

Structural Controls on Migration and Evolution of Antrim Shale Gas in the Michigan Basin



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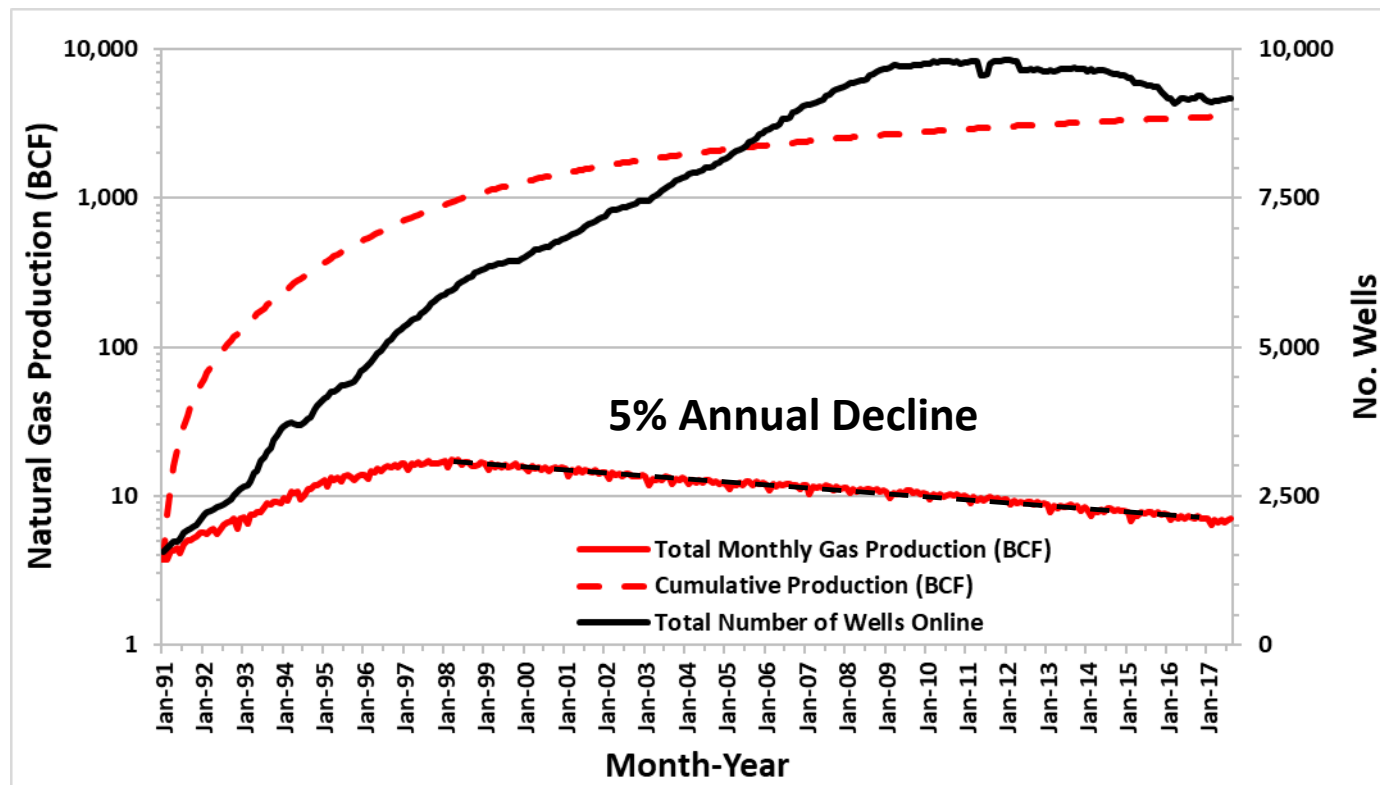
Background | Geologic Context | Observations & Hypothesis | Data & Results | Interpretations

- **Background:**
 - Initial Research Questions
 - Significance
 - Problem
 - Purpose of Study
- **Geologic Context:**
 - Late Devonian – Michigan Basin
 - Antrim Shale Deposition
 - Lithological Properties
 - Hydrocarbon Potential
 - Fracture Distribution
 - Microbial Gas Production
- **Observation & Hypothesis**
- **Data & Results:**
 - Data Acquired
 - Subsurface & Surficial Geology
 - Formation Water
 - Gas Composition
 - Gas Volume
 - Faults & Fractures
- **Interpretations:**
 - Conceptual Model

Questions:

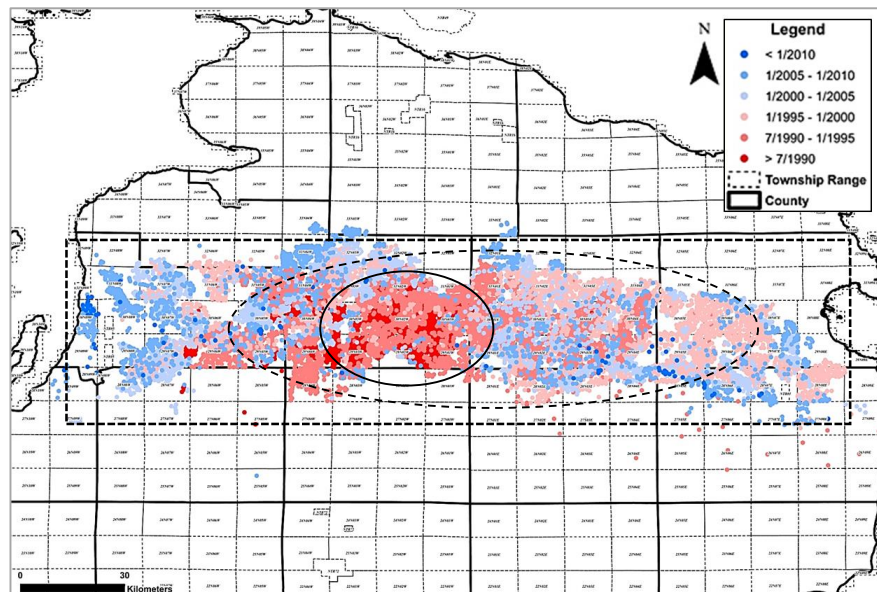
- **What are the controls on natural gas production in the Antrim Shale?**
- **Why do some Antrim wells produce better than others?**
- **How do we predict which wells will be better natural gas producers?**

- Major natural gas resource play in the Michigan (>3.55 TCF – 08/17)
- Peak Monthly Production - 17.614 BCF (03/98)
- 11,314 Total Wells Drilled.
- Peak 9,822 Wells Online (12/12)

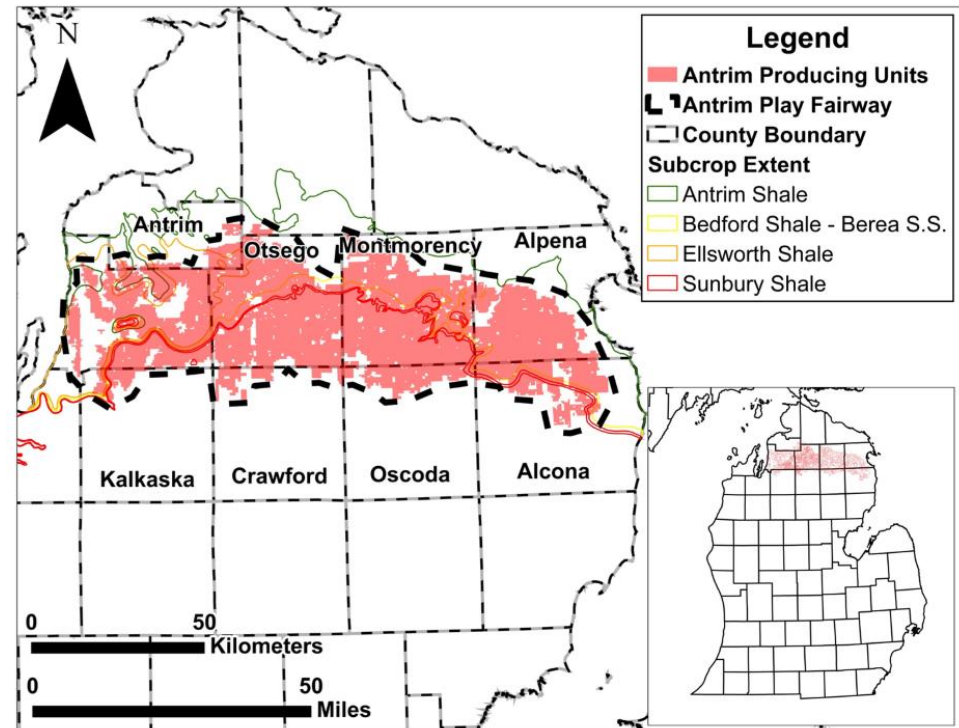


- **Non-Conventional Fuels Tax Incentive (1986 – 1992)**
- **Development of the Antrim Play was based on land acquisition and spacing rather than geological knowledge.**
- **The geological controls on natural gas production have never been evaluated.**

Distribution of Antrim Wells by Spud Date

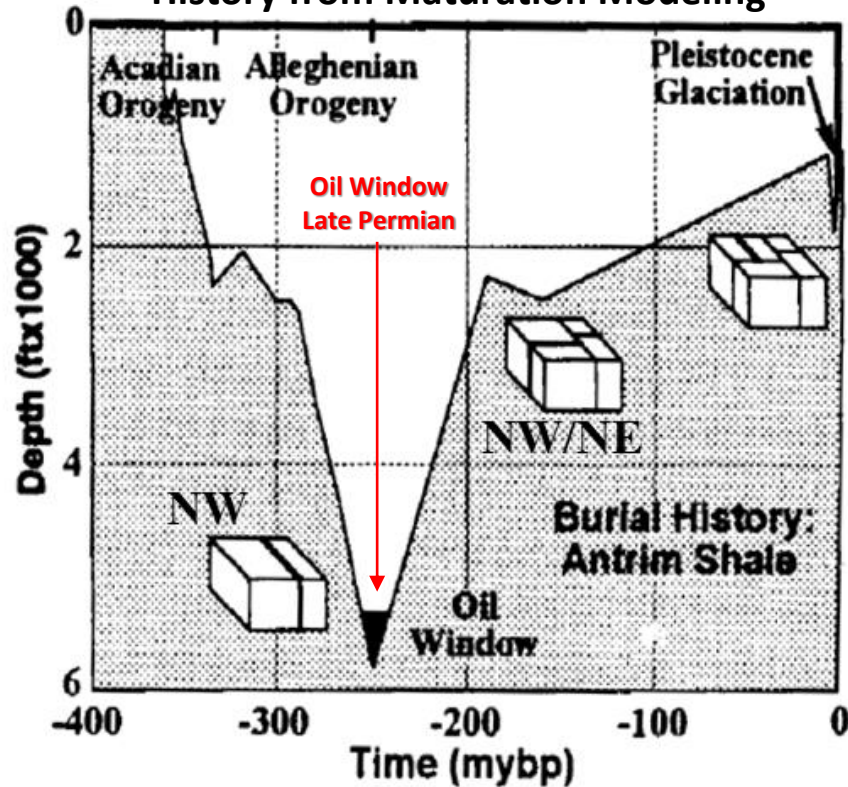


Antrim Play Fairway, Leaseholds, Subcrop Extent



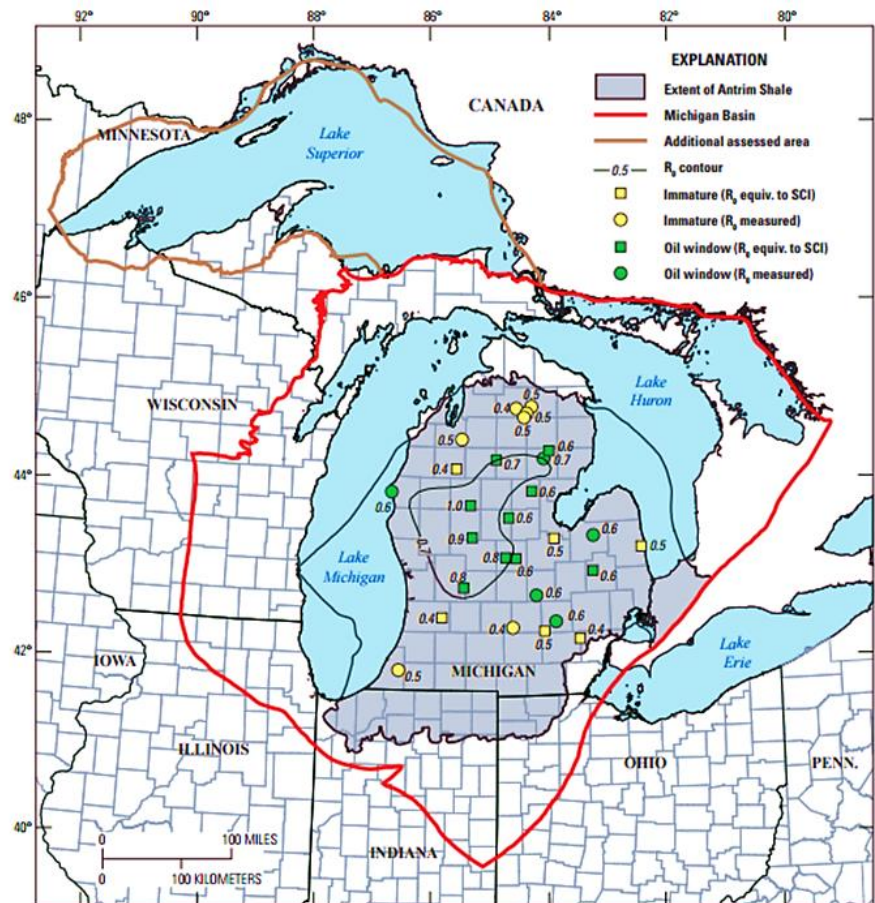
- The Antrim Shale is never reached the gas window, but produces gas.

Approximation of Burial and Thermal History from Maturation Modeling



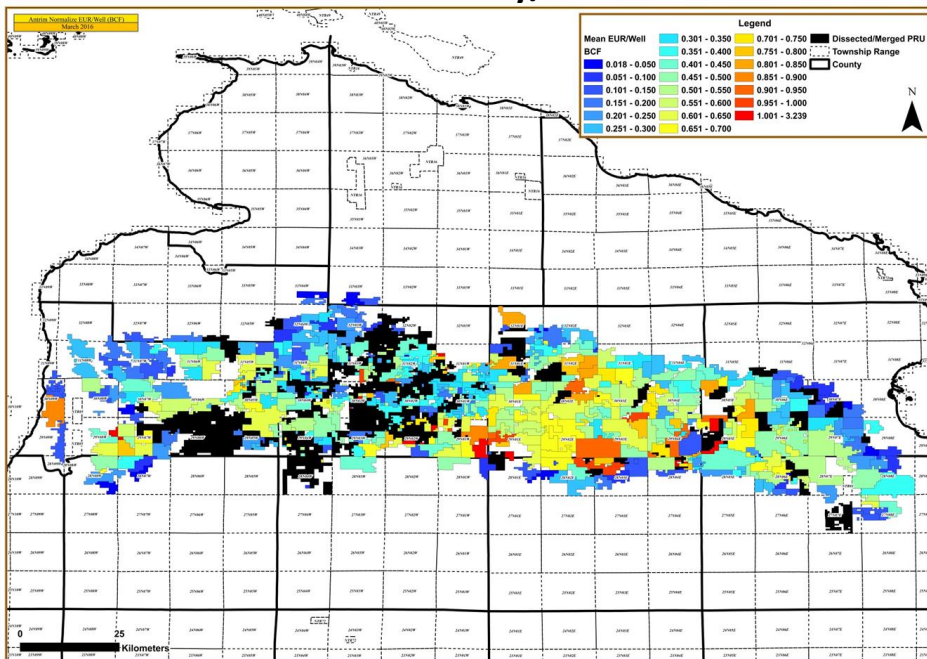
*St. Frederic 1-16 (Crawford County)

Thermal Maturity – Vitrinite Reflectance



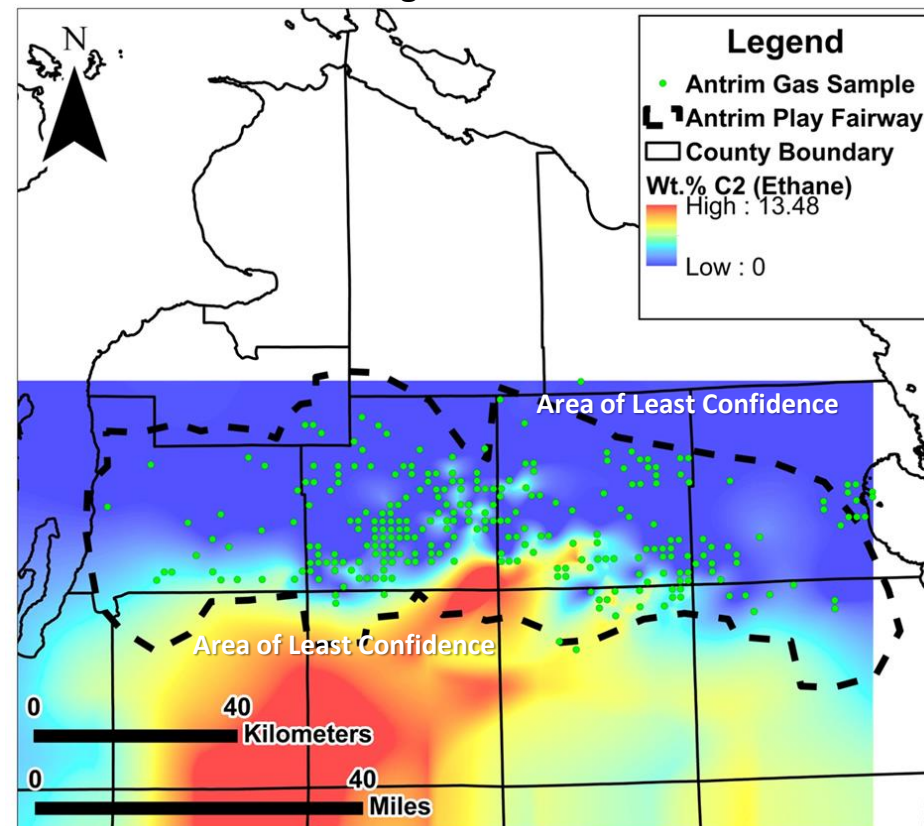
- Gas production and composition varies spatially.
- Localized pockets of thermogenic gas.

