

Oil Generation Rates and Subtle Structural Flexure: Keys to Forming the Bakken Sweetspot in the Parshall Field of Mountrail County, North Dakota*

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Search and Discovery Article #20094 (2010)

Posted October 22, 2010

*Adapted from oral presentation at AAPG Rocky Mountain Section 58th Annual Rocky Mountain Rendezvous, Durango, Colorado, June 13-16, 2010

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Abstract

The recent discovery of several 1000 bbl/d oil wells in the Parshall Field in Mountrail County, North Dakota has focused significant attention on the geologic factors that contribute to this extraordinary production. The Bakken Formation in Mountrail County contains organic-rich upper and lower shales with an intervening mixed carbonate-siliciclastic middle member. The shales contain an average of 11% organic carbon and, together with algal-derived kerogen in the middle member, are believed to be the source of the oil produced at Parshall. The carbonate-siliclastic middle member acts as the reservoir in which natural and artificial fractures provide conduits for oil along horizontal well bores drilled through the tight middle member. The “sweetspot” present in the Parshall Field appears to be related to overpressuring caused by oil generation, induced shale compaction, and the formation of fractures along a subtle structural flexure.

The Parshall Field lies adjacent to, and updip of, a north-south trending organic maturation front that is evidenced by a regional-scale decline in the average hydrogen index (HI) of the Bakken shales. The zone of maximum rate of change in the HI corresponds with a T_{\max} of about 435°C and is therefore interpreted to define the region in which oil-generation rates within the Bakken shales are at a maximum. This is significant because the conversion of load-bearing kerogen to movable oil could result in compaction that injects overpressured fluids into the middle member. Elevated pore pressures in the middle member could also lead to spontaneous fracturing in response to tectonic stresses that form localized structures.

The Bakken Formation in the Parshall Field is significantly overpressured (~6300 psi) and exhibits a subtle monoclinal flexure (convex upward) that is evident on 2nd derivative maps of the Bakken structure and highly exaggerated cross sections made from well data and seismic lines. The flexure appears related to basement faulting that was episodically active until, at least, the Jurassic.

These observations are consistent with a model of maturation-induced compaction that generates pore pressures, which together with stresses associated with subtle local structures, result in significant fracturing and the formation of a “sweetspot” centered in the Parshall Field.

**Presenter’s Notes Accompanying Page 10 of 27 (Slide 8 of 25 with title
“Hydrogen Index as a Function of Depth”)**

Hydrogen index obtained from Rock eval data.

Measure of the potential amount of hydrocarbons present in a rock.

Data are individual analyses.

Grouped into 1000 foot intervals and averaged.

Plotted as diamonds.

HI is constant to a depth of approximately 9000 ft.

HI diminishes with depths below 9000 ft.

If HI was originally constant across the basin, then change in HI indicates the loss of kerogen through maturation to oil.

Reference

Murray, G.H., Jr., 1968, Quantitative fracture study. Sanish pool, McKenzie County, North Dakota: AAPG Bulletin. v. 52, p. 57-65.

Website:

Core photo: <https://www.dmr.nd.gov/oilgas/>

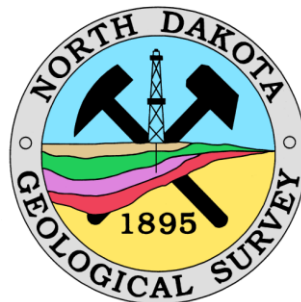
Bakken and Three Forks Formation

GI-4,

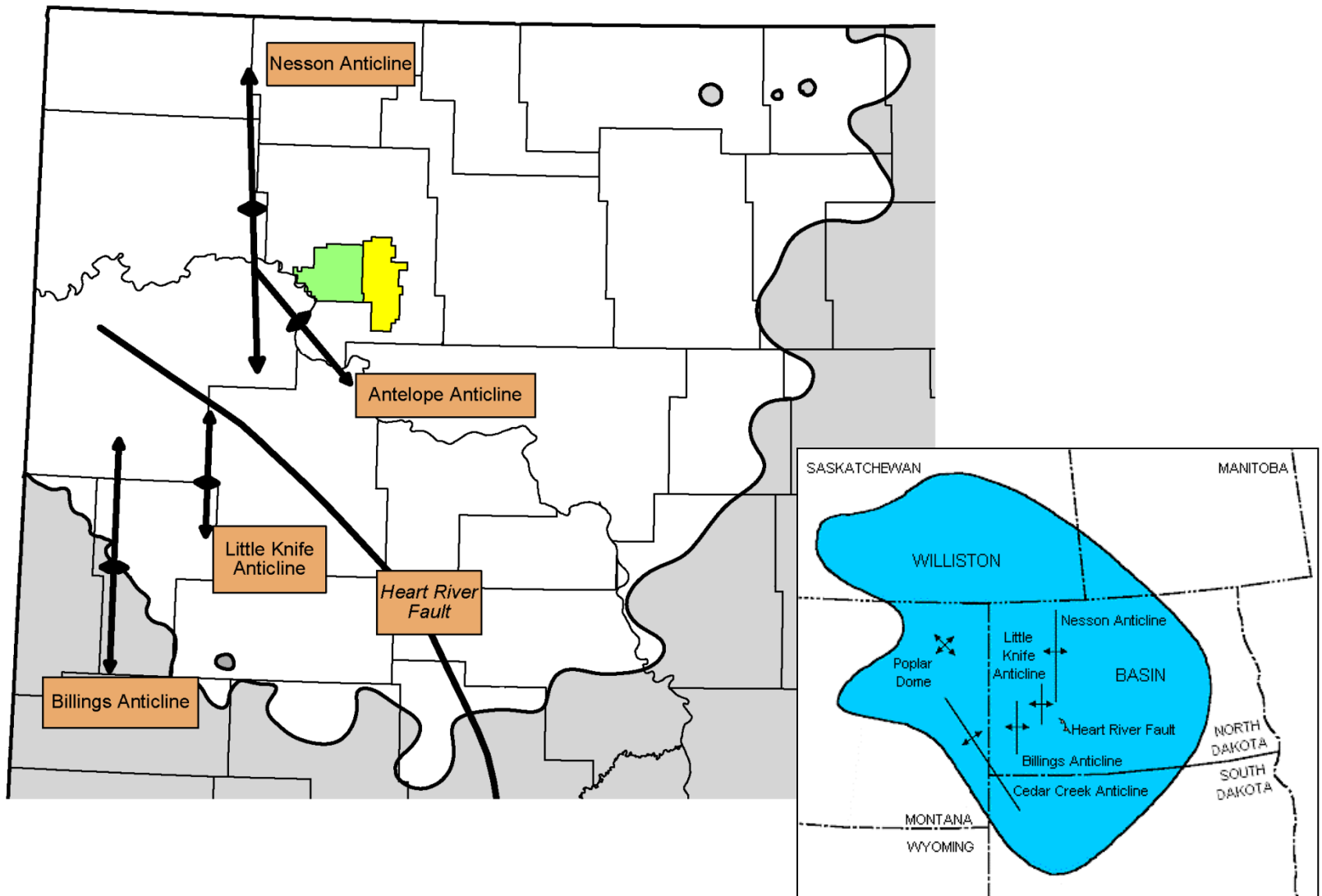
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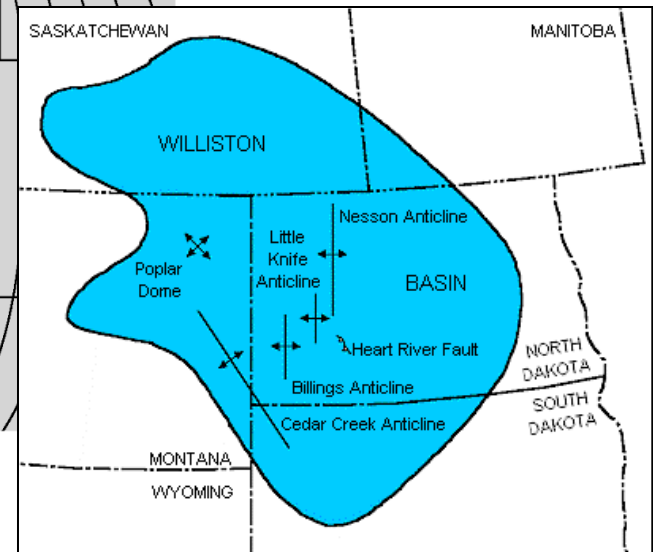
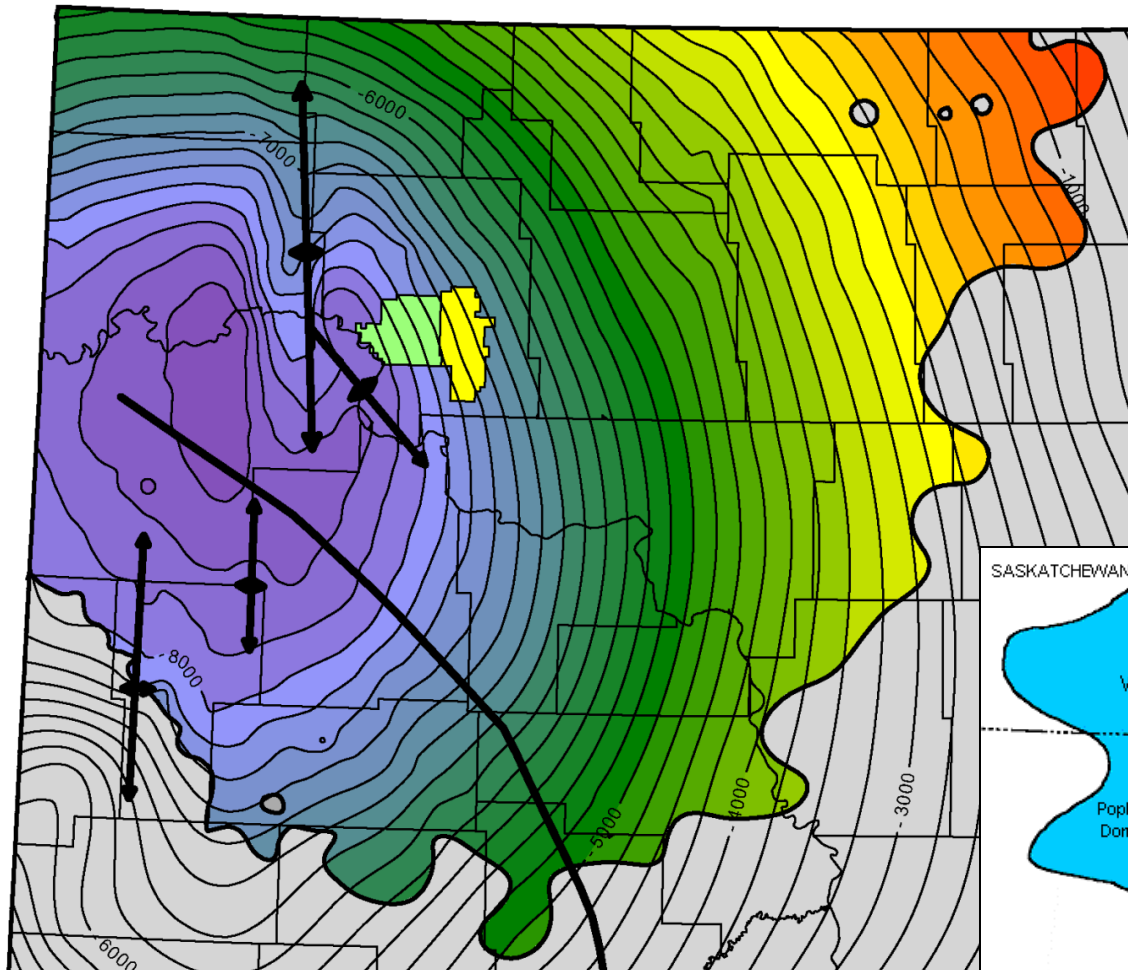


