Michigan’s Antrim Gas Shale Play—A Two-Decade Template for Successful Devonian Gas Shale Development*

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Abstract

Although key wells drilled by early visionaries from the 1940’s to 1960’s proved play viability, it was not until the late 1980’s that Michigan’s Devonian Antrim Shale play established a strong economic foothold. The combination of improved completion technology, regional pipeline capacity seeking new gas in the twilight of the Niagaran pinnacle play, and non-conventional gas tax incentives led to a dramatic burst in Antrim development roughly 20 years ago. Today, over 9,000 completed wells in 700+ discrete projects across a 12-county northern Lower Michigan fairway bear testimony to a successful play that defines one of the ten largest gas fields in the United States. Earlier in 2007, Antrim gas sales exceeded the 2.5 TCF mark.

The Antrim, while producing from the same Upper Devonian sequence that defines many North American non-conventional gas plays, has some fundamental differences from most of the others. Antrim gas pays are shallow (500-2000’); the gas is chiefly biogenic, with Antrim thermal maturities generally below levels required for methanogenesis. Significant associated water is produced, particularly early in a well’s history, resulting in a typical project design where multiple wells feed a central production facility for dehydration and compression.

While essentially all play fairway wells with a preserved Antrim section result in economic completions, areas of enhanced recovery are identifiable through geological and engineering studies. The ultimate performance level of Antrim wells and projects is defined by combining the innate regional geology and reservoir characteristics with surface topography, flowline mechanics, and operational astuteness.
Michigan’s Antrim Gas Shale Play: A Two-Decade Template For Successful Devonian Gas Shale Development

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Today’s Talk

1. History
2. Geologic Setting
3. Biogenic Gas
4. Production and Engineering
Geologic Setting of the Michigan Basin
CUMULATIVE MICHIGAN ANTRIM PRODUCTION

1989-2007

END 2007: CUM. 2.6 TCFG
Roots of the Antrim Shale Play in Northern Michigan
(Pt. 1)


Roots of the Antrim Shale Play in Northern Michigan (Pt. 2)


- 1992: Expiry of NCF Credit-Eligible Wells on 12/31/92 Triggers Antrim Drilling Peak (1189 Compl. Wells)

WELLS DRILLED BY TARGET DEPTH, 1985-2007

DEEPER HORIZONS, INCLUDING NIAGARAN TRAVERSE (CHIEFLY ANTRIM) AND SHALLOWER
Antrim Development Has Focused on Several Counties in Northern Lower Michigan
100 miles
Development History - 1986
Development History - 1992
Development History - 1998
Development History - 2008
Antrim Gas Fields--Relation to Subcrop
Antrim Shale, Paxton Quarry, Alpena
Lachine Member

High TOC’s and Significant High Angle Fracturing
Paxton Member

Calcareous Mudstones, Limited Organic Material
Total Organic Content

Latuszek B1-32, Otsego Co., MI (from Dellapenna, 1991)
Fracture Orientations

Welch-St. Chester #18 Core, South Chester Twp., Otsego County (from Dellapenna, 1991)
Whither the Fractures?

- Terrane Boundaries (NE-SW)(Grenville Front)
- Mid-Continent Rift (NW-SE)
- Paleozoic Tectonics (Chiefly NW-SE)
- Post-Glacial Isostatic Rebound (Enhanced Near Subcrop)
- Hydraulic Pumping
NORTH AMERICAN BASEMENT TECTONIC TRENDS

(After Sanford)
• University of Michigan research

• Large component of producing trend gas

• Mixing zone of meteoric waters along subcrop & deeper brines

• Active methanogenesis in progress

• Thermogenic component increases basinward
Biogenic Gas

Microbial Sampling

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Steve Petsch (Univ. of Mass. - Amherst)
Klaus Nusslein (Univ. of Mass. - Amherst)
CH$_4$ - Methane ($C_1$)

$C_2H_6$ - Ethane ($C_2$)

$C_3H_8$ - Propane ($C_3$)