Estimated Ultimate Recovery/Well – Antrim PRU's



*10 MCFD Cut-Off

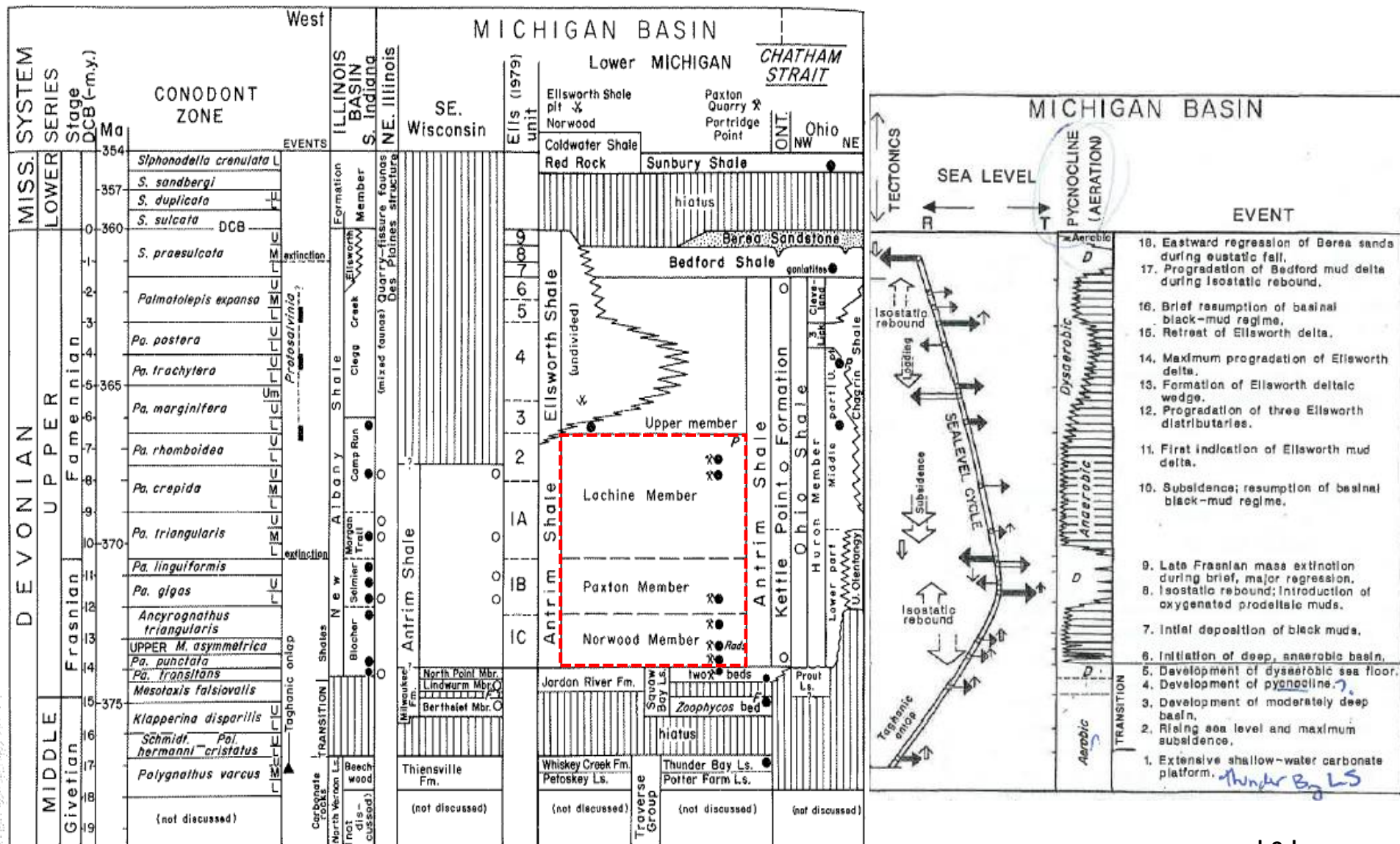
Weight % Ethane



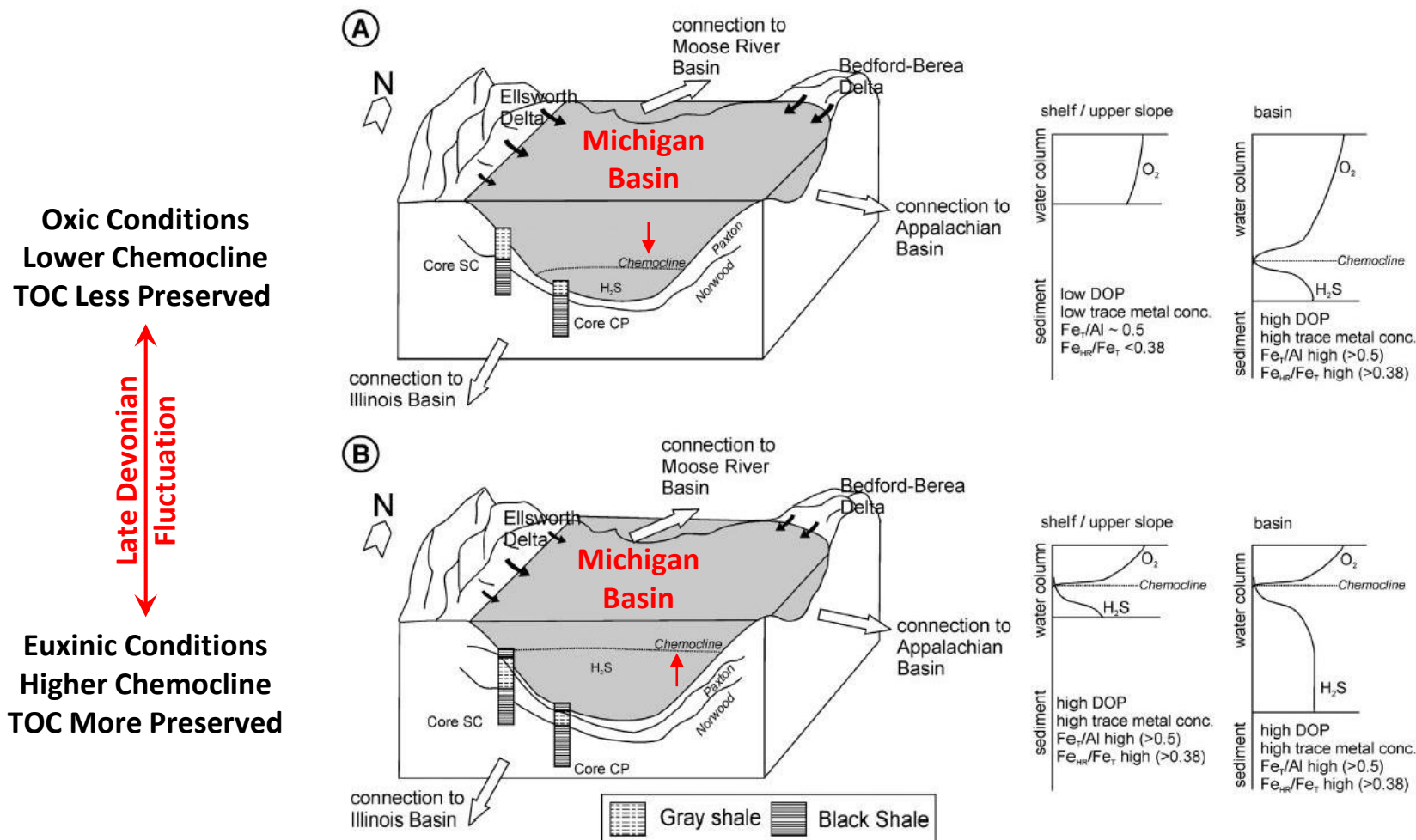
*Longer Chain Hydrocarbons Observed

Research Objective:

- **Determine the geological controls on natural gas accumulation**
- **Determine the origin of Antrim Gas**
- **Provide a new analog to explain controls on natural gas production**



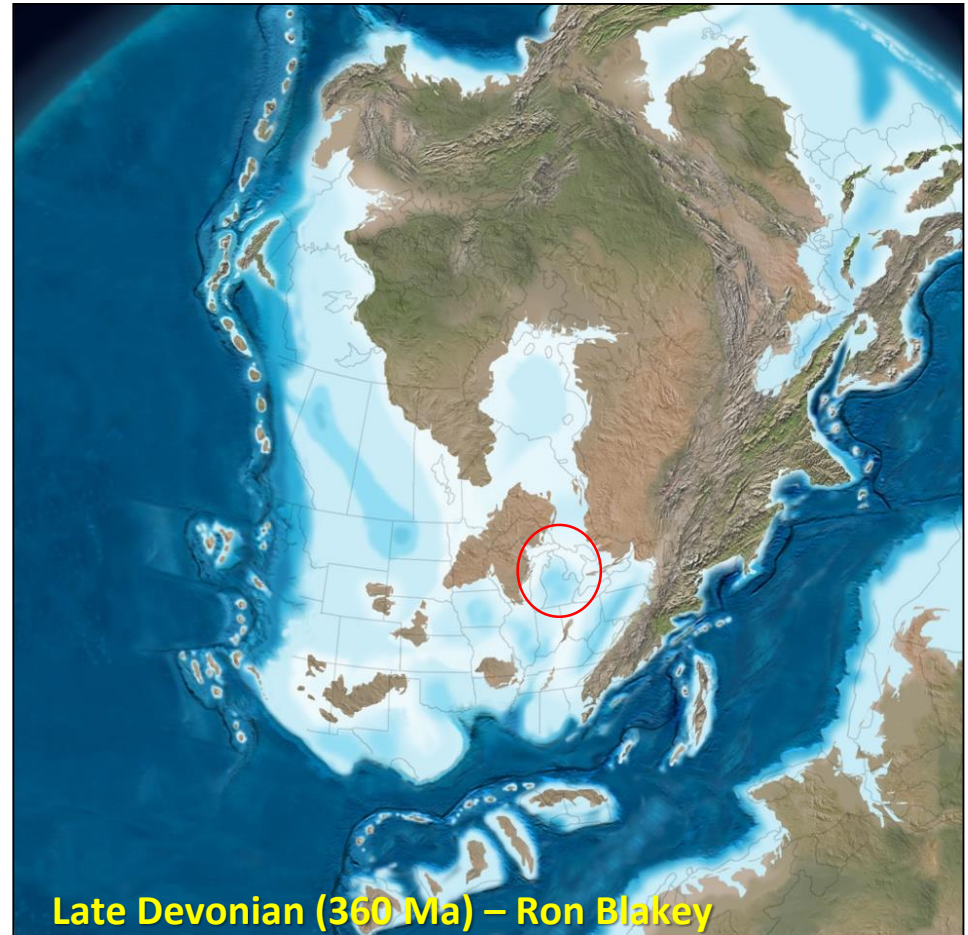
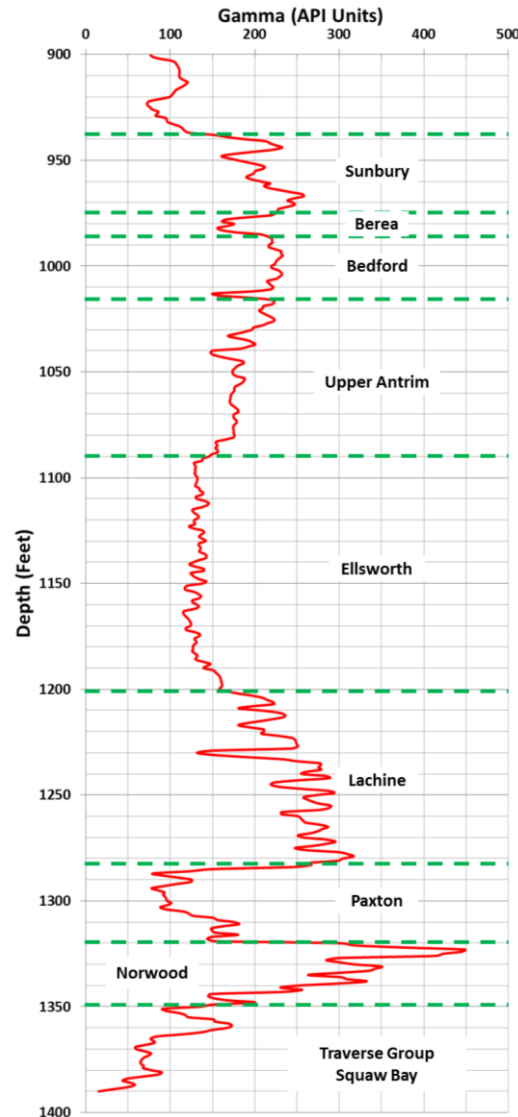
Preservation of organic carbon is attributed to fluctuation in the chemocline