Major Structures



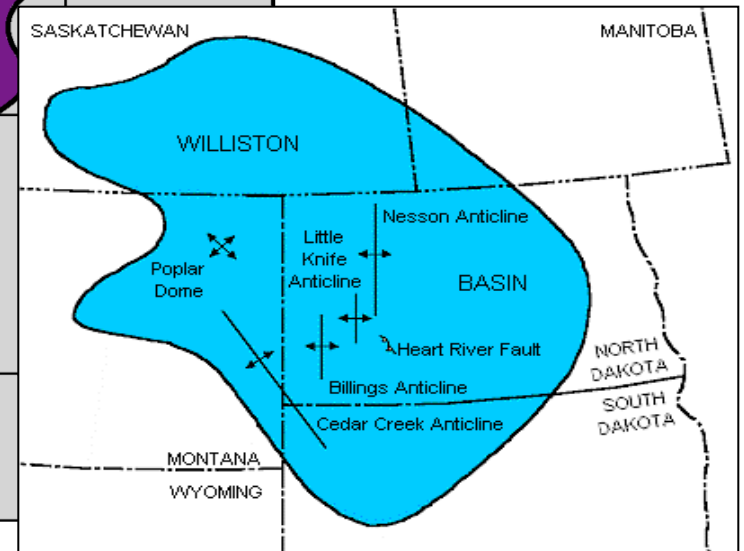
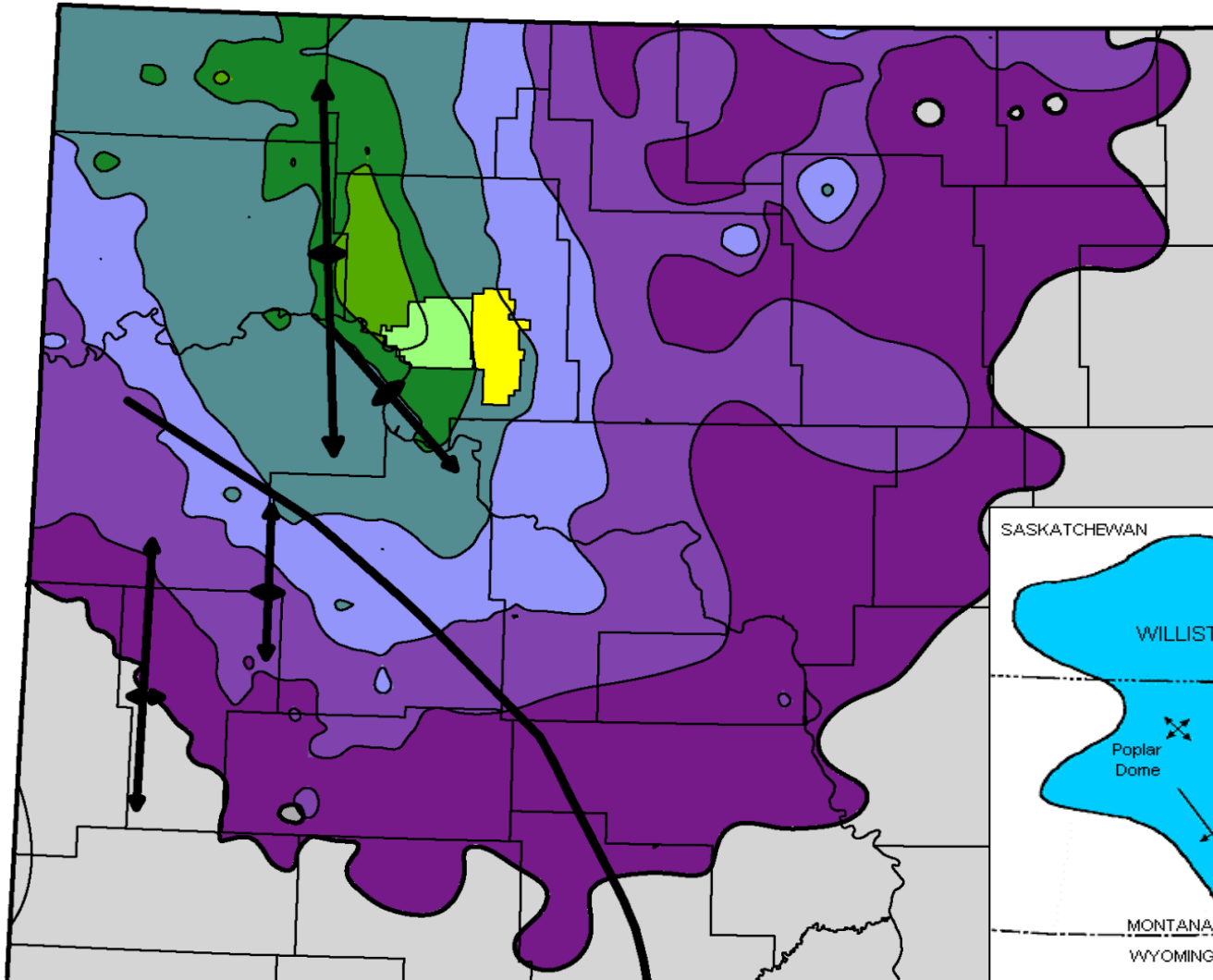
Isopach of the Bakken Fm.

C.I. = 25'



Structure on Bakken/Three Forks

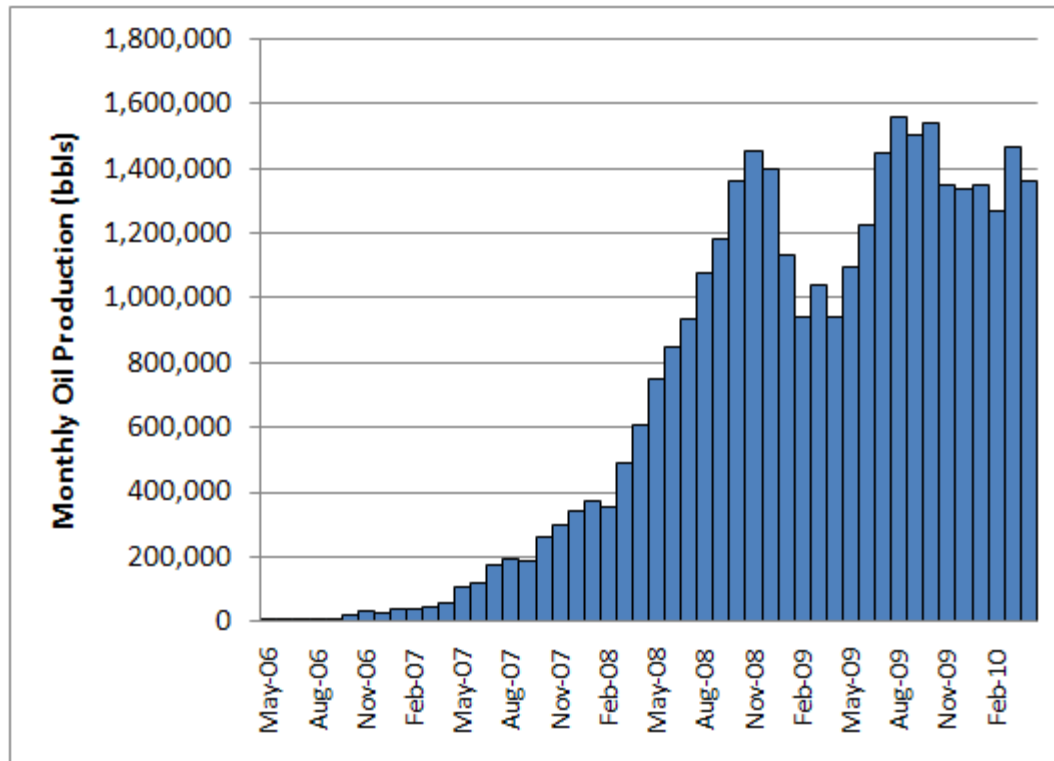
C.I. 250'



Bakken “Pool”

- Source
 - Upper and Lower Bakken Shales
- Reservoirs
 - Upper Bakken Shale
 - Mixed clastic carbonate middle member of the Bakken Fm.
 - Three Forks Fm. Upper 50’
 - Lodgepole (?) Lower 50’

System	Formation	Informal Units
Mississippian	Lodgepole	
	Bakken	upper
middle		
lower		
Devonian	Three Forks	

