

Characterization for Source-Rock Potential of the Bakken Shales in the Williston Basin, North Dakota and Montana*

Hui Jin¹ and Stephen A. Sonnenberg¹

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¹Colorado School of Mines, Golden, CO (hjin@mines.edu)

Abstract

The lower and upper Bakken shales are world class source rocks in the Williston Basin, sourcing reservoirs in the Bakken, upper Three Forks, and lower Lodgepole formations, which comprise the economically significant Bakken Petroleum System (BPS). 10 to 400 billion barrels of oil have been estimated to have been generated from the Bakken shales, charging both unconventional and conventional plays in the BPS.

The objective of this study is to understand the source rocks' potential and its relationship with Bakken oil present in reservoirs of the BPS across the Williston Basin. Important geochemical characteristic parameters of the Bakken shales, such as organic richness, kerogen type, source rock maturity, and kinetics, are derived from the Total Organic Carbon (TOC) and pyrolysis analysis in Rock-Eval and Source Rock AnalyzerTM (SRA). Over three thousand TOC and pyrolysis results, providing good coverage of the North Dakota and Montana portions of the Williston Basin, have been collected from the Colorado School of Mines SRA Lab and US Geological Survey Energy Geochemistry Database.

Based on the TOC and pyrolysis results of Bakken samples, lower and upper Bakken shales exhibit a wide range in TOC contents, laterally from 1 wt.% at shallower basin margins up to 35 wt.% in the deeper basin, and vertically with recurrent patterns in each shale section. This high variation of TOC content may result from mixed effects of the original depositional environment and progressive maturation. Based on the modified van-Krevelen diagram, the kerogen type present in Bakken shale is primarily Type I/II, but along the shallow east flank of the basin there is Type III kerogen input. Original hydrogen index and TOC across the basin are empirically and mathematically restored and averaged at ~600 mg hydrocarbon (HC)/g Carbon and ~19-20 wt.%, respectively. Kinetic analysis suggests that averaged activation energy for Type II kerogen in Bakken shales is ~52 kcal/mol. The pyrolysis temperature of 425°C, production index of 0.1, and conversion fraction of 0.1~0.15 correspond to a threshold of incipient HC generation from mature shales. Due to maturation and HC generation, TOC contents are diminished by about ~7-8 wt.% in thermally mature areas of the Williston Basin. Early results indicate that the upper and lower Bakken shales in the central, deeper Williston Basin are organic-rich, contain oil-prone kerogen, and are thermally mature and in the oil-generation window.

Selected References

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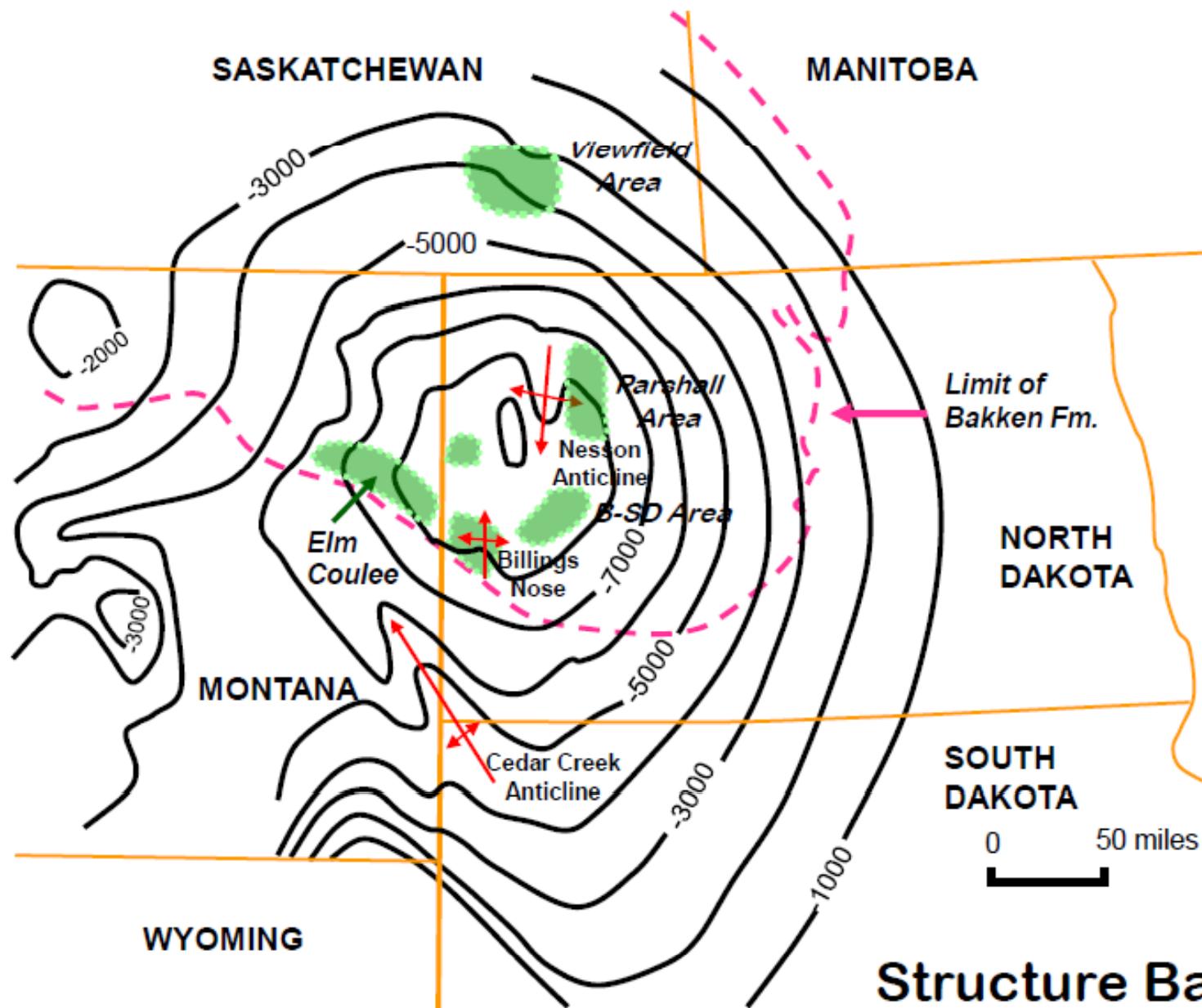
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05/21/2013



Outline

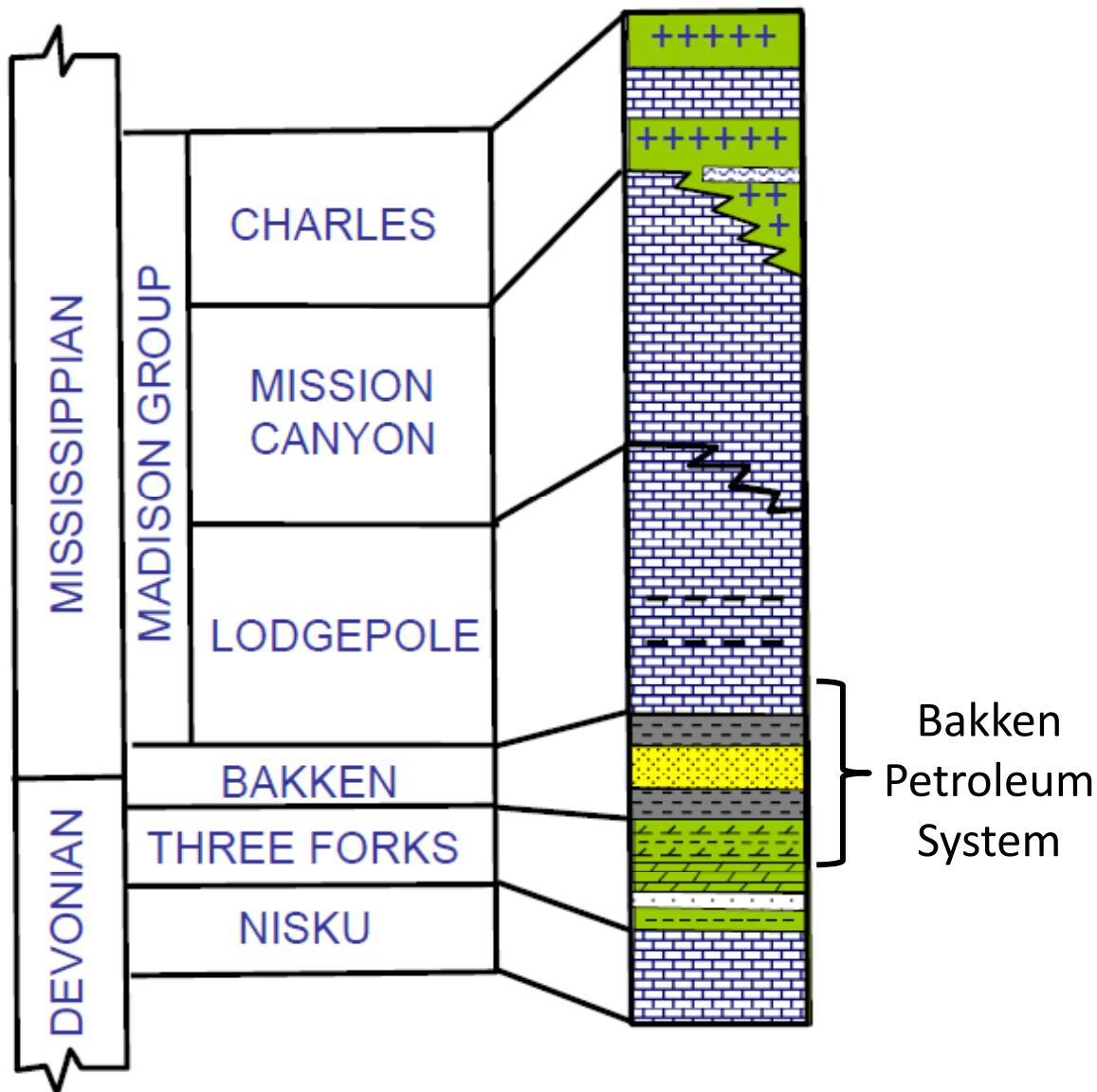
- Geology Background
- Isopach maps
- Organic richness and kerogen type
- Maturity and thresholds
- Stratigraphy
- Conclusions

Geology of Bakken Formation



(From Sonnenberg, 2009)

Geology of Bakken Formation



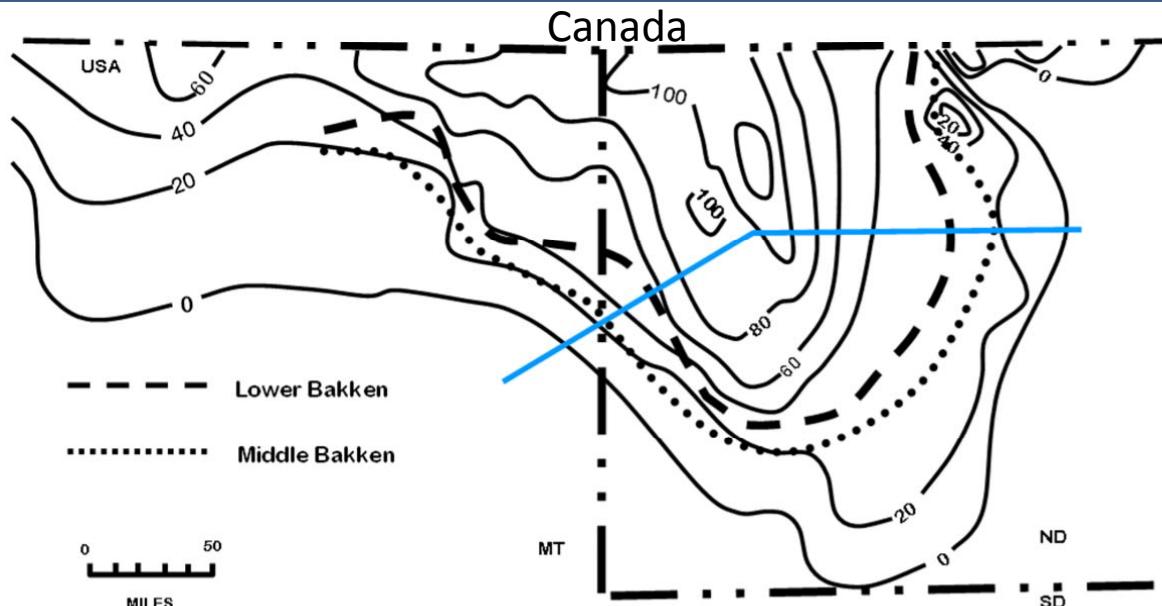
NDIC (2010) estimated ultimate production of Bakken Petroleum System:

Bakken: 2.1 Billion barrels
Three Forks: 1.9 Billion barrels

USGS (2013)
Technically Recoverable Continuous Resources
7375 MMBO
6723 BCFG
283 MMBNGL

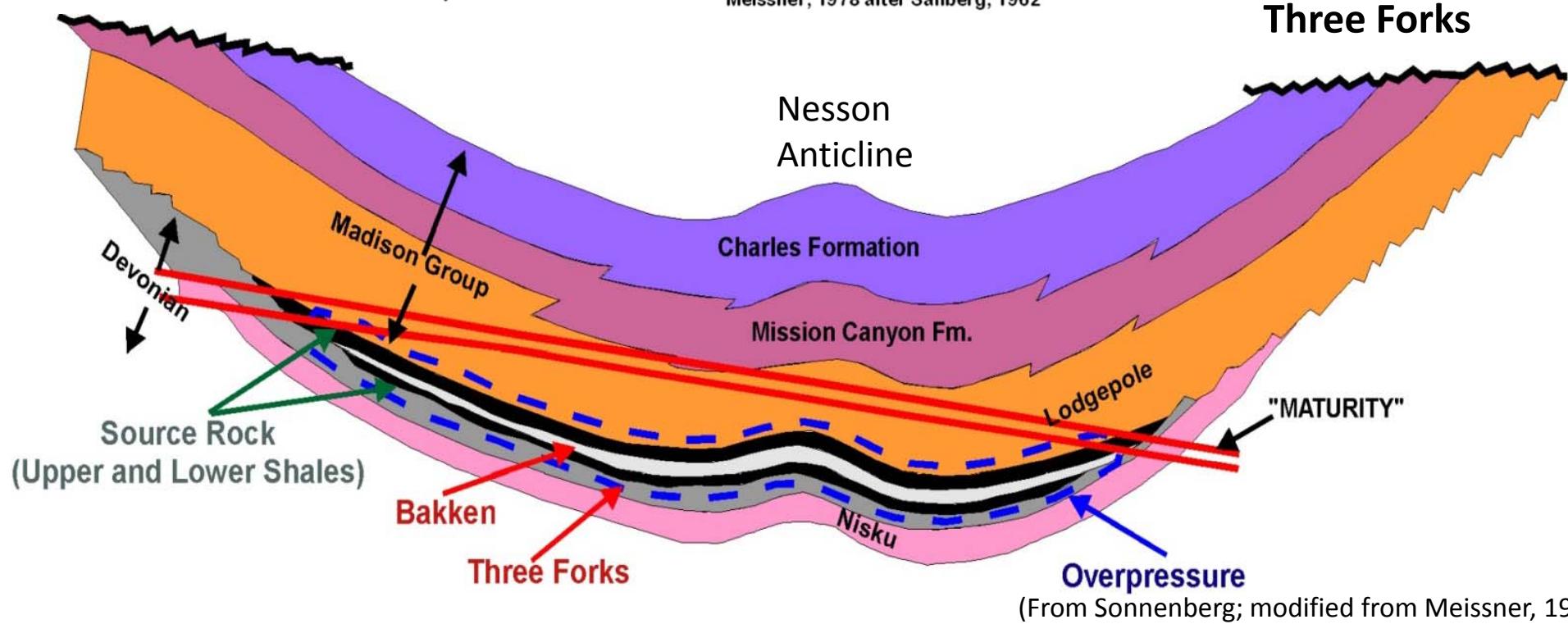
(From Sonnenberg and Pramudito, 2009; modified from Webster, 1984)