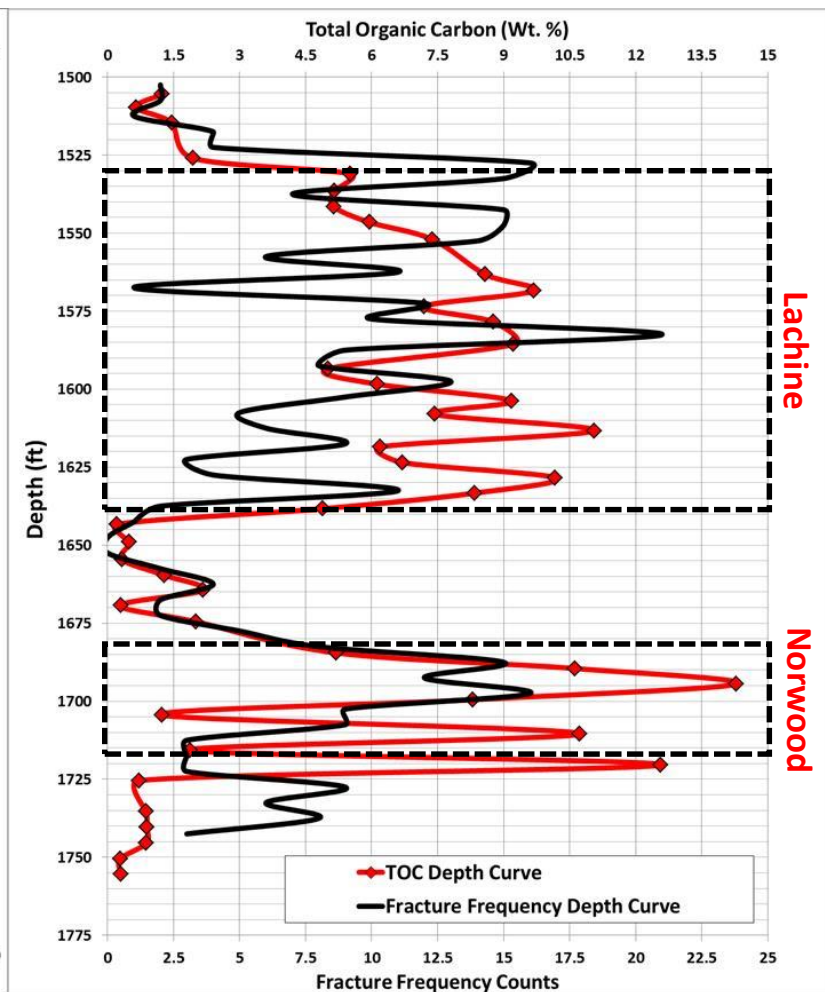
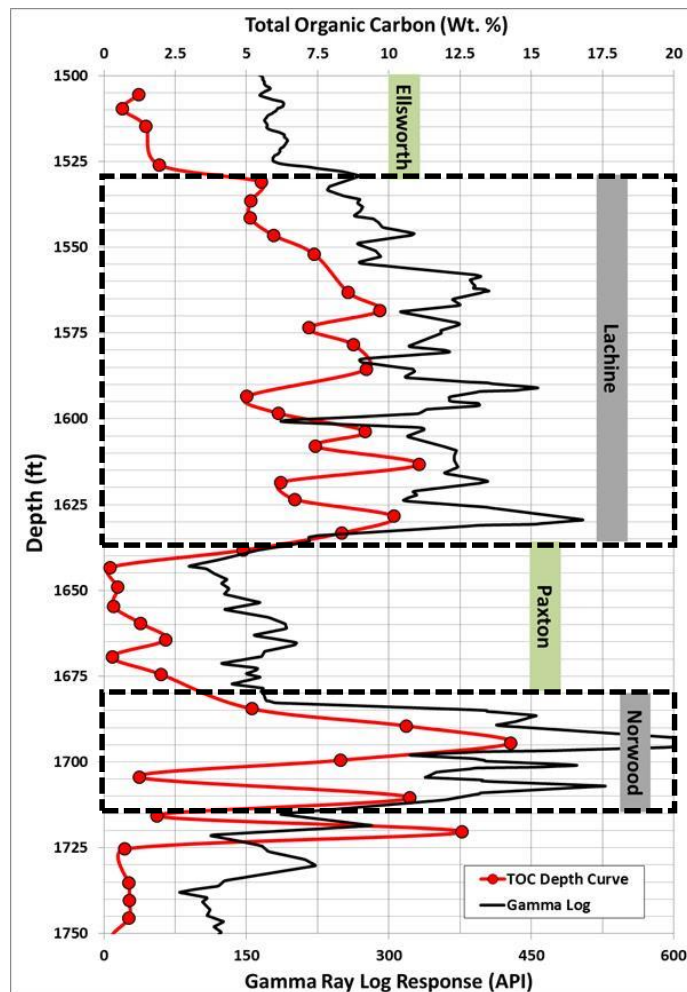
Latuszek B1-32



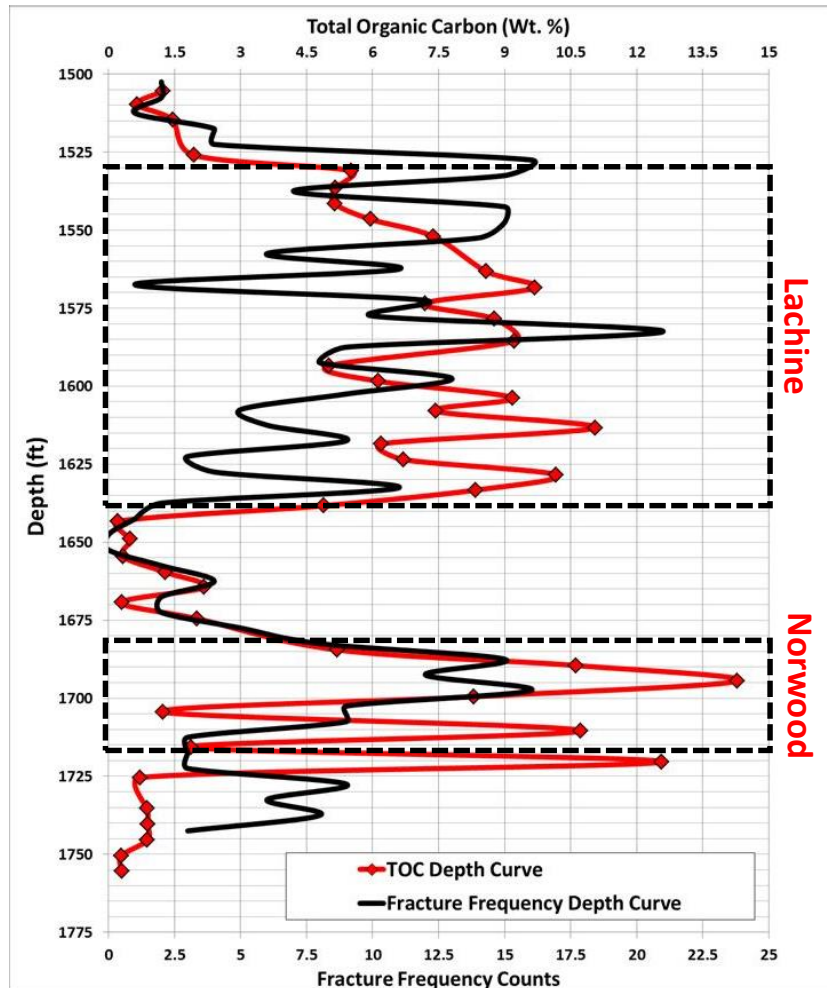
St. Loud D3-20



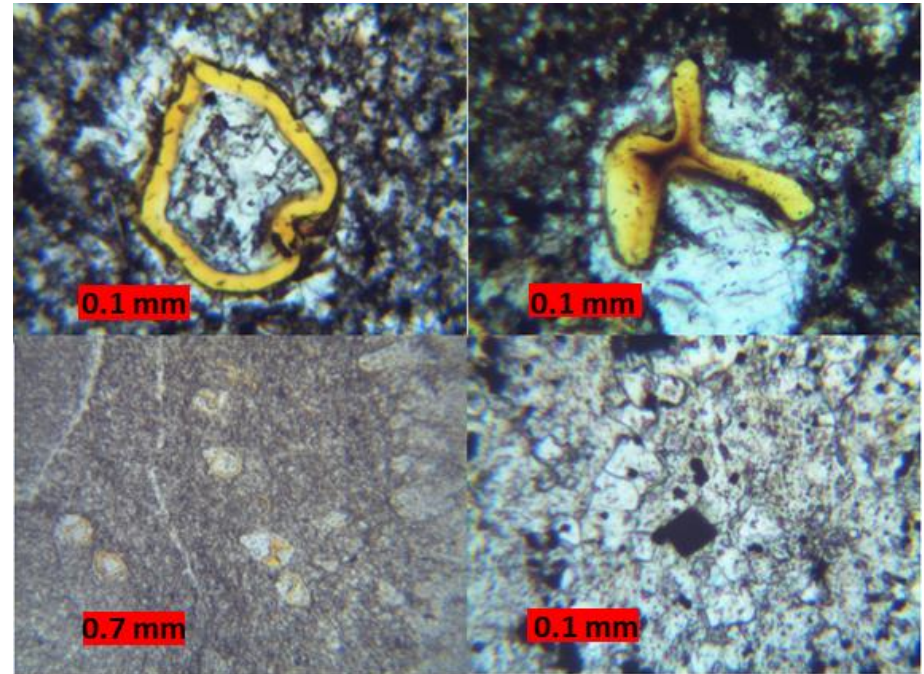
Latuszek B1-32 - Total Organic Content, Fracture Frequency Curve



Latuszek B1-32



Latuszek B1-32 (1602.3') – Silicified *Tasmanites*



Very fine to silt-sized quartz grains. Two sources, authigenic cement and polycrystalline silt particles of neomorphosed *radiolarians*.

Wt.% Quartz: 20 – 41%

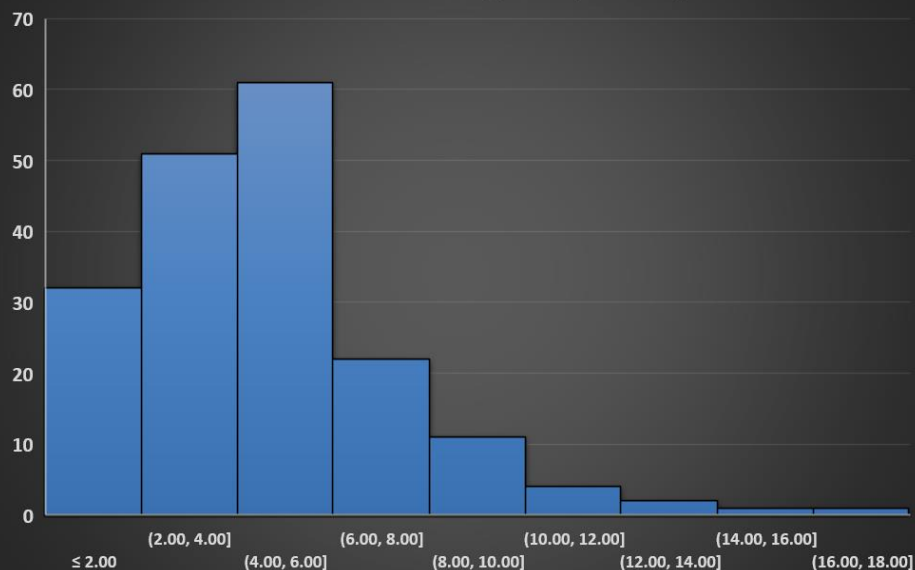
Wt.% TOC: 0.3 – 24%

Source: Ding et al., 2012

All Available Antrim TOC and Rock-Eval. Pyrolysis Data for the Michigan Basin – Central Basin & Margin

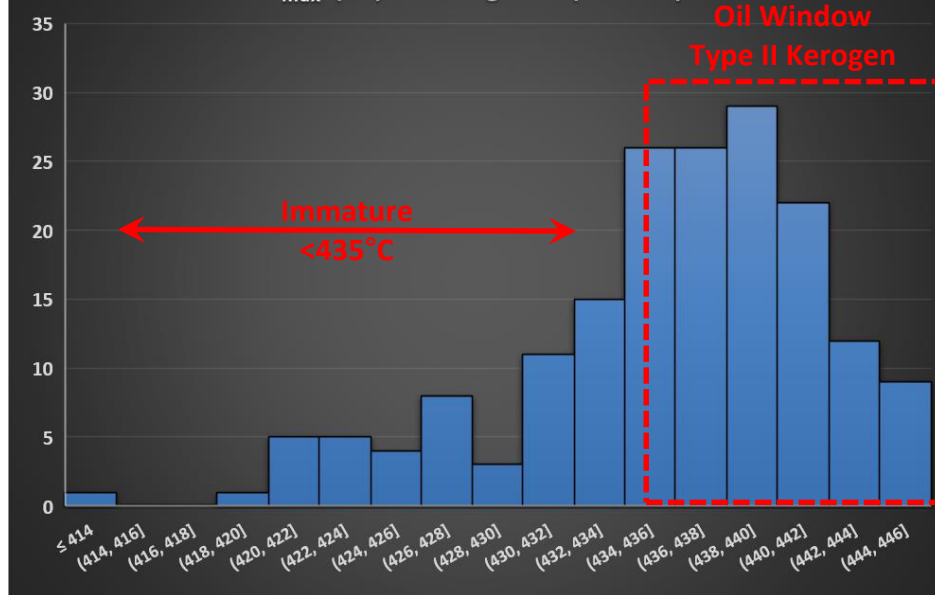
Antrim TOC Measurements

TOC Wt. % - Histogram (N=188)



Antrim Rock-Eval. Pyrolysis

T_{max} (°C)- Histogram (N=188)



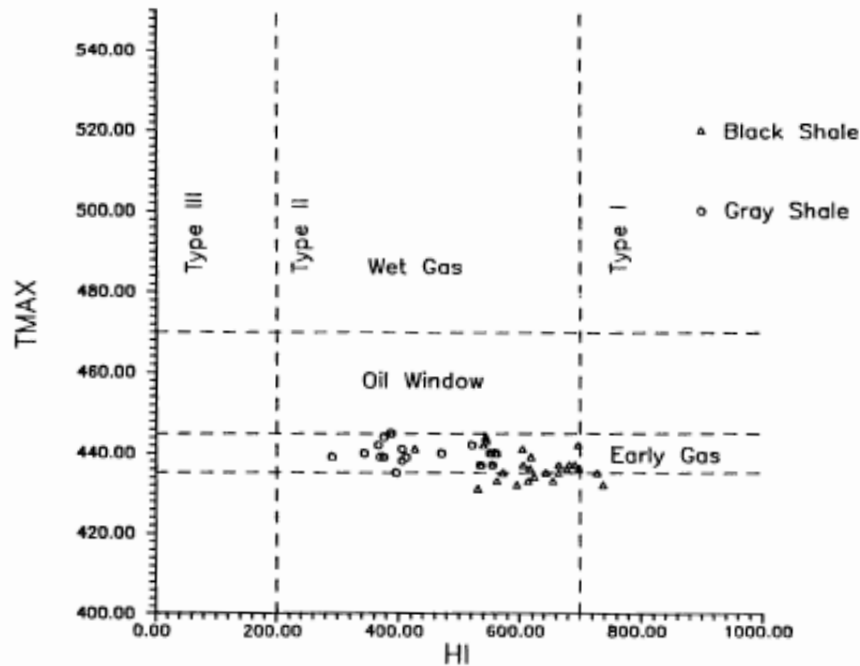
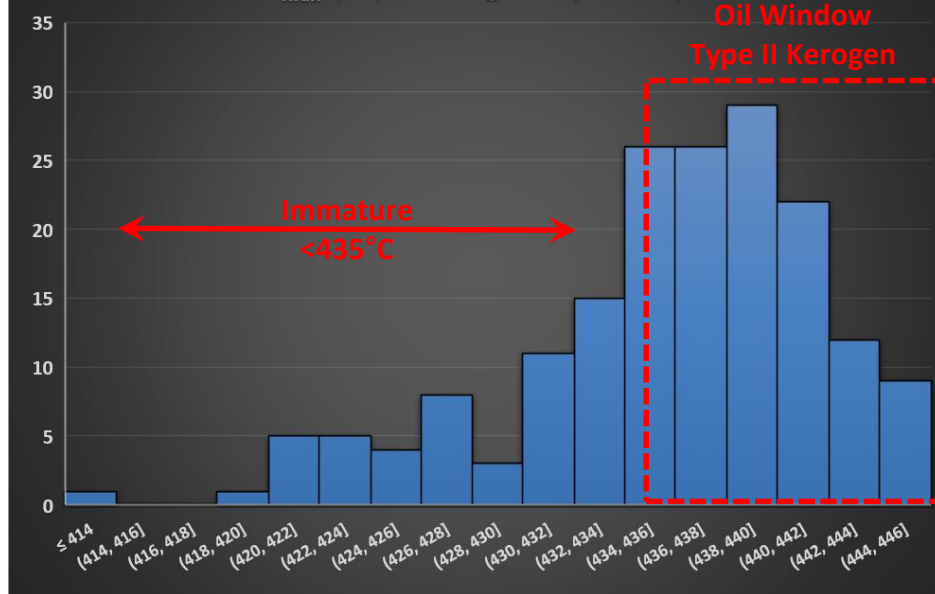


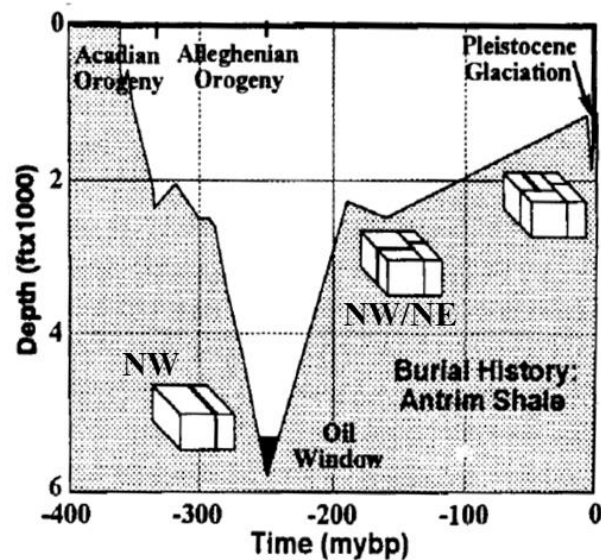
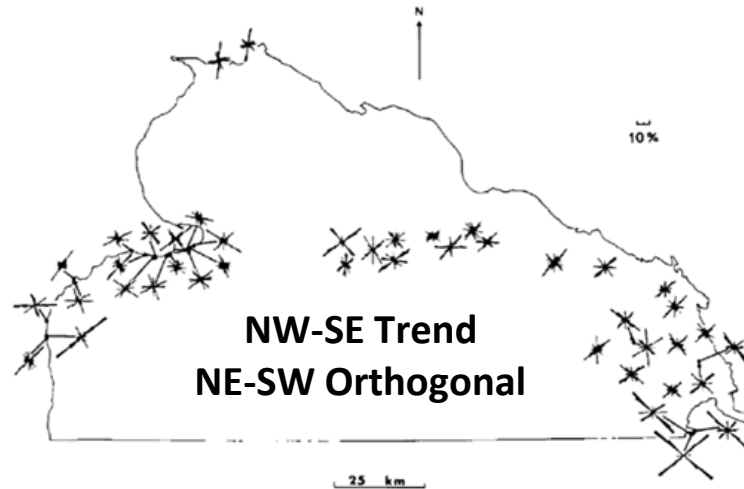
Figure 30. T_{max} Versus Hydrogen Index (HI) With Samples From the Latuszek B1-32, St. Chester 18, and Club 4-40 Cores.