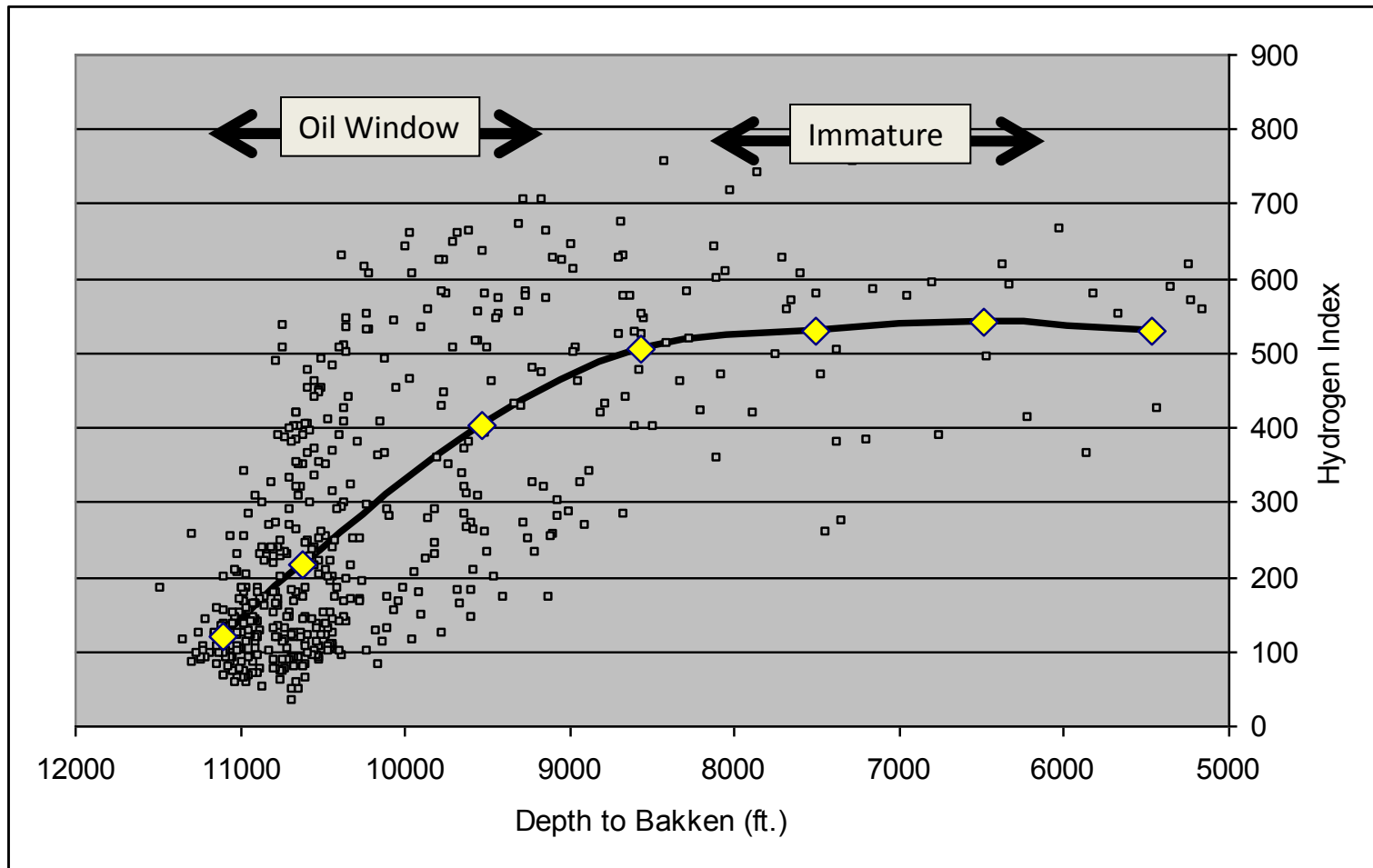


Monthly production from the Parshall Field,
Mountrail County, ND.

Key Elements in the Parshall-Sanish Field Sweetspot

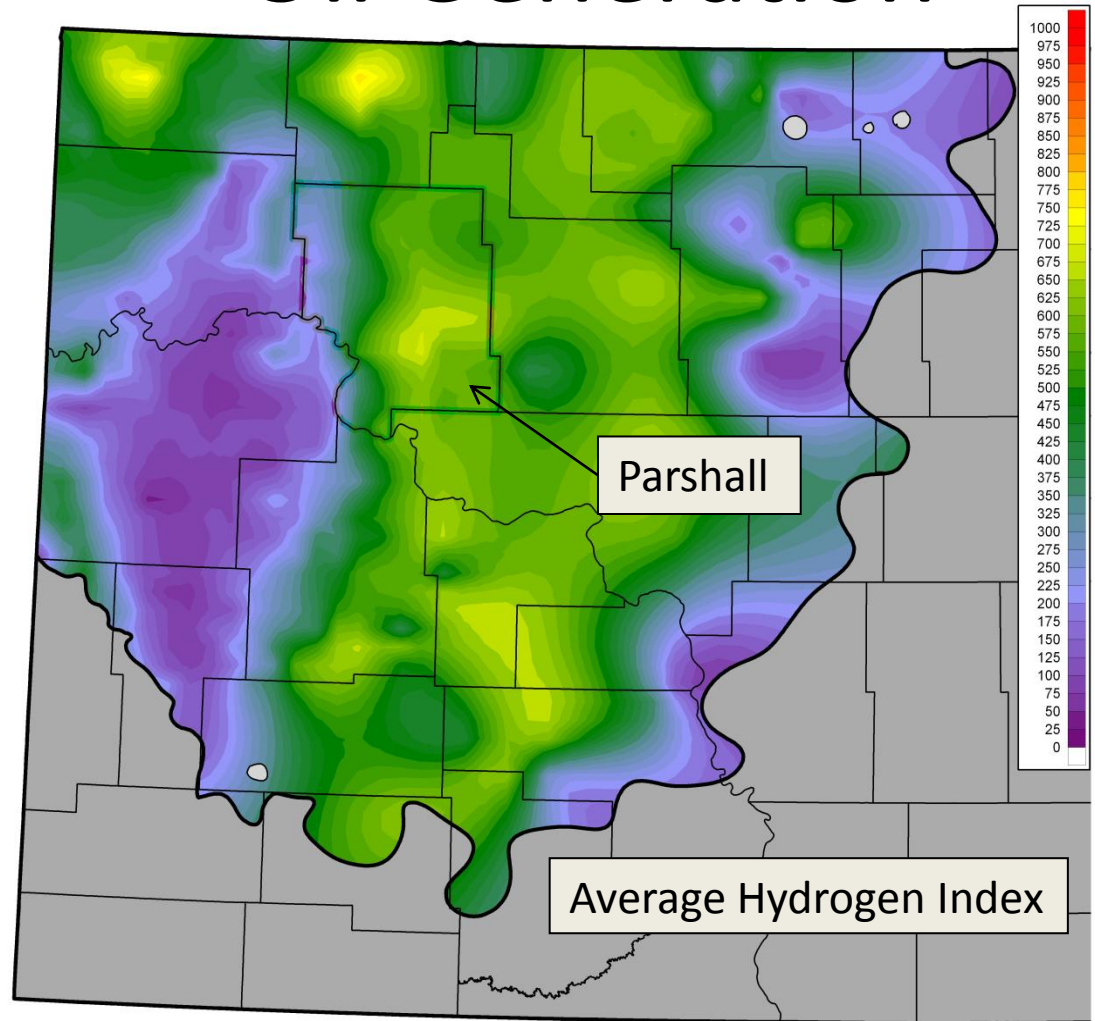
- Source rock maturation (Meissner Model)
 - Maturation enhanced expulsion of pore fluids driven by compaction.
 - Overlying and underlying rocks with very low permeabilities.
- Potential source rock expulsion rate > Transmission rate through adjacent rocks → Overpressure
- Overpressure + Subtle Structural Flexures → Locally enhanced fracture potential.

Hydrogen Index as a Function of Depth



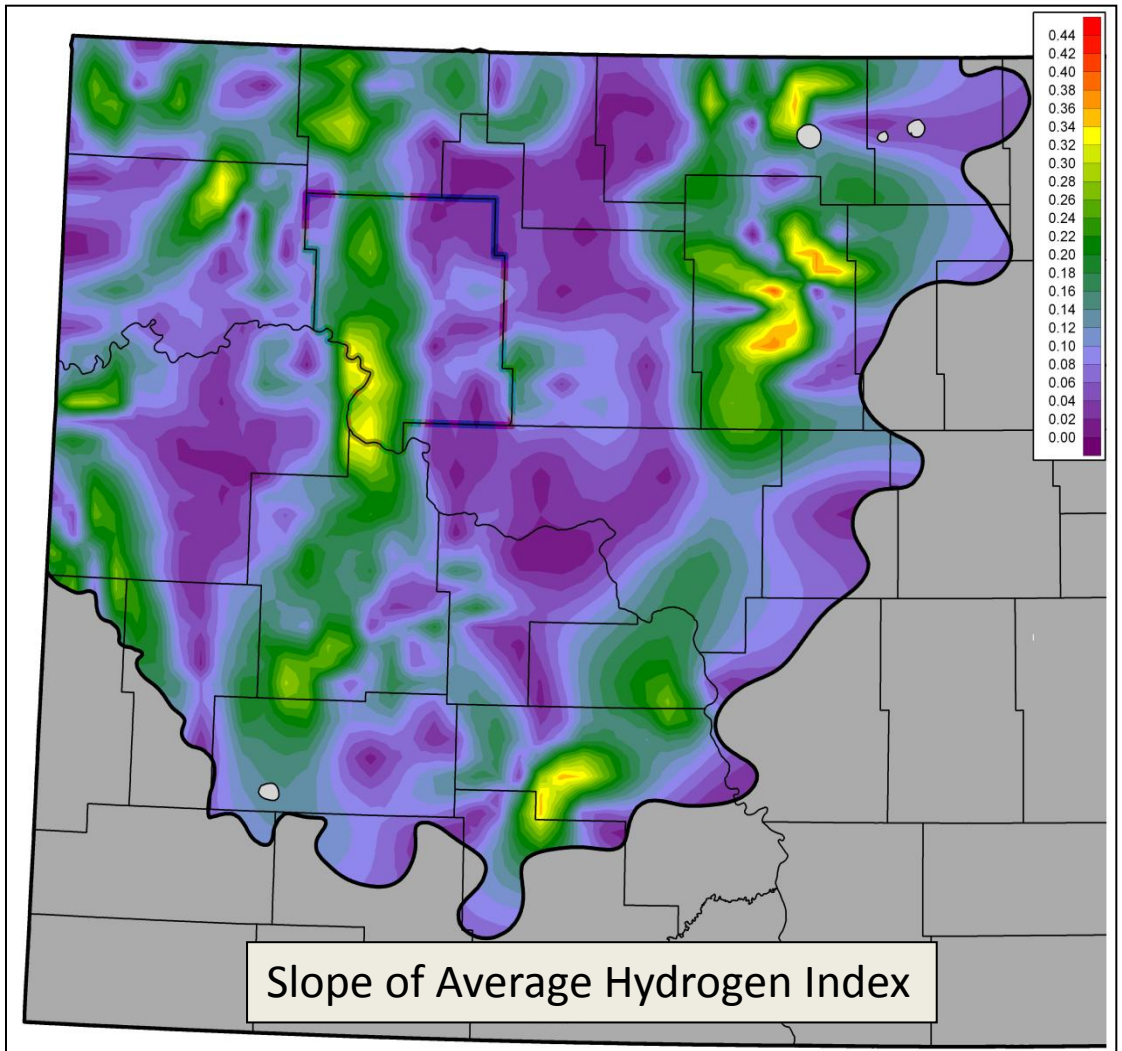
Oil Generation

- Rapid?



