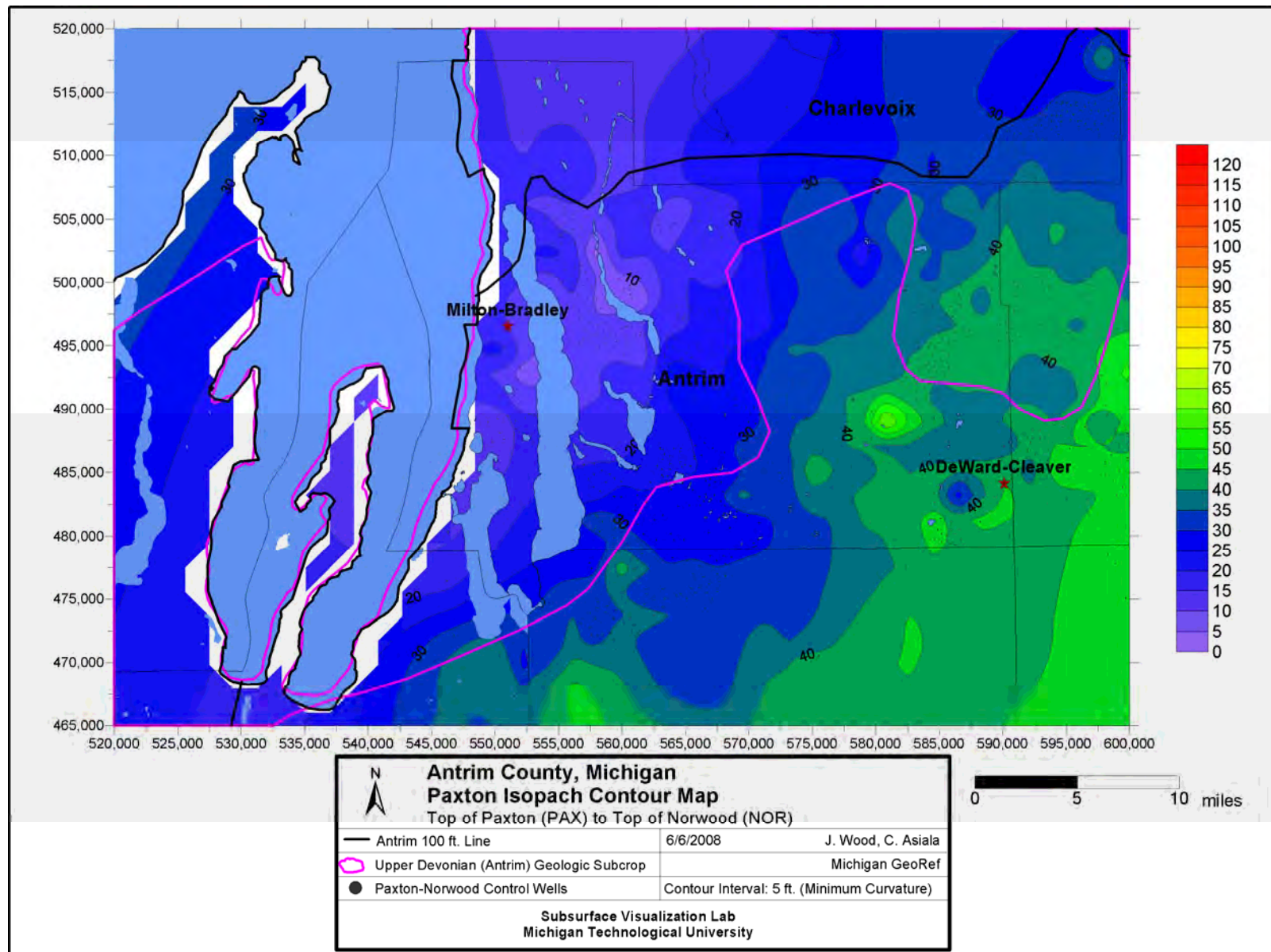


Figure 7-5. Isopach thickness map of the Paxton member of the Antrim formation over Antrim County, MI. Contour interval is 5 feet.

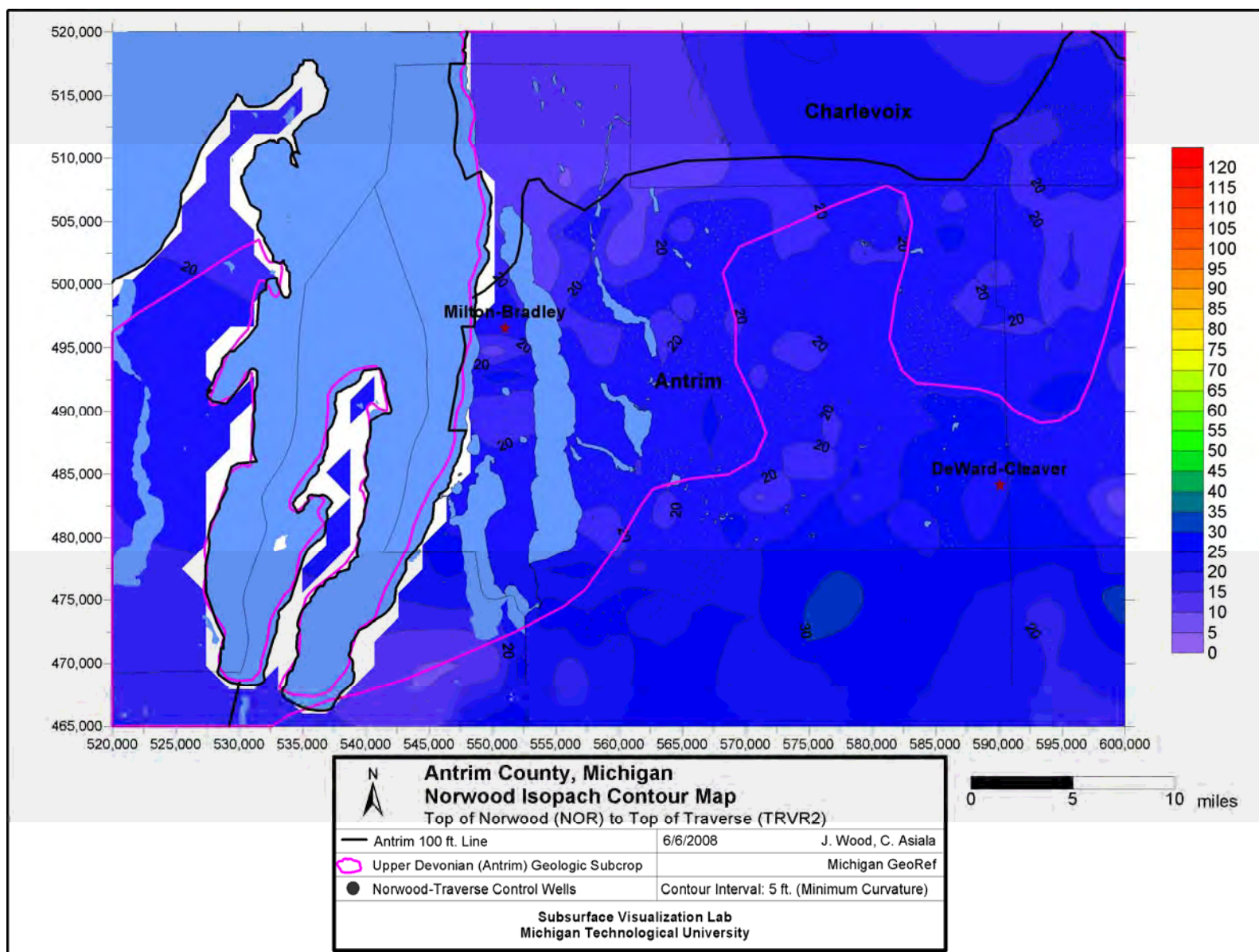


Figure 7-6. Isopach thickness map of the Norwood member of the Antrim formation over Antrim County, MI. Contour interval is 5 feet.

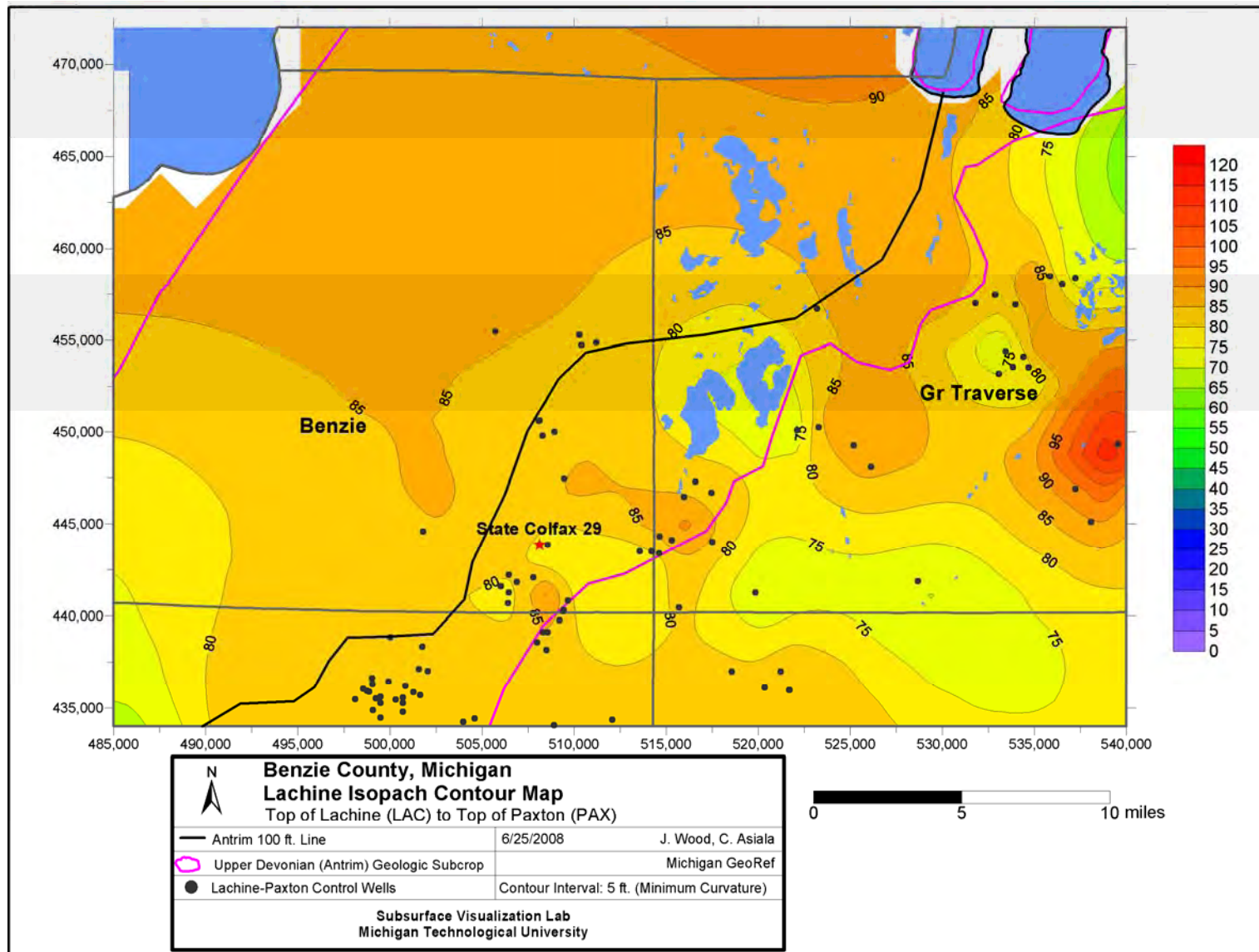


Figure 7-7. Isopach thickness map of the Lachine member of the Antrim formation over Michigan's Benzie and Grand Traverse Counties, contour interval is 5 feet.

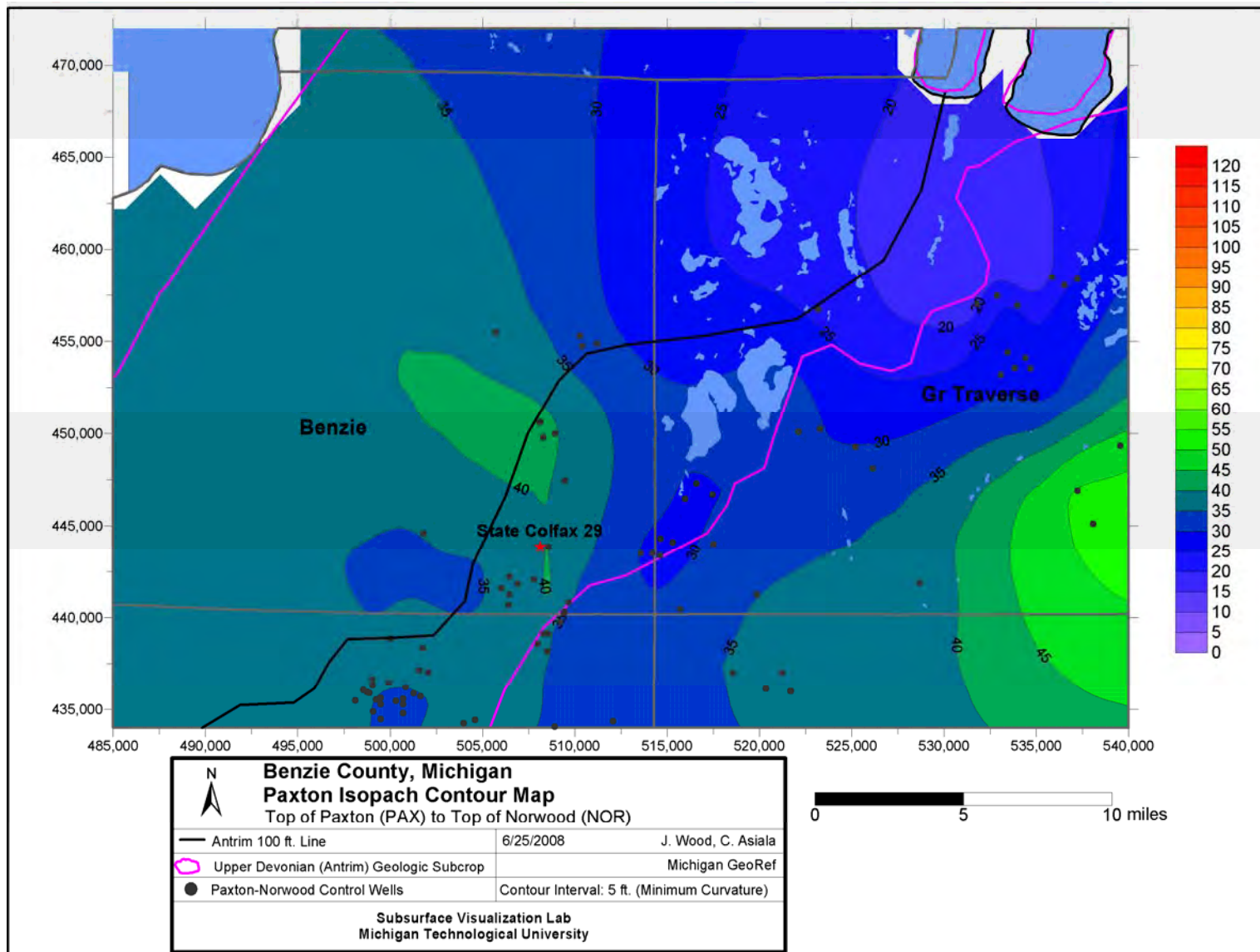


Figure 7-8. Isopach thickness map of the Paxton member of the Antrim formation over Michigan's Benzie and Grand Traverse Counties, contour interval is 5 feet.

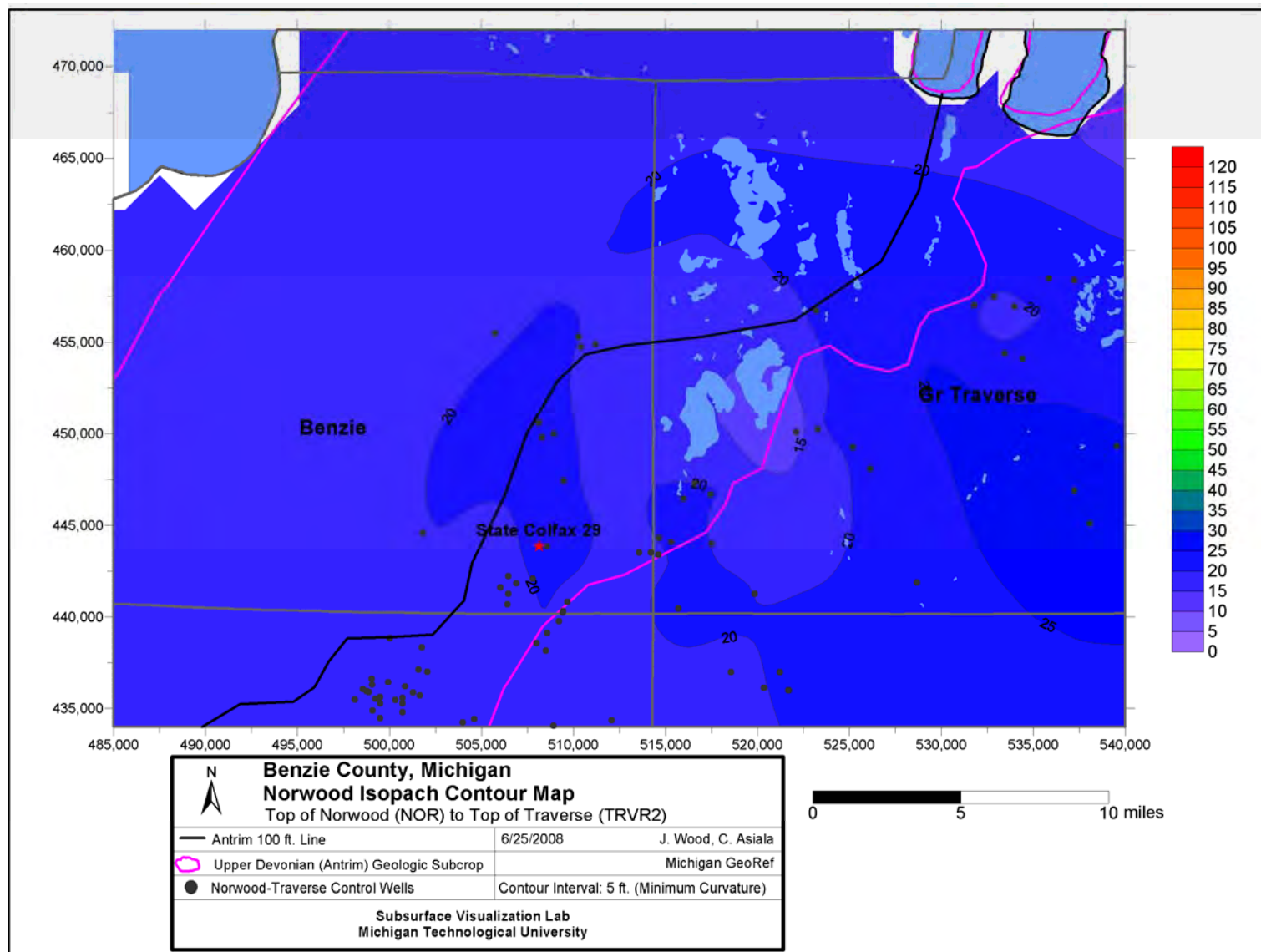


Figure 7-9. Isopach thickness map of the Norwood member of the Antrim formation over Michigan's Benzie and Grand Traverse Counties, contour interval is 5 feet.

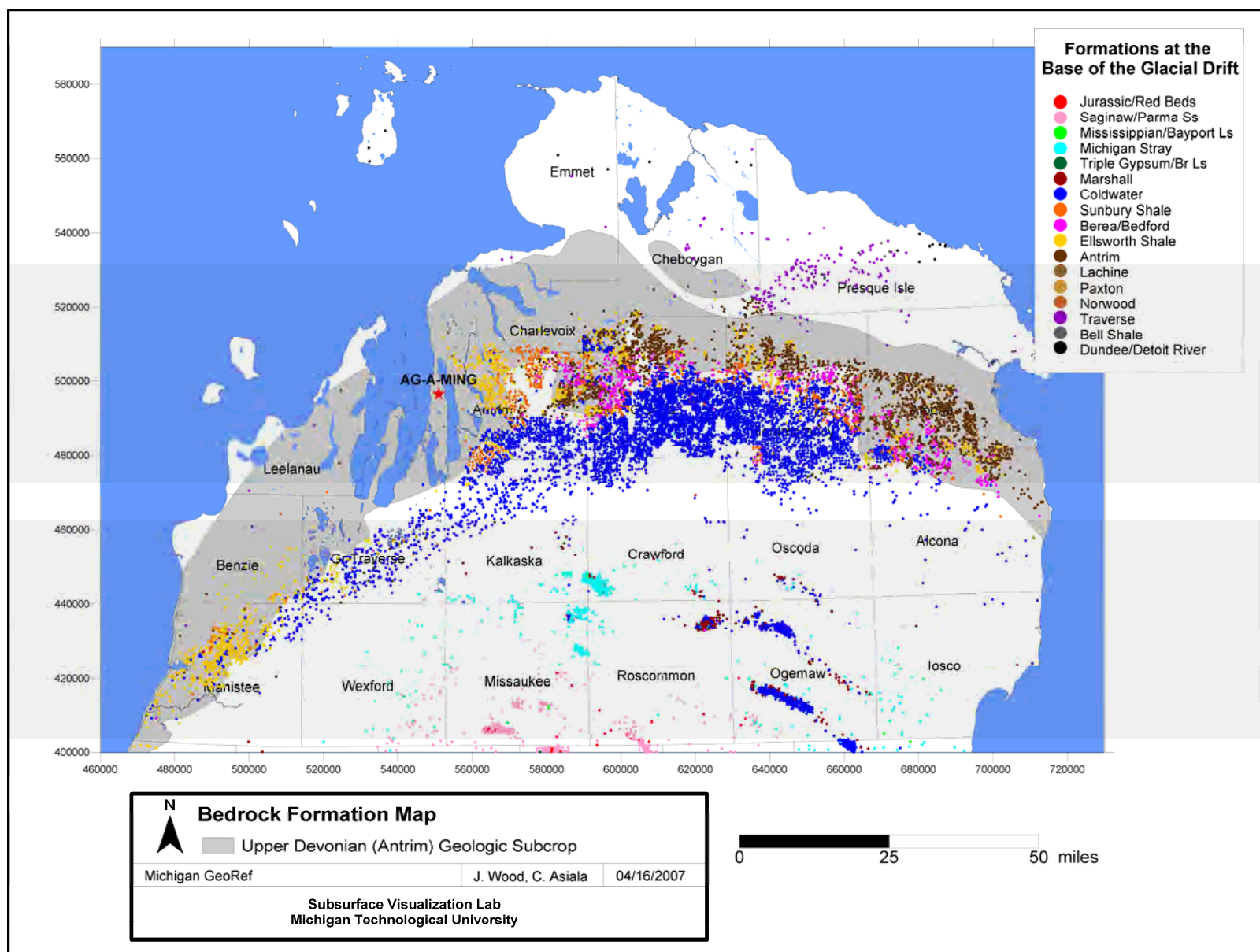


Figure 7-10. Bedrock formation map showing the formation directly below the Glacial Drift.

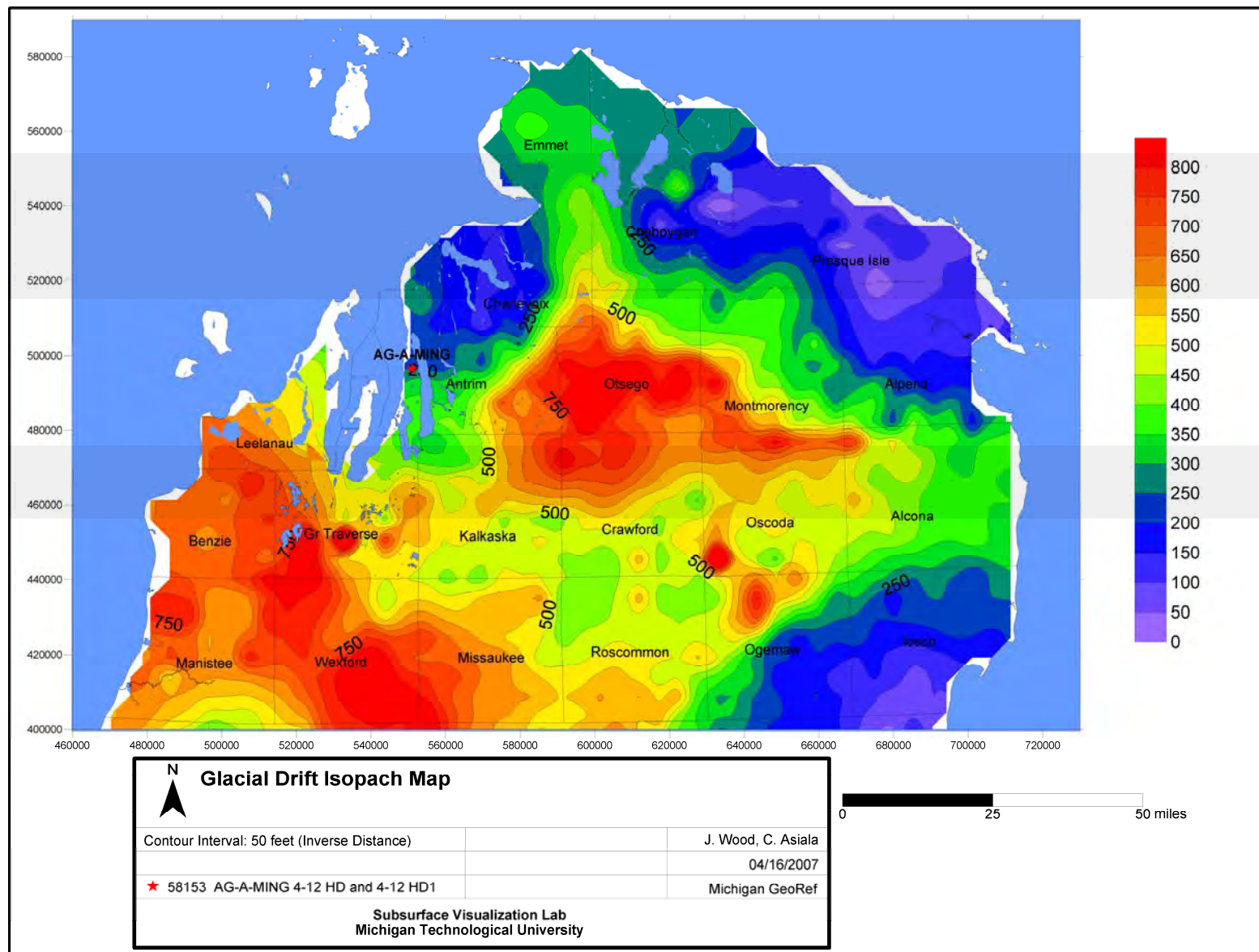


Figure 7-11. Glacial Drift Isopach map with a contour interval of 50 feet, using the Inverse to a Power gridding algorithm.

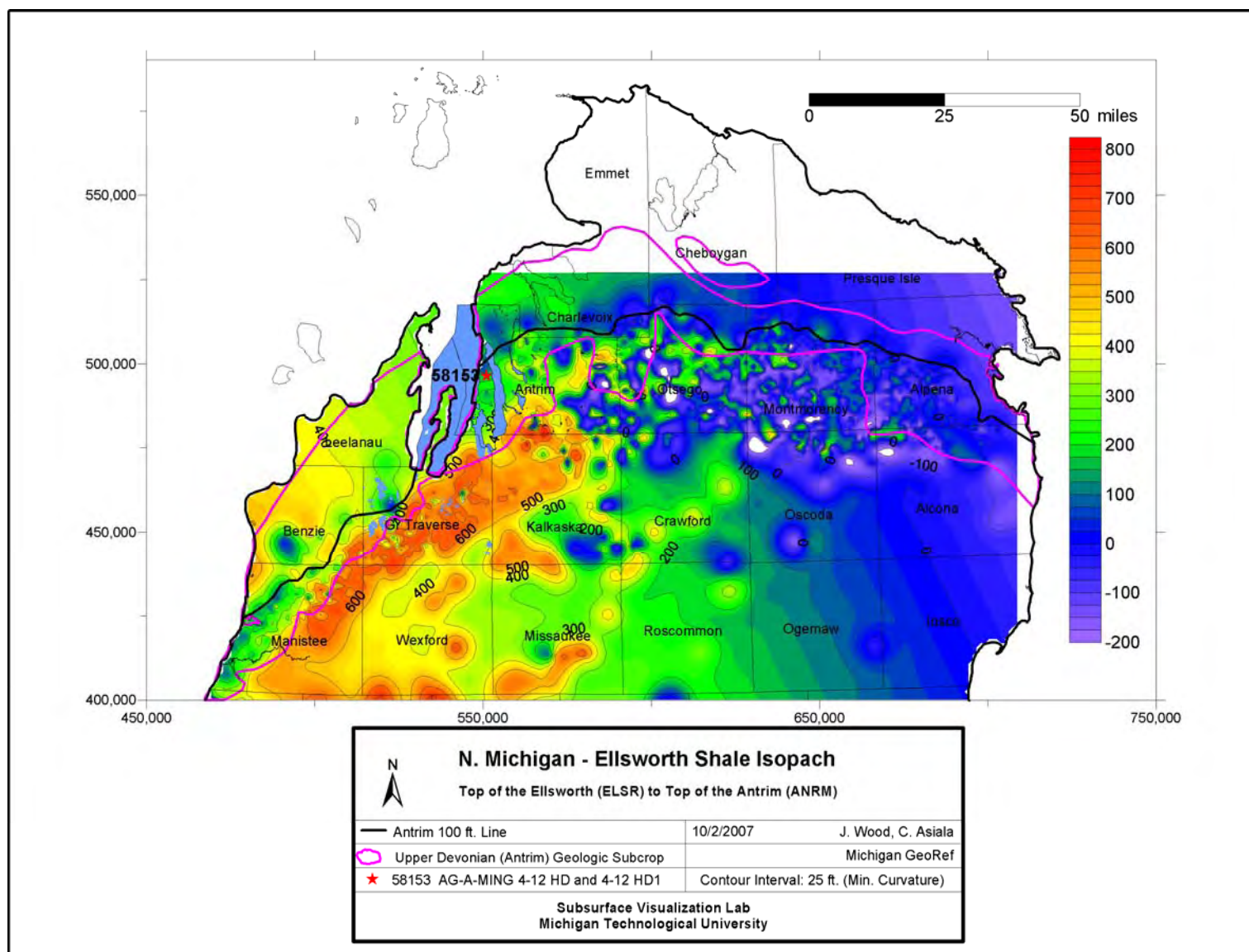


Figure 7-12. Isopach map of the Ellsworth Shale to the top of the Antrim Shale in Northern Michigan. Contour Interval is 25 feet. The Ellsworth Shale exists mostly in the western part of the Michigan Basin.

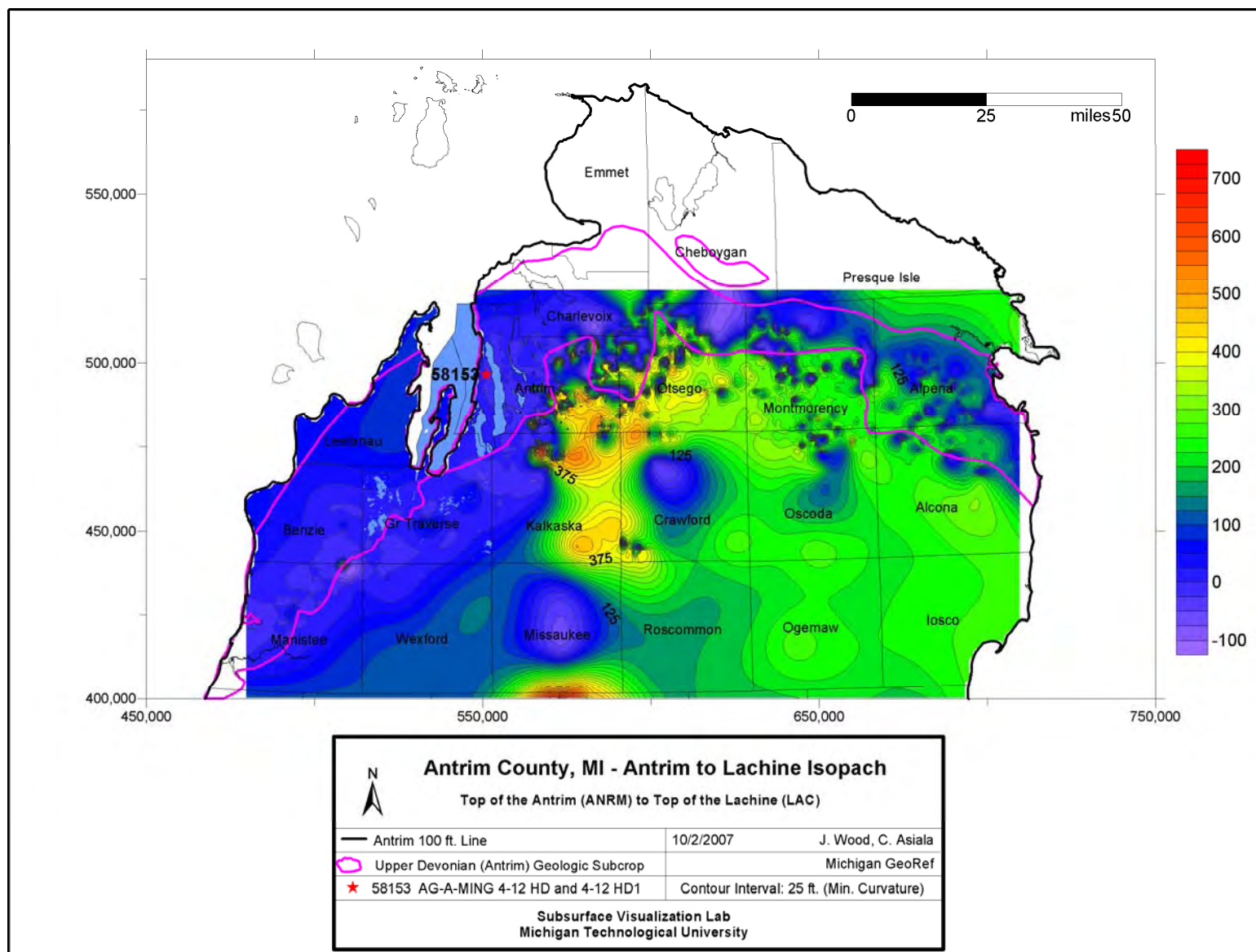


Figure 7-13. Isopach map of the Antrim Shale to the top of the Lachine member of the Antrim Shale in Northern Michigan. Contour Interval is 25 feet.

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 Magnetism 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 Bouguer anomaly maps for Antrim and Benzie Counties, respectively.

