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

By
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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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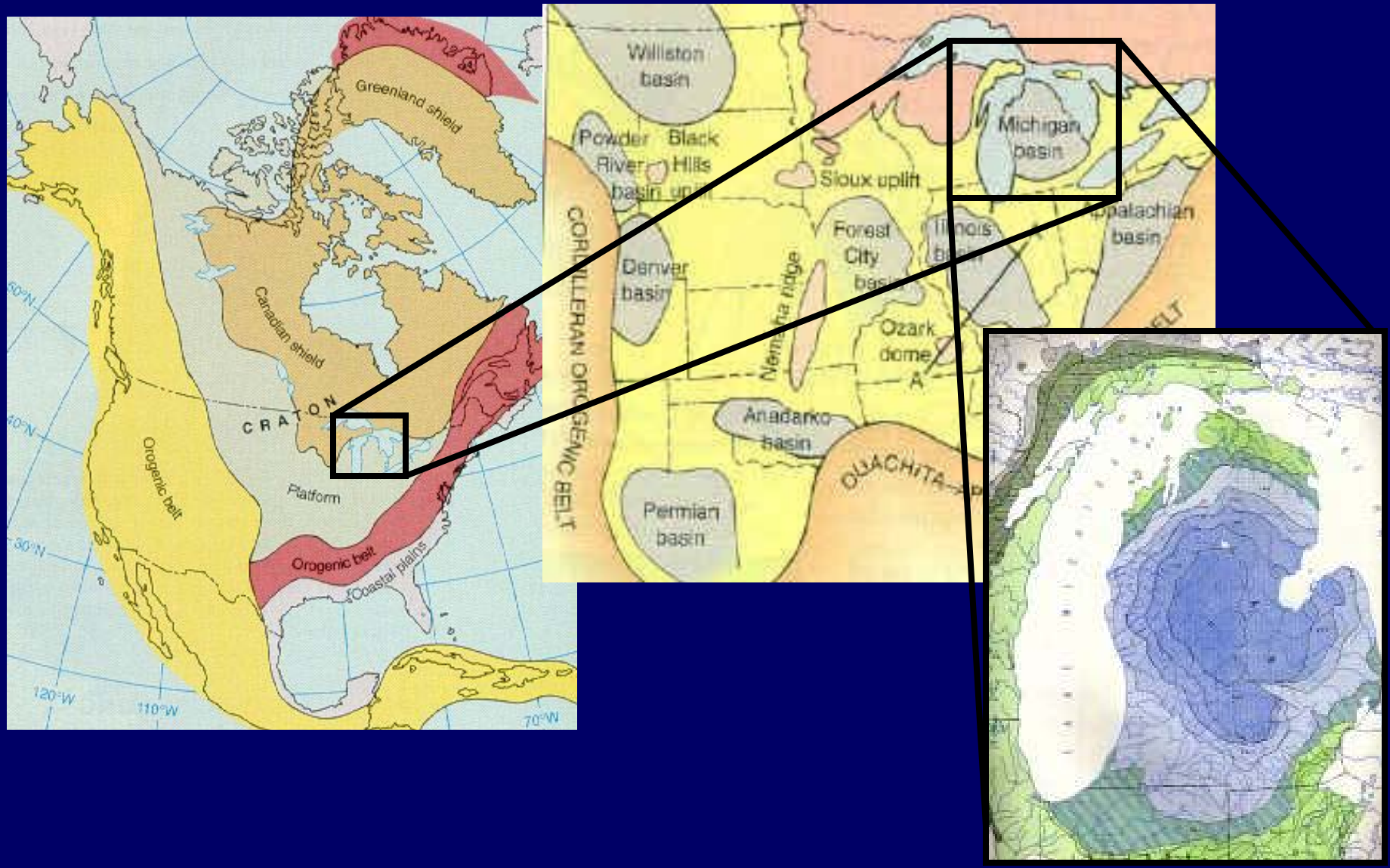
April 23, 2008

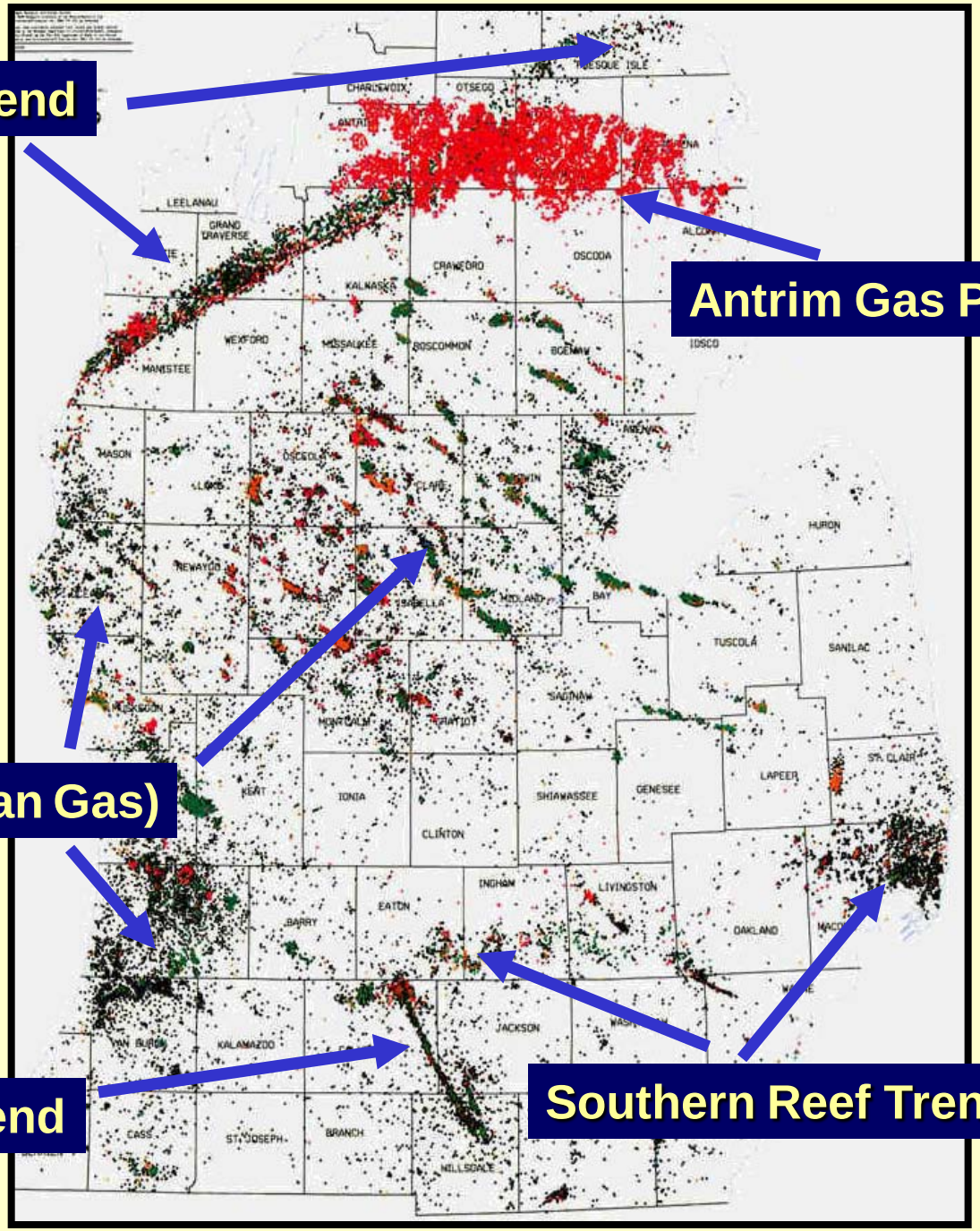
Today's Talk

1. History
2. Geologic Setting
3. Biogenic Gas
4. Production and Engineering

Geologic Setting of the Michigan Basin



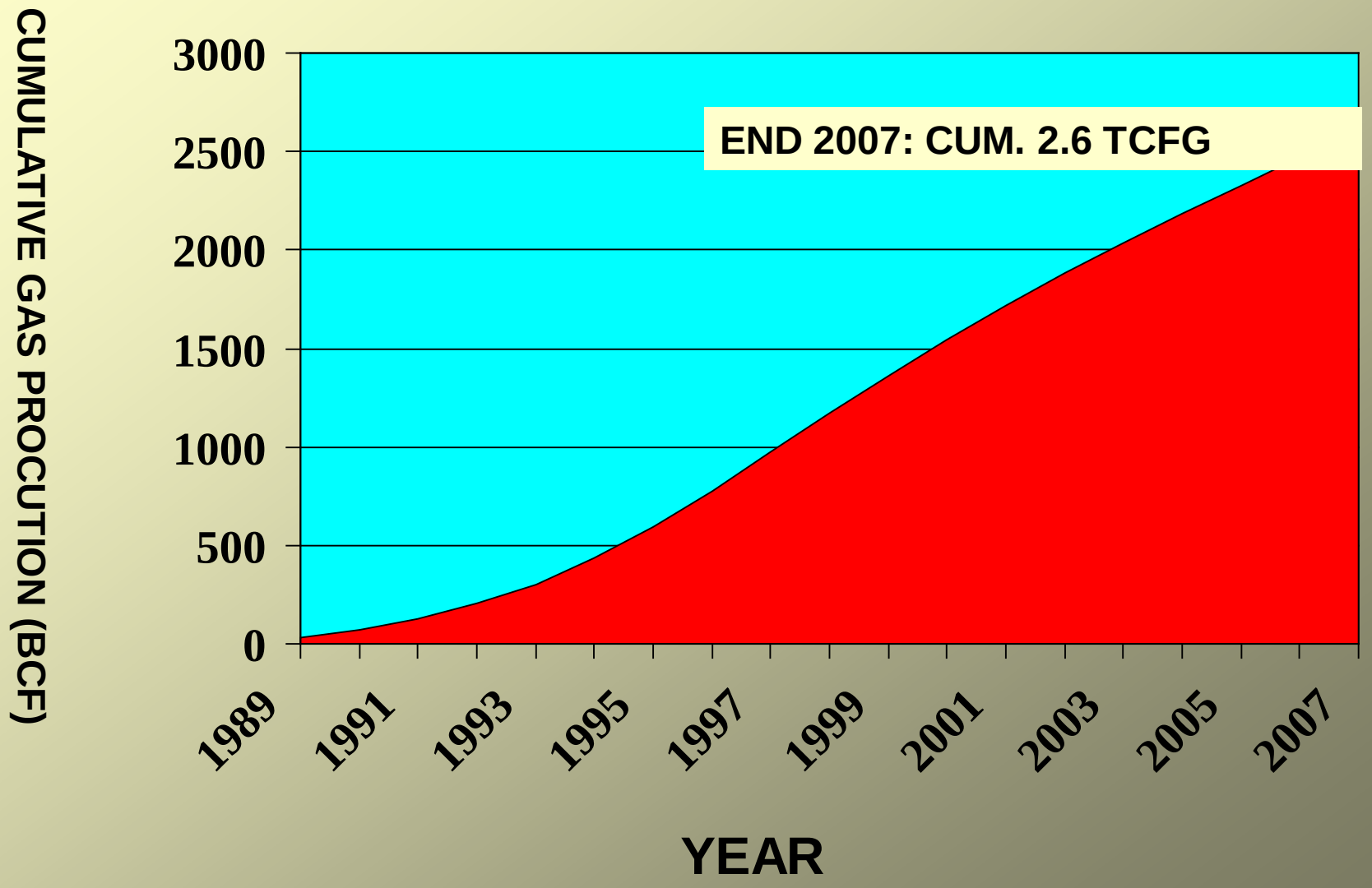
Michigan Oil & Gas Plays



MICHIGAN'S LOWER PENINSULA O&G PROD.

CUMULATIVE MICHIGAN ANTRIM PRODUCTION

1989-2007



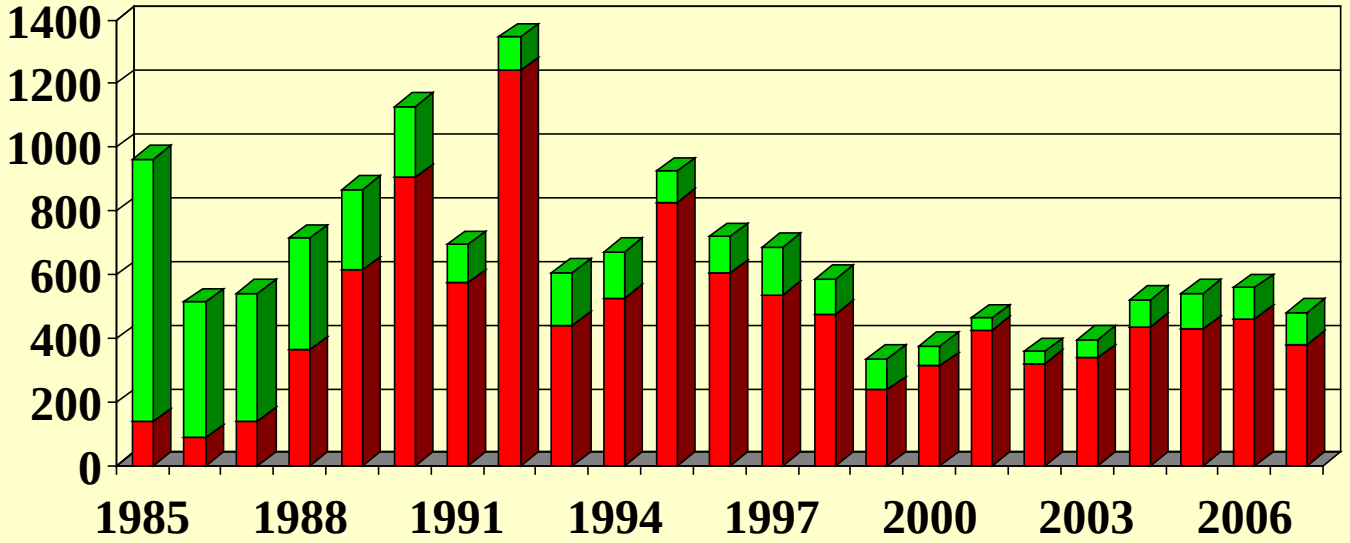
Roots of the Antrim Shale Play in Northern Michigan (Pt. 1)

- 1940: Rinehart & Hickok Antrim Cpln. In Otsego Co. (30N-3W) Sells Minor Gas in Local Market for 2 yrs.
- 1965: Independent Murrell Welch Proves Play Viability with Otsego Co. Antrim Pool Dvpt. (29N-2W)
- 1969 ff.: Niagaran Pinnacle Play Begins in N. MI. Antrim Gas Shows Labeled "Nuisance." Reef Play=Infrastructure.

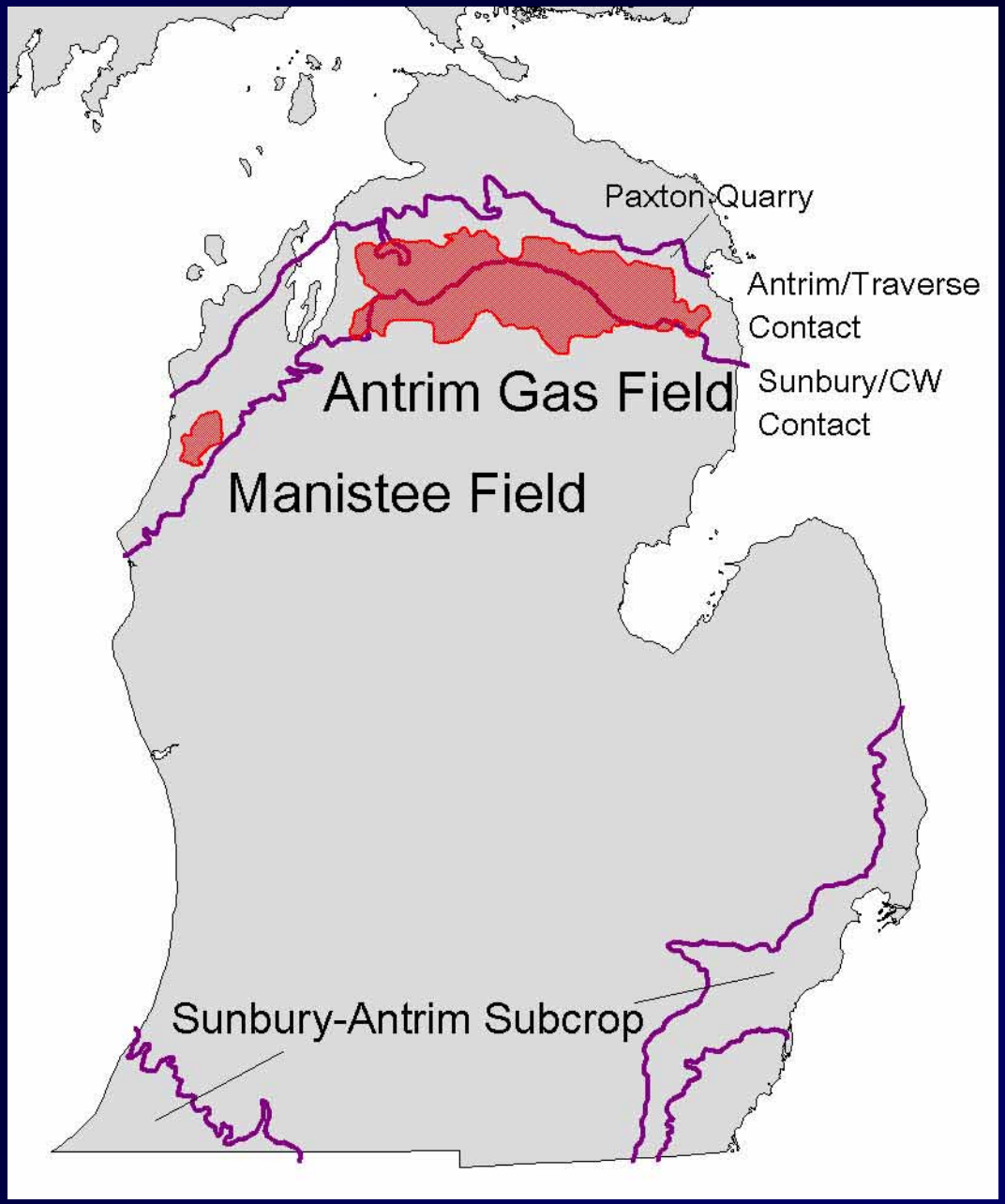
Roots of the Antrim Shale Play in Northern Michigan (Pt. 2)

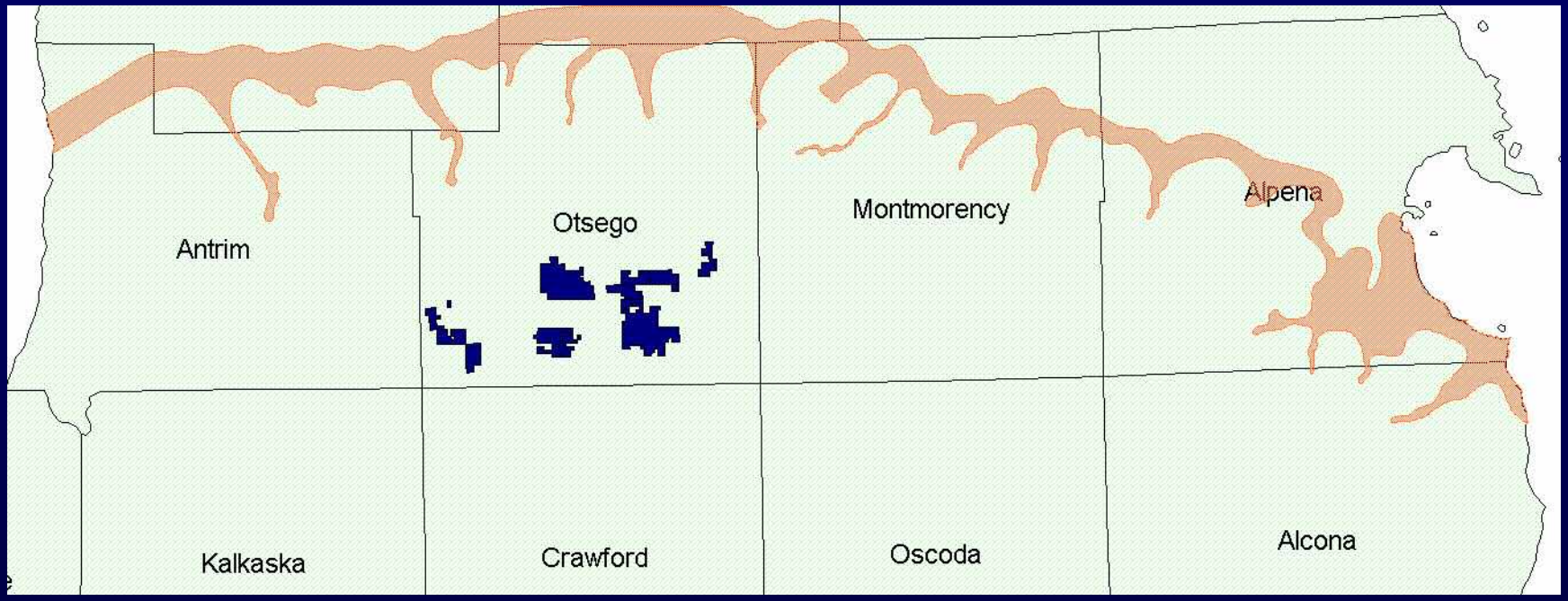
- 1986: Non-Convent. Fuels Tax Incentive + Underutilized Niag. Infrastructure + CPF Concept Trigger Modern Antrim Play
- 1992: Expiry of NCF Credit-Eligible Wells on 12/31/92 Triggers Antrim Drilling Peak (1189 Compl. Wells)
- 1995:Antrim Uniform Spacing Plans (USP) Allow Greater Oper. Discretion in Placing Wells in Projects. 80-Ac. Spacing.