Oil Generation

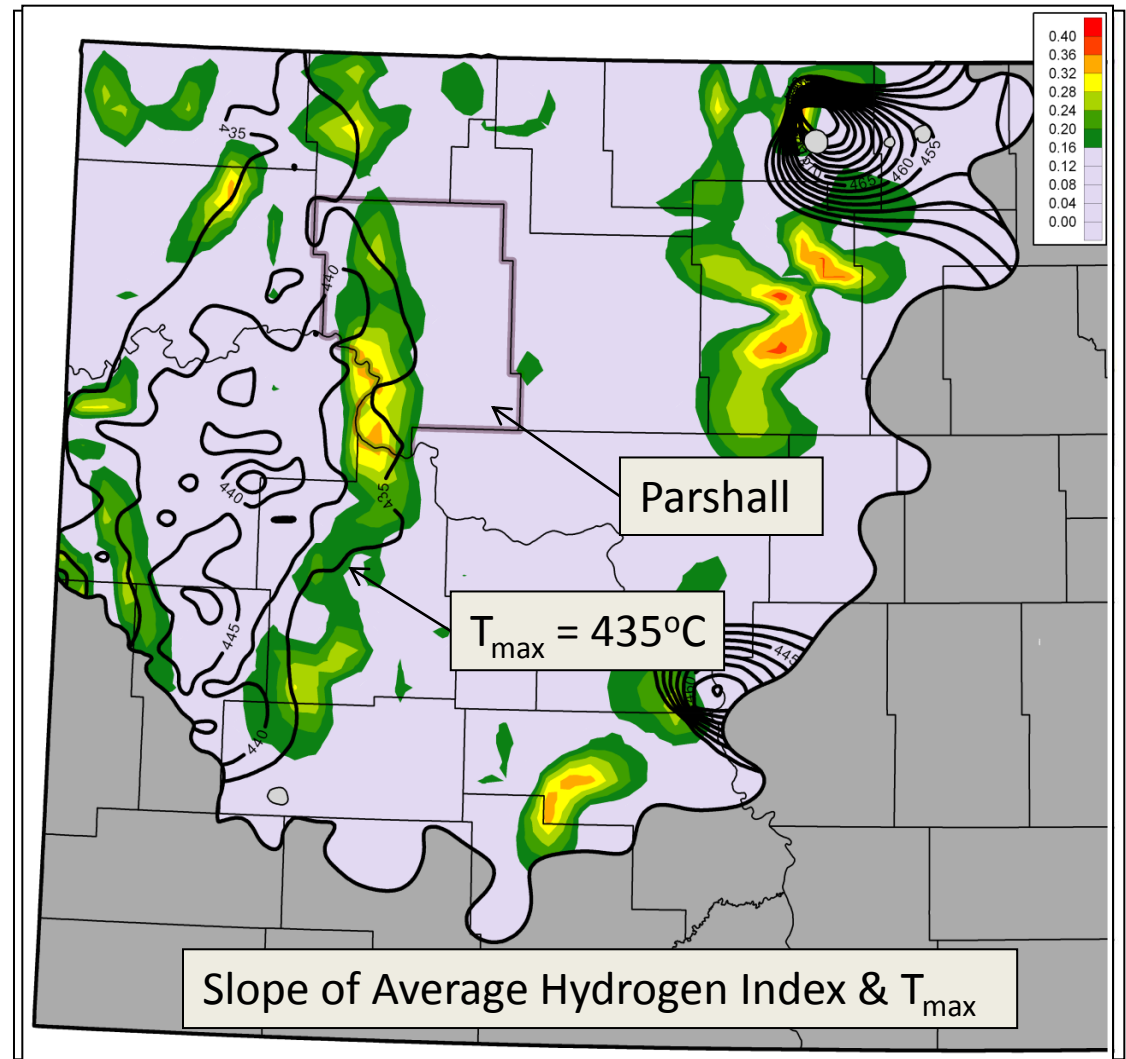
- Rapid?



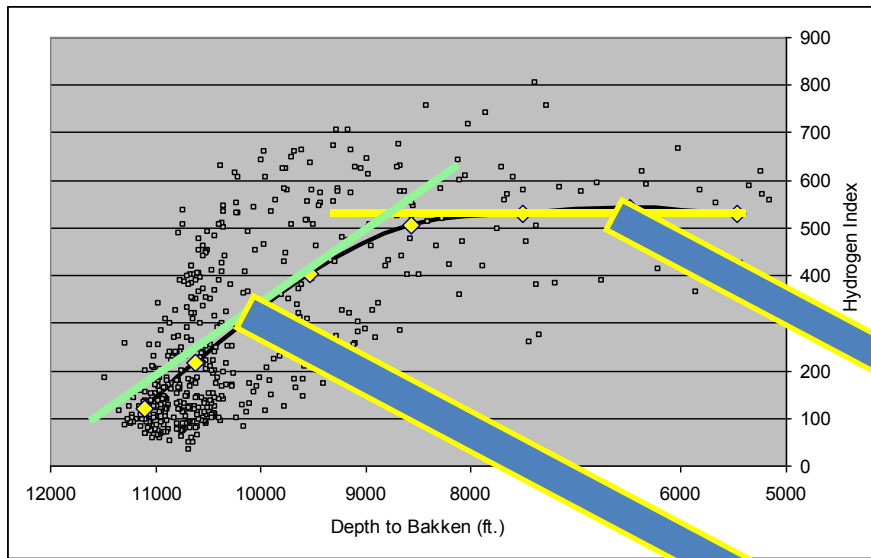
Oil Generation: Where

- Rapid?

T_{\max} of 435°C coincides with oil generation.

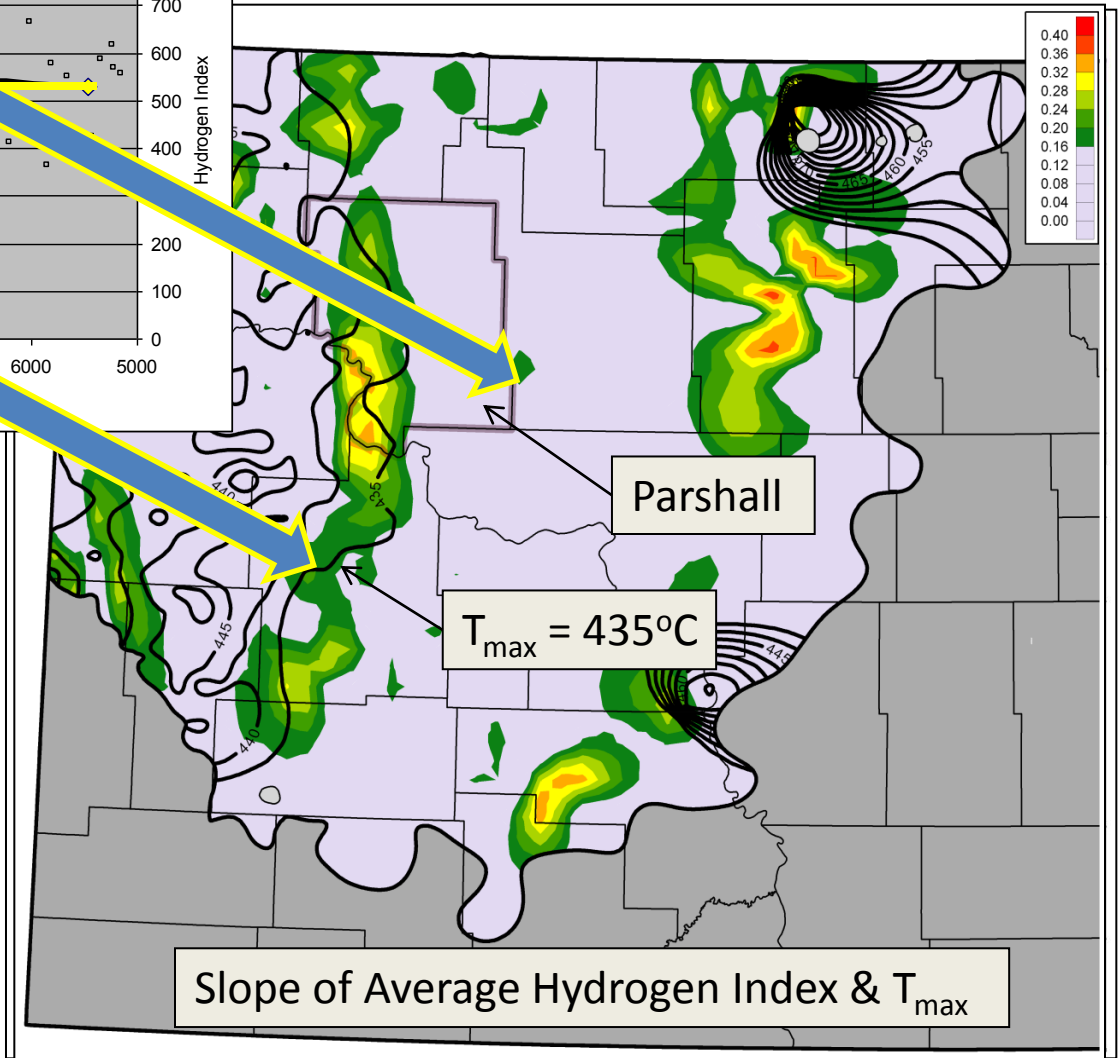


Oil Generation

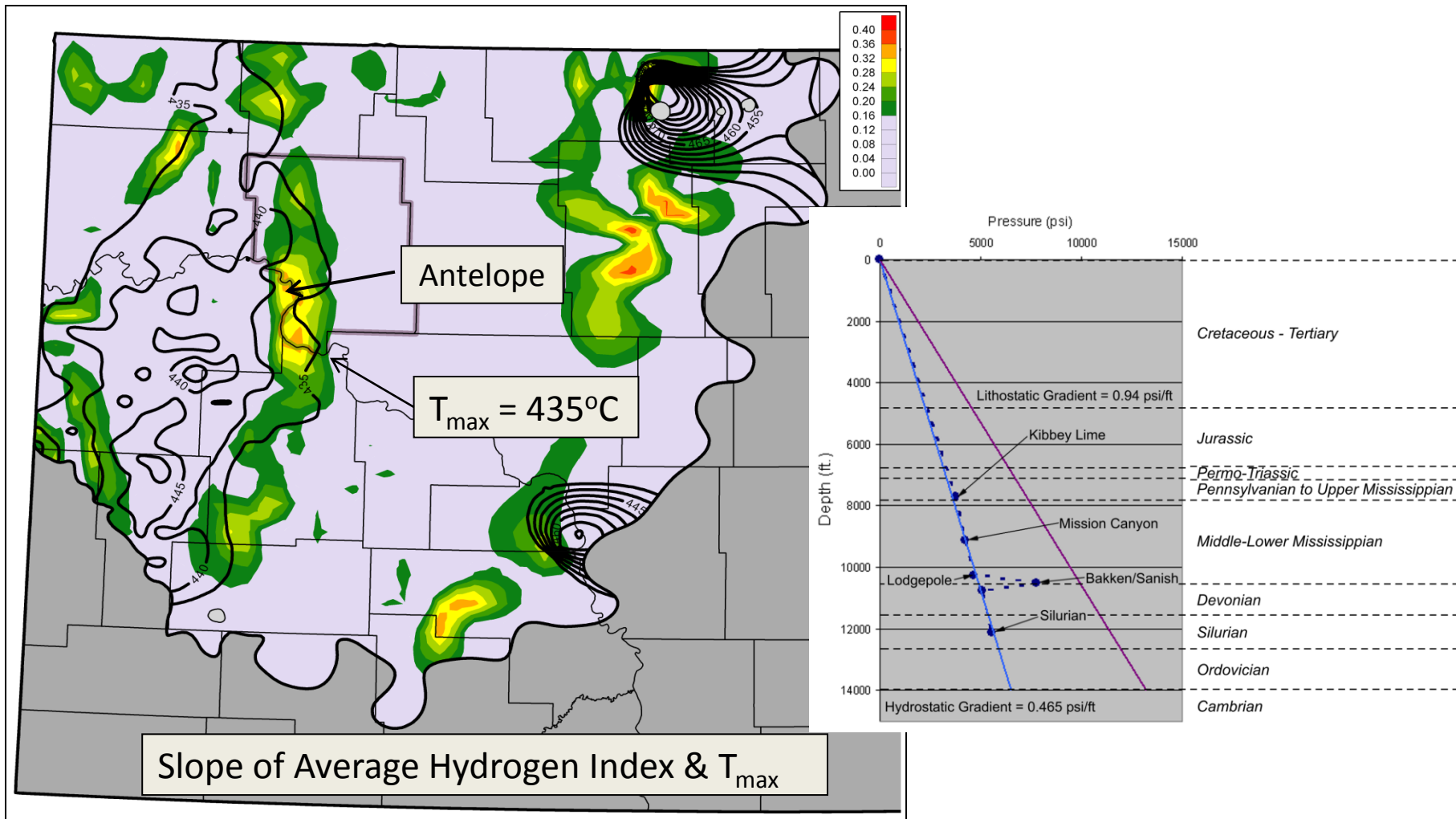


T_{\max} of 435°C coincides with oil generation.