Geology of Bakken Formation



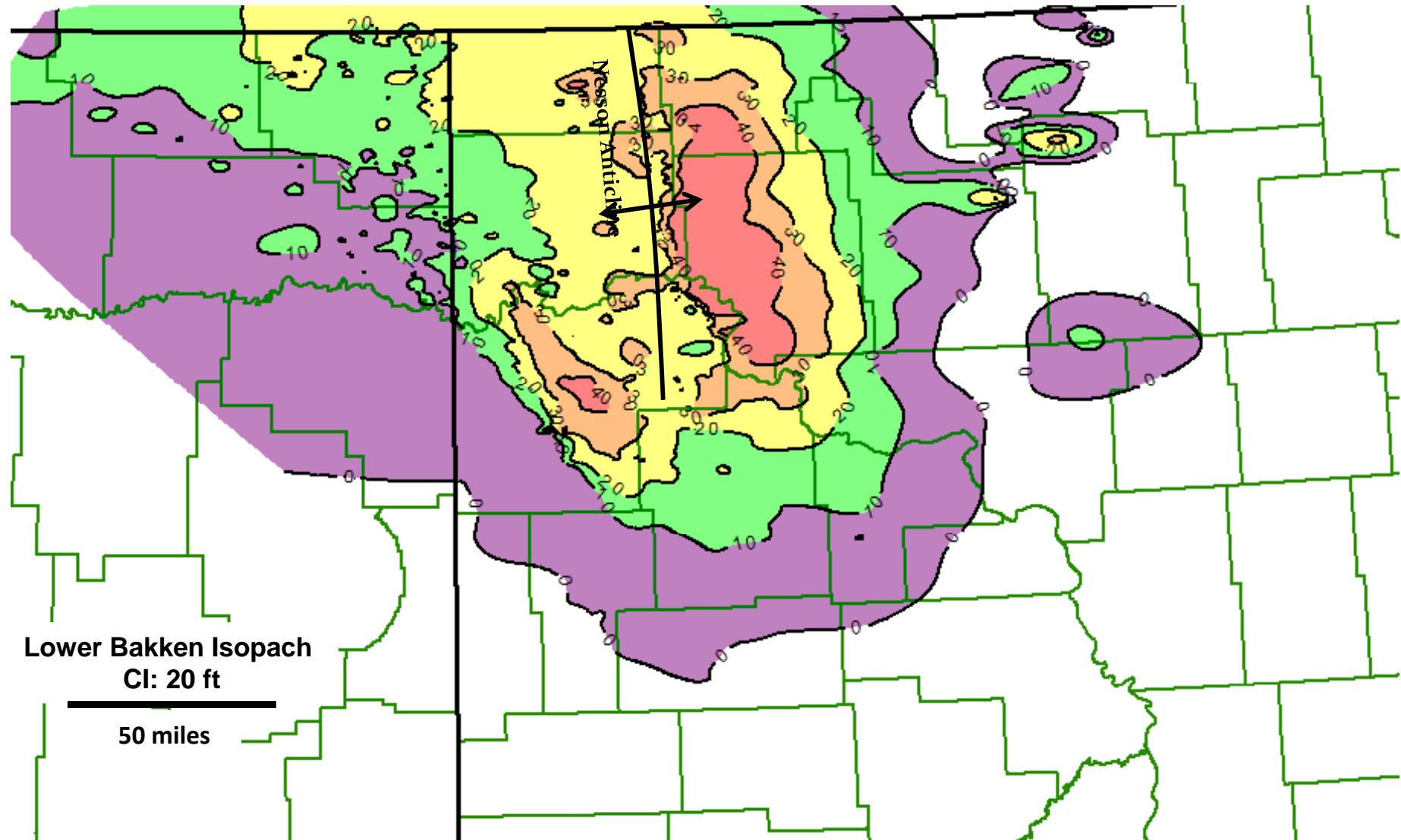
Source Beds:
Upper & Lower
Bakken shales