Antrim Rock-Eval. Pyrolysis

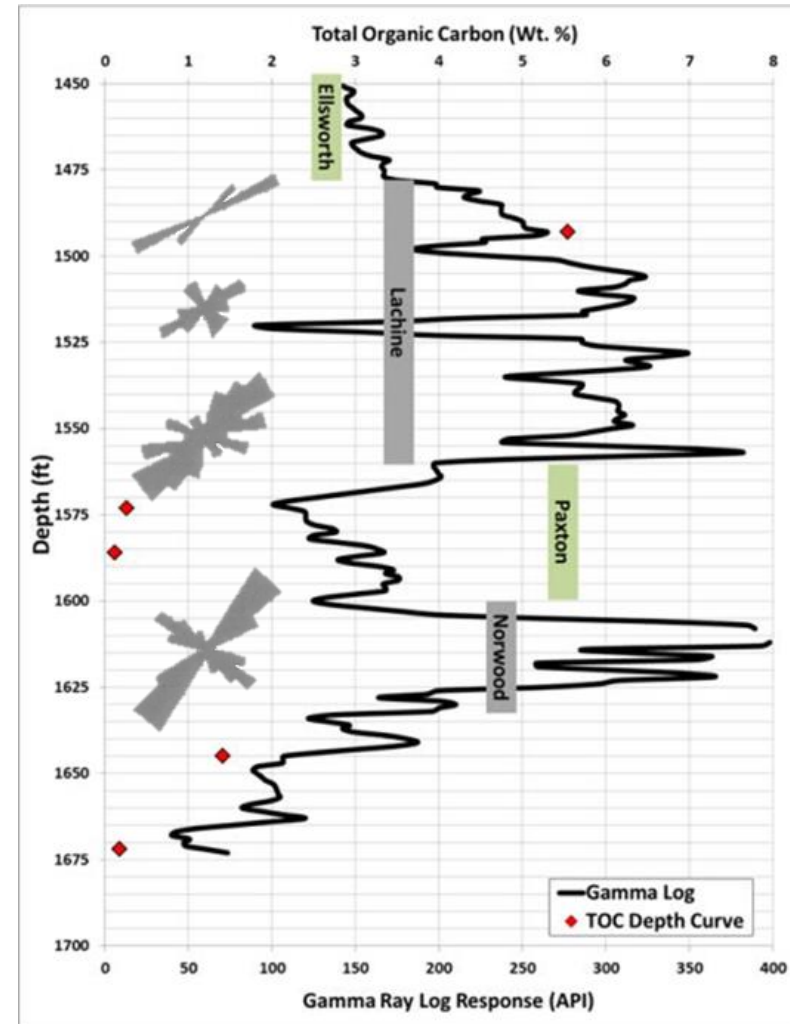
T_{max} (°C)- Histogram (N=188)



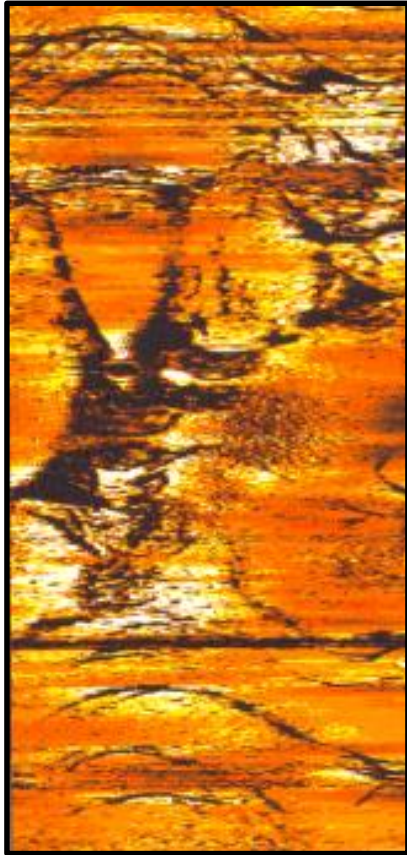
Fracture Trend of the Antrim Shale



St. Chester #18 - Fracture Orientation



Extensively Fractured

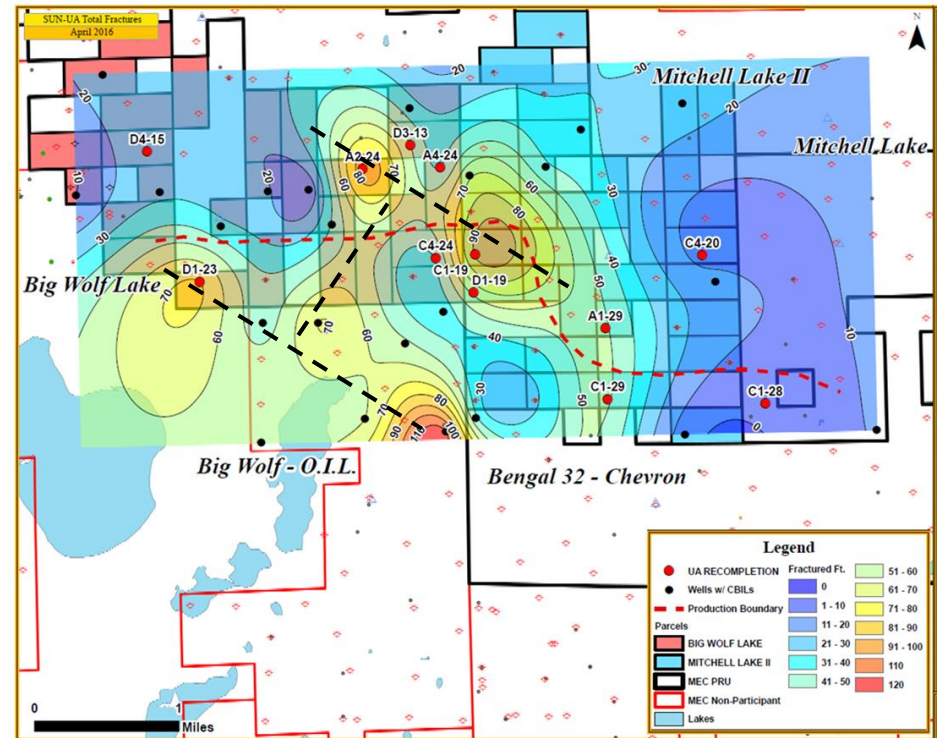


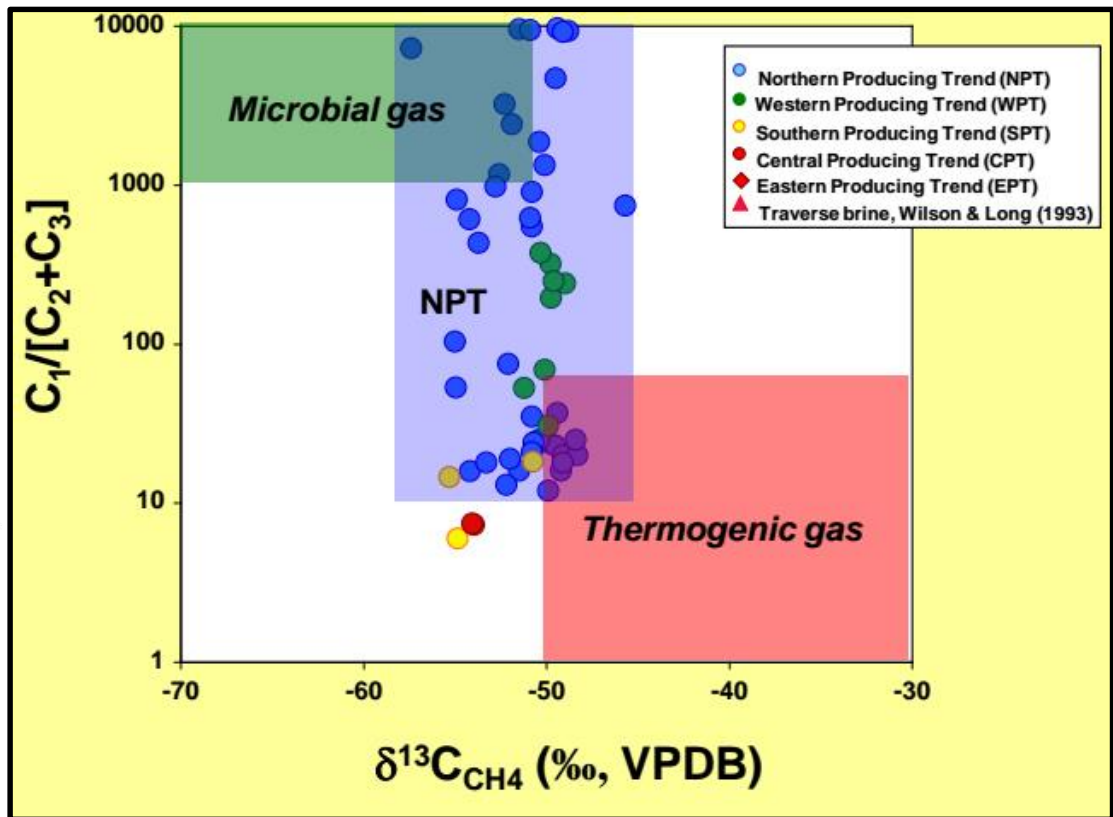
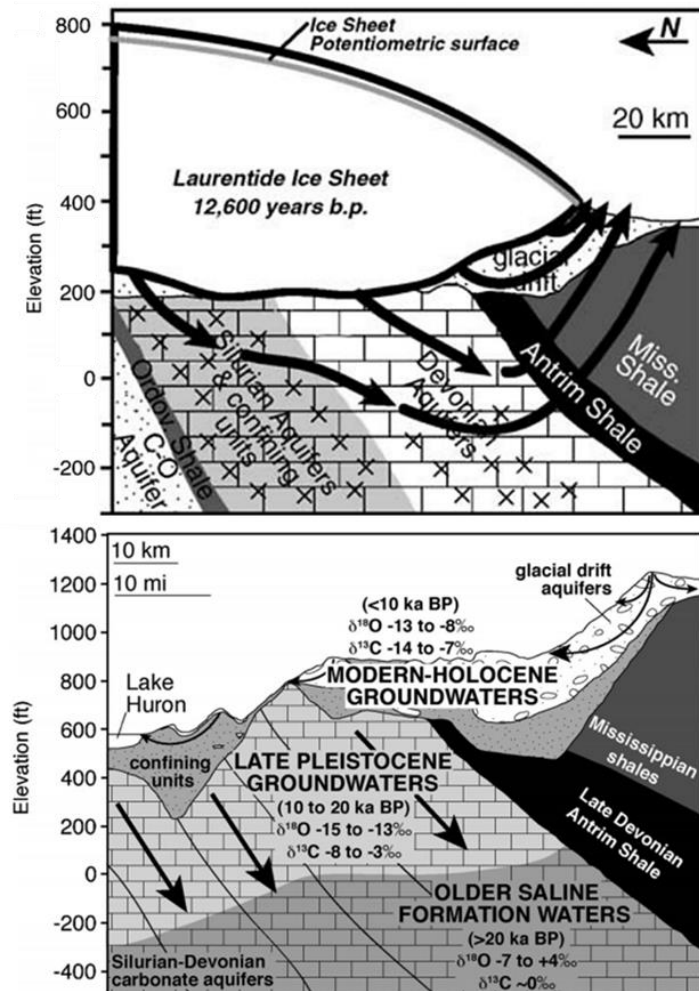
IP: 500 MCFD
BWL B1-24

Poorly Fractured



IP: 50 MCFD
BWL A3-23





✓ **Black Shale Facies – Norwood and Lachine Member**

- High TOC and Quartz
- Most Fractured Interval
- Two Major Fracture Trends: NW-SE and NE-SW Strike
- Fracture Distribution Varies Spatially

✓ **Hydrocarbon Potential & Gas Production**

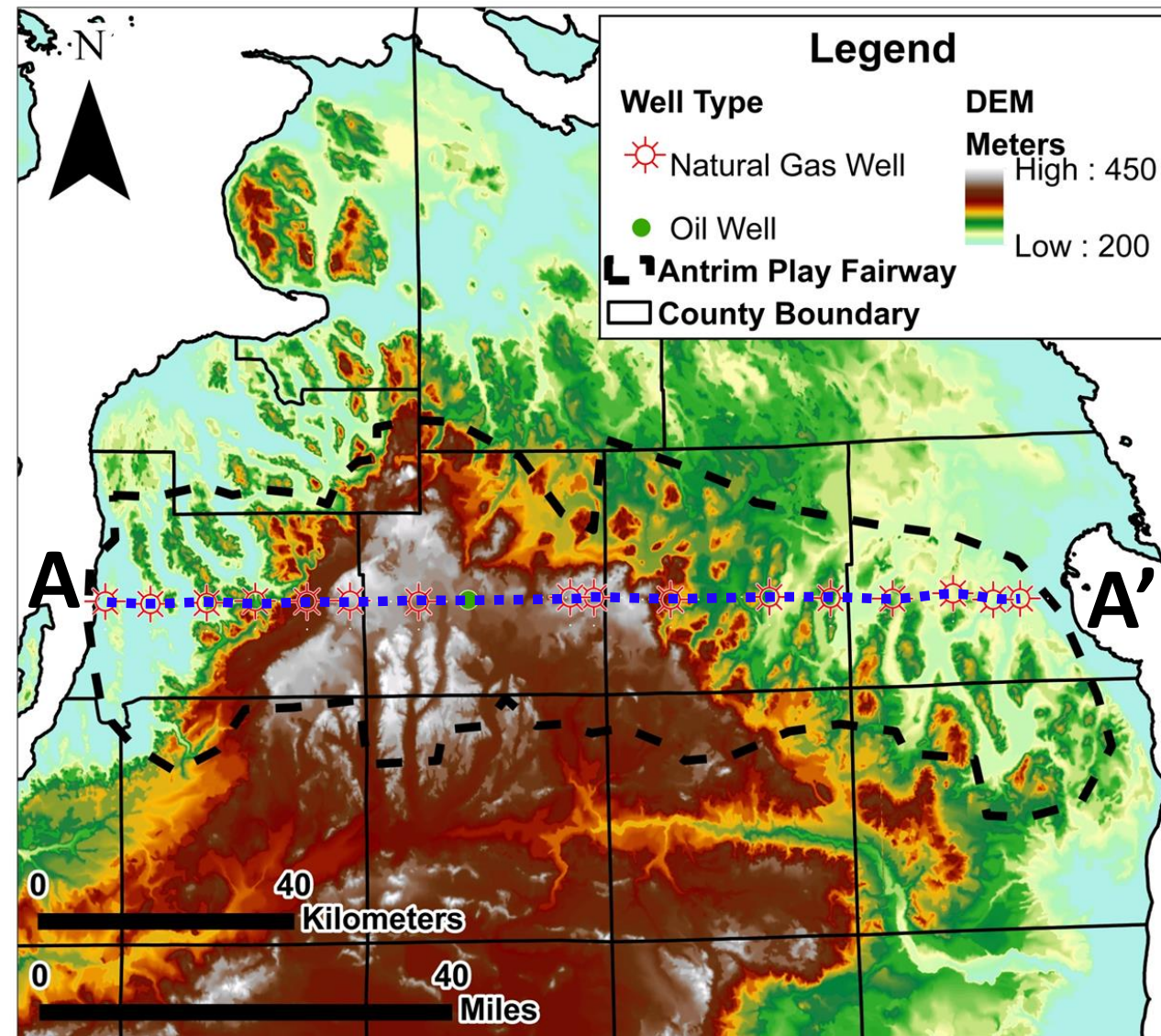
- Thermogenically Immature in the Antrim Play Fairway
- Reaches the Oil Window in the Central Basin
- Wells Penetrating Extensive Fracture Networks have Higher IP Rates
- Gas Composition has Biogenic Signature as well as a Thermogenic Signature