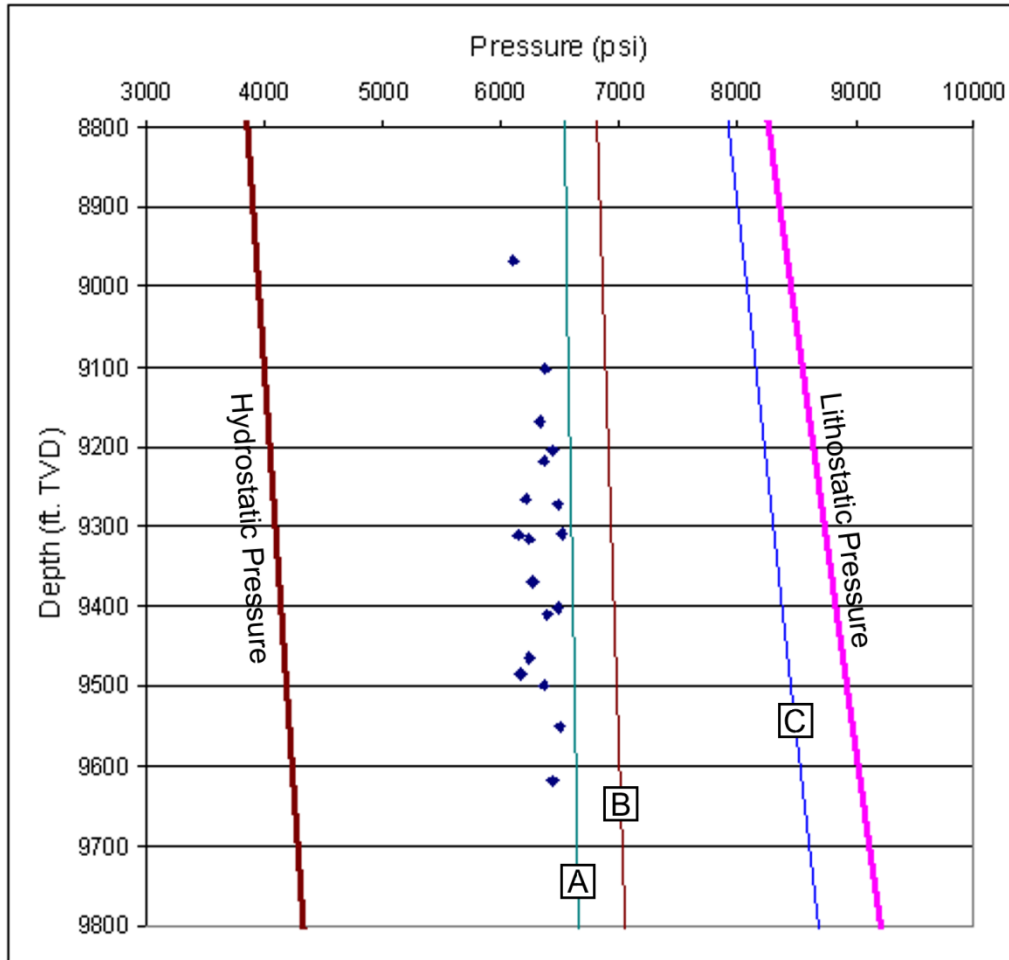
Does this mean that the oil migrated into Parshall?



Antelope Field Analog



Pressure Depth Relationship in the Bakken Fm. – Parshall Field

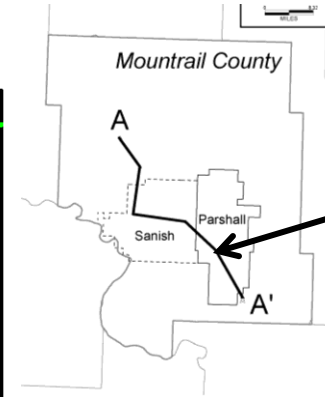
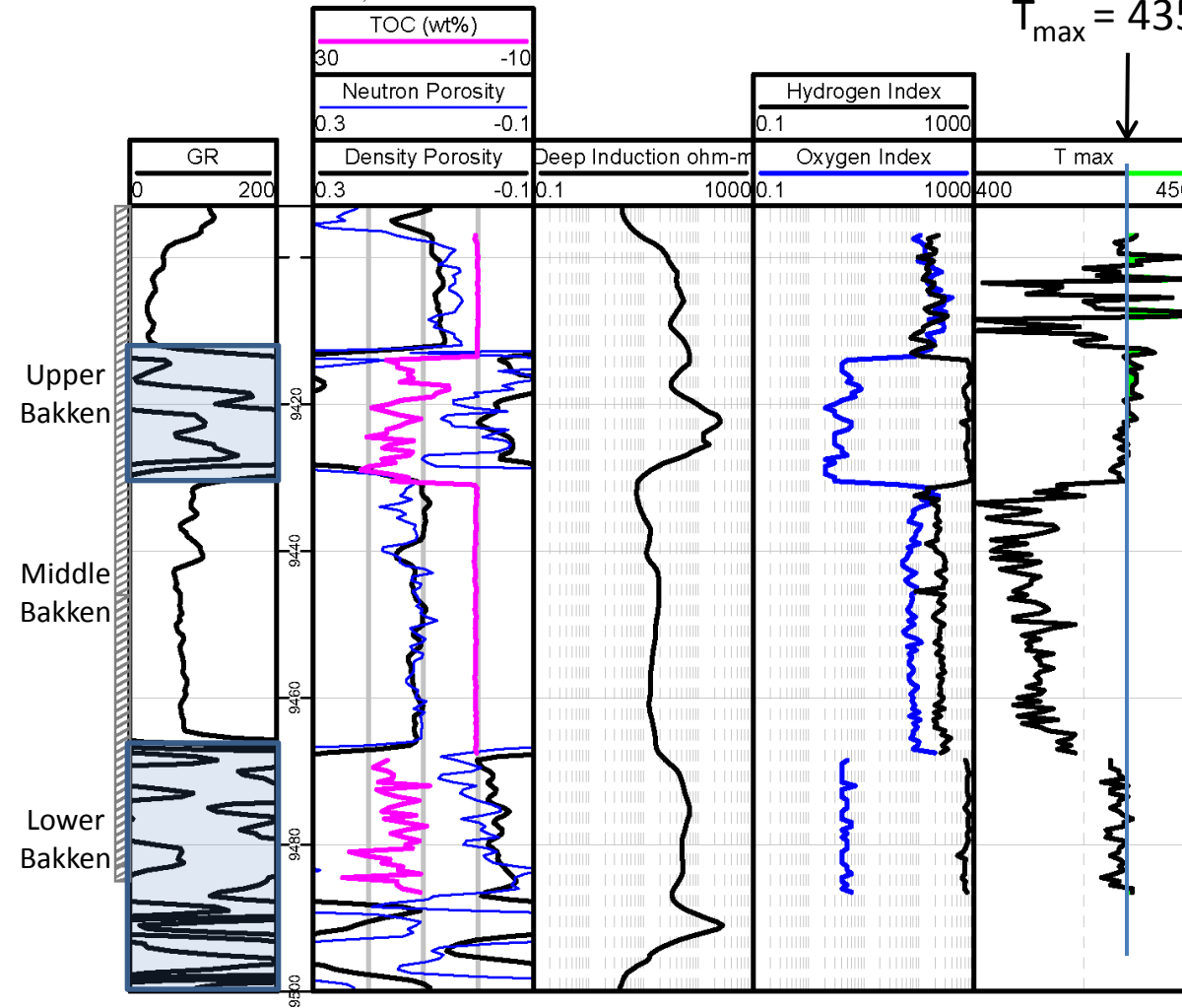


- The heavy line on the left corresponds to a hydrostatic gradient of 0.465 psi/ft. The line on the right is lithostatic pressure that corresponds to a gradient of 0.94 psi/ft.
- Labeled lines show the fracture gradients for rocks with Poisson ratios of: 0.1 (A), 0.2 (B) and 0.45 (C).

N&D 1-05H

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N&D 1-05H
EOG RESOURCES, INC.

$T_{max} = 435^{\circ}\text{C}$



N&D 1-05 H

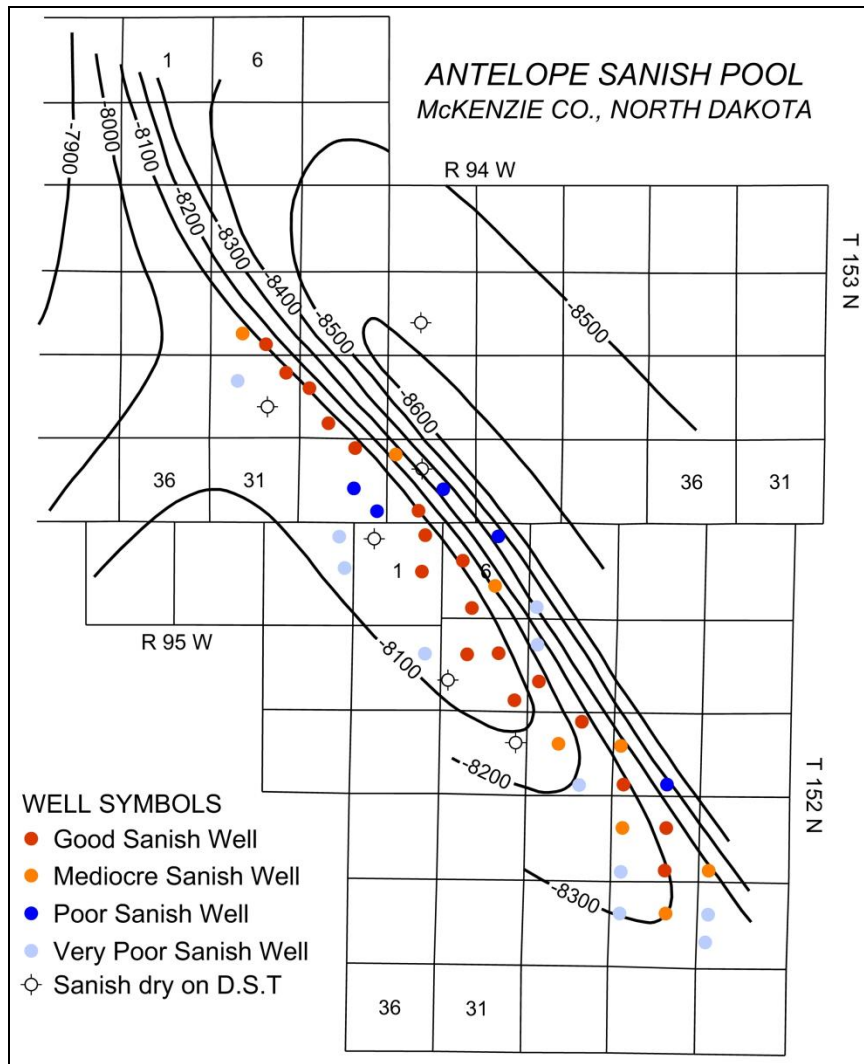
Detailed geochem suggests that the upper half of the upper Bakken is "mature"..