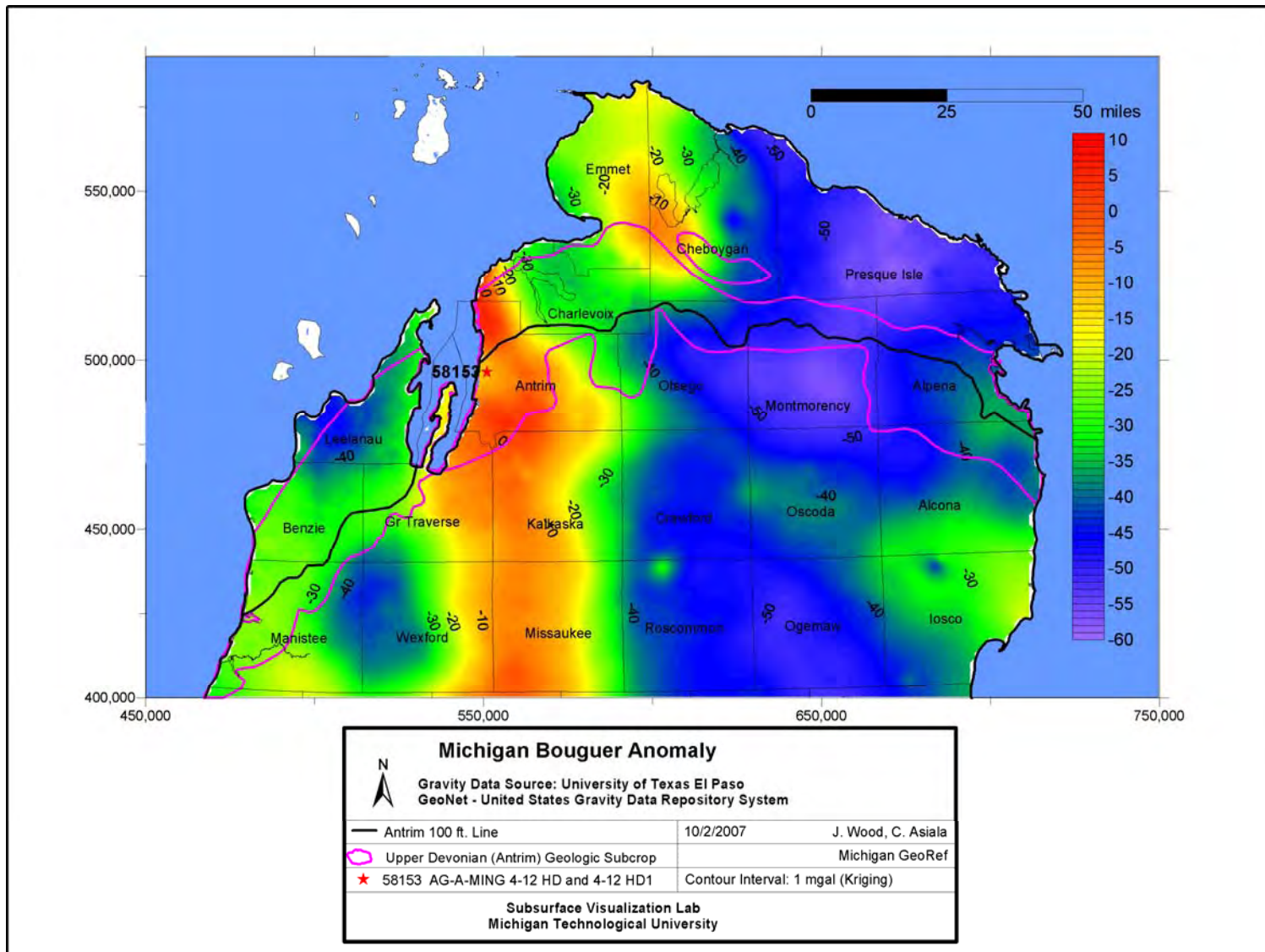


Figure 8-1. Michigan Bouguer Anomaly map created from data obtained from the University of Texas El Paso website for GeoNet Gravity and Magnetic Dataset Repository. (<http://irpsrvgis00.utep.edu/repositorywebsite/>). Color-filled contours are shown from -60 to 10 mgals with a contour interval of 1 mgal.

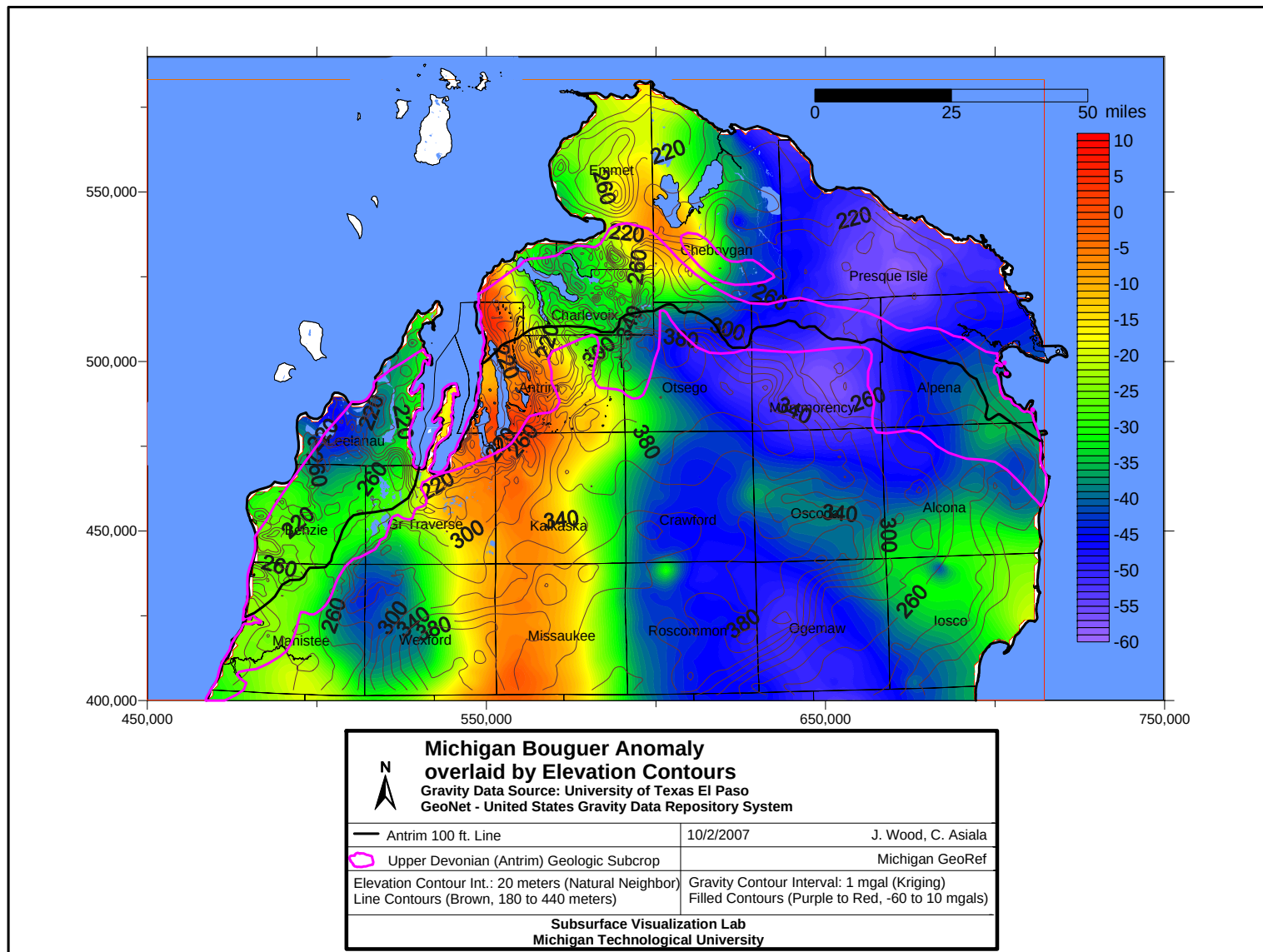


Figure 8-2. Michigan Bouguer Anomaly, as shown in Figure 8-1, overlaid by elevation contour lines. The elevations range from 180 to 440 meters and were contoured at a 20 meter interval.

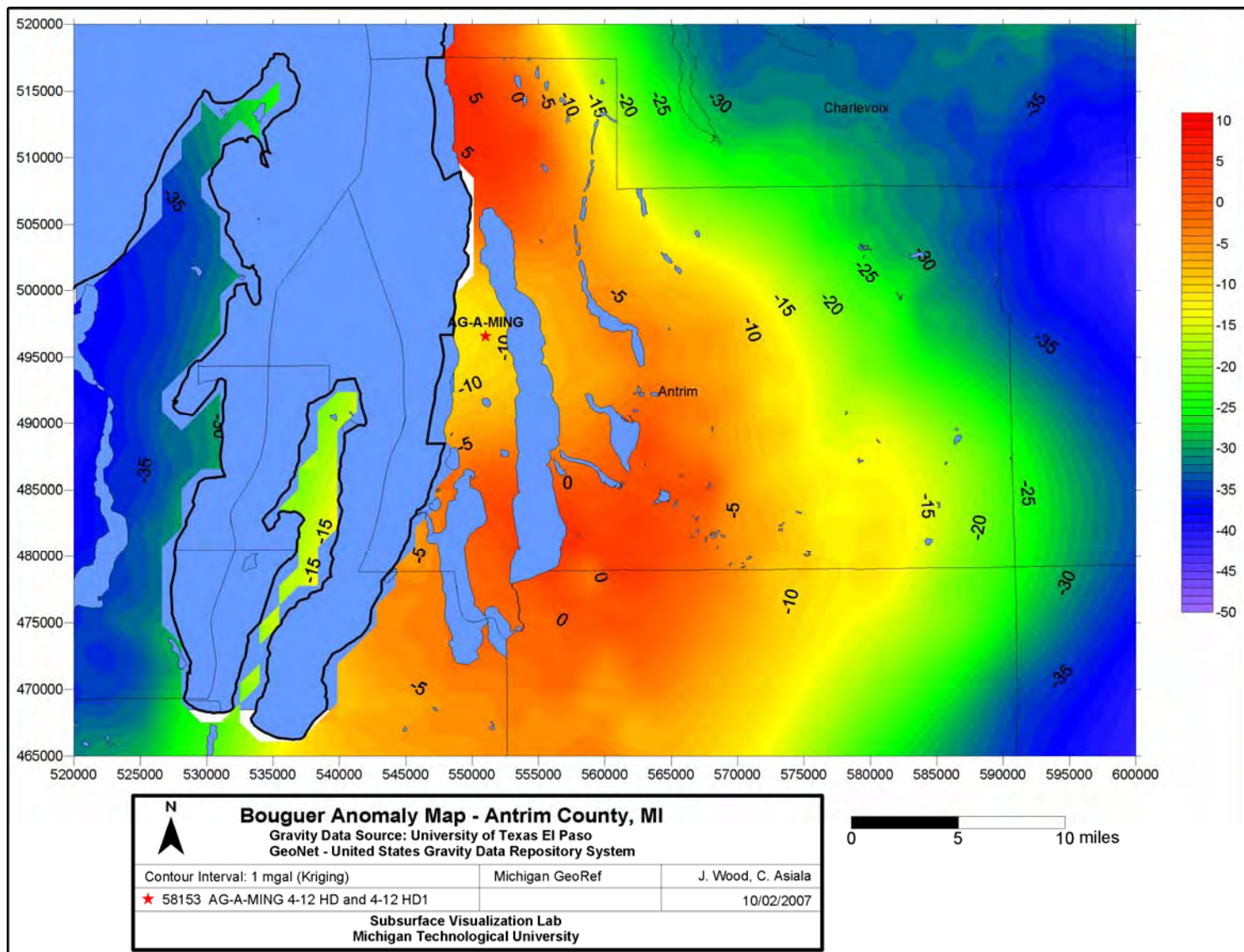


Figure 8-3. Michigan Bouguer Anomaly map zoomed to Antrim County, and created from data obtained from the University of Texas El Paso website for GeoNet – United States Gravity Data Repository System.

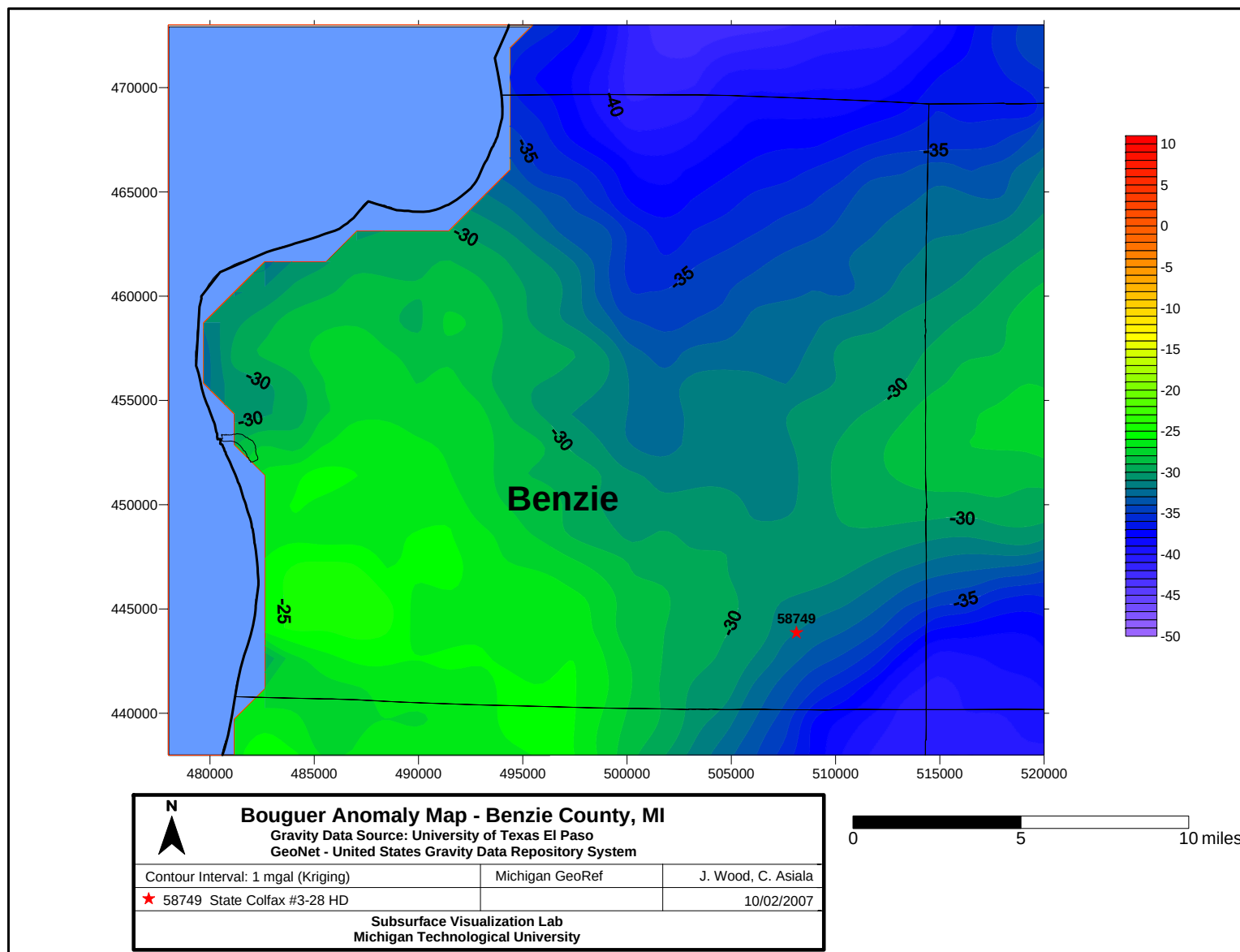


Figure 8-4. Michigan Bouguer Anomaly map zoomed to Benzie County, and created from data obtained from the University of Texas El Paso website for GeoNet – United States Gravity Data Repository System.

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

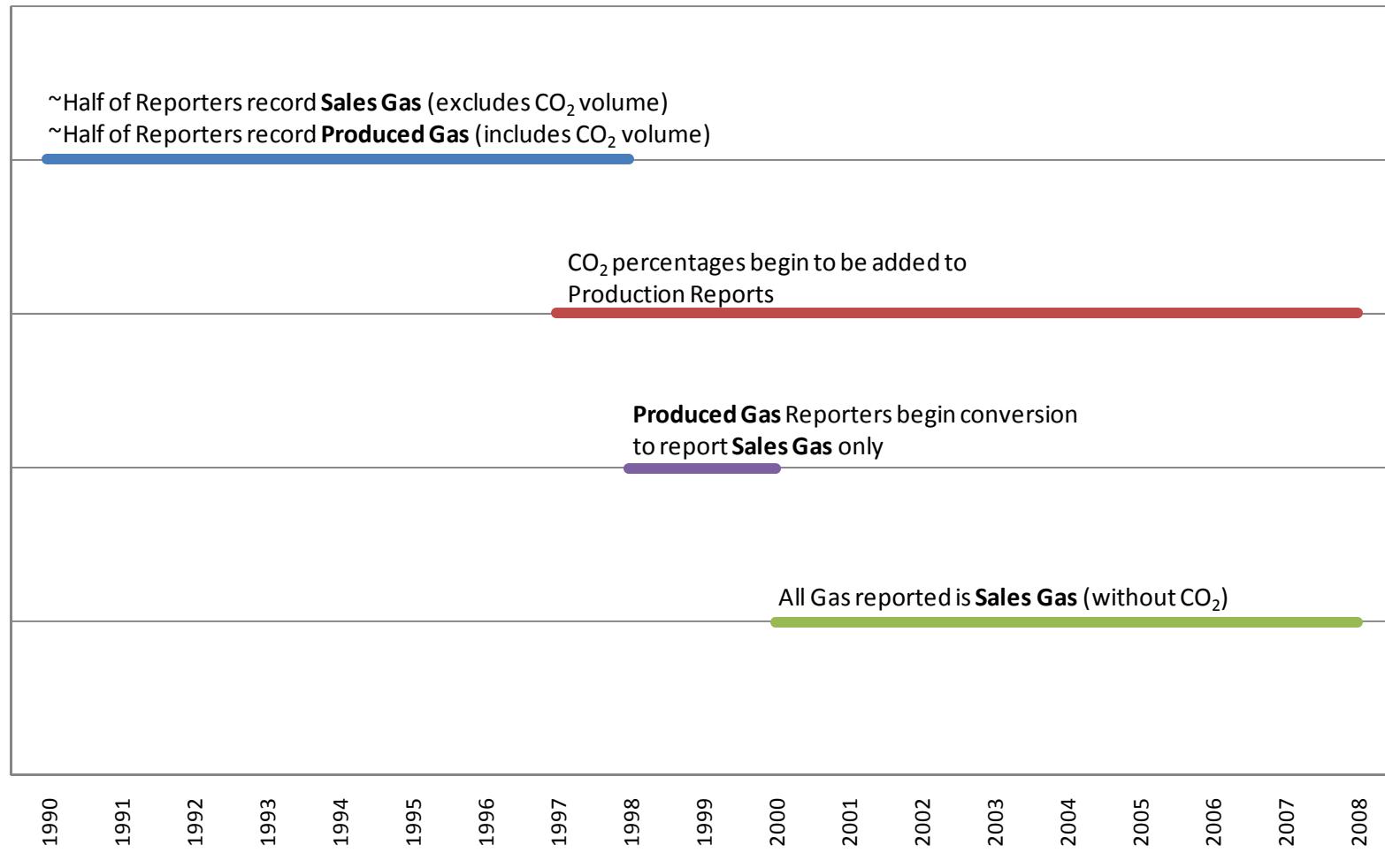


Figure 9-1. Timeline showing the process of how the Michigan Public Service Commission has evolved the reporting standards of Antrim natural gas and CO₂ reporting. The most accurate data analysis will be for the years after 2000.

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}

$$V_T = V_{\text{Sales}} + V_{\text{CO2}}$$

$$V_{\text{CO2}} = \frac{P_{\text{CO2}}}{100} V_T$$

$$V_{\text{CO2}} = \frac{P_{\text{CO2}}}{100} \left(\frac{V_{\text{Sales}}}{1 - \frac{P_{\text{CO2}}}{100}} \right)$$

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.

Sales Gas (mcf)	Percent of CO ₂ in Produced Gas	Volume of CO ₂ (mcf)	Produced Gas (mcf)
MPSC value	MPSC value	$V_{CO_2} = \frac{P_{CO_2}}{100} \left(\frac{V_{Sales}}{1 - \frac{P_{CO_2}}{100}} \right)$	$V_T = V_{Sales} + V_{CO_2}$
V_{Sales}	P_{CO_2}	V_{CO_2}	V_T
9,334	10.35	1,077.600669	10,411.60067
38,468	22	1,0849.94872	49,317.94872

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.

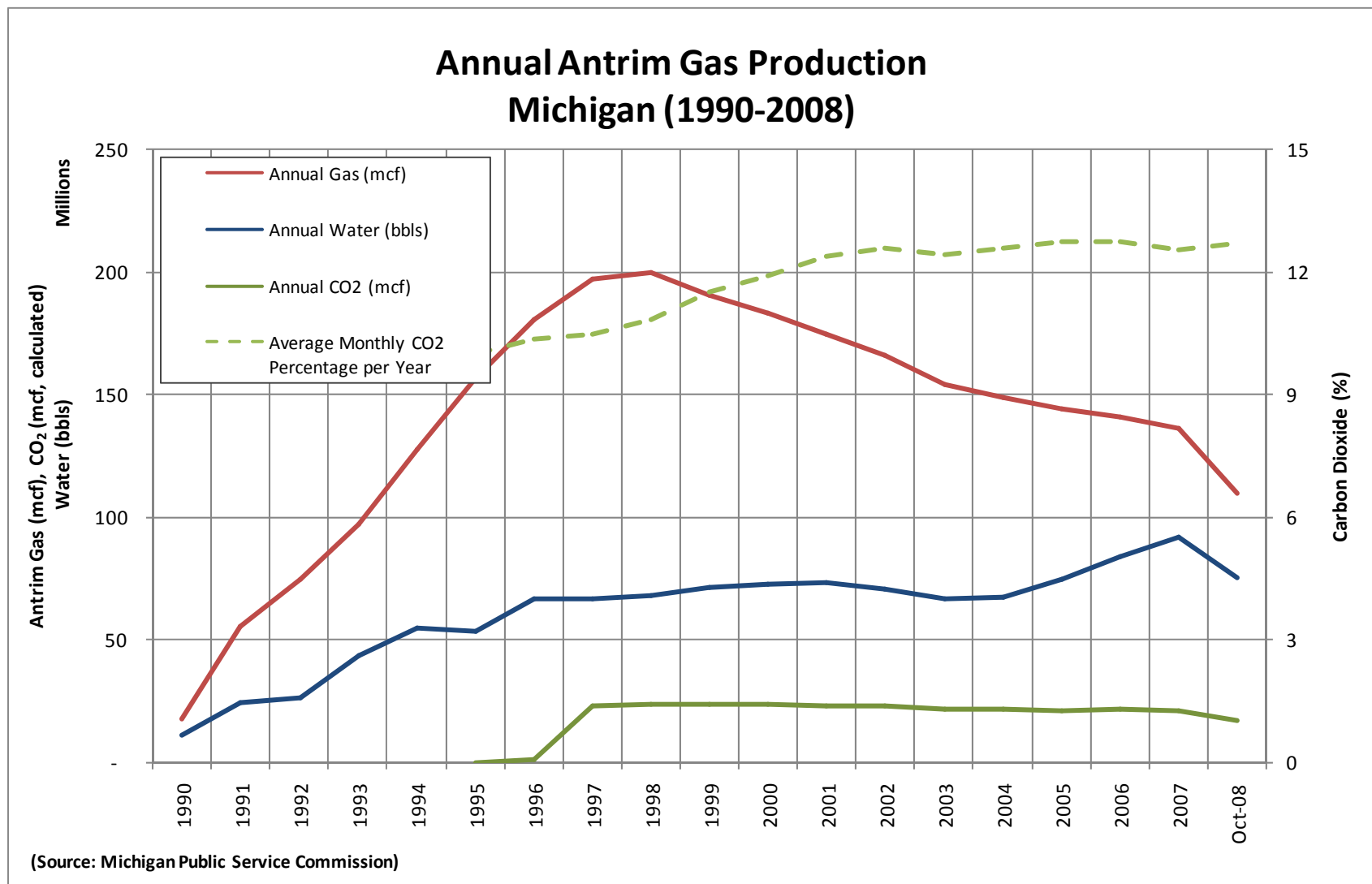
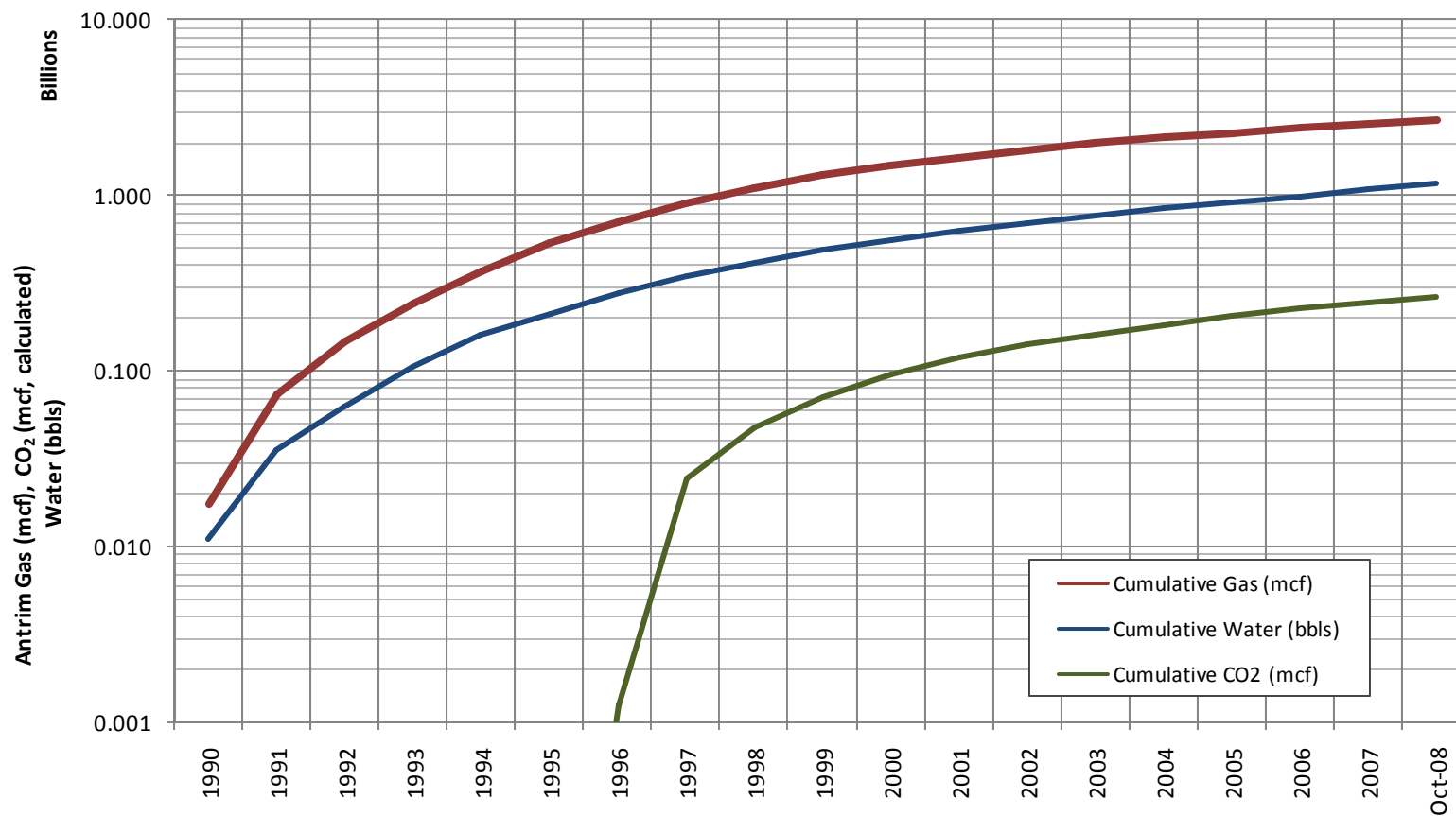


Figure 9-3. Annual Antrim gas (mcf), CO₂ (mcf), and water (bbls) production in Michigan from 1990 through October 2008.

Cumulative Antrim Gas Production Michigan (1990-2008)



(Source: Michigan Public Service Commission)

Figure 9-4. Cumulative Antrim gas (mcf), CO₂ (mcf), and water (bbls) production in Michigan from 1990 through October 2008.

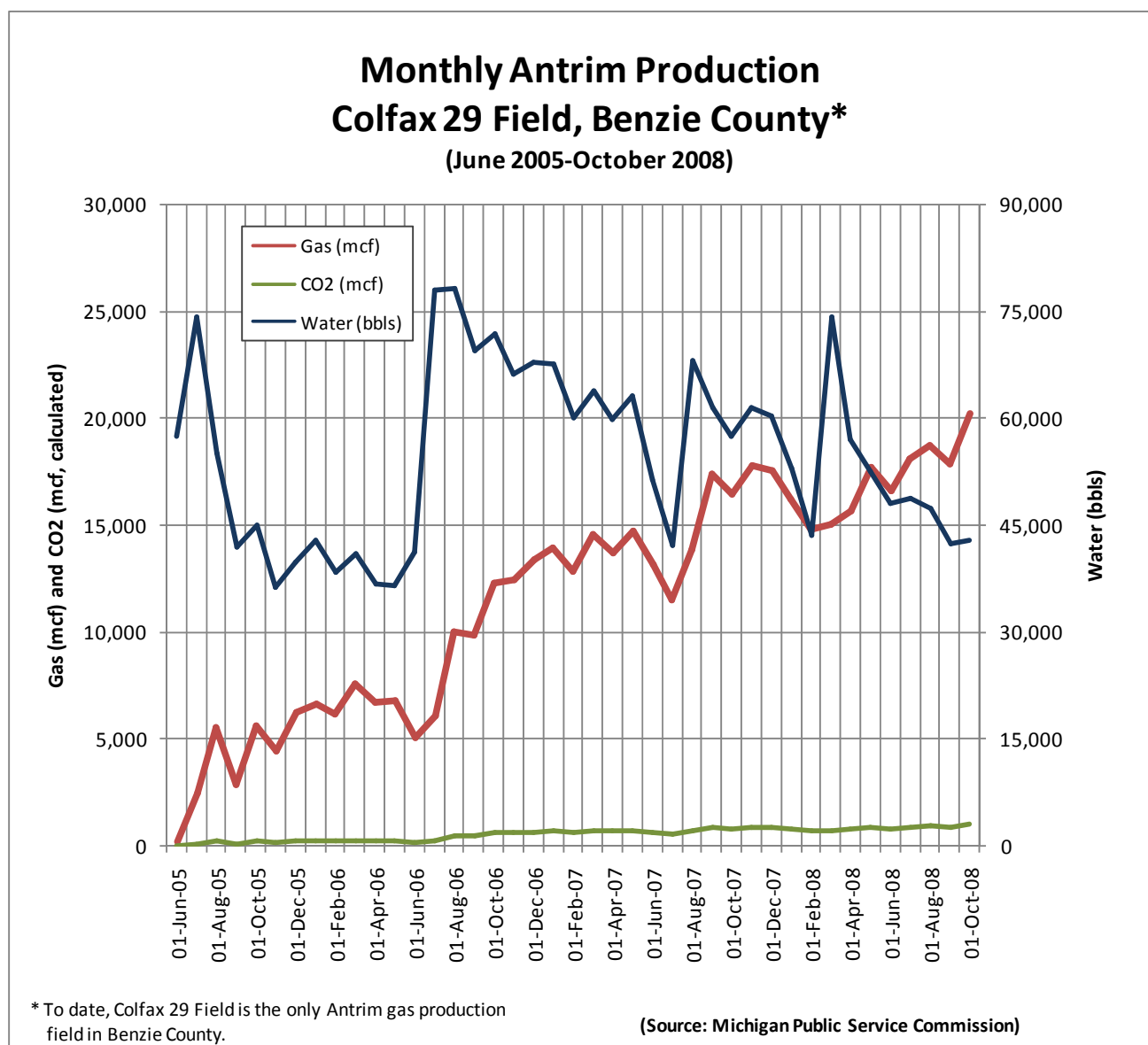


Figure 9-5. Monthly Antrim gas (mcf), CO₂ (mcf), and water (bbls) production from the Colfax 29 Field in Benzie County, Michigan from June 2005 through October 2008.

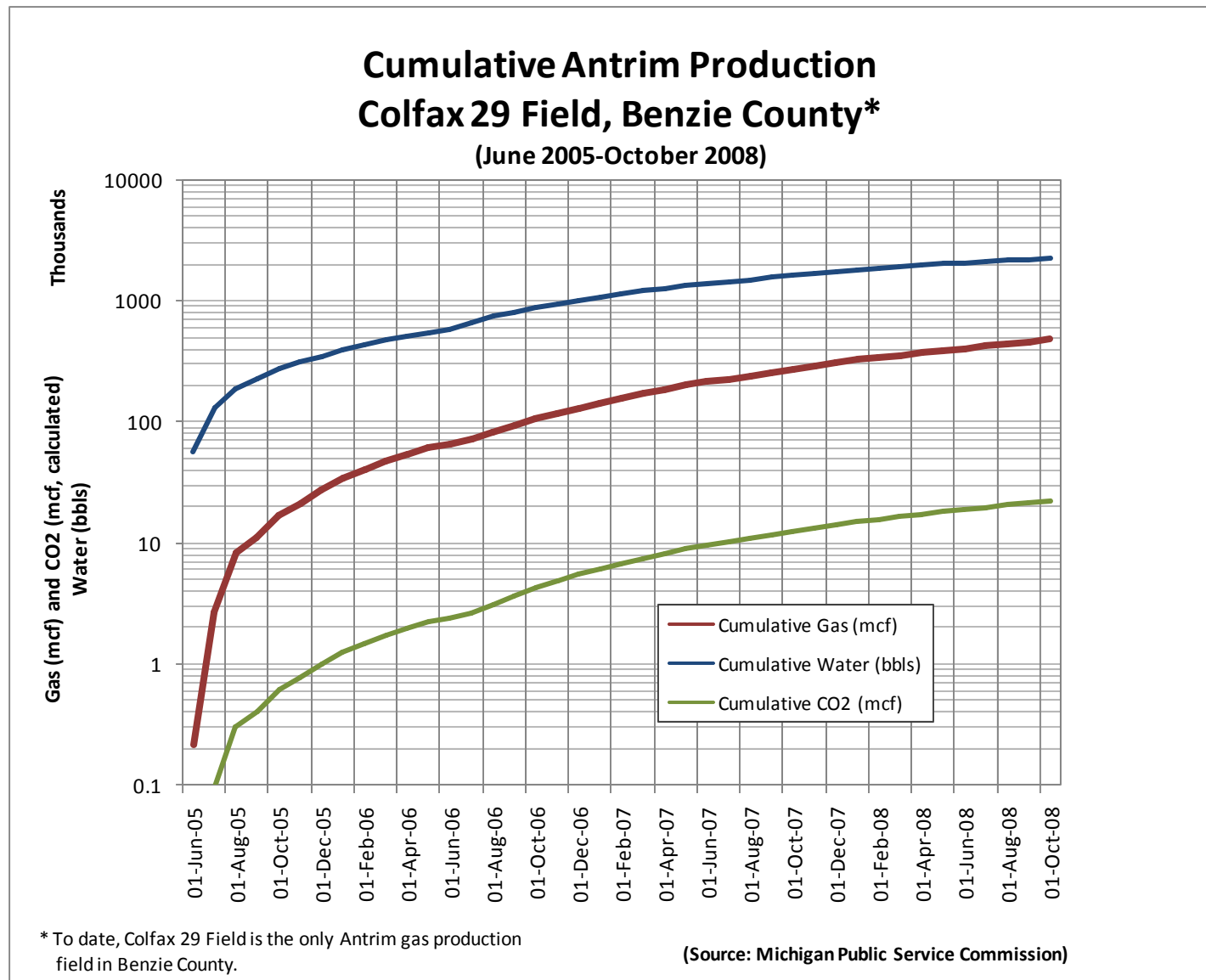


Figure 9-6. Cumulative Antrim gas (mcf), CO₂ (mcf), and water (bbls) production from the Colfax 29 Field in Benzie County, Michigan from June 2005 through October 2008.

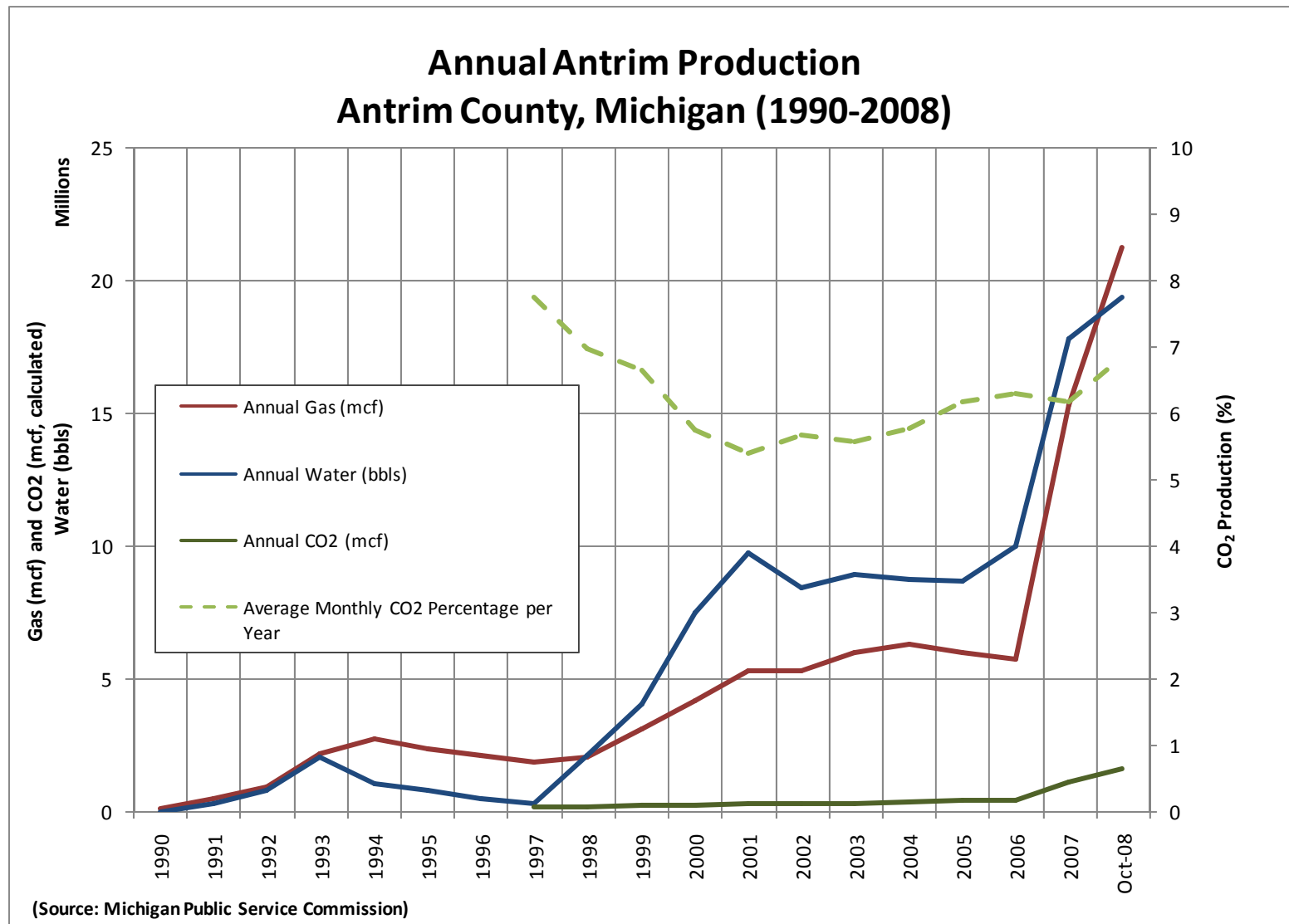


Figure 9-7. Annual Antrim gas (mcf), CO2 (mcf), and water (bbls) production from Antrim County, Michigan from 1990 through October 2008.