- **Fractures within the Antrim Shale are the reservoir**
- **The Antrim Shale is not the source for the natural gas**
- **Natural gas migrated from deeper stratigraphic units into Antrim Shale fractures**
- **Fractures that penetrated the surface allowed glacial meltwater to enter the reservoir resulting in biogenic over printing of thermogenic gas signatures.**

Data & Results

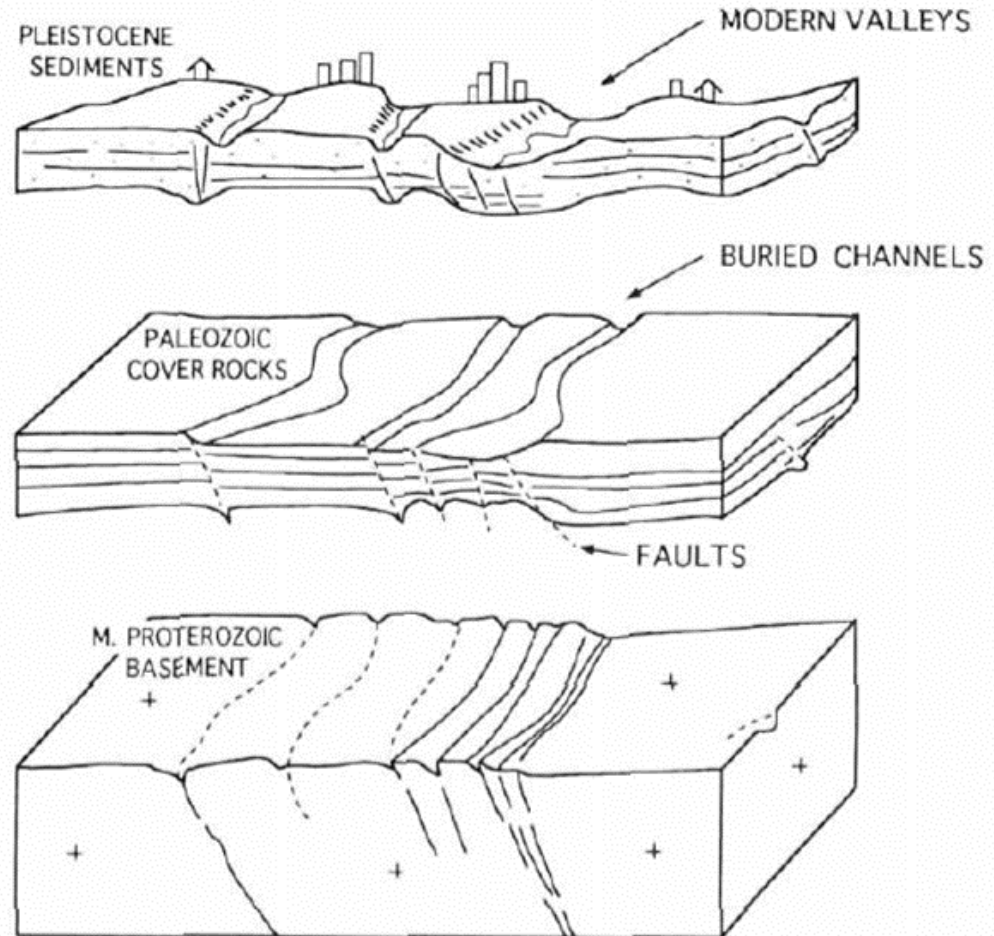
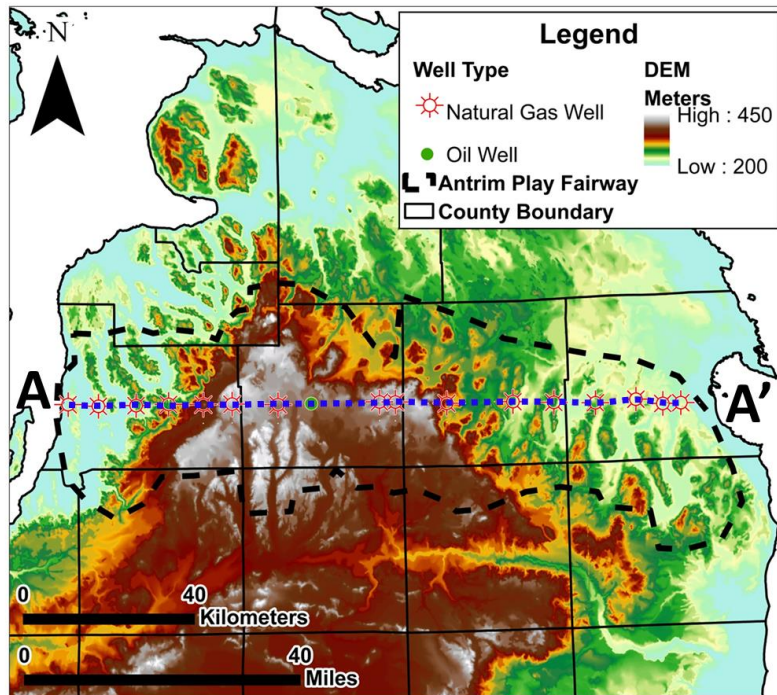
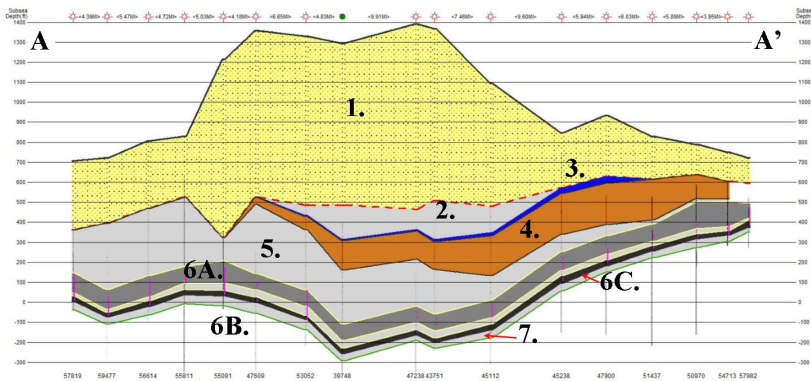
- **Surficial & Subsurface Geology**
- **Formation Fluid Chemistry**
- **Gas Composition**
- **Gas Production**
- **Structural Geology**