Implications:

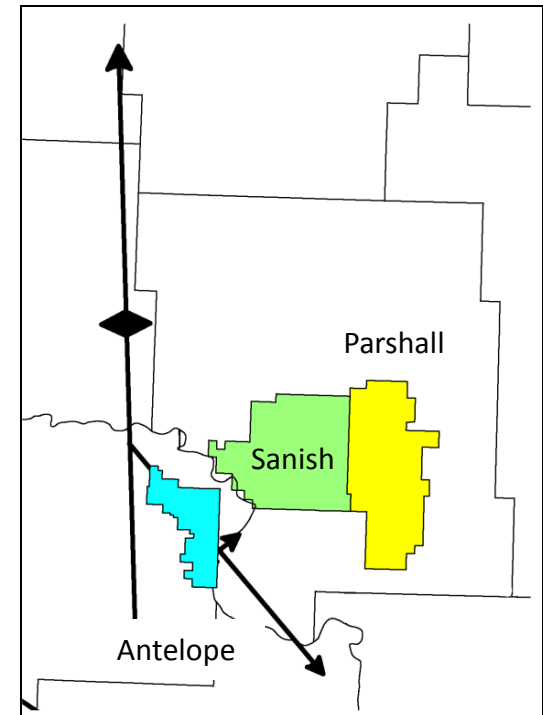
T_{max} suggests a local source for the oil in Parshall/Sanish Fields.

Assuming a homogeneous kerogen will miss significant accumulations.

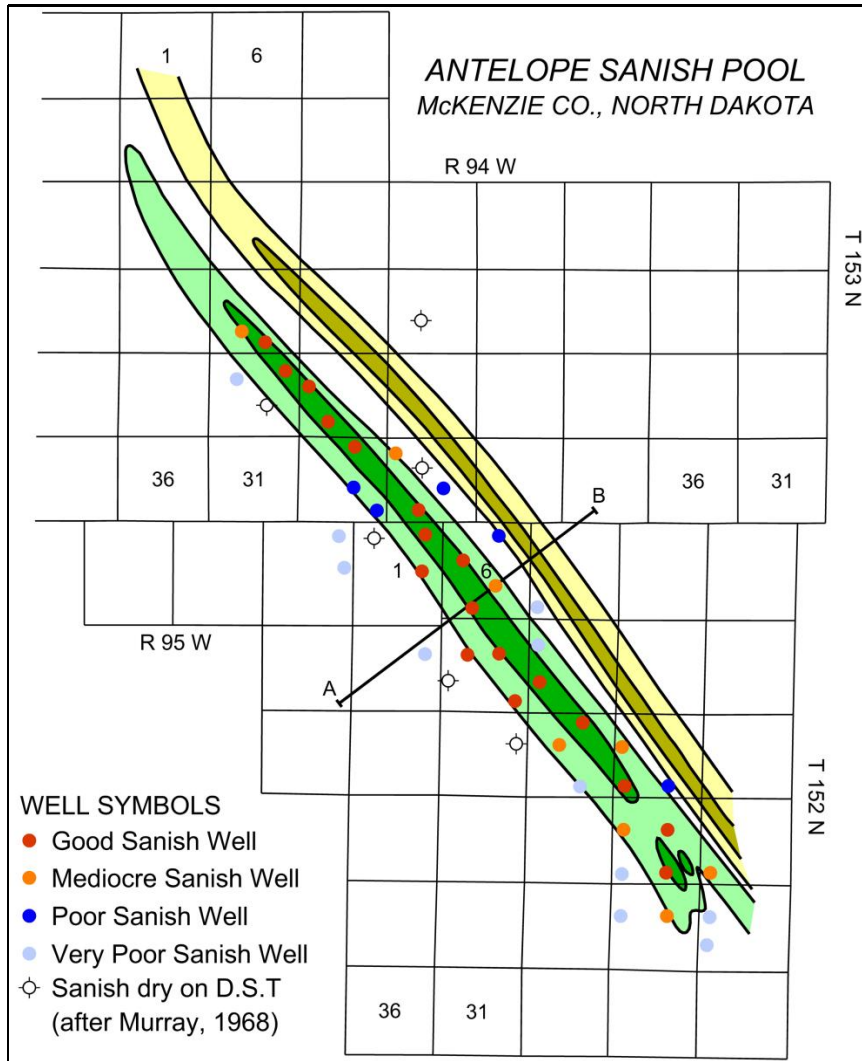
Structural Flexure and Fracturing: Antelope Field



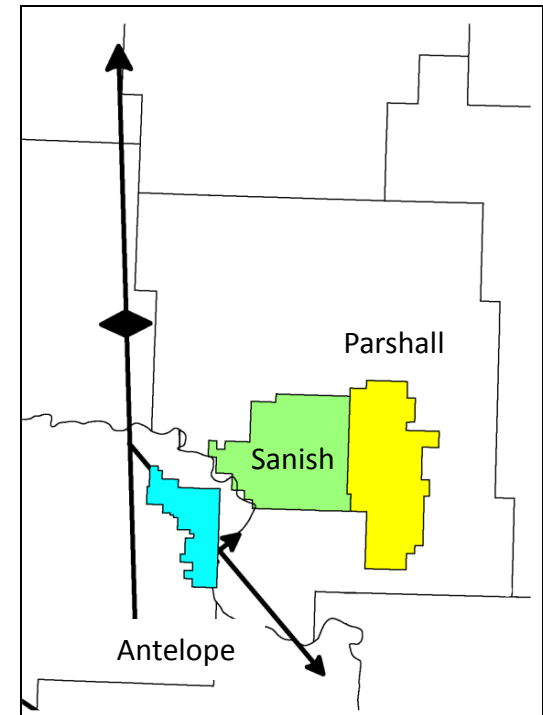
Structure Contour: Top of Bakken Formation