### Natural Gas Basics

<table>
<thead>
<tr>
<th>km</th>
<th>Hydrocarbon Maturity</th>
<th>Max-T $^\circ$C</th>
<th>Vitrinite Reflectance $R_o$ (%)</th>
<th>Hydrocarbon Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<td></td>
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<td>Microbial Methane</td>
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<tr>
<td>1</td>
<td>Methane</td>
<td>60</td>
<td>0.5</td>
<td></td>
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<td>2</td>
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<td>130</td>
<td>1.3</td>
<td>Oil</td>
</tr>
<tr>
<td>3</td>
<td>Ethane &amp; Propane</td>
<td></td>
<td></td>
<td>Wet Gas</td>
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<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>Hi Temp. Methane</td>
</tr>
</tbody>
</table>

- **Natural Gas Basics**
- **Martini**
• Thermogenic vs. Microbial

Concentration: $C_2$ & $C_3 = $ Thermogenic

Isotopic Fractionation: $^{13}C/^{12}C$

Carbon isotope ratios, defined

$$\delta^{13}C = \frac{^{13}C/^{12}C_{sample} - ^{13}C/^{12}C_{std}}{^{13}C/^{12}C_{std}} \times 1000$$

$\delta^{13}C$ values presented in units of permil ($‰$)

**Typical $\delta^{13}C$ Values**

Devonian Organic Matter: $-29‰$

Limestone: $\sim0‰$

Methane from methanogens is extremely depleted in $^{13}C$, $70‰$ more than the CO$_2$ source usually $<-60‰$

*Methane from Thermogenic sources $>-50$ and increases with thermal maturity*
Antrim Shale Gas Composition

Microbial gas

$$\frac{C_1}{[C_2 + C_3]}$$

$$\delta^{13}C_{CH_4} \text{ (‰, VPDB)}$$

Northern Producing Trend (NPT)
Western Producing Trend (WPT)
Southern Producing Trend (SPT)
Central Producing Trend (CPT)
Eastern Producing Trend (EPT)
Spatial Relations of Salinity and Alkalinity

Martini
Carbon Systematics of Antrim Shale Fluids

Martini

![Graph showing Alkalinity (meq/kg) vs. δ¹³C DIC (‰, VPDB) with data points for different producing trends.](image)

- Basinal brine
- Microbial methanogenesis
- Northern Producing Trend (NPT)
- Western Producing Trend (WPT)
- Southern Producing Trend (SPT)
- Central Producing Trend (CPT)
- Eastern Producing Trend (EPT)
Microbial pathway for methane generation

CO₂ Reduction:
\[ \delta D_{\text{CH}_4} = \delta D_{\text{H}_2\text{O}} - 160 \] (Schoell, 1980)

Northern Producing Trend (NPT)
Western Producing Trend (WPT)
Southern Producing Trend (SPT)
Central Producing Trend (CPT)
Eastern Producing Trend (EPT)
Conclusions:

- Antrim Shale shallow margin gas plays dominated by microbial gas, associated with relatively dilute formation waters.
- Genetic link between dilute formation waters and microbial methane.
- Glacial meltwater recharge suppressed the basinal brine salinity, creating an environment conducive to microbial methanogenesis.
- Microbes significantly modified the formation water and gas chemistry.
- Identified microbial community and major processes responsible for microbial methane.
Production & Engineering Aspects
Antrim Units

100 miles

722 Active Projects, 33 Operating Companies
Top 5 Operators Control 50% of Production
Typical Antrim Project

Central Production Facility (compressor, disposal)

Several wells (avg. 13)

~$350K per well (w/ facility)

Peak water in 5 mo. (110 BWPD)

Peak gas in 20 mo. (125 MCFD)

Well Spacing (40-160 Acres)

EUR of ~500 MMCF per 80 acres
Completions

Early wells open hole in Lachine only (thought water was from Traverse)

Wells now cased & selectively perforated through spot acid

Multi-stage Fracs the rule

N₂ Foam, 25-50K lbs 20/40 sand

Various schemes for HD wells

Operators use innovative strategies from the Antrim and other gas shale plays
LIFT SYSTEMS

• Free Flow
• Gas Lift
• Beam Pump
• Progressive Cavity
• Electric Submersible
Michigan’s Antrim Shale Resource, 2008