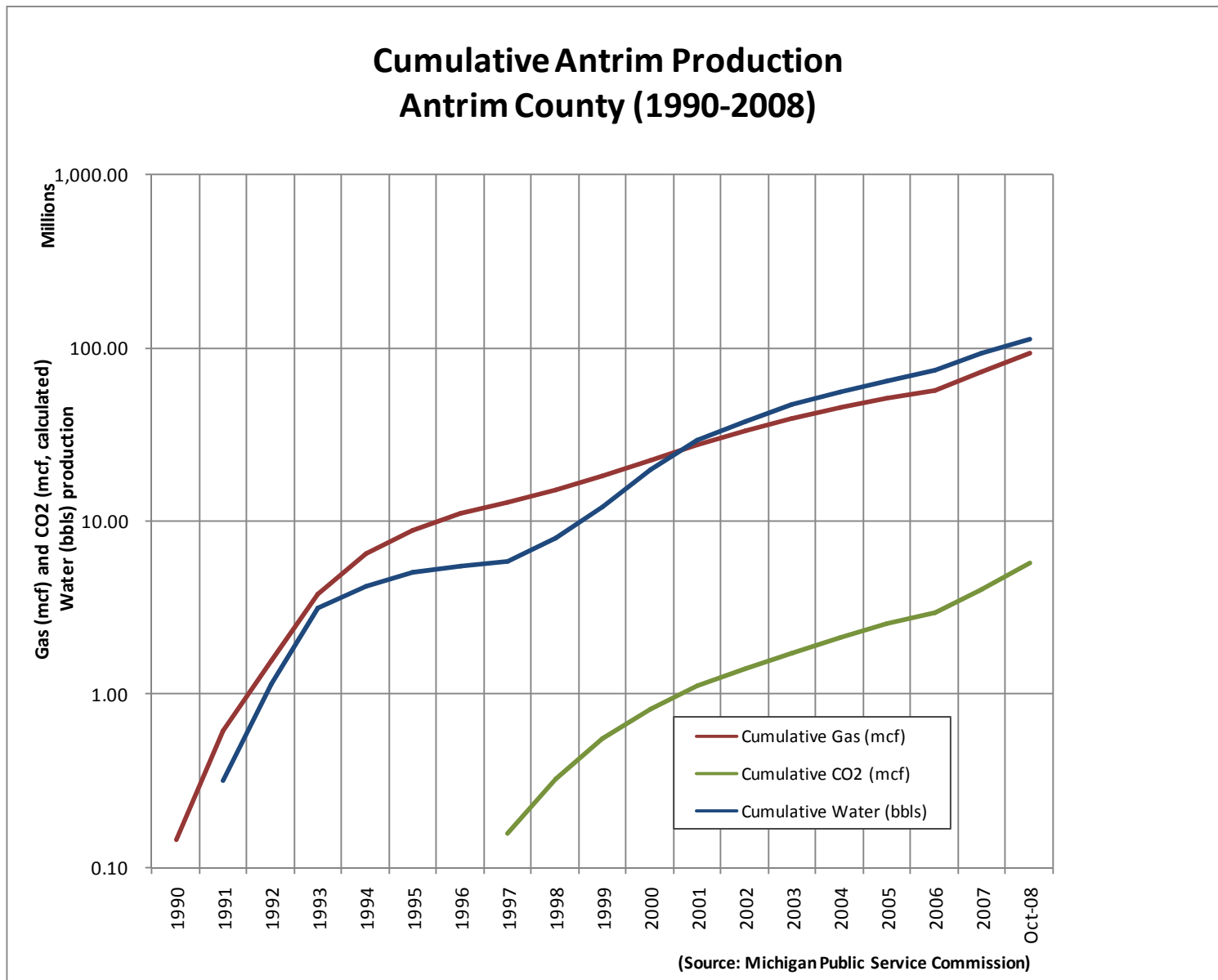


Figure 9-8. Cumulative Antrim gas (mcf), CO₂ (mcf), and water (bbls) production from Antrim County, Michigan from 1990 through October 2008.

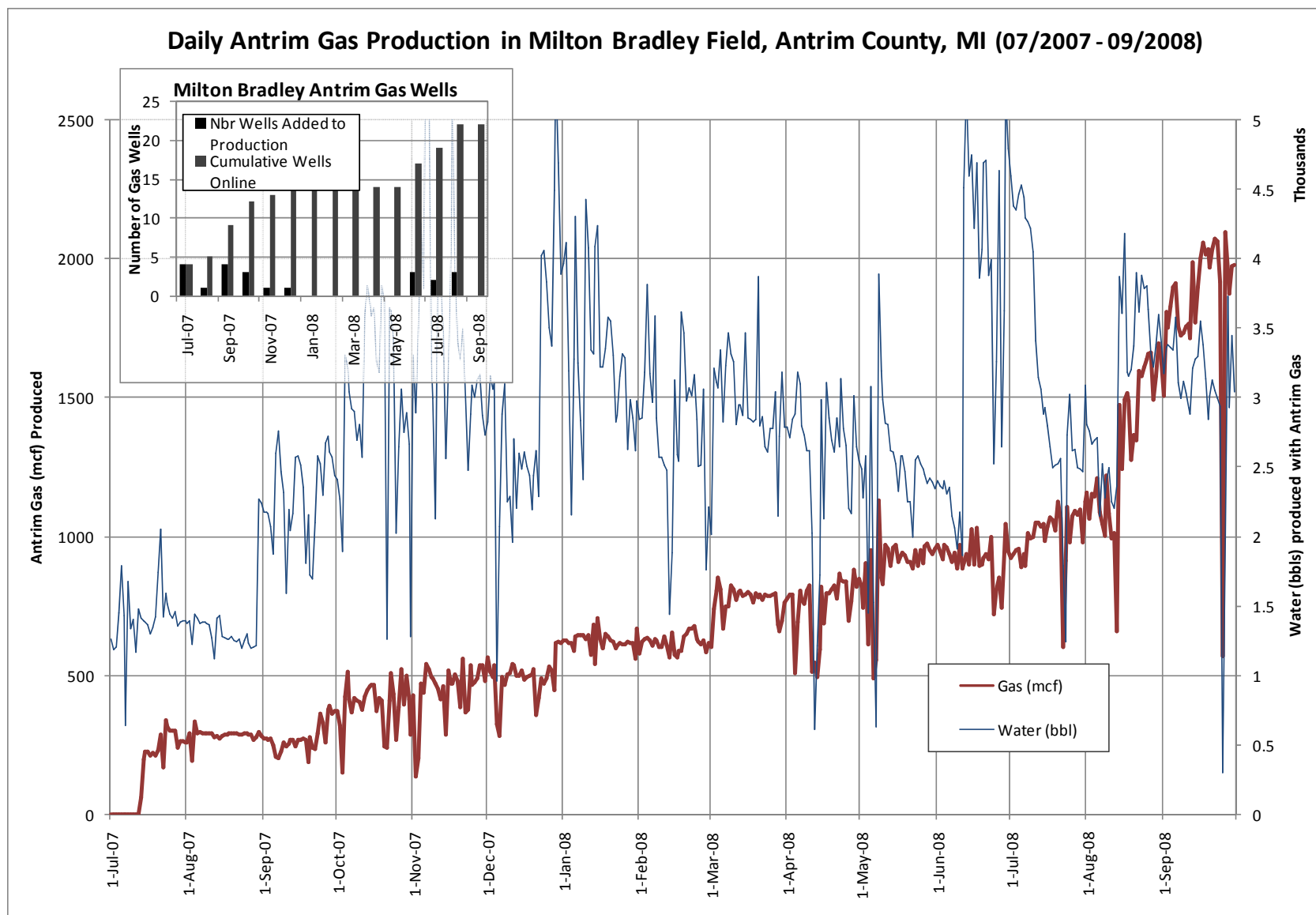


Figure 9-9. Daily Antrim gas (mcf) and water (bbls) production from the Milton Bradley Field in Antrim County, Michigan from July 2007 through September 2008.

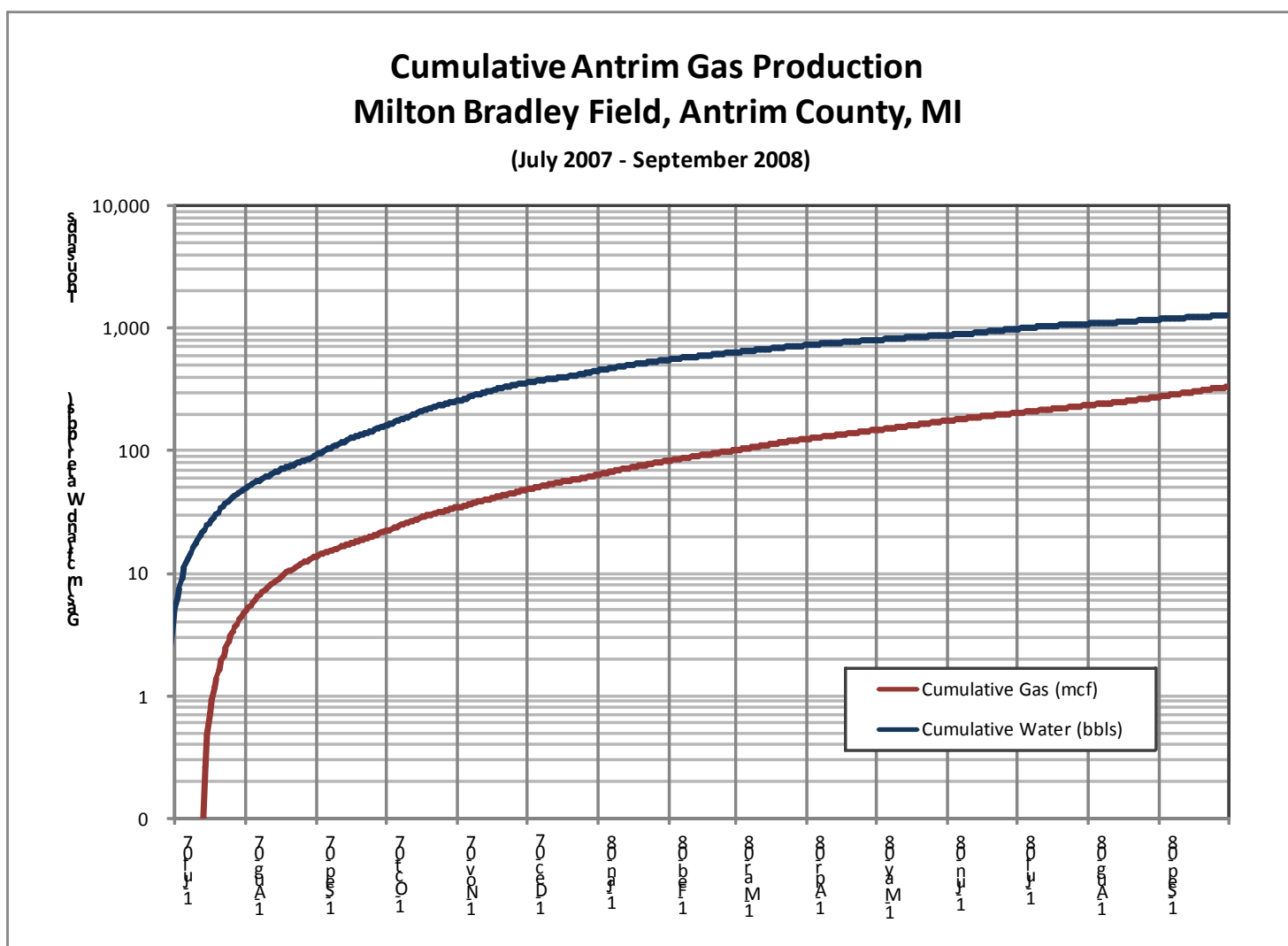


Figure 9-10. Cumulative Antrim gas (mcf) and water (bbls) production from the Milton Bradley Field in Antrim County, Michigan from July 2007 through September 2008.

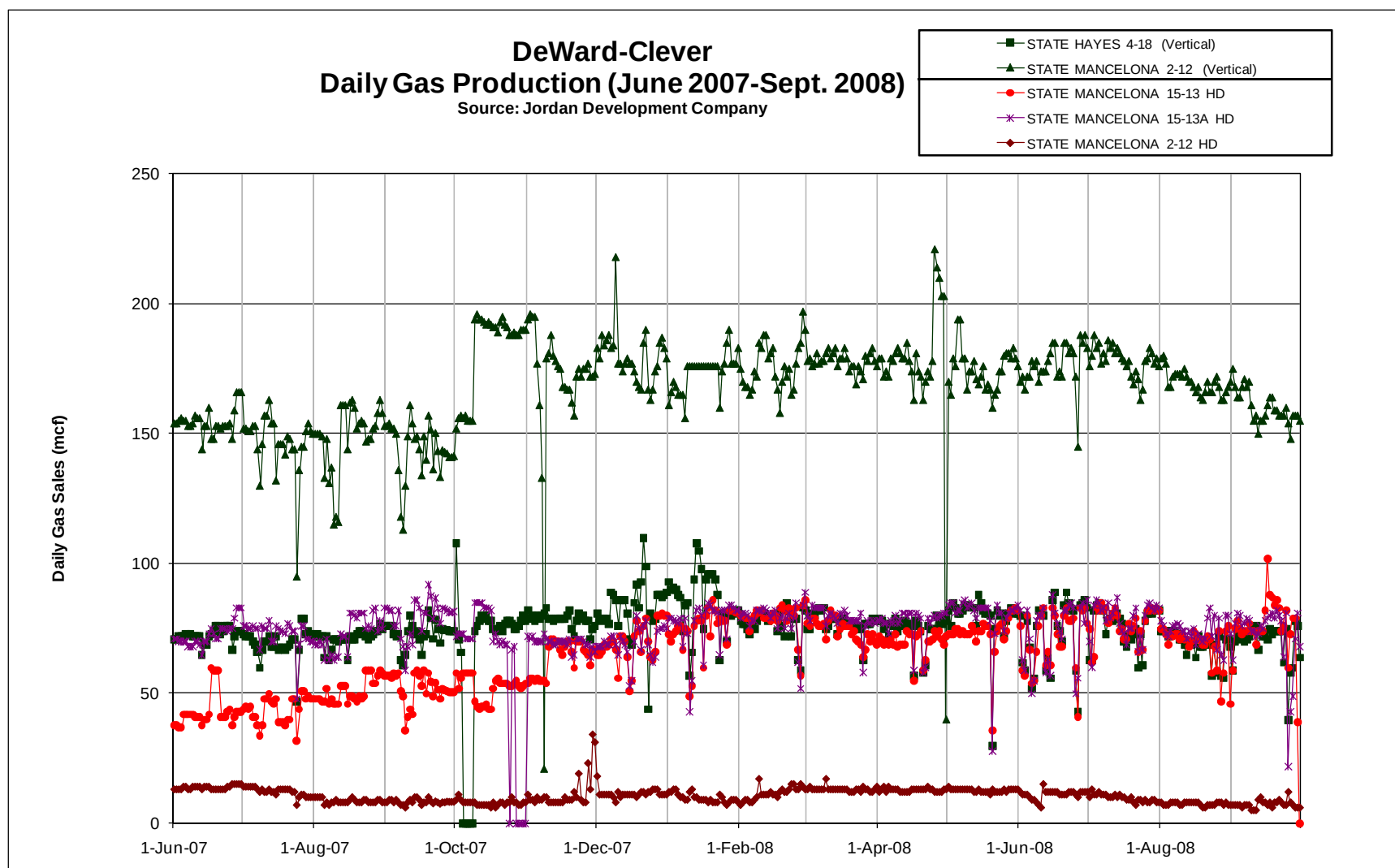


Figure 9-11. Daily Antrim gas (mcf) production by well from the DeWard Cleaver Field in Antrim County, Michigan from June 2007 through September 2008.

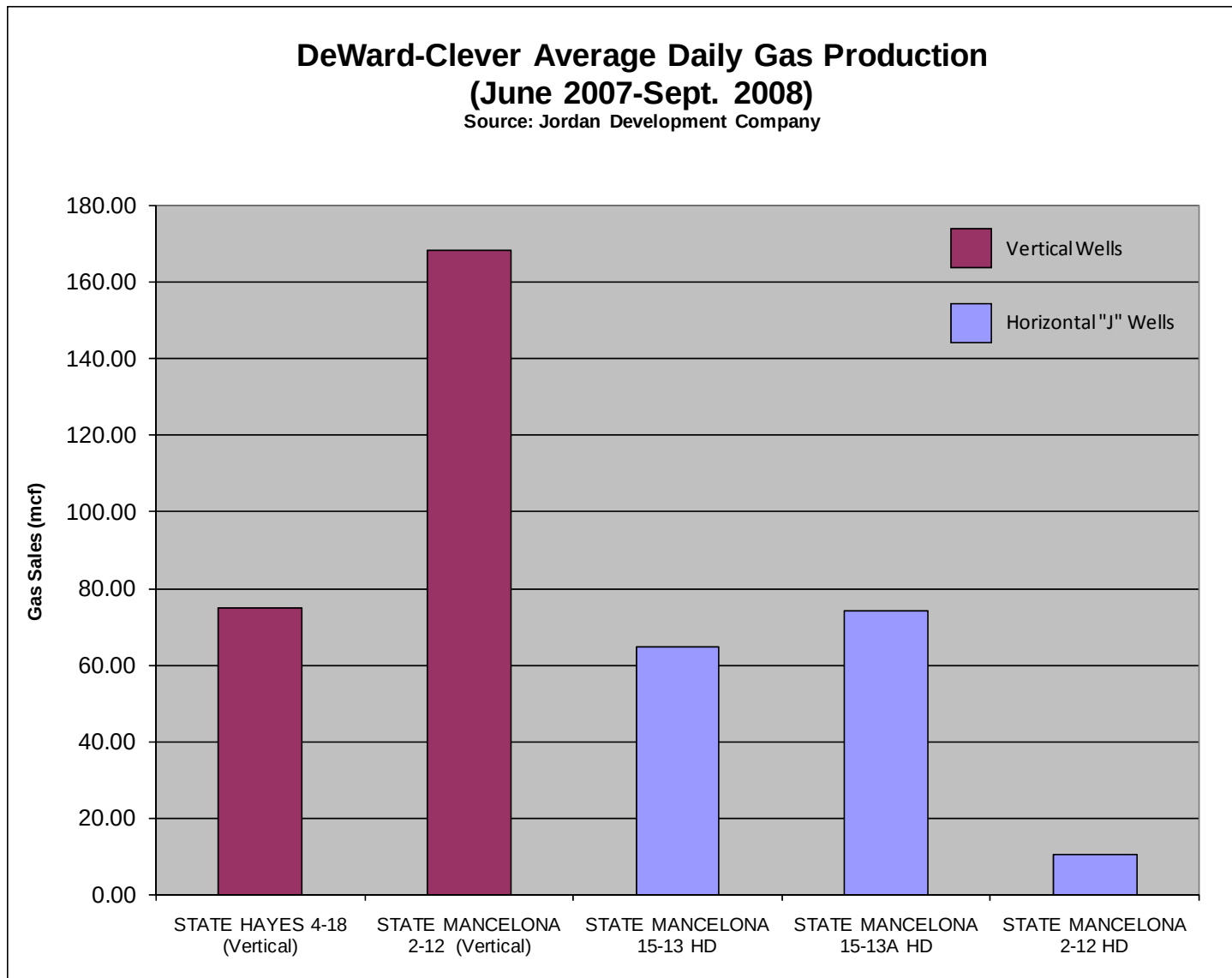


Figure 9-12. Comparison of total Antrim gas (mcf) production by well from the Deward Cleaver Field in Antrim County, Michigan from June 2007 through September 2008. Production from the vertical wells is significantly higher than the horizontal wells with the “J” well configuration in the same field.

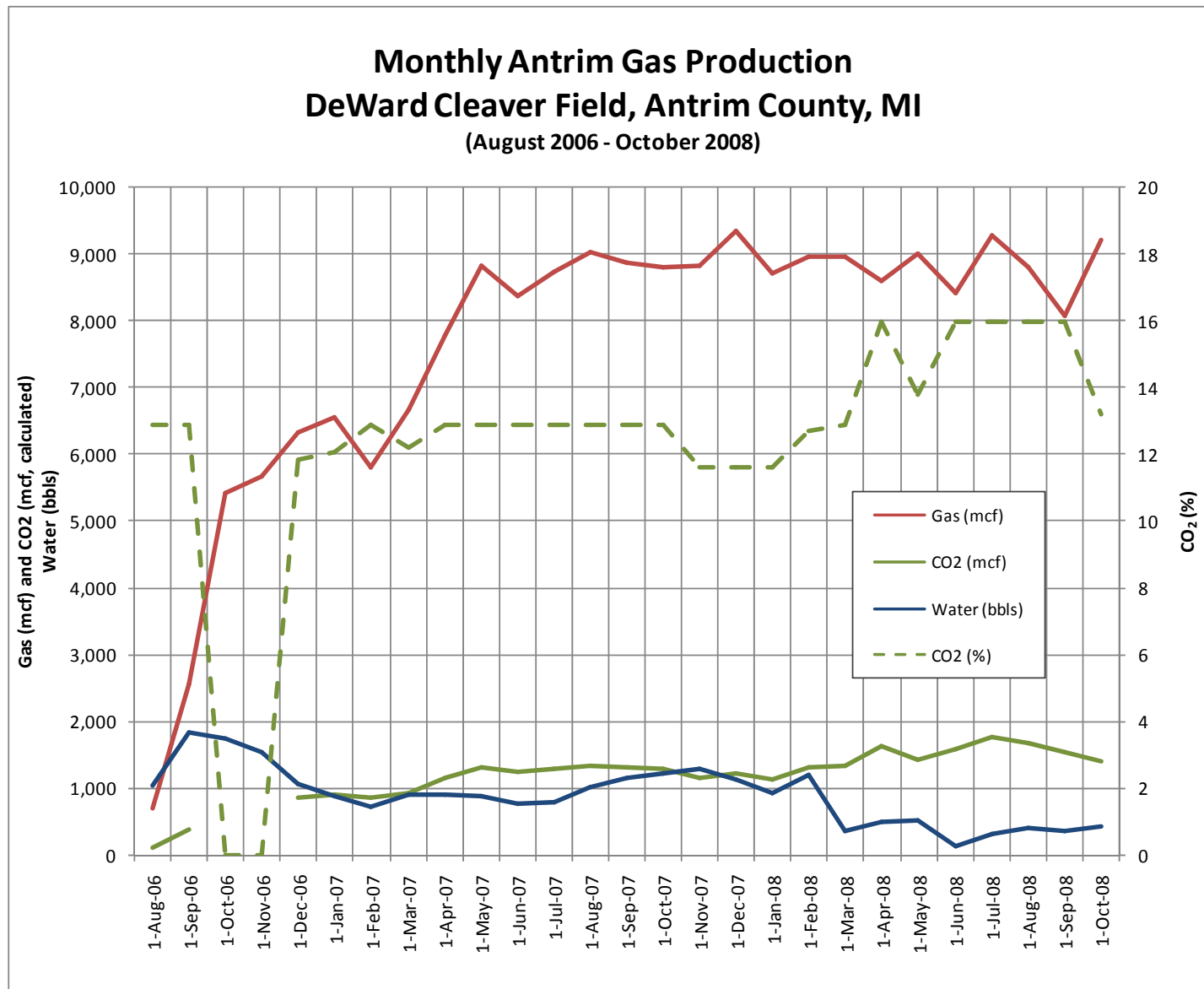


Figure 9-13. Monthly Antrim gas (mcf), CO₂ (mcf), and water (bbls) production from the DeWard-Cleaver Field in Antrim County, Michigan from August 2006 through October 2008.

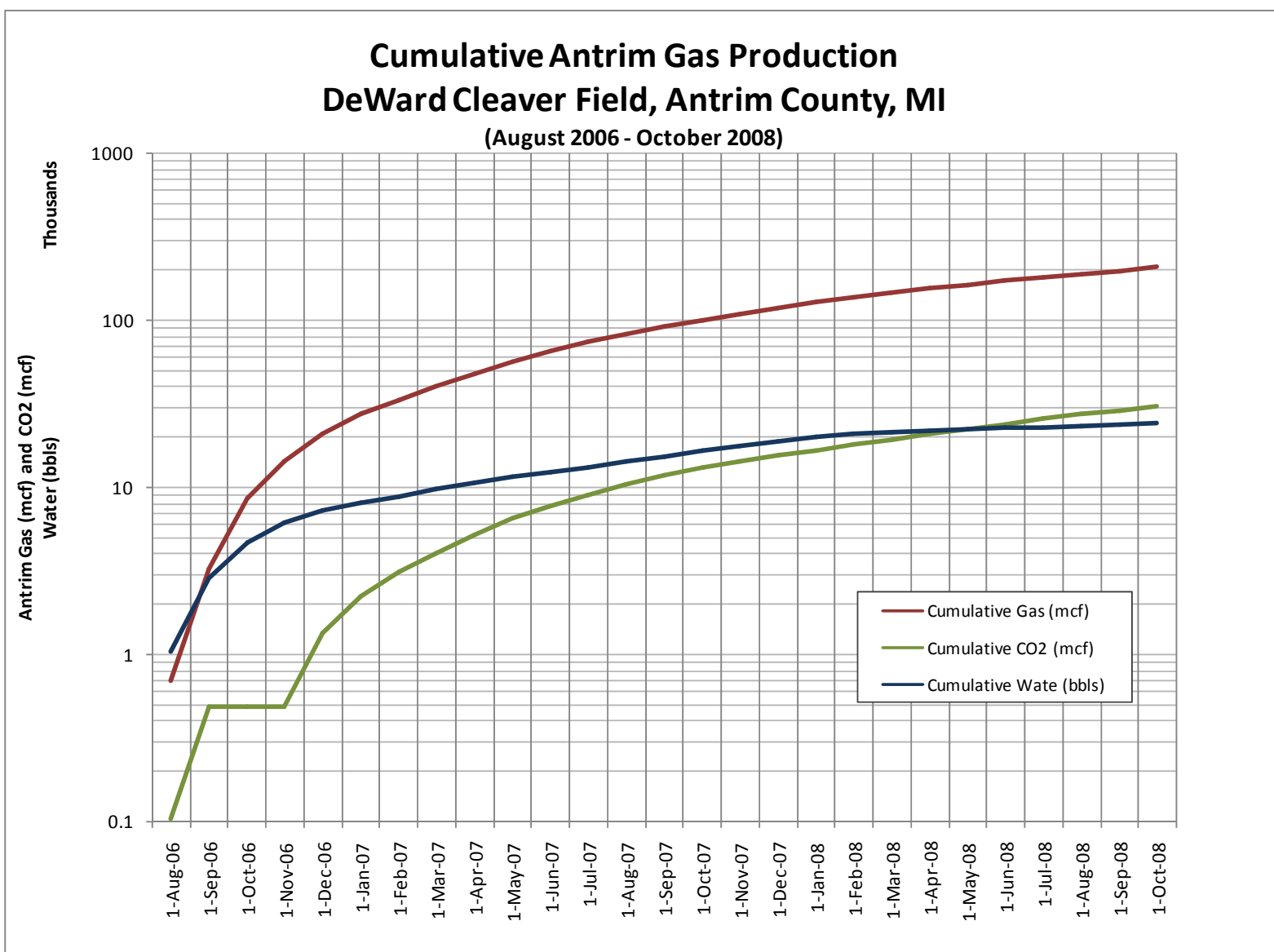


Figure 9-14. Cumulative Antrim gas (mcf), CO₂ (mcf), and water (bbls) production from the DeWard-Cleaver Field in Antrim County, Michigan from August 2006 through October 2008.

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 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.

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.

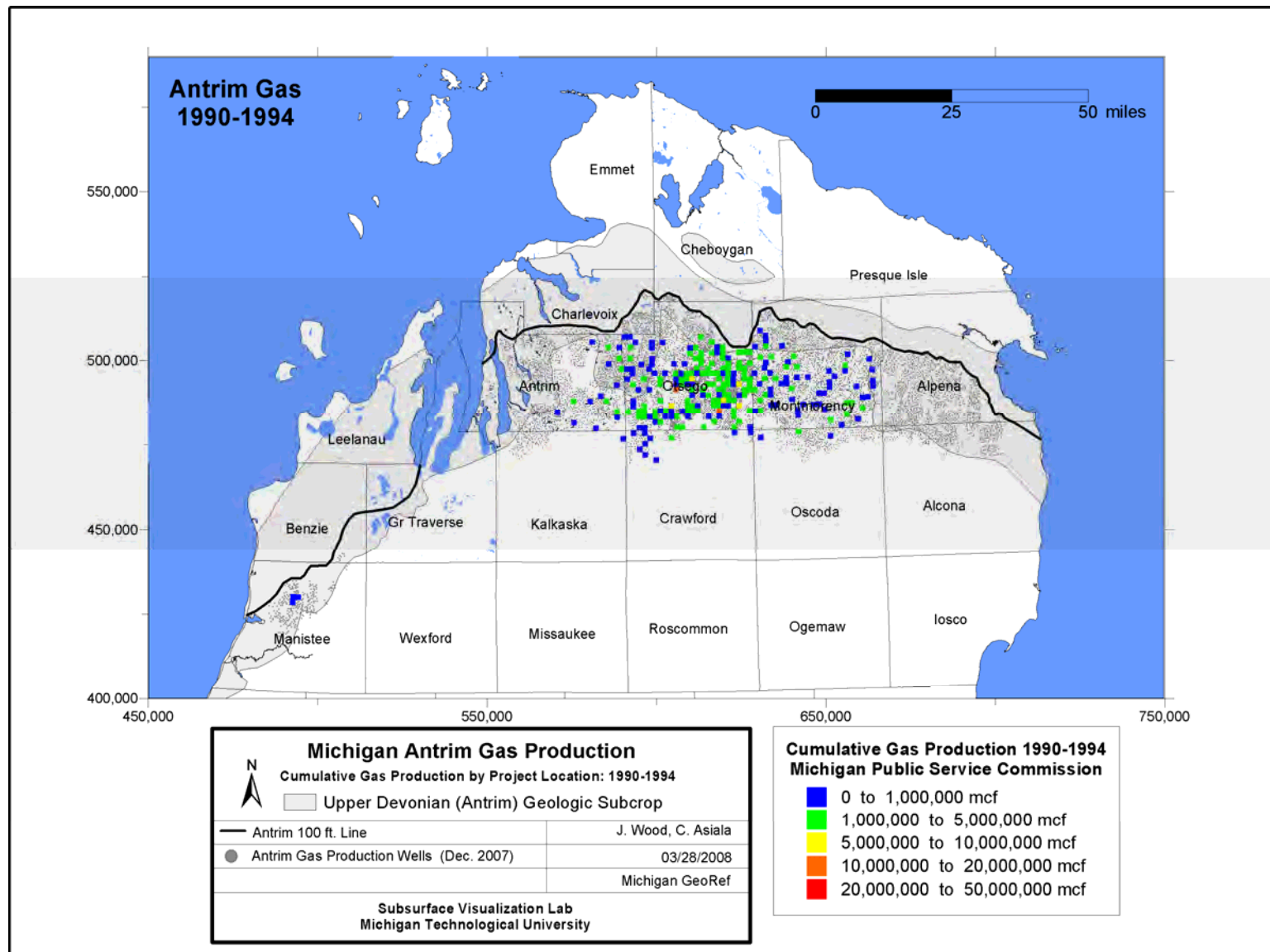


Figure 9-15. Cumulative Antrim gas (mcf) production by Section-Township-Range location from 1990 through 1994. Colored blocks represent the sum of gas produced by Section. Production is included with the Section totals where most of Production Unit's wells are located.

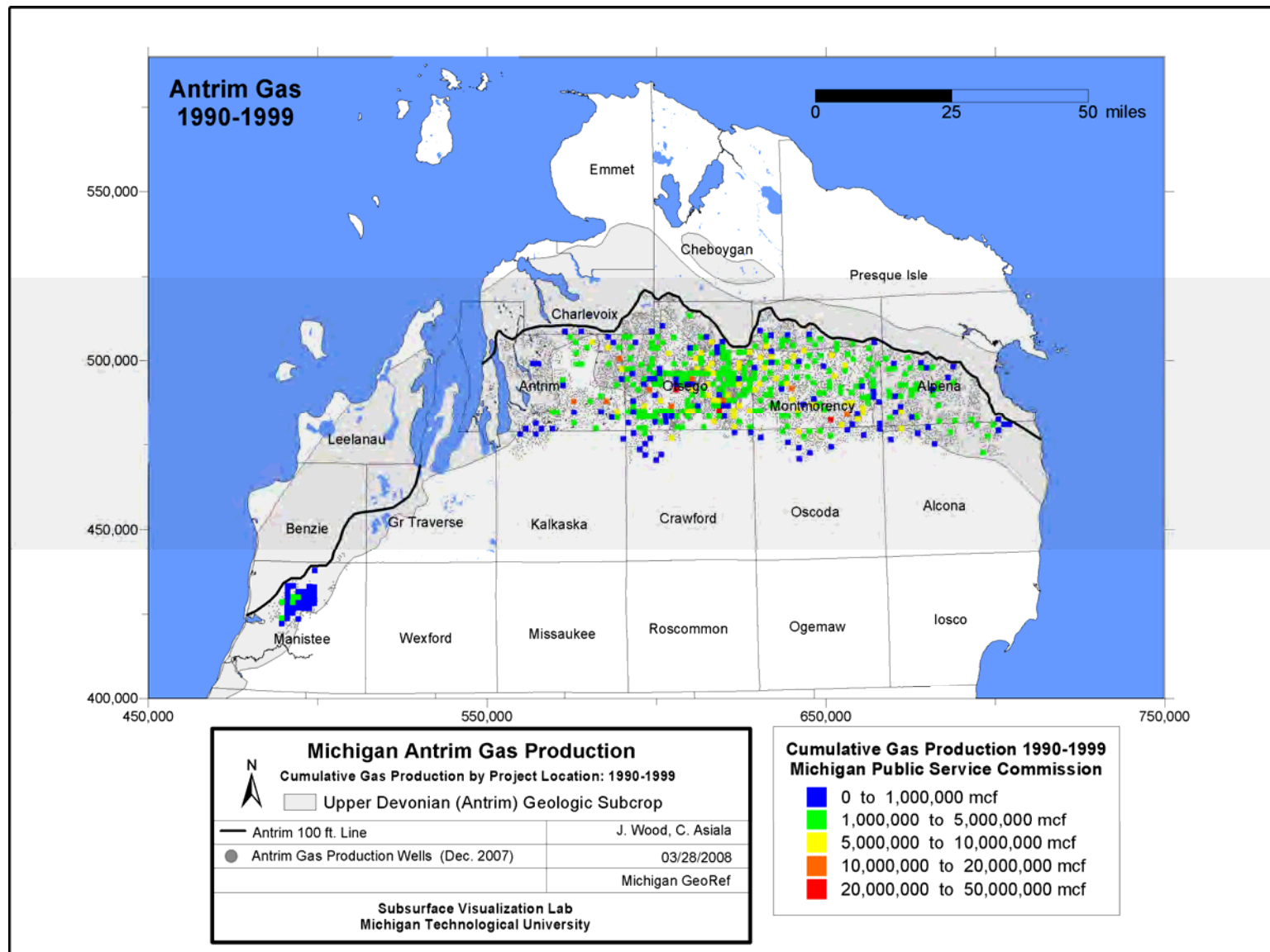


Figure 9-16. Cumulative Antrim gas (mcf) production by Section-Township-Range location from 1990 through 1999. Colored blocks represent the sum of gas produced by Section. Production is included with the Section totals where most of Production Unit's wells are located.