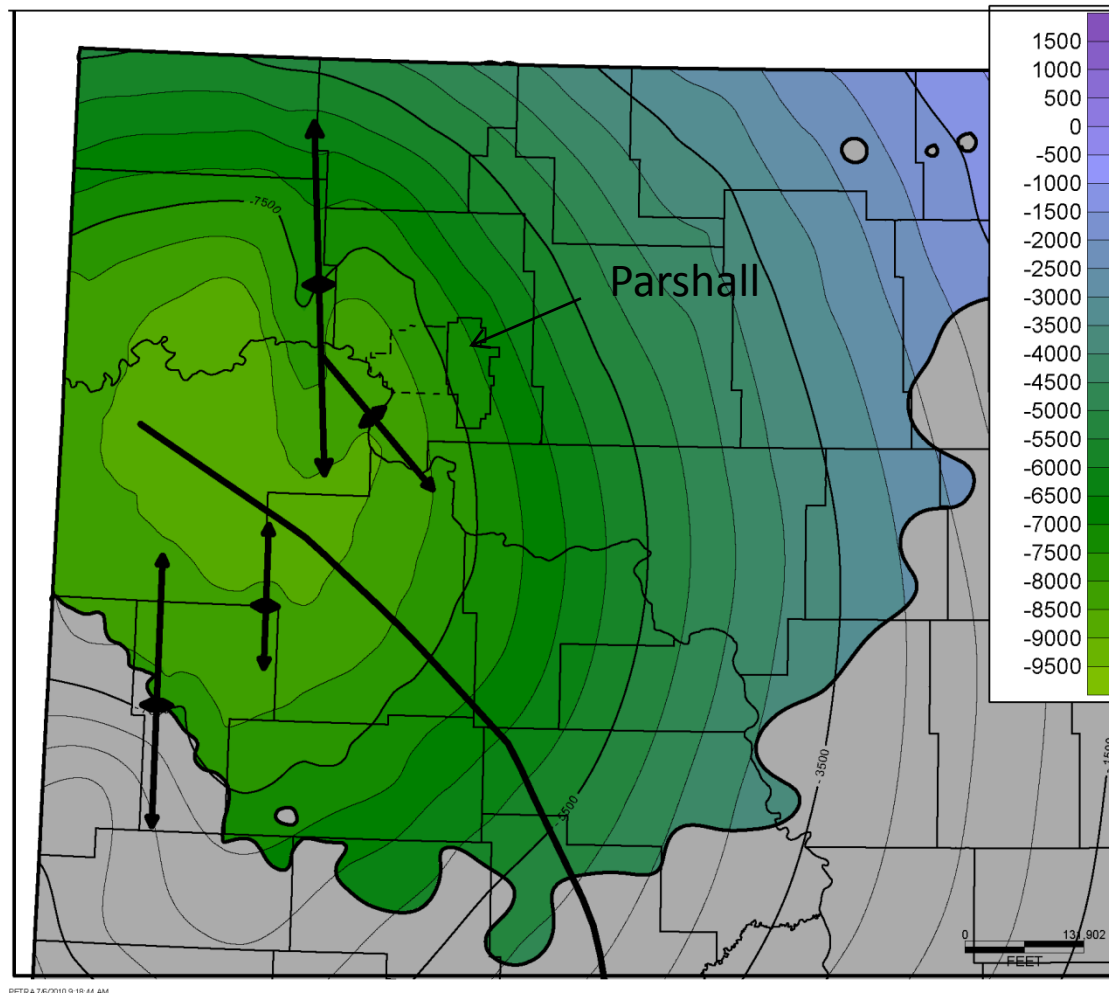
2nd Derivative of the Bakken Structure



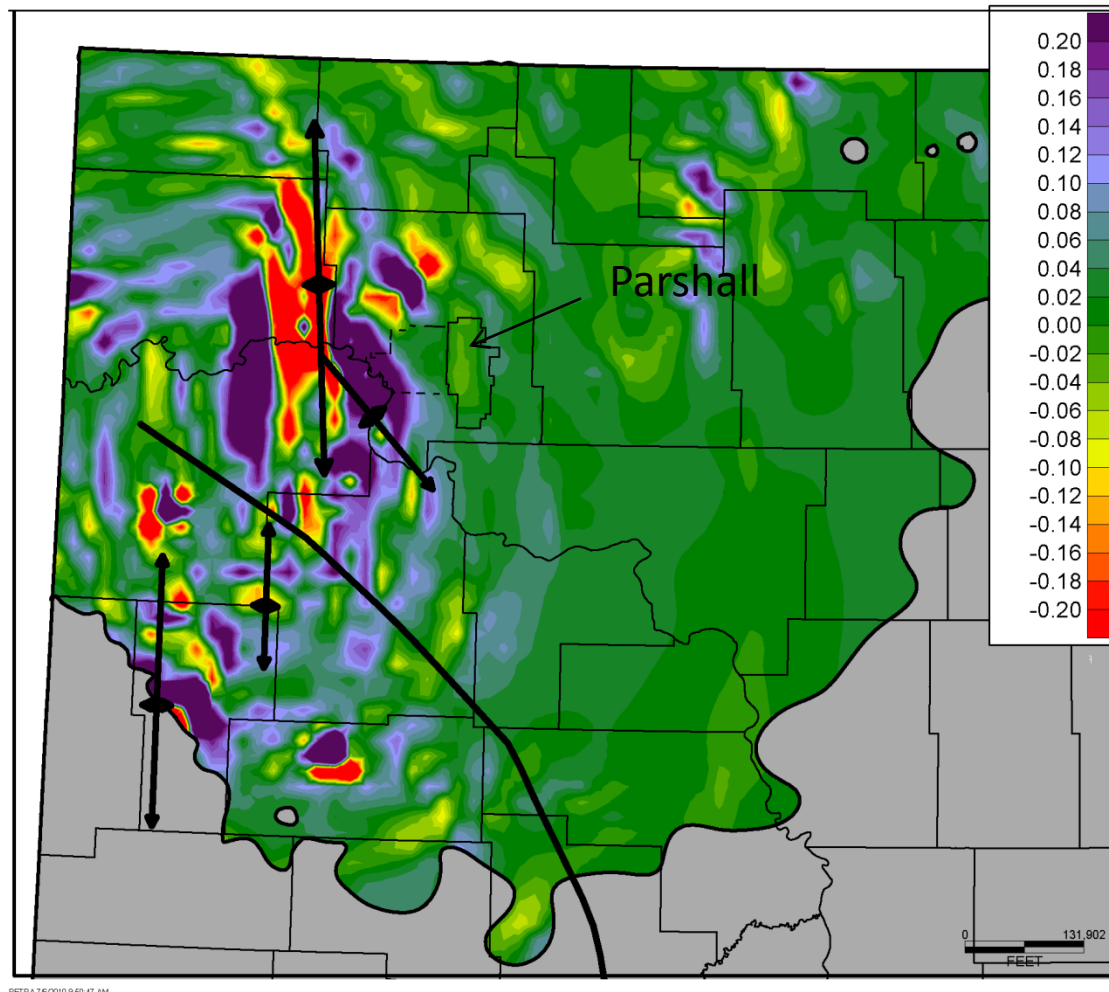
Structural Flexure and Fracturing: Antelope Field



Structure on the Top of the Bakken Fm.



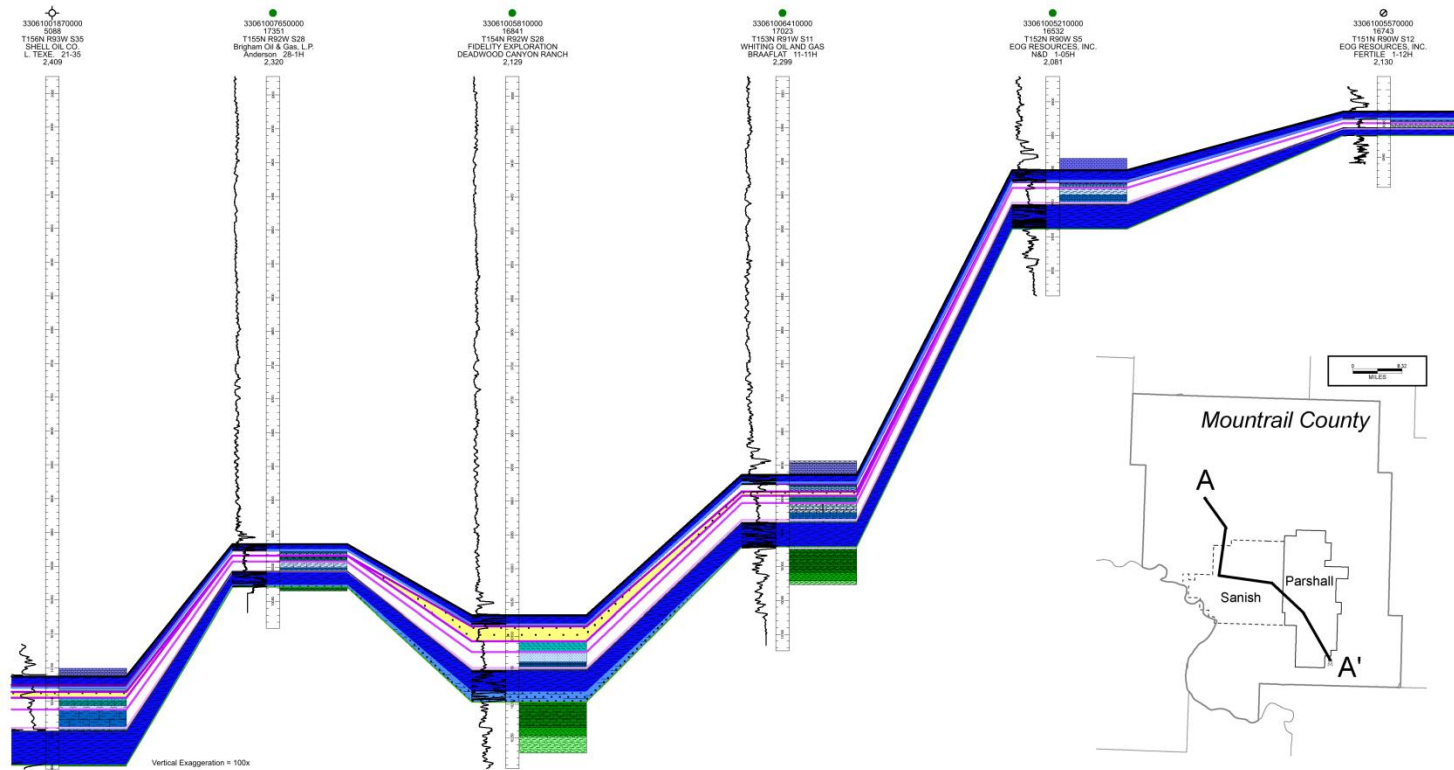
2nd Derivative Map of the Structure on the Top of the Bakken Fm.



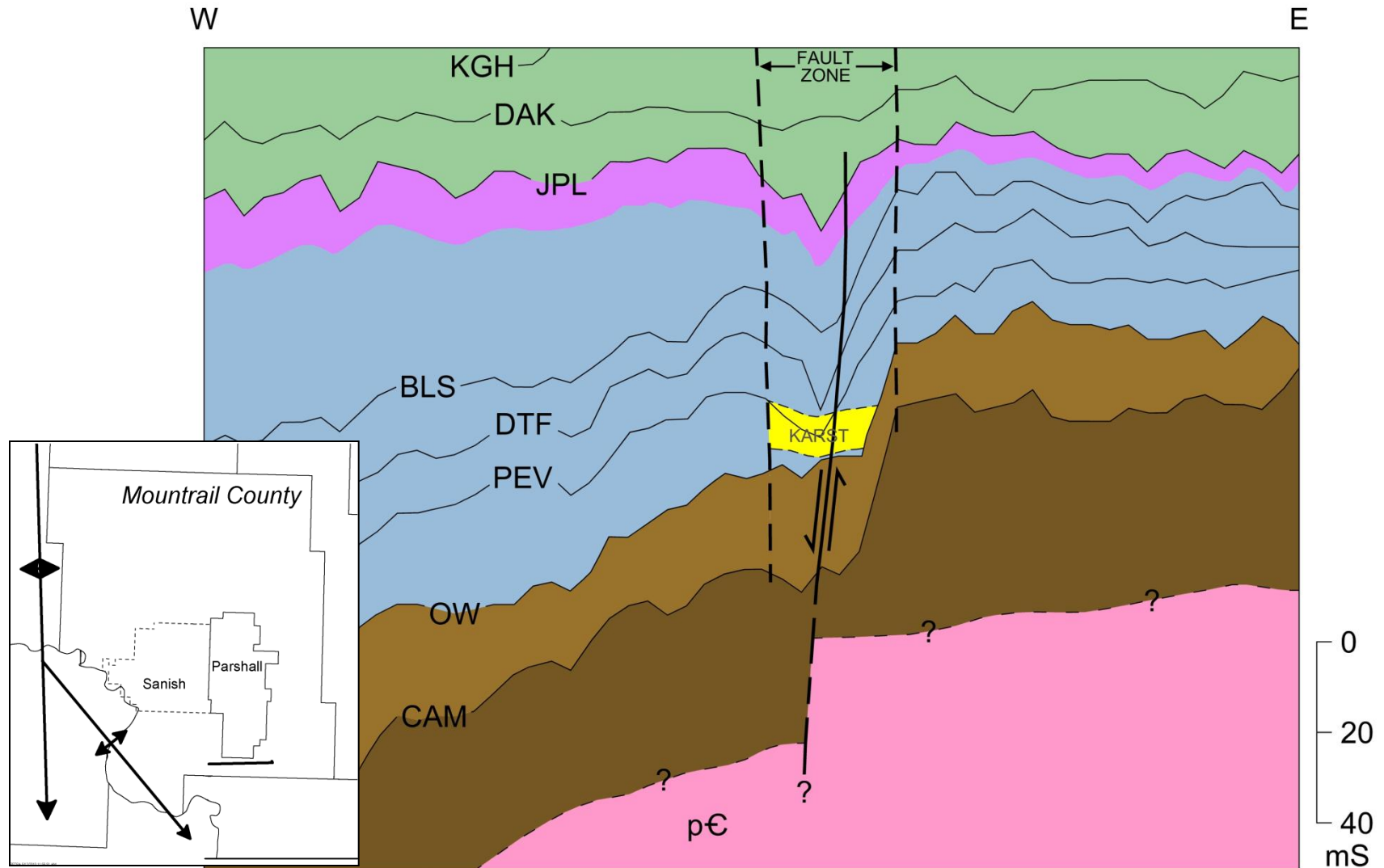
Cross-section illustrating local flexure of the Bakken Fm.