Reservoirs:
Middle Bakken &
Three Forks

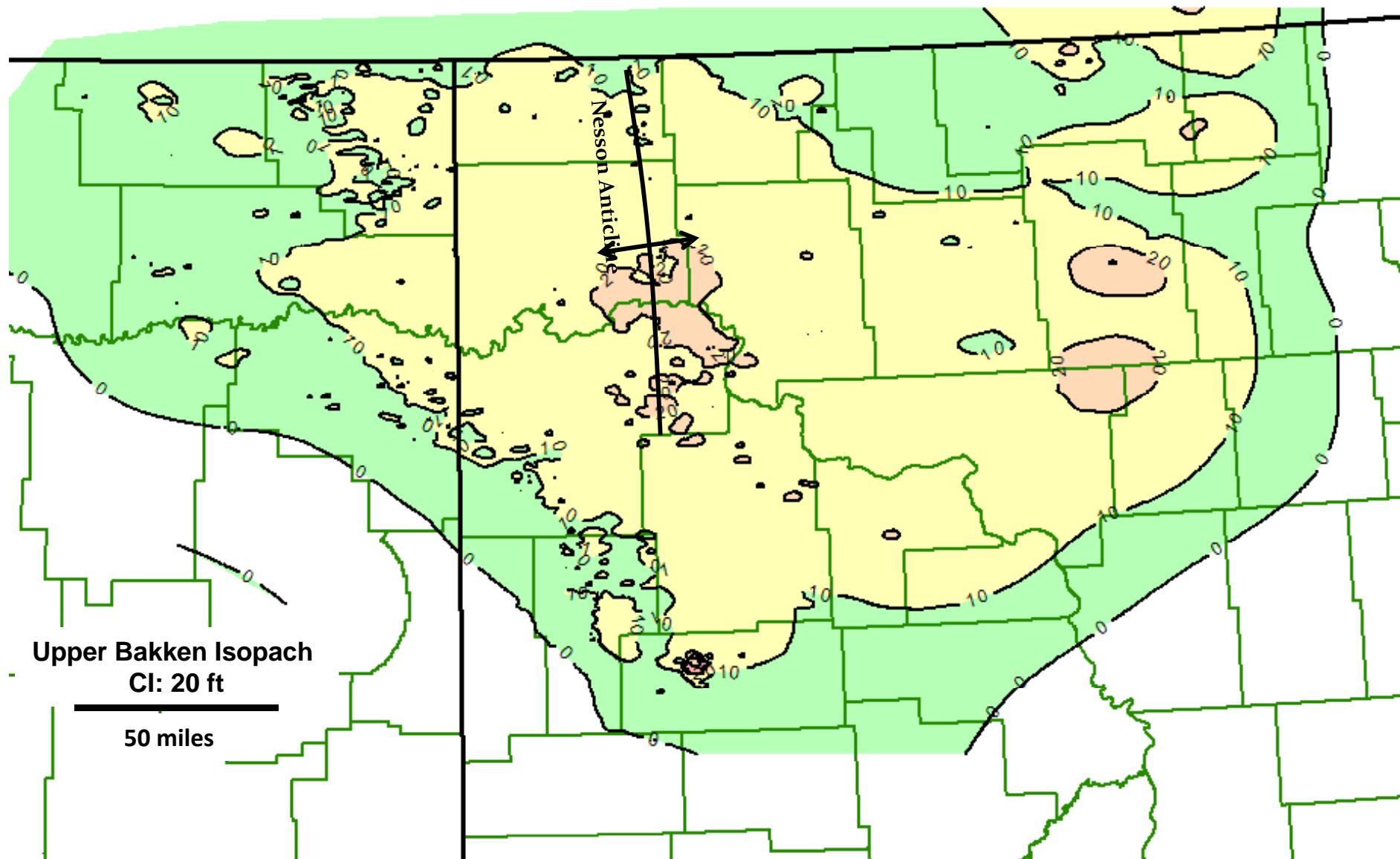




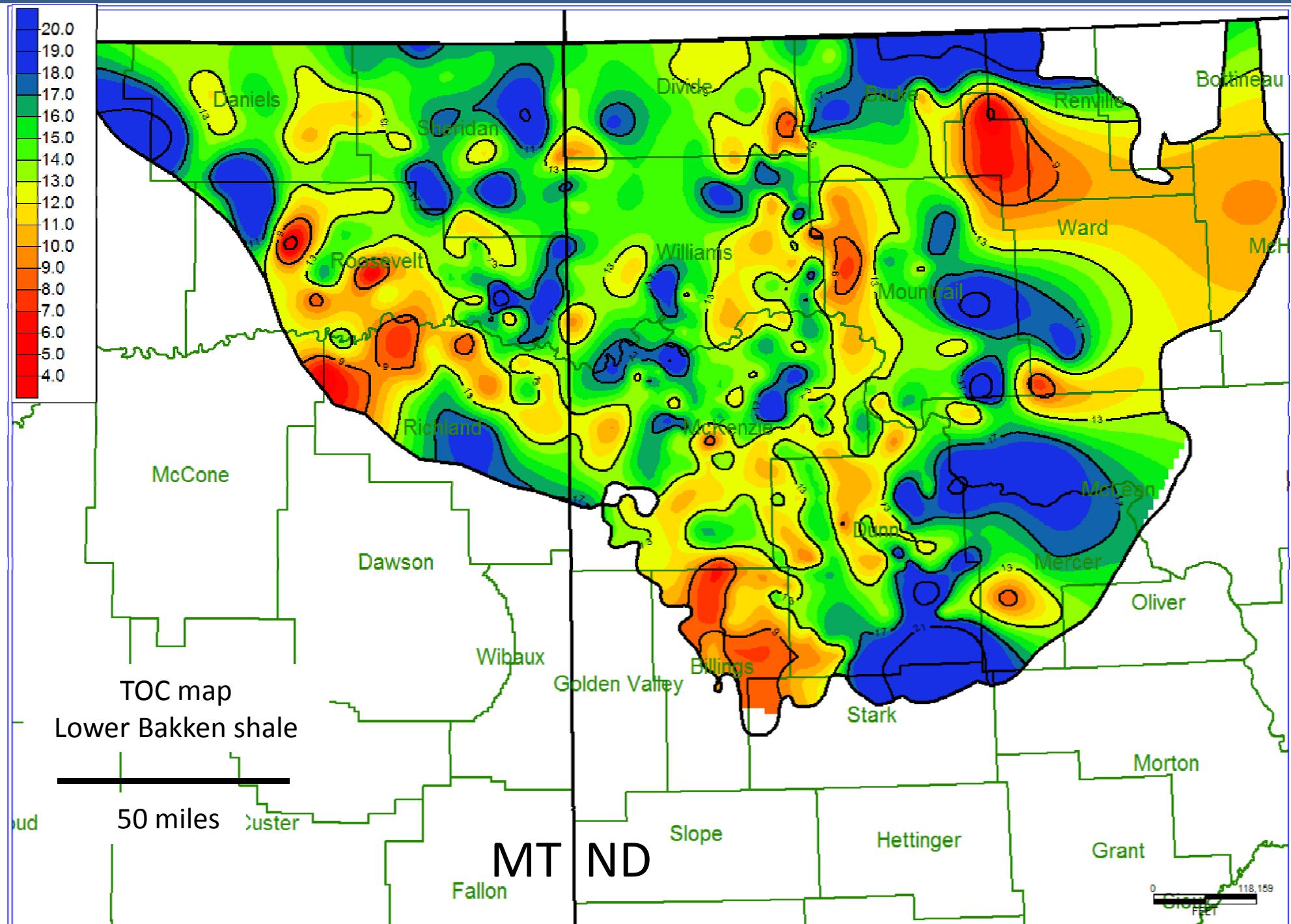
Isopach of lower Bakken shale



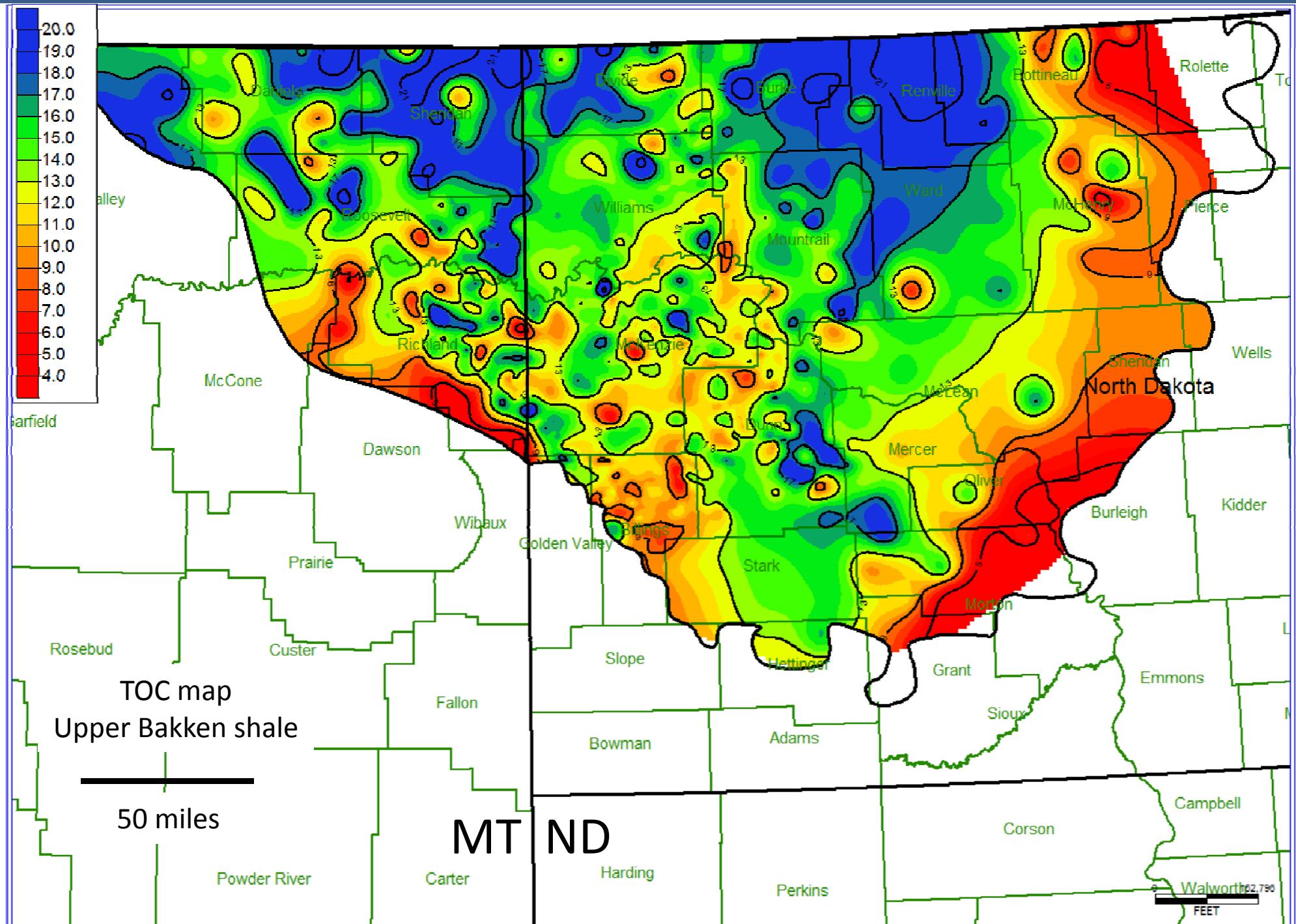
Isopach of upper Bakken shale



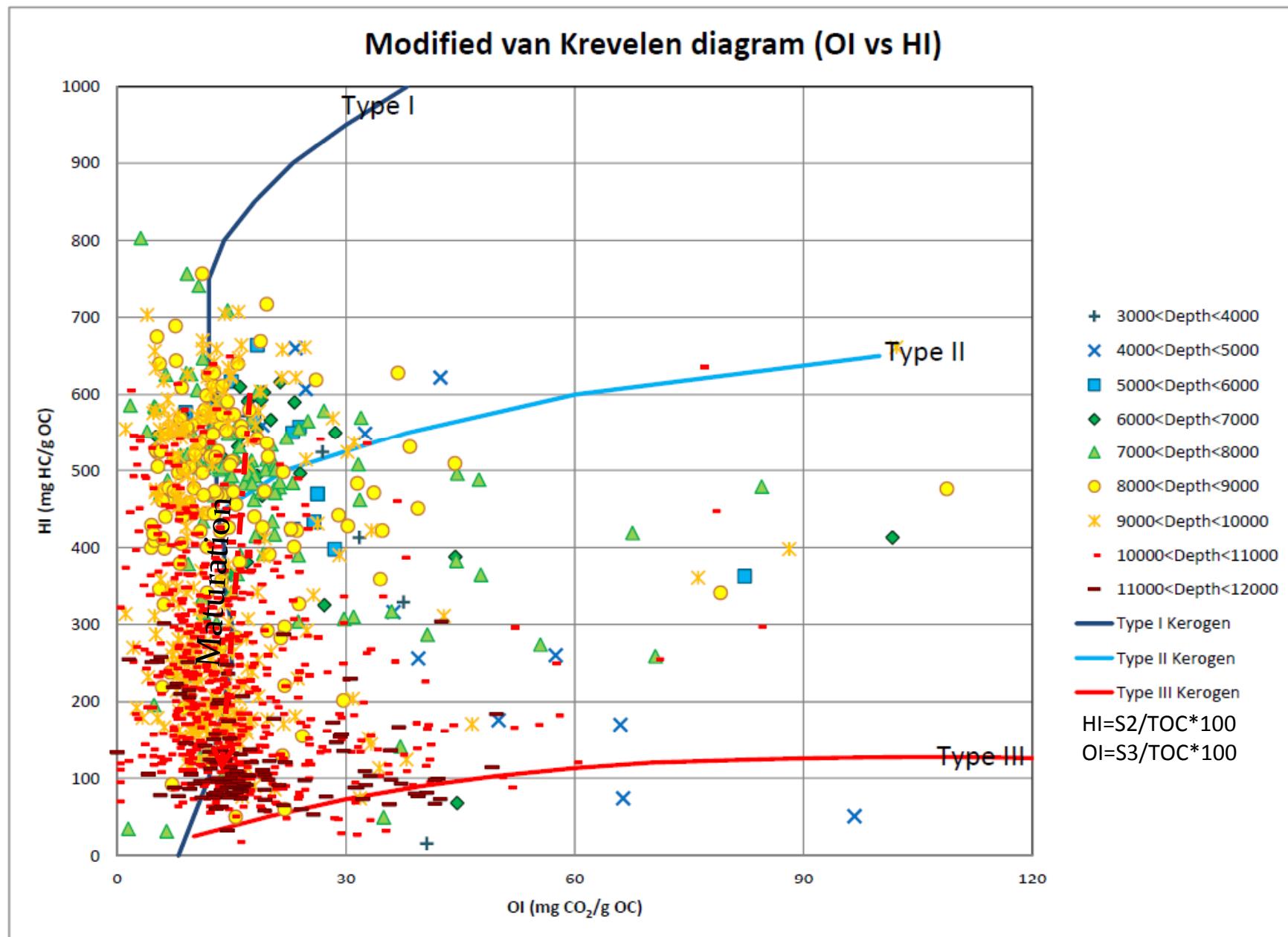
TOC map for lower Bakken shale



TOC map for upper Bakken shale

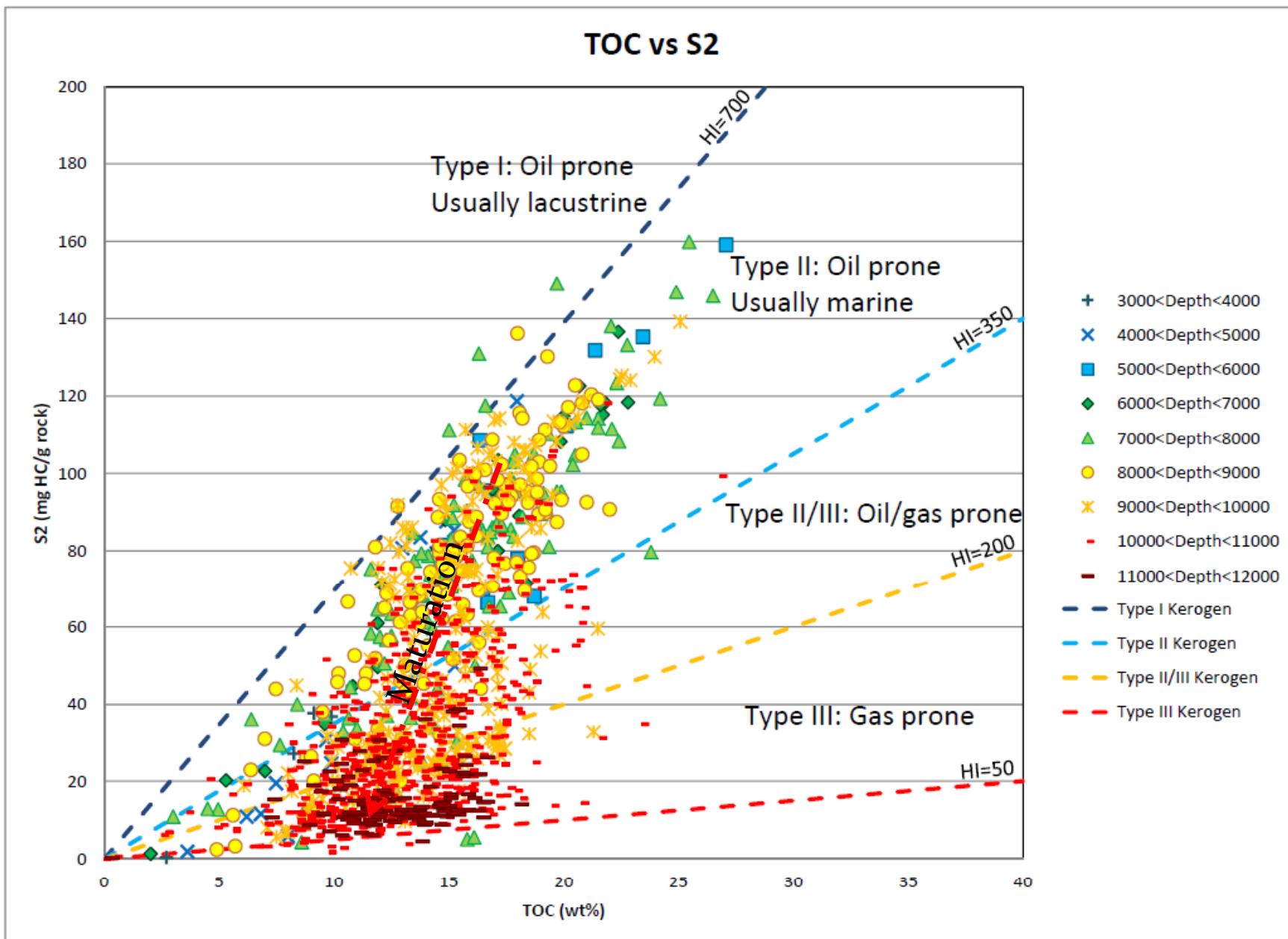


Kerogen type of Bakken shales



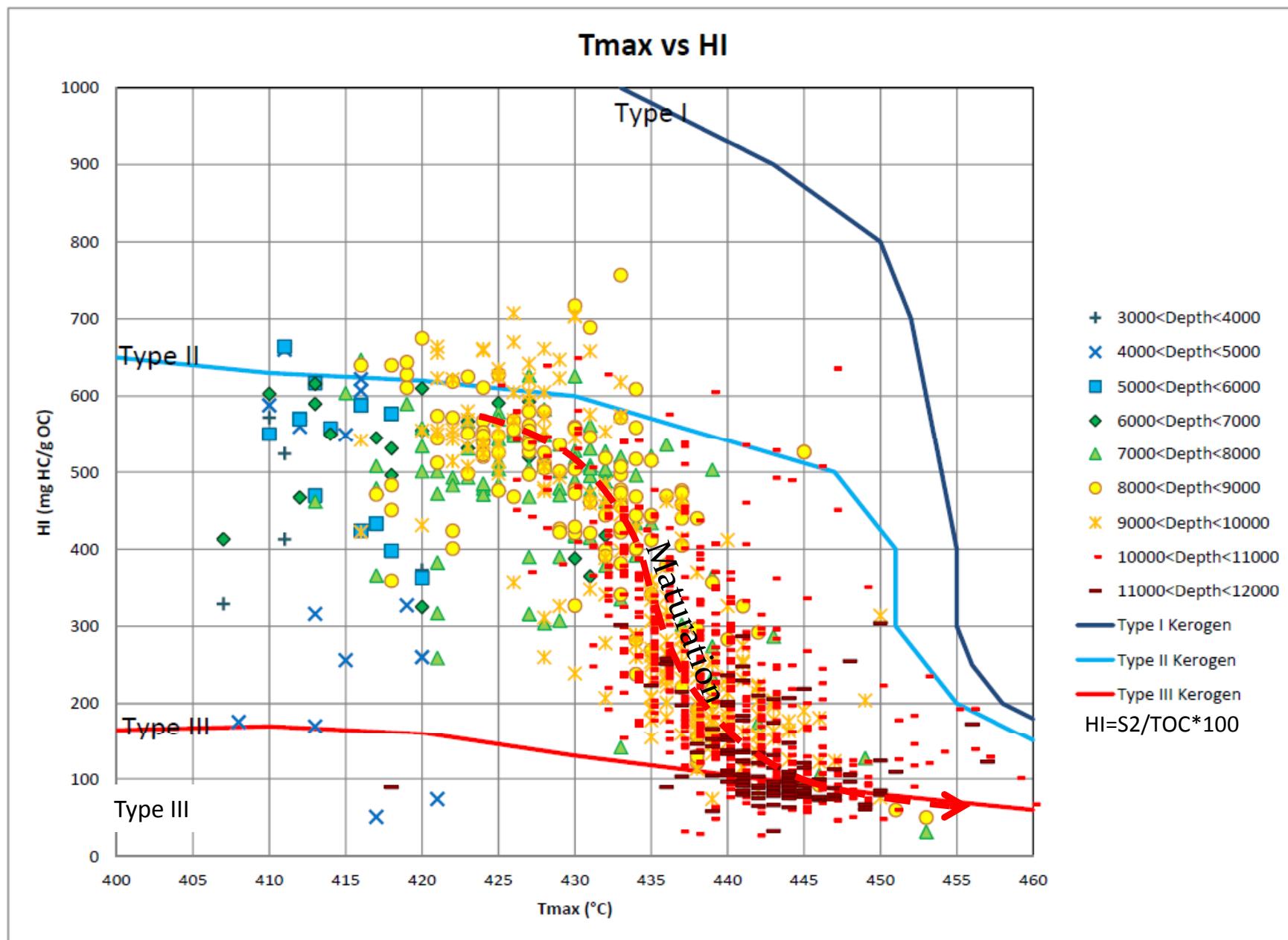


Kerogen type of Bakken shales

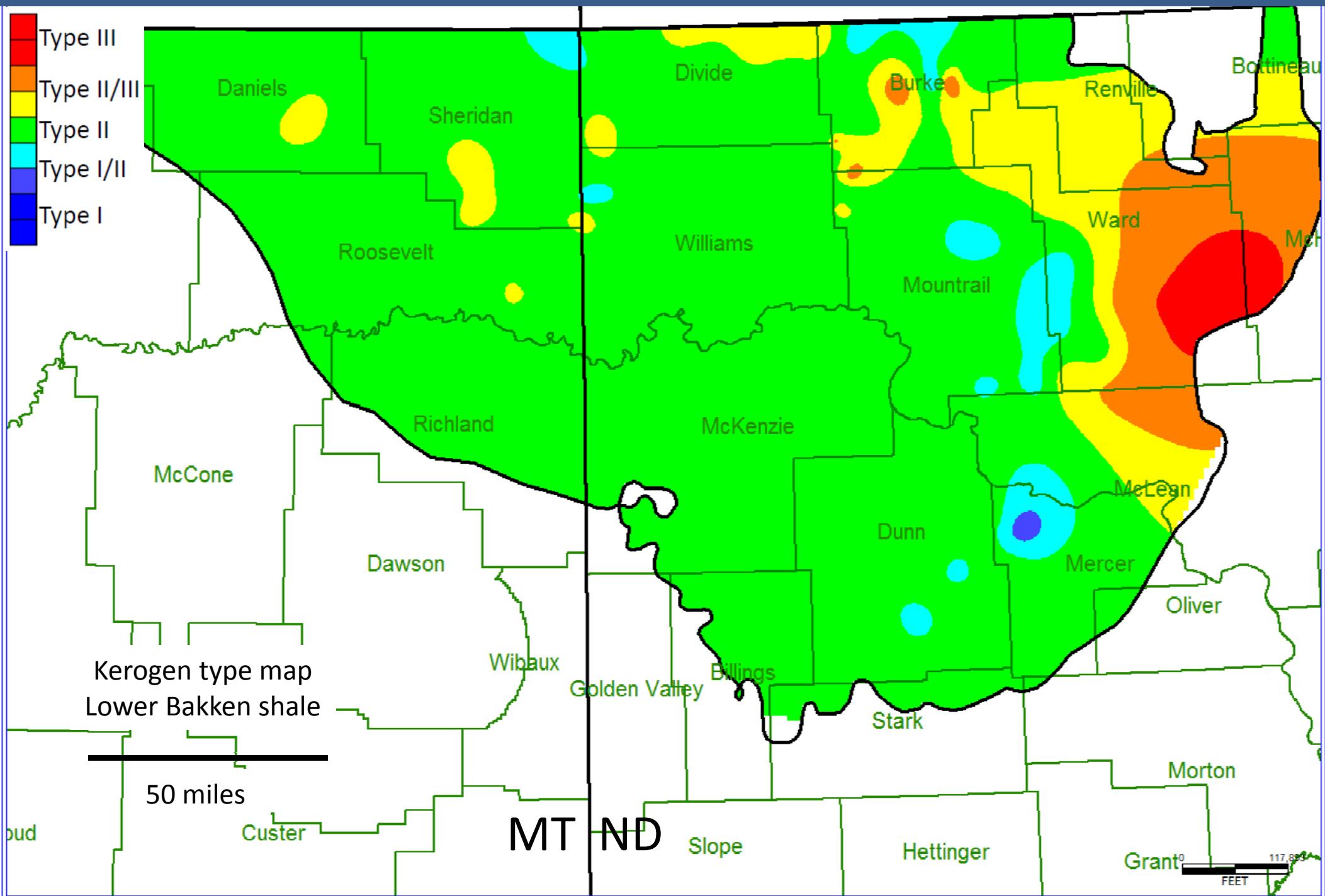




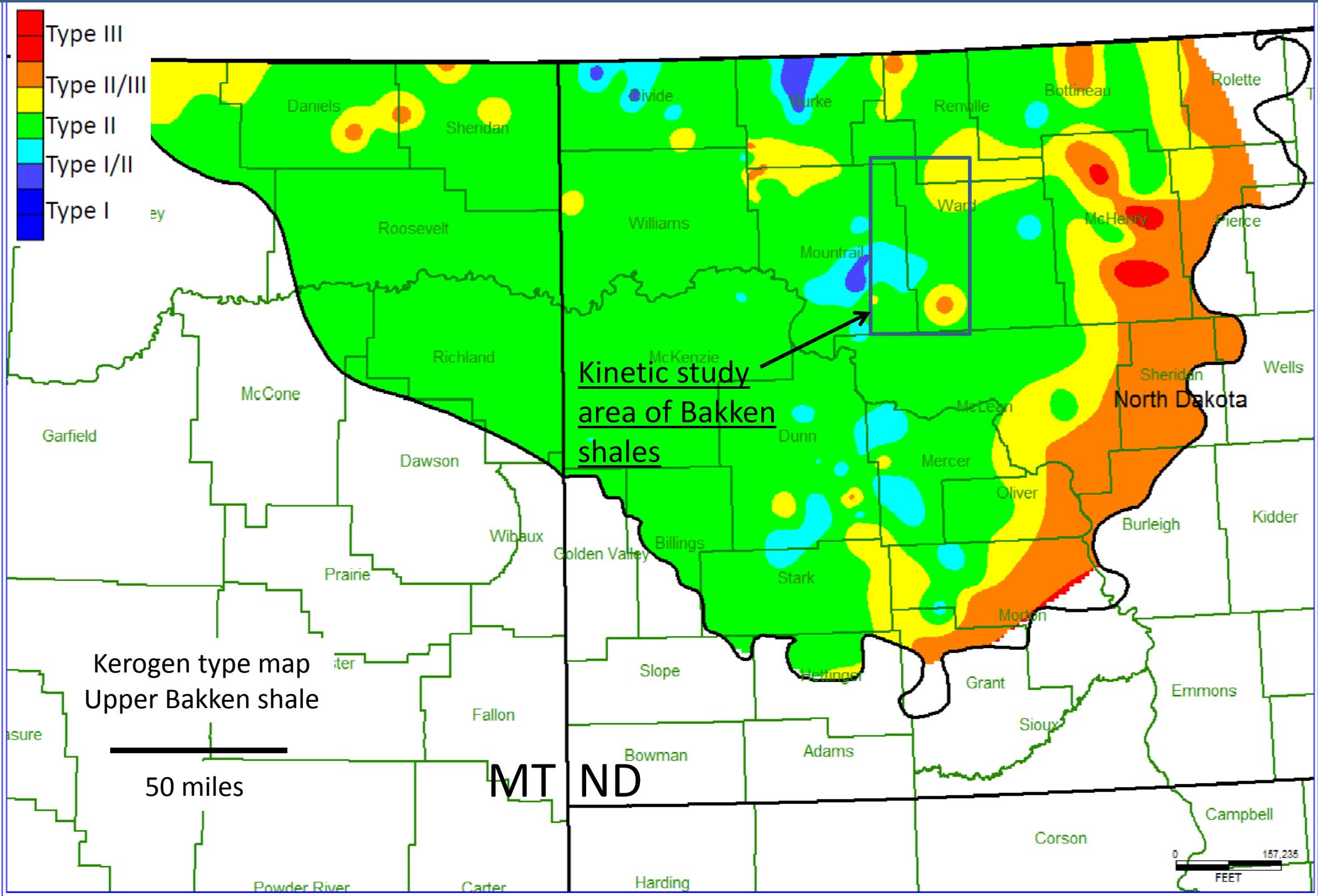
Kerogen type of Bakken shales



Kerogen type map for lower Bakken shale



Kerogen type map for upper Bakken shale



Kerogen kinetics of immature Bakken shales

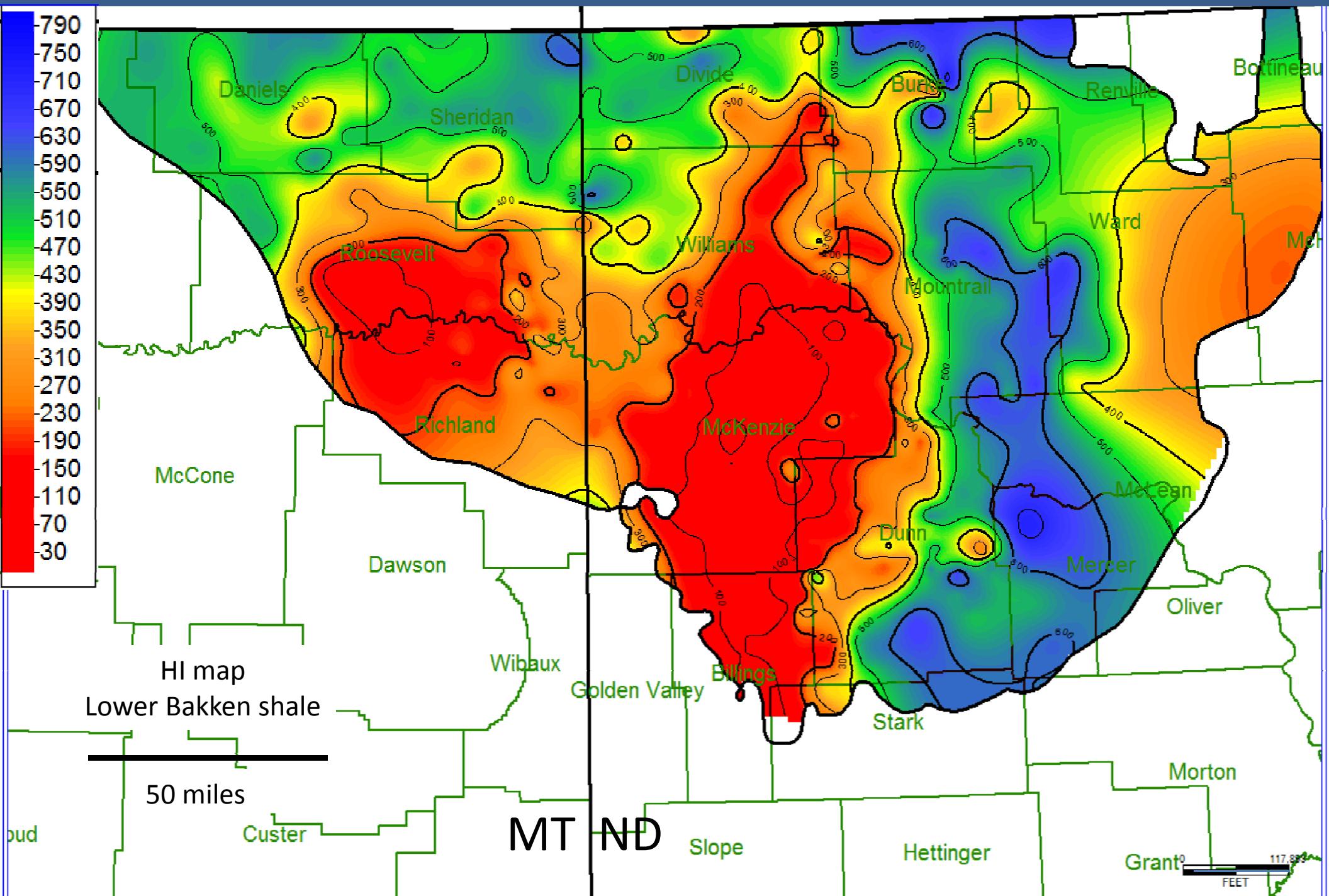


| Well Name | Formation | Depth | | TOC | HI | Ea (Kcal /mole) | Ao (1/m.y.) |
|--|------------------|-------|--------|-------|-----|-----------------|----------------|
| | | Top | Bottom | | | | |