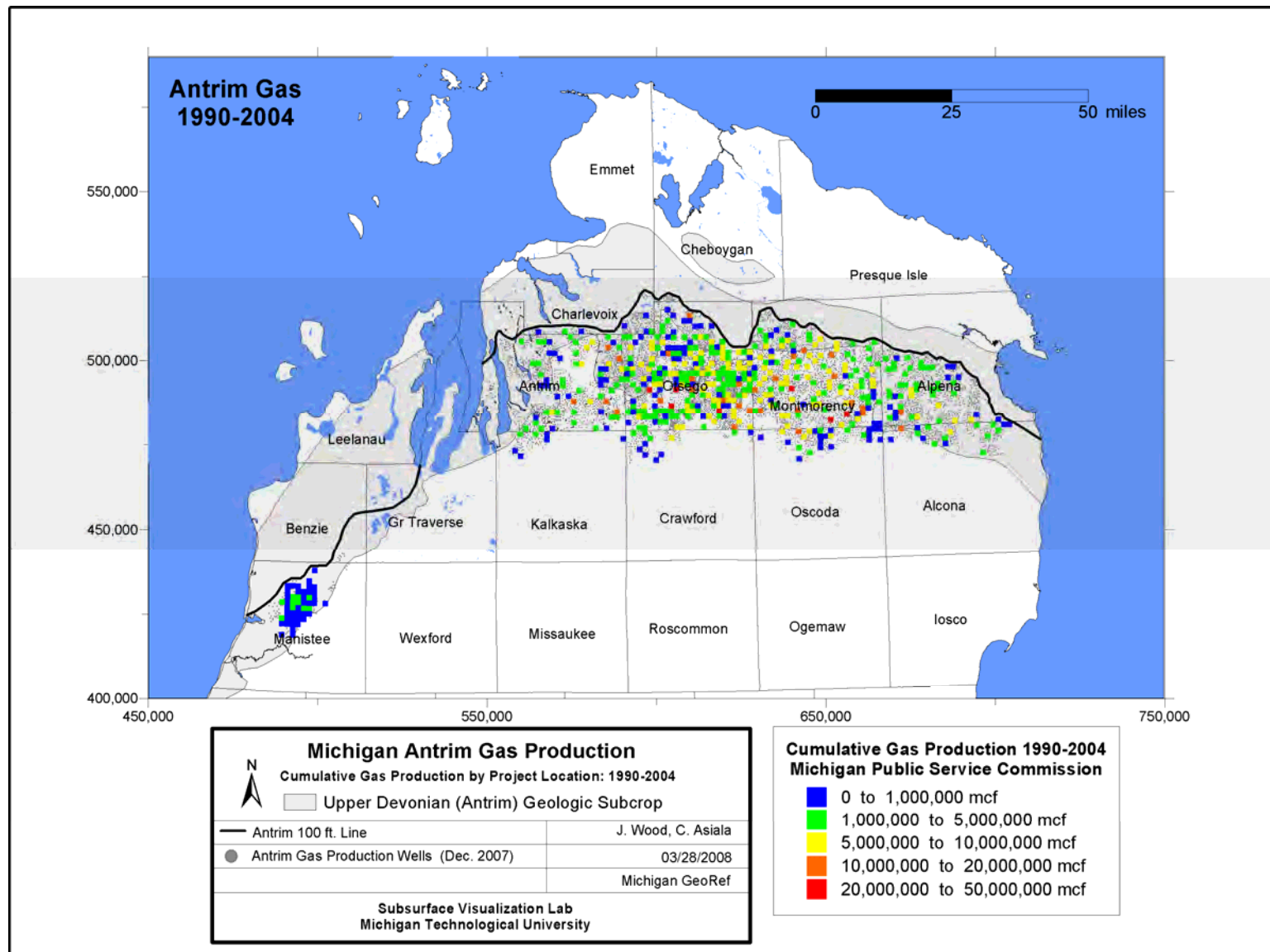


Figure 9-17. Cumulative Antrim gas (mcf) production by Section-Township-Range location from 1990 through 2004. Colored blocks represent the sum of gas produced by Section. Production is included with the Section totals where most of Production Unit's wells are located.

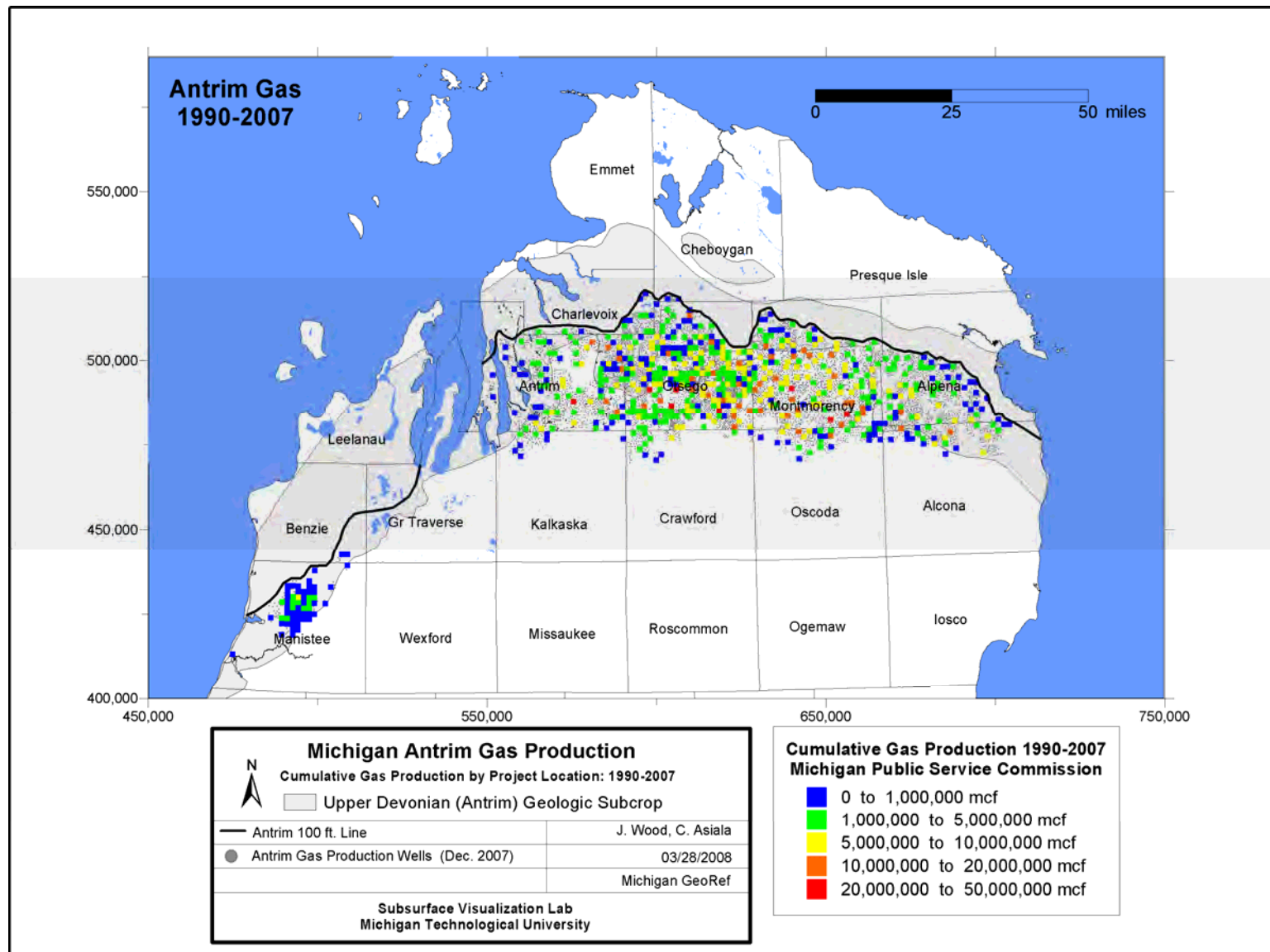


Figure 9-18. Cumulative Antrim gas (mcf) production by Section-Township-Range location from 1990 through 2007. Colored blocks represent the sum of gas produced by Section. Production is included with the Section totals where most of Production Unit's wells are located.

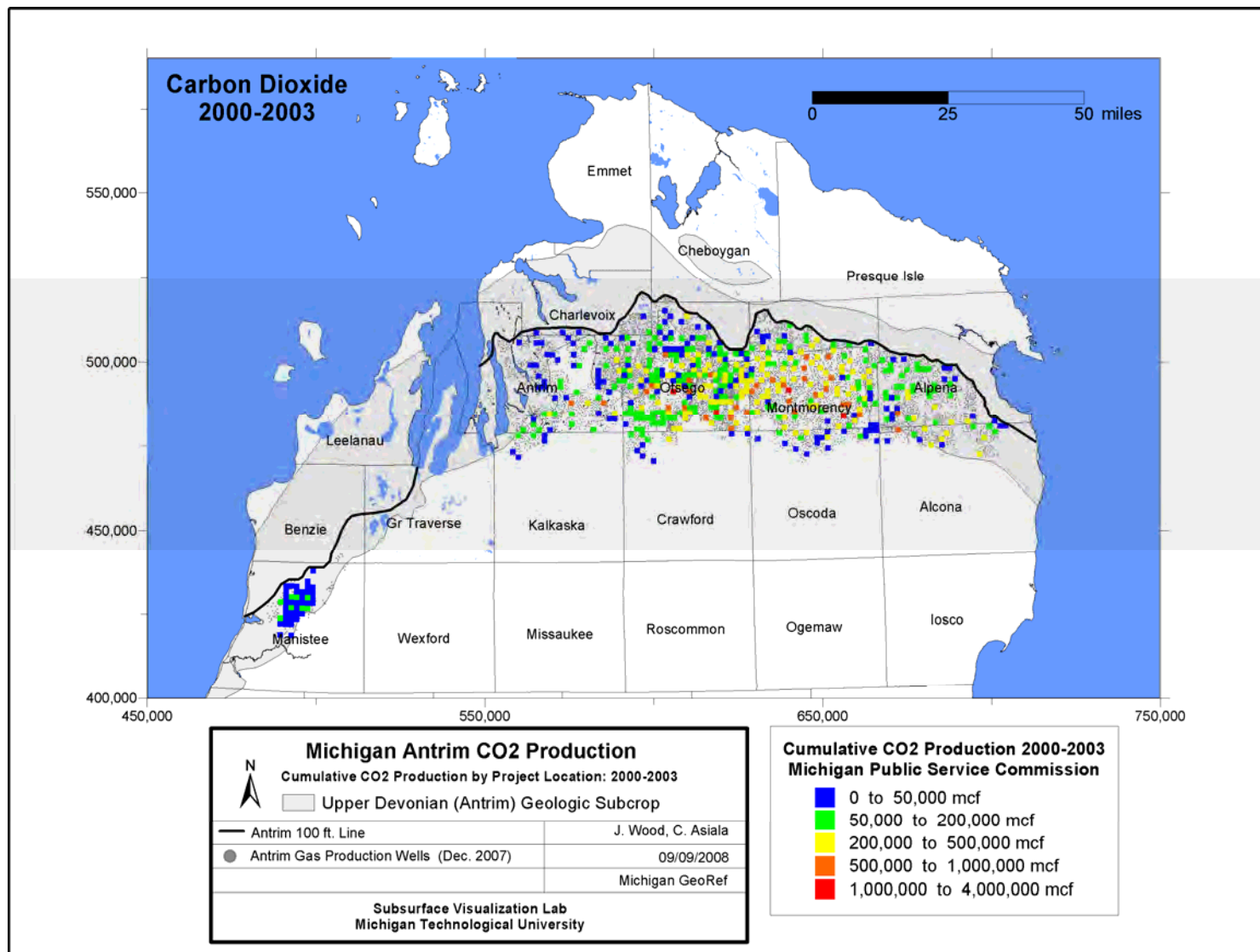


Figure 9-19. Cumulative Antrim co-produced CO₂ production by Section-Township-Range location from 2000 through 2003. Colored blocks represent the sum of CO₂ (mcf) produced by Section. Production is included with the Section totals where most of Production Unit's wells are located.

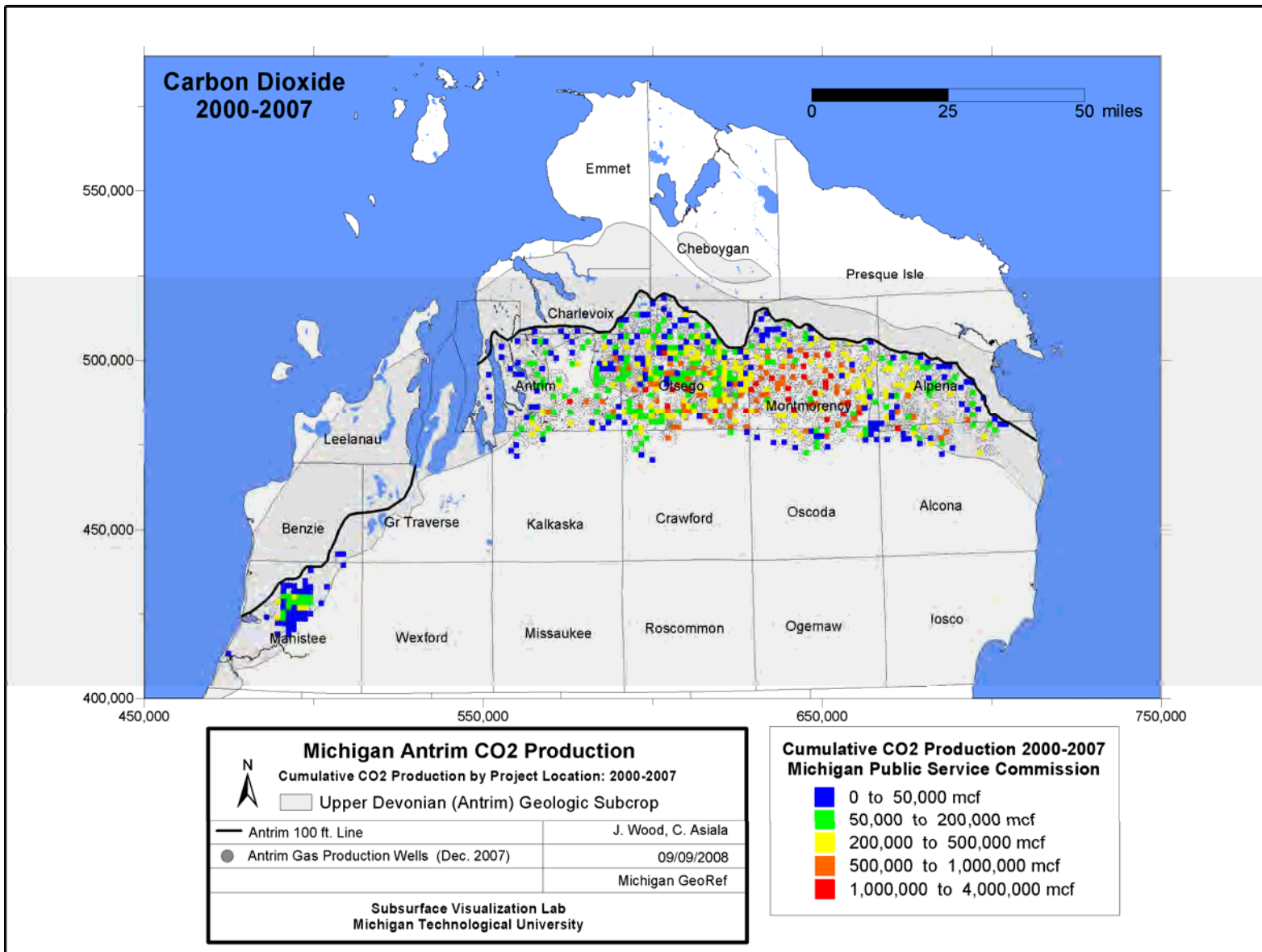


Figure 9-20. Cumulative Antrim co-produced CO₂ production by Section-Township-Range location from 2000 through 2007. Colored blocks represent the sum of CO₂ (mcf) produced by Section. Production is included with the Section totals where most of Production Unit's wells are located.

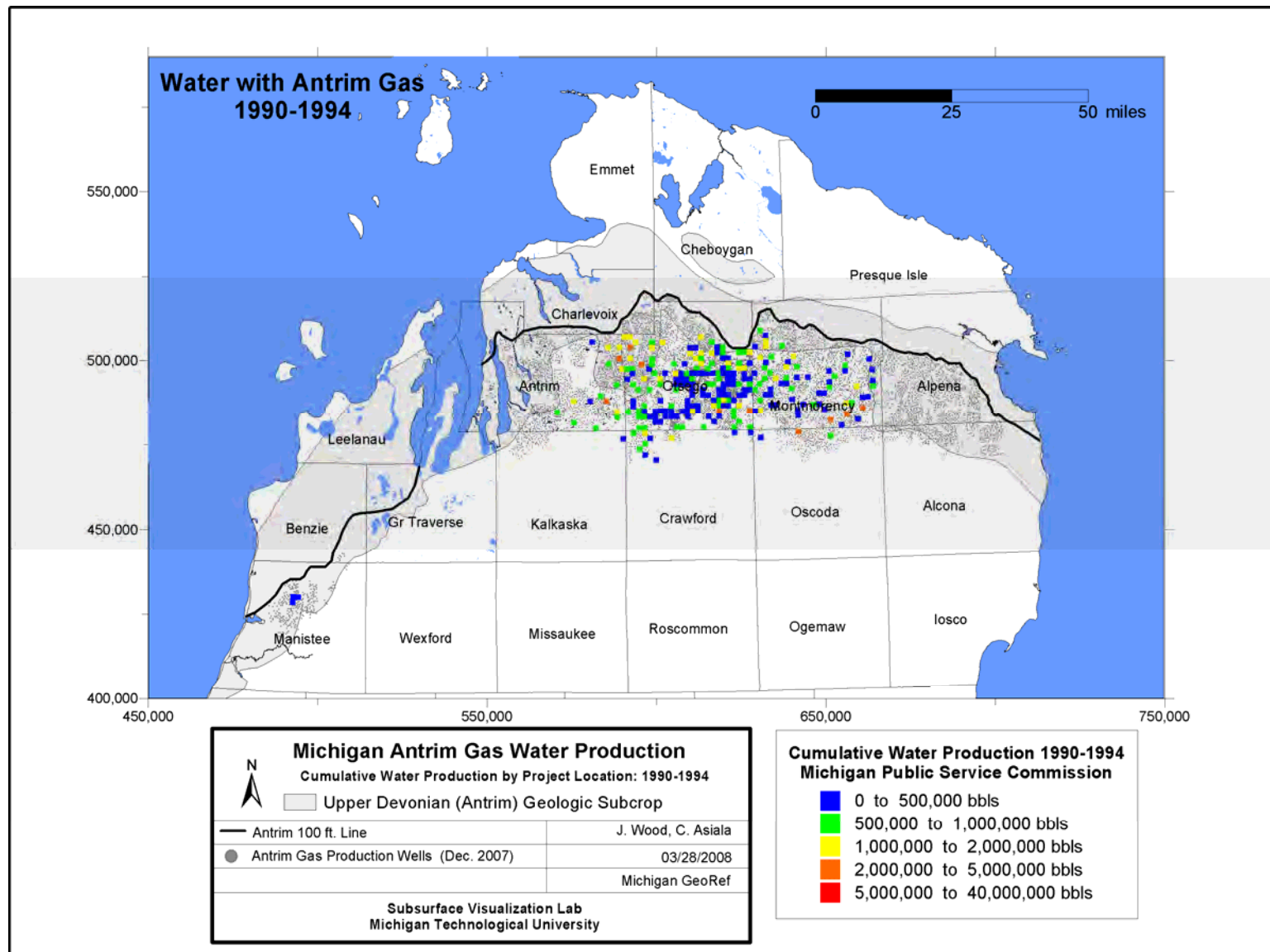


Figure 9-21. Cumulative Antrim co-produced water production by Section-Township-Range location from 1990 through 1994. Colored blocks represent the sum of water (bbls) produced by Section. Production is included with the Section totals where most of Production Unit's wells are located.

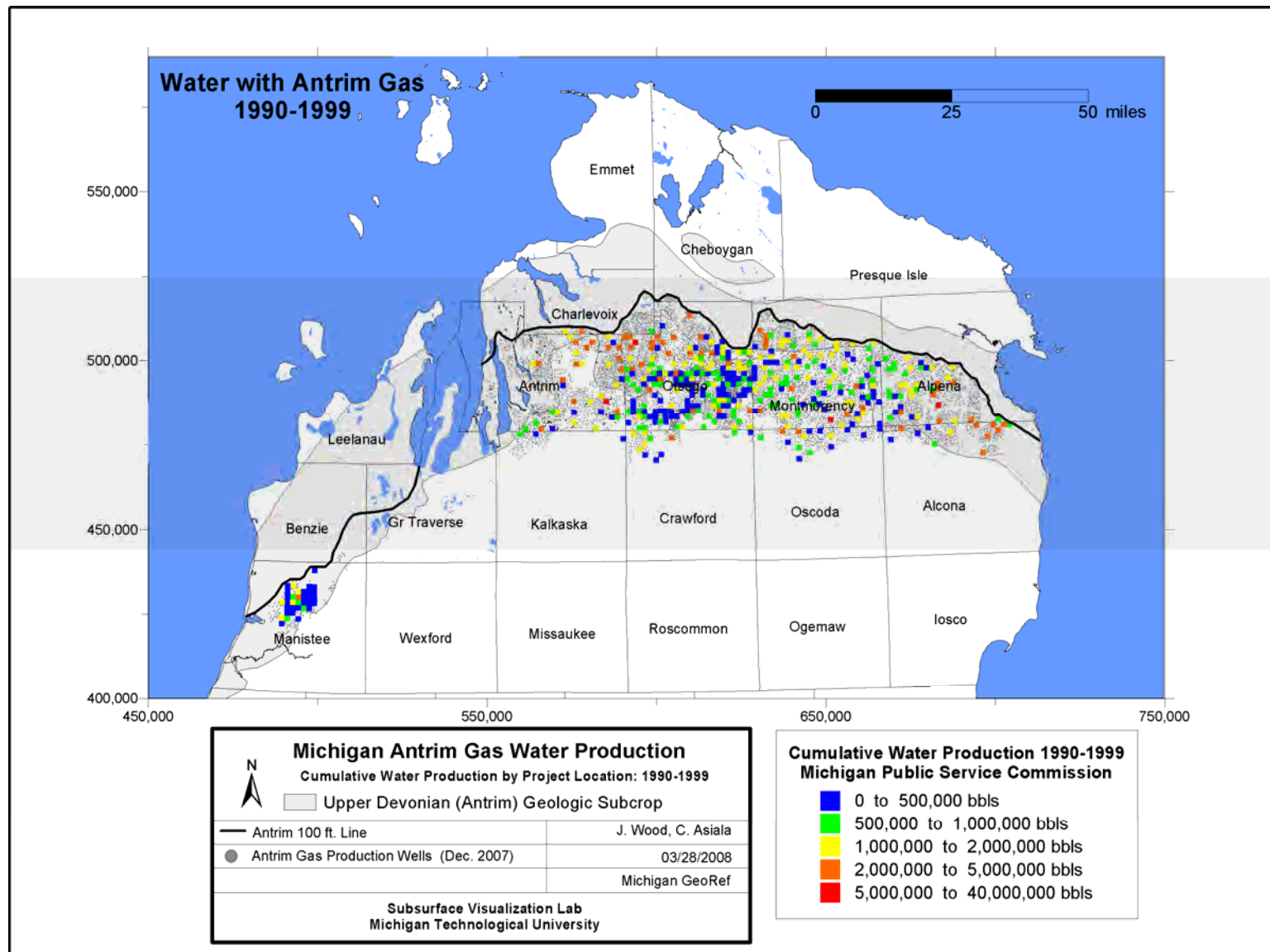


Figure 9-22. Cumulative Antrim co-produced water production by Section-Township-Range location from 1990 through 1999. Colored blocks represent the sum of water (bbls) produced by Section. Production is included with the Section totals where most of Production Unit's wells are located.

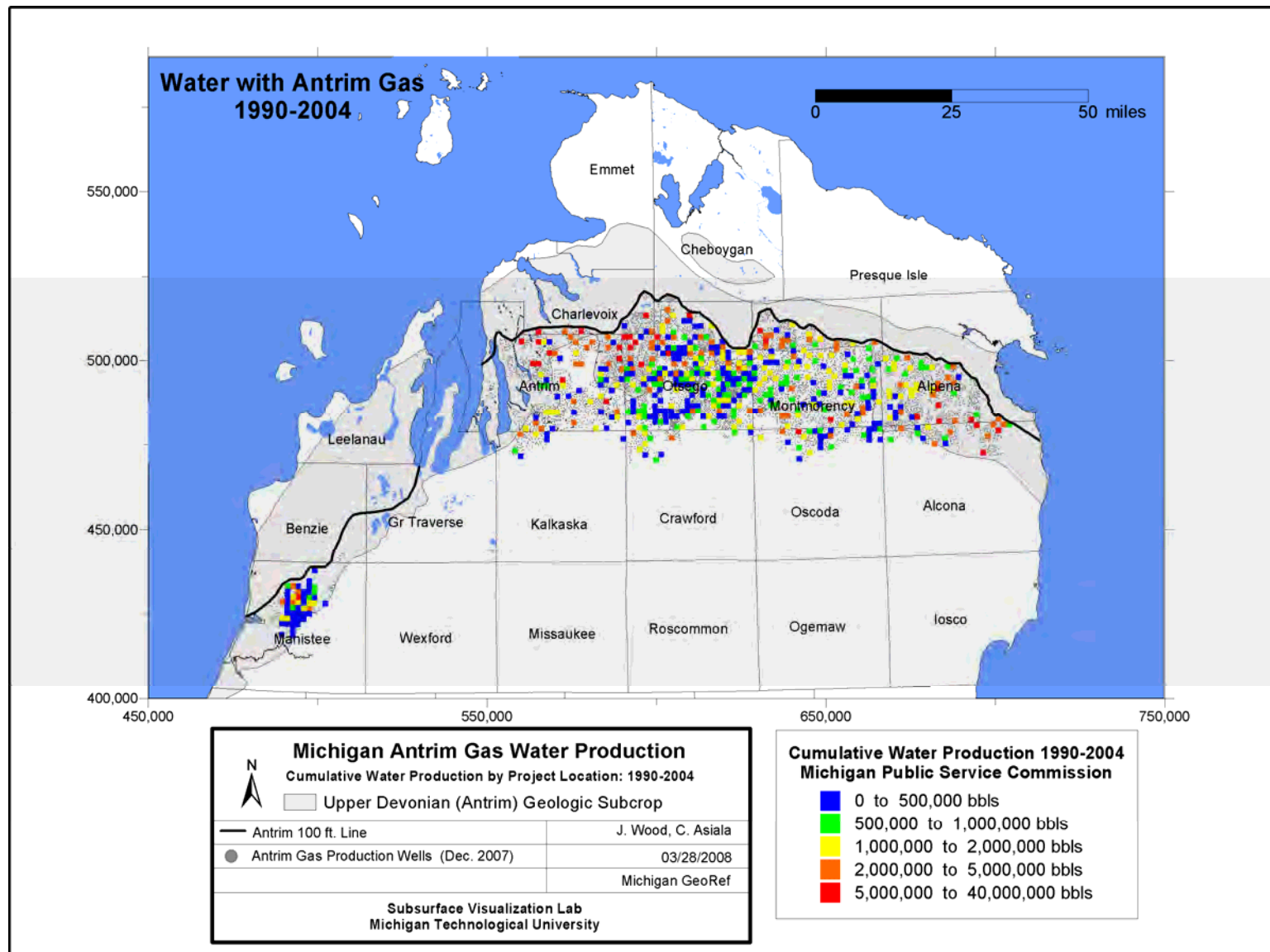


Figure 9-23. Cumulative Antrim co-produced water production by Section-Township-Range location from 1990 through 2004. Colored blocks represent the sum of water (bbls) produced by Section. Production is included with the Section totals where most of Production Unit's wells are located.

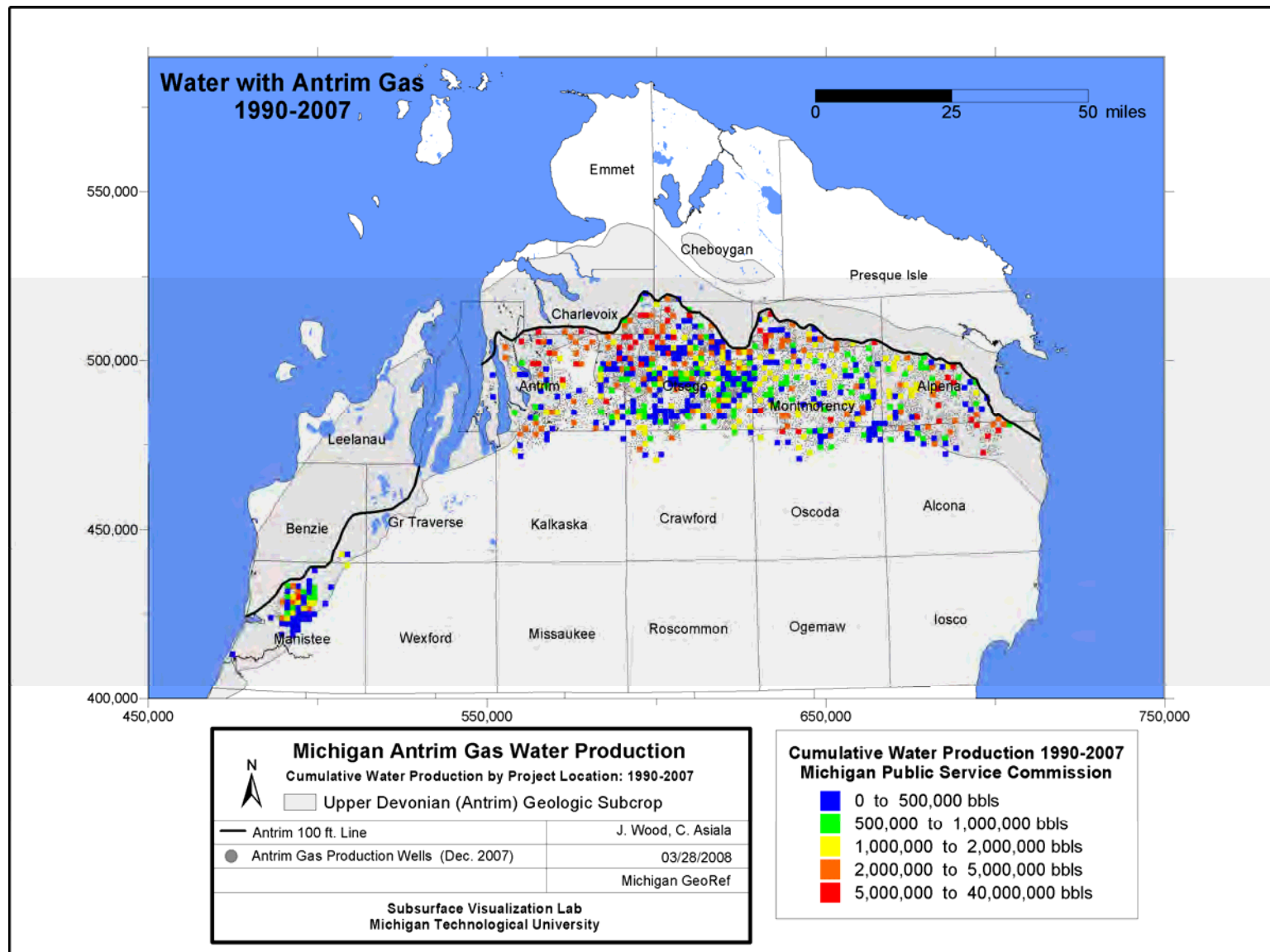


Figure 9-24. Cumulative Antrim co-produced water production by Section-Township-Range location from 1990 through 2007. Colored blocks represent the sum of water (bbls) produced by Section. Production is included with the Section totals where most of Production Unit's wells are located.

10. Project Well Histories – Milton Bradley in Antrim County, MI

Preliminary schematics for planned horizontal well

1.	21-009-58153-0000	AG-A-MING 4-12	Antrim County	Milton-Bradley Project
2.	21-009-57450-0300	State Mancelona #2-12 HD 3	Antrim County	DeWard-Cleaver Project
3.	21-009-57451-0200	State Mancelona #15-13 HD 2	Antrim County	DeWard-Cleaver Project
4.	21-009-57452-0100	State Mancelona #15-13A HD1	Antrim County	DeWard-Cleaver Project
5.	21-009-57452-0200	State Mancelona #15-13A HD2	Antrim County	DeWard-Cleaver Project
6.	21-019-58748-0000	State Colfax #2-28 HD	Benzie County	Colfax 29 Project
7.	21-019-58749-0000	State Colfax #3-28 HD	Benzie County	Colfax 29 Project
8.	21-055-57778-0000	Hubbell C1-9	Grand Traverse Cty	Whitewater Project

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

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

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.