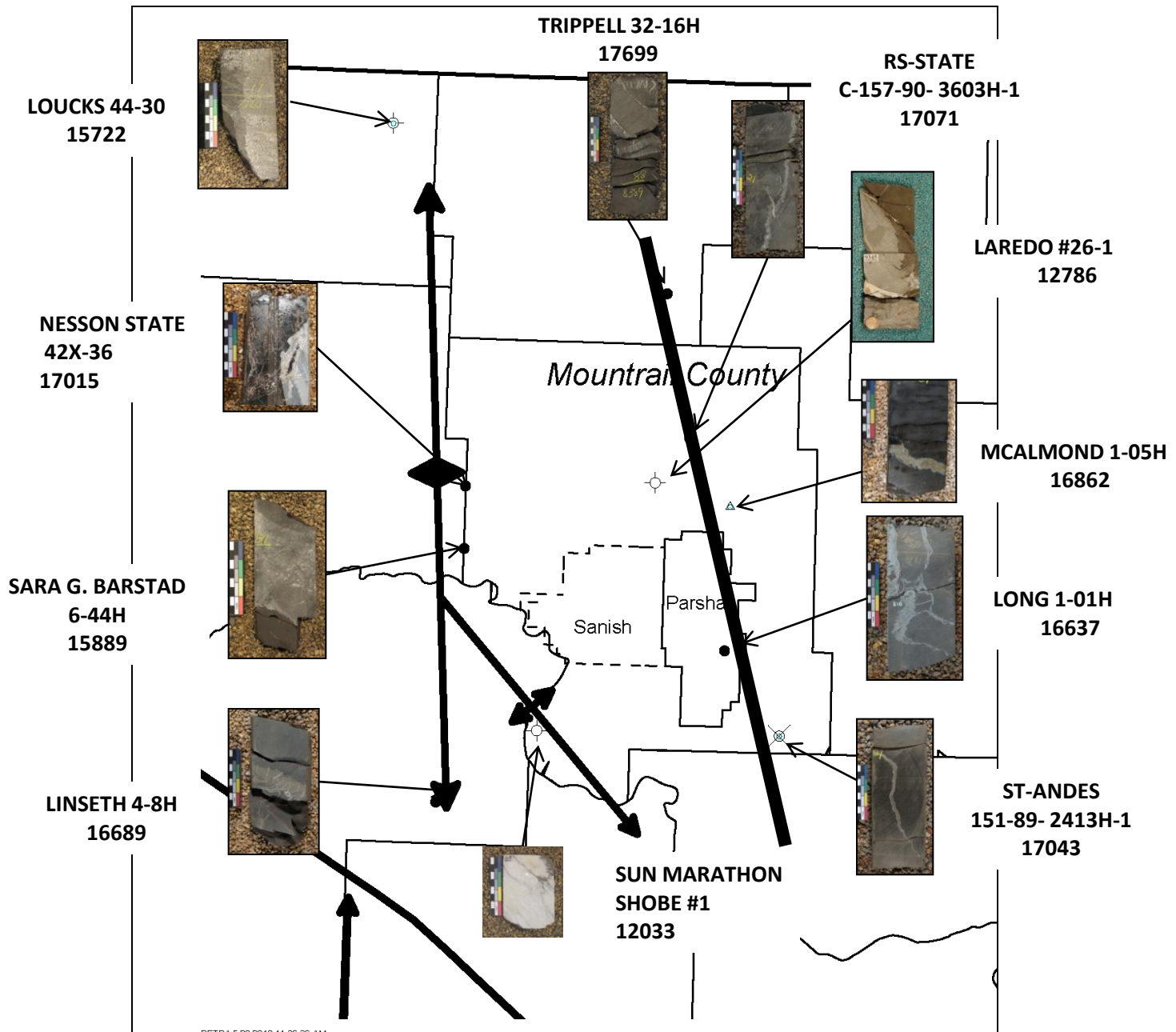
A

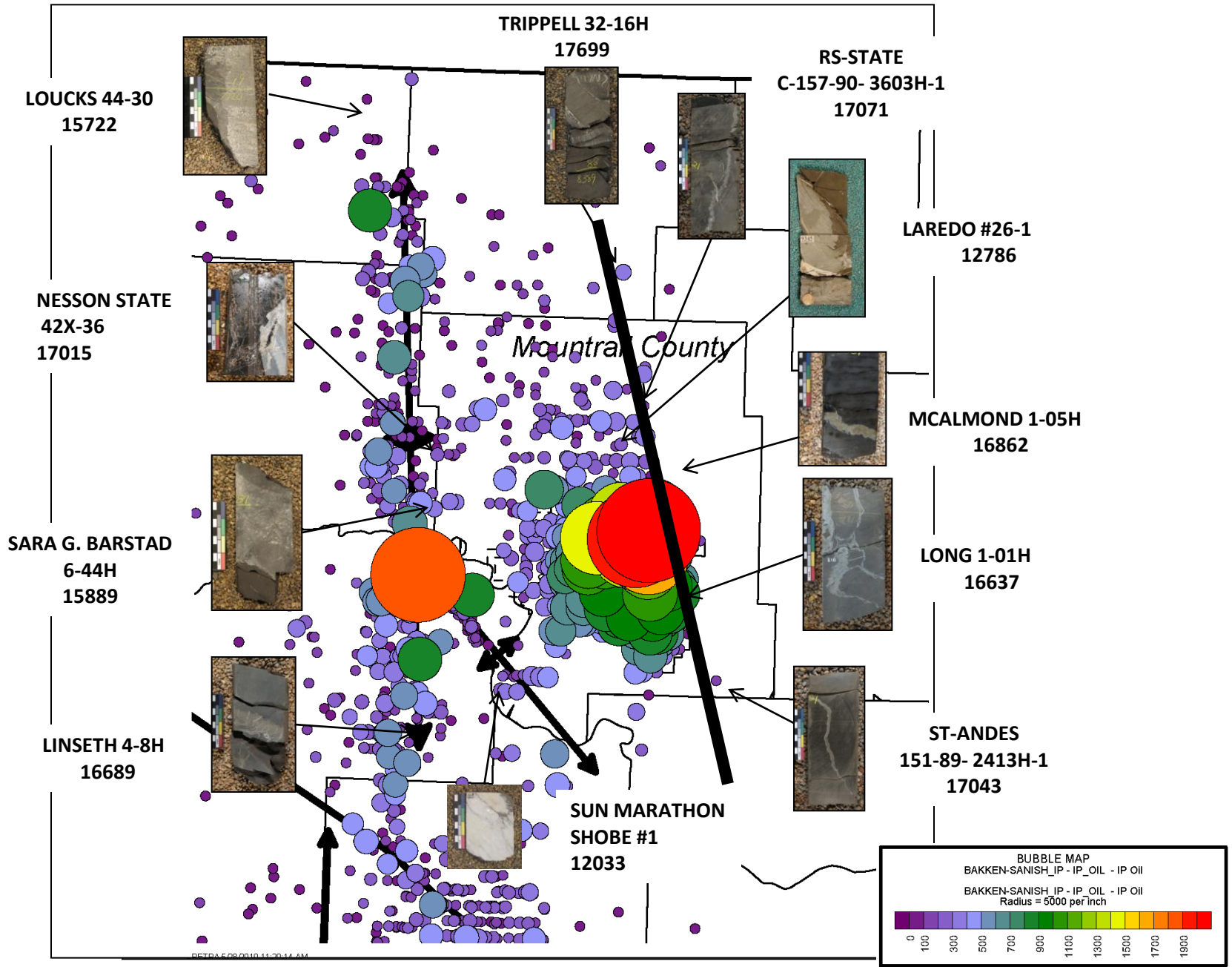
A'



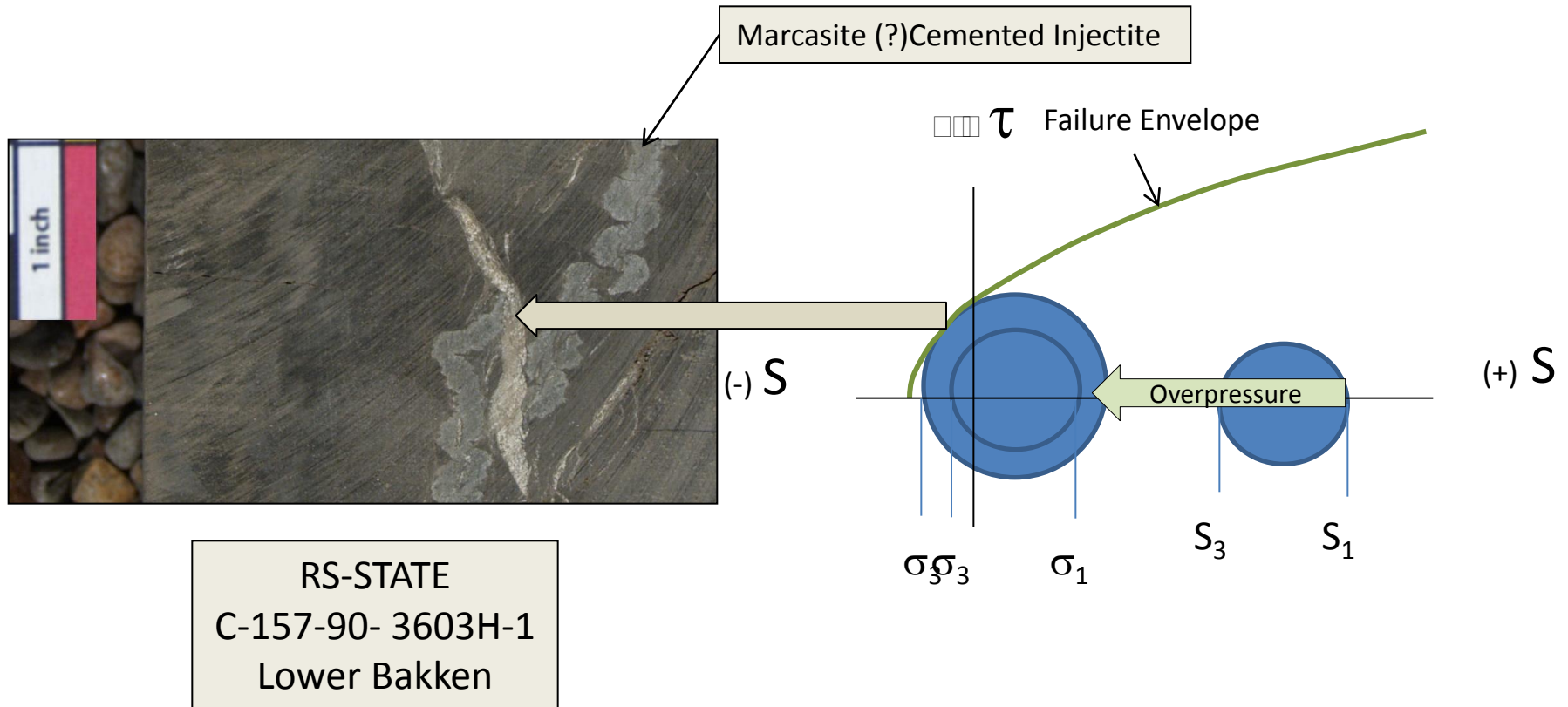
Interpreted 2-D seismic line showing local flexure extending up through section.







Overpressure and Effective Stress



Conclusions

- A significant part of the upper Bakken shale is mature in the Parshall Field.
- Maturation within the upper Bakken may result in or contribute to significant overpressures throughout the Parshall Field.
- Elevated pore pressures combined with localized stresses associated with subtle structures may contribute to natural fracturing and/or enhanced stimulation of the middle Bakken.