| Pullen 1-33 | Upper Bakken Sh. | 7688 | 7688 | 17.43 | 511 | 56.49 | 1.2E+28 |
| Fertile 1-12H | Upper Bakken Sh. | 9365 | 9367 | 16.09 | 510 | 56.52 | 1.4E+28 |
| Jensen 12-44 | Upper Bakken Sh. | 9160 | 9170 | 18.05 | 485 | 56.58 | 1.4E+28 |
| Long 1-01H | Upper Bakken Sh. | 9315 | 9318 | 15.59 | 469 | 56.07 | 1.1E+28 |
| McAlmond 1-05H | Upper Bakken Sh. | 8818 | 8823 | 16.16 | 476 | 56.58 | 1.5E+28 |
| St Andes 13-1H | Upper Bakken Sh. | 9063 | 9079 | 17.36 | 459 | 55.33 | 6.5E+27 |
| Dobrinski 18-44 | Upper Bakken Sh. | 8629 | 8632 | 9.39 | 331 | 56.86 | 2.0E+28 |
| Dobrinski 18-44 | Upper Bakken Sh. | 8632 | 8637 | 17.04 | 472 | 54.83 | 5.1E+27 |
| Walter Waswick #1 | Upper Bakken Sh. | 7562 | 7569 | 11.35 | 337 | 58.91 | 8.1E+28 |
| Walter Waswick #1 | Upper Bakken Sh. | 7569 | 7574 | 18.08 | 465 | 57.09 | 3.2E+28 |
| Averaged kinetics of upper Bakken Shale | | | | | | 56.43 | 1.8E+28 |

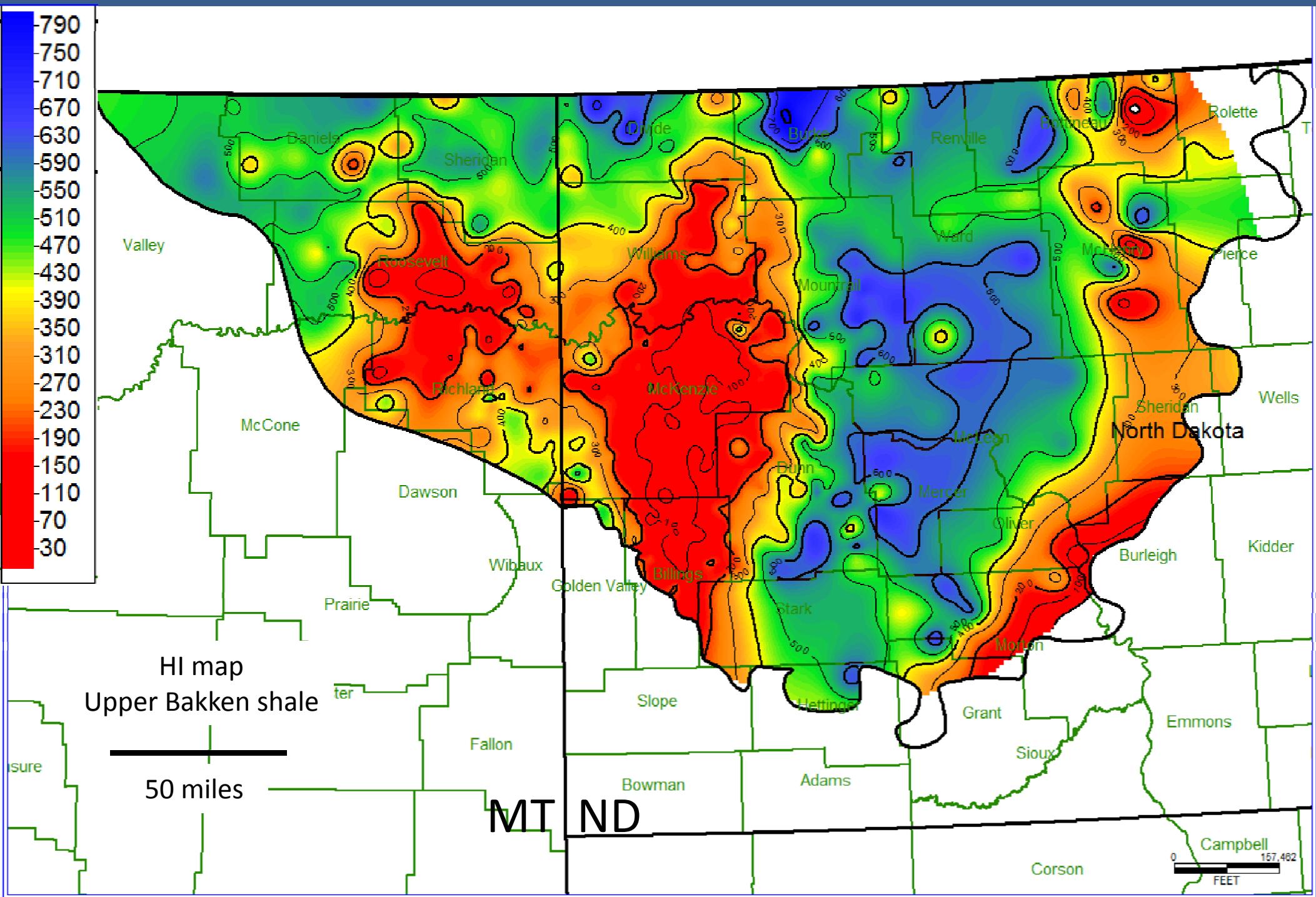
Upper Bakken shale very similar with lower Bakken shale