WELLS DRILLED BY TARGET DEPTH, 1985-2007



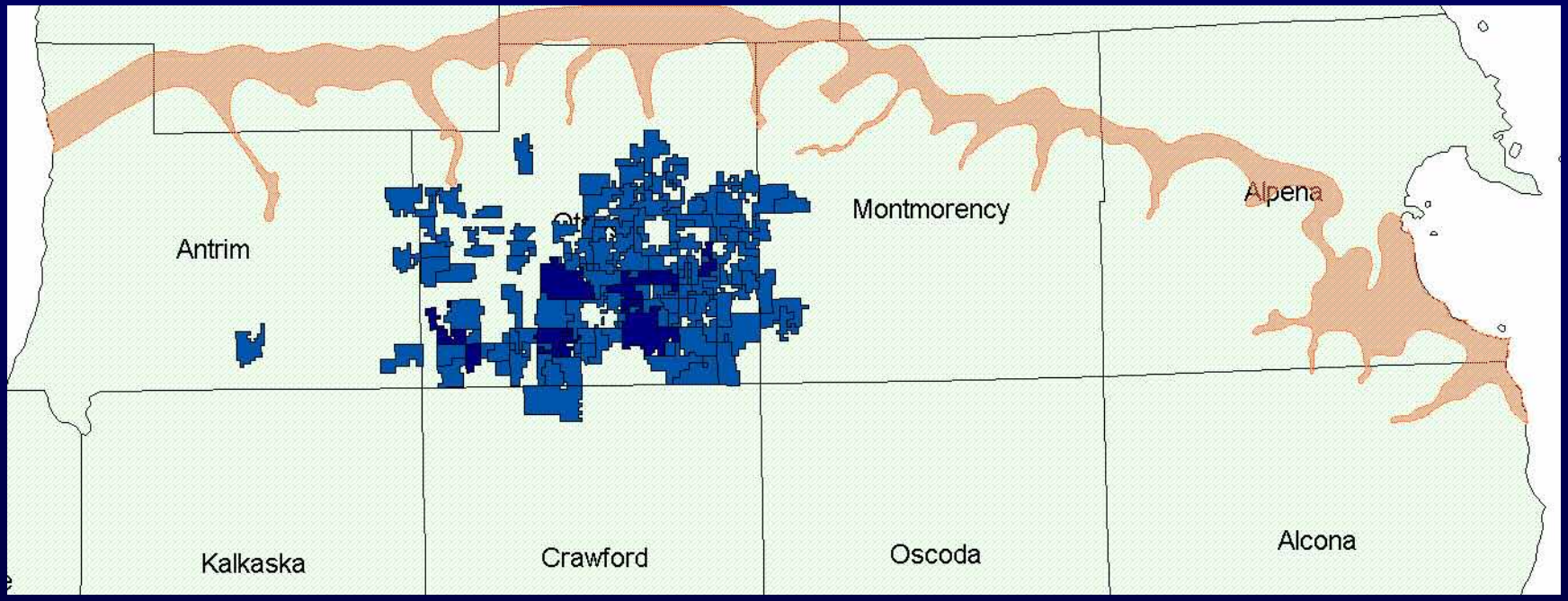
Antrim Development Has Focused on Several Counties in Northern Lower Michigan



