The Effects of Structural Lineament Reactivation on Antrim Shale Natural Gas Development*

Cameron J. Manche[1] and William B. Harrison III[1]

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Abstract

The Upper Devonian Antrim Shale Formation consists of an organic rich, highly fractured, black argillaceous mudstone of relatively low thermal maturity and is the source for major unconventional shale gas reservoirs within the Michigan Basin. Biogenic gas development was attributed to microbial activity stimulated by large volumes of glacial melt water transported through glacial channels and tunnel valleys. The Antrim Shale has proved significant economic viability with the total cumulative gas production reaching +3.39 TCF by the end of 2014. Deep-seated structural lineaments and basements faults within the Michigan Basin have experienced multiple episodes of fault-reactivation and hydrothermal fluid dispersion. Examination of the Traverse Formation's stratigraphic distribution revealed significant variability in the subsurface relief that is postulated to originate from flower structures that resulted from hydrothermal fluid transmission proximal to structural lineaments. These reactivation events not only propagate fracture network development, but also the migration of hot saline basinal brines. The dissemination of excess Cl^{-} can significantly influence biogenic gas production in the Antrim Shale. Advances in spatial analysis technology provide new insights on the geospatial relationship between basinal brine chemistry proximal to structural lineaments and the overall influence on natural gas production. Utilizing an integrated geospatial dataset consisting of geochemical, wireline, structural, stratigraphic, and satellite data it was possible to examine the geospatial controls on biogenic gas development. Ultimately, this study aims to provide valuable insights on natural gas development, distribution, and accessibility through geospatial analysis of the intrinsic and extrinsic geological influences on the Antrim Shale Formation.

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Eastern Section AAPG – Indianapolis, Indiana
September 20 – 22, 2015

Shale & Unconventional Resources II

AAPG
Western Michigan University

Presentation Outline:

- Research Questions
- Background: Antrim Shale
  - Timing of Deposition: Michigan Basin
  - Spatial Distribution
- Distribution of Gas & Brines
- Structural Influence on Gas Development
  - Structure
  - Stratigraphy
- Conclusions
- Future Work
  - Brine Analysis & Stable Isotopes of Gas
  - Regional Mapping of Fracture Distribution
  - Mechanism for Migration: Conceptual Models

Research Questions:

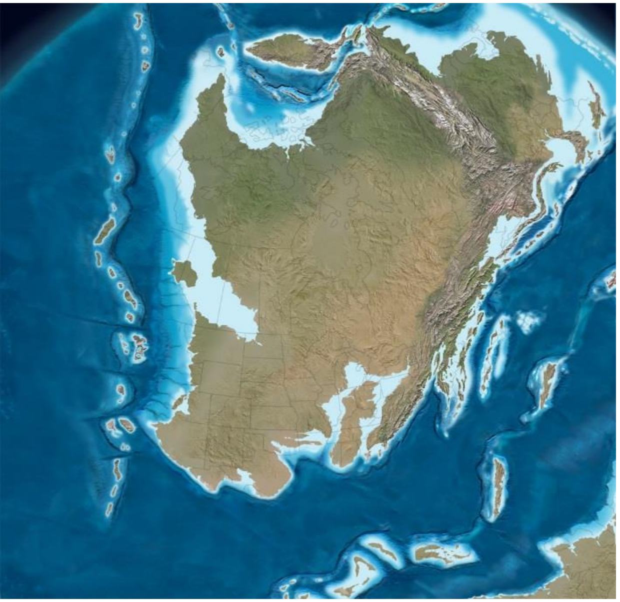
- **Are there observed trends in anomalous thermogenic gas signatures?**
- **Are there observed trends in formation water chemistry?**
- **Does microbial gas generation show a spatial trend?**
- **Does the occurrence of structural lineaments spatially correlate to anomalous thermogenic gas signatures and formation water chemistry?**

Background: Antrim Shale

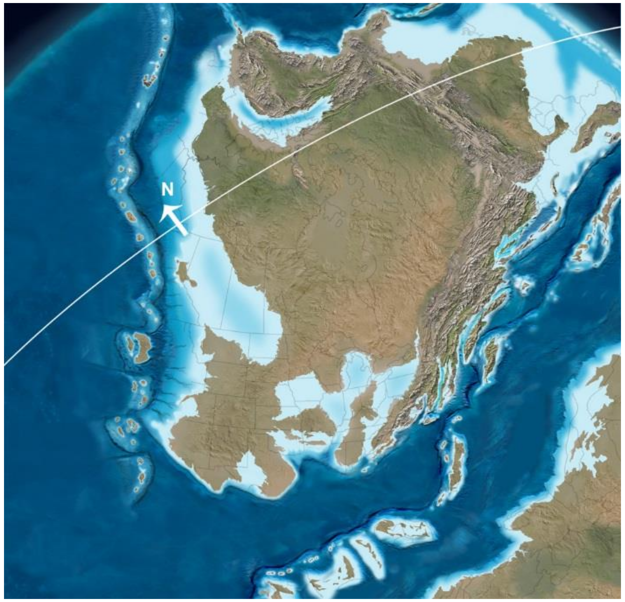
- Timing of Deposition: Michigan Basin
  - Michigan Basin – Middle-Upper Devonian
  - Depositional Facies
  - Characterization of Representative Facies
  - Depositional Environment
- Spatial Distribution
  - Subcrop & North Producing Trend
  - Rifting & Anticline Structures

Timing of Deposition: Michigan Basin

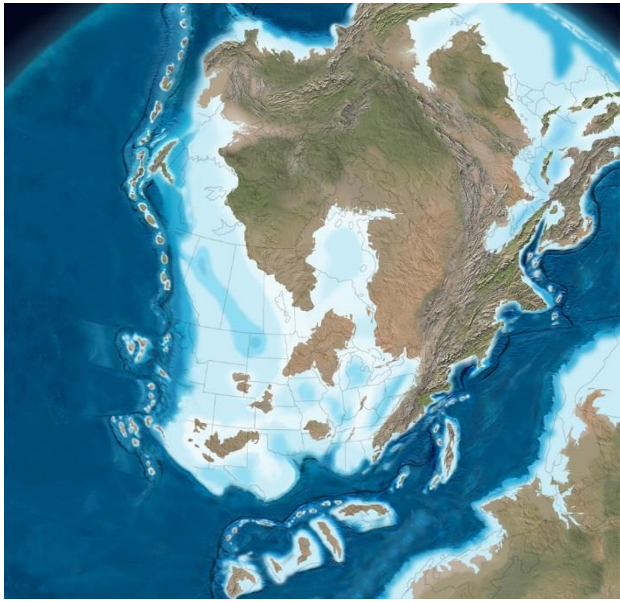
- **Michigan Basin – Middle-Upper Devonian**



Early Devonian
400 Ma



Middle Devonian
385 Ma

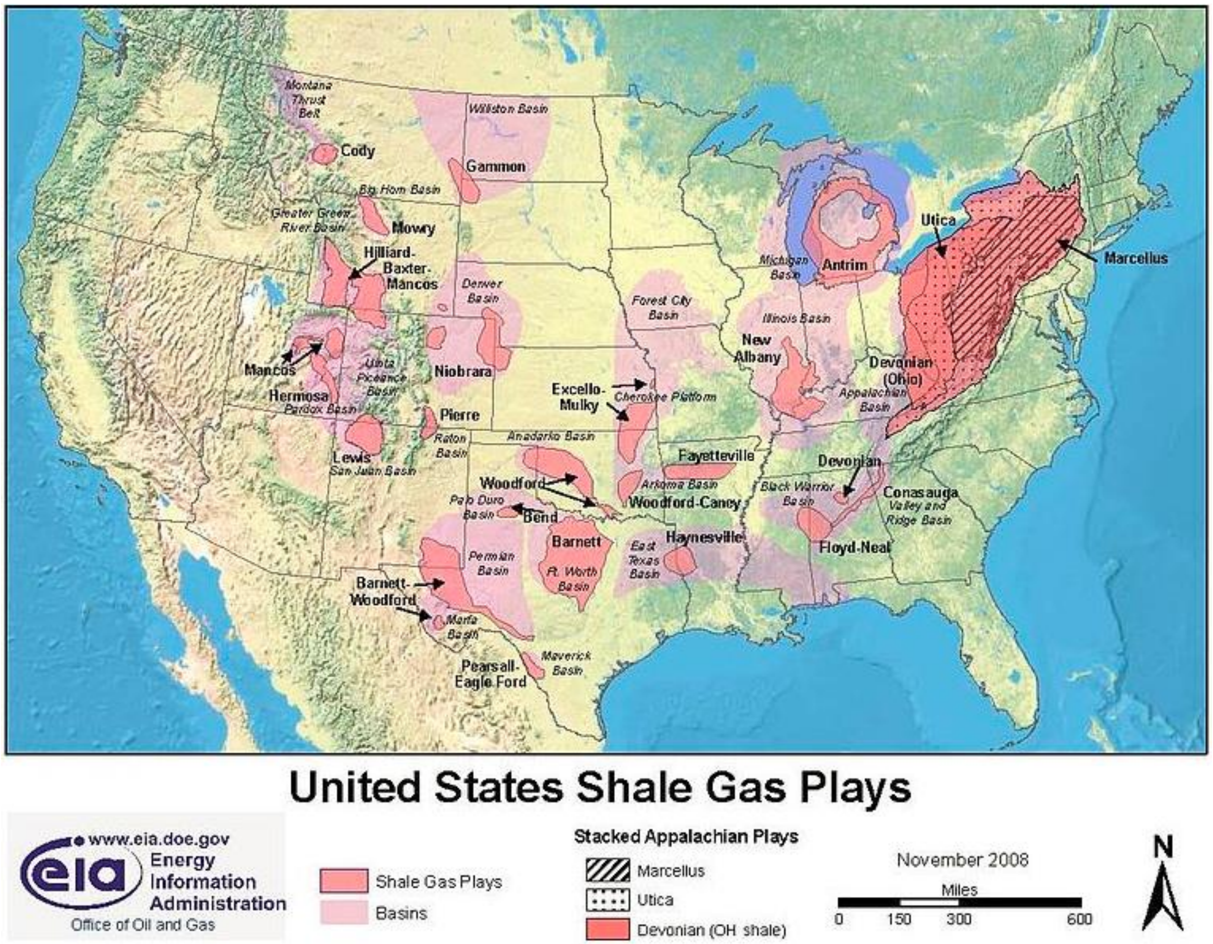


Late Devonian
360 Ma

Blakey, 2007

Timing of Deposition: Michigan Basin

- **Michigan Basin – Middle-Upper Devonian**



Antrim Sh. – Michigan Basin
Bakken Fm – Williston Basin
Marcellus Sh. – Appalachian Basin
New Albany Sh. – Illinois Basin

Timing of Deposition: Michigan Basin

- **Depositional Facies**

Norwood Member
Latuszek B1-32 (41559)
Otsego County, MI
Section 30, 30N 1W

8.

Timing of Deposition: Michigan Basin

- **Depositional Facies**

Paxton/Norwood Member
Latuszek B1-32 (41559)
Otsego County, MI
Section 30, 30N 1W