Topographic Relief of the Antrim Play Fairway

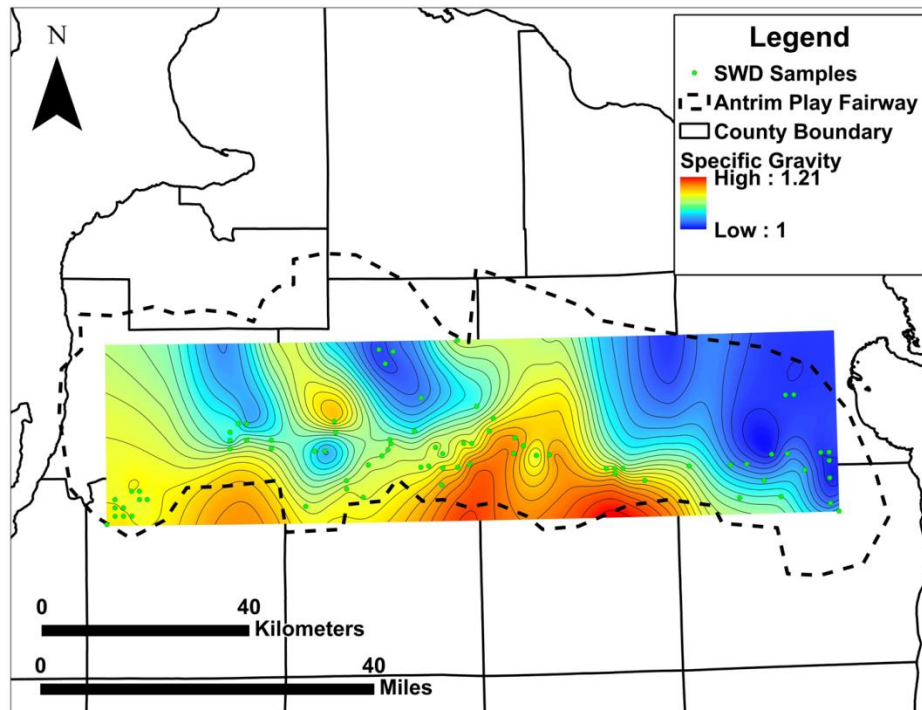




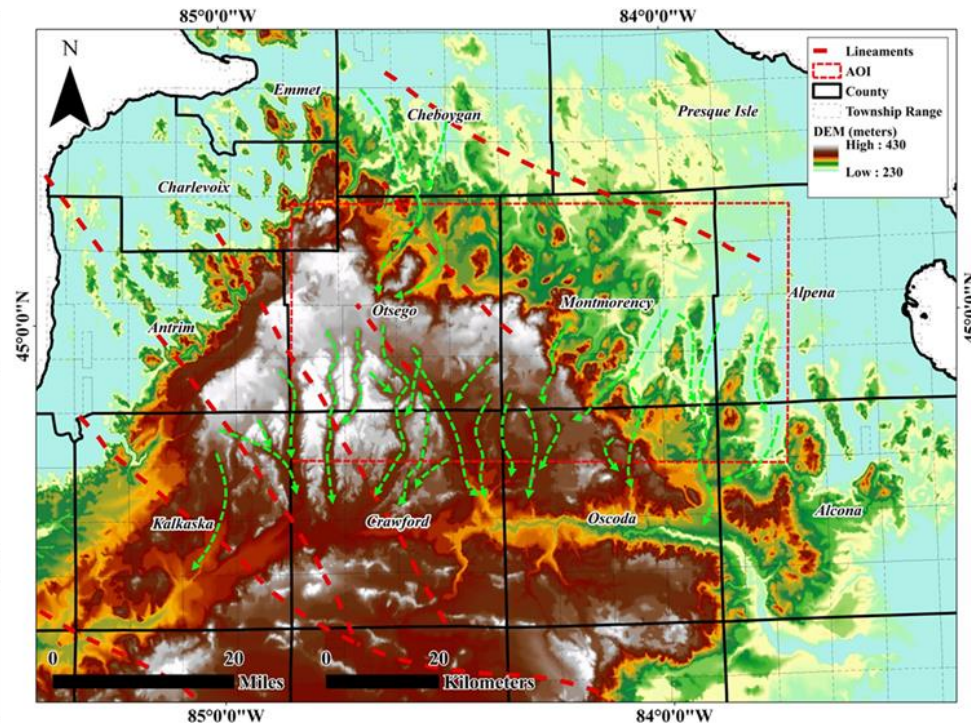
- | 23 |



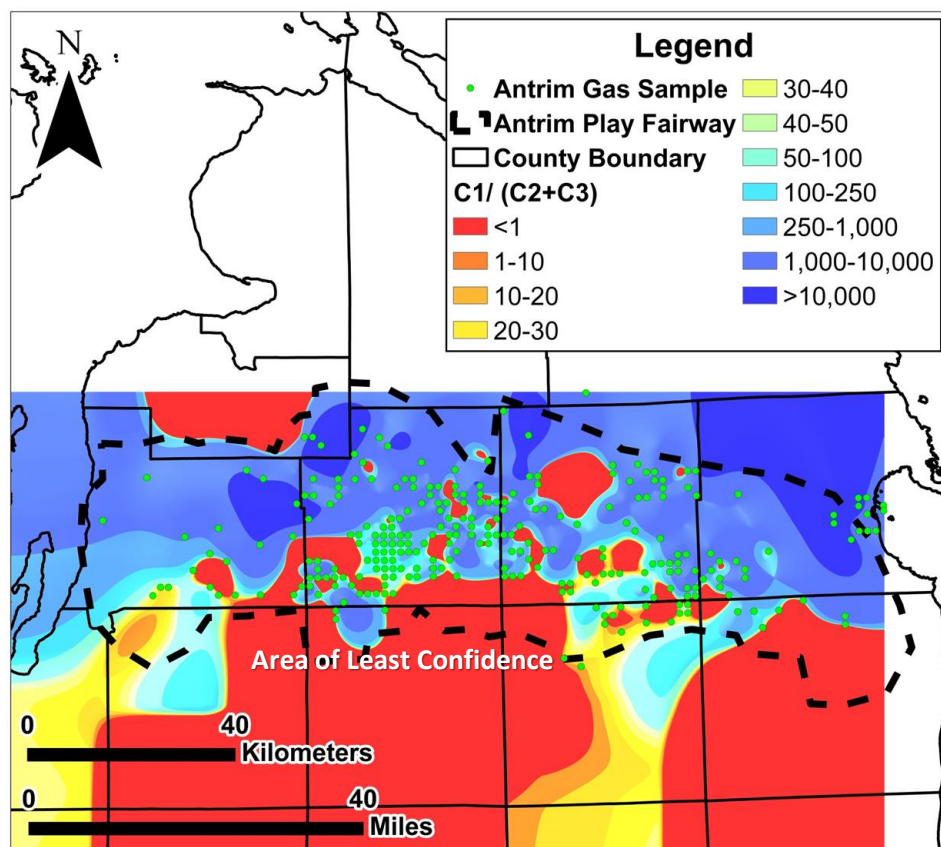
Specific Gravity of Formation Waters



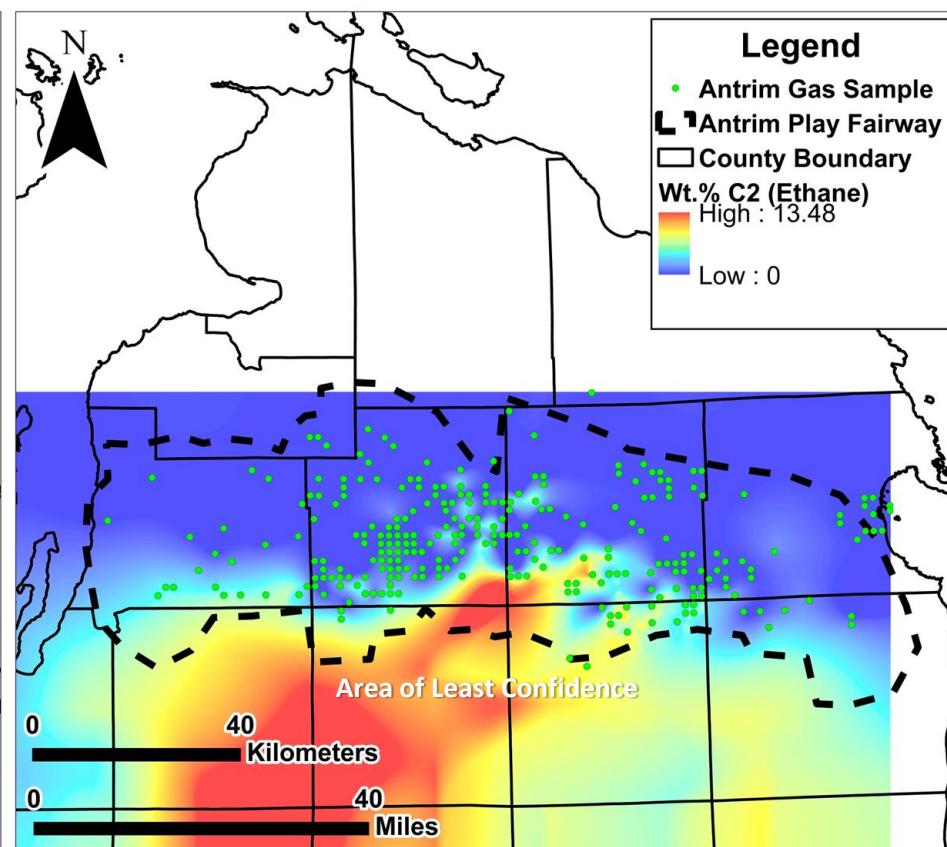
Drainage Features



Gas Composition of Antrim Play Fairway

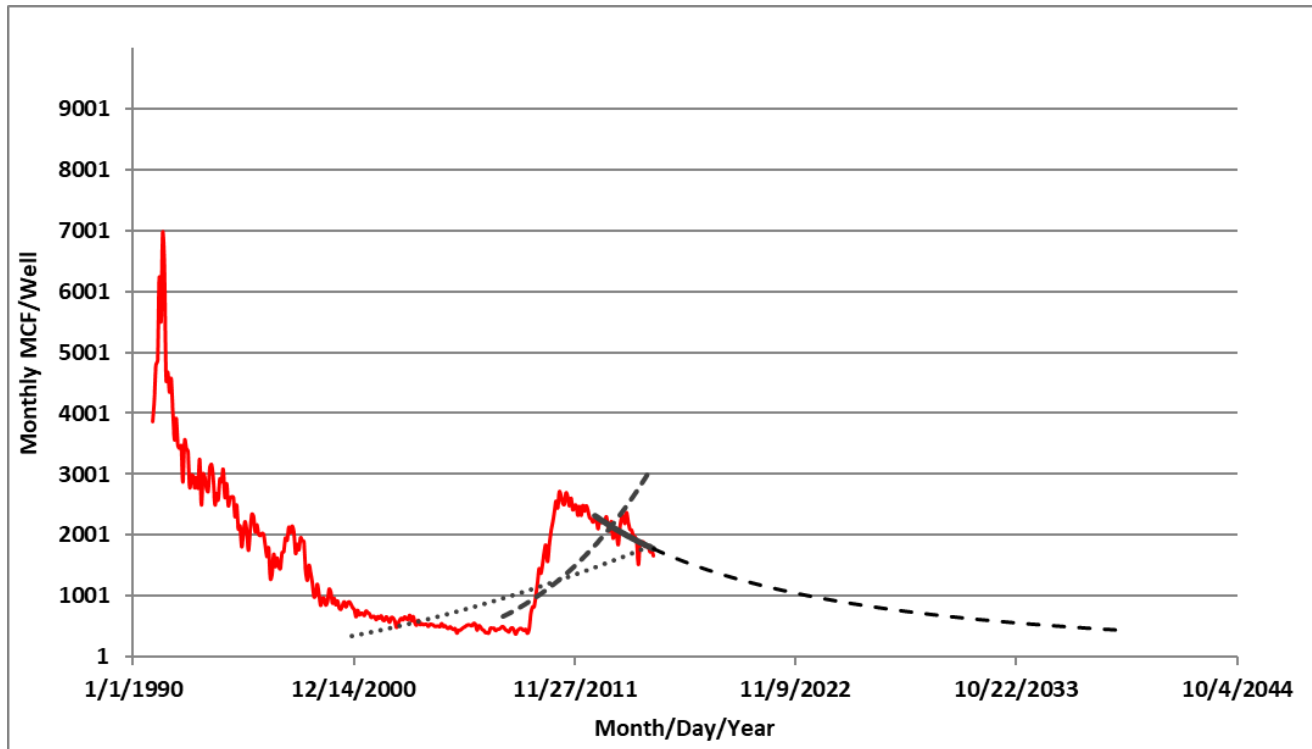


Wt. % Ethane of Antrim Play Fairway

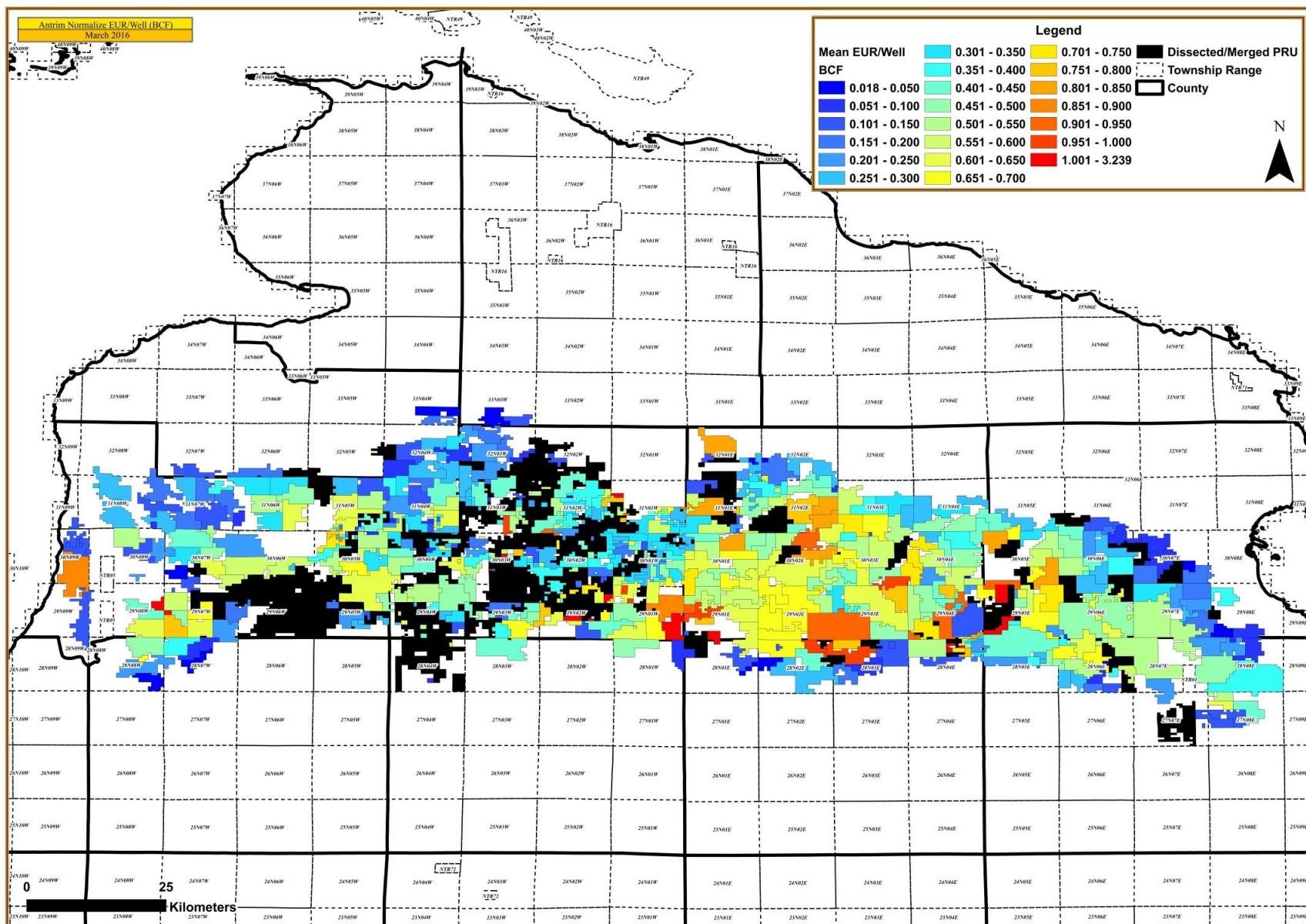


Gas Production - Limitations

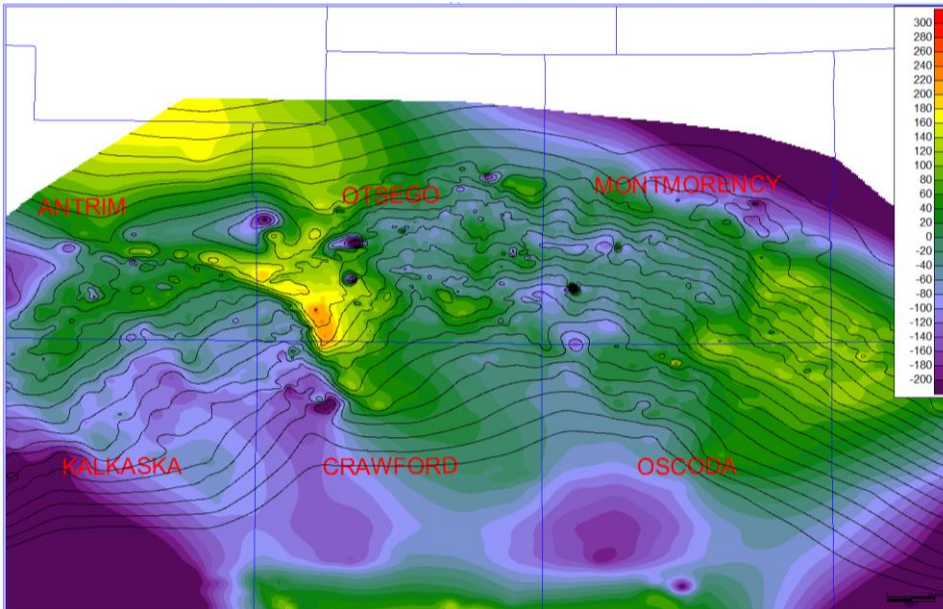
- Gas production is unitized.
- Volume reported to state by PRU.
- PRU's have been merged and divided.
- Wells are drilled and completed differently and in various stages.
 - Lachine
 - Norwood
 - Upper Antrim – Sunbury
- Antrim Gas commingles Ellsworth, Upper Antrim, Bedford-Berea, Sunbury.



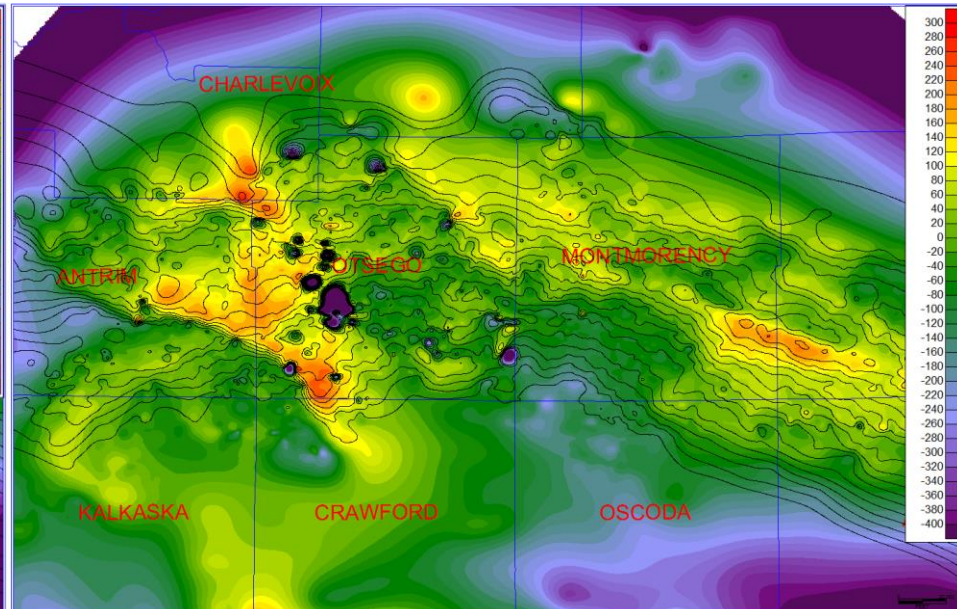
To Date Production	9505321		R2- 180	0.473497	0
Max Wells	20		R2 - 90	0.514364	0
Production per we	475,266		R2-35	0.547109	-2.120709
Projecter per well	248,544		Recomp Flag	TRUE	
EUR/Well BCF	0.72		Start Date	1/1/1991	
Error Flag (Formula	FALSE		Curve Used	R2-35	
Error Flag (Slope)	FALSE				
			Data Table Ke	Browsing Key	
Label	547		22	547	



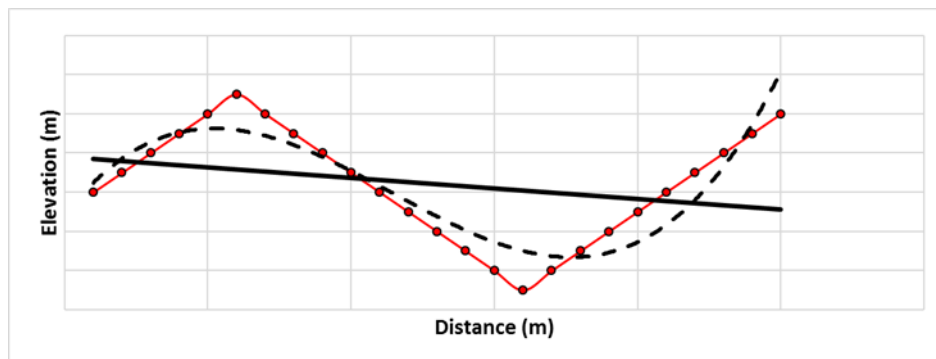
Sunbury Shale



Traverse Limestone



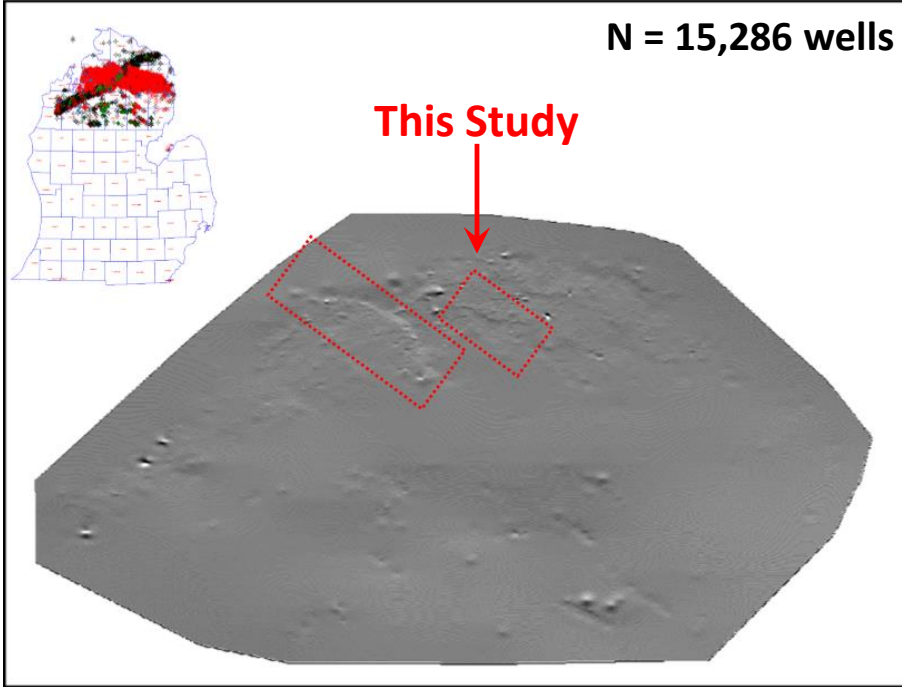
Structure (Contours: 50 ft. Intervals) and 3rd Order Structural Derivative Model (Color Fill: 20 ft. Intervals)