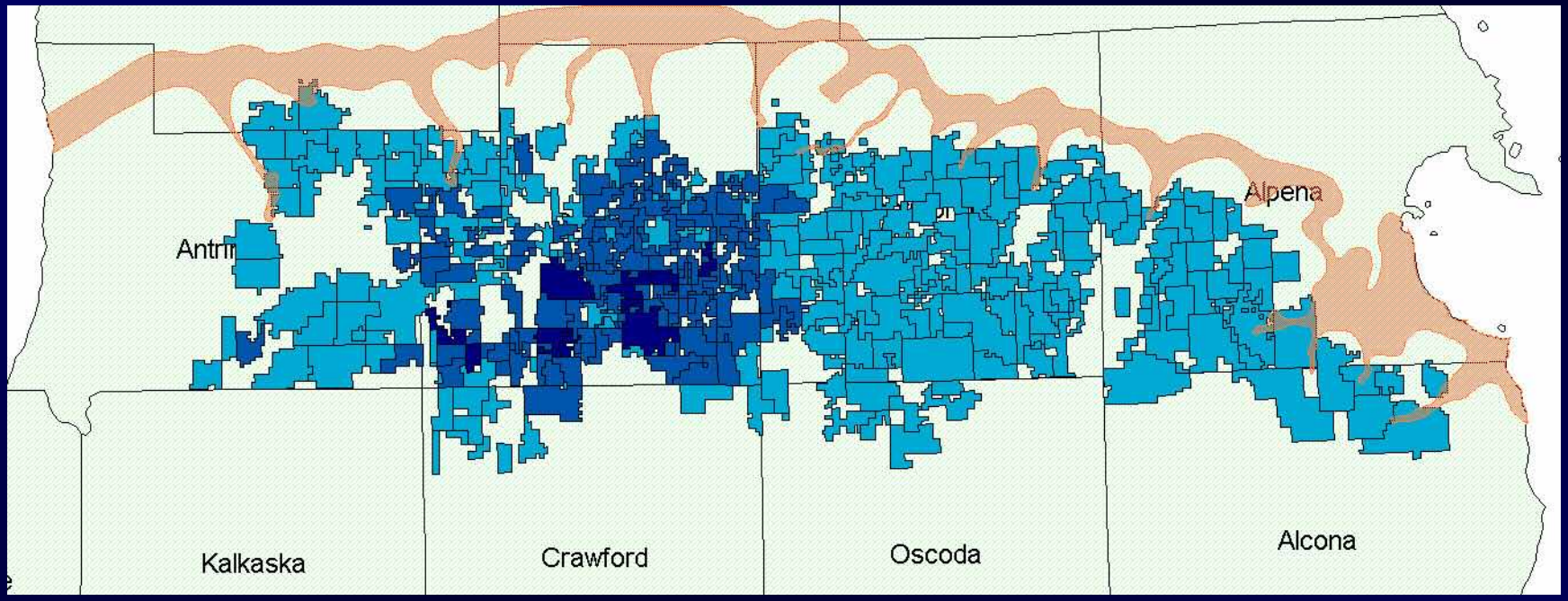


100 miles

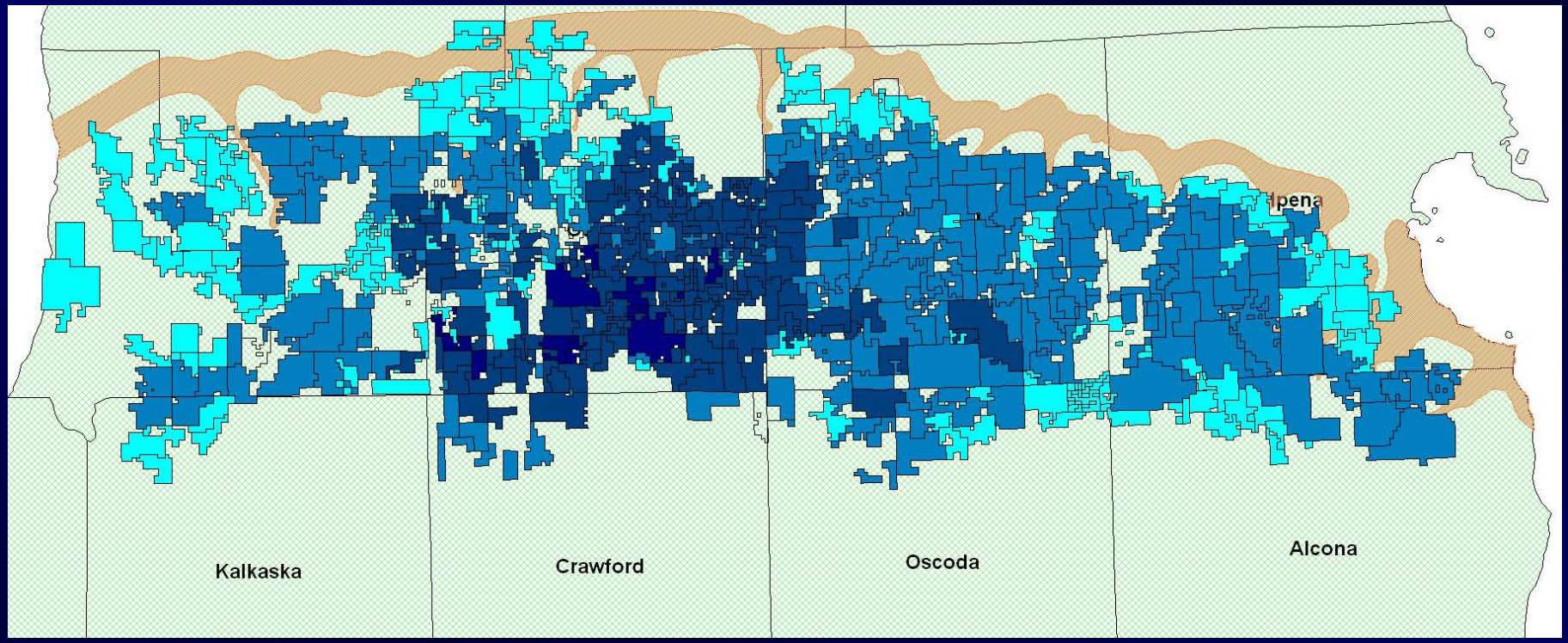
Development History - 1986



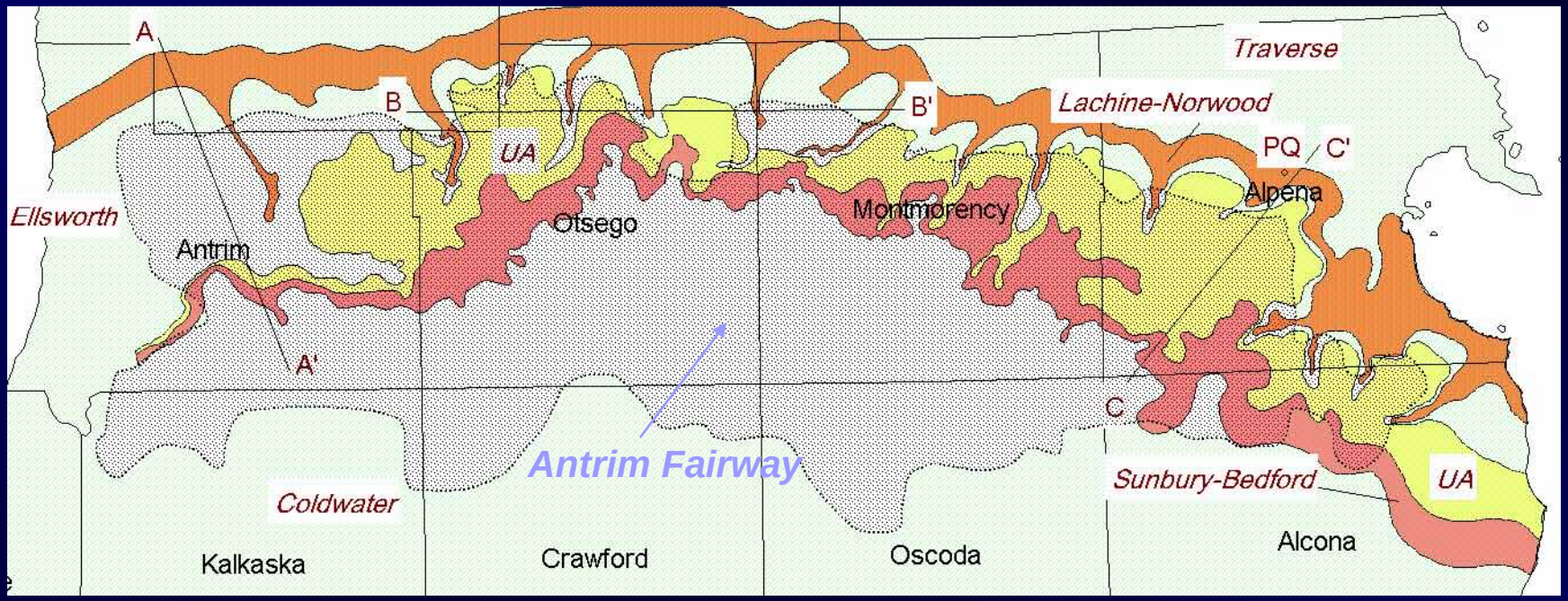
Development History - 1992



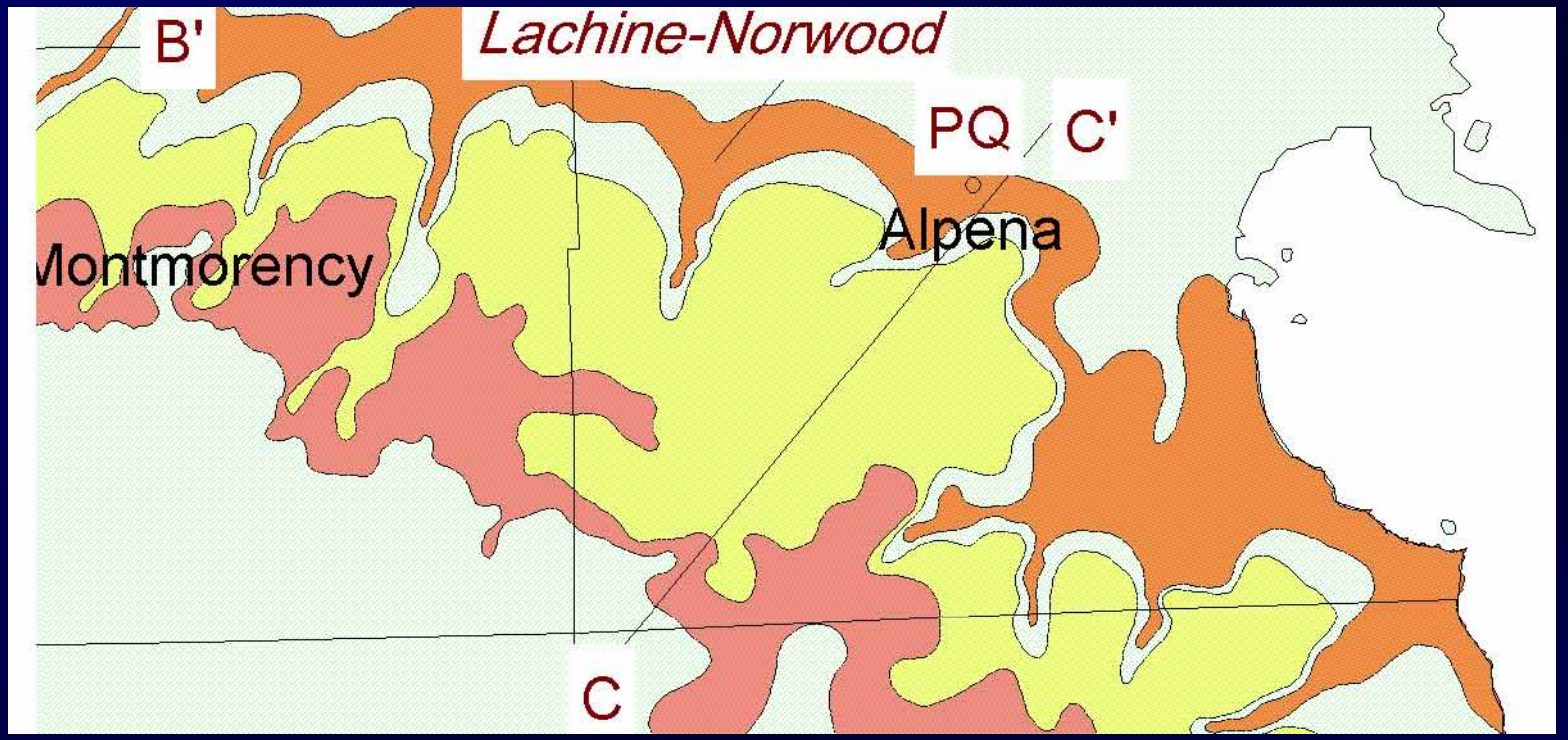
Development History - 1998

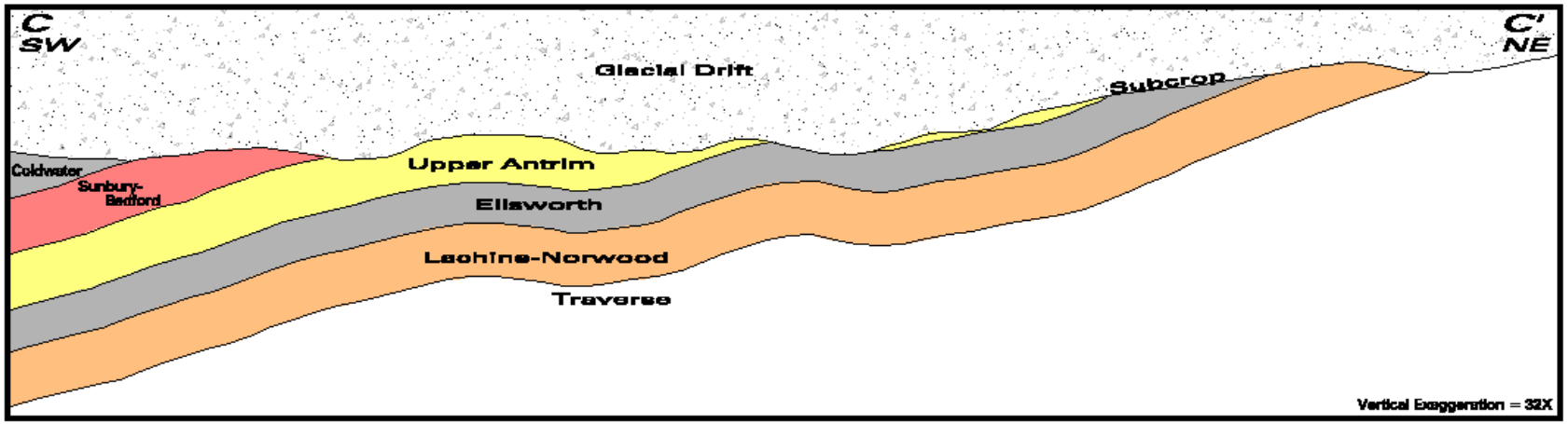


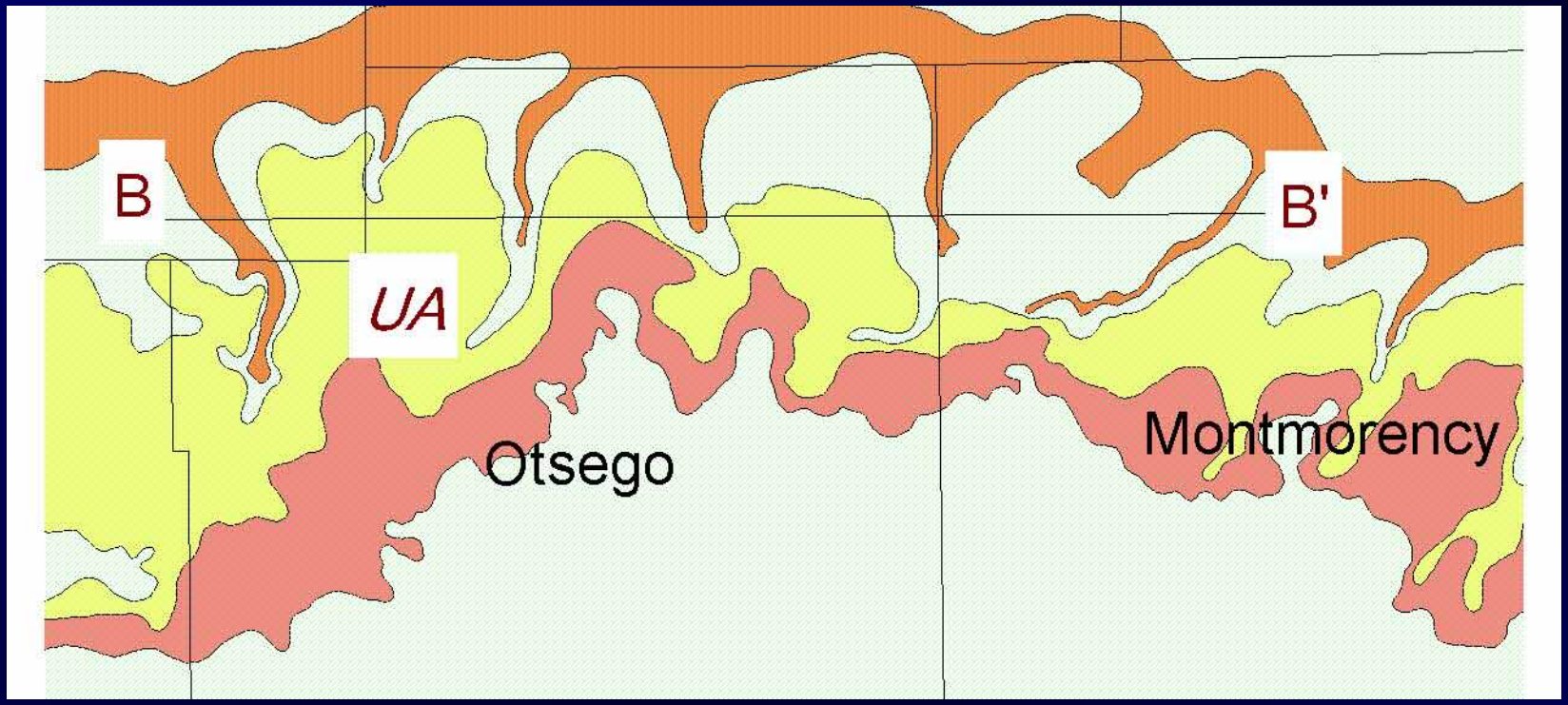
Development History - 2008

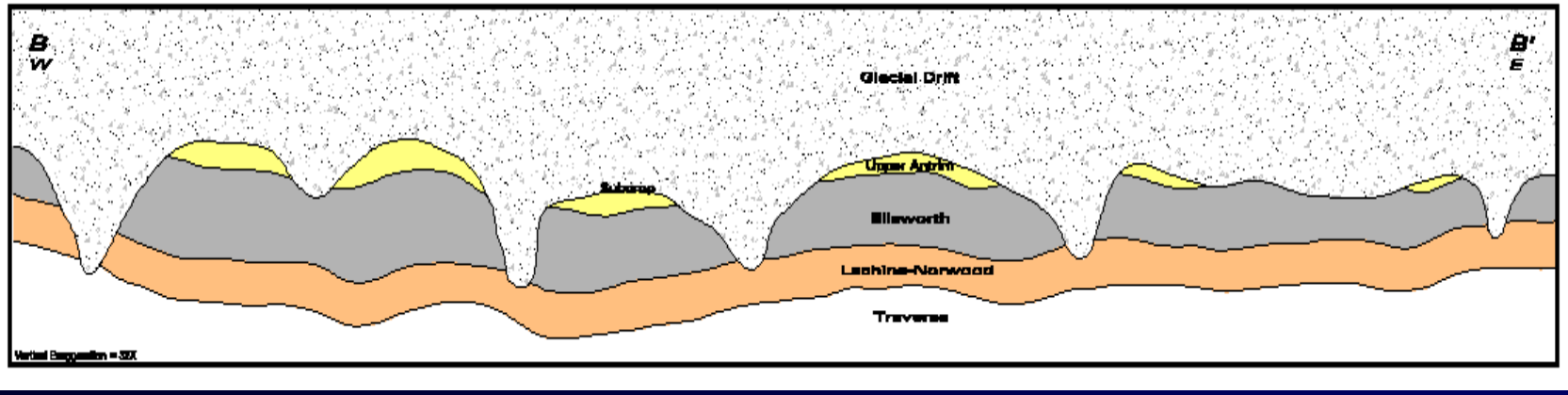


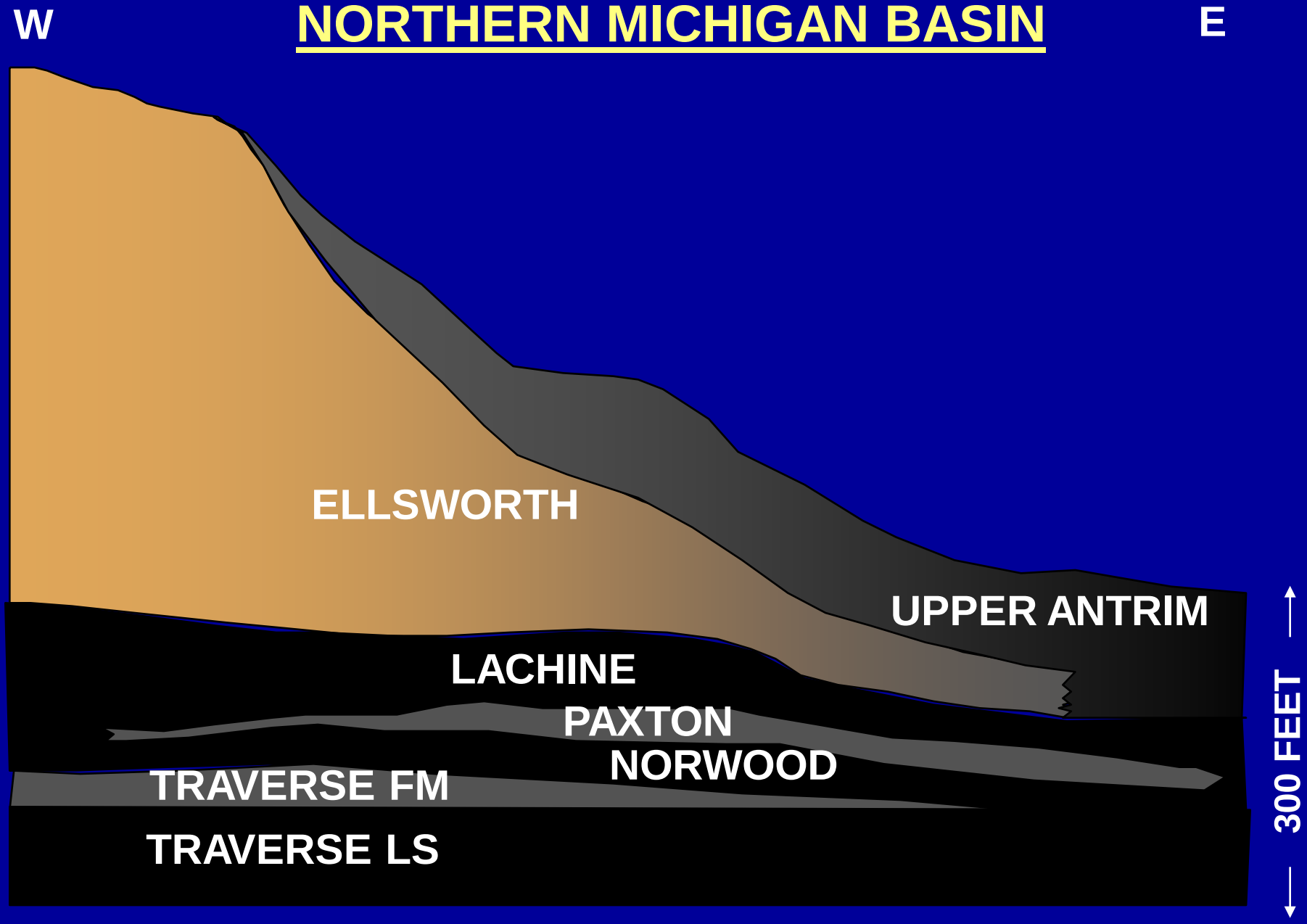
Antrim Gas Fields--Relation to Subcrop

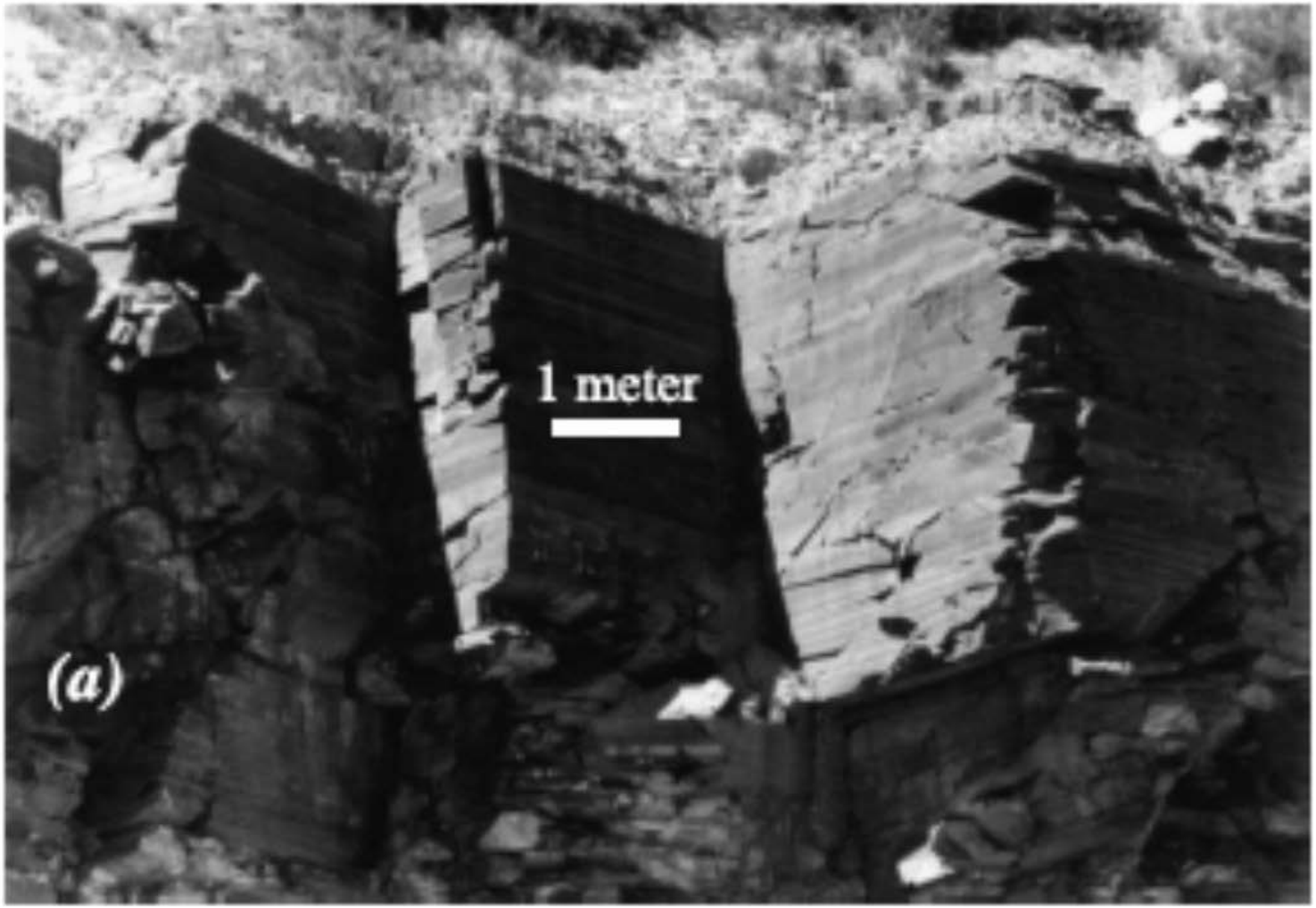

B'
Lachine-Norwood
PQ
C'
Alpena
Montmorency
C


C
SW
C'
NE
Glacial Drift
Subcrop
Coldwater
Sunbury-
Bedford
Upper Antrim
Ellsworth
Lachine-Norwood
Traverse
Vertical Exaggeration = 32X