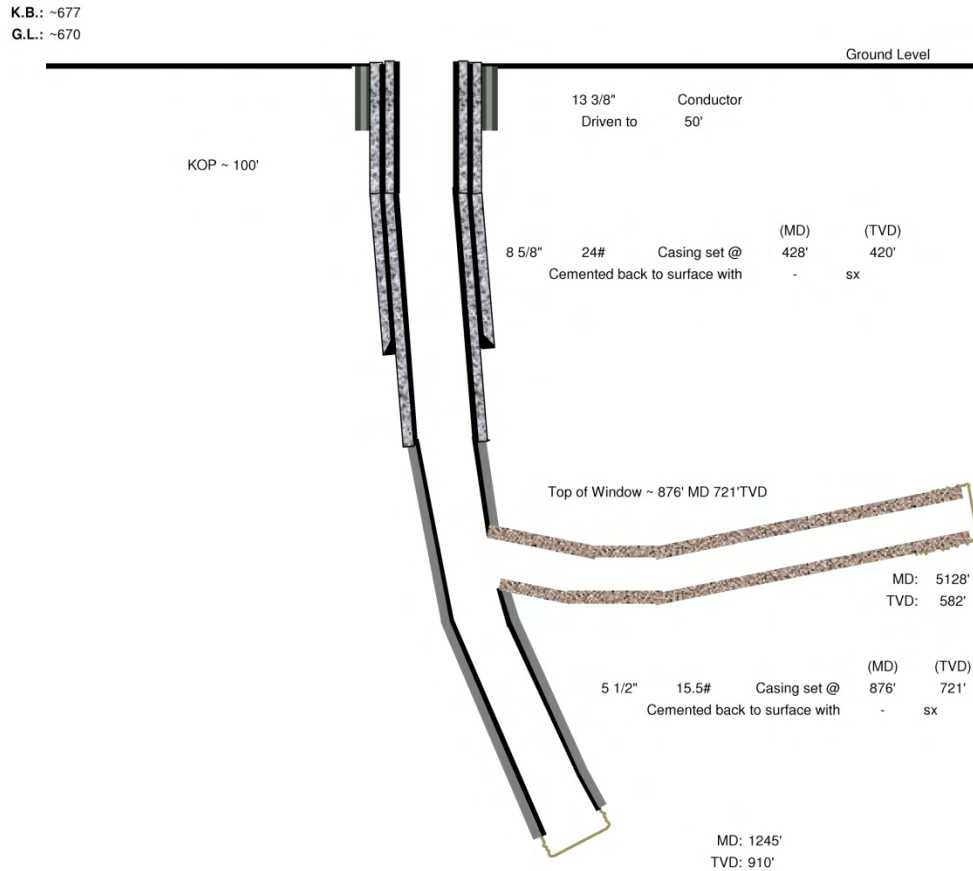
9. Run 5-1/2" 15.5# J-55 LT&C CSG to TD and cement to surface.
10. RU MWL. Run Gauge Ring to PBTD.
11. Run Gamma/CCL/CBL. RD MWL
12. TIH with DP and CIBP and set for combined Norwood and Lachine leg. TOH.
13. RU Baker. TIH with Whipstock and one trip milling system.
14. Orient Whipstock with MWD and set. Mill Window section.
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



Well Name & Number:	A-GA-MING #4-12HD & HD1	MDEQ#	58153
Section:	12 & 1	Township:	T30N
County:	Antrim	Range:	R9W
Township:	Mancelona	State:	Michigan
Spud Date:	-	Country:	United States
Prepared By:	Benjamin J. Nieto	Surface Hole Location:	NW NW NW
		Bottom Hole Location:	SE SW NE
		Last Revision Date:	08/08/07

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

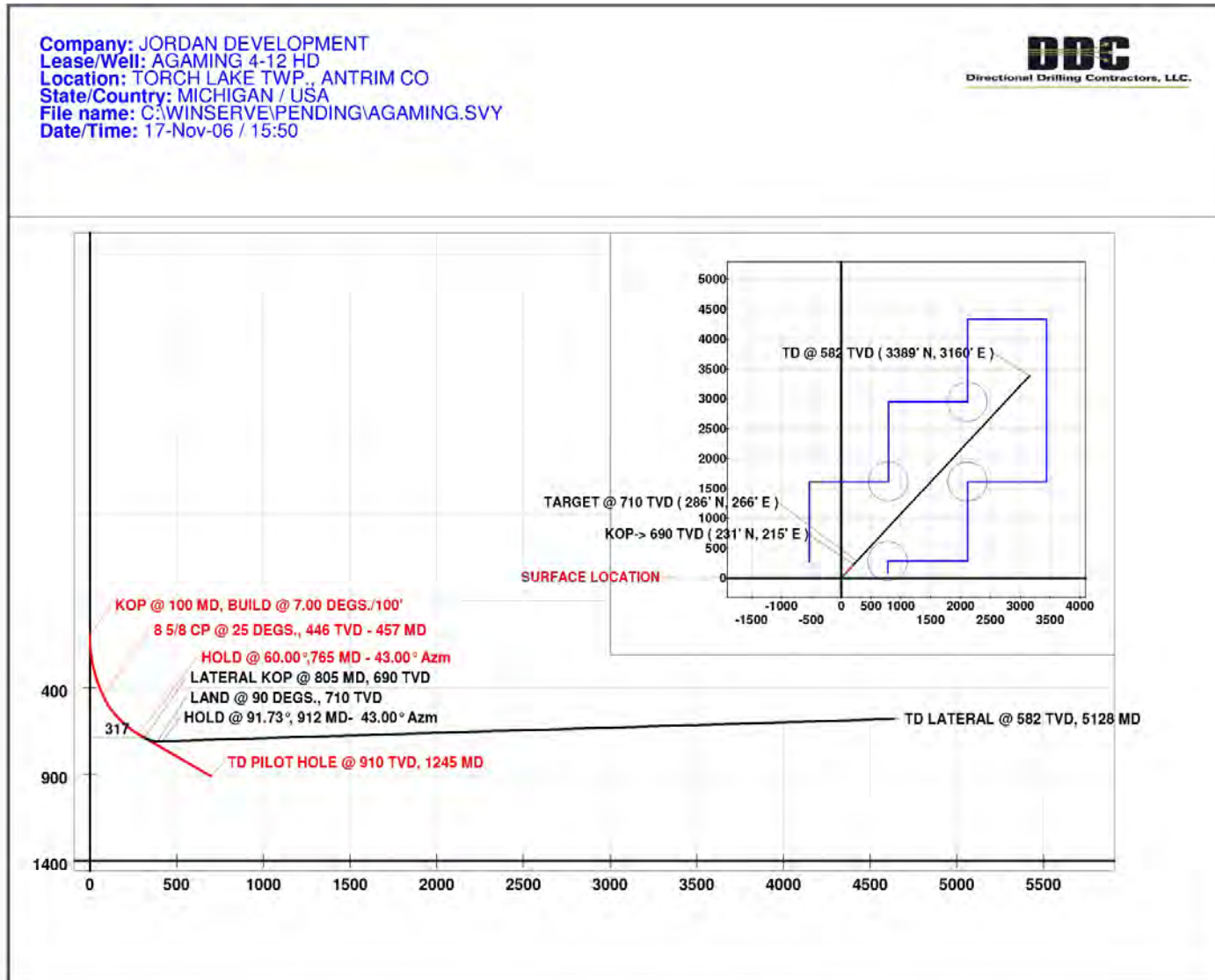


Figure 10-2. Planned drilling survey for the A-GA-MING 4-12 HD in west Antrim County, MI.

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.

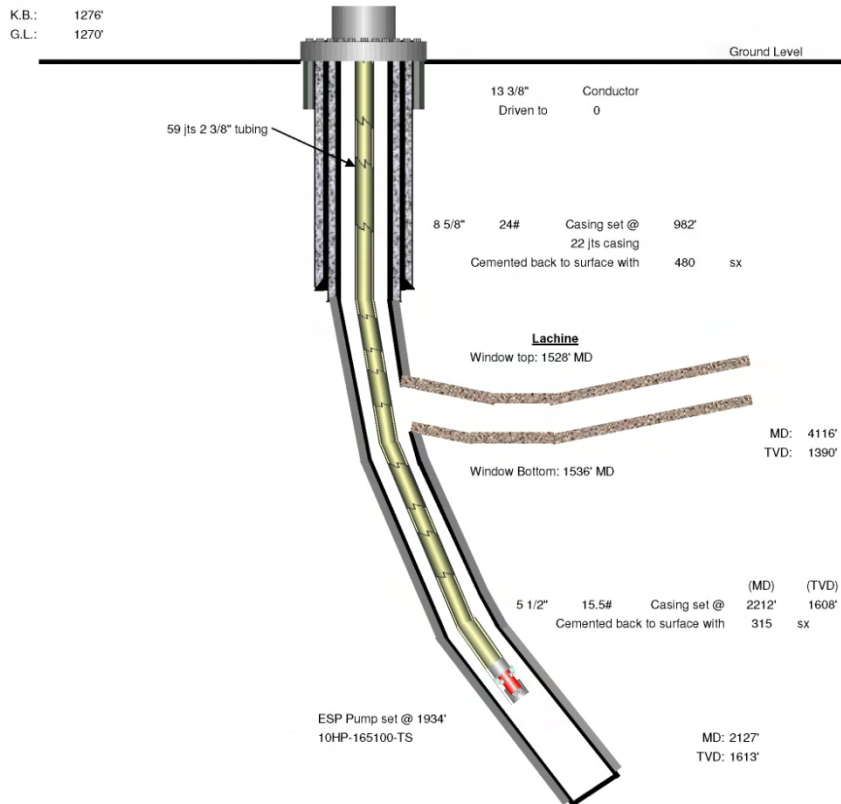
The Deward Cleaver laterals revealed problems with the original design of the “J” well, mainly in terms of disappointing production relative to ordinary vertical wells (Figures 9-11 and 9-12). However, these wells provided an opportunity to redesign and modify the demonstration well before it was drilled. 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 Name & Number:		State Mancelona #2-12 HD3		MDEQ# 57450			
Section:	12	Township:	T29N	Range:	R5W	Surface Hole Location:	NW NW NE
County:	Antrim	State:	Michigan				
Township:	Mancelona	Country:	United States				
Spud Date:	2-12-2007						
Prepared By:	Benjamin J. Nieto			Last Revision Date:	03/19/07		

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.

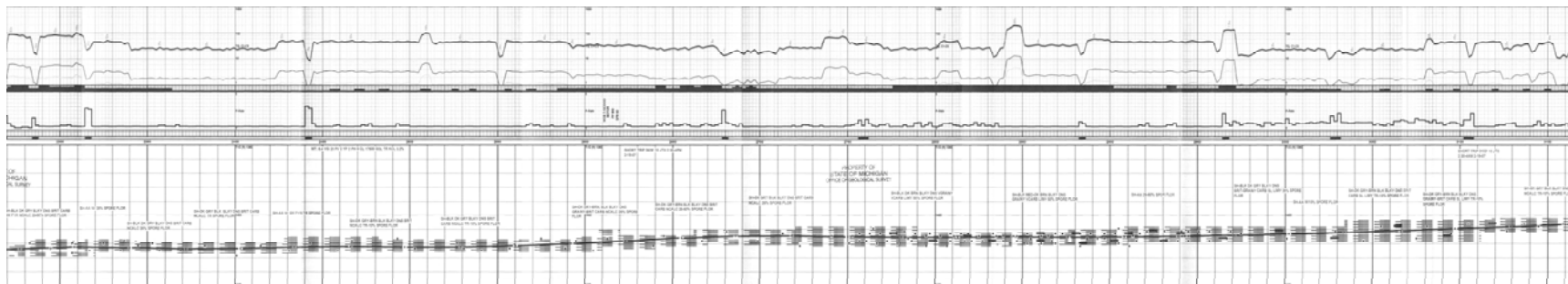


Figure 11-2c. State Mancelona 2-12 HD: Horizontal leg through the Lachine member, measured depth scale is from 2270 - 3170 feet, well bore on bottom track, vertical scale is 1380-1420 feet, true vertical depth.

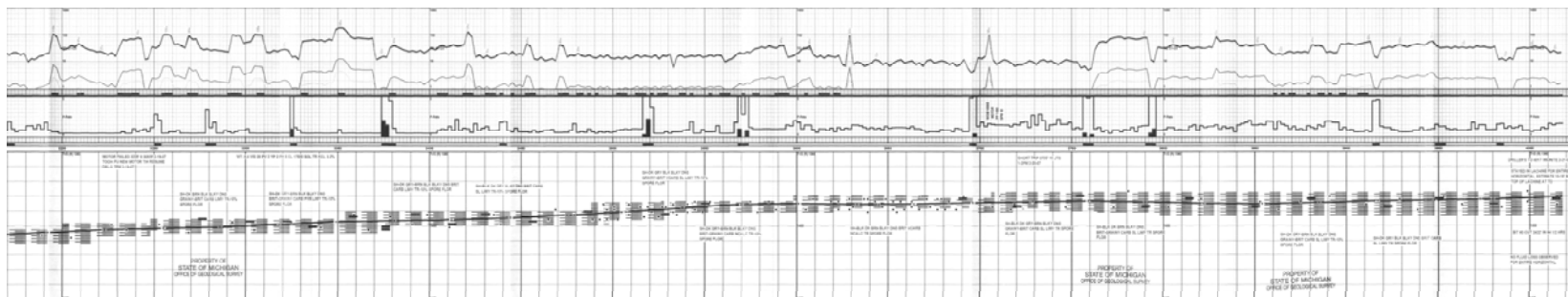
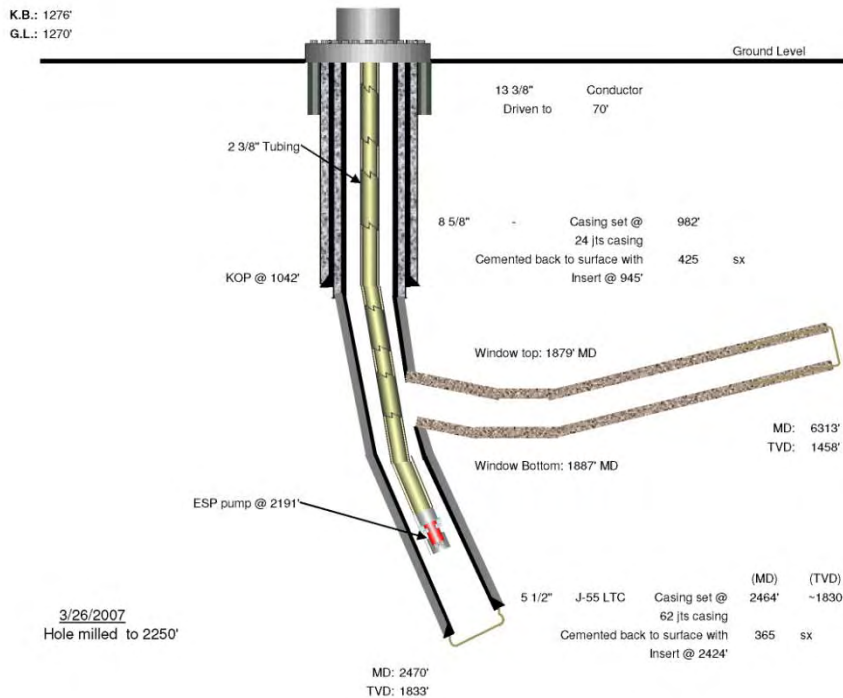


Figure 11-2d. State Mancelona 2-12 HD: Horizontal leg through the Lachine member, measured depth scale is from 3170 - 4030 feet, well bore on bottom track, vertical scale is 1380-1420 feet, true vertical depth.

11.2. State Mancelona #15-13 HD2 (21-009-57451-0200)

11.2.1. Well Bore Schematic

State Mancelona #15-13 HD2



Well Name & Number: State Mancelona #15-13 HD2		MDEQ# 57451	
Sections: 12 & 13	Township: T29N	Range: R5W	SHL, Sec 13: SW SW SE
County: Antrim		State: Michigan	BHL, Sec 12: NW NW NW
Township: Mancelona		Country: United States	
Spud Date: 2-27-2007			
Prepared By: Benjamin J. Nieto		Last Revision Date: 3-28-2007	

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

State Mancelona #15-13A HD1 & HD2

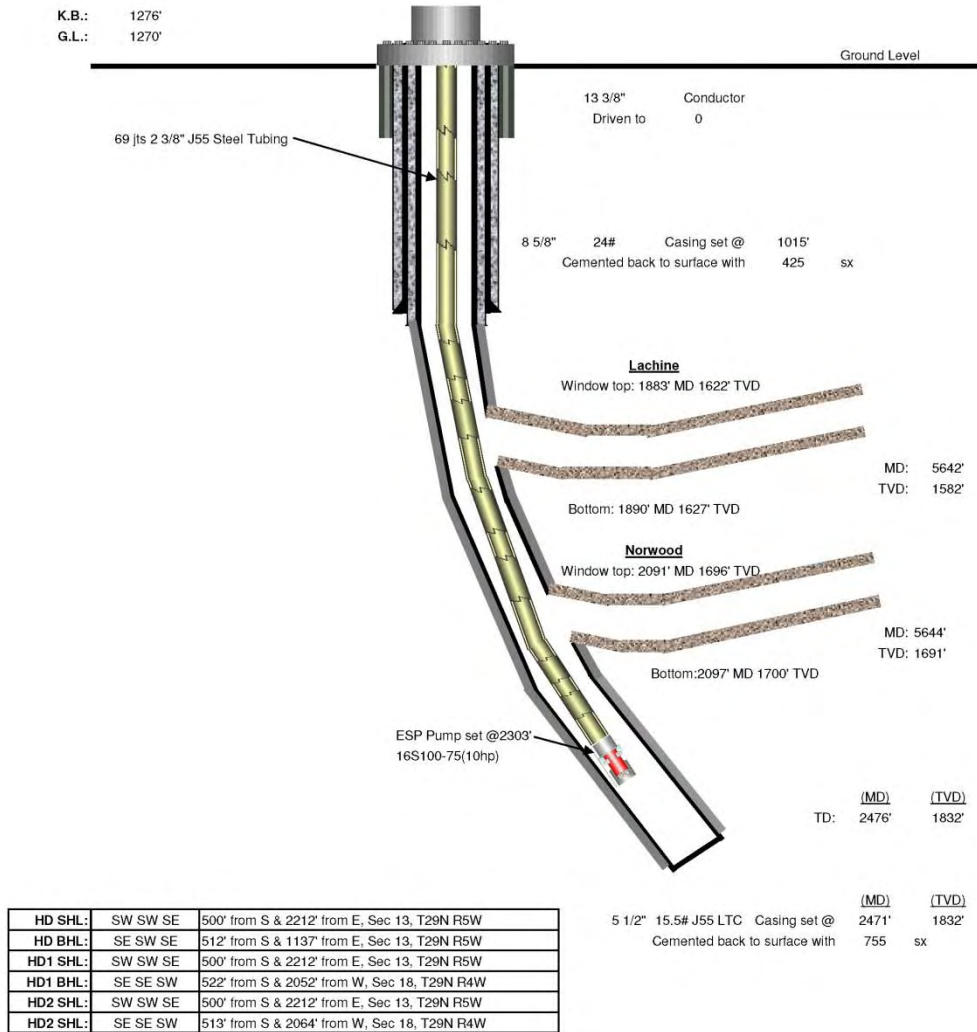


Figure 11-4. Well bore schematic for State Mancelona #15-13A HD1 and HD2 in Antrim County, MI. This well tested the "J" well configuration on two open holes which slanted upwards through the Lachine and the Norwood members of the Antrim formation.

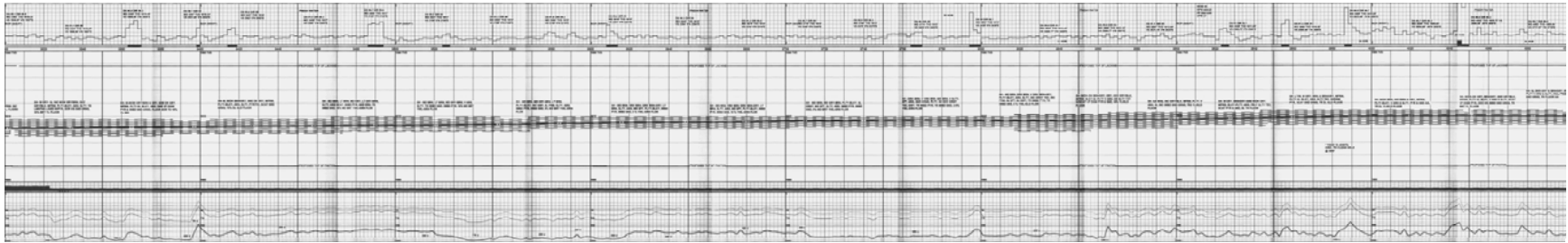


Figure 11-5d. Horizontal leg through the Lachine member, 3300-4100 feet, well bore on center track, vertical scale is 1560-1660 feet, true vertical depth.

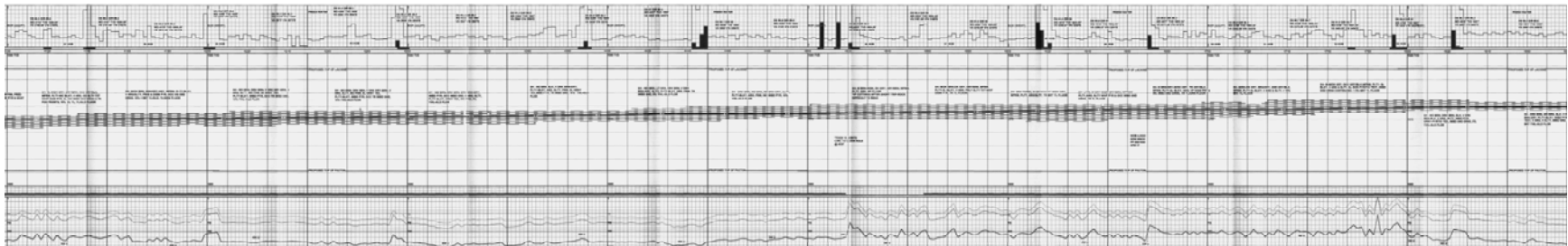


Figure 11-5e. Horizontal leg through the Lachine member, 4100-4900 feet, well bore on center track, vertical scale is 1560-1660 feet, true vertical depth.

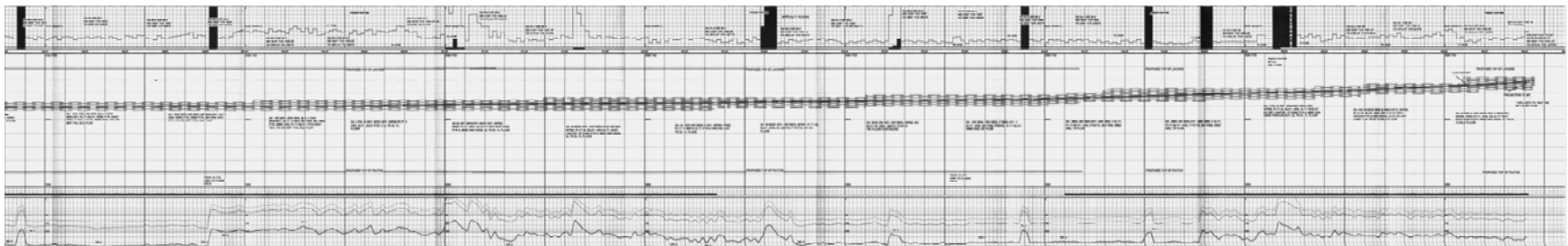


Figure 11-5f. Horizontal leg through the Lachine member, 4900-5660 feet, well bore on center track, vertical scale is 1560-1660 feet, true vertical depth.

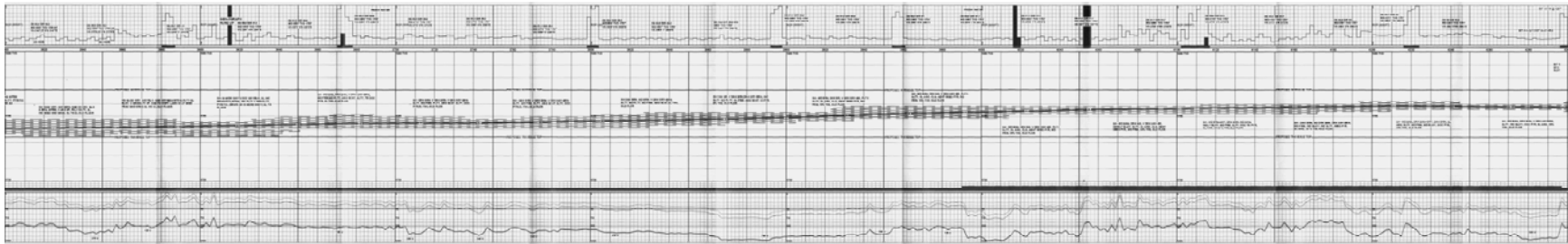


Figure 11-6d. Horizontal leg through the Norwood member, 3500-4300 feet, well bore on center track, vertical scale is 1680-1730 feet, true vertical depth.

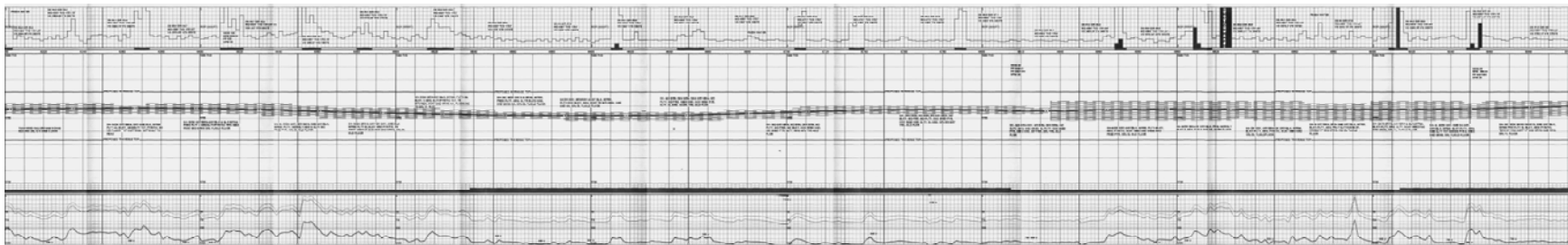


Figure 11-6e. Horizontal leg through the Norwood member, 4300-5100 feet, well bore on center track, vertical scale is 1680-1730 feet, true vertical depth.



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

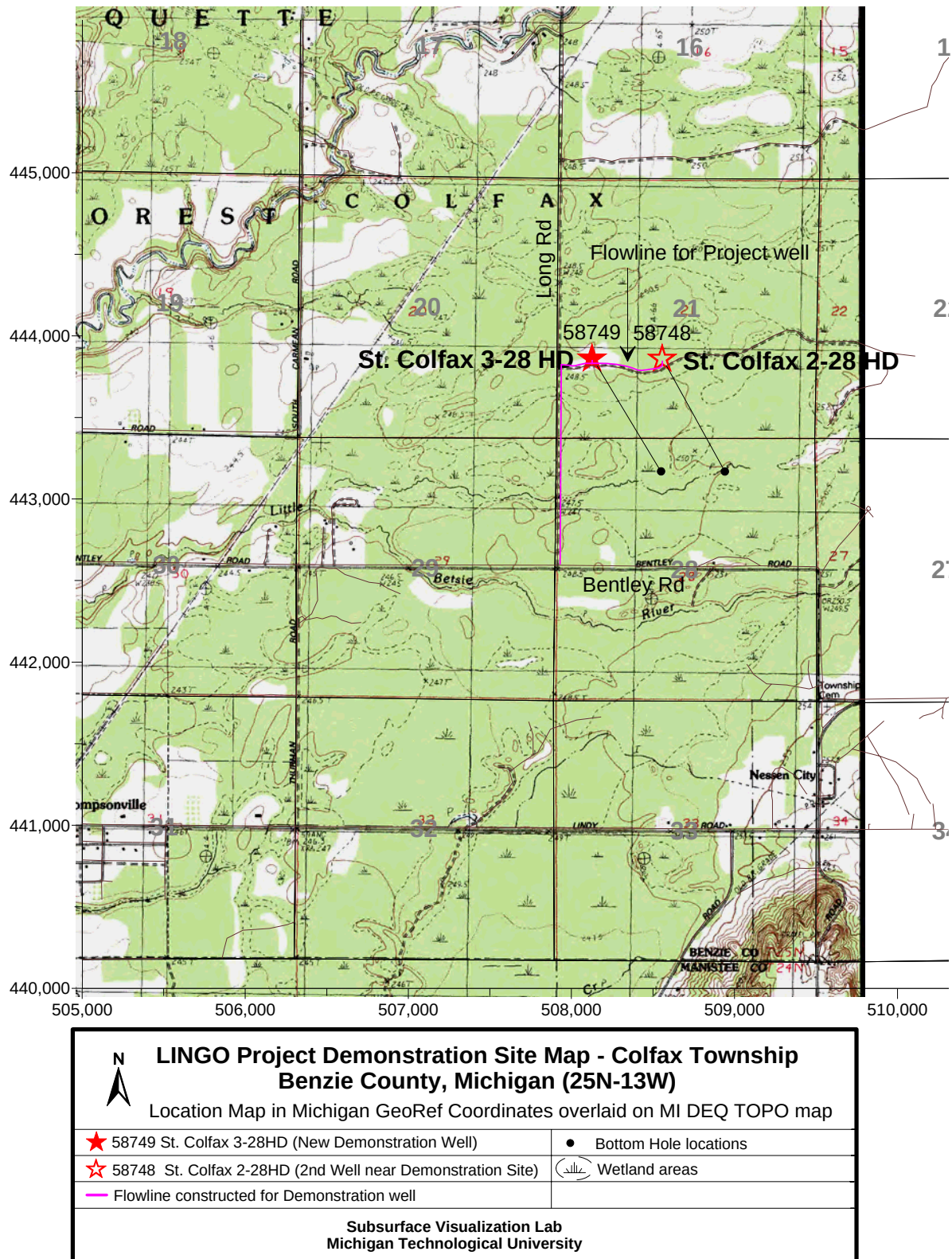


Figure 12-1. Topographic map of the LINGO Project demonstration site, the St. Colfax 3-28 HD and St. Colfax 2-28 HD wells in Benzie County, Michigan.

12.1. St. Colfax 3-28 HD (21-019-58749-0000)

12.1.1. Well Drilling Acronym List

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

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.

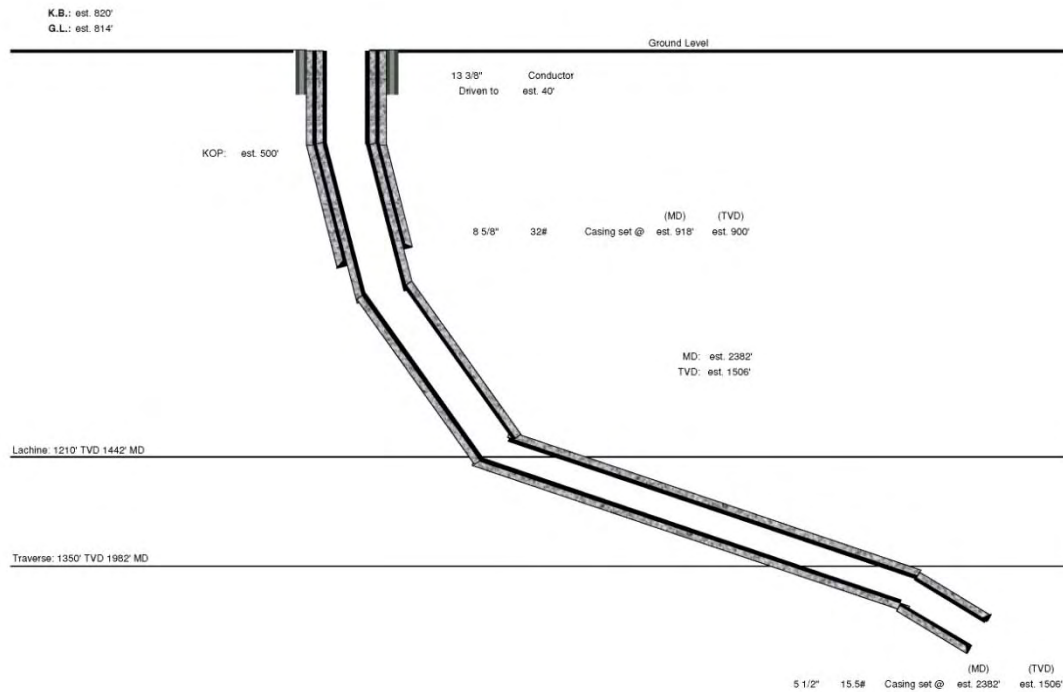
4. Run 32# J-55 8-5/8" CSG to TD and cement to surface.
5. Drill out cement and shoe.
6. TIH with directional tools and 7-7/8" bit. Test CSG and shoe.

****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

Colfax 29



Well Name & Number:	St. Colfax #3-28 HD	MDEQ#	58749						
Section:	21	Township:	T25N	Range:	R13W	Surface Hole Location:	SE NW SW	1599' from South & 699' from West	
County:	Benzie	State:	Michigan	Bottom Hole Location:	SE NE NW	660' from North & 2110' from West			
Township:	Colfax	Country:	United States						
Spud Date:	-								
Prepared By:	Benjamin J. Nieto	Last Revision Date:	12-18-2007						

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: ST. COLFAX 3-28 HD
 Location: COLFAX TWP., BENZIE CO.
 State/Country: MICHIGAN / USA
 File name: C:\WINSERVE\2008\98-2007\2007\COL328.SVY

Date/Time: Friday, January 04, 2008

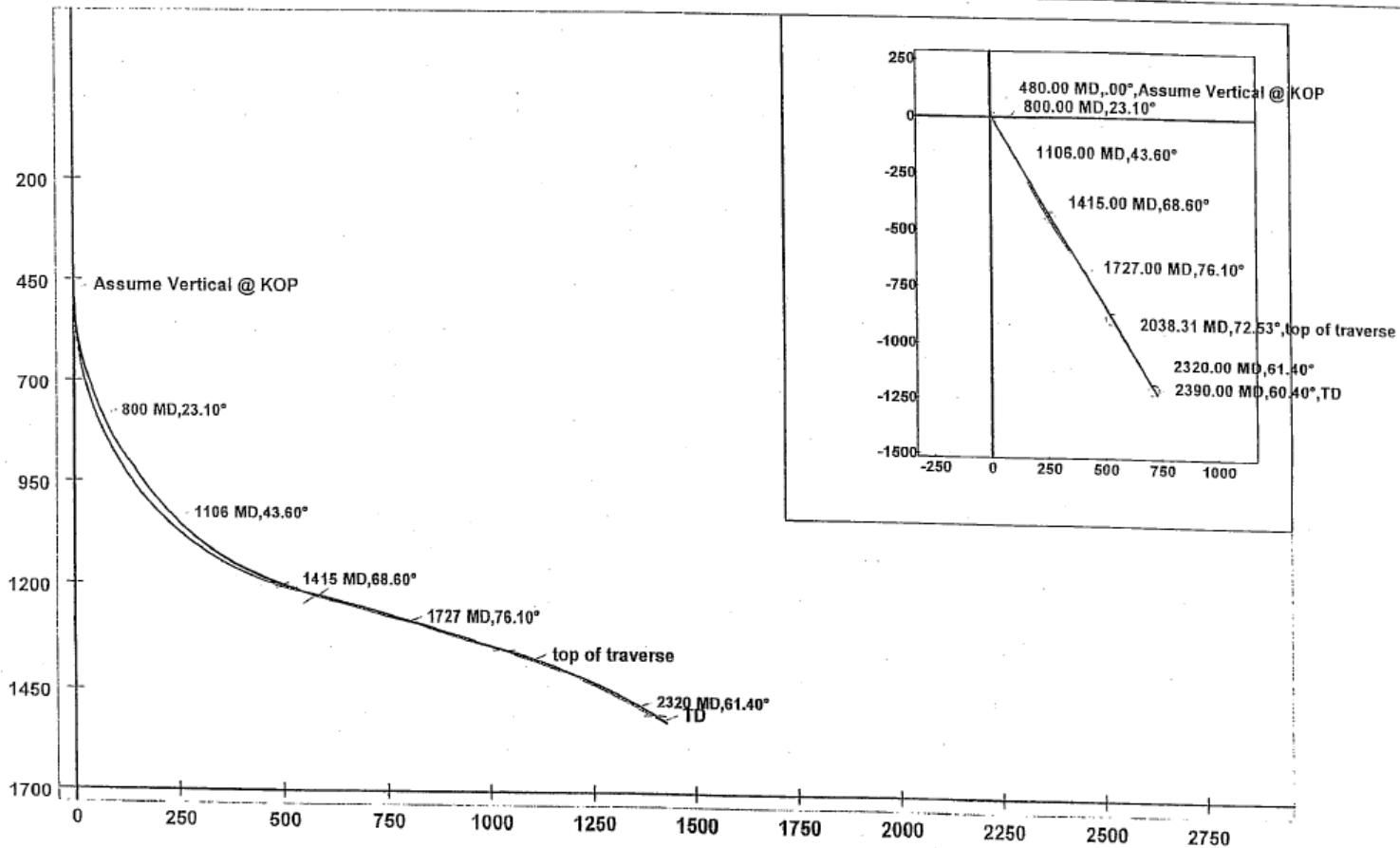


Figure 12-3. Diagram of directional survey of the State Colfax 3-28 HD well in Benzie County, MI.

12.1.5. Gamma Ray Log along Well Path

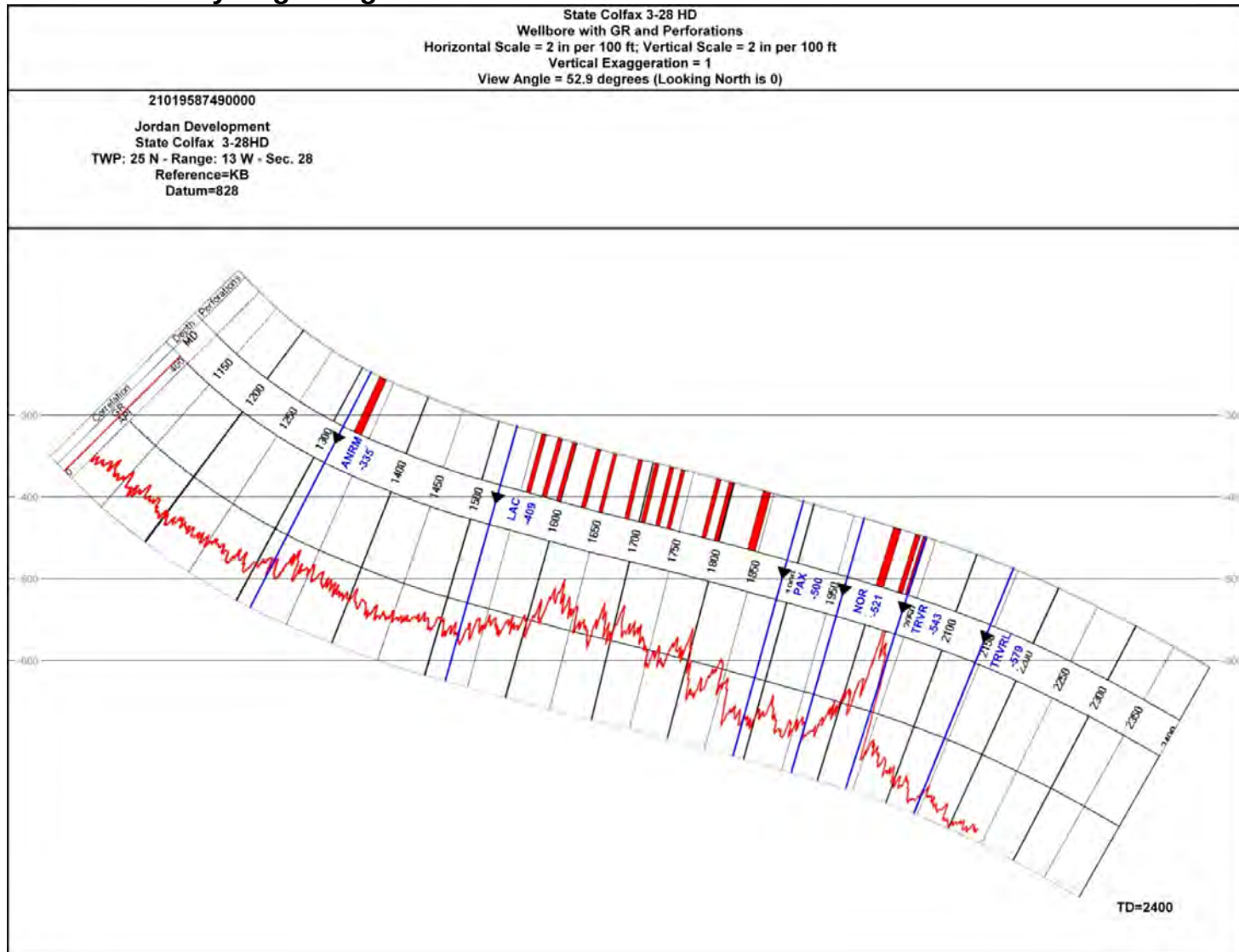


Figure 12-4. Gamma ray log and perforation intervals along the deviation survey of the State Colfax 3-28 HD well in Benzie County. High gamma ray peaks indicate good perforation zones.