| Well Name | Formation | Depth | | TOC | HI | Ea (Kcal /mole) | Ao (1/m.y.) |
|--|------------------|-------|--------|-------|-----|-----------------|----------------|
| | | Top | Bottom | | | | |
| Pierce 1-18 | Lower Bakken Sh. | 6785 | 6790 | 5.76 | 31 | 57.51 | 2.1E+28 |
| Fertile 1-12H | Lower Bakken Sh. | 9401 | 9422 | 17.5 | 463 | 57.29 | 2.2E+28 |
| Jensen 12-44 | Lower Bakken Sh. | 9207 | 9216 | 17.31 | 446 | 56.59 | 1.3E+28 |
| Long 1-01H | Lower Bakken Sh. | 9375 | 9400 | 19.47 | 483 | 56.31 | 1.2E+28 |
| McAlmond 1-05H | Lower Bakken Sh. | 8855 | 8871 | 18.07 | 468 | 57.08 | 1.9E+28 |
| St Andes 13-1H | Lower Bakken Sh. | 9110 | 9129 | 16.91 | 462 | 55.87 | 9.1E+27 |
| Averaged kinetics of lower Bakken Shale | | | | | | 56.78 | 1.6E+28 |

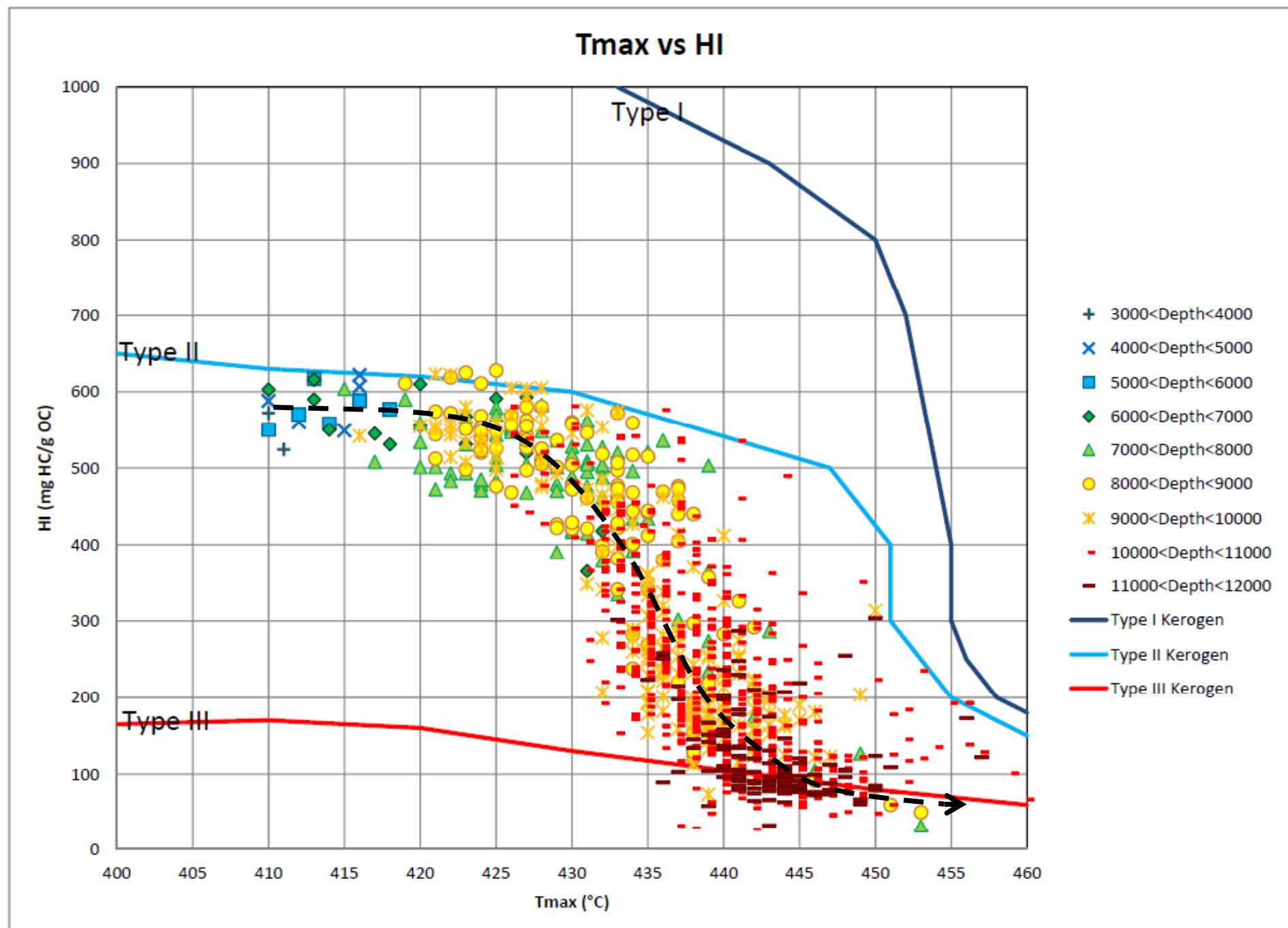
HI map for lower Bakken shale



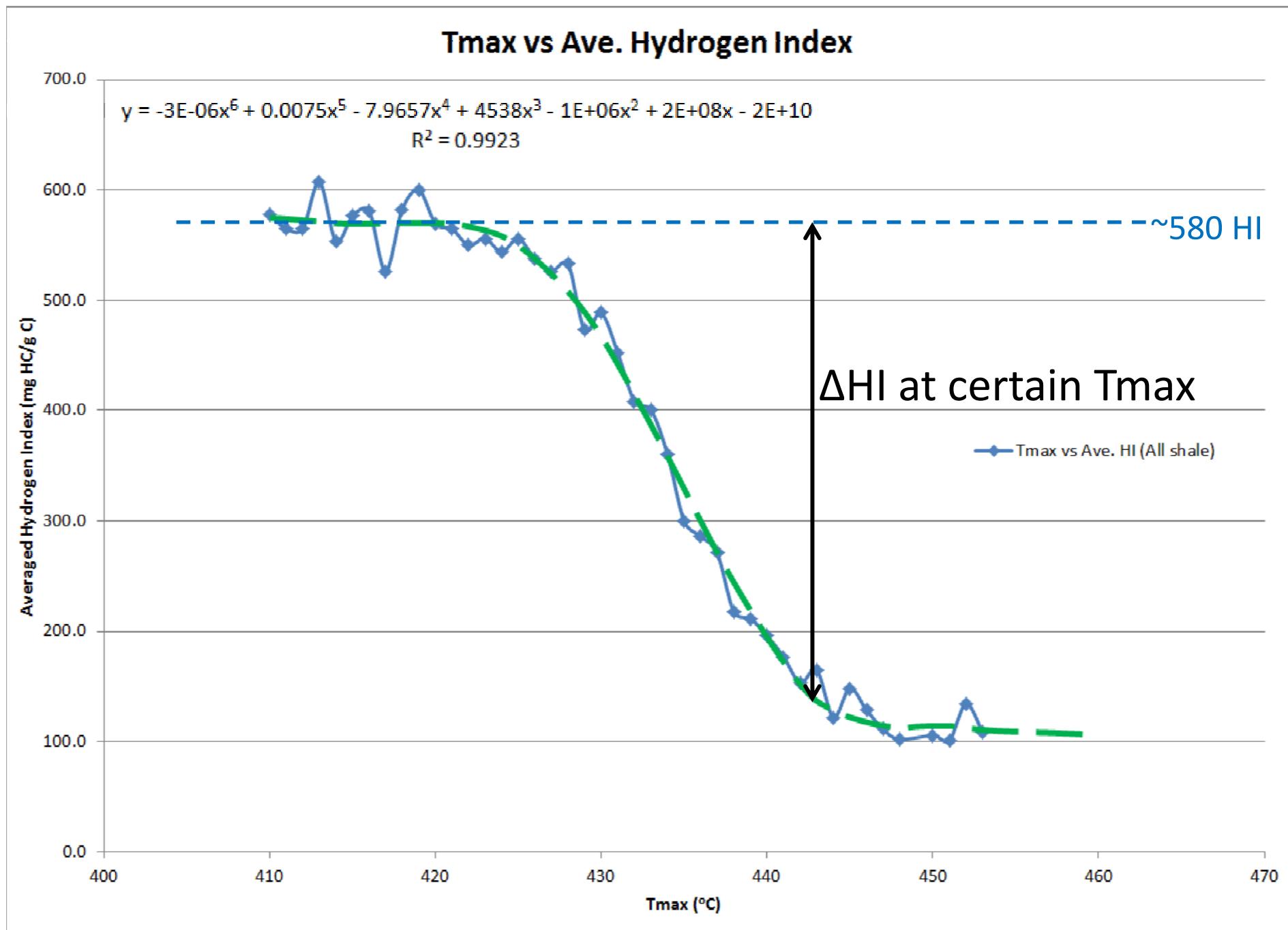
HI map for upper Bakken shale



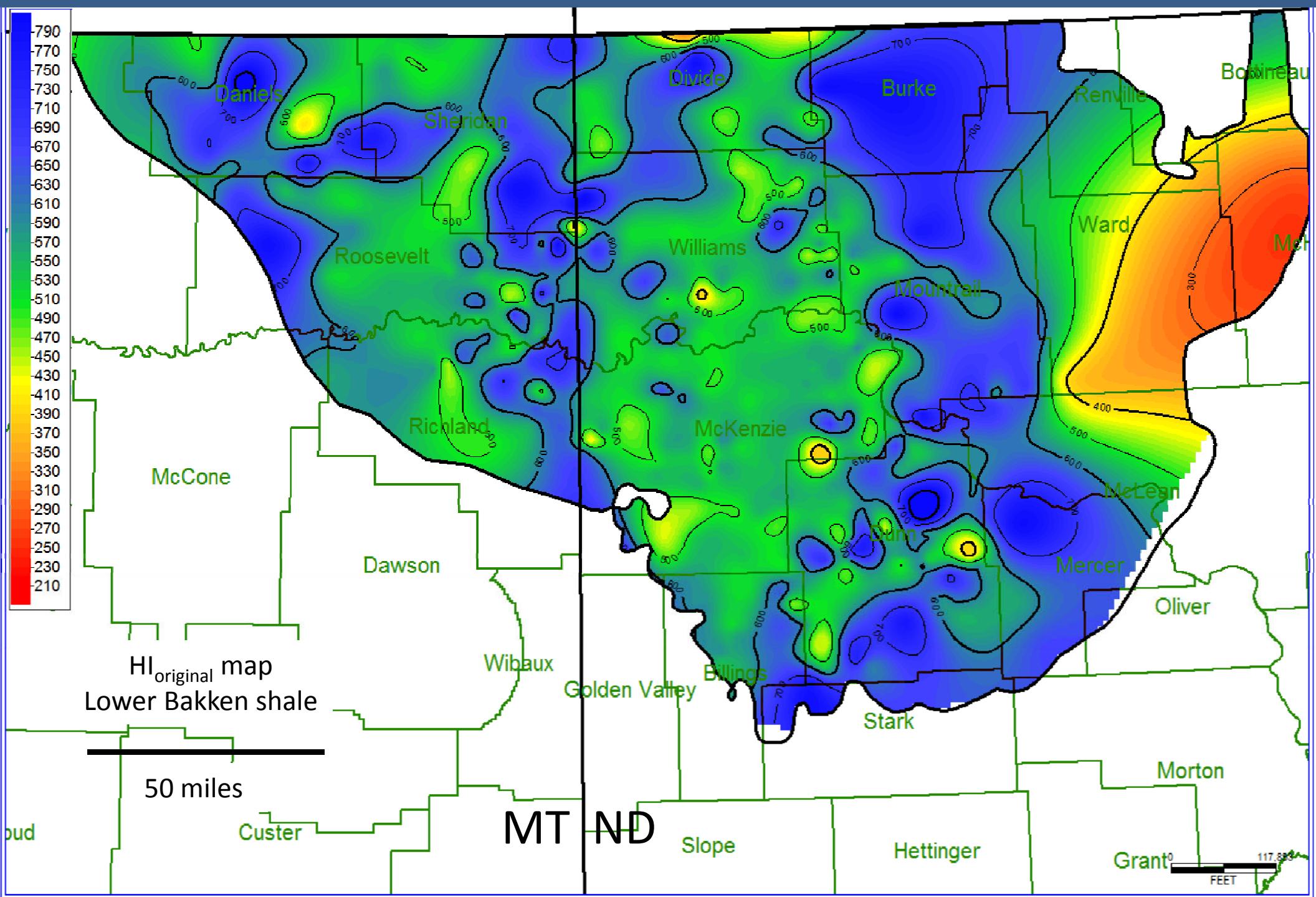
Maturation of Type II kerogen Bakken shale