B
B'
UA
Otsego
Montmorency


B
W
B'
E
Glacial Drift
Upper Antrim
Bellevue
Ellsworth
Lachine-Norwood
Traverse


W
NORTHERN MICHIGAN BASIN
E
ELLSWORTH
UPPER ANTRIM
LACHINE
PAXTON
NORWOOD
TRAVERSE FM
TRAVERSE LS
300 FEET
200 MILES

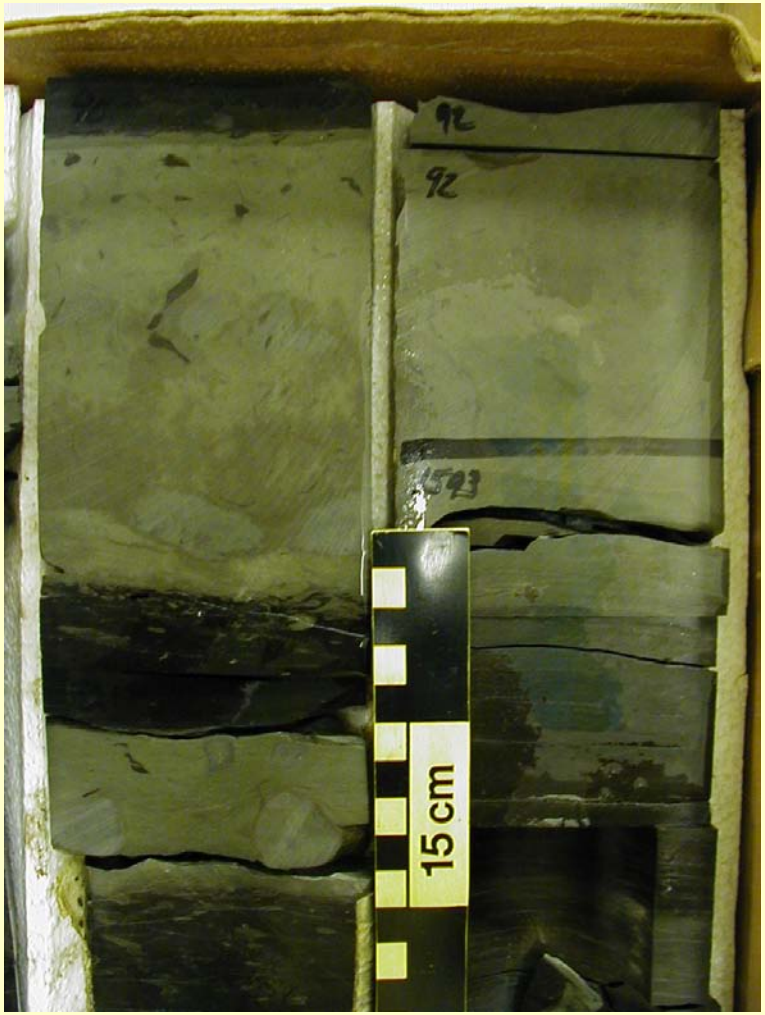


Antrim Shale, Paxton Quarry, Alpena

Lachine Member

High TOC's and Significant High Angle Fracturing

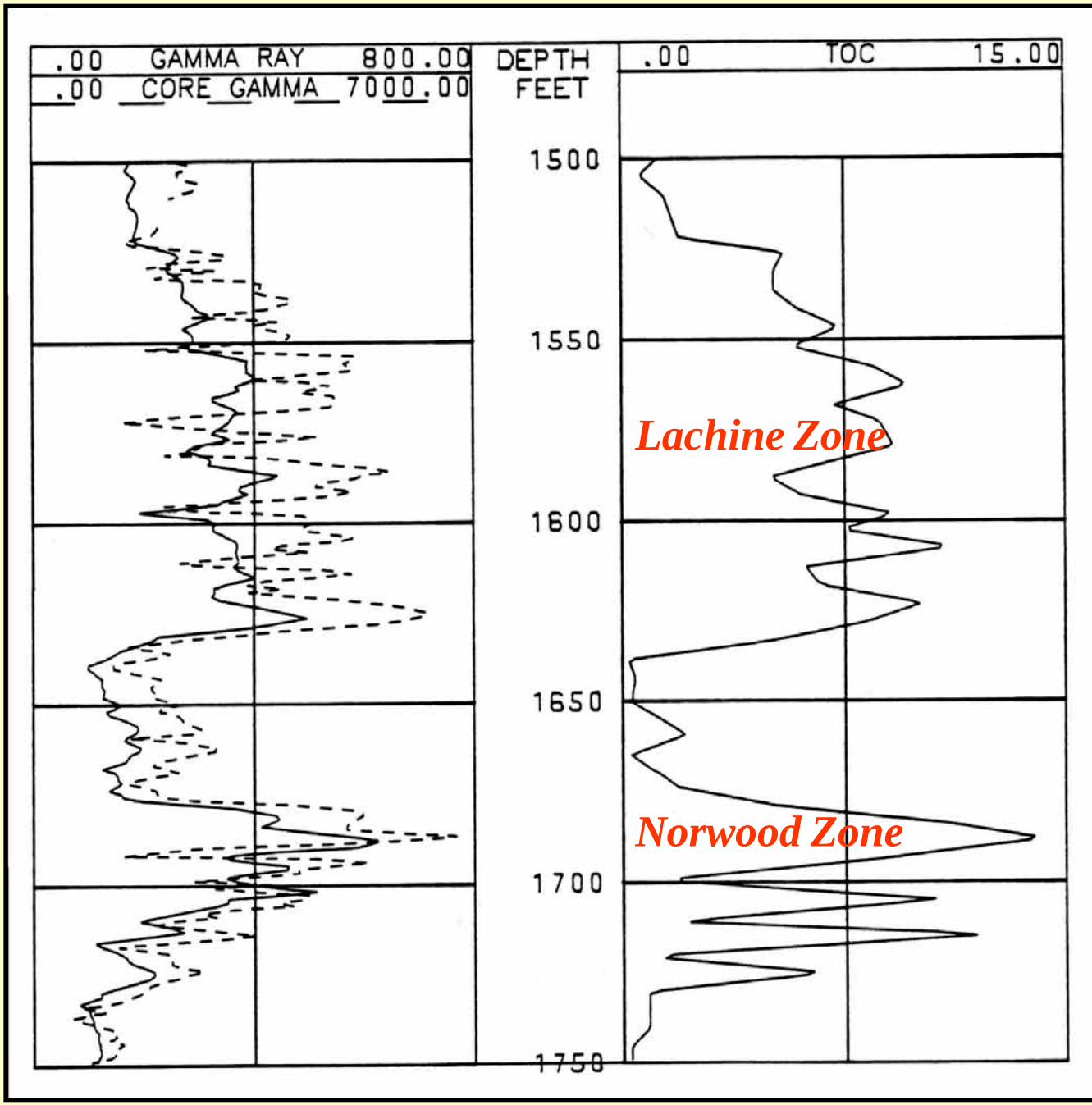
Paxton Member



Calcareous Mudstones, Limited Organic Material

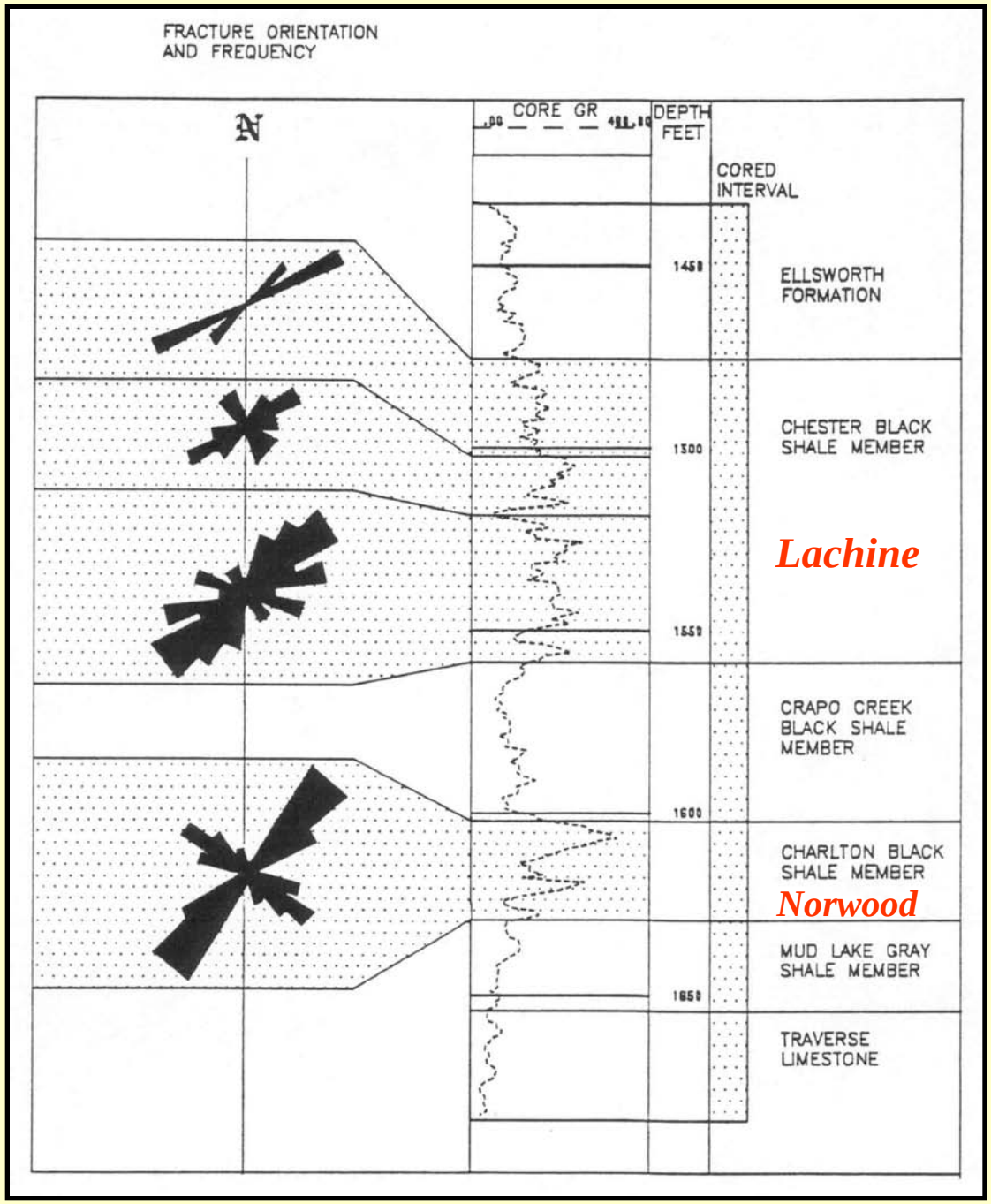
Total Organic Content

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

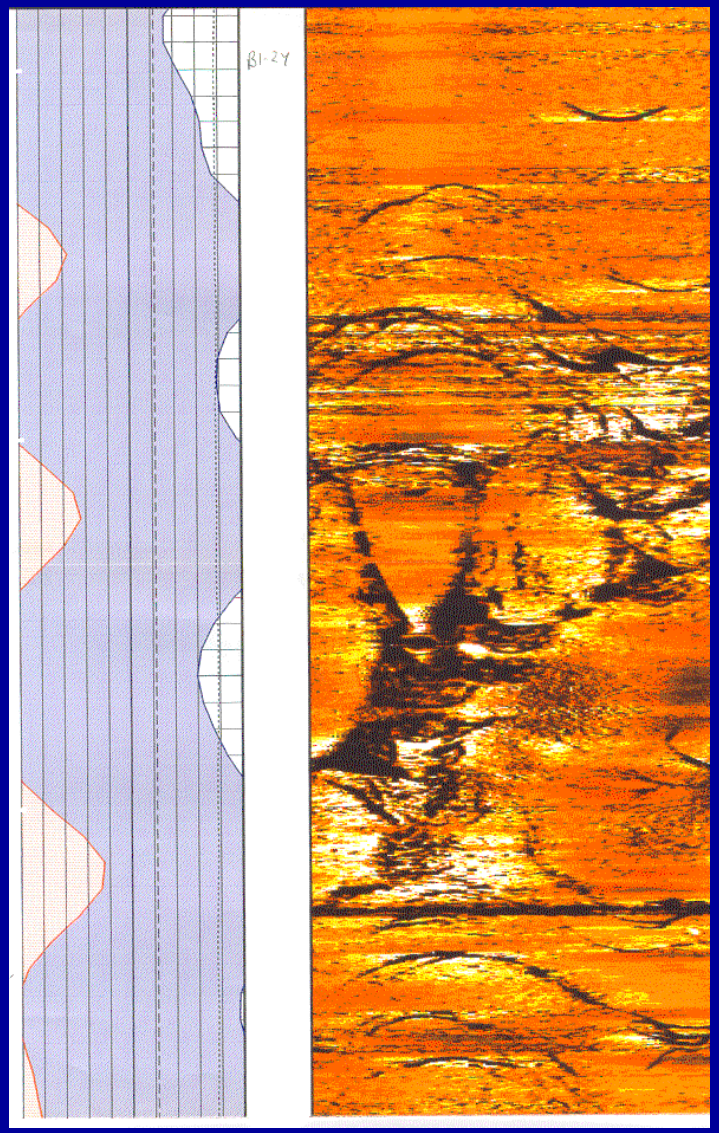


Fracture Orientations

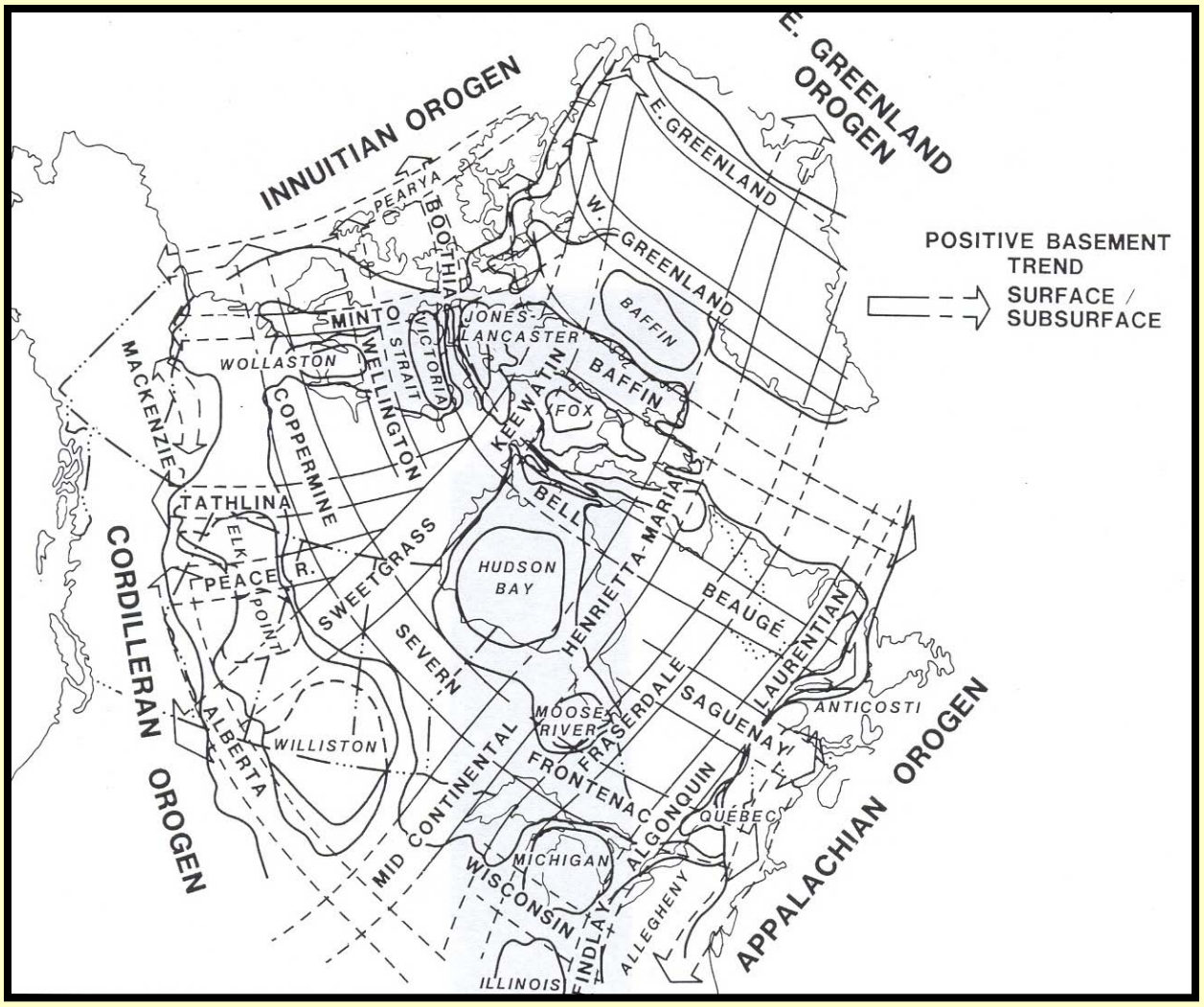
Welch-St. Chester #18 Core, South Chester Twp., Otsego County (from Dellapenna, 1991)



Whither the Fractures?



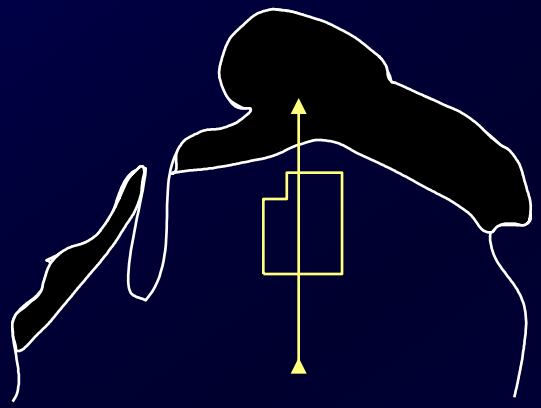
- Terrane Boundaries (NE-SW)(Grenville Front)
- Mid-Continent Rift (NW-SE)
- Paleozoic Tectonics (Chiefly NW-SE)
- Post-Glacial Isostatic Rebound (Enhanced Near Subcrop)
- Hydraulic Pumping



NORTH AMERICAN BASEMENT TECTONIC TRENDS

(After Sanford)

ANTRIM TRAP



OTSEGO COUNTY

METEORIC WATER

GLACIAL DRIFT

TRAVERSE

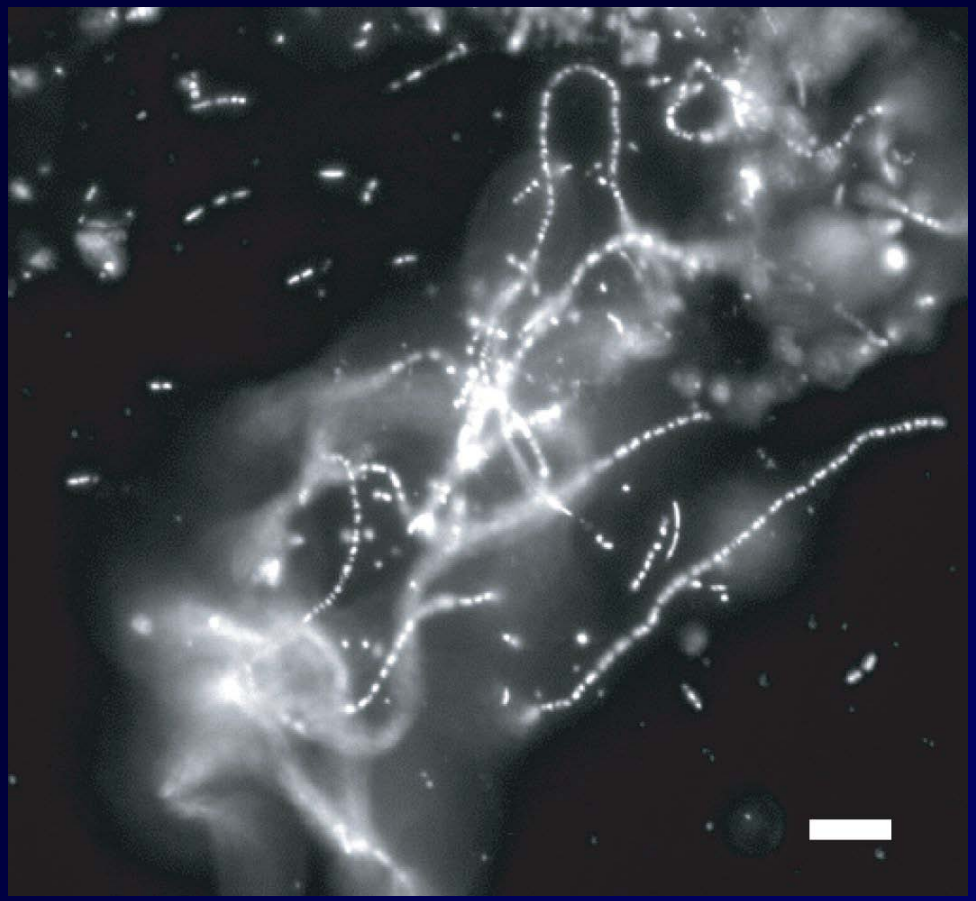
GAS

2000 FEET

60 MILES

Biogenic Gas

- 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



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Biogenic Gas

Microbial Sampling

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Co-authors: **Jennifer C. McIntosh (Johns Hopkins Univ.)**
Steve Petsch (Univ. of Mass. - Amherst)
Klaus Nusslein (Univ. of Mass. - Amherst)

Natural Gas Basics

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CH_4 - Methane (C_1)

C_2H_6 - Ethane (C_2)

C_3H_8 - Propane (C_3)

Thermogenic
C_1, C_2, C_3

Microbial
C_1

(km)	Hydrocarbon Maturity	Max-T °C	Vitrinite Reflectance R_o(%)	Hydrocarbon Product
0				
1		60	0.5	*Microbial Methane*
2	**Methane**			
3	**Oil**			*Oil*
4		130	1.3	
5	**Ethane & Propane**			*Wet Gas* *Hi Temp. Methane*

- Thermogenic vs. Microbial

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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: ~0‰

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

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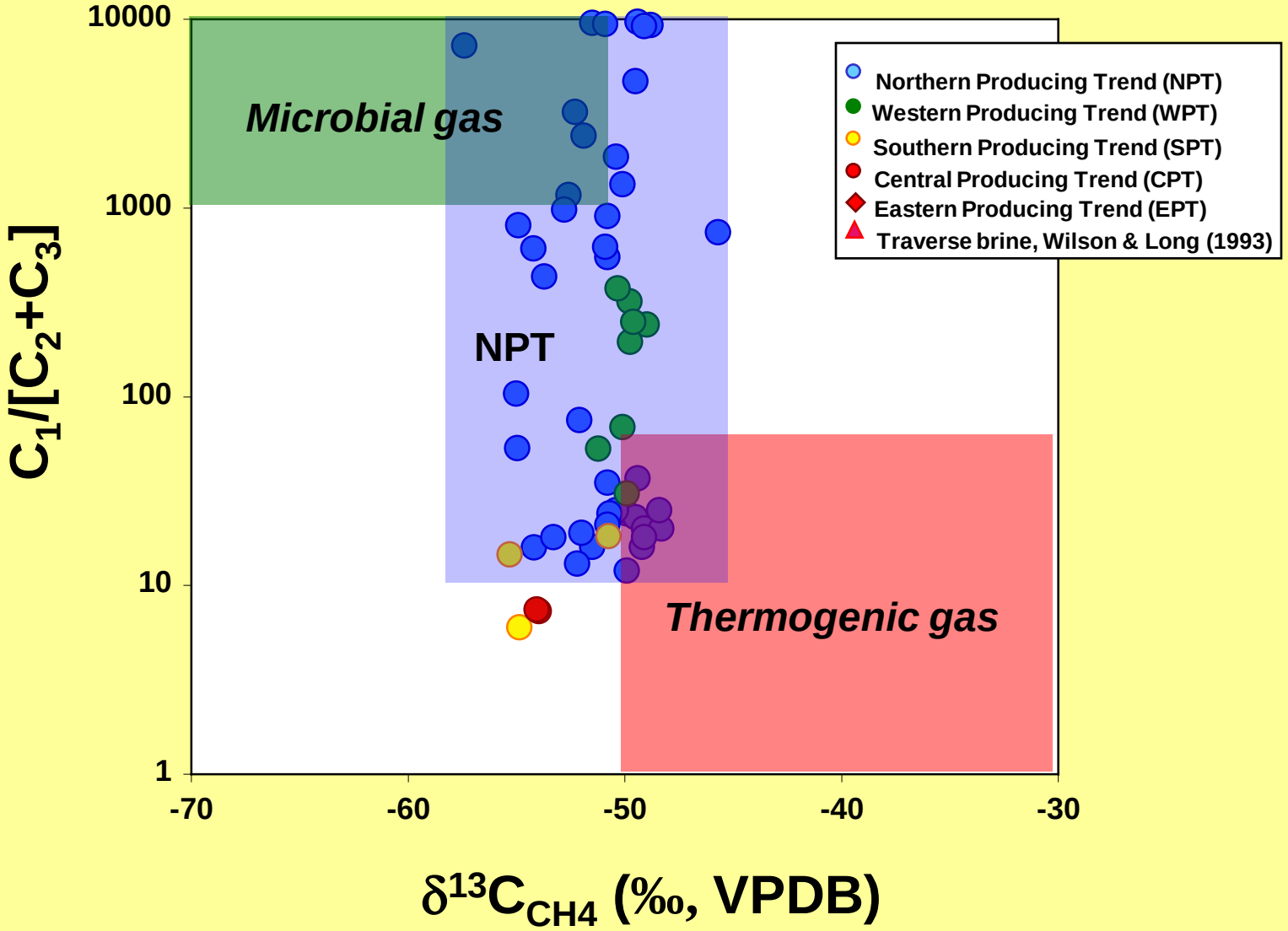
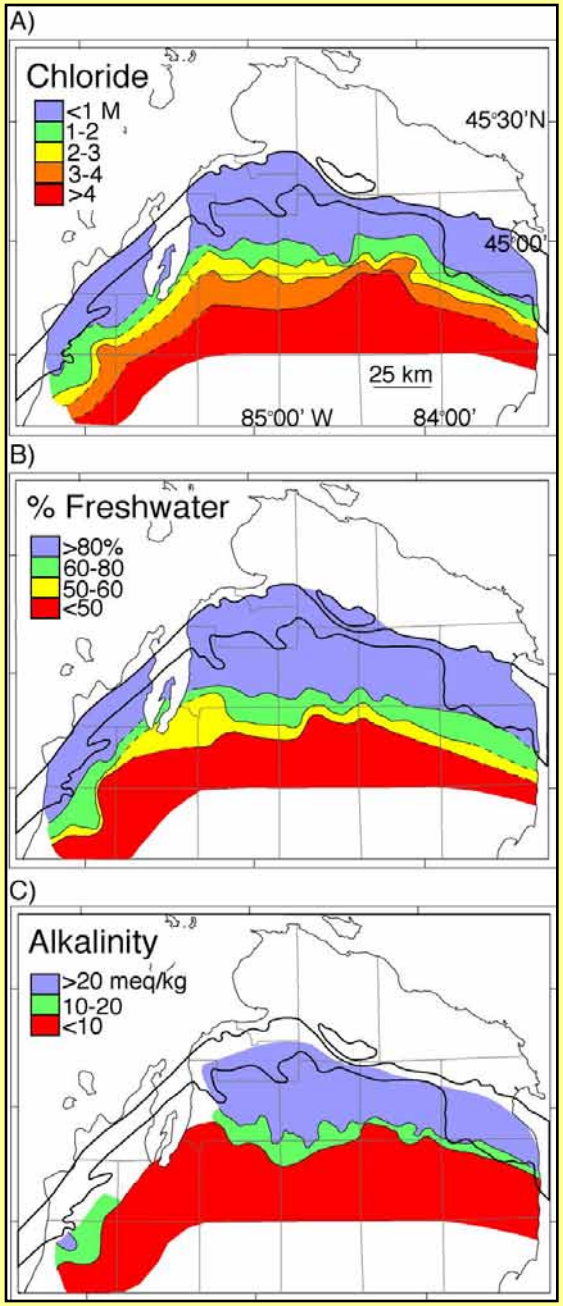


Spatial Relations of Salinity and Alkalinity



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Carbon Systematics of Antrim Shale Fluids