Timing of Deposition: Michigan Basin

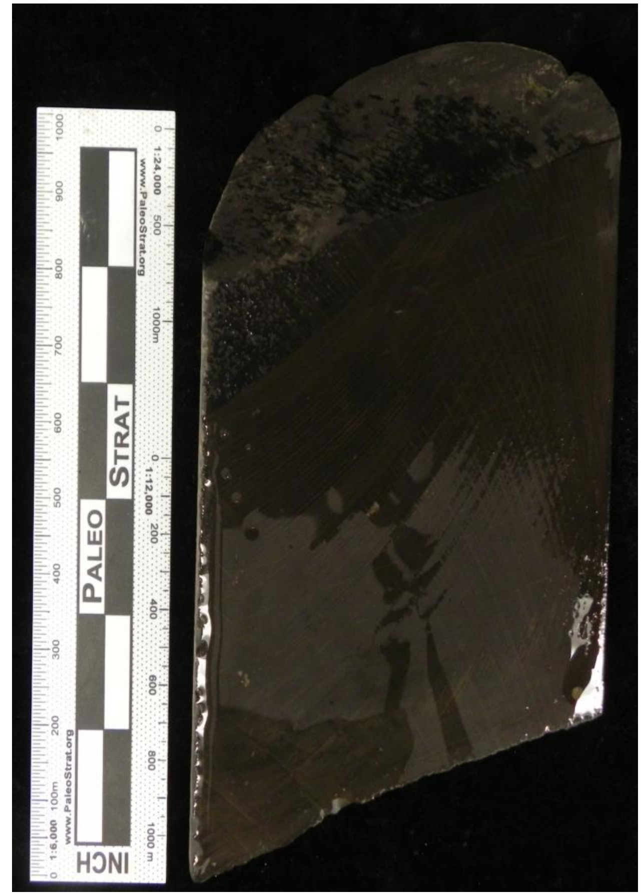
- **Depositional Facies**

Paxton Member
Latuszek B1-32 (41559)
Otsego County, MI
Section 30, 30N 1W

Timing of Deposition: Michigan Basin

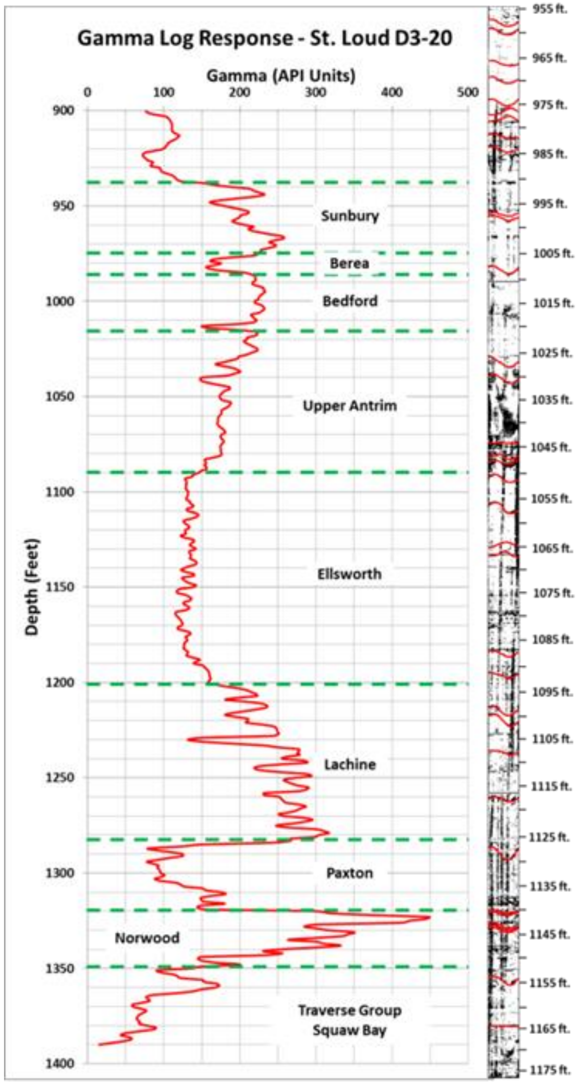
- **Depositional Facies**

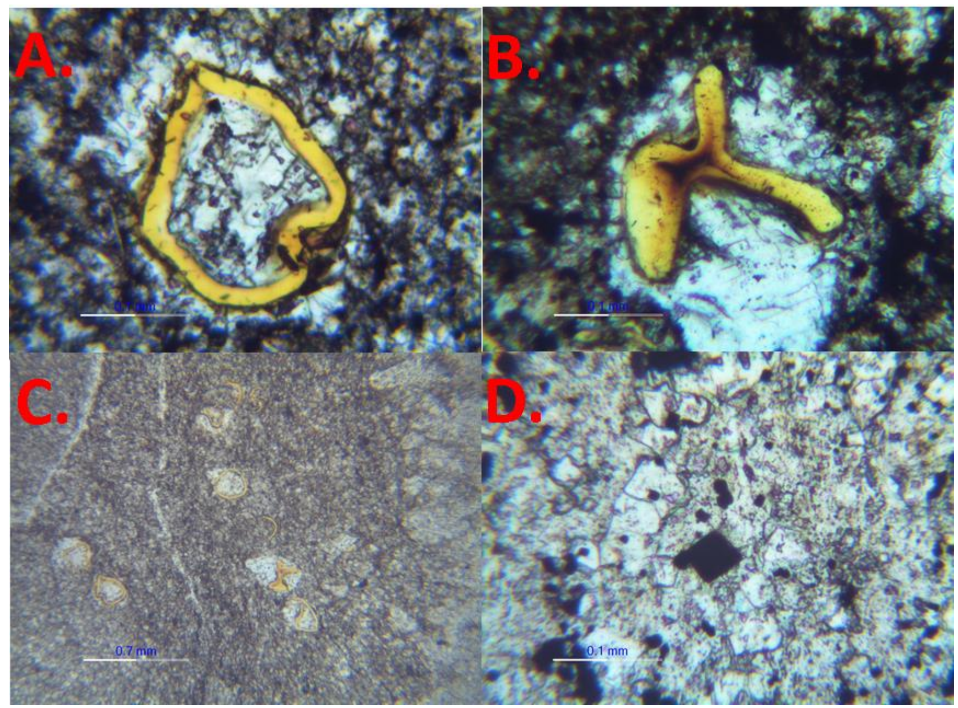
Lachine Member
Latuszek B1-32 (41559)
Otsego County, MI
Section 30, 30N 1W



Timing of Deposition: Michigan Basin

- **Characterization of Representative Facies**

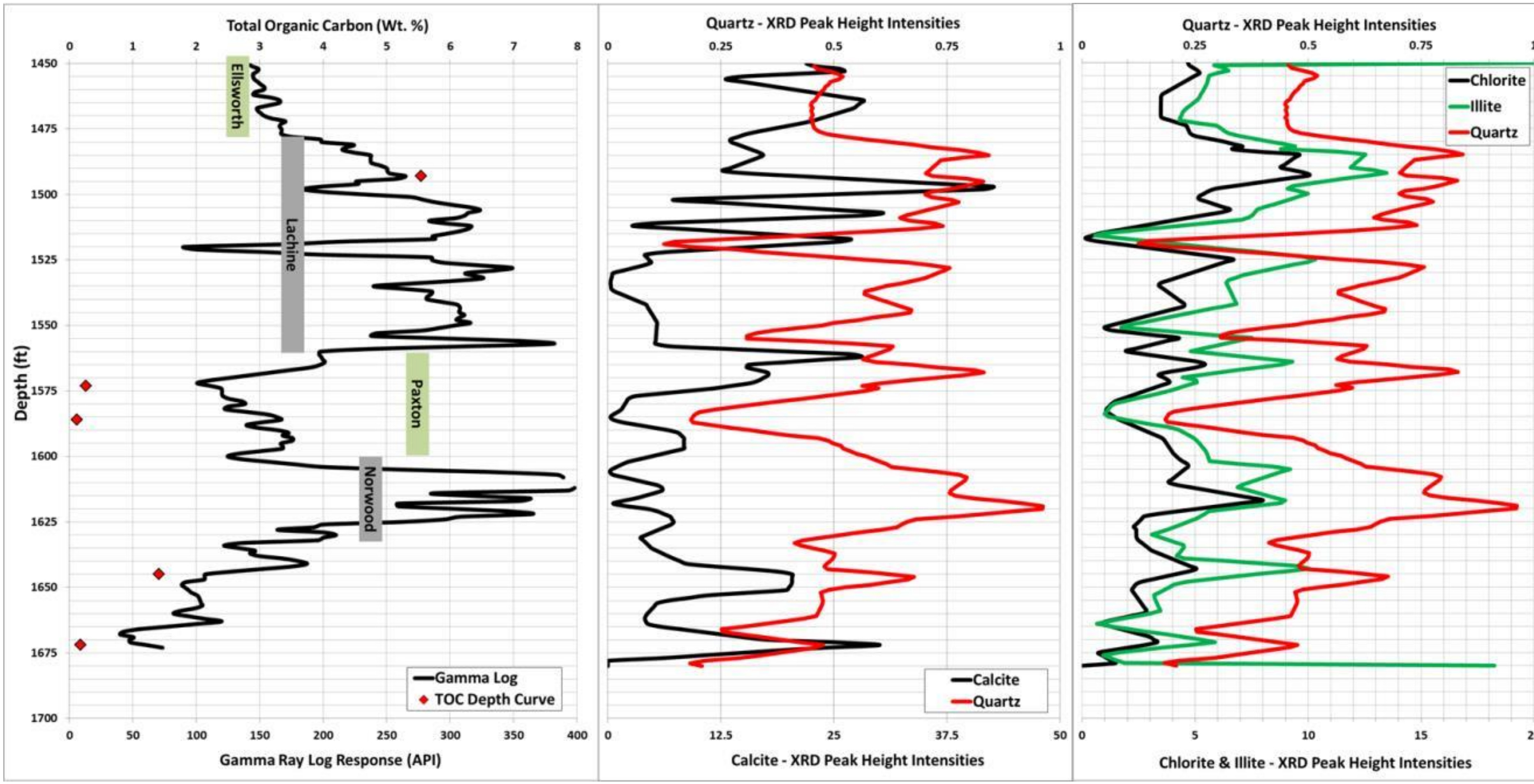




Silicification of *Tasmanites* is evidence of *in-situ* quartz authigenesis. Tasmanites are nucleation points authigenic quartz. Member (1602.3 ft.). Scale for photos A, B, and D is 0.1 mm, photo C is 0.7 mm.

Timing of Deposition: Michigan Basin

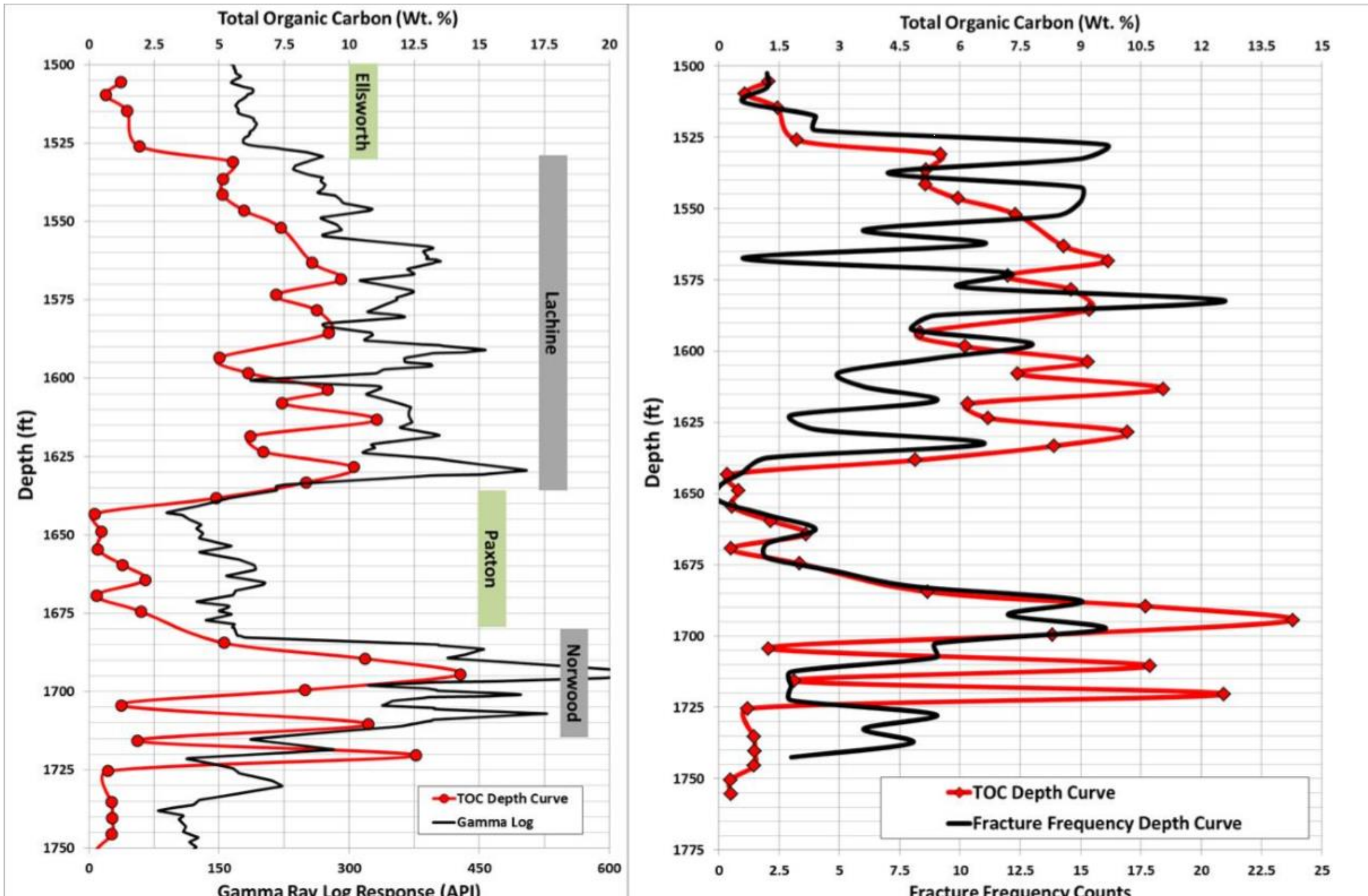
- **Characterization of Representative Facies**



St. Chester 1-18 (Permit #: 33875) – Otsego County, MI Sec. 13 T29N R02W
Data from: Dellapenna, 1991