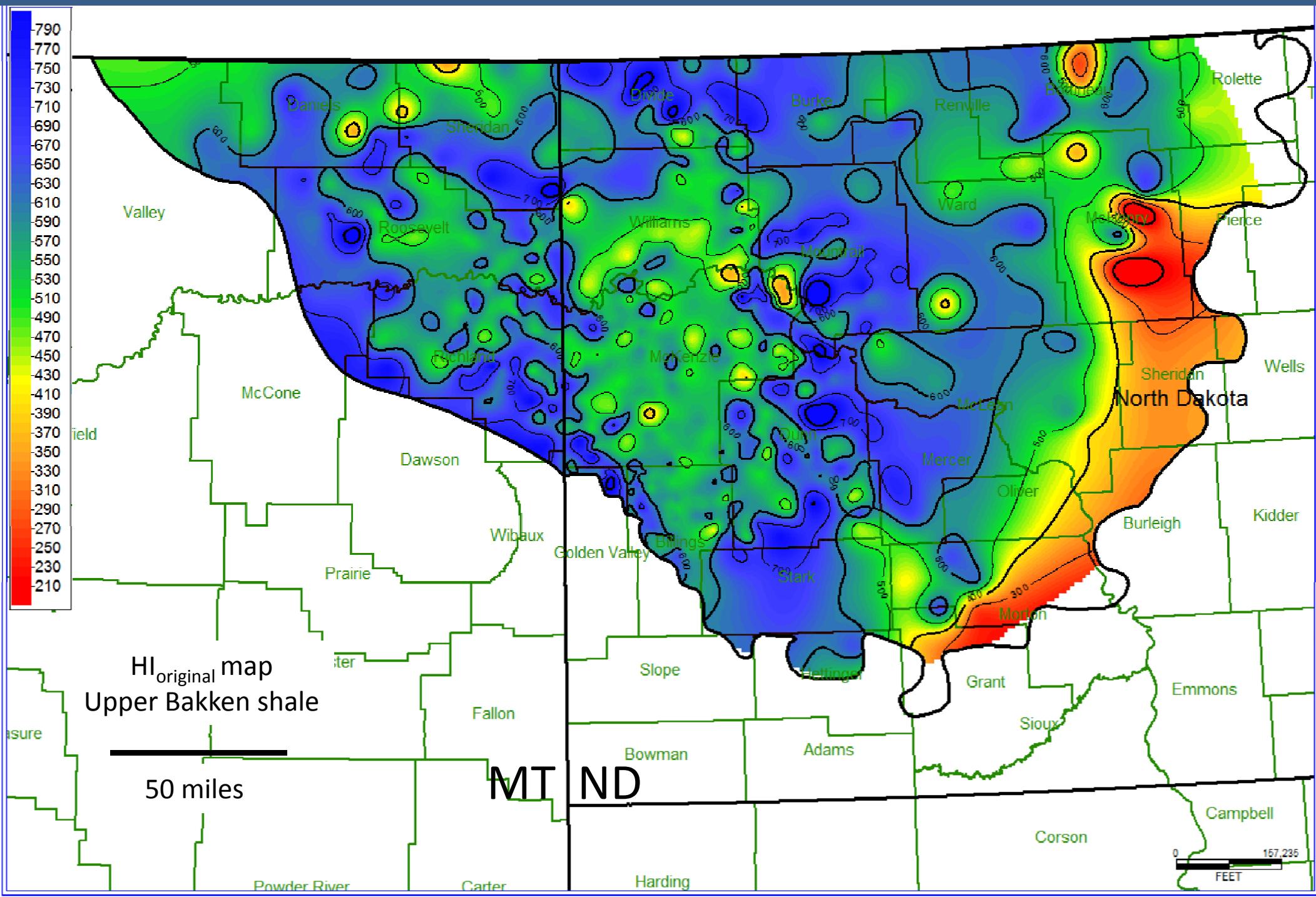
Averaged HI for Type II kerogen Bakken shale



HI_{original} map for lower Bakken shale



HI_{original} map for upper Bakken shale





Equation for conversion fraction (f)

Equation from Peters et al. (2005):

$$f = \frac{1 - HI_x * \left\{ 1200 - \left[\frac{HI_o}{1 - PI_o} \right] \right\}}{HI_o * \left\{ 1200 - \left[\frac{HI_x}{1 - PI_x} \right] \right\}}$$

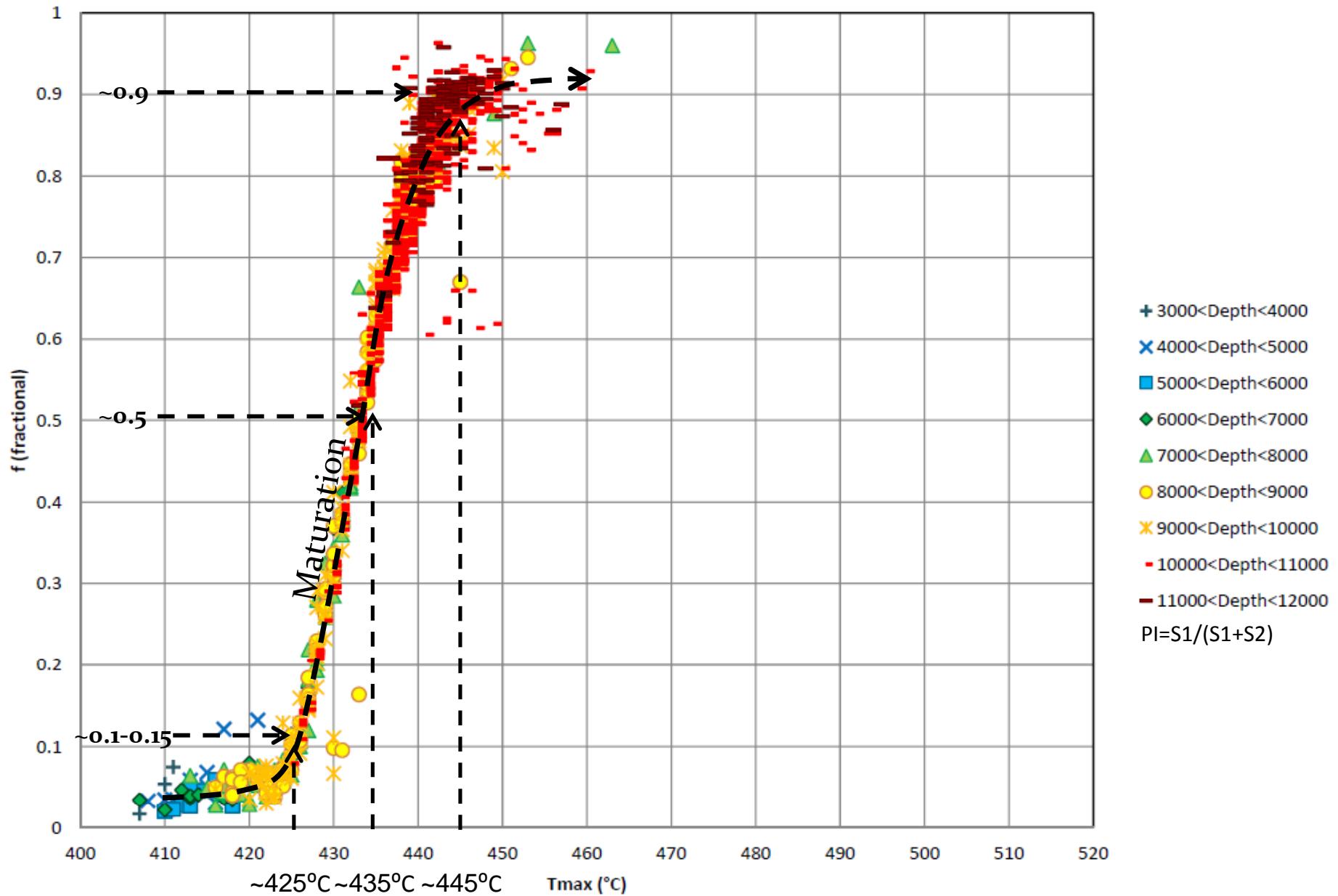
where f is conversion fraction of kerogen to petroleum; HI_x and HI_o represents present-day and original HI, respectively; PI_x and PI_o represents present-day and

original PI, respectively, and PI_o assumed to be 0.03.

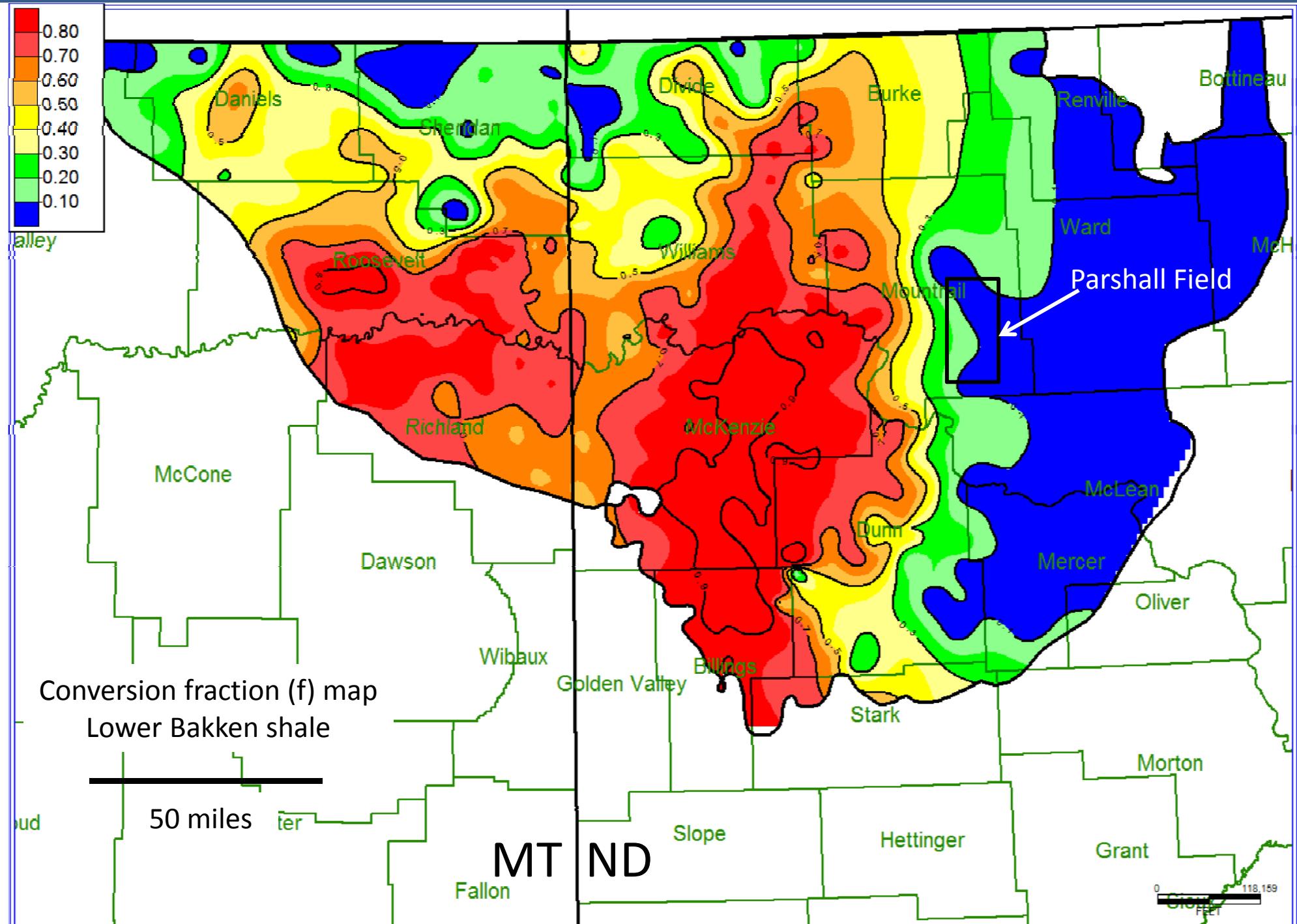
Maturity and oil generation



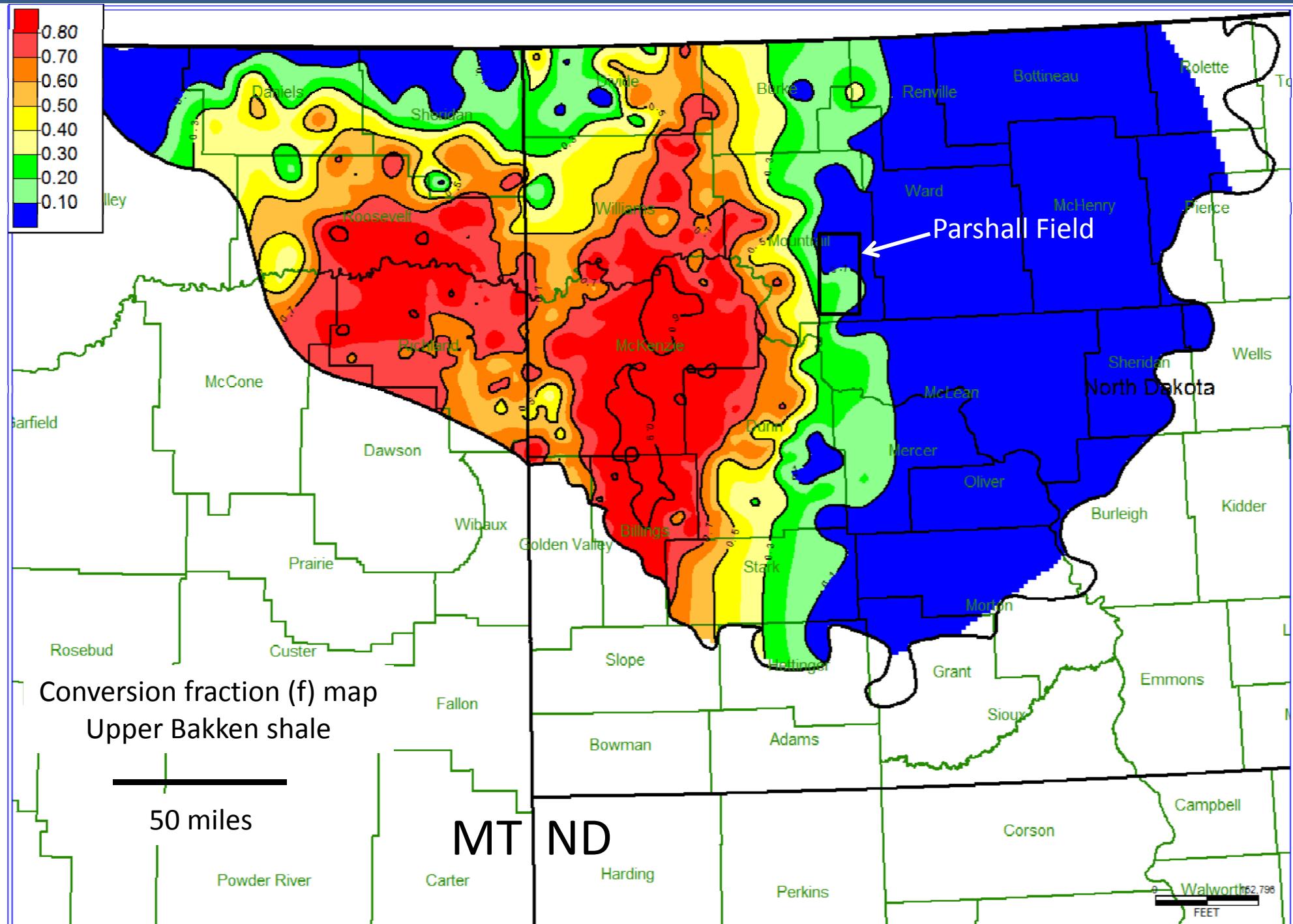
Tmax vs Fractional conversion (f, of kerogens to petroleum)