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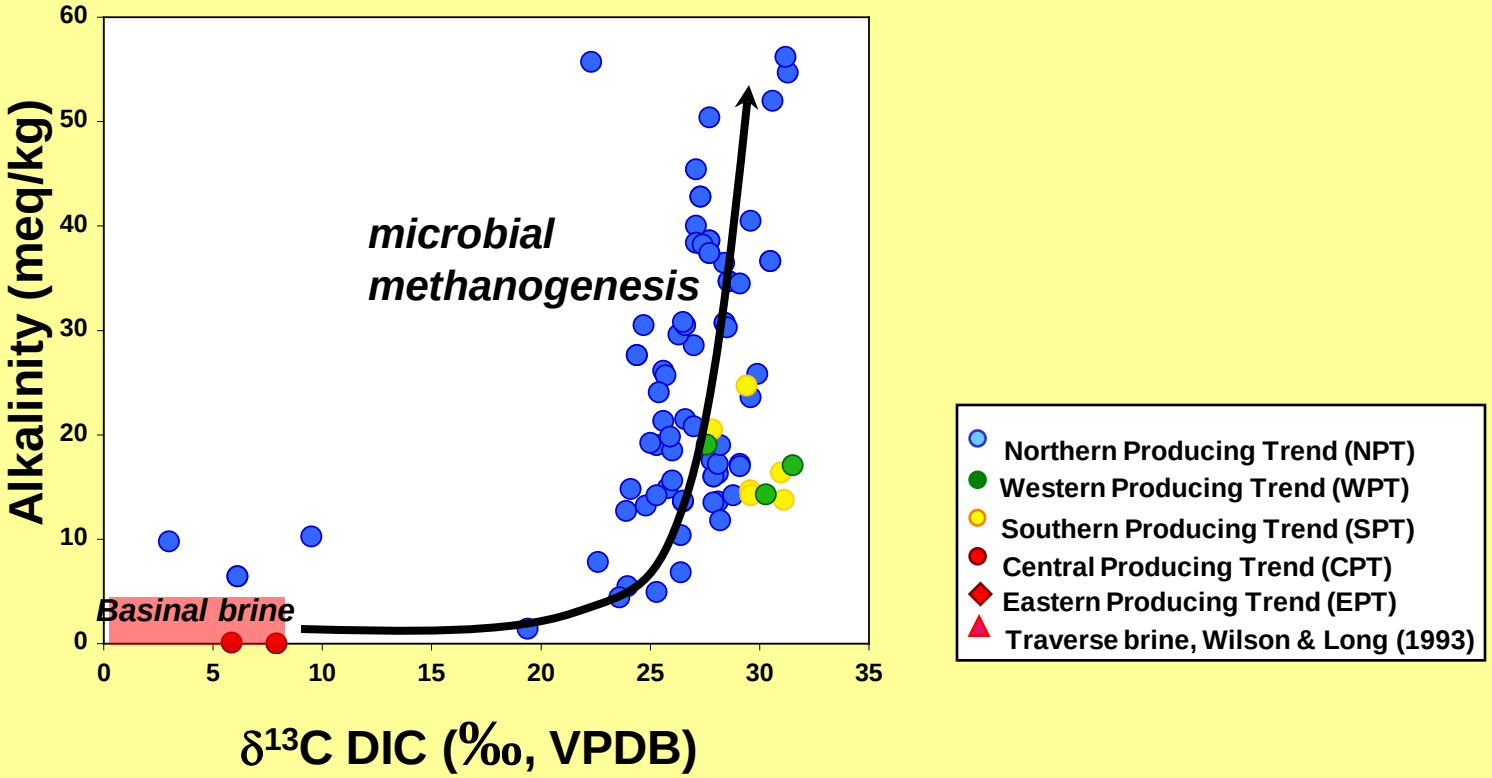

Microbial pathway for methane generation

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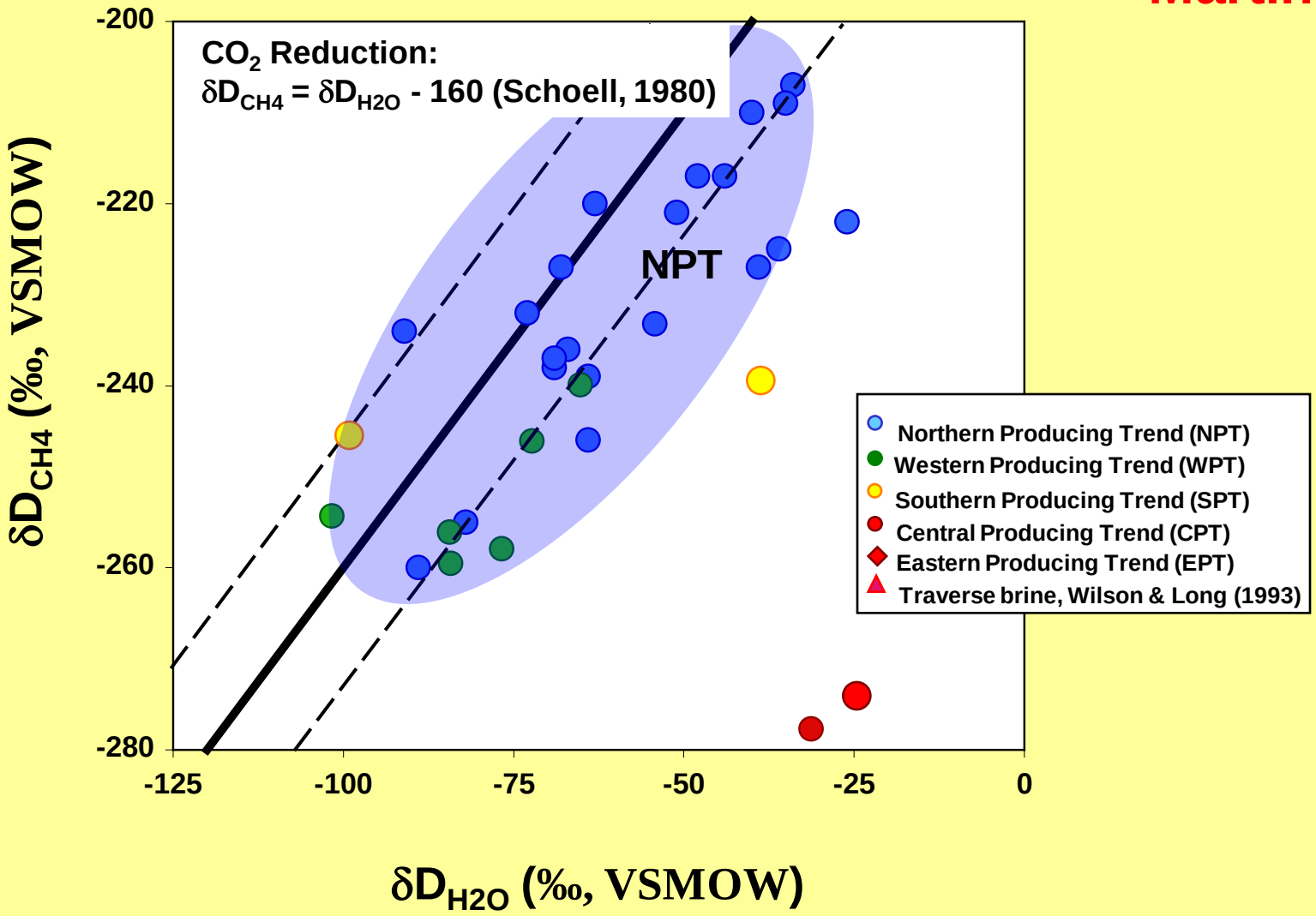

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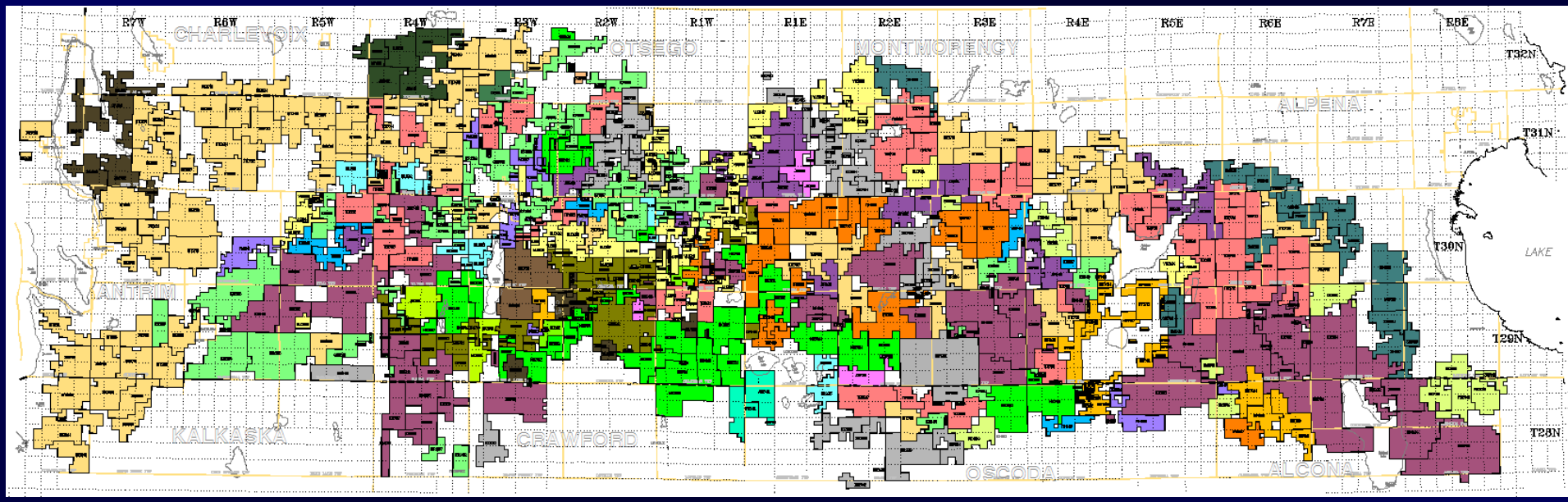
Conclusions:

- 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)

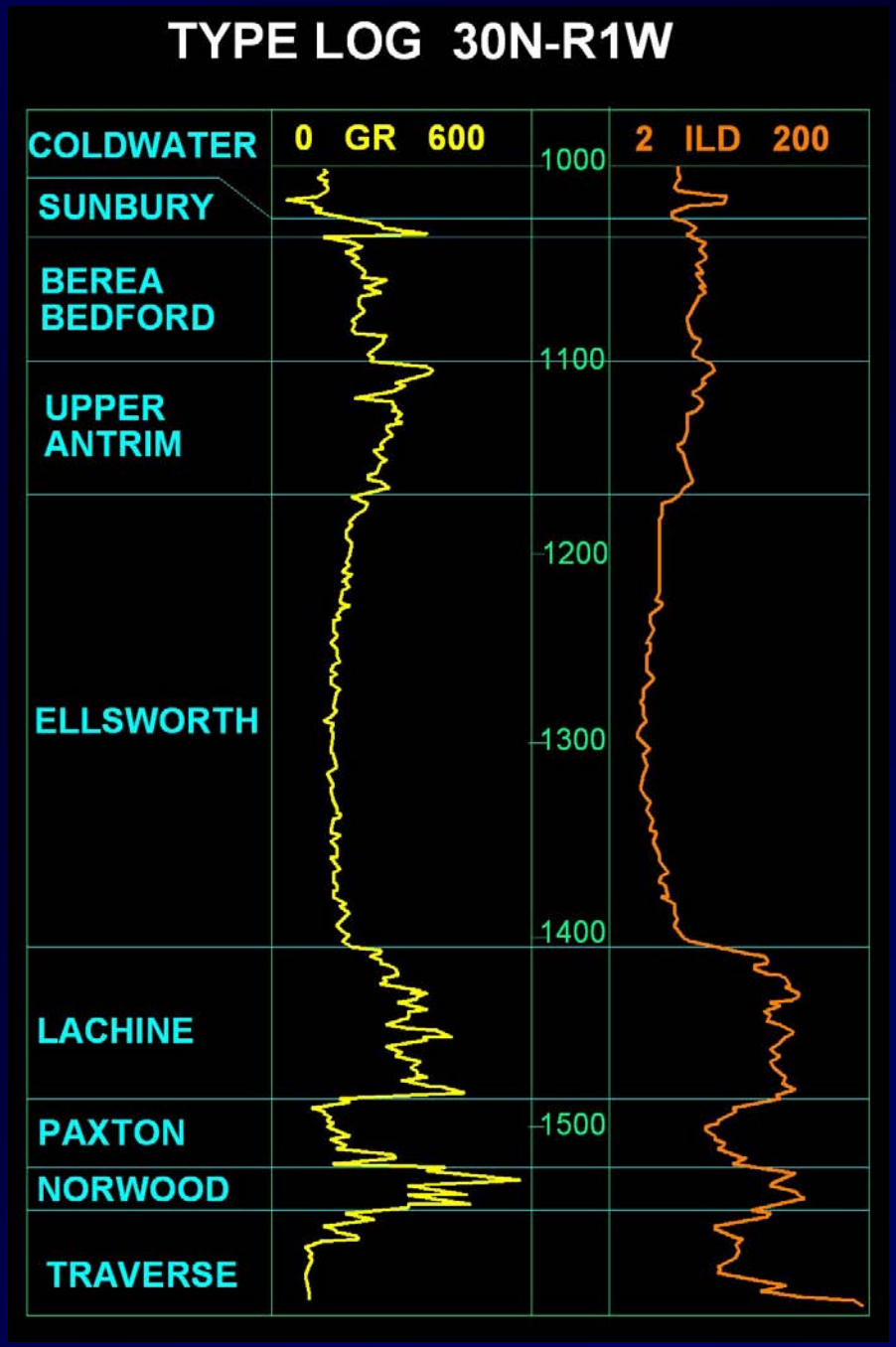
Wells now cased & selectively perforated through spot acid

Multi-stage Fracs the rule

N_2 Foam , 25-50K lbs 20/40 sand

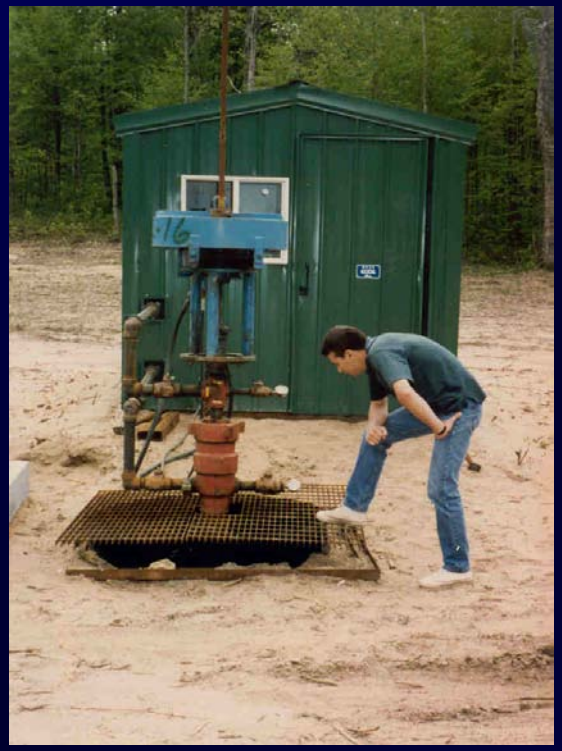
Various schemes for HD wells

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

Gas Processing Plant, Kalkaska

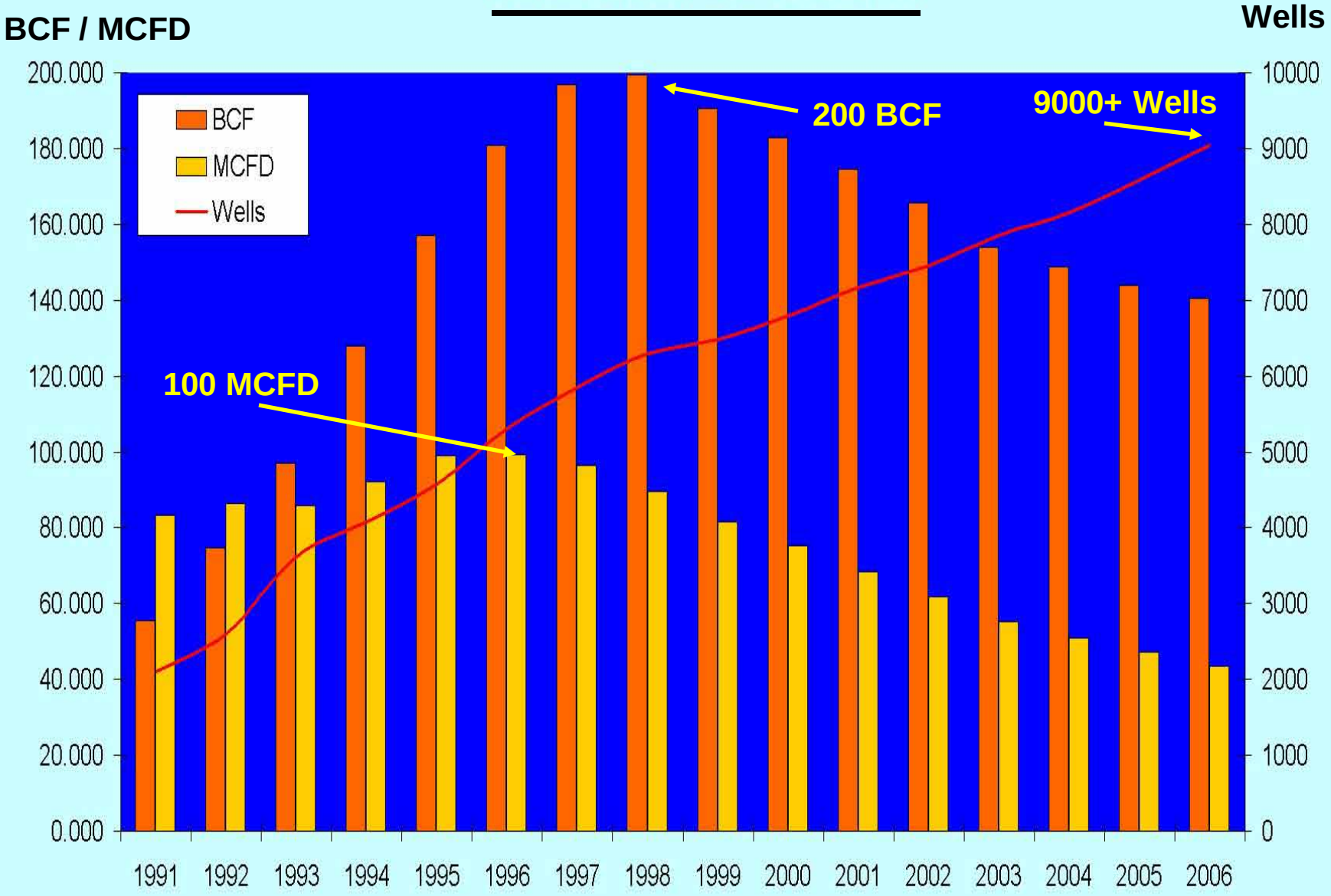
- 9382 Producing Wells in 12 Northern Michigan Counties
- 722 Producing Antrim Projects
- Current Prod. 368 MMCFGPD (39 MCFD/Well)