12.1.6. Colfax 3-28 HD Daily Production Data

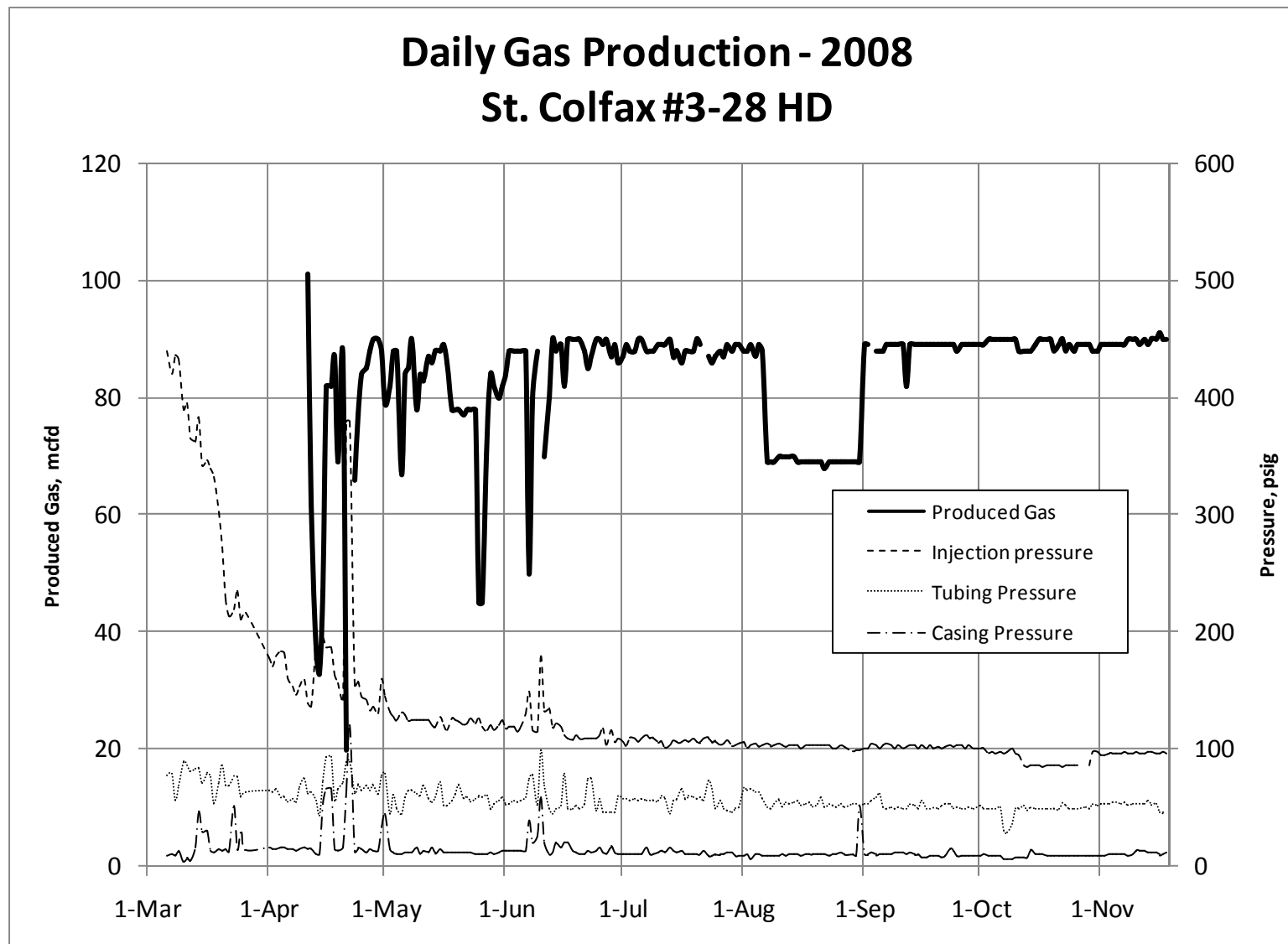


Figure 12-5. Daily gas production and pressure data of the State Colfax 3-28 HD well in Benzie County, MI. Production began in April of 2008, and has averaged 90 mcf/day at the end of 2008.

12.1.7. Record of Well Drilling



MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY - OFFICE OF GEOLOGICAL SURVEY

RECORD OF WELL DRILLING OR DEEPENING

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

Permit number/Deepening number

58749

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

☒ Part 615 Oil/Gas Well ☐ Part 625 Mineral Well

Name and address of permittee		API number	
Jordan Development Company, L.L.C.		21-019-58749-00-00	
1503 Garfield Road North		Well name and number	
Traverse City, MI 49686		State Colfax #3-28 HD	
Name and address of drilling contractor		Surface location	
Advanced Enerav Services, L.L.C.		SE 1/4 of NW 1/4 of SW 1/4 Section 21 T25N R13W	
P.O. Box 85		Township	
5876 Puffer Rd.		Colfax	
South Boardman, Michigan 49680		Benzie	
Date drilling began		Footages North/South East/West	
12-27-2007		1599 ft. from South line and 699 ft. from West line of sec.	
Total depth of well		Directionally drilled (check one)	
Driller 2400' MD Log N/A		☒ Yes ☐ No	
Elevations		Previous permit numbers	
K.B. 827.7 ft. R.F. ft. R.T. ft. Grd 822 ft		N/A	
Date drilling completed		Subsurface location (if directionally drilled)	
1-1-2008		SW 1/4 of SE 1/4 of SW 1/4 Section 21 T 25N R 13W	
Formation at total depth		Township	
Traverse Limestone		County	
Footages North/South East/West		Colfax	
371 ft. from South line and 1430' ft. from West line of sec.		Benzie	
Feet drilled - cable tools		Footages North/South East/West	
from N/A to		371 ft. from South line and 1430' ft. from West line of sec.	
Feet drilled - rotary tools		Directionally drilled (check one)	
from Surface to 2400'		☒ Yes ☐ No	

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	370sx	Surface	N/A	N/A				
5 1/2"	2399' MD	365sx	Surface	N/A	N/A				

Gross Pay Intervals				All Other Oil and Gas Shows Observed or Logged							
Formation	Oil or Gas	From	To	Formation	Oil or Gas	Depth	Where Observed (X)	Sam- ples	Odor	Pits	Mud Line
Antrim Shale	Gas	1524'	2038'								
				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	Name and title (print)	Signature
	Benjamin J. Nieto, Authorized Agent	

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

EQP 7200-5 (rev. 8/2004)

Figure 12-6. St. Colfax 3-28 HD Record of Well Drilling.

FORMATION RECORD Attach additional sheets if necessary			API number		Permit number/Deepening number	
Elevation used 827.7' KB			Geologist name Jon Huggard & Dustin Boerema		Tops taken from ☐ Driller's log ☒ Sample log ☐ Electric log	

Formation (type, color, hardness)			Formation (type, color, hardness)		
From	To		From	To	
Note: if well directionally drilled, add true vertical depth formation tops where appropriate					
MD	Fm Tops				
667'	TVD				
667'	674'	BOD			
	674'	ELLSWORTH- SH-MD GRY,LT			
		GRY,PLTY/BLKY,GRNY,ST-			
		FRM,DNS,S LIMY,NO FLOR			
1314'	1163'	UPPER ANTRIM- SH-MD GRY, LT			
		GRY, DRK BRN, PLTY/BLKY,			
		GRNY, SFT-FRM, DNS, SL LMY,			
		5% YWL SPORE FLOR			
1524'	1237'	LACHINE-SH DRK BRN,DRK GRY,			
		BLK, HD, DNS, PLTY/BLKY,			
		GRNY, DNS, TR FLOR			
1810'	1308'	PAXTON- SH GRY,DRK BRN, LT			
		GRY, MD, FRM-HD, DNS, GRNY			
		PLTY/BLKY, SPORE FLR			
1962'	1349'	NORWOOD- SH- DRK BRN,DRK			
		GRY,BLK,OCC MD GRY,HD,PLTY/			
		BLKY,BRT,DNS,5-10% YWL SPR			
		FLR			
2038'	1371'	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 YWLSPORE FLOR			
2144'	1407'	TRAVERSE LIMESTONE- LMST-			
		DRK BRN,MD BRN,BLKY,MICXLN,			
		TT,HD,DNS SH- MD GRY,LT GRY,			
		BLU,BLK,MD. FM- HD,BLKY/PLTY,			
		SM TR YWL SPORE FLOR			
2400'	1522' TD				

If well was cored, attach core description	
DRILL STEM TEST DATA	
N/A	
LIST ATTACHMENTS	
Certification of Casing and Sealing of Surface Hole Directional Survey Mud Log	
OFFICE OF GEOLOGICAL SURVEY USE ONLY	
Reviewed by	
Date of review	

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.			Permit number/deepening permit no. 58749		API number 21-019-58749-00-00	
(Submit 3 copies within 60 days of well completion.) ☒ Part 615 Oil/Gas Well ☐ Part 625 Mineral Well			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 ¼ Section 21 T 25N R 13W			Subsurface location (if directionally drilled) SW ¼ of SE ¼ of SW ¼ Section 21 T 25N R 13W			
Township Colfax		County Benzie		Township Colfax		
Footages: North/South 1599 Ft. from South line and 699 Ft. from West line of Sec.		Footages: North/South 371 Ft. from South line and 1430 Ft. from West line of Sec.				
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)

Date	Number holes	Perforation or open hole interval	Open	
			Yes	No
2-25-2008	4 SPF	2026'-2032', 2035'-2040', 1998'-2008', 1836'-1846'	X	
2-26-2008	4 SPF	1794'-1799', 1779'-1784', 1735'-1740', 1721'-1726', 1703'-1708', 1682'-1687', 1649'-1654', 1627'-1632', 1596'-1600', 1577'-1582', 1557'-1562', 1330'-1340'	X	

STIMULATION BY ACID OR FRACTURING

Date	Interval treated	Materials and amount used
2-25-2008	2026'-2032', 2035'-2040'	15% Acid: 700 gals, Sand: 47,157# 20/40 4,700# 12/20
2-25-2008	1998'-2008', 1836'-1846'	15% Acid: 1000 gals, Sand: 50,900# 20/40 5,700# 12/20
2-26-2008	1794'-1799', 1779'-1784'	15% Acid: 1000 gals, Sand: 25,800# 20/40 6,000# 12/20
2-26-2008	1735'-1740', 1721'-1726'	15% Acid: 1000 gals, Sand: 26,700# 20/40 1,600# 12/20
2-26-2008	1703'-1708', 1682'-1687'	15% Acid: 1000 gals, Sand: 25,400# 20/40 4,900# 12/20
2-26-2008	1649'-1654', 1627'-1632'	15% Acid: 1000 gals, Sand: 25,500# 20/40 5,900# 12/20
2-26-2008	1596'-1600', 1577'-1582', 1557'-1562'	15% Acid: 1000 gals, Sand: 25,400# 20/40 5,100# 12/20
2-26-2008	1330'-1340'	15% Acid: 1000 gals, Sand: 26,600# 20/40 7,300# 12/20

PRODUCTION TEST DATA

Oil Bbls/day	Gravity °API	Condensate Bbls/day	Gas MCF/day	Water Bbls/day	H ₂ S Grains/100 ft ³	B.H.P. and depth
N/A	N/A	N/A	150 est.	400 est.	N/A	N/A

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	Signature	Date
--	-----------	------

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

EQP 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



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

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.



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

Date: 2/25/2008 **Employee:** Dale Schellie
Well name/number: St. Colfax 3-28 HD **Rig:** Advanced #124
RATE: \$650.00

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. 2035'-2040'
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.



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

Date: 2/26/2008 **Employee:** Dale Schellie

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



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

Date: 2/27/2008 **Employee:** Dale Schellie

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

RATE: \$650.00

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.



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

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 tripin 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 hoel 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.



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

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:

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

Figure 12-9f. St. Colfax 3-28 HD Daily Completion Report while drilling, 2/29/2008.



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

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:

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

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

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

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.

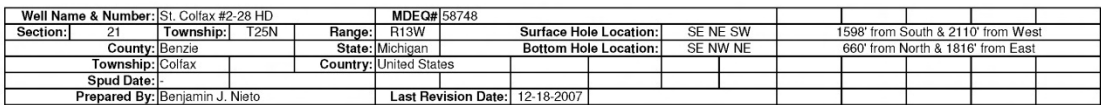
Note: Surface CSG point shall be 100' TVD below BOD.

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

Colfax 29

Lingo Antrim Play: Handbook
DE-FC26-06NT42931

12.2.4. Directional Survey

Job Number: DR-80002
 Company: JORDAN DEVELOPMENT
 Lease/Well: ST. COLFAX 2-28 HD
 Location: COLFAX TWP., BENZIE CO.
 State/Country: MICHIGAN / USA
 File name: C:\WINSERVE\2008\COL228.SVY

Date/Time: 09-Jan-08 / 14:48

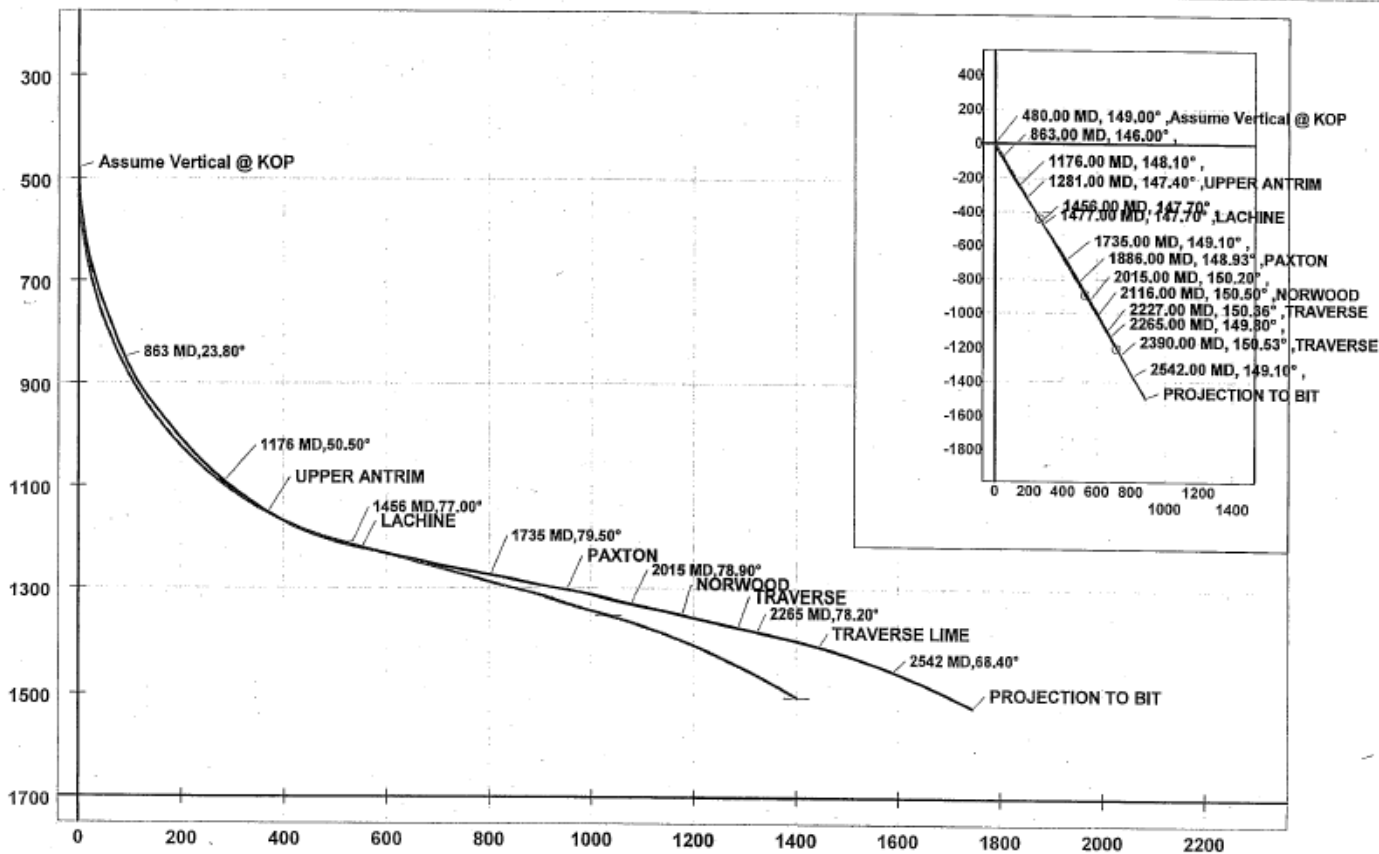


Figure 12-11. Diagram of directional survey performed on the State Colfax 2-28 HD well in Benzie County, MI.

12.2.5. Gamma Ray Log along Well Path

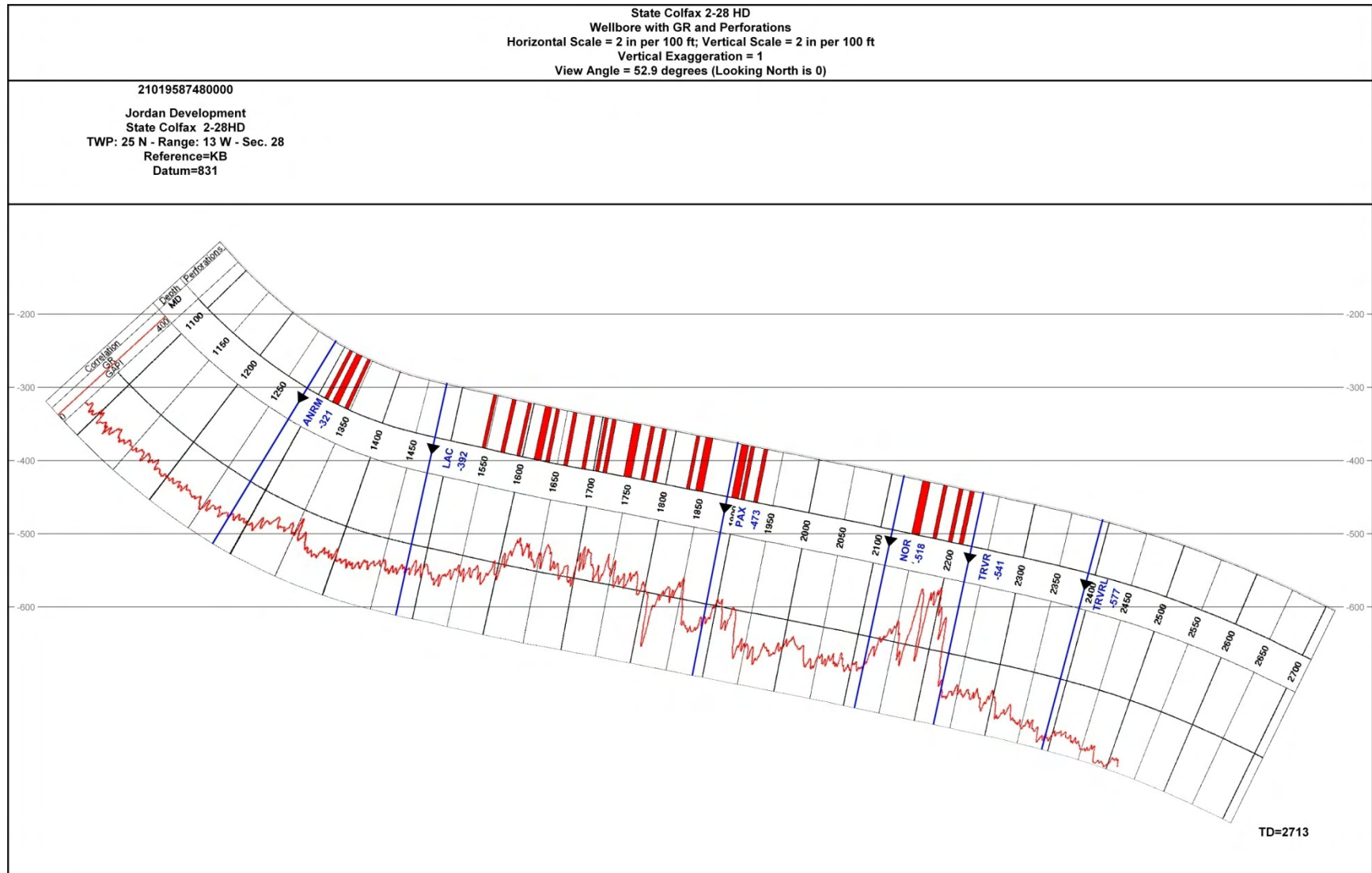


Figure 122-12. Gamma Ray log and perforation intervals shown along the deviation survey of the State Colfax 2-28 HD well in Benzie County, MI. This lateral shows that multiple perforation zones allow greater access to gas resources along the well path as compared to vertical wells.

12.2.6. Colfax 2-28 HD Daily Production Data

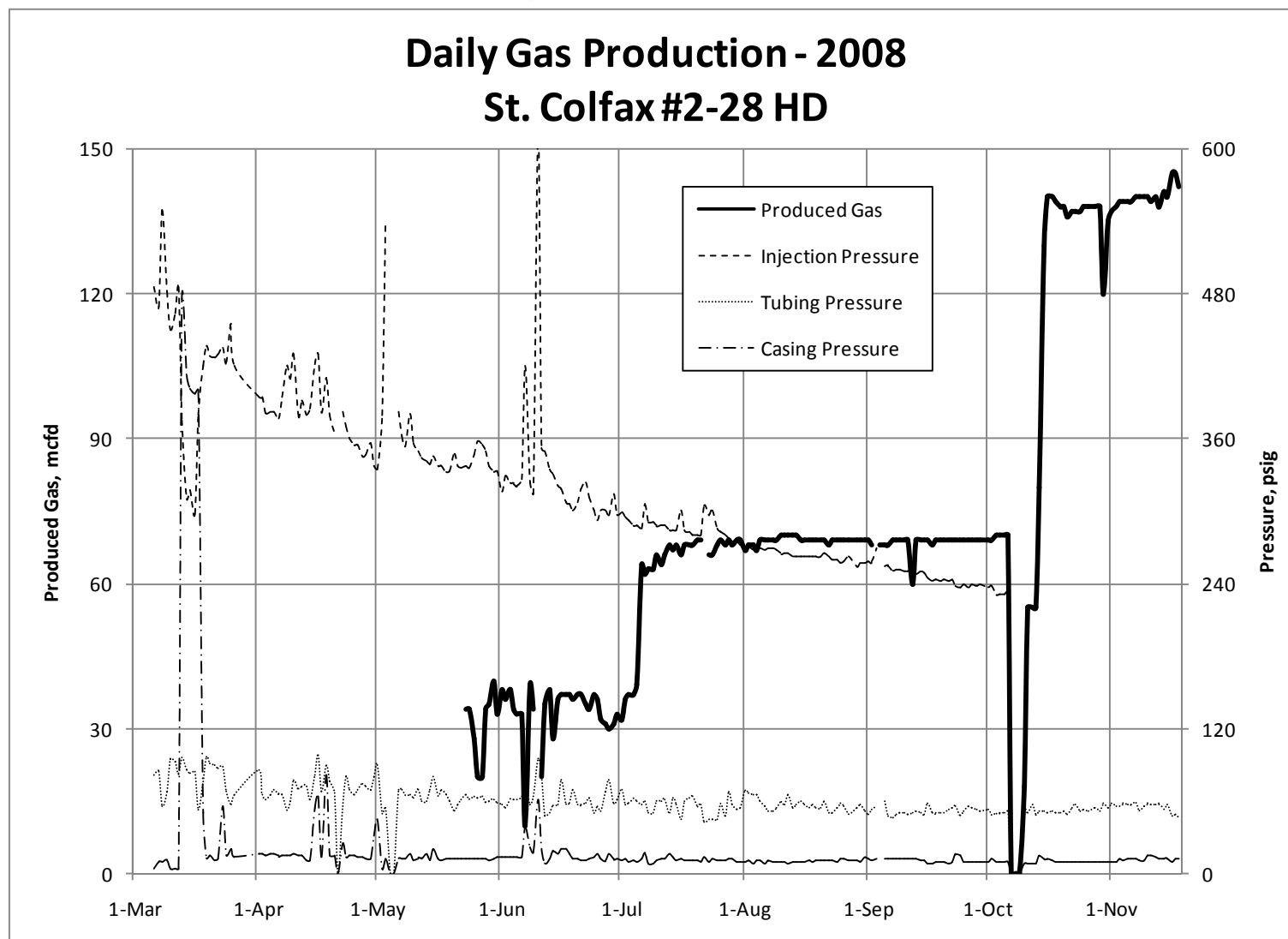


Figure 12-13. Daily gas production at the St. Colfax 2-28 HD well in Benzie County, MI. This well was drilled near the project demonstration well, and shows a sharp increase in production in October when a pump was installed to pump out the gas.

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

Permit number/Deepening number
58748

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

☒ 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		API number 21-019-58748-00-00	
Name and address of drilling contractor Advanced Energy Services, L.L.C. P.O. Box 85 5876 Puffer Rd. South Boardman, Michigan 49680		Well name and number State Colfax #2-28 HD	
Date drilling began 1-2-2008		Surface location SE 1/4 of NE 1/4 of SW 1/4 Section 21 T25N R13W	
Total depth of well Driller 2713' MD Log N/A		Township Colfax	
Elevations K.B. 830.7 ft. R.F. ft. R.T. ft. Grd 825 ft		County Benzie	
Date drilling completed 1-6-2008		Footages North/South East/West 1598 ft. from South line and 2110 ft. from West line of sec.	
Formation at total depth Traverse Limestone		Directionally drilled (check one) ☒ Yes ☐ No	
		Previous permit numbers N/A	
		Subsurface location (if directionally drilled) SW 1/4 of SE 1/4 Section 21 T 25N R 13W	
		Township Colfax	
		County Benzie	
		Footages North/South East/West 95 ft. from South line and 2997 ft. from West line of sec.	
		Feet drilled - cable tools from N/A to	
		Feet drilled - rotary tools from Surface to 2713'	

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"	73'	Driven	N/A	N/A	N/A				
8 5/8"	804' MD	310sx	Surface	N/A	N/A				
5 1/2"	2712' MD	445sx	Surface	N/A	N/A				

Gross Pay Intervals				All Other Oil and Gas Shows Observed or Logged							
Formation	Oil or Gas	From	To	Formation	Oil or Gas	Depth	Where Observed (X)	Sam- ples	Odor	Pits	Mud Line
Antrim Shale	Gas	1477'	2227'								
				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	Name and title (print) Benjamin J. Nieto, Authorized Agent	Signature
------	--	-----------

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

EQP 7200-5 (rev. 8/2004)

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

FORMATION RECORD Attach additional sheets if necessary			API number		Permit number/Deepening number	
Elevation used 830.7' KB		Geologist name Jon Huggard & Dustin Boerema		Tops taken from ☐ Driller's log ☒ Sample log ☐ Electric log		

Formation (type, color, hardness)			Formation (type, color, hardness)		
From	To		From	To	
Note: if well directionally drilled, add true vertical depth formation tops where appropriate					
MD 665' 665	Fm Tops TVD	BOD ELLSWORTH- SH-MGGRY,LT GRY,PLTY/BLKY,GRNY,ST- FRM,DNS,S LIMY,NO FLOR			
1281'	1152'	UPPER ANTRIM- SH-MD GRY, LT GRY, DRK BRN, PLTY/BLKY, GRNY, SFT-FRM, DNS, SL LMY, SM TR SPORE FLOR			
1477'	1223'	LACHINE-SH DRK BRN,DRK GRY, BLK, HD, DNS, BRTLE, PLTY/ BLKY, GRNY, DNS, NO FLOR			
1886'	1303'	PAXTON- SH GRY,DRK BRN, LT GRY, MD, FRM-HD, DNS, GRNY PLTY/BLKY, 5% YWL SPORE FLR	If well was cored, attach core description		
2116'	1349'	NORWOOD- SH- DRK BRN,DRK GRY,BLK,OCC MD GRY,HD,PLTY/ BLKY,BRT,DNS,5% YWL SPR FLR	DRILL STEM TEST DATA		
2227'	1372'	TRAVERSE FORMATION- SH- DRK BRN,MD BRN,BLK,MD GRY, LT GRY,B;U,HD,LMST-DRK BRN, MD GRY,LT GRY,BLU BLK,MD, FRM- HD,BLKY/PLTY,SM TR YWL SPORE FLOR	N/A		
2390'	1408'	TRAVERSE LIMESTONE- LMST- DRK BRN,MD BRN,BLKY,MICXLN, TT,HD,DNS SH- MD GRY,LT GRY, BLU,BLK,MD. FM- HD,BLKY/PLTY, SM TR YWL SPORE FLOR			
2713'	1524' TD		LIST ATTACHMENTS		
			Certification of Casing and Sealing of Surface Hole Directional Survey Mud Log		
OFFICE OF GEOLOGICAL SURVEY USE ONLY					
Reviewed by					
Date of review					

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. 58748		API number 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 ¼ of SW ¼ of SE ¼ Section 21 T 25N R 13W			
Township Colfax		County Benzie		Township Colfax		
Footages: North/South 1598 Ft. from South line and 2110 Ft. from West line of Sec.		Footages: North/South 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)

Date	Number holes	Perforation or open hole interval	Open	
			Yes	No
2-20-2008	4 SPF	2210'-2215'	X	
2-22-2008	4 SPF	1923'-1928', 1905'-1910', 1892'-1902', 1842'-1852', 1829'-1834', 1782'-1787', 1766'-1771', 1742'-1752', 1713'-1718', 1703'-1708', 1684'-1689'	X	
2-23-2008	4 SPF	1659'-1664', 1633'-1638', 1616'-1626', 1592'-1597', 1570'-1575', 1543'-1548', 1342'-1347', 1322'-1332', 1310'-1315'	X	

STIMULATION BY ACID OR FRACTURING

Date	Interval treated	Materials and amount used
2-22-2008	1923'-1928', 1905'-1910', 1892'-1902'	15% Acid: 1000 gals, Sand: 27,000# 20/40 6,000# 12/20
2-22-2008	1842'-1852', 1829'-1834'	15% Acid: 1000 gals, Sand: 26,000# 20/40 5,300# 12/20
2-22-2008	1782'-1787', 1766'-1771', 1742'-1752'	15% Acid: 1000 gals, Sand: 26,300# 20/40 4,100# 12/20
2-22-2008	1713'-1718', 1703'-1708', 1684'-1689'	15% Acid: 1000 gals, Sand: 25,500# 20/40 5,000# 12/20
2-23-2008	1659'-1664', 1633'-1638', 1616'-1626'	15% Acid: 1000 gals, Sand: 27,700# 20/40 6,000# 12/20
2-23-2008	1592'-1597', 1570'-1575', 1543'-1548'	15% Acid: 1000 gals, Sand: 19,600# 20/40
2-23-2008	1342'-1347', 1322'-1332', 1310'-1315'	15% Acid: 1000 gals, Sand: 26,000# 20/40 6,700# 12/20

PRODUCTION TEST DATA

Oil Bbls/day	Gravity °API	Condensate Bbls/day	Gas MCF/day	Water Bbls/day	H ₂ S Grains/100 ft ³	B.H.P. and depth
N/A	N/A	N/A	150 est.	400 est.	N/A	N/A

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	Signature	Date
--	-----------	------

Submit to: OFFICE OF GEOLOGICAL SURVEY
MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY
PO BOX 30256
LANSING 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

Date: 2/20/2008 **Employee:** Dale Schellie

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

RATE: \$650.00

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.



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Gaylord MI 49734

Ph: 989-732-6772

Fax: 989-732-3024

Email: dalemark@voyager.net

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. Perfs 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. 1989 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. Perfs 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. Perfs 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'-1689' 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'-1689' 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.



North Central Production Inc

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Gaylord MI 49734

Ph: 989-732-6772

Fax: 989-732-3024

Email: dalemark@voyager.net

TIME TICKET - Consulting

Date: 2/23/2008 **Employee:** Dale Schellie

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

RATE: \$650.00

Description of work performed:

7:00-9:30	2 1/2 hrs	Fill frac tanks with water well throughout the night 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 a 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. Were only able to get to 1.50# 20/40 sand on this zone. Any higher would have screened 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 1090 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.



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

Date: 2/24/2008 **Employee:** Dale Schellie
Well name/number: St. Colfax 2-28 HD **Rig:** Advanced #124
RATE: \$650.00

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 oin 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.



Ph: 989-732-6772

Fax: 989-732-3024

Email: dalemark@voyager.net

TIME TICKET - Consulting

Date: 2/25/2008 **Employee:** Dale Schellie

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

RATE: \$325.00

Description of work performed:

7:00-8:00	1 hr	Wash down to release 3rd plug.
8:00-9:30	1 1/2 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.



*PO Box 1133
Gaylord MI 49734
Ph: 989-732-6772
Fax: 989-732-3024*

Email: dalemark@voyager.net

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 perms. 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.



North Central Production Inc

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Gaylord MI 49734

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Email: dalemark@voyager.net

TIME TICKET - Consulting

Date: 2/27/2008 **Employee:** Dale Schellie

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

RATE: \$325.00

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

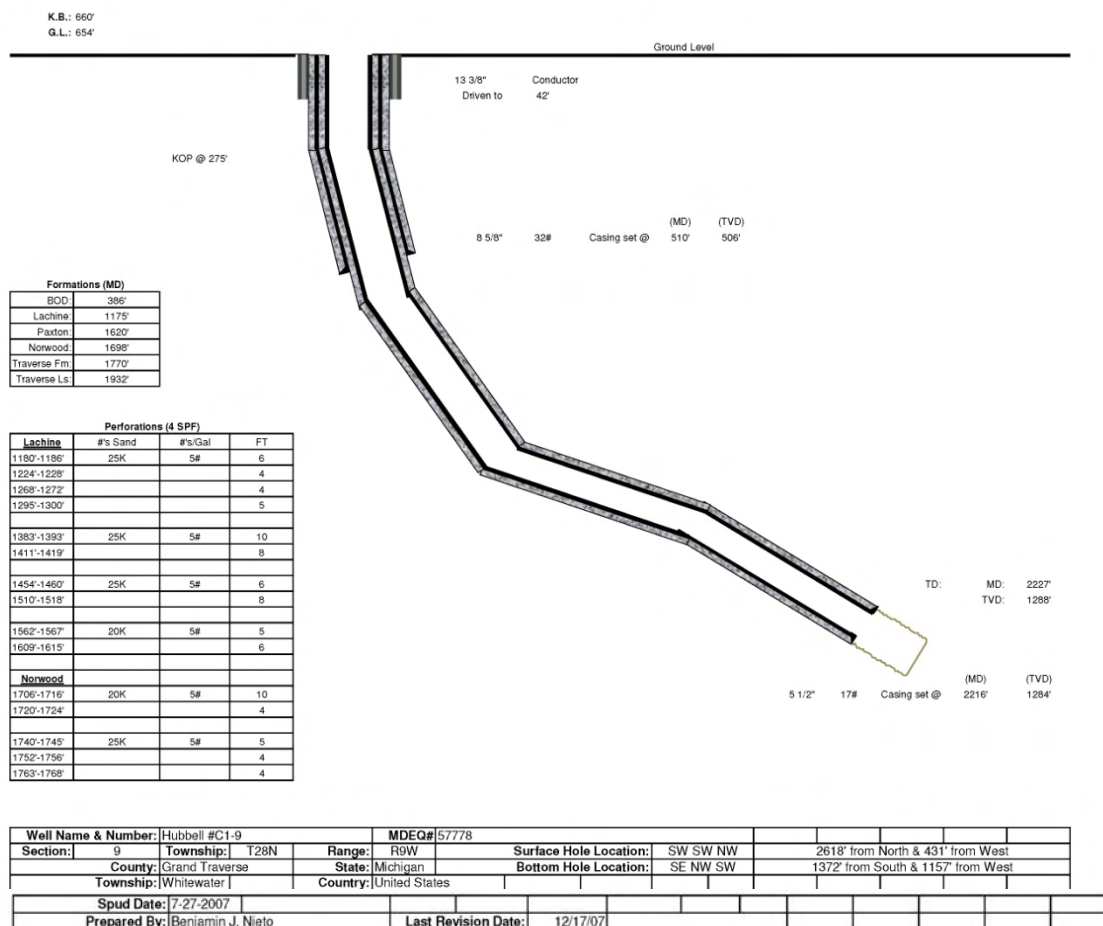


Figure 13-1. Well bore schematic for the Hubbell C1-9 well in Grand Traverse County. The design of this well is similar to the project demonstration well, Colfax #3-28 HD, in Benzie County.