Timing of Deposition: Michigan Basin

- **Characterization of Representative Facies**

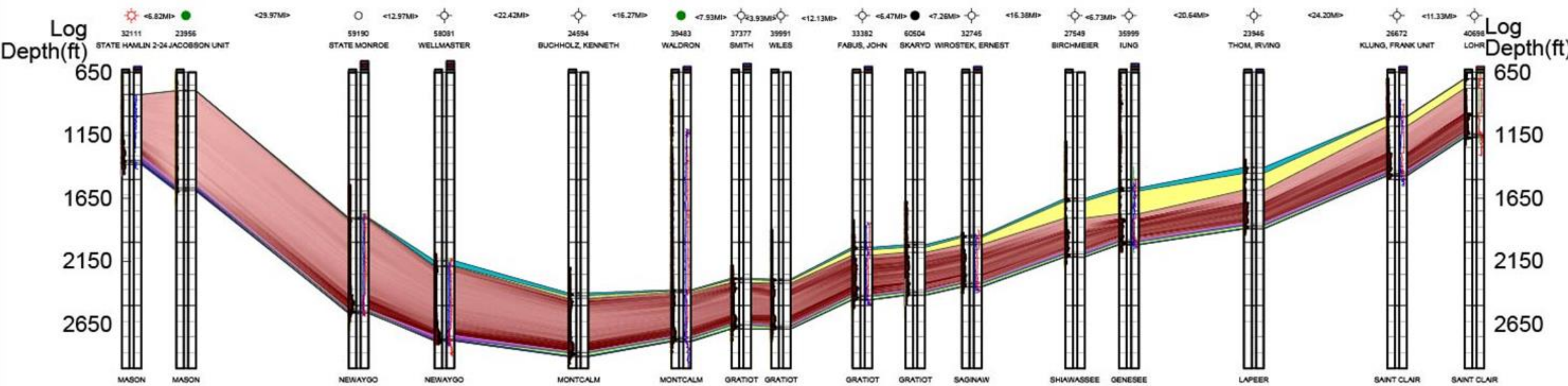


Latuszek B1-32 (Permit #: 41559) – Otsego County, MI Sec. 30 T30N R01W

Timing of Deposition: Michigan Basin

- **Depositional Environment**

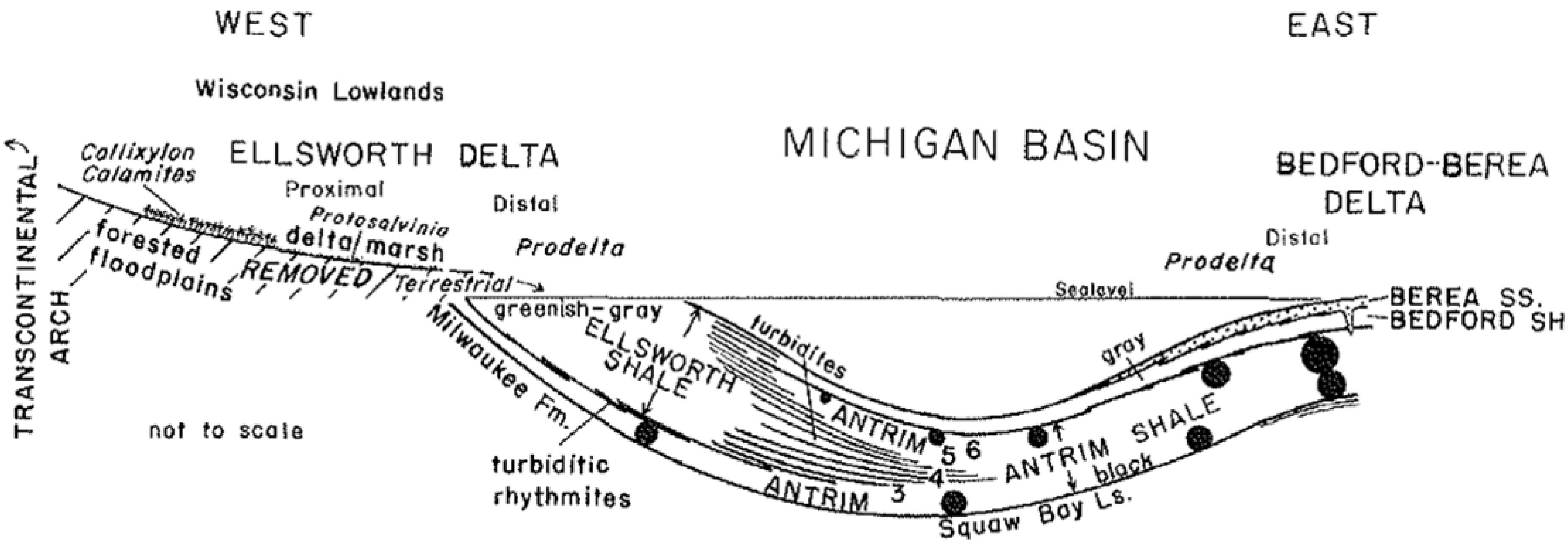
UPPER DEVONIAN TO LOWER MISSISSIPPIAN



N. Panyard, 2015

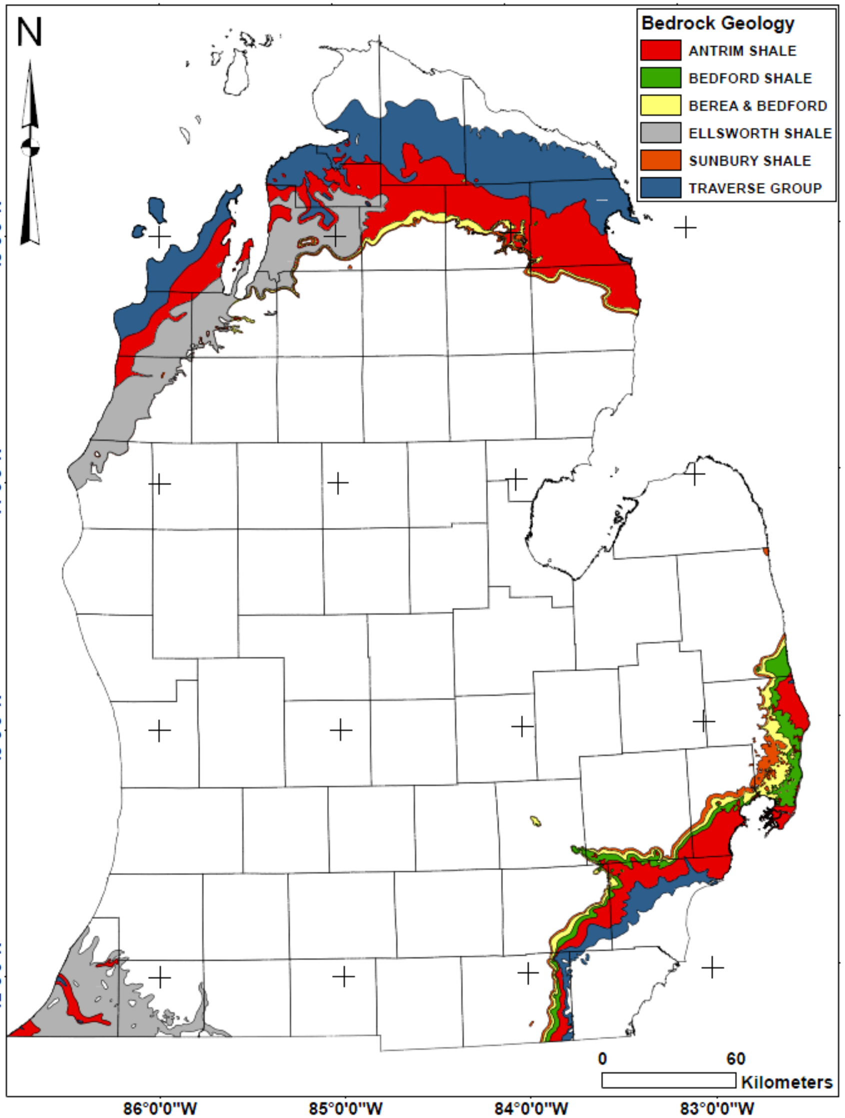
Timing of Deposition: Michigan Basin

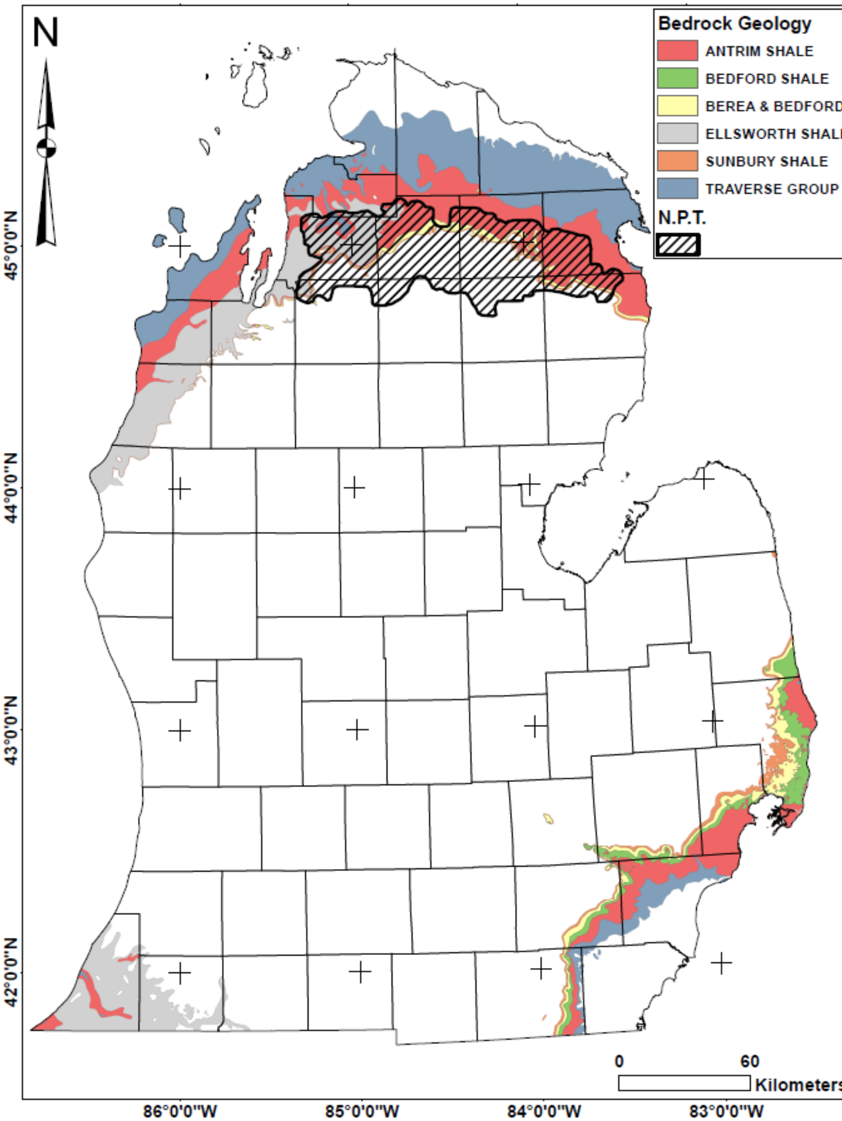
- **Depositional Environment**