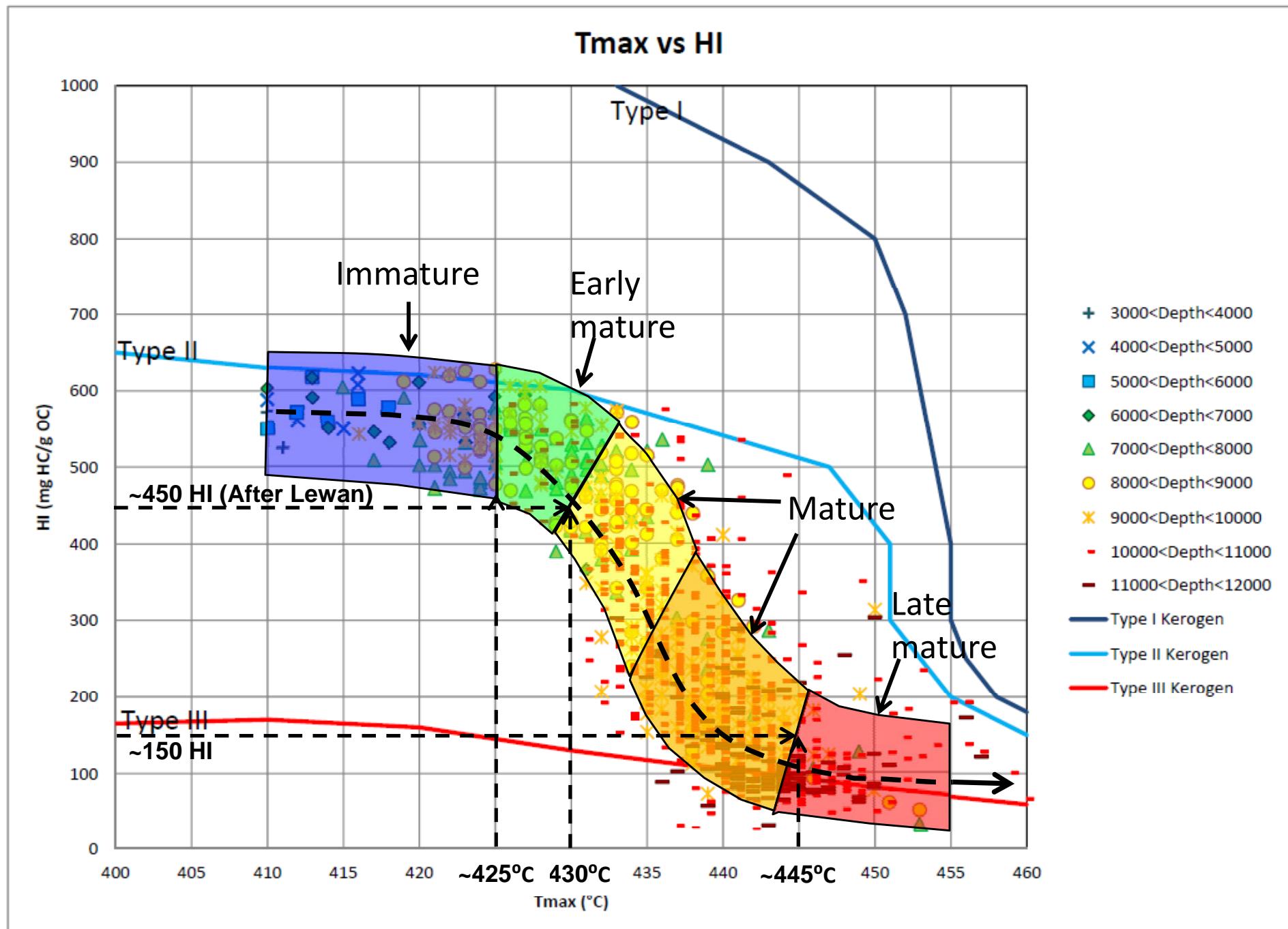
f map for lower Bakken shale



f map for upper Bakken shale

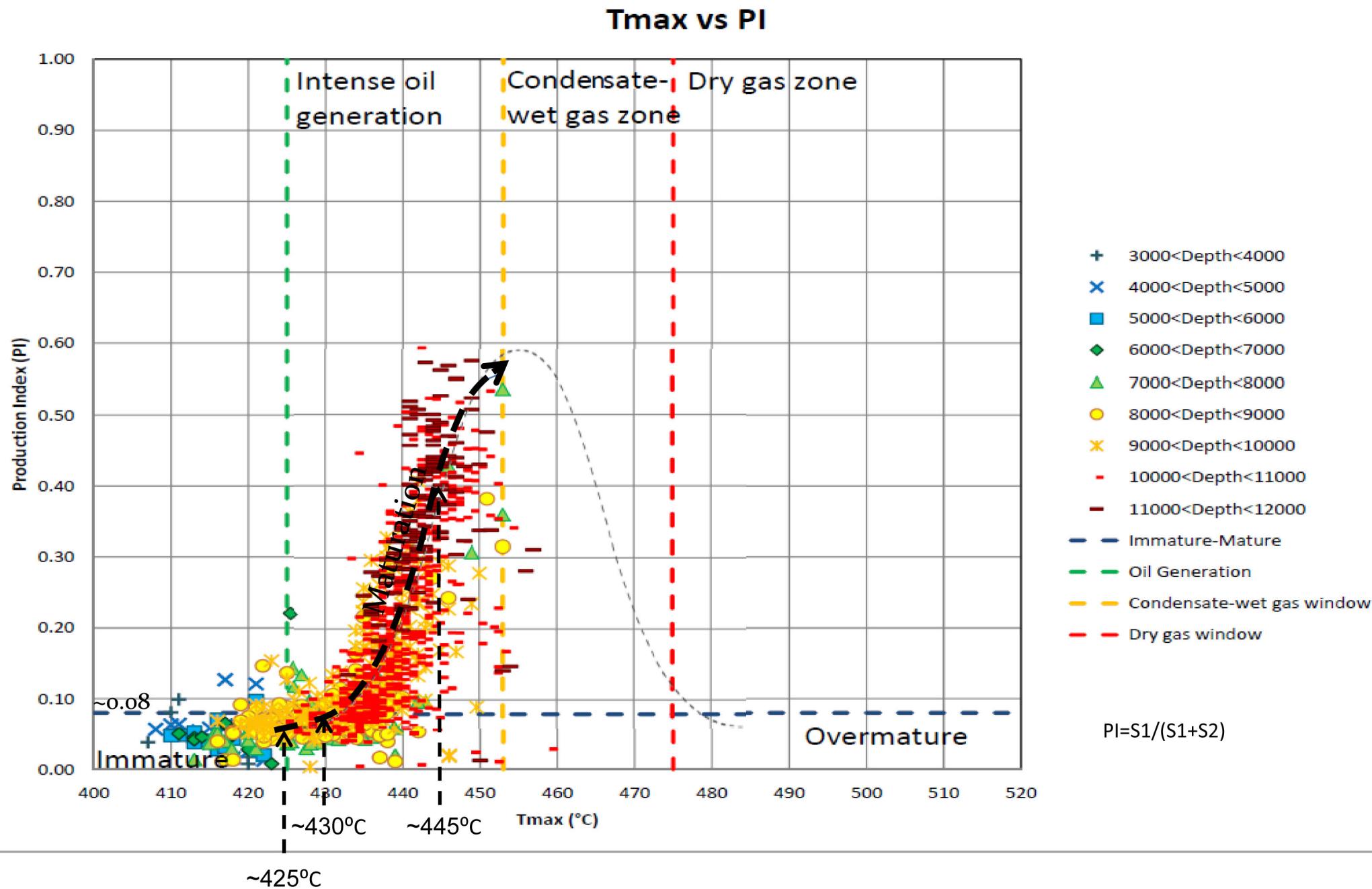


Maturation trend of Type II kerogen Bakken shale

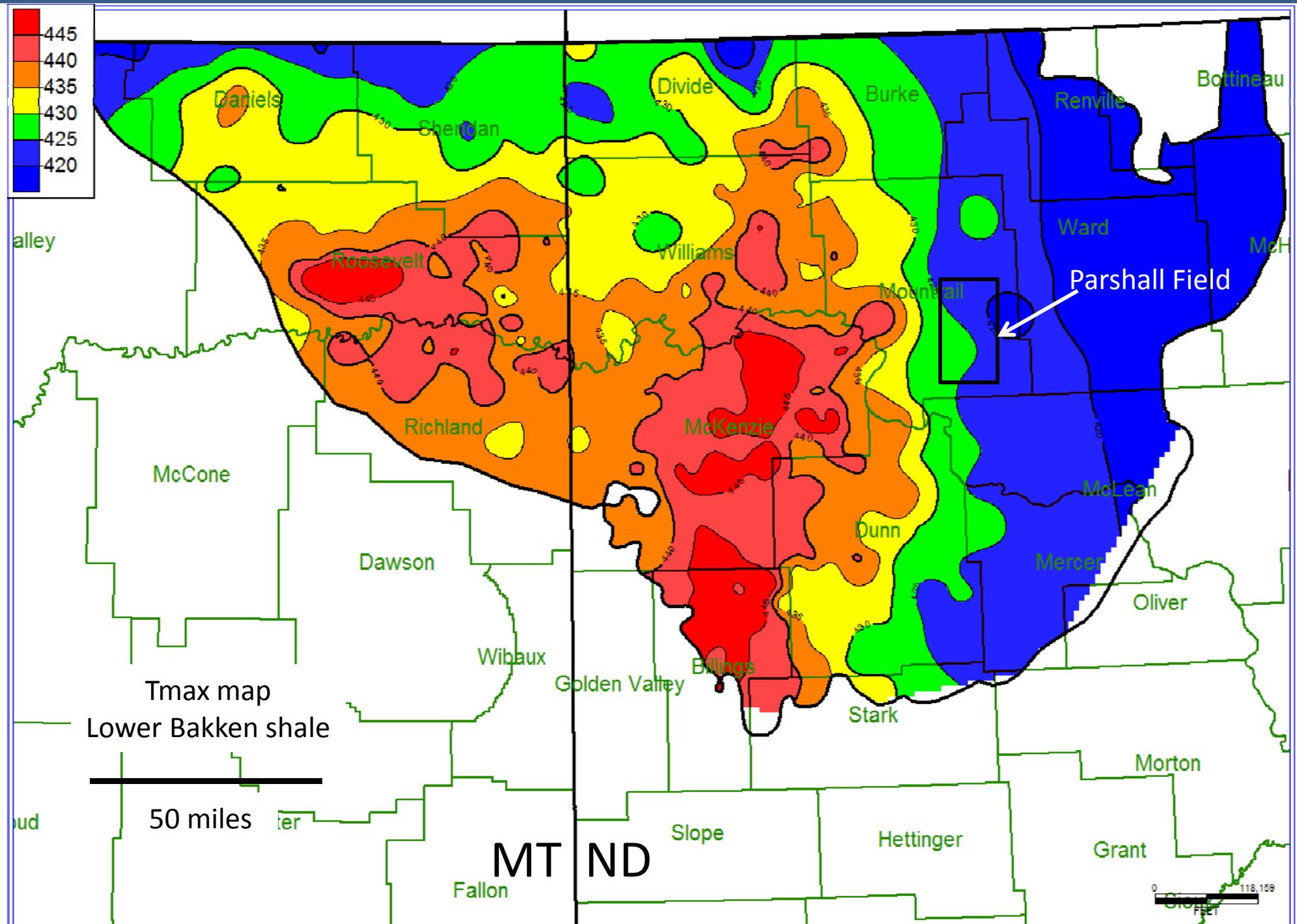




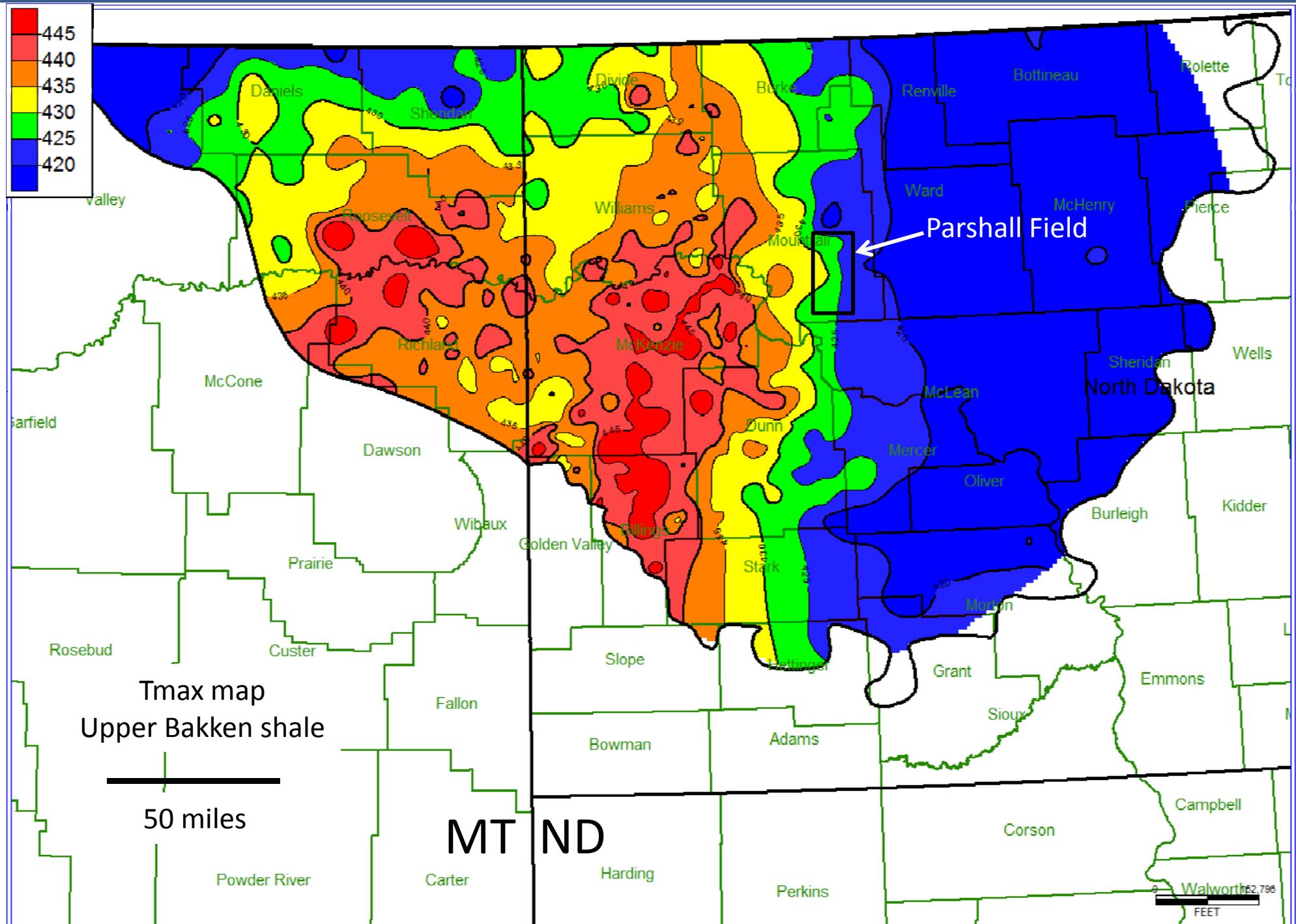
Maturity and oil generation



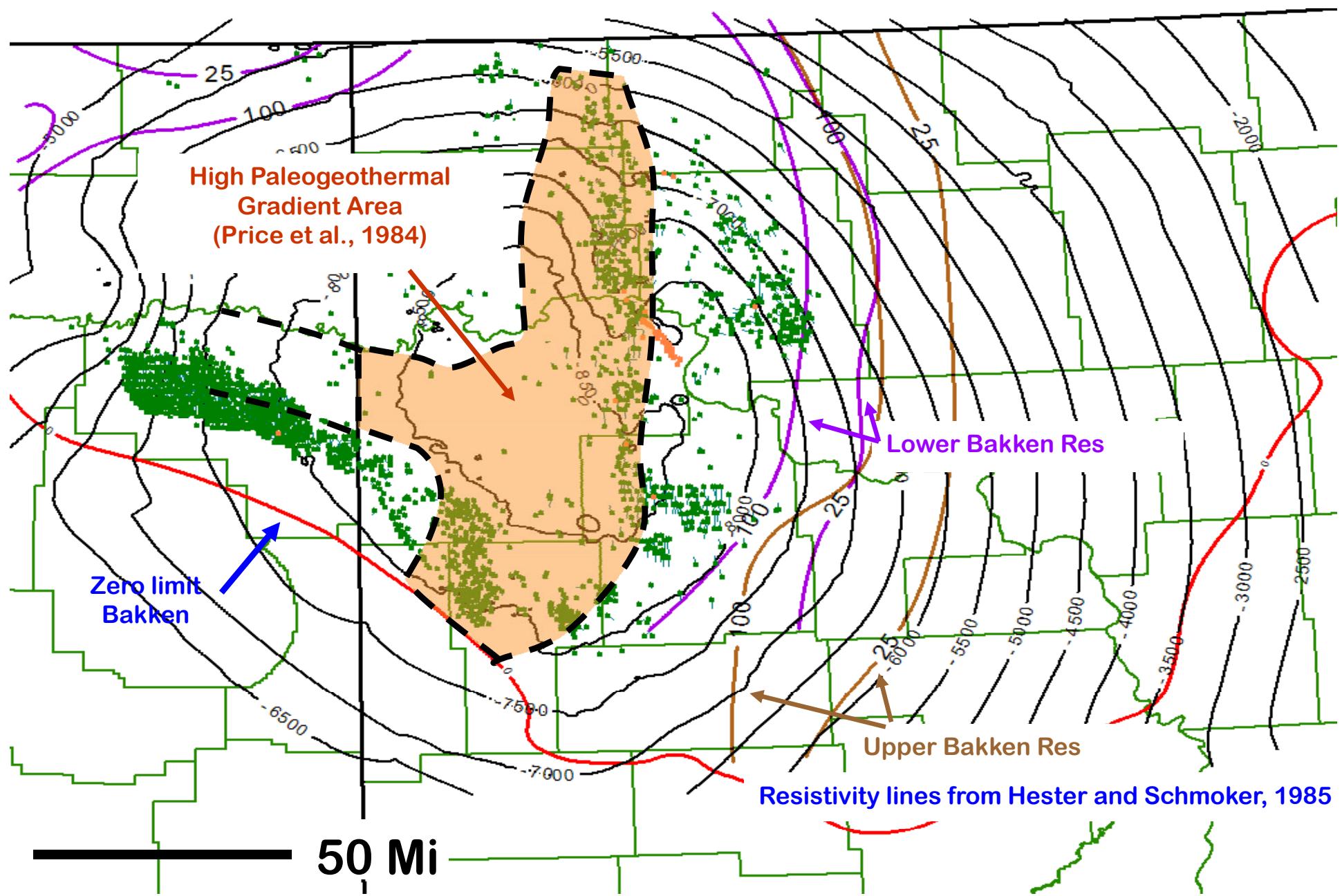
Tmax map for lower Bakken shale with thresholds



Tmax map for upper Bakken shale with thresholds

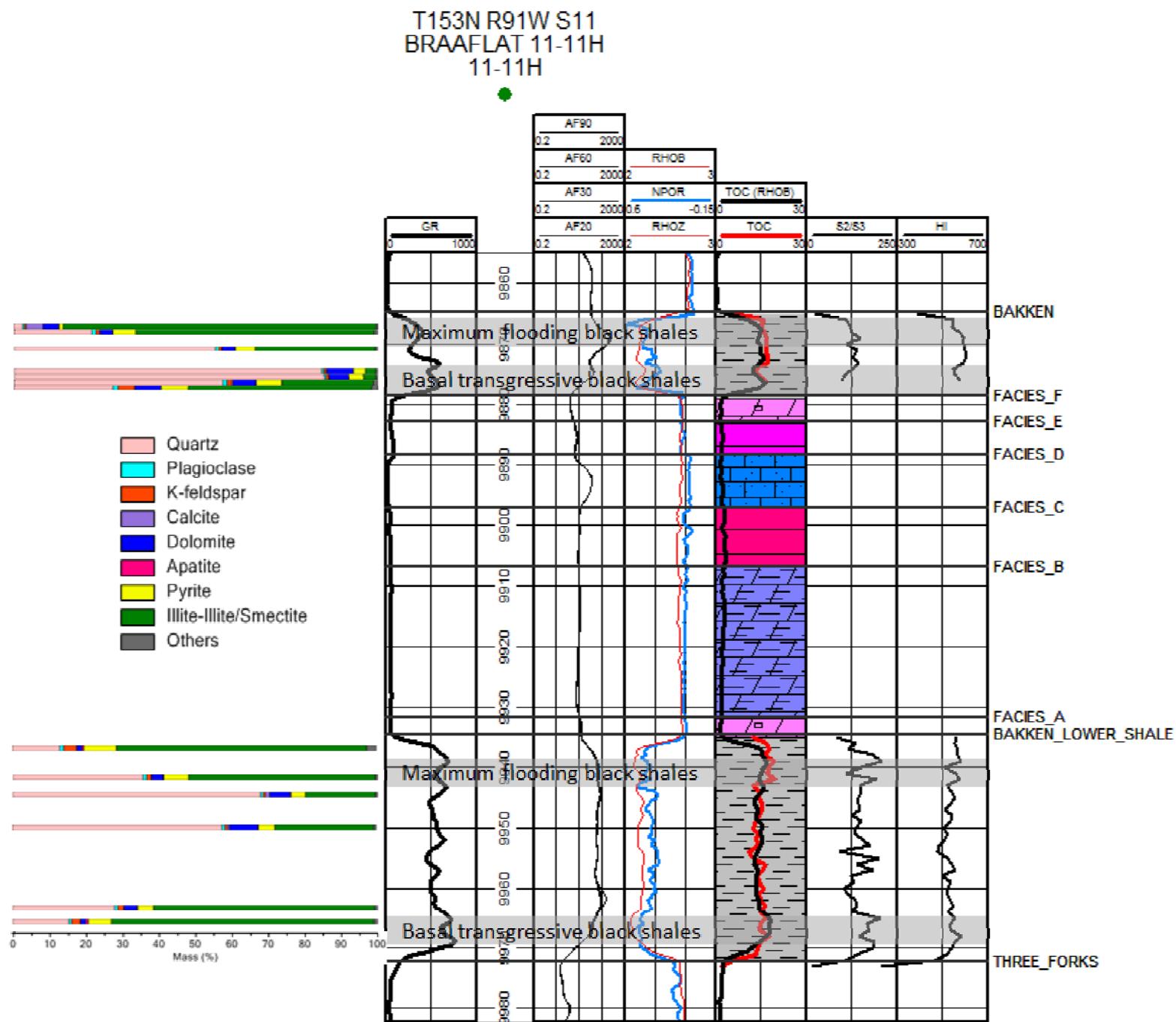


Different paleo-geothermal gradients in basin





Stratigraphy of Bakken shales





Maturity variation of Bakken shales

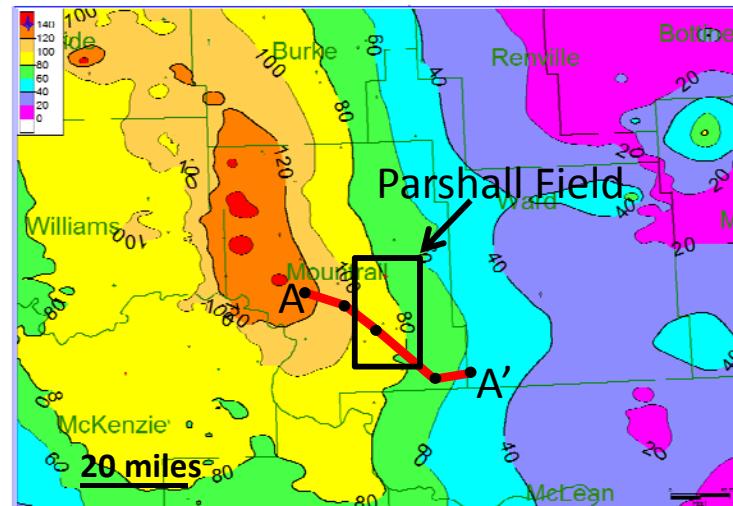
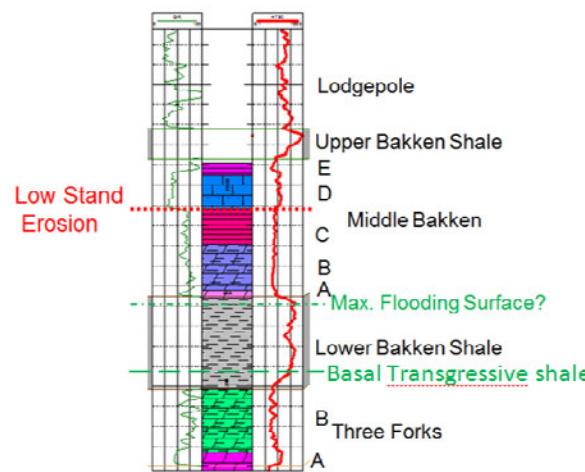
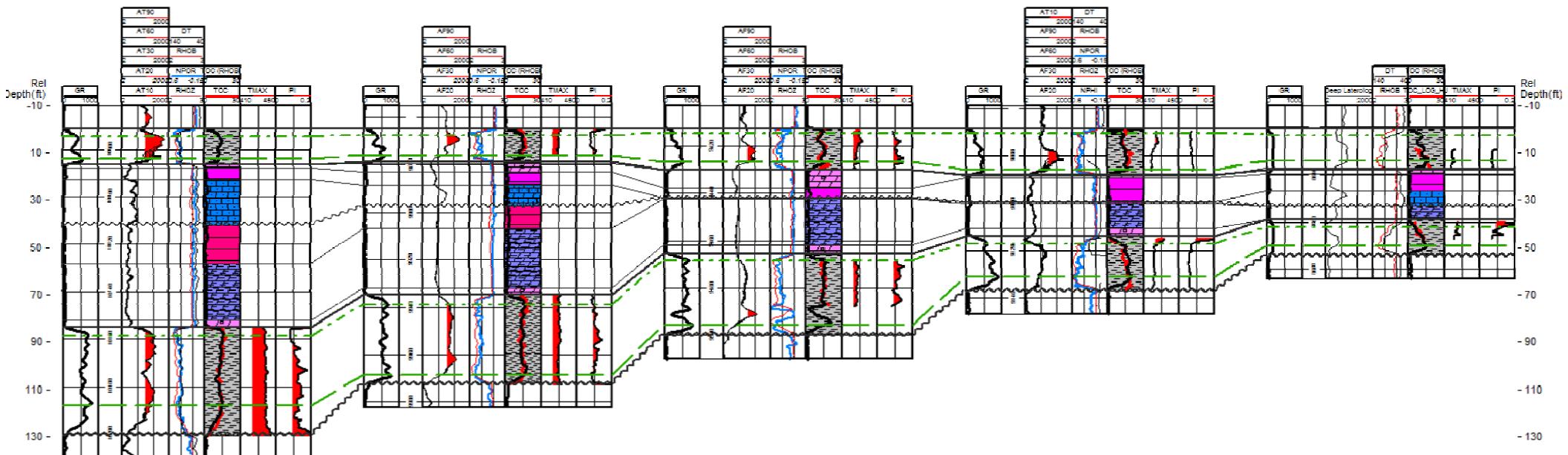
Deadwood Canyon
Ranch 43-28H

Braaflat 11-11H

N&D 1-05H

St Andes-151-89
2413H-1

Dobrinski
18-44



The cutoff for resistivity log is set at 75 ohm-m, the one for Tmax is 425 °C, and the one for PI is 0.1.

Conclusions



- High lateral and vertical TOC variation in Bakken shales;
- Bakken Shale kerogen type: mainly mixed Type I and Type II in deep basin, Type II/III in shallower parts of basin; Bakken shales also having vertical heterogeneity;
- Two kinds of shales classified for Bakken shales: basal transgressive black shales and maximum flooding black shales;
- Bakken shales in the Parshall Field with same organic matter;
- Thresholds for initial bitumen and oil generation in the Bakken: ~ 425°C Tmax, ~ 0.08 PI, and 0.1~0.15 f;
- Main oil window: 430~445°C Tmax; thresholds for intense oil generation: ~ 435°C Tmax, 0.15~0.25 PI, and ~ 0.5 f;
- Maturity: the primary control on oil generation and expulsion.

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- Mike Lewan (USGS)
- John Curtis (CSM)



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 **MarathonOil**

 **HEP**

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