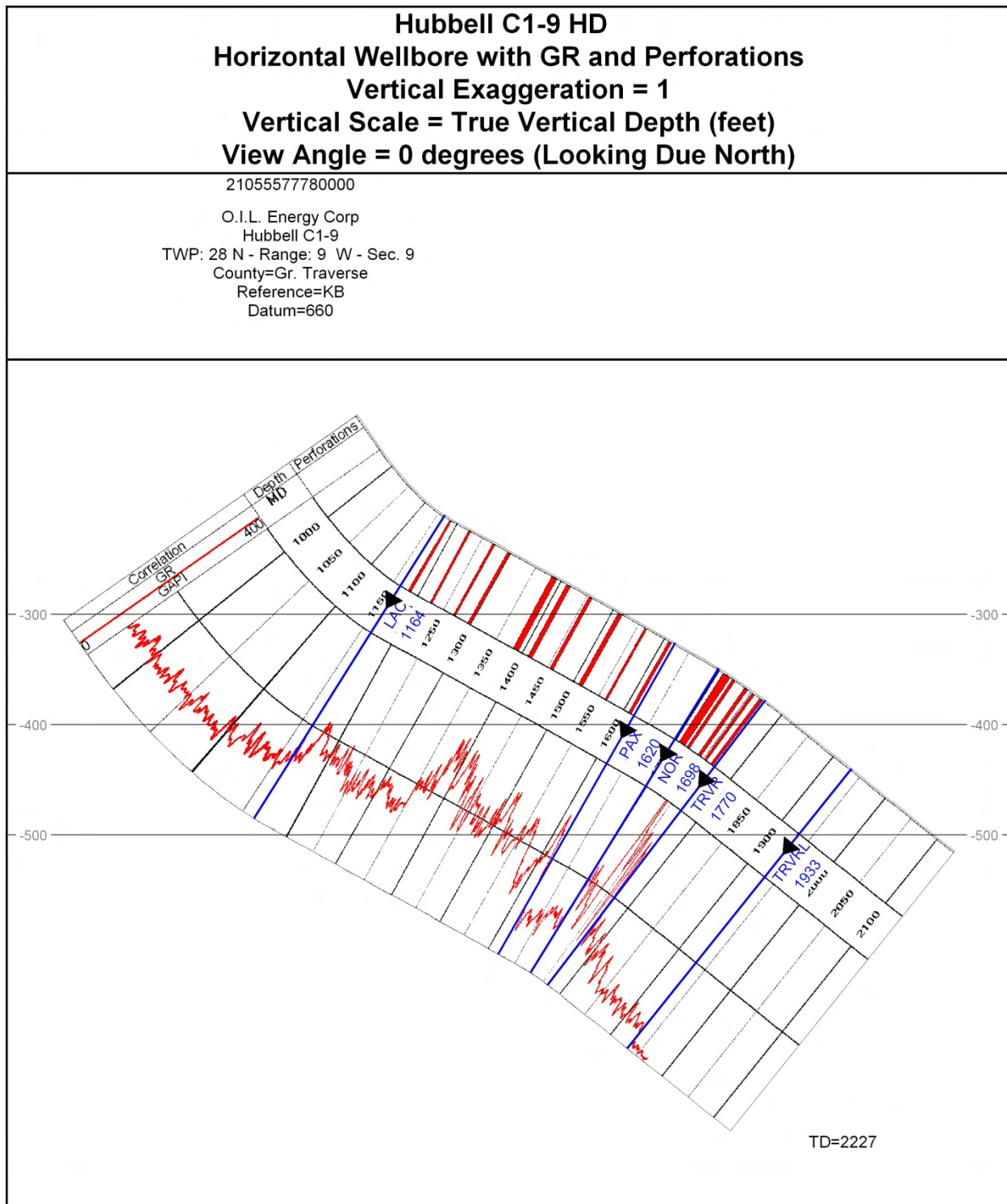


Figure 13-2. Gamma Ray log and perforation intervals shown along the deviation survey of the well path for the Hubbell C1-9 well in Grand Traverse County, MI.

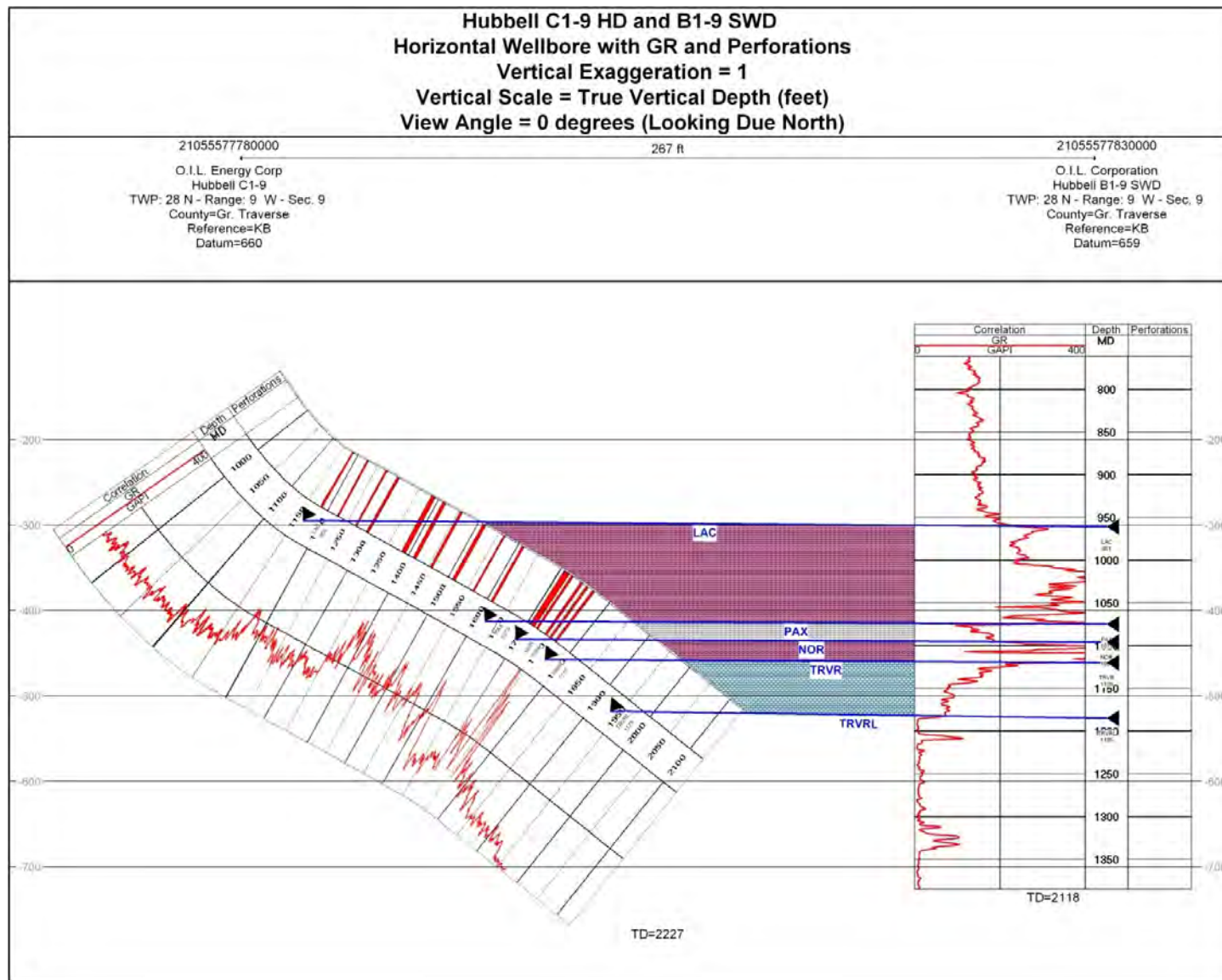


Figure 13-3. Gamma Ray log and perforation intervals shown along the deviation survey of the well path for the Hubbell C1-9 well in Grand Traverse County, MI and shown in relation to subsea depth with the nearby brine disposal well, Hubbell B1-9 SWD.

14. Best Practices for Co-produced CO₂ Disposal

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.

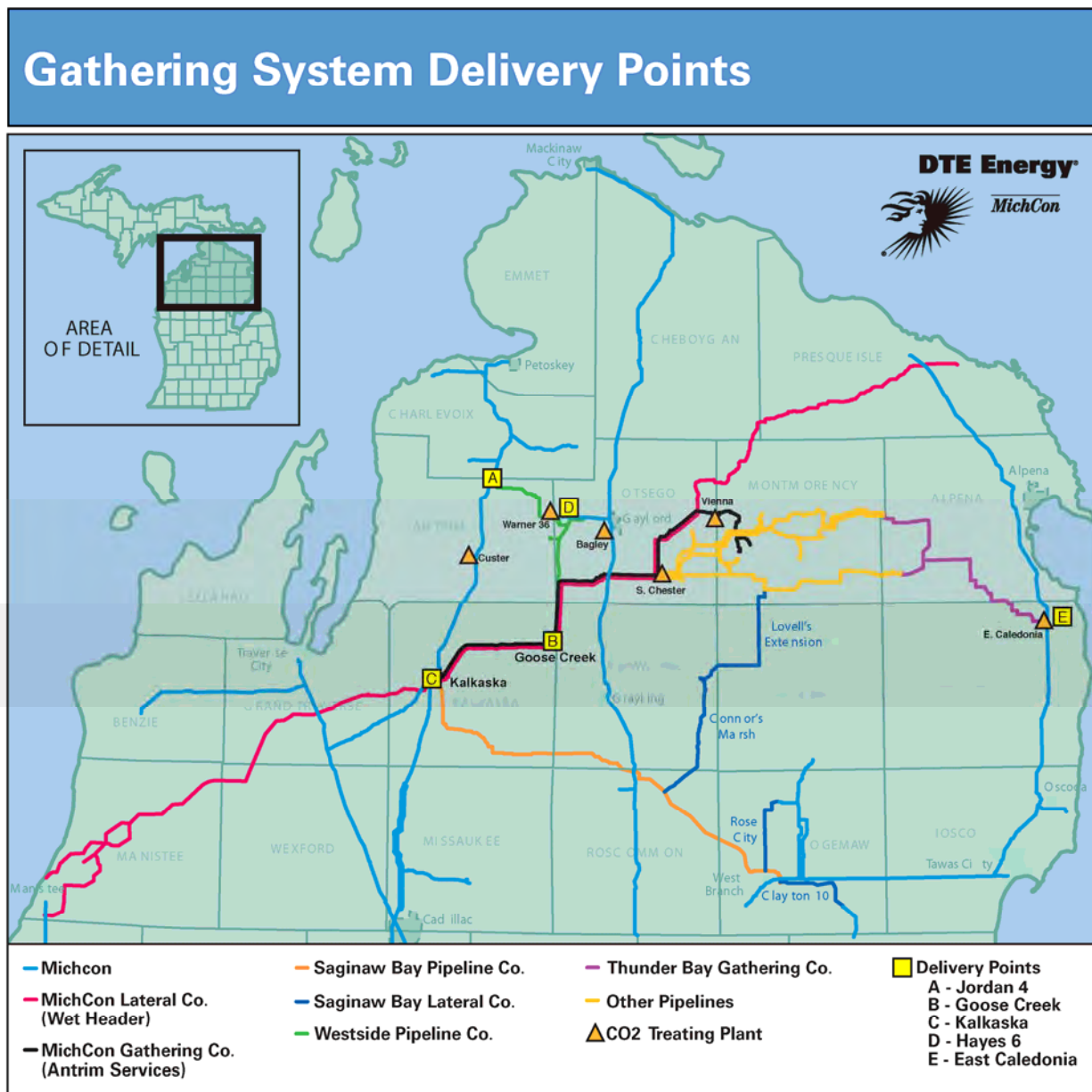


Figure 14-1. Map showing the locations of the pipelines, CO₂ Treating Plants (triangles), and Delivery Points (squares) under the operation of the MichCon Gathering Company.

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

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/>

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

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>).

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

http://www.michigan.gov/documents/deq/ogs-well-locations_222016_7.zip

Formations and Elevations

http://www.michigan.gov/documents/deq/ogs-oilandgas-formationtops_247657_7.zip

- 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*.

API_WellNo	Fmtn_Cd	Top_	TVD	Meth_Obtnd
------------	---------	------	-----	------------

21001522310000	ANRM	665	M
21001522310000	LAC	868	M
21001522310000	PAX	942	M
21001522310000	NOR	966	M
21001522310000	TRVR2	991	M
21007576980000	LAC	312	M
21007576980000	PAX	382	M
21007576980000	NOR	394	M
21007576980000	TRVR2	421	M

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.

Meth_Obtnd	Definition	BestMatch1st	BestMatch2nd
M	MTU	1	1
GLS	MIGS & Company & Sample Picks	2	3
GS	MIGS and Sample Picks	2	2
GL	MIGS & Company Log Picks	2	3
G	MIGS Picks	2	2
L	Company Log Picks	3	3
LS	Company & Sample Picks	3	3
S	Sample Picks	4	4
C	Well Card	5	5
	No Method	6	6

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

API	ExcludeReason
21079570510100	Horizontal Well - Incorrect TVD
21079576770000	Horizontal Well - Incorrect TVD
21101548880000	Deviated Well - TVD depths are for L picks, but G picks match log
21119576140000	Horizontal Well - No TVD
21119576140100	Horizontal Well - Incorrect TVD
21135471400200	Horizontal Well - No TVD

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

```
SELECT [well locations].WH_GeoRef_X, [well locations].WH_GeoRef_Y,  
[Elevations_Master].[Elevation]-[FormationTops].[Top_] AS LAC_SS,  
[Elevations_Master].[Elevation]-[FormationTops].[Top_] AS [LAC_SS-MD],  
[Elevations_Master].[Elevation]-[FormationTops].[TVD] AS [LAC_SS-TVD],  
FormationTops.API_WellNo, [well locations].Slant, FormationTops.Fmtn_Cd,  
FormationTops.Top_, FormationTops.TVD, FormationTops.Meth_Obtnd, [Method  
Obtained_MTU].BestMatch1st, Elevations_Master.Elevation INTO Structure_MI_LAC
```

```
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**)

```
SELECT Structure_MI_LAC.API_WellNo, Structure_MI_LAC.WH_GeoRef_X,
Structure_MI_LAC.WH_GeoRef_Y, Structure_MI_LAC.Slant,
Structure_MI_LAC.Fmtn_Cd, Structure_MI_LAC.Elevation,
First(Structure_MI_LAC.LAC_SS) AS FirstOfLAC_SS,
First(Structure_MI_LAC.Top_) AS FirstOfTop_,
First(Structure_MI_LAC.TVD) AS FirstOfTVD,
First(Structure_MI_LAC.Meth_Obtnd) AS FirstOfMeth_Obtnd,
First(Structure_MI_LAC.BestMatch1st) AS FirstOfBestMatch1st
```

```
FROM Structure_MI_LAC
```

```
GROUP BY Structure_MI_LAC.API_WellNo, Structure_MI_LAC.WH_GeoRef_X,
Structure_MI_LAC.WH_GeoRef_Y, Structure_MI_LAC.Slant,
Structure_MI_LAC.Fmtn_Cd, Structure_MI_LAC.Elevation;
```

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

```
SELECT MTU_Lachine_SubSea.API_WellNo, MTU_Lachine_SubSea.WH_GeoRef_X,
MTU_Lachine_SubSea.WH_GeoRef_Y, MTU_Lachine_SubSea.Slant,
MTU_Lachine_SubSea.Fmtn_Cd, MTU_Lachine_SubSea.Elevation,
MTU_Lachine_SubSea.FirstOfLAC_SS, MTU_Lachine_SubSea.FirstOfTop_,
MTU_Lachine_SubSea.FirstOfTVD, MTU_Lachine_SubSea.FirstOfMeth_Obtnd,
MTU_Lachine_SubSea.FirstOfBestMatch1st
```

```
FROM MTU_Lachine_SubSea
LEFT JOIN ExcludeFromMapping ON MTU_Lachine_SubSea.API_WellNo =
ExcludeFromMapping.API
WHERE (((ExcludeFromMapping.API) Is Null));
```

- 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

source.