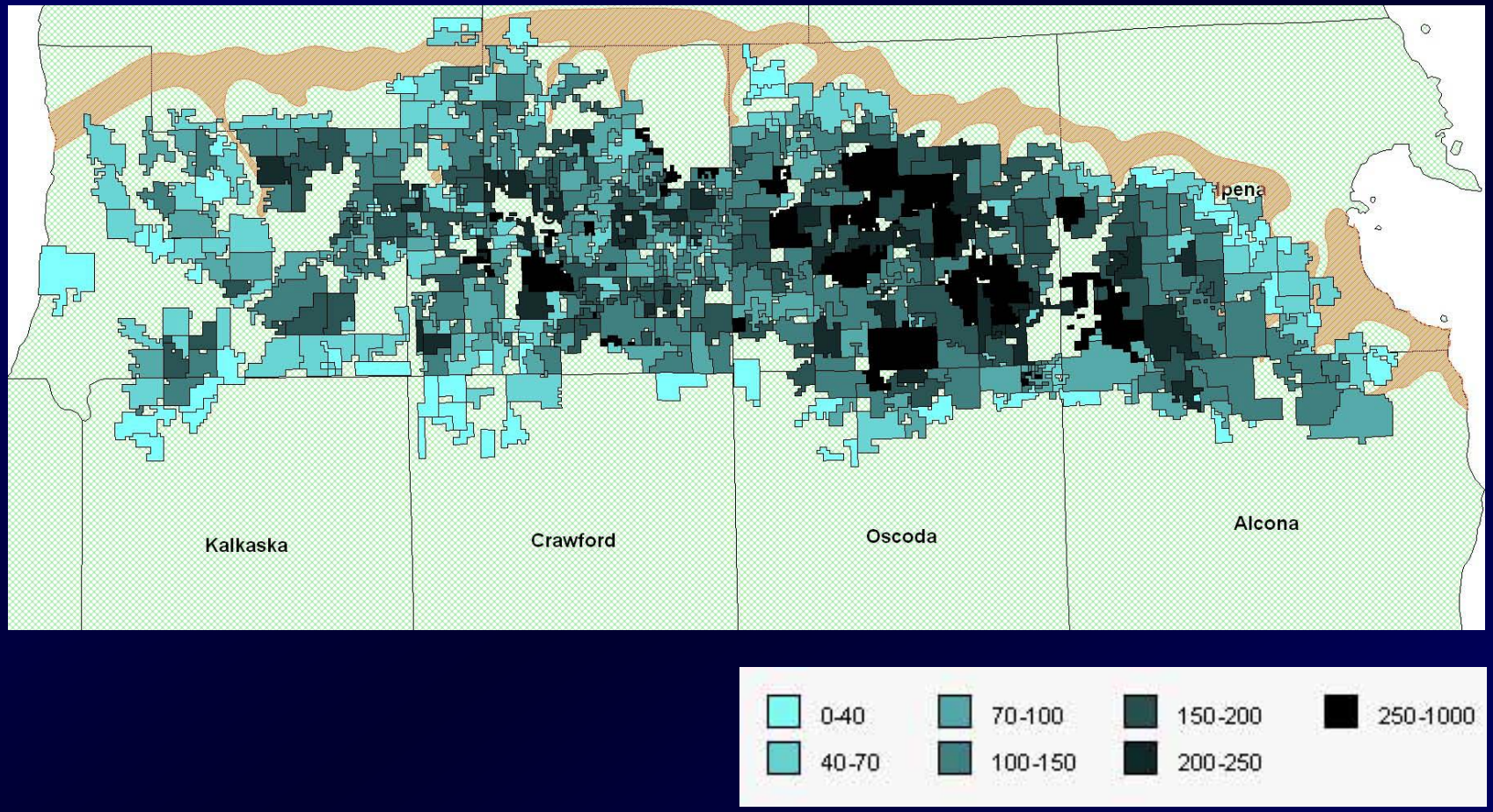
MPSC, Dec 2007 Data

Production Highlights

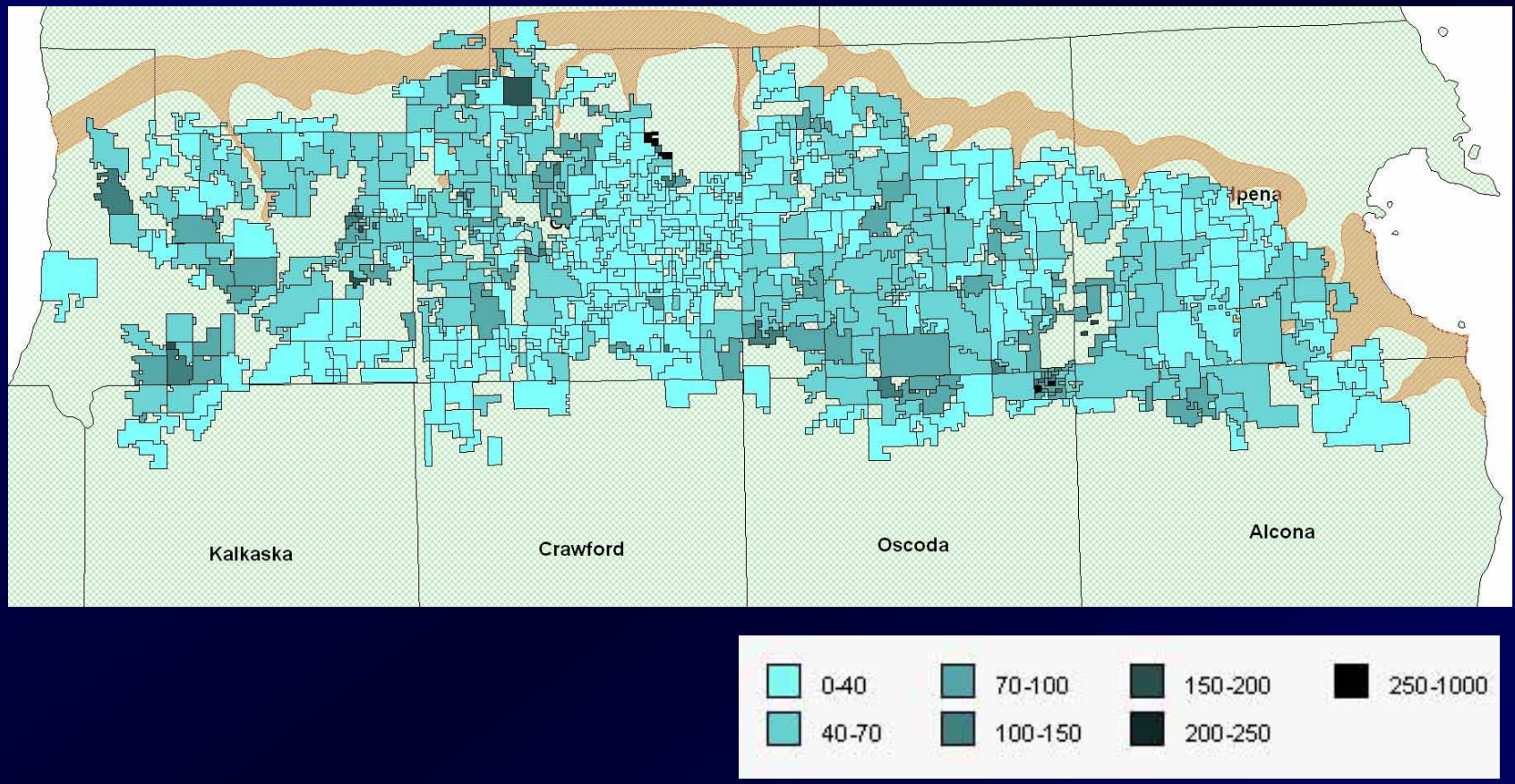
- 2.6 TCFG Through 2007
- 1.1 TBW Prod (1 BW/2.4 MCFG)
- Peak Prod'n: 1998 (546 MMCFGPD)
- Ann. Decline 4-5% Since 1998 (Per Well Decline Rate 9%)

Annual Antrim Gas Production

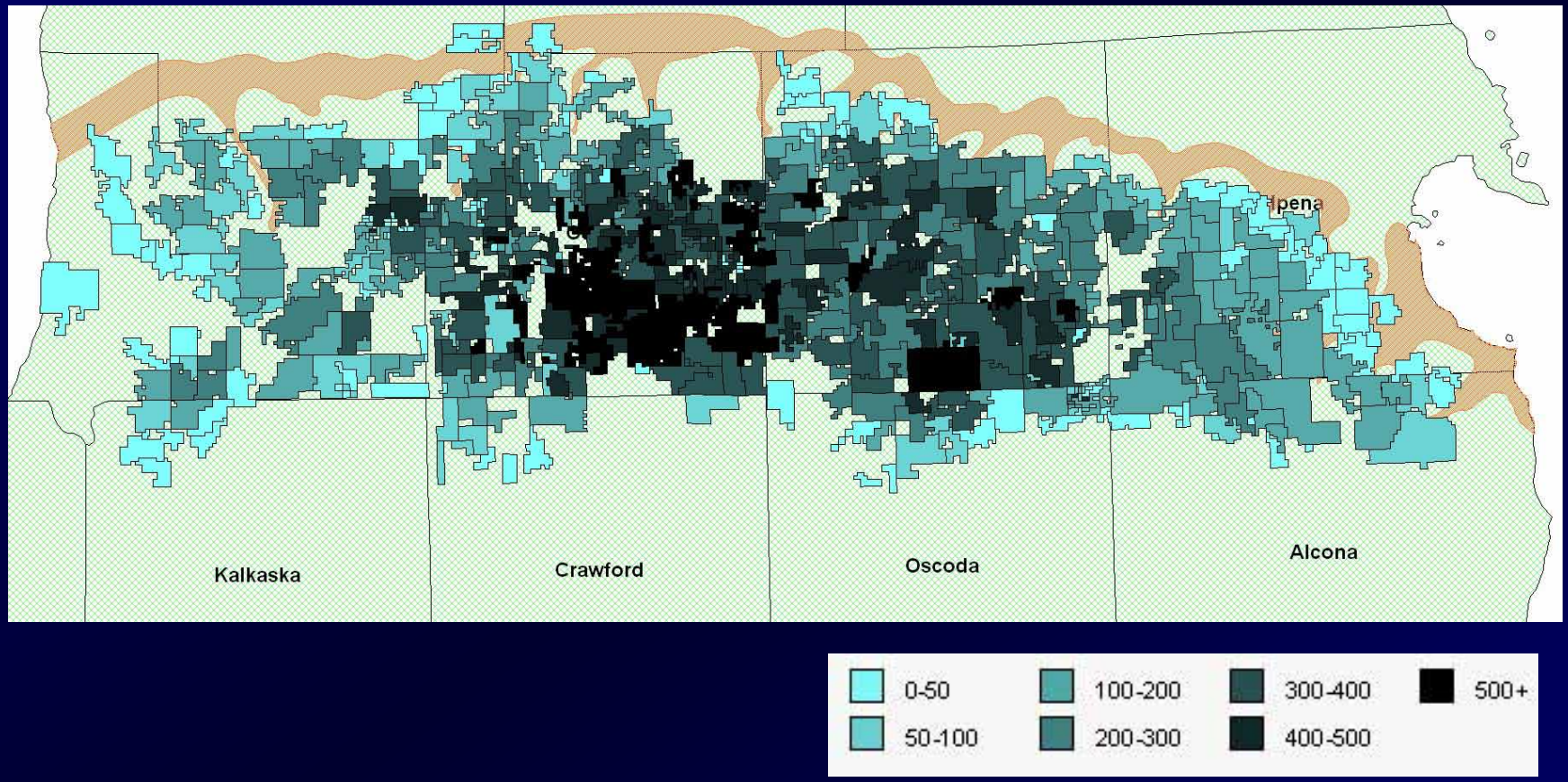




Peak Gas Rate (MCFD/well)



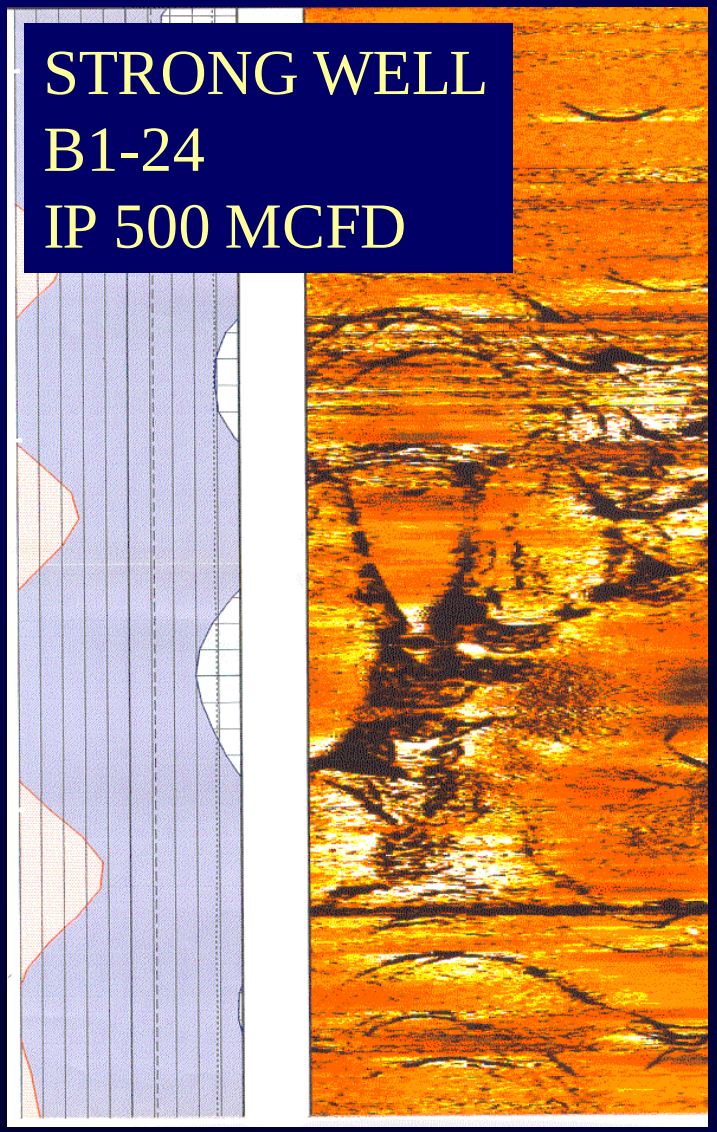
Current Gas Rate (MCFD/well)

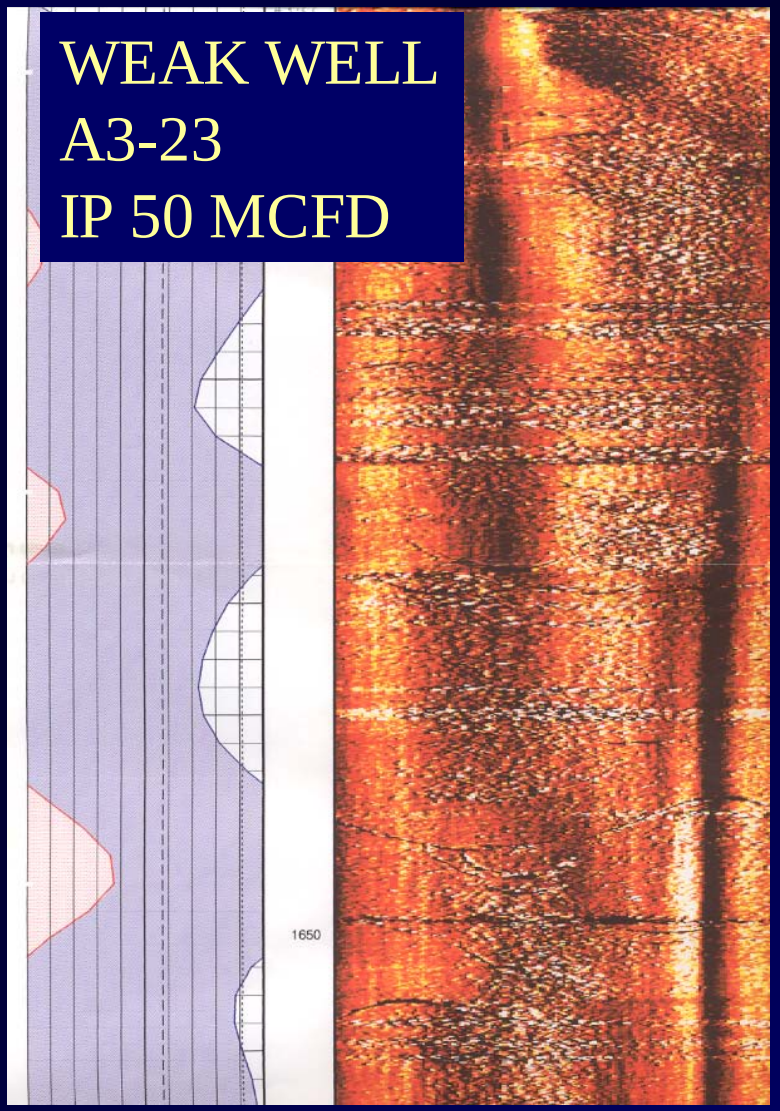


Cumulative Gas (MMCF/80 Acres)

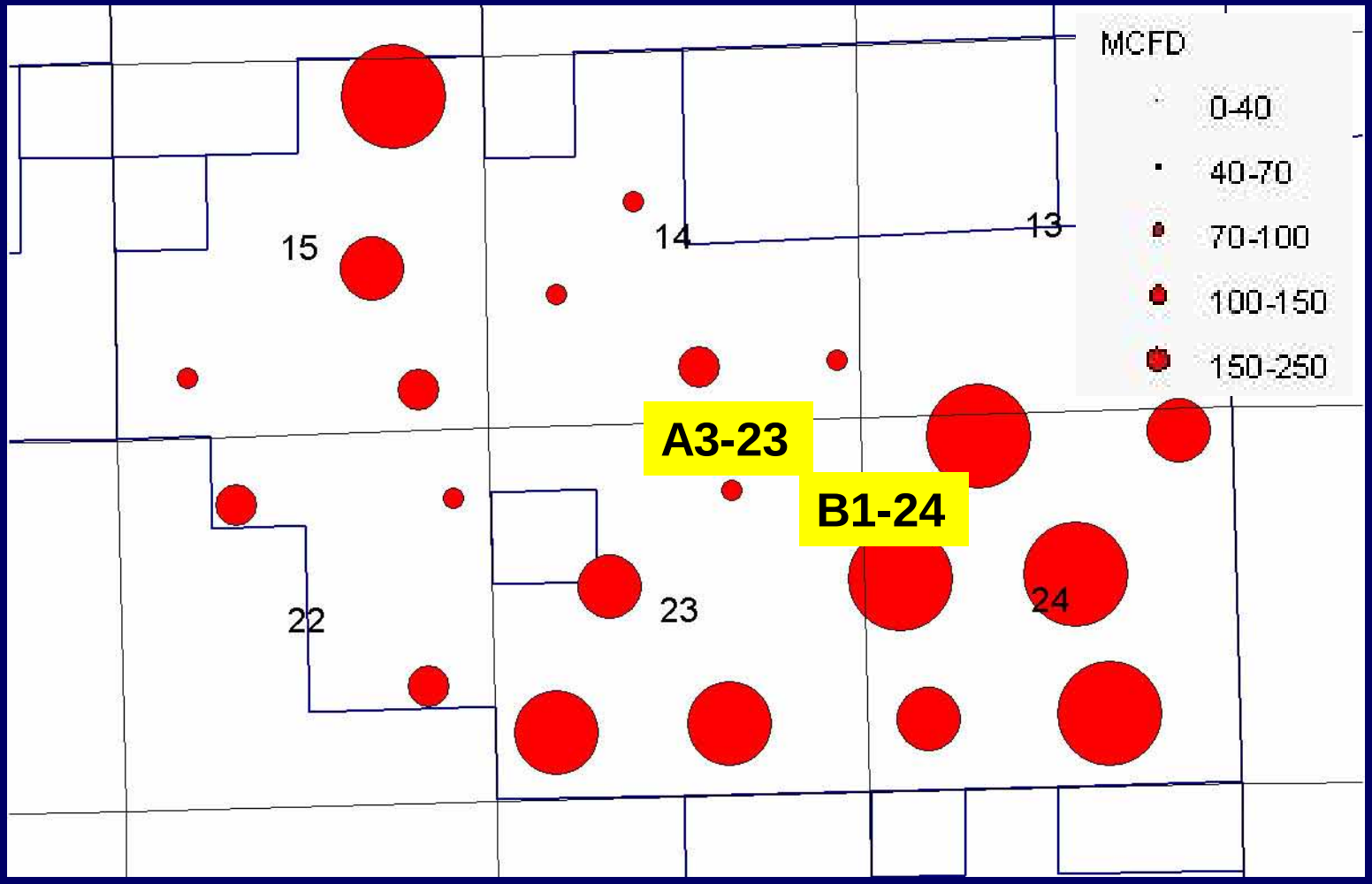
Local Production Variation

- Gas & Water Rates Per Well Show Variability Within Projects
- Productive Sweet Spots Often Link with Fracture Intensity
- Trends Follow Major Fracture Directions