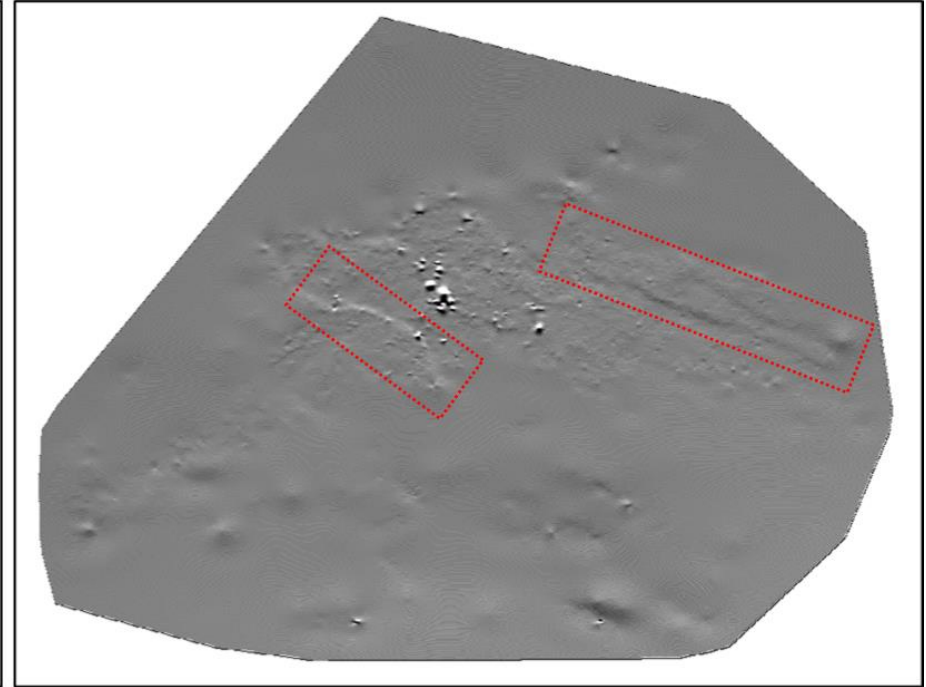
Sunbury Shale

N = 15,286 wells

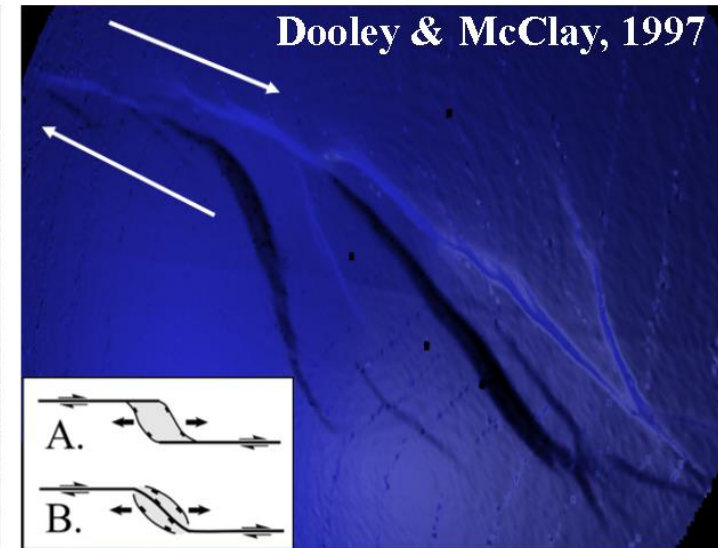
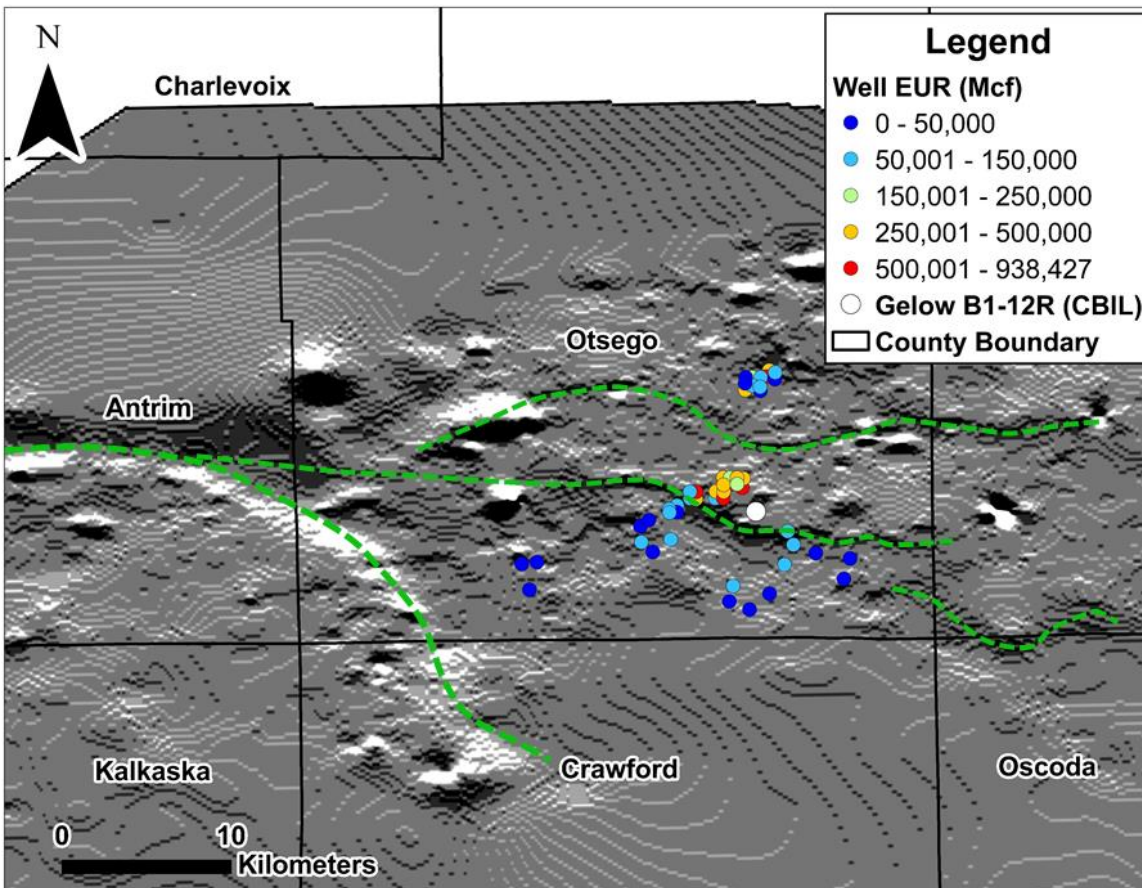
This Study



Traverse Limestone

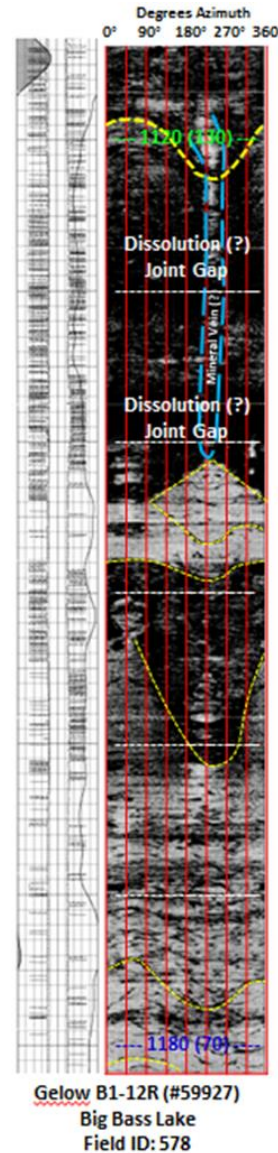
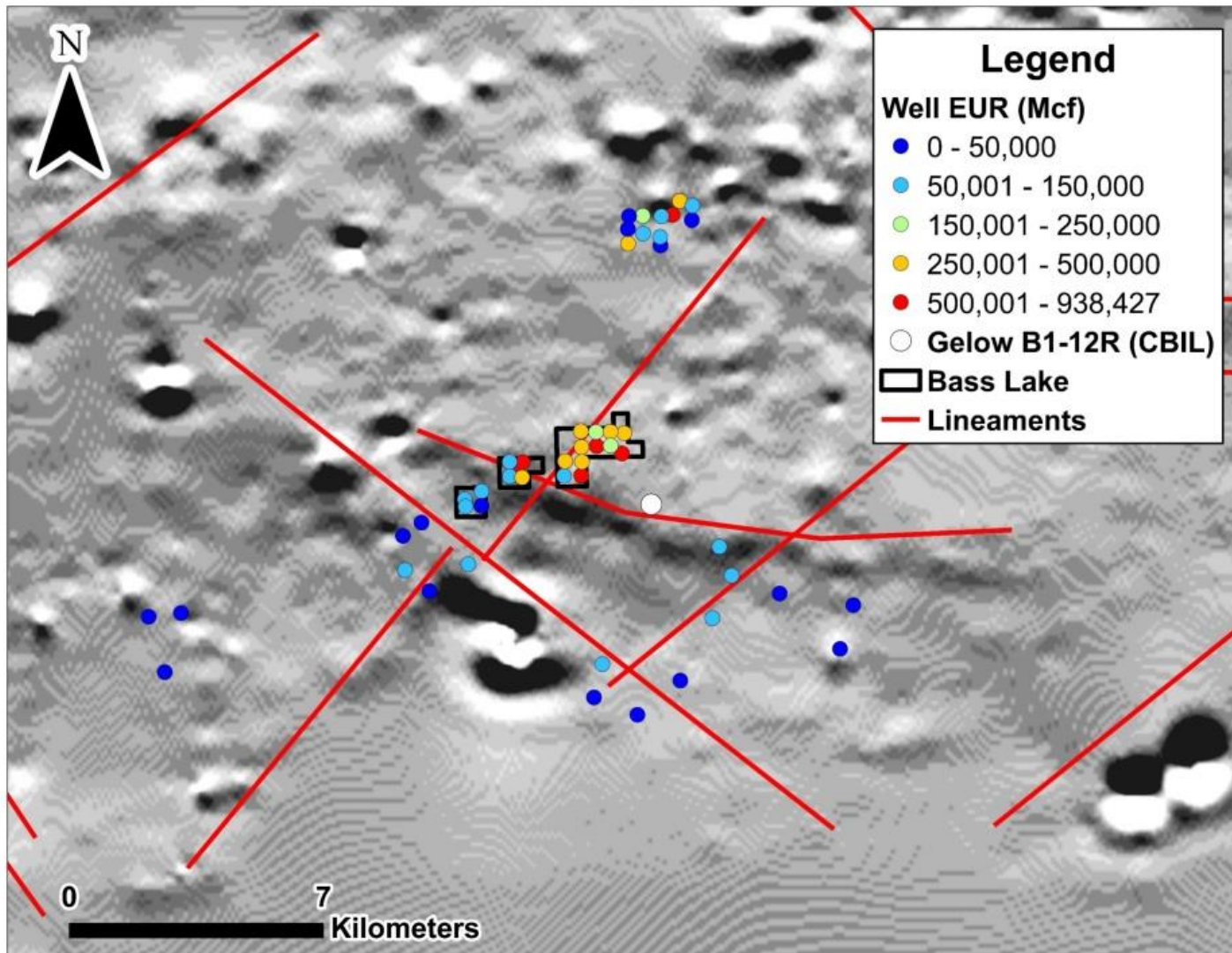


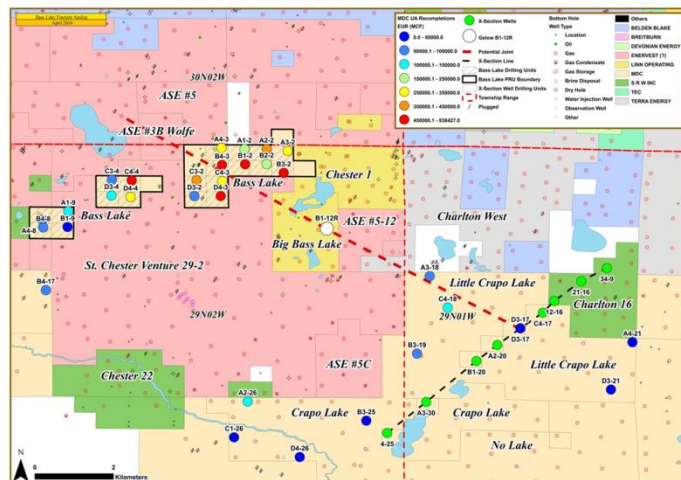
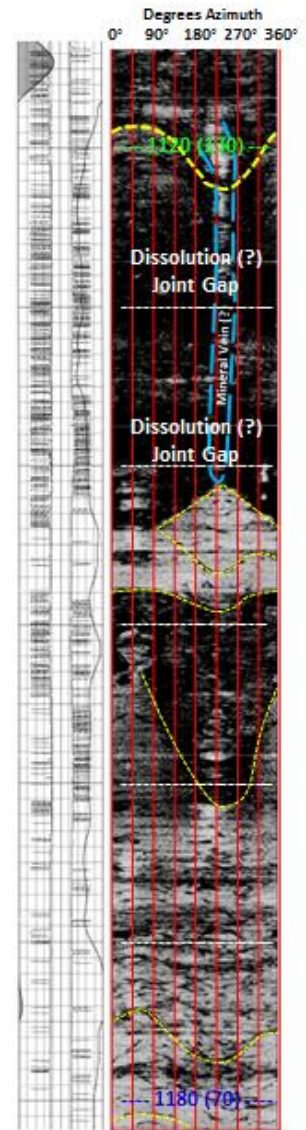
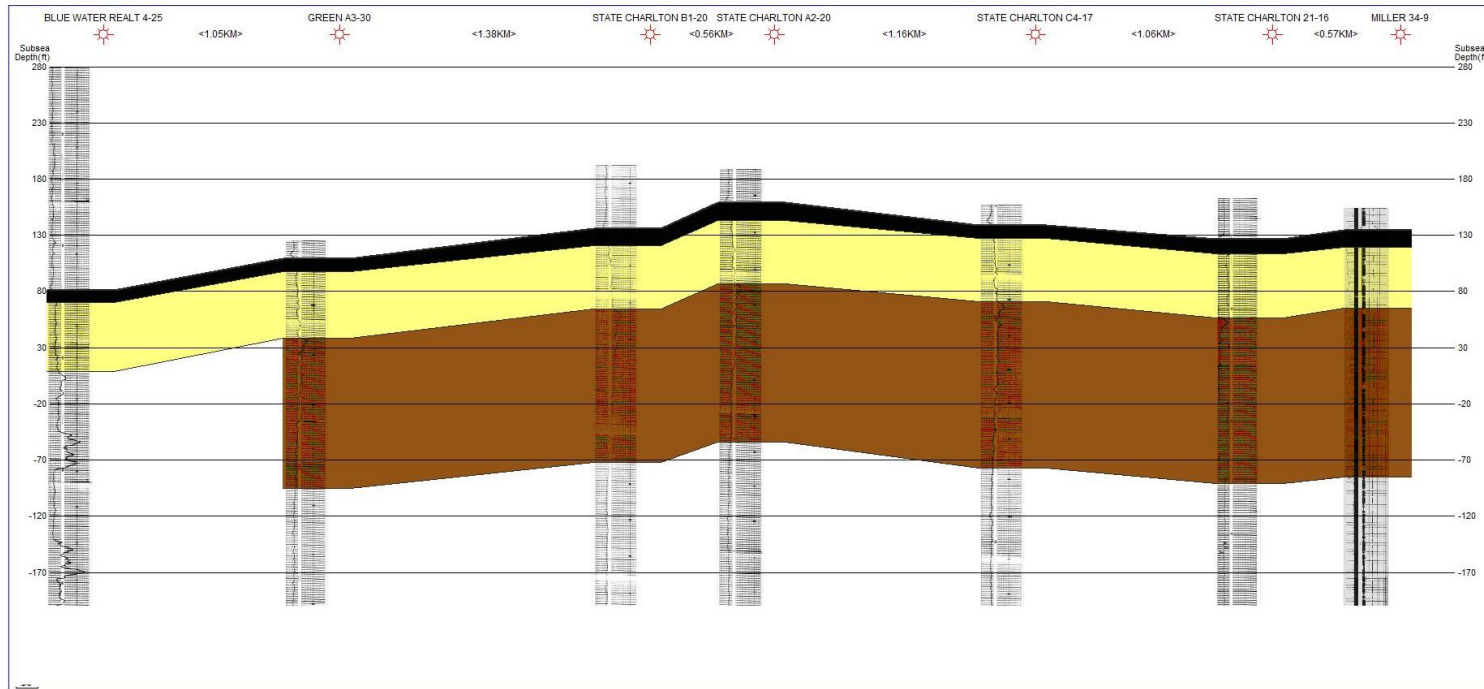
Hill Shade (North Lit) – 3rd Order Structural Derivative