```
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.FirstOfTop_ AS PAX_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.

```
UPDATE [ISO_LAC-PAX] SET [ISO_LAC-PAX].LAC_ISO = [PAX_MD]-
[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([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).

Additional references: Bailey and others (1991), Ells (1979), Dellapenna (1991), Harrell and others (1991), Martin and Straight (1956), Matthews (1993), Newcombe (1933).

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.

Source: Catacosinos, Paul A., William B. Harrison, III, David B. Westjohn, Mark S. Wollensak, and Robert F. Reynolds, 2001, "Stratigraphic Lexicon for Michigan", Bulletin 8, Lansing, Michigan, 2001, MDEQ Geological Survey Division and the Michigan Basin Geological Society, <http://www.deq.state.mi.us/documents/deq-ogs-gimdl-BU08.pdf>.

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".
- 1975:** Northern Michigan land & oil develops successful Antrim projects in Otsego County (29N-3W, 30N-2W).
- 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 in 1992 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"*

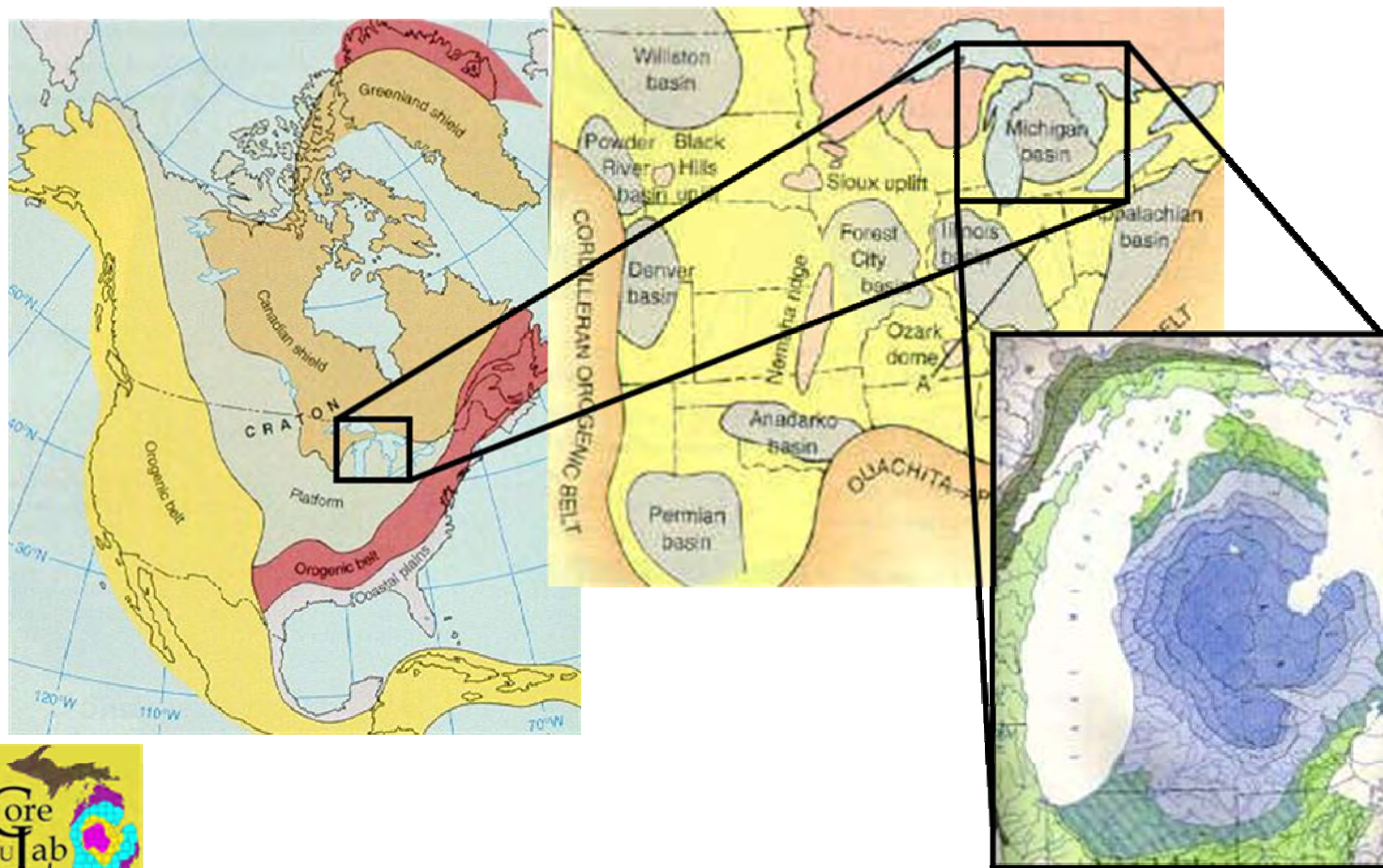


Figure 17-1. Geologic Setting of the Michigan Basin.

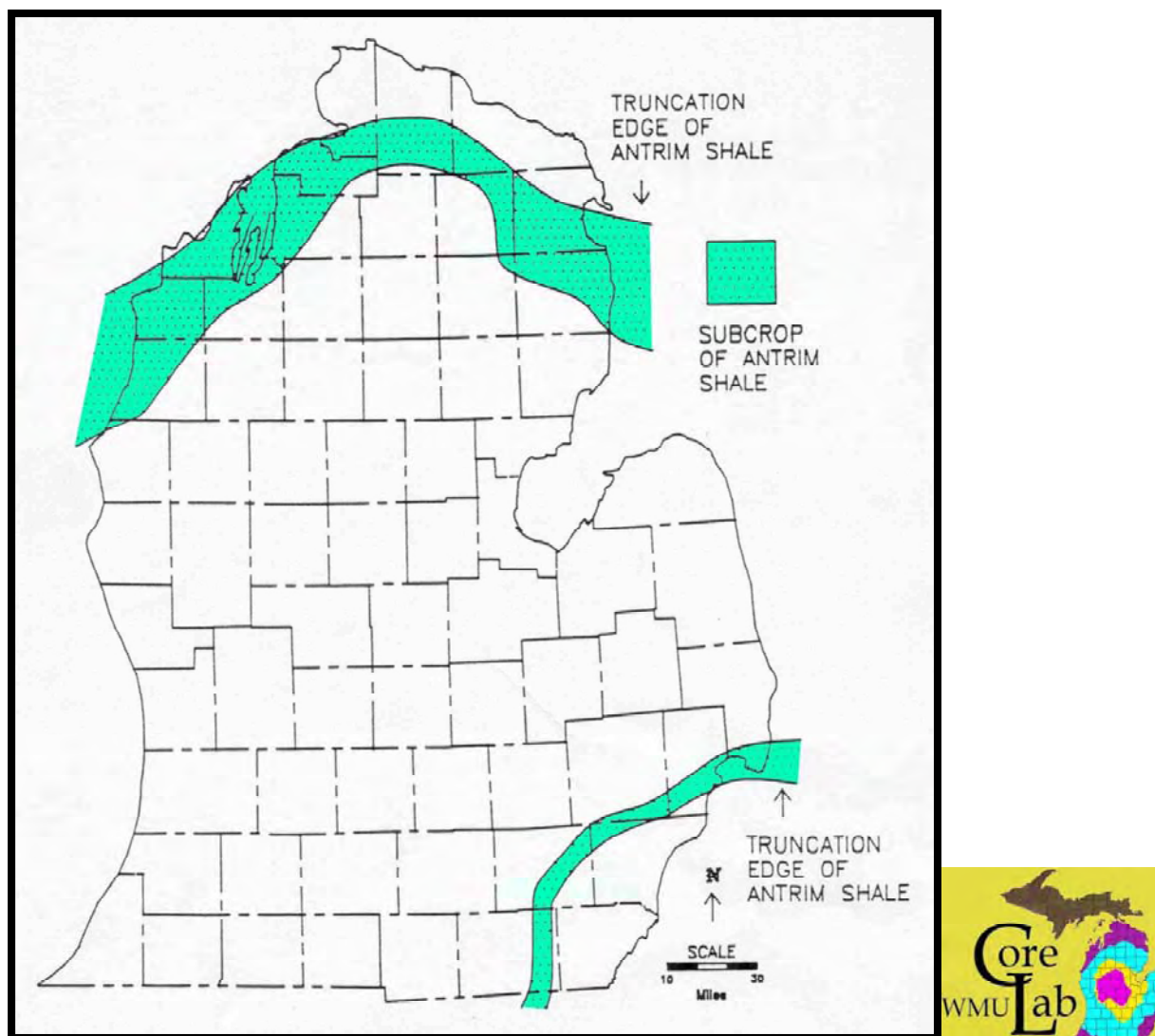


Figure 17-2. Subcrop area of the Antrim Shale in Michigan.

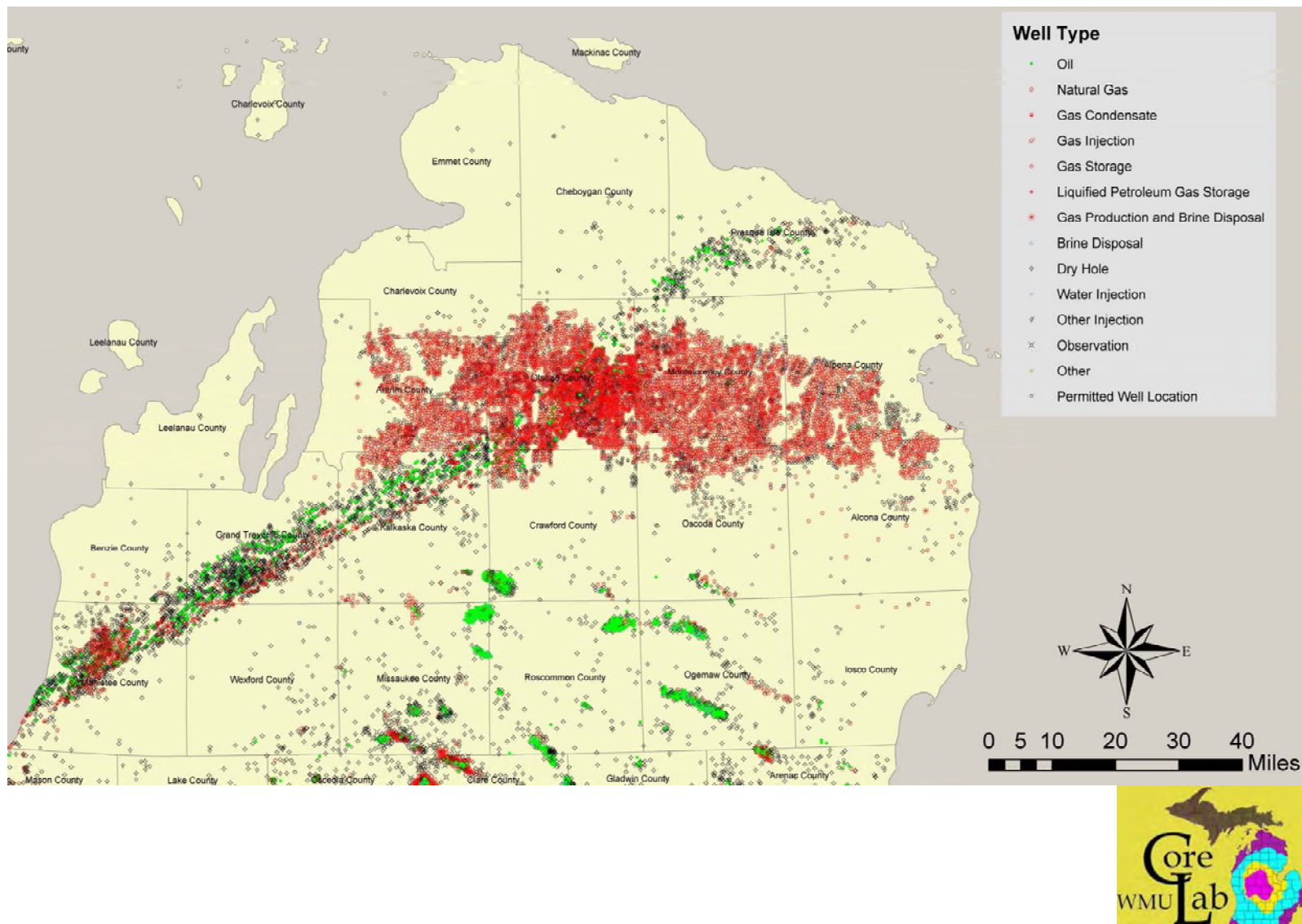


Figure 17-3. Oil and Gas Well Locations in Northern Michigan.

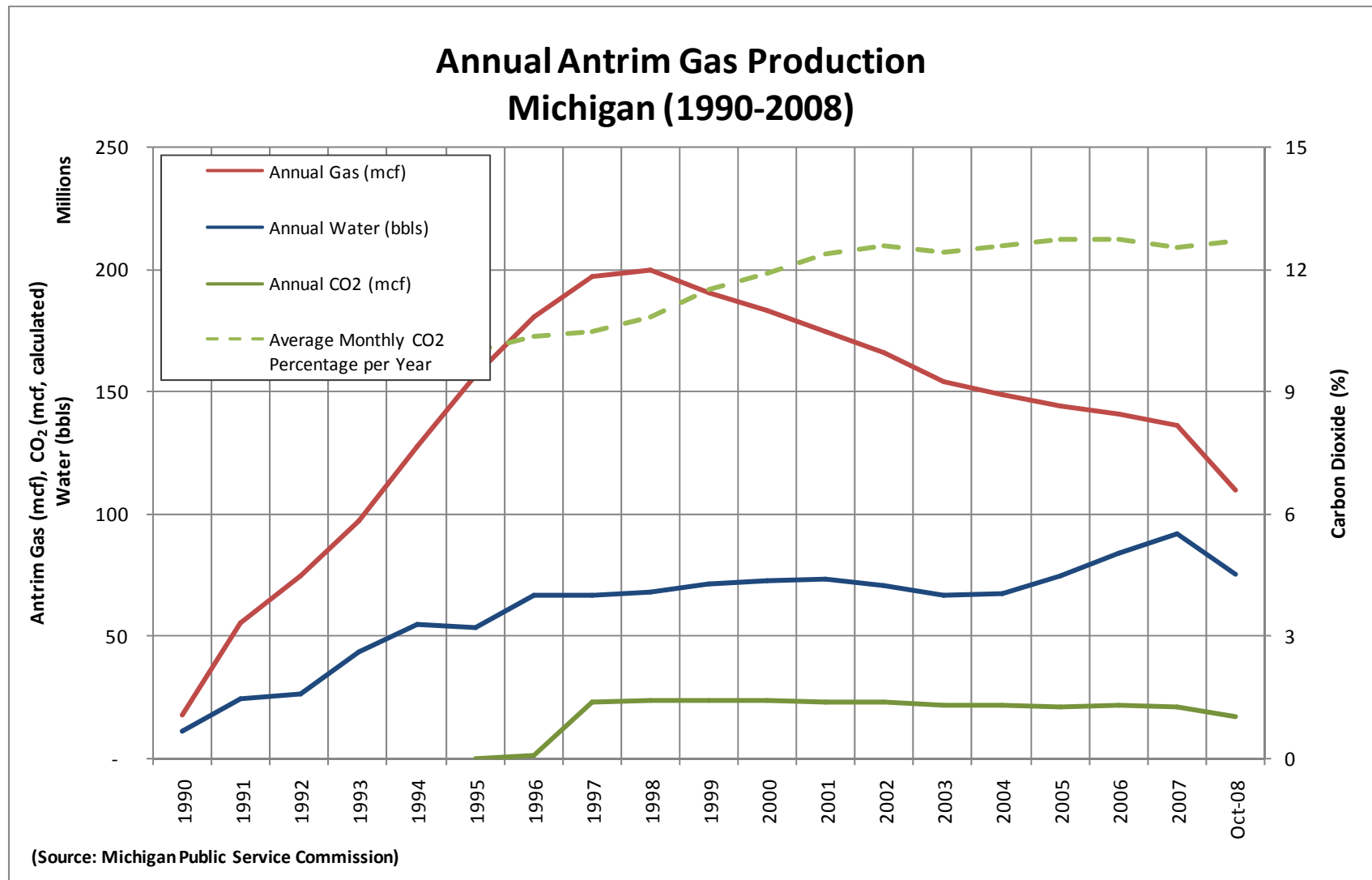
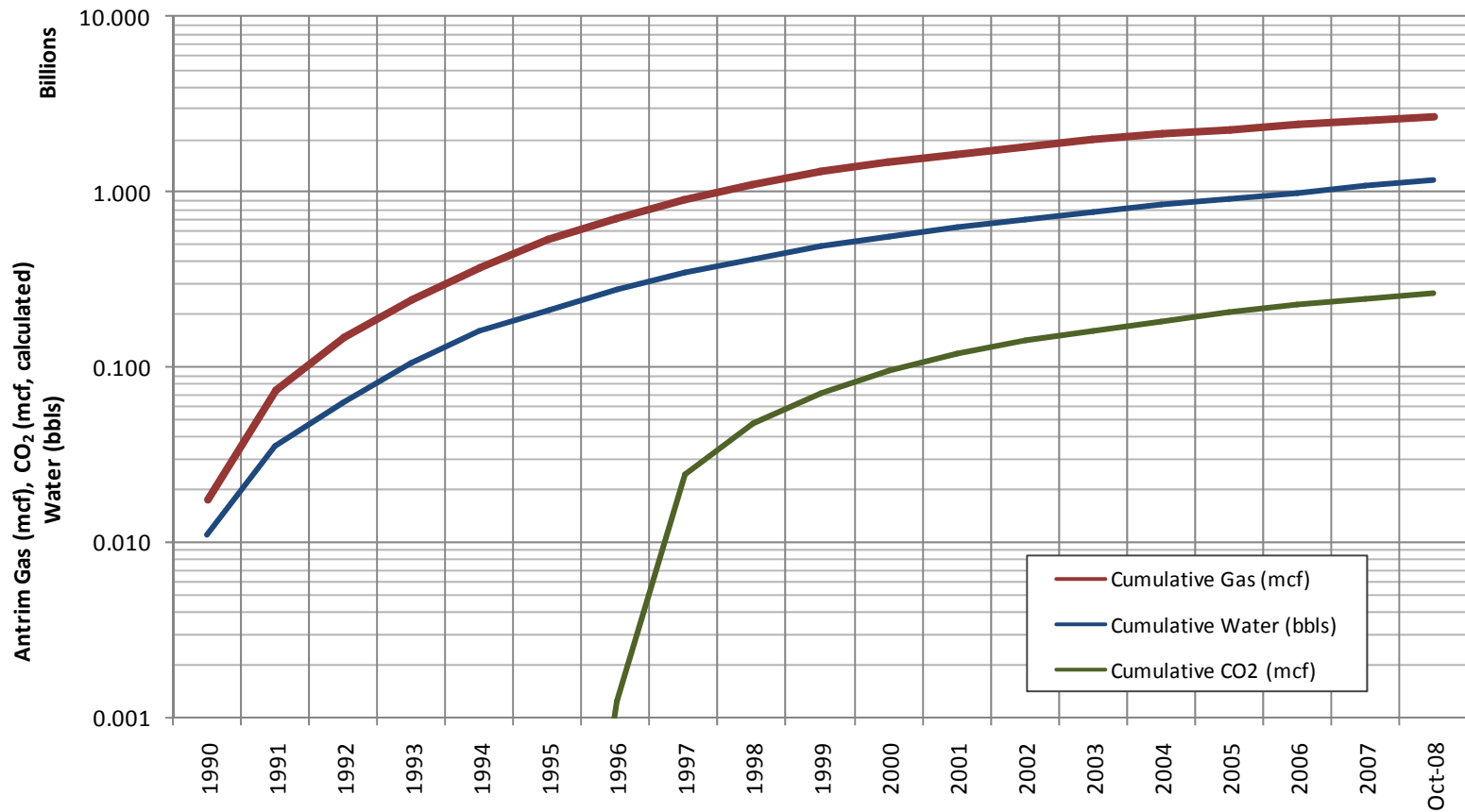


Figure 17-4. Annual Antrim gas (mcf) production in Michigan with associated water (bbls) carbon dioxide (mcf) and percentage of CO₂.

Cumulative Antrim Gas Production Michigan (1990-2008)



(Source: Michigan Public Service Commission)

Figure 17-5. Cumulative Antrim Gas (mcf) production in Michigan with associated water (bbls) and carbon dioxide (mcf).

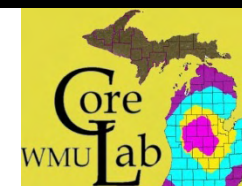
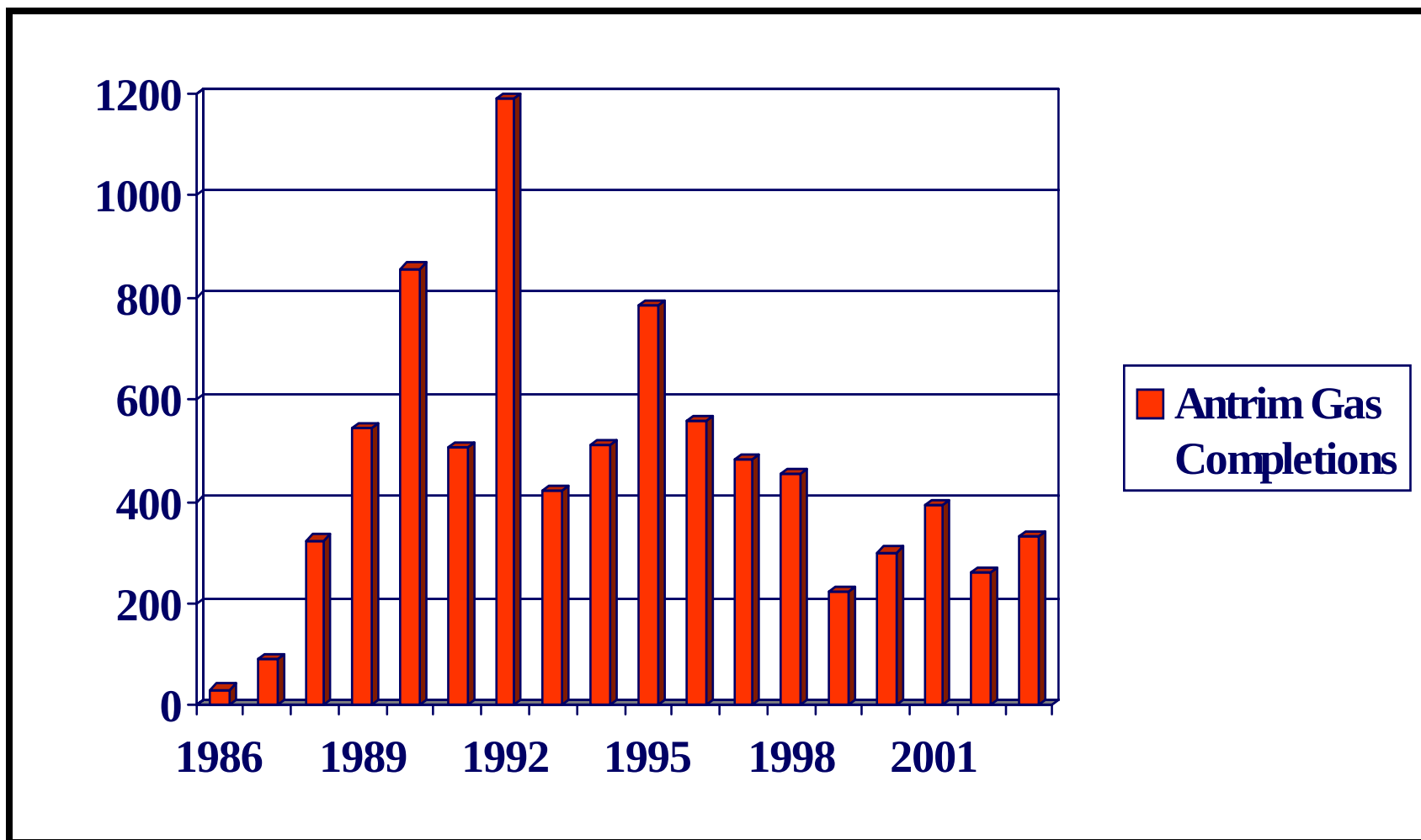


Figure 17-6. Number of Michigan Yearly Antrim Completions.



Figure 177-7. Antrim Surface Production and Processing Facilities.



Michigan Basin Core Research Laboratory

Western Michigan University, Kalamazoo, MI 49008

Log ID: **Murell Welch - St. Chester #18 - P#33875**

Total Depth: **1730 feet**
 Location: **NW,SE,NW 13-29N-2W**
 Latitude: **NOT AVAILABLE**
 Longitude: **NOT AVAILABLE**
 Hole Diameter: **8 5/8" to 780' and 4 1/2" to 1726**
 Elevation (Ground Surface): **1258.8 ft. (KB)**
 Drilling Date: **Started July 29, 1980, Completed September 4, 1980**
 Drilled By: **Michigan Consolidated Gas Company**
 Lithology Logged By: **Tim Dellapenna**
 Geophysical Log Operator: **Schlumberger**

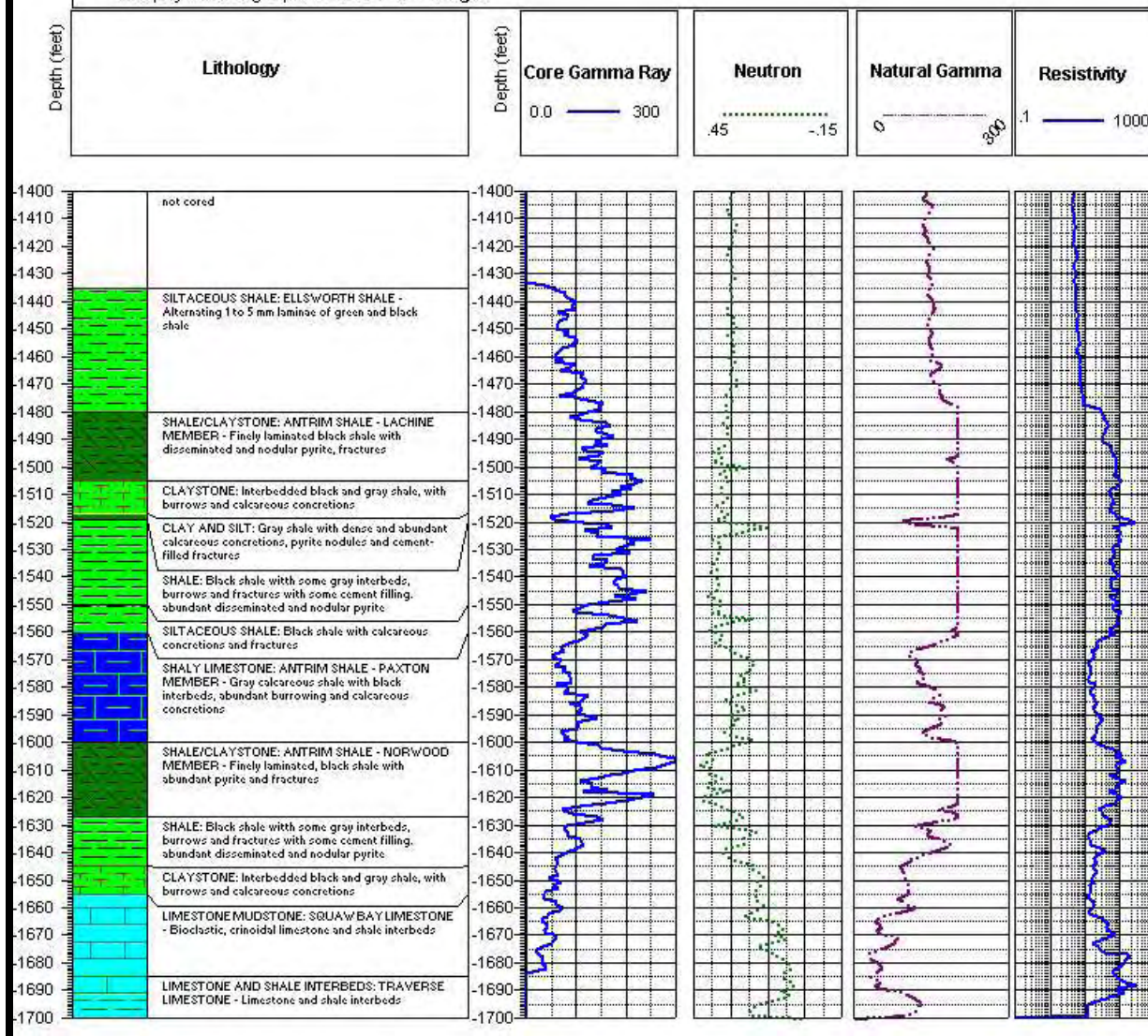


Figure 17-8. Core and Log Analysis of Murell Welch - St. Chester #18 in Otsego County, Michigan.

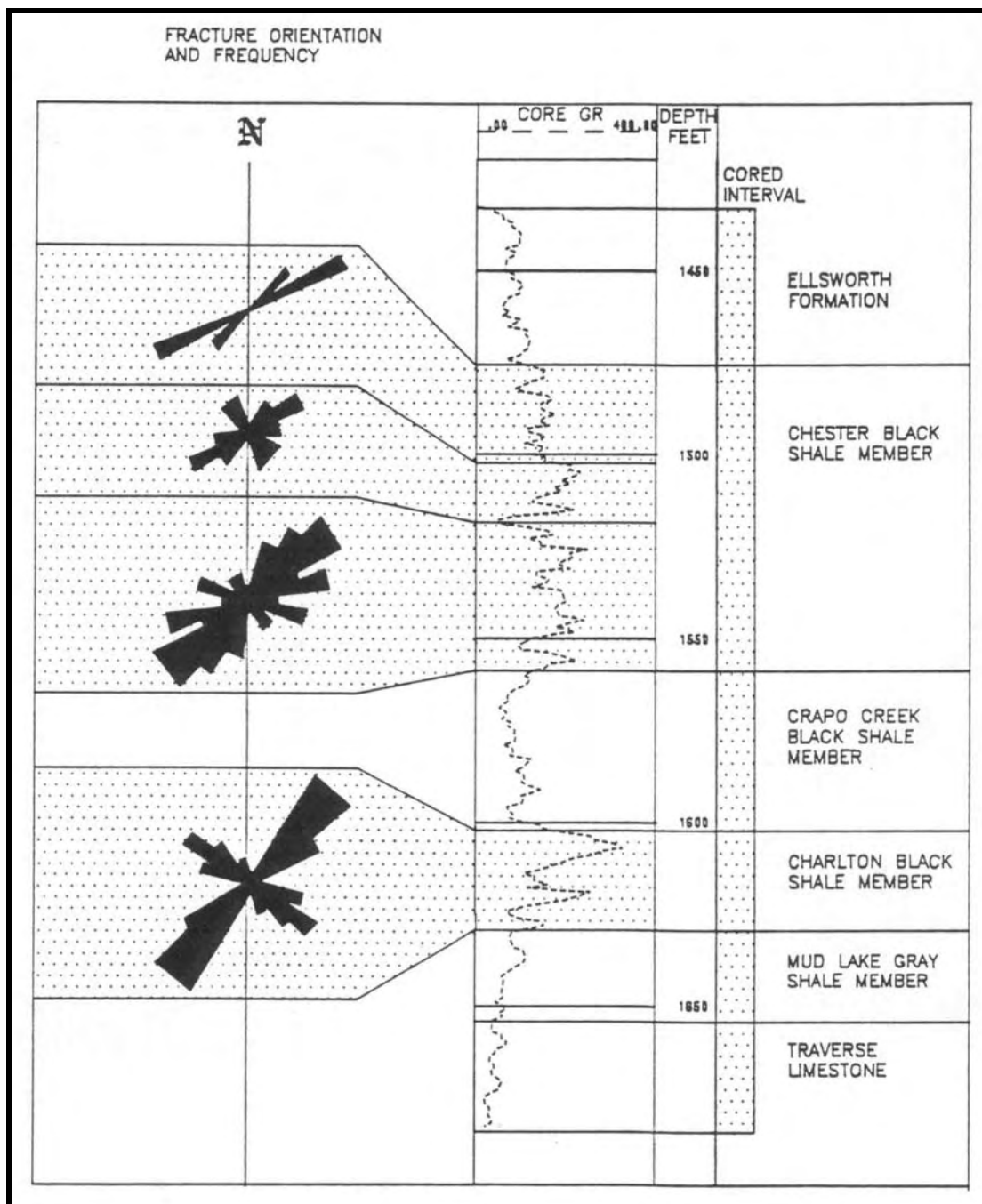


Figure 17-9. Fracture Orientations for Murell Welch - St. Chester #18 Core in South Chester Township, Otsego County, Michigan (from Dellapenna, 1991).

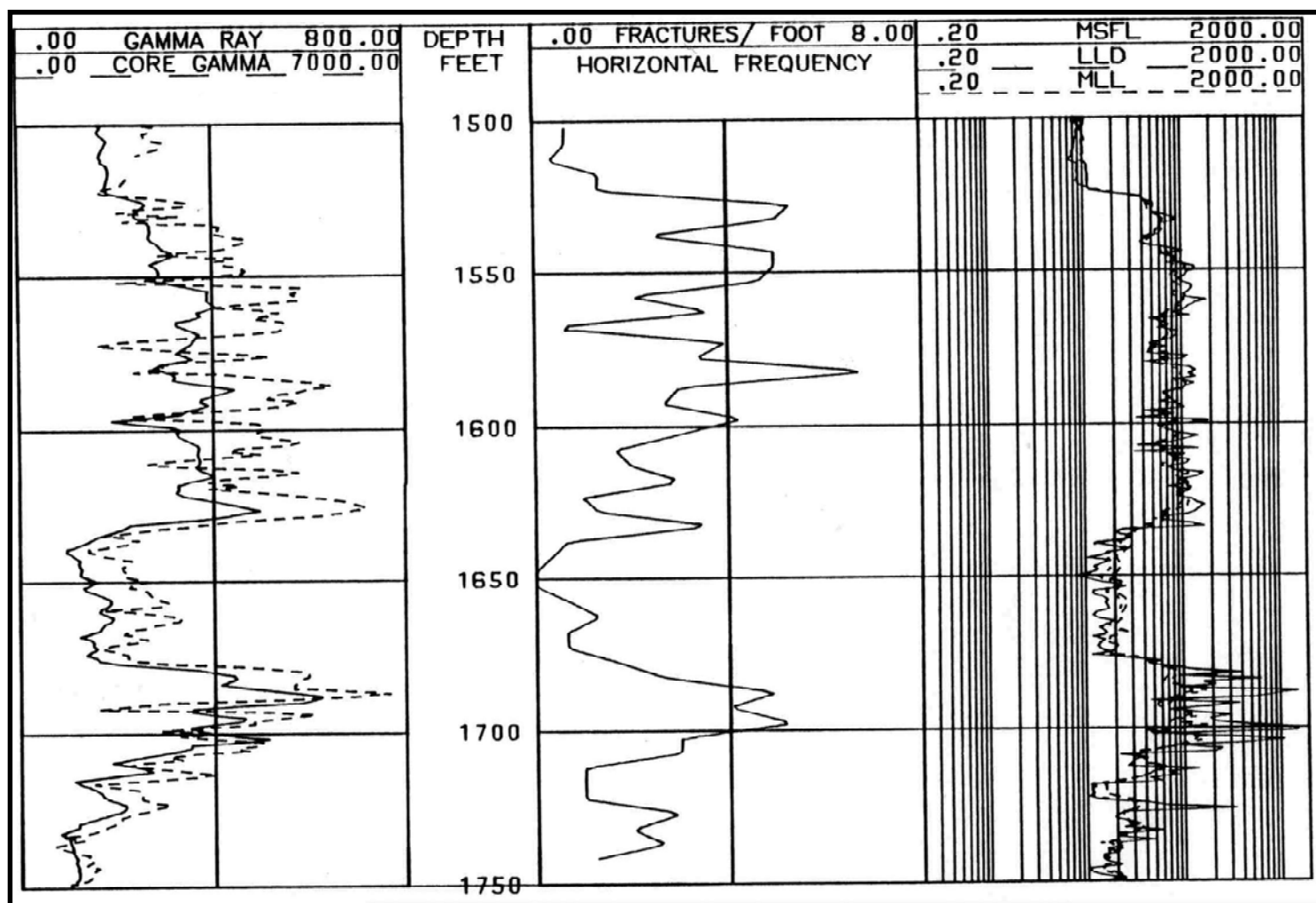


Figure 17-10. Fracture Analysis Data for Murell Welcha - St. Chester #18 Core in South Chester Township, Otsego County, Michigan (from Dellapenna, 1991).

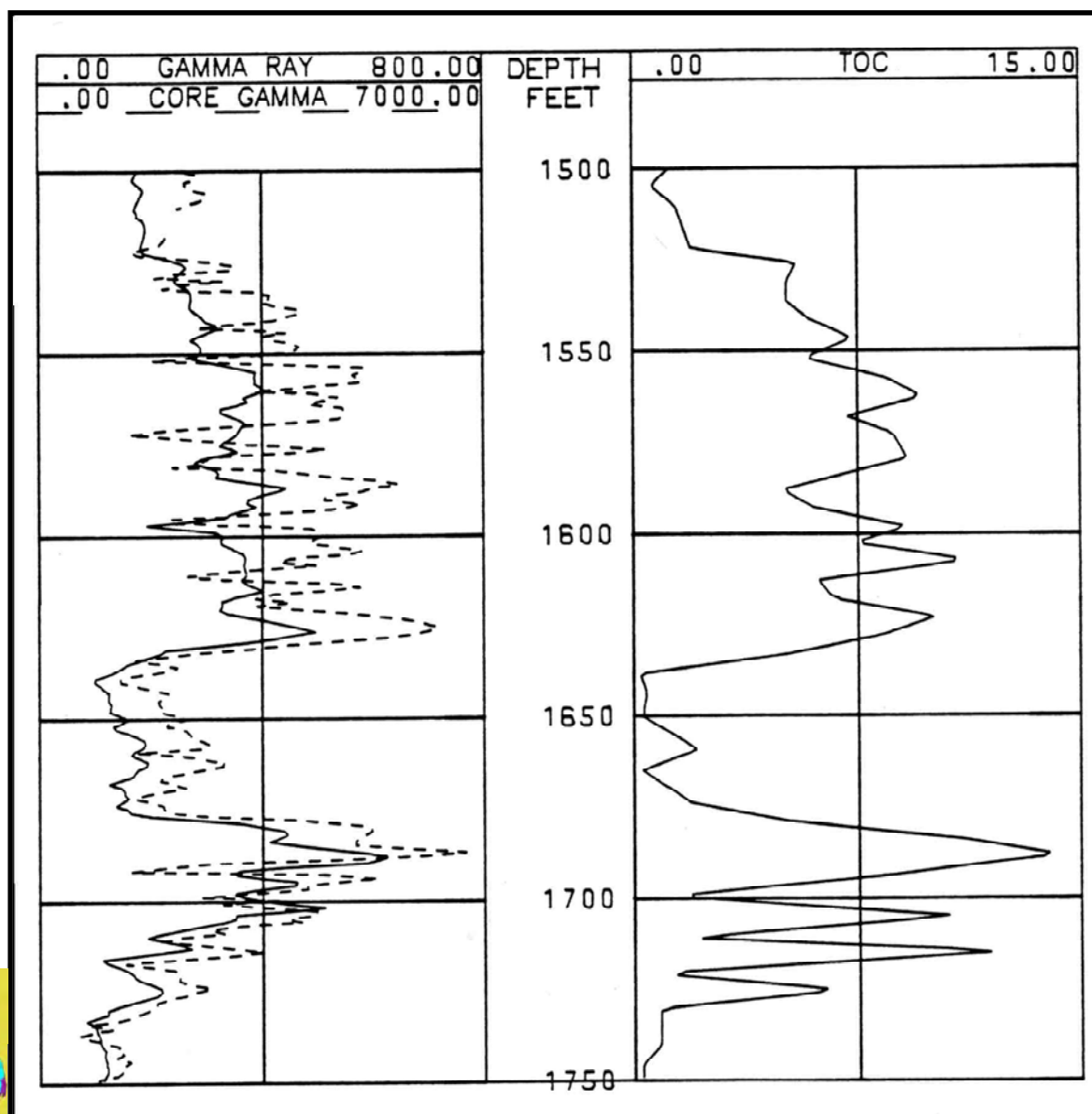
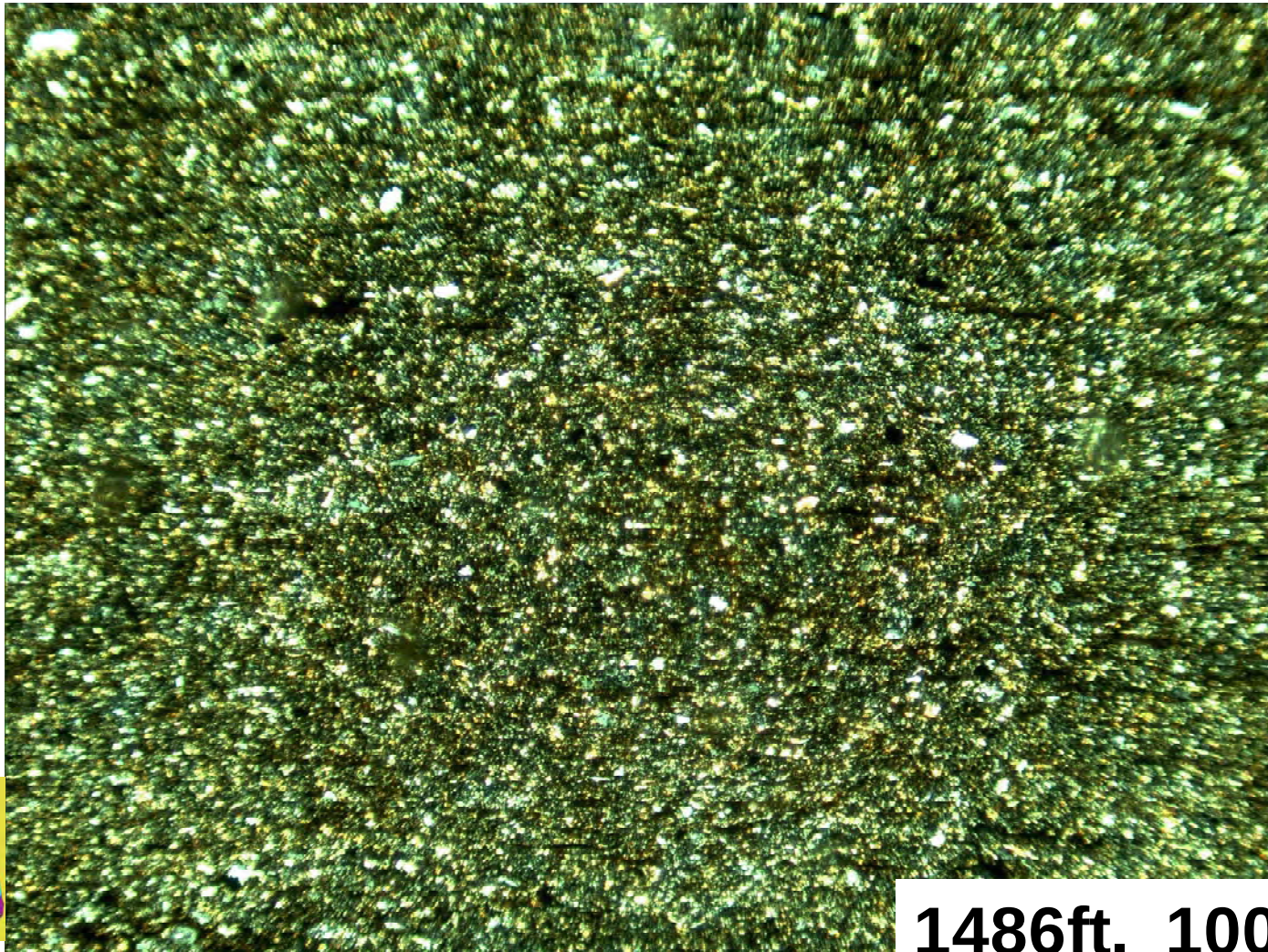


Figure 17-11. Total Organic content from Latuszek B1-32 in Otsego County, Michigan (from Dellapenna, 1991).



Figure 17-12. Core photo of Lachine Member.



1486ft. 100X

Figure 17-13. Thin Section of lachine member in Welch - St. Chester #18 in Otsego County, Michigan.

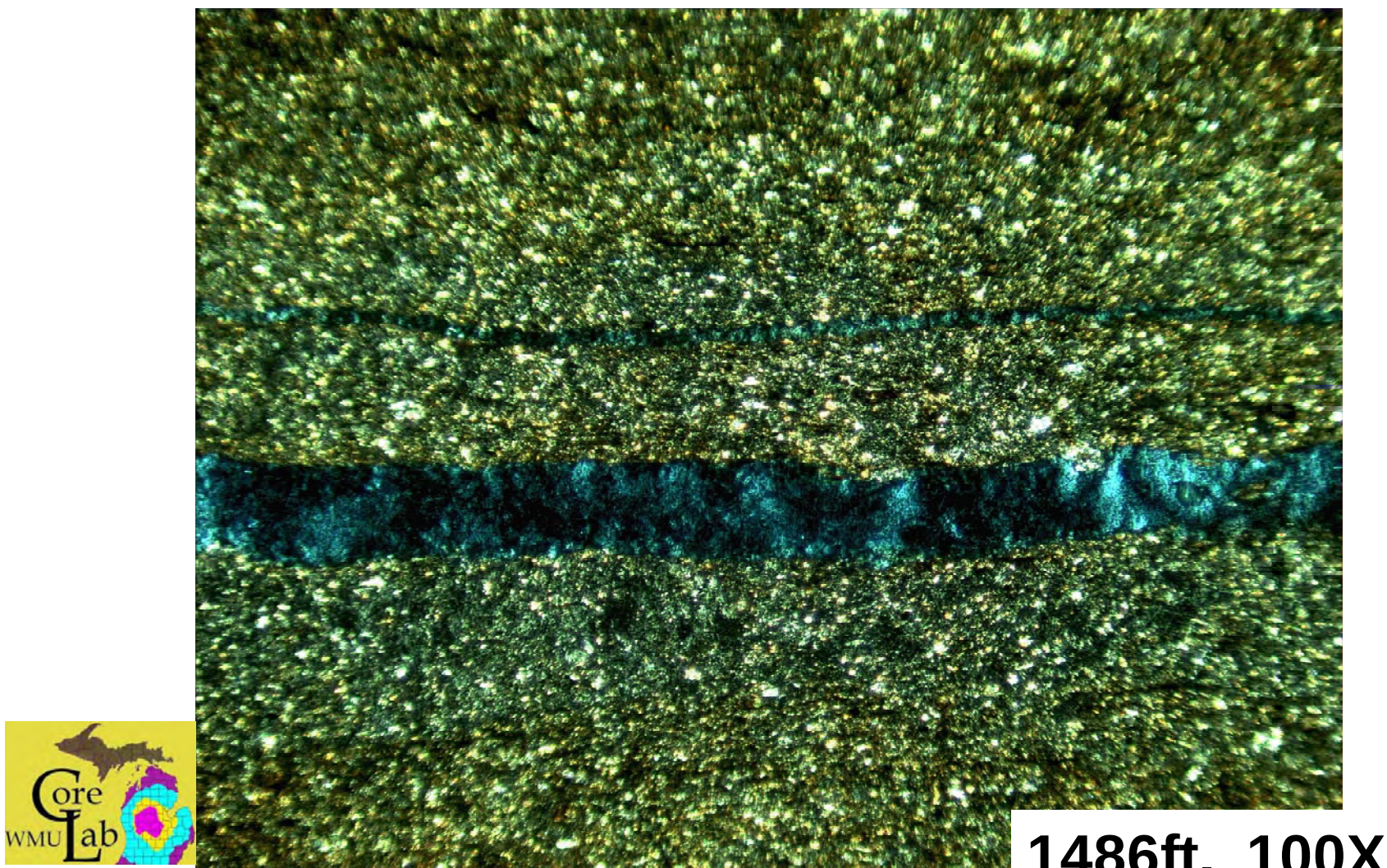


Figure 17-14. Thin Section of lachine member in Welch - St. Chester #18 in Otsego County, Michigan.

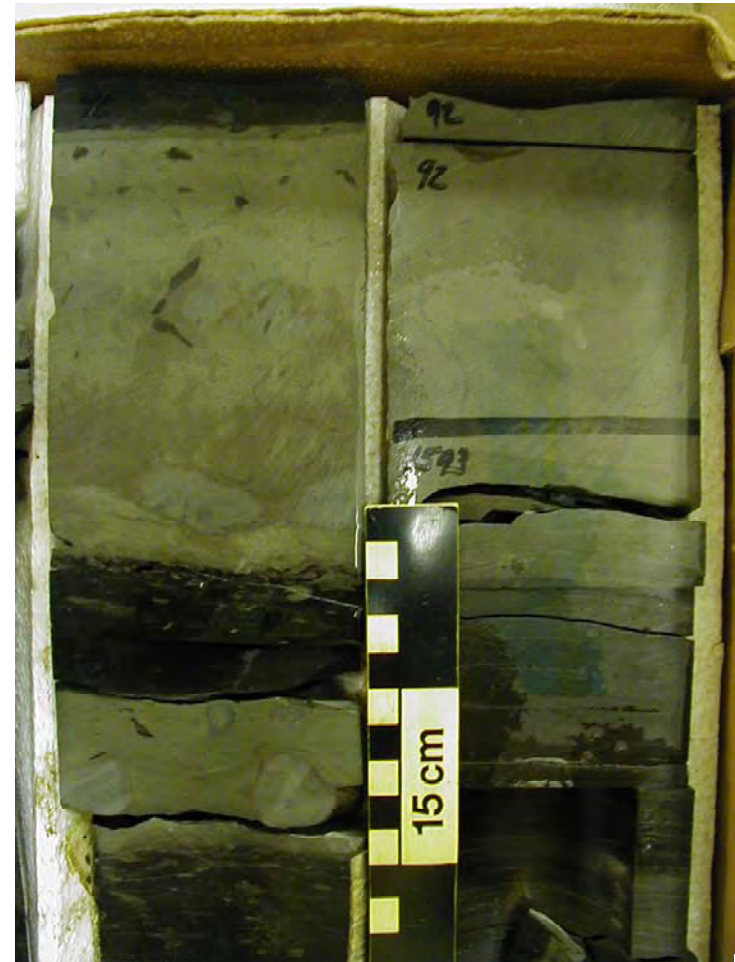
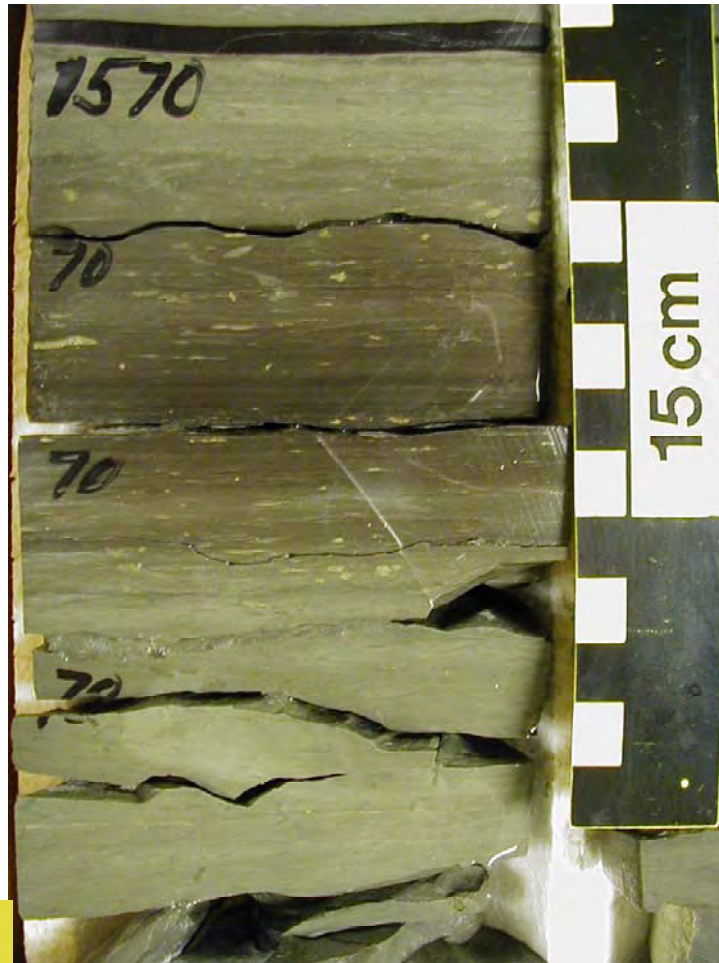
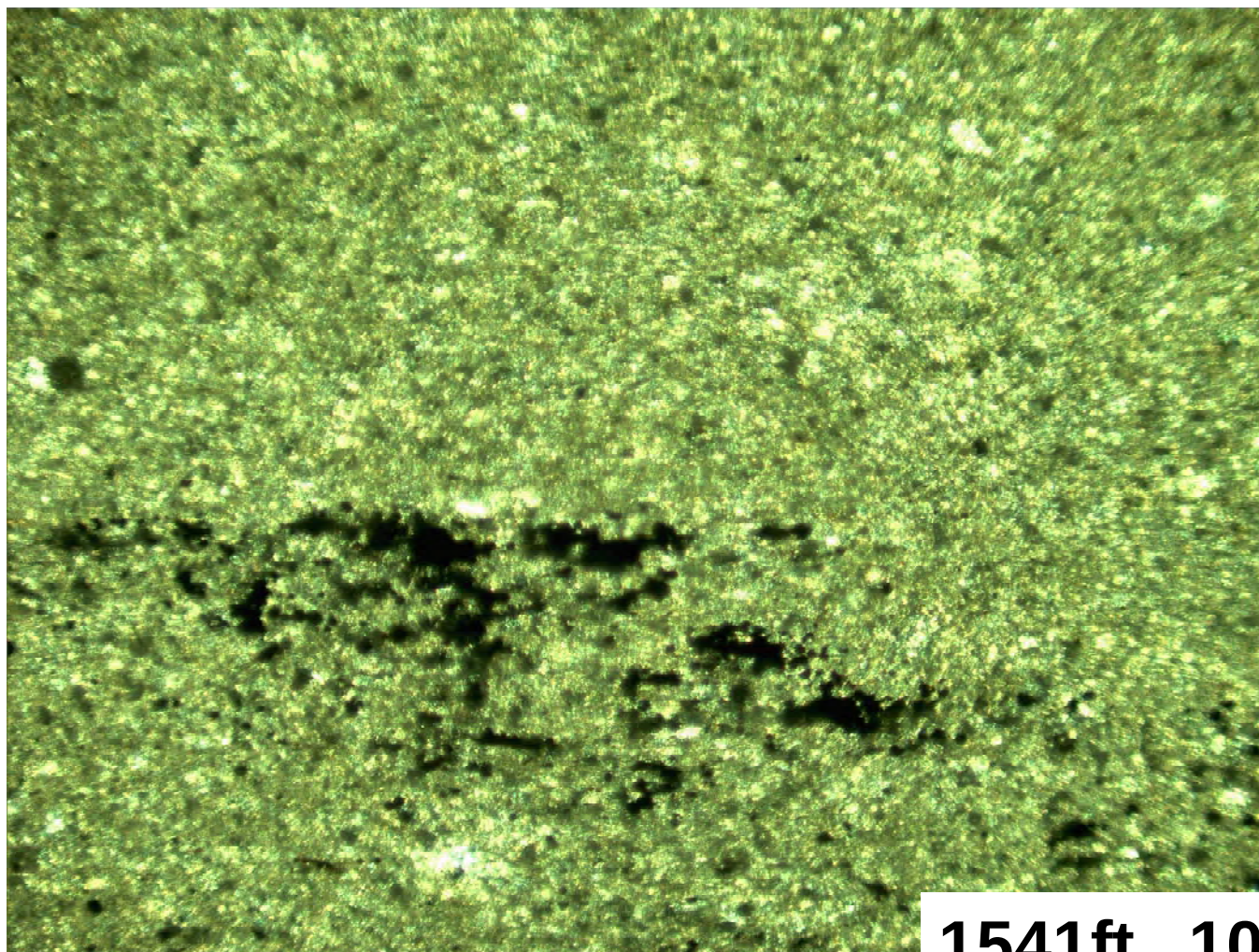


Figure 17-15. Core photo of Paxton member, a lighter gray shale.



1541ft. 100X

Figure 17-16. Thin Section of paxton member in Welch - St. Chester #18 in Otsego County, Michigan.

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