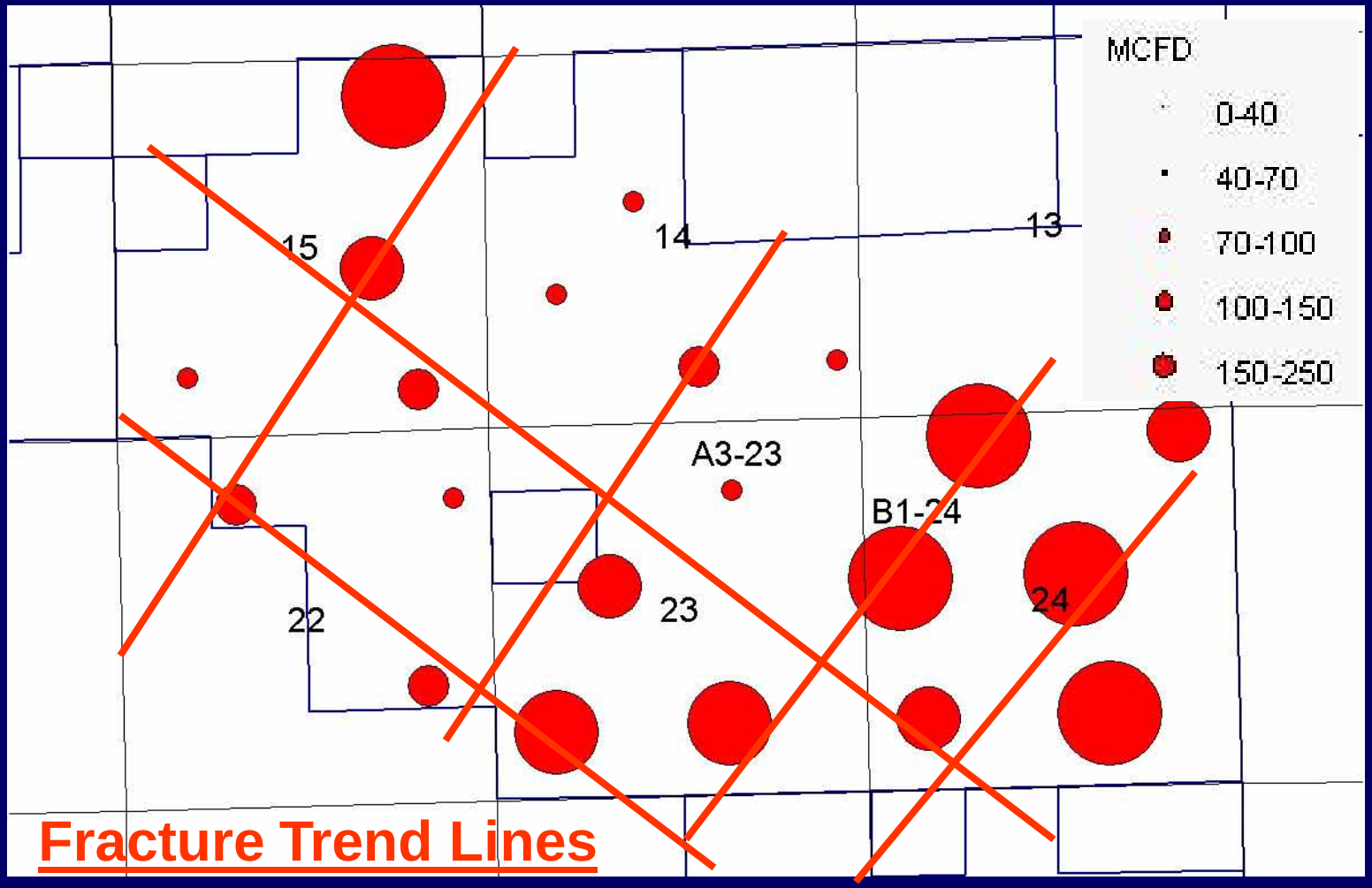


Imaging Logs, MDC Big Wolf Lake Project
(CBIL, CAST, UBI Fracture I.D. Logs)

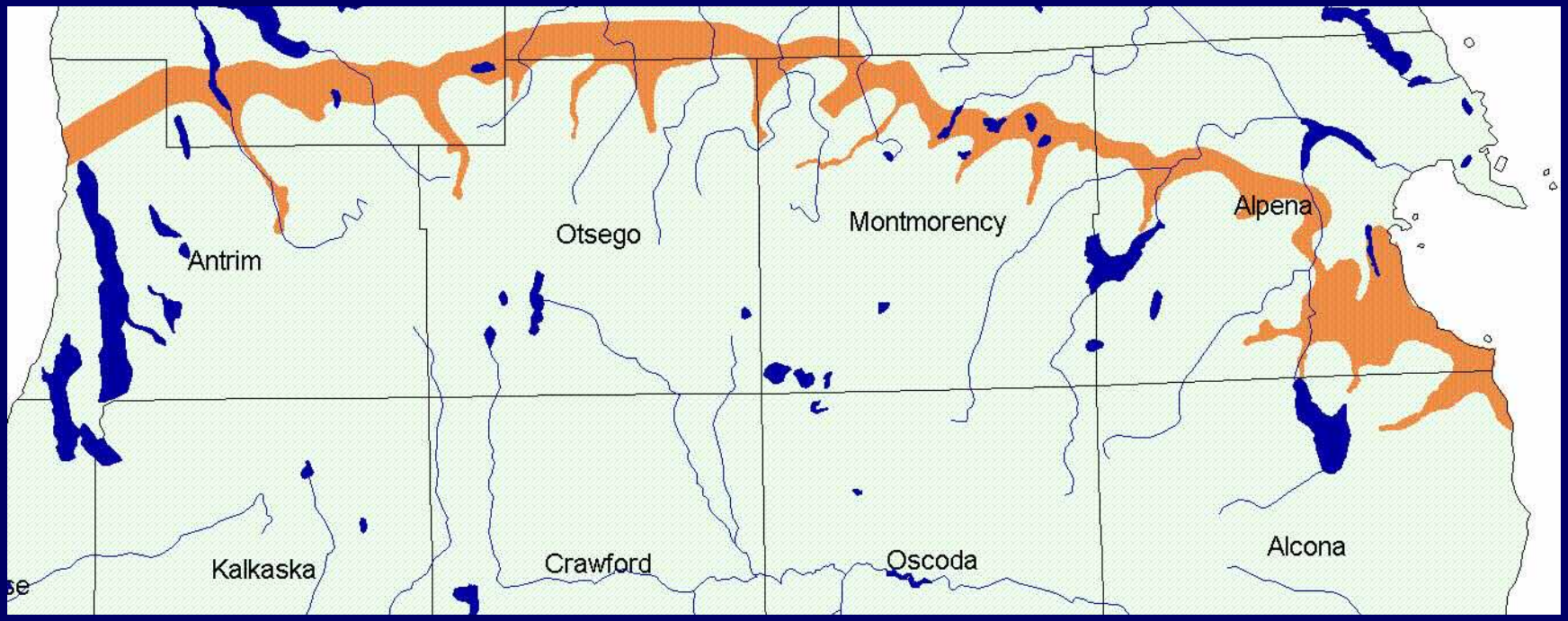


Muskegon, Big Wolf Lake: Current Production

(Western Montmorency CO, Michigan)

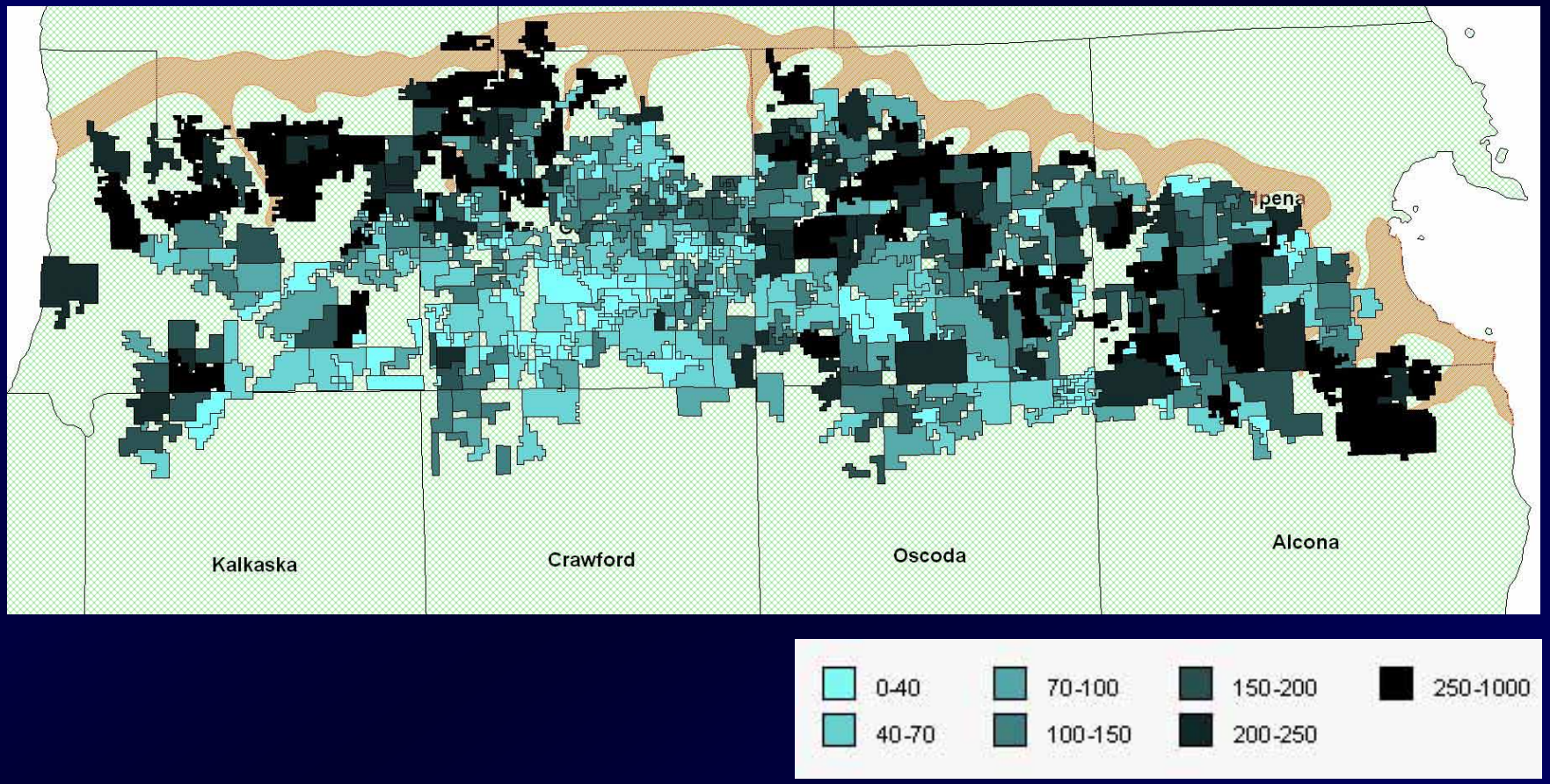


Muskegon, Big Wolf Lake: Current Production

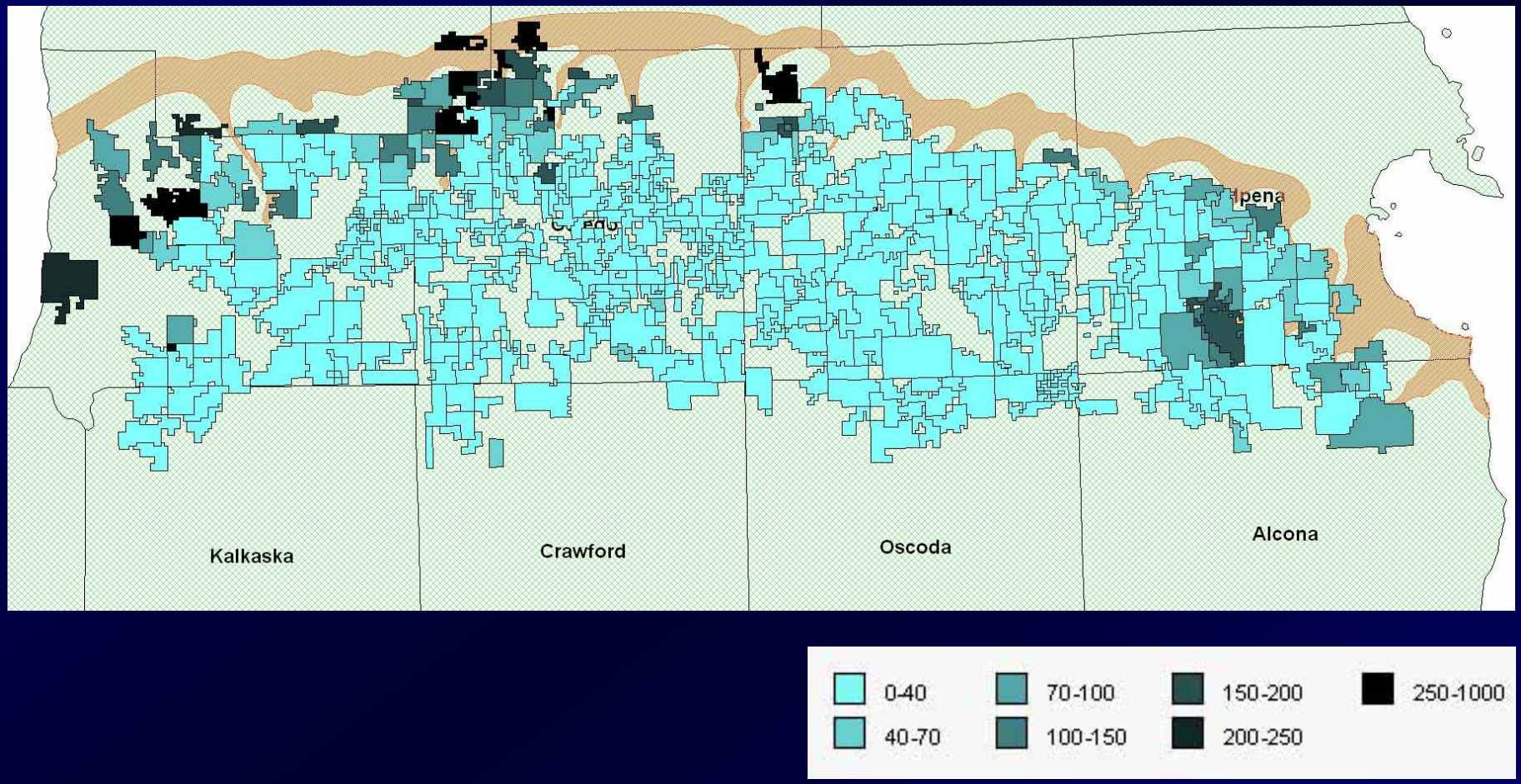


Correlation of Bedrock Scours and Drainage

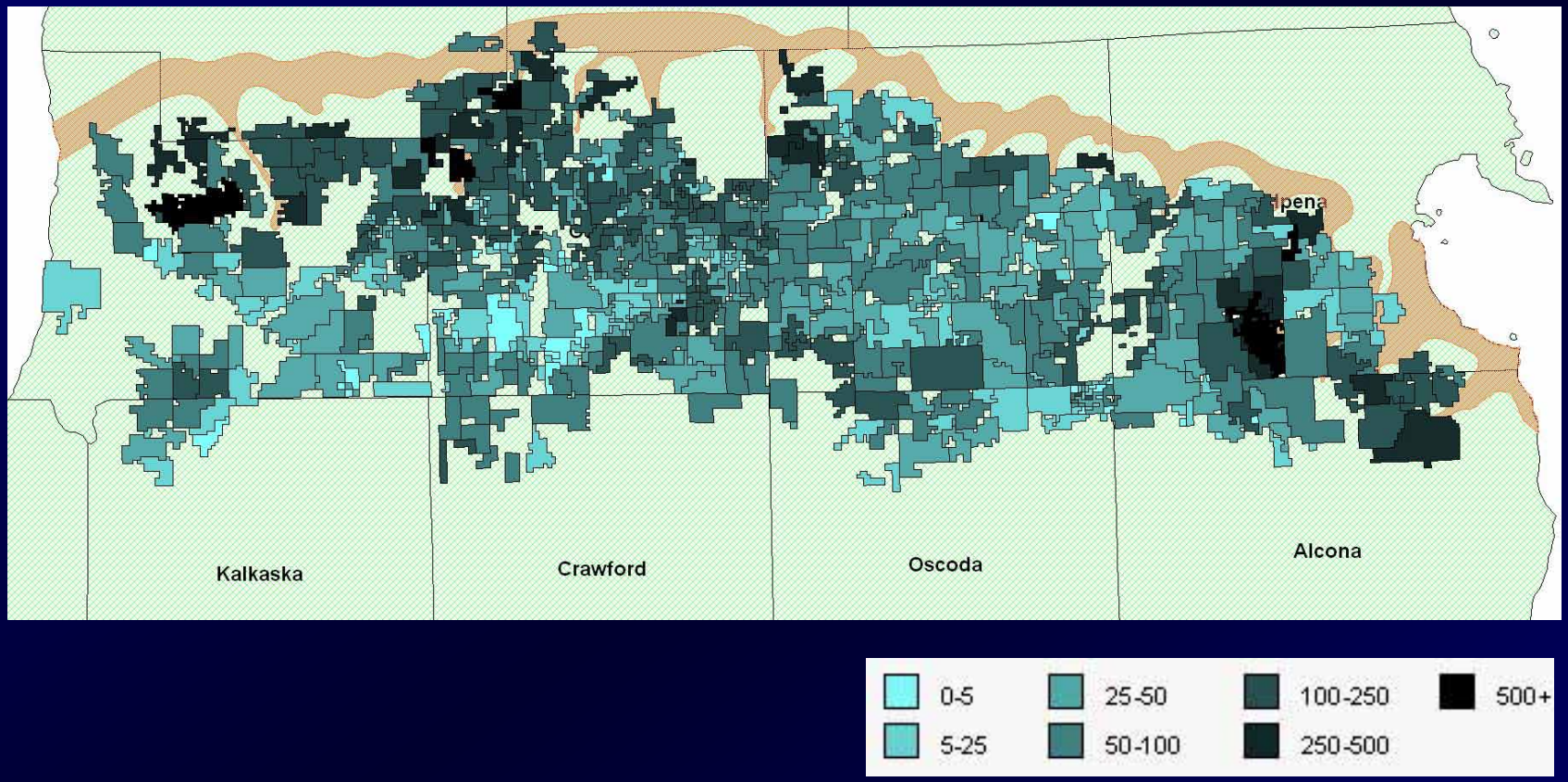
- Many Modern Drainage Systems Follow the Post-Glacial Scours
- Produced Antrim Water is in Part a Function of Subcrop Proximity



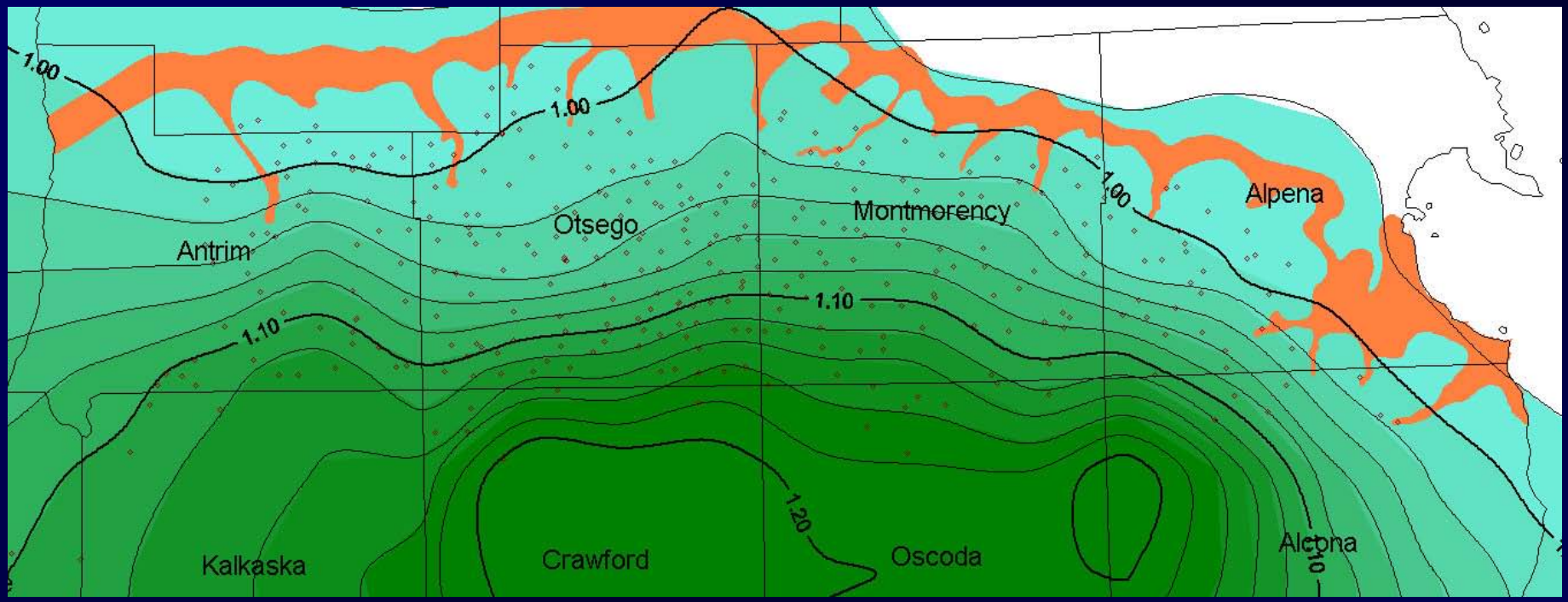
Peak Water Rate (BWPD/well)



Current Water Rate (BWPD/well)



Cumulative Water (MBbls/80 Acres)