Gutschick and Sandberg, 1991

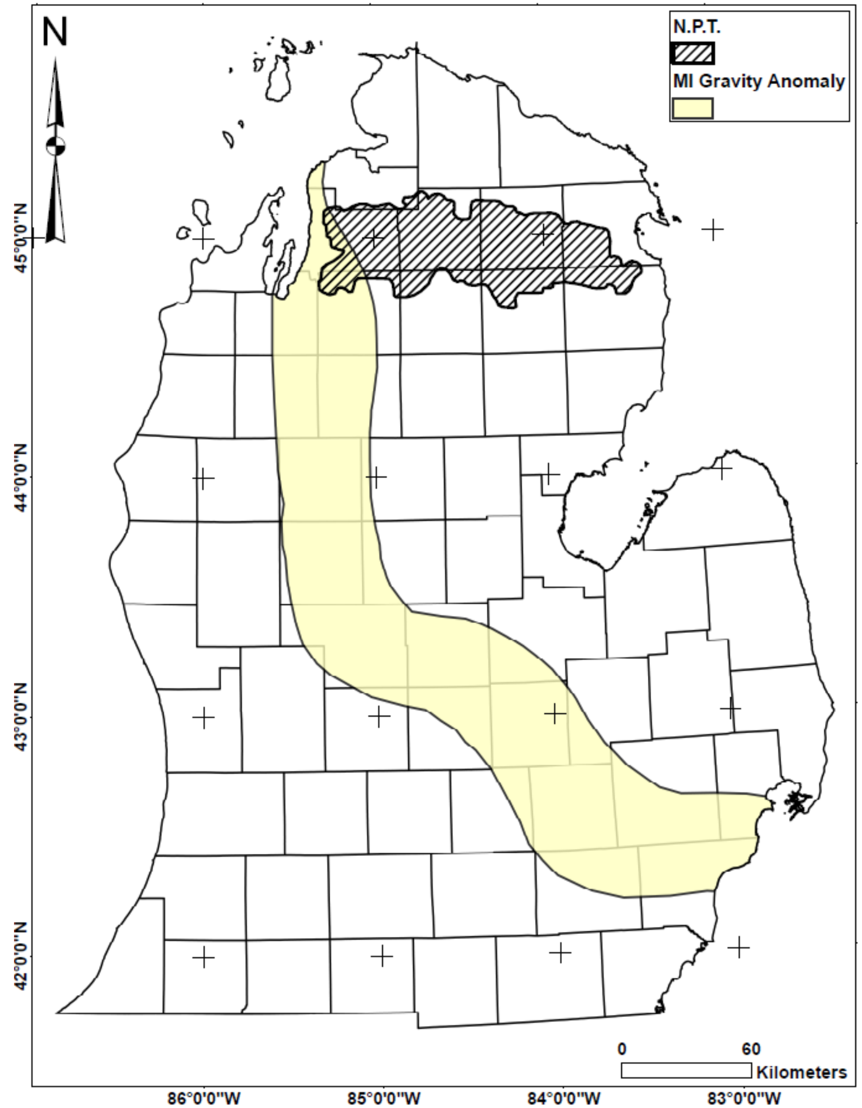
Spatial Distribution

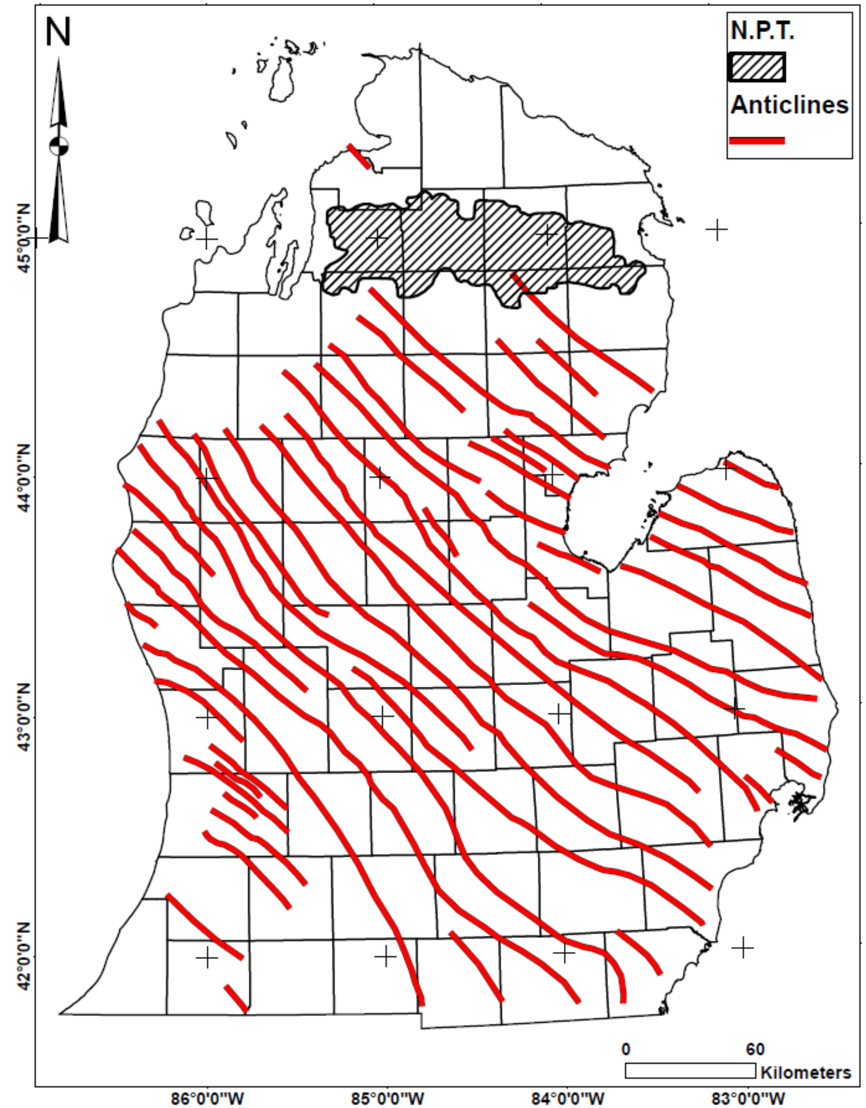




Goodman and Maness, 2008

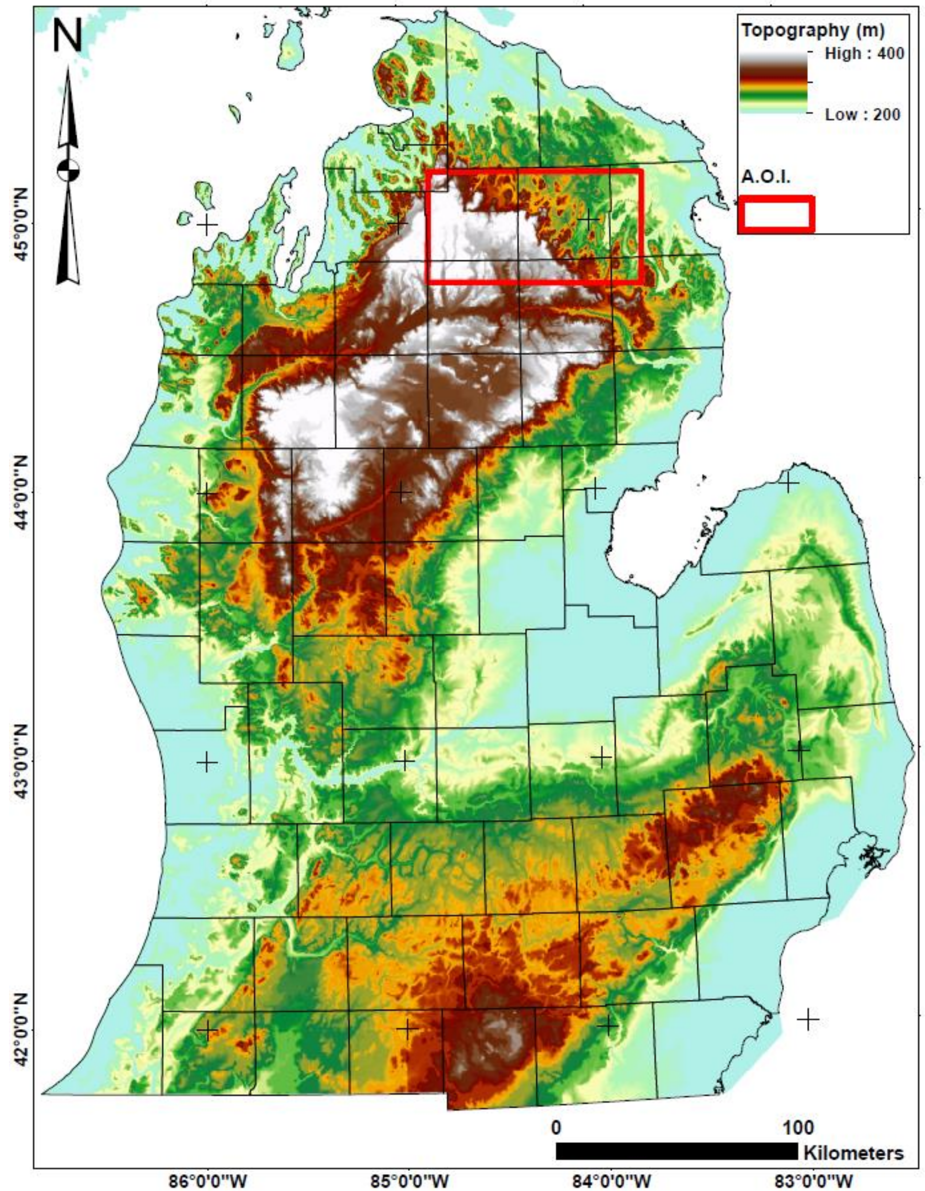
Spatial Distribution

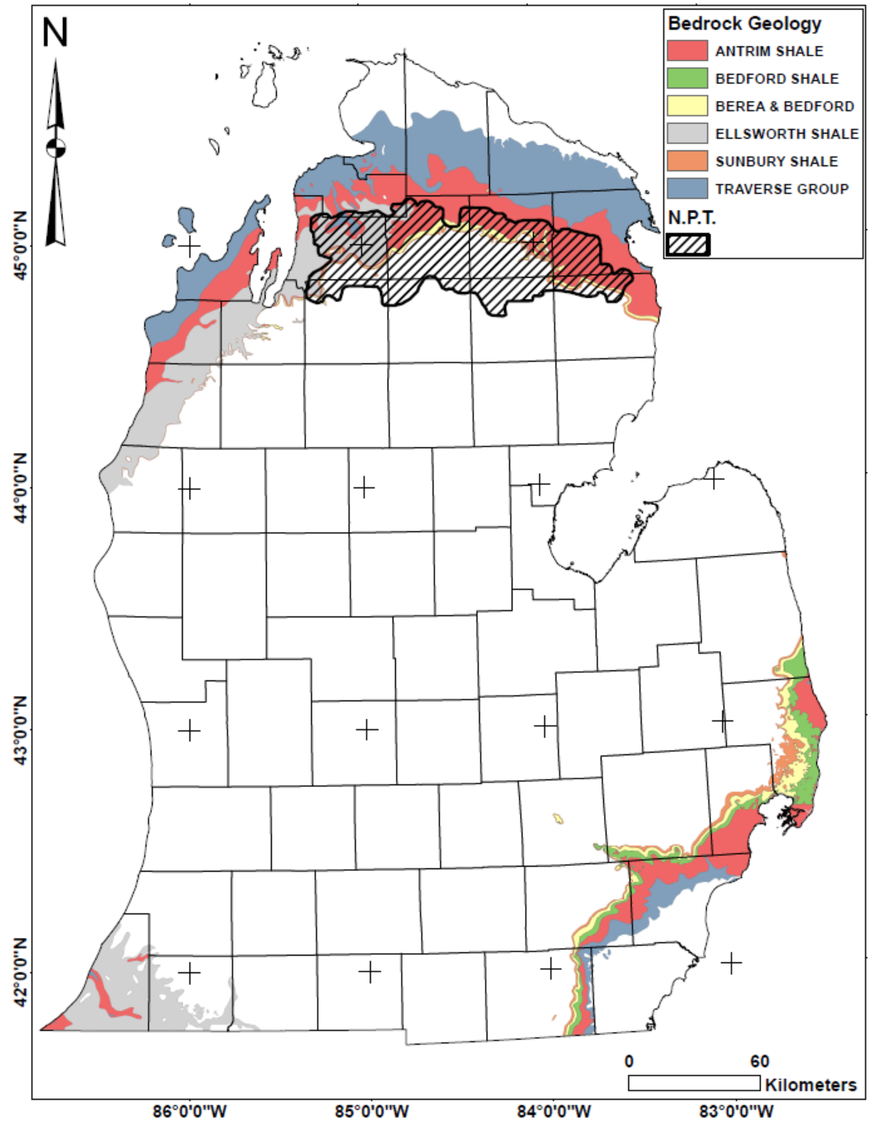




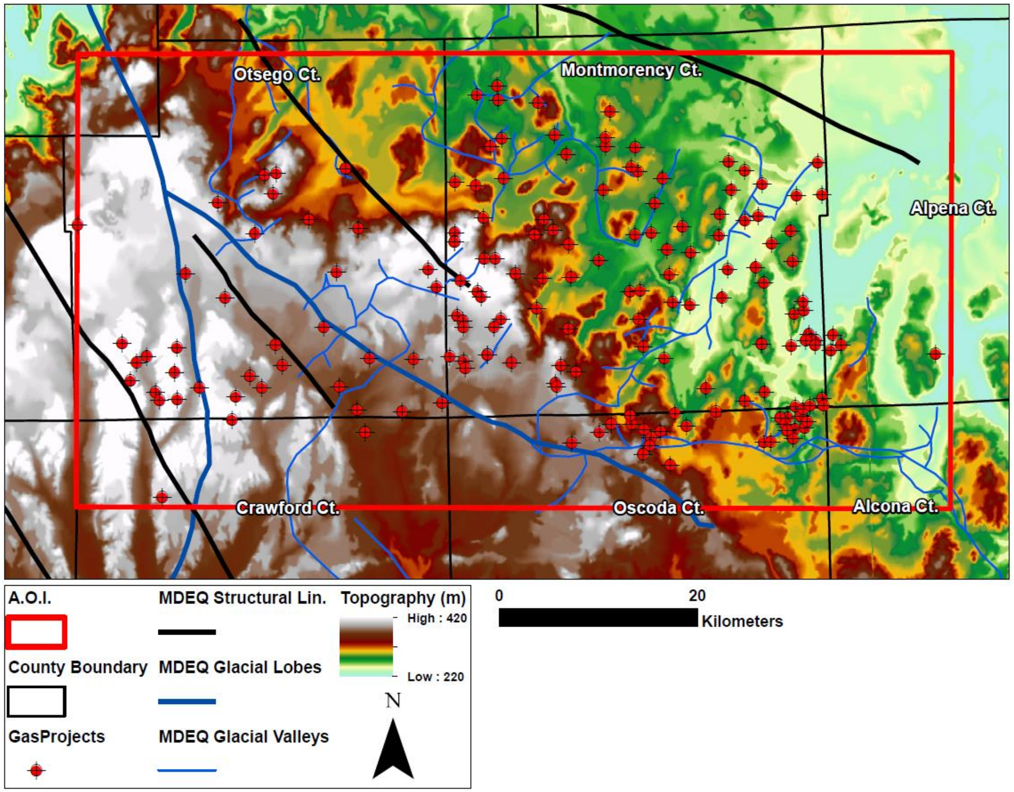
Holst and Foote, 1981

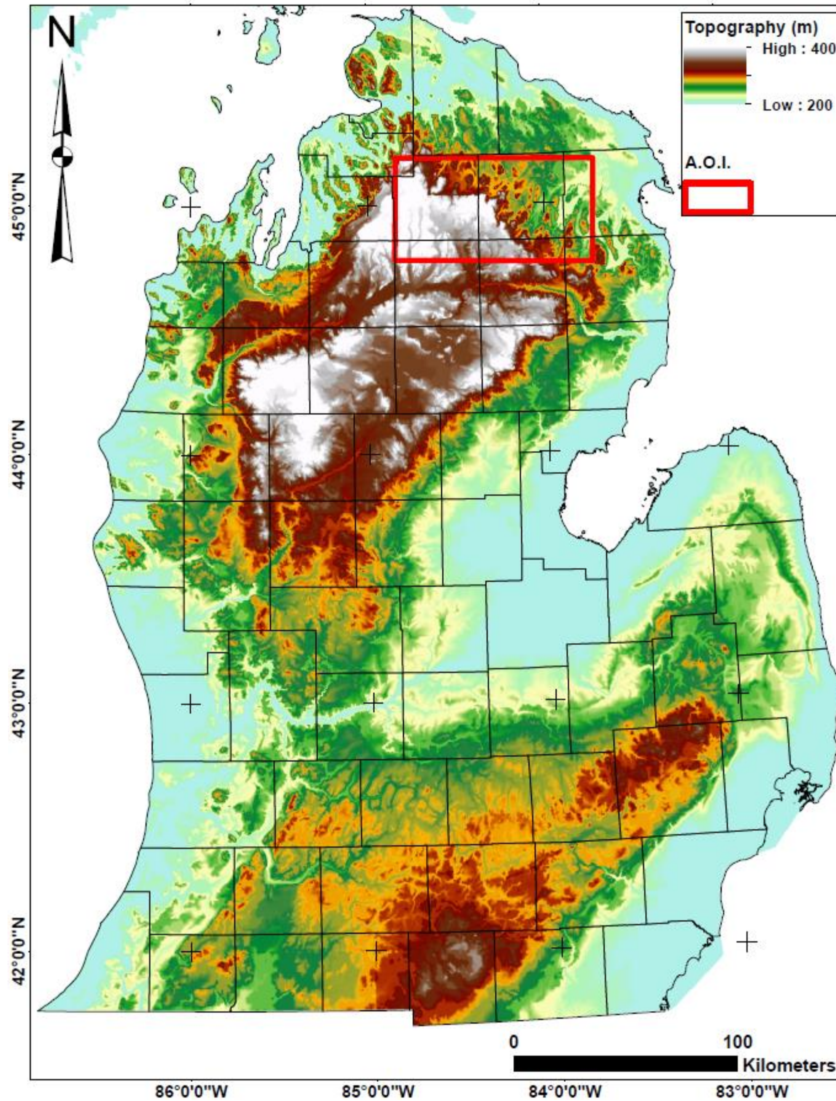
Distribution of Gas & Brines





Distribution of Gas & Brines

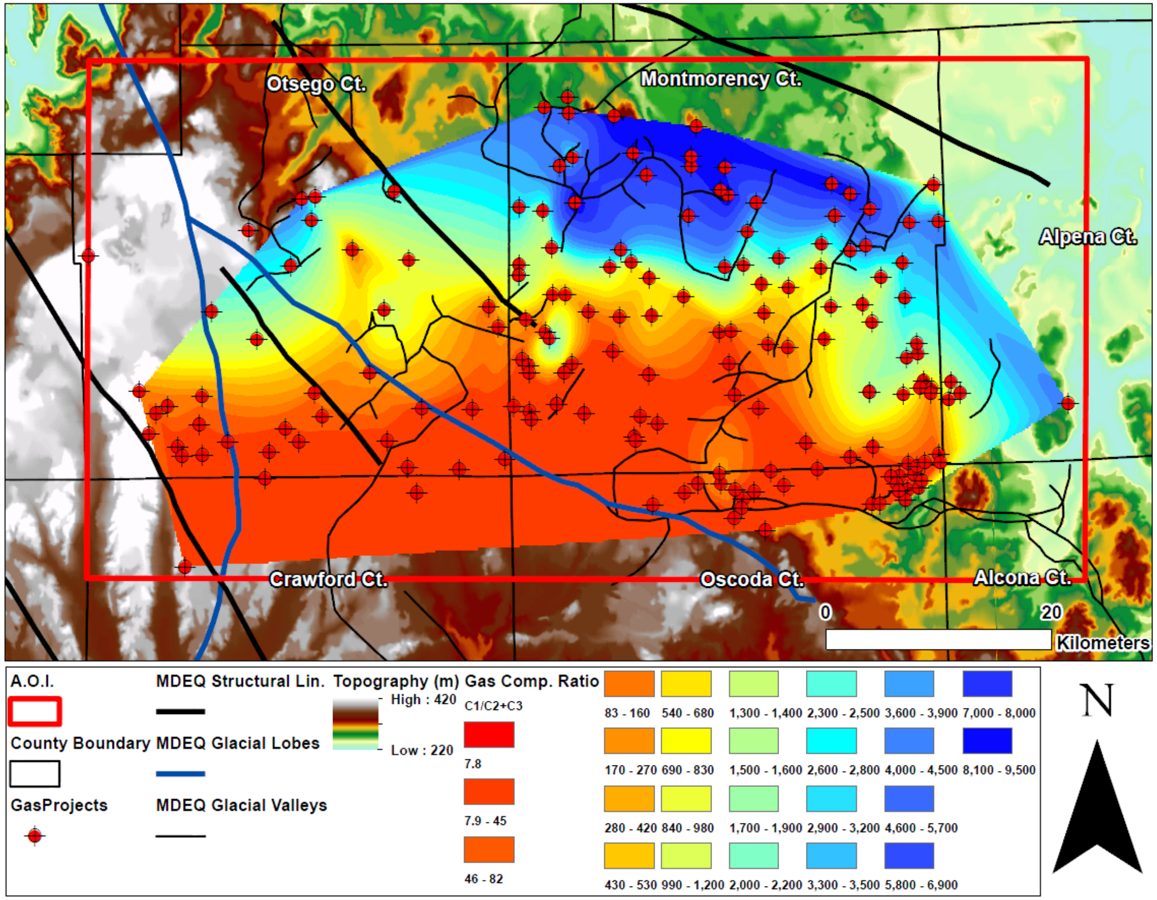


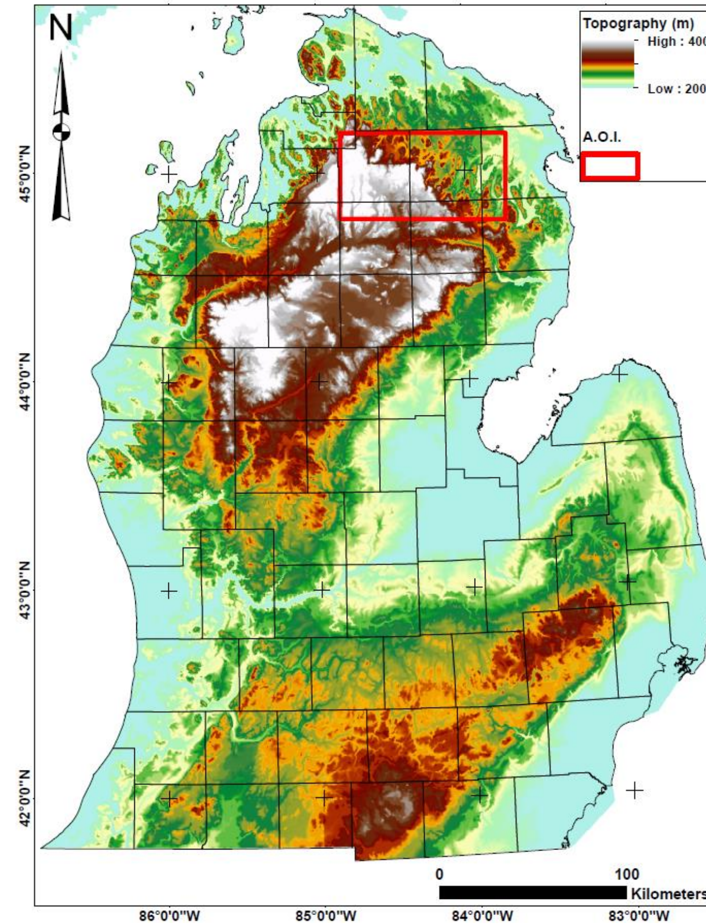


Gas Composition:

- 172 Fields Mapped
- 591 Total Field
- Analyzed: 2007

Distribution of Gas & Brines

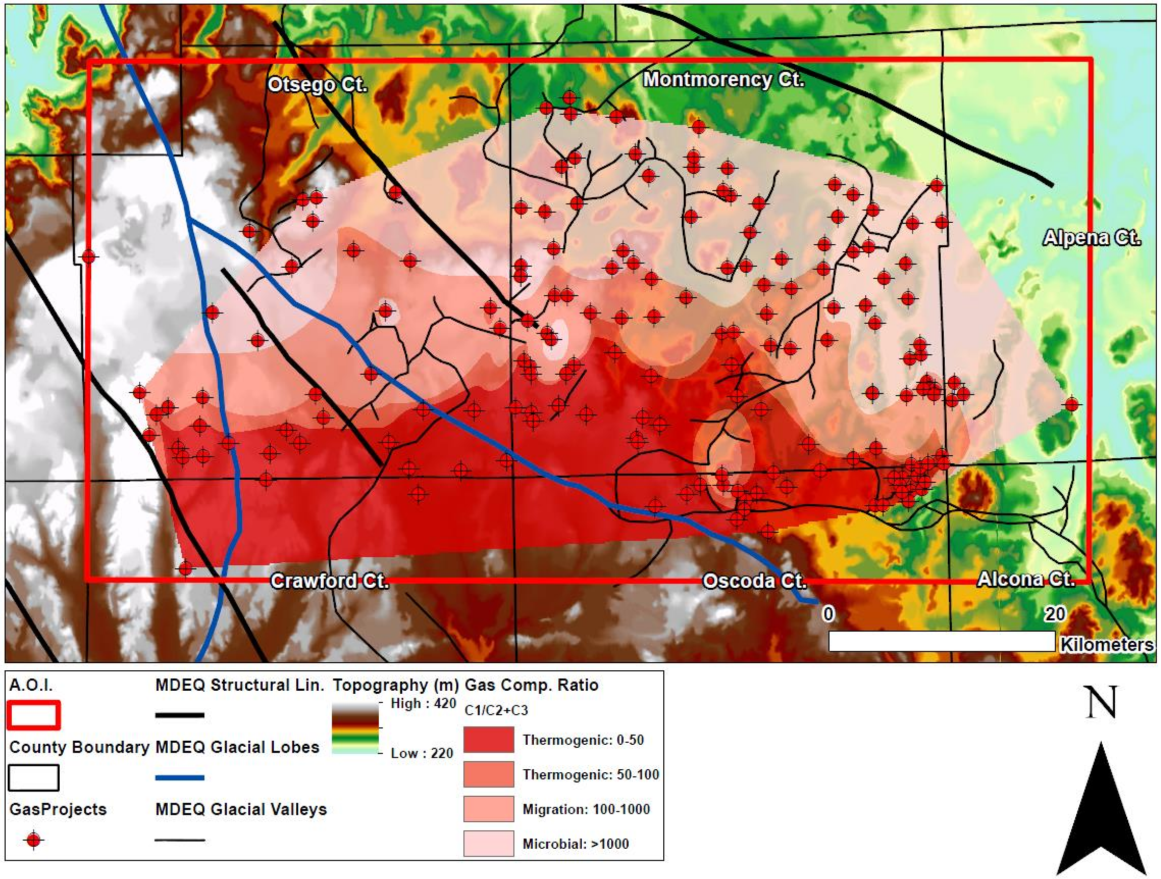


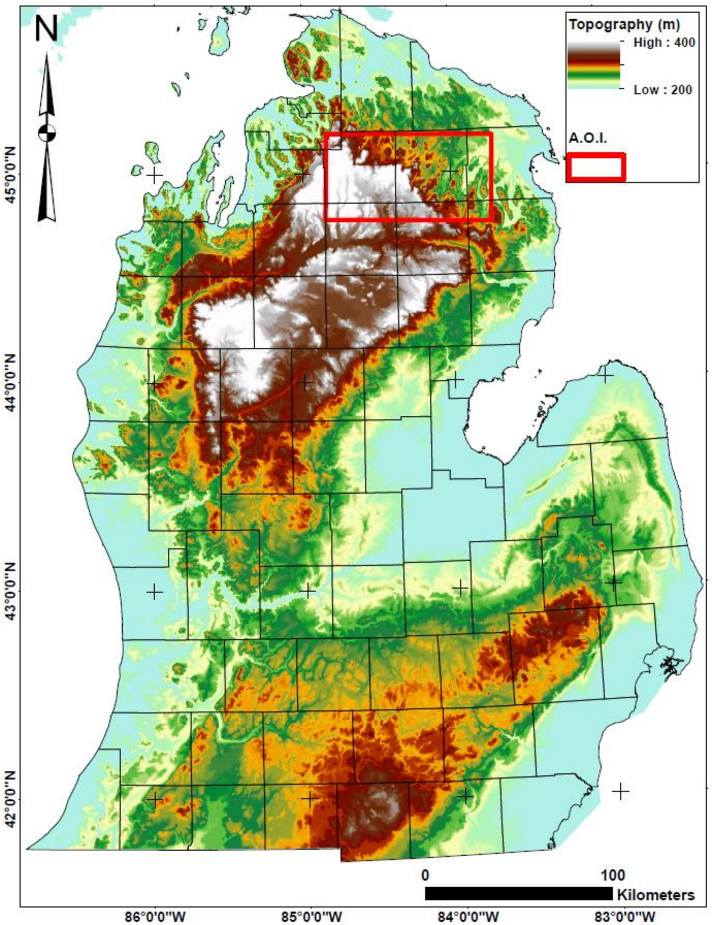


Gas Composition:

- C1/C2+C3
- Methane/Ethane + Propane

Distribution of Gas & Brines

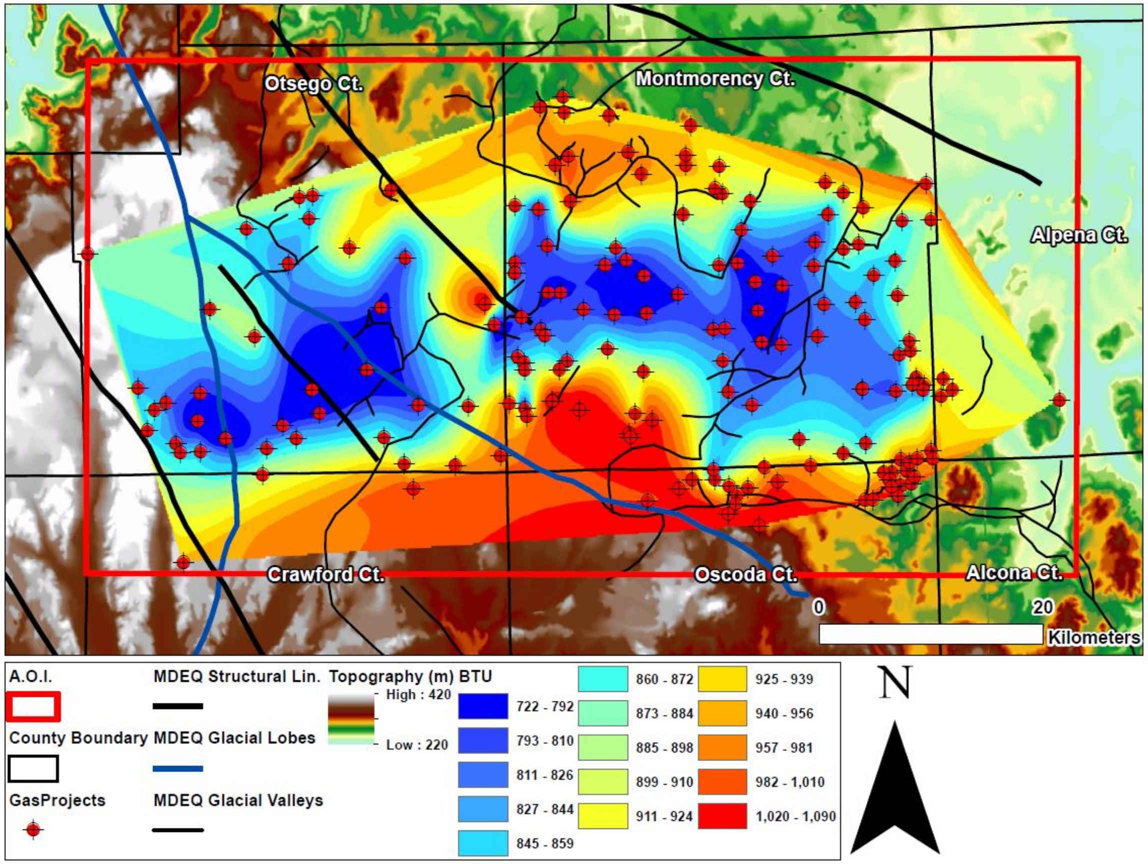


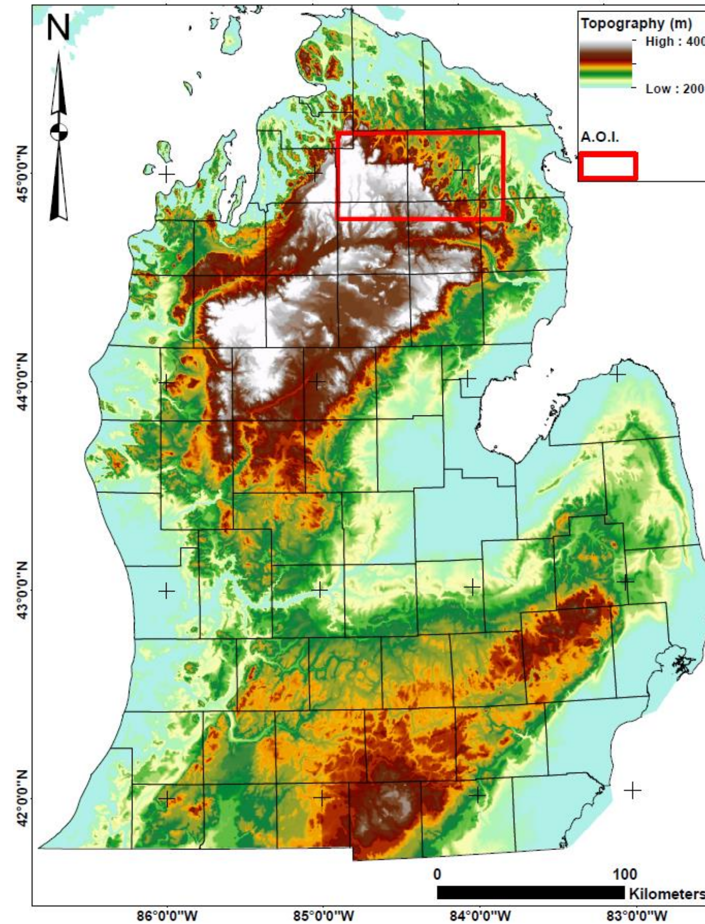


Gas Composition:

- Gas Provenance Zones
- Methane/Ethane + Propane

Distribution of Gas & Brines

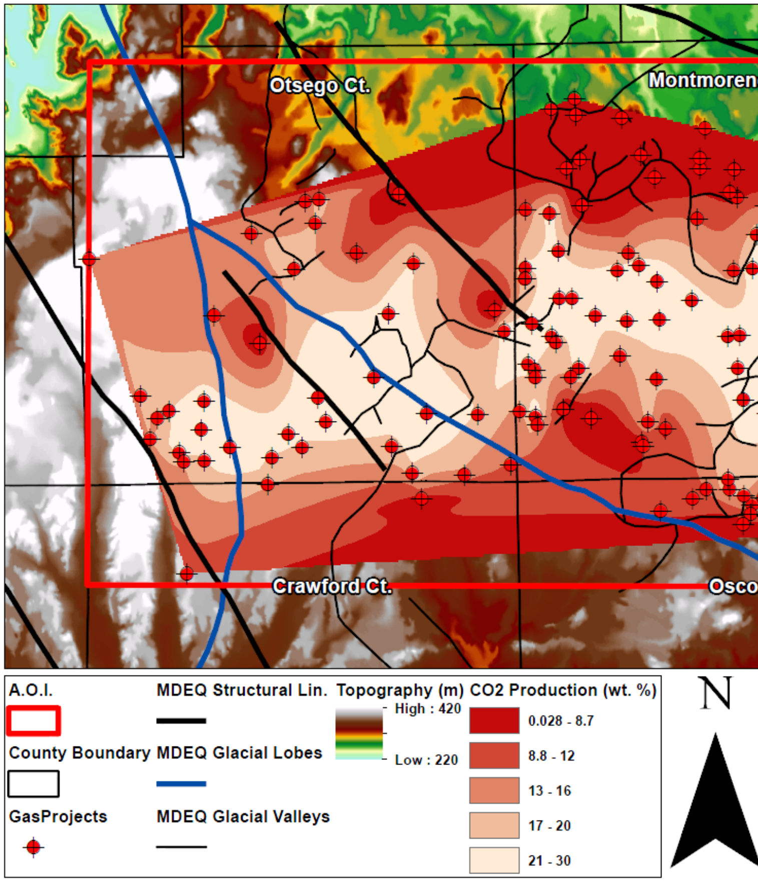


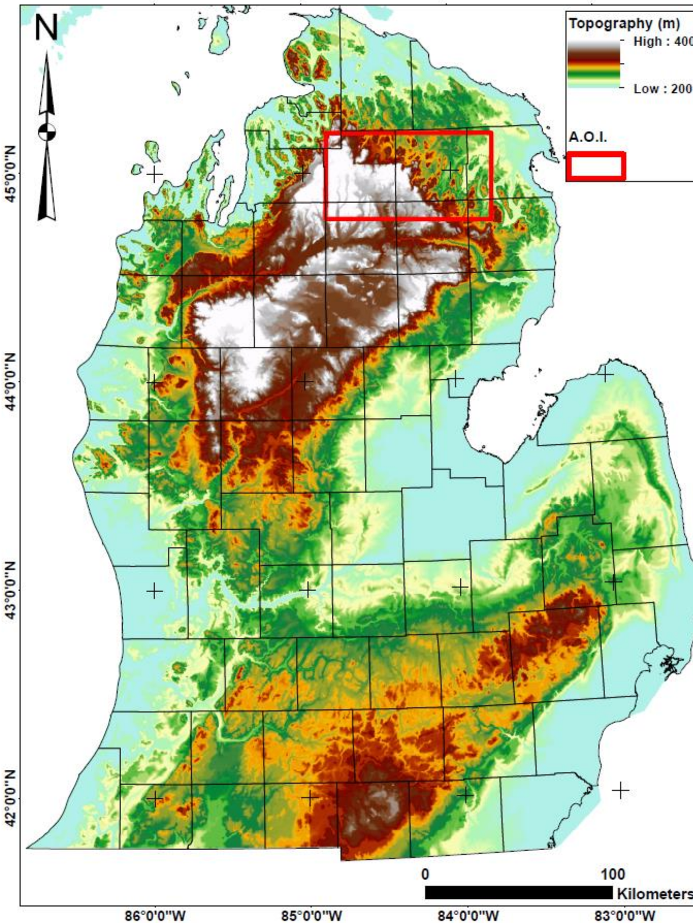


Gas Composition:

- Gas Provenance - BTU
- Methane/Ethane + Propane

Distribution of Gas & Brines

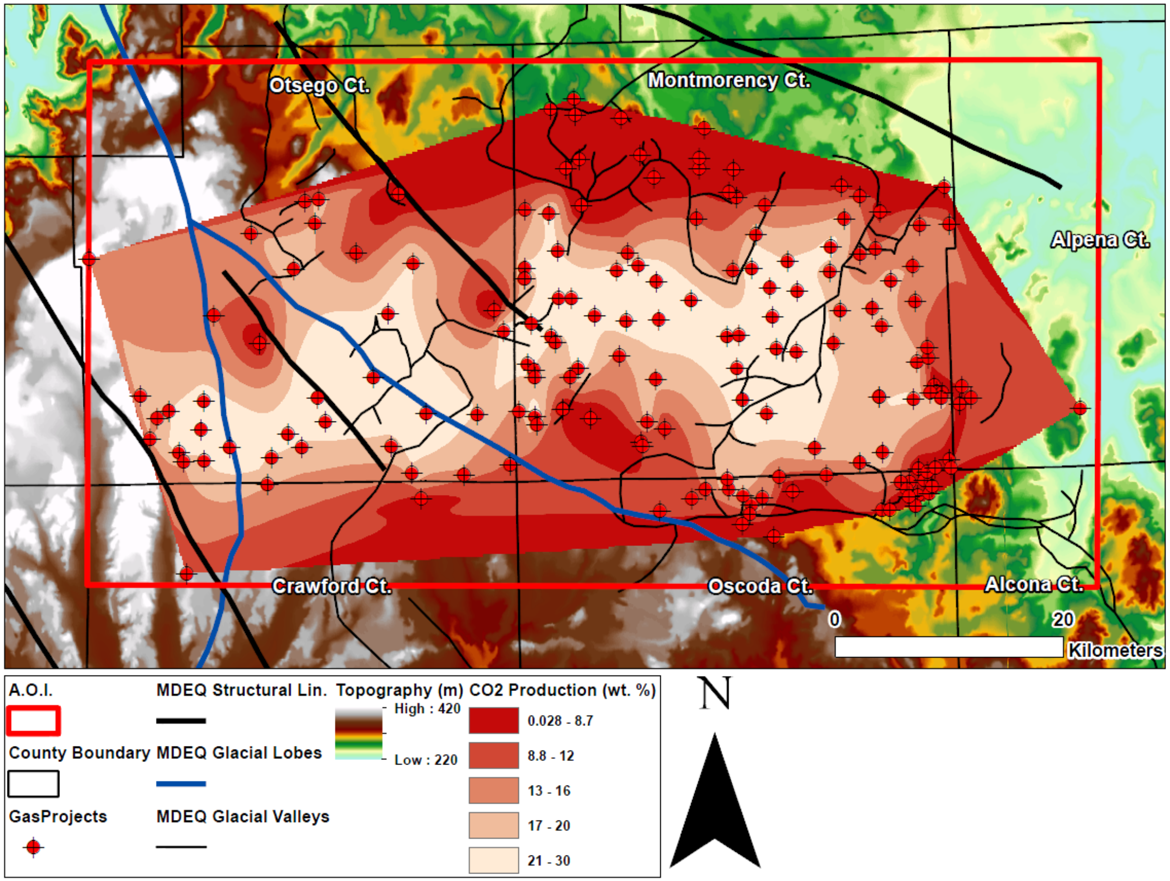


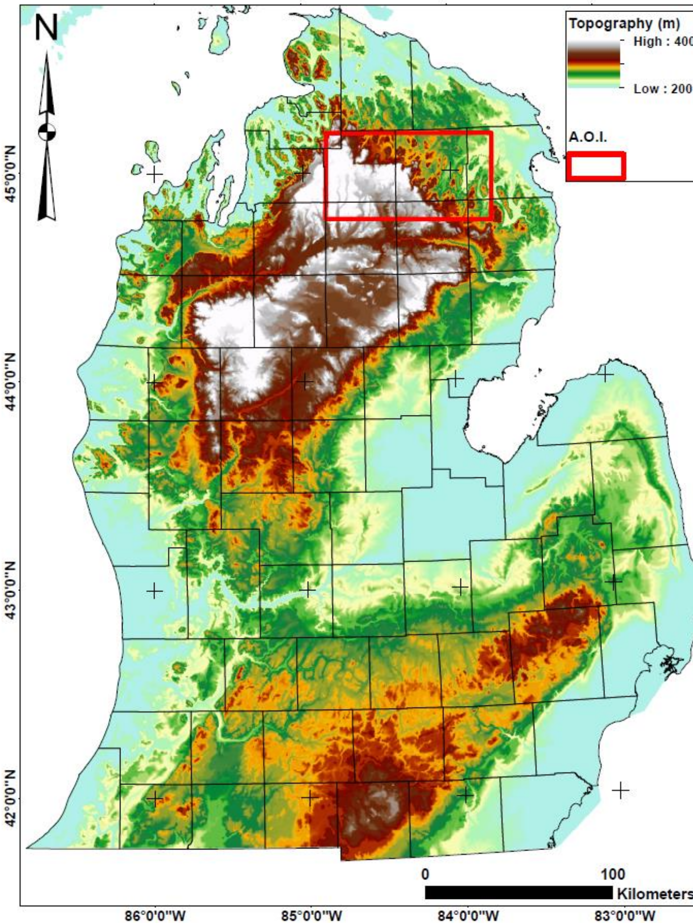


Gas Composition:

- Gas Provenance – CO_2 Production
- Methane/Ethane + Propane

Distribution of Gas & Brines





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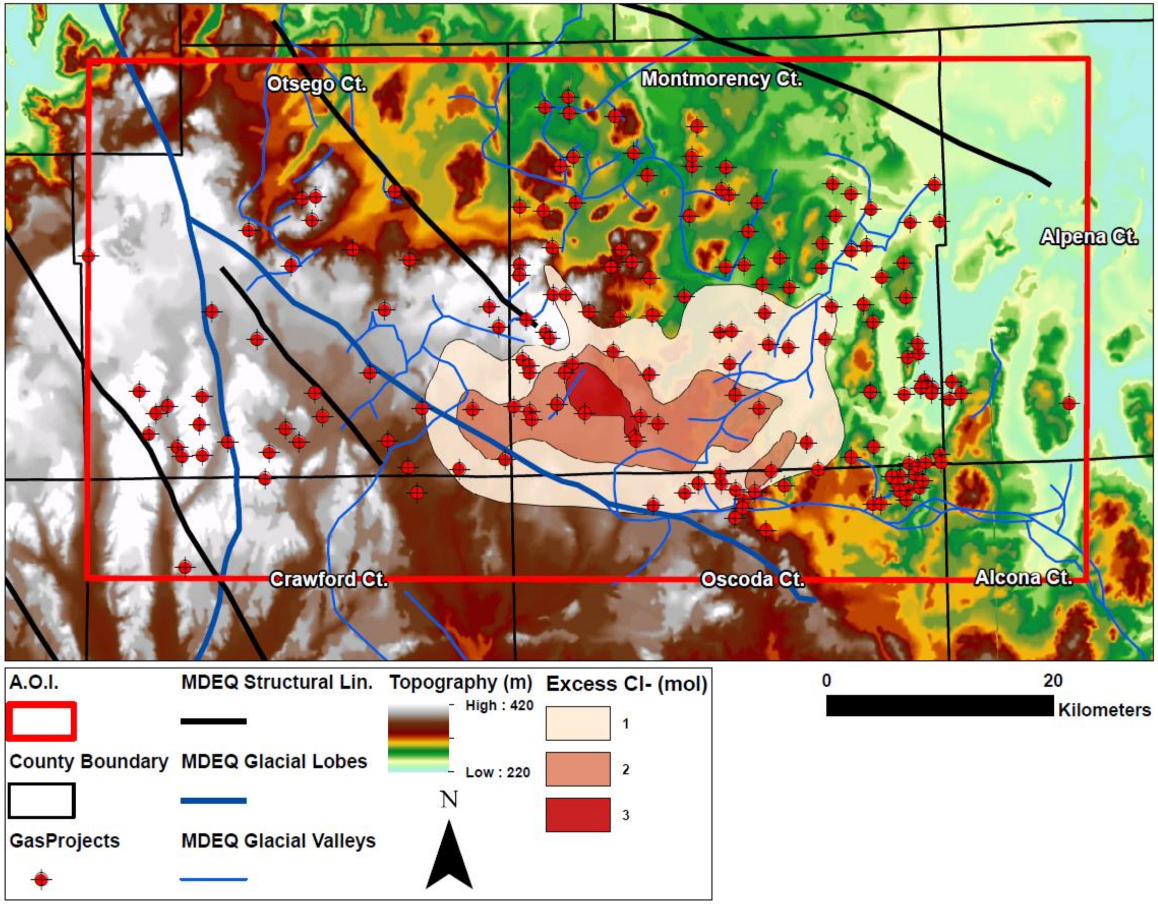
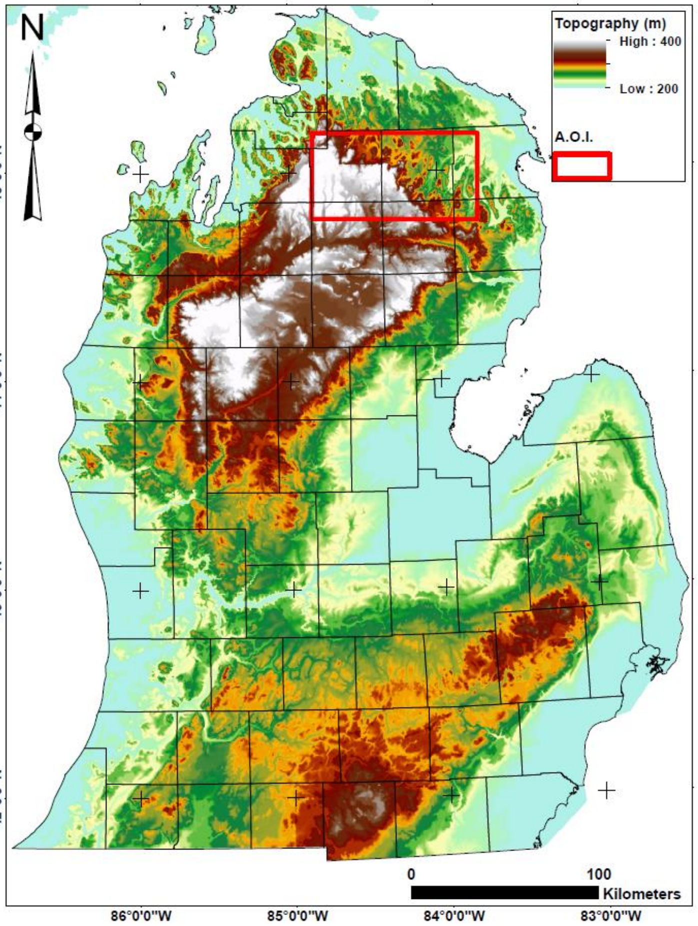