• 9382 Producing Wells in 12 Northern Michigan Counties

• 722 Producing Antrim Projects

• Current Prod. 368 MMCFGPD (39 MCFD/Well)

MPSC, Dec 2007 Data
Production Highlights

• 2.6 TCFG
  Through 2007

• 1.1 TBW Prod
  (1 BW/2.4 MCFG)

• Peak Prod’n: 1998
  (546 MMCFGPD)

• Ann. Decline 4-5%
  Since 1998 (Per Well Decline Rate 9%)
Annual Antrim Gas Production

BCF / MCFD

1000+ Wells

200 BCF

9000+ Wells


BCF
MCFD
Wells
Peak Gas Rate (MCFD/well)
Current Gas Rate (MCFD/well)
Local Production Variation

- Gas & Water Rates Per Well Show Variability Within Projects
- Productive Sweet Spots Often Link with Fracture Intensity
- Trends Follow Major Fracture Directions
Imaging Logs, MDC Big Wolf Lake Project (CBIL, CAST, UBI Fracture I.D. Logs)
Muskegon, Big Wolf Lake: Current Production
(Western Montmorency CO, Michigan)
Muskegon, Big Wolf Lake: Current Production

Fracture Trend Lines
Correlation of Bedrock Scours and Drainage

- Many Modern Drainage Systems Follow the Post-Glacial Scours
- Produced Antrim Water is in Part a Function of Subcrop Proximity
Peak Water Rate (BWPD/well)
Current Water Rate (BWPD/well)
Cumulative Water (MBbls/80 Acres)
Specific Gravity of Disposed Water

A Reduced Fracture Regime + Heavier Water Have Impeded Downdip Success
CO$_2$ Issues:
Production-Enhanced Recovery-Sequestration
CO₂ is a Naturally Occurring By-Product Of Shale Gas Produced By Desorption

DTE Antrim Gas Plant, Chester Twp., Otsego County
CO₂ Levels in Produced Antrim Gas Start Low, But Steadily Grow During A Well’s Productive Life, Eventually Topping 30% in Some Areas

Core Energy CO₂ Plant Otsego County
CO₂ Percentage: 1998
CO₂ Percentage: 2008
Today, Antrim Gas Processing Vents about 3000 Tons of CO$_2$ to the Atmosphere Daily (1100 kt/year)

While Significant, this Volume is Minor Compared to Amounts Vented by Coal-Fired Power Plants, Cement Plants, and Other Industrial Applications

Antrim Gas Processing Plant
Southern Otsego County, MI
Core Energy (Traverse City, MI) Uses Antrim CO₂ for Tertiary Flood Projects in Several Niagaran (Silurian) Pinnacle Reef Fields in Otsego Co., MI

Core, Pomerzynski 6-33 CO₂ Injector Drilled 2007

Core has Injected over 650,000 Tons of CO₂ Since the Inception of Its Enhanced Recovery Projects
A Pilot Project is Underway to Determine the Feasibility of Sequestering Antrim CO$_2$ in Northern MI’s Siluro-Devonian Carbonates

- Bois Blanc and Bass Islands deep saline formations primary target
- Detroit Group shale and salt layers provide containment
- Injection well and monitoring wells completed
Michigan’s Antrim Shale Play: What’s Ahead?

Logging an Antrim Well, Otsego County
Optimization in Existing Units

- Re-Fracs
- Minimizing Back Pressure
- High Angle & HD wells
- Twin Wells in Upper Antrim
- Re-Injecting CO₂ for Profit?
- Microbe Enhancement?
• Most Attractive Areas In Northern MI are Largely Developed

• Analogous Areas In SW and SE MI Have Undefined Potential (& Questions)

• Potential of High-TOC Deep Basin Antrim Shale is Relatively Unknown—it Has Not Been a Target
• At Current Play Decline Rate, Cumulative Prod. Will Nearly Double to 4.4 TCFG by 2030

• Technology, Price, and Wildcatting Could Significantly Change the Forecast
Global Warming Discussions Aside, this Picture defines the Value Of Shale Gas Energy to the Continued Healthy Economy of N. America
References


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