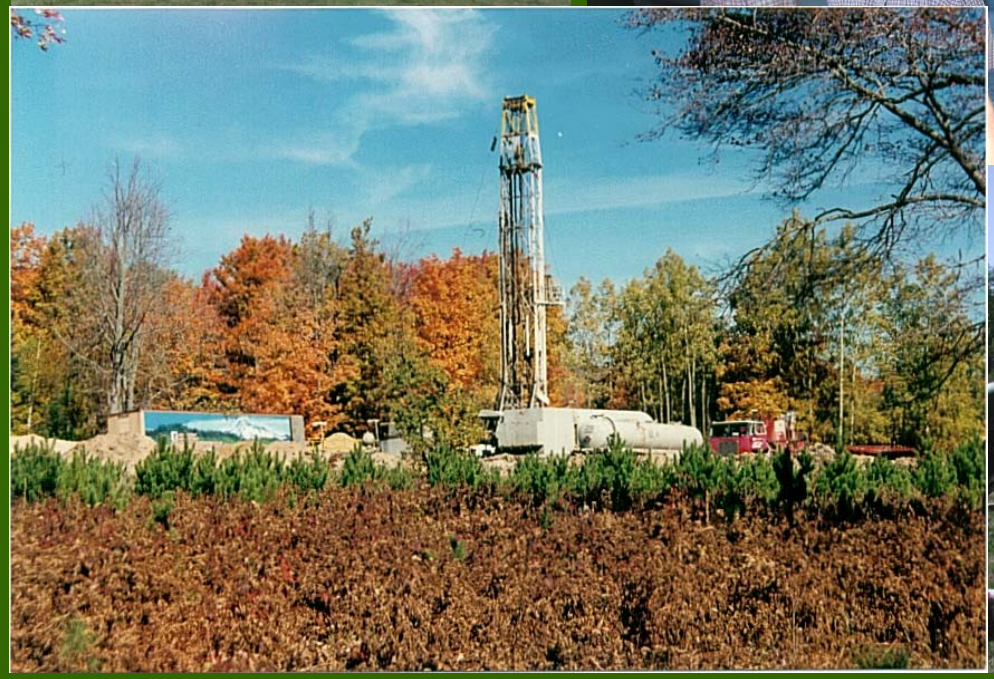


Specific Gravity of Disposed Water

A Reduced Fracture Regime + Heavier Water
Have Impeded Downdip Success

CO_2 Issues:

Production-Enhanced Recovery-Sequestration



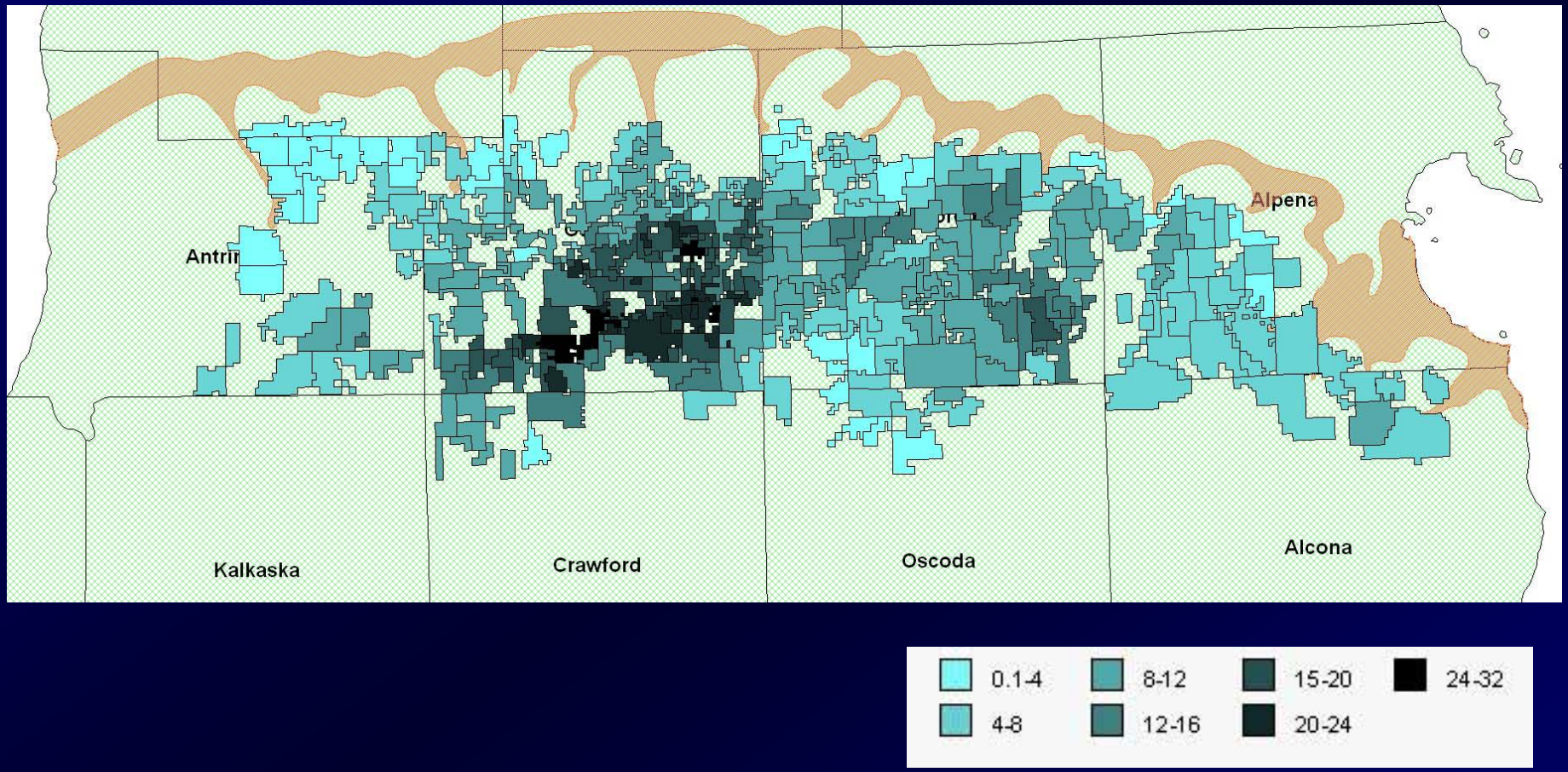
CO_2 is a Naturally Occurring By-Product Of Shale Gas Produced By Desorption

DTE Antrim Gas Plant, Chester Twp., Otsego County

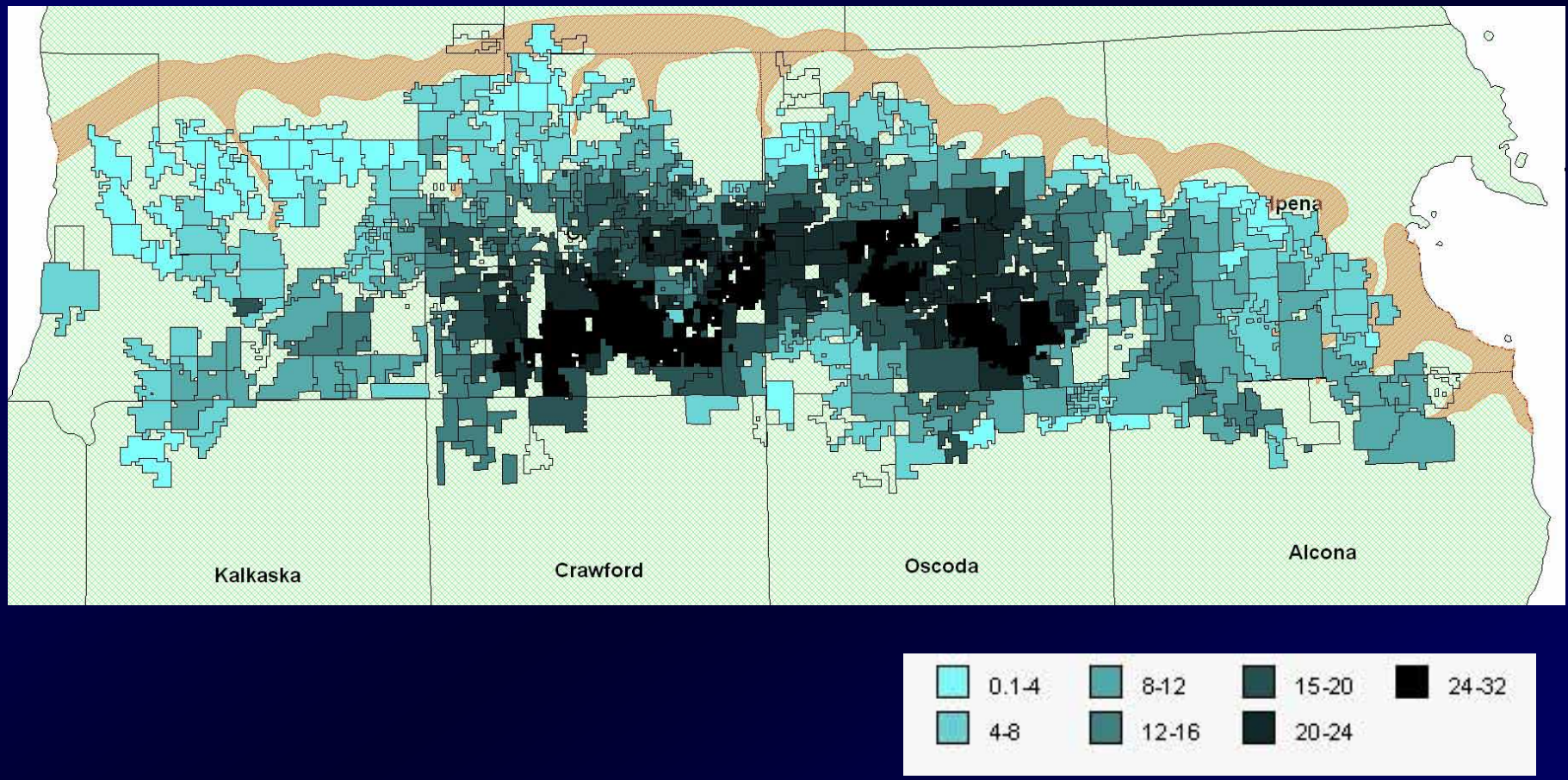
CO_2 Levels

in Produced Antrim Gas Start Low, But Steadily Grow During A Well's Productive Life, Eventually Topping 30% in Some Areas

Core Energy CO_2 Plant
Otsego County



CO_2 Percentage: 1998



CO_2 Percentage: 2008

Antrim Gas Processing Plant
Southern Otsego County, MI

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

Core, Pomerzynski 6-33
CO_2 Injector Drilled 2007

- *Core Energy (Traverse City, MI) Uses Antrim CO_2 for Tertiary Flood Projects in Several Niagaran (Silurian) Pinnacle Reef Fields in Otsego Co., MI*

- *Core has Injected over 650,000 Tons of CO_2 Since the Inception of Its Enhanced Recovery Projects*

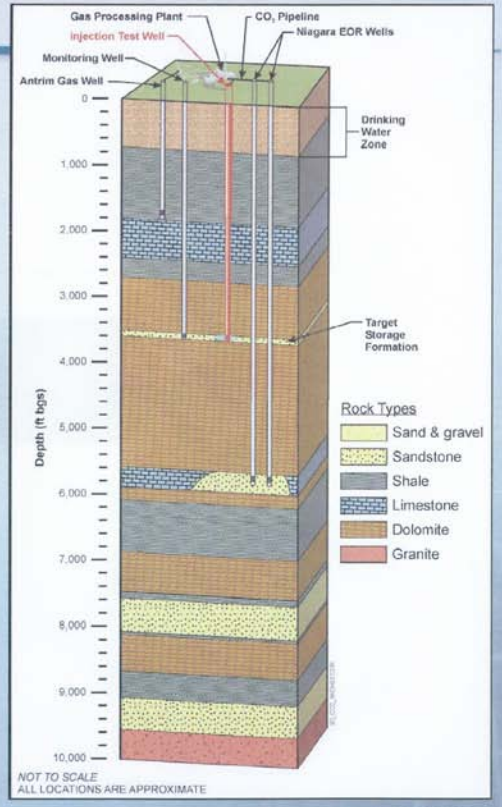
CO_2 Pipeline at Flood Project

DOE-MRCSP

Pilot CO_2 Sequestration Project

Preliminary Conceptual Injection System

- Bois Blanc and Bass Islands deep saline formations primary target
- Detroit Group shale and salt layers provide containment
- Injection well and monitoring wells completed



Battelle

- **A Pilot Project is Underway to Determine the Feasibility of Sequestering Antrim CO_2 in Northern MI's Siluro-Devonian Carbonates**

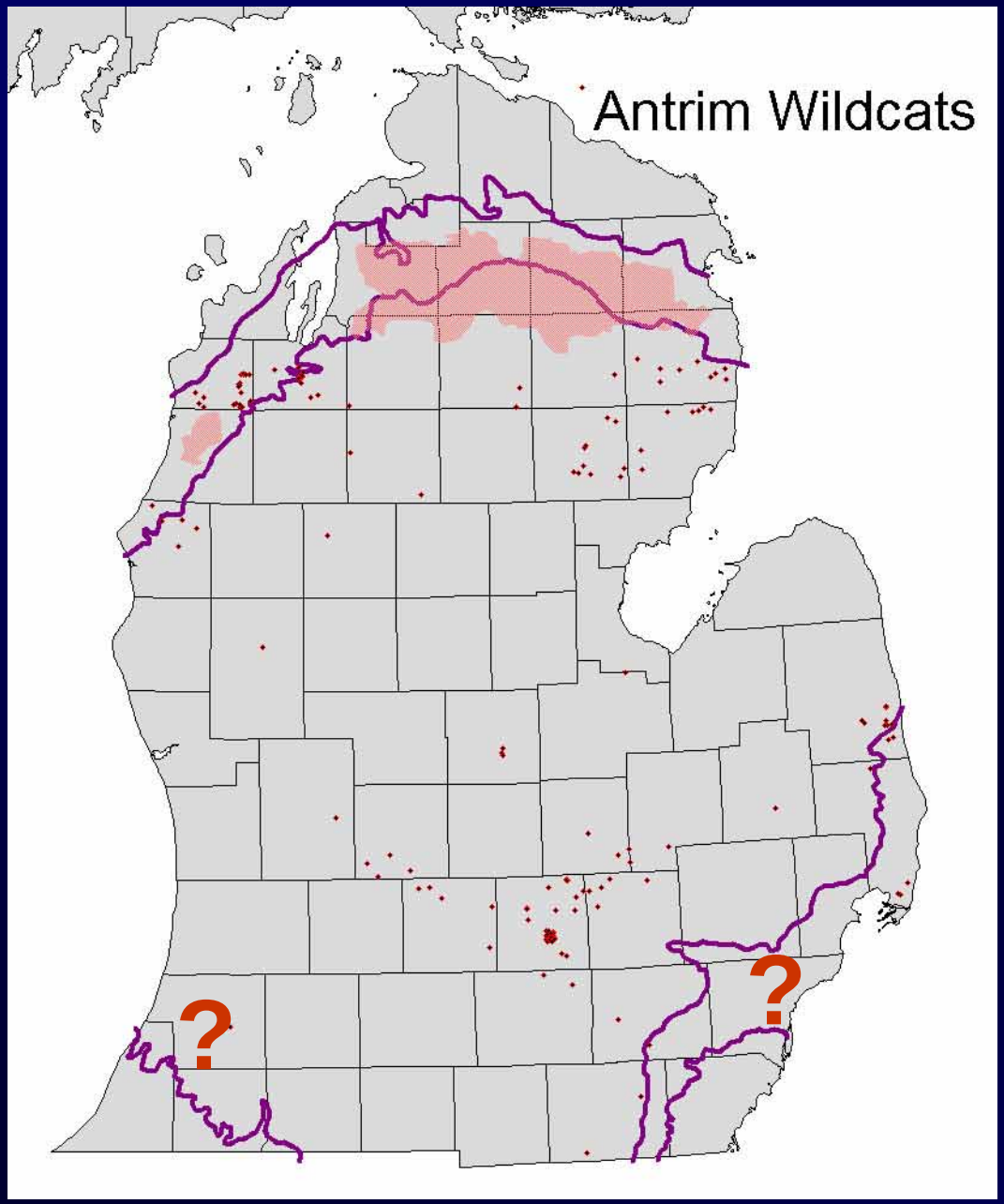
Michigan's Antrim Shale Play:

What's Ahead?

Logging an Antrim Well, Otsego County

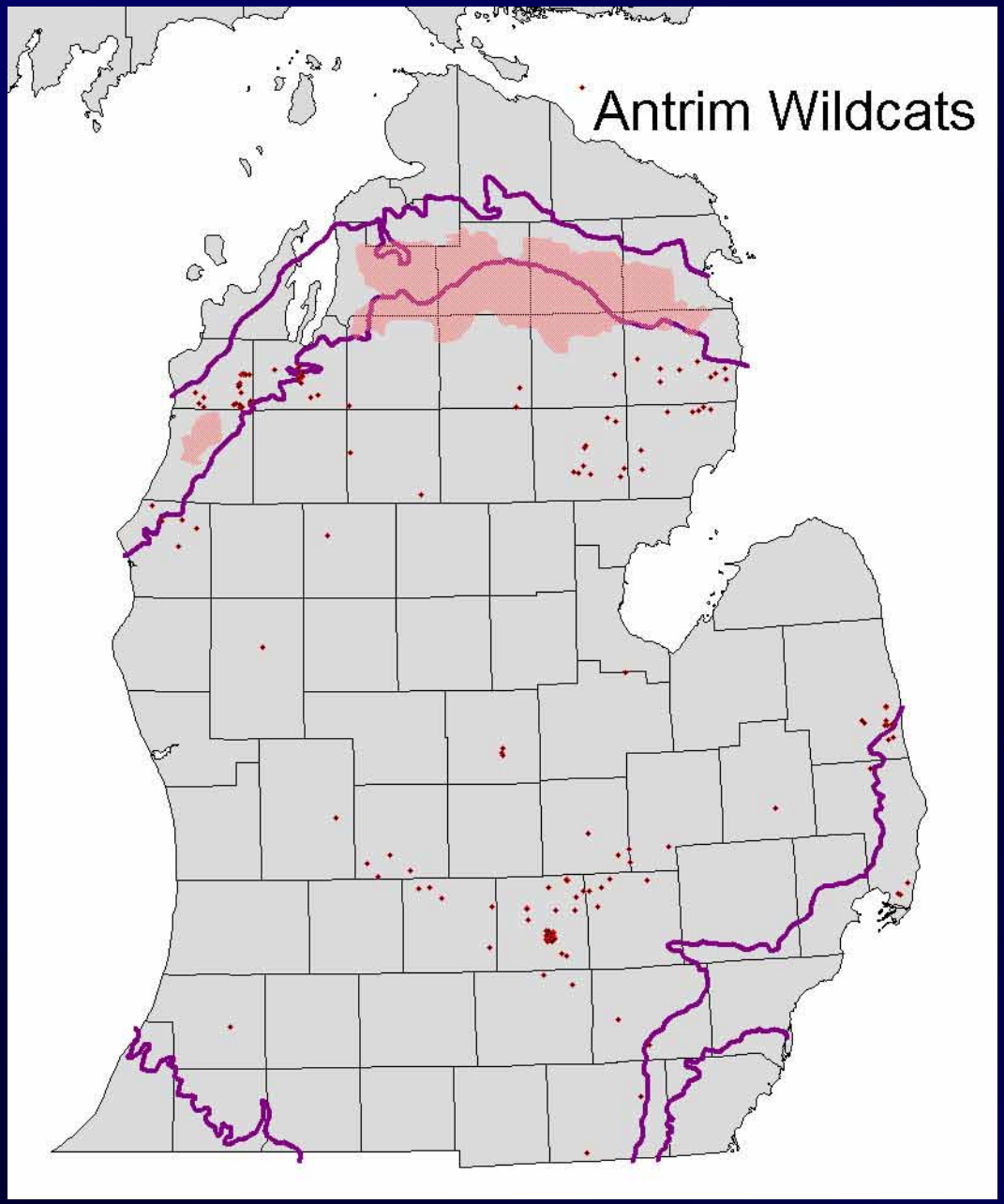
Optimization in Existing Units

- Re-Fracs
- Minimizing Back Pressure
- High Angle & HD wells
- Twin Wells in Upper Antrim
- Re-Injecting CO_2 for Profit?
- Microbe Enhancement?



WHAT'S LEFT?

- 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

Dellapenna, T.M., 1991, Sedimentological, structural, and organic geochemical controls on natural gas occurrence in the Antrim Formation in Otsego County, Michigan: Western Michigan University, Kalamazoo, Michigan, Master's thesis, 147 p.

Sanford, B.V., 1968, Devonian of Ontario and Michigan, *in* Proceedings of the International Symposium on the Devonian System, Calgary, Canada, v. 1, p. 973-999.

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