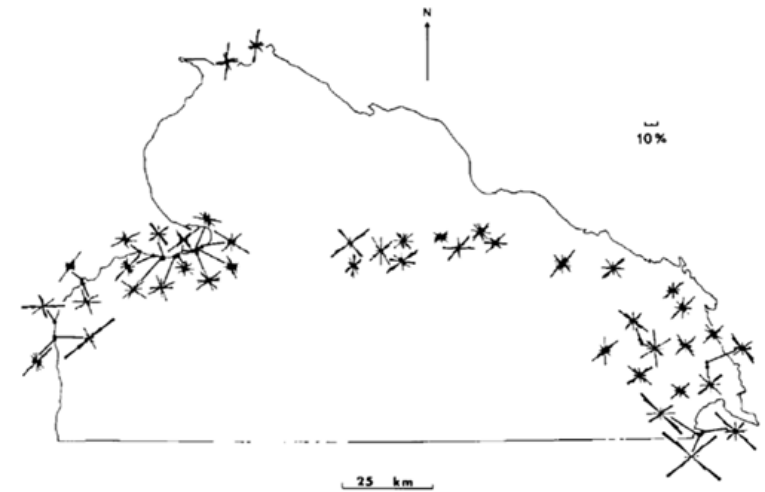
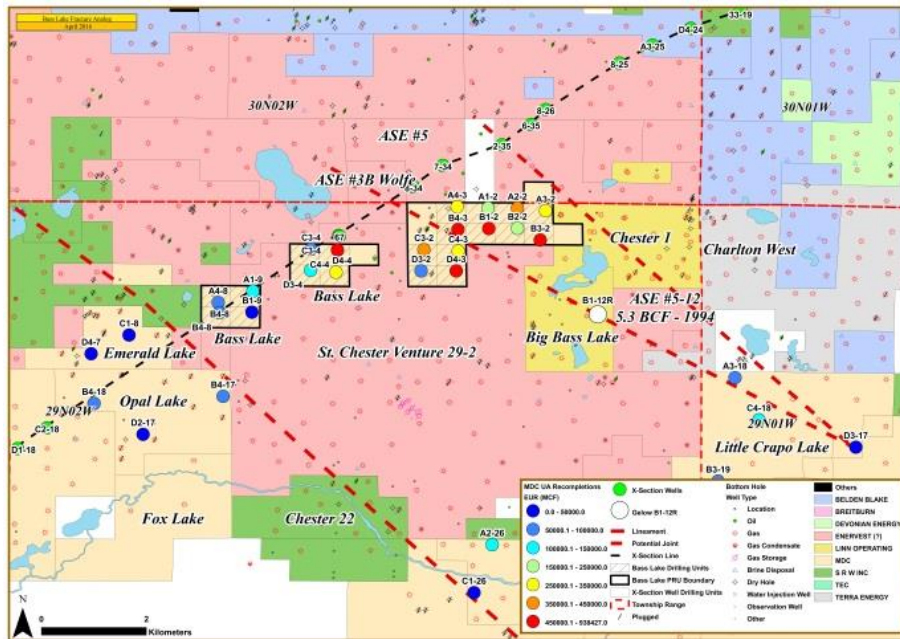
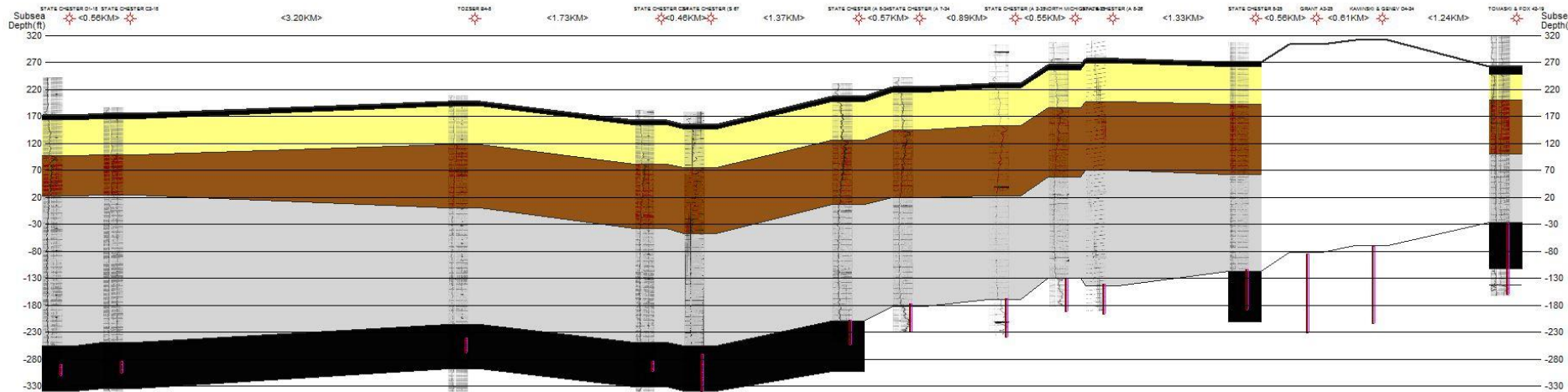
Sand Box Model:
Transtensional Pull-Apart Analog

Hill Shade (North Lit) – 3rd Order Structural Derivative of Sunbury Shale





Gelow B1-12R (#59927)
Big Bass Lake
Field ID: 578



Holst and Foote, 1981

ASE #5-12 (9/2/07):

BTU: 764.7
C1/(C2+C3): 212.9
CO₂: 24.96%
Methane: 74.52%
Ethane: 0.28%

Bass Lake (8/9/07)

BTU: 741.7
C1/(C2+C3): 200.5
CO₂: 26.17%
Methane: 72.17%
Ethane: 0.33%

Bass Lake (6/1/15):

Methane: 82.91%
Ethane: 3.51%
Isobutane: 0.14%
CO₂: 5.37%

Big Bass Lake (7/2/07)

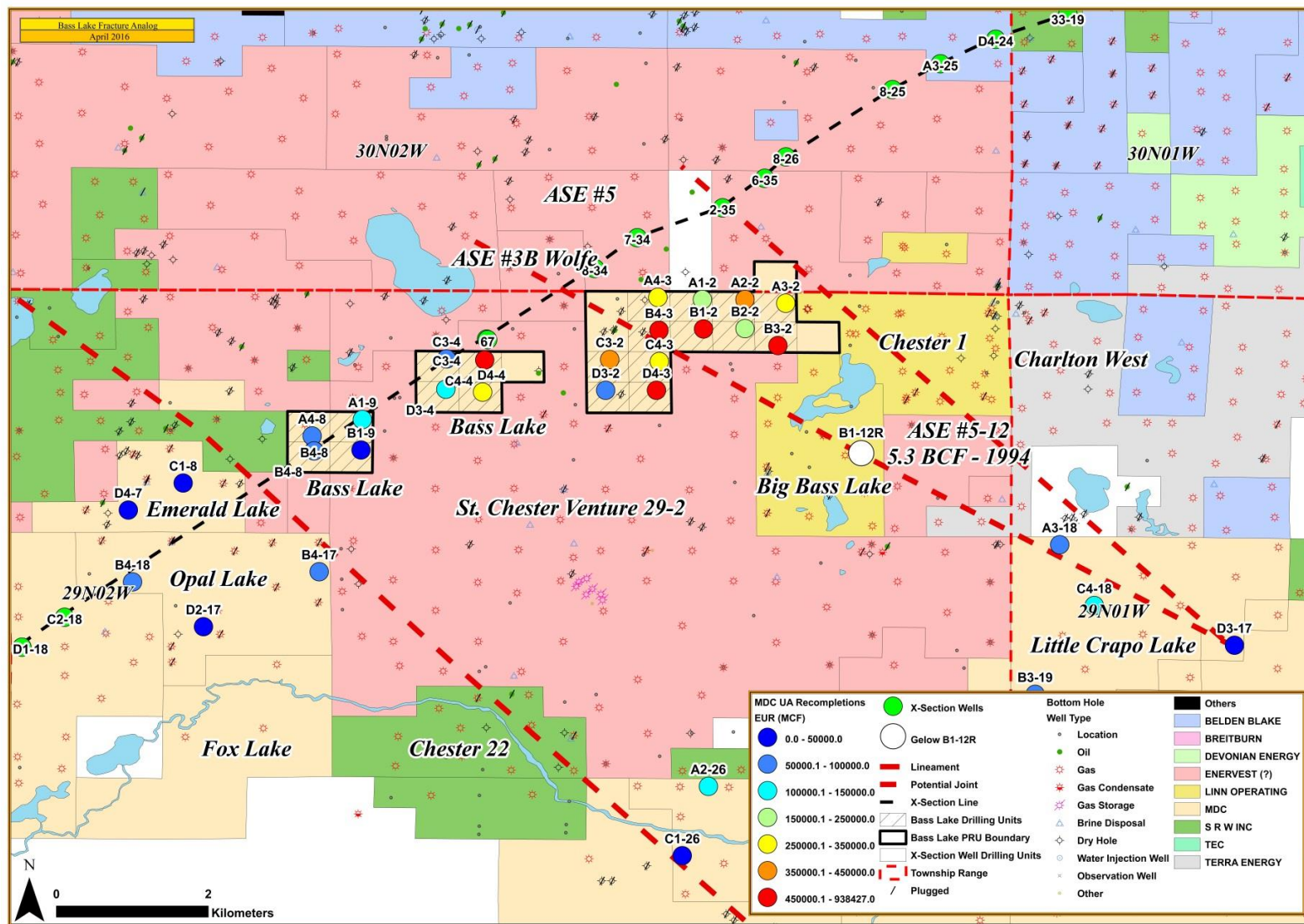
BTU: 820.9
C1/(C2+C3): 276.5
CO₂: 19.11%
Methane: 80.19%
Ethane: 0.23%

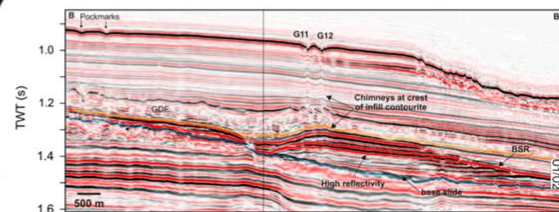
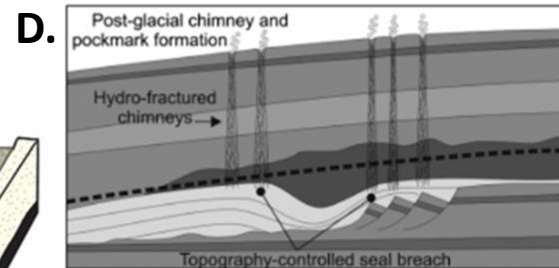
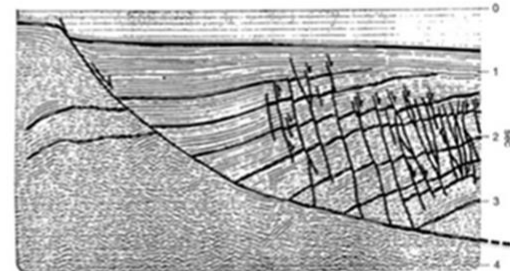
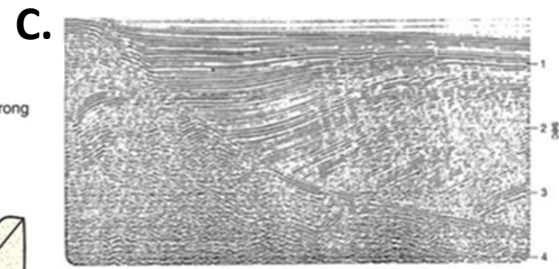
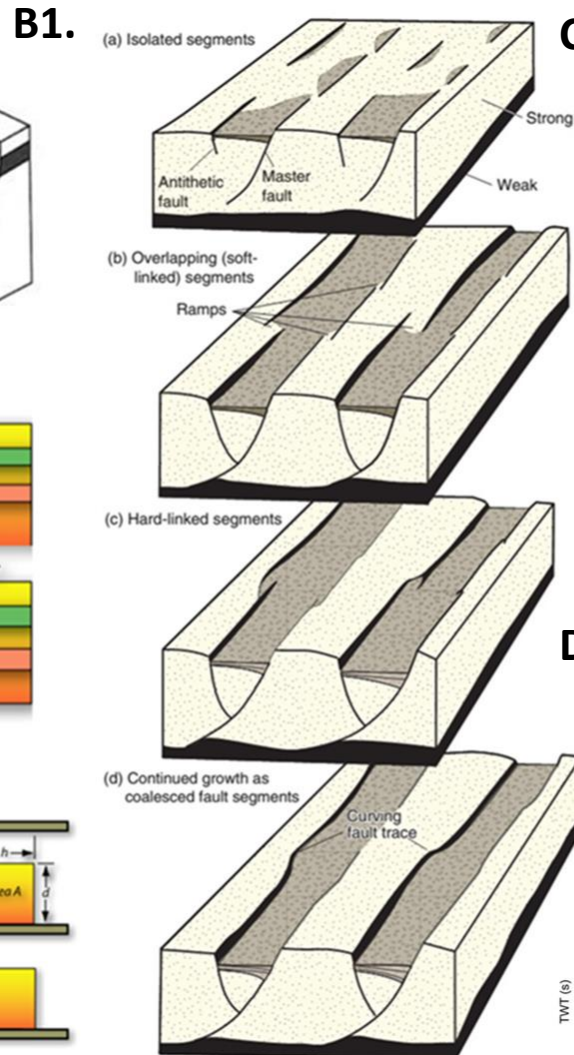
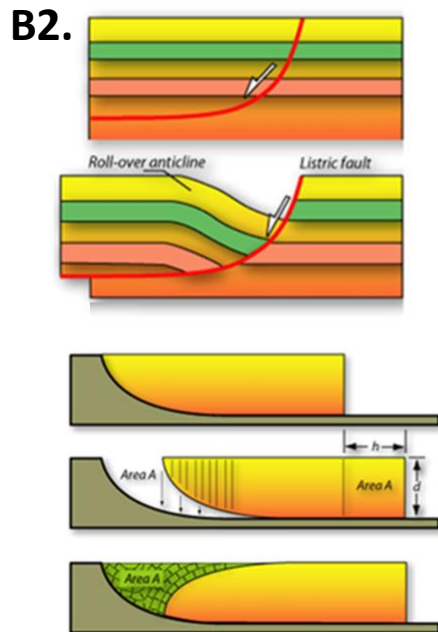
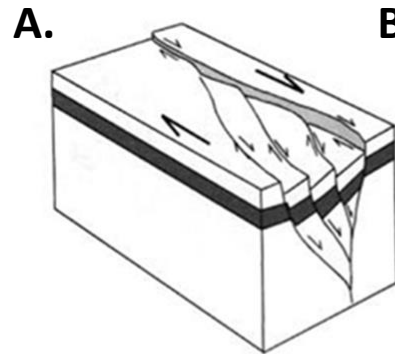
Chester 1 (8/7/07)

BTU: 968.7
C1/(C2+C3): 952.7
CO₂: 4.44%
Methane: 95.27%
Ethane: 0.08%

Chester 22 (2/3/06):

BTU: 852.5
C1/(C2+C3): 30.0
CO₂: 18.58%
Methane: 78.67%
Ethane: 2.03%





A. Twiss & Moore 2007; B. Hustoft et al., 2010

- ✓ **Fractures distribution is localized.**
- ✓ **Fractures appear to control gas production.**
- ✓ **Fractures are proposed to be related to major structural features.**
- ✓ **Gas composition and volume appear to be related, but is difficult to measure due to field unitization.**
- ✓ **Rollover anticlines are believed to best target zones since they are structural traps.**

Thanks To:

- **Miller Energy Company**
 - **Funding & Production Data**
- **Muskegon Development Company**
 - **Funding & Various Datasets**
- **Michigan Geological Repository for Research & Education**
 - **Providing Geological & Education Resources**
- **Michigan Public Service Commission**
 - **Production Data**

Thank You!



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Questions?



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