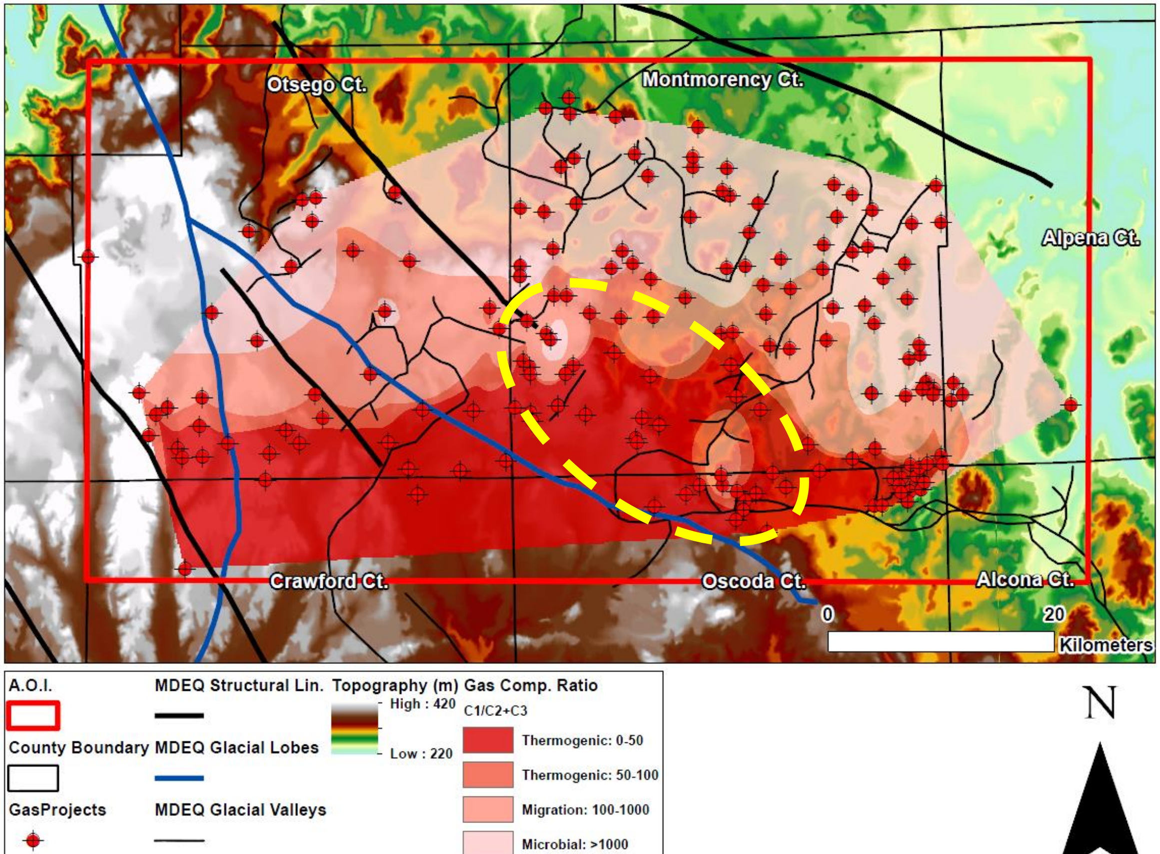


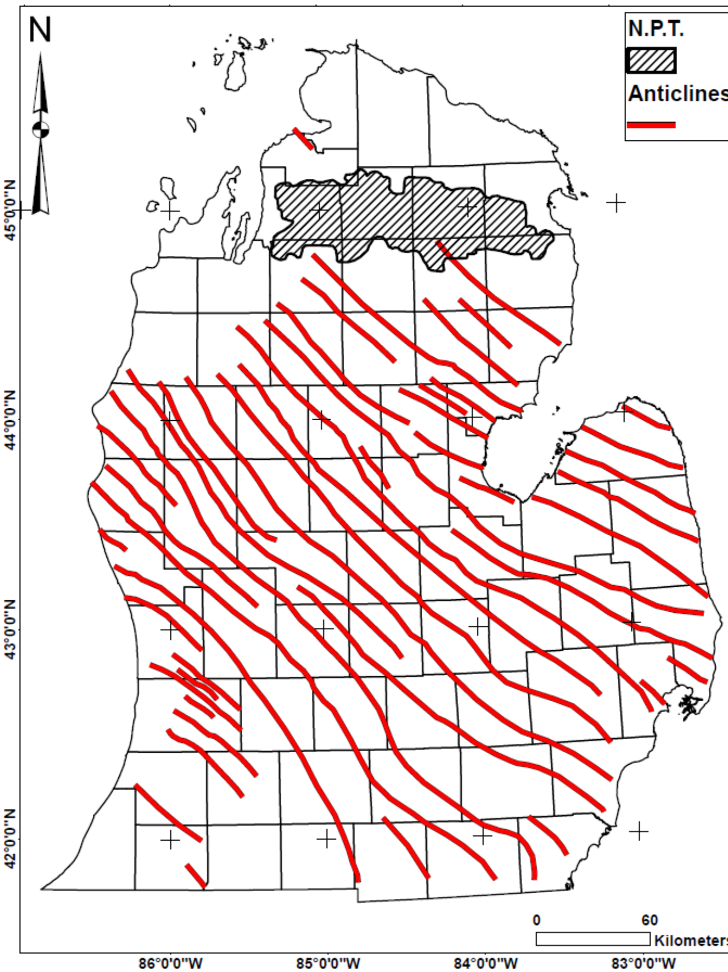
Brine Distribution:

- Chloride Distribution
- Fluid Migration

Martini et al., 1998

Structural Influence of Gas Development

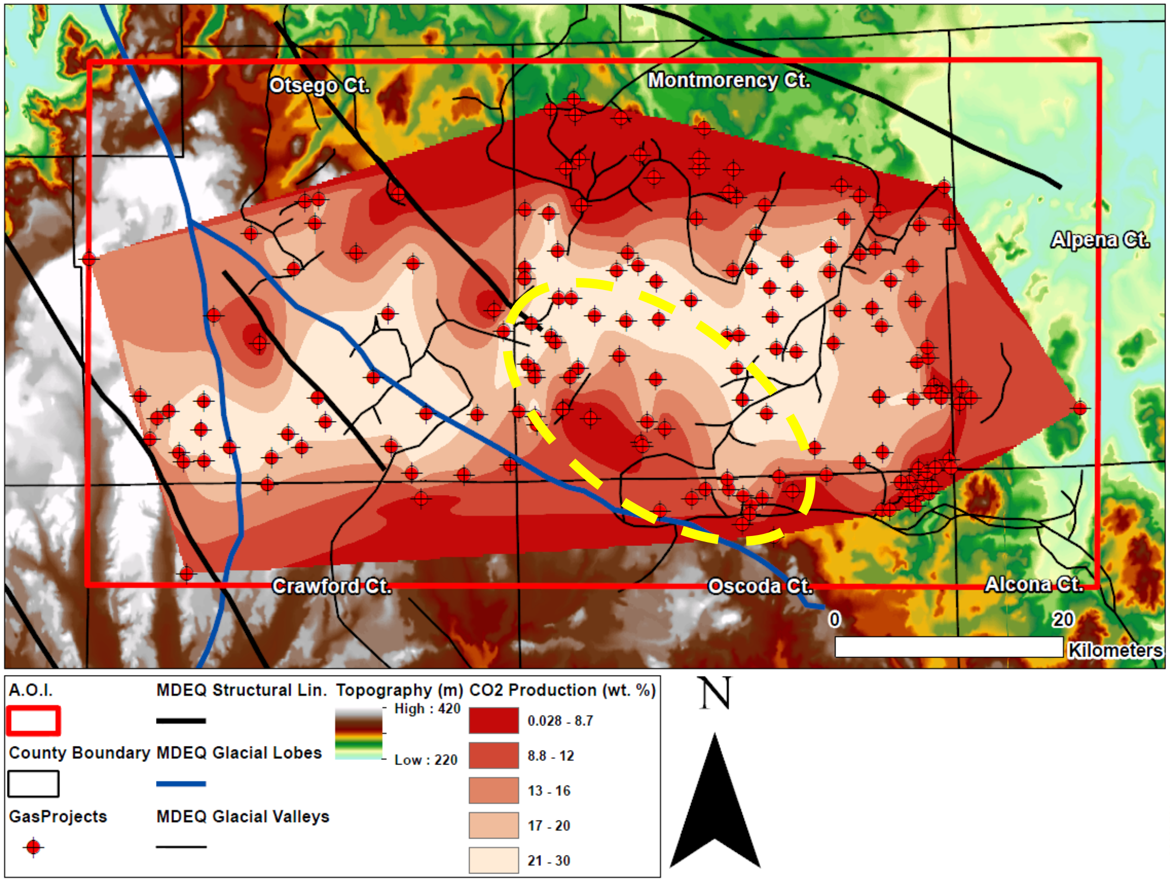


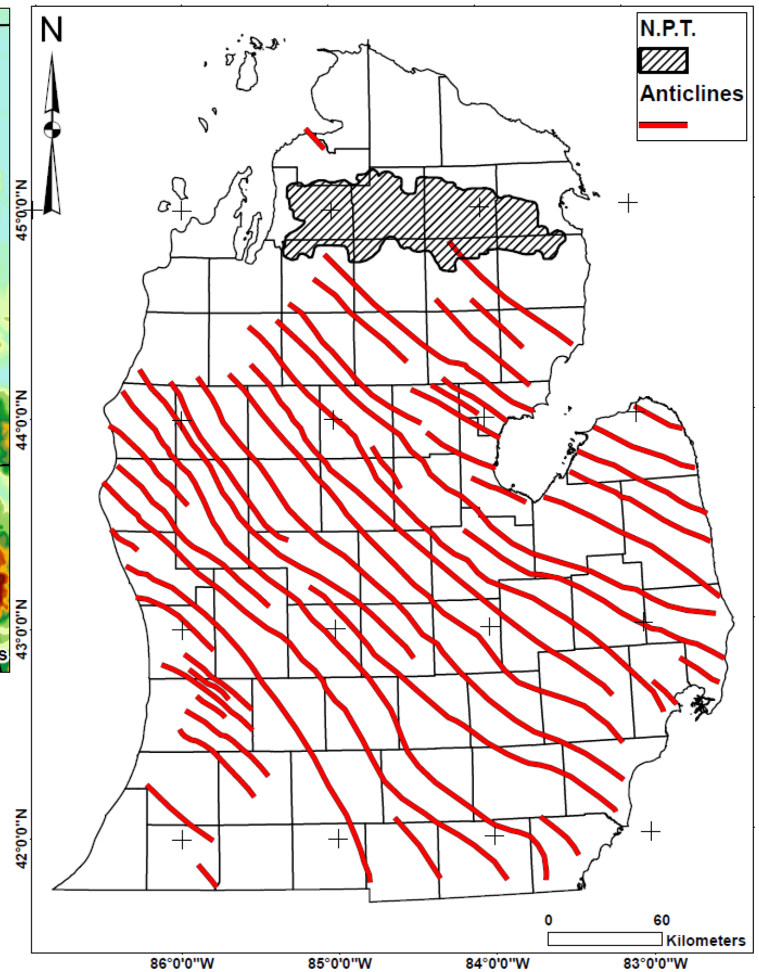


Gas Composition:

- Gas Provenance Zones
- Methane/Ethane + Propane

Structural Influence of Gas Development



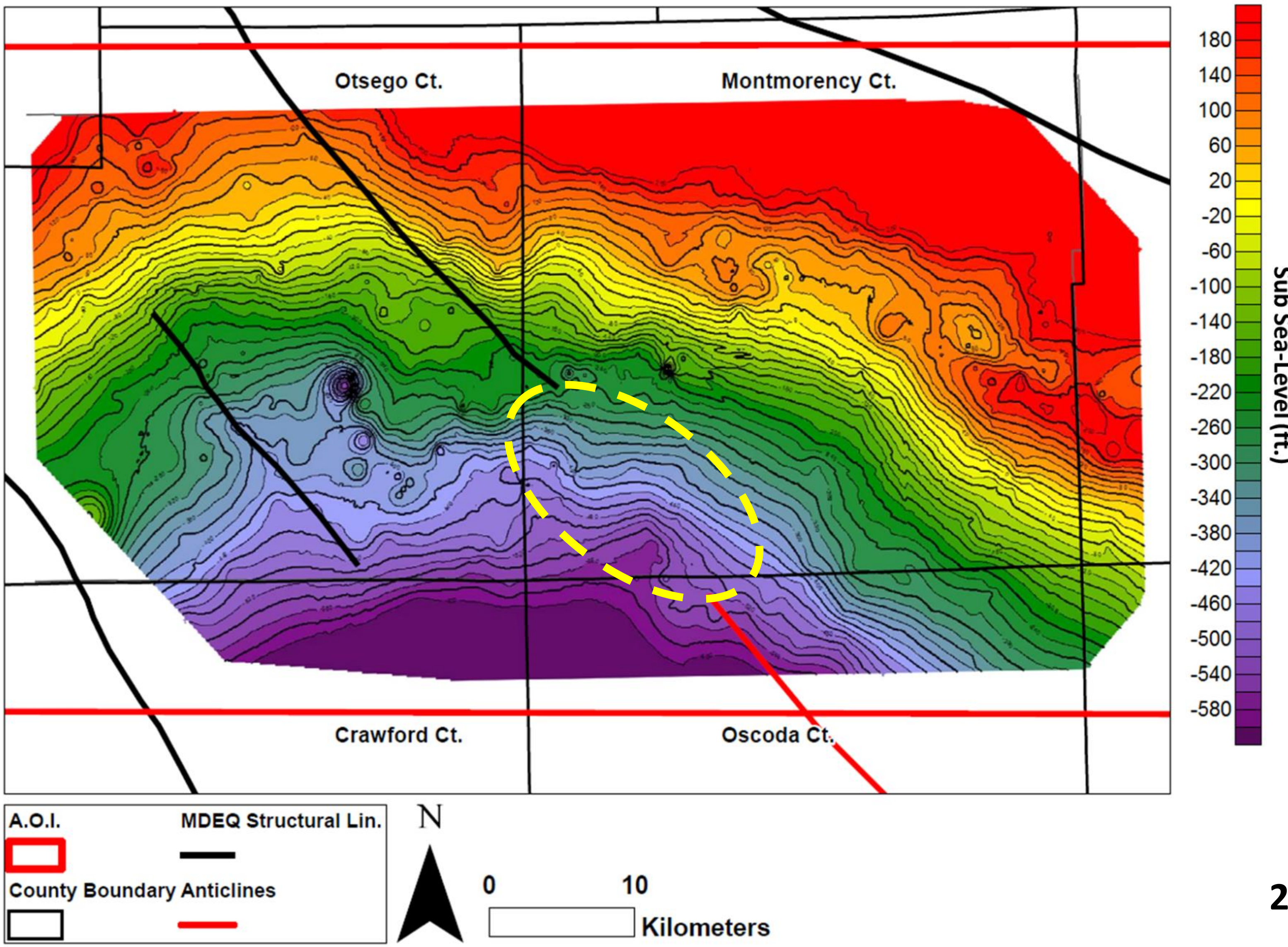


Gas Composition:

- Gas Provenance – CO_2 Production
- Methane/Ethane + Propane

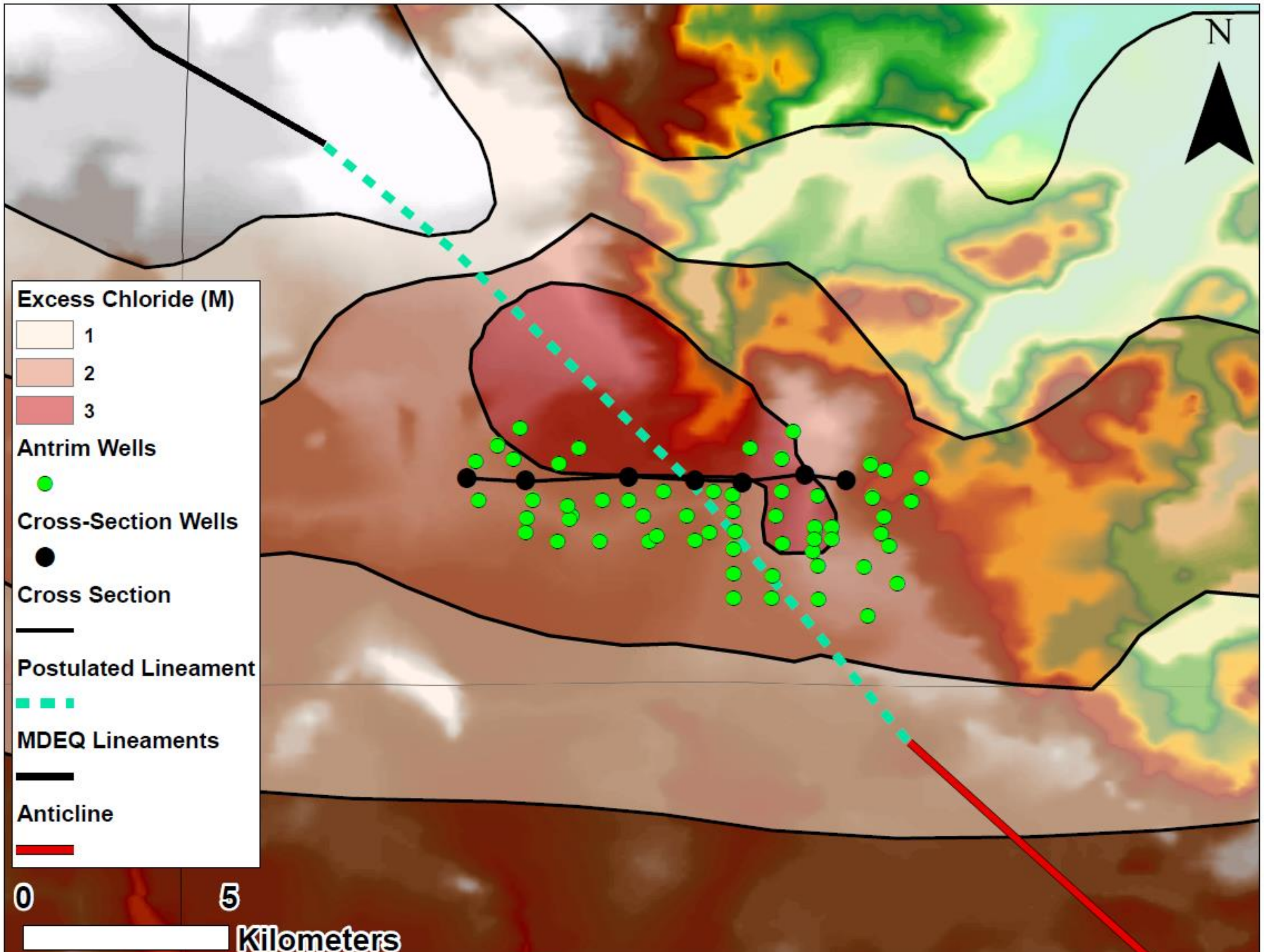
Structural Influence of Gas Development

- Traverse Formation Structure (2833 wells)



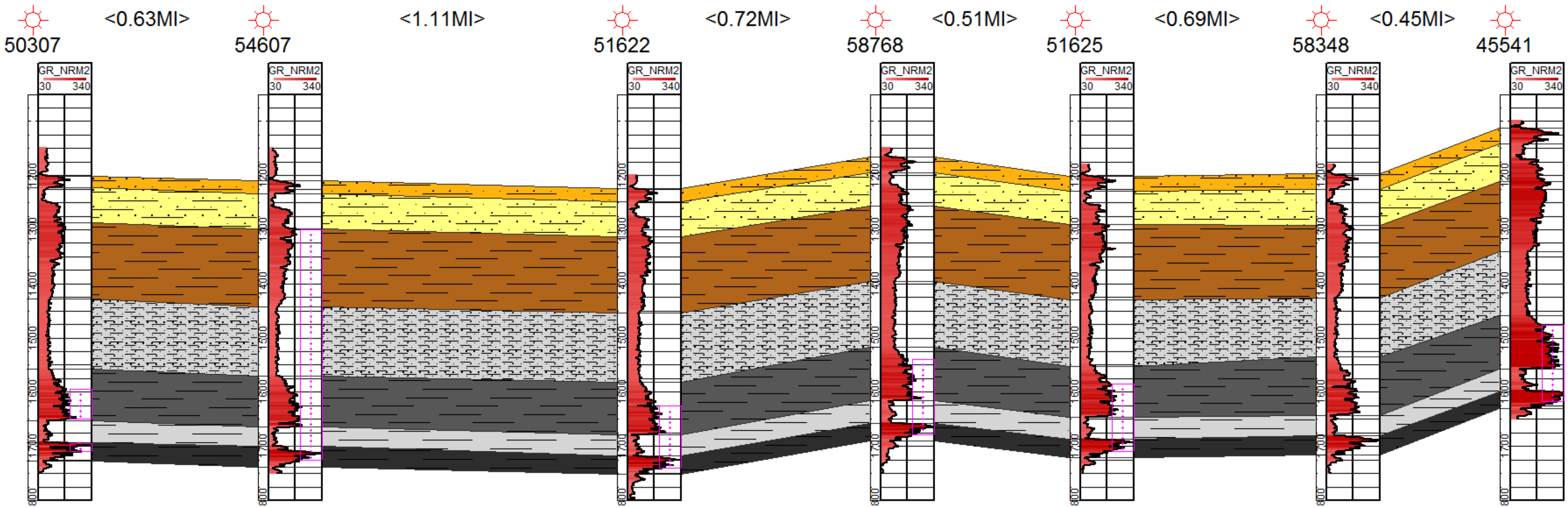
Structural Influence of Gas Development

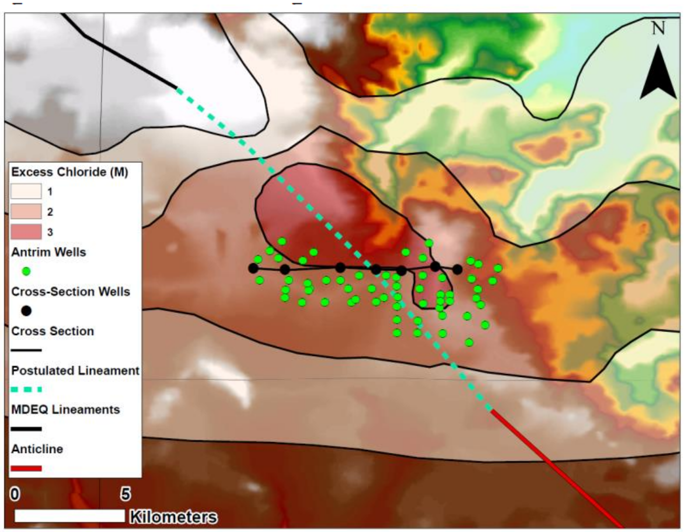
- **Wire-line Analysis/Mapping**

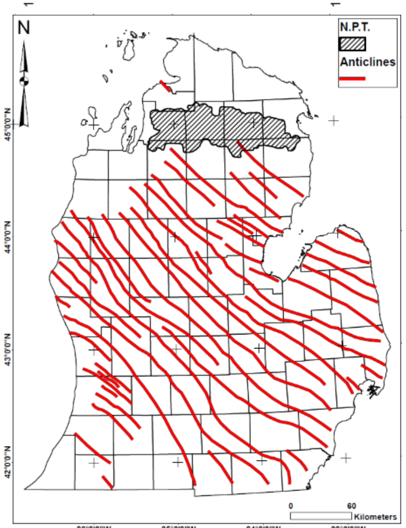


Structural Influence of Gas Development

- **Stratigraphy**







Conclusions

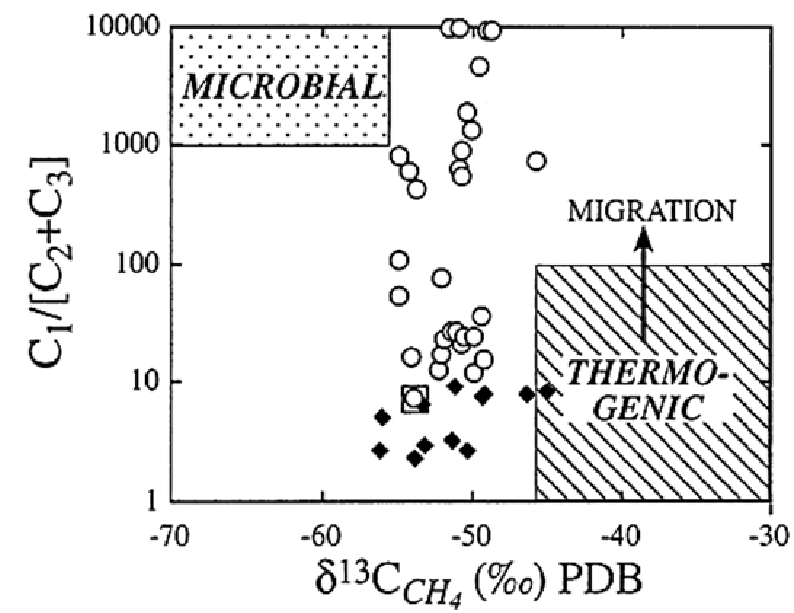
- **The postulated extent of the anticline is spatially proximal to the occurrence of low CO_2 (<8 wt.%), high BTU (>1,020), gas composition ratio (<8), and excess Cl^- (3 M).**

- **Stratigraphic offset is observed to be greater than the average dip of the Michigan Basin (15 ft./Mi). Beds are of equivalent thickness laterally.**

- **Off Structure: Gas composition, CO_2, and BTU are spatially variable. Potentially attributed to fracture development and microbial gas propagation from thermogenic gas.**

Future Work

- **Brine Analysis & Stable Isotopes of Gas**
- Regional Mapping of Fracture Distribution
- Mechanism for Migration: Conceptual Models



Martini et al., 1998

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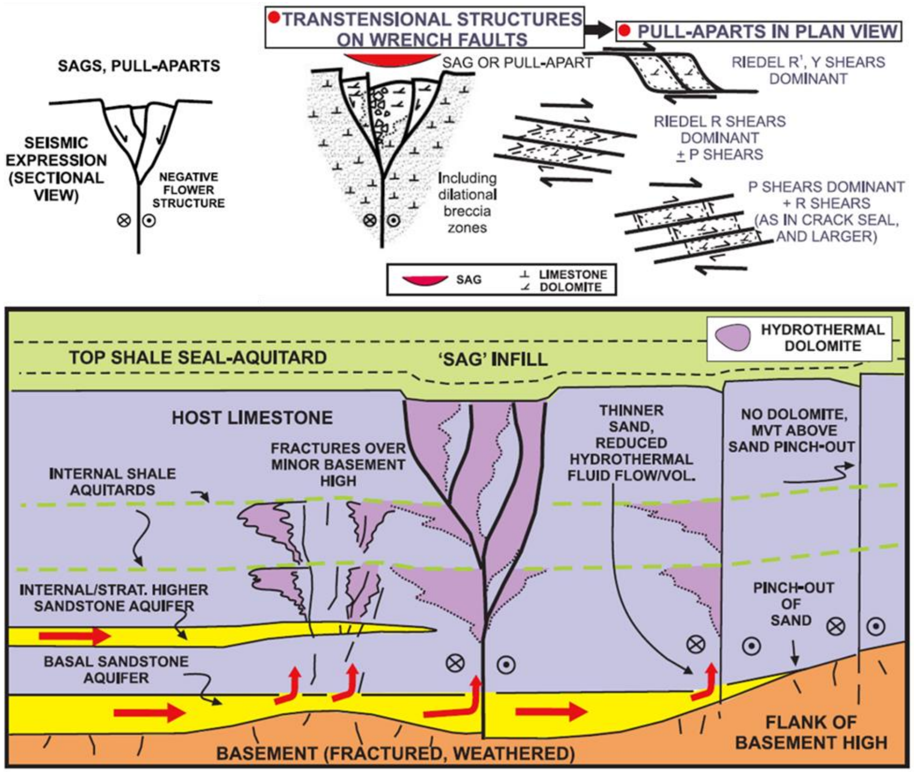

Davies and Smith, 2006

Future Work

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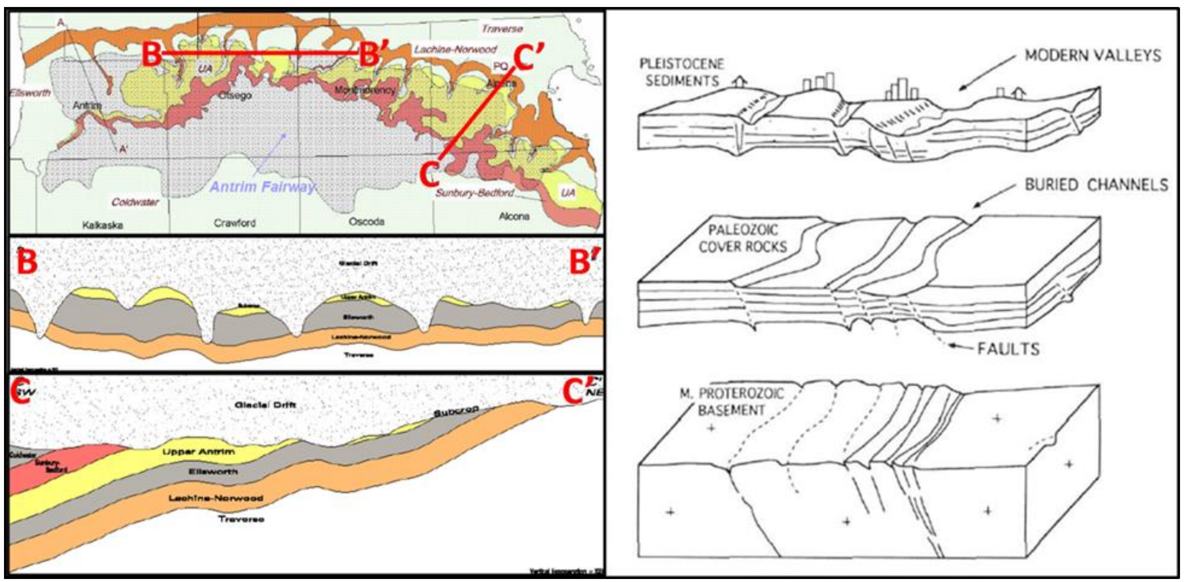

Goodman and Maness, 2008
Eyles and Boyce et al., 1993

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- Michigan Geological Survey
- Western Michigan University
- Miller Energy Company
- Muskegon Development Company